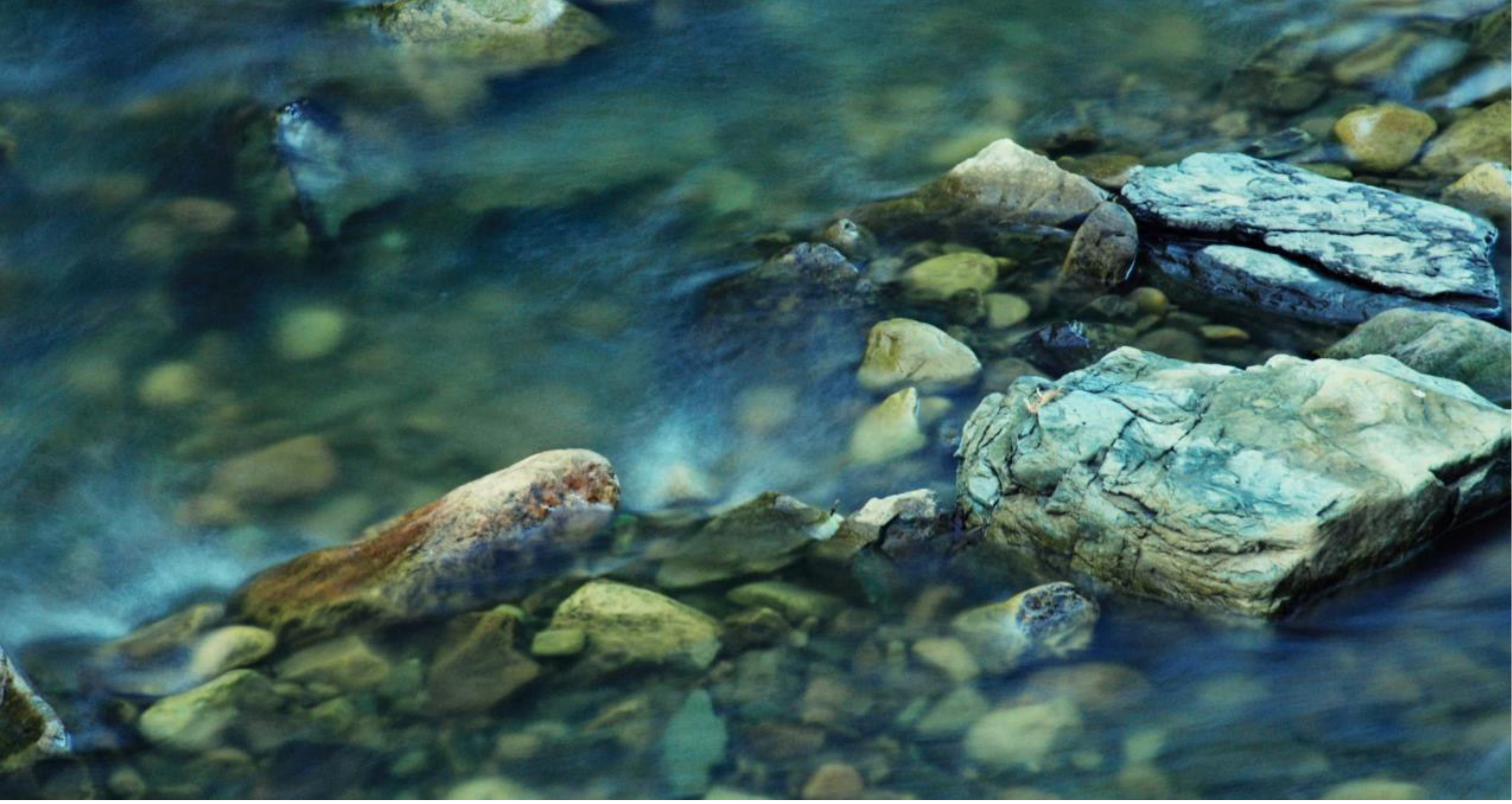
APPENDIX E-8 Sedimentation Study Report



September 2022
Grand Lake Sedimentation Study

Updated Study Report

Prepared for

Grand River Dam Authority

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Prepared for
Grand River Dam Authority
P.O. Box 409
Vinita, Oklahoma 74301

Prepared by
Anchor QEA, LLC
660 West Washington Avenue
Suite 302
Madison, Wisconsin 53715

Simons & Associates
P.O. Box 607
Midway, Utah 84049

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LIST OF ABBREVIATIONS AND TERMS

µm	micrometer
1D	one-dimensional
2D	two-dimensional
3D	three-dimensional
AASHTO	American Association of State Highway and Transportation Officials
ADCP	acoustic Doppler current profiler
BC	boundary condition
cfs	cubic feet per second
cm	centimeter
cm/s	centimeters per second
FERC	Federal Energy Regulatory Commission
ft^2	square feet
ft^3	cubic feet
ft/ft	vertical feet per horizontal foot
g/cm^3	grams per cubic centimeter
GIS	Geographic Information System
GPS	Global Positioning System
Grand Lake	Grand Lake O' the Cherokees
GRDA	Grand River Dam Authority
HEC-RAS	Hydrologic Engineering Center's River Analysis System
HEC-SSP	Hydrologic Engineering Center Statistical Software Package
H&H	hydrology and hydraulics
ISR	Initial Study Report
ITR	Independent Technical Review
lb/ft^2	pounds per square foot
$lb/ft^2/hr$	pounds per square foot per hour
LiDAR	Light Detection and Ranging
mm	millimeter
N/A	not applicable
NED	National Elevation Dataset
NGVD29	National Geodetic Vertical Datum of 1929
NSE	Nash-Sutcliffe Efficiency
OM	Operations Model
Ops	operations
OWRB	Oklahoma Water Resources Board
Pa	Pascal

PBIAS	Percent Bias
pcf	pounds per cubic foot
PD	Pensacola Datum
Project	Pensacola Hydroelectric Project
REAS	Real Estate Adequacy Study
RM	river mile
RMSE	root-mean-square deviation
RSR	RMSE-Observations Standard Deviation Ratio
RTK	Real-Time Kinematic
SBP	Sub-Bottom Profiler
SMD	Study Modification Determination
SPD	Study Plan Determination
SSC	suspended sediment concentration
STM	sediment transport model
TPU	total propagated uncertainty
UHM	Upstream Hydraulic Model
USACE	U.S. Army Corps of Engineers
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
USP	Updated Study Plan
USR	Updated Study Report
USSD	U.S. Society on Dams
UWSFL	University of Wisconsin Soil and Forage Laboratory
WEST	WEST Consultants, Inc.
WSE	water surface elevation
WSLH	Wisconsin State Laboratory of Hygiene

Executive Summary

Anchor QEA, LLC (formerly FreshWater Engineering), and Simons & Associates were retained to support the Grand River Dam Authority (GRDA) as subconsultants to Mead & Hunt for the Federal Energy Regulatory Commission (FERC) relicensing of the Pensacola Hydroelectric Project (Project). Anchor QEA's and Simons & Associates' role, with Mead & Hunt's support, is to perform a Sedimentation Study to determine the rates and locations of sedimentation throughout the Grand Lake O' the Cherokees (Grand Lake) watershed and associated tributaries.

This task culminated in the development of a sediment transport model (STM) using the Hydrologic Engineering Center's River Analysis System (HEC-RAS) fluvial modeling software. Data needed for model development range from topographic information to stream discharge volumes, water surface elevations (WSEs), and sediment parameters both in the lake and streambeds and moving into the system through major tributaries. Anchor QEA evaluated publicly available data sources to compile parameters necessary for model development and to determine where additional field work was required to fill data gaps.

WEST Consultants, Inc. (WEST), provided assistance in the Sedimentation Study. Initially, WEST completed an Independent Technical Review (ITR) of the STM and Initial Study Report. The ITR comments and recommendations are documented in a technical memorandum completed in April 2022 (WEST 2022). WEST provided technical support in the development and calibration of the STM for the Updated Study Report (USR). This effort included providing recommendations to improve model calibration and statistical methods to measure how the model is performing and developing a script to adjust the HEC-RAS geometry to account for consolidation of the future sediment deposits within the reservoir. WEST provided quality assurance reviews of the STM developed for the USR.

Topographic and bathymetric data are available from a range of sources. Grand Lake itself was surveyed by the Oklahoma Water Resources Board in 2009, then again by the U.S. Geological Survey (USGS) in 2019. Upstream surveys of the Neosho River, Spring River, and Elk River were performed as part of the 1998 Real Estate Adequacy Study (REAS), and USGS surveyed those reaches again in 2017. Topographic information was available from surveys performed in support of the 1998 REAS and Light Detection and Ranging (LiDAR) flights conducted in 2011. Other topographic information was obtained from the USGS National Elevation Dataset one-third, arc-second datasets where LiDAR information was unavailable. Circa-1940 topographic maps were digitized for analysis of conditions at the time of dam construction. Additionally, stage-storage curves were available from circa-1940 U.S. Army Corps of Engineers as-built drawings as well as the more recent Grand Lake bathymetry surveys.

Other data are available from USGS gaging stations located throughout the Grand Lake watershed. WSE data and stream discharge information are available along the Neosho, Spring, and Elk rivers, as well as on Tar Creek. These stations also provide sediment transport data in the form of suspended sediment concentration (SSC) measurements taken throughout the period of record at each gage.

Data gaps existed within the period of record for the USGS gaging stations within the Grand Lake watershed, and the gaging network lacked spatial density. As a result, the study team developed a field monitoring system to track WSE throughout the study area and fill data gaps. A set of 16 monitoring locations were selected, and HOBO pressure loggers were installed at each site in December 2016. Over the last 4.5 years, pressure and temperature were recorded at 30-minute intervals. The record provided a detailed dataset of water levels that were used for model development and calibration.

Other data gaps identified were related to sediment properties. Sediment conditions within the basin were evaluated using grab samples to evaluate grain size distributions. In general, the streambeds consist of gravel with limited sand; the lake is primarily silt and clay. Due to the presence of cohesive material (silt and clay) in the lake, Anchor QEA also collected core samples for SEDflume erosion analysis. The erosion analysis was used to determine parameters for sediment movement as part of model development.

Subsurface investigations included sub-bottom profiler (SBP) surveys and core sampling. SBP surveys and core sampling were used to estimate the thickness of deposited silt and clay material in the region of the delta feature. Core samples were also used to provide sediment grain size information and evaluate approximate date of deposition through cesium-137 analysis. Findings indicated a thick layer of cohesive material that is in continual flux, i.e., **not consistently depositional on the delta feature.**

Sediment transport rates were the final missing parameters. The aforementioned SSC measurements occur only occasionally, and samples taken during large flow events are limited. Researchers were also unable to find bedload sediment transport measurements at any location in the watershed. Anchor QEA field work included trips to gather additional SSC measurements to help close data gaps in the record. Technicians also sampled bedload sediment transport and found that even under large flows, the **bulk of sediment transport occurs as cohesive silt and clay in suspension rather thn along the bed**.

Hydraulic calibration of the model consisted of tuning roughness parameters to match measured peak WSEs for a range of flow events. Events that occurred between July 2007 and April 2017 were used for hydraulic calibration. Model tuning relied on adjusting hydraulic roughness coefficients and flow roughness factors. Calibration datasets included the USGS gages throughout the model domain, high water marks, and the Anchor QEA monitoring stations. Model results showed good agreement with the gaged locations.

HEC-RAS has limited capabilities to accurately model cohesive sediment. GRDA discussed this at length in the Updated Study Plan submitted in April 2022 and proposed using a quantitative analysis of bathymetric change in addition to an STM focused on the upper regions of the study area.

In issuing their Determination on Request for Study Modifications (FERC 2022), FERC allowed development of the quantitative analysis and also agreed that HEC-RAS could be used to model portions of the study area above river mile 100, and that trapping efficiency and modeled sediment outflows could be used to evaluate sedimentation within the lower portion of the reservoir.

GRDA used a quantitative analysis of sedimentation to evaluate future deposition within the study area. A relationship between hydraulic bed shear stress as evaluated using a fixed bed HEC-RAS model and measured sediment deposition was developed for this purpose. After evaluation, the results indicated that sediment deposition would occur primarily on the downstream face of the delta feature, which follows typical evolution patterns of such deposits. The end result is that the delta feature is not expected to grow in height over the coming license period.

Sediment model calibration showed reasonable agreement with measured sediment deposition between the circa-1940 datasets and more modern surveys. Discrepancies are attributable to measurement uncertainties, particularly due to the significant limitations of the circa-1940 survey information.

Predictive 50-year simulations included analyses of *High* and *Low Sedimentation* simulations to account for the uncertainties of the available datasets. The calibrated sediment inflows were used to evaluate expected results under both *Baseline* and *Anticipated Operations*; the *High* and *Low Sedimentation* simulations were used to bound the maximum and minimum sedimentation volumes that could reasonably occur in the upcoming license period under anticipated Project operations. These analyses showed that the sediment primarily accumulates on the downstream face of the delta feature, as predicted by literature sources such as Vanoni (2006). The predicted geometry was then imported to the one-dimensional (1D) Upstream Hydraulic Model (UHM) to evaluate impacts to water levels.

Evaluation with the 1D UHM allowed assessment of changes to water levels based on sedimentation. The 1D UHM was used to evaluate the July 2007 flow event and a synthetic 100-year event on the Neosho River for three separate starting pool elevations.

Model results were compared to determine the relative impacts of 50 years of sediment accumulation under expected loading, *High Sedimentation* versus *Low Sedimentation* rates, and *Baseline* versus *Anticipated Operations*. The results indicated that **sediment loading, a natural**

phenomenon outside GRDA's control, generally has the largest impact on upstream water levels in the Neosho River, overshadowing any impacts caused by Project operations. The impacts to water levels in the City of Miami for all evaluations are immaterial. Project operations, sediment loading, and future geometry show immaterial changes to water levels in the vicinity of the City. GRDA does not control the volume of incoming sediment, and the simulations indicate that, much like the findings of the Hydrologic and Hydraulic Study, nature dictates incoming sediment loads and therefore water levels in the study area, *not* Project operations.

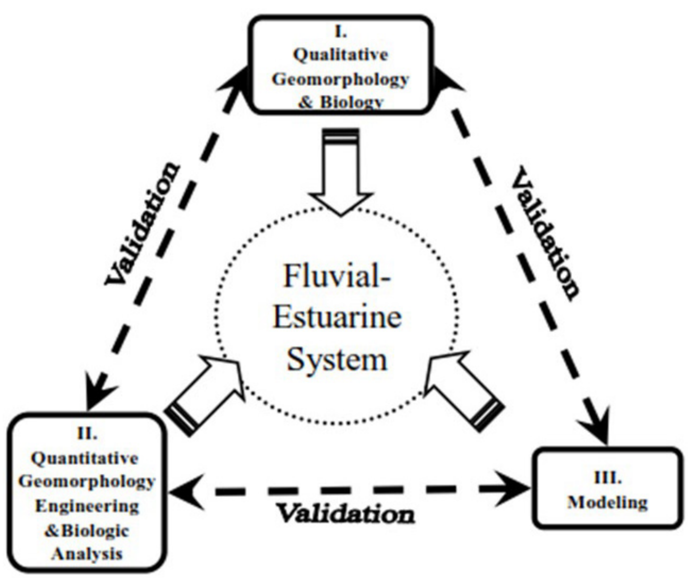
The sedimentation model inputs and outputs have been made available to relicensing participants for download upon request.

1 Introduction

The Sedimentation Study has been divided into three main stages—data collection, model development, and sedimentation predictions. During the initial stage, the study team collected data that were publicly available, analyzed data gaps, and created and executed plans to gather additional information. Model development used the field data to develop and calibrate the sediment transport model (STM). Sedimentation predictions will use the calibrated model to estimate the future deposition and erosion patterns within the study area to help evaluate future flood risks in the basin.

As discussed in the *Updated Study Plan Sedimentation Study* (USP; Anchor QEA et al. 2022), a three-level approach was implemented in conducting the Sedimentation Study. This approach includes qualitative geomorphic analysis, quantitative engineering and geomorphic analysis, and computer modeling (Figure 1). Qualitative geomorphic analysis considers the general trends in the system and how the stream has evolved over time. The quantitative engineering and geomorphic analysis uses measured data and hydraulic shear stress model results to determine the amount of sediment deposited or eroded in the study area, and computer modeling uses Hydrologic Engineering Center's River Analysis System (HEC-RAS) sediment transport features to evaluate sedimentation within the study area. Each individual component of this approach is intended to provide validation to the other components to ensure reasonable and reliable results are obtained.

Figure 1
A Conceptual Schematic of the Three-Level Approach for Analyzing Geomorphology, Sediment Transport, and Sedimentation Processes



Note: Validation must occur between all three levels to ensure that reasonable results have been achieved.

1.1 Study Goals and Objectives

The primary goal of the Sedimentation Study is to determine the potential effect of the Pensacola Hydroelectric Project (Project) operations on sediment transport, erosion, and deposition in the lower reaches of tributaries to Grand Lake upstream of Pensacola Dam. Additionally, the Sedimentation Study is designed to provide an understanding of the sediment transport processes and patterns upstream of Grand Lake on the Neosho, Spring, and Elk rivers, as well as on Tar Creek. An STM will provide estimates of overall sedimentation trends and impacts of sedimentation in the project boundary.

1.2 Study Area

The Pensacola Dam is located near Langley, Oklahoma. It impounds the Neosho River, forming the Grand Lake reservoir (often referred to as Grand Lake O' the Cherokees). The Grand Lake reservoir is split between four counties, including Craig, Ottawa, Delaware, and Mayes in northeastern Oklahoma. The main tributaries that flow into the reservoir are the Neosho, Spring, and Elk rivers. Honey, Drowning, Duck, and Horse creeks also flow into the lake. Additional minor tributaries include Sycamore and Tar creeks.

1.3 Study Plan Proposals and Determinations

Grand River Dam Authority (GRDA) is currently relicensing the Project. A timeline of study plan proposals and determinations is as follows:

1. On April 27, 2018, GRDA filed its Proposed Study Plan (PSP) to address sedimentation modeling in support of its intent to relicense the Project.
2. On September 24, 2018, GRDA filed its Revised Study Plan (RSP).
3. On November 8, 2018, the Federal Energy Regulatory Commission (FERC) issued its Study Plan Determination (SPD) for the Project.
4. On January 23, 2020, FERC issued an Order on the Request for Clarification and Rehearing, which clarified the timeline for certain milestones applicable to the relicensing study plan.
5. On September 30, 2021, GRDA filed its Initial Study Report (ISR).
6. On December 29, 2021, GRDA filed its response comments on the ISR. This document included the following two attachments relevant to the Sedimentation Study:
    a. Appendix D – Sedimentation ISR (updated)
    b. Appendix E – Proposed Modified Study Plan for Sedimentation Study
7. On January 14, 2022, GRDA held a technical meeting for the Sedimentation Study. A summary of the technical meeting was filed with FERC on January 20, 2022.
8. On April 27, 2022, GRDA filed Response Comments on Sedimentation Study and Submission of USP for Approval with FERC. The document included the following three attachments:
    a. Attachment 1 – GRDA Response Comments on Sedimentation Study Plan

    b. Attachment 2 – Independent Technical Review (ITR) of HEC-RAS STM
    c. Attachment 3 – USP
9. On May 27, 2022, FERC issued its Determination on Request for Study Modifications for the Pensacola Hydroelectric Project. This Study Modification Determination (SMD) focused on the Sedimentation Study.
10. On September 30, 2022, GRDA filed this report, the Updated Study Report (USR).

FERC's May 27, 2022 SMD approved GRDA's USP (also referred to by FERC as the second proposed plan modification) with the following modifications:

1. Extend the proposed downstream modeling limit for HEC-RAS to the U.S. Route 59 crossing at river mile (RM) 100.
2. Analyze the effects of sediment on storage capacity in Grand Lake using hydraulic outputs from the Upstream Hydraulic Model (UHM) and the U.S. Army Corps of Engineers (USACE) sediment trapping efficiency calculations downstream of RM 100.
3. Run the UHM using starting reservoir elevations of 740 feet, 745 feet, and 750 feet Pensacola Datum (PD).
4. Run the UHM with the predicted channel geometries and starting reservoir elevations using the simulated 100-year inflow event and the historical July 2007 inflow event.

As documented in this USR, GRDA has completed FERC's requested modifications to GRDA's approved USP.

2 Description of Data

2.1 Existing Data

A significant amount of the necessary data was available to the study team at the beginning of the project. Sources included USACE, the U.S. Geological Survey (USGS), past studies in Grand Lake, and surveys performed by the Oklahoma Water Resources Board (OWRB).

2.1.1 Terrain Information

Multiple datasets were available for potential use in this analysis. The earliest data are survey information from circa 1940. The most recent dataset was collected in 2019. All datasets considered for the study are discussed in chronological order in the following subsections.

Sedimentation deposition and erosion rates are key to the Sedimentation Study. Having reliable survey data collected at a ***known date*** is crucial to develop a useful STM. Without accurate information about the time interval between surveys, it is impossible to estimate a rate of change to calibrate a model. During calibration, model parameters are adjusted to reflect measured changes. For example, if those changes occur over a period of 10 years, the resulting parameters would be significantly different than if the same measured changes occurred over 70 years. Therefore, GRDA has documented the available data and assessed both: 1) the reliability of the data; and 2) whether a ***known date*** of data collection can be established.

2.1.1.1 Circa-1940 Data

The circa-1940 dataset comprises the following three available data sources:

1. 1938 USACE topographic maps with 5-foot contours (USACE 1938)
2. 1941 USACE Pensacola reservoir envelope curve computation folder (USACE 1941)
3. 1942 USACE Pensacola reservoir revised envelope curve computation folder (USACE 1942)

The 1938 USACE maps were used in the 1941 and 1942 USACE computations. The 1941 information does not include cross sections in plotted or tabular format. Rather, the data are presented as elevation/area and elevation/width relationships. The 1942 information includes plotted cross sections, but no data are available below the Neosho River/Spring River confluence.

Because the ***known date*** of the data collection can be established, these three data sources were used to create a single circa-1940 representation of Pensacola Reservoir and the upstream area. The information is imprecise and has significant limitations. Nevertheless, GRDA recognizes that this dataset represents the best available data for conditions at the time of dam construction and used it as the basis for model development in this study.

2.1.1.2 1969 USACE Data

During the Sedimentation Study Technical Meeting, the 1988 Flood Insurance Study was mentioned as a potential source for historical bathymetric information. GRDA reviewed the Flood Insurance Study and found that the bathymetry came from a 1969 USACE study (USACE 1969). GRDA analyzed the data. Even though the ***known date*** of the data collection can be established, unfortunately the data only extend from RM 134.6 upstream to RM 136.9. This 2.3-mile segment of historical bathymetric data is too short for use in STM calibration and validation. Thus, GRDA did not use the 1969 USACE data in STM calibration and validation.

2.1.1.3 1996 Expert Report

The 1998 Real Estate Adequacy Study (REAS; USACE 1998) states that modeling data (i.e., bathymetry) from Pensacola Dam to Twin Bridges State Park were taken from the Rule 26 Expert Report for the Grand (Neosho) River Upstream of Pensacola Dam (see Section VII, Subsection D of the Hydraulic Analysis section of the 1998 REAS). GRDA obtained the 1996 Expert Report (DeVries 1996) from USACE. The following three presentations of bathymetric data were in the 1996 Report:

1. River thalweg elevation profiles
2. Cross-section plots
3. HEC-2 printouts of cross-section data

The report does not state the source of the bathymetric data presented. Therefore, the ***known date*** of the data cannot be established. GRDA compared these data sources against each other. Multiple thalweg elevation profiles were presented in the report. One thalweg profile did not match the other profiles. The other profiles matched each other, matched the inverts of the cross-section plots, and matched the inverts in the HEC-2 printouts. Therefore, the one outlying thalweg profile was disregarded.

Next, the 1996 Expert Report data were compared to the 1998 REAS data. Results of the comparison are displayed in Figure 2. The 1998 REAS claims that data below Twin Bridges were taken from the 1996 Expert Report. However, the two datasets are significantly different. The 1998 REAS data clearly did not come from the 1996 Expert Report dataset.

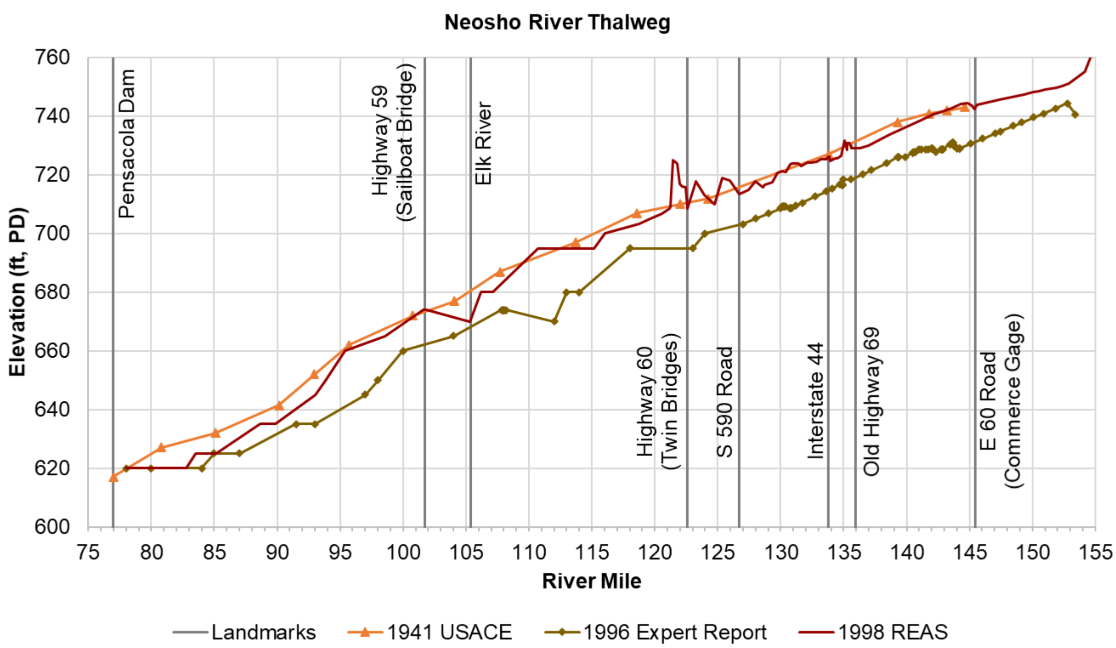
The 1996 Expert Report profile was also compared to the 1941 envelope curve profile to see if the 1996 data originated from the 1941 data. The 1941 profile is also displayed in Figure 2. The 1996 and 1941 data are significantly different from each other. Furthermore, the 1996 Expert Report thalweg is significantly lower than the 1941 thalweg. GRDA considered whether a misreported datum could be the issue, but the differences are on the order of 10 feet or more. This significant decrease in elevation from the 1941 thalweg to the thalweg reported in the 1996 report could only be the result of significant erosion in the lower portion of the reservoir, which is entirely unrealistic.

Summary

1. The ***known date*** of collection for data presented in the 1996 Expert Report cannot be established.
2. The 1996 report data do not match the 1998 REAS data, invalidating the claim that the 1998 REAS data downstream of Twin Bridges came from the 1996 report data.
3. The 1996 report data do not match the 1941 data; the 1996 report data could not have been sourced from the 1941 data.
4. Regardless of the collection date of the 1996 report data, significant and unrealistic erosion would have had to occur after 1941 for the dataset to be valid.

For these reasons, GRDA discarded the 1996 Expert Report data.

Figure 2
1996 Expert Report Thalweg Comparison



2.1.1.4 1998 Real Estate Adequacy Study Data

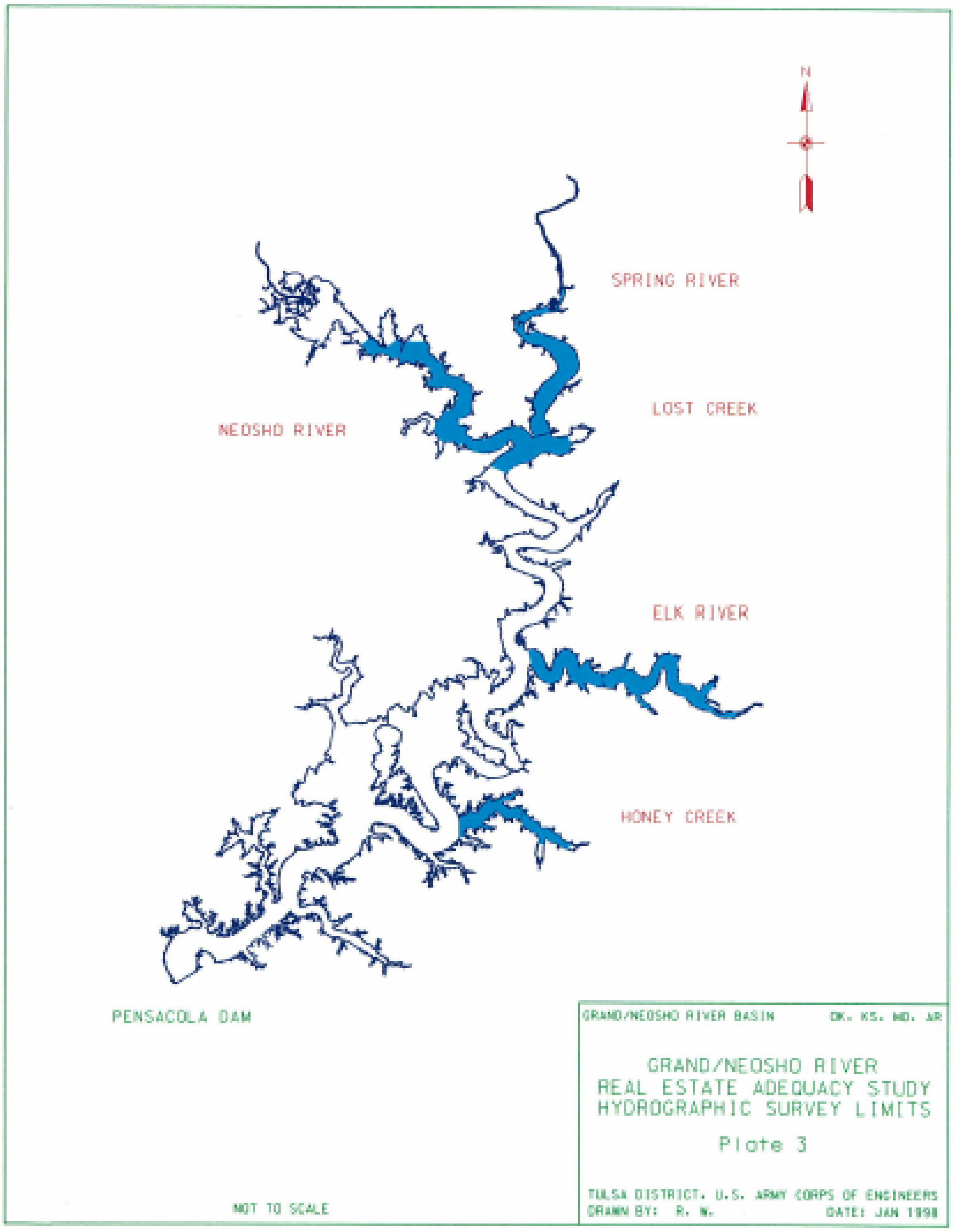
Multiple datasets were presented in the 1998 REAS and are discussed individually in the following subsections.

2.1.1.4.1 Grand and Neosho Downstream Data

The REAS hydrographic survey limits extend downstream to RM 120.1 (approximately 2 miles downstream of the Spring River confluence) along the Neosho River. Data below RM 120.1 were not surveyed as part of the REAS study but were included in the study's analysis. Plate 3 from the 1998

REAS, which documents REAS survey extents, is presented as Figure 3. The solid blue sections represent the area surveyed as part of the REAS.

Figure 3
Hydrographic Survey Limits for REAS



Source: USACE (1998)

As discussed in Section 2.1.1.3, the 1998 REAS states that the 1996 Expert Report downstream data have been invalidated by comparing the two datasets. This fact calls the validity of the REAS downstream data into question. Furthermore, that means the ***known date*** of the data collection cannot be established.

GRDA compared the downstream REAS data to the 1941 envelope curve data in hopes that they would match. This would indicate that the REAS data were from 1941 and would assign a date to the dataset, making it usable for STM calibration and validation. Unfortunately, the downstream data presented in the REAS do not match the 1941 data. Thus, the survey date of the REAS data below RM 120.1 remains unknown. Furthermore, the REAS thalweg is lower than the 1941 thalweg in multiple locations within the downstream reach. Assuming that the REAS data were collected after 1941, that would require erosion in the lower portion of the reservoir, which is extremely unlikely given that low flow velocities and shear stress typically result in sediment depositions within reservoirs.

Summary

1. The REAS directly states that the downstream data were not collected as part of the 1998 study effort.
2. The REAS states that the downstream data came from the 1996 Expert Report. This claim has been invalidated by a comparison of the two datasets.
3. The ***known date*** of collection for the downstream REAS data cannot be established.
4. Unrealistic erosion would have had to occur for the downstream REAS data to be valid.
5. The downstream REAS data do not match any other available datasets. If the data matched, the collection date could be established.

For these reasons, GRDA discarded the downstream portion of the REAS data.

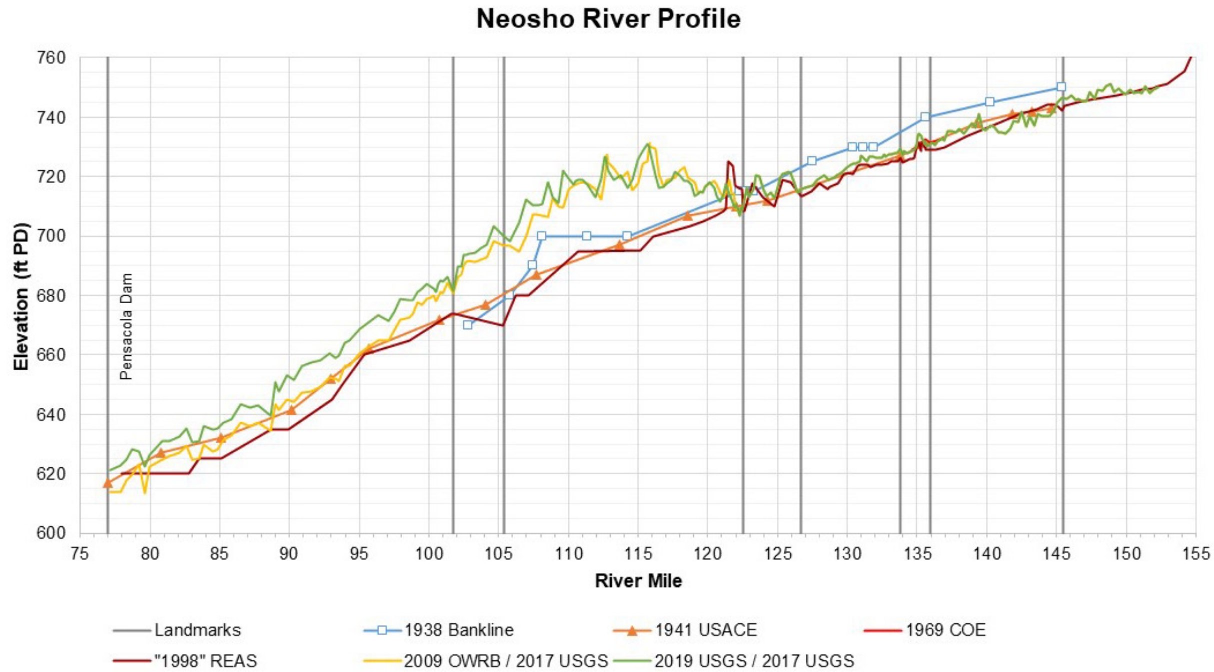
2.1.1.4.1.1 The City's Claims Regarding the Downstream Data

The City of Miami has used the downstream portion of the REAS data to make unsubstantiated claims regarding sedimentation rates and patterns of deposition in the study area. The City claimed that "comparison of the pre-dam river profile with recent bathymetric surveys indicates significant sediment deposition near the head of Grand Lake," and then jumped to the conclusion that sediment deposition in Grand Lake "increases upstream flooding along the Neosho and Spring Rivers."

The foundation of the City's claims is a presumed 1998 date of the downstream REAS data, which cover Grand Lake and extend upstream to RM 120.1. As discussed in Section 2.1.1.4.1, the REAS explicitly states that the downstream data are not from 1998 and were not surveyed as part of the REAS data collection. Regardless, GRDA investigated the City's claims regarding sediment deposition in the study area.

Figure 4 displays multiple thalweg profiles. Even assuming that the "1998" REAS profile was surveyed in 1998 (which it was not), comparison of the datasets would suggest that sediment deposition patterns have changed significantly in ways that cannot be explained solely by the construction of the dam or Project operations.

Figure 4
Historical Neosho River Thalweg Comparison



Note: This plot covers the Neosho River from RM 152.2 at the upstream end to the Pensacola Dam at RM 77.12 on the downstream end.

As shown in Figure 4, the City's claims regarding sediment deposition and erosion patterns would require significant and unrealistic changes since completion of the dam. For a moment, assume that despite the USACE REAS documentation clearly stating otherwise, the City's assumption that the downstream REAS data are from 1998 is correct. If the City is correct, that would mean the following:

1. From 1940 to 1998, sediment eroded in the delta feature region and near the dam.
2. From 1998 to 2009, the sedimentation pattern reversed, and 20 to 30 feet of sediment accumulated at the delta feature in only approximately 11 years.
3. From 2009 to 2019, sedimentation patterns changed again, with virtually no sediment depositing on the top of the delta feature.

This thought experiment reveals how the City's assumptions, which contradict USACE documentation, are flawed.

To further show how the City's assumptions are flawed, GRDA evaluated sediment loading to the reservoir (also referred to as sediment inflow to the reservoir) since completion of the dam in 1940. Using the sediment rating curves developed with USGS data and the field data collected by GRDA, the portion of sediment that entered the study area from 1940 to 1998, 1998 to 2009, and 2009 to 2019 is calculated, assuming that the downstream REAS data were collected in 1998. Sediment loading calculations are presented in Table 1.

Table 1
Relative Sediment Delivery and Measured Deposition Thickness at the Delta Feature by Specified Time Period (if the "1998" REAS Data Are to be Believed)

Time Period	Number of Years	Percentage of Total Sediment Loading	Apparent Deposition in Region of the Delta Feature
1940–"1998"	58	68%	~0 feet
"1998"–2009	11	14%	20–30 feet
2009–2019	10	13%	~0 feet on the top, ~2–3 feet on the downstream face

Most of the deposition (68%) should have occurred between 1940 and "1998"—a period of 58 years—based on historical sediment loading rates. However, the thalweg comparison shows virtually no deposition in the region of the delta feature for this period. Then in the 11 years between "1998" and 2009 with no change in the regulated operations of the reservoir, when only 14% of the deposition should have occurred, there was 20 or 30 feet of deposition at some specific locations within the region of the delta feature. Then in the 10 years between 2009 and 2019, when 13% of the deposition should have occurred, there was 2 to 3 feet of deposition on the downstream face of the delta feature. The City offers no scientific explanation for the complete disconnection between sediment loading and deposition.

Summary

1. The City of Miami has made unsubstantiated claims about sedimentation rates and patterns in the study area.
2. The foundation of the City's claims is based on a presumed (but demonstrably erroneous) 1998 date of the downstream REAS data, which cover Grand Lake and extend up to RM 120.1.
3. The REAS explicitly states that the downstream data are not from 1998.
4. A comparison of the thalweg profiles shows the flaws in the City's assumptions.
5. A comparison of sediment loading to deposition depths shows the flaws in the City's assumptions.
6. The City has offered no scientific data to substantiate their assumptions.

For these reasons and the reasons stated in the previous section, GRDA cannot accept the City's claim that the downstream portion of the REAS data is from 1998.

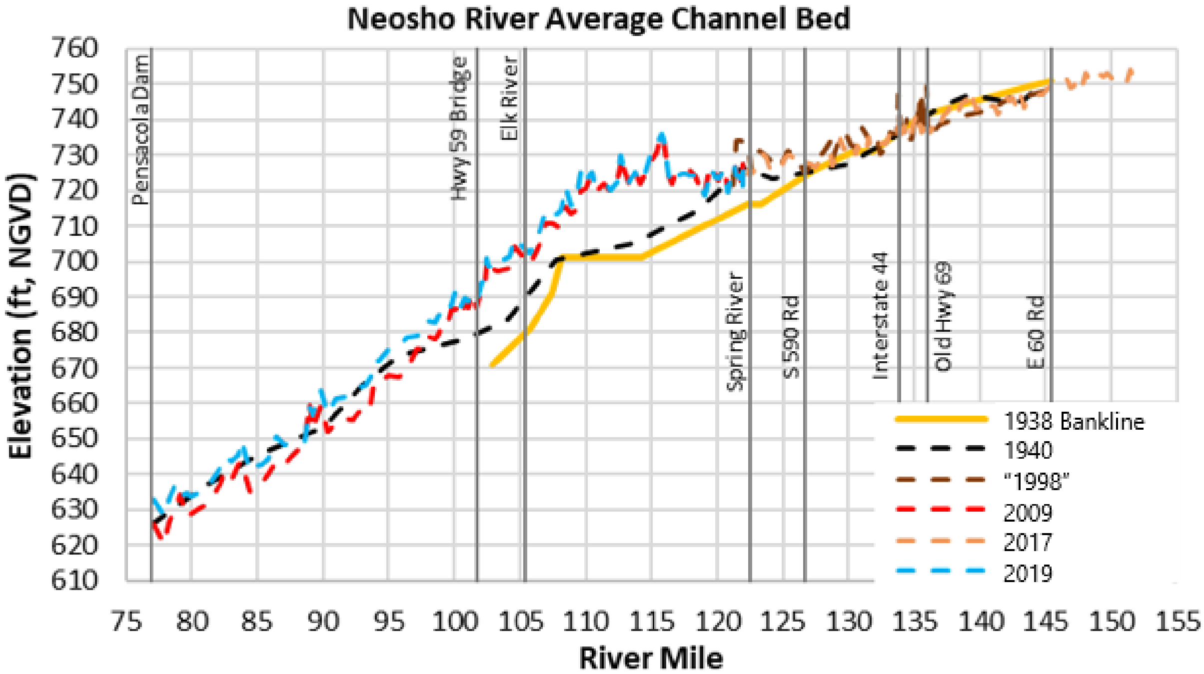
2.1.1.4.2 Neosho and Spring Upstream Data

As displayed in Figure 3, the REAS hydrographic survey limits extend downstream to RM 120.1 along the Neosho River. The Spring River is also included within the upstream REAS survey limits.

In their ITR, WEST Consultants, Inc. (WEST), used the average channel bed profile to compare several datasets against each other, including the REAS geometry (Figure 5). This method of analysis is more representative of overall channel geometries than the simple thalweg profile, because it accounts for portions of the channel that are outside of the thalweg. WEST concluded that the portion of the REAS dataset above RM 120.1 can be used for this study. GRDA agreed that this portion of the REAS dataset can be used in STM development as a calibration dataset. However, there is no quality control documentation in the REAS for this data (see Section 2.1.1.4.4) and the data were obtained using less accurate techniques compared to the more recent datasets. Thus, there is a significant amount of uncertainty regarding this dataset, which influenced the accuracy of the STM calibration and validation.

Determining the rate of sediment accumulation in the study area is critical, and surveyed data with a known collection date is required to calculate rates of sediment accumulation. Although the upstream REAS dataset met the threshold for usability in the STM, the lack of quality control documentation in the REAS casts doubt on the accuracy of the dataset. Nevertheless, because the ***known date*** of the data collection has been established, GRDA recognizes that this dataset represents a usable, comprehensive historical dataset and used the upstream REAS data for STM calibration and validation.

Figure 5
Historical Neosho River Average Channel Bed Comparison



Source: WEST's ITR technical memorandum (WEST 2022)

2.1.1.4.2.1 The City's Recommendations Regarding the Upstream Data

Regarding the upstream REAS data, the City states the following:

> The Neosho River upstream of the City has changed very little since 1940. It may be appropriate to replace the 1998 survey data with the 2019 [sic – the survey is from 2017] survey data for the reach upstream of the City. (City of Miami 2022).

The City proposed to discard the upstream REAS data, which are at least documented in some form, while keeping the least reliable, incorrectly documented data within the REAS—the downstream data that cover Grand Lake. ***The City proposed discarding the only section of the REAS dataset that is based on surveys completed during the 1998 study***. Furthermore, discarding the upstream 1998 REAS data would have prevented GRDA from performing calibration and validation of the STM in the upstream reach. Implementing the City's proposal would have resulted in an STM with less predictive capability.

Therefore, GRDA rejected the City's proposal to discard the documented upstream portion of the REAS dataset.

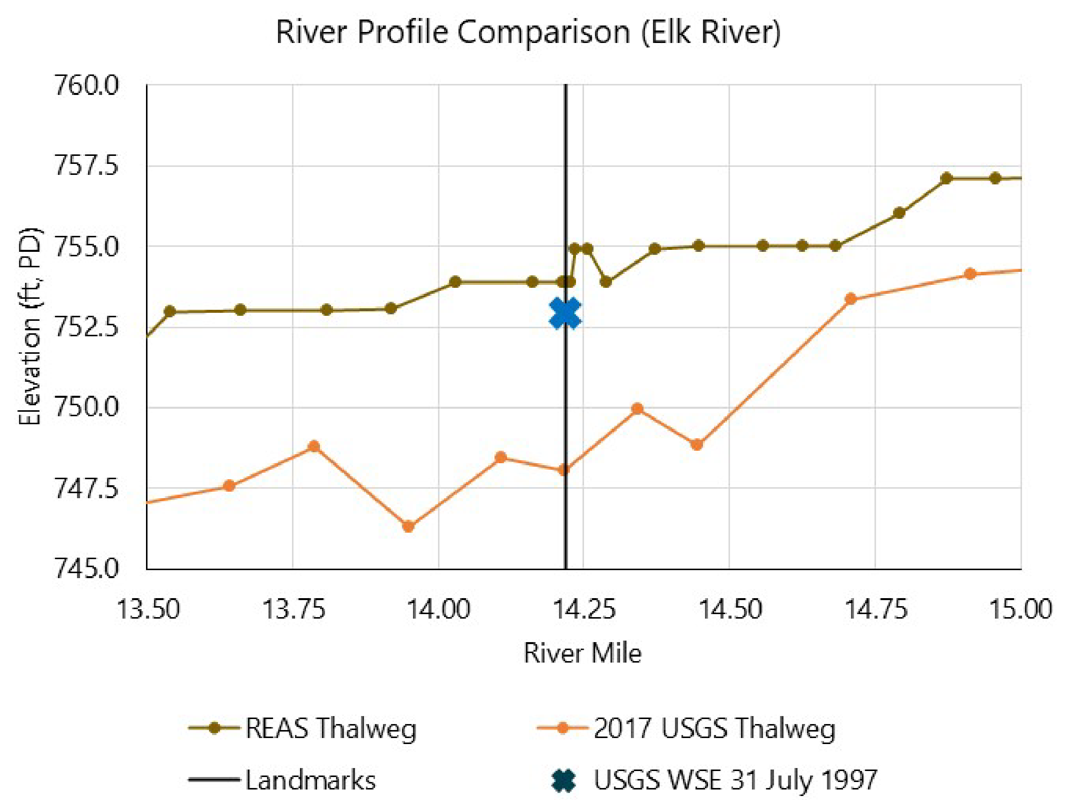
2.1.1.4.3 Elk River Data

As displayed in Figure 3, bathymetry on the Elk River was collected as part of the REAS hydrographic survey. However, there was an obvious issue with the collected data.

A USGS gaging station (07189000 Elk River near Tiff City; USGS 2021a) on the Elk River is located at RM 14.22 on the Highway 43 Bridge. In the REAS dataset, the channel invert at that location is 753.90 feet PD. This is implausible, because that invert elevation is higher than water surface elevations (WSEs) recorded by USGS. REAS documentation states that the survey was performed in July 1997. The USGS reported WSEs were less than 753.90 feet PD at the site for all but 3 days in July 1997, with a low WSE of 752.94 feet PD reported on July 31, 1997 (Figure 6). This is clearly an impossible result, because it suggests the water surface was below ground. As a result, no HEC-RAS model can ever predict the correct WSE at the site during low flow events.

Although the ***known date*** of the data collection has been established, the data are not reliable. For this reason, GRDA did not use the Elk River REAS data in the STM.

Figure 6
Elk River Thalweg Comparison and WSE Measurement



2.1.1.4.4 USACE Stance on Reliability

Given the concerns with the REAS dataset below RM 120.1, GRDA contacted USACE to discuss the REAS data. David Williams, PhD, PE, CFPM, D.WRE, of the Tulsa District stated the following in an email dated January 26, 2022:

> I do have concerns about the applicability of the cross-sectional survey that was used in the 1998 study (for the reasons that have been described), and I have no issue w/ sharing these concerns.

His stated reasons were as follows:

> I did speak with an engineer who previously worked for the Tulsa District, and he pointed out that the survey wasn't subjected to a rigorous QA/QC process.

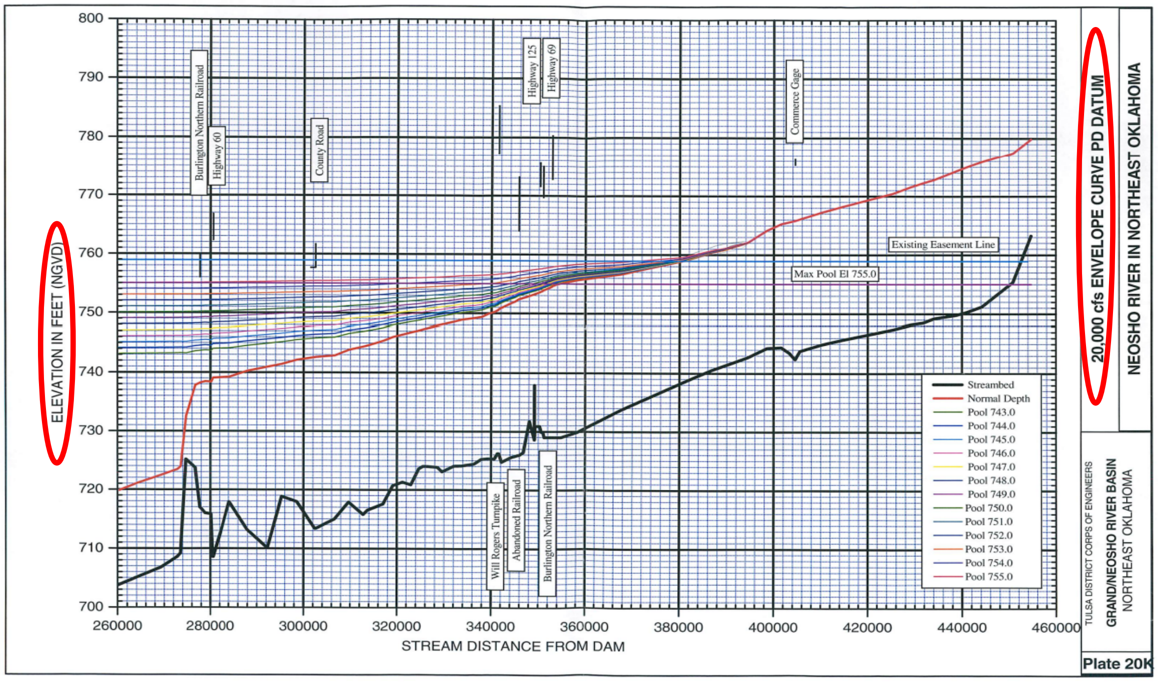
The City itself acknowledged there are problems with the data, suggesting that the datum shift may have been incorrectly applied. In their March 2022 comment submission (City of Miami 2022), the City wrote the following:

> Tetra Tech's review of the REAS dataset indicates that it is about 2 feet higher than other surveys, raising the possibility that the REAS dataset was incorrectly adjusted from Pensacola Datum (PD) to NGVD29.

The City then stated that if that issue is resolved, "the REAS dataset probably may be reliable." The City provided no technical arguments for why the data are reliable or why the datum issue does not call the reliability of the data into question.

GRDA agreed that a datum shift is likely one problem with the data, as evidenced by a plot provided by USACE (Figure 7). In the figure, the vertical axis (on the left) is "Elevation in Feet (NGVD)," but the chart title at right is "20,000 cfs Envelope Curve PD Datum." GRDA compared the streambed in the figure to the channel invert in the REAS data and determined that the vertical datum of the displayed data is PD. This type of error (listing two datums in the same figure) confirms inadequate quality control of the data and contradicts the City's argument that the full REAS dataset "probably may be reliable" (a heavily caveated assertion that itself demonstrates the City's lack of confidence in its own assertion).

Figure 7
USACE Figure Showing Mislabeled Vertical Datum



Note: Figure provided by USACE showing thalweg profile of the Neosho River in the vicinity of Miami, Oklahoma; red outlines added to highlight conflicting vertical datum labels.

The City's argument for inclusion of the full REAS dataset did not rely on technical criteria. The City cited use of the REAS in litigation as a reason to use the full REAS dataset as a basis for STM development. The fact that the REAS was used in litigation proceedings in the past has no bearing on whether the dataset is reliable or useful for the purposes of this study. The City claimed the delta feature was formed in an 11-year span between 1998 and 2009 but, as discussed in Section 2.1.1.4.1, the "1998" data are not actually from 1998. This fact undermines the City's claims regarding delta feature formation. The City's consultant could have easily performed a sediment loading analysis, which would have revealed the City's error. The City asserted that REAS data in the reservoir should be treated as representative of 1998 conditions, ignoring the USACE documentation in the REAS report. Any objective evaluation of the data shows that the REAS data below RM 120.1 cannot reasonably be used for this study.

Summary

1. USACE informed GRDA that the REAS was completed without proper quality control processes, and as a result, the data may not be reliable.
2. The City acknowledged that there are issues with the REAS yet provided no technical arguments for why those issues do not call the reliability of the data into question.

3. The City's claim that the delta feature was formed in an 11-year span between 1998 and 2009 relies on an undated dataset and thus is invalid.

Based on the information presented in Section 2.1.1.4.1 and the information in this section, GRDA discarded the downstream portion of the REAS data.

2.1.1.4.5 Conclusion on 1998 Real Estate Adequacy Study Data Reliability

Portions of the "1998" REAS dataset are usable while other portions are unusable, as summarized in the following:

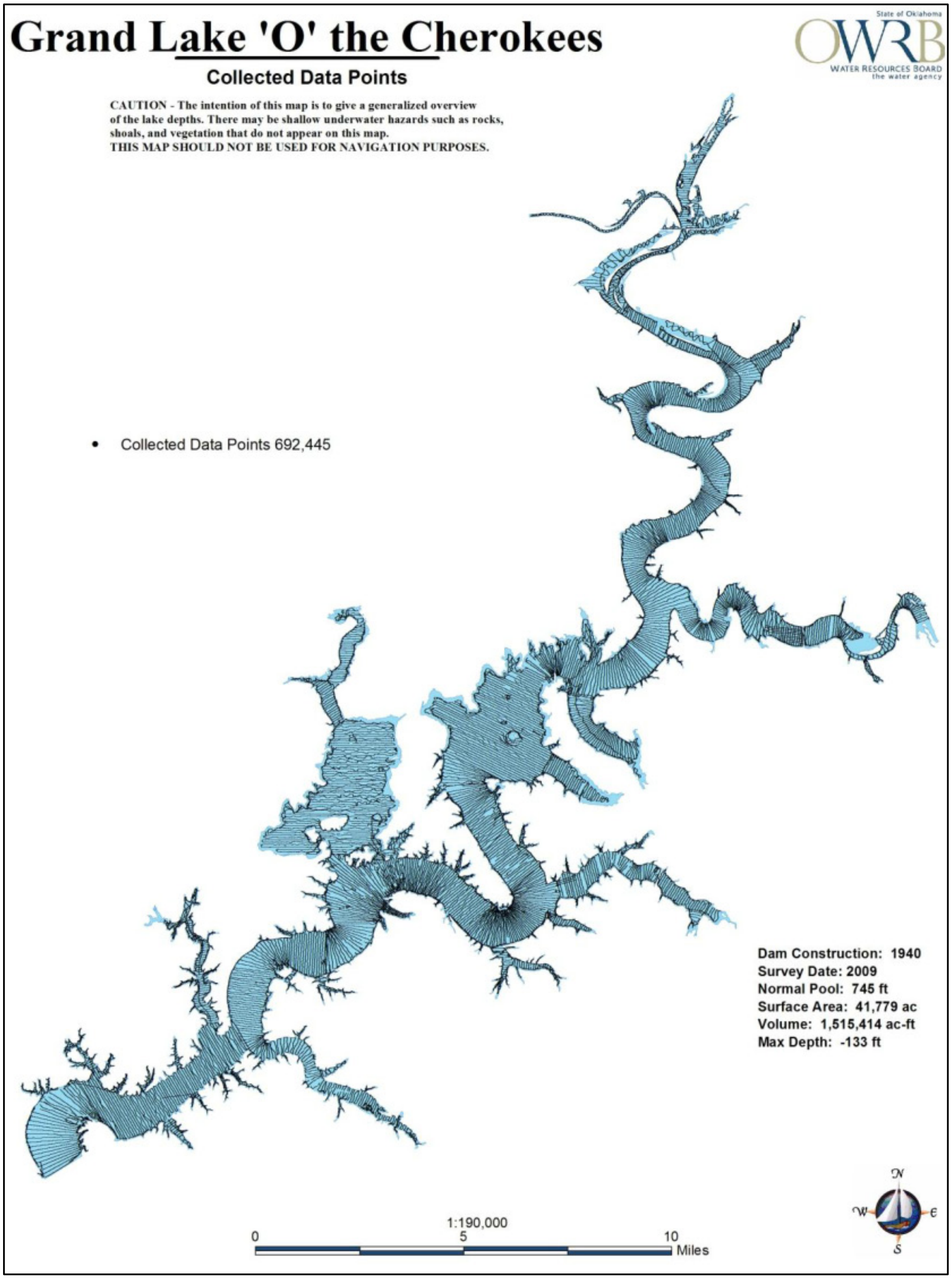
1. The downstream data, which cover Grand Lake below RM 120.1, are not usable and were discarded for the purposes of this study.
2. The upstream data, which cover the Neosho River above RM 120.1 and the Spring River, are usable for this study.
3. The Elk River data are not usable and were discarded for the purposes of this study.

There is a significant amount of uncertainty regarding the usable data. The upstream REAS data meet the threshold of usability in the STM, but the lack of quality control documentation in the REAS casts doubt on the accuracy of the dataset and increases the level of uncertainty in the data. Nevertheless, because the ***known date*** of the upstream REAS data has been established, GRDA recognizes that this dataset represents a usable, comprehensive historical dataset and used the upstream REAS data for STM calibration and validation.

2.1.1.5 2009 Oklahoma Water Resources Board Survey

The 2009 Grand Lake bathymetry data were collected by OWRB using a single-beam echosounder. The coverage of the lake was extensive, with data collected along 1,680 virtual transects (OWRB 2009). The finalized dataset includes nearly 700,000 points. The 2009 OWRB report shows survey track lines; this figure is presented as Figure 8. The 2009 OWRB report includes a section devoted to the discussion of quality control/quality assurance. Intersecting transect lines and channel track lines were compared to assess the estimated accuracy of the survey measurements. OWRB documented that the data quality met or exceeded USACE's performance standards (USACE 2002), with a reported depth accuracy at the 95% confidence level of ±1.3 feet and a bias of 0.5 foot.

Figure 8
Data Density and Survey Track Lines Provided by OWRB in 2009 Grand Lake Survey Report



A review of typical reservoir deposition and siltation patterns shows that fine sediments can be transported far into a reservoir. van Rijn (n.d.) states that inflowing, sediment-laden water may travel under the relatively clear reservoir water as a plume (density or turbidity currents), bringing sediment far closer to the dam than would be allowed through shear stress alone. Zavala (2020) confirms this in a discussion of hyperpycnal flows, or density-driven flows, in which he states that incoming flows can transfer large volumes of sediment even without steep bed slopes. Hyperpycnal flows occur when a relatively denser gravity flow of sediment-laden water enters a marine or lacustrine body of water and the density of the moving water is greater than the density of the standing water, causing the denser, sediment-laden water to flow along the bed, as an underflow below the standing water.

2.1.1.5.1 Quality Concerns

The 2009 OWRB survey was not without problems. Although it is the best available dataset from this timeframe, it shows significantly more sedimentation than is realistic given incoming sediment loads. The total incoming sediment volume from 1940 to 2019 is approximately 234,974 acre-feet with an incoming sediment load of approximately 327,044,375 tons, which converts to a sediment density of 63.9 pounds per cubic foot (pcf). The same calculation based on volume change and sediment load from 1940 to 2009 results in a computed sediment density of approximately 115.5 pcf, whereas the 2009 to 2019 calculation results in a sediment density of 10.6 pcf. This disparity of calculated sediment densities between the 1940 to 2009 and 2009 to 2019 data demonstrates the issue with the bathymetric surveys compared to sediment load. The issue with this dataset is not simply that deposition was near the dam because hyperpycnal flows are capable of bringing sediment to the lower reservoir. The issue is the total volume of deposition given the incoming sediment load.

In an e-mail exchange with USGS, Jason Lewis (2022) indicated they had not found any major issues with the 2009 bathymetric dataset. He also stated the following:

> The 2009 dataset tends to show much greater variability in flat areas compared with 2019 data, so I suspect a lot of that has to do with correction processes such as GPS correction, temperature correction issues, and other issues such as boat movement.

The impossibly high deposition in the lower reservoir led GRDA to use only the portion above RM 100 for calibration purposes. The reservoir downstream of RM 100 was evaluated using only total change from 1940 to 2019 in analysis. This preserves a reasonable long-term estimate of total deposition where impacts are to the conservation pool while not discarding the entire 2009 dataset because it is the best available dataset.

Because the dataset has documented quality control and there is a ***known date*** of data collection, GRDA used the 2009 data for calibration and validation upstream of RM 100. However, as explained above, deposition in the lower reservoir is not realistic given the sediment loading between 1940 and 2009, so the 2019 USGS survey was used for long-term evaluation below RM 100.

2.1.1.6 2017 USGS Upstream Survey

The 2017 USGS upstream survey data cover the Neosho, Spring, and Elk rivers. The 2017 USGS upstream survey data went through a thorough quality control process and, as a result, are considered a reliable data source. USGS calculated quality assurance statistics at the intersection of primary and control transects. The root-mean-square-error (RMSE) of the quality assurance data was less than 0.5 foot for all data collection methods on all rivers (Smith et al. 2017).

Because the dataset has documented quality control and there is a ***known date*** of data collection, GRDA can use the 2017 USGS data for STM calibration and validation.

2.1.1.7 2019 USGS Grand Lake Survey

As part of the FERC SPD, the 2019 USGS Grand Lake bathymetry data were collected by USGS using a multi-beam echosounder. The 2019 USGS survey data went through the highest levels of quality assurance and, as a result, are considered a reliable data source. USGS used literature-based methodologies for quality assurance. Quality assurance measures included beam-angle checks (required to verify that the multi-beam system is operating within USACE-approved standards), patch tests (used to identify and correct systematic errors), and uncertainty estimations (using total propagated uncertainty, or TPU). USGS reported that more than 95% of the TPU values were less than 0.30 foot, which is within the most stringent specifications for an International Hydrographic Organization Special Order survey (IHO 2008).

Yet the City found issue with the 2019 USGS dataset despite the rigorous quality assurance documented by USGS (2020). The City compared thalweg elevations between the 2009 and 2019 datasets and claimed that the aggradation rates were unrealistic (City of Miami 2022).

The City argued that seeing deposition near the dam is unreasonable and indicates there is no explanation for sediment moving that far into the reservoir. The literature is clear that density currents, and other transport mechanisms, operate in reservoirs and carry sediment far into impoundments (Lumborg and Vested 2008; van Rijn n.d.; Zavala 2020).

The City's comments do not cast doubt on the accuracy of the entire 2009 and 2019 datasets. Rather, the disregard for documented reservoir sediment transport phenomena demonstrate that the City's consultant misunderstands basic principles of sediment transport in reservoirs.

Because the dataset has documented quality control and there is a ***known date*** of data collection, GRDA used the 2019 USGS data for STM calibration and validation.

2.1.1.8 Topographic Surveys

Two primary data sources exist for overbank analyses. The first is topographic survey information gathered during the 1998 REAS (USACE 1998). The extents of this survey reach the Oklahoma and Kansas border along both the Neosho and Spring rivers and approximately 5 miles upstream of the Highway 43 Bridge on the Elk River. The second major overbank data source is Light Detection and Ranging (LiDAR) data from a mission flown in 2011 (Dewberry 2011). Where additional data were needed for overbank areas, they were obtained from the USGS National Elevation Dataset (NED) one-third, arc-second dataset (USGS 2017). These combined datasets covered the entire overbank portion of the study area.

2.1.1.9 Terrain Datasets

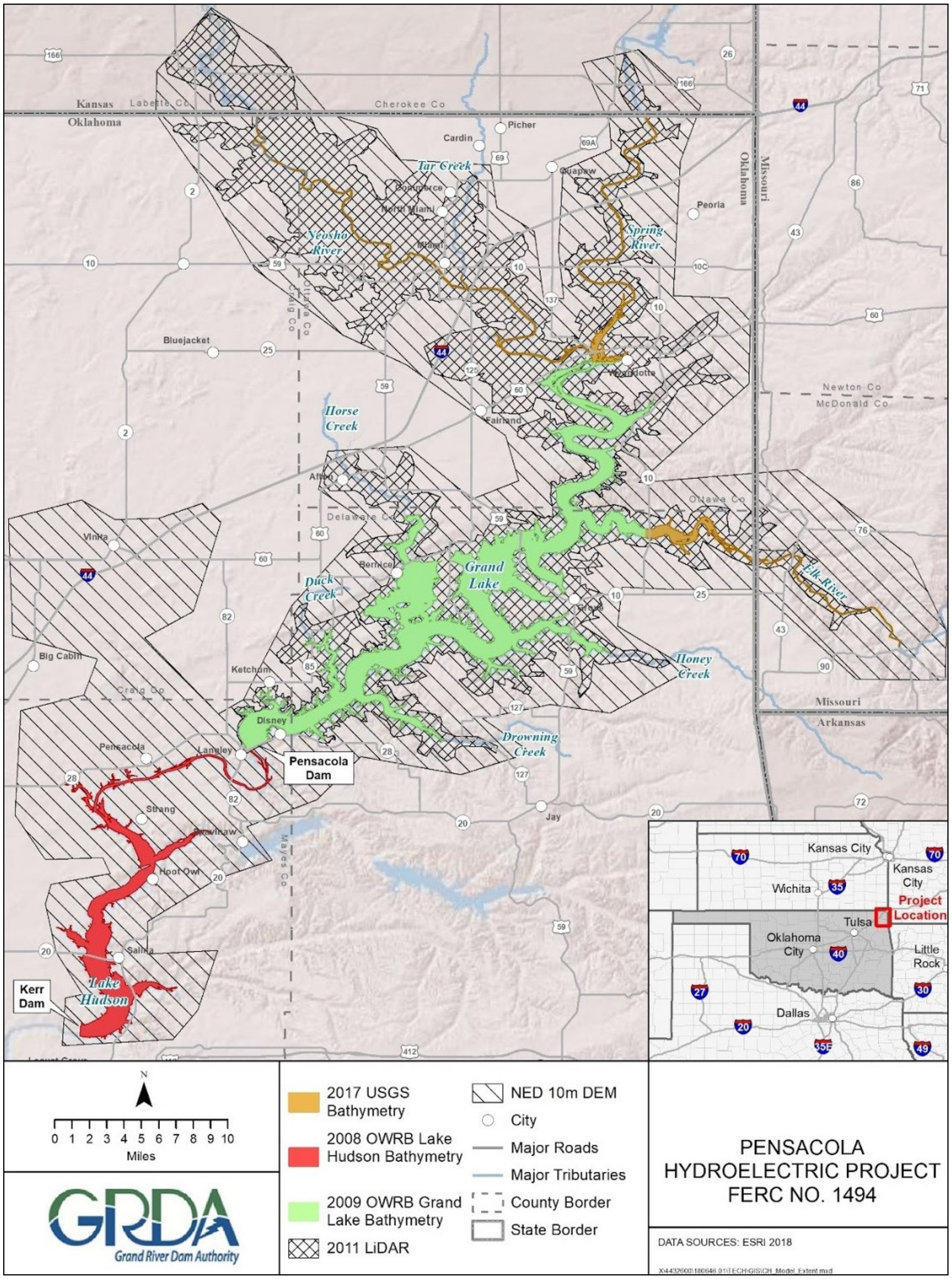
The information gathered from the above-referenced sources was compiled to make three terrain datasets. The datasets served as the basis for all STM geometry development. Although data for each were created from a patchwork of sources measured at different times, for simplicity of naming them, they will be referred to in this report by the year of the relevant Grand Lake survey. Upland topography is stable enough over time that it can be combined with bathymetry data taken at a different point in time. Terrain files contain both bathymetric and topographic information. Table 2 details the terrain names and relevant source materials.

Table 2
Summary of Datasets Used to Create the Three Primary Terrain Files Used in the Sediment Study

Terrain Name	Grand Lake Survey	Upstream Survey	Overbank Survey
"1998" Terrain	Unspecified Circa-1940 Data	1998 REAS	1998 REAS/2011 LiDAR/2017 NED
2009 Terrain	2009 OWRB	2017 USGS	2011 LiDAR/2017 NED
2019 Terrain	2019 USGS	2017 USGS	2011 LiDAR/2017 NED

Figure 9 shows the survey areas for each of the above-referenced surveys, except the 2019 USGS bathymetric survey of Grand Lake and the 1998 REAS survey. The extents of the 2019 Grand Lake survey are approximately the same as those of the 2009 OWRB survey.

Figure 9
Survey Extents of Various Data Sources for Sediment Transport Model Development



2.1.1.10 Stage-Storage Curves

Grand Lake stage-storage curves were available dating back to 1940. USACE created a capacity curve from as-built dimensions and surveys at that time. The 2009 OWRB survey of Grand Lake and the 2019 USGS survey of Grand Lake provide additional stage-storage curves. These were used to estimate the annual volume of sediment deposition within the Grand Lake reservoir as a ground-truthing measure.

2.1.1.11 ADCP Bathymetric Profile Comparison

USGS periodically performs discharge profile measurements near gage stations using an acoustic Doppler current profiler (ADCP), and data are available on request. Although the primary function of the ADCP sampling events is to generate current profiles, the ADCP also measures water depth along the sampling transect. Using the river stage at the time of the event, water depth can be converted to bed elevation. Comparing the multiple profiles taken at a similar location over several years can reveal sediment transport trends.

For each gage, ADCP profile locations vary from event to event. The data were projected onto a single profile line for comparison. The profile lines were placed to represent as many ADCP transects as possible. Given that the transects are not taken at exactly the same location, elevations near the banks are likely unreliable.

2.1.1.11.1 Neosho River near Commerce

Figure 10 displays the ADCP transects taken at the Neosho River near the Commerce USGS station. Only the 2017, 2018, and 2019 data are near enough spatially to be compared. The 2018 and 2019 transects in Figure 11 show a stair-stepping effect, which is likely due to poor Global Positioning System (GPS) signal and reporting. Change in volume cannot be analyzed due to the data gaps in the 2018 and 2019 transects.

Figure 10
Neosho River near Commerce USGS ADCP Transects

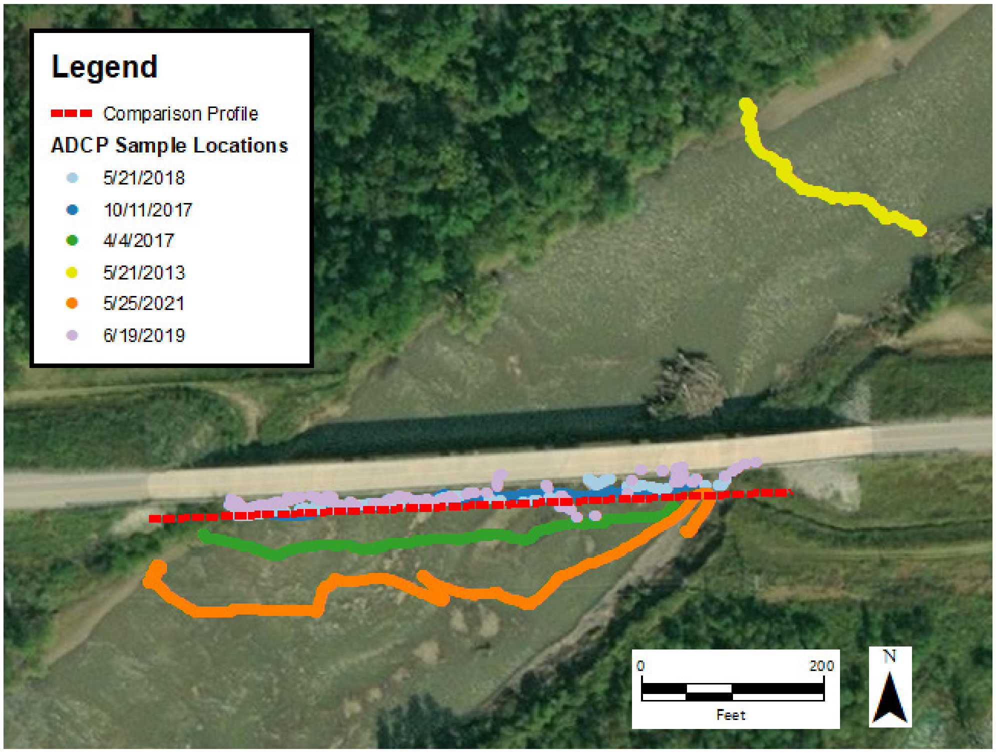
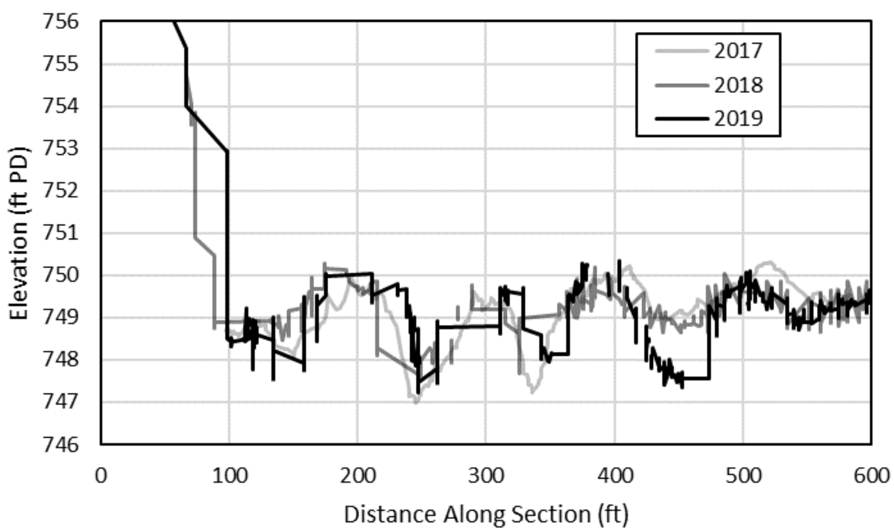


Figure 11
Neosho River near Commerce USGS ADCP Sections



2.1.1.11.2 Neosho River at Miami

The Neosho River at Miami station has data from six sampling events spanning 2017 to 2021. The transects are spaced along approximately 50 feet of river as seen in Figure 12. Three high-quality transects equally spaced in time are displayed in Figure 13. There is almost no change in channel depth from 2017 to 2021.

Figure 12
Neosho River at Miami USGS ADCP Transects

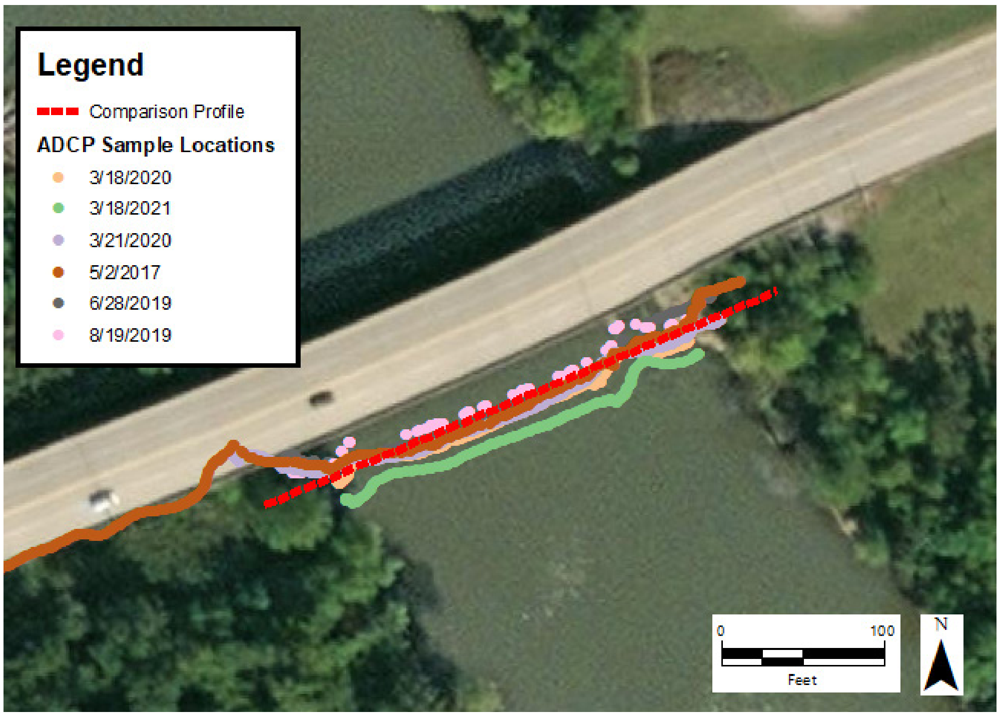
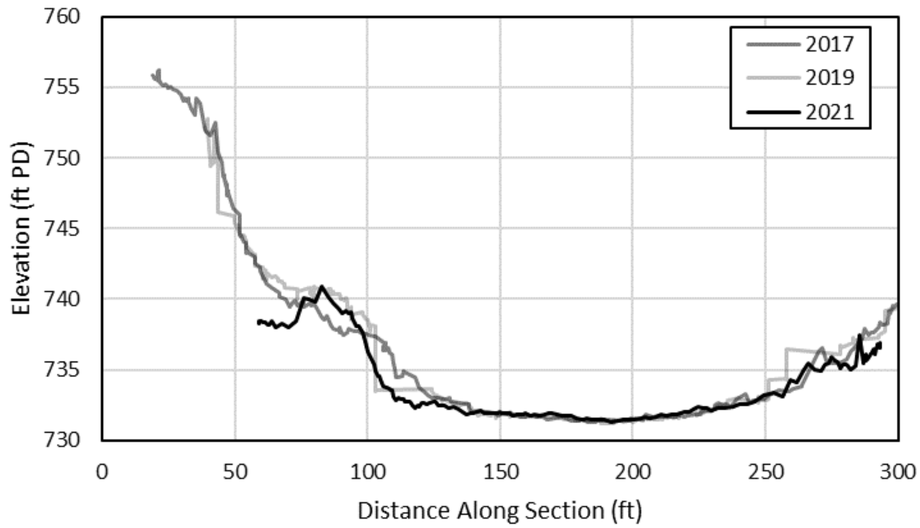


Figure 13
Neosho River at Miami USGS ADCP Sections



2.1.1.11.3 Tar Creek near Commerce

The Tar Creek near Commerce station has data available from four events ranging from 2004 to 2019, taken within 20 feet of each other as seen in Figure 14. The 2019 sample was removed due to data gaps. Figure 15 shows the transects from 2008, 2014, and 2017. Although the 2009 overbank topography is higher than 2014 and 2017, the three sections show a slightly increasing channel elevation, approximately 1 foot from 2008 to 2017.

Figure 14
Tar Creek near Commerce USGS ADCP Transects

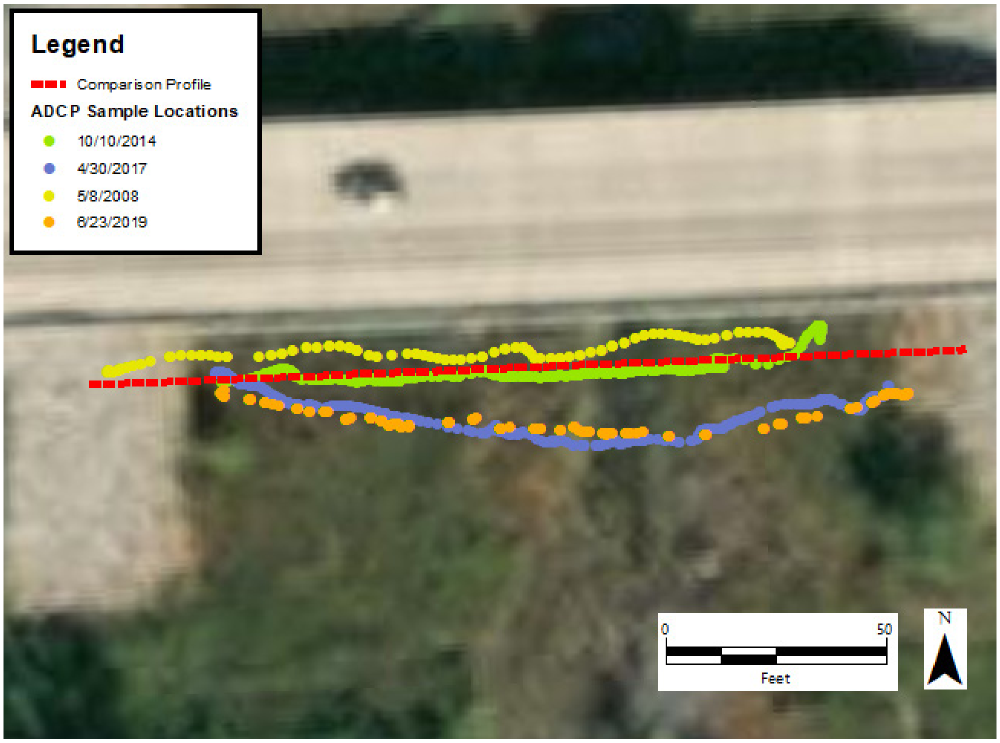
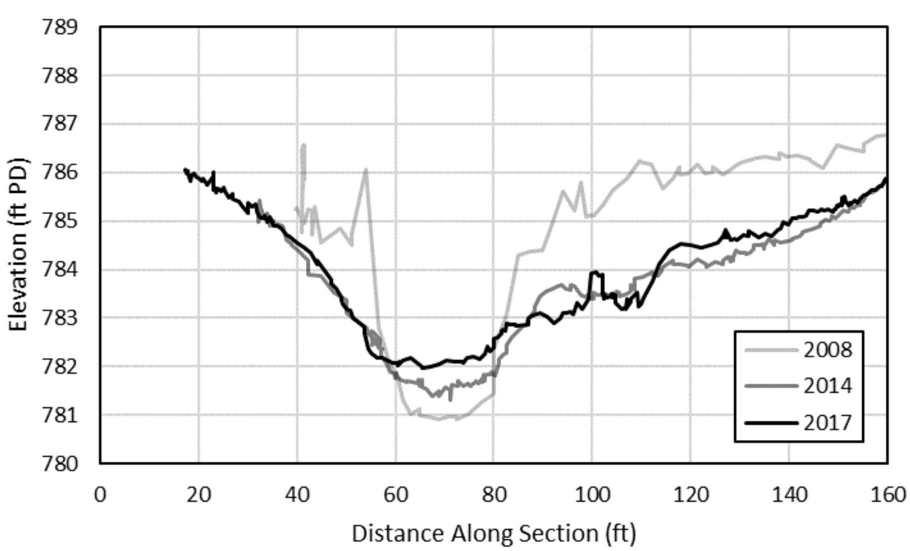


Figure 15
Tar Creek near Commerce USGS ADCP Sections



2.1.1.11.4 Tar Creek at 22nd Street Bridge

Two ADCP sample events were available from Tar Creek at 22nd Street Bridge, taken in 2013 and 2016, spaced approximately 10 feet apart as seen in Figure 16. The data showed no significant change in channel elevation from 2013 to 2016 (Figure 17).

Figure 16
Tar Creek at 22nd Street Bridge USGS ADCP Transects

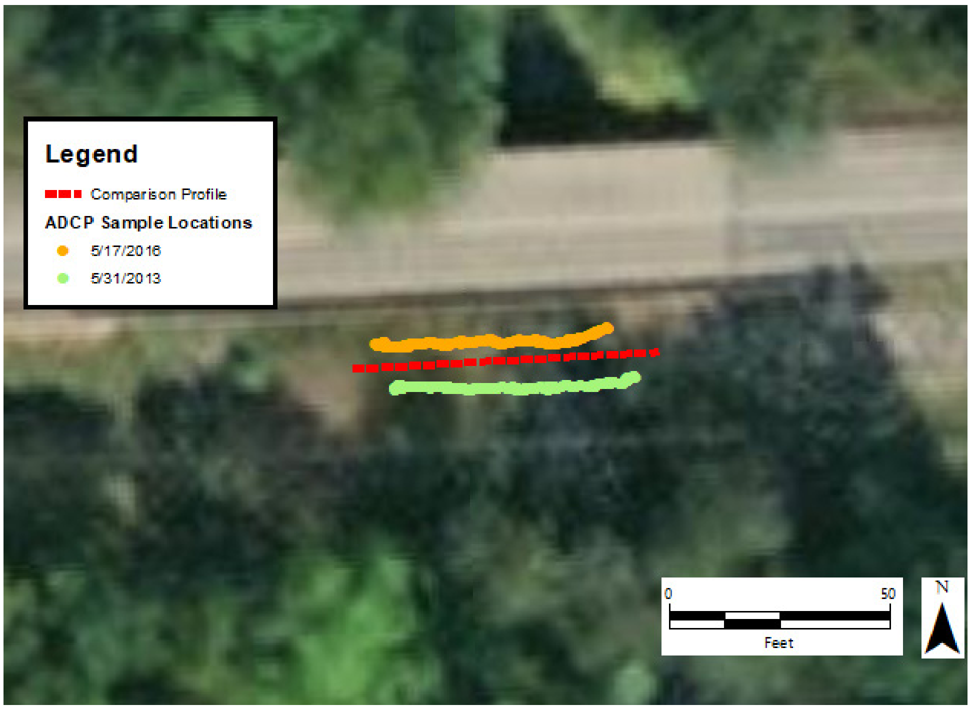
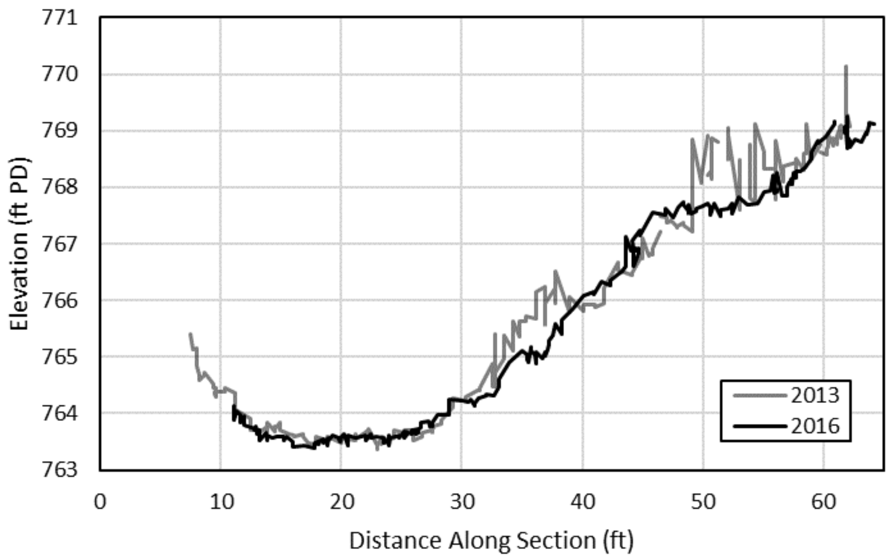


Figure 17
Tar Creek at 22nd Street Bridge USGS ADCP Sections



2.1.1.11.5 Spring River near Quapaw

The USGS has made ADCP data available from seven sampling events at Spring River near Quapaw station, taken from 2009 to 2015, spaced across approximately 60 feet of river as shown in Figure 18. The data from events taken from 2009 to 2015 show a different profile than those taken from 2016 to 2020. Figure 19 shows no change in channel elevation from 2009 to 2015, and Figure 20 shows an increasing channel elevation from 2016 to 2020. The distance between the transects accounts for some of the variation.

Figure 18
Spring River near Quapaw USGS ADCP Transects

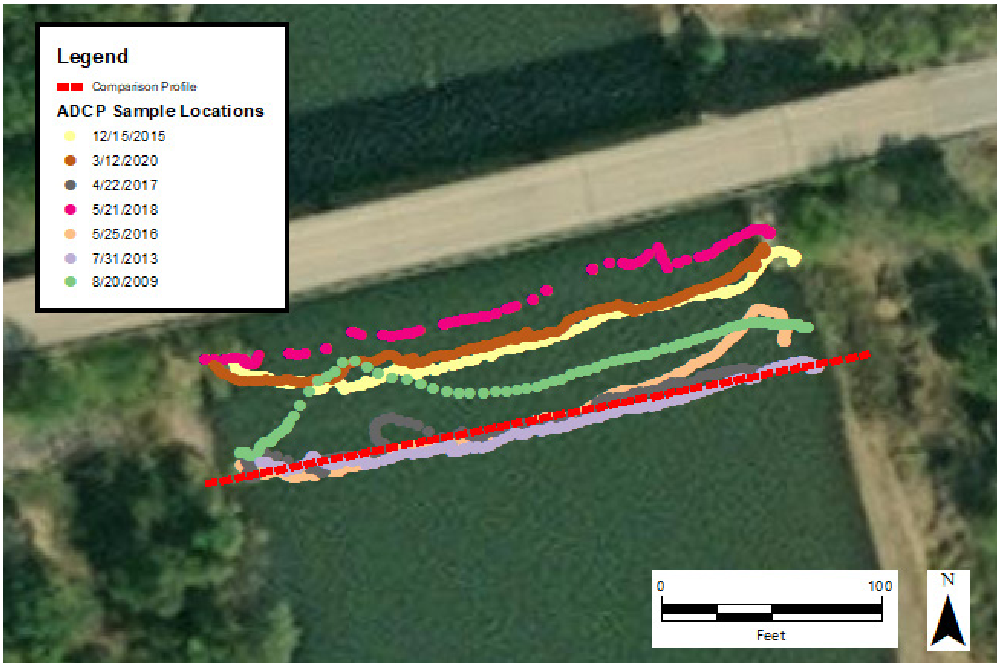


Figure 19
Spring River near Quapaw USGS ADCP Sections

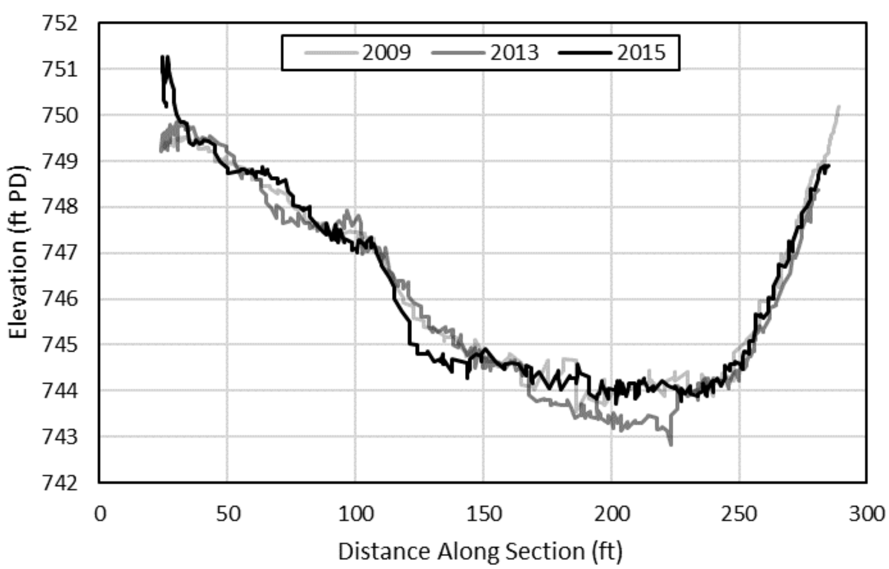
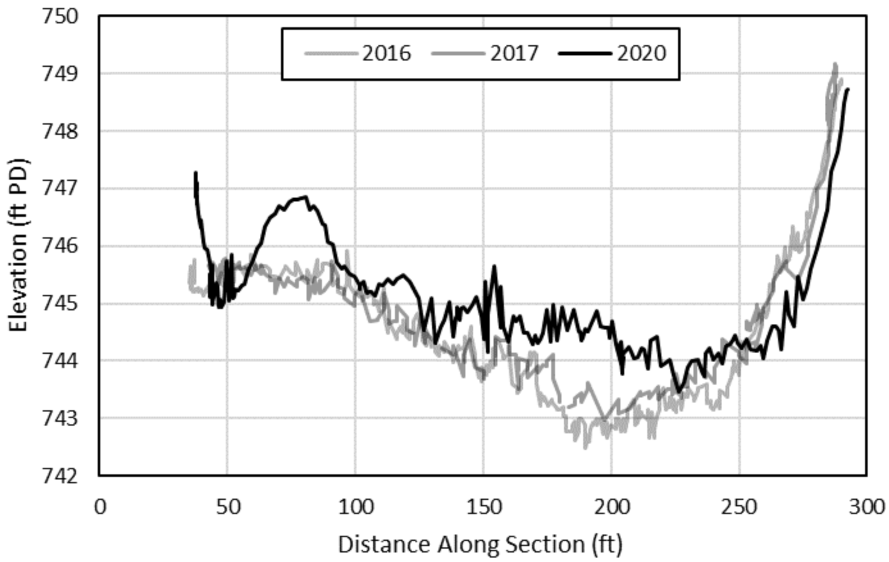


Figure 20
Spring River near Quapaw USGS ADCP Sections



2.1.1.11.6 Elk River near Tiff City

Figure 21 shows USGS ADCP data from six sampling events at Elk River near the Tiff City USGS station. The transects are spaced approximately 50 feet apart, and span 2011 to 2022. High-quality datasets in close proximity to the comparison profile are shown in Figure 22. The sections show some movement in the existing sand bar between the sampling events, and an overall trend toward higher channel elevation.

Figure 21
Elk River near Tiff City USGS ADCP Transects

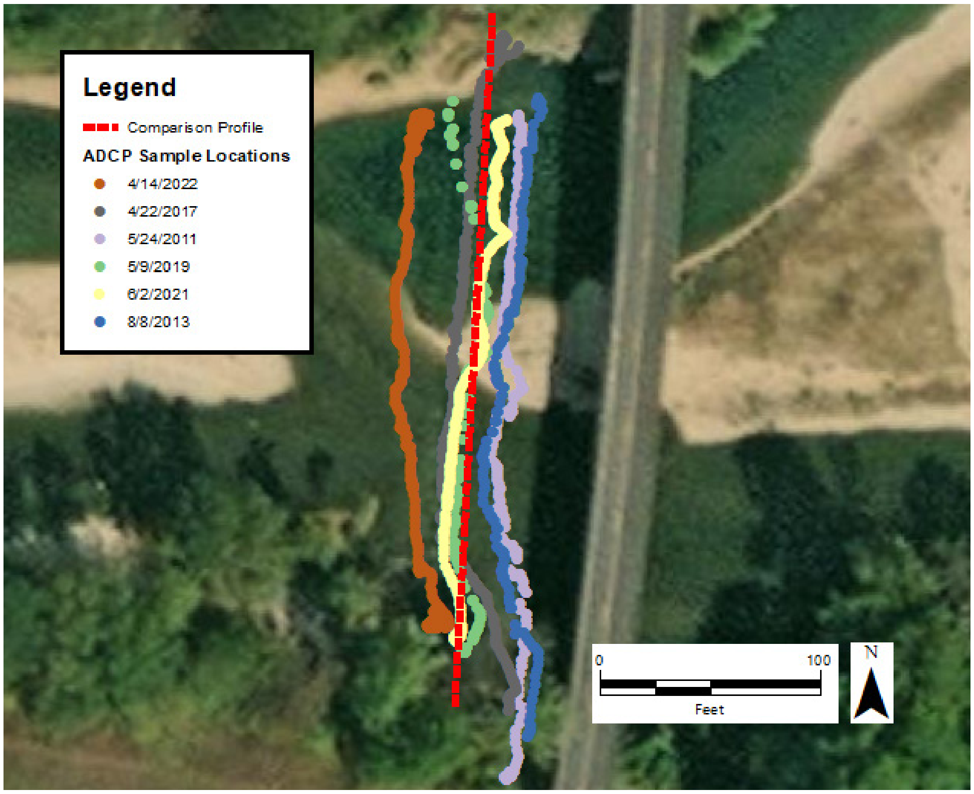
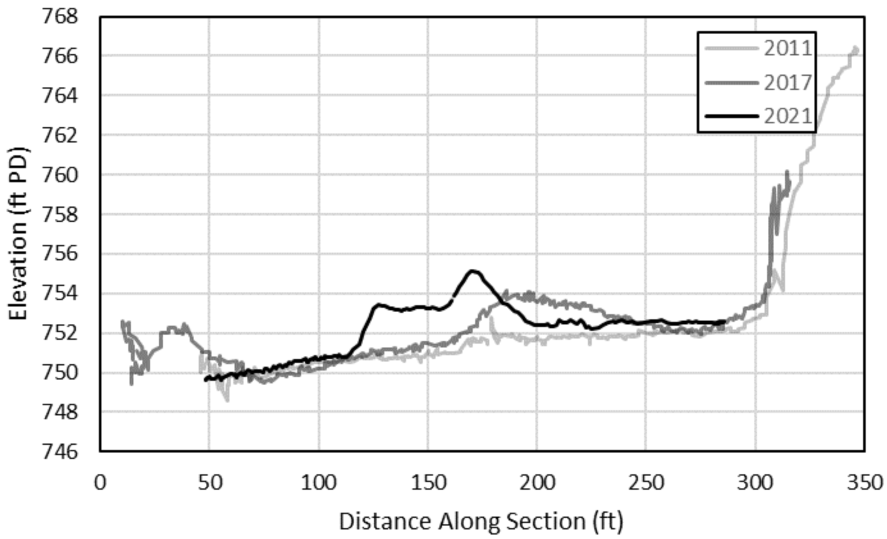


Figure 22
Elk River near Tiff City USGS ADCP Sections



2.1.2 *Water Surface Elevation, Discharge, and Flow Velocity*

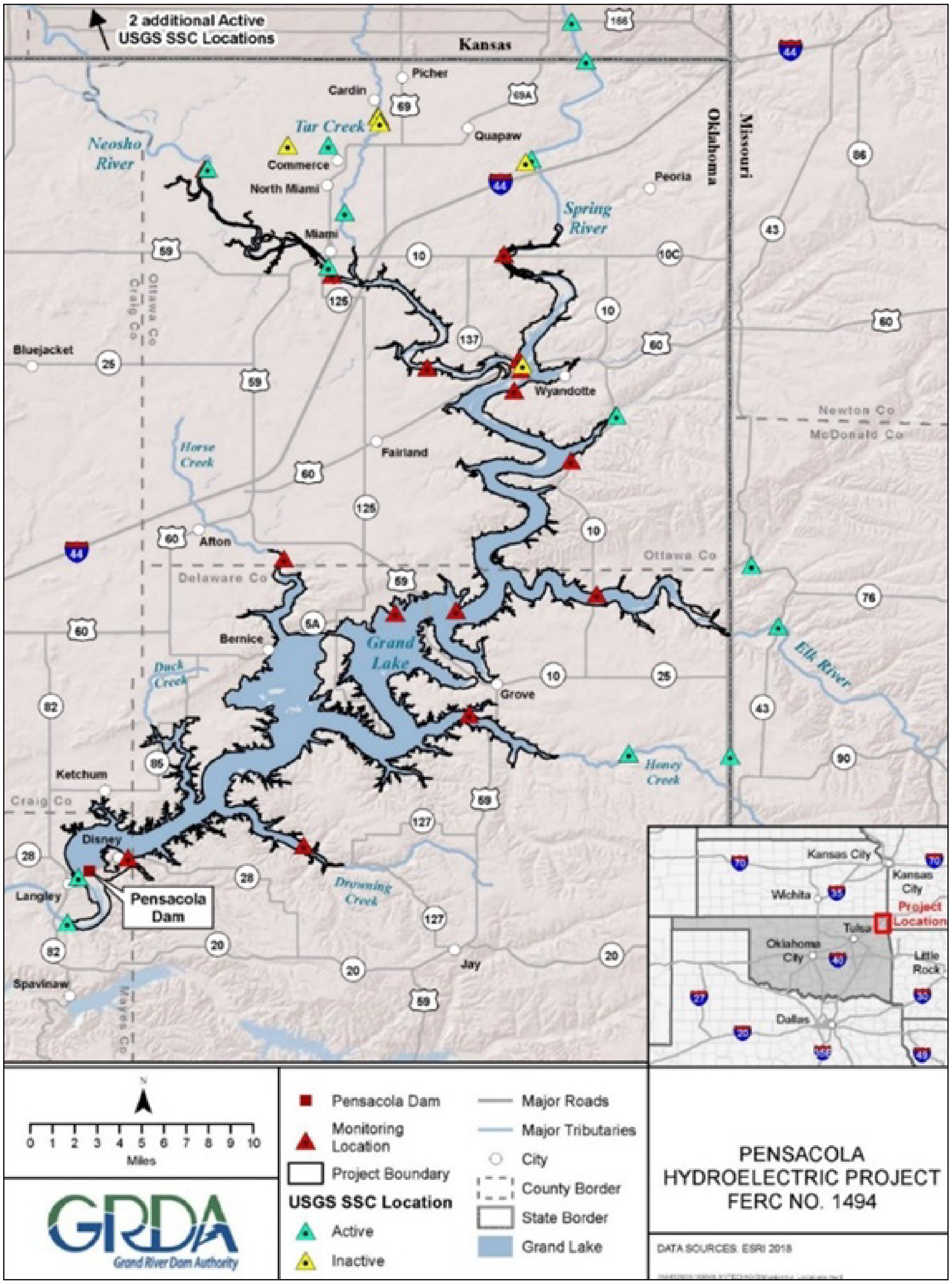
USGS provides monitoring gages in several locations within the study area watershed. These locations are shown in Figure 23, and station information is provided in Table 3. Each station provides WSE information at regular intervals; most also list discharge volumes. These gage readings are available to the public through USGS websites (USGS 2021a, 2021b, 2021c, 2021d, 2021e, 2021f, 2021g).

Table 3
USGS Gages Present in the Grand Lake Watershed and Periods of Record for Parameters Relevant to the Study

USGS Station ID	Site Name	Period of Record		
		Discharge (Continuous Record)	**WSE (Continuous Record)**	**SSC (Intermittent Record)**
07185000	Neosho River near Commerce, Oklahoma	1990–Present	2007–Present	1944–2016
07185080	Neosho River at Miami, Oklahoma	N/A	2007–Present	N/A
07185090	Tar Creek near Commerce, Oklahoma	2007–Present	2007–Present	2004–2016
07185095	Tar Creek at 22nd Street Bridge at Miami, Oklahoma	1989–Present	2007–Present	1988–2006
07188000	Spring River near Quapaw, Oklahoma	1989–Present	2007–Present	1944–Present
07189000	Elk River near Tiff City, Missouri	1990–Present	2007–Present	1993–2009
07190000	Lake O' the Cherokees at Langley, Oklahoma	N/A	2007–Present	N/A

Note:
N/A indicates that the specific data type was not recorded at these locations.

Figure 23
Map of the Study Area Showing Locations of USGS Gaging Stations and Water Surface Elevation Monitoring Sites



USGS also performs periodic discharge profile measurements at the gage stations. These typically use an ADCP. Table 4 provides a summary of the available ADCP data.

Table 4
Acoustic Doppler Current Profiler Data Available from USGS Measurements

USGS Station ID	Site Name	Period of Record	Range of Flows (cubic feet per second)
07185000	Neosho River near Commerce, Oklahoma	2006–Present	931–129,000
07185080	Neosho River at Miami, Oklahoma	2013–2017	172–57,100
07185090	Tar Creek near Commerce, Oklahoma	2008–2017	402–4,930
07185095	Tar Creek at 22nd Street Bridge at Miami, Oklahoma	2012–2016	398–2,400
07188000	Spring River near Quapaw, Oklahoma	2004–Present	639–62,600
07189000	Elk River near Tiff City, Missouri	2008–2017	2,340–24,800

2.1.3 Sediment Information

There are two primary components of sediment information needed for this study. The first is analysis of the bed sediments in the rivers and lake; the second is evaluation of sediment volumes moving into the study area from upstream sources.

2.1.3.1 Bed Sediments

Understanding and analysis of sediment transport through the rivers flowing into Grand Lake require knowledge of the sediment forming the bed of these streams. Only limited information was available regarding bed material of these streams. Several studies investigated sediment in the channel and upland areas within Grand Lake (e.g., Pope 2005; Andrews et al. 2009; Ingersoll et al. 2009; Juracek and Becker 2009; Smith 2016). Although the studies have produced a great deal of sediment analysis, they do not contain information that can be used to determine properties necessary for the proposed study such as critical shear stress or detailed grain size distributions.

Mussetter, in a 1998 report entitled *Evaluation of the Roughness Characteristics of the Neosho River in the Vicinity of Miami, Oklahoma*, photographically documented characteristics of the bed material forming the Neosho River and described the sediment as sand and gravel.

Mussetter (1998) observed the following regarding the bed material of the Neosho River (see):

> Based on field observations and sediment samples taken from bank-attached bars and from the bed of the river, the bed material in the reach upstream from approximately the I-44 Bridge (RM 142) is composed primarily of gravel and sand. Downstream from I-44, the surface bed material at the time of the sampling in late 1996, which was performed when the discharge in the river was relatively low, was primarily silt and clay (Mussetter 1997). There are no obvious factors other than reduced flow velocities caused by backwater from Pensacola Dam that would cause the observed change in character of the river bed in the reach downstream from Miami. Prior to construction of the dam, the bed of the river downstream from Miami was most likely gravel and sand, similar to that found upstream.

Figure 24
Typical Sand and Gravel Material on a Point Bar Along the Left (North) Side of the Neosho River at Approximately RM 147

Source: Mussetter (1998)

In the conclusions of his report, Mussetter continues his observations and speculation regarding the bed of the Neosho River:

> The bed of the Neosho River through and upstream from Miami consists of a mixture of sand and gravel. In contrast, the bed is composed of finer-grained material in the reaches downstream from Miami due to the effects of backwater from Grand Lake. Samples taken from the bed surface at low flow in late 1996 consisted primarily of silt- and clay-sized material. Based on the characteristics of the upstream bed material, it is probable that the silt and clay is entrained and carried farther downstream into the reservoir during higher flows, and that the bed is composed primarily of sand.
> (Mussetter 1998)

The concept that the bed consists primarily of sand was apparently reinforced by the analysis of resistance to flow. In discussing the Manning's *n* values, which quantify resistance to flow in hydraulic modeling, Mussetter states the following:

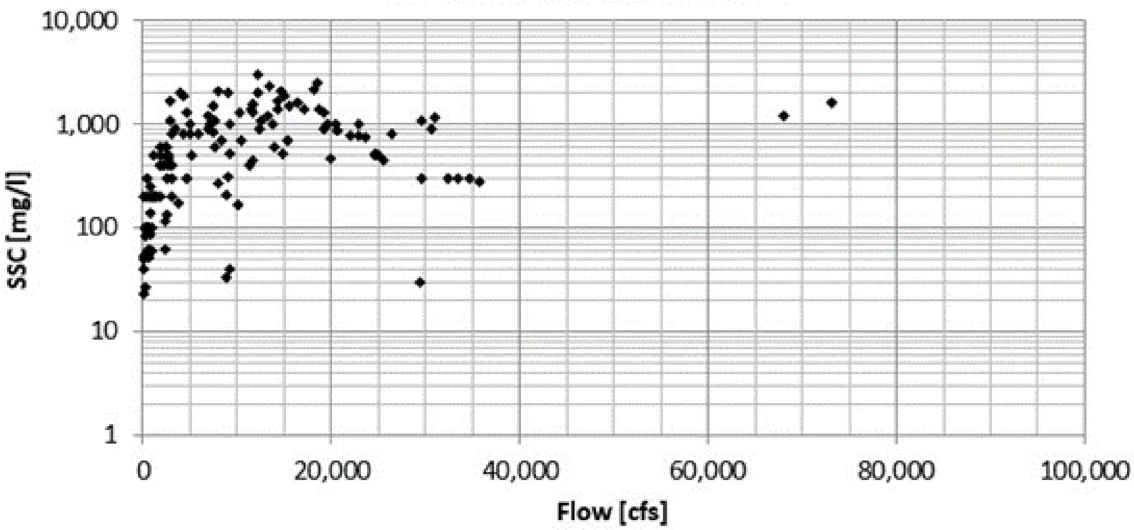
> These values are consistent with observed values in other sand bed streams having dune bedforms. This result indicates that dunes, and therefore relatively high Manning's n values, must be present in the reach downstream from Miami during high flows under with-reservoir conditions.
> (Mussetter 1998)

As demonstrated in subsequent sections of this report, there are a number of factors that contribute to the observed change in character of the bed material from non-cohesive sand and gravel to cohesive silt and clay. Mussetter (1998) focuses only on the presence of Pensacola Dam, but there are other factors influencing those findings. These factors include backwater from bridges, geologic and geomorphic features, and the fact that the river is transporting almost exclusively cohesive silt- and clay-sized material with very little bedload transport of non-cohesive material. In addition, on the recession limb of hydrographs, some sediment being transported by the river may temporarily deposit before being flushed farther downstream during subsequent higher flows resulting in the transition of the bed surface from coarser material to finer and back to coarser again.

2.1.3.2 Sediment Transport

The second sediment analysis required is measurement of sediment volumes flowing into the system. Approximate sediment transport rates can be determined from USGS measurements of suspended sediment concentrations (SSCs; Figure 25). SSC provides a measurement of sediment loading, typically in milligrams per liter, of streamflow. That information can then be multiplied by discharge volumes to determine transport rates within the water column. Table 3 provides a summary of the available period of record for SSC information. However, the datasets are small with samples collected on rare occasions; they do not represent continuous records like the discharge and WSE measurements.

Figure 25
Suspended Sediment Concentration Samples and Stream Discharges During Sampling on the Neosho River Near Commerce (USGS Gage 07185000)



Note: Only two samples were collected at discharges above 40,000 cfs.

SSC measurements focus only on fine materials suspended in the water column. This typically includes silts and clays, with limited sand possible depending on turbulence at the sampling site. It does not, however, measure transport rates along the streambed. Bedload transport is generally dominated by sands, gravels, and cobbles that “roll” downstream along the streambed. This information is critical to understand the full sediment transport regimes of a watershed. Recorded sediment transport rates are limited to SSC calculations because bedload transport has not been reported within the Grand Lake watershed.

2.1.3.3 Contaminated Sediment

City of Miami, Miami Tribe, Eastern Shawnee Tribe, Ottawa Tribe, Seneca Cayuga Nation, Wyandotte Nation, and N. Larry Bork (counsel for the City of Miami citizens) provided a list of existing information to be used in their requested contaminated sediment transport study. The toxicity of the sediments is not within the scope of this study. However, existing data and information available from studies conducted of the Superfund site within the Tar Creek watershed were reviewed and incorporated in the study as appropriate.

2.2 Field Data Collection

Due to information gaps relevant to the study, field data collection was deemed necessary. This consisted primarily of WSE monitoring and sediment and water sampling to provide calibration information for eventual model development.

2.2.1 Water Surface Elevation Monitoring

Anchor QEA collected WSE data throughout the Project site (Figure 23). Sixteen monitoring locations were selected, and HOBO pressure loggers (Figure 26) were installed at each site in December 2016. The loggers record raw pressures and water temperatures at 30-minute intervals to provide a continuous WSE record throughout the basin. Data are stored in onboard memory; with 30-minute recording intervals, the memory capacity is approximately 1.2 years.

Figure 26
Photograph of HOBO Pressure Loggers and Mounting Chamber

Loggers were placed in a mounting chamber and attached to rebar driven into the bed at each location shown in Figure 23. The mounting chamber was constructed of PVC with threaded caps painted black to limit visibility and deter theft or vandalism. Rebar was driven into the bed to a sufficient depth to prevent the loggers from washing away during high flow events.

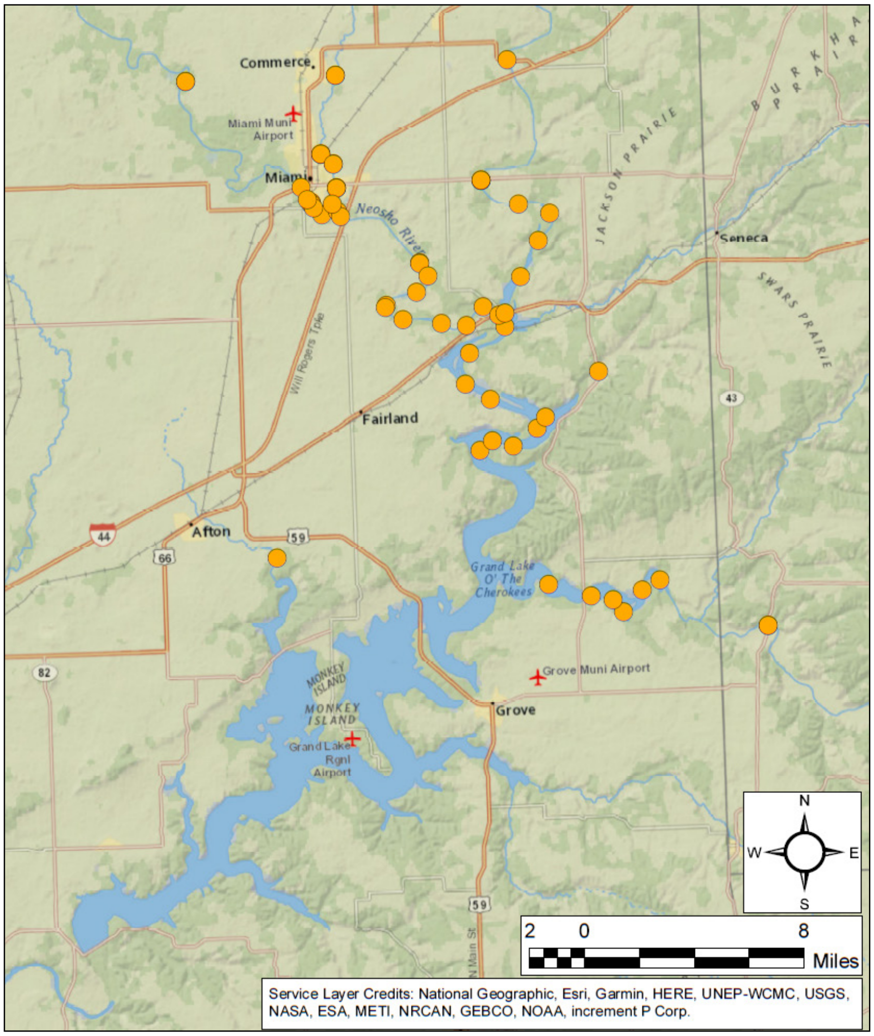
2.2.2 Sediment Grab Samples

The study team first collected surface samples of stream sediment throughout the watershed. A total of 62 samples were collected during a visit in December 2019 (Table 5). Figure 27 shows the locations of the sediment samples. Appendix B provides the plots of the gradations of the sediment grab samples.

Table 5
Surface Sediment Grab Sampling Locations by River and Reach

Stream	Samples Collected
Neosho River North of Spring River	20
Neosho River South of Spring River	9
Tar Creek	13
Spring River	10
Elk River	8
Sycamore Creek	1
Horse Creek	1

Figure 27
Location of Sediment Grab Sampling Efforts within the Grand Lake Watershed



Samples were collected both in the overbank and in-channel areas. Overbank samples were gathered with shovels and in-channel samples were taken with either a PVC push-core sampler, a shovel, or an Ekman dredge (Figure 28). Once collected, the samples were placed into containers for analysis at the University of Wisconsin Soil and Forage Laboratory (UWSFL) in Marshfield, Wisconsin.

2.2.3 SEDflume Core Sampling

Cohesive sediment cores were collected during the study for erosion testing using SEDflume (see Appendix C). Despite initial reports indicating that Grand Lake watershed sediment transport was dominated by sands (Tetra Tech 2018), field information showed that cohesive sediments were prevalent throughout the basin and comprised the majority of sediment moving through the study area. As a result, plans were adapted to account for the presence of silts and clays, which are not eroded or transported in the same way as non-cohesive sediments such as sand and gravel.

Figure 28
Ekman Dredge Used for In-Channel Sediment Sampling

Sediment transport is generally dictated by bed shear stress. Bed shear is a function of bed slope and water depth. It is essentially a measure of frictional drag on the streambed. At low shear stress, sediment is held in place by gravitational forces. At the point of incipient motion, shear and gravitational forces are essentially balanced; the shear stress in this condition is known as the critical shear stress. Above critical shear, the bed sediment becomes mobile and can be transported. Below critical shear, sediment does not move and can settle out of the water column. Depending on sediment properties, critical shear stress can vary widely, with boulders having high critical shear values and fine sand exhibiting low critical shear stresses.

Non-cohesive sediments such as sand, gravel, and cobbles (Figure 29, top photograph) tend to have easily predictable critical shear stress. It is typically proportional to sediment density and grain size and is relatively constant through the entire sediment layer. Generally, grains move relatively independently of each other. As a result, these sediments are comparatively simple to evaluate and model.

Figure 29
Visual Comparison of Different Sediment Types

Note: Top—non-cohesive sand, gravel, and cobbles; bottom—cohesive silt and clay.

Modeling cohesive sediments is far more complex. Critical shear stress is determined primarily by the cohesive forces between silt and clay particles rather than individual grain sizes. This is complicated by the process of consolidation; as sediment is deposited in an area, it applies force to the underlying layers, compressing them and increasing the cohesion, making them less susceptible to erosion. The amount of time spent on the bed also affects consolidation and critical shear stress. Furthermore, erosion typically occurs as clumps break free of the surrounding sediment. Due to the changing resistance to erosion based on depth and the nature of cohesive sediment transport, it is considerably more difficult to accurately model and requires additional information.

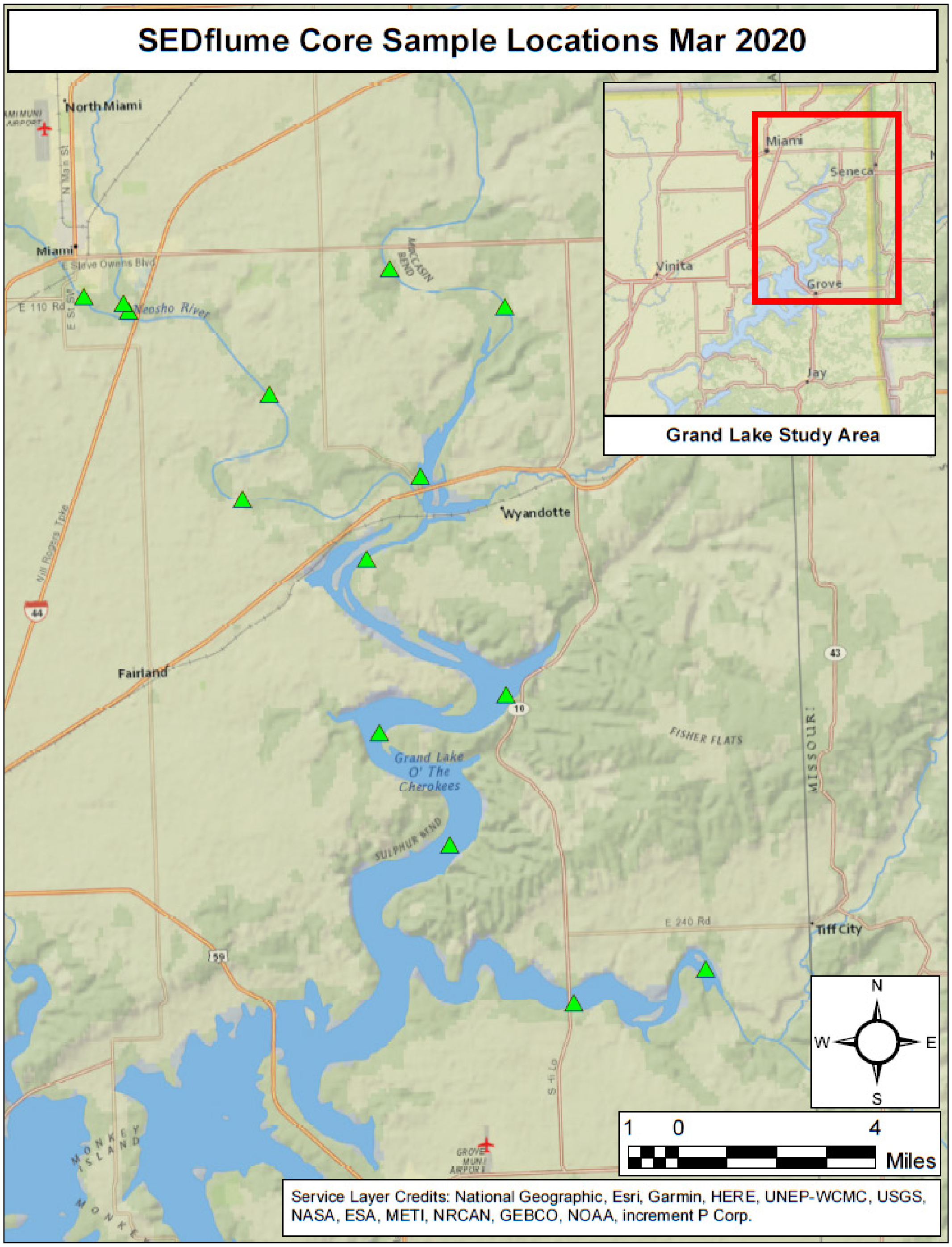
Accurate collection of sediment information can be accomplished through erosion testing on SEDflume (Borrowman et al. 2006; McNeil et al. 1996). The SEDflume testing facility consists of an enclosed flume with a hole in the bed. An undisturbed sediment core sample is placed under the hole, and the surface of the core is raised to be flush with the flume bed. Water is pumped across the sample surface at a known shear stress; as the core erodes, a jack lifts it to keep the surface flush with the flume bed. The rate of erosion is the distance the jack moved per unit time of the test. Bed shear stress can then be increased to evaluate rates at a range of shear values. This test provides information about critical shear stress throughout the sediment core, allowing engineers to evaluate critical shear as a function of depth.

The study team collected core samples for SEDflume analysis in March 2020 (Figure 30). A total of 14 core samples were collected using a box push-core system (Figure 31). The box core was a clear plastic sleeve, which was pressed into the sediment bed. A pressure relief valve at the top of the core allowed air and water to escape as the core sank into the streambed. The resulting suction pressure kept the sample inside the sleeve as it was raised back to the water surface. The sample was then measured, sealed, and transported to the test laboratory for analysis.

Figure 30
SEDflume Core Sampling

Note: Left—technician pulling box core rig out of the bed; center—box core showing sediment fill and measuring depth of sample; right—several collected samples before shipment to the test facility.

Figure 31
Locations of SEDflume Core Samples Collected During the Sediment Investigation



SEDflume analysis also provided particle size analysis. During testing, Integral Consulting used a Beckman Coulter LS particle size analyzer over a range of depths below the surface of the core for each sample.

2.2.4 Sediment Transport Measurements

Sediment transport measurements were also included in the sediment study. These consisted primarily of two forms of data: SSC and bedload transport quantification. Bedload samples were collected immediately following SSC sampling at each site. Dates of sampling efforts and discharges are provided in Table 6.

Table 6
Sampling Dates and Discharge Measurements, per USGS Gaging Station Records

Date	Discharge (cubic feet per second)			
	USGS 07185000 Neosho River at E 60 Rd	**USGS 07185090 Tar Creek at Hwy 69**	**USGS 07188000 Spring River at E 57 Rd**	**USGS 07189000 Elk River at Hwy 43**
August 2019	15,500	10.0	1,240	537
May 2020	37,500	*	8,040	4,940
July 2020	2,930	5.29	3,480	*
April 2021	2,330	*	2,250	*
May 2021	18,900	750	16,500 23,400**	*
July 2021	41,600	500	14,700	*

Notes:
*Samples not taken at this location.
**Spring River was sampled twice during the May 2021 site visit.

2.2.4.1 Suspended Sediment Concentration

A D-74 depth-integrating water sampler was used to collect SSC samples (Figure 32). This sampler features a finned body with a nozzle pointing upstream and a vent pointing downstream. As it is lowered into the water, flow is allowed through the nozzle and into a sampling bottle. The sampler is lowered into the stream until it reaches the bed, then is raised; this is all done at a constant speed. Based on flow conditions at the site, researchers have an array of nozzle sizes and travel speeds to choose to ensure valid data (USGS 2006).

Figure 32
Sampling Equipment Used During Suspended Sediment Concentration Sampling Efforts

Notes: The D-74 water sampler is attached to the crane, and the SonTek M9 ADCP used to measure stream flows is in the lower right. Samples are placed in the carrier at left after collection.

Anchor QEA followed standard USGS protocols for equal width interval water sampling (USGS 2006). The field technicians used a SonTek M9 ADCP or timed a floating object moving a known distance to measure current profiles at each site before sampling began. Based on flow velocities and patterns, they selected appropriate nozzle sizes and descent and ascent velocities for the D-74 sampler following USGS standard procedures (USGS 2006). Following nozzle installation, a calibrated winch lowered the sampler to the stream and raised it at the specified rates. Samples were then capped and sent to the Wisconsin State Laboratory of Hygiene (WSLH) for SSC analysis.

Field notes and a detailed description of the process followed were provided in April 2022 as attachments to GRDA's response comment.

2.2.4.2 Bedload Transport

Anchor QEA used a Helley-Smith bedload sampler (Figure 33) to collect bedload transportation measurements. Sampling sites were the same as those used for SSC measurements to ensure capture of all sediment (SSC and bedload) moving through the system under given flow conditions. The Helley-Smith sampler sits on the streambed with a rectangular opening pointed upstream. Saltating, sliding, and rolling sediment is transported at the bed surface into the opening and trapped in a mesh bag. USGS documentation provides guidelines for the use of this equipment; Anchor QEA followed USGS procedures (Edwards and Glysson 1999) to collect bedload sediment during site visits (Table 6).

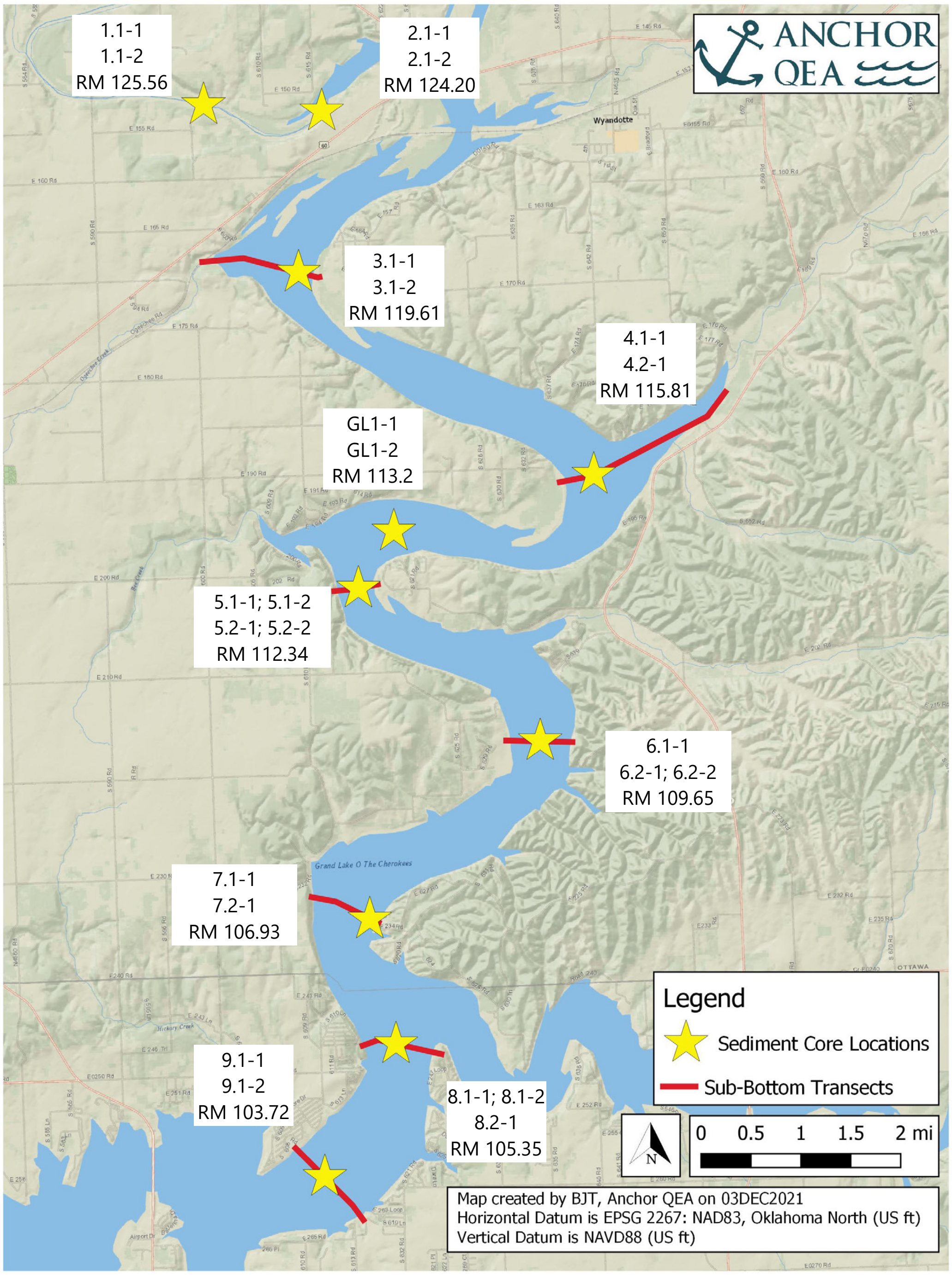
Figure 33
Bedload Transport Measurements Collected Using the Helley-Smith Sampler

Field notes and a full description of the process followed were provided in April 2022 as attachments to GRDA's response comment (GRDA 2022).

2.2.5 Subsurface Investigations

GRDA also performed subsurface investigations of the delta feature. These included two primary components: sub-bottom profiler (SBP) surveying and vibracore sampling. The SBP survey covered nine transects of the Neosho River and was completed in January 2022 (Figure 34). Vibracore sampling included multiple samples at each SBP transect and was completed in February 2022.

Figure 34
Locations of SBP Transects and Sediment Cores Collected by GRDA



An SBP uses sonar pulses to determine depth of a waterbody. There is an emitter and a receiver on the SBP head unit, and by measuring the amount of time necessary for the emitted pulse to reach an object and return to the receiver, the SBP is able to measure the distance the pulse traveled. This allows the SBP to measure bathymetry, but the pulse is also powerful enough to penetrate a soft sediment bed, such as clay, silt, and sand before reaching a harder layer. Using the same principles, the SBP can then estimate the thickness of a soft sediment layer above gravel or bedrock.

Vibracoring uses a motorized head unit to press core tubes into the stream or lakebed. The combined weight and vibration of the head unit allows for deeper penetration than simply pressing the core tube into the bed or relying on gravity coring methods. Once collected, grain size analyses and other testing can be used to determine sediment properties as a function of depth in the sediment layers. The cores were used for two purposes: 1) to confirm SBP survey information and evaluate sediment composition; and 2) an attempt to determine approximate dates of deposition through the use of cesium-137 (Cs-137) analysis.

Cs-137 is an isotope that does not occur in nature. It is created by nuclear fission, which humans began developing in the 1940s. As nuclear weapons testing accelerated, atmospheric Cs-137 increased until a 1963 nuclear test ban treaty. The Cs-137 levels then dropped significantly. Atmospheric Cs-137 concentrations are well-correlated with Cs-137 concentrations in soil, showing the same pattern of increase from the 1940s to 1963, then a marked decrease.

Measurement of relative Cs-137 activity in sediment allows researchers to estimate deposition dates for sediment layers. In areas of continual deposition, Cs-137 analysis will find a pattern of increasing Cs-137 activity moving deeper in the column until reaching the 1963 layer. Below that layer, concentrations drop to zero by the 1940s. In disturbed areas or places with non-continuous deposition, there is usually no clear Cs-137 peak. The combination of SBP, vibracore samples, and Cs-137 provides insight into the volume, rate, and timeline of sediment deposition in the Neosho River.

2.3 Field Results

2.3.1 Water Surface Records

Anchor QEA has visited the site several times to collect and redeploy pressure loggers. Trips to collect WSE monitoring data were performed according to Table 7.

Table 7
WSE Monitoring Site Visit Dates and Logger Retrieval Rates

Date	Loggers Recovered
December 2016	16 Deployed
August 2017	13 of 16
March 2018	2 of 16
April 2019	12 of 16
December 2020	13 of 16

Anchor QEA retrieved the loggers on an approximately annual basis. Upon arrival at each monitoring station, Anchor QEA staff collected Real-Time Kinematic (RTK) GPS measurements of the WSE and surveyed any nearby benchmarks. The loggers were collected, and data were read from them using an optic USB interface. They were then relaunched and placed back in the field; staff measured depth to the loggers and depth to bed before leaving the site. After all loggers were retrieved, the data were processed to produce WSE readings from the pressure data.

The loggers recorded raw pressure measurements that had to be converted to water depths and then WSE. Because pressure readings include both water pressure and atmospheric pressure, it was first necessary to subtract ambient air pressure from the measurements. Records from the Grove Municipal Airport provided atmospheric pressure readings for processing. Python programs were used to subtract the raw readings to water pressure measurements; water density was then used to estimate the depth of the sensors according to Equation 1.

Equation 1

$$h = \frac{P}{\rho g}$$

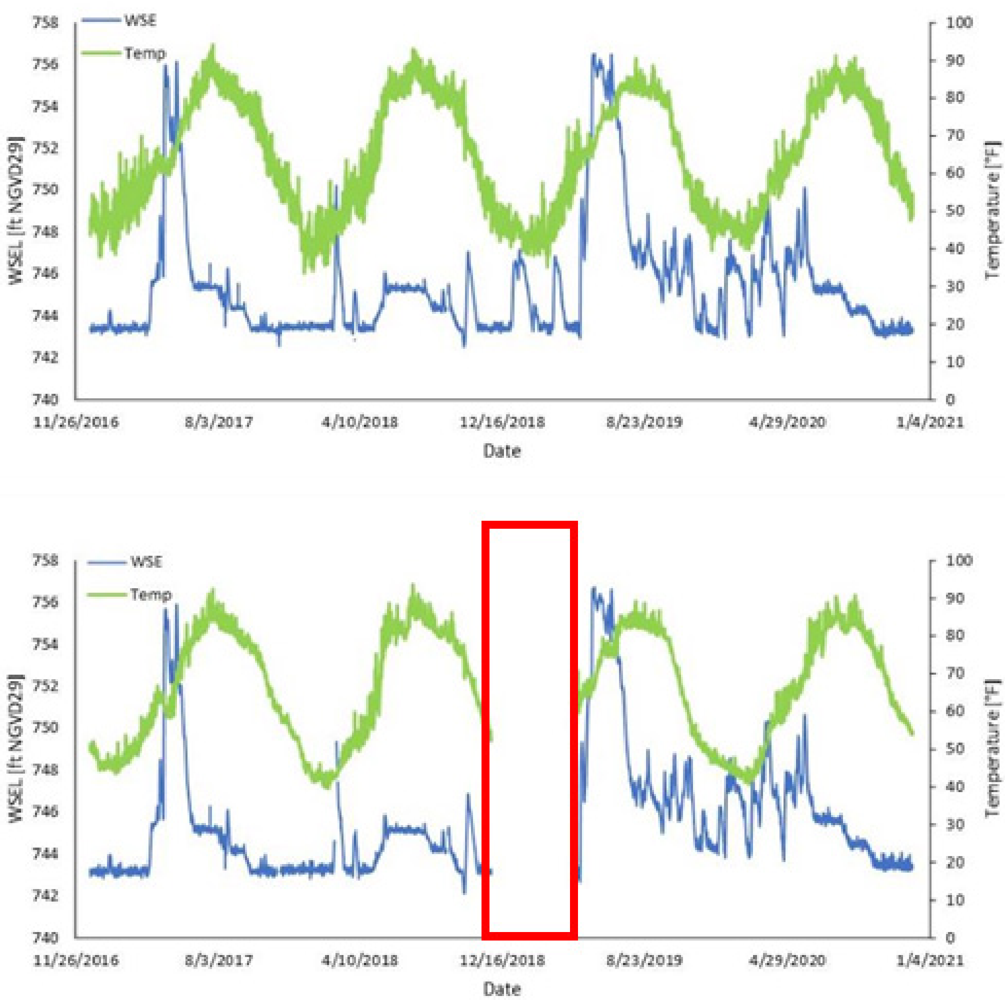
where:

h	=	water depth
P	=	pressure
ρ	=	water density
g	=	acceleration due to gravity

Once water depths were established at the time of retrieval, logger elevation was set based on the measured WSE and recorded depth; data throughout the period of record were thus converted from the raw pressure recordings to WSE measurements (Figure 35). The calculated WSE readings were adjusted to match the RTK GPS measurements taken while on site.

Several loggers had data gaps in the record. At various sites, the loggers were washed away or vandalized, which prevented recovery. One additional data gap was due to an unforeseen high-water event that prevented recovery until after internal storage had been filled. Full datasets are available in Appendix A.

Figure 35
Sample Series

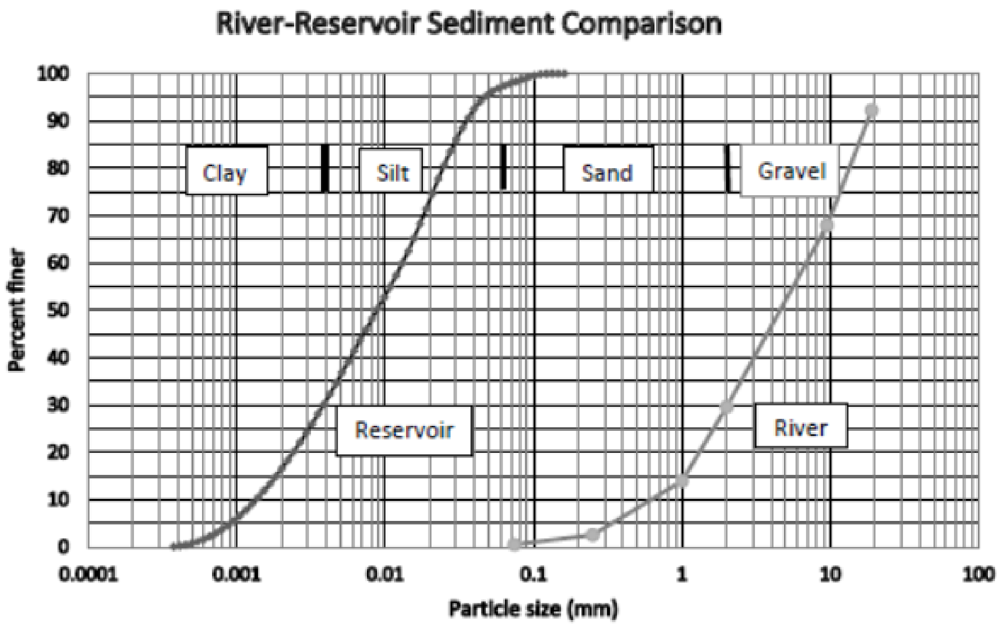


Note: Top: complete dataset; bottom: gap in record.

2.3.2 *Sediment Grain Size Analysis*

Following the December 2019 sediment grab sample collection, Anchor QEA sent 62 sediment samples to UWSFL for grain size analysis. The results of the analysis indicated a bi-modal size distribution, with a majority of streambed sediments consisting of gravels and coarse sediments and a majority of lakebed sediments composed of silt and clay. The results showed limited volumes of sand in either stream or lake sediments, with most of the lakebed being finer than sand and most of the riverbed being coarser than sand (Figure 36).

Figure 36
Particle Size Distributions within the Grand Lake Study Area



As shown in Figure 37, the beds of these streams consist primarily of gravel, with some sand. The surface of the streambeds appears to be armored by gravel and (in the case of areas of Tar Creek) larger particles. Hydraulic and sediment transport analyses, based on particle size distributions, will determine the extent to which these particles are transported downstream into the reservoir.

Figure 37
Sample Photographs Showing the Sediment in the Spring River, Tar Creek, Elk River, and Neosho River

Note: Clockwise from top left, the Spring River, Tar Creek, Elk River, and Neosho River.

Farther downstream, as the tributaries transition into lacustrine conditions, the character of the bed material changes dramatically. Samples collected from the reservoir bed appear to consist primarily of silt and clay (Figure 38).

Figure 38
Sediment Grab Samples Collected from the Reservoir Bed in Grand Lake

Full results for each sample are presented in Appendix B. These results show the significant variability in particle size distributions from reach to reach within streams and even significant differences between samples taken in close proximity.

2.3.3 SEDflume Test Results

SEDflume samples were tested by Integral Consulting at their Santa Cruz, California laboratory. Testing was performed according to the procedures described by McNeil et al. (1996) and Borrowman et al. (2006). The laboratory analysis of the samples included evaluation of erosion parameters, grain size distributions, and bulk density of the samples.

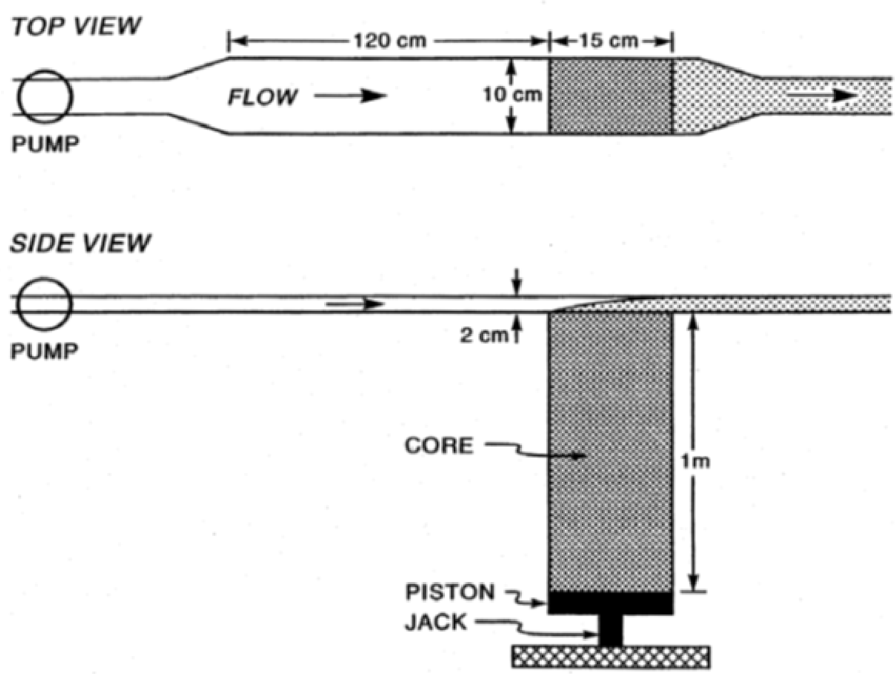
2.3.3.1 Erosion Parameter Analysis

Erosion of cohesive sediment is quantified by two key parameters: critical shear stress at which erosion begins, and the rate of erosion as a function of increasing shear stress greater than critical shear. A standard technology, SEDflume, has been developed to measure these parameters. The SEDflume is described as follows:

> A SEDflume is essentially a straight flume with an open bottom section through which a rectangular, cross-sectional core barrel containing sediment can be inserted [Figure 39]. The main components of the flume are the water tank, pump, inlet flow converter (which establishes uniform, fully developed, turbulent flow), the main duct, test section, hydraulic jack, and the core barrel containing sediment [Figure 40]. The core barrel, test section, flow inlet

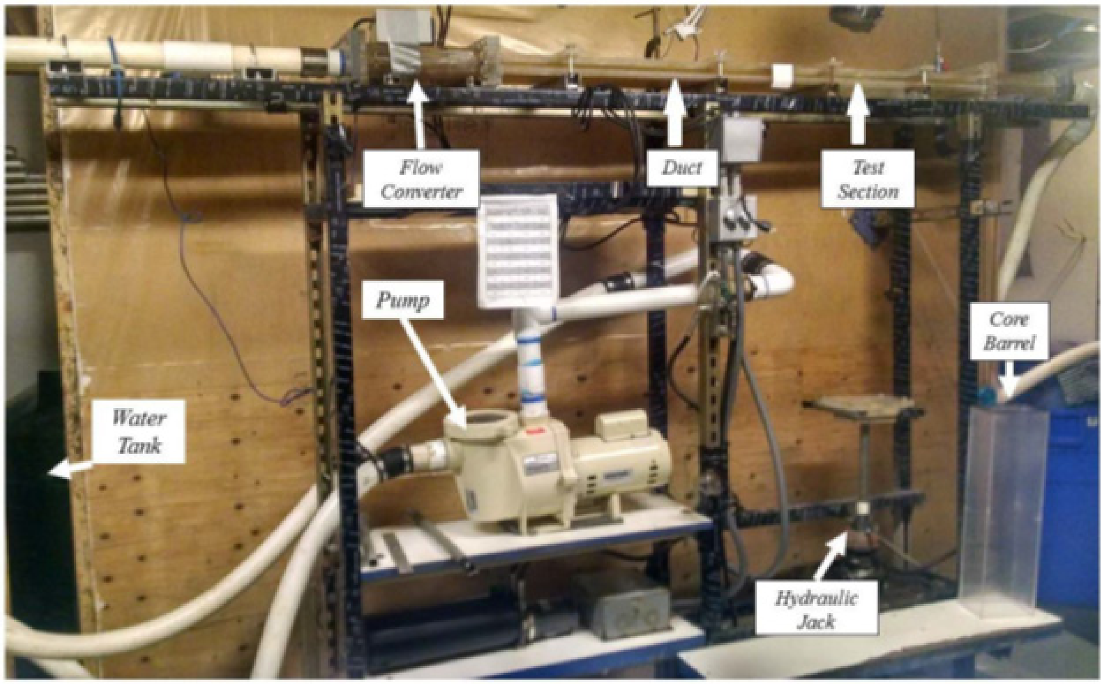
section, and flow exit section are made of transparent acrylic so that the sediment–water interactions can be observed visually. The core barrel has a rectangular cross section, 10 by 15 cm, and a length of 60 cm. (Integral Consulting 2020)

Figure 39
SEDflume Schematic Showing Top and Side Views



Source: Integral Consulting (2020)

Figure 40
Photograph of SEDflume Test System



Source: Integral Consulting (2020)

In its report, Integral Consulting describes the process of conducting the laboratory testing with SEDflume, as follows:

> At the start of each test, a core barrel and the sediment it contains are inserted into the bottom of the test section. The sediment surface is aligned with the bottom of the SEDflume channel. When fully enclosed, water is forced through the duct and test section over the surface of the sediment. The shear stress produced by the flow and imparted on the particles causes sediment erosion. As the sediment on the surface of the core erodes, the remaining sediment in the core barrel is slowly moved upward so that the sediment–water interface remains level with the bottom of the flume. (Integral Consulting 2020)

Integral Consulting then describes the process of taking measurements to develop critical shear and erosion rate data:

> At the start of each core analysis, an initial reference measurement is made of the starting core length. The flume is then operated at a specific flow rate

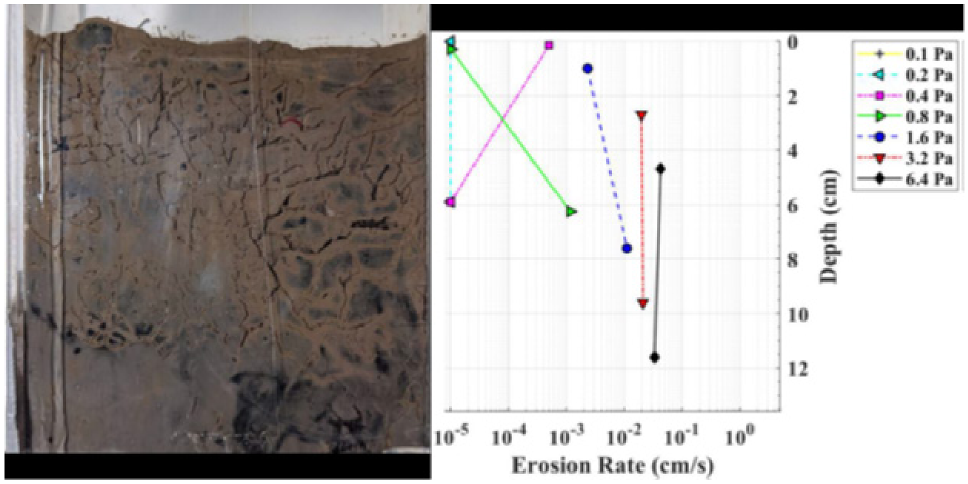
> corresponding to a particular shear stress, and sediment is eroded (McNeil et al. 1996; Jepsen et al. 1997). As erosion proceeds, the core is raised if needed to keep the core's surface level with the bottom of the flume. This process is continued until either 10 minutes has elapsed or the core has been raised roughly 2 cm. (Integral Consulting 2020)

As the flow rate is increased through the flume and as sediment begins to erode from the surface of the core determines the critical shear value above which erosion occurs and below which no erosion occurs. Once the critical shear value is determined for that layer of sediment, the flow rate through the flume is increased and erosion measured over a range of flow or shear stresses. This process is repeated at different levels of the core sample below the surface to develop the critical shear and erosion rates through the depth of the sample. Tabulated results for each of the streams showing the critical shear erosion parameters determined using SEDflume can be seen in Table 8 through Table 11 and Figure 41 through Figure 44 show the erosion rates at the various applied shear stresses over the depth of the core sample for the associated streams.

Table 8
Physical Properties and Derived Critical Shear Stresses of SEDflume Sample NR-130 (Neosho River)

Sample Depth (cm)	Median Grain Size (µm)	Wet Bulk Density (g/cm^3)	Dry Bulk Density (g/cm^3)	Loss on Ignition (%)	τ_{no} (Pa)	τ_1 (Pa)	τ_c Linear (Pa)	τ_c Power (Pa)	Final Critical Shear (Pa)
0.0	8.34	1.49	0.84	3.7	0.2	0.4	0.84	0.33	0.33
5.9	5.20	1.56	1.01	6.8	0.4	0.8	0.44	0.29	0.40
8.6	7.01	1.64	1.10	5.0	---	---	---	---	---
Mean	**6.85**	**1.56**	**0.98**	**5.2**	**0.3**	**0.6**	**0.64**	**0.31**	**0.37**

Figure 41
Photograph of Core NR-130 (Neosho River) Aligned with Applied Shear Stresses and Associated Erosion Rates

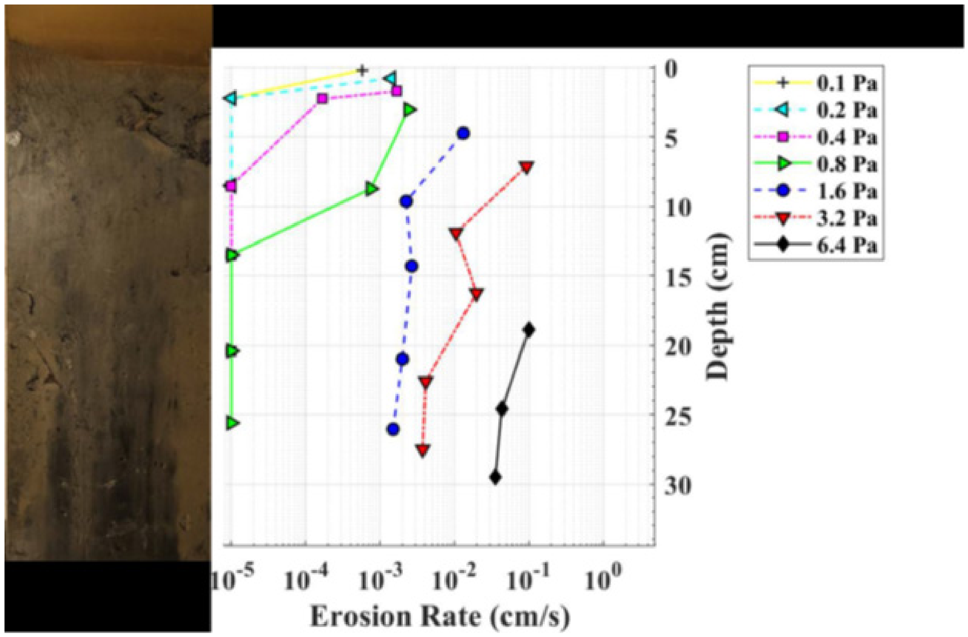


Source: Integral Consulting (2020)

Table 9
Physical Properties and Derived Critical Shear Stresses of SEDflume Sample TC-DS (Tar Creek)

Sample Depth (cm)	Median Grain Size (µm)	Wet Bulk Density (g/cm^3)	Dry Bulk Density (g/cm^3)	Loss on Ignition (%)	τ_{no} (Pa)	τ_1 (Pa)	τ_c Linear (Pa)	τ_c Power (Pa)	Final Critical Shear (Pa)
0.0	7.99	1.15	0.34	8.0	0.05	0.1	0.06	0.04	0.05
2.2	9.76	1.27	0.53	7.7	0.2	0.4	0.32	0.32	0.32
8.5	8.72	1.20	0.43	8.7	0.4	0.8	0.46	0.40	0.40
13.5	10.64	1.40	0.72	5.8	0.8	1.6	0.83	0.71	0.80
20.4	9.37	1.41	0.74	5.8	0.8	1.6	0.84	0.73	0.80
25.6	7.91	1.47	0.84	5.3	0.8	1.6	0.86	0.76	0.80
Mean	**9.07**	**1.32**	**0.60**	**6.9**	**0.5**	**1.0**	**0.56**	**0.49**	**0.53**

Figure 42
Photograph of Core TC-DS (Tar Creek) Aligned with Applied Shear Stresses and Associated Erosion Rates

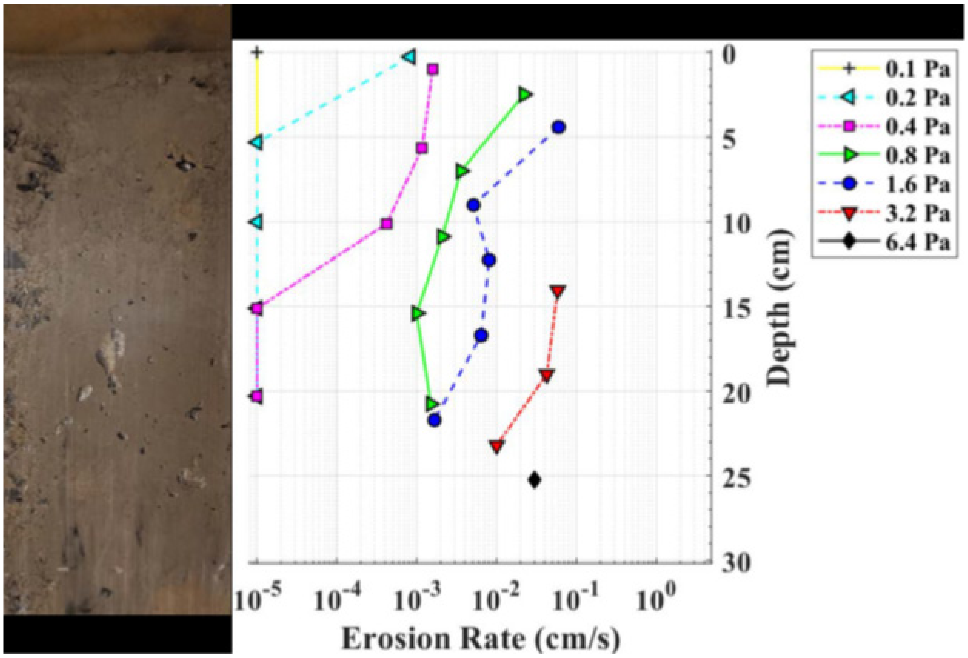


Source: Integral Consulting (2020)

Table 10
Physical Properties and Derived Critical Shear Stresses of SEDflume Sample SR-100 (Spring River)

Sample Depth (cm)	Median Grain Size (µm)	Wet Bulk Density (g/cm³)	Dry Bulk Density (g/cm³)	Loss on Ignition (%)	τ_{no} (Pa)	τ_1 (Pa)	τ_c Linear (Pa)	τ_c Power (Pa)	Final Critical Shear (Pa)
0.0	13.20	1.13	0.34	11.6	0.1	0.2	0.12	0.11	0.11
5.3	112.80	1.26	0.57	12.1	0.2	0.4	0.22	0.16	0.20
10	6.22	1.38	0.70	6.8	0.2	0.4	0.25	0.24	0.24
15.1	13.00	1.34	0.65	8.1	0.4	0.8	0.45	0.41	0.41
20.3	9.37	1.35	0.68	8.2	0.4	0.8	0.43	0.32	0.40
Mean	**30.92**	**1.29**	**0.59**	**9.4**	**0.3**	**0.5**	**0.29**	**0.25**	**0.27**

Figure 43
Photograph of Core SR-100 (Spring River) Aligned with Applied Shear Stresses and Associated Erosion Rates

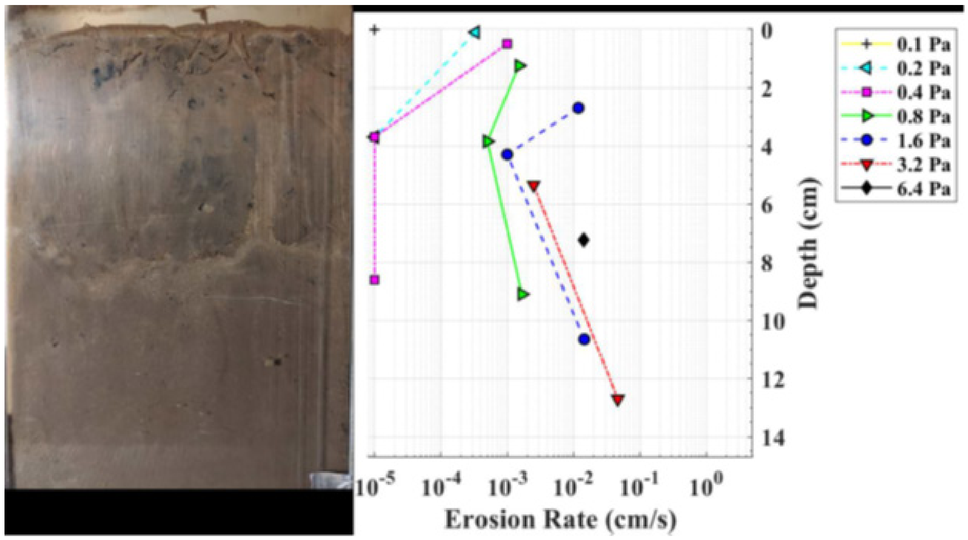


Source: Integral Consulting (2020)

Table 11
Physical Properties and Derived Critical Shear Stresses of SEDflume Sample ER-680 (Elk River)

Sample Depth (cm)	Median Grain Size (µm)	Wet Bulk Density (g/cm^3)	Dry Bulk Density (g/cm^3)	Loss on Ignition (%)	τ_{no} (Pa)	τ_1 (Pa)	τ_c Linear (Pa)	τ_c Power (Pa)	Final Critical Shear (Pa)
0.0	18.95	1.39	0.68	3.4	0.1	0.2	0.13	0.12	0.12
3.7	32.96	1.70	1.16	2.9	0.4	0.8	0.48	0.42	0.42
8.6	16.32	1.66	1.11	3.0	0.4	0.8	0.43	0.37	0.40
13.7	23.18	1.54	0.94	4.2	---	---	---	---	---
Mean	**22.85**	**1.57**	**0.97**	**3.4**	**0.3**	**0.6**	**0.35**	**0.30**	**0.31**

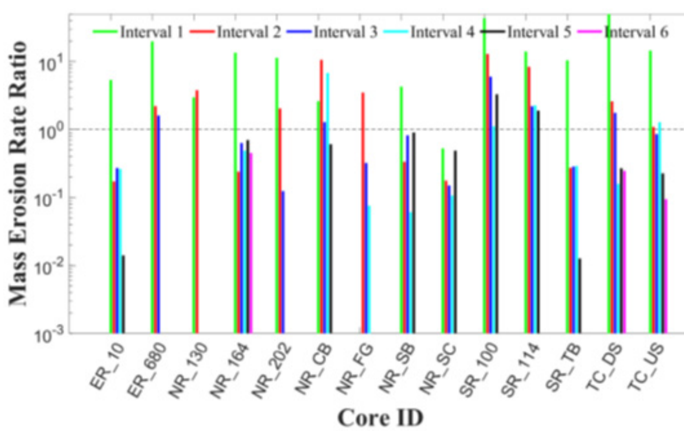
Figure 44
Photograph of Core ER-680 (Elk River) Aligned with Applied Shear Stresses and Associated Erosion Rates



Source: Integral Consulting (2020)

A summary of erosion rates ratios developed by Integral Consulting (Figure 45) shows that erosion rates generally are significantly lower at deeper locations in the sediment columns than at the surface. Interval 1 refers to the top layer of the sediment cores, with each subsequent interval representing a deeper layer of material. Exact interval thicknesses vary, though most are 5 centimeters (cm) or less.

Figure 45
Intracore Erosion Rate by Interval for Each SEDflume Core Sample

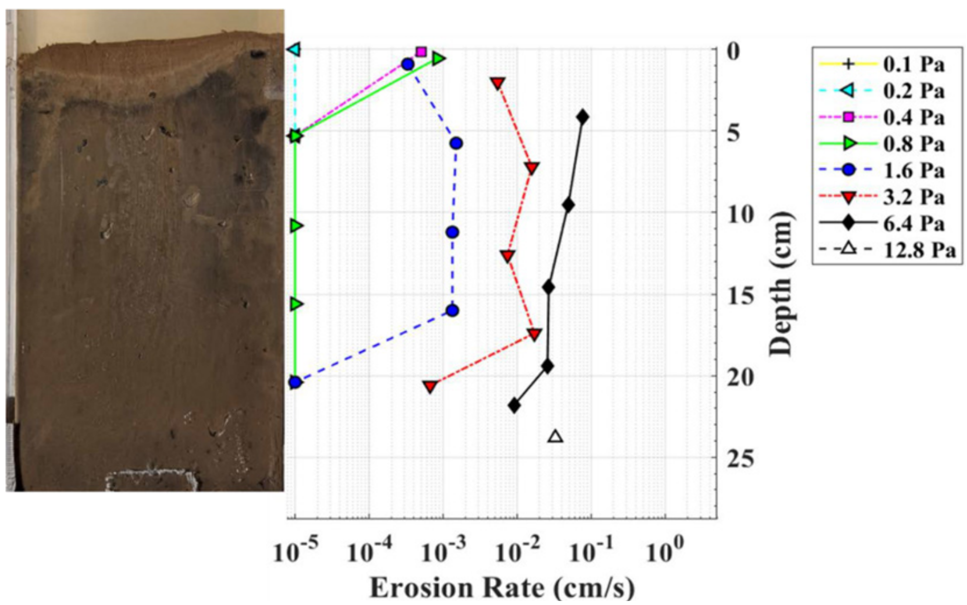


Source: Integral Consulting (2020)

The results of the tests showed expected critical shear patterns. Sediment near the top of the column is more recently deposited and therefore has had less time to consolidate; in general, it is more easily eroded. Lower in the sediment column, the particles have consolidated over time and under higher pressures due to the overlying material; critical shear stress is generally higher as one moves deeper into the core sample.

It is important to understand the high degree of variability of erosion rates as a function of depth below the sediment surface by looking at an example. A sample of the data is shown in Figure 46. The photograph on the left allows visual inspection of the core sample before erosion; the chart on the right provides erosion rate as a function of depth and applied shear stress. It indicates more resistance to erosion at deeper levels of the soil column. For example, at 0.4 pascal (Pa) of shear stress, the surface material eroded at a rate of approximately 4×10^{-3} centimeters per second (cm/s), but at 5 cm of depth, erosion was significantly lower (approximately 10^{-5} cm/s) for the same shear stress.

Figure 46
Example SEDflume Analysis Results



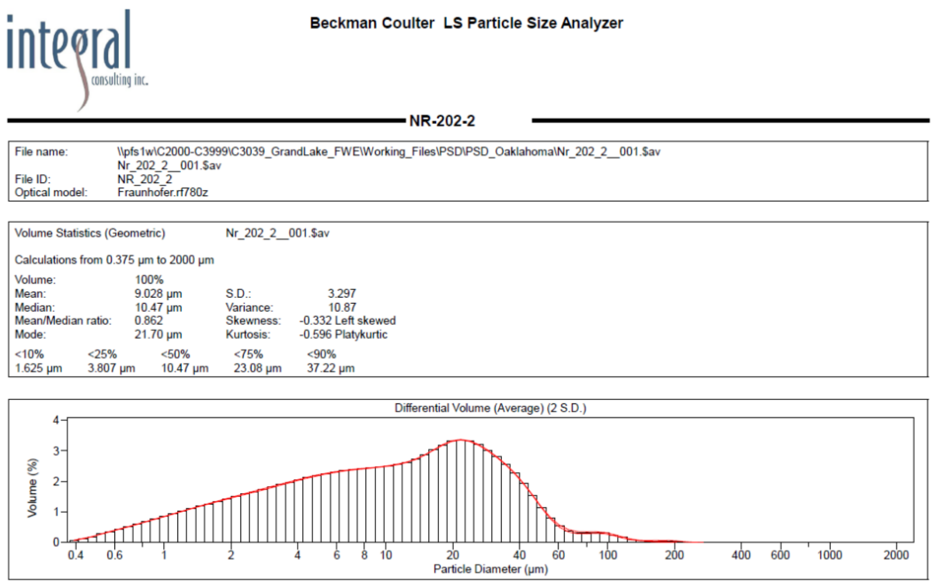
Note: Left: image of sediment core before erosion testing; right: graphical dataset showing erosion rates as a function of bed shear stress and depth in sediment column.
Source: Integral Consulting (2020)

This example and the previous summary of intracore erosion rates show a variation of several orders of magnitude over the depth of samples. This extreme variability affects the development of reasonable erosion parameters to be used in the STM.

2.3.3.2 Sediment Particle Size Analysis

During erosion of the samples, the testing facility used a Beckman Coulter LS particle size analysis system to collect sediment grain size information (Integral Consulting 2020). An example of the output is provided in Figure 47.

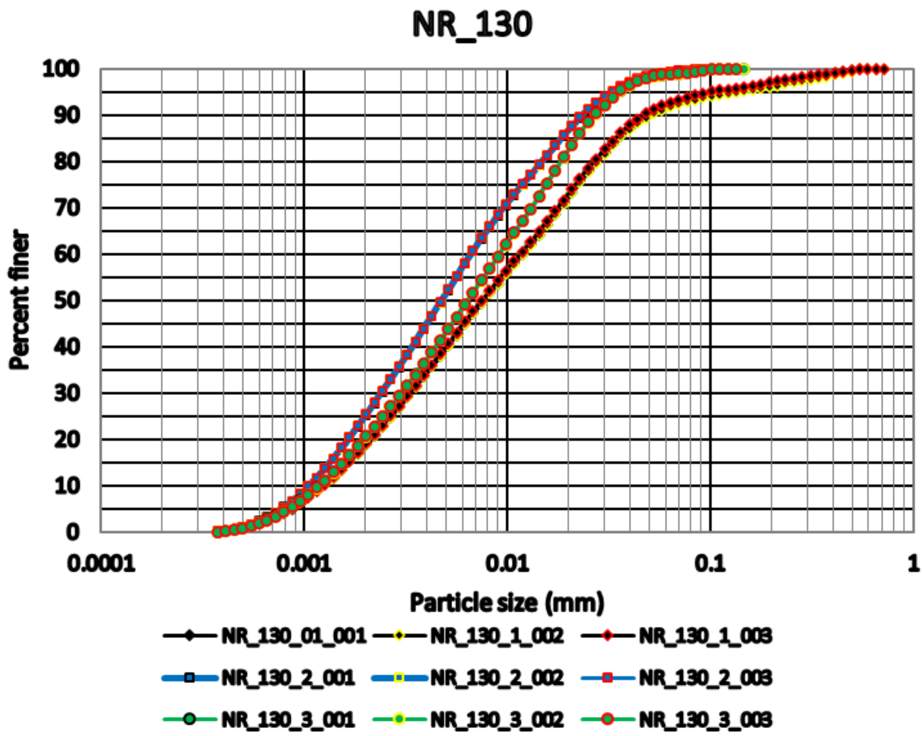
Figure 47
Sample Particle Size Analysis Output from SEDflume Analysis



Source: Integral Consulting (2020)

The particle count analysis shows that most of these samples consist of silt- and clay-sized particles. These data were developed into particle size distribution curves relating sediment size to the percentage of the sample finer than the individual sizes to cover the entire range of sediment sizes in the sample. Figure 48 presents an example of this type of graph. A complete set of particle size distribution graphs for the samples is found in Appendix C.

Figure 48
Sample Particle Size Analysis Output from SEDflume Analysis Showing Cumulative Percent Finer Values for Core NR-130 (Neosho River)



2.3.3.3 Sediment Deposit Bulk Density Analysis

A key factor in understanding silt and clay deposits is the density of sediment and how it varies vertically in the sediment column. Density, along with erodibility and the particle size distribution, are critical parameters for evaluating fluvial transport of this type of sediment.

Although density of sand and gravel deposits fits into a relatively narrow band and does not vary significantly over time, sediment deposits of silt and clay generally settle out of the water column at a low density and then gradually increase in density over time as water is compressed out of the sediment column. As more sediment deposits over the original layers, density of lower layers increases; the consolidation process continues over time until a maximum value is reached. In some situations, this can result in the formation of sedimentary rock such as claystone or shale.

As discussed above, this process also affects the strength or erodibility of sediment. The deeper, more consolidated layers tend to exhibit higher critical shear stress values than the more recently deposited layers near the bed surface.

Density is also the link between sediment transport and deposition. Incoming sediment load is quantified in weight (i.e., tons per day as the unit of sediment transport), whereas sediment deposition as measured by survey is defined in terms of volume. In the case of reservoir sediment deposits, the deposited volume can vary considerably over time and with the depth of the sediment layer.

Sediment density of the upper layer of the sediment deposit was determined in the analysis of sediment cores. Table 12 summarizes the range of sediment density values for the core samples.

Table 12
Density Results from Top Layer Testing of SEDflume Samples

Sediment Core	Minimum Dry Density		Maximum Dry Density		Mean Dry Density (pcf)
	pcf	% of Mean	pcf	% of Mean	
SED-ER-10	28.7	66.7	48.7	113.0	43.1
SED-ER-680	42.5	70.1	72.4	119.6	60.6
SED-NR-130	52.4	85.7	68.7	112.2	61.2
SED-NR-164	76.2	81.9	103.0	110.7	93.0
SED-NR-202	27.5	63.8	53.1	123.2	43.1
SED-NR-CB	37.5	74.1	64.9	128.4	50.6
SED-NR-FG	73.0	90.0	85.5	105.4	81.2
SED-NR-SB	30.6	62.8	62.4	128.2	48.7
SED-NR-SC	48.7	88.6	61.2	111.4	54.9
SED-SR-100	21.2	57.6	43.7	118.6	36.8
SED-SR-114	32.5	69.3	54.9	117.3	46.8
SED-SR-TB	29.3	73.4	46.2	115.6	40.0
SED-TC-DS	21.2	56.7	52.4	140.0	37.5
SED-TC-US	30.0	75.0	46.2	115.6	40.0
Minimum	**21.2**	**56.7**	**43.7**	**105.4**	**36.8**
Mean	**39.4**	**72.6**	**61.7**	**118.5**	**52.7**
Maximum	**76.2**	**90.0**	**103.0**	**140.0**	**93.0**

The summary table shows a significant degree of variability for the dry density values for the sediment cores. For example, the minimum dry density ranges from 21.2 to 76.2 pcf, and the maximum dry density ranges from 43.7 to 103 pcf. For reference, the bulk density of water is 62.4 pcf and solid rock at a specific gravity of 2.65 is 165.4 pcf. Laboratory results for each individual sample analysis are found in Appendix C. Assessment of the data does not reveal any readily apparent spatial trends in sediment density.

Sediment density may be correlated with depth below the surface of the sediment deposit due to the consolidation process as fine sediment deposits generally compress over time. Table 13 through Table 16 display the sediment density from the SEDflume samples in relation to sample depth for each of the streams. Corresponding graphs (Figure 49 through Figure 52) of sediment density with depth below the sediment surface for each stream show this general trend (noting that 1 gram per cubic centimeter [g/cm^3] is equivalent to 62.4 pcf—the density of water). Also shown in the graphs are D_{10}, D_{50}, and D_{90} (the sediment grain diameters that are larger than 10%, 50%, and 90% of the total sample, respectively) to give some perspective on sediment sizes found in the samples.

Table 13
Physical Properties of SEDflume Sample NR-130 (Neosho River)

Sample Depth (cm)	Median Grain Size (µm)	Wet Bulk Density (g/cm^3)	Dry Bulk Density (g/cm^3)	Loss on Ignition (%)
0.0	8.34	1.49	0.84	3.7
5.9	5.20	1.56	1.01	6.8
8.6	7.01	1.64	1.10	5.0
Mean	**6.85**	**1.56**	**0.98**	**5.2**

Figure 49
Physical Properties of SEDflume Sample NR-130 (Neosho River) with Depth

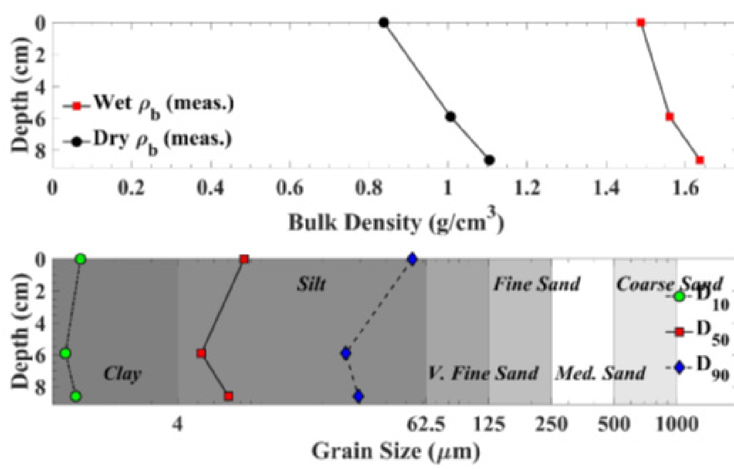


Table 14
Physical Properties of SEDflume Sample SR-100 (Spring River)

Sample Depth (cm)	Median Grain Size (µm)	Wet Bulk Density (g/cm³)	Dry Bulk Density (g/cm³)	Loss on Ignition (%)
0.0	13.20	1.13	0.34	11.6
5.3	112.80	1.26	0.57	12.1
10.0	6.22	1.38	0.70	6.8
15.1	13.00	1.34	0.65	8.1
20.3	9.37	1.35	0.68	8.2
Mean	**30.92**	**1.29**	**0.59**	**9.4**

Figure 50
Physical Properties of SEDflume Sample SR-100 (Spring River) with Depth

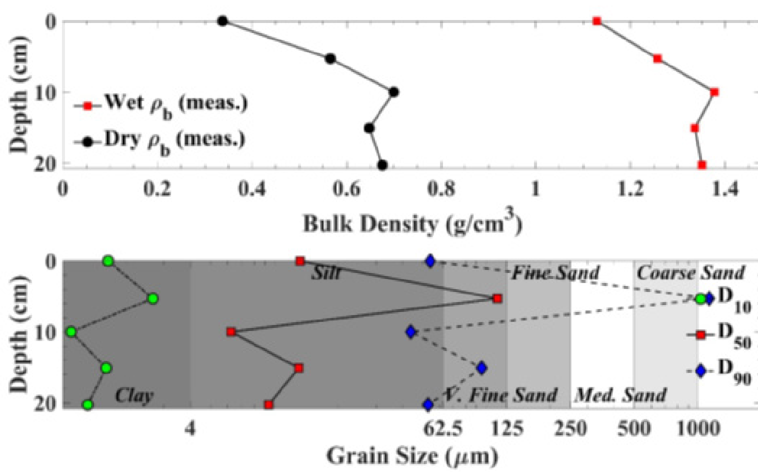


Table 15
Physical Properties of SEDflume Sample TC-DS (Tar Creek)

Sample Depth (cm)	Median Grain Size (µm)	Wet Bulk Density (g/cm³)	Dry Bulk Density (g/cm³)	Loss on Ignition (%)
0.0	7.99	1.15	0.34	8.0
2.2	9.76	1.27	0.53	7.7
8.5	8.72	1.20	0.43	8.7
13.5	10.64	1.40	0.72	5.8
20.4	9.37	1.41	0.74	5.8
25.6	7.91	1.47	0.84	5.3
Mean	**9.07**	**1.32**	**0.60**	**6.9**

Figure 51
Physical Properties of SEDflume Sample TC-DS (Tar Creek) with Depth

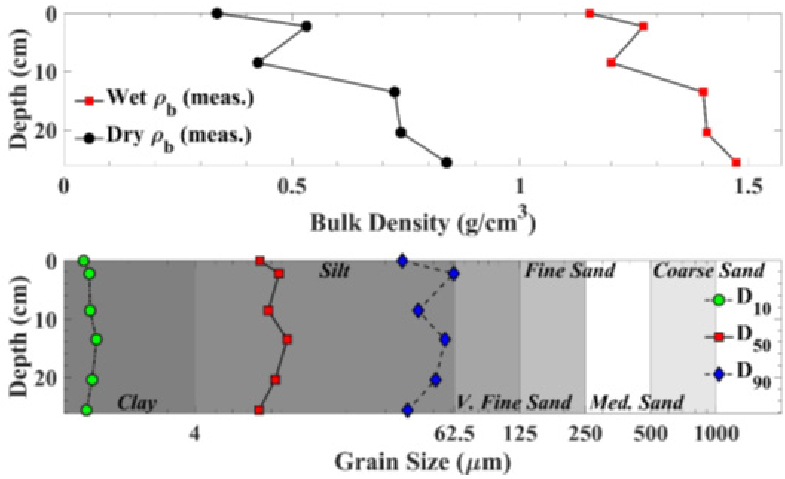
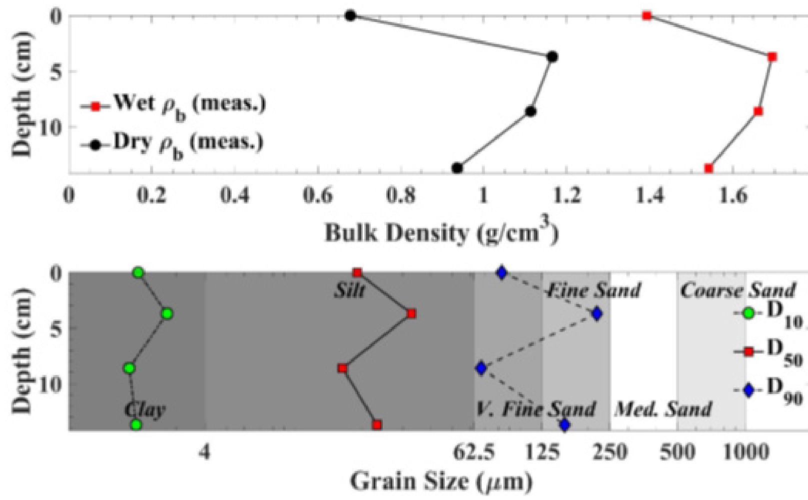


Table 16
Physical Properties of SEDflume Sample ER-680 (Elk River)

Sample Depth (cm)	Median Grain Size (µm)	Wet Bulk Density (g/cm^3)	Dry Bulk Density (g/cm^3)	Loss on Ignition (%)
0.0	18.95	1.39	0.68	3.4
3.7	32.96	1.70	1.16	2.9
8.6	16.32	1.66	1.11	3.0
13.7	23.18	1.54	0.94	4.2
Mean	**22.85**	**1.57**	**0.97**	**3.4**

Figure 52
Physical Properties of SEDflume Sample ER-680 (Elk River) with Depth



2.3.4 *Sediment Transport Measurements*

Sediment transport samples were collected during several site visits and delivered to appropriate laboratories for analysis.

2.3.4.1 Suspended Transport Results

SSC samples were processed by the WSLH. Sample analysis evaluated both total sediment concentration and concentration of sediment with grain sizes less than 63 micrometers (µm; upper limit of silt-sized particles) to assess the percentage of cohesive sediments moving through the system in suspension.

Several samples produced erroneous results due to laboratory processing errors, with cohesive sediment concentrations higher than total sediment concentrations. These results were discarded. Across all samples, particles smaller than 63 µm accounted for 82% of all suspended sediment.

Full reports of SSC sample analysis can be found in Appendix D.

2.3.4.2 Bedload Transport Results

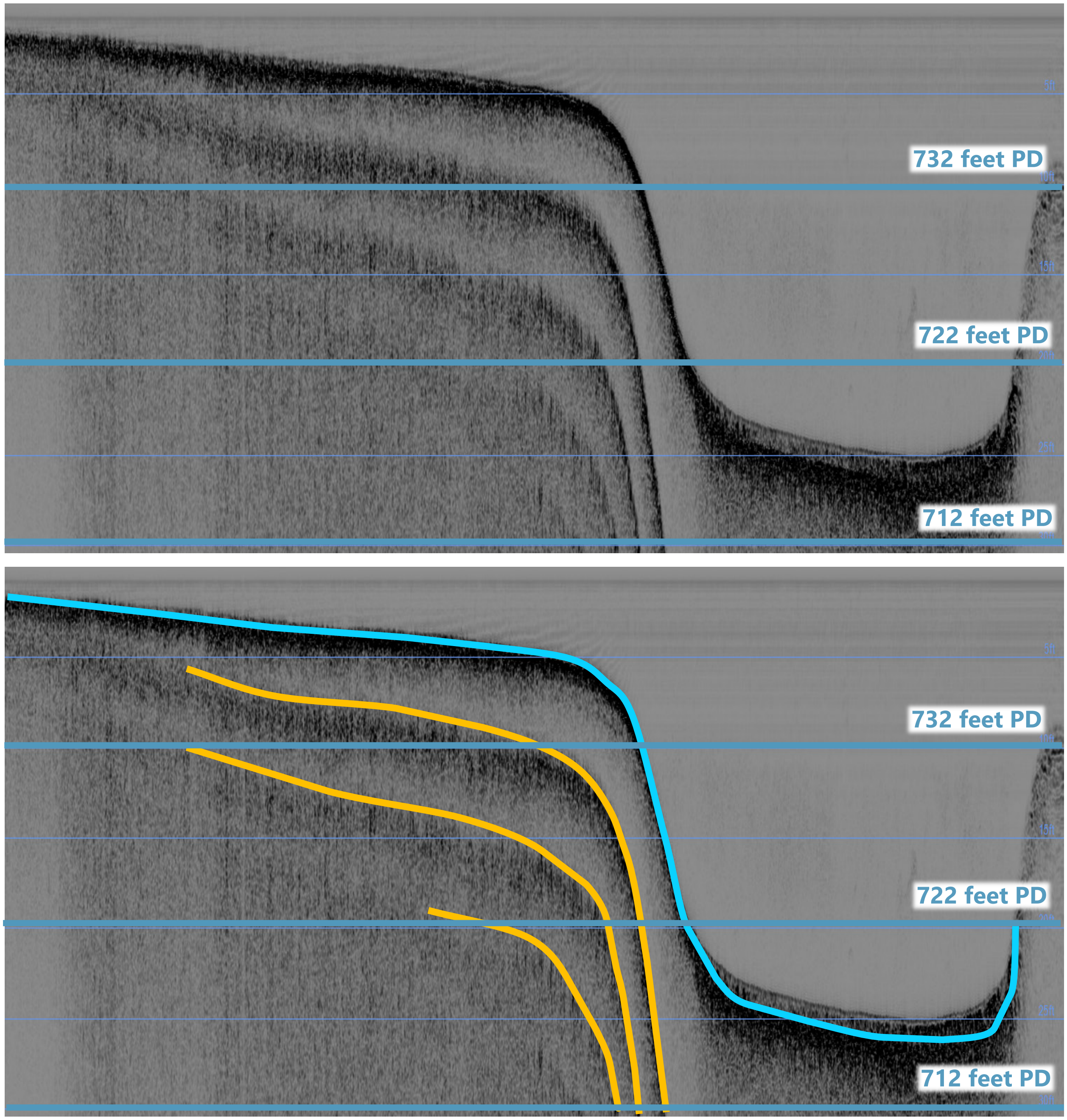
During each SSC sampling trip, Anchor QEA collected bedload transportation measurements as well. At no point did the Helley-Smith sampler bag collect any sediment particles. Flow rates during sampling efforts are shown in Table 6. Data collected to date indicate that for the vast majority of flow conditions experienced on these rivers, very little bedload transport occurs. Bed material particle size distributions, coupled with shear stress calculations over a wider range of flows and standard STM parameters for non-cohesive sediment sizes, will be used in the model to develop a more complete understanding of the relative contribution of bedload transport. Initial indications are that bedload transport does not represent a significant contribution to the overall sediment transport into Grand Lake.

2.3.5 Subsurface Findings

The SBP survey and vibracore sampling results provided information on deposition thicknesses in the area of the delta feature. The SBP survey was the initial field measurement, but it was also important to verify those results with vibracore samples.

The SBP will produce a visual output referred to as a “waterfall” that indicates the distances to different objects. The most powerful return signal is often the lakebed or streambed, and subsequent layers are somewhat weaker signals that are still visible in the data. Another type of signal is referred to as a “multiple,” which is produced by pulses bouncing between the SBP sonar head and the bed, several times, resulting in a series of nearly parallel lines. An example image collected during the SBP survey at RM 112.34 showing this is provided in Figure 53.

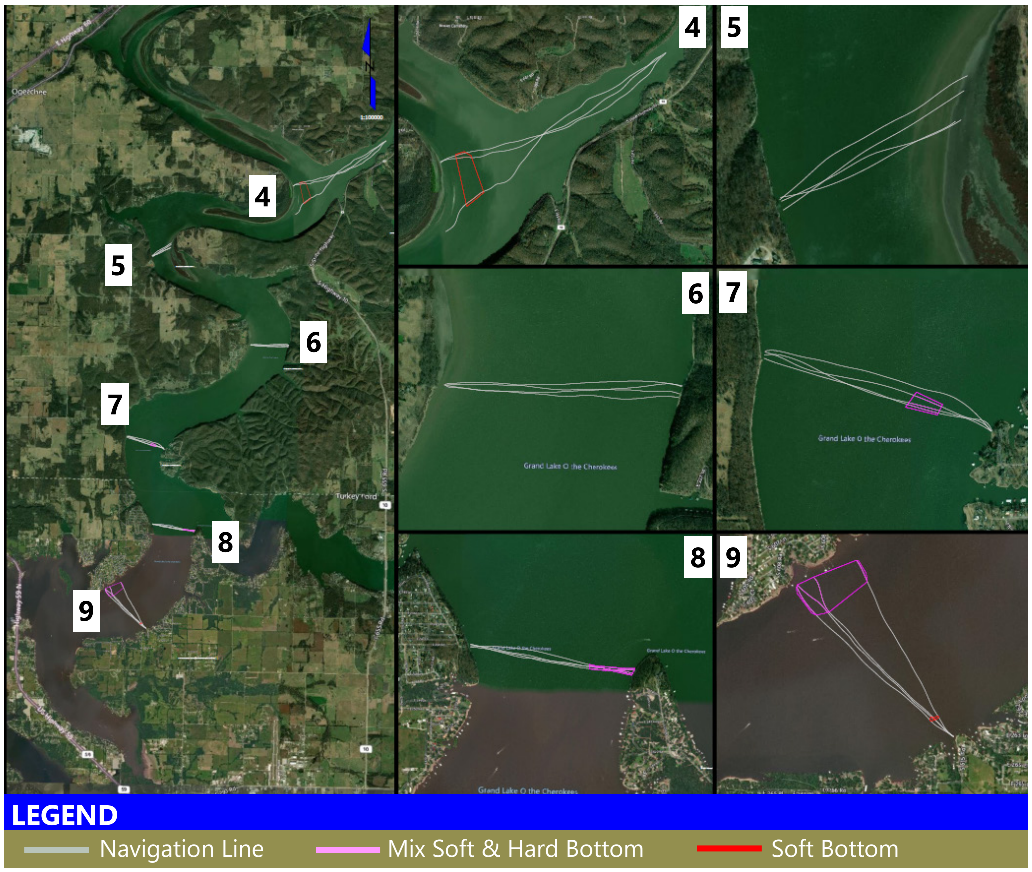
Figure 53
Example SBP Waterfalls showing Layer Transitions and "Multiples"



Notes: Waterfall images taken from SBP survey at RM 112.34 (approximately 1.5 miles upstream of Council Hollow)
Lower image is identical to upper, but locations of layer transitions and multiples are highlighted.
Teal line is the layer transition between soft and hard sediments
Orange lines are "multiples" or secondary reflections

The waterfalls produced during the Neosho River SBP survey showed layer transitions at approximately 2 to 3 feet below the bed surface. This indicated a thin layer of soft material over firmer sediments throughout much of the survey area. The interpretation was confirmed by an SBP expert, and the representative stated that a majority of the areas surveyed were not characterized by soft sediment beds (Figure 54).

Figure 54
Interpretation of SBP Survey Results at Stations 4 through 9

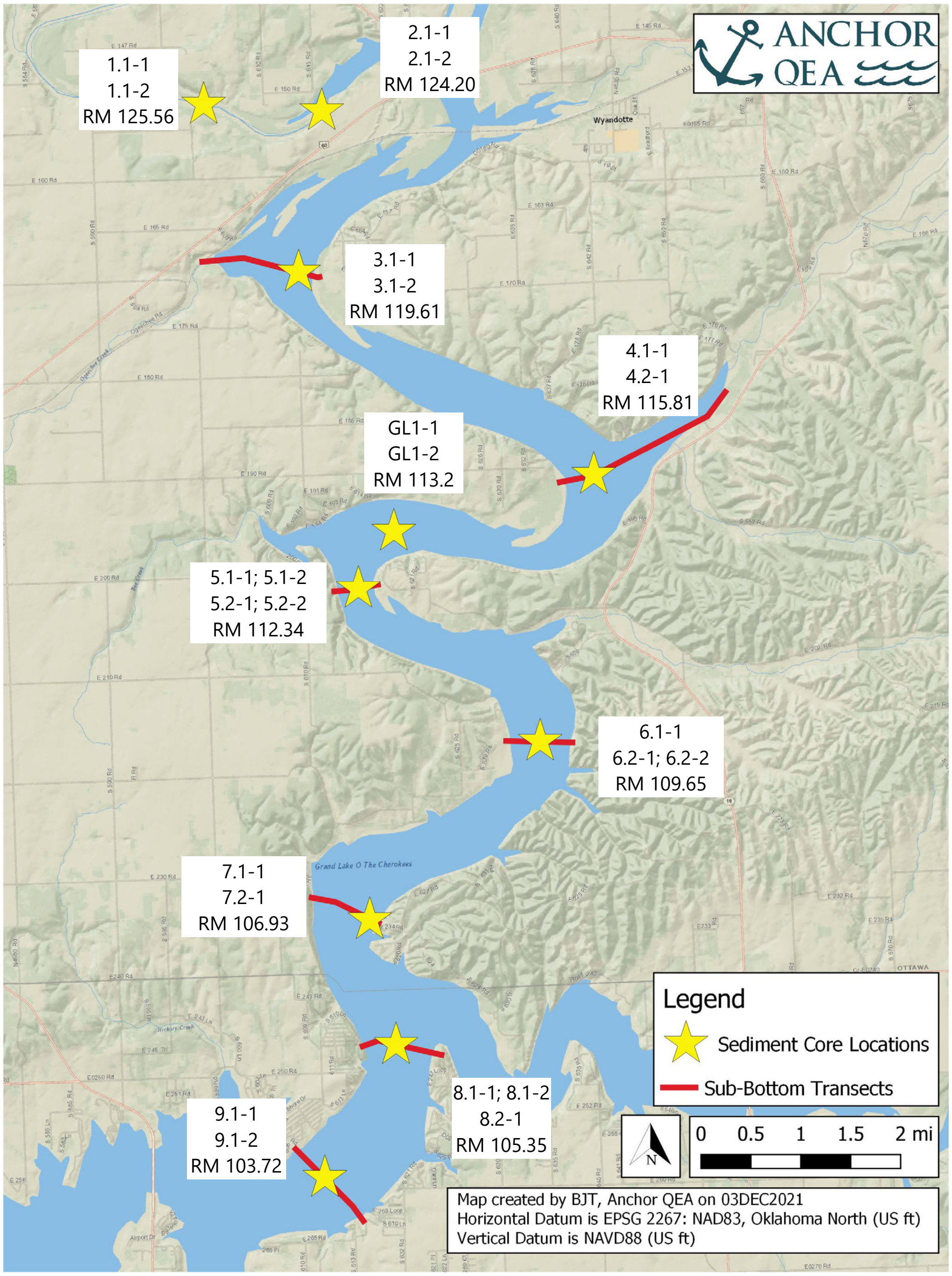


Source: Interpretation of SBP readings; station numbers adjusted from OARS original to reflect GRDA numbers.

Figure 54 shows the navigation lines from the field SBP survey. Where a mixture of soft and hard beds was noted by the SBP expert (for example at transect 9, bottom right), pink outlines were drawn. Red outlines indicate soft bottom materials (transect 4, top center). Areas not colored were interpreted to consist of hard bottom sediments. The vibracore sampling was performed to validate SBP survey results, and they indicated generally thicker layers of deposition than were reported by the SBP.

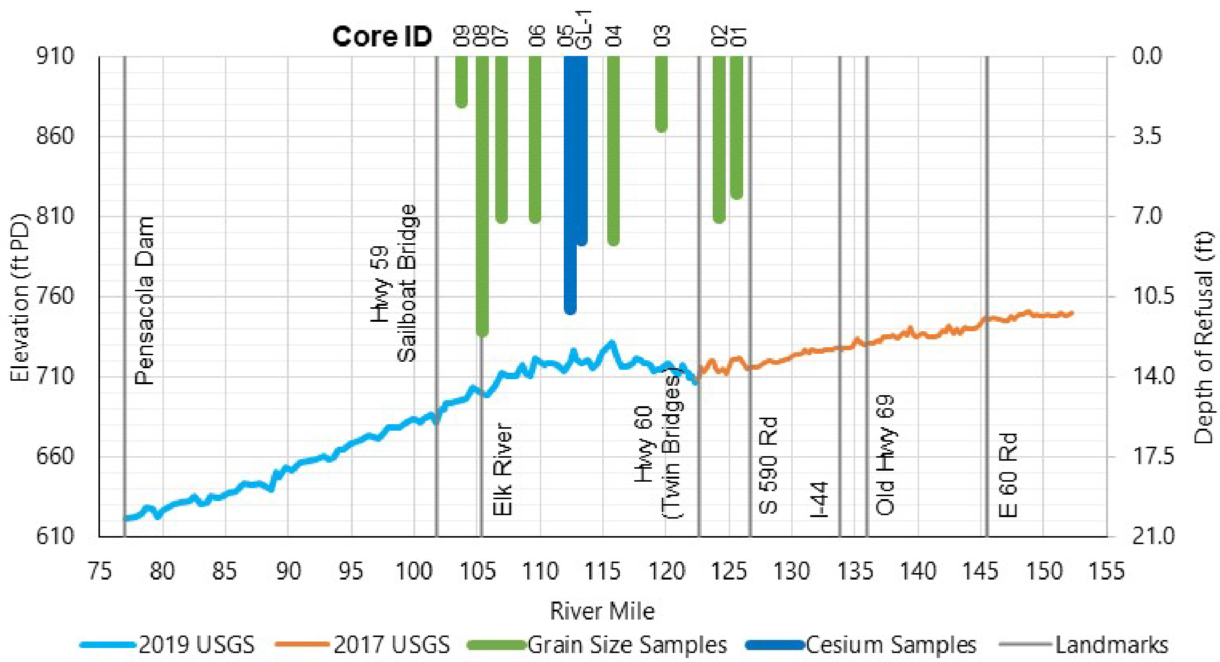
The vibracore pushed core tubes into the riverbed at the locations shown in Figure 55 using 16-foot coring tubes. These were chosen to align with the SBP survey discussed in Section 4.1 as a means of confirming interpretation of the results. SBP survey transects are shown in red with their relationship to the vibracore sample locations.

Figure 55
Locations of Sediment Cores Collected by GRDA



The vibracoring efforts produced 24 core samples for analysis. The cores were pushed to refusal, which ranged from 1.5 to 11 feet in the reach above the Elk River (Figure 56). In the lower reservoir, one core penetrated approximately 12 feet of sediment before refusal. Two cores over 10 feet in length taken in the delta feature (RM 112.34) were evaluated for Cs-137 activity. Cores shorter than 10 feet or taken from the lower reservoir were analyzed only for grain size distribution (see Section 3.3). Figure 56 shows the maximum vibracore penetration depths at each site shown in Figure 55.

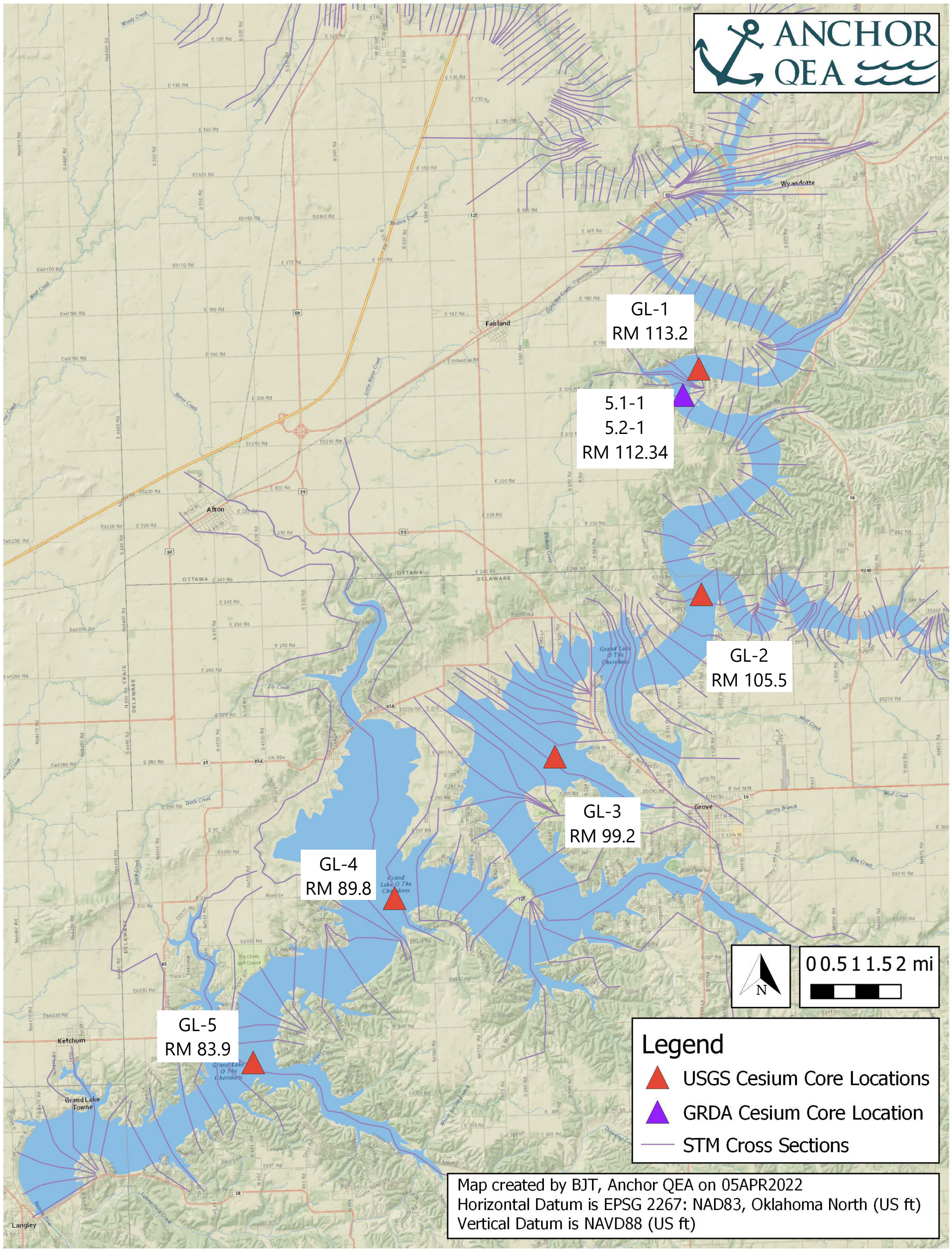
Figure 56
Maximum Vibracore Sample Penetration on Neosho River



Note: GL-1 sample tested for cesium activity by USGS (Juracek and Becker 2009)

The USGS (Juracek and Becker 2009) analyzed sediment Cs-137 levels to determine the approximate age of sediment in various locations within Grand Lake. The 2008 study collected samples from five sites, with one located in the region of the delta feature, one near the confluence with the Elk River, and three others located further downstream in the reservoir (Figure 57). Where USGS data showed a clear, defined Cs-137 peak, the findings were considered settled.

Figure 57
Locations of Sediment Cores Collected for Cesium Analysis



Note: Locations of USGS cores taken from Juracek and Becker (2009).

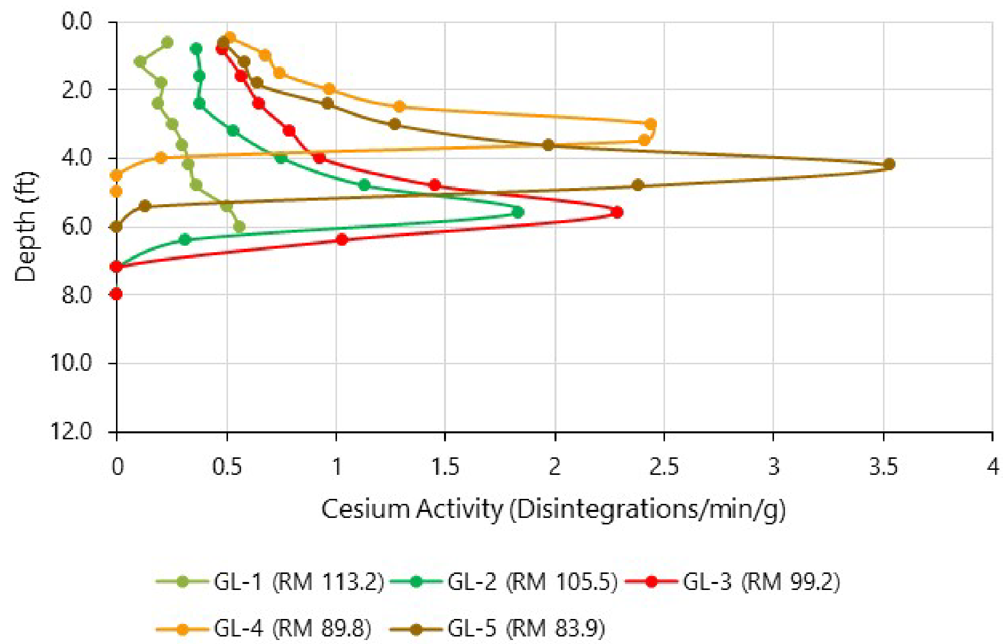
A major goal of sampling was to collect a significantly deeper sample near USGS site GL-1. The USGS sample was approximately 6 feet, and it was decided that a vibracore sample of approximately 10 feet would be sufficient to trigger re-evaluation and Cs-137 analysis. Shorter cores would not likely produce different results from the USGS study (Juracek and Becker 2009). Cores lower in the basin were not analyzed as the USGS dataset was sufficiently robust and were not of interest for delta feature analysis. The cores that met this criterion were 5.1-1 and 5.2-1 as shown in Figure 57.

The vibracore samples show a thicker sediment deposit, which suggests the SBP was not reliably capturing sediment layer thicknesses. Most likely, the penetration of the SBP signal was limited by a layer of biotic activity within the surface of the sediment; several core samples had air bubbles in the top few feet produced by decomposition or other biological activity. This produces readings indicating a softer, air-filled layer above the firmer silt and clay sediment that would register as a separate layer during SBP surveying (Aqua Survey 2004; Science Applications International 2001). As a result, further analyses relied on vibracore sampling rather than SBP results.

Vibracore sampling showed thicker layers of soft sediment deposition, and also provided opportunity to evaluate Cs-137 trends measured by a USGS study (Juracek and Becker 2009).

USGS analysis showed that Cs-137 peaks were located approximately 3 to 6 feet below the bed surface (Figure 58). Those peaks represent sediment that was deposited in approximately 1963, indicating that just 3 to 6 feet of sediment had deposited since 1963 at sites GL-2, -3, -4, and -5 (Figure 57).

Figure 58
Comparisons of Relative Cesium Activity within the USGS Core Samples



Notes: The peak cesium activity indicates the soil layer associated with deposition in approximately 1963. All material above that layer is assumed to have deposited since the nuclear testing ban.

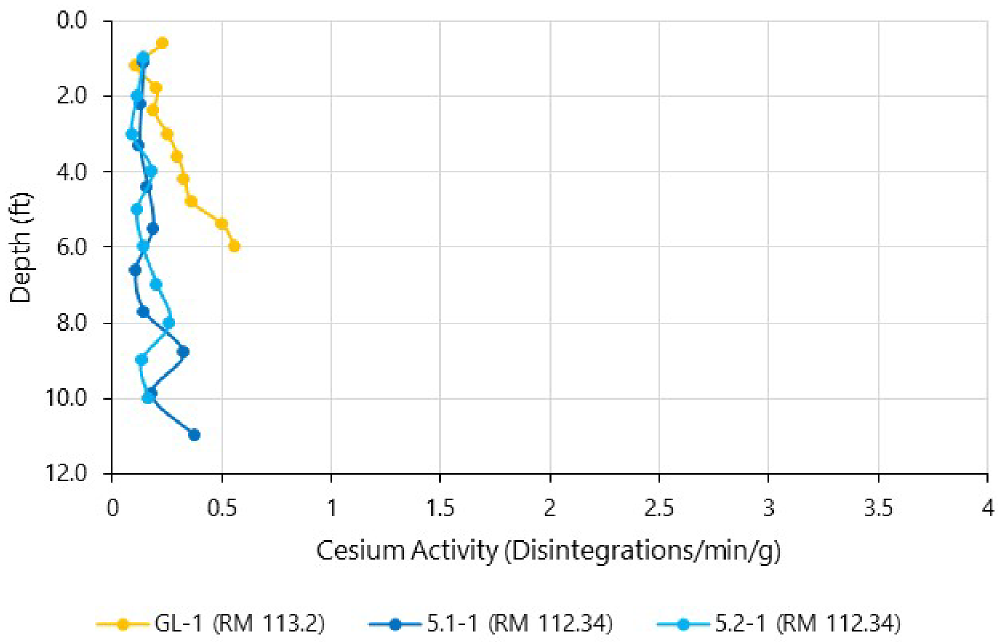
Source: Figure adapted from Juracek and Becker (2009).

The sample in the delta feature (GL-1) showed no spike in Cs-137. Juracek and Becker (2009) concluded the sediment they collected was all deposited post-1963. The USGS interpreted this to indicate that the area was not continually depositional but washes away due to wave action or large flow events before new sediment redeposits. This follows typical reservoir delta feature evolution, with surface sediments at the top of the delta feature washing downstream and extending the delta feature further into the reservoir rather than increasing the top elevation.

During GRDA's vibracore sampling, they repeated the USGS efforts to obtain longer (deeper) cores and see if a longer sample would capture a characteristic Cs-137 spike that denotes a 1963 sediment layer. GRDA collected approximately 11-foot cores near site GL-1 (cores 5.1-1 and 5.2-1) and processed them for Cs-137 analysis. The location of cores 5.1-1 and 5.2-1 are displayed in Figure 57.

GRDA sent 10 samples at equally spaced intervals within each core for Cs-137 evaluation. The results show a similar pattern to those of the USGS study, with no apparent Cs-137 peak (Figure 59).

Figure 59
Comparisons of Relative Cesium Activity Between USGS Core Sample GL-1 and GRDA Samples 5.1-1 and 5.2-1



Notes: GL-1 activity levels taken from Juracek and Becker (2009)
The lack of a defined cesium activity peak indicates that all sediment collected in the core was deposited after 1963.

This further suggests that deposition in the top 10 feet of the soil column is all post-1963 and that the site is not continuously depositional, instead indicating regular mixing of the materials at the top of the delta feature. These results agree with the USGS (Juracek and Becker 2009) findings that this location sees regular disturbance and is not continually depositional and is consistent with typical delta feature evolution patterns (Vanoni 2006).

2.4 Discussion

The field campaign provided valuable insights for the sediment study. Initial understanding of the reservoir indicated the system was dominated by sand and gravel sediments (Mussetter 1998; Tetra Tech 2018). Although that appears to be the case in the riverine components of the overall system, field work results have found cohesive silts and clays play a far more important role than initially anticipated.

The relative dearth of bedload sediment transport and comparatively high concentrations of fines moving in suspension through the watershed have indicated a need to focus extra resources on silt- and clay-sized sediment modeling. Because silt and clay deposits typically exhibit cohesive characteristics, along with several other complicating factors, the complexity of the overall sediment study and associated modeling tasks increases. *Modeling Sediment Movement in Reservoirs*, prepared by the U.S. Society on Dams (USSD) Committee on Hydraulics of Dams, Subcommittee on Reservoir Sedimentation (USSD 2015), presents a discussion of the issues associated with cohesive sediments. Some of the challenges are related to changing density over time through the process of consolidation; others are related to the fact that cohesive sediment particle motion is determined primarily by electrochemical surface forces rather than gravity forces, which dominate sand and gravel motion. Further complicating the development of appropriate input data and parameters is the fact that the data show a wide degree of variability from sample to sample and location to location.

To develop the necessary information, additional efforts for sediment core sampling were required beyond what was originally planned in the Sediment Study Plan. The study team selected locations for and performed sampling of the reservoir bed. The material was then subjected to erosion testing for model parameterization. SEDflume testing provided multiple valuable data points for sediment within the Grand Lake reservoir.

Critical shear stress is perhaps the most important of the SEDflume outputs. The gradual consolidation of fine, cohesive material and its effect on erosion resistance as a function of depth within the sediment column are crucial for accurately modeling sediment transport and deposition within the basin. Its use in developing the STM will allow HEC-RAS to determine whether sediment will erode from the bed or remain in place during a variety of flow conditions, and particle size and density parameters will allow the model to determine whether deposition will occur.

2.4.1 Sediment Transport

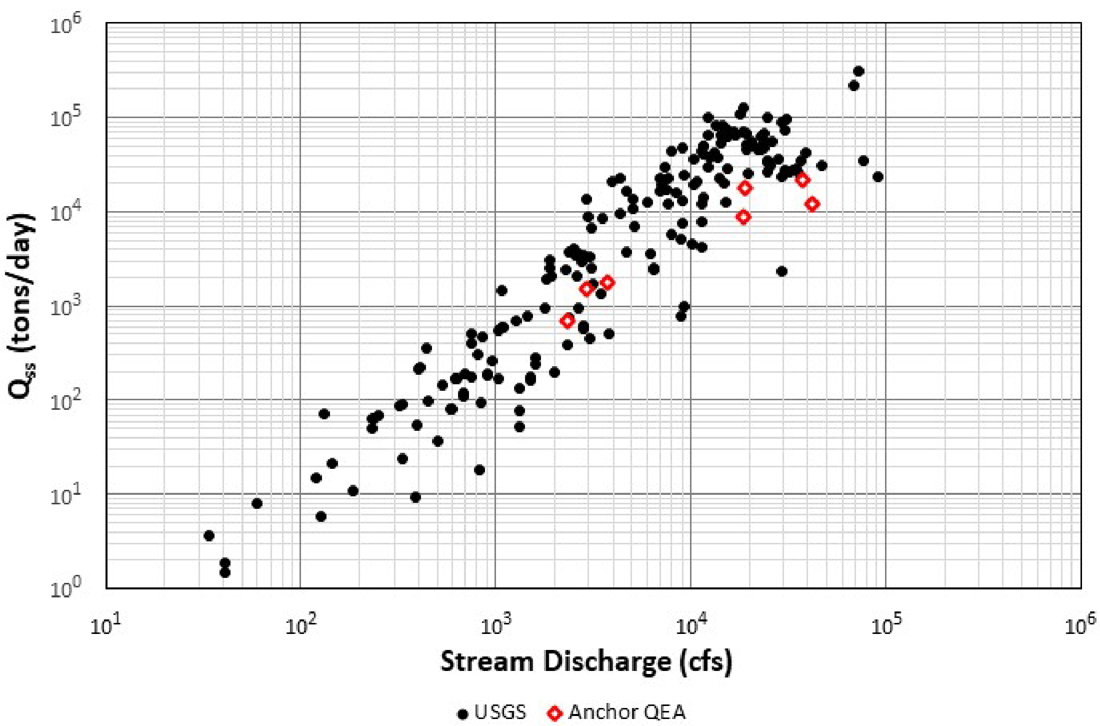
2.4.1.1 Suspended Sediment Transport

Sediment transport data, in the form of suspended sediment sampling, were collected at various USGS stations on the primary rivers of interest flowing into Grand Lake. In addition to the USGS data, suspended sediment samples were collected by Anchor QEA at these same stations. At each station, regression analyses were conducted to develop a numerical relationship between suspended sediment transport (in tons per day) and flow that forms a rating curve between sediment transport and flow. The data used for the development of the suspended sediment transport rating curves include all available data from the USGS through July 8, 2021, and the Anchor QEA data collected through July 1, 2021.

A preliminary assessment of the two sets of data reveals that they both lie within the bounds of variability typically seen in sets of suspended sediment data. The Anchor QEA data, however, generally lie in the middle to lower end of the range of the available data. It is possible that because these data were collected in recent years and the USGS data cover the entire period of record, which dates several decades back in time, there may be a trend toward lower sediment transport from these rivers over time.

Sediment transport data are only collected occasionally so no continuous, or even daily, record of sediment transport exists. With a sediment transport rating curve, the regression equation can be applied to the daily flow data to develop an estimate of the long-term historical quantity of sediment flowing past given stations on these rivers and hence sediment transport into the reservoir. Figure 60 presents an example of the available suspended sediment transport data on the Neosho River near Commerce.

Figure 60
Suspended Sediment Transport Rates and Fluvial Discharge Measured on the Neosho River near Commerce, Oklahoma



Analysis of the particle size distribution of the suspended sediment samples collected by Anchor QEA are shown in Figure 61 through Figure 64. These data show that suspended sediment is predominantly finer than 0.0625 millimeter (mm), which is the break point between sand and silt. Consistent with the bed material in the reservoir, most of the suspended sediment consists of silt and clay-sized sediment, which is being transported into the reservoir.

Figure 61
Fine Sediment as Fraction of Total Suspended Sediment Sampled on the Neosho River near Commerce, Oklahoma

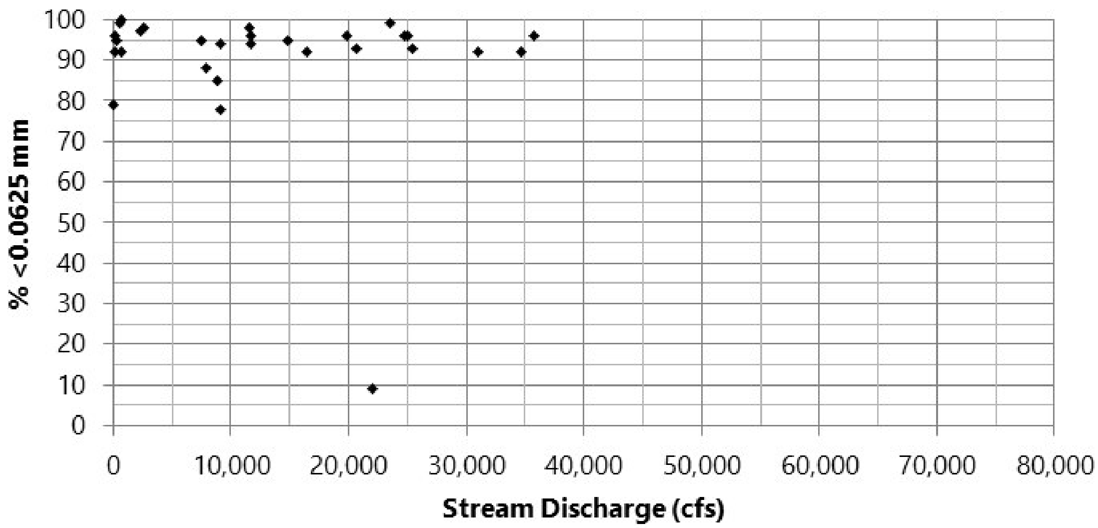


Figure 62
Fine Sediment as Fraction of Total Suspended Sediment Sampled on Tar Creek near Commerce, Oklahoma

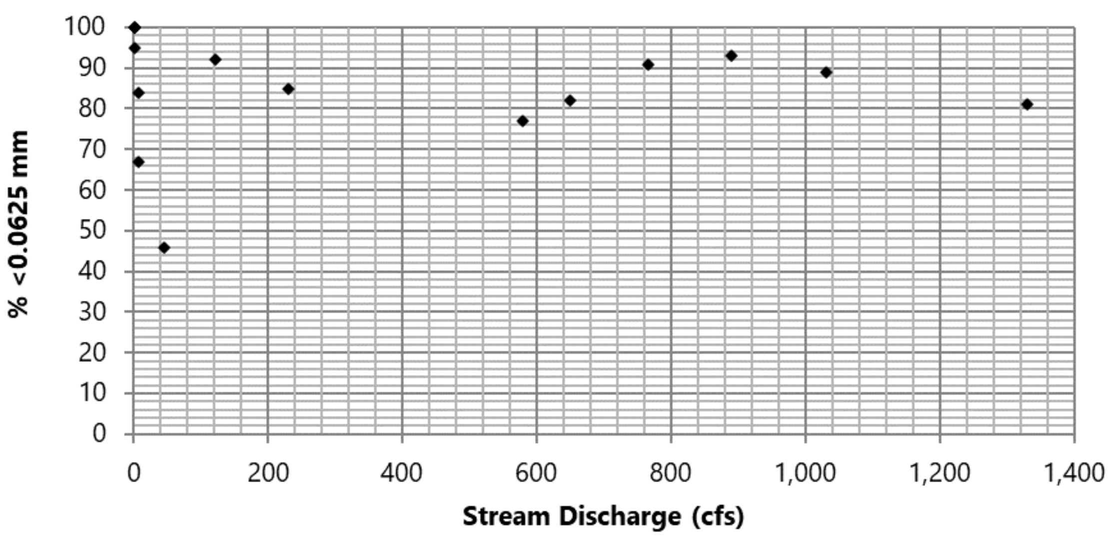


Figure 63
Fine Sediment as Fraction of Total Suspended Sediment Sampled on the Spring River near Quapaw, Oklahoma

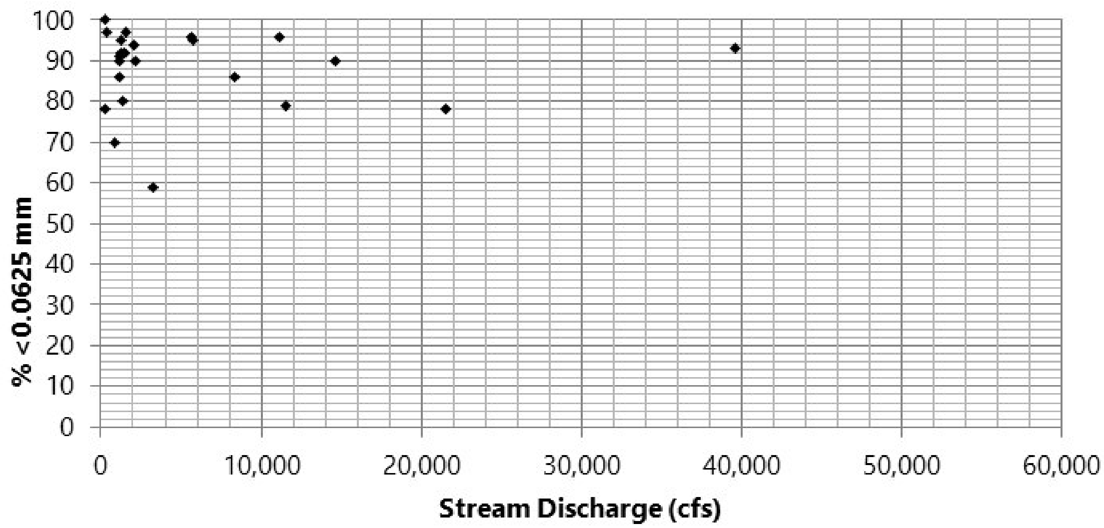
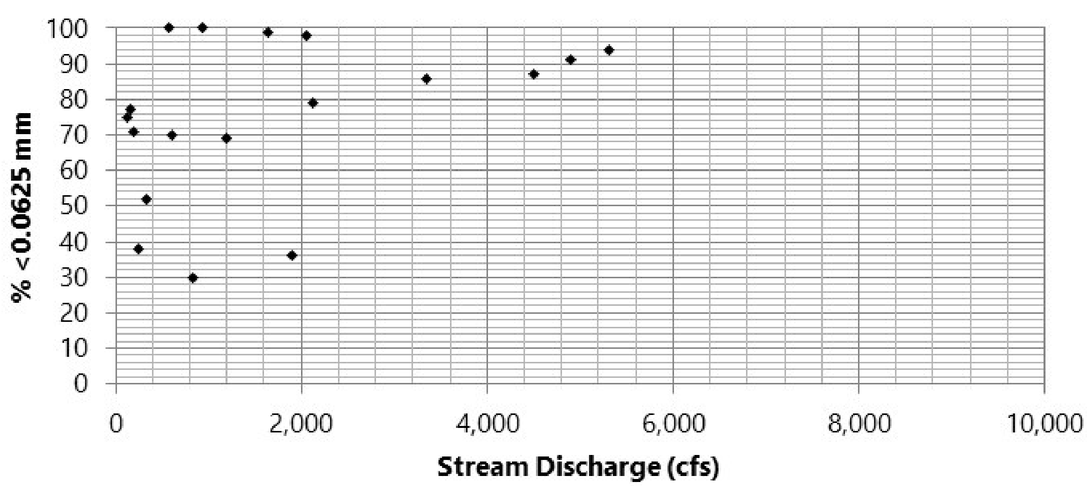


Figure 64
Fine Sediment as Fraction of Total Suspended Sediment Sampled on the Elk River near Tiff City, Missouri



2.4.1.2 Bedload Sediment Transport

Although bedload sediment transport data have been collected, these data indicate virtually no bedload transport. This is likely because shear stresses induced by the velocity of the flowing water have not been sufficient to mobilize, erode, and transport the coarse sediment sizes (primarily gravel) in the upstream river reaches where bedload sampling was conducted. This will be further evaluated in the STM using critical shear criteria for non-cohesive sediments.

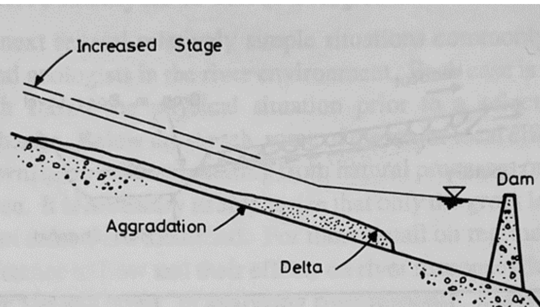
3 Qualitative Geomorphic Analysis

Several physical features affect the geomorphology of the rivers in the study area that either exist naturally or have been constructed. Such features include Pensacola Dam, bridges, and geologic and geomorphic features.

3.1 Pensacola Dam

Pensacola Dam is located at RM 77. With any impounded stream, water velocities decrease near the head of the reservoir, resulting in some amount of sediment deposition. This phenomenon is the expected geomorphic response as found in the scientific literature for virtually any reservoir on an alluvial river (Figure 57; Simons and Senturk 1992). Deltas are also discussed by USACE (1995), U.S. Bureau of Reclamation (Huang et al. 2006), Fan and Morris (1992), and Vanoni (2006).

Figure 65
Typical Geomorphic Response to Dam Construction



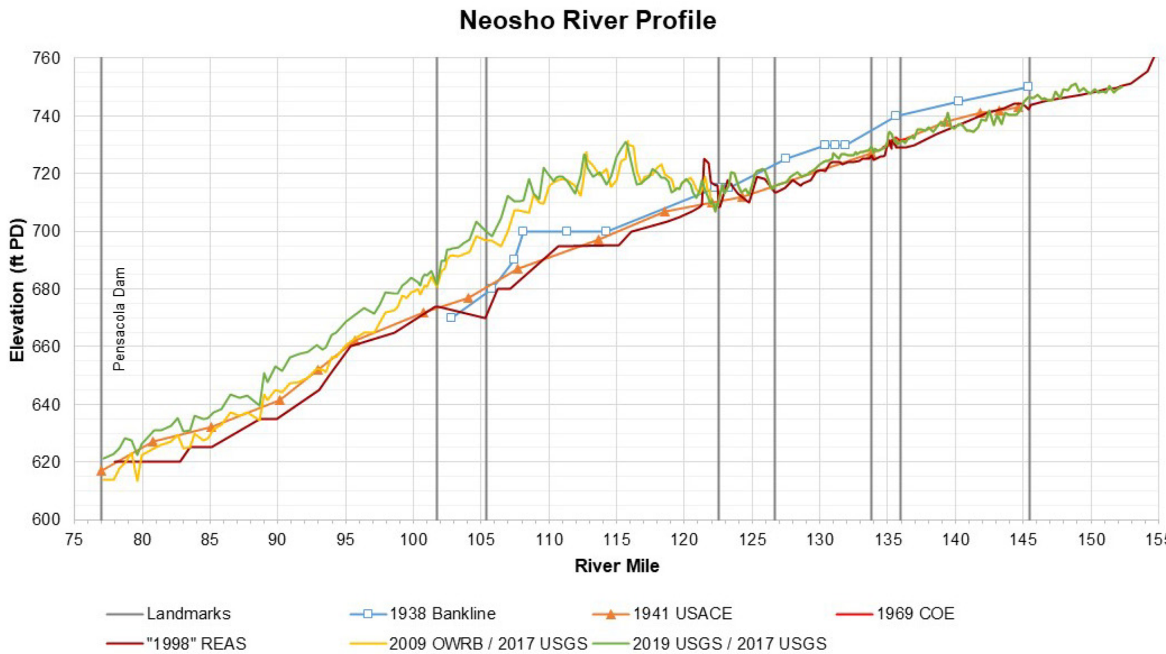
Local Effects	Upstream Effects	Downstream Effects
Aggradation of bed	See local effects	See downstream effects, Fig. 2.18
Loss of waterway capacity	Change in base level for tributaries	
Change in river geometry	Deposition in tributaries near confluences	
Increased flood stage	Aggradation causing a perched river channel to develop a change in the alignment of the main channel	

Source: Simons and Senturk (1992)

The impacts of Project pool elevations are addressed in the hydrology and hydraulics (H&H) study USR, filed concurrently with this report.

Figure 66 shows the Neosho River profile over time. Note that the upstream head of the deltaic feature starts at approximately RM 122 (near the Burlington Northern railroad bridge), which is more than 20 miles downstream of where the WSE of 745 feet PD at the top of the conservation pool intersects the river thalweg approximately 0.5 mile downstream of the USGS Commerce gage at RM 145.4 (East 60th Road Bridge). The bathymetric survey data show that sediment deposition forming the delta feature does not occur until sediment has traveled more than 20 miles downstream into the reservoir.

Figure 66
Historical Neosho River Thalweg Comparison

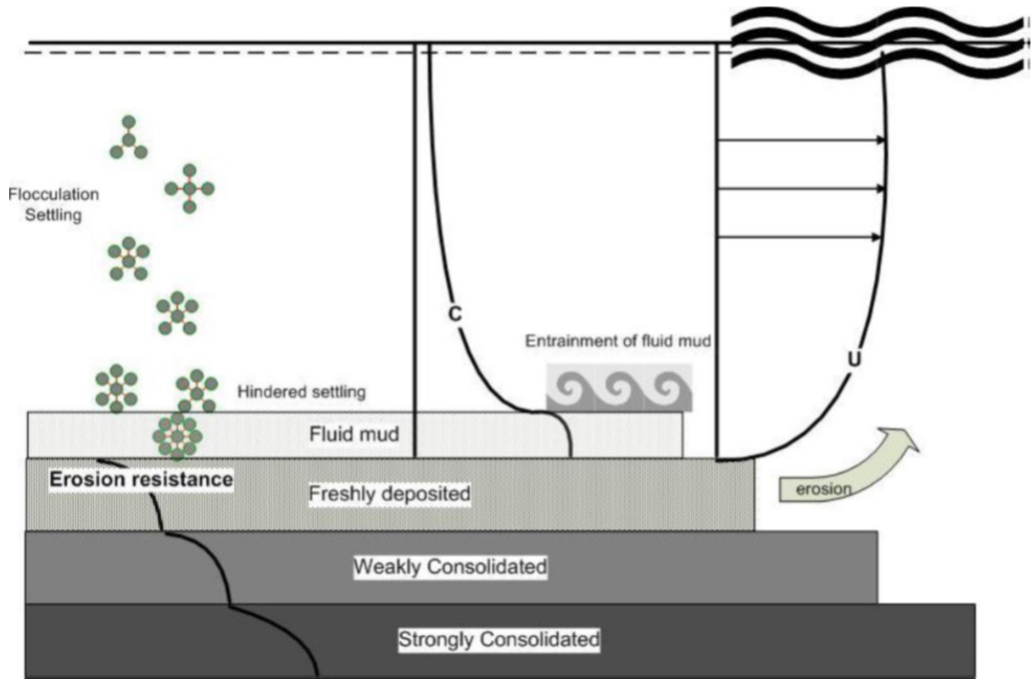


Note: This plot covers the Neosho River from RM 152.2 at the upstream end to the Pensacola Dam at RM 77.12 on the downstream end.

This clearly shows that sediment forming the delta feature is transported a considerable distance downstream into the conservation pool. Because sands and gravels tend to drop out of the water column sooner, if a significant portion of the sediment load consisted of bed material load (sand and gravel), the delta feature would have begun forming much farther upstream near the head of the reservoir. Therefore, the delta feature location further supports what field sampling showed: the feature consists primarily of fine sediment.

Figure 67 from *Modelling of Cohesive Sediment Dynamics* (Lumborg and Vested 2008) shows the various stages and characteristics of sediment as it deposits on the bed of the reservoir. Although this article focuses on coastal deltas, similar processes also occur on reservoir deltas.

Figure 67
Typical Reservoir Sedimentation Processes



Source: Lumborg and Vested (2008)

Suspended sediment forms flocs that deposit at the bed. With increasing currents, the fluid mud layer is re-entrained. Bed shear stresses can be enhanced by short surface waves, and during spring tides or storms the lower sediment layers erode (Lumborg and Vested 2008).

Lumborg and Vested (2008) explain the various stages and characteristics of suspended sediment deposition as follows:

> Fluid mud / hyper concentrated suspensions: The concentration of suspended sediment in the water column increases towards the bed. When the flocs begin to touch each other and interact hydrodynamically the settling velocity is reduced. This phenomenon is known as hindered settling and may lead to high concentration suspensions or fluid mud layers. Fluid mud is a concentration of fine-grained material in which settling is substantially hindered. It forms when the rate of settling exceeds the capacity of dewatering. The process forms a very concentrated suspension that acts neither as a Newtonian fluid nor as a sediment bed. The lower concentration limit of naturally occurring fluid mud layers is often given as about 10 kg m^3. This concentration can often be recognized as a lutocline and it is around this concentration that the suspension transits to become framework supported and much less mobile than the suspension. Fluid mud layers are thus layers with extreme concentrations of

sediment. The layer is moveable but moves as a gel rather than as a Newtonian fluid. Fluid mud layers accomplish a significant challenge for fine-grained sediment modelling.

When the box core samples were collected for the SEDflume testing, those individuals collecting the samples observed the following (Integral Consulting 2020): "In general, sediment consisted of silt and clay with a surface layer of unconsolidated, relatively mobile sediment." They describe a layer of "fluff" of "unconsolidated sediment" on top of the sediment surface and describe the surface material eroding "in clouds" of sediment. The description of an unconsolidated layer of fluff is consistent with the layer of fluid mud as previously described in the scientific literature. These sediment samples were collected in March 2020, months after the last significant runoff (with associated high sediment loading from 2019) and prior to any significant runoff in 2020. This would tend to result in a minimal layer of fluid mud that would result from the recession limb of a high flow event at the time when samples were collected. A more prominent layer of fluid mud would likely be found during or on the recession limb of the inflow hydrograph when sediment loading would be more significant, and this fluid mud layer would likely be a seasonal or temporary feature of the bed. This layer of unconsolidated sediment or fluid mud continues flowing farther downstream into the deeper portions of the reservoir as far as the dam.

As Lumborg and Vested (2008) stated, "The combination of hydrodynamic, sediment and biological processes make it difficult to predict cohesive sediment dynamics." Given that most of the inflowing sediment consists of fine material (silt and clay), and although some of these materials are deposited in the delta feature, significant portions of the sediment load can flow into deeper portions of the reservoir toward the dam. This is indicated by the 2009 and 2019 bathymetry data, which are consistent with the Lumborg and Vested (2008) discussions in the scientific literature.

3.2 Bridges

Several bridges span the rivers of interest and the reservoir. Bridges typically constrict river flow as bridge supports and embankments encroach on the flow area. Bridges also tend to be located at relatively narrow sections of the river to minimize cost of construction.

Because bridges constrict flow, they typically cause backwater effects upstream of the bridge. The backwater effects include increased WSEs and reduction in velocity. At the bridges themselves, the reduced flow areas result in increased velocities. Bridges also potentially trap debris such as floating logs, which further constricts the flow and increases the backwater effect. The effects of hydraulic constrictions at bridges potentially cause sediment deposition upstream of the structure due to the reduced velocities.

An extreme example of bridge encroachment on the river and floodplain is the railroad bridge just downstream of the Twin Bridge area below the confluence of the Neosho and Spring rivers. Figure 68 and Figure 69 present aerial views of this area.

Figure 68
Confluence of Neosho and Spring Rivers at Twin Bridges and the Railroad Bridge

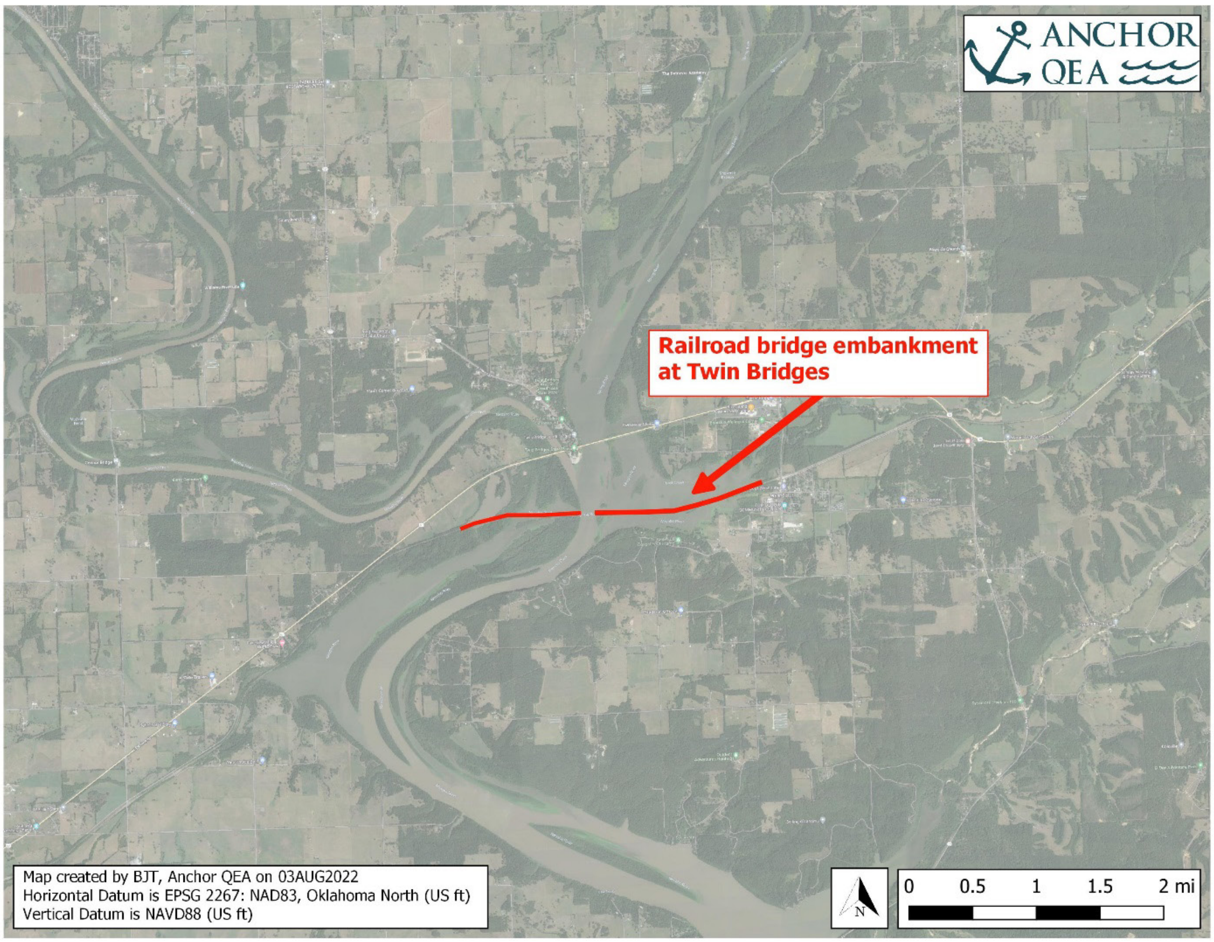
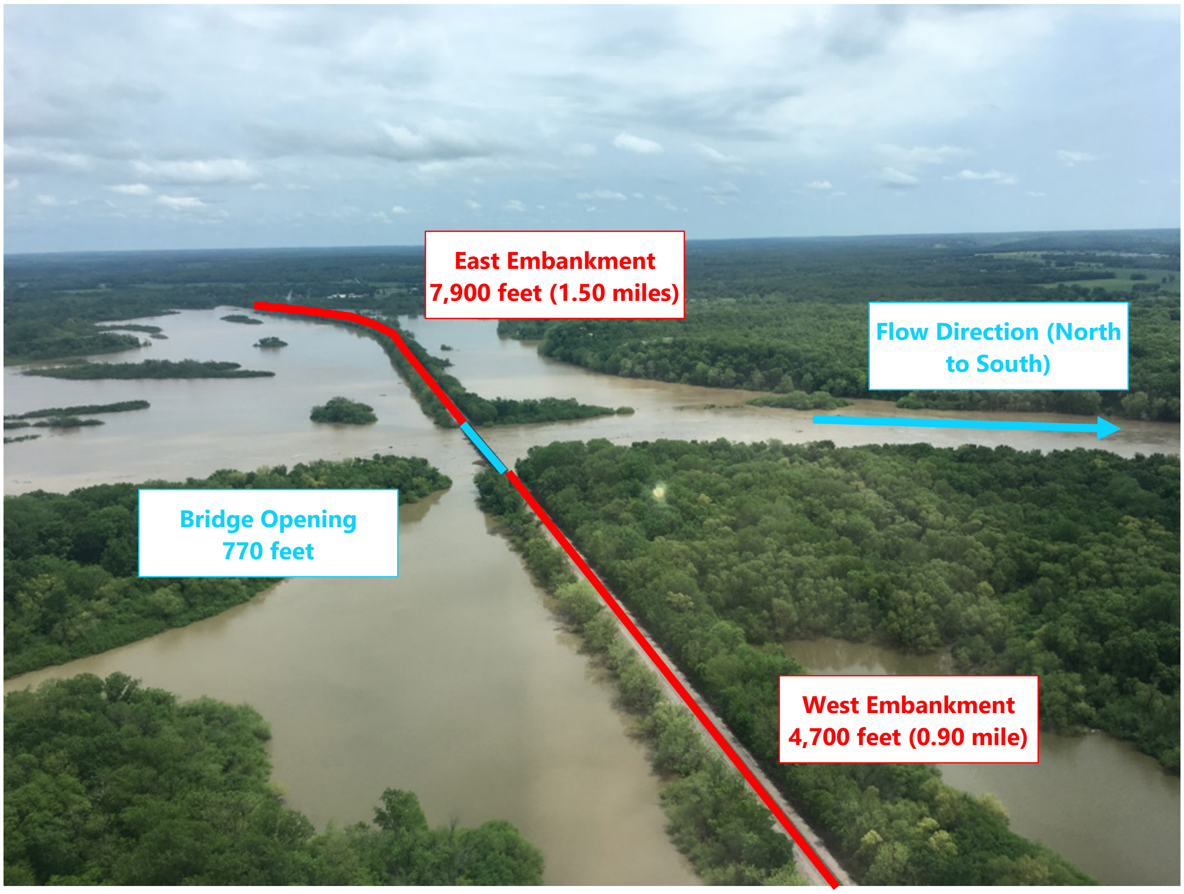


Figure 69
Burlington Northern Railroad Bridge and Embankment near Twin Bridges Photograph Looking East



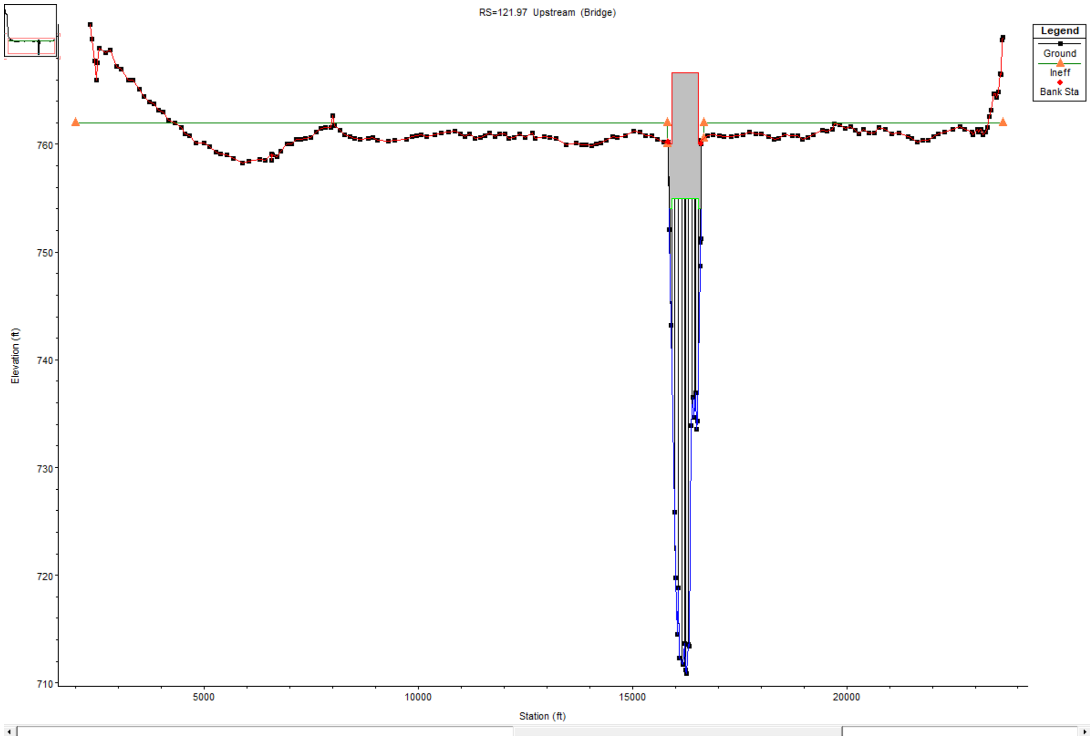
Notes: Photograph taken on May 2, 2019; USGS reported daily discharges were as follows:

- Neosho River near Commerce: 37,700 cfs (USGS 2021a)
- Tar Creek near Commerce: 192 cfs (USGS 2021c)
- Spring River near Quapaw: 48,500 cfs (USGS 2021e)

Flow direction is from left to right, and discharge must pass through the 770-foot bridge constriction.

The cross section at the Burlington Northern Railroad bridge (Figure 70) shows that the top of the embankment across the floodplain is at an average elevation of approximately 758 feet PD (note that the figure is from HEC-RAS and thus has a vertical datum of NGVD29). The width of the bridge opening is approximately 770 feet and the total embankment length is approximately 12,600 feet (2.4 miles).

Figure 70
Burlington Northern Railroad Bridge Cross Section



The aerial image (Figure 68) shows that the flow upstream of the railroad bridge is approximately 11,700 feet (2.22 miles) wide, whereas the width of the Neosho and Spring rivers upstream of Twin Bridges is approximately 2,250 feet wide (Neosho River is approximately 350 feet wide and Spring River is approximately 1,900 feet wide). The significant increase in water width by a factor of approximately five times shows the effect of the bridge in causing a backwater effect and blockage of the floodplain by the embankments.

Bridge piers frequently trap debris because moderate to high flow events carry floating trees and other materials. The following images show debris trapped on bridge piers during the flow event that occurred late in April through May 2019. Peak daily flow on the Neosho River was 90,100 cubic feet per second (cfs) on May 24, 2019; however, the photographs of debris were taken in early May before the flood peak (Figure 71).

Figure 71
May 2019 Photographs of Debris Trapped on Bridge Piers

Additional photographs were taken in December 2019, months after the peak flow in May 2019. The photographs show evidence of debris trapped on bridges, with some debris up on the bridge deck itself (Figure 72).

Figure 72
December 2019 Photographs of Debris Trapped on Bridge Piers

Notes: Top photographs show the abandoned railroad bridge at RM 134.60, approximately 0.6 mile upstream of the Tar Creek confluence.
Bottom photograph is from the East 60th Road Bridge (USGS Neosho River near Commerce gage) at RM 145.4.

3.3 Geologic Features

Vertical rock banks are evident in various reaches along the Neosho River. Examples of vertical rock banks are shown in Figure 73.

Figure 73
Photographs of Vertical Rocky Banks Along the Neosho River

Notes: Top photograph was taken near RM 129.07 on the Neosho River, approximately 2.4 miles upstream of Connors Bridge. Bottom photograph was taken near RM 127.47 on the Neosho River, approximately 0.75 mile upstream of Connors Bridge.

Locations of the examples of rocky banks are shown in Figure 74, Figure 75, and Figure 77.

Reaches of river that are confined by vertical rock banks eliminate the floodplain and confine the flow to a relatively narrow cross section, which constricts the flow, potentially causing upstream backwater effects and sediment deposition.

Figure 74
Locations of Vertical Rocky Banks on Aerial Imagery

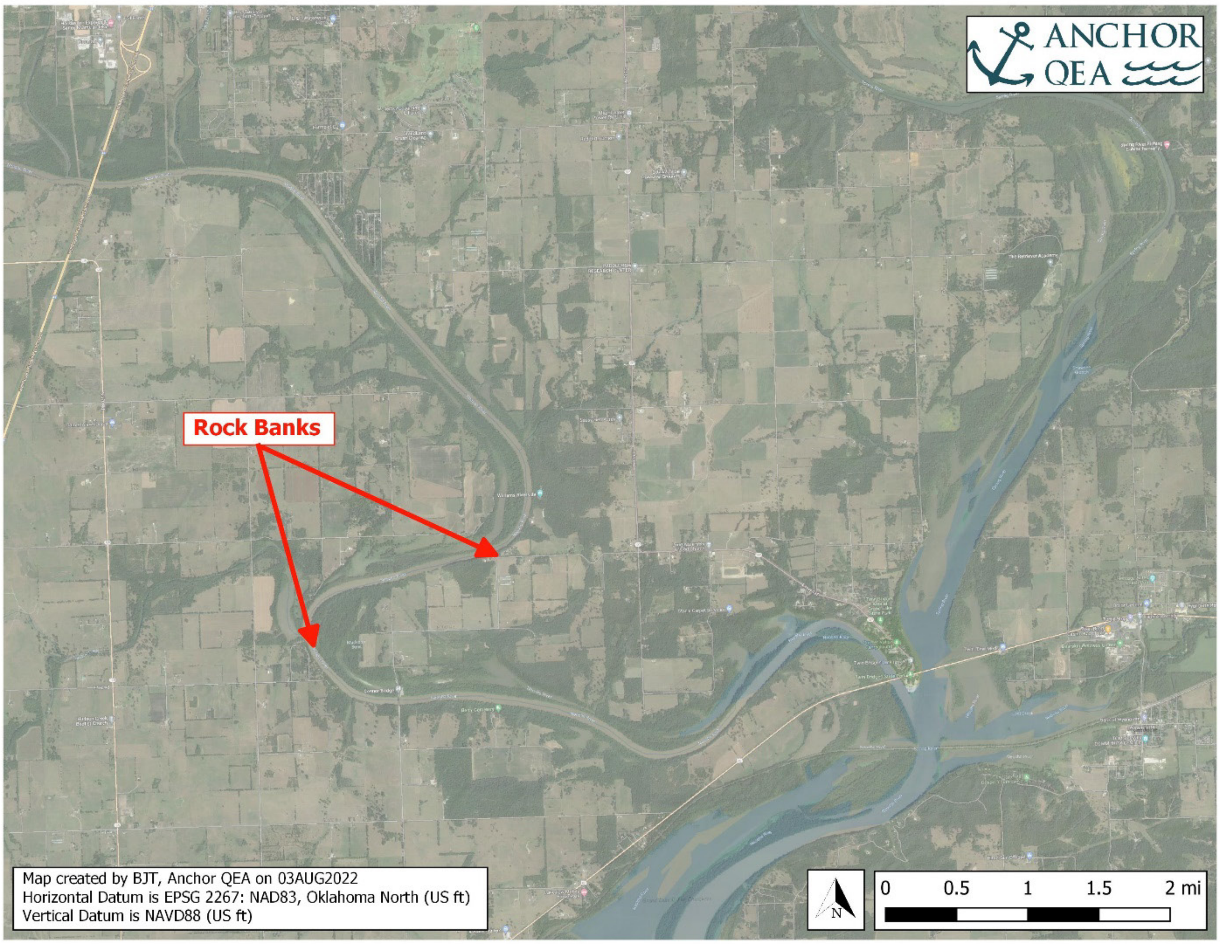
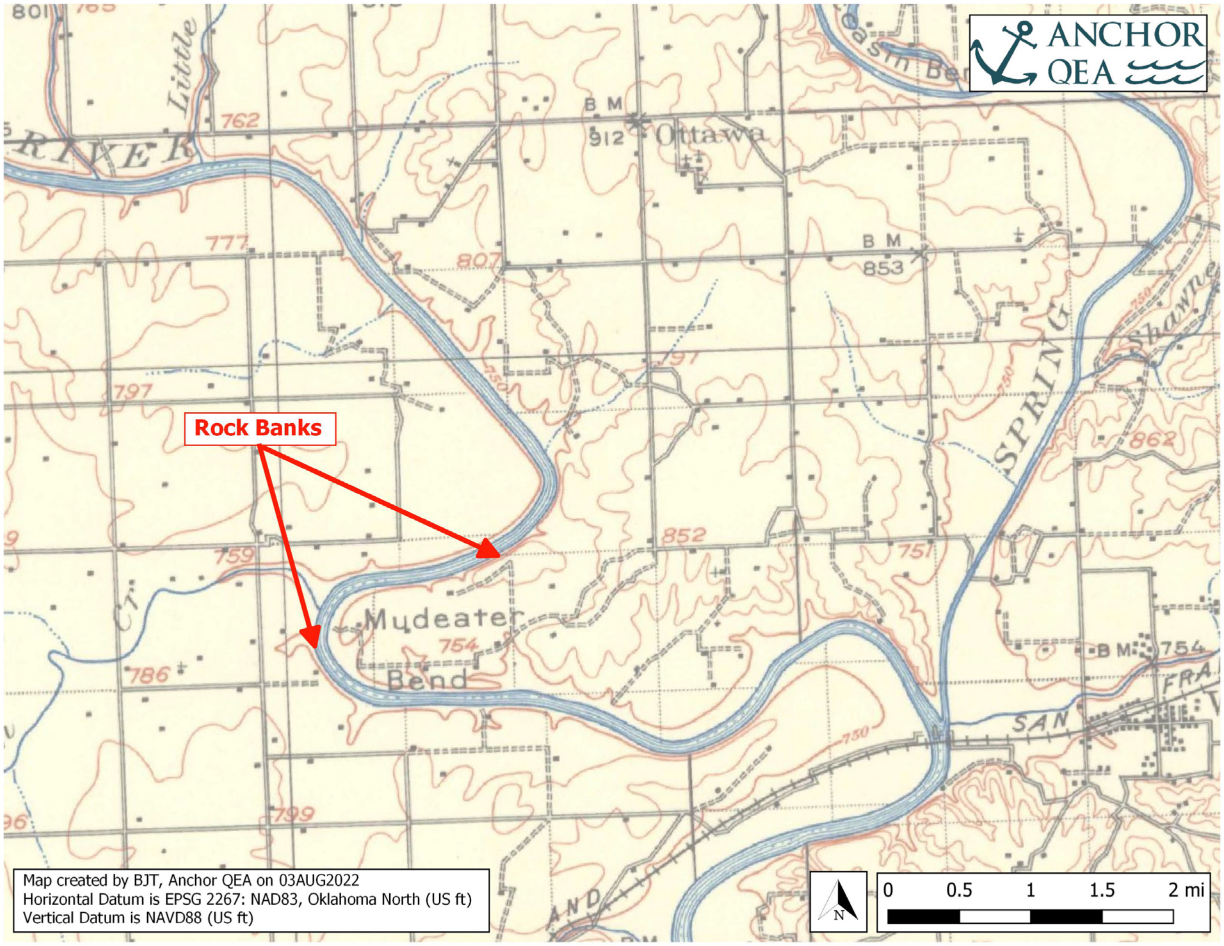


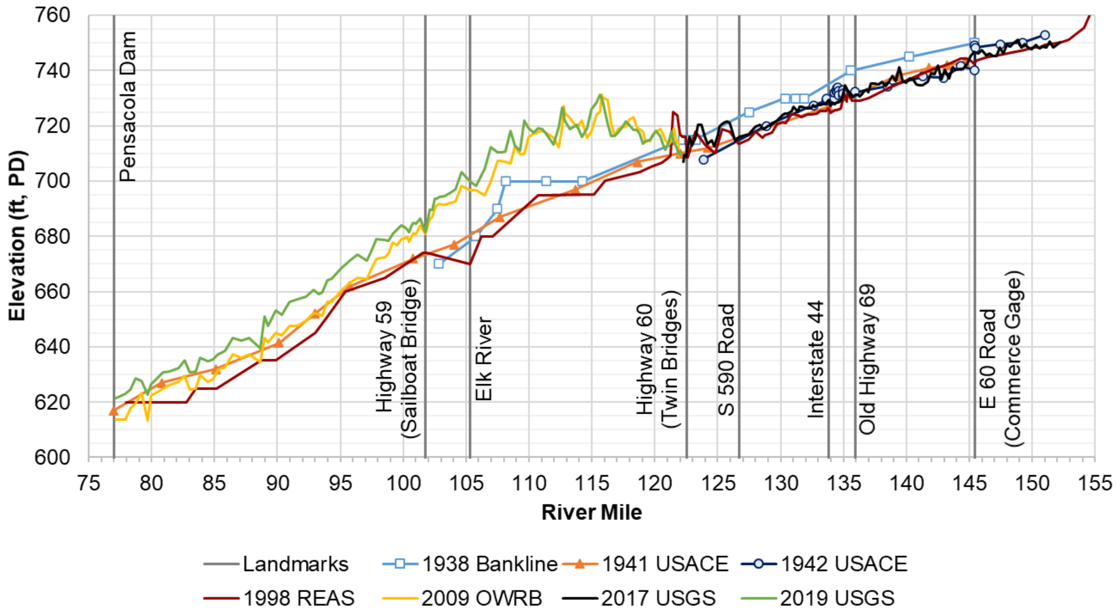
Figure 75
Locations of Vertical Rocky Banks on Topographic Map



Source: Wyandotte, USGS (1907)

A now-submerged bioherm (ridge) composed of erosion-resistant limestone and chert was discussed by McKnight and Fischer (1970) and is located at RM 108. Such structures could also be submerged terraces or talus piles and are part of the southern flank of the exposed and eroding Ozark Uplift often referred to as the Ozark Plateau or Ozark Highlands, but more specifically the Springfield Plateau. They are composed of the Mississippi Boone formation (GRDA 2017) and cause narrowing in the now-submerged valley. Dendritic drainage patterns from the surrounding uplands entering the submerged valley impede the transport of sediment downstream into the lower reaches of the reservoir and cause aggradation of sediment in these sections of submerged river valley. Additional evidence of ridges composed of limestone and chert within the now-submerged valley can be observed in the grade changes of the 1938 bank line elevation profile (Figure 76). The bank line grade change begins at RM 108 and extends upstream to approximately RM 115. Note that the other profile lines in Figure 76 display thalweg elevations. The 1938 profile is the only representation in Figure 76 of the now-submerged valley elevation.

Figure 76
Historical Neosho River Thalweg Comparison



Note: This plot covers the Neosho River from RM 152.2 at the upstream end to the Pensacola Dam at RM 77.12 on the downstream end.

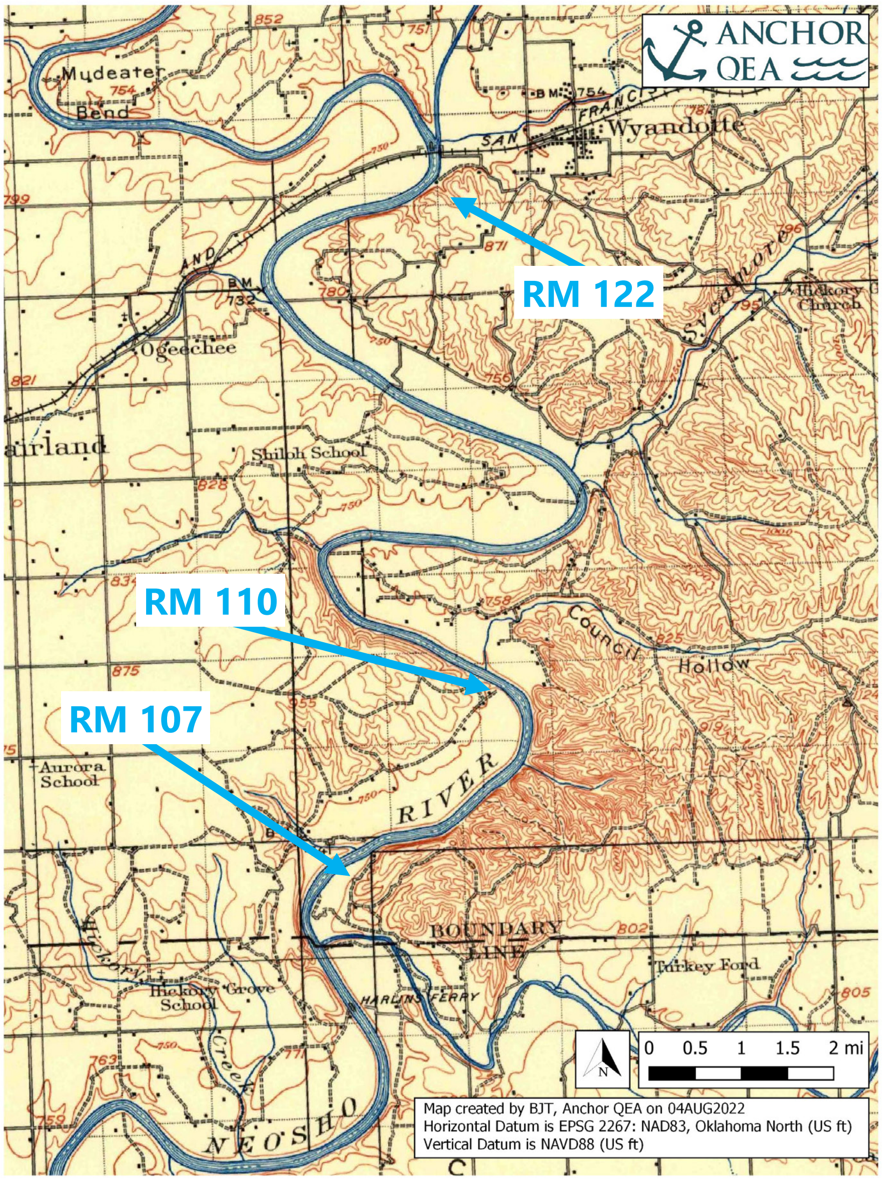
Submerged ridges in the now-submerged valley can act as stable points. Many of these ridges are perpendicular to downstream flow in the valley and can cause sediment to deposit between and amongst the submerged ridges. These stable points are capable of forming the delta feature that is shown in the 2019 USGS profile and the 2009 OWRB profile from RM 100 upstream to RM 122 (Figure 76).

Because McKnight and Fischer (1970) is not a complete catalogue of all erosion-resistant, submerged ridges in the original river valley, it is likely that there are other such ridges in the submerged valley where the delta feature has formed at the edge of the Ozark Uplift.

Evidence of the Ozark Uplift can also be observed on the 1907 topographic map with 50-foot contours shown in Figure 77 (USGS 1907). The entire original river valley from RM 107 to RM 122 displays convoluted and closely spaced contour lines east of the original river channel from RM 107 to RM 120 and on both the east and west sides from RM 107 to RM 110. Therefore, it can be reasonably concluded other ridges submerged in the original river valley that are part of the Ozark

Uplift impede the transport of sediment downstream into the deeper portions of the reservoir and cause the delta feature to form in this location.

Figure 77
Geologic Constrictions along Neosho River in the Region of the Delta Feature



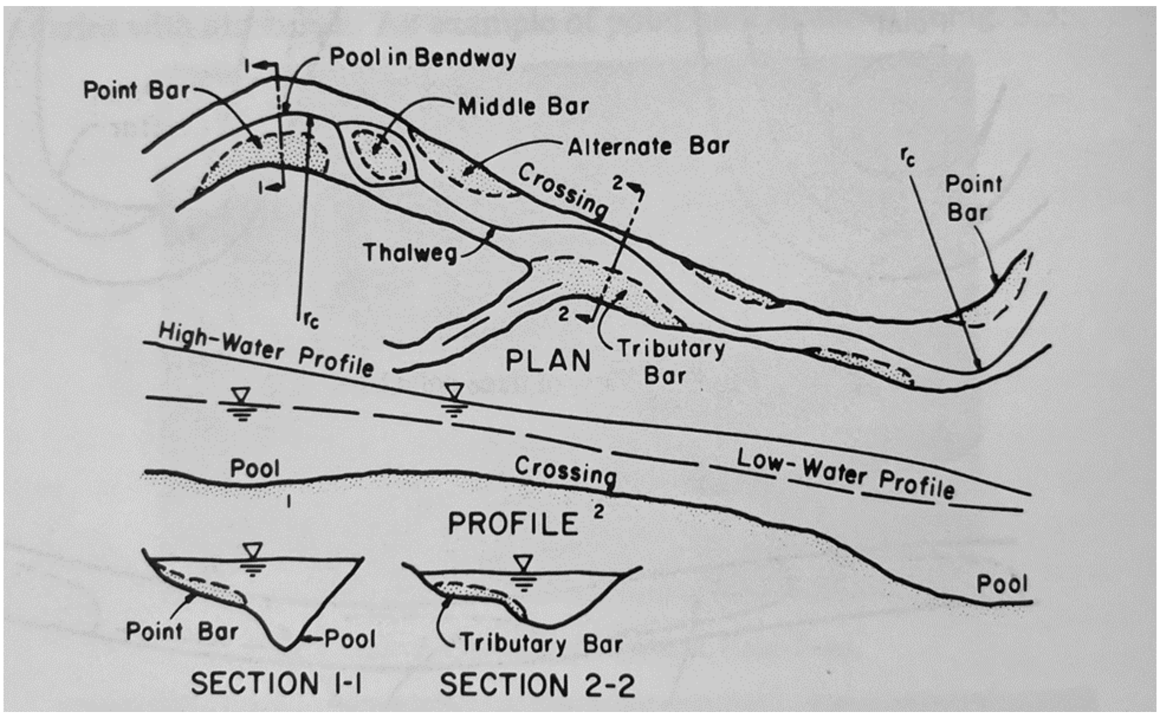
Even in areas without submerged ridges, talus piles, or terraces, the presence of the Ozark Uplift in the vicinity of the delta feature indicates the original channel bottom is likely composed of limestone and chert from the Ozark Uplift that has eroded over time.

The presence of the Ozark Uplift limestone in the area of the delta feature has likely played one of the more significant roles in forming the delta feature to its current size instead of continuous downstream transport of sediment to the location of the dam.

3.4 Riverine Features

At a confluence of a tributary, some of the sediment load from the tributary is frequently deposited, forming a tributary bar within the river (Figure 78).

Figure 78
Illustration of Types of Bars that Occur in Alluvial Channels



Source: Simons and Senturk (1992)

Tributary bars form because the slope of the tributary is typically steeper than the river into which it flows, so some portion of the sediment load cannot be readily transported downstream resulting in sediment deposition. This process also occurs when the tributary transports a high sediment load or a coarser sediment load than the main river.

The slope of the Neosho River bed in the vicinity of the Elk River confluence based on the 1941 USACE data is approximately 2.06 feet per mile. The slope of the Elk River bed upstream of the confluence based on the 2019 data is approximately 3.21 feet per mile, which is approximately 56% steeper than the Neosho River. This difference in riverbed slopes would tend to result in sedimentation in the form of a tributary bar at the confluence. The slope of the Spring River bed is approximately 2.21 feet per mile, which is approximately 7% steeper than the Neosho River.

As stated previously, the Ozark Uplift composed of Mississippi Boone limestone and chert crosses the Neosho River at the confluence of the Elk River. This feature, combined with the steeper slope of the Elk River and the attendant potential for the formation of a tributary bar, suggest a natural tendency for sediment deposition at this location. Although these geomorphic features affect potential sedimentation patterns at this location, it is not possible to quantify these effects on the overall sedimentation pattern.

In addition to the geologic features of the area, there are also flood protection levees upstream that disconnect the river from the floodplains. By building up the streambanks, water is confined to the channel during large flow events, which results in increased water levels because the increased discharge cannot spread to the flat, open areas of the historical floodplains. This can increase flood risk to areas not protected by levees or protected by shorter levees.

4 Quantitative Analysis

The second level of analysis in the three-level approach is quantitative analysis of sedimentation. Beyond the original rationale for the development and application of the three-level approach, additional discussion regarding the quantitative analysis was presented in the USP.

4.1 Quantitative Sediment Transport Evaluation

In addition to the STM, GRDA used a quantitative engineering analysis of sediment transport in the study area. This fulfills the second part of the three-level approach discussed in previous proposals and will focus on the delta feature and the lower reservoir, where the deposition of cohesive materials has the largest potential impacts on the power pool. GRDA used this analysis as a means of validating the model outputs and providing additional confidence in STM results. Recent evaluations of computer modeling by the USSD Committee on Hydraulics of Dams, Subcommittee on Reservoir Sedimentation (2015) suggest that the results of a HEC-RAS model evaluating cohesive sediments may not be reliable. Regarding reservoir sedimentation models, the committee states the following:

> Sediment transport models incorporate a certain degree of simplification to be computationally feasible. Simplified models run into the risk of not obtaining a reliable solution, whereas increasing the model complexity can complicate the problem formulation and incur more input data preparation, calibration, and verification costs. Most of the commonly used numerical sediment transport models were originally developed for the analysis of movable bed rivers having coarse sediments and employ sediment transport equations developed from flume and river data where the effect of fine or wash load on fall velocity, viscosity, and relative density can be ignored. In contrast, reservoir problems may involve the analysis of grain sizes ranging from cobbles in the upstream delta area to clays near the dam. The silts and clays which normally behave as wash load in most rivers, and which are ignored in many river sedimentation models often constitute the majority of the total sediment load in a reservoir. Most 1D sediment transport models, and transport functions, are designed for noncohesive sediment transport. Models often include the addition of simple cohesive sediment computational procedures to enhance model capability. (USSD 2015)

Such is the case with HEC-RAS, where simple cohesive sediment computational procedures were added to a model developed primarily for use in analyzing non-cohesive sediment transport. Specifically, relationships of critical shear and erosion rate developed by Krone (1962) and Partheniades (1962) are the relationships used in HEC-RAS for cohesive sediment.

The USSD (2015) findings also state the following:

> In summary, the sediment transport conditions associated with reservoirs are extremely complex. Detailed analysis of many of these problems lies beyond present knowledge, and only qualitative or rough quantitative estimates can be provided. Caution should be used in the application of numerical techniques in either hand calculations or computer models.

As discussed above, the cohesive sediment modeling routines used in HEC-RAS are limited. It is necessary to have a second analysis to ensure those limitations do not produce erroneous sedimentation predictions. Density currents, mud flows, and other phenomena associated with transported sediment (Lumborg and Vested 2008; van Rijn n.d.; Zavala 2020) are almost certainly active in this system and the routines used in HEC-RAS do not account for those processes. It is expected that this will primarily be of concern lower in the reservoir, hence the decision to directly use the STM only above RM 100 and use a different technique to evaluate sedimentation in the lower reservoir.

For these reasons, GRDA also performed a quantitative engineering analysis of sediment transport within the study area. This approach relied on measured field data including sediment transport, erodibility, and grain size distributions; bathymetric surveys; and overbank topographic information.

Sediment transport equations in the STM for both non-cohesive and cohesive sediments use hydraulic shear stress as the driving force causing erosion and transport of sediment. The quantitative analysis focuses on the relationship between hydraulic shear stress caused by flowing water and the pattern of sediment movement or sedimentation as documented by the change in bathymetric surveys over time.

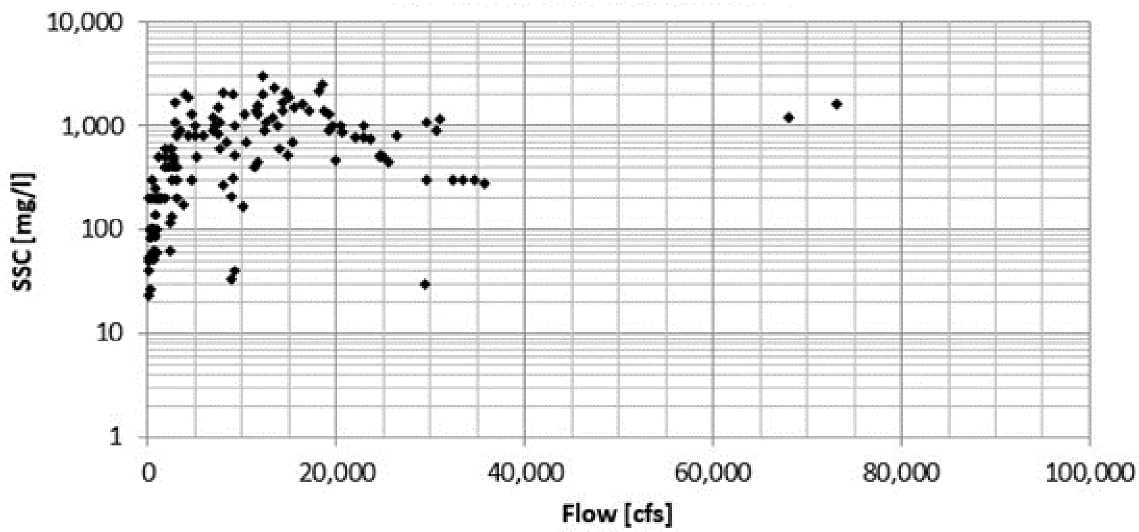
Some supportive analyses of the sediment transport and bathymetric data are necessary to relate the pattern of sedimentation to hydraulic shear stress. These include development of sediment rating curves and sediment density. The sediment rating curves relate sediment transport (in units of tons per day) to the flow of water. The sediment rating curves are applied to the flow data to compute the quantity of sediment being transported down the various rivers and into the reservoir. The density, or specific weight of sediment, in units of pounds per cubic foot, is utilized to convert the tonnage of sediment being transported or deposited to the volume of sediment being deposited.

4.2 Development of Sediment Transport Rating Curves for Quantitative Analysis

Initial development of sediment rating curves was conducted in the ISR. These sediment rating curves have been updated for this quantitative analysis. Significant sets of sediment transport data are available from USGS and collected specifically for this Project by Anchor QEA as discussed in

Section 2. Figure 79 shows the set of suspended sediment transport data for the Neosho River with sediment transport plotted against flow. This graph is plotted on a log-log scale, typically used in showing the relationship between sediment transport and flow. As observed, there is considerable scatter in the data, which is again typical in observations of sediment transport and flow.

Figure 79
Suspended Sediment Concentration Samples and Stream Discharges During Sampling on the Neosho River Near Commerce (USGS Gage 07185000)



Note: Only two samples were collected at discharges above 40,000 cfs.

In analyzing sediment transport whether using a computer model or other quantitative analyses techniques, a sediment rating curve is developed from the data to quantify sediment transport as a function of flow. Typically, a power relationship is utilized because this type of relationship generally fits these data.

To aid in the development of these relationships between sediment transport and flow, a tool has been included in HEC-RAS 6.2 called the "Sediment Rating Curve Analysis Tool" (USACE 2022). Within this tool are two components: bias correction and stationarity to improve the quality of the sediment rating curve. Bias correction rectifies "bias implicit to the log-transform regression used to develop sediment rating curves." Stationarity explores "how sediment data change over time and fit rating curves to temporal sub-sets of the observations."

The following is from the HEC-RAS explanation of the Sediment Rating Curve Analysis Tool:

> Log-transforming the regression makes it relatively easy to fit a power function to log-distributed data. However, it also introduces a bias when the data are untransformed. For example, the observations in the figure below have equal and opposite residuals in the

> logarithmic transformation (0.7). However, when these residuals untransform, the positive residual is larger than the negative residual. Therefore, the log-transformed linear regression ends up with larger positive residuals than negative, making the fit power function systematically low. This rating curve will under-predict sediment load for a given flow.

Applying the bias correction decreases the likelihood that the resulting regression will underpredict the sediment load when using the standard power function for the sediment transport rating curves.

The stationarity concept simply considers the extent to which trends in sediment transport may be occurring over time. This concept is explained in the Sediment Rating Curve Analysis Tool documentation (USACE 2022).

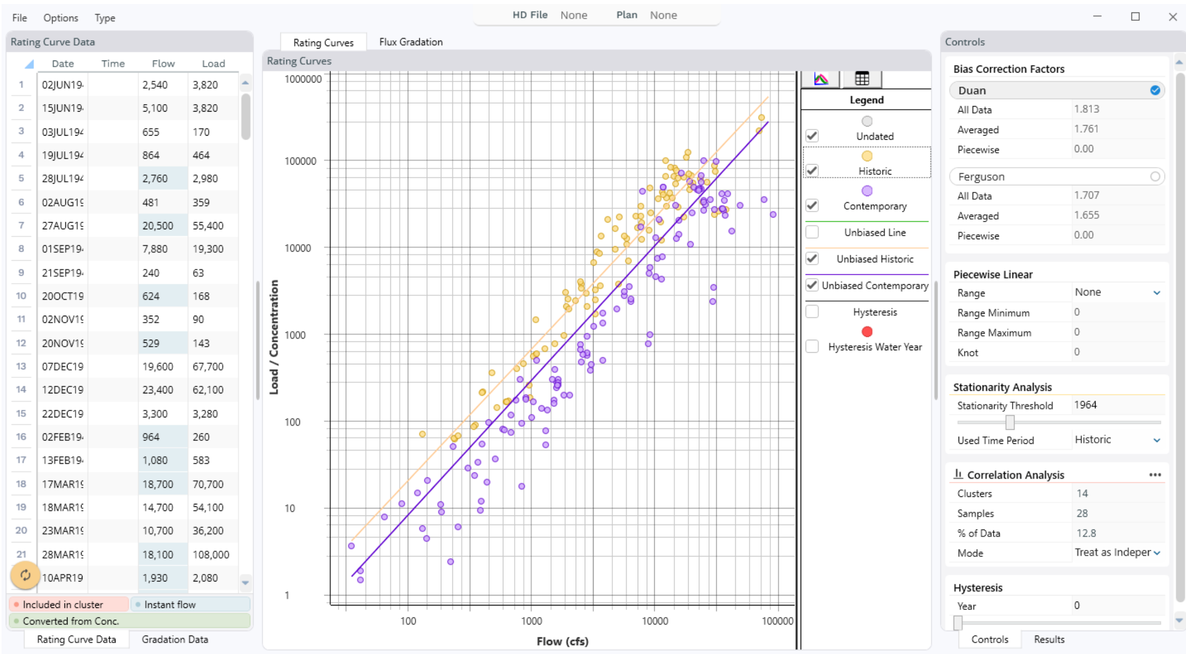
4.2.1 Stationarity Analysis

Sediment load changes over time. Agricultural impacts, land use changes, fires, mass wasting events, dam removals, and eruptions can increase sediment loads, whereas dams, pavement, and improved agricultural practices can decrease sediment loads (Walling and Fang 2003).

Because sediment load data are often scarce, modelers want to make use of all the data available. But it is important to test the load stationarity. The assumption of stationarity is simply that sediment loads do not change over time. Therefore, sediment assessments require analysts to plot and evaluate the data in time blocks, particularly before and after known system changes like a dam or gravel mining policies. If there is a big shift in the rating curve over time, consider using the most recent data to develop the future conditions rating curve.

Figure 80 is an example of a stationarity analysis of a USGS gage (USGS 2021b) as shown in the HEC-RAS stationarity analysis. This particular evaluation compares sediment loading before and after construction of the John Redmond Dam in 1964, and it shows that flows from before its completion carried more sediment than more recent flows. This indicates that the upstream reservoir is trapping sediment and decreasing the loading rates at Grand Lake.

Figure 80
Stationarity Evaluation Example from HEC-RAS



Note: HEC-RAS Sediment Rating Curve Analysis Tool showing stationarity evaluation of USGS Gage 07185000 (Neosho River near Commerce, Oklahoma) with pre-1964 samples in gold and post-1964 samples in purple. This analysis illustrates the decreasing trend in sediment loading over time.

The relationship between flow and load can change systematically over time. If you cannot assume that the relationship between flow and load is "stationary" (constant over time), it may not be appropriate to use all the data for an analysis or model. For example, when calibrating a model in a system with non-stationary sediment data, it is appropriate to use the historical rating curve that reflects the data over the calibration period. Alternately, when forecasting, it is appropriate to use a rating curve based on the most recent relationship. Scientists and modelers should always, at a minimum, evaluate their data stationarity. But if sediment data are non-stationary, they must partition their data to develop a rating curve appropriate for the time period under consideration.

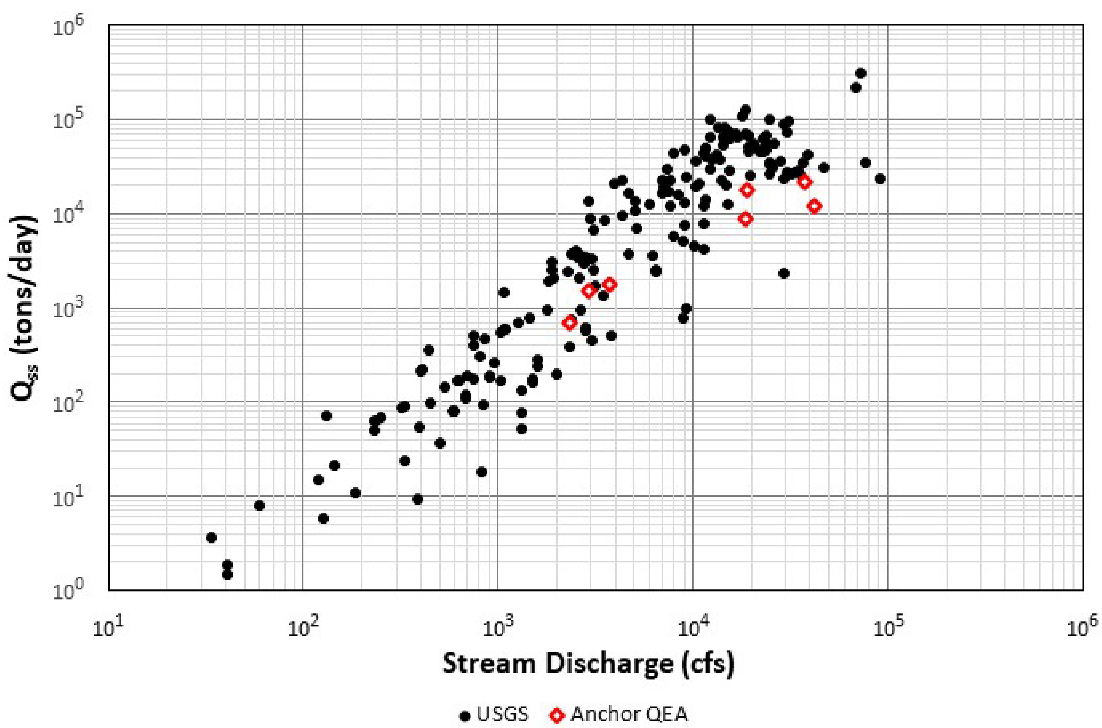
Sediment loading changes over time due to a variety of factors. These include changes in agricultural practices such as the introduction of no-till methods and the use of cover crops, both of which are supported by the Natural Resources Conservation Service (NRCS). Land use changes also affect sediment loading, as forests reduce soil erosion in areas that were previously dominated by agriculture. Furthermore, recent improvements in erosion control and sediment loading practices such as natural stream borders and stormwater retention practices help remove soils from stormwater runoff, reducing sediment loads. In the case of Grand Lake and the Neosho River, the presence of the John Redmond Dam traps significant volumes of sediment and prevents it from reaching the study area.

This study used the Sediment Rating Curve Analysis Tool to correct for bias and the concept of stationarity to account for the reduction in sediment transport over time that exists in the data.

4.3 Suspended Sediment Regression Analyses

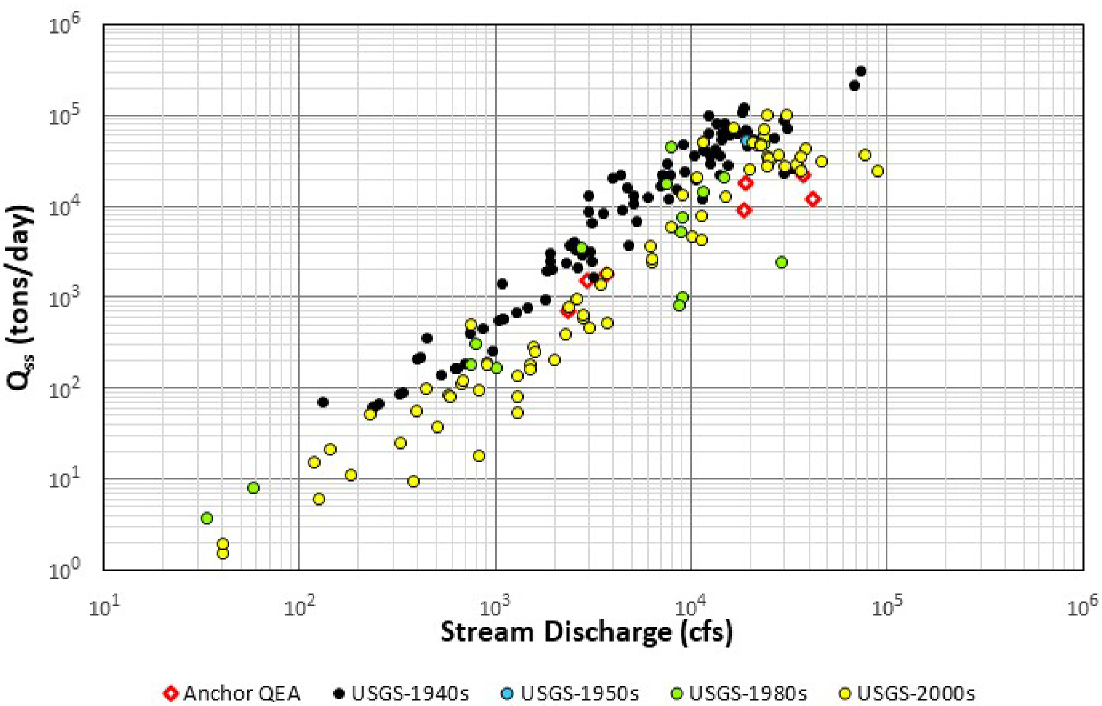
Suspended sediment transport data in tons per day is plotted as a function of flow in Figure 81 for all available data, segregating the USGS data and Anchor QEA data. It must be noted that sediment transport data are typically plotted on a log-log graph. The reason for this is that there is considerable scatter in the data. For example, at a flow of approximately 9,000 cfs, the sediment transport data range from 991 to 48,600 tons per day, which covers a large range, with the higher data point being 49 times greater than the lower data point at the same flow. The uncertainty in fitting a single curve to measured sediment loading data is a significant challenge for sediment transport modeling.

Figure 81
Suspended Sediment Transport: Neosho River Near Commerce



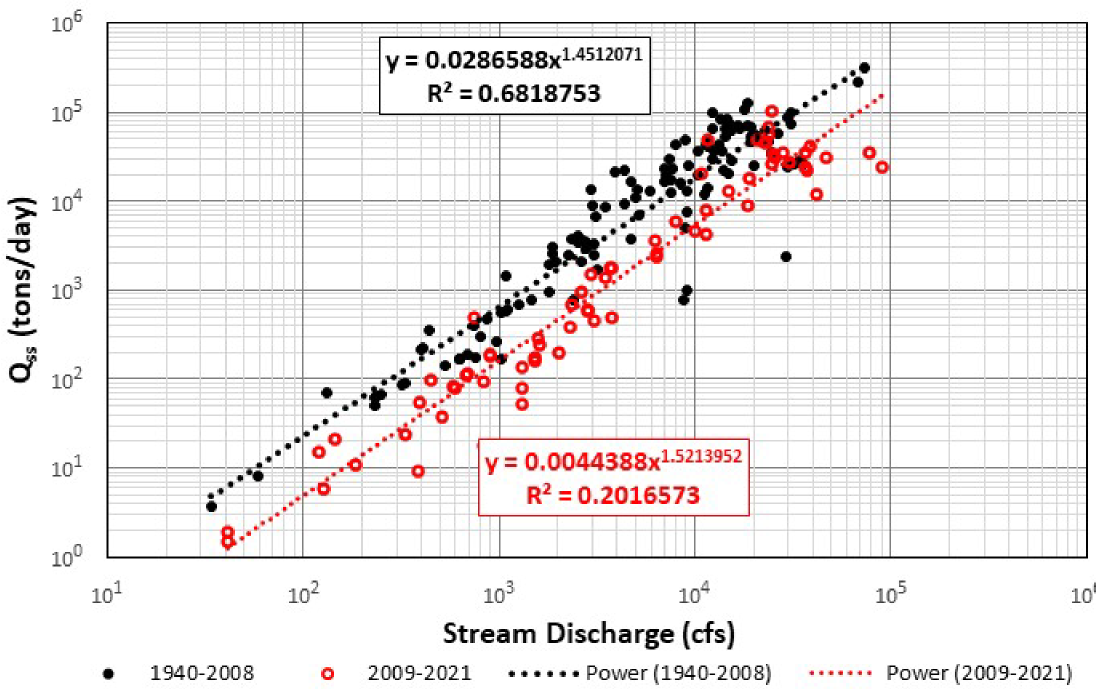
The Anchor QEA data, which were collected in recent years from 2019 to 2021, tended to be on the lower range of the scatter plot typically found in plotting sediment transport data. This prompted an evaluation of whether there were any trends in the relationship between sediment transport and flow as indicated by the data. The Neosho River sediment transport data were collected from 1944 through the present (data for this report extend through summer 2021). Figure 82 presents the same data segregated into various time periods or sets of data over time. As can be seen in the stationarity evaluation, the data show a temporal trend of generally reduced sediment loads with the highest sediment loads occurring in earlier decades and lower sediment loads occurring in recent decades.

Figure 82
Suspended Sediment Transport (Segregated Over Time): Neosho River Near Commerce



Regression analyses were conducted on the data segregated into two sets: 1940 through 2008 and 2009 to 2021 (Figure 83), corresponding to the availability of bathymetric data.

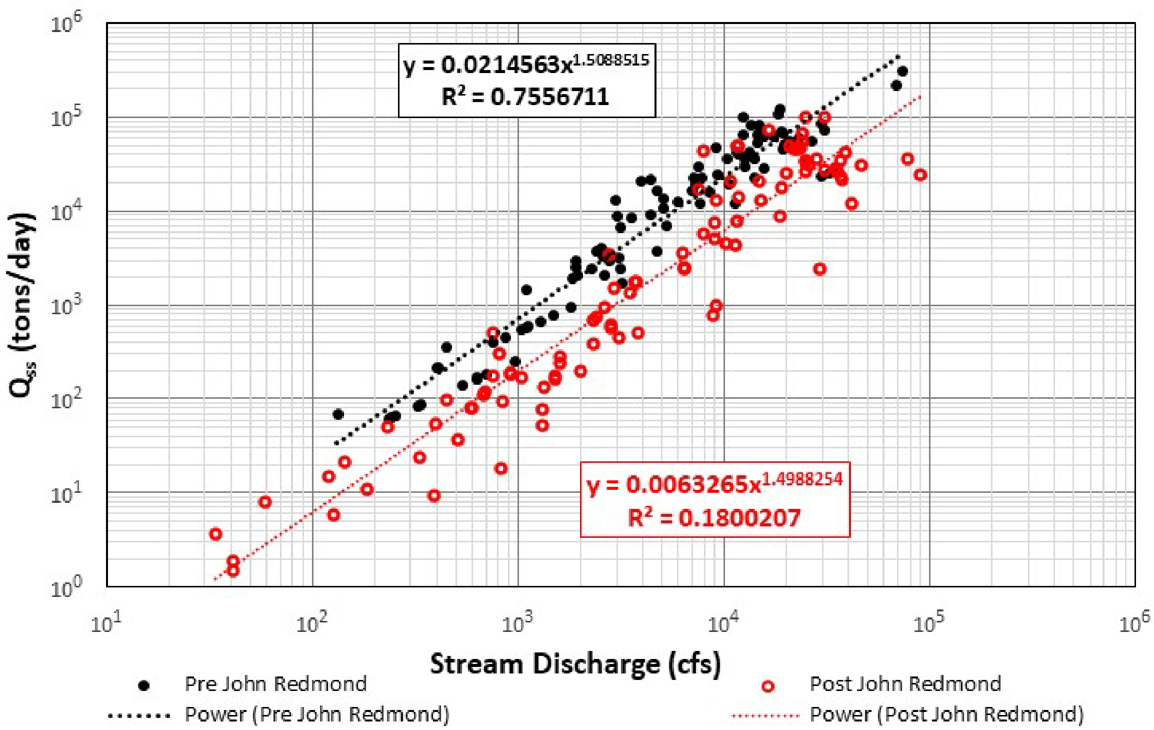
Figure 83
Suspended Sediment Transport Regression Analyses (1940–2008 and 2009–2021): Neosho River Near Commerce



The regression analyses show two distinct relationships with the 1940 to 2008 curve being significantly higher than the 2009 to 2021 curve (again noting that the data and regressions are plotted on a log-log graph). Based on these regression analyses, the suspended sediment transport ranges from approximately 4 times greater at lower flows to approximately 2.9 times greater at higher flows, comparing the 1940 to 2008 curve to the 2009 to 2021 curve. In other words, the data indicate that suspended sediment transport was between approximately 3 to 4 times greater for the earlier time period than the most recent time period. This is a significant decrease in sediment supply over time to consider in the analysis and modeling of sediment transport. One reason there has been a decrease in suspended sediment transport in the Neosho River is the fact that the John Redmond Reservoir on the Neosho River has been trapping sediment since its completion in 1964. Other factors may also have contributed to the trend in decreasing sediment loads over time such as erosion-reduction measures along upstream river channels, land-use changes, and changes in vegetation along the key tributaries; but the effect of sediment trapping in John Redmond Reservoir is a known and significant factor.

Regression analysis was also conducted for the pre- and post-John Redmond Reservoir era as shown in Figure 84. This analysis shows similar results to the pre- and post-2009 because most of the data collected prior to 2009 were collected prior to 1964.

Figure 84
Neosho River Pre- and Post-John Redmond Reservoir Suspended Sediment Relationships with Flow



The final sediment rating curves for the quantitative analysis used the unbiased approach from HEC-RAS and pre- and post-2009 for all rivers. The 2009 break point was chosen because the OWRB survey was completed at that time, making it convenient for comparison of pre- and post-survey sediment loading. The Neosho River was an exception; it uses 1964 as the break point, which coincides with completion of the John Redmond Reservoir and the subsequent reduction in sediment loading to Grand Lake. These rating curves are shown in Figure 85 through Figure 92.

Figure 85 shows the pre-1964 data on the Neosho River in red (along with the associated regression curve and equation), and the equation using output from the unbiased sediment rating curve analysis is shown in black (along with the associated equation). The unbiased equations are the sediment rating curves used in the quantitative analysis for each respective time period.

Figure 85
Neosho River Comparisons of Pre-1964 Biased and Unbiased Sediment Curves

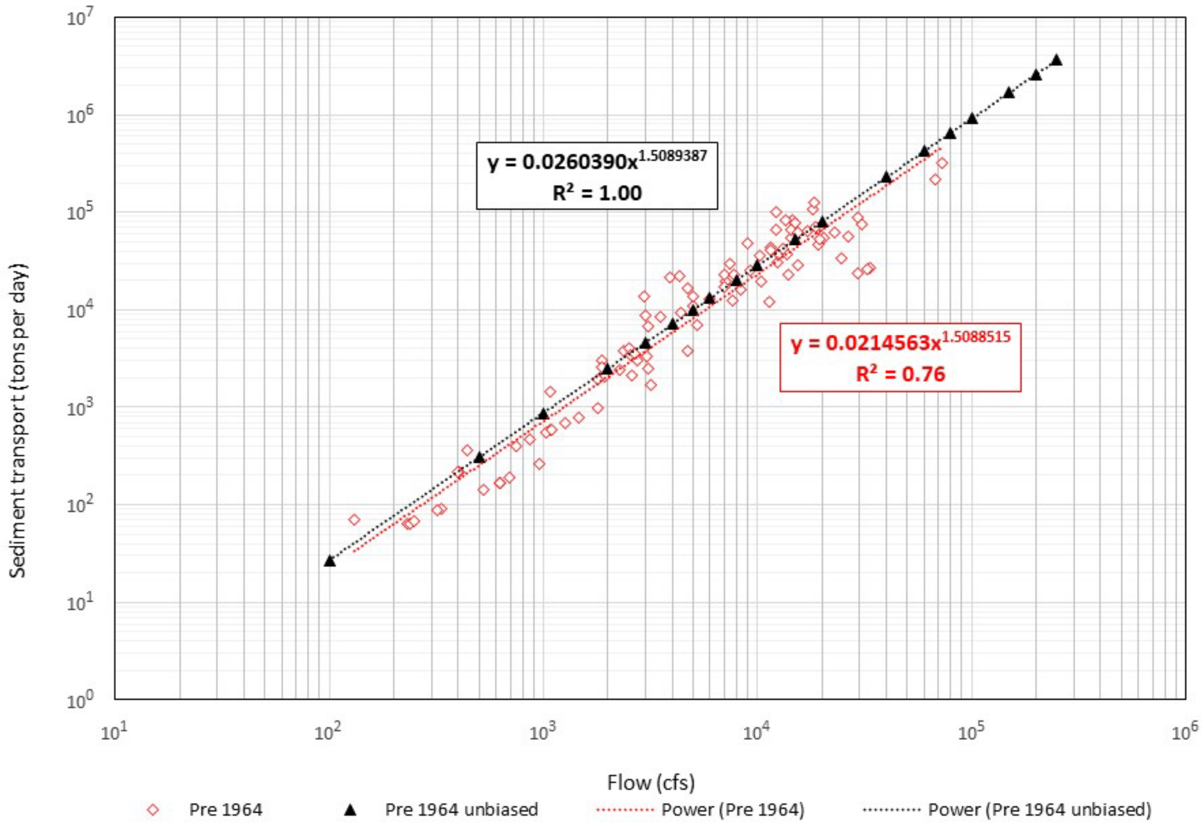


Figure 86 presents the same information for the post-1964 time period, again with the data points shown in red and the unbiased equation shown in black.

Figure 86
Neosho River Comparisons of Post-1964 Biased and Unbiased Sediment Curves

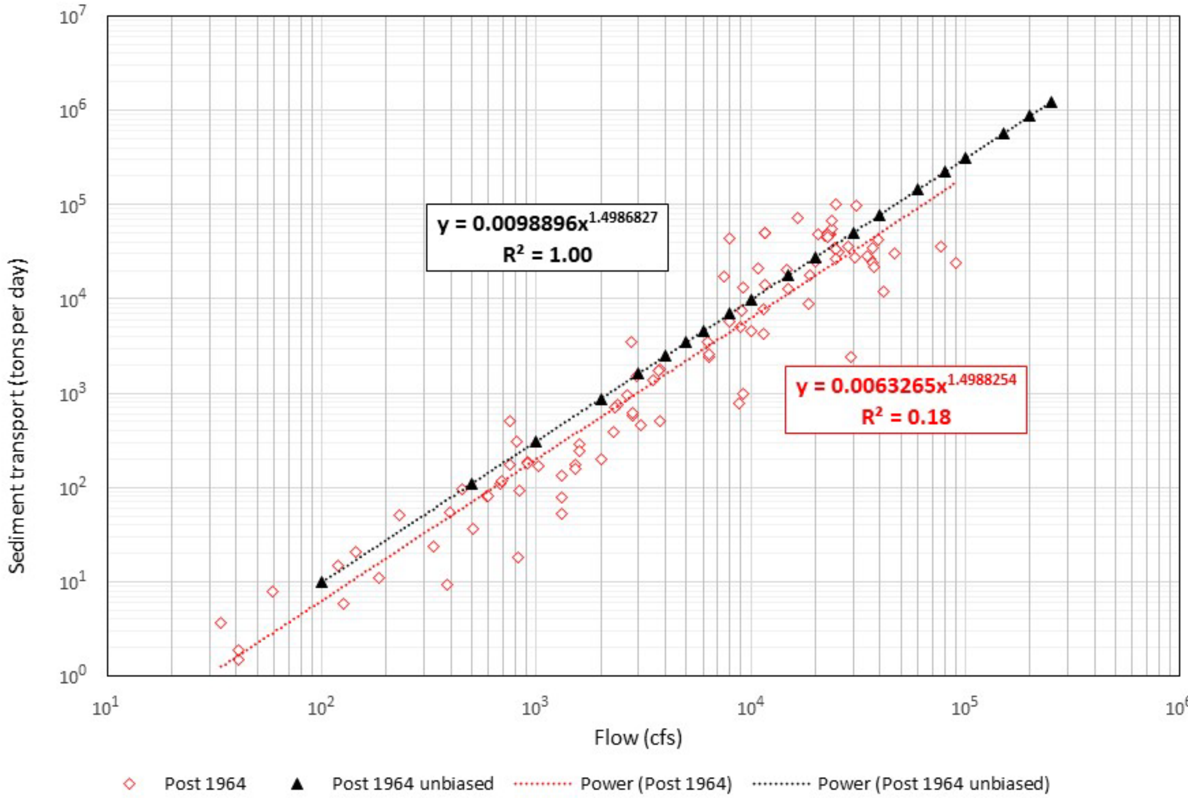


Figure 87 and Figure 88 present the datasets for pre- and post-2009 time periods on the Spring River with the unbiased regressions from the unbiased analysis from HEC-RAS shown in black.

Figure 87
Spring River Comparisons of Pre-2009 Biased and Unbiased Sediment Curves

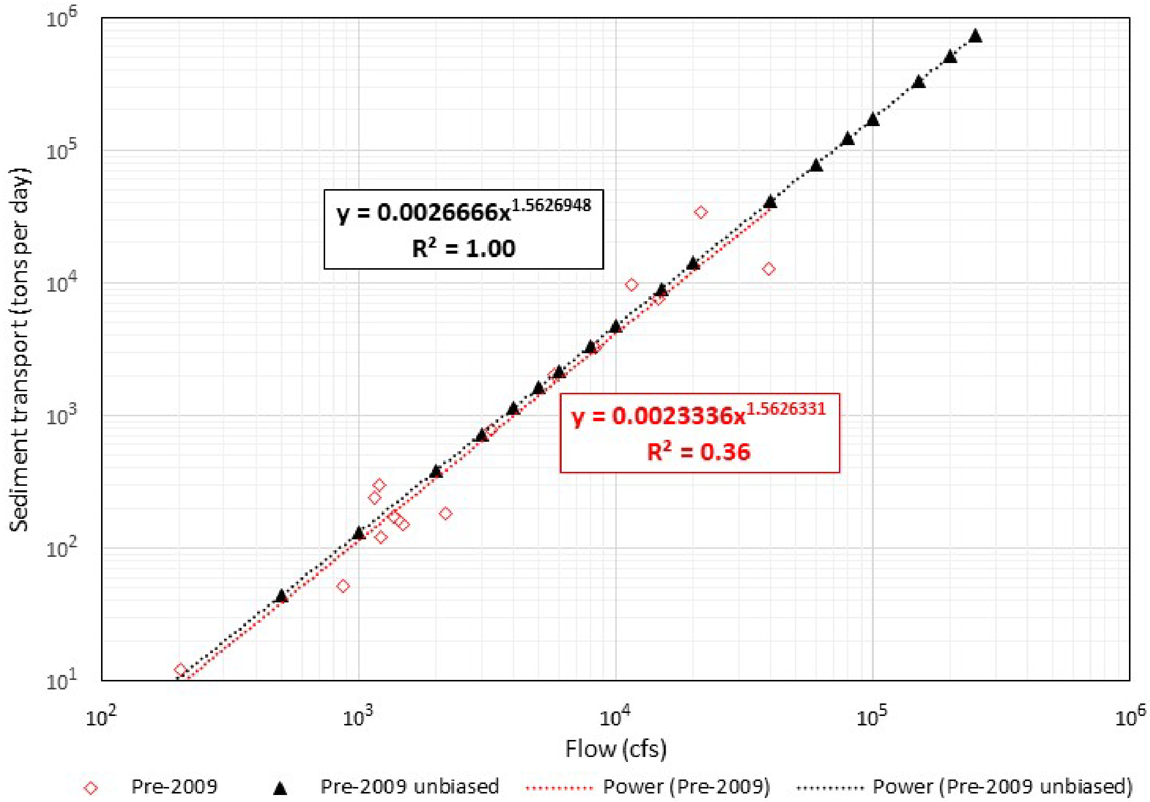


Figure 88
Spring River Comparisons of Post-2009 Biased and Unbiased Sediment Curves

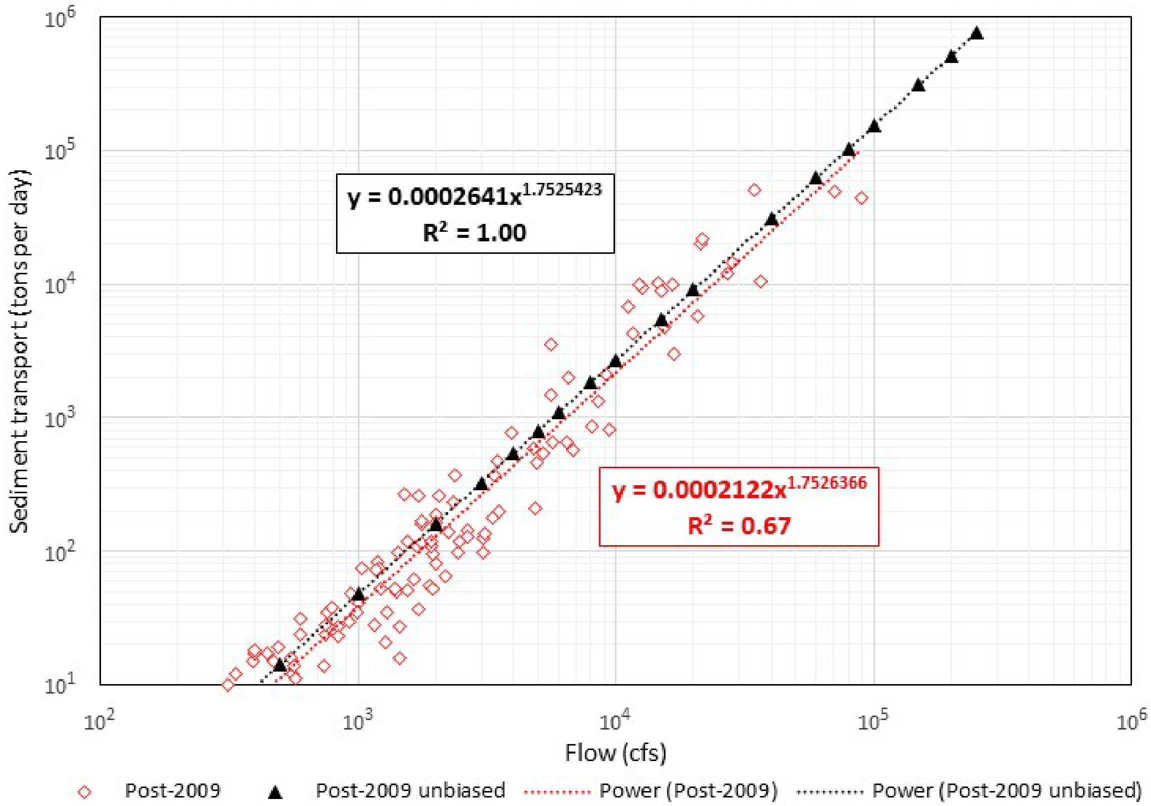


Figure 89 and Figure 90 present the Elk River data for pre- and post-2009 time periods in red and the corresponding unbiased equations for the respective time periods in black.

Figure 89
Elk River Comparisons of Pre-2009 Biased and Unbiased Sediment Curves

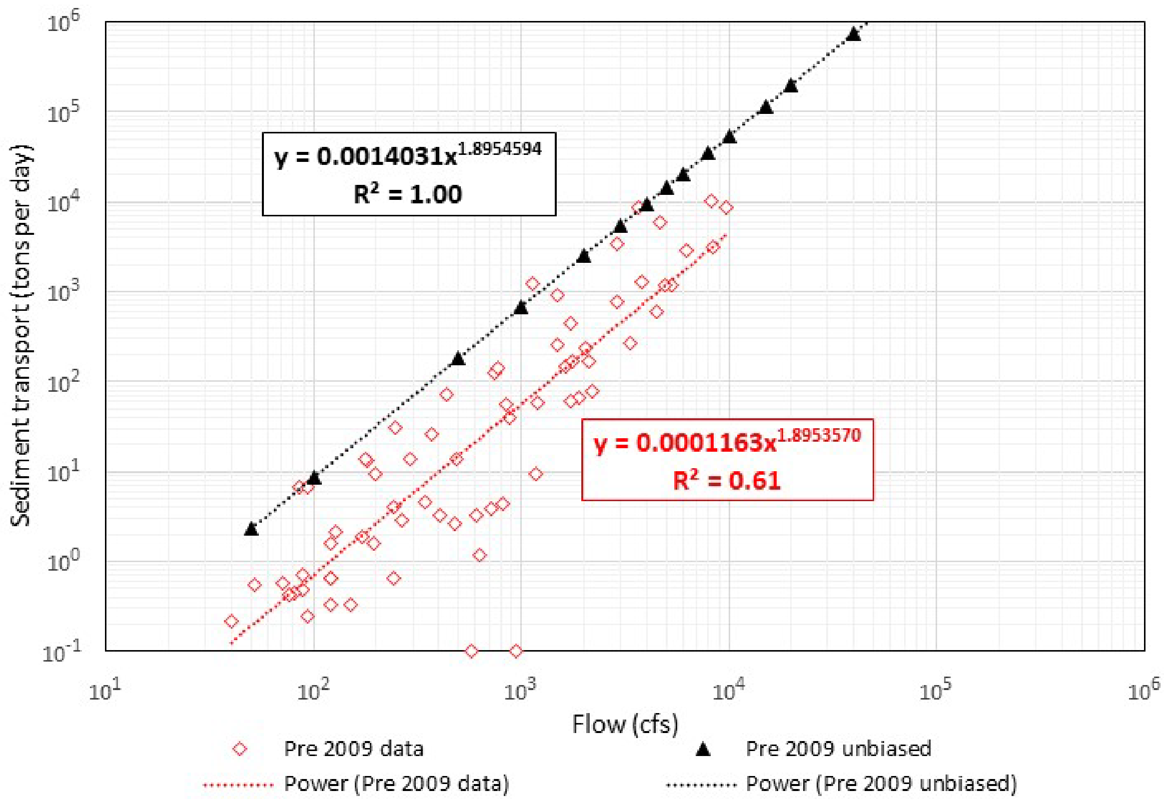


Figure 90
Elk River Comparisons of Post-2009 Biased and Unbiased Sediment Curves

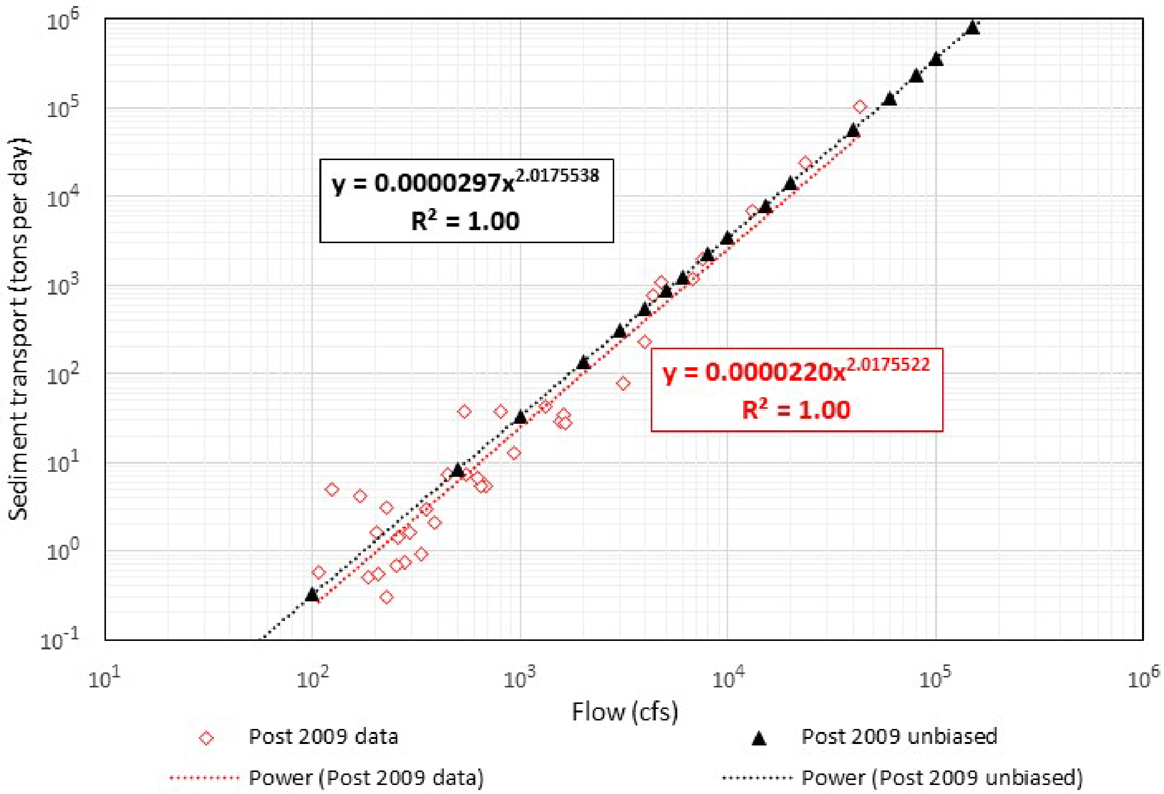


Figure 91 and Figure 92 present the Tar Creek data for pre- and post-2009 time periods in red and the corresponding unbiased equations for the respective time periods in black.

Figure 91
Tar Creek Comparisons of Pre-2009 Biased and Unbiased Sediment Curves

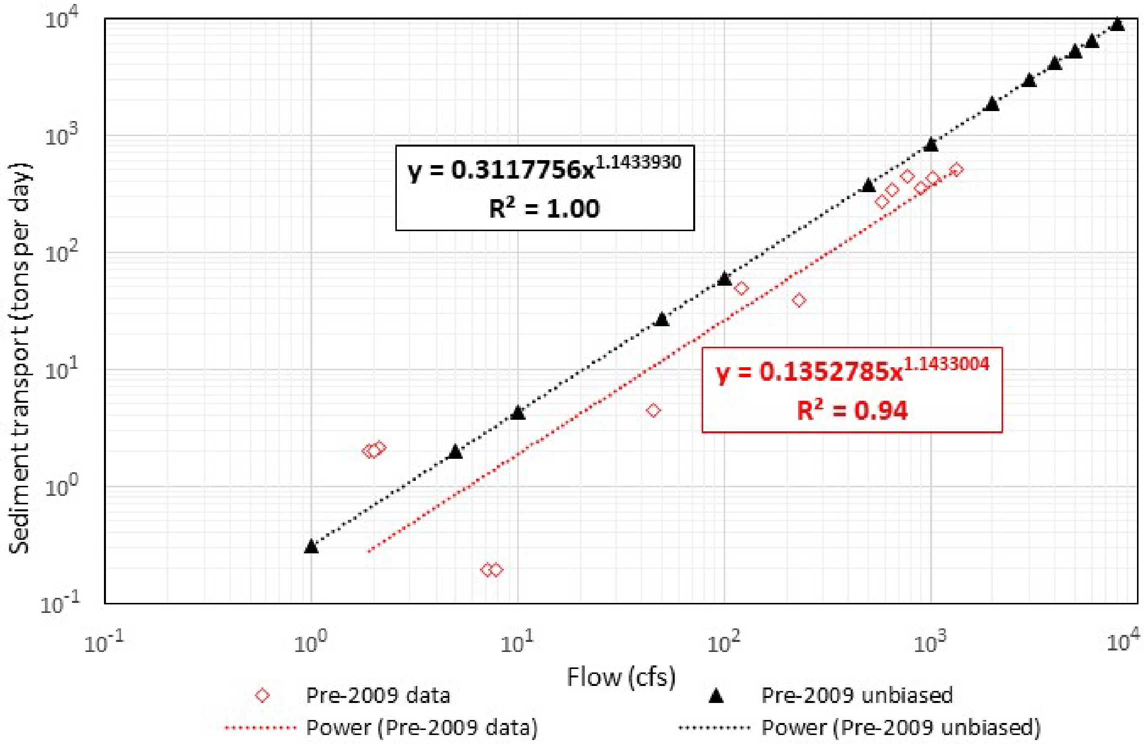
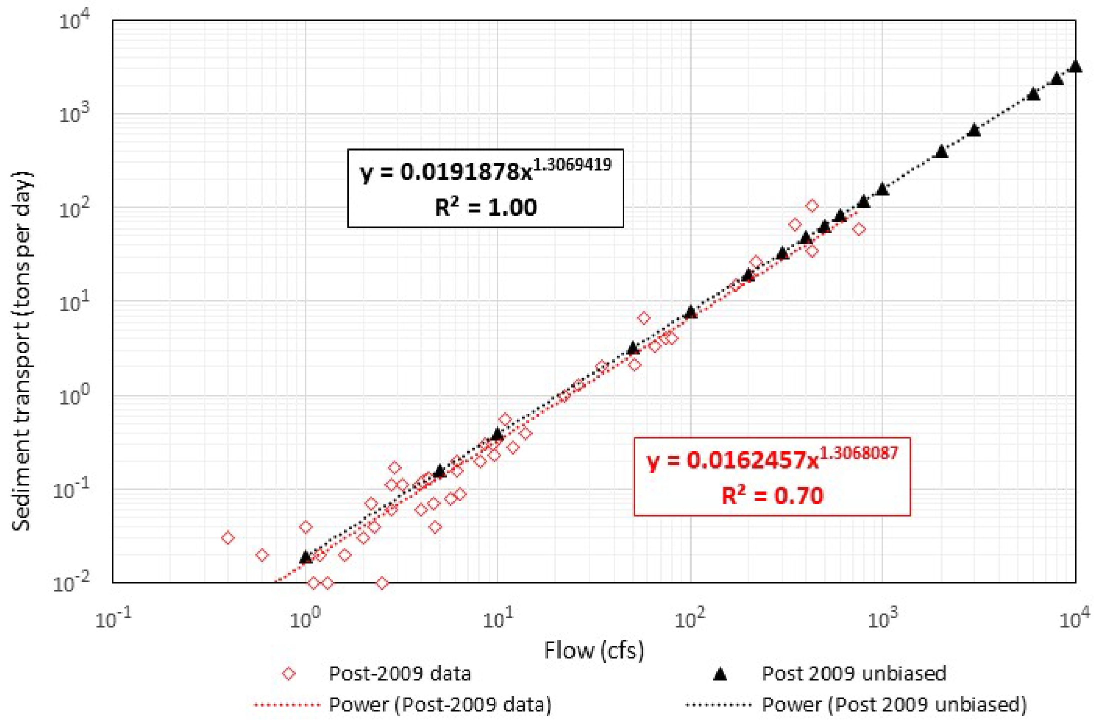


Figure 92
Tar Creek Comparisons of Post-2009 Biased and Unbiased Sediment Curves



A summary of the sediment rating curves is presented in Table 17.

Table 17
Sediment Transport Rating Curve Equations (Unbiased, Considering Stationarity)

River	Pre-2009	Post-2009
Neosho*	Q_{ss} = 0.0260390 $Q^{1.5089387}$	Q_{ss} = 0.0098896 $Q^{1.4986827}$
Tar	Q_{ss} = 0.3117756 $Q^{1.1433930}$	Q_{ss} = 0.0191878 $Q^{1.3069419}$
Spring	Q_{ss} = 0.0026666 $Q^{1.5626948}$	Q_{ss} = 0.0002641 $Q^{1.7525423}$
Elk	Q_{ss} = 0.0014031 $Q^{1.8954594}$	Q_{ss} = 0.0000297 $Q^{2.0175538}$

Note: *Neosho values are pre- and post-1964.

These sediment rating curves were applied to the historical flow data to compute the tonnage of sediment flowing down the rivers and into Grand Lake. They were also applied to the future hydrology to compute the tonnage of sediment for the future scenario.

Summaries of basic flow and water level statistics have been developed, along with corresponding quantities of sediment transported for various time periods of interest using the bias-corrected rating curves considering stationarity. These time periods include 1940 to the beginning of 2009, 2009 through 2019, and future scenarios from 2020 through 2069. For the future scenarios (2020 through 2069), flow and water levels are presented for both anticipated operations and baseline operations (see Section 7 for discussion of anticipated/baseline operations). These summaries provide perspective and comparisons of these key variables between the various time periods.

A summary of flow and WSE averages is presented in Table 18.

Table 18
Summary of Flow and Water Levels

Tributary	1940–2009	2009–2019	2020–2069 Anticipated Operation	2020–2069 Baseline Operation
Neosho River (cfs)	3,818	4,312	4,183	4,183
Tar Creek (cfs)	48	40	55	55
Spring River (cfs)	2,212	2,664	2,526	2,526
Elk River (cfs)	822	953	887	887
Grand Lake Average WSE (feet)	740.95	743.49	742.57	741.65

The tonnage of sediment transported during these various time periods was also computed using the unbiased sediment rating curves and either historical or projected hydrology (Table 19).

Table 19
Summary of Sediment Transport

Tributary	Total Sediment Transport (tons) 1940–2009	Total Sediment Transport (tons) 2009–2019	Total Sediment Transport (tons) 2020–2069
Neosho River	214,264,051	21,144,118	89,616,776
Tar Creek	864,297	19,702	122,593
Spring River	27,464,343	4,088,037	15,866,424
Elk River	57,766,979	1,432,848	3,535,827
Total	**300,359,670**	**26,684,705**	**109,141,619**
No. of years	**69**	**11**	**50**

Table 20 summarizes basic information comparing annual sediment transport for the various time periods of interest.

Table 20
Summary of Annual Sediment Transport

Tributary	Annual Sediment Load (tons/year) 1940–2009	Annual Sediment Load (tons/year) 2009–2019	Annual Sediment Load (tons/year) 2020–2069
Neosho River	3,105,276	1,922,076	1,792,336
Tar Creek	12,526	1,791	2,452
Spring River	398,034	371,640	317,328
Elk River	837,203	1,302,259	70,717
Total	**4,353,039**	**2,425,882**	**2,182,832**

Pursuant to federal law, including the Flood Control Act of 1944 and Section 7612 of the National Defense Authorization Act for 2020, flood control operations at the Project are regulated exclusively by USACE when the reservoir elevation is above 745 feet PD or expected to rise beyond that level.

An analysis of historical data from October 1, 1942 (the first time reservoir elevation data are available), through December 31, 2019, shows that Grand Lake reaches or exceeds elevation 745 feet PD 19.8% of the time. Historical flow data for these periods with a reservoir elevation at or greater than 745 feet PD were segregated, and the sediment rating curves (unbiased, pre/post 1964 for the Neosho River and pre/post 2009 for the Spring River, Elk River, and Tar Creek) were applied to these segregated flow data. The resulting tonnage of sediment delivered to the reservoir when the reservoir was at or above 745 feet PD was compared to the total tonnage of sediment delivered for the entire time period. Table 21 presents the results of this analysis for each stream and for the overall total sediment percentage.

Table 21
Percentage of Sediment Delivered to Grand Lake: Above and Below Water Level 745 feet PD

River	Percentage of sediment delivered >745 feet PD	Percentage of sediment delivered < 745 feet PD
Neosho River	75.1	24.9
Tar Creek	63.2	36.8
Spring River	80.0	20.0
Elk River	75.4	24.6
Total	75.6	24.4

When the reservoir elevation is greater than 745 feet, which only occurs 19.8% of the time, 75.6% of the sediment load is delivered to the reservoir. Under normal operating conditions, which occurs 80.2% of the time, 24.4% of the total sediment load is delivered to the reservoir.

4.4 Sediment Density

Generally, the density of sediment is lower for fine material such as silt and clay and higher for the coarser sand and gravel. In Lane and Koelzer (1943), data were presented regarding the density of sediment deposits in reservoirs. Vanoni (2006) also discusses reservoir sediment density. This study compiled data from a wide variety of sources in the United States as well as Europe and Asia. For reservoirs in Texas, the data showed that for finer silt at the head of reservoirs, the density averaged 82 pcf. In the middle reach of reservoirs, the density was 55 pcf, and for finer material farther downstream that was continually submerged the density was 31 pcf. Deposited sediment in the Missouri River basin ranged from 25.2 to 116 pcf, with a corresponding sand content ranging from 4.9% to 93.5%. The sediment density in a European reservoir ranged from 21.6 to 87.2 pcf, depending on the depth of the sample, which ranged from 1 to 20 meters. Sediment traps in this reservoir showed surface layer deposits ranged from 13.7 to 29.4 pcf. The Soil Conservation Service reported 318 samples of sediment density with a sediment density range of 20.1 to 101.7 pcf. The average density for submerged deposits of fine material for 210 samples was 44 pcf. Vanoni (2006) states the following:

> A determination of unit weight which should be used for reservoir sediment in any case is a complicated problem involving a number of variables. Among them are the manner in which the reservoir will be operated, the size of the sediment particles, the rate of compaction of the sediment, and perhaps other factors.

Lane and Koelzer (1943) presents a figure relating the unit weight of sediment to the percent of sand in the deposit (Figure 93).

Figure 93
Relation of Unit Weight of Deposited Sediments to Percent of Sand

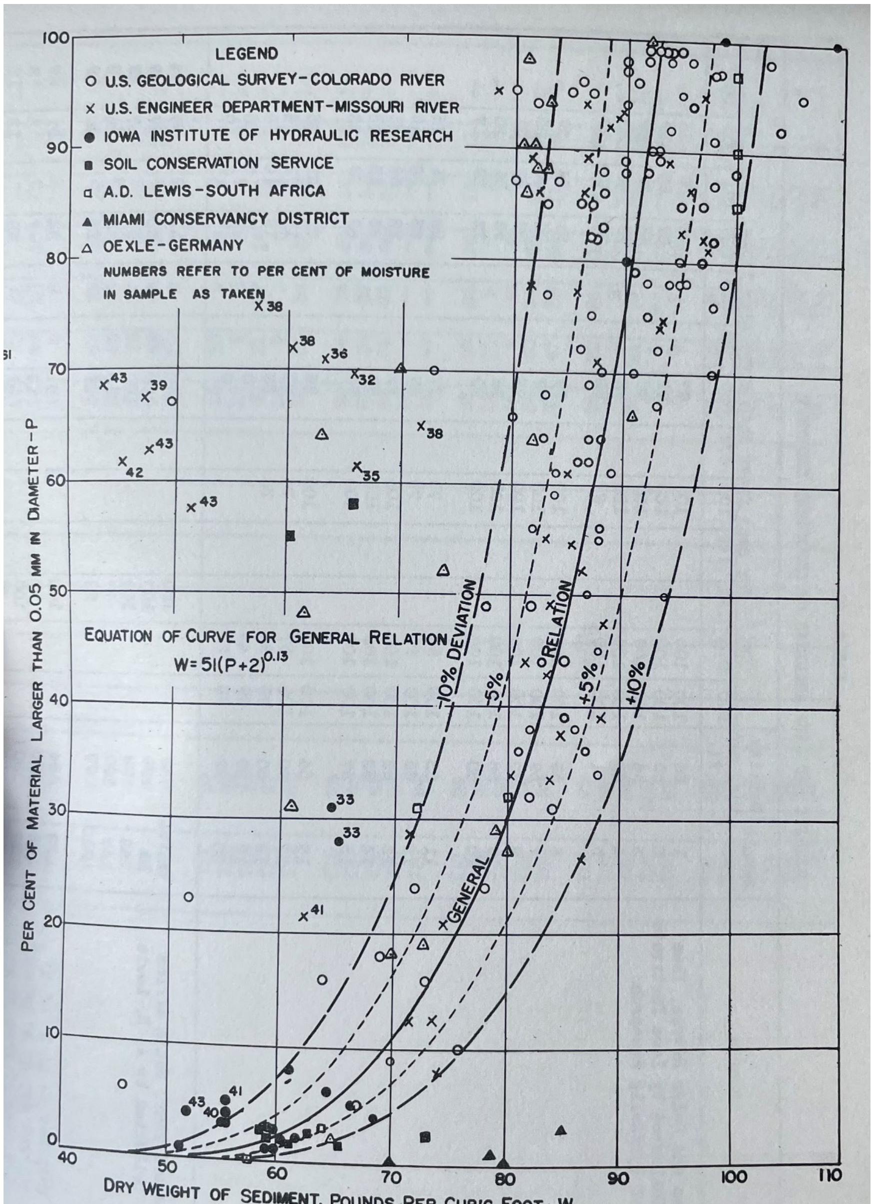


FIG. 2 - RELATION OF UNIT WEIGHT OF DEPOSITED SEDIMENTS TO PER CENT OF SAND

Source: Lane and Koelzer (1943)

The particle size distribution data from the recent core samples collected in 2022 are summarized in Appendix F.

The laboratory that conducted the particle size distribution analysis uses the U.S. Department of Agriculture (USDA) soil classification and size classification. The size breakdown between clay, silt, and sand is shown in Figure 94 from the *Engineering Field Manual* (USDA 1990).

Figure 94
Relationship between Particle Size and the USDA Textural Soil Classes, the Unified Soil Classification System, and the AASHTO Soil Classes

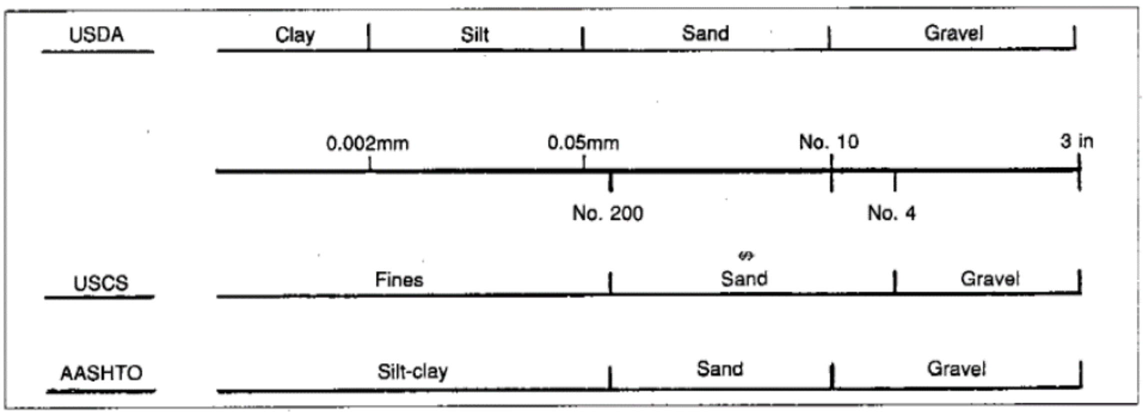


Table 22 presents the breakdown between clay, silt, and sand based on USDA classification.

Table 22
Sediment Type and Size Range

Sediment Type	Sediment Size (mm)
Clay	<0.002
Silt	0.002–0.05
Sand	0.05–2

4.5 Quantitative Analysis of Bathymetric Change Related to Hydraulic Shear Stress

The quantitative analysis of sediment transport consists of using the basic data and quantitative tools to analyze the hydrology, hydraulics, and resulting effect on sedimentation in Grand Lake. This analysis uses the historical bathymetric data combined with the hydraulic analysis of historical flows and reservoir operation to develop a relationship between hydraulic shear stress and sedimentation pattern. Hydraulic shear stress is the driving force behind the transport and deposition of sediment. Hydraulic shear stress is the basic variable used in many sediment transport equations for both cohesive and non-cohesive sediments to determine whether sediment is eroded or deposited, and the rate at which sediment is transported.

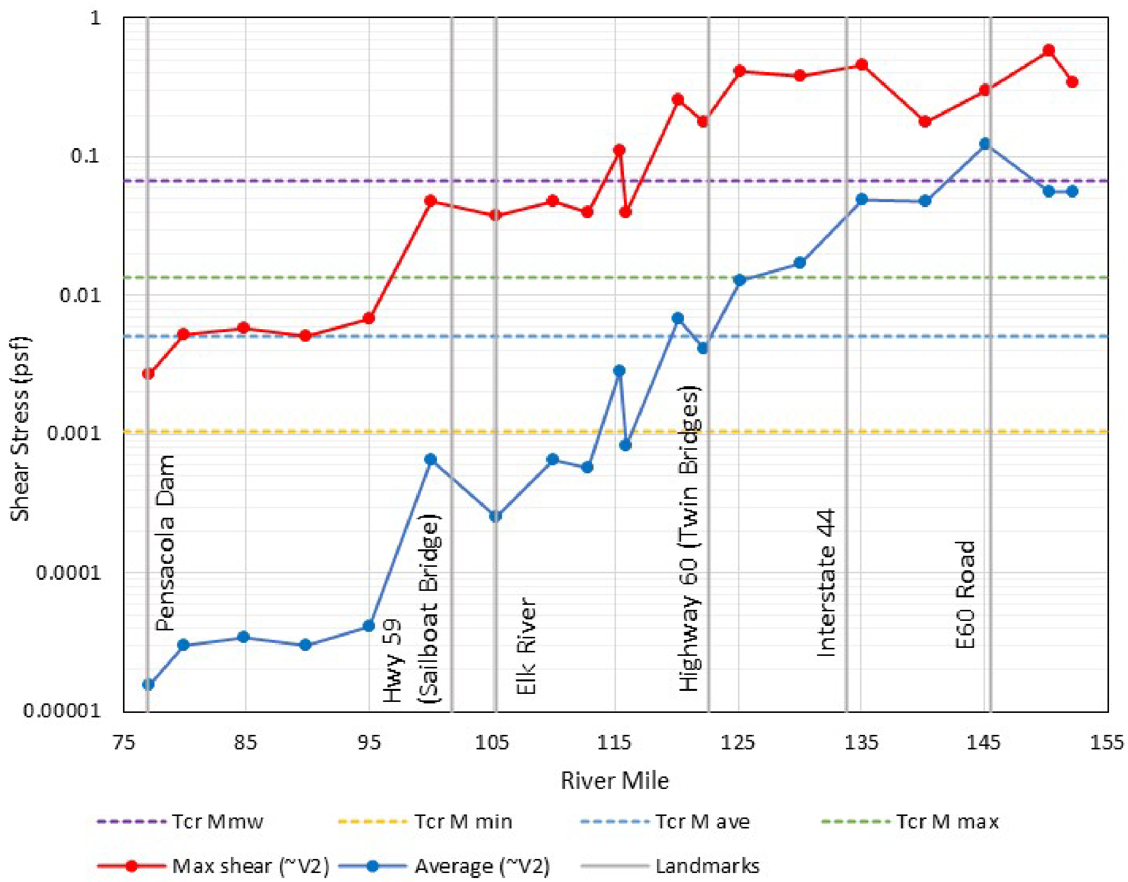
There are two steps in developing a relationship between sediment transport (and associated sedimentation patterns) and hydraulic shear stress. The first step is to run HEC-RAS to calculate hydraulic shear stresses. This step uses the hydraulically calibrated HEC-RAS model over the historical periods of available channel geometry/bathymetric data and hydrologic data of streamflow and historical water levels in the reservoir. The geometry remains fixed based on the surveyed geometry over the time periods utilized. The second step is to determine the pattern of sedimentation based on historical bathymetric surveys. The actual sets of data utilized to compute volume change and pattern of sedimentation are the HEC-RAS input data in the same hydraulic model for the available surveys. Using these two sets of information, the relationship between hydraulic shear stress and sedimentation can then be developed.

It should be noted that the STM itself uses the same data but attempts to simulate the interaction between hydrology, hydraulics, and sedimentation by using upstream sediment input (based on regression analyses of suspended sediment transport data and associated sediment rating curves), bed material particle size distribution data, a standard sediment transport equation (for non-cohesive sediment) available in HEC-RAS, and erosion characteristics of the cohesive sediment (which is the dominant sediment being transported to Grand Lake through the tributaries). The model is run for a given time period starting with the circa-1940 geometry to calibrate parameters in the model such that the computed channel geometry and bathymetry reasonably match the surveyed channel geometry and bathymetry in 2009 at the end of the calibration period. The model is then extended to evaluate whether the results reasonably reproduce the 2019 geometry as a validation process. If the model can be reasonably calibrated and validated, then it can be utilized to predict the future sedimentation patterns for a range of operation and hydrologic scenarios. As noted in the ISR, this is an extremely complicated process given the complex relationship between hydraulic shear stress and the wide variations (five orders of magnitude) in erosion parameters and considerable variability of sediment density, both of which vary with depth below the surface of the sediment column and with time because cohesive sediments consolidate and strengthen with time.

An advantage of the quantitative analysis is that the approach directly utilizes the change in bathymetric data as input to develop relationships between hydraulic shear and sedimentation pattern. In contrast, the STM calibration/verification process attempts to simulate the sedimentation pattern by judicious selection of erosion and related sedimentation parameters in the model (i.e., engineering judgment), with the objective of reasonably matching the change in bathymetric data. In other words, the quantitative analysis process uses the change in bathymetric data as input and the hydraulic shear stresses computed from the fixed-bed model, whereas the STM uses a range of parameters to attempt to match the change in bathymetric data using the hydraulic shear stresses computed from the movable bed model. If the STM could perfectly simulate the complex interaction between erosion parameters and hydraulic shear, it would achieve essentially the same results as the quantitative analysis approach. This is because successful calibration of the STM means that the model reasonably matches the change in bathymetry. The quantitative analysis directly uses this change in bathymetry to develop a relationship between hydraulic shear and sedimentation.

The first step in the quantitative analysis is to determine the hydraulic shear stresses through hydraulic modeling. The STM was modified for the quantitative analysis by setting pass-through nodes (which pass sediment through each cross section without allowing any sediment deposition) at all cross sections as well as not allowing any erosion of the bed, thereby keeping the 2009 channel geometry the same through the entire run to compute the hydraulic conditions from 2009 to 2019. As described in Section 2.6 of the USP, at a number of cross sections (spaced approximately 5 miles apart except more closely spaced over the delta feature), the hydraulic results were analyzed statistically and summarized. These data (maximum and average hydraulic shear stress) were plotted (Figure 95) as a function of longitudinal location (RM).

Figure 95
Hydraulic Shear Stress Profile of Neosho River, 2009 Geometry, 2009–2019 Historical Flows and Operation



Notes:		
	Tcr Mmw	Critical shear stress for mass wasting
	Tcr M min	Minimum critical shear stress for particle erosion across all samples
	Tcr M ave	Average critical shear stress for particle erosion across all samples
	Tcr M max	Maximum critical shear stress for particle erosion across all samples
	Max shear (~V2)	Maximum modeled bed shear stress, proportional to velocity^2
	Average (~V2)	Average modeled bed shear stress, proportional to velocity^2

HEC-RAS (USACE 2016) utilizes a default relationship to compute shear stress for the sediment transport equations as shown in Equation 2.

Equation 2

$$\tau = \gamma dS$$

where:

τ	=	bed shear stress
γ	=	specific weight of water
d	=	water depth
S	=	energy grade slope

Where depths are large, such as in the case of a reservoir, this can overestimate shear stress. Another way of computing shear stress is shown in Equation 3:

Equation 3

$$\tau = \frac{1}{8}\rho f V^2$$

where:

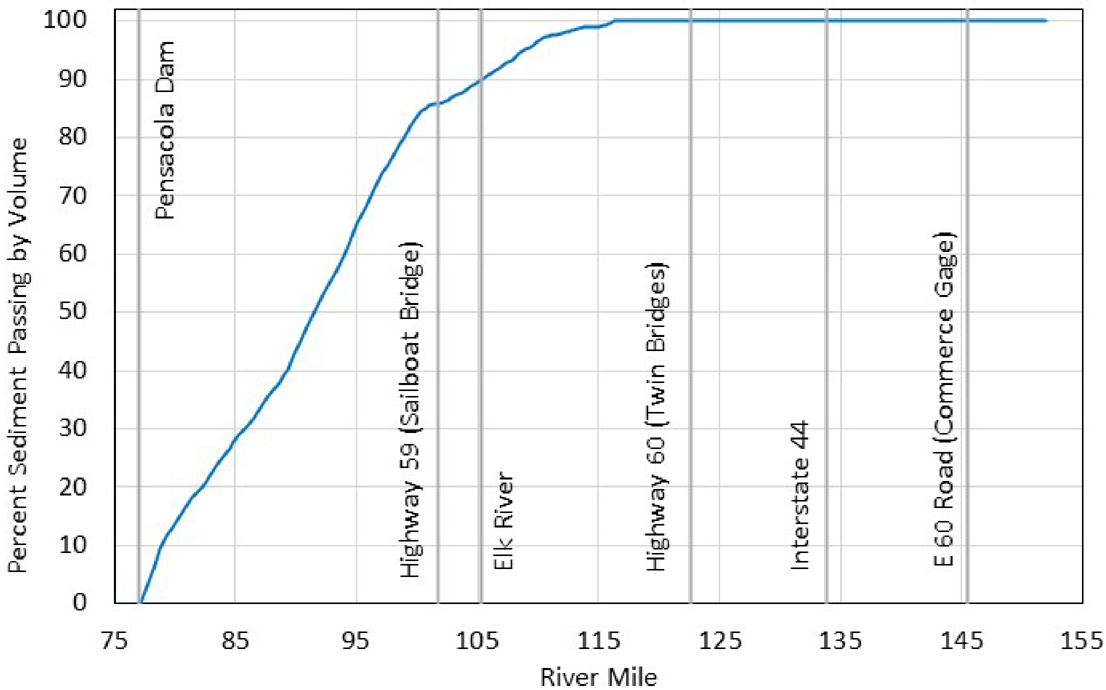
τ	=	bed shear stress
ϱ	=	specific weight of water/acceleration of gravity
f	=	Darcy-Weisbach friction factor
V	=	water velocity

The shear stress computed by Y d S was compared to 1/8 ϱ f V^2. This analysis showed that in the lower part of the reservoir, the shear stress using Y d S is significantly different than shear stress using 1/8 ϱ f V^2. For purposes of this analysis, the approach for computing hydraulic shear stress is the velocity method.

The shear stress generally decreases in the downstream direction as depths and cross-sectional area of the flow increases as it flows into the reservoir. As a point of reference (although not used in this component of the analysis), Figure 95 includes the values of critical shear stress at the surface of the sediment column developed from the SEDflume data and laboratory analysis.

The next component of the analysis is to use the sedimentation pattern that historically occurred based on the change in bathymetric data. Figure 96 presents the percentage of sediment by volume passing each cross section. The volumes were computed directly from the HEC-RAS geometry data using the average end area method from one cross section to the next and the distance by RM between sections.

Figure 96
Cumulative Percentage Sediment Passing by Volume 2009–2019



Note that the location where the percentage of sediment passing begins to drop below 100% is at approximately RM 116. At this location, the average hydraulic shear stress is approximately equal to the minimum critical shear stress for the surface layer of cohesive sediment from the SEDflume laboratory analysis.

These two sets of information were then combined to develop a relationship between hydraulic shear stress and the percentage of sediment passing downstream with the 2009 geometry (Figure-97).

Figure 97
Percentage of Volume Passing vs. Shear Stress on Neosho River, 2009 Geometry

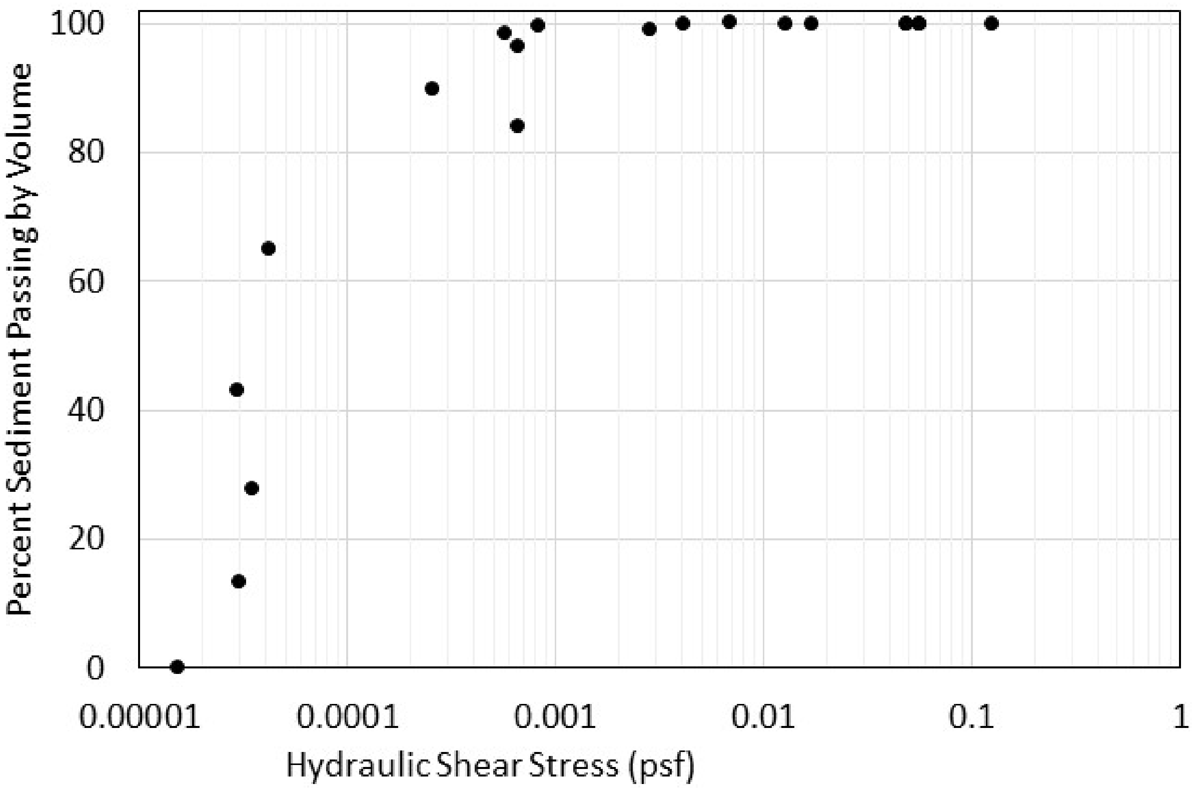
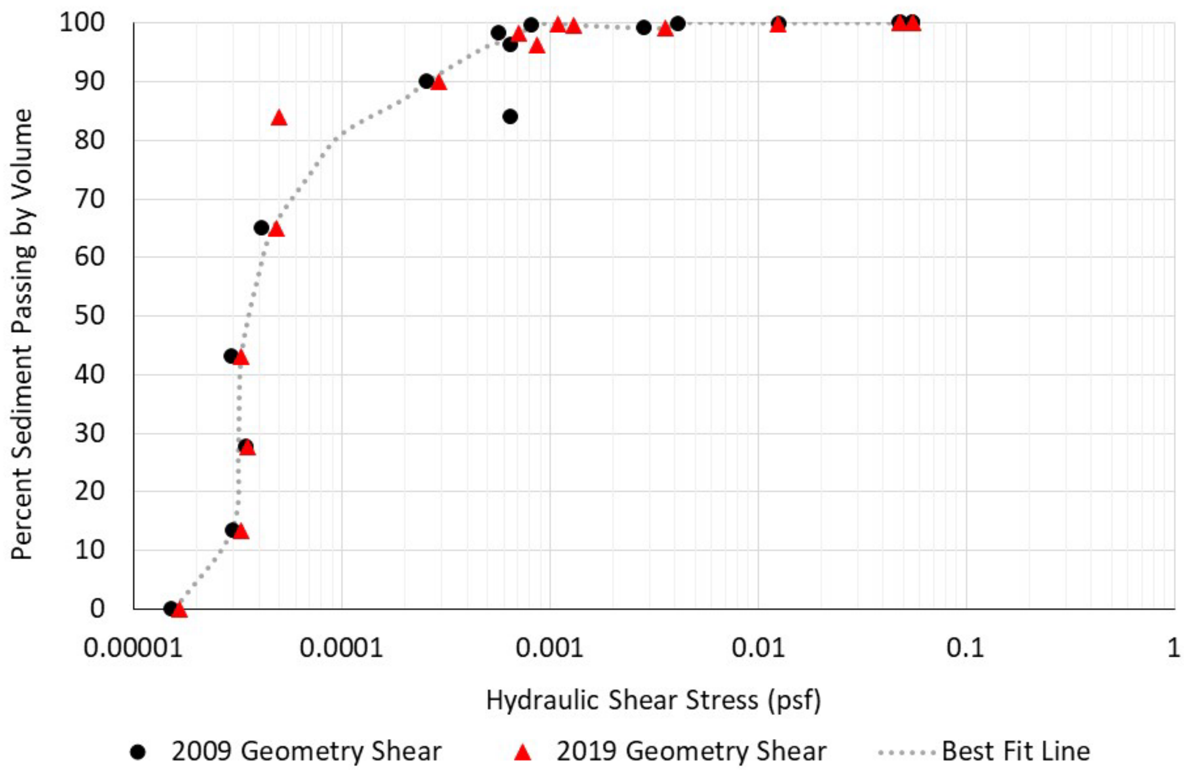


Figure 97 clearly demonstrates that there is a relationship between hydraulic shear stress and sedimentation pattern. To bracket this relationship developed between hydraulic shear stress and sedimentation that occurred between 2009 and 2019, the same information was developed based on applying HEC-RAS using 2019 geometry and the sedimentation that occurred during this time period (Figure 98).

Figure 98
Percentage of Volume Passing vs. Shear Stress on Neosho River, Comparison of 2009 Geometry and 2019 Geometry



The best fit line above correlates to the values shown in Table 23.

Table 23
Relationship between Shear Stress and Percent Sediment Passing by Volume

Shear Stress (lb/ft^2)	Percent Volume Passing (%)
1.59E-05	1.64E-06
2.99E-05	13.48
3.20E-05	27.71
3.30E-05	43.00
4.00E-05	57.00
4.70E-05	65.03
7.00E-05	74.00
1.00E-04	81.00

Shear Stress (lb/ft^2)	Percent Volume Passing (%)
2.00E-04	87.00
2.56E-04	89.93
5.00E-04	96.00
6.54E-04	97.00
8.22E-04	99.50
1.10E-03	99.96
1.31E-03	99.61
2.84E-03	99.12
3.58E-03	99.12
4.14E-03	99.96
6.63E-03	100.04
6.87E-03	100.04
1.24E-02	99.96
1.67E-02	100.00
4.88E-02	100.00
5.55E-02	100.00
5.56E-02	100.00

Using the 2009 or 2019 hydraulics that bracket the 2009 to 2019 change in sedimentation pattern produces essentially the same resulting relationship between hydraulic shear and sedimentation. This lends some confidence in using this relationship to predict future patterns of sedimentation, based on different scenarios of flow and reservoir operations by computing the hydraulics through fixed-bed HEC-RAS simulation for alternative scenarios and then applying the relationship to develop alternative future sedimentation patterns. This is similar to considering the reservoir as a full-scale physical model and developing relationships from the data and analysis to make predictions.

With this relationship based on data and hydraulic analysis (using the hydraulically calibrated HEC-RAS model), the fixed-bed HEC-RAS model was then run using the anticipated reservoir operation and future flow scenario (see Section 7). HEC-RAS produces the longitudinal hydraulic shear distribution under the anticipated operation and future flow scenario. This hydraulic shear distribution is then applied to the above relationship between hydraulic shear and the percentage of sediment passing. From this, the percentage of sediment passing based on hydraulic shear is then related back to location along the profile because the locations where the various hydraulic shear stresses are known are from the output of HEC-RAS.

4.5.1 *Future Scenarios*

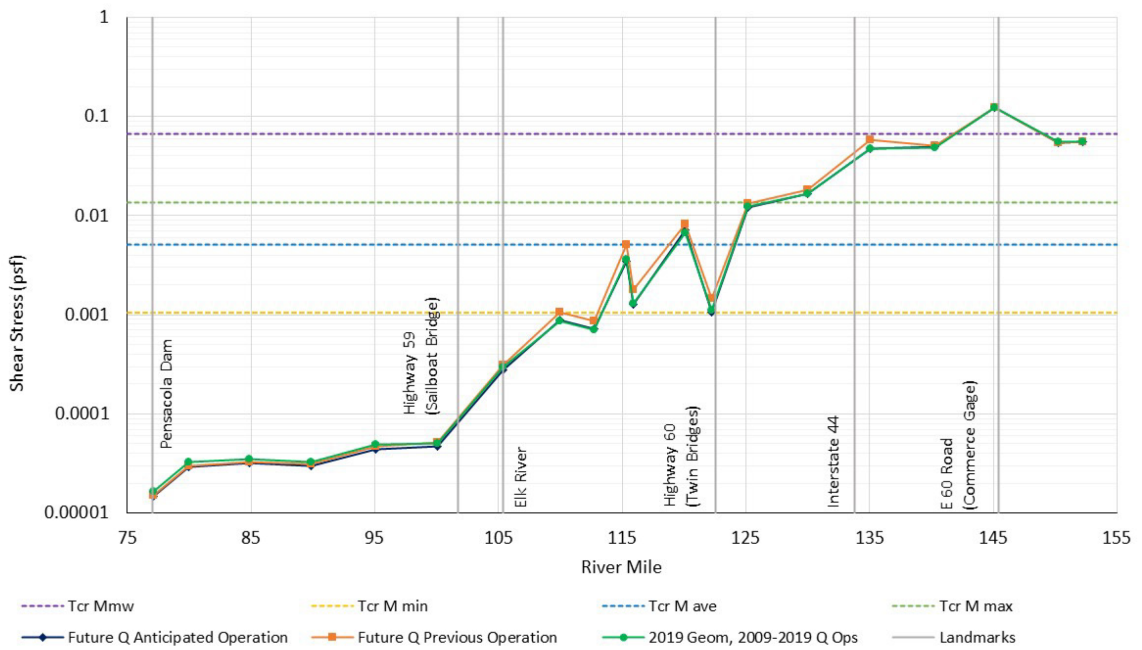
To quantify the effect of future flow and operation scenarios on sedimentation, the hydraulic shear stresses were calculated using the fixed-bed HEC-RAS model for anticipated and baseline operation scenarios using a 50-year period of flow as described in Section 7.1.1. The basic statistics of average flow and water level for these flow and operation scenarios are summarized in Table 24, along with the 1940 to 2009 and 2009 to 2019 historical data for comparison.

Table 24
Average Discharge and WSE at Pensacola Dam for Future Scenario

Tributary	1940–2009	2009–2019	2020–2069 Anticipated	2020–2069 Baseline
Neosho River (cfs)	3818	4312	4183	4183
Tar Creek (cfs)	48	40	55	55
Spring River (cfs)	2212	2664	2526	2526
Elk River (cfs)	822	953	887	887
WSE (feet PD)	740.95	743.49	742.57	741.65

The average hydraulic shear stress for the anticipated operation and baseline operation 50-year scenarios is shown in Figure 99 (also compared to the run using 2019 geometry and 2009 to 2019 historical flows and operation). Note that all three scenarios produce similar results with the future flows, with “baseline operation” resulting in slightly higher shear stresses (by 13%) than the “anticipated operation” due to the lower average water level.

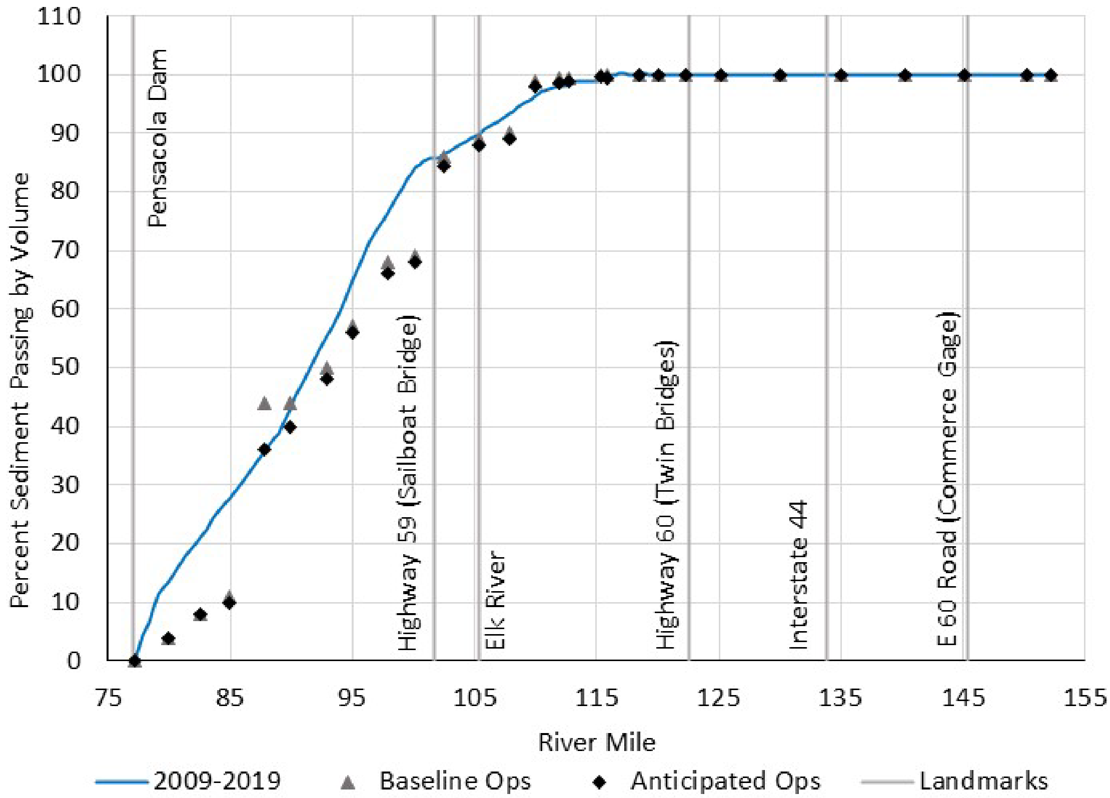
Figure 99
Average Hydraulic Shear Stress Profile on Neosho River during Future Scenario



Notes:		
	Tcr Mmw	Critical shear stress for mass wasting
	Tcr M min	Minimum critical shear stress for particle erosion across all samples
	Tcr M ave	Average critical shear stress for particle erosion across all samples
	Tcr M max	Maximum critical shear stress for particle erosion across all samples
	Future Q Anticipated Operation	Future flows under *Anticipated Operations*
	Future Q Baseline Operation	Future flows under *Baseline Operations*
	2019 Geom, 2009-2019 Q Ops	2009-2019 historical flows and reservoir operations

The hydraulic shear stress from the 2020 to 2069 hydrology with the anticipated and baseline operations were then utilized to develop the percent sediment passing graph. These values were then correlated back to the location along the river profile. This results in the graph shown in Figure 100 (with the previously developed relationship based on change in bathymetric data for comparison).

Figure 100
Cumulative Percentage of Sediment Passing by Volume for Future Scenario



Based on these computed points of percent passing along the profile through the reservoir and the surface area between the cross sections, coupled with the density of sediment, the corresponding vertical deposition of sediment was estimated for the future 50-year scenarios.

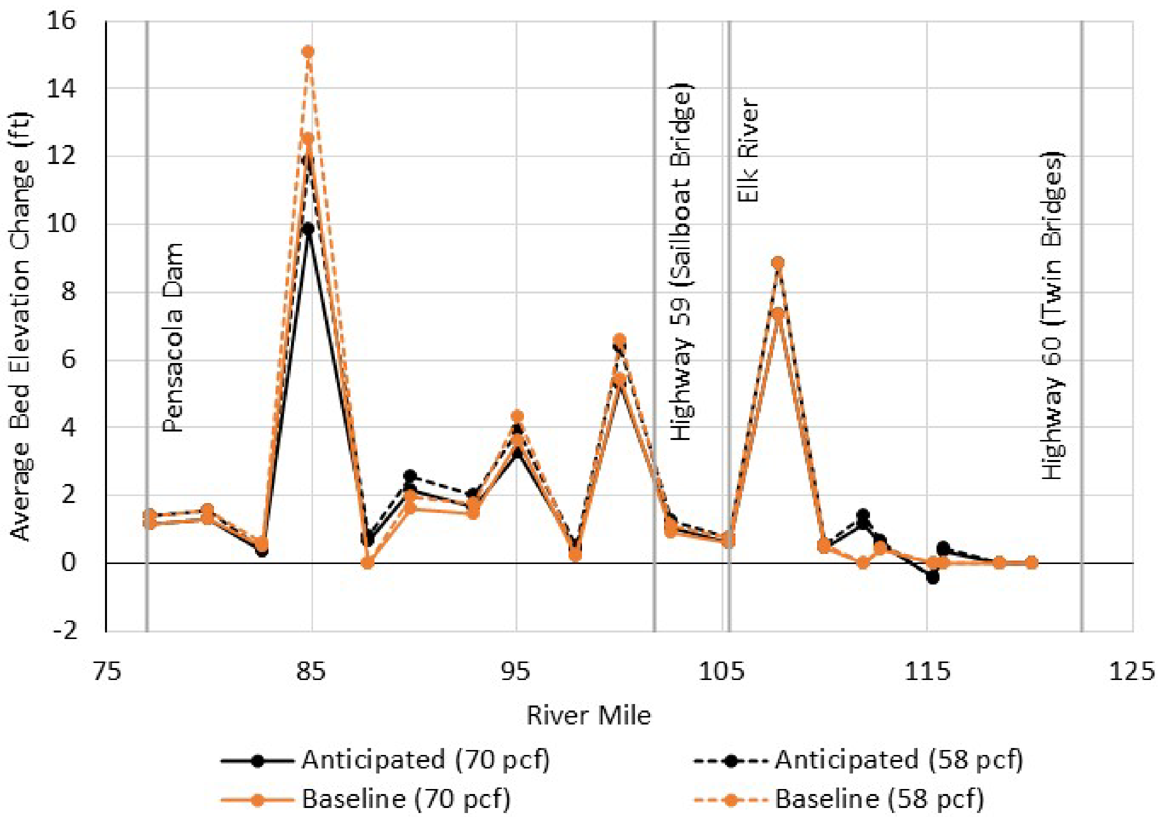
Based on the longitudinal distribution of the percentage of sediment passing cross sections along the river/reservoir profile, the average change in bed elevation due to sediment deposition was calculated along this profile. The tonnage of the incoming sediment load was calculated using the 2020 to 2069 hydrology and the sediment rating curves (unbiased post-1964 for the Neosho River and unbiased post-2009 for the Spring and Elk rivers and Tar Creek). To compute the depth of deposition requires conversion of the tonnage of sediment to volume and then to depth of sediment deposition. Sediment tonnage was then converted to volume using the density or specific weight of the sediment deposit as discussed in the next paragraph. The depth of sediment deposition was then computed by dividing the volume by the surface area over which the sediment is deposited.

Some specific weight data were collected in the upper layers of the sediment deposit as part of the SEDflume data collection program. These data showed that the upper layer (approximately 1 foot) of the sediment deposit ranged from 21.2 to 103 pcf and averaged 52.7 pcf. Although no actual data exist to quantify the specific weight below the surface layer, sediment size distribution data from the core sample dataset show that the sediment deposition in the delta feature region consists primarily of silt and clay (89%) and an average of 11% sand (using the USDA definition of sand being <0.05 mm). This information, combined with the relationship developed by Lane and Koelzer (1943), results in a range of specific weights ranging from 63 to 78 pcf and averaging 70 pcf. The specific weight utilized in the STM (Section 6.2.2) was 58 pcf. Both values are plausible and generally fit within the range of values either found in the sampling of Grand Lake (see Section 2.3.3) or from the analysis of other reservoirs as shown by Lane and Koelzer (1943).

The first level of analysis is to use the tonnage of sediment coming into the reservoir based on the 2020 to 2069 hydrology and sediment rating curves spread uniformly over the surface area of the reservoir (45,000 acres) at an average density of 70 pcf. This results in an average depth of sediment deposition of 1.59 feet over this 50-year time period. Although this basic calculation provides some perspective on the quantity of sediment in terms of depth of deposition, the next step is to distribute this sediment based on the information generated from the longitudinal distribution of hydraulic shear for this 50-year time period and the relationship between hydraulic shear and percentage of sediment passing cross sections along the river/reservoir. Results of this analysis using the percentage passing each location and the surface area of the reservoir, coupled with average density of 70 (58) pcf, and incoming sediment load over the 50-year time period of 109,141,619 tons were plotted along the longitudinal profile from RM 122.25 to RM 77.12 for both future scenarios (Figure 101) showing average bed elevation change and Figure 102 showing volume change). The analysis assumes sediment from the various tributaries comes into the Neosho River rather than subtracting the Elk River component and only including this sediment at the confluence. This compensates to some degree for the fact that approximately 10% of the drainage area is not accounted for in terms of flow and sediment input which, in turn, is counteracted by the fact that the sediment trapping efficiency is somewhat less than 100%. These relatively small percent differences being on the order of 10% or less is well within the scatter exhibited by the sediment transport data and the measurement errors in the flow data.

The quantitative analysis shows very little sediment deposition, with even some scour, down to approximately RM 115. The analysis shows approximately 2 feet (2.6 feet at 58 pcf) of deposition between RM 115 and RM 112.75. This is in an area of relatively lower bed profile between the two higher points at RM 115 and RM 112.75 shown on the thalweg profile. Between RM 112.75 and RM 110, the analysis shows some scour. The quantitative analysis shows no significant rise of the existing high point of the delta as indicated in the 2009 and 2019 bathymetric surveys. Downstream of RM 110, more significant sediment deposition occurs, but the analysis shows some oscillations between sedimentation and scour. This analysis shows minimal sedimentation on the top surface of the delta feature (with some deposition being indicated in the low area between the two existing high points on the thalweg profile). The bulk of the sediment delivered to the reservoir deposits on the lower face of the delta downstream of RM 110. This is consistent with the progression of delta formation in the scientific literature (Figure 103 and Figure 104), where the downstream face of the delta progressively builds in the downstream direction on the foreset slope.

Figure 101
Average Bed Elevation Change 2020–2069 (70 pcf Sediment Density)



Notes: RM 85 is approximately 1.1 miles upstream of the Drowning Creek confluence.

Figure 102
Average Bed Volume Change 2020–2069

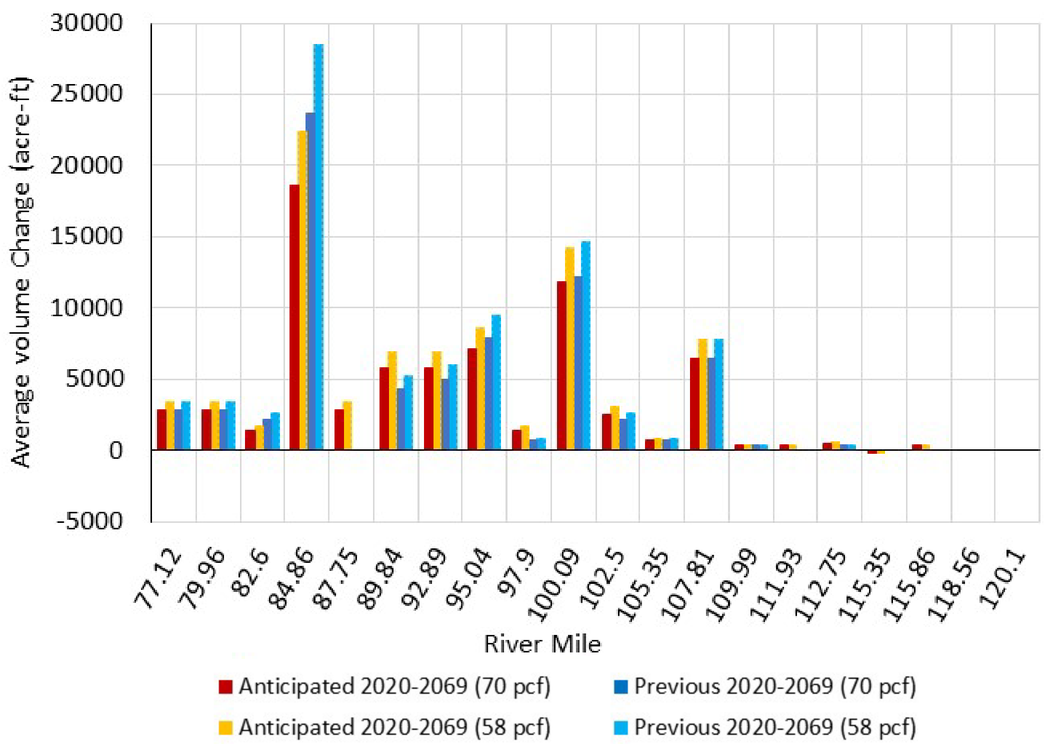
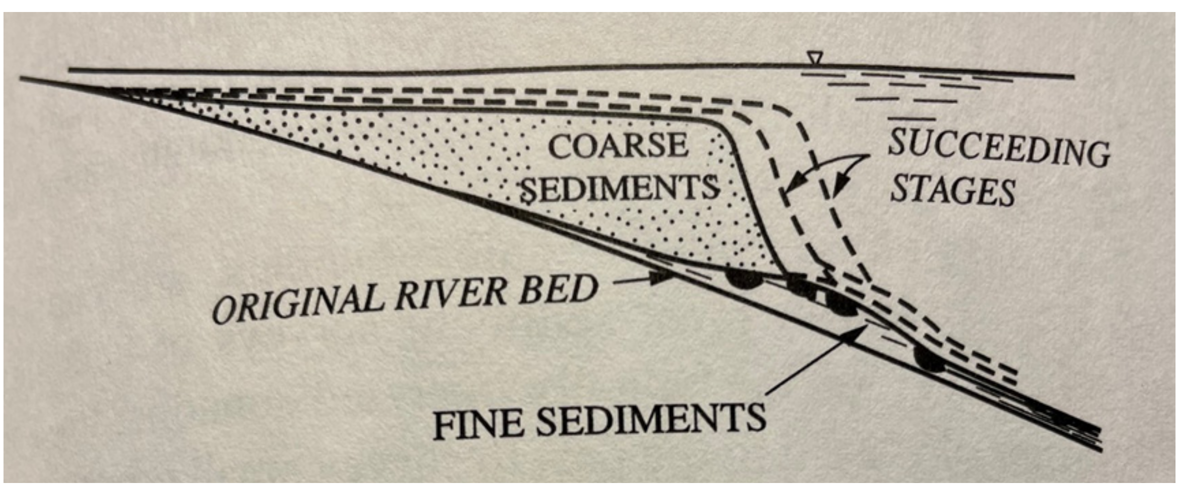
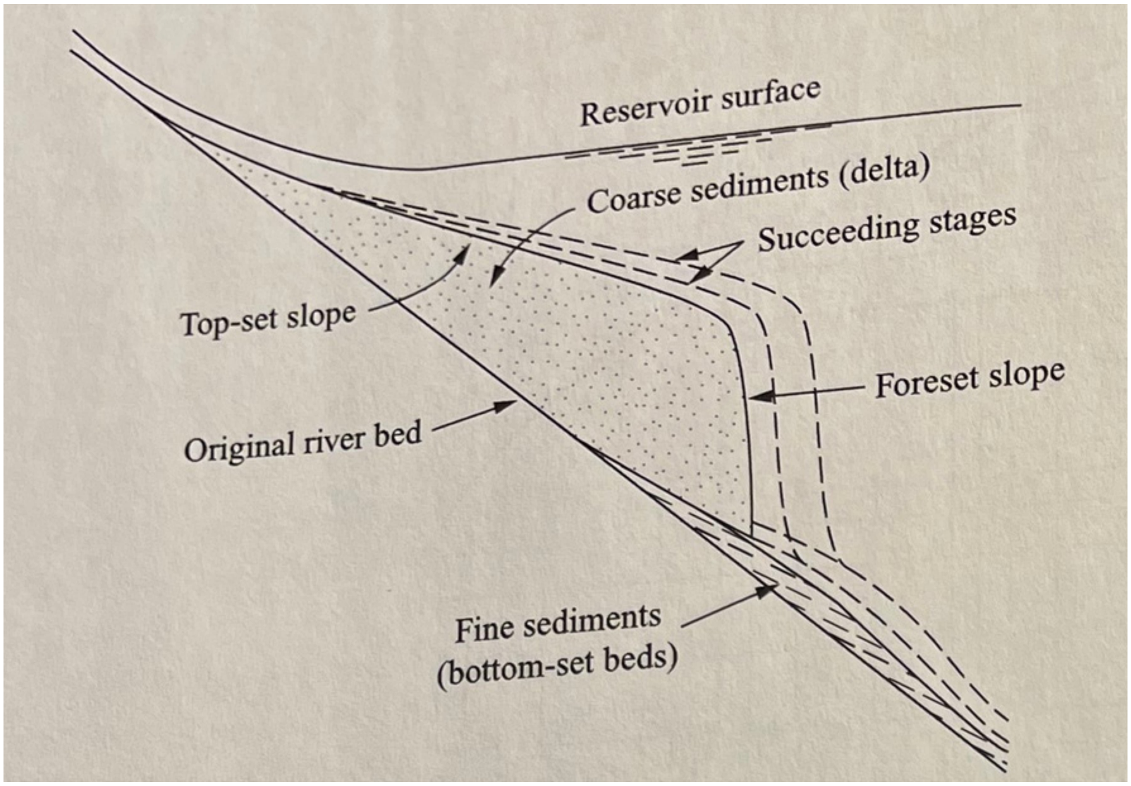


Figure 103
Profile of Typical Reservoir Delta



Source: Figure 3.30, Vanoni (2006)

Figure 104
Reservoir Delta Form



Source: Figure 5.44, Vanoni (2006)

Again, one of the key conclusions is that because the vast majority of the sediment being transported down these rivers and into the reservoir consists of silt- and clay-sized materials (with very little sand or coarser material), this sediment is primarily depositing 35 miles downstream from the upper end of the reservoir (most sedimentation in the future flow and operation scenarios is quantified to be occurring downstream of RM 110).

As discussed in Section 3, there are multiple factors contributing to the delta feature and its location within the study area. The Ozark Uplift formation, confluence of the Spring River, and the confined upstream channels all play a role in the location and elevation of the delta feature.

Furthermore, the delta feature is currently in dynamic equilibrium, with all available evidence suggesting that deposition on the crest during low flows is washed further downstream during high flows. Dynamic equilibrium, in engineering terms regarding sedimentation, occurs when the bed experiences relatively minor fluctuations about a mean bed elevation with no significant long-term trend.

The long-term growth of the feature is expected to be on the downstream face, where it will affect storage volume. Its presence and predicted future evolution do not provide evidence that future upstream water levels will significantly increase due to sedimentation.

Regardless of that fact, it is also relevant to note that the USACE dictates Project operations whenever WSE at the dam is above 745 feet PD or expected to rise above that level. GRDA has no control over the incoming streamflow, nor do they even control dam operations during the largest events. As shown in the analysis of sediment inflow at or above 745 feet PD, which only occurs 19.8% of the time, delivers 75.6% of the incoming sediment load to the reservoir. This sediment inflow is a result of upstream erosion and sediment transport over which the Project has no control and most of the sediment is delivered to the reservoir when USACE is in operational control of Grand Lake.

4.6 Trapping Efficiency

Several methods have been developed to estimate the sediment trapping efficiency, which are typically based on such factors as the inflow rate compared to storage capacity and residence time of water in the reservoir. These relationships were developed based on data from several reservoirs for which such data exist.

A significant set of data exists on sediment trapping efficiency of a major reservoir on the Neosho River, the John Redmond Reservoir located upstream of Grand Lake. Data have been collected for a considerable time that include the volume of sediment deposited as well as the incoming sediment load and release of sediment downstream of the dam. This set of data is more extensive and complete than most datasets used in the development of the typical sediment trapping efficiency relationship. It is also noteworthy that these data were collected on the river with the greatest sediment load (Neosho River) that contributes to Grand Lake.

John Redmond Reservoir is primarily a flood control reservoir with a relatively small conservation pool and a large flood control pool above the conservation pool. The conservation pool provides 50,501 acre-feet of storage and the flood control pool provides 524,417 acre-feet of storage (Engineering-Environmental Management, Inc. 2013).

The top of the conservation pool is at elevation 1,039 feet above the National Geodetic Vertical Datum of 1929 (NGVD29) and the top of the flood control pool is at elevation 1,068 feet NGVD29. The reservoir covers 29,800 acres and the length of the reservoir is approximately 4.5 miles from where water enters the reservoir to the dam. A source of information on the studies of reservoir sedimentation in John Redmond Reservoir is found in a 2021 USGS report (Kramer et al. 2021). The following information is summarized from this report.

The drainage area contributing to John Redmond Reservoir is 3,015 square miles and has a storage capacity of 816,795 acre-feet.

During years with a complete data record at Neosho Rapids and Burlington (2010, 2014 to 2019), the trapping efficiency of the reservoir ranged from 82% to 94% (mean: 89%).

Different reservoir outflow management strategies, including operating near normal capacity as opposed to higher flood pool levels, could reduce the total reservoir storage lost by 3% (approximately 261 acre-feet).

Grand Lake is significantly larger than John Redmond Reservoir. Grand Lake is approximately 68 miles long and the storage capacity is approximately 1.44 million acre-feet (at elevation 745 feet PD). Being significantly longer and with a larger storage capacity, it is likely that the sediment trapping efficiency of Grand Lake is greater than that of John Redmond Reservoir. Because the sediment trapping efficiency of John Redmond Reservoir averages 89% (with a range of 82% to 94% over recent years), the sediment trapping efficiency of Grand Lake is well into the 90%-plus range, if not approaching the high 90% range. A review of aerial images shows some clear water released from Pensacola Dam at relatively high flows (with quite turbid water flowing into the reservoir), but on other images some turbid water is being released through the dam. This suggests that under some circumstances the sediment trapping efficiency is not 100%. Based on the comparison with John Redmond Reservoir, which recently averaged 89%, again it is likely that the sediment trapping efficiency of Grand Lake is in the high 90% range based on these comparisons and observations.

Regarding the effect of operations on flushing sediment through John Redmond Reservoir, the USGS study found that operating John Redmond Reservoir at an elevation of 1,039 feet NGVD29 (which is the top of the conservation pool) was 3% more effective in reducing storage loss than operating the reservoir "to higher flood pool" levels (top of flood pool is 1,068 feet NGVD29). So, a reduction in water level of up to 29 feet only produced a 3% reduction in sediment trapping. This was determined by continuous water quality monitoring coupled with a two-dimensional (2D) hydrodynamic model (CE-QUAL-W2) to evaluate sediment trapping reduction by altering reservoir operations. The specific study (Lee and Foster 2013) as summarized in Kramer et al. (2021) concluded that "The idealized alternative outflow management scenario was projected to reduce sediment trapping in the reservoir by about 3 percent."

Given that Grand Lake is significantly larger and operates the conservation pool at a range of 3 feet, lowering the water level only a few feet will not produce significant benefits in terms of sediment trapping.

Based on the quantity of sediment computed using the sediment transport rating curves over the 50-year future scenario, approximately 109 million tons of sediment are delivered to Grand Lake. This converts to a volume of 71,587 acre-feet at 70 pcf and 86,398 acre-feet at 58 pcf (assuming a 100% sediment trapping efficiency). This volume of sediment resulting in storage loss to the reservoir would be distributed according to the results of the hydraulic shear stress analysis for the anticipated (or baseline) operations as shown in Figure 93. This figure shows that no sediment is deposited upstream of RM 116, approximately 10% of the sediment is deposited between RM 116 and RM 105 (Elk River confluence), approximately 22% is deposited between RM 105 and RM 100, and the remaining 68% is deposited between RM 100 and the dam.

4.7 Summary and Conclusions of Quantitative Analysis

The quantitative analysis developed a relationship between hydraulic shear stress and the pattern of sedimentation specifically in terms of the percent of sediment passing each cross section based on the change in historical bathymetry using historical flows and operation.

The quantitative analysis of the future 50 years of hydrology and operation shows no significant sediment deposition on top of the delta feature that would adversely affect existing hydraulic control in upstream reaches. Most of the sediment delivered to the reservoir is transported past the top of the delta feature, farther downstream to the downstream face of the feature. Approximately 98% to 99% of the incoming sediment load is transported past RM 110. The future flows with baseline operations cause slightly reduced deposition on the downstream face of the delta feature and shift the deposition slightly downstream compared to the anticipated operation. This comparison of computed sediment deposition pattern demonstrates the very small effect on sedimentation of operating the reservoir according to baseline operations.

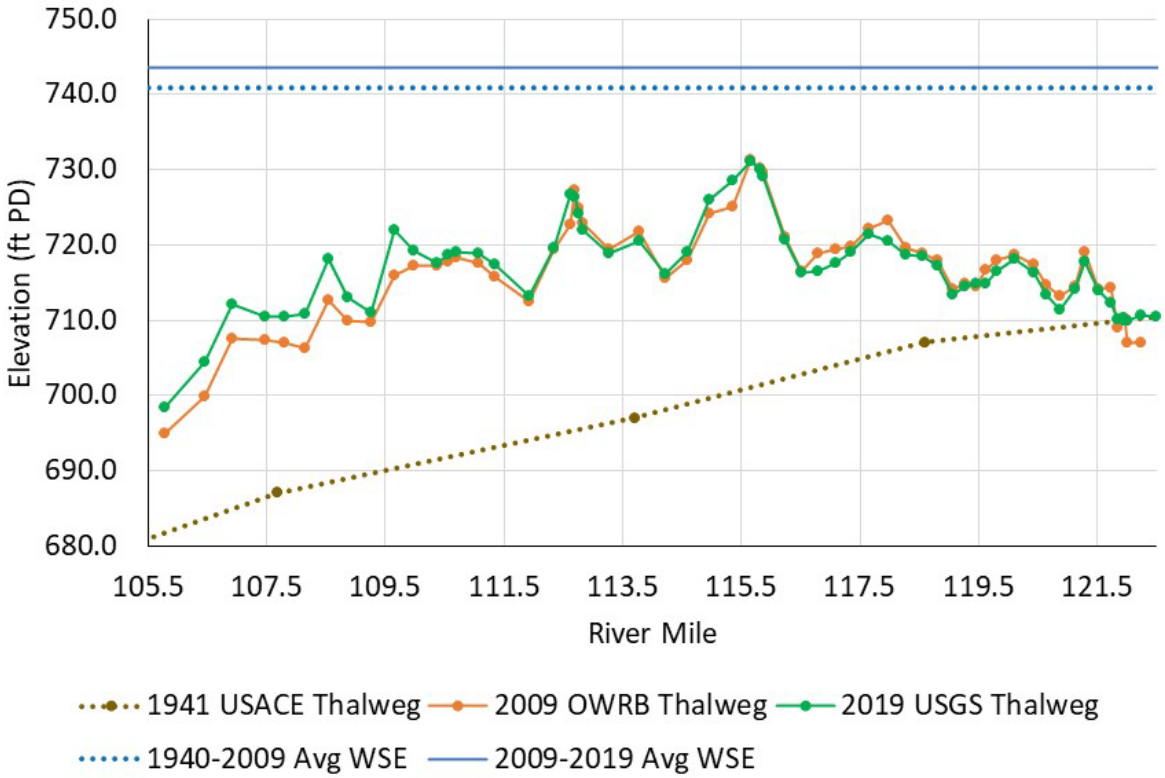
The average hydraulic shear stress for future flow conditions remains greater than the minimum critical shear stress determined by the SEDFlume analysis down to approximately RM 110. Sedimentation downstream of RM 110 is in the reach of the reservoir that is several feet below the highest elevation of the delta feature, which occurs farther upstream at approximately RM 116. For example, the predicted elevation of the delta feature with an average of 3 to 4 feet of deposition after 50 years reaches an elevation of approximately 724 feet PD. The highest elevation in the delta feature based on the 2019 data, which occurs at approximately RM 116 (approximately elevation 729 feet PD), remains without significant aggradation at that location after 50 years. The quantitative analysis demonstrates that the top surface of the delta feature is in a state of dynamic equilibrium. This state of dynamic equilibrium is consistent with the fact that the average shear stress over the top of the delta feature is generally equal to or greater than the minimum critical shear from the SEDflume analysis. In addition, considering that much of the sediment passing through this area continues farther downstream being in a state of fluid mud, rather than actual stationary deposition as discussed in the scientific literature, this further suggests a state of dynamic equilibrium of the top of the delta feature.

With this pattern of predicted sediment deposition, located downstream of the high point on the delta feature and at an elevation several feet below this high point, it cannot reasonably be expected to adversely affect upstream hydraulics and flooding. Based on the relatively small change in effectiveness of moving sediment downstream with the comparison between the future flows with anticipated operation and baseline operation, as well as the USGS analysis of the effect of significant changes in water level resulting in very limited changes in sediment storage in John Redmond Reservoir, there is no basis to conclude that there would be any significant benefit in continuing to operate Grand Lake as it has been under baseline conditions or at lower levels.

Bathymetric data from 1940 to 2009 show the development of the delta feature. Again, as discussed in Section 3, there are multiple factors contributing to the location and size of the delta feature. It is located on the Ozark Uplift, which slows water and increases deposition. The steeper Spring River contributes additional sediment loading that is likely to deposit near the confluence as flow velocities decrease. Additionally, the rocky cliffs and levees confining the Neosho River channel upstream of the confluence result in raised velocities and sediment carrying capacity. As flow reaches the site of the delta feature, flows can spread, velocities and corresponding bed shear stresses decrease, and sediment drops out of the water column.

The average water level at Pensacola Dam between 1942 (at the start of the earliest reliable records) and 2009 was 740.95 feet PD. From 2009 to 2019, there was no significant rise of the top of the delta surface on what is called the top-set slope, yet the average water level was 743.49 feet PD. The data show delta formation and growth on the top-set slope from 1940 to 2009 when the average water level was 2.49 feet lower than the 2009 to 2019 time period when virtually no upward growth on top of the top-set slope occurred. Figure 105 shows the delta feature evolution. As discussed previously, there is no indication that the crest elevation of the delta feature is expected to increase over the next 50 years either in literature (Vanoni 2006) or in this analysis. The data contradict the theory that operating at a lower level would keep the level of the top of the top-set slope lower. Although this could be considered contradictory to the approach suggested by the City to keep the delta surface low, it emphasizes the complexities of interaction between flow, sediment transport, critical shear, and water level to eventuate equilibrium.

Figure 105
Comparison of Historical Thalweg Profiles on the Neosho River



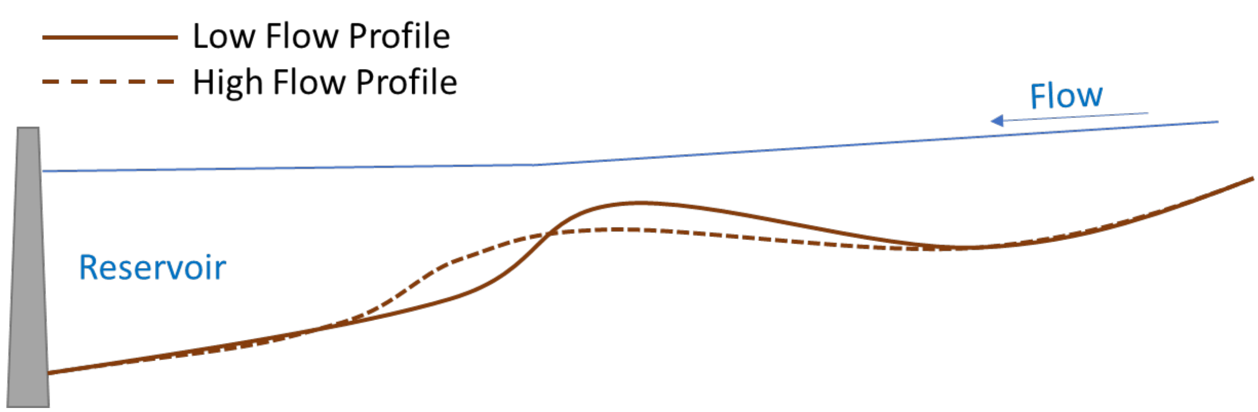
Note that the delta feature accumulation occurred primarily during the lower water levels from 1940 to 2009, and vertical growth was essentially stopped from 2009 to 2019 when average water levels were higher despite the City's claims that increased water levels will create a higher delta feature. By 2019, further deposition is only expected to occur on the downstream face of the delta feature rather than on the crest as predicted by scientific literature (Vanoni 2006).

Once the top of the top-set slope reached the level where the hydraulic shear equals or exceeds the critical shear of the sediment surface over a sufficient portion of time, then no significant sediment deposition occurs on this key portion of the delta feature, and a state of dynamic equilibrium has developed. This is consistent with the findings of the studies on John Redmond Reservoir, where operating the reservoir at a significantly lower water level only improved sediment transport through the reservoir by 3%.

Based on the quantity of sediment computed using the sediment transport rating curves over the 50-year future scenario, approximately 109 million tons of sediment are delivered to Grand Lake. This converts to a volume of 71,587 acre-feet at 70 pcf and 86,398 acre-feet at 58 pcf (assuming a 100% trapping efficiency). This volume of sediment (storage loss from the reservoir) would be distributed according to the results of the hydraulic shear stress analysis for the anticipated (or baseline) operations. The analysis shows that virtually no sediment is deposited upstream of RM 116, approximately 10% of the sediment is deposited between RM 116 and RM 105 (Elk River confluence), approximately 22% is deposited between RM 105 and RM 100, and the remaining 68% is deposited between RM 100 and the *dam*.

It is logical to conclude the delta feature is currently in dynamic equilibrium because the quantitative analysis relating shear to percentage of sediment being transported farther downstream indicates no significant sediment deposition on the top surface of the delta feature (topset slope). A riverine-like system such as the upper reservoir, which includes the delta feature, moves sediment according to the shear stress created by inflows. As inflows increase, shear stress increases proportionately. In other words, the upper reservoir's ability to move sediment increases proportionally with inflow. Therefore, if there is a significant inflow event, rather than creating a significant backwater effect, the finer sediments composing the delta feature will be moved farther downstream and out of the way because they will not have the ability to hold back the water and create a backwater effect (Figure 106). As shown by the hydraulic analysis, the average shear stress is generally greater than the critical shear stress on the topset portion of the delta feature. The quantitative analysis shows that most of the sediment deposition occurs downstream of the topset slope where hydraulic shears progressively decrease below critical shear for the cohesive sediment. To believe the delta feature has the ability to hold back a significant inflow event and create a backwater effect when it is composed primarily of fine sediments as the City asserts is contradictory to the fundamental scientific principles of shear stress and dynamic equilibrium.

Figure 106
Conceptual Delta Formation under Low and High Flow Conditions



It is important to remember that Grand Lake is under operational control of USACE when the water level approaches or exceeds elevation 745 feet PD and that under these conditions, which only occur 19.8% of the time, delivers 75.6% of the incoming sediment load to the reservoir. Neither the upstream sediment load nor operational control of Grand Lake is controlled by GRDA at that time.

5 Sediment Transport Model Development

Following the data-gathering phase of the project, the team developed the STM. Terrain files, USGS gaging station records, sediment transport rates, and sediment sampling information were used as inputs for the model.

The STM was developed using HEC-RAS v. 6.2 as available from USACE. The software is one of the leading fluvial system modeling packages and is frequently used for flood evaluations, hydrologic and hydraulic studies, and sediment transport estimates. The original version of the STM as submitted in December 2021 was built in HEC-RAS v. 5.0.7. This decision to use the newer software was made to take advantage of more robust sediment transport code that was included with the software updates.

The STM directly models the system above RM 100 as requested in FERC's May 27, 2022 SMD (page B-6). This modification to the original plan allows more accurate modeling of sediment deposition patterns by focusing primarily on the non-cohesive portion of sediment loading (and cohesive sedimentation not defined by density currents) and its impacts on water levels, which HEC-RAS was developed to evaluate. HEC-RAS is less well-suited to model the cohesive sediment that is found lower in the reservoir.

As discussed in the USP and subsequent SMD, the results of the STM were exported to a one-dimensional (1D) UHM for hydraulic evaluation. The 1D UHM was based on the STM and was developed in HEC-RAS v. 6.2 to maintain consistency with the STM. The 1D UHM is distinct from the STM and was run in fully unsteady hydraulic-only mode. More detailed discussion of this model is included in Section 7.4 of this report.

5.1 Terrain Information

Terrain files were developed to provide input geometries for the STM. These files were compilations from a range of surveys performed between approximately 1940 and 2019. A full description of the available datasets can be found in Section 2.1.1 of this report. All elevations are reported in reference to the PD unless otherwise noted.

5.1.1 Circa-1940 Terrain

The circa-1940 terrain was built from digitized 1938 USACE topographic maps and surveyed channel information from 1941 and 1942. Topographic maps were georeferenced using Geographic Information System (GIS) software and contour lines were traced and assigned elevations.

These topographic data came from several sets of contour maps. One was a relatively high-resolution set of 1:10,000 maps with labeled contours. Another was a 1:31,680 maps that did not contain legible contours. Where the 1:10,000 maps were available, they were used to develop the topographic surface; the 1:31,680 maps were only used where the others could not be used (Figure 107).

Figure 107
Graphic Showing Map Coverage of the Study Area

Publish Date: 2022/08/05, 9:38 AM | User: epipkin
Filepath: Q:\Jobs\Mead_and_Hunt_2451\Sedimentation_Study_GRDA\Maps\Topography Sources.mxd

Note: The maps on white background are the 1:10,000 scale contour maps with legible, labeled contour elevations; maps with a brown background are the 1:31,680 scale with no legible contour elevation labels.
Source: USACE (1938)

Once all contours had been compiled, GIS software was used to create a three-dimensional (3D) surface, which provided a basis for the overbank portions of the system.

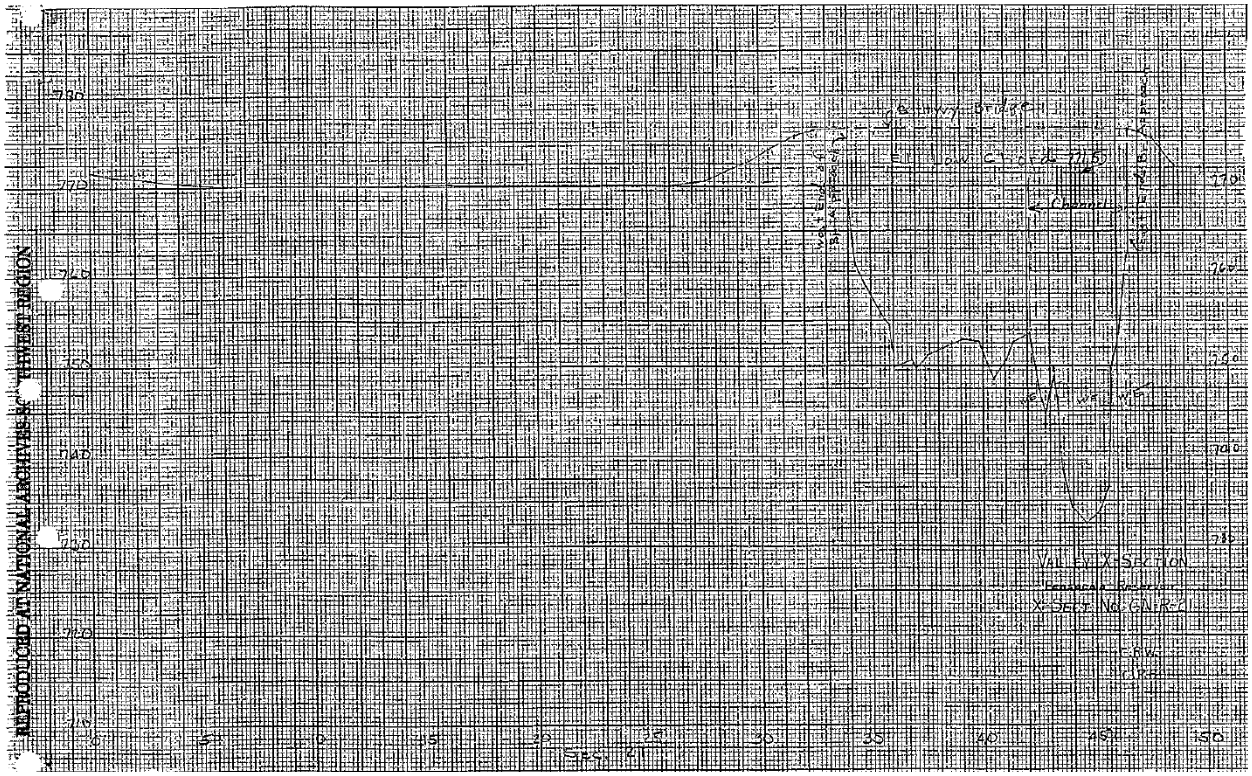
Channel surveys completed by USACE in 1941 and 1942 were then used to cut stream channels into the topography. As discussed in Section 2.1.1.1 of this report, there were no station/elevation data available for the Neosho River below the Neosho River/Spring River confluence. Instead, that data were estimated from elevation/area and elevation/width relationships.

The USACE reports mention plates that present the geographic location of surveyed cross sections, but the plates were not included in the files retrieved from USACE archives. Therefore, exact locations of surveyed cross sections were unknown. The USACE reports did include downstream reach lengths between cross sections. Given the changing stream meanders, uncertainty of circa-1940 survey measurements, and imprecise definition of reference points provided in the 1941 and 1942 USACE reports, there is uncertainty in the georeferenced location of many of these cross sections.

To address this shortcoming, known landmarks such as bridges were used to estimate the geographic location of surveyed cross sections. Between these landmarks, cross sections were placed according to documented downstream reach lengths. Linear scaling factors were applied to downstream reach lengths when the sum of documented reach lengths between landmarks did not match the physical distance between landmarks. This process was effective for portions of the Neosho River near the City of Miami where multiple, closely spaced bridges could be used as landmarks but was less effective along the Elk River where bridge locations were not documented in the circa-1940 cross-sectional surveys.

Several of the cross-section surveys included bridge geometries, which allowed for accurate placement of those cross sections. One example is shown in Figure 108, which is taken from the USACE (1942) revised envelope curve document and shows cross section GN-R-21 at the U.S. Highway 66 Bridge near Miami. Between known reference points, the distances were adjusted with a linear scaling factor to place cross sections more accurately.

Figure 108
Published Cross-Section Information for GN-R-21 Showing U.S. Highway 66 Bridge



Source: USACE (1942)

This figure is a typical image of the cross-sectional surveys and was chosen to illustrate the difficulty of using the circa-1940 survey data; it is difficult to read, horizontal scales are not explicitly stated, and hand-written notes are occasionally illegible. Regardless, this also represents the most complete dataset of site conditions at the time of Project construction.

On the Elk River, no bridges were included in the surveys (USACE 1941). Downstream reach lengths listed in the report were initially used to locate the surveyed cross sections. However, using these initial locations, the cross sections were approximately 20 feet above the topographic data. To better locate these cross sections, bank elevations were extracted from the reported surveys compared to streambank elevations in the 1938 USACE topographic maps. Correlation between surveyed cross-section bank elevations and topographic bank elevations were used to georeference the cross sections. The documented downstream reach lengths between the surveyed cross sections were maintained in the georeferenced set of cross sections to maintain the surveyed bed slope.

Once the locations of the channel cross-section surveys were defined, the channels were cut into the topographic surface along the stream thalwegs to produce a full circa-1940 terrain file. This was imported to HEC-RAS and model cross sections were cut from the terrain.

Model quality is sensitive to the quality of data available for model development. The terrain data represent one of the largest sources of uncertainty in this study. Data from circa 1940 is limited by the resolution of digital maps, lateral accuracy of original measurements, vertical accuracy of the available equipment, and legibility of contour labels on the available maps. There is also uncertainty regarding the georeferencing of the contour mapping and the exact locations of many of the surveyed cross sections, and there are no longer records available of the station-elevation data from many of the circa-1940 surveys.

These are imperfect datasets, but they also represent the *best available data for this time period*. These shortcomings in data quality were discussed in detail in both the USP submitted by GRDA in April 2022 and in Section 2.1.1 of this report. To address this, the STM was used to simulate bounding scenarios of high and low sedimentation as a means of accounting for the potential range of outcomes as discussed in Section 7.1.2 of this report.

5.1.1.1 Manning's n Values

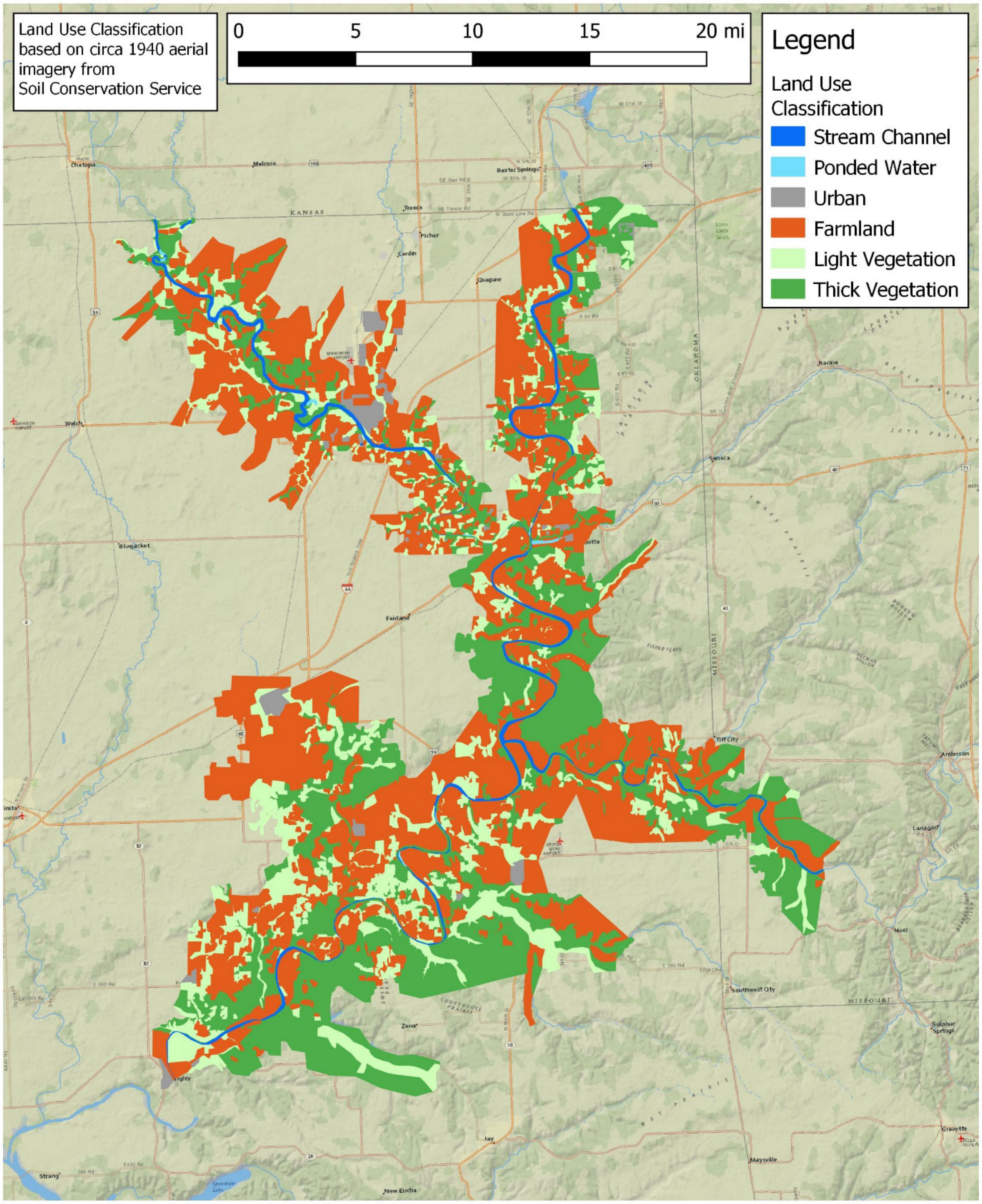
Manning's *n* values were assigned based on aerial imagery collected by the USDA (USDA 1938, 1939a, 1939b, 1940). The land use was visually identified and roughness parameters were developed according to Arcement and Schneider (1989). The parameters were assigned based on the composite roughness values shown in Table 25 and Figure 109.

Table 25
Composite Manning's *n* Values for Circa-1940 Land Use

Land Use Classification	Composite Manning's *n*
Stream Channel[1]	0.03
Ponded Water	0.04
Urban	0.07
Farmland	0.08
Light Vegetation	0.10
Thick Vegetation	0.15

Notes:
Composite values based on Arcement and Schneider (1989).
1. Stream channel roughness assigned based on typical bed channels.

Figure 109
Land Use Classifications of the Grand Lake Study Area as Determined from Circa-1940 Soil Conservation Service Aerial Imagery



5.1.2 Modern Terrain

The UHM's 2D flow areas were converted to 1D cross sections. These were cut from the relevant model terrain using built-in features of the HEC-RAS geometry editor. Cross-section stations were then filtered to limit station-elevation points at each cross section to a maximum of 500 individual values in accordance with HEC-RAS modeling requirements. Filtering was also performed using standard HEC-RAS features; data were filtered using the program's "Minimize Area Change" option.

Land use patterns were used to determine the base Manning's *n* values for the model. Where cross sections were copied from the UHM to the STM, these were left unchanged. Where 2D flow areas had been converted to 1D cross sections, river stations were used to define the Manning's *n* values to match the UHM values at those locations.

Bridge geometry information was gathered from the Oklahoma Department of Transportation, Missouri Department of Transportation, local and county road commissions, and measurements provided by GRDA. Bridge geometries in HEC-RAS typically are input as separate structures, with bridge deck geometry, support piles, and abutments entered into the program along with widths and cross sections immediately upstream and downstream of the structure.

5.2 Streams

The STM consisted of four streams: the Neosho, Spring, and Elk rivers, as well as Tar Creek.

5.2.1 Neosho River

The Neosho River was modeled from RM 152.25 to RM 99.82, approximately 22 miles upstream of Pensacola Dam (USGS gage 07190000). It was divided into three reaches with junctions at the confluence with the Spring and Elk rivers (upstream of RM 122.25 and 105.35, respectively).

5.2.2 Spring River

The Spring River was modeled from RM 21 to its confluence with the Neosho River at RM 0.

5.2.3 Elk River

The Elk River was modeled from RM 19.59 to the confluence with the Neosho River and Grand Lake at RM 0.

5.2.4 Tar Creek

Tar Creek was modeled from RM 7.6 to the confluence with the Neosho River. The downstream end of Tar Creek was modeled with normal depth, as discussed in Section 5.3. Geometry of the lateral structure was cut from the terrain and filtered to 500 data points to comply with model requirements. The STM therefore does not contain cross sections below Tar Creek RM 1.6; the rest of the creek was included in the lateral extent of Neosho River cross sections.

5.3 Boundary Conditions

Boundary conditions (BCs) define parameters at the model limits. HEC-RAS offers several options for BC types, including WSE, discharge, and normal depths. WSE and discharge can be set as a specified time series, and normal depths can be calculated based on the friction slope. For the STM, upstream BCs (at the upstream extents of the Neosho, Spring, and Elk rivers, as well as Tar Creek) were defined by USGS discharge measurements stepped at intervals ranging from 15 to 60 minutes. The downstream BC was set as normal depth with a friction slope of 0.0033 vertical feet per horizontal feet [ft/ft] (for Tar Creek) and recorded WSE at Pensacola Dam (Neosho River). WSE measurements taken at Pensacola Dam were used to set the downstream water levels in the model. These data points are provided at 1-hour intervals. These inputs were used to run the model in Quasi-Unsteady Mode.

Water temperature can also be defined in *Quasi-Unsteady* models and is an important component of STMs. Water viscosity is related to temperature, with higher temperatures producing lower viscosity values. The decreased viscosity reduces sediment transport capacity and is therefore a necessary input parameter. Because this affects sedimentation, it was included in the sensitivity analysis discussed in Section 7.4.2.2 of this document.

5.4 Sediment Data

Input data for the STM includes the sediment supply for the upstream boundary for each stream, the sediment characterizing the bed of each stream through the various reaches, and the erosion parameters defining the cohesive sediment where it is found in the river or lake beds. Data from field work was adapted to create the inputs. Specific parameters are described in the following subsections.

5.4.1 Upstream Sediment Supply

The upstream sediment supply applies the suspended sediment regression curves to develop a sediment rating curve (table of suspended sediment transport rate in tons per day with flow). This table is input into the HEC-RAS model for each stream: Neosho River, Tar Creek, Spring River, and Elk River. These tables can be seen as input files for the STM. The model then computes suspended sediment inflow at the upstream boundary of each stream for each time step of the model using the flow data for the calibration time period (1942 through 2019). The upstream sediment supply for these rivers and creek are tabulated versions of the regression equations developed in Section 4.3.

5.4.2 Bed Material

For each cross section and for each stream, a bed material size distribution was developed as input into the STM. These data are based on the particle size distributions for the bed material and core sampling analysis and can be seen as input tables of the particle size distribution for each cross section.

As previously shown (see Section 2.3.2), the bed of these streams and the reservoir consist of a wide range of sediment sizes resulting in a bi-modal distribution of sediment, one of which is fine, cohesive material (primarily silt and clay), and the other distribution being non-cohesive material (primarily gravel with some sand and finer material as well as cobble-sized material). Further complicating the bi-modal distributions, samples of primarily non-cohesive gravel exist near samples of predominantly cohesive silt and clay. In addition, samples do not show any clear longitudinal trend of sediment characteristics where an upstream sample may be fine, cohesive sediment and the next sample farther downstream may be coarse, non-cohesive sediment. This range of longitudinal distributions of sediment in close proximity complicates development of input data that describe the characteristics of the bed of these streams. The following examples demonstrate this complexity.

Figure 110 and Figure 111 show the wide range of bed material sizes along the Neosho River. Locations of the sediment samples are included in Appendix B.

Figure 110
Neosho River Sediment Size Gradation Results Comparison

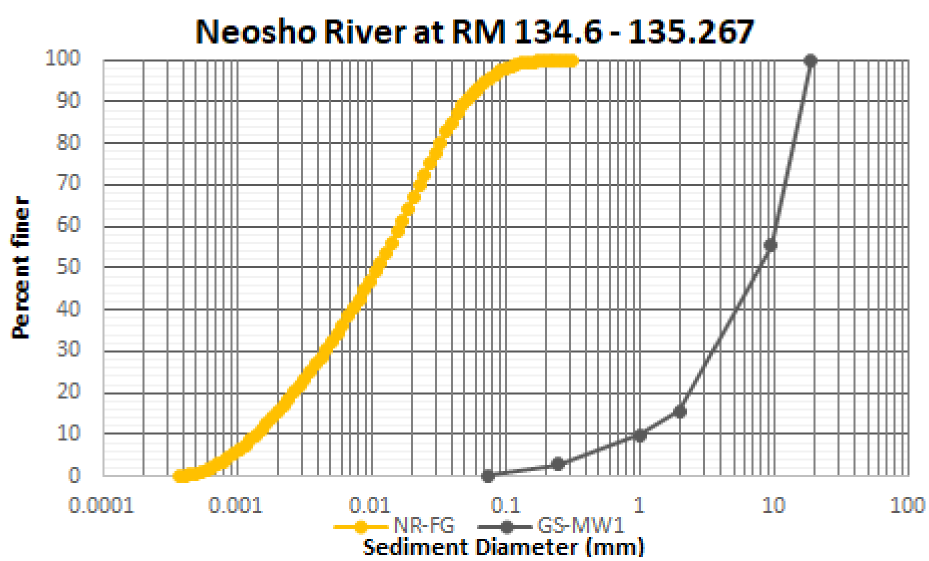
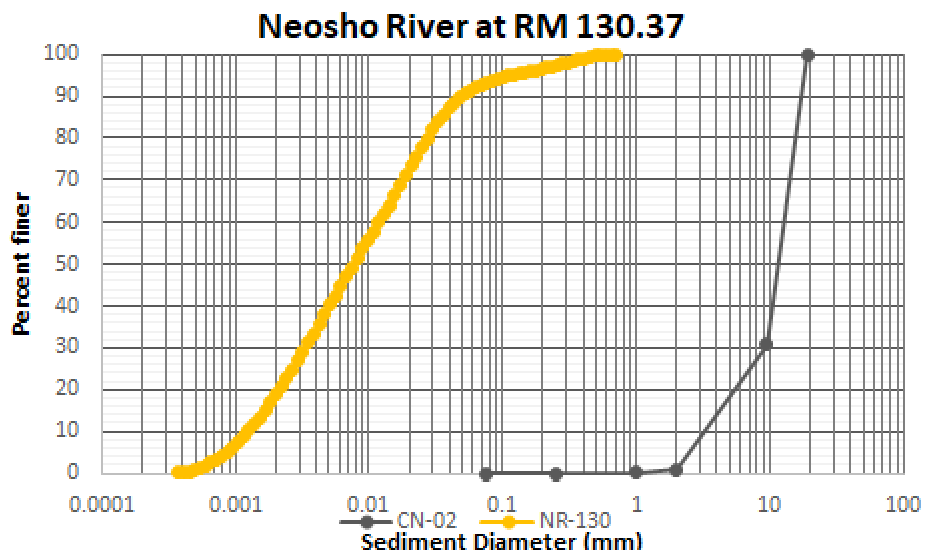


Figure 111
Neosho River Sediment Size Gradation Results Comparison



Farther downstream in the upper reservoir, this same wide range in bed material size distributions continue in close proximity to these separate samples (Figure 112 and Figure 113).

Figure 112
Upper Grand Lake Sediment Size Gradation Results Comparison

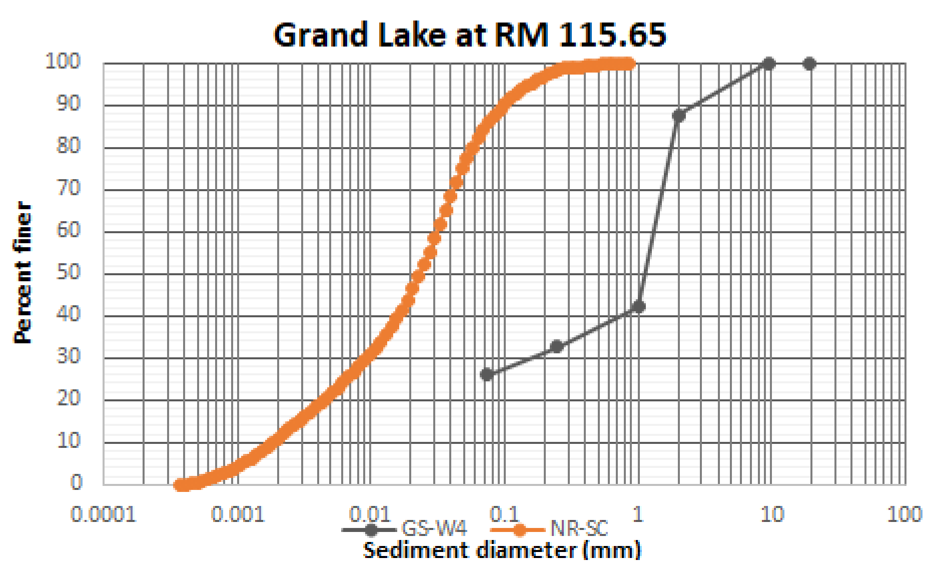
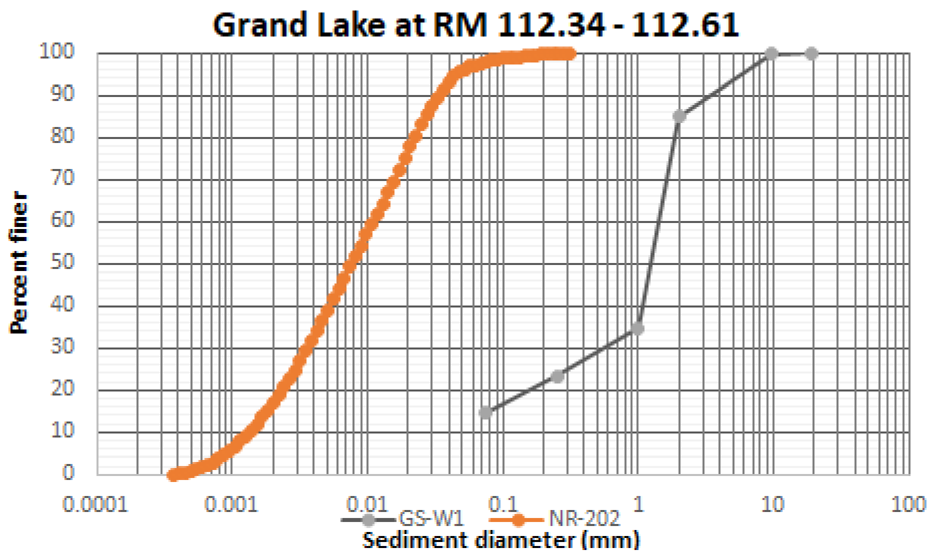


Figure 113
Upper Grand Lake Sediment Size Gradation Results Comparison



This same disparity in adjacent samples continues on the tributaries as well (Figure 114 through Figure 119).

Figure 114
Tar Creek Sediment Size Gradation Results Comparison

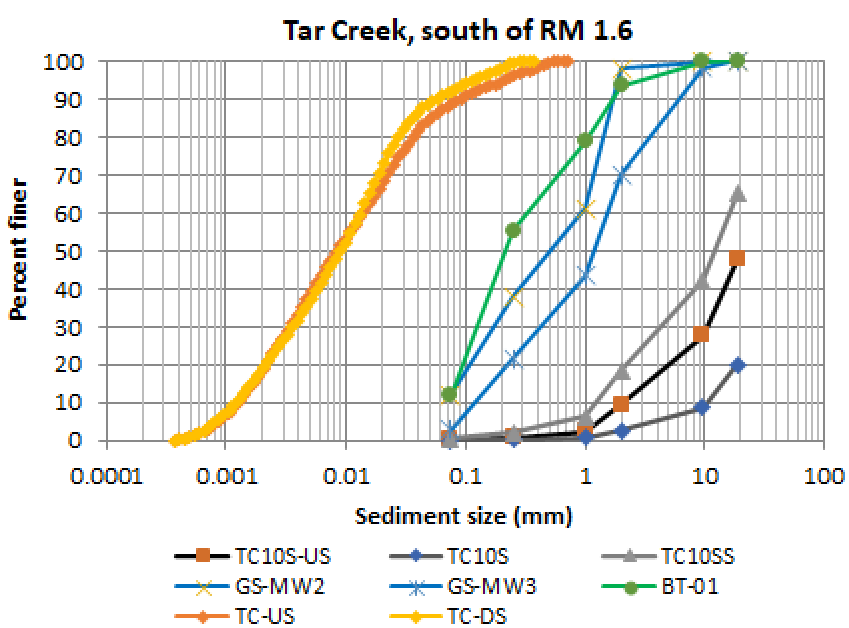


Figure 115
Spring River Sediment Size Gradation Results Comparison

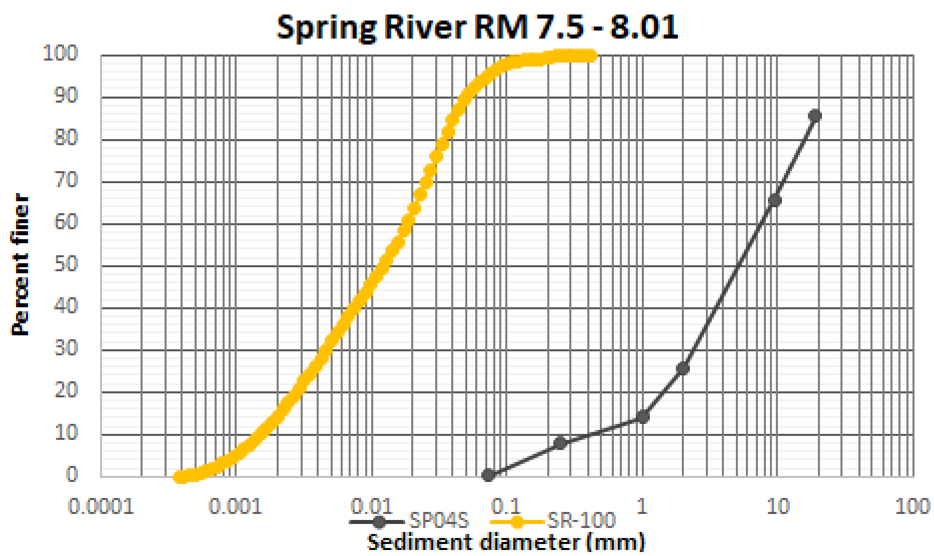


Figure 116
Spring River Sediment Size Gradation Results Comparison

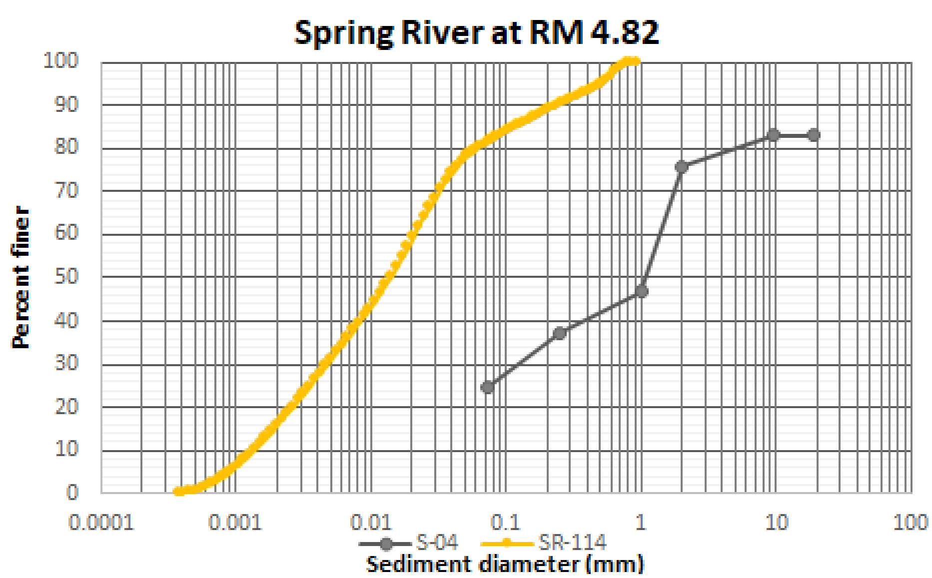


Figure 117
Spring River Sediment Size Gradation Results Comparison

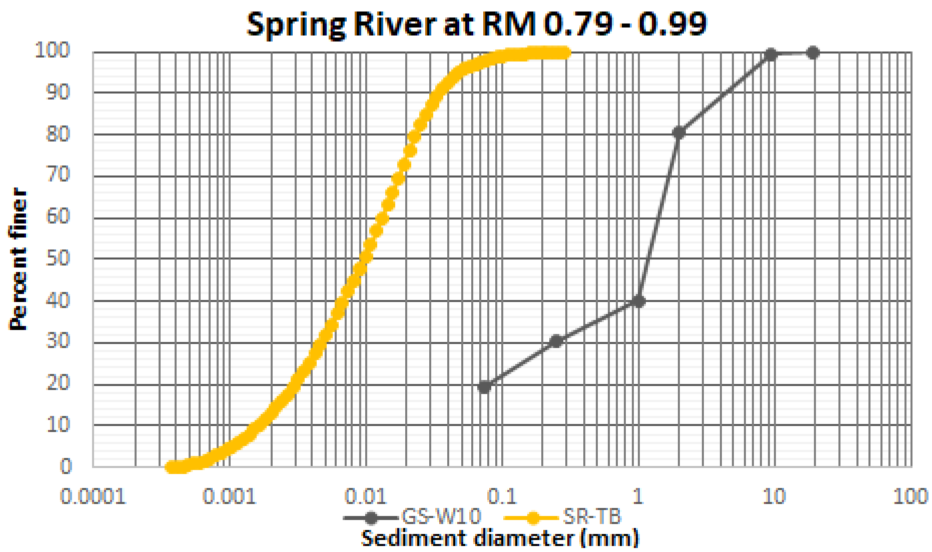


Figure 118
Elk River Sediment Size Gradation Results Comparison

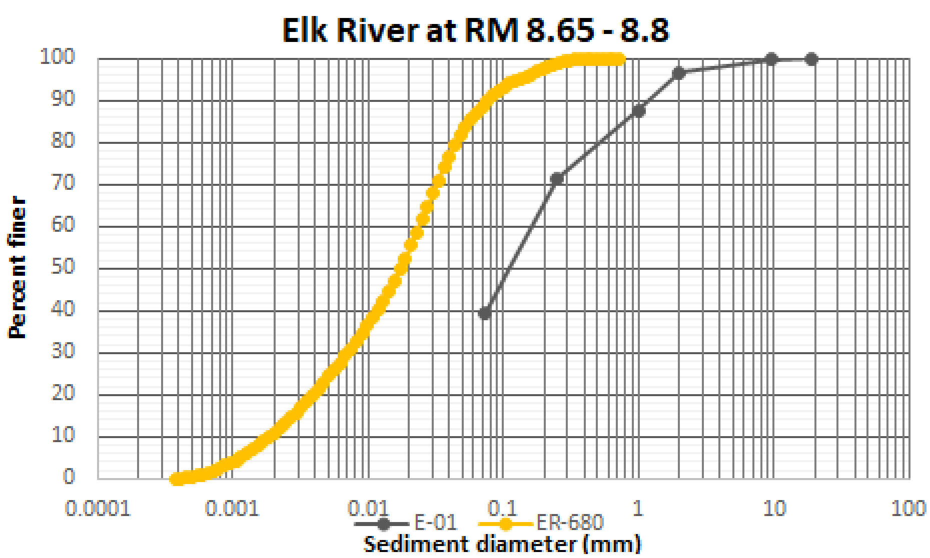
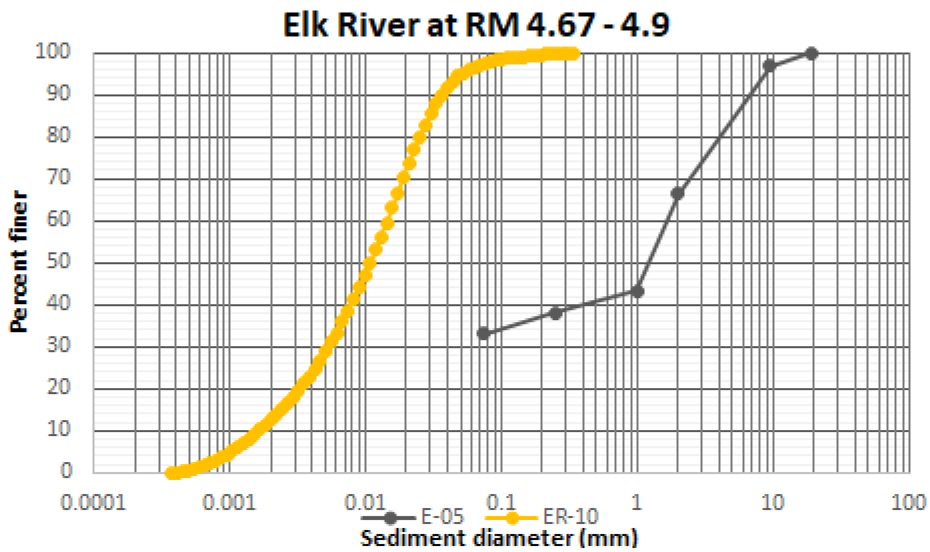


Figure 119
Elk River Sediment Size Gradation Results Comparison



The above plots show that samples taken along the Neosho, Spring, and Elk rivers, as well as Tar Creek, include both fine cohesive sediment (primarily silt and clay) near non-cohesive sediment (primarily gravel along with some finer sediment and coarser sediment). These bi-modal distributions cover six log cycles of sediment size in samples collected in relatively close proximity (but different times: December 2019 and March 2020). This wide range of sediment types and sizes is due to fine sediment being transported down river and deposited in the reservoir during certain events or seasons and then flushed farther downstream under other flow and reservoir conditions.

As discussed in Section 2.1.3.1, under some conditions, the bed consists of fine-sized sediment (silt and clay), and under other conditions, in close proximity to the fine samples, the bed consists primarily of coarser, non-cohesive sediment (gravel and sand). The data and observations indicate that the fine sediment transported down river into the upstream reaches of the reservoir as suspended load tends to deposit temporarily under some hydrologic and hydraulic conditions and then is flushed farther downstream under other hydrologic and hydraulic conditions as suggested previously by Mussetter (1998).

Tetra Tech's discussion from both the 2015 and 2016 reports, *Hydraulic Analysis to Evaluate the Impacts of the Rule Curve Change at Pensacola Dam on Neosho River Flooding in the Vicinity of Miami, Oklahoma* (Tetra Tech 2015, 2016), make comparisons between 1940, 1998, and 2015 survey data and basic hydraulic and sediment transport concepts to conclude that:

> Because the amount of sediment that can be carried by the river is controlled by the local hydraulic energy, and the required amount of energy increases with increasing particle size, the coarser-grained portion of the sediment load (i.e., sands and gravels) will typically deposit on the river bed near the head of the reservoir and the finer grained sediment will be carried progressively farther downstream into the reservoir. (Tetra Tech 2016)

And regarding the quantities of deposition:

> Based on the bank elevations, there has been approximately 15 feet of overbank deposition in the vicinity of Twin Bridges between 1940 and 2015.
>
> Comparison of the thalweg (i.e., minimum bed elevation) profiles from the 2015 bathymetry with thalweg elevations measured in 1940 indicates that the bed has aggraded by an average of about 5 feet, with over 10 feet of aggradation in some locations in the 6- to 7-mile reach upstream from Twin Bridges/U.S. Highway 60. (Tetra Tech 2016)

Although Tetra Tech presents a logical position that the coarser-grained portion of the sediment load (sands and gravels) would tend to deposit in the upper reach of the reservoir, recent collection of bedload transport data showed virtually no transport of those grain sizes in the rivers. The sediment team used equipment specifically designed to capture sands and gravels and found no evidence of coarse material transport even at the highest flows sampled in 2019 and 2020, which represents more than 90% of the recorded flow regime. It is difficult to conclude significant deposition of these sizes of sediment is occurring on the bed when no movement of such materials has been measured.

Sediment transport sampling shows that virtually all sediment transport consists of fine silts and clays, and that bed samples at a given location alternate between stationary coarse materials and more mobile fines. Therefore, it is clear the earlier observation of Mussetter and current observations of the transitory nature of fine sediment deposition are valid and most of the fine sediment load is eventually moved farther down into the reservoir without permanent or ongoing deposition in the more riverine sections of the river. These are the complexities of the sediment transport analysis, which were addressed through the data collection, analysis, and modeling process. Any previous quantification and conclusions regarding the sediment transport and deposition process must be evaluated considering these complexities, significantly increased data, and further analysis including the modeling process.

Several factors contribute to a complicated analysis and model development effort, as follows:

- Sediment sizes and types are quite different, even when collected near other samples representing entirely different sediments.
- There is a wide range in sediment density from sample to sample and depth below sediment surface.
- Non-cohesive sediments are expected to follow standard transport equations and parameters and are found in certain bed samples but not in the bulk of the incoming sediment load.
- Incoming sediment load consists primarily of fine sediment that will deposit under some conditions and exhibit a wide range of erosion and transport parameters that vary location to location and depth below sediment surface.

Further complicating the physical characteristics of the diversity of sediment types, sizes, and characteristics is the fact that the bulk of data collected to develop the sediment characteristics were collected in 2019 and 2020, whereas the model calibration period starts in 2009. If these types of data were collected in 2009, they were collected before this study began and the findings have not been available to the STM development team. As a result, although channel and reservoir geometry were surveyed in 2009, the river and lakebed sediment characteristics for 2009 are based on data collected a decade later, which may or may not represent conditions at the beginning of the calibration period. STM setup and calibration present a very complicated and challenging task.

6 Sediment Transport Model Calibration

STM calibration was performed in two components. As with any model calibration procedure, it is easiest to start with the simplest format available, ensure accuracy, then increase complexity. For the STM, that meant beginning with hydraulic calibration and neglecting sediment movement, erosion, and deposition. Once the hydraulics were well-calibrated, sediment transport was added to the STM, and the sediment model parameters were finalized.

Sediment calibration and validation simulations ran from 1942 to 2019. Results were then compared against measured data from 1998 REAS surveys, the 2009 OWRB survey, and USGS surveys performed in 2017 and 2019 as discussed in Section 6.2.2.

The overall goal of this step was to create a baseline geometry using the 2019 terrain dataset that could be used to predict future sediment transport, erosion, and deposition patterns.

6.1 Hydraulic Calibration

6.1.1 Circa-1940 Geometry

Hydraulic data for calibrating the circa-1940 model is not available in the upper reaches of the study area. WSE data are not available for the circa-1940 model, so calibration was performed by assigning Manning's *n* roughness parameters based on land use as described in Section 5.1.1.1.

6.1.2 Modern Geometry

Hydraulic calibration for the modern geometry focused on matching peak WSE records. WSE information was provided by a collection of USGS gages, WSE monitoring stations placed by the project team, and high water mark information provided by Tetra Tech.

6.1.2.1 Model Inputs

Model input parameters were developed specifically for the hydraulic calibration components. Sediment modeling was not included in this part of the calibration procedure.

6.1.2.1.1 Sediment Information

The process started with hydraulic calibration. To remove any sediment influence, an empty sediment dataset was created for the entire model domain. This dataset included an arbitrary bed gradation and set maximum erodible depths to 0 feet throughout the model. The BCs were set to clear water inflow conditions, and all cross sections were defined as pass-through nodes (meaning sediment would not deposit and instead be transported downstream).

6.1.2.1.2 Modeled Events

Hydraulic calibration involved using known parameters from USGS data. BCs were defined as described in Section 5.3 for several flow events. The modeling team selected six events for calibration; these were also used for UHM calibration procedures. The timing of specific events and peak stream discharges used for hydraulic calibration are listed in Table 26.

Table 26
Modeled Flow Events and Stream Discharges

	Peak Stream Discharge (cfs)			
Event Date	Elk River at Highway 43	Neosho River at East 60th Road	Tar Creek at East 50th Road	Spring River at East 57th Road
July 2007	4,830	141,000	2,490	105,000
October 2009	39,300	46,100	5,150	66,200
December 2015	107,000	45,400	3,320	151,000
January 2017	1,140	10,200	672	15,900
April 2017	107,000	58,200	2,980	114,000
May 2019	66,500	91,400	6,410	109,000

The downstream WSE at Pensacola Dam was defined by USGS gage records, and the downstream BC for Tar Creek at its confluence with the Neosho River was set at normal depth with a friction slope of 0.0033 ft/ft.

6.1.2.2 Roughness Parameters

Calibration of hydraulic models in HEC-RAS relies primarily on hydraulic roughness parameters. These are typically reported as Manning's *n* values and are usually defined within a set range by land cover type (Table 27). The STM values were based on UHM roughness parameters throughout the model domain. Generally, higher *n* values produce slower flows and raise WSE, whereas lower *n* values decrease WSE.

Table 27
Typical Overland Manning's *n* Values by Land Cover

Land Cover	*n* Value
Field crops	0.040
Pasture	0.080
Urban	0.070
Urban, dense	0.090
Water	0.040

Land Cover	*n* Value
Woody vegetation	0.100
Woody vegetation, dense	0.150

In-channel Manning's *n* values were adjusted iteratively until simulated WSE results showed reasonable agreement with recorded measurements. Table 28 lists in-channel roughness values developed during the calibration process.

Table 28
Base Manning's *n* Roughness Parameters for Streams in the Sediment Transport Model

Reach	*n* Value
Grand Lake (reservoir, up to RM 121.29)	0.020
Neosho River (RM 121.51 up to RM 122.33)	0.025
Neosho River (RM 122.46 up to RM 130.87)	0.024
Neosho River (RM 131.01 up to RM 133.99)	0.035
Neosho River (RM 134.09 up to RM 135.37)	0.015
Neosho River (RM 135.46 up to RM 152.2)	0.030
Elk River	0.015–0.053
Spring River (full reach)	0.0332
Tar Creek	0.027–0.100

These base roughness values were then modified based on changes in stream discharge values. River bedforms have a significant influence on hydraulic roughness. As stated by Mussetter (1998), the bedforms are affected by flow volumes, generating different bed roughness values as a function of total discharge. In HEC-RAS, "Flow Roughness Factors" were used to tune the model to account for changes in bed roughness at higher or lower flow rates. These parameters are shown in Table 29 and Table 30.

Table 29
Flow Roughness Parameters for Elk and Spring Rivers and Tar Creek in the Sediment Transport Model

Elk River		Spring River		Tar Creek	
Discharge (cfs)	Flow Roughness	Discharge (cfs)	Flow Roughness	Discharge (cfs)	Flow Roughness
0	1.30	0	0.90	0	0.80
40,000	1.25	50,000	1.00	4,600	0.95
66,500	0.85	110,000	1.00	4,700	0.90

Elk River		Spring River		Tar Creek	
Discharge (cfs)	**Flow Roughness**	**Discharge (cfs)**	**Flow Roughness**	**Discharge (cfs)**	**Flow Roughness**
75,000	0.80	120,000	1.20	4,800	1.00
105,000	0.80	151,000	1.20	5,500	1.00
110,000	1.00	152,000	1.00	6,400	0.90
				6,500	1.00

Table 30
Flow Roughness Parameters for the Neosho River in the Sediment Transport Model

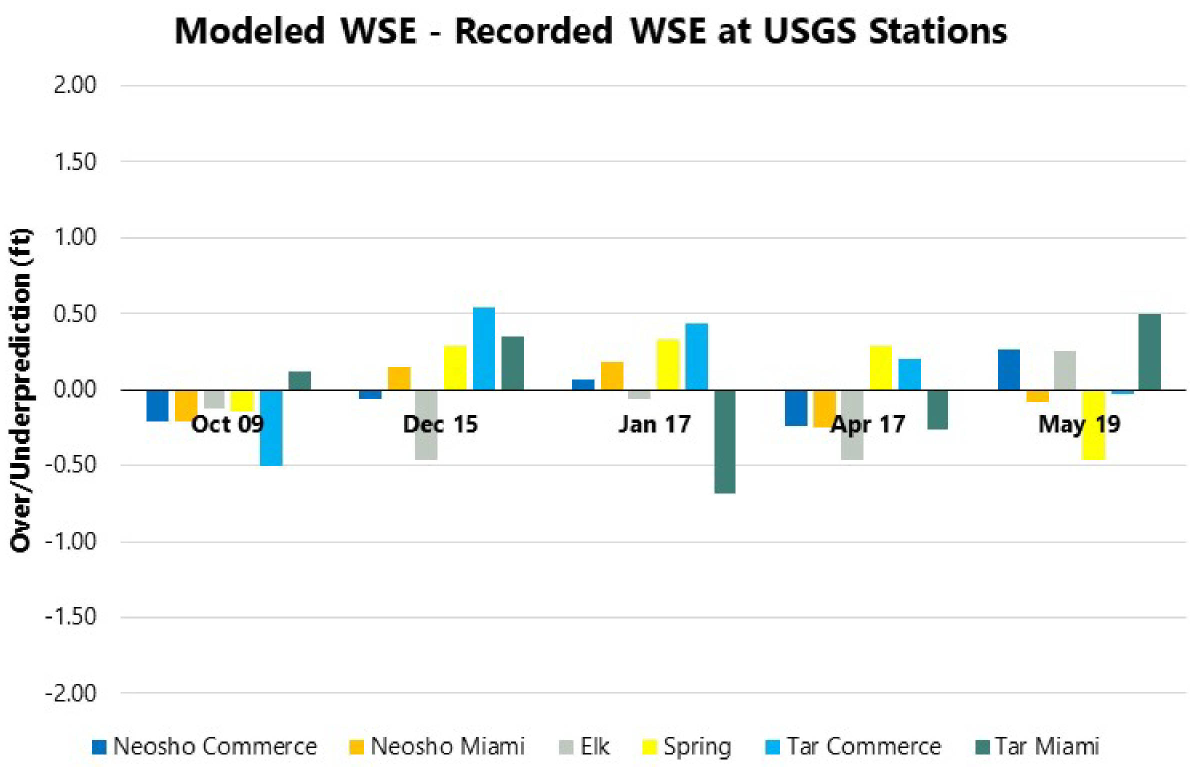
RM 130.54–135.267		RM 135.37–152.25	
Discharge (cfs)	**Flow Roughness**	**Discharge (cfs)**	**Flow Roughness**
0	0.80	0	0.80
45,000	0.80	45,000	1.10
60,000	1.30	60,000	1.20
65,000	1.30	91,000	1.10
91,000	1.30	92,000	1.00
92,000	1.00		

6.1.2.3 Results

Model calibration results showed good agreement with measured WSEs, as discussed herein.

Model calibration results as compared to USGS gages are shown in Figure 120. The average difference between simulated maximum WSE and measured maximum USGS gage WSEs is 0.06 foot; the model slightly overpredicts WSE at the USGS gages for the calibration events.

Figure 120
Overprediction and Underprediction of Simulated WSE at USGS Gages



STM calibration results were also compared to high water marks as compiled by Tetra Tech (2016). Model results from the July 2007, October 2009, and December 2015 calibration run are shown in Figure 121 through Figure 123. Average model difference is 0.29 feet for July 2007, -0.59 feet for October 2009, and -0.66 feet for December 2015; the model overpredicted WSEs during the July 2007 event and underpredicted for the October 2009 and December 2015 events when compared to measured high water marks.

Quasi-unsteady modeling presents difficulties when evaluating WSE measurements downstream of tributaries. WSE is heavily influenced by the arrival times of peak flow pulses from contributing streams. Because quasi-unsteady models change the relative arrival times downstream of confluences, it is difficult to accurately model maximum WSE at those locations. For STMs, it is impractical to model with fully unsteady flows; for WSE evaluations, the UHM is a more fitting tool.

Figure 121
Comparison of STM WSE Results and Measured High Water Marks during the July 2007 Event

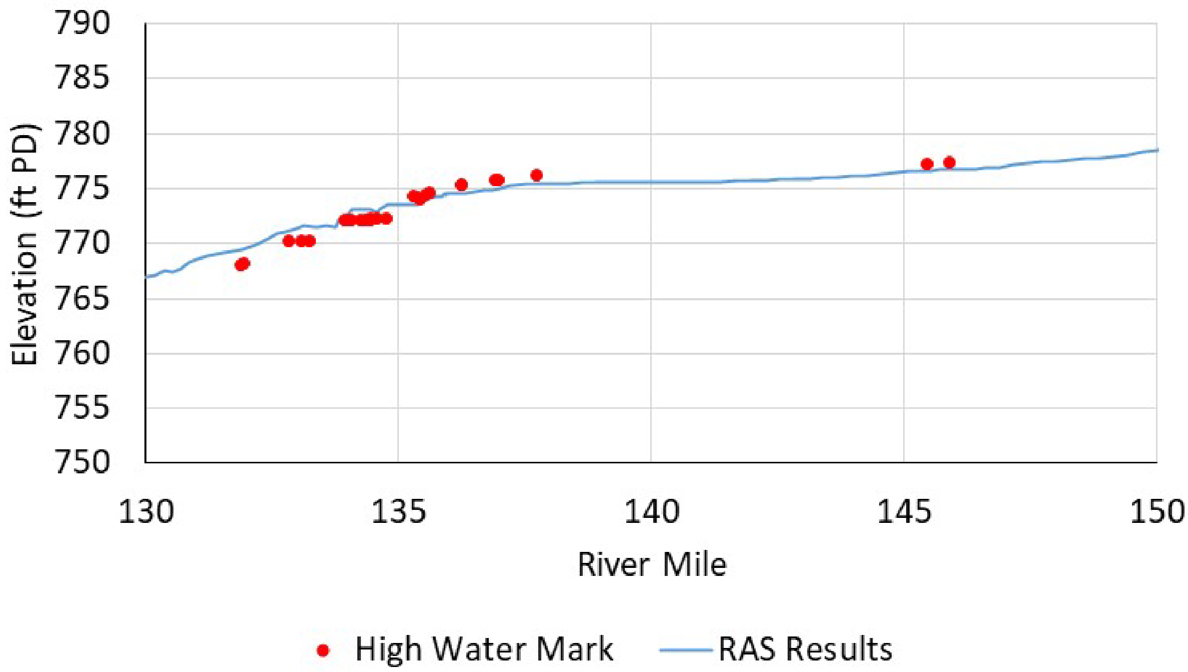


Figure 122
Comparison of STM WSE Results and Measured High Water Marks during the October 2009 Event

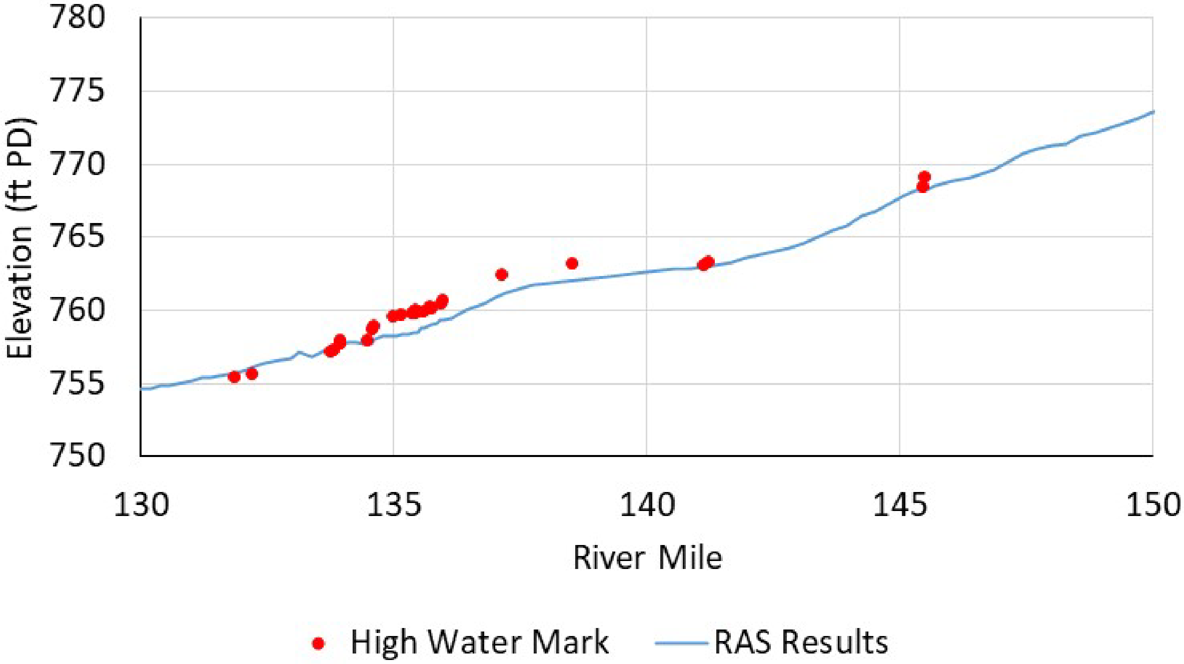
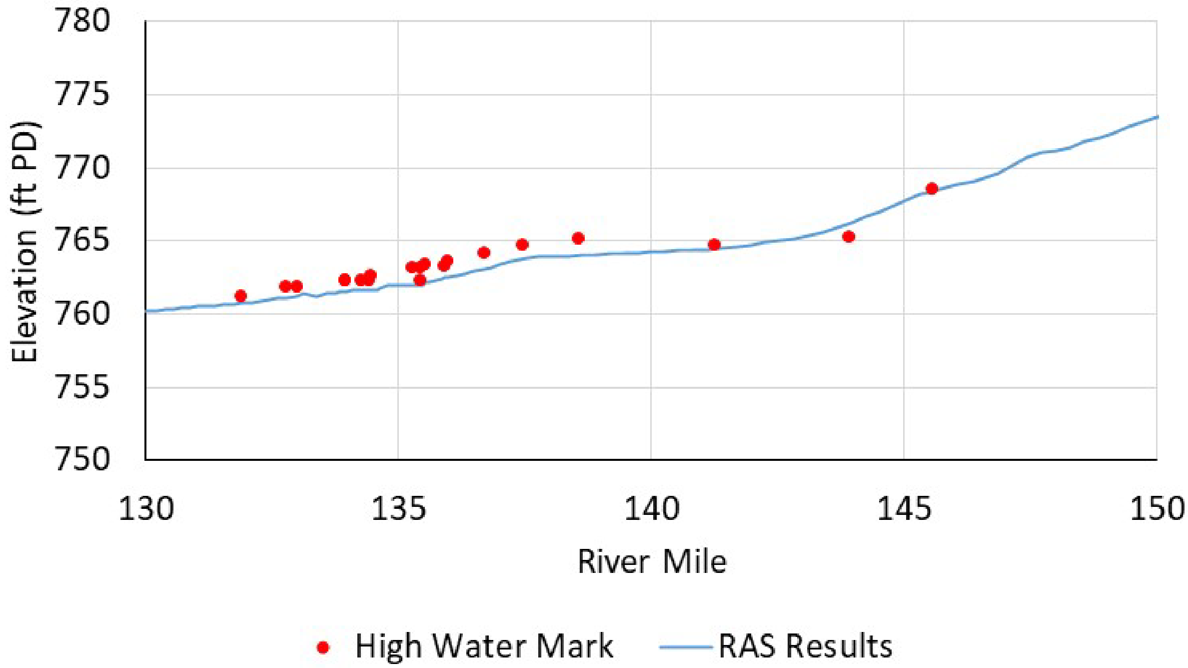
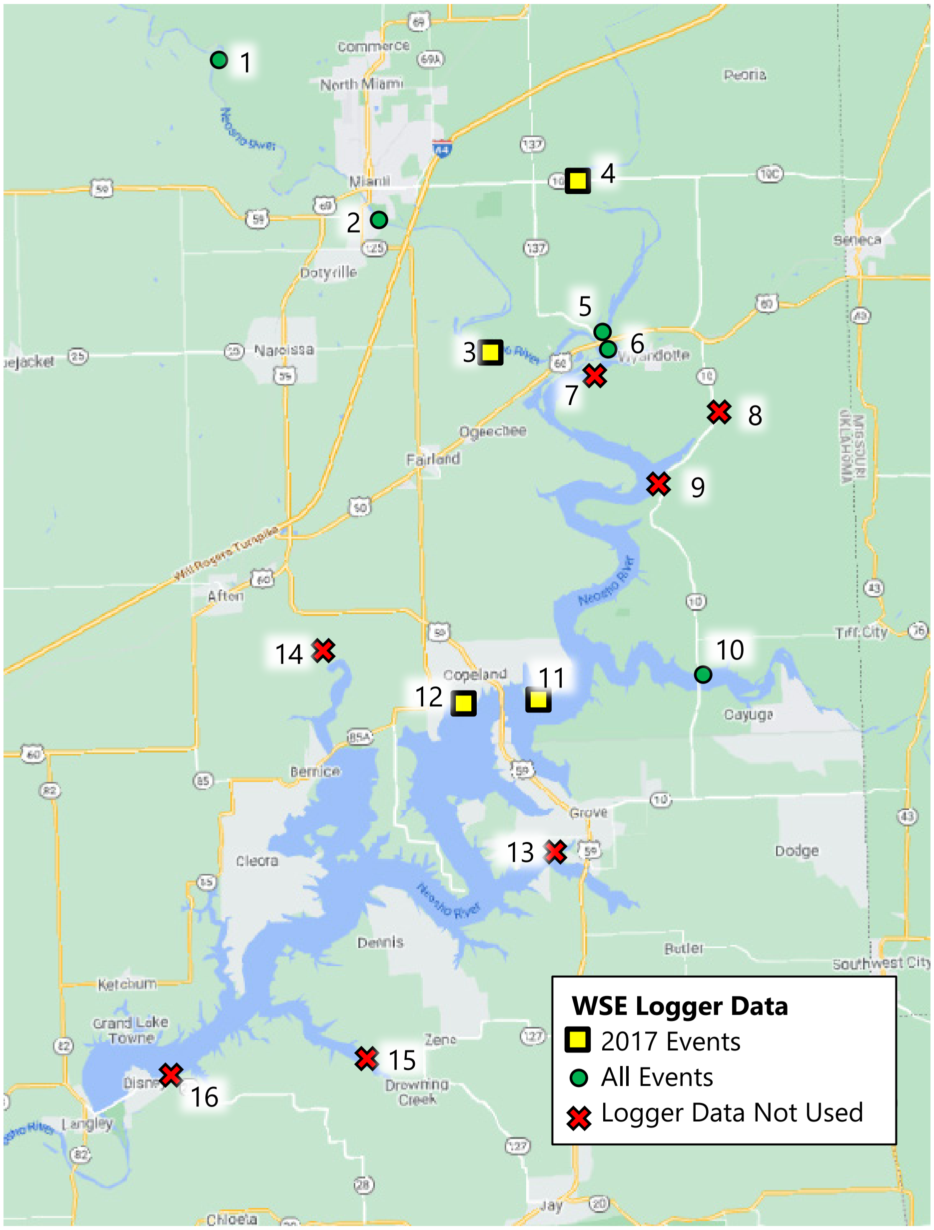


Figure 123
Comparison of STM WSE Results and Measured High Water Marks during the December 2015 Event



A third source of calibration WSEs was the field monitoring data collected during the study. The WSE loggers were in place for three of the calibration events: January 2017, April 2017, and May 2019. Not all logger locations have data for a given event; some were washed away or vandalized when attempts were made to retrieve data. Logger 9 was missing for both events, and data from loggers 7 and 8 were not included in calibration because they were located in areas where incoming, ungaged streams affected WSE reporting. These were initially placed before model parameters had been fully defined. Loggers 13, 14, 15, and 16 were located downstream of model extents. Figure 124 shows the location of loggers used in the calibration process.

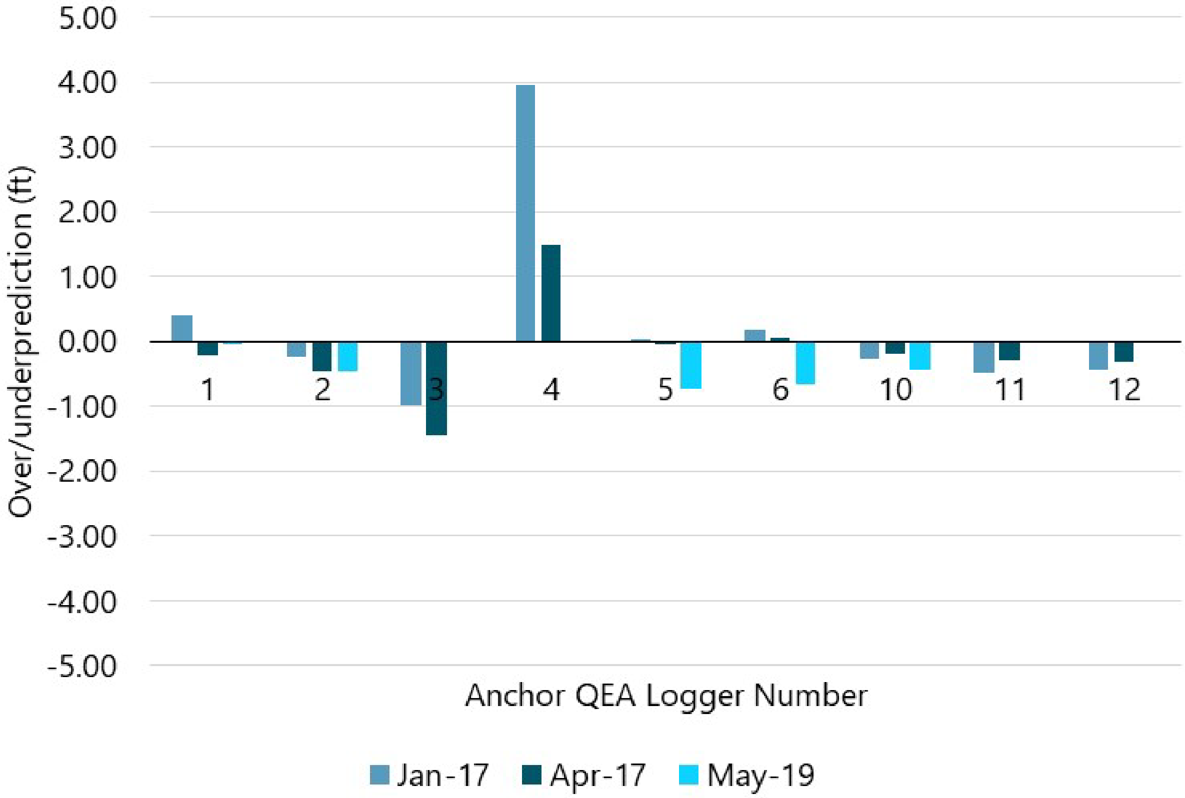
Figure 124
Locations of Anchor QEA Loggers



Note: Data from loggers 7, 8, 9, 13, 14, 15, and 16 were not used in the analysis as discussed above.

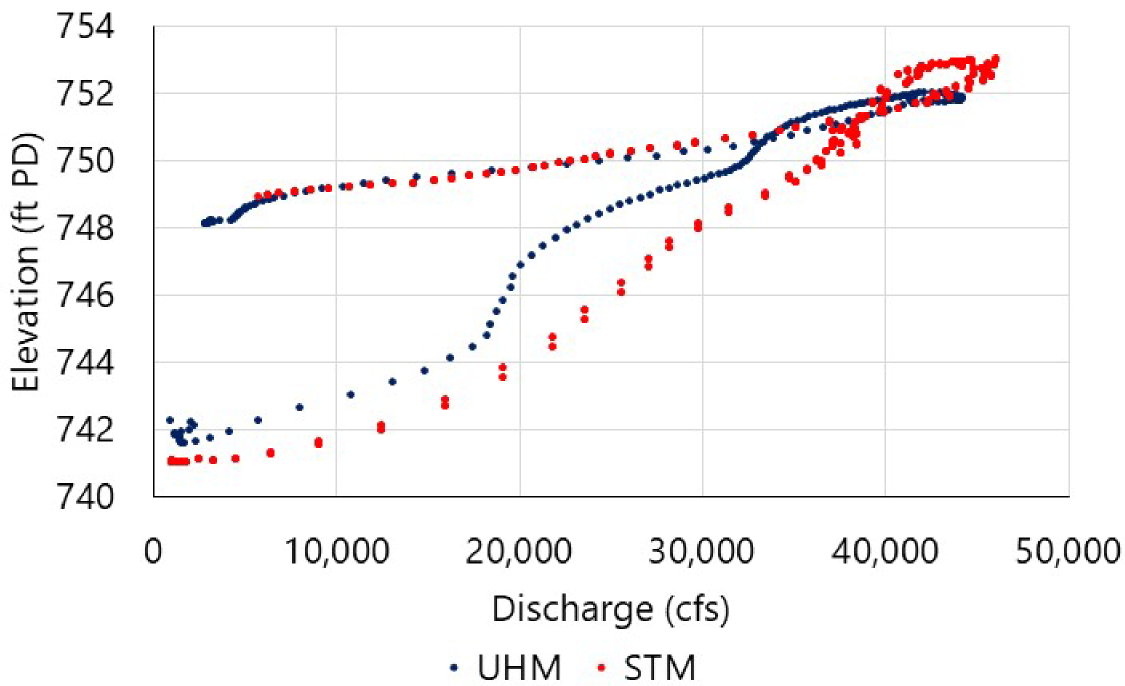
Figure 125 shows the overprediction and underprediction of peak WSE at the logger locations for those loggers used as calibration points. During the January 2017 event, the model averaged an overprediction of WSE by 0.23 foot. During the April 2017 event, the model averaged an underprediction of 0.15 foot. For the May 2019 event, the model averaged an underprediction of 0.47 foot.

Figure 125
Comparison of STM WSE Results and Measured Values from Anchor QEA Loggers



The STM hydraulic results were also compared to UHM simulations. The comparisons shown in the WEST ITR (2022) indicated significant differences between the models. By using the HEC-RAS bridge routines instead of lidded cross sections, the STM showed improved agreement with the UHM as presented in Figure 126 and Figure 127.

Figure 126
Neosho River WSE at RM 122.75, Upstream of Highway 60 near Twin Bridges State Park with STM Bridge Routines



Similar results were found at RM 122, which is between the Highway 60 and Burlington Northern railroad bridges.

Figure 127
Neosho River WSE at RM 122, Between US-60 and Burlington Northern Railroad Bridges near Twin Bridges State Park with STM Bridge Routines

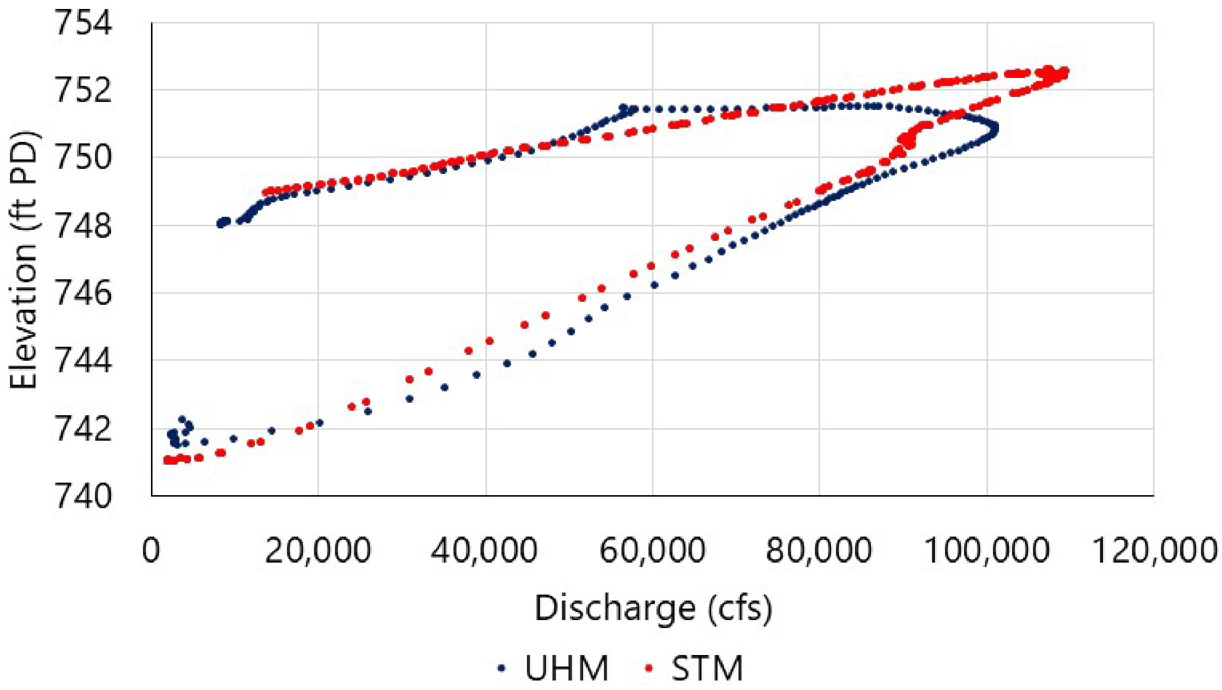


Figure 128 shows the Burlington Northern Railroad bridge and embankment backing up high flows in May 2019.

Figure 128
Burlington Northern Railroad Bridge and Embankment Viewed from Twin Bridges Boat Launch in May 2019

Source: GRDA, May 2019

6.2 Sediment Calibration

6.2.1 Model Inputs

6.2.1.1 Hydraulic Parameters

Sediment transport calibration was performed between 1942 and 2019. This was a function of available hydraulic information; continuous USGS (2021g) reservoir storage records at Pensacola Dam date to October 1942. The original WSE data are unavailable, but the USGS provided the historical stage-storage curves and dates of use (Strong 2022). Storage volumes were converted to elevations with those curves and used to set downstream WSEs in the calibration runs.

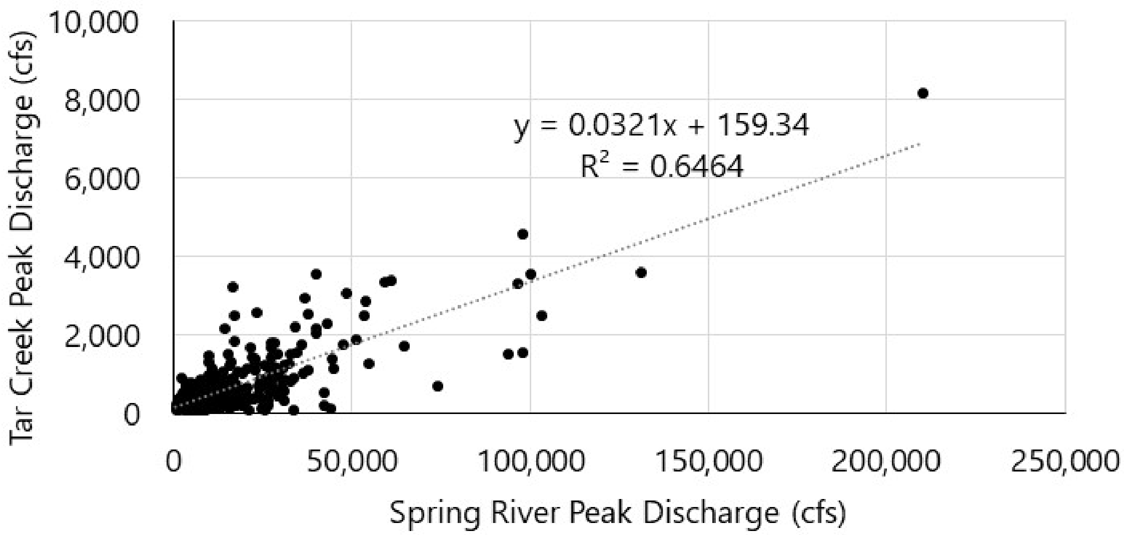
Historical flow data available from USGS gages (USGS 2021a, 2021b, 2021f) provided inflow volumes dating back to 1940 on the Neosho, Elk, and Spring rivers. Inflow volumes were recorded from 1984 to 1990 and 2004 to present on Tar Creek (USGS 2021e).

Due to the lack of available data for Tar Creek from 1940 to 1984, a synthetic hydrograph was generated using the Spring River as a reference hydrograph. The available flow data for Tar Creek (1984 to 2022) were compared to the same date range for Spring River. Spring River was chosen based on similarities in location and geographical extent of the watershed, despite the fact that Spring River is a significantly larger system than Tar Creek.

Linear regression comparing all peak daily discharges of Spring River and Tar Creek for the available data record resulted in a relatively poor correlation (R^2 = 0.29). Visual comparison of typical event hydrographs showed Tar Creek to recede more quickly to baseflow after precipitation events as would be expected of a smaller watershed. To account for this, relative peaks in the daily discharge were used for the comparison between the two watersheds. Relative peaks above the 10% daily exceedance flow for Tar Creek (110 cfs) were identified using Hydrologic Engineering Center Statistical Software Package (HEC-SSP) data filtering. The timing of Tar Creek peaks was compared to relative peaks of the Spring River daily discharge data and found that a Spring River daily discharge peak occurred within ±2 days of the Tar Creek peak discharge for 87% of the events. The linear relationship between these two peaks was much higher than when using all flows (R^2 = 0.65, Figure 129), and this linear relationship was used to determine Tar Creek peak flows during the missing period of record (1940 to 1984).

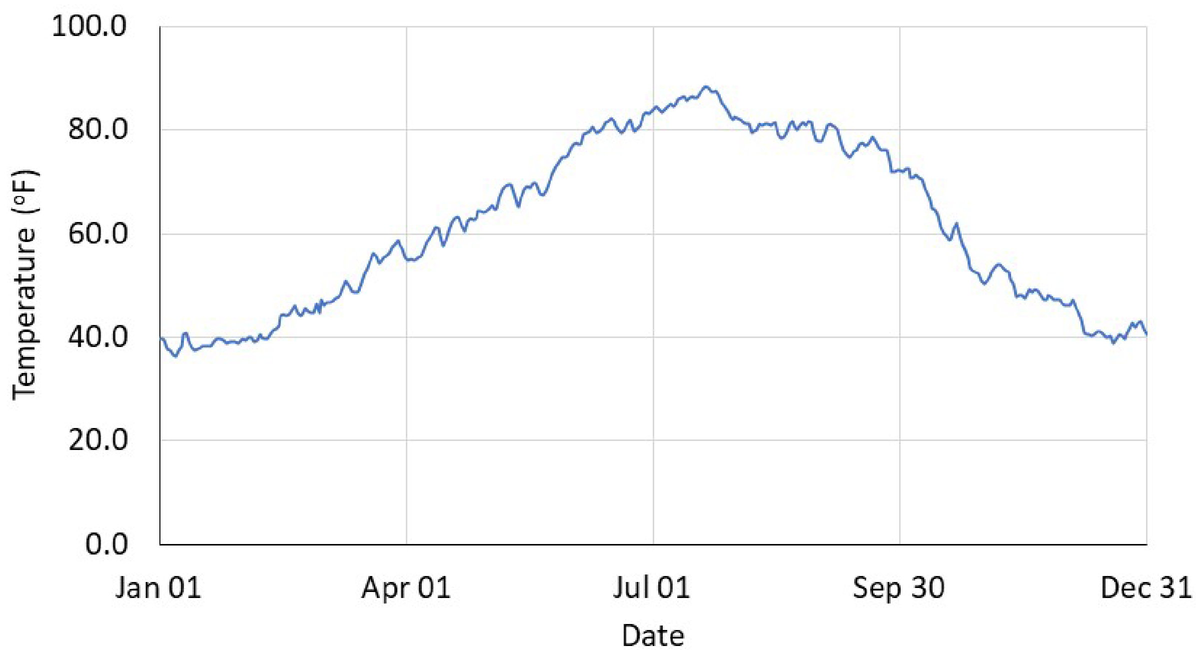
The majority of Tar Creek peak flows occurred 1 day before the peak flow of Spring River, and therefore the estimated peaks for Tar Creek throughout the missing period of record were assumed to occur 1 day before the Spring River peaks of that same time period. Based on visual examination, Tar Creek event hydrographs typically rose to the peak in a single day and then receded to pre-event levels in 2 to 3 days. Therefore, in the synthetic hydrograph for Tar Creek, event discharges were reduced to 50% of the peak for the following day, and to 25% of the peak the second day following the event. For all other daily flows in the synthetic hydrograph, the daily percent exceedance flow of Spring River was matched to the daily percent exceedance flow of Tar Creek to develop the background flow data. The same relationship was used to fill the data gap in Tar Creek daily discharge between 1994 and 2004.

Figure 129
Comparison of Tar Creek and Spring Creek Peak Events Over the 10% Daily Exceedance Flow (1984–2022)



Another important part of the hydraulic inputs for STMs is the water temperature in the system. These data were derived from water level logger measurements collected from December 2016. Daily average temperatures of the Neosho River from East 60th Road were used as an approximation of temperatures throughout the year and applied for the period of evaluation (Figure 130).

Figure 130
Temperature Time Series for 1 Year of STM Simulation



Note: Temperature data were repeated for each year throughout the duration of each simulation

6.2.1.2 Sediment Parameters

6.2.1.2.1 Bed Sediment

There are no known sediment data from pre-Project conditions in the modeled tributaries. Sediment properties were therefore assumed to have been similar to present-day sediment at the upstream extents of the reaches. Sediment grab samples collected during this study were used to define starting bed sediments as shown in Table 31 and their locations are highlighted in Figure 131.

Mobile bed limits were set to bank stations with a maximum erodible depth of 5 feet, and the Rubey falling velocity was used.

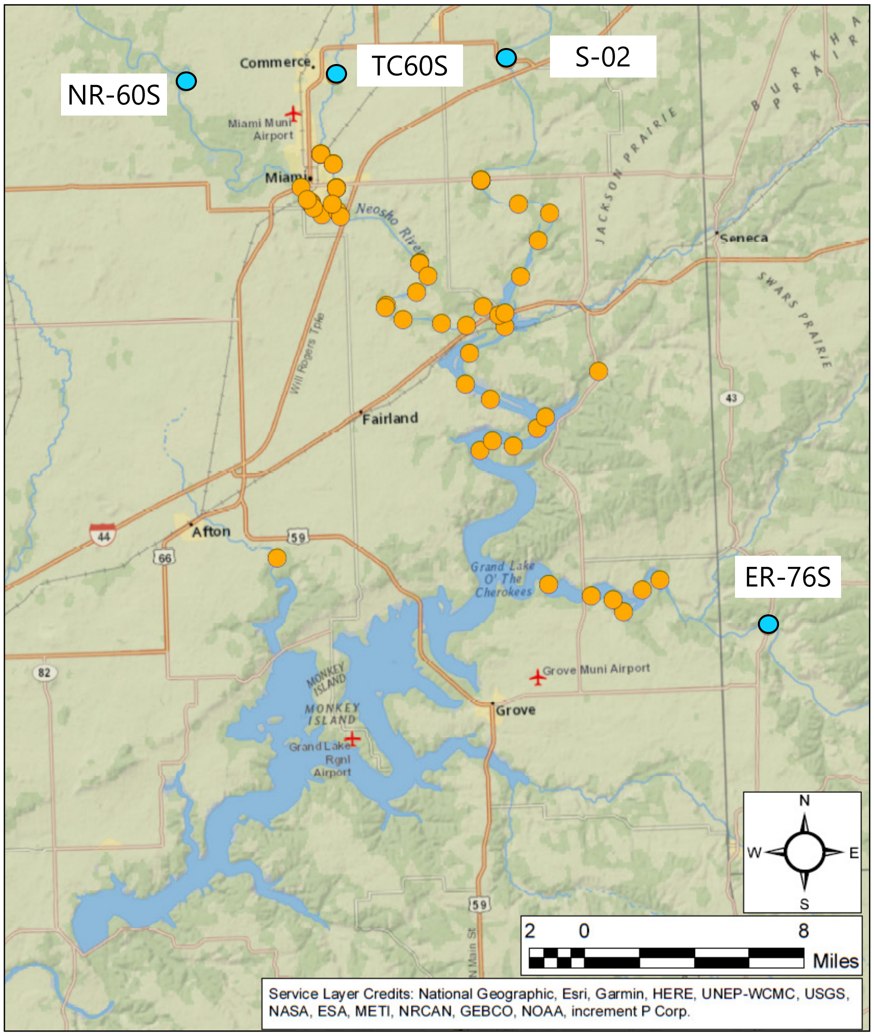
Table 31
Sediment Samples Used to Define Circa-1940 Bed Material

Stream	Sample	Cohesive Sediment Parameters			
Stream	Sample	Critical Shear Stress (lb/ft^2)	Erosion Rate, M (lb/ft^2/hr)	Critical Mass Wasting Shear Stress (lb/ft^2)	Mass Wasting Erosion Rate, M_{MW} (lb/ft^2/hr)
Neosho River	NR-60S	0.008352	0.00062	0.066816	0.08700
Spring River	S-02	0.002297	0.05053	0.066816	34.75437
Elk River	ER-76S	0.002506	0.06772	0.066816	9.04153
Tar Creek	TC60S	0.003550	0.03483	0.006816	22.70010

Note:
Detailed sediment information is included in Appendix B of this report.

The cohesive parameters of the samples were also used for model development and played an important role in determining the erosive characteristics of the bed sediments. HEC-RAS uses the Krone-Partheniades relationship to parameterize the sediments (USACE 2016). The SEDflume (Integral Consulting 2020) results informed selection of the parameters presented in Table 31.

Figure 131
Location of Sediment Grab Sampling Efforts within the Grand Lake Watershed



Notes:
Samples shown in teal (NR-60S, TC60S, S-02, and ER-76S) mark the most upstream locations of grab samples collected during this phase of the study. They were used to define circa-1940 bed conditions.
Samples shown in orange were used to define the bed conditions for future-looking sediment simulation runs.

6.2.1.2.2 Sediment Inflows

Sediment inflow information is sparse during the period of record as discussed in Section 2.1.3.2. The data were supplemented with measurements collected during this study (see Section 2.2.4).

The sediment inflow rating curves were developed from USGS measurements and supplemented with those discussed in Section 2.2.4. The Sediment Rating Curve Analysis Tool in HEC-RAS v. 6.2 was used to develop sediment rating curves for upstream boundaries of the model. This tool downloads

SSC information from user-selected USGS gages and allows importation of user data to create rating curves.

Sediment rating curves are often presented in the form of Equation 4.

Equation 4

$$Q_{ss} = aQ^b$$

where:

Q_{ss}	=	sediment load
a and b	=	constants
Q	=	stream discharge

When fitting this power function, most systems use the Least Mean Squares Error method, introducing implicit bias and resulting in an underprediction of incoming sediment loads. It is important to correct this bias when developing sediment rating curves for models. A more detailed discussion of this issue is presented in the HEC-RAS User's Manual (USACE 2016).

The Sediment Rating Curve Analysis Tool has built-in methods to remove that bias and present a more accurate sediment rating curve as explained in Section 1 of this report.

The rating curves shown in Table 32 were selected for this study.

Table 32
Sediment Rating Curves for STM Inflow Boundaries

Stream	Equation
Neosho River	$2.6039 \cdot 10^{-2} Q^{1.5089387}$
Spring River	$8.239 \cdot 10^{-3} Q^{1.5043}$
Elk River	$1.4031 \cdot 10^{-3} Q^{1.895494}$
Tar Creek	$3.117756 \cdot 10^{-1} Q^{1.143393}$

Note:
Rating curve equations were developed from a combination of data collected as part of this study and USGS gaging station information. Equations were then developed using the Duan method (Duan 1983) in the HEC-RAS Sediment Rating Curve Analysis Tool.

The sediment gradation data were taken from the measurements performed as part of this study. The information in Table 33 shows the distribution of grain sizes selected for incoming flow data.

Table 33
Grain Size Distributions of the Incoming Sediment Load

Stream	% Clay (< 0.004 mm)	% Very Fine Silt (0.004–0.008 mm)	% Fine Silt (0.008–0.016 mm)	% Medium Silt (0.016–0.032 mm)	% Coarse Silt (0.032–0.0625 mm)	% Very Fine Sand (0.0625–0.125 mm)
Neosho River	50	11	12	12	13	2
Spring River	40	10	11	15	20	4
Elk River	50	10	11	11	10	8
Tar Creek	50	10	11	11	10	8

Inflowing sediment erosive parameters are shown in Table 34. This was based on evaluation of sediment in the system and was also used for calibration parameters during model development.

Table 34
Incoming Sediment Erosive Parameters

Critical Shear Stress (lb/ft^2)	Erosion Rate, M ($lb/ft^2/hr$)	Critical Mass Wasting Shear Stress (lb/ft^2)	Mass Wasting Erosion Rate, M_{MW} ($lb/ft^2/hr$)
0.002506	0.06772	0.066816	9.04153

6.2.2 Calibration Evaluation

The primary metric used for model evaluation was sediment deposition volumes. This information was extracted from model runs by comparing the mass of sediment deposited between the start of the simulation and the next available bathymetry survey according to Figure 132 and Table 35.

Figure 132
Modeled Reaches Used for Calibration and Validation by Available Survey Data (All Starting Geometry was Based on Circa-1940 Data)

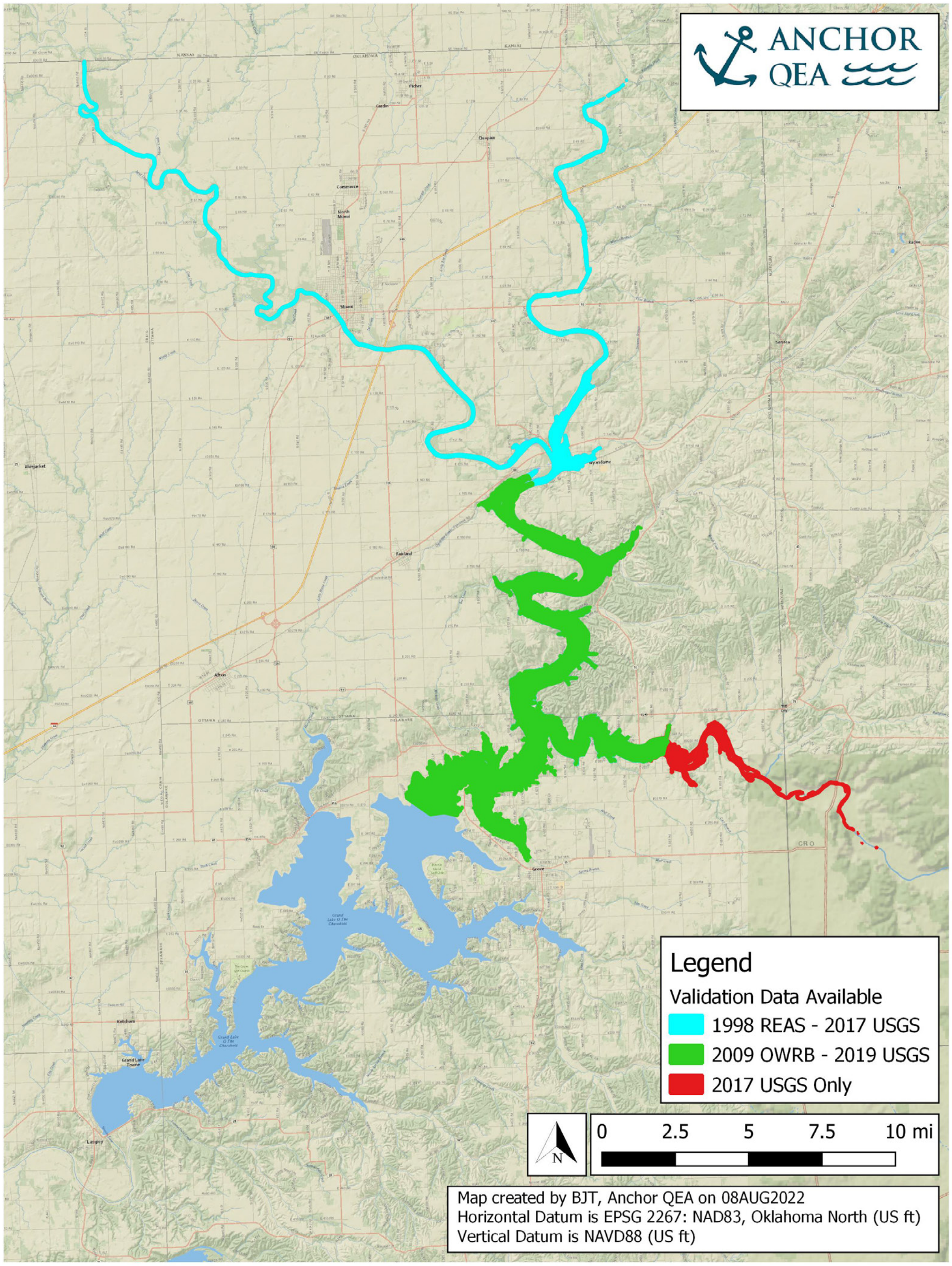


Table 35
Model Reaches and Available Survey Data for STM Development

Reach	Starting Survey	Calibration Survey	Validation Survey
Upper (Above RM 120.1)	Circa-1940 USACE	Circa-1998 REAS	2017 USGS
Lower (RM 120.1–RM 100)	Circa-1940 USACE	2009 OWRB	2019 USGS
Elk River (Above RM 5.47)	Circa-1940 USACE	2017 USGS	N/A
Reservoir (Below RM 100)	Circa-1940 USACE	2009 OWRB*	2019 USGS

Note:
*2009 OWRB data were not used for long-term analysis downstream of RM 100 (Section 2.1.1.5.1). Sedimentation rates from 1940 to 2009 were implausibly different than 2009 to 2019, so an assessment of deposition from 1940 to 2019 was used instead.

Sediment calibration runs simulated flow from October 1942 through October 2019. Evaluation of the results was based on the available survey information for the Neosho River, Spring River, and Elk River. Cross-sectional data from 1941 were digitized from survey data obtained from USACE surveys (1941). For the Neosho River below the Spring River and the Elk River, the current dataset was obtained from the 2019 bathymetric survey data. For the Spring River and the Neosho River upstream of the Spring River, the 2017 bathymetric survey data were used since the 2019 data extents did not include these areas.

River mile stations of the cross sections from the 1941 data were used to identify the most comparable cross sections in the contemporary datasets. Not all the 1941 cross sections had an exact river mile station match in the current data, so the nearest possible cross section was used—with most comparisons being within 0.05 river mile. The river mile stations of each river are shown in Table 36 through Table 39. Horizontal stationing differed between 1941 and 2017/2019 due to a lack of precise geographical information on where the 1941 cross sections are located. To match the horizontal position of 1941 and 2017/2019 cross sections, the horizontal stationing for the 1941 data were shifted based on visual comparison with the contemporary datasets.

Cross-sectional channel area was calculated based on a reference elevation set at the approximate high water level for each cross section, with the same elevation being used between each set of 1941 cross sections and 2017/2019 cross sections. The area under this elevation and above the cross-section elevation was considered the cross-sectional area and these were differenced to find the cross-sectional change in channel capacity. Figure 133 through Figure 136 provide examples for each river, showing the 1941 cross sections, 2017/2019 cross sections, and the reference elevation. Finally, the volume change was calculated using the same approach used by HEC-RAS in defining the representative bed sediment volume for a cross section, which multiplies cross-sectional change in area by the average of upstream and downstream reach lengths. Table 36 through Table 39 show the reference elevation, cross-section areas for 2017 and 2019, change in cross-sectional areas, and the volumetric change in channel cross sections in millions of cubic feet for each river.

Table 36
Elk River 1941 to 2017 Cross-Section Comparison

1941 Cross Section (RM)	2017 Cross Section (RM)	Reference Elevation (feet PD)	1941 Area (ft²)	2017 Area (ft²)	Change In Area (ft²)	Change In Volume (ft³ x 10⁶)
0.76	0.8	758.93	118,092	105,556	12,536	107
3.22	2.96	758.93	132,363	114,771	17,592	220
5.50	5.18	758.93	98,125	77,321	20,804	218
7.20	6.44	758.93	109,768	77,994	31,773	318
9.28	8.41	763.93	118,092	110,807	7,285	74
11.03	10.08	763.93	55,118	44,891	10,227	91
12.64	11.68	763.93	22,140	18,833	3,308	34
13.77	12.8	763.93	18,459	19,849	-1,390	-4
					Reach Total	**617**

Figure 133
Example Elk River Cross Section RM 9.28

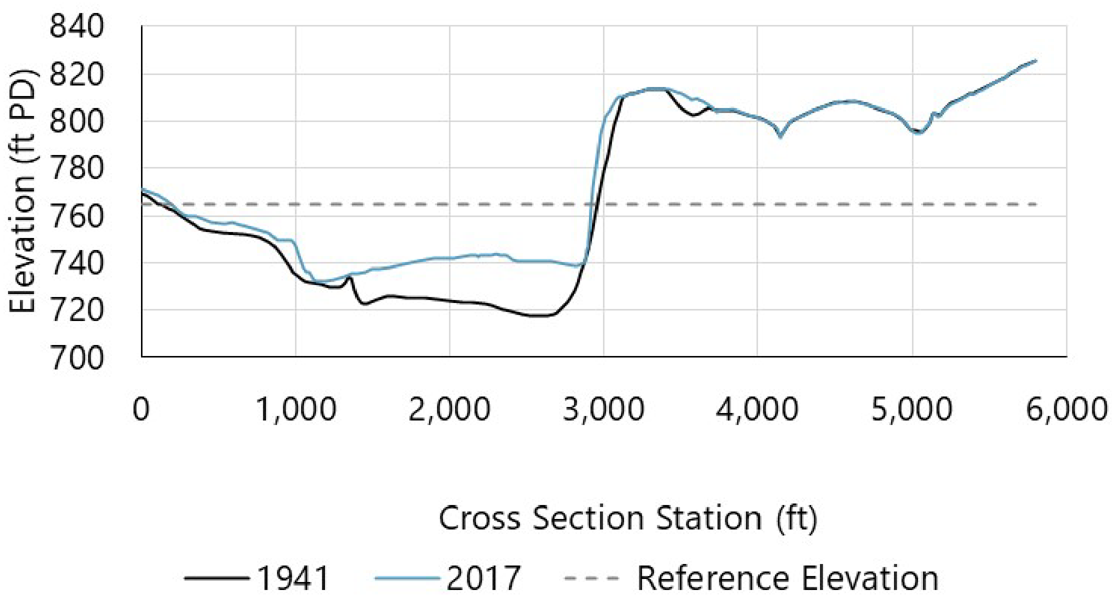


Table 37
Neosho – Below Spring River 1941 to 2019 Cross-Section Comparison

1941 Cross Section (RM)	2019 Cross Section (RM)	Reference Elevation (feet PD)	1941 Area (ft^2)	2019 Area (ft^2)	Change In Area (ft^2)	Change In Volume ($ft^3 \times 10^6$)
100.78	100.82	758.93	347,839	308,627	39,212	555
104.07	104.18	758.93	260,683	212,408	48,275	874
107.68	107.81	758.93	156,905	109,099	47,806	1,000
113.70	113.79	758.93	97,942	61,154	36,788	1,060
118.60	118.56	758.93	72,891	52,126	20,765	268
					Reach Total	**3,757**

Figure 134
Example Neosho River – Below Spring River Cross Section RM 118.60

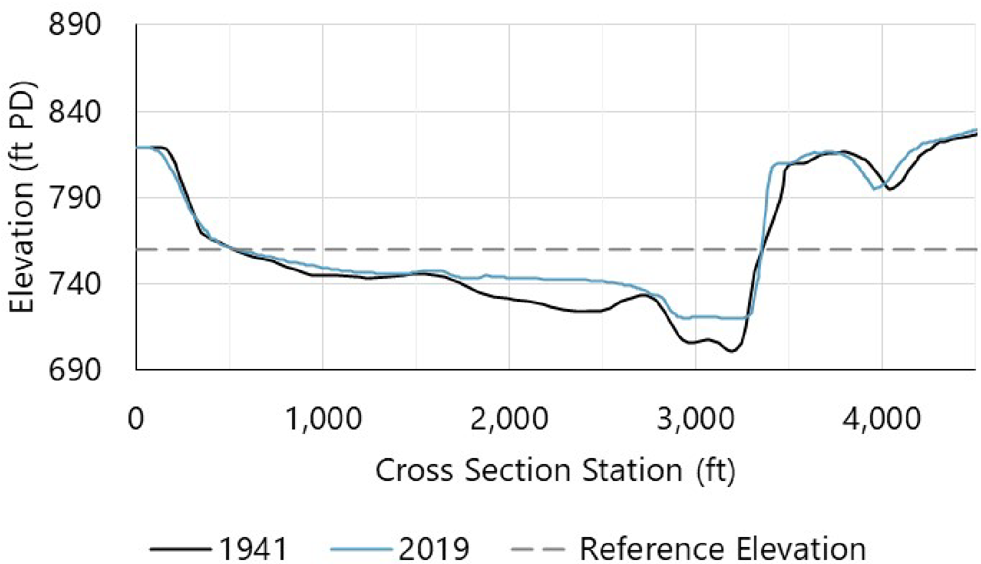


Table 38
Neosho – Above Spring River 1941 to 2017 Cross-Section Comparison

1941 Cross Section (RM)	2017 Cross Section (RM)	Reference Elevation (feet PD)	1941 Area (ft^2)	2017 Area (ft^2)	Change In Area (ft^2)	Change In Volume ($ft^3 \times 10^6$)
124.25	124.20	748.93	16,177	12,082	4,095	70
129.98	130.01	753.93	41,877	26,911	14,967	377
133.79	133.80	753.93	13,037	8,500	4,537	85

1941 Cross Section (RM)	2017 Cross Section (RM)	Reference Elevation (feet PD)	1941 Area (ft^2)	2017 Area (ft^2)	Change In Area (ft^2)	Change In Volume (ft^3 x 10^6)
137.07	136.98	753.93	7,849	6,655	1,193	17
139.26	139.19	758.93	8,807	7,902	905	11
141.80	141.67	763.93	17,090	12,737	4,353	46
143.23	143.38	763.93	7,442	6,520	922	10
144.64	144.52	763.93	6,865	5,340	1,526	70
					Reach Total	**617**

Figure 135
Example Neosho River – Above Spring River Cross Section RM 124.25

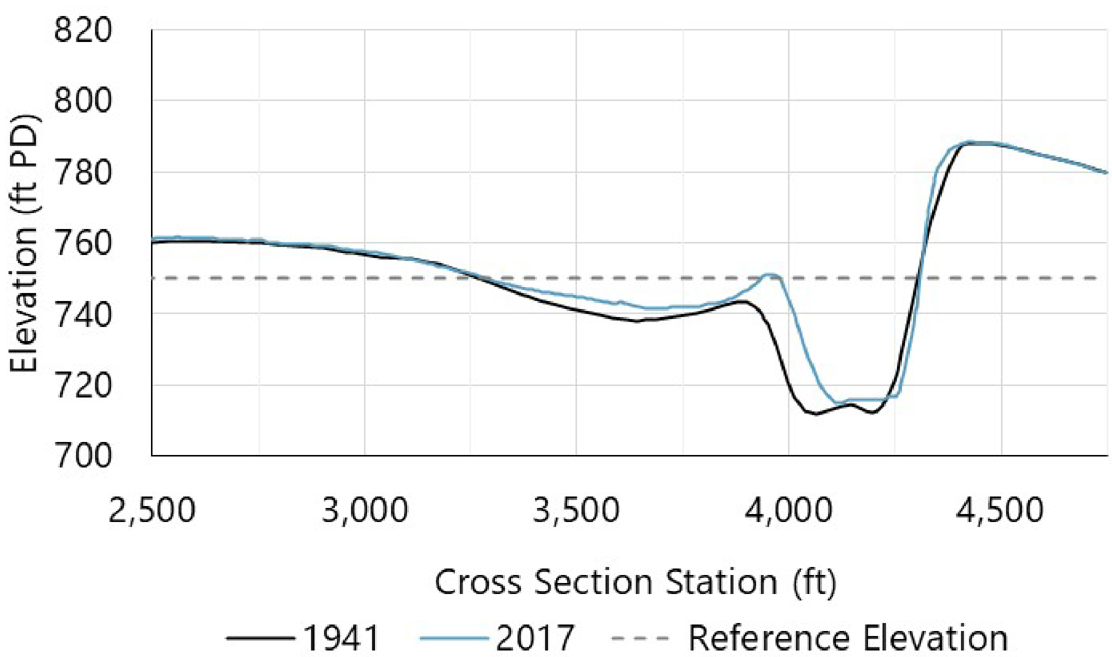
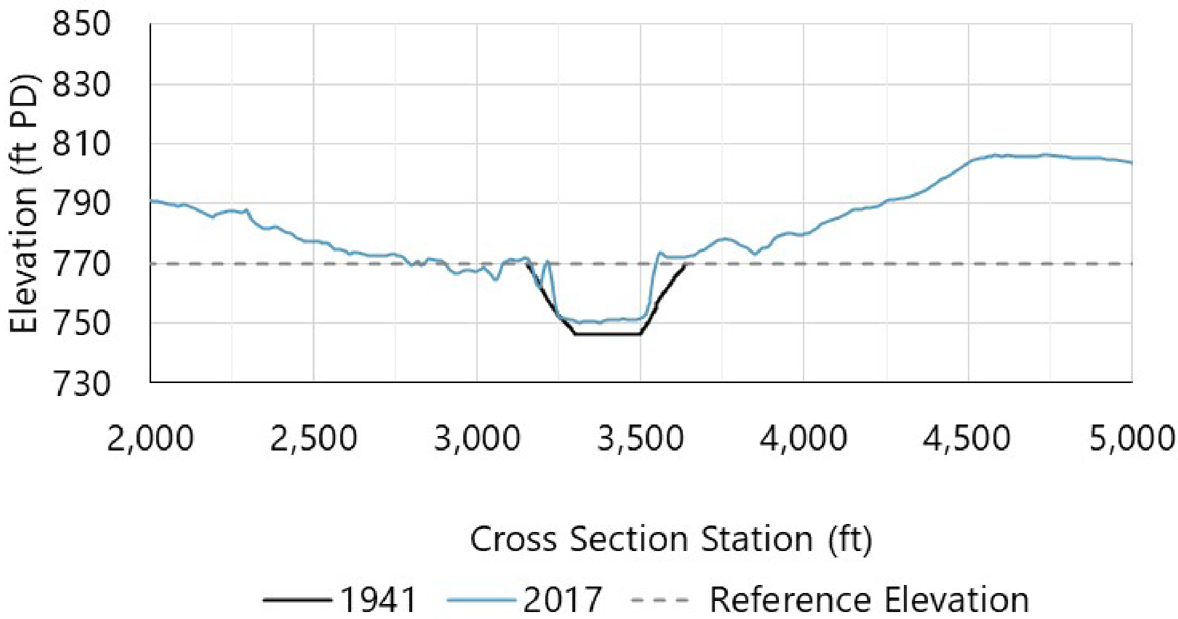


Table 39
Spring River 1941 to 2017 Cross-Section Comparison

1941 Cross Section (RM)	2017 Cross Section (RM)	Reference Elevation (feet PD)	1941 Area (ft^2)	2017 Area (ft^2)	Change In Area (ft^2)	Change In Volume (ft^3 x 10^6)
0.78	0.79	748.93	24,892	19,476	5,415	74
5.19	5.1	748.93	9,721	6,945	2,776	43
6.63	6.64	753.93	8,897	8,388	508	7

1941 Cross Section (RM)	2017 Cross Section (RM)	Reference Elevation (feet PD)	1941 Area (ft^2)	2017 Area (ft^2)	Change In Area (ft^2)	Change In Volume ($ft^3 \times 10^6$)
10.49	10.51	753.93	7,846	4,440	3,406	51
12.35	12.43	768.93	11,400	12,884	-1,484	-21
15.89	15.93	768.93	8,187	6,074	2,113	25
16.84	16.88	768.93	9,240	4,784	4,456	11
					Reach Total	**191**

Figure 136
Example Spring River Cross Section RM 15.89



The simulation data were then compared to measured data using metrics defined by Moriasi et al. (2007). Specifically, the Nash-Sutcliffe Efficiency (NSE), which evaluates the ratio of noise to measured data variance (Nash and Sutcliffe 1970) as defined in Equation 5.

Equation 5

$$NSE = 1 - \left[\frac{\sum_{i=1}^{n}\left(Y_i^{obs} - Y_i^{sim}\right)^2}{\sum_{i=1}^{n}\left(Y_i^{obs} - Y^{mean}\right)^2}\right]$$

where:

Y_i^{obs} = the *i*th observation for the constituent being evaluated

Y_i^{sim} = the *i*th simulated value for said constituent

Y^{mean} = the mean of observed data

n = the total number of observations

Another metric used was the Percent Bias (PBIAS) as defined by Gupta et al. (1999). This is used as a measure of the tendency for the simulation to overpredict or underpredict the constituent of interest and is defined in Equation 6.

Equation 6

$$PBIAS = \left[\frac{\sum_{i=1}^{n}\left(Y_i^{obs} - Y_i^{sim}\right) \cdot (100)}{\sum_{i=1}^{n}\left(Y_i^{obs}\right)}\right]$$

where:

$PBIAS$ = percent bias

Where *PBIAS* is expressed as a percentage, and it is consistent with percent difference in volume.

The third metric from Moriasi et al. (2007) used in this study was the RMSE-Observations Standard Deviation Ratio (RSR) as defined by Singh et al. (2004). This measure is a reformulation of the RMSE that normalizes results so an ideal model will produce an RSR of 0. It is defined as shown in Equation 7.

Equation 7

$$RSR = \frac{RMSE}{STDEV_{obs}} = \frac{\left[\sqrt{\sum_{i=1}^{n}\left(Y_i^{obs} - Y_i^{sim}\right)^2}\right]}{\left[\sqrt{\sum_{i=1}^{n}\left(Y_i^{obs} - Y^{mean}\right)^2}\right]}$$

where:

RMSE = root mean square error

$STDEV_{obs}$ = standard deviation of the observed values

C = the sum of A and B

Table 40 shows typical criteria adopted by Moriasi et al. (2007) for sediment modeling.

Table 40
Statistical Criteria for Sediment Model Performance

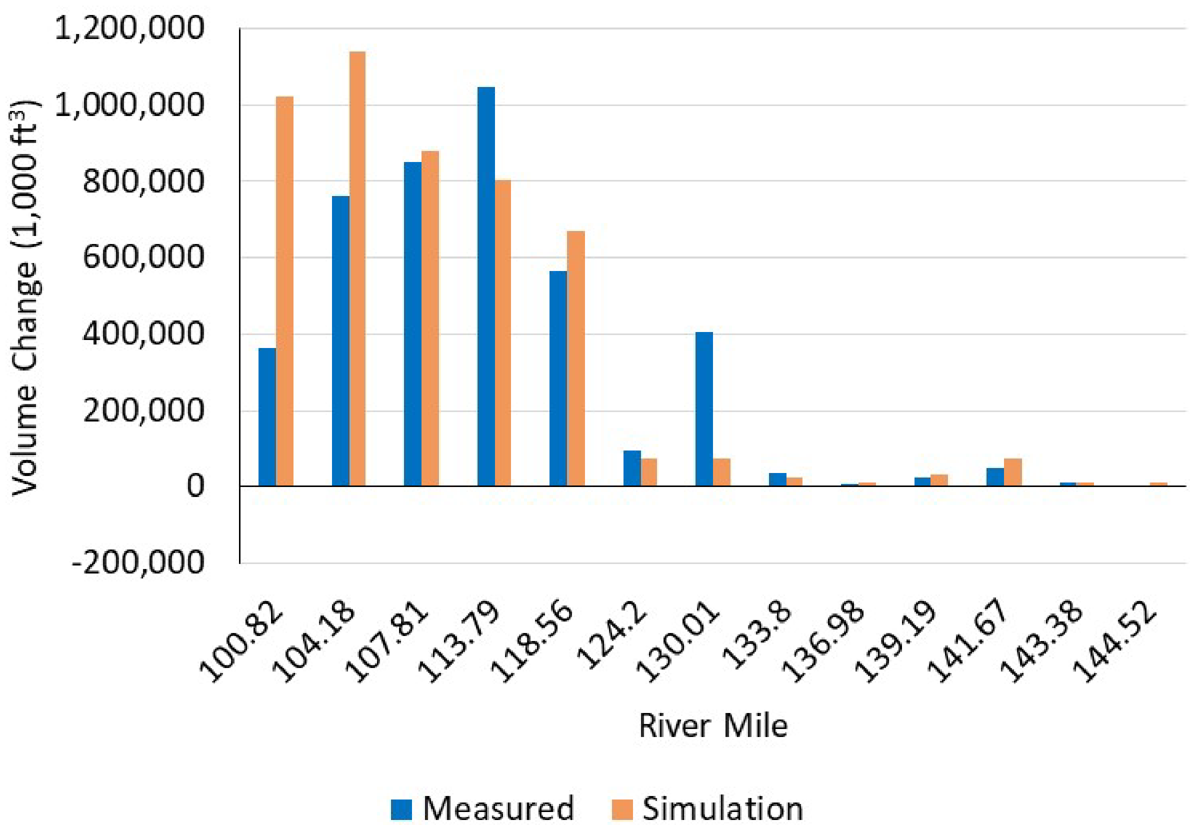
Model Performance	NSE	PBIAS	RSR
Very Good	0.75 < NSE ≤ 1.00	|PBIAS| < 15	0.00 ≤ NSE ≤ 0.50
Good	0.65 < NSE ≤ 0.75	15 ≤ |PBIAS| < 30	0.50 ≤ NSE ≤ 0.60
Satisfactory	0.50 < NSE ≤ 0.65	30 ≤ |PBIAS| < 55	0.60 ≤ NSE ≤ 0.70
Unsatisfactory	NSE ≤ 0.50	|PBIAS| ≥ 55	RSR > 0.70

Note: Adapted from Moriasi et al. (2007)

6.2.2.1 Results

The model performed well in most areas of the Neosho River (Figure 137). The model agrees with measured data in most of the reach upstream of RM 120.1, with the exception of RM 130.01, and it also agrees on the upstream face of the delta feature (RM 120.1 to RM 105), where GRDA asserted in the April 2022 USP the model was able to reasonably predict sediment deposition. Below that point, lacustrine dynamics and the prevalence of cohesive sediments decrease HEC-RAS's suitability for modeling deposition.

Figure 137
Neosho River Volume Change from Circa 1940



Notes: Model results above RM 120.1 are compared to 1998 REAS data.
Model results below RM 120.1 are compared to 2009 OWRB data.

There are two locations where the modeled results match poorly with the measured datasets. It underpredicts deposition on the Neosho River near RM 130.01 and overpredicts deposition on the downstream face of the delta feature (RM 104.18 and 100.82). Removing those locations from the analysis result in a much-improved calibration. The statistical analysis of calibration results with and without those cross sections are shown in Table 41.

Table 41
Statistical Calibration Evaluation Parameters of STM on the Neosho River

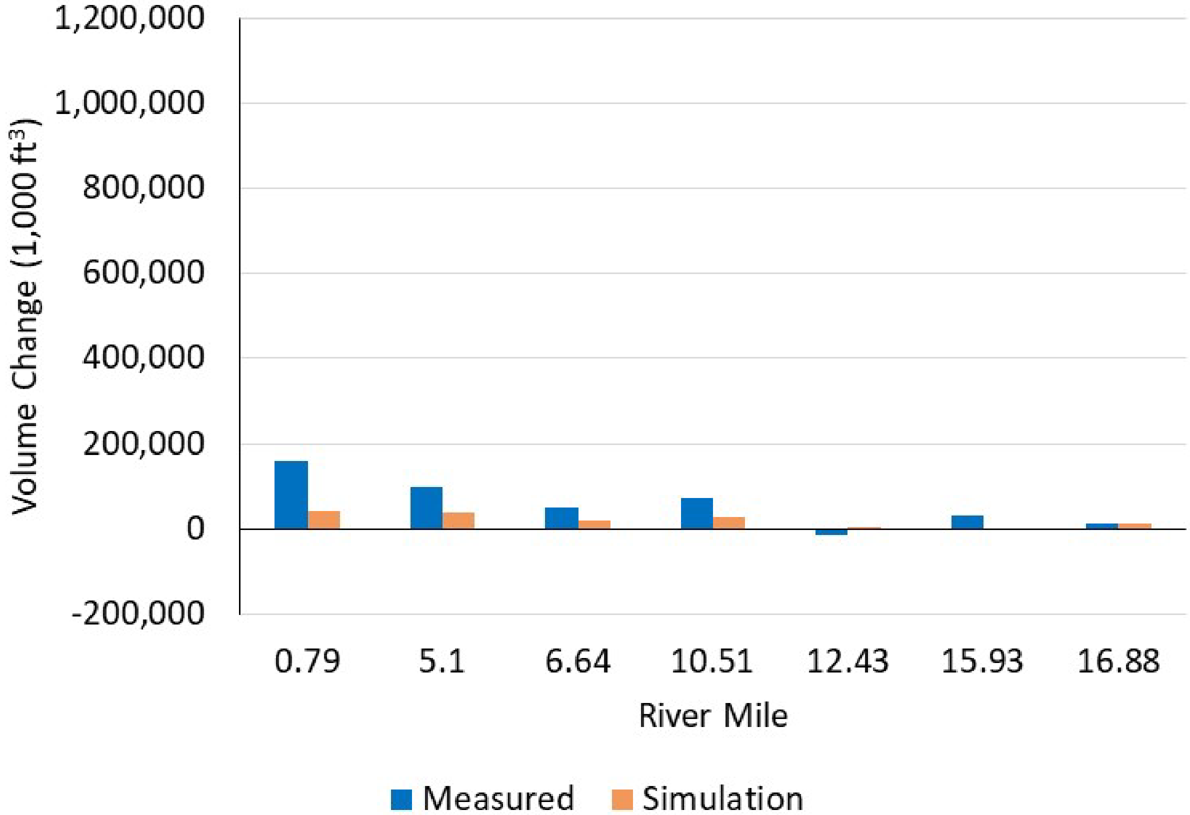
Reach	NSE (Target: > 0.5)	PBIAS (|Target|: < 0.55)	RSR (Target: < 0.70)
All Locations	-0.94	0.19	0.69
Excluding RM 130.01, 104.18, 100.82	0.95	0.01	0.22

Note:
Calibration of the model showed significant underprediction at RM 130.01 and overprediction on the downstream face of the delta feature (RM 104.18, 100.82).

Results on the Spring and Elk rivers were less accurate due to poor historical data quality. As discussed in Sections 2.1.1 and 6.1.1 of this report, the limitations of the data reduce the ability to perfectly simulate sediment transport. As discussed previously, the exact locations of the circa-1940 cross-sectional surveys were estimated based on reported stream distances (USACE 1941, 1942) and placed on the 1938 topographic maps (USACE 1938). Uncertainty of the placement of the cross-section survey data contributes to reduced model calibration results.

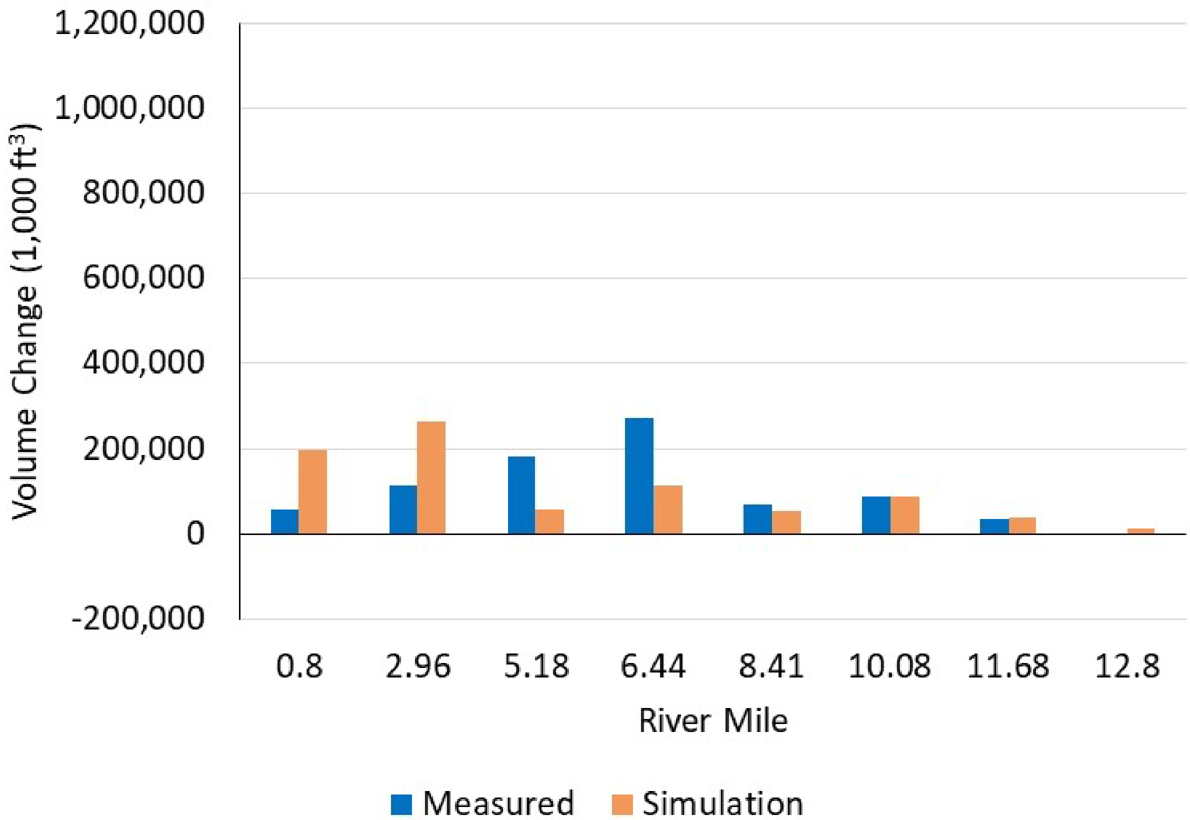
Spring River results are presented in Figure 138 and Elk River results are shown in Figure 139.

Figure 138
Spring River Volume Change from Circa 1940



Note: Model results are compared to 1998 REAS data.

Figure 139
Elk River Volume Change from Circa 1940



Notes: Model results above RM 5.47 are compared to 2017 USGS data.
Model results below RM 5.47 are compared to 2009 OWRB data.

The statistical analysis of the Spring and Elk river model results is presented in Table 42.

Table 42
Statistical Calibration Evaluation Parameters of STM on the Spring and Elk Rivers

Reach	NSE (Target: > 0.5)	PBIAS (|Target|: < 0.55)	RSR (Target: < 0.70)
Spring River	0.04	-0.62	0.98
Elk River	-0.55	0.03	1.24

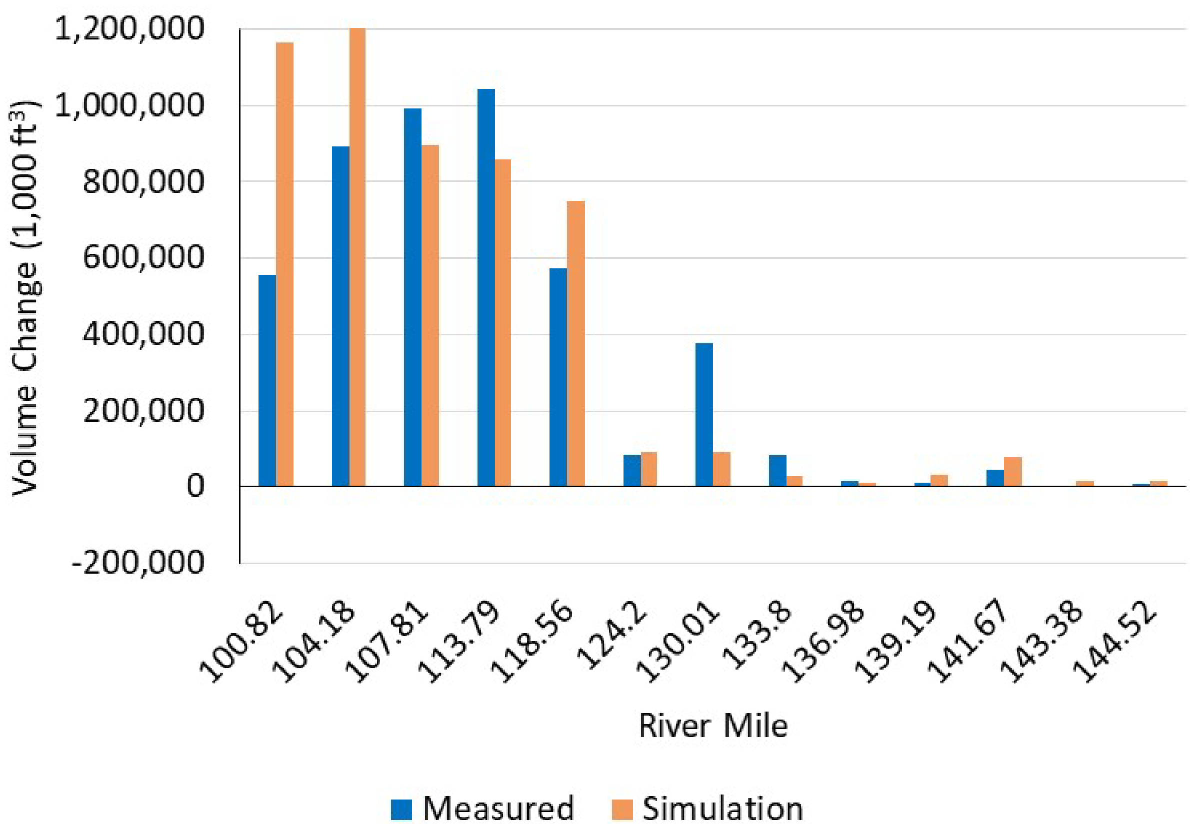
The model tends to underpredict sediment deposition on the Spring River and overpredict deposition on the Elk River. These rivers have the least reliable cross-sectional survey placements, with no bridges to reference for cross-section locations.

Another method of comparing the model results to measured data is to compare predicted and measured geometry. Two of the more useful means of evaluating channel evolution with HEC-RAS models are average channel and average section elevations. These metrics contain far more geometry information than a simple thalweg plot; a thalweg plot looks only at the lowest point of the cross section, whereas the other metrics incorporate the trends across the entire stream channel and submerged portion of the model. These are more closely related to hydraulic flow areas and are in many cases a better means of condensing channel geometry into a simple profile.

6.2.2.2 Calibration Validation

After calibration, the model performance was compared to the latest available modern surveys as shown in Figure 140. The results are presented below.

Figure 140
Neosho River Volume Change Validation



Notes: Model results above RM 120.1 are compared to 2017 USGS data.
Model results below RM 120.1 are compared to 2019 USGS data.

The validation results on the Neosho River showed similar patterns to those in the calibration; deposition was significantly overpredicted on the downstream face of the delta feature (below RM 105) and underpredicted near RM 130.01. Statistical evaluations are shown in Table 43.

Table 43
Statistical Validation Evaluation Parameters of STM on the Neosho River

Reach	NSE (Target: > 0.5)	PBIAS (|Target|: < 0.55)	RSR (Target: < 0.70)
All Locations	-0.64	0.25	0.69
Excluding RM 130.01, 104.18, 100.82	0.80	0.13	0.44

Notes:
Calibration of the model showed significant underprediction at RM 130.01 and overprediction on the downstream face of the delta feature (RM 104.18, 100.82)

Validation on the Elk and Spring rivers was less precise than on the Neosho River, similar to the calibration results (Figure 141 and Figure 142).

Figure 141
Spring River Volume Change Validation

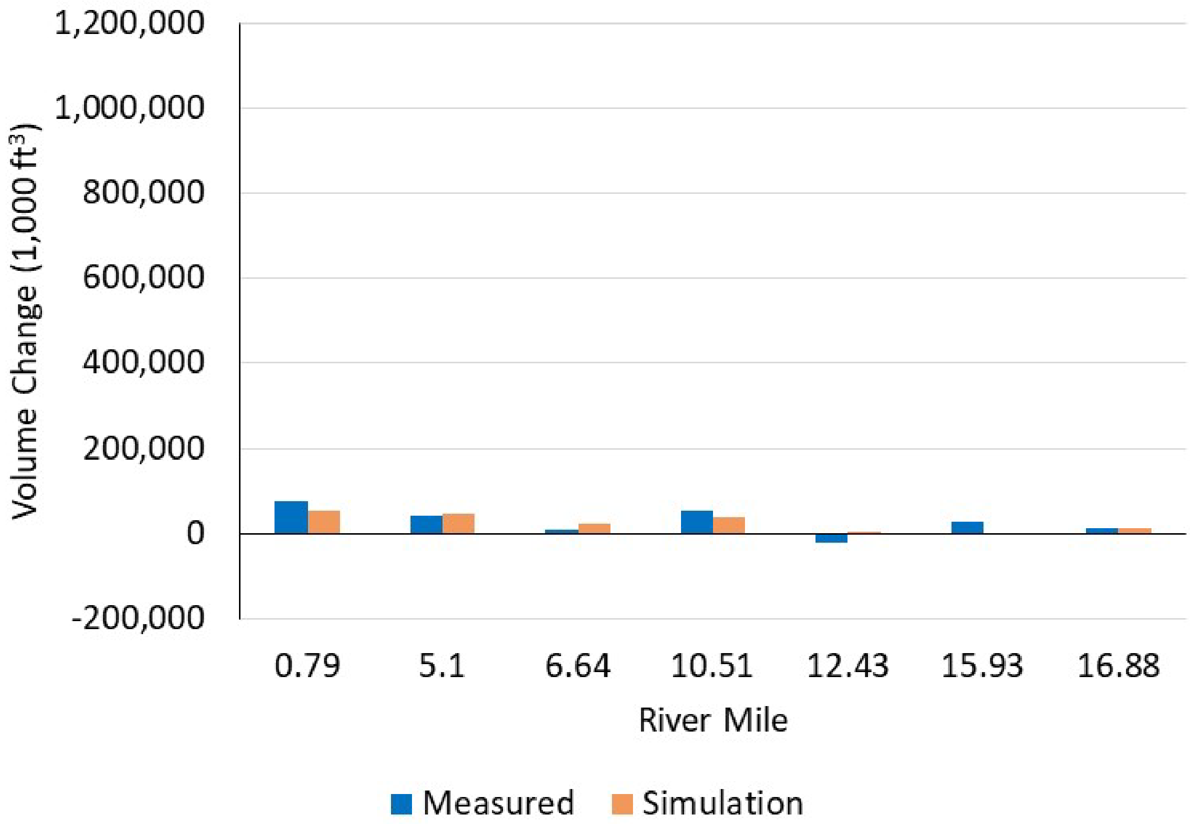
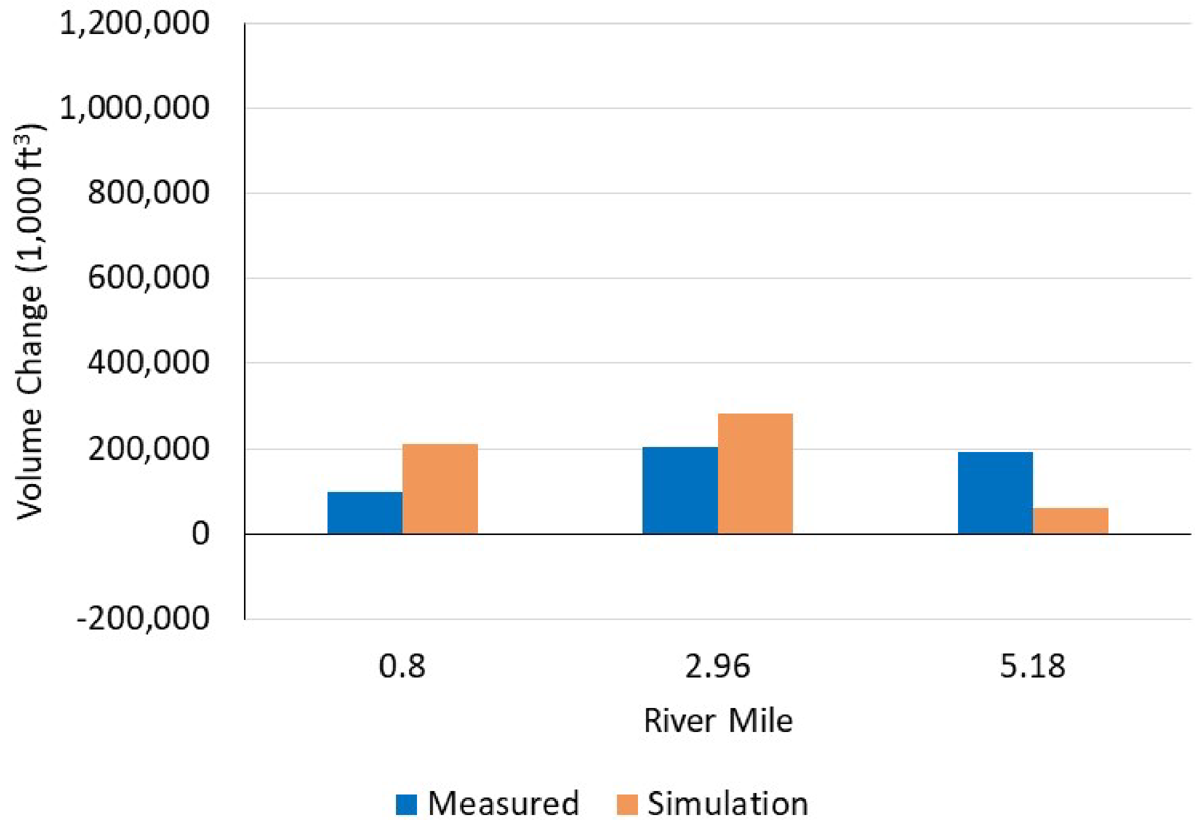


Figure 142
Elk River Volume Change Validation



Note: There is no available validation data on the Elk River above RM 5.46 as shown in Table 35.

The statistical analysis of the validation fits for the Elk River and Spring River is shown in Table 44.

Table 44
Statistical Validation Evaluation Parameters of STM on the Spring and Elk Rivers

Reach	NSE (Target: > 0.5)	PBIAS (|Target|: < 0.55)	RSR (Target: < 0.70)
Spring River	0.62	-0.09	0.62
Elk River	0.08	-0.04	0.98

As during calibration, the model performance in validation runs is limited by the quality of available datasets. This was a known issue during model development and was discussed in the USP. To address this issue, the model was run using several input conditions for sedimentation as a means of bounding the expected sediment deposition and transport within the study area.

Another method to evaluate STMs is comparing average channel and average section profiles. This was discussed by WEST in their ITR (2022) in detail, but a brief summary of the measurement is provided here. The average channel and average section profiles are a more effective means of showing stream geometry than a simple thalweg profile. The thalweg *only* uses one point per cross section to show a stream profile; average section and average channel take the entire channel or entire cross section into consideration, condensing for more information into the profile plot. This also provides a more representative method of evaluating hydraulic characteristics, because it accounts for the cross-section geometry as well as the thalweg.

The Neosho River average channel and average section profiles are shown in Figure 143 and . Mean error in channel elevation on the river compared to measured modern geometry data is -1.1 feet, meaning the model underpredicts bed elevations as compared to measured values. Mean error in average section elevations was -1.8 feet.

Figure 143
Neosho River Comparison of Measured and Modeled Average Channel Profiles

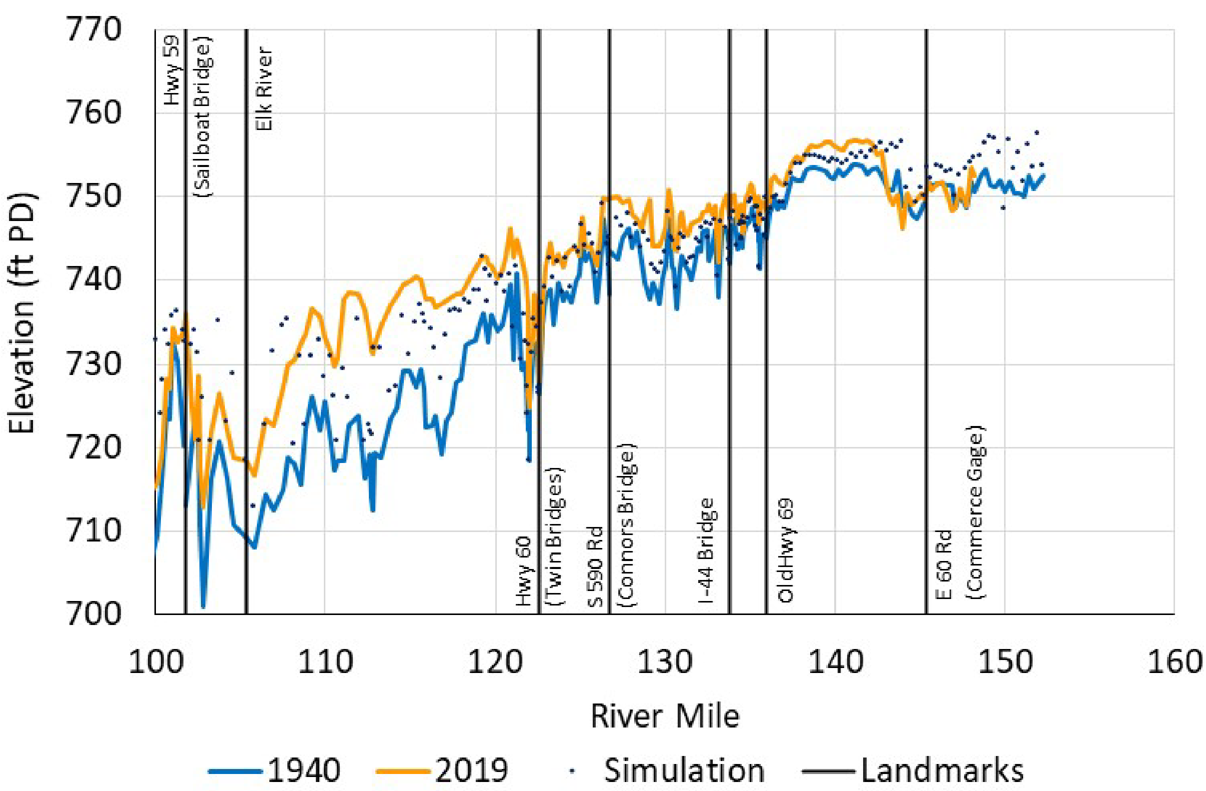
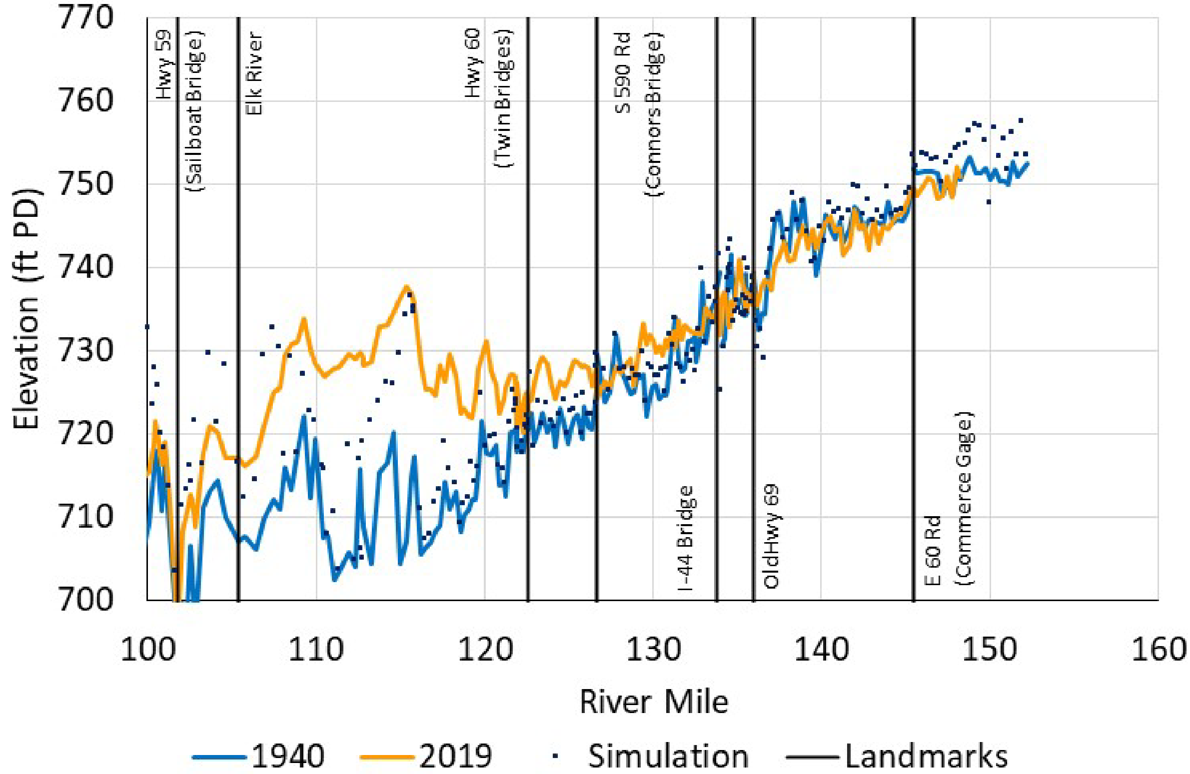


Figure 144
Neosho River Comparison of Measured and Modeled Average Section Profiles



The differences in average channel and average section are largely explained by the poor quality of the circa-1940 geometry. The circa-1940 geometry relies on far fewer measured cross sections that were then interpolated to produce the circa-1940 geometry. Overbank areas are based on poorly scanned topographic maps, resulting in uncertainty when digitizing contour lines. These resulted in several areas of relatively wide channels between measured cross sections.

In contrast, the 2019 geometry is based on high-resolution data. The channels are far narrower in this geometry. As a result, the circa 1940 channel is often wider than its 2019 counterpart and would require significantly more deposition to match total volume changes between measured portions of the river.

HEC-RAS provides outputs showing cumulative volume in a river reach. This calculation finds the volume at every cross section in the model. For the reach between RM 145.4 (East 60th Road, USGS Commerce gage) and the confluence with the Spring River, HEC-RAS reports a volume difference of

53,700 acre-feet between the digitized and interpolated 1940 geometry and the measured 2019 geometry.

Where historical channel cross-section information is available, the model shows good correlation with sediment deposition volumes as shown in the above results. Using only the measured cross sections as shown above results in expected deposition of just 18,500 acre-feet. This matches well with the reported model deposition of approximately 15,300 acre-feet.

In contrast, the large change reported by HEC-RAS cumulative volume outputs from 1940 to 2019 reinforces the conclusion that unsurveyed, interpolated, circa 1940 cross sections are too wide. By including all model cross sections instead of only using those with known survey data, the amount of deposition needed to match the 2019 terrain is approximately three times what is shown when using *only* surveyed locations. This significant discrepancy could only occur if the unsurveyed portions of the circa 1940 terrain had much wider channels than existed in reality. Because the data for these unsurveyed sections are based on poorly scanned contour maps, they are far less reliable than the more accurate survey information used in the above analyses.

7 Predictive Simulations

After model calibration, predictive simulations were performed to evaluate future conditions within the study area and evaluate the impact of sedimentation on upstream water levels and the power pool.

7.1 Model Inputs

Model inputs for the predictive simulations included synthetic hydrographs, bed characteristics recorded from field measurements, and sediment rating curves.

There were four separate predictive simulations to address the uncertainties associated with the available terrain information discussed earlier in this report. These included expected loading simulations under both *Baseline* and *Anticipated* operations, a *High Sedimentation* simulation with adjusted parameters to increase sediment deposition in the study area, and a *Low Sedimentation* scenario with adjusted parameters to place a lower bound on the predicted sedimentation. These will be discussed in more detail in the following sections.

7.1.1 Hydraulic Parameters

To run future sediment simulations, synthetic future hydrographs for the 50-year period of January 1, 2020, to December 31, 2069 (2020 to 2070), were generated for each of the USGS gage locations (USGS 2021a, 2021c, 2021e, 2021f) and the corresponding synthetic Tar Creek hydrograph discussed in Section 5.2.1.1 of this report. Peak annual maximum flows were examined for each of the hydrographs to identity any trends in the peak flows. No significant trends were observed at any of the locations and introduction of a scaling factor to artificially increase or decrease the severity or duration of inflow events was not warranted. Therefore, the yearly hydrographs for 2020 to 2070 were assumed to approximately repeat the set of flows from January 1, 1970, to December 31, 2019 (1970 to 2020). To create some variability in the data, the order in which the flow years occurred was randomized when applied to the future hydrographs. This created a set of randomized hydrographs that would preserve the subannual patterns of individual water years and keep the statistical peak flow events the same between past and future hydrographs. Water years were separated into leap years and non-leap years and a separate randomization was applied, such that historical leap years would only be transposed to future predicted leap years. Because there are more leap years in the projected period of record, one non-leap year was projected to a future leap year and the February 28 flow data were projected to February 29. The same generated randomization of years was applied to each gage location so that peak flows would match between locations.

Downstream WSE BCs were set based on Operations Model (OM) outputs. The OM results were then imported to the STM for future simulations.

7.1.1.1 Stream Temperature

Sediment transport is affected by water temperatures. Water temperature is related to water viscosity, which can increase or decrease the potential for sediment entrainment and transport or deposition.

To bound the potential sediment deposition range, temperature was adjusted for the various future scenarios. In the *Baseline* and *Anticipated* scenarios, temperatures were set to match the measured values as discussed in Section 6.2.1.1 of this report. The *High Sedimentation* and *Low Sedimentation* scenarios (bounding scenarios) used water temperatures increased by 5°F and decreased by 5°F, respectively.

7.1.2 Sediment Parameters

7.1.2.1 Bed Sediment

Bed sediment conditions were selected based on the measured grain size distributions and bed shear stresses measured in the field as part of this study. The properties were assigned to the corresponding locations on the relevant tributaries, and HEC-RAS interpolation functions were used to gradually transition bed materials between locations.

7.1.2.2 Sediment Inflows

Rating curves were adjusted for bounding scenarios, but no changes were made to incoming sediment gradations. The *Anticipated* and *Baseline* operations scenarios used the same incoming sediment rating curves as the calibration run. The *High Sedimentation* scenario increased sediment discharge by 20%, and the *Low Sedimentation* scenario decreased sediment discharge by 20%. This was applied by a simple multiplication factor applied to the rating curves and imported into the HEC-RAS sediment input file.

7.1.2.3 Fall Velocity Method

The other parameter adjusted for the bounding scenarios was the fall velocity method. The *Baseline* and *Anticipated* scenarios used the Rubey method. Analysis of the various methods available in HEC-RAS indicated that van Rijn would increase fall velocity and thus deposition, so it was used in the *High Sedimentation* run, and Dietrich was used for the *Low Sedimentation* simulation.

7.2 Data Processing

The predictive STM simulation required an iterative process to account for potential changes in OM due to future reservoir sedimentation. To evaluate predictive STM simulations, it was necessary to iteratively adjust stage-storage curves within the study area. This iterative process is described as follows:

1. The initial stage-storage curve was extracted from the 2019 HEC-RAS terrain.

2. This initial curve with the synthetic hydrographs was run in the OM to determine the downstream WSE hydrograph. The STM was then run with the downstream WSE boundary computed by the OM.
3. Upon completion of the HEC-RAS sediment simulation, the resulting geometry was processed and stage-storage upstream of RM 100 was extracted from the model. This method does not provide information about the impacts on storage downstream of the model domain. Adjustments to account for the loss of storage below RM 100 are provided below.
4. The OM was re-run with a dynamic stage-storage curve, based on a temporal linear interpolation between the starting 2019 curve and the curve output from Step 3.
5. The STM was then re-run with the downstream WSE boundary computed by the second storage-interpolated iteration of the OM. The stage-storage output from this second STM run was compared to the initial output to determine if storage values changed significantly, which would indicate the need for another iteration.

To estimate stage-storage impacts on the downstream portion of the study area, the measured historical vertical accumulation rate at the dam was projected forward in time to estimate the minimum storage elevation at the dam. Table 45 provides the estimated minimum storage elevation at the dam and total change in storage estimated from measured stage-storage curves (USACE 1941; USGS 2020) for the various future conditions.

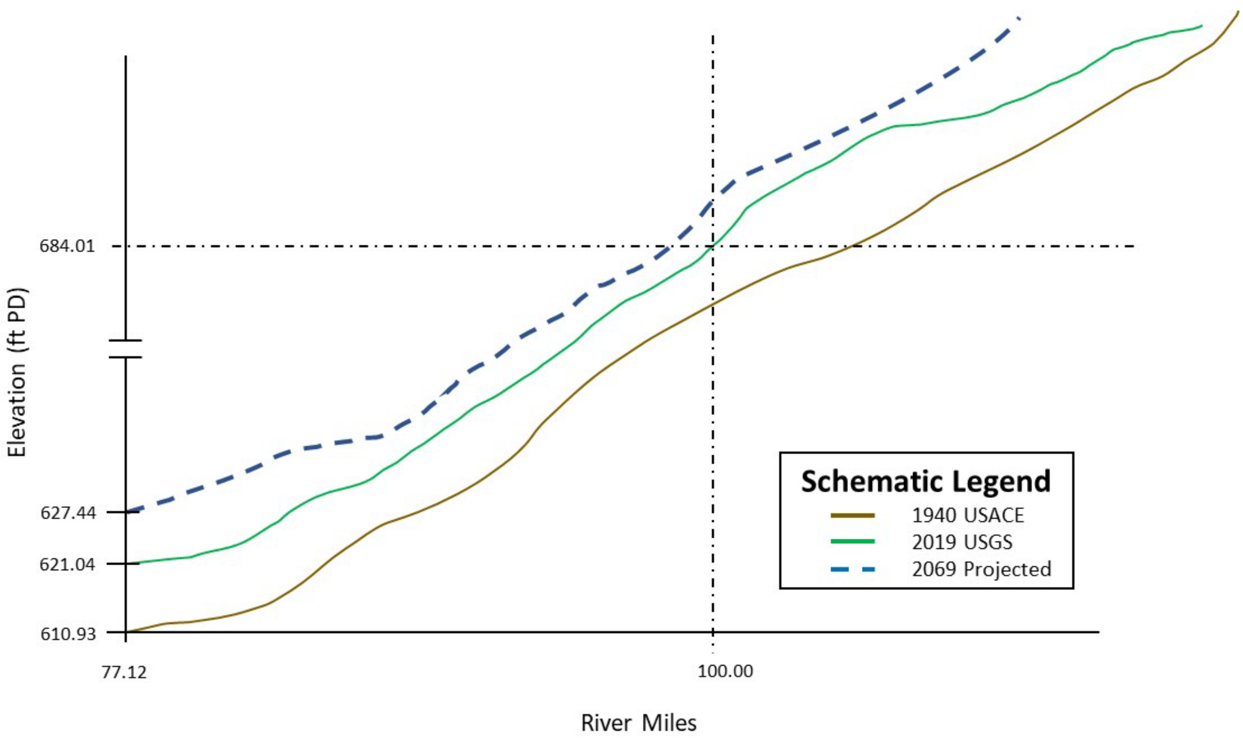
Table 45
Historical Stage-Storage Information Used to Develop Future Stage-Storage Curves Downstream of RM 100

Stage-Storage Curve	Lowest Storage Elevation (feet PD)	Total Change in Storage (acre-feet)
1940 USACE	610.93	--
2019 USGS	621.04	319,473
2069 (Baseline Ops)	627.44	224,332
2069 (Anticipated Ops)	627.44	224,332
2069 (High Sedimentation)	627.44	269,258
2069 (Low Sedimentation)	627.44	179,505

Based on the change in storage between 1940 and 2019, the long-term sediment deposition at the base of Pensacola Dam is approximately 0.13 foot per year. Projecting that rate into the future provides an estimated low point of approximately 627.44 feet. Because dam operations depend on storage changes, but not the specific location of sediment deposition near the dam, the low point is relatively unimportant to overall storage volume change and was therefore held constant for all predictive simulations.

To determine approximate storage volume change downstream of RM 100, the thalweg elevation at RM 100 was used as a reference point (Figure 145). This elevation was 684.01 feet at the time of the 2019 USGS survey.

Figure 145
Schematic Representation of Neosho River Thalweg for Illustration Purposes



All material deposited below an elevation of 684.01 feet was therefore necessarily deposited downstream of RM 100. Material deposited upstream of RM 100 is modeled directly in the STM simulations. The remaining volume was accounted for through the use of trap efficiencies and relative sediment loading.

The volume of sediment entering, depositing in, and leaving the model domain in each simulation is summarized in Table 46.

Table 46
Modeled Sediment Loading

Simulation	Modeled Incoming Load (acre-feet)	Modeled Outgoing Load (acre-feet)	Deposited in Modeled Reach (acre-feet)	Deposited Below RM 100 (acre-feet)	Total Storage Volume Change (acre-feet)
1942–2019	402,733	236,242	166,491	152,982	319,473 (measured)
2020–2069 (Baseline Ops)	280,481	173,978	106,503	117,882	224,385
2020–2069 (Anticipated Ops)	280,481	166,282	114,200	110,185	224,385
2020–2069 (High Sediment)	336,573	202,377	134,196	135,062	269,258
2020–2069 (Low Sediment)	224,382	127,682	96,700	82,806	179,506

Note: *Values are approximated by converting to volume using a sediment density of 58 pcf.

Total change in storage within the reservoir between 1940 and 2019 can be evaluated based on published stage-storage curves from USACE and USGS. For this period, the total sediment inflow as modeled was approximately 402,733 acre-feet, and total measured storage volume change was approximately 319,473 acre-feet. This corresponds to a trap efficiency of approximately 0.8.

Trap efficiency of the entire system is not expected to change drastically from one simulation to the next, so the same study-area-wide trap efficiency of 0.8 was used for all analyses. It should be noted that this may differ from trap efficiencies calculated by other methods; it relies on measured data and model results to ensure consistency through the analysis. It is not the trap efficiency for the unmodeled area alone; it includes deposition and erosion upstream of RM 100.

For the *Baseline Operations* and *Anticipated Operations* simulations, the total inflow volume of sediment was identical, and the expected trapping efficiency is the same. Therefore, the total expected change in storage volume is also expected to match (Table 46).

Relative sediment loading rates were used to calculate the storage volume change in the lower left quadrant of the schematic in Figure 145. The volume lost in that quadrant between 1940 and 2019 was measured to be 69,926 acre-feet. Storage volume change was assumed to scale with inflow volumes and adjusted accordingly (Table 47).

Table 47
Sediment Loading Compared to Storage Volume Change Below Elevation 684.01 feet PD and Storage Total Volume Change Downstream of RM 100

Simulation	Modeled Incoming Load (acre-feet)	Total Storage Change Below 684.01 feet PD (acre-feet)	Total Storage Change Downstream of RM 100 (acre-feet)
1942–2019	402,733	69,926 (measured)	--
2020–2069 (Baseline Ops)	280,481	48,668	132,450
2020–2069 (Anticipated Ops)	280,481	48,668	123,926
2020–2069 (High Sediment)	336,573	58,038	141,973
2020–2069 (Low Sediment)	224,382	38,949	87,389

Note: *Loss downstream of RM includes both the upper and lower quadrants of Figure 145 and cannot be precisely determined through available rating curves.

This storage volume change was applied to elevations below 684.01 feet at a rate proportional to the additional storage volume increment at each elevation step.

Accounting for additional storage changes in the upper left quadrant of Figure 145 used a similar approach. The difference between modeled deposition and calculated by the method above was assumed to have been in the upper left quadrant. It was assumed to also apply at a rate proportional to the incremental change in storage volume at each elevation step.

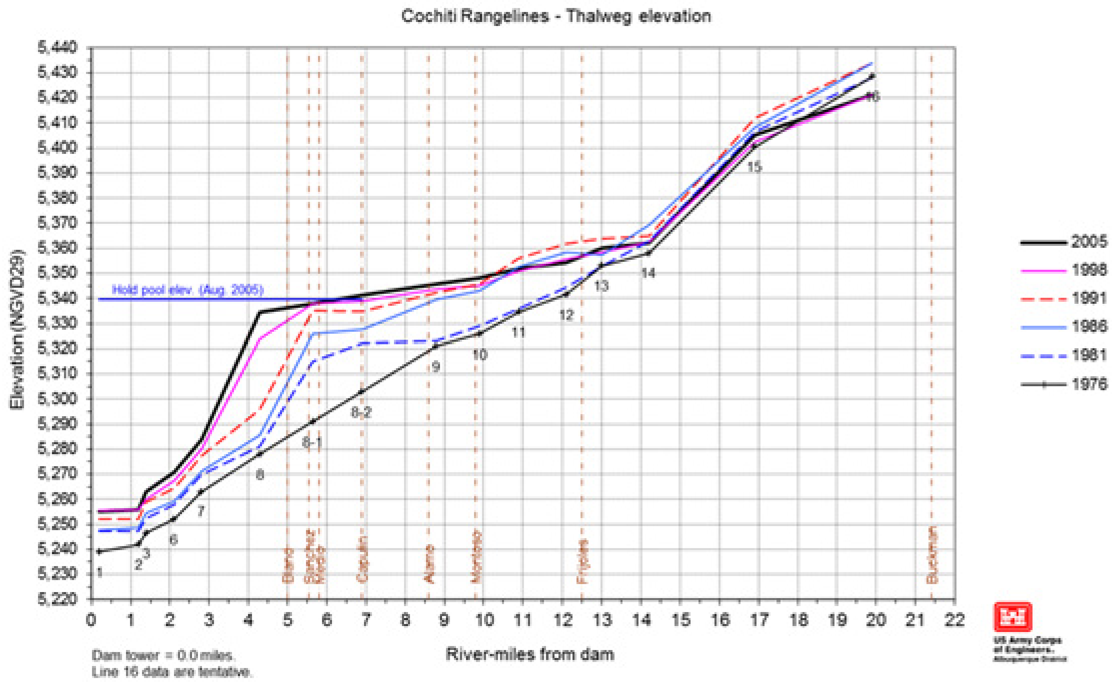
The change in total storage below 684.01 feet PD was assumed to be identical under *Baseline Operations* and *Anticipated Operations* scenarios. There is no information to determine the exact location of deposition downstream of RM 99.82, but the expected total change in volume is identical between the scenarios as discussed above. No changes were made to storage change below 684.01 feet PD, but the expected storage change was accounted for when calculating deposition in the upper left quadrant of Figure 145.

This resulted in the stage-storage curves for projected future bathymetry discussed below.

7.3 Deposition Patterns

Typical sediment deposition patterns in reservoirs follow a standard process (Vanoni 2006) illustrated in Figure 146. Sediment being carried by streamflow moves to the reservoir headwaters. As it reaches the headwaters and flow velocities decrease, sediment drops out of suspension and deposits, gradually forming a delta. Inflowing tributaries, stream geometry, bridges, and other features can also influence this process.

Figure 146
Typical Reservoir Delta Formation and Evolution—Progressive Bathymetric Surveys of the Cochiti Reservoir Delta, Rio Grande River, New Mexico



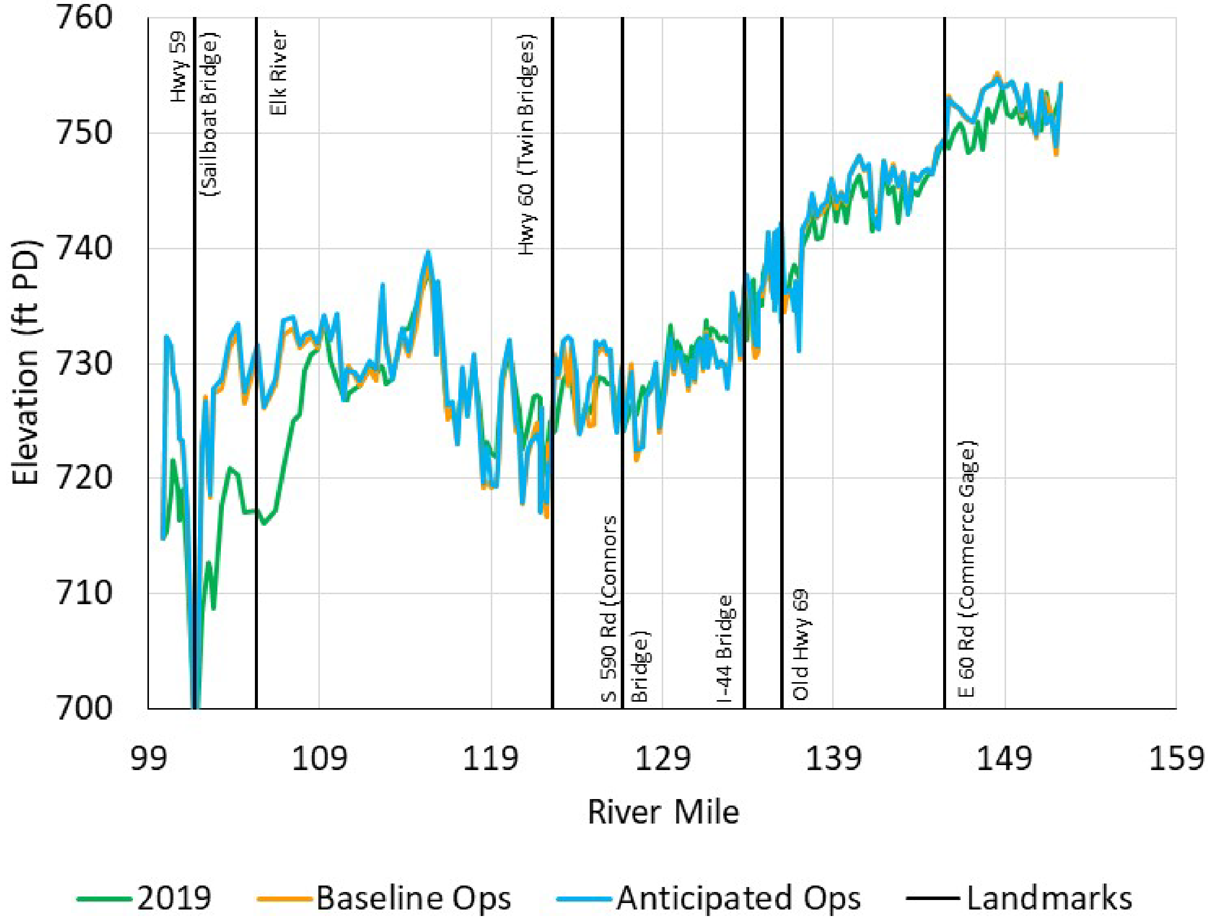
Source: WEST (2012)

Over time, the delta feature grows in height and decreases flow area within the channel. This results in raised stream velocities and associated bed shear stresses, which are the hydraulic drag forces on bed sediment. As the bed shear increases, it eventually reaches a dynamic equilibrium with the sediment critical shear stress (the bed shear stress at which sediment begins moving). The peak elevation of the delta feature stays relatively constant, gradually growing during normal and low flow events and eroding during large flow events.

As additional sediment moves into the system, it deposits further into the reservoir, adding to the downstream face of the delta feature (Vanoni 2006). Reviewing the results of the STM for future conditions shows that this typical pattern is followed in the Grand Lake reservoir.

As discussed in Section 6.2.2.1 of this document, the average channel profile provides a summary review of the final geometry that incorporates significantly more information than a simple thalweg profile. The results from the future simulations on the Neosho River are presented in Figure 147 and Figure 148.

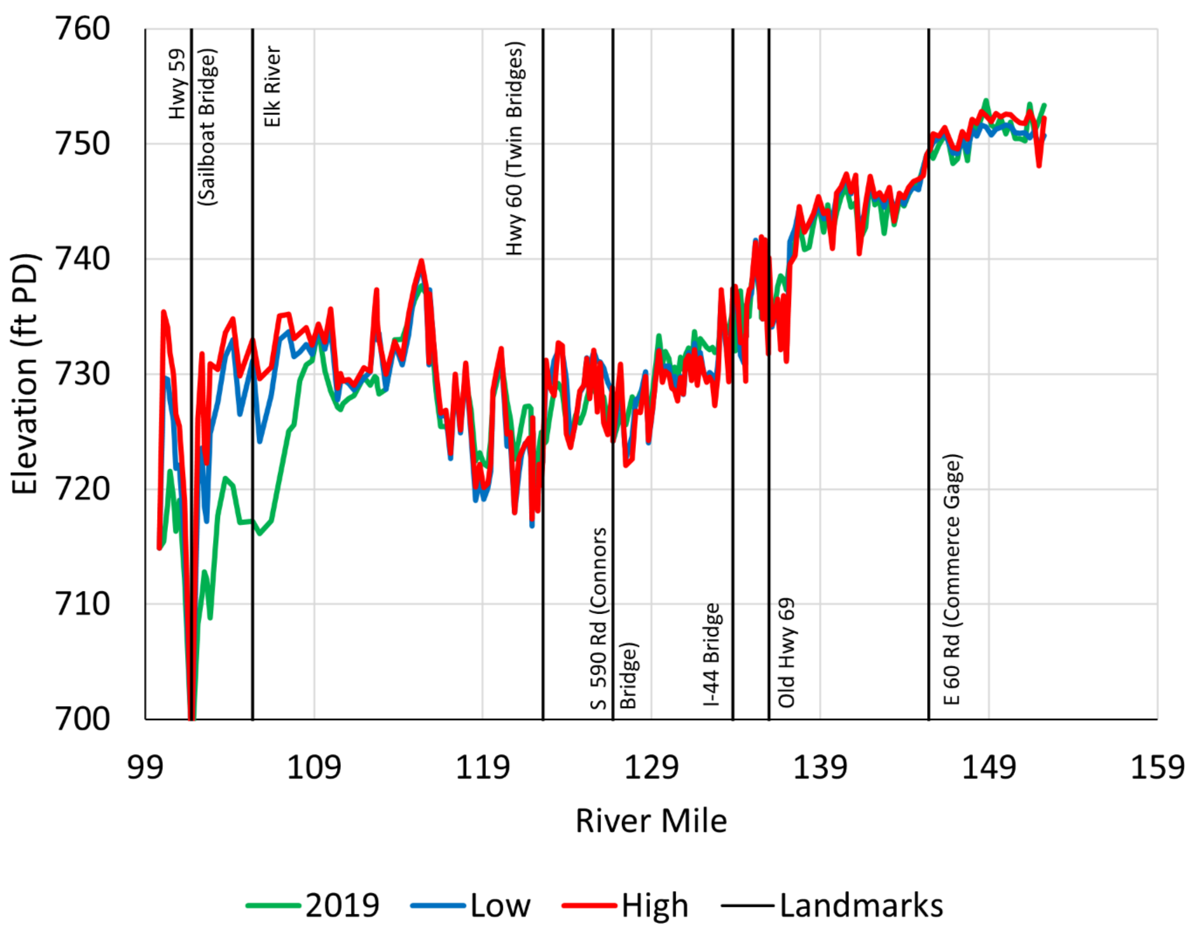
Figure 147
Neosho River Average Channel Showing Predicted Effects of Operations



As shown above, project operations have a limited impact on sediment deposition patterns. Most of the sediment is expected to deposit on the downstream face of the delta feature (below approximately RM 109) and wash further into the reservoir.

The mean difference is just 0.24 foot of increased bed elevation under the *Anticipated* operations as compared to *Baseline* operations, and the mean absolute difference is 0.49 foot.

Figure 148
Neosho River Average Channel Showing Predicted Effects of Sediment Loading



The differences between the bounding scenarios for potential sediment loading conditions are more significant than between operations parameters as shown in Table 48. The table shows a global change in average channel elevations as well as changes covering the entire delta feature and changes on the downstream face of the delta feature.

Table 48
Comparison of Average Channel Changes between Sediment Loading and Operations Scenarios

Comparison	Mean Change in Average Channel (feet)	Mean Change in Average Channel Below RM 122 (feet)	Mean Change in Average Channel Below RM 115.35 (feet)
High Sediment – Low Sediment	0.47	1.45	2.09
Anticipated Ops – Baseline Ops	0.24	0.38	0.45

As shown above, the sediment loading would account for approximately 2.54 times the deposition depth on the delta feature and 3.76 times the deposition depth on the downstream face of the feature as compared to the Project operational scenarios. Project operations, therefore, do not drive the majority of future sediment deposition within the reservoir.

Model results indicate that sediment loading to the system plays a larger role than Project operations. This is an important point to note because future sediment loading is projected to be lower than the long-term historical dataset indicates. This is attributable to a range of factors including the presence and operation of John Redmond Dam, which serves as a sediment barrier upstream of Grand Lake. Other changes include land use patterns, which show increased vegetation density since Project construction and a change from agriculture to woodland as well as changes to agricultural practices including no-till and cover crop programs that are incentivized by the NRCS. This change also decreases the amount of sediment entering the system from stormwater runoff, lowering future sediment deposition volumes. The model was run using the historical sediment inflow rating curves, which means predicted deposition is *higher* than anticipated future sediment deposition, and therefore represents a conservative estimate of future sedimentation and its impacts.

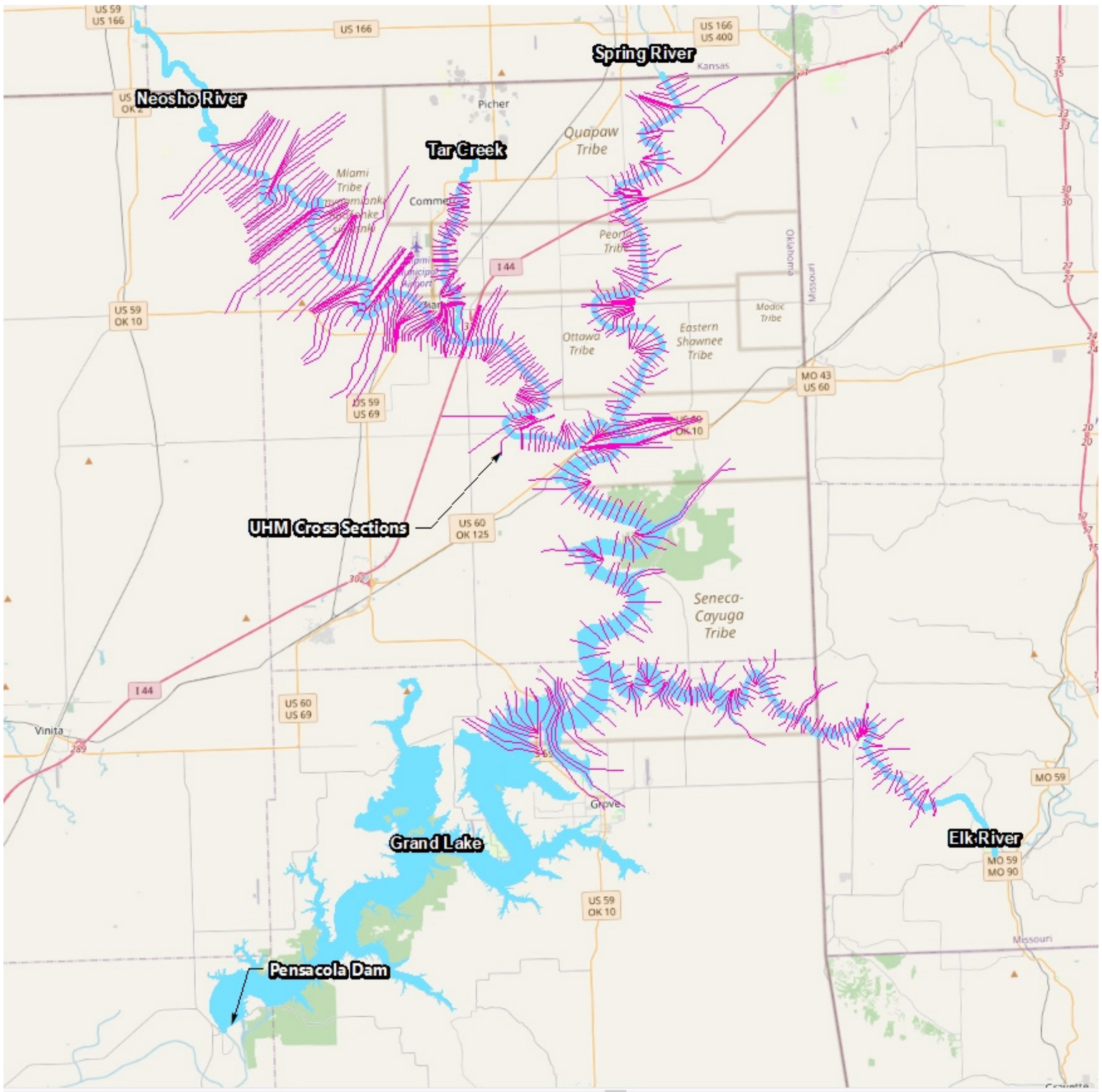
For all modeled scenarios, the sediment deposition follows typical reservoir deposition patterns, with sedimentation largely occurring downstream of the existing delta feature rather than continuing to increase the delta elevation. To evaluate the impacts of sediment deposition on upstream water levels, the final model geometries were used to create 1D UHMs.

7.4 1D Upstream Hydraulic Model Simulations

7.4.1 Background

The geometry files from the long-term STM simulations were imported to the 1D UHM for hydraulic analysis. Mead & Hunt developed the UHM to analyze the flooding impacts of modeled sedimentation. The 1D UHM was based on the STM and was developed in HEC-RAS v. 6.2 to maintain consistency with the STM. This model is distinct from the STM because it is run in hydraulic-only simulations using the fully unsteady mode. It is also distinct from the 1D/2D UHM discussed in the H&H study report. Figure 149 displays the 1D UHM model cross sections and extent.

Figure 149
1D UHM Model Cross Sections and Extent



The calibrated 1D UHM was used to assess the hydraulic impact of sediment transport from 2019 to 2069 as estimated by the STM. Mead & Hunt performed hydraulic simulations of the 2069 geometry using a variety of sedimentation scenarios and dam operations in combination with the starting pool elevations and inflow events specified by FERC in its May 27, 2022 SMD (Table 49).

Table 49
1D UHM Simulation Runs Completed

Inflow Event and Starting WSE (feet PD)	Existing Stage-Storage	Future Stage-Storage			
		Anticipated Ops			***Baseline Ops***
	Sediment Rate N/A	**Expected Sediment**	**Low Sediment**	**High Sediment**	**Expected Sediment**
July 2007, 740	✔	✔	✔	✔	✔
July 2007, 745	✔	✔	✔	✔	✔
July 2007, 750	✔	✔	✔	✔	✔
100-Year, 740	✔	✔	✔	✔	✔
100-Year, 745	✔	✔	✔	✔	✔
100-Year, 750	✔	✔	✔	✔	✔

As shown in the table, the evaluations considered three starting WSEs, three sediment loading rates, and two operational scenarios and compared them against existing conditions.

The 2069 STM geometry represents the predicted topo-bathymetric surface after 50 years of simulated sediment transport. The impact of dam operations on sediment transport diminishes with distance from the dam. Sediment transport is a natural process and significant geomorphic changes would occur in the study area regardless of the dam operation. The changes in WSE shown in the 1D UHM results are based on changes in bathymetry.

With any model results, boundary effects can skew data at the edges of the domain. This is apparent in the STM where coarser sediments dropped out of suspension near the upstream ends; based on measured changes in these portions of the river, it is clear that this is a numerical artifact rather than a real result. Therefore, the analyses have considered *only* the portions of the model not impacted by these BCs. The following analyses cover the river reaches shown in Table 50.

Table 50
River Reaches Considered in WSE Analyses

Stream	Analyzed Region
Neosho River	99.82–145.40
Tar Creek	1.60–7.00
Spring River	0.00–17.00
Elk River	0.00–15.00

7.4.2 Results and Discussion

The results demonstrate that future sediment inflow volumes play the primary role in determining upstream water levels during large flow events. Project operations are less important than the total volume of sediment entering the system. The following sections detail the findings on the Neosho River. Spring River, Elk River, and Tar Creek figures and tables are presented in Appendix F.

7.4.2.1 Future Anticipated Operations versus Existing Conditions

The first comparisons were made between the STM-generated 2069 geometry and existing 2019 geometry. Both sets of simulations were performed using anticipated operations, so differences shown in Table 51 are purely the result of the different geometries.

Table 51
WSE Changes from Future Geometry Compared to Existing Conditions under *Anticipated Operations* during Two Flow Events

Starting Stage (feet PD)	July 2007 (4-Year) Event				100-Year Event			
	Neosho River	Spring River	Elk River	Tar Creek	Neosho River	Spring River	Elk River	Tar Creek
Maximum Increase in WSE								
740	1.28	0.36	1.13	-0.03	1.24	0.60	1.29	0.07
745	1.19	0.21	1.08	-0.03	1.25	0.61	1.29	0.07
750	0.57	0.09	1.04	-0.04	1.25	0.64	1.29	0.07
Max	**1.28**	**0.36**	**1.13**	**-0.03**	**1.25**	**0.64**	**1.29**	**0.07**
Maximum Decrease in WSE								
740	-0.07	-2.19	-0.39	-0.94	-0.01	-1.79	-0.67	-0.70
745	-0.07	-2.18	-0.22	-0.94	-0.01	-1.78	-0.67	-0.70
750	-0.68	-2.18	-0.35	-0.94	-0.01	-1.77	-0.67	-0.70
Min	**-0.68**	**-2.19**	**-0.39**	**-0.94**	**-0.01**	**-1.79**	**-0.67**	**-0.70**
Average Change in WSE (feet)								
740	0.27	-0.26	0.15	-0.36	0.40	-0.09	0.13	-0.13
745	0.23	-0.29	0.08	-0.36	0.40	-0.09	0.16	-0.13
750	-0.04	-0.55	-0.07	-0.37	0.41	-0.07	0.13	-0.13

Notes: Positive values indicate increased WSE under 2069 geometry as compared to 2019 geometry.
"Max" provides the largest increase in WSE across all starting pool elevations and locations within a stream.
"Min" provides the largest decrease (or smallest increase) in WSE across all starting pool elevations and locations within a stream.

The level of impact increases as starting pool elevation decreases for the July 2007 event and increases as starting pool elevation increases for the 100-year event.

Figure 150 shows the changes in WSE from RM 130 to RM 140 on the Neosho River for the July 2007 event. It indicates that the changes in WSE near the City of Miami are generally negligible during the July 2007 event simulation, meaning future geometry under *Anticipated Operations* predicts a *similar* WSE to existing conditions. The largest positive change between RM 133 and RM 137 occurs with starting pool elevations of 740 feet PD and 745 feet PD; the future geometry resulted in water levels 0.11 foot higher at RM 134.28 upstream of the Tar Creek confluence for both starting pool elevations.

Figure 150
Changes in July 2007 Event WSE Due to 50 Years of Expected Sedimentation under *Anticipated Operations* Compared to Existing Conditions from RM 130 to RM 140

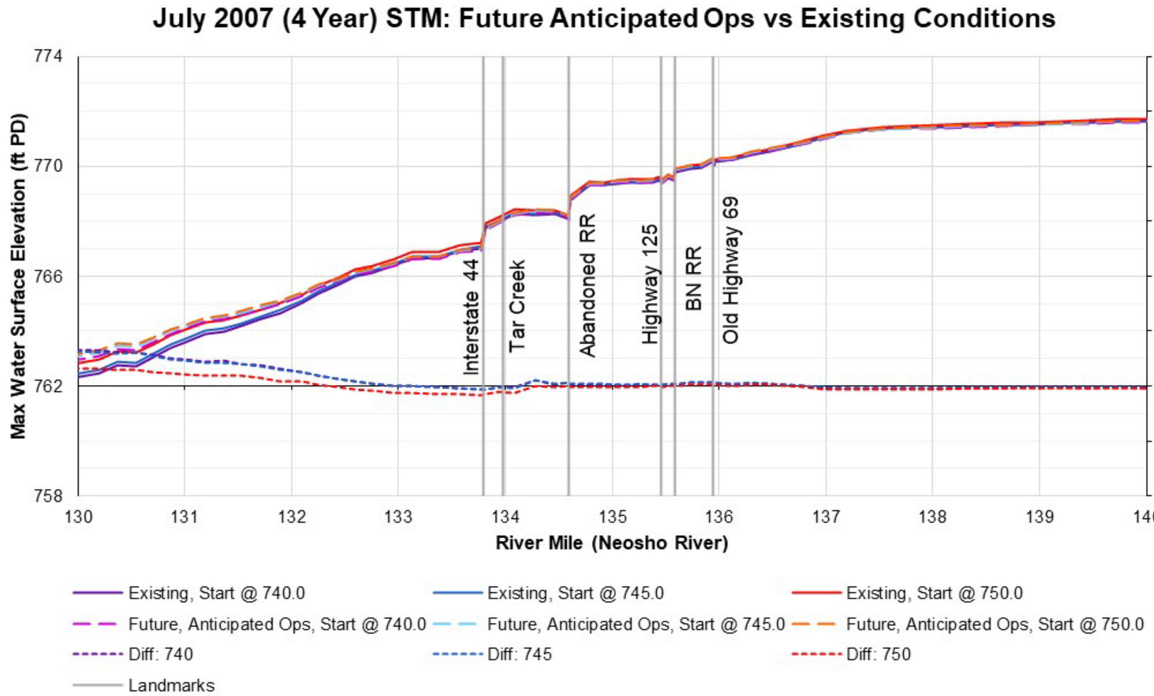
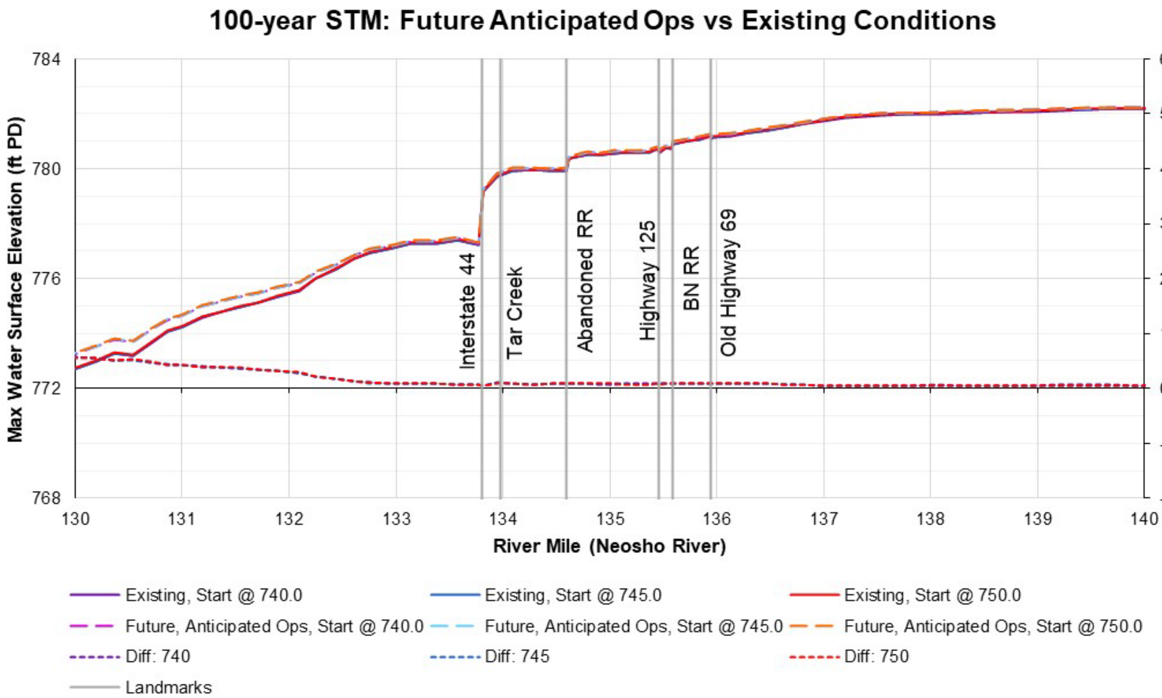


Figure 151 shows the changes in WSE from RM 130 to RM 140 on the Neosho River for the 100-year event. It indicates that the changes in WSE near the City of Miami are generally negligible during the 100-year event simulation, meaning future geometry under *Anticipated Operations* predicts a *similar* WSE to existing conditions. The largest positive change between RM 133 and RM 137 occurs with starting pool elevations of 740 feet and 745 feet PD; the future geometry resulted in water levels 0.11 foot higher at RM 133.94 near the confluence with Tar Creek.

Figure 151
Changes in 100-Year Event WSE Due to 50 Years of Expected Sedimentation under *Anticipated Operations* Compared to Existing Conditions from RM 130 to RM 140



These results indicate that under both the July 2007 and 100-year flow events, water levels near Miami are expected to remain virtually unchanged despite 50 years of future sediment deposition under the anticipated operations.

Figure 152 shows the changes in WSE farther downstream, from RM 120 to RM 130 on the Neosho River for the July 2007 event. It indicates that the changes in WSE during the July 2007 event simulation are largest downstream of Miami, peaking near South 590 Road (Connors Bridge). The largest positive change between RM 120 and RM 130 occurs with a starting pool elevation of 740 feet PD; the future geometry resulted in water levels 1.28 feet higher at RM 126.39, with an average WSE impact of less than 0.30 foot.

Figure 152
Changes in July 2007 Event WSE Due to 50 Years of Expected Sedimentation under *Anticipated Operations* Compared to Existing Conditions from RM 120 to RM 130

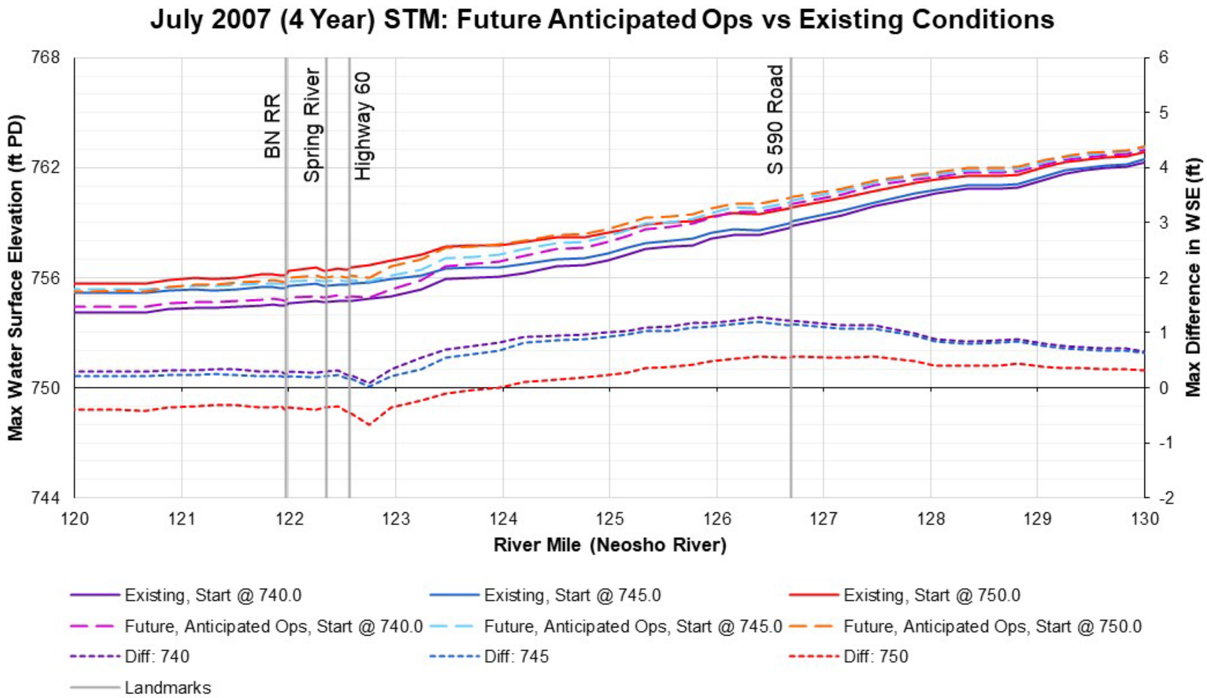
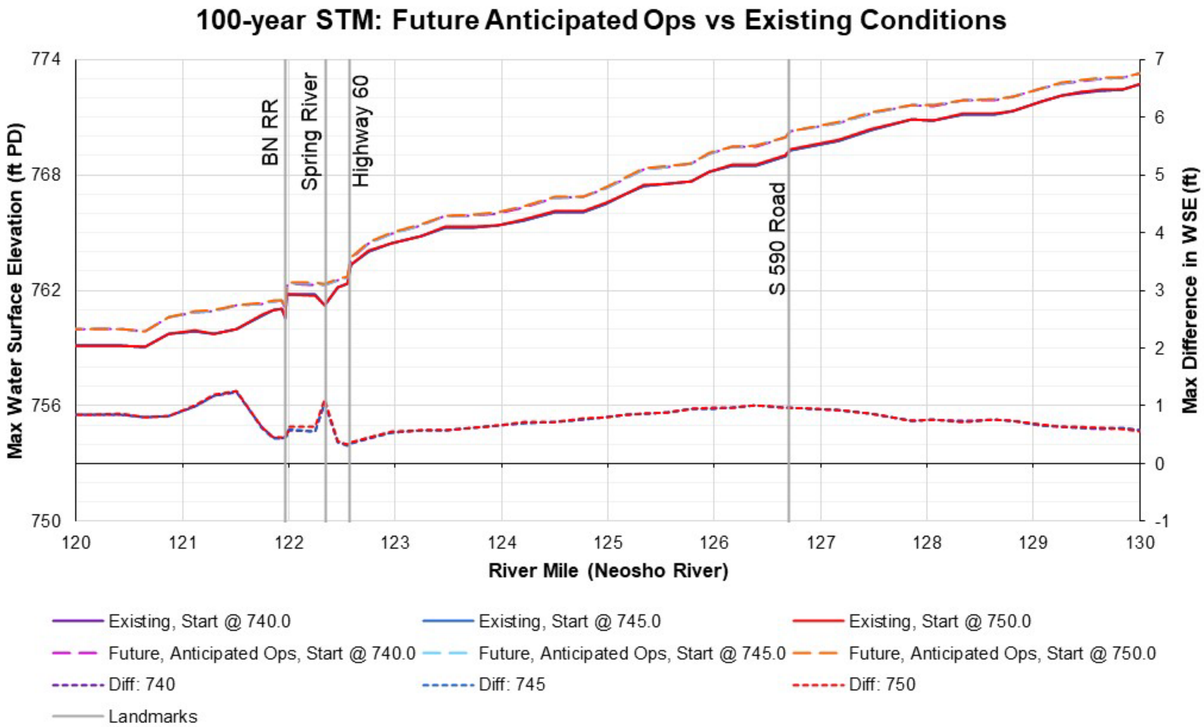


Figure 153 shows the changes in WSE from RM 120 to RM 130 on the Neosho River for the 100-year event. It indicates that the changes in WSE during the 100-year event simulation are largest downstream of Miami, peaking below Twin Bridges. The largest positive change between RM 120 and RM 130 occurs with a starting pool elevation of 750 feet PD; the future geometry resulted in water levels 1.06 feet higher at RM 121.29, with an average WSE impact of 0.30 foot or less.

Figure 153
Changes in 100-Year Event WSE Due to 50 Years of Expected Sedimentation under *Anticipated Operations* Compared to Existing Conditions from RM 120 to RM 130



These results indicate that under both the July 2007 and 100-year flow events, water levels on the Neosho River are expected to remain similar despite 50 years of future sediment deposition under the anticipated operations. The largest impacts to WSE occur downstream of the urbanized area of Miami and are no more than 1.25 feet anywhere on the Neosho River. There is no indication that the expected future sedimentation will significantly impact inundation near heavily populated areas of Miami.

7.4.2.2 Sedimentation Rate Sensitivity

The next comparisons were performed to evaluate the impact of sediment loading on upstream WSEs. The following figures compare simulated WSE profiles for *High Sedimentation* rates and *Low Sedimentation* rates. These simulations used anticipated operations and results are shown in Table 52.

Table 52
WSE Changes between *High Sedimentation* and *Low Sedimentation* Scenarios during Two Flow Events

Starting Stage (feet PD)	July 2007 (4-Year) Event				100-Year Event			
	Neosho River	Spring River	Elk River	Tar Creek	Neosho River	Spring River	Elk River	Tar Creek
Maximum Increase in WSE								
740	0.41	0.33	0.24	0.12	1.21	0.46	0.28	0.09
745	1.38	1.13	0.20	0.12	1.21	0.46	0.28	0.09
750	0.26	0.26	0.20	0.12	0.80	0.52	0.28	0.09
Max	**1.38**	**1.13**	**0.24**	**0.12**	**1.21**	**0.52**	**0.28**	**0.09**
Maximum Decrease in WSE								
740	-0.34	0.05	0.01	-0.06	-0.03	-0.01	-0.05	-0.02
745	-0.30	0.10	0.01	-0.03	-0.03	-0.01	-0.05	-0.02
750	-0.38	0.10	0.00	-0.08	-0.02	0.00	-0.05	-0.02
Min	**-0.38**	**0.05**	**0.00**	**-0.08**	**-0.03**	**-0.01**	**-0.05**	**-0.02**
Average Change in WSE (feet)								
740	0.06	0.19	0.15	0.01	0.22	0.24	0.13	0.01
745	0.30	0.59	0.14	0.02	0.22	0.24	0.14	0.01
750	0.02	0.18	0.02	0.00	0.20	0.27	0.15	0.01

Notes: Positive values indicate increased WSE under *High Sedimentation* loads compared to *Low Sedimentation* loads.
"Max" provides the largest increase in WSE across all starting pool elevations and locations within a stream.
"Min" provides the largest decrease (or smallest increase) in WSE across all starting pool elevations and locations within a stream.

Figure 154 shows the changes in WSE from RM 130 to RM 140 on the Neosho River for the July 2007 event. It indicates that the changes in WSE near the City of Miami are 0.06 foot or less during the July 2007 event simulation, meaning future geometry under high sediment loading predicts slightly higher WSE as compared to low sediment loading under anticipated operations. The largest positive change between RM 133 and RM 137 occurs with a starting pool elevation of 745 feet PD; the *High Sedimentation* geometry resulted in water levels 0.06 foot higher at RM 134.585 near the abandoned railroad bridge.

Figure 154
Changes in July 2007 Event WSE Due to 50 Years of Sedimentation under *High* and *Low Sedimentation* Conditions from RM 130 to RM 140

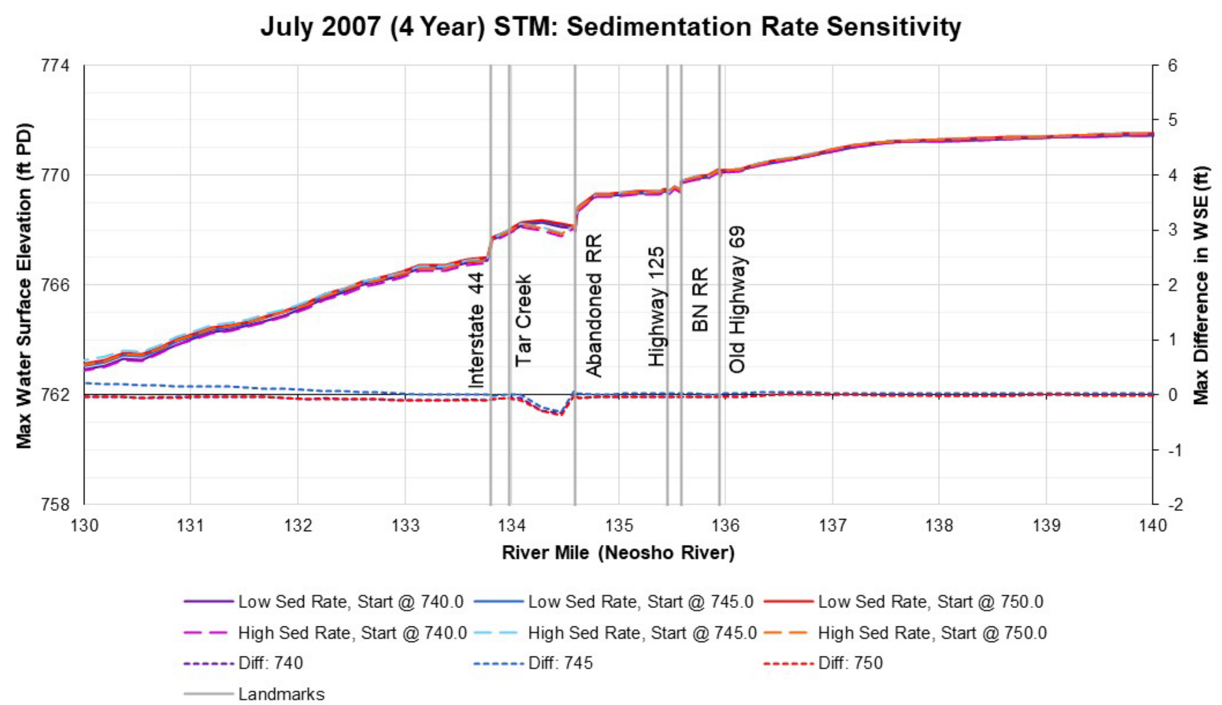
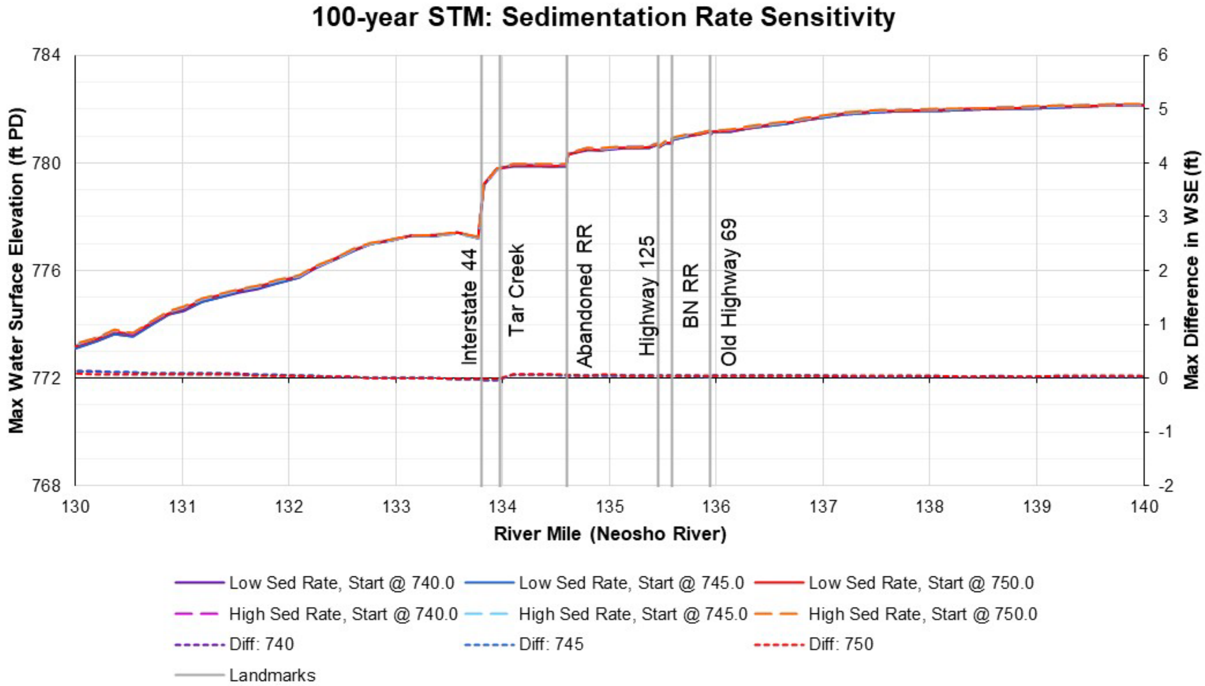


Figure 155 shows the changes in WSE from RM 130 to RM 140 on the Neosho River for the 100-year event. It indicates that the changes in WSE near the City of Miami are generally 0.04 foot or less during the 100-year event simulation, meaning future geometry under high sediment loading predicts similar WSE as compared to low sediment loading under anticipated operations. The largest positive change between RM 133 and RM 137 occurs with a starting pool elevation of 750 feet PD; the *High Sedimentation* geometry resulted in water levels 0.07 foot higher at RM 134.46 near the confluence with Tar Creek.

Figure 155
Changes in 100-Year Event WSE Due to 50 Years of Sedimentation under *High* and *Low Sedimentation* Conditions from RM 130 to RM 140



These results indicate that under both the July 2007 and 100-year flow events, water levels near Miami are expected to remain nearly constant regardless of sediment loading to the study area despite 50 years of future sediment deposition under the anticipated operations.

Figure 156 shows the changes in WSE from RM 120 to RM 130 on the Neosho River for the July 2007 event. It indicates that the changes in WSE during the July 2007 event simulation are largest downstream of Miami, peaking approximately 0.5 mile upstream of Twin Bridges. The largest positive change between RM 120 and RM 130 occurs with a starting pool elevation of 745 feet PD; the future geometry resulted in water levels 1.38 feet higher at RM 123.24 upstream of Twin Bridges.

Figure 156
Changes in July 2007 Event WSE Due to 50 Years of Sedimentation under *High* and *Low* *Sedimentation* Conditions from RM 120 to RM 130

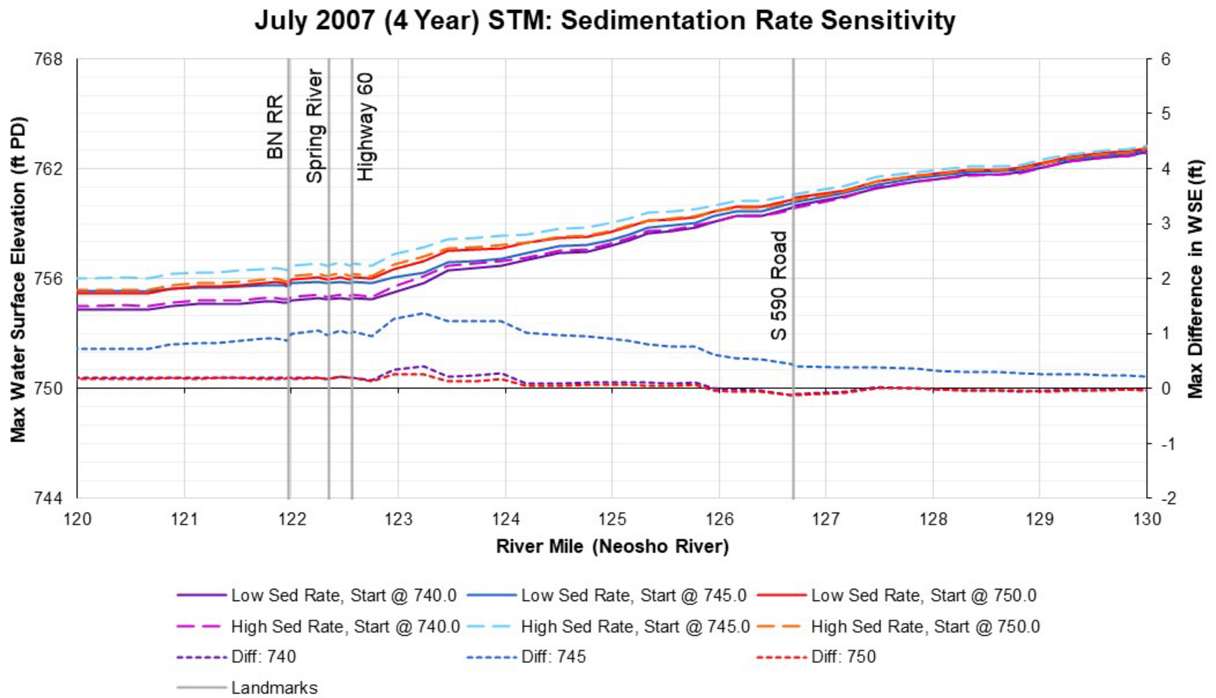
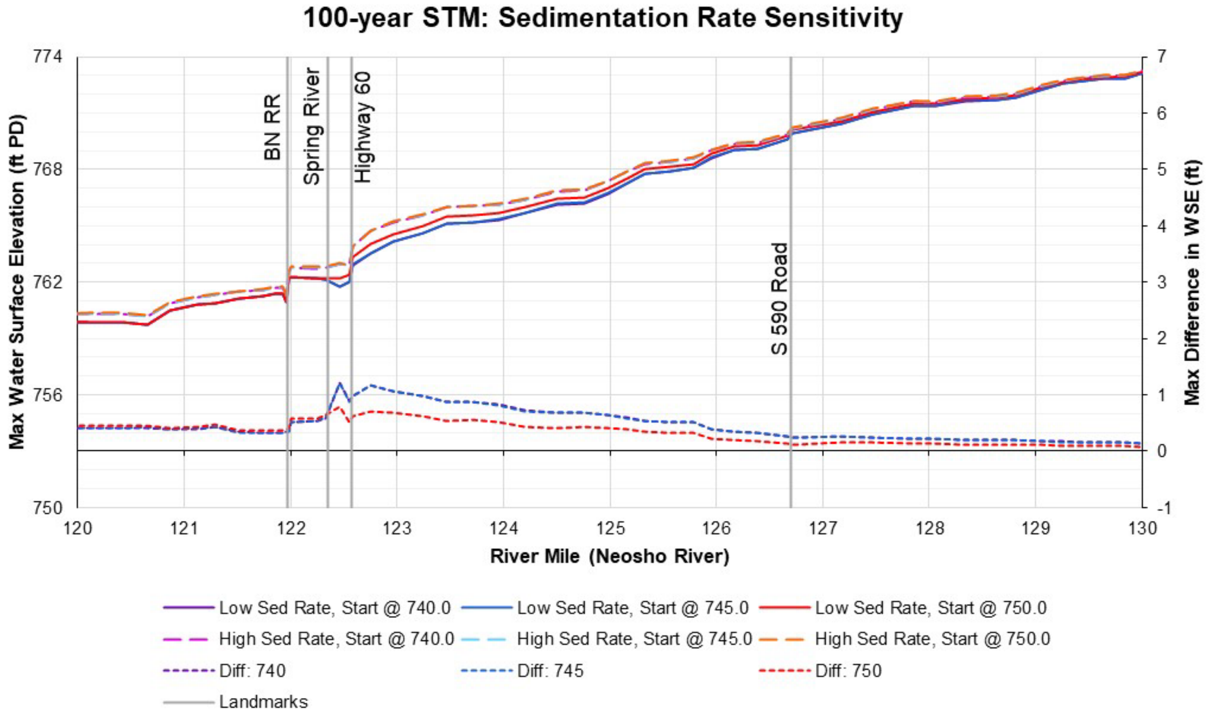


Figure 157 shows the changes in WSE from RM 120 to RM 130 on the Neosho River for the 100-year event. It indicates that the changes in WSE during the 100-year event simulation are largest downstream of Miami, peaking near the Spring River confluence. The largest positive change between RM 120 and RM 130 occurs with a starting pool elevation of 745 feet PD; the future geometry resulted in water levels 1.21 feet higher at RM 122.46 near Twin Bridges.

Figure 157
Changes in 100-Year Event WSE Due to 50 Years of Sedimentation under *High* and *Low Sedimentation* Conditions from RM 120 to RM 130



These results indicate that under both the July 2007 and 100-year flow events, water levels on the Neosho River are expected to change by as much as 1.38 feet due to the variability of sediment loading. The largest impacts to WSE occur downstream of the urbanized area of Miami near Twin Bridges. There is no indication that the future sedimentation will significantly impact inundation near heavily populated areas of Miami.

The impacts of sediment loading rates on upstream water levels are similar to those found between current and future conditions. Further, the impacts occur primarily downstream of the City of Miami. The results show that the predicted range of inflowing sediment quantity, which is not controlled by GRDA, is similar to the expected changes between 2019 and 2069 under anticipated operations.

7.4.2.3 Operations Sensitivity

The third comparison was performed to evaluate the impact of Project operations on upstream water levels. The following section compares WSE impacts between 50 years of simulated *Baseline Operations* and 50 years of simulated *Anticipated Operations*. Sediment loading was identical for these simulations. Both simulations represent a future (2069) bed condition. The only difference was Project operation. The findings are summarized in Table 53.

Table 53
WSE Changes between *Anticipated Operations* and *Baseline Operations* Scenarios during Two Flow Events

Starting Stage (feet PD)	July 2007 (4-Year) Event				100-Year Event			
	Neosho River	Spring River	Elk River	Tar Creek	Neosho River	Spring River	Elk River	Tar Creek
Maximum Increase in WSE								
740	0.09	0.07	-0.09	0.09	1.09	0.27	0.06	0.17
745	0.03	0.07	0.00	0.09	1.11	0.26	0.06	0.17
750	0.26	0.06	0.02	0.09	1.14	0.29	0.06	0.17
Max	**0.26**	**0.07**	**0.02**	**0.09**	**1.14**	**0.29**	**0.06**	**0.17**
Maximum Decrease in WSE								
740	-1.39	-1.30	-0.89	-0.11	0.00	-0.02	-0.13	-0.05
745	-1.07	-0.87	-0.14	-0.13	0.00	-0.02	-0.13	-0.05
750	-0.17	-0.29	-0.21	-0.13	0.00	-0.03	-0.13	-0.05
Min	**-1.39**	**-1.30**	**-0.89**	**-0.13**	**0.00**	**-0.03**	**-0.13**	**-0.05**
Average Change in WSE (feet)								
740	-0.48	-0.51	-0.81	-0.02	0.22	0.13	0.03	0.01
745	-0.19	-0.36	-0.07	-0.02	0.22	0.14	0.02	0.01
750	-0.03	-0.03	-0.04	-0.02	0.22	0.14	0.02	0.02

Notes: Positive values indicate increased WSE under *Anticipated Operations* compared to *Baseline Operations.*
"Max" provides the largest increase in WSE across all starting pool elevations and locations within a stream.
"Min" provides the largest decrease (or smallest increase) in WSE across all starting pool elevations and locations within a stream.

Figure 158 shows the changes in WSE from RM 130 to RM 140 on the Neosho River for the July 2007 event. It indicates that the changes in WSE near the City of Miami are generally negative during the July 2007 event simulation, meaning future geometry under *Anticipated Operations* predicts *lower* WSE as compared to future geometry under *Baseline Operations*. The largest positive change between RM 133 and RM 137 occurs with a starting pool elevation of 740 feet PD; the *Anticipated Operations* geometry resulted in water levels 0.03 foot higher at RM 135.96 near the Old Highway 69 Bridge.

Figure 158
Changes in July 2007 Event WSE Due to 50 Years of Expected Sedimentation under *Anticipated* and *Baseline Operations* Conditions from RM 130 to RM 140

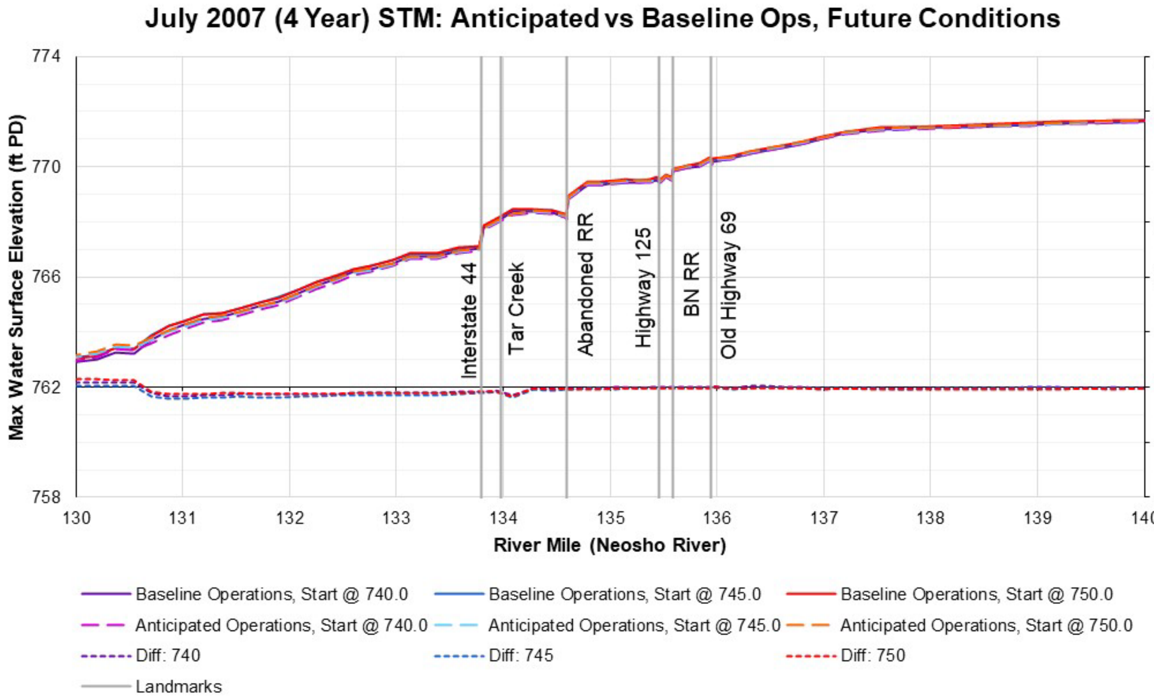
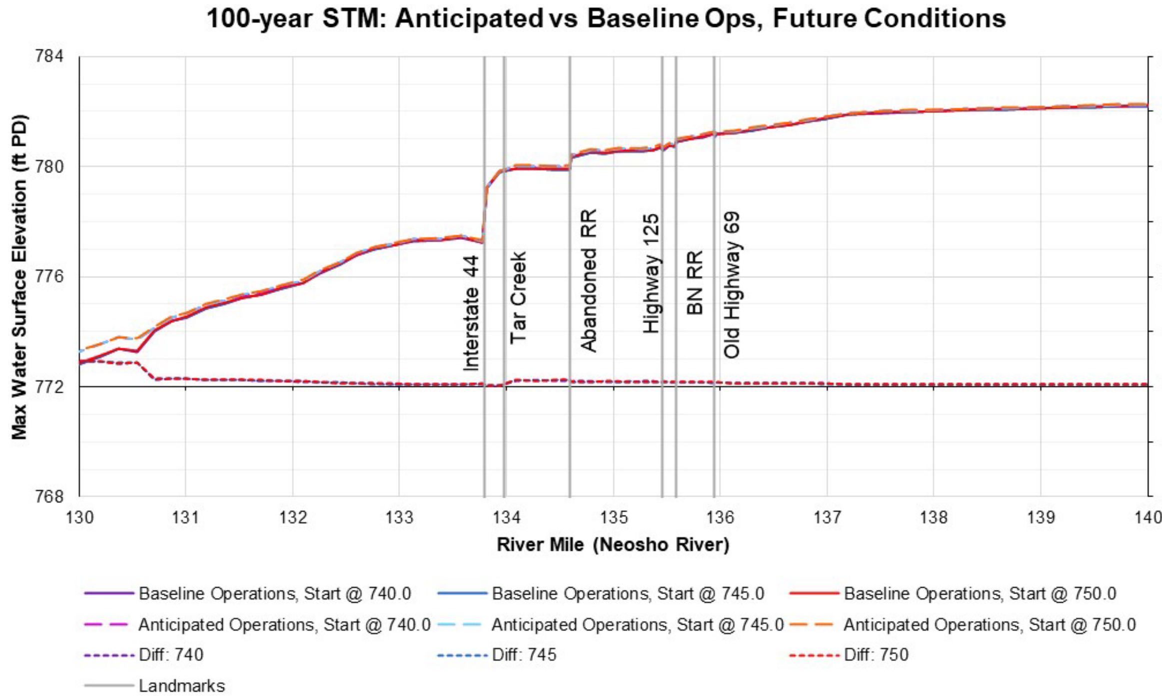


Figure 159 shows the changes in WSE from RM 130 to RM 140 on the Neosho River for the 100-year event. It indicates that average changes in WSE near the City of Miami are 0.05 foot during the 100-year event simulation, meaning future geometry under *Anticipated Operations* predicts similar WSE as compared to future geometry under *Baseline Operations*. The largest positive change between RM 133 and RM 137 occurs with a starting pool elevation of 750 feet PD; the *Anticipated Operations* geometry resulted in water levels 0.12 foot higher near RM 134.46 upstream of Tar Creek.

Figure 159
Changes in 100-Year Event WSE Due to 50 Years of Expected Sedimentation under *Anticipated* and *Baseline Operations* Conditions from RM 130 to RM 140



These results indicate that under both the July 2007 and 100-year flow events, water levels near Miami are expected to remain similar regardless of Project operations despite 50 years of future sediment deposition. In the smaller, more frequent July 2007 event, *Anticipated Operations* resulted in decreased average water levels near the urbanized areas of Miami.

Figure 160 shows the changes in WSE from RM 120 to RM 130 on the Neosho River for the July 2007 event. It indicates that the increases in WSE during the July 2007 event simulation are largest downstream of Miami, peaking between South 590 Road (Connors Bridge) and Twin Bridges. The largest positive change between RM 120 and RM 130 occurs with a starting pool elevation of 750 feet PD; the *Anticipated Operations* geometry resulted in water levels 0.26 foot higher at RM 125.78 downstream of Connors Bridge. It also indicates that water levels are typically *lower* under *Anticipated Operations* as compared to *Baseline Operations* with a maximum *decrease* of 1.39 feet at RM 122.96 upstream of Twin Bridges with a starting pool elevation of 740 feet PD.

Figure 160
Changes in July 2007 Event WSE Due to 50 Years of Expected Sedimentation under *Anticipated* and *Baseline Operations* Conditions from RM 120 to RM 130

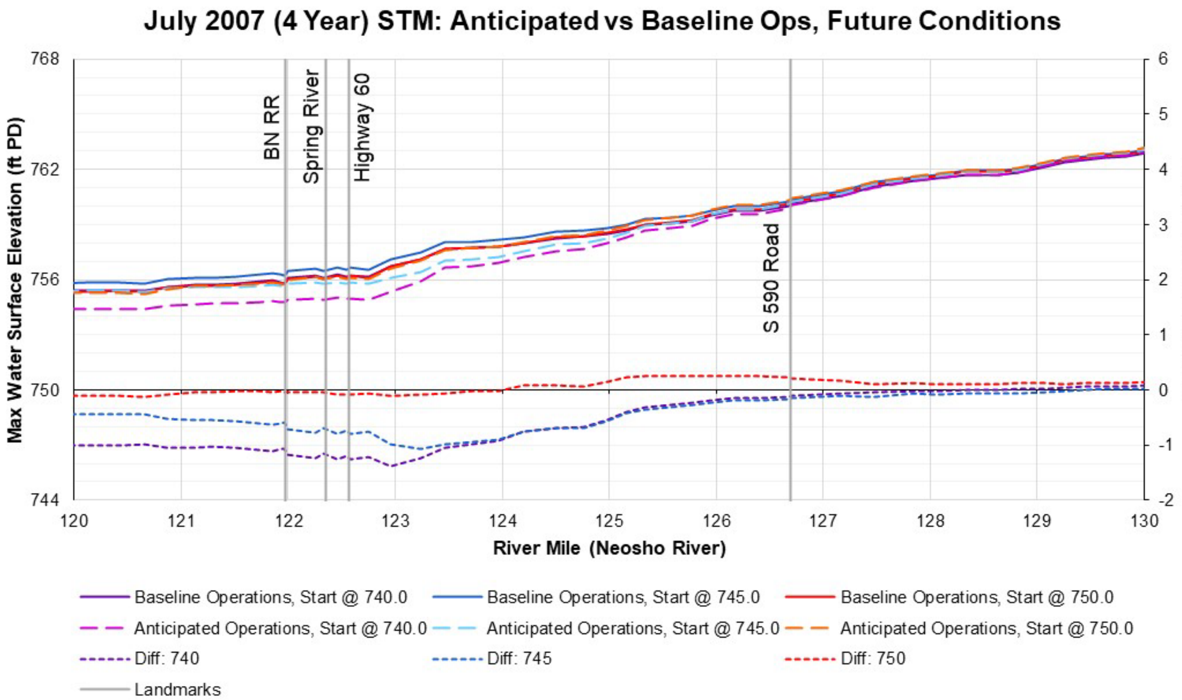
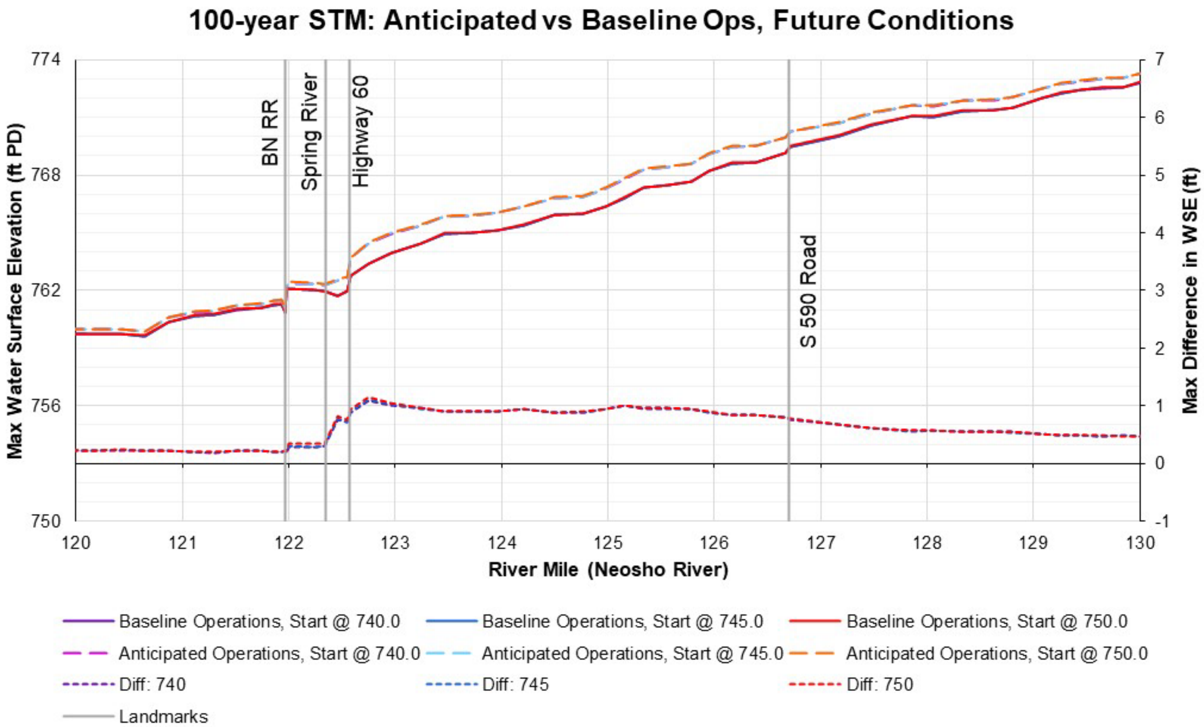


Figure 161 shows the changes in WSE from RM 120 to RM 130 on the Neosho River for the 100-year event. It indicates that the changes in WSE during the 100-year event simulation are largest downstream of Miami, peaking upstream of Twin Bridges. The largest positive change between RM 120 and RM 130 occurs with a starting pool elevation of 750 feet PD; the *Anticipated Operations* geometry resulted in water levels 1.14 feet higher at RM 122.75, upstream of the Highway 60 Bridge.

Figure 161
Changes in 100-Year Event WSE Due to 50 Years of Expected Sedimentation under *Anticipated* and *Baseline Operations* Conditions from RM 120 to RM 130



These results indicate that under the July 2007 event, average water levels on the Neosho River are expected to decrease by 0.35 foot, with a maximum decrease of 1.39 feet under *Anticipated Operations*. During 100-year flow events, average water levels on the Neosho River are expected to increase 0.22 foot under *Anticipated Operations*. There is no indication that the future Project operations will significantly impact inundation near heavily populated areas of Miami.

The impacts of Project operations on upstream water levels are limited and occur primarily downstream of the City of Miami. The results show that during the more typical 4-year flows such as the July 2007 event, *Anticipated Operations* will result in *lower* average water levels, and the changes in WSE near Miami are immaterial.

7.4.3 1D UHM Summary

The results show that potential impacts to WSE due to sedimentation are primarily the result of future sediment loading to the study area (Table 54).

Table 54
Maximum WSE Increases on the Entire Neosho River during Simulated Events

Compared Scenarios	Maximum WSE Increase, July 2007 (feet)	Average WSE Increase, July 2007 (feet)	Maximum WSE Increase, 100-Year (feet)	Average WSE Increase, 100-Year (feet)
Future Geometry vs. Current Geometry	1.28	0.27	1.25	0.41
High Sedimentation vs. *Low Sedimentation*	1.38	0.30	1.21	0.22
Anticipated Operations vs. *Baseline Operations*	0.26	-0.03	1.14	0.22

The simulations show that sediment loading has the biggest impact on upstream water levels, particularly for the historical July 2007 event. Results indicate that the impact of sedimentation loading is more than 5 times the impact of Project operations during the July 2007 event and approximately 1.1 times as large during the 100-year event.

In all evaluations, the average impacts to WSE on the Neosho River during large flow events are expected to be 0.41 foot or less. The maximum impacts are related to differences in sediment loading under the July 2007 event. This fact is unsurprising and is again related to sediment moving into the reservoir; GRDA has no ability to prevent sediment from flowing downstream, and the simulation results do not suggest Project operations are the driving contributor to water level impacts.

These results are similar to the findings of the H&H study, which quantified how *nature* plays the defining role in upstream water levels rather than Project operations. GRDA exerts no more control over incoming sediment than it does over incoming water, and the quantity of incoming sediment is the biggest driver of increases in upstream WSE over the 50-year license period.

Further, all scenarios indicated the impacts to WSE in the City of Miami due to sedimentation or Project operations are immaterial (Table 55). For the evaluations shown, "Vicinity of Miami, OK" was defined as the reach of the Neosho River from RM 133 to RM 137.

Table 55
Maximum WSE Increases on the Neosho River in the Vicinity of Miami, Oklahoma, during Simulated Events

Compared Scenarios	Maximum WSE Increase, July 2007 (feet)	Average WSE Increase, July 2007 (feet)	Maximum WSE Increase, 100-Year (feet)	Average WSE Increase, 100-Year (feet)
Future Geometry vs. Current Geometry	0.11	0.03	0.11	0.08
High Sedimentation vs. *Low Sedimentation*	0.06	0.00	0.07	0.04
Anticipated Operations vs. *Baseline Operations*	0.03	-0.03	0.12	0.08

Notes: Vicinity of Miami is defined as between RM 133 and RM 137.

The results indicate that the impacts of sedimentation on WSE are immaterial in urbanized areas, regardless of loading rates, Project operations, or future versus current geometry. This finding further confirms the fact that Project operations are not a major contributor to increased upstream water levels in the City of Miami or other urbanized portions of the study area. Downstream of Miami, sediment loading, a natural phenomenon outside GRDA’s control, has the biggest impact on WSE.

8 Conclusions

The Sedimentation Study produced several significant findings. The first major change in available information was that the sediment moving through the study area was dominated by cohesive material rather than sand and gravel as claimed by the City (2018). A second significant finding is that the delta feature apparent in the 2009 OWRB survey but not visible in bathymetry claimed by the City's consultant to be surveyed circa 1998 did *not* in fact form over a period of 11 years. The third major finding is that sedimentation is primarily driven by the amount of sediment conveyed into the system and *not* by Project operations.

The City argued in their 2018 response to GRDA's preliminary study plan that "The cohesive sediment is carried as wash load well downstream into the reservoir, and deposition and re-entrainment of that material has very little, if any effect, on upstream channel capacity and flooding." This statement implied that cohesive material was unimportant to understanding sediment transport within the study area, and that the only material of interest was the non-cohesive sands and gravels. Multiple sampling efforts of bedload and suspended sediment load by GRDA revealed virtually no coarse material moving through the system.

The importance of cohesive material complicated STM development. HEC-RAS is an excellent tool for evaluating hydraulics and non-cohesive sediment transport but is more limited in its ability to simulate cohesive sediment transport. As a result, it was necessary to model only the upper portions of the system rather than extending the model to Pensacola Dam where cohesive materials reduce the reliability of predictive HEC-RAS models. Calibration required more comprehensive inputs to evaluate critical shear stress, erosion rates, and mobility parameters with the cohesive sediments.

This increased relevance of cohesive materials also introduced uncertainty to the model. Spatial variations in erosive parameters are present in all sedimentation studies, but cohesive material introduces significant temporal variability as well. As cohesive material accumulates, it compresses and consolidates, increasing density and critical shear stress.

The second major discovery of the Sedimentation Study was that the terrain information initially proposed for use in the study was unreliable. This is covered in significant detail in Section 2.1.1, but the key takeaways are as follows:

- The 1998 REAS dataset did *not* extend downstream of RM 120.1 and the data below that point are from an unknown time period, likely circa 1940, despite the City's arguments that GRDA should be required to use the REAS terrain for the entire system (City 2022).
- There is limited information available from circa 1940 including topographic maps of varying quality and cross-sectional survey information within the study area.

As detailed above, the reliable portions of the available datasets were used for STM development. However, although the data used represent the best available information, they are imperfect and introduce uncertainty to any measurements, particularly the circa-1940 data.

These datasets were flawed but nonetheless are also the most complete available for the relevant time periods. The data were used to evaluate sedimentation and future impacts through two separate approaches as part of the three-level process: the quantitative analysis and the STM. The objective of the three-level approach is to ensure that reasonable and reliable results are obtained. This is achieved if there is consistency between the results of the quantitative analysis and the STM.

The quantitative analysis approach utilized the hydraulic component of HEC-RAS to compute hydraulic shear stresses for historical flows and operation and future scenarios. The historical change in bathymetry was then related to hydraulic shear stresses for historical flows and operation to develop a relationship between hydraulic shear stress and the sedimentation pattern. The HEC-RAS hydraulic component was then run for future flow and operation scenarios to compute the hydraulic shear stresses under these future conditions. The resulting shear stresses were then used in the relationship between hydraulic shear and sedimentation pattern to compute sedimentation for the future scenarios. The quantitative analysis (Section 4) concluded the following:

> The quantitative analysis of the future 50 years of hydrology and operation shows no significant sediment deposition on top of the delta feature that would adversely affect existing hydraulic control in upstream reaches. Most of the sediment delivered to the reservoir is transported past the top of the delta feature, farther downstream to the downstream face of the feature. Approximately 98 to 99 percent of the incoming sediment load is transported past RM 110.
>
> The quantitative analysis demonstrates that the top surface of the delta feature is in a state of dynamic equilibrium. This state of dynamic equilibrium is consistent with the fact that the average shear stress over the top of the delta feature is generally equal to or greater than the minimum critical shear from the SEDFlume analysis.
>
> This pattern of predicted sediment deposition, located downstream of the high point on the delta feature and at an elevation several feet below this high point, cannot reasonably be expected to adversely affect upstream hydraulics and flooding. Based on the relatively small change in effectiveness of moving sediment downstream with the comparison between the future flows with anticipated operation and baseline operation, as well as the USGS analysis of the effect of significant changes in water level resulting in very limited changes in sediment storage in John Redmond Reservoir; there is no basis to conclude that there would be any significant benefit in operating Grand Lake at a lower level.

> It is important to remember that Grand Lake is under operational control of USACE when the water level approaches or exceeds elevation 745 feet PD and that under these conditions, which only occur 19.8% of the time, delivers 75.6% of the incoming sediment load to the reservoir. Neither the upstream sediment load nor operational control of Grand Lake is controlled by GRDA at that time.

The STM utilized the HEC-RAS model with available bathymetric data to describe the channel/reservoir geometry, analysis of sediment sampling to describe the physical characteristics of the sediment (including particle size distributions, erosion parameters, and sediment density), and inflow hydrology along with sediment inflow rates using sediment rating curves based on sediment transport and flow data. This was an extremely complex process due to the nature of the dominance of cohesive sediment (silt and clay) for which densities, critical shear, and erosion rates vary widely.

The uncertainties associated with both the sediment properties and the available topographic and bathymetric data contributed to difficulties in model calibration and validation. The Neosho River was captured with reasonable accuracy, but modeled changes on the Elk and Spring rivers were somewhat less reliable.

To manage the uncertainties associated with both the cohesive sediment and terrain information, the model evaluated *High Sedimentation* and *Low Sedimentation* scenarios in addition to the *Baseline Operations* and *Anticipated Operations* simulations. The *High* and *Low Sedimentation* scenarios provided bounding possibilities for future sediment deposition. Differences between those scenarios in terms of sediment deposition depths were larger than the differences between modeled Project operations. This also holds true for storage volume changes over time, with the operational scenarios showing relatively little difference and sediment loading playing a larger role.

Each of these scenarios used a high sediment loading condition based on older, higher sediment rating curves. This was the same loading used for calibration and validation, and it is considered a conservative evaluation. As discussed in Section 4.2.1 of this report, changes in land use, increased use of no-till, and cover crop agricultural practices, and the presence of John Redmond Dam, have all contributed to a *decrease* in total sediment loading to the system. It is almost certain that future sedimentation impacts will be *smaller* than those reported here.

The City has implied that the delta feature is solely attributable to Project operations and changes in those operations would remove it. However, there are a range of factors that influence the exact location of sediment deposition in this area. The presence of the Ozark Uplift changes the bed slope and increases the likelihood of deposition at that location, which coincides with the current delta feature. Sediment carried by the steeper Spring River empties into the Neosho River just upstream of the delta feature; the decreased sediment carrying capacity of the Neosho River below this point results in increased sedimentation downstream of that confluence. The fact that the stream is more well-connected to the floodplain at this location means flows are able to spread laterally, decreasing stream velocity and allowing for deposition; upstream of this area, rocky cliffs prevent this lateral flow expansion and keep fine material in suspension until lower in the system.

The City claimed that ongoing sedimentation would increase the height of the delta feature. The STM showed that is not the case, with simulations showing deposition on the downstream face of the delta feature rather than on the crest, which is typical of such formations as documented by Vanoni (2006) and others in scientific literature. This finding confirmed that the delta feature is not growing appreciably in height, and that neither Project operations nor incoming sediment is expected to have a significant impact on delta feature crest elevations.

The City's claims also neglect the role of bridges and associated embankments on flood risks. The Burlington Northern railroad bridge features an extensive embankment that constricts the flow from a width of 1.80 miles (9,500 feet) upstream of the bridge to just 770 feet at the bridge opening. Multiple bridges in the area also show large masses of debris trapped on piles. This debris reduces flow capacity at those bridges and creates backwater effects that increase water levels upstream. Disregarding these contributing factors and instead placing all blame for high water levels on Project operations is disingenuous and ignores basic hydraulic flow characteristics.

Results of the STM and 1D UHM demonstrate that **sedimentation rates in Grand Lake and the associated tributaries are dictated primarily by the future incoming sediment load rather than Project operations**. The differences in deposition rates and patterns for the *Baseline Operations* and *Anticipated Operations* scenarios are smaller than the differences between the *High Sedimentation* and *Low Sedimentation* scenarios. Furthermore, for all modeled scenarios, the sediment deposition follows typical reservoir deposition patterns, with sedimentation largely occurring downstream of the existing delta feature rather than continuing to increase the delta feature crest elevation.

The City claimed Project operations would increase the delta feature size, thereby raising water levels in Miami. To assess the impact of Project operations on the delta feature size and upstream water levels, geometry from the predicted future sedimentation pattern was imported to the 1D UHM to evaluate flooding events and the effect on flooding in upstream reaches of the Neosho River through the City of Miami. The findings did not support the City's claims. Sediment loading rates, not GRDA's operations, produced the largest impacts to both storage volume change and upstream water levels. Furthermore, the STM showed a majority of incoming material depositing on the downstream face of the delta feature as expected and the 1D UHM results showed immaterial impacts to upstream water levels in the City of Miami.

In the City of Miami, **impacts to water levels due to Project operations are immaterial**. Neither operations nor sedimentation rates produce an appreciable difference in WSE between RM 133 and RM 137. Over a 50-year time period, there is virtually no increase to water levels in the City of Miami due to Project operations, and average water levels were shown to decrease during the July 2007 flow event under anticipated operations. Further, in the vicinity of Miami, the impacts due to sediment loading, Project operations, and expected future deposition produce only immaterial changes to water levels. Any meaningful increase in water levels due to sedimentation is further downstream and is primarily driven by the incoming sediment load.

Sedimentation and associated impacts to water levels are not driven by Project operations. This finding is similar to that of the H&H study, which showed that Project operations have limited ability to dictate WSE upstream of Pensacola Dam. GRDA has no control over the incoming sediment loads, and adjusting Project operations does not have a meaningful impact to sediment depositional patterns. Impacts of future sedimentation are the result of incoming material, and *not* Project operations.

The Sedimentation Study has shown that the sediment moving through the system is fine, cohesive material. It has also evaluated a range of datasets for stream bathymetry and overland topography in the study area and concluded that significant portions of the 1998 REAS data are unreliable and that the circa-1940 data are limited. To bound the uncertainties of the available datasets, multiple sediment transport simulations were performed, and the study showed that nature, not Project operations, dictates the rate of sedimentation in Grand Lake. Any material impacts to upstream WSE during large flow events are the result of sediment loading, which GRDA does not control. Furthermore, when the water level in Grand Lake is above 745 feet PD or expected to rise beyond that level, USACE dictates operation of the reservoir to mitigate downstream flooding, and under these conditions most of the sediment (75.6%) is delivered to the reservoir.

9 References

Anchor QEA, LLC, Simons & Associates, and Mead & Hunt, 2022. *Updated Study Plan Sedimentation Study.* Prepared for Grand River Dam Authority. April 2022.

Andrews, W.J., M.F. Becker, S.L. Mashburn, and S.J. Smith, 2009. *Selected Metals in Sediments and Streams in the Oklahoma Part of the Tri-State Mining District, 2000–2006*. U.S. Geological Survey Scientific Investigations Report SIR 2009-5032. July 2009.

Aqua Survey, 2004. *Technical Report Environmental Dredging and Sediment Decontamination Technology Demonstration Pilot Study Lower Passaic River Restoration Project Magnetometer and Sub-Bottom Profiler Debris Survey*. December 3, 2004.

Arcement, G.K., and V.R. Schneider, 1989. *Guide for Selecting Manning's Roughness Coefficients for Natural Channels and Floodplains*. U.S. Geological Survey Water Supply Paper 2339.

Borrowman, T.D., E.R. Smith, J.Z. Gailani, and L. Caviness, 2006. *Erodibility Study of Passaic River Sediments Using USACE SEDflume*. Dredging Operations and Environmental Research Program. U.S. Army Engineer Research and Development Center, Vicksburg, Mississippi Environmental Laboratory. September 2006.

City of Miami, 2018. Letter to: Kimberly D. Bose. Regarding: Comments of the City of Miami, Oklahoma on GRDA's Revised Study Plan Pensacola Hydroelectric Project, Project No. 1494-438. October 24, 2018.

City of Miami, 2022. Letter to: Kimberly D. Bose. Regarding: Pensacola Hydroelectric Project, FERC Project No. 1494-438; Supplemental Comments on GRDA's Untimely Request to Modify Sedimentation Study and Requests for Study Modifications to Conform with Approved Study Plan. March 28, 2022.

DeVries, R.N., 1996. *Rule 26 Expert Report: An Evaluation of the Water Surface Elevations of the Grand (Neosho) River Upstream of the Pensacola Dam*. March 14, 1996.

Dewberry, 2011. *USGS Grand Lake, OK LiDAR Project.* Prepared for the U.S. Geological Survey.

Duan, N., 1983. "Smearing estimate: A nonparametric retransformation method." *Journal of the American Statistical Association* 78(383):605–610.

Edwards, T.K., and G.D. Glysson, 1999. "Field Methods for Measurement of Fluvial Sediment." *Technique of Water-Resources Investigations of the U.S. Geological Survey*. Book 3, Chapter C2. Denver, Colorado: U.S. Geological Survey.

Engineering-Environmental Management, Inc., 2013. *Final Supplement to the Final Environmental Statement Volume 1*. Prepared for Storage Reallocation John Redmond Dam and Reservoir, Kansas.

Fan, J., and G.L. Morris, 1992. "Reservoir sedimentation I. Delta and density current deposits." *Journal of Hydraulic Engineering* 118(3):354–69.

FERC (Federal Energy Regulatory Commission), 2022. *Determination on Request for Study Modifications for Project No. 1494-438*.

GRDA (Grand River Dam Authority), 2017. *Pensacola Hydroelectric Project, FERC No. 1494 Pre-Application Document*.

GRDA, 2018. Letter to: Kimberly D. Bose. Regarding: Pensacola Hydroelectric Project (FERC No. 1494-438); Filing of Revised Study Plan. September 24, 2018.

GRDA, 2022. GRDA Response Comments on Sedimentation Study Plan: Pensacola Hydroelectric Project No. 1494 FERC Relicensing.

Gupta, H.V., S. Sorooshian, and P.O. Yap, 1999. "Status of automatic calibration for hydrologic models: Comparison with multilevel expert calibration." *Journal of Hydrologic Engineering* 4(2) 135–143.

Huang, J., R.C. Hilldate, and B.P. Greiman, 2006. *Erosion and Sedimentation Manual*. US Department of the Interior. United States Bureau of Reclamation.

IHO (International Hydrographic Organization), 2008. *IHO standards for hydrographic surveys (5th ed.): International Hydrographic Organization Special Publication no. 44*, 28 p. Accessed April 20, 2022. Available at: https://iho.int/uploads/user/pubs/standards/s-44/S-44_5E.pdf.

Ingersoll, C.G., C.D. Ivey, W.G. Brumbaugh, J.M. Besser, N.E. Kemble, and S. Dudding, 2009. *Toxicity Assessment of Sediments from the Grand Lake O' the Cherokees with the Amphipod* Hyalella azteca. U.S. Geological Survey Administrative Report CERC-8335-FY09-20-01.

Integral Consulting, 2020. *Grand Lake Waterways SEDflume Analysis: Grand Lake o' the Cherokees, Oklahoma*. SEDflume Study, Grand Lake o' the Cherokees. Santa Cruz, California.

Juracek, K.E., and M.F. Becker, 2009. *Occurrence and Trends of Selected Chemical Constituents in Bottom Sediment, Grand Lake O' the Cherokees, Northeast Oklahoma, 1940-2008*. U.S. Geological Survey Scientific Investigations Report 2009-5258, 28 p.

Kramer, A.R., C.L. Peterman-Phipps, M.D. Mahoney, and B.S. Lukasz, 2021. *Sediment Concentrations and Loads Upstream from and through John Redmond Reservoir, East-Central Kansas, 2010–19*. Scientific Investigations Report 2021–5037. U.S. Geological Survey.

Krone R.B., 1962. "Flume studies of the transport of sediment in estuarial shoaling processes." Hydrologic Engineering Laboratory, University of California at Berkely.

Lane, E.W., and V.A. Koelzer, 1943. *Density of sediments deposited in reservoirs, a case study of methods used in measurement and analysis of sediment loads in streams*. Report No. 9, Interagency Committee on Water Resources.

Lee, C., and G. Foster, 2013. "Assessing the potential of reservoir outflow management to reduce sedimentation using continuous turbidity monitoring and reservoir modelling." *Hydrological Processes* v. 27, No. 10, p. 1426–1439.

Lewis, J., 2022. Regarding [EXTERNAL] 2009 OWRB Survey of Grand Lake O' the Cherokees. Email to: Brent Teske (Anchor QEA). April 20, 2022.

Lumborg, U., and H. Vested, 2008. *Modelling of Cohesive Sediment Dynamics* (Chapter 6).

McKnight, E.T., and R.P. Fischer, 1970. *Geology and Ore Deposits of the Picher Field Oklahoma and Kansas*. Geological Survey Professional Paper 588. U.S. Department of Interior.

McNeil, J., C. Taylor, and W. Lick, 1996. "Measurements of Erosion of Undisturbed Bottom Sediments with Depth." *Journal of Hydraulic Engineering* 122(6):316–324.

Moriasi, D.N., J.G. Arnold, M.W. Van Liew, R.L. Bingner, R.D. Harmel, and T.L. Veith, 2007. "Model Evaluation Guidelines for Systematic Quantification of Accuracy in Watershed Simulations." *Transactions of the American Society of Agricultural and Biological Engineers* 50(3): 885–900.

Mussetter, B., 1997. *Analysis of Backwater Conditions Caused by Pensacola Dam on the Neosho River in the Vicinity of Miami, Oklahoma*. Fort Collins, Colorado.

Mussetter, B., 1998. *Evaluation of the Roughness Characteristics of the Neosho River in the Vicinity of Miami, Oklahoma*. Fort Collins, Colorado.

Nash, J.E., and J.V. Sutcliffe, 1970. "River flow forecasting through conceptual models: Part 1. A discussion of principles." *Journal of Hydrology* 10(3): 282–290.

OWRB (Oklahoma Water Resources Board), 2009. *Hydrographic Survey of Grand Lake*.

Partheniades, E., 1962. "A study of erosion of cohesive soils in salt water." University of California at Berkely PhD Dissertation.

Pope, L.M., 2005. *Assessment of Contaminated Streambed Sediment in the Kansas Part of the Historic Tri-State Lead and Zinc Mining District, Cherokee County, 2004.* No. 2005-5251.

Science Applications International Corporation, 2001. *Results of the March 2001 Sub-Bottom Profiling and Sediment Profile Imaging of the Outer Gloucester Harbor*. SAIC Report 541. June 2001.

Simons, D.B., and F. Senturk, 1992. *Sediment Transport Technology Water and Sediment Dynamics*. Water Resource Publications.

Singh, J., H.V. Knapp, and M. Demissie, 2004. *Hydrologic modeling of the Iroquois River watershed using HSPF and SWAT*. ISCW CR 2004-08. Champaign, Ill.: Illinois State Water Survey.

Smith, D.C., 2016. *Occurrence, Distribution, and Volume of Metals-Contaminated Sediment of Selected Streams Draining the Tri-State Mining District, Missouri, Oklahoma, and Kansas, 2011*-12. U.S. Geological Survey Scientific Investigations Report 2016-5144, 86 p., Available at: http://dx.doi.org/10.3133/sir20165144.

Smith, S., S. Hunter, and C. Ashworth, 2017. *Bathymetric Surveys of the Neosho River, Spring River, and Elk River, Northeastern Oklahoma and Southwestern Missouri, 2016-2017.* Denver, Colorado: U.S. Geological Survey.

Strong, S., 2022. Regarding Lake O' the Cherokees (Grand Lake) gage questions. Email to: Jesse Piotrowski, Ryan Greif (Mead & Hunt); Jason Lewis (USGS). March 22, 2022.

Tetra Tech, 2015. *Hydraulic Analysis of the Effects of Pensacola Dam on Neosho River in the Vicinity of Miami, Oklahoma*. Prepared for City of Miami. December 9, 2015.

Tetra Tech, 2016. *Hydraulic Analysis to Evaluate the Impacts of the Rule Curve Change at Pensacola Dam on Neosho River Flooding in the Vicinity of Miami, Oklahoma*. Prepared for City of Miami. February 3, 2016.

Tetra Tech, 2018. *Pensacola hydropower project FERC Project No. 1494-438: Sedimentation Study Plan*. Fort Collins, Colorado: Tetra Tech, Inc.

USACE (U.S. Army Corps of Engineers), 1938. *Photostatic Copies of Plane Table Sheets of the Pensacola Reservoir Area Survey.*

USACE, 1941. *Pensacola Reservoir Computation Folder for Envelope Curve of Water Surface in Reservoir*.

USACE, 1942. *Pensacola Reservoir Computation Folder for Revised Envelope Curve of Water Surface in Reservoir*.

USACE, 1969. *Flood Plain Information, Neosho River and Tar Creek, Miami Oklahoma*. Tulsa, Oklahoma: USACE Tulsa District.

USACE, 1995. *Engineering Manual 1110-2-4000: Engineering and Design – Sedimentation Investigations of Rivers and Reservoirs*.

USACE, 1996. *Rule 26 Expert Report: An Evaluation of the Water Surface Elevations of the Grand (Neosho) River Upstream of the Pensacola Dam*. Prepared by Richard N. DeVries. March 14, 1996.

USACE, 1998. *Grand Lake, Oklahoma Real Estate Adequacy Study*.

USACE, 2002. *Engineering Manual 1110-2-1003: Engineering and Design – Hydrographic Surveying Version 3*.

USACE, 2016. *HEC-RAS River Analysis System User's Manual.* Davis: Hydrologic Engineering Center.

USACE, 2022. "Sediment Rating Curve Analysis Tool." Available at: Sediment Rating Curve Analysis Tool (army.mil).

USDA (U.S. Department of Agriculture), 1938. Aerial photography of McDonald County, MO. Aerial Photography Field Office, Washington, D.C.

USDA, 1939a. Aerial photography of Delaware County, OK. Aerial Photography Field Office, Washington, D.C.

USDA, 1939b. Aerial photography of Ottawa County, OK. Aerial Photography Field Office, Washington, D.C.

USDA, 1940. Aerial photography of Mayes County, OK. Aerial Photography Field Office, Washington, D.C.

USDA, 1990. *Engineering Field Manual, Chapter 4. Elementary Soil Engineering*. U.S. Department of Agriculture, Soil Conservation Service.

USGS (U.S. Geological Survey), 1907. *Wyandotte, OK-MO-KS Historical Map 125000-Scale*.

USGS, 2006. Collection of Water Samples (ver. 2.0). *U.S. Geological Survey Techniques of Water-Resources Investigations,* Book 9.

USGS, 2017. "National Geospatial Program." *The National Map Viewer*. Available at: https://www.usgs.gov/core-science-systems/national-geospatial-program/national-map.

USGS, 2020. *Bathymetric Map, Surface Area, and Capacity of Grand Lake O' the Cherokees, Northeastern Oklahoma, 2019*. Available at: https://pubs.er.usgs.gov/publication/sim3467.

USGS, 2021a. "USGS 07189000 Elk River near Tiff City, Mo." *National Water Information System*. Accessed February 5, 2021. Available at: https://waterdata.usgs.gov/mo/nwis/uv?site_no=07189000.

USGS, 2021b. "USGS 07185000 Neosho River near Commerce, OK." *National Water Information System*. Accessed February 5, 2021. Available at: https://waterdata.usgs.gov/nwis/uv?site_no=07185000.

USGS, 2021c. "USGS 07185080 Neosho River at Miami, OK." *National Water Information System*. Accessed February 5, 2021. Available at: https://waterdata.usgs.gov/ok/nwis/uv?site_no=07185080.

USGS, 2021d. "USGS 07185095 Tar Creek near Commerce, OK." *National Water Information System*. Accessed February 5, 2021. Available at: https://waterdata.usgs.gov/nwis/uv?site_no=07185090.

USGS, 2021e. "USGS 07185095 Tar Creek at 22nd Street Bridge at Miami, OK." *National Water Information System*. Accessed February 5, 2021. Available at: https://waterdata.usgs.gov/nwis/uv?site_no=07185095.

USGS, 2021f. "USGS 07188000 Spring River near Quapaw, OK." *National Water Information System*. Accessed February 5, 2021. Available at: https://waterdata.usgs.gov/nwis/uv?site_no=07188000.

USGS, 2021g. "USGS 07190000 Lake O' the Cherokees at Langley, OK." *National Water Information System*. Accessed February 5, 2021. Available at: https://waterdata.usgs.gov/ok/nwis/uv?site_no=07190000.

USSD (U.S. Society on Dams), 2015. *Modeling Sediment Movement in Reservoirs.* Prepared by the U.S. Society on Dams Committee on Hydraulics of Dams, Subcommittee on Reservoir Sedimentation, June 2015.

van Rijn, L.C., (n.d.). *Sedimentation of Sand and Mud in Reservoirs in Rivers*. Accessed April 11, 2022. Available at: https://www.leovanrijn-sediment.com/.

Vanoni, V.A. ed., 2006. *Sedimentation engineering*. American Society of Civil Engineers. March 2006.

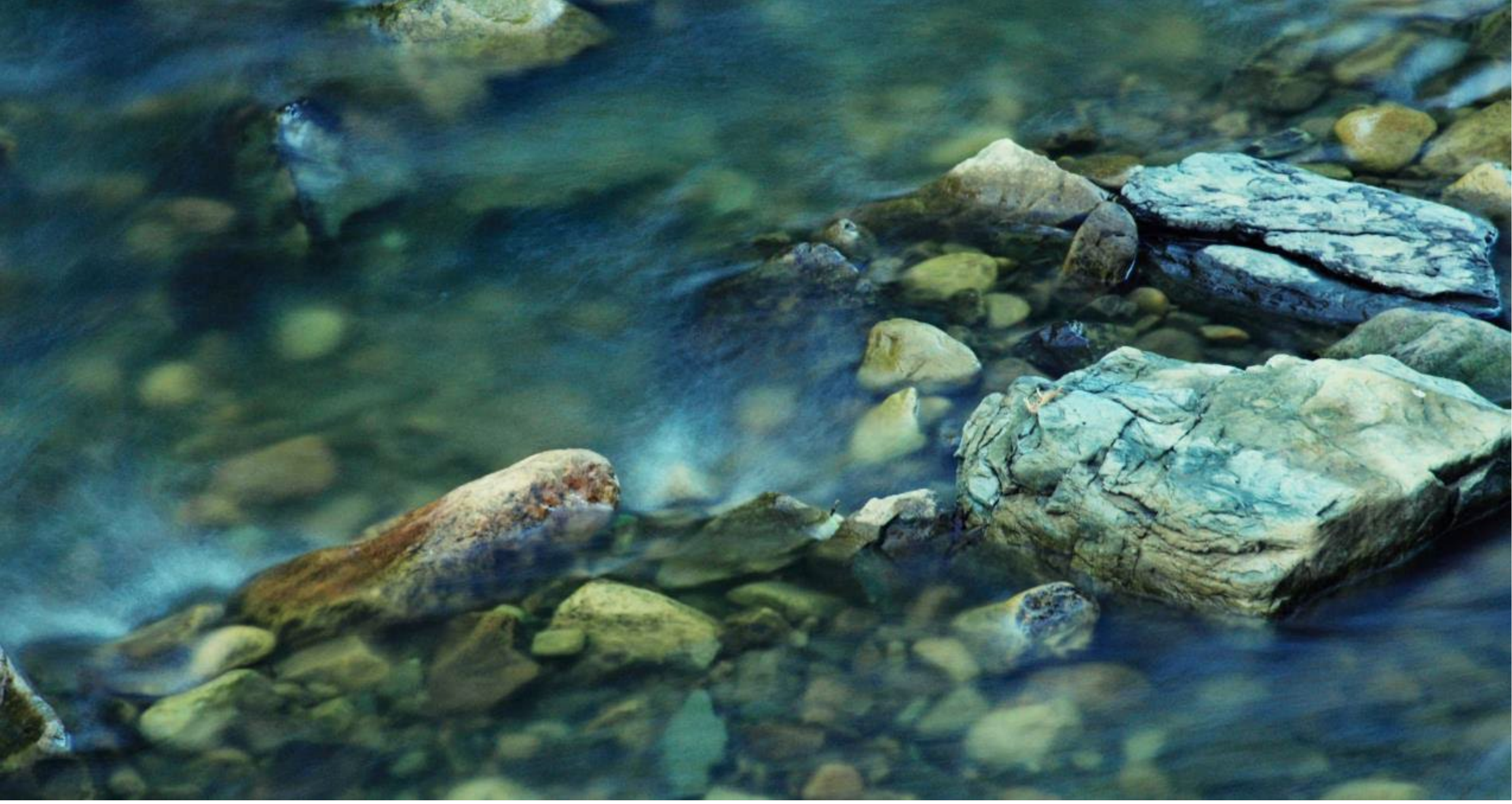
Walling D.E., and D. Fang, 2003. "Recent trends in the suspended sediment loads of the world's rivers." *Global and Planetary Change* 39:111–126.

WEST (WEST Consultants), 2012. *Hydraulic and Sedimentation Modeling in HEC-RAS – Cochiti Baseline Study: Sediment Transport Modeling.* Prepared for the Pueblo de Cochiti and the U.S. Army Corps of Engineers, ABQ District.

WEST, 2022. Independent Technical Review of HEC-RAS Sediment Transport Model.

Zavala, C., 2020. "Hyperpycnal (over density) flows and deposits." *Journal of Palaeogeography 9*(1):1–21.

Appendix A
Water Surface Elevation Monitoring



March 2022
Sedimentation Study

2021 Grand River Water Level Monitoring

Prepared for Grand River Dam Authority

March 2022
Sedimentation Study

2022 Grand River Water Level Monitoring

Prepared for
Grand River Dam Authority
226 West Dwain Willis
Vinita, OK 74301

Prepared by
Anchor QEA, LLC
660 West Washington Avenue
Suite 302
Madison, WI, 53715

Executive Summary

At the request of council, this report presents the findings of the first 60 months of a multi-year water level monitoring study in the Grand Lake watershed. Anchor QEA is conducting the study as part of the Grand River Dam Authority project team for the Pensacola Dam relicensing project. The objective of the water level monitoring project is to collect high-quality water level data in the Grand Lake reservoir and upstream tributaries to assist hydraulic modeling and any potential sediment transport study efforts of the relicensing project.

Anchor QEA installed 16 HOBO water level loggers in the study area in late December 2016 at locations selected to maximize insights into the watershed response to varying hydrologic conditions or flow events. The loggers are deployed throughout the Grand Lake reservoir, near bridge crossings, at upstream locations in the Neosho and Spring Rivers, and in Horse Creek and Sycamore Creek. The loggers are set to record data at 30-minute increments. Water level data at these locations will provide information on the characteristics of floods which can be used to calibrate and validate hydraulic models of the watershed.

HOBO loggers directly measure pressure, which can be converted to a water depth using atmospheric pressure measurements and the unit weight of water. A reference elevation of the logger must be known to tie in water depth measurements to a datum and make measurements useful for modeling and analysis. Site visits to the loggers included a precise GPS survey of the logger elevation in addition to data retrieval and logger re-installation. Hand measurements prior to logger removal and after re-installation provided a reference to estimate logger measurement errors. A site visit in August 2017 retrieved data from 13 of 16 loggers while a visit in March 2018 was less successful due to an unforeseen minor flood event, and only 2 of 16 loggers were accessible. Due to unusually high water levels throughout the fall and winter of 2018-19, a trip to collect water level data was not possible again until April 2019. As a result, some loggers filled their available data storage capacity and stopped logging, though 12 pressure sensors were recovered and re-deployed at that time. Data loggers were again recovered and re-deployed in December 2020, with 13 of 16 collected. In December 2021 and February 2022, the remaining 12 loggers were permanently removed. The loss of data loggers due to washouts and/or tampering has limited records at several locations.

Water level monitoring in 2017 captured uneventful ‘base’ winter conditions, several small flood events, and a large late spring flood which featured sustained water levels over 10 feet higher than low-water conditions. Monitoring has also captured the large flood events in spring, most notably those in the spring of 2017 and the spring/summer of 2019. Errors compared to hand measurements and nearby USGS gages were small, generally less than 0.06 feet. The data provides insight into the

flood hydrology of the reservoir, but its real value was its use in hydraulic modeling to assess the effects of hydraulic structures, operational changes, or sedimentation in the watershed.

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1 Introduction

Anchor QEA was retained by Mead & Hunt to assist the Grand River Dam Authority (GRDA) in the Pensacola Dam relicensing project. The Pensacola Dam relicensing project is a large-scale, multi-year effort mandated by the Federal Energy Regulatory Commission (FERC). Specifically, Anchor QEA's role in the project was to collect water level data for a 12-month period beginning in December 2016, with the option of continuing monitoring after that period. Anchor QEA collected water level data through February 2022. The water level monitoring study was conducted to provide data with necessary spatial and temporal resolution to assist in the creation of a hydraulic model for the reservoir and upstream reaches, and to provide data for any potential sediment transport study in the watershed.

Water level is a critical piece of information necessary for analysis of any fluvial environment, including rivers and reservoirs. The depth of water in a river is related to the quantity of water flowing in a river and the speed at which the water is moving; the variation of which, in space and time, is essential to modeling and understanding hydraulic systems. This understanding can help researchers understand how structures impact flooding, how flashy the riverine environment is, how sediment is transported through the watershed, and the fate of transported materials, as well as many other aspects of the fluvial system.

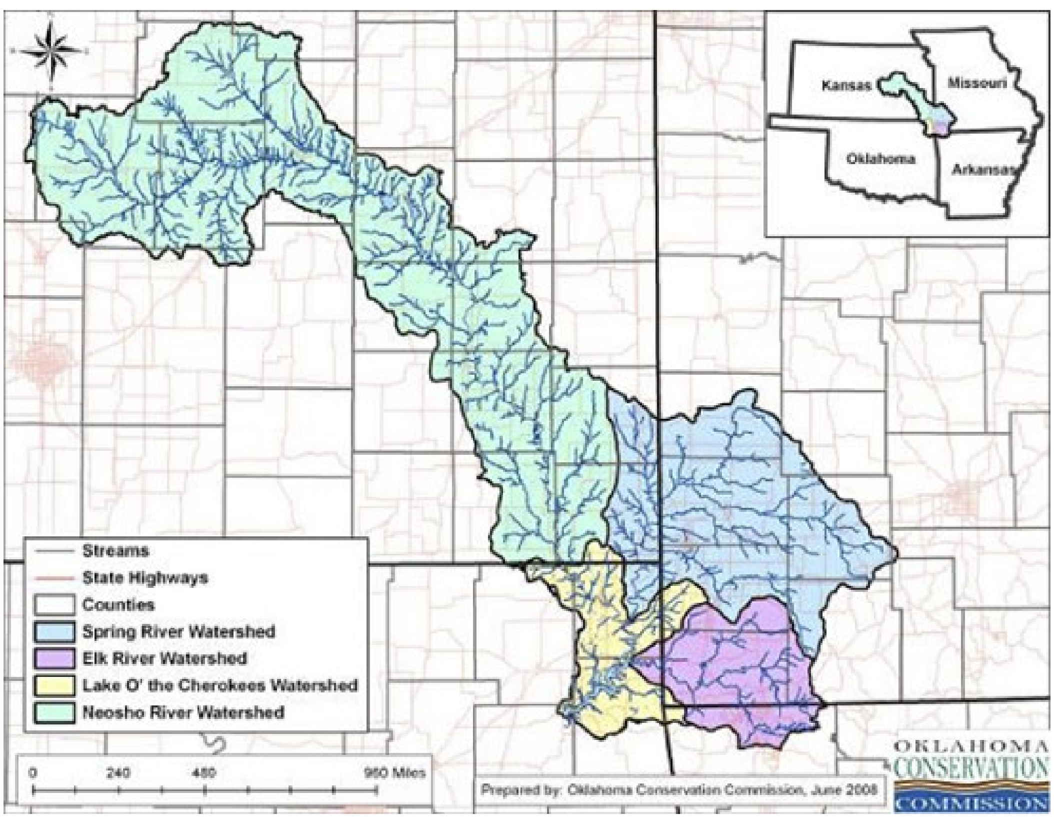
The purpose of this water level study is to provide continuous water level data for a time period of five years at locations distributed through the Grand Lake watershed. This water level data will be used to calibrate and validate hydraulic models of the watershed, understand the nature of flooding in the watershed, and provide data useful for future investigations in the area. At a basic level, the data collected in this phase of the project provides a foundation for other scientific studies of the watershed. This report presents the methodology and preliminary findings of 5 years of the water level monitoring study.

2 Study Area

Pensacola Dam is located at the downstream end of the Grand Lake O' the Cherokees (Grand Lake) reservoir. The reservoir is located downstream of the watersheds of the Spring, Elk, and Neosho Rivers, in addition to the Grand Lake watershed (Figure 1). The drainage area to the Pensacola Dam includes parts of Oklahoma, Missouri, Kansas, and Arkansas. In addition to Pensacola Dam, several large bridges cross the reservoir and tributaries. Highway and railroad bridges are often built with embankments constricting large portions of the river, which may exacerbate flooding.

The watershed is located in a region that typically experiences hot, humid summers with intense rainstorms that can lead to flooding. Floods in the watershed can cause serious damage to homes, businesses, and infrastructure. Recently, focus has turned to the effects of hydraulic structures on flooding. Previous investigations of flooding in the Grand Lake watershed have differed in determining the impacts Pensacola Dam and other structures have on upstream flooding. Nevertheless, high quality field data is missing with regards to the impacts of Pensacola Dam and other structures under current operational scenarios.

Figure 1
Map of Grand Lake watershed



3 Methods

Water levels in the Grand Lake watershed were measured using HOBO water level loggers. HOBO loggers contain a pressure transducer that responds to the weight of overlying water and atmospheric pressure, a thermometer, and an internal data logger which stores over a year of data. Figure 2 shows a HOBO logger prior to installation. HOBO loggers were installed in approximately 18 inches of water during a period of low water levels to ensure that the loggers were always submerged. Loggers are programmed to record pressure and temperature data every 30 minutes.

Figure 2
HOBO water level logger prior to deployment

Loggers were deployed at 16 locations throughout the watershed in December 2016, as shown in Figure 3. Locations of logger deployment were selected to span the length of the area of interest in the watershed, on important tributaries, and upstream and downstream of major constrictions. Loggers at stations 1 and 16 are located near USGS gaging stations on the Neosho River and at Pensacola Dam, respectively.

Raw logger data contains absolute pressure readings, which must be converted to a water depth or water surface elevation. To convert pressure data to a water depth, a reference elevation of the logger and atmospheric pressure must be known. A Real-Time Kinematic (RTK) GPS was used at logger installation and all follow-up visits to measure the water surface elevation and temporary and established benchmarks. A measuring stick was also used to measure the water depth to the logger, establishing the reference elevation of the logger. Pressure data was post-processed by subtracting atmospheric pressure data recorded at the nearby Grove, OK airport from the recorded data, then converting the hydrostatic pressure to a water depth.

Water level records begin in late December 2016, when the loggers were installed. A follow-up site visit in August 2017 downloaded data from 13 of the 16 water level loggers (Table 1). Another follow-up visit in March 2018 was able to only download data from 2 loggers because of a flood event that occurred during the visit. The remaining loggers continued to record data and most were retrieved during a visit in April 2019. Another visit occurred in December 2019, during which 11 loggers were retrieved. Data loggers were again recovered and re-deployed in December 2020, with 13 of 16 collected. In December 2021 and February 2022, the 12 remaining loggers were permanently removed.

Figure 3
Location of HOBO loggers in the study area.

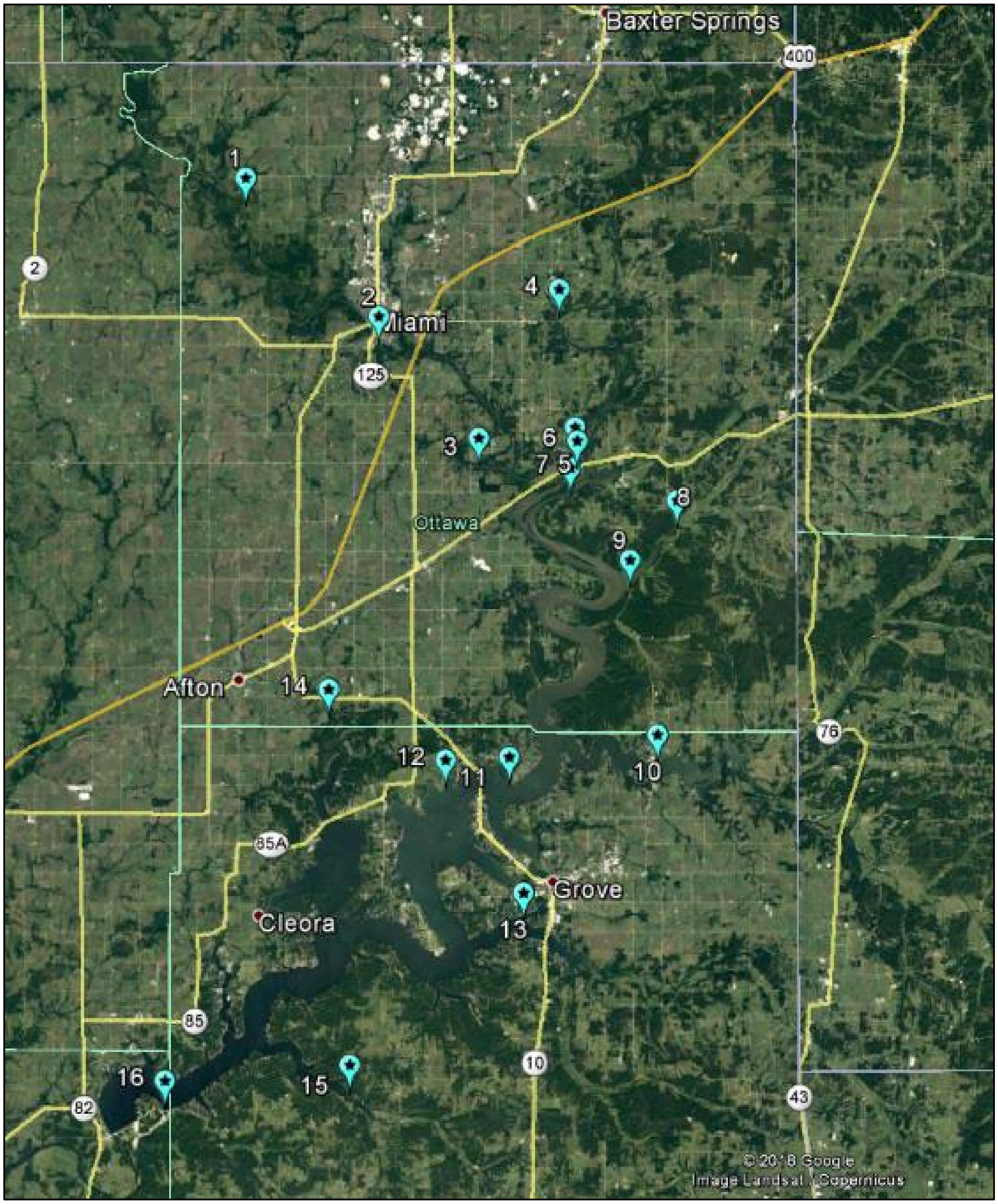


Table 1
Location of HOBO data loggers in the Grand Lake watershed

Sta.	Lat.	Long.	Location	Duration of Data
1	36°55'41.35"N	94°57'32.22"W	Neosho River at E 64 Rd near Commerce, OK	Dec 2016-Dec 2020
2	36°51'34.36"N	94°52'35.20"W	Neosho River at Riverview Park, Miami, OK	Dec 2016-Aug 2017 Apr 2019-Dec 2021
3	36°47'57.17"N	94°48'52.36"W	Neosho River near Connors Bridge on S 590 Rd.	Dec 2016-Mar 2018 Dec 2019-Feb 2022
4	36°52'22.42"N	94°45'53.19"W	Spring River upstream of Hwy 10 Bridge	Dec 2016-Nov 2018 Dec 2019-Dec 2021
5	36°48'16.24"N	94°45'18.05"W	Spring River at Twin Bridges Area at Grand Lake State Park boat launch	Dec 2016-Nov 2018 Apr 2019- Feb 2022
6	36°47'52.17"N	94°45'13.37"W	Confluence of Spring and Neosho at Twin Bridges Area at Grand Lake State Park	Dec 2016-Nov 2018 Apr 2019- Feb 2022
7	36°47'4.21"N	94°45'28.75"W	Neosho River off E157 Rd downstream of railroad bridge	Dec 2016- Feb 2022
8	36°46'5.58"N	94°41'31.88"W	Sycamore Creek at Hwy 10 bridge	Dec 2016-Aug 2017 Dec 2020 - Dec 2021
9	36°44'19.69"N	94°43'16.46"W	Neosho River downstream of roadside park off Hwy 10	Never recovered
10	36°39'8.19"N	94°42'16.21"W	Grand Lake/Elk River US of Hwy 10 bridge north of Grove, OK	Dec 2016-Aug 2017 Apr 2019-Dec 2020
11	36°38'29.32"N	94°47'45.57"W	Grand Lake at Hickory Point, US of Hwy 59 bridge	Dec 2016-Nov 2018 Apr 2019- Feb 2022
12	36°38'24.09"N	94°50'7.12"W	Grand Lake at public access point off S. 580 Rd, DS of Hwy 59 bridge	Dec 2016-Aug 2017 Re-installed Dec 2020
13	36°34'27.15"N	94°47'14.41"W	Grand Lake at Honey Creek State Park	Dec 2016-Nov 2018 Apr 2019-Dec 2021
14	36°40'30.13"N	94°54'26.81"W	Horse Creek off E 240 Rd	Dec 2016-Nov 2018 Apr 2019-Dec 2020
15	36°29'20.45"N	94°53'40.87"W	Grand Lake near Woods Spring Branch off S 560 & E 360 Rd.	Dec 2016-Dec 2020
16	36°28'51.72"N	95° 0'31.36"W	Grand Lake at Cherokee State Park Boat Ramp, Disney, OK	Dec 2016-Nov 2018 Apr 2019-Dec 2021

3.1 Existing Data Sources

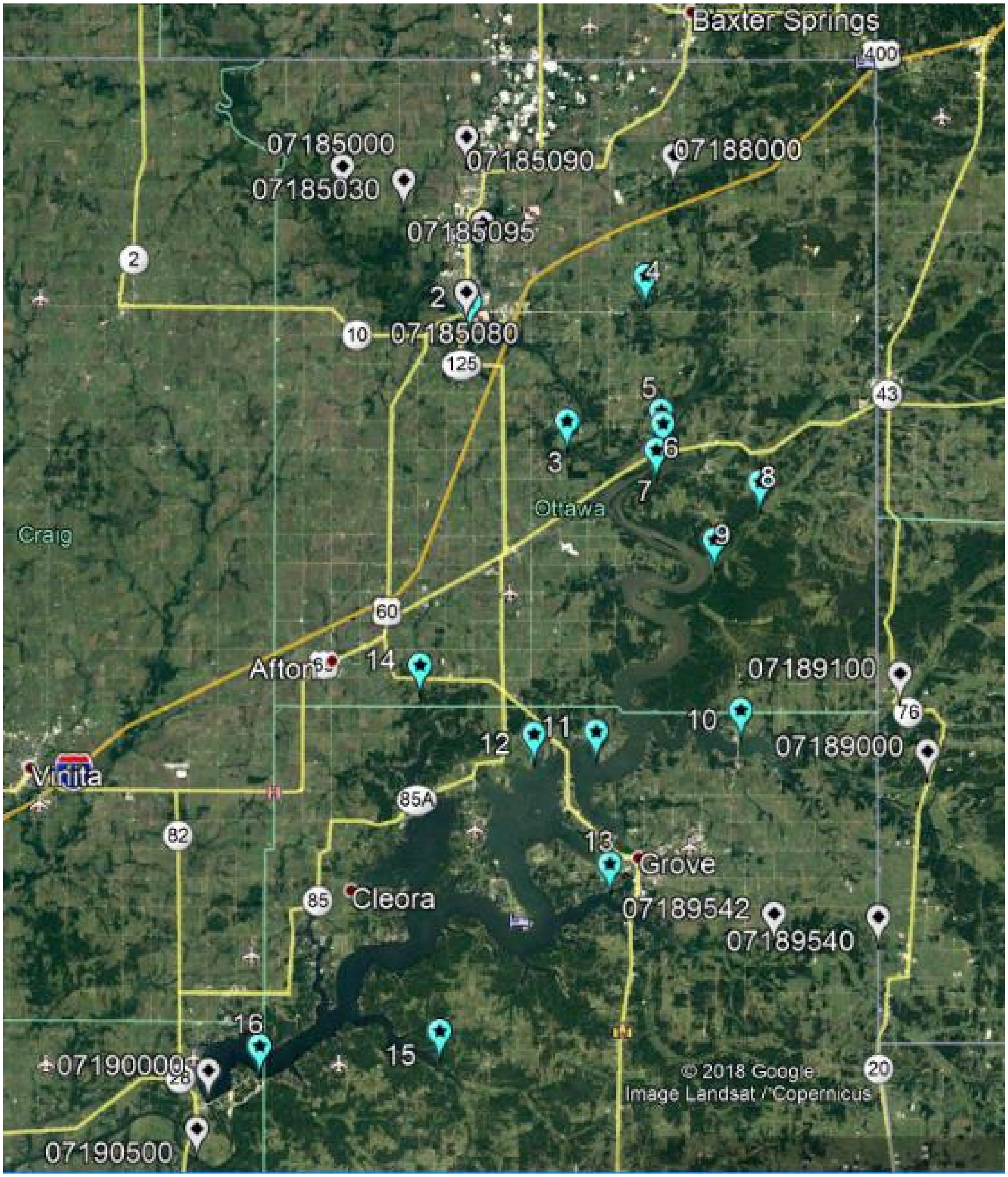
Grand Lake has been extensively studied and has several existing data sources. USGS gages are present throughout the watershed and are located near HOBO loggers at locations 1 and 16 (Table 2). Those USGS gages were used to verify water level measurements from the HOBO loggers. Station 1 is located on a bridge pier adjacent to USGS Gage 07185000 (Neosho River near Commerce, OK), and readings from the two instruments show generally good agreement. Station 16 is located near the emergency spillway of Pensacola Dam, about 2 miles upstream of USGS Gage 07190000, but because the reservoir surface was nearly always horizontal at this downstream location, the data is useful for validation of the HOBO measurements.

Table 2
USGS gaging stations located near HOBO loggers in the study area

USGS Station ID	Location	Lat.	Long.	Datum
7185000	Neosho River near Commerce, OK	36° 55' 43" N	94° 57' 26" W	NGVD29
7190000	Lake O' the Cherokees (Grand Lake) at Langley, OK	36° 28' 07" N	95° 02' 28" W	Pensacola Datum

The Grand Lake watershed has a total of 13 USGS stations on the Grand/Neosho, Spring, and Elk Rivers as well as several tributaries such as Tar and Sycamore Creeks. The USGS stations (shown with gray markers in Figure 4) are actively recording water levels and other environmental data. When combined with the data from the HOBO loggers, the entire dataset provides a total of 29 locations recording water levels, creating a robust data set in the watershed. The study area is sufficiently monitored with water level data to aid in analysis of the system.

Figure 4
Location of HOBO loggers and USGS gaging stations within the study area



Benchmarks established by the USGS are present at several locations throughout the watershed and are used as validation points for the accuracy of the RTK-GPS used for surveying. Table 3 shows the locations and elevations of the benchmarks in addition to the surveyed elevations. Surveyed benchmark elevations are 1-minute averages of elevation measurements taken once a second with a Fixed RTK-GPS signal. USGS benchmark elevations are provided as the average of 2 to 15 individual measurements.

Table 3
Benchmarks surveyed during field visits.

Benchmark	Location	Lat. (Dec. Deg.)	Long. (Dec. Deg.)	BM Elevation (ft, NAVD88)	Surveyed Elevation (ft, NAVD88)
RM-G	Concrete anchor bolt at boat ramp at Oklahoma State Highway 10 bridge near Grove, Oklahoma	36.652419	-94.707825	754.295	754.2
RM-C	Concrete anchor bolt at boat ramp near S 590 Road (Connors) bridge near Fairland, Oklahoma	36.799278	-94.818872	752.376	752.413

4 Results

4.1 Water Level Data

Hydrographs showing time series of water surface elevation and temperature for the HOBO loggers accessible during site visits are provided in Appendix I. Water surface elevation data is also available in spreadsheet form in a separate file. Taken together, these hydrographs provide a rich dataset that can be used with hydraulic models to better understand the behavior of the Grand Lake watershed.

HOBO loggers at Stations 1 and 16 showed generally good agreement with the USGS gauging stations (Appendix II). Station 1 has one period of significant deviation from USGS water level records from April to August 2018. The presence of a mass of debris may have affected water level readings by directing flow away from the pier and producing artificially lower WSE readings. It appears to have been removed or washed away sometime around 15 August 2018. Station 16 data matches very well until 5:30 PM on 7 May 2018, when there is a shift of 0.3 feet. The sensor may have been moved by an unknown individual or hit by a boat, driftwood, or other debris, causing it to record the offset WSEs. The offset is consistent throughout the rest of the period of record.

At one point during the period of record, approximately one year elapsed between site visits, during which only a handful of sensors were retrievable. Due to the large length of time between site visits, several of the loggers reached their internal storage capacity and stopped recording. There is therefore a data gap between November 2018 and April 2019 at many of the stations as shown in Table 1, above. The field team was delayed by repeated high water levels, which prevent logger retrieval. Following a site visit in April 2019, all loggers were retrieved and data recording was restarted. Recording continued through site visits to retrieve loggers and data in December 2020 and again in December 2021.

Loggers deployed over a large portion of the Grand Lake watershed since December 2016 have recorded a wide range of hydrologic events, including rule curve changes, long periods of 'baseline' behavior, small flood events, and large sustained flood events. The two most notable flood events captured in the data record occurred between late April and late June 2017 and from May to August 2019. Loggers located at upstream locations show a series of sharp peaks in water surface elevation, indicative of high flows due to storms over the watershed. Downstream loggers in Grand Lake recorded a broad peak as floodwaters collected in the reservoir before being released.

Water level records differ significantly in character depending on location in the watershed. During a flood event, upstream areas display a sharp rise and fall in water levels, referred to as a 'rising limb' and 'falling limb' of a hydrograph, respectively. At locations further downstream, the rising limb of a flood hydrograph typically becomes lower and more gradually sloped than upstream areas, while the falling limb will display a more gradual lowering of water levels. This effect is especially prominent in dammed reservoirs, where operational procedures often have significant influence on hydrographs. Land use and topography also play large roles in hydrograph character, in addition to watershed position.

An example of the differences of hydrographs at logger locations is shown in Figure 5 for a series of three floods between August 4th and August 21st, 2017. The hydrographs at Stations 1 and 2 are on upstream reaches of the Neosho River, Station 6 is at the confluence of the Neosho and Spring Rivers, and Stations 12 and 16 are located 22 and 1.5 miles above Pensacola Dam, respectively. Each hydrograph is adjusted so that 0 ft in elevation is the pre-flooding water level at each station.

The hydrographs shown in Figure 5 provide an example of a typical flooding scenario in the Grand Lake watershed. A large pulse of water in the upstream reaches of the Neosho River results in a water level rise of 8-14 feet, and a falling limb of the hydrograph that is slightly less steep than the rising limb. Areas downstream show progressively lower peaks in the flood hydrograph, with a peak rise of only 1.61 feet at Station 16 at Pensacola Dam (Table 4). There is a delay in peak water level at downstream locations and the falling limb of the hydrograph is much more gradual than the rising limb at these locations. These phenomena are typical of floods in the Grand Lake watershed and can be observed for large and small events throughout the period of water level monitoring.

Figure 5
Flood hydrographs of a series of three floods in August 2017. Selected HOBO logging stations are shown to display differences in hydrograph character throughout the watershed.

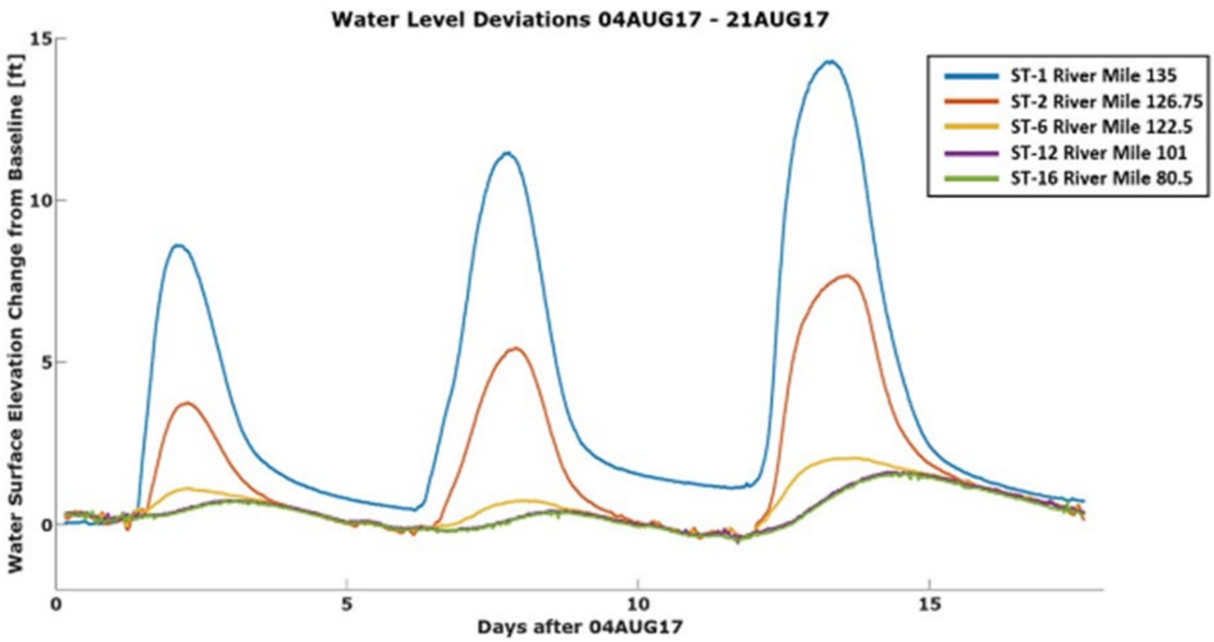


Table 4
Key parameters of the August 2017 floods shown in Figure 5

Station, River Mile	Peak Level Above Pre-Flood (ft)	Date and Time of Flood Peak	Date and Time of Return to Low Stage
Station 1, RM 135	14.3	August 14, 04:30	August 26, 22:30
Station 2, RM 126.75	7.69	August 14, 11:00	August 27, 13:30
Station 6, RM 122.5	2.05	August 14, 14:30	August 27, 21:00
Station 16, RM 80.5	1.61	August 15, 13:30	August 28, 01:30

4.2 Temperature Data

HOBO loggers recorded water temperature in addition to pressure data. Temperature timeseries are provided in Appendix I and in accompanying spreadsheet files. While hydraulic modeling studies typically do not need to consider temperature of the water, this data could potentially be useful for ecological studies or pollutant/contaminant transport studies in the watershed.

4.3 Measurement Error and Uncertainty

Recorded data error was calculated by comparing data records with water depths measured during site visits ('measure-down'). Table 5 shows average errors at each site. Measurement error is less than 0.16 feet at all sites and are typically less than 0.08 ft. Potential sources of error and uncertainty in pressure measurements include instrument drift, synoptic errors, atmospheric pressure changes, waves, and slight differences in water density. 'Measure-down' uncertainty is estimated to be 0.25 inches (0.021 ft).

Table 5
Mean error between HOBO loggers and water depth measurements.

Station	Root Mean Squared Error (ft)
1	0.1528
2	0.0632
3	0.0709
4	0.0707
5	0.0767
6	0.0543
7	0.0712
8	0.0024
9	N/A
10	0.0473
11	0.0854
12	0.054
13	0.0432
14	0.0584
15	0.0519
16	0.0962

HOBO loggers were located near USGS gages at stations 1 and 16. Comparisons between USGS gage data and collected HOBO data show that differences between the two are small compared to the magnitude of water level fluctuations, though HOBO loggers tended to record lower water surface elevations during flood peaks (Table 6 and Appendix II). Sources of differences between HOBO water level data and USGS gage data include mean water surface elevation differences at the two nearby locations, measurement technique and instrument errors, and differences in timing. Larger differences in the data records during peaks in flood events may be due to local hydraulic effects caused by blockages in the river or differences in the timing of measurements, given the rapid nature of flood peaks in upstream areas. Station 1 in particular has had large blockages affecting the data.

Figure 6
Photo of blockage taken in August 2019. Debris pile remains in place and has grown since photo was taken.

Table 6
RMS error between HOBO water level loggers and nearby USGS gaging stations.

Station/USGS gage	RMSE (ft)
Station 1/USGS 07185000	1.128 (excluding May-Aug 2018)
Station 16/USGS 07190000	0.49

4.4 RTK-GPS Measurement Adjustments

Initial logger deployment was done without the aid of RTK-GPS instrumentation. As a result, exact elevations were unknown, and logger elevations were measured in reference to a set benchmark. The benchmarks were later measured with RTK-GPS equipment to define logger elevations. In some locations, RTK-GPS signals are limited, and the elevations were based on the best available data at the time.

Since initial deployment, field technicians have been able to fix elevations with RTK-GPS measurements. Sites 4 (Spring River) and 15 (Drowning Creek) are two such sites where significant adjustments have been made to WSE measurements. In both cases, processing involved evaluating vertical offsets between HOBO measurements validated by RTK-GPS recorded between April 2019 and February 2022 and USGS WSE records during the same time period. HOBO data from before the April 2019 WSE measurements was then adjusted so the offsets before April 2019 match the more recent values.

5 Discussion and Conclusions

Water level data has been collected in the Grand Lake watershed to gain a better understanding of flood hydrology in the area. HOBO loggers installed near streambanks have collected water level data every 30 minutes from December 2016 to February 2022 with one gap from November 2018 to April 2019 at several locations. The water level timeseries collected will serve multiple purposes in the Pensacola Dam relicensing project, including as a high-quality dataset for hydraulic model calibration and verification; as an important dataset for a proposed sediment transport study; and as information that can be used to support other activities on the reservoir, including infrastructure, planning, and research projects.

Water levels are the foundation of hydrologic and hydraulic investigations. This investigation provides more than 60 months of half-hourly records at 16 locations in the watershed. Alone, water level data provides insight into flood impacts, hydraulic characteristics of the river, and the effects of structures in the watershed. When combined with other information such as the composition and slope of the river bottom and flow in the river, one can determine the impacts of future storms, understand the impacts dam regulation plays on water surface elevations, and predict how sediment and particles move through the watershed.

The findings of the water level monitoring captured several small flood events and two large flood events. The spring 2017 flood caused significant damage within the watershed as water levels rose over 10 feet higher than the low-pool elevation. For the second large flood event in spring 2019, flooding was similar in magnitude in the Grand Lake reservoir but had higher peaks upstream and a longer duration than the spring 2017 event. The hydrographs presented in Appendix I show that flooding persists the longest in Grand Lake with lower peaks, while areas further upstream experience sharper peaks of flooding that pass more quickly. The data is shown to be high quality, as error analysis shows differences between HOBO loggers and nearby USGS gages were small compared to fluctuations in the water levels, as were differences between the loggers and 'measure-down' records.

Unfortunately, due to multiple flood events in the basin, some of the loggers were not retrievable between August 2017 and April 2019. The internal data storage is only sufficient for a period of approximately 14 months, so some of the monitoring data was lost. Several loggers were washed away by flood events, debris, or boat traffic, resulting in further lost data.

The water level monitoring work described in this document provides important information that will be used in several other aspects of the Pensacola Dam relicensing project. Please see Appendices I and II for collected data described in this report.

Appendix I
Water Level Monitoring Data

Figure A1
Station 1: Neosho River near Commerce, OK

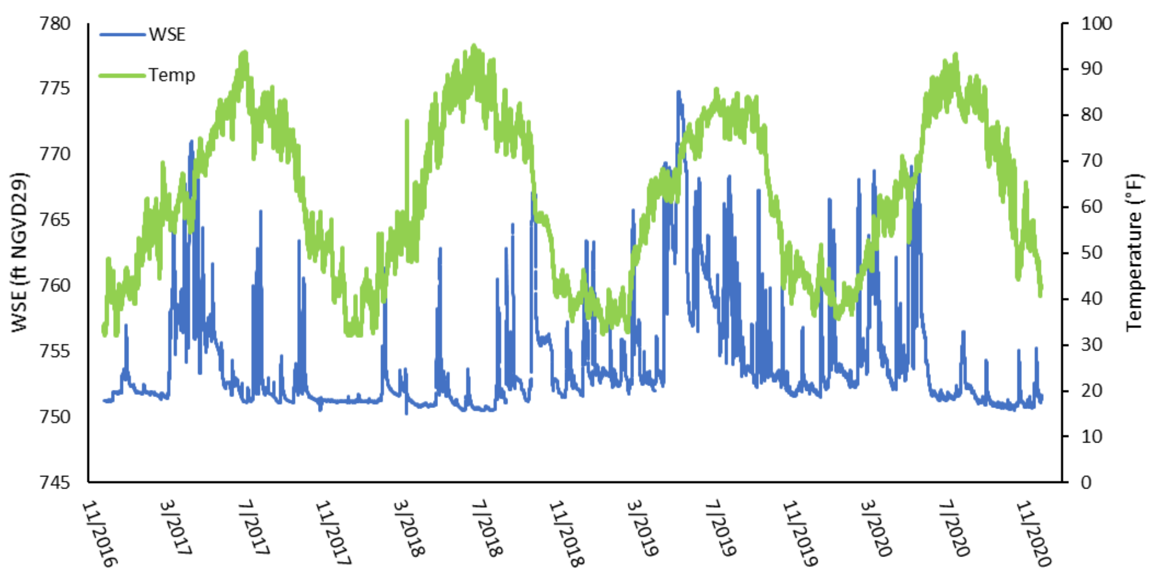


Figure A2
Station 2: Neosho River at Riverview Park, Miami, OK

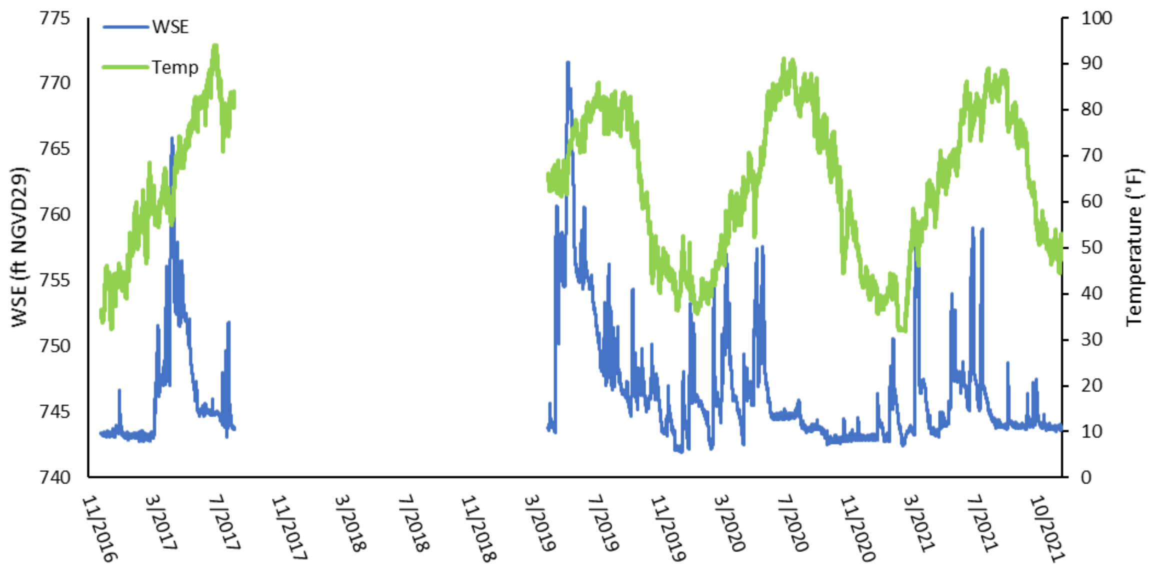


Figure A3
Station 3: Neosho River at Connors Bridge at S 590 Rd.

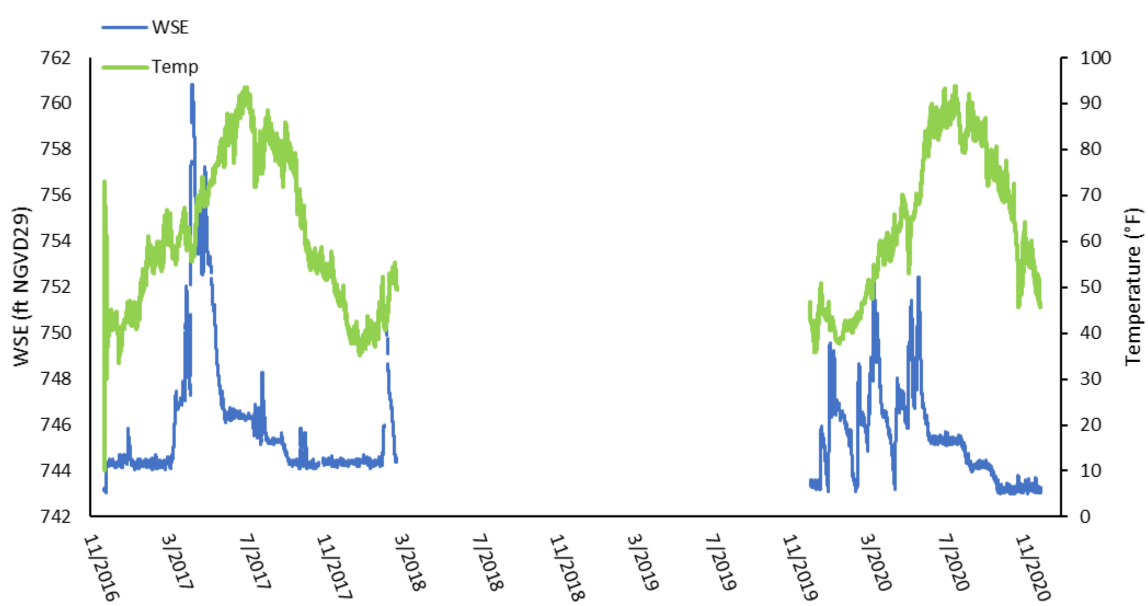


Figure A4
Station 4: Spring River upstream of Hwy 10 bridge

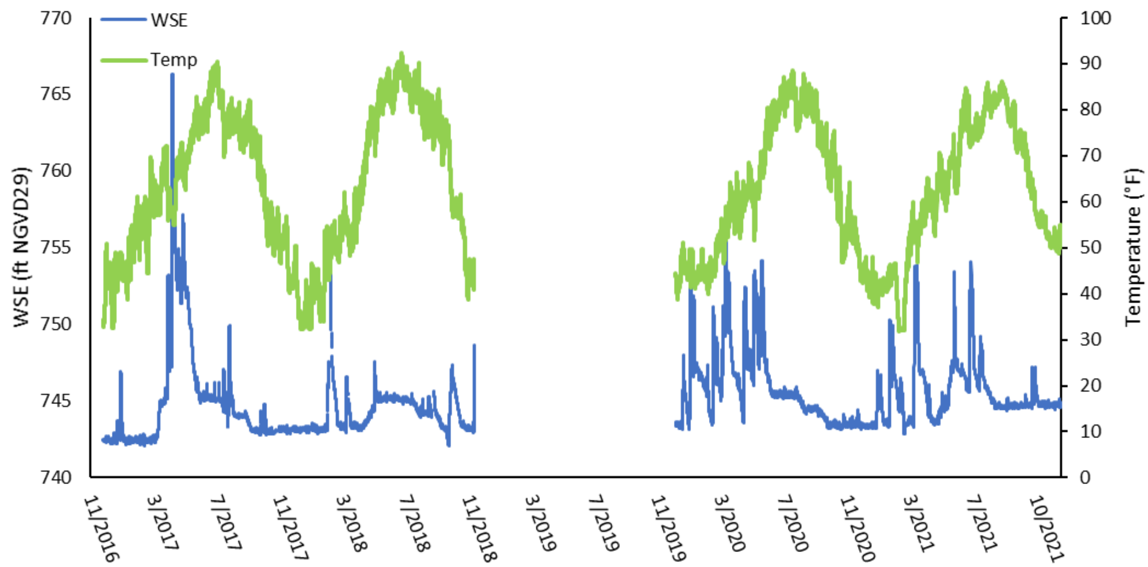


Figure A5
Station 5: Spring River at Twin Bridges Area at Grand Lake State Park boat launch

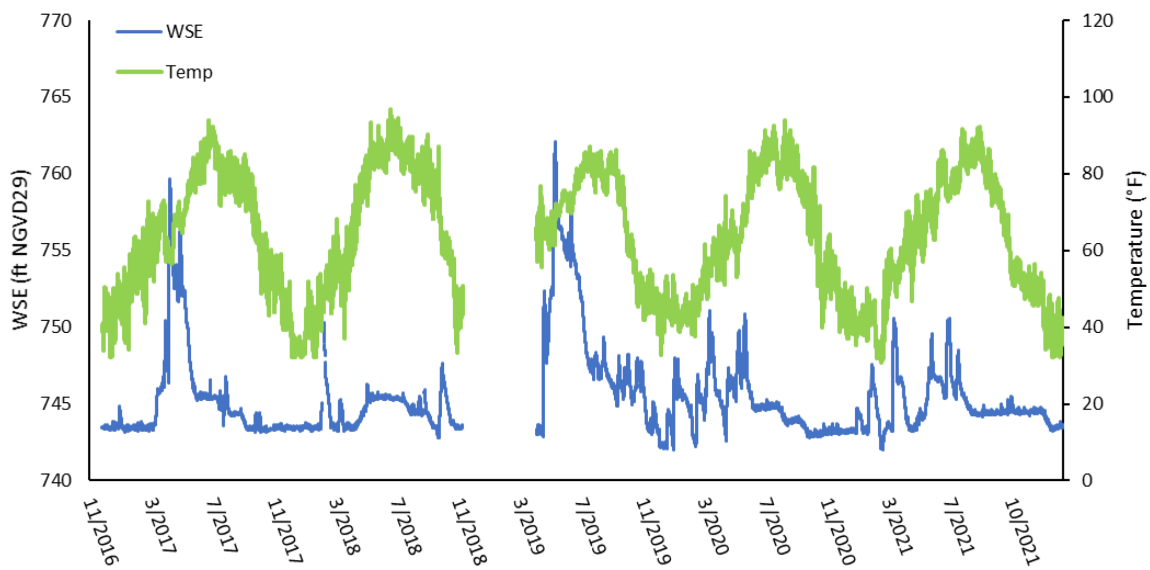


Figure A6
Station 6: Confluence of Neosho and Spring Rivers at Twin Bridges Area at Grand Lake State Park

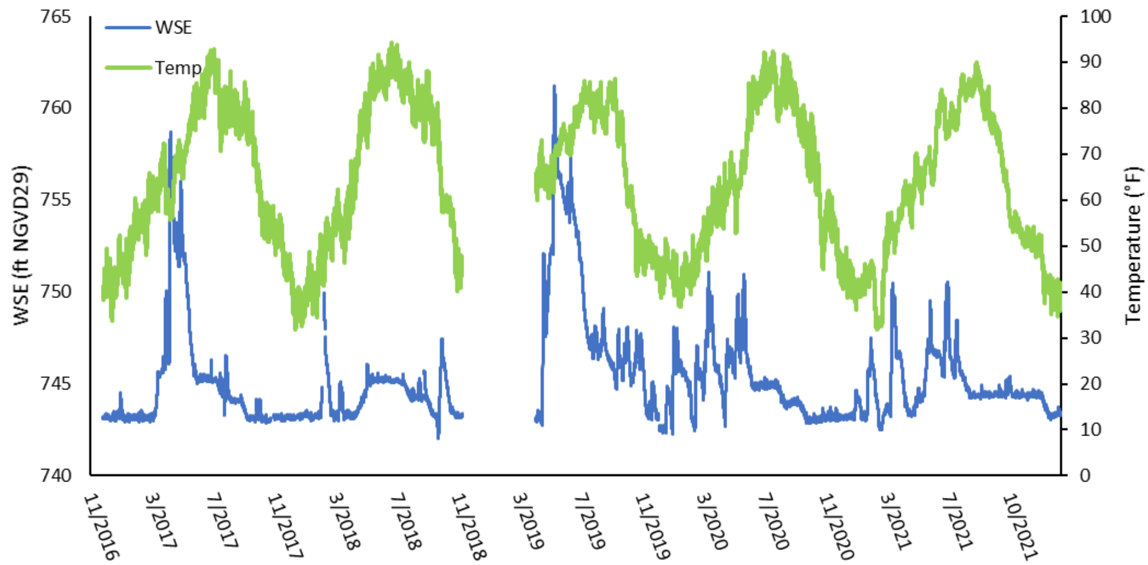


Figure A7
Station 7: Neosho River off E157 Road downstream of railroad bridge

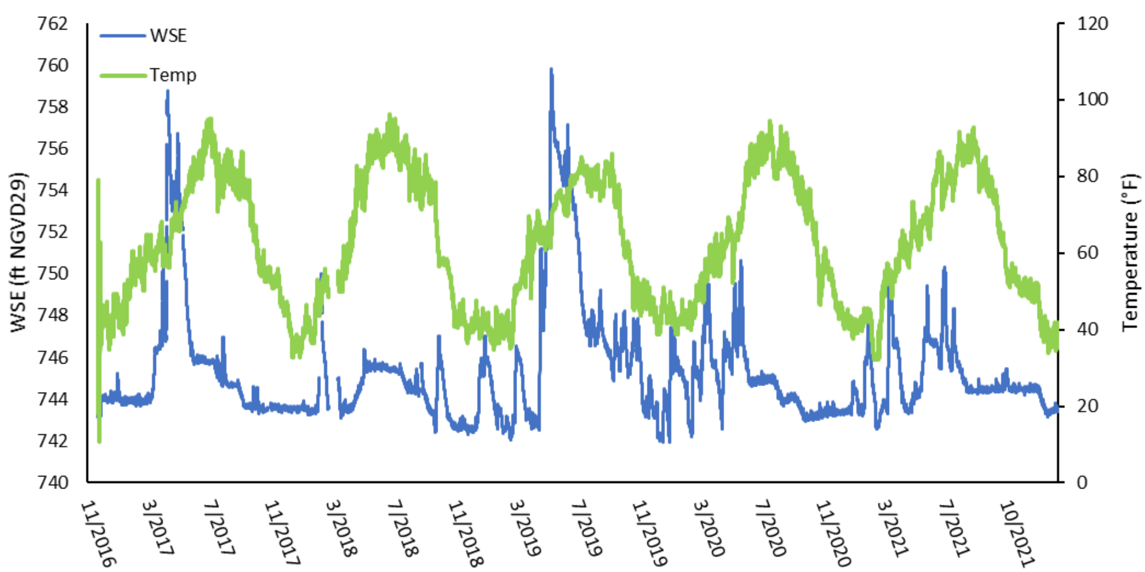


Figure A8
Station 8: Sycamore Creek at Hwy 10 bridge

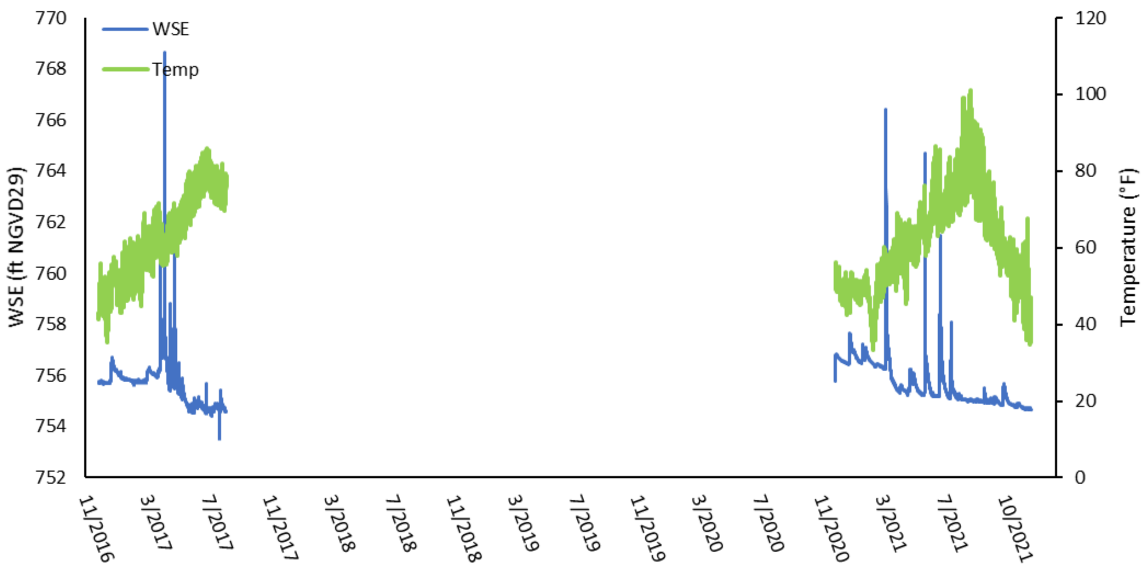


Figure A9
Station 10: Grand Lake/Elk River upstream of Hwy 10 bridge north of Grove, OK

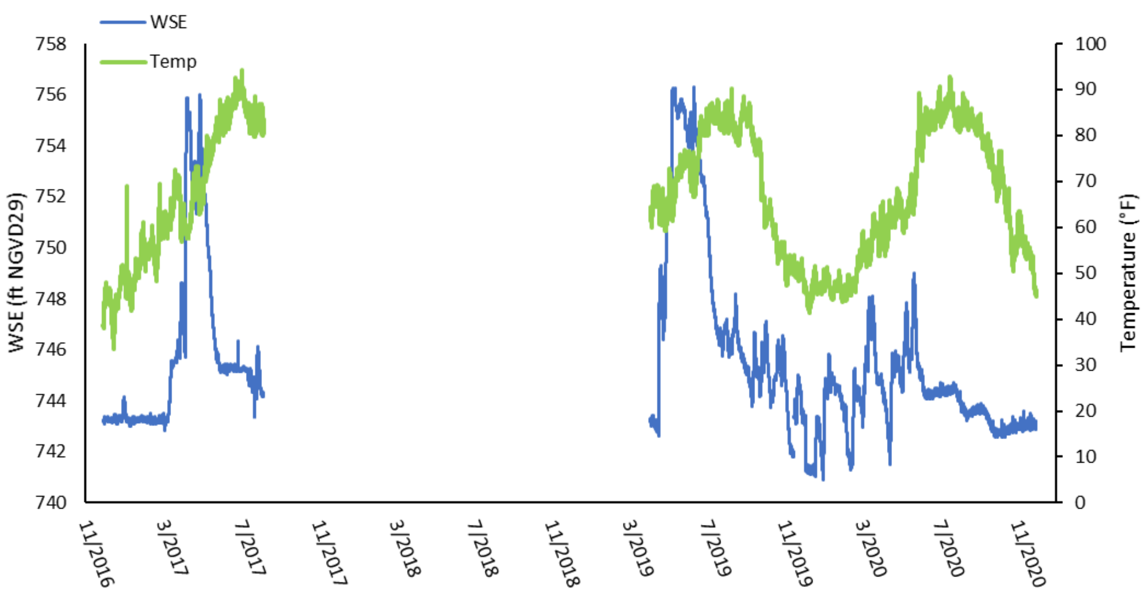


Figure A10
Station 11: Grand Lake at Hickory Point, upstream of Hwy 59 bridge

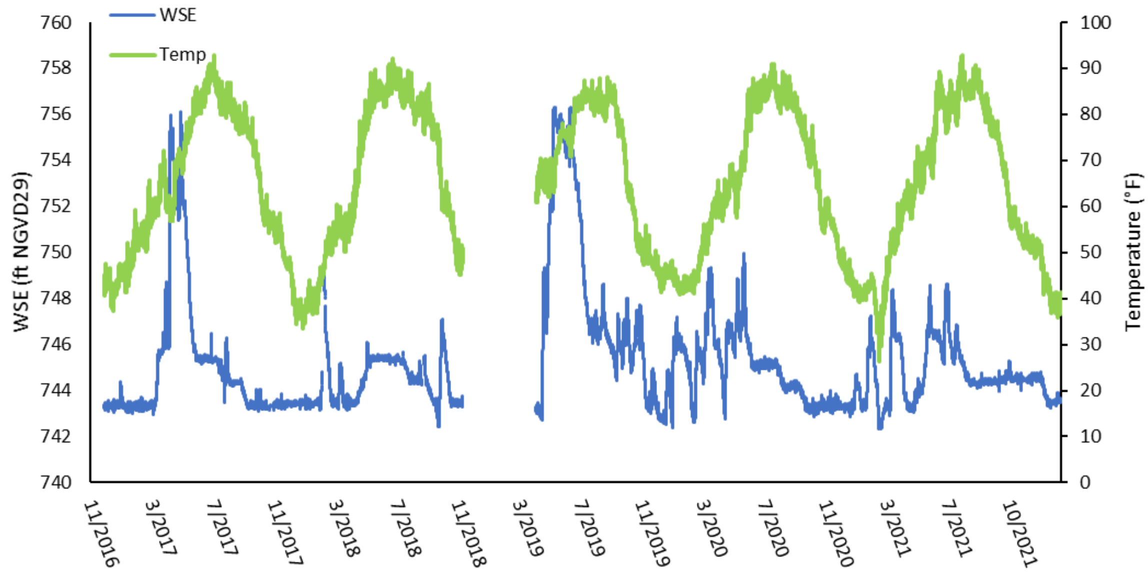


Figure A11
Station 12: Grand Lake at public access off S. 580 Rd, downstream of Hwy 59 bridge

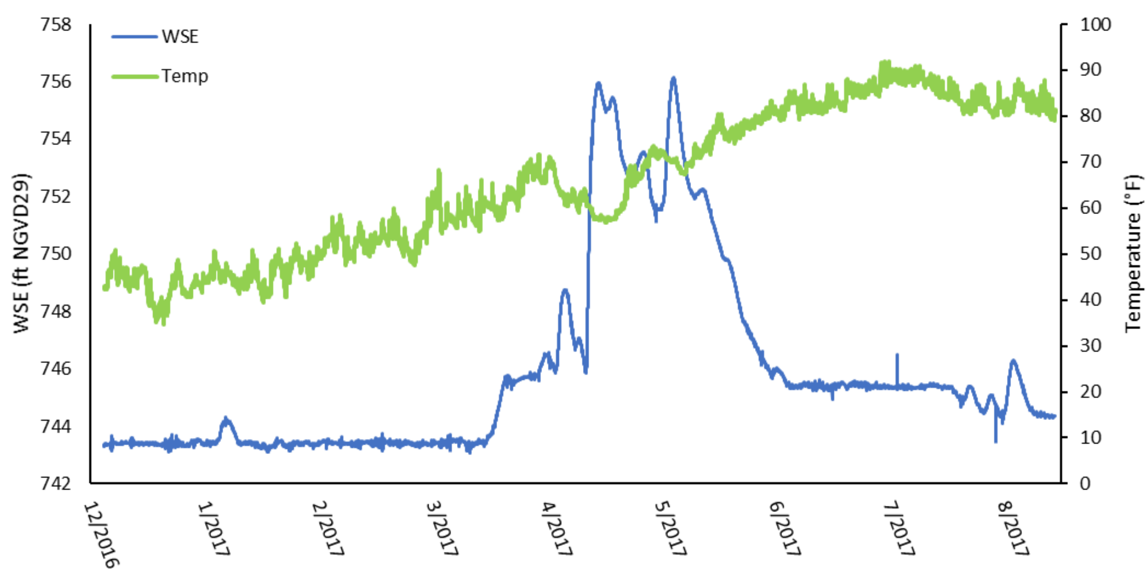


Figure A12
Station 13: Grand Lake at Honey Creek State Park

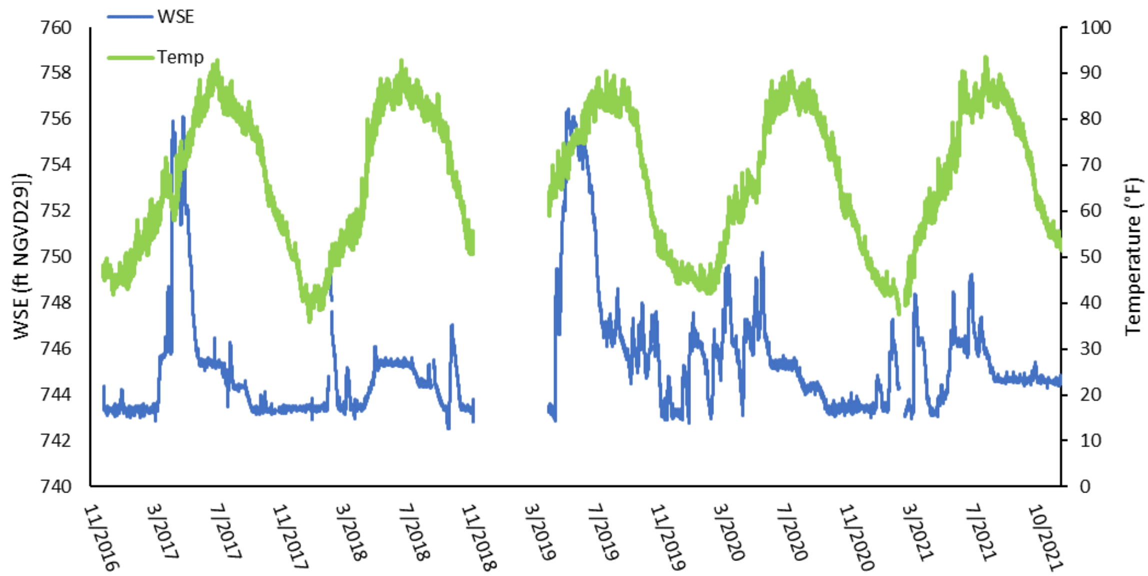


Figure A13
Station 14: Horse Creek off E 249 Rd

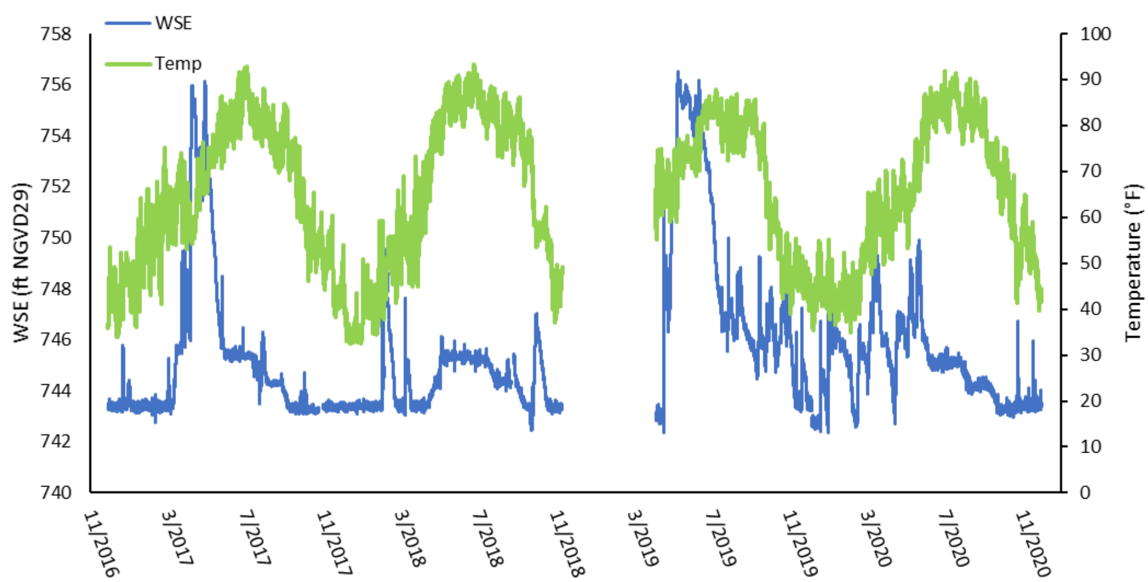


Figure A14
Station 15: Grand Lake near Woods Spring Branch off S 560 Rd & E 360 Rd

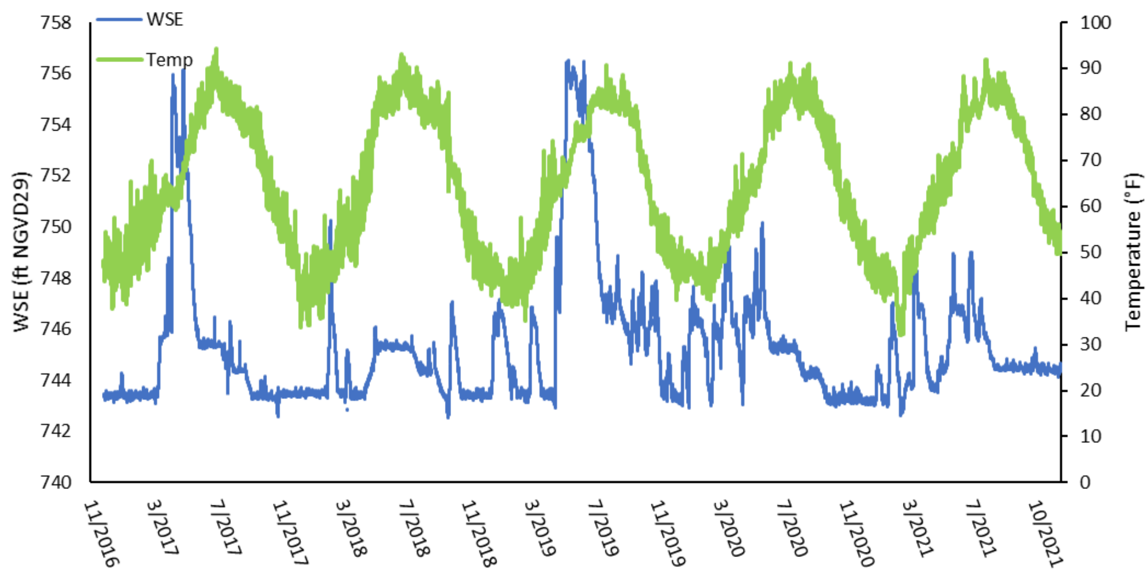
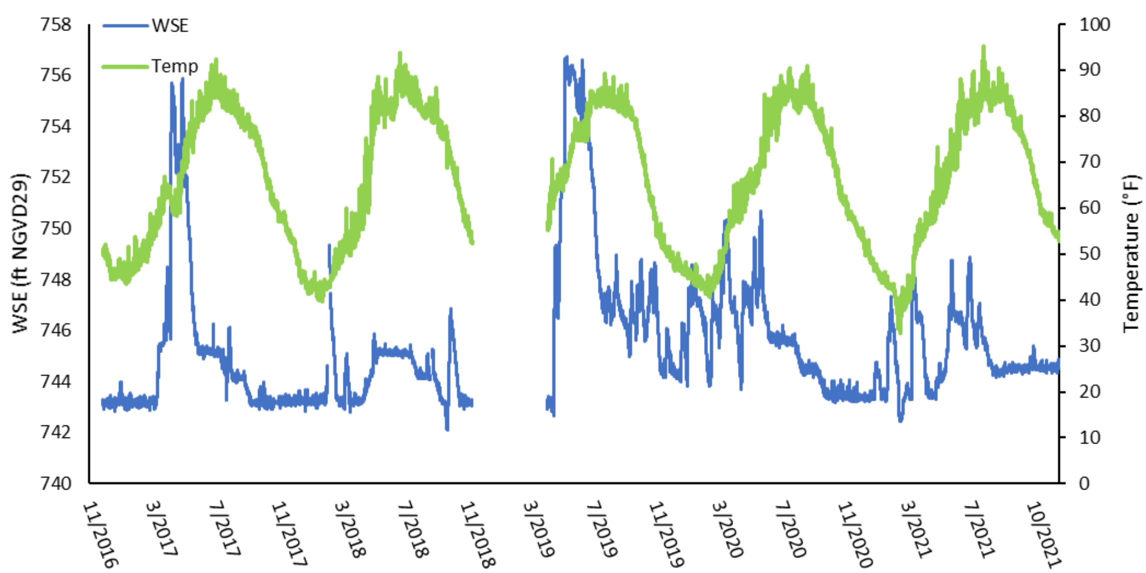
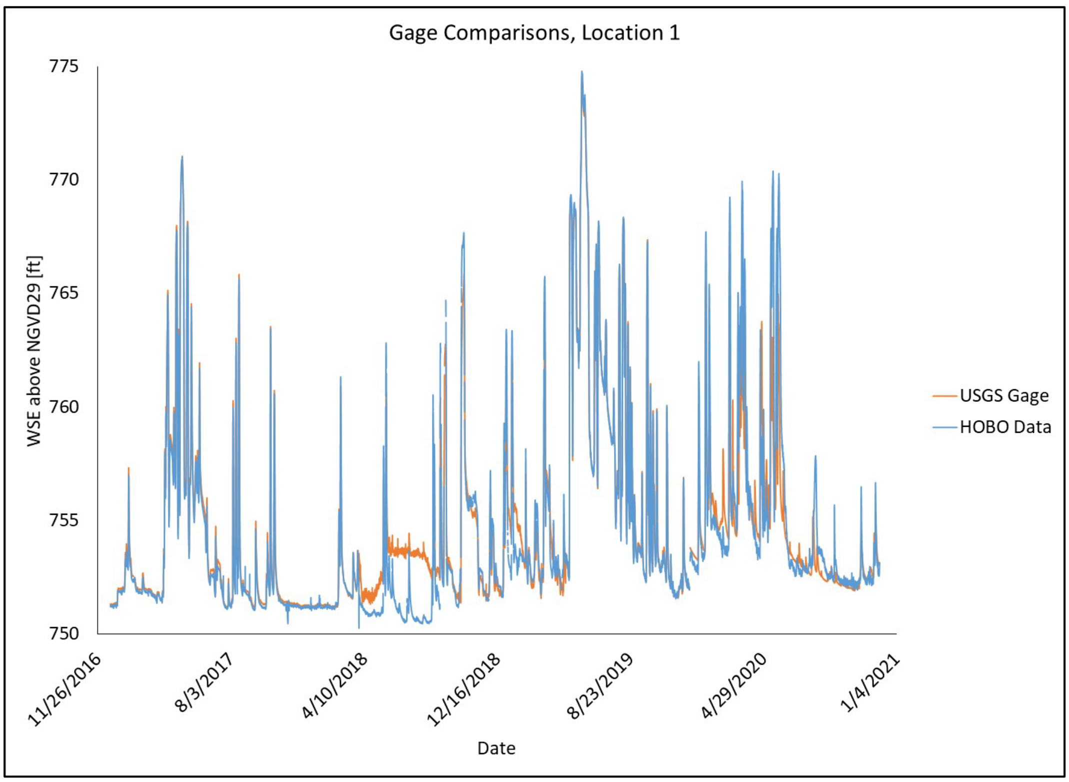


Figure A15
Station 16: Grand Lake at Cherokee State Park Boat Ramp, Disney, OK



Appendix II Comparison of HOBO Logger Data and USGS Gage Data

Figure A16
Station 1 compared to USGS Gage 07185000 (Neosho River near Commerce, OK).



Data shows generally good agreement between USGS gaging station and HOBO logger, with some deviations during later part of record (see detail below).

Figure A17
Station 1 2020 data compared to USGS Gage 07185000 (Neosho River near Commerce, OK).

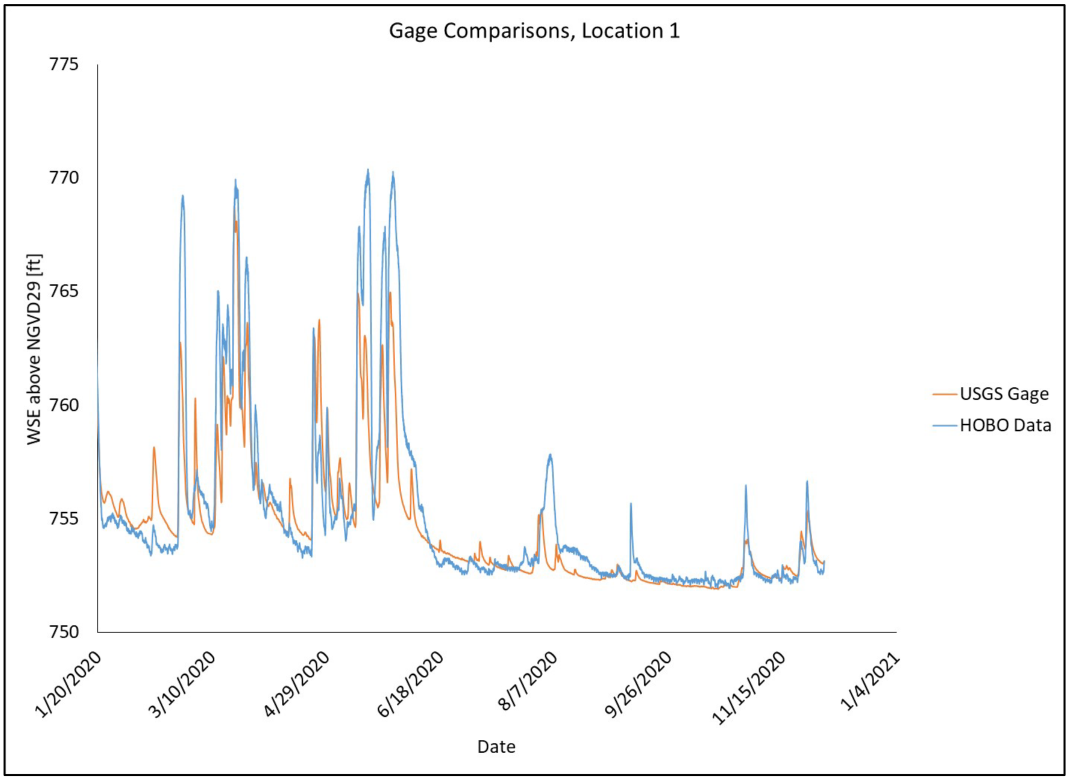
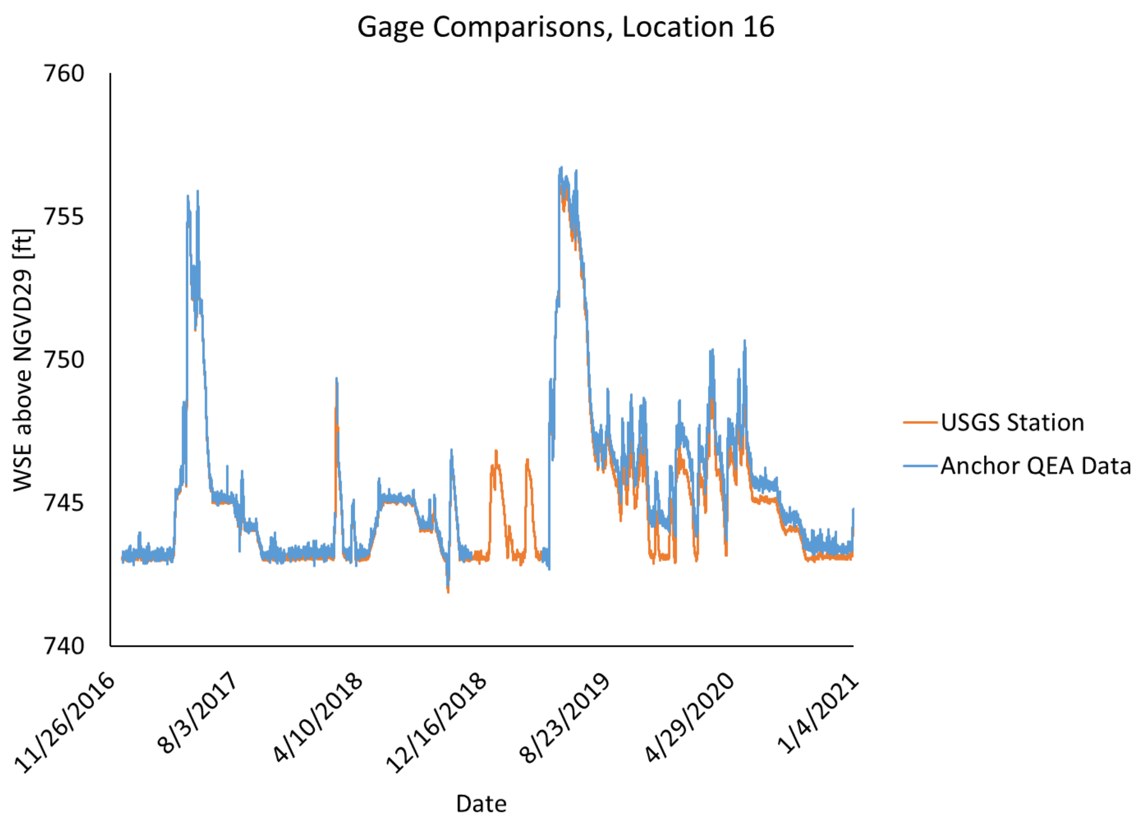


Figure A18
Station 16 compared to USGS Gage 07190000 (Lake O' the Cherokees at Langley, OK).



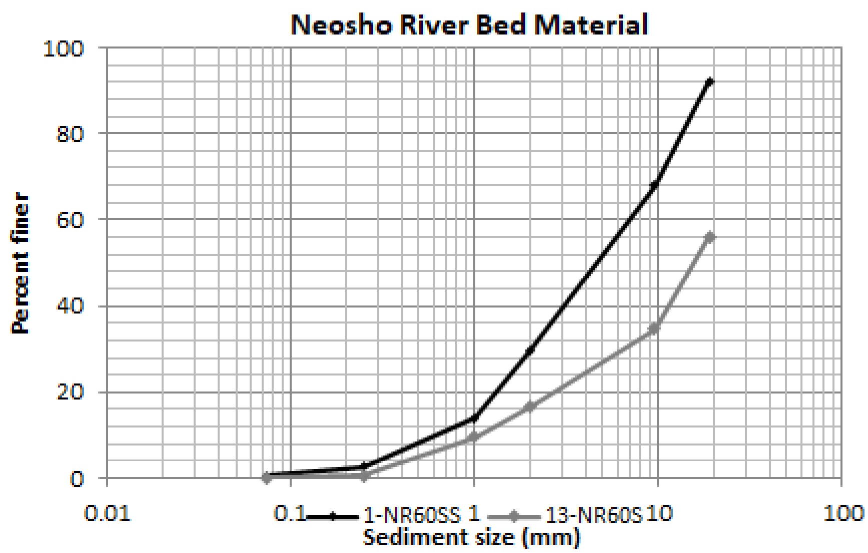
Appendix B
Sediment Grab Sampling

Particle Size Distribution Results

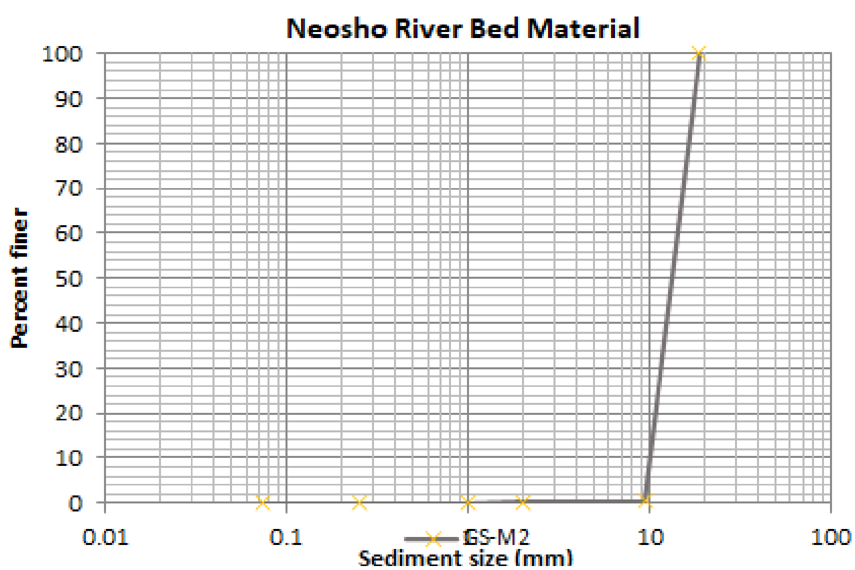
Note: Graphs are provided for each stream in an upstream to downstream direction showing HEC-RAS River Mile for each sample. Core sample particle size distributions are also included with other samples to provide context and completeness. Unless otherwise noted, samples are from the riverbed.

Neosho River above Tar Creek

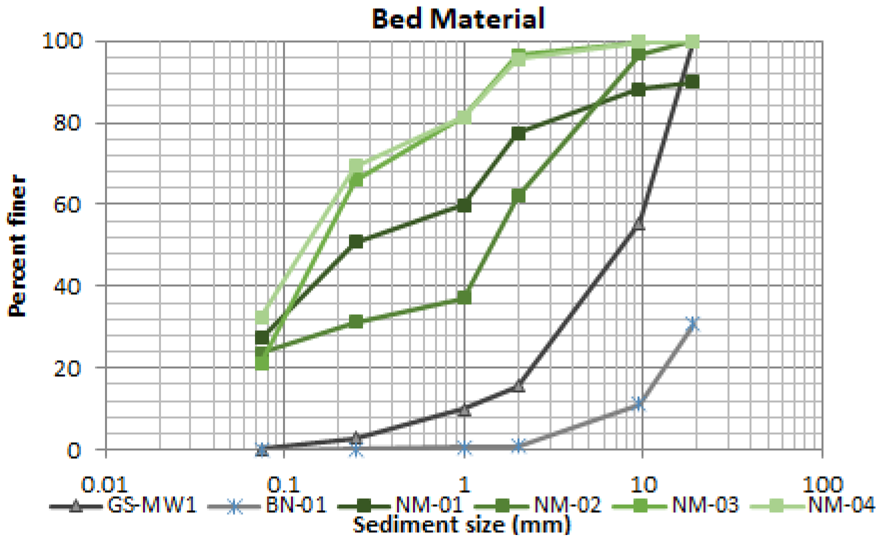
River Mile 145.5



River Mile 135.95

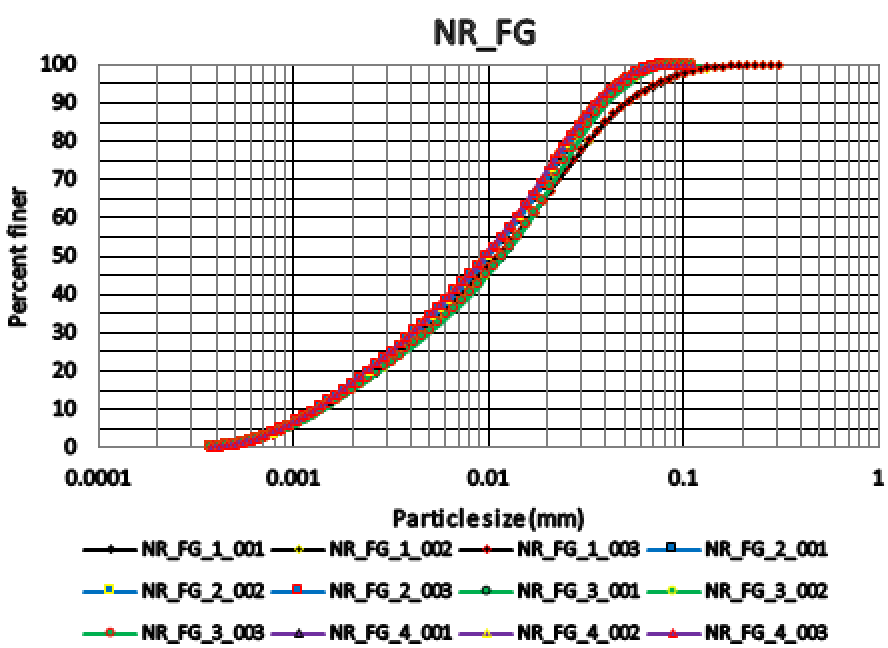


River Mile 134.6–135.46

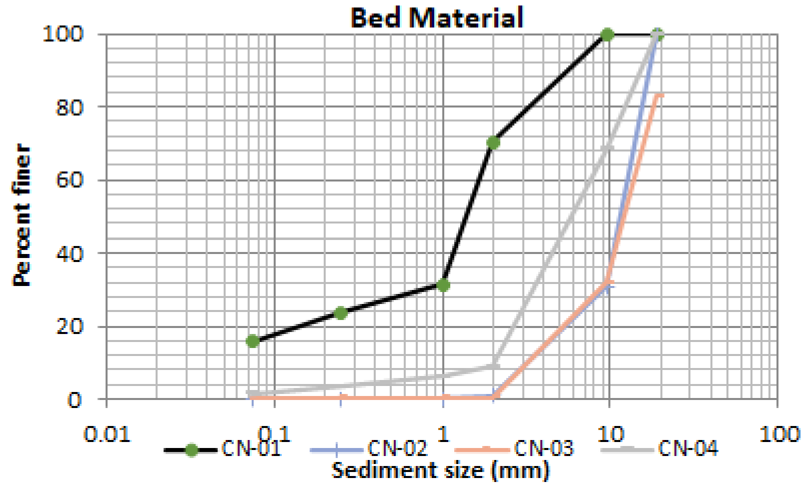


Note: NM-01 – left bank surface, NM-02 – floodplain surface, NM-04 – right bank surface

River Mile 135.04

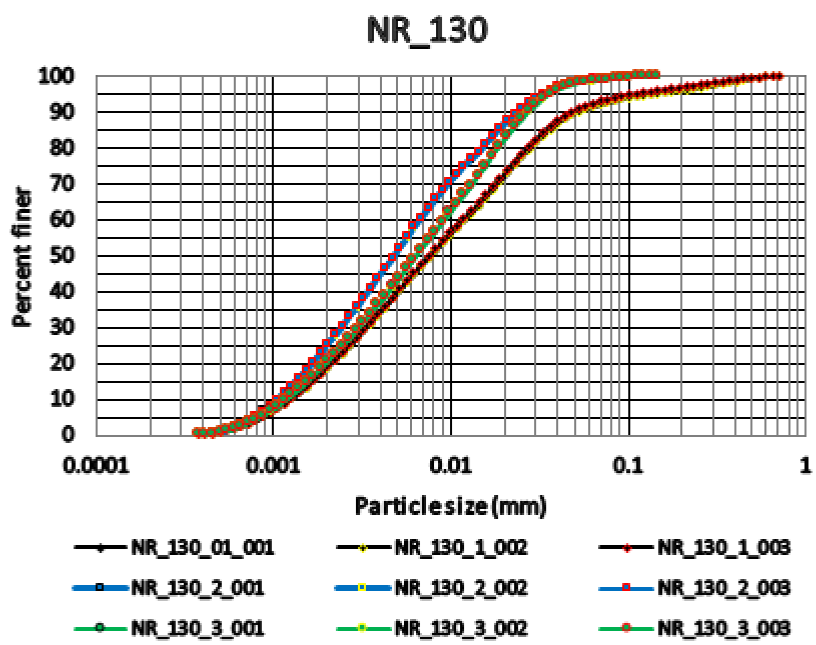


River Mile 128.81–130.37

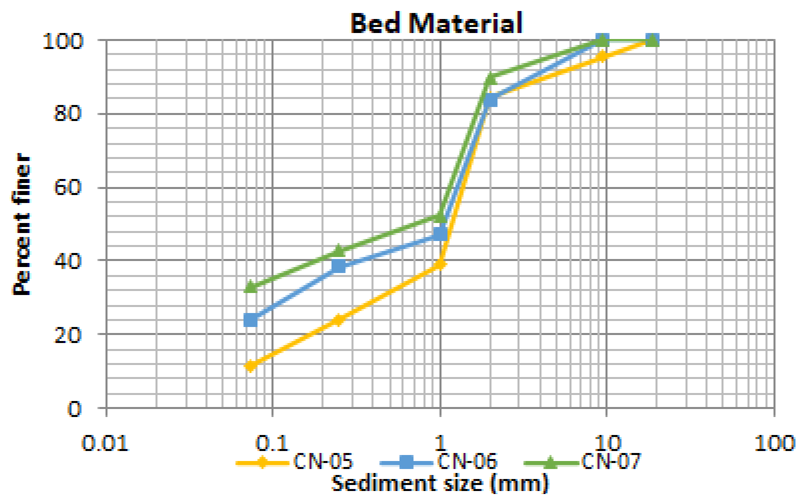


Note: CN-01 – bank

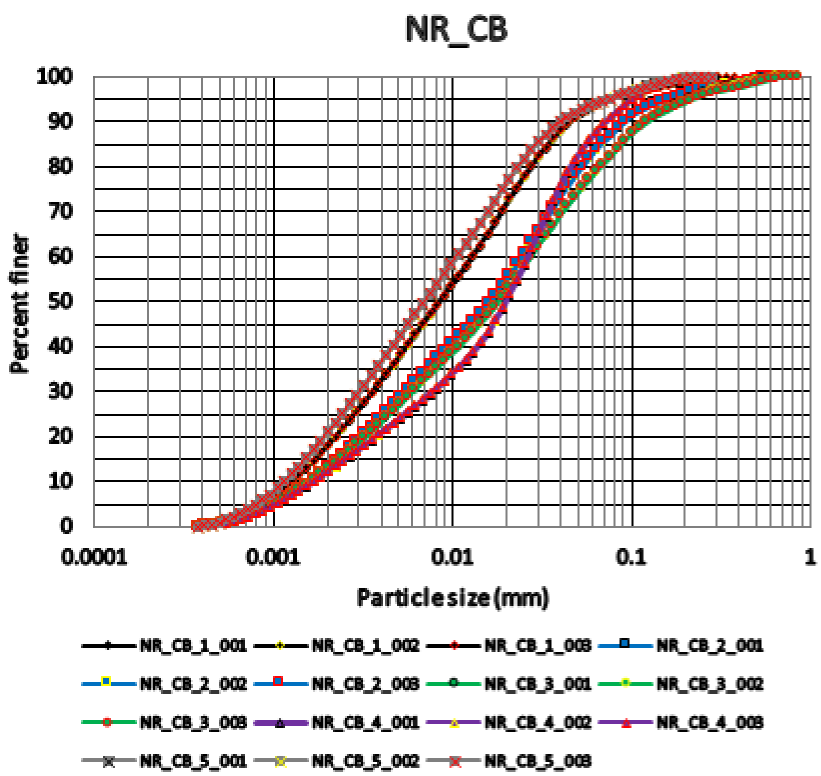
River Mile 130.37



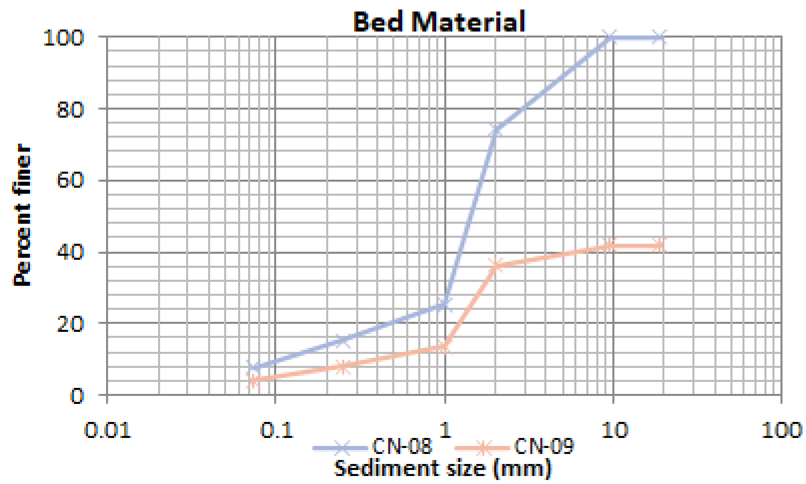
River Mile 126.69–127.85



River Mile 126.69

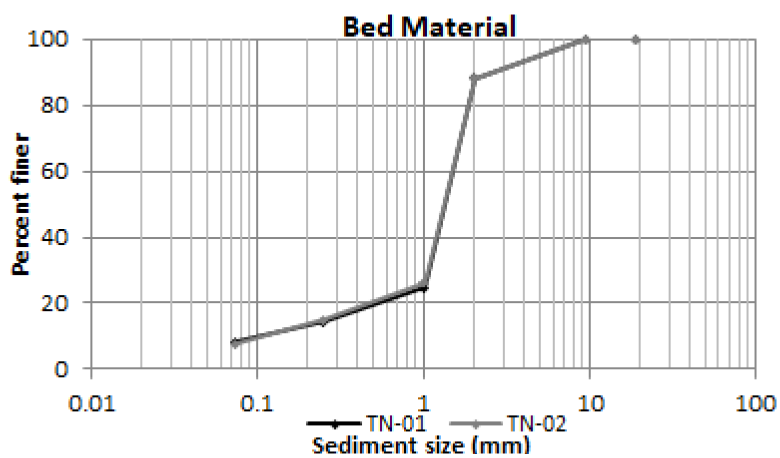


River Mile 124.2–125.33



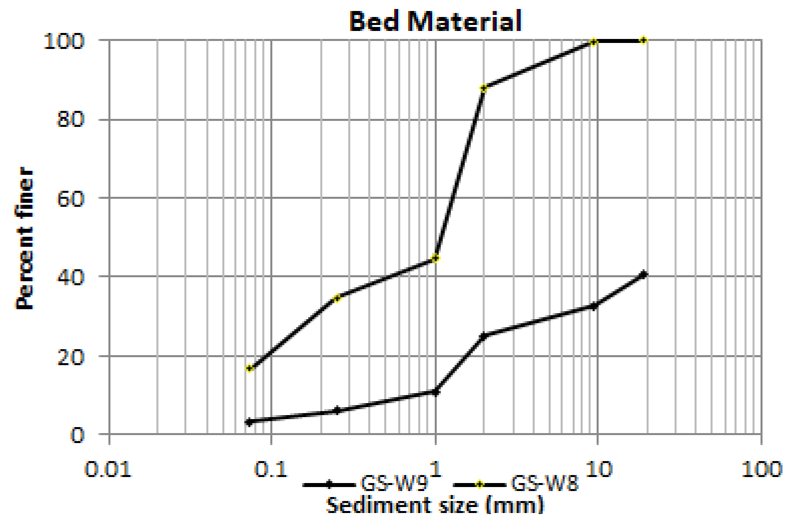
Note: CN-08 – left bank

River Mile 122.57–123.24

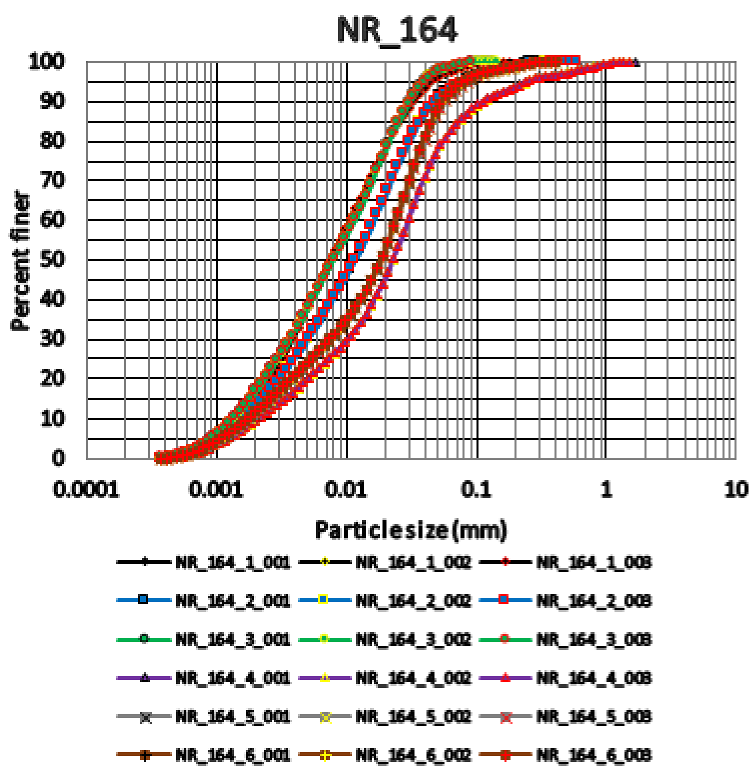


Neosho River – Grand Lake

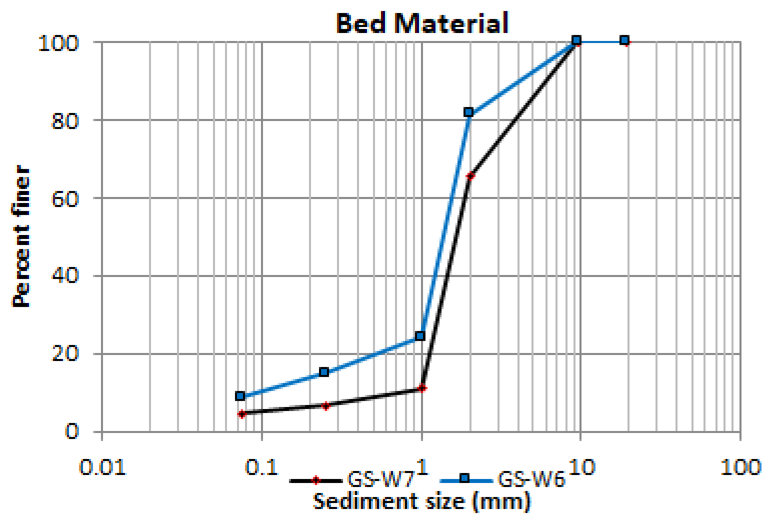
River Mile 120.1–122.25



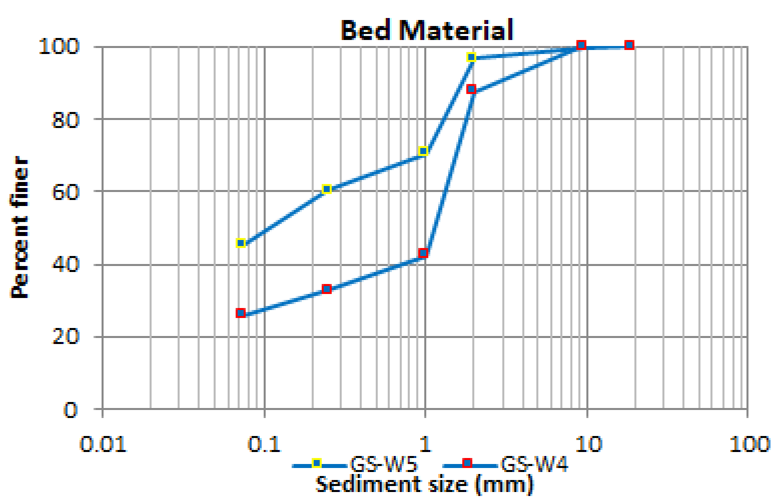
River Mile 120.1–120.43



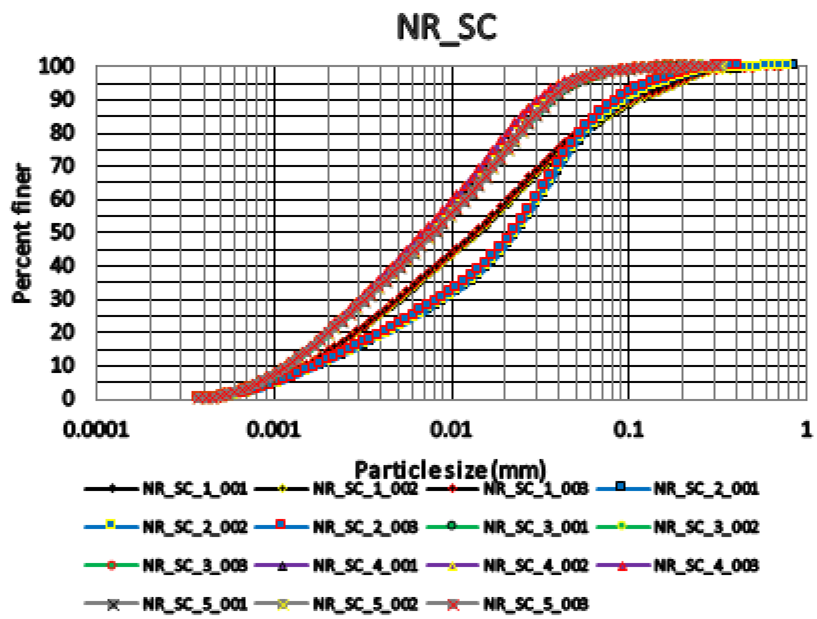
River Mile 117.66–119.06



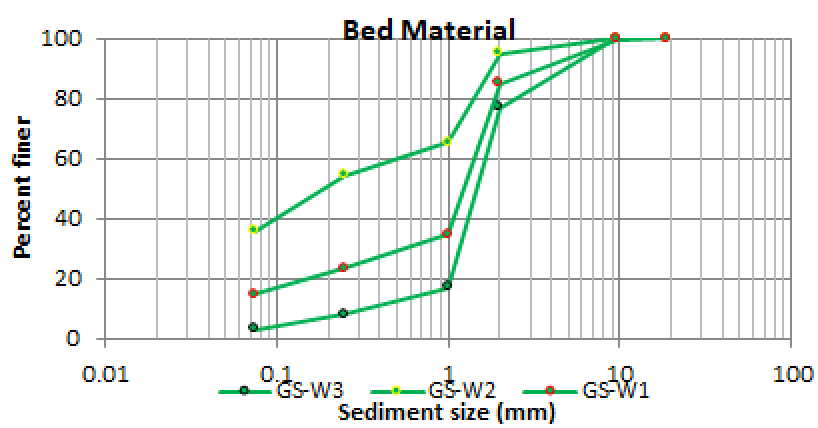
River Station 115.65–115.86



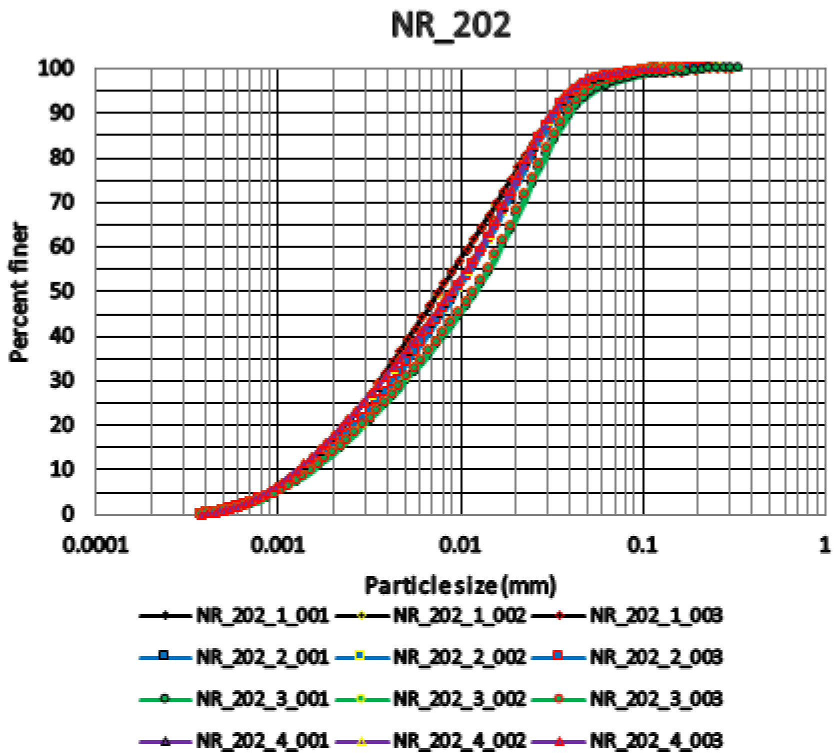
River Station 115.65–115.86



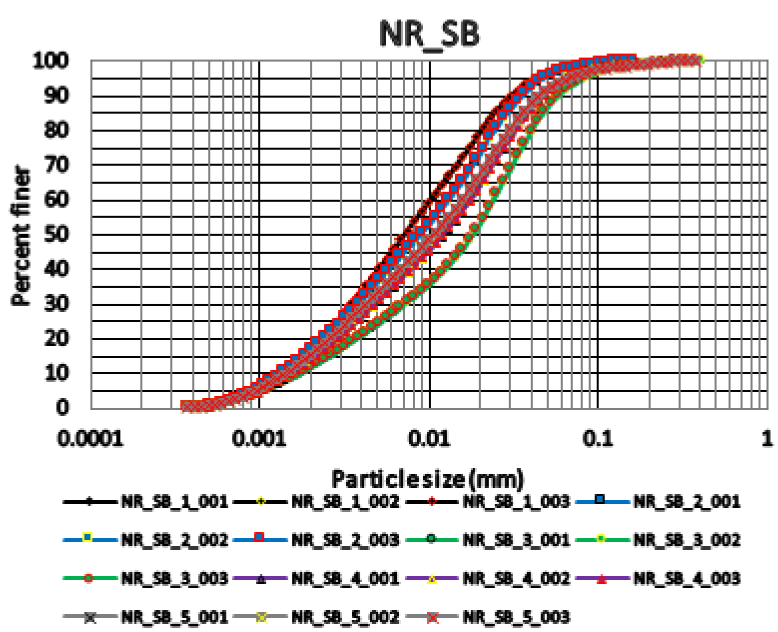
River Mile 112.34–114.21



River Mile 112.34–112.61

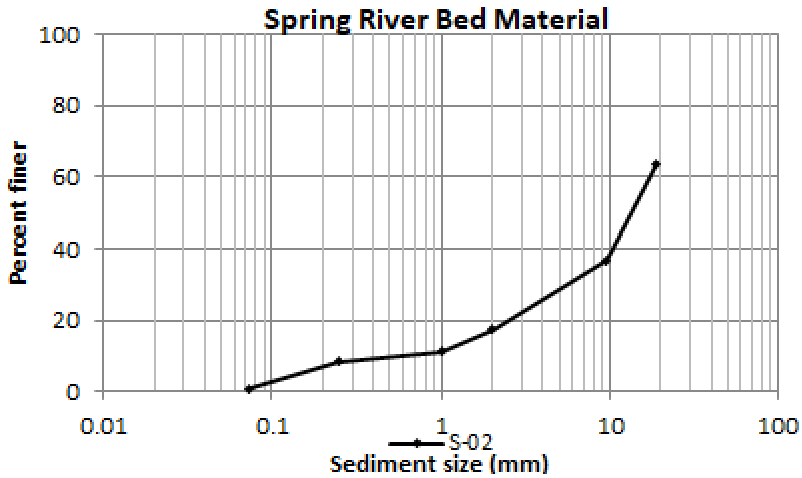


River Mile 108.87–109.25

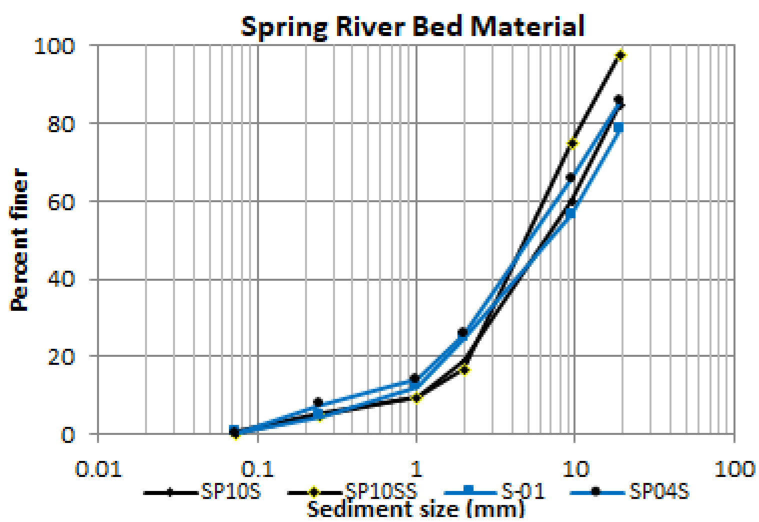


Spring River

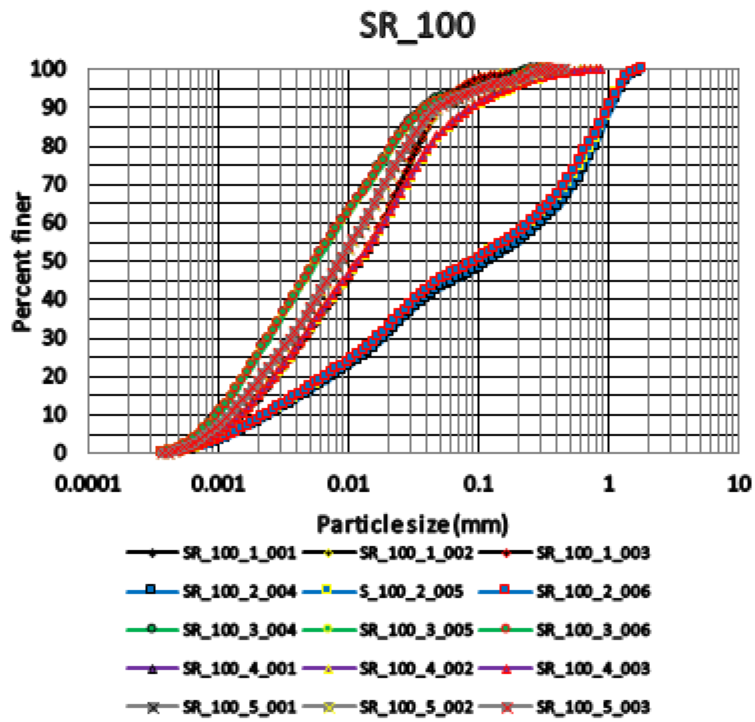
River Mile 14.16



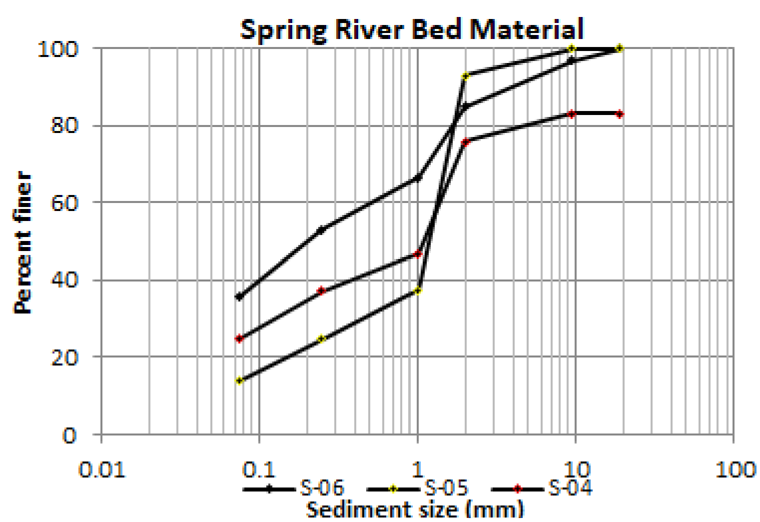
River Mile 8.01



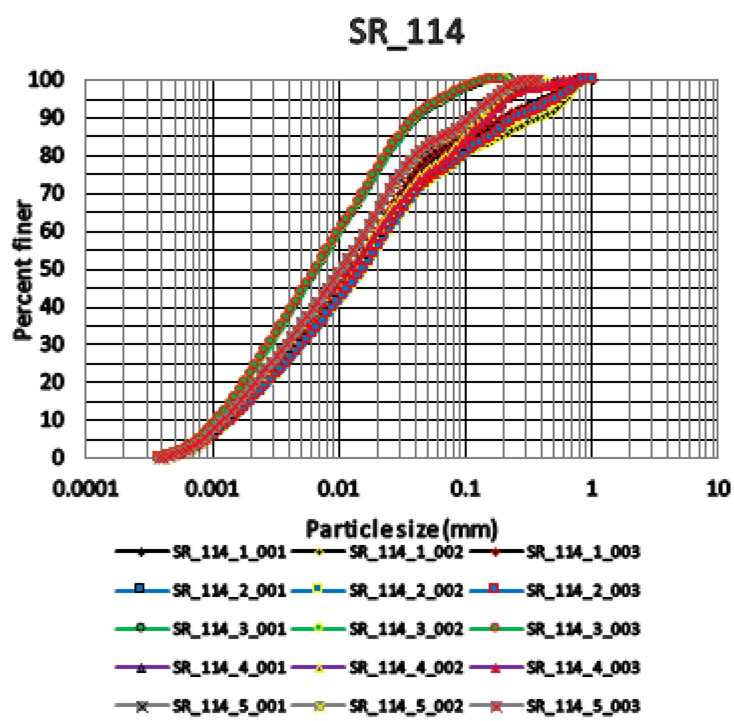
River Mile 7.5



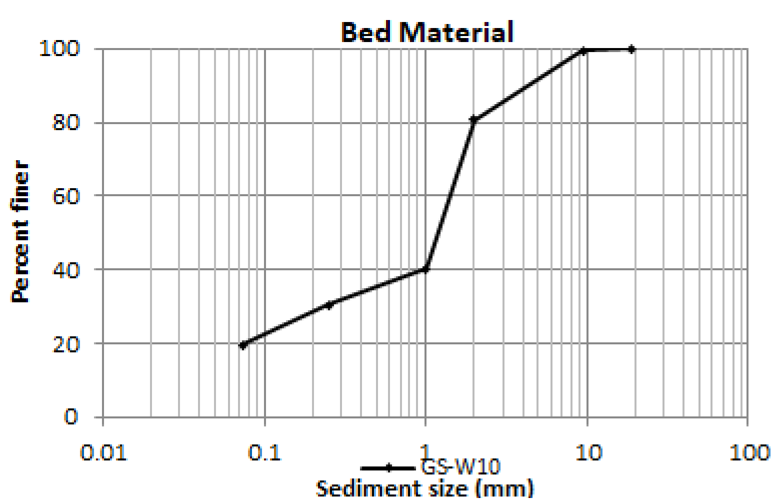
River Mile 2.26–5.1



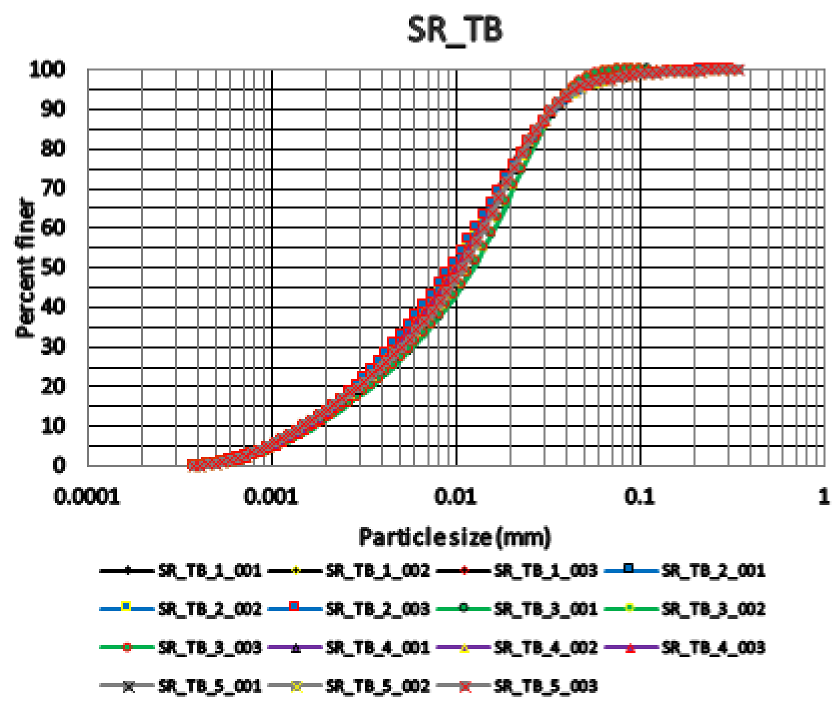
River Mile 4.82



River Mile 0.57–0.69

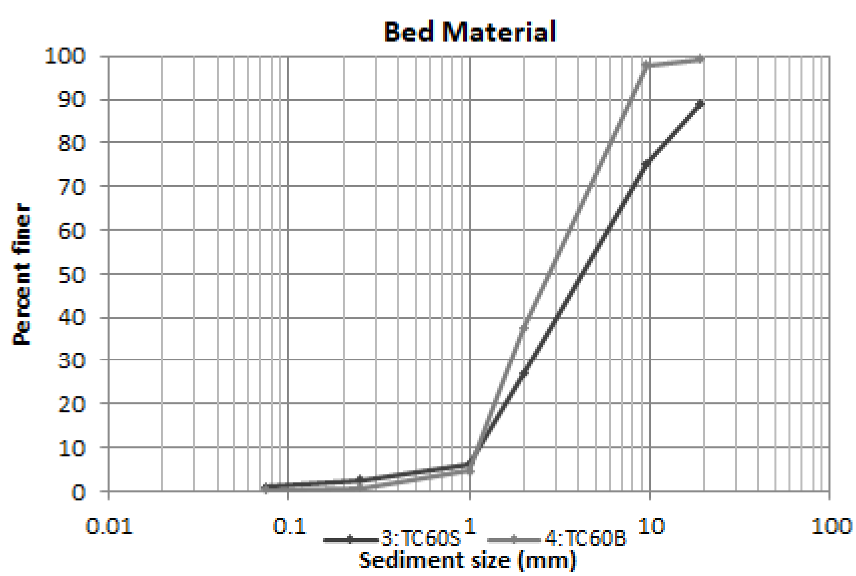


River Mile 0.79–0.99

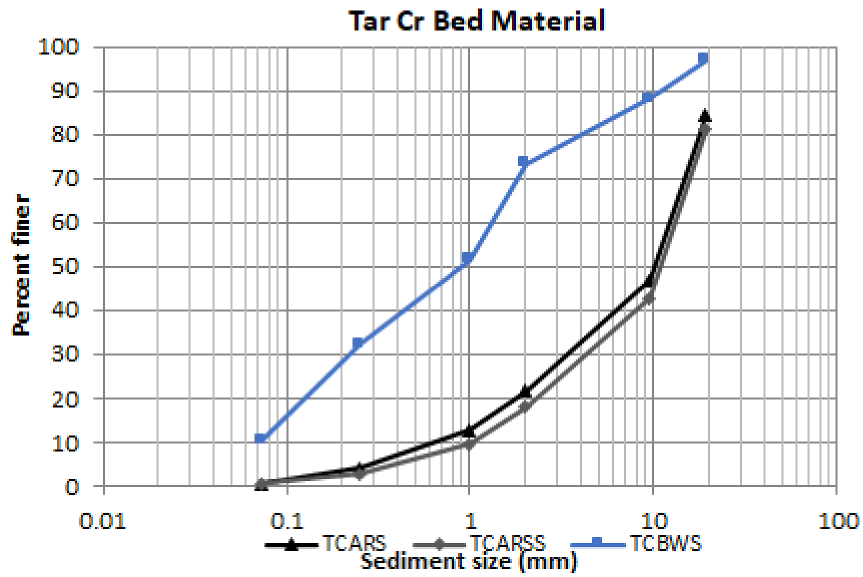


Tar Creek

River Mile 6.33

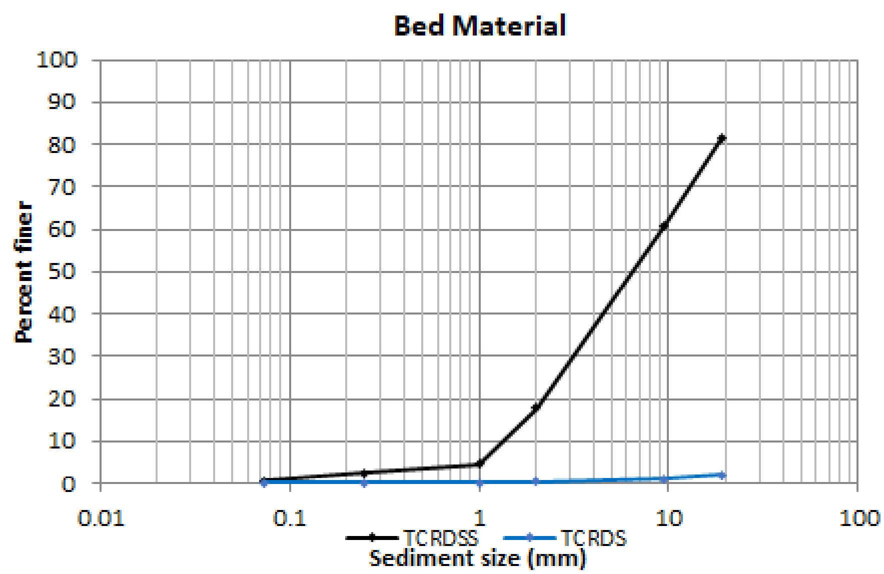


River Mile 2.74–2.98

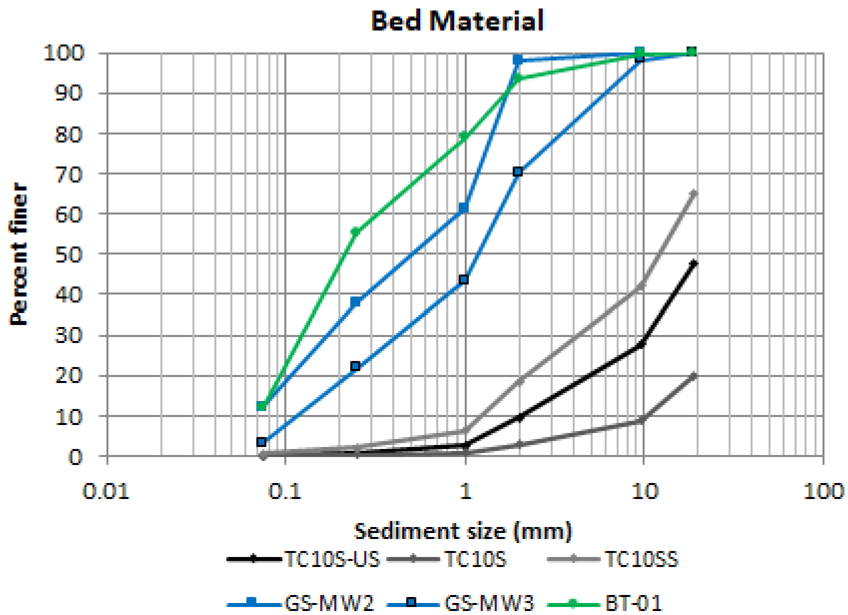


Note: BW: backwater

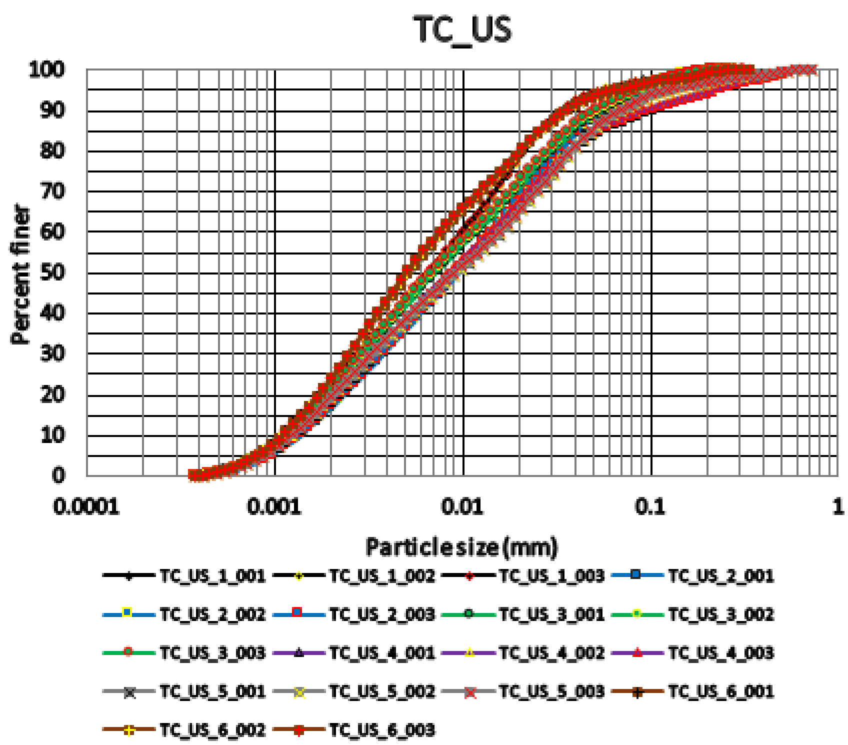
River Mile 2.23



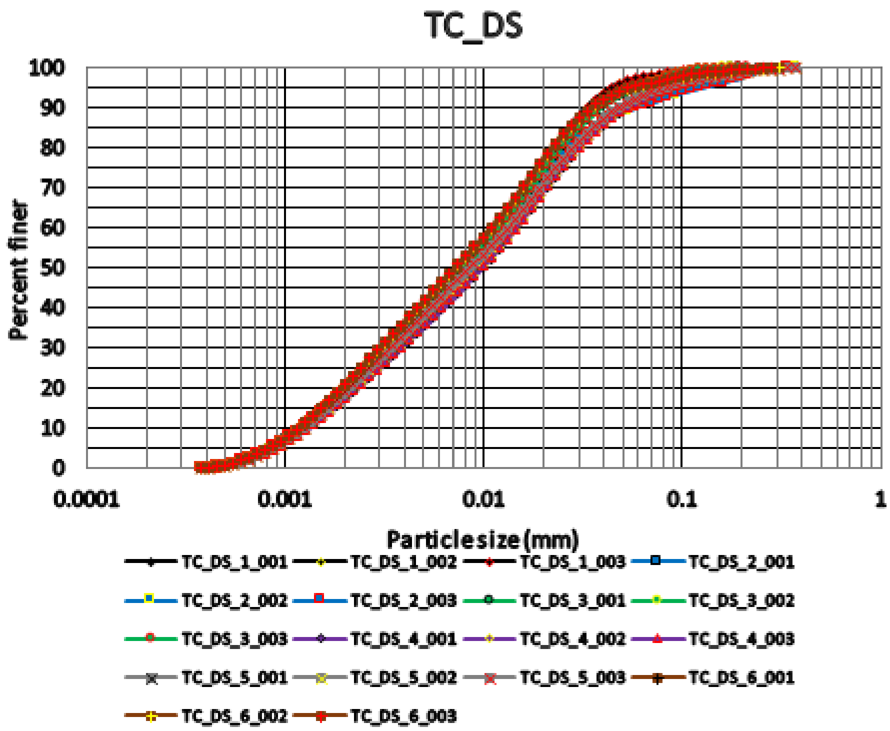
River Mile 1.6



River Mile 1.6

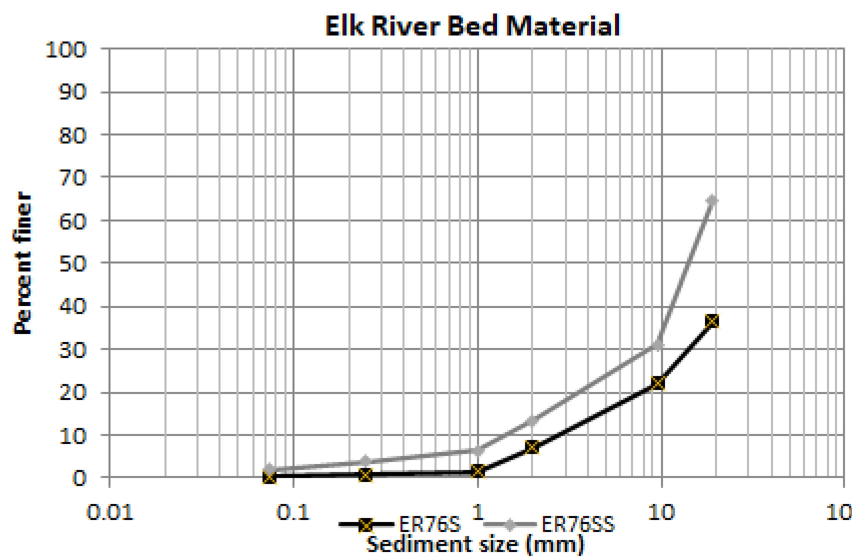


River Mile 1.6

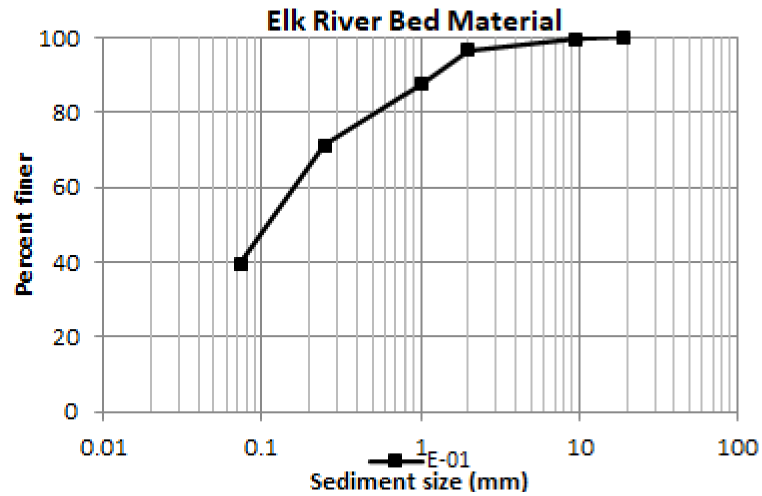


Elk River

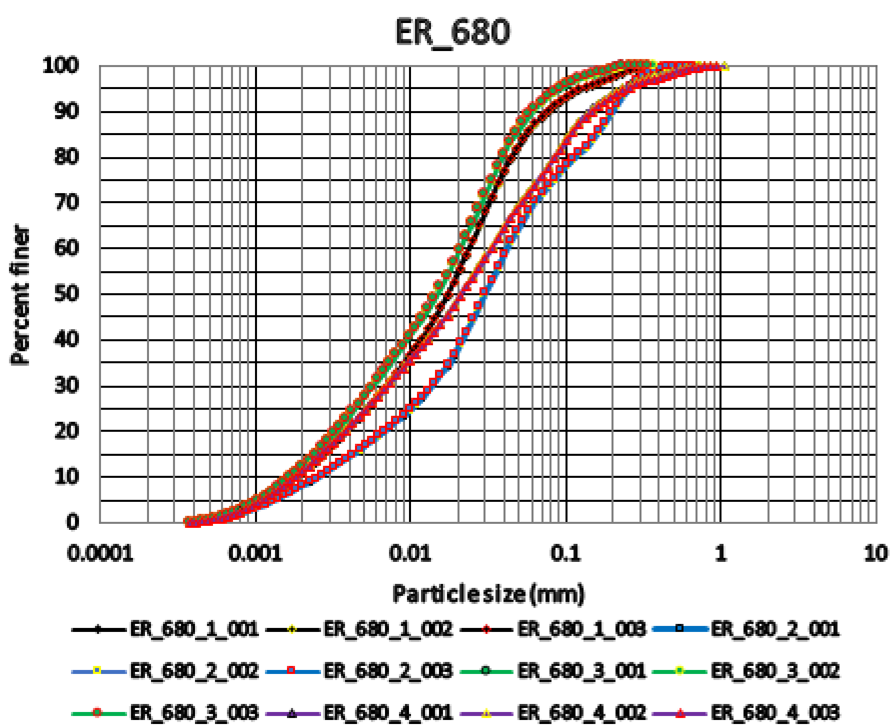
River Mile 14.22



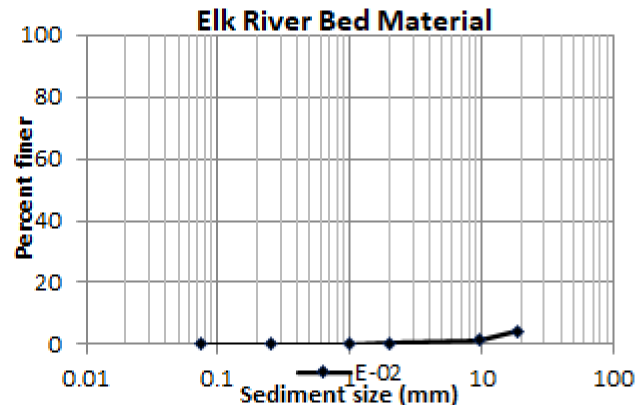
River Mile 8.8



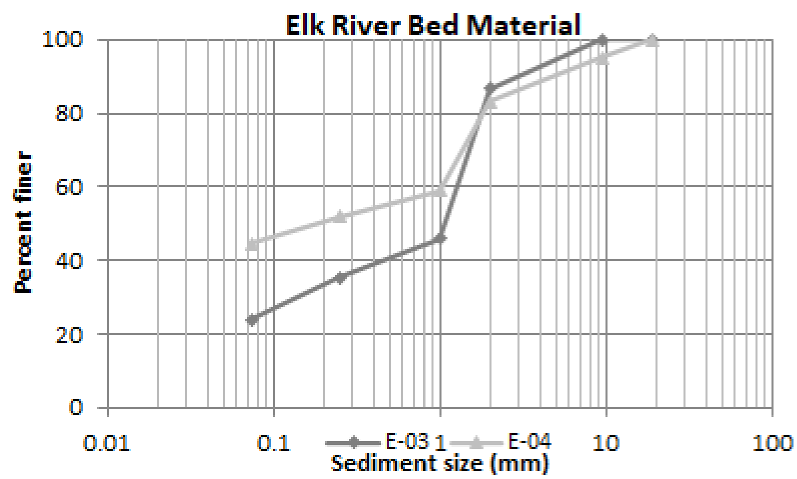
River Mile 8.8



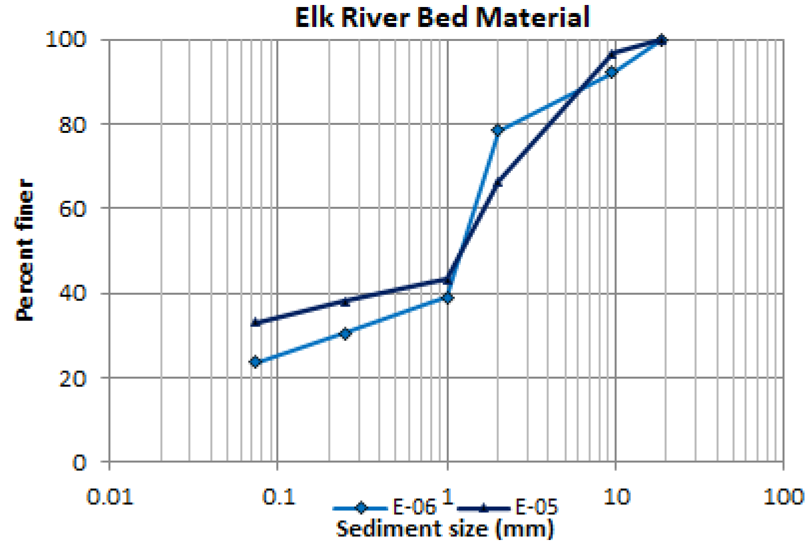
River Mile 7.5-7.79



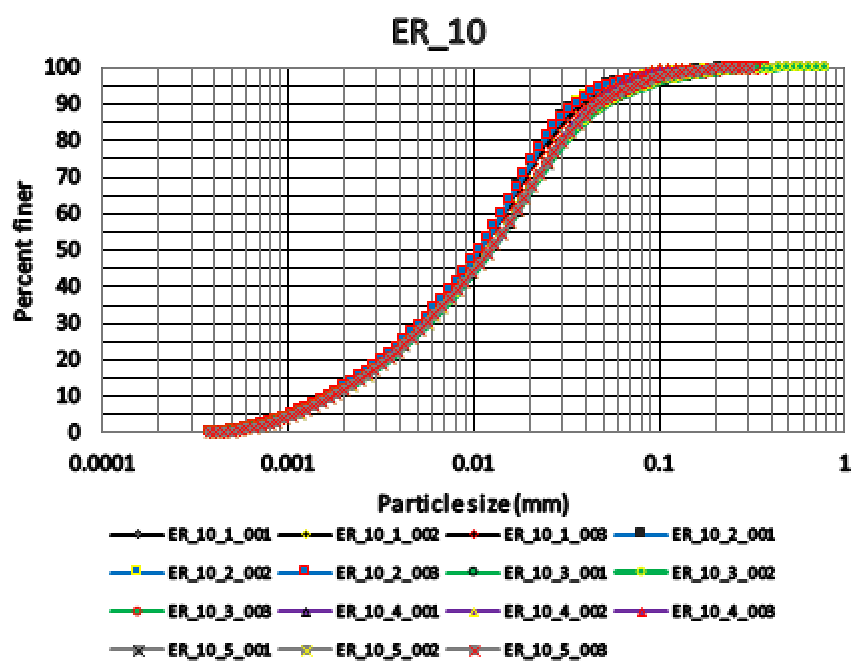
River Mile 5.86–6.57



River Mile 4.67–4.9 (E-05 and ER_10)



River Mile 3.2–3.43 E-06



Sediment Grab Sampling

Date: 12 DEC 2019

Staff: RS, TK

Weather: 27F, windy

Stream Name: Neosho (North of Tar & Spring)

Station No: BN-01

Site Description and Flow Observations:

Surface sample from streambed

Bed Sediment Sampling

Sampling Platform: ☐Wading ☐Cable ☐Ice ☑Boat ☐Bridge

Type of Sampler Used: Ekman

Northing: 692,411

Easting: 2,881,745

Datum: OK N (USft)

Total Number of Samples Collected: 1

Sediment Grab Sampling

Date: 12 DEC 2019

Staff: TK, RS

Weather: 25F, windy

Stream Name: Tar Creek

Station No: BT-01

Site Description and Flow Observations:

Taken from bed surface

Bed Sediment Sampling

Sampling Platform: ☐Wading ☐Cable ☐Ice ☑Boat ☐Bridge

Type of Sampler Used: Ekman

Northing: 690,921

Easting: 2,886,846

Datum: OK N (USft)

Total Number of Samples Collected: 1

Sediment Grab Sampling

Date: 12 DEC 2019

Staff: RS, TK

Weather: 27F, windy

Stream Name: Neosho (North of Tar & Spring)

Station No: GS-M2

Site Description and Flow Observations:

Surface sample from streambed

Bed Sediment Sampling

Sampling Platform: ☐Wading ☐Cable ☐Ice ☑Boat ☐Bridge

Type of Sampler Used: Ekman

Northing: 695,578

Easting: 2,879,827

Datum: OK N (USft)

Total Number of Samples Collected: 1

Sediment Grab Sampling

Date: 12 DEC 2019

Staff: RS, TK

Weather: 27F, windy

Stream Name: Neosho (North of Tar & Spring)

Station No: GS-MW1

Site Description and Flow Observations:

Surface sample from streambed

Bed Sediment Sampling

Sampling Platform: ☐Wading ☐Cable ☐Ice ☑Boat ☐Bridge

Type of Sampler Used: Ekman

Northing: 690,281

Easting: 2,883,797

Datum: OK N (USft)

Total Number of Samples Collected: 1

Sediment Grab Sampling

Date: 12 DEC 2019

Staff: TK, RS

Weather: 26F, windy

Stream Name: Tar Creek

Station No: GS-MW2

Site Description and Flow Observations:

Taken from bed surface off boat

Bed Sediment Sampling

Sampling Platform: ☐Wading ☐Cable ☐Ice ☑Boat ☐Bridge

Type of Sampler Used: Core

Northing: 690,059

Easting: 2,887,392

Datum: OK N (USft)

Total Number of Samples Collected: 1

Sediment Grab Sampling

Date: 12 DEC 2019

Staff: TK, RS

Weather: 26F, windy

Stream Name: Tar Creek

Station No: GS-MW3

Site Description and Flow Observations:

Taken from bed surface off boat

Bed Sediment Sampling

Sampling Platform: ☐Wading ☐Cable ☐Ice ☑Boat ☐Bridge

Type of Sampler Used: Core

Northing: 692,363

Easting: 2,885,869

Datum: OK N (USft)

Total Number of Samples Collected: 1

Sediment Grab Sampling

Date: 13 DEC 2019

Staff: TK, RS

Weather: 29F, windy

Stream Name: Neosho North of Spring

Station No: CN-01

Site Description and Flow Observations:

Taken near bank

Bed Sediment Sampling

Sampling Platform: ☐Wading ☐Cable ☐Ice ☑Boat ☐Bridge

Type of Sampler Used: Ekman

Northing: 681,389

Easting: 2,902,395

Datum: OK N (USft)

Total Number of Samples Collected: 1

Sediment Grab Sampling

Date: 13 DEC 2019

Staff: TK, RS

Weather: 30F Clouds/windy

Stream Name: Neosho River North of Spring

Station No: CN-02

Site Description and Flow Observations:

Taken from middle of channel
Few pieces of gravel, sand

Bed Sediment Sampling

Sampling Platform: ☐Wading ☐Cable ☐Ice ☑Boat ☐Bridge

Type of Sampler Used: Ekman

Northing: 681,261

Easting: 2,902,343

Datum: OK N (USft)

Total Number of Samples Collected: 1

Sediment Grab Sampling

Date: 13 DEC 2019

Staff: TK, RS

Weather: 30F, windy

Stream Name: Neosho North of Spring

Station No: CN-03

Site Description and Flow Observations:

Taken from middle of channel, mostly gravel

Bed Sediment Sampling

Sampling Platform: ☐Wading ☐Cable ☐Ice ☑Boat ☐Bridge

Type of Sampler Used: Ekman

Northing: 678,308

Easting: 2,904,418

Datum: OK N (USft)

Total Number of Samples Collected: 1

Sediment Grab Sampling

Date: 13 DEC 2019

Staff: TK, RS

Weather: 30F, windy

Stream Name: Neosho North of Spring

Station No: CN-04

Site Description and Flow Observations:

Taken from middle of channel, mostly gravel

Bed Sediment Sampling

Sampling Platform: ☐Wading ☐Cable ☐Ice ☑Boat ☐Bridge

Type of Sampler Used: Ekman

Northing: 675,328

Easting: 2,902,125

Datum: OK N (USft)

Total Number of Samples Collected: 1

Sediment Grab Sampling

Date: 13 DEC 2019

Staff: TK, RS

Weather: 30F, windy

Stream Name: Neosho North of Spring

Station No: CN-05

Site Description and Flow Observations:

Taken from middle of channel

Bed Sediment Sampling

Sampling Platform: ☐Wading ☐Cable ☐Ice ☑Boat ☐Bridge

Type of Sampler Used: Ekman

Northing: 672,798

Easting: 2,896,344

Datum: OK N (USft)

Total Number of Samples Collected: 1

Sediment Grab Sampling

Date: 13 DEC 2019

Staff: TK, RS

Weather: 30F, windy

Stream Name: Neosho North of Spring

Station No: CN-06

Site Description and Flow Observations:

Taken from bed surface

Bed Sediment Sampling

Sampling Platform: ☐Wading ☐Cable ☐Ice ☑Boat ☐Bridge

Type of Sampler Used: Ekman

Northing: 672,469

Easting: 2,896,019

Datum: OK N (USft)

Total Number of Samples Collected: 1

Sediment Grab Sampling

Date: 13 DEC 2019

Staff: TK, RS

Weather: 31F, windy

Stream Name: Neosho North of Spring

Station No: CN-07

Site Description and Flow Observations:

Taken from bed surface

Bed Sediment Sampling

Sampling Platform: ☐Wading ☐Cable ☐Ice ☑Boat ☐Bridge

Type of Sampler Used: Ekman

Northing: 670,065

Easting: 2,899,504

Datum: OK N (USft)

Total Number of Samples Collected: 1

Sediment Grab Sampling

Date: 13 DEC 2019

Staff: TK, RS

Weather: 31F, windy

Stream Name: Neosho North of Spring

Station No: CN-08

Site Description and Flow Observations:

Taken from bed surface

Bed Sediment Sampling

Sampling Platform: ☐Wading ☐Cable ☐Ice ☑Boat ☐Bridge

Type of Sampler Used: Ekman

Northing: 669,361

Easting: 2,906,967

Datum: OK N (USft)

Total Number of Samples Collected: 1

Sediment Grab Sampling

Date: 13 DEC 2019

Staff: TK, RS

Weather: 30F, windy

Stream Name: Neosho North of Spring

Station No: CN-09

Site Description and Flow Observations:

Taken from bed surface

Bed Sediment Sampling

Sampling Platform: ☐Wading ☐Cable ☐Ice ☑Boat ☐Bridge

Type of Sampler Used: Ekman

Northing: 668,979

Easting: 2,911,669

Datum: OK N (USft)

Total Number of Samples Collected: 1

Sediment Grab Sampling

FRESHWATER ENGINEERING

Date: 14 DEC 2019

Staff: TK, RS

Weather: 27F, windy

Stream Name: Neosho South of Spring

Station No: GS-W1

Site Description and Flow Observations:

Taken from bed surface in shallow area

Bed Sediment Sampling

Sampling Platform: ☐Wading ☐Cable ☐Ice ☑Boat ☐Bridge

Type of Sampler Used: Shovel

Northing: 644,851

Easting: 2,914,163

Datum: OK N (USft)

Total Number of Samples Collected: 1

Sediment Grab Sampling

Date: 14 DEC 2019

Staff: TK, RS

Weather: 27F, windy

Stream Name: Neosho South of Spring

Station No: GS-W2

Site Description and Flow Observations:

Taken from bed surface

Bed Sediment Sampling

Sampling Platform: ☐Wading ☐Cable ☐Ice ☑Boat ☐Bridge

Type of Sampler Used: Ekman

Northing: 646,875

Easting: 2,916,794

Datum: OK N (USft)

Total Number of Samples Collected: 1

Sediment Grab Sampling

Date: 14 DEC 2019

Staff: TK, RS

Weather: 27F, windy

Stream Name: Neosho South of Spring

Station No: GS-W3

Site Description and Flow Observations:

Taken from bed surface

Bed Sediment Sampling

Sampling Platform: ☐Wading ☐Cable ☐Ice ☑Boat ☐Bridge

Type of Sampler Used: Ekman

Northing: 645,759

Easting: 2,920,602

Datum: OK N (USft)

Total Number of Samples Collected: 1

Sediment Grab Sampling

Date: 14 DEC 2019

Staff: TK, RS

Weather: 27F, windy

Stream Name: Neosho South of Spring

Station No: GS-W4

Site Description and Flow Observations:

Taken from bed surface

Bed Sediment Sampling

Sampling Platform: ☐Wading ☐Cable ☐Ice ☑Boat ☐Bridge

Type of Sampler Used: Ekman

Northing: 649,504

Easting: 2,925,265

Datum: OK N (USft)

Total Number of Samples Collected: 1

Sediment Grab Sampling

Date: 14 DEC 2019

Staff: TK, RS

Weather: 28F, windy

Stream Name: Neosho South of Spring

Station No: GS-W5

Site Description and Flow Observations:

Taken from bed surface in shallow area

Bed Sediment Sampling

Sampling Platform: ☐Wading ☐Cable ☐Ice ☑Boat ☐Bridge

Type of Sampler Used: Shovel

Northing: 651,197

Easting: 2,926,663

Datum: OK N (USft)

Total Number of Samples Collected: 1

Sediment Grab Sampling

Date: 14 DEC 2019

Staff: TK, RS

Weather: 28F, windy

Stream Name: Neosho South of Spring

Station No: GS-W6

Site Description and Flow Observations:

Taken from bed surface

Bed Sediment Sampling

Sampling Platform: ☐Wading ☐Cable ☐Ice ☑Boat ☐Bridge

Type of Sampler Used: Ekman

Northing: 654,346

Easting: 2,916,738

Datum: OK N (USft)

Total Number of Samples Collected: 1

Sediment Grab Sampling

Date: 14 DEC 2019

Staff: TK, RS

Weather: 28F, windy

Stream Name: Neosho South of Spring

Station No: GS-W7

Site Description and Flow Observations:

Taken from bed surface

Bed Sediment Sampling

Sampling Platform: ☐Wading ☐Cable ☐Ice ☑Boat ☐Bridge

Type of Sampler Used: Ekman

Northing: 657,497

Easting: 2,911,603

Datum: OK N (USft)

Total Number of Samples Collected: 1

Sediment Grab Sampling

Date: 14 DEC 2019

Staff: TK, RS

Weather: 28F, windy

Stream Name: Neosho South of Spring

Station No: GS-W8

Site Description and Flow Observations:

Taken from bed surface

Bed Sediment Sampling

Sampling Platform: ☐Wading ☐Cable ☐Ice ☑Boat ☐Bridge

Type of Sampler Used: Ekman

Northing: 663,866

Easting: 2,912,784

Datum: OK N (USft)

Total Number of Samples Collected: 1

Sediment Grab Sampling

Date: 14 DEC 2019

Staff: TK, RS

Weather: 28F, windy

Stream Name: Neosho South of Spring

Station No: GS-W9

Site Description and Flow Observations:

Taken from bed surface between bridges

Bed Sediment Sampling

Sampling Platform: ☐Wading ☐Cable ☐Ice ☑Boat ☐Bridge

Type of Sampler Used: Ekman

Northing: 668,841

Easting: 2,919,164

Datum: OK N (USft)

Total Number of Samples Collected: 1

Sediment Grab Sampling

Date: 14 DEC 2019

Staff: TK, RS

Weather: 28F, windy

Stream Name: Spring River, North of Twin Bridges

Station No: GS-W10

Site Description and Flow Observations:

Taken from channel bed surface

Bed Sediment Sampling

Sampling Platform: ☐Wading ☐Cable ☐Ice ☑Boat ☐Bridge

Type of Sampler Used: Ekman

Northing: 671,462

Easting: 2,919,130

Datum: OK N (USft)

Total Number of Samples Collected: 1

Sediment Grab Sampling

Date: 14 DEC 2019

Staff: TK, RS

Weather: 26F, windy

Stream Name: Neosho North of Spring

Station No: TN-01

Site Description and Flow Observations:

Taken from middle of channel

Bed Sediment Sampling

Sampling Platform: ☐Wading ☐Cable ☐Ice ☑Boat ☐Bridge

Type of Sampler Used: Ekman

Northing: 672,542

Easting: 2,914,879

Datum: OK N (USft)

Total Number of Samples Collected: 1

Sediment Grab Sampling

FRESHWATER ENGINEERING

Date: 14 DEC 2019

Staff: TK, RS

Weather: 26F, windy

Stream Name: Neosho North of Spring

Station No: TN-02

Site Description and Flow Observations:

Taken from middle of channel

Bed Sediment Sampling

Sampling Platform: ☐Wading ☐Cable ☐Ice ☑Boat ☐Bridge

Type of Sampler Used: Ekman

Northing: 671,019

Easting: 2,917,954

Datum: OK N (USft)

Total Number of Samples Collected: 1

Sediment Grab Sampling

Date: 15 DEC 2019

Staff: TK, RS

Weather: 28F, windy

Stream Name: Elk River

Station No: E-01

Site Description and Flow Observations:

Taken from surface of streambed

Bed Sediment Sampling

Sampling Platform: ☐Wading ☐Cable ☐Ice ☑Boat ☐Bridge

Type of Sampler Used: Ekman

Northing: 619,855

Easting: 2,949,007

Datum: OK N (USft)

Total Number of Samples Collected: 1

Sediment Grab Sampling

Date: 15 DEC 2019

Staff: TK, RS

Weather: 28F, windy

Stream Name: Elk River

Station No: E-02

Site Description and Flow Observations:

Taken from surface of streambed

Bed Sediment Sampling

Sampling Platform: ☐Wading ☐Cable ☐Ice ☑Boat ☐Bridge

Type of Sampler Used: Ekman

Northing: 617,795

Easting: 2,945,419

Datum: OK N (USft)

Total Number of Samples Collected: 1

FRESHWATER ENGINEERING

Sediment Grab Sampling

Date: 15 DEC 2019

Staff: TK, RS

Weather: 28F, windy

Stream Name: Elk River

Station No: E-03

Site Description and Flow Observations:

Taken from surface of streambed

Bed Sediment Sampling

Sampling Platform: ☐Wading ☐Cable ☐Ice ☑Boat ☐Bridge

Type of Sampler Used: Ekman

Northing: 613,838

Easting: 2,941,958

Datum: OK N (USft)

Total Number of Samples Collected: 1

Sediment Grab Sampling

Date: 15 DEC 2019

Staff: TK, RS

Weather: 28F, windy

Stream Name: Elk River

Station No: E-04

Site Description and Flow Observations:

Taken from surface of streambed

Bed Sediment Sampling

Sampling Platform: ☐Wading ☐Cable ☐Ice ☑Boat ☐Bridge

Type of Sampler Used: Ekman

Northing: 616,342

Easting: 2,940,034

Datum: OK N (USft)

Total Number of Samples Collected: 1

Sediment Grab Sampling

Date: 15 DEC 2019

Staff: TK, RS

Weather: 28F, windy

Stream Name: Elk River

Station No: E-05

Site Description and Flow Observations:

Taken from surface of streambed

Bed Sediment Sampling

Sampling Platform: ☐Wading ☐Cable ☐Ice ☑Boat ☐Bridge

Type of Sampler Used: Ekman

Northing: 616,836

Easting: 2,935,568

Datum: OK N (USft)

Total Number of Samples Collected: 1

Sediment Grab Sampling

Date: 15 DEC 2019

Staff: TK, RS

Weather: 29F, windy

Stream Name: Elk River

Station No: E-06

Site Description and Flow Observations:

Taken from surface of streambed

Bed Sediment Sampling

Sampling Platform: ☐Wading ☐Cable ☐Ice ☑Boat ☐Bridge

Type of Sampler Used: Ekman

Northing: 618,739

Easting: 2,927,992

Datum: OK N (USft)

Total Number of Samples Collected: 1

Sediment Grab Sampling

Date: 15 DEC 2019

Staff: BT, BD

Weather: 28F, breezy

Stream Name: Horse Creek

Station No: HC14S

Site Description and Flow Observations:

Taken from edge of channel near access point on S 540 Rd/E 240 Rd (near WSE monitoring site 14)

Bed Sediment Sampling

Sampling Platform: ☑Wading ☐Cable ☐Ice ☐Boat ☐Bridge

Type of Sampler Used: Shovel

Northing: 624,204

Easting: 2,875,288

Datum: OK N (USft)

Total Number of Samples Collected: 1

Sediment Grab Sampling

Date: 15 DEC 2019

Staff: TK, RS

Weather: 27F, windy

Stream Name: Spring River

Station No: S-01

Site Description and Flow Observations:

Taken from gravel bar near HWY 10 bridge

Bed Sediment Sampling

Sampling Platform: ☑Wading ☐Cable ☐Ice ☐Boat ☐Bridge

Type of Sampler Used: Shovel

Northing: 696,874

Easting: 2,914,550

Datum: OK N (USft)

Total Number of Samples Collected: 1

Sediment Grab Sampling

Date: 15 DEC 2019

Staff: TK, RS

Weather: 28F, windy

Stream Name: Spring River

Station No: S-02

Site Description and Flow Observations:

Taken from gravel bar near E 57 Rd bridge

Bed Sediment Sampling

Sampling Platform: ☑Wading ☐Cable ☐Ice ☐Boat ☐Bridge

Type of Sampler Used: Shovel

Northing: 720,124

Easting: 2,919,626

Datum: OK N (USft)

Total Number of Samples Collected: 1

Sediment Grab Sampling

Date: 15 DEC 2019

Staff: TK, RS

Weather: 28F, windy

Stream Name: Spring River

Station No: S-03

Site Description and Flow Observations:

Taken from middle of channel

Bed Sediment Sampling

Sampling Platform: ☐Wading ☐Cable ☐Ice ☑Boat ☐Bridge

Type of Sampler Used: Ekman

Northing: 692,379

Easting: 2,921,645

Datum: OK N (USft)

Total Number of Samples Collected: 1

Sediment Grab Sampling

Date: 15 DEC 2019

Staff: TK, RS

Weather: 28F, windy

Stream Name: Spring River

Station No: S-04

Site Description and Flow Observations:

Taken from middle of stream channel

Bed Sediment Sampling

Sampling Platform: ☐Wading ☐Cable ☐Ice ☑Boat ☐Bridge

Type of Sampler Used: Ekman

Northing: 690,680

Easting: 2,927,648

Datum: OK N (USft)

Total Number of Samples Collected: 1

Sediment Grab Sampling

Date: 15 DEC 2019

Staff: TK, RS

Weather: 28F, windy

Stream Name: Spring River

Station No: S-05

Site Description and Flow Observations:

Taken from bed surface

Bed Sediment Sampling

Sampling Platform: ☐Wading ☐Cable ☐Ice ☑Boat ☐Bridge

Type of Sampler Used: Ekman

Northing: 685,207

Easting: 2,925,403

Datum: OK N (USft)

Total Number of Samples Collected: 1

Sediment Grab Sampling

Date: 15 DEC 2019

Staff: TK, RS

Weather: 28F, windy

Stream Name: Spring River

Station No: S-06

Site Description and Flow Observations:

Taken from middle of channel

Bed Sediment Sampling

Sampling Platform: ☐Wading ☐Cable ☐Ice ☑Boat ☐Bridge

Type of Sampler Used: Ekman

Northing: 677,999

Easting: 2,921,911

Datum: OK N (USft)

Total Number of Samples Collected: 1

Sediment Grab Sampling

Date: 15 DEC 2019

Staff: BT, BD

Weather: 28F, breezy

Stream Name: Sycamore Creek

Station No: SC08S

Site Description and Flow Observations:

Taken from natural surface armor of streambed near HWY 10 bridge (WSE monitoring site 8)

Bed Sediment Sampling

Sampling Platform: ☑Wading ☐Cable ☐Ice ☐Boat ☐Bridge

Type of Sampler Used: Shovel

Northing: 660,189

Easting: 2,937,225

Datum: OK N (USft)

Total Number of Samples Collected: 1

Sediment Grab Sampling

Date: 15 DEC 2019

Staff: BT, BD

Weather: 30F, calm

Stream Name: Spring River North of Neosho

Station No: SP04S

Site Description and Flow Observations:

Bank edge surface (armor) sample near boat launch and Hwy 10 bridge piers
Near WSE monitoring site 4

Bed Sediment Sampling

Sampling Platform: ☑Wading ☐Cable ☐Ice ☐Boat ☐Bridge

Type of Sampler Used: Shovel

Northing: 696,932

Easting: 2,914,549

Datum: OK N (USft)

Total Number of Samples Collected: 1

Sediment Grab Sampling

Date: 16 DEC 2019

Staff: RS

Weather: 27F, windy

Stream Name: Elk River

Station No: ER76S

Site Description and Flow Observations:

Surface sample (natural armor layer) upstream of bridge

Bed Sediment Sampling

Sampling Platform: ☑Wading ☐Cable ☐Ice ☐Boat ☐Bridge

Type of Sampler Used: Shovel

Northing: 611,473

Easting: 2,969,867

Datum: OK N (USft)

Total Number of Samples Collected: 1

Sediment Grab Sampling

Date: 16 DEC 2019

Staff: RS

Weather: 30F, cloudy/windy

Stream Name: Elk River

Station No: ER76SS

Site Description and Flow Observations:

Sample was taken from the subsurface (below natural armoring) upstream of bridge

Bed Sediment Sampling

Sampling Platform: ☒Wading ☐Cable ☐Ice ☐Boat ☐Bridge

Type of Sampler Used: Shovel

Northing: 611,473

Easting: 2,969,867

Datum: OK N (USft)

Total Number of Samples Collected: 1

Sediment Grab Sampling

Date: 16 DEC 2019

Staff: TK, BT, BD

Weather: 29F, breezy, cloudy

Stream Name: Neosho (North of Tar & Spring)

Station No: NM-01

Site Description and Flow Observations:

Taken from left bank downstream of logjam; some silt deposits immediately downstream, this taken from ~30' beyond logs

Bed Sediment Sampling

Sampling Platform: ☑Wading ☐Cable ☐Ice ☐Boat ☐Bridge

Type of Sampler Used: Shovel

Northing: 692,354

Easting: 2,882,005

Datum: OK N (USft)

Total Number of Samples Collected: 1

Sediment Grab Sampling

Date: 16 DEC 2019

Staff: TK, BT, BD

Weather: 29F, cloudy, breezy

Stream Name: Neosho (North of Spring & Tar)

Station No: NM-02

Site Description and Flow Observations:

Taken from parking lot scrape pile (left after high water)

Bed Sediment Sampling

Sampling Platform: ▯Wading ▯Cable ▯Ice ▯Boat ▯Bridge

Type of Sampler Used: Shovel

Northing: 692,620

Easting: 2,882,018

Datum: OK N (USft)

Total Number of Samples Collected: 1

Sediment Grab Sampling

Date: 16 DEC 2019

Staff: TK, BT, BD

Weather: 29F, breezy, cloudy

Stream Name: Neosho (North of Tar & Spring)

Station No: NM-03

Site Description and Flow Observations:

Taken from right edge of stream very near WSE monitoring station 2 (Miami fairgrounds)

Bed Sediment Sampling

Sampling Platform: ☑Wading ☐Cable ☐Ice ☐Boat ☐Bridge

Type of Sampler Used: Shovel

Northing: 691,689

Easting: 2,882,196

Datum: OK N (USft)

Total Number of Samples Collected: 1

Sediment Grab Sampling

Date: 16 DEC 2019

Staff: TK, BT, BD

Weather: 29F, breezy, cloudy

Stream Name: Neosho (North of Tar & Spring)

Station No: NM-04

Site Description and Flow Observations:

Taken at boat launch by fairgrounds under bridge (right bank); site is sheltered from direct flows by riprap-armored banks

Bed Sediment Sampling

Sampling Platform: ☑Wading ☐Cable ☐Ice ☐Boat ☐Bridge

Type of Sampler Used: Shovel

Northing: 693,153

Easting: 2,881,134

Datum: OK N (USft)

Total Number of Samples Collected: 1

Sediment Grab Sampling

Date: 16 DEC 2019

Staff: RS

Weather: 30F clouds & wind

Stream Name: Neosho River North of Spring & Tar

Station No: NR60S

Site Description and Flow Observations:

Sample was taken from surface layer (natural armor) of Neosho River upstream of E 60 Rd bridge

Bed Sediment Sampling

Sampling Platform: ☑Wading ☐Cable ☐Ice ☐Boat ☐Bridge

Type of Sampler Used: Shovel

Northing: 716,021

Easting: 2,857,805

Datum: OK N (USft)

Total Number of Samples Collected: 1

Sediment Grab Sampling

Date: 16 DEC 2019

Staff: RS

Weather: 30F, windy, cloudy

Stream Name: Neosho (North of Spring & Tar)

Station No: NR60SS

Site Description and Flow Observations:

Sub-surface (taken from under natural armoring layer) upstream of E 60 Rd bridge

Bed Sediment Sampling

Sampling Platform: ☑Wading ☐Cable ☐Ice ☐Boat ☐Bridge

Type of Sampler Used: Shovel

Northing: 716,021

Easting: 2,857,805

Datum: OK N (USft)

Total Number of Samples Collected: 1

Sediment Grab Sampling

Date: 16 DEC 2019

Staff: RS

Weather: 28F, cloudy, windy

Stream Name: Spring River

Station No: SP10S

Site Description and Flow Observations:

Taken from riverbed, natural armor layer, near bridge

Bed Sediment Sampling

Sampling Platform: ☑Wading ☐Cable ☐Ice ☐Boat ☐Bridge

Type of Sampler Used: Shovel

Northing: 696,942

Easting: 2,914,547

Datum: OK N (USft)

Total Number of Samples Collected: 1

Sediment Grab Sampling

Date: 16 DEC 2019

Staff: RS

Weather: 30F, cloudy/windy

Stream Name: Spring River

Station No: SP10SS

Site Description and Flow Observations:

Sample was taken from the subsurface (below natural armoring) downstream of Hwy 10 Bridge

Bed Sediment Sampling

Sampling Platform: ☑Wading ☐Cable ☐Ice ☐Boat ☐Bridge

Type of Sampler Used: Shovel

Northing: 696,942

Easting: 2,914,547

Datum: OK N (USft)

Total Number of Samples Collected: 1

Sediment Grab Sampling

Date: 16 DEC 2019

Staff: RS

Weather: 29F, cloudy, windy

Stream Name: Tar Creek

Station No: TC10S

Site Description and Flow Observations:

Taken from surface of riverbed downstream of bridge

Bed Sediment Sampling

Sampling Platform: ☑Wading ☐Cable ☐Ice ☐Boat ☐Bridge

Type of Sampler Used: Shovel

Northing: 695,518

Easting: 2,886,708

Datum: OK N (USft)

Total Number of Samples Collected: 1

Sediment Grab Sampling

Date: 16 DEC 2019

Staff: RS

Weather: 30F, clouds/wind

Stream Name: Tar Creek

Station No: TC10SS

Site Description and Flow Observations:

Sample was taken from the subsurface (below natural armoring) downstream of HWY 10 bridge

Bed Sediment Sampling

Sampling Platform: ☑Wading ☐Cable ☐Ice ☐Boat ☐Bridge

Type of Sampler Used: Shovel

Northing: 695,518

Easting: 2,886,708

Datum: OK N (USft)

Total Number of Samples Collected: 1

Sediment Grab Sampling

Date: 16 DEC 2019

Staff: RS

Weather: 29F, cloudy, windy

Stream Name: Tar Creek

Station No: TC10S-US

Site Description and Flow Observations:

Sample was taken from surface layer (natural armor) of Tar Creek upstream of Hwy 10 bridge

Bed Sediment Sampling

Sampling Platform: ☑Wading ☐Cable ☐Ice ☐Boat ☐Bridge

Type of Sampler Used: Shovel

Northing: 695,518

Easting: 2,886,708

Datum: OK N (USft)

Total Number of Samples Collected: 1

Sediment Grab Sampling

Date: 16 DEC 2019

Staff: RS

Weather: 30F, clouds, wind

Stream Name: Tar Creek

Station No: TC60B

Site Description and Flow Observations:

Sample was taken from gravel bar in stream at E 60 Rd bridge

Bed Sediment Sampling

Sampling Platform: ☑ Wading ☐ Cable ☐ Ice ☐ Boat ☐ Bridge

Type of Sampler Used: Shovel

Northing: 717,081

Easting: 2,886,495

Datum: OK N (USft)

Total Number of Samples Collected: 1

Sediment Grab Sampling

Date: 16 DEC 2019

Staff: RS

Weather: 28F

Stream Name: Tar Creek

Station No: TC60S

Site Description and Flow Observations:

Taken from surface of riverbed

Bed Sediment Sampling

Sampling Platform: ☑Wading ☐Cable ☐Ice ☐Boat ☐Bridge

Type of Sampler Used: Shovel

Northing: 717,081

Easting: 2,886,495

Datum: OK N (USft)

Total Number of Samples Collected: 1

Sediment Grab Sampling

Date: 16 DEC 2019

Staff: TK, BT, BD

Weather: 30F windy, cloudy

Stream Name: Tar Creek

Station No: TCARS

FRESHWATER ENGINEERING

Site Description and Flow Observations:

Sample from right (west) bank of stream surface sample of natural armoring
Near dirt access road

Bed Sediment Sampling

Sampling Platform: ☑Wading ☐Cable ☐Ice ☐Boat ☐Bridge

Type of Sampler Used: Shovel

Northing: 701,914

Easting: 2,883,699

Datum: OK N (USft)

Total Number of Samples Collected: 1

Sediment Grab Sampling

Date: 16 DEC 2019

Staff: TK, BT, BD

Weather: 30F windy, cloudy

Stream Name: Tar Creek

Station No: TCARSS

Site Description and Flow Observations:

Sample from right (west) streambank subsurface (below natural armoring)
Near dirt access road

Bed Sediment Sampling

Sampling Platform: ☑Wading ☐Cable ☐Ice ☐Boat ☐Bridge

Type of Sampler Used: Shovel

Northing: 701,914

Easting: 2,883,699

Datum: OK N (USft)

Total Number of Samples Collected: 1

Sediment Grab Sampling

Date: 16 DEC 2019

Staff: TK, BT, BD

Weather: 30F cloudy, windy

Stream Name: Tar Creek

Station No: TCBWS

Site Description and Flow Observations:

Sample was taken from the edge of a backwater area protected by a spit-like bar
Near dirt access road

Bed Sediment Sampling

Sampling Platform: ☑Wading ☐Cable ☐Ice ☐Boat ☐Bridge

Type of Sampler Used: Shovel

Northing: 701,914

Easting: 2,883,699

Datum: OK N (USft)

Total Number of Samples Collected: 1

Sediment Grab Sampling

Date: 16 DEC 2019

Staff: RS

Weather: 30F clouds/wind

Stream Name: Tar Creek

Station No: TCRDS

Site Description and Flow Observations:

Sample was taken from natural armoring layer of the bed

Bed Sediment Sampling

Sampling Platform: ☑Wading ☐Cable ☐Ice ☐Boat ☐Bridge

Type of Sampler Used: Shovel

Northing: 700,055

Easting: 2,886,160

Datum: OK N (USft)

Total Number of Samples Collected: 1

Sediment Grab Sampling

Date: 16 DEC 2019

Staff: RS

Weather: 30F, cloudy/windy

Stream Name: Tar Creek

Station No: TCRDSS

Site Description and Flow Observations:

Sample was taken from the subsurface (below natural armoring) downstream of Rockdale Road bridge

Bed Sediment Sampling

Sampling Platform: ☑Wading ☐Cable ☐Ice ☐Boat ☐Bridge

Type of Sampler Used: Shovel

Northing: 700,055

Easting: 2,886,160

Datum: OK N (USft)

Total Number of Samples Collected: 1

Please see the following file for grab sample locations:

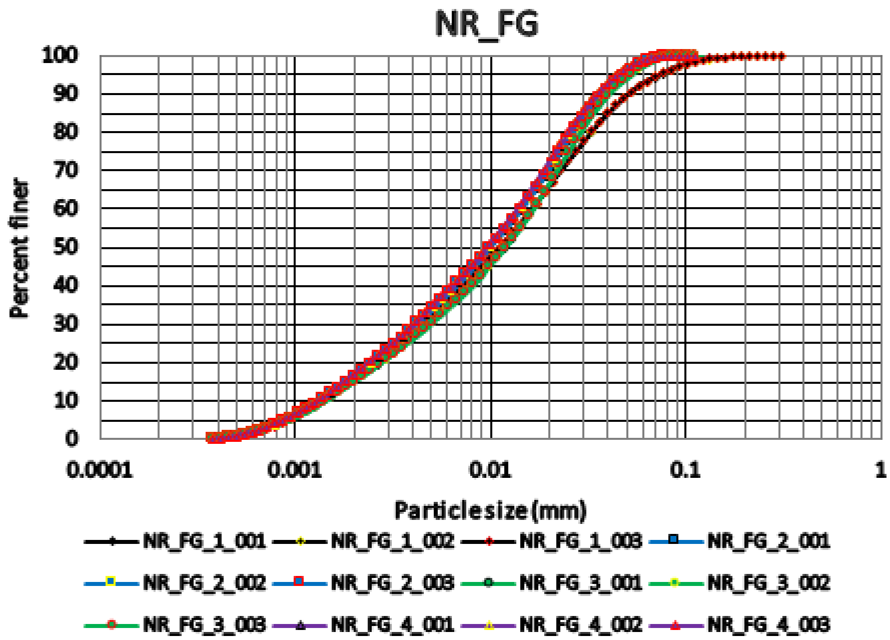
- GrabSampleLocations.csv

Appendix C
SEDflume Core Sampling

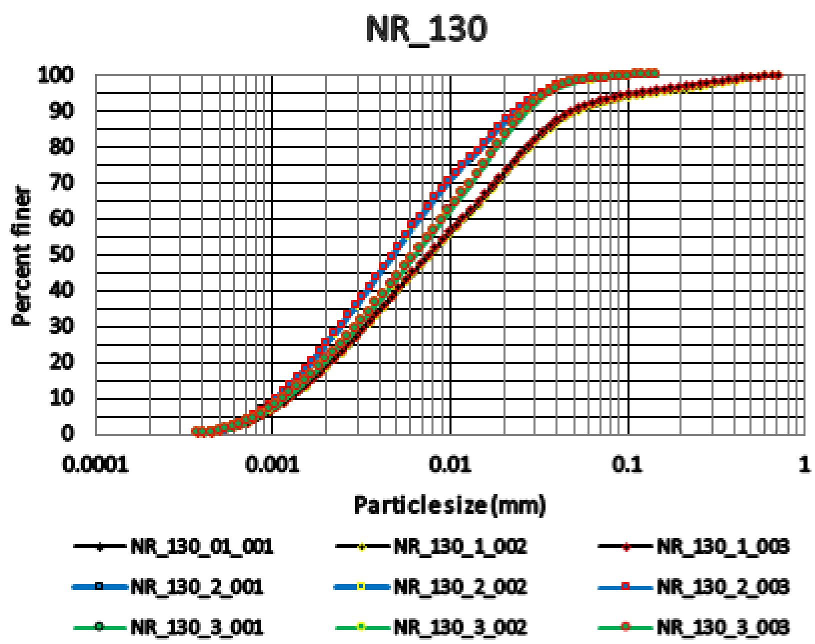
Particle Size Distribution Results

Neosho River above Tar Creek

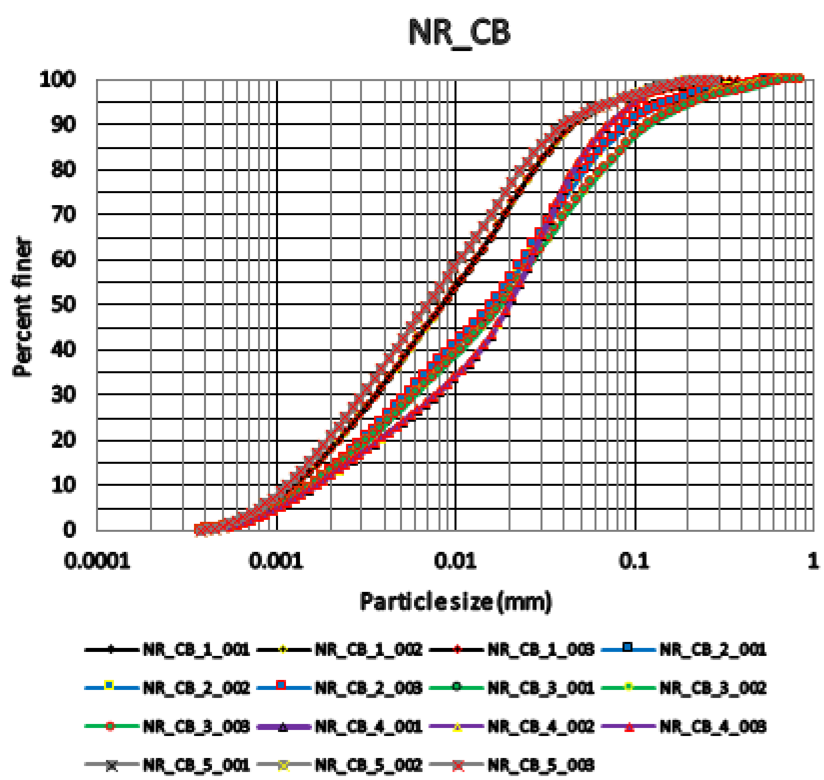
River Mile 135.15



River Mile 130.54

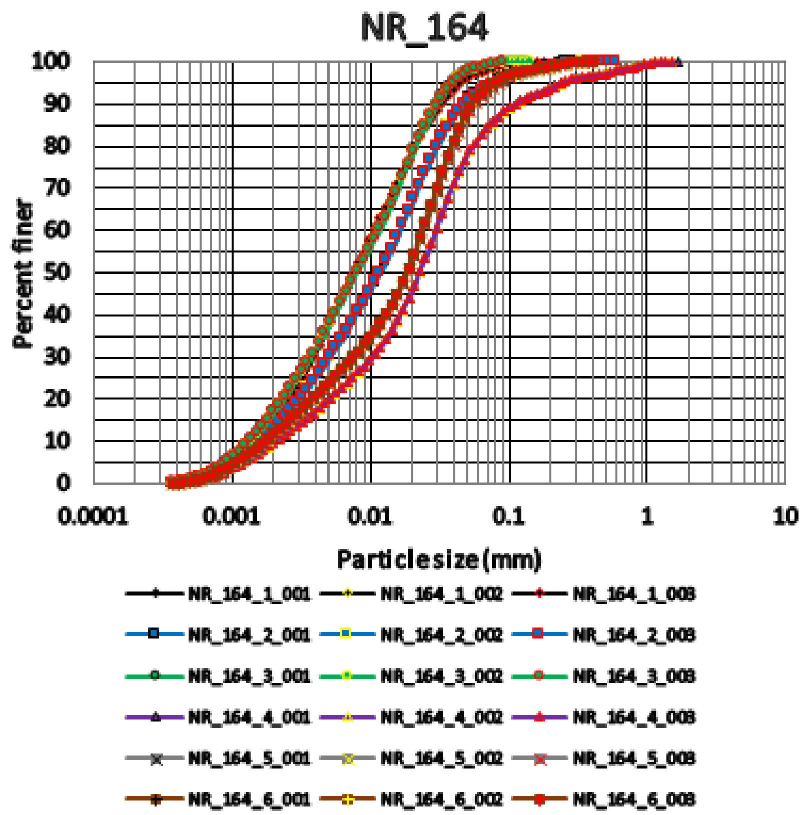


River Mile 126.69

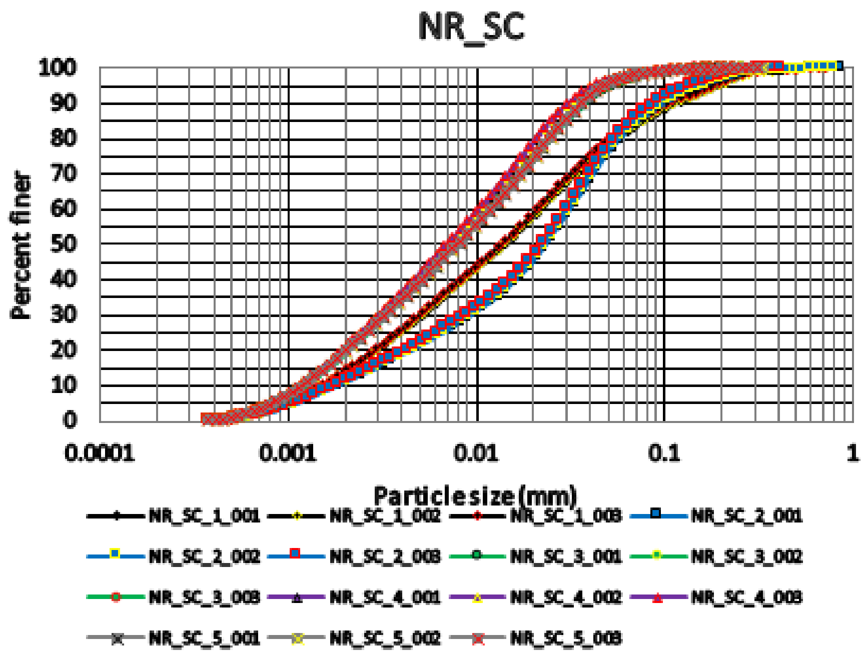


Neosho River – Grand Lake

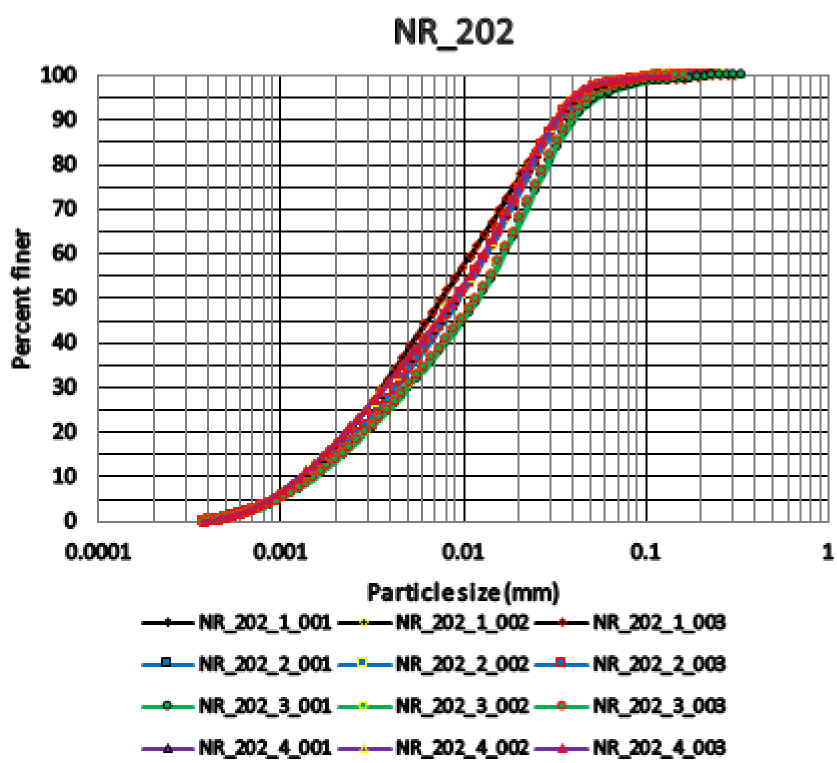
River Mile 120.43



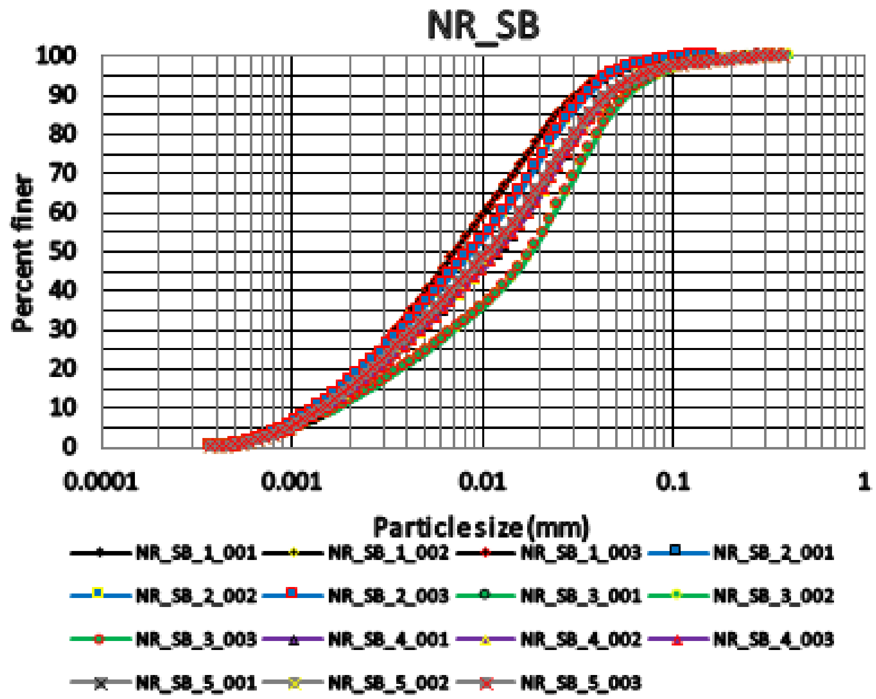
River Mile 115.81



River Mile 112.69

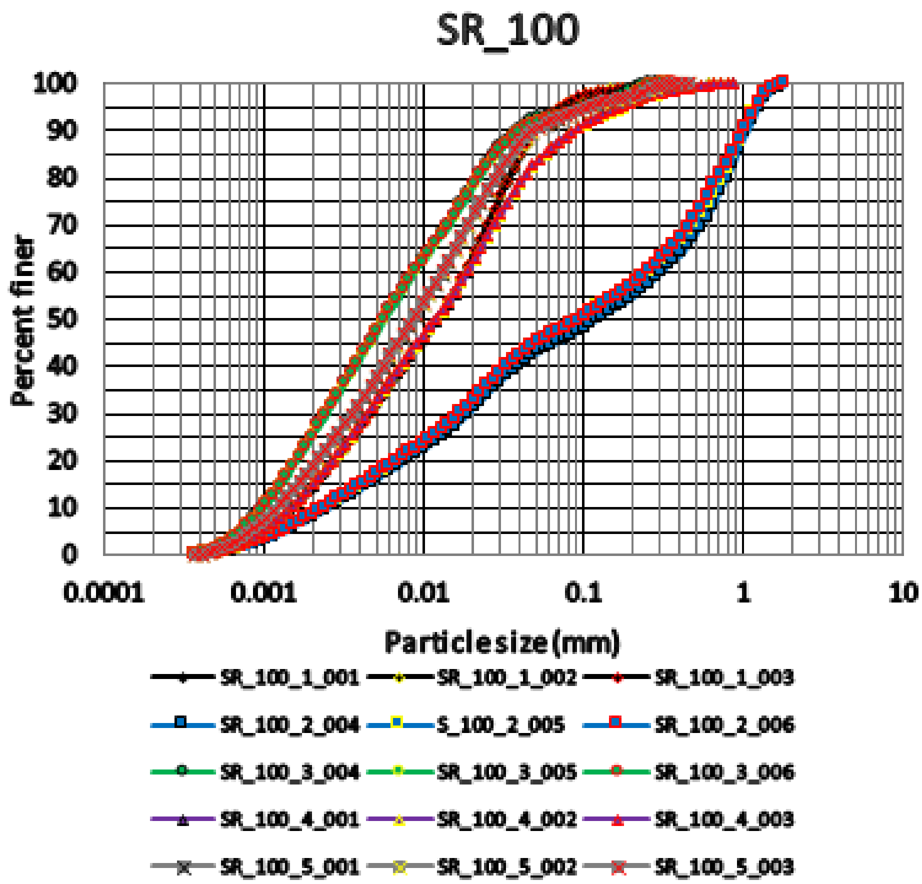


River Station 109.65

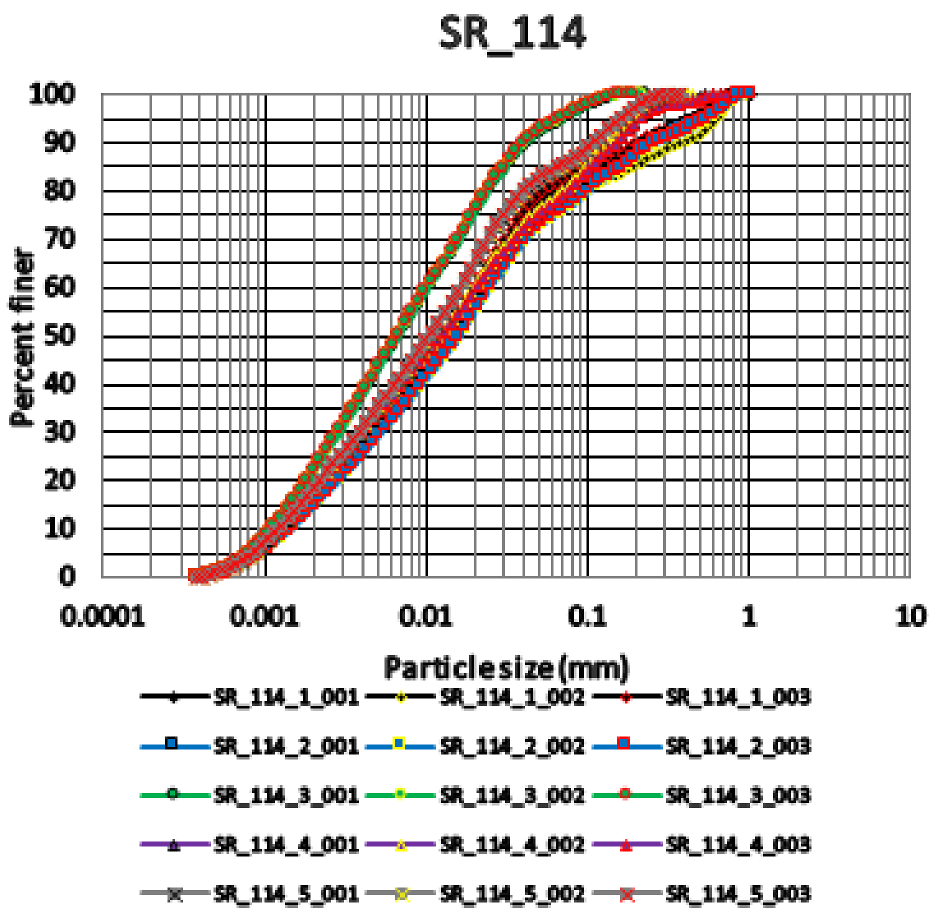


Spring River

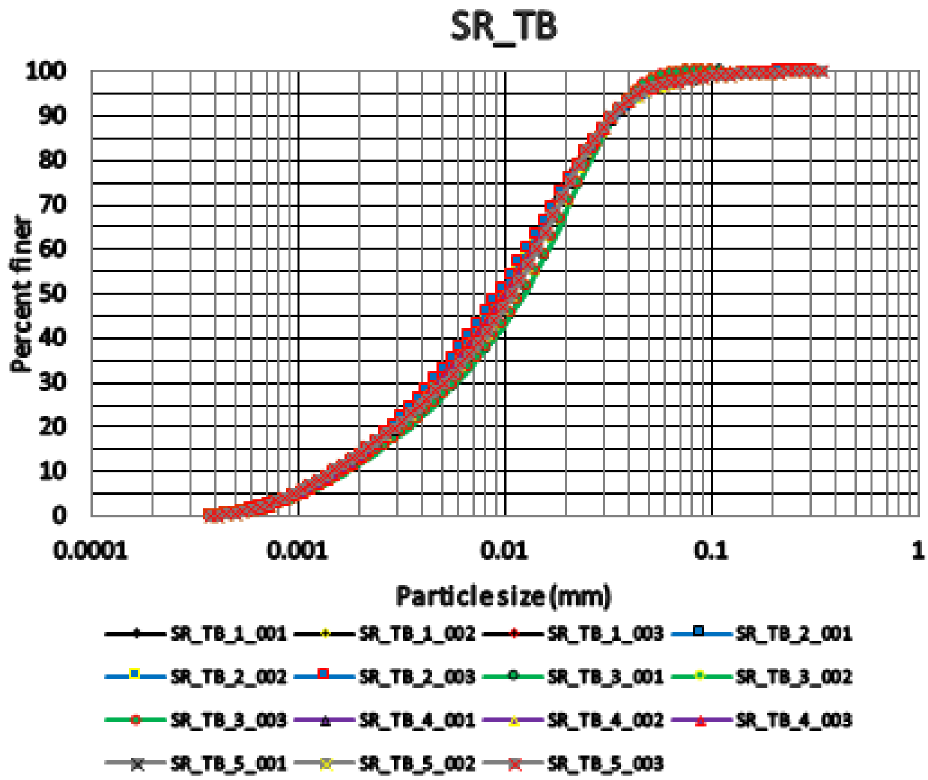
River Mile 7.5



River Mile 4.82

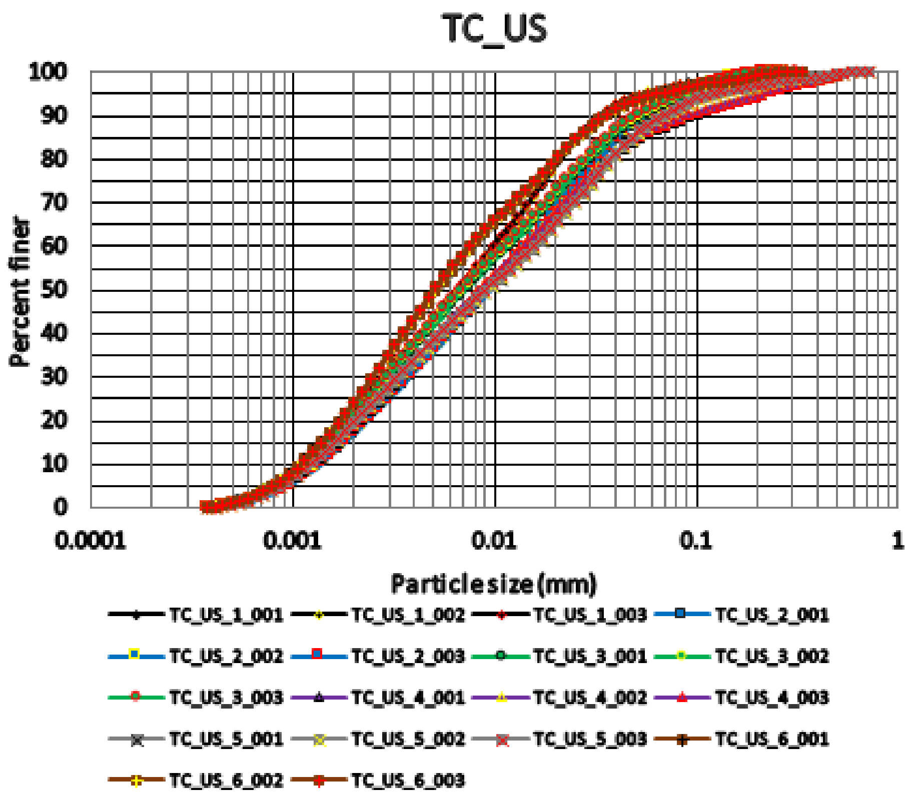


River Mile 0.79

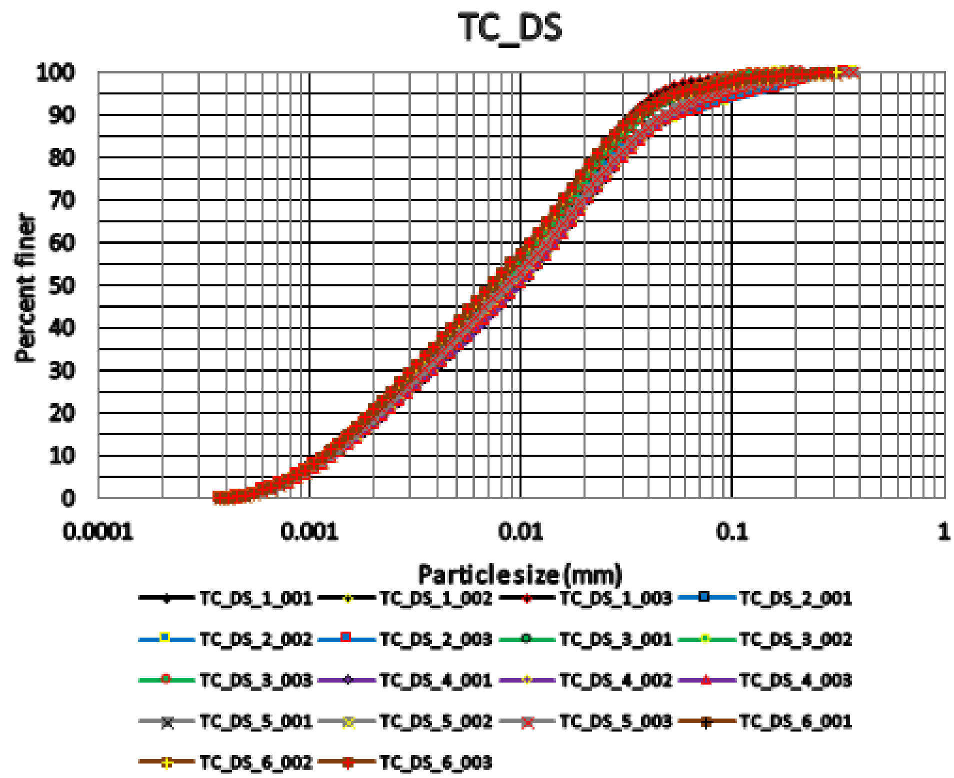


Tar Creek

Downstream of River Mile 1.6

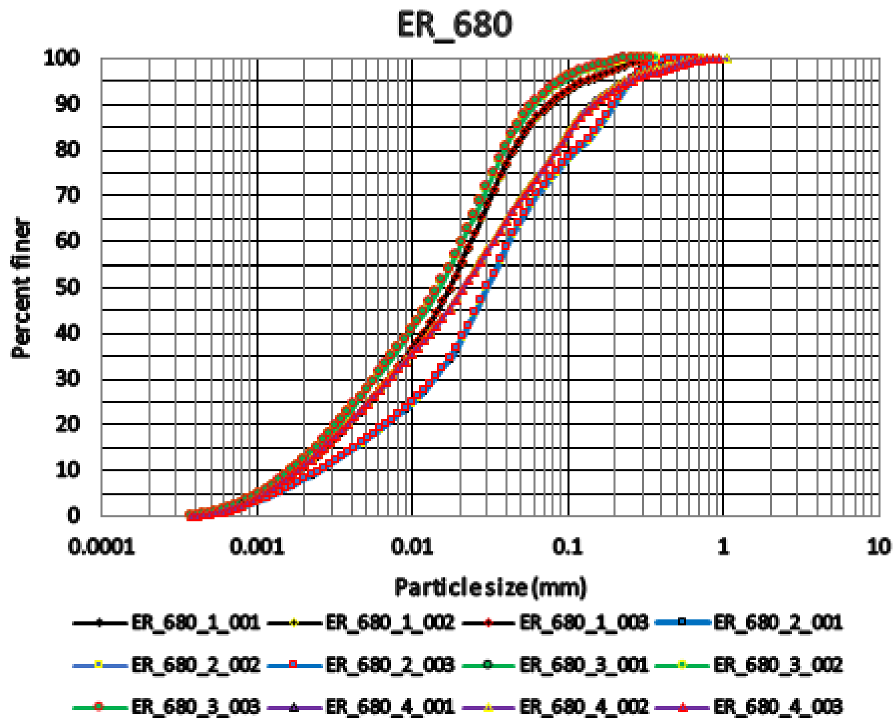


Downstream of River Mile 1.6

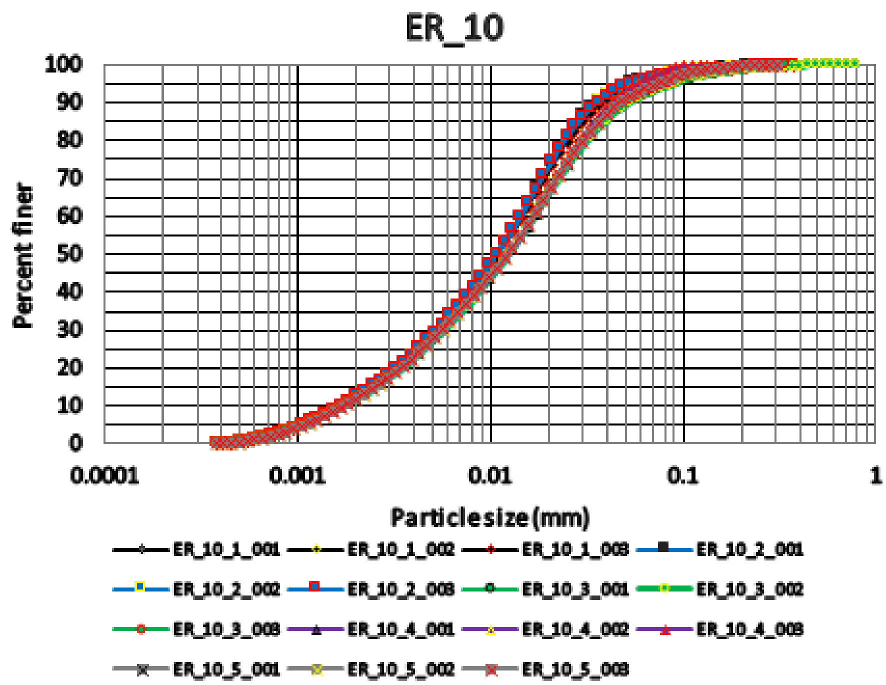


Elk River

River Mile 8.41



River Mile 4.67



Grand Lake Waterways SEDflume Analysis

Grand Lake o' the Cherokees, OK

Prepared for

FreshWater Engineering

Prepared by

integral consulting inc.

200 Washington Street
Suite 201
Santa Cruz, CA 95060

May 2020

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ACRONYMS AND ABBREVIATIONS

Grand Lake	Grand Lake o' the Cherokees
Integral	Integral Consulting Inc.
LISST	laser *in situ* scattering and transmissometry
SEDflume	sediment-erosion-at-depth flume

EXECUTIVE SUMMARY

The complex and dynamically linked relationships between biological activity, hydrodynamic forcing, and sediment properties can regulate morphological bed changes in aquatic systems. The ongoing investigation of sediment mobility within the tributaries and waterways of the Grand Lake o' the Cherokees (Grand Lake) calls for the development of a site-specific sediment transport model. Quantification of the erosional and physical characteristics of a sediment bed can help define ranges of values to bound uncertainty in sediment transport models. Integral Consulting Inc. collected and conducted a sediment-erosion at depth flume (SEDflume) analysis on 14 sediment cores representing a range of bed types and areas within the system. SEDflume analysis produced erosion rate data, determined critical bed shear stresses, and measured particle size distribution and bulk density across multiple sediment types and depths within the sediment bed.

This report provides a summary of the SEDflume analysis for each SEDflume core collected during field sampling efforts. Laboratory measurements of erosion rates at applied shear stresses, ranging from 0.1 to 12.8 Pa, were used to determine the critical shear stress for erosion at multiple depth intervals within each sediment core. The critical shear stress for erosion governs the threshold at which sediment may become suspended. Coefficients relating shear stress and erosion rate based on a power law fit are provided. Supplemental data of grain size distributions via laser diffraction and bulk density measurements at each depth interval are also provided to characterize the physical characteristics of the sediment bed.

In general, sediment consisted of silt and clay with a surface layer of unconsolidated, relatively mobile sediment. Below the surface layer, sediment became more consolidated resulting in larger computed critical shear stresses. Prominent biotic activity, such as invertebrate burrows, extended up to 10 cm from the surface, resulting in a range of erosion conditions. Leaves and root structures present within some samples also modified the erosional properties of the surrounding sediment. Measured and computed parameters varied between different water bodies. It is advised that SEDflume results be analyzed in conjunction with other system characteristics, such as hydrodynamic forcing, to assess overall site stability and sediment transport trends.

1 INTRODUCTION TO SEDFLUME

Analysis of sediment erosion properties using SEDflume can provide quantitative information on sediment bed characteristics. The sediment bed is governed by a complex and dynamically linked relationship between biologic activity, hydrodynamic forcing, and the physical and chemical makeup of the bed. SEDflume provides measurements of erosion rates to inform how the bedded sediment responds to controlled, measurable hydrodynamic flow. The following section outlines collection efforts of 16 cores within the Grand Lake connected waters. An overview of SEDflume setup and processing procedures, as well as methods used for determining the critical shear stresses for erosion. Supplemental information regarding physical characteristic analyses including particle size distribution and bulk density is also provided.

1.1 SAMPLE COLLECTION

Sample collection occurred between March 9 and March 12, 2020. Samples were collected via a box-core collection system by staff from Integral Consulting Inc. (Integral) and FreshWater Engineering. A summary of samples collected and their locations is provided in Table 1. Of the 16 proposed sampling sites, 14 were successfully collected. Alterations to originally proposed locations were determined based on viability of collection on site. The presence of tree limbs and gravel at some sites necessitated the field team to move to more conducive sampling areas. Soft, sediment-rich banks of the river were targeted rather than deeper center channels where gravel and cobble are present.

Samples were collected using a push coring system to penetrate clear acrylic box cores into the sediment bed. When pushing by hand did not result in sufficient penetration, blows from a post-hole hammer were applied. At some sites, such as ER-680, multiple attempts to collect a sufficient sample were performed. Further description of sampling efforts is provided on a core-by-core basis in Sections 2.1 through 2.16.

Table 1. Summary of SEDflume samples

Sample ID	Date	Time	Water depth (ft)	Length (cm)	Latitude	Longitude
SED-ER-10	3/12/2020	3:30:00 PM	8	30	36.64759	-94.704862
SED-ER-640	3/12/2020	----	----	----	36.65529	-94.728458
SED-ER-680	3/9/2020	5:30:00 PM	5	22	36.65639	-94.656731
SED-NR-130	3/11/2020	4:00:00 PM	1	17	36.82961	-94.808654
SED-NR-164	3/10/2020	6:00:00 PM	5	41	36.7801	-94.774844
SED-NR-202	3/10/2020	4:35:00 PM	5	23	36.72824	-94.772617

Sample ID	Date	Time	Water depth (ft)	Length (cm)	Latitude	Longitude
SED-NR-CB	3/11/2020	5:02:00 PM	1	32	36.79897	-94.819643
SED-NR-FG	3/11/2020	11:00:00 AM	1	23	36.85977	-94.875079
SED-NR-HP	3/12/2020	---	---	---	36.64564	-94.779563
SED-NR-SB	3/10/2020	2:00:00 PM	6	37	36.69502	-94.748474
SED-NR-SC	3/10/2020	5:10:00 PM	6	27	36.73894	-94.726088
SED-SR-100	3/10/2020	11:40:00 AM	5	43	36.86481	-94.762871
SED-SR-114	3/10/2020	12:30:00 PM	5	41	36.85253	-94.721566
SED-SR-TB	3/10/2020	11:10:00 AM	4	32	36.8039	-94.754402
SED-TC-DS	3/11/2020	2:30:00 PM	8	44	36.85475	-94.858931
SED-TC-US	3/11/2020	2:00:00 PM	6	44	36.85717	-94.860699

1.2 EXPERIMENTAL PROCEDURES

Detailed descriptions of SEDflume analysis and its application are given in McNeil et al. (1996), Jepsen et al. (1997), and Roberts et al. (1998). The following sections supplement those reports with a general description of the SEDflume analysis procedures used in this study. Supplemental analyses of grain size distribution using laser diffraction (ISO Standard 13-320), water content (ASTM Method D2216-05), and bulk density (ASTM Method D2216-10; Håkanson and Jansson 1983), and loss on ignition (ASTM Method D7348-13) were also implemented at the beginning of each interval to quantify physical sediment characteristics.

1.2.1 SEDflume Setup

A SEDflume is essentially a straight flume with an open bottom section through which a rectangular, cross-sectional core barrel containing sediment can be inserted (Figure 1). The main components of the flume are the water tank, pump, inlet flow converter (which establishes uniform, fully developed, turbulent flow), the main duct, test section, hydraulic jack, and the core barrel containing sediment (Figure 2). The core barrel, test section, flow inlet section, and flow exit section are made of transparent acrylic so that the sediment–water interactions can be observed visually. The core barrel has a rectangular cross section, 10 by 15 cm, and a length of 60 cm.

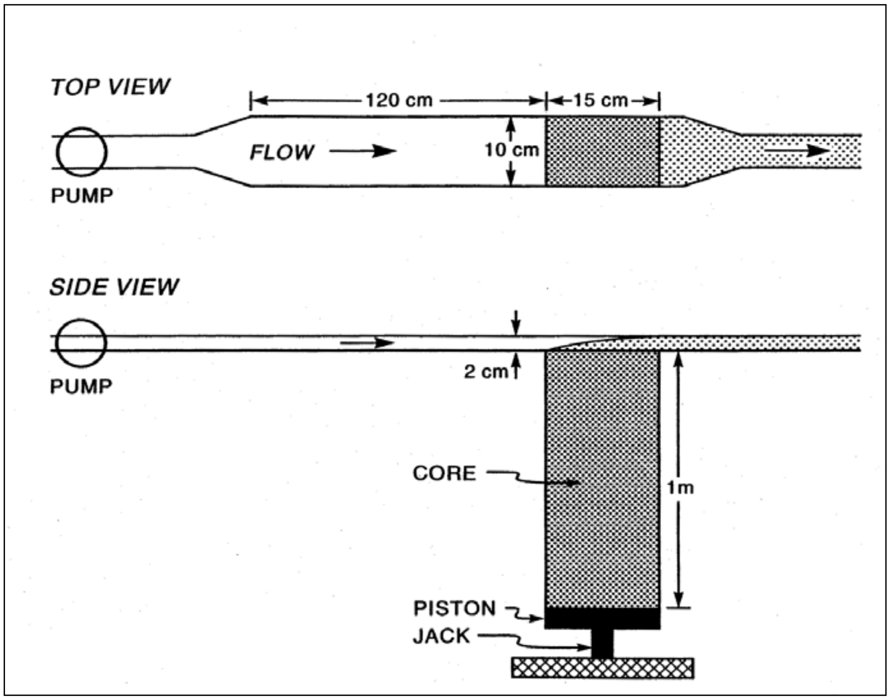

Figure 1. Schematic of SEDflume setup showing top and side views

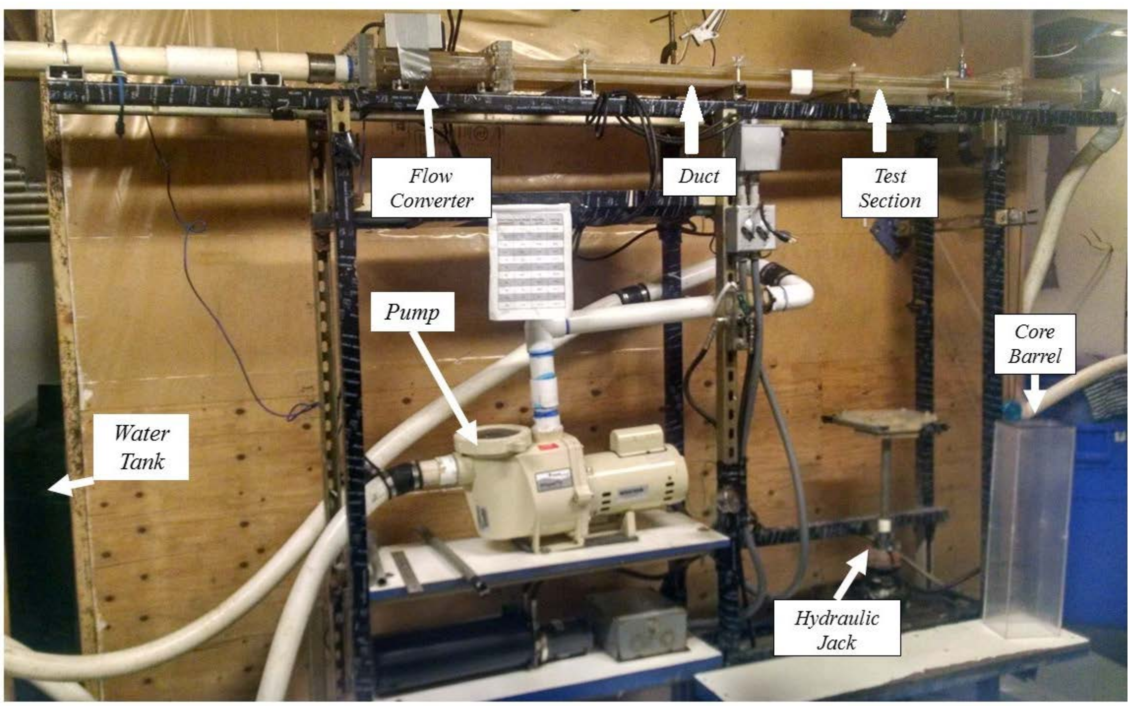

Figure 2. SEDflume in Integral's laboratory, Santa Cruz, California

Water is pumped from a 300-gallon storage tank into a 5-cm-diameter pipe and then through the flow converter into the main duct. The duct is rectangular, 2 cm in height, 10 cm in width, and 120 cm in length; it connects to the test section, which has the same cross-sectional area (2 by 10 cm) and is 15 cm long. The flow converter changes the shape of the cross section from circular to rectangular while maintaining a constant cross-sectional area. A ball valve regulates the amount of water entering the flume so that the flow rates can be carefully controlled. The flume also has a small valve immediately downstream from the test section that opens to the atmosphere, preventing a pressure vacuum from forming and enhancing erosion.

At the start of each test, a core barrel and the sediment it contains are inserted into the bottom of the test section. The sediment surface is aligned with the bottom of the SEDflume channel. When fully enclosed, water is forced through the duct and test section over the surface of the sediment. The shear stress produced by the flow and imparted on the particles causes sediment erosion. As the sediment on the surface of the core erodes, the remaining sediment in the core barrel is slowly moved upward so that the sediment–water interface remains level with the bottom of the flume.

An operator moves the sediment upward using a hydraulically controlled piston that is inside the core barrel. The jack is driven by a release of pressure that is regulated with a switch and valve system. In this manner, the sediment can be raised and made level with the bottom of the test section. The movement of the hydraulic jack can be controlled for measurable increments as small as 0.5 mm.

1.2.2 Measurements of Sediment Erosion Rate

At the start of each core analysis, an initial reference measurement is made of the starting core length. The flume is then operated at a specific flow rate corresponding to a particular shear stress, and sediment is eroded (McNeil et al. 1996; Jepsen et al. 1997). As erosion proceeds, the core is raised if needed to keep the core's surface level with the bottom of the flume. This process is continued until either 10 minutes has elapsed or the core has been raised roughly 2 cm. The erosion rate for the applied shear stress is then calculated as:

$$E = \frac{\Delta z}{T} \quad [1]$$

Where:

E	=	erosion rate
Δz	=	distance that sediment is raised during a particular measurement period
T	=	measurement time interval

Because material is eroded and the core structure is broken down, repetitive erosion measurements at a given depth are not possible. The following procedures were performed for all Grand Lake waterway cores to best determine the erosion rate at several different shear stresses and depths using only one core:

1. The core was inserted into the bottom of the SEDflume test section.
2. The total length of sediment in the core barrel was measured and recorded.
3. Two 5 g (approximately) subsamples of sediment from the core surface were collected using a clean spoon. Sediment sampling was constrained to the downstream (relative to the SEDflume flow direction) end of the sediment surface, to minimize potential scour effects.
4. Shear stresses (from low to high) were applied to the core's surface, and sediment erosion was measured (if it occurred; 0.5 mm of erosion in 10 minutes was considered quantifiable). Applied shear stresses started at 0.1 Pa and were sequentially doubled until a given shear stress caused approximately 2 cm of erosion in 20 seconds, or a maximum of 5 cm was eroded in a given interval (defined as a continuous succession of increasing shear stress cycles where erosion is measured). Each shear stress cycle was applied for a minimum of 20 seconds and a maximum of 10 minutes. To the extent possible, no more than 2 cm of sediment was allowed to erode at a single shear stress.
5. Once the threshold—2 cm of erosion in 20 seconds, or a maximum of 5 cm of erosion in a single interval—was met, a new depth interval was started. Steps 3 and 4 were repeated.[1] Also, if the sediment composition changed noticeably in appearance or erosion properties, the depth interval was stopped, sediment subsamples were collected, and a new depth interval was started (Step 4).
6. Where practicable, at least three and up to five depth intervals were tested per core.

1.2.2.1 Determination of Critical Shear Stress

The critical shear stress of a sediment bed, τ_{cr}, is the applied shear stress at which sediment motion is initiated. In this study, it is operationally defined as the shear stress required to produce 0.001 mm of erosion in 1 second. This represents an erosion rate of 10^{-4} cm/s, or roughly 1 mm of erosion in 15 minutes.[2]

---

[1] If a particular shear stress did not cause any observable erosion over a 10-minute period for consecutive depth intervals (e.g., less than 0.5 mm eroded in 10 minutes), that shear stress was removed from subsequent testing cycles; higher shear stresses were added, as appropriate, to attempt to measure at least three erosion rates.

[2] Though other definitions of critical shear stress erosion rate thresholds can be argued (and considered valid), the value of 10^{-4} cm/s threshold is used here for consistency with previous SEDflume efforts and to keep testing times to a practical duration.

Because it is difficult to measure τ_{cr} exactly at the 10^{-4} cm/s threshold, erosion was instead measured over a range of shear stresses designed to bracket the initiation of erosion threshold. The highest applied shear stress where erosion *did not occur* is defined by τ_{no}, and τ_{first} is the lowest applied shear stress where erosion *did occur*.

Using the measured erosion rate data in each depth interval, a power law regression analysis (described below) was employed to determine the shear stress (τ_{power}) required to cause 10^{-4} cm/s of erosion. Assimilating the bracketed shear stress values (τ_0 and τ_1) and τ_{power}, the critical shear stress of each interval was then chosen according to the following criteria (where τ_{no} and τ_{first} are determined directly from the SEDflume measurements):

- If $\tau_{no} \leq \tau_{power} \leq \tau_{first}$, then τ_{power} was the selected critical shear stress, τ_{cr}, for the interval.
- If $\tau_{no} \geq \tau_{power}$, then τ_{no} was the selected critical shear stress for the interval.
- If $\tau_{power} \geq \tau_{first}$, then τ_{first} was the selected critical shear stress for the interval.
- If $r^2 < r^2_{thresh}$, then τ_{linear} was selected as the critical shear stress for the interval.

The τ_{cr} criteria allowed for selection of critical shear stresses using the power law results where the regression analysis was in agreement with measured erosion rate data.

1.2.2.2 Power Law Regression

Following the methods of Roberts et al. (1998), the erosion rates for sediment can be approximated by the power law regression:

$$E = A\tau^n \rho^m \qquad [2]$$

Where:

E	=	erosion rate (cm/s)
τ	=	bed shear stress (Pa)
ρ	=	sediment bulk density (g/cm^3)
A, n, and m	=	constants that depend on sediment characteristics

The equation used in the present analysis is an abbreviated variation of Equation 2:

$$E = A\tau^n \qquad [3]$$

where the constant A is a function of the sediment bulk density and other difficult properties to measure, such as sediment geochemistry and biological influences. The variation of erosion rate with density typically cannot be determined for field sediment because of natural variation in other sediment properties (e.g., mineralogy, particle size, and electrochemical forces). Therefore, the density term from the equation above, for a particular interval of approximately constant density, is incorporated into the constant *A*.

For each depth interval, the measured erosion rates (*E*) and applied shear stresses (τ) were used to determine the *A* and *n* constants that provide a best-fit power law curve to the data for that interval. Good regression fits of these parameters, where they existed, were then used to estimate the critical shear stress for the respective intervals. A coefficient of determination (r^2) of 0.70 was used as a threshold criterion for acceptance.[3]

1.2.3 Measurement of Sediment Bulk Properties

In addition to the measurement of erosion rates during the analysis, sediment subsamples were periodically collected at depth to determine the water content, particle size distribution, and loss on ignition of the sediment in each core. Water content and loss on ignition values are incorporated into the determination of wet and dry bulk densities. Subsamples were collected from the undisturbed core surface (prior to analysis) as well as the sediment surface at the beginning of each subsequent depth interval. Samples were weighed, dried, and reweighed to determine the mass of water. Samples were then subjected to sufficient heat to ignite the organic material to determine loss on ignition.

Wet bulk density was determined by first measuring the wet and dry weight of the collected sample to determine the water content (*W)* as described in Håkanson and Jansson (1983):

$$W = \frac{M_w - M_d}{M_w} * 100\% \qquad [4]$$

Where:

W = water content
M_w = wet weight of sample
M_d = dry weight of sample

For the determination of wet bulk density, water content in this formulation have value from 0 to 1. Wet bulk densities were then determined using the method described by Håkanson and Jansson (1983):

[3]The coefficient of determination, r^2, is a function of Pearson's *r*, which is a measure of the linear dependence (correlation) between two variables. Pearson's *r* can be positive or negative, and is a value between –1 and +1. The more common usage of the correlation coefficient is to square Pearson's *r*, r^2, and report that value.

$$\rho_{wet} = \frac{(100 * \rho_s)}{100 + (W + IG)(\rho_s - 1)} \qquad [5]$$

Where

ρ_w	=	density of water (assumed 1 g/cm^3)
ρ_s	=	density of sediment particle (assumed 2.65 g/cm^3)
IG	=	% loss on ignition based on wet weight (ASTM Method D7348-13)

Dry bulk densities are based on the moisture content (*MC*) defined by ASTM D2216-05 as

$$MC = \frac{M_w - M_d}{M_d} \qquad [6]$$

This formulation represents the ratio of water to solids. Using the moisture content value, dry bulk densities were calculated using the following relationship:

$$\rho_{dry} = \frac{\rho_{wet}}{1 + MC} \qquad [7]$$

Particle size distributions were determined using laser diffraction analysis at Integral's laboratory in Santa Cruz, California. Sediment samples were screened with a 2,000-µm sieve to remove large pieces of organic material, dispersed in water, and inserted into a Beckman Coulter LS 13-320 laser diffraction analyzer. Each sample was analyzed in three 1-minute intervals, and the results of the three analyses were averaged automatically by the instrument. The Beckman Coulter LS 13-320 measures volumetric distribution of particles from 0.4 to 2,000 µm. Caution should be taken when comparing directly to more narrowly ranged instruments such as a laser *in situ* scattering and transmissometry (LISST) instrument or traditional mass-based sieve and hydrometer studies. A LISST measures aggregated particles in the natural environment and has detection ranges different from that of the desktop instrument. Use of the Beckman Coulter involves the disaggregation of particles so any direct comparison must consider these factors.

The relationships used to determine sediment bulk properties are summarized in Table 2.

Table 2. Parameters measured and computed during the SEDflume analysis

Measurement	Definition	Units	Detection Limit	Internal Consistency
Water Content	$W = \frac{M_w - M_d}{M_w}$	Dimensionless	0.001 g in sample weight ranging from 1 to 50 g	0 < W < 1
Moisture Content	$MC = \frac{M_w - M_d}{M_d}$	Dimensionless	0.001 g in sample weight ranging from 1 to 50 g	
Wet Bulk Density	$\rho_{wet} = \frac{(100 * \rho_s)}{100 + (W + IG)(\rho_s - 1)}$	g/cm³	0.001 g in sample weight ranging from 1 to 50 g	$\rho_w < \rho_{wet} <$ 2.6 ρ_w
Dry Bulk Density	$\rho_{dry} = \frac{\rho_{wet}}{1 + MC}$	g/cm³	0.001 g in sample weight ranging from 1 to 50 g	$\rho_w < \rho_{dry} < \rho_{wet}$
Particle size distribution below 2,000 µm	Distribution of particle sizes by volume percentage using laser diffraction	µm	Method specific	1 µm < grain size < 2,000 µm

Notes:
M_w = wet weight of sample
M_d = dry weight of sample
ρw = density of water (assumed 1 g/cm³)
ρs = density of sediment particle (assumed 2.65 g/cm³)

1.2.4 Intra- and Intercore Comparisons

A potentially useful method of comparing sediment characteristics at a specific site is to compute intracore and intercore erosion rates. This method provides a means to quantify the erosion rates within each core (intracore) as well as the general erosion rates of the cores across the site (intercore).

1.2.4.1 Intracore Erosion Rate Ratios

Once the power law regression *A* and *n* coefficients for each depth interval within an individual core were known, the *interval-average* erosion rate for the core was determined using Equation 3 and the logarithmic average of the range of shear stresses tested in the SEDflume analysis.[4] C*ore-average* erosion rates were then computed by:

1. Log-averaging the *A* coefficient values from each depth interval within a core to arrive at an average *A* coefficient for the entire core
2. Arithmetically averaging the *n* coefficient values from each depth interval within a core to arrive at an average *n* coefficient for the entire core
3. Solving for the core-average erosion rate following Equation 3 and using the log-average of the range of shear stresses applied to the depth interval (1.13 Pa).

An intracore erosion-rate-ratio was then defined by dividing the interval-average erosion rate by the core-average erosion rate, providing a quantitative estimation of the relative erosion susceptibility of each depth interval. This method highlights the core intervals that are more or less susceptible to erosion within a particular core, and may indicate layering within a core.

1.2.4.2 Intercore Erosion Rate Ratios

Two additional ratios were computed to evaluate large-scale spatial erosion susceptibility. An intercore erosion rate ratio was computed by comparing the individual core-average erosion rate with a site-wide average erosion rate. The site-wide average erosion rate was computed by:

1. Log-averaging the core-average *A* coefficient values from each core to arrive at an average *A* coefficient for the entire site
2. Arithmetically averaging the core-average *n* coefficient values in each core to arrive at an average *n* coefficient for the entire site
3. Solving for the site-wide average erosion rate following Equation 3 and using the log-average of the range of shear stresses (1.13 Pa).

The intercore erosion rate ratio computed in this manner provided a qualitative estimate of the erosion susceptibility of each core (as a whole) relative to other cores in the site, potentially indicating spatial locations that are more or less susceptible to erosion than other locations.

[4] The shear stress values averaged were 0.1, 0.2, 0.4, 0.8, 1.6, 3.2, 6.4, and 12.8 Pa. The logarithmic average of these, used to compute erosion rate ratios, was 1.13 Pa.

2 RESULTS

This section of the report contains both qualitative and quantitative findings from the SEDflume analysis. Results are presented on a core-by-core basis. Appendix A contains additional grain size statistics and distribution plots for each interval in each core. Raw data from the grain size analysis can be provided upon request.

Results are presented both graphically and in tabular form. Erosion rates at applied shear stresses are presented with depths adjacent to an image of the core. The indication of no erosion measured refers to the thin dotted line at 10^{-5} cm/s. As described in the previous sections, values of 10^{-4} cm/s are defined as the erosion rate related to minimum measurable critical shear stress. Tables of the derived constants A and n are provided with the r^2 value. Mean values are also presented over the entire core. The coefficient A is log-averaged because of the order of magnitude variations that can occur within its values, while n is arithmetically averaged because its range is narrow. Values of n typically range from 1 to 4, and values outside of this range may also indicate a spurious data fit.

A table of particle sizes, wet and dry bulk densities, loss on ignition, greatest applied shear with no erosion measured, first applied shear with erosion measured, and power law derived critical shear is also presented. The power law-derived critical shear was determined using the A and n values from tables also provided for each sample. A column labeled "Final Critical Shear" provides the recommended value based on the criteria outlined in Section 1.2.2.1.

Qualitative descriptions of the type of erosion are included when necessary to highlight changing processes. Erosion of the core surface generally occurs via individual particles becoming suspended, aggregated clumps of sediment (clump erosion) breaking off causing an uneven surface, or sheets of material peeling off the sediment bed. Noncohesive materials such as sands, in the absence of any organic matter acting as a "glue," will erode as individual particles. Fine-grained sediment such as silts and clays can bind together and will move together under an applied shear. Cracks and uneven sedimentation may cause these bonded sediments to move together as clumps. Sediment deposited cyclically may deposit in uniform layers and can erode as thin sheets.

Cores were processed according to the procedures in Section 1.2.2. Cores were processed until at least five intervals were completed or processing came within 5 cm from the end of the core.

2.1 SED-ER-10

Core ER-10 was collected on March 12, 2020, at 3:30 p.m. in 8 ft of water. The 30 cm length of core was collected east of the Highway 10 Bridge using a combination of hand pressure and post-hammer blows. Collected sediment consisted of olive, brown silty material with a uniform fine texture throughout with a lighter oxidized layer extending up to 3 cm from the surface. Worm tubes and possible feeding voids 0.25 to 0.5 cm in diameter were observed up to 15 cm below the surface. Sediment below the biotic influenced zone was uniform in olive color and silty texture. Leaves and stems were uncovered 25 cm below the surface but were not observed prior to that depth.

A photograph of the recovered sediment aligned with applied shear stresses and resulting erosion rates is presented in Figure 3. Shear stresses ranging from 0.1 to 12.8 Pa were applied during five shear stress intervals. Not all shear stresses were included in each interval as described in Section 1.2.2. The surface was more erodible than underlying sediment. Intervals 2, 3, and 4 exhibited uniform erosion rates and erodibility while interval 5 encompassed the least erodible sediment analyzed in ER-10 (Figure 4). In interval 1 extending 5.3 cm from the surface, sediment eroded evenly across the bed as individual grains or pieces of the surface were suspended. As depth and shear stress increased, erosion occurred when pieces or larger clumps of the surface broke free. Pieces ranged in size relative to applied shear stress and the surface eroded unevenly.

Sediment properties were relatively uniform throughout the core with the exception of low-density sediment at the surface (Figure 5, Table 3). The low-density material is associated with the lowest critical shear stresses determined from the measured erosion rates. Table 3 provides a summary of shear stress measurement as well the final critical shear stress based on the criteria outlined in Section 1.2.2.1. Derived critical shear stresses ranged from 0.25 to 1.73 Pa. Power law fit parameters relating the erosion rate to applied shear stress are presented in Table 4.

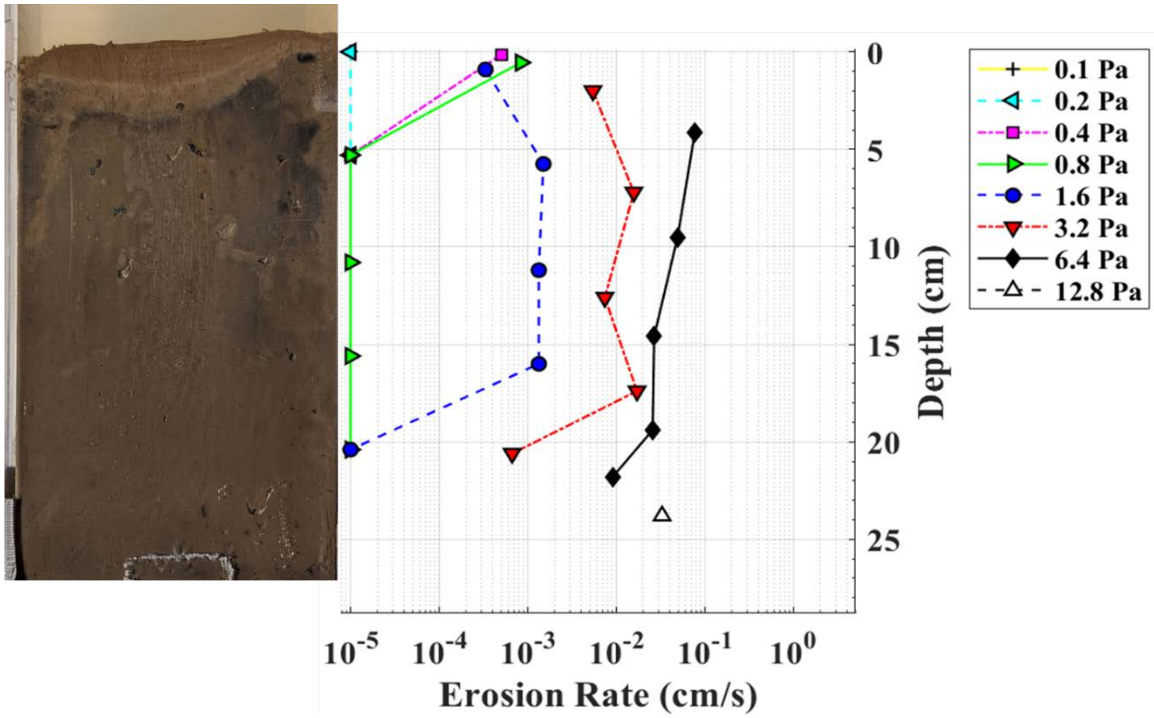

Figure 3. Photograph of Core ER-10 aligned with applied shear stresses and associated erosion rates

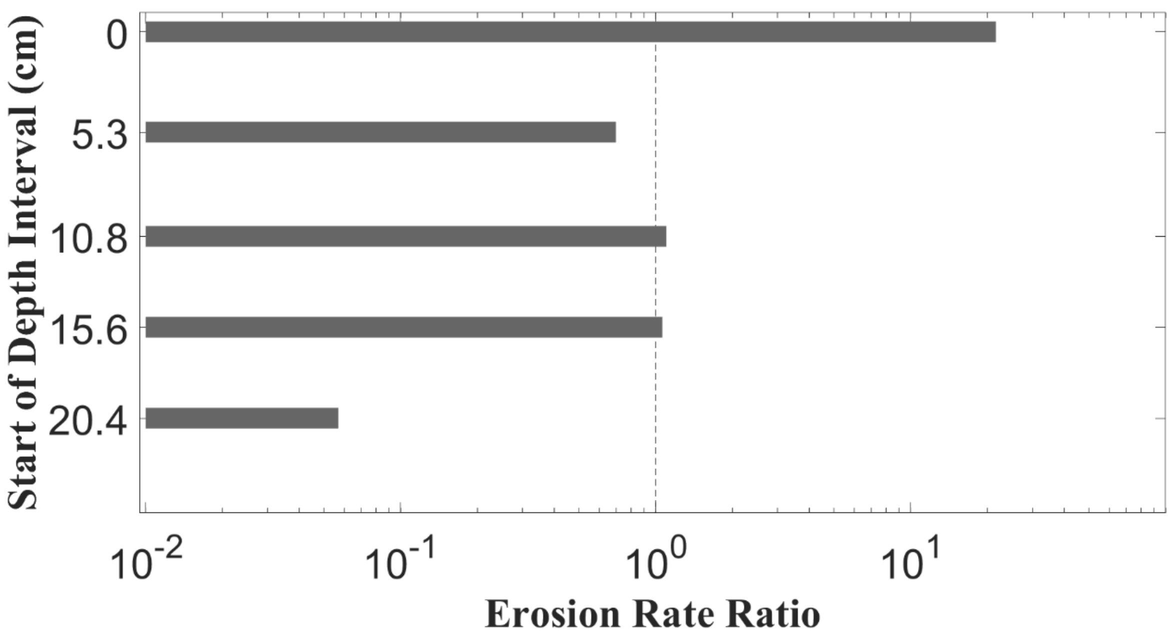

Figure 4. Intracore erosion rates of ER-10

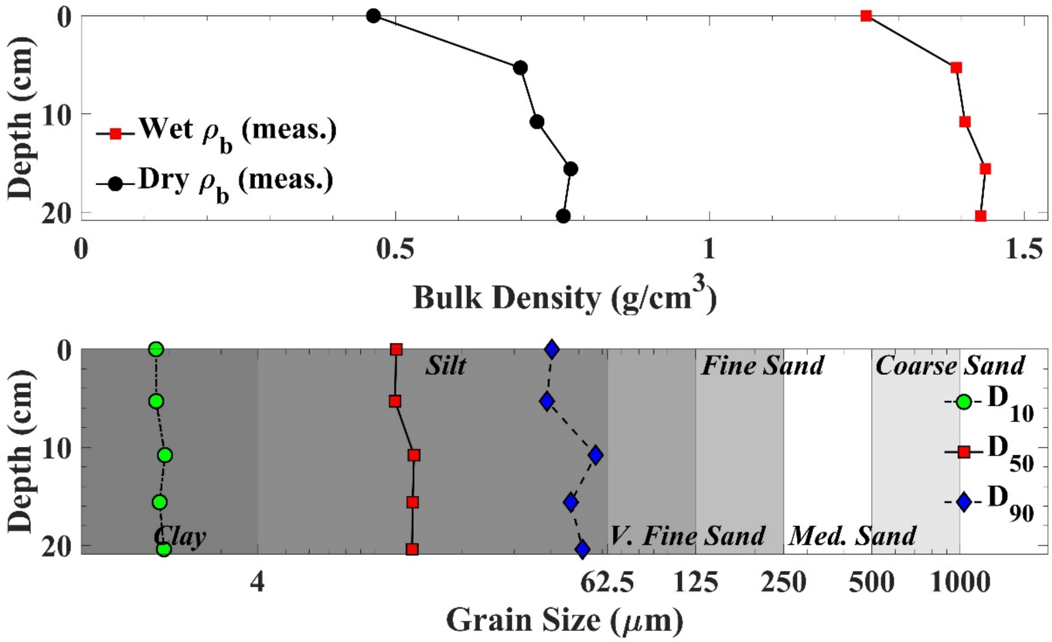

Figure 5. Physical properties of ER-10 with depth

Table 3. Physical properties and derived critical shear stresses of ER-10

Sample Depth (cm)	Median Grain Size (µm)	Wet Bulk Density (g/cm³)	Dry Bulk Density (g/cm³)	Loss on Ignition (%)	Tau_no (Pa)	Tau_first (Pa)	Tau Crit Linear (Pa)	Tau Crit Power (Pa)	Final Critical Shear (Pa)
0.0	11.89	1.25	0.46	5.2%	0.2	0.4	0.24	0.25	0.25
5.3	11.78	1.39	0.7	5.0%	0.8	1.6	0.86	0.75	0.8
10.8	13.68	1.41	0.73	5.2%	0.8	1.6	0.86	0.74	0.8
15.6	13.54	1.44	0.78	5.2%	0.8	1.6	0.86	0.72	0.8
20.4	13.47	1.43	0.77	5.3%	1.6	3.2	1.84	1.73	1.73
Mean	12.87	1.38	0.69	5.2%	0.84	1.68	0.93	0.84	0.88

Table 4. Power law fit parameters for SED-ER-10

Interval	Depth Start (cm)	Depth Finish (cm)	A	n	r^2
1	0.0	5.3	2.1E-05	1.69	0.79
2	5.3	10.8	1.93E-07	3.1	0.96
3	10.8	15.6	4.21E-07	2.74	0.97
4	15.6	20.4	3.71E-07	2.84	0.92
5	20.4	24.8	1.64E-08	3.06	0.98

2.2 SED-ER-680

Core ER-680 was collected on March 9, 2020, at 5:30 p.m. in 5 ft of water and is the easternmost sample in the Elk River. This was the first core collected during the study and required multiple attempts and the use of a post-hammer to achieve adequate penetration resulting in 22 cm of sediment collected. The sample contained evidence of biotic activity at the surface in the upper 10 cm of the sample in form of tubes and possible feeding voids. Below a 1–3 cm surface layer of lighter sediment, an olive gray mixture of silt and sand extended throughout the sample. On the surface, the sediment was unconsolidated, yellow-tan material with some biotic mounds present. A translucent fish approximately 2 cm in length was also observed in the overlying water and burrowed into the sand when disturbed.

A photograph of the recovered sediment aligned with applied shear stress and associated erosion rates is presented in Figure 6. Shear stresses of 0.1 to 6.4 Pa were applied in three intervals utilizing 13.7 cm of material. The unconsolidated surface material eroded more easily than the underlying material possibly due to bioturbation (Figure 7). Sediment eroded in streams of individual grains as the loose sandy material eroded from the surface. Below the surface interval, sediment eroded as individual grains giving way to larger pieces of the surface 1–3 mm in diameter breaking away. Pockets of interspersed sandy material eroded as individual grains causing the exposed sediment level to erode unevenly. Critical shear stresses ranged from 0.12 to 0.4 Pa from the first to third interval (Table 5). Intervals 2 and 3 had similar properties resulting in an average critical shear stress of 0.3 Pa. Power law fit parameters governing the relationship between shear stress and erosion rate are provided in Table 6. The r^2 values show an excellent fit relating the two variables.

Four subsamples of material were collected for density and particle size distribution testing. The first three correlate to the beginning of each shear stress interval and the fourth corresponds to the end of the third interval. The low-density surface material comprised sand, silt, and clay

(Figure 8, Table 5). Below, sediment had a larger density and the proportions of sand, silt, and clay varied.

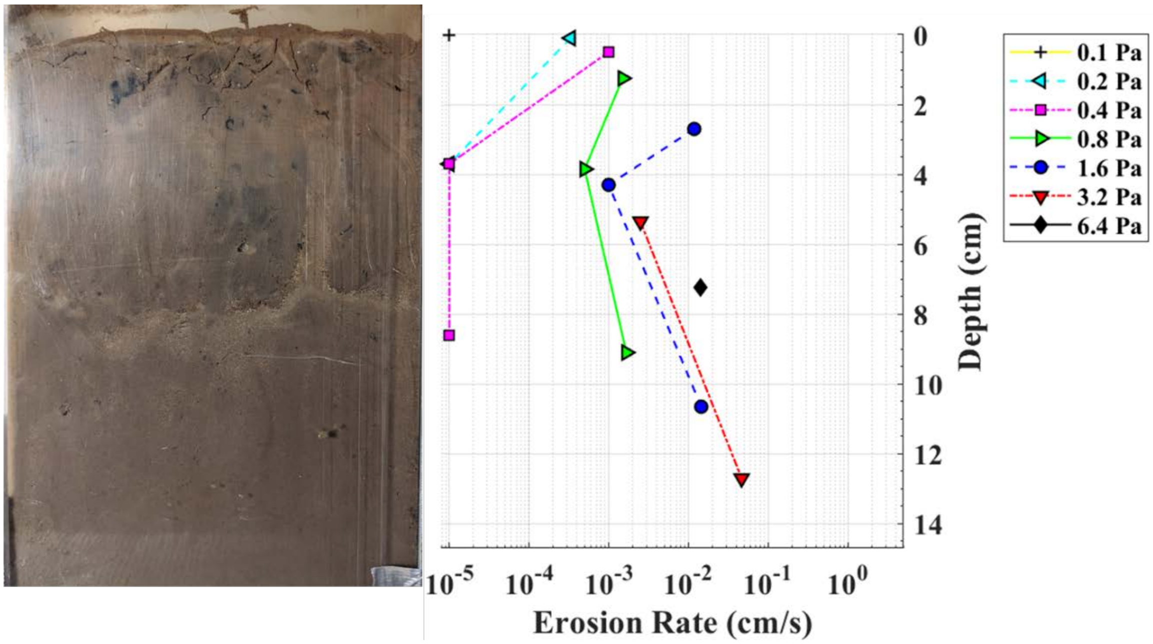

Figure 6. Photograph of Core ER-680 aligned with applied shear stresses and associated erosion rates

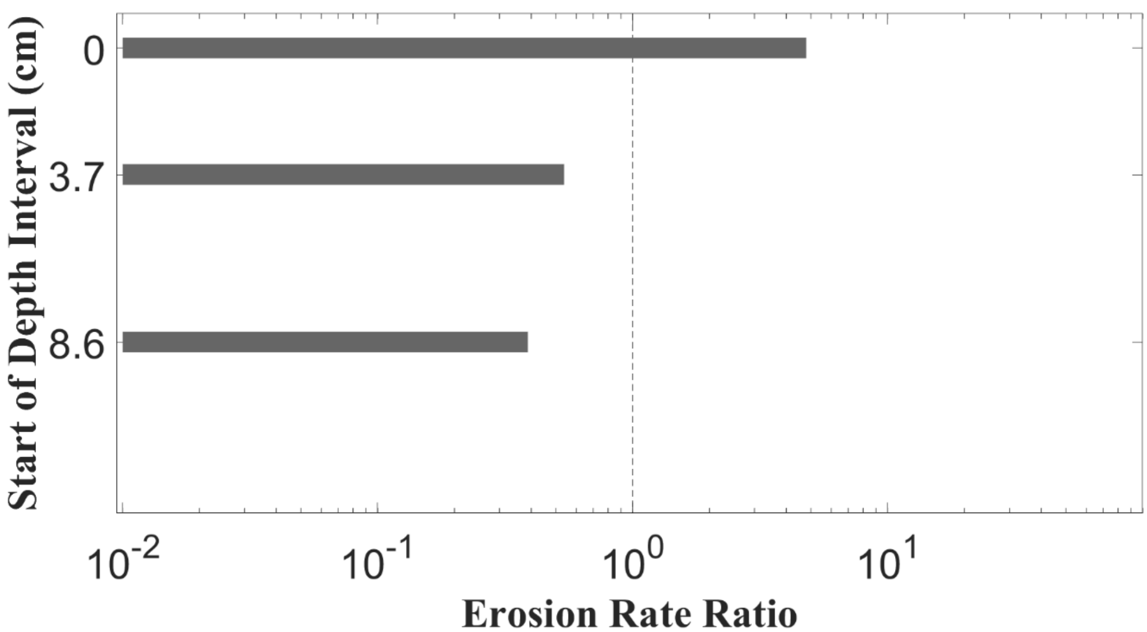

Figure 7. Intracore erosion rates in ER-680

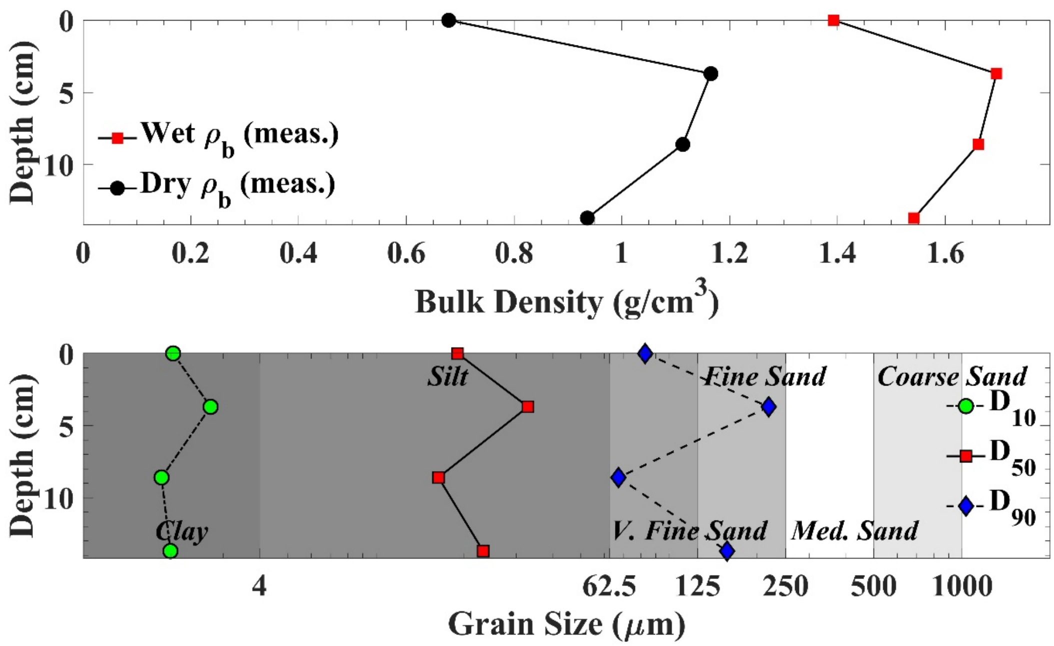

Figure 8. Physical properties of ER-680 with depth

Table 5. Physical properties and derived critical shear stresses of ER-680

Sample Depth (cm)	Median Grain Size (µm)	Wet Bulk Density (g/cm^3)	Dry Bulk Density (g/cm^3)	Loss on Ignition (%)	Tau_no (Pa)	Tau_first (Pa)	Tau Crit Linear (Pa)	Tau Crit Power (Pa)	Final Critical Shear (Pa)
0	18.95	1.39	0.68	3.4%	0.1	0.2	0.13	0.12	0.12
3.7	32.96	1.7	1.16	2.9%	0.4	0.8	0.48	0.42	0.42
8.6	16.32	1.66	1.11	3.0%	0.4	0.8	0.43	0.37	0.4
13.7	23.18	1.54	0.94	4.2%	---	---	---	---	---
Mean	22.85	1.57	0.97	3.4%	0.3	0.6	0.35	0.30	0.31

Table 6. Power law fit parameters of ER-680

Interval	Depth Start (cm)	Depth Finish (cm)	A	n	r^2
1	0.0	3.7	7.64E-05	1.71	0.95
2	3.7	8.4	8.35E-06	1.74	0.97
3	8.6	13.7	1.88E-06	3.05	0.96

2.3 SED-NR-130

Core NR-130 was collected on March 11, 2020, at 4:00 p.m. on the east bank of the Neosho River. The sample was collected along the bank due to the flow of the river. The core recovery length was 17 cm, and a post-hammer was required to achieve penetration through the sediment. Shown in Figure 9, the collected sediment contained invertebrate burrows and tubes that extended and criss-crossed throughout the sample. An example of the worm observed in this core as well as other collected samples and presumably responsible for these burrows is shown in Figure 10. Patches of oxic sediment associated with the presence of worm tubes extended 10−12 cm below the surface. Darker patches of olive silt were present in the absence of worm tubes.

A photograph of the collected sediment core and applied shear stresses is provided in Figure 9. Due to the limited material collected at NR-130, shear stresses ranging from 0.1 to 6.4 Pa were applied to only two intervals of the sediment. Both intervals exhibited similar erosive (Figure 11) and physical properties as summarized in Table 7 and visualized in Figure 12. Critical shear stresses ranged from 0.33 to 0.4 Pa and fit parameters suggest good agreement with a power law relationship relating shear stress and erosion rate (Table 8). Grain sizes were consistent down-core, and densities increased with depth.

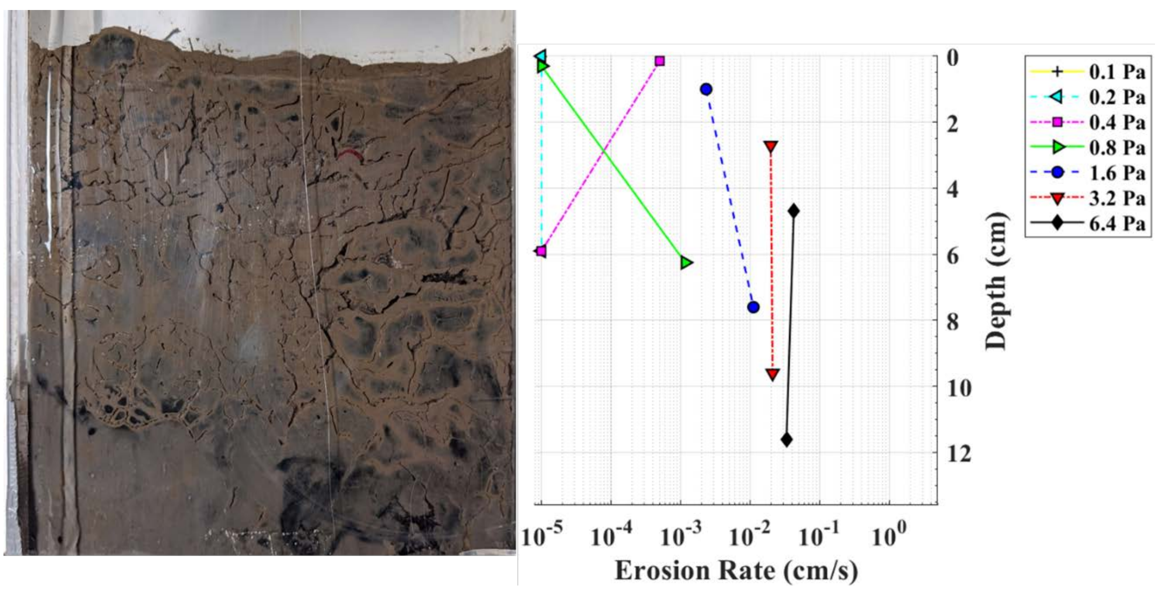

Figure 9. Photograph of Core NR-130 aligned with applied shear stresses and associated erosion rates

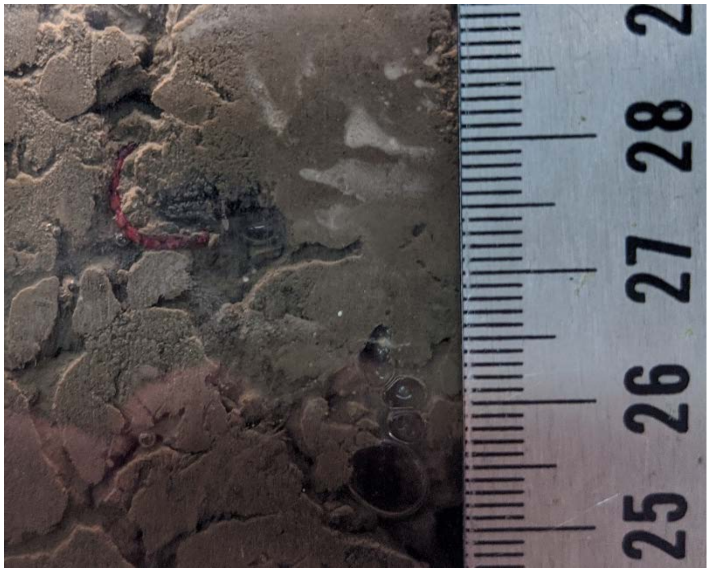

Figure 10. Invertebrate in burrow in NR-130

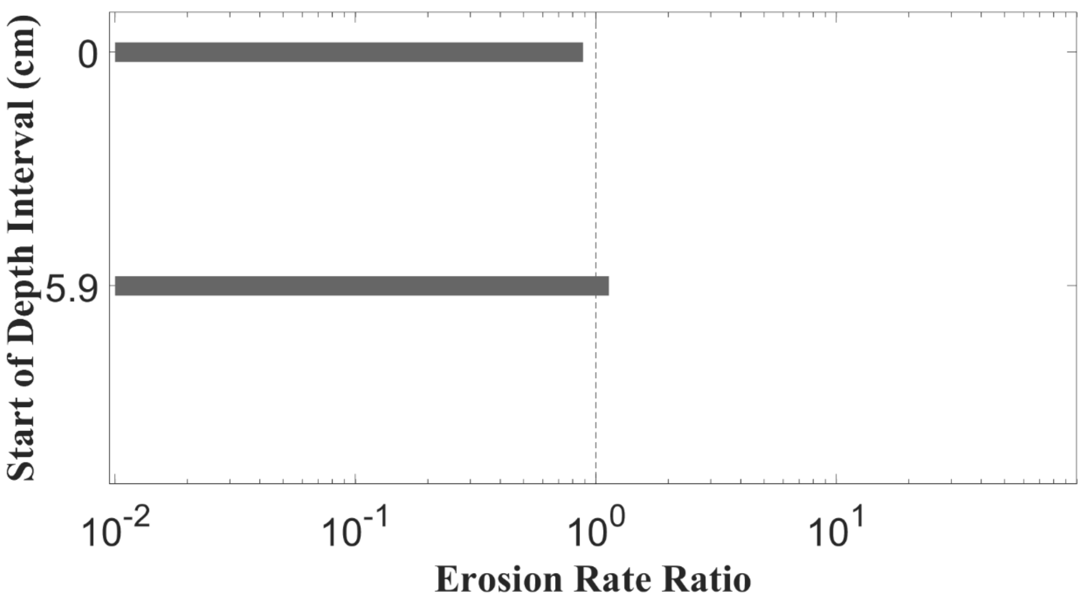

Figure 11. Intracore erosion rates in NR-130

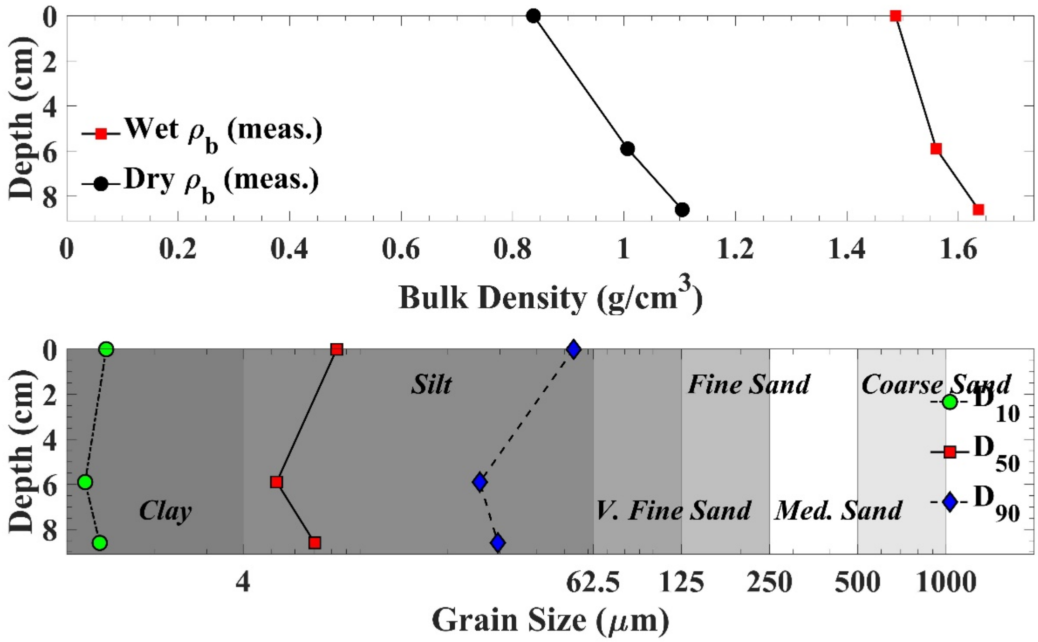

Figure 12. Physical properties of NR-130 with depth

Table 7. Physical properties and derived critical shear stresses of NR-130

Sample Depth (cm)	Median Grain Size (µm)	Wet Bulk Density (g/cm³)	Dry Bulk Density (g/cm³)	Loss on Ignition (%)	Tau_no (Pa)	Tau_first (Pa)	Tau Crit Linear (Pa)	Tau Crit Power (Pa)	Final Critical Shear (Pa)
0.0	8.34	1.49	0.84	3.7%	0.2	0.4	0.84	0.33	0.33
5.9	5.2	1.56	1.01	6.8%	0.4	0.8	0.44	0.29	0.4
8.6	7.01	1.64	1.1	5.0%	---	---	---	---	---
Mean	6.85	1.56	0.98	5.2%	0.30	0.60	0.64	0.31	0.37

Table 8. Power law fit parameters for NR-130

Interval	Depth Start (cm)	Depth Finish (cm)	A	n	r^2
1	0.0	5.7	8.57E-06	2.04	0.78
2	5.9	12.6	1.01E-05	2.13	0.88

2.4 SED-NR-164

Core NR-164 was collected on the eastern bank of the Neosho River downstream of the confluence of the Neosho and Spring rivers. Sampling required light blows from the post-hammer and resulted in the recovery of 41 cm of sediment. Recovered material appeared dark brown or olive in color with a lighter oxidized layer 1–2 cm on the surface. Sediment less than 10 cm from the surface showed signs of biotic activity and contained leaves and twigs.

A photograph of the recovered sediment aligned with applied shear stresses and resulting erosion rates is presented in Figure 13. Shear stresses ranging from 0.1 to 12.8 Pa were applied to six intervals of sediment in the upper 25 cm of sample. The first interval extended 1.8 cm from the original surface and ended when the unconsolidated material was eroded away leaving a much firmer looking, gray material. In subsequent intervals, bedded material did not respond to applied shear stresses less than 1.6 Pa. The material contained worms (Figure 14) and their structures and eroded in pieces or in some instances larger episodes of multiple millimeters of sediment peeled away. The sediment in intervals 2 through 6 behaved in a similar way to the applied shear stresses (Figure 15).

Low-density surface material gave way to generally denser material down-core. Sediment grain size distributions varied with some sand present intermittently around 10 cm below the recovered surface (Figure 16, Table 9). Derived critical shear stresses ranged from 0.12 at the surface to a uniform 0.8 Pa at deeper intervals. The 0.8 value was determined using the criteria in Section 1.2.2.1 because the critical shear stress derived using the power law fell below the *tau_no* value. Power law fit parameters indicate that despite the critical shear stress values being lower than the *tau_no*, there is still generally good agreement with the erosion rates and shear stresses (Table 10).

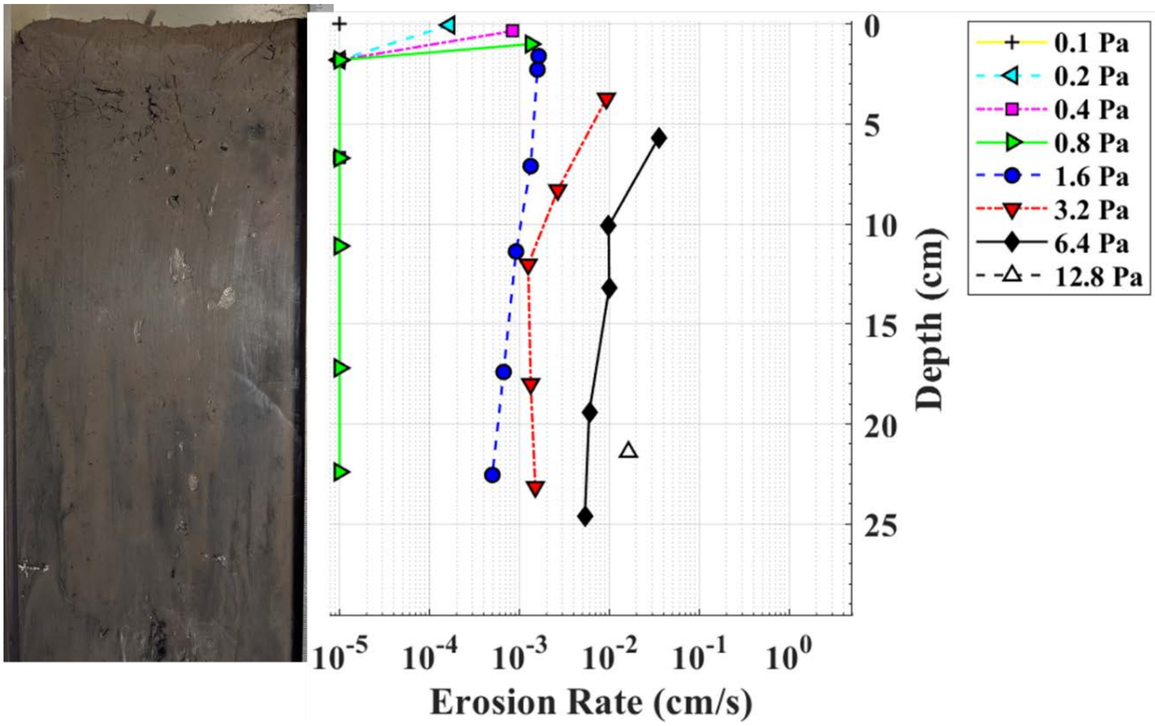

Figure 13. Photograph of Core NR-164 aligned with applied shear stresses and associated erosion rates

Figure 14. Grouping of invertebrates in NR-164

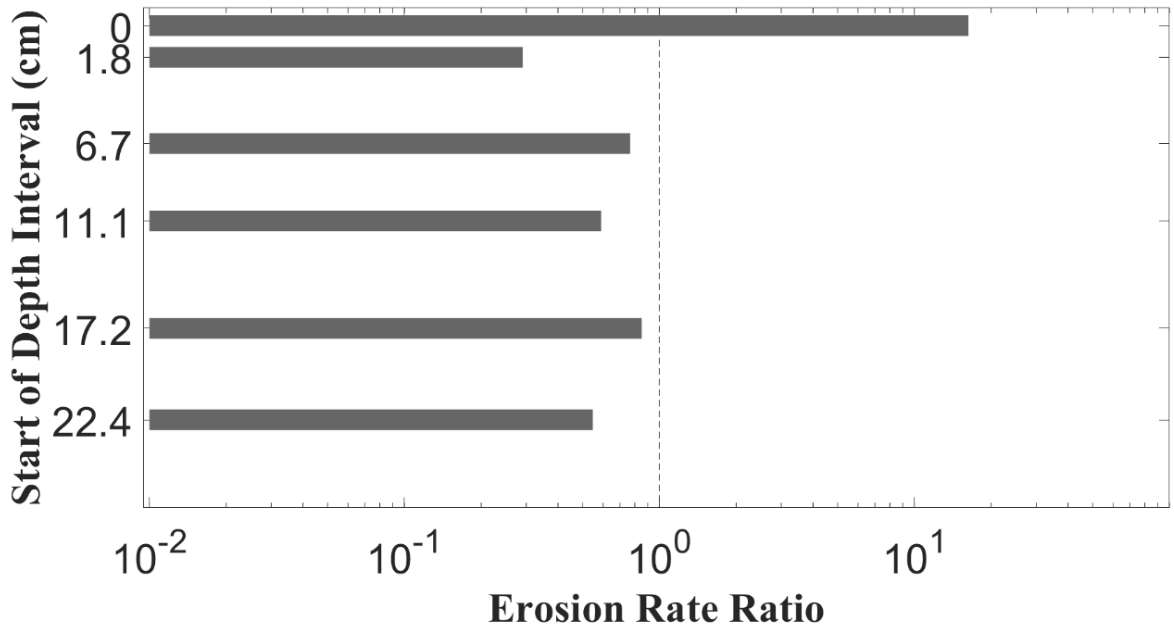

Figure 15. Intracore erosion rates in NR-164

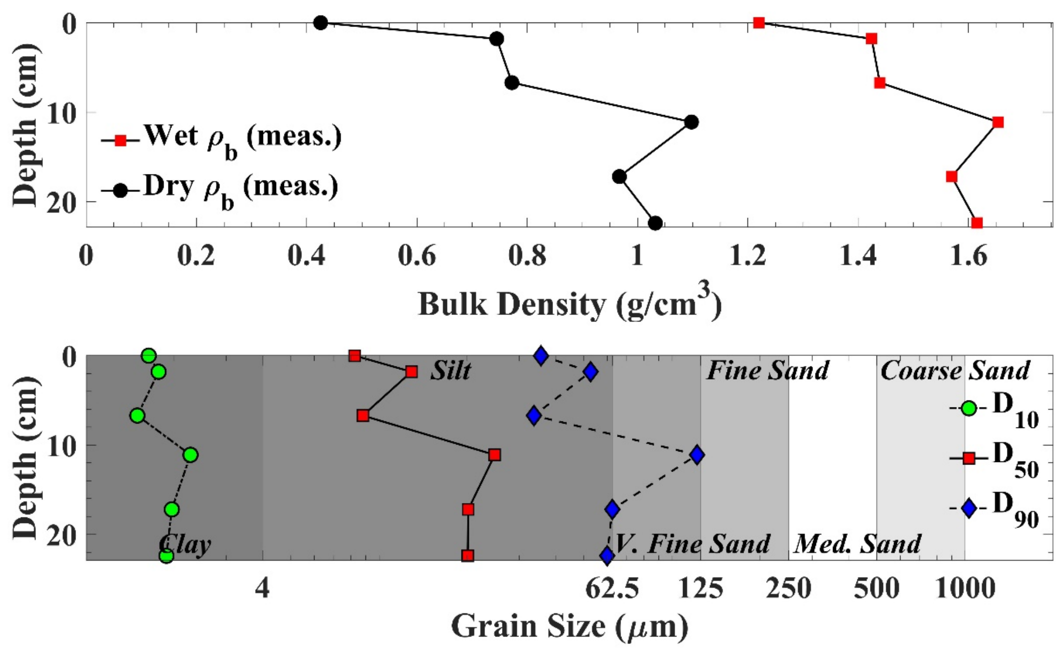

Figure 16. Physical properties of NR-164 with depth

Table 9. Physical properties and derived critical shear stresses of NR-164

Sample Depth (cm)	Median Grain Size (µm)	Wet Bulk Density (g/cm^3)	Dry Bulk Density (g/cm^3)	Loss on Ignition (%)	Tau_no (Pa)	Tau_first (Pa)	Tau Crit Linear (Pa)	Tau Crit Power (Pa)	Final Critical Shear (Pa)
0.0	8.25	1.22	0.43	5.9%	0.1	0.2	0.16	0.12	0.12
1.8	12.89	1.42	0.74	4.4%	0.8	1.6	0.86	0.73	0.8
6.7	8.8	1.44	0.77	4.6%	0.8	1.6	0.86	0.68	0.8
11.1	24.8	1.65	1.1	2.9%	0.8	1.6	0.89	0.77	0.8
17.2	20.15	1.57	0.97	3.3%	0.8	1.6	0.92	0.75	0.8
22.4	20.05	1.62	1.03	2.7%	0.8	1.6	0.96	0.85	0.85
Mean	15.82	1.49	0.84	4.0%	0.68	1.37	0.78	0.65	0.70

Table 10. Power law fit parameters in NR-164

Interval	Depth Start (cm)	Depth Finish (cm)	A	n	r^2
1	0.0	1.8	7.93E-05	1.24	0.88
2	1.8	6.7	3.32E-07	2.87	0.96
3	6.7	11.1	1.68E-06	2.14	0.92
4	11.1	14	1.31E-06	2.12	0.93
5	17.2	22.4	2.41E-06	1.85	0.97
6	22.4	25.6	1.33E-06	2.02	0.98

2.5 SED-NR-202

Core NR-202 was collected on March 10, 2020, at 4:35 p.m. in 5 ft of water. The sediment bed resisted penetration and required multiple blows from a post-hammer to achieve a core recovery length of 23 cm from the eastern bank along the inside bend of the Neosho River. A 3.5 cm layer of oxidized, unconsolidated sediment covered dark, anoxic silty material. The presence of visible worm tubes in the upper 7 cm of sediment suggests that observations on the undisturbed surface are the result of bioturbation and biotic mounds.

A photograph of NR-202 aligned with applied shear stresses and resulting shear stresses highlights the reduction in erodibility with depth (Figure 17). The surface sediment eroded at lower shear stresses and more easily than the material below (Figure 15). The reduction in erodibility correlates with the increase in density with depth (Figure 16, Table 11). Critical shear stresses ranges from 0.15 to 1.14 and fit parameters indicate excellent agreement in measurements and the use of a power law relationship (Table 12). When erosion occurred, sediment suspended in the form of cloud erosion at the surface and individual grains and pieces of the bed as depth increased.

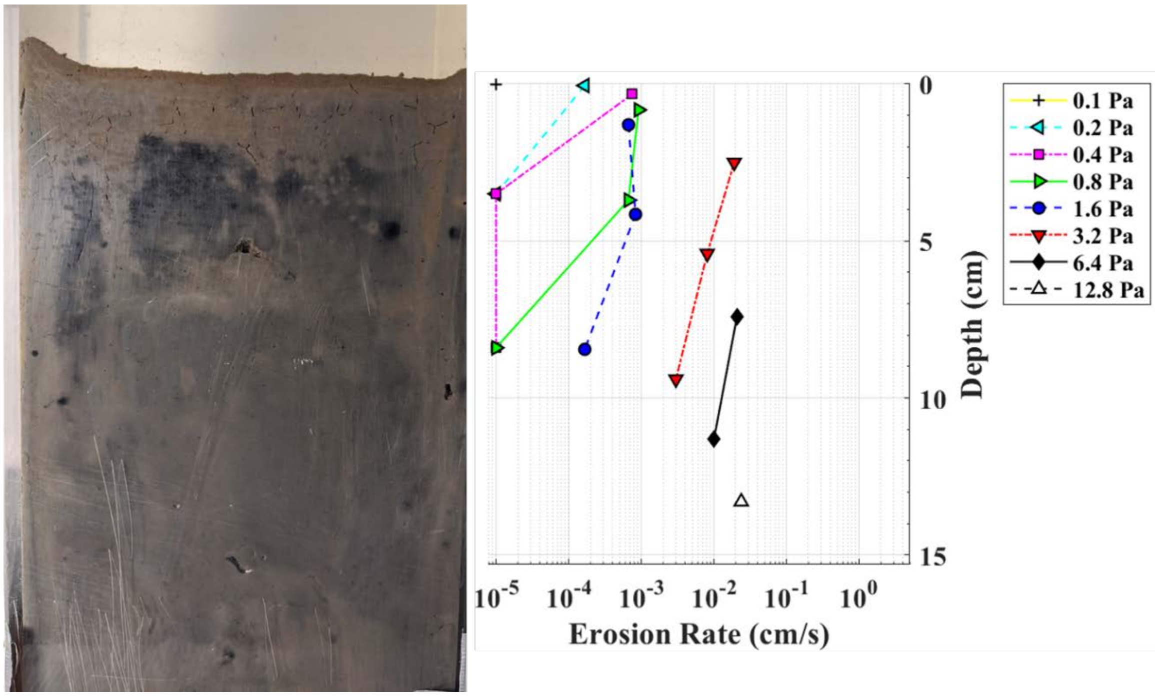

Figure 17. Photograph of Core NR-202 aligned with applied shear stresses and associated erosion rates

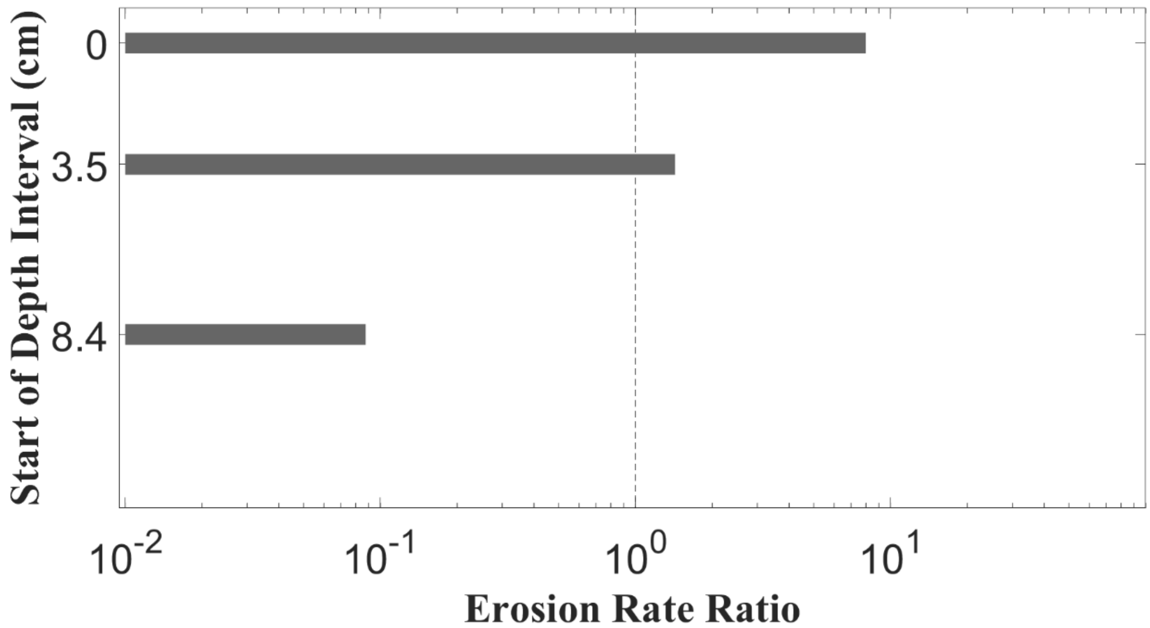

Figure 18. Intracore erosion rates in NR-202

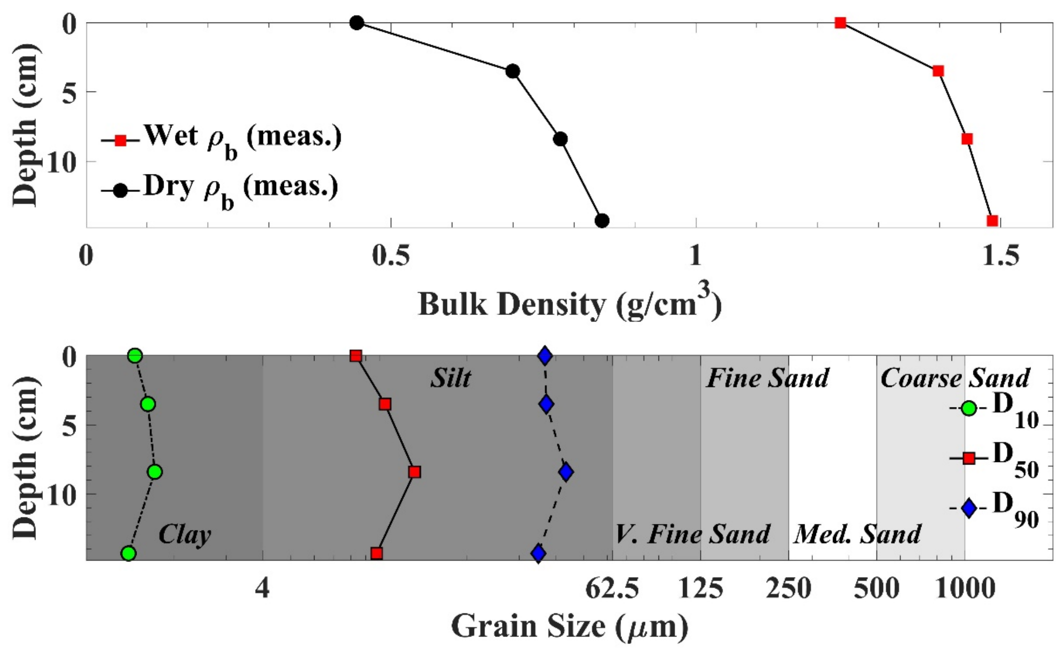

Figure 19. Physical properties of NR-202 with depth

Table 11. Physical properties and derived critical shear stresses of NR-202

Sample Depth (cm)	Median Grain Size (µm)	Wet Bulk Density (g/cm³)	Dry Bulk Density (g/cm³)	Loss on Ignition (%)	Tau_no (Pa)	Tau_first (Pa)	Tau Crit Linear (Pa)	Tau Crit Power (Pa)	Final Critical Shear (Pa)
0.0	8.33	1.24	0.44	5.1%	0.1	0.2	0.16	0.15	0.15
3.5	10.47	1.4	0.7	4.3%	0.4	0.8	0.46	0.41	0.41
8.4	13.22	1.44	0.78	4.4%	0.8	1.6	1.28	1.14	1.14
14.3	9.81	1.49	0.85	4.4%	---	---	---	---	---
Mean	10.46	1.39	0.69	4.6%	0.43	0.87	0.63	0.57	0.57

Table 12. Power law fit parameters for NR-202

Interval	Depth Start (cm)	Depth Finish (cm)	A	n	r^2
1	0.0	3.5	5.85E-05	1.39	0.8
2	3.5	8.4	6.22E-06	1.97	0.95
3	8.4	14.3	2.43E-07	2.48	0.95

2.6 SED-NR-CB

Core NR-CB was collected on the Neosho River north of Connors Bridge at 5:02 p.m. on March 11, 2020. Sampling occurred on the bank of the river away from the known gravel and rocky substrate in the center of the river. The steep slope of the bank resulted in multiple attempts to collect a sample. Samples were pushed by hand in the upper 10 cm but required post-hammer blows to recover 32 cm of sediment.

A photograph of NR-CB aligned with applied shear stresses and resulting erosion rates is presented in Figure 20. Light gray sediment at the surface contained evidence of biotic activity that extended up to 12 cm into the sediment bed. Below the surface layer, sediment was silty in texture and transitioned from olive to dark gray material approximately 15 cm below the surface. Resulting erosion rates varied with the most erodible sediment occurring in the second interval (Figure 21). This may be due to the effects of wetting and drying associated with the shallow bank where the core was collected.

Variations in density mimic trends in erodibility but median grain sizes generally increased throughout the sample (Figure 22, Table 13). Critical shear stresses also varied in a similar manner to density ranging from 0.2 in interval 2 to 0.8 Pa at interval 5. Fit parameters indicate good and excellent fits relating shear stress to erosion rate (Table 14).

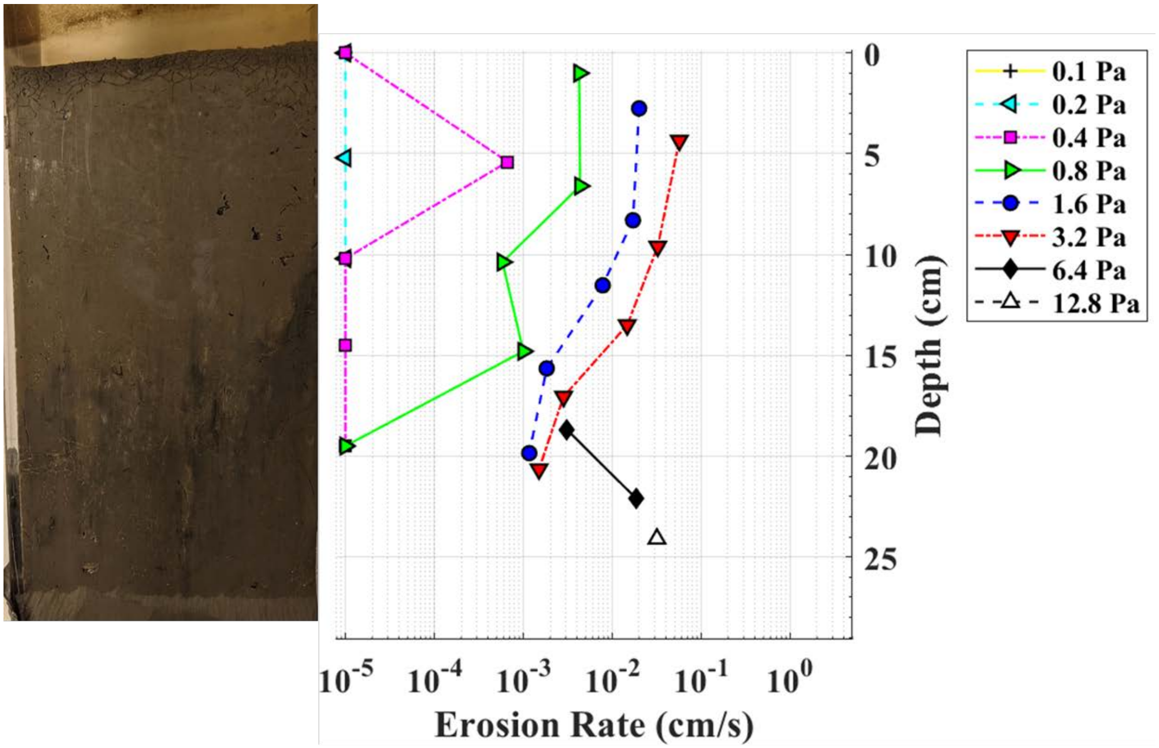

Figure 20. Photograph of Core NR-CB aligned with applied shear stresses and associated erosion rates

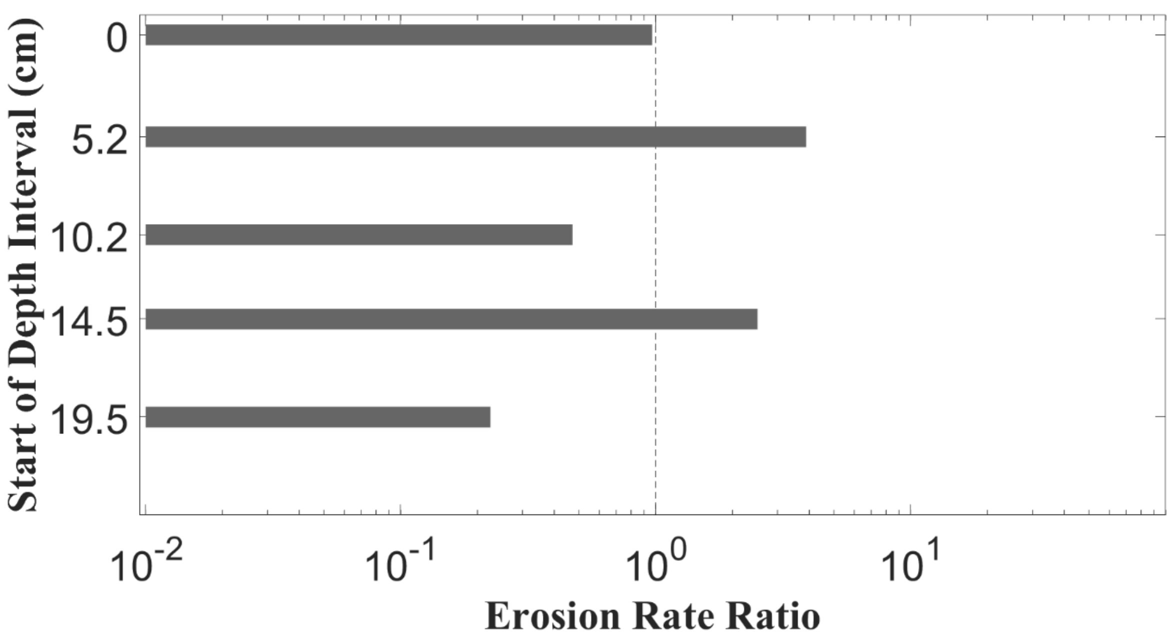

Figure 21. Intracore erosion rates in NR-CB

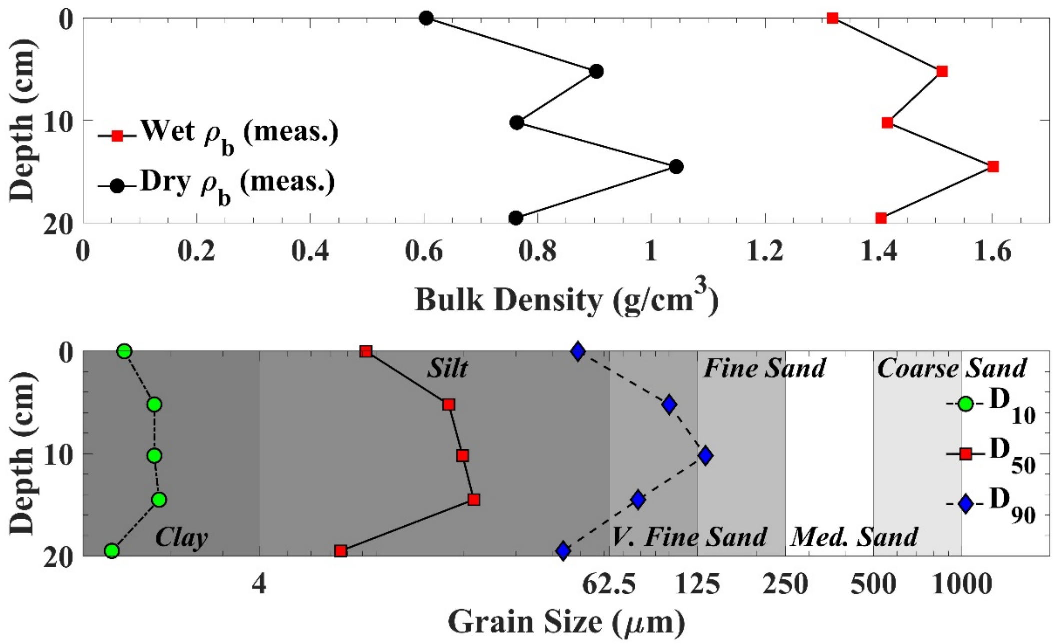

Figure 22. Physical properties of NR-CB with depth

Table 13. Physical properties and derived critical shear stresses of NR-CB

Sample Depth (cm)	Median Grain Size (µm)	Wet Bulk Density (g/cm³)	Dry Bulk Density (g/cm³)	Loss on Ignition (%)	Tau_no (Pa)	Tau_first (Pa)	Tau Crit Linear (Pa)	Tau Crit Power (Pa)	Final Critical Shear (Pa)
0.0	9.23	1.32	0.6	7.0%	0.4	0.8	0.41	0.31	0.4
5.2	17.73	1.51	0.9	5.4%	0.2	0.4	0.23	0.18	0.2
10.2	19.76	1.42	0.76	6.8%	0.4	0.8	0.47	0.42	0.42
14.5	21.58	1.6	1.04	4.9%	0.4	0.8	0.45	0.21	0.4
19.5	7.58	1.4	0.76	8.0%	0.8	1.6	0.87	0.7	0.8
Mean	15.18	1.45	0.81	6.4%	0.44	0.88	0.49	0.36	0.44

Table 14. Power law fit parameters in NR-CB

Interval	Depth Start (cm)	Depth Finish (cm)	A	n	r^2
1	0.0	5.2	3.24E-06	2.99	0.91
2	5.2	10.2	2.62E-05	2.21	0.96
3	10.2	14.5	2.05E-06	2.7	0.94
4	14.5	19.5	4.31E-05	1.16	0.75
5	19.5	25.1	1.66E-06	2.1	0.94

2.7 SED-NR-FG

Core NR-FG was collected near the Miami fairgrounds on March 11, 2020, at 11:00 a.m. The 23 cm length of core was collected from the east bank of the river. The area was noted to be seasonally wet and dry by the FreshWater Engineering team members. The surface was covered in clumps of sediment and resisted penetration from the coring system due to the presence of stiff sediment. Sediment at NR-FG was light gray or tan with evidence of anoxic patches as depth increased.

A photograph of NR-FG with applied shear stresses and resulting erosion rates is presented in Figure 23. Shear stress was applied successfully to three intervals of the sample. The loose surface material that formed broken clumps was tested for grain size distribution and density but was not considered for critical shear stress determination. To reduce anthropogenic disturbance, the clumpy material was subjected to a 1.6 Pa flow that removed the clumps from the surface. After their removal, processing took place as normal. Sediment properties remained relatively constant with depth but erodibility (and subsequently critical shear stress) declined as depth increased (Figure 24, Figure 25).

Critical shear stresses increased an order of magnitude from 0.4 Pa at interval 1 to 2.46 Pa in interval 3 located 10 cm below the surface (Table 15). Sediment eroded unevenly across the surface and sporadically during the application of shear stresses. The sediment appeared to be crumbly and eroded by pieces breaking away often resulting in a subsequent event occurring where more particles or pieces eroded. Power law fit parameters provided in Table 16 were used to determine the critical shear stresses for each successful interval.

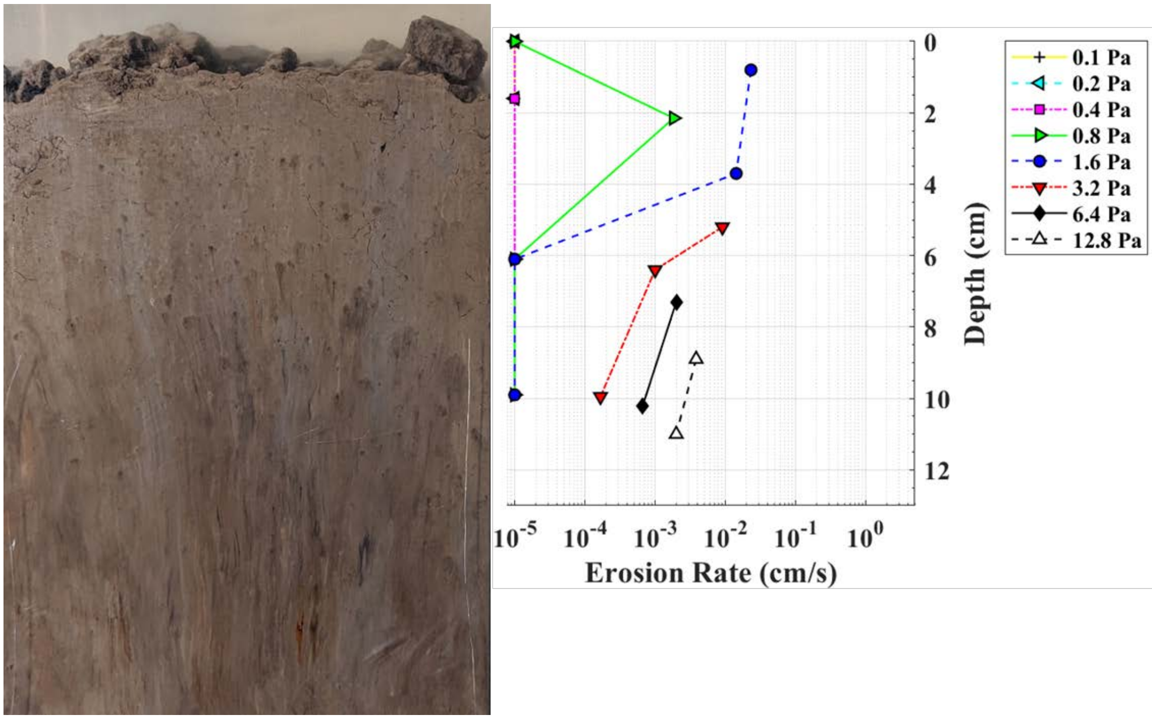

Figure 23. Photograph of Core NR-FG aligned with applied shear stresses and associated erosion rates

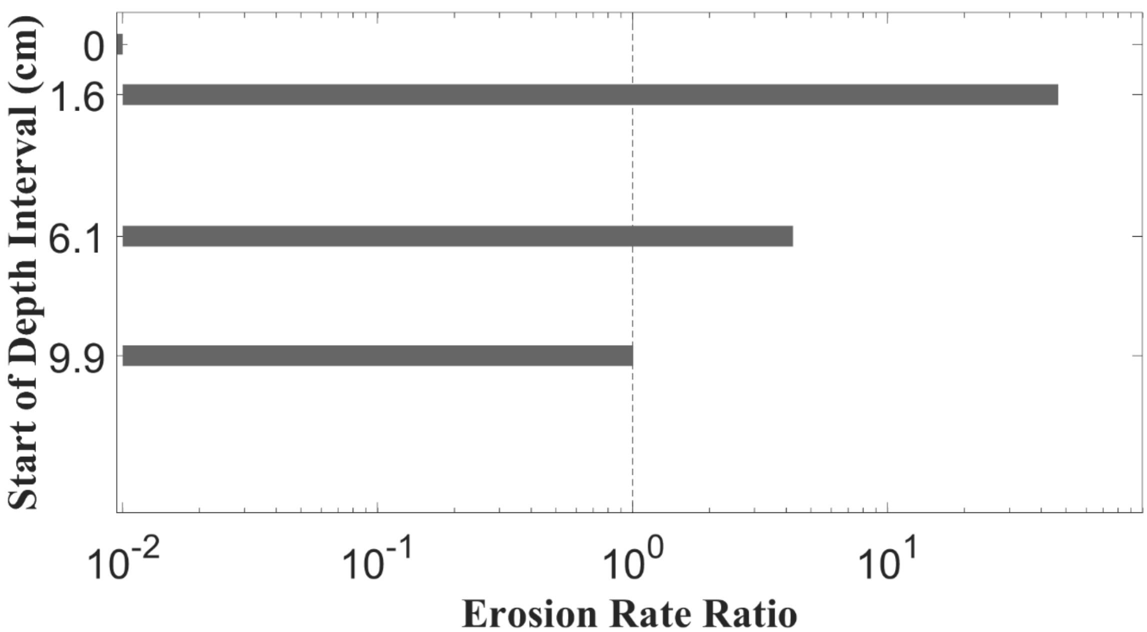

Figure 24. Intracore erosion rates in NR-FG

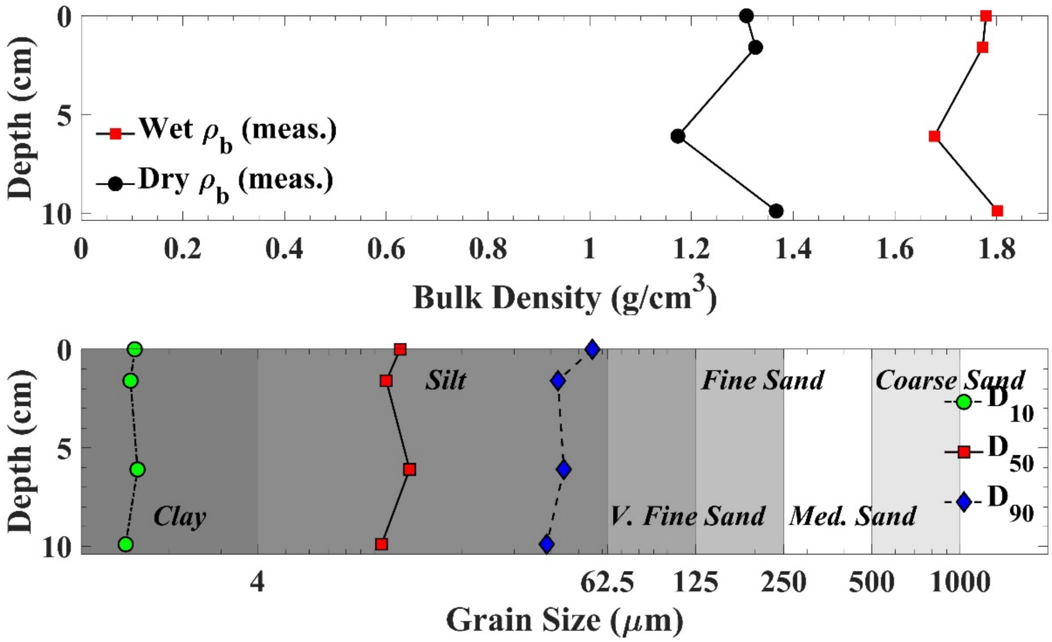

Figure 25. Physical properties of NR-FG with depth

Table 15. Physical properties and derived critical shear stresses of NR-FG

Sample Depth (cm)	Median Grain Size (µm)	Wet Bulk Density (g/cm³)	Dry Bulk Density (g/cm³)	Loss on Ignition (%)	Tau_no (Pa)	Tau_first (Pa)	Tau Crit Linear (Pa)	Tau Crit Power (Pa)	Final Critical Shear (Pa)
0.0	12.27	1.78	1.31	3.2%	---	---	---	---	---
1.6	11	1.77	1.33	4.8%	0.4	0.8	0.43	0.3	0.4
6.1	13.21	1.68	1.17	5.1%	1.6	3.2	1.77	1.27	1.6
9.9	10.6	1.8	1.37	4.4%	1.6	3.2	2.56	2.46	2.46
Mean	11.77	1.76	1.30	4.4%	1.1	2.2	1.39	1.21	1.32

Table 16. Power law fit parameters in NR-FG

Interval	Depth Start (cm)	Depth Finish (cm)	A	n	r^2
1	---	---	---	---	---
2	1.6	5.7	8.1E-06	2.29	0.79
3	6.1	9.9	1.22E-06	1.73	0.87
4	9.9	11.6	2.57E-07	1.86	1.0

2.8 SED-NR-SB

Core NR-SB was collected in the Neosho River on March 10, 2020, at 2:00 p.m. On the second collection attempt, a 37 cm length of sediment core was collected in 6 ft of water from the center of the river. The sample contained silty, gray sediment with a 2- to 3-cm oxic surface layer and evidence of biotic activity in the upper 10 cm.

Shear stresses ranging from 0.1 to 12.8 Pa were applied to the upper 24.6 cm of collected sediment (Figure 26). The unconsolidated surface layer was easily eroded relative to the rest of the sample. Properties such as erodibility varied with depth (Figure 27). During testing, erosion processes varied from individual grains producing even erosion across the surface to clumps of sediment breaking away leaving an uneven surface. The change in behavior was attributed to variations in grain size within the sediment bed (Figure 28, Table 17). Density increased with depth up to 20 cm below the surface.

Critical shear stresses ranged from 0.27 to 1.6 Pa and generally increased with depth.
Core NR-SB exhibits properties consistent with others from the site by having an erodible, unconsolidated surface layer and more uniform properties in the firmer sediments below. Parameters relating to erosion rate and shear stress suggest good agreement between measurements using a power law fit (Table 18).

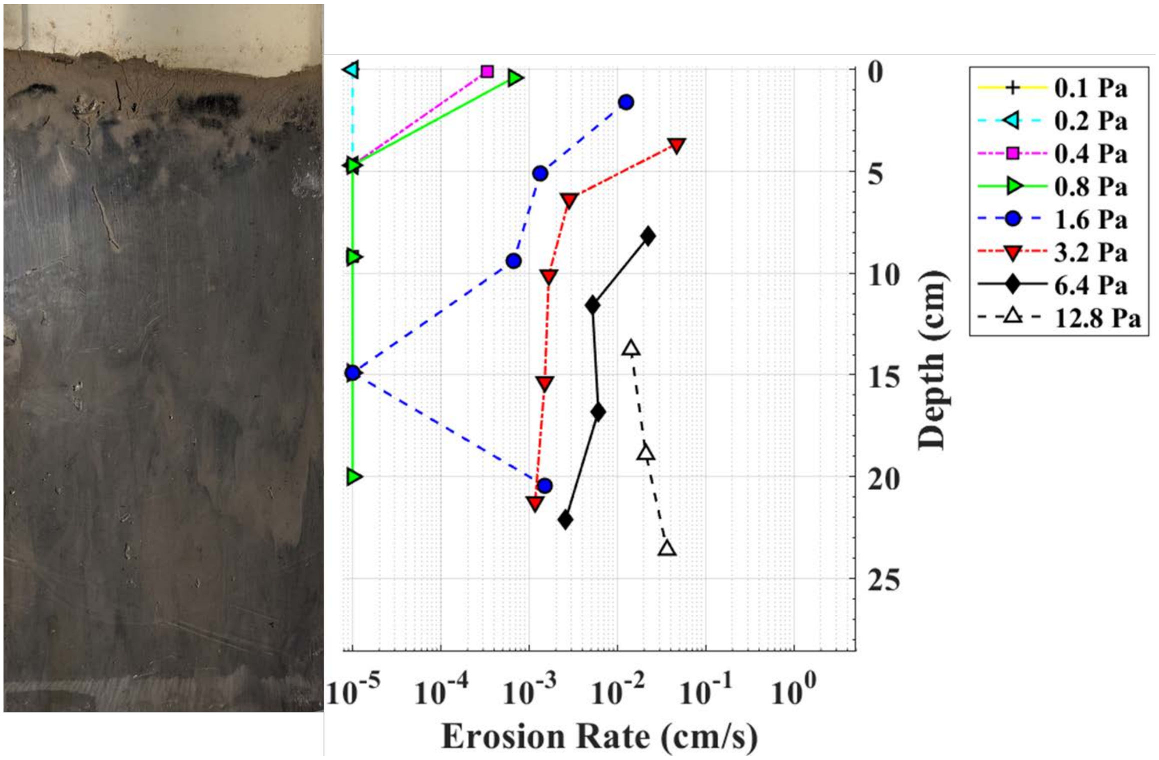

Figure 26. Photograph of Core NR-SB aligned with applied shear stresses and associated erosion rates

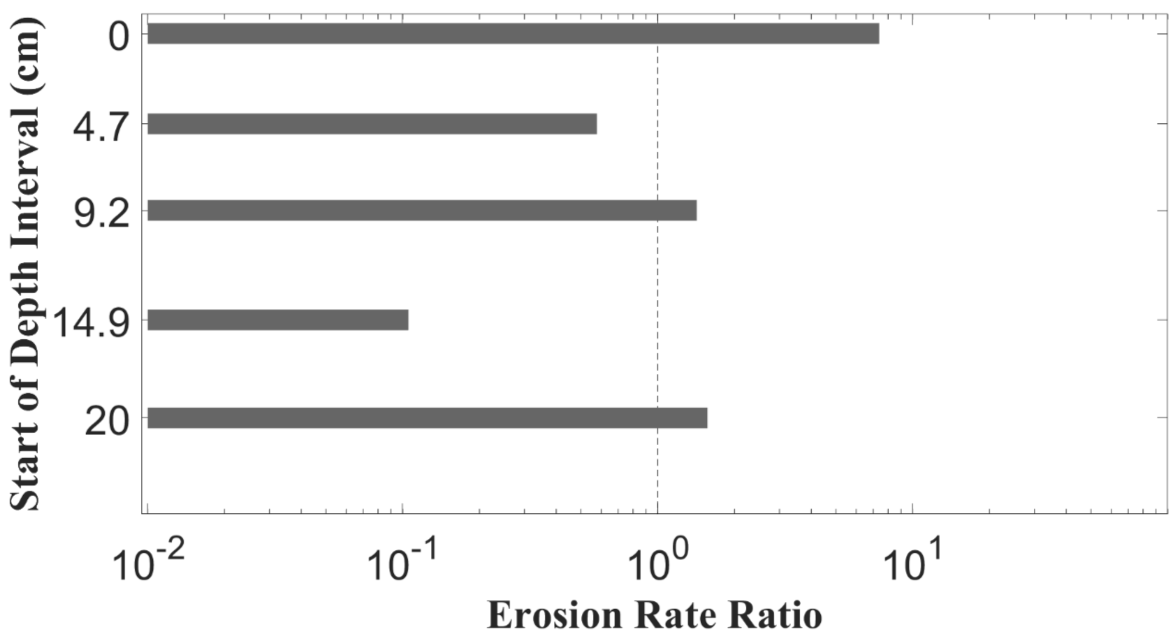

Figure 27. Intracore erosion rates for NR-SB

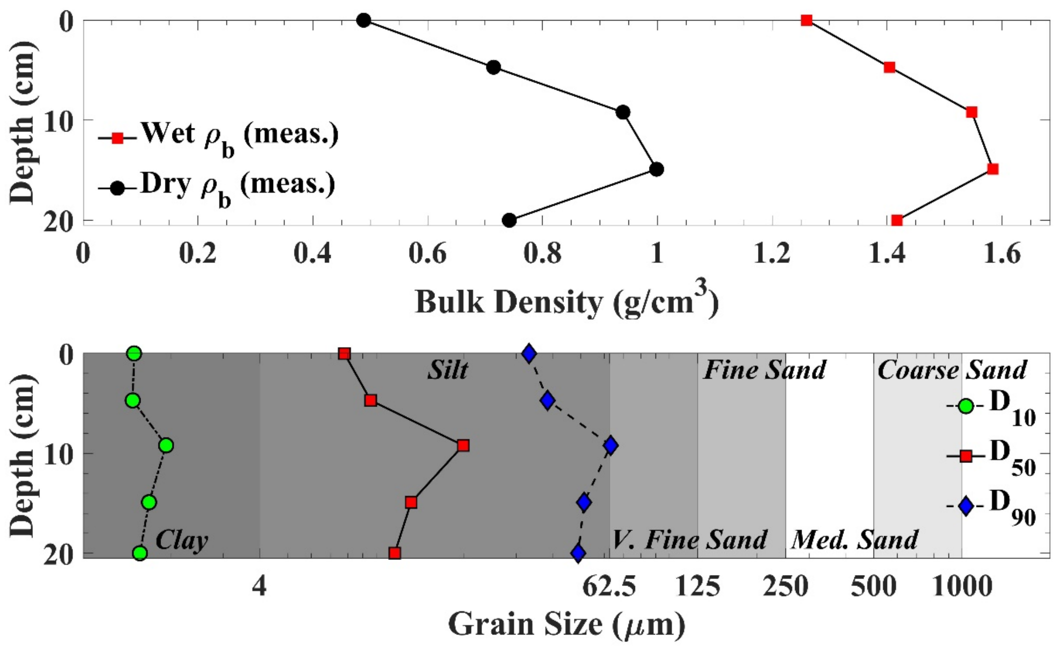

Figure 28. Physical properties of NR-SB with depth

Table 17. Physical properties and derived critical shear stresses of NR-SB

Sample Depth (cm)	Median Grain Size (µm)	Wet Bulk Density (g/cm³)	Dry Bulk Density (g/cm³)	Loss on Ignition (%)	Tau_no (Pa)	Tau_first (Pa)	Tau Crit Linear (Pa)	Tau Crit Power (Pa)	Final Critical Shear (Pa)
0.0	7.79	1.26	0.49	5.6%	0.2	0.4	0.26	0.27	0.27
4.7	9.57	1.4	0.71	4.6%	0.8	1.6	0.86	0.75	0.8
9.2	19.82	1.55	0.94	3.9%	0.8	1.6	0.92	0.72	0.8
14.9	13.16	1.58	1.00	3.8%	1.6	3.2	1.71	1.41	1.6
20.0	11.57	1.42	0.74	5.1%	0.8	1.6	0.86	0.67	0.8
Mean	12.38	1.44	0.78	4.6%	0.84	1.68	0.92	0.76	0.85

Table 18. Power law fit parameters of NR-SB

Interval	Depth Start (cm)	Depth Finish (cm)	A	n	r^2
1	0.0	4.7	8.24E-06	2.49	0.97
2	4.7	9.2	6.28E-07	2.52	0.95
3	9.2	14.9	2.98E-06	1.79	0.97
4	14.9	20	1.09E-07	2.58	0.95
5	20	24.6	3.21E-06	1.81	0.85

2.9 SED-NR-SC

Core NR-SC was collected on the Neosho River on March 10, 2020, at 5:10 p.m. Located on the outer portion of a bend in the river, collection efforts in 6 ft of water resulted in a core recovery length of 27 cm. Unlike other samples from the Neosho River, NR-SC did not present evidence of biotic activity such as worm tubes, but upon processing, worms and their pathways were intermittently uncovered. In the upper 10 cm, sandier material was mixed with olive silty material (Figure 29).

Applied shear stresses ranged from 0.1 to 12.8 Pa in five intervals. Erosion rates at a given shear stress did not exhibit a consistent trend (Figure 29). The first and fifth intervals are shown to be most erodible but critical shear stresses across the sample ranged from 0.65 Pa, peaking in interval 3 at 1.6 Pa and then decreasing again to 0.8 (Figure 30, Table 19). The changes to critical shear stresses did not follow an obvious pattern with physical properties (Figure 31). Coefficients and fit parameters linking erosion rate and shear stress suggest an excellent power law relationship between the two variables (Table 20).

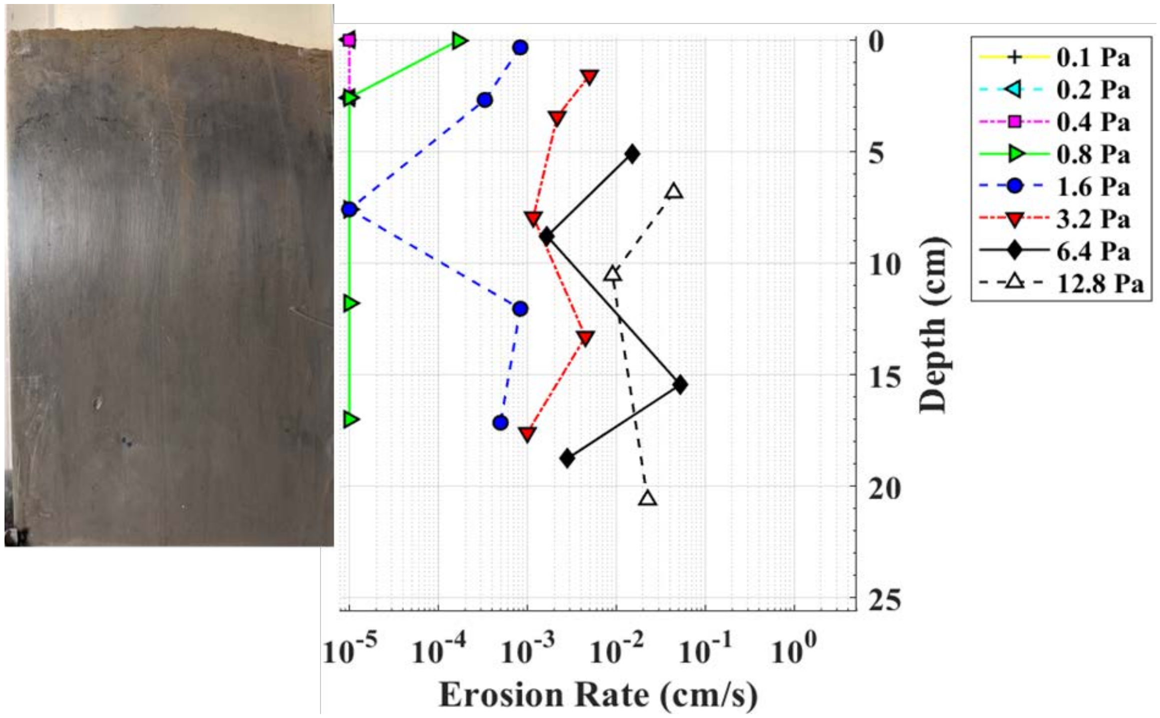

Figure 29. Photograph of Core NR-SC aligned with applied shear stresses and associated erosion rates

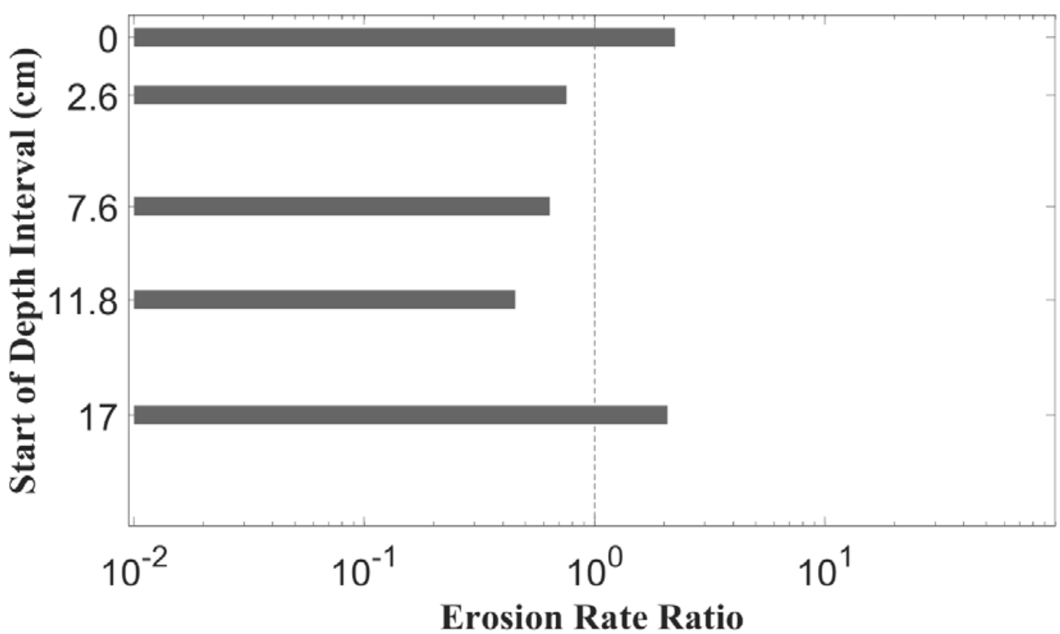

Figure 30. Intracore erosion rates of NR-SC

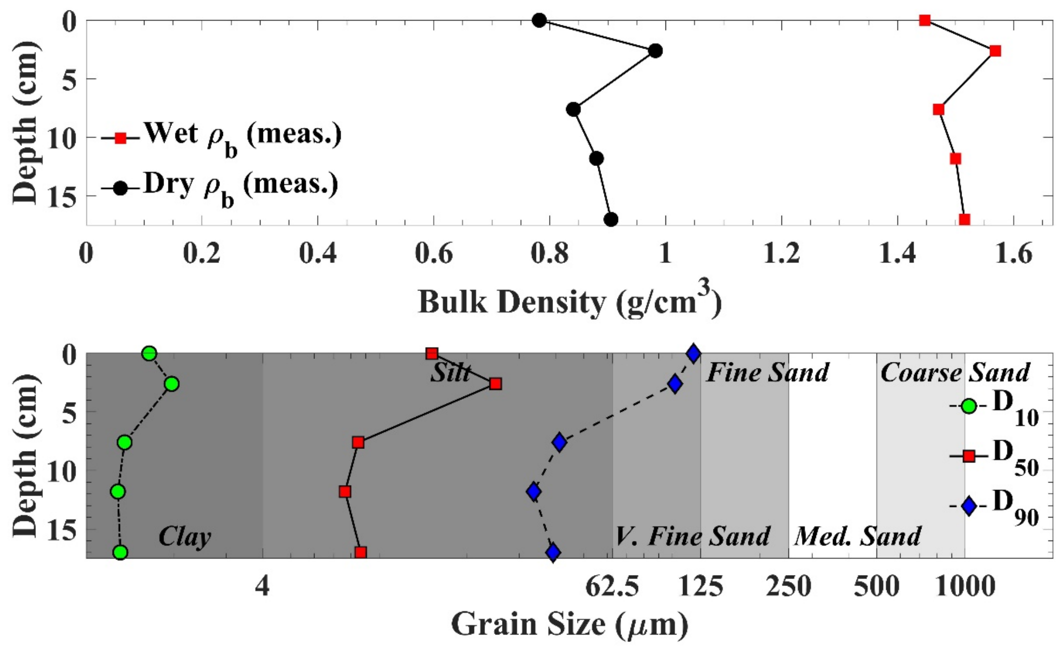

Figure 31. Physical properties of NR-SC with depth

Table 19. Physical properties and derived critical shear stresses of NR-SC

Sample Depth (cm)	Median Grain Size (µm)	Wet Bulk Density (g/cm³)	Dry Bulk Density (g/cm³)	Loss on Ignition (%)	Tau_no (Pa)	Tau_first (Pa)	Tau Crit Linear (Pa)	Tau Crit Power (Pa)	Final Critical Shear (Pa)
0.0	15.14	1.45	0.78	4.4%	0.4	0.8	0.64	0.65	0.65
2.6	24.98	1.57	0.98	4.4%	0.8	1.6	1.04	0.98	0.98
7.6	8.48	1.47	0.84	5.8%	1.6	3.2	1.74	1.41	1.6
11.8	7.65	1.5	0.88	5.1%	0.8	1.6	0.9	0.87	0.87
17.0	8.65	1.52	0.91	5.1%	0.8	1.6	0.96	0.88	0.88
Mean	12.98	1.50	0.88	5.0%	0.88	1.76	1.06	0.96	1.00

Table 20. Power law fit parameters of NR-SC

Interval	Depth Start (cm)	Depth Finish (cm)	A	n	r^2
1	0.0	2.6	1.08E-06	2.42	1.0
2	2.6	7.6	3.45E-07	2.49	0.99
3	7.6	11.8	4.26E-07	2.06	0.92
4	11.8	16.6	1.19E-07	3.11	0.99
5	17.0	21.6	1.59E-06	1.91	0.97

2.10 SED-SR-100

Core SR-100 was collected in 5 ft of water on March 10, 2020, at 11:40 a.m. SR-100 is located on the Spring River and is the northernmost sample collected. Sampling took place on the eastern bank to avoid the steep slope and rocky bed on the western bank and resulted in the collection of 43 cm of sediment. Soft, brown sediment with pockets of sand and leafy debris extended throughout the sample (Figure 32). The surface contained evidence of invertebrate activity but evidence down-core was difficult to ascertain due to the presence of leaves and plant matter. Pockets present in the photograph may be attributed to biotic activity or gas pockets of decaying matter.

Applied shear stresses ranging from 0.1 to 6.4 Pa were applied to SR-100 over 26.2 cm of the recovered sample (Figure 33). Erosion rates at a specified shear stress generally decreased with depth (Figure 36). Because of the sandy material present, sediment eroded in individual grains in bedload and "clouds" as shear stress increased. Leaves and plant matter affected the sediment by alternatively sheltering sediment below and then eroding in events as the leaves broke away from the surface. The concentration of leafy material increased with depth.

Physical properties varied with depth with density increasing and grain size changing depending on the quantity of sand present (Figure 37, Table 21). Critical shear stresses increased with depth and ranged from 0.11 to 0.41 Pa. Each interval spanned approximately 5 cm of sediment and fit parameters suggest an excellent relationship using a power law relationship between erosion rate and critical shear stress (Table 22).

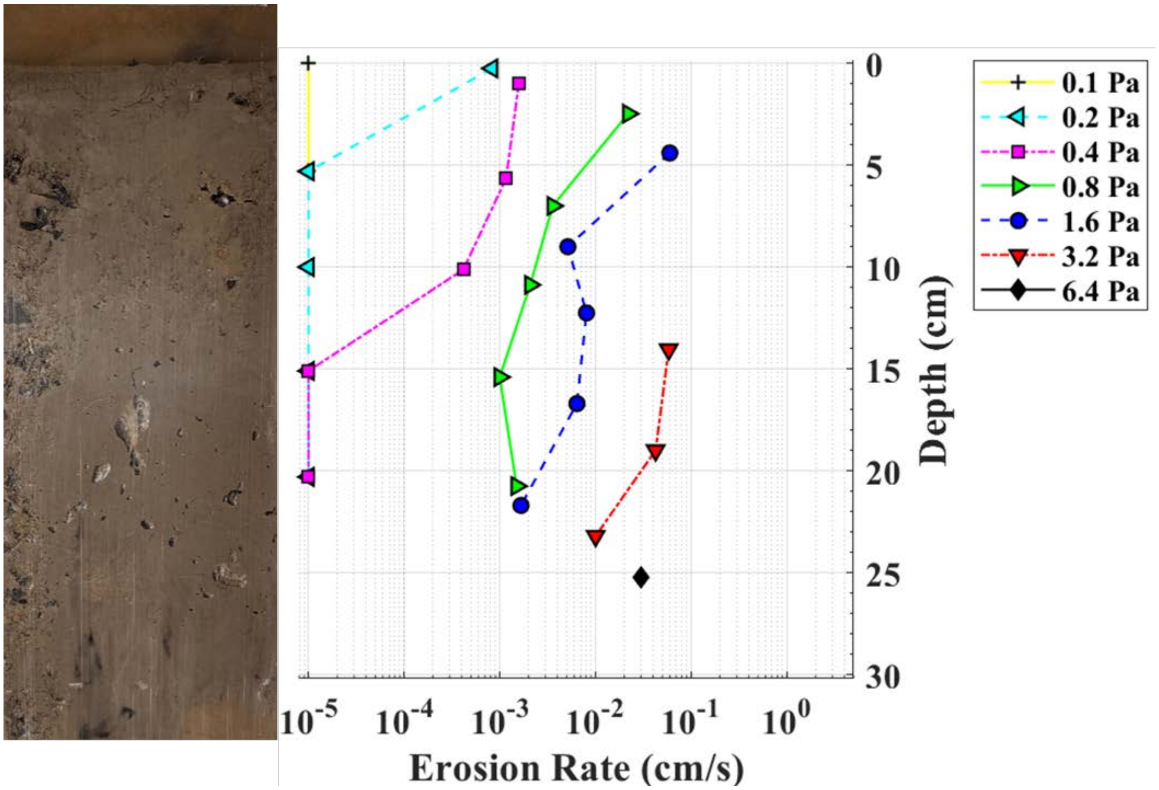

Figure 32. Photograph of Core SR-100 aligned with applied shear stresses and associated erosion rates

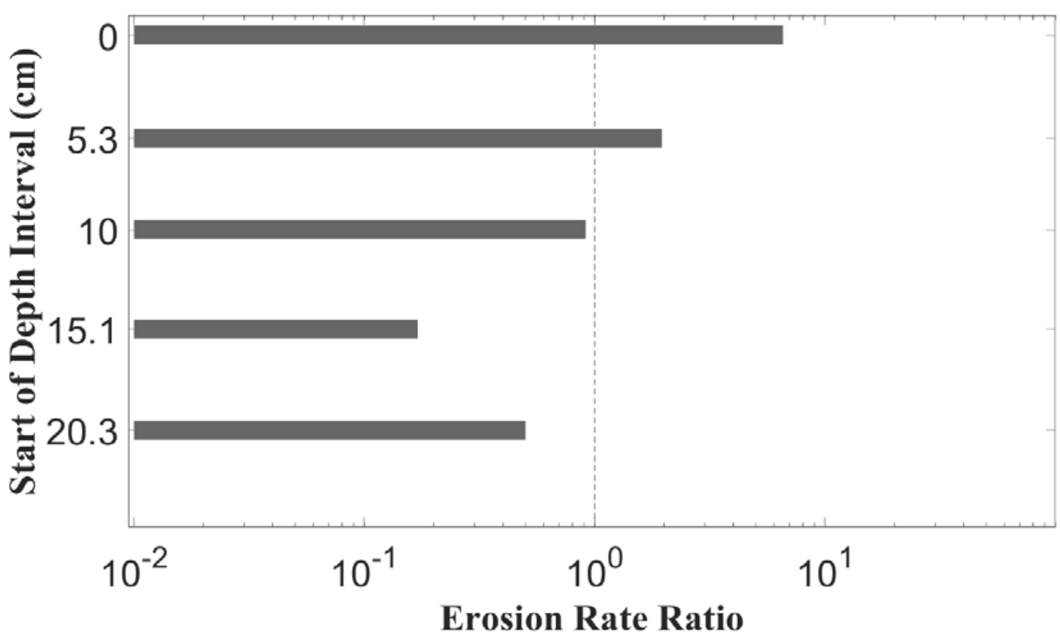

Figure 33. Intracore erosion rates for SR-100

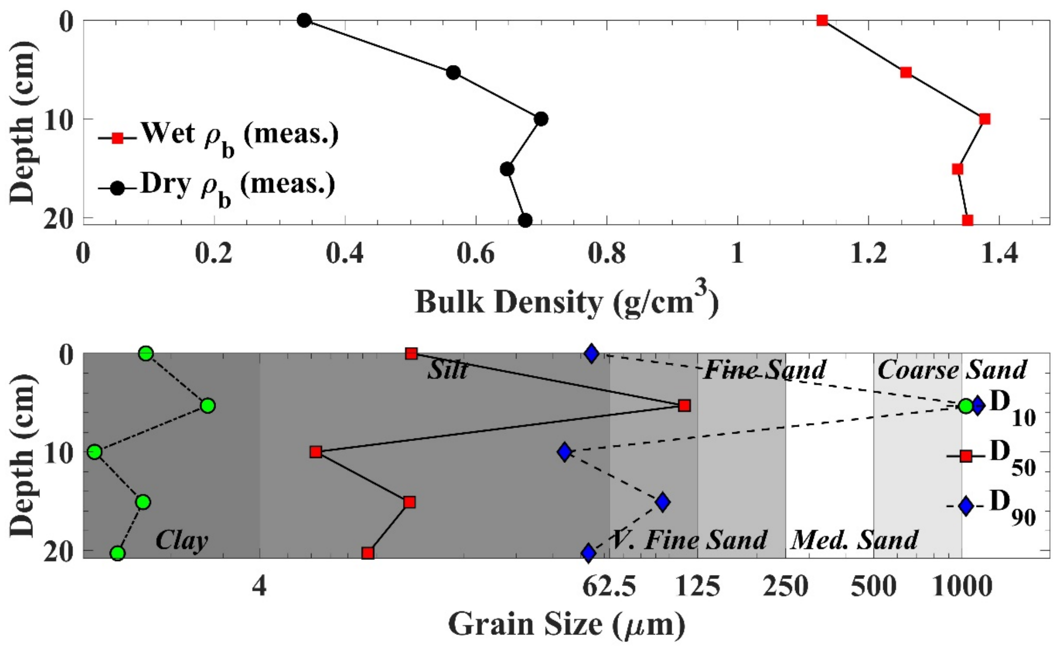

Figure 34. Physical properties of SR-100 with depth

Table 21. Physical properties and derived critical shear stresses of SR-100

Sample Depth (cm)	Median Grain Size (µm)	Wet Bulk Density (g/cm³)	Dry Bulk Density (g/cm³)	Loss on Ignition (%)	Tau_no (Pa)	Tau_first (Pa)	Tau Crit Linear (Pa)	Tau Crit Power (Pa)	Final Critical Shear (Pa)
0.0	13.2	1.13	0.34	11.6%	0.1	0.2	0.12	0.11	0.11
5.3	112.8	1.26	0.57	12.1%	0.2	0.4	0.22	0.16	0.2
10	6.22	1.38	0.7	6.8%	0.2	0.4	0.25	0.24	0.24
15.1	13	1.34	0.65	8.1%	0.4	0.8	0.45	0.41	0.41
20.3	9.37	1.35	0.68	8.2%	0.4	0.8	0.43	0.32	0.4
Mean	30.92	1.29	0.59	9.4%	0.26	0.52	0.29	0.25	0.27

Table 22. Power law fit parameters of SR-100

Interval	Depth Start (cm)	Depth Finish (cm)	A	n	r^2
1	0.0	5.3	8.79E-05	2.43	0.97
2	5.3	10.0	4.14E-05	1.92	0.86
3	10.0	15.1	1.24E-05	2.41	1.0
4	15.1	20.3	1.34E-06	3.03	0.99
5	20.3	26.2	1.03E-05	1.95	0.93

2.11 SED-SR-114

Core SR-114 was collected on the Spring River on March 10, 2020, at 12:30 p.m. Located on the western bank in 5 ft of water, the bed allowed easy penetration and only one attempt was needed to recover 41 cm of sediment. The sample contained a variable mixture of organic matter, biotic activity, and sandy regions amid the predominantly silty material. A thin surface layer less than 1 cm of lighter, unconsolidated sediment was present over the olive colored mixture of silt, sand, and clay.

Applied shear stresses aligned with the core SR-114 ranged from 0.1 to 3.2 Pa in five intervals (Figure 35). Responses to individual shear stresses did not follow a consistent pattern relative to depth but overall erodibility decreased with depth (Figure 35, Figure 36). Resulting critical shear stresses determined from the power law fit and *tau_no* values ranged from 0.2 to 0.4 Pa. The under-prediction of critical shear stress by the power law fit method is attributed to the volume of organic matter in the core that can alter erosion mechanisms. The organic matter at times shielded the bed from erosion until giving way in larger events, slowing the rate of erosion measured in the 10-minute period of applied shear stress. An example of the woody debris found in the core is shown in Figure 38. However, the fit parameters still suggest that a power law relationship provides a good relationship overall for erosion rate and applied shear stress once the critical shear stress has been met (Table 24). The sandy sediment eroded in individual grains and streams of grains around the organic matter and left uneven surfaces of the firmer silt and clay mixtures. Erodibility trends correlated with the increase in density and grain size distributions. The noted trends were potentially modulated by the amount of sandy material in the interval (Figure 37, Table 23).

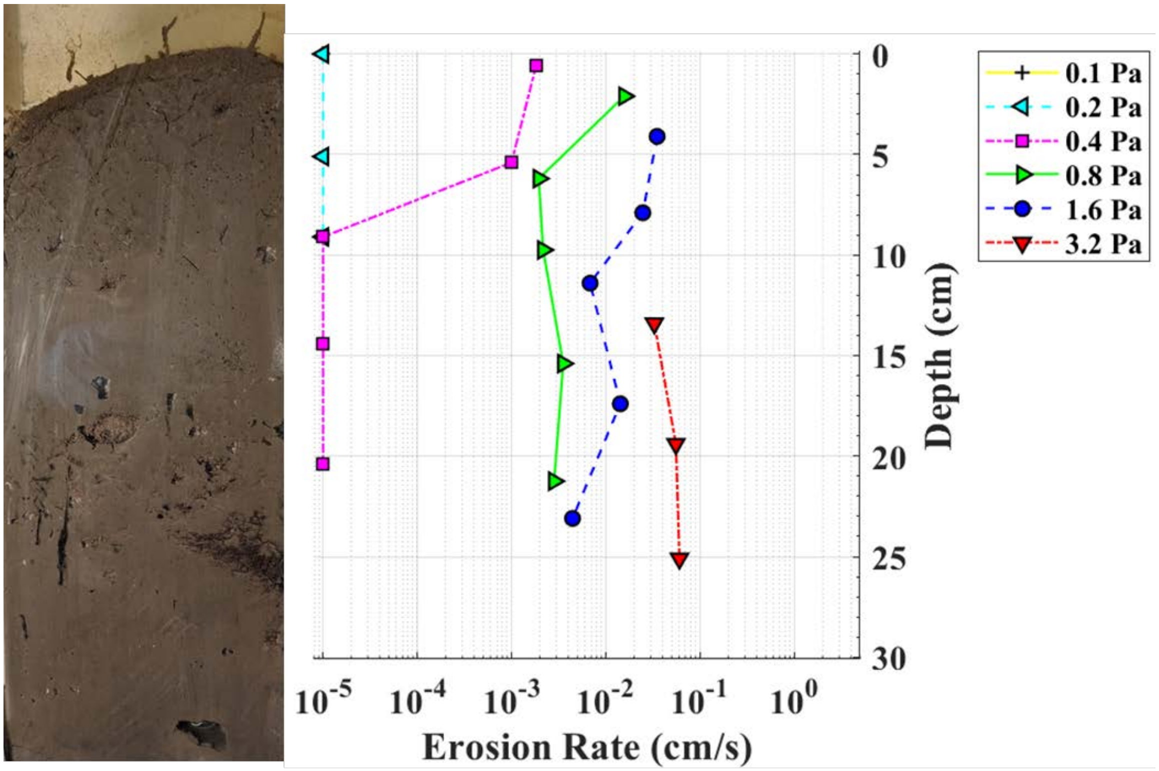

Figure 35. Photograph of Core SR-114 aligned with applied shear stresses and associated erosion rates

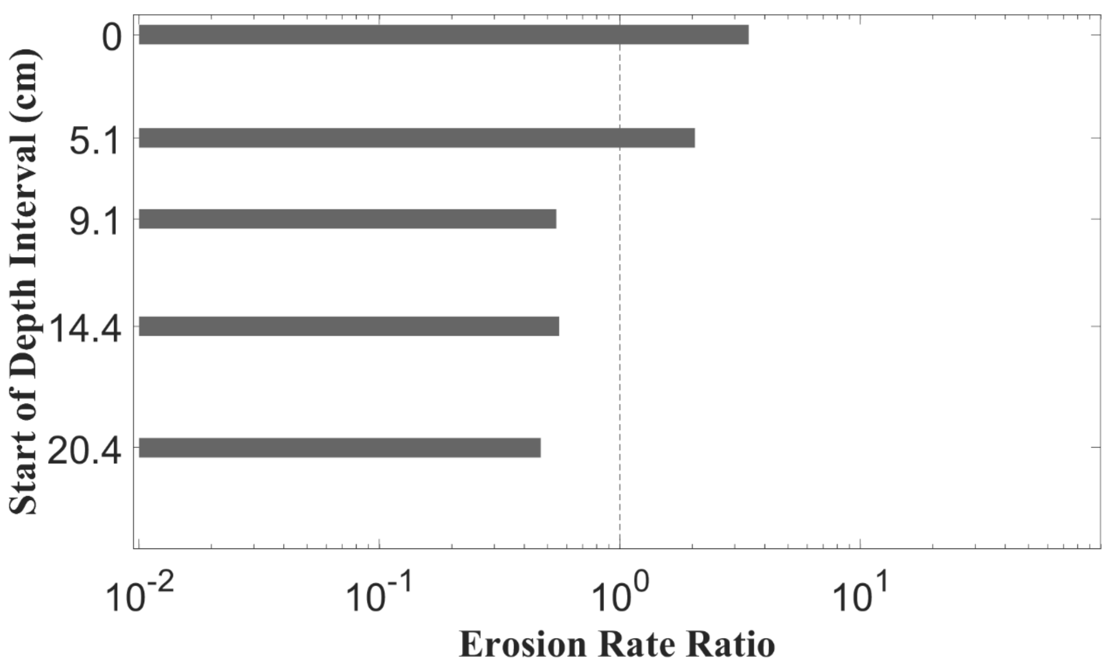

Figure 36. Intracore erosion rates of SR-114

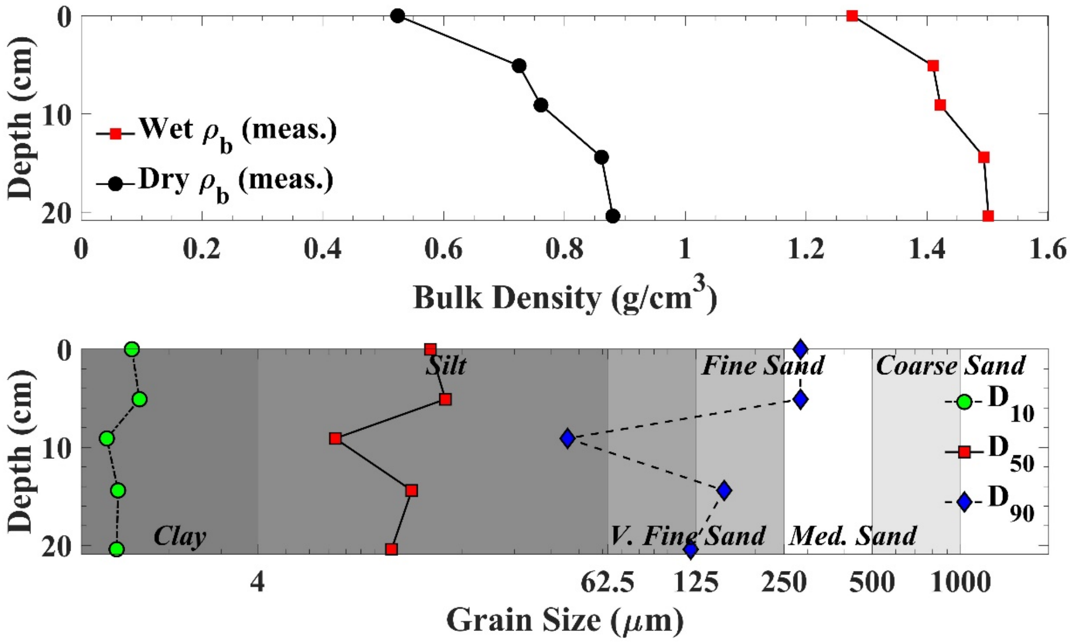

Figure 37. Physical properties of SR-114 with depth

Figure 38. Wood chips found in SR-114

Table 23. Physical properties and derived critical shear stresses of SR-114

Sample Depth (cm)	Median Grain Size (µm)	Wet Bulk Density (g/cm³)	Dry Bulk Density (g/cm³)	Loss on Ignition (%)	Tau_no (Pa)	Tau_first (Pa)	Tau Crit Linear (Pa)	Tau Crit Power (Pa)	Final Critical Shear (Pa)
0.0	15.53	1.28	0.52	6.2%	0.2	0.4	0.22	0.18	0.2
5.1	17.47	1.41	0.72	4.7%	0.2	0.4	0.23	0.21	0.21
9.1	7.36	1.42	0.76	5.8%	0.4	0.8	0.42	0.34	0.4
14.4	13.42	1.49	0.86	4.5%	0.4	0.8	0.42	0.33	0.4
20.4	11.45	1.5	0.88	4.9%	0.4	0.8	0.42	0.35	0.4
Mean	13.05	1.42	0.75	5.2%	0.32	0.64	0.34	0.28	0.32

Table 24. Power law fit parameters of SR-114

Interval	Depth Start (cm)	Depth Finish (cm)	A	n	r^2
1	0.0	5.1	1.8E-05	2.94	0.93
2	5.1	9.1	1.43E-05	2.63	0.95
3	9.1	14.4	3.49E-06	2.72	0.95
4	14.4	20.4	2.83E-06	2.99	0.93
5	20.4	26.1	2.58E-06	2.89	0.93

2.12 SED-SR-TB

Core SR-TB was collected on March 10, 2020, at 11:10 a.m. in an area north of Highway 60 in the Spring River. The 32 cm long sample was collected on the second attempt after stiff material resisted initial efforts to produce a sufficient recovery length. Recovered sediment contained an unconsolidated surface layer with evidence of biotic activity such as excavation mounds seen in Figure 39. Sediment appeared to have a homogenous, fine texture, with varied color ranging from light gray to olive gray, and contained scattered gas or feeding voids.

Shear stresses applied to SR-TB produced erosion rates that decreased with depth for each shear value (Figure 40). The resulting computed critical shear stresses increased with depth, ranging from 0.2 to 1.73 Pa and correlated to an increase in sediment density (Table 25, Figure 45). While density varied with depth, the particle size distributions remained constant throughout the core (Figure 42).

The surface eroded in clouds and streams of individual grains and small (<0.5 mm) pieces of the surface. During the first interval, an event occurred at the application of 1.6 Pa resulting in a 0.7 cm layer of sediment eroding in less than 10 seconds. After the first interval, sediment eroded sporadically in fractured pieces of the surface initialized around invertebrate structures and intermittent leafy debris. Parameters relating shear stress and erosion rates suggest a good correlation using a power law fit between the two variables (Table 26).

Figure 39. Evidence of biotic activity on surface of SR-TB

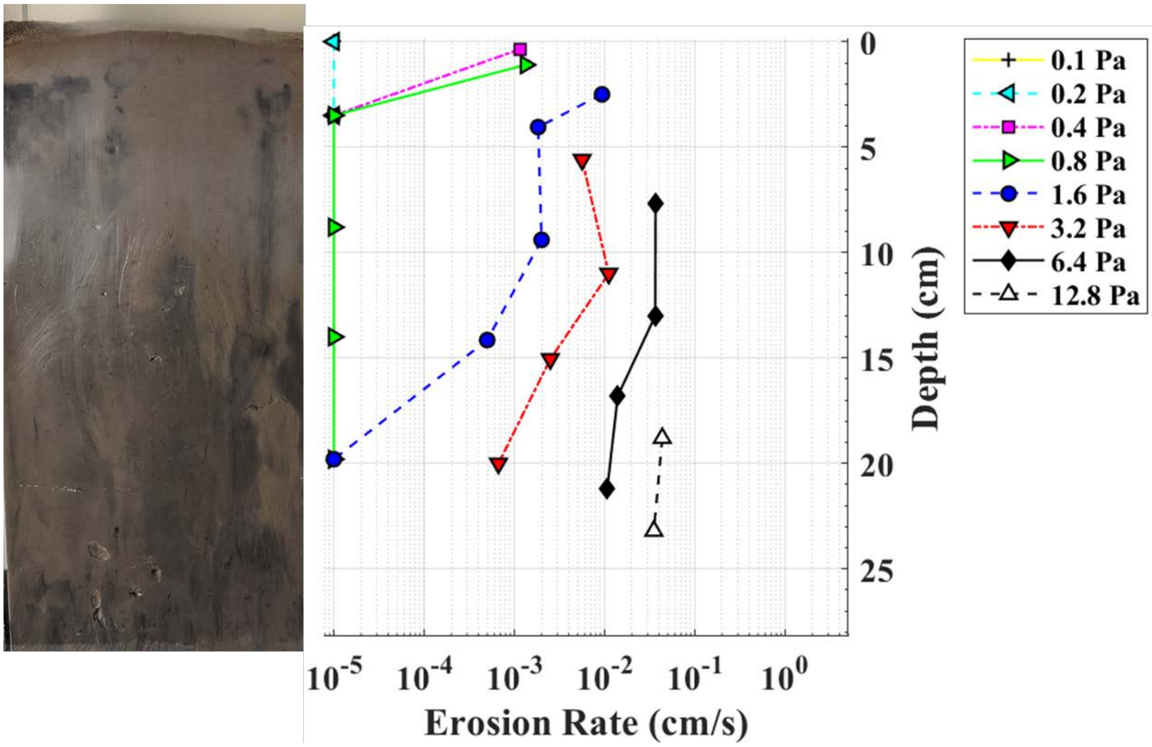

Figure 40. Photograph of Core SR-TB aligned with applied shear stresses and associated erosion rates

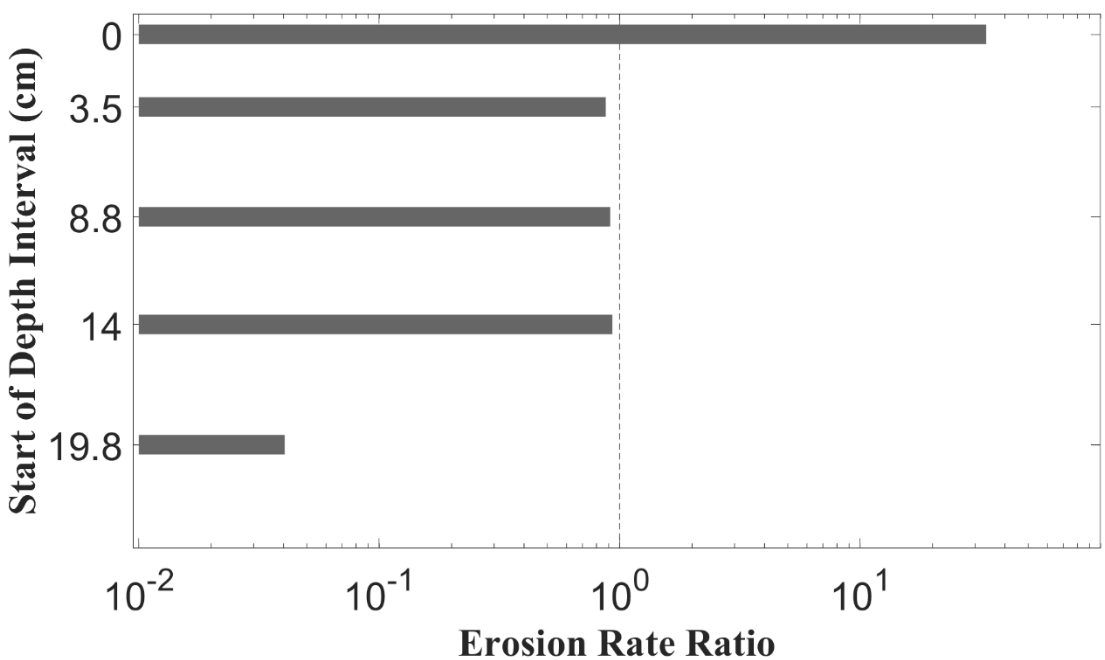

Figure 41. Intracore erosion rate of SR-TB

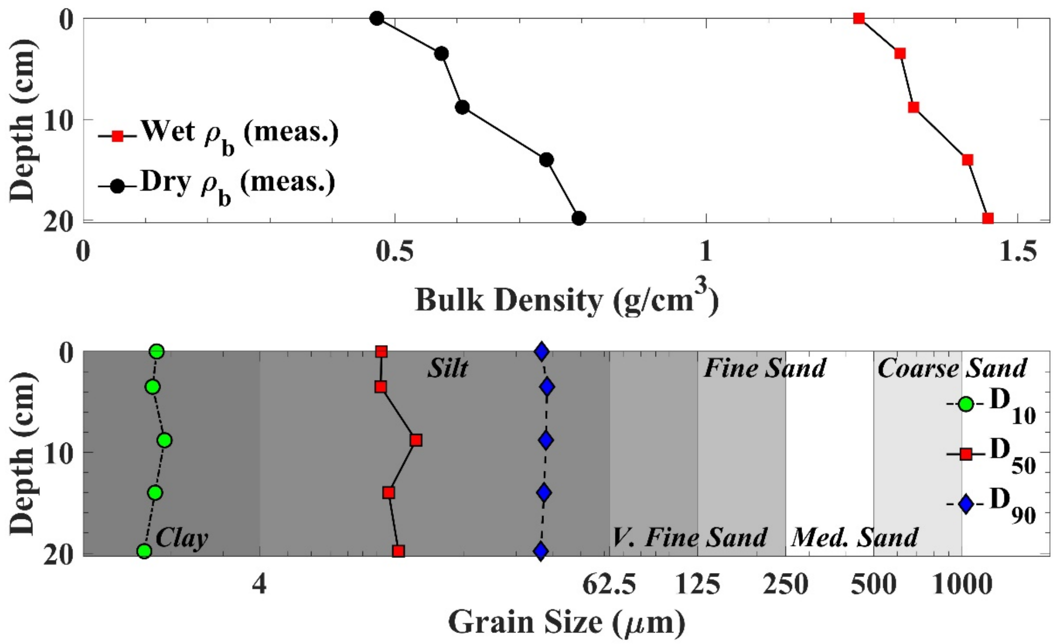

Figure 42. Physical properties of SR-TB with depth

Table 25. Physical properties and derived critical shear stresses of SR-TB

Sample Depth (cm)	Median Grain Size (µm)	Wet Bulk Density (g/cm³)	Dry Bulk Density (g/cm³)	Loss on Ignition (%)	Tau_no (Pa)	Tau_first (Pa)	Tau Crit Linear (Pa)	Tau Crit Power (Pa)	Final Critical Shear (Pa)
0.0	10.42	1.24	0.47	6.3%	0.2	0.4	0.22	0.18	0.2
3.5	10.37	1.31	0.58	5.8%	0.8	1.6	0.85	0.72	0.8
8.8	13.67	1.33	0.61	5.6%	0.8	1.6	0.84	0.69	0.8
14	11.03	1.42	0.74	5.0%	0.8	1.6	0.96	0.86	0.86
19.8	11.92	1.45	0.8	4.8%	1.6	3.2	1.84	1.73	1.73
Mean	11.48	1.35	0.64	5.5%	0.84	1.68	0.94	0.84	0.88

Table 26. Power law fit parameters of SR-TB

Interval	Depth Start (cm)	Depth Finish (cm)	A	n	r^2
1	0.0	3.5	2.99E-05	2.05	0.9
2	3.5	8.8	4.09E-07	2.78	0.96
3	8.8	14	4.01E-07	2.85	0.95
4	14	19.8	6.4E-07	2.35	0.99
5	19.8	24.2	1.4E-08	3.11	0.97

2.13 SED-TC-DS

Core TC-DS was collected on March 11, 2020, at 2:30 p.m. from Tar Creek. Relative to TC-US, TC-DS is downstream closer to the Neosho River. TC-DS was collected in 8 ft of water in the center of the channel. Soft, easy to penetrate material containing leaves and twigs was collected resulting in a recovery length of 44 cm. Recovered sediment consisted of dark gray silt with pockets of leaves throughout and voids in the upper 10 cm.

Shear stresses ranging from 0.1 to 0.64 Pa were applied to the sediment core shown in Figure 43. Erosion rates were greatest at the surface, decreasing with depth but stabilizing below 20 cm (Figure 43, Figure 44). The surface responded to the lowest applied shear (0.1 Pa), which resulted in a critical shear stress determination of 0.05 Pa. The material at the surface was very soft, unconsolidated silt. Further down-core, density increased while particle size distributions stayed relatively constant (Figure 48, Table 27). Erosion in the first two intervals occurred evenly and consistently as loose particles were suspended. As depth increased, erosion was affected by the presence of leafy debris and changes in density resulting in more sporadic erosion events. A power law relationship between erosion rate and shear stress is applicable as shown by the high r^2 values and coefficients that fall into ranges typical of cohesive sediment (Table 28).

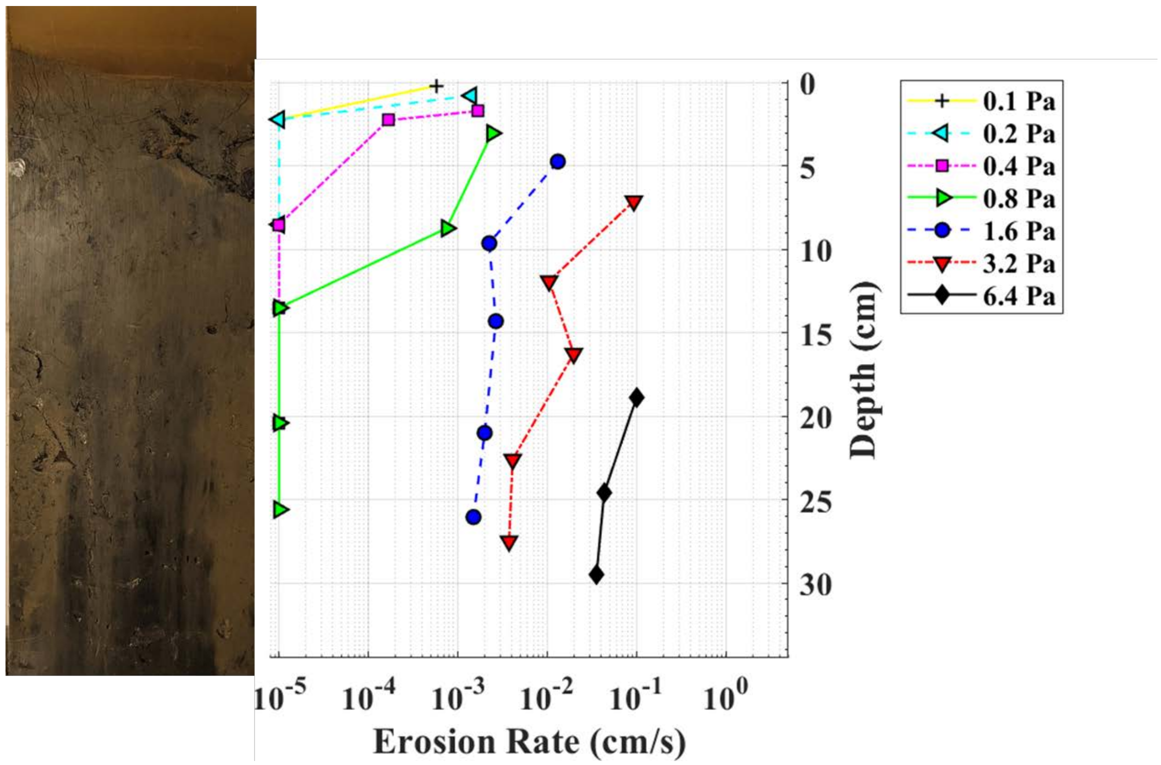

Figure 43. Photograph of Core TC-DS aligned with applied shear stresses and associated erosion rates

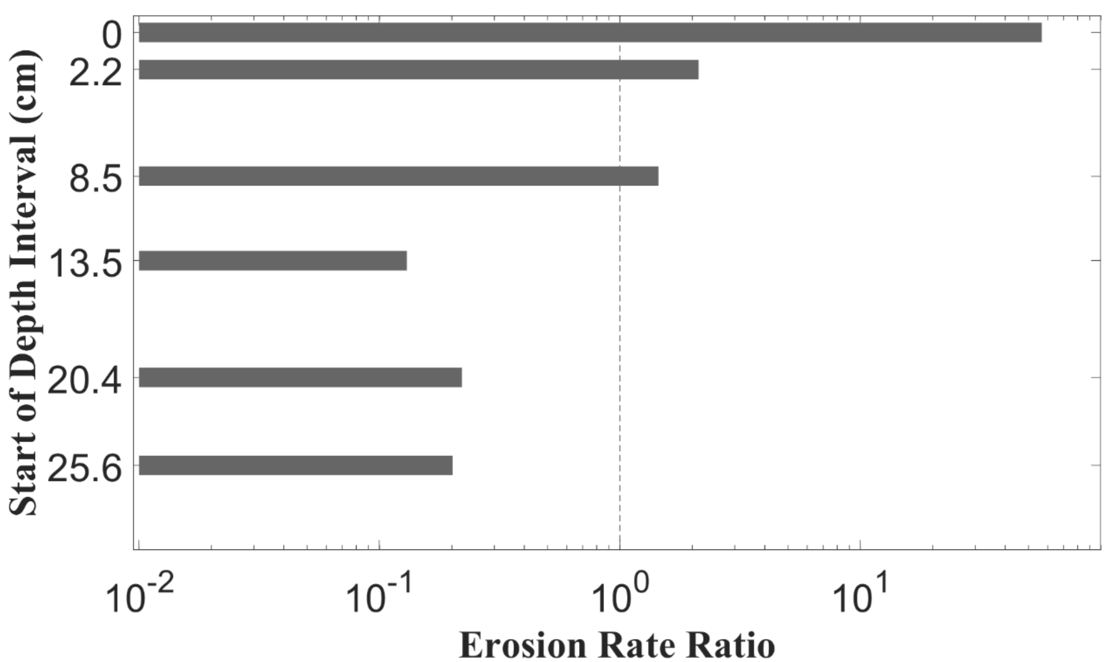

Figure 44. Intracore erosion rates of TC-DS

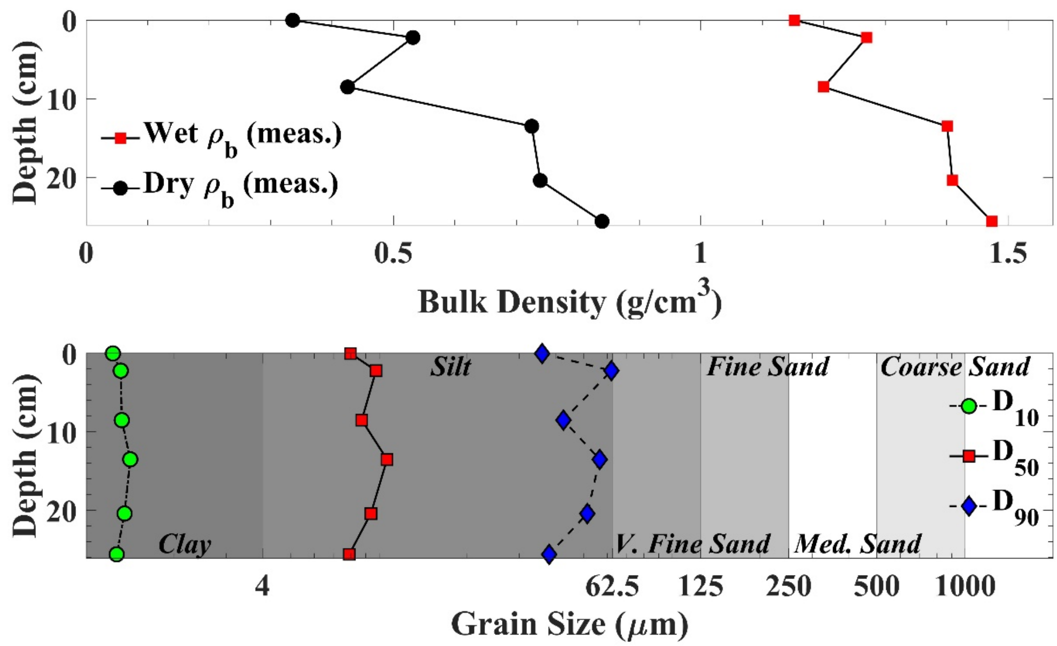

Figure 45. Physical properties of TC-DS with depth

Table 27. Physical properties and derived critical shear stresses of TC-DS

Sample Depth (cm)	Median Grain Size (µm)	Wet Bulk Density (g/cm³)	Dry Bulk Density (g/cm³)	Loss on Ignition (%)	Tau_no (Pa)	Tau_first (Pa)	Tau Crit Linear (Pa)	Tau Crit Power (Pa)	Final Critical Shear (Pa)
0.0	7.99	1.15	0.34	8.0%	0.05	0.1	0.06	0.04	0.05
2.2	9.76	1.27	0.53	7.7%	0.2	0.4	0.32	0.32	0.32
8.5	8.72	1.2	0.43	8.7%	0.4	0.8	0.46	0.4	0.4
13.5	10.64	1.4	0.72	5.8%	0.8	1.6	0.83	0.71	0.8
20.4	9.37	1.41	0.74	5.8%	0.8	1.6	0.84	0.73	0.8
25.6	7.91	1.47	0.84	5.3%	0.8	1.6	0.86	0.76	0.8
Mean	9.07	1.32	0.60	6.9%	0.51	1.02	0.56	0.49	0.53

Table 28. Power law fit parameters of TC-DS

Interval	Depth Start (cm)	Depth Finish (cm)	A	n	r^2
1	0.0	2.2	3.49E-04	1.42	0.82
2	2.2	8.5	3.17E-06	3.01	0.99
3	8.5	13.5	4.07E-06	2.3	0.97
4	13.5	20.4	1.46E-07	3.32	0.97
5	20.4	25.6	4.0E-07	2.78	0.95
6	25.6	30.5	3.77E-07	2.75	0.96

2.14 SED-TC-US

Core TC-US was collected on March 11, 2020, at 2:00 p.m. TC-US is located upstream of TC-DS in Tar Creek. Sampling efforts produced 44 cm of sediment without the need for added force via use of a post-hammer. Root structures along the bank necessitated multiple attempts before successful collection was achieved. A 2 cm layer of unconsolidated, light colored, oxidized silt blanketed darker sediment containing voids, leaves, and sticks.

Shear stresses, ranging from 0.1 to 6.4 Pa were applied to TC-US over six intervals (Figure 46). The unconsolidated surface layer was shown to be the most erodible, consistent with many other cores processed in this study (Figure 47). As depth increased, erodibility relative to the core average varied as did grain size and density (Figure 47, Figure 48, Table 29). The unconsolidated and sandier sections of the core eroded in streams of particles or clouds of suspended sediment depending on shear stress magnitude. Finer sediment regimes tended to erode in larger pieces or clumps unevenly across the surface.

Derived critical shear stresses varied from 0.17 to 0.8 Pa from the first to the sixth interval. Parameters defining the relationship between erosion rate and shear stress indicate a good power law relationship between the two variables (Table 30).

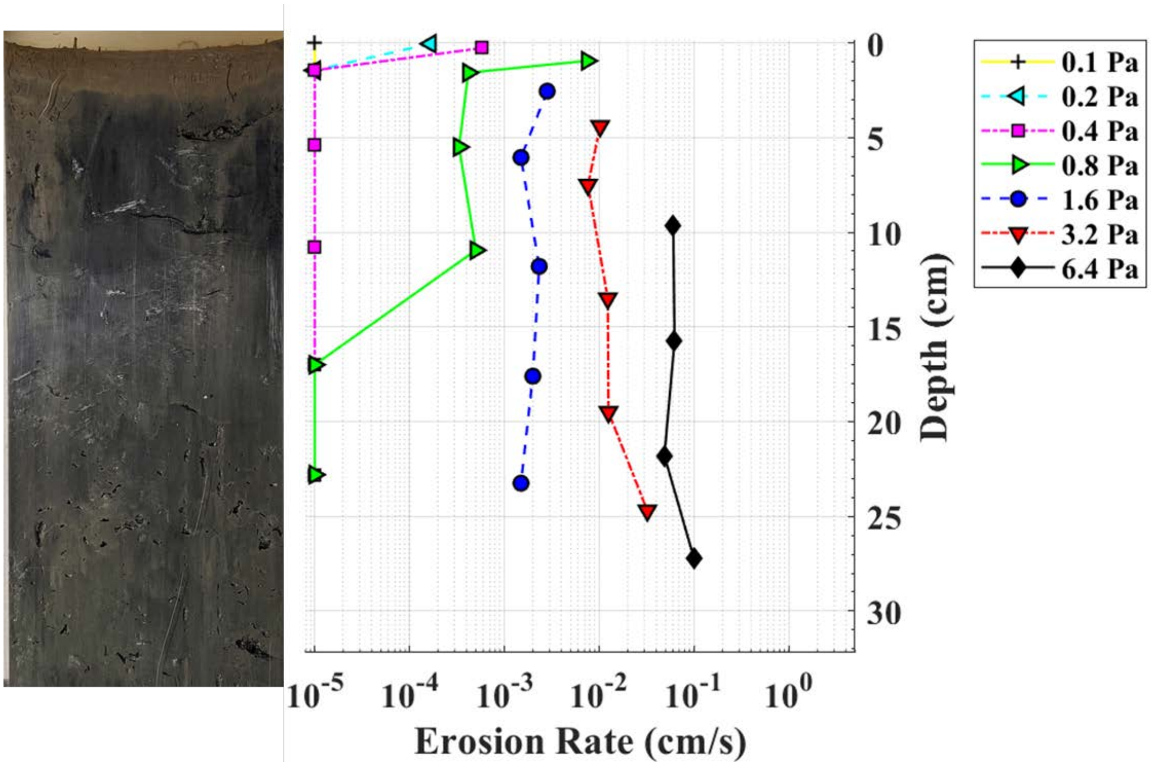

Figure 46. Photograph of Core TC-US aligned with applied shear stresses and associated erosion rates

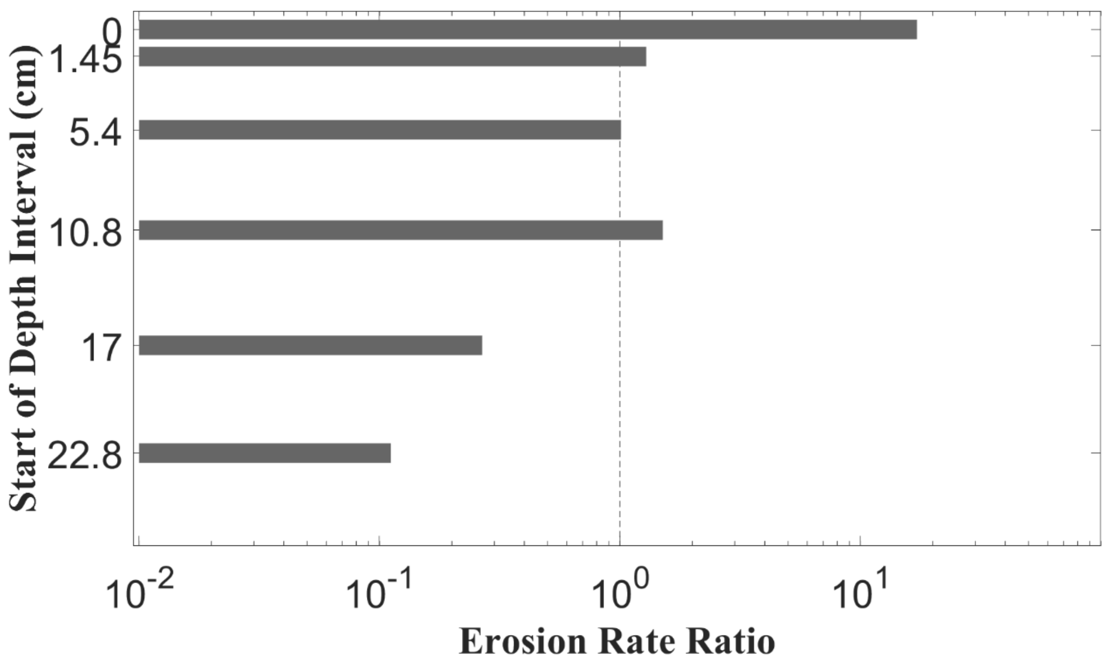

Figure 47. Intracore erosion rates for TC-US

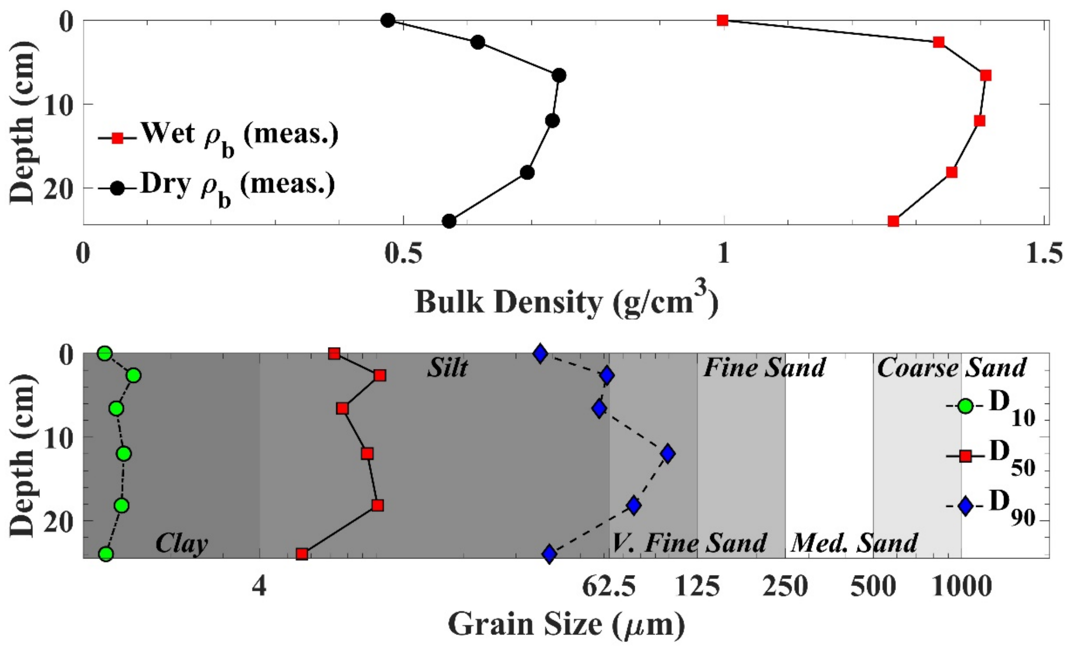

Figure 48. Physical properties of TC-US with depth

Table 29. Physical properties and derived critical shear stresses of TC-US

Sample Depth (cm)	Median Grain Size (µm)	Wet Bulk Density (g/cm³)	Dry Bulk Density (g/cm³)	Loss on Ignition (%)	Tau_no (Pa)	Tau_first (Pa)	Tau Crit Linear (Pa)	Tau Crit Power (Pa)	Final Critical Shear (Pa)
0.0	7.2	1	0.48	48.1%	0.1	0.2	0.16	0.17	0.17
1.45	10.31	1.34	0.62	5.8%	0.4	0.8	0.5	0.47	0.47
5.4	7.68	1.41	0.74	6.1%	0.4	0.8	0.52	0.52	0.52
10.8	9.34	1.4	0.73	6.5%	0.4	0.8	0.48	0.45	0.45
17.0	10.13	1.36	0.69	9.0%	0.8	1.6	0.84	0.71	0.8
22.8	5.58	1.26	0.57	11.6%	0.8	1.6	0.86	0.78	0.8
Mean	8.37	1.30	0.64	14.5%	0.48	0.97	0.56	0.52	0.54

Table 30. Power law fit parameters of TC-US

Interval	Depth Start (cm)	Depth Finish (cm)	A	n	r^2
1	0.0	1.45	2.55E-05	2.61	0.97
2	1.45	5.4	2.08E-06	2.51	0.99
3	5.4	10.8	1.66E-06	2.49	1.0
4	10.8	17.0	2.58E-06	2.44	1.0
5	17.0	22.8	2.79E-07	3.0	0.96
6	22.8	28.7	7.23E-08	3.53	0.96

2.15 SED-ER-640

No sample was recovered at ER-640, located west of the Highway 10 Bridge. The sediment bed near ER-640 was known to contain substantial portions of gravel and rock that would limit the effectiveness of collecting a sample.

2.16 SED-NR-HB

No sample was collected at ER-640. Multiple attempts were made to collect a sample, but no viable sample was produced. Despite ample penetration, recovered material was either not intact or absent in recovery of the core barrel. Unfavorable weather conditions of high winds and waves resulted in the field team aborting further attempts.

3 SUMMARY

Integral conducted a SEDflume analysis on 14 sediment cores collected from waterways connected to Grand Lake o' the Cherokees in northeast Oklahoma. The goal of this work was to characterize the erosion rates, critical shear stresses for erosion, and physical properties of the bedded sediment within the Elk River, Neosho River, Spring River, and Tar Creek. The SEDflume study results provide a baseline for the development of site-specific sediment parameters to support transport studies and bolster the conceptual understanding of dynamics within the system.

The cores were subjected to shear stresses ranging from 0.1 to 12.8 Pa to determine erosion rates as a function of shear stress and depth. In addition, cores were subsampled during the analysis to determine sediment bulk density, loss on ignition, and particle size distributions related to each shear stress interval. Critical shear stresses were calculated from the measured erosion rate data and ranged from less than 0.1 Pa in surface sediment to 2.46 Pa in deeper bedded sediment.

To better visualize the relative erodibility of the sediment throughout the system, the ratio of the mean erosion rate of each core (core vertically averaged erosion rate) to the average mean erosion rate of all cores at the site was calculated and plotted in Figure 49. The dashed line denotes a site-wide average erosion rate ratio of 1.0 Pa. A value above this line generally means that the core is more susceptible to erosion than those cores below. A similar figure to compare individual intervals between cores is also provided in Figure 50.

A few trends of note were observed. Surface intervals were the most erosive due to the presence of an unconsolidated layer up to 3 cm thick (see green bars in Figure 50). Below the "fluff" layer, sediment was pitted and pockmarked from the invertebrates present, and the sediment tended to erode in clumps nucleated by the biotic structures. The presence of leaves, twigs, stems, and worm burrows also influenced the sediment erosion by breaking away and drawing material away from the surface. Similar properties were observed in some cores collected from the same waterway. This was most obvious in the Tar Creek samples, TC-US and TC-DS. However, samples from the Neosho River exhibited a wider range of erodibility and sediment properties. Samples such as NR-FG, taken near the fairgrounds and in an area known to have wet and dry cycles, were less erosive than samples from further downriver such as NR-CB or NR-202. While predominantly silt, the presence of some fine sand in cores such as NR-CB and the Spring River samples may influence erodibility as it moves through the system.

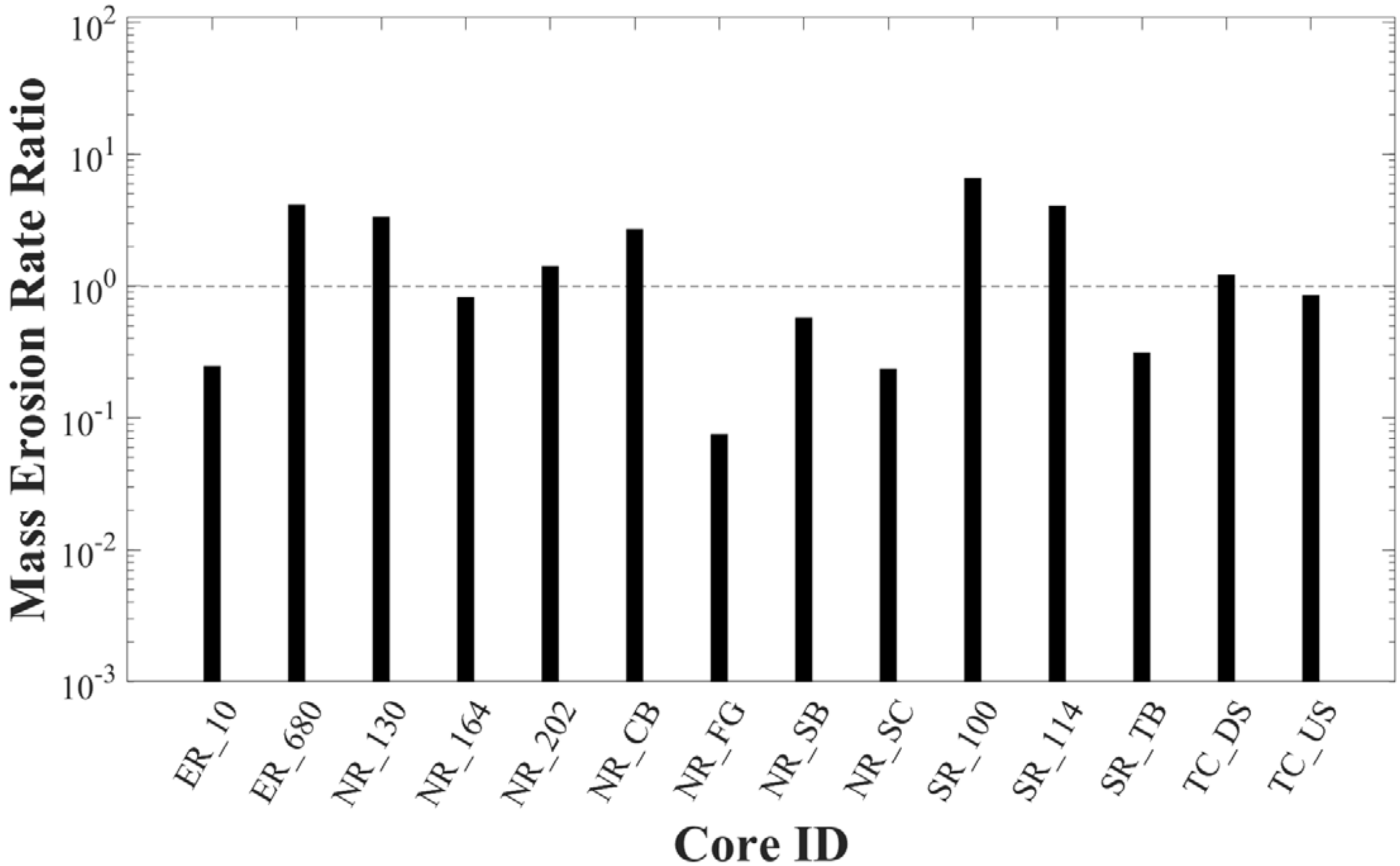

Figure 49. Intercore erosion rate ratios: Depth-averaged core erosion rates compared to the site-wide average erosion rates.

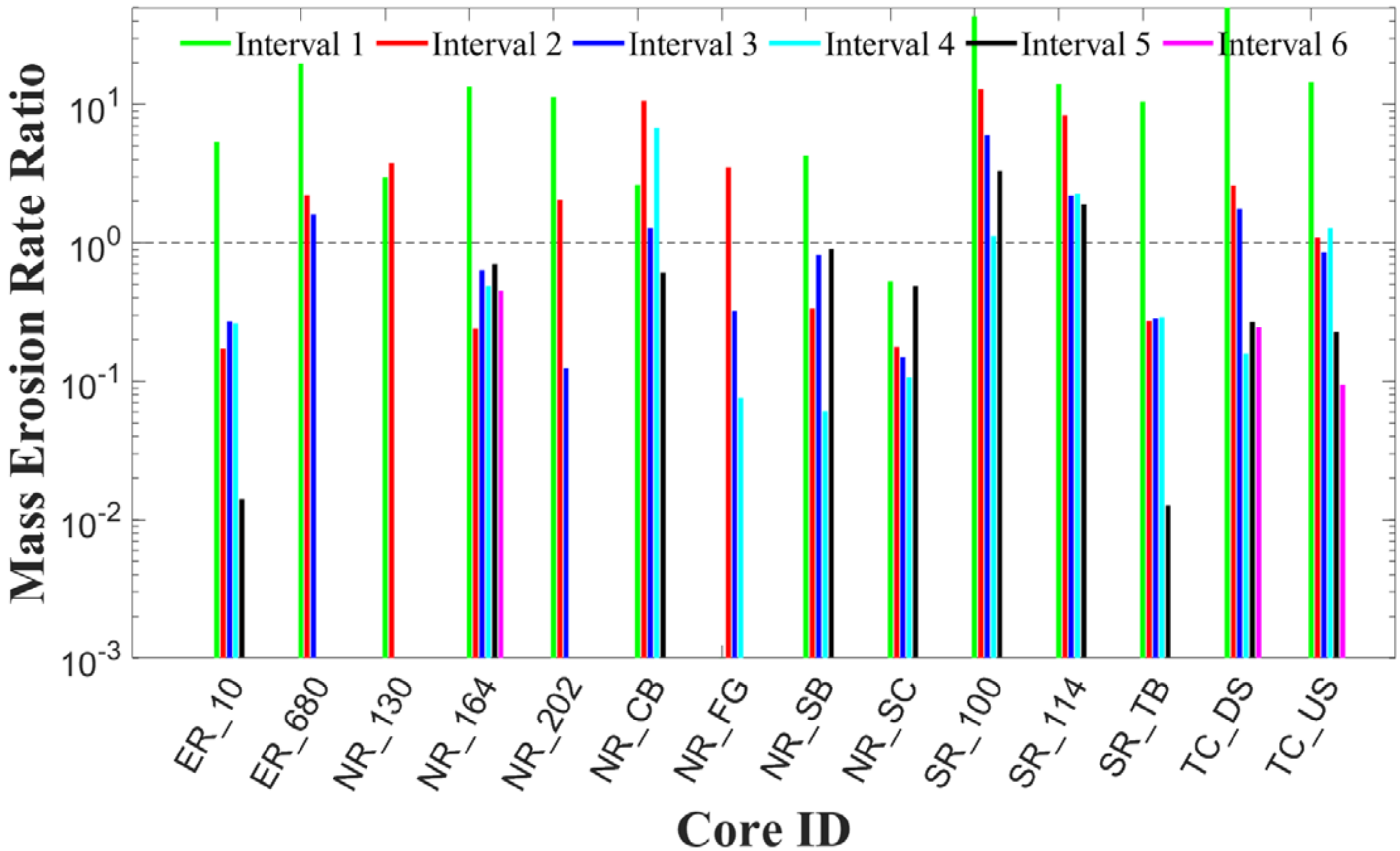

Figure 50. Intracore erosion rate by interval for each core.

4 REFERENCES

ASTM. 2007. *Annual book of ASTM standards.* Vol. 04.08, Soil and Rock (I): D420–D5611. ASTM International, West Conshohocken, PA. pp. 314–315.

Håkanson, L., and M. Jansson. 1983. *Principles of Lake Sedimentology*. 320 pp. Berlin–New York: Springer-Verlag. ISBN 3–540 (Berlin) 0–387 (New York)–12645–7. DM 98, *Int. Revue ges. Hydrobiol.*

Jepsen, R., J. Roberts, and W. Lick. 1997. Effects of bulk density on sediment erosion rates. *Water Air Soil Pollut.* 99:21–31.

McNeil, J., C. Taylor, and W. Lick. 1996. Measurements of erosion of undisturbed bottom sediments with depth. *J. Hydr. Engr.* 122(6):316–324.

Roberts, J., R. Jepsen, D. Gotthard, and W. Lick. 1998. Effects of particle size and bulk density on erosion of quartz particles. *J. Hydr. Engr.* 124(12):1261–1267.

Appendix D
Suspended Sediment Concentration Measurements

SSC/Bedload Sampling

Site: Neosho @ Commerce

Staff: TJK, BJT, LLR Date: 8/14/2019 Time: 10:57

Weather: Sunny, clear, still Stream Width: 550'

Stream Name: Neosho River Gage Reading: 12.8' Discharge: 15,500 CFS

USGS Station: 07185000 Mean Flow Vel: 3 FPS WSE: 761.9'

Max Water Depth: 15' Datum: NAVD88 Stage ☐Rising ☑Falling ☐Steady ☐Peak

Temperature: Air: 87 Water: ______

Suspended Sediment Sampling

Time	*Sample No.*	*Station*
15:06	24.3A,24.3B	24.3
15:23	72.9A,72.9B	72.9
15:31	121.5A,121.5B	121.5
15:39	170.1A,170.1B	170.1
15:51	218.7A,218.7B	218.7
16:05	267.3A,267.3B	267.3
16:17	315.9A,315.9B	315.9
16:28	364.5A,364.5B	364.5
16:48	413.1A,413.1B	413.1
16:48	461.7A,461.7B	461.7
17:03	520.3A,520.3B	520.3

Method: Cable and crane off bridge

Type of Sampler Used: D-74

Nozzle Size: 1/4"

Transit Rate: 1.2 fps

No. of SSC Samples Collected: 22

Notes:

Bedload Sediment Transport Sampling

Sampler: Helley-Smith Time: 10:57 No. Samples: 48

Stations: 14, 42, 70*, 98, 126, 154, 182, 210*, 238, 266, 294, 322, 350*, 378, 406, 434, 462, 490*, 518, 546 Bridge ~10 feet below gage

Notes: (SEWI, *=MEWI x 5)

Sample times 1-10 min; Collected few grains of sand, occasional gravel; not measurable

General Remarks:

SSC/Bedload Sampling

Site: Elk River at Hwy 43

Staff: TJK, BJT, LLR Date: 8/15/2019 Time: 09:18

Weather: Sunny, still Stream Width: 300'

Stream Name: Elk River Gage Reading: 4.04' Discharge: 537 CFS

USGS Station: 07189000 Mean Flow Vel: 3.9 FPS WSE: 764.65'

Max Water Depth: 6' Datum: NGVD29 Stage: ☐ Rising ☑ Falling ☐ Steady ☐ Peak

Temperature: Air: 80 Water: ______

Suspended Sediment Sampling

Time	*Sample No.*	*Station*
09:45	12A,12B	12
09:51	36A,36B	36
09:57	60A,60B	60
10:03	84A,84B	84
10:10	108A,108B	108
10:20	132A,132B	132
10:28	156A,156B	156
10:40	180A,180B	180
10:50	262A,262B	262
10:57	282A,282B	282

Method: Cable and crane off bridge

Type of Sampler Used: D-74

Nozzle Size: 1/8"

Transit Rate: 0.20 fps

No. of SSC Samples Collected: 20

Notes:

Gravel bar from 220-250

Bedload Sediment Transport Sampling

Sampler: Helley-Smith Time: 09:18 No. Samples: 45

Stations: 8, 23, 38*, 53, 68, 83, 98, 113*, 128, 143, Bridge ~10 feet below gage

158, 173, 188*, 203, 218, 250, 260, 270*, 280, 290

Notes:

(SEWI, *=MEWI x 5) - Gravel bar from 220-250

Sample times 1-10 min; no sediment in bag after sampling

General Remarks:

Gravel bar in channel was dry, did not sample on bar

SSC/Bedload Sampling

Site: Spring at E 57 Rd

Staff: TJK, BJT, LLR   Date: 8/15/2019   Time: 13:25

Weather: Clear, light wind   Stream Width: 263'

Stream Name: Spring River   Gage Reading: 7.26'   Discharge: 1240 CFS

USGS Station: 07188000   Mean Flow Vel: 1.1 FPS   WSE: 753.54'

Max Water Depth: 10.1'   Datum: NAVD88   Stage: ☐ Rising ☑ Falling ☐ Steady ☐ Peak

Temperature: Air: 86   Water: ____

FreshWater Engineering

Suspended Sediment Sampling

Time	*Sample No.*	*Station*
14:48	13A,13B	13
14:57	39A,39B	39
15:04	65A,65B	65
15:12	91A,91B	91
15:24	117A,117B	117
15:34	143A,143B	143
15:43	169A,169B	169
15:48	195A,195B	195
15:55	221A,221B	221
16:02	247A,247B	247

Method: Cable and crane off bridge

Type of Sampler Used: D-74

Nozzle Size: 1/4"

Transit Rate: 0.28 FPS

No. of SSC Samples Collected: 20

Notes:

Bedload Sediment Transport Sampling

Sampler: Helley-Smith   Time: 13:25   No. Samples: 45

Stations: 7, 20, 33*, 46, 59, 72, 85, 98*, 111, 124,   Bridge   ~10 feet below gage

137, 150, 163*, 176, 189, 202, 215, 228*, 241, 254

Notes:

(SEWI, *=MEWI x 5)

Sample times 1-10 min; Collected few grains of sand; not measurable

General Remarks:

SSC/Bedload Sampling

Site: Tar Creek @ HWY 69

Staff: TJK, BJT, LLR   Date: 8/16/2019   Time: 14:28

Weather: Cloudy, light rain, light wind   Stream Width: 18'

Stream Name: Tar Creek   Gage Reading: 8.55'   Discharge: 10 CFS

USGS Station: 07185090   Mean Flow Vel: 1 FPS   WSE: 783.71'

Max Water Depth: 1'   Datum: NAVD88   Stage: ☑ Rising ☐ Falling ☐ Steady ☐ Peak

Temperature: Air: 75   Water:

Suspended Sediment Sampling

Time	*Sample No.*	*Station*
14:50	A,B	0.9
14:57	A,B	2.7
15:05	A,B	4.5
15:13	A,B	6.3
15:48	A,B	8.1
15:56	A,B	9.9
16:02	A,B	11.7
16:12	A,B	13.5
16:18	A,B	15.3
16:31	A,B	17.1

Method: Cable and crane off bridge

Type of Sampler Used: D-74

Nozzle Size: 1/4"

Transit Rate: 0.02 fps

No. of SSC Samples Collected: 20

Notes:

Samples combined

Bedload Sediment Transport Sampling

Sampler: Helley-Smith   Time: 14:28   No. Samples: 42

Stations: 1, 2, 3*, 4, 5, 6, 7*, 8, 9, 10, 11, 12*, 13, 14, 15, 16*, 17, 18   Bridge   ~10 feet below gage

Notes:

(SEWI, *=MEWI x 5) - Narrow stream, so only 18 sample locations

Sample times 1-10 min; No sample in bag

General Remarks:

SSC/Bedload Sampling

Site: Elk River at Hwy 43

Staff: TJK, BLD, LLR, EAF   Date: 5/17/2020   Time: 16:15

FRESHWATER ENGINEERING

Weather: Cloudy, mod. winds   Stream Width: 340'

Stream Name: Elk River   Gage Reading: 8.13'   Discharge: 4,940 CFS

USGS Station: 07189000   Mean Flow Vel: 5.9 FPS   WSE: 758.74'

Max Water Depth: 6.6'   Datum: NGVD29   Stage: ☐ Rising ☑ Falling ☐ Steady ☐ Peak

Temperature: Air: 65   Water: ______

Suspended Sediment Sampling

Time	*Sample No.*	*Station*
17:02	40A,40B	40
17:16	70A,70B	70
17:25	100A,100B	100
17:39	130A,130B	130
17:46	160A,160B	160
17:51	190A,190B	190
18:00	220A,220B	220
18:09	250A,250B	250
18:19	280A,280B	280
18:28	310A,310B	310

Method: Cable and crane off bridge

Type of Sampler Used: D-74

Nozzle Size: 3/16"

Transit Rate: 0.6 FPS

No. of SSC Samples Collected: 20

Notes:

Single transit for SSC measurements

Bedload Sediment Transport Sampling

Sampler: Helley-Smith   Time: 16:15   No. Samples: 42

Stations: 9, 26, 43*, 60, 77, 94, 111, 128*, 145,   Bridge   ~10 feet below gage

162, 179, 196, 213*, 230, 247, 264, 281, 298*, 315, 332

Notes:

(SEWI, *=MEWI x 5)

Sample times 1-10 min; No sediment collected in bag

General Remarks:

SSC/Bedload Sampling

Site: Neosho River at Commerce

Staff: TJK, BLD, LLR, EAF Date: 5/17/2020 Time: 11:00

Weather: Cloudy, mod winds Stream Width: 600'

Stream Name: Neosho Gage Reading: 19.78' Discharge: 37,500 CFS

USGS Station: 07185000 Mean Flow Vel: 4.5 FPS WSE: 768.88'

Max Water Depth: 21.4' Datum: NAVD88 Stage: ☐ Rising ☐ Falling ☑ Steady ☐ Peak

Temperature: Air: 64 Water: ______

Suspended Sediment Sampling

Time	*Sample No.*	*Station*
11:34	30A,30B	30
12:12	90A,90B	90
12:28	150A,150B	150
12:44	210A,210B	210
13:00	270A,270B	270
13:14	330A,330B	330
13:30	430A,430B	430
13:44	450A,450B	450
14:14	520A,520B	520
14:25	570A,570B	570

Method: Cable and crane off bridge

Type of Sampler Used: D-74

Nozzle Size: 1/4"

Transit Rate: 1.8 FPS

No. of SSC Samples Collected: 20

Notes:

Bedload Sediment Transport Sampling

Sampler: Helley-Smith Time: 11:00 No. Samples: 42

Stations: 15, 45, 75*, 105, 135, 165, 195, 225*, Bridge ~10 feet below gage

255, 285, 315, 345, 375*, 405, 435, 465, 495, 525*, 555, 585

Notes:

(SEWI, *=MEWI x 5)

Sample times 1-10 min; Collected few grains of sand, one gravel; not measurable

General Remarks:

SSC/Bedload Sampling

FRESHWATER ENGINEERING

Site: Spring River at E 57Rd

Staff: TJK, BLD, LLR, EAF Date: 5/18/2020 Time: 10:15

Weather: Cloudy, windy Stream Width: 280'

Stream Name: Spring Gage Reading: 10.87' Discharge: 8,040 CFS

USGS Station: 07188000 Mean Flow Vel: 2.8 FPS WSE: 757.15'

Max Water Depth: 13.7' Datum: NAVD88 Stage: ☐ Rising ☑ Falling ☐ Steady ☐ Peak

Temperature: Air: 60 Water:

Suspended Sediment Sampling

Time	*Sample No.*	*Station*
10:30	14A,14B	14
10:40	42A,42B	42
10:48	70A,70B	70
10:55	98A,98B	98
11:04	126A,126B	126
11:13	154A,154B	154
11:21	182A,182B	182
11:28	210A,210B	210
11:35	238A,238B	238
11:44	266A,266B	266

Method: Cable and crane off bridge

Type of Sampler Used: D-74

Nozzle Size: 3/16"

Transit Rate: 0.5 FPS

No. of SSC Samples Collected: 20

Notes:

Bedload Sediment Transport Sampling

Sampler: Helley-Smith Time: No. Samples: 42

Stations: 7, 21, 35*, 49, 63, 77, 91, 105*, 119, 133, Bridge ~10 feet below gage

147, 161, 175*, 189, 203, 217, 231, 245*, 259, 273

Notes:

(SEWI, *=MEWI x 5)

Sample times 1-10 min; No sediment collected in bag

General Remarks:

SSC/Bedload Sampling

FreshWater Engineering

Site: Neosho at Commerce

Staff: TJK, BLD　Date: 7/31/2020　Time: 17:00

Weather: Cloudy, windy　Stream Width: 530'

Stream Name: Neosho　Gage Reading: 4.16'　Discharge: 2,930 CFS

USGS Station: 07185000　Mean Flow Vel: 3.6 FPS　WSE: 753.25'

Max Water Depth: 5.8'　Datum: NAVD88　Stage: ☑ Rising ☐ Falling ☐ Steady ☐ Peak

Temperature: Air: 76　Water: ______

Suspended Sediment Sampling

Time	*Sample No.*	*Station*
17:15	10A,10B	10
17:30	63A,63B	63
17:39	116A,116B	116
17:52	169A,169B	169
18:05	222A,222B	222
18:23	275A,275B	275
18:34	313A,313B	313
18:47	381A,381B	381
18:56	424A,424B	424
19:10	519A,519B	519

Method: Cable and crane off bridge

Type of Sampler Used: D-74

Nozzle Size: 3/16"

Transit Rate: 0.47

No. of SSC Samples Collected: 20

Notes:

Bedload Sediment Transport Sampling

Sampler: Helley-Smith　Time: 17:00　No. Samples: 42

Stations: 13, 40, 67*, 94, 121, 148, 175, 202*,　Bridge　~10 feet below gage

229, 256, 283, 310, 337*, 364, 391, 418, 445, 472*, 499, 526

Notes:

(SEWI, *=MEWI x 5)

Sample times 1-10 min; Collected few grains of sand, organic debris; not measurable

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General Remarks:

SSC/Bedload Sampling

FRESHWATER ENGINEERING

Site: Spring River at E 57 Rd

Staff: TJK, BLD | Date: 7/31/2020 | Time: 10:30

Weather: Cloudy, windy | Stream Width: 260'

Stream Name: Spring River | Gage Reading: 8.63' | Discharge: 3,480 CFS

USGS Station: 07188000 | Mean Flow Vel: 1.8 FPS | WSE: 754.91'

Max Water Depth: 11.5' | Datum: NAVD88 | Stage: ☐ Rising ☑ Falling ☐ Steady ☐ Peak

Temperature: Air: 76 Water: ____

Suspended Sediment Sampling

Time	*Sample No.*	*Station*
11:45	10A,10B	10
12:05	28A,28B	28
12:18	56A,56B	56
12:28	84A,84B	84
12:40	112A,112B	112
13:28	140A,140B	140
13:42	168A,168B	168
13:49	196A,196B	196
14:00	224A,224B	224
14:15	252A,252B	252

Method: Cable and crane off bridge

Type of Sampler Used: D-74

Nozzle Size: 1/4"

Transit Rate: 0.55

No. of SSC Samples Collected: 20

Notes:

Bedload Sediment Transport Sampling

Sampler: Helley-Smith | Time: 10:30 | No. Samples: 42

Stations: 7, 20, 33*, 46, 59, 72, 85, 98*, 111, 124, 137, 150, 163*, 176, 189, 202, 215, 228*, 241, 254

Bridge ~10 feet below gage

Notes:

(SEWI, *=MEWI x 5)

Sample times 1-10 min; Collected few grains of sand, organic debris; not measurable

General Remarks:

SSC/Bedload Sampling

Site: Tar Creek at HWY 69

Staff: TJK, BLD Date: 7/31/2020 Time: 15:00

FRESHWATER ENGINEERING

Weather: Cloudy, windy Stream Width: 20'

Stream Name: Tar Creek Gage Reading: 8.25' Discharge: 5.29 CFS

USGS Station: 07185090 Mean Flow Vel: 1 FPS WSE: 783.41'

Max Water Depth: 0.7' Datum: NAVD88 Stage: ☐ Rising ☐ Falling ☑ Steady ☐ Peak

Temperature: Air: 75 Water: ______

Suspended Sediment Sampling

Time	*Sample No.*	*Station*
15:20	9A,9B	9

Method: Cable and crane off bridge

Type of Sampler Used: D-74

Nozzle Size: 1/8"

Transit Rate: 0.2 FPS

No. of SSC Samples Collected: 2

Notes:

Bedload Sediment Transport Sampling

Sampler: Helley-Smith Time: 15:00 No. Samples: 42

Stations: 1, 2, 3*, 4, 5, 6, 7, 8*, 9, 10, 11, 12, 13*, 14, 15, 16, 17, 18*, 19, 20

Bridge ~10 feet below gage

Notes:

(SEWI, *=MEWI x 5)

Sample times 1-10 min; No sediment collected in mesh bag; not measurable

General Remarks:

SSC/Bedload Sampling

Site: Neosho River @ E 60 Rd

Staff: TJK, BLD   Date: 4/30/2021   Time: 15:30

FRESHWATER ENGINEERING

Weather: Warm, overcast   Stream Width: 500'

Stream Name: Neosho River   Gage Reading: 4.10'   Discharge: 2,330 CFS

USGS Station: 07185000   Mean Flow Vel: 3.5 FPS   WSE: 753.20'

Max Water Depth: 5.7'   Datum: NAVD88   Stage: ☑ Rising ☐ Falling ☐ Steady ☐ Peak

Temperature: Air: 76   Water: ______

Suspended Sediment Sampling

Time	*Sample No.*	*Station*
15:45	0A, 0B	25
15:55	50A, 50B	75
16:00	100A, 100B	125
16:10	150A, 150B	175
16:17	200A, 200B	225
16:25	250A, 250B	275
16:35	300A, 300B	325
16:49	350A, 350B	375
16:58	400A, 400B	425
17:06	450A, 450B	475

Method: Cable and crane off bridge

Type of Sampler Used: D-74

Nozzle Size: 3/16"

Transit Rate: 0.3 FPS

No. of SSC Samples Collected: 20

Notes:

Bedload Sediment Transport Sampling

Sampler: Helley-Smith   Time: 15:30   No. Samples: 42

Stations: 13, 38, 63*, 88, 113, 138, 163, 188*, 213,   Bridge   ~10 feet below gage

238, 263, 288, 313*, 338, 363, 388, 413, 438*, 463, 488

Notes:

(SEWI, *=MEWI x 5)

Sample times 1-10 min; Collected few grains of sand, organics; not measurable

---

General Remarks:

SSC/Bedload Sampling

Site: Spring River @ E 57 Rd

Staff: TJK, BLD   Date: 4/30/2021   Time: 10:30

Weather: Warm, overcast   Stream Width: 270'

Stream Name: Spring River   Gage Reading: 7.75'   Discharge: 2,250 CFS

USGS Station: 07188000   Mean Flow Vel: 1.1 FPS   WSE: 754.03'

Max Water Depth: 10.6'   Datum: NAVD88   Stage: ☑ Rising ☐ Falling ☐ Steady ☐ Peak

Temperature: Air: 74   Water: ______

Suspended Sediment Sampling

Time	*Sample No.*	*Station*
12:00	14A, 14B	14
12:14	41A, 41B	41
12:23	68A, 68B	68
12:32	95A, 95B	95
12:40	122A, 122B	122
12:46	149A, 149B	149
12:55	176A, 176B	176
13:02	203A, 203B	203
13:12	230A, 230B	230
13:21	257A, 257B	257

Method: Cable and crane off bridge

Type of Sampler Used: D-74

Nozzle Size: 1/4"

Transit Rate: 0.28 FPS

No. of SSC Samples Collected: 20

Notes:

Bedload Sediment Transport Sampling

Sampler: Helley-Smith   Time: 10:30   No. Samples: 42

Stations: 7, 20, 33*, 46, 59, 72, 85, 98*, 111, 124,   Bridge   ~10 feet below gage

137, 150, 163*, 176, 189, 202, 215, 228*, 241, 254

Notes:

(SEWI, *=MEWI x 5)

Sample times 1-10 min; Collected few grains of sand, organics; not measurable

General Remarks:

SSC/Bedload Sampling

FreshWater Engineering

Site: Neosho River @ E 60 Rd

Staff: TJK, BLD Date: 5/28/2021 Time: 17:10

Weather: Warm, overcast Stream Width: 640'

Stream Name: Neosho River Gage Reading: 13.36' Discharge: 18,900 CFS

USGS Station: 07185000 Mean Flow Vel: 3.6 FPS WSE: 762.46'

Max Water Depth: 15.0' Datum: NAVD88 Stage: ☐ Rising ☑ Falling ☐ Steady ☐ Peak

Temperature: Air: 76 Water: ______

Suspended Sediment Sampling

Time	*Sample No.*	*Station*
18:32	58A, 58B	58
18:40	116A, 116B	116
19:03	174A, 174B	174
19:09	232A, 232B	232
19:16	290A, 290B	290
19:21	348A, 348B	348
19:26	406A, 406B	406
19:32	464A, 464B	464
19:37	522A, 522B	522
19:43	580A, 580B	580

Method: Cable and crane off bridge

Type of Sampler Used: D-74

Nozzle Size: 3/16"

Transit Rate: 44 seconds in water

No. of SSC Samples Collected: 20

Notes:

Bedload Sediment Transport Sampling

Sampler: Helley-Smith Time: 17:10 No. Samples: 42

Stations: 16, 48, 80*, 112, 144, 176, 208, 240*, 272, 304, 336, 368, 400*, 432, 464, 496, 528, 560*, 592, 624 Bridge ~10 feet below gage

Notes:

(SEWI, *=MEWI x 5)

Sample times 1-10 min; Collected grains of sand, three gravel, debris; no measurable sample

General Remarks:

SSC/Bedload Sampling

Site: Spring River @ E 57 Rd

Staff: TJK, BLD Date: 5/28/2021 Time: 9:28

FRESHWATER ENGINEERING

Weather: Warm, overcast Stream Width: 270'

Stream Name: Spring River Gage Reading: 14.41' Discharge: 16,500 CFS

USGS Station: 07188000 Mean Flow Vel: 4.3 FPS WSE: 760.69'

Max Water Depth: 17.3' Datum: NAVD88 Stage: ☐Rising ☑Falling ☐Steady ☐Peak

Temperature: Air: 63 Water:

Suspended Sediment Sampling

Time	*Sample No.*	*Station*
10:03	14A, 14B	14
10:12	25A, 25B	25
10:23	68A, 68B	68
10:28	95A, 95B	95
10:36	122A, 122B	122
10:42	149A, 149B	149
10:49	176A, 176B	176
10:56	203A, 203B	203
11:06	230A, 230B	230
11:20	257A, 257B	257

Method: Cable and crane off bridge

Type of Sampler Used: D-74

Nozzle Size: 3/16"

Transit Rate: 0.94 FPS

No. of SSC Samples Collected: 20

Notes:

Bedload Sediment Transport Sampling

Sampler: Helley-Smith Time: 9:28 No. Samples: 42

Stations: 7, 21, 35*, 49, 63, 77, 91, 105*, 119, 133, Bridge ~10 feet below gage

147, 161, 175*, 189, 203, 217, 231, 245*, 259, 268

Notes:

(SEWI, *=MEWI x 5)

Sample times 1-10 min; Collected grains of sand, organic material, leaves, stick; no measurable sediment

General Remarks:

SSC/Bedload Sampling

Site: Tar Creek @ HWY 69

Staff: TJK, BLD   Date: 5/28/2021   Time: 12:01

FRESHWATER ENGINEERING

Weather: Warm, overcast   Stream Width: 172'

Stream Name: Tar Creek   Gage Reading: 13.12'   Discharge: 750 CFS

USGS Station: 07185090   Mean Flow Vel: 1.2 FPS   WSE: 788.28'

Max Water Depth: 5.6'   Datum: NAVD88   Stage: ☐Rising ☑Falling ☐Steady ☐Peak

Temperature: Air: 65   Water: ______

Suspended Sediment Sampling

Time	*Sample No.*	*Station*
12:37	22A, 22B	22
12:39	29A, 29B	29
12:44	44A,44B	44
12:49	59A, 59B	59
12:53	74A, 74B	74
12:58	89A, 89B	89
13:03	104A, 104B	104
13:09	119A, 119B	119
13:18	134A, 134B	134
13:22	149A, 149B	149

Method: Cable and crane off bridge

Type of Sampler Used: D-74

Nozzle Size: 1/4"

Transit Rate: 0.15 FPS

No. of SSC Samples Collected: 20

Notes:

Bedload Sediment Transport Sampling

Sampler: Helley-Smith   Time: 12:01   No. Samples: 42

Stations: 4, 12, 20*, 28, 36, 44, 52, 60*, 68, 76, 84,   Bridge   ~10 feet below gage

92, 100*, 108, 116, 124, 132, 140*, 148, 156

Notes:

(SEWI, *=MEWI x 5)

Sample times 1-10 min; No measurable sample, nothing collected in bag

---

General Remarks:

SSC/Bedload Sampling

Site: Spring River @ E 57 Rd

Staff: TJK, BLD Date: 5/29/2021 Time: 8:58

Weather: Warm, overcast Stream Width: 303'

Stream Name: Spring River Gage Reading: 16.82' Discharge: 23,400 CFS

USGS Station: 07188000 Mean Flow Vel: 5.2 FPS WSE: 763.10'

Max Water Depth: 19.7' Datum: NAVD88 Stage: ☐Rising ☑Falling ☐Steady ☐Peak

Temperature: Air: 62 Water: ______

Suspended Sediment Sampling

Time	*Sample No.*	*Station*
9:29	25A, 25B	25
9:37	50A, 50B	50
9:50	100A, 100B	100
9:58	125A, 125B	125
10:10	150A, 150B	150
10:45	175A, 175B	175
10:56	200A, 200B	200
11:06	225A, 225B	225
11:17	250A, 250B	250
11:31	275A, 275B	275

Method: Cable and crane off bridge

Type of Sampler Used: D-74

Nozzle Size: 3/16"

Transit Rate: 1.1 FPS

No. of SSC Samples Collected: 20

Notes:

Bedload Sediment Transport Sampling

Sampler: Helley-Smith Time: 8:58 No. Samples: 42

Stations: 8, 23, 38*, 53, 68, 83, 98, 113*, 128, 143, Bridge ~10 feet below gage

158, 173, 188*, 203, 218, 233, 248, 263*, 278, 293

Notes:

(SEWI, *=MEWI x 5)

Sample times 1-10 min; Collected few grains of sand; no measurable quantity

General Remarks:

SSC/Bedload Sampling

Site: Neosho River @ E 60 Rd

Staff: TJK, BLD   Date: 7/1/2021   Time: 14:30

Weather: Warm, overcast   Stream Width: 604'

Stream Name: Neosho River   Gage Reading: 20.34'   Discharge: 41,600 CFS

USGS Station: 07185000   Mean Flow Vel: 4.8 FPS   WSE: 769.44'

Max Water Depth: 21.9'   Datum: NAVD88   Stage: ☐ Rising ☐ Falling ☑ Steady ☐ Peak

Temperature: Air: 80   Water: ______

Suspended Sediment Sampling

Time	*Sample No.*	*Station*
16:54	32A, 32B	32
17:01	95.5A, 95.5B	95.5
17:07	159A, 159B	159
17:14	222.5A, 222.5B	222.5
17:18	286A, 286B	286
17:27	349.5A, 349.5B	349.5
17:34	413A, 413B	413
17:43	476.5A, 476.5B	476.5
17:48	540A, 540B	540
17:55	572A, 572B	572

Method: Cable and crane off bridge

Type of Sampler Used: D-74

Nozzle Size: 1/8"

Transit Rate: 0.47 FPS

No. of SSC Samples Collected: 20

Notes:

Bedload Sediment Transport Sampling

Sampler: Helley-Smith   Time: 14:30   No. Samples: 42

Stations: 15, 45, 75*, 105, 135, 165, 195, 225*,   Bridge   ~10 feet below gage

255, 285, 315, 345, 375*, 405, 435, 465, 495, 525*, 555, 585

Notes:

(SEWI, *=MEWI x 5)

Sample times 1-10 min; Collected grains of sand, debris; not measurable

General Remarks:

SSC/Bedload Sampling

Site: Spring River @ E 57 Rd

Staff: TJK, BLD   Date: 7/1/2021   Time: 19:00

Weather: Warm, overcast   Stream Width: 280'

Stream Name: Spring River   Gage Reading: 13.75'   Discharge: 14,700 CFS

USGS Station: 07188000   Mean Flow Vel: 4.0 FPS   WSE: 760.03'

Max Water Depth: 16.6'   Datum: NAVD88   Stage: ☑ Rising ☐ Falling ☐ Steady ☐ Peak

Temperature: Air: 78   Water: ______

Suspended Sediment Sampling

Time	*Sample No.*	*Station*
19:26	14A, 14B	14
19:36	42A, 42B	42
19:42	70A, 70B	70
19:46	98A, 98B	98
19:52	126A, 126B	126
19:57	154A, 154B	154
20:04	182A, 182B	182
20:07	210A, 210B	210
20:12	238A, 238B	238
20:18	266A, 266B	266

Method: Cable and crane off bridge

Type of Sampler Used: D-74

Nozzle Size: 3/16"

Transit Rate: 0.88 FPS

No. of SSC Samples Collected: 20

Notes:

Bedload Sediment Transport Sampling

Sampler: Helley-Smith   Time: 19:00   No. Samples: 42

Stations: 7, 21, 35*, 49, 63, 77, 91, 105*, 119, 133,   Bridge   ~10 feet below gage

147, 161, 175*, 189, 203, 217, 231, 245*, 259, 273

Notes:

(SEWI, *=MEWI x 5)

Sample times 1-10 min; Collected grains of sand, debris; not measurable

General Remarks:

SSC/Bedload Sampling

Site: Tar Creek @ HWY 69

Staff: TJK, BLD | Date: 7/1/2021 | Time: 10:30

Weather: Warm, overcast | Stream Width: 70'

Stream Name: Tar Creek | Gage Reading: 11.72' | Discharge: 500 CFS

USGS Station: 07185090 | Mean Flow Vel: 1.1 FPS | WSE: 786.79'

Max Water Depth: 4.2' | Datum: NAVD88 | Stage: ☐ Rising ☑ Falling ☐ Steady ☐ Peak

Temperature: Air: 76 | Water: ______

Suspended Sediment Sampling

Method: Cable and crane off bridge

Type of Sampler Used: D-74

Nozzle Size: 1/4"

Transit Rate: 0.15

No. of SSC Samples Collected: 20

Notes:

Time	*Sample No.*	*Station*
12:11	23A, 23B	23"
12:22	68.5A, 68.5B	68.5"
12:29	114A, 114B	114"
12:35	159.5A, 159.5B	159.5"
12:40	205A, 205B	205"
12:46	250.5A, 250.5B	250.5"
12:51	296A, 296B	296"
12:56	341.5A, 341.5B	341.5"
13:02	387A, 387B	387"
13:07	410A, 410B	410"

Bedload Sediment Transport Sampling

Sampler: Helley-Smith | Time: 10:30 | No. Samples: 42

Stations: 2, 5.5, 9*, 12.5, 16, 19.5, 23, 26.5*, 30, | Bridge | ~10 feet below gage

33.5, 37, 40.5, 44*, 47.5, 51, 54.5, 58, 61.5*, 65, 68.5

Notes:

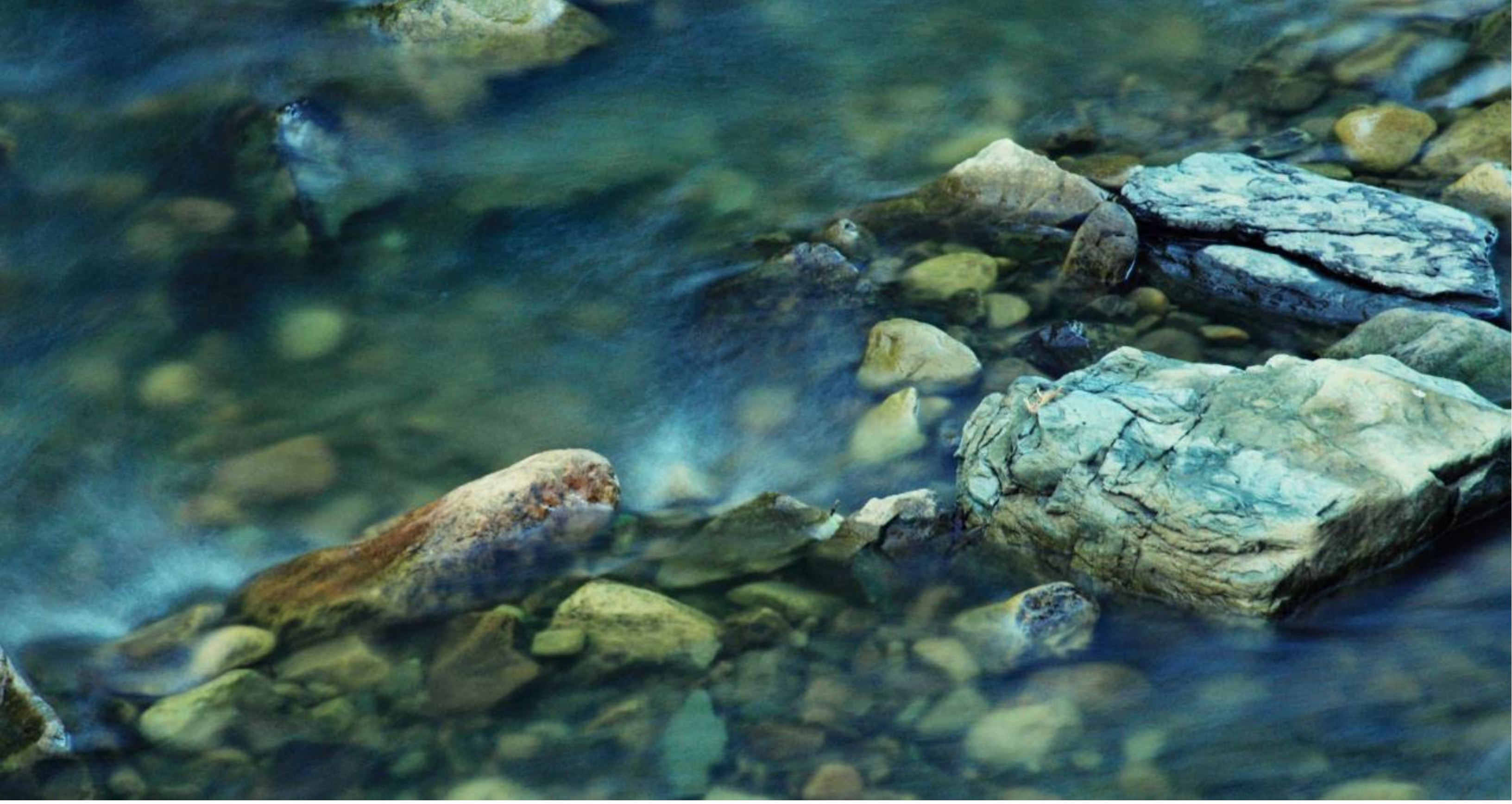
(SEWI, *=MEWI x 5)

Sample times 1-10 min; No measurable sample material

General Remarks:

Appendix E

Subsurface Investigation



August 2022
Oklahoma Dam Relicensing

Grand Lake Subsurface Investigation Field Report

Prepared for Grand River Dam Authority

August 2022
Oklahoma Dam Relicensing

Grand Lake Subsurface Investigation Field Report

Prepared for
Grand River Dam Authority
P.O. Box 409
Vinita, Oklahoma 74301

Prepared by
Anchor QEA, LLC
660 West Washington Avenue
Suite 302
Madison, Wisconsin 53715

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APPENDICES

1 Introduction

GRDA performed an investigation of sediment deposition on the Neosho River at multiple locations to estimate bottom sediment layer thicknesses. The goal of the survey was to determine the volume of sediment deposited in these areas since the construction of the Pensacola Dam. Historical records indicate that a delta feature had accumulated in this reach of the system, and GRDA used a sub-bottom profiler (SBP) to assess deposition thicknesses.

Two methods were used to investigate the sediment accumulation. The first was an SBP survey, and the second was vibracoring for sediment samples. The SBP survey covered nine transects of the Neosho River and was completed in January 2022. The vibracore sampling was completed in February 2022 and included multiple samples at each SBP transect.

An SBP uses sonar pulses to determine depth of a water body. There is an emitter and a receiver on the SBP head unit, and by measuring the amount of time necessary for the emitted pulse to reach an object and return to the receiver, the SBP is able to measure the distance the pulse traveled. This allows the SBP to measure bathymetry, but the pulse is also powerful enough to penetrate a soft sediment bed, such as clay, silt, and sand before reaching a harder layer. Using the same principles, the SBP can then estimate the thickness of a soft sediment layer above gravel or bedrock.

Vibracoring uses a motorized head unit to press core tubes into the stream- or lakebed. The combined weight and vibration of the head unit allows for deeper penetration than simply pressing the core tube into the bed or relying on gravity coring methods. Once collected, grain size analyses and other testing can be used to determine sediment properties as a function of depth in the sediment layers. The cores were used for two purposes: one was to confirm SBP survey information and evaluate sediment composition; the other was an attempt to determine approximate dates of deposition through the use of cesium-137 (Cs-137) analysis.

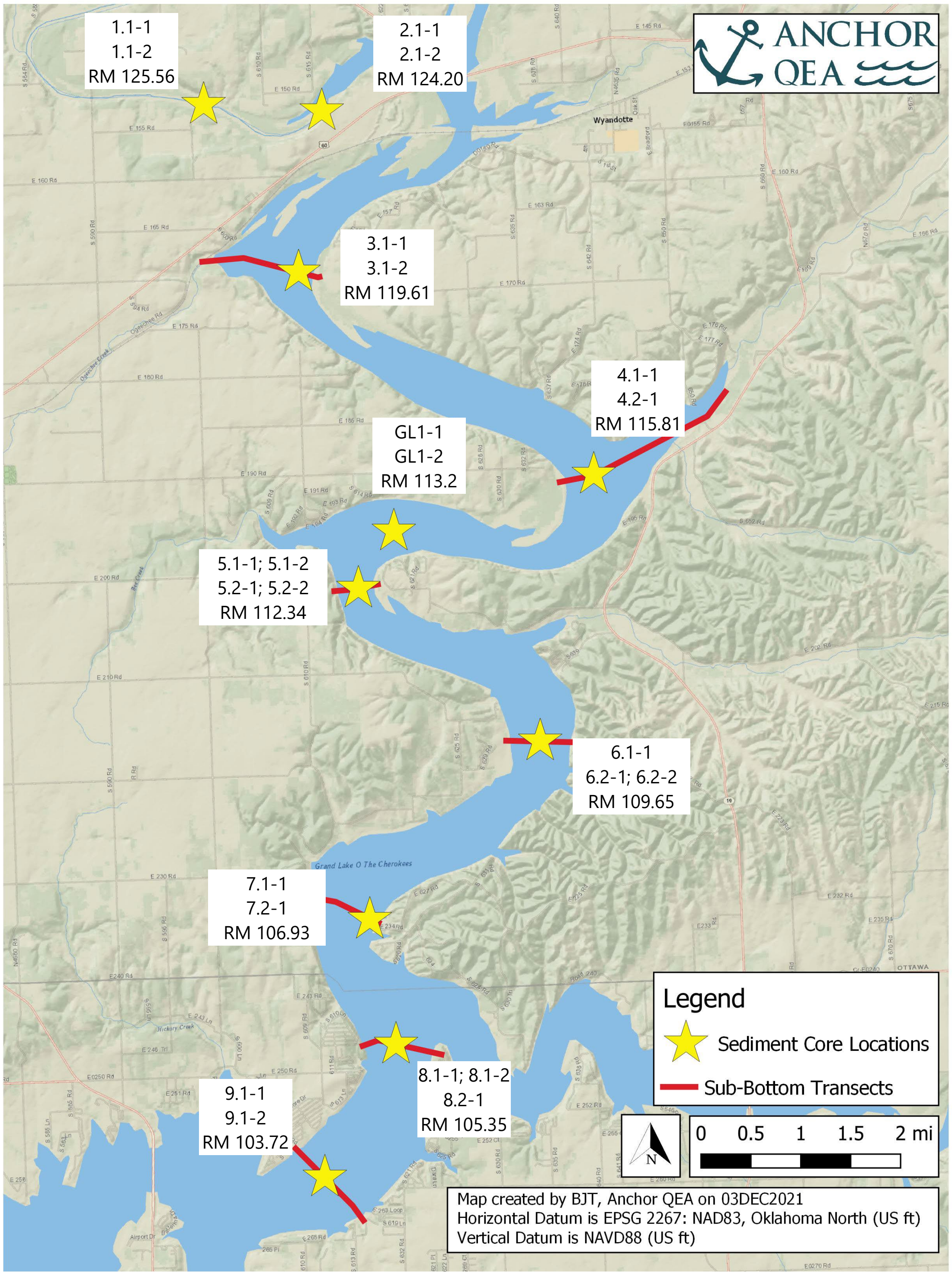
Cs-137 is an isotope that does not occur in nature. It is created by nuclear fission, which humans began developing in the 1940s. As nuclear weapons testing accelerated, atmospheric Cs-137 increased until a 1963 nuclear test ban treaty. The Cs-137 levels then dropped significantly. Atmospheric Cs-137 concentrations are well-correlated with Cs-137 concentrations in soil, showing the same pattern of increase from the 1940s to 1963, then a marked decrease.

Measurement of relative Cs-137 activity in sediment allows researchers to estimate deposition dates for sediment layers. In areas of continual deposition, Cs-137 analysis will find a pattern of increasing Cs-137 activity moving deeper in the column until reaching the 1963 layer. Below that layer, concentrations drop to zero by the 1940s. In disturbed areas or places with non-continuous deposition, there is usually no clear Cs-137 peak. The combination of SBP, vibracore samples, and Cs-137 provides insight into the volume, rate, and timeline of sediment deposition in the Neosho River.

2 Study Area

The study area for this survey was the Neosho River between river mile (RM) 125.56 approximately one mile downstream of Connors Bridge and RM 103.72 approximately two miles below the Elk River confluence. The survey team collected SBP transects at 9 locations to determine sediment layer thicknesses (Figure 1). At least two vibracore samples were collected at each transect. In addition, two additional samples at RM 113.2 for Cs-137 assessment to replicate an earlier USGS (Juracek and Becker 2009) effort.

Figure 1
Locations of SBP Transects and Sediment Cores Collected by GRDA



3 Equipment

3.1 Sub-Bottom Profiler

The survey team used a 19-ft vessel to tow an EdgeTech SB-424 towfish (Figure 2). The towfish was pulled across each of the nine transects on the Neosho River to collect SBP data. The system was processed onboard using the EdgeTech 3100-P portable sub-bottom topside electronics and Discover software that displayed and stored data. The reported SB-424 specifications are shown in Table 1.

Figure 2
EdgeTech 424 Sub-Bottom Profiler Towfish

Note: The EdgeTech SB-424 is a tow vehicle that was pulled across the measured transects. The topside 3100-P portable sub-bottom profiling system with Discover software is not shown in this image.

Table 1
EdgeTech SB-424 Specifications

EdgeTech SB-424 Characteristics	Text
Frequency Range	4-24 kHz
Pulses (user selected)	4-24 kHz, 4-20 kHz, 4-16 kHz
Vertical Resolution	4 cm / 4-24 kHz 6 cm / 4-20 kHz 8 cm / 4-16 kHz
Penetration (typical)	In coarse calcareous sand – 2 m In clay – 40 m
Beam Width (depends on center frequency)	16° / 4-24 kHz 19° / 2-20 kHz 23° / 2-16 kHz
Size (cm)	L – 77 W – 50 H – 34

EdgeTech SB-424 Characteristics	Text
Weight (kg)	45
Optimum Tow height	3-5 m above bed
Tow Speed	3-4 knots optimal, 7 knots maximum safe

The data was geolocated using a Differential GPS (DPGS) antenna. Track lines were set to follow cross sections aligned with the HEC-RAS computer model of the river system as shown in Figure 1.

3.2 Vibracore

The vibracore used for this effort was a Rossfelder P-3 system. The head clamped onto 16-ft clear ceramic tubes and was lowered to the bed with an electric winch from a vessel-mounted tripod system (Figure 3). Location data was collected with an RTK-GPS unit onboard the sampling boat.

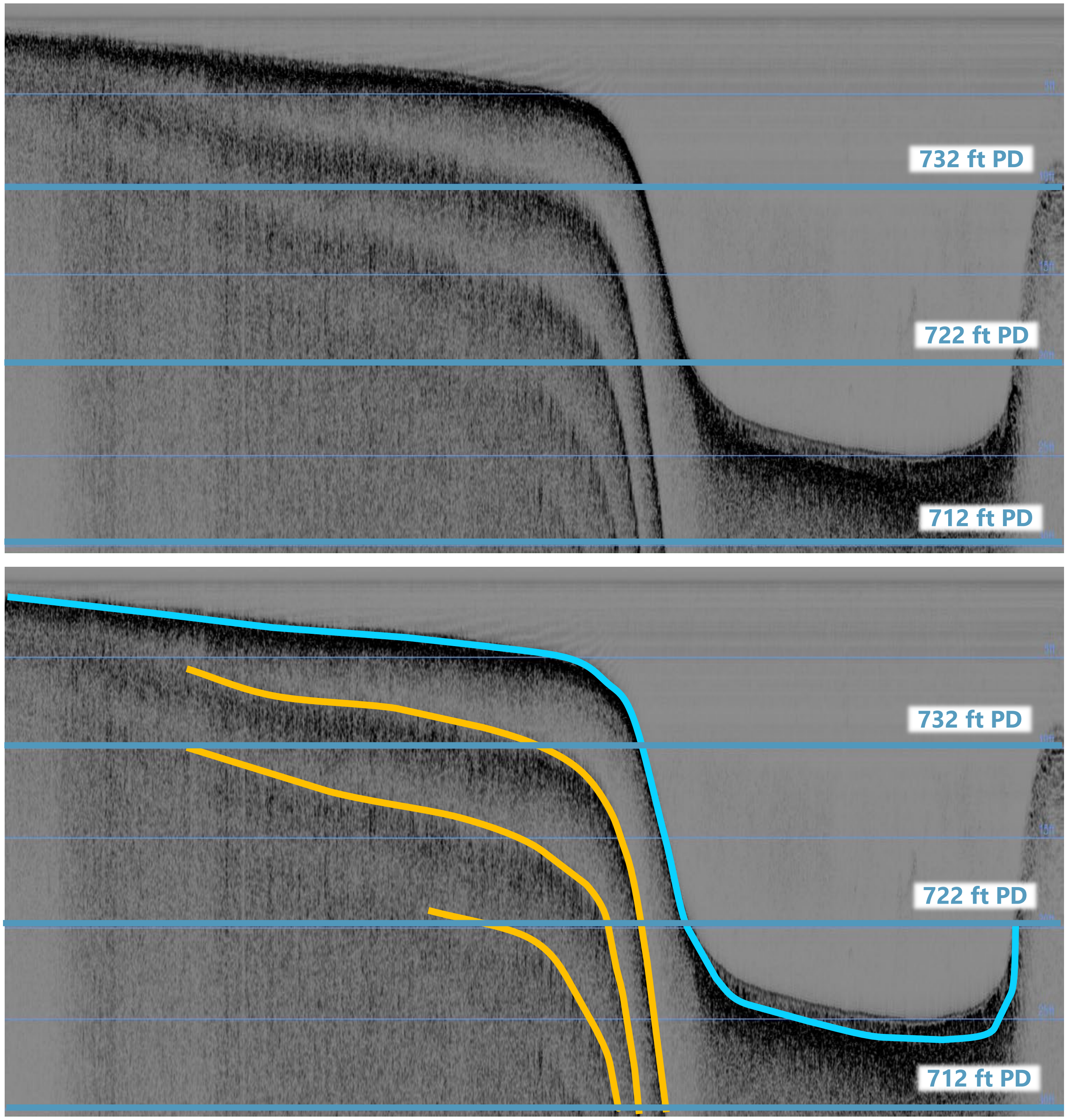
Figure 3
Vibracore System Used during February 2022 Sample Collection

4 Results

4.1 Sub-Bottom Survey Outputs

The SBP will produce a visual output referred to as a "waterfall" that indicates the distances to different objects. The most powerful return signal is often the lakebed or streambed, and subsequent layers are somewhat weaker signals that are still visible in the data. Another type of signal is referred to as a "multiple," which is produced by pulses bouncing between the SBP sonar head and the bed, several times, resulting in a series of nearly parallel lines. An example image collected during the SBP survey at RM 112.34 showing this is provided in Figure 4. Full images are included in Appendix I.

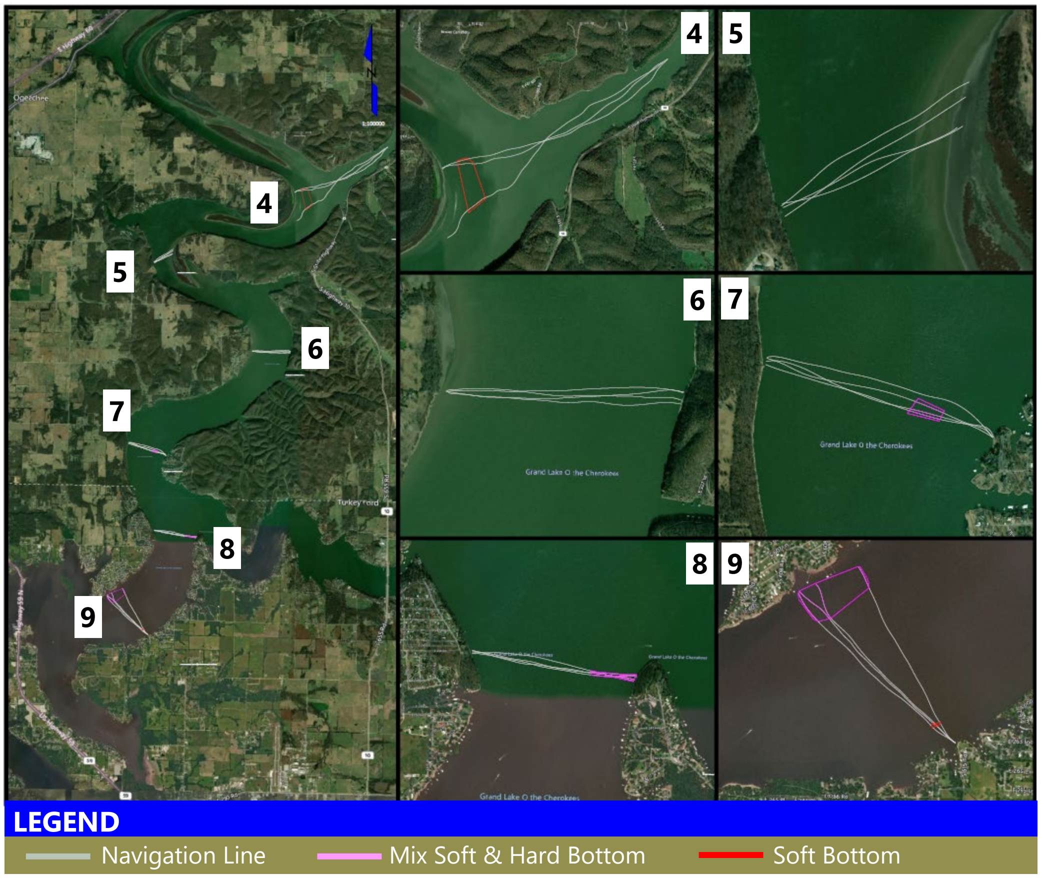
Figure 4
Example SBP Waterfalls showing Layer Transitions and “Multiples”



Notes: Waterfall images taken from SBP survey at RM 112.34 (approximately 1.5 miles upstream of Council Hollow)
Lower image is identical to upper, but locations of layer transitions and multiples are highlighted.
Teal line is the layer transition between soft and hard sediments
Orange lines are “multiples” or secondary reflections

The waterfalls produced during the Neosho River SBP survey showed layer transitions at approximately 2-3 ft below the bed surface. This indicated a thin layer of soft material over firmer sediments throughout much of the survey area. The interpretation was confirmed by an SBP expert, and the representative stated that a majority of the areas surveyed were not characterized by soft sediment beds (Figure 5).

Figure 5
Interpretation of SBP Survey Results at Stations 4 through 9



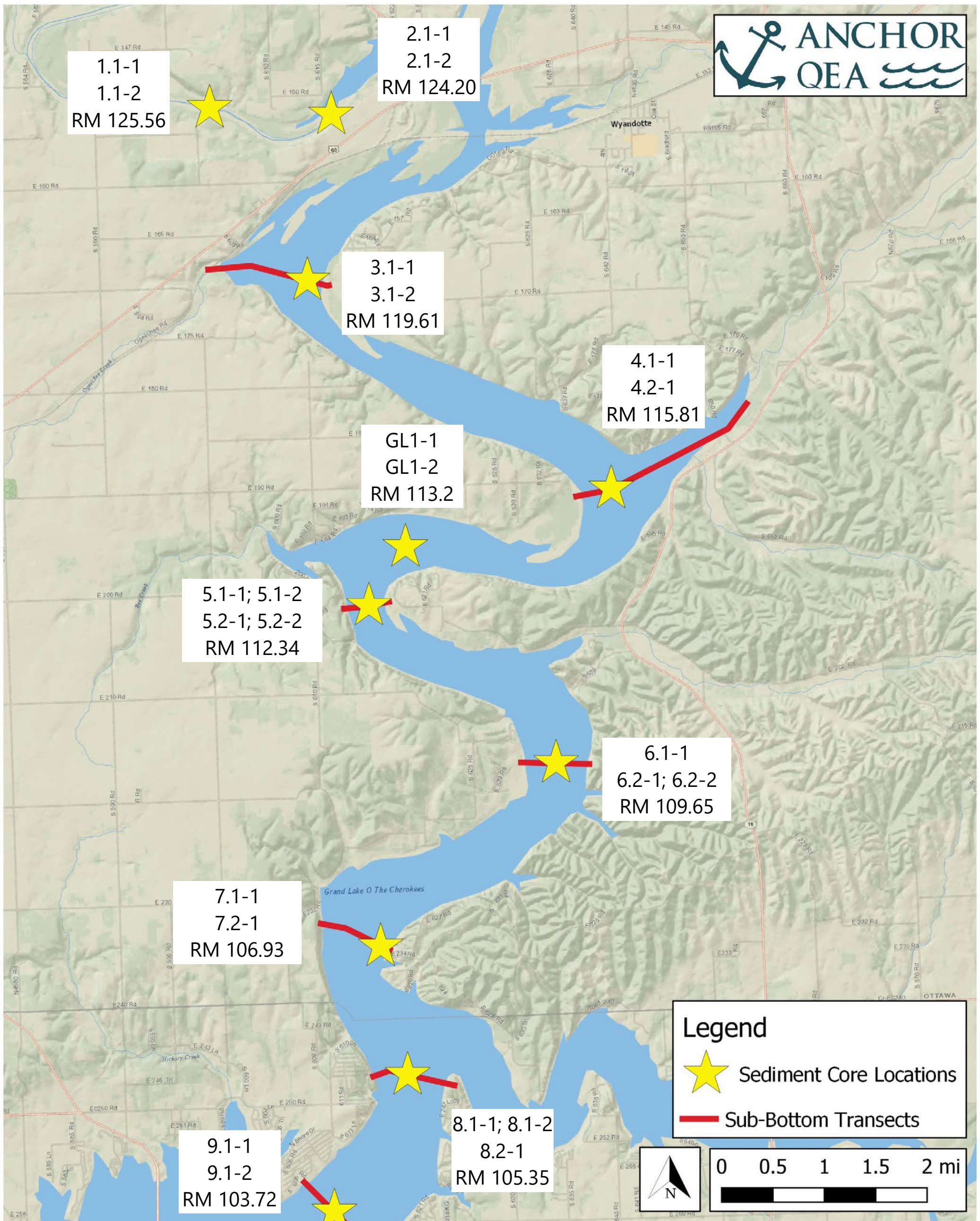
Source: Interpretation of SBP readings; station numbers adjusted from OARS original to reflect GRDA numbers

Figure 5 shows the navigation lines from the field SBP survey. Where a mixture of soft and hard beds were noted by the SBP expert (for example at transect 9, bottom right), pink outlines were drawn. Red outlines indicate soft bottom materials (transect 4, top center). Areas not colored were interpreted to consist of hard bottom sediments.

4.2 Vibracore Analysis

The vibracore pushed core tubes into the riverbed at the locations shown in Figure 6 using 16-foot coring tubes. These were chosen to align with the SBP survey discussed in Section 4.1 as a means of confirming interpretation of the results. SBP survey transects are shown in red with their relationship to the vibracore sample locations.

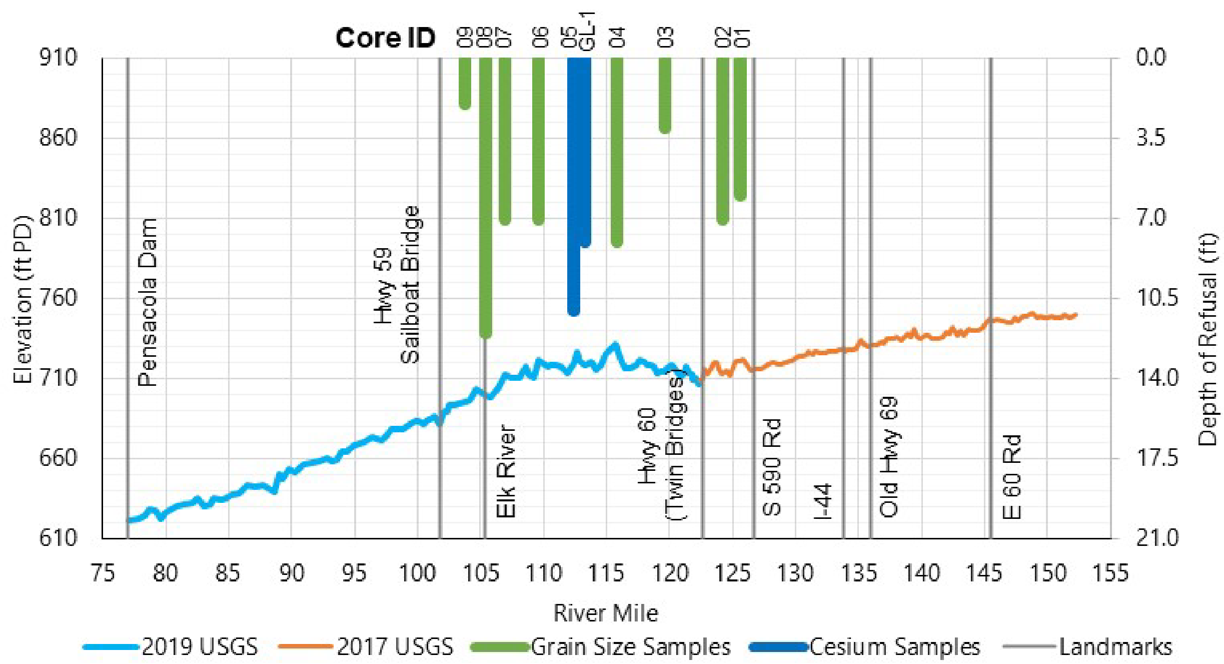
Figure 6
Locations of Sediment Cores Collected by GRDA



Map created by BJT, Anchor QEA on 03DEC2021
Horizontal Datum is EPSG 2267: NAD83, Oklahoma North (US ft)
Vertical Datum is NAVD88 (US ft)

The vibracoring efforts produced 24 core samples for analysis. The cores were pushed to refusal, which ranged from 1.5 to 11 feet in the reach above the Elk River (Figure 7). In the lower reservoir, one core penetrated approximately 12 feet of sediment before refusal. Two cores over 10 feet in length taken in the delta feature (RM 112.34) were evaluated for Cesium-137 (Cs-137) activity. Cores shorter than 10 feet or taken from the lower reservoir were analyzed only for grain size distribution (see Section 3.3). Figure 7 shows the maximum vibracore penetration depths at each site shown in Figure 6.

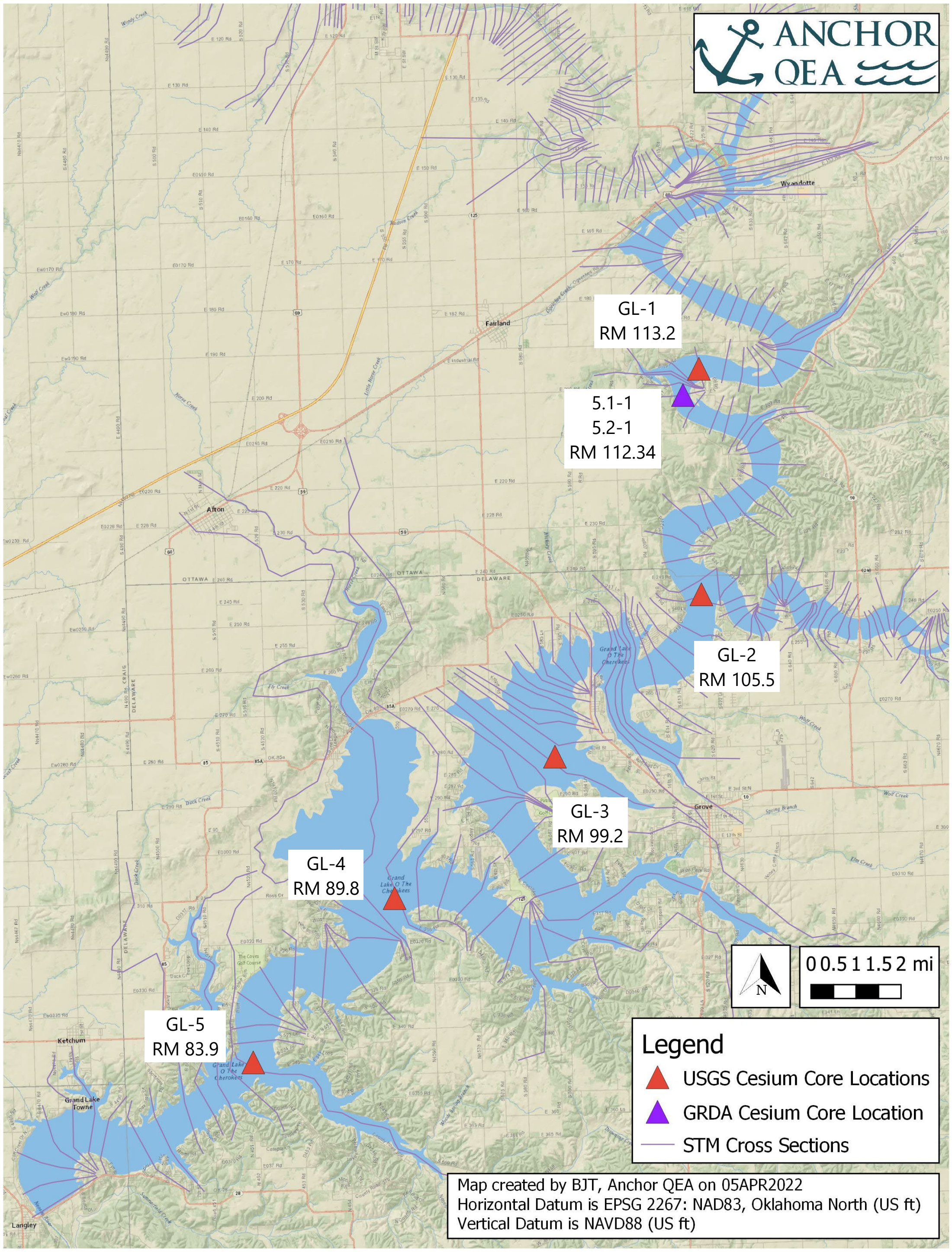
Figure 7
Maximum Vibracore Sample Penetration on Neosho River



Note: GL-1 sample tested for cesium activity by USGS (Juracek and Becker 2009)

The USGS (Juracek and Becker 2009) analyzed sediment Cs-137 levels to determine the approximate age of sediment in various locations within Grand Lake. The 2008 study collected samples from five sites, with one located in the region of the delta feature, one near the confluence with the Elk River, and three others located further downstream in the reservoir (Figure 8). Where USGS data showed a clear, defined Cs-137 peak, the findings were considered settled.

Figure 8
Locations of Sediment Cores Collected for Cesium Analysis



Note: Locations of USGS cores taken from Juracek and Becker (2009)

A major goal of sampling was to collect a significantly deeper sample near USGS site GL-1. The USGS sample was approximately 6 ft, and it was decided that a vibracore sample of approximately 10 ft would be sufficient to trigger re-evaluation and Cs-137 analysis. Shorter cores would not likely produce different results from the USGS (2009) study. Cores lower in the basin were not analyzed as the USGS dataset was sufficiently robust and were not of interest for delta feature analysis. The cores that met this criteria were 5.1-1 and 5.2-1 as shown in Figure 8.

Sediment cores were subdivided by cutting along the length of the core tube using an electric shear. Total recovered length was measured and recorded (Figure 9). Plastic spoons were used to mark the divisions between samples. Cores sent for grain size analyses were divided into 1-ft segments, and Cs-137 samples into 4-cm increments for laboratory assessment by Teledyne Brown Engineering. The spoons were then used to scoop samples into a clean container while avoiding the outer 1.5 cm of the core sample to prevent mixing of material smeared along the sample tube itself. Once used, the spoons were discarded to avoid contamination of any other samples. Sample containers were labeled, sealed, and packaged for transport. Because these were for grain size and Cs-137 analysis, there was no need for preservatives or cooling.

Figure 9
Image of Core 5.1-2 during Processing

Grain size results showed primarily silts and clays throughout each core. Full results are presented in Appendix II. Cs-137 analysis showed no obvious trend in the activity levels. See Appendix III for the laboratory report.

5 Discussion

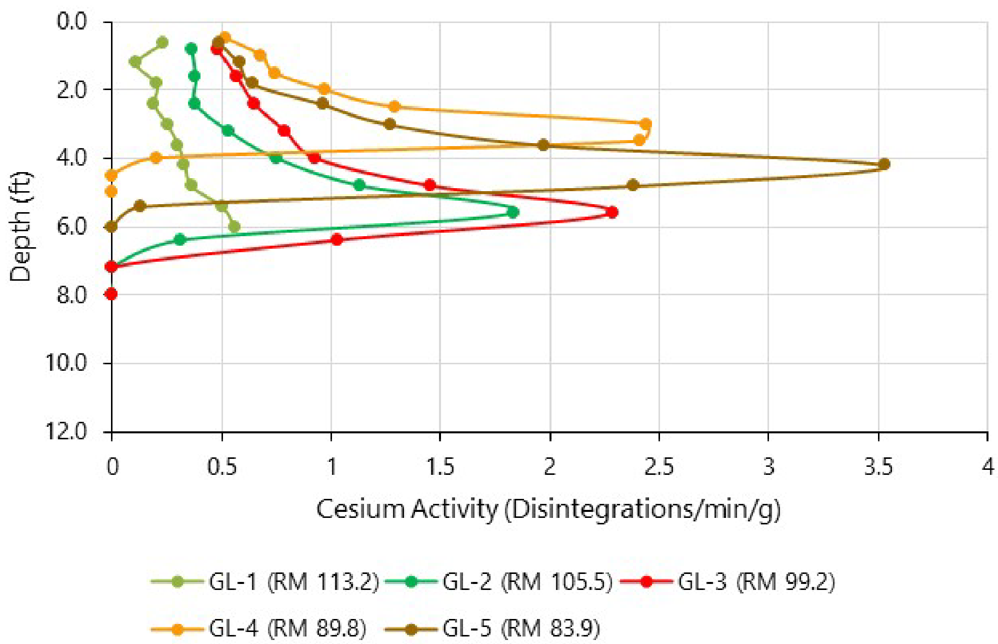
SBP results indicate a primarily firm bed with limited deposition of softer silts and clays. This suggests relatively limited deposition of soft cohesive material. However, these results are contingent upon field sampling to confirm the readings.

The vibracore samples show a thicker sediment deposit which suggests the SBP was not reliably capturing sediment layer thicknesses. Most likely, the penetration of the SBP signal was limited by a layer of biotic activity within the surface of the sediment; several core samples had air bubbles in the top few feet produced by decomposition or other biological activity. This produces readings indicating a softer, air-filled layer above the firmer silt and clay sediment that would register as a separate layer during SBP surveying (Aqua Survey 2004, Science Applications International 2001). As a result, further analyses relied on vibracore sampling rather than SBP results.

Vibracore sampling showed thicker layers of soft sediment deposition, and also provided opportunity to evaluate Cs-137 trends measured by a USGS study (Juracek and Becker 2009).

USGS analysis showed that Cs-137 peaks were located approximately 3 to 6 feet below the bed surface (Figure 10). Those peaks represent sediment that was deposited in approximately 1963, indicating that just 3 to 6 feet of sediment had deposited since 1963 at sites GL-2, -3, -4, and -5 (Figure 8).

Figure 10
Comparisons of Relative Cesium Activity within the USGS Core Samples



Notes: The peak cesium activity indicates the soil layer associated with deposition in approximately 1963. All material above that layer is assumed to have deposited since the nuclear testing ban.

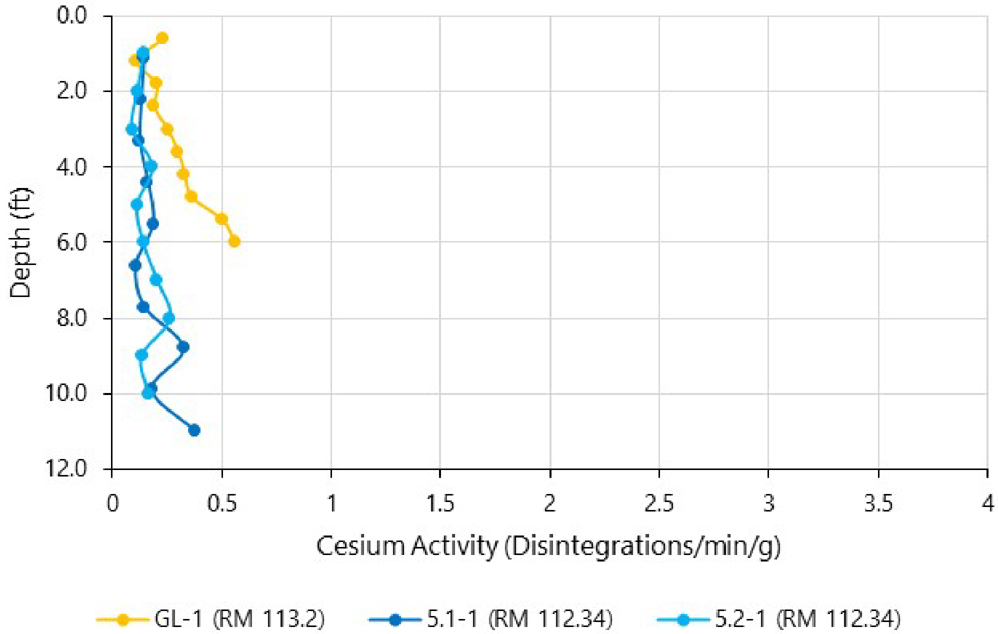
Source: Figure adapted from Juracek and Becker (2009).

The sample in the delta feature (GL-1) showed no spike in Cs-137. Juracek and Becker (2009) concluded the sediment they collected was all deposited post-1963. The USGS interpreted this to indicate that the area was not continually depositional but washes away due to wave action or large flow events before new sediment redeposits. This follows typical reservoir delta feature evolution, with surface sediments at the top of the delta feature washing downstream and extending the delta feature further into the reservoir rather than increasing the top elevation.

During GRDA's vibracore sampling, they repeated the USGS efforts to obtain longer (deeper) cores and see if a longer sample would capture a characteristic Cs-137 spike that denotes a 1963 sediment layer. GRDA collected approximately 11-foot cores near site GL-1 (cores 5.1-1 and 5.2-1) and processed them for Cs-137 analysis. The location of cores 5.1-1 and 5.2-1 are displayed in Figure 8.

GRDA sent 10 samples at equally spaced intervals within each core for Cs-137 evaluation. The results show a similar pattern to those of the USGS study, with no apparent Cs-137 peak (Figure 11).

Figure 11
Comparisons of Relative Cesium Activity Between USGS Core Sample GL-1 and GRDA Samples 5.1-1 and 5.2-1



Notes: GL-1 activity levels taken from Juracek and Becker (2009)
The lack of a defined cesium activity peak indicates that all sediment collected in the core was deposited after 1963.

This further suggests that deposition in the top 10 feet of the soil column is all post-1963 and that the site is not continuously depositional, instead indicating regular mixing of the materials at the top of the delta feature. These results agree with the USGS (Juracek and Becker 2009) findings that this location sees regular disturbance and is not continually depositional.

6 References

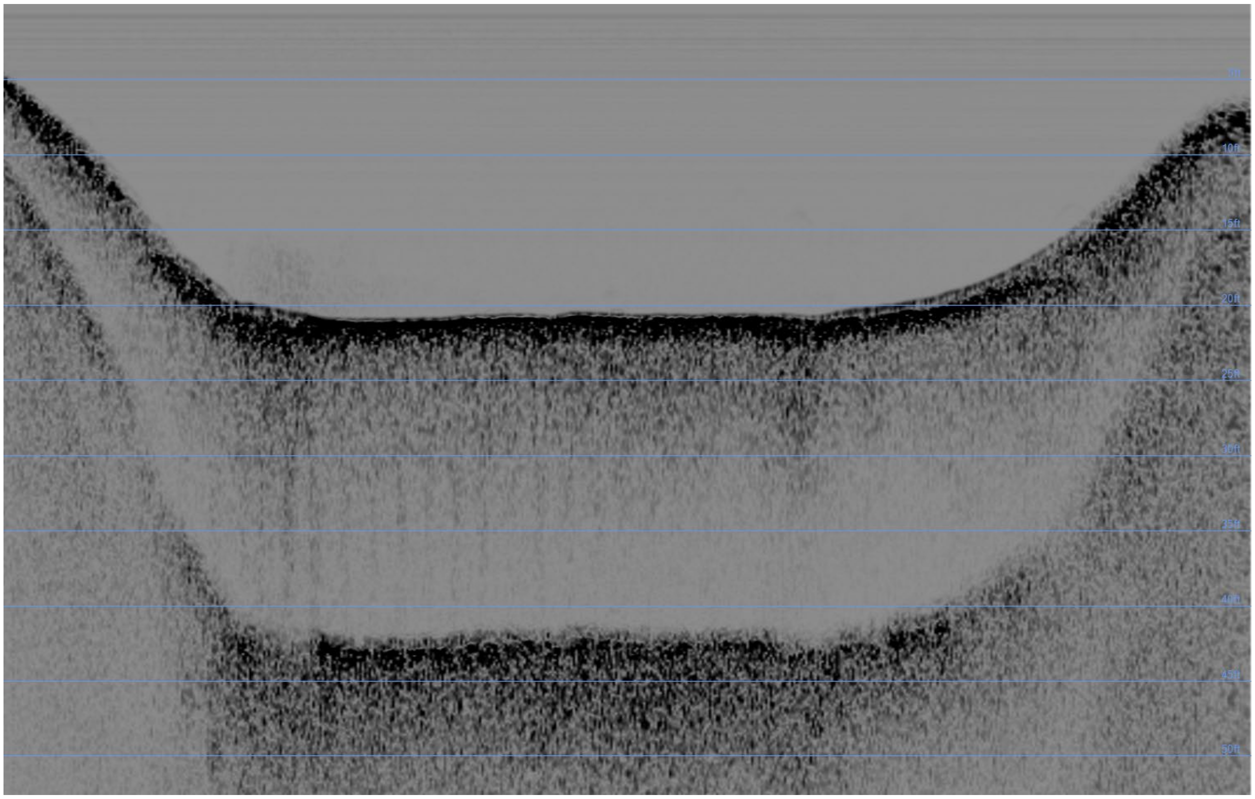
Aqua Survey, 2004. *Technical Report Environmental Dredging and Sediment Decontamination Technology Demonstration Pilot Study Lower Passaic River Restoration Project Magnetometer and Sub-Bottom Profiler Debris Survey*. December 3, 2004.

Juracek, K.E. and M.F. Becker, 2009. *Occurrence and Trends of Selected Chemical Constituents in Bottom Sediment, Grand Lake O' the Cherokees, Northeast Oklahoma, 1940–2008*. U.S. Geological Survey Scientific Investigations Report 2009–5258, 28 p.

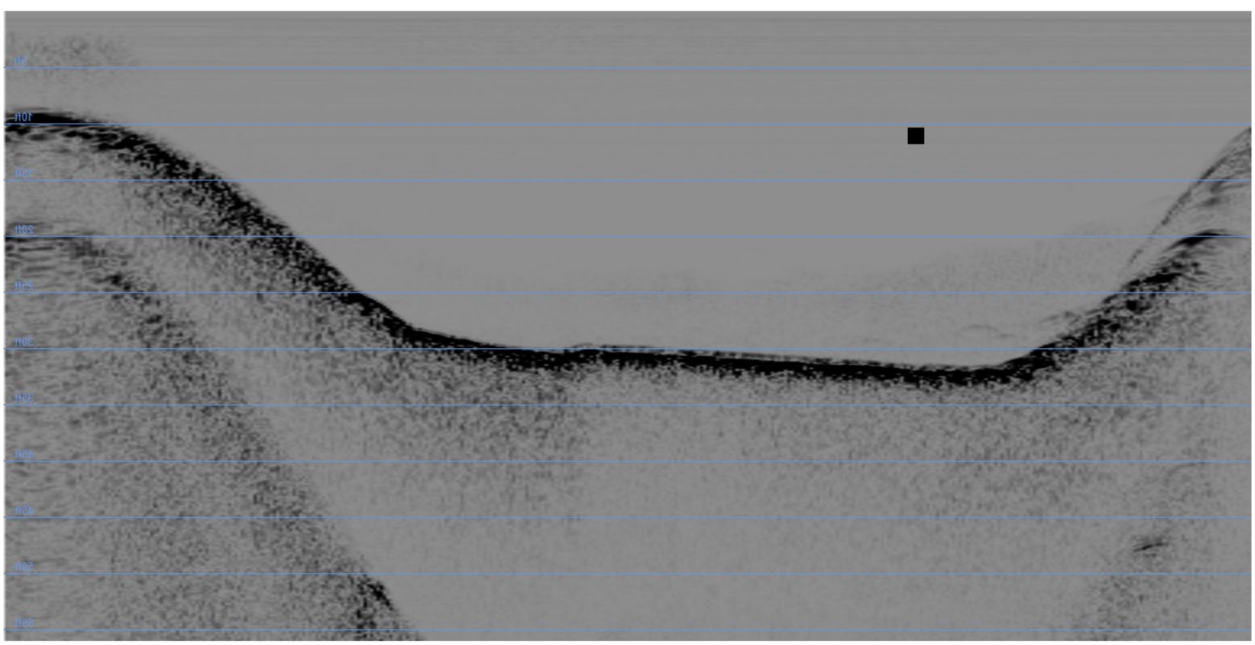
Science Applications International Corporation, 2001. *Results of the March 2001 Sub-Bottom Profiling and Sediment Profile Imaging of the Outer Gloucester Harbor*. SAIC Report 541. June 2001.

Appendix I
Waterfall Images from Sub-Bottom Survey

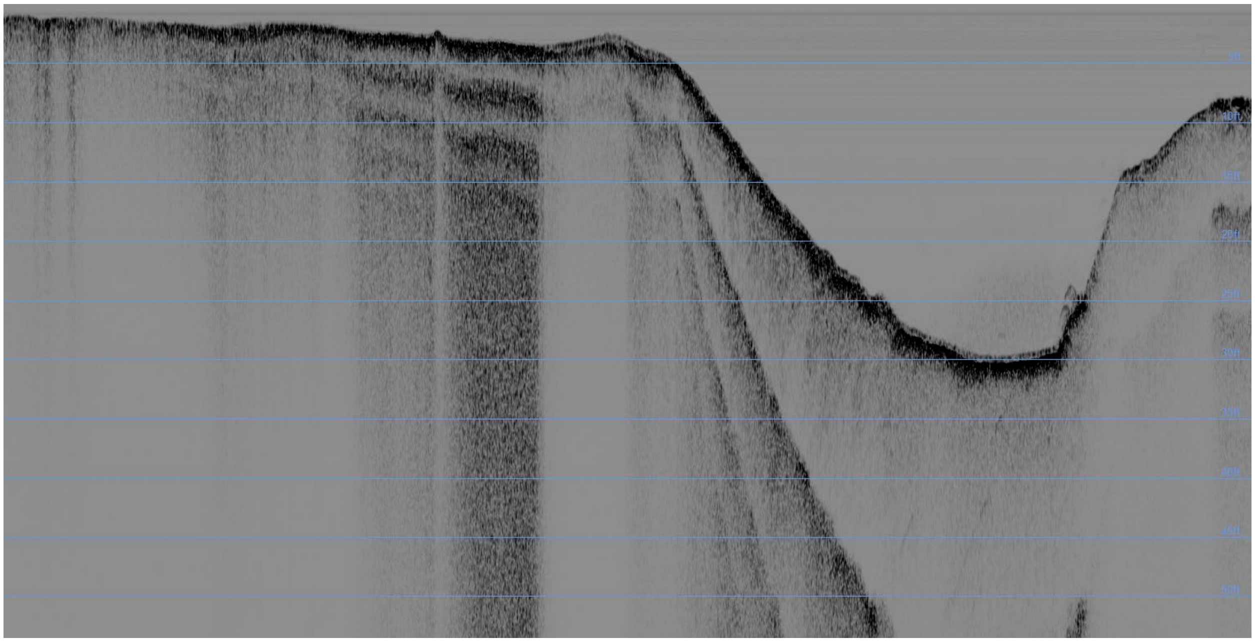
AI.1 Transect 1



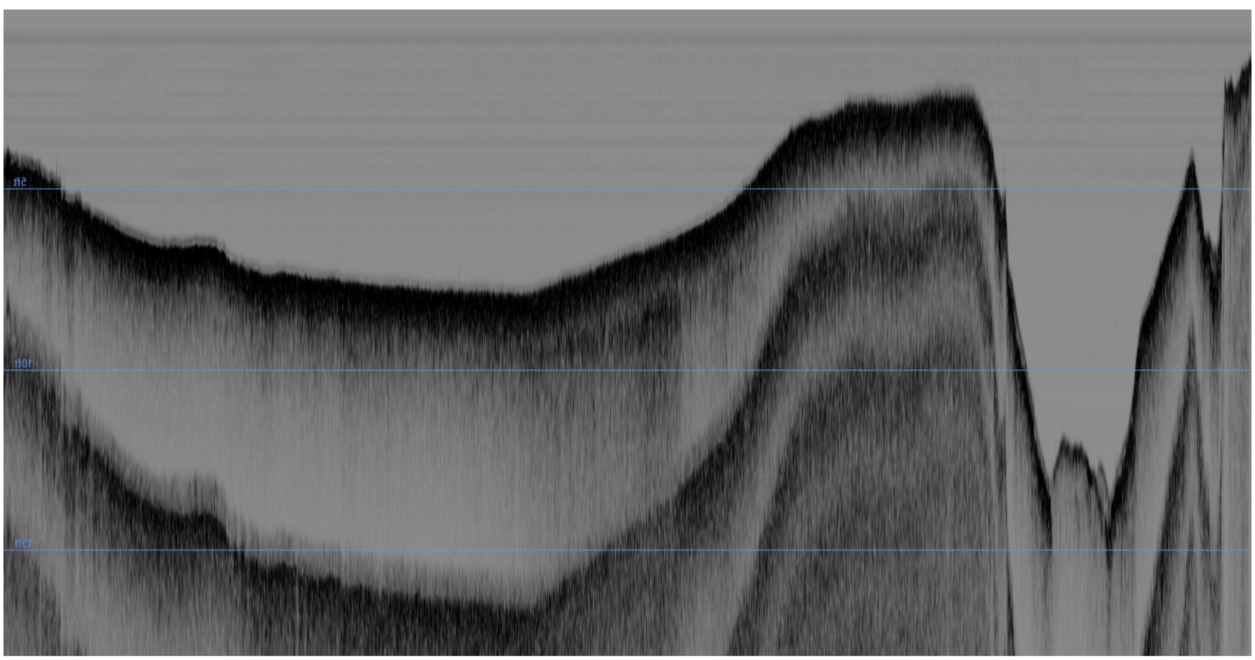
AI.2 Transect 2



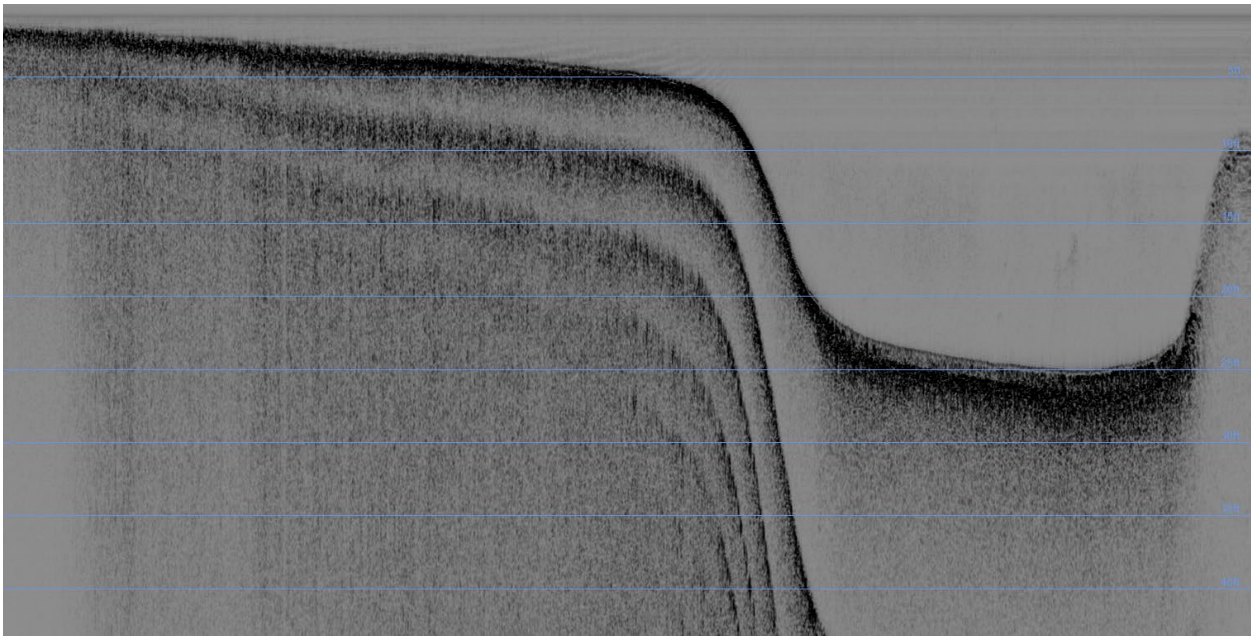
AI.3 Transect 3



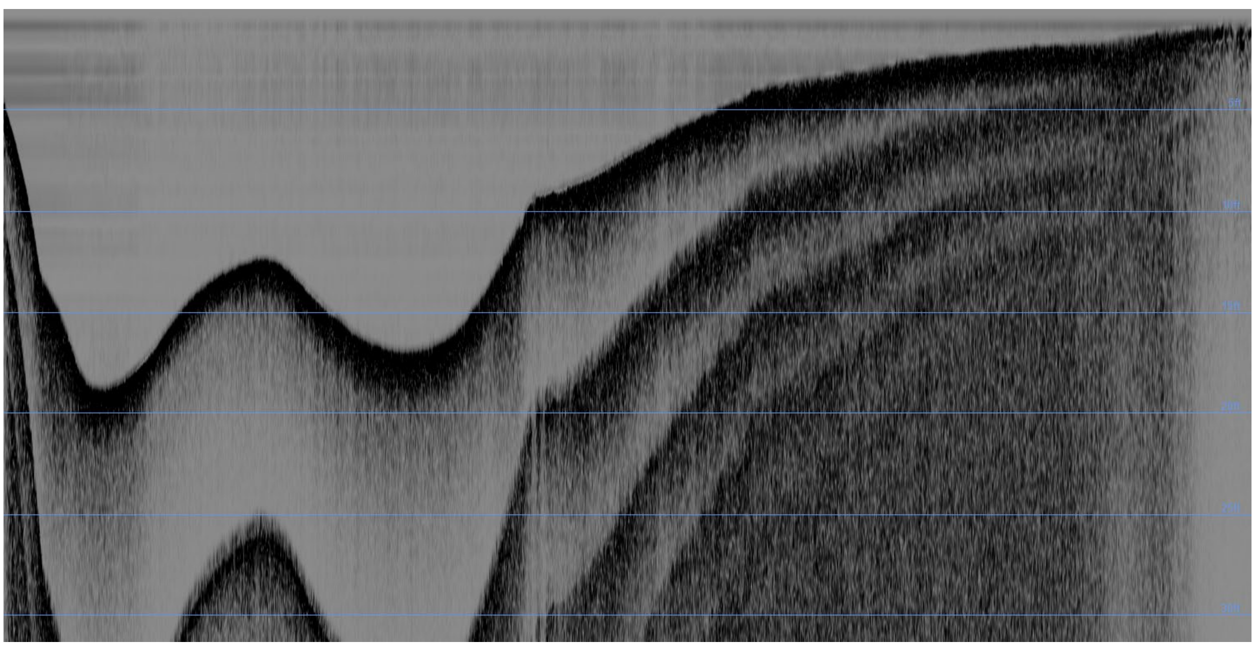
AI.4 Transect 4



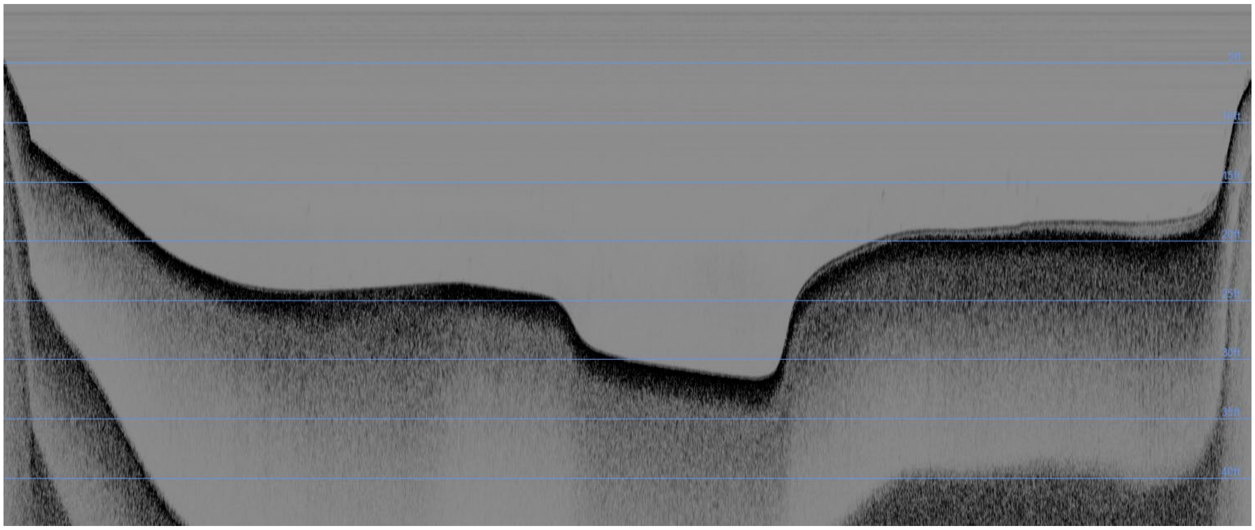
AI.5 Transect 5



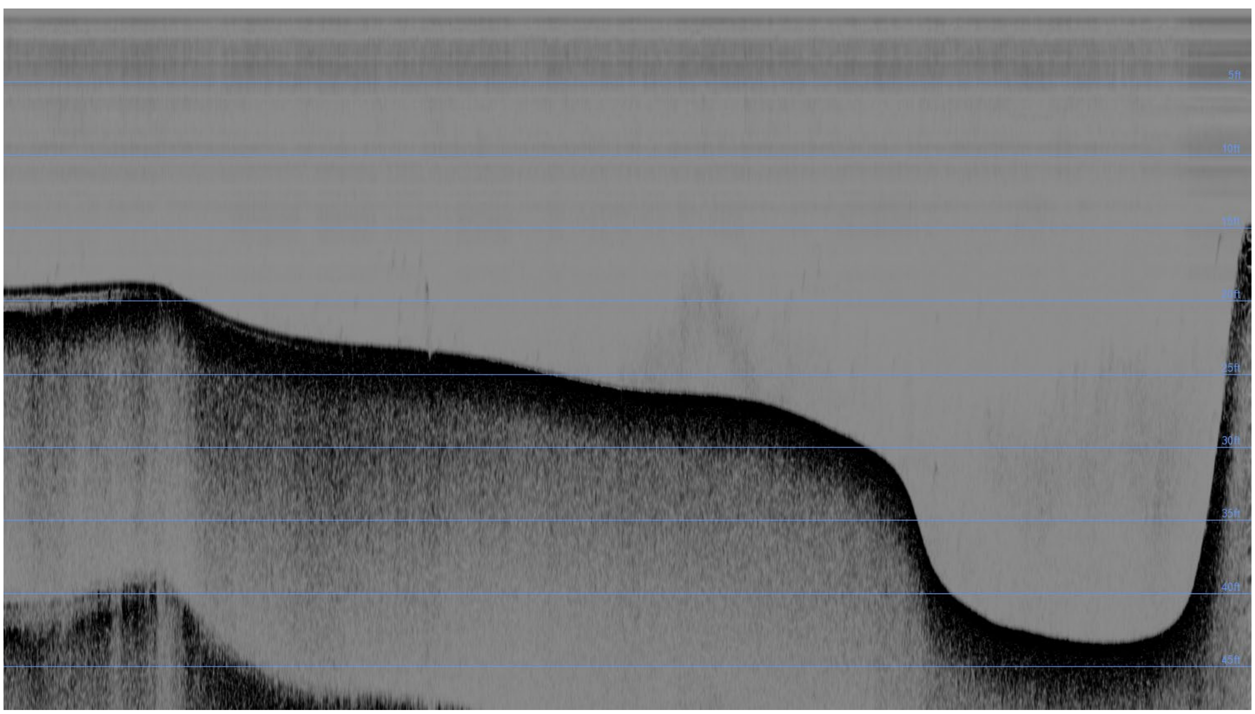
AI.6 Transect 6



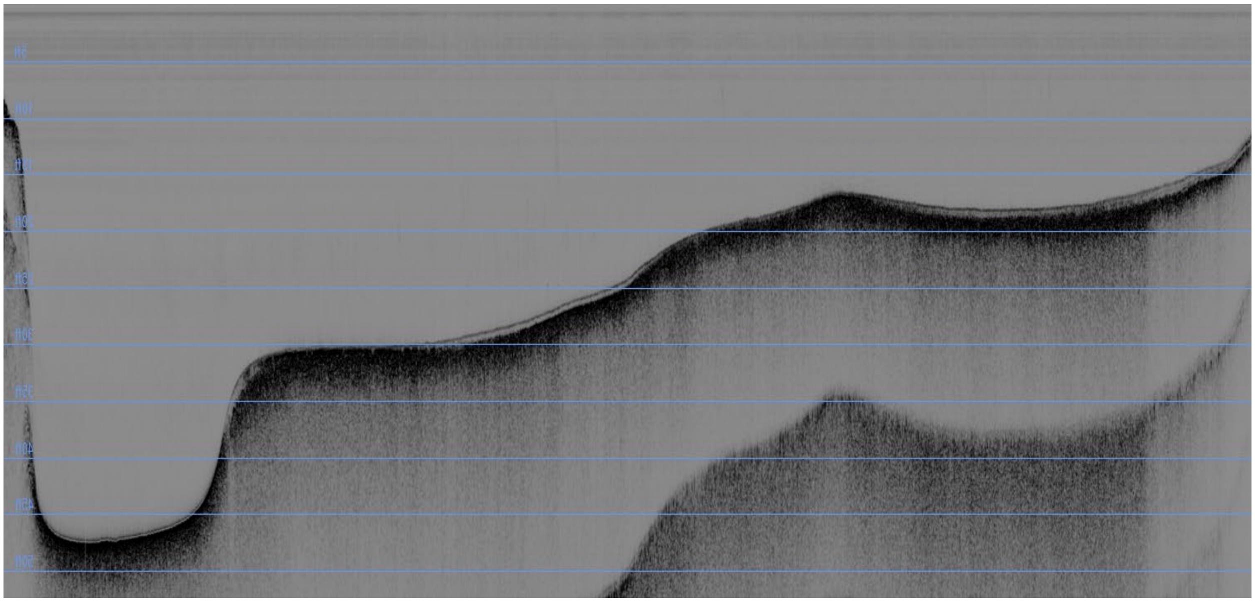
AI.7 Transect 7



AI.8 Transect 8



AI.9 Transect 9



Appendix II
Grain Size Analysis

Soil and Forage Analysis Lab
WISCONSIN STATE LABORATORY OF HYGIENE
UNIVERSITY OF WISCONSIN–MADISON

4702 University Ave
Madison, WI 53705
(608) 262-4364
http://uwlab.soils.wisc.edu

Date 4/18/2022
Acct # 559106
Report # 1228

Anchor QEA, LLC
30 W Mifflin St, Ste 801
Madison, WI 53713

Comments

Soil Texture Analysis

Sample Number	Sample Name Core	Depth (in)	SAND %	SILT %	Clay %	Soil Type
1	01.1-1	0-12	9.0	57.0	34	Silty Clay Loam
2		12 to 24	9.0	47.0	44	Silty Clay
3		24-36	17.0	41.0	42	Silty Clay.
4		36-48	17.0	39.0	44	Clay
5	01.1-2	0-12	5.0	59.0	36	Silty Clay Loam
6		12 to 24	9.0	37.0	54	Clay
7		24-36	9.0	49.0	42	Silty Clay
8		36-48	17.0	43.0	40	Silty Clay
9		48-60	8.0	44.0	48	Silty Clay
10		60-63	2.0	44.0	54	Silty Clay
11	02.1-1	0-12	16.0	52.0	32	Silty Clay Loam
12		12 to 24	12.0	50.0	38	Silty Clay Loam
13		24 to 36	14.0	42.0	44	Silty Clay
14		36 - 48	5.0	50.0	42	Silty Clay
15		48 - 60	14.0	42.0	44	Silty Clay
16		60 - 63	20.0	42.0	38	Silty Clay Loam
17	02.1-2	0 - 12	14.0	48.0	38	Silty Clay Loam
18		12 to 24	16.0	42.0	42	Silty Clay
19		24 to 36	18.0	42.0	40	Silty Clay
20		36 - 48	14.0	44.0	42	Silty Clay
21		48 - 60	32.0	30.0	38	Silty Clay Loam
22		60 - 72	18.0	44.0	38	Silty Clay Loam
23	03.1-1	0 - 12	30.0	34.0	36	Silty Clay Loam
24		12 to 24	14.0	48.0	38	Silty Clay Loam
25		12 to 24	18.0	42.0	40	Silty Clay
26		24 - 33	30.0	40.0	30	Clay Loam
27	03.1-2	0 - 12	14.0	52.0	34	Silty Clay Loam
28		24 - 36	16.0	44.0	40	Silty Clay
29	04.1-1	0 - 12	12.0	52.0	36	Silty Clay Loam
30		12 to 24	8.0	56.0	36	Silty Clay Loam
31		24 - 36	6.0	56.0	38	Silty Clay Loam
32		36 - 43	6.0	50.0	44	Silty Clay Loam
33		0 - 12	26.0	54.0	20	Silt Loam

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Acct # 559106
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Madison, WI 53713

Comments

Soil Texture Analysis

Sample Number	Sample Name Core	Depth (in)	SAND %	SILT %	Clay %	Soil Type
34	04.2-1	12 to 24	16.0	56.0	28	Silty Clay Loam
35		24 - 36	16.0	52.0	32	Silty Clay Loam
36		36 - 48	12.0	54.0	34	Silty Clay Loam
37		48 - 60	12.0	54.0	34	Silty Clay Loam
38		60 - 72	14.0	50.0	36	Silty Clay Loam
39		72 - 84	8.0	54.0	38	Silty Clay Loam
40		84 - 92	8.0	52.0	40	Silty Clay
41	05.1-2	0 - 12	8.0	58.0	34	Silty Clay Loam
42		12 to 24	8.0	56.0	36	Silty Clay Loam
43		24 - 36	12.0	54.0	34	Silty Clay Loam
44		36 - 48	8.0	58.0	34	Silty Clay Loam
45		48 - 60	9.0	52.0	39	Silty Clay Loam
46		60 - 72	9.0	50.0	41	Silty Clay
47		72 - 84	7.0	50.0	43	Silty Clay
48		84 - 96	13.0	48.0	39	Silty Clay Loam
49		96 - 102	18.8	48.0	33	Silty Clay Loam
50	05.2-2	0 - 12	12.8	50.0	37	Silty Clay Loam
51		12 to 24	28.8	44.0	27	Clay Loam
52		24 - 36	16.8	52.0	31	Silty Clay Loam
53		36 - 48	18.8	50.0	31	Silty Clay Loam
54		48 - 60	10.8	48.0	41	Silty Clay
55		60 - 72	8.8	52.0	39	Silty Clay Loam
56		72 - 84	10.8	56.0	33	Silty Clay Loam
57		84 - 96	12.8	50.0	37	Silty Clay Loam
58		96 - 102	10.8	54.0	35	Silty Clay Loam
59	06.1-1	0 - 12	10.8	52.0	37	Silty Clay Loam
60	06.2-1	0 - 12	14.8	52.0	33	Silty Clay Loam
61		12 to 24	8.8	54.0	37	Silty Clay Loam
62		24 - 36	6.8	56.0	37	Silty Clay Loam
63		36 - 48	4.8	58.0	37	Silty Clay Loam
64		48 - 60	4.8	56.0	39	Silty Clay Loam
65		60 - 72	4.8	52.0	43	Silty Clay Loam
66	06.2-2	0 - 12	6.8	58.0	35	Silty Clay Loam
67		12 to 24	4.8	58.0	37	Silty Clay Loam
68		24 - 36	8.8	56.0	35	Silty Clay Loam
69		36 - 48	6.8	58.0	35	Silty Clay Loam
70		48 - 60	4.8	56.0	39	Silty Clay Loam
71		60 - 72	2.8	58.0	39	Silty Clay Loam

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Madison, WI 53713

Comments

Soil Texture Analysis

Sample Number	Sample Name Core	Depth (in)	SAND %	SILT %	Clay %	Soil Type
72		72 - 81	0.8	58.0	41	Silty Clay
73	07.1-1	0 - 12	0.8	56.0	43	Silty Clay
74		12 to 24	0.8	60.0	39	Silty Clay Loam
75		24 - 36	2.8	58.0	39	Silty Clay Loam
76		36 - 48	2.8	54.0	43	Silty Clay
77		48 - 53	18.8	42.0	39	Silty Clay Loam
78	07.2-1	0 - 12	0.8	60.0	39	Silty Clay Loam
79		12 to 24	0.8	58.0	41	Silty Clay
80		24 - 36	0.8	56.0	43	Silty Clay
81		36 - 48	6.8	50.0	43	Silty Clay
82		48 - 60	6.8	48.0	45	Silty Clay
83		60 -72	2.8	46.0	51	Silty Clay
84		72 - 79	2.8	44.0	53	Silty Clay
85	08.1-1	0 - 12	4.8	52.0	43	Silty Clay
86		81 - 93	2.8	40.0	57	Silty Clay
87	08.1-2	0 - 12	10.8	52.0	37	Silty Clay Loam
88		117 - 129	2.8	34.0	63	Clay Loam
89	08.2-1	0 - 12	4.8	44.0	51	Silty Clay
90		12 to 24	6.8	42.0	51	Silty Clay
91	09.1-1	0 - 6	12.8	48.0	39	Silty Clay Loam
92		6 to 18	40.8	40.0	19	Silty Clay
93	09.1-2	0 - 12	42.8	36.0	21	Silty Clay
94	GL1-1	0 - 12	20.8	50.0	29	Clay Loam
95		12 to 24	10.8	54.0	35	Silty Clay Loam
96		24 - 36	8.8	54.0	37	Silty Clay Loam
97		36-48	7.0	52.0	41	Silty Clay
98		48-60	9.0	50.0	41	Silty Clay
99		60-72	8.0	52.0	40	Silty Clay
100		72-84	4.0	50.0	46	Silty Clay
101	GL1-2	0-12	16.0	52.0	32	Silty Clay Loam
102		12 to 24	8.0	56.0	36	Silty Clay Loam
103		24-36	10.0	56.0	34	Silty Clay Loam
104		36-48	8.0	52.0	40	Silty Clay
105		48-60	10.0	50.0	40	Silty Clay
106		60-72	4.0	48.0	48	Silty Clay
107		72-84	6.0	42.0	52	Silty Clay
108		84-90	6.0	38.0	56	Clay

Appendix III

Cesium-137 Analysis Results

TELEDYNE
BROWN ENGINEERING, INC.
A Teledyne Technologies Company
2508 Quality Lane
Knoxville, TN 37931-3133
865-690-6819

Work Order #: L95403

ANCHOR QEA

March 23, 2022

Table of Contents

TELEDYNE
BROWN ENGINEERING, INC.
A Teledyne Technologies Company
2508 Quality Lane
Knoxville, TN 37931-3133

Brent Teske
1201 3rd Ave, Suite 2600
Seattle WA 98101

Case Narrative - L95403
AN003-3EREGBTESKE-22

03/23/2022 14:01

Sample Receipt

The following sample(s) were received on March 10, 2022 in good condition, unless otherwise noted.

Cross Reference Table

Client ID	Laboratory ID	Station ID(if applicable)
1; 5.2-1	L95403-1	0-4 CM
8; 5.2-1	L95403-2	28-32 CM
15; 5.2-1	L95403-3	56-60 CM
22; 5.2-1	L95403-4	84-88 CM
29; 5.2-1	L95403-5	112-116 CM
36; 5.2-1	L95403-6	140-144 CM
43; 5.2-1	L95403-7	168-172 CM
50; 5.2-1	L95403-8	196-200 CM
57; 5.2-1	L95403-9	224-228 CM
63; 5.2-1	L95403-10	248-252 CM
64; 5.1-1	L95403-11	0-4 CM
72; 5.1-1	L95403-12	32-36 CM
80; 5.1-1	L95403-13	64-68 CM
88; 5.1-1	L95403-14	96-100 CM
96; 5.1-1	L95403-15	128-132 CM
104; 5.1-1	L95403-16	160-164 CM
112; 5.1-1	L95403-17	192-196 CM
120; 5.1-1	L95403-18	224-228 CM
128; 5.1-1	L95403-19	256-260 CM
137; 5.1-1	L95403-20	292-296 CM

Sample Analysis

Instrument(s) used for all analyses were in calibration.
Standard solution(s) used in analyses were National Institute of Standards and Technology (NIST) traceable.

Analytical Method Cross Reference Table

Radiological Parameter	TBE Knoxville Method	Reference Method
Gamma Spectrometry	TBE-2007	EPA 901.1

TELEDYNE
BROWN ENGINEERING, INC.
A Teledyne Technologies Company
2508 Quality Lane
Knoxville, TN 37931-3133

Case Narrative - L95403
AN003-3EREGBTESKE-22

03/23/2022 14:01

Special Considerations

Gamma Spectroscopy

Quality Control

Quality control sample(s) analyzed as WG38781, WG38795.

Duplicate Sample

All duplicate result(s) were within acceptance limits, unless otherwise noted. Duplicate(s) were analyzed for the following sample(s).

Client ID	Laboratory ID	QC Sample #
JORDAN COVE W	L95387-1	WG38781-1
SA-GAM-13E3	L95392-1	WG38795-1

Certification

This is to certify that Teledyne Brown Engineering - Environmental Services, located at 2508 Quality Lane, Knoxville, Tennessee, 37931, has analyzed, tested and documented samples as specified in the applicable purchase order.

This also certifies that requirements of applicable codes, standards and specifications have been fully met and that any quality assurance documentation which verified conformance to the purchase order is on file and may be examined upon request.

I hereby certify that the above statements are true and correct.

Keith Jeter
Operations Manager

ANALYTICAL RESULTS

Report of Analysis

03/23/22 14:01

L95403

TELEDYNE BROWN ENGINEERING, INC.
A Teledyne Technologies Company

Brent Teske

AN003-3EREGBTESKE-22

Sample ID:	**1; 5.2-1**	Collect Start:	02/13/2022 13:34	Matrix:	Sediment/Silt (SS)
Station:	0-4 CM	Collect Stop:	02/13/2022 13:40	Volume:	
Description:		Receive Date:	03/10/2022	% Moisture:	35.53
LIMS Number:	L95403-1				

Radionuclide	SOP#	Activity Conc	Uncertainty 2 Sigma	MDC	Units	Run #	Aliquot Volume	Aliquot Units	Reference Date	Count Date	Count Time	Count Units	Flag Values		
CS-137	2007	1.81E-02	3.95E-02	**6.62E-02**	pCi/g Dry		21.4	g dry	02/13/22 13:40	03/17/22	62071	Sec	U		No

Sample ID:	**8; 5.2-1**	Collect Start:	02/13/2022 13:34	Matrix:	Sediment/Silt (SS)
Station:	28-32 CM	Collect Stop:	02/13/2022 13:40	Volume:	
Description:		Receive Date:	03/10/2022	% Moisture:	33.49
LIMS Number:	L95403-2				

Radionuclide	SOP#	Activity Conc	Uncertainty 2 Sigma	MDC	Units	Run #	Aliquot Volume	Aliquot Units	Reference Date	Count Date	Count Time	Count Units	Flag Values		
CS-137	2007	3.63E-02	3.00E-02	**5.25E-02**	pCi/g Dry		32.3	g dry	02/13/22 13:40	03/18/22	64800	Sec	U		No

Sample ID:	**15; 5.2-1**	Collect Start:	02/13/2022 13:34	Matrix:	Sediment/Silt (SS)
Station:	56-60 CM	Collect Stop:	02/13/2022 13:40	Volume:	
Description:		Receive Date:	03/10/2022	% Moisture:	35.8
LIMS Number:	L95403-3				

Radionuclide	SOP#	Activity Conc	Uncertainty 2 Sigma	MDC	Units	Run #	Aliquot Volume	Aliquot Units	Reference Date	Count Date	Count Time	Count Units	Flag Values		
CS-137	2007	4.54E-02	3.94E-02	**4.20E-02**	pCi/g Dry		35.7	g dry	02/13/22 13:40	03/18/22	64800	Sec	U		Yes

Sample ID:	**22; 5.2-1**	Collect Start:	02/13/2022 13:34	Matrix:	Sediment/Silt (SS)
Station:	84-88 CM	Collect Stop:	02/13/2022 13:40	Volume:	
Description:		Receive Date:	03/10/2022	% Moisture:	36.82
LIMS Number:	L95403-4				

Radionuclide	SOP#	Activity Conc	Uncertainty 2 Sigma	MDC	Units	Run #	Aliquot Volume	Aliquot Units	Reference Date	Count Date	Count Time	Count Units	Flag Values		
CS-137	2007	3.26E-02	4.89E-02	**8.32E-02**	pCi/g Dry		26.7	g dry	02/13/22 13:40	03/17/22	62056	Sec	U		No

Flag Values

U	=	Compound/Analyte not detected (< MDC) or less than 3 sigma
+	=	Activity concentration exceeds MDC and 3 sigma; peak identified(gamma only)
U*	=	Compound/Analyte not detected. Peak not identified, but forced activity concentration exceeds MDC and 3 sigma
High	=	Activity concentration exceeds customer reporting value
Spec	=	MDC exceeds customer technical specification
L	=	Low recovery
H	=	High recovery

Bolded text indicates reportable value.

No = Peak not identified in gamma spectrum
Yes = Peak identified in gamma spectrum

**** Unless otherwise noted, the analytical results reported are related only to the samples tested in the condition they are received by the laboratory.

MDC - Minimum Detectable Concentration

TBE-ROA013

Report of Analysis

03/23/22 14:01

TELEDYNE BROWN ENGINEERING, INC.
A Teledyne Technologies Company

L95403

Brent Teske

AN003-3EREGBTESKE-22

Sample ID: **29; 5.2-1**
Station: 112-116 CM
Description:
LIMS Number: L95403-5

Collect Start: 02/13/2022 13:34
Collect Stop: 02/13/2022 13:40
Receive Date: 03/10/2022

Matrix: Sediment/Silt (SS)
Volume:
% Moisture: 30.69

Radionuclide	SOP#	Activity Conc	Uncertainty 2 Sigma	MDC	Units	Run #	Aliquot Volume	Aliquot Units	Reference Date	Count Date	Count Time	Count Units	Flag Values		
CS-137	2007	2.74E-02	3.08E-02	**5.19E-02**	pCi/g Dry		30.4	g dry	02/13/22 13:40	03/18/22	64800	Sec	U		No

Sample ID: **36; 5.2-1**
Station: 140-144 CM
Description:
LIMS Number: L95403-6

Collect Start: 02/13/2022 13:34
Collect Stop: 02/13/2022 13:40
Receive Date: 03/10/2022

Matrix: Sediment/Silt (SS)
Volume:
% Moisture: 41.21

Radionuclide	SOP#	Activity Conc	Uncertainty 2 Sigma	MDC	Units	Run #	Aliquot Volume	Aliquot Units	Reference Date	Count Date	Count Time	Count Units	Flag Values		
CS-137	2007	4.68E-02	3.65E-02	**6.43E-02**	pCi/g Dry		24.6	g dry	02/13/22 13:40	03/17/22	62086	Sec	U		No

Sample ID: **43; 5.2-1**
Station: 168-172 CM
Description:
LIMS Number: L95403-7

Collect Start: 02/13/2022 13:34
Collect Stop: 02/13/2022 13:40
Receive Date: 03/10/2022

Matrix: Sediment/Silt (SS)
Volume:
% Moisture: 40.14

Radionuclide	SOP#	Activity Conc	Uncertainty 2 Sigma	MDC	Units	Run #	Aliquot Volume	Aliquot Units	Reference Date	Count Date	Count Time	Count Units	Flag Values		
CS-137	2007	**9.32E-02**	3.46E-02	4.29E-02	pCi/g Dry		27.4	g dry	02/13/22 13:40	03/18/22	64800	Sec	+		Yes

Sample ID: **50; 5.2-1**
Station: 196-200 CM
Description:
LIMS Number: L95403-8

Collect Start: 02/13/2022 13:34
Collect Stop: 02/13/2022 13:40
Receive Date: 03/10/2022

Matrix: Sediment/Silt (SS)
Volume:
% Moisture: 34.07

Radionuclide	SOP#	Activity Conc	Uncertainty 2 Sigma	MDC	Units	Run #	Aliquot Volume	Aliquot Units	Reference Date	Count Date	Count Time	Count Units	Flag Values		
CS-137	2007	**1.19E-01**	5.25E-02	6.65E-02	pCi/g Dry		45.9	g dry	02/13/22 13:40	03/18/22	64800	Sec	+		Yes

Flag Values
U = Compound/Analyte not detected (< MDC) or less than 3 sigma
+ = Activity concentration exceeds MDC and 3 sigma; peak identified(gamma only)
U* = Compound/Analyte not detected. Peak not identified, but forced activity concentration exceeds MDC and 3 sigma
High = Activity concentration exceeds customer reporting value
Spec = MDC exceeds customer technical specification
L = Low recovery
H = High recovery

Bolded text indicates reportable value.

No = Peak not identified in gamma spectrum
Yes = Peak identified in gamma spectrum

**** Unless otherwise noted, the analytical results reported are related only to the samples tested in the condition they are received by the laboratory.

MDC - Minimum Detectable Concentration

TBE-ROA013

Report of Analysis

03/23/22 14:01

L95403

TELEDYNE BROWN ENGINEERING, INC.
A Teledyne Technologies Company

Brent Teske — AN003-3EREGBTESKE-22

Sample ID: **57; 5.2-1** | Station: 224-228 CM | Description: | LIMS Number: L95403-9
Collect Start: 02/13/2022 13:34 | Collect Stop: 02/13/2022 13:40 | Receive Date: 03/10/2022
Matrix: Sediment/Silt (SS) | Volume: | % Moisture: 27.7

Radionuclide	SOP#	Activity Conc	Uncertainty 2 Sigma	MDC	Units	Run #	Aliquot Volume	Aliquot Units	Reference Date	Count Date	Count Time	Count Units	Flag Values		
CS-137	2007	4.68E-02	3.56E-02	**6.08E-02**	pCi/g Dry		31.1	g dry	02/13/22 13:40	03/18/22	64800	Sec	U		No

Sample ID: **63; 5.2-1** | Station: 248-252 CM | Description: | LIMS Number: L95403-10
Collect Start: 02/13/2022 13:34 | Collect Stop: 02/13/2022 13:40 | Receive Date: 03/10/2022
Matrix: Sediment/Silt (SS) | Volume: | % Moisture: 34.86

Radionuclide	SOP#	Activity Conc	Uncertainty 2 Sigma	MDC	Units	Run #	Aliquot Volume	Aliquot Units	Reference Date	Count Date	Count Time	Count Units	Flag Values		
CS-137	2007	3.53E-02	4.48E-02	**7.55E-02**	pCi/g Dry		24.8	g dry	02/13/22 13:40	03/17/22	62078	Sec	U		No

Sample ID: **64; 5.1-1** | Station: 0-4 CM | Description: | LIMS Number: L95403-11
Collect Start: 02/13/2022 12:52 | Collect Stop: 02/13/2022 13:00 | Receive Date: 03/10/2022
Matrix: Sediment/Silt (SS) | Volume: | % Moisture: 36.13

Radionuclide	SOP#	Activity Conc	Uncertainty 2 Sigma	MDC	Units	Run #	Aliquot Volume	Aliquot Units	Reference Date	Count Date	Count Time	Count Units	Flag Values		
CS-137	2007	2.68E-02	3.92E-02	**6.46E-02**	pCi/g Dry		25.5	g dry	02/13/22 13:00	03/17/22	62093	Sec	U		No

Sample ID: **72; 5.1-1** | Station: 32-36 CM | Description: | LIMS Number: L95403-12
Collect Start: 02/13/2022 12:52 | Collect Stop: 02/13/2022 13:00 | Receive Date: 03/10/2022
Matrix: Sediment/Silt (SS) | Volume: | % Moisture: 40.9

Radionuclide	SOP#	Activity Conc	Uncertainty 2 Sigma	MDC	Units	Run #	Aliquot Volume	Aliquot Units	Reference Date	Count Date	Count Time	Count Units	Flag Values		
CS-137	2007	-1.16E-02	3.62E-02	**5.91E-02**	pCi/g Dry		26.9	g dry	02/13/22 13:00	03/17/22	62081	Sec	U		No

Flag Values
U = Compound/Analyte not detected (< MDC) or less than 3 sigma
+ = Activity concentration exceeds MDC and 3 sigma; peak identified(gamma only)
U* = Compound/Analyte not detected. Peak not identified, but forced activity concentration exceeds MDC and 3 sigma
High = Activity concentration exceeds customer reporting value
Spec = MDC exceeds customer technical specification
L = Low recovery
H = High recovery

Bolded text indicates reportable value.

No = Peak not identified in gamma spectrum
Yes = Peak identified in gamma spectrum

**** Unless otherwise noted, the analytical results reported are related only to the samples tested in the condition they are received by the laboratory.

MDC - Minimum Detectable Concentration

Report of Analysis

03/23/22 14:01

L95403

TELEDYNE BROWN ENGINEERING, INC.
A Teledyne Technologies Company

Brent Teske

AN003-3EREGBTESKE-22

Sample ID: **80; 5.1-1**
Station: 64-68 CM
Description:
LIMS Number: L95403-13
Collect Start: 02/13/2022 12:52
Collect Stop: 02/13/2022 13:00
Receive Date: 03/10/2022
Matrix: Sediment/Silt (SS)
Volume:
% Moisture: 29.79

Radionuclide	SOP#	Activity Conc	Uncertainty 2 Sigma	MDC	Units	Run #	Aliquot Volume	Aliquot Units	Reference Date	Count Date	Count Time	Count Units	Flag Values		
CS-137	2007	3.94E-02	3.16E-02	**5.59E-02**	pCi/g Dry		21.4	g dry	02/13/22 13:00	03/17/22	62106	Sec	U		No

Sample ID: **88; 5.1-1**
Station: 96-100 CM
Description:
LIMS Number: L95403-14
Collect Start: 02/13/2022 12:52
Collect Stop: 02/13/2022 13:00
Receive Date: 03/10/2022
Matrix: Sediment/Silt (SS)
Volume:
% Moisture: 35.63

Radionuclide	SOP#	Activity Conc	Uncertainty 2 Sigma	MDC	Units	Run #	Aliquot Volume	Aliquot Units	Reference Date	Count Date	Count Time	Count Units	Flag Values		
CS-137	2007	1.83E-02	4.36E-02	**7.35E-02**	pCi/g Dry		41.7	g dry	02/13/22 13:00	03/18/22	64800	Sec	U		No

Sample ID: **96; 5.1-1**
Station: 128-132 CM
Description:
LIMS Number: L95403-15
Collect Start: 02/13/2022 12:52
Collect Stop: 02/13/2022 13:00
Receive Date: 03/10/2022
Matrix: Sediment/Silt (SS)
Volume:
% Moisture: 35.73

Radionuclide	SOP#	Activity Conc	Uncertainty 2 Sigma	MDC	Units	Run #	Aliquot Volume	Aliquot Units	Reference Date	Count Date	Count Time	Count Units	Flag Values		
CS-137	2007	7.64E-02	4.74E-02	**8.37E-02**	pCi/g Dry		27.3	g dry	02/13/22 13:00	03/17/22	62114	Sec	U		No

Sample ID: **104; 5.1-1**
Station: 160-164 CM
Description:
LIMS Number: L95403-16
Collect Start: 02/13/2022 12:52
Collect Stop: 02/13/2022 13:00
Receive Date: 03/10/2022
Matrix: Sediment/Silt (SS)
Volume:
% Moisture: 33.69

Radionuclide	SOP#	Activity Conc	Uncertainty 2 Sigma	MDC	Units	Run #	Aliquot Volume	Aliquot Units	Reference Date	Count Date	Count Time	Count Units	Flag Values		
CS-137	2007	5.08E-02	3.81E-02	**4.70E-02**	pCi/g Dry		30	g dry	02/13/22 13:00	03/18/22	64800	Sec	U		Yes

Flag Values
U = Compound/Analyte not detected (< MDC) or less than 3 sigma
\+ = Activity concentration exceeds MDC and 3 sigma; peak identified(gamma only)
U* = Compound/Analyte not detected. Peak not identified, but forced activity concentration exceeds MDC and 3 sigma
High = Activity concentration exceeds customer reporting value
Spec = MDC exceeds customer technical specification
L = Low recovery
H = High recovery

Bolded text indicates reportable value.

No = Peak not identified in gamma spectrum
Yes = Peak identified in gamma spectrum

**** Unless otherwise noted, the analytical results reported are related only to the samples tested in the condition they are received by the laboratory.

MDC - Minimum Detectable Concentration

TBE-ROA013

Report of Analysis

03/23/22 14:01

TELEDYNE BROWN ENGINEERING, INC.
A Teledyne Technologies Company

L95403

Brent Teske

AN003-3EREGBTESKE-22

Sample ID: **112; 5.1-1**	Collect Start: 02/13/2022 12:52	Matrix: Sediment/Silt	(SS)
Station: 192-196 CM	Collect Stop: 02/13/2022 13:00	Volume:	
Description:	Receive Date: 03/10/2022	% Moisture: 34.13	
LIMS Number: L95403-17			

Radionuclide	SOP#	Activity Conc	Uncertainty 2 Sigma	MDC	Units	Run #	Aliquot Volume	Aliquot Units	Reference Date	Count Date	Count Time	Count Units	Flag Values		
CS-137	2007	6.14E-02	3.75E-02	**6.51E-02**	pCi/g Dry		44.1	g dry	02/13/22 13:00	03/18/22	64800	Sec	U		No

Sample ID: **120; 5.1-1**	Collect Start: 02/13/2022 12:52	Matrix: Sediment/Silt	(SS)
Station: 224-228 CM	Collect Stop: 02/13/2022 13:00	Volume:	
Description:	Receive Date: 03/10/2022	% Moisture: 34.26	
LIMS Number: L95403-18			

Radionuclide	SOP#	Activity Conc	Uncertainty 2 Sigma	MDC	Units	Run #	Aliquot Volume	Aliquot Units	Reference Date	Count Date	Count Time	Count Units	Flag Values		
CS-137	2007	**1.48E-01**	5.30E-02	6.01E-02	pCi/g Dry		23.6	g dry	02/13/22 13:00	03/17/22	62133	Sec	+		Yes

Sample ID: **128; 5.1-1**	Collect Start: 02/13/2022 12:52	Matrix: Sediment/Silt	(SS)
Station: 256-260 CM	Collect Stop: 02/13/2022 13:00	Volume:	
Description:	Receive Date: 03/10/2022	% Moisture: 31.74	
LIMS Number: L95403-19			

Radionuclide	SOP#	Activity Conc	Uncertainty 2 Sigma	MDC	Units	Run #	Aliquot Volume	Aliquot Units	Reference Date	Count Date	Count Time	Count Units	Flag Values		
CS-137	2007	**8.09E-02**	5.28E-02	5.56E-02	pCi/g Dry		49.1	g dry	02/13/22 13:00	03/21/22	63387	Sec	+		Yes

Sample ID: **137; 5.1-1**	Collect Start: 02/13/2022 13:00	Matrix: Sediment/Silt	(SS)
Station: 292-296 CM	Collect Stop: 02/13/2022 13:00	Volume:	
Description:	Receive Date: 03/10/2022	% Moisture: 33.22	
LIMS Number: L95403-20			

Radionuclide	SOP#	Activity Conc	Uncertainty 2 Sigma	MDC	Units	Run #	Aliquot Volume	Aliquot Units	Reference Date	Count Date	Count Time	Count Units	Flag Values		
CS-137	2007	**1.73E-01**	5.35E-02	6.11E-02	pCi/g Dry		53.6	g dry	02/13/22 13:00	03/21/22	63423	Sec	+		Yes

Flag Values
U = Compound/Analyte not detected (< MDC) or less than 3 sigma
\+ = Activity concentration exceeds MDC and 3 sigma; peak identified(gamma only)
U* = Compound/Analyte not detected. Peak not identified, but forced activity concentration exceeds MDC and 3 sigma
High = Activity concentration exceeds customer reporting value
Spec = MDC exceeds customer technical specification
L = Low recovery
H = High recovery

Bolded text indicates reportable value.

No = Peak not identified in gamma spectrum
Yes = Peak identified in gamma spectrum

**** Unless otherwise noted, the analytical results reported are related only to the samples tested in the condition they are received by the laboratory.

MDC - Minimum Detectable Concentration

QC RESULTS

QC Summary Report for L95403

AN003-3EREGBTESKE-22

03/23/2022 14:01

TELEDYNE BROWN ENGINEERING Everywhereyoulook™

GAMMA

Duplicate Summary

TBE Sample ID	Radionuclide	Matrix	Count Date/Time	Original Result	DUP Result	Units	RPD	Range	Qualifier	P/F
WG38781-1 L95387-1	K-40	VA	03/10/2022 12:48	6.561E+00	5.754E+00	pCi/g Wet	13.1	<50	+	P
WG38795-1 L95392-1	K-40	AN	03/11/2022 11:21	3.007E+03	3.013E+03	pCi/kg Wet	0.2	<50	+	P

GAMMA

Associated Samples for WG38781

Sample #	Client ID
L95403-1	1; 5.2-1
L95403-2	8; 5.2-1
L95403-3	15; 5.2-1
L95403-4	22; 5.2-1
L95403-5	29; 5.2-1
L95403-6	36; 5.2-1
L95403-7	43; 5.2-1
L95403-8	50; 5.2-1
L95403-9	57; 5.2-1
L95403-10	63; 5.2-1

+	Positive Result
U	Compound/analyte was analyzed, peak not identified and/or not detected above MDC
*	< 5 times the MDC are not evaluated
**	Nuclide not detected
***	Spiking level < 5 times activity
P	Pass
F	Fail
NE	Not evaluated

QC Summary Report for L95403
AN003-3EREGBTESKE-22

03/23/2022 14:01

GAMMA

GAMMA
Associated Samples for **WG38795**

Sample #	Client ID
L95403-11	64; 5.1-1
L95403-12	72; 5.1-1
L95403-13	80; 5.1-1
L95403-14	88; 5.1-1
L95403-15	96; 5.1-1
L95403-16	104; 5.1-1
L95403-17	112; 5.1-1
L95403-18	120; 5.1-1
L95403-19	128; 5.1-1
L95403-20	137; 5.1-1

+	Positive Result
U	Compound/analyte was analyzed, peak not identified and/or not detected above MDC
*	< 5 times the MDC are not evaluated
**	Nuclide not detected
***	Spiking level < 5 times activity
P	Pass
F	Fail
NE	Not evaluated

SAMPLE RECEIPT

TELEDYNE BROWN ENGINEERING
A Teledyne Technologies Company

Analysis Request
Chain of Custody

E - Environmental: E
P - 10CFR61, 10CFR50, Other high level:
Turn-around-time 14 days
Purchase order:

Lims# L95403 (for lab use)

Client name: Anchor QEA
Client address: 1201 3rd Ave, Suite 2600
Seattle, WA 98101
Phone Number 608-616-9450
Cell number:
email; bteske@Anchorqea.com
Contact: Brent Teske

T.I. Number (for lab use)	Client Sample ID	Description	Station	Collection Date/Time Start		Collection Date/Time Stop		Volume	Units	Matrix or type	Analysis Request
	1; 5.2-1	0-4 cm		2/13/2022	13:34	2/13/2022	13:40			SS	GELI, Sample Prep
	8; 5.2-1	28-32 cm		2/13/2022	13:34	2/13/2022	13:40			SS	GELI, Sample Prep
	15; 5.2-1	56-60 cm		2/13/2022	13:34	2/13/2022	13:40			SS	GELI, Sample Prep
	22; 5.2-1	84-88 cm		2/13/2022	13:34	2/13/2022	13:40			SS	GELI, Sample Prep
	29; 5.2-1	112-116 cm		2/13/2022	13:34	2/13/2022	13:40			SS	GELI, Sample Prep
	36; 5.2-1	140-144 cm		2/13/2022	13:34	2/13/2022	13:40			SS	GELI, Sample Prep
	43; 5.2-1	168-172 cm		2/13/2022	13:34	2/13/2022	13:40			SS	GELI, Sample Prep
	50; 5.2-1	196-200 cm		2/13/2022	13:34	2/13/2022	13:40			SS	GELI, Sample Prep
	57; 5.2-1	224-228 cm		2/13/2022	13:34	2/13/2022	13:40			SS	GELI, Sample Prep
	63; 5.2-1	248-252 cm		2/13/2022	13:34	2/13/2022	13:40			SS	GELI, Sample Prep
	64; 5.1-1	0-4 cm		2/13/2022	12:52	2/13/2022	13:00			SS	GELI, Sample Prep
	72; 5.1-1	32-36 cm		2/13/2022	12:52	2/13/2022	13:00			SS	GELI, Sample Prep
	80; 5.1-1	64-68 cm		2/13/2022	12:52	2/13/2022	13:00			SS	GELI, Sample Prep
	88; 5.1-1	96-100 cm		2/13/2022	12:52	2/13/2022	13:00			SS	GELI, Sample Prep
	96; 5.1-1	128-132 cm		2/13/2022	12:52	2/13/2022	13:00			SS	GELI, Sample Prep
	104; 5.1-1	160-164 cm		2/13/2022	12:52	2/13/2022	13:00			SS	GELI, Sample Prep
	112; 5.1-1	192-196 cm		2/13/2022	12:52	2/13/2022	13:00			SS	GELI, Sample Prep
	120; 5.1-1	224-228 cm		2/13/2022	12:52	2/13/2022	13:00			SS	GELI, Sample Prep
	128; 5.1-1	256-260 cm		2/13/2022	12:52	2/13/2022	13:00			SS	GELI, Sample Prep
	137; 5.1-1	292-296 cm		2/13/2022	13:00	2/13/2022	13:00			SS	GELI, Sample Prep

Special Instructions:

Relinquished by:	Date:	Relinquished by:	Date:	Relinquished by:	Date:
Received by: [signature]	Date: 5-10-22	Received by:	Date:	Received by:	Date:

TELEDYNE
BROWN ENGINEERING, INC.
A Teledyne Technologies Company
2508 Quality Lane
Knoxville, TN 37931-3133
865-690-6819

General Information

Quote#: Q685
Quote Date: 02/10/2022
Description: 120 Soil Core samples for Cs-137 dating.
Client: Anchor QEA
Address: 1201 3rd Ave, Suite 2600
Seattle, WA 98101

Contact: Brent Teske
Phone #: (608)616-9450 **Ext.**
Fax #:
Email: bteske@Anchorqea.com

Project Manager: Karli Arterburn
Email: Karli.Arterburn@Teledyne.com
Phone: (865)934-0371
Fax:

Ship samples to:
Teledyne Brown Engineering
2508 Quality Lane
Knoxville, TN 37931
Attention: Sample Receiving

Project Requirements

Data Deliverable: Level 4 - Full 3Sigma
Electronic Deliverable: EQuis,AQ_EZEDD,EDI Anchor QEA
Regulatory Agency:

Estimated Start Date:
Quote Expiration: 12/31/2022
Terms: Net 30

Comments: Standard turn around time may be extended depending on how many sample are sent to be analyzed due the additional step of drying and grinding.

Price per Sample

Matrix	Product Code	30 Day TAT
Sediment/Silt	Gamma *Cs-137 0.1 pCi/g (extended count)*	$126.00
Sediment/Silt	~~Lead 210~~ ~~*Pb-210 0.1 pCi/g*~~	~~$84.00~~
Sediment/Silt	Sample Prep *Drying, grinding, and sieving samples.*	$25.00

Special Considerations

Unless otherwise instructed, batch Laboratory QC will be used and is included in pricing.

Disclaimer

Receipt of samples from the above referenced project shall constitute acceptance of TBE payments terms of and acceptance of the Laboratory Terms and Conditions.

Batch QC is included in pricing.
Client specific QC will be billed at the above rate.

03/23/22 14:09

SR #: SR73957

Client: Anchor QEA, LLC

Teledyne Brown Engineering
Sample Receipt Verification/Variance Report

Project #: AN003-3EREGBTESKE-22 LIMS #L95403

Initiated By: KNOXLAB
Init Date: 03/10/22 Receive Date: 03/10/22

Notification of Variance

Person Notified: Contacted By:
Notify Date:
Notify Method:
Notify Comment:

Client Response

Person Responding:
Response Date:
Response Method:
Response Comment:

	Criteria	Yes No NA	Comment
1	Shipping container custody seals present and intact.	NA	
2	Sample container custody seals present and intact.	NA	
3	Sample containers received in good condition.	Y	
4	Chain of custody received with samples.	Y	
5	All samples listed on chain of custody received.	Y	
6	Sample container labels present and legible.	Y	
7	Information on container labels correspond with chain of custody.	Y	
8	Sample(s) properly preserved.	Y	
9	Sample(s) appropriate container(s).	Y	
10	Other. (Describe)	NA	
For Hazardous Materials Only:			
11	Paperwork shows TBE and shippers name, address and phone number.	NA	
12	Paperwork shows sample quantity information.	NA	

INTERNAL CHAIN OF CUSTODY

Internal Chain of Custody

****

Sample # L95403-1 Containernum 1

Prod GELI Analyst DH

SAMPLE PREP

Relinquish Date	Relinquish By	Received By	
03/10/2022 00:00		099999	Sample Custodian

****

Sample # L95403-2 Containernum 1

Prod GELI Analyst DH

SAMPLE PREP

Relinquish Date	Relinquish By	Received By	
03/10/2022 00:00		099999	Sample Custodian

****

Sample # L95403-3 Containernum 1

Prod GELI Analyst DH

SAMPLE PREP

Relinquish Date	Relinquish By	Received By	
03/10/2022 00:00		099999	Sample Custodian

****

Sample # L95403-4 Containernum 1

Prod GELI Analyst DH

SAMPLE PREP

Relinquish Date	Relinquish By	Received By	
03/10/2022 00:00		099999	Sample Custodian

****

Sample # L95403-5 Containernum 1

Prod GELI Analyst DH

SAMPLE PREP

Relinquish Date	Relinquish By	Received By	
03/10/2022 00:00		099999	Sample Custodian

****

Sample # L95403-6 Containernum 1

Prod GELI Analyst DH

SAMPLE PREP

Relinquish Date	Relinquish By	Received By	
03/10/2022 00:00		099999	Sample Custodian

****

Sample # L95403-7 Containernum 1

Prod GELI Analyst DH

SAMPLE PREP

Relinquish Date	Relinquish By	Received By	
03/10/2022 00:00		099999	Sample Custodian

****

****

Sample # L95403-8 Containernum 1

Prod Analyst
GELI DH

SAMPLE PREP

Relinquish Date Relinquish By Received By
03/10/2022 00:00 099999 Sample Custodian

****

Sample # L95403-9 Containernum 1

Prod Analyst
GELI DH

SAMPLE PREP

Relinquish Date Relinquish By Received By
03/10/2022 00:00 099999 Sample Custodian

****

Sample # L95403-10 Containernum 1

Prod Analyst
GELI DH

SAMPLE PREP

Relinquish Date Relinquish By Received By
03/10/2022 00:00 099999 Sample Custodian

****

Sample # L95403-11 Containernum 1

Prod Analyst
GELI DH

SAMPLE PREP

Relinquish Date Relinquish By Received By
03/10/2022 00:00 099999 Sample Custodian

****

Sample # L95403-12 Containernum 1

Prod Analyst
GELI DH

SAMPLE PREP

Relinquish Date Relinquish By Received By
03/10/2022 00:00 099999 Sample Custodian

****

Sample # L95403-13 Containernum 1

Prod Analyst
GELI DH

SAMPLE PREP

Relinquish Date Relinquish By Received By
03/10/2022 00:00 099999 Sample Custodian

****

Sample # L95403-14 Containernum 1

Prod Analyst
GELI DH

SAMPLE PREP

Relinquish Date Relinquish By Received By
03/10/2022 00:00 099999 Sample Custodian

****

****
Sample # L95403-15 Containernum 1

Prod Analyst
GELI DH

SAMPLE PREP

Relinquish Date Relinquish By Received By
03/10/2022 00:00 099999 Sample Custodian

****
Sample # L95403-16 Containernum 1

Prod Analyst
GELI DH

SAMPLE PREP

Relinquish Date Relinquish By Received By
03/10/2022 00:00 099999 Sample Custodian

****
Sample # L95403-17 Containernum 1

Prod Analyst
GELI DH

SAMPLE PREP

Relinquish Date Relinquish By Received By
03/10/2022 00:00 099999 Sample Custodian

****
Sample # L95403-18 Containernum 1

Prod Analyst
GELI DH

SAMPLE PREP

Relinquish Date Relinquish By Received By
03/10/2022 00:00 099999 Sample Custodian

****
Sample # L95403-19 Containernum 1

Prod Analyst
GELI DH

SAMPLE PREP

Relinquish Date Relinquish By Received By
03/10/2022 00:00 099999 Sample Custodian

****
Sample # L95403-20 Containernum 1

Prod Analyst
GELI DH

SAMPLE PREP

Relinquish Date Relinquish By Received By
03/10/2022 00:00 099999 Sample Custodian

Teledyne Brown Engineering
Internal Chain of Custody
Supplemental Sheet

L95403

****

L95403-1 SS 1; 5.2-1

Process step	Prod	Analyst	Date
Login		KARTERBURN	03/10/22
%Moisture		DH	03/10/22
Aliquot	GELI	DH	03/16/22
Aliquot	SAMPLE PREP		
Count Room	GELI	SMC	03/17/22

****

L95403-2 SS 8; 5.2-1

Process step	Prod	Analyst	Date
Login		KARTERBURN	03/10/22
%Moisture		DH	03/10/22
Aliquot	GELI	DH	03/16/22
Aliquot	SAMPLE PREP		
Count Room	GELI	SMC	03/18/22

****

L95403-3 SS 15; 5.2-1

Process step	Prod	Analyst	Date
Login		KARTERBURN	03/10/22
%Moisture		DH	03/10/22
Aliquot	GELI	DH	03/16/22
Aliquot	SAMPLE PREP		
Count Room	GELI	SMC	03/18/22

****

L95403-4 SS 22; 5.2-1

Process step	Prod	Analyst	Date
Login		KARTERBURN	03/10/22
%Moisture		DH	03/10/22
Aliquot	GELI	DH	03/16/22
Aliquot	SAMPLE PREP		
Count Room	GELI	SMC	03/17/22

****

L95403-5 SS 29; 5.2-1

Process step	Prod	Analyst	Date
Login		KARTERBURN	03/10/22
%Moisture		DH	03/10/22
Aliquot	GELI	DH	03/16/22
Aliquot	SAMPLE PREP		
Count Room	GELI	SMC	03/18/22

****

L95403-6 SS 36; 5.2-1

Process step	Prod	Analyst	Date
Login		KARTERBURN	03/10/22
%Moisture		DH	03/10/22
Aliquot	GELI	DH	03/16/22
Aliquot	SAMPLE PREP		
Count Room	GELI	SMC	03/17/22

Internal Chain of Custody
Supplemental Sheet

L95403

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L95403-7 SS 43; 5.2-1

Process step	Prod	Analyst	Date
Login		KARTERBURN	03/10/22
%Moisture		DH	03/10/22
Aliquot	GELI	DH	03/16/22
Aliquot	SAMPLE PREP		
Count Room	GELI	SMC	03/18/22

****

L95403-8 SS 50; 5.2-1

Process step	Prod	Analyst	Date
Login		KARTERBURN	03/10/22
%Moisture		DH	03/10/22
Aliquot	GELI	DH	03/16/22
Aliquot	SAMPLE PREP		
Count Room	GELI	SMC	03/18/22

****

L95403-9 SS 57; 5.2-1

Process step	Prod	Analyst	Date
Login		KARTERBURN	03/10/22
%Moisture		DH	03/10/22
Aliquot	GELI	DH	03/16/22
Aliquot	SAMPLE PREP		
Count Room	GELI	SMC	03/18/22

****

L95403-10 SS 63; 5.2-1

Process step	Prod	Analyst	Date
Login		KARTERBURN	03/10/22
%Moisture		DH	03/10/22
Aliquot	GELI	DH	03/16/22
Aliquot	SAMPLE PREP		
Count Room	GELI	SMC	03/17/22

****

L95403-11 SS 64; 5.1-1

Process step	Prod	Analyst	Date
Login		KARTERBURN	03/10/22
%Moisture		DH	03/10/22
Aliquot	GELI	DH	03/16/22
Aliquot	SAMPLE PREP		
Count Room	GELI	SMC	03/17/22

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L95403-12 SS 72; 5.1-1

Process step	Prod	Analyst	Date
Login		KARTERBURN	03/10/22
%Moisture		DH	03/10/22
Aliquot	GELI	DH	03/16/22
Aliquot	SAMPLE PREP		
Count Room	GELI	SMC	03/17/22

Internal Chain of Custody
Supplemental Sheet

L95403

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L95403-13 SS 80; 5.1-1

Process step	Prod	Analyst	Date
Login		KARTERBURN	03/10/22
%Moisture		DH	03/10/22
Aliquot	GELI	DH	03/16/22
Aliquot	SAMPLE PREP		
Count Room	GELI	SMC	03/17/22

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L95403-14 SS 88; 5.1-1

Process step	Prod	Analyst	Date
Login		KARTERBURN	03/10/22
%Moisture		DH	03/10/22
Aliquot	GELI	DH	03/16/22
Aliquot	SAMPLE PREP		
Count Room	GELI	SMC	03/18/22

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L95403-15 SS 96; 5.1-1

Process step	Prod	Analyst	Date
Login		KARTERBURN	03/10/22
%Moisture		DH	03/10/22
Aliquot	GELI	DH	03/16/22
Aliquot	SAMPLE PREP		
Count Room	GELI	SMC	03/17/22

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L95403-16 SS 104; 5.1-1

Process step	Prod	Analyst	Date
Login		KARTERBURN	03/10/22
%Moisture		DH	03/10/22
Aliquot	GELI	DH	03/16/22
Aliquot	SAMPLE PREP		
Count Room	GELI	SMC	03/18/22

****

L95403-17 SS 112; 5.1-1

Process step	Prod	Analyst	Date
Login		KARTERBURN	03/10/22
%Moisture		DH	03/10/22
Aliquot	GELI	DH	03/16/22
Aliquot	SAMPLE PREP		
Count Room	GELI	SMC	03/18/22

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L95403-18 SS 120; 5.1-1

Process step	Prod	Analyst	Date
Login		KARTERBURN	03/10/22
%Moisture		DH	03/10/22
Aliquot	GELI	DH	03/16/22
Aliquot	SAMPLE PREP		
Count Room	GELI	SMC	03/17/22

Teledyne Brown Engineering
Internal Chain of Custody
Supplemental Sheet

L95403

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L95403-19 SS 128; 5.1-1

Process step	Prod	Analyst	Date
Login		KARTERBURN	03/10/22
%Moisture		DH	03/10/22
Aliquot	GELI	DH	03/16/22
Aliquot	SAMPLE PREP		
Count Room	GELI	SMC	03/21/22

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L95403-20 SS 137; 5.1-1

Process step	Prod	Analyst	Date
Login		KARTERBURN	03/10/22
%Moisture		DH	03/10/22
Aliquot	GELI	DH	03/16/22
Aliquot	SAMPLE PREP		
Count Room	GELI	SMC	03/21/22

GAMMA SPECTROSCOPY

Gamma Spectroscopy

Background

Analyst:

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VAX/VMS Teledyne Brown Eng. Laboratory Gamma Report: 7-MAR-2022 09:20:18.81
TBE01 33-TP20784A HpGe ******* Aquisition Date/Time: 4-MAR-2022 12:08:17.00

LIMS No., Customer Name, Client ID: BKG

Sample ID : 01BG030422MT
Sample Type : PCI
Quantity : 1.00000E+00 TOTAL
Start Channel : 80 Energy Tol : 2.00000
End Channel : 4090 Pk Srch Sens: 5.00000
MDA Multiple : 1.30890ELibrary Used: LIBD
Peak Evaluation - Identified and Unidentified

Smple Date: 4-MAR-2022 00:00:00.0
Geometry : 01FT082219
BKGFILE : NOBKG
Real Time : 2 12:00:21.41
Live time : 2 12:00:00.00

Pk	It	Energy	Area	Bkgnd	FWHM	Channel	Left	Pw	Cts/Sec	%Err	Fit
1	1	63.13	415	3905	1.04	126.70	124	7	1.92E-03	25.2	4.09E+00
2	2	72.70	722	3223	0.95	145.82	136	18	3.34E-03	13.0	3.42E+00
3	2	74.95	1455	3213	0.94	150.30	136	18	6.73E-03	6.8	
4	1	84.62	1018	3868	1.28	169.62	166	8	4.71E-03	11.0	2.47E+00
5	1	87.37	324	2763	1.20	175.11	174	6	1.50E-03	26.2	1.23E+00
6	1	92.63	1891	3426	1.16	185.62	182	8	8.75E-03	5.8	8.00E-01
7	1	139.75	325	2702	1.00	279.71	277	7	1.50E-03	27.1	1.80E+00
8	1	143.61	430	3003	1.36	287.41	284	8	1.99E-03	22.6	8.91E-01
9	1	185.76	1485	3390	1.01	371.59	367	9	6.88E-03	7.5	8.30E-01
10	1	198.23	404	2434	1.05	396.50	393	7	1.87E-03	20.8	3.48E+00
11	1	238.72	696	2898	1.13	477.36	473	9	3.22E-03	14.4	1.40E+00
12	1	295.20	323	2212	1.22	590.15	587	9	1.50E-03	26.8	2.69E+00
13	1	352.17	748	2455	1.62	703.93	698	13	3.46E-03	14.2	3.66E+00
14	1	511.16	5839	2717	2.72	1021.45	1014	18	2.70E-02	2.5	1.65E+00
15	1	569.91	211	1175	1.61	1138.81	1134	10	9.75E-04	31.2	9.53E-01
16	1	583.42	348	1227	1.42	1165.79	1161	11	1.61E-03	20.2	4.58E-01
17	1	609.49	657	1206	1.75	1217.87	1213	10	3.04E-03	10.7	7.81E-01
18	1	803.17	210	635	1.82	1604.75	1600	10	9.71E-04	23.7	1.08E+00
19	1	847.08	640	1123	2.31	1692.46	1683	17	2.96E-03	12.7	2.65E+00
20	1	911.71	212	589	1.84	1821.56	1816	11	9.79E-04	23.3	8.40E-01
21	1	969.33	91	467	1.88	1936.67	1933	9	4.23E-04	44.3	1.61E+00
22	1	1001.51	188	508	2.59	2000.96	1996	11	8.69E-04	24.4	5.49E-01
23	1	1120.56	165	486	2.13	2238.80	2233	12	7.63E-04	28.0	2.45E+00
24	1	1238.84	160	345	2.21	2475.13	2470	11	7.39E-04	24.1	1.24E+00
25	1	1461.58	853	360	2.54	2920.19	2913	16	3.95E-03	6.1	2.07E+00
26	1	1764.95	183	279	2.26	3526.47	3519	17	8.47E-04	22.3	2.01E+00

Analyst:

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VAX/VMS Teledyne Brown Eng. Laboratory Gamma Report: 7-MAR-2022 09:20:27.96
TBE02 51-TP42214B HpGe ******* Aquisition Date/Time: 4-MAR-2022 12:08:17.80

LIMS No., Customer Name, Client ID: BKG

Sample ID : 02BG030422MT
Sample Type : PCI
Quantity : 1.00000E+00 TOTAL
Start Channel : 80 Energy Tol : 2.00000
End Channel : 4090 Pk Srch Sens: 5.00000
MDA Multiple : 1.30890ELibrary Used: LIBD
Peak Evaluation - Identified and Unidentified

Smple Date: 4-MAR-2022 00:00:00.0
Geometry : 02FT082119
BKGFILE : NOBKG
Real Time : 2 12:00:27.07
Live time : 2 12:00:00.00

Pk	It	Energy	Area	Bkgnd	FWHM	Channel	Left	Pw	Cts/Sec	%Err	Fit
1	3	63.39	658	3038	0.96	111.51	108	13	3.05E-03	13.9	1.86E+00
2	3	66.35	478	3064	1.06	117.47	108	13	2.21E-03	18.9	
3	2	72.91	1228	3413	0.98	130.66	126	16	5.69E-03	8.1	3.87E+00
4	2	74.96	2423	2773	0.88	134.80	126	16	1.12E-02	3.9	
5	2	77.05	365	2156	0.70	139.00	126	16	1.69E-03	18.9	
6	0	84.72	1248	3807	1.31	154.43	151	7	5.78E-03	8.7	
7	0	87.14	400	3166	0.85	159.30	158	6	1.85E-03	22.9	
8	0	92.65	1789	4082	1.09	170.39	167	8	8.28E-03	6.6	
9	0	139.99	341	4092	1.16	265.63	262	8	1.58E-03	32.9	
10	0	143.91	278	3628	0.87	273.54	271	7	1.29E-03	36.4	
11	0	185.90	1384	3956	1.05	358.03	354	9	6.41E-03	8.6	
12	0	238.64	740	2649	0.93	464.15	461	7	3.43E-03	12.1	
13	0	241.42	172	2614	1.57	469.73	468	7	7.97E-04	49.9	
14	0	295.32	459	2381	1.18	578.20	574	9	2.13E-03	19.7	
15	0	338.08	137	1857	0.87	664.24	661	8	6.35E-04	55.1	
16	0	351.98	1012	2014	1.24	692.22	688	10	4.69E-03	8.9	
17	0	511.01	5511	2426	2.55	1012.24	1004	20	2.55E-02	2.6	
18	0	583.44	331	923	1.11	1158.00	1153	9	1.53E-03	17.5	
19	0	609.38	790	1192	1.40	1210.21	1205	11	3.66E-03	9.2	
20	0	802.76	238	533	2.20	1599.40	1595	10	1.10E-03	19.2	
21	0	846.77	508	823	1.67	1687.98	1681	14	2.35E-03	12.8	
22	0	911.27	243	662	1.89	1817.80	1812	13	1.13E-03	22.8	
23	0	1001.15	99	422	1.23	1998.71	1994	10	4.57E-04	40.2	
24	0	1120.55	222	415	1.50	2239.04	2233	11	1.03E-03	19.1	
25	0	1460.60	979	340	2.25	2923.55	2913	19	4.53E-03	5.5	
26	0	1764.71	276	197	2.10	3535.80	3529	16	1.28E-03	13.0	

Analyst:

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VAX/VMS Teledyne Brown Eng. Laboratory Gamma Report: 7-MAR-2022 09:20:47.60
TBE06 33-TP10933A HpGe ******* Aquisition Date/Time: 4-MAR-2022 12:08:18.51

LIMS No., Customer Name, Client ID: BKG

Sample ID : 06BG030422MT
Sample Type : PCI
Quantity : 1.00000E+00 TOTAL
Start Channel : 80 Energy Tol : 2.00000
End Channel : 4090 Pk Srch Sens: 5.00000
MDA Multiple : 1.30890ELibrary Used: LIBD
Peak Evaluation - Identified and Unidentified

Smple Date: 4-MAR-2022 00:00:00.0
Geometry : 06FT012721
BKGFILE : NOBKG
Real Time : 2 12:00:35.23
Live time : 2 12:00:00.00

Pk	It	Energy	Area	Bkgnd	FWHM	Channel	Left	Pw	Cts/Sec	%Err	Fit
1	0	75.01	742	3487	0.94	150.49	148	6	3.44E-03	13.1	
2	0	84.60	629	3875	1.11	169.64	166	8	2.91E-03	17.6	
3	0	92.64	708	3734	1.10	185.69	182	8	3.28E-03	15.4	
4	0	140.03	319	3416	0.94	280.30	277	8	1.48E-03	32.2	
5	0	185.73	1003	3681	1.14	371.52	368	9	4.64E-03	11.3	
6	0	198.35	359	3248	1.43	396.72	393	8	1.66E-03	28.0	
7	0	238.64	795	2857	1.16	477.14	473	8	3.68E-03	12.2	
8	0	295.36	363	2507	1.12	590.37	587	9	1.68E-03	25.4	
9	0	352.12	660	2282	1.12	703.67	699	10	3.06E-03	14.1	
10	0	511.00	5491	2729	2.52	1020.80	1013	17	2.54E-02	2.6	
11	0	569.88	237	1277	1.26	1138.33	1134	10	1.10E-03	28.9	
12	0	583.40	453	1178	1.21	1165.31	1161	10	2.10E-03	14.9	
13	0	609.48	607	1354	1.48	1217.38	1213	10	2.81E-03	12.1	
14	0	727.50	108	515	1.49	1452.92	1450	6	5.00E-04	34.6	
15	0	803.18	206	757	1.76	1603.96	1600	10	9.55E-04	25.9	
16	0	847.01	236	940	1.97	1691.43	1686	11	1.09E-03	26.0	
17	0	911.29	479	646	1.83	1819.72	1814	12	2.22E-03	11.6	
18	0	969.52	126	648	1.16	1935.93	1930	10	5.82E-04	39.0	
19	0	1120.47	261	555	1.16	2237.17	2233	11	1.21E-03	18.5	
20	0	1238.80	90	395	0.84	2473.29	2469	9	4.15E-04	41.5	
21	0	1461.07	1626	449	1.88	2916.79	2909	17	7.53E-03	3.9	
22	0	1764.87	295	263	2.01	3522.92	3517	13	1.37E-03	12.7	

Analyst:

VAX/VMS Teledyne Brown Eng. Laboratory Gamma Report: 7-MAR-2022 09:21:11.85
TBE07 31-TP10768B HpGe ******* Aquisition Date/Time: 4-MAR-2022 12:08:19.02

LIMS No., Customer Name, Client ID: BKG

Sample ID : 07BG030422MT
Sample Type : PCI
Quantity : 1.00000E+00 TOTAL
Start Channel : 80 Energy Tol : 2.00000
End Channel : 4090 Pk Srch Sens: 5.00000
MDA Multiple : 1.30890ELibrary Used: LIBD
Peak Evaluation - Identified and Unidentified

Smple Date: 4-MAR-2022 00:00:00.0
Geometry : 07FT082119
BKGFILE : NOBKG
Real Time : 2 12:00:23.56
Live time : 2 12:00:00.00

Pk	It	Energy	Area	Bkgnd	FWHM	Channel	Left	Pw	Cts/Sec	%Err	Fit
1	3	63.42	482	3069	1.22	126.63	123	14	2.23E-03	19.7	1.49E+00
2	3	66.33	574	3670	1.31	132.45	123	14	2.66E-03	18.6	
3	3	72.80	1584	4219	1.38	145.41	141	18	7.34E-03	7.5	5.84E-01
4	3	74.99	3129	3945	1.31	149.79	141	18	1.45E-02	4.0	
5	3	77.17	455	2809	1.07	154.15	141	18	2.11E-03	20.4	
6	3	84.78	1794	4024	1.57	169.37	162	16	8.30E-03	6.8	5.80E-01
7	3	87.34	530	3003	1.15	174.49	162	16	2.45E-03	18.3	
8	1	92.67	1647	3871	1.30	185.15	181	9	7.63E-03	7.2	2.86E+00
9	1	139.75	329	3405	1.31	279.34	276	8	1.53E-03	31.1	1.11E-01
10	1	143.62	268	3466	1.41	287.09	284	8	1.24E-03	38.5	3.29E-01
11	1	185.74	1207	4104	1.56	371.35	367	10	5.59E-03	10.3	2.41E-01
12	1	198.33	479	3212	1.47	396.54	393	8	2.22E-03	21.0	7.29E-01
13	1	238.49	1156	3370	1.27	476.89	473	9	5.35E-03	9.5	2.50E+00
14	1	295.12	437	2428	0.89	590.18	586	8	2.03E-03	20.1	1.01E+00
15	1	338.75	487	2283	2.14	677.47	673	9	2.25E-03	18.1	5.58E+00
16	1	351.73	935	2937	1.59	703.43	698	12	4.33E-03	12.0	5.71E-01
17	1	510.78	7517	3512	2.98	1021.59	1012	22	3.48E-02	2.3	2.96E+00
18	1	569.60	201	1457	1.81	1139.25	1134	10	9.33E-04	36.0	4.73E-01
19	1	582.98	749	1371	2.31	1166.03	1160	11	3.47E-03	10.2	1.83E+00
20	1	609.23	994	2116	1.84	1218.52	1213	13	4.60E-03	10.1	7.69E-01
21	1	802.54	398	1559	2.94	1605.18	1595	20	1.84E-03	24.9	7.44E-01
22	1	846.38	581	1449	2.08	1692.87	1685	16	2.69E-03	15.2	8.73E-01
23	1	910.84	409	889	2.05	1821.79	1816	12	1.89E-03	15.4	6.34E-01
24	1	968.99	273	699	1.99	1938.08	1933	11	1.27E-03	19.8	5.26E-01
25	1	1120.01	263	613	2.15	2240.11	2235	11	1.22E-03	19.2	7.10E-01
26	1	1460.25	2023	627	2.44	2920.48	2909	22	9.36E-03	3.9	8.75E-01
27	1	1727.69	112	531	6.96	3455.19	3445	27	5.19E-04	57.8	1.77E+00
28	1	1763.58	426	460	3.11	3526.94	3515	24	1.97E-03	14.3	1.26E+00

Analyst:

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VAX/VMS Teledyne Brown Eng. Laboratory Gamma Report:  7-MAR-2022 09:21:29.94
TBE08 31-TP20610B HpGe ******** Aquisition Date/Time: 4-MAR-2022 12:08:18.05
--------------------------------------------------------------------------------
LIMS No., Customer Name, Client ID: BKG

Sample ID       : 08BG030422MT                        Smple Date: 4-MAR-2022 00:00:00.0
Sample Type     : PCI                                 Geometry  : 08FT082019
Quantity        : 1.00000E+00 TOTAL                   BKGFILE   : NOBKG
Start Channel   : 80       Energy Tol   : 2.00000     Real Time : 2 12:01:26.92
End Channel     : 4090     Pk Srch Sens: 5.00000      Live time : 2 12:00:00.00
MDA Multiple    : 1.30890ELibrary Used: LIBD
Peak Evaluation - Identified and Unidentified
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Pk	It	Energy	Area	Bkgnd	FWHM	Channel	Left	Pw	Cts/Sec	%Err	Fit
1	1	67.04	394	3094	1.09	140.22	138	6	1.83E-03	22.9	1.60E+00
2	1	75.63	1335	4718	0.82	157.37	154	7	6.18E-03	8.9	2.85E+00
3	1	85.35	1032	3996	1.41	176.76	173	8	4.78E-03	11.0	2.53E+00
4	1	93.30	971	4116	1.21	192.62	188	9	4.49E-03	12.3	5.06E-01
5	1	186.46	914	3785	1.19	378.42	375	9	4.23E-03	12.6	4.12E-01
6	1	199.36	291	3110	1.36	404.13	401	8	1.35E-03	33.8	6.84E-01
7	1	239.27	1199	2908	1.21	483.72	480	8	5.55E-03	8.3	9.13E-01
8	1	242.86	339	2714	1.35	490.89	487	8	1.57E-03	27.3	2.71E+00
9	1	296.01	402	2760	1.75	596.87	592	10	1.86E-03	25.0	4.46E-01
10	1	338.90	201	1980	1.30	682.39	679	8	9.32E-04	38.8	9.19E-01
11	1	352.64	1082	2838	2.21	709.79	704	13	5.01E-03	10.5	6.54E+00
12	1	511.45	5343	2541	2.85	1026.40	1018	17	2.47E-02	2.6	2.10E+00
13	1	583.64	501	1354	1.63	1170.29	1165	11	2.32E-03	14.9	8.17E-01
14	1	609.79	749	1392	1.64	1222.41	1217	11	3.47E-03	10.3	5.03E-01
15	1	846.97	353	1029	1.78	1695.08	1689	14	1.63E-03	20.1	1.77E+00
16	1	911.34	492	820	1.91	1823.34	1817	14	2.28E-03	13.2	9.14E-01
17	1	969.21	198	650	1.48	1938.64	1932	11	9.18E-04	25.8	1.91E+00
18	1	1120.50	205	476	1.73	2240.00	2235	10	9.50E-04	21.1	1.21E+00
19	1	1237.89	170	459	2.47	2473.81	2468	12	7.87E-04	26.5	1.48E+00
20	1	1377.76	84	239	1.64	2752.32	2749	9	3.91E-04	34.7	6.54E-01
21	1	1460.96	1492	435	1.99	2917.97	2910	16	6.91E-03	4.1	7.37E-01
22	1	1764.53	338	237	2.98	3522.24	3515	18	1.57E-03	12.0	1.53E+00

Analyst:

VAX/VMS Teledyne Brown Eng. Laboratory Gamma Report: 7-MAR-2022 09:21:39.23
TBE11 59-TN51806A HpGe ******* Aquisition Date/Time: 4-MAR-2022 12:08:19.72

LIMS No., Customer Name, Client ID: BKG

Sample ID : 11BG030422MT
Sample Type : PCI
Quantity : 1.00000E+00 TOTAL
Start Channel : 80 Energy Tol : 2.00000
End Channel : 4090 Pk Srch Sens: 4.00000
MDA Multiple : 1.30890ELibrary Used: LIBD
Peak Evaluation - Identified and Unidentified

Smple Date: 4-MAR-2022 00:00:00.0
Geometry : 11FT112019
BKGFILE : NOBKG
Real Time : 2 12:01:41.91
Live time : 2 12:00:00.00

Pk	It	Energy	Area	Bkgnd	FWHM	Channel	Left	Pw	Cts/Sec	%Err	Fit
1	0	46.61	2817	4750	1.13	91.85	87	10	1.30E-02	5.0	
2	0	53.39	277	2723	1.50	105.39	103	6	1.28E-03	30.4	
3	3	63.30	2213	3526	1.19	125.22	121	15	1.02E-02	5.0	1.62E+00
4	3	66.07	426	4705	1.50	130.75	121	15	1.97E-03	30.0	
5	7	71.27	718	5839	2.21	141.15	136	22	3.33E-03	22.4	2.22E+00
6	7	72.95	3478	3686	1.18	144.51	136	22	1.61E-02	3.5	
7	7	75.05	6480	3615	1.21	148.71	136	22	3.00E-02	2.1	
8	7	77.11	484	3044	0.99	152.82	136	22	2.24E-03	20.3	
9	3	84.85	3034	4253	1.45	168.30	163	15	1.40E-02	4.3	1.27E+00
10	3	87.36	769	2885	0.98	173.33	163	15	3.56E-03	11.9	
11	0	92.82	3115	5019	1.35	184.24	179	11	1.44E-02	4.8	
12	0	139.86	254	3096	1.58	278.28	276	7	1.18E-03	36.8	
13	0	143.85	421	3568	1.42	286.26	283	8	1.95E-03	25.1	
14	0	185.97	1331	4281	1.29	370.47	366	10	6.16E-03	9.6	
15	0	198.46	324	3229	1.33	395.45	392	8	1.50E-03	30.8	
16	0	238.88	674	3441	1.36	476.26	472	9	3.12E-03	16.2	
17	0	295.53	340	2219	1.11	589.53	586	8	1.57E-03	24.6	
18	0	352.20	531	2069	1.39	702.83	699	9	2.46E-03	16.1	
19	0	511.41	7452	3541	2.84	1021.15	1012	24	3.45E-02	2.4	
20	0	570.00	175	1182	2.75	1138.30	1135	9	8.11E-04	36.1	
21	0	583.45	491	1513	1.42	1165.20	1159	12	2.27E-03	16.5	
22	0	609.63	736	2046	1.59	1217.54	1210	14	3.41E-03	13.6	
23	0	796.03	82	788	0.93	1590.22	1585	10	3.78E-04	65.5	
24	0	803.26	183	864	1.23	1604.70	1601	10	8.49E-04	30.8	
25	0	846.93	633	1109	1.64	1692.00	1686	13	2.93E-03	11.5	
26	0	911.30	399	827	1.37	1820.71	1814	14	1.84E-03	16.1	
27	0	969.73	122	588	2.06	1937.53	1932	10	5.63E-04	38.5	
28	0	1120.36	249	710	2.33	2238.72	2232	15	1.15E-03	24.2	
29	0	1238.79	183	611	1.21	2475.50	2468	15	8.47E-04	30.4	
30	0	1246.46	103	551	5.67	2490.85	2483	15	4.79E-04	50.5	
31	0	1461.19	1228	659	2.41	2920.19	2910	22	5.68E-03	6.0	
32	0	1556.32	8	232	3.23	3110.41	3107	11	3.73E-05	366.8	
33	0	1765.22	188	338	1.79	3528.09	3519	15	8.71E-04	22.5	

Analyst:

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VAX/VMS Teledyne Brown Eng. Laboratory Gamma Report: 7-MAR-2022 09:21:20.77
TBE13 31-TP10727B HpGe ******* Aquisition Date/Time: 4-MAR-2022 12:08:20.32

LIMS No., Customer Name, Client ID: BKG

Sample ID : 13BG030422MT
Sample Type : PCI
Quantity : 1.00000E+00 TOTAL
Start Channel : 80 Energy Tol : 2.00000
End Channel : 4090 Pk Srch Sens: 5.00000
MDA Multiple : 1.30890ELibrary Used: LIBD
Peak Evaluation - Identified and Unidentfied

Smple Date: 4-MAR-2022 00:00:00.0
Geometry : 13FT012021
BKGFILE : NOBKG
Real Time : 2 12:00:44.85
Live time : 2 12:00:00.00

Pk	It	Energy	Area	Bkgnd	FWHM	Channel	Left	Pw	Cts/Sec	%Err	Fit
1	1	63.16	313	2283	0.84	126.28	124	6	1.45E-03	24.6	1.48E+00
2	1	66.52	161	2266	0.86	132.98	131	6	7.46E-04	47.4	1.89E+00
3	10	69.87	548	2728	1.64	139.67	136	22	2.54E-03	17.4	6.33E+00
4	10	72.70	1226	2436	1.13	145.31	136	22	5.68E-03	7.4	
5	10	74.79	1922	2135	0.93	149.48	136	22	8.90E-03	4.5	
6	10	76.92	583	2529	1.22	153.73	136	22	2.70E-03	15.6	
7	6	84.59	998	2498	1.14	169.03	165	13	4.62E-03	8.9	1.33E+00
8	6	87.15	458	2063	1.01	174.14	165	13	2.12E-03	16.6	
9	1	92.51	910	2961	1.05	184.84	181	8	4.22E-03	10.8	6.23E+00
10	1	139.94	340	2893	1.15	279.47	276	8	1.57E-03	27.9	2.33E+00
11	1	185.47	880	2796	1.00	370.33	367	8	4.07E-03	10.9	2.12E+00
12	1	198.09	312	2689	0.91	395.51	392	8	1.44E-03	29.3	3.21E-01
13	1	238.43	1067	2975	0.96	476.02	471	10	4.94E-03	10.0	1.82E+00
14	1	294.93	383	1786	1.04	588.78	585	8	1.78E-03	19.7	6.09E-01
15	1	338.34	323	1716	1.52	675.42	671	9	1.50E-03	23.7	1.39E+00
16	1	351.68	827	1763	1.41	702.05	697	10	3.83E-03	10.1	2.45E+00
17	7	510.54	4009	1876	2.45	1019.21	1012	22	1.86E-02	3.0	5.74E+00
18	7	511.58	1345	1338	1.84	1021.29	1012	22	6.23E-03	7.5	
19	1	582.92	438	1003	1.65	1163.75	1158	11	2.03E-03	14.8	7.51E-01
20	1	609.06	592	1054	1.34	1215.95	1211	10	2.74E-03	11.1	7.23E-01
21	1	726.98	106	566	1.07	1451.49	1449	8	4.93E-04	39.5	8.30E-01
22	1	802.69	188	518	1.59	1602.74	1599	9	8.71E-04	22.9	6.26E-01
23	1	846.28	507	899	2.20	1689.85	1681	15	2.35E-03	13.6	3.67E+00
24	1	911.00	374	590	1.71	1819.16	1813	13	1.73E-03	14.4	1.58E+00
25	1	968.60	122	368	1.24	1934.27	1930	8	5.66E-04	28.8	7.85E-01
26	1	1120.42	215	481	2.02	2237.75	2231	14	9.96E-04	22.9	1.84E+00
27	1	1238.59	94	366	2.04	2474.01	2470	10	4.37E-04	39.2	9.19E-01
28	1	1460.58	1176	365	1.99	2918.02	2909	19	5.44E-03	4.9	7.92E-01
29	1	1764.25	230	193	2.91	3525.67	3518	16	1.07E-03	14.9	9.62E-01

Analyst:

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VAX/VMS Teledyne Brown Eng. Laboratory Gamma Report:  7-MAR-2022 09:20:56.91
TBE14 54-TP42603C HpGe ******* Aquisition Date/Time: 4-MAR-2022 12:08:18.70
------------------------------------------------------------------------------
LIMS No., Customer Name, Client ID: BKG

Sample ID      : 14BG030422MT                     Smple Date: 4-MAR-2022 00:00:00.0
Sample Type    : PCI                              Geometry  : 14FT082119
Quantity       : 1.00000E+00 TOTAL                BKGFILE   : NOBKG
Start Channel  : 80       Energy Tol   : 2.00000  Real Time : 2 12:00:34.29
End Channel    : 4090     Pk Srch Sens: 5.00000   Live time : 2 12:00:00.00
MDA Multiple   : 1.30890ELibrary Used: LIBD
Peak Evaluation - Identified and Unidentified
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Pk	It	Energy	Area	Bkgnd	FWHM	Channel	Left	Pw	Cts/Sec	%Err	Fit
1	1	46.72	247	3283	0.96	90.52	88	7	1.14E-03	39.0	1.96E-01
2	1	63.35	215	2126	0.82	123.83	122	5	9.93E-04	32.9	9.28E-01
3	1	66.31	419	2855	1.20	129.75	127	7	1.94E-03	21.7	4.07E+00
4	2	72.83	749	2222	0.80	142.80	139	13	3.47E-03	10.1	5.25E-01
5	2	74.97	1531	2192	0.76	147.09	139	13	7.09E-03	5.3	
6	4	84.75	1162	2462	1.25	166.68	161	15	5.38E-03	7.7	2.18E+00
7	4	87.42	438	2760	1.25	172.01	161	15	2.03E-03	21.7	
8	1	92.60	787	3197	0.92	182.38	178	9	3.64E-03	13.5	5.64E-01
9	1	139.72	252	2685	1.34	276.73	273	8	1.17E-03	36.1	1.04E+00
10	1	185.77	856	3051	1.32	368.94	364	10	3.96E-03	12.6	8.93E-01
11	1	198.29	217	1497	0.75	394.01	392	5	1.01E-03	27.5	4.94E-01
12	1	238.54	485	2733	1.09	474.58	470	10	2.24E-03	20.6	9.76E-01
13	1	294.99	302	1396	1.58	587.63	584	7	1.40E-03	21.2	3.42E+00
14	1	351.84	493	1267	1.15	701.46	698	8	2.28E-03	13.3	4.31E-01
15	1	510.87	4330	2104	2.74	1019.91	1012	20	2.00E-02	3.0	1.17E+00
16	1	583.34	220	904	1.73	1165.05	1160	10	1.02E-03	26.4	1.63E+00
17	1	609.22	365	976	1.39	1216.87	1212	10	1.69E-03	16.9	6.38E-01
18	1	802.48	105	645	2.52	1603.95	1599	12	4.88E-04	49.4	2.41E+00
19	1	846.63	413	669	1.85	1692.37	1688	13	1.91E-03	13.9	1.74E+00
20	1	910.82	173	397	1.61	1820.95	1817	9	8.00E-04	22.2	1.12E+00
21	1	968.82	107	426	1.97	1937.13	1932	11	4.95E-04	39.3	2.43E+00
22	1	1120.02	125	375	1.83	2240.02	2233	12	5.76E-04	32.3	4.53E-01
23	1	1460.25	805	345	2.11	2921.67	2912	18	3.72E-03	6.5	2.23E+00
24	1	1764.07	129	251	2.78	3530.51	3522	16	5.96E-04	28.9	2.53E+00

Analyst:

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VAX/VMS Teledyne Brown Eng. Laboratory Gamma Report: 7-MAR-2022 09:20:36.66
TBE23 11410 HpGe ********** Aquisition Date/Time: 4-MAR-2022 12:08:18.26

LIMS No., Customer Name, Client ID: BKG

Sample ID : 23BG030422MT
Sample Type : PCI
Quantity : 1.00000E+00 TOTAL
Start Channel : 80 Energy Tol : 2.00000
End Channel : 4090 Pk Srch Sens: 5.00000
MDA Multiple : 1.30890ELibrary Used: LIBD
Peak Evaluation - Identified and Unidentified

Smple Date: 4-MAR-2022 00:00:00.0
Geometry : 23FT121020
BKGFILE : NOBKG
Real Time : 2 12:00:24.00
Live time : 2 12:00:00.00

Pk	It	Energy	Area	Bkgnd	FWHM	Channel	Left	Pw	Cts/Sec	%Err	Fit
1	0	46.45	1509	4082	0.96	92.95	88	10	6.99E-03	8.3	
2	8	63.36	1691	2598	1.12	126.74	122	15	7.83E-03	5.5	8.72E+00
3	8	66.36	566	3281	1.44	132.72	122	15	2.62E-03	19.0	
4	2	74.89	1011	2466	1.04	149.77	144	15	4.68E-03	8.3	2.73E+00
5	2	77.19	1451	2312	0.99	154.36	144	15	6.72E-03	6.0	
6	0	84.27	511	3045	0.99	168.52	165	8	2.37E-03	19.2	
7	0	87.30	357	2736	1.04	174.57	172	7	1.65E-03	24.9	
8	0	92.83	2476	3220	1.09	185.61	181	8	1.15E-02	4.5	
9	0	112.74	221	2048	0.75	225.39	223	6	1.02E-03	33.1	
10	0	139.66	419	2600	1.08	279.19	276	8	1.94E-03	21.6	
11	0	143.70	405	2282	1.04	287.26	284	7	1.87E-03	20.2	
12	0	185.77	1407	2849	1.00	371.33	367	9	6.51E-03	7.3	
13	0	198.31	339	2603	0.92	396.39	393	8	1.57E-03	26.6	
14	0	204.96	152	1767	0.93	409.67	408	6	7.03E-04	44.5	
15	1	238.67	3300	1597	0.97	477.05	473	13	1.53E-02	2.6	1.62E+00
16	1	241.07	320	1835	1.16	481.84	473	13	1.48E-03	24.9	
17	0	295.40	183	1410	1.30	590.42	587	7	8.49E-04	34.8	
18	0	299.64	256	2322	1.01	598.91	594	11	1.18E-03	37.0	
19	0	351.95	402	1199	1.24	703.48	700	7	1.86E-03	15.1	
20	0	511.02	5670	2073	2.57	1021.51	1014	17	2.63E-02	2.3	
21	0	569.98	468	1161	1.48	1139.42	1134	12	2.17E-03	15.3	
22	0	583.29	958	1054	1.39	1166.04	1161	11	4.44E-03	7.3	
23	0	609.19	324	1147	1.04	1217.83	1214	9	1.50E-03	19.6	
24	0	669.42	101	593	1.34	1338.32	1336	8	4.68E-04	42.8	
25	0	727.59	147	744	1.19	1454.69	1450	10	6.80E-04	35.7	
26	0	803.22	189	653	1.55	1605.99	1601	10	8.73E-04	26.4	
27	0	860.60	145	546	1.43	1720.81	1717	9	6.69E-04	30.3	
28	0	911.19	213	487	1.94	1822.05	1817	11	9.84E-04	21.2	
29	0	962.03	105	634	1.16	1923.80	1917	12	4.84E-04	49.1	
30	0	1001.27	156	437	2.21	2002.34	1997	11	7.21E-04	27.3	
31	0	1063.71	276	486	1.45	2127.34	2121	13	1.28E-03	17.5	
32	0	1120.25	63	403	1.29	2240.55	2237	9	2.92E-04	58.6	
33	0	1460.89	621	258	2.08	2922.81	2915	13	2.87E-03	6.7	
34	0	1764.78	103	219	1.20	3531.86	3524	12	4.77E-04	30.4	

GAMMA SPECTROSCOPY

Initial Calibration

E & Z 2088-10-1 Mixed Gamma
6/1/19 12:00 PM

S25 Bottle

		Orig. Wt	5.1617	Volume	50				
		Wt Used	4.4184	Aliquot	5.0000	Certificate	Aliquoted	Actual	Percent
	Half-Life	Energy(KeV)	ate G/s/	%err	%abn	Bq/Tot	G/S	Bq/Tot	Diff
Cd-109	462.9d	88.0	84.75		3.72%	1006.61	37.45	1006.0	-0.06%
Co-57	271.8d	122.1	77.25		85.51%	39.92	34.13	40.0	0.14%
Ce-139	137.64d	165.9	92.68		80.35%	50.96	40.95	51.1	0.34%
Hg-203	46.6d	279.2	273		77.30%	156.04	120.62	143.9	-7.78%
Sn-113	115.09d	391.7	280		64.90%	190.62	123.72	192.6	1.04%
Sr-85	64.849	514.0	547.9		98.40%	246.02	242.08	242.2	-1.55%
Cs-137	30.17y	661.6	330.6		85.12%	171.61	146.07	175.4	2.21%
Y-88	106.65d	898.0	858.7		93.40%	406.22	379.41	393.8	-3.06%
Co-60	5.27y	1173.2	460.4		100.00%	203.42	203.42	202.8	-0.31%
Co-60	5.27y	1332.5	460.9		100.00%	203.64	203.64	207.4	1.84%
Y-88	106.65d	1836.0	908		99.38%	403.69	401.19	401.6	-0.52%

Eff. Name: **01S25121819**

Analyst: KOJ

Analyst:

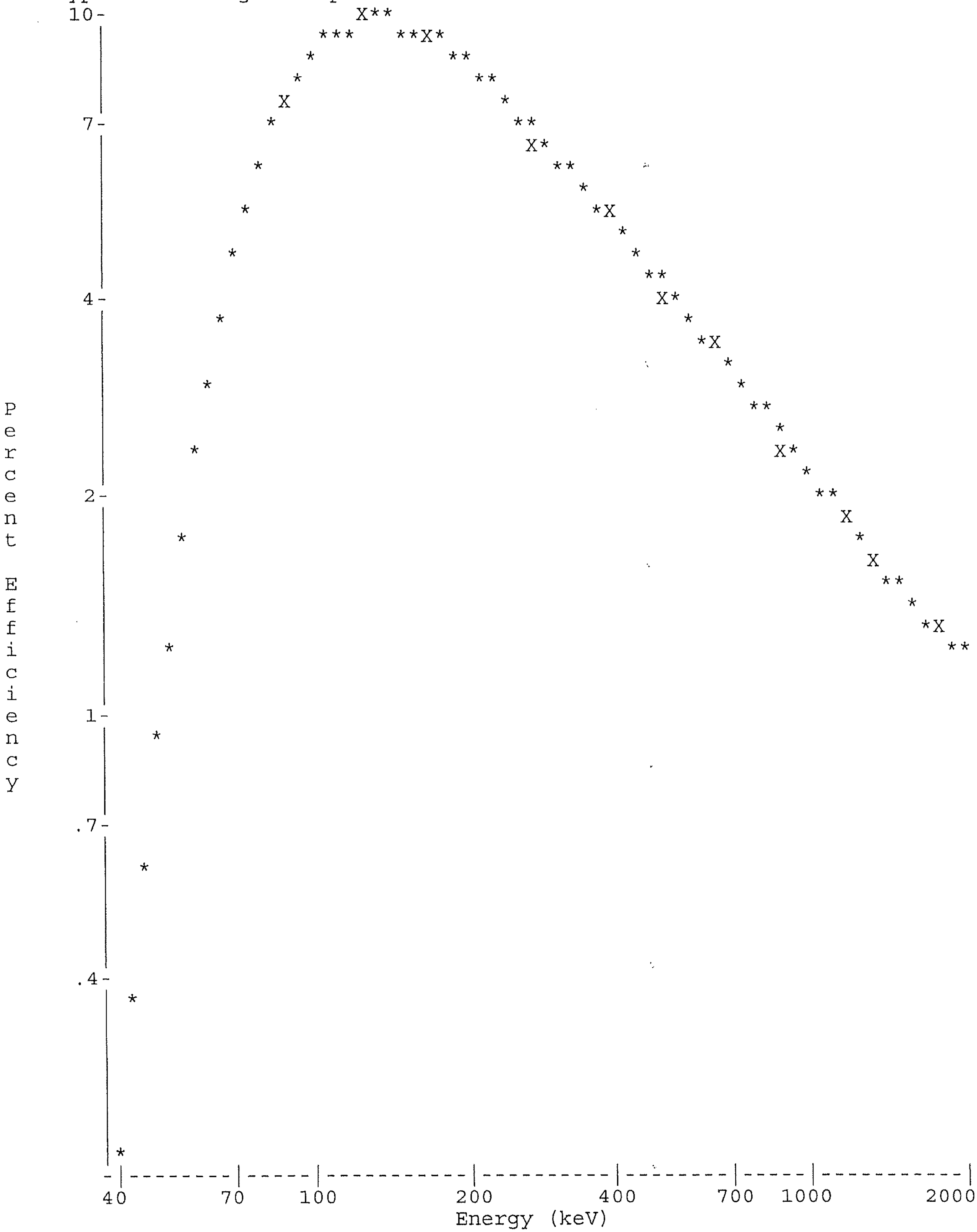
VAX/VMS Teledyne Brown Eng. Laboratory Gamma Report: 26-DEC-2019 12:04:39.66
TBE01 33-TP20784A HpGe ******* Aquisition Date/Time: 18-DEC-2019 12:47:40.18

LIMS No., Customer Name, Client ID: S25 5ML MIXED GAMMA CALIBRATION

Sample ID : 01S25121819 Smple Date: 1-JUN-2019 12:00:00.0
Sample Type : STD Geometry : 01S25121819
Quantity : 1.00000E+00 TOTAL BKGFILE : 01BG112719MT
Start Channel : 80 Energy Tol : 2.00000 Real Time : 0 02:06:53.02
End Channel : 4090 Pk Srch Sens: 7.00000 Live time : 0 02:06:29.39
MDA Multiple : 4.6600 Library Used: CALIBRATION
Peak Evaluation - Identified and Unidentified

Pk	It	Energy	Area	Bkgnd	FWHM	Channel	%Eff	Cts/Sec	%Err	Fit
1	1	46.45	873	3808	1.00	93.40	7.53E-01	1.15E-01	12.2	3.75E+00
2	1	88.03	16295	6174	0.91	176.45	7.74E+00	2.15E+00	1.2	9.74E-01
3	1	122.06	15462	5708	0.93	244.42	9.95E+00	2.04E+00	1.3	1.85E+00
4	1	136.46	1848	3995	0.93	273.18	1.00E+01	2.44E-01	6.6	4.08E-01
5	1	165.87	10934	4511	0.98	331.91	9.60E+00	1.44E+00	1.5	2.21E+00
6	1	255.13	773	3303	1.28	510.20	7.43E+00	1.02E-01	13.8	1.74E+00
7	1	279.18	3150	3109	1.14	558.24	6.94E+00	4.15E-01	3.6	2.14E+00
8	1	391.74	14953	3343	1.21	783.06	5.26E+00	1.97E+00	1.1	1.41E+00
9	1	513.99	8925	3061	1.24	1027.27	4.15E+00	1.18E+00	1.6	5.91E-01
10	1	661.59	36880	2841	1.41	1322.13	3.30E+00	4.86E+00	0.6	7.72E-01
11	1	813.93	273	1389	1.86	1626.49	2.71E+00	3.60E-02	26.0	2.58E+00
12	1	898.00	18696	2476	1.63	1794.47	2.46E+00	2.46E+00	0.9	1.34E+00
13	1	1173.24	27075	1426	1.85	2344.43	1.89E+00	3.57E+00	0.7	4.76E+00
14	1	1324.88	289	668	2.56	2647.44	1.68E+00	3.81E-02	19.9	7.84E-01
15	1	1332.54	24528	764	1.96	2662.75	1.67E+00	3.23E+00	0.7	2.70E+00
16	1	1835.98	10624	255	2.33	3668.96	1.29E+00	1.40E+00	1.0	4.72E+00

Spectrum   : MCA0:[NDSCOUNT]TBE01$1
Calib Date: 26-DEC-2019 12:04
Detector   :   Geometry   : 01S25121819
Fit type   : 5th Degree Empirical



Analyst:

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==============================================================================
VAX/VMS Teledyne Brown Eng. Laboratory Gamma Report: 26-DEC-2019 12:05:42.41
TBE01 33-TP20784A HpGe ******* Aquisition Date/Time: 18-DEC-2019 12:47:40.18
------------------------------------------------------------------------------
LIMS No., Customer Name, Client ID: S25 5ML MIXED GAMMA CALIBRATION

Sample ID      : 01S25121819                    Smple Date: 1-JUN-2019 12:00:00.0
Sample Type    : STD                            Geometry  : 01S25121819
Quantity       : 1.00000E+00 TOTAL              BKGFILE   : 01BG112719MT
Start Channel  : 80      Energy Tol    : 2.00000  Real Time : 0 02:06:53.02
End Channel    : 4090    Pk Srch Sens: 7.00000  Live time : 0 02:06:29.39
MDA Multiple   : 4.6600  Library Used: CALIBRATION
Peak Evaluation - Identified and Unidentified
```

Pk	It	Energy	Area	Bkgnd	FWHM	Channel	%Eff	Cts/Sec	%Err	Fit
1	1	46.45	873	3808	1.00	93.40	7.53E-01	1.15E-01	12.2	3.75E+00
2	1	88.03	16295	6174	0.91	176.45	7.74E+00	2.15E+00	1.2	9.74E-01
3	1	122.06	15462	5708	0.93	244.42	9.95E+00	2.04E+00	1.3	1.85E+00
4	1	136.46	1848	3995	0.93	273.18	1.00E+01	2.44E-01	6.6	4.08E-01
5	1	165.87	10934	4511	0.98	331.91	9.60E+00	1.44E+00	1.5	2.21E+00
6	1	255.13	773	3303	1.28	510.20	7.43E+00	1.02E-01	13.8	1.74E+00
7	1	279.18	3150	3109	1.14	558.24	6.94E+00	4.15E-01	3.6	2.14E+00
8	1	391.74	14953	3343	1.21	783.06	5.26E+00	1.97E+00	1.1	1.41E+00
9	1	513.99	8925	3061	1.24	1027.27	4.15E+00	1.18E+00	1.6	5.91E-01
10	1	661.59	36880	2841	1.41	1322.13	3.30E+00	4.86E+00	0.6	7.72E-01
11	1	813.93	273	1389	1.86	1626.49	2.71E+00	3.60E-02	26.0	2.58E+00
12	1	898.00	18696	2476	1.63	1794.47	2.46E+00	2.46E+00	0.9	1.34E+00
13	1	1173.24	27075	1426	1.85	2344.43	1.89E+00	3.57E+00	0.7	4.76E+00
14	1	1324.88	289	668	2.56	2647.44	1.68E+00	3.81E-02	19.9	7.84E-01
15	1	1332.54	24528	764	1.96	2662.75	1.67E+00	3.23E+00	0.7	2.70E+00
16	1	1835.98	10624	255	2.33	3668.96	1.29E+00	1.40E+00	1.0	4.72E+00

Flag: "*" = Peak area was modified by background subtraction

Nuclide Line Activity Report

Nuclide Type:

Nuclide	Energy	Area	%Abn	%Eff	Uncorrected BQ/TOTAL	Decay Corr BQ/TOTAL	2-Sigma %Error
02-CD109	88.03	16295	3.72*	7.738E+00	7.459E+02	1.006E+03	2.45
03-CO57	122.06	15462	85.51*	9.946E+00	2.395E+01	3.997E+01	2.54
04-CE139	165.85	10934	80.35*	9.601E+00	1.867E+01	5.114E+01	3.07
05-HG203	279.20	3150	81.46*	6.936E+00	7.346E+00	1.439E+02	7.30
06-SN113	391.69	14953	64.90*	5.260E+00	5.771E+01	1.926E+02	2.29
07-SR85	513.99	8925	99.27*	4.152E+00	2.853E+01	2.422E+02	3.28
08-CS137	661.65	36880	85.12*	3.296E+00	1.732E+02	1.754E+02	1.22
09-Y88	898.02	18696	93.40*	2.458E+00	1.073E+02	3.938E+02	1.89
10-CO60	1173.22	27075	100.00	1.891E+00	1.887E+02	2.028E+02	1.38
	1332.49	24528	100.00*	1.674E+00	1.930E+02	2.074E+02	1.39
12-Y88	1836.01	10624	99.38*	1.287E+00	1.094E+02	4.016E+02	2.08

Flag: "*" = Keyline

Summary of Nuclide Activity
Sample ID : 01S25121819

Acquisition date : 18-DEC-2019 12:47:40

Total number of lines in spectrum	16	
Number of unidentified lines	5	
Number of lines tentatively identified by NID	11	68.75%

Nuclide Type :

Nuclide	Hlife	Decay	Uncorrected BQ/TOTAL	Decay Corr BQ/TOTAL	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
02-CD109	462.90D	1.35	7.459E+02	1.006E+03	0.025E+03	2.45	
03-CO57	270.90D	1.67	2.395E+01	3.997E+01	0.101E+01	2.54	
04-CE139	137.66D	2.74	1.867E+01	5.114E+01	0.157E+01	3.07	
05-HG203	46.61D	19.6	7.346E+00	1.439E+02	0.105E+02	7.30	
06-SN113	115.10D	3.34	5.771E+01	1.926E+02	0.044E+02	2.29	
07-SR85	64.84D	8.49	2.853E+01	2.422E+02	0.079E+02	3.28	
08-CS137	30.17Y	1.01	1.732E+02	1.754E+02	0.021E+02	1.22	
09-Y88	106.65D	3.67	1.073E+02	3.938E+02	0.074E+02	1.89	
10-CO60	5.27Y	1.07	1.930E+02	2.074E+02	0.029E+02	1.39	
12-Y88	106.65D	3.67	1.094E+02	4.016E+02	0.084E+02	2.08	
			---------	---------			
	Total Activity :		1.465E+03	2.855E+03			

Grand Total Activity : 1.465E+03 2.855E+03

Flags: "K" = Keyline not found "M" = Manually accepted
"E" = Manually edited "A" = Nuclide specific abn. limit

Sample ID : 01S25121819 Acquisition date : 18-DEC-2019 12:47:40

It	Energy	Area	Bkgnd	FWHM	Channel	Left	Pw	Cts/Sec	%Err	%Eff	Flags
1	46.45	873	3808	1.00	93.40	90	7	1.15E-01	24.3	7.53E-01	
1	136.46	1848	3995	0.93	273.18	269	9	2.44E-01	13.2	1.00E+01	
1	255.13	773	3303	1.28	510.20	506	9	1.02E-01	27.7	7.43E+00	
1	813.93	273	1389	1.86	1626.49	1622	10	3.60E-02	52.1	2.71E+00	
1	1324.88	289	668	2.56	2647.44	2641	14	3.81E-02	39.7	1.68E+00	

Flags: "T" = Tentatively associated

Summary of Nuclide Activity

Total number of lines in spectrum 16
Number of unidentified lines 5
Number of lines tentatively identified by NID 11 68.75%

Nuclide Type :

Nuclide	Hlife	Decay	Wtd Mean Uncorrected BQ/TOTAL	Wtd Mean Decay Corr BQ/TOTAL	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
02-CD109	462.90D	1.35	7.459E+02	1.006E+03	0.025E+03	2.45	
03-CO57	270.90D	1.67	2.395E+01	3.997E+01	0.101E+01	2.54	
04-CE139	137.66D	2.74	1.867E+01	5.114E+01	0.157E+01	3.07	
05-HG203	46.61D	19.6	7.346E+00	1.439E+02	0.105E+02	7.30	
06-SN113	115.10D	3.34	5.771E+01	1.926E+02	0.044E+02	2.29	
07-SR85	64.84D	8.49	2.853E+01	2.422E+02	0.079E+02	3.28	
08-CS137	30.17Y	1.01	1.732E+02	1.754E+02	0.021E+02	1.22	
09-Y88	106.65D	3.67	1.073E+02	3.938E+02	0.074E+02	1.89	
10-CO60	5.27Y	1.07	1.908E+02	2.051E+02	0.020E+02	0.98	
12-Y88	106.65D	3.67	1.094E+02	4.016E+02	0.084E+02	2.08	
			---------	---------			
	Total Activity :		1.463E+03	2.852E+03			
	Grand Total Activity :		1.463E+03	2.852E+03			

Flags: "K" = Keyline not found "M" = Manually accepted
"E" = Manually edited "A" = Nuclide specific abn. limit

Interference Report

No interference correction performed

Combined Activity-MDA Report

---- Identified Nuclides ----

Nuclide	Activity (BQ/TOTAL)	Act error	MDA (BQ/TOTAL)	MDA error	Act/MDA
02-CD109	1.006E+03	2.464E+01	1.546E+01	0.000E+00	65.101
03-CO57	3.997E+01	1.014E+00	6.132E-01	0.000E+00	65.179
04-CE139	5.114E+01	1.570E+00	1.070E+00	0.000E+00	47.778
05-HG203	1.439E+02	1.051E+01	1.033E+01	0.000E+00	13.933
06-SN113	1.926E+02	4.407E+00	2.722E+00	0.000E+00	70.732

07-SR85	2.422E+02	7.940E+00	5.671E+00	0.000E+00	42.717
08-CS137	1.754E+02	2.138E+00	8.972E-01	0.000E+00	195.463
09-Y88	3.938E+02	7.444E+00	3.952E+00	0.000E+00	99.670
10-CO60	2.051E+02	2.007E+00	8.230E-01	0.000E+00	249.140
12-Y88	4.016E+02	8.365E+00	2.259E+00	0.000E+00	177.763

---- Non-Identified Nuclides ----

Nuclide	Key-Line Activity (BQ/TOTAL)	K.L. Ided	Act error	MDA (BQ/TOTAL)	MDA error	Act/MDA
01-AM241	-5.914E-01		1.827E+00	2.908E+00	0.000E+00	-0.203

```
A,01S25121819     ,12/26/2019 12:05,06/01/2019 12:00,   1.000E+00,S25 5ML MIXED
B,01S25121819     ,CALIBRATION         ,12/26/2019 12:04,01S25121819
C,02-CD109,YES,   1.006E+03,   2.464E+01,   1.546E+01,,   65.101
C,03-CO57 ,YES,   3.997E+01,   1.014E+00,   6.132E-01,,   65.179
C,04-CE139,YES,   5.114E+01,   1.570E+00,   1.070E+00,,   47.778
C,05-HG203,YES,   1.439E+02,   1.051E+01,   1.033E+01,,   13.933
C,06-SN113,YES,   1.926E+02,   4.407E+00,   2.722E+00,,   70.732
C,07-SR85 ,YES,   2.422E+02,   7.940E+00,   5.671E+00,,   42.717
C,08-CS137,YES,   1.754E+02,   2.138E+00,   8.972E-01,,  195.463
C,09-Y88  ,YES,   3.938E+02,   7.444E+00,   3.952E+00,,   99.670
C,10-CO60 ,YES,   2.051E+02,   2.007E+00,   8.230E-01,,  249.140
C,12-Y88  ,YES,   4.016E+02,   8.365E+00,   2.259E+00,,  177.763
C,01-AM241,NO ,  -5.914E-01,   1.827E+00,   2.908E+00,,   -0.203
```

E & Z 2088-10-1 Mixed Gamma
6/1/19 12:00 PM

S25 Bottle

		Orig. Wt	5.1617	Volume	50				
		Wt Used	4.4184	Aliquot	5.0000	Certificate	Aliquoted	Actual	Percent
	Half-Life	Energy(KeV)	ate G/s	%err	%abn	Bq/Tot	G/S	Bq/Tot	Diff
Cd-109	462.9d	88.0	84.75		3.72%	1006.61	37.45	1003.0	-0.36%
Co-57	271.8d	122.1	77.25		85.51%	39.92	34.13	40.5	1.56%
Ce-139	137.64d	165.9	92.68		80.35%	50.96	40.95	50.0	-1.83%
Hg-203	46.6d	279.2	273		77.30%	156.04	120.62	149.2	-4.39%
Sn-113	115.09d	391.7	280		64.90%	190.62	123.72	192.7	1.09%
Sr-85	64.849	514.0	547.9		98.40%	246.02	242.08	239.1	-2.81%
Cs-137	30.17y	661.6	330.6		85.12%	171.61	146.07	175.3	2.15%
Y-88	106.65d	898.0	858.7		93.40%	406.22	379.41	395.1	-2.74%
Co-60	5.27y	1173.2	460.4		100.00%	203.42	203.42	206.2	1.37%
Co-60	5.27y	1332.5	460.9		100.00%	203.64	203.64	204.0	0.17%
Y-88	106.65d	1836.0	908		99.38%	403.69	401.19	402.5	-0.30%

Eff. Name: **02S25121819**

Analyst: KOJ

Analyst:

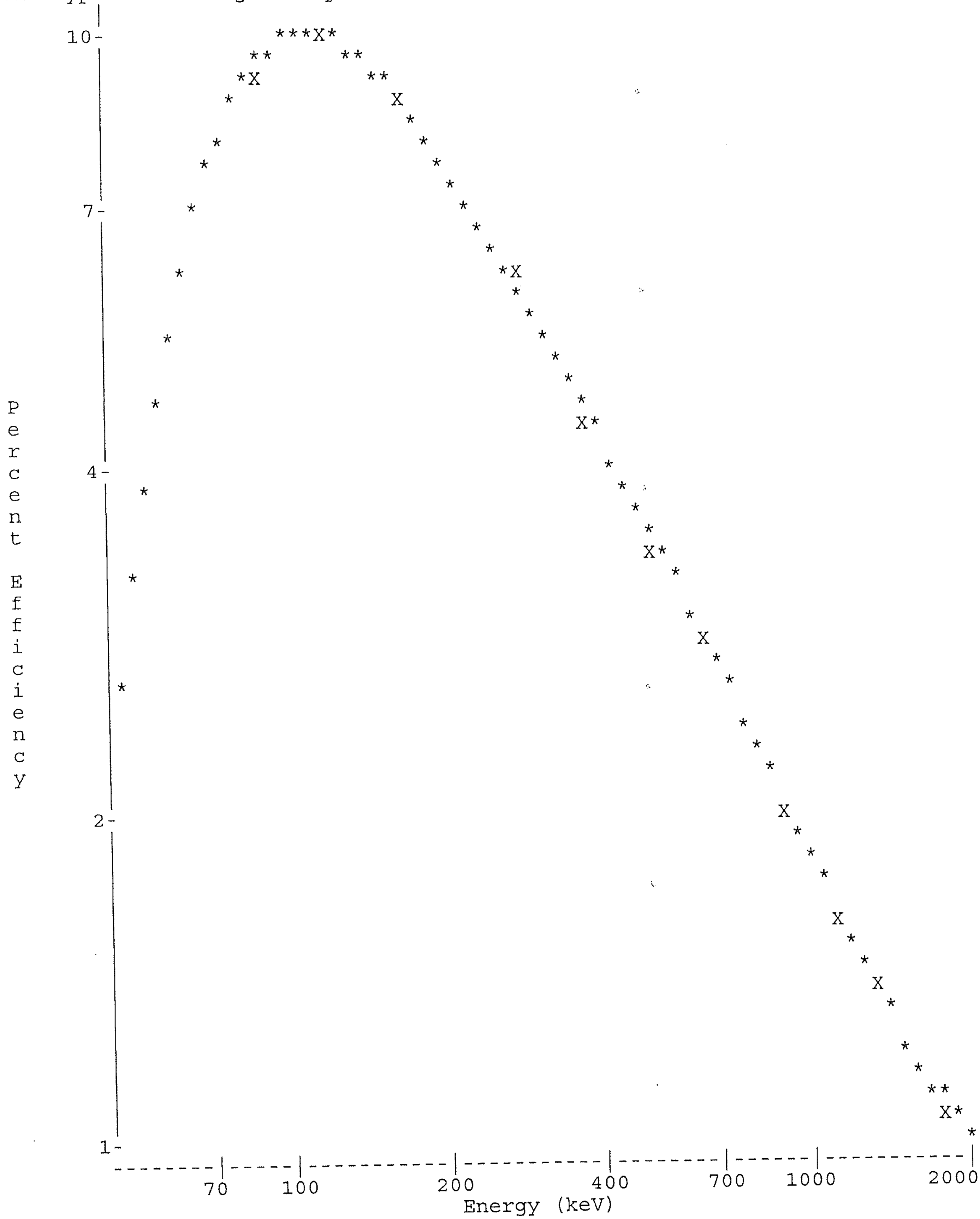
===
VAX/VMS Teledyne Brown Eng. Laboratory Gamma Report: 26-DEC-2019 15:31:26.63
TBE02 51-TP42214B HpGe ******* Aquisition Date/Time: 18-DEC-2019 18:27:24.76

LIMS No., Customer Name, Client ID: S25 5ML MIXED GAMMA CALIBRATION

Sample ID : 02S25121819 Smple Date: 1-JUN-2019 12:00:00.0
Sample Type : STD Geometry : 02S25121819
Quantity : 1.00000E+00 TOTAL BKGFILE : 02BG112719MT
Start Channel : 80 Energy Tol : 2.00000 Real Time : 0 04:00:55.90
End Channel : 4090 Pk Srch Sens: 9.00000 Live time : 0 04:00:00.00
MDA Multiple : 4.6600 Library Used: CALIBRATION
Peak Evaluation - Identified and Unidentified

Pk	It	Energy	Area	Bkgnd	FWHM	Channel	%Eff	Cts/Sec	%Err	Fit
1	0	88.00	37891	11475	0.91	160.79	9.51E+00	2.63E+00	0.8	
2	0	122.02	30362	9762	0.98	229.23	1.02E+01	2.11E+00	0.9	
3	0	136.42	3890	6454	1.03	258.18	9.85E+00	2.70E-01	4.1	
4	0	165.86	18919	7972	1.06	317.42	8.96E+00	1.31E+00	1.2	
5	0	255.18	1383	5277	1.23	497.07	6.55E+00	9.60E-02	9.9	
6	0	279.23	5403	5694	1.14	545.46	6.07E+00	3.75E-01	3.0	
7	0	391.70	24333	5851	1.20	771.69	4.52E+00	1.69E+00	0.9	
8	0	514.06	14116	4868	1.28	1017.85	3.52E+00	9.80E-01	1.3	
9	0	661.65	58552	5074	1.46	1314.80	2.76E+00	4.07E+00	0.5	
10	0	814.01	328	2126	1.39	1621.33	2.25E+00	2.28E-02	25.9	
11	0	898.02	29394	4236	1.63	1790.38	2.03E+00	2.04E+00	0.8	
12	0	1173.19	42934	2084	1.83	2344.08	1.55E+00	2.98E+00	0.5	
13	0	1332.45	37534	1525	1.96	2664.60	1.37E+00	2.61E+00	0.6	
14	0	1836.03	16498	472	2.27	3678.18	1.05E+00	1.15E+00	0.9	

Spectrum : MCA0:[NDSCOUNT]TBE02$1
Calib Date: 26-DEC-2019 15:31
Detector : Geometry : 02S25121819
Fit type : 5th Degree Empirical



Analyst:

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================================================================================
VAX/VMS Teledyne Brown Eng. Laboratory Gamma Report: 26-DEC-2019 15:32:31.22
TBE02 51-TP42214B HpGe ******* Aquisition Date/Time: 18-DEC-2019 18:27:24.76
--------------------------------------------------------------------------------
LIMS No., Customer Name, Client ID: S25 5ML MIXED GAMMA CALIBRATION

Sample ID      : 02S25121819                        Smple Date: 1-JUN-2019 12:00:00.0
Sample Type    : STD                                Geometry  : 02S25121819
Quantity       : 1.00000E+00 TOTAL                  BKGFILE   : 02BG112719MT
Start Channel  : 80       Energy Tol    : 2.00000   Real Time : 0 04:00:55.90
End Channel    : 4090     Pk Srch Sens: 9.00000     Live time : 0 04:00:00.00
MDA Multiple   : 4.6600   Library Used: CALIBRATION
Peak Evaluation - Identified and Unidentified
```

Pk	It	Energy	Area	Bkgnd	FWHM	Channel	%Eff	Cts/Sec	%Err	Fit
1	0	88.00*	37869	11475	0.91	160.79	9.51E+00	2.63E+00	0.8	
2	0	122.02	30362	9762	0.98	229.23	1.02E+01	2.11E+00	0.9	
3	0	136.42	3890	6454	1.03	258.18	9.85E+00	2.70E-01	4.1	
4	0	165.86	18919	7972	1.06	317.42	8.96E+00	1.31E+00	1.2	
5	0	255.18	1383	5277	1.23	497.07	6.55E+00	9.60E-02	9.9	
6	0	279.23	5403	5694	1.14	545.46	6.07E+00	3.75E-01	3.0	
7	0	391.70	24333	5851	1.20	771.69	4.52E+00	1.69E+00	0.9	
8	0	514.06	14116	4868	1.28	1017.85	3.52E+00	9.80E-01	1.3	
9	0	661.65	58552	5074	1.46	1314.80	2.76E+00	4.07E+00	0.5	
10	0	814.01	328	2126	1.39	1621.33	2.25E+00	2.28E-02	25.9	
11	0	898.02	29394	4236	1.63	1790.38	2.03E+00	2.04E+00	0.8	
12	0	1173.19	42934	2084	1.83	2344.08	1.55E+00	2.98E+00	0.5	
13	0	1332.45	37534	1525	1.96	2664.60	1.37E+00	2.61E+00	0.6	
14	0	1836.03	16498	472	2.27	3678.18	1.05E+00	1.15E+00	0.9	

Flag: "*" = Peak area was modified by background subtraction

Nuclide Line Activity Report

Nuclide Type:

Nuclide	Energy	Area	%Abn	%Eff	Uncorrected BQ/TOTAL	Decay Corr BQ/TOTAL	2-Sigma %Error
02-CD109	88.03	37869	3.72*	9.511E+00	7.433E+02	1.003E+03	1.51
03-CO57	122.06	30362	85.51*	1.015E+01	2.428E+01	4.054E+01	1.74
04-CE139	165.85	18919	80.35*	8.962E+00	1.824E+01	5.003E+01	2.34
05-HG203	279.20	5403	81.46*	6.074E+00	7.583E+00	1.492E+02	5.90
06-SN113	391.69	24333	64.90*	4.516E+00	5.766E+01	1.927E+02	1.82
07-SR85	513.99	14116	99.27*	3.516E+00	2.809E+01	2.391E+02	2.63
08-CS137	661.65	58552	85.12*	2.760E+00	1.731E+02	1.753E+02	0.99
09-Y88	898.02	29394	93.40*	2.034E+00	1.074E+02	3.951E+02	1.53
10-CO60	1173.22	42934	100.00	1.554E+00	1.919E+02	2.062E+02	1.08
	1332.49	37534	100.00*	1.374E+00	1.898E+02	2.040E+02	1.14
12-Y88	1836.01	16498	99.38*	1.053E+00	1.095E+02	4.025E+02	1.70

Flag: "*" = Keyline

Summary of Nuclide Activity
Sample ID : 02S25121819

Acquisition date : 18-DEC-2019 18:27:24

Total number of lines in spectrum	14	
Number of unidentified lines	3	
Number of lines tentatively identified by NID	11	78.57%

Nuclide Type :

Nuclide	Hlife	Decay	Uncorrected BQ/TOTAL	Decay Corr BQ/TOTAL	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
02-CD109	462.90D	1.35	7.433E+02	1.003E+03	0.015E+03	1.51	
03-CO57	270.90D	1.67	2.428E+01	4.054E+01	0.070E+01	1.74	
04-CE139	137.66D	2.74	1.824E+01	5.003E+01	0.117E+01	2.34	
05-HG203	46.61D	19.7	7.583E+00	1.492E+02	0.088E+02	5.90	
06-SN113	115.10D	3.34	5.766E+01	1.927E+02	0.035E+02	1.82	
07-SR85	64.84D	8.51	2.809E+01	2.391E+02	0.063E+02	2.63	
08-CS137	30.17Y	1.01	1.731E+02	1.753E+02	0.017E+02	0.99	
09-Y88	106.65D	3.68	1.074E+02	3.951E+02	0.060E+02	1.53	
10-CO60	5.27Y	1.07	1.898E+02	2.040E+02	0.023E+02	1.14	
12-Y88	106.65D	3.68	1.095E+02	4.025E+02	0.069E+02	1.70	
		Total Activity :	1.459E+03	2.852E+03			
		Grand Total Activity :	1.459E+03	2.852E+03			

Flags: "K" = Keyline not found
"E" = Manually edited
"M" = Manually accepted
"A" = Nuclide specific abn. limit

Unidentified Energy Lines
Sample ID : 02S25121819

Acquisition date : 18-DEC-2019 18:27:24

It	Energy	Area	Bkgnd	FWHM	Channel	Left	Pw	Cts/Sec	%Err	%Eff	Flags
0	136.42	3890	6454	1.03	258.18	254	9	2.70E-01	8.1	9.85E+00	
0	255.18	1383	5277	1.23	497.07	493	9	9.60E-02	19.7	6.55E+00	
0	814.01	328	2126	1.39	1621.33	1618	9	2.28E-02	51.8	2.25E+00	

Flags: "T" = Tentatively associated

Summary of Nuclide Activity

Total number of lines in spectrum	14	
Number of unidentified lines	3	
Number of lines tentatively identified by NID	11	78.57%

Nuclide Type :

Nuclide	Hlife	Decay	Wtd Mean Uncorrected BQ/TOTAL	Wtd Mean Decay Corr BQ/TOTAL	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
02-CD109	462.90D	1.35	7.433E+02	1.003E+03	0.015E+03	1.51	
03-CO57	270.90D	1.67	2.428E+01	4.054E+01	0.070E+01	1.74	
04-CE139	137.66D	2.74	1.824E+01	5.003E+01	0.117E+01	2.34	
05-HG203	46.61D	19.7	7.583E+00	1.492E+02	0.088E+02	5.90	
06-SN113	115.10D	3.34	5.766E+01	1.927E+02	0.035E+02	1.82	
07-SR85	64.84D	8.51	2.809E+01	2.391E+02	0.063E+02	2.63	
08-CS137	30.17Y	1.01	1.731E+02	1.753E+02	0.017E+02	0.99	
09-Y88	106.65D	3.68	1.074E+02	3.951E+02	0.060E+02	1.53	
10-CO60	5.27Y	1.07	1.909E+02	2.051E+02	0.016E+02	0.78	
12-Y88	106.65D	3.68	1.095E+02	4.025E+02	0.069E+02	1.70	
			---------	---------			
	Total Activity :		1.460E+03	2.853E+03			

Grand Total Activity : 1.460E+03 2.853E+03

Flags: "K" = Keyline not found "M" = Manually accepted
"E" = Manually edited "A" = Nuclide specific abn. limit

Interference Report

No interference correction performed

Combined Activity-MDA Report

---- Identified Nuclides ----

Nuclide	Activity (BQ/TOTAL)	Act error	MDA (BQ/TOTAL)	MDA error	Act/MDA
02-CD109	1.003E+03	1.518E+01	9.288E+00	0.000E+00	108.029
03-CO57	4.054E+01	7.037E-01	4.185E-01	0.000E+00	96.891
04-CE139	5.003E+01	1.169E+00	8.113E-01	0.000E+00	61.669
05-HG203	1.492E+02	8.804E+00	8.128E+00	0.000E+00	18.357
06-SN113	1.927E+02	3.513E+00	2.198E+00	0.000E+00	87.654
07-SR85	2.391E+02	6.279E+00	4.569E+00	0.000E+00	52.341
08-CS137	1.753E+02	1.735E+00	7.369E-01	0.000E+00	237.891

09-Y88	3.951E+02	6.045E+00	3.245E+00	0.000E+00	121.744
10-CO60	2.051E+02	1.607E+00	8.533E-01	0.000E+00	240.402
12-Y88	4.025E+02	6.851E+00	1.857E+00	0.000E+00	216.801

---- Non-Identified Nuclides ----

Nuclide	Key-Line Activity (BQ/TOTAL)	K.L. Ided	Act error	MDA (BQ/TOTAL)	MDA error	Act/MDA
01-AM241	-5.736E-01		7.199E-01	1.117E+00	0.000E+00	-0.513

A,02S25121819   ,12/26/2019 15:32,06/01/2019 12:00,   1.000E+00,S25 5ML MIXED
B,02S25121819   ,CALIBRATION   ,12/26/2019 15:31,02S25121819
C,02-CD109,YES, 1.003E+03, 1.518E+01, 9.288E+00,, 108.029
C,03-CO57 ,YES, 4.054E+01, 7.037E-01, 4.185E-01,, 96.891
C,04-CE139,YES, 5.003E+01, 1.169E+00, 8.113E-01,, 61.669
C,05-HG203,YES, 1.492E+02, 8.804E+00, 8.128E+00,, 18.357
C,06-SN113,YES, 1.927E+02, 3.513E+00, 2.198E+00,, 87.654
C,07-SR85 ,YES, 2.391E+02, 6.279E+00, 4.569E+00,, 52.341
C,08-CS137,YES, 1.753E+02, 1.735E+00, 7.369E-01,, 237.891
C,09-Y88 ,YES, 3.951E+02, 6.045E+00, 3.245E+00,, 121.744
C,10-CO60 ,YES, 2.051E+02, 1.607E+00, 8.533E-01,, 240.402
C,12-Y88 ,YES, 4.025E+02, 6.851E+00, 1.857E+00,, 216.801
C,01-AM241,NO , -5.736E-01, 7.199E-01, 1.117E+00,, -0.513

E & Z 2088-10-1 Mixed Gamma
6/1/19 12:00 PM

S25 Bottle

		Orig. Wt	5.1617	Volume	50				
		Wt Used	4.4184	Aliquot	5.0000	Certificate	Aliquoted	Actual	Percent
	Half-Life	Energy(KeV)	.ate G/s/	%err	%abn	Bq/Tot	G/S	Bq/Tot	Diff
Pb-210	22.26Y	46.6	72.1		4.18%	762.12	31.86		
Cd-109	462.9d	88.0	84.75		3.72%	1006.61	37.45	1009.0	0.24%
Co-57	271.8d	122.1	77.25		85.51%	39.92	34.13	40.0	0.29%
Ce-139	137.64d	165.9	92.68		80.35%	50.96	40.95	50.8	-0.32%
Hg-203	46.6d	279.2	273		77.30%	156.04	120.62		
Sn-113	115.09d	391.7	280		64.90%	190.62	123.72	190.1	-0.28%
Sr-85	64.849	514.0	547.9		98.40%	246.02	242.08		
Cs-137	30.17y	661.6	330.6		85.12%	171.61	146.07	173.6	1.16%
Y-88	106.65d	898.0	858.7		93.40%	406.22	379.41	396.4	-2.42%
Co-60	5.27y	1173.2	460.4		100.00%	203.42	203.42	203.4	-0.01%
Co-60	5.27y	1332.5	460.9		100.00%	203.64	203.64	205.4	0.86%
Y-88	106.65d	1836.0	908		99.38%	403.69	401.19	401.9	-0.44%

Eff. Name: **06S25031921**

Analyst: KOJ

Analyst:

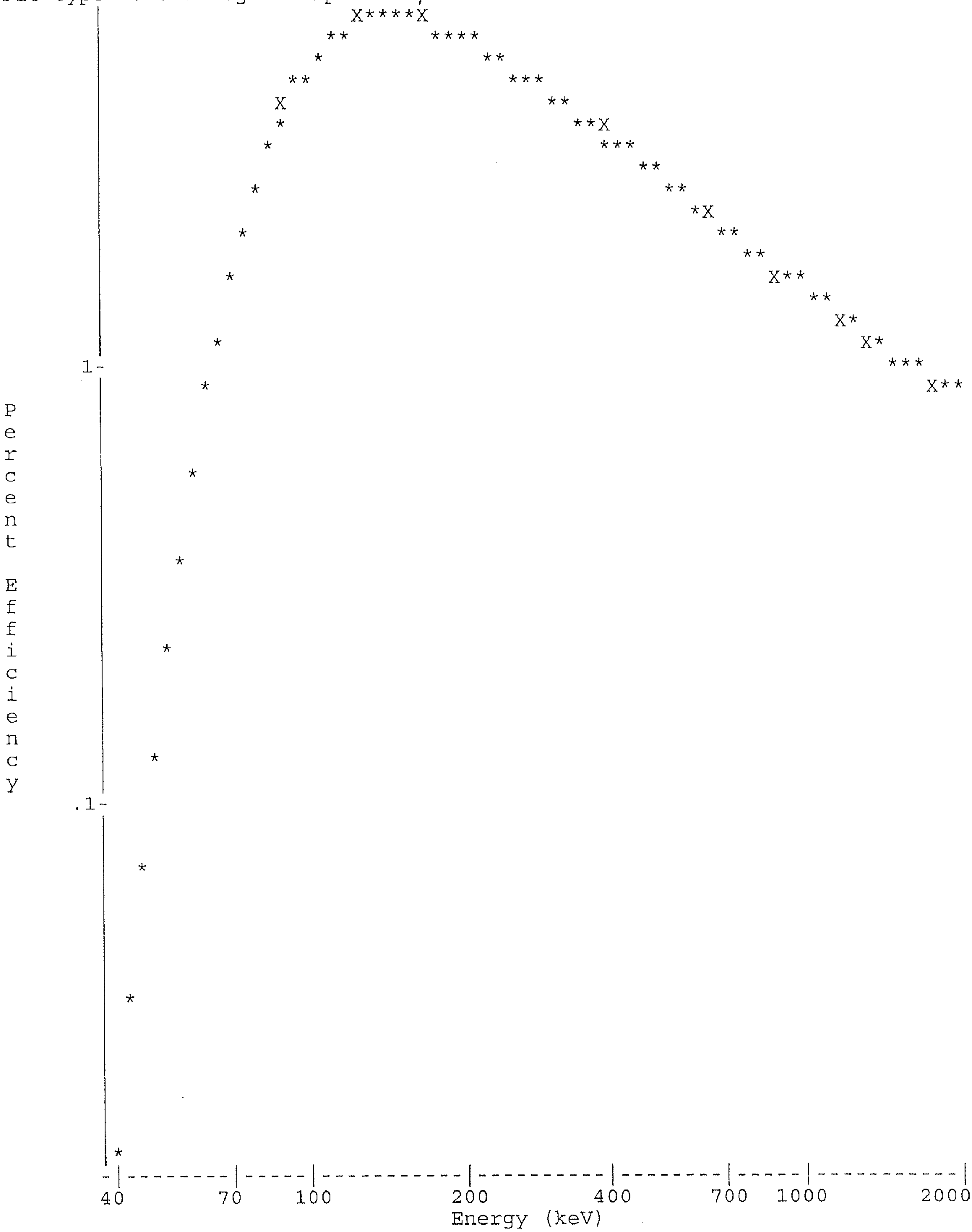
VAX/VMS Teledyne Brown Eng. Laboratory Gamma Report: 22-MAR-2021 07:40:38.83
TBE06 33-TP10933A HpGe ******* Aquisition Date/Time: 19-MAR-2021 14:45:58.43

LIMS No., Customer Name, Client ID: S25 5ML MIXED GAMMA CALIBRATION

Sample ID : 06S25031921 Smple Date: 1-JUN-2019 12:00:00.0
Sample Type : STD Geometry : 06S25031921
Quantity : 1.00000E+00 TOTAL BKGFILE : NOBKG
Start Channel : 80 Energy Tol : 2.00000 Real Time : 2 16:43:37.11
End Channel : 4090 Pk Srch Sens: 9.00000 Live time : 2 16:39:12.77
MDA Multiple : 4.6600 Library Used: CALIBRATION
Peak Evaluation - Identified and Unidentified

Pk	It	Energy	Area	Bkgnd	FWHM	Channel	%Eff	Cts/Sec	%Err	Fit
1	0	46.49	1952	34584	0.92	93.80	9.94E-02	8.39E-03	14.5	
2	0	74.78	1441	47490	0.94	150.37	2.39E+00	6.19E-03	25.2	
3	0	88.01	128267	68527	0.97	176.82	3.94E+00	5.51E-01	0.5	
4	0	122.05	92059	59957	0.99	244.90	6.23E+00	3.96E-01	0.6	
5	0	136.44	11811	51850	1.00	273.67	6.50E+00	5.07E-02	3.6	
6	0	165.86	22108	55027	1.10	332.52	6.41E+00	9.50E-02	2.1	
7	0	391.75	19042	41769	1.19	784.24	3.50E+00	8.18E-02	2.1	
8	0	510.77	4028	39854	2.05	1022.23	2.78E+00	1.73E-02	9.7	
9	0	609.07	1127	19831	1.79	1218.80	2.38E+00	4.84E-03	21.8	
10	0	661.61	730914	38504	1.41	1323.85	2.21E+00	3.14E+00	0.1	
11	0	898.04	19946	33401	1.55	1796.59	1.67E+00	8.57E-02	2.0	
12	0	1173.20	485697	20164	1.69	2346.73	1.30E+00	2.09E+00	0.2	
13	0	1332.49	437484	6704	1.77	2665.19	1.16E+00	1.88E+00	0.2	
14	0	1460.73	1780	2060	2.03	2921.57	1.07E+00	7.65E-03	5.8	
15	0	1836.01	11866	1676	2.05	3671.75	9.22E-01	5.10E-02	1.2	

Spectrum   : MCA0:[NDSCOUNT]TBE06$1
Calib Date: 22-MAR-2021 07:40
Detector   :   Geometry   : 06S25031921
Fit type   : 5th Degree Empirical,



Analyst:

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==============================================================================
VAX/VMS Teledyne Brown Eng. Laboratory Gamma Report: 22-MAR-2021 07:41:45.73
TBE06 33-TP10933A HpGe ******* Aquisition Date/Time: 19-MAR-2021 14:45:58.43
------------------------------------------------------------------------------
LIMS No., Customer Name, Client ID: S25 5ML MIXED GAMMA CALIBRATION

Sample ID       : 06S25031921                  Smple Date: 1-JUN-2019 12:00:00.0
Sample Type     : STD                          Geometry  : 06S25031921
Quantity        : 1.00000E+00 TOTAL            BKGFILE   : NOBKG
Start Channel   : 80      Energy Tol   : 2.00000  Real Time : 2 16:43:37.11
End Channel     : 4090    Pk Srch Sens: 9.00000  Live time : 2 16:39:12.77
MDA Multiple    : 4.6600  Library Used: CALIBRATION
Peak Evaluation - Identified and Unidentified
```

Pk	It	Energy	Area	Bkgnd	FWHM	Channel	%Eff	Cts/Sec	%Err	Fit
1	0	46.49	1952	34584	0.92	93.80	9.94E-02	8.39E-03	14.5	
2	0	74.78	1441	47490	0.94	150.37	2.39E+00	6.19E-03	25.2	
3	0	88.01	128267	68527	0.97	176.82	3.94E+00	5.51E-01	0.5	
4	0	122.05	92059	59957	0.99	244.90	6.23E+00	3.96E-01	0.6	
5	0	136.44	11811	51850	1.00	273.67	6.50E+00	5.07E-02	3.6	
6	0	165.86	22108	55027	1.10	332.52	6.41E+00	9.50E-02	2.1	
7	0	391.75	19042	41769	1.19	784.24	3.50E+00	8.18E-02	2.1	
8	0	510.77	4028	39854	2.05	1022.23	2.78E+00	1.73E-02	9.7	
9	0	609.07	1127	19831	1.79	1218.80	2.38E+00	4.84E-03	21.8	
10	0	661.61	730914	38504	1.41	1323.85	2.21E+00	3.14E+00	0.1	
11	0	898.04	19946	33401	1.55	1796.59	1.67E+00	8.57E-02	2.0	
12	0	1173.20	485697	20164	1.69	2346.73	1.30E+00	2.09E+00	0.2	
13	0	1332.49	437484	6704	1.77	2665.19	1.16E+00	1.88E+00	0.2	
14	0	1460.73	1780	2060	2.03	2921.57	1.07E+00	7.65E-03	5.8	
15	0	1836.01	11866	1676	2.05	3671.75	9.22E-01	5.10E-02	1.2	

Nuclide Line Activity Report

Nuclide Type:

Nuclide	Energy	Area	%Abn	%Eff	Uncorrected BQ/TOTAL	Decay Corr BQ/TOTAL	2-Sigma %Error
02-CD109	88.03	128267	3.72*	3.936E+00	3.764E+02	1.009E+03	0.95
03-CO57	122.06	92059	85.51*	6.230E+00	7.425E+00	4.003E+01	1.19
04-CE139	165.85	22108	80.35*	6.407E+00	1.845E+00	5.080E+01	4.19
06-SN113	391.69	19042	64.90*	3.498E+00	3.604E+00	1.901E+02	4.13
08-CS137	661.65	730914	85.12*	2.215E+00	1.666E+02	1.736E+02	0.26
09-Y88	898.02	19946	93.40*	1.671E+00	5.490E+00	3.964E+02	3.93
10-CO60	1173.22	485697	100.00	1.301E+00	1.604E+02	2.034E+02	0.32
	1332.49	437484	100.00*	1.160E+00	1.620E+02	2.054E+02	0.31
12-Y88	1836.01	11866	99.38*	9.216E-01	5.566E+00	4.019E+02	2.47

Flag: "*" = Keyline

Total number of lines in spectrum	15		
Number of unidentified lines	6		
Number of lines tentatively identified by NID	9	60.00%	

Nuclide Type :

Nuclide	Hlife	Decay	Uncorrected BQ/TOTAL	Decay Corr BQ/TOTAL	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
02-CD109	462.90D	2.68	3.764E+02	1.009E+03	0.001E+04	0.95	
03-CO57	270.90D	5.39	7.425E+00	4.003E+01	0.048E+01	1.19	
04-CE139	137.66D	27.5	1.845E+00	5.080E+01	0.213E+01	4.19	
06-SN113	115.10D	52.7	3.604E+00	1.901E+02	0.079E+02	4.13	
08-CS137	30.17Y	1.04	1.666E+02	1.736E+02	0.005E+02	0.26	
09-Y88	106.65D	72.2	5.490E+00	3.964E+02	0.156E+02	3.93	
10-CO60	5.27Y	1.27	1.620E+02	2.054E+02	0.006E+02	0.31	
12-Y88	106.65D	72.2	5.566E+00	4.019E+02	0.099E+02	2.47	
			---------	---------			
	Total Activity :		7.289E+02	2.467E+03			
	Grand Total Activity :		7.289E+02	2.467E+03			

Flags: "K" = Keyline not found "M" = Manually accepted
"E" = Manually edited "A" = Nuclide specific abn. limit

It	Energy	Area	Bkgnd	FWHM	Channel	Left	Pw	Cts/Sec	%Err	%Eff	Flags
0	46.49	1952	34584	0.92	93.80	92	5	8.39E-03	29.0	9.94E-02	
0	74.78	1441	47490	0.94	150.37	148	7	6.19E-03	50.4	2.39E+00	
0	136.44	11811	51850	1.00	273.67	270	9	5.07E-02	7.2	6.50E+00	
0	510.77	4028	39854	2.05	1022.23	1017	11	1.73E-02	19.4	2.78E+00	
0	609.07	1127	19831	1.79	1218.80	1216	8	4.84E-03	43.6	2.38E+00	
0	1460.73	1780	2060	2.03	2921.57	2915	13	7.65E-03	11.5	1.07E+00	

Flags: "T" = Tentatively associated

Summary of Nuclide Activity

Total number of lines in spectrum 15
Number of unidentified lines 6
Number of lines tentatively identified by NID 9 60.00%

Nuclide Type :

Nuclide	Hlife	Decay	Wtd Mean Uncorrected BQ/TOTAL	Wtd Mean Decay Corr BQ/TOTAL	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
02-CD109	462.90D	2.68	3.764E+02	1.009E+03	0.001E+04	0.95	
03-CO57	270.90D	5.39	7.425E+00	4.003E+01	0.048E+01	1.19	
04-CE139	137.66D	27.5	1.845E+00	5.080E+01	0.213E+01	4.19	
06-SN113	115.10D	52.7	3.604E+00	1.901E+02	0.079E+02	4.13	
08-CS137	30.17Y	1.04	1.666E+02	1.736E+02	0.005E+02	0.26	
09-Y88	106.65D	72.2	5.490E+00	3.964E+02	0.156E+02	3.93	
10-CO60	5.27Y	1.27	1.620E+02	2.054E+02	0.006E+02	0.31	
12-Y88	106.65D	72.2	5.566E+00	4.019E+02	0.099E+02	2.47	
			---------	---------			
	Total Activity :		7.289E+02	2.467E+03			
	Grand Total Activity :		7.289E+02	2.467E+03			

Flags: "K" = Keyline not found "M" = Manually accepted
"E" = Manually edited "A" = Nuclide specific abn. limit

Interference Report

No interference correction performed

Combined Activity-MDA Report

---- Identified Nuclides ----

Nuclide	Activity (BQ/TOTAL)	Act error	MDA (BQ/TOTAL)	MDA error	Act/MDA
02-CD109	1.009E+03	9.567E+00	7.229E+00	0.000E+00	139.569
03-CO57	4.003E+01	4.783E-01	3.829E-01	0.000E+00	104.556
04-CE139	5.080E+01	2.131E+00	1.982E+00	0.000E+00	25.632
06-SN113	1.901E+02	7.858E+00	8.714E+00	0.000E+00	21.813
08-CS137	1.736E+02	4.566E-01	1.586E-01	0.000E+00	1094.419
09-Y88	3.964E+02	1.558E+01	1.503E+01	0.000E+00	26.383

10-CO60	2.054E+02	6.469E-01	1.376E-01	0.000E+00	1492.376
12-Y88	4.019E+02	9.945E+00	5.425E+00	0.000E+00	74.088

---- Non-Identified Nuclides ----

Nuclide	Key-Line Activity (BQ/TOTAL)	K.L. Ided	Act error	MDA (BQ/TOTAL)	MDA error	Act/MDA
01-AM241	7.460E-02		7.931E-01	1.344E+00	0.000E+00	0.056
05-HG203	2.768E+02		1.141E+03	1.805E+03	0.000E+00	0.153
07-SR85	4.560E+02		9.668E+01	1.427E+02	0.000E+00	3.195

```
A,06S25031921      ,03/22/2021 07:41,06/01/2019 12:00,   1.000E+00,S25 5ML MIXED
B,06S25031921      ,CALIBRATION         ,03/22/2021 07:40,06S25031921
C,02-CD109,YES,   1.009E+03,   9.567E+00,   7.229E+00,,  139.569
C,03-CO57 ,YES,   4.003E+01,   4.783E-01,   3.829E-01,,  104.556
C,04-CE139,YES,   5.080E+01,   2.131E+00,   1.982E+00,,   25.632
C,06-SN113,YES,   1.901E+02,   7.858E+00,   8.714E+00,,   21.813
C,08-CS137,YES,   1.736E+02,   4.566E-01,   1.586E-01,, 1094.419
C,09-Y88  ,YES,   3.964E+02,   1.558E+01,   1.503E+01,,   26.383
C,10-CO60 ,YES,   2.054E+02,   6.469E-01,   1.376E-01,, 1492.376
C,12-Y88  ,YES,   4.019E+02,   9.945E+00,   5.425E+00,,   74.088
C,01-AM241,NO ,   7.460E-02,   7.931E-01,   1.344E+00,,    0.056
C,05-HG203,NO ,   2.768E+02,   1.141E+03,   1.805E+03,,    0.153
C,07-SR85 ,NO ,   4.560E+02,   9.668E+01,   1.427E+02,,    3.195
```

E & Z 2088-10-1 Mixed Gamma
6/1/19 12:00 PM

S50 Bottle

		Orig. Wt	5.1617	Volume	50				
		Wt Used	4.4184	Aliquot	5.0000	Certificate	Aliquoted	Actual	Percent
	Half-Life	Energy(KeV)	ate G/s	%err	%abn	Bq/Tot	G/S	Bq/Tot	Diff
Pb-210	22.26Y	46.6	72.1		4.18%	762.12	31.86		
Cd-109	462.9d	88.0	84.75		3.72%	1006.61	37.45	1008.0	0.14%
Co-57	271.8d	122.1	77.25		85.51%	39.92	34.13	39.9	0.01%
Ce-139	137.64d	165.9	92.68		80.35%	50.96	40.95	51.0	0.15%
Hg-203	46.6d	279.2	273		77.30%	156.04	120.62		
Sn-113	115.09d	391.7	280		64.90%	190.62	123.72	188.9	-0.90%
Sr-85	64.849	514.0	547.9		98.40%	246.02	242.08		
Cs-137	30.17y	661.6	330.6		85.12%	171.61	146.07	174.9	1.92%
Y-88	106.65d	898.0	858.7		93.40%	406.22	379.41	391.6	-3.60%
Co-60	5.27y	1173.2	460.4		100.00%	203.42	203.42	204.2	0.38%
Co-60	5.27y	1332.5	460.9		100.00%	203.64	203.64	205.1	0.71%
Y-88	106.65d	1836.0	908		99.38%	403.69	401.19	401.9	-0.44%

Eff. Name: **06S50031621**

Analyst: KOJ

Analyst:

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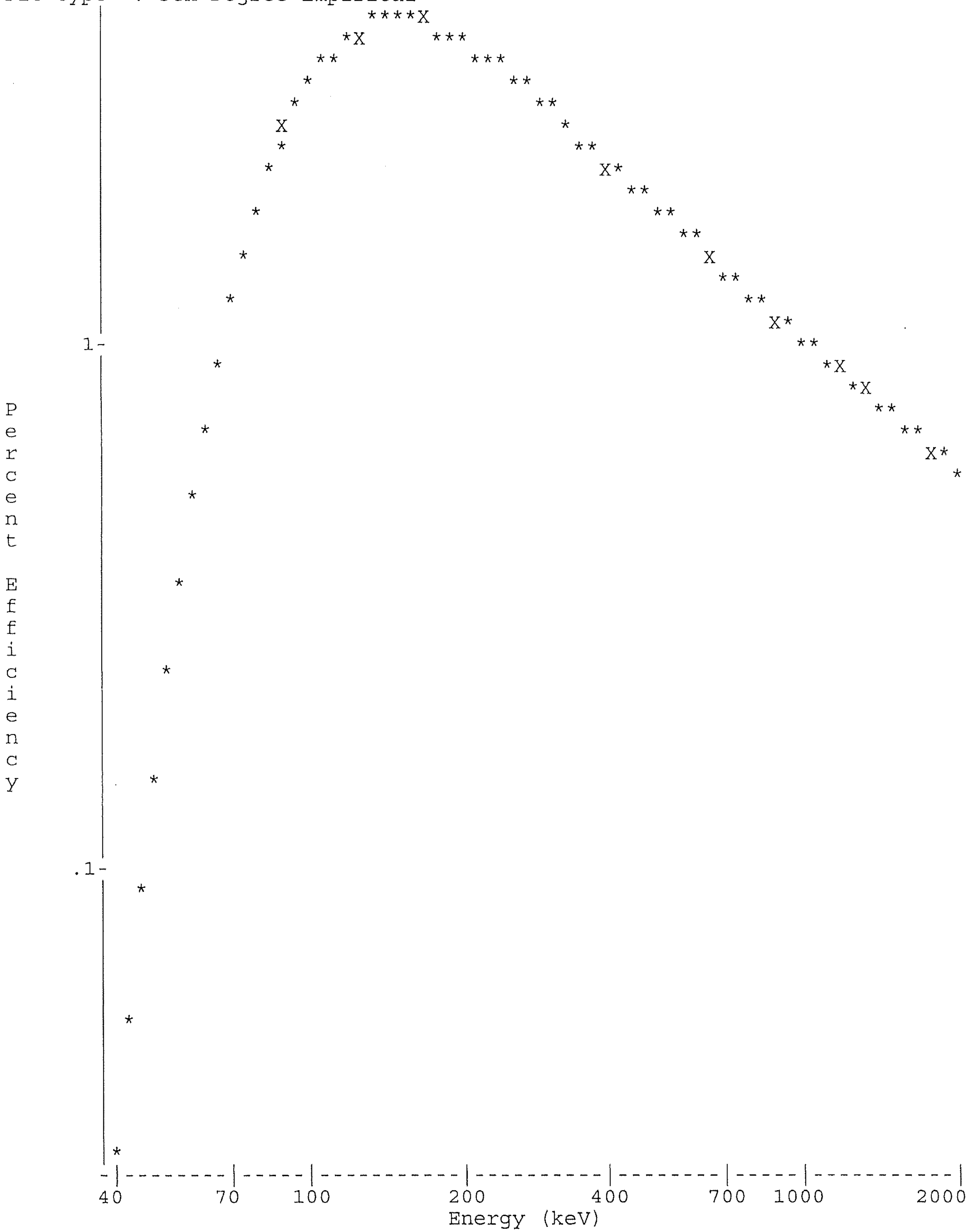
VAX/VMS Teledyne Brown Eng. Laboratory Gamma Report: 22-MAR-2021 09:44:01.72
TBE06 33-TP10933A HpGe ******* Aquisition Date/Time: 16-MAR-2021 08:49:41.57

LIMS No., Customer Name, Client ID: S50 5ML MIXED GAMMA CALIBRATION

Sample ID : 06S50031621 Smple Date: 1-JUN-2019 12:00:00.0
Sample Type : STD Geometry : 06S50031621
Quantity : 1.00000E+00 TOTAL BKGFILE : NOBKG
Start Channel : 80 Energy Tol : 2.00000 Real Time : 3 07:08:03.15
End Channel : 4090 Pk Srch Sens: 9.00000 Live time : 3 07:04:03.86
MDA Multiple : 4.6600 Library Used: CALIBRATION
Peak Evaluation - Identified and Unidentified

Pk	It	Energy	Area	Bkgnd	FWHM	Channel	%Eff	Cts/Sec	%Err	Fit
1	0	46.48	1992	42775	1.15	93.77	1.26E-01	7.00E-03	17.4	
2	0	74.90	1912	30566	1.00	150.61	1.68E+00	6.72E-03	13.9	
3	10	85.40	6727	89463	2.43	171.60	2.42E+00	2.36E-02	10.8	1.56E+01
4	10	88.01	103303	34137	0.96	176.82	2.58E+00	3.63E-01	0.4	
5	0	122.04	72172	54617	0.98	244.87	3.97E+00	2.54E-01	0.7	
6	0	136.46	9186	41242	1.06	273.70	4.17E+00	3.23E-02	4.0	
7	0	165.87	17944	44649	1.12	332.51	4.17E+00	6.30E-02	2.3	
8	0	185.73	1831	37630	1.36	372.23	4.02E+00	6.43E-03	17.7	
9	0	391.74	15588	36578	1.25	784.15	2.31E+00	5.48E-02	2.4	
10	0	510.95	5205	35452	2.11	1022.50	1.83E+00	1.83E-02	7.1	
11	0	661.63	594880	31745	1.41	1323.77	1.46E+00	2.09E+00	0.1	
12	0	898.00	16557	26885	1.57	1796.35	1.13E+00	5.82E-02	2.1	
13	0	1173.22	412497	19014	1.73	2346.57	8.99E-01	1.45E+00	0.2	
14	0	1332.51	372411	5543	1.78	2665.00	8.08E-01	1.31E+00	0.2	
15	0	1460.90	2381	1616	2.06	2921.67	7.48E-01	8.37E-03	4.0	
16	0	1764.40	424	1111	1.61	3528.32	6.43E-01	1.49E-03	17.4	
17	0	1836.00	10002	1215	2.07	3671.44	6.23E-01	3.51E-02	1.3	

Spectrum : MCA0:[NDSCOUNT]TBE06$1
Calib Date: 22-MAR-2021 09:44
Detector : Geometry : 06S50031621
Fit type : 5th Degree Empirical



Analyst:

VAX/VMS Teledyne Brown Eng. Laboratory Gamma Report: 22-MAR-2021 09:48:13.84
TBE06 33-TP10933A HpGe ******* Aquisition Date/Time: 16-MAR-2021 08:49:41.57

LIMS No., Customer Name, Client ID: S50 5ML MIXED GAMMA CALIBRATION

Sample ID : 06S50031621 | Smple Date: 1-JUN-2019 12:00:00.0
Sample Type : STD | Geometry : 06S50031621
Quantity : 1.00000E+00 TOTAL | BKGFILE : NOBKG
Start Channel : 80 | Energy Tol : 2.00000 | Real Time : 3 07:08:03.15
End Channel : 4090 | Pk Srch Sens: 9.00000 | Live time : 3 07:04:03.86
MDA Multiple : 4.6600 | Library Used: CALIBRATION
Peak Evaluation - Identified and Unidentified

Pk	It	Energy	Area	Bkgnd	FWHM	Channel	%Eff	Cts/Sec	%Err	Fit
1	0	46.48	1992	42775	1.15	93.77	1.26E-01	7.00E-03	17.4	
2	0	74.90	1912	30566	1.00	150.61	1.68E+00	6.72E-03	13.9	
3	10	85.40	6727	89463	2.43	171.60	2.42E+00	2.36E-02	10.8	1.56E+01
4	10	88.01	103303	34137	0.96	176.82	2.58E+00	3.63E-01	0.4	
5	0	122.04	72172	54617	0.98	244.87	3.97E+00	2.54E-01	0.7	
6	0	136.46	9186	41242	1.06	273.70	4.17E+00	3.23E-02	4.0	
7	0	165.87	17944	44649	1.12	332.51	4.17E+00	6.30E-02	2.3	
8	0	185.73	1831	37630	1.36	372.23	4.02E+00	6.43E-03	17.7	
9	0	391.74	15588	36578	1.25	784.15	2.31E+00	5.48E-02	2.4	
10	0	510.95	5205	35452	2.11	1022.50	1.83E+00	1.83E-02	7.1	
11	0	661.63	594880	31745	1.41	1323.77	1.46E+00	2.09E+00	0.1	
12	0	898.00	16557	26885	1.57	1796.35	1.13E+00	5.82E-02	2.1	
13	0	1173.22	412497	19014	1.73	2346.57	8.99E-01	1.45E+00	0.2	
14	0	1332.51	372411	5543	1.78	2665.00	8.08E-01	1.31E+00	0.2	
15	0	1460.90	2381	1616	2.06	2921.67	7.48E-01	8.37E-03	4.0	
16	0	1764.40	424	1111	1.61	3528.32	6.43E-01	1.49E-03	17.4	
17	0	1836.00	10002	1215	2.07	3671.44	6.23E-01	3.51E-02	1.3	

Nuclide Line Activity Report

Nuclide Type:

Nuclide	Energy	Area	%Abn	%Eff	Uncorrected BQ/TOTAL	Decay Corr BQ/TOTAL	2-Sigma %Error
02-CD109	88.03	103303	3.72*	2.584E+00	3.775E+02	1.008E+03	0.85
03-CO57	122.06	72172	85.51*	3.975E+00	7.460E+00	3.992E+01	1.42
04-CE139	165.85	17944	80.35*	4.170E+00	1.881E+00	5.104E+01	4.50
06-SN113	391.69	15588	64.90*	2.315E+00	3.646E+00	1.889E+02	4.71
08-CS137	661.65	594880	85.12*	1.463E+00	1.679E+02	1.749E+02	0.29
09-Y88	898.02	16557	93.40*	1.127E+00	5.528E+00	3.916E+02	4.14
10-CO60	1173.22	412497	100.00	8.986E-01	1.613E+02	2.042E+02	0.35
	1332.49	372411	100.00*	8.076E-01	1.620E+02	2.051E+02	0.34
12-Y88	1836.01	10002	99.38*	6.232E-01	5.674E+00	4.019E+02	2.54

Flag: "*" = Keyline

Sample ID : 06S50031621   Acquisition date : 16-MAR-2021 08:49:41

Total number of lines in spectrum	17	
Number of unidentified lines	8	
Number of lines tentatively identified by NID	9	52.94%

Nuclide Type :

Nuclide	Hlife	Decay	Uncorrected BQ/TOTAL	Decay Corr BQ/TOTAL	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
02-CD109	462.90D	2.67	3.775E+02	1.008E+03	0.009E+03	0.85	
03-CO57	270.90D	5.35	7.460E+00	3.992E+01	0.057E+01	1.42	
04-CE139	137.66D	27.1	1.881E+00	5.104E+01	0.230E+01	4.50	
06-SN113	115.10D	51.8	3.646E+00	1.889E+02	0.089E+02	4.71	
08-CS137	30.17Y	1.04	1.679E+02	1.749E+02	0.005E+02	0.29	
09-Y88	106.65D	70.8	5.528E+00	3.916E+02	0.162E+02	4.14	
10-CO60	5.27Y	1.27	1.620E+02	2.051E+02	0.007E+02	0.34	
12-Y88	106.65D	70.8	5.674E+00	4.019E+02	0.102E+02	2.54	
			---------	---------			
	Total Activity :		7.316E+02	2.461E+03			
	Grand Total Activity :		7.316E+02	2.461E+03			

Flags: "K" = Keyline not found   "M" = Manually accepted
       "E" = Manually edited   "A" = Nuclide specific abn. limit

It	Energy	Area	Bkgnd	FWHM	Channel	Left	Pw	Cts/Sec	%Err	%Eff	Flags
0	46.48	1992	42775	1.15	93.77	91	7	7.00E-03	34.7	1.26E-01	
0	74.90	1912	30566	1.00	150.61	149	5	6.72E-03	27.8	1.68E+00	
10	85.40	6727	89463	2.43	171.60	164	18	2.36E-02	21.6	2.42E+00	
0	136.46	9186	41242	1.06	273.70	270	8	3.23E-02	7.9	4.17E+00	
0	185.73	1831	37630	1.36	372.23	370	7	6.43E-03	35.4	4.02E+00	
0	510.95	5205	35452	2.11	1022.50	1017	11	1.83E-02	14.3	1.83E+00	
0	1460.90	2381	1616	2.06	2921.67	2915	13	8.37E-03	8.1	7.48E-01	
0	1764.40	424	1111	1.61	3528.32	3522	14	1.49E-03	34.7	6.43E-01	

Flags: "T" = Tentatively associated

Summary of Nuclide Activity

Total number of lines in spectrum	17	
Number of unidentified lines	8	
Number of lines tentatively identified by NID	9	52.94%

Nuclide Type :

Nuclide	Hlife	Decay	Wtd Mean Uncorrected BQ/TOTAL	Wtd Mean Decay Corr BQ/TOTAL	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
02-CD109	462.90D	2.67	3.775E+02	1.008E+03	0.009E+03	0.85	
03-CO57	270.90D	5.35	7.460E+00	3.992E+01	0.057E+01	1.42	
04-CE139	137.66D	27.1	1.881E+00	5.104E+01	0.230E+01	4.50	
06-SN113	115.10D	51.8	3.646E+00	1.889E+02	0.089E+02	4.71	
08-CS137	30.17Y	1.04	1.679E+02	1.749E+02	0.005E+02	0.29	
09-Y88	106.65D	70.8	5.528E+00	3.916E+02	0.162E+02	4.14	
10-CO60	5.27Y	1.27	1.616E+02	2.047E+02	0.005E+02	0.24	
12-Y88	106.65D	70.8	5.674E+00	4.019E+02	0.102E+02	2.54	
			---------	---------			
	Total Activity :		7.312E+02	2.460E+03			
	Grand Total Activity :		7.312E+02	2.460E+03			

Flags: "K" = Keyline not found "M" = Manually accepted
"E" = Manually edited "A" = Nuclide specific abn. limit

Interference Report

No interference correction performed

Combined Activity-MDA Report

---- Identified Nuclides ----

Nuclide	Activity (BQ/TOTAL)	Act error	MDA (BQ/TOTAL)	MDA error	Act/MDA
02-CD109	1.008E+03	8.546E+00	8.191E+00	0.000E+00	123.002
03-CO57	3.992E+01	5.681E-01	4.654E-01	0.000E+00	85.778
04-CE139	5.104E+01	2.299E+00	2.363E+00	0.000E+00	21.597
06-SN113	1.889E+02	8.890E+00	9.893E+00	0.000E+00	19.094

08-CS137	1.749E+02	5.077E-01	1.849E-01	0.000E+00	946.222
09-Y88	3.916E+02	1.620E+01	1.675E+01	0.000E+00	23.380
10-CO60	2.047E+02	5.012E-01	1.475E-01	0.000E+00	1387.846
12-Y88	4.019E+02	1.019E+01	5.711E+00	0.000E+00	70.369

---- Non-Identified Nuclides ----

Nuclide	Key-Line Activity (BQ/TOTAL)	K.L. Ided	Act error	MDA (BQ/TOTAL)	MDA error	Act/MDA
01-AM241	-4.434E-01		7.290E-01	1.230E+00	0.000E+00	-0.360
05-HG203	6.524E+02		1.179E+03	2.003E+03	0.000E+00	0.326
07-SR85	5.684E+02		1.104E+02	1.632E+02	0.000E+00	3.483

```
A,06S50031621      ,03/22/2021 09:48,06/01/2019 12:00,   1.000E+00,S50 5ML MIXED
B,06S50031621      ,CALIBRATION         ,03/22/2021 09:44,06S50031621
C,02-CD109,YES,   1.008E+03,   8.546E+00,   8.191E+00,,  123.002
C,03-CO57 ,YES,   3.992E+01,   5.681E-01,   4.654E-01,,   85.778
C,04-CE139,YES,   5.104E+01,   2.299E+00,   2.363E+00,,   21.597
C,06-SN113,YES,   1.889E+02,   8.890E+00,   9.893E+00,,   19.094
C,08-CS137,YES,   1.749E+02,   5.077E-01,   1.849E-01,,  946.222
C,09-Y88  ,YES,   3.916E+02,   1.620E+01,   1.675E+01,,   23.380
C,10-CO60 ,YES,   2.047E+02,   5.012E-01,   1.475E-01,, 1387.846
C,12-Y88  ,YES,   4.019E+02,   1.019E+01,   5.711E+00,,   70.369
C,01-AM241,NO ,  -4.434E-01,   7.290E-01,   1.230E+00,,   -0.360
C,05-HG203,NO ,   6.524E+02,   1.179E+03,   2.003E+03,,    0.326
C,07-SR85 ,NO ,   5.684E+02,   1.104E+02,   1.632E+02,,    3.483
```

E & Z 2088-10-1 Mixed Gamma
6/1/19 12:00 PM

S25 Bottle

		Orig. Wt	5.1617	Volume	50				
		Wt Used	4.4184	Aliquot	5.0000	Certificate	Aliquoted	Actual	Percent
	Half-Life	Energy(KeV)	ate G/s	%err	%abn	Bq/Tot	G/S	Bq/Tot	Diff
Cd-109	462.9d	88.0	84.75		3.72%	1006.61	37.45	1005.0	-0.16%
Co-57	271.8d	122.1	77.25		85.51%	39.92	34.13	40.0	0.14%
Ce-139	137.64d	165.9	92.68		80.35%	50.96	40.95	50.9	-0.05%
Hg-203	46.6d	279.2	273		77.30%	156.04	120.62	143.3	-8.17%
Sn-113	115.09d	391.7	280		64.90%	190.62	123.72	191.3	0.35%
Sr-85	64.849	514.0	547.9		98.40%	246.02	242.08	247.8	0.72%
Cs-137	30.17y	661.6	330.6		85.12%	171.61	146.07	173.9	1.34%
Y-88	106.65d	898.0	858.7		93.40%	406.22	379.41	390.3	-3.92%
Co-60	5.27y	1173.2	460.4		100.00%	203.42	203.42	204.9	0.73%
Co-60	5.27y	1332.5	460.9		100.00%	203.64	203.64	207.6	1.94%
Y-88	106.65d	1836.0	908		99.38%	403.69	401.19	401.3	-0.59%

Eff. Name: **07S25121819**

Analyst: KOJ

Analyst:

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VAX/VMS Teledyne Brown Eng. Laboratory Gamma Report: 26-DEC-2019 10:27:43.64
TBE07 31-TP10768B HpGe ******* Aquisition Date/Time: 18-DEC-2019 14:56:31.96

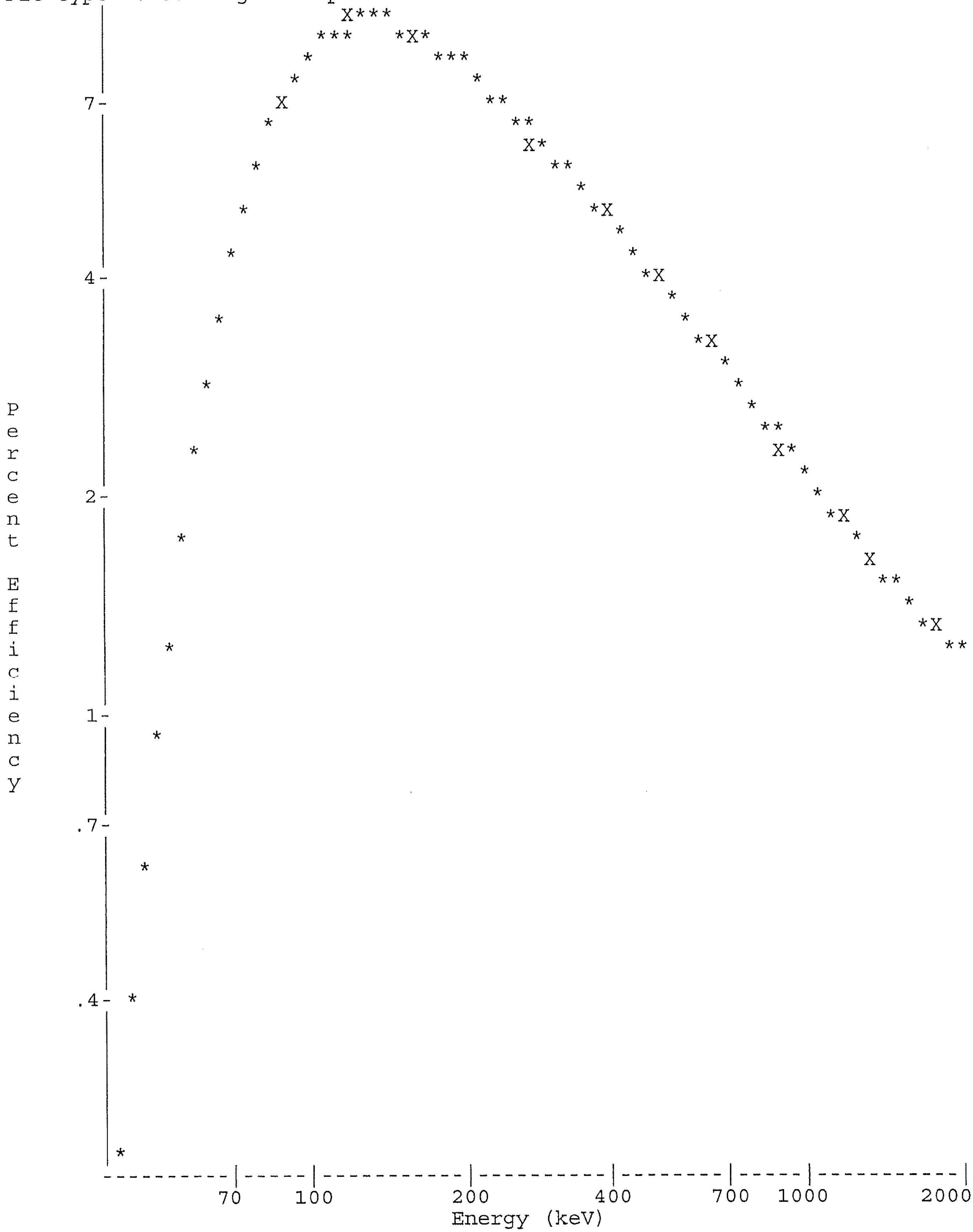
LIMS No., Customer Name, Client ID: S25 5ML MIXED GAMMA CALIBRATION

Sample ID : 07S25121819
Sample Type : STD
Quantity : 1.00000E+00 TOTAL
Start Channel : 80 Energy Tol : 2.00000
End Channel : 4090 Pk Srch Sens: 9.00000
MDA Multiple : 4.6600 Library Used: CALIBRATION
Peak Evaluation - Identified and Unidentified

Smple Date: 1-JUN-2019 12:00:00.0
Geometry : 07S25121819
BKGFILE : 07BG112719MT
Real Time : 0 02:17:08.44
Live time : 0 02:16:43.01

Pk	It	Energy	Area	Bkgnd	FWHM	Channel	%Eff	Cts/Sec	%Err	Fit
1	1	46.64	773	4715	1.33	92.73	7.18E-01	9.43E-02	16.4	7.52E-01
2	1	88.05	15405	5939	1.26	175.52	6.78E+00	1.88E+00	1.3	5.87E-01
3	1	122.07	14618	4613	1.29	243.53	8.70E+00	1.78E+00	1.2	6.83E-01
4	1	136.44	2070	4130	1.47	272.27	8.80E+00	2.52E-01	6.2	4.05E+00
5	1	165.84	10361	5634	1.38	331.06	8.46E+00	1.26E+00	1.8	1.03E+00
6	1	255.21	771	3174	1.55	509.71	6.63E+00	9.39E-02	13.6	2.09E+00
7	1	279.18	3032	3952	1.44	557.65	6.21E+00	3.70E-01	4.5	4.54E-01
8	1	391.68	14556	3443	1.54	782.53	4.77E+00	1.77E+00	1.2	1.82E+00
9	1	514.00	9029	3517	1.66	1027.05	3.80E+00	1.10E+00	1.8	4.47E+00
10	1	661.65	36547	2915	1.77	1322.19	3.05E+00	4.46E+00	0.6	4.17E+00
11	1	898.04	18756	2766	2.00	1794.67	2.30E+00	2.29E+00	1.0	6.67E+00
12	1	1173.22	28118	1516	2.24	2344.63	1.80E+00	3.43E+00	0.7	5.22E+00
13	1	1332.48	25432	837	2.41	2662.88	1.60E+00	3.10E+00	0.7	1.02E+01
14	1	1836.00	11248	356	2.94	3668.97	1.26E+00	1.37E+00	1.0	1.21E+01

Spectrum : MCA0:[NDSCOUNT]TBE07$1
Calib Date: 26-DEC-2019 10:27
Detector : Geometry : 07S25121819
Fit type : 5th Degree Empirical



Analyst:

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VAX/VMS Teledyne Brown Eng. Laboratory Gamma Report: 26-DEC-2019 10:29:22.88
TBE07 31-TP10768B HpGe ******* Aquisition Date/Time: 18-DEC-2019 14:56:31.96

LIMS No., Customer Name, Client ID: S25 5ML MIXED GAMMA CALIBRATION

Sample ID : 07S25121819 Smple Date: 1-JUN-2019 12:00:00.0
Sample Type : STD Geometry : 07S25121819
Quantity : 1.00000E+00 TOTAL BKGFILE : 07BG112719MT
Start Channel : 80 Energy Tol : 2.00000 Real Time : 0 02:17:08.44
End Channel : 4090 Pk Srch Sens: 9.00000 Live time : 0 02:16:43.01
MDA Multiple : 4.6600 Library Used: CALIBRATION
Peak Evaluation - Identified and Unidentified

Pk	It	Energy	Area	Bkgnd	FWHM	Channel	%Eff	Cts/Sec	%Err	Fit
1	1	46.64	773	4715	1.33	92.73	7.18E-01	9.43E-02	16.4	7.52E-01
2	1	88.05	15405	5939	1.26	175.52	6.78E+00	1.88E+00	1.3	5.87E-01
3	1	122.07	14618	4613	1.29	243.53	8.70E+00	1.78E+00	1.2	6.83E-01
4	1	136.44	2070	4130	1.47	272.27	8.80E+00	2.52E-01	6.2	4.05E+00
5	1	165.84	10361	5634	1.38	331.06	8.46E+00	1.26E+00	1.8	1.03E+00
6	1	255.21	771	3174	1.55	509.71	6.63E+00	9.39E-02	13.6	2.09E+00
7	1	279.18	3032	3952	1.44	557.65	6.21E+00	3.70E-01	4.5	4.54E-01
8	1	391.68	14556	3443	1.54	782.53	4.77E+00	1.77E+00	1.2	1.82E+00
9	1	514.00	9029	3517	1.66	1027.05	3.80E+00	1.10E+00	1.8	4.47E+00
10	1	661.65	36547	2915	1.77	1322.19	3.05E+00	4.46E+00	0.6	4.17E+00
11	1	898.04	18756	2766	2.00	1794.67	2.30E+00	2.29E+00	1.0	6.67E+00
12	1	1173.22	28118	1516	2.24	2344.63	1.80E+00	3.43E+00	0.7	5.22E+00
13	1	1332.48	25432	837	2.41	2662.88	1.60E+00	3.10E+00	0.7	1.02E+01
14	1	1836.00	11248	356	2.94	3668.97	1.26E+00	1.37E+00	1.0	1.21E+01

Flag: "*" = Peak area was modified by background subtraction

Nuclide Line Activity Report

Nuclide Type:

Nuclide	Energy	Area	%Abn	%Eff	Uncorrected BQ/TOTAL	Decay Corr BQ/TOTAL	2-Sigma %Error
02-CD109	88.03	15405	3.72*	6.778E+00	7.448E+02	1.005E+03	2.55
03-CO57	122.06	14618	85.51*	8.701E+00	2.395E+01	3.997E+01	2.41
04-CE139	165.85	10361	80.35*	8.456E+00	1.859E+01	5.094E+01	3.65
05-HG203	279.20	3032	81.46*	6.215E+00	7.301E+00	1.433E+02	9.06
06-SN113	391.69	14556	64.90*	4.771E+00	5.731E+01	1.913E+02	2.31
07-SR85	513.99	9029	99.27*	3.802E+00	2.916E+01	2.478E+02	3.62
08-CS137	661.65	36547	85.12*	3.048E+00	1.717E+02	1.739E+02	1.24
09-Y88	898.02	18756	93.40*	2.304E+00	1.063E+02	3.903E+02	1.95
10-CO60	1173.22	28118	100.00	1.798E+00	1.907E+02	2.049E+02	1.37
	1332.49	25432	100.00*	1.605E+00	1.932E+02	2.076E+02	1.39
12-Y88	1836.01	11248	99.38*	1.263E+00	1.093E+02	4.013E+02	2.07

Flag: "*" = Keyline

Summary of Nuclide Activity
Sample ID : 07S25121819

Acquisition date : 18-DEC-2019 14:56:31

Total number of lines in spectrum	14	
Number of unidentified lines	3	
Number of lines tentatively identified by NID	11	78.57%

Nuclide Type :

Nuclide	Hlife	Decay	Uncorrected BQ/TOTAL	Decay Corr BQ/TOTAL	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
02-CD109	462.90D	1.35	7.448E+02	1.005E+03	0.026E+03	2.55	
03-CO57	270.90D	1.67	2.395E+01	3.997E+01	0.096E+01	2.41	
04-CE139	137.66D	2.74	1.859E+01	5.094E+01	0.186E+01	3.65	
05-HG203	46.61D	19.6	7.301E+00	1.433E+02	0.130E+02	9.06	
06-SN113	115.10D	3.34	5.731E+01	1.913E+02	0.044E+02	2.31	
07-SR85	64.84D	8.50	2.916E+01	2.478E+02	0.090E+02	3.62	
08-CS137	30.17Y	1.01	1.717E+02	1.739E+02	0.022E+02	1.24	
09-Y88	106.65D	3.67	1.063E+02	3.903E+02	0.076E+02	1.95	
10-CO60	5.27Y	1.07	1.932E+02	2.076E+02	0.029E+02	1.39	
12-Y88	106.65D	3.67	1.093E+02	4.013E+02	0.083E+02	2.07	
			---------	---------			
	Total Activity :		1.462E+03	2.852E+03			
	Grand Total Activity :		1.462E+03	2.852E+03			

Flags: "K" = Keyline not found "M" = Manually accepted
"E" = Manually edited "A" = Nuclide specific abn. limit

Unidentified Energy Lines
Sample ID : 07S25121819

Acquisition date : 18-DEC-2019 14:56:31

It	Energy	Area	Bkgnd	FWHM	Channel	Left	Pw	Cts/Sec	%Err	%Eff	Flags
1	46.64	773	4715	1.33	92.73	89	9	9.43E-02	32.9	7.18E-01	
1	136.44	2070	4130	1.47	272.27	267	10	2.52E-01	12.4	8.80E+00	
1	255.21	771	3174	1.55	509.71	506	9	9.39E-02	27.3	6.63E+00	

Flags: "T" = Tentatively associated

Summary of Nuclide Activity

Total number of lines in spectrum	14	
Number of unidentified lines	3	
Number of lines tentatively identified by NID	11	78.57%

Nuclide Type :

Nuclide	Hlife	Decay	Wtd Mean Uncorrected BQ/TOTAL	Wtd Mean Decay Corr BQ/TOTAL	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
02-CD109	462.90D	1.35	7.448E+02	1.005E+03	0.026E+03	2.55	
03-CO57	270.90D	1.67	2.395E+01	3.997E+01	0.096E+01	2.41	
04-CE139	137.66D	2.74	1.859E+01	5.094E+01	0.186E+01	3.65	
05-HG203	46.61D	19.6	7.301E+00	1.433E+02	0.130E+02	9.06	
06-SN113	115.10D	3.34	5.731E+01	1.913E+02	0.044E+02	2.31	
07-SR85	64.84D	8.50	2.916E+01	2.478E+02	0.090E+02	3.62	
08-CS137	30.17Y	1.01	1.717E+02	1.739E+02	0.022E+02	1.24	
09-Y88	106.65D	3.67	1.063E+02	3.903E+02	0.076E+02	1.95	
10-CO60	5.27Y	1.07	1.919E+02	2.062E+02	0.020E+02	0.97	
12-Y88	106.65D	3.67	1.093E+02	4.013E+02	0.083E+02	2.07	
			---------	---------			
Total Activity :			1.460E+03	2.850E+03			

Grand Total Activity : 1.460E+03 2.850E+03

Flags: "K" = Keyline not found "M" = Manually accepted
"E" = Manually edited "A" = Nuclide specific abn. limit

Interference Report

No interference correction performed

Combined Activity-MDA Report

---- Identified Nuclides ----

Nuclide	Activity (BQ/TOTAL)	Act error	MDA (BQ/TOTAL)	MDA error	Act/MDA
02-CD109	1.005E+03	2.559E+01	1.912E+01	0.000E+00	52.567
03-CO57	3.997E+01	9.624E-01	7.562E-01	0.000E+00	52.860
04-CE139	5.094E+01	1.861E+00	1.275E+00	0.000E+00	39.947
05-HG203	1.433E+02	1.298E+01	1.199E+01	0.000E+00	11.946
06-SN113	1.913E+02	4.427E+00	3.216E+00	0.000E+00	59.495
07-SR85	2.478E+02	8.982E+00	6.105E+00	0.000E+00	40.592
08-CS137	1.739E+02	2.157E+00	1.016E+00	0.000E+00	171.218

09-Y88	3.903E+02	7.605E+00	4.371E+00	0.000E+00	89.291
10-CO60	2.062E+02	2.009E+00	1.090E+00	0.000E+00	189.159
12-Y88	4.013E+02	8.294E+00	2.498E+00	0.000E+00	160.653

---- Non-Identified Nuclides ----

Nuclide	Key-Line Activity (BQ/TOTAL)	K.L. Ided	Act error	MDA (BQ/TOTAL)	MDA error	Act/MDA
01-AM241	4.223E-01		2.177E+00	3.537E+00	0.000E+00	0.119

```
A,07S25121819       ,12/26/2019 10:29,06/01/2019 12:00,   1.000E+00,S25 5ML MIXED
B,07S25121819       ,CALIBRATION          ,12/26/2019 10:27,07S25121819
C,02-CD109,YES,    1.005E+03,   2.559E+01,   1.912E+01,,    52.567
C,03-CO57 ,YES,    3.997E+01,   9.624E-01,   7.562E-01,,    52.860
C,04-CE139,YES,    5.094E+01,   1.861E+00,   1.275E+00,,    39.947
C,05-HG203,YES,    1.433E+02,   1.298E+01,   1.199E+01,,    11.946
C,06-SN113,YES,    1.913E+02,   4.427E+00,   3.216E+00,,    59.495
C,07-SR85 ,YES,    2.478E+02,   8.982E+00,   6.105E+00,,    40.592
C,08-CS137,YES,    1.739E+02,   2.157E+00,   1.016E+00,,   171.218
C,09-Y88  ,YES,    3.903E+02,   7.605E+00,   4.371E+00,,    89.291
C,10-CO60 ,YES,    2.062E+02,   2.009E+00,   1.090E+00,,   189.159
C,12-Y88  ,YES,    4.013E+02,   8.294E+00,   2.498E+00,,   160.653
C,01-AM241,NO ,    4.223E-01,   2.177E+00,   3.537E+00,,     0.119
```

E & Z 2088-10-1 Mixed Gamma
6/1/19 12:00 PM

S25 Bottle

		Orig. Wt	5.1617	Volume	50				
		Wt Used	4.4184	Aliquot	5.0000	Certificate	Aliquoted	Actual	Percent
	Half-Life	Energy(KeV)	.ate G/s/	%err	%abn	Bq/Tot	G/S	Bq/Tot	Diff
Cd-109	462.9d	88.0	84.75		3.72%	1006.61	37.45	1008.0	0.14%
Co-57	271.8d	122.1	77.25		85.51%	39.92	34.13	40.1	0.49%
Ce-139	137.64d	165.9	92.68		80.35%	50.96	40.95	50.8	-0.38%
Hg-203	46.6d	279.2	273		77.30%	156.04	120.62	146.5	-6.12%
Sn-113	115.09d	391.7	280		64.90%	190.62	123.72	192.2	0.83%
Sr-85	64.849	514.0	547.9		98.40%	246.02	242.08	240.0	-2.45%
Cs-137	30.17y	661.6	330.6		85.12%	171.61	146.07	175.4	2.21%
Y-88	106.65d	898.0	858.7		93.40%	406.22	379.41	396.8	-2.32%
Co-60	5.27y	1173.2	460.4		100.00%	203.42	203.42	202.8	-0.31%
Co-60	5.27y	1332.5	460.9		100.00%	203.64	203.64	206.4	1.35%
Y-88	106.65d	1836.0	908		99.38%	403.69	401.19	402.2	-0.37%

Eff. Name: **08S25121919**

Analyst: KOJ

Analyst:

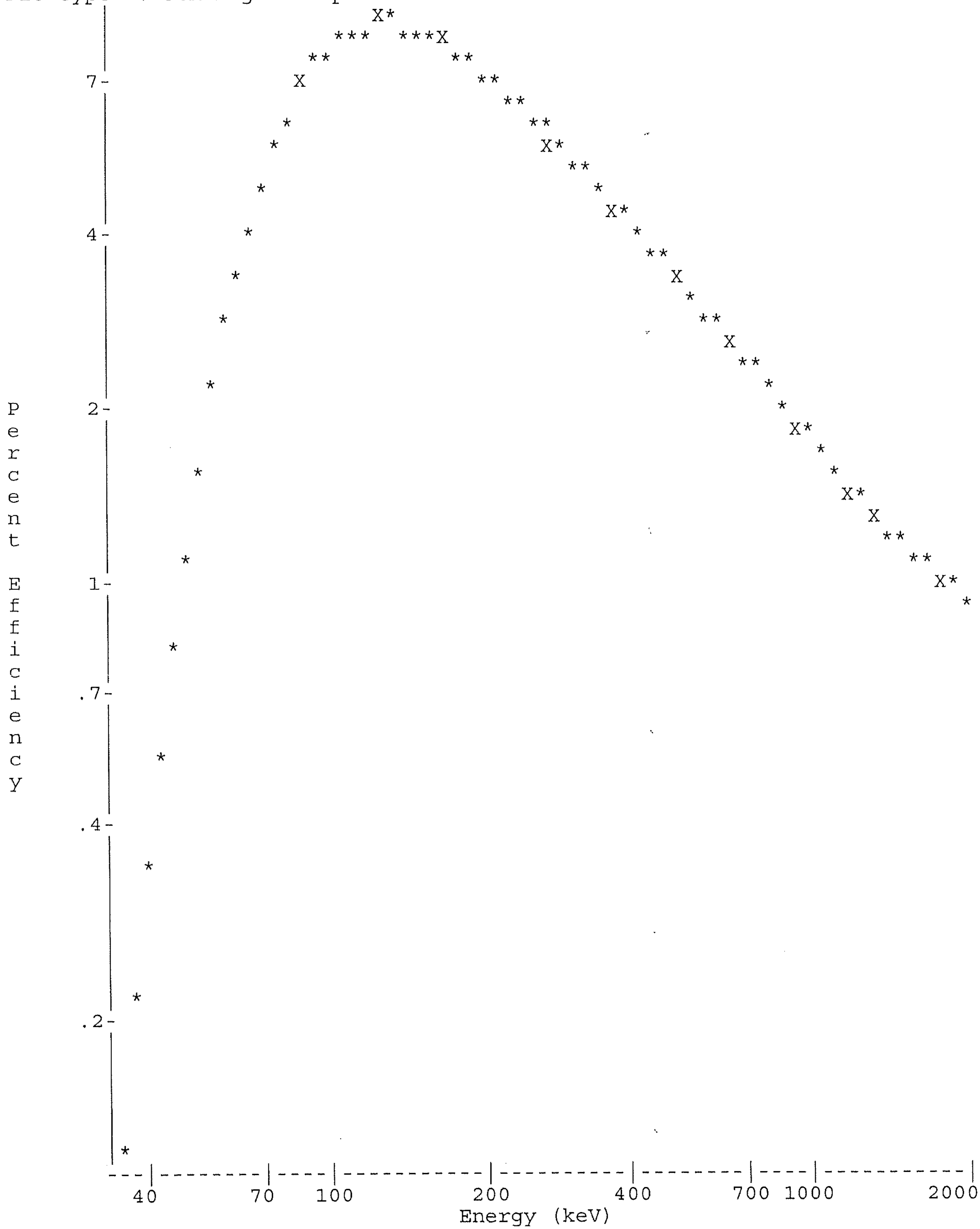
VAX/VMS Teledyne Brown Eng. Laboratory Gamma Report: 26-DEC-2019 11:55:49.52
TBE08 31-TP20610B HpGe ******** Aquisition Date/Time: 19-DEC-2019 09:30:14.76

LIMS No., Customer Name, Client ID: S25 5ML MIXED GAMMA CALIBRATION

Sample ID : 08S25121919 Smple Date: 1-JUN-2019 12:00:00.0
Sample Type : STD Geometry : 08S25121919
Quantity : 1.00000E+00 TOTAL BKGFILE : 08BG112719MT
Start Channel : 80 Energy Tol : 2.00000 Real Time : 0 02:22:09.14
End Channel : 4090 Pk Srch Sens: 9.00000 Live time : 0 02:21:40.56
MDA Multiple : 4.6600 Library Used: CALIBRATION
Peak Evaluation - Identified and Unidentified

Pk	It	Energy	Area	Bkgnd	FWHM	Channel	%Eff	Cts/Sec	%Err	Fit
1	1	46.22	968	4222	1.09	100.32	7.97E-01	1.14E-01	12.1	7.72E-01
2	1	87.92	16445	5243	1.23	183.54	6.97E+00	1.93E+00	1.1	2.31E+00
3	1	122.05	15075	5614	1.26	251.65	8.65E+00	1.77E+00	1.3	7.88E-01
4	1	136.49	2140	4042	1.49	280.46	8.65E+00	2.52E-01	6.0	1.70E+00
5	1	165.89	10292	4634	1.34	339.14	8.16E+00	1.21E+00	1.7	9.22E-01
6	1	255.24	566	3634	1.33	517.46	6.16E+00	6.66E-02	20.3	1.29E+00
7	1	279.23	2924	3581	1.40	565.32	5.72E+00	3.44E-01	4.4	1.10E+00
8	1	391.76	13449	3344	1.46	789.87	4.25E+00	1.58E+00	1.2	2.30E+00
9	1	514.04	7815	3136	1.53	1033.88	3.31E+00	9.19E-01	1.9	8.36E-01
10	1	661.65	32506	2608	1.64	1328.41	2.59E+00	3.82E+00	0.7	1.21E+00
11	1	898.01	16369	2548	1.78	1800.01	1.92E+00	1.93E+00	1.0	8.30E-01
12	1	1173.18	23661	1206	1.92	2348.99	1.48E+00	2.78E+00	0.7	5.31E-01
13	1	1332.45	21386	633	2.00	2666.73	1.31E+00	2.52E+00	0.7	6.28E-01
14	1	1836.03	9422	225	2.27	3671.21	1.02E+00	1.11E+00	1.1	1.35E+00

Spectrum   : MCA0:[NDSCOUNT]TBE08$1
Calib Date: 26-DEC-2019 11:55
Detector :   Geometry   : 08S25121919
Fit type : 5th Degree Empirical



Analyst:

==
VAX/VMS Teledyne Brown Eng. Laboratory Gamma Report: 26-DEC-2019 11:57:03.65
TBE08 31-TP20610B HpGe ******** Aquisition Date/Time: 19-DEC-2019 09:30:14.76

LIMS No., Customer Name, Client ID: S25 5ML MIXED GAMMA CALIBRATION

Sample ID : 08S25121919
Sample Type : STD
Quantity : 1.00000E+00 TOTAL
Start Channel : 80 Energy Tol : 2.00000
End Channel : 4090 Pk Srch Sens: 9.00000
MDA Multiple : 4.6600 Library Used: CALIBRATION
Peak Evaluation - Identified and Unidentified

Smple Date: 1-JUN-2019 12:00:00.0
Geometry : 08S25121919
BKGFILE : 08BG112719MT
Real Time : 0 02:22:09.14
Live time : 0 02:21:40.56

Pk	It	Energy	Area	Bkgnd	FWHM	Channel	%Eff	Cts/Sec	%Err	Fit
1	1	46.22	968	4222	1.09	100.32	7.97E-01	1.14E-01	12.1	7.72E-01
2	1	87.92	16445	5243	1.23	183.54	6.97E+00	1.93E+00	1.1	2.31E+00
3	1	122.05	15075	5614	1.26	251.65	8.65E+00	1.77E+00	1.3	7.88E-01
4	1	136.49	2140	4042	1.49	280.46	8.65E+00	2.52E-01	6.0	1.70E+00
5	1	165.89	10292	4634	1.34	339.14	8.16E+00	1.21E+00	1.7	9.22E-01
6	1	255.24	566	3634	1.33	517.46	6.16E+00	6.66E-02	20.3	1.29E+00
7	1	279.23	2924	3581	1.40	565.32	5.72E+00	3.44E-01	4.4	1.10E+00
8	1	391.76	13449	3344	1.46	789.87	4.25E+00	1.58E+00	1.2	2.30E+00
9	1	514.04	7815	3136	1.53	1033.88	3.31E+00	9.19E-01	1.9	8.36E-01
10	1	661.65	32506	2608	1.64	1328.41	2.59E+00	3.82E+00	0.7	1.21E+00
11	1	898.01	16369	2548	1.78	1800.01	1.92E+00	1.93E+00	1.0	8.30E-01
12	1	1173.18	23661	1206	1.92	2348.99	1.48E+00	2.78E+00	0.7	5.31E-01
13	1	1332.45	21386	633	2.00	2666.73	1.31E+00	2.52E+00	0.7	6.28E-01
14	1	1836.03	9422	225	2.27	3671.21	1.02E+00	1.11E+00	1.1	1.35E+00

Flag: "*" = Peak area was modified by background subtraction

Nuclide Line Activity Report

Nuclide Type:

Nuclide	Energy	Area	%Abn	%Eff	Uncorrected BQ/TOTAL	Decay Corr BQ/TOTAL	2-Sigma %Error
02-CD109	88.03	16445	3.72*	6.973E+00	7.457E+02	1.008E+03	2.29
03-CO57	122.06	15075	85.51*	8.646E+00	2.399E+01	4.011E+01	2.57
04-CE139	165.85	10292	80.35*	8.164E+00	1.846E+01	5.077E+01	3.30
05-HG203	279.20	2924	81.46*	5.722E+00	7.379E+00	1.465E+02	8.76
06-SN113	391.69	13449	64.90*	4.254E+00	5.731E+01	1.922E+02	2.48
07-SR85	513.99	7815	99.27*	3.306E+00	2.801E+01	2.400E+02	3.83
08-CS137	661.65	32506	85.12*	2.594E+00	1.732E+02	1.754E+02	1.31
09-Y88	898.02	16369	93.40*	1.918E+00	1.075E+02	3.968E+02	2.09
10-CO60	1173.22	23661	100.00	1.475E+00	1.887E+02	2.028E+02	1.47
	1332.49	21386	100.00*	1.311E+00	1.920E+02	2.064E+02	1.47
12-Y88	1836.01	9422	99.38*	1.024E+00	1.090E+02	4.022E+02	2.23

Flag: "*" = Keyline

Summary of Nuclide Activity
Sample ID : 08S25121919

Acquisition date : 19-DEC-2019 09:30:14

Total number of lines in spectrum	14	
Number of unidentified lines	3	
Number of lines tentatively identified by NID	11	78.57%

Nuclide Type :

Nuclide	Hlife	Decay	Uncorrected BQ/TOTAL	Decay Corr BQ/TOTAL	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
02-CD109	462.90D	1.35	7.457E+02	1.008E+03	0.023E+03	2.29	
03-CO57	270.90D	1.67	2.399E+01	4.011E+01	0.103E+01	2.57	
04-CE139	137.66D	2.75	1.846E+01	5.077E+01	0.168E+01	3.30	
05-HG203	46.61D	19.8	7.379E+00	1.465E+02	0.128E+02	8.76	
06-SN113	115.10D	3.35	5.731E+01	1.922E+02	0.048E+02	2.48	
07-SR85	64.84D	8.57	2.801E+01	2.400E+02	0.092E+02	3.83	
08-CS137	30.17Y	1.01	1.732E+02	1.754E+02	0.023E+02	1.31	
09-Y88	106.65D	3.69	1.075E+02	3.968E+02	0.083E+02	2.09	
10-CO60	5.27Y	1.08	1.920E+02	2.064E+02	0.030E+02	1.47	
12-Y88	106.65D	3.69	1.090E+02	4.022E+02	0.089E+02	2.23	
			---------	---------			
	Total Activity :		1.462E+03	2.858E+03			
	Grand Total Activity :		1.462E+03	2.858E+03			

Flags: "K" = Keyline not found   "M" = Manually accepted
"E" = Manually edited   "A" = Nuclide specific abn. limit

Sample ID : 08S25121919 Acquisition date : 19-DEC-2019 09:30:14

It	Energy	Area	Bkgnd	FWHM	Channel	Left	Pw	Cts/Sec	%Err	%Eff	Flags
1	46.22	968	4222	1.09	100.32	97	8	1.14E-01	24.2	7.97E-01	
1	136.49	2140	4042	1.49	280.46	276	10	2.52E-01	11.9	8.65E+00	
1	255.24	566	3634	1.33	517.46	512	10	6.66E-02	40.6	6.16E+00	

Flags: "T" = Tentatively associated

Summary of Nuclide Activity

Total number of lines in spectrum	14	
Number of unidentified lines	3	
Number of lines tentatively identified by NID	11	78.57%

Nuclide Type :

Nuclide	Hlife	Decay	Wtd Mean Uncorrected BQ/TOTAL	Wtd Mean Decay Corr BQ/TOTAL	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
02-CD109	462.90D	1.35	7.457E+02	1.008E+03	0.023E+03	2.29	
03-CO57	270.90D	1.67	2.399E+01	4.011E+01	0.103E+01	2.57	
04-CE139	137.66D	2.75	1.846E+01	5.077E+01	0.168E+01	3.30	
05-HG203	46.61D	19.8	7.379E+00	1.465E+02	0.128E+02	8.76	
06-SN113	115.10D	3.35	5.731E+01	1.922E+02	0.048E+02	2.48	
07-SR85	64.84D	8.57	2.801E+01	2.400E+02	0.092E+02	3.83	
08-CS137	30.17Y	1.01	1.732E+02	1.754E+02	0.023E+02	1.31	
09-Y88	106.65D	3.69	1.075E+02	3.968E+02	0.083E+02	2.09	
10-CO60	5.27Y	1.08	1.903E+02	2.046E+02	0.021E+02	1.04	
12-Y88	106.65D	3.69	1.090E+02	4.022E+02	0.089E+02	2.23	
			---------	---------			
	Total Activity :		1.461E+03	2.856E+03			

Grand Total Activity : 1.461E+03 2.856E+03

Flags: "K" = Keyline not found "M" = Manually accepted
"E" = Manually edited "A" = Nuclide specific abn. limit

Interference Report

No interference correction performed

Combined Activity-MDA Report

---- Identified Nuclides ----

Nuclide	Activity (BQ/TOTAL)	Act error	MDA (BQ/TOTAL)	MDA error	Act/MDA
02-CD109	1.008E+03	2.311E+01	1.822E+01	0.000E+00	55.299
03-CO57	4.011E+01	1.031E+00	7.340E-01	0.000E+00	54.648
04-CE139	5.077E+01	1.678E+00	1.305E+00	0.000E+00	38.902
05-HG203	1.465E+02	1.282E+01	1.242E+01	0.000E+00	11.794
06-SN113	1.922E+02	4.763E+00	3.294E+00	0.000E+00	58.358
07-SR85	2.400E+02	9.188E+00	6.549E+00	0.000E+00	36.647
08-CS137	1.754E+02	2.292E+00	1.071E+00	0.000E+00	163.721

09-Y88	3.968E+02		8.278E+00	4.619E+00	0.000E+00	85.910
10-CO60	2.046E+02		2.127E+00	1.090E+00	0.000E+00	187.592
12-Y88	4.022E+02		8.950E+00	2.374E+00	0.000E+00	169.424

---- Non-Identified Nuclides ----

Nuclide	Key-Line Activity (BQ/TOTAL)	K.L. Ided	Act error	MDA (BQ/TOTAL)	MDA error	Act/MDA
01-AM241	6.813E-02		2.018E+00	3.218E+00	0.000E+00	0.021

```
A,08S25121919       ,12/26/2019 11:57,06/01/2019 12:00,    1.000E+00,S25 5ML MIXED
B,08S25121919       ,CALIBRATION         ,12/26/2019 11:55,08S25121919
C,02-CD109,YES,   1.008E+03,   2.311E+01,   1.822E+01,,   55.299
C,03-CO57 ,YES,   4.011E+01,   1.031E+00,   7.340E-01,,   54.648
C,04-CE139,YES,   5.077E+01,   1.678E+00,   1.305E+00,,   38.902
C,05-HG203,YES,   1.465E+02,   1.282E+01,   1.242E+01,,   11.794
C,06-SN113,YES,   1.922E+02,   4.763E+00,   3.294E+00,,   58.358
C,07-SR85 ,YES,   2.400E+02,   9.188E+00,   6.549E+00,,   36.647
C,08-CS137,YES,   1.754E+02,   2.292E+00,   1.071E+00,,  163.721
C,09-Y88  ,YES,   3.968E+02,   8.278E+00,   4.619E+00,,   85.910
C,10-CO60 ,YES,   2.046E+02,   2.127E+00,   1.090E+00,,  187.592
C,12-Y88  ,YES,   4.022E+02,   8.950E+00,   2.374E+00,,  169.424
C,01-AM241,NO ,   6.813E-02,   2.018E+00,   3.218E+00,,    0.021
```

E & Z 2088-10-1 Mixed Gamma
6/1/19 12:00 PM

S50 Bottle

		Orig. Wt	5.1617	Volume	50				
		Wt Used	4.4184	Aliquot	5.0000	Certificate	Aliquoted	Actual	Percent
	Half-Life	Energy(KeV)	ate G/s/	%err	%abn	Bq/Tot	G/S	Bq/Tot	Diff
Cd-109	462.9d	88.0	84.75		3.72%	1006.61	37.45	1011.0	0.44%
Co-57	271.8d	122.1	77.25		85.51%	39.92	34.13	39.7	-0.47%
Ce-139	137.64d	165.9	92.68		80.35%	50.96	40.95	51.7	1.35%
Hg-203	46.6d	279.2	273		77.30%	156.04	120.62	145.0	-7.08%
Sn-113	115.09d	391.7	280		64.90%	190.62	123.72	188.9	-0.90%
Sr-85	64.849	514.0	547.9		98.40%	246.02	242.08	246.5	0.19%
Cs-137	30.17y	661.6	330.6		85.12%	171.61	146.07	174.8	1.86%
Y-88	106.65d	898.0	858.7		93.40%	406.22	379.41	395.5	-2.64%
Co-60	5.27y	1173.2	460.4		100.00%	203.42	203.42	203.2	-0.11%
Co-60	5.27y	1332.5	460.9		100.00%	203.64	203.64	206.2	1.26%
Y-88	106.65d	1836.0	908		99.38%	403.69	401.19	402.3	-0.35%

Eff. Name: **08S50121919**

Analyst: KOJ [signature]

Analyst:

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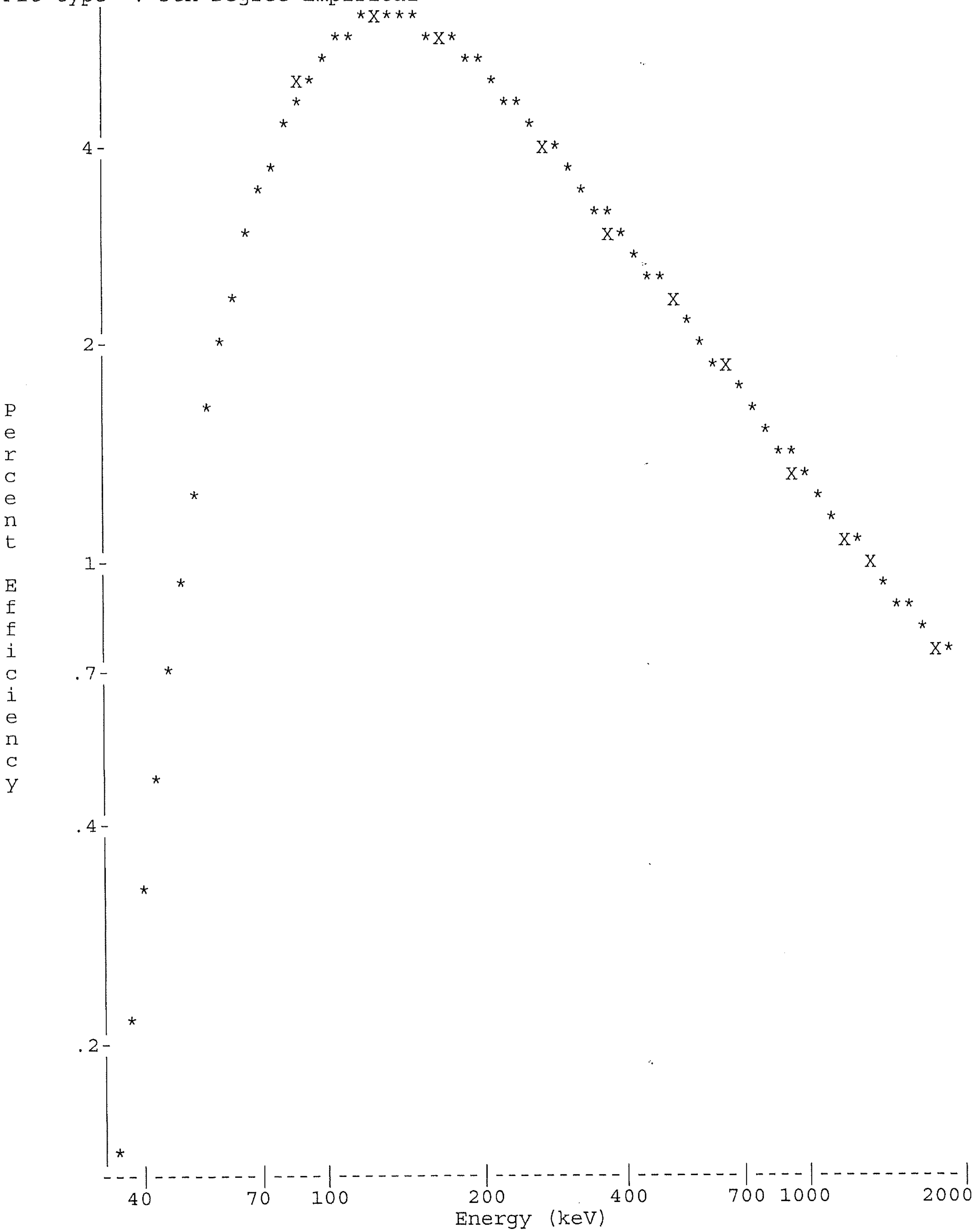
VAX/VMS Teledyne Brown Eng. Laboratory Gamma Report: 26-DEC-2019 11:59:44.02
TBE08 31-TP20610B HpGe ******** Aquisition Date/Time: 19-DEC-2019 14:24:25.59

LIMS No., Customer Name, Client ID: S50 5ML MIXED GAMMA CALIBRATION

Sample ID : 08S50121919 Smple Date: 1-JUN-2019 12:00:00.0
Sample Type : STD Geometry : 08S50121919
Quantity : 1.00000E+00 TOTAL BKGFILE : 08BG112719MT
Start Channel : 80 Energy Tol : 2.00000 Real Time : 0 03:30:31.74
End Channel : 4090 Pk Srch Sens: 9.00000 Live time : 0 03:30:00.00
MDA Multiple : 4.6600 Library Used: CALIBRATION
Peak Evaluation - Identified and Unidentified

Pk	It	Energy	Area	Bkgnd	FWHM	Channel	%Eff	Cts/Sec	%Err	Fit
1	1	46.22	1277	5281	1.50	100.46	7.01E-01	1.01E-01	10.6	1.75E+00
2	1	87.92	16596	6858	1.24	183.66	4.74E+00	1.32E+00	1.2	2.05E-01
3	1	122.05	15088	5409	1.26	251.78	5.90E+00	1.20E+00	1.2	5.56E-01
4	1	136.46	2057	5308	1.46	280.53	5.94E+00	1.63E-01	7.2	6.20E-01
5	1	165.90	10778	5471	1.35	339.29	5.68E+00	8.55E-01	1.7	7.49E-01
6	1	255.16	647	3704	1.43	517.41	4.35E+00	5.13E-02	17.4	3.53E-01
7	1	279.24	3024	4125	1.37	565.47	4.05E+00	2.40E-01	4.5	9.44E-01
8	1	391.75	13827	4116	1.45	789.97	3.01E+00	1.10E+00	1.3	2.11E+00
9	1	514.02	8393	4272	1.57	1033.96	2.34E+00	6.66E-01	2.1	4.31E+00
10	1	661.65	34173	2764	1.64	1328.51	1.85E+00	2.71E+00	0.6	1.83E+00
11	1	814.11	316	1342	1.40	1632.71	1.52E+00	2.51E-02	21.5	1.13E+00
12	1	898.01	17482	2500	1.78	1800.10	1.39E+00	1.39E+00	1.0	7.35E-01
13	1	1173.18	25897	1364	1.89	2349.07	1.09E+00	2.06E+00	0.7	1.16E+00
14	1	1332.46	23483	689	2.00	2666.79	9.72E-01	1.86E+00	0.7	1.07E+00
15	1	1836.03	10194	166	2.26	3671.21	7.48E-01	8.09E-01	1.0	6.49E-01

Spectrum : MCA0:[NDSCOUNT]TBE08$1
Calib Date: 26-DEC-2019 11:59
Detector : Geometry : 08S50121919
Fit type : 5th Degree Empirical



Analyst:

VAX/VMS Teledyne Brown Eng. Laboratory Gamma Report: 26-DEC-2019 12:02:28.82
TBE08 31-TP20610B HpGe ******** Aquisition Date/Time: 19-DEC-2019 14:24:25.59

LIMS No., Customer Name, Client ID: S50 5ML MIXED GAMMA CALIBRATION

Sample ID : 08S50121919
Sample Type : STD
Quantity : 1.00000E+00 TOTAL
Start Channel : 80 Energy Tol : 2.00000
End Channel : 4090 Pk Srch Sens: 9.00000
MDA Multiple : 4.6600 Library Used: CALIBRATION
Peak Evaluation - Identified and Unidentified

Smple Date: 1-JUN-2019 12:00:00.0
Geometry : 08S50121919
BKGFILE : 08BG112719MT
Real Time : 0 03:30:31.74
Live time : 0 03:30:00.00

Pk	It	Energy	Area	Bkgnd	FWHM	Channel	%Eff	Cts/Sec	%Err	Fit
1	1	46.22	1277	5281	1.50	100.46	7.01E-01	1.01E-01	10.6	1.75E+00
2	1	87.92	16596	6858	1.24	183.66	4.74E+00	1.32E+00	1.2	2.05E-01
3	1	122.05	15088	5409	1.26	251.78	5.90E+00	1.20E+00	1.2	5.56E-01
4	1	136.46	2057	5308	1.46	280.53	5.94E+00	1.63E-01	7.2	6.20E-01
5	1	165.90	10778	5471	1.35	339.29	5.68E+00	8.55E-01	1.7	7.49E-01
6	1	255.16	647	3704	1.43	517.41	4.35E+00	5.13E-02	17.4	3.53E-01
7	1	279.24	3024	4125	1.37	565.47	4.05E+00	2.40E-01	4.5	9.44E-01
8	1	391.75	13827	4116	1.45	789.97	3.01E+00	1.10E+00	1.3	2.11E+00
9	1	514.02	8393	4272	1.57	1033.96	2.34E+00	6.66E-01	2.1	4.31E+00
10	1	661.65	34173	2764	1.64	1328.51	1.85E+00	2.71E+00	0.6	1.83E+00
11	1	814.11	316	1342	1.40	1632.71	1.52E+00	2.51E-02	21.5	1.13E+00
12	1	898.01	17482	2500	1.78	1800.10	1.39E+00	1.39E+00	1.0	7.35E-01
13	1	1173.18	25897	1364	1.89	2349.07	1.09E+00	2.06E+00	0.7	1.16E+00
14	1	1332.46	23483	689	2.00	2666.79	9.72E-01	1.86E+00	0.7	1.07E+00
15	1	1836.03	10194	166	2.26	3671.21	7.48E-01	8.09E-01	1.0	6.49E-01

Flag: "*" = Peak area was modified by background subtraction

Nuclide Line Activity Report

Nuclide Type:

Nuclide	Energy	Area	%Abn	%Eff	Uncorrected BQ/TOTAL	Decay Corr BQ/TOTAL	2-Sigma %Error
02-CD109	88.03	16596	3.72*	4.736E+00	7.477E+02	1.011E+03	2.49
03-CO57	122.06	15088	85.51*	5.897E+00	2.374E+01	3.973E+01	2.45
04-CE139	165.85	10778	80.35*	5.676E+00	1.876E+01	5.165E+01	3.36
05-HG203	279.20	3024	81.46*	4.047E+00	7.281E+00	1.450E+02	8.99
06-SN113	391.69	13827	64.90*	3.007E+00	5.623E+01	1.889E+02	2.56
07-SR85	513.99	8393	99.27*	2.338E+00	2.869E+01	2.465E+02	4.28
08-CS137	661.65	34173	85.12*	1.846E+00	1.726E+02	1.748E+02	1.28
09-Y88	898.02	17482	93.40*	1.389E+00	1.070E+02	3.955E+02	1.96
10-CO60	1173.22	25897	100.00	1.088E+00	1.890E+02	2.032E+02	1.41
	1332.49	23483	100.00*	9.718E-01	1.918E+02	2.062E+02	1.41
12-Y88	1836.01	10194	99.38*	7.480E-01	1.088E+02	4.023E+02	2.08

Flag: "*" = Keyline

Sample ID : 08S50121919 Acquisition date : 19-DEC-2019 14:24:25

Total number of lines in spectrum	15	
Number of unidentified lines	4	
Number of lines tentatively identified by NID	11	73.33%

Nuclide Type :

Nuclide	Hlife	Decay	Uncorrected BQ/TOTAL	Decay Corr BQ/TOTAL	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
02-CD109	462.90D	1.35	7.477E+02	1.011E+03	0.025E+03	2.49	
03-CO57	270.90D	1.67	2.374E+01	3.973E+01	0.097E+01	2.45	
04-CE139	137.66D	2.75	1.876E+01	5.165E+01	0.174E+01	3.36	
05-HG203	46.61D	19.9	7.281E+00	1.450E+02	0.130E+02	8.99	
06-SN113	115.10D	3.36	5.623E+01	1.889E+02	0.048E+02	2.56	
07-SR85	64.84D	8.59	2.869E+01	2.465E+02	0.106E+02	4.28	
08-CS137	30.17Y	1.01	1.726E+02	1.748E+02	0.022E+02	1.28	
09-Y88	106.65D	3.70	1.070E+02	3.955E+02	0.078E+02	1.96	
10-CO60	5.27Y	1.08	1.918E+02	2.062E+02	0.029E+02	1.41	
12-Y88	106.65D	3.70	1.088E+02	4.023E+02	0.084E+02	2.08	
			---------	---------			
	Total Activity :		1.463E+03	2.861E+03			
	Grand Total Activity :		1.463E+03	2.861E+03			

Flags: "K" = Keyline not found "M" = Manually accepted
"E" = Manually edited "A" = Nuclide specific abn. limit

Sample ID : 08S50121919 Acquisition date : 19-DEC-2019 14:24:25

It	Energy	Area	Bkgnd	FWHM	Channel	Left	Pw	Cts/Sec	%Err	%Eff	Flags
1	46.22	1277	5281	1.50	100.46	96	9	1.01E-01	21.3	7.01E-01	
1	136.46	2057	5308	1.46	280.53	275	11	1.63E-01	14.4	5.94E+00	
1	255.16	647	3704	1.43	517.41	514	9	5.13E-02	34.9	4.35E+00	
1	814.11	316	1342	1.40	1632.71	1628	9	2.51E-02	43.1	1.52E+00	

Flags: "T" = Tentatively associated

Summary of Nuclide Activity

Total number of lines in spectrum	15	
Number of unidentified lines	4	
Number of lines tentatively identified by NID	11	73.33%

Nuclide Type :

Nuclide	Hlife	Decay	Wtd Mean Uncorrected BQ/TOTAL	Wtd Mean Decay Corr BQ/TOTAL	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
02-CD109	462.90D	1.35	7.477E+02	1.011E+03	0.025E+03	2.49	
03-CO57	270.90D	1.67	2.374E+01	3.973E+01	0.097E+01	2.45	
04-CE139	137.66D	2.75	1.876E+01	5.165E+01	0.174E+01	3.36	
05-HG203	46.61D	19.9	7.281E+00	1.450E+02	0.130E+02	8.99	
06-SN113	115.10D	3.36	5.623E+01	1.889E+02	0.048E+02	2.56	
07-SR85	64.84D	8.59	2.869E+01	2.465E+02	0.106E+02	4.28	
08-CS137	30.17Y	1.01	1.726E+02	1.748E+02	0.022E+02	1.28	
09-Y88	106.65D	3.70	1.070E+02	3.955E+02	0.078E+02	1.96	
10-CO60	5.27Y	1.08	1.904E+02	2.047E+02	0.020E+02	1.00	
12-Y88	106.65D	3.70	1.088E+02	4.023E+02	0.084E+02	2.08	
			---------	---------			
	Total Activity :		1.461E+03	2.859E+03			
	Grand Total Activity :		1.461E+03	2.859E+03			

Flags: "K" = Keyline not found "M" = Manually accepted
"E" = Manually edited "A" = Nuclide specific abn. limit

Interference Report

No interference correction performed

Combined Activity-MDA Report

---- Identified Nuclides ----

Nuclide	Activity (BQ/TOTAL)	Act error	MDA (BQ/TOTAL)	MDA error	Act/MDA
02-CD109	1.011E+03	2.512E+01	1.884E+01	0.000E+00	53.628
03-CO57	3.973E+01	9.733E-01	7.871E-01	0.000E+00	50.475
04-CE139	5.165E+01	1.737E+00	1.332E+00	0.000E+00	38.790
05-HG203	1.450E+02	1.303E+01	1.248E+01	0.000E+00	11.620
06-SN113	1.889E+02	4.831E+00	3.407E+00	0.000E+00	55.431
07-SR85	2.465E+02	1.055E+01	6.386E+00	0.000E+00	38.593

08-CS137	1.748E+02	2.230E+00	1.062E+00	0.000E+00	164.526
09-Y88	3.955E+02	7.764E+00	4.579E+00	0.000E+00	86.362
10-CO60	2.047E+02	2.041E+00	1.007E+00	0.000E+00	203.154
12-Y88	4.023E+02	8.355E+00	2.125E+00	0.000E+00	189.307

---- Non-Identified Nuclides ----

Nuclide	Key-Line Activity (BQ/TOTAL)	K.L. Ided	Act error	MDA (BQ/TOTAL)	MDA error	Act/MDA
01-AM241	-1.459E+00		1.968E+00	3.106E+00	0.000E+00	-0.470

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A,08S50121919      ,12/26/2019 12:02,06/01/2019 12:00,   1.000E+00,S50 5ML MIXED
B,08S50121919      ,CALIBRATION          ,12/26/2019 11:59,08S50121919
C,02-CD109,YES,   1.011E+03,   2.512E+01,   1.884E+01,,   53.628
C,03-CO57 ,YES,   3.973E+01,   9.733E-01,   7.871E-01,,   50.475
C,04-CE139,YES,   5.165E+01,   1.737E+00,   1.332E+00,,   38.790
C,05-HG203,YES,   1.450E+02,   1.303E+01,   1.248E+01,,   11.620
C,06-SN113,YES,   1.889E+02,   4.831E+00,   3.407E+00,,   55.431
C,07-SR85 ,YES,   2.465E+02,   1.055E+01,   6.386E+00,,   38.593
C,08-CS137,YES,   1.748E+02,   2.230E+00,   1.062E+00,,  164.526
C,09-Y88  ,YES,   3.955E+02,   7.764E+00,   4.579E+00,,   86.362
C,10-CO60 ,YES,   2.047E+02,   2.041E+00,   1.007E+00,,  203.154
C,12-Y88  ,YES,   4.023E+02,   8.355E+00,   2.125E+00,,  189.307
C,01-AM241,NO ,  -1.459E+00,   1.968E+00,   3.106E+00,,   -0.470
```

E & Z 2088-10-1 Mixed Gamma
6/1/19 12:00 PM

S25 Bottle

		Orig. Wt	5.1617	Volume	50				
		Wt Used	4.4184	Aliquot	5.0000	Certificate	Aliquoted	Actual	Percent
	Half-Life	Energy(KeV)	ate G/s	%err	%abn	Bq/Tot	G/S	Bq/Tot	Diff
Cd-109	462.9d	88.0	84.75		3.72%	1006.61	37.45	993.6	-1.29%
Co-57	271.8d	122.1	77.25		85.51%	39.92	34.13	42.1	5.37%
Ce-139	137.64d	165.9	92.68		80.35%	50.96	40.95	47.8	-6.25%
Hg-203	46.6d	279.2	273		77.30%	156.04	120.62	156.1	0.04%
Sn-113	115.09d	391.7	280		64.90%	190.62	123.72	191.6	0.51%
Sr-85	64.849	514.0	547.9		98.40%	246.02	242.08	246.5	0.19%
Cs-137	30.17y	661.6	330.6		85.12%	171.61	146.07	172.8	0.69%
Y-88	106.65d	898.0	858.7		93.40%	406.22	379.41	386.9	-4.76%
Co-60	5.27y	1173.2	460.4		100.00%	203.42	203.42	204.0	0.28%
Co-60	5.27y	1332.5	460.9		100.00%	203.64	203.64	207.4	1.84%
Y-88	106.65d	1836.0	908		99.38%	403.69	401.19	400.1	-0.89%

Eff. Name: **11S25121819**

Analyst: KOJ [signature]

Analyst:

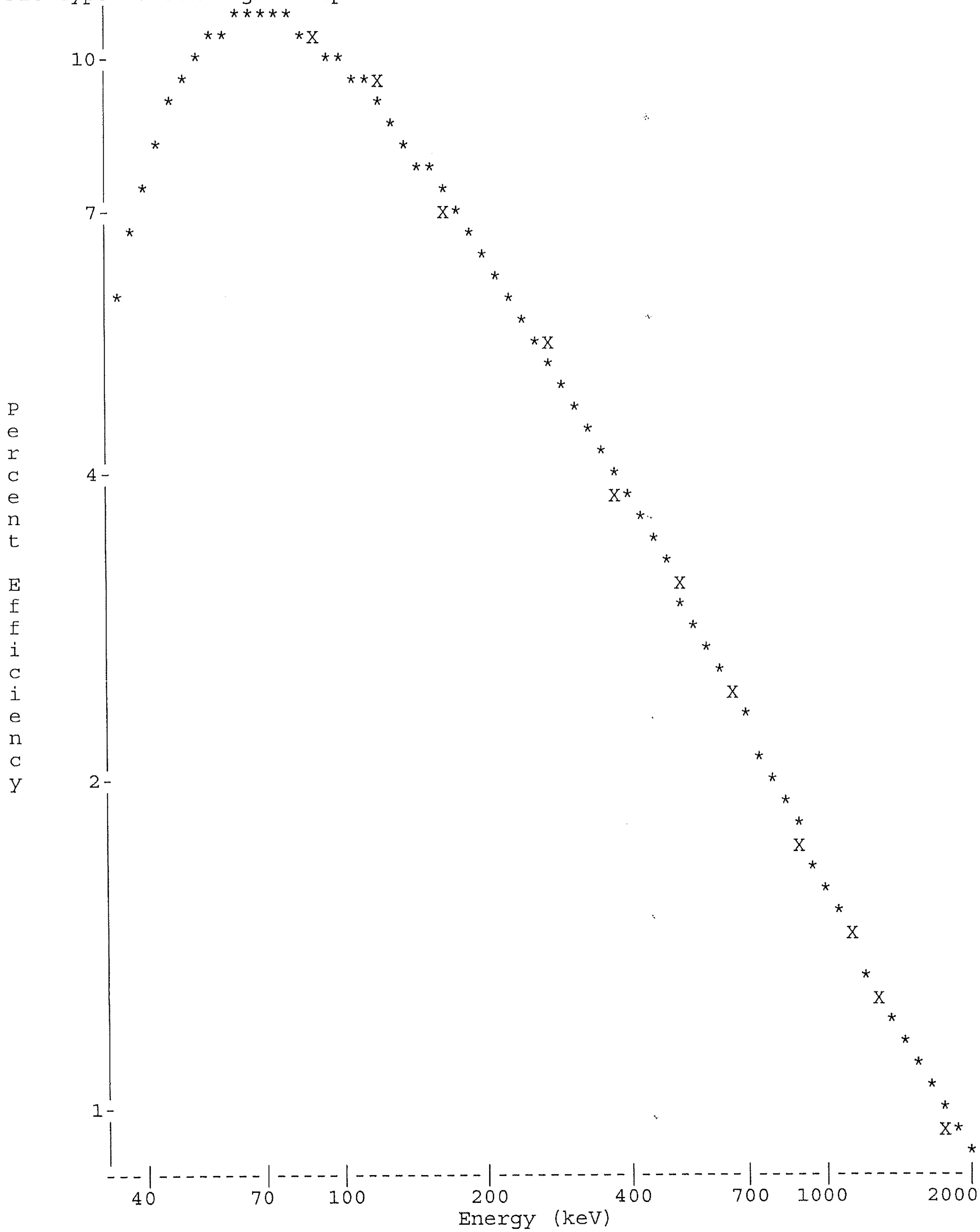
VAX/VMS Teledyne Brown Eng. Laboratory Gamma Report: 26-DEC-2019 12:23:32.17
TBE11 59-TN51806A HpGe ******* Aquisition Date/Time: 18-DEC-2019 09:33:11.11

LIMS No., Customer Name, Client ID: S25 5ML MIXED GAMMA CALIBRATION

Sample ID : 11S25121819 | Smple Date: 1-JUN-2019 12:00:00.0
Sample Type : STD | Geometry : 11S25121819
Quantity : 1.00000E+00 TOTAL | BKGFILE : 11BG112719MT
Start Channel : 70 | Energy Tol : 2.00000 | Real Time : 0 03:11:53.14
End Channel : 4090 | Pk Srch Sens: 9.00000 | Live time : 0 03:11:03.28
MDA Multiple : 4.6600 | Library Used: CALIBRATION
Peak Evaluation - Identified and Unidentified

Pk	It	Energy	Area	Bkgnd	FWHM	Channel	%Eff	Cts/Sec	%Err	Fit
1	0	46.47	35805	13059	1.40	91.92	9.09E+00	3.12E+00	0.9	
2	0	88.02	33122	7436	1.42	175.07	1.05E+01	2.89E+00	0.8	
3	0	122.04	22326	7271	1.51	243.14	9.03E+00	1.95E+00	1.1	
4	0	136.43	2706	4424	1.36	271.93	8.44E+00	2.36E-01	5.0	
5	0	165.87	11911	5271	1.51	330.83	7.41E+00	1.04E+00	1.5	
6	0	199.04	676	4281	1.71	397.18	6.51E+00	5.90E-02	17.9	
7	0	255.21	882	3762	1.57	509.58	5.41E+00	7.69E-02	13.5	
8	0	279.20	3759	5069	1.56	557.57	5.05E+00	3.28E-01	4.3	
9	0	391.75	16494	4392	1.66	782.76	3.86E+00	1.44E+00	1.2	
10	0	513.92	10151	3822	1.80	1027.19	3.07E+00	8.86E-01	1.7	
11	0	661.66	40746	3429	1.88	1322.79	2.45E+00	3.55E+00	0.6	
12	0	898.01	20678	3829	2.05	1795.69	1.83E+00	1.80E+00	1.0	
13	0	1173.22	31189	1914	2.27	2346.36	1.41E+00	2.72E+00	0.7	
14	0	1332.52	27709	1290	2.33	2665.10	1.25E+00	2.42E+00	0.7	
15	0	1835.99	11913	387	2.75	3672.54	9.59E-01	1.04E+00	1.0	

Spectrum : MCA0:[NDSCOUNT]TBE11$1
Calib Date: 26-DEC-2019 12:23
Detector : Geometry : 11S25121819
Fit type : 5th Degree Empirical



Analyst:

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VAX/VMS Teledyne Brown Eng. Laboratory Gamma Report: 26-DEC-2019 12:24:28.73
TBE11 59-TN51806A HpGe ******* Aquisition Date/Time: 18-DEC-2019 09:33:11.11

LIMS No., Customer Name, Client ID: S25 5ML MIXED GAMMA CALIBRATION

Sample ID : 11S25121819 Smple Date: 1-JUN-2019 12:00:00.0
Sample Type : STD Geometry : 11S25121819
Quantity : 1.00000E+00 TOTAL BKGFILE : 11BG112719MT
Start Channel : 70 Energy Tol : 2.00000 Real Time : 0 03:11:53.14
End Channel : 4090 Pk Srch Sens: 9.00000 Live time : 0 03:11:03.28
MDA Multiple : 4.6600 Library Used: CALIBRATION
Peak Evaluation - Identified and Unidentified

Pk	It	Energy	Area	Bkgnd	FWHM	Channel	%Eff	Cts/Sec	%Err	Fit
1	0	46.47*	35629	13059	1.40	91.92	9.09E+00	3.11E+00	0.9	
2	0	88.02*	33070	7436	1.42	175.07	1.05E+01	2.88E+00	0.8	
3	0	122.04	22326	7271	1.51	243.14	9.03E+00	1.95E+00	1.1	
4	0	136.43	2706	4424	1.36	271.93	8.44E+00	2.36E-01	5.0	
5	0	165.87	11911	5271	1.51	330.83	7.41E+00	1.04E+00	1.5	
6	0	199.04	676	4281	1.71	397.18	6.51E+00	5.90E-02	17.9	
7	0	255.21	882	3762	1.57	509.58	5.41E+00	7.69E-02	13.5	
8	0	279.20	3759	5069	1.56	557.57	5.05E+00	3.28E-01	4.3	
9	0	391.75	16494	4392	1.66	782.76	3.86E+00	1.44E+00	1.2	
10	0	513.92	10151	3822	1.80	1027.19	3.07E+00	8.86E-01	1.7	
11	0	661.66	40746	3429	1.88	1322.79	2.45E+00	3.55E+00	0.6	
12	0	898.01	20678	3829	2.05	1795.69	1.83E+00	1.80E+00	1.0	
13	0	1173.22	31189	1914	2.27	2346.36	1.41E+00	2.72E+00	0.7	
14	0	1332.52	27709	1290	2.33	2665.10	1.25E+00	2.42E+00	0.7	
15	0	1835.99	11913	387	2.75	3672.54	9.59E-01	1.04E+00	1.0	

Flag: "*" = Peak area was modified by background subtraction

Nuclide Line Activity Report

Nuclide Type:

Nuclide	Energy	Area	%Abn	%Eff	Uncorrected BQ/TOTAL	Decay Corr BQ/TOTAL	2-Sigma %Error
02-CD109	88.03	33070	3.72*	1.053E+01	7.365E+02	9.936E+02	1.51
03-CO57	122.06	22326	85.51*	9.032E+00	2.522E+01	4.206E+01	2.13
04-CE139	165.85	11911	80.35*	7.407E+00	1.746E+01	4.778E+01	3.05
05-HG203	279.20	3759	81.46*	5.046E+00	7.978E+00	1.561E+02	8.67
06-SN113	391.69	16494	64.90*	3.858E+00	5.747E+01	1.916E+02	2.34
07-SR85	513.99	10151	99.27*	3.069E+00	2.907E+01	2.465E+02	3.37
08-CS137	661.65	40746	85.12*	2.447E+00	1.707E+02	1.728E+02	1.19
09-Y88	898.02	20678	93.40*	1.831E+00	1.055E+02	3.869E+02	2.02
10-CO60	1173.22	31189	100.00	1.413E+00	1.926E+02	2.070E+02	1.35
	1332.49	27709	100.00*	1.253E+00	1.930E+02	2.074E+02	1.36
12-Y88	1836.01	11913	99.38*	9.586E-01	1.091E+02	4.001E+02	2.07

Flag: "*" = Keyline

Total number of lines in spectrum 15
Number of unidentified lines 4
Number of lines tentatively identified by NID 11 73.33%

Nuclide Type :

Nuclide	Hlife	Decay	Uncorrected BQ/TOTAL	Decay Corr. BQ/TOTAL	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
02-CD109	462.90D	1.35	7.365E+02	9.936E+02	0.150E+02	1.51	
03-CO57	270.90D	1.67	2.522E+01	4.206E+01	0.090E+01	2.13	
04-CE139	137.66D	2.74	1.746E+01	4.778E+01	0.146E+01	3.05	
05-HG203	46.61D	19.6	7.978E+00	1.561E+02	0.135E+02	8.67	
06-SN113	115.10D	3.33	5.747E+01	1.916E+02	0.045E+02	2.34	
07-SR85	64.84D	8.48	2.907E+01	2.465E+02	0.083E+02	3.37	
08-CS137	30.17Y	1.01	1.707E+02	1.728E+02	0.021E+02	1.19	
09-Y88	106.65D	3.67	1.055E+02	3.869E+02	0.078E+02	2.02	
10-CO60	5.27Y	1.07	1.930E+02	2.074E+02	0.028E+02	1.36	
12-Y88	106.65D	3.67	1.091E+02	4.001E+02	0.083E+02	2.07	
			---------	---------			
	Total Activity :		1.452E+03	2.845E+03			

Grand Total Activity : 1.452E+03 2.845E+03

Flags: "K" = Keyline not found "M" = Manually accepted
"E" = Manually edited "A" = Nuclide specific abn. limit

It	Energy	Area	Bkgnd	FWHM	Channel	Left	Pw	Cts/Sec	%Err	%Eff	Flags
0	46.47	35629	13059	1.40	91.92	84	16	3.11E+00	1.8	9.09E+00	
0	136.43	2706	4424	1.36	271.93	267	10	2.36E-01	10.0	8.44E+00	
0	199.04	676	4281	1.71	397.18	393	9	5.90E-02	35.8	6.51E+00	
0	255.21	882	3762	1.57	509.58	505	10	7.69E-02	26.9	5.41E+00	

Flags: "T" = Tentatively associated

Summary of Nuclide Activity

Total number of lines in spectrum	15	
Number of unidentified lines	4	
Number of lines tentatively identified by NID	11	73.33%

Nuclide Type :

Nuclide	Hlife	Decay	Wtd Mean Uncorrected BQ/TOTAL	Wtd Mean Decay Corr BQ/TOTAL	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
02-CD109	462.90D	1.35	7.365E+02	9.936E+02	0.150E+02	1.51	
03-CO57	270.90D	1.67	2.522E+01	4.206E+01	0.090E+01	2.13	
04-CE139	137.66D	2.74	1.746E+01	4.778E+01	0.146E+01	3.05	
05-HG203	46.61D	19.6	7.978E+00	1.561E+02	0.135E+02	8.67	
06-SN113	115.10D	3.33	5.747E+01	1.916E+02	0.045E+02	2.34	
07-SR85	64.84D	8.48	2.907E+01	2.465E+02	0.083E+02	3.37	
08-CS137	30.17Y	1.01	1.707E+02	1.728E+02	0.021E+02	1.19	
09-Y88	106.65D	3.67	1.055E+02	3.869E+02	0.078E+02	2.02	
10-CO60	5.27Y	1.07	1.928E+02	2.072E+02	0.020E+02	0.96	
12-Y88	106.65D	3.67	1.091E+02	4.001E+02	0.083E+02	2.07	
			---------	---------			
	Total Activity :		1.452E+03	2.845E+03			

Grand Total Activity : 1.452E+03 2.845E+03

Flags: "K" = Keyline not found "M" = Manually accepted
"E" = Manually edited "A" = Nuclide specific abn. limit

Interference Report

No interference correction performed

Combined Activity-MDA Report

---- Identified Nuclides ----

Nuclide	Activity (BQ/TOTAL)	Act error	MDA (BQ/TOTAL)	MDA error	Act/MDA
02-CD109	9.936E+02	1.498E+01	1.082E+01	0.000E+00	91.870
03-CO57	4.206E+01	8.978E-01	5.806E-01	0.000E+00	72.446
04-CE139	4.778E+01	1.458E+00	1.184E+00	0.000E+00	40.361
05-HG203	1.561E+02	1.354E+01	1.154E+01	0.000E+00	13.519
06-SN113	1.916E+02	4.489E+00	3.055E+00	0.000E+00	62.714
07-SR85	2.465E+02	8.295E+00	5.803E+00	0.000E+00	42.472

08-CS137	1.728E+02	2.055E+00	9.699E-01	0.000E+00	178.192
09-Y88	3.869E+02	7.819E+00	4.238E+00	0.000E+00	91.296
10-CO60	2.072E+02	1.985E+00	1.064E+00	0.000E+00	194.716
12-Y88	4.001E+02	8.273E+00	2.392E+00	0.000E+00	167.287

---- Non-Identified Nuclides ----

Nuclide	Key-Line Activity (BQ/TOTAL)	K.L. Ided	Act error	MDA (BQ/TOTAL)	MDA error	Act/MDA
01-AM241	3.178E-01		4.178E-01	7.052E-01	0.000E+00	0.451

```
A,11S25121819     ,12/26/2019 12:24,06/01/2019 12:00,   1.000E+00,S25 5ML MIXED
B,11S25121819     ,CALIBRATION         ,12/26/2019 12:23,11S25121819
C,02-CD109,YES,   9.936E+02,   1.498E+01,   1.082E+01,,   91.870
C,03-CO57 ,YES,   4.206E+01,   8.978E-01,   5.806E-01,,   72.446
C,04-CE139,YES,   4.778E+01,   1.458E+00,   1.184E+00,,   40.361
C,05-HG203,YES,   1.561E+02,   1.354E+01,   1.154E+01,,   13.519
C,06-SN113,YES,   1.916E+02,   4.489E+00,   3.055E+00,,   62.714
C,07-SR85 ,YES,   2.465E+02,   8.295E+00,   5.803E+00,,   42.472
C,08-CS137,YES,   1.728E+02,   2.055E+00,   9.699E-01,,  178.192
C,09-Y88  ,YES,   3.869E+02,   7.819E+00,   4.238E+00,,   91.296
C,10-CO60 ,YES,   2.072E+02,   1.985E+00,   1.064E+00,,  194.716
C,12-Y88  ,YES,   4.001E+02,   8.273E+00,   2.392E+00,,  167.287
C,01-AM241,NO ,   3.178E-01,   4.178E-01,   7.052E-01,,    0.451
```

E & Z 2088-10-1 Mixed Gamma
6/1/19 12:00 PM

S50 Bottle

		Orig. Wt	5.1617	Volume	50				
		Wt Used	4.4184	Aliquot	5.0000	Certificate	Aliquoted	Actual	Percent
	Half-Life	Energy(KeV)	ate G/s/	%err	%abn	Bq/Tot	G/S	Bq/Tot	Diff
Cd-109	462.9d	88.0	84.75		3.72%	1006.61	37.45	1006.0	-0.06%
Co-57	271.8d	122.1	77.25		85.51%	39.92	34.13	41.5	3.92%
Ce-139	137.64d	165.9	92.68		80.35%	50.96	40.95	48.2	-5.44%
Hg-203	46.6d	279.2	273		77.30%	156.04	120.62	161.2	3.30%
Sn-113	115.09d	391.7	280		64.90%	190.62	123.72	195.4	2.51%
Sr-85	64.849	514.0	547.9		98.40%	246.02	242.08	237.4	-3.50%
Cs-137	30.17y	661.6	330.6		85.12%	171.61	146.07	177.2	3.26%
Y-88	106.65d	898.0	858.7		93.40%	406.22	379.41	401.1	-1.26%
Co-60	5.27y	1173.2	460.4		100.00%	203.42	203.42	205.2	0.87%
Co-60	5.27y	1332.5	460.9		100.00%	203.64	203.64	203.0	-0.32%
Y-88	106.65d	1836.0	908		99.38%	403.69	401.19	403.2	-0.12%

Eff. Name: **11S50121819**

Analyst: KOJ [signature]

Analyst:

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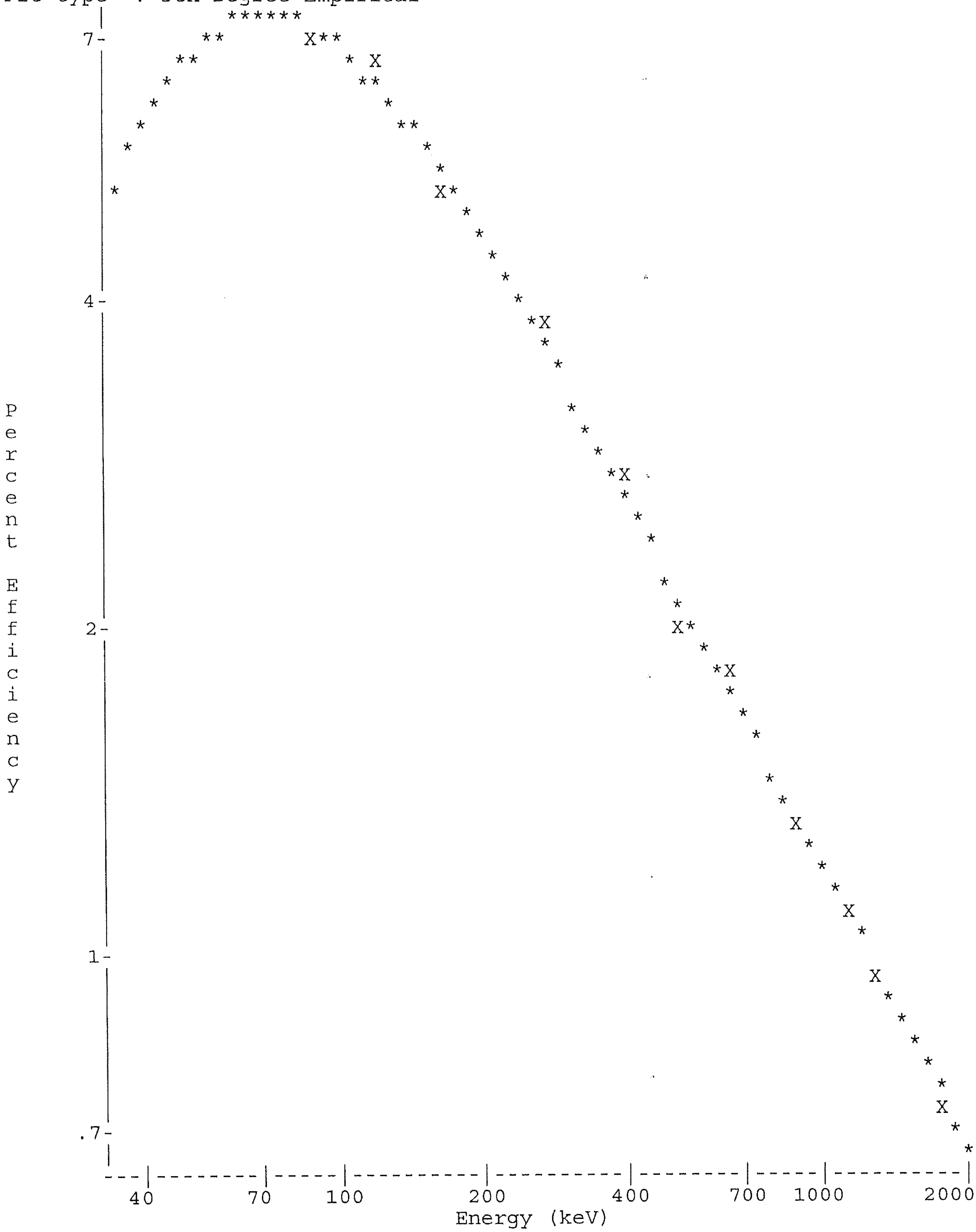
VAX/VMS Teledyne Brown Eng. Laboratory Gamma Report: 26-DEC-2019 12:13:14.79
TBE11 59-TN51806A HpGe ******* Aquisition Date/Time: 18-DEC-2019 12:47:43.02

LIMS No., Customer Name, Client ID: S50 5ML MIXED GAMMA CALIBRATION

Sample ID : 11S50121819 Smple Date: 1-JUN-2019 12:00:00.0
Sample Type : STD Geometry : 11S50121819
Quantity : 1.00000E+00 TOTAL BKGFILE : 11BG112719MT
Start Channel : 70 Energy Tol : 2.00000 Real Time : 0 03:46:41.61
End Channel : 4090 Pk Srch Sens: 9.00000 Live time : 0 03:45:57.97
MDA Multiple : 4.6600 Library Used: CALIBRATION
Peak Evaluation - Identified and Unidentified

Pk	It	Energy	Area	Bkgnd	FWHM	Channel	%Eff	Cts/Sec	%Err	Fit
1	0	46.49	28911	9660	1.40	92.06	6.56E+00	2.13E+00	0.9	
2	0	75.22	520	6287	0.90	149.55	7.43E+00	3.84E-02	27.0	
3	0	88.03	27395	7771	1.41	175.20	7.27E+00	2.02E+00	0.9	
4	0	122.05	18602	6243	1.46	243.27	6.46E+00	1.37E+00	1.1	
5	0	136.49	2351	4406	1.44	272.17	6.08E+00	1.73E-01	5.7	
6	0	165.86	10336	4773	1.52	330.94	5.39E+00	7.62E-01	1.6	
7	0	199.23	418	3693	1.51	397.70	4.74E+00	3.09E-02	25.6	
8	0	255.31	472	3399	1.11	509.93	3.91E+00	3.48E-02	22.7	
9	0	279.10	3299	4526	1.55	557.54	3.63E+00	2.43E-01	4.7	
10	0	391.72	14071	4008	1.68	782.88	2.73E+00	1.04E+00	1.3	
11	0	514.04	8152	3688	1.71	1027.64	2.17E+00	6.01E-01	2.0	
12	0	661.64	35340	3260	1.87	1322.97	1.75E+00	2.61E+00	0.6	
13	0	898.01	18766	3059	2.00	1795.90	1.36E+00	1.38E+00	1.0	
14	0	1173.19	28107	1699	2.23	2346.47	1.09E+00	2.07E+00	0.7	
15	0	1332.49	24977	1153	2.36	2665.17	9.75E-01	1.84E+00	0.7	
16	0	1836.01	10864	297	2.57	3672.49	7.34E-01	8.01E-01	1.0	

Spectrum : MCA0:[NDSCOUNT]TBE11$1
Calib Date: 26-DEC-2019 12:13
Detector : Geometry : 11S50121819
Fit type : 5th Degree Empirical



Analyst:

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VAX/VMS Teledyne Brown Eng. Laboratory Gamma Report: 26-DEC-2019 12:14:19.85
TBE11 59-TN51806A HpGe ******* Aquisition Date/Time: 18-DEC-2019 12:47:43.02

LIMS No., Customer Name, Client ID: S50 5ML MIXED GAMMA CALIBRATION

```
Sample ID      : 11S50121819                      Smple Date: 1-JUN-2019 12:00:00.0
Sample Type    : STD                              Geometry  : 11S50121819
Quantity       : 1.00000E+00 TOTAL                BKGFILE   : 11BG112719MT
Start Channel  : 70       Energy Tol   : 2.00000  Real Time : 0 03:46:41.61
End Channel    : 4090     Pk Srch Sens: 9.00000   Live time : 0 03:45:57.97
MDA Multiple   : 4.6600   Library Used: CALIBRATION
Peak Evaluation - Identified and Unidentified
```

Pk	It	Energy	Area	Bkgnd	FWHM	Channel	%Eff	Cts/Sec	%Err	Fit
1	0	46.49*	28703	9660	1.40	92.06	6.56E+00	2.12E+00	0.9	
2	0	75.22*	72	6287	0.90	149.55	7.43E+00	5.31E-03	196.1	
3	0	88.03*	27332	7771	1.41	175.20	7.27E+00	2.02E+00	0.9	
4	0	122.05	18602	6243	1.46	243.27	6.46E+00	1.37E+00	1.1	
5	0	136.49	2351	4406	1.44	272.17	6.08E+00	1.73E-01	5.7	
6	0	165.86	10336	4773	1.52	330.94	5.39E+00	7.62E-01	1.6	
7	0	199.23	418	3693	1.51	397.70	4.74E+00	3.09E-02	25.6	
8	0	255.31	472	3399	1.11	509.93	3.91E+00	3.48E-02	22.7	
9	0	279.10	3299	4526	1.55	557.54	3.63E+00	2.43E-01	4.7	
10	0	391.72	14071	4008	1.68	782.88	2.73E+00	1.04E+00	1.3	
11	0	514.04	8152	3688	1.71	1027.64	2.17E+00	6.01E-01	2.0	
12	0	661.64	35340	3260	1.87	1322.97	1.75E+00	2.61E+00	0.6	
13	0	898.01	18766	3059	2.00	1795.90	1.36E+00	1.38E+00	1.0	
14	0	1173.19	28107	1699	2.23	2346.47	1.09E+00	2.07E+00	0.7	
15	0	1332.49	24977	1153	2.36	2665.17	9.75E-01	1.84E+00	0.7	
16	0	1836.01	10864	297	2.57	3672.49	7.34E-01	8.01E-01	1.0	

Flag: "*" = Peak area was modified by background subtraction

Nuclide Line Activity Report

Nuclide Type:

Nuclide	Energy	Area	%Abn	%Eff	Uncorrected BQ/TOTAL	Decay Corr BQ/TOTAL	2-Sigma %Error
02-CD109	88.03	27332	3.72*	7.270E+00	7.455E+02	1.006E+03	1.80
03-CO57	122.06	18602	85.51*	6.455E+00	2.486E+01	4.148E+01	2.29
04-CE139	165.85	10336	80.35*	5.393E+00	1.759E+01	4.819E+01	3.25
05-HG203	279.20	3299	81.46*	3.633E+00	8.224E+00	1.612E+02	9.32
06-SN113	391.69	14071	64.90*	2.731E+00	5.855E+01	1.954E+02	2.55
07-SR85	513.99	8152	99.27*	2.166E+00	2.796E+01	2.374E+02	3.92
08-CS137	661.65	35340	85.12*	1.750E+00	1.750E+02	1.772E+02	1.30
09-Y88	898.02	18766	93.40*	1.357E+00	1.092E+02	4.011E+02	2.03
10-CO60	1173.22	28107	100.00	1.086E+00	1.909E+02	2.052E+02	1.42
	1332.49	24977	100.00*	9.751E-01	1.889E+02	2.030E+02	1.42
12-Y88	1836.01	10864	99.38*	7.343E-01	1.098E+02	4.032E+02	2.09

Flag: "*" = Keyline

Sample ID : 11S50121819 Acquisition date : 18-DEC-2019 12:47:43

Total number of lines in spectrum 16
Number of unidentified lines 5
Number of lines tentatively identified by NID 11 68.75%

Nuclide Type :

Nuclide	Hlife	Decay	Uncorrected BQ/TOTAL	Decay Corr BQ/TOTAL	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
02-CD109	462.90D	1.35	7.455E+02	1.006E+03	0.018E+03	1.80	
03-CO57	270.90D	1.67	2.486E+01	4.148E+01	0.095E+01	2.29	
04-CE139	137.66D	2.74	1.759E+01	4.819E+01	0.157E+01	3.25	
05-HG203	46.61D	19.6	8.224E+00	1.612E+02	0.150E+02	9.32	
06-SN113	115.10D	3.34	5.855E+01	1.954E+02	0.050E+02	2.55	
07-SR85	64.84D	8.49	2.796E+01	2.374E+02	0.093E+02	3.92	
08-CS137	30.17Y	1.01	1.750E+02	1.772E+02	0.023E+02	1.30	
09-Y88	106.65D	3.67	1.092E+02	4.011E+02	0.081E+02	2.03	
10-CO60	5.27Y	1.07	1.889E+02	2.030E+02	0.029E+02	1.42	
12-Y88	106.65D	3.67	1.098E+02	4.032E+02	0.084E+02	2.09	
			---------	---------			
	Total Activity :		1.466E+03	2.874E+03			
	Grand Total Activity :		1.466E+03	2.874E+03			

Flags: "K" = Keyline not found "M" = Manually accepted
"E" = Manually edited "A" = Nuclide specific abn. limit

Sample ID : 11S50121819 Acquisition date : 18-DEC-2019 12:47:43

It	Energy	Area	Bkgnd	FWHM	Channel	Left	Pw	Cts/Sec	%Err	%Eff	Flags
0	46.49	28703	9660	1.40	92.06	86	13	2.12E+00	1.9	6.56E+00	
0	75.22	72	6287	0.90	149.55	146	8	5.31E-03	****	7.43E+00	
0	136.49	2351	4406	1.44	272.17	267	10	1.73E-01	11.3	6.08E+00	
0	199.23	418	3693	1.51	397.70	395	8	3.09E-02	51.3	4.74E+00	
0	255.31	472	3399	1.11	509.93	506	9	3.48E-02	45.5	3.91E+00	

Flags: "T" = Tentatively associated

Summary of Nuclide Activity

Total number of lines in spectrum	16	
Number of unidentified lines	5	
Number of lines tentatively identified by NID	11	68.75%

Nuclide Type :

Nuclide	Hlife	Decay	Wtd Mean Uncorrected BQ/TOTAL	Wtd Mean Decay Corr BQ/TOTAL	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
02-CD109	462.90D	1.35	7.455E+02	1.006E+03	0.018E+03	1.80	
03-CO57	270.90D	1.67	2.486E+01	4.148E+01	0.095E+01	2.29	
04-CE139	137.66D	2.74	1.759E+01	4.819E+01	0.157E+01	3.25	
05-HG203	46.61D	19.6	8.224E+00	1.612E+02	0.150E+02	9.32	
06-SN113	115.10D	3.34	5.855E+01	1.954E+02	0.050E+02	2.55	
07-SR85	64.84D	8.49	2.796E+01	2.374E+02	0.093E+02	3.92	
08-CS137	30.17Y	1.01	1.750E+02	1.772E+02	0.023E+02	1.30	
09-Y88	106.65D	3.67	1.092E+02	4.011E+02	0.081E+02	2.03	
10-CO60	5.27Y	1.07	1.899E+02	2.041E+02	0.020E+02	1.00	
12-Y88	106.65D	3.67	1.098E+02	4.032E+02	0.084E+02	2.09	
			---------	---------			
	Total Activity :		1.467E+03	2.875E+03			
	Grand Total Activity :		1.467E+03	2.875E+03			

Flags: "K" = Keyline not found "M" = Manually accepted
"E" = Manually edited "A" = Nuclide specific abn. limit

Interference Report

No interference correction performed

Combined Activity-MDA Report

---- Identified Nuclides ----

Nuclide	Activity (BQ/TOTAL)	Act error	MDA (BQ/TOTAL)	MDA error	Act/MDA
02-CD109	1.006E+03	1.807E+01	1.322E+01	0.000E+00	76.080
03-CO57	4.148E+01	9.485E-01	6.726E-01	0.000E+00	61.665
04-CE139	4.819E+01	1.566E+00	1.358E+00	0.000E+00	35.490
05-HG203	1.612E+02	1.503E+01	1.309E+01	0.000E+00	12.319
06-SN113	1.954E+02	4.977E+00	3.498E+00	0.000E+00	55.856

07-SR85	2.374E+02	9.307E+00	7.023E+00	0.000E+00	33.813
08-CS137	1.772E+02	2.297E+00	1.100E+00	0.000E+00	161.086
09-Y88	4.011E+02	8.140E+00	4.509E+00	0.000E+00	88.957
10-CO60	2.041E+02	2.049E+00	1.112E+00	0.000E+00	183.540
12-Y88	4.032E+02	8.438E+00	2.376E+00	0.000E+00	169.648

---- Non-Identified Nuclides ----

Nuclide	Key-Line Activity (BQ/TOTAL)	K.L. Ided	Act error	MDA (BQ/TOTAL)	MDA error	Act/MDA
01-AM241	-4.500E-01		5.041E-01	8.374E-01	0.000E+00	-0.537

```
A,11S50121819     ,12/26/2019 12:14,06/01/2019 12:00,    1.000E+00,S50 5ML MIXED
B,11S50121819     ,CALIBRATION          ,12/26/2019 12:13,11S50121819
C,02-CD109,YES,    1.006E+03,   1.807E+01,   1.322E+01,,   76.080
C,03-CO57 ,YES,    4.148E+01,   9.485E-01,   6.726E-01,,   61.665
C,04-CE139,YES,    4.819E+01,   1.566E+00,   1.358E+00,,   35.490
C,05-HG203,YES,    1.612E+02,   1.503E+01,   1.309E+01,,   12.319
C,06-SN113,YES,    1.954E+02,   4.977E+00,   3.498E+00,,   55.856
C,07-SR85 ,YES,    2.374E+02,   9.307E+00,   7.023E+00,,   33.813
C,08-CS137,YES,    1.772E+02,   2.297E+00,   1.100E+00,,  161.086
C,09-Y88  ,YES,    4.011E+02,   8.140E+00,   4.509E+00,,   88.957
C,10-CO60 ,YES,    2.041E+02,   2.049E+00,   1.112E+00,,  183.540
C,12-Y88  ,YES,    4.032E+02,   8.438E+00,   2.376E+00,,  169.648
C,01-AM241,NO ,  -4.500E-01,   5.041E-01,   8.374E-01,,   -0.537
```

E & Z 2088-10-1 Mixed Gamma
6/1/19 12:00 PM

S25 Bottle

		Orig. Wt	5.1617	Volume	50				
		Wt Used	4.4184	Aliquot	5.0000	Certificate	Aliquoted	Actual	Percent
	Half-Life	Energy(KeV)	ate G/s	%err	%abn	Bq/Tot	G/S	Bq/Tot	Diff
Pb-210	22.26Y	46.6	72.1		4.18%	762.12	31.86		
Cd-109	462.9d	88.0	84.75		3.72%	1006.61	37.45	1006.0	-0.06%
Co-57	271.8d	122.1	77.25		85.51%	39.92	34.13	40.2	0.76%
Ce-139	137.64d	165.9	92.68		80.35%	50.96	40.95	50.5	-0.89%
Hg-203	46.6d	279.2	273		77.30%	156.04	120.62		
Sn-113	115.09d	391.7	280		64.90%	190.62	123.72	190.5	-0.07%
Sr-85	64.849	514.0	547.9		98.40%	246.02	242.08	245.0	-0.41%
Cs-137	30.17y	661.6	330.6		85.12%	171.61	146.07	174.3	1.57%
Y-88	106.65d	898.0	858.7		93.40%	406.22	379.41	392.8	-3.30%
Co-60	5.27y	1173.2	460.4		100.00%	203.42	203.42	203.4	-0.01%
Co-60	5.27y	1332.5	460.9		100.00%	203.64	203.64	206.5	1.40%
Y-88	106.65d	1836.0	908		99.38%	403.69	401.19	401.3	-0.59%

Eff. Name: **13S25030421**

Analyst: KOJ

Analyst:

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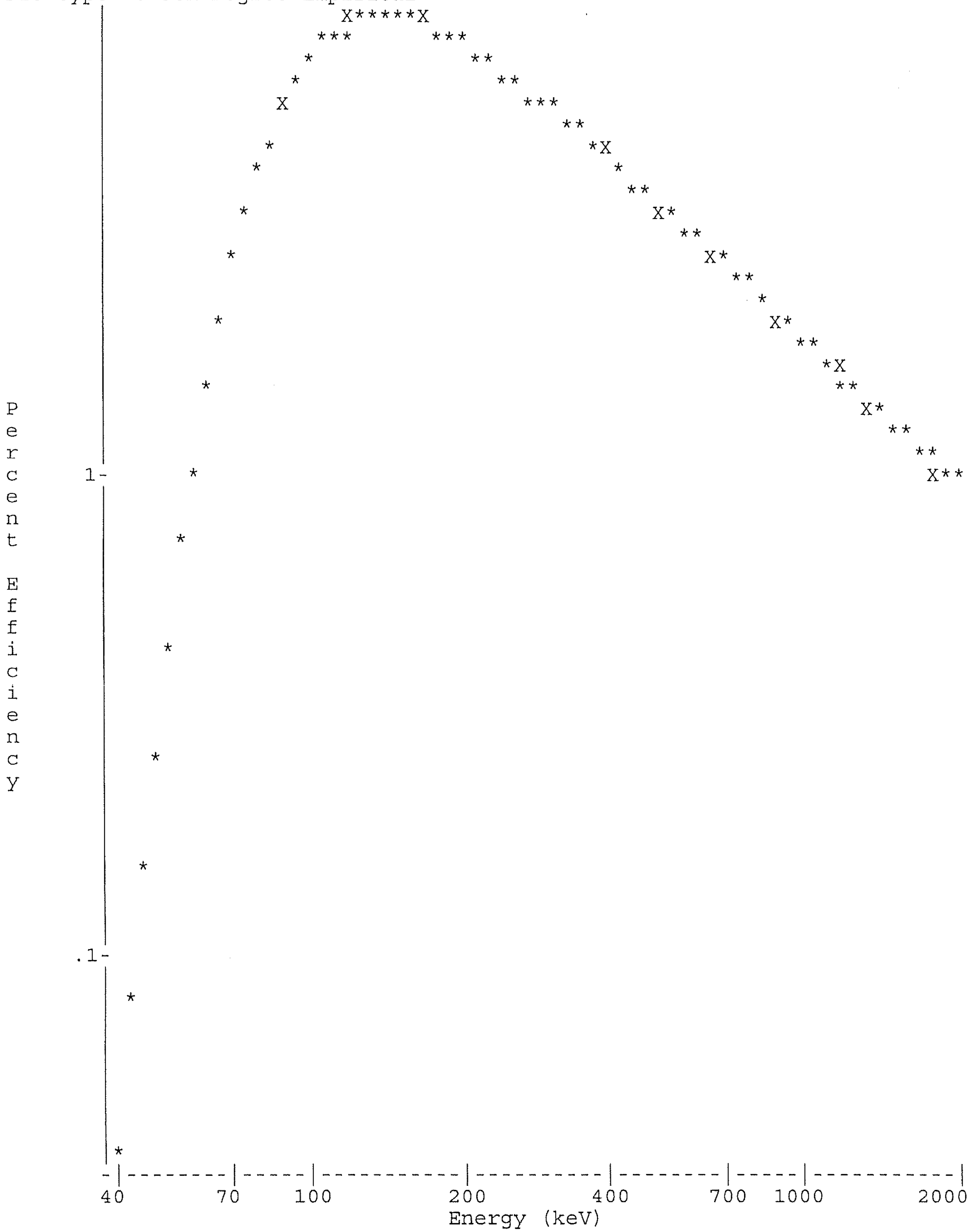
VAX/VMS Teledyne Brown Eng. Laboratory Gamma Report: 10-MAR-2021 08:32:24.00
TBE13 31-TP10727B HpGe ******* Aquisition Date/Time: 4-MAR-2021 08:26:35.99

LIMS No., Customer Name, Client ID: S25 BOTTLE 5ML MIXED GAMMA CALIBRATION

Sample ID : 13S25030421 Smple Date: 1-JUN-2019 12:00:00.0
Sample Type : PCI Geometry : 13S25030421
Quantity : 1.00000E+00 TOTAL BKGFILE : NOBKG
Start Channel : 80 Energy Tol : 2.00000 Real Time : 2 07:44:10.81
End Channel : 4090 Pk Srch Sens: 9.00000 Live time : 2 07:39:05.39
MDA Multiple : 4.6600 Library Used: CALIBRATION
Peak Evaluation - Identified and Unidentfied

Pk	It	Energy	Area	Bkgnd	FWHM	Channel	%Eff	Cts/Sec	%Err	Fit
1	1	46.58	4989	51226	0.71	93.19	2.06E-01	2.49E-02	7.7	1.43E+00
2	1	74.96	2858	35428	0.67	149.83	3.49E+00	1.43E-02	10.1	2.59E+00
3	10	85.57	4415	72939	1.67	171.01	5.06E+00	2.20E-02	12.1	3.44E+01
4	10	88.07	154794	33915	0.76	176.01	5.39E+00	7.73E-01	0.3	
5	1	122.09	105952	56401	0.79	243.91	7.97E+00	5.29E-01	0.5	2.91E+00
6	1	136.48	13314	45983	0.78	272.65	8.21E+00	6.65E-02	2.9	4.73E-01
7	1	165.86	25526	49624	0.83	331.30	8.00E+00	1.27E-01	1.7	6.24E-01
8	1	310.50	1311	28512	0.92	620.13	5.27E+00	6.54E-03	20.6	2.48E+00
9	1	391.71	22323	45189	1.05	782.32	4.33E+00	1.11E-01	1.9	9.26E-01
10	8	510.92	5205	46624	2.32	1020.48	3.44E+00	2.60E-02	8.9	1.27E+00
11	8	513.91	1724	19763	1.08	1026.44	3.42E+00	8.60E-03	13.3	
12	1	661.55	776934	37953	1.32	1321.48	2.72E+00	3.88E+00	0.1	2.25E+01
13	1	897.98	22837	31299	1.57	1794.09	2.03E+00	1.14E-01	1.7	2.35E+00
14	1	1173.32	500545	19886	1.75	2344.81	1.55E+00	2.50E+00	0.2	2.91E+01
15	1	1332.60	447055	7966	1.87	2663.50	1.36E+00	2.23E+00	0.2	3.48E+01
16	1	1460.82	1361	2233	2.07	2920.14	1.25E+00	6.79E-03	7.6	1.11E+00
17	1	1835.93	12509	1930	2.24	3671.32	1.02E+00	6.24E-02	1.2	2.42E+00

Spectrum : MCA0:[NDSCOUNT]TBE13$1
Calib Date: 10-MAR-2021 08:32
Detector :   Geometry   : 13S25030421
Fit type : 5th Degree Empirical



Analyst:

VAX/VMS Teledyne Brown Eng. Laboratory Gamma Report: 10-MAR-2021 08:33:36.47
TBE13 31-TP10727B HpGe ******* Aquisition Date/Time: 4-MAR-2021 08:26:35.99

LIMS No., Customer Name, Client ID: S25 BOTTLE 5ML MIXED GAMMA CALIBRATION

Sample ID : 13S25030421 Smple Date: 1-JUN-2019 12:00:00.0
Sample Type : PCI Geometry : 13S25030421
Quantity : 1.00000E+00 TOTAL BKGFILE : 13BG030521MT
Start Channel : 80 Energy Tol : 2.00000 Real Time : 2 07:44:10.81
End Channel : 4090 Pk Srch Sens: 9.00000 Live time : 2 07:39:05.39
MDA Multiple : 4.6600 Library Used: CALIBRATION
Peak Evaluation - Identified and Unidentfied

Pk	It	Energy	Area	Bkgnd	FWHM	Channel	%Eff	Cts/Sec	%Err	Fit
1	1	46.58	4989	51226	0.71	93.19	2.06E-01	2.49E-02	7.7	1.43E+00
2	1	74.96*	1332	35428	0.67	149.83	3.49E+00	6.65E-03	22.2	2.59E+00
3	10	85.57*	3228	72939	1.67	171.01	5.06E+00	1.61E-02	16.7	3.44E+01
4	10	88.07*	154300	33915	0.76	176.01	5.39E+00	7.70E-01	0.3	
5	1	122.09	105952	56401	0.79	243.91	7.97E+00	5.29E-01	0.5	2.91E+00
6	1	136.48	13314	45983	0.78	272.65	8.21E+00	6.65E-02	2.9	4.73E-01
7	1	165.86	25526	49624	0.83	331.30	8.00E+00	1.27E-01	1.7	6.24E-01
8	1	310.50	1311	28512	0.92	620.13	5.27E+00	6.54E-03	20.6	2.48E+00
9	1	391.71	22323	45189	1.05	782.32	4.33E+00	1.11E-01	1.9	9.26E-01
10	8	510.92*	115	46624	2.32	1020.48	3.44E+00	5.75E-04	419.6	1.27E+00
11	8	513.91	1724	19763	1.08	1026.44	3.42E+00	8.60E-03	13.3	
12	1	661.55	776934	37953	1.32	1321.48	2.72E+00	3.88E+00	0.1	2.25E+01
13	1	897.98	22837	31299	1.57	1794.09	2.03E+00	1.14E-01	1.7	2.35E+00
14	1	1173.32	500545	19886	1.75	2344.81	1.55E+00	2.50E+00	0.2	2.91E+01
15	1	1332.60	447055	7966	1.87	2663.50	1.36E+00	2.23E+00	0.2	3.48E+01
16	1	1460.82*	252	2233	2.07	2920.14	1.25E+00	1.26E-03	46.5	1.11E+00
17	1	1835.93	12509	1930	2.24	3671.32	1.02E+00	6.24E-02	1.2	2.42E+00

Flag: "*" = Peak area was modified by background subtraction

Nuclide Line Activity Report

Nuclide Type:

Nuclide	Energy	Area	%Abn	%Eff	Uncorrected BQ/TOTAL	Decay Corr BQ/TOTAL	2-Sigma %Error
02-CD109	88.03	154300	3.72*	5.388E+00	3.842E+02	1.006E+03	0.63
03-CO57	122.06	105952	85.51*	7.969E+00	7.761E+00	4.022E+01	1.02
04-CE139	165.85	25526	80.35*	7.997E+00	1.983E+00	5.051E+01	3.39
06-SN113	391.69	22323	64.90*	4.330E+00	3.965E+00	1.905E+02	3.81
07-SR85	513.99	1724	99.27*	3.420E+00	2.534E-01	2.450E+02	26.51
08-CS137	661.65	776934	85.12*	2.722E+00	1.674E+02	1.743E+02	0.25
09-Y88	898.02	22837	93.40*	2.029E+00	6.014E+00	3.928E+02	3.37
10-CO60	1173.22	500545	100.00	1.549E+00	1.613E+02	2.034E+02	0.31
	1332.49	447055	100.00*	1.362E+00	1.638E+02	2.065E+02	0.31
12-Y88	1836.01	12509	99.38*	1.023E+00	6.144E+00	4.013E+02	2.41

Flag: "*" = Keyline

Sample ID : 13S25030421 Acquisition date : 4-MAR-2021 08:26:35

Total number of lines in spectrum	17	
Number of unidentified lines	7	
Number of lines tentatively identified by NID	10	58.82%

Nuclide Type :

Nuclide	Hlife	Decay	Uncorrected BQ/TOTAL	Decay Corr BQ/TOTAL	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
02-CD109	462.90D	2.62	3.842E+02	1.006E+03	0.006E+03	0.63	
03-CO57	270.90D	5.18	7.761E+00	4.022E+01	0.041E+01	1.02	
04-CE139	137.66D	25.5	1.983E+00	5.051E+01	0.171E+01	3.39	
06-SN113	115.10D	48.1	3.965E+00	1.905E+02	0.073E+02	3.81	
07-SR85	64.84D	967.	2.534E-01	2.450E+02	0.649E+02	26.51	
08-CS137	30.17Y	1.04	1.674E+02	1.743E+02	0.004E+02	0.25	
09-Y88	106.65D	65.3	6.014E+00	3.928E+02	0.132E+02	3.37	
10-CO60	5.27Y	1.26	1.638E+02	2.065E+02	0.006E+02	0.31	
12-Y88	106.65D	65.3	6.144E+00	4.013E+02	0.097E+02	2.41	
			---------	---------			
	Total Activity :		7.415E+02	2.707E+03			
	Grand Total Activity :		7.415E+02	2.707E+03			

Flags: "K" = Keyline not found "M" = Manually accepted
"E" = Manually edited "A" = Nuclide specific abn. limit

Sample ID : 13S25030421 Acquisition date : 4-MAR-2021 08:26:35

It	Energy	Area	Bkgnd	FWHM	Channel	Left	Pw	Cts/Sec	%Err	%Eff	Flags
1	46.58	4989	51226	0.71	93.19	90	7	2.49E-02	15.3	2.06E-01	
1	74.96	1332	35428	0.67	149.83	148	5	6.65E-03	44.4	3.49E+00	
10	85.57	3228	72939	1.67	171.01	164	20	1.61E-02	33.4	5.06E+00	
1	136.48	13314	45983	0.78	272.65	269	8	6.65E-02	5.8	8.21E+00	
1	310.50	1311	28512	0.92	620.13	618	6	6.54E-03	41.1	5.27E+00	
8	510.92	115	46624	2.32	1020.48	1012	18	5.75E-04	****	3.44E+00	
1	1460.82	252	2233	2.07	2920.14	2914	13	1.26E-03	93.1	1.25E+00	

Flags: "T" = Tentatively associated

Summary of Nuclide Activity

Total number of lines in spectrum 17
Number of unidentified lines 7
Number of lines tentatively identified by NID 10 58.82%

Nuclide Type :

Nuclide	Hlife	Decay	Wtd Mean Uncorrected BQ/TOTAL	Wtd Mean Decay Corr BQ/TOTAL	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
02-CD109	462.90D	2.62	3.842E+02	1.006E+03	0.006E+03	0.63	
03-CO57	270.90D	5.18	7.761E+00	4.022E+01	0.041E+01	1.02	
04-CE139	137.66D	25.5	1.983E+00	5.051E+01	0.171E+01	3.39	
06-SN113	115.10D	48.1	3.965E+00	1.905E+02	0.073E+02	3.81	
07-SR85	64.84D	967.	2.534E-01	2.450E+02	0.649E+02	26.51	
08-CS137	30.17Y	1.04	1.674E+02	1.743E+02	0.004E+02	0.25	
09-Y88	106.65D	65.3	6.014E+00	3.928E+02	0.132E+02	3.37	
10-CO60	5.27Y	1.26	1.638E+02	2.065E+02	0.006E+02	0.31	
12-Y88	106.65D	65.3	6.144E+00	4.013E+02	0.097E+02	2.41	
			---------	---------			
	Total Activity :		7.415E+02	2.707E+03			

Grand Total Activity : 7.415E+02 2.707E+03

Flags: "K" = Keyline not found "M" = Manually accepted
"E" = Manually edited "A" = Nuclide specific abn. limit

Combined Activity-MDA Report

---- Identified Nuclides ----

Nuclide	Activity (BQ/TOTAL)	Act error	MDA (BQ/TOTAL)	MDA error	Act/MDA
02-CD109	1.006E+03	6.368E+00	5.037E+00	0.000E+00	199.787
03-CO57	4.022E+01	4.086E-01	2.913E-01	0.000E+00	138.061
04-CE139	5.051E+01	1.712E+00	1.505E+00	0.000E+00	33.569
06-SN113	1.905E+02	7.250E+00	6.868E+00	0.000E+00	27.740
07-SR85	2.450E+02	6.495E+01	1.023E+02	0.000E+00	2.394
08-CS137	1.743E+02	4.422E-01	1.464E-01	0.000E+00	1190.429
09-Y88	3.928E+02	1.324E+01	1.260E+01	0.000E+00	31.174
10-CO60	2.065E+02	6.499E-01	1.422E-01	0.000E+00	1452.522
12-Y88	4.013E+02	9.652E+00	5.648E+00	0.000E+00	71.048

---- Non-Identified Nuclides ----

Nuclide	Key-Line Activity (BQ/TOTAL)	K.L. Ided	Act error	MDA (BQ/TOTAL)	MDA error	Act/MDA
01-AM241	-2.898E-01		4.645E-01	7.886E-01	0.000E+00	-0.368
05-HG203	-2.264E+02		7.343E+02	1.213E+03	0.000E+00	-0.187

```
A,13S25030421     ,03/10/2021 08:33,06/01/2019 12:00,   1.000E+00,S25 BOTTLE 5ML
B,13S25030421     ,CALIBRATION        ,03/10/2021 08:32,13S25030421
C,02-CD109,YES,   1.006E+03,   6.368E+00,   5.037E+00,,  199.787
C,03-CO57 ,YES,   4.022E+01,   4.086E-01,   2.913E-01,,  138.061
C,04-CE139,YES,   5.051E+01,   1.712E+00,   1.505E+00,,   33.569
C,06-SN113,YES,   1.905E+02,   7.250E+00,   6.868E+00,,   27.740
C,07-SR85 ,YES,   2.450E+02,   6.495E+01,   1.023E+02,,    2.394
C,08-CS137,YES,   1.743E+02,   4.422E-01,   1.464E-01,, 1190.429
C,09-Y88  ,YES,   3.928E+02,   1.324E+01,   1.260E+01,,   31.174
C,10-CO60 ,YES,   2.065E+02,   6.499E-01,   1.422E-01,, 1452.522
C,12-Y88  ,YES,   4.013E+02,   9.652E+00,   5.648E+00,,   71.048
C,01-AM241,NO ,  -2.898E-01,   4.645E-01,   7.886E-01,,   -0.368
C,05-HG203,NO ,  -2.264E+02,   7.343E+02,   1.213E+03,,   -0.187
```

E & Z 2088-10-1 Mixed Gamma
6/1/19 12:00 PM

S25 Bottle

		Orig. Wt	5.1617	Volume	50				
		Wt Used	4.4184	Aliquot	5.0000	Certificate	Aliquoted	Actual	Percent
	Half-Life	Energy(KeV)	.ate G/s/	%err	%abn	Bq/Tot	G/S	Bq/Tot	Diff
Cd-109	462.9d	88.0	84.75		3.72%	1006.61	37.45	1006.0	-0.06%
Co-57	271.8d	122.1	77.25		85.51%	39.92	34.13	39.9	0.04%
Ce-139	137.64d	165.9	92.68		80.35%	50.96	40.95	51.1	0.21%
Hg-203	46.6d	279.2	273		77.30%	156.04	120.62	146.7	-5.99%
Sn-113	115.09d	391.7	280		64.90%	190.62	123.72	190.2	-0.22%
Sr-85	64.849	514.0	547.9		98.40%	246.02	242.08	243.7	-0.94%
Cs-137	30.17y	661.6	330.6		85.12%	171.61	146.07	175.7	2.38%
Y-88	106.65d	898.0	858.7		93.40%	406.22	379.41	393.7	-3.08%
Co-60	5.27y	1173.2	460.4		100.00%	203.42	203.42	203.1	-0.16%
Co-60	5.27y	1332.5	460.9		100.00%	203.64	203.64	207.0	1.65%
Y-88	106.65d	1836.0	908		99.38%	403.69	401.19	401.9	-0.44%

Eff. Name: **14S25121719**

Analyst: KOJ

Analyst:

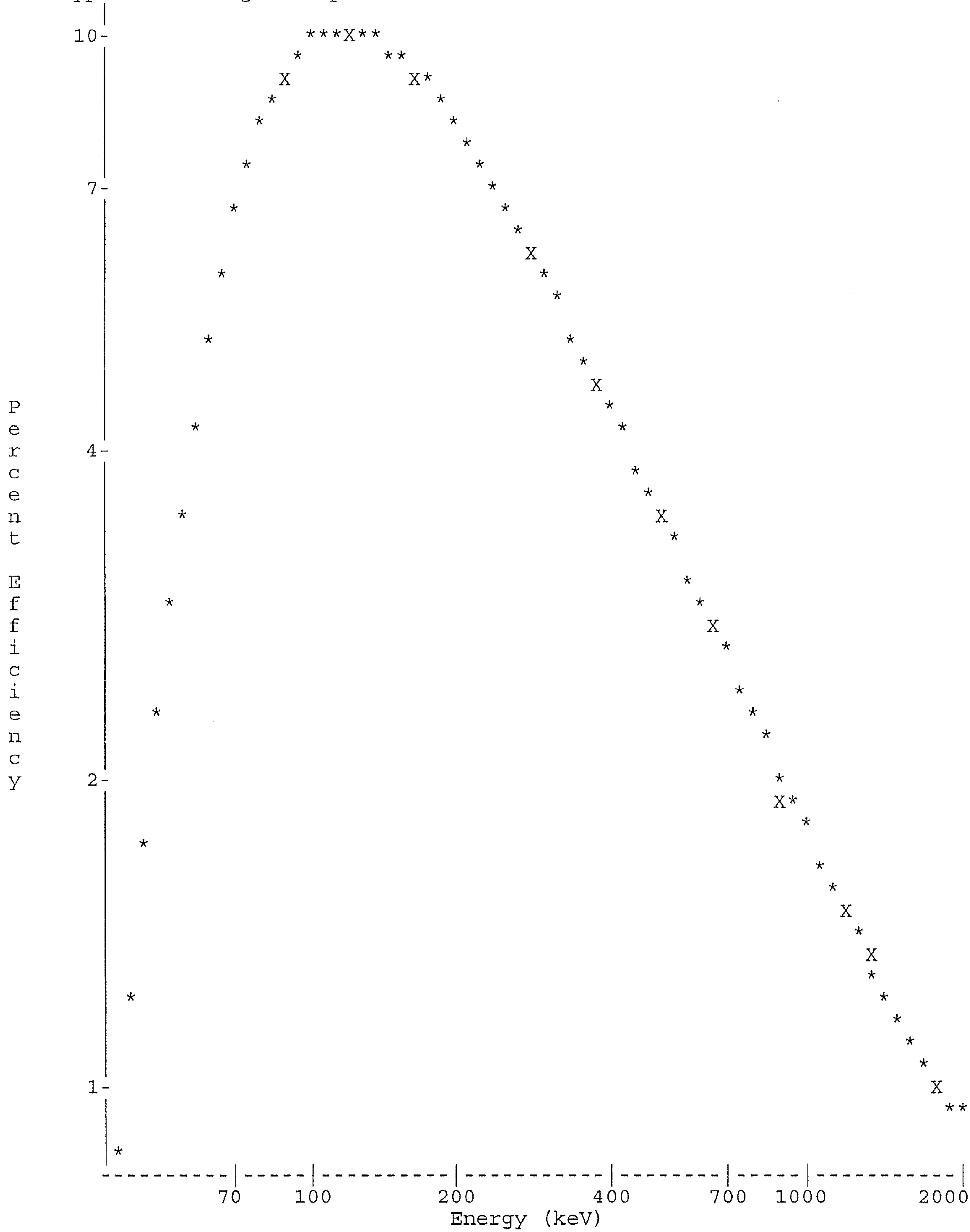
VAX/VMS Teledyne Brown Eng. Laboratory Gamma Report: 26-DEC-2019 10:18:27.43
TBE14 54-TP42603C HpGe ******* Aquisition Date/Time: 17-DEC-2019 17:50:38.86

LIMS No., Customer Name, Client ID: S25 5ML MIXED GAMMA CALIBRATION

Sample ID : 14S25121719 Smple Date: 1-JUN-2019 12:00:00.0
Sample Type : STD Geometry : 14S25121719
Quantity : 1.00000E+00 TOTAL BKGFILE : 14BG112719MT
Start Channel : 80 Energy Tol : 2.00000 Real Time : 0 04:01:00.29
End Channel : 4090 Pk Srch Sens: 9.00000 Live time : 0 04:00:00.00
MDA Multiple : 4.6600 Library Used: CALIBRATION
Peak Evaluation - Identified and Unidentified

Pk	It	Energy	Area	Bkgnd	FWHM	Channel	%Eff	Cts/Sec	%Err	Fit
1	1	46.59	4672	6896	0.82	89.97	1.64E+00	3.24E-01	3.3	4.79E+00
2	1	88.04	35463	10516	0.84	172.85	8.86E+00	2.46E+00	0.8	4.00E+00
3	1	122.05	29780	8564	0.87	240.85	1.01E+01	2.07E+00	0.8	4.38E+00
4	1	136.46	3698	7567	0.89	269.66	9.91E+00	2.57E-01	4.7	1.24E+00
5	1	165.85	19824	6625	0.93	328.42	9.15E+00	1.38E+00	1.0	1.01E+00
6	1	255.11	1157	5861	0.95	506.90	6.71E+00	8.04E-02	12.3	3.79E-01
7	1	279.19	5512	6288	1.08	555.04	6.21E+00	3.83E-01	3.1	3.04E+00
8	1	391.70	24307	6255	1.14	780.03	4.54E+00	1.69E+00	0.9	2.52E+00
9	1	514.00	14414	5472	1.23	1024.59	3.48E+00	1.00E+00	1.4	7.45E+00
10	1	661.64	57433	5272	1.37	1319.86	2.70E+00	3.99E+00	0.5	1.58E+01
11	1	814.11	540	2411	1.47	1624.82	2.18E+00	3.75E-02	17.5	1.46E+00
12	1	898.03	28517	4449	1.54	1792.67	1.97E+00	1.98E+00	0.8	1.01E+01
13	1	1173.22	40660	2487	1.72	2343.16	1.49E+00	2.82E+00	0.6	1.86E+01
14	4	1325.51	582	1036	2.68	2647.85	1.32E+00	4.04E-02	13.1	1.27E+01
15	4	1332.48	36574	668	1.86	2661.80	1.32E+00	2.54E+00	0.5	
16	1	1836.00	15871	453	2.16	3669.35	1.01E+00	1.10E+00	0.9	1.15E+01

```
Spectrum  : MCA0:[NDSCOUNT]TBE14$1
Calib Date: 26-DEC-2019 10:18
Detector  :                                    Geometry      : 14S25121719
Fit type  : 5th Degree Empirical
```



Analyst:

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==================================================================================
VAX/VMS Teledyne Brown Eng. Laboratory Gamma Report: 26-DEC-2019 10:19:43.49
TBE14 54-TP42603C HpGe ******* Aquisition Date/Time: 17-DEC-2019 17:50:38.86
----------------------------------------------------------------------------------
LIMS No., Customer Name, Client ID: S25 5ML MIXED GAMMA CALIBRATION

Sample ID      : 14S25121719                     Smple Date: 1-JUN-2019 12:00:00.0
Sample Type    : STD                             Geometry  : 14S25121719
Quantity       : 1.00000E+00 TOTAL               BKGFILE   : 14BG112719MT
Start Channel  : 80      Energy Tol   : 2.00000  Real Time : 0 04:01:00.29
End Channel    : 4090    Pk Srch Sens: 9.00000   Live time : 0 04:00:00.00
MDA Multiple   : 4.6600  Library Used: CALIBRATION
Peak Evaluation - Identified and Unidentified
```

Pk	It	Energy	Area	Bkgnd	FWHM	Channel	%Eff	Cts/Sec	%Err	Fit
1	1	46.59	4672	6896	0.82	89.97	1.64E+00	3.24E-01	3.3	4.79E+00
2	1	88.04*	35436	10516	0.84	172.85	8.86E+00	2.46E+00	0.8	4.00E+00
3	1	122.05	29780	8564	0.87	240.85	1.01E+01	2.07E+00	0.8	4.38E+00
4	1	136.46	3698	7567	0.89	269.66	9.91E+00	2.57E-01	4.7	1.24E+00
5	1	165.85	19824	6625	0.93	328.42	9.15E+00	1.38E+00	1.0	1.01E+00
6	1	255.11	1157	5861	0.95	506.90	6.71E+00	8.04E-02	12.3	3.79E-01
7	1	279.19	5512	6288	1.08	555.04	6.21E+00	3.83E-01	3.1	3.04E+00
8	1	391.70	24307	6255	1.14	780.03	4.54E+00	1.69E+00	0.9	2.52E+00
9	1	514.00	14414	5472	1.23	1024.59	3.48E+00	1.00E+00	1.4	7.45E+00
10	1	661.64	57433	5272	1.37	1319.86	2.70E+00	3.99E+00	0.5	1.58E+01
11	1	814.11	540	2411	1.47	1624.82	2.18E+00	3.75E-02	17.5	1.46E+00
12	1	898.03	28517	4449	1.54	1792.67	1.97E+00	1.98E+00	0.8	1.01E+01
13	1	1173.22	40660	2487	1.72	2343.16	1.49E+00	2.82E+00	0.6	1.86E+01
14	4	1325.51	582	1036	2.68	2647.85	1.32E+00	4.04E-02	13.1	1.27E+01
15	4	1332.48	36574	668	1.86	2661.80	1.32E+00	2.54E+00	0.5	
16	1	1836.00	15871	453	2.16	3669.35	1.01E+00	1.10E+00	0.9	1.15E+01

Flag: "*" = Peak area was modified by background subtraction

Nuclide Line Activity Report

Nuclide Type:

Nuclide	Energy	Area	%Abn	%Eff	Uncorrected BQ/TOTAL	Decay Corr BQ/TOTAL	2-Sigma %Error
02-CD109	88.03	35436	3.72*	8.862E+00	7.464E+02	1.006E+03	1.52
03-CO57	122.06	29780	85.51*	1.009E+01	2.398E+01	3.993E+01	1.65
04-CE139	165.85	19824	80.35*	9.153E+00	1.872E+01	5.107E+01	2.06
05-HG203	279.20	5512	81.46*	6.208E+00	7.569E+00	1.467E+02	6.21
06-SN113	391.69	24307	64.90*	4.543E+00	5.725E+01	1.902E+02	1.86
07-SR85	513.99	14414	99.27*	3.485E+00	2.893E+01	2.437E+02	2.75
08-CS137	661.65	57433	85.12*	2.700E+00	1.735E+02	1.757E+02	1.01
09-Y88	898.02	28517	93.40*	1.967E+00	1.078E+02	3.937E+02	1.58
10-CO60	1173.22	40660	100.00	1.494E+00	1.890E+02	2.031E+02	1.14
	1332.49	36574	100.00*	1.318E+00	1.927E+02	2.070E+02	1.08
12-Y88	1836.01	15871	99.38*	1.008E+00	1.100E+02	4.019E+02	1.73

Flag: "*" = Keyline

Total number of lines in spectrum	16	
Number of unidentified lines	5	
Number of lines tentatively identified by NID	11	68.75%

Nuclide Type :

Nuclide	Hlife	Decay	Uncorrected BQ/TOTAL	Decay Corr BQ/TOTAL	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
02-CD109	462.90D	1.35	7.464E+02	1.006E+03	0.015E+03	1.52	
03-CO57	270.90D	1.67	2.398E+01	3.993E+01	0.066E+01	1.65	
04-CE139	137.66D	2.73	1.872E+01	5.107E+01	0.105E+01	2.06	
05-HG203	46.61D	19.4	7.569E+00	1.467E+02	0.091E+02	6.21	
06-SN113	115.10D	3.32	5.725E+01	1.902E+02	0.035E+02	1.86	
07-SR85	64.84D	8.42	2.893E+01	2.437E+02	0.067E+02	2.75	
08-CS137	30.17Y	1.01	1.735E+02	1.757E+02	0.018E+02	1.01	
09-Y88	106.65D	3.65	1.078E+02	3.937E+02	0.062E+02	1.58	
10-CO60	5.27Y	1.07	1.927E+02	2.070E+02	0.022E+02	1.08	
12-Y88	106.65D	3.65	1.100E+02	4.019E+02	0.070E+02	1.73	
	Total Activity :		1.467E+03	2.856E+03			
	Grand Total Activity :		1.467E+03	2.856E+03			

Flags: "K" = Keyline not found "M" = Manually accepted
"E" = Manually edited "A" = Nuclide specific abn. limit

It	Energy	Area	Bkgnd	FWHM	Channel	Left	Pw	Cts/Sec	%Err	%Eff	Flags
1	46.59	4672	6896	0.82	89.97	86	7	3.24E-01	6.6	1.64E+00	
1	136.46	3698	7567	0.89	269.66	265	10	2.57E-01	9.4	9.91E+00	
1	255.11	1157	5861	0.95	506.90	503	9	8.04E-02	24.6	6.71E+00	
1	814.11	540	2411	1.47	1624.82	1620	10	3.75E-02	35.0	2.18E+00	
4	1325.51	582	1036	2.68	2647.85	2637	33	4.04E-02	26.2	1.32E+00	

Flags: "T" = Tentatively associated

Summary of Nuclide Activity

Total number of lines in spectrum	16	
Number of unidentified lines	5	
Number of lines tentatively identified by NID	11	68.75%

Nuclide Type :

Nuclide	Hlife	Decay	Wtd Mean Uncorrected BQ/TOTAL	Wtd Mean Decay Corr BQ/TOTAL	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
02-CD109	462.90D	1.35	7.464E+02	1.006E+03	0.015E+03	1.52	
03-CO57	270.90D	1.67	2.398E+01	3.993E+01	0.066E+01	1.65	
04-CE139	137.66D	2.73	1.872E+01	5.107E+01	0.105E+01	2.06	
05-HG203	46.61D	19.4	7.569E+00	1.467E+02	0.091E+02	6.21	
06-SN113	115.10D	3.32	5.725E+01	1.902E+02	0.035E+02	1.86	
07-SR85	64.84D	8.42	2.893E+01	2.437E+02	0.067E+02	2.75	
08-CS137	30.17Y	1.01	1.735E+02	1.757E+02	0.018E+02	1.01	
09-Y88	106.65D	3.65	1.078E+02	3.937E+02	0.062E+02	1.58	
10-CO60	5.27Y	1.07	1.909E+02	2.051E+02	0.016E+02	0.79	
12-Y88	106.65D	3.65	1.100E+02	4.019E+02	0.070E+02	1.73	
			---------	---------			
	Total Activity :		1.465E+03	2.854E+03			
	Grand Total Activity :		1.465E+03	2.854E+03			

Flags: "K" = Keyline not found "M" = Manually accepted
"E" = Manually edited "A" = Nuclide specific abn. limit

Interference Report

No interference correction performed

Combined Activity-MDA Report

---- Identified Nuclides ----

Nuclide	Activity (BQ/TOTAL)	Act error	MDA (BQ/TOTAL)	MDA error	Act/MDA
02-CD109	1.006E+03	1.533E+01	9.506E+00	0.000E+00	105.834
03-CO57	3.993E+01	6.577E-01	4.039E-01	0.000E+00	98.864
04-CE139	5.107E+01	1.051E+00	7.760E-01	0.000E+00	65.808
05-HG203	1.467E+02	9.105E+00	7.581E+00	0.000E+00	19.347
06-SN113	1.902E+02	3.544E+00	2.145E+00	0.000E+00	88.653

07-SR85	2.437E+02	6.705E+00	4.296E+00	0.000E+00	56.725
08-CS137	1.757E+02	1.777E+00	7.350E-01	0.000E+00	239.076
09-Y88	3.937E+02	6.236E+00	3.279E+00	0.000E+00	120.049
10-CO60	2.051E+02	1.611E+00	6.845E-01	0.000E+00	299.620
12-Y88	4.019E+02	6.973E+00	1.890E+00	0.000E+00	212.590

---- Non-Identified Nuclides ----

Nuclide	Key-Line Activity (BQ/TOTAL)	K.L. Ided	Act error	MDA (BQ/TOTAL)	MDA error	Act/MDA
01-AM241	3.895E-01		8.108E-01	1.321E+00	0.000E+00	0.295

```
A,14S25121719       ,12/26/2019 10:19,06/01/2019 12:00,   1.000E+00,S25 5ML MIXED
B,14S25121719       ,CALIBRATION          ,12/26/2019 10:18,14S25121719
C,02-CD109,YES,   1.006E+03,   1.533E+01,   9.506E+00,,  105.834
C,03-CO57 ,YES,   3.993E+01,   6.577E-01,   4.039E-01,,   98.864
C,04-CE139,YES,   5.107E+01,   1.051E+00,   7.760E-01,,   65.808
C,05-HG203,YES,   1.467E+02,   9.105E+00,   7.581E+00,,   19.347
C,06-SN113,YES,   1.902E+02,   3.544E+00,   2.145E+00,,   88.653
C,07-SR85 ,YES,   2.437E+02,   6.705E+00,   4.296E+00,,   56.725
C,08-CS137,YES,   1.757E+02,   1.777E+00,   7.350E-01,,  239.076
C,09-Y88  ,YES,   3.937E+02,   6.236E+00,   3.279E+00,,  120.049
C,10-CO60 ,YES,   2.051E+02,   1.611E+00,   6.845E-01,,  299.620
C,12-Y88  ,YES,   4.019E+02,   6.973E+00,   1.890E+00,,  212.590
C,01-AM241,NO ,   3.895E-01,   8.108E-01,   1.321E+00,,    0.295
```

E & Z 2088-10-1 Mixed Gamma
6/1/19 12:00 PM

S25 Bottle

		Orig. Wt	5.1617	Volume	50				
		Wt Used	4.4184	Aliquot	5.0000	Certificate	Aliquoted	Actual	Percent
	Half-Life	Energy(KeV)	ate G/s/	%err	%abn	Bq/Tot	G/S	Bq/Tot	Diff
Pb-210	22.26Y	46.6	72.1		4.18%	762.12	31.86	787.2	3.29%
Cd-109	462.9d	88.0	84.75		3.72%	1006.61	37.45	1001.0	-0.56%
Co-57	271.8d	122.1	77.25		85.51%	39.92	34.13	40.7	1.84%
Ce-139	137.64d	165.9	92.68		80.35%	50.96	40.95	49.9	-2.05%
Hg-203	46.6d	279.2	273		77.30%	156.04	120.62		
Sn-113	115.09d	391.7	280		64.90%	190.62	123.72	191.2	0.30%
Sr-85	64.849	514.0	547.9		98.40%	246.02	242.08	262.8	6.82%
Cs-137	30.17y	661.6	330.6		85.12%	171.61	146.07	172.9	0.75%
Y-88	106.65d	898.0	858.7		93.40%	406.22	379.41	392.2	-3.45%
Co-60	5.27y	1173.2	460.4		100.00%	203.42	203.42	203.5	0.04%
Co-60	5.27y	1332.5	460.9		100.00%	203.64	203.64	207.2	1.75%
Y-88	106.65d	1836.0	908		99.38%	403.69	401.19	400.7	-0.74%

Eff. Name: **23S25122820**

Analyst: KOJ

Analyst:

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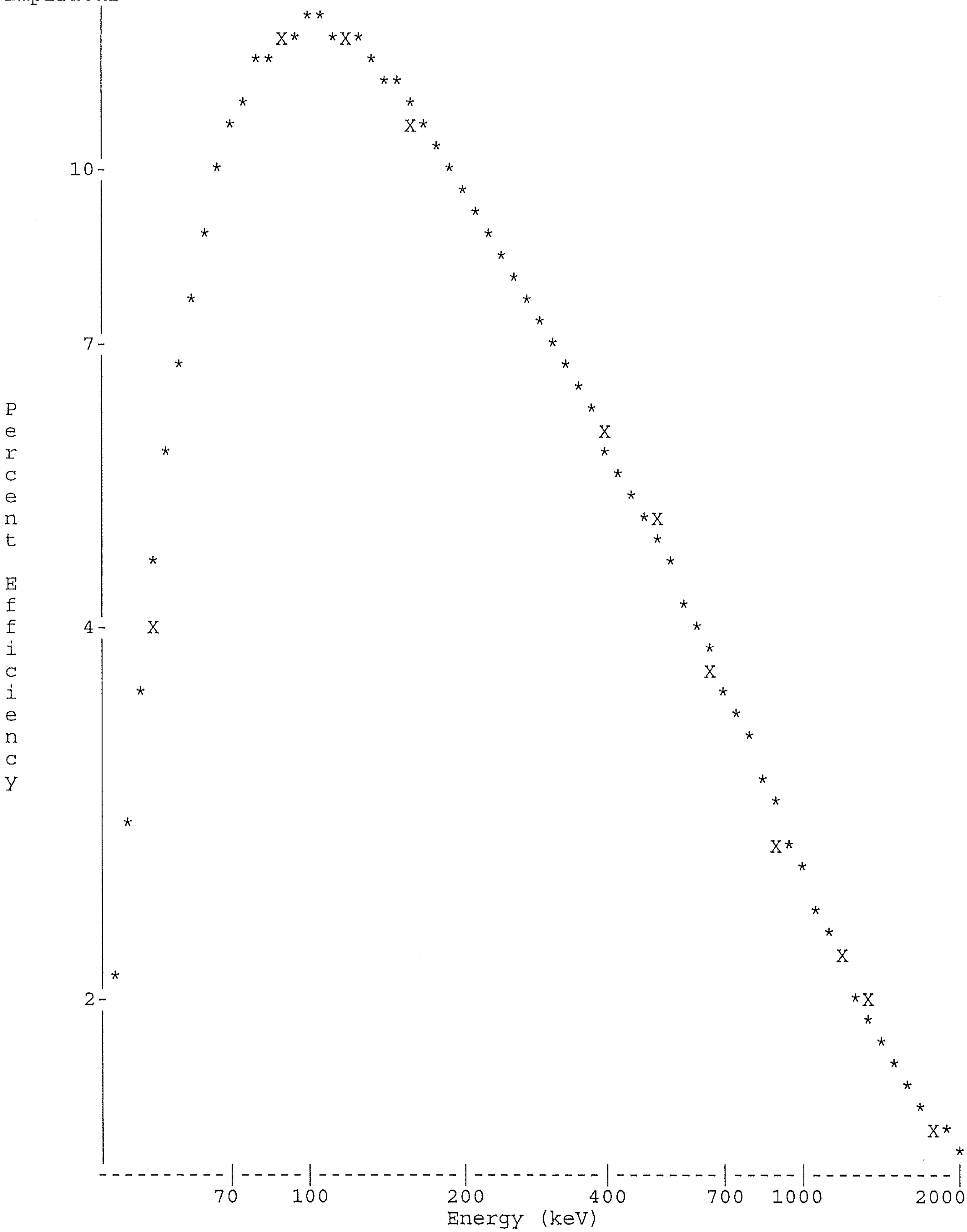
VAX/VMS Teledyne Brown Eng. Laboratory Gamma Report: 29-DEC-2020 13:35:55.26
TBE23 03017322 HpGe ********** Aquisition Date/Time: 28-DEC-2020 18:21:02.51

LIMS No., Customer Name, Client ID: S25 5ML MIXED GAMMA CALIBRATION

```
Sample ID      : 23S25122820                          Smple Date: 1-JUN-2019 12:00:00.0
Sample Type    : STD                                  Geometry  : 23S25122820
Quantity       : 1.00000E+00 TOTAL                    BKGFILE   : 23BG121820MT
Start Channel  : 80        Energy Tol    : 2.00000    Real Time : 0 19:13:29.87
End Channel    : 4090      Pk Srch Sens: 9.00000      Live time : 0 19:11:37.83
MDA Multiple   : 4.6600    Library Used: CALIBRATION_PB
Peak Evaluation - Identified and Unidentified
```

Pk	It	Energy	Area	Bkgnd	FWHM	Channel	%Eff	Cts/Sec	%Err	Fit
1	0	46.53	86419	50241	0.92	92.99	4.10E+00	1.25E+00	0.6	
2	0	88.12	138391	33792	0.84	176.13	1.27E+01	2.00E+00	0.4	
3	0	122.12	68998	23643	0.85	244.08	1.26E+01	9.99E-01	0.6	
4	0	136.52	8600	18857	0.90	272.86	1.20E+01	1.24E-01	3.1	
5	0	165.87	16442	17766	1.05	331.53	1.08E+01	2.38E-01	1.7	
6	0	238.50	1672	14948	1.01	476.73	8.50E+00	2.42E-02	12.4	
7	0	255.14	919	9890	1.16	509.98	8.10E+00	1.33E-02	16.6	
8	0	391.65	15689	19175	1.13	782.93	5.90E+00	2.27E-01	1.9	
9	8	510.96	2394	16558	2.57	1021.50	4.76E+00	3.46E-02	11.3	4.72E-01
10	8	513.94	1795	8681	1.18	1027.47	4.74E+00	2.60E-02	9.1	
11	0	661.54	371403	14393	1.31	1322.68	3.79E+00	5.38E+00	0.2	
12	0	898.01	16812	13215	1.45	1795.77	2.82E+00	2.43E-01	1.6	
13	0	1173.30	247064	7466	1.63	2346.71	2.16E+00	3.58E+00	0.2	
14	0	1332.58	223705	3266	1.72	2665.57	1.92E+00	3.24E+00	0.2	
15	0	1461.05	254	975	1.45	2922.81	1.78E+00	3.68E-03	24.6	
16	0	1835.94	10026	1055	1.99	3673.69	1.55E+00	1.45E-01	1.3	

Spectrum : MCA0:[NDSCOUNT]TBE23$1
Calib Date: 29-DEC-2020 13:35
Detector : TBE17 Geometry : 23S25122820
Empirical



Analyst:

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VAX/VMS Teledyne Brown Eng. Laboratory Gamma Report: 29-DEC-2020 13:41:19.35
TBE23 03017322 HpGe ********** Aquisition Date/Time: 28-DEC-2020 18:21:02.51

LIMS No., Customer Name, Client ID: S25 5ML MIXED GAMMA CALIBRATION

Sample ID	: 23S25122820			Smple Date:	1-JUN-2019 12:00:00.0
Sample Type	: STD			Geometry :	23S25122820
Quantity	: 1.00000E+00 TOTAL			BKGFILE :	23BG121820MT
Start Channel	: 80	Energy Tol :	2.00000	Real Time :	0 19:13:29.87
End Channel	: 4090	Pk Srch Sens:	9.00000	Live time :	0 19:11:37.83
MDA Multiple	: 4.6600	Library Used:	CALIBRATION_PB		

Peak Evaluation - Identified and Unidentified

Pk	It	Energy	Area	Bkgnd	FWHM	Channel	%Eff	Cts/Sec	%Err	Fit
1	0	46.53*	85939	50241	0.92	92.99	4.10E+00	1.24E+00	0.6	
2	0	88.12*	138155	33792	0.84	176.13	1.27E+01	2.00E+00	0.4	
3	0	122.12	68998	23643	0.85	244.08	1.26E+01	9.99E-01	0.6	
4	0	136.52	8600	18857	0.90	272.86	1.20E+01	1.24E-01	3.1	
5	0	165.87	16442	17766	1.05	331.53	1.08E+01	2.38E-01	1.7	
6	0	238.50*	202	14948	1.01	476.73	8.50E+00	2.93E-03	103.4	
7	0	255.14	919	9890	1.16	509.98	8.10E+00	1.33E-02	16.6	
8	0	391.65	15689	19175	1.13	782.93	5.90E+00	2.27E-01	1.9	
9	8	510.96*	546	16558	2.57	1021.50	4.76E+00	7.90E-03	50.2	4.72E-01
10	8	513.94	1795	8681	1.18	1027.47	4.74E+00	2.60E-02	9.1	
11	0	661.54	371403	14393	1.31	1322.68	3.79E+00	5.38E+00	0.2	
12	0	898.01	16812	13215	1.45	1795.77	2.82E+00	2.43E-01	1.6	
13	0	1173.30	247064	7466	1.63	2346.71	2.16E+00	3.58E+00	0.2	
14	0	1332.58	223705	3266	1.72	2665.57	1.92E+00	3.24E+00	0.2	
15	0	1461.05*	53	975	1.45	2922.81	1.78E+00	7.63E-04	122.0	
16	0	1835.94	10026	1055	1.99	3673.69	1.55E+00	1.45E-01	1.3	

Flag: "*" = Peak area was modified by background subtraction

Nuclide Line Activity Report

Nuclide Type:

Nuclide	Energy	Area	%Abn	%Eff	Uncorrected BQ/TOTAL	Decay Corr BQ/TOTAL	2-Sigma %Error
03-PB210	46.50	85939	4.05*	4.098E+00	7.495E+02	7.872E+02	1.26
04-CD109	88.03	138155	3.72*	1.273E+01	4.223E+02	1.001E+03	0.74
05-CO57	122.06	68998	85.51*	1.256E+01	9.296E+00	4.065E+01	1.13
06-CE139	165.85	16442	80.35*	1.082E+01	2.737E+00	4.992E+01	3.31
08-SN113	391.69	15689	64.90*	5.897E+00	5.932E+00	1.912E+02	3.77
09-SR85	513.99	1795	99.27*	4.736E+00	5.524E-01	2.628E+02	18.12
10-CS137	661.65	371403	85.12*	3.787E+00	1.667E+02	1.729E+02	0.36
11-Y88	898.02	16812	93.40*	2.818E+00	9.244E+00	3.922E+02	3.14
12-CO60	1173.22	247064	100.00	2.163E+00	1.653E+02	2.035E+02	0.43
	1332.49	223705	100.00*	1.923E+00	1.684E+02	2.072E+02	0.44
14-Y88	1836.01	10026	99.38*	1.546E+00	9.444E+00	4.007E+02	2.55

Flag: "*" = Keyline

Sample ID : 23S25122820 Acquisition date : 28-DEC-2020 18:21:02

Total number of lines in spectrum 16
Number of unidentified lines 5
Number of lines tentatively identified by NID 11 68.75%

Nuclide Type :

Nuclide	Hlife	Decay	Uncorrected BQ/TOTAL	Decay Corr BQ/TOTAL	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
03-PB210	22.26Y	1.05	7.495E+02	7.872E+02	0.099E+02	1.26	
04-CD109	462.90D	2.37	4.223E+02	1.001E+03	0.007E+03	0.74	
05-CO57	270.90D	4.37	9.296E+00	4.065E+01	0.046E+01	1.13	
06-CE139	137.66D	18.2	2.737E+00	4.992E+01	0.165E+01	3.31	
08-SN113	115.10D	32.2	5.932E+00	1.912E+02	0.072E+02	3.77	
09-SR85	64.84D	476.	5.524E-01	2.628E+02	0.476E+02	18.12	
10-CS137	30.17Y	1.04	1.667E+02	1.729E+02	0.006E+02	0.36	
11-Y88	106.65D	42.4	9.244E+00	3.922E+02	0.123E+02	3.14	
12-CO60	5.27Y	1.23	1.684E+02	2.072E+02	0.009E+02	0.44	
14-Y88	106.65D	42.4	9.444E+00	4.007E+02	0.102E+02	2.55	
			---------	---------			
	Total Activity :		1.544E+03	3.506E+03			
	Grand Total Activity :		1.544E+03	3.506E+03			

Flags: "K" = Keyline not found "M" = Manually accepted
"E" = Manually edited "A" = Nuclide specific abn. limit

Sample ID : 23S25122820 Acquisition date : 28-DEC-2020 18:21:02

It	Energy	Area	Bkgnd	FWHM	Channel	Left	Pw	Cts/Sec	%Err	%Eff	Flags
0	136.52	8600	18857	0.90	272.86	269	9	1.24E-01	6.2	1.20E+01	
0	238.50	202	14948	1.01	476.73	474	7	2.93E-03	****	8.50E+00	
0	255.14	919	9890	1.16	509.98	508	5	1.33E-02	33.2	8.10E+00	
8	510.96	546	16558	2.57	1021.50	1015	17	7.90E-03	****	4.76E+00	
0	1461.05	53	975	1.45	2922.81	2917	11	7.63E-04	****	1.78E+00	

Flags: "T" = Tentatively associated

Summary of Nuclide Activity

Total number of lines in spectrum	16	
Number of unidentified lines	5	
Number of lines tentatively identified by NID	11	68.75%

Nuclide Type :

Nuclide	Hlife	Decay	Wtd Mean Uncorrected BQ/TOTAL	Wtd Mean Decay Corr BQ/TOTAL	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
03-PB210	22.26Y	1.05	7.495E+02	7.872E+02	0.099E+02	1.26	
04-CD109	462.90D	2.37	4.223E+02	1.001E+03	0.007E+03	0.74	
05-CO57	270.90D	4.37	9.296E+00	4.065E+01	0.046E+01	1.13	
06-CE139	137.66D	18.2	2.737E+00	4.992E+01	0.165E+01	3.31	
08-SN113	115.10D	32.2	5.932E+00	1.912E+02	0.072E+02	3.77	
09-SR85	64.84D	476.	5.524E-01	2.628E+02	0.476E+02	18.12	
10-CS137	30.17Y	1.04	1.667E+02	1.729E+02	0.006E+02	0.36	
11-Y88	106.65D	42.4	9.244E+00	3.922E+02	0.123E+02	3.14	
12-CO60	5.27Y	1.23	1.684E+02	2.072E+02	0.009E+02	0.44	
14-Y88	106.65D	42.4	9.444E+00	4.007E+02	0.102E+02	2.55	
			---------	---------			
	Total Activity :		1.544E+03	3.506E+03			

Grand Total Activity : 1.544E+03 3.506E+03

Flags: "K" = Keyline not found "M" = Manually accepted
"E" = Manually edited "A" = Nuclide specific abn. limit

Interference Report

No interference correction performed

Combined Activity-MDA Report

---- Identified Nuclides ----

Nuclide	Activity (BQ/TOTAL)	Act error	MDA (BQ/TOTAL)	MDA error	Act/MDA
03-PB210	7.872E+02	9.939E+00	6.075E+00	0.000E+00	129.589
04-CD109	1.001E+03	7.361E+00	4.462E+00	0.000E+00	224.459
05-CO57	4.065E+01	4.593E-01	3.123E-01	0.000E+00	130.166
06-CE139	4.992E+01	1.654E+00	1.537E+00	0.000E+00	32.476
08-SN113	1.912E+02	7.215E+00	6.389E+00	0.000E+00	29.923

09-SR85	2.628E+02	4.760E+01	6.769E+01	0.000E+00	3.882
10-CS137	1.729E+02	6.173E-01	1.925E-01	0.000E+00	898.197
11-Y88	3.922E+02	1.232E+01	1.095E+01	0.000E+00	35.833
12-CO60	2.072E+02	9.144E-01	1.834E-01	0.000E+00	1129.809
14-Y88	4.007E+02	1.022E+01	4.758E+00	0.000E+00	84.219

---- Non-Identified Nuclides ----

Nuclide	Key-Line Activity (BQ/TOTAL)	K.L. Ided	Act error	MDA (BQ/TOTAL)	MDA error	Act/MDA
01-CO57	0.000E+00		0.000E+00	1.333E+05	0.000E+00	0.000
02-CE139	-6.502E+01		5.161E+01	8.172E+01	0.000E+00	-0.796
07-HG203	1.778E+02		4.019E+02	6.518E+02	0.000E+00	0.273

```
A,23S25122820      ,12/29/2020 13:41,06/01/2019 12:00,   1.000E+00,S25 5ML MIXED
B,23S25122820      ,CALIBRATION_PB      ,12/29/2020 13:35,23S25122820
C,03-PB210,YES,   7.872E+02,   9.939E+00,   6.075E+00,,  129.589
C,04-CD109,YES,   1.001E+03,   7.361E+00,   4.462E+00,,  224.459
C,05-CO57 ,YES,   4.065E+01,   4.593E-01,   3.123E-01,,  130.166
C,06-CE139,YES,   4.992E+01,   1.654E+00,   1.537E+00,,   32.476
C,08-SN113,YES,   1.912E+02,   7.215E+00,   6.389E+00,,   29.923
C,09-SR85 ,YES,   2.628E+02,   4.760E+01,   6.769E+01,,    3.882
C,10-CS137,YES,   1.729E+02,   6.173E-01,   1.925E-01,,  898.197
C,11-Y88  ,YES,   3.922E+02,   1.232E+01,   1.095E+01,,   35.833
C,12-CO60 ,YES,   2.072E+02,   9.144E-01,   1.834E-01,, 1129.809
C,14-Y88  ,YES,   4.007E+02,   1.022E+01,   4.758E+00,,   84.219
C,02-CE139,NO ,  -6.502E+01,   5.161E+01,   8.172E+01,,   -0.796
C,07-HG203,NO ,   1.778E+02,   4.019E+02,   6.518E+02,,    0.273
```

E & Z 2088-10-1 Mixed Gamma
6/1/19 12:00 PM

3.5L MARINELLI

		Orig. Wt	5.1617	Volume	50				
		Wt Used	4.4184	Aliquot	5.0000	Certificate	Aliquoted	Actual	Percent
	Half-Life	Energy(KeV)	ate G/s/	%err	%abn	Bq/Tot	G/S	Bq/Tot	Diff
Pb-210	22.26Y	46.6	72.1		4.18%	762.12	31.86	765.5	0.44%
Cd-109	462.9d	88.0	84.75		3.72%	1006.61	37.45	1001.0	-0.56%
Co-57	271.8d	122.1	77.25		85.51%	39.92	34.13	40.0	0.26%
Ce-139	137.64d	165.9	92.68		80.35%	50.96	40.95	50.1	-1.72%
Hg-203	46.6d	279.2	273		77.30%	156.04	120.62	152.0	-2.59%
Sn-113	115.09d	391.7	280		64.90%	190.62	123.72	195.8	2.72%
Sr-85	64.849	514.0	547.9		98.40%	246.02	242.08	238.1	-3.22%
Cs-137	30.17y	661.6	330.6		85.12%	171.61	146.07	175.2	2.09%
Y-88	106.65d	898.0	858.7		93.40%	406.22	379.41	406.9	0.17%
Co-60	5.27y	1173.2	460.4		100.00%	203.42	203.42	204.5	0.53%
Co-60	5.27y	1332.5	460.9		100.00%	203.64	203.64	202.1	-0.76%
Y-88	106.65d	1836.0	908		99.38%	403.69	401.19	402.6	-0.27%

Eff. Name: **1135L1203[illegible]**

Analyst: KOJ

Sec. Review: Analyst:

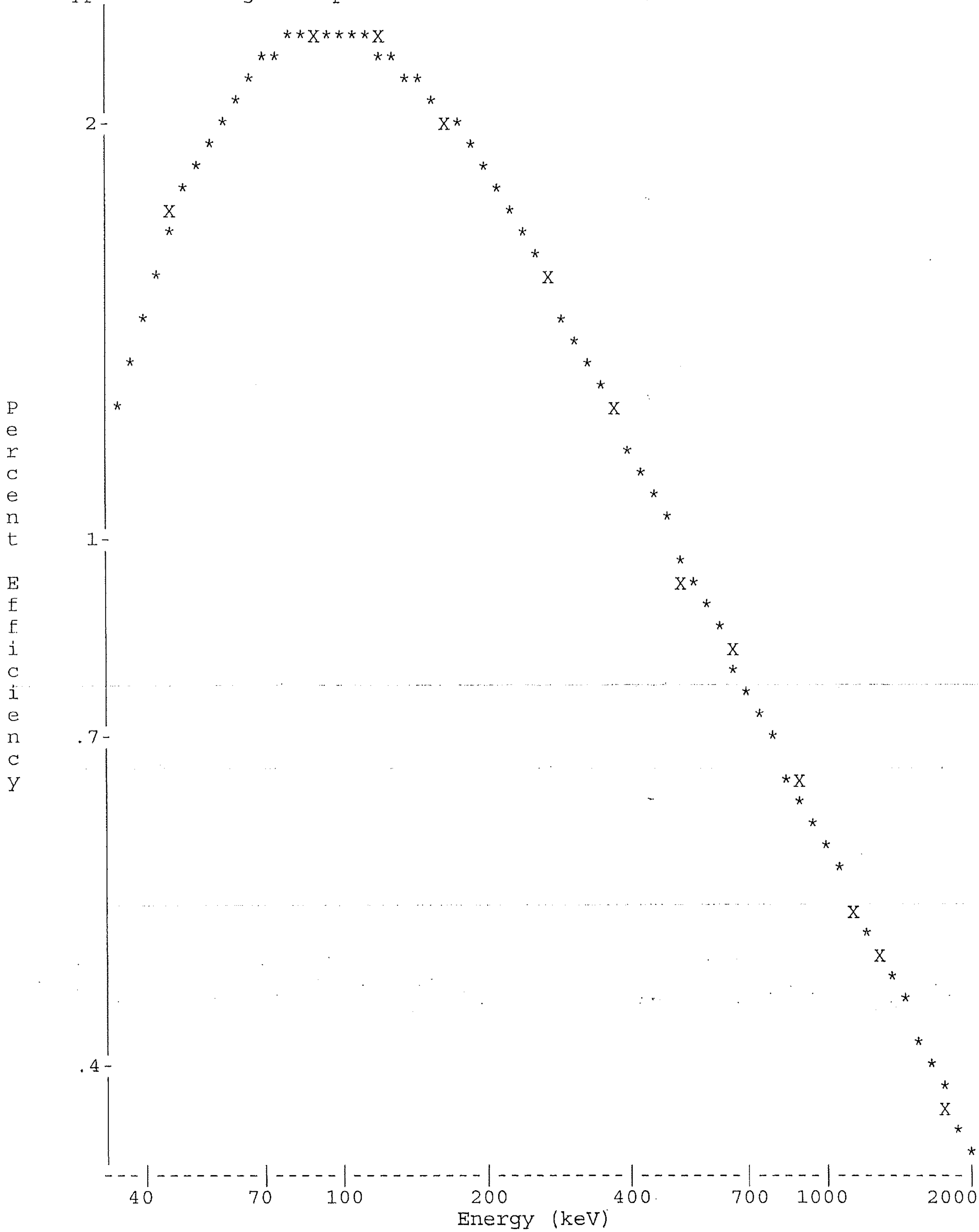
==
VAX/VMS Teledyne Brown Eng. Laboratory Gamma Report: 4-DEC-2019 09:55:50.82
TBE11 31-TP20610B HpGe ******* Aquisition Date/Time: 3-DEC-2019 18:03:23.85

LIMS No., Customer Name, Client ID: 3.5L 5ML MIXED GAMMA CALIBRATION

Sample ID	: 1135L120319			Smple Date:	1-JUN-2019 12:00:00.0
Sample Type	: STD			Geometry	: 1135L120319
Quantity	: 1.00000E+00 TOTAL			BKGFILE	: 11BG112719MT
Start Channel	: 70	Energy Tol	: 2.00000	Real Time	: 0 12:01:18.85
End Channel	: 4090	Pk Srch Sens:	7.00000	Live time	: 0 12:00:00.00
MDA Multiple	: 4.6600	Library Used:	CALIBRATION		

Pk	It	Energy	Area	Bkgnd	FWHM	Channel	%Eff	Cts/Sec	%Err	Fit
1	0	46.47	23288	21494	1.43	91.94	1.72E+00	5.39E-01	1.4	
2	0	75.04	1490	15930	1.23	149.12	2.30E+00	3.45E-02	13.7	
3	0	88.06	29119	27294	1.39	175.19	2.37E+00	6.74E-01	1.3	
4	0	122.08	21359	20676	1.44	243.27	2.32E+00	4.94E-01	1.5	
5	0	136.54	2384	13793	1.56	272.23	2.25E+00	5.52E-02	8.8	
6	0	165.90	14266	16553	1.51	330.98	2.09E+00	3.30E-01	1.9	
7	0	255.18	1030	9324	1.66	509.68	1.63E+00	2.38E-02	17.2	
8	0	279.20	5197	9831	1.56	557.74	1.53E+00	1.20E-01	3.9	
9	0	391.73	21490	7663	1.62	782.96	1.20E+00	4.97E-01	1.1	
10	0	514.03	13669	7212	1.68	1027.72	9.73E-01	3.16E-01	1.6	
11	0	661.65	51118	5928	1.78	1323.12	8.03E-01	1.18E+00	0.6	
12	0	814.14	464	3039	1.73	1628.27	6.88E-01	1.07E-02	24.2	
13	0	898.00	31453	5022	1.96	1796.07	6.40E-01	7.28E-01	0.8	
14	0	1173.15	43501	2652	2.15	2346.60	5.26E-01	1.01E+00	0.6	
15	2	1325.28	508	896	2.75	2650.95	4.81E-01	1.17E-02	11.8	2.07E+01
16	2	1332.48	39138	949	2.38	2665.36	4.79E-01	9.06E-01	0.5	
17	0	1460.95	307	999	1.89	2922.36	4.47E-01	7.11E-03	23.7	
18	0	1836.04	19366	460	2.67	3672.67	3.74E-01	4.48E-01	0.8	

Spectrum : MCA0:[NDSCOUNT]TBE11$1
Calib Date: 4-DEC-2019 09:55:
Detector : Geometry : 1135L120319
Fit type : 5th Degree Empirical



Sec. Review: Analyst:

VAX/VMS Teledyne Brown Eng. Laboratory Gamma Report: 4-DEC-2019 10:00:37.78
TBE11 31-TP20610B HpGe ******* Aquisition Date/Time: 3-DEC-2019 18:03:23.85

LIMS No., Customer Name, Client ID: 3.5L 5ML MIXED GAMMA CALIBRATION

Sample ID : 1135L120319 Smple Date: 1-JUN-2019 12:00:00.0
Sample Type : STD Geometry : 1135L120319
Quantity : 1.00000E+00 TOTAL BKGFILE : 11BG112719MT
Start Channel : 70 Energy Tol : 2.00000 Real Time : 0 12:01:18.85
End Channel : 4090 Pk Srch Sens: 7.00000 Live time : 0 12:00:00.00
MDA Multiple : 4.6600 Library Used: CALIBRATION_PB

Pk	It	Energy	Area	Bkgnd	FWHM	Channel	%Eff	Cts/Sec	%Err	Fit
1	0	46.47*	22623	21494	1.43	91.94	1.72E+00	5.24E-01	1.4	
2	0	75.04*	61	15930	1.23	149.12	2.30E+00	1.41E-03	338.5	
3	0	88.06*	28919	27294	1.39	175.19	2.37E+00	6.69E-01	1.3	
4	0	122.08	21359	20676	1.44	243.27	2.32E+00	4.94E-01	1.5	
5	0	136.54	2384	13793	1.56	272.23	2.25E+00	5.52E-02	8.8	
6	0	165.90	14266	16553	1.51	330.98	2.09E+00	3.30E-01	1.9	
7	0	255.18	1030	9324	1.66	509.68	1.63E+00	2.38E-02	17.2	
8	0	279.20	5197	9831	1.56	557.74	1.53E+00	1.20E-01	3.9	
9	0	391.73	21490	7663	1.62	782.96	1.20E+00	4.97E-01	1.1	
10	0	514.03	13669	7212	1.68	1027.72	9.73E-01	3.16E-01	1.6	
11	0	661.65	51118	5928	1.78	1323.12	8.03E-01	1.18E+00	0.6	
12	0	814.14	464	3039	1.73	1628.27	6.88E-01	1.07E-02	24.2	
13	0	898.00	31453	5022	1.96	1796.07	6.40E-01	7.28E-01	0.8	
14	0	1173.15	43501	2652	2.15	2346.60	5.26E-01	1.01E+00	0.6	
15	2	1325.28	508	896	2.75	2650.95	4.81E-01	1.17E-02	11.8	2.07E+01
16	2	1332.48	39138	949	2.38	2665.36	4.79E-01	9.06E-01	0.5	
17	0	1460.95*	58	999	1.89	2922.36	4.47E-01	1.35E-03	126.9	
18	0	1836.04	19366	460	2.67	3672.67	3.74E-01	4.48E-01	0.8	

Flag: "*" = Peak area was modified by background subtraction

Nuclide Line Activity Report

Nuclide Type:

Nuclide	Energy	Area	%Abn	%Eff	Uncorrected BQ/TOTAL	Decay Corr BQ/TOTAL	2-Sigma %Error
03-PB210	46.50	22623	4.05*	1.716E+00	7.535E+02	7.655E+02	2.87
04-CD109	88.03	28919	3.72*	2.374E+00	7.582E+02	1.001E+03	2.52
05-CO57	122.06	21359	85.51*	2.323E+00	2.490E+01	4.002E+01	2.95
06-CE139	165.85	14266	80.35*	2.088E+00	1.968E+01	5.009E+01	3.88
07-HG203	279.20	5197	81.46*	1.533E+00	9.633E+00	1.520E+02	7.89
08-SN113	391.69	21490	64.90*	1.197E+00	6.405E+01	1.958E+02	2.20
09-SR85	513.99	13669	99.27*	9.725E-01	3.277E+01	2.381E+02	3.11
10-CS137	661.65	51118	85.12*	8.027E-01	1.732E+02	1.752E+02	1.12
11-Y88	898.02	31453	93.40*	6.397E-01	1.219E+02	4.069E+02	1.55
12-CO60	1173.22	43501	100.00	5.263E-01	1.913E+02	2.045E+02	1.12
	1332.49	39138	100.00*	4.793E-01	1.890E+02	2.021E+02	1.07
14-Y88	1836.01	19366	99.38*	3.741E-01	1.206E+02	4.026E+02	1.57

Flag: "*" = Keyline

Total number of lines in spectrum 18
Number of unidentified lines 6
Number of lines tentatively identified by NID 12 66.67%

Nuclide Type :

Nuclide	Hlife	Decay	Uncorrected BQ/TOTAL	Decay Corr BQ/TOTAL	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
03-PB210	22.26Y	1.02	7.535E+02	7.655E+02	0.220E+02	2.87	
04-CD109	462.90D	1.32	7.582E+02	1.001E+03	0.025E+03	2.52	
05-CO57	270.90D	1.61	2.490E+01	4.002E+01	0.118E+01	2.95	
06-CE139	137.66D	2.54	1.968E+01	5.009E+01	0.194E+01	3.88	
07-HG203	46.61D	15.8	9.633E+00	1.520E+02	0.120E+02	7.89	
08-SN113	115.10D	3.06	6.405E+01	1.958E+02	0.043E+02	2.20	
09-SR85	64.84D	7.26	3.277E+01	2.381E+02	0.074E+02	3.11	
10-CS137	30.17Y	1.01	1.732E+02	1.752E+02	0.020E+02	1.12	
11-Y88	106.65D	3.34	1.219E+02	4.069E+02	0.063E+02	1.55	
12-CO60	5.27Y	1.07	1.890E+02	2.021E+02	0.022E+02	1.07	
14-Y88	106.65D	3.34	1.206E+02	4.026E+02	0.063E+02	1.57	
		Total Activity :	2.267E+03	3.629E+03			

Grand Total Activity : 2.267E+03 3.629E+03

Flags: "K" = Keyline not found "M" = Manually accepted
"E" = Manually edited "A" = Nuclide specific abn. limit

It	Energy	Area	Bkgnd	FWHM	Channel	Left	Pw	Cts/Sec	%Err	%Eff	Flags
0	75.04	61	15930	1.23	149.12	147	6	1.41E-03	****	2.30E+00	
0	136.54	2384	13793	1.56	272.23	268	8	5.52E-02	17.6	2.25E+00	
0	255.18	1030	9324	1.66	509.68	506	9	2.38E-02	34.4	1.63E+00	
0	814.14	464	3039	1.73	1628.27	1622	12	1.07E-02	48.5	6.88E-01	
2	1325.28	508	896	2.75	2650.95	2646	31	1.17E-02	23.5	4.81E-01	
0	1460.95	58	999	1.89	2922.36	2915	16	1.35E-03	****	4.47E-01	

Flags: "T" = Tentatively associated

Summary of Nuclide Activity

Total number of lines in spectrum	18	
Number of unidentified lines	6	
Number of lines tentatively identified by NID	12	66.67%

Nuclide Type :

Nuclide	Hlife	Decay	Uncorrected BQ/TOTAL	Decay Corr BQ/TOTAL	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
			Wtd Mean	Wtd Mean			
03-PB210	22.26Y	1.02	7.535E+02	7.655E+02	0.220E+02	2.87	
04-CD109	462.90D	1.32	7.582E+02	1.001E+03	0.025E+03	2.52	
05-CO57	270.90D	1.61	2.490E+01	4.002E+01	0.118E+01	2.95	
06-CE139	137.66D	2.54	1.968E+01	5.009E+01	0.194E+01	3.88	
07-HG203	46.61D	15.8	9.633E+00	1.520E+02	0.120E+02	7.89	
08-SN113	115.10D	3.06	6.405E+01	1.958E+02	0.043E+02	2.20	
09-SR85	64.84D	7.26	3.277E+01	2.381E+02	0.074E+02	3.11	
10-CS137	30.17Y	1.01	1.732E+02	1.752E+02	0.020E+02	1.12	
11-Y88	106.65D	3.34	1.219E+02	4.069E+02	0.063E+02	1.55	
12-CO60	5.27Y	1.07	1.901E+02	2.032E+02	0.016E+02	0.77	
14-Y88	106.65D	3.34	1.206E+02	4.026E+02	0.063E+02	1.57	
			---------	---------			
	Total Activity :		2.268E+03	3.630E+03			
	Grand Total Activity :		2.268E+03	3.630E+03			

Flags: "K" = Keyline not found "M" = Manually accepted
"E" = Manually edited "A" = Nuclide specific abn. limit

Interference Report

No interference correction performed

Combined Activity-MDA Report

---- Identified Nuclides ----

Nuclide	Activity (BQ/TOTAL)	Act error	MDA (BQ/TOTAL)	MDA error	Act/MDA
03-PB210	7.655E+02	2.196E+01	1.954E+01	0.000E+00	39.183
04-CD109	1.001E+03	2.527E+01	2.310E+01	0.000E+00	43.332
05-CO57	4.002E+01	1.180E+00	1.105E+00	0.000E+00	36.208

06-CE139	5.009E+01	1.942E+00	1.895E+00	0.000E+00	26.438
07-HG203	1.520E+02	1.199E+01	1.279E+01	0.000E+00	11.879
08-SN113	1.958E+02	4.310E+00	3.265E+00	0.000E+00	59.960
09-SR85	2.381E+02	7.394E+00	6.020E+00	0.000E+00	39.550
10-CS137	1.752E+02	1.965E+00	1.015E+00	0.000E+00	172.707
11-Y88	4.069E+02	6.288E+00	3.608E+00	0.000E+00	112.764
12-CO60	2.032E+02	1.570E+00	7.111E-01	0.000E+00	285.814
14-Y88	4.026E+02	6.308E+00	1.591E+00	0.000E+00	253.009

---- Non-Identified Nuclides ----

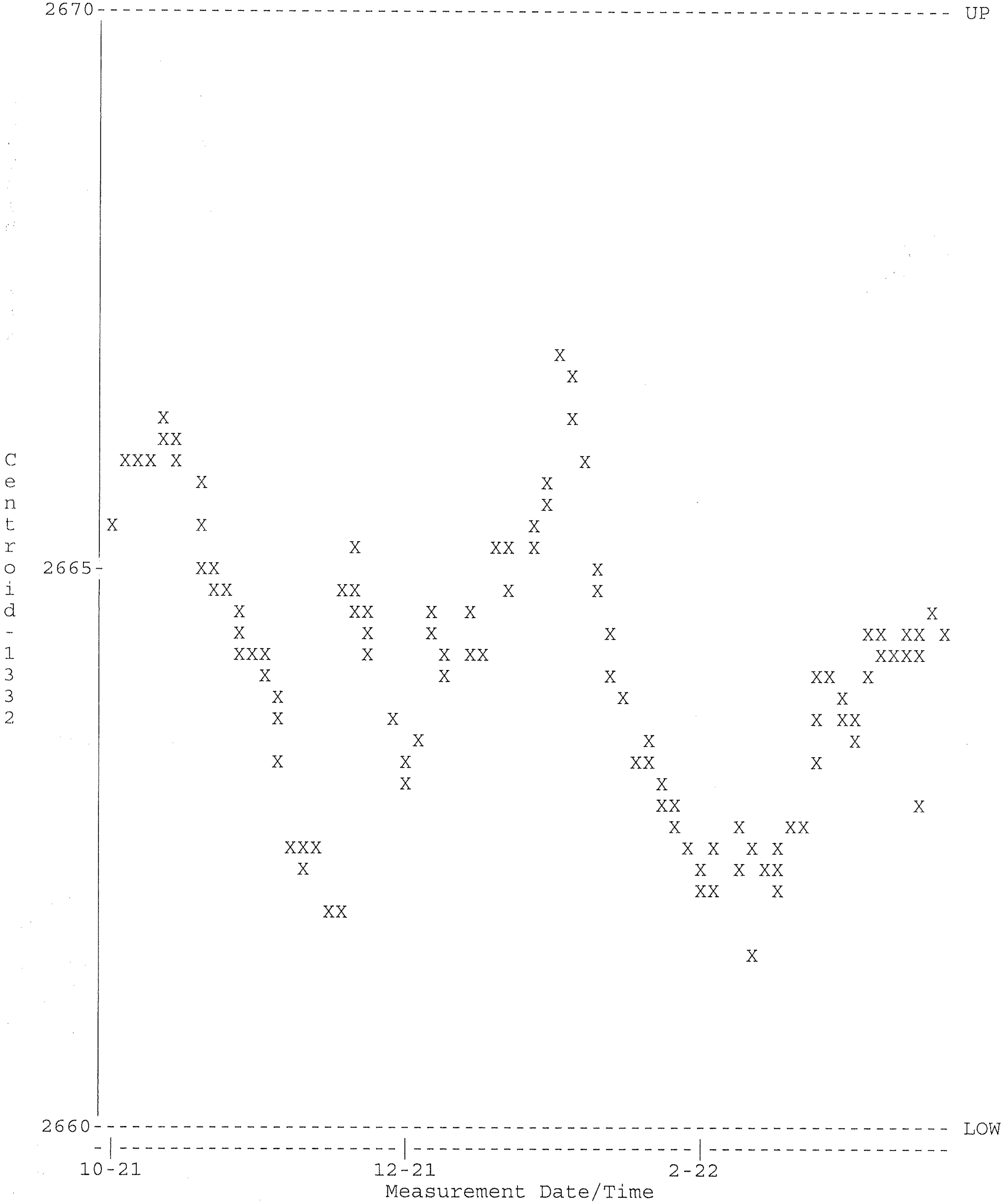
Nuclide	Key-Line Activity (BQ/TOTAL)	K.L. Ided	Act error	MDA (BQ/TOTAL)	MDA error	Act/MDA
01-CO57	1.806E+03		7.032E+01	1.295E+02	0.000E+00	13.951
02-CE139	9.777E+00		9.876E+00	1.669E+01	0.000E+00	0.586

```
A,1135L120319      ,12/04/2019 10:00,06/01/2019 12:00,   1.000E+00,3.5L 5ML MIXED
B,1135L120319      ,CALIBRATION_PB       ,12/04/2019 09:55,1135L120319
C,03-PB210,YES,    7.655E+02,   2.196E+01,   1.954E+01,,   39.183
C,04-CD109,YES,    1.001E+03,   2.527E+01,   2.310E+01,,   43.332
C,05-CO57 ,YES,    4.002E+01,   1.180E+00,   1.105E+00,,   36.208
C,06-CE139,YES,    5.009E+01,   1.942E+00,   1.895E+00,,   26.438
C,07-HG203,YES,    1.520E+02,   1.199E+01,   1.279E+01,,   11.879
C,08-SN113,YES,    1.958E+02,   4.310E+00,   3.265E+00,,   59.960
C,09-SR85 ,YES,    2.381E+02,   7.394E+00,   6.020E+00,,   39.550
C,10-CS137,YES,    1.752E+02,   1.965E+00,   1.015E+00,,  172.707
C,11-Y88  ,YES,    4.069E+02,   6.288E+00,   3.608E+00,,  112.764
C,12-CO60 ,YES,    2.032E+02,   1.570E+00,   7.111E-01,,  285.814
C,14-Y88  ,YES,    4.026E+02,   6.308E+00,   1.591E+00,,  253.009
C,01-CO57 ,NO ,    1.806E+03,   7.032E+01,   1.295E+02,,   13.951
C,02-CE139,NO ,    9.777E+00,   9.876E+00,   1.669E+01,,    0.586
```

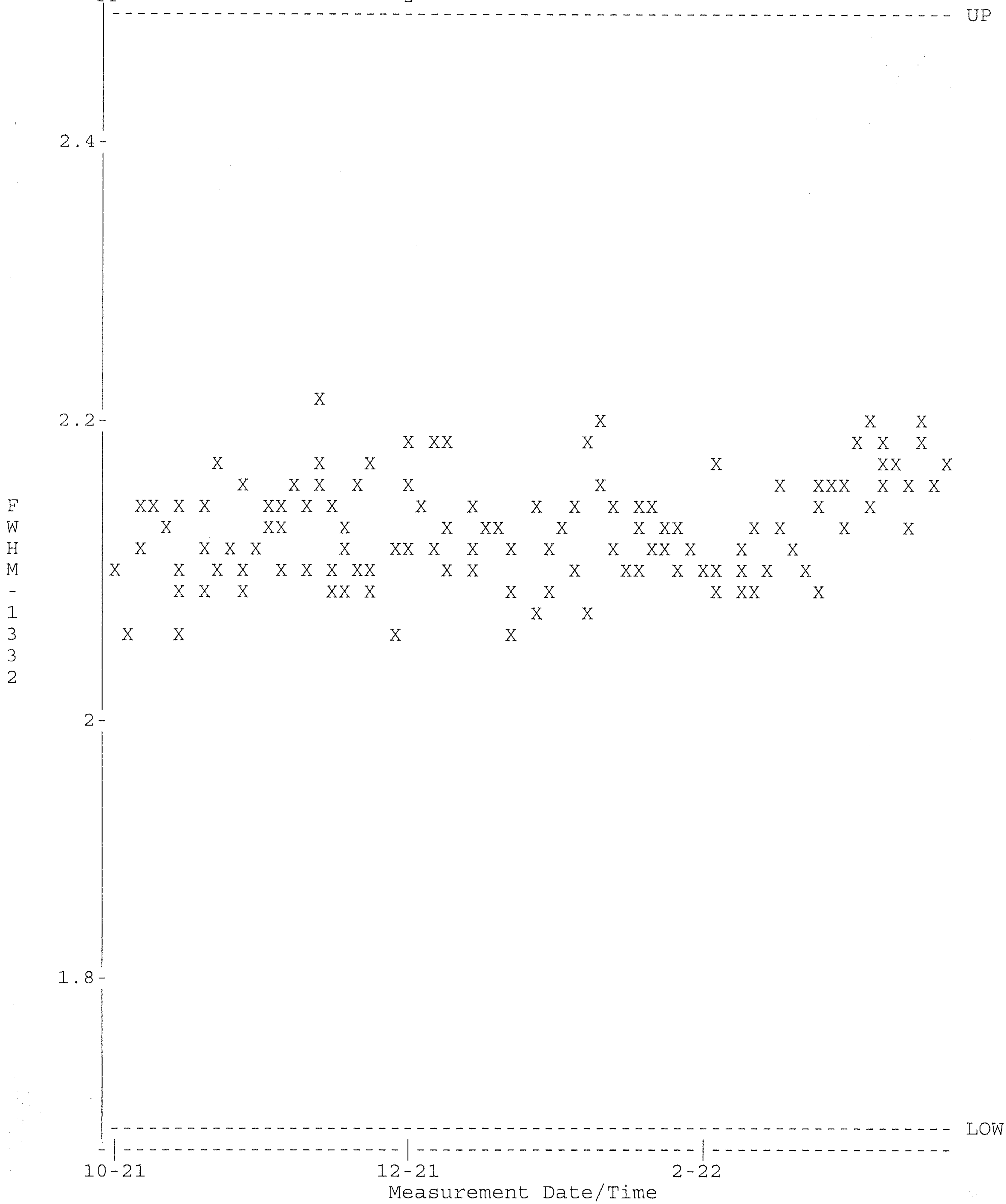
GAMMA SPECTROSCOPY

Daily Source and Background Checks

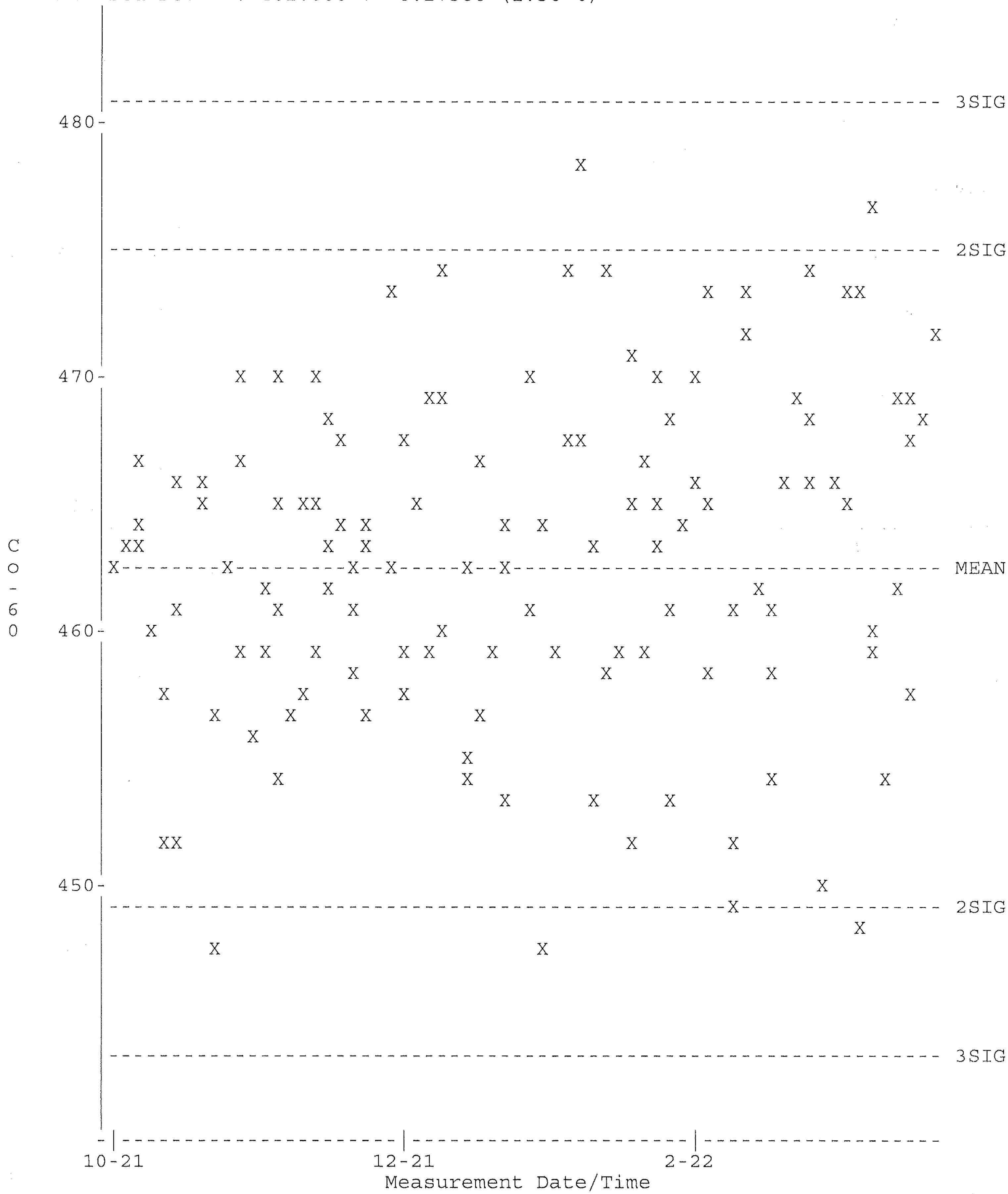
QA filename : DKB100:[GAMMA.QUALITY]NEW_TBE01_QC.QAF;1
Parameter Name : PSCENTRD (Centroid-1332)
Start/End Dates : 1-OCT-2021 08:41 through 23-MAR-2022 00:00
Lower/Upper Lmts: 2660.00 through 2670.00



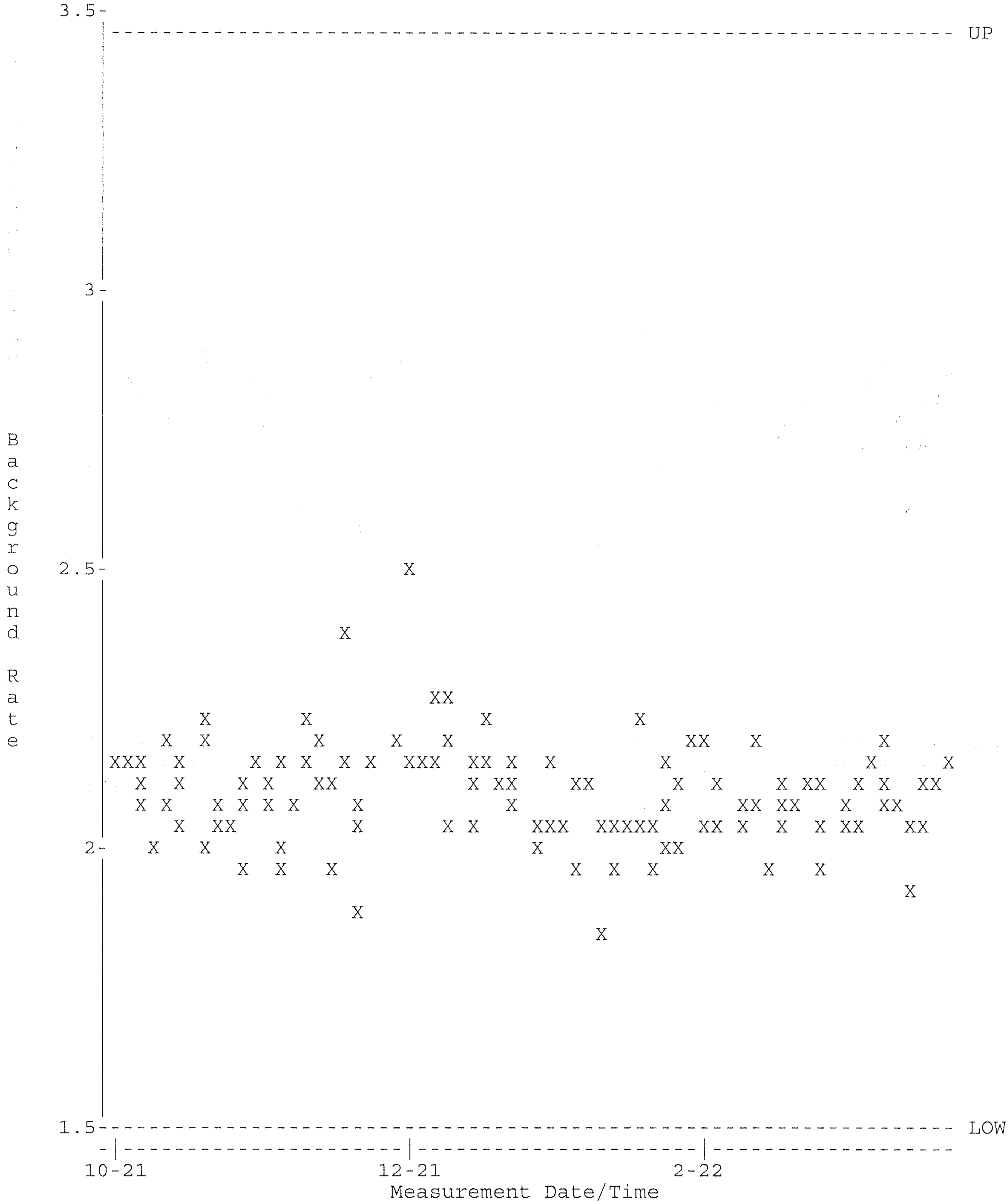
QA filename   : DKB100:[GAMMA.QUALITY]NEW_TBE01_QC.QAF;1
Parameter Name   : PSFWHM-1332 (FWHM-1332)
Start/End Dates   : 1-OCT-2021 08:41 through 23-MAR-2022 00:00
Lower/Upper Lmts: 1.70000 through 2.50000



QA filename : DKB100:[GAMMA.QUALITY]NEW_TBE01_QC.QAF;1
Parameter Name : NCLWTMEAN-CO60 (Co-60)
Start/End Dates : 1-OCT-2021 08:41 through 23-MAR-2022 00:00
Mean +- Std Dev : 462.666 +- 6.27386 (1.36 %)



QA filename : DKB100:[GAMMA.QUALITY]TBE01_BKG_QC.QAF;1
Parameter Name : BACKRATE (Background Rate)
Start/End Dates : 1-OCT-2021 08:57 through 23-MAR-2022 00:00
Lower/Upper Lmts: 1.50000 through 3.50000



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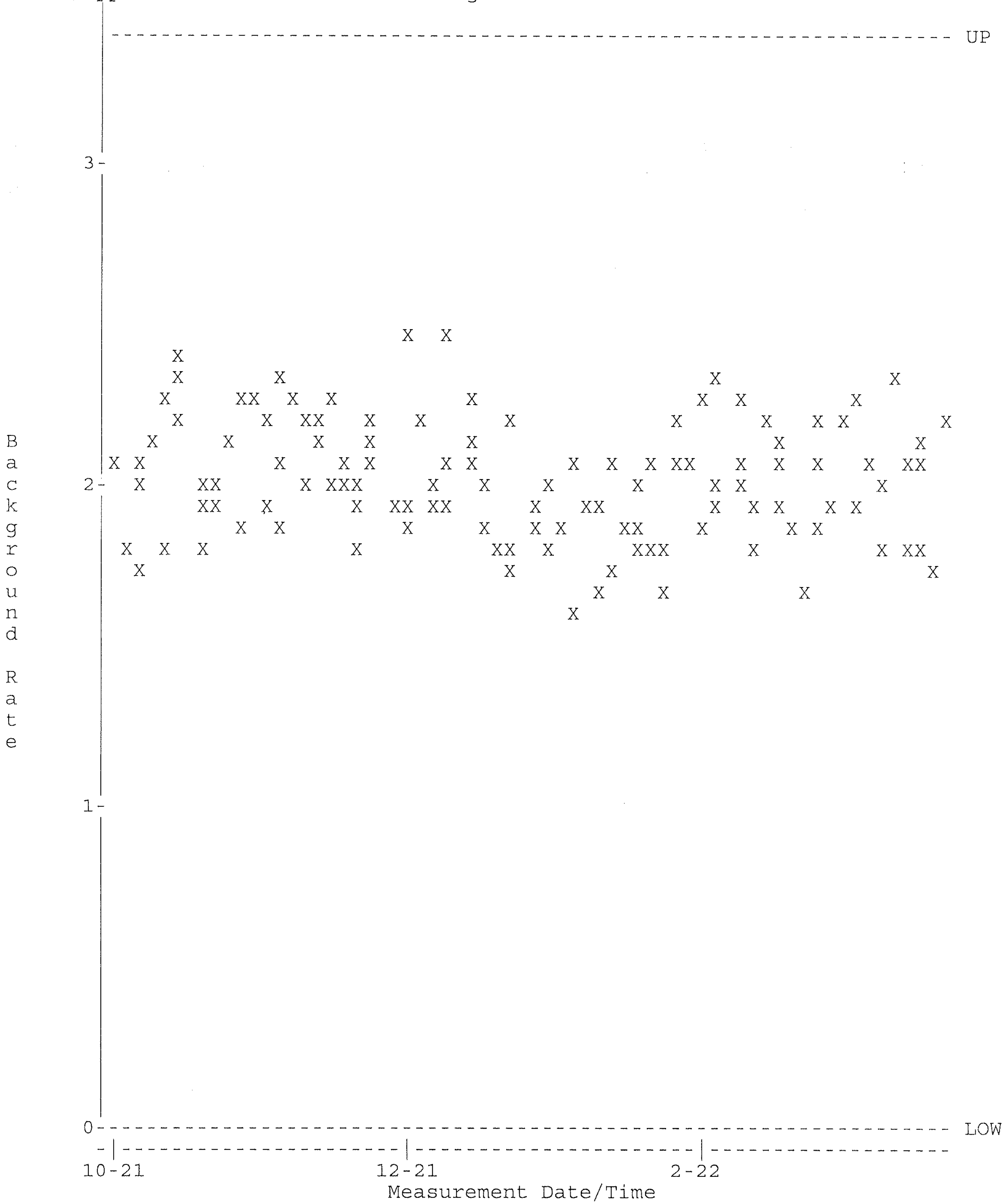
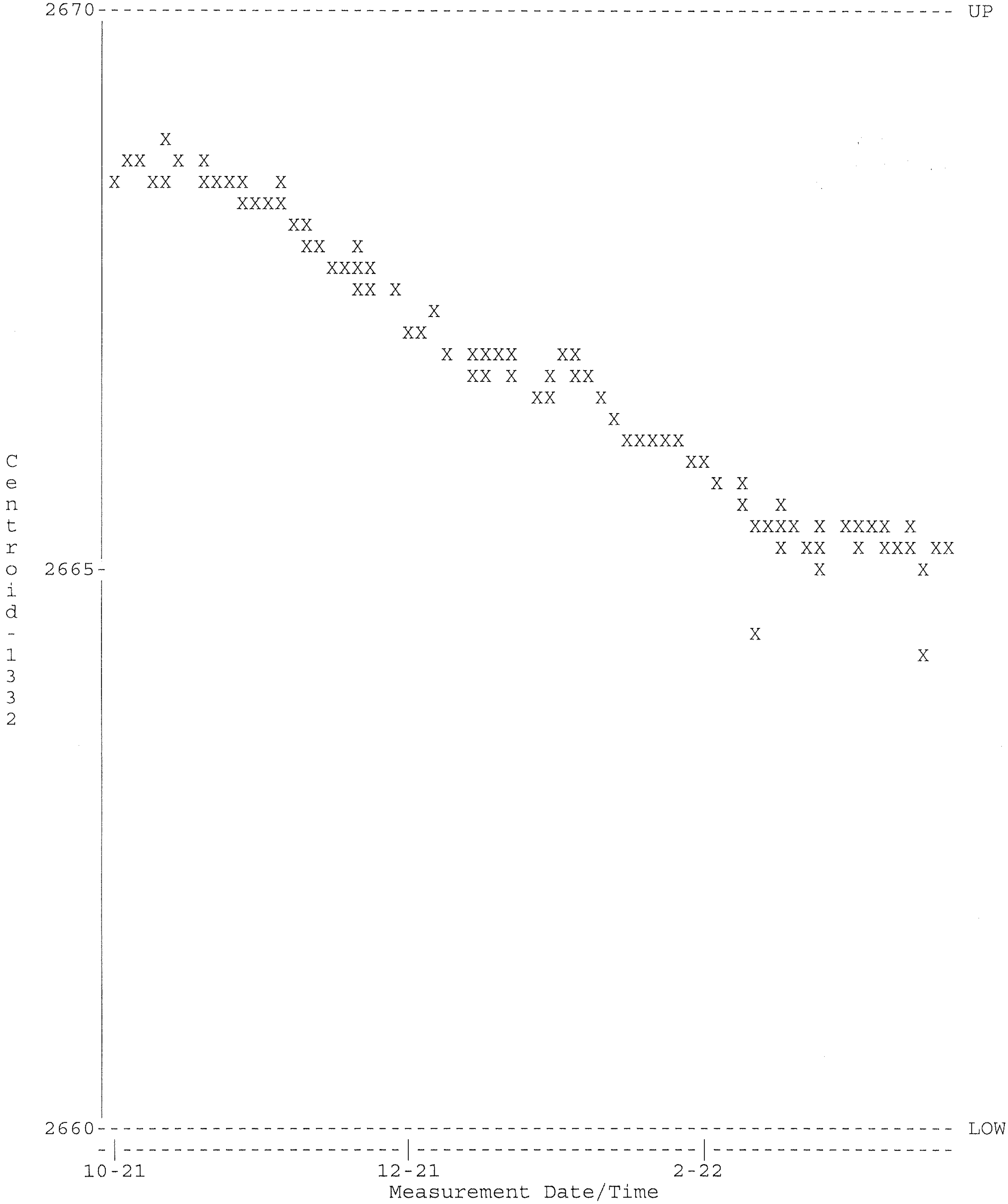
QA filename         : DKB100:[GAMMA.QUALITY]NEW_TBE01_QC.QAF;1
Parameter Name      : PSCENTRD-59 (Centroid-59)
Start/End Dates     : 1-OCT-2021 08:41 through 23-MAR-2022 00:00
Lower/Upper Lmts: 118.500 through 120.500
   120.5-
        |------------------------------------------------------------------ UP
        |
        |
     120-
        |
        |                                     X
C       |     X                           XXX X
e       |XXXXXX X           X      X  X X  X   X                       X
n       |  X    XX X X     XXX    X  X XX       X                 X  X   XX
t       |  X  X XXXXXXX  X  XX   X X X    X   X X XXX X   XX    X  XXXX X
r 119.5-|          X  X   X    XX  X XX          X  XX X       X XX    XX
o       |               X XX                      X XX  X XXXXX X
i       |              XXX X    X                      XX X
d       |                 X     X
-       |
5       |
9       |
     119-
        |
        |
   118.5------------------------------------------------------------------- LOW
        -|----------------------|----------------------|-------------------
       10-21                  12-21                   2-22
                        Measurement Date/Time
```

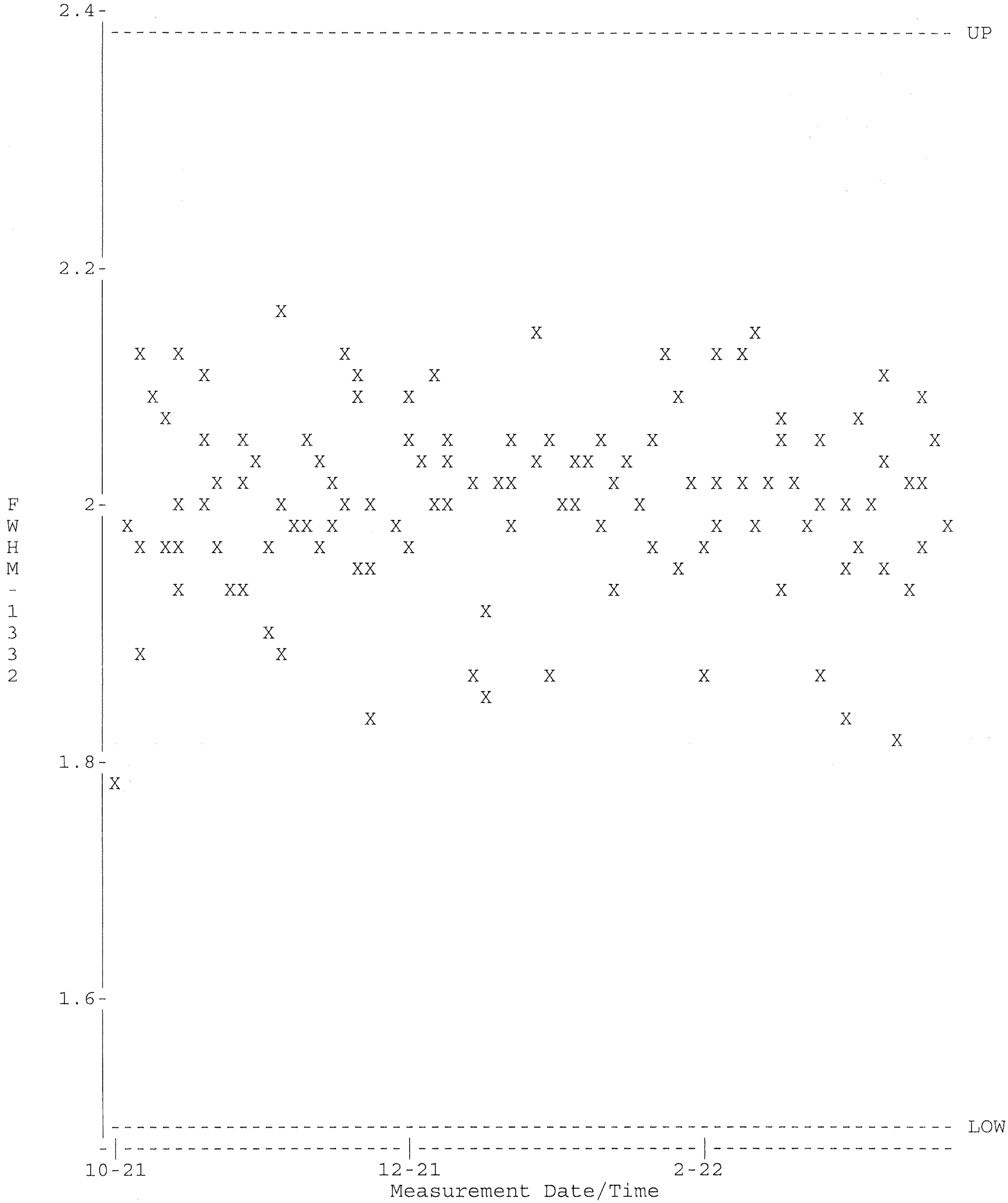
QA filename   : DKB100:[GAMMA.QUALITY]TBE02_BKG_QC.QAF;1
Parameter Name   : BACKRATE (Background Rate)
Start/End Dates   : 1-OCT-2021 08:41 through 23-MAR-2022 00:00
Lower/Upper Lmts: 0.000000E+00 through 3.50000



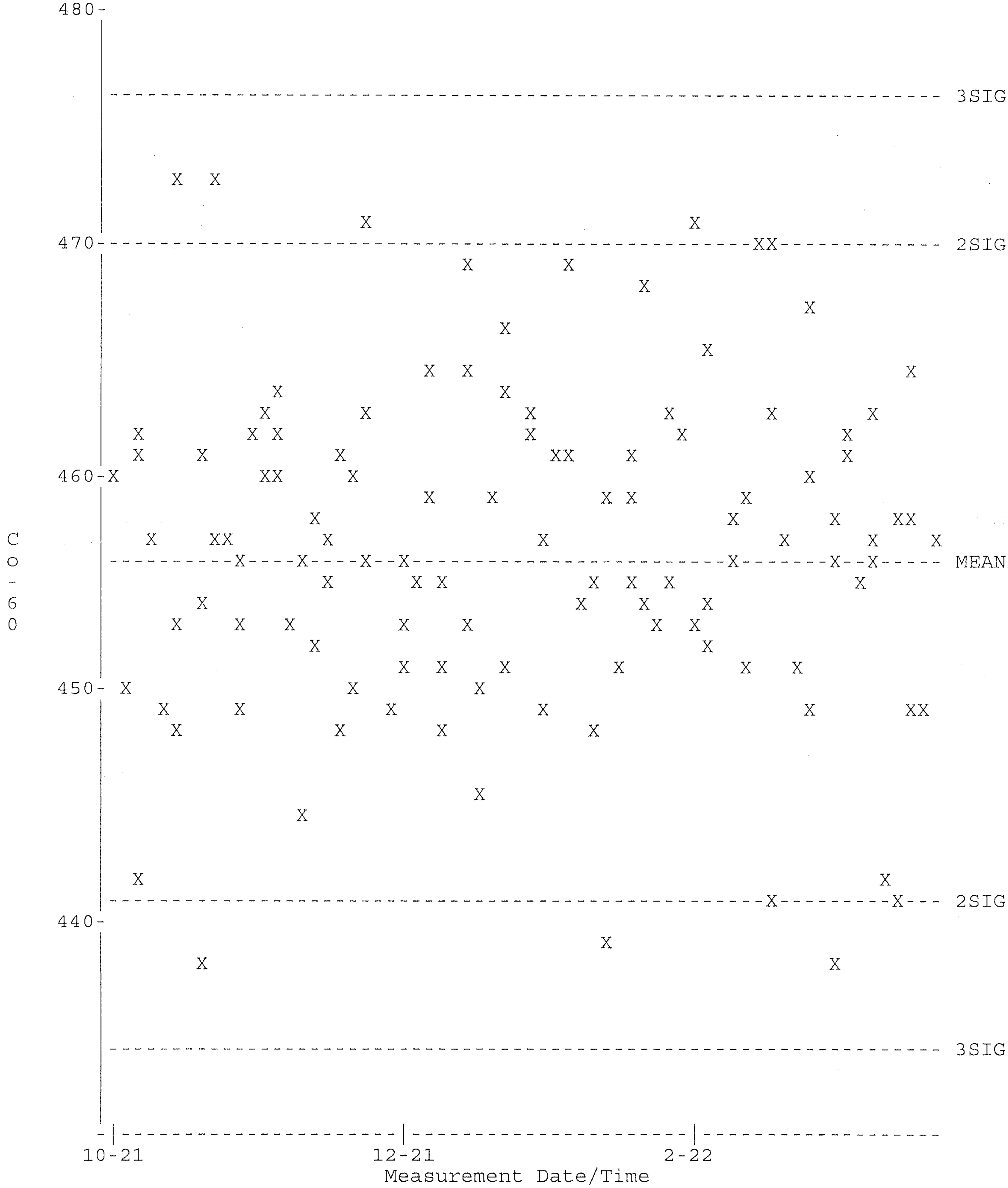
QA filename   : DKB100:[GAMMA.QUALITY]NEW_TBE02_QC.QAF;1
Parameter Name   : PSCENTRD (Centroid-1332)
Start/End Dates   : 1-OCT-2021 08:57 through 23-MAR-2022 00:00
Lower/Upper Lmts: 2660.00 through 2670.00



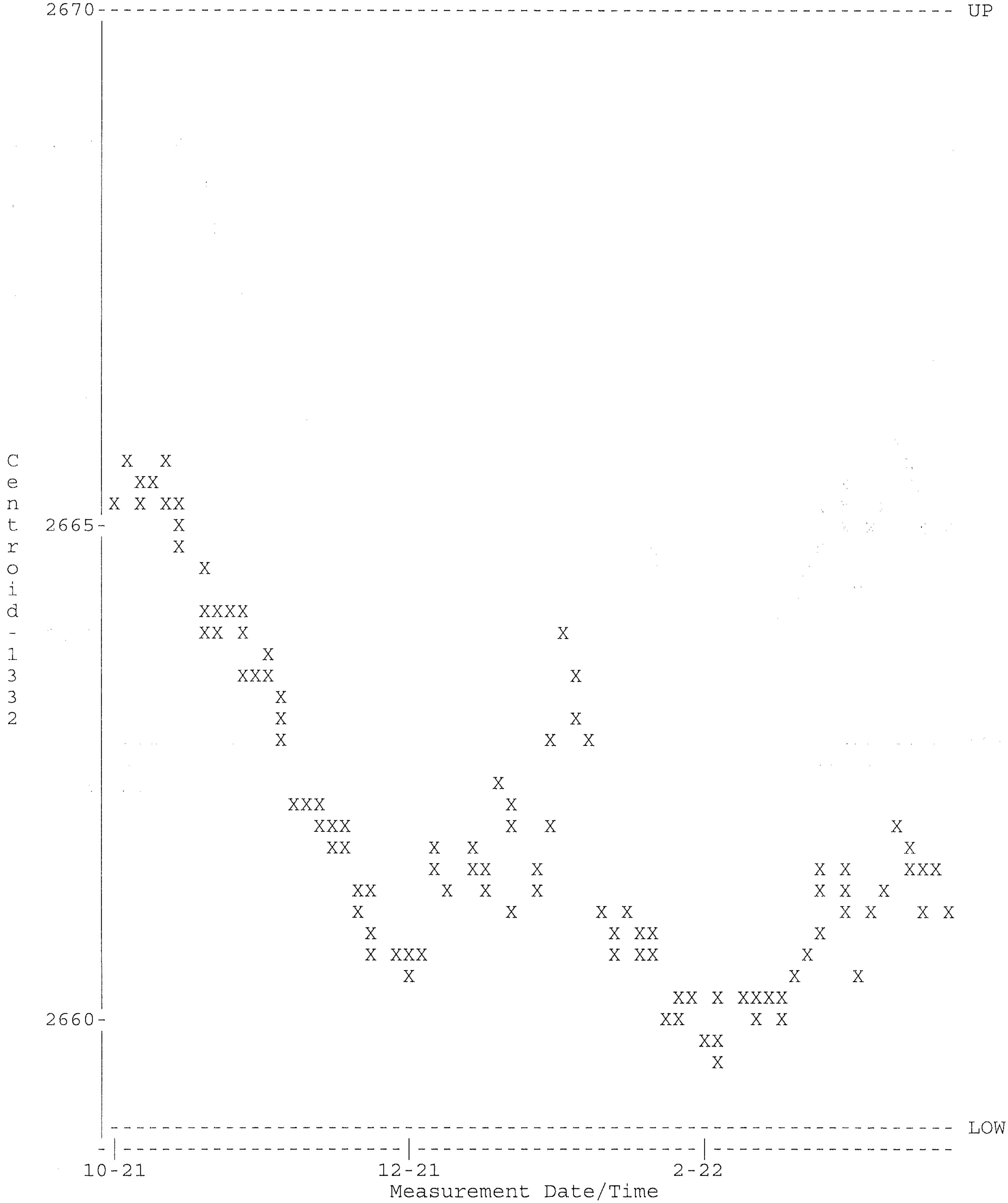
QA filename   : DKB100:[GAMMA.QUALITY]NEW_TBE02_QC.QAF;1
Parameter Name   : PSFWHM-1332 (FWHM-1332)
Start/End Dates   : 1-OCT-2021 08:57 through 23-MAR-2022 00:00
Lower/Upper Lmts: 1.50000 through 2.40000



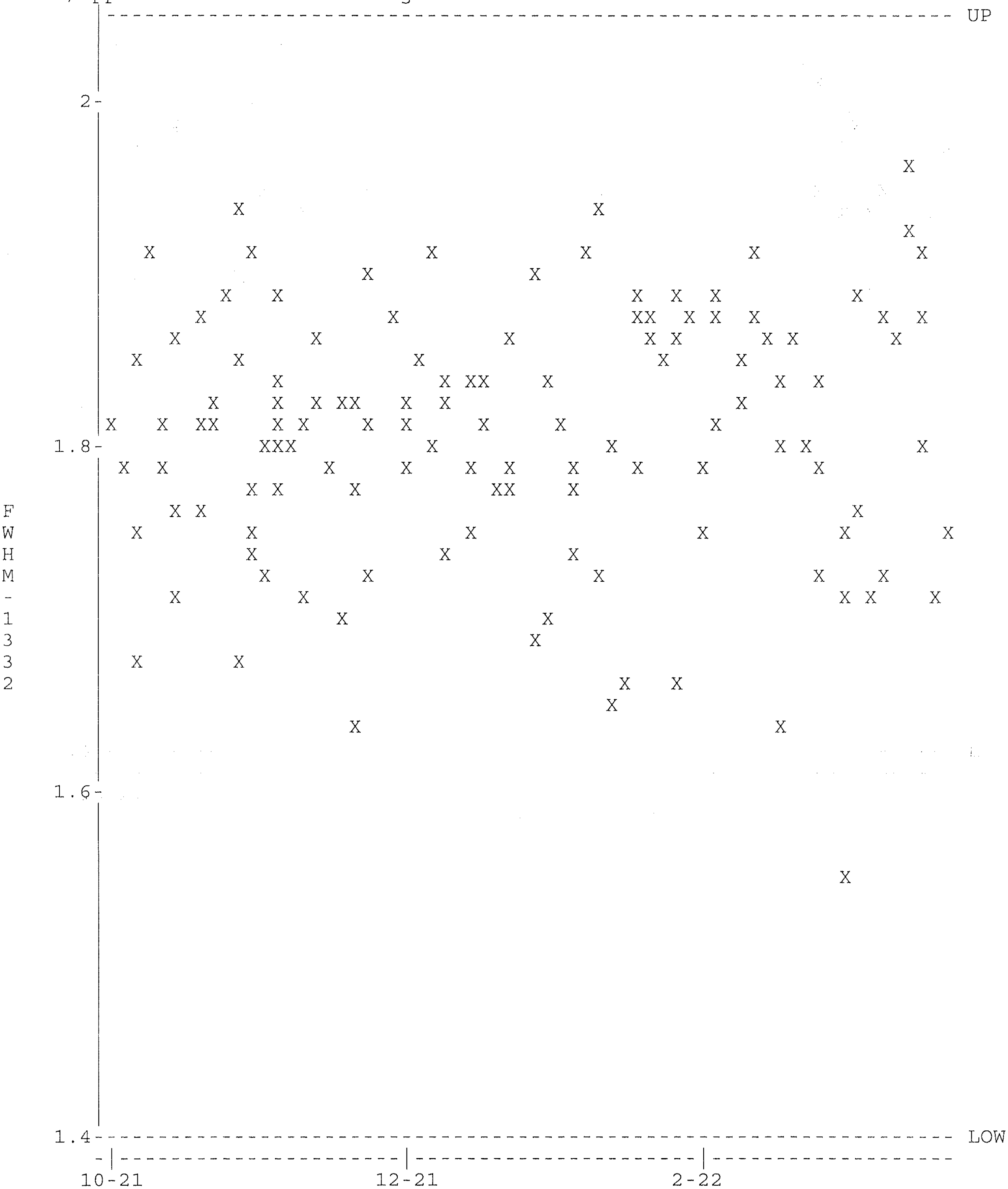
QA filename : DKB100:[GAMMA.QUALITY]NEW_TBE02_QC.QAF;1
Parameter Name : NCLWTMEAN-CO60 (Co-60)
Start/End Dates : 1-OCT-2021 08:57 through 23-MAR-2022 00:00
Mean +- Std Dev : 455.948 +- 7.03561 (1.54 %)



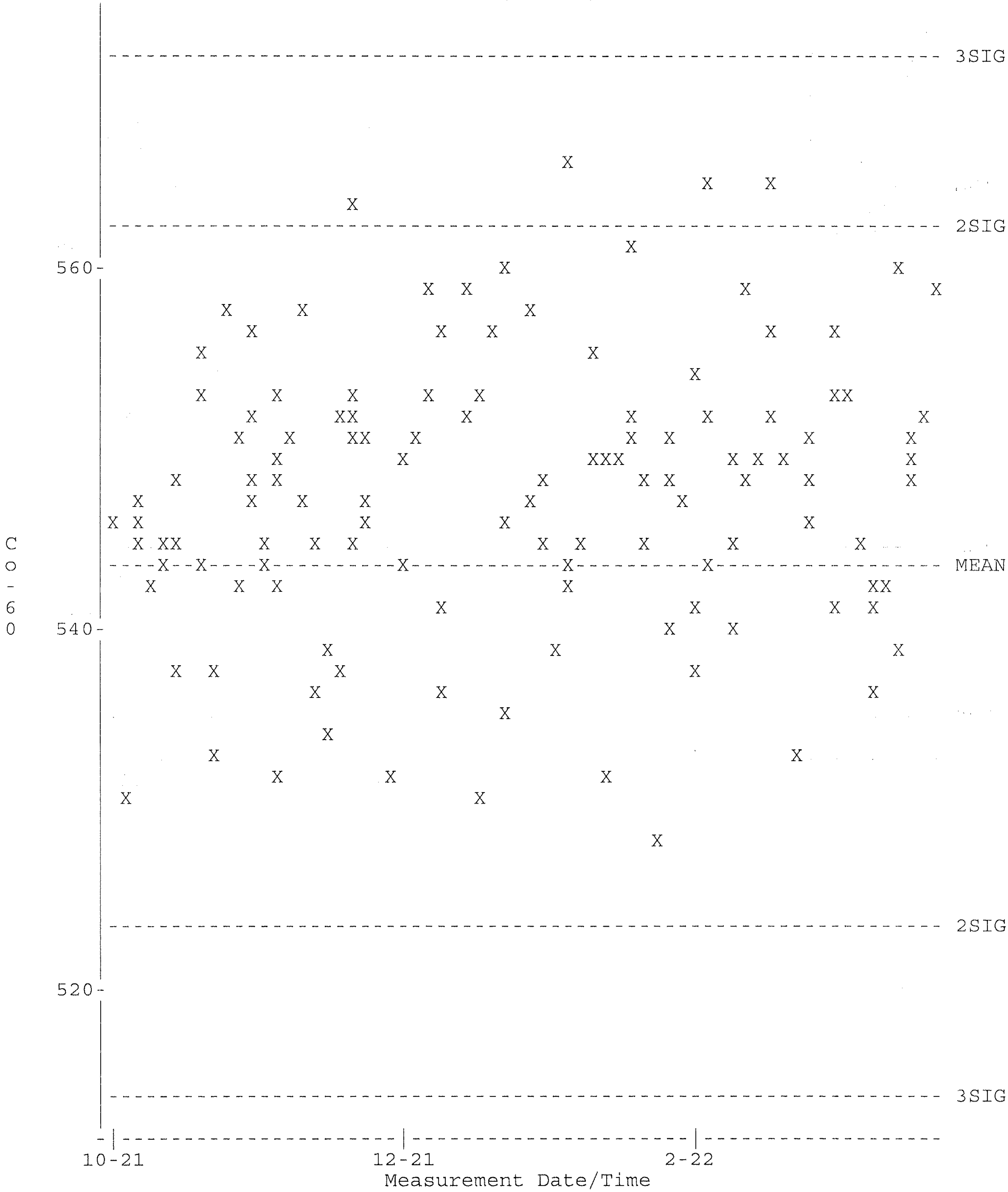
```
QA filename        : DKB100:[GAMMA.QUALITY]NEW_TBE06_QC.QAF;1
Parameter Name     : PSCENTRD (Centroid-1332)
Start/End Dates    : 1-OCT-2021 08:57 through 23-MAR-2022 00:00
Lower/Upper Lmts: 2659.00 through 2670.00
```



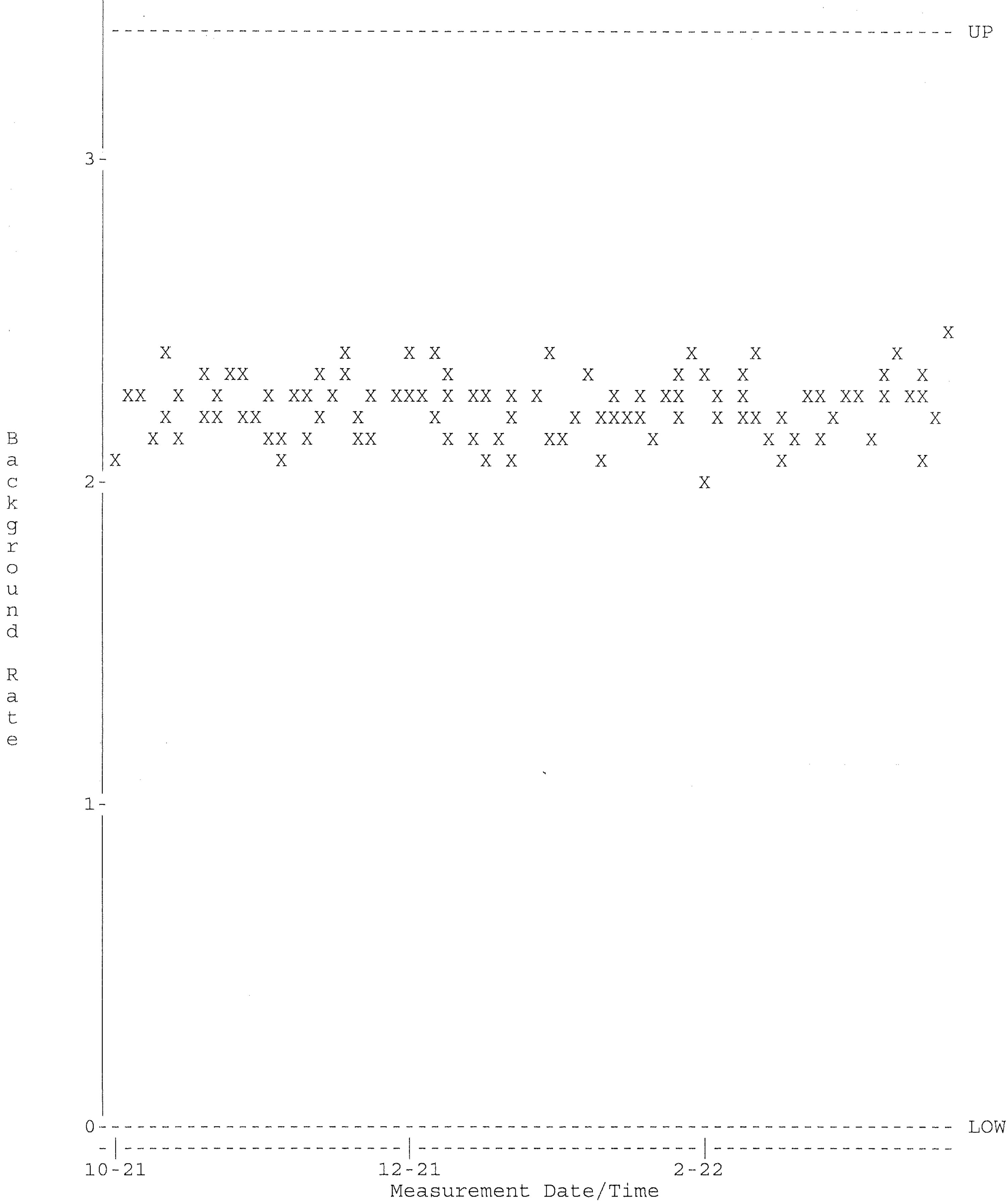
QA filename : DKB100:[GAMMA.QUALITY]NEW_TBE06_QC.QAF;1
Parameter Name : PSFWHM-1332 (FWHM-1332)
Start/End Dates : 1-OCT-2021 08:57 through 23-MAR-2022 00:00
Lower/Upper Lmts: 1.40000 through 2.05000



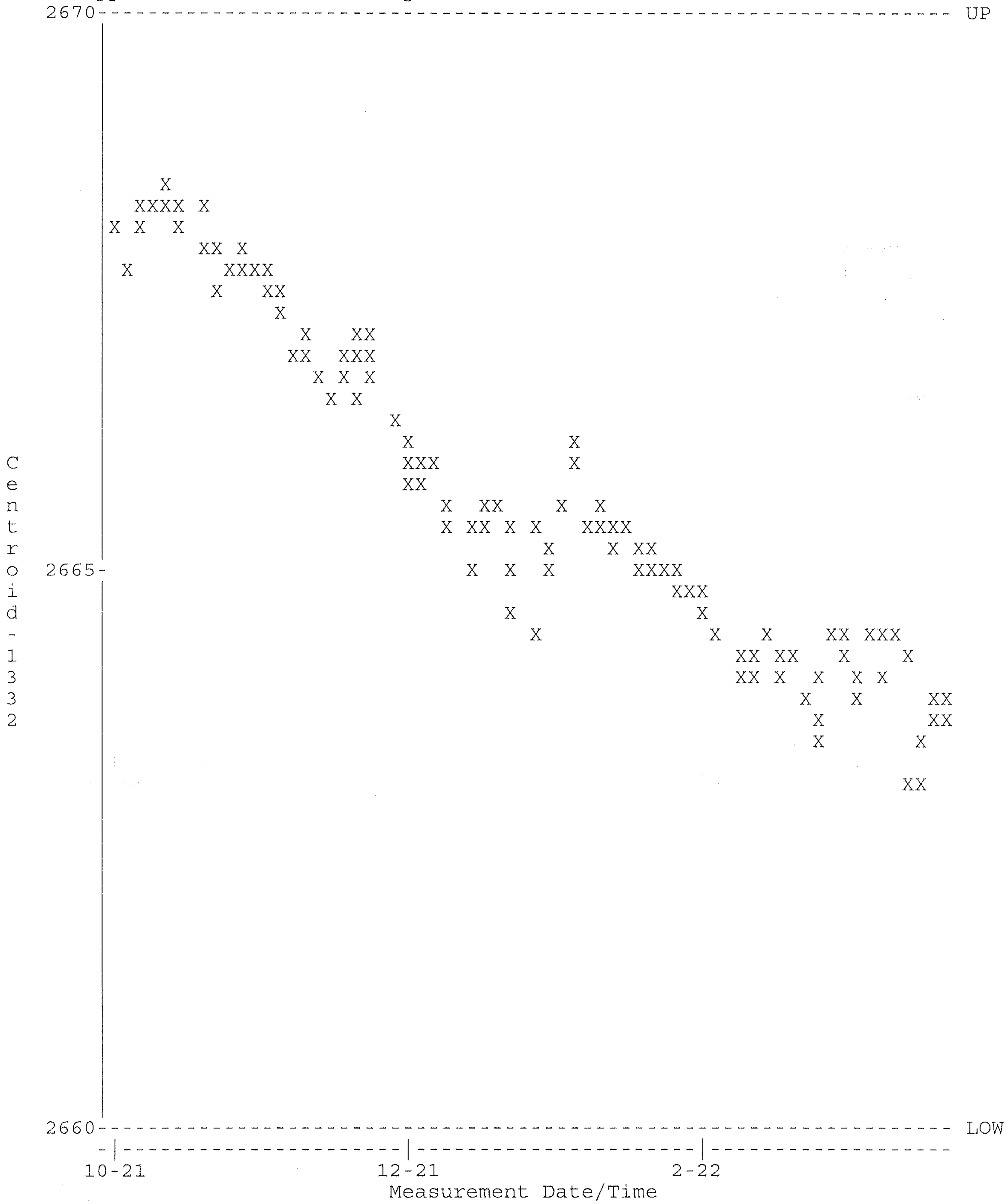
QA filename : DKB100:[GAMMA.QUALITY]NEW_TBE06_QC.QAF;1
Parameter Name : NCLWTMEAN-CO60 (Co-60)
Start/End Dates : 1-OCT-2021 08:57 through 23-MAR-2022 00:00
Mean +- Std Dev : 543.576 +- 9.55063 (1.76 %)



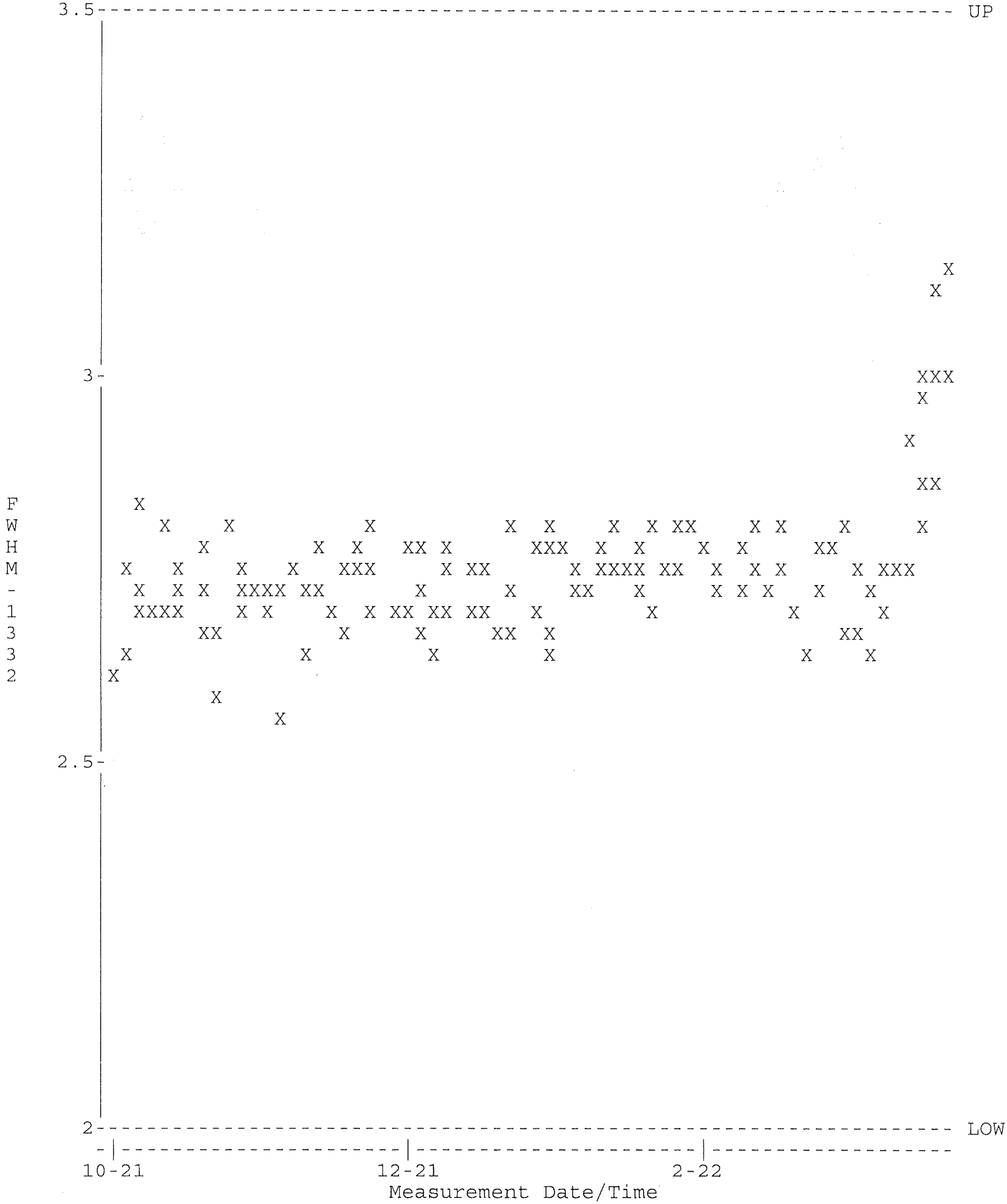
QA filename : DKB100:[GAMMA.QUALITY]TBE06_BKG_QC.QAF;1
Parameter Name : BACKRATE (Background Rate)
Start/End Dates : 1-OCT-2021 08:41 through 23-MAR-2022 00:00
Lower/Upper Lmts: 0.000000E+00 through 3.50000



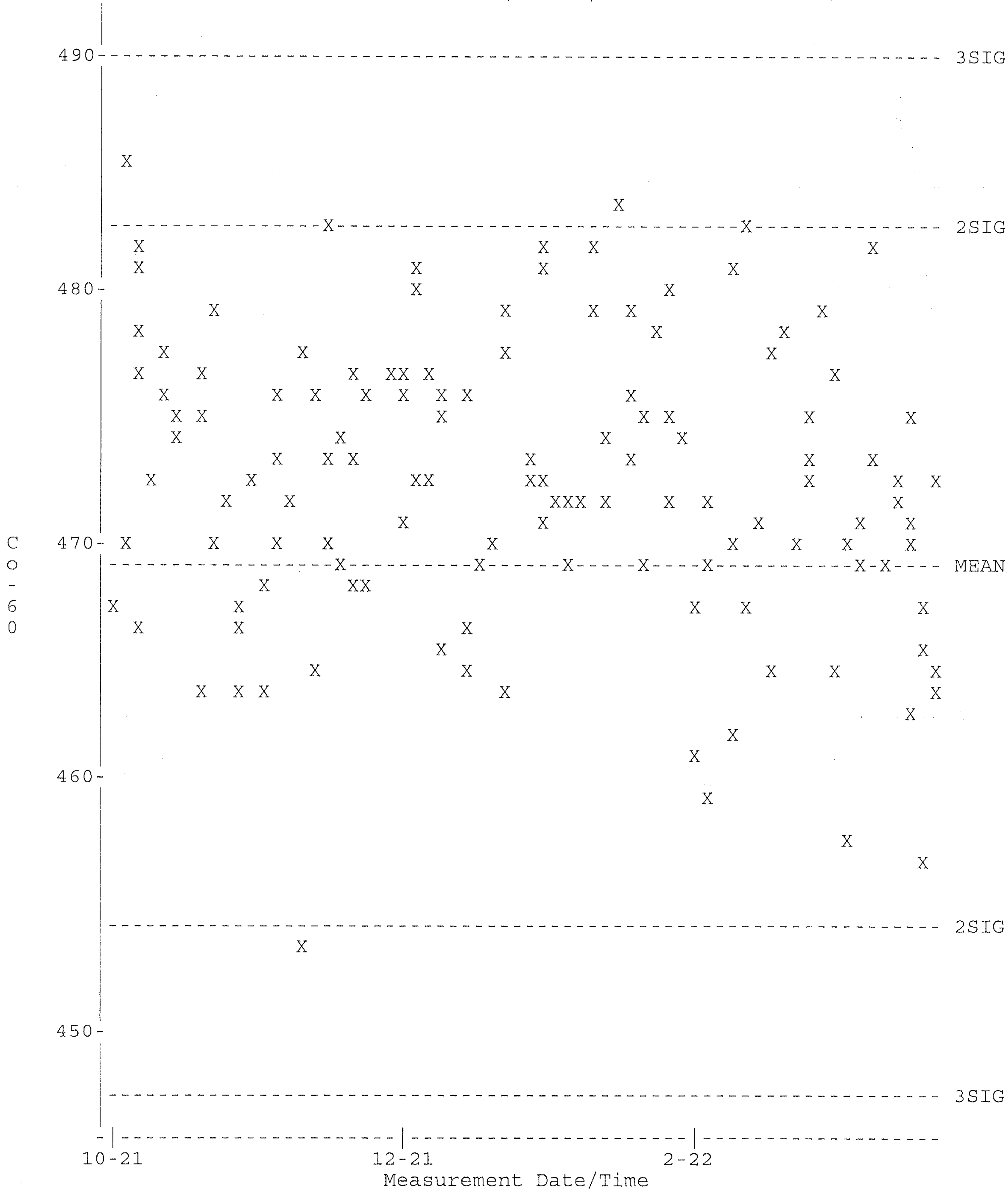
QA filename : DKB100:[GAMMA.QUALITY]NEW_TBE07_QC.QAF;1
Parameter Name : PSCENTRD (Centroid-1332)
Start/End Dates : 1-OCT-2021 08:41 through 23-MAR-2022 00:00
Lower/Upper Lmts: 2660.00 through 2670.00



QA filename : DKB100:[GAMMA.QUALITY]NEW_TBE07_QC.QAF;1
Parameter Name : PSFWHM-1332 (FWHM-1332)
Start/End Dates : 1-OCT-2021 08:41 through 23-MAR-2022 00:00
Lower/Upper Lmts: 2.00000 through 3.50000



QA filename : DKB100:[GAMMA.QUALITY]NEW_TBE07_QC.QAF;1
Parameter Name : NCLWTMEAN-CO60 (Co-60)
Start/End Dates : 1-OCT-2021 08:41 through 23-MAR-2022 00:00
Mean +- Std Dev : 468.955 +- 7.11591 (1.52 %)



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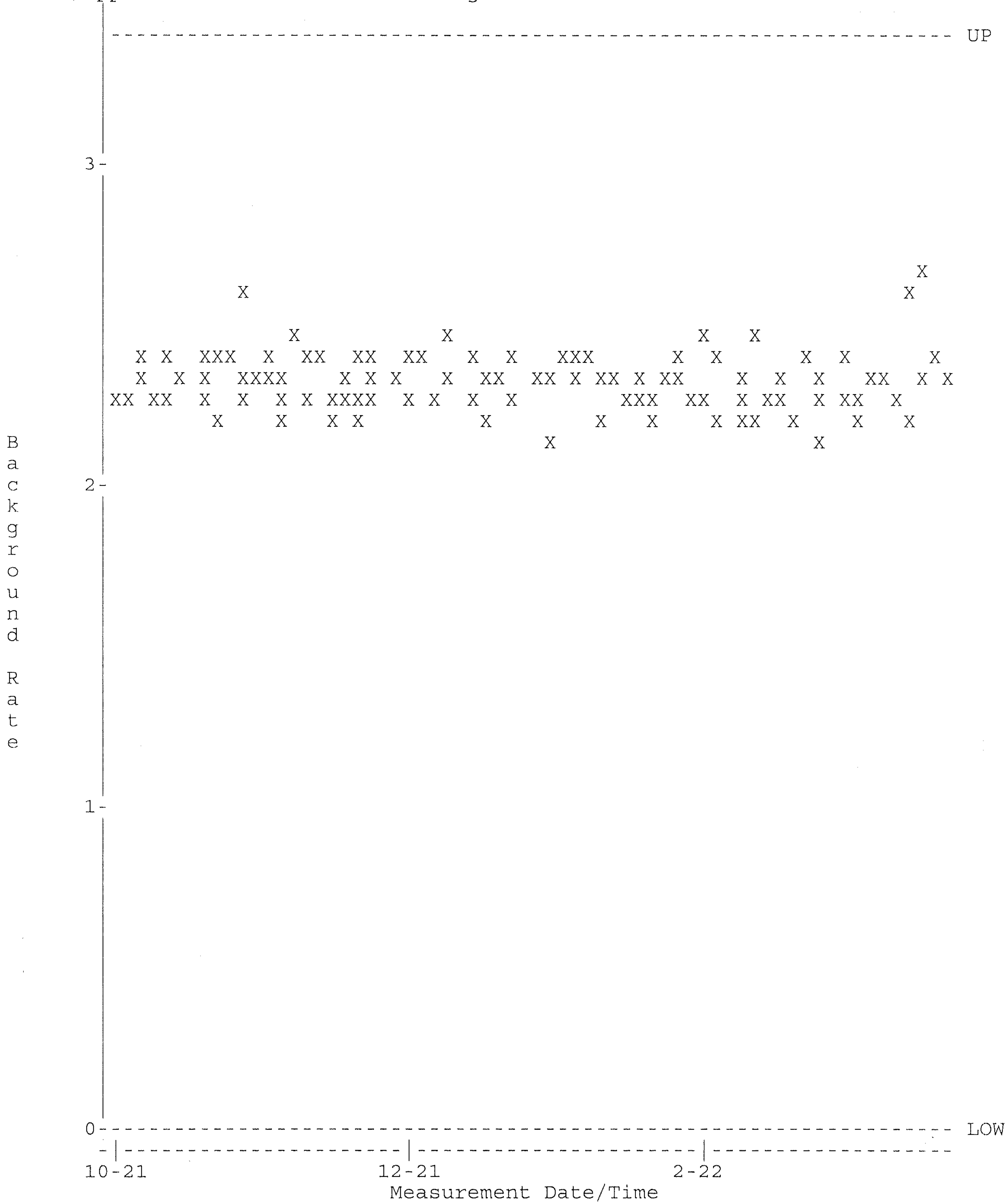
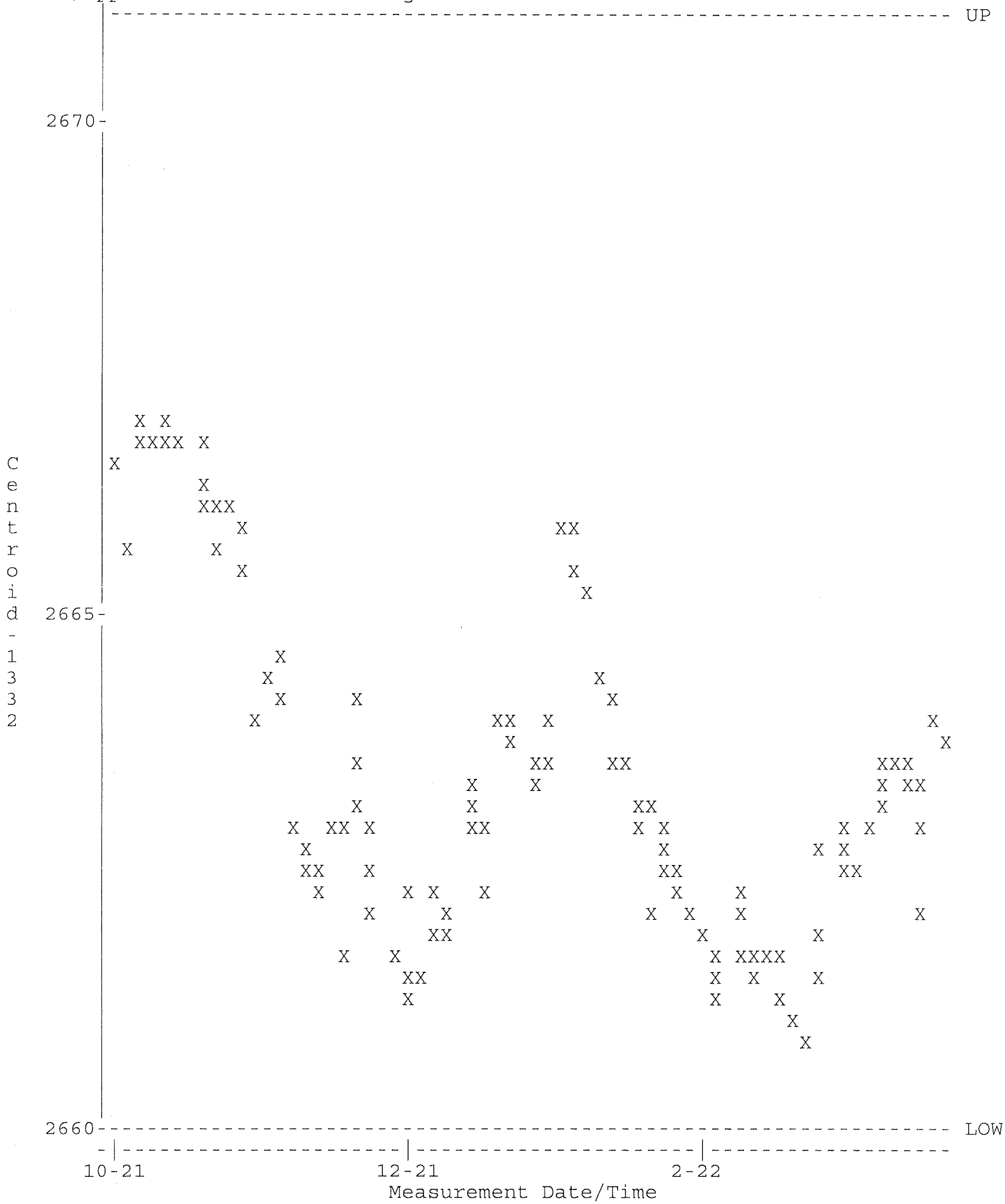
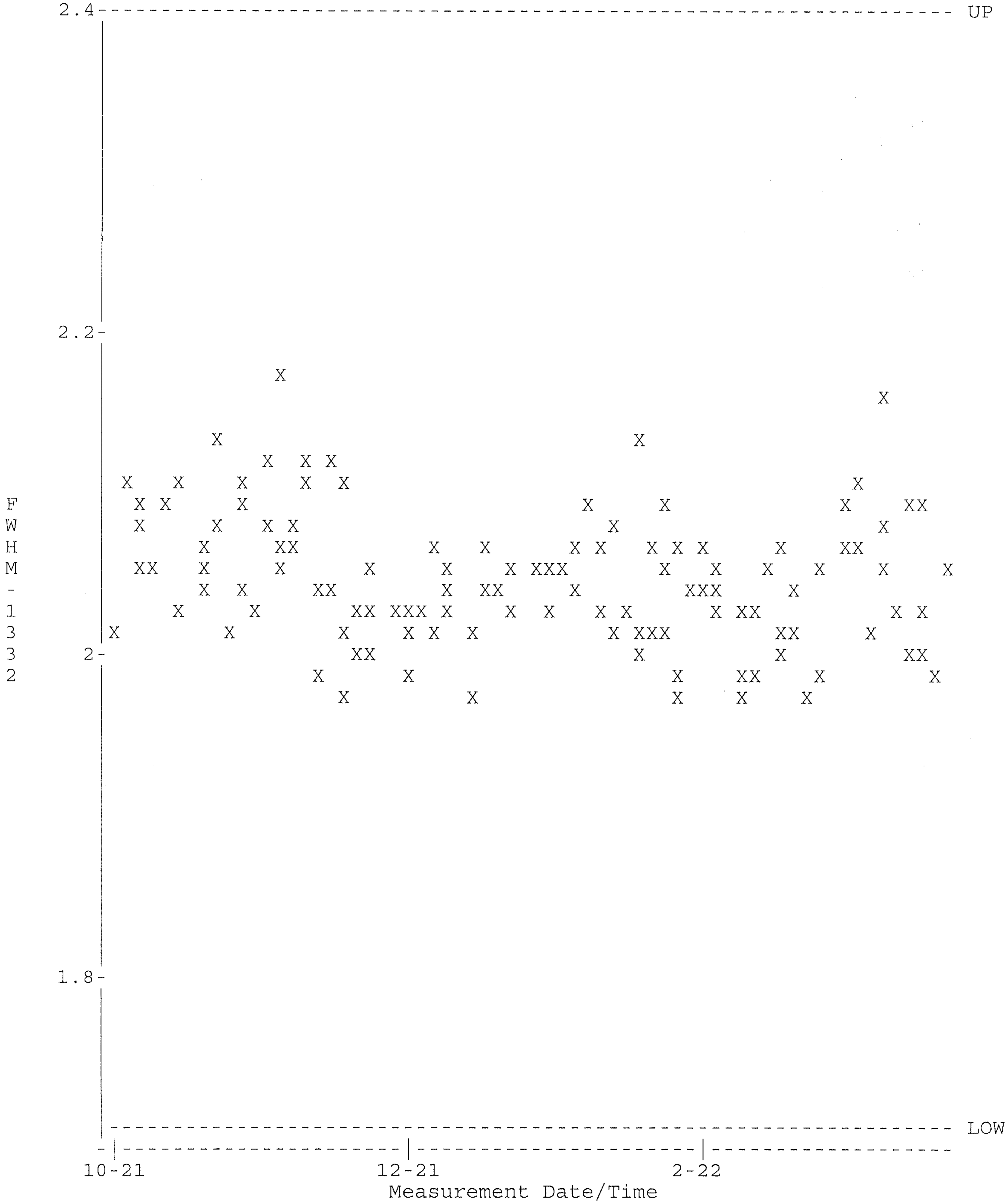
QA filename        : DKB100:[GAMMA.QUALITY]TBE07_BKG_QC.QAF;1
Parameter Name     : BACKRATE (Background Rate)
Start/End Dates    : 1-OCT-2021 08:57 through 23-MAR-2022 00:00
Lower/Upper Lmts: 0.000000E+00 through 3.50000
```



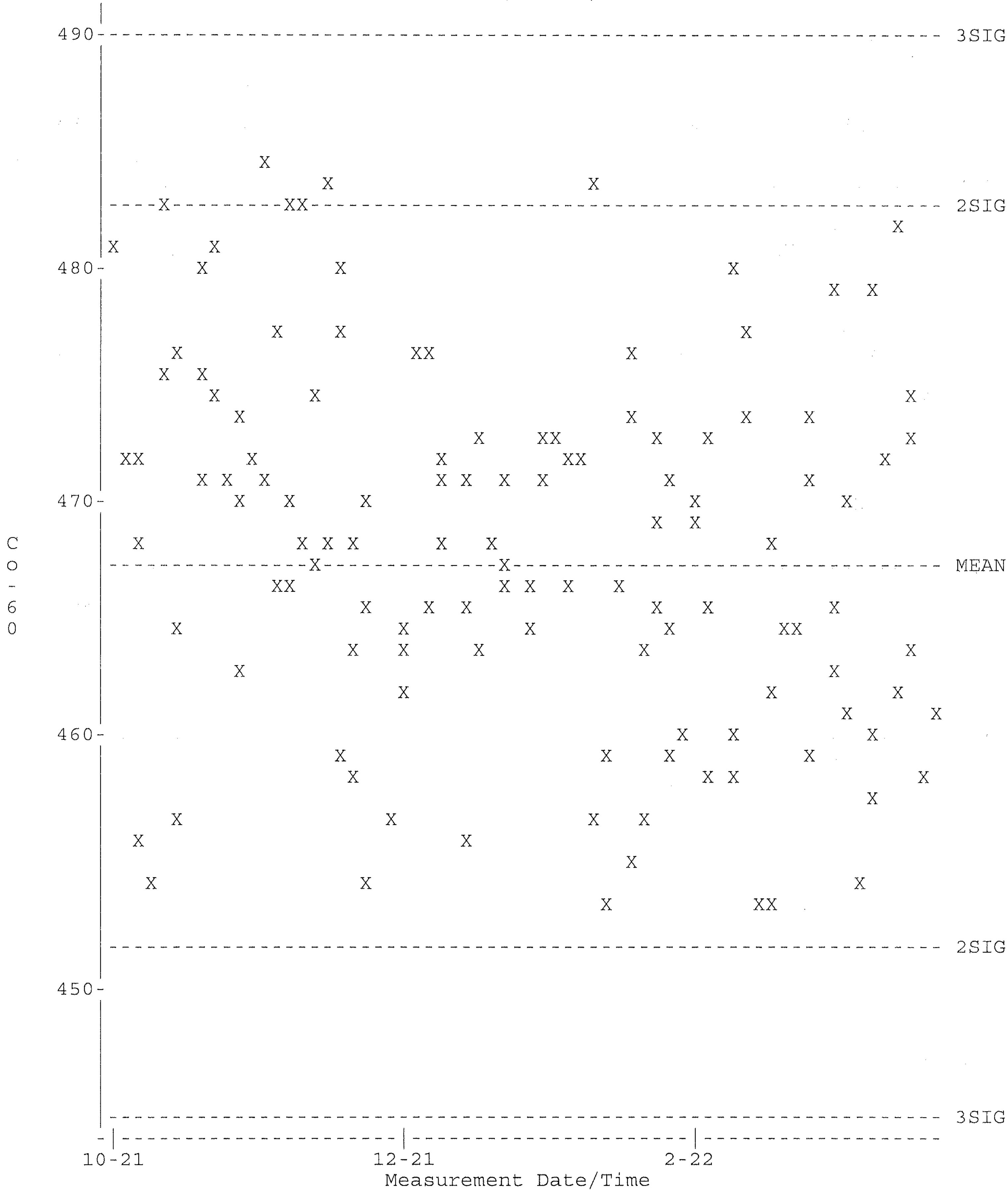
QA filename : DKB100:[GAMMA.QUALITY]NEW_TBE08_QC.QAF;1
Parameter Name : PSCENTRD (Centroid-1332)
Start/End Dates : 1-OCT-2021 08:57 through 23-MAR-2022 00:00
Lower/Upper Lmts: 2660.00 through 2671.00



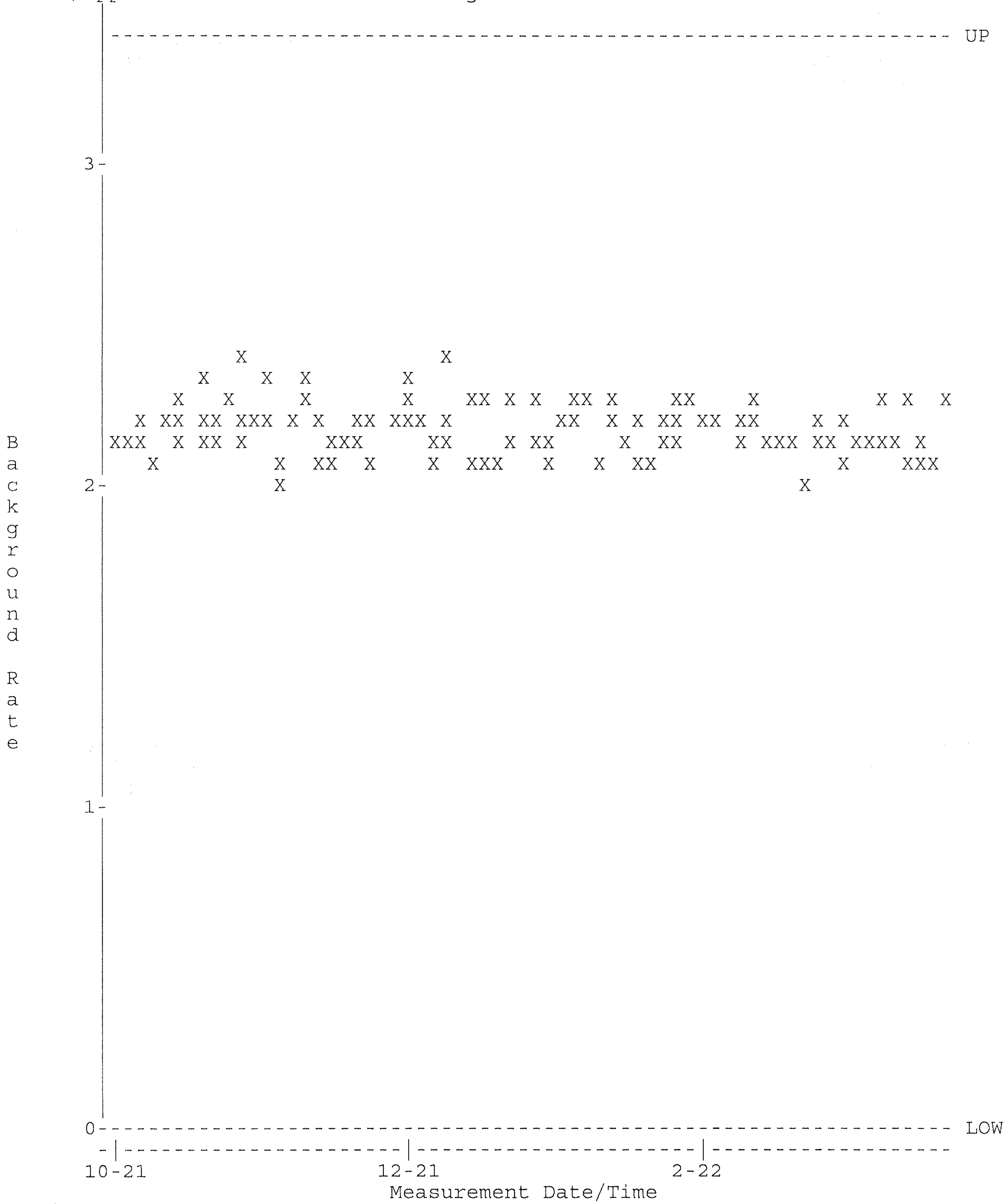
QA filename : DKB100:[GAMMA.QUALITY]NEW_TBE08_QC.QAF;1
Parameter Name : PSFWHM-1332 (FWHM-1332)
Start/End Dates : 1-OCT-2021 08:57 through 23-MAR-2022 00:00
Lower/Upper Lmts: 1.70000 through 2.40000



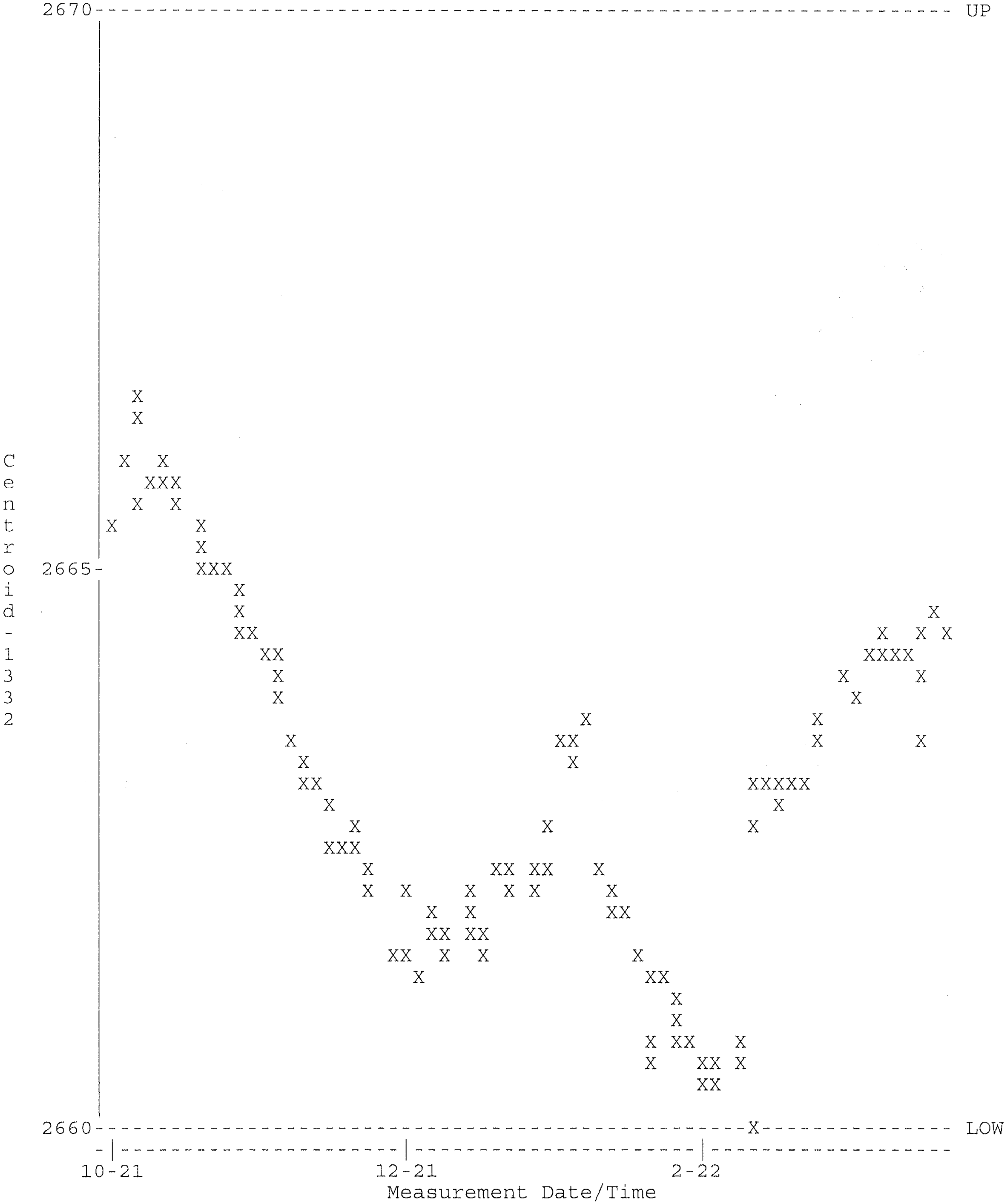
QA filename : DKB100:[GAMMA.QUALITY]NEW_TBE08_QC.QAF;1
Parameter Name : NCLWTMEAN-CO60 (Co-60)
Start/End Dates : 1-OCT-2021 08:57 through 23-MAR-2022 00:00
Mean +- Std Dev : 467.622 +- 7.71396 (1.65 %)



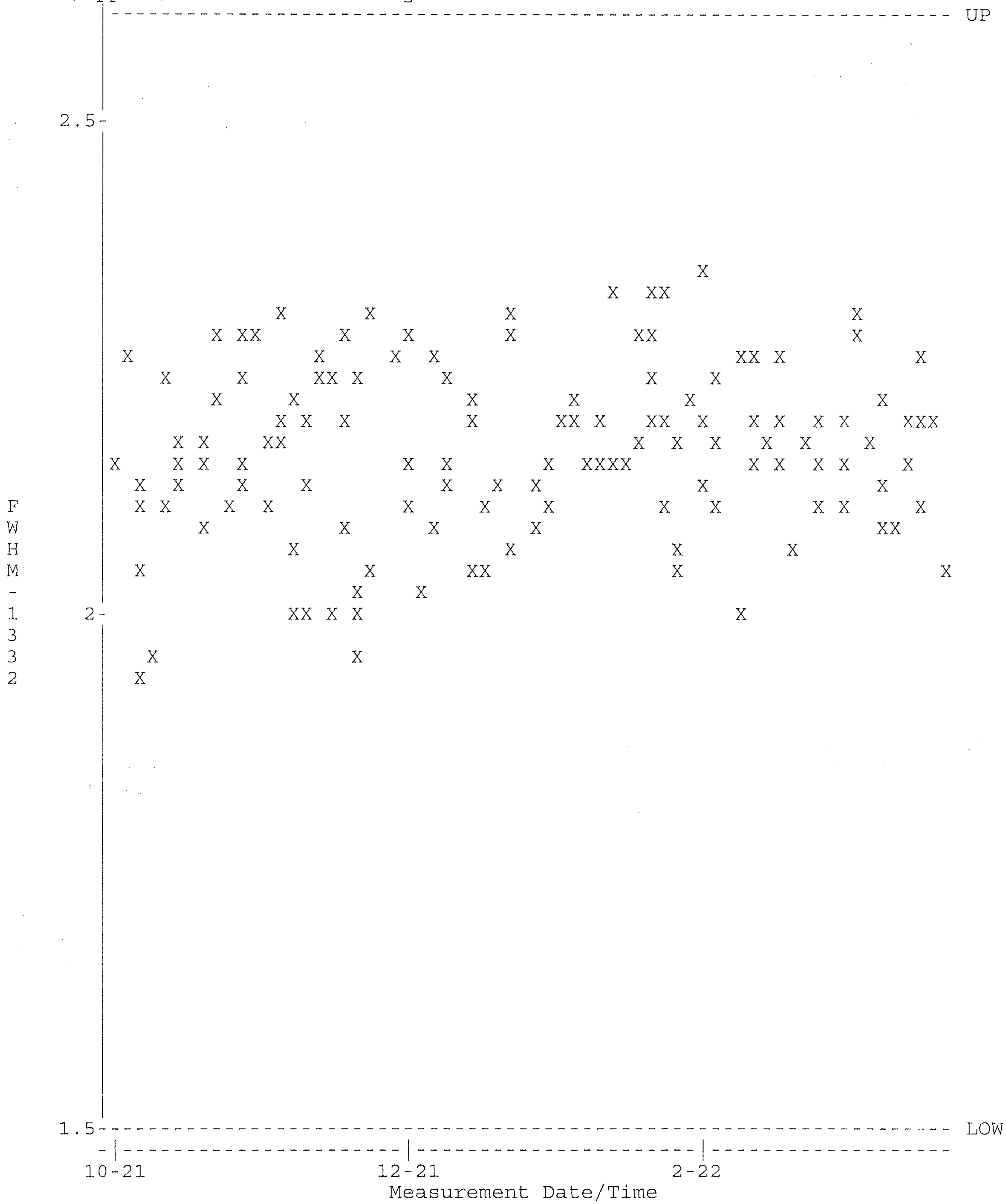
QA filename : DKB100:[GAMMA.QUALITY]TBE08_BKG_QC.QAF;1
Parameter Name : BACKRATE (Background Rate)
Start/End Dates : 1-OCT-2021 08:41 through 23-MAR-2022 00:00
Lower/Upper Lmts: 0.000000E+00 through 3.50000



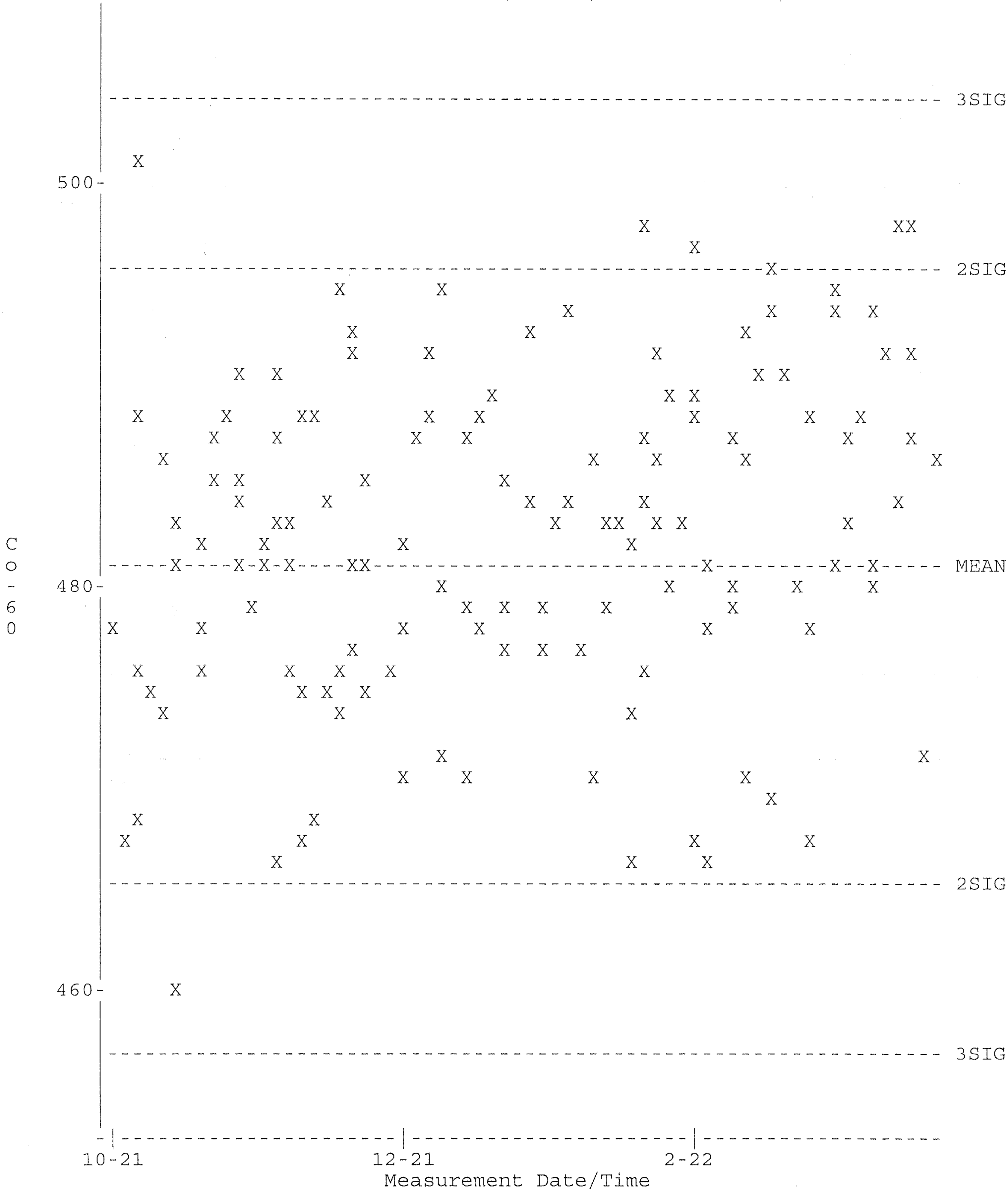
QA filename   : DKB100:[GAMMA.QUALITY]NEW_TBE11_QC.QAF;1
Parameter Name   : PSCENTRD (Centroid-1332)
Start/End Dates   : 1-OCT-2021 08:57 through 23-MAR-2022 00:00
Lower/Upper Lmts: 2660.00 through 2670.00



QA filename : DKB100:[GAMMA.QUALITY]NEW_TBE11_QC.QAF;1
Parameter Name : PSFWHM-1332 (FWHM-1332)
Start/End Dates : 1-OCT-2021 08:57 through 23-MAR-2022 00:00
Lower/Upper Lmts: 1.50000 through 2.60000



QA filename : DKB100:[GAMMA.QUALITY]NEW_TBE11_QC.QAF;1
Parameter Name : NCLWTMEAN-CO60 (Co-60)
Start/End Dates : 1-OCT-2021 08:57 through 23-MAR-2022 00:00
Mean +- Std Dev : 480.605 +- 7.84103 (1.63 %)



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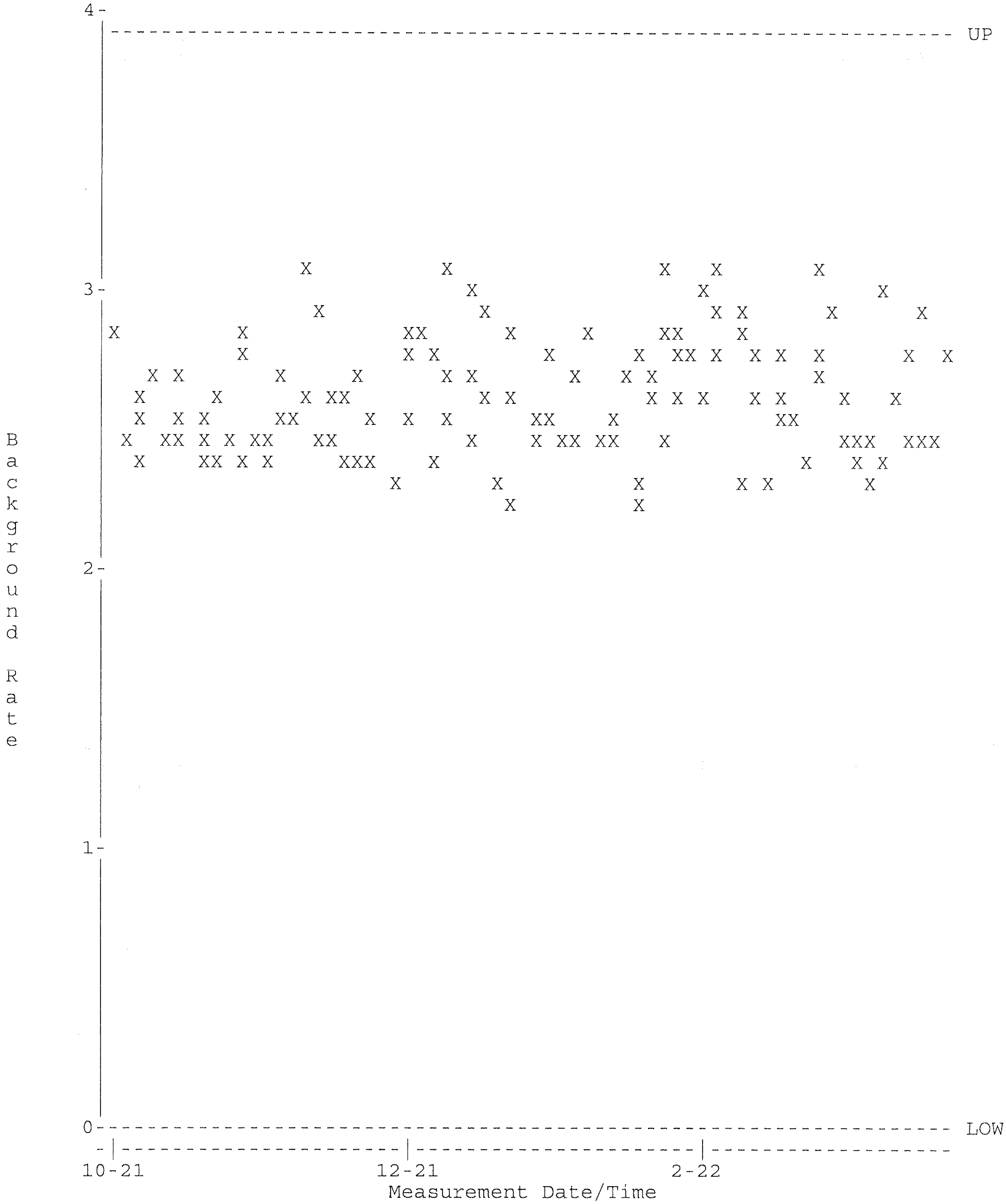
QA filename         : DKB100:[GAMMA.QUALITY]TBE11_BKG_QC.QAF;1
Parameter Name      : BACKRATE (Background Rate)
Start/End Dates     : 1-OCT-2021 08:41 through 23-MAR-2022 00:00
Lower/Upper Lmts: 0.000000E+00 through 4.00000
```



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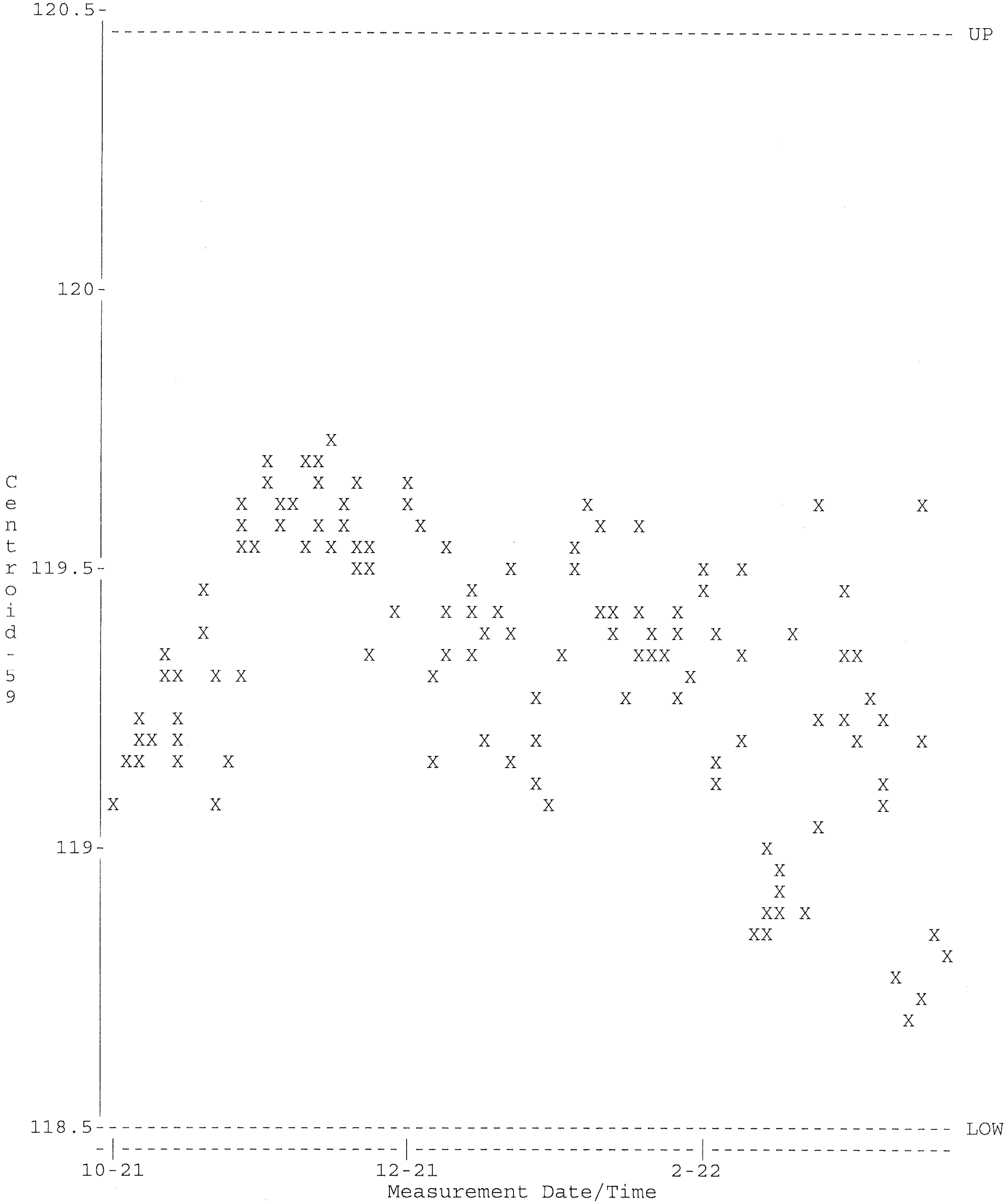
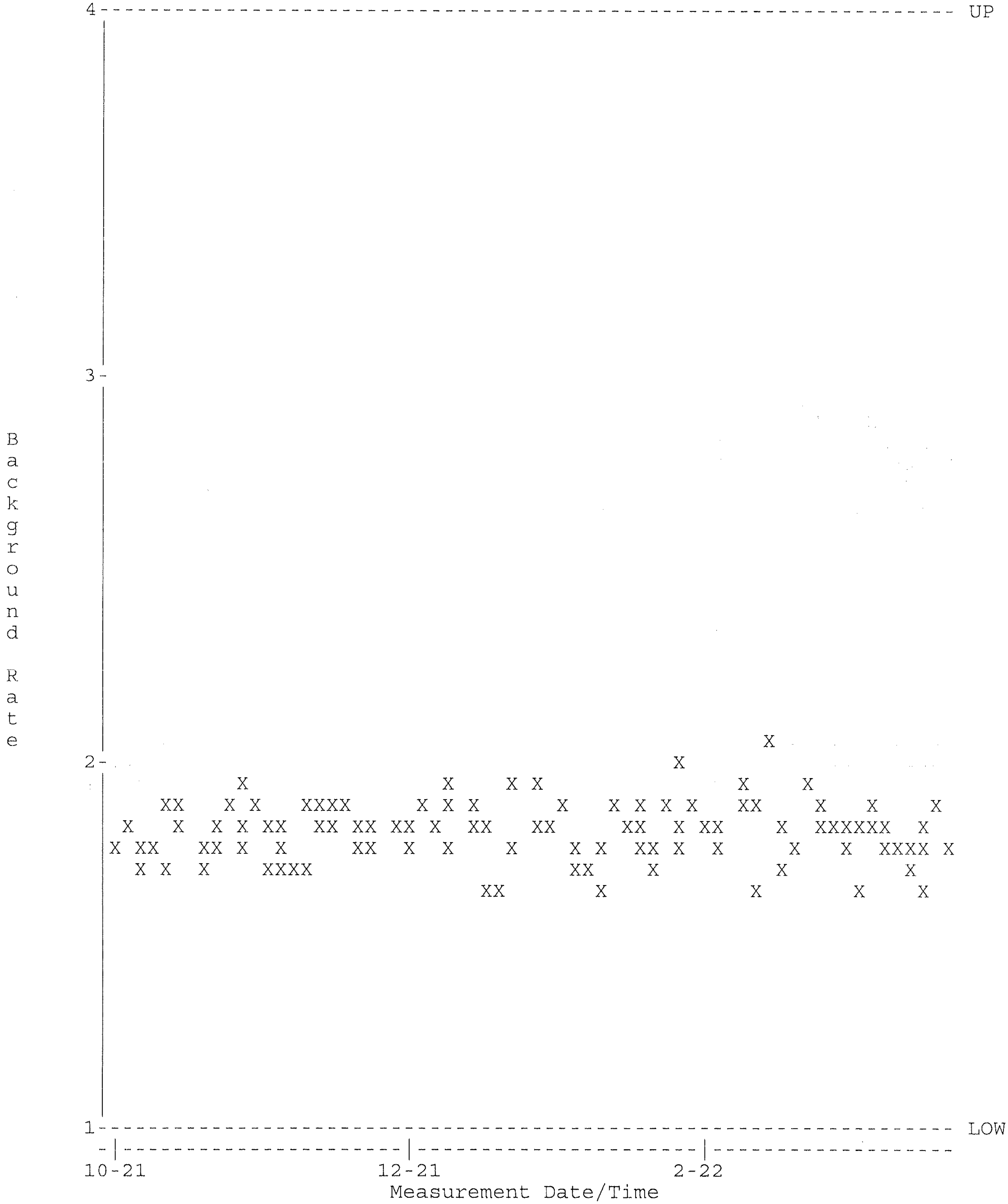
QA filename       : DKB100:[GAMMA.QUALITY]NEW_TBE11_QC.QAF;1
Parameter Name    : PSCENTRD-59 (Centroid-59)
Start/End Dates   : 1-OCT-2021 08:57 through 23-MAR-2022 00:00
Lower/Upper Lmts: 117.000 through 121.000
    121-
       |------------------------------------------------------------------ UP
       |
       |
       |
       |
       |
       |
       |
       |
       |
       |
       |
    120-
       |
       |
       |
       |
       |
       |
       |
       |
C      |
e      |
n      |
t      |
r   119-
o      |
i      |
d      |
-      |
5      |
9      |
       |
       |
       |
       |
       |
       |  X
    118-XXXXXX XX X
       |     X XXXXX X
       |       X  X XXX                                             X
       |            X XXXXXXX             XXXX              XX X X XX  XXX
       |                  XXX XX XX X XX X    X X         X X XX  X  XXX
       |                       XX   XX X      XX XXXX  X  XX
       |                                          XXXXXX X
       |                                              X  XX
       |
       |
       |
       |
       |
    117------------------------------------------------------------------- LOW
       -|----------------------|----------------------|-------------------
      10-21                  12-21                  2-22
                              Measurement Date/Time
```

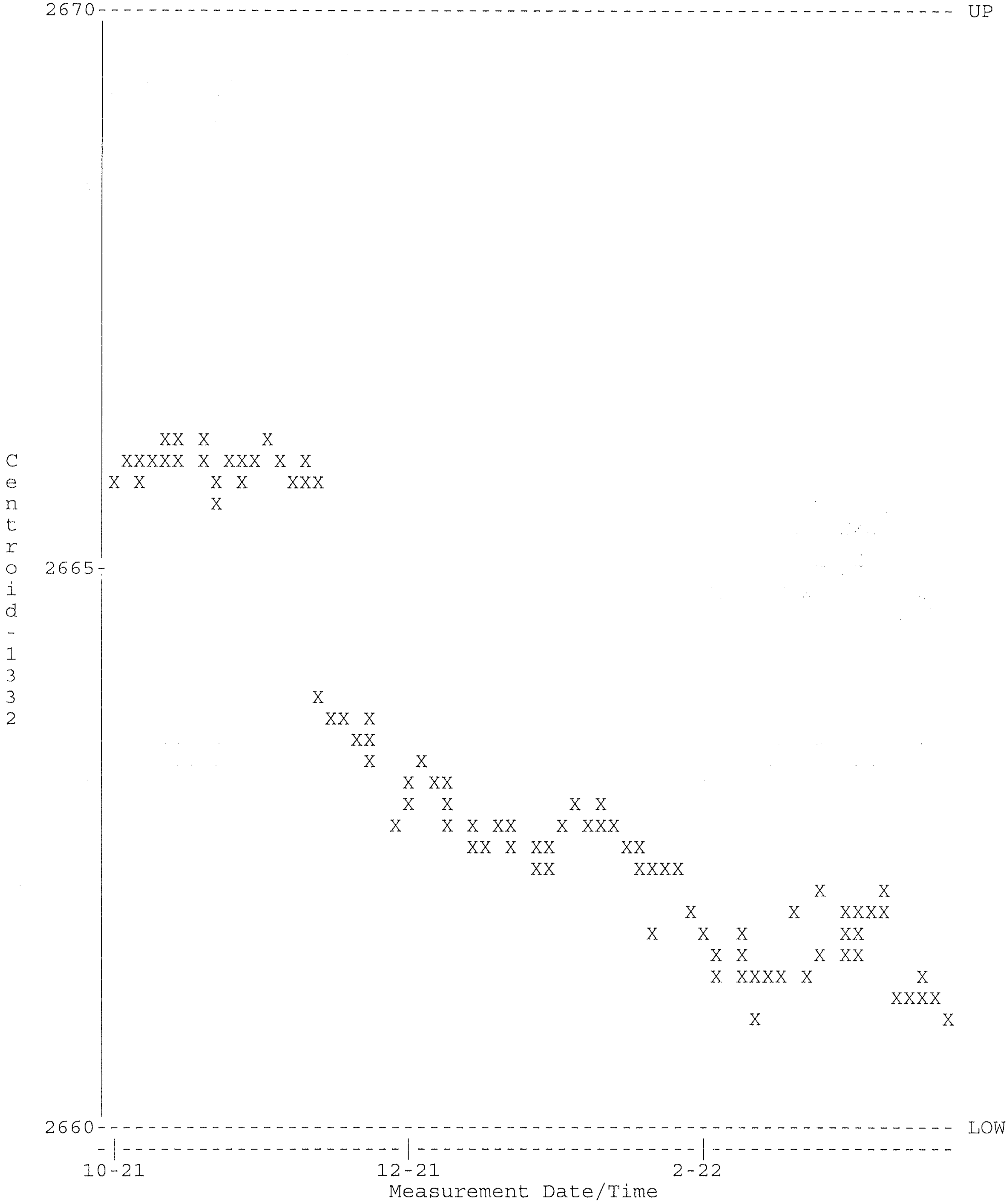
QA filename : DKB100:[GAMMA.QUALITY]NEW_TBE13_QC.QAF;1
Parameter Name : PSCENTRD-59 (Centroid-59)
Start/End Dates : 1-OCT-2021 08:57 through 23-MAR-2022 00:00
Lower/Upper Lmts: 118.500 through 120.500



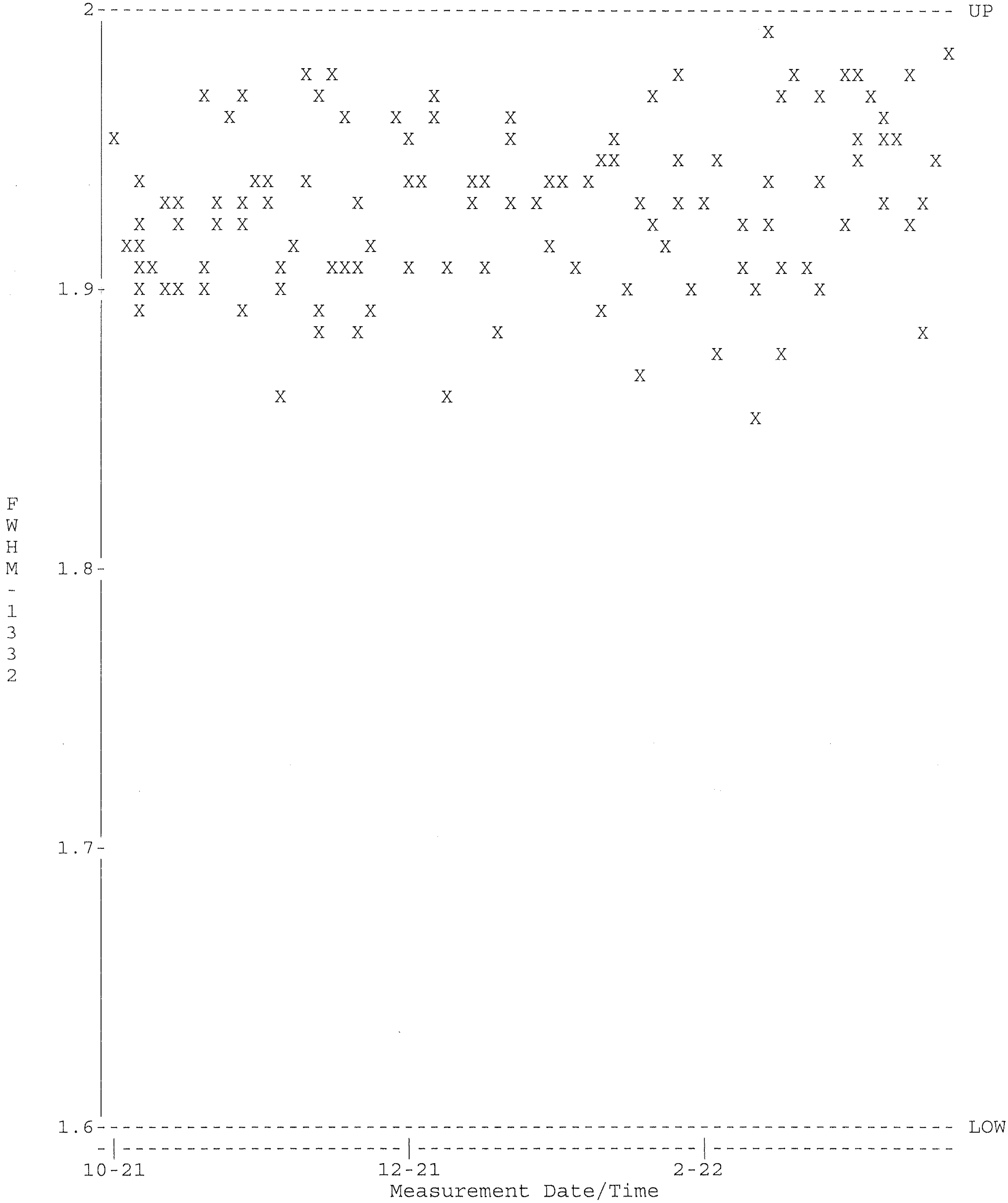
QA filename : DKB100:[GAMMA.QUALITY]TBE13_BKG_QC.QAF;1
Parameter Name : BACKRATE (Background Rate)
Start/End Dates : 1-OCT-2021 08:41 through 23-MAR-2022 00:00
Lower/Upper Lmts: 1.00000 through 4.00000



QA filename : DKB100:[GAMMA.QUALITY]NEW_TBE13_QC.QAF;1
Parameter Name : PSCENTRD (Centroid-1332)
Start/End Dates : 1-OCT-2021 08:57 through 23-MAR-2022 00:00
Lower/Upper Lmts: 2660.00 through 2670.00



QA filename : DKB100:[GAMMA.QUALITY]NEW_TBE13_QC.QAF;1
Parameter Name : PSFWHM-1332 (FWHM-1332)
Start/End Dates : 1-OCT-2021 08:57 through 23-MAR-2022 00:00
Lower/Upper Lmts: 1.60000 through 2.00000



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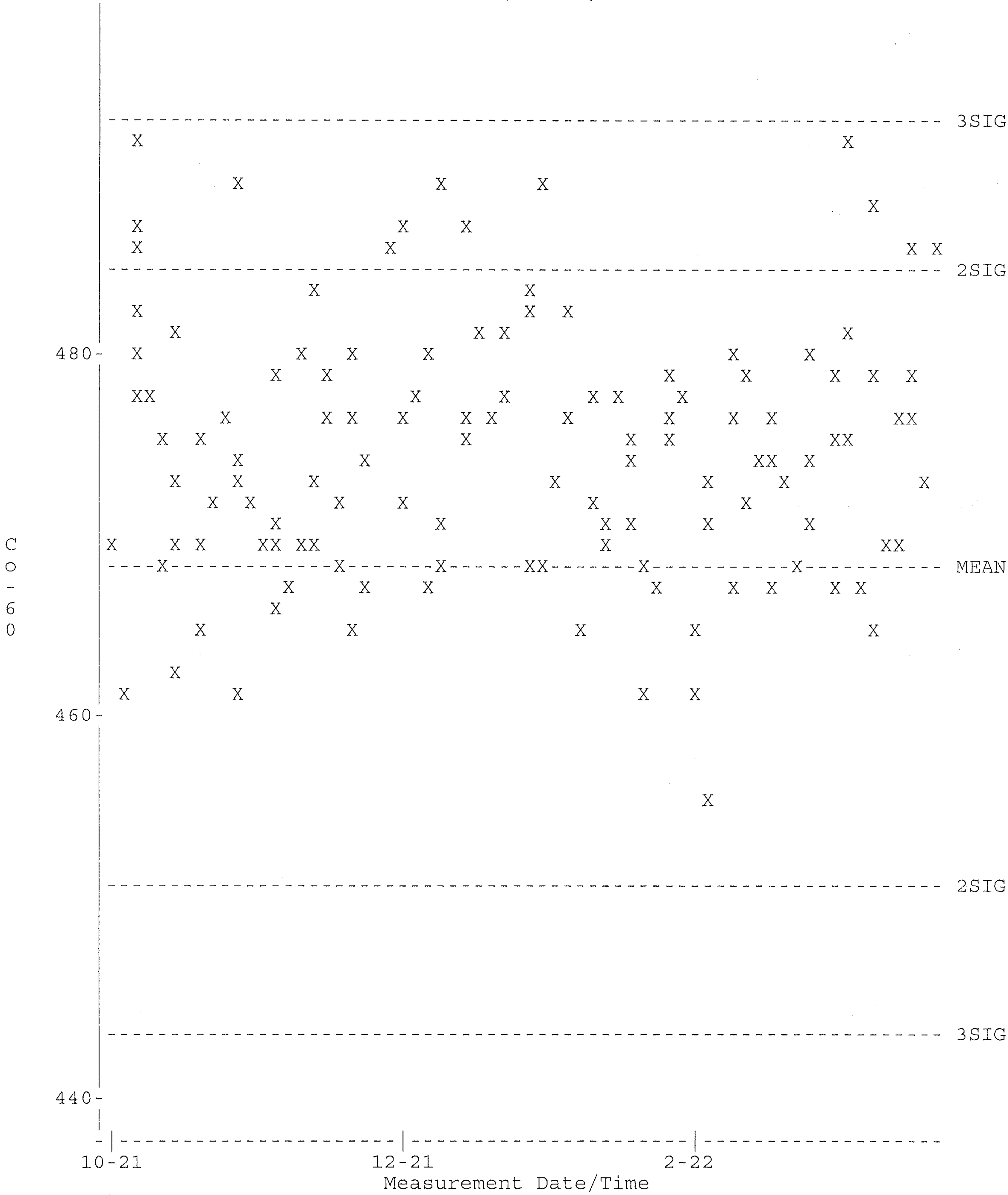
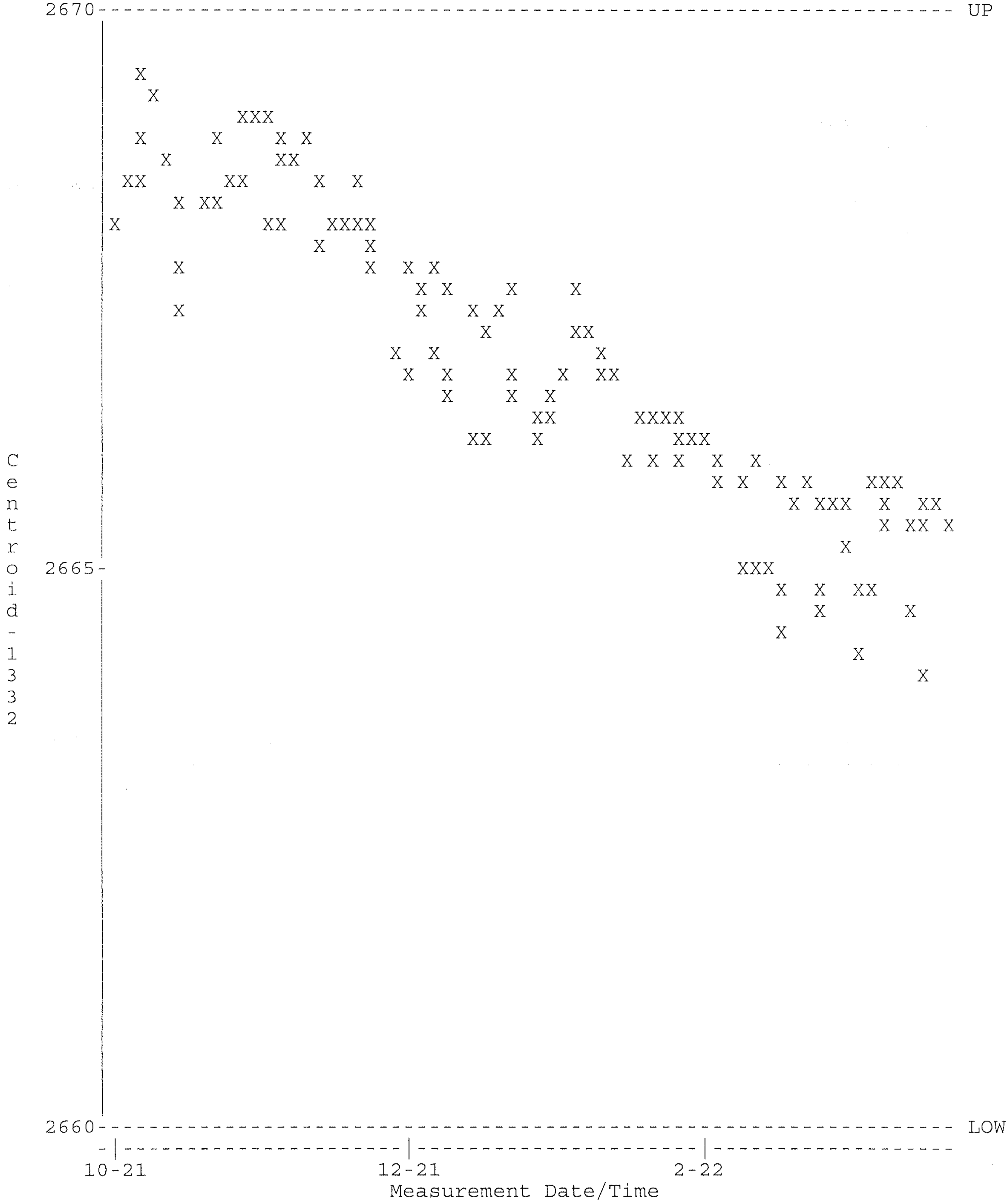
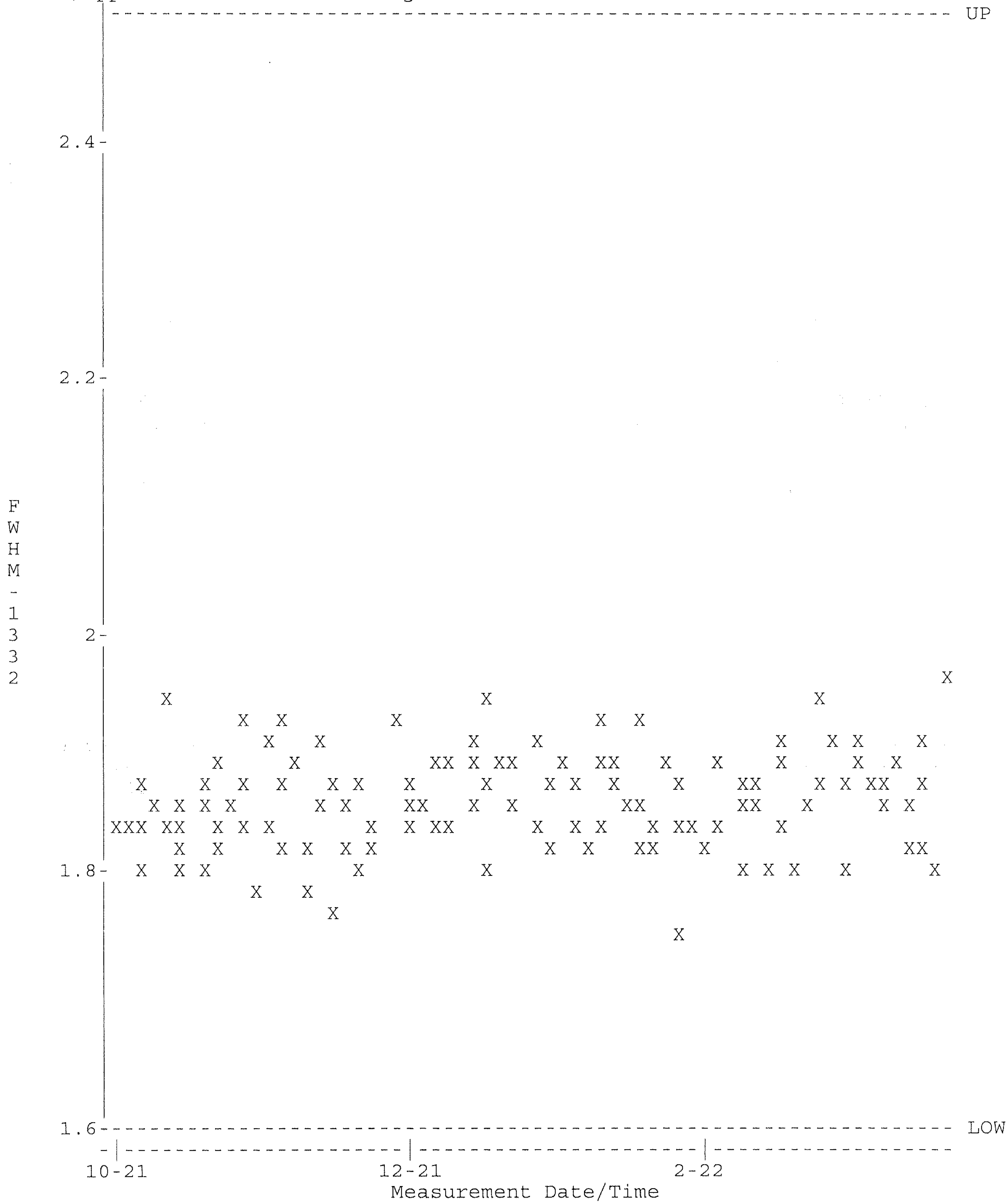
QA filename          : DKB100:[GAMMA.QUALITY]NEW_TBE13_QC.QAF;1
Parameter Name       : NCLWTMEAN-CO60 (Co-60)
Start/End Dates      : 1-OCT-2021 08:57 through 23-MAR-2022 00:00
Mean +- Std Dev      : 468.570 +- 8.25776 (1.76 %)
```



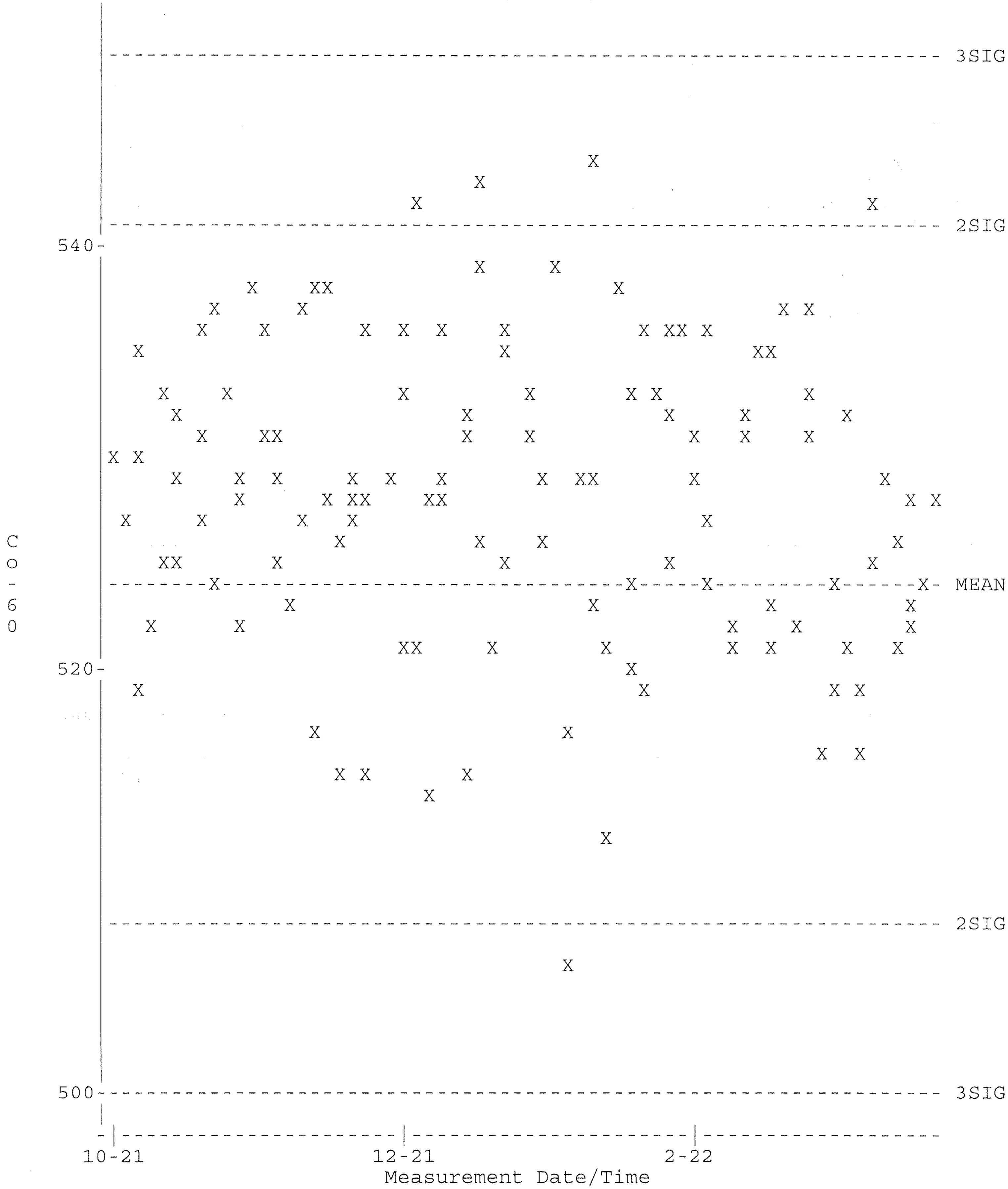
QA filename : DKB100:[GAMMA.QUALITY]NEW_TBE14_QC.QAF;1
Parameter Name : PSCENTRD (Centroid-1332)
Start/End Dates : 1-OCT-2021 08:41 through 23-MAR-2022 00:00
Lower/Upper Lmts: 2660.00 through 2670.00



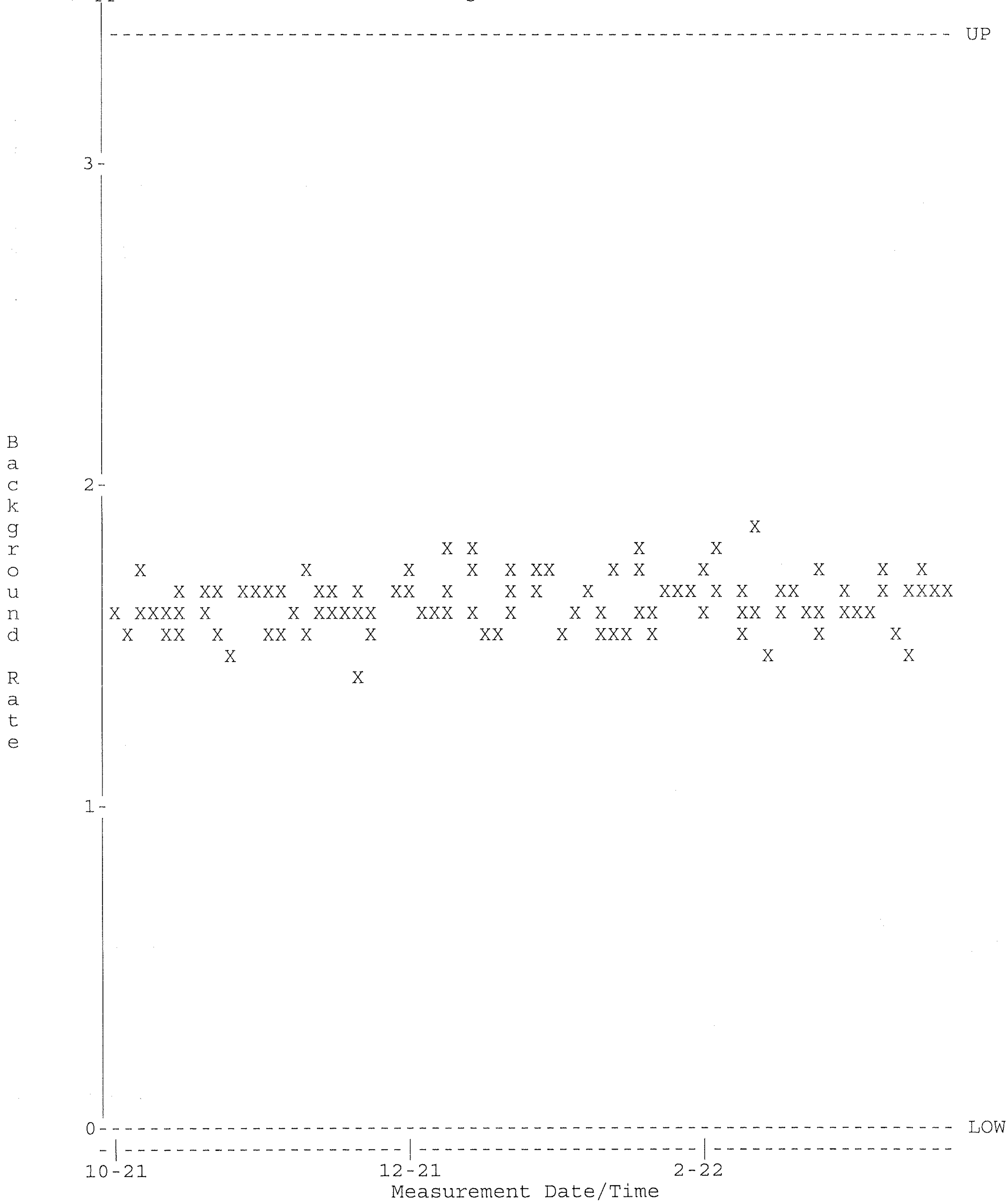
QA filename   : DKB100:[GAMMA.QUALITY]NEW_TBE14_QC.QAF;1
Parameter Name   : PSFWHM-1332 (FWHM-1332)
Start/End Dates   : 1-OCT-2021 08:41 through 23-MAR-2022 00:00
Lower/Upper Lmts: 1.60000 through 2.50000



QA filename : DKB100:[GAMMA.QUALITY]NEW_TBE14_QC.QAF;1
Parameter Name : NCLWTMEAN-CO60 (Co-60)
Start/End Dates : 1-OCT-2021 08:41 through 23-MAR-2022 00:00
Mean +- Std Dev : 524.852 +- 8.11129 (1.55 %)



```
QA filename        : DKB100:[GAMMA.QUALITY]TBE14_BKG_QC.QAF;1
Parameter Name     : BACKRATE (Background Rate)
Start/End Dates    : 1-OCT-2021 08:57 through 23-MAR-2022 00:00
Lower/Upper Lmts: 0.000000E+00 through 3.50000
```



```
QA filename       : DKB100:[GAMMA.QUALITY]NEW_TBE23_QC.QAF;1
Parameter Name    : PSCENTRD (Centroid-1332)
Start/End Dates   : 1-OCT-2021 08:41 through 23-MAR-2022 00:00
Lower/Upper Lmts: 2660.00 through 2670.00
   2670-------------------------------------------------------------------- UP
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       |                                                           X
       |
       |                                              X
       |                   X             X    XX  X  XXX     X X  XXX  X X
       |   XX     X XXXXXXX X  XX   XXXX XXXXXXXXXX X  X X XX  XXXXXXXXXX
C      |XXX  X XX X  X   X XX XX XX X  X           XX    XXXX X  X    XX
e      |         X X           X  X
n      |
t      |
r      |
o  2665-
i      |
d      |
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1      |
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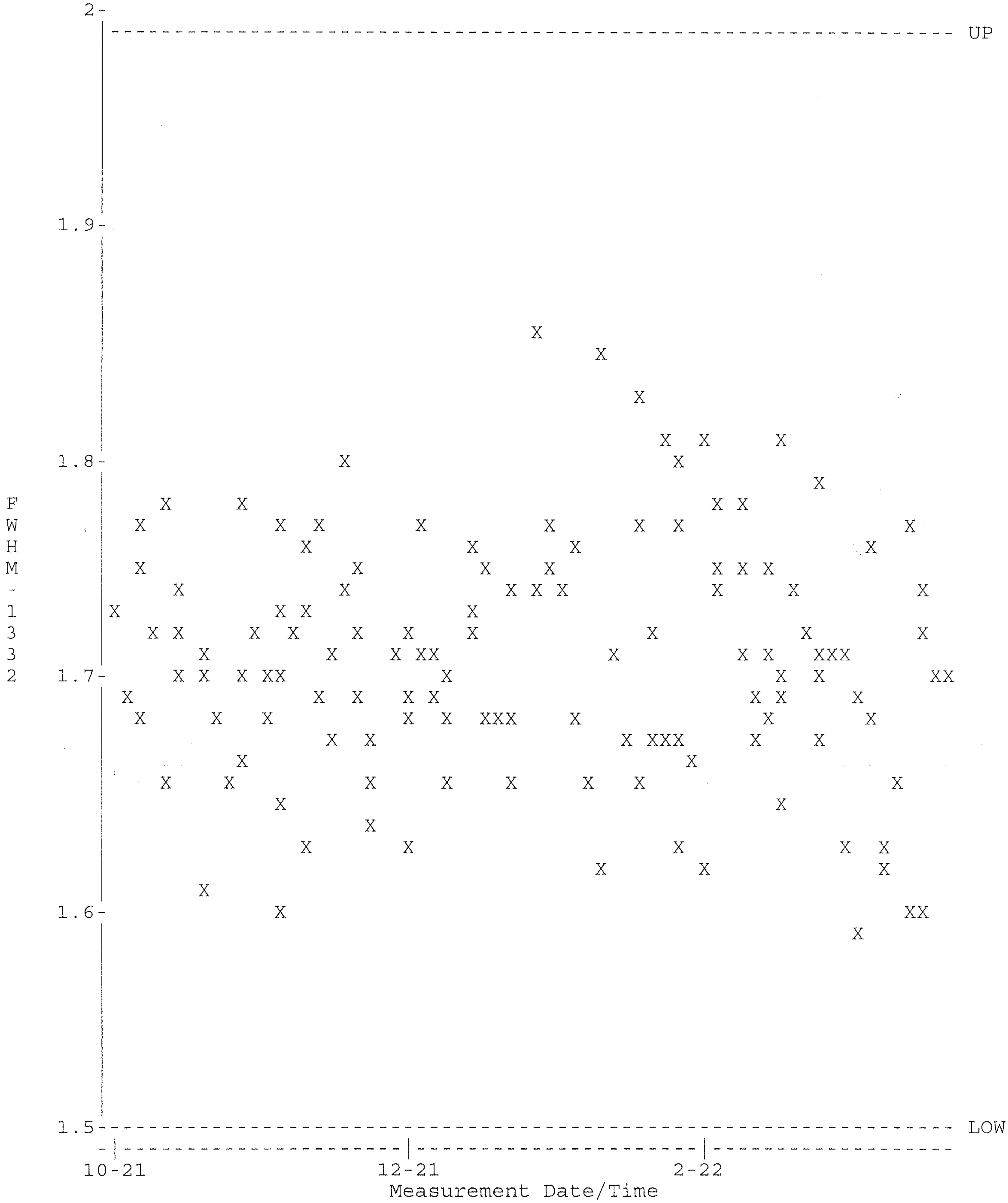
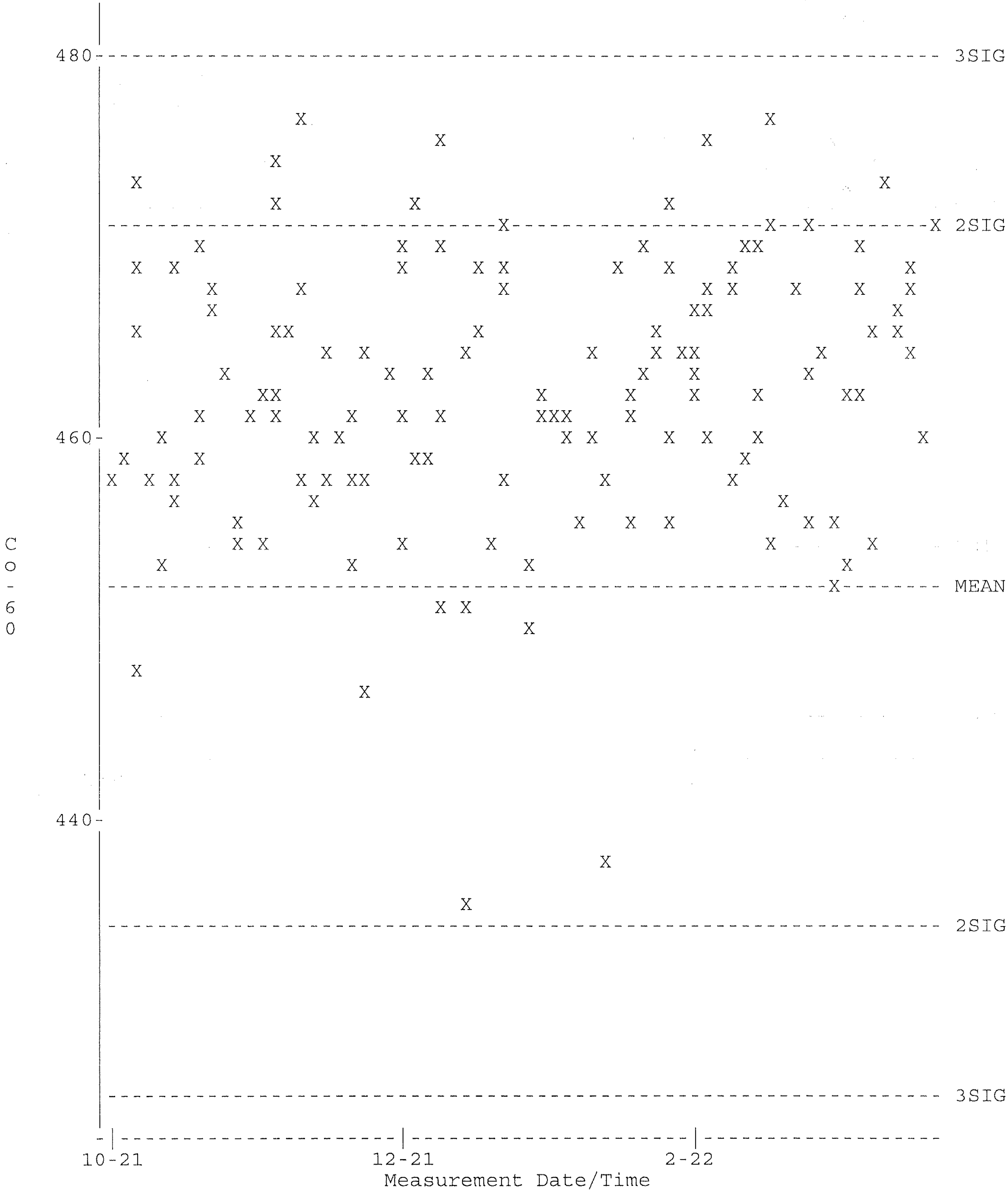
       |
   2660-------------------------------------------------------------------- LOW
       -|----------------------|----------------------|--------------------
      10-21                 12-21                  2-22
                              Measurement Date/Time
```

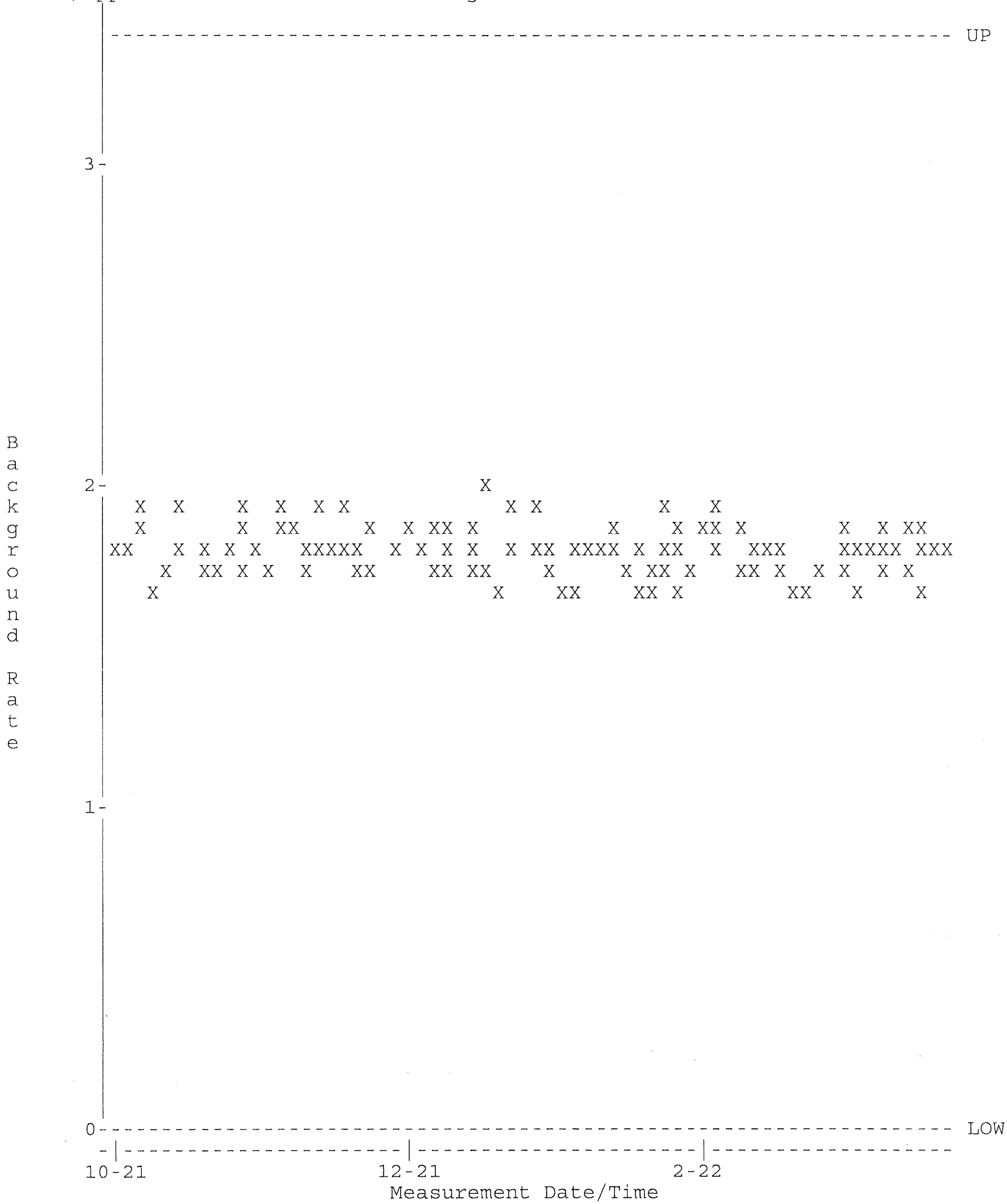
QA filename   : DKB100:[GAMMA.QUALITY]NEW_TBE23_QC.QAF;1
Parameter Name   : PSFWHM-1332 (FWHM-1332)
Start/End Dates   : 1-OCT-2021 08:41 through 23-MAR-2022 00:00
Lower/Upper Lmts: 1.50000 through 2.00000



```
QA filename        : DKB100:[GAMMA.QUALITY]NEW_TBE23_QC.QAF;1
Parameter Name     : NCLWTMEAN-CO60 (Co-60)
Start/End Dates    : 1-OCT-2021 08:41 through 23-MAR-2022 00:00
Mean +- Std Dev    : 453.245 +- 9.00635 (1.99 %)
```



```
QA filename         : DKB100:[GAMMA.QUALITY]TBE23_BKG_QC.QAF;1
Parameter Name      : BACKRATE (Background Rate)
Start/End Dates     : 1-OCT-2021 08:57 through 23-MAR-2022 00:00
Lower/Upper Lmts: 0.000000E+00 through 3.50000
```



GAMMA SPECTROSCOPY

Sample and QC Raw Data

Analyst:

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VAX/VMS Teledyne Brown Eng. Laboratory Gamma Report: 18-MAR-2022 08:06:57.99
TBE01 33-TP20784A HpGe ******* Aquisition Date/Time: 17-MAR-2022 14:52:09.25

LIMS No., Customer Name, Client ID: L95403-1 SS ANCHOR QEA

Sample ID : 01L95403-1
Sample Type : SS
Quantity : 2.14000E+01 g Dry
Start Channel : 80 Energy Tol : 2.00000
End Channel : 4090 Pk Srch Sens: 9.00000
MDA Multiple : 4.6600 Library Used: NORMK
Peak Evaluation - Identified and Unidentified

Smple Date: 13-FEB-2022 13:37:00.
Geometry : 01S25121819
BKGFILE : 01BG030422MT
Real Time : 0 17:14:38.71
Live time : 0 17:14:30.86

Pk	It	Energy	Area	Bkgnd	FWHM	Channel	%Eff	Cts/Sec	%Err	Fit
1	3	74.88*	211	1427	0.77	150.30	5.72E+00	3.39E-03	31.4	9.12E+00
2	3	77.11	575	1303	0.82	154.75	6.11E+00	9.27E-03	10.2	
3	1	87.32*	263	1190	1.12	175.15	7.65E+00	4.24E-03	24.0	9.79E-01
4	1	92.81*	477	1876	1.62	186.13	8.29E+00	7.69E-03	19.4	7.74E+00
5	1	185.83*	398	1411	1.38	372.03	9.12E+00	6.41E-03	20.7	1.43E+00
6	4	238.61*	1904	774	1.13	477.52	7.80E+00	3.07E-02	3.8	1.93E+00
7	4	241.56	677	1146	1.86	483.41	7.73E+00	1.09E-02	11.7	
8	1	295.13*	737	834	1.24	590.49	6.64E+00	1.19E-02	8.7	1.00E+00
9	1	338.21	466	869	1.55	676.59	5.95E+00	7.51E-03	13.1	5.31E-01
10	1	351.90*	1167	1076	1.40	703.94	5.76E+00	1.88E-02	7.4	1.77E+00
11	1	510.80*	273	925	2.66	1021.56	4.18E+00	4.40E-03	35.4	1.53E+00
12	1	583.02*	577	534	1.46	1165.93	3.71E+00	9.30E-03	10.0	9.72E-01
13	1	609.10*	828	613	1.47	1218.05	3.56E+00	1.33E-02	7.5	9.67E-01
14	1	910.89*	402	366	1.73	1821.39	2.42E+00	6.48E-03	12.4	7.36E-01
15	1	968.88*	275	180	1.92	1937.32	2.28E+00	4.43E-03	11.8	2.11E+00
16	1	1120.33*	185	215	1.98	2240.15	1.98E+00	2.97E-03	19.3	2.00E+00
17	1	1460.59*	1097	257	2.27	2920.55	1.54E+00	1.77E-02	5.0	1.30E+00
18	1	1764.45*	157	67	2.89	3528.27	1.32E+00	2.53E-03	16.5	1.38E+00

Flag: "*" = Peak area was modified by background subtraction

Nuclide Line Activity Report

Nuclide Type:

Nuclide	Energy	Area	%Abn	%Eff	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	2-Sigma %Error
K-40	1460.81	1097	10.67*	1.540E+00	1.358E+01	1.358E+01	10.02
BI-214	609.31	828	46.30	3.560E+00	1.022E+00	1.022E+00	15.01
	1120.29	185	15.10*	1.978E+00	1.258E+00	1.258E+00	38.62
	1764.49	157	15.80	1.323E+00	1.531E+00	1.531E+00	32.92
RA-226	186.21	398	3.28*	9.116E+00	2.706E+00	2.706E+00	41.32
RA-228	93.35	477	3.50	8.292E+00	3.344E+00	3.380E+00	38.78
	969.11	275	16.60*	2.281E+00	1.476E+00	1.492E+00	23.69
TH-234	63.29	------	3.80*	3.510E+00	------	Line Not Found	------
	92.60	477	5.41	8.292E+00	2.164E+00	2.164E+00	38.78
U-235	143.76	------	10.50*	9.986E+00	------	Line Not Found	------

	163.35	------	4.70	9.656E+00	------	Line Not Found	------
	185.71	398	54.00	9.116E+00	1.644E-01	1.644E-01	41.32
	205.31	------	4.70	8.614E+00	------	Line Not Found	------

Nuclide Type: NATURAL

Nuclide	Energy	Area	%Abn	%Eff	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	2-Sigma %Error
TL-208	583.17	577	30.25*	3.705E+00	1.048E+00	1.082E+00	20.07
PB-212	238.63	1904	44.60*	7.796E+00	1.114E+00	1.151E+00	7.50
PB-214	295.21	737	19.20	6.641E+00	1.175E+00	1.176E+00	17.45
	351.92	1167	37.20*	5.756E+00	1.109E+00	1.109E+00	14.76
TH-232	911.21	402	27.70*	2.424E+00	1.219E+00	1.219E+00	24.84

Nuclide Type: natural

Nuclide	Energy	Area	%Abn	%Eff	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	2-Sigma %Error
AC-228	835.50	------	1.75	2.638E+00	------	Line Not Found	------
	911.07	402	27.70*	2.424E+00	1.219E+00	1.232E+00	24.84

Flag: "*" = Keyline

Total number of lines in spectrum	18	
Number of unidentified lines	6	
Number of lines tentatively identified by NID	12	66.67%

Nuclide Type :

Nuclide	Hlife	Decay	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
K-40	1.28E+09Y	1.00	1.358E+01	1.358E+01	0.136E+01	10.02	
BI-214	1600.00Y	1.00	1.258E+00	1.258E+00	0.486E+00	38.62	
RA-226	1600.00Y	1.00	2.706E+00	2.706E+00	1.118E+00	41.32	
RA-228	5.75Y	1.01	1.476E+00	1.492E+00	0.354E+00	23.69	
TH-234	4.47E+09Y	1.00	2.164E+00	2.164E+00	0.839E+00	38.78	K
U-235	7.04E+08Y	1.00	1.644E-01	1.644E-01	0.679E-01	41.32	K
			---------	---------			
	Total Activity :		2.135E+01	2.136E+01			

Nuclide Type : NATURAL

Nuclide	Hlife	Decay	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
TL-208	1.91Y	1.03	1.048E+00	1.082E+00	0.217E+00	20.07	
PB-212	1.91Y	1.03	1.114E+00	1.151E+00	0.086E+00	7.50	
PB-214	1600.00Y	1.00	1.109E+00	1.109E+00	0.164E+00	14.76	
TH-232	1.41E+10Y	1.00	1.219E+00	1.219E+00	0.303E+00	24.84	
			---------	---------			
	Total Activity :		4.490E+00	4.561E+00			

Nuclide Type : natural

Nuclide	Hlife	Decay	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
AC-228	5.75Y	1.01	1.219E+00	1.232E+00	0.306E+00	24.84	
			---------	---------			
	Total Activity :		1.219E+00	1.232E+00			

Grand Total Activity : 2.706E+01 2.715E+01

Flags: "K" = Keyline not found "M" = Manually accepted
"E" = Manually edited "A" = Nuclide specific abn. limit

It	Energy	Area	Bkgnd	FWHM	Channel	Left	Pw	Cts/Sec	%Err	%Eff	Flags
3	74.88	211	1427	0.77	150.30	147	11	3.39E-03	62.7	5.72E+00	
3	77.11	575	1303	0.82	154.75	147	11	9.27E-03	20.4	6.11E+00	
1	87.32	263	1190	1.12	175.15	173	6	4.24E-03	47.9	7.65E+00	
4	241.56	677	1146	1.86	483.41	470	20	1.09E-02	23.3	7.73E+00	
1	338.21	466	869	1.55	676.59	671	11	7.51E-03	26.1	5.95E+00	
1	510.80	273	925	2.66	1021.56	1013	20	4.40E-03	70.9	4.18E+00	

Flags: "T" = Tentatively associated

Summary of Nuclide Activity

Total number of lines in spectrum	18	
Number of unidentified lines	6	
Number of lines tentatively identified by NID	12	66.67%

Nuclide Type :

Nuclide	Hlife	Decay	Wtd Mean Uncorrected pCi/g Dry	Wtd Mean Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
K-40	1.28E+09Y	1.00	1.358E+01	1.358E+01	0.136E+01	10.02	
BI-214	1600.00Y	1.00	1.081E+00	1.081E+00	0.140E+00	12.99	
RA-226	1600.00Y	1.00	2.706E+00	2.706E+00	1.118E+00	41.32	
RA-228	5.75Y	1.01	1.476E+00	1.492E+00	0.354E+00	23.69	
			---------	---------			
	Total Activity :		1.884E+01	1.886E+01			

Nuclide Type : NATURAL

Nuclide	Hlife	Decay	Wtd Mean Uncorrected pCi/g Dry	Wtd Mean Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
TL-208	1.91Y	1.03	1.048E+00	1.082E+00	0.217E+00	20.07	
PB-212	1.91Y	1.03	1.114E+00	1.151E+00	0.086E+00	7.50	
PB-214	1600.00Y	1.00	1.135E+00	1.135E+00	0.128E+00	11.27	
TH-232	1.41E+10Y	1.00	1.219E+00	1.219E+00	0.303E+00	24.84	
			---------	---------			
	Total Activity :		4.516E+00	4.587E+00			

Nuclide Type : natural

Nuclide	Hlife	Decay	Wtd Mean Uncorrected pCi/g Dry	Wtd Mean Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
AC-228	5.75Y	1.01	1.219E+00	1.232E+00	0.306E+00	24.84	
			---------	---------			
	Total Activity :		1.219E+00	1.232E+00			

Grand Total Activity : 2.458E+01 2.468E+01

Flags: "K" = Keyline not found "M" = Manually accepted
"E" = Manually edited "A" = Nuclide specific abn. limit

Interference Report

No interference correction performed

Combined Activity-MDA Report

---- Identified Nuclides ----

Nuclide	Activity (pCi/g Dry)	Act error	MDA (pCi/g Dry)	MDA error	Act/MDA
K-40	1.358E+01	1.360E+00	6.965E-01	0.000E+00	19.493
TL-208	1.082E+00	2.172E-01	1.791E-01	0.000E+00	6.043
PB-212	1.151E+00	8.629E-02	8.237E-02	0.000E+00	13.967
BI-214	1.081E+00	1.405E-01	4.700E-01	0.000E+00	2.301
PB-214	1.135E+00	1.280E-01	1.114E-01	0.000E+00	10.190
RA-226	2.706E+00	1.118E+00	1.017E+00	0.000E+00	2.661
AC-228	1.232E+00	3.061E-01	2.313E-01	0.000E+00	5.327
RA-228	1.492E+00	3.535E-01	4.220E-01	0.000E+00	3.536
TH-232	1.219E+00	3.028E-01	2.289E-01	0.000E+00	5.326

---- Non-Identified Nuclides ----

Nuclide	Key-Line Activity (pCi/g Dry)	K.L. Ided	Act error	MDA (pCi/g Dry)	MDA error	Act/MDA
CO-60	2.373E-02		4.376E-02	7.376E-02	0.000E+00	0.322
CS-137	1.809E-02		3.945E-02	6.620E-02	0.000E+00	0.273
LA-138	-1.311E-02		6.369E-02	1.021E-01	0.000E+00	-0.128
BI-212	1.532E+00		5.193E-01	9.377E-01	0.000E+00	1.634
PA-234M	-2.786E+00		5.066E+00	7.426E+00	0.000E+00	-0.375
TH-234	3.169E-01		1.833E+00	2.692E+00	0.000E+00	0.118
U-235	6.268E-02		2.156E-01	3.086E-01	0.000E+00	0.203
U-238	-2.786E+00		5.066E+00	7.426E+00	0.000E+00	-0.375

```
A,01L95403-1        ,03/18/2022 08:06,02/13/2022 13:37,   2.140E+01,L95403-1 SS AN
B,01L95403-1        ,NORMK             ,11/17/2021 15:33,01S25121819
C,K-40     ,YES,   1.358E+01,   1.360E+00,   6.965E-01,,   19.493
C,TL-208   ,YES,   1.082E+00,   2.172E-01,   1.791E-01,,    6.043
C,PB-212   ,YES,   1.151E+00,   8.629E-02,   8.237E-02,,   13.967
C,BI-214   ,YES,   1.081E+00,   1.405E-01,   4.700E-01,,    2.301
C,PB-214   ,YES,   1.135E+00,   1.280E-01,   1.114E-01,,   10.190
C,RA-226   ,YES,   2.706E+00,   1.118E+00,   1.017E+00,,    2.661
C,AC-228   ,YES,   1.232E+00,   3.061E-01,   2.313E-01,,    5.327
C,RA-228   ,YES,   1.492E+00,   3.535E-01,   4.220E-01,,    3.536
C,TH-232   ,YES,   1.219E+00,   3.028E-01,   2.289E-01,,    5.326
C,CO-60    ,NO ,   2.373E-02,   4.376E-02,   7.376E-02,,    0.322
C,CS-137   ,NO ,   1.809E-02,   3.945E-02,   6.620E-02,,    0.273
C,LA-138   ,NO ,  -1.311E-02,   6.369E-02,   1.021E-01,,   -0.128
C,BI-212   ,NO ,   1.532E+00,   5.193E-01,   9.377E-01,,    1.634
C,PA-234M  ,NO ,  -2.786E+00,   5.066E+00,   7.426E+00,,   -0.375
C,TH-234   ,NO ,   3.169E-01,   1.833E+00,   2.692E+00,,    0.118
C,U-235    ,NO ,   6.268E-02,   2.156E-01,   3.086E-01,,    0.203
C,U-238    ,NO ,  -2.786E+00,   5.066E+00,   7.426E+00,,   -0.375
```

Analyst:

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VAX/VMS Teledyne Brown Eng. Laboratory Gamma Report: 19-MAR-2022 05:31:28.83
TBE02 51-TP42214B HpGe ******* Aquisition Date/Time: 18-MAR-2022 11:31:04.83

LIMS No., Customer Name, Client ID: L95403-2 SS ANCHOR QEA

Sample ID : 02L95403-2 Smple Date: 13-FEB-2022 13:37:00.
Sample Type : SS Geometry : 02S25121819
Quantity : 3.23000E+01 g Dry BKGFILE : 02BG030422MT
Start Channel : 80 Energy Tol : 2.00000 Real Time : 0 18:00:10.93
End Channel : 4090 Pk Srch Sens: 9.00000 Live time : 0 18:00:00.00
MDA Multiple : 4.6600 Library Used: NORMK
Peak Evaluation - Identified and Unidentified

Pk	It	Energy	Area	Bkgnd	FWHM	Channel	%Eff	Cts/Sec	%Err	Fit
1	0	63.14*	192	2312	1.04	111.02	6.08E+00	2.96E-03	48.5	
2	0	77.11*	1313	1760	0.91	139.12	8.44E+00	2.03E-02	6.1	
3	5	87.14*	821	1801	1.34	159.30	9.45E+00	1.27E-02	10.3	1.92E+01
4	5	89.80	547	1511	1.23	164.65	9.63E+00	8.44E-03	12.6	
5	5	92.78*	728	1650	1.38	170.64	9.81E+00	1.12E-02	12.2	
6	0	185.87*	512	1786	1.01	357.95	8.34E+00	7.91E-03	18.0	
7	0	209.21	329	1246	0.85	404.92	7.66E+00	5.07E-03	19.4	
8	5	238.60*	2652	959	1.02	464.07	6.92E+00	4.09E-02	2.9	2.70E+00
9	5	241.60*	582	1326	1.51	470.11	6.85E+00	8.99E-03	13.2	
10	0	295.07*	770	1200	1.14	577.70	5.79E+00	1.19E-02	10.4	
11	0	338.33*	524	776	0.96	664.75	5.15E+00	8.08E-03	11.2	
12	0	351.86*	1260	875	1.19	691.97	4.97E+00	1.94E-02	6.0	
13	0	463.02	212	460	1.25	915.68	3.88E+00	3.27E-03	19.6	
14	0	510.88*	373	859	2.20	1011.99	3.54E+00	5.75E-03	24.8	
15	0	583.03*	787	493	1.30	1157.19	3.12E+00	1.22E-02	7.4	
16	0	609.14*	897	681	1.38	1209.74	2.99E+00	1.38E-02	7.9	
17	0	727.15	227	252	2.04	1447.24	2.51E+00	3.50E-03	14.8	
18	0	911.06*	545	363	1.65	1817.39	2.00E+00	8.41E-03	9.6	
19	0	968.83	334	170	1.71	1933.64	1.88E+00	5.16E-03	9.2	
20	0	1120.05*	202	261	1.99	2238.04	1.63E+00	3.12E-03	21.3	
21	0	1460.37*	1549	116	2.20	2923.10	1.26E+00	2.39E-02	3.3	
22	0	1764.20*	132	55	2.07	3534.78	1.08E+00	2.03E-03	17.6	

Flag: "*" = Peak area was modified by background subtraction

Nuclide Line Activity Report

Nuclide Type:

Nuclide	Energy	Area	%Abn	%Eff	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	2-Sigma %Error
K-40	1460.81	1549	10.67*	1.263E+00	1.484E+01	1.484E+01	6.69
BI-214	609.31	897	46.30	2.991E+00	8.362E-01	8.362E-01	15.79
	1120.29	202	15.10*	1.627E+00	1.064E+00	1.064E+00	42.69
	1764.49	132	15.80	1.083E+00	9.930E-01	9.931E-01	35.26
RA-226	186.21	512	3.28*	8.336E+00	2.420E+00	2.420E+00	35.95
RA-228	93.35	728	3.50	9.805E+00	2.739E+00	2.769E+00	24.34

	969.11	334	16.60*	1.883E+00	1.381E+00	1.396E+00	18.36
TH-234	63.29	192	3.80*	6.076E+00	1.073E+00	1.073E+00	96.91
	92.60	728	5.41	9.805E+00	1.772E+00	1.772E+00	24.34
U-235	143.76	------	10.50*	9.647E+00	------	Line Not Found	------
	163.35	------	4.70	9.042E+00	------	Line Not Found	------
	185.71	512	54.00	8.336E+00	1.470E-01	1.470E-01	35.95
	205.31	------	4.70	7.767E+00	------	Line Not Found	------

Nuclide Type: NATURAL

Nuclide	Energy	Area	%Abn	%Eff	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	2-Sigma %Error
TL-208	583.17	787	30.25*	3.120E+00	1.077E+00	1.114E+00	14.83
BI-212	727.17	227	7.56*	2.514E+00	1.539E+00	1.590E+00	29.59
PB-212	238.63	2652	44.60*	6.915E+00	1.110E+00	1.147E+00	5.82
PB-214	295.21	770	19.20	5.795E+00	8.941E-01	8.942E-01	20.84
	351.92	1260	37.20*	4.970E+00	8.797E-01	8.797E-01	12.09
TH-232	911.21	545	27.70*	2.005E+00	1.267E+00	1.267E+00	19.12

Nuclide Type: natural

Nuclide	Energy	Area	%Abn	%Eff	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	2-Sigma %Error
AC-228	835.50	------	1.75	2.188E+00	------	Line Not Found	------
	911.07	545	27.70*	2.005E+00	1.267E+00	1.281E+00	19.12

Flag: "*" = Keyline

Sample ID : 02L95403-2 Acquisition date : 18-MAR-2022 11:31:04

Total number of lines in spectrum	22	
Number of unidentified lines	8	
Number of lines tentatively identified by NID	14	63.64%

Nuclide Type :

Nuclide	Hlife	Decay	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
K-40	1.28E+09Y	1.00	1.484E+01	1.484E+01	0.099E+01	6.69	
BI-214	1600.00Y	1.00	1.064E+00	1.064E+00	0.454E+00	42.69	
RA-226	1600.00Y	1.00	2.420E+00	2.420E+00	0.870E+00	35.95	
RA-228	5.75Y	1.01	1.381E+00	1.396E+00	0.256E+00	18.36	
TH-234	4.47E+09Y	1.00	1.073E+00	1.073E+00	1.039E+00	96.91	
U-235	7.04E+08Y	1.00	1.470E-01	1.470E-01	0.528E-01	35.95	K
			---------	---------			
	Total Activity :		2.093E+01	2.094E+01			

Nuclide Type : NATURAL

Nuclide	Hlife	Decay	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
TL-208	1.91Y	1.03	1.077E+00	1.114E+00	0.165E+00	14.83	
BI-212	1.91Y	1.03	1.539E+00	1.590E+00	0.471E+00	29.59	
PB-212	1.91Y	1.03	1.110E+00	1.147E+00	0.067E+00	5.82	
PB-214	1600.00Y	1.00	8.797E-01	8.797E-01	1.063E-01	12.09	
TH-232	1.41E+10Y	1.00	1.267E+00	1.267E+00	0.242E+00	19.12	
			---------	---------			
	Total Activity :		5.874E+00	5.999E+00			

Nuclide Type : natural

Nuclide	Hlife	Decay	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
AC-228	5.75Y	1.01	1.267E+00	1.281E+00	0.245E+00	19.12	
			---------	---------			
	Total Activity :		1.267E+00	1.281E+00			

Grand Total Activity : 2.807E+01 2.822E+01

Flags: "K" = Keyline not found "M" = Manually accepted
"E" = Manually edited "A" = Nuclide specific abn. limit

Sample ID : 02L95403-2 Acquisition date : 18-MAR-2022 11:31:04

It	Energy	Area	Bkgnd	FWHM	Channel	Left	Pw	Cts/Sec	%Err	%Eff	Flags
0	77.11	1313	1760	0.91	139.12	137	6	2.03E-02	12.2	8.44E+00	
5	87.14	821	1801	1.34	159.30	149	29	1.27E-02	20.7	9.45E+00	
5	89.80	547	1511	1.23	164.65	149	29	8.44E-03	25.3	9.63E+00	
0	209.21	329	1246	0.85	404.92	402	8	5.07E-03	38.7	7.66E+00	
5	241.60	582	1326	1.51	470.11	459	16	8.99E-03	26.3	6.85E+00	
0	338.33	524	776	0.96	664.75	661	8	8.08E-03	22.3	5.15E+00	
0	463.02	212	460	1.25	915.68	912	9	3.27E-03	39.1	3.88E+00	
0	510.88	373	859	2.20	1011.99	1003	18	5.75E-03	49.7	3.54E+00	

Flags: "T" = Tentatively associated

Summary of Nuclide Activity

Total number of lines in spectrum	22	
Number of unidentified lines	8	
Number of lines tentatively identified by NID	14	63.64%

Nuclide Type :

Nuclide	Hlife	Decay	Wtd Mean Uncorrected pCi/g Dry	Wtd Mean Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
K-40	1.28E+09Y	1.00	1.484E+01	1.484E+01	0.099E+01	6.69	
BI-214	1600.00Y	1.00	8.700E-01	8.701E-01	1.192E-01	13.70	
RA-226	1600.00Y	1.00	2.420E+00	2.420E+00	0.870E+00	35.95	
RA-228	5.75Y	1.01	1.381E+00	1.396E+00	0.256E+00	18.36	
TH-234	4.47E+09Y	1.00	1.073E+00	1.073E+00	1.039E+00	96.91	
			---------	---------			
	Total Activity :		2.059E+01	2.060E+01			

Nuclide Type : NATURAL

Nuclide	Hlife	Decay	Wtd Mean Uncorrected pCi/g Dry	Wtd Mean Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
TL-208	1.91Y	1.03	1.077E+00	1.114E+00	0.165E+00	14.83	
BI-212	1.91Y	1.03	1.539E+00	1.590E+00	0.471E+00	29.59	
PB-212	1.91Y	1.03	1.110E+00	1.147E+00	0.067E+00	5.82	
PB-214	1600.00Y	1.00	8.832E-01	8.833E-01	0.924E-01	10.46	
TH-232	1.41E+10Y	1.00	1.267E+00	1.267E+00	0.242E+00	19.12	
			---------	---------			
	Total Activity :		5.877E+00	6.002E+00			

Nuclide Type : natural

Nuclide	Hlife	Decay	Wtd Mean Uncorrected pCi/g Dry	Wtd Mean Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
AC-228	5.75Y	1.01	1.267E+00	1.281E+00	0.245E+00	19.12	
			---------	---------			
	Total Activity :		1.267E+00	1.281E+00			

Grand Total Activity : 2.773E+01 2.789E+01

Flags: "K" = Keyline not found "M" = Manually accepted
"E" = Manually edited "A" = Nuclide specific abn. limit

Interference Report

No interference correction performed

Combined Activity-MDA Report

---- Identified Nuclides ----

Nuclide	Activity (pCi/g Dry)	Act error	MDA (pCi/g Dry)	MDA error	Act/MDA
K-40	1.484E+01	9.933E-01	4.345E-01	0.000E+00	34.167
TL-208	1.114E+00	1.652E-01	1.200E-01	0.000E+00	9.277
BI-212	1.590E+00	4.705E-01	5.317E-01	0.000E+00	2.991
PB-212	1.147E+00	6.672E-02	6.172E-02	0.000E+00	18.590
BI-214	8.701E-01	1.192E-01	3.223E-01	0.000E+00	2.699
PB-214	8.833E-01	9.235E-02	7.771E-02	0.000E+00	11.366
RA-226	2.420E+00	8.700E-01	7.375E-01	0.000E+00	3.281
AC-228	1.281E+00	2.450E-01	1.565E-01	0.000E+00	8.189
RA-228	1.396E+00	2.563E-01	3.292E-01	0.000E+00	4.241
TH-232	1.267E+00	2.423E-01	1.548E-01	0.000E+00	8.188
TH-234	1.073E+00	1.039E+00	9.231E-01	0.000E+00	1.162

---- Non-Identified Nuclides ----

Nuclide	Key-Line Activity (pCi/g Dry)	K.L. Ided	Act error	MDA (pCi/g Dry)	MDA error	Act/MDA
CO-60	9.394E-03		3.120E-02	5.256E-02	0.000E+00	0.179
CS-137	3.628E-02		2.996E-02	5.245E-02	0.000E+00	0.692
LA-138	2.455E-02		4.447E-02	7.582E-02	0.000E+00	0.324
PA-234M	-6.569E-01		3.770E+00	5.480E+00	0.000E+00	-0.120
U-235	1.716E-01		1.494E-01	2.211E-01	0.000E+00	0.776
U-238	-6.569E-01		3.770E+00	5.480E+00	0.000E+00	-0.120

```
A,02L95403-2        ,03/19/2022 05:31,02/13/2022 13:37,    3.230E+01,L95403-2 SS AN
B,02L95403-2        ,NORMK                  ,08/20/2021 05:25,02S25121819
C,K-40      ,YES,   1.484E+01,    9.933E-01,    4.345E-01,,    34.167
C,TL-208    ,YES,   1.114E+00,    1.652E-01,    1.200E-01,,     9.277
C,BI-212    ,YES,   1.590E+00,    4.705E-01,    5.317E-01,,     2.991
C,PB-212    ,YES,   1.147E+00,    6.672E-02,    6.172E-02,,    18.590
C,BI-214    ,YES,   8.701E-01,    1.192E-01,    3.223E-01,,     2.699
C,PB-214    ,YES,   8.833E-01,    9.235E-02,    7.771E-02,,    11.366
C,RA-226    ,YES,   2.420E+00,    8.700E-01,    7.375E-01,,     3.281
C,AC-228    ,YES,   1.281E+00,    2.450E-01,    1.565E-01,,     8.189
C,RA-228    ,YES,   1.396E+00,    2.563E-01,    3.292E-01,,     4.241
C,TH-232    ,YES,   1.267E+00,    2.423E-01,    1.548E-01,,     8.188
C,TH-234    ,YES,   1.073E+00,    1.039E+00,    9.231E-01,,     1.162
C,CO-60     ,NO ,   9.394E-03,    3.120E-02,    5.256E-02,,     0.179
C,CS-137    ,NO ,   3.628E-02,    2.996E-02,    5.245E-02,,     0.692
C,LA-138    ,NO ,   2.455E-02,    4.447E-02,    7.582E-02,,     0.324
C,PA-234M   ,NO ,  -6.569E-01,    3.770E+00,    5.480E+00,,    -0.120
C,U-235     ,NO ,   1.716E-01,    1.494E-01,    2.211E-01,,     0.776
C,U-238     ,NO ,  -6.569E-01,    3.770E+00,    5.480E+00,,    -0.120
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Analyst:

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VAX/VMS Teledyne Brown Eng. Laboratory Gamma Report: 19-MAR-2022 05:14:14.64
TBE14 54-TP42603C HpGe ******* Aquisition Date/Time: 18-MAR-2022 11:13:46.19

LIMS No., Customer Name, Client ID: L95403-3 SS ANCHOR QEA

Sample ID : 14L95403-3
Sample Type : SS
Quantity : 3.57000E+01 g Dry
Start Channel : 80 Energy Tol : 2.00000
End Channel : 4090 Pk Srch Sens: 9.00000
MDA Multiple : 4.6600 Library Used: NORMK
Peak Evaluation - Identified and Unidentified

Smple Date: 13-FEB-2022 13:37:00.
Geometry : 14S25121719
BKGFILE : 14BG030422MT
Real Time : 0 18:00:12.89
Live time : 0 18:00:00.00

Pk	It	Energy	Area	Bkgnd	FWHM	Channel	%Eff	Cts/Sec	%Err	Fit
1	4	74.94*	514	1425	0.77	147.04	7.23E+00	7.93E-03	13.1	8.30E+00
2	4	77.16	1220	1116	0.81	151.49	7.57E+00	1.88E-02	5.2	
3	6	84.40*	86	1467	1.20	165.98	8.49E+00	1.33E-03	83.9	4.47E+00
4	6	87.22*	351	1067	0.84	171.63	8.78E+00	5.41E-03	17.3	
5	5	89.95	405	660	0.96	177.08	9.03E+00	6.26E-03	10.2	2.67E+00
6	5	92.89*	633	1312	1.40	182.98	9.26E+00	9.77E-03	12.1	
7	1	185.97*	515	1260	1.21	369.32	8.55E+00	7.94E-03	15.4	1.40E+00
8	1	209.31	303	1062	1.13	416.06	7.87E+00	4.68E-03	20.2	1.41E+00
9	6	238.65*	2289	709	0.99	474.81	7.10E+00	3.53E-02	3.1	2.12E+00
10	6	241.46	580	1021	1.64	480.43	7.03E+00	8.95E-03	12.0	
11	1	295.22*	637	671	1.05	588.08	5.91E+00	9.83E-03	8.7	6.43E-01
12	1	338.32	497	692	0.97	674.39	5.22E+00	7.66E-03	10.5	8.49E-01
13	1	351.92*	1000	669	1.21	701.63	5.03E+00	1.54E-02	6.2	9.22E-01
14	1	510.90*	159	724	2.55	1019.97	3.51E+00	2.45E-03	52.0	1.16E+00
15	1	583.16*	604	381	1.27	1164.68	3.07E+00	9.31E-03	7.9	2.15E+00
16	1	609.27*	749	483	1.44	1216.97	2.94E+00	1.16E-02	7.6	1.84E+00
17	1	661.51	89	376	1.07	1321.59	2.70E+00	1.38E-03	43.4	1.13E+00
18	1	727.61	110	336	1.79	1454.00	2.45E+00	1.70E-03	35.0	2.16E+00
19	1	911.10*	464	245	1.81	1821.50	1.94E+00	7.15E-03	9.3	6.72E-01
20	1	968.94*	190	363	1.57	1937.38	1.82E+00	2.93E-03	22.3	4.07E+00
21	1	1120.28*	77	209	1.41	2240.54	1.57E+00	1.19E-03	41.1	2.34E+00
22	1	1460.65*	1273	168	1.92	2922.47	1.21E+00	1.97E-02	4.0	1.71E+00
23	1	1764.31*	140	67	2.36	3530.99	1.04E+00	2.16E-03	18.1	6.67E-01

Flag: "*" = Peak area was modified by background subtraction

Nuclide Line Activity Report

Nuclide Type:

Nuclide	Energy	Area	%Abn	%Eff	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	2-Sigma %Error
K-40	1460.81	1273	10.67*	1.210E+00	1.152E+01	1.152E+01	8.00
CS-137	661.66	89	85.12*	2.701E+00	4.535E-02	4.544E-02	86.79
BI-214	609.31	749	46.30	2.937E+00	6.436E-01	6.436E-01	15.21
	1120.29	77	15.10*	1.565E+00	3.816E-01	3.816E-01	82.12
	1764.49	140	15.80	1.037E+00	9.986E-01	9.986E-01	36.28

RA-226	186.21	515	3.28*	8.546E+00	2.145E+00	2.146E+00	30.70
RA-228	93.35	633	3.50	9.263E+00	2.281E+00	2.306E+00	24.21
	969.11	190	16.60*	1.818E+00	7.363E-01	7.444E-01	44.67
TH-234	63.29	------	3.80*	5.083E+00	------	Line Not Found	------
	92.60	633	5.41	9.263E+00	1.476E+00	1.476E+00	24.21
U-235	143.76	------	10.50*	9.757E+00	------	Line Not Found	------
	163.35	------	4.70	9.227E+00	------	Line Not Found	------
	185.71	515	54.00	8.546E+00	1.303E-01	1.303E-01	30.70
	205.31	------	4.70	7.978E+00	------	Line Not Found	------

Nuclide Type: NATURAL

Nuclide	Energy	Area	%Abn	%Eff	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	2-Sigma %Error
TL-208	583.17	604	30.25*	3.071E+00	7.591E-01	7.846E-01	15.85
BI-212	727.17	110	7.56*	2.448E+00	6.959E-01	7.193E-01	69.95
PB-212	238.63	2289	44.60*	7.096E+00	8.448E-01	8.732E-01	6.21
PB-214	295.21	637	19.20	5.908E+00	6.561E-01	6.561E-01	17.47
	351.92	1000	37.20*	5.027E+00	6.246E-01	6.246E-01	12.43
TH-232	911.21	464	27.70*	1.938E+00	1.009E+00	1.009E+00	18.63

Nuclide Type: natural

Nuclide	Energy	Area	%Abn	%Eff	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	2-Sigma %Error
AC-228	835.50	------	1.75	2.121E+00	------	Line Not Found	------
	911.07	464	27.70*	1.938E+00	1.009E+00	1.020E+00	18.63

Flag: "*" = Keyline

Total number of lines in spectrum	23	
Number of unidentified lines	9	
Number of lines tentatively identified by NID	14	60.87%

Nuclide Type :

Nuclide	Hlife	Decay	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
K-40	1.28E+09Y	1.00	1.152E+01	1.152E+01	0.092E+01	8.00	
CS-137	30.07Y	1.00	4.535E-02	4.544E-02	3.944E-02	86.79	
BI-214	1600.00Y	1.00	3.816E-01	3.816E-01	3.134E-01	82.12	
RA-226	1600.00Y	1.00	2.145E+00	2.146E+00	0.659E+00	30.70	
RA-228	5.75Y	1.01	7.363E-01	7.444E-01	3.326E-01	44.67	
TH-234	4.47E+09Y	1.00	1.476E+00	1.476E+00	0.357E+00	24.21	K
U-235	7.04E+08Y	1.00	1.303E-01	1.303E-01	0.400E-01	30.70	K
			---------	---------			
	Total Activity :		1.643E+01	1.644E+01			

Nuclide Type : NATURAL

Nuclide	Hlife	Decay	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
TL-208	1.91Y	1.03	7.591E-01	7.846E-01	1.244E-01	15.85	
BI-212	1.91Y	1.03	6.959E-01	7.193E-01	5.031E-01	69.95	
PB-212	1.91Y	1.03	8.448E-01	8.732E-01	0.542E-01	6.21	
PB-214	1600.00Y	1.00	6.246E-01	6.246E-01	0.777E-01	12.43	
TH-232	1.41E+10Y	1.00	1.009E+00	1.009E+00	0.188E+00	18.63	
			---------	---------			
	Total Activity :		3.933E+00	4.011E+00			

Nuclide Type : natural

Nuclide	Hlife	Decay	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
AC-228	5.75Y	1.01	1.009E+00	1.020E+00	0.190E+00	18.63	
			---------	---------			
	Total Activity :		1.009E+00	1.020E+00			

Grand Total Activity : 2.138E+01 2.147E+01

Flags: "K" = Keyline not found "M" = Manually accepted
"E" = Manually edited "A" = Nuclide specific abn. limit

It	Energy	Area	Bkgnd	FWHM	Channel	Left	Pw	Cts/Sec	%Err	%Eff	Flags
4	74.94	514	1425	0.77	147.04	144	11	7.93E-03	26.2	7.23E+00	
4	77.16	1220	1116	0.81	151.49	144	11	1.88E-02	10.3	7.57E+00	
6	84.40	86	1467	1.20	165.98	161	15	1.33E-03	****	8.49E+00	
6	87.22	351	1067	0.84	171.63	161	15	5.41E-03	34.5	8.78E+00	
5	89.95	405	660	0.96	177.08	175	15	6.26E-03	20.4	9.03E+00	
1	209.31	303	1062	1.13	416.06	412	9	4.68E-03	40.4	7.87E+00	
6	241.46	580	1021	1.64	480.43	470	21	8.95E-03	24.1	7.03E+00	
1	338.32	497	692	0.97	674.39	670	9	7.66E-03	21.0	5.22E+00	
1	510.90	159	724	2.55	1019.97	1012	17	2.45E-03	****	3.51E+00	

Flags: "T" = Tentatively associated

Summary of Nuclide Activity

Total number of lines in spectrum	23	
Number of unidentified lines	9	
Number of lines tentatively identified by NID	14	60.87%

Nuclide Type :

Nuclide	Hlife	Decay	Wtd Mean Uncorrected pCi/g Dry	Wtd Mean Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
K-40	1.28E+09Y	1.00	1.152E+01	1.152E+01	0.092E+01	8.00	
CS-137	30.07Y	1.00	4.535E-02	4.544E-02	3.944E-02	86.79	
BI-214	1600.00Y	1.00	6.439E-01	6.439E-01	0.905E-01	14.05	
RA-226	1600.00Y	1.00	2.145E+00	2.146E+00	0.659E+00	30.70	
RA-228	5.75Y	1.01	7.363E-01	7.444E-01	3.326E-01	44.67	
			---------	---------			
	Total Activity :		1.509E+01	1.510E+01			

Nuclide Type : NATURAL

Nuclide	Hlife	Decay	Wtd Mean Uncorrected pCi/g Dry	Wtd Mean Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
TL-208	1.91Y	1.03	7.591E-01	7.846E-01	1.244E-01	15.85	
BI-212	1.91Y	1.03	6.959E-01	7.193E-01	5.031E-01	69.95	
PB-212	1.91Y	1.03	8.448E-01	8.732E-01	0.542E-01	6.21	
PB-214	1600.00Y	1.00	6.345E-01	6.345E-01	0.643E-01	10.13	
TH-232	1.41E+10Y	1.00	1.009E+00	1.009E+00	0.188E+00	18.63	
			---------	---------			
	Total Activity :		3.943E+00	4.020E+00			

Nuclide Type : natural

Nuclide	Hlife	Decay	Wtd Mean Uncorrected pCi/g Dry	Wtd Mean Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
AC-228	5.75Y	1.01	1.009E+00	1.020E+00	0.190E+00	18.63	
			---------	---------			
	Total Activity :		1.009E+00	1.020E+00			

Grand Total Activity : 2.004E+01 2.014E+01

Flags: "K" = Keyline not found "M" = Manually accepted
"E" = Manually edited "A" = Nuclide specific abn. limit

Interference Report

No interference correction performed

Combined Activity-MDA Report

---- Identified Nuclides ----

Nuclide	Activity (pCi/g Dry)	Act error	MDA (pCi/g Dry)	MDA error	Act/MDA
K-40	1.152E+01	9.220E-01	4.250E-01	0.000E+00	27.108
CS-137	4.544E-02	3.944E-02	4.199E-02	0.000E+00	1.082
TL-208	7.846E-01	1.244E-01	1.120E-01	0.000E+00	7.003
BI-212	7.193E-01	5.031E-01	4.996E-01	0.000E+00	1.440
PB-212	8.732E-01	5.424E-02	4.816E-02	0.000E+00	18.133
BI-214	6.439E-01	9.046E-02	3.255E-01	0.000E+00	1.978
PB-214	6.345E-01	6.430E-02	6.623E-02	0.000E+00	9.581
RA-226	2.146E+00	6.587E-01	5.670E-01	0.000E+00	3.784
AC-228	1.020E+00	1.901E-01	1.412E-01	0.000E+00	7.225
RA-228	7.444E-01	3.326E-01	2.472E-01	0.000E+00	3.012
TH-232	1.009E+00	1.880E-01	1.397E-01	0.000E+00	7.224

---- Non-Identified Nuclides ----

Nuclide	Key-Line Activity (pCi/g Dry)	K.L. Ided	Act error	MDA (pCi/g Dry)	MDA error	Act/MDA
CO-60	-9.852E-03		2.792E-02	4.553E-02	0.000E+00	-0.216
LA-138	2.089E-02		3.731E-02	6.434E-02	0.000E+00	0.325
PA-234M	2.587E+00		2.831E+00	4.845E+00	0.000E+00	0.534
TH-234	3.381E-01		6.488E-01	9.629E-01	0.000E+00	0.351
U-235	9.583E-02		9.860E-02	1.676E-01	0.000E+00	0.572
U-238	2.587E+00		2.831E+00	4.845E+00	0.000E+00	0.534

```
A,14L95403-3        ,03/19/2022 05:14,02/13/2022 13:37,   3.570E+01,L95403-3 SS AN
B,14L95403-3        ,NORMK                    ,08/11/2021 12:59,14S25121719
C,K-40      ,YES,   1.152E+01,    9.220E-01,    4.250E-01,,   27.108
C,CS-137    ,YES,   4.544E-02,    3.944E-02,    4.199E-02,,    1.082
C,TL-208    ,YES,   7.846E-01,    1.244E-01,    1.120E-01,,    7.003
C,BI-212    ,YES,   7.193E-01,    5.031E-01,    4.996E-01,,    1.440
C,PB-212    ,YES,   8.732E-01,    5.424E-02,    4.816E-02,,   18.133
C,BI-214    ,YES,   6.439E-01,    9.046E-02,    3.255E-01,,    1.978
C,PB-214    ,YES,   6.345E-01,    6.430E-02,    6.623E-02,,    9.581
C,RA-226    ,YES,   2.146E+00,    6.587E-01,    5.670E-01,,    3.784
C,AC-228    ,YES,   1.020E+00,    1.901E-01,    1.412E-01,,    7.225
C,RA-228    ,YES,   7.444E-01,    3.326E-01,    2.472E-01,,    3.012
C,TH-232    ,YES,   1.009E+00,    1.880E-01,    1.397E-01,,    7.224
C,CO-60     ,NO ,  -9.852E-03,    2.792E-02,    4.553E-02,,   -0.216
C,LA-138    ,NO ,   2.089E-02,    3.731E-02,    6.434E-02,,    0.325
C,PA-234M   ,NO ,   2.587E+00,    2.831E+00,    4.845E+00,,    0.534
C,TH-234    ,NO ,   3.381E-01,    6.488E-01,    9.629E-01,,    0.351
C,U-235     ,NO ,   9.583E-02,    9.860E-02,    1.676E-01,,    0.572
C,U-238     ,NO ,   2.587E+00,    2.831E+00,    4.845E+00,,    0.534
```

Analyst:

VAX/VMS Teledyne Brown Eng. Laboratory Gamma Report: 18-MAR-2022 08:07:09.71
TBE11 59-TN51806A HpGe ******* Aquisition Date/Time: 17-MAR-2022 14:52:09.62

LIMS No., Customer Name, Client ID: L95403-4 SS ANCHOR QEA

Sample ID : 11L95403-4
Sample Type : SS
Quantity : 2.67000E+01 g Dry
Start Channel : 80 Energy Tol : 2.00000
End Channel : 4090 Pk Srch Sens: 9.00000
MDA Multiple : 4.6600 Library Used: NORMK
Peak Evaluation - Identified and Unidentified

Smple Date: 13-FEB-2022 13:37:00.
Geometry : 11S25121819
BKGFILE : 11BG030422MT
Real Time : 0 17:14:46.96
Live time : 0 17:14:15.60

Pk	It	Energy	Area	Bkgnd	FWHM	Channel	%Eff	Cts/Sec	%Err	Fit
1	0	46.48*	483	2243	1.10	91.59	9.09E+00	7.78E-03	22.0	
2	0	63.39*	207	2438	1.09	125.39	1.09E+01	3.33E-03	47.7	
3	0	77.39*	1096	2306	1.00	153.39	1.09E+01	1.77E-02	8.3	
4	2	84.71*	283	1987	1.41	168.02	1.07E+01	4.55E-03	32.9	2.18E+00
5	2	87.29*	487	1529	1.08	173.17	1.06E+01	7.85E-03	15.0	
6	2	90.16	356	1218	1.13	178.91	1.04E+01	5.73E-03	15.2	4.19E+00
7	2	92.88*	556	1910	1.43	184.35	1.03E+01	8.96E-03	17.8	
8	0	186.12*	293	1817	1.33	370.78	6.83E+00	4.72E-03	31.3	
9	4	238.87*	1875	1050	1.41	476.24	5.68E+00	3.02E-02	4.2	1.77E+00
10	4	241.82	644	1445	1.79	482.15	5.63E+00	1.04E-02	12.9	
11	0	295.37*	699	1105	1.42	589.22	4.83E+00	1.13E-02	10.3	
12	0	338.34	426	1036	1.42	675.13	4.34E+00	6.87E-03	15.4	
13	0	352.26*	1403	1048	1.43	702.95	4.20E+00	2.26E-02	5.8	
14	0	511.35*	383	1107	2.59	1021.04	3.08E+00	6.17E-03	29.2	
15	0	583.60*	507	652	1.60	1165.49	2.74E+00	8.16E-03	12.5	
16	0	609.66*	1052	728	1.54	1217.60	2.64E+00	1.69E-02	7.2	
17	0	911.62*	425	316	1.92	1821.36	1.80E+00	6.86E-03	11.5	
18	0	969.56*	252	245	2.00	1937.18	1.70E+00	4.06E-03	14.8	
19	0	1120.74*	219	334	2.67	2239.48	1.48E+00	3.53E-03	22.5	
20	0	1461.39*	1265	209	1.96	2920.59	1.15E+00	2.04E-02	4.6	
21	0	1765.21*	214	133	2.21	3528.07	9.86E-01	3.45E-03	16.9	

Flag: "*" = Peak area was modified by background subtraction

Nuclide Line Activity Report

Nuclide Type:

Nuclide	Energy	Area	%Abn	%Eff	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	2-Sigma %Error
K-40	1460.81	1265	10.67*	1.152E+00	1.678E+01	1.678E+01	9.26
BI-214	609.31	1052	46.30	2.637E+00	1.405E+00	1.405E+00	14.43
	1120.29	219	15.10*	1.476E+00	1.601E+00	1.601E+00	44.98
	1764.49	214	15.80	9.865E-01	2.239E+00	2.239E+00	33.82
RA-226	186.21	293	3.28*	6.828E+00	2.132E+00	2.132E+00	62.56
RA-228	93.35	556	3.50	1.033E+01	2.508E+00	2.535E+00	35.59
	969.11	252	16.60*	1.700E+00	1.458E+00	1.473E+00	29.61

TH-234	63.29	207	3.80*	1.086E+01	8.176E-01	8.176E-01	95.47
	92.60	556	5.41	1.033E+01	1.623E+00	1.623E+00	35.59

Nuclide Type: NATURAL

Nuclide	Energy	Area	%Abn	%Eff	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	2-Sigma %Error
TL-208	583.17	507	30.25*	2.743E+00	9.958E-01	1.028E+00	24.92
PB-212	238.63	1875	44.60*	5.683E+00	1.207E+00	1.246E+00	8.43
PB-214	295.21	699	19.20	4.831E+00	1.229E+00	1.229E+00	20.66
	351.92	1403	37.20*	4.204E+00	1.464E+00	1.464E+00	11.63
TH-232	911.21	425	27.70*	1.804E+00	1.389E+00	1.389E+00	22.92

Nuclide Type: natural

Nuclide	Energy	Area	%Abn	%Eff	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	2-Sigma %Error
AC-228	835.50	------	1.75	1.963E+00	------	Line Not Found	------
	911.07	425	27.70*	1.804E+00	1.389E+00	1.403E+00	22.92

Flag: "*" = Keyline

Total number of lines in spectrum	21	
Number of unidentified lines	8	
Number of lines tentatively identified by NID	13	61.90%

Nuclide Type :

Nuclide	Hlife	Decay	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
K-40	1.28E+09Y	1.00	1.678E+01	1.678E+01	0.155E+01	9.26	
BI-214	1600.00Y	1.00	1.601E+00	1.601E+00	0.720E+00	44.98	
RA-226	1600.00Y	1.00	2.132E+00	2.132E+00	1.334E+00	62.56	
RA-228	5.75Y	1.01	1.458E+00	1.473E+00	0.436E+00	29.61	
TH-234	4.47E+09Y	1.00	8.176E-01	8.176E-01	7.805E-01	95.47	
			---------	---------			
	Total Activity :		2.279E+01	2.281E+01			

Nuclide Type : NATURAL

Nuclide	Hlife	Decay	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
TL-208	1.91Y	1.03	9.958E-01	1.028E+00	0.256E+00	24.92	
PB-212	1.91Y	1.03	1.207E+00	1.246E+00	0.105E+00	8.43	
PB-214	1600.00Y	1.00	1.464E+00	1.464E+00	0.170E+00	11.63	
TH-232	1.41E+10Y	1.00	1.389E+00	1.389E+00	0.318E+00	22.92	
			---------	---------			
	Total Activity :		5.055E+00	5.127E+00			

Nuclide Type : natural

Nuclide	Hlife	Decay	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
AC-228	5.75Y	1.01	1.389E+00	1.403E+00	0.322E+00	22.92	
			---------	---------			
	Total Activity :		1.389E+00	1.403E+00			

Grand Total Activity : 2.923E+01 2.934E+01

Flags: "K" = Keyline not found "M" = Manually accepted
"E" = Manually edited "A" = Nuclide specific abn. limit

It	Energy	Area	Bkgnd	FWHM	Channel	Left	Pw	Cts/Sec	%Err	%Eff	Flags
0	46.48	483	2243	1.10	91.59	86	11	7.78E-03	44.1	9.09E+00	
0	77.39	1096	2306	1.00	153.39	151	6	1.77E-02	16.5	1.09E+01	
2	84.71	283	1987	1.41	168.02	163	14	4.55E-03	65.9	1.07E+01	
2	87.29	487	1529	1.08	173.17	163	14	7.85E-03	29.9	1.06E+01	
2	90.16	356	1218	1.13	178.91	177	14	5.73E-03	30.5	1.04E+01	
4	241.82	644	1445	1.79	482.15	468	21	1.04E-02	25.8	5.63E+00	
0	338.34	426	1036	1.42	675.13	670	11	6.87E-03	30.7	4.34E+00	
0	511.35	383	1107	2.59	1021.04	1012	22	6.17E-03	58.5	3.08E+00	

Flags: "T" = Tentatively associated

Summary of Nuclide Activity

Total number of lines in spectrum	21	
Number of unidentified lines	8	
Number of lines tentatively identified by NID	13	61.90%

Nuclide Type :

Nuclide	Hlife	Decay	Wtd Mean Uncorrected pCi/g Dry	Wtd Mean Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
K-40	1.28E+09Y	1.00	1.678E+01	1.678E+01	0.155E+01	9.26	
BI-214	1600.00Y	1.00	1.470E+00	1.470E+00	0.189E+00	12.85	
RA-226	1600.00Y	1.00	2.132E+00	2.132E+00	1.334E+00	62.56	
RA-228	5.75Y	1.01	1.458E+00	1.473E+00	0.436E+00	29.61	
TH-234	4.47E+09Y	1.00	8.176E-01	8.176E-01	7.805E-01	95.47	
			---------	---------			
	Total Activity :		2.266E+01	2.268E+01			

Nuclide Type : NATURAL

Nuclide	Hlife	Decay	Wtd Mean Uncorrected pCi/g Dry	Wtd Mean Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
TL-208	1.91Y	1.03	9.958E-01	1.028E+00	0.256E+00	24.92	
PB-212	1.91Y	1.03	1.207E+00	1.246E+00	0.105E+00	8.43	
PB-214	1600.00Y	1.00	1.391E+00	1.391E+00	0.141E+00	10.16	
TH-232	1.41E+10Y	1.00	1.389E+00	1.389E+00	0.318E+00	22.92	
			---------	---------			
	Total Activity :		4.982E+00	5.054E+00			

Nuclide Type : natural

Nuclide	Hlife	Decay	Wtd Mean Uncorrected pCi/g Dry	Wtd Mean Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
AC-228	5.75Y	1.01	1.389E+00	1.403E+00	0.322E+00	22.92	
			---------	---------			
	Total Activity :		1.389E+00	1.403E+00			

Grand Total Activity : 2.903E+01 2.913E+01

Flags: "K" = Keyline not found "M" = Manually accepted
"E" = Manually edited "A" = Nuclide specific abn. limit

Interference Report

No interference correction performed

Combined Activity-MDA Report

---- Identified Nuclides ----

Nuclide	Activity (pCi/g Dry)	Act error	MDA (pCi/g Dry)	MDA error	Act/MDA
K-40	1.678E+01	1.555E+00	7.497E-01	0.000E+00	22.385
TL-208	1.028E+00	2.563E-01	2.157E-01	0.000E+00	4.768
PB-212	1.246E+00	1.050E-01	1.043E-01	0.000E+00	11.943
BI-214	1.470E+00	1.890E-01	5.569E-01	0.000E+00	2.640
PB-214	1.391E+00	1.414E-01	1.444E-01	0.000E+00	9.635
RA-226	2.132E+00	1.334E+00	1.296E+00	0.000E+00	1.644
AC-228	1.403E+00	3.216E-01	2.754E-01	0.000E+00	5.096
RA-228	1.473E+00	4.363E-01	5.049E-01	0.000E+00	2.918
TH-232	1.389E+00	3.182E-01	2.725E-01	0.000E+00	5.095
TH-234	8.176E-01	7.805E-01	7.981E-01	0.000E+00	1.024

---- Non-Identified Nuclides ----

Nuclide	Key-Line Activity (pCi/g Dry)	K.L. Ided	Act error	MDA (pCi/g Dry)	MDA error	Act/MDA
CO-60	6.016E-02		5.007E-02	8.966E-02	0.000E+00	0.671
CS-137	3.262E-02		4.891E-02	8.317E-02	0.000E+00	0.392
LA-138	1.077E-02		6.984E-02	1.232E-01	0.000E+00	0.087
BI-212	1.629E+00		6.298E-01	1.127E+00	0.000E+00	1.445
PA-234M	8.169E+00		5.190E+00	9.382E+00	0.000E+00	0.871
U-235	-1.355E-01		2.442E-01	3.662E-01	0.000E+00	-0.370
U-238	8.169E+00		5.190E+00	9.382E+00	0.000E+00	0.871

```
A,11L95403-4       ,03/18/2022 08:07,02/13/2022 13:37,   2.670E+01,L95403-4 SS AN
B,11L95403-4       ,NORMK                    ,02/10/2022 09:58,11S25121819
C,K-40     ,YES,   1.678E+01,   1.555E+00,   7.497E-01,,   22.385
C,TL-208   ,YES,   1.028E+00,   2.563E-01,   2.157E-01,,    4.768
C,PB-212   ,YES,   1.246E+00,   1.050E-01,   1.043E-01,,   11.943
C,BI-214   ,YES,   1.470E+00,   1.890E-01,   5.569E-01,,    2.640
C,PB-214   ,YES,   1.391E+00,   1.414E-01,   1.444E-01,,    9.635
C,RA-226   ,YES,   2.132E+00,   1.334E+00,   1.296E+00,,    1.644
C,AC-228   ,YES,   1.403E+00,   3.216E-01,   2.754E-01,,    5.096
C,RA-228   ,YES,   1.473E+00,   4.363E-01,   5.049E-01,,    2.918
C,TH-232   ,YES,   1.389E+00,   3.182E-01,   2.725E-01,,    5.095
C,TH-234   ,YES,   8.176E-01,   7.805E-01,   7.981E-01,,    1.024
C,CO-60    ,NO ,   6.016E-02,   5.007E-02,   8.966E-02,,    0.671
C,CS-137   ,NO ,   3.262E-02,   4.891E-02,   8.317E-02,,    0.392
C,LA-138   ,NO ,   1.077E-02,   6.984E-02,   1.232E-01,,    0.087
C,BI-212   ,NO ,   1.629E+00,   6.298E-01,   1.127E+00,,    1.445
C,PA-234M  ,NO ,   8.169E+00,   5.190E+00,   9.382E+00,,    0.871
C,U-235    ,NO ,  -1.355E-01,   2.442E-01,   3.662E-01,,   -0.370
C,U-238    ,NO ,   8.169E+00,   5.190E+00,   9.382E+00,,    0.871
```

Analyst:

VAX/VMS Teledyne Brown Eng. Laboratory Gamma Report: 19-MAR-2022 05:14:38.90
TBE13 31-TP10727B HpGe ******* Aquisition Date/Time: 18-MAR-2022 11:13:56.06

LIMS No., Customer Name, Client ID: L95403-5 SS ANCHOR QEA

Sample ID : 13L95403-5
Sample Type : SS
Quantity : 3.04000E+01 g Dry
Start Channel : 80 Energy Tol : 2.00000
End Channel : 4090 Pk Srch Sens: 9.00000
MDA Multiple : 4.6600 Library Used: NORMK
Peak Evaluation - Identified and Unidentfied

Smple Date: 13-FEB-2022 13:37:00.
Geometry : 13S25030421
BKGFILE : 13BG030422MT
Real Time : 0 18:00:15.23
Live time : 0 18:00:00.00

Pk	It	Energy	Area	Bkgnd	FWHM	Channel	%Eff	Cts/Sec	%Err	Fit
1	1	74.95*	168	1533	0.71	149.81	3.49E+00	2.59E-03	42.9	8.98E+00
2	1	77.15*	482	1120	0.84	154.19	3.83E+00	7.43E-03	13.5	3.92E+00
3	1	84.51*	162	1375	1.36	168.88	4.91E+00	2.51E-03	44.6	4.02E+00
4	1	87.30*	285	1007	0.90	174.44	5.29E+00	4.40E-03	20.5	3.30E+00
5	1	92.71*	430	1292	1.18	185.24	5.95E+00	6.63E-03	17.1	6.73E-01
6	1	185.74*	446	1395	1.29	370.86	7.62E+00	6.89E-03	17.9	2.76E+00
7	1	209.10	242	1084	1.02	417.49	7.11E+00	3.73E-03	24.4	6.71E-01
8	6	238.51*	2079	669	0.97	476.18	6.49E+00	3.21E-02	3.4	9.37E-01
9	6	241.47	614	1108	1.68	482.07	6.43E+00	9.48E-03	11.9	
10	1	295.06*	663	880	1.10	589.04	5.49E+00	1.02E-02	10.0	1.48E+00
11	1	299.84	206	673	1.12	598.57	5.42E+00	3.18E-03	22.8	1.26E+00
12	1	338.19*	489	785	1.32	675.12	4.91E+00	7.55E-03	13.0	1.55E+00
13	1	351.72*	1065	730	1.10	702.14	4.75E+00	1.64E-02	6.3	9.47E-01
14	1	510.66*	575	887	2.59	1019.47	3.44E+00	8.87E-03	15.7	1.83E+00
15	1	582.96*	634	326	1.38	1163.84	3.06E+00	9.79E-03	7.5	1.37E+00
16	1	609.03*	804	497	1.42	1215.89	2.94E+00	1.24E-02	7.2	4.52E-01
17	1	727.16*	113	297	1.29	1451.85	2.49E+00	1.74E-03	32.2	6.32E+00
18	1	910.89*	466	323	1.72	1818.95	2.00E+00	7.19E-03	10.9	1.16E+00
19	1	968.80*	272	270	2.12	1934.68	1.88E+00	4.19E-03	14.9	1.54E+00
20	1	1120.29*	139	166	1.92	2237.48	1.62E+00	2.14E-03	23.3	8.96E-01
21	1	1460.47*	1242	142	1.97	2917.78	1.25E+00	1.92E-02	4.2	9.22E-01
22	1	1763.91*	149	63	2.14	3524.99	1.05E+00	2.29E-03	16.7	1.38E+00

Flag: "*" = Peak area was modified by background subtraction

Nuclide Line Activity Report

Nuclide Type:

Nuclide	Energy	Area	%Abn	%Eff	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	2-Sigma %Error
K-40	1460.81	1242	10.67*	1.246E+00	1.282E+01	1.282E+01	8.31
BI-214	609.31	804	46.30	2.937E+00	8.115E-01	8.116E-01	14.41
	1120.29	139	15.10*	1.623E+00	7.773E-01	7.773E-01	46.62
	1764.49	149	15.80	1.054E+00	1.224E+00	1.224E+00	33.33
RA-226	186.21	446	3.28*	7.616E+00	2.451E+00	2.451E+00	35.88
RA-228	93.35	430	3.50	5.952E+00	2.832E+00	2.863E+00	34.29

	969.11	272	16.60*	1.881E+00	1.193E+00	1.206E+00	29.88
TH-234	63.29	------	3.80*	1.737E+00	------	Line Not Found	------
	92.60	430	5.41	5.952E+00	1.832E+00	1.832E+00	34.29
U-235	143.76	------	10.50*	8.228E+00	------	Line Not Found	------
	163.35	------	4.70	8.037E+00	------	Line Not Found	------
	185.71	446	54.00	7.616E+00	1.489E-01	1.489E-01	35.88
	205.31	------	4.70	7.191E+00	------	Line Not Found	------

Nuclide Type: NATURAL

					Uncorrected	Decay Corr	2-Sigma
Nuclide	Energy	Area	%Abn	%Eff	pCi/g Dry	pCi/g Dry	%Error
TL-208	583.17	634	30.25*	3.056E+00	9.416E-01	9.732E-01	15.04
BI-212	727.17	113	7.56*	2.491E+00	8.203E-01	8.479E-01	64.48
PB-212	238.63	2079	44.60*	6.489E+00	9.854E-01	1.019E+00	6.88
PB-214	295.21	663	19.20	5.494E+00	8.620E-01	8.621E-01	20.00
	351.92	1065	37.20*	4.746E+00	8.279E-01	8.279E-01	12.58
TH-232	911.21	466	27.70*	2.001E+00	1.154E+00	1.154E+00	21.81

Nuclide Type: natural

					Uncorrected	Decay Corr	2-Sigma
Nuclide	Energy	Area	%Abn	%Eff	pCi/g Dry	pCi/g Dry	%Error
AC-228	835.50	------	1.75	2.179E+00	------	Line Not Found	------
	911.07	466	27.70*	2.001E+00	1.154E+00	1.166E+00	21.81

Flag: "*" = Keyline

Total number of lines in spectrum 22
Number of unidentified lines 9
Number of lines tentatively identified by NID 13 59.09%

Nuclide Type :

Nuclide	Hlife	Decay	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
K-40	1.28E+09Y	1.00	1.282E+01	1.282E+01	0.106E+01	8.31	
BI-214	1600.00Y	1.00	7.773E-01	7.773E-01	3.624E-01	46.62	
RA-226	1600.00Y	1.00	2.451E+00	2.451E+00	0.879E+00	35.88	
RA-228	5.75Y	1.01	1.193E+00	1.206E+00	0.360E+00	29.88	
TH-234	4.47E+09Y	1.00	1.832E+00	1.832E+00	0.628E+00	34.29	K
U-235	7.04E+08Y	1.00	1.489E-01	1.489E-01	0.534E-01	35.88	K
			---------	---------			
	Total Activity :		1.922E+01	1.923E+01			

Nuclide Type : NATURAL

Nuclide	Hlife	Decay	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
TL-208	1.91Y	1.03	9.416E-01	9.732E-01	1.463E-01	15.04	
BI-212	1.91Y	1.03	8.203E-01	8.479E-01	5.467E-01	64.48	
PB-212	1.91Y	1.03	9.854E-01	1.019E+00	0.070E+00	6.88	
PB-214	1600.00Y	1.00	8.279E-01	8.279E-01	1.042E-01	12.58	
TH-232	1.41E+10Y	1.00	1.154E+00	1.154E+00	0.252E+00	21.81	
			---------	---------			
	Total Activity :		4.729E+00	4.821E+00			

Nuclide Type : natural

Nuclide	Hlife	Decay	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
AC-228	5.75Y	1.01	1.154E+00	1.166E+00	0.254E+00	21.81	
			---------	---------			
	Total Activity :		1.154E+00	1.166E+00			

Grand Total Activity : 2.510E+01 2.522E+01

Flags: "K" = Keyline not found "M" = Manually accepted
"E" = Manually edited "A" = Nuclide specific abn. limit

It	Energy	Area	Bkgnd	FWHM	Channel	Left	Pw	Cts/Sec	%Err	%Eff	Flags
1	74.95	168	1533	0.71	149.81	147	6	2.59E-03	85.7	3.49E+00	
1	77.15	482	1120	0.84	154.19	153	6	7.43E-03	27.0	3.83E+00	
1	84.51	162	1375	1.36	168.88	165	8	2.51E-03	89.1	4.91E+00	
1	87.30	285	1007	0.90	174.44	172	6	4.40E-03	41.0	5.29E+00	
1	209.10	242	1084	1.02	417.49	414	8	3.73E-03	48.7	7.11E+00	
6	241.47	614	1108	1.68	482.07	470	18	9.48E-03	23.7	6.43E+00	
1	299.84	206	673	1.12	598.57	595	8	3.18E-03	45.6	5.42E+00	
1	338.19	489	785	1.32	675.12	670	11	7.55E-03	26.1	4.91E+00	
1	510.66	575	887	2.59	1019.47	1012	19	8.87E-03	31.5	3.44E+00	

Flags: "T" = Tentatively associated

Summary of Nuclide Activity

Total number of lines in spectrum	22	
Number of unidentified lines	9	
Number of lines tentatively identified by NID	13	59.09%

Nuclide Type :

Nuclide	Hlife	Decay	Wtd Mean Uncorrected pCi/g Dry	Wtd Mean Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
K-40	1.28E+09Y	1.00	1.282E+01	1.282E+01	0.106E+01	8.31	
BI-214	1600.00Y	1.00	8.371E-01	8.371E-01	1.074E-01	12.83	
RA-226	1600.00Y	1.00	2.451E+00	2.451E+00	0.879E+00	35.88	
RA-228	5.75Y	1.01	1.193E+00	1.206E+00	0.360E+00	29.88	
			---------	---------			
	Total Activity :		1.730E+01	1.731E+01			

Nuclide Type : NATURAL

Nuclide	Hlife	Decay	Wtd Mean Uncorrected pCi/g Dry	Wtd Mean Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
TL-208	1.91Y	1.03	9.416E-01	9.732E-01	1.463E-01	15.04	
BI-212	1.91Y	1.03	8.203E-01	8.479E-01	5.467E-01	64.48	
PB-212	1.91Y	1.03	9.854E-01	1.019E+00	0.070E+00	6.88	
PB-214	1600.00Y	1.00	8.370E-01	8.370E-01	0.891E-01	10.65	
TH-232	1.41E+10Y	1.00	1.154E+00	1.154E+00	0.252E+00	21.81	
			---------	---------			
	Total Activity :		4.738E+00	4.830E+00			

Nuclide Type : natural

Nuclide	Hlife	Decay	Wtd Mean Uncorrected pCi/g Dry	Wtd Mean Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
AC-228	5.75Y	1.01	1.154E+00	1.166E+00	0.254E+00	21.81	
			---------	---------			
	Total Activity :		1.154E+00	1.166E+00			

Grand Total Activity : 2.319E+01 2.331E+01

Flags: "K" = Keyline not found "M" = Manually accepted
"E" = Manually edited "A" = Nuclide specific abn. limit

Interference Report

No interference correction performed

Combined Activity-MDA Report

---- Identified Nuclides ----

Nuclide	Activity (pCi/g Dry)	Act error	MDA (pCi/g Dry)	MDA error	Act/MDA
K-40	1.282E+01	1.065E+00	4.820E-01	0.000E+00	26.597
TL-208	9.732E-01	1.463E-01	1.243E-01	0.000E+00	7.829
BI-212	8.479E-01	5.467E-01	5.457E-01	0.000E+00	1.554
PB-212	1.019E+00	7.004E-02	5.823E-02	0.000E+00	17.492
BI-214	8.371E-01	1.074E-01	3.417E-01	0.000E+00	2.450
PB-214	8.370E-01	8.915E-02	8.110E-02	0.000E+00	10.321
RA-226	2.451E+00	8.794E-01	7.004E-01	0.000E+00	3.499
AC-228	1.166E+00	2.543E-01	1.692E-01	0.000E+00	6.892
RA-228	1.206E+00	3.605E-01	3.356E-01	0.000E+00	3.595
TH-232	1.154E+00	2.515E-01	1.674E-01	0.000E+00	6.891

---- Non-Identified Nuclides ----

Nuclide	Key-Line Activity (pCi/g Dry)	K.L. Ided	Act error	MDA (pCi/g Dry)	MDA error	Act/MDA
CO-60	-5.218E-03		3.143E-02	5.206E-02	0.000E+00	-0.100
CS-137	2.739E-02		3.084E-02	5.192E-02	0.000E+00	0.528
LA-138	-6.998E-04		4.726E-02	7.836E-02	0.000E+00	-0.009
PA-234M	2.694E+00		3.267E+00	5.601E+00	0.000E+00	0.481
TH-234	-2.048E-02		1.816E+00	2.663E+00	0.000E+00	-0.008
U-235	1.177E-01		1.302E-01	2.101E-01	0.000E+00	0.560
U-238	2.694E+00		3.267E+00	5.601E+00	0.000E+00	0.481

```
A,13L95403-5       ,03/19/2022 05:14,02/13/2022 13:37,   3.040E+01,L95403-5 SS AN
B,13L95403-5       ,NORMK                ,03/22/2021 07:43,13S25030421
C,K-40     ,YES,   1.282E+01,   1.065E+00,   4.820E-01,,   26.597
C,TL-208   ,YES,   9.732E-01,   1.463E-01,   1.243E-01,,    7.829
C,BI-212   ,YES,   8.479E-01,   5.467E-01,   5.457E-01,,    1.554
C,PB-212   ,YES,   1.019E+00,   7.004E-02,   5.823E-02,,   17.492
C,BI-214   ,YES,   8.371E-01,   1.074E-01,   3.417E-01,,    2.450
C,PB-214   ,YES,   8.370E-01,   8.915E-02,   8.110E-02,,   10.321
C,RA-226   ,YES,   2.451E+00,   8.794E-01,   7.004E-01,,    3.499
C,AC-228   ,YES,   1.166E+00,   2.543E-01,   1.692E-01,,    6.892
C,RA-228   ,YES,   1.206E+00,   3.605E-01,   3.356E-01,,    3.595
C,TH-232   ,YES,   1.154E+00,   2.515E-01,   1.674E-01,,    6.891
C,CO-60    ,NO ,  -5.218E-03,   3.143E-02,   5.206E-02,,   -0.100
C,CS-137   ,NO ,   2.739E-02,   3.084E-02,   5.192E-02,,    0.528
C,LA-138   ,NO ,  -6.998E-04,   4.726E-02,   7.836E-02,,   -0.009
C,PA-234M  ,NO ,   2.694E+00,   3.267E+00,   5.601E+00,,    0.481
C,TH-234   ,NO ,  -2.048E-02,   1.816E+00,   2.663E+00,,   -0.008
C,U-235    ,NO ,   1.177E-01,   1.302E-01,   2.101E-01,,    0.560
C,U-238    ,NO ,   2.694E+00,   3.267E+00,   5.601E+00,,    0.481
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Analyst:

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================================================================================
VAX/VMS Teledyne Brown Eng. Laboratory Gamma Report: 18-MAR-2022 08:07:05.12
TBE02 51-TP42214B HpGe ******* Aquisition Date/Time: 17-MAR-2022 14:52:09.95
--------------------------------------------------------------------------------
LIMS No., Customer Name, Client ID: L95403-6 SS ANCHOR QEA

Sample ID      : 02L95403-6                          Smple Date: 13-FEB-2022 13:37:00.
Sample Type    : SS                                  Geometry  : 02S25121819
Quantity       : 2.46000E+01 g Dry                   BKGFILE   : 02BG030422MT
Start Channel  : 80      Energy Tol   : 2.00000      Real Time : 0 17:14:54.85
End Channel    : 4090    Pk Srch Sens: 9.00000       Live time : 0 17:14:45.89
MDA Multiple   : 4.6600  Library Used: NORMK
Peak Evaluation - Identified and Unidentified
```

Pk	It	Energy	Area	Bkgnd	FWHM	Channel	%Eff	Cts/Sec	%Err	Fit
1	0	74.83*	135	1788	0.90	134.52	8.13E+00	2.18E-03	57.3	
2	0	77.17*	821	1377	0.79	139.23	8.44E+00	1.32E-02	8.5	
3	5	87.18*	311	1193	0.95	159.38	9.45E+00	5.01E-03	20.4	3.50E+00
4	0	92.93*	387	1470	1.37	170.95	9.81E+00	6.24E-03	21.4	
5	0	185.90*	358	1442	1.10	358.02	8.33E+00	5.77E-03	23.9	
6	0	209.36	273	1023	1.03	405.22	7.66E+00	4.40E-03	22.0	
7	5	238.61*	1891	616	1.00	464.09	6.92E+00	3.05E-02	3.5	1.17E+00
8	5	241.71*	574	1004	1.76	470.32	6.84E+00	9.24E-03	13.4	
9	0	269.95	201	751	1.15	527.14	6.25E+00	3.24E-03	25.5	
10	0	295.08*	591	903	1.07	577.71	5.79E+00	9.52E-03	11.7	
11	0	338.19*	388	659	1.22	664.47	5.15E+00	6.24E-03	14.2	
12	0	351.88*	916	903	1.17	692.02	4.97E+00	1.47E-02	8.3	
13	0	583.21*	491	442	1.45	1157.54	3.12E+00	7.91E-03	10.7	
14	0	609.21*	758	432	1.43	1209.87	2.99E+00	1.22E-02	7.5	
15	0	727.26	161	276	1.51	1447.45	2.51E+00	2.59E-03	22.1	
16	0	911.13*	406	166	1.62	1817.52	2.00E+00	6.54E-03	9.4	
17	0	968.88	238	201	1.34	1933.74	1.88E+00	3.84E-03	13.2	
18	0	1120.28*	149	187	1.79	2238.50	1.63E+00	2.41E-03	22.4	
19	0	1460.44*	1037	128	2.10	2923.24	1.26E+00	1.67E-02	4.5	
20	0	1764.31*	115	93	2.13	3535.00	1.08E+00	1.85E-03	25.0	

Flag: "*" = Peak area was modified by background subtraction

Nuclide Line Activity Report

Nuclide Type:

Nuclide	Energy	Area	%Abn	%Eff	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	2-Sigma %Error
K-40	1460.81	1037	10.67*	1.263E+00	1.362E+01	1.362E+01	9.07
BI-214	609.31	758	46.30	2.990E+00	9.685E-01	9.685E-01	15.09
	1120.29	149	15.10*	1.627E+00	1.076E+00	1.076E+00	44.71
	1764.49	115	15.80	1.083E+00	1.186E+00	1.186E+00	50.01
RA-226	186.21	358	3.28*	8.335E+00	2.320E+00	2.320E+00	47.88
RA-228	93.35	387	3.50	9.813E+00	1.995E+00	2.016E+00	42.89
	969.11	238	16.60*	1.883E+00	1.349E+00	1.363E+00	26.42
TH-234	63.29	------	3.80*	6.106E+00	------	Line Not Found	------

	92.60	387	5.41	9.813E+00	1.291E+00	1.291E+00	42.89
U-235	143.76	------	10.50*	9.647E+00	------	Line Not Found	------
	163.35	------	4.70	9.042E+00	------	Line Not Found	------
	185.71	358	54.00	8.335E+00	1.409E-01	1.409E-01	47.88
	205.31	------	4.70	7.767E+00	------	Line Not Found	------

Nuclide Type: NATURAL

Nuclide	Energy	Area	%Abn	%Eff	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	2-Sigma %Error
TL-208	583.17	491	30.25*	3.119E+00	9.211E-01	9.512E-01	21.45
BI-212	727.17	161	7.56*	2.514E+00	1.499E+00	1.548E+00	44.18
PB-212	238.63	1891	44.60*	6.915E+00	1.085E+00	1.121E+00	6.94
PB-214	295.21	591	19.20	5.795E+00	9.400E-01	9.401E-01	23.41
	351.92	916	37.20*	4.970E+00	8.763E-01	8.763E-01	16.53
TH-232	911.21	406	27.70*	2.004E+00	1.294E+00	1.294E+00	18.73

Nuclide Type: natural

Nuclide	Energy	Area	%Abn	%Eff	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	2-Sigma %Error
AC-228	835.50	------	1.75	2.188E+00	------	Line Not Found	------
	911.07	406	27.70*	2.004E+00	1.294E+00	1.308E+00	18.73

Flag: "*" = Keyline

Sample ID : 02L95403-6 Acquisition date : 17-MAR-2022 14:52:09

Total number of lines in spectrum	20	
Number of unidentified lines	7	
Number of lines tentatively identified by NID	13	65.00%

Nuclide Type :

Nuclide	Hlife	Decay	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
K-40	1.28E+09Y	1.00	1.362E+01	1.362E+01	0.124E+01	9.07	
BI-214	1600.00Y	1.00	1.076E+00	1.076E+00	0.481E+00	44.71	
RA-226	1600.00Y	1.00	2.320E+00	2.320E+00	1.111E+00	47.88	
RA-228	5.75Y	1.01	1.349E+00	1.363E+00	0.360E+00	26.42	
TH-234	4.47E+09Y	1.00	1.291E+00	1.291E+00	0.554E+00	42.89	K
U-235	7.04E+08Y	1.00	1.409E-01	1.409E-01	0.675E-01	47.88	K
			---------	---------			
	Total Activity :		1.979E+01	1.981E+01			

Nuclide Type : NATURAL

Nuclide	Hlife	Decay	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
TL-208	1.91Y	1.03	9.211E-01	9.512E-01	2.040E-01	21.45	
BI-212	1.91Y	1.03	1.499E+00	1.548E+00	0.684E+00	44.18	
PB-212	1.91Y	1.03	1.085E+00	1.121E+00	0.078E+00	6.94	
PB-214	1600.00Y	1.00	8.763E-01	8.763E-01	1.448E-01	16.53	
TH-232	1.41E+10Y	1.00	1.294E+00	1.294E+00	0.242E+00	18.73	
			---------	---------			
	Total Activity :		5.676E+00	5.790E+00			

Nuclide Type : natural

Nuclide	Hlife	Decay	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
AC-228	5.75Y	1.01	1.294E+00	1.308E+00	0.245E+00	18.73	
			---------	---------			
	Total Activity :		1.294E+00	1.308E+00			

Grand Total Activity : 2.676E+01 2.691E+01

Flags: "K" = Keyline not found "M" = Manually accepted
"E" = Manually edited "A" = Nuclide specific abn. limit

Sample ID : 02L95403-6 Acquisition date : 17-MAR-2022 14:52:09

It	Energy	Area	Bkgnd	FWHM	Channel	Left	Pw	Cts/Sec	%Err	%Eff	Flags
0	74.83	135	1788	0.90	134.52	132	6	2.18E-03	****	8.13E+00	
0	77.17	821	1377	0.79	139.23	137	6	1.32E-02	17.0	8.44E+00	
5	87.18	311	1193	0.95	159.38	150	14	5.01E-03	40.8	9.45E+00	
0	209.36	273	1023	1.03	405.22	401	9	4.40E-03	44.1	7.66E+00	
5	241.71	574	1004	1.76	470.32	458	18	9.24E-03	26.8	6.84E+00	
0	269.95	201	751	1.15	527.14	523	9	3.24E-03	51.0	6.25E+00	
0	338.19	388	659	1.22	664.47	661	9	6.24E-03	28.4	5.15E+00	

Flags: "T" = Tentatively associated

Summary of Nuclide Activity

Total number of lines in spectrum	20	
Number of unidentified lines	7	
Number of lines tentatively identified by NID	13	65.00%

Nuclide Type :

Nuclide	Hlife	Decay	Wtd Mean Uncorrected pCi/g Dry	Wtd Mean Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
K-40	1.28E+09Y	1.00	1.362E+01	1.362E+01	0.124E+01	9.07	
BI-214	1600.00Y	1.00	9.885E-01	9.886E-01	1.361E-01	13.77	
RA-226	1600.00Y	1.00	2.320E+00	2.320E+00	1.111E+00	47.88	
RA-228	5.75Y	1.01	1.349E+00	1.363E+00	0.360E+00	26.42	
			---------	---------			
	Total Activity :		1.828E+01	1.829E+01			

Nuclide Type : NATURAL

Nuclide	Hlife	Decay	Wtd Mean Uncorrected pCi/g Dry	Wtd Mean Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
TL-208	1.91Y	1.03	9.211E-01	9.512E-01	2.040E-01	21.45	
BI-212	1.91Y	1.03	1.499E+00	1.548E+00	0.684E+00	44.18	
PB-212	1.91Y	1.03	1.085E+00	1.121E+00	0.078E+00	6.94	
PB-214	1600.00Y	1.00	8.956E-01	8.956E-01	1.210E-01	13.51	
TH-232	1.41E+10Y	1.00	1.294E+00	1.294E+00	0.242E+00	18.73	
			---------	---------			
	Total Activity :		5.695E+00	5.809E+00			

Nuclide Type : natural

Nuclide	Hlife	Decay	Wtd Mean Uncorrected pCi/g Dry	Wtd Mean Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
AC-228	5.75Y	1.01	1.294E+00	1.308E+00	0.245E+00	18.73	
			---------	---------			
	Total Activity :		1.294E+00	1.308E+00			

Grand Total Activity : 2.526E+01 2.541E+01

Flags: "K" = Keyline not found "M" = Manually accepted
"E" = Manually edited "A" = Nuclide specific abn. limit

Interference Report

No interference correction performed

Combined Activity-MDA Report

---- Identified Nuclides ----

Nuclide	Activity (pCi/g Dry)	Act error	MDA (pCi/g Dry)	MDA error	Act/MDA
K-40	1.362E+01	1.235E+00	6.431E-01	0.000E+00	21.176
TL-208	9.512E-01	2.040E-01	1.581E-01	0.000E+00	6.017
BI-212	1.548E+00	6.840E-01	6.866E-01	0.000E+00	2.255
PB-212	1.121E+00	7.772E-02	7.368E-02	0.000E+00	15.210
BI-214	9.886E-01	1.361E-01	4.472E-01	0.000E+00	2.210
PB-214	8.956E-01	1.210E-01	1.017E-01	0.000E+00	8.809
RA-226	2.320E+00	1.111E+00	8.559E-01	0.000E+00	2.711
AC-228	1.308E+00	2.449E-01	1.978E-01	0.000E+00	6.611
RA-228	1.363E+00	3.602E-01	3.263E-01	0.000E+00	4.178
TH-232	1.294E+00	2.423E-01	1.957E-01	0.000E+00	6.610

---- Non-Identified Nuclides ----

Nuclide	Key-Line Activity (pCi/g Dry)	K.L. Ided	Act error	MDA (pCi/g Dry)	MDA error	Act/MDA
CO-60	1.763E-02		3.839E-02	6.545E-02	0.000E+00	0.269
CS-137	4.681E-02		3.647E-02	6.431E-02	0.000E+00	0.728
LA-138	-3.180E-03		5.866E-02	9.605E-02	0.000E+00	-0.033
PA-234M	-1.989E-01		4.702E+00	6.806E+00	0.000E+00	-0.029
TH-234	8.234E-01		8.431E-01	1.250E+00	0.000E+00	0.659
U-235	6.684E-02		1.804E-01	2.553E-01	0.000E+00	0.262
U-238	-1.989E-01		4.702E+00	6.806E+00	0.000E+00	-0.029

```
A,02L95403-6      ,03/18/2022 08:07,02/13/2022 13:37,   2.460E+01,L95403-6 SS AN
B,02L95403-6      ,NORMK                      ,08/20/2021 05:25,02S25121819
C,K-40     ,YES,   1.362E+01,    1.235E+00,    6.431E-01,,    21.176
C,TL-208   ,YES,   9.512E-01,    2.040E-01,    1.581E-01,,     6.017
C,BI-212   ,YES,   1.548E+00,    6.840E-01,    6.866E-01,,     2.255
C,PB-212   ,YES,   1.121E+00,    7.772E-02,    7.368E-02,,    15.210
C,BI-214   ,YES,   9.886E-01,    1.361E-01,    4.472E-01,,     2.210
C,PB-214   ,YES,   8.956E-01,    1.210E-01,    1.017E-01,,     8.809
C,RA-226   ,YES,   2.320E+00,    1.111E+00,    8.559E-01,,     2.711
C,AC-228   ,YES,   1.308E+00,    2.449E-01,    1.978E-01,,     6.611
C,RA-228   ,YES,   1.363E+00,    3.602E-01,    3.263E-01,,     4.178
C,TH-232   ,YES,   1.294E+00,    2.423E-01,    1.957E-01,,     6.610
C,CO-60    ,NO ,   1.763E-02,    3.839E-02,    6.545E-02,,     0.269
C,CS-137   ,NO ,   4.681E-02,    3.647E-02,    6.431E-02,,     0.728
C,LA-138   ,NO ,  -3.180E-03,    5.866E-02,    9.605E-02,,    -0.033
C,PA-234M  ,NO ,  -1.989E-01,    4.702E+00,    6.806E+00,,    -0.029
C,TH-234   ,NO ,   8.234E-01,    8.431E-01,    1.250E+00,,     0.659
C,U-235    ,NO ,   6.684E-02,    1.804E-01,    2.553E-01,,     0.262
C,U-238    ,NO ,  -1.989E-01,    4.702E+00,    6.806E+00,,    -0.029
```

Analyst:

VAX/VMS Teledyne Brown Eng. Laboratory Gamma Report: 19-MAR-2022 05:14:14.39
TBE23 11410 HpGe ********** Aquisition Date/Time: 18-MAR-2022 11:13:49.13

LIMS No., Customer Name, Client ID: L95403-7 SS ANCHOR QEA

Sample ID : 23L95403-7 Smple Date: 13-FEB-2022 13:37:00.
Sample Type : SS Geometry : 23S25122820
Quantity : 2.74000E+01 g Dry BKGFILE : 23BG030422MT
Start Channel : 80 Energy Tol : 2.00000 Real Time : 0 18:00:09.18
End Channel : 4090 Pk Srch Sens: 9.00000 Live time : 0 18:00:00.00
MDA Multiple : 4.6600 Library Used: NORMK
Peak Evaluation - Identified and Unidentified

Pk	It	Energy	Area	Bkgnd	FWHM	Channel	%Eff	Cts/Sec	%Err	Fit
1	0	46.42*	42	1950	0.94	93.11	4.06E+00	6.53E-04	216.6	
2	0	63.08*	277	1786	0.93	126.41	9.27E+00	4.28E-03	30.0	
3	3	74.76*	1237	1305	0.84	149.75	1.15E+01	1.91E-02	5.8	2.31E+00
4	3	77.07*	1909	1241	0.83	154.37	1.18E+01	2.95E-02	4.0	
5	3	84.08*	403	1332	1.24	168.38	1.25E+01	6.23E-03	17.6	4.83E+00
6	3	87.18*	933	1294	1.25	174.58	1.27E+01	1.44E-02	7.7	
7	3	89.81	667	1253	1.10	179.84	1.28E+01	1.03E-02	9.7	
8	3	92.68*	912	1382	1.26	185.58	1.29E+01	1.41E-02	9.3	
9	0	128.88	238	962	0.77	257.94	1.23E+01	3.68E-03	21.6	
10	0	185.83*	666	1666	1.14	371.79	1.01E+01	1.03E-02	14.0	
11	0	209.18	287	1050	1.07	418.46	9.31E+00	4.43E-03	20.4	
12	4	238.48*	3023	703	0.98	477.05	8.50E+00	4.67E-02	2.6	1.07E+00
13	4	241.36*	697	983	1.55	482.79	8.43E+00	1.08E-02	10.9	
14	0	270.16	314	823	1.23	540.39	7.78E+00	4.85E-03	17.4	
15	0	295.09*	771	885	0.93	590.24	7.29E+00	1.19E-02	8.3	
16	0	299.57*	96	732	0.96	599.19	7.21E+00	1.49E-03	58.4	
17	0	327.72	158	601	1.00	655.50	6.75E+00	2.44E-03	27.0	
18	0	338.27	740	841	1.05	676.59	6.59E+00	1.14E-02	8.4	
19	0	351.69*	1521	723	1.14	703.44	6.40E+00	2.35E-02	4.4	
20	0	462.66	221	392	1.24	925.39	5.17E+00	3.41E-03	16.9	
21	0	510.59*	315	850	2.12	1021.28	4.76E+00	4.86E-03	28.7	
22	0	582.91*	880	351	1.38	1165.98	4.25E+00	1.36E-02	6.0	
23	0	608.96*	1084	668	1.11	1218.10	4.08E+00	1.67E-02	6.2	
24	0	661.23	197	352	0.84	1322.72	3.79E+00	3.04E-03	18.6	
25	0	726.92*	209	319	1.56	1454.19	3.47E+00	3.23E-03	19.7	
26	0	859.91*	137	315	0.75	1720.44	2.94E+00	2.11E-03	30.8	
27	0	910.70*	681	218	1.70	1822.15	2.78E+00	1.05E-02	6.0	
28	0	968.60	447	187	1.45	1938.09	2.61E+00	6.90E-03	7.4	
29	0	1119.66*	240	304	1.88	2240.68	2.26E+00	3.70E-03	17.8	
30	0	1459.97*	1952	135	1.75	2922.75	1.78E+00	3.01E-02	2.8	
31	0	1763.28*	168	74	1.73	3531.11	1.57E+00	2.59E-03	14.2	

Flag: "*" = Peak area was modified by background subtraction

Nuclide Line Activity Report

Nuclide Type:

Nuclide	Energy	Area	%Abn	%Eff	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	2-Sigma %Error
K-40	1460.81	1952	10.67*	1.781E+00	1.564E+01	1.564E+01	5.59
CS-137	661.66	197	85.12*	3.789E+00	9.297E-02	9.317E-02	37.15
BI-214	609.31	1084	46.30	4.085E+00	8.727E-01	8.728E-01	12.44
	1120.29	240	15.10*	2.263E+00	1.069E+00	1.069E+00	35.60
	1764.49	168	15.80	1.574E+00	1.028E+00	1.028E+00	28.32
RA-226	186.21	666	3.28*	1.008E+01	3.068E+00	3.068E+00	28.07
RA-228	93.35	912	3.50	1.290E+01	3.077E+00	3.111E+00	18.52
	969.11	447	16.60*	2.613E+00	1.570E+00	1.587E+00	14.89
TH-234	63.29	277	3.80*	9.271E+00	1.198E+00	1.198E+00	60.06
	92.60	912	5.41	1.290E+01	1.990E+00	1.990E+00	18.52

Nuclide Type: NATURAL

Nuclide	Energy	Area	%Abn	%Eff	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	2-Sigma %Error
TL-208	583.17	880	30.25*	4.247E+00	1.043E+00	1.078E+00	12.09
BI-212	727.17	209	7.56*	3.466E+00	1.217E+00	1.257E+00	39.44
PB-212	238.63	3023	44.60*	8.500E+00	1.214E+00	1.255E+00	5.30
PB-214	295.21	771	19.20	7.294E+00	8.384E-01	8.384E-01	16.56
	351.92	1521	37.20*	6.403E+00	9.717E-01	9.717E-01	8.83
TH-232	911.21	681	27.70*	2.779E+00	1.346E+00	1.346E+00	12.03

Nuclide Type: natural

Nuclide	Energy	Area	%Abn	%Eff	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	2-Sigma %Error
AC-228	835.50	------	1.75	3.027E+00	------	Line Not Found	------
	911.07	681	27.70*	2.779E+00	1.346E+00	1.361E+00	12.03

Flag: "*" = Keyline

Total number of lines in spectrum	31	
Number of unidentified lines	16	
Number of lines tentatively identified by NID	15	48.39%

Nuclide Type :

Nuclide	Hlife	Decay	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
K-40	1.28E+09Y	1.00	1.564E+01	1.564E+01	0.087E+01	5.59	
CS-137	30.07Y	1.00	9.297E-02	9.317E-02	3.461E-02	37.15	
BI-214	1600.00Y	1.00	1.069E+00	1.069E+00	0.381E+00	35.60	
RA-226	1600.00Y	1.00	3.068E+00	3.068E+00	0.861E+00	28.07	
RA-228	5.75Y	1.01	1.570E+00	1.587E+00	0.236E+00	14.89	
TH-234	4.47E+09Y	1.00	1.198E+00	1.198E+00	0.720E+00	60.06	
			---------	---------			
	Total Activity :		2.263E+01	2.265E+01			

Nuclide Type : NATURAL

Nuclide	Hlife	Decay	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
TL-208	1.91Y	1.03	1.043E+00	1.078E+00	0.130E+00	12.09	
BI-212	1.91Y	1.03	1.217E+00	1.257E+00	0.496E+00	39.44	
PB-212	1.91Y	1.03	1.214E+00	1.255E+00	0.066E+00	5.30	
PB-214	1600.00Y	1.00	9.717E-01	9.717E-01	0.858E-01	8.83	
TH-232	1.41E+10Y	1.00	1.346E+00	1.346E+00	0.162E+00	12.03	
			---------	---------			
	Total Activity :		5.791E+00	5.907E+00			

Nuclide Type : natural

Nuclide	Hlife	Decay	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
AC-228	5.75Y	1.01	1.346E+00	1.361E+00	0.164E+00	12.03	
			---------	---------			
	Total Activity :		1.346E+00	1.361E+00			

Grand Total Activity : 2.977E+01 2.992E+01

Flags: "K" = Keyline not found "M" = Manually accepted
"E" = Manually edited "A" = Nuclide specific abn. limit

Sample ID : 23L95403-7 Acquisition date : 18-MAR-2022 11:13:49

It	Energy	Area	Bkgnd	FWHM	Channel	Left	Pw	Cts/Sec	%Err	%Eff	Flags
0	46.42	42	1950	0.94	93.11	90	9	6.53E-04	****	4.06E+00	
3	74.76	1237	1305	0.84	149.75	143	16	1.91E-02	11.6	1.15E+01	
3	77.07	1909	1241	0.83	154.37	143	16	2.95E-02	8.0	1.18E+01	
3	84.08	403	1332	1.24	168.38	165	27	6.23E-03	35.2	1.25E+01	
3	87.18	933	1294	1.25	174.58	165	27	1.44E-02	15.5	1.27E+01	
3	89.81	667	1253	1.10	179.84	165	27	1.03E-02	19.4	1.28E+01	
0	128.88	238	962	0.77	257.94	255	6	3.68E-03	43.2	1.23E+01	
0	209.18	287	1050	1.07	418.46	415	8	4.43E-03	40.9	9.31E+00	
4	241.36	697	983	1.55	482.79	470	22	1.08E-02	21.9	8.43E+00	
0	270.16	314	823	1.23	540.39	536	9	4.85E-03	34.7	7.78E+00	
0	299.57	96	732	0.96	599.19	596	8	1.49E-03	****	7.21E+00	
0	327.72	158	601	1.00	655.50	652	7	2.44E-03	54.0	6.75E+00	
0	338.27	740	841	1.05	676.59	672	11	1.14E-02	16.9	6.59E+00	
0	462.66	221	392	1.24	925.39	921	8	3.41E-03	33.9	5.17E+00	
0	510.59	315	850	2.12	1021.28	1014	18	4.86E-03	57.4	4.76E+00	
0	859.91	137	315	0.75	1720.44	1714	14	2.11E-03	61.6	2.94E+00	

Flags: "T" = Tentatively associated

Summary of Nuclide Activity

Total number of lines in spectrum 31
Number of unidentified lines 16
Number of lines tentatively identified by NID 15 48.39%

Nuclide Type :

Nuclide	Hlife	Decay	Wtd Mean Uncorrected pCi/g Dry	Wtd Mean Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
K-40	1.28E+09Y	1.00	1.564E+01	1.564E+01	0.087E+01	5.59	
CS-137	30.07Y	1.00	9.297E-02	9.317E-02	3.461E-02	37.15	
BI-214	1600.00Y	1.00	9.035E-01	9.035E-01	0.983E-01	10.88	
RA-226	1600.00Y	1.00	3.068E+00	3.068E+00	0.861E+00	28.07	
RA-228	5.75Y	1.01	1.570E+00	1.587E+00	0.236E+00	14.89	
TH-234	4.47E+09Y	1.00	1.198E+00	1.198E+00	0.720E+00	60.06	
			---------	---------			
	Total Activity :		2.247E+01	2.249E+01			

Nuclide Type : NATURAL

Nuclide	Hlife	Decay	Wtd Mean Uncorrected pCi/g Dry	Wtd Mean Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
TL-208	1.91Y	1.03	1.043E+00	1.078E+00	0.130E+00	12.09	
BI-212	1.91Y	1.03	1.217E+00	1.257E+00	0.496E+00	39.44	
PB-212	1.91Y	1.03	1.214E+00	1.255E+00	0.066E+00	5.30	
PB-214	1600.00Y	1.00	9.349E-01	9.349E-01	0.730E-01	7.81	
TH-232	1.41E+10Y	1.00	1.346E+00	1.346E+00	0.162E+00	12.03	
			---------	---------			
	Total Activity :		5.754E+00	5.871E+00			

Nuclide Type : natural

Nuclide	Hlife	Decay	Wtd Mean Uncorrected pCi/g Dry	Wtd Mean Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
AC-228	5.75Y	1.01	1.346E+00	1.361E+00	0.164E+00	12.03	

	---------	---------
Total Activity :	1.346E+00	1.361E+00
Grand Total Activity :	2.957E+01	2.972E+01

Flags: "K" = Keyline not found "M" = Manually accepted
"E" = Manually edited "A" = Nuclide specific abn. limit

Interference Report

No interference correction performed

Combined Activity-MDA Report

---- Identified Nuclides ----

Nuclide	Activity (pCi/g Dry)	Act error	MDA (pCi/g Dry)	MDA error	Act/MDA
K-40	1.564E+01	8.734E-01	4.145E-01	0.000E+00	37.724
CS-137	9.317E-02	3.461E-02	4.288E-02	0.000E+00	2.173
TL-208	1.078E+00	1.303E-01	1.048E-01	0.000E+00	10.282
BI-212	1.257E+00	4.959E-01	4.693E-01	0.000E+00	2.680
PB-212	1.255E+00	6.645E-02	5.560E-02	0.000E+00	22.565
BI-214	9.035E-01	9.831E-02	2.985E-01	0.000E+00	3.027
PB-214	9.349E-01	7.297E-02	7.113E-02	0.000E+00	13.143
RA-226	3.068E+00	8.611E-01	6.701E-01	0.000E+00	4.578
AC-228	1.361E+00	1.637E-01	1.403E-01	0.000E+00	9.700
RA-228	1.587E+00	2.363E-01	2.383E-01	0.000E+00	6.661
TH-232	1.346E+00	1.619E-01	1.422E-01	0.000E+00	9.462
TH-234	1.198E+00	7.196E-01	7.470E-01	0.000E+00	1.604

---- Non-Identified Nuclides ----

Nuclide	Key-Line Activity (pCi/g Dry)	K.L. Ided	Act error	MDA (pCi/g Dry)	MDA error	Act/MDA
CO-60	1.861E-02		2.722E-02	4.885E-02	0.000E+00	0.381
LA-138	1.714E-02		3.851E-02	6.854E-02	0.000E+00	0.250
PA-234M	1.181E+00		3.132E+00	4.945E+00	0.000E+00	0.239
U-235	-8.097E-03		1.265E-01	1.908E-01	0.000E+00	-0.042
U-238	1.181E+00		3.132E+00	4.945E+00	0.000E+00	0.239

A,23L95403-7 ,03/19/2022 05:14,02/13/2022 13:37, 2.740E+01,L95403-7 SS AN
B,23L95403-7 ,NORMK ,03/07/2022 09:36,23S25122820
C,K-40 ,YES, 1.564E+01, 8.734E-01, 4.145E-01,, 37.724
C,CS-137 ,YES, 9.317E-02, 3.461E-02, 4.288E-02,, 2.173
C,TL-208 ,YES, 1.078E+00, 1.303E-01, 1.048E-01,, 10.282
C,BI-212 ,YES, 1.257E+00, 4.959E-01, 4.693E-01,, 2.680
C,PB-212 ,YES, 1.255E+00, 6.645E-02, 5.560E-02,, 22.565
C,BI-214 ,YES, 9.035E-01, 9.831E-02, 2.985E-01,, 3.027
C,PB-214 ,YES, 9.349E-01, 7.297E-02, 7.113E-02,, 13.143
C,RA-226 ,YES, 3.068E+00, 8.611E-01, 6.701E-01,, 4.578
C,AC-228 ,YES, 1.361E+00, 1.637E-01, 1.403E-01,, 9.700
C,RA-228 ,YES, 1.587E+00, 2.363E-01, 2.383E-01,, 6.661
C,TH-232 ,YES, 1.346E+00, 1.619E-01, 1.422E-01,, 9.462
C,TH-234 ,YES, 1.198E+00, 7.196E-01, 7.470E-01,, 1.604
C,CO-60 ,NO , 1.861E-02, 2.722E-02, 4.885E-02,, 0.381
C,LA-138 ,NO , 1.714E-02, 3.851E-02, 6.854E-02,, 0.250
C,PA-234M ,NO , 1.181E+00, 3.132E+00, 4.945E+00,, 0.239
C,U-235 ,NO , -8.097E-03, 1.265E-01, 1.908E-01,, -0.042
C,U-238 ,NO , 1.181E+00, 3.132E+00, 4.945E+00,, 0.239

Analyst:

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VAX/VMS Teledyne Brown Eng. Laboratory Gamma Report: 19-MAR-2022 05:14:26.27
TBE06 33-TP10933A HpGe ******* Aquisition Date/Time: 18-MAR-2022 11:13:49.45

LIMS No., Customer Name, Client ID: L95403-8 SS ANCHOR QEA

Sample ID : 06L95403-8   Smple Date: 13-FEB-2022 13:37:00.
Sample Type : SS   Geometry : 06S50031621
Quantity : 4.59000E+01 g Dry   BKGFILE : 06BG030422MT
Start Channel : 80   Energy Tol : 2.00000   Real Time : 0 18:00:12.15
End Channel : 4090   Pk Srch Sens: 9.00000   Live time : 0 18:00:00.00
MDA Multiple : 4.6600   Library Used: NORMK
Peak Evaluation - Identified and Unidentified

Pk	It	Energy	Area	Bkgnd	FWHM	Channel	%Eff	Cts/Sec	%Err	Fit
1	3	74.92*	454	1273	1.06	150.31	1.68E+00	7.01E-03	15.2	5.11E+00
2	3	77.10	625	1236	1.00	154.66	1.84E+00	9.64E-03	9.9	
3	0	87.11	210	1268	0.87	174.65	2.53E+00	3.25E-03	27.7	
4	0	93.31*	187	2211	1.46	187.03	2.90E+00	2.89E-03	51.4	
5	0	186.07*	396	1545	1.27	372.19	4.02E+00	6.11E-03	21.0	
6	4	238.76*	2290	962	1.15	477.39	3.48E+00	3.53E-02	3.4	2.25E+00
7	4	241.80	604	1482	1.77	483.45	3.45E+00	9.32E-03	14.2	
8	0	295.34*	646	1167	1.10	590.32	2.95E+00	9.97E-03	11.9	
9	0	338.41	535	975	1.18	676.30	2.63E+00	8.26E-03	11.7	
10	0	351.99*	1086	990	1.15	703.42	2.54E+00	1.68E-02	7.1	
11	0	511.11*	352	908	2.31	1021.03	1.83E+00	5.44E-03	26.2	
12	0	583.21*	817	662	1.39	1164.93	1.63E+00	1.26E-02	8.4	
13	0	609.49*	765	672	1.31	1217.38	1.57E+00	1.18E-02	8.4	
14	0	661.98	162	347	0.98	1322.15	1.46E+00	2.50E-03	22.2	
15	0	727.60*	131	329	1.33	1453.11	1.35E+00	2.02E-03	28.3	
16	0	911.63*	388	457	1.51	1820.40	1.11E+00	5.99E-03	13.9	
17	0	969.98*	193	419	1.50	1936.85	1.06E+00	2.97E-03	24.6	
18	0	1120.59*	220	258	1.55	2237.40	9.34E-01	3.39E-03	18.9	
19	0	1461.35*	1298	127	1.90	2917.36	7.48E-01	2.00E-02	4.0	
20	0	1765.29*	120	89	2.15	3523.76	6.42E-01	1.86E-03	23.1	

Flag: "*" = Peak area was modified by background subtraction

Nuclide Line Activity Report

Nuclide Type:

Nuclide	Energy	Area	%Abn	%Eff	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	2-Sigma %Error
K-40	1460.81	1298	10.67*	7.481E-01	1.478E+01	1.478E+01	7.95
CS-137	661.66	162	85.12*	1.462E+00	1.183E-01	1.186E-01	44.30
BI-214	609.31	765	46.30	1.570E+00	9.557E-01	9.558E-01	16.82
	1120.29	220	15.10*	9.340E-01	1.417E+00	1.417E+00	37.74
	1764.49	120	15.80	6.424E-01	1.078E+00	1.078E+00	46.30
RA-226	186.21	396	3.28*	4.017E+00	2.731E+00	2.731E+00	41.91
RA-228	93.35	187	3.50	2.901E+00	1.676E+00	1.695E+00	102.80
	969.11	193	16.60*	1.055E+00	9.986E-01	1.010E+00	49.26

TH-234	63.29	------	3.80*	8.696E-01	------	Line Not Found	------
	92.60	187	5.41	2.901E+00	1.084E+00	1.084E+00	102.80
U-235	143.76	------	10.50*	4.209E+00	------	Line Not Found	------
	163.35	------	4.70	4.183E+00	------	Line Not Found	------
	185.71	396	54.00	4.017E+00	1.659E-01	1.659E-01	41.91
	205.31	------	4.70	3.827E+00	------	Line Not Found	------

Nuclide Type: NATURAL

Nuclide	Energy	Area	%Abn	%Eff	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	2-Sigma %Error
TL-208	583.17	817	30.25*	1.632E+00	1.504E+00	1.555E+00	16.75
BI-212	727.17	131	7.56*	1.348E+00	1.169E+00	1.209E+00	56.52
PB-212	238.63	2290	44.60*	3.477E+00	1.342E+00	1.387E+00	6.78
PB-214	295.21	646	19.20	2.951E+00	1.036E+00	1.036E+00	23.78
	351.92	1086	37.20*	2.542E+00	1.044E+00	1.044E+00	14.29
TH-232	911.21	388	27.70*	1.112E+00	1.144E+00	1.144E+00	27.74

Nuclide Type: natural

Nuclide	Energy	Area	%Abn	%Eff	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	2-Sigma %Error
AC-228	835.50	------	1.75	1.198E+00	------	Line Not Found	------
	911.07	388	27.70*	1.112E+00	1.144E+00	1.157E+00	27.74

Flag: "*" = Keyline

Total number of lines in spectrum 20
Number of unidentified lines 6
Number of lines tentatively identified by NID 14 70.00%

Nuclide Type :

Nuclide	Hlife	Decay	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
K-40	1.28E+09Y	1.00	1.478E+01	1.478E+01	0.117E+01	7.95	
CS-137	30.07Y	1.00	1.183E-01	1.186E-01	0.525E-01	44.30	
BI-214	1600.00Y	1.00	1.417E+00	1.417E+00	0.535E+00	37.74	
RA-226	1600.00Y	1.00	2.731E+00	2.731E+00	1.144E+00	41.91	
RA-228	5.75Y	1.01	9.986E-01	1.010E+00	0.497E+00	49.26	
TH-234	4.47E+09Y	1.00	1.084E+00	1.084E+00	1.115E+00	102.80	K
U-235	7.04E+08Y	1.00	1.659E-01	1.659E-01	0.695E-01	41.91	K
			---------	---------			
	Total Activity :		2.129E+01	2.130E+01			

Nuclide Type : NATURAL

Nuclide	Hlife	Decay	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
TL-208	1.91Y	1.03	1.504E+00	1.555E+00	0.260E+00	16.75	
BI-212	1.91Y	1.03	1.169E+00	1.209E+00	0.683E+00	56.52	
PB-212	1.91Y	1.03	1.342E+00	1.387E+00	0.094E+00	6.78	
PB-214	1600.00Y	1.00	1.044E+00	1.044E+00	0.149E+00	14.29	
TH-232	1.41E+10Y	1.00	1.144E+00	1.144E+00	0.317E+00	27.74	
			---------	---------			
	Total Activity :		6.204E+00	6.338E+00			

Nuclide Type : natural

Nuclide	Hlife	Decay	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
AC-228	5.75Y	1.01	1.144E+00	1.157E+00	0.321E+00	27.74	
			---------	---------			
	Total Activity :		1.144E+00	1.157E+00			

Grand Total Activity : 2.864E+01 2.880E+01

Flags: "K" = Keyline not found "M" = Manually accepted
"E" = Manually edited "A" = Nuclide specific abn. limit

Sample ID : 06L95403-8 Acquisition date : 18-MAR-2022 11:13:49

It	Energy	Area	Bkgnd	FWHM	Channel	Left	Pw	Cts/Sec	%Err	%Eff	Flags
3	74.92	454	1273	1.06	150.31	143	16	7.01E-03	30.4	1.68E+00	
3	77.10	625	1236	1.00	154.66	143	16	9.64E-03	19.7	1.84E+00	
0	87.11	210	1268	0.87	174.65	173	6	3.25E-03	55.4	2.53E+00	
4	241.80	604	1482	1.77	483.45	470	19	9.32E-03	28.4	3.45E+00	
0	338.41	535	975	1.18	676.30	672	10	8.26E-03	23.4	2.63E+00	
0	511.11	352	908	2.31	1021.03	1013	17	5.44E-03	52.4	1.83E+00	

Flags: "T" = Tentatively associated

Summary of Nuclide Activity

Total number of lines in spectrum	20	
Number of unidentified lines	6	
Number of lines tentatively identified by NID	14	70.00%

Nuclide Type :

Nuclide	Hlife	Decay	Wtd Mean Uncorrected pCi/g Dry	Wtd Mean Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
K-40	1.28E+09Y	1.00	1.478E+01	1.478E+01	0.117E+01	7.95	
CS-137	30.07Y	1.00	1.183E-01	1.186E-01	0.525E-01	44.30	
BI-214	1600.00Y	1.00	1.001E+00	1.001E+00	0.147E+00	14.69	
RA-226	1600.00Y	1.00	2.731E+00	2.731E+00	1.144E+00	41.91	
RA-228	5.75Y	1.01	9.986E-01	1.010E+00	0.497E+00	49.26	
			---------	---------			
	Total Activity :		1.962E+01	1.964E+01			

Nuclide Type : NATURAL

Nuclide	Hlife	Decay	Wtd Mean Uncorrected pCi/g Dry	Wtd Mean Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
TL-208	1.91Y	1.03	1.504E+00	1.555E+00	0.260E+00	16.75	
BI-212	1.91Y	1.03	1.169E+00	1.209E+00	0.683E+00	56.52	
PB-212	1.91Y	1.03	1.342E+00	1.387E+00	0.094E+00	6.78	
PB-214	1600.00Y	1.00	1.042E+00	1.042E+00	0.128E+00	12.25	
TH-232	1.41E+10Y	1.00	1.144E+00	1.144E+00	0.317E+00	27.74	
			---------	---------			
	Total Activity :		6.202E+00	6.336E+00			

Nuclide Type : natural

Nuclide	Hlife	Decay	Wtd Mean Uncorrected pCi/g Dry	Wtd Mean Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
AC-228	5.75Y	1.01	1.144E+00	1.157E+00	0.321E+00	27.74	
			---------	---------			
	Total Activity :		1.144E+00	1.157E+00			

Grand Total Activity : 2.697E+01 2.713E+01

Flags: "K" = Keyline not found "M" = Manually accepted
"E" = Manually edited "A" = Nuclide specific abn. limit

Interference Report

No interference correction performed

Combined Activity-MDA Report

---- Identified Nuclides ----

Nuclide	Activity (pCi/g Dry)	Act error	MDA (pCi/g Dry)	MDA error	Act/MDA
K-40	1.478E+01	1.174E+00	6.392E-01	0.000E+00	23.114
CS-137	1.186E-01	5.253E-02	6.648E-02	0.000E+00	1.784
TL-208	1.555E+00	2.604E-01	1.831E-01	0.000E+00	8.494
BI-212	1.209E+00	6.830E-01	8.377E-01	0.000E+00	1.443
PB-212	1.387E+00	9.398E-02	8.960E-02	0.000E+00	15.480
BI-214	1.001E+00	1.471E-01	4.066E-01	0.000E+00	2.463
PB-214	1.042E+00	1.276E-01	1.197E-01	0.000E+00	8.704
RA-226	2.731E+00	1.144E+00	1.113E+00	0.000E+00	2.454
AC-228	1.157E+00	3.208E-01	2.349E-01	0.000E+00	4.925
RA-228	1.010E+00	4.974E-01	4.351E-01	0.000E+00	2.321
TH-232	1.144E+00	3.173E-01	2.324E-01	0.000E+00	4.924

---- Non-Identified Nuclides ----

Nuclide	Key-Line Activity (pCi/g Dry)	K.L. Ided	Act error	MDA (pCi/g Dry)	MDA error	Act/MDA
CO-60	4.897E-02		4.137E-02	7.332E-02	0.000E+00	0.668
LA-138	2.065E-03		5.691E-02	9.494E-02	0.000E+00	0.022
PA-234M	2.378E+00		4.473E+00	7.478E+00	0.000E+00	0.318
TH-234	-9.429E-02		2.785E+00	4.609E+00	0.000E+00	-0.020
U-235	1.180E-01		2.077E-01	3.376E-01	0.000E+00	0.349
U-238	2.378E+00		4.473E+00	7.478E+00	0.000E+00	0.318

```
A,06L95403-8        ,03/19/2022 05:14,02/13/2022 13:37,   4.590E+01,L95403-8 SS AN
B,06L95403-8        ,NORMK                   ,10/29/2021 09:14,06S50031621
C,K-40     ,YES,   1.478E+01,    1.174E+00,    6.392E-01,,   23.114
C,CS-137   ,YES,   1.186E-01,    5.253E-02,    6.648E-02,,    1.784
C,TL-208   ,YES,   1.555E+00,    2.604E-01,    1.831E-01,,    8.494
C,BI-212   ,YES,   1.209E+00,    6.830E-01,    8.377E-01,,    1.443
C,PB-212   ,YES,   1.387E+00,    9.398E-02,    8.960E-02,,   15.480
C,BI-214   ,YES,   1.001E+00,    1.471E-01,    4.066E-01,,    2.463
C,PB-214   ,YES,   1.042E+00,    1.276E-01,    1.197E-01,,    8.704
C,RA-226   ,YES,   2.731E+00,    1.144E+00,    1.113E+00,,    2.454
C,AC-228   ,YES,   1.157E+00,    3.208E-01,    2.349E-01,,    4.925
C,RA-228   ,YES,   1.010E+00,    4.974E-01,    4.351E-01,,    2.321
C,TH-232   ,YES,   1.144E+00,    3.173E-01,    2.324E-01,,    4.924
C,CO-60    ,NO ,   4.897E-02,    4.137E-02,    7.332E-02,,    0.668
C,LA-138   ,NO ,   2.065E-03,    5.691E-02,    9.494E-02,,    0.022
C,PA-234M  ,NO ,   2.378E+00,    4.473E+00,    7.478E+00,,    0.318
C,TH-234   ,NO ,  -9.429E-02,    2.785E+00,    4.609E+00,,   -0.020
C,U-235    ,NO ,   1.180E-01,    2.077E-01,    3.376E-01,,    0.349
C,U-238    ,NO ,   2.378E+00,    4.473E+00,    7.478E+00,,    0.318
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Analyst:

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VAX/VMS Teledyne Brown Eng. Laboratory Gamma Report: 19-MAR-2022 05:14:44.84
TBE07 31-TP10768B HpGe ******* Aquisition Date/Time: 18-MAR-2022 11:13:49.76
------------------------------------------------------------------------------------------
LIMS No., Customer Name, Client ID: L95403-9 SS ANCHOR QEA

Sample ID      : 07L95403-9                           Smple Date: 13-FEB-2022 13:37:00.
Sample Type    : SS                                   Geometry  : 07S25121819
Quantity       : 3.11000E+01 g Dry                    BKGFILE   : 07BG030422MT
Start Channel  : 80      Energy Tol   : 2.00000       Real Time : 0 18:00:26.81
End Channel    : 4090    Pk Srch Sens: 9.00000        Live time : 0 18:00:00.00
MDA Multiple   : 4.6600  Library Used: NORMK
Peak Evaluation - Identified and Unidentified
```

Pk	It	Energy	Area	Bkgnd	FWHM	Channel	%Eff	Cts/Sec	%Err	Fit
1	1	93.05*	320	2700	1.89	185.91	7.28E+00	4.93E-03	34.7	2.51E+00
2	1	185.76*	574	1962	2.10	371.39	8.06E+00	8.86E-03	17.5	3.28E+00
3	3	238.53*	2464	1502	1.83	476.97	6.95E+00	3.80E-02	4.0	2.47E+00
4	3	241.55	622	1583	1.99	483.02	6.89E+00	9.60E-03	15.1	
5	1	295.09*	750	1487	1.89	590.13	5.96E+00	1.16E-02	11.8	7.19E-01
6	1	338.11*	445	1355	1.82	676.19	5.37E+00	6.87E-03	19.4	3.46E+00
7	1	351.80*	1276	1377	2.00	703.58	5.20E+00	1.97E-02	7.5	1.44E+00
8	1	510.78*	301	1349	3.28	1021.59	3.82E+00	4.64E-03	40.0	2.05E+00
9	1	582.94*	749	778	2.54	1165.93	3.41E+00	1.16E-02	9.8	3.71E+00
10	1	609.11*	931	1021	2.34	1218.29	3.28E+00	1.44E-02	9.7	3.12E+00
11	1	910.55*	493	525	2.24	1821.20	2.27E+00	7.60E-03	12.9	8.50E-01
12	1	968.71*	249	446	2.38	1937.52	2.15E+00	3.84E-03	21.7	1.34E+00
13	1	1459.84*	1589	307	3.10	2919.65	1.49E+00	2.45E-02	4.5	2.60E+00
14	1	1763.15*	198	98	3.39	3526.08	1.29E+00	3.06E-03	18.6	2.13E+00

Flag: "*" = Peak area was modified by background subtraction

Nuclide Line Activity Report

Nuclide Type:

Nuclide	Energy	Area	%Abn	%Eff	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	2-Sigma %Error
K-40	1460.81	1589	10.67*	1.486E+00	1.344E+01	1.344E+01	9.02
BI-214	609.31	931	46.30	3.281E+00	8.219E-01	8.220E-01	19.34
	1120.29	------	15.10*	1.875E+00	------	Line Not Found	------
	1764.49	198	15.80	1.294E+00	1.299E+00	1.299E+00	37.24
RA-226	186.21	574	3.28*	8.057E+00	2.913E+00	2.913E+00	34.98
RA-228	93.35	320	3.50	7.276E+00	1.684E+00	1.702E+00	69.46
	969.11	249	16.60*	2.147E+00	9.357E-01	9.460E-01	43.45

Nuclide Type: NATURAL

Nuclide	Energy	Area	%Abn	%Eff	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	2-Sigma %Error
TL-208	583.17	749	30.25*	3.410E+00	9.733E-01	1.006E+00	19.61
PB-212	238.63	2464	44.60*	6.948E+00	1.066E+00	1.102E+00	7.95

PB-214	295.21	750	19.20	5.962E+00	8.789E-01	8.789E-01	23.68
	351.92	1276	37.20*	5.201E+00	8.845E-01	8.845E-01	15.08
TH-232	911.21	493	27.70*	2.274E+00	1.049E+00	1.049E+00	25.77

Nuclide Type: natural

Nuclide	Energy	Area	%Abn	%Eff	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	2-Sigma %Error
AC-228	835.50	------	1.75	2.464E+00	------	Line Not Found	------
	911.07	493	27.70*	2.274E+00	1.049E+00	1.060E+00	25.77

Flag: "*" = Keyline

Sample ID : 07L95403-9 Acquisition date : 18-MAR-2022 11:13:49

Total number of lines in spectrum 14
Number of unidentified lines 3
Number of lines tentatively identified by NID 11 78.57%

Nuclide Type :

Nuclide	Hlife	Decay	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
K-40	1.28E+09Y	1.00	1.344E+01	1.344E+01	0.121E+01	9.02	
BI-214	1600.00Y	1.00	8.219E-01	8.220E-01	1.589E-01	19.34	K
RA-226	1600.00Y	1.00	2.913E+00	2.913E+00	1.019E+00	34.98	
RA-228	5.75Y	1.01	9.357E-01	9.460E-01	4.111E-01	43.45	
			---------	---------			
	Total Activity :		1.811E+01	1.813E+01			

Nuclide Type : NATURAL

Nuclide	Hlife	Decay	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
TL-208	1.91Y	1.03	9.733E-01	1.006E+00	0.197E+00	19.61	
PB-212	1.91Y	1.03	1.066E+00	1.102E+00	0.088E+00	7.95	
PB-214	1600.00Y	1.00	8.845E-01	8.845E-01	1.334E-01	15.08	
TH-232	1.41E+10Y	1.00	1.049E+00	1.049E+00	0.270E+00	25.77	
			---------	---------			
	Total Activity :		3.973E+00	4.041E+00			

Nuclide Type : natural

Nuclide	Hlife	Decay	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
AC-228	5.75Y	1.01	1.049E+00	1.060E+00	0.273E+00	25.77	
			---------	---------			
	Total Activity :		1.049E+00	1.060E+00			

Grand Total Activity : 2.314E+01 2.323E+01

Flags: "K" = Keyline not found "M" = Manually accepted
"E" = Manually edited "A" = Nuclide specific abn. limit

Sample ID : 07L95403-9 Acquisition date : 18-MAR-2022 11:13:49

It	Energy	Area	Bkgnd	FWHM	Channel	Left	Pw	Cts/Sec	%Err	%Eff	Flags
3	241.55	622	1583	1.99	483.02	469	21	9.60E-03	30.3	6.89E+00	
1	338.11	445	1355	1.82	676.19	670	14	6.87E-03	38.7	5.37E+00	
1	510.78	301	1349	3.28	1021.59	1011	23	4.64E-03	79.9	3.82E+00	

Flags: "T" = Tentatively associated

Summary of Nuclide Activity

Total number of lines in spectrum	14	
Number of unidentified lines	3	
Number of lines tentatively identified by NID	11	78.57%

Nuclide Type :

Nuclide	Hlife	Decay	Wtd Mean Uncorrected pCi/g Dry	Wtd Mean Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
K-40	1.28E+09Y	1.00	1.344E+01	1.344E+01	0.121E+01	9.02	
BI-214	1600.00Y	1.00	8.684E-01	8.684E-01	1.510E-01	17.39	
RA-226	1600.00Y	1.00	2.913E+00	2.913E+00	1.019E+00	34.98	
RA-228	5.75Y	1.01	1.016E+00	1.028E+00	0.388E+00	37.79	
			---------	---------			
	Total Activity :		1.824E+01	1.825E+01			

Nuclide Type : NATURAL

Nuclide	Hlife	Decay	Wtd Mean Uncorrected pCi/g Dry	Wtd Mean Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
TL-208	1.91Y	1.03	9.733E-01	1.006E+00	0.197E+00	19.61	
PB-212	1.91Y	1.03	1.066E+00	1.102E+00	0.088E+00	7.95	
PB-214	1600.00Y	1.00	8.829E-01	8.829E-01	1.123E-01	12.72	
TH-232	1.41E+10Y	1.00	1.049E+00	1.049E+00	0.270E+00	25.77	
			---------	---------			
	Total Activity :		3.971E+00	4.040E+00			

Nuclide Type : natural

Nuclide	Hlife	Decay	Wtd Mean Uncorrected pCi/g Dry	Wtd Mean Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
AC-228	5.75Y	1.01	1.049E+00	1.060E+00	0.273E+00	25.77	
			---------	---------			
	Total Activity :		1.049E+00	1.060E+00			

Grand Total Activity : 2.326E+01 2.335E+01

Flags: "K" = Keyline not found "M" = Manually accepted
"E" = Manually edited "A" = Nuclide specific abn. limit

Interference Report

No interference correction performed

Combined Activity-MDA Report

---- Identified Nuclides ----

Nuclide	Activity (pCi/g Dry)	Act error	MDA (pCi/g Dry)	MDA error	Act/MDA
K-40	1.344E+01	1.212E+00	5.273E-01	0.000E+00	25.496
TL-208	1.006E+00	1.973E-01	1.581E-01	0.000E+00	6.363
PB-212	1.102E+00	8.760E-02	7.159E-02	0.000E+00	15.394
BI-214	8.684E-01	1.510E-01	5.283E-01	0.000E+00	1.644
PB-214	8.829E-01	1.123E-01	9.748E-02	0.000E+00	9.057
RA-226	2.913E+00	1.019E+00	8.913E-01	0.000E+00	3.268
AC-228	1.060E+00	2.732E-01	1.865E-01	0.000E+00	5.685
RA-228	1.028E+00	3.883E-01	3.753E-01	0.000E+00	2.738
TH-232	1.049E+00	2.702E-01	1.845E-01	0.000E+00	5.684

---- Non-Identified Nuclides ----

Nuclide	Key-Line Activity (pCi/g Dry)	K.L. Ided	Act error	MDA (pCi/g Dry)	MDA error	Act/MDA
CO-60	1.882E-02		3.556E-02	5.902E-02	0.000E+00	0.319
CS-137	4.678E-02		3.557E-02	6.081E-02	0.000E+00	0.769
LA-138	1.692E-02		5.040E-02	8.515E-02	0.000E+00	0.199
BI-212	1.094E+00		4.479E-01	7.845E-01	0.000E+00	1.395
PA-234M	3.917E+00		3.722E+00	6.399E+00	0.000E+00	0.612
TH-234	5.189E-01		1.512E+00	2.242E+00	0.000E+00	0.231
U-235	-1.392E-01		1.947E-01	2.834E-01	0.000E+00	-0.491
U-238	3.917E+00		3.722E+00	6.399E+00	0.000E+00	0.612

```
A,07L95403-9       ,03/19/2022 05:14,02/13/2022 13:37,   3.110E+01,L95403-9 SS AN
B,07L95403-9       ,NORMK                 ,08/12/2021 14:20,07S25121819
C,K-40      ,YES,   1.344E+01,   1.212E+00,   5.273E-01,,   25.496
C,TL-208    ,YES,   1.006E+00,   1.973E-01,   1.581E-01,,    6.363
C,PB-212    ,YES,   1.102E+00,   8.760E-02,   7.159E-02,,   15.394
C,BI-214    ,YES,   8.684E-01,   1.510E-01,   5.283E-01,,    1.644
C,PB-214    ,YES,   8.829E-01,   1.123E-01,   9.748E-02,,    9.057
C,RA-226    ,YES,   2.913E+00,   1.019E+00,   8.913E-01,,    3.268
C,AC-228    ,YES,   1.060E+00,   2.732E-01,   1.865E-01,,    5.685
C,RA-228    ,YES,   1.028E+00,   3.883E-01,   3.753E-01,,    2.738
C,TH-232    ,YES,   1.049E+00,   2.702E-01,   1.845E-01,,    5.684
C,CO-60     ,NO ,   1.882E-02,   3.556E-02,   5.902E-02,,    0.319
C,CS-137    ,NO ,   4.678E-02,   3.557E-02,   6.081E-02,,    0.769
C,LA-138    ,NO ,   1.692E-02,   5.040E-02,   8.515E-02,,    0.199
C,BI-212    ,NO ,   1.094E+00,   4.479E-01,   7.845E-01,,    1.395
C,PA-234M   ,NO ,   3.917E+00,   3.722E+00,   6.399E+00,,    0.612
C,TH-234    ,NO ,   5.189E-01,   1.512E+00,   2.242E+00,,    0.231
C,U-235     ,NO ,  -1.392E-01,   1.947E-01,   2.834E-01,,   -0.491
C,U-238     ,NO ,   3.917E+00,   3.722E+00,   6.399E+00,,    0.612
```

Analyst:

VAX/VMS Teledyne Brown Eng. Laboratory Gamma Report: 18-MAR-2022 08:07:13.85
TBE07 31-TP10768B HpGe ******* Aquisition Date/Time: 17-MAR-2022 14:52:10.17

LIMS No., Customer Name, Client ID: L95403-10 SS ANCHOR QEA

```
Sample ID      : 07L95403-10                      Smple Date: 13-FEB-2022 13:37:00.
Sample Type    : SS                               Geometry  : 07S25121819
Quantity       : 2.48000E+01 g Dry                BKGFILE   : 07BG030422MT
Start Channel  : 80       Energy Tol   : 2.00000  Real Time : 0 17:14:57.54
End Channel    : 4090     Pk Srch Sens: 9.00000   Live time : 0 17:14:38.09
MDA Multiple   : 4.6600   Library Used: NORMK
Peak Evaluation - Identified and Unidentified
```

Pk	It	Energy	Area	Bkgnd	FWHM	Channel	%Eff	Cts/Sec	%Err	Fit
1	2	74.94*	334	1726	1.41	149.69	5.05E+00	5.37E-03	27.3	1.07E+01
2	2	77.17*	742	1857	1.42	154.15	5.39E+00	1.20E-02	12.5	
3	1	185.81*	442	2050	2.10	371.49	8.06E+00	7.12E-03	24.1	9.47E-01
4	1	238.51*	1395	2061	1.44	476.92	6.95E+00	2.25E-02	7.3	1.72E+00
5	1	295.15*	575	1221	1.73	590.24	5.96E+00	9.27E-03	13.7	2.15E+00
6	1	338.09*	381	1275	1.99	676.14	5.37E+00	6.13E-03	21.8	1.09E+00
7	1	351.74*	1141	1486	1.94	703.46	5.20E+00	1.84E-02	9.0	2.41E+00
8	1	582.82*	638	736	2.50	1165.69	3.41E+00	1.03E-02	11.3	2.38E+00
9	1	608.94*	958	693	2.14	1217.95	3.28E+00	1.54E-02	7.5	1.36E+00
10	1	910.69*	420	430	2.11	1821.49	2.27E+00	6.76E-03	12.9	9.00E-01
11	1	968.53*	183	532	2.17	1937.17	2.15E+00	2.95E-03	32.4	1.02E+00
12	1	1459.91*	1084	347	2.81	2919.80	1.49E+00	1.75E-02	6.0	1.68E+00

Flag: "*" = Peak area was modified by background subtraction

Nuclide Line Activity Report

Nuclide Type:

Nuclide	Energy	Area	%Abn	%Eff	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	2-Sigma %Error
K-40	1460.81	1084	10.67*	1.486E+00	1.201E+01	1.201E+01	12.05
RA-226	186.21	442	3.28*	8.056E+00	2.935E+00	2.935E+00	48.13
RA-228	93.35	------	3.50	7.303E+00	------	Line Not Found	------
	969.11	183	16.60*	2.147E+00	9.021E-01	9.118E-01	64.89

Nuclide Type: NATURAL

Nuclide	Energy	Area	%Abn	%Eff	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	2-Sigma %Error
TL-208	583.17	638	30.25*	3.410E+00	1.085E+00	1.121E+00	22.56
PB-212	238.63	1395	44.60*	6.949E+00	7.900E-01	8.159E-01	14.65
PB-214	295.21	575	19.20	5.962E+00	8.826E-01	8.827E-01	27.41
	351.92	1141	37.20*	5.202E+00	1.035E+00	1.035E+00	18.09
TH-232	911.21	420	27.70*	2.274E+00	1.169E+00	1.169E+00	25.71

Nuclide Type: natural

Nuclide	Energy	Area	%Abn	%Eff	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	2-Sigma %Error
AC-228	835.50	------	1.75	2.464E+00	------	Line Not Found	------
	911.07	420	27.70*	2.274E+00	1.169E+00	1.182E+00	25.71

Flag: "*" = Keyline

Total number of lines in spectrum	12	
Number of unidentified lines	3	
Number of lines tentatively identified by NID	9	75.00%

Nuclide Type :

Nuclide	Hlife	Decay	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
K-40	1.28E+09Y	1.00	1.201E+01	1.201E+01	0.145E+01	12.05	
RA-226	1600.00Y	1.00	2.935E+00	2.935E+00	1.413E+00	48.13	
RA-228	5.75Y	1.01	9.021E-01	9.118E-01	5.917E-01	64.89	
			---------	---------			
	Total Activity :		1.584E+01	1.585E+01			

Nuclide Type : NATURAL

Nuclide	Hlife	Decay	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
TL-208	1.91Y	1.03	1.085E+00	1.121E+00	0.253E+00	22.56	
PB-212	1.91Y	1.03	7.900E-01	8.159E-01	1.195E-01	14.65	
PB-214	1600.00Y	1.00	1.035E+00	1.035E+00	0.187E+00	18.09	
TH-232	1.41E+10Y	1.00	1.169E+00	1.169E+00	0.301E+00	25.71	
			---------	---------			
	Total Activity :		4.080E+00	4.141E+00			

Nuclide Type : natural

Nuclide	Hlife	Decay	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
AC-228	5.75Y	1.01	1.169E+00	1.182E+00	0.304E+00	25.71	
			---------	---------			
	Total Activity :		1.169E+00	1.182E+00			

Grand Total Activity : 2.109E+01 2.118E+01

Flags: "K" = Keyline not found "M" = Manually accepted
"E" = Manually edited "A" = Nuclide specific abn. limit

It	Energy	Area	Bkgnd	FWHM	Channel	Left	Pw	Cts/Sec	%Err	%Eff	Flags
2	74.94	334	1726	1.41	149.69	142	22	5.37E-03	54.5	5.05E+00	
2	77.17	742	1857	1.42	154.15	142	22	1.20E-02	25.0	5.39E+00	
1	338.09	381	1275	1.99	676.14	669	14	6.13E-03	43.6	5.37E+00	
1	608.94	958	693	2.14	1217.95	1211	14	1.54E-02	15.0	3.28E+00	T

Flags: "T" = Tentatively associated

Summary of Nuclide Activity

Total number of lines in spectrum	12	
Number of unidentified lines	3	
Number of lines tentatively identified by NID	9	75.00%

Nuclide Type :

Nuclide	Hlife	Decay	Wtd Mean Uncorrected pCi/g Dry	Wtd Mean Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
K-40	1.28E+09Y	1.00	1.201E+01	1.201E+01	0.145E+01	12.05	
RA-226	1600.00Y	1.00	2.935E+00	2.935E+00	1.413E+00	48.13	
RA-228	5.75Y	1.01	9.021E-01	9.118E-01	5.917E-01	64.89	
			---------	---------			
	Total Activity :		1.584E+01	1.585E+01			

Nuclide Type : NATURAL

Nuclide	Hlife	Decay	Wtd Mean Uncorrected pCi/g Dry	Wtd Mean Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
TL-208	1.91Y	1.03	1.085E+00	1.121E+00	0.253E+00	22.56	
PB-212	1.91Y	1.03	7.900E-01	8.159E-01	1.195E-01	14.65	
PB-214	1600.00Y	1.00	9.780E-01	9.780E-01	1.481E-01	15.14	
TH-232	1.41E+10Y	1.00	1.169E+00	1.169E+00	0.301E+00	25.71	
			---------	---------			
	Total Activity :		4.023E+00	4.084E+00			

Nuclide Type : natural

Nuclide	Hlife	Decay	Wtd Mean Uncorrected pCi/g Dry	Wtd Mean Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
AC-228	5.75Y	1.01	1.169E+00	1.182E+00	0.304E+00	25.71	
			---------	---------			
	Total Activity :		1.169E+00	1.182E+00			

Grand Total Activity : 2.104E+01 2.112E+01

Flags: "K" = Keyline not found "M" = Manually accepted
"E" = Manually edited "A" = Nuclide specific abn. limit

Interference Report

No interference correction performed

Combined Activity-MDA Report

---- Identified Nuclides ----

Nuclide	Activity (pCi/g Dry)	Act error	MDA (pCi/g Dry)	MDA error	Act/MDA
K-40	1.201E+01	1.446E+00	6.847E-01	0.000E+00	17.536
TL-208	1.121E+00	2.528E-01	1.909E-01	0.000E+00	5.870
PB-212	8.159E-01	1.195E-01	1.214E-01	0.000E+00	6.722
PB-214	9.780E-01	1.481E-01	1.225E-01	0.000E+00	7.986
RA-226	2.935E+00	1.413E+00	1.110E+00	0.000E+00	2.644
AC-228	1.182E+00	3.039E-01	2.316E-01	0.000E+00	5.105
RA-228	9.118E-01	5.917E-01	4.541E-01	0.000E+00	2.008
TH-232	1.169E+00	3.007E-01	2.291E-01	0.000E+00	5.104

---- Non-Identified Nuclides ----

Nuclide	Key-Line Activity (pCi/g Dry)	K.L. Ided	Act error	MDA (pCi/g Dry)	MDA error	Act/MDA
CO-60	-3.353E-02		4.306E-02	6.657E-02	0.000E+00	-0.504
CS-137	3.526E-02		4.476E-02	7.550E-02	0.000E+00	0.467
LA-138	1.229E-02		6.669E-02	1.118E-01	0.000E+00	0.110
BI-212	1.268E+00		5.593E-01	9.779E-01	0.000E+00	1.297
BI-214	1.221E+00		4.013E-01	6.781E-01	0.000E+00	1.800
PA-234M	6.341E+00		4.587E+00	7.997E+00	0.000E+00	0.793
TH-234	-4.950E-01		1.878E+00	2.749E+00	0.000E+00	-0.180
U-235	-1.388E-03		2.391E-01	3.511E-01	0.000E+00	-0.004
U-238	6.341E+00		4.587E+00	7.997E+00	0.000E+00	0.793

```
A,07L95403-10      ,03/18/2022 08:07,02/13/2022 13:37,   2.480E+01,L95403-10 SS A
B,07L95403-10      ,NORMK                      ,08/12/2021 14:20,07S25121819
C,K-40     ,YES,   1.201E+01,   1.446E+00,   6.847E-01,,   17.536
C,TL-208   ,YES,   1.121E+00,   2.528E-01,   1.909E-01,,    5.870
C,PB-212   ,YES,   8.159E-01,   1.195E-01,   1.214E-01,,    6.722
C,PB-214   ,YES,   9.780E-01,   1.481E-01,   1.225E-01,,    7.986
C,RA-226   ,YES,   2.935E+00,   1.413E+00,   1.110E+00,,    2.644
C,AC-228   ,YES,   1.182E+00,   3.039E-01,   2.316E-01,,    5.105
C,RA-228   ,YES,   9.118E-01,   5.917E-01,   4.541E-01,,    2.008
C,TH-232   ,YES,   1.169E+00,   3.007E-01,   2.291E-01,,    5.104
C,CO-60    ,NO ,  -3.353E-02,   4.306E-02,   6.657E-02,,   -0.504
C,CS-137   ,NO ,   3.526E-02,   4.476E-02,   7.550E-02,,    0.467
C,LA-138   ,NO ,   1.229E-02,   6.669E-02,   1.118E-01,,    0.110
C,BI-212   ,NO ,   1.268E+00,   5.593E-01,   9.779E-01,,    1.297
C,BI-214   ,NO ,   1.221E+00,   4.013E-01,   6.781E-01,,    1.800
C,PA-234M  ,NO ,   6.341E+00,   4.587E+00,   7.997E+00,,    0.793
C,TH-234   ,NO ,  -4.950E-01,   1.878E+00,   2.749E+00,,   -0.180
C,U-235    ,NO ,  -1.388E-03,   2.391E-01,   3.511E-01,,   -0.004
C,U-238    ,NO ,   6.341E+00,   4.587E+00,   7.997E+00,,    0.793
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Analyst:

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VAX/VMS Teledyne Brown Eng. Laboratory Gamma Report: 18-MAR-2022 08:07:27.64
TBE14 54-TP42603C HpGe ******* Aquisition Date/Time: 17-MAR-2022 14:52:10.82

LIMS No., Customer Name, Client ID: L95403-11 SS ANCHOR QEA

Sample ID : 14L95403-11
Sample Type : SS
Quantity : 2.55000E+01 g Dry
Start Channel : 80 Energy Tol : 2.00000
End Channel : 4090 Pk Srch Sens: 9.00000
MDA Multiple : 4.6600 Library Used: NORMK
Peak Evaluation - Identified and Unidentified

Smple Date: 13-FEB-2022 12:56:00.
Geometry : 14S25121719
BKGFILE : 14BG030422MT
Real Time : 0 17:15:04.54
Live time : 0 17:14:52.79

Pk	It	Energy	Area	Bkgnd	FWHM	Channel	%Eff	Cts/Sec	%Err	Fit
1	1	74.90*	369	1557	0.74	146.95	7.22E+00	5.94E-03	19.4	1.06E+01
2	1	77.18	911	1328	0.84	151.52	7.57E+00	1.47E-02	7.1	1.49E+01
3	4	84.52*	33	1210	1.25	166.21	8.51E+00	5.29E-04	202.9	1.98E+00
4	4	87.19*	310	913	0.89	171.55	8.78E+00	4.99E-03	18.3	
5	1	92.95*	627	1687	1.77	183.08	9.27E+00	1.01E-02	14.7	4.47E+00
6	1	185.84*	377	1366	1.15	369.07	8.55E+00	6.07E-03	22.4	2.73E+00
7	7	238.61*	1770	595	1.05	474.74	7.10E+00	2.85E-02	3.7	2.87E+00
8	7	241.66	607	1004	1.90	480.83	7.02E+00	9.78E-03	12.4	
9	1	295.19*	574	856	0.98	588.03	5.91E+00	9.25E-03	11.7	1.37E+00
10	1	338.26	387	581	1.16	674.27	5.22E+00	6.23E-03	12.3	1.74E+00
11	1	351.98*	1002	667	1.17	701.73	5.03E+00	1.61E-02	6.3	1.20E+00
12	1	510.90*	81	736	2.47	1019.98	3.51E+00	1.31E-03	101.9	1.46E+00
13	1	583.03*	465	413	1.37	1164.42	3.07E+00	7.48E-03	10.9	1.06E+00
14	1	609.24*	766	365	1.32	1216.92	2.94E+00	1.23E-02	6.9	9.42E-01
15	1	911.05*	313	214	1.70	1821.40	1.94E+00	5.05E-03	11.6	5.51E-01
16	1	969.00*	206	177	1.81	1937.49	1.82E+00	3.32E-03	15.7	1.30E+00
17	1	1120.00*	217	120	2.71	2239.98	1.57E+00	3.49E-03	13.8	1.34E+00
18	1	1460.58*	1000	72	2.02	2922.33	1.21E+00	1.61E-02	4.3	1.45E+00
19	1	1764.08*	79	87	2.07	3530.53	1.04E+00	1.27E-03	32.4	1.30E+00

Flag: "*" = Peak area was modified by background subtraction

Nuclide Line Activity Report

Nuclide Type:

Nuclide	Energy	Area	%Abn	%Eff	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	2-Sigma %Error
K-40	1460.81	1000	10.67*	1.211E+00	1.321E+01	1.321E+01	8.55
BI-214	609.31	766	46.30	2.937E+00	9.608E-01	9.609E-01	13.72
	1120.29	217	15.10*	1.566E+00	1.564E+00	1.564E+00	27.70
	1764.49	79	15.80	1.037E+00	8.218E-01	8.219E-01	64.79
RA-226	186.21	377	3.28*	8.550E+00	2.292E+00	2.292E+00	44.80
RA-228	93.35	627	3.50	9.267E+00	3.299E+00	3.335E+00	29.39
	969.11	206	16.60*	1.817E+00	1.166E+00	1.179E+00	31.43
TH-234	63.29	------	3.80*	5.083E+00	------	Line Not Found	------
	92.60	627	5.41	9.267E+00	2.134E+00	2.134E+00	29.39

U-235	143.76	------	10.50*	9.757E+00	------	Line Not Found	------
	163.35	------	4.70	9.227E+00	------	Line Not Found	------
	185.71	377	54.00	8.550E+00	1.392E-01	1.392E-01	44.80
	205.31	------	4.70	7.978E+00	------	Line Not Found	------

Nuclide Type: NATURAL

Nuclide	Energy	Area	%Abn	%Eff	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	2-Sigma %Error
TL-208	583.17	465	30.25*	3.071E+00	8.539E-01	8.818E-01	21.82
PB-212	238.63	1770	44.60*	7.097E+00	9.548E-01	9.860E-01	7.32
PB-214	295.21	574	19.20	5.908E+00	8.642E-01	8.642E-01	23.31
	351.92	1002	37.20*	5.027E+00	9.150E-01	9.150E-01	12.67
TH-232	911.21	313	27.70*	1.938E+00	9.964E-01	9.964E-01	23.28

Nuclide Type: natural

Nuclide	Energy	Area	%Abn	%Eff	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	2-Sigma %Error
AC-228	835.50	------	1.75	2.121E+00	------	Line Not Found	------
	911.07	313	27.70*	1.938E+00	9.964E-01	1.007E+00	23.28

Flag: "*" = Keyline

Summary of Nuclide Activity
Sample ID : 14L95403-11

Acquisition date : 17-MAR-2022 14:52:10

Total number of lines in spectrum	19	
Number of unidentified lines	7	
Number of lines tentatively identified by NID	12	63.16%

Nuclide Type :

Nuclide	Hlife	Decay	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
K-40	1.28E+09Y	1.00	1.321E+01	1.321E+01	0.113E+01	8.55	
BI-214	1600.00Y	1.00	1.564E+00	1.564E+00	0.433E+00	27.70	
RA-226	1600.00Y	1.00	2.292E+00	2.292E+00	1.027E+00	44.80	
RA-228	5.75Y	1.01	1.166E+00	1.179E+00	0.371E+00	31.43	
TH-234	4.47E+09Y	1.00	2.134E+00	2.134E+00	0.627E+00	29.39	K
U-235	7.04E+08Y	1.00	1.392E-01	1.392E-01	0.624E-01	44.80	K
			---------	---------			
	Total Activity :		2.051E+01	2.052E+01			

Nuclide Type : NATURAL

Nuclide	Hlife	Decay	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
TL-208	1.91Y	1.03	8.539E-01	8.818E-01	1.925E-01	21.82	
PB-212	1.91Y	1.03	9.548E-01	9.860E-01	0.722E-01	7.32	
PB-214	1600.00Y	1.00	9.150E-01	9.150E-01	1.159E-01	12.67	
TH-232	1.41E+10Y	1.00	9.964E-01	9.964E-01	2.320E-01	23.28	
			---------	---------			
	Total Activity :		3.720E+00	3.779E+00			

Nuclide Type : natural

Nuclide	Hlife	Decay	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
AC-228	5.75Y	1.01	9.964E-01	1.007E+00	0.235E+00	23.28	
			---------	---------			
	Total Activity :		9.964E-01	1.007E+00			

Grand Total Activity : 2.522E+01 2.531E+01

Flags: "K" = Keyline not found "M" = Manually accepted
"E" = Manually edited "A" = Nuclide specific abn. limit

It	Energy	Area	Bkgnd	FWHM	Channel	Left	Pw	Cts/Sec	%Err	%Eff	Flags
1	74.90	369	1557	0.74	146.95	144	6	5.94E-03	38.9	7.22E+00	
1	77.18	911	1328	0.84	151.52	149	6	1.47E-02	14.3	7.57E+00	
4	84.52	33	1210	1.25	166.21	162	14	5.29E-04	****	8.51E+00	
4	87.19	310	913	0.89	171.55	162	14	4.99E-03	36.5	8.78E+00	
7	241.66	607	1004	1.90	480.83	470	17	9.78E-03	24.8	7.02E+00	
1	338.26	387	581	1.16	674.27	669	9	6.23E-03	24.6	5.22E+00	
1	510.90	81	736	2.47	1019.98	1013	18	1.31E-03	****	3.51E+00	

Flags: "T" = Tentatively associated

Summary of Nuclide Activity

Total number of lines in spectrum	19	
Number of unidentified lines	7	
Number of lines tentatively identified by NID	12	63.16%

Nuclide Type :

Nuclide	Hlife	Decay	Wtd Mean Uncorrected pCi/g Dry	Wtd Mean Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
K-40	1.28E+09Y	1.00	1.321E+01	1.321E+01	0.113E+01	8.55	
BI-214	1600.00Y	1.00	1.002E+00	1.002E+00	0.123E+00	12.25	
RA-226	1600.00Y	1.00	2.292E+00	2.292E+00	1.027E+00	44.80	
RA-228	5.75Y	1.01	1.166E+00	1.179E+00	0.371E+00	31.43	
			---------	---------			
	Total Activity :		1.767E+01	1.768E+01			

Nuclide Type : NATURAL

Nuclide	Hlife	Decay	Wtd Mean Uncorrected pCi/g Dry	Wtd Mean Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
TL-208	1.91Y	1.03	8.539E-01	8.818E-01	1.925E-01	21.82	
PB-212	1.91Y	1.03	9.548E-01	9.860E-01	0.722E-01	7.32	
PB-214	1600.00Y	1.00	9.024E-01	9.024E-01	1.005E-01	11.14	
TH-232	1.41E+10Y	1.00	9.964E-01	9.964E-01	2.320E-01	23.28	
			---------	---------			
	Total Activity :		3.707E+00	3.767E+00			

Nuclide Type : natural

Nuclide	Hlife	Decay	Wtd Mean Uncorrected pCi/g Dry	Wtd Mean Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
AC-228	5.75Y	1.01	9.964E-01	1.007E+00	0.235E+00	23.28	
			---------	---------			
	Total Activity :		9.964E-01	1.007E+00			

Grand Total Activity : 2.237E+01 2.246E+01

Flags: "K" = Keyline not found "M" = Manually accepted
"E" = Manually edited "A" = Nuclide specific abn. limit

Interference Report

No interference correction performed

Combined Activity-MDA Report

---- Identified Nuclides ----

Nuclide	Activity (pCi/g Dry)	Act error	MDA (pCi/g Dry)	MDA error	Act/MDA
K-40	1.321E+01	1.129E+00	5.472E-01	0.000E+00	24.143
TL-208	8.818E-01	1.925E-01	1.457E-01	0.000E+00	6.054
PB-212	9.860E-01	7.222E-02	6.547E-02	0.000E+00	15.060
BI-214	1.002E+00	1.227E-01	4.151E-01	0.000E+00	2.414
PB-214	9.024E-01	1.005E-01	9.283E-02	0.000E+00	9.721
RA-226	2.292E+00	1.027E+00	7.700E-01	0.000E+00	2.977
AC-228	1.007E+00	2.345E-01	1.956E-01	0.000E+00	5.149
RA-228	1.179E+00	3.705E-01	3.937E-01	0.000E+00	2.994
TH-232	9.964E-01	2.320E-01	1.936E-01	0.000E+00	5.148

---- Non-Identified Nuclides ----

Nuclide	Key-Line Activity (pCi/g Dry)	K.L. Ided	Act error	MDA (pCi/g Dry)	MDA error	Act/MDA
CO-60	-3.210E-03		3.552E-02	5.883E-02	0.000E+00	-0.055
CS-137	2.678E-02		3.921E-02	6.457E-02	0.000E+00	0.415
LA-138	4.274E-03		5.562E-02	9.262E-02	0.000E+00	0.046
BI-212	7.248E-01		4.450E-01	7.943E-01	0.000E+00	0.913
PA-234M	4.230E+00		3.951E+00	6.830E+00	0.000E+00	0.619
TH-234	1.237E+00		8.768E-01	1.328E+00	0.000E+00	0.932
U-235	2.024E-01		1.314E-01	2.267E-01	0.000E+00	0.893
U-238	4.230E+00		3.951E+00	6.830E+00	0.000E+00	0.619

```
A,14L95403-11       ,03/18/2022 08:07,02/13/2022 12:56,   2.550E+01,L95403-11 SS A
B,14L95403-11       ,NORMK                     ,08/11/2021 12:59,14S25121719
C,K-40      ,YES,   1.321E+01,    1.129E+00,    5.472E-01,,    24.143
C,TL-208    ,YES,   8.818E-01,    1.925E-01,    1.457E-01,,     6.054
C,PB-212    ,YES,   9.860E-01,    7.222E-02,    6.547E-02,,    15.060
C,BI-214    ,YES,   1.002E+00,    1.227E-01,    4.151E-01,,     2.414
C,PB-214    ,YES,   9.024E-01,    1.005E-01,    9.283E-02,,     9.721
C,RA-226    ,YES,   2.292E+00,    1.027E+00,    7.700E-01,,     2.977
C,AC-228    ,YES,   1.007E+00,    2.345E-01,    1.956E-01,,     5.149
C,RA-228    ,YES,   1.179E+00,    3.705E-01,    3.937E-01,,     2.994
C,TH-232    ,YES,   9.964E-01,    2.320E-01,    1.936E-01,,     5.148
C,CO-60     ,NO ,  -3.210E-03,    3.552E-02,    5.883E-02,,    -0.055
C,CS-137    ,NO ,   2.678E-02,    3.921E-02,    6.457E-02,,     0.415
C,LA-138    ,NO ,   4.274E-03,    5.562E-02,    9.262E-02,,     0.046
C,BI-212    ,NO ,   7.248E-01,    4.450E-01,    7.943E-01,,     0.913
C,PA-234M   ,NO ,   4.230E+00,    3.951E+00,    6.830E+00,,     0.619
C,TH-234    ,NO ,   1.237E+00,    8.768E-01,    1.328E+00,,     0.932
C,U-235     ,NO ,   2.024E-01,    1.314E-01,    2.267E-01,,     0.893
C,U-238     ,NO ,   4.230E+00,    3.951E+00,    6.830E+00,,     0.619
```

Analyst:

VAX/VMS Teledyne Brown Eng. Laboratory Gamma Report: 18-MAR-2022 08:07:27.82
TBE08 31-TP20610B HpGe ******** Aquisition Date/Time: 17-MAR-2022 14:52:11.25

LIMS No., Customer Name, Client ID: L95403-12 SS ANCHOR QEA

Sample ID : 08L95403-12
Sample Type : SS
Quantity : 2.69000E+01 g Dry
Start Channel : 80 Energy Tol : 2.00000
End Channel : 4090 Pk Srch Sens: 9.00000
MDA Multiple : 4.6600 Library Used: NORMK
Peak Evaluation - Identified and Unidentified

Smple Date: 13-FEB-2022 12:56:00.
Geometry : 08S25121919
BKGFILE : 08BG030422MT
Real Time : 0 17:15:07.49
Live time : 0 17:14:41.40

Pk	It	Energy	Area	Bkgnd	FWHM	Channel	%Eff	Cts/Sec	%Err	Fit
1	1	75.30*	0	1522	0.94	156.70	5.38E+00	3.25E-06	*****	1.70E+00
2	1	85.00*	26	1059	1.20	176.06	6.66E+00	4.21E-04	249.7	1.89E+00
3	1	93.28*	144	1413	1.76	192.58	7.47E+00	2.33E-03	55.9	3.71E+00
4	1	186.23*	25	1589	1.23	377.95	7.69E+00	3.97E-04	356.9	6.92E-01
5	1	239.09*	216	1213	1.27	483.37	6.48E+00	3.48E-03	34.5	9.91E-01
6	1	295.70*	240	866	1.43	596.25	5.45E+00	3.87E-03	27.0	8.37E-01
7	1	352.39*	323	716	1.71	709.30	4.68E+00	5.20E-03	20.5	1.42E+00
8	1	511.35*	33	825	2.77	1026.20	3.32E+00	5.39E-04	265.1	1.77E+00
9	1	583.77*	113	404	1.92	1170.55	2.93E+00	1.83E-03	42.8	1.42E+00
10	1	609.73*	348	623	1.96	1222.30	2.81E+00	5.61E-03	19.0	2.14E+00
11	1	911.27*	30	219	2.03	1823.20	1.89E+00	4.87E-04	126.8	1.45E+00
12	1	1120.18*	104	159	2.86	2239.36	1.54E+00	1.67E-03	31.3	1.97E+00
13	1	1461.06*	181	118	2.33	2918.17	1.21E+00	2.91E-03	22.3	1.51E+00
14	1	1765.09*	96	32	2.63	3523.35	1.05E+00	1.54E-03	23.4	1.23E+00

Flag: "*" = Peak area was modified by background subtraction

Nuclide Line Activity Report

Nuclide Type:

Nuclide	Energy	Area	%Abn	%Eff	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	2-Sigma %Error
K-40	1460.81	181	10.67*	1.209E+00	2.266E+00	2.266E+00	44.52
BI-214	609.31	348	46.30	2.808E+00	4.337E-01	4.337E-01	38.08
	1120.29	104	15.10*	1.542E+00	7.201E-01	7.201E-01	62.58
	1764.49	96	15.80	1.049E+00	9.355E-01	9.355E-01	46.79
RA-226	186.21	25	3.28*	7.690E+00	1.581E-01	1.582E-01	713.77

Nuclide Type: NATURAL

Nuclide	Energy	Area	%Abn	%Eff	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	2-Sigma %Error
TL-208	583.17	113	30.25*	2.929E+00	2.070E-01	2.138E-01	85.66
PB-212	238.63	216	44.60*	6.480E+00	1.210E-01	1.250E-01	69.07
PB-214	295.21	240	19.20	5.452E+00	3.714E-01	3.714E-01	53.91
	351.92	323	37.20*	4.679E+00	3.001E-01	3.001E-01	40.92

TH-232	911.21	30	27.70*	1.890E+00	9.349E-02	9.349E-02	253.55

Nuclide Type: natural

Nuclide	Energy	Area	%Abn	%Eff	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	2-Sigma %Error
AC-228	835.50	------	1.75	2.061E+00	------	Line Not Found	------
	911.07	30	27.70*	1.890E+00	9.349E-02	9.450E-02	253.55

Flag: "*" = Keyline

Sample ID : 08L95403-12 Acquisition date : 17-MAR-2022 14:52:11

Total number of lines in spectrum	14	
Number of unidentified lines	3	
Number of lines tentatively identified by NID	11	78.57%

Nuclide Type :

Nuclide	Hlife	Decay	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
K-40	1.28E+09Y	1.00	2.266E+00	2.266E+00	1.009E+00	44.52	
BI-214	1600.00Y	1.00	7.201E-01	7.201E-01	4.507E-01	62.58	
RA-226	1600.00Y	1.00	1.581E-01	1.582E-01	11.29E-01	713.77	
			---------	---------			
	Total Activity :		3.144E+00	3.144E+00			

Nuclide Type : NATURAL

Nuclide	Hlife	Decay	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
TL-208	1.91Y	1.03	2.070E-01	2.138E-01	1.831E-01	85.66	
PB-212	1.91Y	1.03	1.210E-01	1.250E-01	0.863E-01	69.07	
PB-214	1600.00Y	1.00	3.001E-01	3.001E-01	1.228E-01	40.92	
TH-232	1.41E+10Y	1.00	9.349E-02	9.349E-02	23.70E-02	253.55	
			---------	---------			
	Total Activity :		7.216E-01	7.324E-01			

Nuclide Type : natural

Nuclide	Hlife	Decay	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
AC-228	5.75Y	1.01	9.349E-02	9.450E-02	23.96E-02	253.55	
			---------	---------			
	Total Activity :		9.349E-02	9.450E-02			

Grand Total Activity : 3.959E+00 3.971E+00

Flags: "K" = Keyline not found "M" = Manually accepted
"E" = Manually edited "A" = Nuclide specific abn. limit

It	Energy	Area	Bkgnd	FWHM	Channel	Left	Pw	Cts/Sec	%Err	%Eff	Flags
1	75.30	0	1522	0.94	156.70	153	7	3.25E-06	****	5.38E+00	
1	85.00	26	1059	1.20	176.06	173	7	4.21E-04	****	6.66E+00	
1	93.28	144	1413	1.76	192.58	188	10	2.33E-03	****	7.47E+00	T
1	511.35	33	825	2.77	1026.20	1017	19	5.39E-04	****	3.32E+00	

Flags: "T" = Tentatively associated

Summary of Nuclide Activity

Total number of lines in spectrum 14
Number of unidentified lines 3
Number of lines tentatively identified by NID 11 78.57%

Nuclide Type :

Nuclide	Hlife	Decay	Wtd Mean Uncorrected pCi/g Dry	Wtd Mean Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
K-40	1.28E+09Y	1.00	2.266E+00	2.266E+00	1.009E+00	44.52	
BI-214	1600.00Y	1.00	5.197E-01	5.197E-01	1.462E-01	28.12	
RA-226	1600.00Y	1.00	1.581E-01	1.582E-01	11.29E-01	713.77	
			---------	---------			
	Total Activity :		2.944E+00	2.944E+00			

Nuclide Type : NATURAL

Nuclide	Hlife	Decay	Wtd Mean Uncorrected pCi/g Dry	Wtd Mean Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
TL-208	1.91Y	1.03	2.070E-01	2.138E-01	1.831E-01	85.66	
PB-212	1.91Y	1.03	1.210E-01	1.250E-01	0.863E-01	69.07	
PB-214	1600.00Y	1.00	3.196E-01	3.196E-01	1.047E-01	32.75	
TH-232	1.41E+10Y	1.00	9.349E-02	9.349E-02	23.70E-02	253.55	
			---------	---------			
	Total Activity :		7.411E-01	7.519E-01			

Nuclide Type : natural

Nuclide	Hlife	Decay	Wtd Mean Uncorrected pCi/g Dry	Wtd Mean Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
AC-228	5.75Y	1.01	9.349E-02	9.450E-02	23.96E-02	253.55	
			---------	---------			
	Total Activity :		9.349E-02	9.450E-02			

Grand Total Activity : 3.778E+00 3.790E+00

Flags: "K" = Keyline not found "M" = Manually accepted
"E" = Manually edited "A" = Nuclide specific abn. limit

Interference Report

No interference correction performed

Combined Activity-MDA Report

---- Identified Nuclides ----

Nuclide	Activity (pCi/g Dry)	Act error	MDA (pCi/g Dry)	MDA error	Act/MDA
K-40	2.266E+00	1.009E+00	5.480E-01	0.000E+00	4.135
TL-208	2.138E-01	1.831E-01	1.656E-01	0.000E+00	1.291
PB-212	1.250E-01	8.633E-02	7.932E-02	0.000E+00	1.576
BI-214	5.197E-01	1.462E-01	4.251E-01	0.000E+00	1.223
PB-214	3.196E-01	1.047E-01	1.076E-01	0.000E+00	2.971
RA-226	1.582E-01	1.129E+00	9.285E-01	0.000E+00	0.170
AC-228	9.450E-02	2.396E-01	1.974E-01	0.000E+00	0.479
TH-232	9.349E-02	2.370E-01	1.963E-01	0.000E+00	0.476

---- Non-Identified Nuclides ----

Nuclide	Key-Line Activity (pCi/g Dry)	K.L. Ided	Act error	MDA (pCi/g Dry)	MDA error	Act/MDA
CO-60	3.182E-02		3.506E-02	6.168E-02	0.000E+00	0.516
CS-137	-1.163E-02		3.622E-02	5.912E-02	0.000E+00	-0.197
LA-138	1.051E-02		5.619E-02	9.391E-02	0.000E+00	0.112
BI-212	2.862E-01		4.534E-01	7.651E-01	0.000E+00	0.374
RA-228	-2.899E-02		2.950E-01	4.197E-01	0.000E+00	-0.069
PA-234M	3.390E+00		3.971E+00	6.704E+00	0.000E+00	0.506
TH-234	-2.814E-01		1.237E+00	1.962E+00	0.000E+00	-0.143
U-235	1.243E-03		1.636E-01	2.739E-01	0.000E+00	0.005
U-238	3.390E+00		3.971E+00	6.704E+00	0.000E+00	0.506

```
A,08L95403-12      ,03/18/2022 08:07,02/13/2022 12:56,   2.690E+01,L95403-12 SS A
B,08L95403-12      ,NORMK                    ,11/17/2021 15:23,08S25121919
C,K-40     ,YES,   2.266E+00,   1.009E+00,   5.480E-01,,    4.135
C,TL-208   ,YES,   2.138E-01,   1.831E-01,   1.656E-01,,    1.291
C,PB-212   ,YES,   1.250E-01,   8.633E-02,   7.932E-02,,    1.576
C,BI-214   ,YES,   5.197E-01,   1.462E-01,   4.251E-01,,    1.223
C,PB-214   ,YES,   3.196E-01,   1.047E-01,   1.076E-01,,    2.971
C,RA-226   ,YES,   1.582E-01,   1.129E+00,   9.285E-01,,    0.170
C,AC-228   ,YES,   9.450E-02,   2.396E-01,   1.974E-01,,    0.479
C,TH-232   ,YES,   9.349E-02,   2.370E-01,   1.963E-01,,    0.476
C,CO-60    ,NO ,   3.182E-02,   3.506E-02,   6.168E-02,,    0.516
C,CS-137   ,NO ,  -1.163E-02,   3.622E-02,   5.912E-02,,   -0.197
C,LA-138   ,NO ,   1.051E-02,   5.619E-02,   9.391E-02,,    0.112
C,BI-212   ,NO ,   2.862E-01,   4.534E-01,   7.651E-01,,    0.374
C,RA-228   ,NO ,  -2.899E-02,   2.950E-01,   4.197E-01,,   -0.069
C,PA-234M  ,NO ,   3.390E+00,   3.971E+00,   6.704E+00,,    0.506
C,TH-234   ,NO ,  -2.814E-01,   1.237E+00,   1.962E+00,,   -0.143
C,U-235    ,NO ,   1.243E-03,   1.636E-01,   2.739E-01,,    0.005
C,U-238    ,NO ,   3.390E+00,   3.971E+00,   6.704E+00,,    0.506
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Analyst: [signature]

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VAX/VMS Teledyne Brown Eng. Laboratory Gamma Report: 18-MAR-2022 08:07:41.69
TBE23 11410 HpGe ********** Aquisition Date/Time: 17-MAR-2022 14:52:11.98

LIMS No., Customer Name, Client ID: L95403-13 SS ANCHOR QEA

Sample ID : 23L95403-13
Sample Type : SS
Quantity : 2.14000E+01 g Dry
Start Channel : 80 Energy Tol : 2.00000
End Channel : 4090 Pk Srch Sens: 9.00000
MDA Multiple : 4.6600 Library Used: NORMK
Peak Evaluation - Identified and Unidentified

Smple Date: 13-FEB-2022 12:56:00.
Geometry : 23S25122820
BKGFILE : 23BG030422MT
Real Time : 0 17:15:14.38
Live time : 0 17:15:06.03

Pk	It	Energy	Area	Bkgnd	FWHM	Channel	%Eff	Cts/Sec	%Err	Fit
1	0	46.13*	334	1859	0.95	92.54	3.97E+00	5.37E-03	28.5	
2	0	63.27*	58	1627	0.92	126.80	9.32E+00	9.27E-04	135.9	
3	2	74.78*	1054	1050	0.89	149.79	1.15E+01	1.70E-02	6.2	2.89E+00
4	2	77.04*	1551	941	0.86	154.31	1.18E+01	2.50E-02	4.5	
5	0	84.11*	202	1061	1.09	168.45	1.25E+01	3.26E-03	30.4	
6	0	86.94*	444	1414	1.07	174.10	1.27E+01	7.15E-03	16.0	
7	0	92.72*	538	1446	1.25	185.65	1.29E+01	8.66E-03	15.1	
8	0	185.76*	559	1309	1.19	371.64	1.01E+01	9.00E-03	14.7	
9	0	209.11	303	734	1.12	418.33	9.31E+00	4.88E-03	16.0	
10	6	238.48*	2220	666	0.99	477.04	8.50E+00	3.57E-02	3.3	1.71E+00
11	6	241.49*	619	957	1.67	483.07	8.42E+00	9.97E-03	12.2	
12	0	270.19	224	888	1.47	540.45	7.78E+00	3.61E-03	25.8	
13	0	295.04*	778	777	1.10	590.15	7.29E+00	1.25E-02	8.0	
14	0	338.11	536	784	1.00	676.27	6.60E+00	8.64E-03	11.0	
15	0	351.70*	1265	606	1.18	703.45	6.40E+00	2.04E-02	4.9	
16	0	462.59	134	383	1.09	925.26	5.17E+00	2.15E-03	26.8	
17	0	510.83*	411	733	1.95	1021.76	4.76E+00	6.62E-03	21.4	
18	0	582.92*	614	453	1.17	1166.00	4.25E+00	9.89E-03	9.1	
19	0	608.94*	1010	479	1.26	1218.06	4.08E+00	1.63E-02	5.5	
20	0	727.08*	213	338	1.20	1454.52	3.47E+00	3.44E-03	20.6	
21	0	860.33*	91	194	1.40	1721.27	2.94E+00	1.47E-03	34.3	
22	0	910.82*	388	231	1.51	1822.37	2.78E+00	6.25E-03	9.9	
23	0	968.43	306	209	1.60	1937.75	2.61E+00	4.93E-03	10.8	
24	0	1119.94*	170	174	1.37	2241.24	2.26E+00	2.74E-03	18.0	
25	0	1459.93*	1420	115	1.94	2922.68	1.78E+00	2.29E-02	3.3	
26	0	1763.21*	224	54	2.32	3530.96	1.57E+00	3.61E-03	10.7	

Flag: "*" = Peak area was modified by background subtraction

Nuclide Line Activity Report

Nuclide Type:

Nuclide	Energy	Area	%Abn	%Eff	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	2-Sigma %Error
K-40	1460.81	1420	10.67*	1.781E+00	1.520E+01	1.520E+01	6.68
BI-214	609.31	1010	46.30	4.085E+00	1.086E+00	1.086E+00	11.05

	1120.29	170	15.10*	2.263E+00	1.014E+00	1.014E+00	35.92
	1764.49	224	15.80	1.574E+00	1.834E+00	1.834E+00	21.33
RA-226	186.21	559	3.28*	1.008E+01	3.437E+00	3.438E+00	29.43
RA-228	93.35	538	3.50	1.290E+01	2.422E+00	2.448E+00	30.24
	969.11	306	16.60*	2.613E+00	1.434E+00	1.450E+00	21.58
TH-234	63.29	58	3.80*	9.319E+00	3.308E-01	3.308E-01	271.77
	92.60	538	5.41	1.290E+01	1.567E+00	1.567E+00	30.24

Nuclide Type: NATURAL

Nuclide	Energy	Area	%Abn	%Eff	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	2-Sigma %Error
TL-208	583.17	614	30.25*	4.247E+00	9.719E-01	1.004E+00	18.24
BI-212	727.17	213	7.56*	3.465E+00	1.657E+00	1.711E+00	41.17
PB-212	238.63	2220	44.60*	8.500E+00	1.191E+00	1.230E+00	6.60
PB-214	295.21	778	19.20	7.295E+00	1.129E+00	1.129E+00	16.03
	351.92	1265	37.20*	6.403E+00	1.080E+00	1.080E+00	9.75
TH-232	911.21	388	27.70*	2.779E+00	1.025E+00	1.025E+00	19.84

Nuclide Type: natural

Nuclide	Energy	Area	%Abn	%Eff	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	2-Sigma %Error
AC-228	835.50	------	1.75	3.027E+00	------	Line Not Found	------
	911.07	388	27.70*	2.779E+00	1.025E+00	1.037E+00	19.84

Flag: "*" = Keyline

Total number of lines in spectrum	26	
Number of unidentified lines	12	
Number of lines tentatively identified by NID	14	53.85%

Nuclide Type :

Nuclide	Hlife	Decay	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
K-40	1.28E+09Y	1.00	1.520E+01	1.520E+01	0.101E+01	6.68	
BI-214	1600.00Y	1.00	1.014E+00	1.014E+00	0.364E+00	35.92	
RA-226	1600.00Y	1.00	3.437E+00	3.438E+00	1.012E+00	29.43	
RA-228	5.75Y	1.01	1.434E+00	1.450E+00	0.313E+00	21.58	
TH-234	4.47E+09Y	1.00	3.308E-01	3.308E-01	8.989E-01	271.77	
		Total Activity :	2.142E+01	2.143E+01			

Nuclide Type : NATURAL

Nuclide	Hlife	Decay	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
TL-208	1.91Y	1.03	9.719E-01	1.004E+00	0.183E+00	18.24	
BI-212	1.91Y	1.03	1.657E+00	1.711E+00	0.704E+00	41.17	
PB-212	1.91Y	1.03	1.191E+00	1.230E+00	0.081E+00	6.60	
PB-214	1600.00Y	1.00	1.080E+00	1.080E+00	0.105E+00	9.75	
TH-232	1.41E+10Y	1.00	1.025E+00	1.025E+00	0.203E+00	19.84	
		Total Activity :	5.925E+00	6.050E+00			

Nuclide Type : natural

Nuclide	Hlife	Decay	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
AC-228	5.75Y	1.01	1.025E+00	1.037E+00	0.206E+00	19.84	
		Total Activity :	1.025E+00	1.037E+00			

Grand Total Activity : 2.837E+01 2.852E+01

Flags: "K" = Keyline not found "M" = Manually accepted
"E" = Manually edited "A" = Nuclide specific abn. limit

It	Energy	Area	Bkgnd	FWHM	Channel	Left	Pw	Cts/Sec	%Err	%Eff	Flags
0	46.13	334	1859	0.95	92.54	87	11	5.37E-03	57.1	3.97E+00	
2	74.78	1054	1050	0.89	149.79	144	21	1.70E-02	12.3	1.15E+01	
2	77.04	1551	941	0.86	154.31	144	21	2.50E-02	8.9	1.18E+01	
0	84.11	202	1061	1.09	168.45	166	6	3.26E-03	60.9	1.25E+01	
0	86.94	444	1414	1.07	174.10	172	7	7.15E-03	32.0	1.27E+01	
0	209.11	303	734	1.12	418.33	415	7	4.88E-03	31.9	9.31E+00	
6	241.49	619	957	1.67	483.07	472	17	9.97E-03	24.5	8.42E+00	
0	270.19	224	888	1.47	540.45	535	10	3.61E-03	51.6	7.78E+00	
0	338.11	536	784	1.00	676.27	671	11	8.64E-03	22.0	6.60E+00	
0	462.59	134	383	1.09	925.26	922	8	2.15E-03	53.6	5.17E+00	
0	510.83	411	733	1.95	1021.76	1014	19	6.62E-03	42.7	4.76E+00	
0	860.33	91	194	1.40	1721.27	1717	10	1.47E-03	68.5	2.94E+00	

Flags: "T" = Tentatively associated

Summary of Nuclide Activity

Total number of lines in spectrum	26	
Number of unidentified lines	12	
Number of lines tentatively identified by NID	14	53.85%

Nuclide Type :

Nuclide	Hlife	Decay	Wtd Mean Uncorrected pCi/g Dry	Wtd Mean Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
K-40	1.28E+09Y	1.00	1.520E+01	1.520E+01	0.101E+01	6.68	
BI-214	1600.00Y	1.00	1.079E+00	1.079E+00	0.114E+00	10.57	
RA-226	1600.00Y	1.00	3.437E+00	3.438E+00	1.012E+00	29.43	
RA-228	5.75Y	1.01	1.434E+00	1.450E+00	0.313E+00	21.58	
TH-234	4.47E+09Y	1.00	3.308E-01	3.308E-01	8.989E-01	271.77	
			---------	---------			
	Total Activity :		2.148E+01	2.150E+01			

Nuclide Type : NATURAL

Nuclide	Hlife	Decay	Wtd Mean Uncorrected pCi/g Dry	Wtd Mean Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
TL-208	1.91Y	1.03	9.719E-01	1.004E+00	0.183E+00	18.24	
BI-212	1.91Y	1.03	1.657E+00	1.711E+00	0.704E+00	41.17	
PB-212	1.91Y	1.03	1.191E+00	1.230E+00	0.081E+00	6.60	
PB-214	1600.00Y	1.00	1.093E+00	1.093E+00	0.091E+00	8.33	
TH-232	1.41E+10Y	1.00	1.025E+00	1.025E+00	0.203E+00	19.84	
			---------	---------			
	Total Activity :		5.938E+00	6.063E+00			

Nuclide Type : natural

Nuclide	Hlife	Decay	Wtd Mean Uncorrected pCi/g Dry	Wtd Mean Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
AC-228	5.75Y	1.01	1.025E+00	1.037E+00	0.206E+00	19.84	
			---------	---------			
	Total Activity :		1.025E+00	1.037E+00			

Grand Total Activity : 2.844E+01 2.860E+01

Flags: "K" = Keyline not found "M" = Manually accepted
"E" = Manually edited "A" = Nuclide specific abn. limit

Interference Report

No interference correction performed

Combined Activity-MDA Report

---- Identified Nuclides ----

Nuclide	Activity (pCi/g Dry)	Act error	MDA (pCi/g Dry)	MDA error	Act/MDA
K-40	1.520E+01	1.015E+00	4.903E-01	0.000E+00	31.003
TL-208	1.004E+00	1.830E-01	1.441E-01	0.000E+00	6.966
BI-212	1.711E+00	7.044E-01	5.815E-01	0.000E+00	2.942
PB-212	1.230E+00	8.120E-02	7.032E-02	0.000E+00	17.491
BI-214	1.079E+00	1.140E-01	3.550E-01	0.000E+00	3.039
PB-214	1.093E+00	9.105E-02	9.142E-02	0.000E+00	11.951
RA-226	3.438E+00	1.012E+00	8.055E-01	0.000E+00	4.267
AC-228	1.037E+00	2.057E-01	1.835E-01	0.000E+00	5.649
RA-228	1.450E+00	3.128E-01	2.869E-01	0.000E+00	5.054
TH-232	1.025E+00	2.035E-01	1.723E-01	0.000E+00	5.951
TH-234	3.308E-01	8.989E-01	9.145E-01	0.000E+00	0.362

---- Non-Identified Nuclides ----

Nuclide	Key-Line Activity (pCi/g Dry)	K.L. Ided	Act error	MDA (pCi/g Dry)	MDA error	Act/MDA
CO-60	1.518E-02		3.319E-02	5.925E-02	0.000E+00	0.256
CS-137	3.936E-02		3.155E-02	5.589E-02	0.000E+00	0.704
LA-138	1.418E-02		4.498E-02	8.022E-02	0.000E+00	0.177
PA-234M	-1.230E+00		3.940E+00	6.019E+00	0.000E+00	-0.204
U-235	-9.843E-02		1.595E-01	2.368E-01	0.000E+00	-0.416
U-238	-1.230E+00		3.940E+00	6.019E+00	0.000E+00	-0.204

```
A,23L95403-13      ,03/18/2022 08:07,02/13/2022 12:56,   2.140E+01,L95403-13 SS A
B,23L95403-13      ,NORMK                ,03/07/2022 09:36,23S25122820
C,K-40     ,YES,   1.520E+01,   1.015E+00,   4.903E-01,,   31.003
C,TL-208   ,YES,   1.004E+00,   1.830E-01,   1.441E-01,,    6.966
C,BI-212   ,YES,   1.711E+00,   7.044E-01,   5.815E-01,,    2.942
C,PB-212   ,YES,   1.230E+00,   8.120E-02,   7.032E-02,,   17.491
C,BI-214   ,YES,   1.079E+00,   1.140E-01,   3.550E-01,,    3.039
C,PB-214   ,YES,   1.093E+00,   9.105E-02,   9.142E-02,,   11.951
C,RA-226   ,YES,   3.438E+00,   1.012E+00,   8.055E-01,,    4.267
C,AC-228   ,YES,   1.037E+00,   2.057E-01,   1.835E-01,,    5.649
C,RA-228   ,YES,   1.450E+00,   3.128E-01,   2.869E-01,,    5.054
C,TH-232   ,YES,   1.025E+00,   2.035E-01,   1.723E-01,,    5.951
C,TH-234   ,YES,   3.308E-01,   8.989E-01,   9.145E-01,,    0.362
C,CO-60    ,NO ,   1.518E-02,   3.319E-02,   5.925E-02,,    0.256
C,CS-137   ,NO ,   3.936E-02,   3.155E-02,   5.589E-02,,    0.704
C,LA-138   ,NO ,   1.418E-02,   4.498E-02,   8.022E-02,,    0.177
C,PA-234M  ,NO ,  -1.230E+00,   3.940E+00,   6.019E+00,,   -0.204
C,U-235    ,NO ,  -9.843E-02,   1.595E-01,   2.368E-01,,   -0.416
C,U-238    ,NO ,  -1.230E+00,   3.940E+00,   6.019E+00,,   -0.204
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Analyst: [signature]

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VAX/VMS Teledyne Brown Eng. Laboratory Gamma Report: 19-MAR-2022 05:14:47.09
TBE11 59-TN51806A HpGe ******* Aquisition Date/Time: 18-MAR-2022 11:13:52.41

LIMS No., Customer Name, Client ID: L95403-14 SS ANCHOR QEA

Sample ID : 11L95403-14
Sample Type : SS
Quantity : 4.17000E+01 g Dry
Start Channel : 80 Energy Tol : 2.00000
End Channel : 4090 Pk Srch Sens: 9.00000
MDA Multiple : 4.6600 Library Used: NORMK
Peak Evaluation - Identified and Unidentified

Smple Date: 13-FEB-2022 12:56:00.
Geometry : 11S50121819
BKGFILE : 11BG030422MT
Real Time : 0 18:00:32.57
Live time : 0 18:00:00.00

Pk	It	Energy	Area	Bkgnd	FWHM	Channel	%Eff	Cts/Sec	%Err	Fit
1	0	46.49*	680	2219	1.14	91.61	6.56E+00	1.05E-02	15.9	
2	0	63.36*	275	2084	1.33	125.34	7.37E+00	4.25E-03	33.0	
3	0	77.36*	1294	2679	1.07	153.33	7.42E+00	2.00E-02	7.9	
4	3	84.68*	329	1666	1.55	167.97	7.33E+00	5.07E-03	26.2	1.67E+00
5	3	87.36*	507	1494	1.05	173.31	7.28E+00	7.82E-03	14.4	
6	0	92.95*	645	2202	1.42	184.50	7.17E+00	9.95E-03	16.6	
7	0	185.96*	405	2097	1.46	370.45	4.98E+00	6.25E-03	25.5	
8	0	209.46	219	1285	1.42	417.44	4.56E+00	3.38E-03	29.1	
9	3	238.86*	2671	1055	1.35	476.22	4.12E+00	4.12E-02	3.2	1.97E+00
10	3	241.79	735	1432	1.84	482.08	4.08E+00	1.13E-02	11.6	
11	0	295.32*	722	1271	1.44	589.12	3.47E+00	1.11E-02	11.2	
12	0	338.60	509	1047	1.16	675.65	3.09E+00	7.86E-03	12.7	
13	0	352.13*	1402	1159	1.54	702.69	2.99E+00	2.16E-02	6.3	
14	0	511.27*	350	1045	2.56	1020.88	2.18E+00	5.40E-03	31.1	
15	0	583.49*	664	548	1.56	1165.29	1.95E+00	1.02E-02	9.0	
16	0	609.72*	842	823	1.50	1217.72	1.87E+00	1.30E-02	9.1	
17	0	727.75	198	459	1.51	1453.72	1.62E+00	3.05E-03	23.5	
18	0	846.88*	98	409	1.80	1691.90	1.42E+00	1.52E-03	53.2	
19	0	911.39*	490	359	2.04	1820.89	1.34E+00	7.57E-03	10.6	
20	0	969.61*	295	412	1.56	1937.29	1.27E+00	4.55E-03	17.0	
21	0	1121.43*	137	352	2.04	2240.85	1.13E+00	2.12E-03	34.3	
22	0	1461.37*	1456	293	2.27	2920.56	9.01E-01	2.25E-02	4.5	
23	0	1765.80*	134	108	1.61	3529.25	7.61E-01	2.07E-03	22.8	

Flag: "*" = Peak area was modified by background subtraction

Nuclide Line Activity Report

Nuclide Type:

Nuclide	Energy	Area	%Abn	%Eff	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	2-Sigma %Error
K-40	1460.81	1456	10.67*	9.006E-01	1.515E+01	1.515E+01	9.01
BI-214	609.31	842	46.30	1.875E+00	9.706E-01	9.706E-01	18.20
	1120.29	137	15.10*	1.128E+00	8.076E-01	8.076E-01	68.63
	1764.49	134	15.80	7.611E-01	1.113E+00	1.113E+00	45.55
RA-226	186.21	405	3.28*	4.982E+00	2.480E+00	2.480E+00	50.95

RA-228	93.35	645	3.50	7.173E+00	2.568E+00	2.597E+00	33.16
	969.11	295	16.60*	1.273E+00	1.396E+00	1.411E+00	34.01
TH-234	63.29	275	3.80*	7.368E+00	9.842E-01	9.842E-01	66.05
	92.60	645	5.41	7.173E+00	1.662E+00	1.662E+00	33.16

Nuclide Type: NATURAL

Nuclide	Energy	Area	%Abn	%Eff	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	2-Sigma %Error
TL-208	583.17	664	30.25*	1.946E+00	1.128E+00	1.166E+00	18.06
BI-212	727.17	198	7.56*	1.616E+00	1.617E+00	1.671E+00	47.03
PB-212	238.63	2671	44.60*	4.120E+00	1.454E+00	1.503E+00	6.34
PB-214	295.21	722	19.20	3.467E+00	1.085E+00	1.085E+00	22.36
	351.92	1402	37.20*	2.990E+00	1.261E+00	1.261E+00	12.53
TH-232	911.21	490	27.70*	1.340E+00	1.321E+00	1.321E+00	21.15

Nuclide Type: natural

Nuclide	Energy	Area	%Abn	%Eff	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	2-Sigma %Error
AC-228	835.50	------	1.75	1.440E+00	------	Line Not Found	------
	911.07	490	27.70*	1.340E+00	1.321E+00	1.336E+00	21.15

Flag: "*" = Keyline

Total number of lines in spectrum 23
Number of unidentified lines 9
Number of lines tentatively identified by NID 14 60.87%

Nuclide Type :

Nuclide	Hlife	Decay	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
K-40	1.28E+09Y	1.00	1.515E+01	1.515E+01	0.136E+01	9.01	
BI-214	1600.00Y	1.00	8.076E-01	8.076E-01	5.542E-01	68.63	
RA-226	1600.00Y	1.00	2.480E+00	2.480E+00	1.263E+00	50.95	
RA-228	5.75Y	1.01	1.396E+00	1.411E+00	0.480E+00	34.01	
TH-234	4.47E+09Y	1.00	9.842E-01	9.842E-01	6.501E-01	66.05	
			---------	---------			
	Total Activity :		2.082E+01	2.084E+01			

Nuclide Type : NATURAL

Nuclide	Hlife	Decay	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
TL-208	1.91Y	1.03	1.128E+00	1.166E+00	0.211E+00	18.06	
BI-212	1.91Y	1.03	1.617E+00	1.671E+00	0.786E+00	47.03	
PB-212	1.91Y	1.03	1.454E+00	1.503E+00	0.095E+00	6.34	
PB-214	1600.00Y	1.00	1.261E+00	1.261E+00	0.158E+00	12.53	
TH-232	1.41E+10Y	1.00	1.321E+00	1.321E+00	0.280E+00	21.15	
			---------	---------			
	Total Activity :		6.782E+00	6.923E+00			

Nuclide Type : natural

Nuclide	Hlife	Decay	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
AC-228	5.75Y	1.01	1.321E+00	1.336E+00	0.283E+00	21.15	
			---------	---------			
	Total Activity :		1.321E+00	1.336E+00			

Grand Total Activity : 2.892E+01 2.909E+01

Flags: "K" = Keyline not found "M" = Manually accepted
"E" = Manually edited "A" = Nuclide specific abn. limit

It	Energy	Area	Bkgnd	FWHM	Channel	Left	Pw	Cts/Sec	%Err	%Eff	Flags
0	46.49	680	2219	1.14	91.61	87	11	1.05E-02	31.7	6.56E+00	
0	77.36	1294	2679	1.07	153.33	151	7	2.00E-02	15.8	7.42E+00	
3	84.68	329	1666	1.55	167.97	164	13	5.07E-03	52.4	7.33E+00	
3	87.36	507	1494	1.05	173.31	164	13	7.82E-03	28.8	7.28E+00	
0	209.46	219	1285	1.42	417.44	414	8	3.38E-03	58.3	4.56E+00	
3	241.79	735	1432	1.84	482.08	469	19	1.13E-02	23.1	4.08E+00	
0	338.60	509	1047	1.16	675.65	671	10	7.86E-03	25.4	3.09E+00	
0	511.27	350	1045	2.56	1020.88	1012	20	5.40E-03	62.1	2.18E+00	
0	846.88	98	409	1.80	1691.90	1684	15	1.52E-03	****	1.42E+00	

Flags: "T" = Tentatively associated

Summary of Nuclide Activity

Total number of lines in spectrum	23	
Number of unidentified lines	9	
Number of lines tentatively identified by NID	14	60.87%

Nuclide Type :

Nuclide	Hlife	Decay	Wtd Mean Uncorrected pCi/g Dry	Wtd Mean Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
K-40	1.28E+09Y	1.00	1.515E+01	1.515E+01	0.136E+01	9.01	
BI-214	1600.00Y	1.00	9.712E-01	9.712E-01	1.597E-01	16.45	
RA-226	1600.00Y	1.00	2.480E+00	2.480E+00	1.263E+00	50.95	
RA-228	5.75Y	1.01	1.396E+00	1.411E+00	0.480E+00	34.01	
TH-234	4.47E+09Y	1.00	9.842E-01	9.842E-01	6.501E-01	66.05	
			---------	---------			
	Total Activity :		2.098E+01	2.100E+01			

Nuclide Type : NATURAL

Nuclide	Hlife	Decay	Wtd Mean Uncorrected pCi/g Dry	Wtd Mean Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
TL-208	1.91Y	1.03	1.128E+00	1.166E+00	0.211E+00	18.06	
BI-212	1.91Y	1.03	1.617E+00	1.671E+00	0.786E+00	47.03	
PB-212	1.91Y	1.03	1.454E+00	1.503E+00	0.095E+00	6.34	
PB-214	1600.00Y	1.00	1.208E+00	1.208E+00	0.132E+00	10.96	
TH-232	1.41E+10Y	1.00	1.321E+00	1.321E+00	0.280E+00	21.15	
			---------	---------			
	Total Activity :		6.729E+00	6.870E+00			

Nuclide Type : natural

Nuclide	Hlife	Decay	Wtd Mean Uncorrected pCi/g Dry	Wtd Mean Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
AC-228	5.75Y	1.01	1.321E+00	1.336E+00	0.283E+00	21.15	
			---------	---------			
	Total Activity :		1.321E+00	1.336E+00			

Grand Total Activity : 2.903E+01 2.921E+01

Flags: "K" = Keyline not found "M" = Manually accepted
"E" = Manually edited "A" = Nuclide specific abn. limit

Interference Report

No interference correction performed

Combined Activity-MDA Report

---- Identified Nuclides ----

Nuclide	Activity (pCi/g Dry)	Act error	MDA (pCi/g Dry)	MDA error	Act/MDA
K-40	1.515E+01	1.365E+00	5.901E-01	0.000E+00	25.680
TL-208	1.166E+00	2.106E-01	1.934E-01	0.000E+00	6.030
BI-212	1.671E+00	7.860E-01	8.171E-01	0.000E+00	2.046
PB-212	1.503E+00	9.526E-02	8.974E-02	0.000E+00	16.747
BI-214	9.712E-01	1.597E-01	4.827E-01	0.000E+00	2.012
PB-214	1.208E+00	1.324E-01	1.236E-01	0.000E+00	9.777
RA-226	2.480E+00	1.263E+00	1.063E+00	0.000E+00	2.332
AC-228	1.336E+00	2.826E-01	2.405E-01	0.000E+00	5.555
RA-228	1.411E+00	4.801E-01	4.568E-01	0.000E+00	3.090
TH-232	1.321E+00	2.795E-01	2.379E-01	0.000E+00	5.554
TH-234	9.842E-01	6.501E-01	7.594E-01	0.000E+00	1.296

---- Non-Identified Nuclides ----

Nuclide	Key-Line Activity (pCi/g Dry)	K.L. Ided	Act error	MDA (pCi/g Dry)	MDA error	Act/MDA
CO-60	5.008E-03		3.931E-02	6.667E-02	0.000E+00	0.075
CS-137	1.830E-02		4.361E-02	7.346E-02	0.000E+00	0.249
LA-138	-2.932E-04		5.592E-02	9.768E-02	0.000E+00	-0.003
PA-234M	4.433E+00		4.301E+00	7.617E+00	0.000E+00	0.582
U-235	-2.692E-01		2.017E-01	2.921E-01	0.000E+00	-0.922
U-238	4.433E+00		4.301E+00	7.617E+00	0.000E+00	0.582

```
A,11L95403-14      ,03/19/2022 05:14,02/13/2022 12:56,   4.170E+01,L95403-14 SS A
B,11L95403-14      ,NORMK                          ,02/10/2022 09:58,11S50121819
C,K-40     ,YES,   1.515E+01,    1.365E+00,    5.901E-01,,    25.680
C,TL-208   ,YES,   1.166E+00,    2.106E-01,    1.934E-01,,     6.030
C,BI-212   ,YES,   1.671E+00,    7.860E-01,    8.171E-01,,     2.046
C,PB-212   ,YES,   1.503E+00,    9.526E-02,    8.974E-02,,    16.747
C,BI-214   ,YES,   9.712E-01,    1.597E-01,    4.827E-01,,     2.012
C,PB-214   ,YES,   1.208E+00,    1.324E-01,    1.236E-01,,     9.777
C,RA-226   ,YES,   2.480E+00,    1.263E+00,    1.063E+00,,     2.332
C,AC-228   ,YES,   1.336E+00,    2.826E-01,    2.405E-01,,     5.555
C,RA-228   ,YES,   1.411E+00,    4.801E-01,    4.568E-01,,     3.090
C,TH-232   ,YES,   1.321E+00,    2.795E-01,    2.379E-01,,     5.554
C,TH-234   ,YES,   9.842E-01,    6.501E-01,    7.594E-01,,     1.296
C,CO-60    ,NO ,   5.008E-03,    3.931E-02,    6.667E-02,,     0.075
C,CS-137   ,NO ,   1.830E-02,    4.361E-02,    7.346E-02,,     0.249
C,LA-138   ,NO ,  -2.932E-04,    5.592E-02,    9.768E-02,,    -0.003
C,PA-234M  ,NO ,   4.433E+00,    4.301E+00,    7.617E+00,,     0.582
C,U-235    ,NO ,  -2.692E-01,    2.017E-01,    2.921E-01,,    -0.922
C,U-238    ,NO ,   4.433E+00,    4.301E+00,    7.617E+00,,     0.582
```

Analyst:

VAX/VMS Teledyne Brown Eng. Laboratory Gamma Report: 18-MAR-2022 08:07:48.56
TBE06 33-TP10933A HpGe ******* Aquisition Date/Time: 17-MAR-2022 14:52:13.44

LIMS No., Customer Name, Client ID: L95403-15 SS ANCHOR QEA

Sample ID : 06L95403-15
Sample Type : SS
Quantity : 2.73000E+01 g Dry
Start Channel : 80 Energy Tol : 2.00000
End Channel : 4090 Pk Srch Sens: 9.00000
MDA Multiple : 4.6600 Library Used: NORMK
Peak Evaluation - Identified and Unidentified

Smple Date: 13-FEB-2022 12:56:00.
Geometry : 06S25031921
BKGFILE : 06BG030422MT
Real Time : 0 17:15:25.24
Live time : 0 17:15:14.02

Pk	It	Energy	Area	Bkgnd	FWHM	Channel	%Eff	Cts/Sec	%Err	Fit
1	0	77.22	365	1158	0.85	154.90	2.68E+00	5.88E-03	15.7	
2	0	92.95*	313	1500	1.71	186.30	4.44E+00	5.05E-03	25.5	
3	0	185.64*	276	1672	0.93	371.33	6.13E+00	4.45E-03	32.1	
4	4	238.73*	1535	878	1.10	477.32	5.23E+00	2.47E-02	4.6	1.02E+00
5	4	242.02	483	1056	1.77	483.90	5.18E+00	7.78E-03	13.2	
6	0	295.50*	501	1130	1.19	590.64	4.43E+00	8.07E-03	14.9	
7	0	338.40	439	804	1.18	676.28	3.96E+00	7.06E-03	12.6	
8	0	352.12*	1078	761	1.22	703.67	3.83E+00	1.74E-02	6.5	
9	0	583.24*	416	517	1.37	1164.99	2.48E+00	6.69E-03	12.9	
10	0	609.40*	742	604	1.23	1217.21	2.38E+00	1.20E-02	8.4	
11	0	911.59*	334	332	1.78	1820.33	1.65E+00	5.38E-03	14.7	
12	0	969.40*	214	316	1.69	1935.69	1.56E+00	3.45E-03	20.4	
13	0	1120.55*	112	290	1.39	2237.33	1.36E+00	1.80E-03	35.8	
14	0	1461.16*	935	58	1.67	2916.98	1.07E+00	1.50E-02	4.8	
15	0	1765.00*	133	96	1.90	3523.18	9.41E-01	2.14E-03	21.2	

Flag: "*" = Peak area was modified by background subtraction

Nuclide Line Activity Report

Nuclide Type:

Nuclide	Energy	Area	%Abn	%Eff	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	2-Sigma %Error
K-40	1460.81	935	10.67*	1.074E+00	1.300E+01	1.300E+01	9.61
BI-214	609.31	742	46.30	2.384E+00	1.072E+00	1.072E+00	16.87
	1120.29	112	15.10*	1.357E+00	8.709E-01	8.709E-01	71.67
	1764.49	133	15.80	9.412E-01	1.425E+00	1.425E+00	42.45
RA-226	186.21	276	3.28*	6.127E+00	2.192E+00	2.192E+00	64.30
RA-228	93.35	313	3.50	4.441E+00	3.214E+00	3.249E+00	51.09
	969.11	214	16.60*	1.555E+00	1.322E+00	1.337E+00	40.74
TH-234	63.29	------	3.80*	1.100E+00	------	Line Not Found	------
	92.60	313	5.41	4.441E+00	2.080E+00	2.080E+00	51.09
U-235	143.76	------	10.50*	6.538E+00	------	Line Not Found	------
	163.35	------	4.70	6.435E+00	------	Line Not Found	------
	185.71	276	54.00	6.127E+00	1.332E-01	1.332E-01	64.30
	205.31	------	4.70	5.795E+00	------	Line Not Found	------

Nuclide Type: NATURAL

Nuclide	Energy	Area	%Abn	%Eff	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	2-Sigma %Error
TL-208	583.17	416	30.25*	2.478E+00	8.836E-01	9.125E-01	25.72
PB-212	238.63	1535	44.60*	5.234E+00	1.048E+00	1.082E+00	9.14
PB-214	295.21	501	19.20	4.431E+00	9.393E-01	9.393E-01	29.72
	351.92	1078	37.20*	3.829E+00	1.207E+00	1.207E+00	12.92
TH-232	911.21	334	27.70*	1.648E+00	1.167E+00	1.167E+00	29.33

Nuclide Type: natural

Nuclide	Energy	Area	%Abn	%Eff	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	2-Sigma %Error
AC-228	835.50	------	1.75	1.788E+00	------	Line Not Found	------
	911.07	334	27.70*	1.648E+00	1.167E+00	1.179E+00	29.33

Flag: "*" = Keyline

Total number of lines in spectrum	15	
Number of unidentified lines	3	
Number of lines tentatively identified by NID	12	80.00%

Nuclide Type :

Nuclide	Hlife	Decay	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
K-40	1.28E+09Y	1.00	1.300E+01	1.300E+01	0.125E+01	9.61	
BI-214	1600.00Y	1.00	8.709E-01	8.709E-01	6.242E-01	71.67	
RA-226	1600.00Y	1.00	2.192E+00	2.192E+00	1.410E+00	64.30	
RA-228	5.75Y	1.01	1.322E+00	1.337E+00	0.545E+00	40.74	
TH-234	4.47E+09Y	1.00	2.080E+00	2.080E+00	1.063E+00	51.09	K
U-235	7.04E+08Y	1.00	1.332E-01	1.332E-01	0.856E-01	64.30	K
			---------	---------			
	Total Activity :		1.960E+01	1.961E+01			

Nuclide Type : NATURAL

Nuclide	Hlife	Decay	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
TL-208	1.91Y	1.03	8.836E-01	9.125E-01	2.347E-01	25.72	
PB-212	1.91Y	1.03	1.048E+00	1.082E+00	0.099E+00	9.14	
PB-214	1600.00Y	1.00	1.207E+00	1.207E+00	0.156E+00	12.92	
TH-232	1.41E+10Y	1.00	1.167E+00	1.167E+00	0.342E+00	29.33	
			---------	---------			
	Total Activity :		4.305E+00	4.368E+00			

Nuclide Type : natural

Nuclide	Hlife	Decay	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
AC-228	5.75Y	1.01	1.167E+00	1.179E+00	0.346E+00	29.33	
			---------	---------			
	Total Activity :		1.167E+00	1.179E+00			

Grand Total Activity : 2.507E+01 2.516E+01

Flags: "K" = Keyline not found "M" = Manually accepted
"E" = Manually edited "A" = Nuclide specific abn. limit

It	Energy	Area	Bkgnd	FWHM	Channel	Left	Pw	Cts/Sec	%Err	%Eff	Flags
0	77.22	365	1158	0.85	154.90	153	6	5.88E-03	31.5	2.68E+00	
4	242.02	483	1056	1.77	483.90	472	17	7.78E-03	26.3	5.18E+00	
0	338.40	439	804	1.18	676.28	672	9	7.06E-03	25.2	3.96E+00	

Flags: "T" = Tentatively associated

Summary of Nuclide Activity

Total number of lines in spectrum	15	
Number of unidentified lines	3	
Number of lines tentatively identified by NID	12	80.00%

Nuclide Type :

Nuclide	Hlife	Decay	Wtd Mean Uncorrected pCi/g Dry	Wtd Mean Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
K-40	1.28E+09Y	1.00	1.300E+01	1.300E+01	0.125E+01	9.61	
BI-214	1600.00Y	1.00	1.085E+00	1.085E+00	0.167E+00	15.39	
RA-226	1600.00Y	1.00	2.192E+00	2.192E+00	1.410E+00	64.30	
RA-228	5.75Y	1.01	1.322E+00	1.337E+00	0.545E+00	40.74	
			---------	---------			
	Total Activity :		1.760E+01	1.761E+01			

Nuclide Type : NATURAL

Nuclide	Hlife	Decay	Wtd Mean Uncorrected pCi/g Dry	Wtd Mean Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
TL-208	1.91Y	1.03	8.836E-01	9.125E-01	2.347E-01	25.72	
PB-212	1.91Y	1.03	1.048E+00	1.082E+00	0.099E+00	9.14	
PB-214	1600.00Y	1.00	1.143E+00	1.143E+00	0.136E+00	11.91	
TH-232	1.41E+10Y	1.00	1.167E+00	1.167E+00	0.342E+00	29.33	
			---------	---------			
	Total Activity :		4.241E+00	4.305E+00			

Nuclide Type : natural

Nuclide	Hlife	Decay	Wtd Mean Uncorrected pCi/g Dry	Wtd Mean Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
AC-228	5.75Y	1.01	1.167E+00	1.179E+00	0.346E+00	29.33	
			---------	---------			
	Total Activity :		1.167E+00	1.179E+00			

Grand Total Activity : 2.301E+01 2.310E+01

Flags: "K" = Keyline not found "M" = Manually accepted
"E" = Manually edited "A" = Nuclide specific abn. limit

Interference Report

No interference correction performed

Combined Activity-MDA Report

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A,06L95403-15      ,03/18/2022 08:07,02/13/2022 12:56,    2.730E+01,L95403-15 SS A
B,06L95403-15      ,NORMK                ,10/29/2021 09:14,06S25031921
C,K-40     ,YES,   1.300E+01,   1.249E+00,   6.662E-01,,   19.510
C,TL-208   ,YES,   9.125E-01,   2.347E-01,   2.057E-01,,    4.437
C,PB-212   ,YES,   1.082E+00,   9.896E-02,   9.928E-02,,   10.901
C,BI-214   ,YES,   1.085E+00,   1.670E-01,   5.182E-01,,    2.093
C,PB-214   ,YES,   1.143E+00,   1.361E-01,   1.323E-01,,    8.641
C,RA-226   ,YES,   2.192E+00,   1.410E+00,   1.229E+00,,    1.783
C,AC-228   ,YES,   1.179E+00,   3.459E-01,   2.543E-01,,    4.637
C,RA-228   ,YES,   1.337E+00,   5.446E-01,   5.559E-01,,    2.404
C,TH-232   ,YES,   1.167E+00,   3.423E-01,   2.517E-01,,    4.636
C,CO-60    ,NO ,   8.179E-02,   4.951E-02,   8.972E-02,,    0.912
C,CS-137   ,NO ,   7.635E-02,   4.737E-02,   8.369E-02,,    0.912
C,LA-138   ,NO ,  -1.622E-03,   6.178E-02,   1.026E-01,,   -0.016
C,BI-212   ,NO ,   4.119E-01,   6.205E-01,   1.005E+00,,    0.410
C,PA-234M  ,NO ,   7.441E+00,   5.008E+00,   8.736E+00,,    0.852
C,TH-234   ,NO ,   1.282E+00,   3.628E+00,   6.052E+00,,    0.212
C,U-235    ,NO ,   1.491E-02,   2.197E-01,   3.533E-01,,    0.042
C,U-238    ,NO ,   7.441E+00,   5.008E+00,   8.736E+00,,    0.852
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Analyst:

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VAX/VMS Teledyne Brown Eng. Laboratory Gamma Report: 19-MAR-2022 05:14:35.81
TBE01 33-TP20784A HpGe ******* Aquisition Date/Time: 18-MAR-2022 11:13:54.25

LIMS No., Customer Name, Client ID: L95403-16 SS ANCHOR QEA

Sample ID : 01L95403-16
Sample Type : SS
Quantity : 3.00000E+01 g Dry
Start Channel : 80 Energy Tol : 2.00000
End Channel : 4090 Pk Srch Sens: 9.00000
MDA Multiple : 4.6600 Library Used: NORMK
Peak Evaluation - Identified and Unidentified

Smple Date: 13-FEB-2022 12:56:00.
Geometry : 01S25121819
BKGFILE : 01BG030422MT
Real Time : 0 18:00:08.67
Live time : 0 18:00:00.00

Pk	It	Energy	Area	Bkgnd	FWHM	Channel	%Eff	Cts/Sec	%Err	Fit
1	2	74.79*	642	1734	1.22	150.12	5.71E+00	9.91E-03	12.8	6.88E+00
2	2	77.04	1005	1336	0.94	154.61	6.10E+00	1.55E-02	6.7	
3	1	87.35*	214	2424	0.93	175.21	7.65E+00	3.31E-03	44.0	3.72E+00
4	1	92.86*	570	2067	1.64	186.22	8.30E+00	8.80E-03	17.5	4.02E+00
5	1	185.81*	601	1727	1.47	371.98	9.12E+00	9.27E-03	15.4	1.20E+00
6	1	209.36	321	1163	1.10	419.06	8.51E+00	4.96E-03	19.2	1.87E+00
7	3	238.61*	2690	897	1.13	477.51	7.80E+00	4.15E-02	2.9	1.67E+00
8	3	241.58	690	1172	1.52	483.45	7.73E+00	1.06E-02	10.1	
9	1	270.36	390	923	1.69	540.96	7.11E+00	6.02E-03	14.9	1.25E+00
10	1	295.19*	744	997	1.16	590.61	6.64E+00	1.15E-02	9.5	6.46E-01
11	1	338.31	708	934	1.31	676.78	5.95E+00	1.09E-02	9.2	2.23E+00
12	1	351.91*	1300	1132	1.29	703.96	5.76E+00	2.01E-02	6.8	1.15E+00
13	1	462.96	261	716	1.85	925.93	4.55E+00	4.03E-03	22.8	1.35E+00
14	1	510.85*	307	921	2.79	1021.65	4.17E+00	4.74E-03	31.5	2.30E+00
15	1	583.06*	804	456	1.67	1166.00	3.71E+00	1.24E-02	6.9	3.63E+00
16	1	609.16*	878	440	1.55	1218.19	3.56E+00	1.36E-02	6.1	5.21E+00
17	1	661.68	102	387	1.31	1323.17	3.30E+00	1.58E-03	37.5	7.54E-01
18	1	727.11	316	405	3.03	1453.97	3.02E+00	4.88E-03	15.0	3.02E+00
19	1	911.05*	581	472	1.68	1821.71	2.42E+00	8.97E-03	9.9	3.23E+00
20	1	968.99*	301	297	1.85	1937.55	2.28E+00	4.64E-03	13.7	2.22E+00
21	1	1120.42*	130	284	1.99	2240.33	1.98E+00	2.00E-03	30.8	1.61E+00
22	1	1460.71*	1670	123	2.38	2920.80	1.54E+00	2.58E-02	3.2	2.57E+00
23	1	1764.34*	153	74	2.44	3528.06	1.32E+00	2.36E-03	17.7	2.37E+00

Flag: "*" = Peak area was modified by background subtraction

Nuclide Line Activity Report

Nuclide Type:

Nuclide	Energy	Area	%Abn	%Eff	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	2-Sigma %Error
K-40	1460.81	1670	10.67*	1.540E+00	1.413E+01	1.413E+01	6.39
CS-137	661.66	102	85.12*	3.296E+00	5.072E-02	5.083E-02	74.99
BI-214	609.31	878	46.30	3.559E+00	7.411E-01	7.411E-01	12.28
	1120.29	130	15.10*	1.977E+00	6.047E-01	6.047E-01	61.55
	1764.49	153	15.80	1.323E+00	1.015E+00	1.016E+00	35.33

RA-226	186.21	601	3.28*	9.117E+00	2.794E+00	2.794E+00	30.87
RA-228	93.35	570	3.50	8.297E+00	2.729E+00	2.759E+00	35.07
	969.11	301	16.60*	2.281E+00	1.105E+00	1.117E+00	27.39
TH-234	63.29	------	3.80*	3.510E+00	------	Line Not Found	------
	92.60	570	5.41	8.297E+00	1.765E+00	1.765E+00	35.07
U-235	143.76	------	10.50*	9.986E+00	------	Line Not Found	------
	163.35	------	4.70	9.656E+00	------	Line Not Found	------
	185.71	601	54.00	9.117E+00	1.697E-01	1.697E-01	30.87
	205.31	------	4.70	8.614E+00	------	Line Not Found	------

Nuclide Type: NATURAL

Nuclide	Energy	Area	%Abn	%Eff	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	2-Sigma %Error
TL-208	583.17	804	30.25*	3.705E+00	9.968E-01	1.030E+00	13.73
BI-212	727.17	316	7.56*	3.015E+00	1.928E+00	1.993E+00	29.96
PB-212	238.63	2690	44.60*	7.796E+00	1.076E+00	1.112E+00	5.90
PB-214	295.21	744	19.20	6.640E+00	8.117E-01	8.117E-01	19.02
	351.92	1300	37.20*	5.756E+00	8.442E-01	8.442E-01	13.51
TH-232	911.21	581	27.70*	2.424E+00	1.204E+00	1.204E+00	19.75

Nuclide Type: natural

Nuclide	Energy	Area	%Abn	%Eff	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	2-Sigma %Error
AC-228	835.50	------	1.75	2.638E+00	------	Line Not Found	------
	911.07	581	27.70*	2.424E+00	1.204E+00	1.217E+00	19.75

Flag: "*" = Keyline

Total number of lines in spectrum	23	
Number of unidentified lines	9	
Number of lines tentatively identified by NID	14	60.87%

Nuclide Type :

Nuclide	Hlife	Decay	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
K-40	1.28E+09Y	1.00	1.413E+01	1.413E+01	0.090E+01	6.39	
CS-137	30.07Y	1.00	5.072E-02	5.083E-02	3.811E-02	74.99	
BI-214	1600.00Y	1.00	6.047E-01	6.047E-01	3.722E-01	61.55	
RA-226	1600.00Y	1.00	2.794E+00	2.794E+00	0.863E+00	30.87	
RA-228	5.75Y	1.01	1.105E+00	1.117E+00	0.306E+00	27.39	
TH-234	4.47E+09Y	1.00	1.765E+00	1.765E+00	0.619E+00	35.07	K
U-235	7.04E+08Y	1.00	1.697E-01	1.697E-01	0.524E-01	30.87	K
			---------	---------			
	Total Activity :		2.062E+01	2.063E+01			

Nuclide Type : NATURAL

Nuclide	Hlife	Decay	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
TL-208	1.91Y	1.03	9.968E-01	1.030E+00	0.141E+00	13.73	
BI-212	1.91Y	1.03	1.928E+00	1.993E+00	0.597E+00	29.96	
PB-212	1.91Y	1.03	1.076E+00	1.112E+00	0.066E+00	5.90	
PB-214	1600.00Y	1.00	8.442E-01	8.442E-01	1.140E-01	13.51	
TH-232	1.41E+10Y	1.00	1.204E+00	1.204E+00	0.238E+00	19.75	
			---------	---------			
	Total Activity :		6.049E+00	6.183E+00			

Nuclide Type : natural

Nuclide	Hlife	Decay	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
AC-228	5.75Y	1.01	1.204E+00	1.217E+00	0.240E+00	19.75	
			---------	---------			
	Total Activity :		1.204E+00	1.217E+00			

Grand Total Activity : 2.787E+01 2.803E+01

Flags: "K" = Keyline not found "M" = Manually accepted
"E" = Manually edited "A" = Nuclide specific abn. limit

It	Energy	Area	Bkgnd	FWHM	Channel	Left	Pw	Cts/Sec	%Err	%Eff	Flags
2	74.79	642	1734	1.22	150.12	144	14	9.91E-03	25.6	5.71E+00	
2	77.04	1005	1336	0.94	154.61	144	14	1.55E-02	13.5	6.10E+00	
1	87.35	214	2424	0.93	175.21	170	9	3.31E-03	88.0	7.65E+00	
1	209.36	321	1163	1.10	419.06	415	8	4.96E-03	38.3	8.51E+00	
3	241.58	690	1172	1.52	483.45	470	19	1.06E-02	20.2	7.73E+00	
1	270.36	390	923	1.69	540.96	537	9	6.02E-03	29.8	7.11E+00	
1	338.31	708	934	1.31	676.78	671	11	1.09E-02	18.4	5.95E+00	
1	462.96	261	716	1.85	925.93	919	14	4.03E-03	45.6	4.55E+00	
1	510.85	307	921	2.79	1021.65	1013	19	4.74E-03	62.9	4.17E+00	

Flags: "T" = Tentatively associated

Summary of Nuclide Activity

Total number of lines in spectrum 23
Number of unidentified lines 9
Number of lines tentatively identified by NID 14 60.87%

Nuclide Type :

Nuclide	Hlife	Decay	Wtd Mean Uncorrected pCi/g Dry	Wtd Mean Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
K-40	1.28E+09Y	1.00	1.413E+01	1.413E+01	0.090E+01	6.39	
CS-137	30.07Y	1.00	5.072E-02	5.083E-02	3.811E-02	74.99	
BI-214	1600.00Y	1.00	7.495E-01	7.496E-01	0.859E-01	11.45	
RA-226	1600.00Y	1.00	2.794E+00	2.794E+00	0.863E+00	30.87	
RA-228	5.75Y	1.01	1.105E+00	1.117E+00	0.306E+00	27.39	
			---------	---------			
	Total Activity :		1.883E+01	1.884E+01			

Nuclide Type : NATURAL

Nuclide	Hlife	Decay	Wtd Mean Uncorrected pCi/g Dry	Wtd Mean Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
TL-208	1.91Y	1.03	9.968E-01	1.030E+00	0.141E+00	13.73	
BI-212	1.91Y	1.03	1.928E+00	1.993E+00	0.597E+00	29.96	
PB-212	1.91Y	1.03	1.076E+00	1.112E+00	0.066E+00	5.90	
PB-214	1600.00Y	1.00	8.327E-01	8.327E-01	0.917E-01	11.01	
TH-232	1.41E+10Y	1.00	1.204E+00	1.204E+00	0.238E+00	19.75	
			---------	---------			
	Total Activity :		6.037E+00	6.172E+00			

Nuclide Type : natural

Nuclide	Hlife	Decay	Wtd Mean Uncorrected pCi/g Dry	Wtd Mean Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
AC-228	5.75Y	1.01	1.204E+00	1.217E+00	0.240E+00	19.75	
			---------	---------			
	Total Activity :		1.204E+00	1.217E+00			

Grand Total Activity : 2.607E+01 2.623E+01

Flags: "K" = Keyline not found "M" = Manually accepted
"E" = Manually edited "A" = Nuclide specific abn. limit

Interference Report

No interference correction performed

Combined Activity-MDA Report

---- Identified Nuclides ----

Nuclide	Activity (pCi/g Dry)	Act error	MDA (pCi/g Dry)	MDA error	Act/MDA
K-40	1.413E+01	9.021E-01	4.186E-01	0.000E+00	33.745
CS-137	5.083E-02	3.811E-02	4.702E-02	0.000E+00	1.081
TL-208	1.030E+00	1.415E-01	1.276E-01	0.000E+00	8.074
BI-212	1.993E+00	5.971E-01	5.521E-01	0.000E+00	3.610
PB-212	1.112E+00	6.556E-02	6.110E-02	0.000E+00	18.197
BI-214	7.496E-01	8.586E-02	3.184E-01	0.000E+00	2.354
PB-214	8.327E-01	9.171E-02	8.104E-02	0.000E+00	10.276
RA-226	2.794E+00	8.625E-01	7.439E-01	0.000E+00	3.756
AC-228	1.217E+00	2.404E-01	1.597E-01	0.000E+00	7.620
RA-228	1.117E+00	3.059E-01	3.209E-01	0.000E+00	3.480
TH-232	1.204E+00	2.377E-01	1.580E-01	0.000E+00	7.618

---- Non-Identified Nuclides ----

Nuclide	Key-Line Activity (pCi/g Dry)	K.L. Ided	Act error	MDA (pCi/g Dry)	MDA error	Act/MDA
CO-60	2.590E-02		3.103E-02	5.304E-02	0.000E+00	0.488
LA-138	-1.497E-02		4.241E-02	6.723E-02	0.000E+00	-0.223
PA-234M	1.675E+00		3.619E+00	5.544E+00	0.000E+00	0.302
TH-234	-1.911E-01		1.304E+00	1.899E+00	0.000E+00	-0.101
U-235	-9.953E-02		1.562E-01	2.190E-01	0.000E+00	-0.454
U-238	1.675E+00		3.619E+00	5.544E+00	0.000E+00	0.302

A,01L95403-16 ,03/19/2022 05:14,02/13/2022 12:56, 3.000E+01,L95403-16 SS A
B,01L95403-16 ,NORMK ,11/17/2021 15:33,01S25121819
C,K-40 ,YES, 1.413E+01, 9.021E-01, 4.186E-01,, 33.745
C,CS-137 ,YES, 5.083E-02, 3.811E-02, 4.702E-02,, 1.081
C,TL-208 ,YES, 1.030E+00, 1.415E-01, 1.276E-01,, 8.074
C,BI-212 ,YES, 1.993E+00, 5.971E-01, 5.521E-01,, 3.610
C,PB-212 ,YES, 1.112E+00, 6.556E-02, 6.110E-02,, 18.197
C,BI-214 ,YES, 7.496E-01, 8.586E-02, 3.184E-01,, 2.354
C,PB-214 ,YES, 8.327E-01, 9.171E-02, 8.104E-02,, 10.276
C,RA-226 ,YES, 2.794E+00, 8.625E-01, 7.439E-01,, 3.756
C,AC-228 ,YES, 1.217E+00, 2.404E-01, 1.597E-01,, 7.620
C,RA-228 ,YES, 1.117E+00, 3.059E-01, 3.209E-01,, 3.480
C,TH-232 ,YES, 1.204E+00, 2.377E-01, 1.580E-01,, 7.618
C,CO-60 ,NO , 2.590E-02, 3.103E-02, 5.304E-02,, 0.488
C,LA-138 ,NO , -1.497E-02, 4.241E-02, 6.723E-02,, -0.223
C,PA-234M ,NO , 1.675E+00, 3.619E+00, 5.544E+00,, 0.302
C,TH-234 ,NO , -1.911E-01, 1.304E+00, 1.899E+00,, -0.101
C,U-235 ,NO , -9.953E-02, 1.562E-01, 2.190E-01,, -0.454
C,U-238 ,NO , 1.675E+00, 3.619E+00, 5.544E+00,, 0.302

Analyst:

VAX/VMS Teledyne Brown Eng. Laboratory Gamma Report: 19-MAR-2022 05:19:13.81
TBE08 31-TP20610B HpGe ******** Aquisition Date/Time: 18-MAR-2022 11:18:21.75

LIMS No., Customer Name, Client ID: L95403-17 SS ANCHOR QEA

Sample ID : 08L95403-17
Sample Type : SS
Quantity : 4.41000E+01 g Dry
Start Channel : 80 Energy Tol : 2.00000
End Channel : 4090 Pk Srch Sens: 9.00000
MDA Multiple : 4.6600 Library Used: NORMK
Peak Evaluation - Identified and Unidentified

Smple Date: 13-FEB-2022 12:56:00.
Geometry : 08S50121919
BKGFILE : 08BG030422MT
Real Time : 0 18:00:31.65
Live time : 0 18:00:00.00

Pk	It	Energy	Area	Bkgnd	FWHM	Channel	%Eff	Cts/Sec	%Err	Fit
1	4	75.26*	914	2487	1.70	156.63	3.71E+00	1.41E-02	12.1	6.17E+00
2	4	77.50*	820	1870	1.29	161.10	3.92E+00	1.27E-02	11.6	
3	2	87.73	430	1485	1.27	181.49	4.72E+00	6.64E-03	14.6	4.52E+00
4	2	90.30	354	2056	1.43	186.63	4.89E+00	5.46E-03	23.8	
5	2	93.17*	362	1419	1.25	192.36	5.05E+00	5.58E-03	21.8	
6	1	186.47*	543	2117	1.61	378.43	5.38E+00	8.37E-03	19.4	1.88E+00
7	1	209.84	365	1335	1.55	425.04	5.01E+00	5.63E-03	18.8	9.23E-01
8	5	239.22*	2770	1174	1.44	483.62	4.57E+00	4.28E-02	3.2	9.76E-01
9	5	242.16*	624	1424	2.01	489.48	4.53E+00	9.62E-03	16.2	
10	1	295.77*	754	951	1.51	596.39	3.86E+00	1.16E-02	9.2	2.27E+00
11	1	338.98*	670	1200	1.63	682.55	3.43E+00	1.03E-02	11.6	2.59E+00
12	1	352.43*	1137	1211	1.62	709.37	3.31E+00	1.75E-02	7.9	2.12E+00
13	1	463.55	183	622	1.75	930.91	2.57E+00	2.83E-03	26.7	1.27E+00
14	1	511.40*	263	1159	3.15	1026.29	2.35E+00	4.06E-03	40.3	1.39E+00
15	1	583.63*	801	631	1.60	1170.27	2.08E+00	1.24E-02	8.2	1.63E+00
16	1	609.63*	868	1052	1.74	1222.11	1.99E+00	1.34E-02	10.0	2.01E+00
17	1	727.31	214	441	1.93	1456.63	1.69E+00	3.30E-03	20.7	1.66E+00
18	1	911.28*	547	256	2.48	1823.21	1.37E+00	8.45E-03	8.8	4.86E+00
19	1	969.38*	335	270	2.11	1938.98	1.29E+00	5.18E-03	12.2	1.23E+00
20	1	1120.48*	223	310	2.36	2239.97	1.13E+00	3.44E-03	20.6	8.50E-01
21	1	1461.21*	1489	185	2.13	2918.48	8.98E-01	2.30E-02	3.9	5.21E-01
22	1	1765.13*	144	73	2.53	3523.42	7.71E-01	2.23E-03	19.3	1.43E+00

Flag: "*" = Peak area was modified by background subtraction

Nuclide Line Activity Report

Nuclide Type:

Nuclide	Energy	Area	%Abn	%Eff	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	2-Sigma %Error
K-40	1460.81	1489	10.67*	8.978E-01	1.470E+01	1.470E+01	7.76
BI-214	609.31	868	46.30	1.993E+00	8.898E-01	8.898E-01	20.09
	1120.29	223	15.10*	1.134E+00	1.231E+00	1.231E+00	41.22
	1764.49	144	15.80	7.706E-01	1.121E+00	1.121E+00	38.60
RA-226	186.21	543	3.28*	5.376E+00	2.910E+00	2.910E+00	38.72
RA-228	93.35	362	3.50	5.054E+00	1.934E+00	1.955E+00	43.66

	969.11	335	16.60*	1.294E+00	1.477E+00	1.493E+00	24.32

Nuclide Type: NATURAL

Nuclide	Energy	Area	%Abn	%Eff	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	2-Sigma %Error
TL-208	583.17	801	30.25*	2.076E+00	1.205E+00	1.246E+00	16.41
BI-212	727.17	214	7.56*	1.690E+00	1.585E+00	1.638E+00	41.43
PB-212	238.63	2770	44.60*	4.572E+00	1.285E+00	1.328E+00	6.41
PB-214	295.21	754	19.20	3.857E+00	9.632E-01	9.633E-01	18.45
	351.92	1137	37.20*	3.309E+00	8.735E-01	8.735E-01	15.82
TH-232	911.21	547	27.70*	1.370E+00	1.364E+00	1.364E+00	17.61

Nuclide Type: natural

Nuclide	Energy	Area	%Abn	%Eff	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	2-Sigma %Error
AC-228	835.50	------	1.75	1.485E+00	------	Line Not Found	------
	911.07	547	27.70*	1.370E+00	1.364E+00	1.379E+00	17.61

Flag: "*" = Keyline

Total number of lines in spectrum	22	
Number of unidentified lines	9	
Number of lines tentatively identified by NID	13	59.09%

Nuclide Type :

Nuclide	Hlife	Decay	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
K-40	1.28E+09Y	1.00	1.470E+01	1.470E+01	0.114E+01	7.76	
BI-214	1600.00Y	1.00	1.231E+00	1.231E+00	0.507E+00	41.22	
RA-226	1600.00Y	1.00	2.910E+00	2.910E+00	1.127E+00	38.72	
RA-228	5.75Y	1.01	1.477E+00	1.493E+00	0.363E+00	24.32	
			---------	---------			
	Total Activity :		2.031E+01	2.033E+01			

Nuclide Type : NATURAL

Nuclide	Hlife	Decay	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
TL-208	1.91Y	1.03	1.205E+00	1.246E+00	0.204E+00	16.41	
BI-212	1.91Y	1.03	1.585E+00	1.638E+00	0.679E+00	41.43	
PB-212	1.91Y	1.03	1.285E+00	1.328E+00	0.085E+00	6.41	
PB-214	1600.00Y	1.00	8.735E-01	8.735E-01	1.382E-01	15.82	
TH-232	1.41E+10Y	1.00	1.364E+00	1.364E+00	0.240E+00	17.61	
			---------	---------			
	Total Activity :		6.312E+00	6.449E+00			

Nuclide Type : natural

Nuclide	Hlife	Decay	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
AC-228	5.75Y	1.01	1.364E+00	1.379E+00	0.243E+00	17.61	
			---------	---------			
	Total Activity :		1.364E+00	1.379E+00			

Grand Total Activity : 2.799E+01 2.816E+01

Flags: "K" = Keyline not found "M" = Manually accepted
"E" = Manually edited "A" = Nuclide specific abn. limit

It	Energy	Area	Bkgnd	FWHM	Channel	Left	Pw	Cts/Sec	%Err	%Eff	Flags
4	75.26	914	2487	1.70	156.63	149	17	1.41E-02	24.2	3.71E+00	
4	77.50	820	1870	1.29	161.10	149	17	1.27E-02	23.2	3.92E+00	
2	87.73	430	1485	1.27	181.49	179	20	6.64E-03	29.1	4.72E+00	
2	90.30	354	2056	1.43	186.63	179	20	5.46E-03	47.5	4.89E+00	
1	209.84	365	1335	1.55	425.04	421	9	5.63E-03	37.6	5.01E+00	
5	242.16	624	1424	2.01	489.48	476	19	9.62E-03	32.3	4.53E+00	
1	338.98	670	1200	1.63	682.55	676	12	1.03E-02	23.2	3.43E+00	
1	463.55	183	622	1.75	930.91	926	10	2.83E-03	53.4	2.57E+00	
1	511.40	263	1159	3.15	1026.29	1018	22	4.06E-03	80.7	2.35E+00	

Flags: "T" = Tentatively associated

Summary of Nuclide Activity

Total number of lines in spectrum 22
Number of unidentified lines 9
Number of lines tentatively identified by NID 13 59.09%

Nuclide Type :

Nuclide	Hlife	Decay	Wtd Mean Uncorrected pCi/g Dry	Wtd Mean Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
K-40	1.28E+09Y	1.00	1.470E+01	1.470E+01	0.114E+01	7.76	
BI-214	1600.00Y	1.00	9.530E-01	9.530E-01	1.571E-01	16.49	
RA-226	1600.00Y	1.00	2.910E+00	2.910E+00	1.127E+00	38.72	
RA-228	5.75Y	1.01	1.547E+00	1.564E+00	0.334E+00	21.37	
			---------	---------			
	Total Activity :		2.011E+01	2.012E+01			

Nuclide Type : NATURAL

Nuclide	Hlife	Decay	Wtd Mean Uncorrected pCi/g Dry	Wtd Mean Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
TL-208	1.91Y	1.03	1.205E+00	1.246E+00	0.204E+00	16.41	
BI-212	1.91Y	1.03	1.585E+00	1.638E+00	0.679E+00	41.43	
PB-212	1.91Y	1.03	1.285E+00	1.328E+00	0.085E+00	6.41	
PB-214	1600.00Y	1.00	9.073E-01	9.074E-01	1.091E-01	12.02	
TH-232	1.41E+10Y	1.00	1.364E+00	1.364E+00	0.240E+00	17.61	
			---------	---------			
	Total Activity :		6.346E+00	6.483E+00			

Nuclide Type : natural

Nuclide	Hlife	Decay	Wtd Mean Uncorrected pCi/g Dry	Wtd Mean Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
AC-228	5.75Y	1.01	1.364E+00	1.379E+00	0.243E+00	17.61	
			---------	---------			
	Total Activity :		1.364E+00	1.379E+00			

Grand Total Activity : 2.782E+01 2.798E+01

Flags: "K" = Keyline not found "M" = Manually accepted
"E" = Manually edited "A" = Nuclide specific abn. limit

Interference Report

No interference correction performed

Combined Activity-MDA Report

---- Identified Nuclides ----

Nuclide	Activity (pCi/g Dry)	Act error	MDA (pCi/g Dry)	MDA error	Act/MDA
K-40	1.470E+01	1.140E+00	4.844E-01	0.000E+00	30.336
TL-208	1.246E+00	2.045E-01	1.597E-01	0.000E+00	7.800
BI-212	1.638E+00	6.786E-01	7.183E-01	0.000E+00	2.280
PB-212	1.328E+00	8.515E-02	7.475E-02	0.000E+00	17.767
BI-214	9.530E-01	1.571E-01	3.643E-01	0.000E+00	2.616
PB-214	9.074E-01	1.091E-01	9.955E-02	0.000E+00	9.115
RA-226	2.910E+00	1.127E+00	9.135E-01	0.000E+00	3.186
AC-228	1.379E+00	2.429E-01	1.870E-01	0.000E+00	7.375
RA-228	1.564E+00	3.341E-01	4.057E-01	0.000E+00	3.855
TH-232	1.364E+00	2.402E-01	1.850E-01	0.000E+00	7.374

---- Non-Identified Nuclides ----

Nuclide	Key-Line Activity (pCi/g Dry)	K.L. Ided	Act error	MDA (pCi/g Dry)	MDA error	Act/MDA
CO-60	2.719E-02		3.567E-02	6.152E-02	0.000E+00	0.442
CS-137	6.139E-02		3.749E-02	6.514E-02	0.000E+00	0.942
LA-138	-1.650E-02		4.947E-02	7.987E-02	0.000E+00	-0.207
PA-234M	3.558E+00		3.697E+00	6.234E+00	0.000E+00	0.571
TH-234	1.751E+00		1.207E+00	1.978E+00	0.000E+00	0.885
U-235	1.195E-01		1.628E-01	2.761E-01	0.000E+00	0.433
U-238	3.558E+00		3.697E+00	6.234E+00	0.000E+00	0.571

```
A,08L95403-17      ,03/19/2022 05:19,02/13/2022 12:56,    4.410E+01,L95403-17 SS A
B,08L95403-17      ,NORMK                        ,11/17/2021 15:23,08S50121919
C,K-40     ,YES,   1.470E+01,   1.140E+00,   4.844E-01,,   30.336
C,TL-208   ,YES,   1.246E+00,   2.045E-01,   1.597E-01,,    7.800
C,BI-212   ,YES,   1.638E+00,   6.786E-01,   7.183E-01,,    2.280
C,PB-212   ,YES,   1.328E+00,   8.515E-02,   7.475E-02,,   17.767
C,BI-214   ,YES,   9.530E-01,   1.571E-01,   3.643E-01,,    2.616
C,PB-214   ,YES,   9.074E-01,   1.091E-01,   9.955E-02,,    9.115
C,RA-226   ,YES,   2.910E+00,   1.127E+00,   9.135E-01,,    3.186
C,AC-228   ,YES,   1.379E+00,   2.429E-01,   1.870E-01,,    7.375
C,RA-228   ,YES,   1.564E+00,   3.341E-01,   4.057E-01,,    3.855
C,TH-232   ,YES,   1.364E+00,   2.402E-01,   1.850E-01,,    7.374
C,CO-60    ,NO ,   2.719E-02,   3.567E-02,   6.152E-02,,    0.442
C,CS-137   ,NO ,   6.139E-02,   3.749E-02,   6.514E-02,,    0.942
C,LA-138   ,NO ,  -1.650E-02,   4.947E-02,   7.987E-02,,   -0.207
C,PA-234M  ,NO ,   3.558E+00,   3.697E+00,   6.234E+00,,    0.571
C,TH-234   ,NO ,   1.751E+00,   1.207E+00,   1.978E+00,,    0.885
C,U-235    ,NO ,   1.195E-01,   1.628E-01,   2.761E-01,,    0.433
C,U-238    ,NO ,   3.558E+00,   3.697E+00,   6.234E+00,,    0.571
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Analyst:

VAX/VMS Teledyne Brown Eng. Laboratory Gamma Report: 18-MAR-2022 08:08:11.83
TBE13 31-TP10727B HpGe ******* Aquisition Date/Time: 17-MAR-2022 14:52:14.24

LIMS No., Customer Name, Client ID: L95403-18 SS ANCHOR QEA

Sample ID : 13L95403-18		Smple Date:	13-FEB-2022 12:56:00.
Sample Type : SS		Geometry :	13S25030421
Quantity : 2.36000E+01 g Dry		BKGFILE :	13BG030422MT
Start Channel : 80	Energy Tol : 2.00000	Real Time :	0 17:15:47.79
End Channel : 4090	Pk Srch Sens: 9.00000	Live time :	0 17:15:33.44
MDA Multiple : 4.6600	Library Used: NORMK		

Peak Evaluation - Identified and Unidentfied

Pk	It	Energy	Area	Bkgnd	FWHM	Channel	%Eff	Cts/Sec	%Err	Fit
1	1	74.93*	160	1516	0.70	149.77	3.49E+00	2.58E-03	43.3	1.95E+01
2	1	77.16*	338	927	0.69	154.21	3.83E+00	5.43E-03	15.7	4.61E+01
3	8	84.63*	182	1231	1.28	169.11	4.93E+00	2.93E-03	37.9	1.48E+00
4	8	87.18*	348	1017	1.10	174.20	5.27E+00	5.60E-03	17.8	
5	1	92.78*	366	1123	1.13	185.37	5.96E+00	5.90E-03	18.3	5.19E+00
6	1	185.74*	327	1279	1.06	370.86	7.62E+00	5.26E-03	22.6	1.78E+00
7	1	208.79	316	932	1.36	416.86	7.12E+00	5.09E-03	17.4	5.76E+00
8	5	238.47*	1991	650	0.94	476.10	6.49E+00	3.20E-02	3.5	5.76E+00
9	5	241.36	659	857	1.53	481.87	6.43E+00	1.06E-02	10.0	
10	1	295.01*	684	987	1.20	588.94	5.49E+00	1.10E-02	10.6	1.05E+00
11	1	338.13*	428	669	1.05	675.01	4.91E+00	6.90E-03	13.1	1.15E+00
12	1	351.70*	997	809	1.12	702.09	4.75E+00	1.60E-02	7.2	1.59E+00
13	1	463.01	157	477	1.46	924.32	3.75E+00	2.53E-03	27.3	3.58E+00
14	1	510.70*	436	856	2.38	1019.53	3.44E+00	7.01E-03	19.3	1.16E+00
15	1	582.90*	516	469	1.30	1163.72	3.06E+00	8.31E-03	10.2	6.49E-01
16	1	608.97*	784	463	1.26	1215.79	2.94E+00	1.26E-02	7.3	2.00E+00
17	1	661.33	186	254	1.96	1320.36	2.72E+00	2.99E-03	17.9	2.32E+00
18	1	726.93*	122	392	1.53	1451.39	2.49E+00	1.96E-03	36.3	9.36E-01
19	1	910.82*	436	189	2.03	1818.80	2.00E+00	7.02E-03	9.4	3.59E+00
20	1	968.83*	218	183	1.76	1934.73	1.88E+00	3.51E-03	14.6	2.49E+00
21	1	1120.24*	148	234	2.21	2237.39	1.62E+00	2.38E-03	27.4	8.74E-01
22	1	1460.38*	1182	77	2.15	2917.62	1.25E+00	1.90E-02	3.9	2.22E+00
23	1	1764.09*	102	84	2.15	3525.35	1.05E+00	1.65E-03	27.0	8.73E-01

Flag: "*" = Peak area was modified by background subtraction

Nuclide Line Activity Report

Nuclide Type:

Nuclide	Energy	Area	%Abn	%Eff	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	2-Sigma %Error
K-40	1460.81	1182	10.67*	1.246E+00	1.639E+01	1.639E+01	7.86
CS-137	661.66	186	85.12*	2.723E+00	1.477E-01	1.480E-01	35.79
BI-214	609.31	784	46.30	2.937E+00	1.062E+00	1.062E+00	14.69
	1120.29	148	15.10*	1.623E+00	1.114E+00	1.114E+00	54.78
	1764.49	102	15.80	1.054E+00	1.134E+00	1.134E+00	54.01

RA-226	186.21	327	3.28*	7.616E+00	2.413E+00	2.413E+00	45.13
RA-228	93.35	366	3.50	5.959E+00	3.238E+00	3.273E+00	36.56
	969.11	218	16.60*	1.881E+00	1.287E+00	1.301E+00	29.28
TH-234	63.29	------	3.80*	1.737E+00	------	Line Not Found	------
	92.60	366	5.41	5.959E+00	2.095E+00	2.095E+00	36.56
U-235	143.76	------	10.50*	8.228E+00	------	Line Not Found	------
	163.35	------	4.70	8.037E+00	------	Line Not Found	------
	185.71	327	54.00	7.616E+00	1.466E-01	1.466E-01	45.13
	205.31	------	4.70	7.191E+00	------	Line Not Found	------

Nuclide Type: NATURAL

Nuclide	Energy	Area	%Abn	%Eff	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	2-Sigma %Error
TL-208	583.17	516	30.25*	3.056E+00	1.030E+00	1.063E+00	20.35
BI-212	727.17	122	7.56*	2.492E+00	1.194E+00	1.233E+00	72.64
PB-212	238.63	1991	44.60*	6.490E+00	1.268E+00	1.310E+00	6.97
PB-214	295.21	684	19.20	5.495E+00	1.195E+00	1.195E+00	21.13
	351.92	997	37.20*	4.746E+00	1.041E+00	1.041E+00	14.32
TH-232	911.21	436	27.70*	2.001E+00	1.451E+00	1.451E+00	18.81

Nuclide Type: natural

Nuclide	Energy	Area	%Abn	%Eff	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	2-Sigma %Error
AC-228	835.50	------	1.75	2.179E+00	------	Line Not Found	------
	911.07	436	27.70*	2.001E+00	1.451E+00	1.466E+00	18.81

Flag: "*" = Keyline

Total number of lines in spectrum 23
Number of unidentified lines 9
Number of lines tentatively identified by NID 14 60.87%

Nuclide Type :

Nuclide	Hlife	Decay	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
K-40	1.28E+09Y	1.00	1.639E+01	1.639E+01	0.129E+01	7.86	
CS-137	30.07Y	1.00	1.477E-01	1.480E-01	0.530E-01	35.79	
BI-214	1600.00Y	1.00	1.114E+00	1.114E+00	0.610E+00	54.78	
RA-226	1600.00Y	1.00	2.413E+00	2.413E+00	1.089E+00	45.13	
RA-228	5.75Y	1.01	1.287E+00	1.301E+00	0.381E+00	29.28	
TH-234	4.47E+09Y	1.00	2.095E+00	2.095E+00	0.766E+00	36.56	K
U-235	7.04E+08Y	1.00	1.466E-01	1.466E-01	0.662E-01	45.13	K
			---------	---------			
	Total Activity :		2.360E+01	2.361E+01			

Nuclide Type : NATURAL

Nuclide	Hlife	Decay	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
TL-208	1.91Y	1.03	1.030E+00	1.063E+00	0.216E+00	20.35	
BI-212	1.91Y	1.03	1.194E+00	1.233E+00	0.896E+00	72.64	
PB-212	1.91Y	1.03	1.268E+00	1.310E+00	0.091E+00	6.97	
PB-214	1600.00Y	1.00	1.041E+00	1.041E+00	0.149E+00	14.32	
TH-232	1.41E+10Y	1.00	1.451E+00	1.451E+00	0.273E+00	18.81	
			---------	---------			
	Total Activity :		5.983E+00	6.097E+00			

Nuclide Type : natural

Nuclide	Hlife	Decay	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
AC-228	5.75Y	1.01	1.451E+00	1.466E+00	0.276E+00	18.81	
			---------	---------			
	Total Activity :		1.451E+00	1.466E+00			

Grand Total Activity : 3.103E+01 3.117E+01

Flags: "K" = Keyline not found "M" = Manually accepted
"E" = Manually edited "A" = Nuclide specific abn. limit

Sample ID : 13L95403-18 Acquisition date : 17-MAR-2022 14:52:14

It	Energy	Area	Bkgnd	FWHM	Channel	Left	Pw	Cts/Sec	%Err	%Eff	Flags
1	74.93	160	1516	0.70	149.77	147	6	2.58E-03	86.6	3.49E+00	
1	77.16	338	927	0.69	154.21	153	4	5.43E-03	31.5	3.83E+00	
8	84.63	182	1231	1.28	169.11	165	13	2.93E-03	75.9	4.93E+00	
8	87.18	348	1017	1.10	174.20	165	13	5.60E-03	35.6	5.27E+00	
1	208.79	316	932	1.36	416.86	413	8	5.09E-03	34.9	7.12E+00	
5	241.36	659	857	1.53	481.87	472	14	1.06E-02	19.9	6.43E+00	
1	338.13	428	669	1.05	675.01	671	9	6.90E-03	26.2	4.91E+00	
1	463.01	157	477	1.46	924.32	920	10	2.53E-03	54.6	3.75E+00	
1	510.70	436	856	2.38	1019.53	1013	16	7.01E-03	38.5	3.44E+00	

Flags: "T" = Tentatively associated

Summary of Nuclide Activity

Total number of lines in spectrum	23	
Number of unidentified lines	9	
Number of lines tentatively identified by NID	14	60.87%

Nuclide Type :

Nuclide	Hlife	Decay	Wtd Mean Uncorrected pCi/g Dry	Wtd Mean Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
K-40	1.28E+09Y	1.00	1.639E+01	1.639E+01	0.129E+01	7.86	
CS-137	30.07Y	1.00	1.477E-01	1.480E-01	0.530E-01	35.79	
BI-214	1600.00Y	1.00	1.069E+00	1.069E+00	0.147E+00	13.73	
RA-226	1600.00Y	1.00	2.413E+00	2.413E+00	1.089E+00	45.13	
RA-228	5.75Y	1.01	1.287E+00	1.301E+00	0.381E+00	29.28	
			---------	---------			
	Total Activity :		2.131E+01	2.132E+01			

Nuclide Type : NATURAL

Nuclide	Hlife	Decay	Wtd Mean Uncorrected pCi/g Dry	Wtd Mean Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
TL-208	1.91Y	1.03	1.030E+00	1.063E+00	0.216E+00	20.35	
BI-212	1.91Y	1.03	1.194E+00	1.233E+00	0.896E+00	72.64	
PB-212	1.91Y	1.03	1.268E+00	1.310E+00	0.091E+00	6.97	
PB-214	1600.00Y	1.00	1.081E+00	1.081E+00	0.128E+00	11.88	
TH-232	1.41E+10Y	1.00	1.451E+00	1.451E+00	0.273E+00	18.81	
			---------	---------			
	Total Activity :		6.023E+00	6.137E+00			

Nuclide Type : natural

Nuclide	Hlife	Decay	Wtd Mean Uncorrected pCi/g Dry	Wtd Mean Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
AC-228	5.75Y	1.01	1.451E+00	1.466E+00	0.276E+00	18.81	
			---------	---------			
	Total Activity :		1.451E+00	1.466E+00			

Grand Total Activity : 2.878E+01 2.893E+01

Flags: "K" = Keyline not found "M" = Manually accepted
"E" = Manually edited "A" = Nuclide specific abn. limit

Interference Report

No interference correction performed

Combined Activity-MDA Report

---- Identified Nuclides ----

Nuclide	Activity (pCi/g Dry)	Act error	MDA (pCi/g Dry)	MDA error	Act/MDA
K-40	1.639E+01	1.289E+00	6.188E-01	0.000E+00	26.492
CS-137	1.480E-01	5.297E-02	6.012E-02	0.000E+00	2.462
TL-208	1.063E+00	2.164E-01	1.671E-01	0.000E+00	6.361
BI-212	1.233E+00	8.959E-01	7.092E-01	0.000E+00	1.739
PB-212	1.310E+00	9.121E-02	7.900E-02	0.000E+00	16.576
BI-214	1.069E+00	1.468E-01	4.646E-01	0.000E+00	2.302
PB-214	1.081E+00	1.284E-01	1.014E-01	0.000E+00	10.659
RA-226	2.413E+00	1.089E+00	9.201E-01	0.000E+00	2.623
AC-228	1.466E+00	2.758E-01	2.018E-01	0.000E+00	7.266
RA-228	1.301E+00	3.809E-01	4.371E-01	0.000E+00	2.975
TH-232	1.451E+00	2.728E-01	1.997E-01	0.000E+00	7.265

---- Non-Identified Nuclides ----

Nuclide	Key-Line Activity (pCi/g Dry)	K.L. Ided	Act error	MDA (pCi/g Dry)	MDA error	Act/MDA
CO-60	-7.143E-03		4.221E-02	6.988E-02	0.000E+00	-0.102
LA-138	-8.849E-03		5.964E-02	9.794E-02	0.000E+00	-0.090
PA-234M	2.807E+00		4.029E+00	6.886E+00	0.000E+00	0.408
TH-234	6.827E-01		2.341E+00	3.468E+00	0.000E+00	0.197
U-235	4.240E-02		1.709E-01	2.707E-01	0.000E+00	0.157
U-238	2.807E+00		4.029E+00	6.886E+00	0.000E+00	0.408

```
A,13L95403-18      ,03/18/2022 08:08,02/13/2022 12:56,   2.360E+01,L95403-18 SS A
B,13L95403-18      ,NORMK                     ,03/22/2021 07:43,13S25030421
C,K-40     ,YES,   1.639E+01,    1.289E+00,    6.188E-01,,   26.492
C,CS-137   ,YES,   1.480E-01,    5.297E-02,    6.012E-02,,    2.462
C,TL-208   ,YES,   1.063E+00,    2.164E-01,    1.671E-01,,    6.361
C,BI-212   ,YES,   1.233E+00,    8.959E-01,    7.092E-01,,    1.739
C,PB-212   ,YES,   1.310E+00,    9.121E-02,    7.900E-02,,   16.576
C,BI-214   ,YES,   1.069E+00,    1.468E-01,    4.646E-01,,    2.302
C,PB-214   ,YES,   1.081E+00,    1.284E-01,    1.014E-01,,   10.659
C,RA-226   ,YES,   2.413E+00,    1.089E+00,    9.201E-01,,    2.623
C,AC-228   ,YES,   1.466E+00,    2.758E-01,    2.018E-01,,    7.266
C,RA-228   ,YES,   1.301E+00,    3.809E-01,    4.371E-01,,    2.975
C,TH-232   ,YES,   1.451E+00,    2.728E-01,    1.997E-01,,    7.265
C,CO-60    ,NO ,  -7.143E-03,    4.221E-02,    6.988E-02,,   -0.102
C,LA-138   ,NO ,  -8.849E-03,    5.964E-02,    9.794E-02,,   -0.090
C,PA-234M  ,NO ,   2.807E+00,    4.029E+00,    6.886E+00,,    0.408
C,TH-234   ,NO ,   6.827E-01,    2.341E+00,    3.468E+00,,    0.197
C,U-235    ,NO ,   4.240E-02,    1.709E-01,    2.707E-01,,    0.157
C,U-238    ,NO ,   2.807E+00,    4.029E+00,    6.886E+00,,    0.408
```

Analyst:

VAX/VMS Teledyne Brown Eng. Laboratory Gamma Report: 22-MAR-2022 07:26:21.60
TBE08 31-TP20610B HpGe ******** Aquisition Date/Time: 21-MAR-2022 13:49:14.08

LIMS No., Customer Name, Client ID: L95403-19 SS ANCHOR QEA

Sample ID : 08L95403-19
Sample Type : SS
Quantity : 4.91000E+01 g Dry
Start Channel : 80 Energy Tol : 2.00000
End Channel : 4090 Pk Srch Sens: 9.00000
MDA Multiple : 4.6600 Library Used: NORMK
Peak Evaluation - Identified and Unidentified

Smple Date: 13-FEB-2022 12:56:00.
Geometry : 08S50121919
BKGFILE : 08BG030422MT
Real Time : 0 17:36:58.83
Live time : 0 17:36:27.25

Pk	It	Energy	Area	Bkgnd	FWHM	Channel	%Eff	Cts/Sec	%Err	Fit
1	3	73.36	461	1741	1.54	152.83	3.53E+00	7.27E-03	15.8	1.51E+00
2	3	75.58*	975	1974	1.26	157.26	3.74E+00	1.54E-02	9.7	
3	3	77.72	1319	1709	1.19	161.54	3.94E+00	2.08E-02	6.1	
4	6	85.22*	443	1860	1.89	176.49	4.55E+00	6.99E-03	19.9	2.78E+00
5	6	88.00	599	1411	1.22	182.04	4.74E+00	9.45E-03	11.4	
6	6	90.59	452	1764	1.44	187.21	4.91E+00	7.13E-03	17.8	
7	6	93.43*	600	1720	1.49	192.87	5.07E+00	9.46E-03	15.0	
8	1	186.78*	529	1955	1.47	379.05	5.37E+00	8.35E-03	18.2	1.18E+00
9	1	210.01	290	1681	1.37	425.37	5.01E+00	4.57E-03	27.0	1.89E+00
10	1	239.46*	2563	1800	1.22	484.10	4.57E+00	4.04E-02	3.8	1.94E+00
11	1	242.58*	454	1088	1.44	490.33	4.52E+00	7.17E-03	14.7	3.79E-01
12	1	296.03*	1003	1321	1.43	596.90	3.85E+00	1.58E-02	8.5	4.96E-01
13	1	339.16*	649	918	1.44	682.90	3.42E+00	1.02E-02	10.3	6.11E-01
14	1	352.71*	1557	962	1.47	709.93	3.31E+00	2.46E-02	5.2	1.00E+00
15	1	511.54*	453	1006	2.87	1026.58	2.35E+00	7.15E-03	21.4	2.09E+00
16	1	583.89*	816	631	1.57	1170.79	2.08E+00	1.29E-02	7.8	3.07E-01
17	1	609.95*	1167	612	1.67	1222.74	1.99E+00	1.84E-02	5.8	8.70E-01
18	1	662.38	146	531	1.43	1327.23	1.84E+00	2.30E-03	32.6	8.81E-01
19	1	727.77	235	317	1.66	1457.56	1.69E+00	3.71E-03	15.2	4.92E+00
20	1	768.74	242	375	2.83	1539.21	1.60E+00	3.83E-03	17.7	1.55E+00
21	1	911.81*	549	356	1.76	1824.28	1.37E+00	8.66E-03	9.2	6.68E-01
22	1	969.90*	391	304	2.20	1940.00	1.29E+00	6.17E-03	11.9	3.48E+00
23	1	1120.87*	242	247	2.34	2240.73	1.13E+00	3.83E-03	16.1	5.38E-01
24	1	1461.59*	1659	122	2.19	2919.24	8.98E-01	2.62E-02	3.3	1.21E+00
25	1	1765.70*	234	79	2.27	3524.56	7.70E-01	3.70E-03	12.8	9.21E-01

Flag: "*" = Peak area was modified by background subtraction

Nuclide Line Activity Report

Nuclide Type:

Nuclide	Energy	Area	%Abn	%Eff	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	2-Sigma %Error
K-40	1460.81	1659	10.67*	8.976E-01	1.505E+01	1.505E+01	6.69
CS-137	661.66	146	85.12*	1.844E+00	8.068E-02	8.087E-02	65.27
BI-214	609.31	1167	46.30	1.992E+00	1.099E+00	1.099E+00	11.52

	1120.29	242	15.10*	1.133E+00	1.230E+00	1.231E+00	32.18
	1764.49	234	15.80	7.704E-01	1.672E+00	1.673E+00	25.64
RA-226	186.21	529	3.28*	5.371E+00	2.610E+00	2.610E+00	36.32
RA-228	93.35	600	3.50	5.068E+00	2.937E+00	2.973E+00	30.05
	969.11	391	16.60*	1.293E+00	1.582E+00	1.601E+00	23.86

Nuclide Type: NATURAL

Nuclide	Energy	Area	%Abn	%Eff	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	2-Sigma %Error
TL-208	583.17	816	30.25*	2.076E+00	1.129E+00	1.170E+00	15.70
BI-212	727.17	235	7.56*	1.689E+00	1.598E+00	1.657E+00	30.36
PB-212	238.63	2563	44.60*	4.569E+00	1.092E+00	1.132E+00	7.65
PB-214	295.21	1003	19.20	3.854E+00	1.178E+00	1.178E+00	16.99
	351.92	1557	37.20*	3.307E+00	1.099E+00	1.099E+00	10.42
TH-232	911.21	549	27.70*	1.369E+00	1.257E+00	1.257E+00	18.44

Nuclide Type: natural

Nuclide	Energy	Area	%Abn	%Eff	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	2-Sigma %Error
AC-228	835.50	------	1.75	1.485E+00	------	Line Not Found	------
	911.07	549	27.70*	1.369E+00	1.257E+00	1.272E+00	18.44

Flag: "*" = Keyline

Total number of lines in spectrum 25
Number of unidentified lines 11
Number of lines tentatively identified by NID 14 56.00%

Nuclide Type :

Nuclide	Hlife	Decay	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
K-40	1.28E+09Y	1.00	1.505E+01	1.505E+01	0.101E+01	6.69	
CS-137	30.07Y	1.00	8.068E-02	8.087E-02	5.278E-02	65.27	
BI-214	1600.00Y	1.00	1.230E+00	1.231E+00	0.396E+00	32.18	
RA-226	1600.00Y	1.00	2.610E+00	2.610E+00	0.948E+00	36.32	
RA-228	5.75Y	1.01	1.582E+00	1.601E+00	0.382E+00	23.86	
			---------	---------			
	Total Activity :		2.055E+01	2.057E+01			

Nuclide Type : NATURAL

Nuclide	Hlife	Decay	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
TL-208	1.91Y	1.04	1.129E+00	1.170E+00	0.184E+00	15.70	
BI-212	1.91Y	1.04	1.598E+00	1.657E+00	0.503E+00	30.36	
PB-212	1.91Y	1.04	1.092E+00	1.132E+00	0.087E+00	7.65	
PB-214	1600.00Y	1.00	1.099E+00	1.099E+00	0.115E+00	10.42	
TH-232	1.41E+10Y	1.00	1.257E+00	1.257E+00	0.232E+00	18.44	
			---------	---------			
	Total Activity :		6.176E+00	6.316E+00			

Nuclide Type : natural

Nuclide	Hlife	Decay	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
AC-228	5.75Y	1.01	1.257E+00	1.272E+00	0.235E+00	18.44	
			---------	---------			
	Total Activity :		1.257E+00	1.272E+00			

Grand Total Activity : 2.798E+01 2.816E+01

Flags: "K" = Keyline not found "M" = Manually accepted
"E" = Manually edited "A" = Nuclide specific abn. limit

It	Energy	Area	Bkgnd	FWHM	Channel	Left	Pw	Cts/Sec	%Err	%Eff	Flags
3	73.36	461	1741	1.54	152.83	149	17	7.27E-03	31.6	3.53E+00	
3	75.58	975	1974	1.26	157.26	149	17	1.54E-02	19.4	3.74E+00	
3	77.72	1319	1709	1.19	161.54	149	17	2.08E-02	12.3	3.94E+00	
6	85.22	443	1860	1.89	176.49	172	28	6.99E-03	39.7	4.55E+00	
6	88.00	599	1411	1.22	182.04	172	28	9.45E-03	22.8	4.74E+00	
6	90.59	452	1764	1.44	187.21	172	28	7.13E-03	35.7	4.91E+00	
1	210.01	290	1681	1.37	425.37	421	10	4.57E-03	53.9	5.01E+00	
1	242.58	454	1088	1.44	490.33	488	7	7.17E-03	29.5	4.52E+00	
1	339.16	649	918	1.44	682.90	678	10	1.02E-02	20.5	3.42E+00	
1	511.54	453	1006	2.87	1026.58	1019	19	7.15E-03	42.7	2.35E+00	
1	768.74	242	375	2.83	1539.21	1533	13	3.83E-03	35.5	1.60E+00	

Flags: "T" = Tentatively associated

Summary of Nuclide Activity

Total number of lines in spectrum	25	
Number of unidentified lines	11	
Number of lines tentatively identified by NID	14	56.00%

Nuclide Type :

Nuclide	Hlife	Decay	Wtd Mean Uncorrected pCi/g Dry	Wtd Mean Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
K-40	1.28E+09Y	1.00	1.505E+01	1.505E+01	0.101E+01	6.69	
CS-137	30.07Y	1.00	8.068E-02	8.087E-02	5.278E-02	65.27	
BI-214	1600.00Y	1.00	1.152E+00	1.152E+00	0.116E+00	10.07	
RA-226	1600.00Y	1.00	2.610E+00	2.610E+00	0.948E+00	36.32	
RA-228	5.75Y	1.01	1.791E+00	1.813E+00	0.351E+00	19.37	
			---------	---------			
	Total Activity :		2.068E+01	2.070E+01			

Nuclide Type : NATURAL

Nuclide	Hlife	Decay	Wtd Mean Uncorrected pCi/g Dry	Wtd Mean Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
TL-208	1.91Y	1.04	1.129E+00	1.170E+00	0.184E+00	15.70	
BI-212	1.91Y	1.04	1.598E+00	1.657E+00	0.503E+00	30.36	
PB-212	1.91Y	1.04	1.092E+00	1.132E+00	0.087E+00	7.65	
PB-214	1600.00Y	1.00	1.119E+00	1.119E+00	0.099E+00	8.89	
TH-232	1.41E+10Y	1.00	1.257E+00	1.257E+00	0.232E+00	18.44	
			---------	---------			
	Total Activity :		6.195E+00	6.335E+00			

Nuclide Type : natural

Nuclide	Hlife	Decay	Wtd Mean Uncorrected pCi/g Dry	Wtd Mean Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
AC-228	5.75Y	1.01	1.257E+00	1.272E+00	0.235E+00	18.44	
			---------	---------			
	Total Activity :		1.257E+00	1.272E+00			

Grand Total Activity : 2.813E+01 2.831E+01

Flags: "K" = Keyline not found "M" = Manually accepted
"E" = Manually edited "A" = Nuclide specific abn. limit

Interference Report

No interference correction performed

Combined Activity-MDA Report

---- Identified Nuclides ----

Nuclide	Activity (pCi/g Dry)	Act error	MDA (pCi/g Dry)	MDA error	Act/MDA
K-40	1.505E+01	1.007E+00	4.644E-01	0.000E+00	32.397
CS-137	8.087E-02	5.278E-02	5.564E-02	0.000E+00	1.454
TL-208	1.170E+00	1.837E-01	1.391E-01	0.000E+00	8.417
BI-212	1.657E+00	5.030E-01	6.480E-01	0.000E+00	2.557
PB-212	1.132E+00	8.669E-02	7.357E-02	0.000E+00	15.392
BI-214	1.152E+00	1.161E-01	3.670E-01	0.000E+00	3.139
PB-214	1.119E+00	9.945E-02	9.115E-02	0.000E+00	12.274
RA-226	2.610E+00	9.479E-01	8.758E-01	0.000E+00	2.980
AC-228	1.272E+00	2.347E-01	1.936E-01	0.000E+00	6.571
RA-228	1.813E+00	3.512E-01	3.933E-01	0.000E+00	4.609
TH-232	1.257E+00	2.319E-01	1.858E-01	0.000E+00	6.766

---- Non-Identified Nuclides ----

Nuclide	Key-Line Activity (pCi/g Dry)	K.L. Ided	Act error	MDA (pCi/g Dry)	MDA error	Act/MDA
CO-60	3.305E-03		3.066E-02	5.114E-02	0.000E+00	0.065
LA-138	2.527E-03		4.490E-02	7.435E-02	0.000E+00	0.034
PA-234M	3.023E+00		3.568E+00	5.974E+00	0.000E+00	0.506
TH-234	3.321E-02		1.124E+00	1.793E+00	0.000E+00	0.019
U-235	-5.777E-02		1.509E-01	2.508E-01	0.000E+00	-0.230
U-238	3.023E+00		3.568E+00	5.974E+00	0.000E+00	0.506

A,08L95403-19 ,03/22/2022 07:26,02/13/2022 12:56, 4.910E+01,L95403-19 SS A
B,08L95403-19 ,NORMK ,11/17/2021 15:23,08S50121919
C,K-40 ,YES, 1.505E+01, 1.007E+00, 4.644E-01,, 32.397
C,CS-137 ,YES, 8.087E-02, 5.278E-02, 5.564E-02,, 1.454
C,TL-208 ,YES, 1.170E+00, 1.837E-01, 1.391E-01,, 8.417
C,BI-212 ,YES, 1.657E+00, 5.030E-01, 6.480E-01,, 2.557
C,PB-212 ,YES, 1.132E+00, 8.669E-02, 7.357E-02,, 15.392
C,BI-214 ,YES, 1.152E+00, 1.161E-01, 3.670E-01,, 3.139
C,PB-214 ,YES, 1.119E+00, 9.945E-02, 9.115E-02,, 12.274
C,RA-226 ,YES, 2.610E+00, 9.479E-01, 8.758E-01,, 2.980
C,AC-228 ,YES, 1.272E+00, 2.347E-01, 1.936E-01,, 6.571
C,RA-228 ,YES, 1.813E+00, 3.512E-01, 3.933E-01,, 4.609
C,TH-232 ,YES, 1.257E+00, 2.319E-01, 1.858E-01,, 6.766
C,CO-60 ,NO , 3.305E-03, 3.066E-02, 5.114E-02,, 0.065
C,LA-138 ,NO , 2.527E-03, 4.490E-02, 7.435E-02,, 0.034
C,PA-234M ,NO , 3.023E+00, 3.568E+00, 5.974E+00,, 0.506
C,TH-234 ,NO , 3.321E-02, 1.124E+00, 1.793E+00,, 0.019
C,U-235 ,NO , -5.777E-02, 1.509E-01, 2.508E-01,, -0.230
C,U-238 ,NO , 3.023E+00, 3.568E+00, 5.974E+00,, 0.506

Analyst:

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==============================================================================
VAX/VMS Teledyne Brown Eng. Laboratory Gamma Report: 22-MAR-2022 07:26:34.51
TBE06 33-TP10933A HpGe ******* Aquisition Date/Time: 21-MAR-2022 13:49:13.85
------------------------------------------------------------------------------
LIMS No., Customer Name, Client ID: L95403-20 SS ANCHOR QEA

Sample ID      : 06L95403-20                     Smple Date: 13-FEB-2022 13:00:00.
Sample Type    : SS                              Geometry  : 06S50031621
Quantity       : 5.36000E+01 g Dry               BKGFILE   : 06BG030422MT
Start Channel  : 80      Energy Tol   : 2.00000  Real Time : 0 17:37:14.99
End Channel    : 4090    Pk Srch Sens: 9.00000   Live time : 0 17:37:02.96
MDA Multiple   : 4.6600  Library Used: NORMK
Peak Evaluation - Identified and Unidentified
```

Pk	It	Energy	Area	Bkgnd	FWHM	Channel	%Eff	Cts/Sec	%Err	Fit
1	3	74.90*	407	1332	0.85	150.27	1.68E+00	6.42E-03	16.1	1.44E+00
2	3	77.14	573	1215	0.82	154.74	1.84E+00	9.04E-03	10.1	
3	0	87.24	376	1309	1.19	174.90	2.53E+00	5.93E-03	16.0	
4	0	92.84*	383	1504	1.32	186.09	2.87E+00	6.04E-03	19.8	
5	0	185.91*	437	1412	1.21	371.89	4.02E+00	6.88E-03	17.9	
6	0	209.33	250	1136	0.79	418.63	3.79E+00	3.94E-03	23.2	
7	4	238.78*	2518	947	1.08	477.41	3.48E+00	3.97E-02	3.0	1.82E+00
8	4	241.75	812	1507	1.77	483.35	3.45E+00	1.28E-02	11.1	
9	0	295.39*	862	1477	1.21	590.42	2.95E+00	1.36E-02	10.1	
10	0	338.56	596	1168	1.25	676.60	2.63E+00	9.39E-03	11.8	
11	0	352.11*	1795	1155	1.18	703.66	2.54E+00	2.83E-02	4.9	
12	0	511.16*	339	1140	2.20	1021.12	1.83E+00	5.34E-03	30.6	
13	0	583.26*	840	724	1.45	1165.03	1.63E+00	1.32E-02	8.1	
14	0	609.41*	1364	701	1.41	1217.23	1.57E+00	2.15E-02	5.3	
15	0	661.61	271	422	1.62	1321.42	1.46E+00	4.27E-03	15.4	
16	0	727.55*	221	410	1.51	1453.02	1.35E+00	3.48E-03	20.9	
17	0	911.49*	510	269	1.69	1820.12	1.11E+00	8.04E-03	8.6	
18	0	969.68*	254	397	1.31	1936.25	1.06E+00	4.01E-03	18.4	
19	0	1120.69*	300	256	1.77	2237.61	9.34E-01	4.73E-03	13.8	
20	0	1238.39*	113	236	1.29	2472.48	8.59E-01	1.79E-03	29.7	
21	0	1461.35*	1539	136	2.00	2917.36	7.48E-01	2.43E-02	3.6	
22	0	1765.31*	225	120	2.03	3523.80	6.42E-01	3.55E-03	15.1	

Flag: "*" = Peak area was modified by background subtraction

Nuclide Line Activity Report

Nuclide Type:

Nuclide	Energy	Area	%Abn	%Eff	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	2-Sigma %Error
K-40	1460.81	1539	10.67*	7.481E-01	1.532E+01	1.532E+01	7.17
CS-137	661.66	271	85.12*	1.463E+00	1.730E-01	1.734E-01	30.87
BI-214	609.31	1364	46.30	1.570E+00	1.491E+00	1.491E+00	10.53
	1120.29	300	15.10*	9.340E-01	1.691E+00	1.691E+00	27.62
	1764.49	225	15.80	6.424E-01	1.765E+00	1.765E+00	30.14
RA-226	186.21	437	3.28*	4.018E+00	2.633E+00	2.633E+00	35.74

RA-228	93.35	383	3.50	2.875E+00	3.027E+00	3.064E+00	39.60
	969.11	254	16.60*	1.056E+00	1.154E+00	1.168E+00	36.83
TH-234	63.29	------	3.80*	8.696E-01	------	Line Not Found	------
	92.60	383	5.41	2.875E+00	1.958E+00	1.958E+00	39.60
U-235	143.76	------	10.50*	4.209E+00	------	Line Not Found	------
	163.35	------	4.70	4.183E+00	------	Line Not Found	------
	185.71	437	54.00	4.018E+00	1.599E-01	1.599E-01	35.74
	205.31	------	4.70	3.827E+00	------	Line Not Found	------

Nuclide Type: NATURAL

Nuclide	Energy	Area	%Abn	%Eff	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	2-Sigma %Error
TL-208	583.17	840	30.25*	1.631E+00	1.353E+00	1.403E+00	16.20
BI-212	727.17	221	7.56*	1.348E+00	1.723E+00	1.786E+00	41.74
PB-212	238.63	2518	44.60*	3.477E+00	1.291E+00	1.339E+00	6.07
PB-214	295.21	862	19.20	2.950E+00	1.210E+00	1.210E+00	20.25
	351.92	1795	37.20*	2.541E+00	1.510E+00	1.510E+00	9.75
TH-232	911.21	510	27.70*	1.112E+00	1.316E+00	1.316E+00	17.20

Nuclide Type: natural

Nuclide	Energy	Area	%Abn	%Eff	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	2-Sigma %Error
AC-228	835.50	------	1.75	1.198E+00	------	Line Not Found	------
	911.07	510	27.70*	1.112E+00	1.316E+00	1.332E+00	17.20

Flag: "*" = Keyline

Total number of lines in spectrum 22
Number of unidentified lines 8
Number of lines tentatively identified by NID 14 63.64%

Nuclide Type :

Nuclide	Hlife	Decay	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
K-40	1.28E+09Y	1.00	1.532E+01	1.532E+01	0.110E+01	7.17	
CS-137	30.07Y	1.00	1.730E-01	1.734E-01	0.535E-01	30.87	
BI-214	1600.00Y	1.00	1.691E+00	1.691E+00	0.467E+00	27.62	
RA-226	1600.00Y	1.00	2.633E+00	2.633E+00	0.941E+00	35.74	
RA-228	5.75Y	1.01	1.154E+00	1.168E+00	0.430E+00	36.83	
TH-234	4.47E+09Y	1.00	1.958E+00	1.958E+00	0.775E+00	39.60	K
U-235	7.04E+08Y	1.00	1.599E-01	1.599E-01	0.572E-01	35.74	K
			---------	---------			
	Total Activity :		2.309E+01	2.311E+01			

Nuclide Type : NATURAL

Nuclide	Hlife	Decay	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
TL-208	1.91Y	1.04	1.353E+00	1.403E+00	0.227E+00	16.20	
BI-212	1.91Y	1.04	1.723E+00	1.786E+00	0.746E+00	41.74	
PB-212	1.91Y	1.04	1.291E+00	1.339E+00	0.081E+00	6.07	
PB-214	1600.00Y	1.00	1.510E+00	1.510E+00	0.147E+00	9.75	
TH-232	1.41E+10Y	1.00	1.316E+00	1.316E+00	0.226E+00	17.20	
			---------	---------			
	Total Activity :		7.193E+00	7.354E+00			

Nuclide Type : natural

Nuclide	Hlife	Decay	Uncorrected pCi/g Dry	Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
AC-228	5.75Y	1.01	1.316E+00	1.332E+00	0.229E+00	17.20	
			---------	---------			
	Total Activity :		1.316E+00	1.332E+00			

Grand Total Activity : 3.160E+01 3.180E+01

Flags: "K" = Keyline not found "M" = Manually accepted
"E" = Manually edited "A" = Nuclide specific abn. limit

It	Energy	Area	Bkgnd	FWHM	Channel	Left	Pw	Cts/Sec	%Err	%Eff	Flags
3	74.90	407	1332	0.85	150.27	147	19	6.42E-03	32.2	1.68E+00	
3	77.14	573	1215	0.82	154.74	147	19	9.04E-03	20.2	1.84E+00	
0	87.24	376	1309	1.19	174.90	173	6	5.93E-03	32.0	2.53E+00	
0	209.33	250	1136	0.79	418.63	415	7	3.94E-03	46.5	3.79E+00	
4	241.75	812	1507	1.77	483.35	473	17	1.28E-02	22.2	3.45E+00	
0	338.56	596	1168	1.25	676.60	672	11	9.39E-03	23.7	2.63E+00	
0	511.16	339	1140	2.20	1021.12	1012	21	5.34E-03	61.3	1.83E+00	
0	1238.39	113	236	1.29	2472.48	2468	11	1.79E-03	59.5	8.59E-01	

Flags: "T" = Tentatively associated

Summary of Nuclide Activity

Total number of lines in spectrum 22
Number of unidentified lines 8
Number of lines tentatively identified by NID 14 63.64%

Nuclide Type :

Nuclide	Hlife	Decay	Wtd Mean Uncorrected pCi/g Dry	Wtd Mean Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
K-40	1.28E+09Y	1.00	1.532E+01	1.532E+01	0.110E+01	7.17	
CS-137	30.07Y	1.00	1.730E-01	1.734E-01	0.535E-01	30.87	
BI-214	1600.00Y	1.00	1.530E+00	1.530E+00	0.143E+00	9.37	
RA-226	1600.00Y	1.00	2.633E+00	2.633E+00	0.941E+00	35.74	
RA-228	5.75Y	1.01	1.154E+00	1.168E+00	0.430E+00	36.83	
			---------	---------			
	Total Activity :		2.082E+01	2.083E+01			

Nuclide Type : NATURAL

Nuclide	Hlife	Decay	Wtd Mean Uncorrected pCi/g Dry	Wtd Mean Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
TL-208	1.91Y	1.04	1.353E+00	1.403E+00	0.227E+00	16.20	
BI-212	1.91Y	1.04	1.723E+00	1.786E+00	0.746E+00	41.74	
PB-212	1.91Y	1.04	1.291E+00	1.339E+00	0.081E+00	6.07	
PB-214	1600.00Y	1.00	1.430E+00	1.430E+00	0.126E+00	8.82	
TH-232	1.41E+10Y	1.00	1.316E+00	1.316E+00	0.226E+00	17.20	
			---------	---------			
	Total Activity :		7.114E+00	7.275E+00			

Nuclide Type : natural

Nuclide	Hlife	Decay	Wtd Mean Uncorrected pCi/g Dry	Wtd Mean Decay Corr pCi/g Dry	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
AC-228	5.75Y	1.01	1.316E+00	1.332E+00	0.229E+00	17.20	
			---------	---------			
	Total Activity :		1.316E+00	1.332E+00			

Grand Total Activity : 2.925E+01 2.944E+01

Flags: "K" = Keyline not found "M" = Manually accepted
"E" = Manually edited "A" = Nuclide specific abn. limit

Interference Report

No interference correction performed

Combined Activity-MDA Report

---- Identified Nuclides ----

Nuclide	Activity (pCi/g Dry)	Act error	MDA (pCi/g Dry)	MDA error	Act/MDA
K-40	1.532E+01	1.098E+00	4.834E-01	0.000E+00	31.699
CS-137	1.734E-01	5.354E-02	6.114E-02	0.000E+00	2.836
TL-208	1.403E+00	2.272E-01	1.637E-01	0.000E+00	8.568
BI-212	1.786E+00	7.457E-01	7.206E-01	0.000E+00	2.479
PB-212	1.339E+00	8.121E-02	8.068E-02	0.000E+00	16.591
BI-214	1.530E+00	1.434E-01	3.973E-01	0.000E+00	3.852
PB-214	1.430E+00	1.261E-01	1.057E-01	0.000E+00	13.530
RA-226	2.633E+00	9.411E-01	1.004E+00	0.000E+00	2.623
AC-228	1.332E+00	2.292E-01	1.973E-01	0.000E+00	6.751
RA-228	1.168E+00	4.302E-01	4.328E-01	0.000E+00	2.699
TH-232	1.316E+00	2.264E-01	1.975E-01	0.000E+00	6.667

---- Non-Identified Nuclides ----

Nuclide	Key-Line Activity (pCi/g Dry)	K.L. Ided	Act error	MDA (pCi/g Dry)	MDA error	Act/MDA
CO-60	4.112E-02		3.663E-02	6.470E-02	0.000E+00	0.636
LA-138	-8.255E-03		4.780E-02	7.869E-02	0.000E+00	-0.105
PA-234M	3.466E+00		3.837E+00	6.520E+00	0.000E+00	0.532
TH-234	1.674E+00		2.469E+00	4.141E+00	0.000E+00	0.404
U-235	4.466E-02		1.898E-01	3.063E-01	0.000E+00	0.146
U-238	3.466E+00		3.837E+00	6.520E+00	0.000E+00	0.532

```
A,06L95403-20      ,03/22/2022 07:26,02/13/2022 13:00,   5.360E+01,L95403-20 SS A
B,06L95403-20      ,NORMK                    ,10/29/2021 09:14,06S50031621
C,K-40      ,YES,   1.532E+01,   1.098E+00,   4.834E-01,,   31.699
C,CS-137    ,YES,   1.734E-01,   5.354E-02,   6.114E-02,,    2.836
C,TL-208    ,YES,   1.403E+00,   2.272E-01,   1.637E-01,,    8.568
C,BI-212    ,YES,   1.786E+00,   7.457E-01,   7.206E-01,,    2.479
C,PB-212    ,YES,   1.339E+00,   8.121E-02,   8.068E-02,,   16.591
C,BI-214    ,YES,   1.530E+00,   1.434E-01,   3.973E-01,,    3.852
C,PB-214    ,YES,   1.430E+00,   1.261E-01,   1.057E-01,,   13.530
C,RA-226    ,YES,   2.633E+00,   9.411E-01,   1.004E+00,,    2.623
C,AC-228    ,YES,   1.332E+00,   2.292E-01,   1.973E-01,,    6.751
C,RA-228    ,YES,   1.168E+00,   4.302E-01,   4.328E-01,,    2.699
C,TH-232    ,YES,   1.316E+00,   2.264E-01,   1.975E-01,,    6.667
C,CO-60     ,NO ,   4.112E-02,   3.663E-02,   6.470E-02,,    0.636
C,LA-138    ,NO ,  -8.255E-03,   4.780E-02,   7.869E-02,,   -0.105
C,PA-234M   ,NO ,   3.466E+00,   3.837E+00,   6.520E+00,,    0.532
C,TH-234    ,NO ,   1.674E+00,   2.469E+00,   4.141E+00,,    0.404
C,U-235     ,NO ,   4.466E-02,   1.898E-01,   3.063E-01,,    0.146
C,U-238     ,NO ,   3.466E+00,   3.837E+00,   6.520E+00,,    0.532
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Analyst:

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=============================================================================
VAX/VMS Teledyne Brown Eng. Laboratory Gamma Report: 11-MAR-2022 12:49:49.47
TBE11 59-TN51806A HpGe ******* Aquisition Date/Time: 11-MAR-2022 11:21:02.87
-----------------------------------------------------------------------------
LIMS No., Customer Name, Client ID: WG38795-1 AN PSEG -SALEM/HC

Sample ID      : 11WG38795-1                           Smple Date: 7-MAR-2022 12:00:00.0
Sample Type    : AN                                    Geometry  : 1135L120319
Quantity       : 2.48010E+00 Kg Wet                    BKGFILE   : 11BG030422MT
Start Channel  : 80       Energy Tol   : 2.00000      Real Time : 0 01:28:36.82
End Channel    : 4090     Pk Srch Sens: 9.00000       Live time : 0 01:28:33.85
MDA Multiple   : 4.6600   Library Used: LIBD
Peak Evaluation - Identified and Unidentified
```

Pk	It	Energy	Area	Bkgnd	FWHM	Channel	%Eff	Cts/Sec	%Err	Fit
1	0	1461.17*	701	8	2.35	2920.16	4.47E-01	1.32E-01	4.0	

Flag: "*" = Peak area was modified by background subtraction

Nuclide Line Activity Report

Nuclide Type: natural

Nuclide	Energy	Area	%Abn	%Eff	Uncorrected pCi/Kg Wet	Decay Corr pCi/Kg Wet	2-Sigma %Error
K-40	1460.81	701	10.67*	4.474E-01	3.013E+03	3.013E+03	7.92

Flag: "*" = Keyline

Total number of lines in spectrum 1
Number of unidentified lines 0
Number of lines tentatively identified by NID 1 100.00%

Nuclide Type : natural

Nuclide	Hlife	Decay	Uncorrected pCi/Kg Wet	Decay Corr pCi/Kg Wet	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
K-40	1.28E+09Y	1.00	3.013E+03	3.013E+03	0.239E+03	7.92	
			---------	---------			
	Total Activity :		3.013E+03	3.013E+03			
	Grand Total Activity :		3.013E+03	3.013E+03			

Flags: "K" = Keyline not found "M" = Manually accepted
"E" = Manually edited "A" = Nuclide specific abn. limit

None

Flags: "T" = Tentatively associated

Summary of Nuclide Activity

Total number of lines in spectrum	1	
Number of unidentified lines	0	
Number of lines tentatively identified by NID	1	100.00%

Nuclide Type : natural

Nuclide	Hlife	Decay	Wtd Mean Uncorrected pCi/Kg Wet	Wtd Mean Decay Corr pCi/Kg Wet	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
K-40	1.28E+09Y	1.00	3.013E+03	3.013E+03	0.239E+03	7.92	
			---------	---------			
	Total Activity :		3.013E+03	3.013E+03			
	Grand Total Activity :		3.013E+03	3.013E+03			

Flags: "K" = Keyline not found "M" = Manually accepted
"E" = Manually edited "A" = Nuclide specific abn. limit

Interference Report

No interference correction performed

Combined Activity-MDA Report

---- Identified Nuclides ----

Nuclide	Activity (pCi/Kg Wet)	Act error	MDA (pCi/Kg Wet)	MDA error	Act/MDA
K-40	3.013E+03	2.385E+02	9.648E+01	0.000E+00	31.230

---- Non-Identified Nuclides ----

Nuclide	Key-Line Activity (pCi/Kg Wet)	K.L. Ided	Act error	MDA (pCi/Kg Wet)	MDA error	Act/MDA
BE-7	-1.223E+00		4.457E+01	7.903E+01	0.000E+00	-0.015
NA-22	-5.402E-01		6.323E+00	1.124E+01	0.000E+00	-0.048
NA-24	-1.034E+02		3.900E+02	7.212E+02	0.000E+00	-0.143
CR-51	-1.599E+01		4.417E+01	7.304E+01	0.000E+00	-0.219
MN-54	-9.385E-01		5.571E+00	9.966E+00	0.000E+00	-0.094
CO-56	2.315E+00		6.231E+00	1.220E+01	0.000E+00	0.190
CO-57	3.046E+00		3.874E+00	7.027E+00	0.000E+00	0.433
CO-58	5.002E+00		5.717E+00	1.122E+01	0.000E+00	0.446
FE-59	3.696E+00		1.261E+01	2.320E+01	0.000E+00	0.159
CO-60	-1.905E+00		5.441E+00	9.398E+00	0.000E+00	-0.203
ZN-65	-1.521E+01		1.328E+01	2.066E+01	0.000E+00	-0.736
SE-75	-1.224E+00		6.845E+00	1.154E+01	0.000E+00	-0.106

Y-88	2.210E+00	4.273E+00	9.435E+00	0.000E+00	0.234
NB-94	-4.073E+00	5.725E+00	9.645E+00	0.000E+00	-0.422
NB-95	7.055E+00	5.152E+00	1.064E+01	0.000E+00	0.663
ZR-95	-8.294E+00	8.748E+00	1.358E+01	0.000E+00	-0.611
ZRNB-95	7.054E+00	5.152E+00	1.064E+01	0.000E+00	0.663
MO-99	8.811E+01	1.055E+02	2.024E+02	0.000E+00	0.435
RU-103	-2.934E+00	5.266E+00	8.904E+00	0.000E+00	-0.329
RU-106	-3.857E+00	4.636E+01	8.152E+01	0.000E+00	-0.047
AG-110m	-2.055E+00	5.100E+00	8.621E+00	0.000E+00	-0.238
SN-113	-3.922E+00	5.876E+00	9.991E+00	0.000E+00	-0.393
SB-124	-3.638E+00	4.849E+00	7.925E+00	0.000E+00	-0.459
SB-125	-1.749E+00	1.450E+01	2.560E+01	0.000E+00	-0.068
TE-129M	-3.901E+01	5.843E+01	9.829E+01	0.000E+00	-0.397
I-131	4.583E+00	7.012E+00	1.310E+01	0.000E+00	0.350
TE-132	8.088E+00	1.035E+01	1.852E+01	0.000E+00	0.437
BA-133	-9.175E+00	7.215E+00	1.178E+01	0.000E+00	-0.779
CS-134	2.368E+00	5.674E+00	1.088E+01	0.000E+00	0.218
CS-136	-2.543E+00	5.997E+00	1.053E+01	0.000E+00	-0.242
CS-137	4.715E+00	6.151E+00	1.154E+01	0.000E+00	0.409
CE-139	-1.216E+00	4.435E+00	7.569E+00	0.000E+00	-0.161
BA-140	3.626E+00	2.271E+01	4.081E+01	0.000E+00	0.089
BALA140	3.975E+00	6.451E+00	1.359E+01	0.000E+00	0.292
LA-140	3.975E+00	6.451E+00	1.359E+01	0.000E+00	0.292
CE-141	-9.139E-01	7.993E+00	1.386E+01	0.000E+00	-0.066
CE-144	-1.571E+01	3.135E+01	5.333E+01	0.000E+00	-0.295
EU-152	-1.006E+01	1.515E+01	2.591E+01	0.000E+00	-0.388
EU-154	-9.827E-01	8.353E+00	1.452E+01	0.000E+00	-0.068
RA-226	7.227E+00	1.145E+02	2.042E+02	0.000E+00	0.035
AC-228	1.504E+01	2.328E+01	4.541E+01	0.000E+00	0.331
TH-228	7.433E+00	9.813E+00	1.761E+01	0.000E+00	0.422
TH-232	1.502E+01	2.325E+01	4.535E+01	0.000E+00	0.331

---- Non-Identified Nuclides ----

Nuclide	Key-Line Activity (pCi/Kg Wet)	K.L. Ided	Act error	MDA (pCi/Kg Wet)	MDA error	Act/MDA
U-235	-1.460E+01		3.493E+01	5.963E+01	0.000E+00	-0.245
U-238	4.322E+02		6.508E+02	1.254E+03	0.000E+00	0.345
NP-239	-2.862E+01		4.828E+01	8.247E+01	0.000E+00	-0.347
AM-241	1.549E+00		1.158E+01	1.941E+01	0.000E+00	0.080

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A,11WG38795-1      ,03/11/2022 12:49,03/07/2022 12:00,   2.480E+00,WG38795-1 AN P
B,11WG38795-1      ,LIBD                    ,02/10/2022 09:58,1135L120319
C,K-40     ,YES,   3.013E+03,   2.385E+02,   9.648E+01,,   31.230
C,BE-7     ,NO ,  -1.223E+00,   4.457E+01,   7.903E+01,,   -0.015
C,NA-22    ,NO ,  -5.402E-01,   6.323E+00,   1.124E+01,,   -0.048
C,NA-24    ,NO ,  -1.034E+02,   3.900E+02,   7.212E+02,,   -0.143
C,CR-51    ,NO ,  -1.599E+01,   4.417E+01,   7.304E+01,,   -0.219
C,MN-54    ,NO ,  -9.385E-01,   5.571E+00,   9.966E+00,,   -0.094
C,CO-56    ,NO ,   2.315E+00,   6.231E+00,   1.220E+01,,    0.190
C,CO-57    ,NO ,   3.046E+00,   3.874E+00,   7.027E+00,,    0.433
C,CO-58    ,NO ,   5.002E+00,   5.717E+00,   1.122E+01,,    0.446
C,FE-59    ,NO ,   3.696E+00,   1.261E+01,   2.320E+01,,    0.159
C,CO-60    ,NO ,  -1.905E+00,   5.441E+00,   9.398E+00,,   -0.203
C,ZN-65    ,NO ,  -1.521E+01,   1.328E+01,   2.066E+01,,   -0.736
C,SE-75    ,NO ,  -1.224E+00,   6.845E+00,   1.154E+01,,   -0.106
C,Y-88     ,NO ,   2.210E+00,   4.273E+00,   9.435E+00,,    0.234
C,NB-94    ,NO ,  -4.073E+00,   5.725E+00,   9.645E+00,,   -0.422
C,NB-95    ,NO ,   7.055E+00,   5.152E+00,   1.064E+01,,    0.663
C,ZR-95    ,NO ,  -8.294E+00,   8.748E+00,   1.358E+01,,   -0.611
C,ZRNB-95  ,NO ,   7.054E+00,   5.152E+00,   1.064E+01,,    0.663
C,MO-99    ,NO ,   8.811E+01,   1.055E+02,   2.024E+02,,    0.435
C,RU-103   ,NO ,  -2.934E+00,   5.266E+00,   8.904E+00,,   -0.329
C,RU-106   ,NO ,  -3.857E+00,   4.636E+01,   8.152E+01,,   -0.047
C,AG-110m  ,NO ,  -2.055E+00,   5.100E+00,   8.621E+00,,   -0.238
C,SN-113   ,NO ,  -3.922E+00,   5.876E+00,   9.991E+00,,   -0.393
C,SB-124   ,NO ,  -3.638E+00,   4.849E+00,   7.925E+00,,   -0.459
C,SB-125   ,NO ,  -1.749E+00,   1.450E+01,   2.560E+01,,   -0.068
C,TE-129M  ,NO ,  -3.901E+01,   5.843E+01,   9.829E+01,,   -0.397
C,I-131    ,NO ,   4.583E+00,   7.012E+00,   1.310E+01,,    0.350
C,TE-132   ,NO ,   8.088E+00,   1.035E+01,   1.852E+01,,    0.437
C,BA-133   ,NO ,  -9.175E+00,   7.215E+00,   1.178E+01,,   -0.779
C,CS-134   ,NO ,   2.368E+00,   5.674E+00,   1.088E+01,,    0.218
C,CS-136   ,NO ,  -2.543E+00,   5.997E+00,   1.053E+01,,   -0.242
C,CS-137   ,NO ,   4.715E+00,   6.151E+00,   1.154E+01,,    0.409
C,CE-139   ,NO ,  -1.216E+00,   4.435E+00,   7.569E+00,,   -0.161
C,BA-140   ,NO ,   3.626E+00,   2.271E+01,   4.081E+01,,    0.089
C,BALA140  ,NO ,   3.975E+00,   6.451E+00,   1.359E+01,,    0.292
C,LA-140   ,NO ,   3.975E+00,   6.451E+00,   1.359E+01,,    0.292
C,CE-141   ,NO ,  -9.139E-01,   7.993E+00,   1.386E+01,,   -0.066
C,CE-144   ,NO ,  -1.571E+01,   3.135E+01,   5.333E+01,,   -0.295
C,EU-152   ,NO ,  -1.006E+01,   1.515E+01,   2.591E+01,,   -0.388
C,EU-154   ,NO ,  -9.827E-01,   8.353E+00,   1.452E+01,,   -0.068
C,RA-226   ,NO ,   7.227E+00,   1.145E+02,   2.042E+02,,    0.035
C,AC-228   ,NO ,   1.504E+01,   2.328E+01,   4.541E+01,,    0.331
C,TH-228   ,NO ,   7.433E+00,   9.813E+00,   1.761E+01,,    0.422
C,TH-232   ,NO ,   1.502E+01,   2.325E+01,   4.535E+01,,    0.331
C,U-235    ,NO ,  -1.460E+01,   3.493E+01,   5.963E+01,,   -0.245
C,U-238    ,NO ,   4.322E+02,   6.508E+02,   1.254E+03,,    0.345
C,NP-239   ,NO ,  -2.862E+01,   4.828E+01,   8.247E+01,,   -0.347
C,AM-241   ,NO ,   1.549E+00,   1.158E+01,   1.941E+01,,    0.080
```

Analyst:

VAX/VMS Teledyne Brown Eng. Laboratory Gamma Report: 10-MAR-2022 13:48:57.49
TBE11 59-TN51806A HpGe ******* Aquisition Date/Time: 10-MAR-2022 12:48:40.89

LIMS No., Customer Name, Client ID: WG38781-1 VA DOMINION - MILLSTONE REMP

Sample ID : 11WG38781-1
Sample Type : VA
Quantity : 1.37640E+03 g Wet
Start Channel : 80 Energy Tol : 2.00000
End Channel : 4090 Pk Srch Sens: 9.00000
MDA Multiple : 4.6600 Library Used: LIBD
Peak Evaluation - Identified and Unidentified

Smple Date: 7-MAR-2022 08:55:00.0
Geometry : 1135L120319
BKGFILE : 11BG030422MT
Real Time : 0 01:00:01.96
Live time : 0 01:00:00.00

Pk	It	Energy	Area	Bkgnd	FWHM	Channel	%Eff	Cts/Sec	%Err	Fit
1	0	239.51*	80	102	1.39	477.53	1.70E+00	2.23E-02	28.5	
2	0	478.29	39	33	0.68	954.93	1.03E+00	1.07E-02	34.6	
3	0	1461.36*	504	0	2.38	2920.52	4.47E-01	1.40E-01	4.6	

Flag: "*" = Peak area was modified by background subtraction

Nuclide Line Activity Report

Nuclide Type: activation

Nuclide	Energy	Area	%Abn	%Eff	Uncorrected pCi/g Wet	Decay Corr pCi/g Wet	2-Sigma %Error
BE-7	477.59	39	10.42*	1.028E+00	1.964E-01	2.047E-01	69.25

Nuclide Type: natural

Nuclide	Energy	Area	%Abn	%Eff	Uncorrected pCi/g Wet	Decay Corr pCi/g Wet	2-Sigma %Error
K-40	1460.81	504	10.67*	4.473E-01	5.754E+00	5.754E+00	9.11
TH-228	238.63	80	44.60*	1.700E+00	5.779E-02	5.797E-02	57.05
	240.98	80	3.95	1.700E+00	6.525E-01	6.545E-01	57.05

Flag: "*" = Keyline

Total number of lines in spectrum	3	
Number of unidentified lines	0	
Number of lines tentatively identified by NID	3	100.00%

Nuclide Type : activation

Nuclide	Hlife	Decay	Uncorrected pCi/g Wet	Decay Corr pCi/g Wet	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
BE-7	53.44D	1.04	1.964E-01	2.047E-01	1.418E-01	69.25	
			---------	---------			
	Total Activity :		1.964E-01	2.047E-01			

Nuclide Type : natural

Nuclide	Hlife	Decay	Uncorrected pCi/g Wet	Decay Corr pCi/g Wet	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
K-40	1.28E+09Y	1.00	5.754E+00	5.754E+00	0.524E+00	9.11	
TH-228	1.91Y	1.00	5.779E-02	5.797E-02	3.307E-02	57.05	
			---------	---------			
	Total Activity :		5.812E+00	5.812E+00			

Grand Total Activity : 6.009E+00 6.017E+00

Flags: "K" = Keyline not found "M" = Manually accepted
"E" = Manually edited "A" = Nuclide specific abn. limit

None

Flags: "T" = Tentatively associated

Summary of Nuclide Activity

Total number of lines in spectrum	3	
Number of unidentified lines	0	
Number of lines tentatively identified by NID	3	100.00%

Nuclide Type : activation

Nuclide	Hlife	Decay	Wtd Mean Uncorrected pCi/g Wet	Wtd Mean Decay Corr pCi/g Wet	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
BE-7	53.44D	1.04	1.964E-01	2.047E-01	1.418E-01	69.25	
			---------	---------			
	Total Activity :		1.964E-01	2.047E-01			

Nuclide Type : natural

Nuclide	Hlife	Decay	Wtd Mean Uncorrected pCi/g Wet	Wtd Mean Decay Corr pCi/g Wet	Decay Corr 2-Sigma Error	2-Sigma %Error	Flags
K-40	1.28E+09Y	1.00	5.754E+00	5.754E+00	0.524E+00	9.11	
TH-228	1.91Y	1.00	5.779E-02	5.797E-02	3.307E-02	57.05	
			---------	---------			
	Total Activity :		5.812E+00	5.812E+00			

Grand Total Activity : 6.009E+00 6.017E+00

Flags: "K" = Keyline not found "M" = Manually accepted
"E" = Manually edited "A" = Nuclide specific abn. limit

Interference Report

No interference correction performed

Combined Activity-MDA Report

---- Identified Nuclides ----

Nuclide	Activity (pCi/g Wet)	Act error	MDA (pCi/g Wet)	MDA error	Act/MDA
BE-7	2.047E-01	1.418E-01	1.582E-01	0.000E+00	1.294
K-40	5.754E+00	5.240E-01	1.862E-01	0.000E+00	30.900
TH-228	5.797E-02	3.307E-02	3.095E-02	0.000E+00	1.873

---- Non-Identified Nuclides ----

Nuclide	Key-Line Activity (pCi/g Wet)	K.L. Ided	Act error	MDA (pCi/g Wet)	MDA error	Act/MDA
NA-22	-4.033E-03		1.475E-02	2.580E-02	0.000E+00	-0.156

NA-24	9.854E-02	3.254E-01	6.877E-01	0.000E+00	0.143
CR-51	8.129E-03	1.013E-01	1.751E-01	0.000E+00	0.046
MN-54	-8.210E-03	1.290E-02	2.204E-02	0.000E+00	-0.372
CO-56	-2.661E-03	1.284E-02	2.468E-02	0.000E+00	-0.108
CO-57	-1.934E-03	8.011E-03	1.397E-02	0.000E+00	-0.138
CO-58	1.671E-04	1.125E-02	2.108E-02	0.000E+00	0.008
FE-59	-1.338E-02	2.655E-02	4.523E-02	0.000E+00	-0.296
CO-60	-4.402E-04	1.398E-02	2.551E-02	0.000E+00	-0.017
ZN-65	-2.706E-02	2.818E-02	4.458E-02	0.000E+00	-0.607
SE-75	1.072E-03	1.437E-02	2.498E-02	0.000E+00	0.043
Y-88	-1.622E-03	9.112E-03	1.803E-02	0.000E+00	-0.090
NB-94	-5.926E-03	1.161E-02	2.019E-02	0.000E+00	-0.293
NB-95	1.162E-03	1.100E-02	2.085E-02	0.000E+00	0.056
ZR-95	2.782E-02	2.115E-02	4.375E-02	0.000E+00	0.636
ZRNB-95	1.162E-03	1.100E-02	2.085E-02	0.000E+00	0.056
MO-99	1.017E-01	1.998E-01	3.784E-01	0.000E+00	0.269
RU-103	1.023E-02	1.191E-02	2.315E-02	0.000E+00	0.442
RU-106	-2.488E-02	1.067E-01	1.863E-01	0.000E+00	-0.134
AG-110m	2.894E-03	1.162E-02	2.139E-02	0.000E+00	0.135
SN-113	-4.192E-03	1.364E-02	2.409E-02	0.000E+00	-0.174
SB-124	3.361E-03	1.123E-02	2.080E-02	0.000E+00	0.162
SB-125	1.549E-02	2.969E-02	5.664E-02	0.000E+00	0.274
TE-129M	-1.145E-01	1.369E-01	2.264E-01	0.000E+00	-0.506
I-131	2.224E-02	1.593E-02	3.151E-02	0.000E+00	0.706
TE-132	-7.551E-03	1.836E-02	3.083E-02	0.000E+00	-0.245
BA-133	-8.112E-03	1.518E-02	2.627E-02	0.000E+00	-0.309
CS-134	9.141E-03	1.336E-02	2.682E-02	0.000E+00	0.341
CS-136	-1.734E-03	1.217E-02	2.248E-02	0.000E+00	-0.077
CS-137	-9.355E-03	1.345E-02	2.197E-02	0.000E+00	-0.426
CE-139	2.000E-03	9.336E-03	1.658E-02	0.000E+00	0.121
BA-140	2.215E-02	4.280E-02	8.232E-02	0.000E+00	0.269
BALA140	-3.950E-04	1.094E-02	2.228E-02	0.000E+00	-0.018
LA-140	-3.950E-04	1.094E-02	2.228E-02	0.000E+00	-0.018
CE-141	-2.846E-04	1.632E-02	2.884E-02	0.000E+00	-0.010
CE-144	-3.393E-02	6.718E-02	1.147E-01	0.000E+00	-0.296
EU-152	1.714E-02	3.575E-02	6.674E-02	0.000E+00	0.257
EU-154	-9.943E-03	1.726E-02	2.944E-02	0.000E+00	-0.338
RA-226	2.668E-01	2.668E-01	5.032E-01	0.000E+00	0.530
AC-228	5.458E-02	5.441E-02	1.110E-01	0.000E+00	0.492
TH-232	5.452E-02	5.435E-02	1.109E-01	0.000E+00	0.492

---- Non-Identified Nuclides ----

Nuclide	Key-Line Activity (pCi/g Wet)	K.L. Ided	Act error	MDA (pCi/g Wet)	MDA error	Act/MDA
U-235	-3.331E-02		7.320E-02	1.258E-01	0.000E+00	-0.265
U-238	3.423E-01		1.535E+00	2.873E+00	0.000E+00	0.119
NP-239	-9.673E-03		7.295E-02	1.289E-01	0.000E+00	-0.075
AM-241	1.040E-02		2.512E-02	4.325E-02	0.000E+00	0.240

A,11WG38781-1 ,03/10/2022 13:48,03/07/2022 08:55, 1.376E+03,WG38781-1 VA D
B,11WG38781-1 ,LIBD ,02/10/2022 09:58,1135L120319

C	BE-7	YES	2.047E-01	1.418E-01	1.582E-01	1.294
C	K-40	YES	5.754E+00	5.240E-01	1.862E-01	30.900
C	TH-228	YES	5.797E-02	3.307E-02	3.095E-02	1.873
C	NA-22	NO	-4.033E-03	1.475E-02	2.580E-02	-0.156
C	NA-24	NO	9.854E-02	3.254E-01	6.877E-01	0.143
C	CR-51	NO	8.129E-03	1.013E-01	1.751E-01	0.046
C	MN-54	NO	-8.210E-03	1.290E-02	2.204E-02	-0.372
C	CO-56	NO	-2.661E-03	1.284E-02	2.468E-02	-0.108
C	CO-57	NO	-1.934E-03	8.011E-03	1.397E-02	-0.138
C	CO-58	NO	1.671E-04	1.125E-02	2.108E-02	0.008
C	FE-59	NO	-1.338E-02	2.655E-02	4.523E-02	-0.296
C	CO-60	NO	-4.402E-04	1.398E-02	2.551E-02	-0.017
C	ZN-65	NO	-2.706E-02	2.818E-02	4.458E-02	-0.607
C	SE-75	NO	1.072E-03	1.437E-02	2.498E-02	0.043
C	Y-88	NO	-1.622E-03	9.112E-03	1.803E-02	-0.090
C	NB-94	NO	-5.926E-03	1.161E-02	2.019E-02	-0.293
C	NB-95	NO	1.162E-03	1.100E-02	2.085E-02	0.056
C	ZR-95	NO	2.782E-02	2.115E-02	4.375E-02	0.636
C	ZRNB-95	NO	1.162E-03	1.100E-02	2.085E-02	0.056
C	MO-99	NO	1.017E-01	1.998E-01	3.784E-01	0.269
C	RU-103	NO	1.023E-02	1.191E-02	2.315E-02	0.442
C	RU-106	NO	-2.488E-02	1.067E-01	1.863E-01	-0.134
C	AG-110m	NO	2.894E-03	1.162E-02	2.139E-02	0.135
C	SN-113	NO	-4.192E-03	1.364E-02	2.409E-02	-0.174
C	SB-124	NO	3.361E-03	1.123E-02	2.080E-02	0.162
C	SB-125	NO	1.549E-02	2.969E-02	5.664E-02	0.274
C	TE-129M	NO	-1.145E-01	1.369E-01	2.264E-01	-0.506
C	I-131	NO	2.224E-02	1.593E-02	3.151E-02	0.706
C	TE-132	NO	-7.551E-03	1.836E-02	3.083E-02	-0.245
C	BA-133	NO	-8.112E-03	1.518E-02	2.627E-02	-0.309
C	CS-134	NO	9.141E-03	1.336E-02	2.682E-02	0.341
C	CS-136	NO	-1.734E-03	1.217E-02	2.248E-02	-0.077
C	CS-137	NO	-9.355E-03	1.345E-02	2.197E-02	-0.426
C	CE-139	NO	2.000E-03	9.336E-03	1.658E-02	0.121
C	BA-140	NO	2.215E-02	4.280E-02	8.232E-02	0.269
C	BALA140	NO	-3.950E-04	1.094E-02	2.228E-02	-0.018
C	LA-140	NO	-3.950E-04	1.094E-02	2.228E-02	-0.018
C	CE-141	NO	-2.846E-04	1.632E-02	2.884E-02	-0.010
C	CE-144	NO	-3.393E-02	6.718E-02	1.147E-01	-0.296
C	EU-152	NO	1.714E-02	3.575E-02	6.674E-02	0.257
C	EU-154	NO	-9.943E-03	1.726E-02	2.944E-02	-0.338
C	RA-226	NO	2.668E-01	2.668E-01	5.032E-01	0.530
C	AC-228	NO	5.458E-02	5.441E-02	1.110E-01	0.492
C	TH-232	NO	5.452E-02	5.435E-02	1.109E-01	0.492
C	U-235	NO	-3.331E-02	7.320E-02	1.258E-01	-0.265
C	U-238	NO	3.423E-01	1.535E+00	2.873E+00	0.119
C	NP-239	NO	-9.673E-03	7.295E-02	1.289E-01	-0.075
C	AM-241	NO	1.040E-02	2.512E-02	4.325E-02	0.240

GAMMA SPECTROSCOPY

Prep and Run Logs

Logbook Page

L95403

GELI

Sample#	Matrix	QC	Analysis	Aliquot Volume / Units	Aliquot Date	Analyst	Aliquot Instrument	Tare Weight	Tare Balance	Final Weight	Final Balance	Mount Weight	Mount Date	Workgroup
WG38781-1	VA	DUP	GELI	1376.4 g wet	03/10/22	DH	BALANCE 15							WG38781
WG38795-1	AN	DUP	GELI	2480.1 g wet	03/10/22	DH	BALANCE 15							WG38795
L95403-1	SS		GELI	21.4 g dry	03/16/22	DH	BALANCE 15							WG38781
L95403-2	SS		GELI	32.3 g dry	03/16/22	DH	BALANCE 15							WG38781
L95403-3	SS		GELI	35.7 g dry	03/16/22	DH	BALANCE 15							WG38781
L95403-4	SS		GELI	26.7 g dry	03/16/22	DH	BALANCE 15							WG38781
L95403-5	SS		GELI	30.4 g dry	03/16/22	DH	BALANCE 15							WG38781
L95403-6	SS		GELI	24.6 g dry	03/16/22	DH	BALANCE 15							WG38781
L95403-7	SS		GELI	27.4 g dry	03/16/22	DH	BALANCE 15							WG38781
L95403-8	SS		GELI	45.9 g dry	03/16/22	DH	BALANCE 15							WG38781
L95403-9	SS		GELI	31.1 g dry	03/16/22	DH	BALANCE 15							WG38781
L95403-10	SS		GELI	24.8 g dry	03/16/22	DH	BALANCE 15							WG38781
L95403-11	SS		GELI	25.5 g dry	03/16/22	DH	BALANCE 15							WG38795
L95403-12	SS		GELI	26.9 g dry	03/16/22	DH	BALANCE 15							WG38795
L95403-13	SS		GELI	21.4 g dry	03/16/22	DH	BALANCE 15							WG38795
L95403-14	SS		GELI	41.7 g dry	03/16/22	DH	BALANCE 15							WG38795
L95403-15	SS		GELI	27.3 g dry	03/16/22	DH	BALANCE 15							WG38795
L95403-16	SS		GELI	30 g dry	03/16/22	DH	BALANCE 15							WG38795
L95403-17	SS		GELI	44.1 g dry	03/16/22	DH	BALANCE 15							WG38795
L95403-18	SS		GELI	23.6 g dry	03/16/22	DH	BALANCE 15							WG38795
L95403-19	SS		GELI	49.1 g dry	03/16/22	DH	BALANCE 15							WG38795
L95403-20	SS		GELI	53.6 g dry	03/16/22	DH	BALANCE 15							WG38795

Teledyne Analytical Laboratory
2508 Quality Lane
Knoxville, Tennessee 37931

TELEDYNE BROWN ENGINEERING
Gamma Worksheet/Run log (gammaws_L)
Mar 23 2022, 02:04 pm

L95403 - Origin: E
Due Date: 03/21/22

GELI

Det. ID/Date	Sample ID	Client ID / ID Verification	Reference Date/Time	Mat	Product		Reporting Units		Nuclide	MDC

Anchor QEA, LLC
AN003-3EREGBTESKE-22 ANCHOR QEA
Report Format: Level 4 - Full 3Sigma
LLD Formula None
Countroom Library: NORMK
Project Manager: K.ARTERBURN

Technical Notes/Instructions

MS/MSD recovery 70 - 130, RPD < 30%
Uncertainty Less than 30%.

Due Date: 03/21/22

Det.	CountDate	Verify		Reference Date/Time	Mat	Product		Reporting Units		Nuclide	MDC
01	031722	☑ L95403-1 S25	1; 5.21	02/13/2022 13:37 (P/M)	SS	GELI	2.1400E+01 Dry	pCi/g Dry	SS	CS-137	1.000E-01
02	031822	☑ L95403-2 S25	8; 5.21	02/13/2022 13:37 (P/M)	SS	GELI	3.2300E+01 Dry	pCi/g Dry			
14	↓	☑ L95403-3 S25	15; 5.21	02/13/2022 13:37 (P/M)	SS	GELI	3.5700E+01 Dry	pCi/g Dry			
11	031722	☑ L95403-4 S25	22; 5.21	02/13/2022 13:37 (P/M)	SS	GELI	2.6700E+01 Dry	pCi/g Dry			
13	031822	☑ L95403-5 S25	29; 5.21	02/13/2022 13:37 (P/M)	SS	GELI	3.0400E+01 Dry	pCi/g Dry			
02	031722	☑ L95403-6 S25	36; 5.21	02/13/2022 13:37 (P/M)	SS	GELI	2.4600E+01 Dry	pCi/g Dry			
23	031822	☑ L95403-7 S25	43; 5.21	02/13/2022 13:37 (P/M)	SS	GELI	2.7400E+01 Dry	pCi/g Dry			
06	|	☑ L95403-8 S50	50; 5.21	02/13/2022 13:37 (P/M)	SS	GELI	4.5900E+01 Dry	pCi/g Dry			
07	↓	☑ L95403-9 S25	57; 5.21	02/13/2022 13:37 (P/M)	SS	GELI	3.1100E+01 Dry	pCi/g Dry			
07	031722	☑ L95403-10 S25	63; 5.21	02/13/2022 13:37 (P/M)	SS	GELI	2.4800E+01 Dry	pCi/g Dry			
14	|	☑ L95403-11 S25	64; 5.11	02/13/2022 12:56 (P/M)	SS	GELI	2.5500E+01 Dry	pCi/g Dry			
08	|	☑ L95403-12 S25	72; 5.11	02/13/2022 12:56 (P/M)	SS	GELI	2.6900E+01 Dry	pCi/g Dry			
23	↓	☑ L95403-13 S25	80; 5.11	02/13/2022 12:56 (P/M)	SS	GELI	2.1400E+01 Dry	pCi/g Dry			
11	031822	☑ L95403-14 S50	88; 5.11	02/13/2022 12:56 (P/M)	SS	GELI	4.1700E+01 Dry	pCi/g Dry			
06	031722	☑ L95403-15 S25	96; 5.11	02/13/2022 12:56 (P/M)	SS	GELI	2.7300E+01 Dry	pCi/g Dry			
01	031822	☑ L95403-16 S25	104; 5.11	02/13/2022 12:56 (P/M)	SS	GELI	3.0000E+01 Dry	pCi/g Dry			
08	↓	☑ L95403-17 S50	112; 5.11	02/13/2022 12:56 (P/M)	SS	GELI	4.4100E+01 Dry	pCi/g Dry			
13	031722	☑ L95403-18 S25	120; 5.11	02/13/2022 12:56 (P/M)	SS	GELI	2.3600E+01 Dry	pCi/g Dry			
08	032122	☑ L95403-19 S50	128; 5.11	02/13/2022 12:56 (P/M)	SS	GELI	4.9100E+01 Dry	pCi/g Dry			
06	↓	☑ L95403-20 S50	137; 5.11	02/13/2022 13:00 (P/M)	SS	GELI	5.3600E+01 Dry	pCi/g Dry			

Teledyne Analytical Laboratory
2508 Quality Lane
Knoxville, Tennessee 37931

TELEDYNE BROWN ENGINEERING
Gamma Worksheet/Run log (gammaws_wg)
Mar 23 2022, 02:05 pm

WG38781 - Origin: E
Due Date: 03/21/22

GELI

Det. ID/Date	ID Verification Sample ID	Client ID	Reference Date/Time	Mat	Product	Reporting Units	Nuclide	MDC

Teledyne Brown Engineering
TE511-LABQC Internal Lab QC (Bla
Report Format: Level 1 - Full 3Sigma
LLD Formula None
Countroom Library: LIBD
Project Manager: S.NORTHCUTT

Technical Notes/Instructions

Due Date: 04/04/22

Det.	CountDate	Verify	Sample ID	Client ID	Reference Date/Time	Mat	Product	Reporting Units
11	03/11/22	☑	WG38781-1 (L95387-1)	JORDAN COVE W	03/07/2022 08:55 (F/M)	VA	GELI	1.3764E+03 Wet pCi/g Wet

Teledyne Analytical Laboratory
2508 Quality Lane
Knoxville, Tennessee 37931

TELEDYNE BROWN ENGINEERING
Gamma Worksheet/Run log (gammaws_wg)
Mar 23 2022, 02:04 pm

WG38795 - Origin: E

GELI **Due Date: 03/21/22**

Det.	ID/Date	ID Verification Sample ID	Client ID	Reference Date/Time	Mat	Product	Reporting Units	Nuclide	MDC

Teledyne Brown Engineering
TE511-LABQC Internal Lab QC (Bla
Report Format: Level 1 - Full 3Sigma
LLD Formula None
Countroom Library: LIBD
Project Manager: S.NORTHCUTT

Technical Notes/Instructions

Due Date: 04/04/22

Det.	CountDate	Verify	Sample ID	Client ID	Reference Date/Time	Mat	Product		Reporting Units
11	031022	☐	WG38795-1 (L95392-1)	SAGAM13E3	03/07/2022 12:00 (F/E)	AN	GELI	2.4801E+00 Wet	pCi/Kg Wet

GAMMA SPECTROSCOPY

Balance and Pipette Check

Daily Balance Tolerance Check Reports

for : L95403

Instrument: BALANCE 15

Model: A&D GX-6001A

Serial Number: T2008157

Description: A&D 6100 g capacity top loading balance.

Known Weight: Initial calibration by PCS 06/17/21

Check Date: 10-MAR-22

Analyst: DH

Weight Set Used: WTSET 3

Tolerance: 1%

Out of Range: N

	Result Weight
1.0000	1.0000
100.0000	100.0000
1000.0000	1000.0000

Prod

NONE BALANCE 15 10-MAR-22

Daily Balance Tolerance Check Reports

for : L95403

Instrument: BALANCE 15

Model: A&D GX-6001A

Serial Number: T2008157

Description: A&D 6100 g capacity top loading balance.

Known Weight: Initial calibration by PCS 06/17/21

Check Date: 16-MAR-22

Analyst: DH

Weight Set Used: WTSET 3

Tolerance: 1%

Out of Range: N

Known Weight	Result Weight
1.0000	1.0000
100.0000	100.0000
1000.0000	1000.0000

Prod		
GELI	BALANCE 15	16-MAR-22
NONE	BALANCE 15	16-MAR-22

Gamma Standard

Eckert & Ziegler
Isotope Products

24937 Avenue Tibbitts
Valencia, California 91355

Tel 661•309•1010
Fax 661•257•8303

CERTIFICATE OF CALIBRATION
MULTINUCLIDE STANDARD SOLUTION

Customer:	TELEDYNE BROWN ENGINEERING, INC.	**Source No.:**	2088-10-1
P.O. No.:	PO00149995	**Reference Date:**	1-Jun-19 12:00 PST
Catalog No.:	7602	**Contained Radioactivity:**	1.026 µCi 37.96 kBq

Physical Description:

A. Mass of solution: 5.16168 grams in 5 mL flame-sealed ampoule
B. Chemical form: Multinuclide in 2M HCl
C. Carrier content: See attached sheet
D. Density: 1.033 g/mL @ 20°C

Total wt. 8.7382
tare wt. 8.0137
Final wt. = 0.7245 g
empty wt 3.5953
4.4184 g

Gamma-Ray Energy (keV)	Nuclide	Half-life	Branching Ratio (%)	Conc. (nCi/g)	Gammas per second per gram	Total Uncert.
47	Pb-210	22.3 ± 0.2 years	4.18	46.62	72.10	4.1 %
88	Cd-109	462.6 ± 0.7 days	3.63	63.10	84.75	3.0 %
122	Co-57	271.79 ± 0.09 days	85.6	2.439	77.25	3.1 %
166	Ce-139	137.640 ± 0.023 days	79.9	3.135	92.68	3.1 %
279	Hg-203	46.595 ± 0.013 days	81.5	9.054	273.0	3.1 %
392	Sn-113	115.09 ± 0.04 days	64.9	11.66	280.0	3.0 %
514	Sr-85	64.849 ± 0.004 days	98.4	15.05	547.9	3.0 %
662	Cs-137	30.17 ± 0.16 years	85.1	10.50	330.6	3.0 %
898	Y-88	106.630 ± 0.025 days	94.0	24.69	858.7	3.0 %
1173	Co-60	5.272 ± 0.001 years	99.86	12.46	460.4	3.0 %
1333	Co-60	5.272 ± 0.001 years	99.98	12.46	460.9	3.0 %
1836	Y-88	106.630 ± 0.025 days	99.4	24.69	908.0	3.0 %

Method of Calibration:

This source was prepared from weighed aliquots of solutions whose concentrations in µCi/g were determined by gamma spectrometry.

Undiluted STD
0.7245 g in Filter Petri Dish

Diluted STD
4.4184 g / 50 ml (85.6%)

Notes:

- See reverse side for leak test(s) performed on this source.
- EZIP participates in a NIST measurement assurance program to establish and maintain implicit traceability for a number of nuclides, based on the blind assay (and later NIST certification) of Standard Reference Materials (as in NRC Regulatory Guide 4.15).
- Nuclear data was taken from IAEA-TECDOC-619, 1991.
- Overall uncertainty is calculated at the 99% confidence level.
- This source has a recommended working life of 1 year.

Dilution by: Keith [signature] 6/17/19

Daniel James VanDalsem
Quality Control

27-May-19
Date

EZIP Ref. No.: 2088-10

ISO 9001 CERTIFIED

E & Z 2088-10-1 Mixed Gamma
6/1/19 12:00 PM

FULL 20 ML LSC VIAL

		Orig. Wt	5.1617	Volume	50				
		Wt Used	4.4184	Aliquot	2.0000	Certificate	Aliquoted	Actual	Percent
Nuclide	Half-Life	Energy(KeV)	.ate G/s/	%err	%abn	Bq/Tot	G/S	Bq/Tot	Diff
Cd-109	462.9d	88.0	84.75		3.72%	402.64	14.98		
Co-57	271.8d	122.1	77.25		85.51%	15.97	13.65		
Ce-139	137.64d	165.9	92.68		80.35%	20.39	16.38		
Hg-203	46.6d	279.2	273		77.30%	62.42	48.25		
Sn-113	115.09d	391.7	280		64.90%	76.25	49.49		
Sr-85	64.849	514.0	547.9		98.40%	98.41	96.83		
Cs-137	30.17y	661.6	330.6		85.12%	68.64	58.43		
Y-88	106.65d	898.0	858.7		93.40%	162.49	151.76		
Co-60	5.27y	1173.2	460.4		100.00%	81.37	81.37		
Co-60	5.27y	1332.5	460.9		100.00%	81.46	81.46		
Y-88	106.65d	1836.0	908		99.38%	161.48	160.48		

Eff. Name:

Analyst: KOJ

PERCENT MOISTURE

Run Date: 03/23/2022

Percent Moisture Report

L95403

Sample#	Client ID	Tare Wt	Wet Wt	Dry Wt	Tare Balance/Date		Dry Balance/Date		Analyst	% Moist
L95403-1	1; 5.2-1	124.5	159.4	147	BALANCE 15	03/10/22	BALANCE 15	03/16/22	DH	35.53
L95403-2	8; 5.2-1	124.6	211.5	182.4	BALANCE 15	03/10/22	BALANCE 15	03/16/22	DH	33.49
L95403-3	15; 5.2-1	124.5	200.2	173.1	BALANCE 15	03/10/22	BALANCE 15	03/16/22	DH	35.8
L95403-4	22; 5.2-1	124.2	175.8	156.8	BALANCE 15	03/10/22	BALANCE 15	03/16/22	DH	36.82
L95403-5	29; 5.2-1	124.2	176	160.1	BALANCE 15	03/10/22	BALANCE 15	03/16/22	DH	30.69
L95403-6	36; 5.2-1	123.8	173.3	152.9	BALANCE 15	03/10/22	BALANCE 15	03/16/22	DH	41.21
L95403-7	43; 5.2-1	123.8	181.1	158.1	BALANCE 15	03/10/22	BALANCE 15	03/16/22	DH	40.14
L95403-8	50; 5.2-1	123.8	196.6	171.8	BALANCE 15	03/10/22	BALANCE 15	03/16/22	DH	34.07
L95403-9	57; 5.2-1	123.3	177.1	162.2	BALANCE 15	03/10/22	BALANCE 15	03/16/22	DH	27.7
L95403-10	63; 5.2-1	123.3	166.9	151.7	BALANCE 15	03/10/22	BALANCE 15	03/16/22	DH	34.86
L95403-11	64; 5.1-1	123.3	166.2	150.7	BALANCE 15	03/10/22	BALANCE 15	03/16/22	DH	36.13
L95403-12	72; 5.1-1	124	175.1	154.2	BALANCE 15	03/10/22	BALANCE 15	03/16/22	DH	40.9
L95403-13	80; 5.1-1	123.7	156.6	146.8	BALANCE 15	03/10/22	BALANCE 15	03/16/22	DH	29.79
L95403-14	88; 5.1-1	124.1	192.3	168	BALANCE 15	03/10/22	BALANCE 15	03/16/22	DH	35.63
L95403-15	96; 5.1-1	123.4	169.3	152.9	BALANCE 15	03/10/22	BALANCE 15	03/16/22	DH	35.73
L95403-16	104; 5.1-1	123.7	180.4	161.3	BALANCE 15	03/10/22	BALANCE 15	03/16/22	DH	33.69
L95403-17	112; 5.1-1	123.8	194.7	170.5	BALANCE 15	03/10/22	BALANCE 15	03/16/22	DH	34.13
L95403-18	120; 5.1-1	123	162.4	148.9	BALANCE 15	03/10/22	BALANCE 15	03/16/22	DH	34.26
L95403-19	128; 5.1-1	124.2	199.5	175.6	BALANCE 15	03/10/22	BALANCE 15	03/16/22	DH	31.74
L95403-20	137; 5.1-1	123	208.2	179.9	BALANCE 15	03/10/22	BALANCE 15	03/16/22	DH	33.22

Appendix IV
Field Notes

Sediment Core Collection Log

Job: Grand Lake Vibracore	**Station ID:** **08.1-1**
Job No: 212451-01.01	**Attempt No.** 1
Field Staff: RC, TK, BT	**Date:** 2/10/2022
Contractor: N/A	**Logged By:** **BT**
Vertical Datum: NAVD88	**Horizontal Datum:** OK State Plane N

Field Collection Coordinates:

Lat/Northing: 619980 ft

Long/Easting: 2915758 ft

A. Water Depth

DTM Depth Sounder: 23 ft

DTM Lead Line:

B. Water Level Measurements

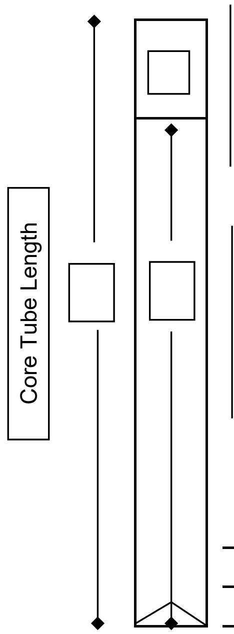
Time: 14:09

Height: 743.5 ft

C. Mudline Elevation

723.5 ft

Recovery Measurements (prior to cuts)



Core Collection Recovery Details:

Core Accepted: Yes

Core Tube Length: 16 ft

Drive Penetration: 9.5-10 ft

Headspace Measurement: 3 in

Recovery Measurement: 93 in

Recovery Percentage: 82%

Total Length of Core To Process: 93 in (7.75 ft)

Drive Notes:

Soft sediment

Core Field Observations and Description:

Sediment type, moisture, color, minor modifier, MAJOR modifier, other constituents, odor, sheen, layering, anoxic layer, debris, plant matter, shells, biota

Gray w/ brownish streaks, silt-clay, firmer in deeper part of core

Notes:

Took grain size sample from top & bottom 1 ft of core

Sediment Core Collection Log

Job: Grand Lake Vibracore	**Station ID:** 08.1-2
Job No: 212451-01.01	**Attempt No.** 2
Field Staff: RC, TK, BT	**Date:** 2/10/2022
Contractor: N/A	**Logged By:** BT
Vertical Datum: NAVD88	**Horizontal Datum:** OK State Plane N

Field Collection Coordinates:

Lat/Northing: 619980 ft

Long/Easting: 2915758 ft

A. Water Depth

DTM Depth Sounder: 23 ft

DTM Lead Line:

B. Water Level Measurements

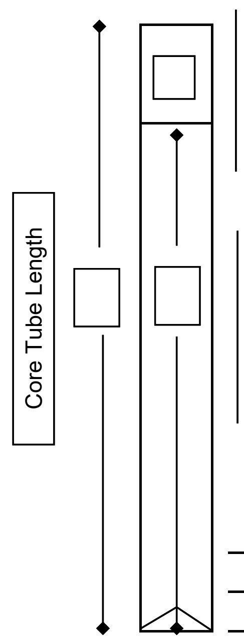
Time: 14:30

Height: 743.5 ft

C. Mudline Elevation

723.5 ft

Recovery Measurements (prior to cuts)



Core Collection Recovery Details:

Core Accepted: Yes

Core Tube Length: 11 ft

Drive Penetration: 144 in

Headspace Measurement: 3 in

Recovery Measurement: 129 in

Recovery Percentage: 90%

Total Length of Core To Process: 129 in

Drive Notes:

Soft sediment; drive to refusal at ~12 ft

Core Field Observations and Description:

Sediment type, moisture, color, minor modifier, MAJOR modifier, other constituents, odor, sheen, layering, anoxic layer, debris, plant matter, shells, biota

Gray w/ brownish streaks, silt-clay, firmer in deeper part of core; no visible layering

Notes:

Took grain size sample from top & bottom 1 ft of core

Sediment Core Collection Log

Job: Grand Lake Vibracore		**Station ID:**	**01.1-1**
Job No: 212451-01.01		**Attempt No.**	1
Field Staff: RC, TK, BT		**Date:**	2/11/2022
Contractor: N/A		**Logged By:**	**BT**
Vertical Datum: NAVD88		**Horizontal Datum:**	OK State Plane N

Field Collection Coordinates:

Lat/Northing: 669690 ft

Long/Easting: 2905562 ft

A. Water Depth

DTM Depth Sounder: 18 ft

DTM Lead Line:

B. Water Level Measurements

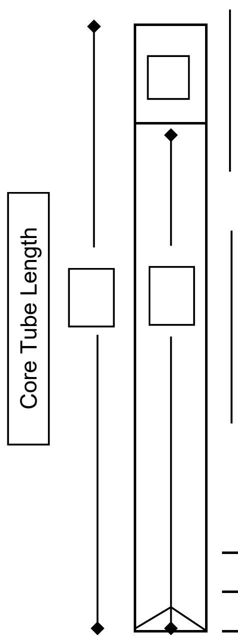
Time: 13:30

Height: 744.3 ft

C. Mudline Elevation

726.3 ft

Recovery Measurements (prior to cuts)



Core Collection Recovery Details:

Core Accepted: Yes

Core Tube Length: 16 ft

Drive Penetration: 4.5 ft

Headspace Measurement: 2 in

Recovery Measurement: 48 in

Recovery Percentage: 89%

Total Length of Core To Process: 48 in

Drive Notes:

Drove to refusal

Core Field Observations and Description:

Sediment type, moisture, color, minor modifier, MAJOR modifier, other constituents, odor, sheen, layering, anoxic layer, debris, plant matter, shells, biota

No visible layers, grayish clay throughout core

Firmer material at bottom of core tube

Notes:

Grain size samples @ 1 ft intervals

Sediment Core Collection Log

Job: Grand Lake Vibracore		**Station ID:**	**01.1-2**
Job No: 212451-01.01		**Attempt No.**	2
Field Staff: RC, TK, BT		**Date:**	2/11/2022
Contractor: N/A		**Logged By:**	**BT**
Vertical Datum: NAVD88		**Horizontal Datum:**	OK State Plane N

Field Collection Coordinates:

Lat/Northing: 669690 ft

Long/Easting: 2905562 ft

A. Water Depth

DTM Depth Sounder: 18 ft

DTM Lead Line:

B. Water Level Measurements

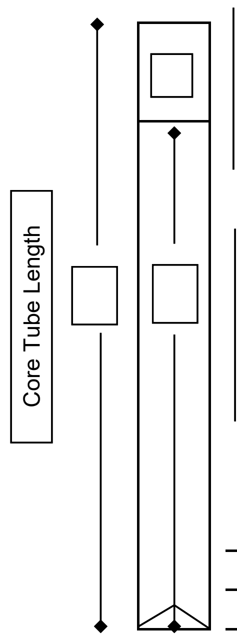
Time: 13:45

Height: 744.3 ft

C. Mudline Elevation

726.3 ft

Recovery Measurements (prior to cuts)



Core Collection Recovery Details:

Core Accepted: Yes

Core Tube Length: 8 ft

Drive Penetration: 6 ft

Headspace Measurement: 3in

Recovery Measurement: 5 ft 3 in = 63 in

Recovery Percentage: 66%

Total Length of Core To Process: 63 in

Drive Notes:

Drive went to refusal

Core Field Observations and Description:

Sediment type, moisture, color, minor modifier, MAJOR modifier, other constituents, odor, sheen, layering, anoxic layer, debris, plant matter, shells, biota

No visible layers, grayish clay throughout core

Firmer near bottom, no significant difference in texture otherwise

Notes:

Grain size samples @ 1 ft intervals

ANCHOR QEA

Sediment Core Collection Log

Job: Grand Lake Vibracore		**Station ID:**	**02.1-1**
Job No: 212451-01.01		**Attempt No.**	1
Field Staff: RC, TK, BT		**Date:**	2/11/2022
Contractor: N/A		**Logged By:**	**BT**
Vertical Datum: NAVD88		**Horizontal Datum:**	OK State Plane N

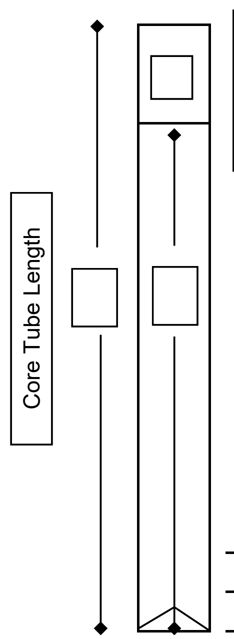
Field Collection Coordinates:

Lat/Northing: 669340 ft

Long/Easting: 2911790 ft

A. Water Depth		**B. Water Level Measurements**		**C. Mudline Elevation**
DTM Depth Sounder:	14 ft	Time:	14:30	730.0 ft
DTM Lead Line:		Height:	744.0 ft	

Recovery Measurements (prior to cuts)



Core Collection Recovery Details:

Core Accepted:	Yes
Core Tube Length:	16 ft
Drive Penetration:	6 ft
Headspace Measurement:	1 in
Recovery Measurement:	5' 3" = 63 in
Recovery Percentage:	88%
Total Length of Core To Process:	63 in

Drive Notes:

Drove to refusal

Core Field Observations and Description: Sediment type, moisture, color, minor modifier, MAJOR modifier, other constituents, odor, sheen, layering, anoxic layer, debris, plant matter, shells, biota

No visible layers in core, grayish clay throughout

Softer near surface

Notes:

Grain size samples @ 1 ft intervals

ANCHOR QEA

Sediment Core Collection Log

Job: Grand Lake Vibracore		**Station ID:**	**02.1-2**
Job No: 212451-01.01		**Attempt No.**	2
Field Staff: RC, TK, BT		**Date:**	2/11/2022
Contractor: N/A		**Logged By:**	**BT**
Vertical Datum: NAVD88		**Horizontal Datum:**	OK State Plane N

Field Collection Coordinates:

Lat/Northing: 669340 ft

Long/Easting: 2911790 ft

A. Water Depth

DTM Depth Sounder: 14 ft

DTM Lead Line:

B. Water Level Measurements

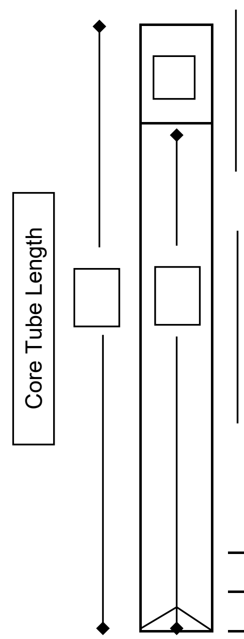
Time: 14:45

Height: 744.0 ft

C. Mudline Elevation

730.0 ft

Recovery Measurements (prior to cuts)



Core Collection Recovery Details:

Core Accepted: Yes

Core Tube Length: 8 ft

Drive Penetration: 7 ft

Headspace Measurement: 1 in

Recovery Measurement: 6 ft = 72 in

Recovery Percentage: 86%

Total Length of Core To Process: 72 in

Drive Notes:

Drove to refusal

Core Field Observations and Description:

Sediment type, moisture, color, minor modifier, MAJOR modifier, other constituents, odor, sheen, layering, anoxic layer, debris, plant matter, shells, biota

No visible layers, grayish clay throughout core

Notes:

Grain size samples @ 1-ft intervals

Sediment Core Collection Log

Job: Grand Lake Vibracore		**Station ID:**	**03.1-1**
Job No: 212451-01.01		**Attempt No.**	1
Field Staff: RC, TK, BT		**Date:**	2/11/2022
Contractor: N/A		**Logged By:**	**BT**
Vertical Datum: NAVD88		**Horizontal Datum:**	OK State Plan N

Field Collection Coordinates:

Lat/Northing: 660811 ft

Long/Easting: 2910646 ft

A. Water Depth

DTM Depth Sounder: 1.5 ft

DTM Lead Line:

B. Water Level Measurements

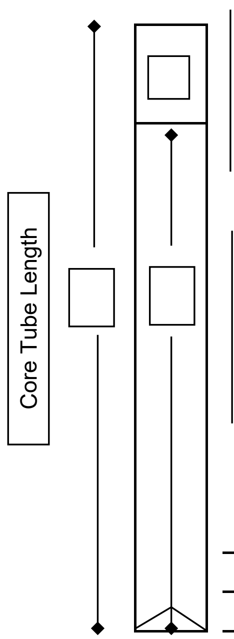
Time: 15:30

Height: 744.2 ft

C. Mudline Elevation

742.7 ft

Recovery Measurements (prior to cuts)



Core Collection Recovery Details:

Core Accepted: Yes

Core Tube Length: 11 ft

Drive Penetration: 36 in

Headspace Measurement: 3 in

Recovery Measurement: 2 ft 9 in = 33 in

Recovery Percentage: 92%

Total Length of Core To Process: 33 in

Drive Notes:

Drove to refusal

Thick clay

Core Field Observations and Description:

Sediment type, moisture, color, minor modifier, MAJOR modifier, other constituents, odor, sheen, layering, anoxic layer, debris, plant matter, shells, biota

Appears to be clay, no visible layers

Very firm, limited penetration

Notes:

Grain size samples @ 1-ft intervals

Sediment Core Collection Log

Job: Grand Lake Vibracore		**Station ID:**	**03.1-2**
Job No: 212451-01.01		**Attempt No.**	2
Field Staff: RC, TK, BT		**Date:**	2/11/2022
Contractor: N/A		**Logged By:**	**BT**
Vertical Datum: NAVD88		**Horizontal Datum:**	OK State Plan N

Field Collection Coordinates:

Lat/Northing:	660811 ft	Long/Easting:	2910646 ft

A. Water Depth

DTM Depth Sounder: 1.5 ft

DTM Lead Line:

B. Water Level Measurements

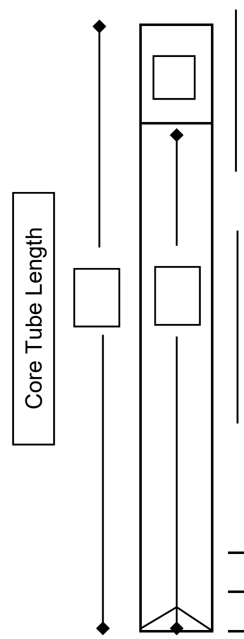
Time: 15:45

Height: 744.2 ft

C. Mudline Elevation

742.7 ft

Recovery Measurements (prior to cuts)



Core Collection Recovery Details:

Core Accepted:	Yes
Core Tube Length:	8 ft
Drive Penetration:	3.0 ft
Headspace Measurement:	1 in
Recovery Measurement:	35 in
Recovery Percentage:	97%
Total Length of Core To Process:	35 in

Drive Notes:

Drove to refusal

Core Field Observations and Description: Sediment type, moisture, color, minor modifier, MAJOR modifier, other constituents, odor, sheen, layering, anoxic layer, debris, plant matter, shells, biota

Some air bubbles in top foot; limited elsewhere

Thick, hard clay material

Notes:

Grain size samples @ 1-ft intervals

Sediment Core Collection Log

Job: Grand Lake Vibracore		**Station ID:**	**9.1-1**
Job No: 212451-01.01		**Attempt No.**	1
Field Staff: RC, TK, BT		**Date:**	2/12/2022
Contractor: N/A		**Logged By:**	**BT**
Vertical Datum: NAVD88		**Horizontal Datum:**	OK State Plane N

Field Collection Coordinates:

Lat/Northing:	612772 ft	Long/Easting:	2912054 ft

A. Water Depth

DTM Depth Sounder: 14.5 ft

DTM Lead Line:

B. Water Level Measurements

Time: 12:55

Height: 744.5 ft

C. Mudline Elevation

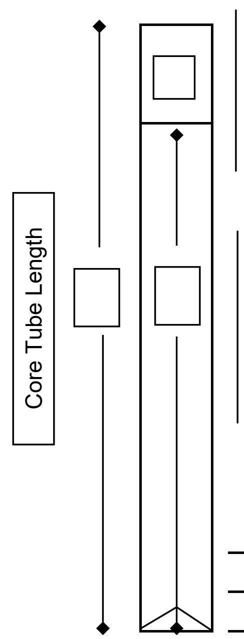
730.0 ft

Recovery Measurements (prior to cuts)

Core Collection Recovery Details:

Core Accepted: Yes

Core Tube Length:	16 ft
Drive Penetration:	2 ft
Headspace Measurement:	3 in
Recovery Measurement:	18 in
Recovery Percentage:	75%
Total Length of Core To Process:	18 in



Drive Notes:

Driven to refusal

Core Field Observations and Description:

Sediment type, moisture, color, minor modifier, MAJOR modifier, other constituents, odor, sheen, layering, anoxic layer, debris, plant matter, shells, biota

Soft to ~6 in, firmer below

Gray silt/clay with no apparent layering

Notes:

Collected grain size samples @ 1-ft intervals

Sediment Core Collection Log

Job: Grand Lake Vibracore		**Station ID:**	**9.1-2**
Job No: 212451-01.01		**Attempt No.**	2
Field Staff: RC, TK, BT		**Date:**	2/12/2022
Contractor: N/A		**Logged By:**	**BT**
Vertical Datum: NAVD88		**Horizontal Datum:**	OK State Plane N

Field Collection Coordinates:

Lat/Northing: 612772 ft

Long/Easting: 2912054 ft

A. Water Depth

DTM Depth Sounder: 14.5 ft

DTM Lead Line:

B. Water Level Measurements

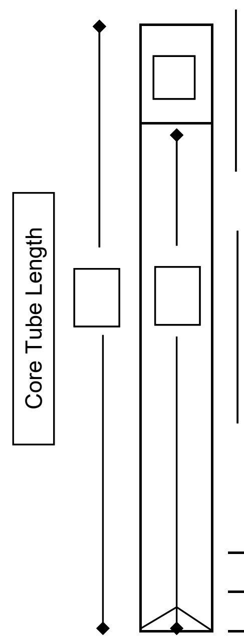
Time: 12:55

Height: 744.5 ft

C. Mudline Elevation

730.0 ft

Recovery Measurements (prior to cuts)



Core Collection Recovery Details:

Core Accepted: Yes

Core Tube Length: 8 ft

Drive Penetration: 2 ft

Headspace Measurement: 8 in

Recovery Measurement: 12 in

Recovery Percentage: 50%

Total Length of Core To Process: 12 in

Drive Notes:

Driven to refusal

Core Field Observations and Description:

Sediment type, moisture, color, minor modifier, MAJOR modifier, other constituents, odor, sheen, layering, anoxic layer, debris, plant matter, shells, biota

Soft material in top ~6 in, firmer below

Gray silt/clay with no visible layers

Notes:

Grain size sampling @ 1-ft intervals

ANCHOR QEA

Sediment Core Collection Log

Job: Grand Lake Vibracore		**Station ID:**	**8.2-1**
Job No: 212451-01.01		**Attempt No.**	1
Field Staff: RC, TK, BT		**Date:**	2/12/2022
Contractor: N/A		**Logged By:**	**BT**
Vertical Datum: NAVD88		**Horizontal Datum:**	OK State Plane N

Field Collection Coordinates:

Lat/Northing: 619613 ft

Long/Easting: 2917399 ft

A. Water Depth

DTM Depth Sounder: 17.5 ft

DTM Lead Line:

B. Water Level Measurements

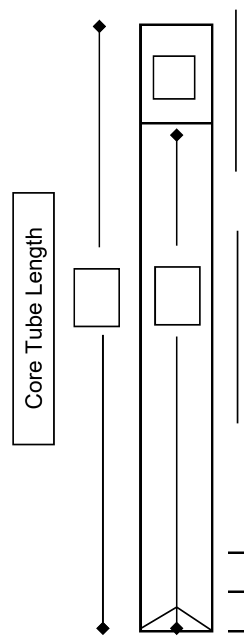
Time: 13:55

Height: 744.5 ft

C. Mudline Elevation

727.0 ft

Recovery Measurements (prior to cuts)



Core Collection Recovery Details:

Core Accepted: Yes

Core Tube Length: 16 ft

Drive Penetration: 3 ft

Headspace Measurement: 2 in

Recovery Measurement: 24 in

Recovery Percentage: 67%

Total Length of Core To Process: 24 in

Drive Notes:

Driven to refusal

Core Field Observations and Description:

Sediment type, moisture, color, minor modifier, MAJOR modifier, other constituents, odor, sheen, layering, anoxic layer, debris, plant matter, shells, biota

Softer, water-logged clay in first ~12 in, firmer ~12-24 in

Notes:

Grain size sampling @ 1-ft intervals

Sediment Core Collection Log

Job: Grand Lake Vibracore		**Station ID:**	**6.1-1**
Job No: 212451-01.01		**Attempt No.**	1
Field Staff: RC, TK, BT		**Date:**	2/12/2022
Contractor: N/A		**Logged By:**	**BT**
Vertical Datum: NAVD88		**Horizontal Datum:**	OK State Plane N

Field Collection Coordinates:

Lat/Northing: 636016 ft

Long/Easting: 2923350 ft

A. Water Depth

DTM Depth Sounder: 7.5 ft

DTM Lead Line:

B. Water Level Measurements

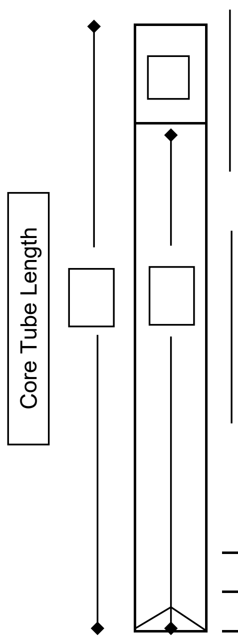
Time: 14:45

Height: 744.4 ft

C. Mudline Elevation

726.9 ft

Recovery Measurements (prior to cuts)



Core Collection Recovery Details:

Core Accepted: Yes

Core Tube Length:	16 ft
Drive Penetration:	1.5 ft
Headspace Measurement:	6 in
Recovery Measurement:	12 in
Recovery Percentage:	67%
Total Length of Core To Process:	12 in

Drive Notes:

Driven to refusal

Possibly hung up on underwater debris or buried log/rock

Core Field Observations and Description:	Sediment type, moisture, color, minor modifier, MAJOR modifier, other constituents, odor, sheen, layering, anoxic layer, debris, plant matter, shells, biota

Soft, grayish silt/clay - suggests caught on buried material or would have driven further

Notes:

Grain size samples collected @ 1-ft intervals

Sediment Core Collection Log

Job: Grand Lake Vibracore	**Station ID:** 06.2-1
Job No: 212451-01.01	**Attempt No.** 1
Field Staff: RC, TK, BT	**Date:** 2/12/2022
Contractor: N/A	**Logged By:** BT
Vertical Datum: NAVD88	**Horizontal Datum:** OK State Plane N

Field Collection Coordinates:

Lat/Northing: 636017 ft

Long/Easting: 2923048 ft

A. Water Depth

DTM Depth Sounder: 4.5 ft

DTM Lead Line:

B. Water Level Measurements

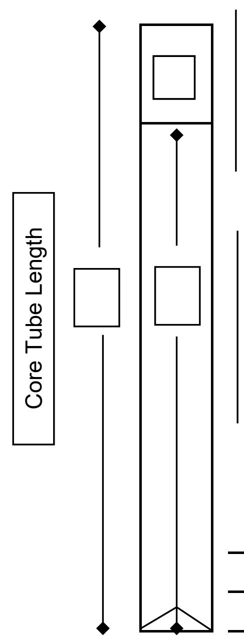
Time: 15:00

Height: 744.2 ft

C. Mudline Elevation

739.7 ft

Recovery Measurements (prior to cuts)



Core Collection Recovery Details:

Core Accepted: Yes

Core Tube Length: 16 ft

Drive Penetration: 7 ft

Headspace Measurement: 4 in

Recovery Measurement: 76 in

Recovery Percentage: 90%

Total Length of Core To Process: 76 in

Drive Notes:

Driven to refusal

Core Field Observations and Description:	Sediment type, moisture, color, minor modifier, MAJOR modifier, other constituents, odor, sheen, layering, anoxic layer, debris, plant matter, shells, biota

Grayish silt/clay throughout, no obvious layers

Firmer clay near bottom

Notes:

Grain size samples @ 1-ft intervals

Sediment Core Collection Log

Job: Grand Lake Vibracore	**Station ID:** **06.2-2**
Job No: 212451-01.01	**Attempt No.** 2
Field Staff: RC, TK, BT	**Date:** 2/12/2022
Contractor: N/A	**Logged By:** **BT**
Vertical Datum: NAVD88	**Horizontal Datum:** OK State Plane N

Field Collection Coordinates:

Lat/Northing: 636017 ft

Long/Easting: 2923048 ft

A. Water Depth

DTM Depth Sounder: 4.5 ft

DTM Lead Line:

B. Water Level Measurements

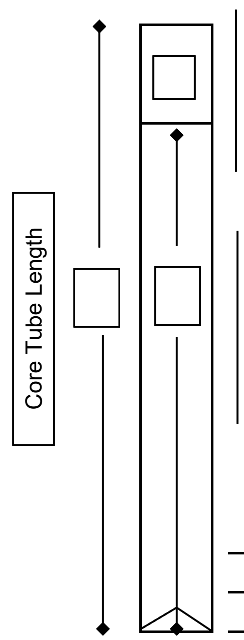
Time: 15:20

Height: 744.2 ft

C. Mudline Elevation

739.7 ft

Recovery Measurements (prior to cuts)



Core Collection Recovery Details:

Core Accepted: Yes

Core Tube Length: 10 ft

Drive Penetration: 7 ft

Headspace Measurement: 2 in

Recovery Measurement: 81 in

Recovery Percentage: 96%

Total Length of Core To Process: 81 in

Drive Notes:

Driven to refusal

Core Field Observations and Description:

Sediment type, moisture, color, minor modifier, MAJOR modifier, other constituents, odor, sheen, layering, anoxic layer, debris, plant matter, shells, biota

Grayish silt/clay throughout, no obvious layers

Firm, especially near bottom of core

Notes:

Grain size sampling @ 1 ft intervals

Sediment Core Collection Log

Job: Grand Lake Vibracore		**Station ID:**	**07.1-1**
Job No: 212451-01.01		**Attempt No.**	1
Field Staff: RC, TK, BT		**Date:**	2/12/2022
Contractor: N/A		**Logged By:**	**BT**
Vertical Datum: NAVD88		**Horizontal Datum:**	OK State Plane N

Field Collection Coordinates:

Lat/Northing: 626482 ft

Long/Easting: 2914670 ft

A. Water Depth

DTM Depth Sounder: 6 ft

DTM Lead Line:

B. Water Level Measurements

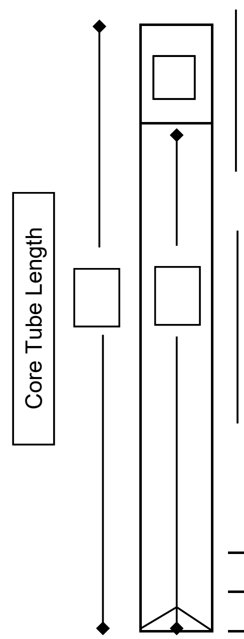
Time: 16:00

Height: 744.5 ft

C. Mudline Elevation

738.5 ft

Recovery Measurements (prior to cuts)



Core Collection Recovery Details:

Core Accepted: Yes

Core Tube Length: 16 ft

Drive Penetration: 5.5 ft

Headspace Measurement: 5 in

Recovery Measurement: 57 in

Recovery Percentage: 86%

Total Length of Core To Process: 57 in

Drive Notes:

Driven to refusal

Core Field Observations and Description:	Sediment type, moisture, color, minor modifier, MAJOR modifier, other constituents, odor, sheen, layering, anoxic layer, debris, plant matter, shells, biota

Worm @ ~6 in from surface, signs of biotic activity

Gray silt/clay, no visible layers

Notes:

Grain size samples @ 1 ft intervals

Sediment Core Collection Log

Job: Grand Lake Vibracore		**Station ID:**	**7.2-1**
Job No: 212451-01.01		**Attempt No.**	1
Field Staff: RC, TK, BT		**Date:**	2/12/2022
Contractor: N/A		**Logged By:**	**BT**
Vertical Datum: NAVD88		**Horizontal Datum:**	OK State Plane N

Field Collection Coordinates:

Lat/Northing: 626591 ft

Long/Easting: 2914380 ft

A. Water Depth

DTM Depth Sounder: 17.5 ft

DTM Lead Line:

B. Water Level Measurements

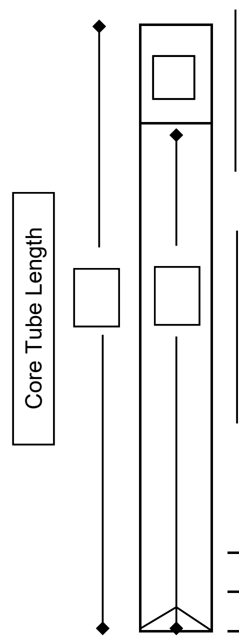
Time: 16:15

Height: 744.3 ft

C. Mudline Elevation

726.8 ft

Recovery Measurements (prior to cuts)



Core Collection Recovery Details:

Core Accepted: Yes

Core Tube Length: 16 ft

Drive Penetration: 7 ft

Headspace Measurement: 2 in

Recovery Measurement: 79 in

Recovery Percentage: 94%

Total Length of Core To Process: 79 in

Drive Notes:

Driven to refusal

Core Field Observations and Description:

Sediment type, moisture, color, minor modifier, MAJOR modifier, other constituents, odor, sheen, layering, anoxic layer, debris, plant matter, shells, biota

Significant texture change @ ~12 in, softer above, visibly similar clay/silt

Notes:

Grain size samples @ 1-ft interval

Sediment Core Collection Log

Job: Grand Lake Vibracore	**Station ID:** 4.1-1
Job No: 212451-01.01	**Attempt No.** 1
Field Staff: RC, TK, BT	**Date:** 2/13/2022
Contractor: N/A	**Logged By:** BT
Vertical Datum: NAVD88	**Horizontal Datum:** OK State Plane N

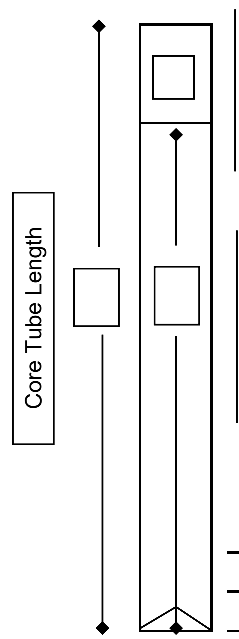
Field Collection Coordinates:

Lat/Northing: 649883 ft

Long/Easting: 2925261 ft

A. Water Depth	**B. Water Level Measurements**	**C. Mudline Elevation**
DTM Depth Sounder: 6 ft	Time: 10:50	738.5 ft
DTM Lead Line:	Height: 744.5 ft	

Recovery Measurements (prior to cuts)



Core Collection Recovery Details:

Core Accepted: Yes

Core Tube Length: 11 ft

Drive Penetration: 5 ft

Headspace Measurement: 3 in

Recovery Measurement: 49 in

Recovery Percentage: 82%

Total Length of Core To Process: 49 in

Drive Notes:

Possibly caught on buried tree branch or other debris

Core Field Observations and Description:

Sediment type, moisture, color, minor modifier, MAJOR modifier, other constituents, odor, sheen, layering, anoxic layer, debris, plant matter, shells, biota

Core catcher shoved into core tube suggests it wasn't caught on debris; thick clay layer stopping drive more likely

Firm clay near bottom, soft silty/clayey layers above; gradual transition with no distinct layering

Notes:

Grain size sampling @ 1-ft intervals

Sediment Core Collection Log

Job: Grand Lake Vibracore		**Station ID:**	**4.2-1**
Job No: 212451-01.01		**Attempt No.**	1
Field Staff: RC, TK, BT		**Date:**	2/13/2022
Contractor: N/A		**Logged By:**	**BT**
Vertical Datum: NAVD88		**Horizontal Datum:**	OK State Plane N

Field Collection Coordinates:

Lat/Northing: 650123 ft

Long/Easting: 2926237 ft

A. Water Depth

DTM Depth Sounder: 2 ft

DTM Lead Line:

B. Water Level Measurements

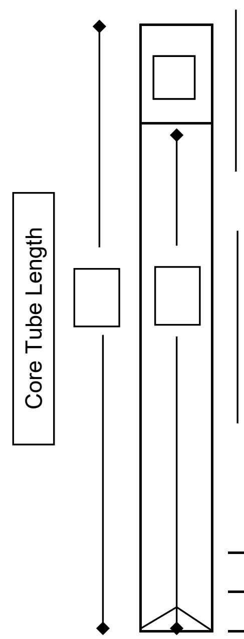
Time: 11:20

Height: 744.5 ft

C. Mudline Elevation

742.5 ft

Recovery Measurements (prior to cuts)



Core Collection Recovery Details:

Core Accepted: Yes

Core Tube Length: 12 ft

Drive Penetration: 8 ft

Headspace Measurement: 2 in

Recovery Measurement: 92 in

Recovery Percentage: 96%

Total Length of Core To Process: 92 in

Drive Notes:

Significantly deeper penetration here than nearby Site 4.1

Drove to refusal

Core Field Observations and Description:

Sediment type, moisture, color, minor modifier, MAJOR modifier, other constituents, odor, sheen, layering, anoxic layer, debris, plant matter, shells, biota

Organic debris on surface of core (~1-2 inches) - sticks & leaves

Softer material @ surface, firmer in deeper parts of core

Notes:

Grain size samples @ 1-ft interval

Sediment Core Collection Log

Job: Grand Lake Vibracore		**Station ID:**	**GL1-1**
Job No: 212451-01.01		**Attempt No.**	1
Field Staff: RC, TK, BT		**Date:**	2/13/2022
Contractor: N/A		**Logged By:**	**BT**
Vertical Datum: NAVD88		**Horizontal Datum:**	OK State Plane N

Field Collection Coordinates:

Lat/Northing: 647148 ft

Long/Easting: 2915104 ft

A. Water Depth

DTM Depth Sounder: 2 ft

DTM Lead Line:

B. Water Level Measurements

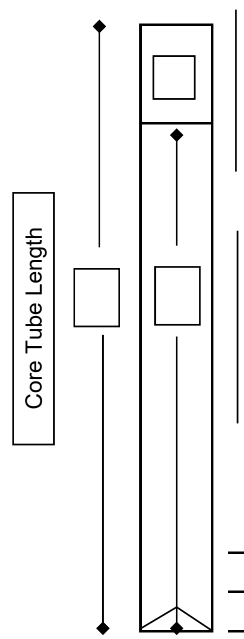
Time: 12:05

Height: 744.4 ft

C. Mudline Elevation

742.4 ft

Recovery Measurements (prior to cuts)



Core Collection Recovery Details:

Core Accepted: Yes

Core Tube Length: 14 ft

Drive Penetration: 8 ft

Headspace Measurement: 3 in

Recovery Measurement: 90 in

Recovery Percentage: 94%

Total Length of Core To Process: 90 in

Drive Notes:

Drove to refusal

Core Field Observations and Description:

Sediment type, moisture, color, minor modifier, MAJOR modifier, other constituents, odor, sheen, layering, anoxic layer, debris, plant matter, shells, biota

Silt and clay, no clear layering

Notes:

Grain size sampling @ 1 ft intervals

ANCHOR QEA

Sediment Core Collection Log

Job: Grand Lake Vibracore
Job No: 212451-01.01
Field Staff: RC, TK, BT
Contractor: N/A
Vertical Datum: NAVD88

Station ID: GL1-2
Attempt No. 2
Date: 2/13/2022
Logged By: BT
Horizontal Datum: OK State Plane N

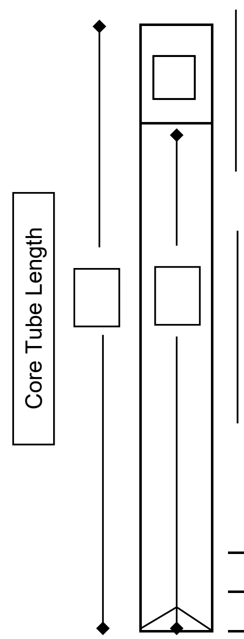
Field Collection Coordinates:
Lat/Northing: 647148 ft
Long/Easting: 2915104 ft

A. Water Depth
DTM Depth Sounder: 2 ft
DTM Lead Line:

B. Water Level Measurements
Time: 12:22
Height: 744.4 ft

C. Mudline Elevation
742.4 ft

Recovery Measurements (prior to cuts)



Core Collection Recovery Details:
Core Accepted: Yes
Core Tube Length: 14 ft
Drive Penetration: 8 ft
Headspace Measurement: 5 in
Recovery Measurement: 84 in
Recovery Percentage: 88%
Total Length of Core To Process: 84 in

Drive Notes:
Driven to refusal

Core Field Observations and Description:
Sediment type, moisture, color, minor modifier, MAJOR modifier, other constituents, odor, sheen, layering, anoxic layer, debris, plant matter, shells, biota

Sticks and organic debris in top ~12 in of core

Notes:

Grain size samples @ 1-ft interval

Sediment Core Collection Log

Job: Grand Lake Vibracore		**Station ID:**	**05.1-1**
Job No: 212451-01.01		**Attempt No.**	1
Field Staff: RC, TK, BT		**Date:**	2/13/2022
Contractor: N/A		**Logged By:**	**BT**
Vertical Datum: NAVD88		**Horizontal Datum:**	OK State Plane N

Field Collection Coordinates:

Lat/Northing: 644108 ft

Long/Easting: 2913784 ft

A. Water Depth

DTM Depth Sounder: 2 ft

DTM Lead Line:

B. Water Level Measurements

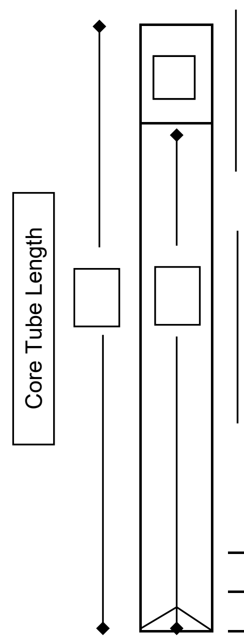
Time: 13:00

Height: 744.5 ft

C. Mudline Elevation

742.5 ft

Recovery Measurements (prior to cuts)



Core Collection Recovery Details:

Core Accepted: Yes

Core Tube Length: 12 ft

Drive Penetration: 11 ft

Headspace Measurement: 1 in

Recovery Measurement: 117 in (9'9")

Recovery Percentage: 89%

Total Length of Core To Process: 117 in (9'9")

Drive Notes:

Driven to refusal, firmer material near bottom of drive

Core Field Observations and Description:

Sediment type, moisture, color, minor modifier, MAJOR modifier, other constituents, odor, sheen, layering, anoxic layer, debris, plant matter, shells, biota

Air bubbles in top ~18 in

Relatively soft silt/clay material throughout, no visible layers; grayish sediment

Notes:

Divided into 4 cm samples for Cs-137 testing

Sediment Core Collection Log

Job: Grand Lake Vibracore		**Station ID:**	**05.1-2**
Job No: 212451-01.01		**Attempt No.**	2
Field Staff: RC, TK, BT		**Date:**	2/13/2022
Contractor: N/A		**Logged By:**	**BT**
Vertical Datum: NAVD88		**Horizontal Datum:**	OK State Plane N

Field Collection Coordinates:

Lat/Northing:	644108 ft	Long/Easting:	2913784 ft

A. Water Depth

DTM Depth Sounder: 2 ft

DTM Lead Line:

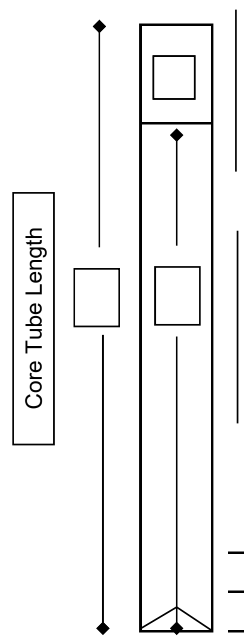
B. Water Level Measurements

Time: 13:00

Height: 744.5 ft

C. Mudline Elevation

Recovery Measurements (prior to cuts)



Core Collection Recovery Details:

Core Accepted: Yes

Core Tube Length:	12 ft
Drive Penetration:	9.5 ft
Headspace Measurement:	2 in
Recovery Measurement:	102 in
Recovery Percentage:	89%
Total Length of Core To Process:	102 in

Drive Notes:

Driven to refusal, similar to core 05.1-1

Core Field Observations and Description: Sediment type, moisture, color, minor modifier, MAJOR modifier, other constituents, odor, sheen, layering, anoxic layer, debris, plant matter, shells, biota

Silt/clay misture throughout core, no obvious layers

Grayish material, firmer at bottom

Notes:

Grain size samples @ 1 ft intervals

Sediment Core Collection Log

Job: Grand Lake Vibracore		**Station ID:**	**05.2-1**
Job No: 212451-01.01		**Attempt No.**	1
Field Staff: RC, TK, BT		**Date:**	2/13/2022
Contractor: N/A		**Logged By:**	**BT**
Vertical Datum: NAVD88		**Horizontal Datum:**	OK State Plane N

Field Collection Coordinates:

Lat/Northing: 644002 ft

Long/Easting: 2913396 ft

A. Water Depth

DTM Depth Sounder: 5.5 ft

DTM Lead Line:

B. Water Level Measurements

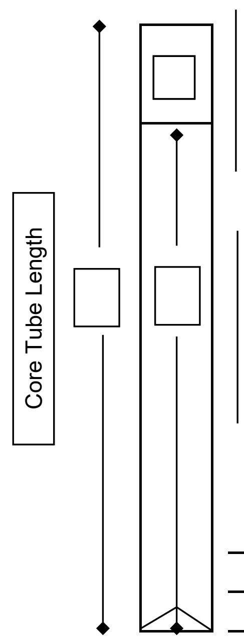
Time: 13:22

Height: 744.4 ft

C. Mudline Elevation

738.9 ft

Recovery Measurements (prior to cuts)



Core Collection Recovery Details:

Core Accepted: Yes

Core Tube Length: 16 ft

Drive Penetration: 10 ft

Headspace Measurement: 1 in

Recovery Measurement: 107 in

Recovery Percentage: 89%

Total Length of Core To Process: 107 in

Drive Notes:

Driven to refusal; Similar to Site 05.1

Core Field Observations and Description:

Sediment type, moisture, color, minor modifier, MAJOR modifier, other constituents, odor, sheen, layering, anoxic layer, debris, plant matter, shells, biota

No visible layers; grayish silt/clay throughout core, softer near surface, but all was malleable

Notes:

Collected samples for cesium-137 analysis every 4 cm

Sediment Core Collection Log

Job: Grand Lake Vibracore	**Station ID:** **05.2-2**
Job No: 212451-01.01	**Attempt No.** 2
Field Staff: RC, TK, BT	**Date:** 2/13/2022
Contractor: N/A	**Logged By:** **BT**
Vertical Datum: NAVD88	**Horizontal Datum:** OK State Plane N

Field Collection Coordinates:

Lat/Northing: 644002 ft

Long/Easting: 2913396 ft

A. Water Depth

DTM Depth Sounder: 5.5 ft

DTM Lead Line:

B. Water Level Measurements

Time: 13:40

Height: 744.4 ft

C. Mudline Elevation

738.9 ft

Recovery Measurements (prior to cuts)

Core Collection Recovery Details:

Core Accepted: Yes

Core Tube Length: 16ft

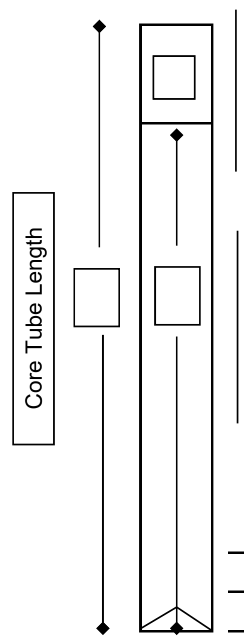
Drive Penetration: 10 ft

Headspace Measurement: 2 in

Recovery Measurement: 102 in

Recovery Percentage: 85%

Total Length of Core To Process: 102 in



Drive Notes:

Driven to refusal

Core Field Observations and Description:	Sediment type, moisture, color, minor modifier, MAJOR modifier, other constituents, odor, sheen, layering, anoxic layer, debris, plant matter, shells, biota

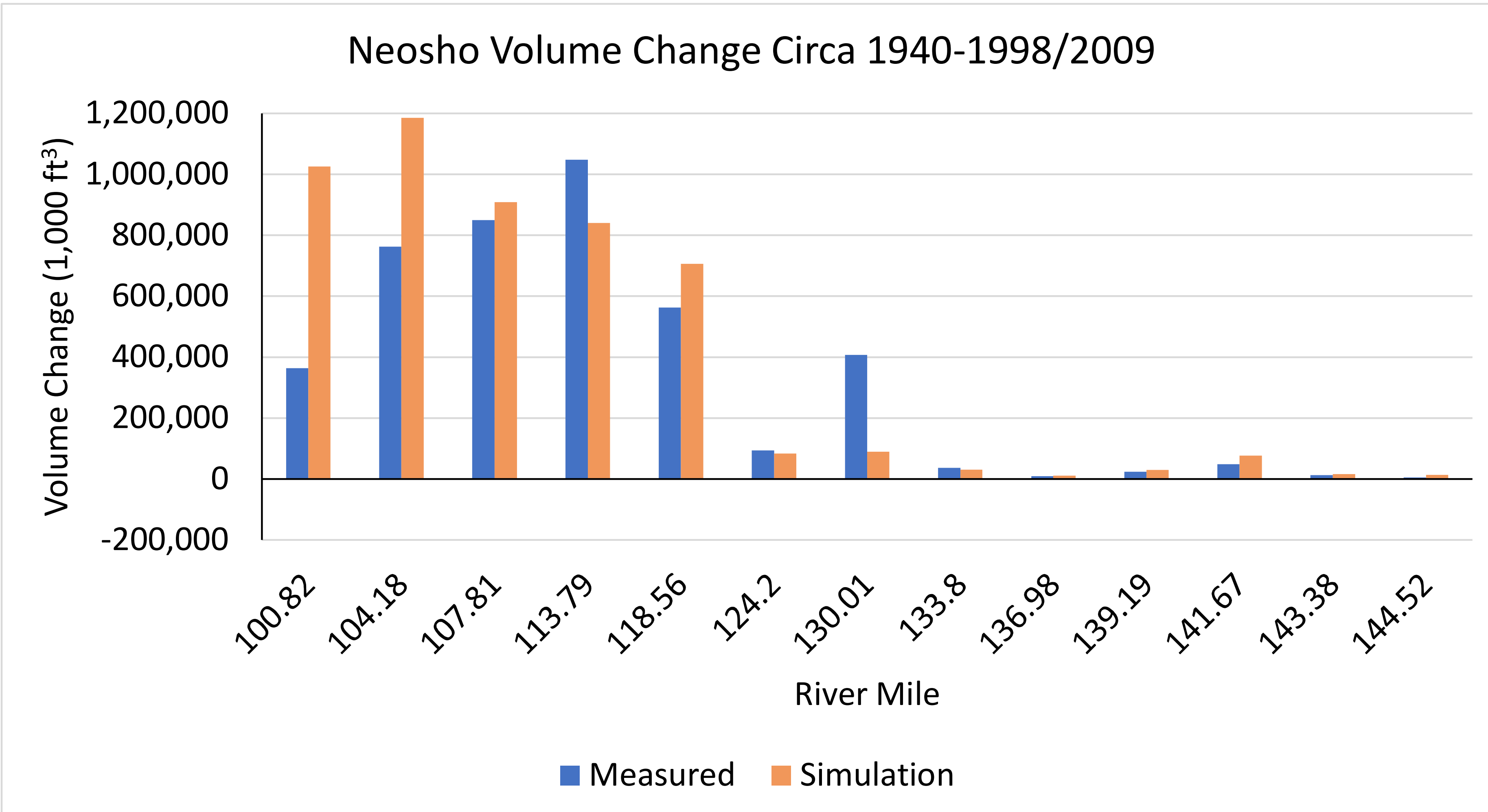
Grayish silt/clay throughout, very malleable; softer at surface, no visible layers

Notes:

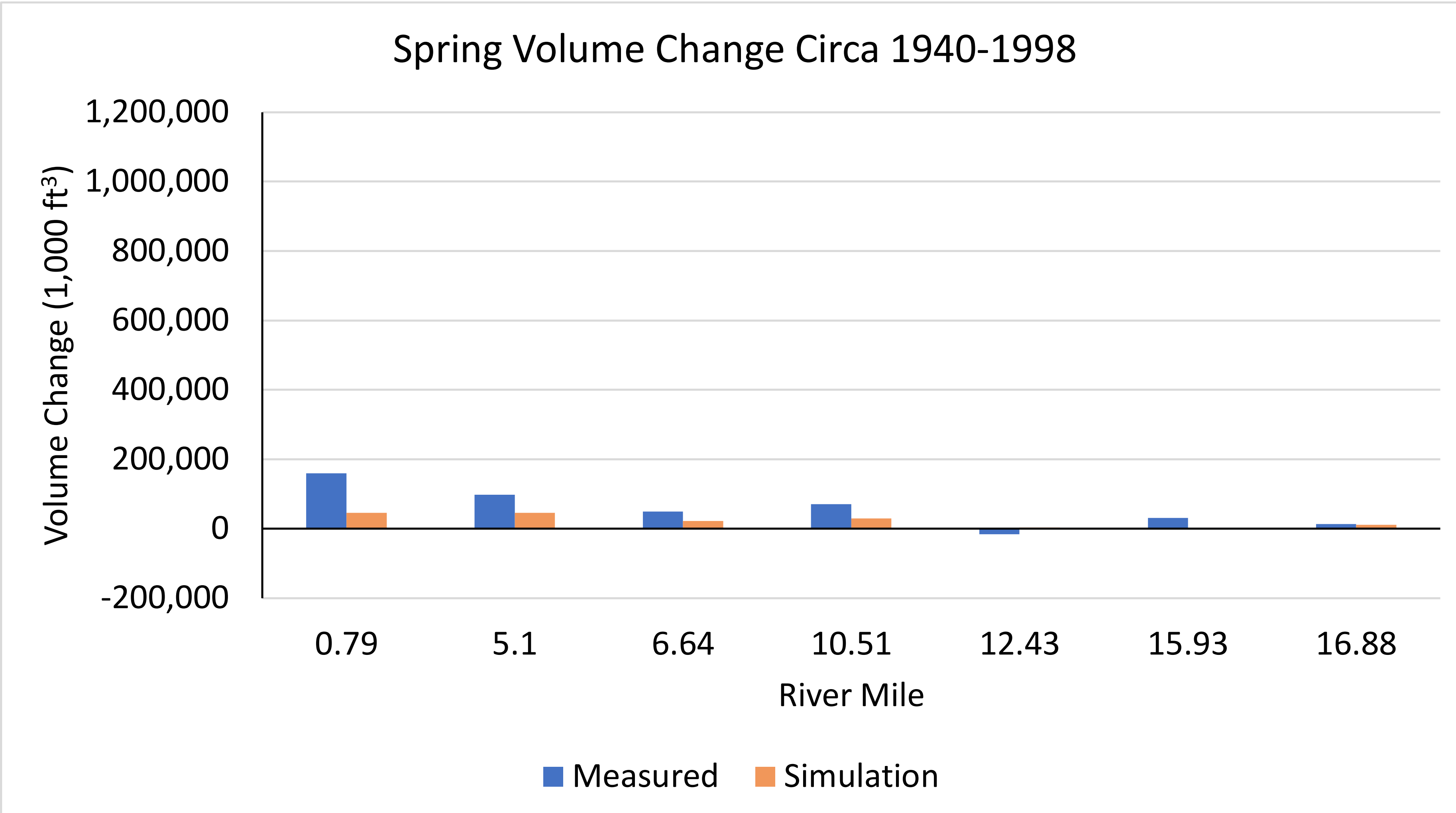
Collected grain size samples @ 1 ft intervals

Appendix F
STM Results

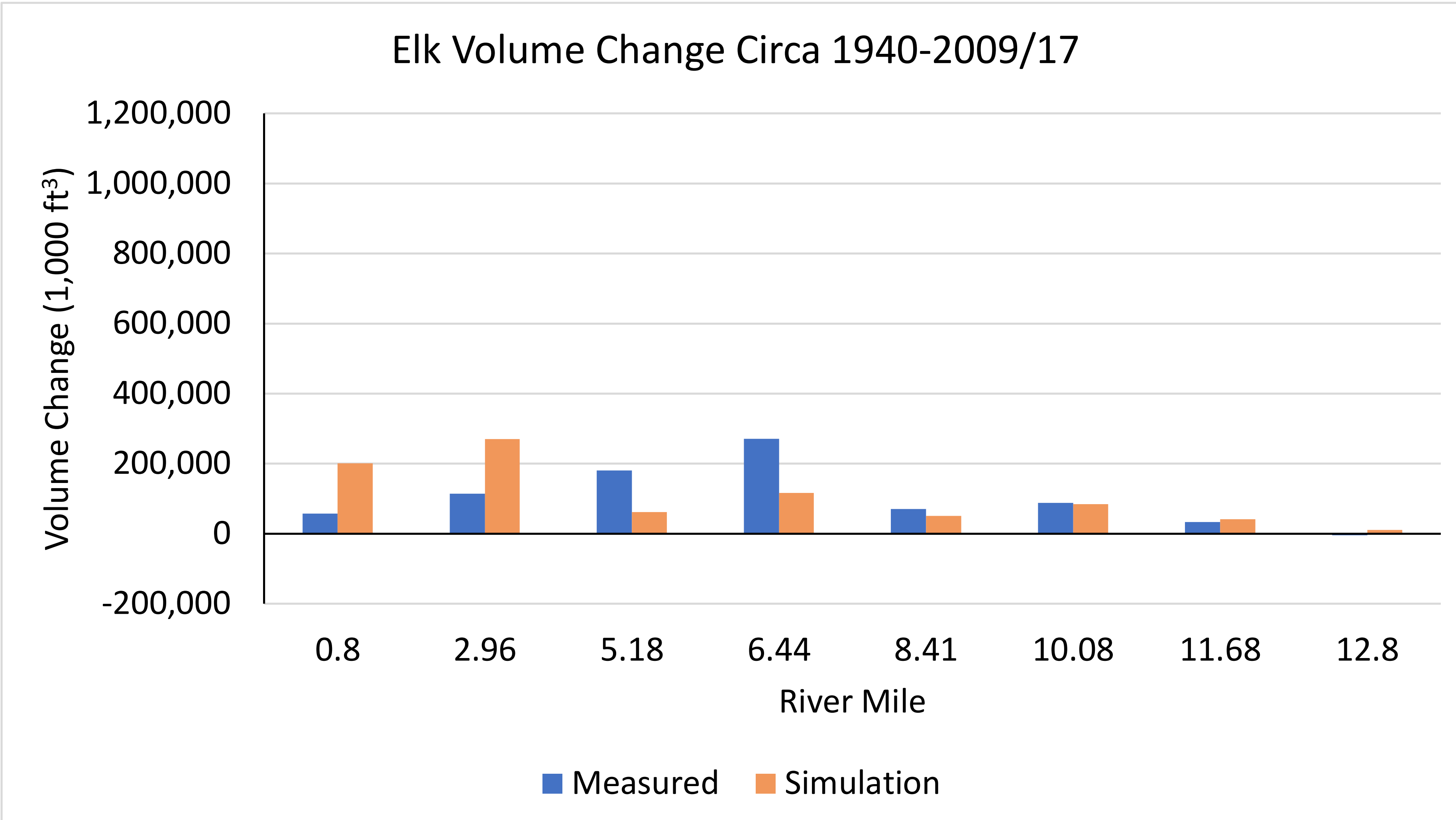
Calibration Plots



Neosho Volume Change Circa 1940-1998/2009
Volume Change (1,000 ft³)
1,200,000
1,000,000
800,000
600,000
400,000
200,000
0
-200,000
100.82
104.18
107.81
113.79
118.56
124.2
130.01
133.8
136.98
139.19
141.67
143.38
144.52
River Mile
Measured
Simulation

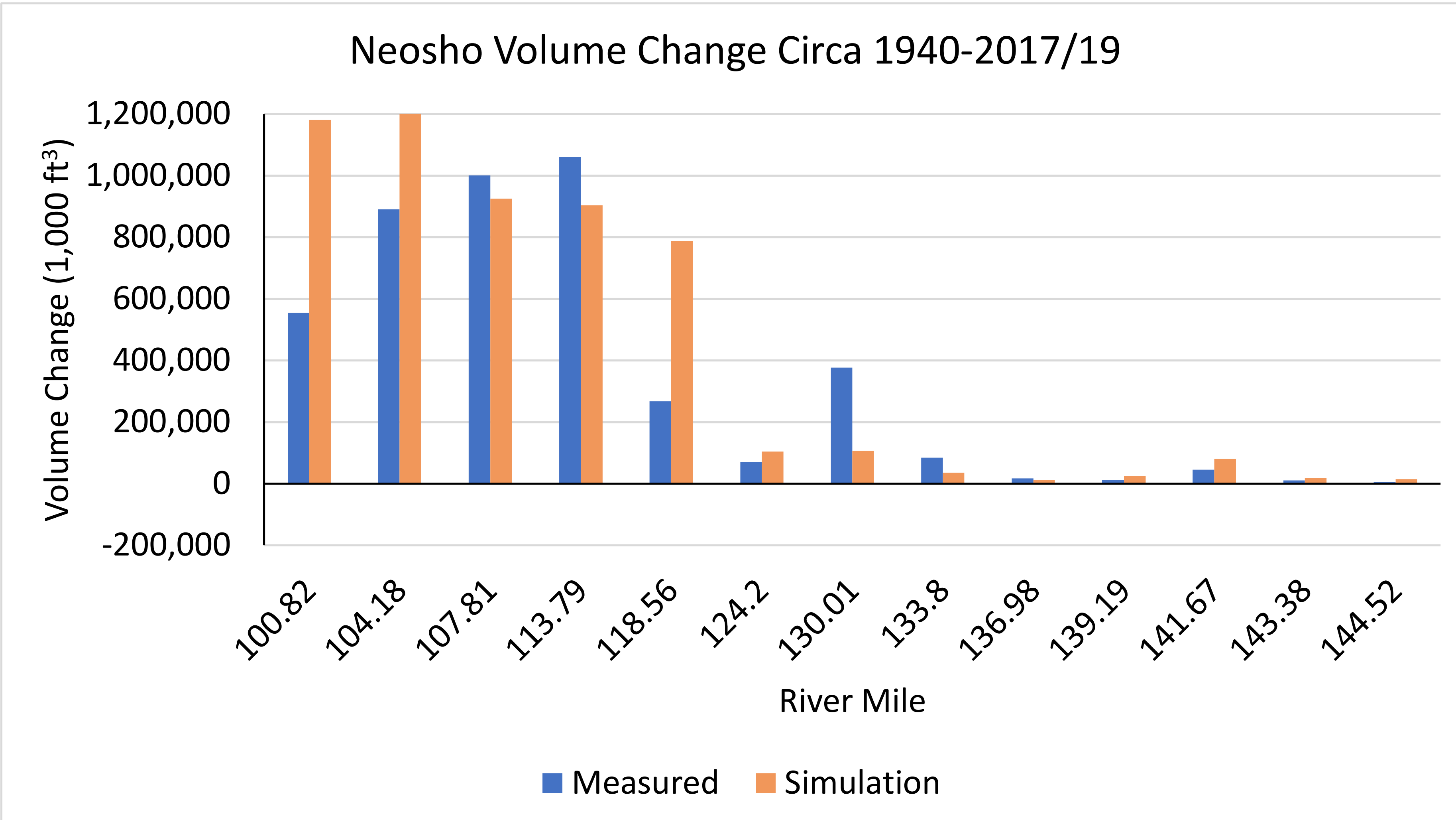


Spring Volume Change Circa 1940-1998
Volume Change (1,000 ft³)
1,200,000
1,000,000
800,000
600,000
400,000
200,000
0
-200,000
0.79
5.1
6.64
10.51
12.43
15.93
16.88
River Mile
Measured
Simulation

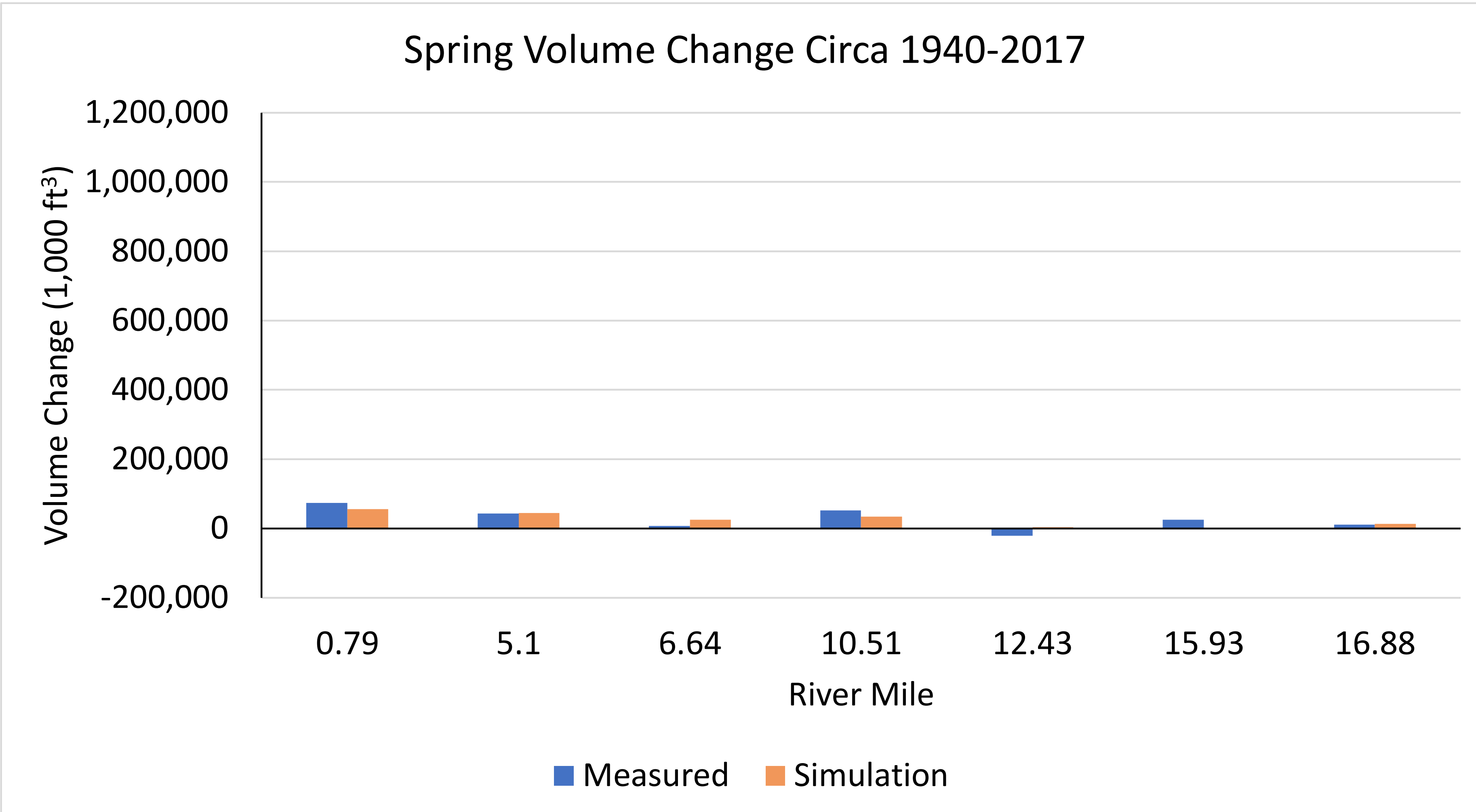


Elk Volume Change Circa 1940-2009/17
Volume Change (1,000 ft3)
1,200,000
1,000,000
800,000
600,000
400,000
200,000
0
-200,000
0.8
2.96
5.18
6.44
8.41
10.08
11.68
12.8
River Mile
Measured
Simulation

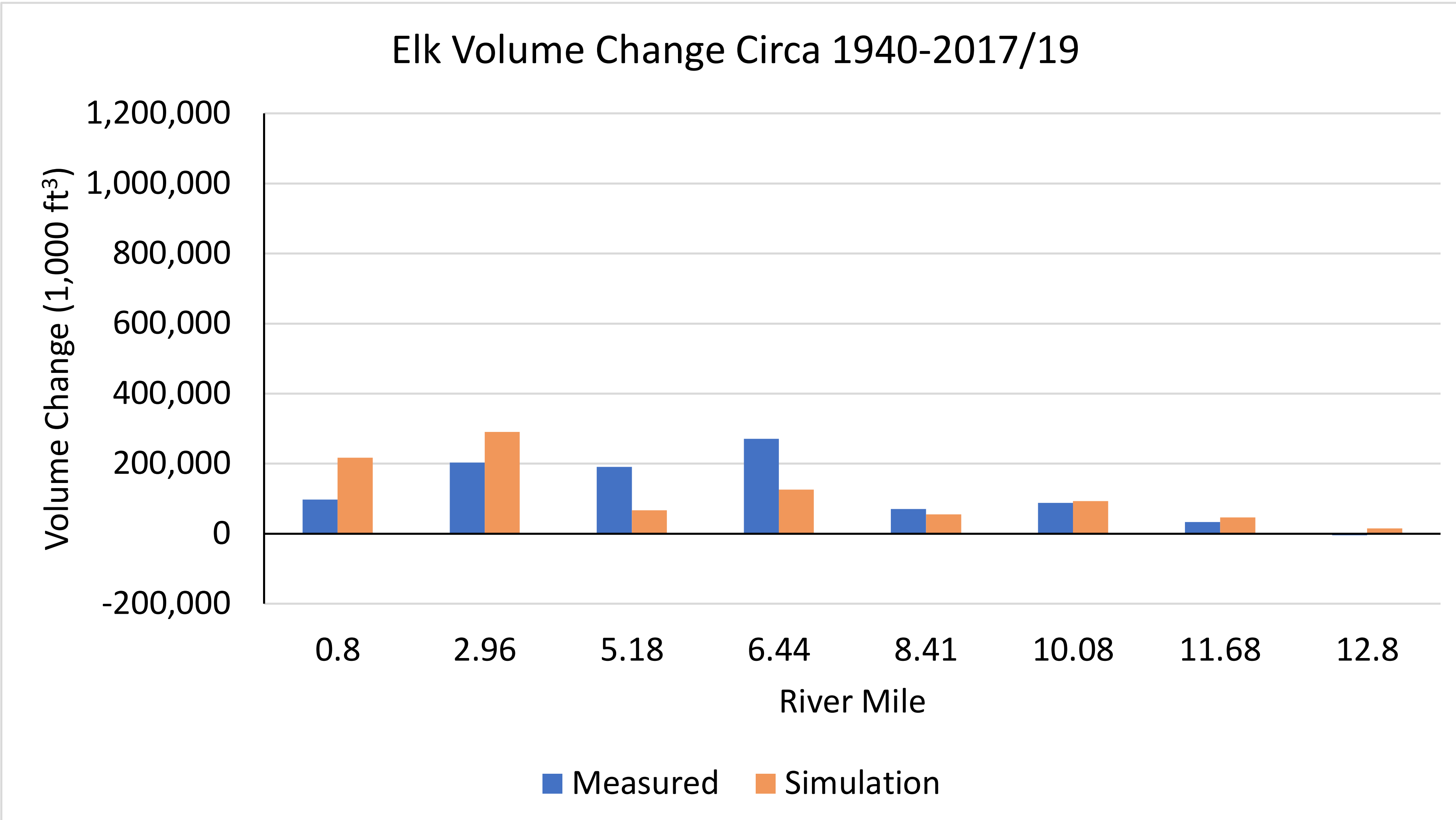
Validation Plots



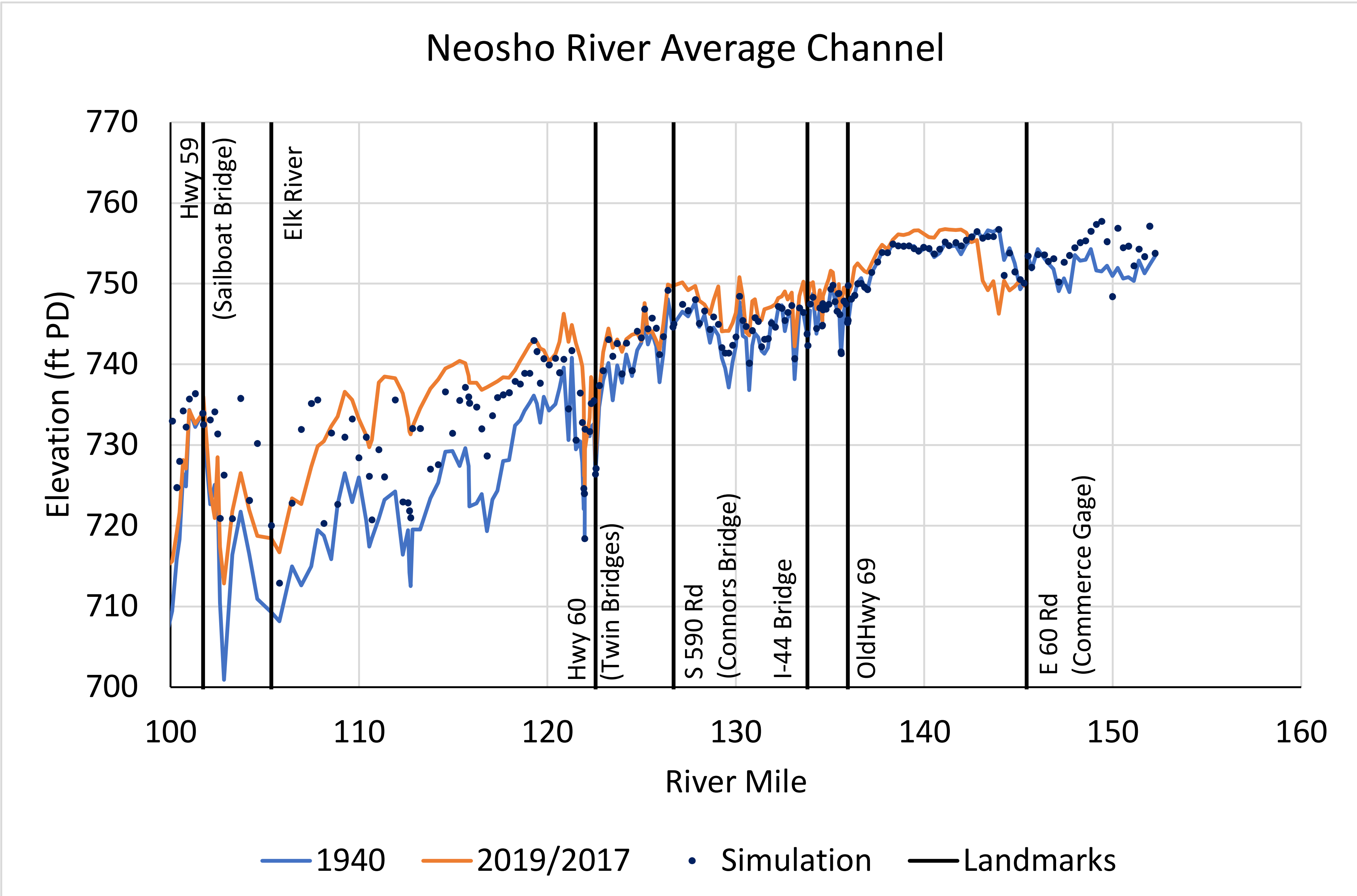
Neosho Volume Change Circa 1940-2017/19
Volume Change (1,000 ft³)
1,200,000
1,000,000
800,000
600,000
400,000
200,000
0
-200,000
100.82
104.18
107.81
113.79
118.56
124.2
130.01
133.8
136.98
139.19
141.67
143.38
144.52
River Mile
Measured
Simulation

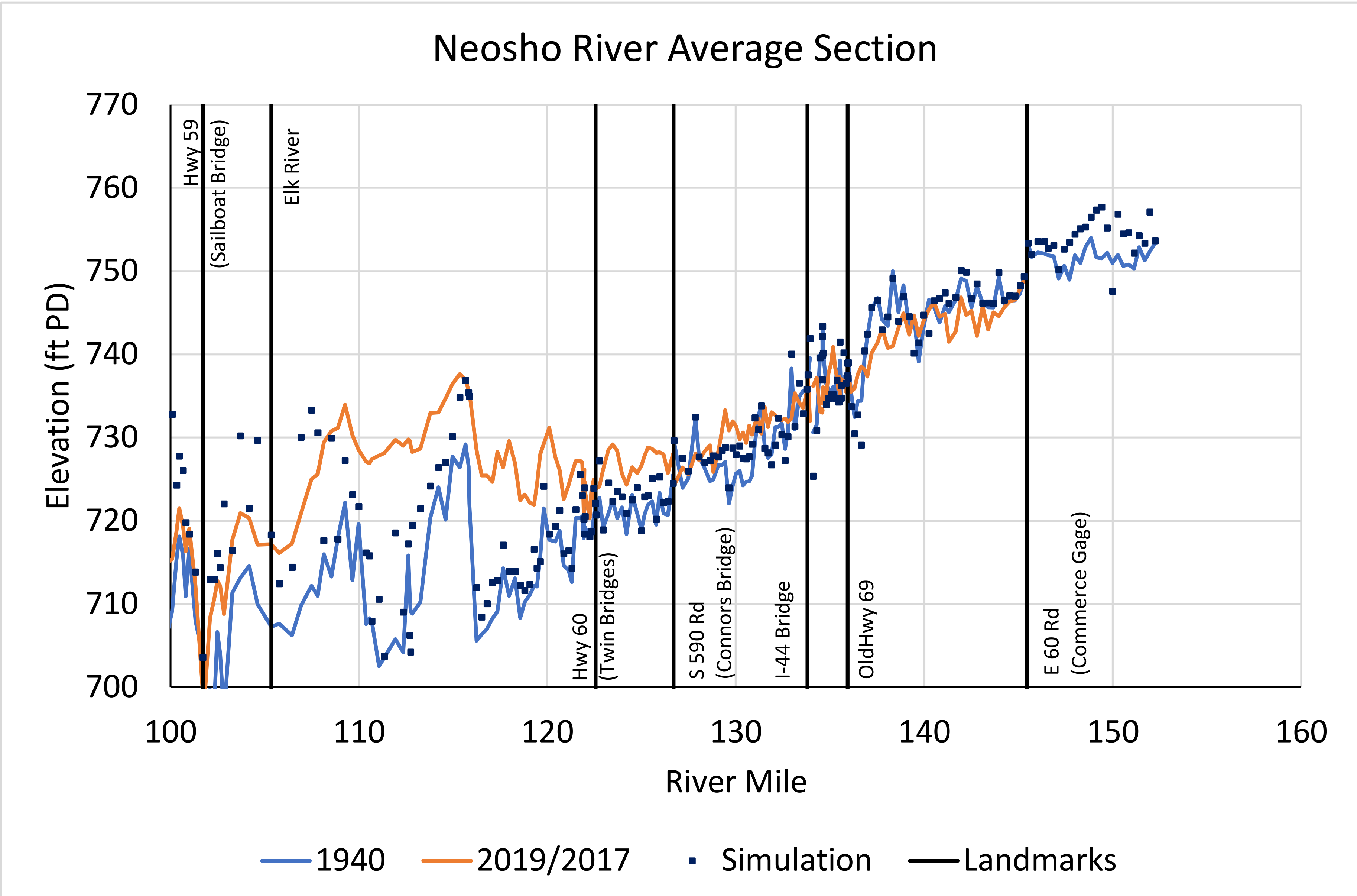


Spring Volume Change Circa 1940-2017
Volume Change (1,000 ft³)
1,200,000
1,000,000
800,000
600,000
400,000
200,000
0
-200,000
0.79
5.1
6.64
10.51
12.43
15.93
16.88
River Mile
Measured
Simulation

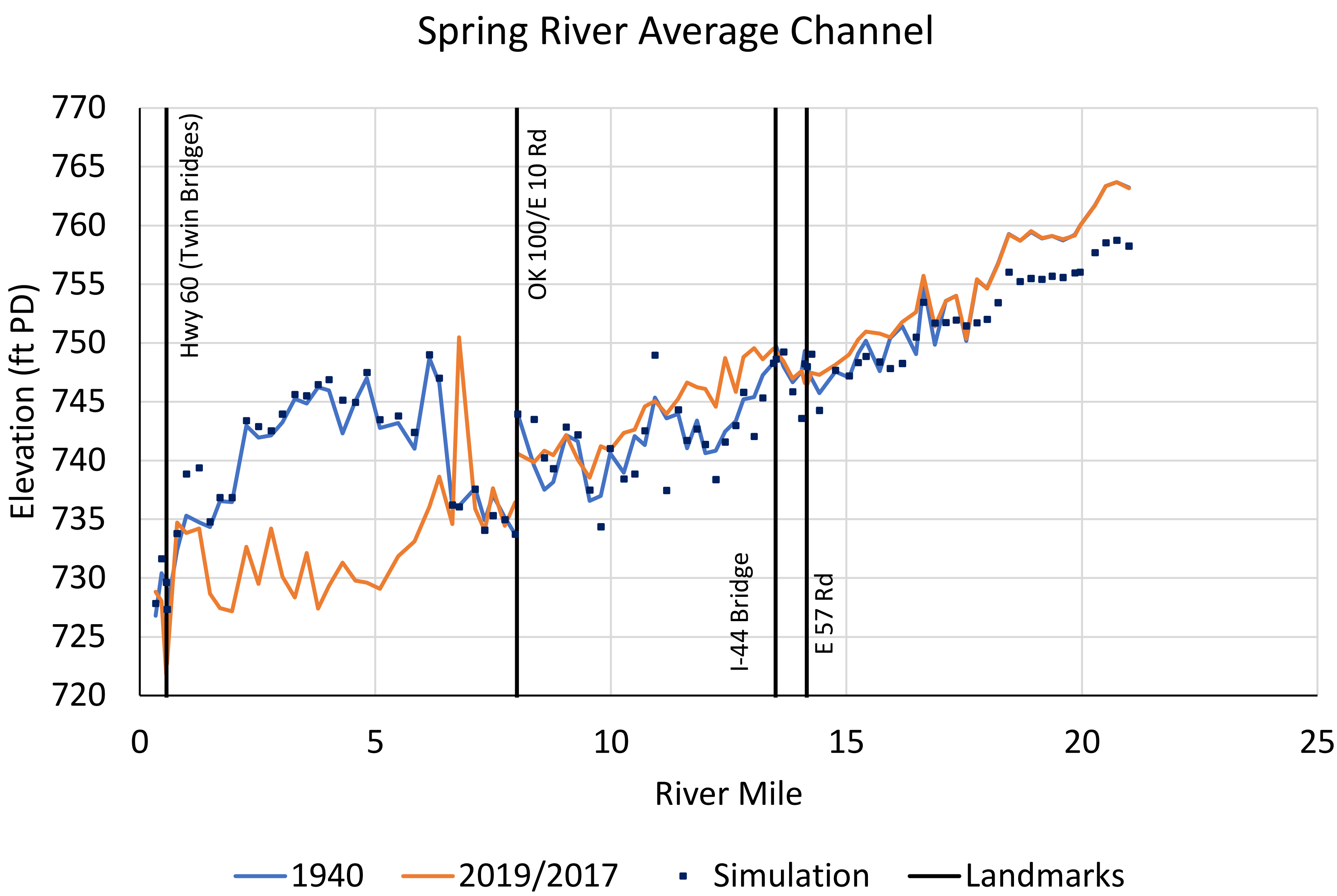

Elk Volume Change Circa 1940-2017/19
Volume Change (1,000 ft³)
1,200,000
1,000,000
800,000
600,000
400,000
200,000
0
-200,000
0.8
2.96
5.18
6.44
8.41
10.08
11.68
12.8
River Mile
Measured
Simulation

Simulated 2019 Average Channel and Average Section Plots

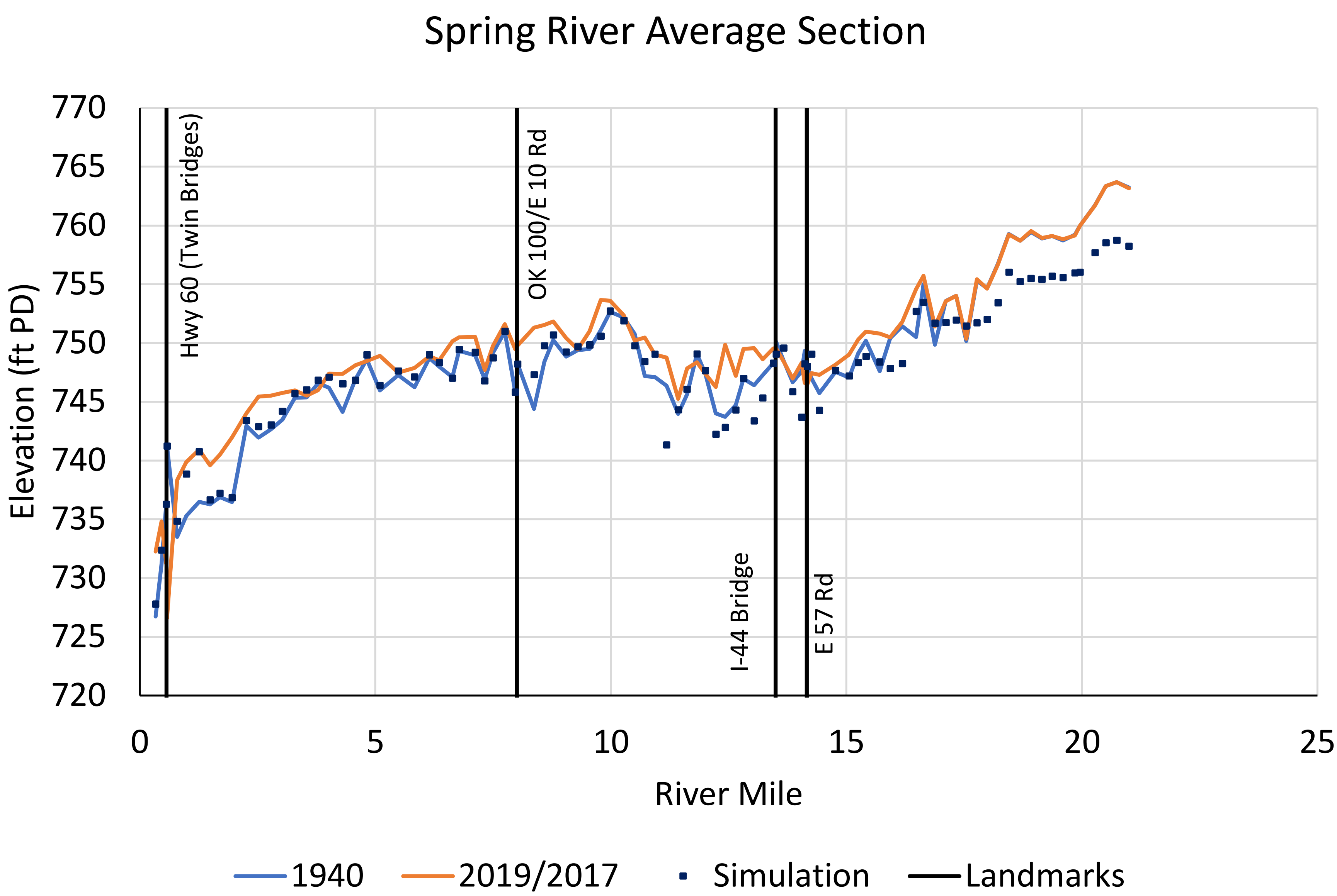

Neosho River Average Channel
Elevation (ft PD)
770
760
750
740
730
720
710
700
100
110
120
130
140
150
160
River Mile
Hwy 59
(Sailboat Bridge)
Elk River
Hwy 60
(Twin Bridges)
S 590 Rd
(Connors Bridge)
I-44 Bridge
OldHwy 69
E 60 Rd
(Commerce Gage)
1940
2019/2017
Simulation
Landmarks



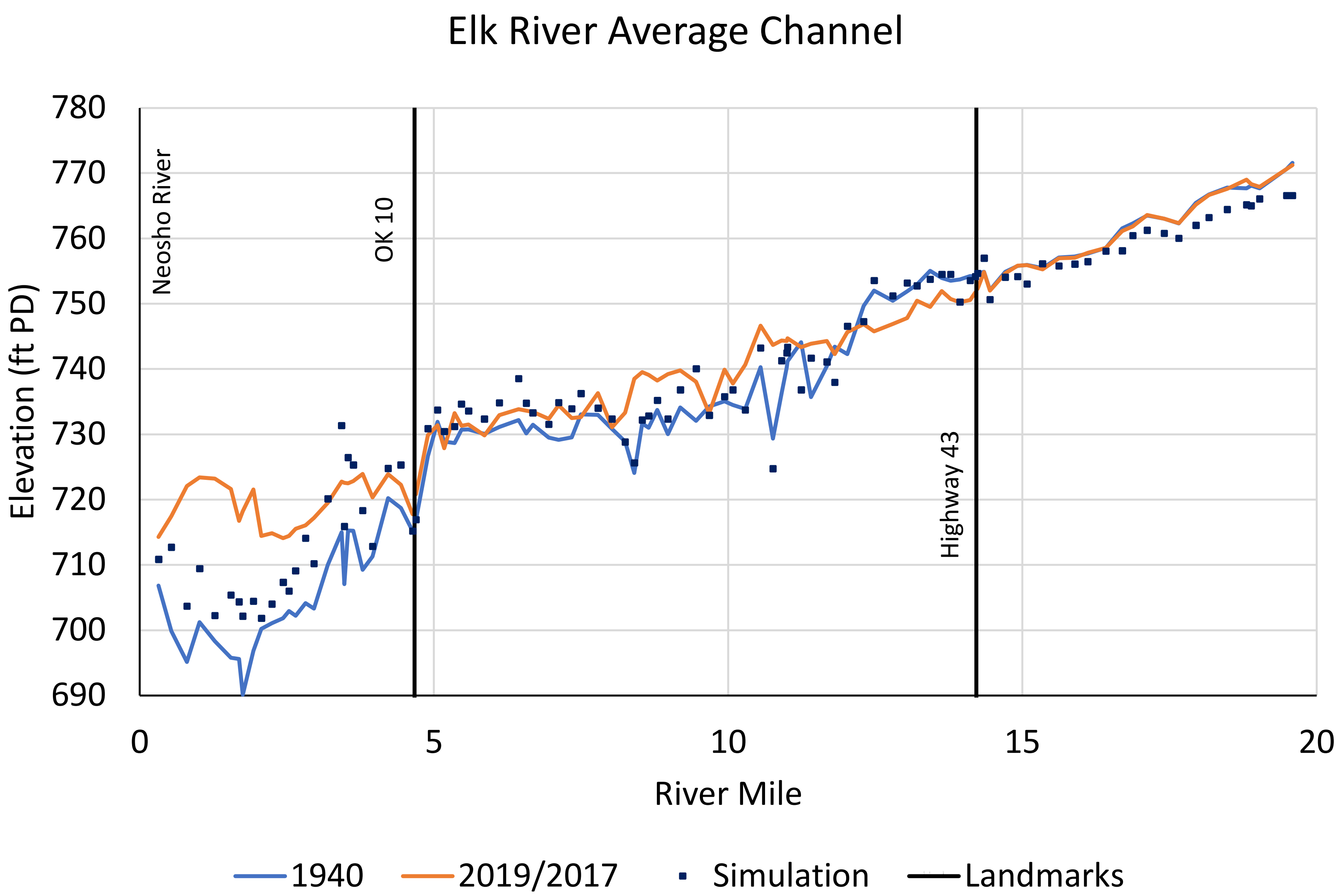
Neosho River Average Section
Elevation (ft PD)
770
760
750
740
730
720
710
700
100
110
120
130
140
150
160
River Mile
Hwy 59
(Sailboat Bridge)
Elk River
Hwy 60
(Twin Bridges)
S 590 Rd
(Connors Bridge)
I-44 Bridge
OldHwy 69
E 60 Rd
(Commerce Gage)
1940
2019/2017
Simulation
Landmarks

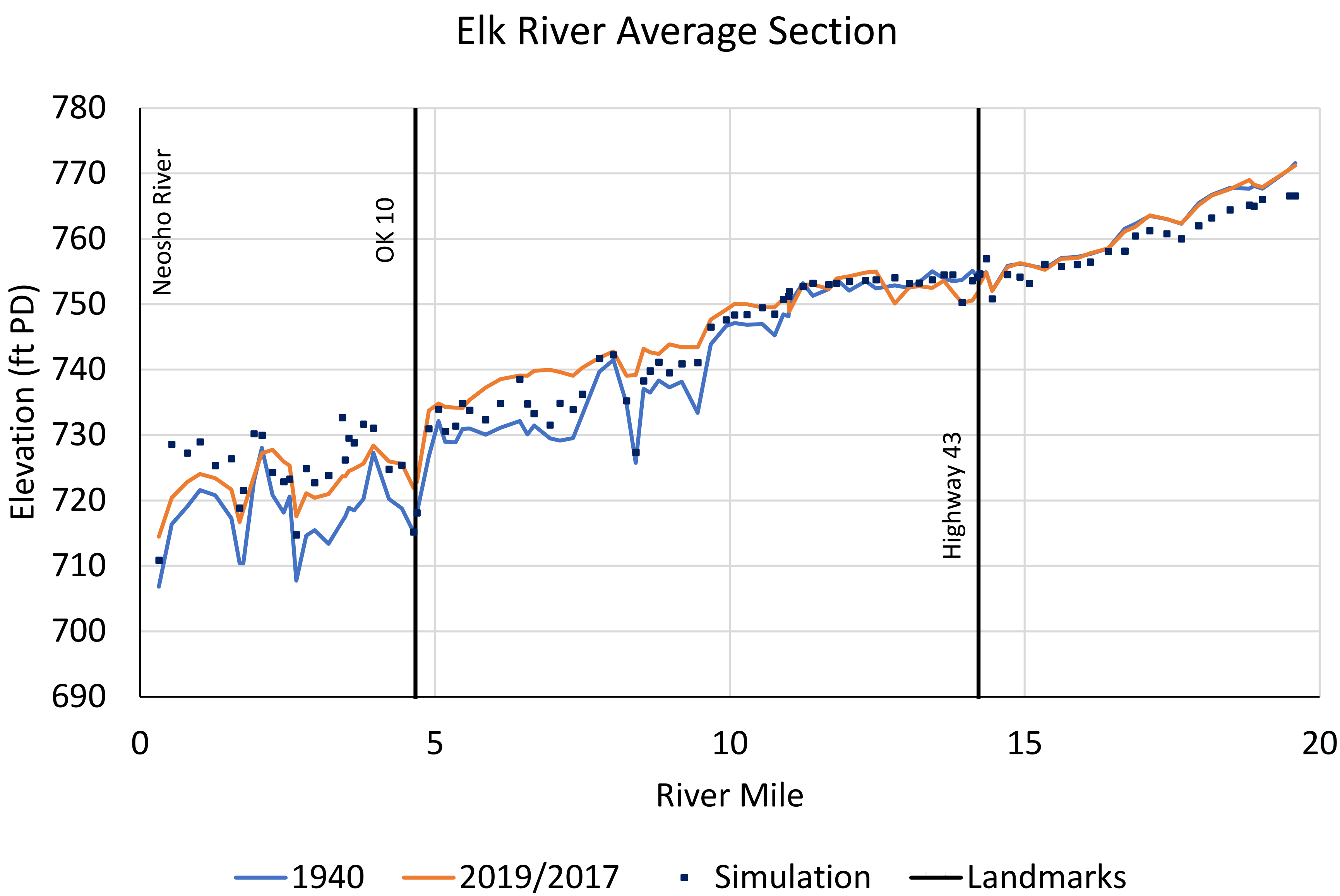


Spring River Average Channel
Elevation (ft PD)
770
765
760
755
750
745
740
735
730
725
720
0
5
10
15
20
25
River Mile
Hwy 60 (Twin Bridges)
OK 100/E 10 Rd
I-44 Bridge
E 57 Rd
1940
2019/2017
Simulation
Landmarks

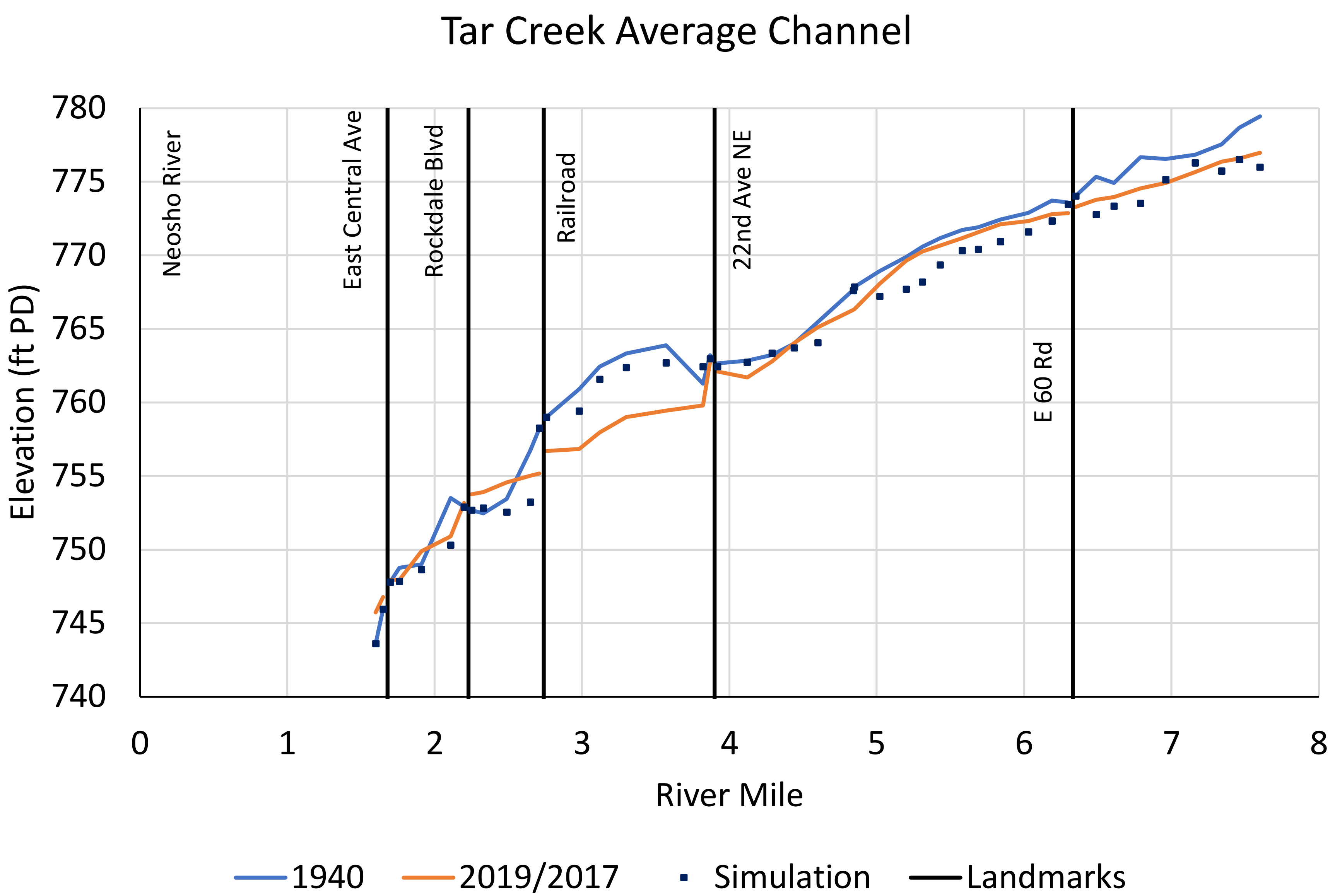


Spring River Average Section
Elevation (ft PD)
770
765
760
755
750
745
740
735
730
725
720
Hwy 60 (Twin Bridges)
OK 100/E 10 Rd
I-44 Bridge
E 57 Rd
0
5
10
15
20
25
River Mile
1940
2019/2017
Simulation
Landmarks

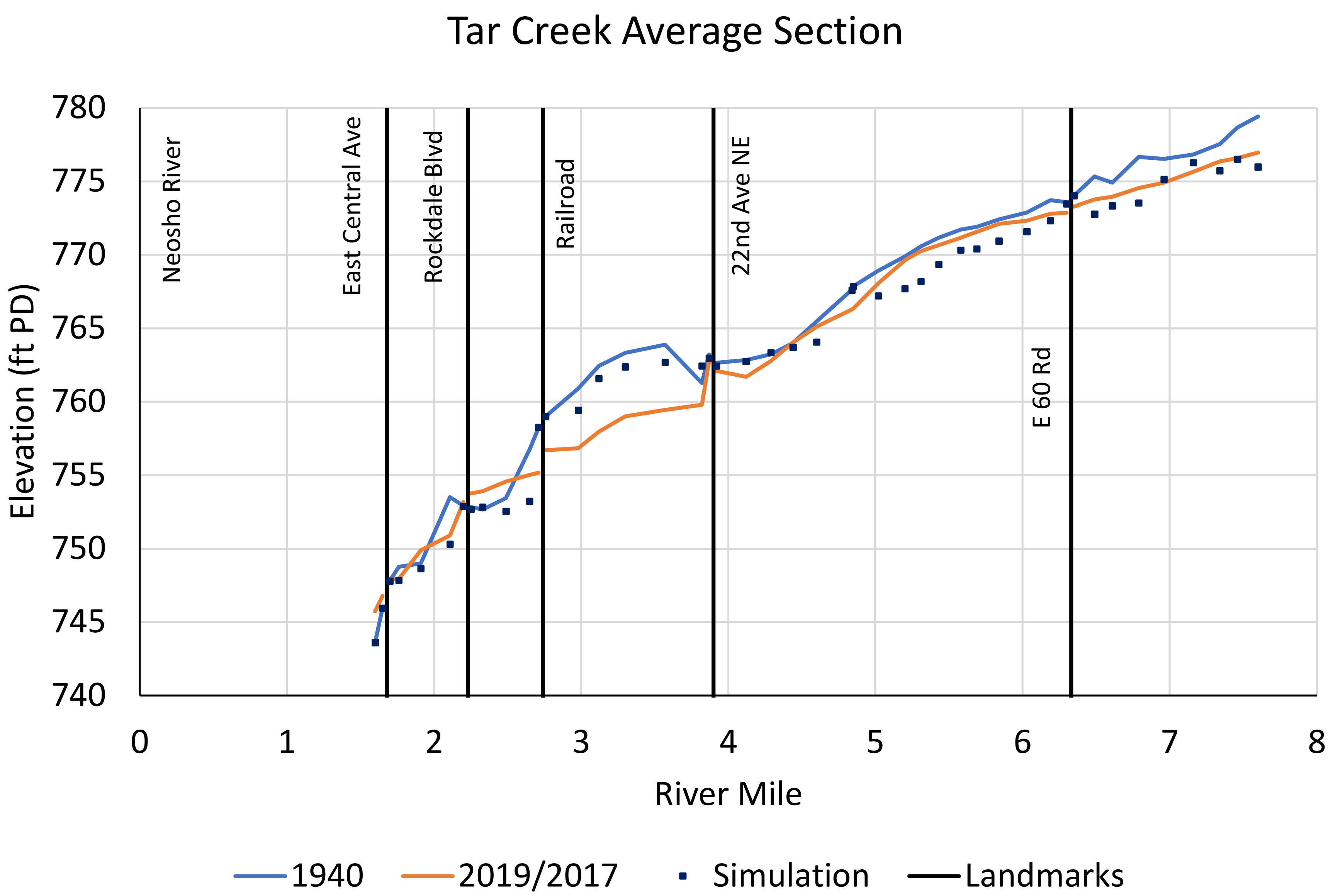

Elk River Average Channel
Elevation (ft PD)
River Mile
780
770
760
750
740
730
720
710
700
690
0
5
10
15
20
Neosho River
OK 10
Highway 43
1940
2019/2017
Simulation
Landmarks



Elk River Average Section
Elevation (ft PD)
780
770
760
750
740
730
720
710
700
690
0
5
10
15
20
River Mile
Neosho River
OK 10
Highway 43
1940
2019/2017
Simulation
Landmarks

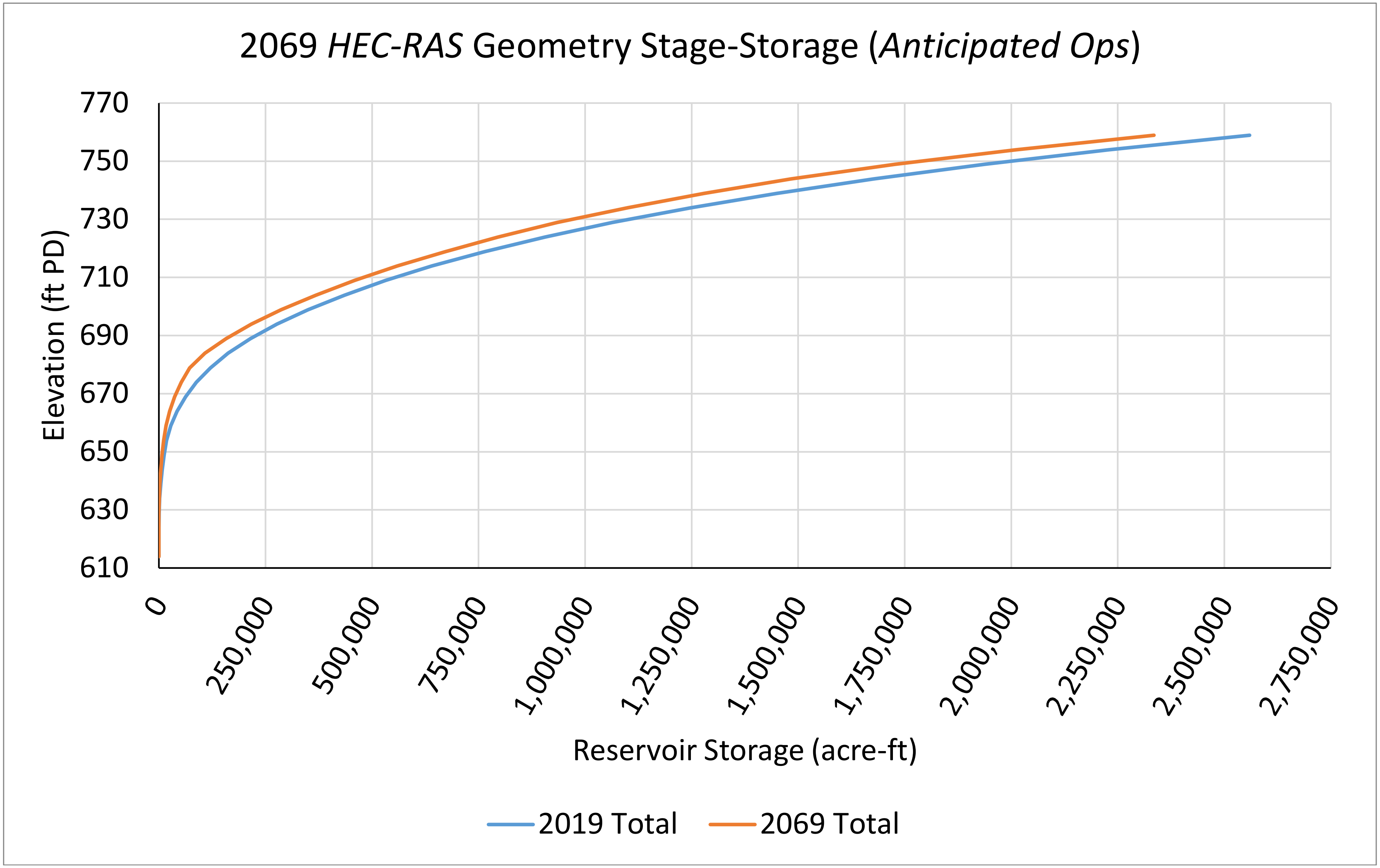


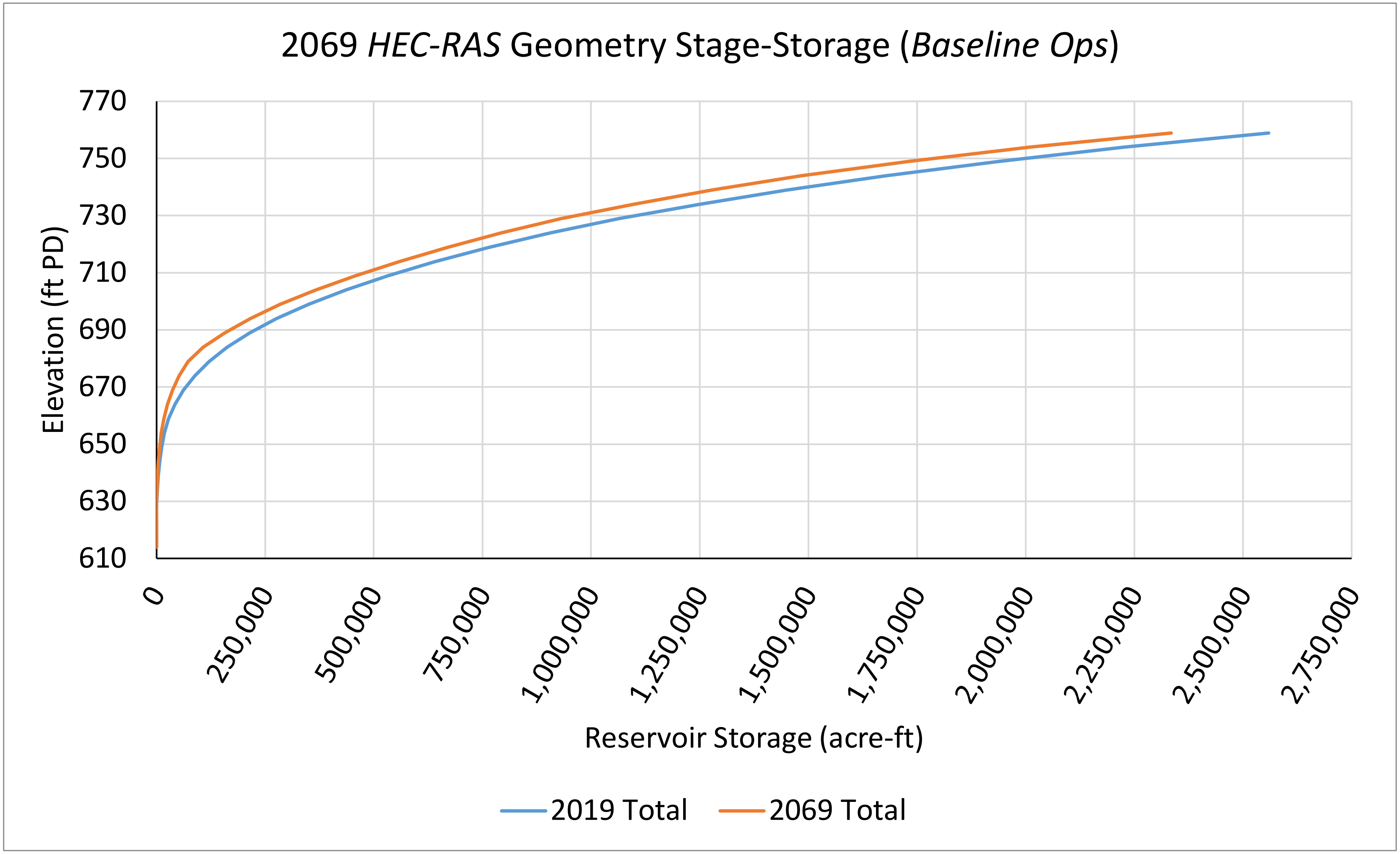
Tar Creek Average Channel
780
775
770
765
760
755
750
745
740
Elevation (ft PD)
0
1
2
3
4
5
6
7
8
River Mile
Neosho River
East Central Ave
Rockdale Blvd
Railroad
22nd Ave NE
E 60 Rd
1940
2019/2017
Simulation
Landmarks

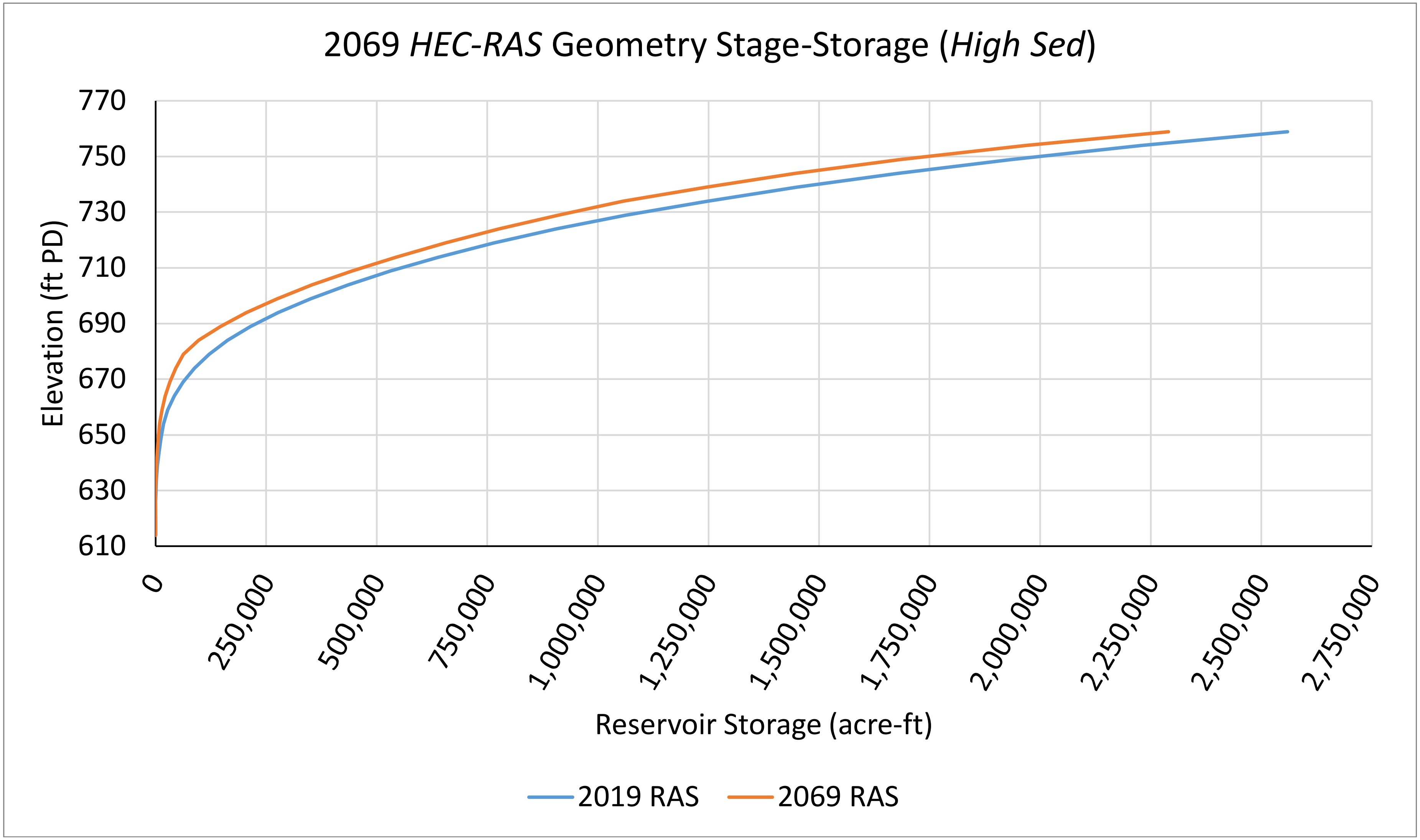


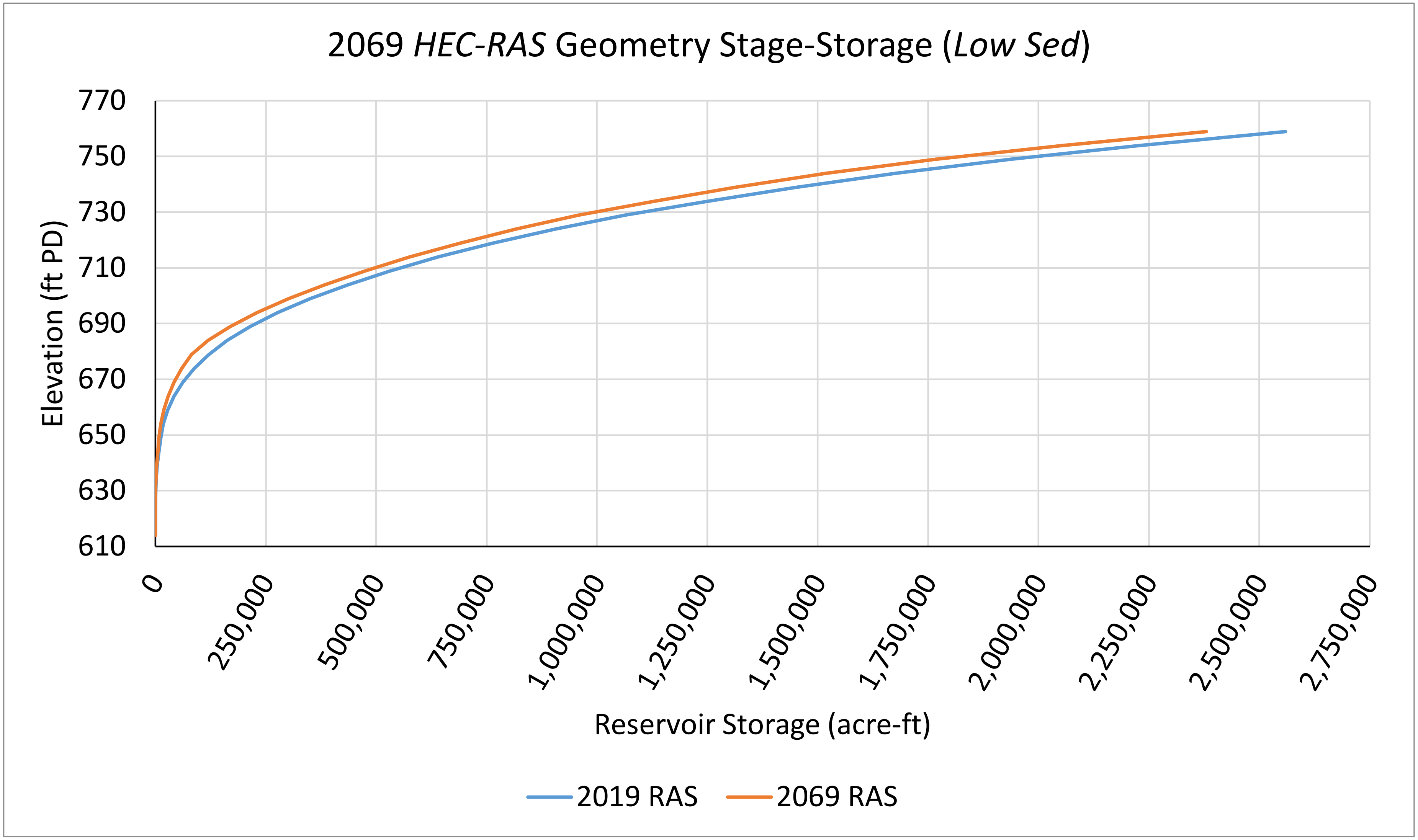
Tar Creek Average Section
780
775
770
765
760
755
750
745
740
Elevation (ft PD)
Neosho River
East Central Ave
Rockdale Blvd
Railroad
22nd Ave NE
E 60 Rd
0
1
2
3
4
5
6
7
8
River Mile
1940
2019/2017
Simulation
Landmarks

Simulated HEC-RAS Stage-Storage Curves


2069 *HEC-RAS* Geometry Stage-Storage (*Anticipated Ops*)
Elevation (ft PD)
770
750
730
710
690
670
650
630
610
0
250,000
500,000
750,000
1,000,000
1,250,000
1,500,000
1,750,000
2,000,000
2,250,000
2,500,000
2,750,000
Reservoir Storage (acre-ft)
2019 Total
2069 Total

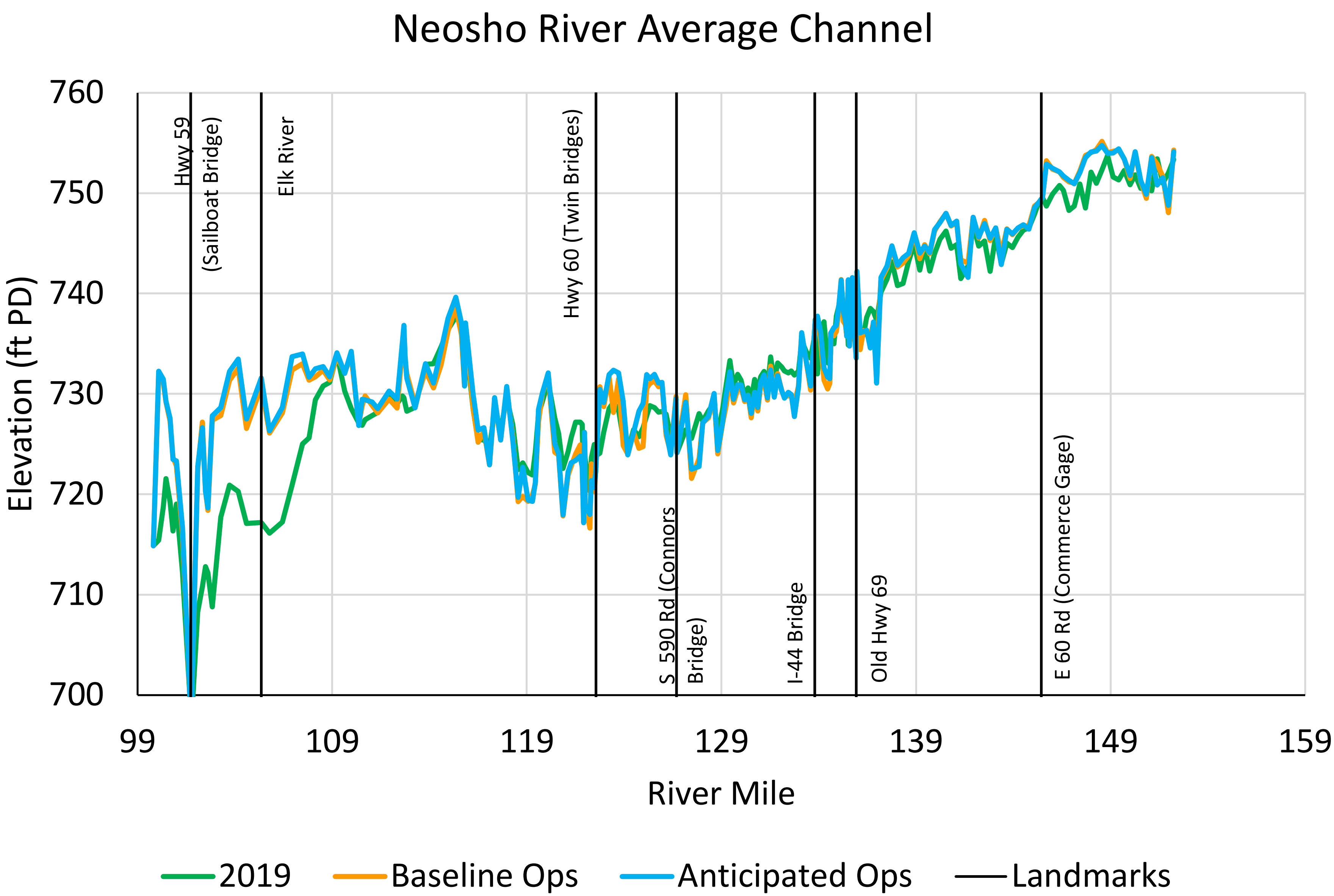

2069 HEC-RAS Geometry Stage-Storage (Baseline Ops)
Elevation (ft PD)
770
750
730
710
690
670
650
630
610
0
250,000
500,000
750,000
1,000,000
1,250,000
1,500,000
1,750,000
2,000,000
2,250,000
2,500,000
2,750,000
Reservoir Storage (acre-ft)
2019 Total
2069 Total


2069 *HEC-RAS* Geometry Stage-Storage (*High Sed*)
Elevation (ft PD)
770
750
730
710
690
670
650
630
610
0
250,000
500,000
750,000
1,000,000
1,250,000
1,500,000
1,750,000
2,000,000
2,250,000
2,500,000
2,750,000
Reservoir Storage (acre-ft)
2019 RAS
2069 RAS

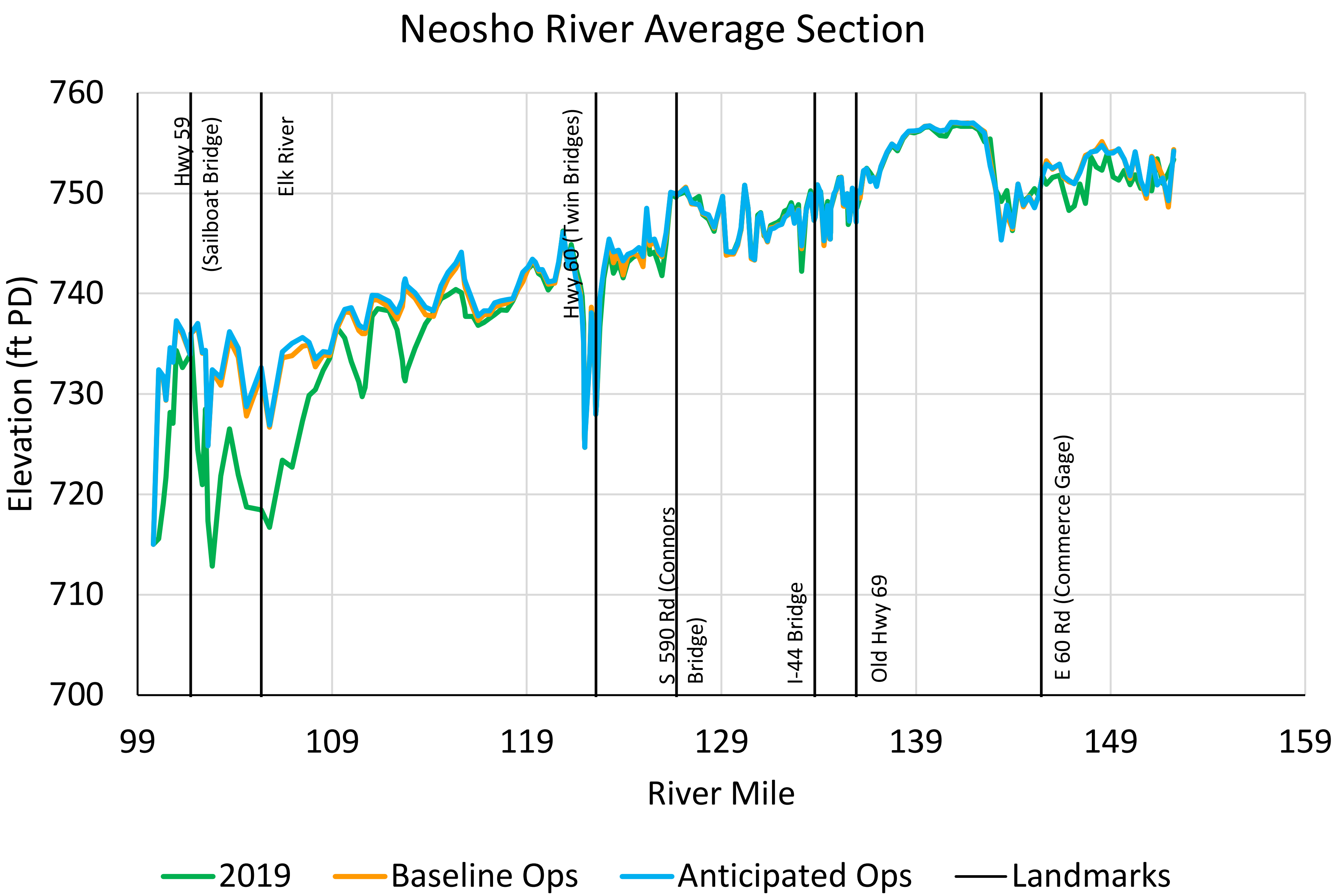


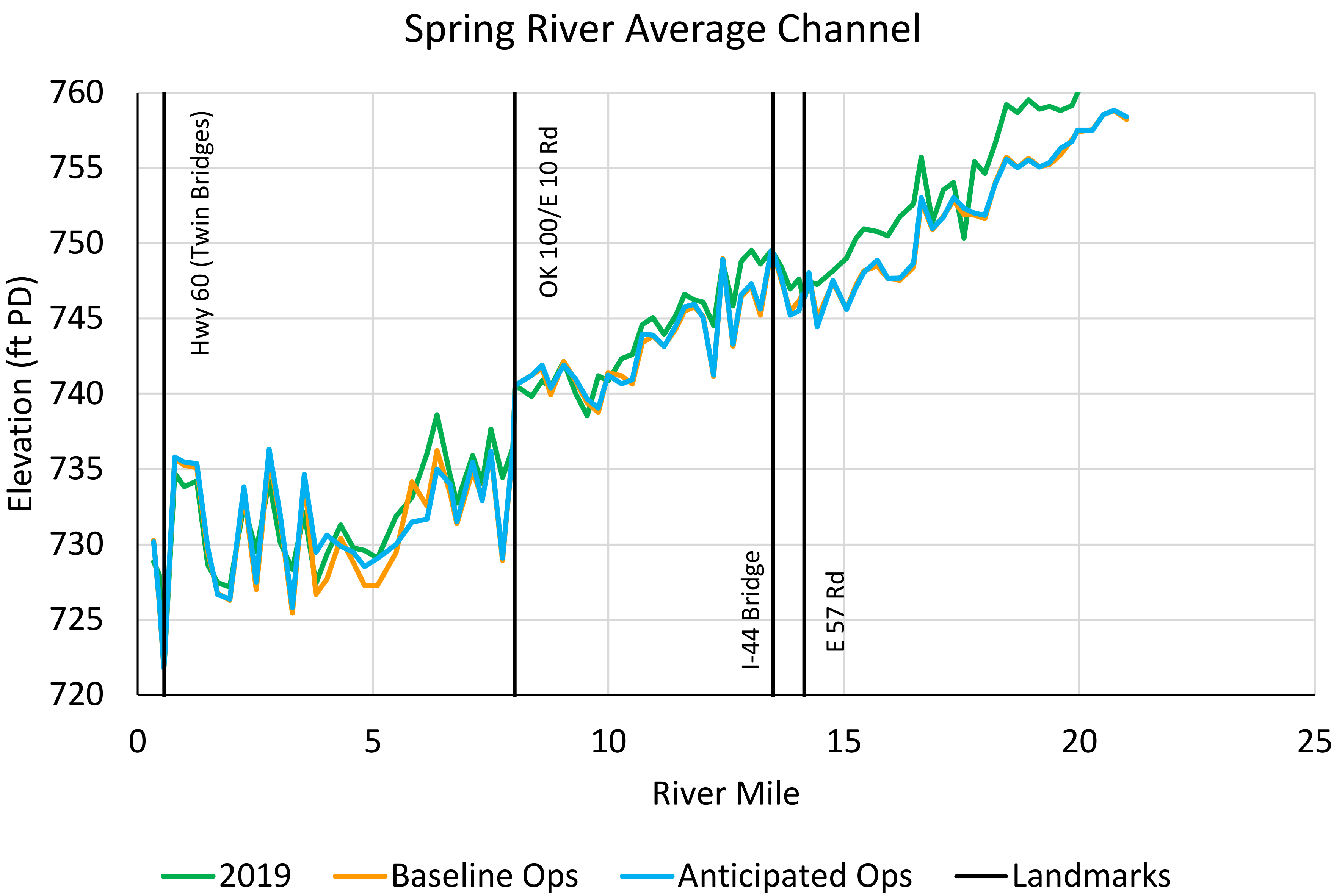
2069 *HEC-RAS* Geometry Stage-Storage (*Low Sed*)
Elevation (ft PD)
770
750
730
710
690
670
650
630
610
0
250,000
500,000
750,000
1,000,000
1,250,000
1,500,000
1,750,000
2,000,000
2,250,000
2,500,000
2,750,000
Reservoir Storage (acre-ft)
2019 RAS
2069 RAS

Simulated Future Average Channel and Average Section Plots – Operations Comparison

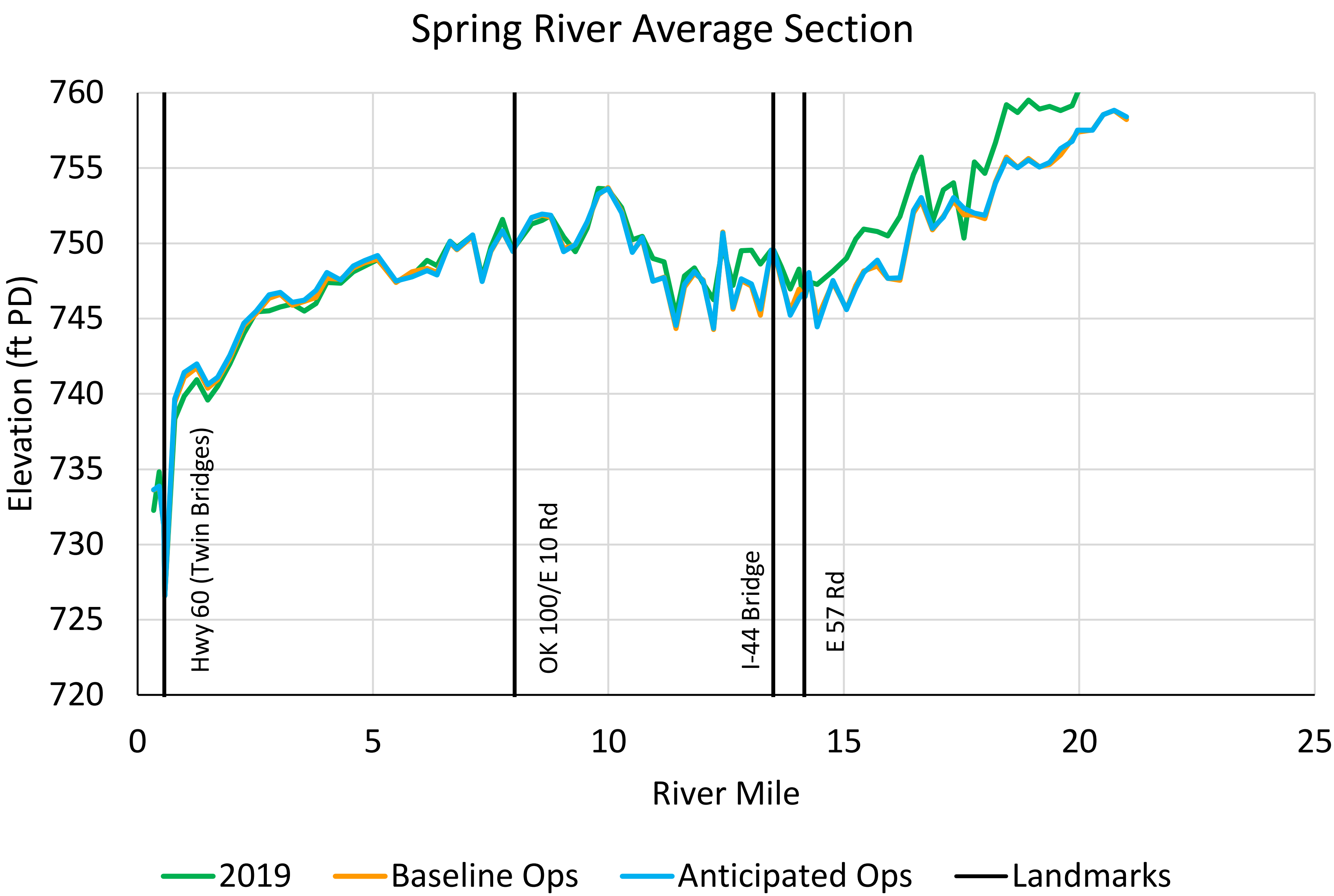


Neosho River Average Channel
Elevation (ft PD)
760
750
740
730
720
710
700
99
109
119
129
139
149
159
River Mile
Hwy 59
(Sailboat Bridge)
Elk River
Hwy 60 (Twin Bridges)
S 590 Rd (Connors
Bridge)
I-44 Bridge
Old Hwy 69
E 60 Rd (Commerce Gage)
2019
Baseline Ops
Anticipated Ops
Landmarks

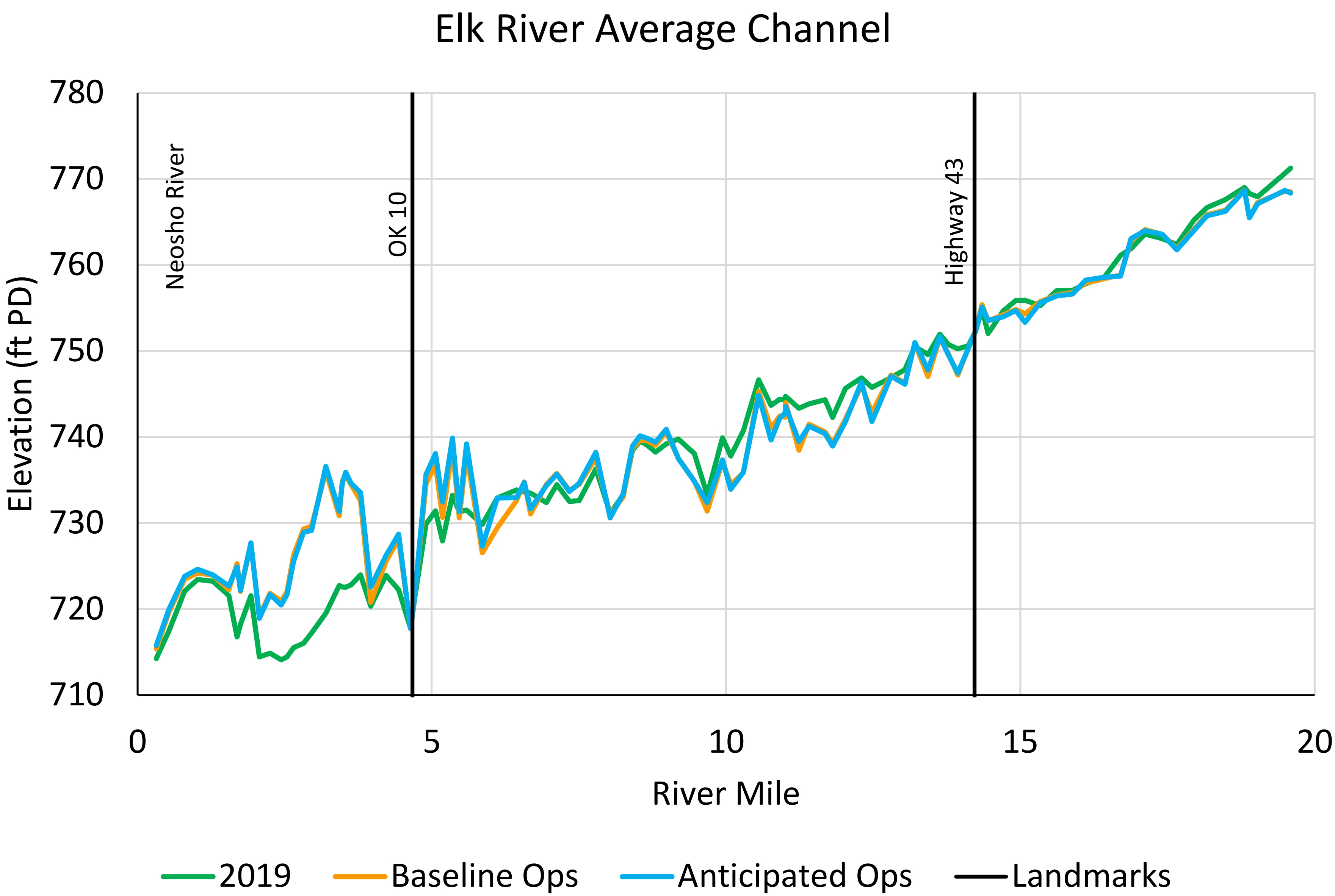

Neosho River Average Section
Elevation (ft PD)
760
750
740
730
720
710
700
99
109
119
129
139
149
159
River Mile
Hwy 59
(Sailboat Bridge)
Elk River
Hwy 60 (Twin Bridges)
S 590 Rd (Connors
Bridge)
I-44 Bridge
Old Hwy 69
E 60 Rd (Commerce Gage)
2019
Baseline Ops
Anticipated Ops
Landmarks

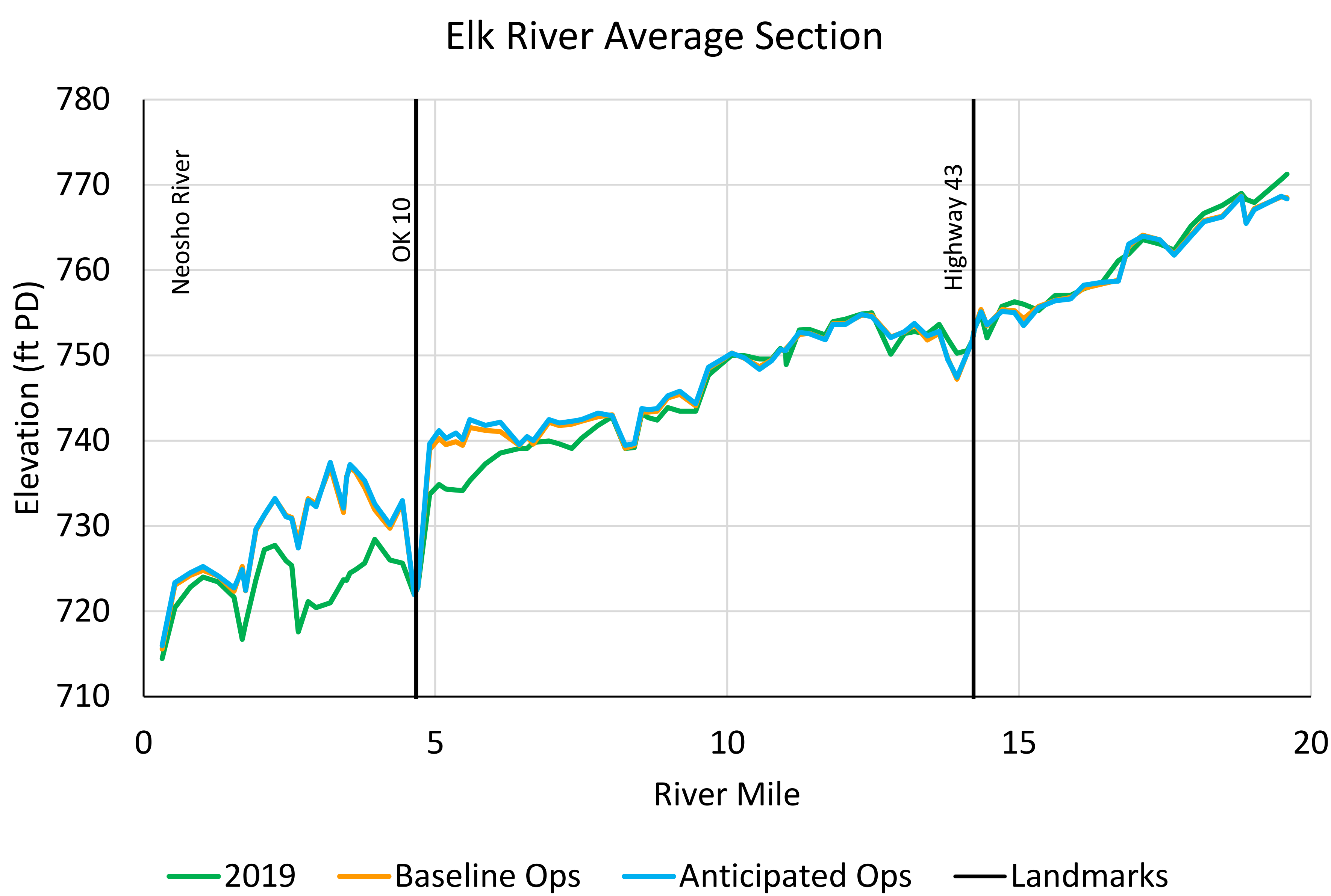


Spring River Average Channel
760
755
750
745
740
735
730
725
720
Elevation (ft PD)
0
5
10
15
20
25
River Mile
Hwy 60 (Twin Bridges)
OK 100/E 10 Rd
I-44 Bridge
E 57 Rd
2019
Baseline Ops
Anticipated Ops
Landmarks

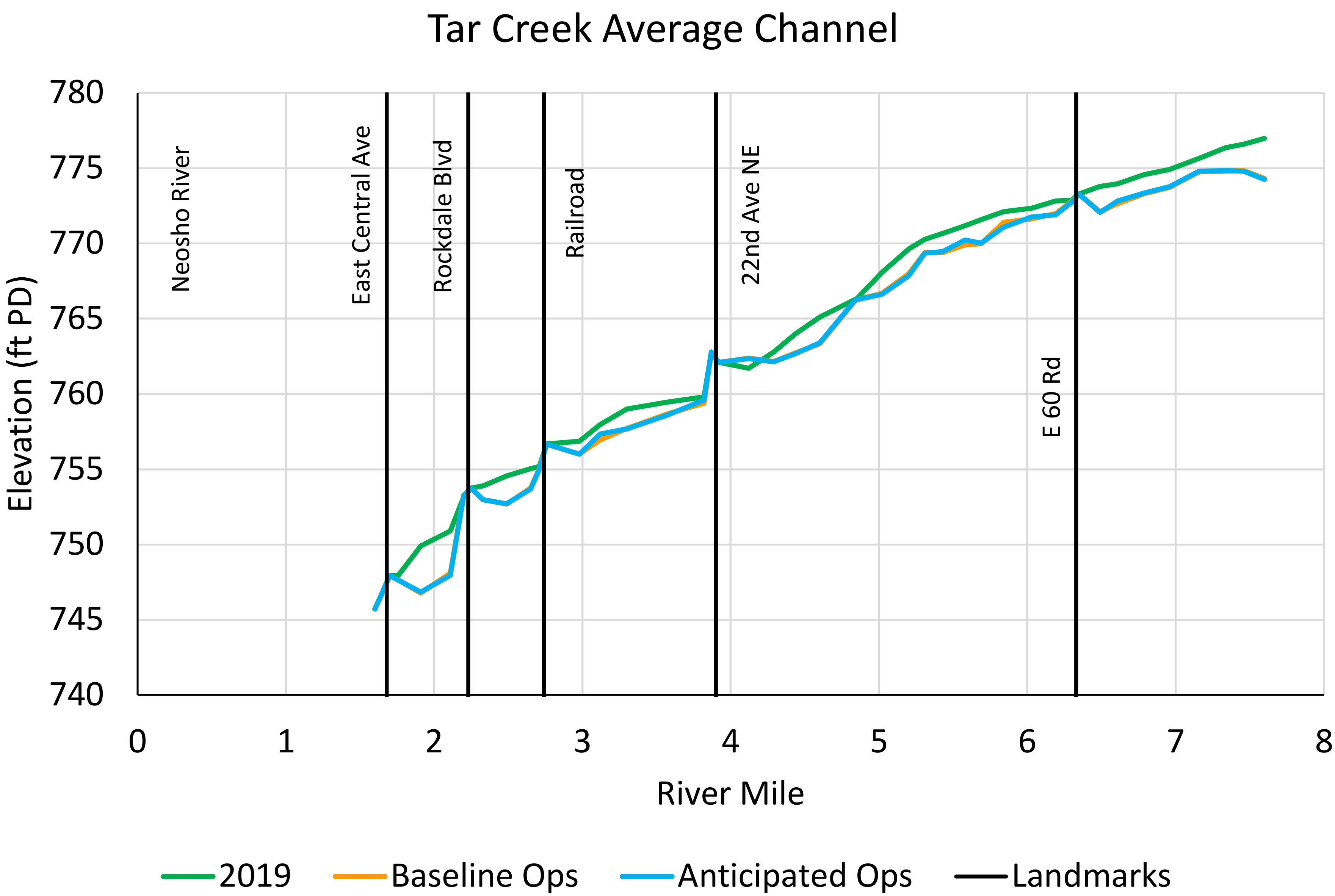


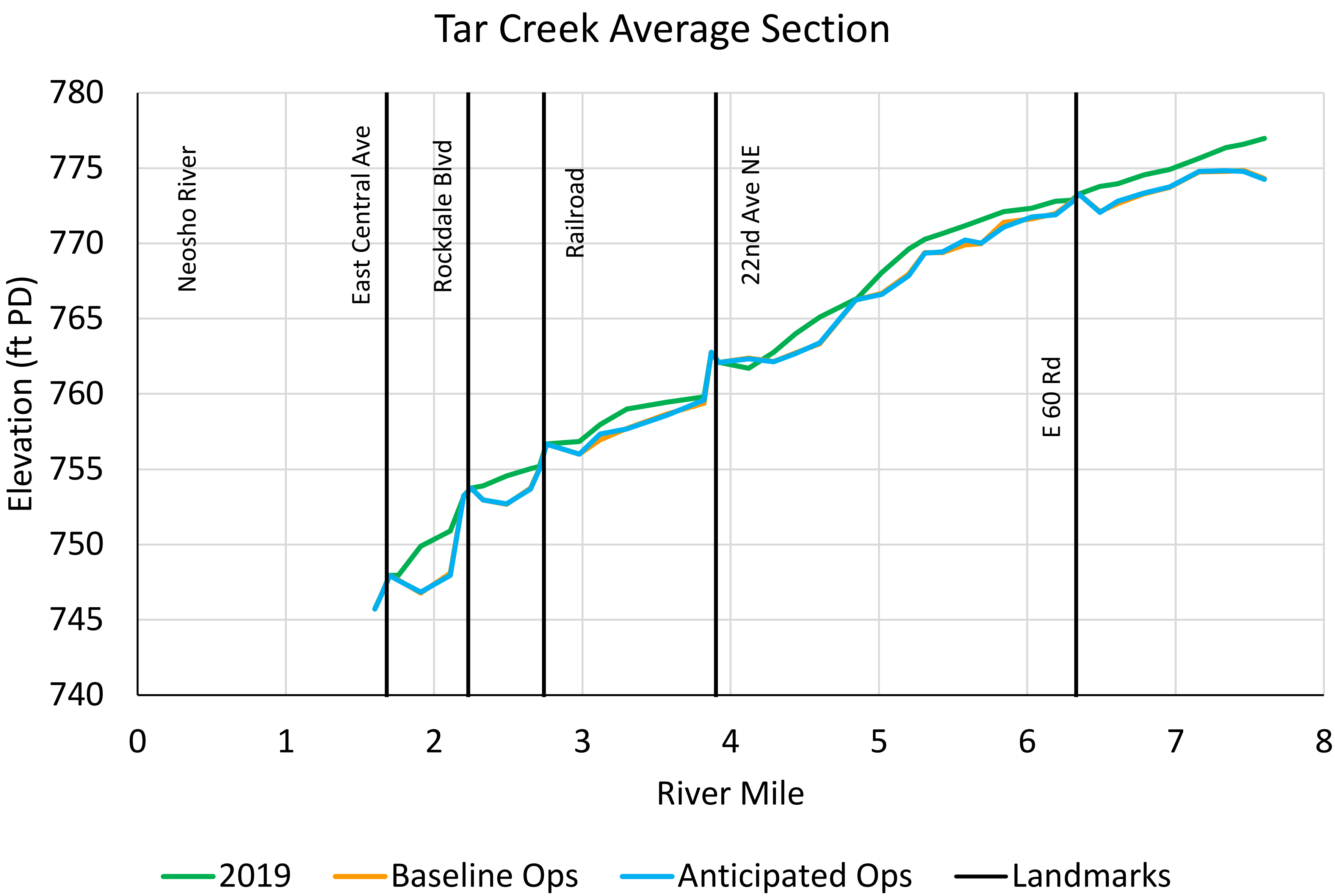
Spring River Average Section
Elevation (ft PD)
760
755
750
745
740
735
730
725
720
0
5
10
15
20
25
River Mile
Hwy 60 (Twin Bridges)
OK 100/E 10 Rd
I-44 Bridge
E 57 Rd
2019
Baseline Ops
Anticipated Ops
Landmarks


Elk River Average Channel
Elevation (ft PD)
780
770
760
750
740
730
720
710
0
5
10
15
20
River Mile
Neosho River
OK 10
Highway 43
2019
Baseline Ops
Anticipated Ops
Landmarks



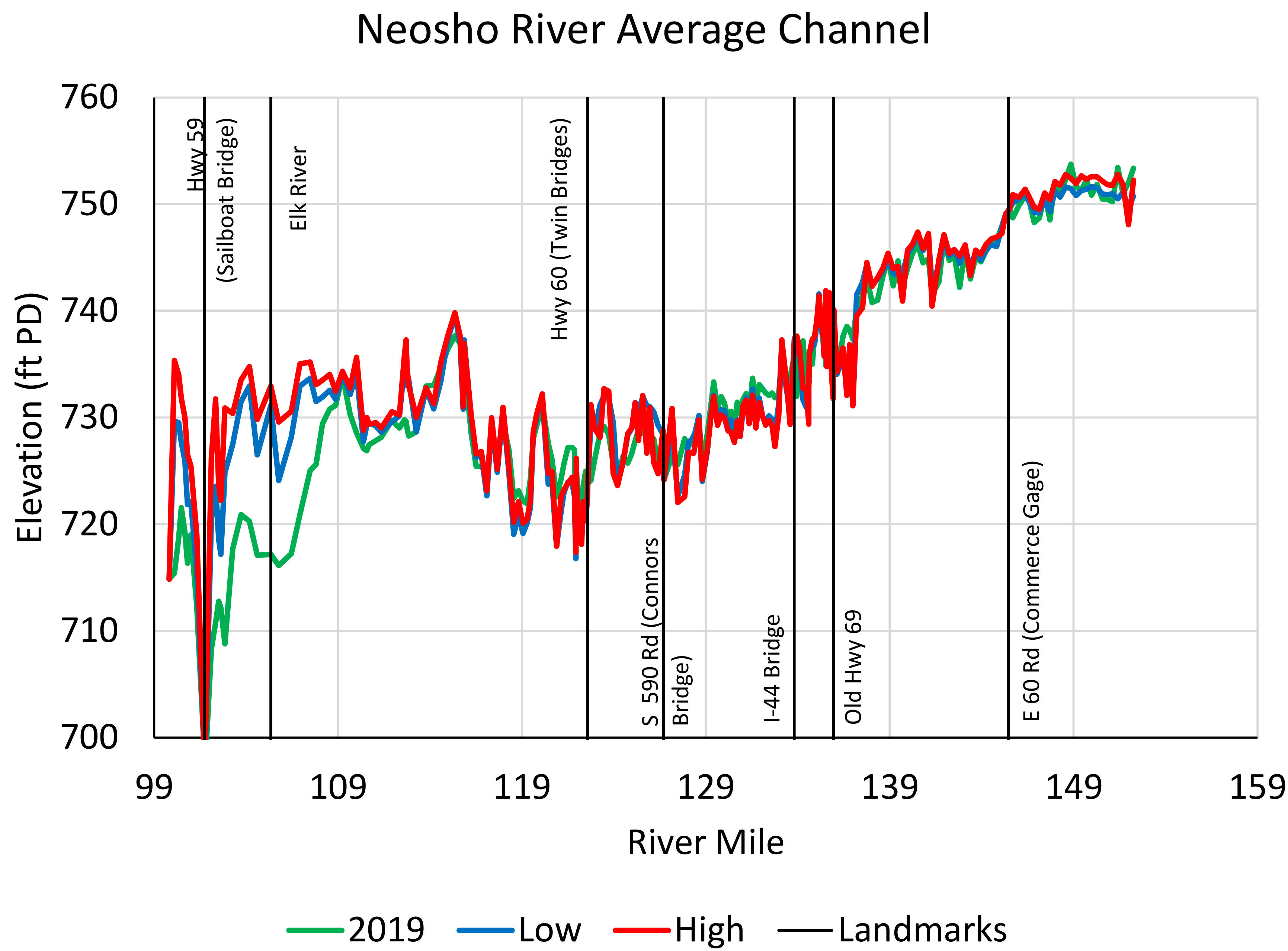
Elk River Average Section
Elevation (ft PD)
780
770
760
750
740
730
720
710
0
5
10
15
20
River Mile
Neosho River
OK 10
Highway 43
2019
Baseline Ops
Anticipated Ops
Landmarks


Tar Creek Average Channel
Elevation (ft PD)
780
775
770
765
760
755
750
745
740
River Mile
0
1
2
3
4
5
6
7
8
Neosho River
East Central Ave
Rockdale Blvd
Railroad
22nd Ave NE
E 60 Rd
2019
Baseline Ops
Anticipated Ops
Landmarks

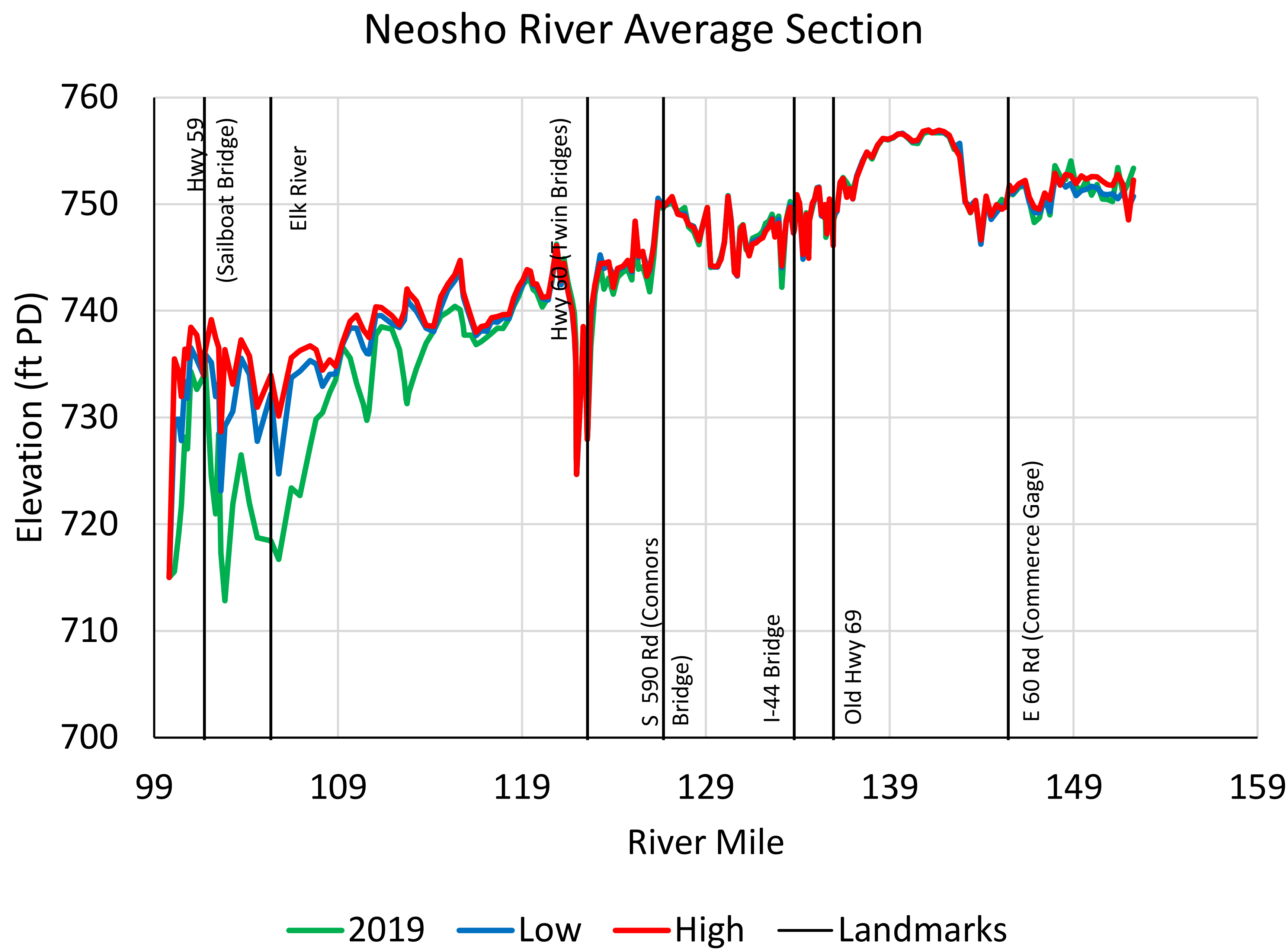


Tar Creek Average Section
Elevation (ft PD)
780
775
770
765
760
755
750
745
740
0
1
2
3
4
5
6
7
8
River Mile
Neosho River
East Central Ave
Rockdale Blvd
Railroad
22nd Ave NE
E 60 Rd
2019
Baseline Ops
Anticipated Ops
Landmarks

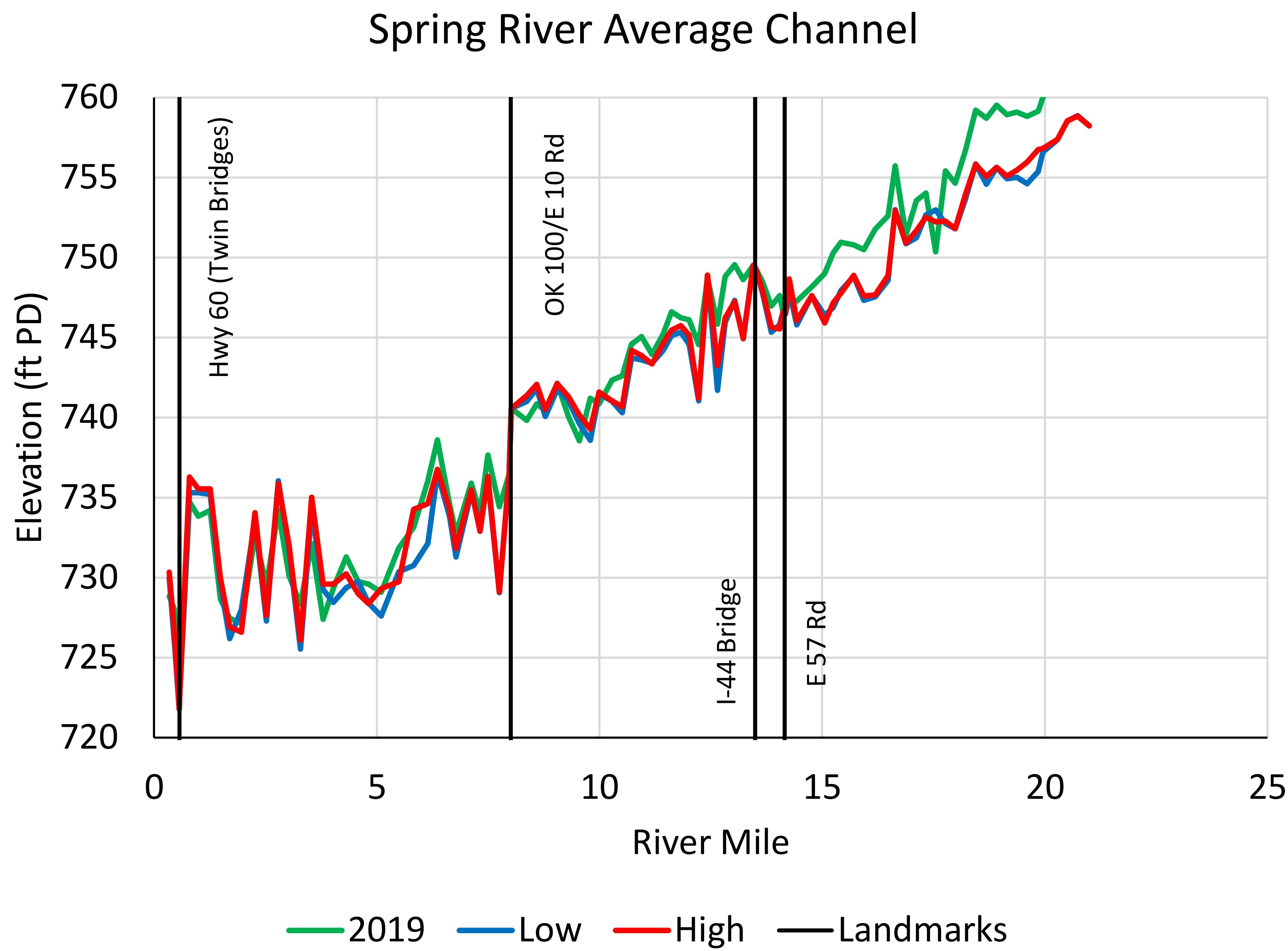
Simulated Future Average Channel and Average Section Plots – Sediment Loading Comparison



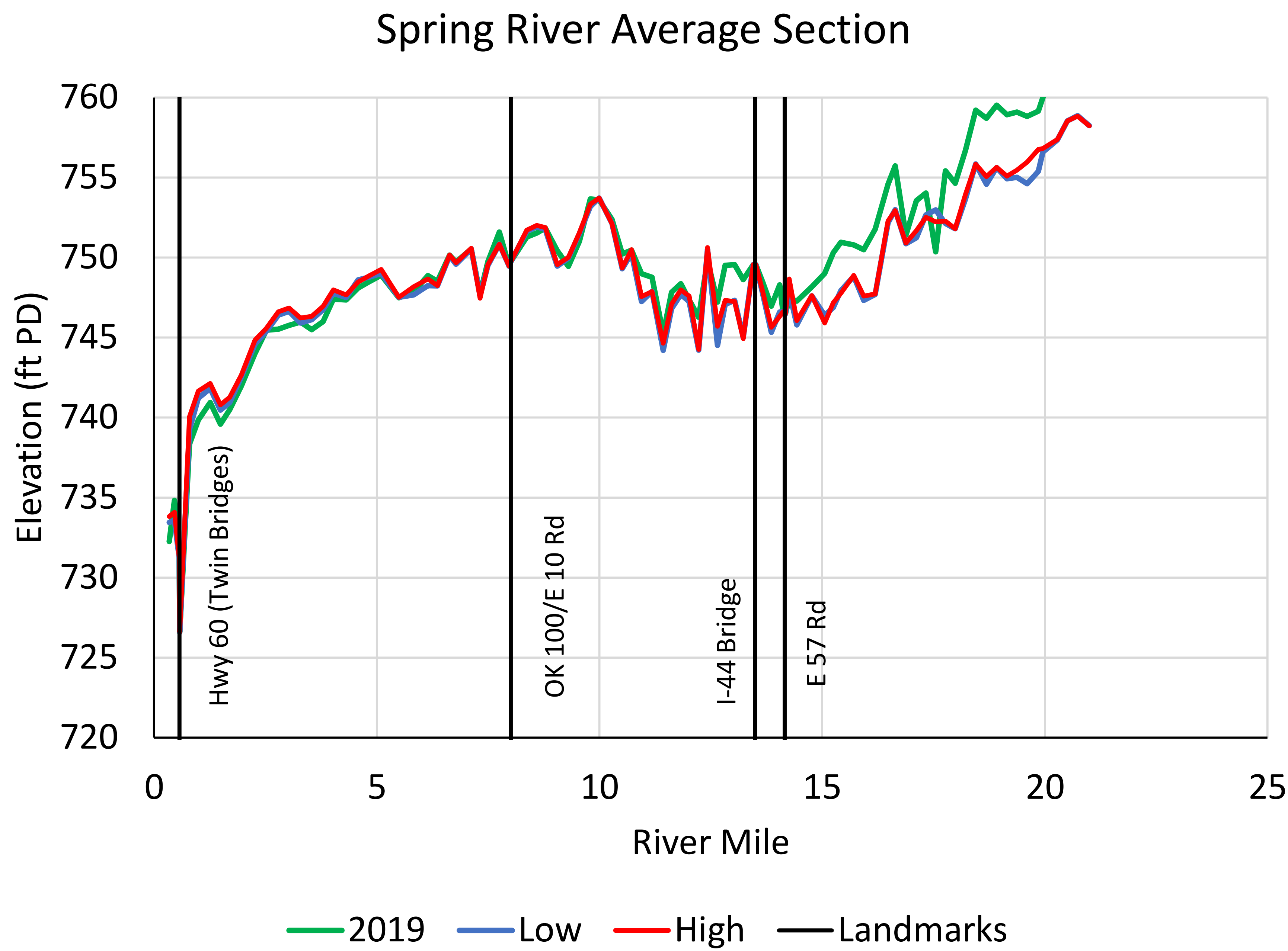
Neosho River Average Channel
Elevation (ft PD)
760
750
740
730
720
710
700
99
109
119
129
139
149
159
River Mile
Hwy 59
(Sailboat Bridge)
Elk River
Hwy 60 (Twin Bridges)
S 590 Rd (Connors
Bridge)
I-44 Bridge
Old Hwy 69
E 60 Rd (Commerce Gage)
2019
Low
High
Landmarks



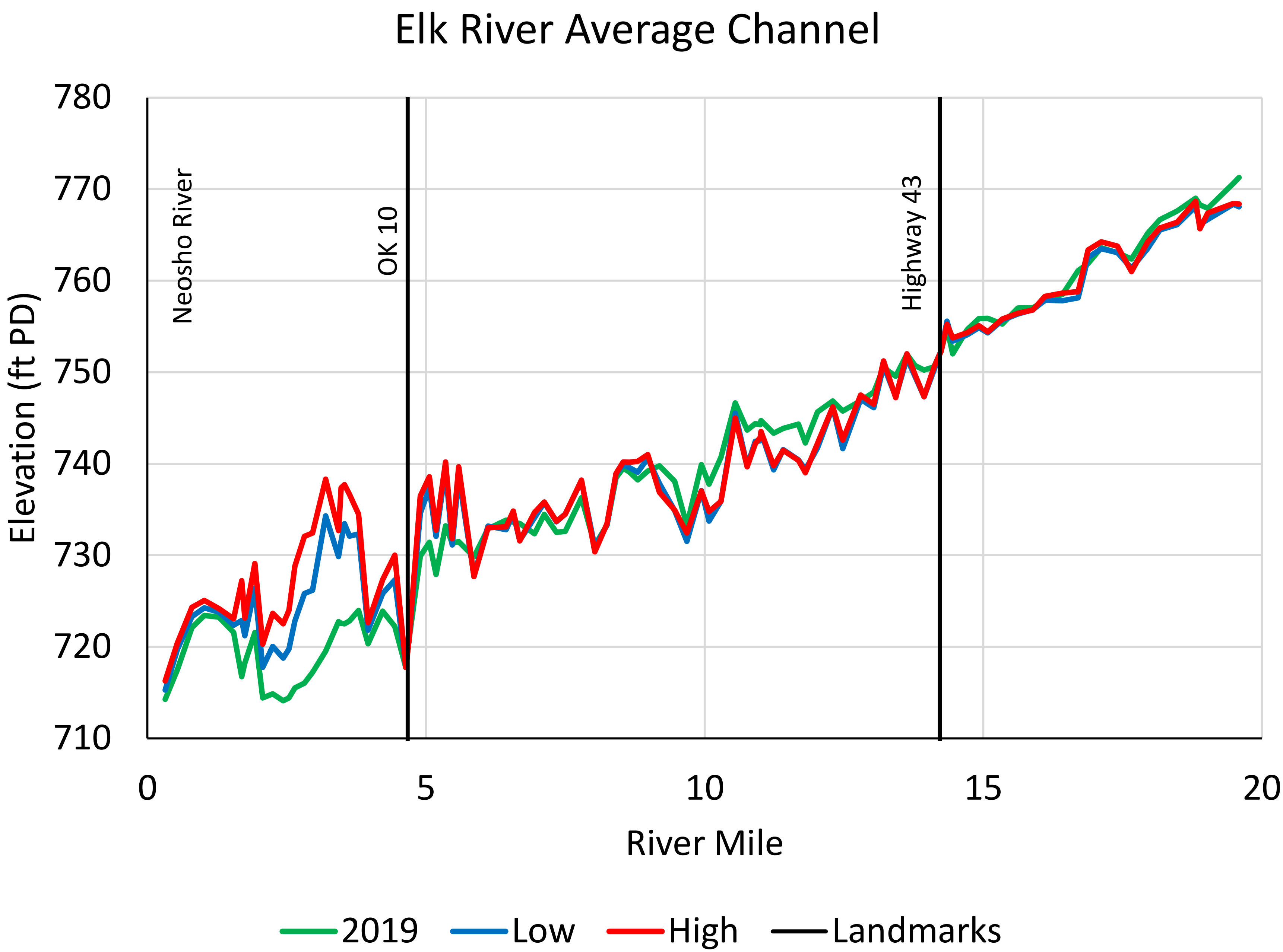
Neosho River Average Section
Elevation (ft PD)
760
750
740
730
720
710
700
99
109
119
129
139
149
159
River Mile
Hwy 59
(Sailboat Bridge)
Elk River
Hwy 60 (Twin Bridges)
S 590 Rd (Connors
Bridge)
I-44 Bridge
Old Hwy 69
E 60 Rd (Commerce Gage)
2019
Low
High
Landmarks

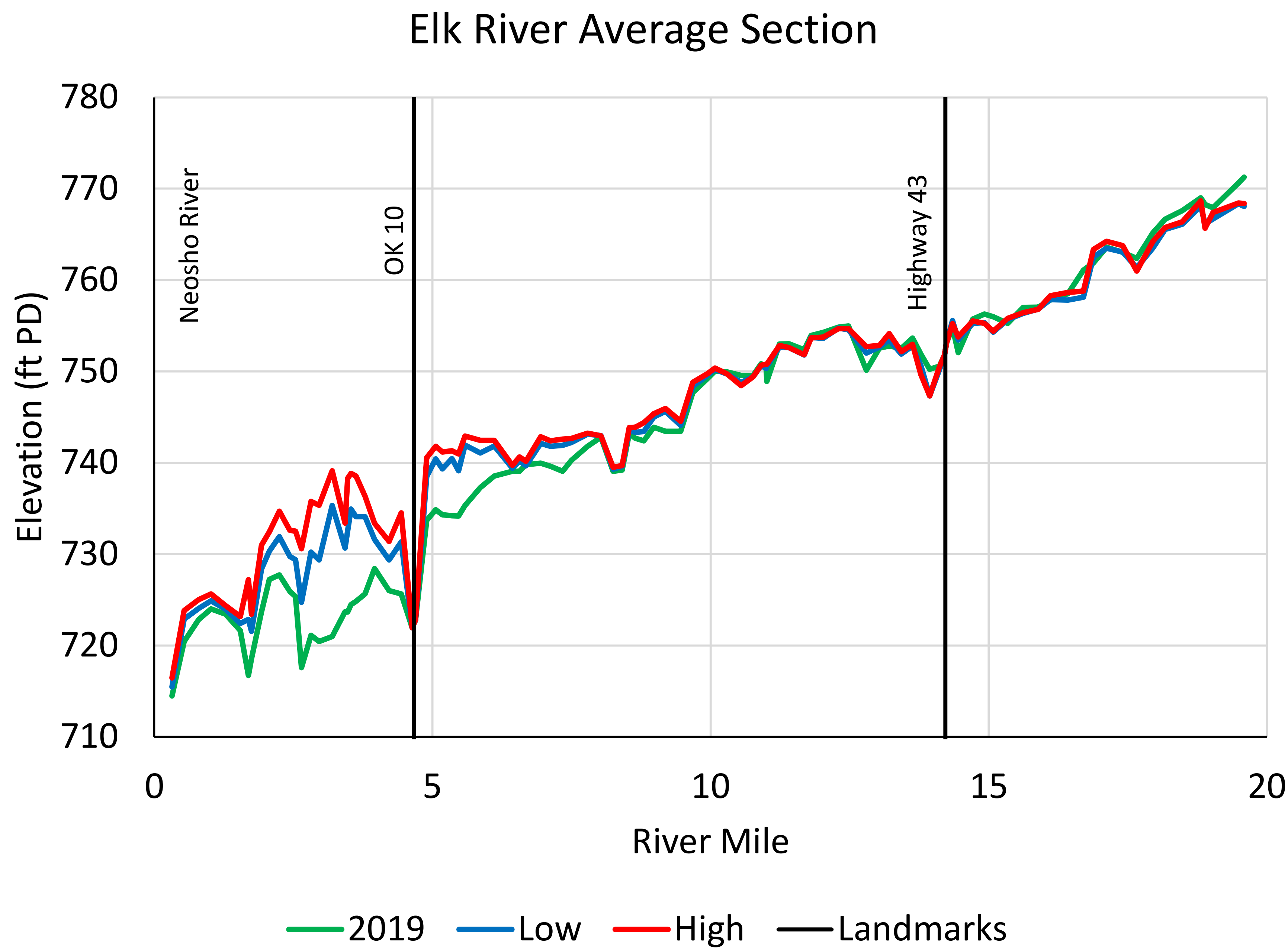


Spring River Average Channel
Elevation (ft PD)
760
755
750
745
740
735
730
725
720
Hwy 60 (Twin Bridges)
OK 100/E 10 Rd
I-44 Bridge
E 57 Rd
0
5
10
15
20
25
River Mile
2019
Low
High
Landmarks

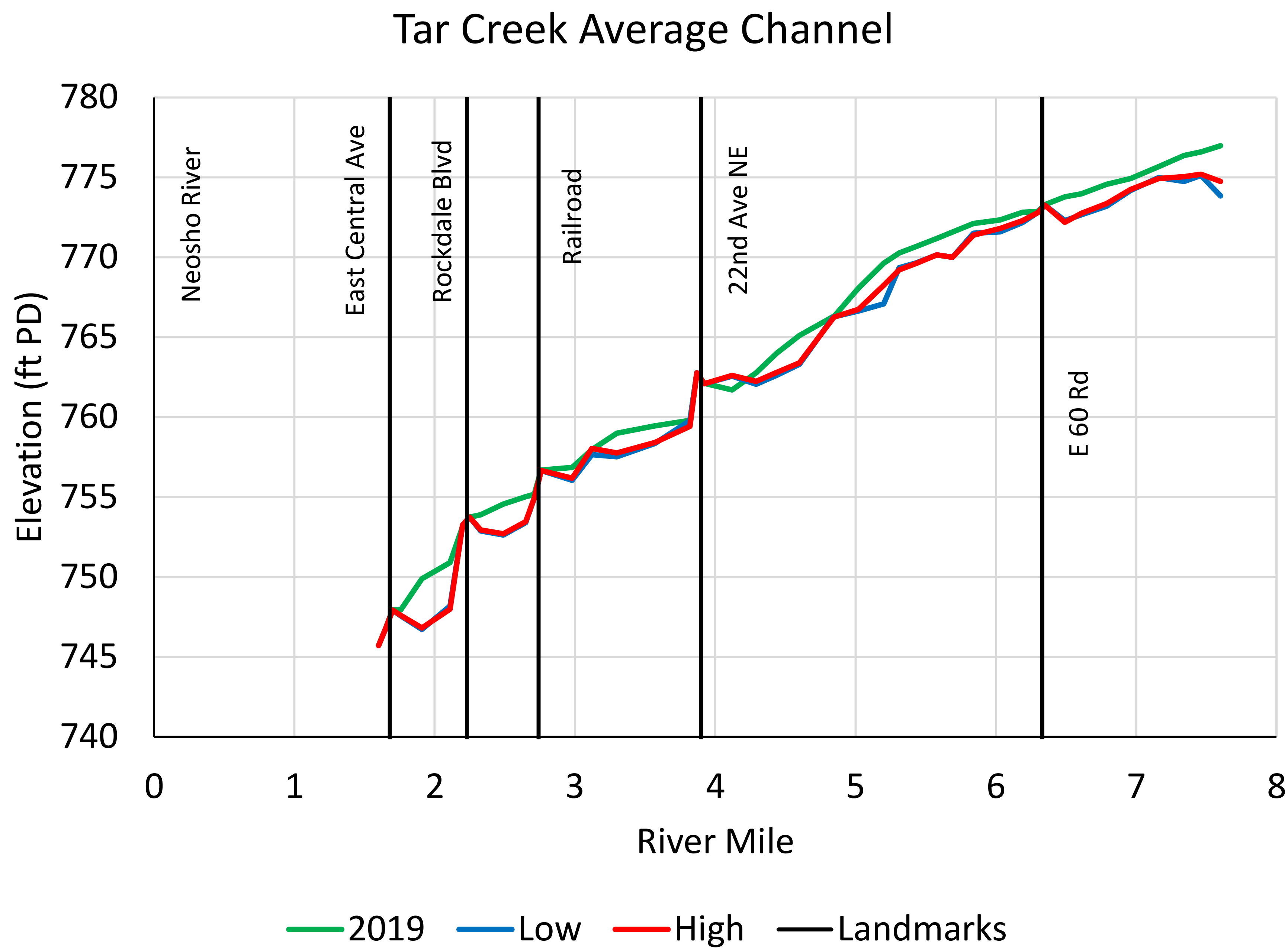


Spring River Average Section
Elevation (ft PD)
760
755
750
745
740
735
730
725
720
0
5
10
15
20
25
River Mile
Hwy 60 (Twin Bridges)
OK 100/E 10 Rd
I-44 Bridge
E 57 Rd
2019
Low
High
Landmarks

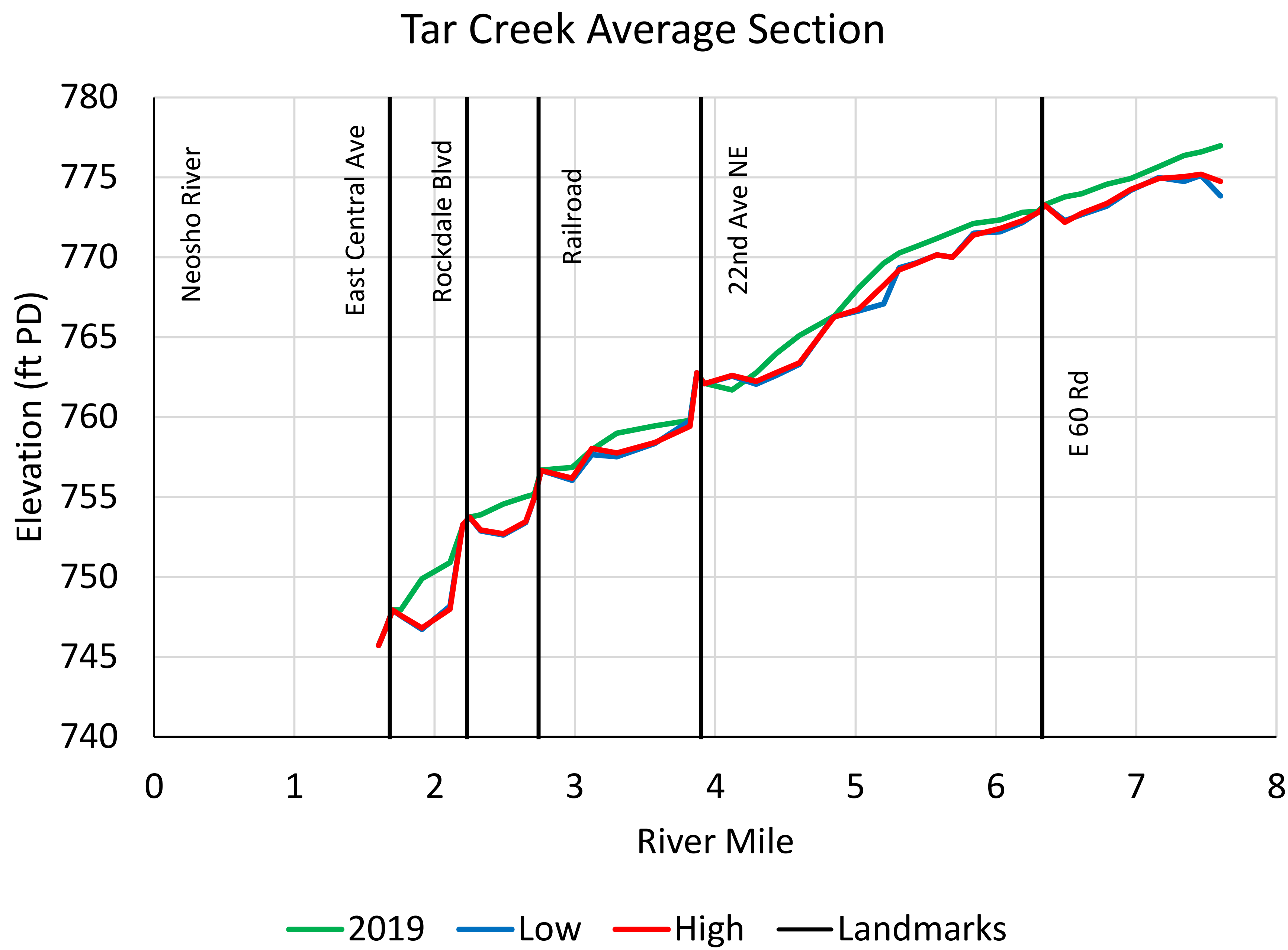

Elk River Average Channel
Elevation (ft PD)
780
770
760
750
740
730
720
710
0
5
10
15
20
River Mile
Neosho River
OK 10
Highway 43
2019
Low
High
Landmarks



Elk River Average Section
Elevation (ft PD)
780
770
760
750
740
730
720
710
0
5
10
15
20
River Mile
Neosho River
OK 10
Highway 43
2019
Low
High
Landmarks



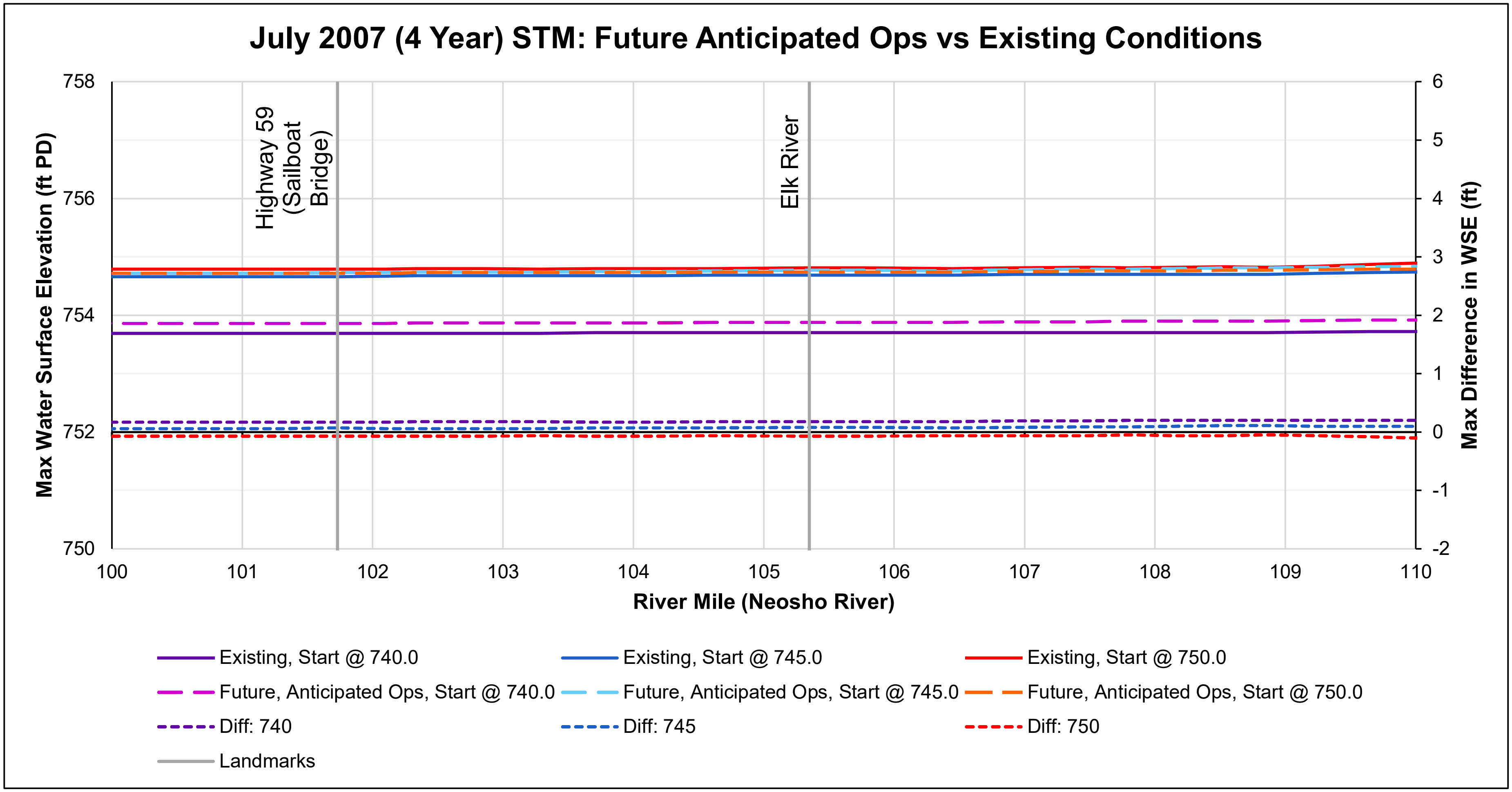
Tar Creek Average Channel
Elevation (ft PD)
780
775
770
765
760
755
750
745
740
0
1
2
3
4
5
6
7
8
River Mile
Neosho River
East Central Ave
Rockdale Blvd
Railroad
22nd Ave NE
E 60 Rd
2019
Low
High
Landmarks


Tar Creek Average Section
Elevation (ft PD)
780
775
770
765
760
755
750
745
740
River Mile
0
1
2
3
4
5
6
7
8
Neosho River
East Central Ave
Rockdale Blvd
Railroad
22nd Ave NE
E 60 Rd
2019
Low
High
Landmarks

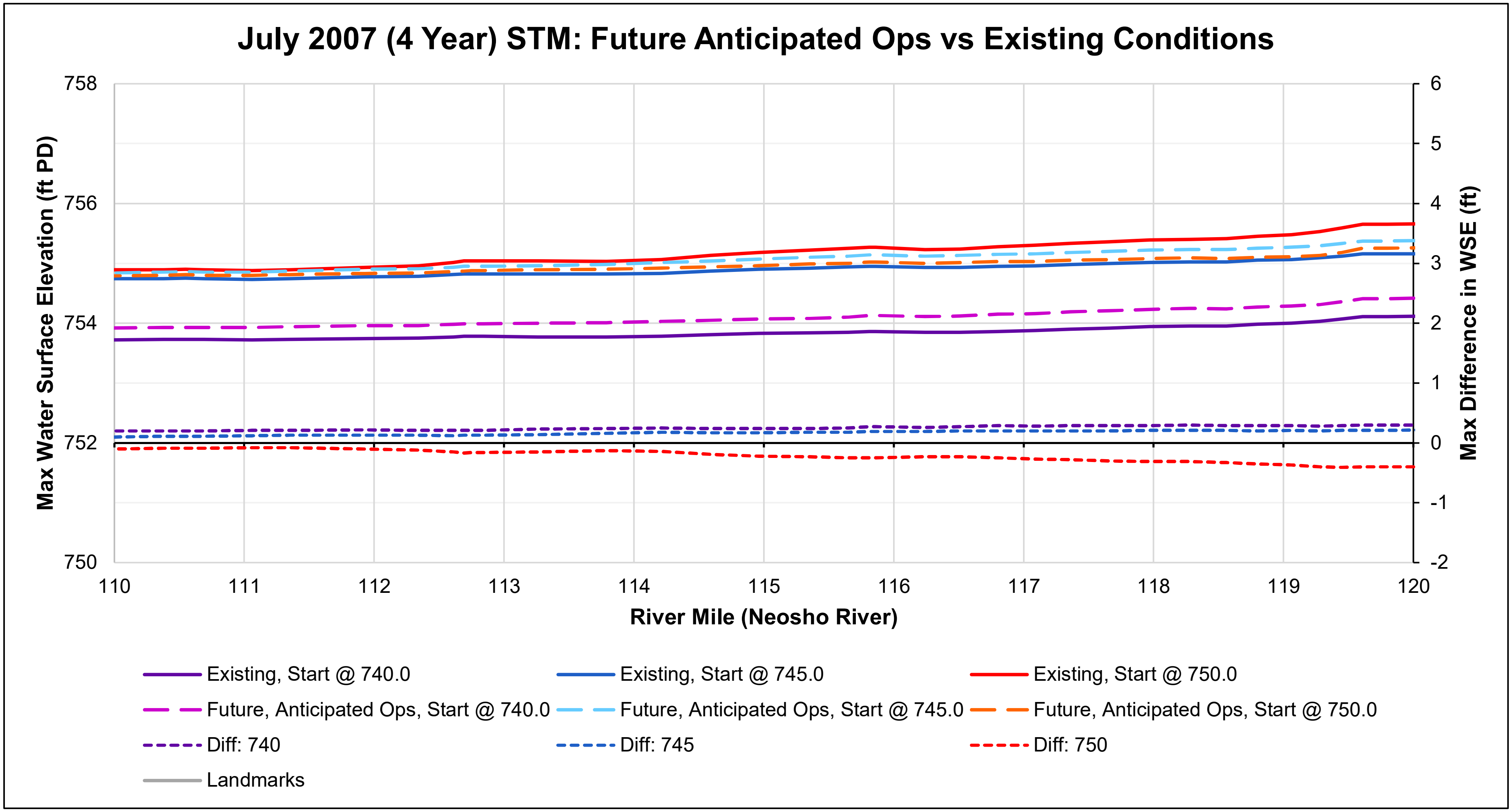
Please see following spreadsheets for cross section analyses:

- ElkRiver-XS_Analysis
- NeoshoRiver-XS_Analysis-01
- NeoshoRiver-XS_Analysis-02
- NeoshoRiver-XS_Analysis-03
- SpringRiver-XS_Analysis

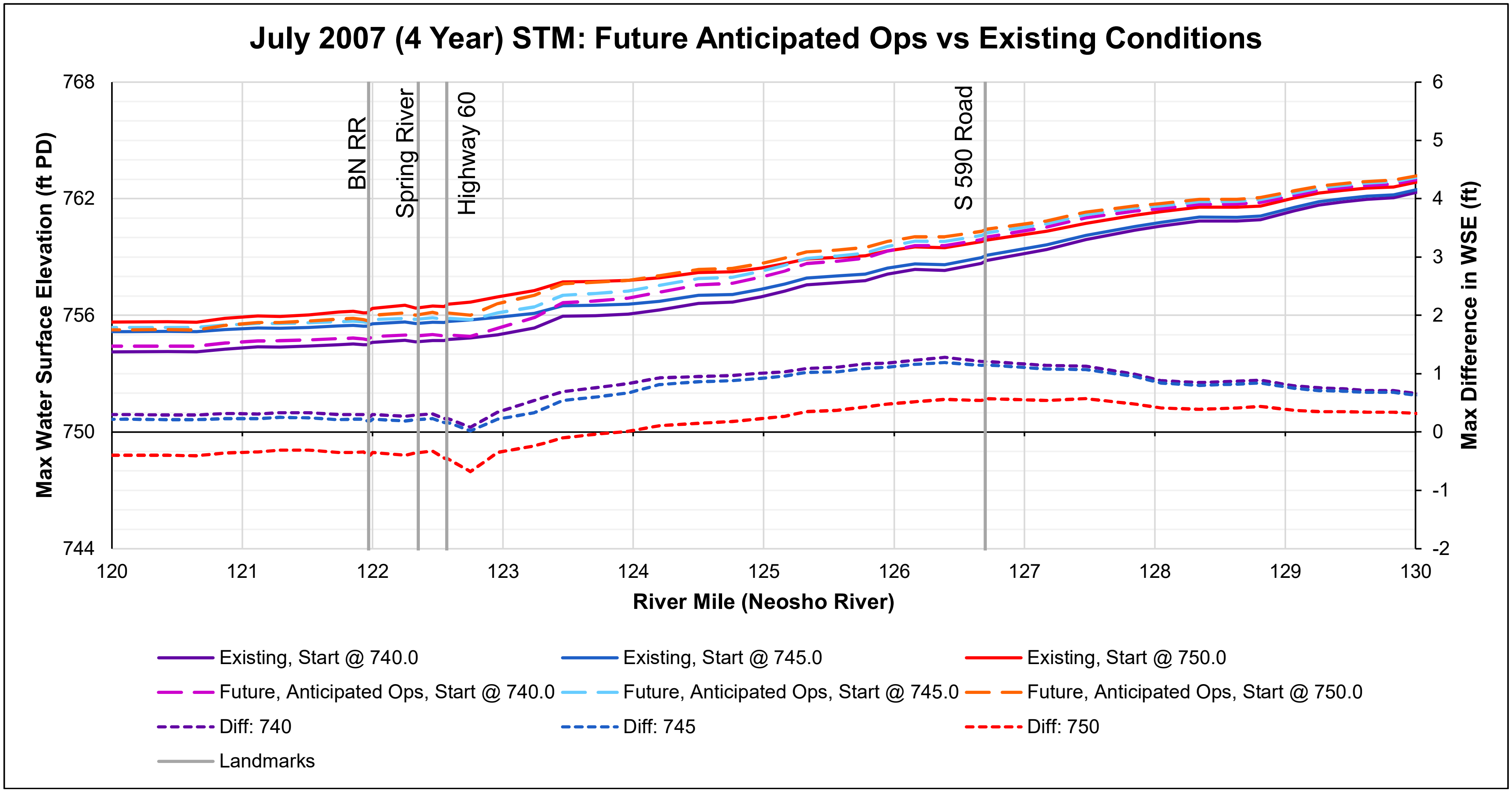
Appendix G
1D UHM Results



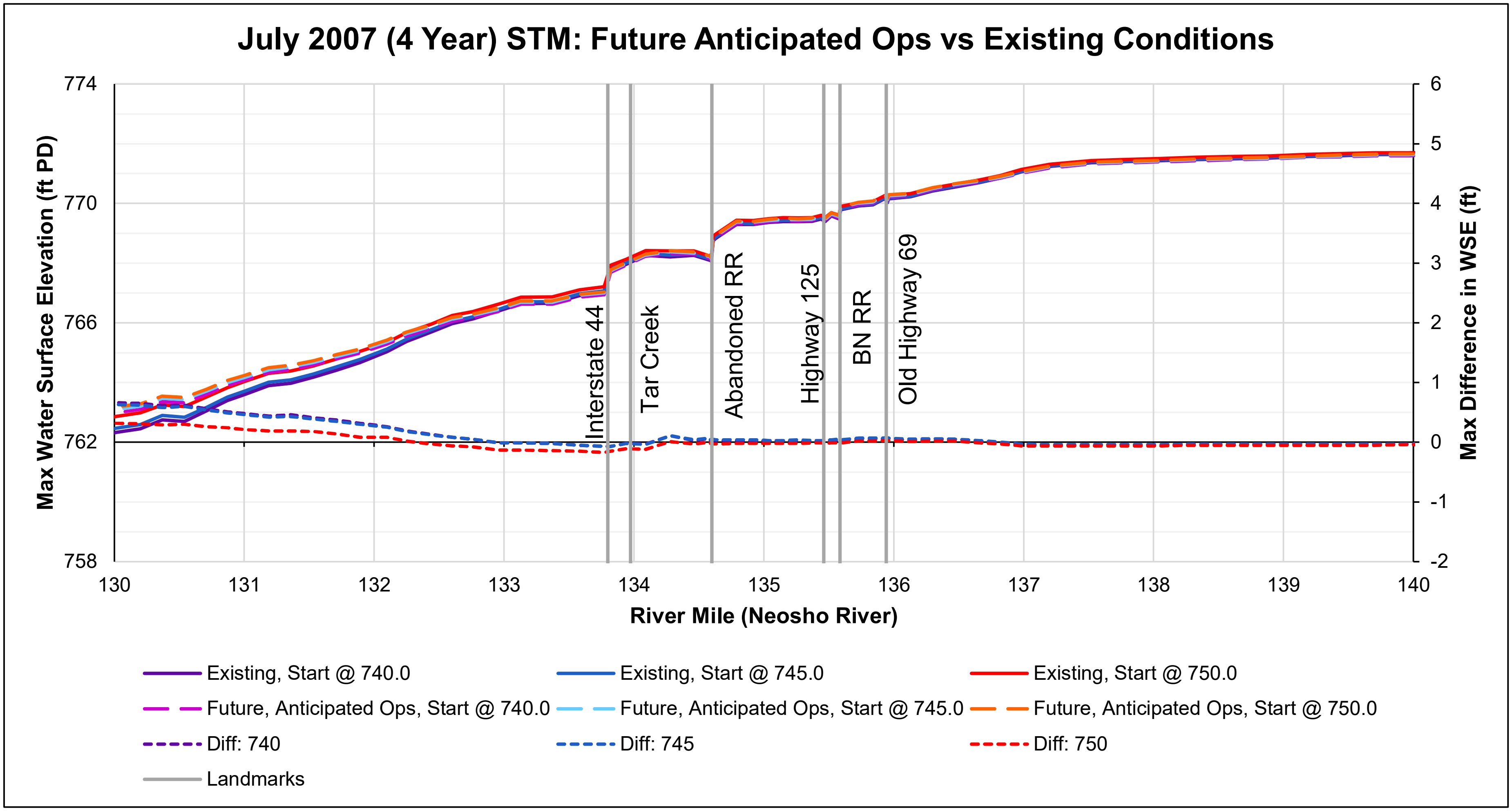
July 2007 (4 Year) STM: Future Anticipated Ops vs Existing Conditions
Max Water Surface Elevation (ft PD)
758
756
754
752
750
Max Difference in WSE (ft)
6
5
4
3
2
1
0
-1
-2
Highway 59 (Sailboat Bridge)
Elk River
100
101
102
103
104
105
106
107
108
109
110
River Mile (Neosho River)
Existing, Start @ 740.0
Existing, Start @ 745.0
Existing, Start @ 750.0
Future, Anticipated Ops, Start @ 740.0
Future, Anticipated Ops, Start @ 745.0
Future, Anticipated Ops, Start @ 750.0
Diff: 740
Diff: 745
Diff: 750
Landmarks



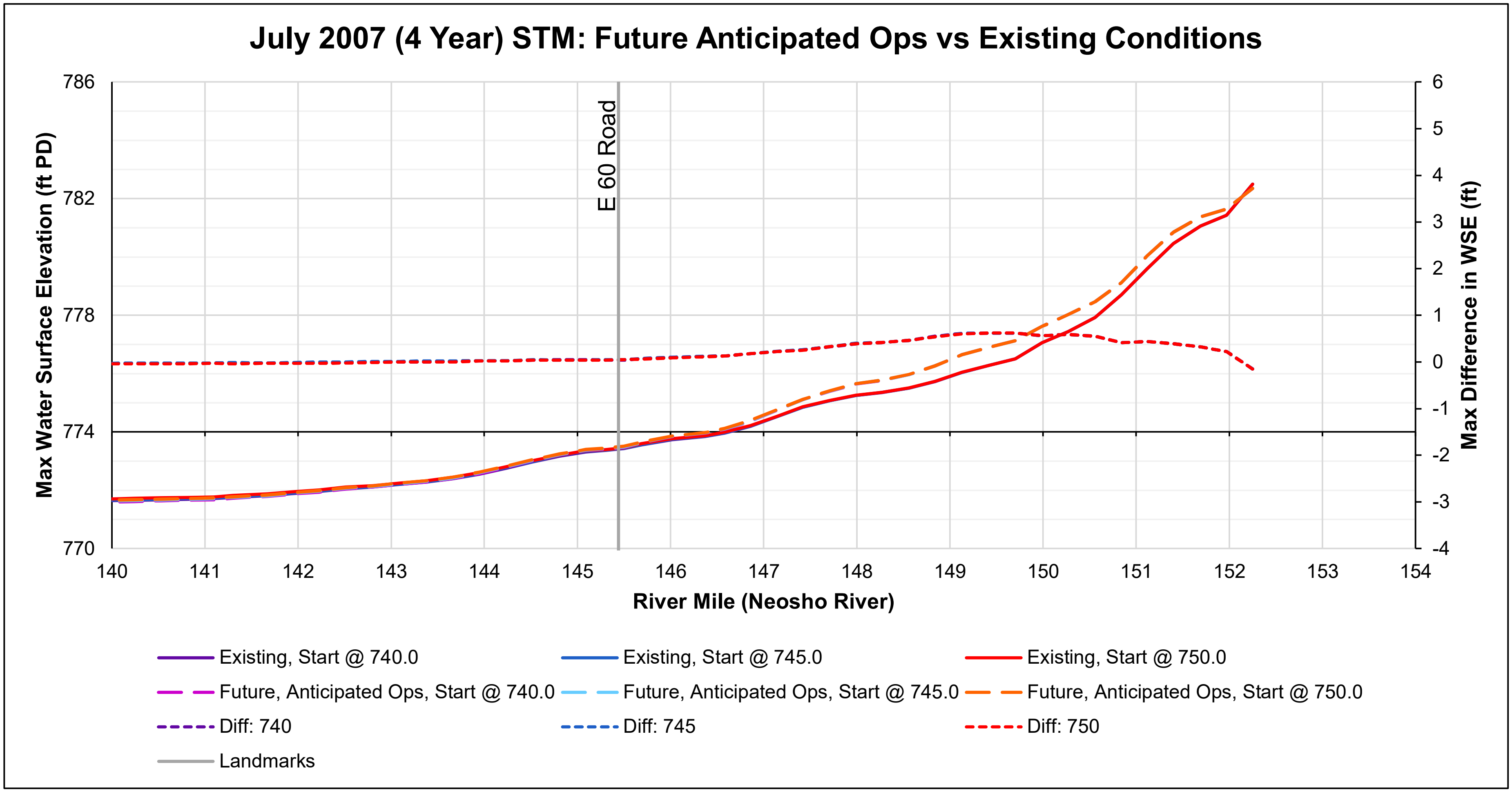
July 2007 (4 Year) STM: Future Anticipated Ops vs Existing Conditions
Max Water Surface Elevation (ft PD)
758
756
754
752
750
Max Difference in WSE (ft)
6
5
4
3
2
1
0
-1
-2
110
111
112
113
114
115
116
117
118
119
120
River Mile (Neosho River)
Existing, Start @ 740.0
Existing, Start @ 745.0
Existing, Start @ 750.0
Future, Anticipated Ops, Start @ 740.0
Future, Anticipated Ops, Start @ 745.0
Future, Anticipated Ops, Start @ 750.0
Diff: 740
Diff: 745
Diff: 750
Landmarks



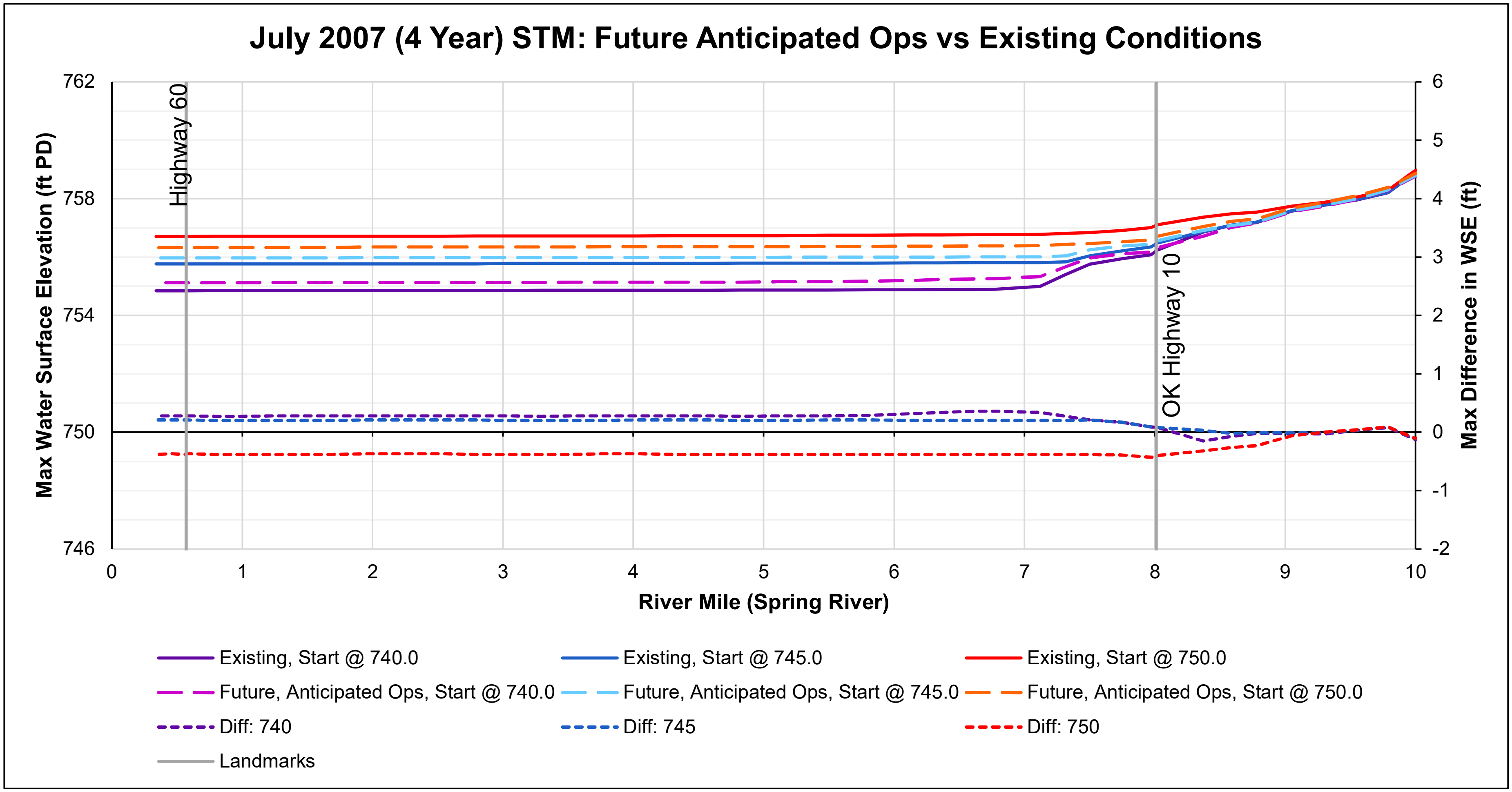
July 2007 (4 Year) STM: Future Anticipated Ops vs Existing Conditions
Max Water Surface Elevation (ft PD)
Max Difference in WSE (ft)
River Mile (Neosho River)
BN RR
Spring River
Highway 60
S 590 Road
768
762
756
750
744
6
5
4
3
2
1
0
-1
-2
120
121
122
123
124
125
126
127
128
129
130
Existing, Start @ 740.0
Existing, Start @ 745.0
Existing, Start @ 750.0
Future, Anticipated Ops, Start @ 740.0
Future, Anticipated Ops, Start @ 745.0
Future, Anticipated Ops, Start @ 750.0
Diff: 740
Diff: 745
Diff: 750
Landmarks



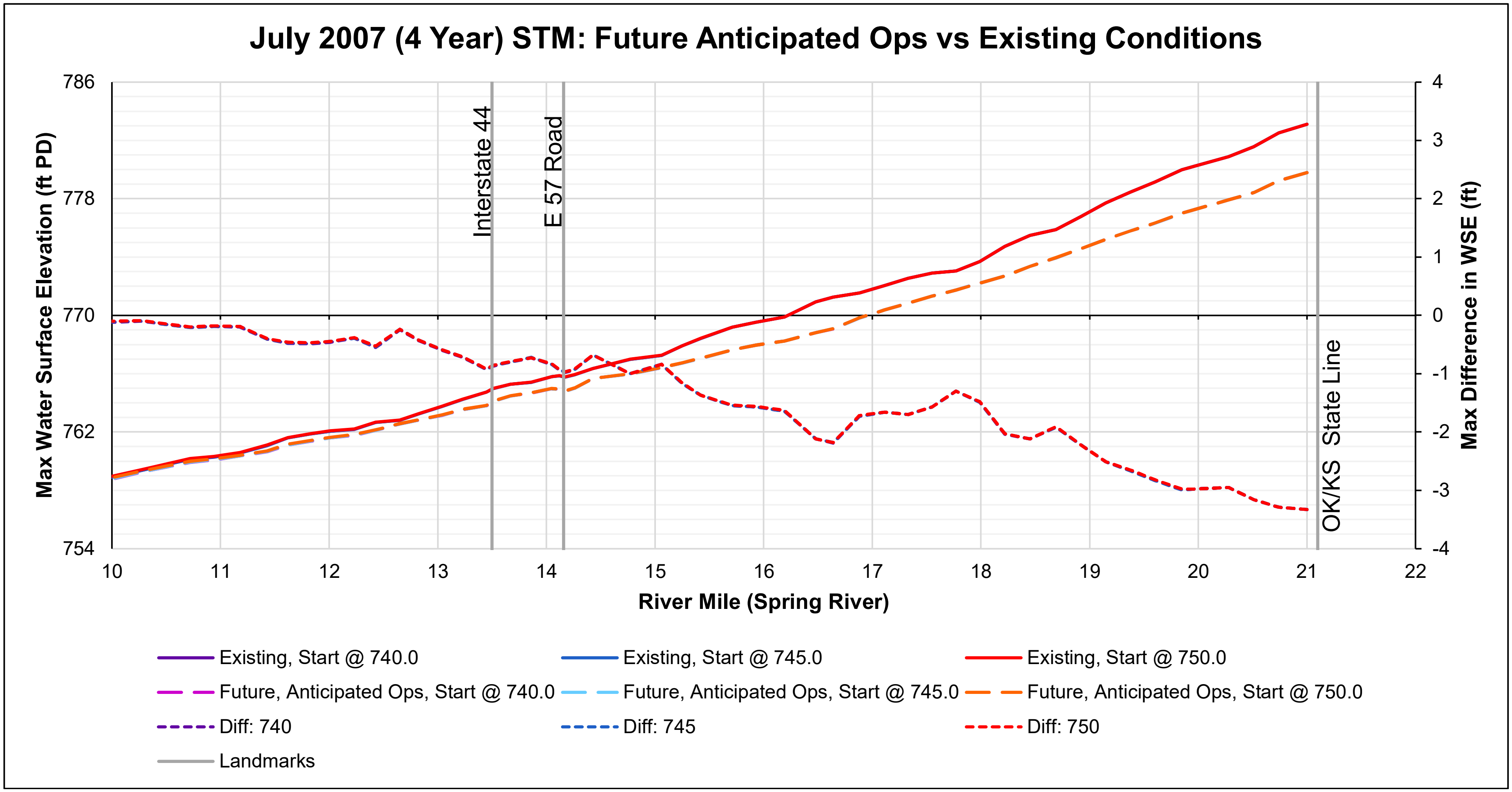
July 2007 (4 Year) STM: Future Anticipated Ops vs Existing Conditions
Max Water Surface Elevation (ft PD)
Max Difference in WSE (ft)
River Mile (Neosho River)
774
770
766
762
758
6
5
4
3
2
1
0
-1
-2
130
131
132
133
134
135
136
137
138
139
140
Interstate 44
Tar Creek
Abandoned RR
Highway 125
BN RR
Old Highway 69
Existing, Start @ 740.0
Existing, Start @ 745.0
Existing, Start @ 750.0
Future, Anticipated Ops, Start @ 740.0
Future, Anticipated Ops, Start @ 745.0
Future, Anticipated Ops, Start @ 750.0
Diff: 740
Diff: 745
Diff: 750
Landmarks

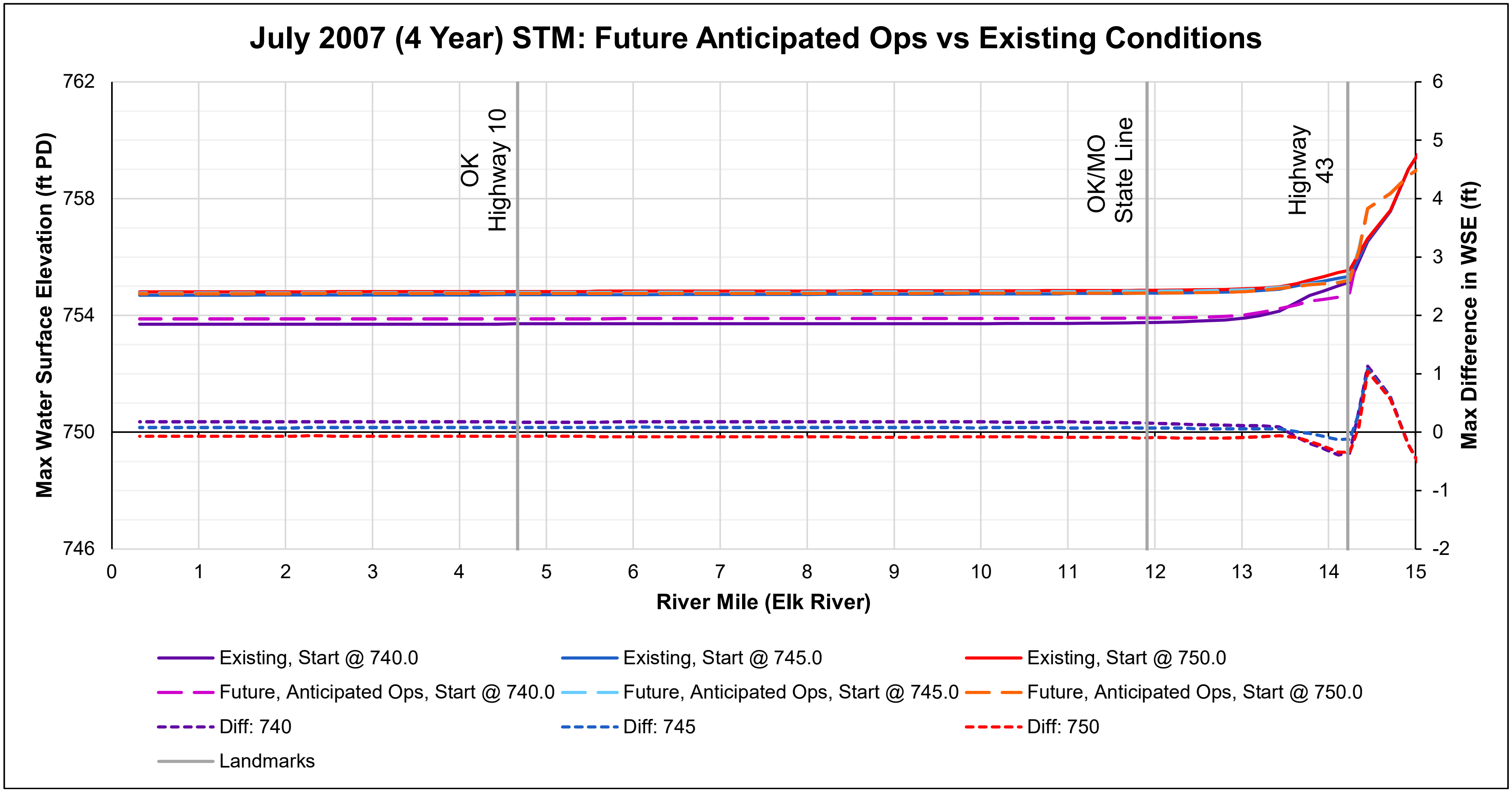


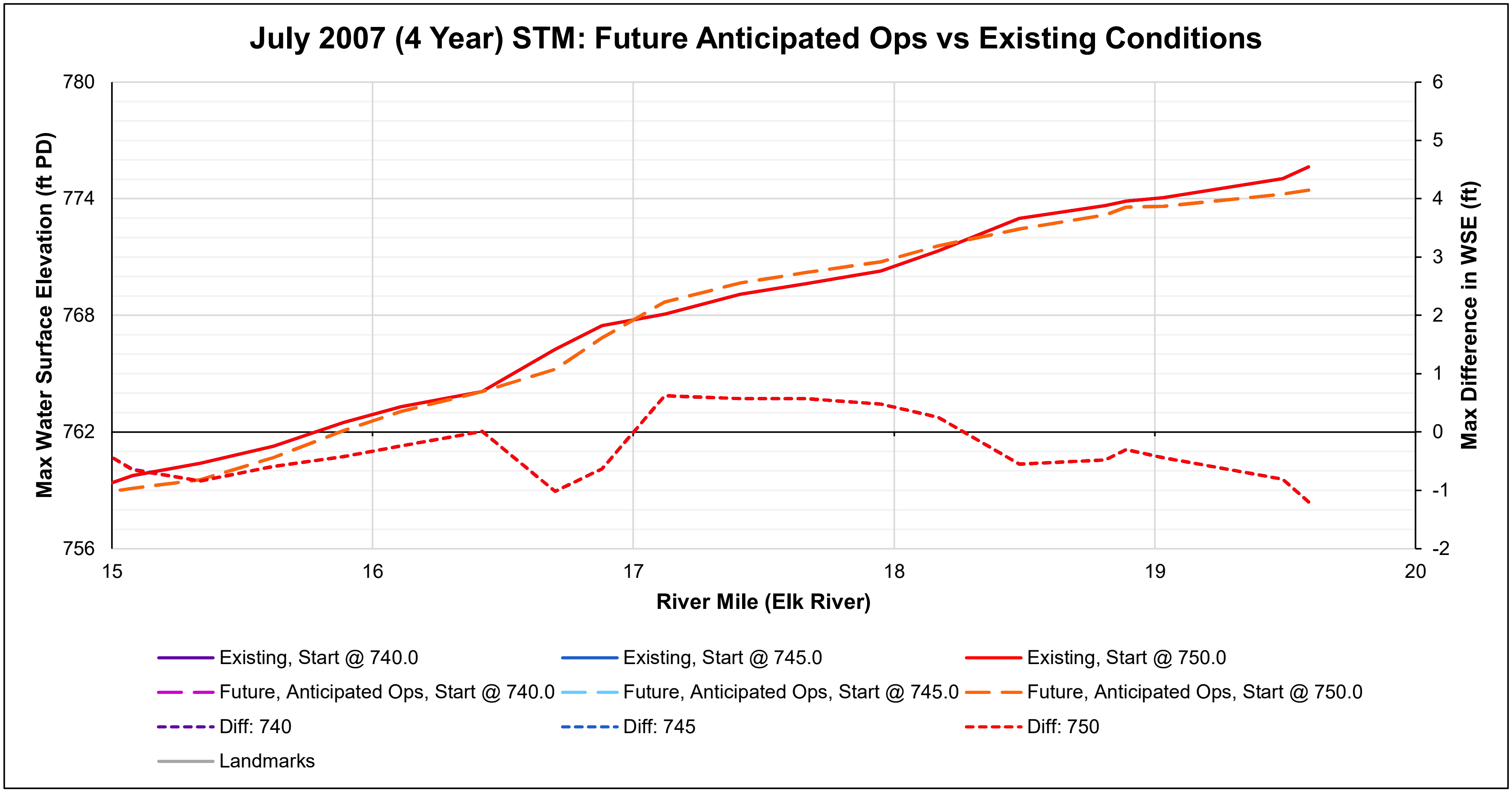
July 2007 (4 Year) STM: Future Anticipated Ops vs Existing Conditions
Max Water Surface Elevation (ft PD)
786
782
778
774
770
E 60 Road
6
5
4
3
2
1
0
-1
-2
-3
-4
Max Difference in WSE (ft)
140
141
142
143
144
145
146
147
148
149
150
151
152
153
154
River Mile (Neosho River)
Existing, Start @ 740.0
Existing, Start @ 745.0
Existing, Start @ 750.0
Future, Anticipated Ops, Start @ 740.0
Future, Anticipated Ops, Start @ 745.0
Future, Anticipated Ops, Start @ 750.0
Diff: 740
Diff: 745
Diff: 750
Landmarks



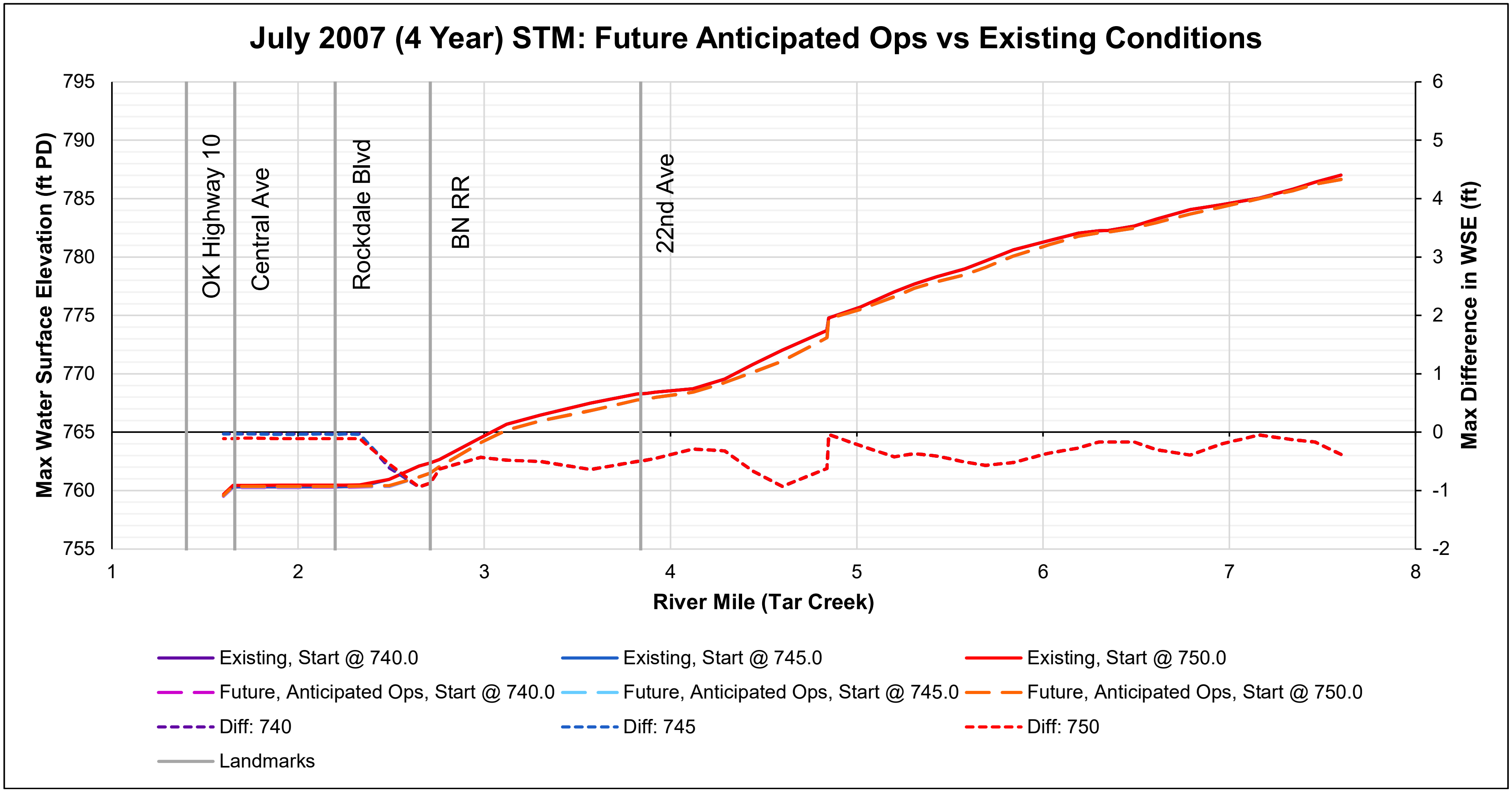
July 2007 (4 Year) STM: Future Anticipated Ops vs Existing Conditions
Max Water Surface Elevation (ft PD)
Max Difference in WSE (ft)
River Mile (Spring River)
762
758
754
750
746
6
5
4
3
2
1
0
-1
-2
0
1
2
3
4
5
6
7
8
9
10
Highway 60
OK Highway 10
Existing, Start @ 740.0
Existing, Start @ 745.0
Existing, Start @ 750.0
Future, Anticipated Ops, Start @ 740.0
Future, Anticipated Ops, Start @ 745.0
Future, Anticipated Ops, Start @ 750.0
Diff: 740
Diff: 745
Diff: 750
Landmarks


July 2007 (4 Year) STM: Future Anticipated Ops vs Existing Conditions
Max Water Surface Elevation (ft PD)
Max Difference in WSE (ft)
River Mile (Spring River)
786
778
770
762
754
4
3
2
1
0
-1
-2
-3
-4
10
11
12
13
14
15
16
17
18
19
20
21
22
Interstate 44
E 57 Road
OK/KS State Line
Existing, Start @ 740.0
Existing, Start @ 745.0
Existing, Start @ 750.0
Future, Anticipated Ops, Start @ 740.0
Future, Anticipated Ops, Start @ 745.0
Future, Anticipated Ops, Start @ 750.0
Diff: 740
Diff: 745
Diff: 750
Landmarks

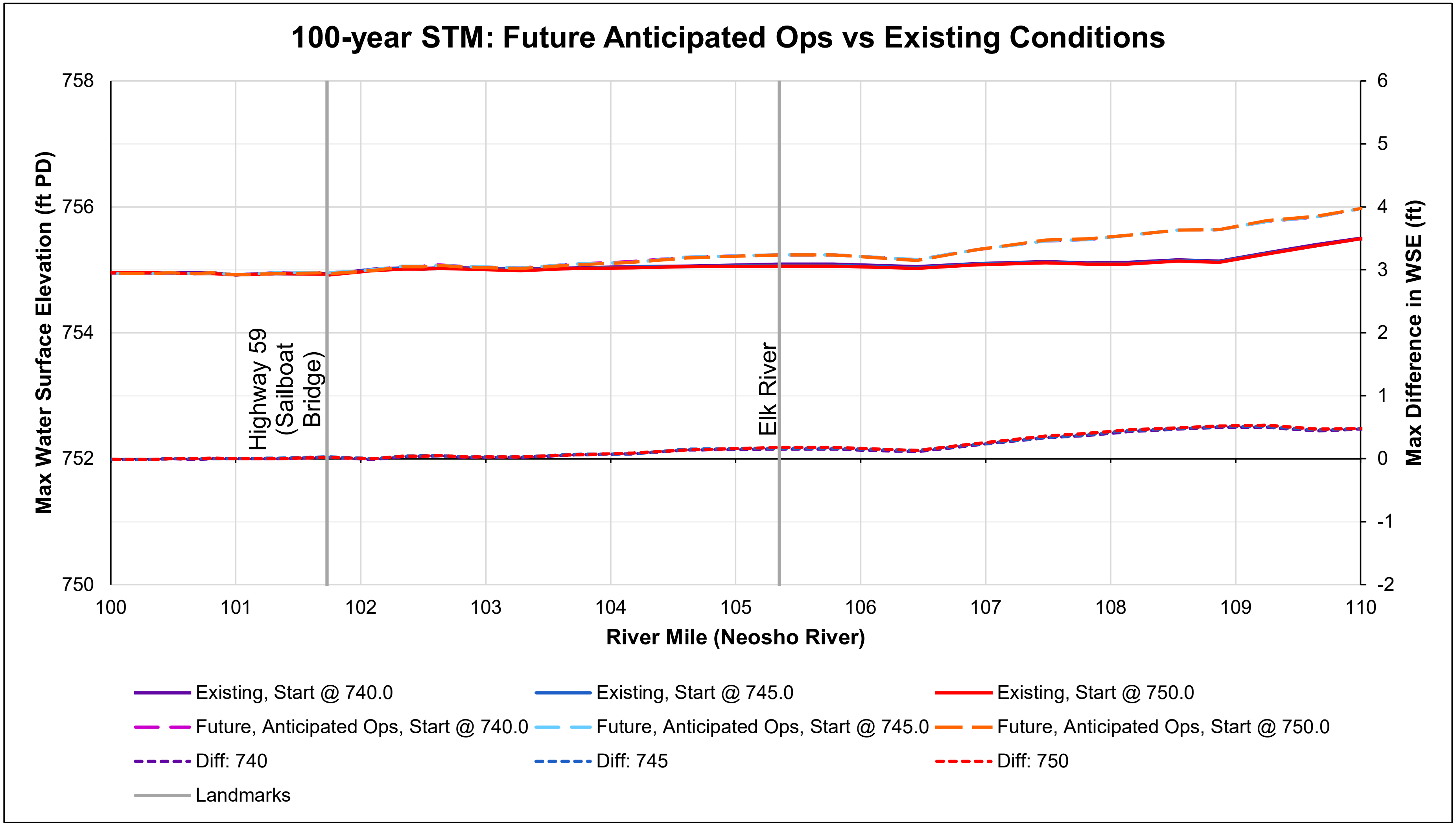

July 2007 (4 Year) STM: Future Anticipated Ops vs Existing Conditions
Max Water Surface Elevation (ft PD)
Max Difference in WSE (ft)
River Mile (Elk River)
OK Highway 10
OK/MO State Line
Highway 43
762
758
754
750
746
6
5
4
3
2
1
0
-1
-2
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
Existing, Start @ 740.0
Existing, Start @ 745.0
Existing, Start @ 750.0
Future, Anticipated Ops, Start @ 740.0
Future, Anticipated Ops, Start @ 745.0
Future, Anticipated Ops, Start @ 750.0
Diff: 740
Diff: 745
Diff: 750
Landmarks

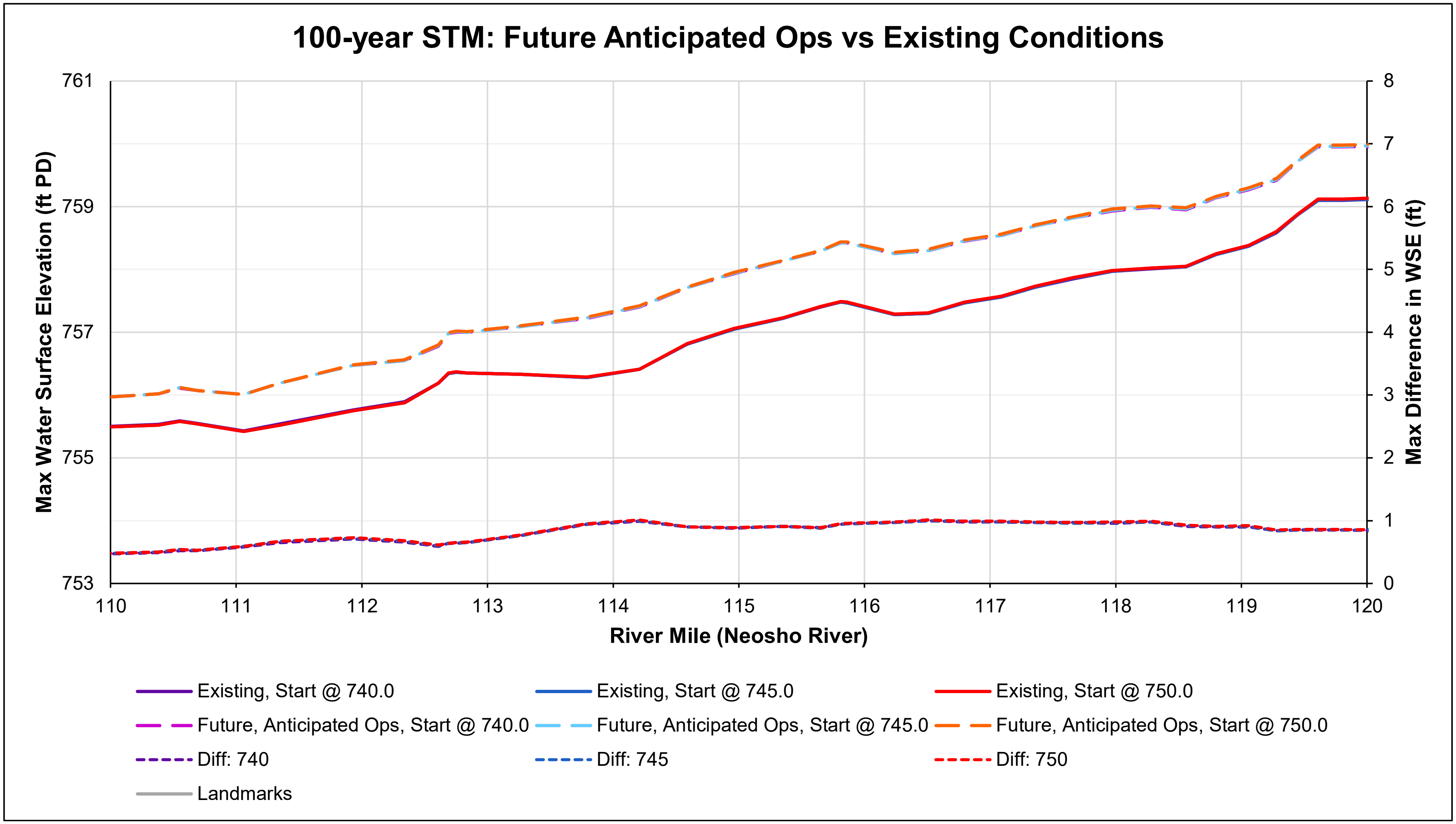


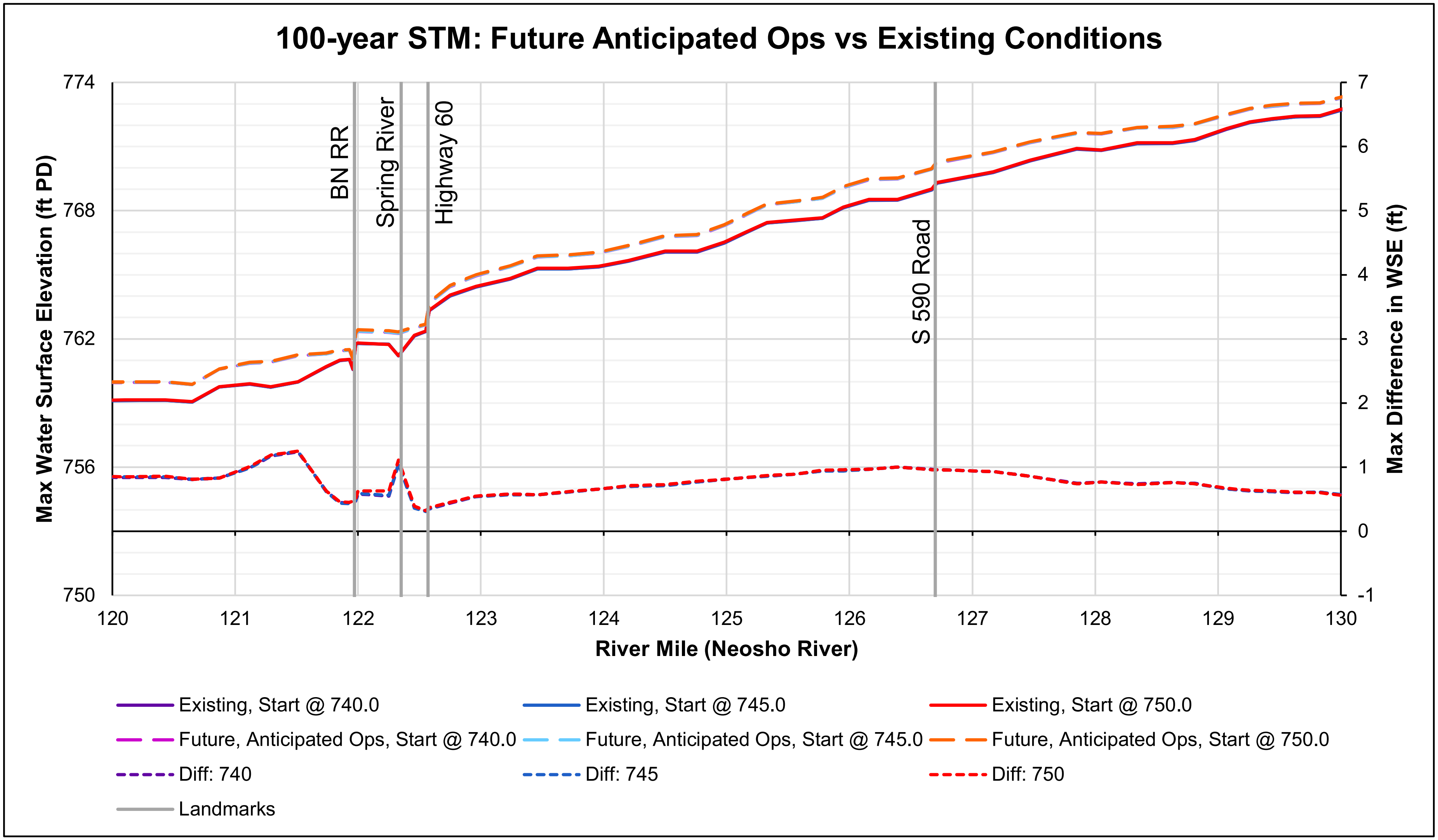
July 2007 (4 Year) STM: Future Anticipated Ops vs Existing Conditions
Max Water Surface Elevation (ft PD)
780
774
768
762
756
Max Difference in WSE (ft)
6
5
4
3
2
1
0
-1
-2
15
16
17
18
19
20
River Mile (Elk River)
Existing, Start @ 740.0
Existing, Start @ 745.0
Existing, Start @ 750.0
Future, Anticipated Ops, Start @ 740.0
Future, Anticipated Ops, Start @ 745.0
Future, Anticipated Ops, Start @ 750.0
Diff: 740
Diff: 745
Diff: 750
Landmarks



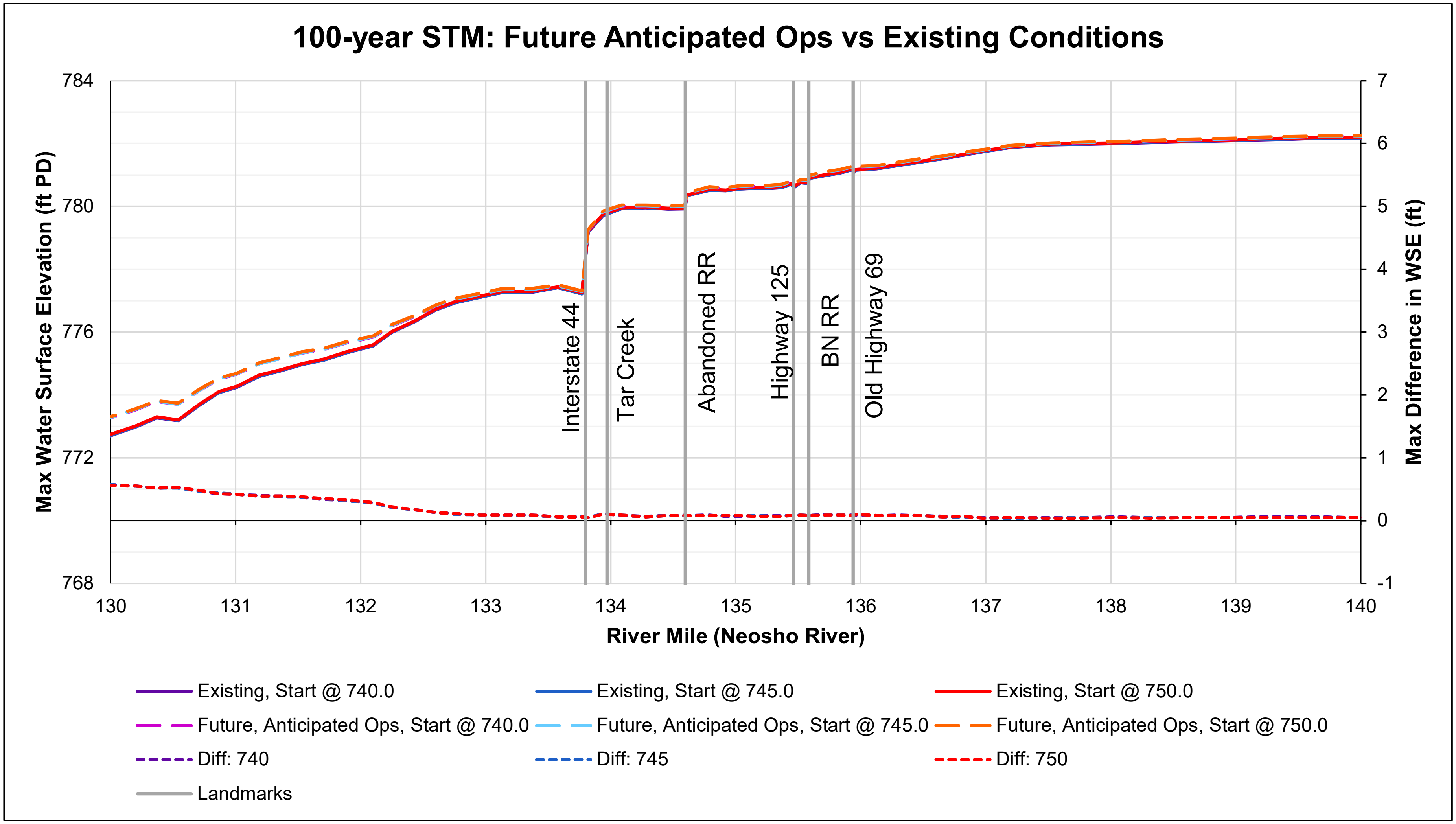
July 2007 (4 Year) STM: Future Anticipated Ops vs Existing Conditions
Max Water Surface Elevation (ft PD)
Max Difference in WSE (ft)
River Mile (Tar Creek)
OK Highway 10
Central Ave
Rockdale Blvd
BN RR
22nd Ave
795
790
785
780
775
770
765
760
755
6
5
4
3
2
1
0
-1
-2
1
2
3
4
5
6
7
8
Existing, Start @ 740.0
Existing, Start @ 745.0
Existing, Start @ 750.0
Future, Anticipated Ops, Start @ 740.0
Future, Anticipated Ops, Start @ 745.0
Future, Anticipated Ops, Start @ 750.0
Diff: 740
Diff: 745
Diff: 750
Landmarks


100-year STM: Future Anticipated Ops vs Existing Conditions
Max Water Surface Elevation (ft PD)
Max Difference in WSE (ft)
River Mile (Neosho River)
Highway 59 (Sailboat Bridge)
Elk River
758
756
754
752
750
6
5
4
3
2
1
0
-1
-2
100
101
102
103
104
105
106
107
108
109
110
Existing, Start @ 740.0
Existing, Start @ 745.0
Existing, Start @ 750.0
Future, Anticipated Ops, Start @ 740.0
Future, Anticipated Ops, Start @ 745.0
Future, Anticipated Ops, Start @ 750.0
Diff: 740
Diff: 745
Diff: 750
Landmarks

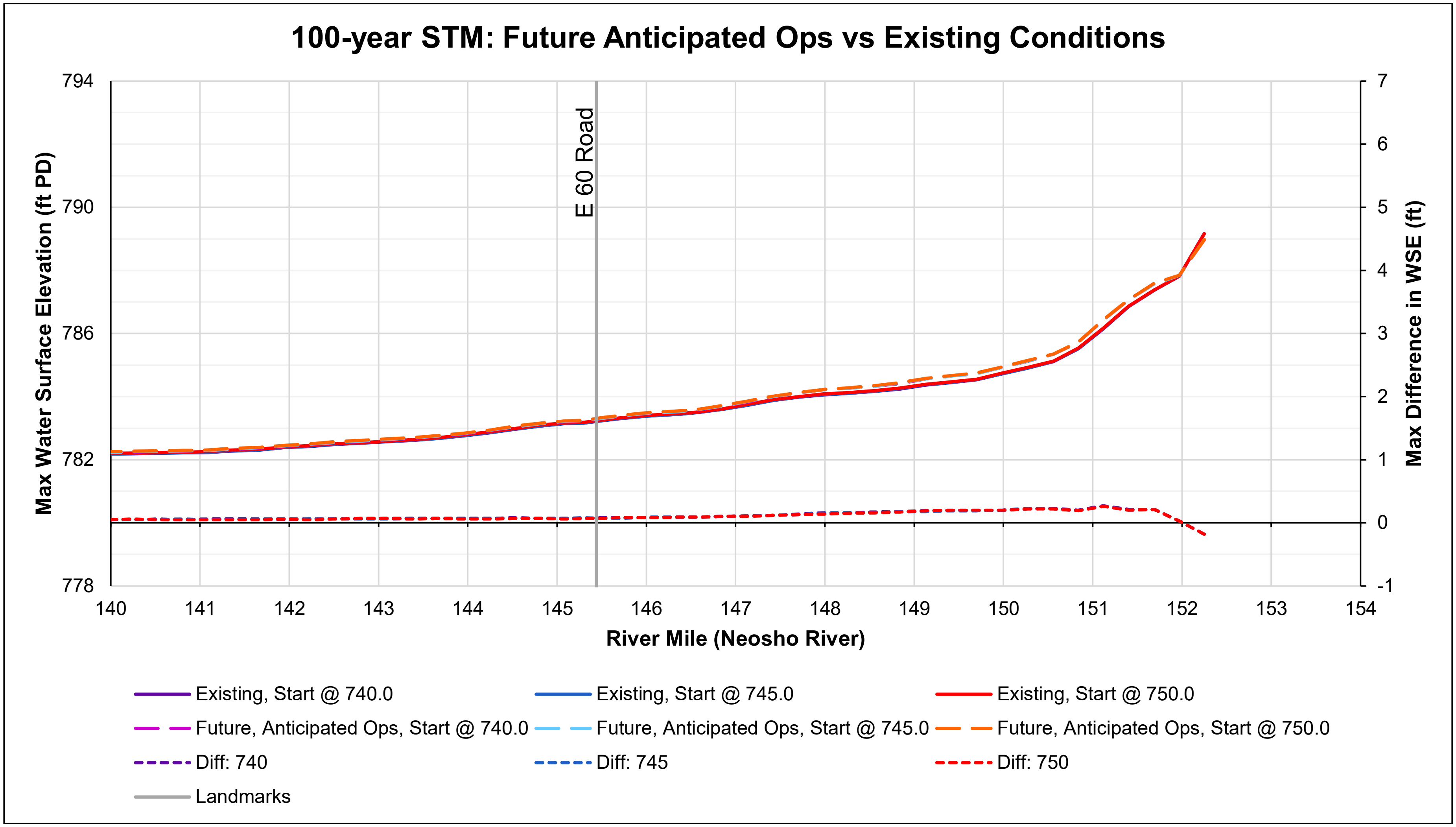

100-year STM: Future Anticipated Ops vs Existing Conditions
Max Water Surface Elevation (ft PD)
Max Difference in WSE (ft)
River Mile (Neosho River)
761
759
757
755
753
8
7
6
5
4
3
2
1
0
110
111
112
113
114
115
116
117
118
119
120
Existing, Start @ 740.0
Existing, Start @ 745.0
Existing, Start @ 750.0
Future, Anticipated Ops, Start @ 740.0
Future, Anticipated Ops, Start @ 745.0
Future, Anticipated Ops, Start @ 750.0
Diff: 740
Diff: 745
Diff: 750
Landmarks



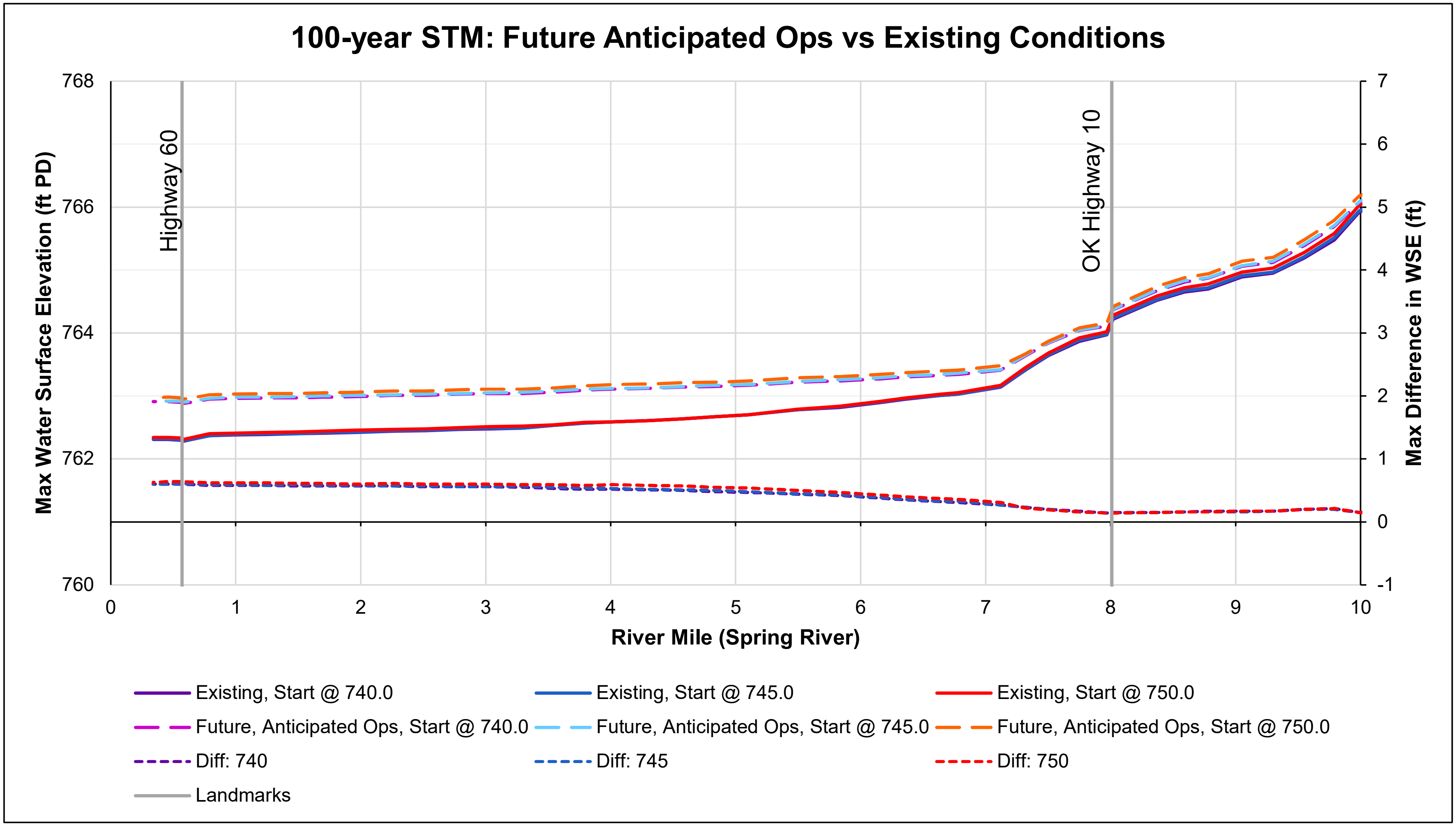
100-year STM: Future Anticipated Ops vs Existing Conditions
Max Water Surface Elevation (ft PD)
Max Difference in WSE (ft)
River Mile (Neosho River)
BN RR
Spring River
Highway 60
S 590 Road
774
768
762
756
750
7
6
5
4
3
2
1
0
-1
120
121
122
123
124
125
126
127
128
129
130
Existing, Start @ 740.0
Existing, Start @ 745.0
Existing, Start @ 750.0
Future, Anticipated Ops, Start @ 740.0
Future, Anticipated Ops, Start @ 745.0
Future, Anticipated Ops, Start @ 750.0
Diff: 740
Diff: 745
Diff: 750
Landmarks



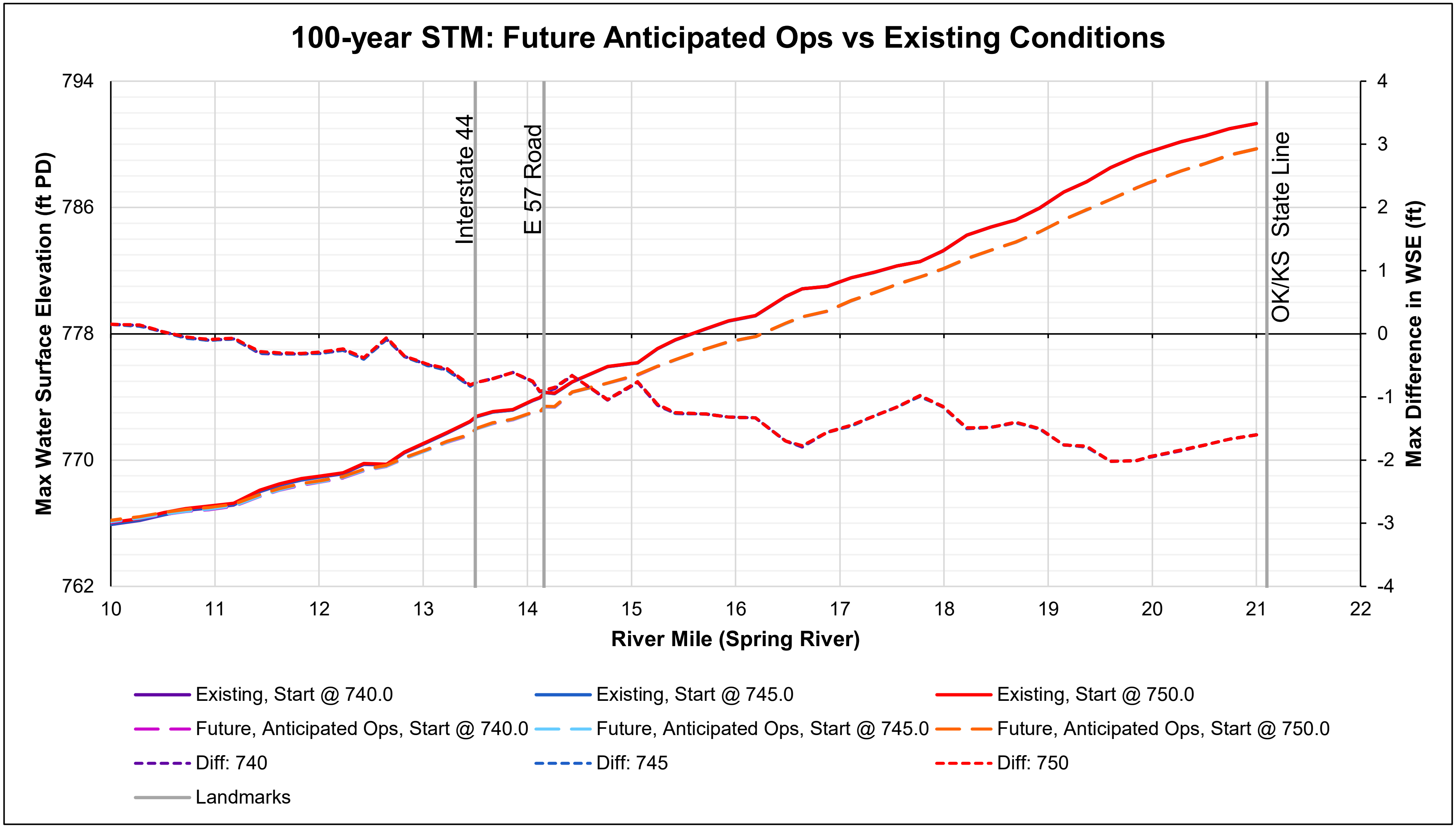
100-year STM: Future Anticipated Ops vs Existing Conditions
Max Water Surface Elevation (ft PD)
Max Difference in WSE (ft)
River Mile (Neosho River)
784
780
776
772
768
7
6
5
4
3
2
1
0
-1
130
131
132
133
134
135
136
137
138
139
140
Interstate 44
Tar Creek
Abandoned RR
Highway 125
BN RR
Old Highway 69
Existing, Start @ 740.0
Existing, Start @ 745.0
Existing, Start @ 750.0
Future, Anticipated Ops, Start @ 740.0
Future, Anticipated Ops, Start @ 745.0
Future, Anticipated Ops, Start @ 750.0
Diff: 740
Diff: 745
Diff: 750
Landmarks

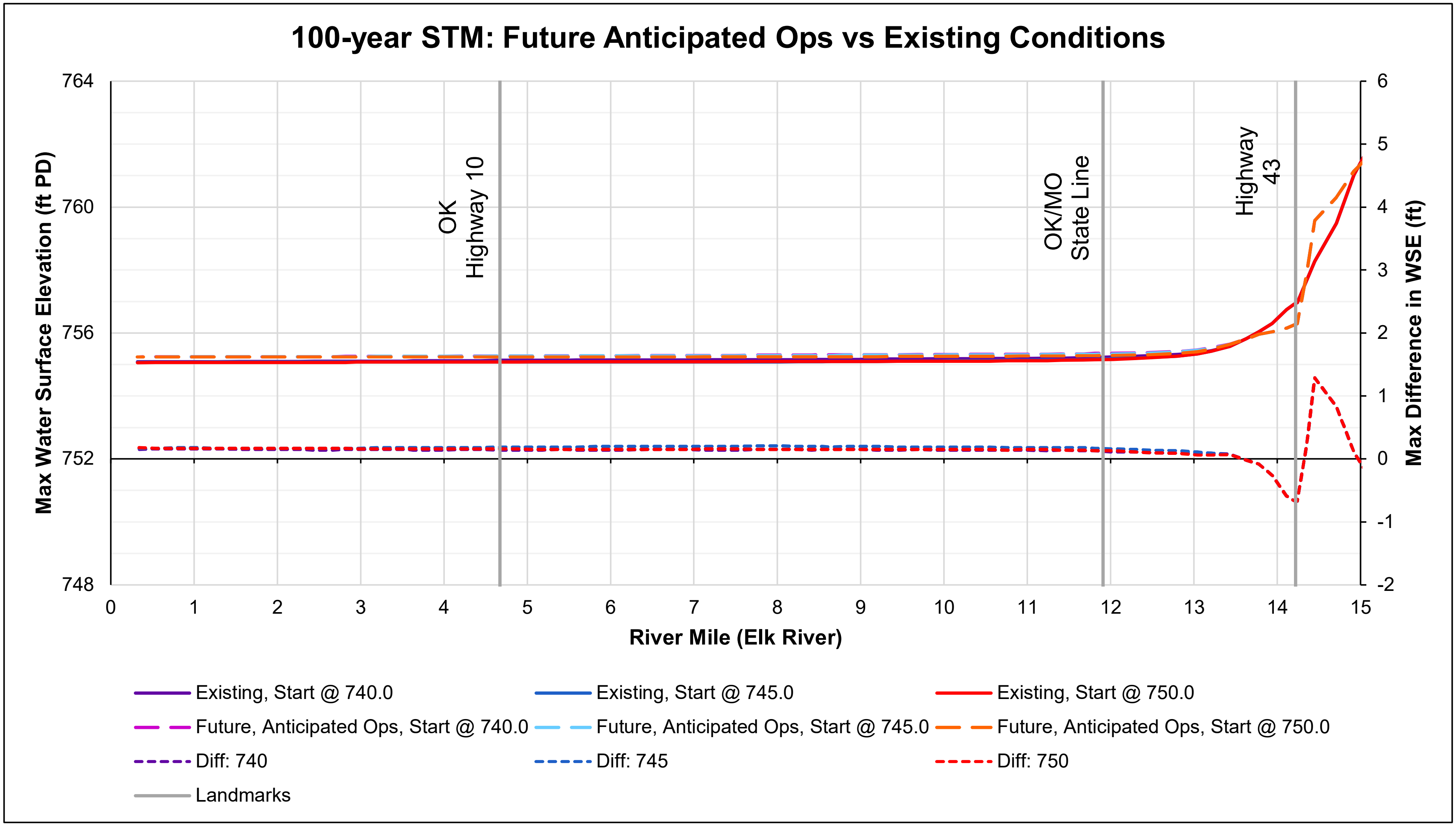


100-year STM: Future Anticipated Ops vs Existing Conditions
Max Water Surface Elevation (ft PD)
794
790
786
782
778
Max Difference in WSE (ft)
7
6
5
4
3
2
1
0
-1
140
141
142
143
144
145
146
147
148
149
150
151
152
153
154
River Mile (Neosho River)
E 60 Road
Existing, Start @ 740.0
Existing, Start @ 745.0
Existing, Start @ 750.0
Future, Anticipated Ops, Start @ 740.0
Future, Anticipated Ops, Start @ 745.0
Future, Anticipated Ops, Start @ 750.0
Diff: 740
Diff: 745
Diff: 750
Landmarks

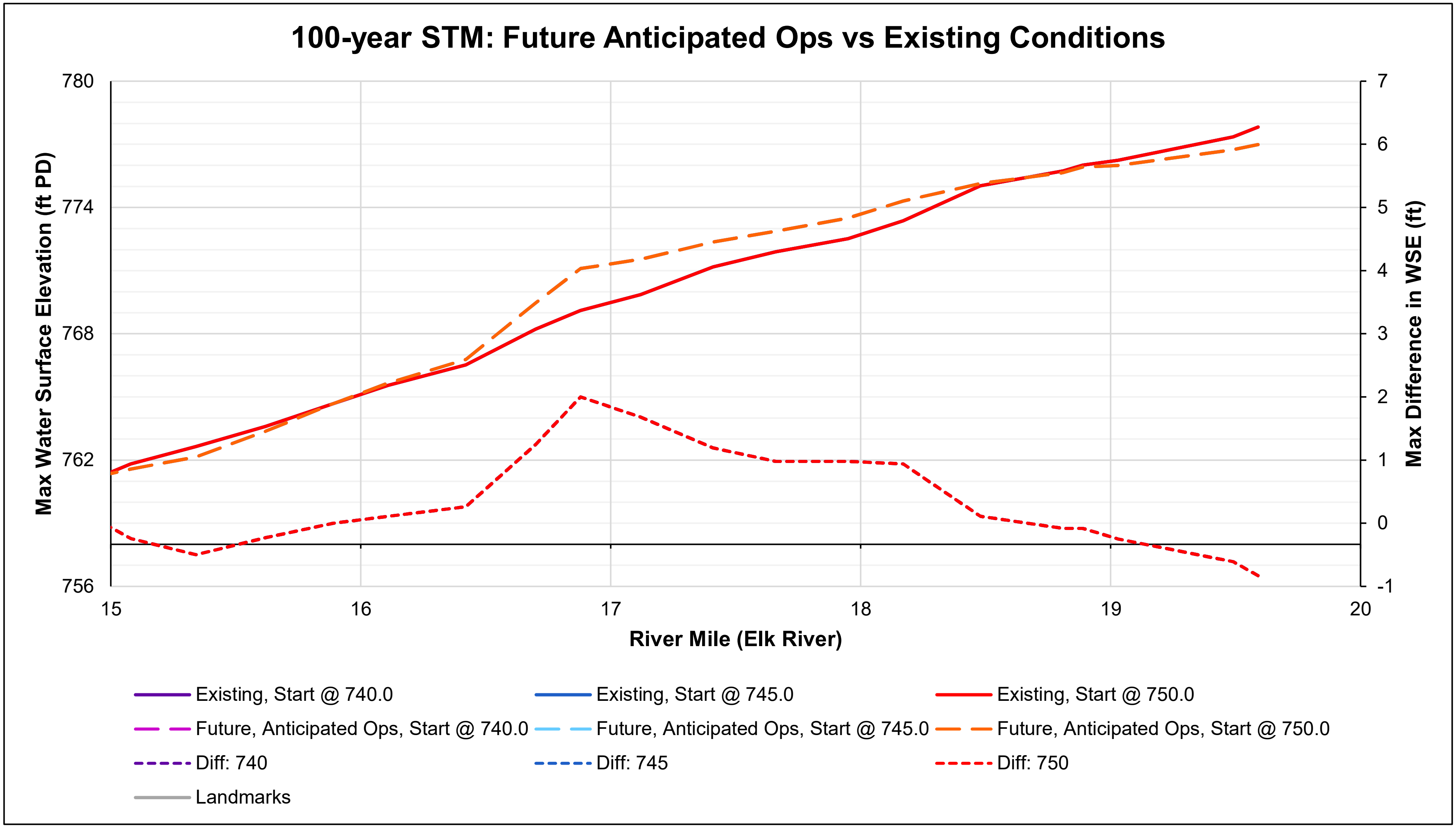


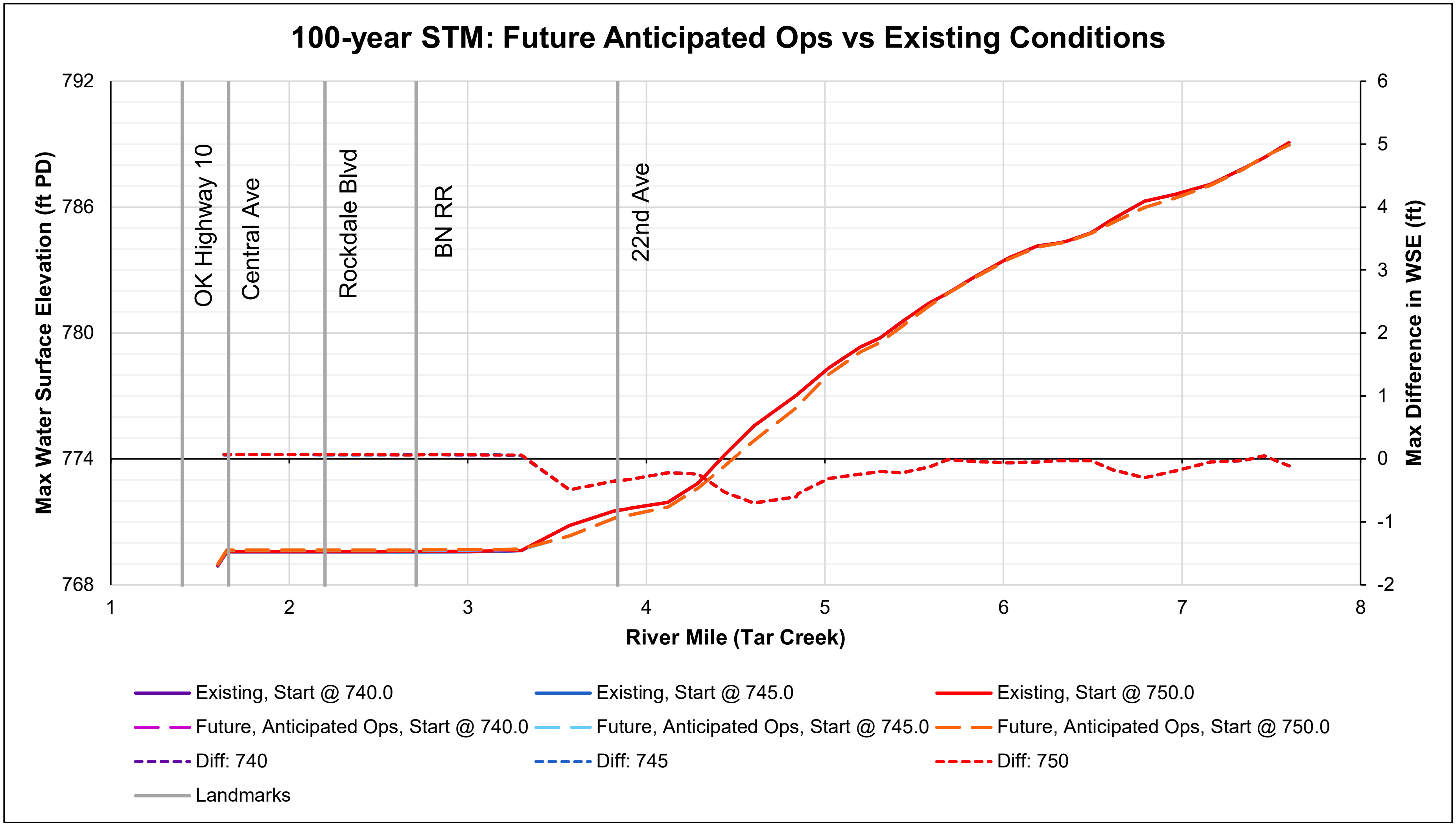
100-year STM: Future Anticipated Ops vs Existing Conditions
Max Water Surface Elevation (ft PD)
Max Difference in WSE (ft)
River Mile (Spring River)
Highway 60
OK Highway 10
768
766
764
762
760
7
6
5
4
3
2
1
0
-1
0
1
2
3
4
5
6
7
8
9
10
Existing, Start @ 740.0
Existing, Start @ 745.0
Existing, Start @ 750.0
Future, Anticipated Ops, Start @ 740.0
Future, Anticipated Ops, Start @ 745.0
Future, Anticipated Ops, Start @ 750.0
Diff: 740
Diff: 745
Diff: 750
Landmarks


100-year STM: Future Anticipated Ops vs Existing Conditions
Max Water Surface Elevation (ft PD)
Max Difference in WSE (ft)
River Mile (Spring River)
Interstate 44
E 57 Road
OK/KS State Line
794
786
778
770
762
4
3
2
1
0
-1
-2
-3
-4
10
11
12
13
14
15
16
17
18
19
20
21
22
Existing, Start @ 740.0
Existing, Start @ 745.0
Existing, Start @ 750.0
Future, Anticipated Ops, Start @ 740.0
Future, Anticipated Ops, Start @ 745.0
Future, Anticipated Ops, Start @ 750.0
Diff: 740
Diff: 745
Diff: 750
Landmarks

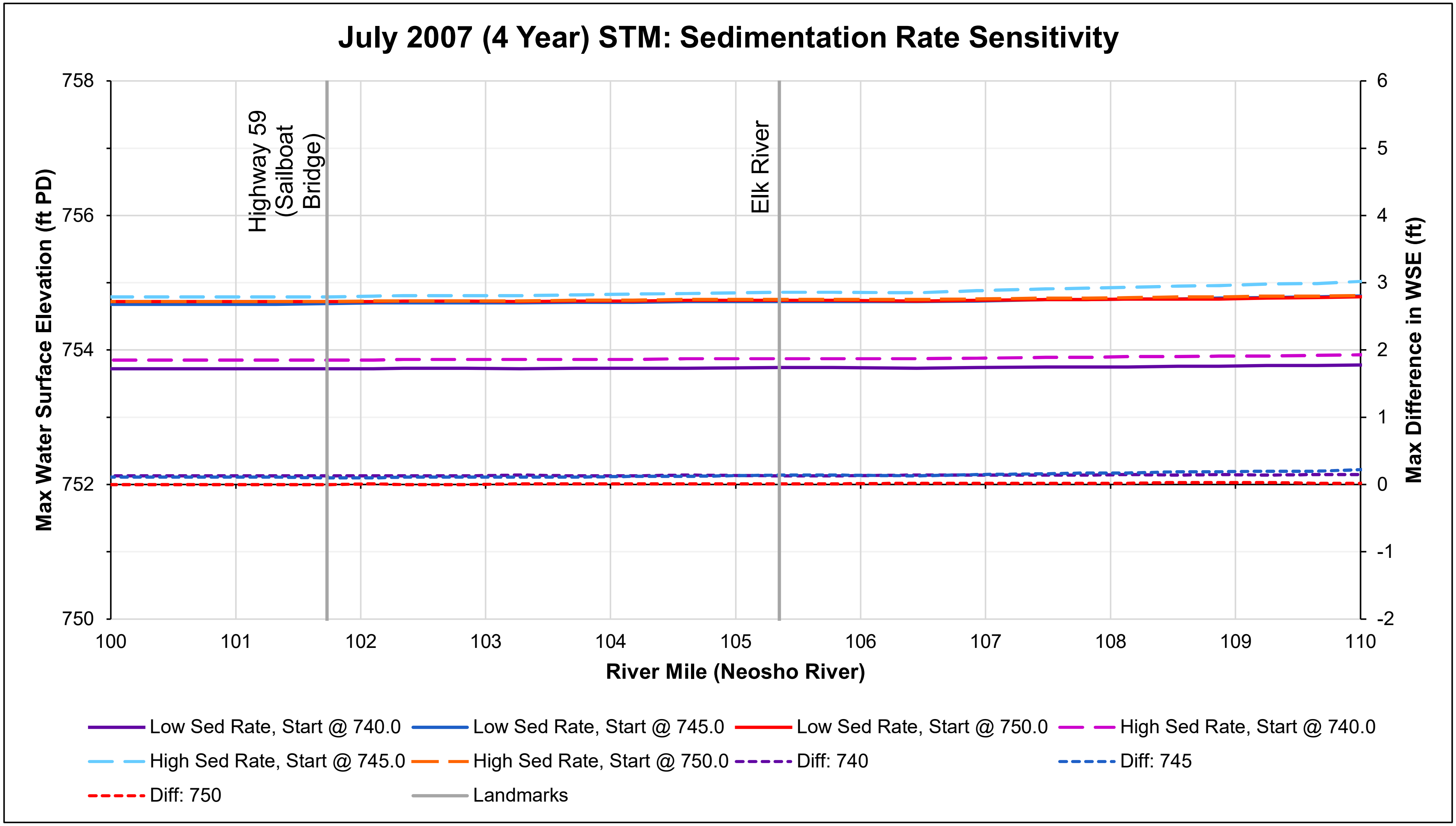


100-year STM: Future Anticipated Ops vs Existing Conditions
Max Water Surface Elevation (ft PD)
764
760
756
752
748
Max Difference in WSE (ft)
6
5
4
3
2
1
0
-1
-2
River Mile (Elk River)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
OK Highway 10
OK/MO State Line
Highway 43
Existing, Start @ 740.0
Existing, Start @ 745.0
Existing, Start @ 750.0
Future, Anticipated Ops, Start @ 740.0
Future, Anticipated Ops, Start @ 745.0
Future, Anticipated Ops, Start @ 750.0
Diff: 740
Diff: 745
Diff: 750
Landmarks

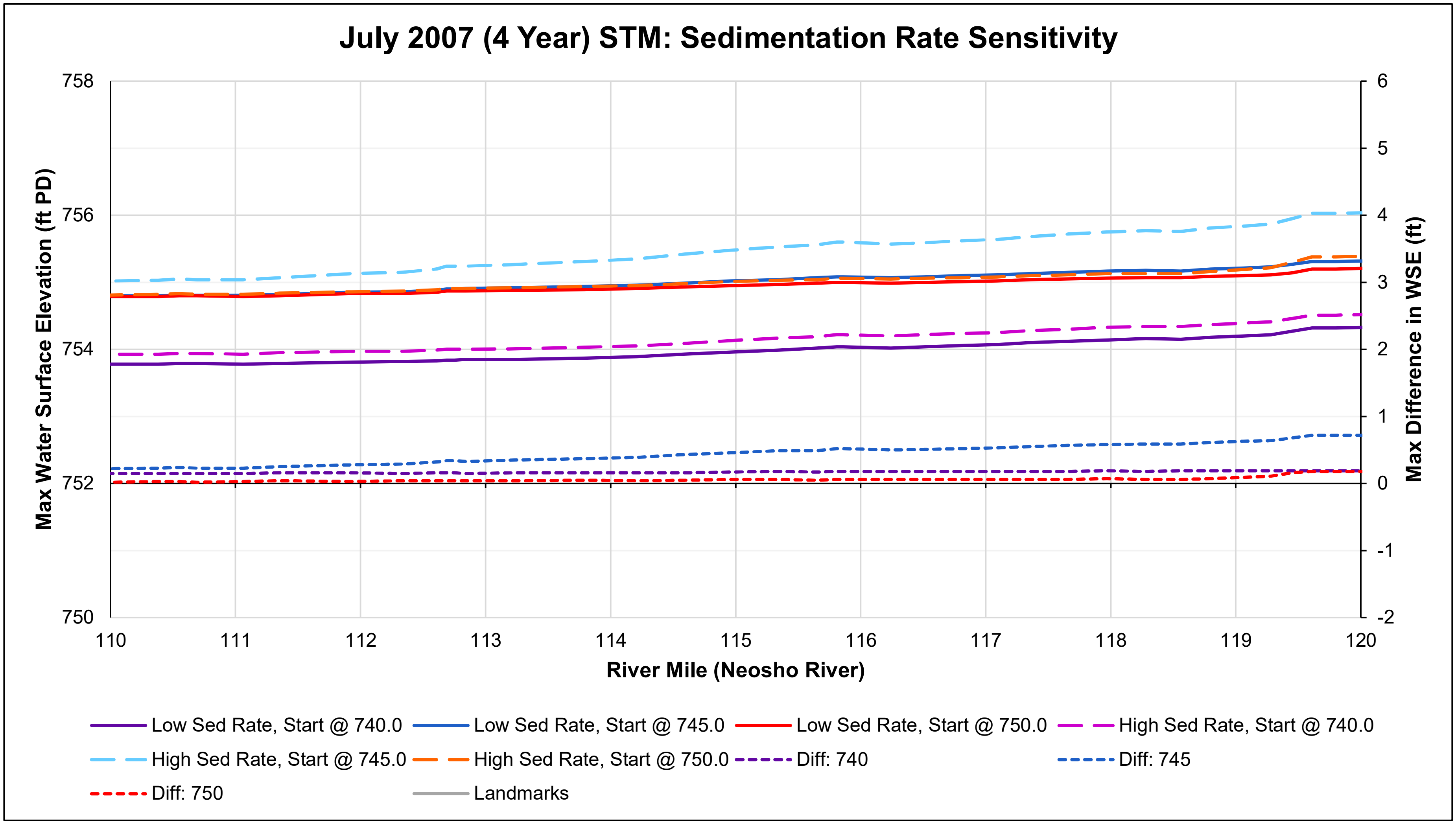

100-year STM: Future Anticipated Ops vs Existing Conditions
Max Water Surface Elevation (ft PD)
780
774
768
762
756
Max Difference in WSE (ft)
7
6
5
4
3
2
1
0
-1
15
16
17
18
19
20
River Mile (Elk River)
Existing, Start @ 740.0
Existing, Start @ 745.0
Existing, Start @ 750.0
Future, Anticipated Ops, Start @ 740.0
Future, Anticipated Ops, Start @ 745.0
Future, Anticipated Ops, Start @ 750.0
Diff: 740
Diff: 745
Diff: 750
Landmarks



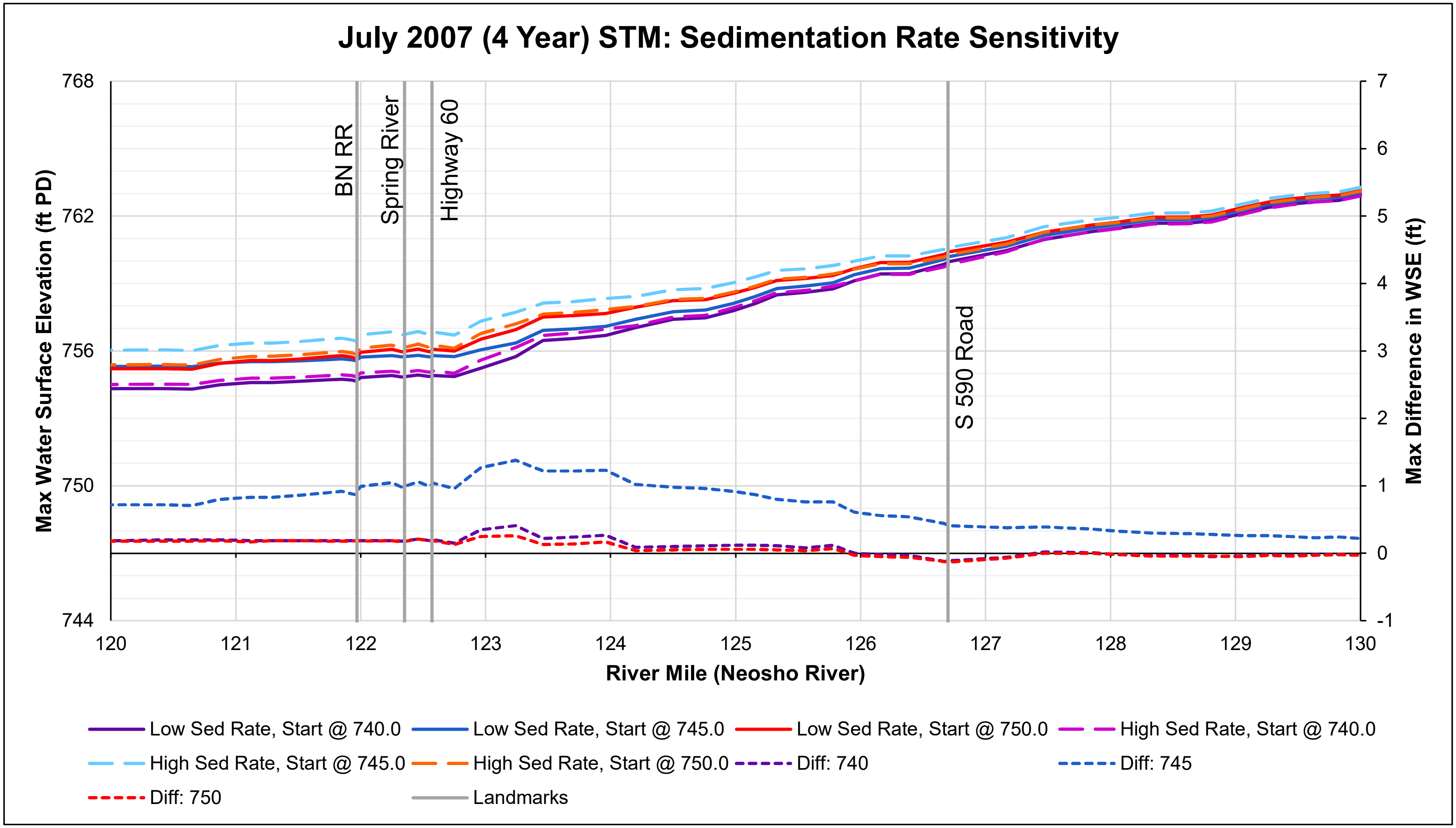
100-year STM: Future Anticipated Ops vs Existing Conditions
Max Water Surface Elevation (ft PD)
Max Difference in WSE (ft)
River Mile (Tar Creek)
OK Highway 10
Central Ave
Rockdale Blvd
BN RR
22nd Ave
792
786
780
774
768
6
5
4
3
2
1
0
-1
-2
1
2
3
4
5
6
7
8
Existing, Start @ 740.0
Existing, Start @ 745.0
Existing, Start @ 750.0
Future, Anticipated Ops, Start @ 740.0
Future, Anticipated Ops, Start @ 745.0
Future, Anticipated Ops, Start @ 750.0
Diff: 740
Diff: 745
Diff: 750
Landmarks

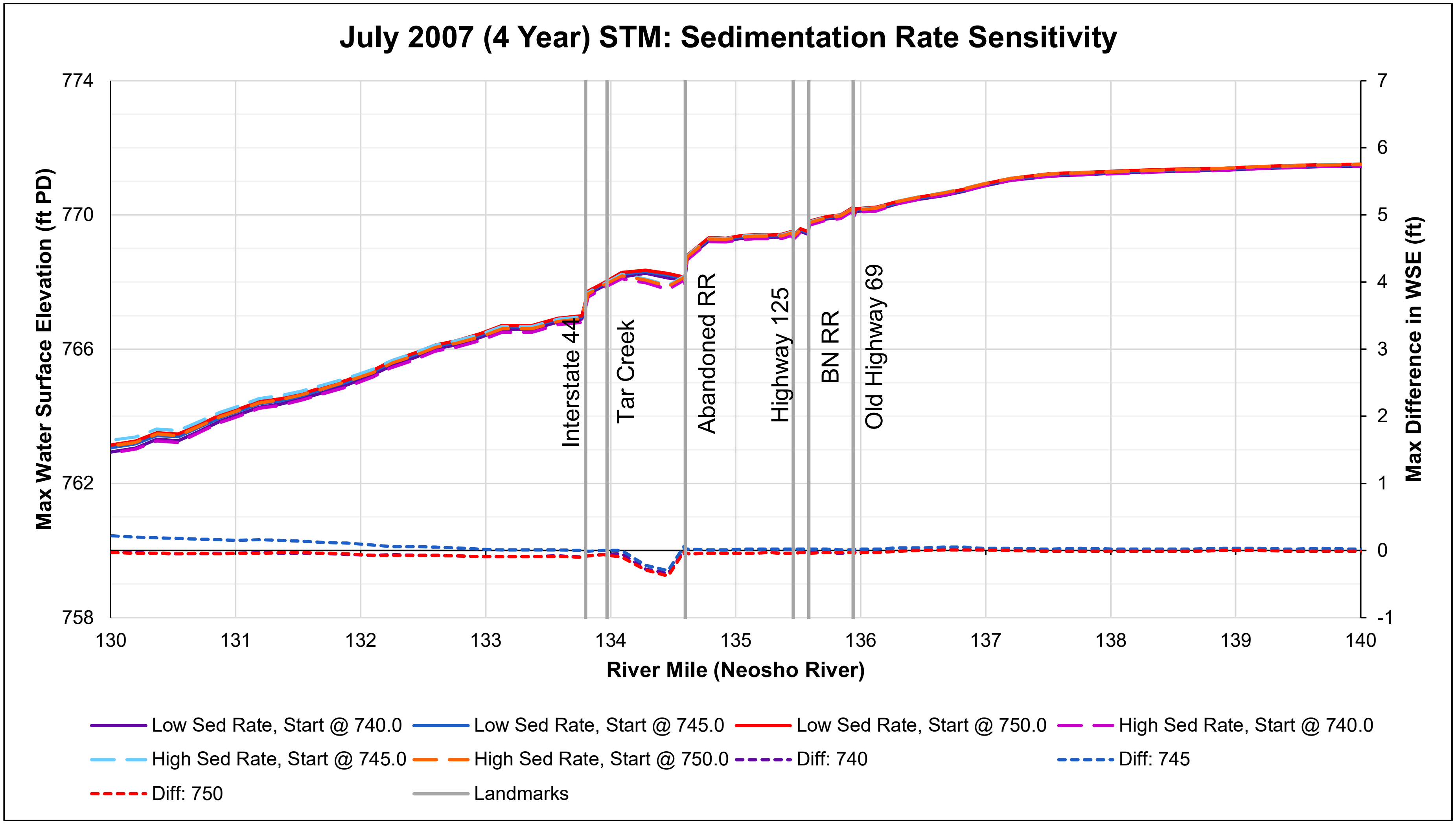


July 2007 (4 Year) STM: Sedimentation Rate Sensitivity
Highway 59 (Sailboat Bridge)
Elk River
Max Water Surface Elevation (ft PD)
Max Difference in WSE (ft)
River Mile (Neosho River)
758
756
754
752
750
6
5
4
3
2
1
0
-1
-2
100
101
102
103
104
105
106
107
108
109
110
Low Sed Rate, Start @ 740.0
Low Sed Rate, Start @ 745.0
Low Sed Rate, Start @ 750.0
High Sed Rate, Start @ 740.0
High Sed Rate, Start @ 745.0
High Sed Rate, Start @ 750.0
Diff: 740
Diff: 745
Diff: 750
Landmarks

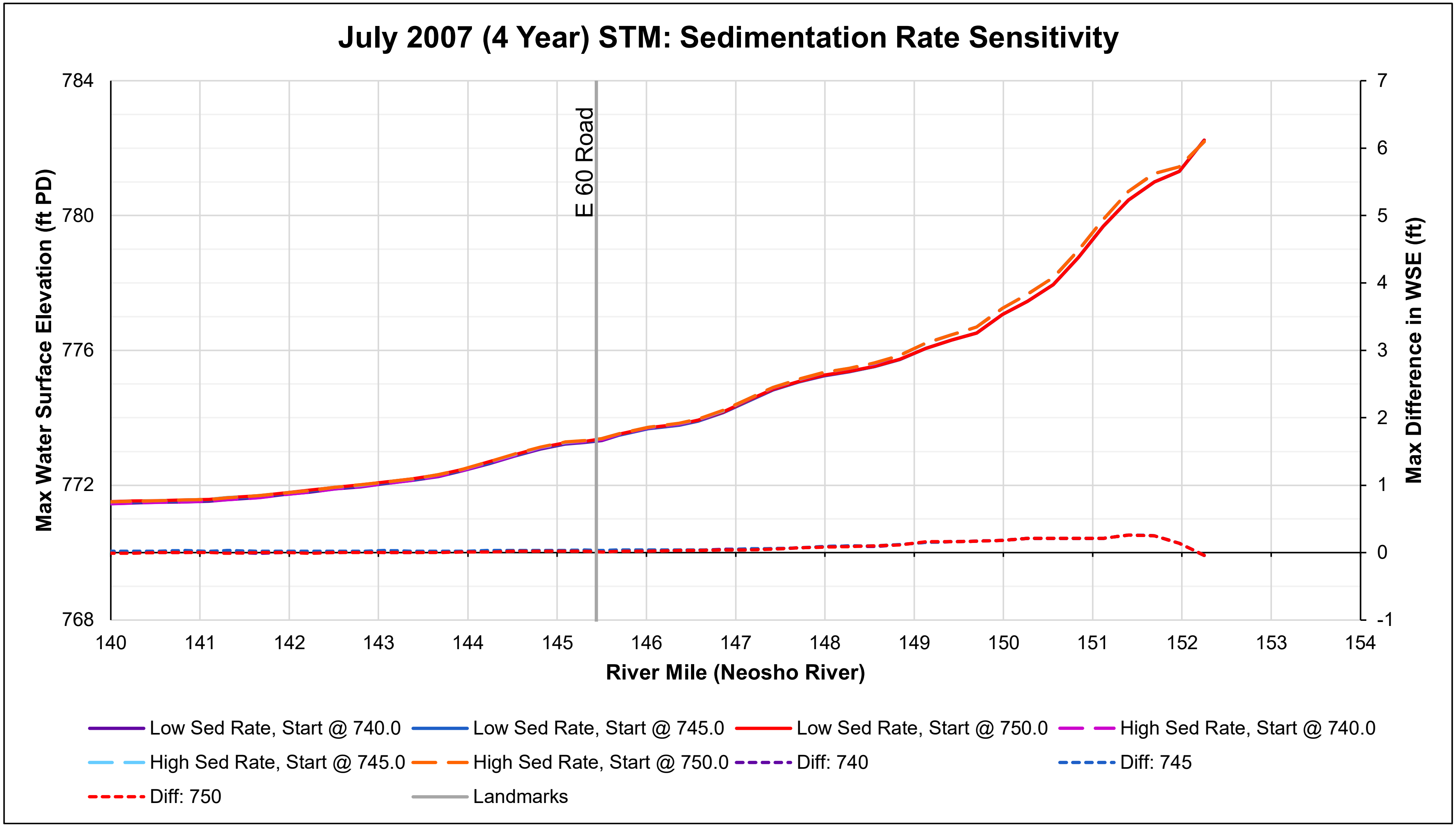


July 2007 (4 Year) STM: Sedimentation Rate Sensitivity
Max Water Surface Elevation (ft PD)
758
756
754
752
750
Max Difference in WSE (ft)
6
5
4
3
2
1
0
-1
-2
110
111
112
113
114
115
116
117
118
119
120
River Mile (Neosho River)
Low Sed Rate, Start @ 740.0
Low Sed Rate, Start @ 745.0
Low Sed Rate, Start @ 750.0
High Sed Rate, Start @ 740.0
High Sed Rate, Start @ 745.0
High Sed Rate, Start @ 750.0
Diff: 740
Diff: 745
Diff: 750
Landmarks

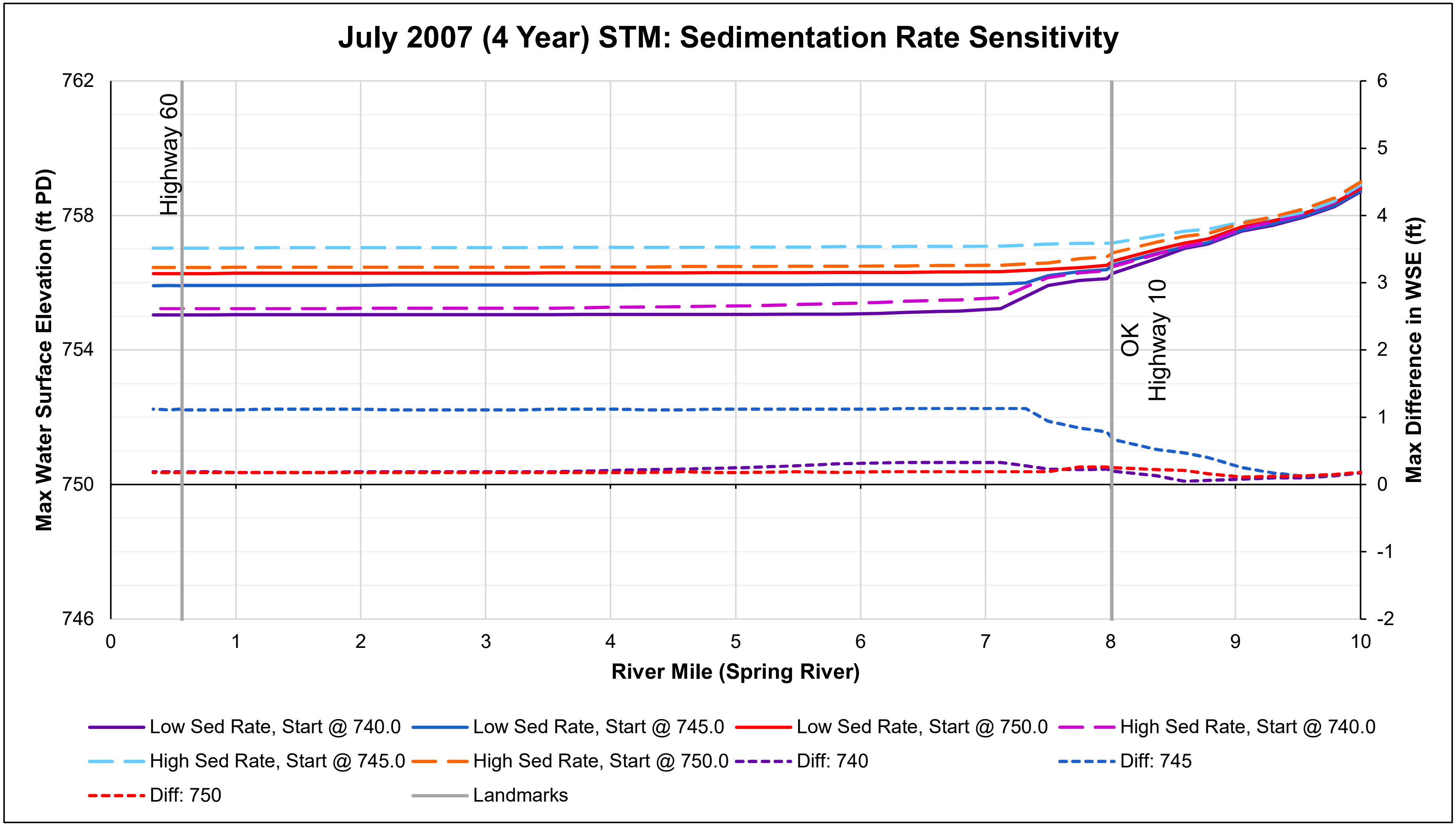

July 2007 (4 Year) STM: Sedimentation Rate Sensitivity
Max Water Surface Elevation (ft PD)
Max Difference in WSE (ft)
River Mile (Neosho River)
768
762
756
750
744
7
6
5
4
3
2
1
0
-1
120
121
122
123
124
125
126
127
128
129
130
BN RR
Spring River
Highway 60
S 590 Road
Low Sed Rate, Start @ 740.0
Low Sed Rate, Start @ 745.0
Low Sed Rate, Start @ 750.0
High Sed Rate, Start @ 740.0
High Sed Rate, Start @ 745.0
High Sed Rate, Start @ 750.0
Diff: 740
Diff: 745
Diff: 750
Landmarks

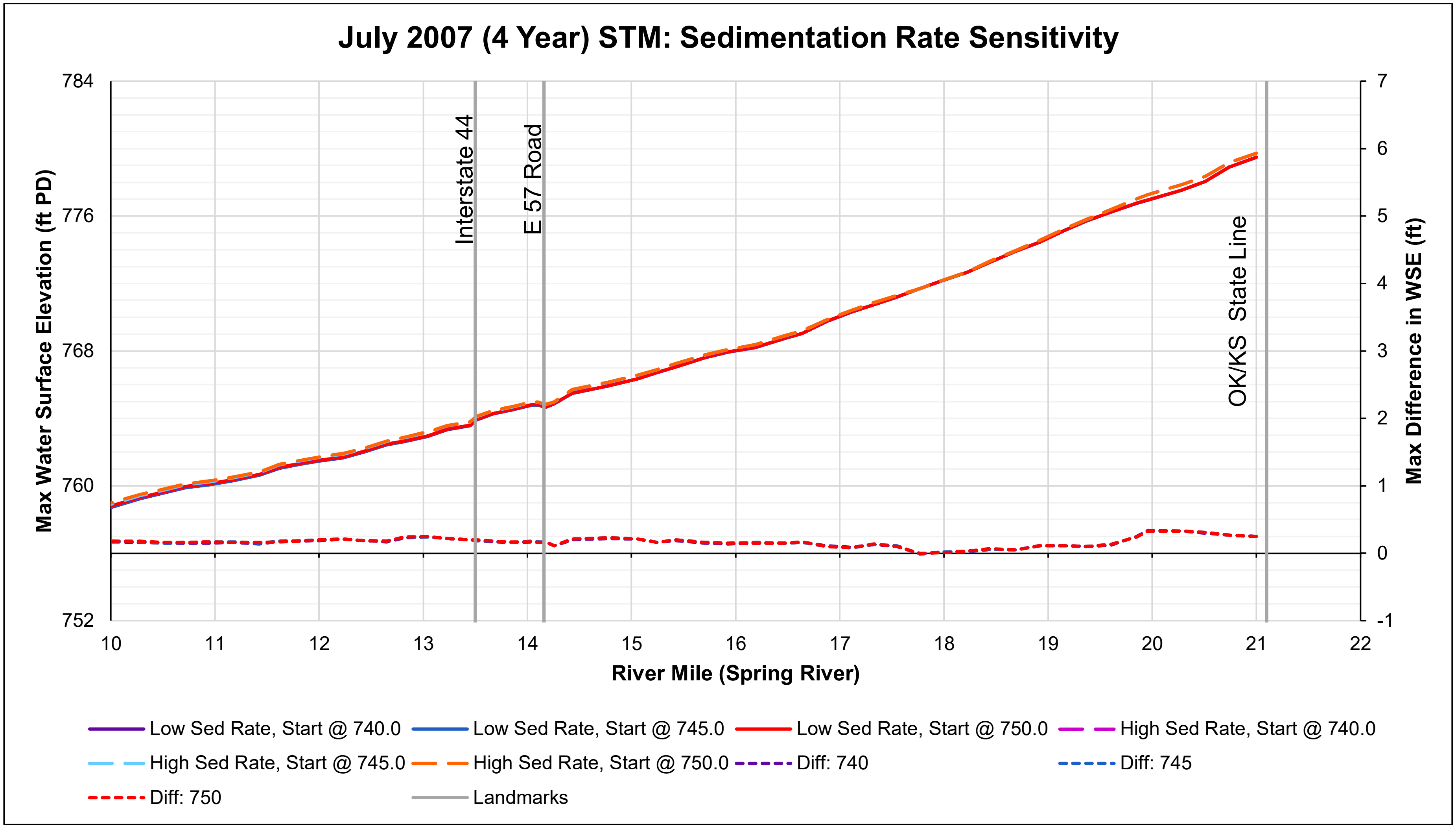


July 2007 (4 Year) STM: Sedimentation Rate Sensitivity
Max Water Surface Elevation (ft PD)
774
770
766
762
758
Max Difference in WSE (ft)
7
6
5
4
3
2
1
0
-1
130
131
132
133
134
135
136
137
138
139
140
River Mile (Neosho River)
Interstate 44
Tar Creek
Abandoned RR
Highway 125
BN RR
Old Highway 69
Low Sed Rate, Start @ 740.0
Low Sed Rate, Start @ 745.0
Low Sed Rate, Start @ 750.0
High Sed Rate, Start @ 740.0
High Sed Rate, Start @ 745.0
High Sed Rate, Start @ 750.0
Diff: 740
Diff: 745
Diff: 750
Landmarks

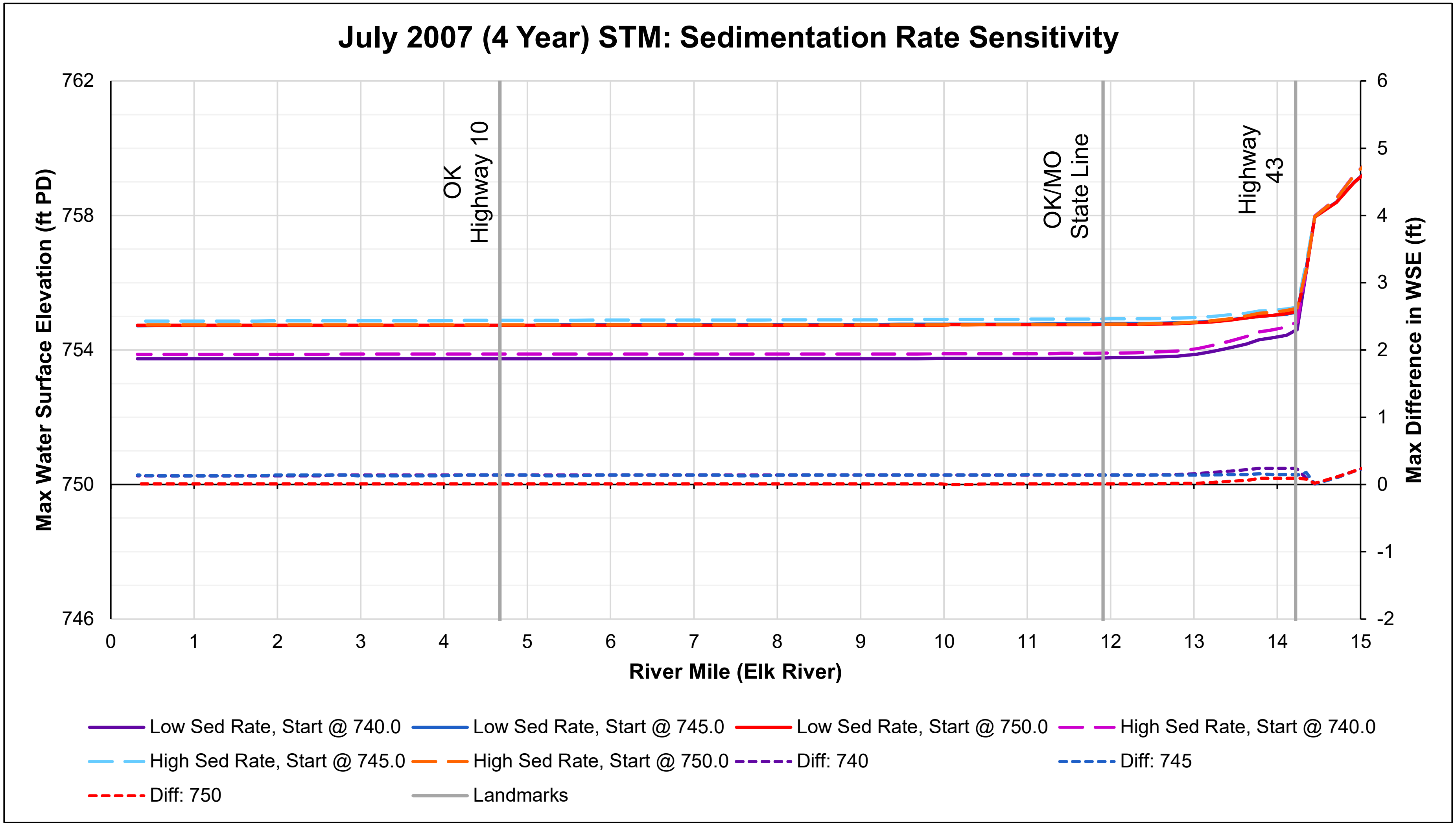


July 2007 (4 Year) STM: Sedimentation Rate Sensitivity
Max Water Surface Elevation (ft PD)
Max Difference in WSE (ft)
River Mile (Neosho River)
E 60 Road
784
780
776
772
768
7
6
5
4
3
2
1
0
-1
140
141
142
143
144
145
146
147
148
149
150
151
152
153
154
Low Sed Rate, Start @ 740.0
Low Sed Rate, Start @ 745.0
Low Sed Rate, Start @ 750.0
High Sed Rate, Start @ 740.0
High Sed Rate, Start @ 745.0
High Sed Rate, Start @ 750.0
Diff: 740
Diff: 745
Diff: 750
Landmarks

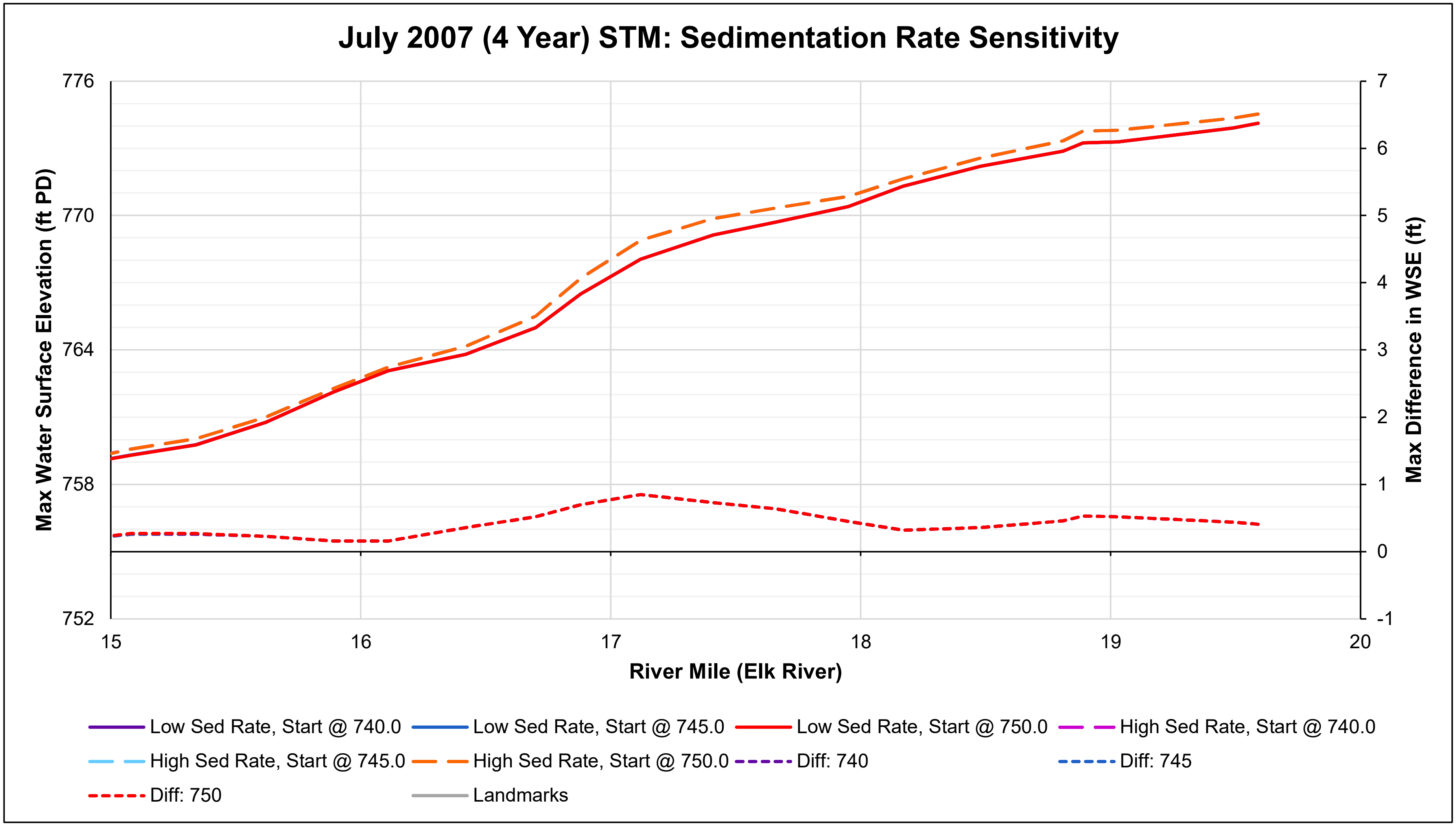

July 2007 (4 Year) STM: Sedimentation Rate Sensitivity
Max Water Surface Elevation (ft PD)
Max Difference in WSE (ft)
River Mile (Spring River)
Highway 60
OK Highway 10
762
758
754
750
746
6
5
4
3
2
1
0
-1
-2
0
1
2
3
4
5
6
7
8
9
10
Low Sed Rate, Start @ 740.0
Low Sed Rate, Start @ 745.0
Low Sed Rate, Start @ 750.0
High Sed Rate, Start @ 740.0
High Sed Rate, Start @ 745.0
High Sed Rate, Start @ 750.0
Diff: 740
Diff: 745
Diff: 750
Landmarks



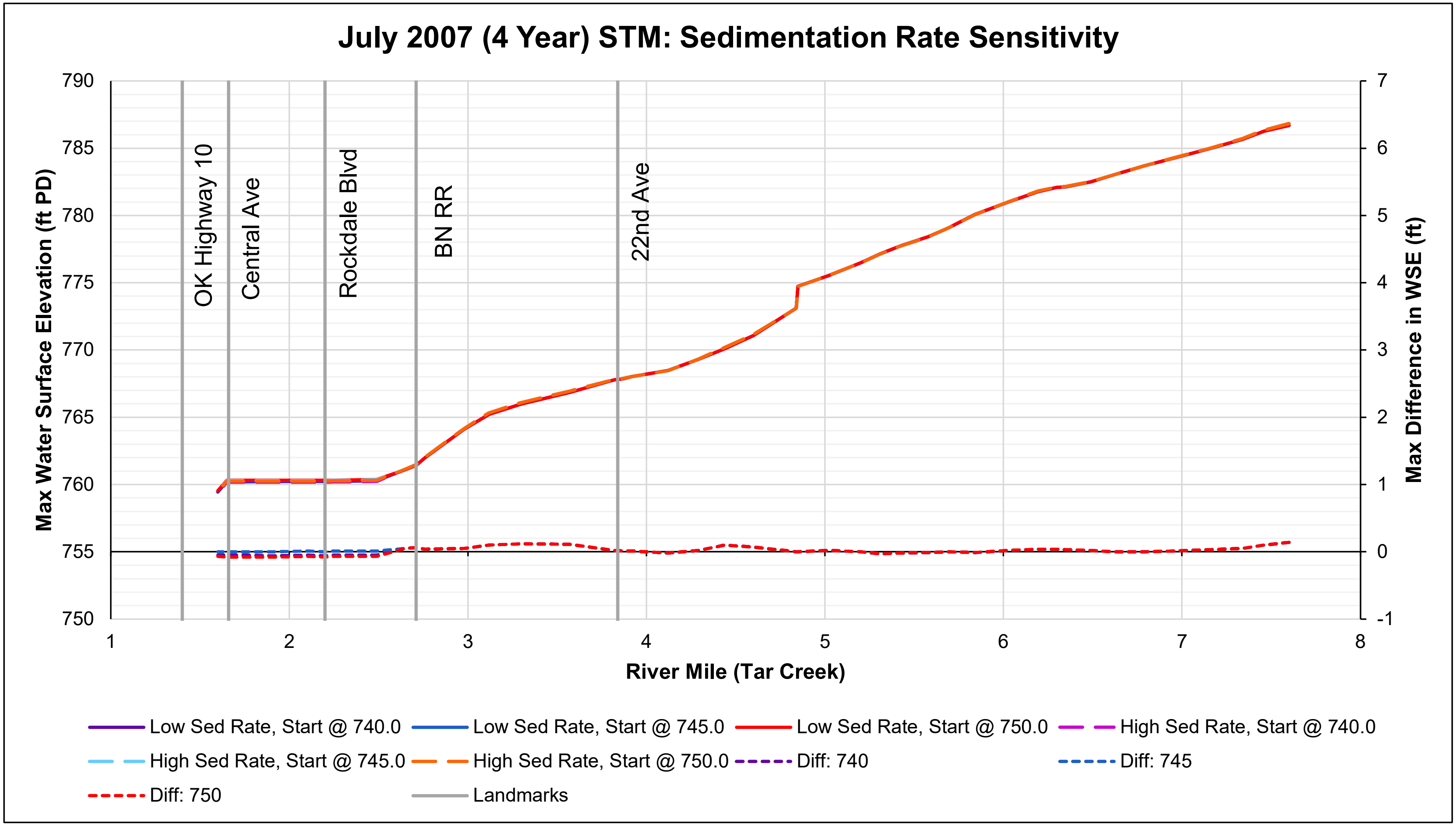
July 2007 (4 Year) STM: Sedimentation Rate Sensitivity
Max Water Surface Elevation (ft PD)
Max Difference in WSE (ft)
River Mile (Spring River)
784
776
768
760
752
7
6
5
4
3
2
1
0
-1
10
11
12
13
14
15
16
17
18
19
20
21
22
Interstate 44
E 57 Road
OK/KS State Line
Low Sed Rate, Start @ 740.0
Low Sed Rate, Start @ 745.0
Low Sed Rate, Start @ 750.0
High Sed Rate, Start @ 740.0
High Sed Rate, Start @ 745.0
High Sed Rate, Start @ 750.0
Diff: 740
Diff: 745
Diff: 750
Landmarks



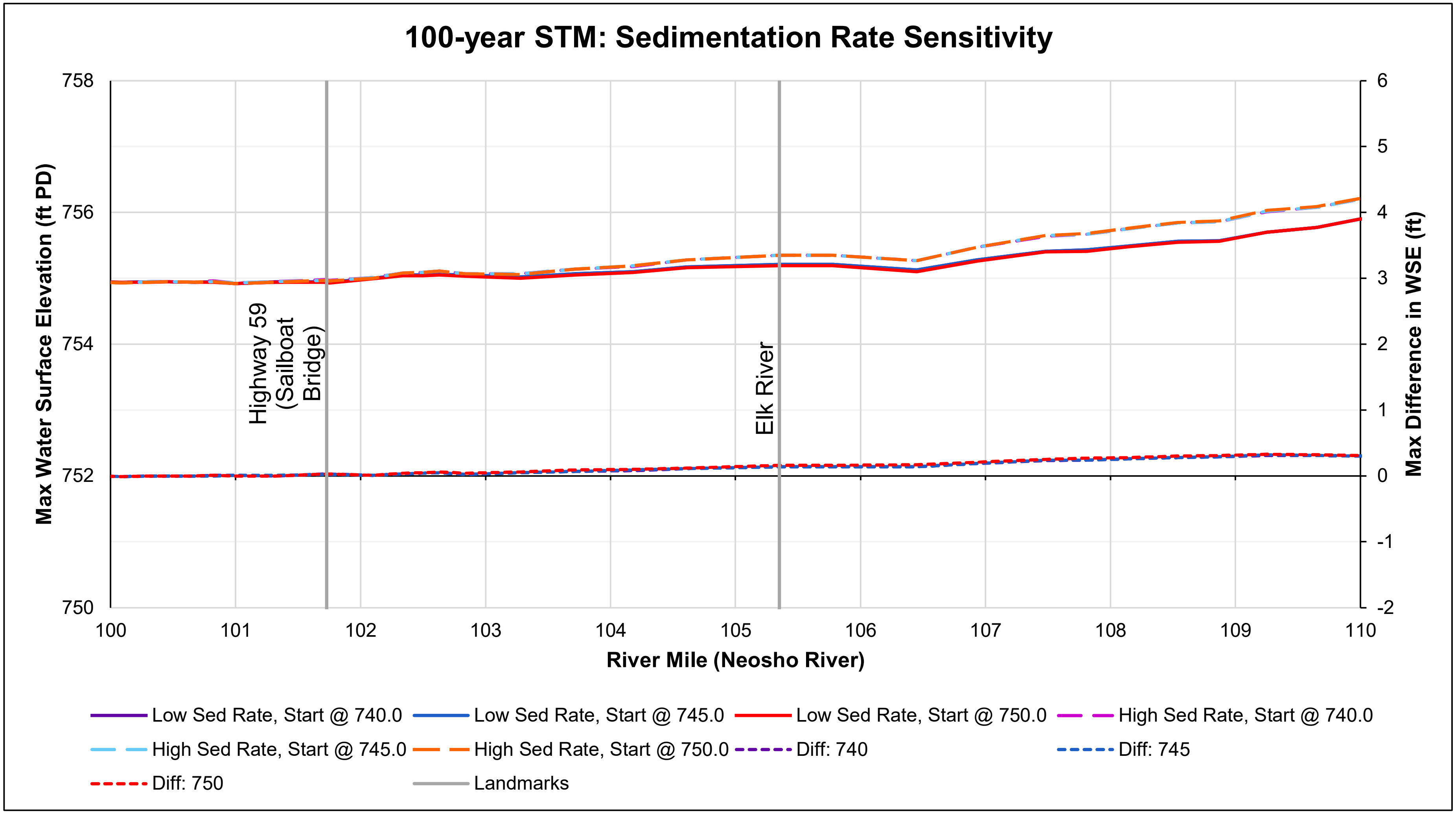
July 2007 (4 Year) STM: Sedimentation Rate Sensitivity
Max Water Surface Elevation (ft PD)
Max Difference in WSE (ft)
River Mile (Elk River)
762
758
754
750
746
6
5
4
3
2
1
0
-1
-2
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
OK
Highway 10
OK/MO
State Line
Highway
43
Low Sed Rate, Start @ 740.0
Low Sed Rate, Start @ 745.0
Low Sed Rate, Start @ 750.0
High Sed Rate, Start @ 740.0
High Sed Rate, Start @ 745.0
High Sed Rate, Start @ 750.0
Diff: 740
Diff: 745
Diff: 750
Landmarks

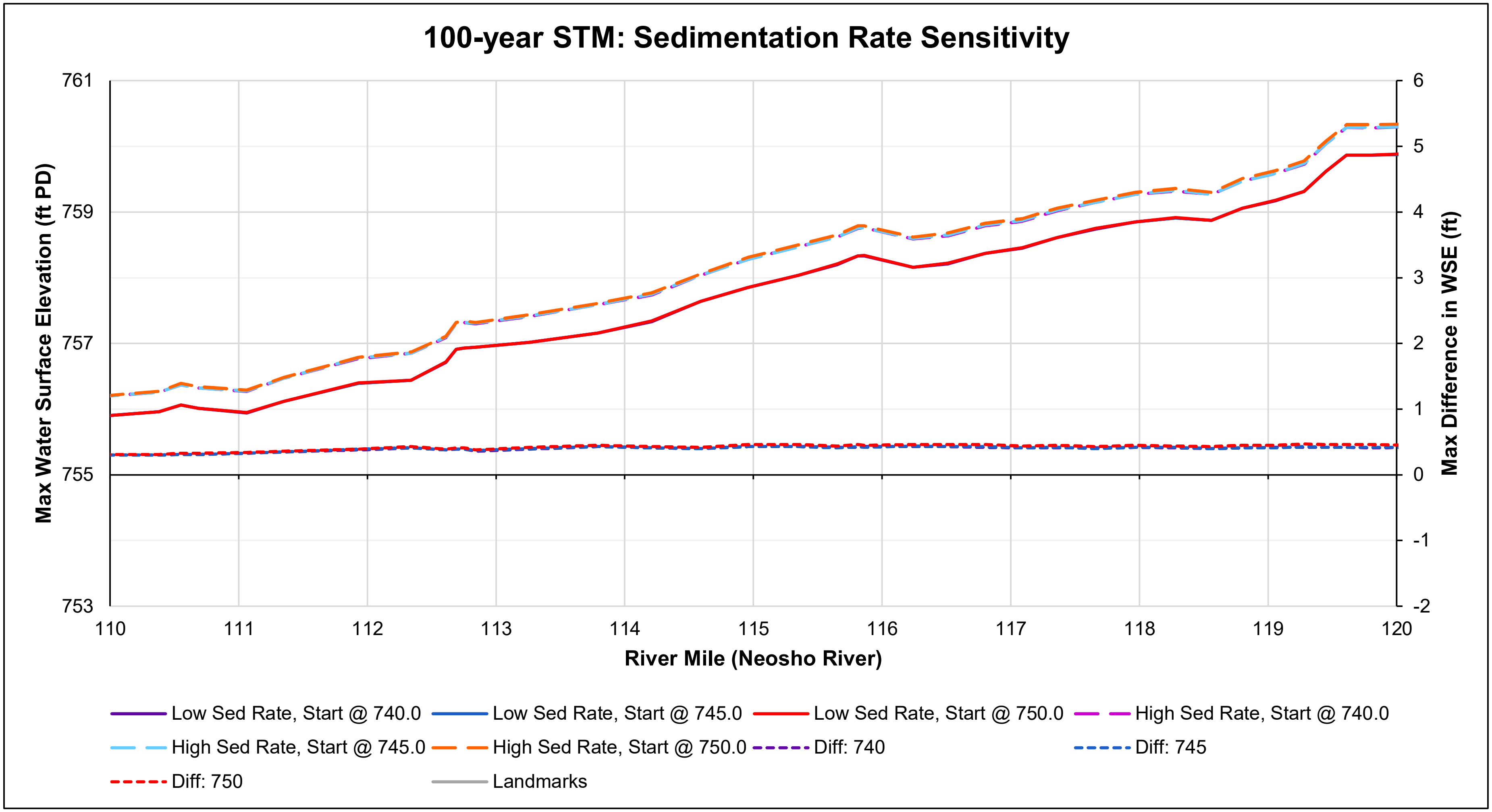


July 2007 (4 Year) STM: Sedimentation Rate Sensitivity
Max Water Surface Elevation (ft PD)
776
770
764
758
752
Max Difference in WSE (ft)
7
6
5
4
3
2
1
0
-1
15
16
17
18
19
20
River Mile (Elk River)
Low Sed Rate, Start @ 740.0
Low Sed Rate, Start @ 745.0
Low Sed Rate, Start @ 750.0
High Sed Rate, Start @ 740.0
High Sed Rate, Start @ 745.0
High Sed Rate, Start @ 750.0
Diff: 740
Diff: 745
Diff: 750
Landmarks

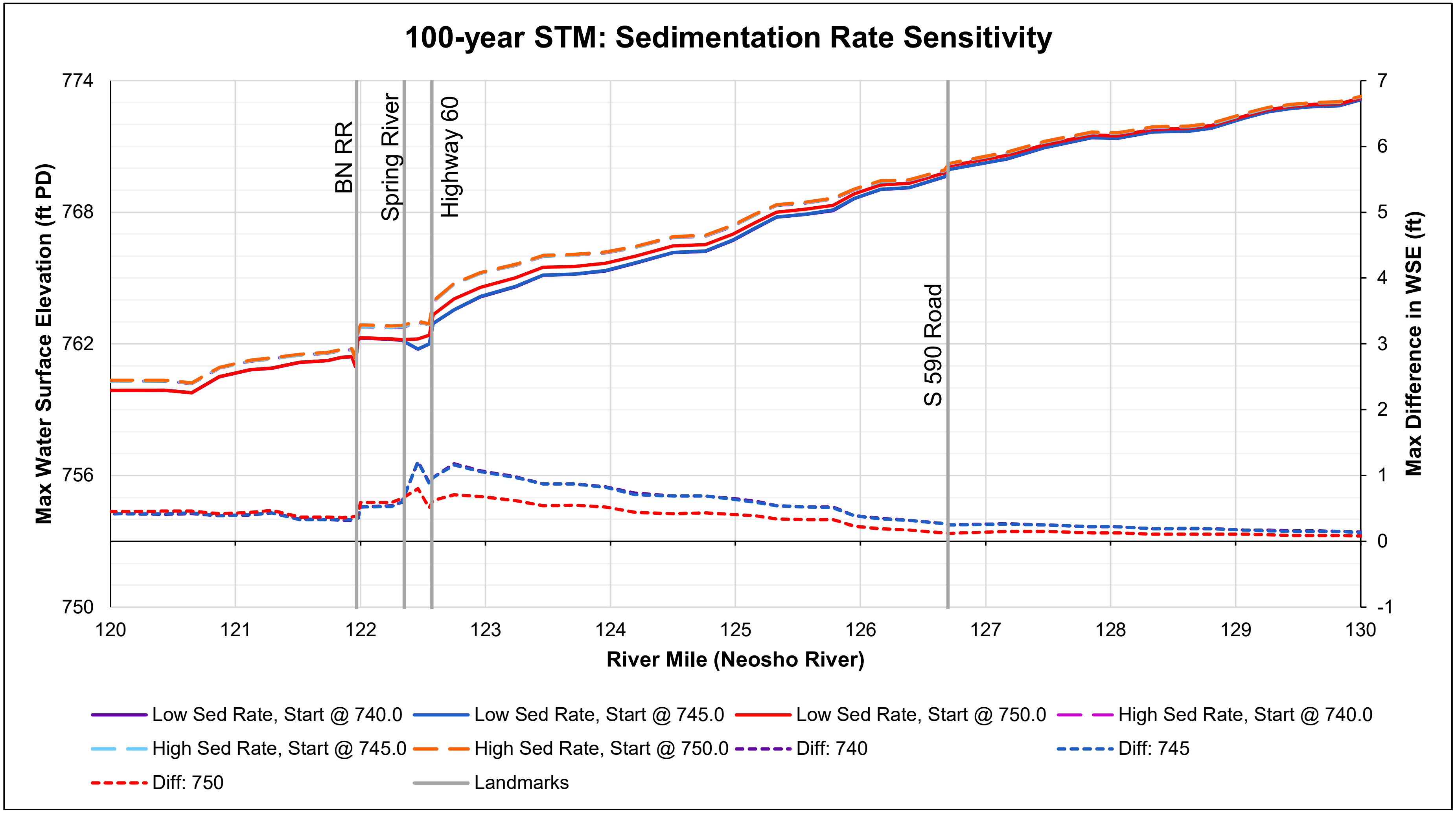


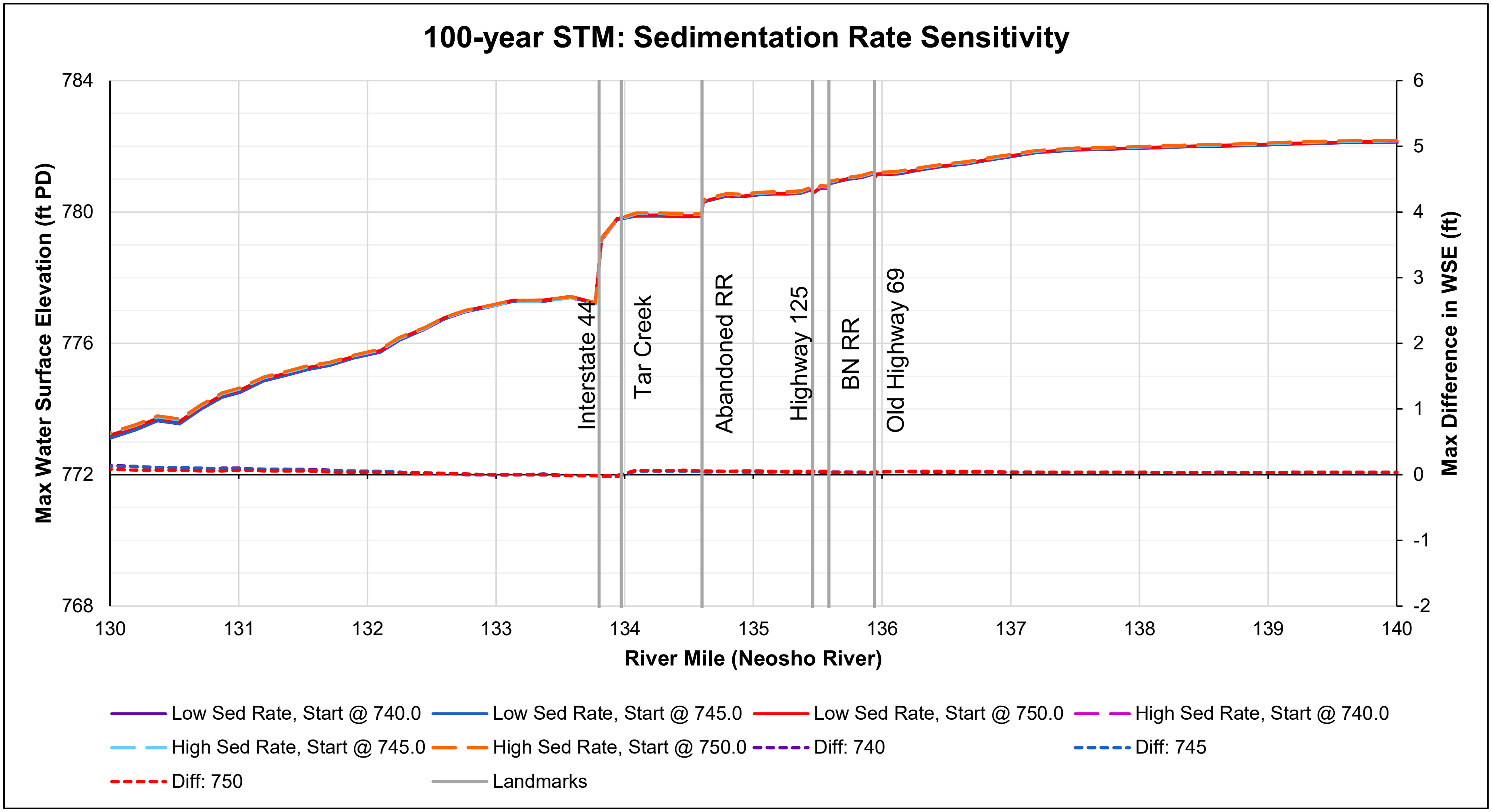
July 2007 (4 Year) STM: Sedimentation Rate Sensitivity
Max Water Surface Elevation (ft PD)
790
785
780
775
770
765
760
755
750
Max Difference in WSE (ft)
7
6
5
4
3
2
1
0
-1
River Mile (Tar Creek)
1
2
3
4
5
6
7
8
OK Highway 10
Central Ave
Rockdale Blvd
BN RR
22nd Ave
Low Sed Rate, Start @ 740.0
Low Sed Rate, Start @ 745.0
Low Sed Rate, Start @ 750.0
High Sed Rate, Start @ 740.0
High Sed Rate, Start @ 745.0
High Sed Rate, Start @ 750.0
Diff: 740
Diff: 745
Diff: 750
Landmarks


100-year STM: Sedimentation Rate Sensitivity
Max Water Surface Elevation (ft PD)
Max Difference in WSE (ft)
River Mile (Neosho River)
758
756
754
752
750
6
5
4
3
2
1
0
-1
-2
100
101
102
103
104
105
106
107
108
109
110
Highway 59 (Sailboat Bridge)
Elk River
Low Sed Rate, Start @ 740.0
Low Sed Rate, Start @ 745.0
Low Sed Rate, Start @ 750.0
High Sed Rate, Start @ 740.0
High Sed Rate, Start @ 745.0
High Sed Rate, Start @ 750.0
Diff: 740
Diff: 745
Diff: 750
Landmarks

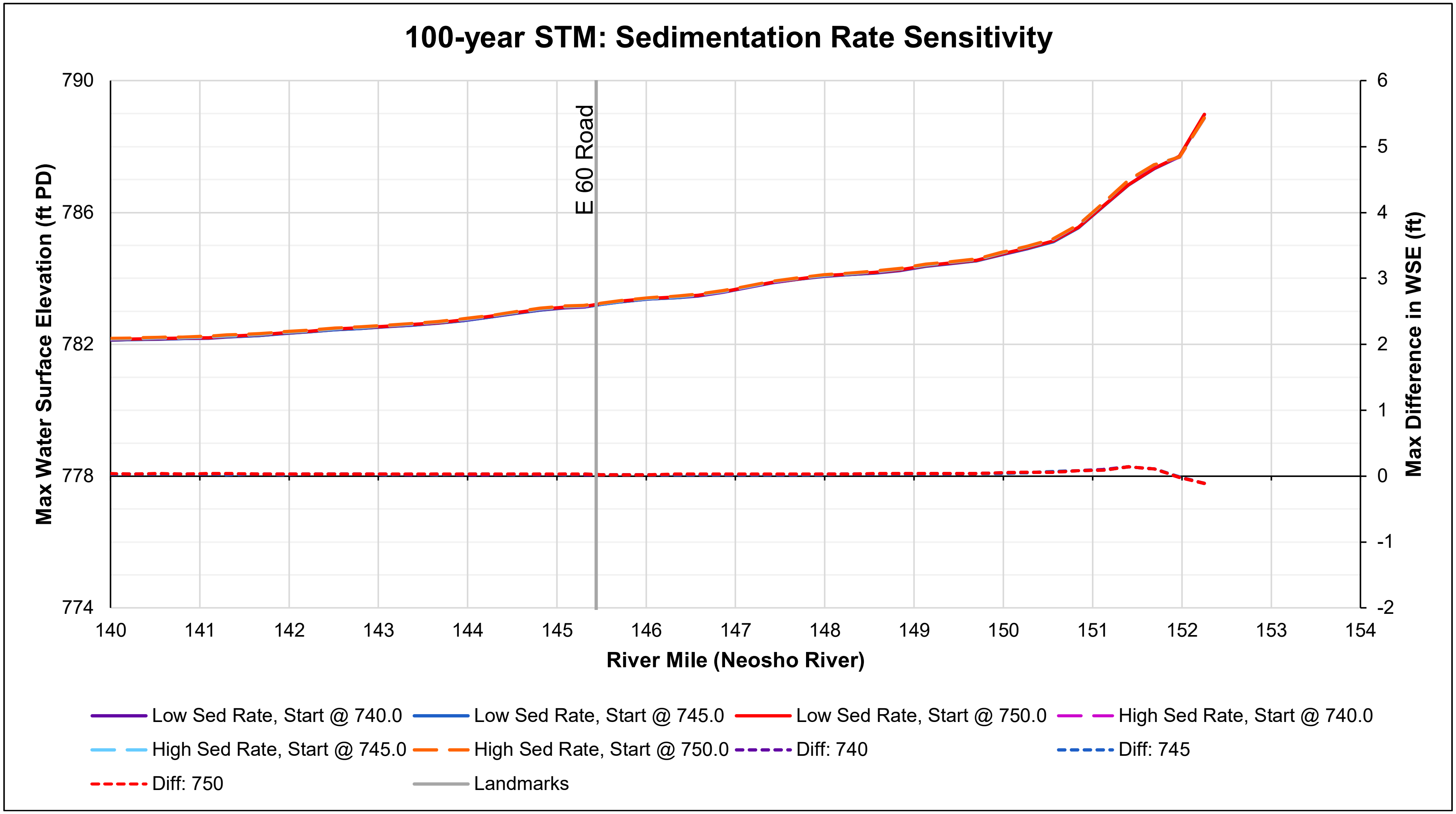


100-year STM: Sedimentation Rate Sensitivity
Max Water Surface Elevation (ft PD)
Max Difference in WSE (ft)
River Mile (Neosho River)
761
759
757
755
753
6
5
4
3
2
1
0
-1
-2
110
111
112
113
114
115
116
117
118
119
120
Low Sed Rate, Start @ 740.0
Low Sed Rate, Start @ 745.0
Low Sed Rate, Start @ 750.0
High Sed Rate, Start @ 740.0
High Sed Rate, Start @ 745.0
High Sed Rate, Start @ 750.0
Diff: 740
Diff: 745
Diff: 750
Landmarks

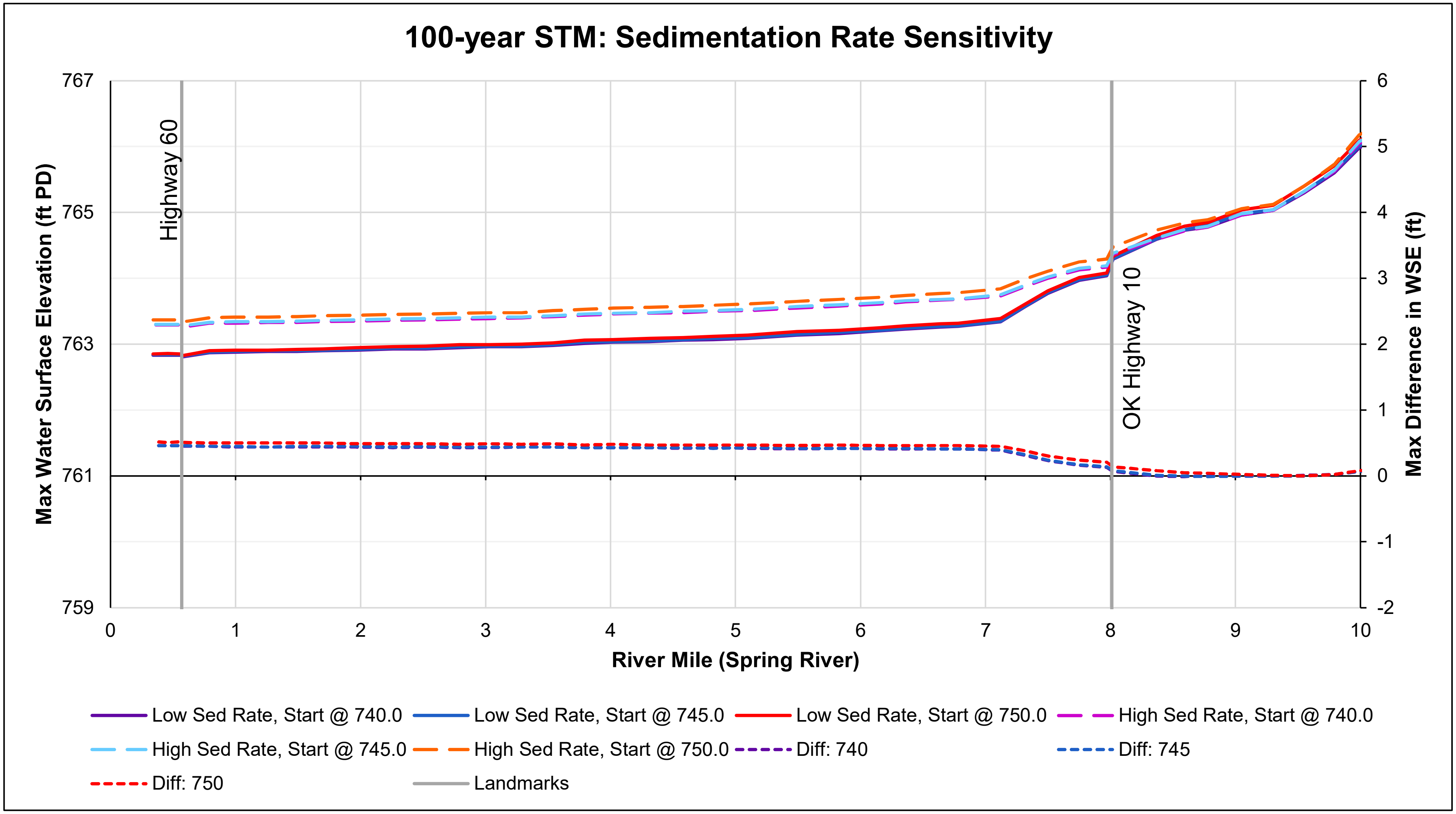

100-year STM: Sedimentation Rate Sensitivity
Max Water Surface Elevation (ft PD)
Max Difference in WSE (ft)
River Mile (Neosho River)
774
768
762
756
750
7
6
5
4
3
2
1
0
-1
120
121
122
123
124
125
126
127
128
129
130
BN RR
Spring River
Highway 60
S 590 Road
Low Sed Rate, Start @ 740.0
Low Sed Rate, Start @ 745.0
Low Sed Rate, Start @ 750.0
High Sed Rate, Start @ 740.0
High Sed Rate, Start @ 745.0
High Sed Rate, Start @ 750.0
Diff: 740
Diff: 745
Diff: 750
Landmarks



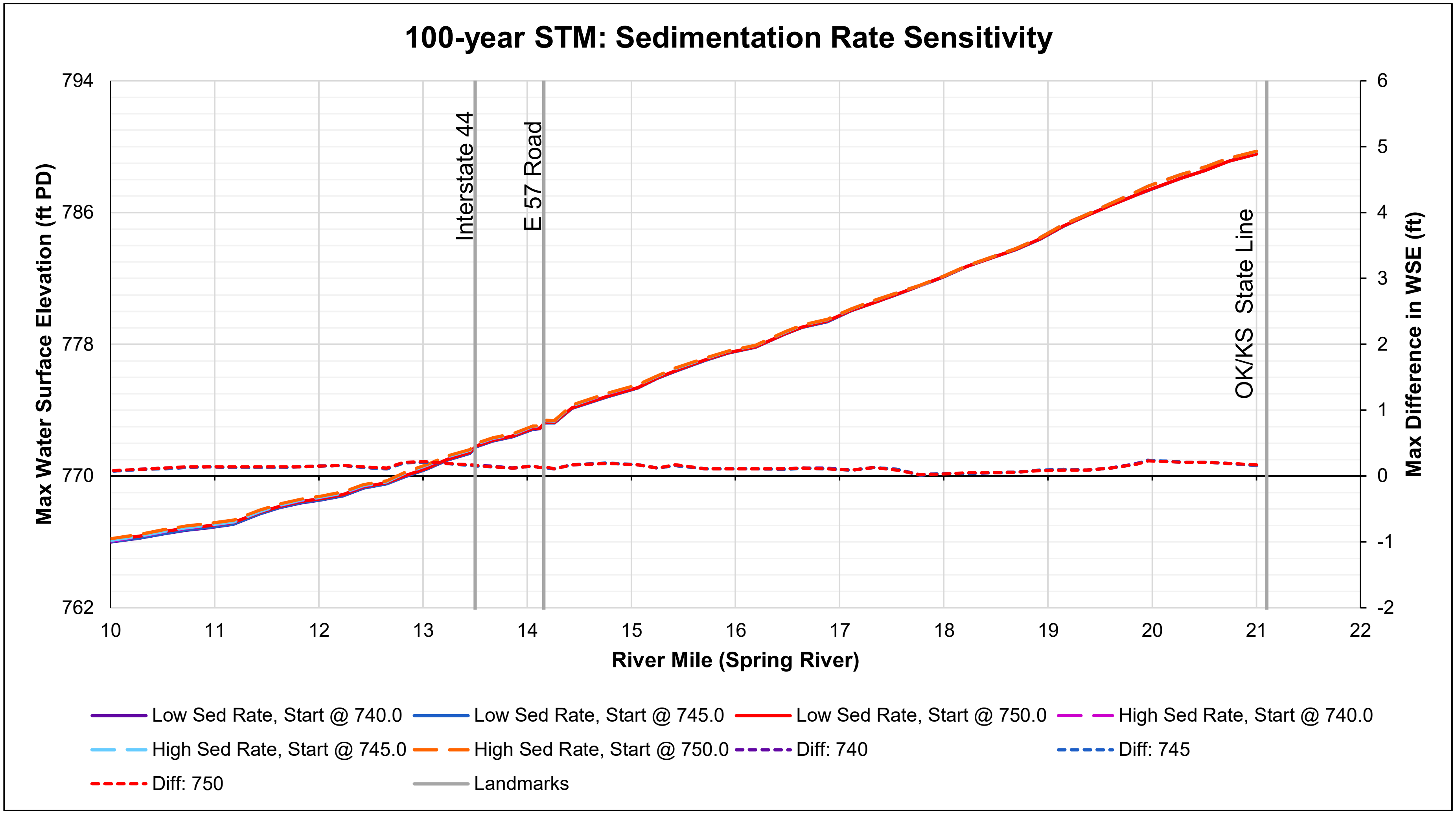
100-year STM: Sedimentation Rate Sensitivity
Max Water Surface Elevation (ft PD)
Max Difference in WSE (ft)
River Mile (Neosho River)
784
780
776
772
768
6
5
4
3
2
1
0
-1
-2
130
131
132
133
134
135
136
137
138
139
140
Interstate 44
Tar Creek
Abandoned RR
Highway 125
BN RR
Old Highway 69
Low Sed Rate, Start @ 740.0
Low Sed Rate, Start @ 745.0
Low Sed Rate, Start @ 750.0
High Sed Rate, Start @ 740.0
High Sed Rate, Start @ 745.0
High Sed Rate, Start @ 750.0
Diff: 740
Diff: 745
Diff: 750
Landmarks



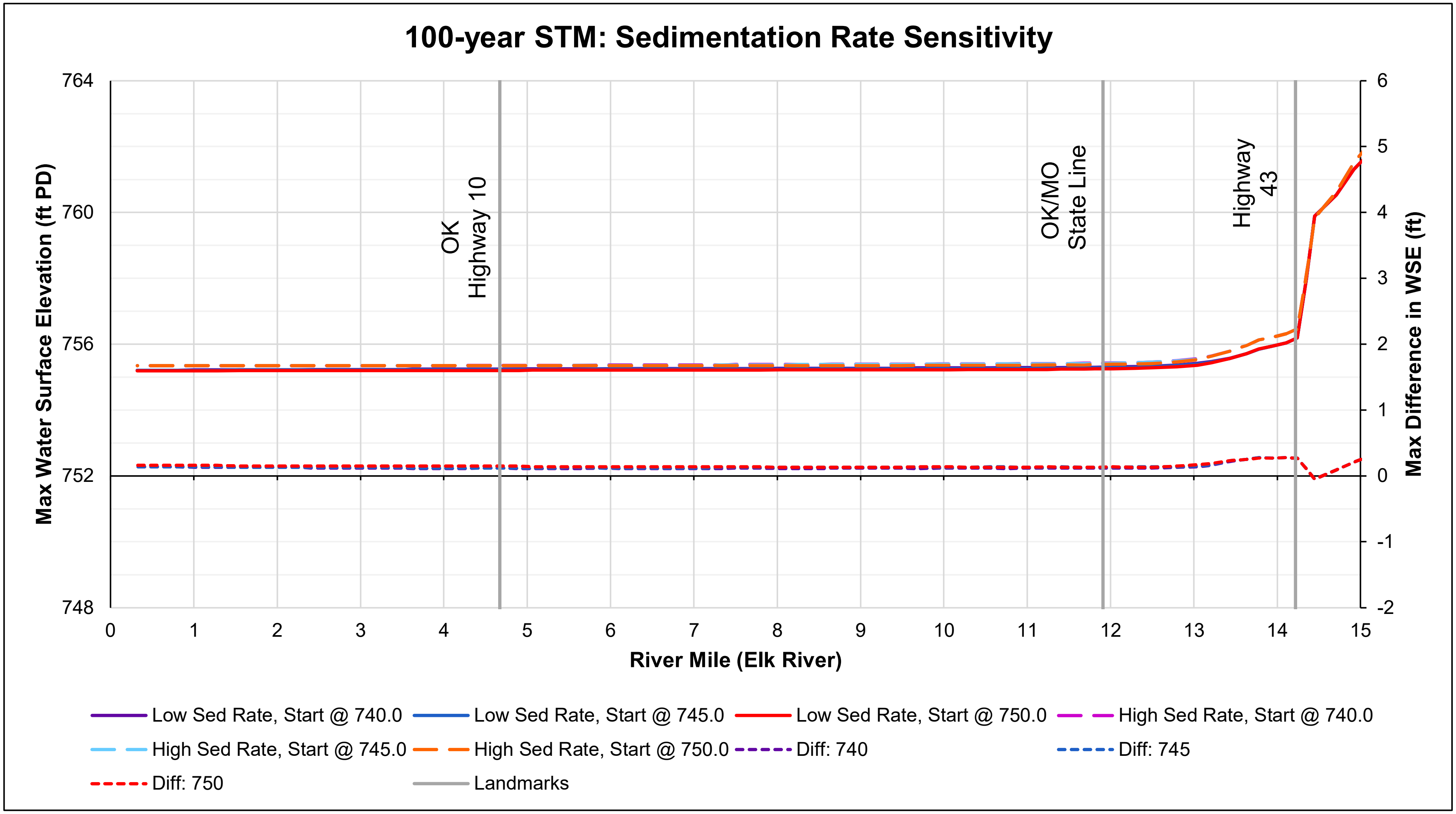
100-year STM: Sedimentation Rate Sensitivity
Max Water Surface Elevation (ft PD)
Max Difference in WSE (ft)
River Mile (Neosho River)
E 60 Road
790
786
782
778
774
6
5
4
3
2
1
0
-1
-2
140
141
142
143
144
145
146
147
148
149
150
151
152
153
154
Low Sed Rate, Start @ 740.0
Low Sed Rate, Start @ 745.0
Low Sed Rate, Start @ 750.0
High Sed Rate, Start @ 740.0
High Sed Rate, Start @ 745.0
High Sed Rate, Start @ 750.0
Diff: 740
Diff: 745
Diff: 750
Landmarks



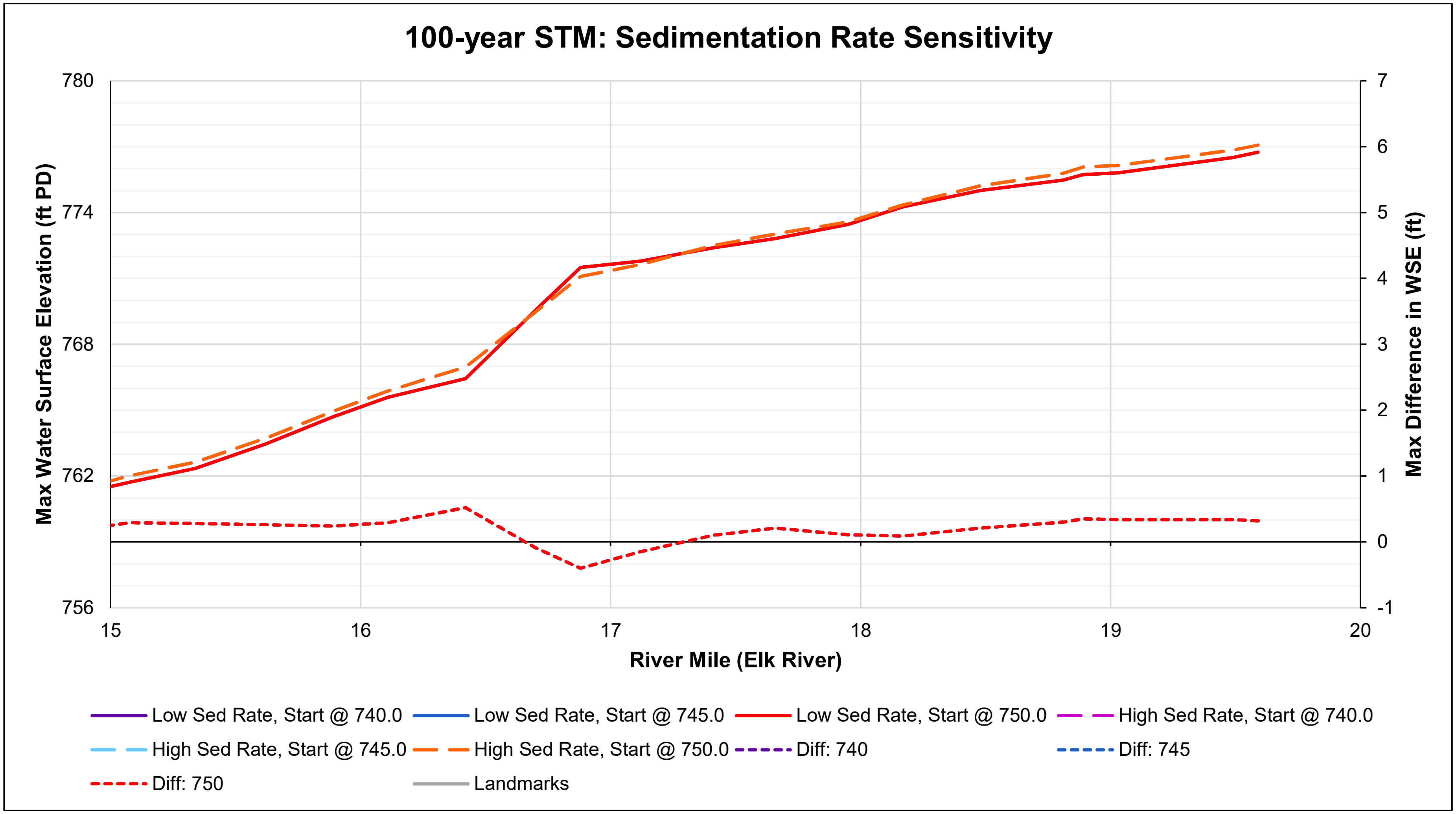
100-year STM: Sedimentation Rate Sensitivity
Max Water Surface Elevation (ft PD)
Max Difference in WSE (ft)
River Mile (Spring River)
767
765
763
761
759
6
5
4
3
2
1
0
-1
-2
0
1
2
3
4
5
6
7
8
9
10
Highway 60
OK Highway 10
Low Sed Rate, Start @ 740.0
Low Sed Rate, Start @ 745.0
Low Sed Rate, Start @ 750.0
High Sed Rate, Start @ 740.0
High Sed Rate, Start @ 745.0
High Sed Rate, Start @ 750.0
Diff: 740
Diff: 745
Diff: 750
Landmarks



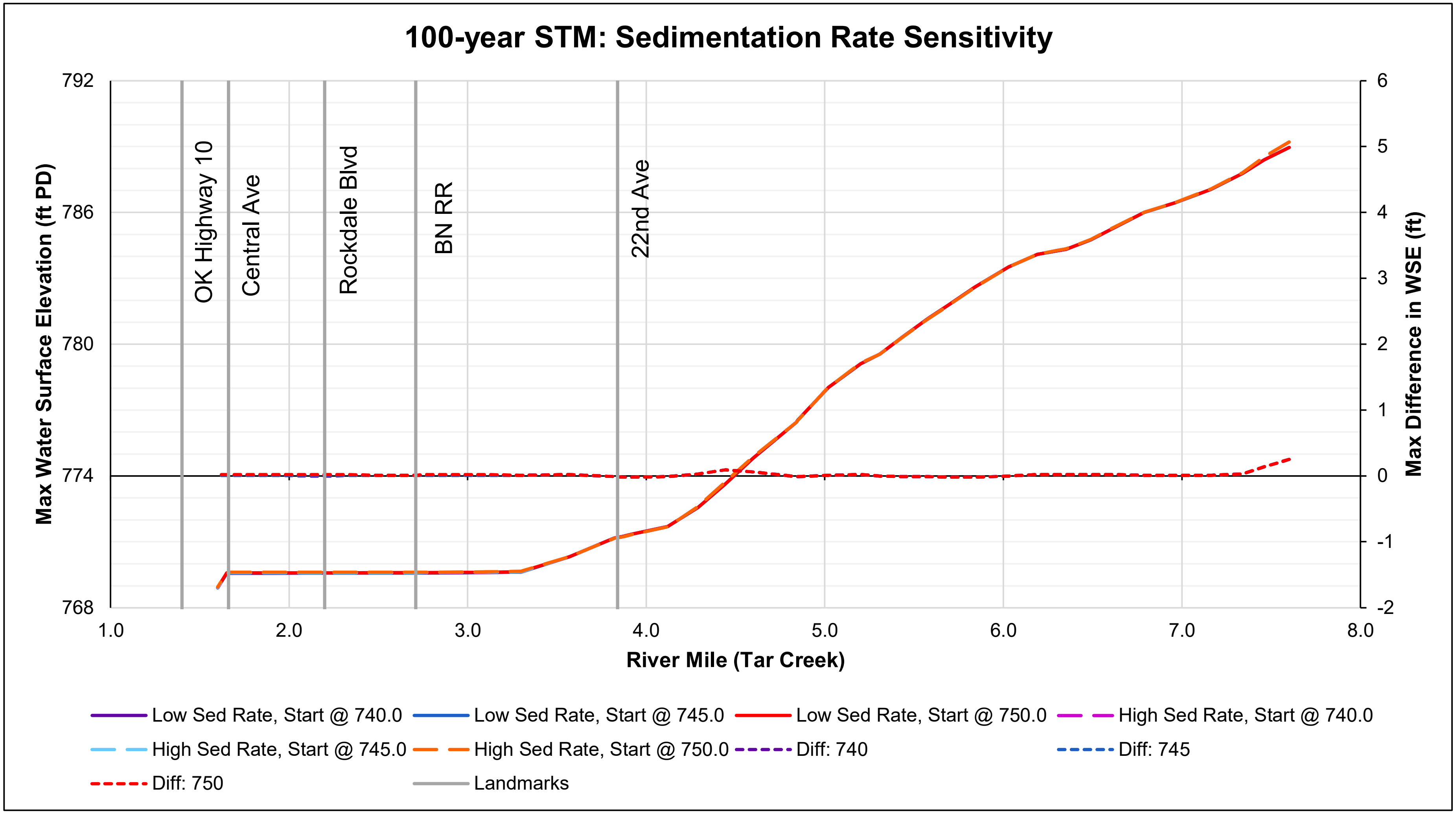
100-year STM: Sedimentation Rate Sensitivity
Max Water Surface Elevation (ft PD)
794
786
778
770
762
Max Difference in WSE (ft)
6
5
4
3
2
1
0
-1
-2
10
11
12
13
14
15
16
17
18
19
20
21
22
River Mile (Spring River)
Interstate 44
E 57 Road
OK/KS State Line
Low Sed Rate, Start @ 740.0
Low Sed Rate, Start @ 745.0
Low Sed Rate, Start @ 750.0
High Sed Rate, Start @ 740.0
High Sed Rate, Start @ 745.0
High Sed Rate, Start @ 750.0
Diff: 740
Diff: 745
Diff: 750
Landmarks



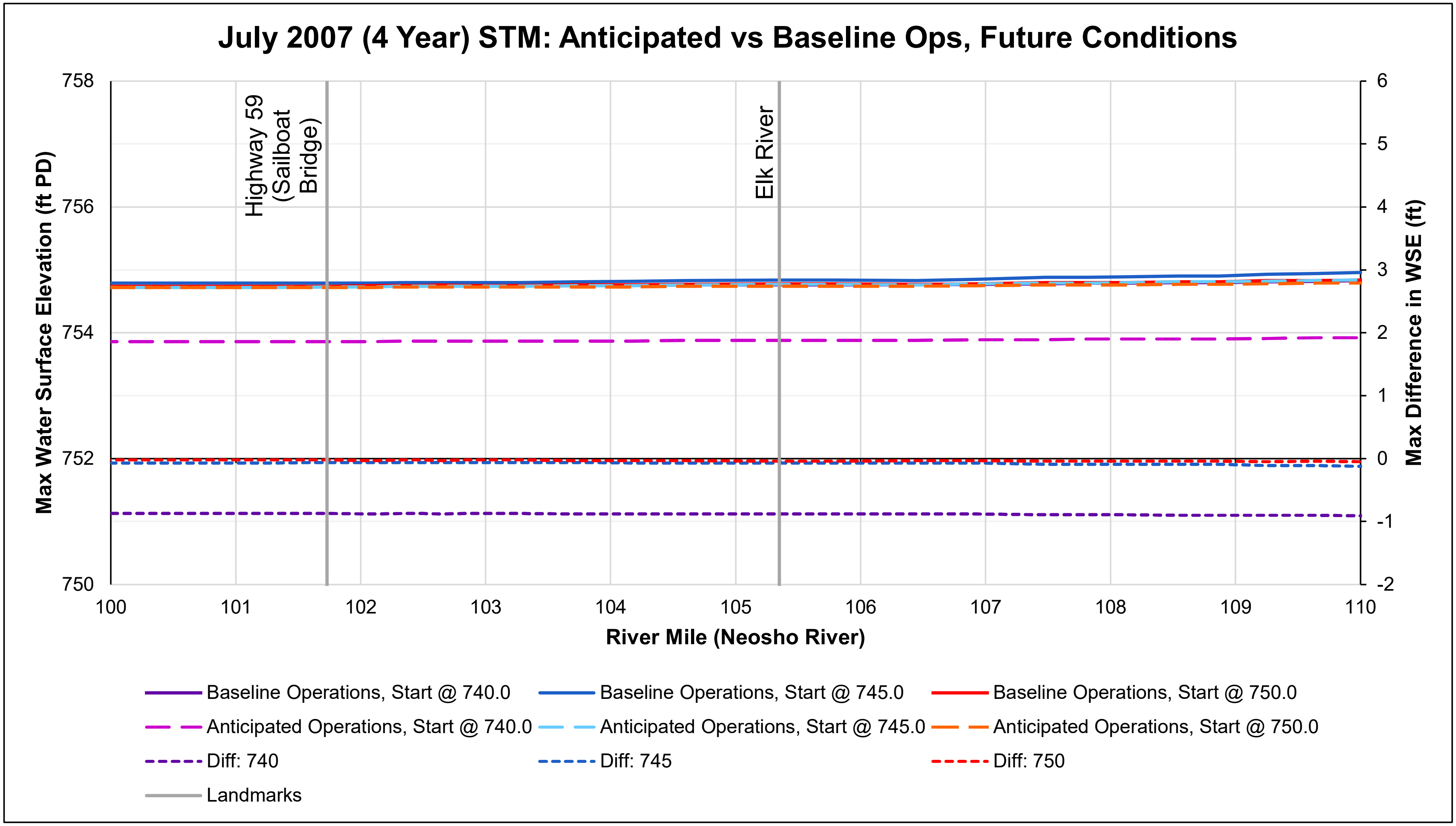
100-year STM: Sedimentation Rate Sensitivity
Max Water Surface Elevation (ft PD)
764
760
756
752
748
Max Difference in WSE (ft)
6
5
4
3
2
1
0
-1
-2
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
River Mile (Elk River)
OK Highway 10
OK/MO State Line
Highway 43
Low Sed Rate, Start @ 740.0
Low Sed Rate, Start @ 745.0
Low Sed Rate, Start @ 750.0
High Sed Rate, Start @ 740.0
High Sed Rate, Start @ 745.0
High Sed Rate, Start @ 750.0
Diff: 740
Diff: 745
Diff: 750
Landmarks



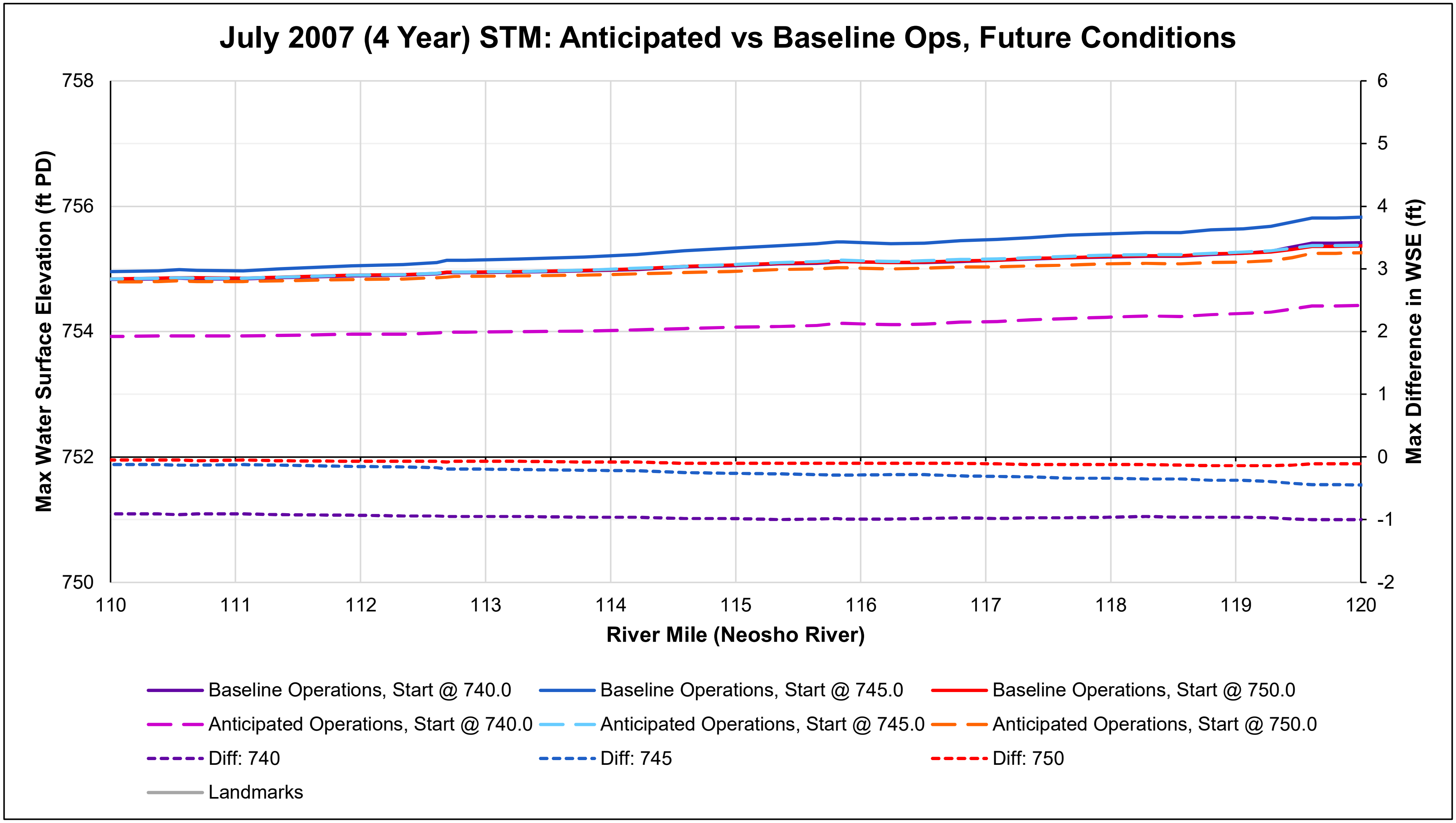
100-year STM: Sedimentation Rate Sensitivity
Max Water Surface Elevation (ft PD)
780
774
768
762
756
Max Difference in WSE (ft)
7
6
5
4
3
2
1
0
-1
15
16
17
18
19
20
River Mile (Elk River)
Low Sed Rate, Start @ 740.0
Low Sed Rate, Start @ 745.0
Low Sed Rate, Start @ 750.0
High Sed Rate, Start @ 740.0
High Sed Rate, Start @ 745.0
High Sed Rate, Start @ 750.0
Diff: 740
Diff: 745
Diff: 750
Landmarks



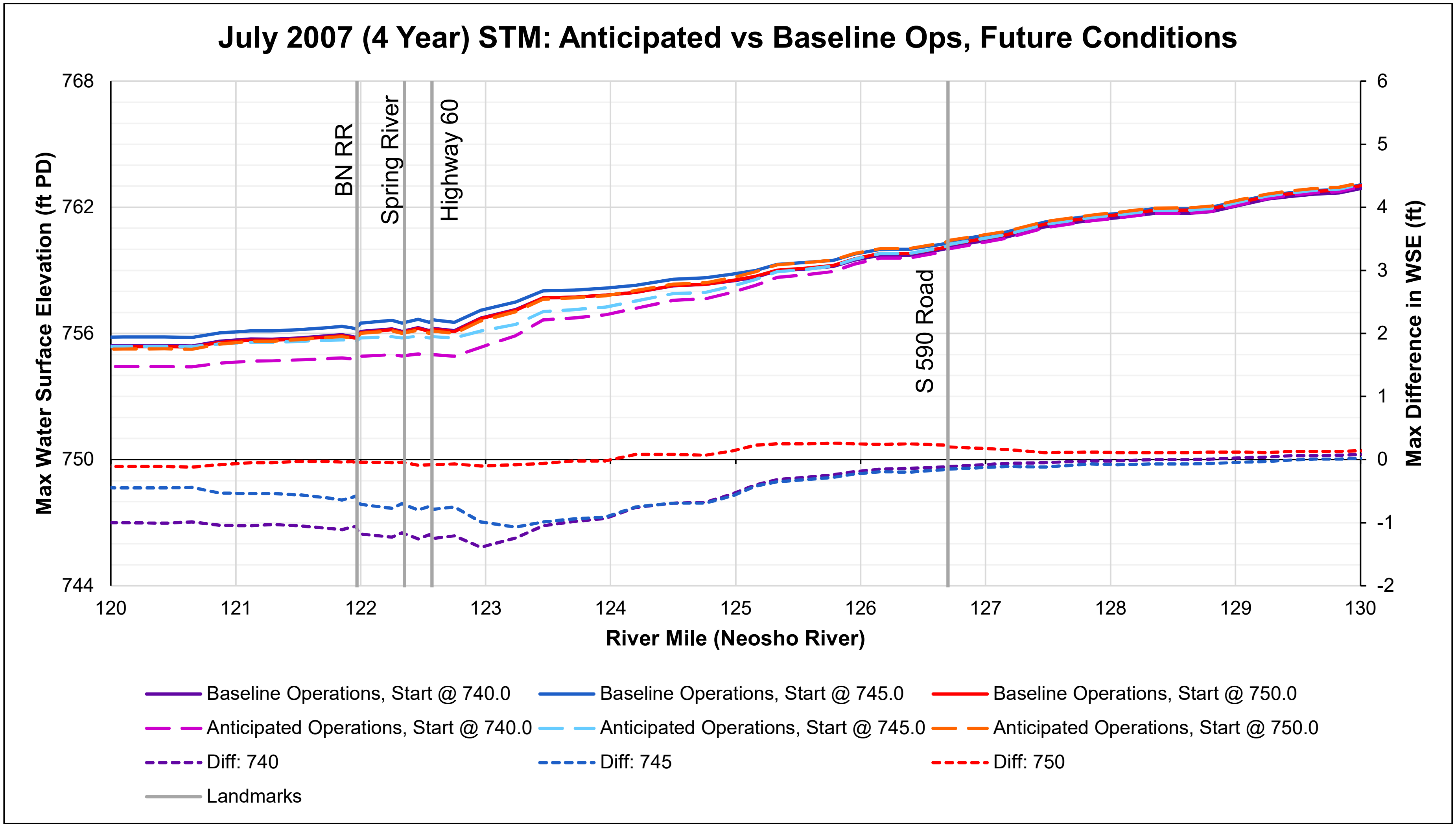
100-year STM: Sedimentation Rate Sensitivity
Max Water Surface Elevation (ft PD)
792
786
780
774
768
Max Difference in WSE (ft)
6
5
4
3
2
1
0
-1
-2
River Mile (Tar Creek)
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
OK Highway 10
Central Ave
Rockdale Blvd
BN RR
22nd Ave
Low Sed Rate, Start @ 740.0
Low Sed Rate, Start @ 745.0
Low Sed Rate, Start @ 750.0
High Sed Rate, Start @ 740.0
High Sed Rate, Start @ 745.0
High Sed Rate, Start @ 750.0
Diff: 740
Diff: 745
Diff: 750
Landmarks



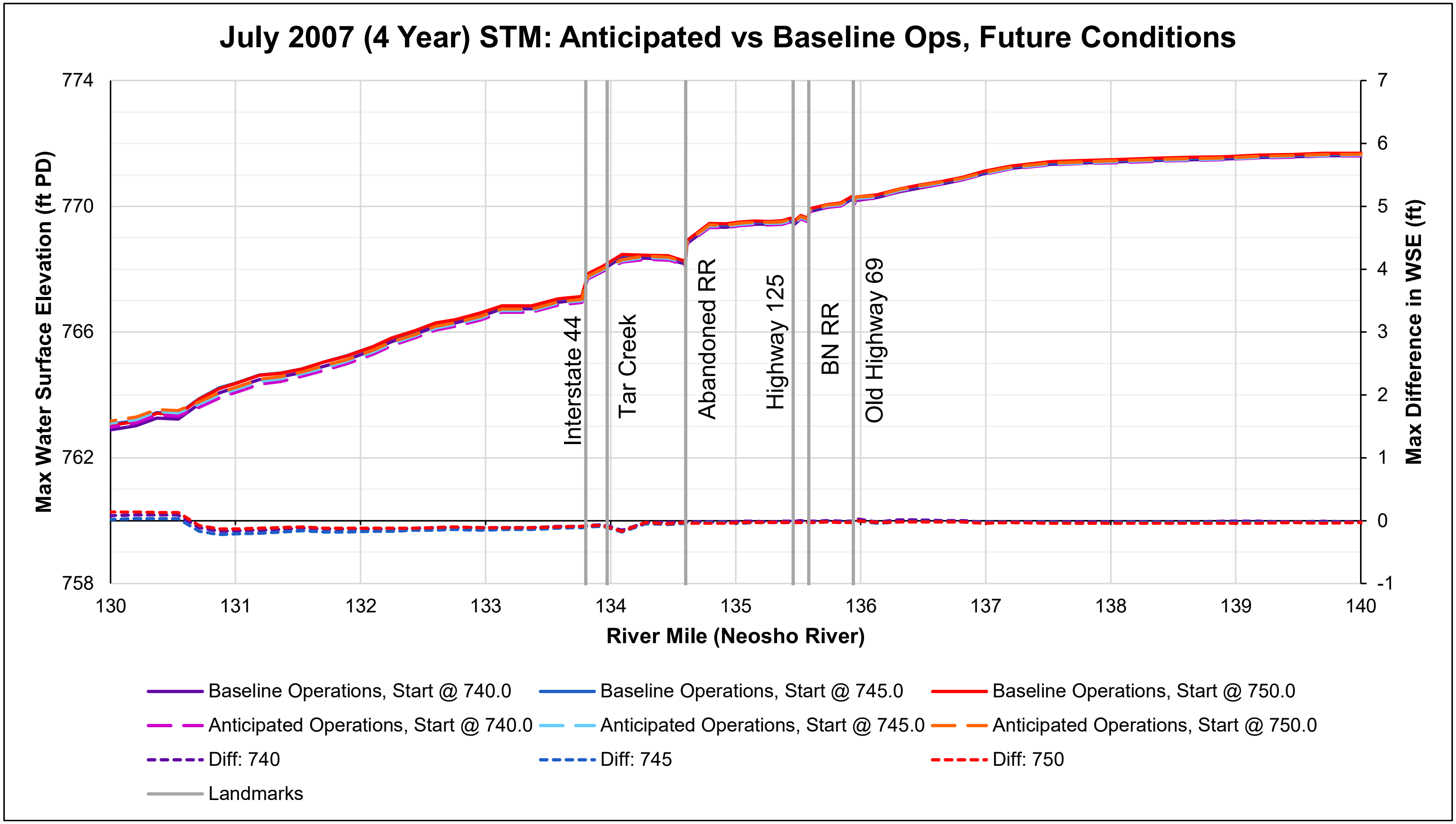
July 2007 (4 Year) STM: Anticipated vs Baseline Ops, Future Conditions
Max Water Surface Elevation (ft PD)
758
756
754
752
750
Max Difference in WSE (ft)
6
5
4
3
2
1
0
-1
-2
Highway 59 (Sailboat Bridge)
Elk River
100
101
102
103
104
105
106
107
108
109
110
River Mile (Neosho River)
Baseline Operations, Start @ 740.0
Baseline Operations, Start @ 745.0
Baseline Operations, Start @ 750.0
Anticipated Operations, Start @ 740.0
Anticipated Operations, Start @ 745.0
Anticipated Operations, Start @ 750.0
Diff: 740
Diff: 745
Diff: 750
Landmarks



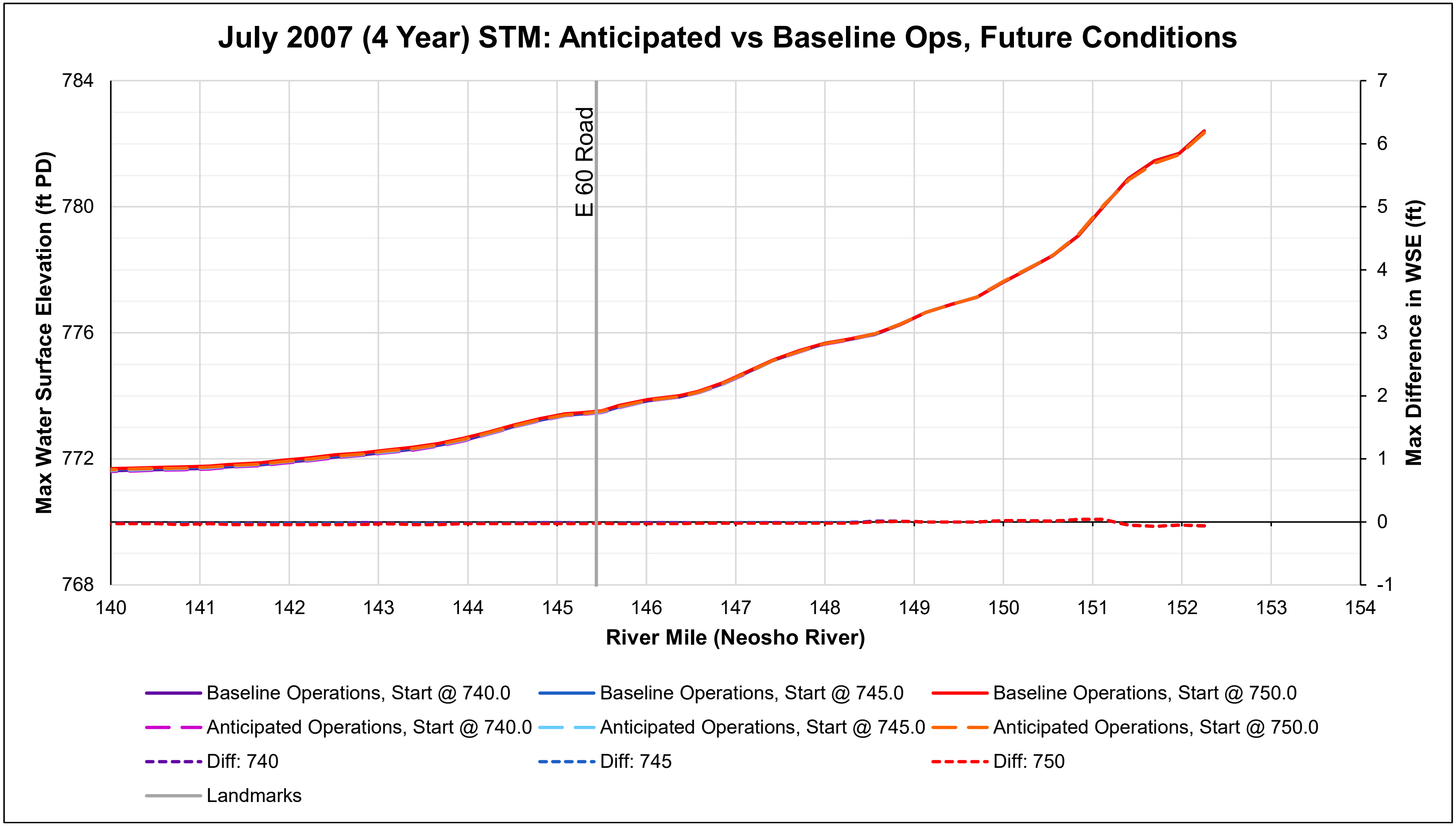
July 2007 (4 Year) STM: Anticipated vs Baseline Ops, Future Conditions
Max Water Surface Elevation (ft PD)
758
756
754
752
750
Max Difference in WSE (ft)
6
5
4
3
2
1
0
-1
-2
110
111
112
113
114
115
116
117
118
119
120
River Mile (Neosho River)
Baseline Operations, Start @ 740.0
Baseline Operations, Start @ 745.0
Baseline Operations, Start @ 750.0
Anticipated Operations, Start @ 740.0
Anticipated Operations, Start @ 745.0
Anticipated Operations, Start @ 750.0
Diff: 740
Diff: 745
Diff: 750
Landmarks



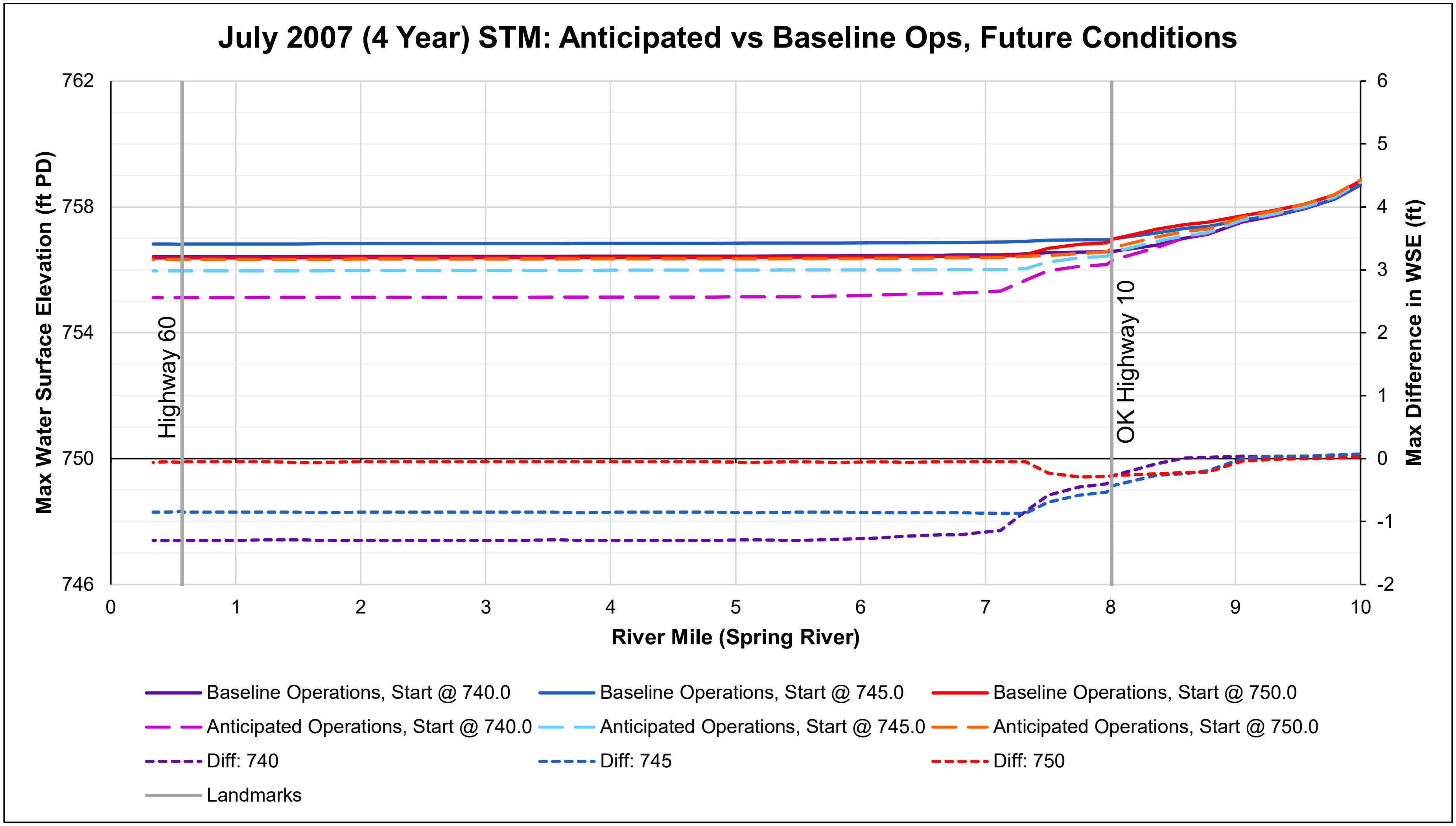
July 2007 (4 Year) STM: Anticipated vs Baseline Ops, Future Conditions
Max Water Surface Elevation (ft PD)
Max Difference in WSE (ft)
River Mile (Neosho River)
768
762
756
750
744
6
5
4
3
2
1
0
-1
-2
120
121
122
123
124
125
126
127
128
129
130
BN RR
Spring River
Highway 60
S 590 Road
Baseline Operations, Start @ 740.0
Baseline Operations, Start @ 745.0
Baseline Operations, Start @ 750.0
Anticipated Operations, Start @ 740.0
Anticipated Operations, Start @ 745.0
Anticipated Operations, Start @ 750.0
Diff: 740
Diff: 745
Diff: 750
Landmarks



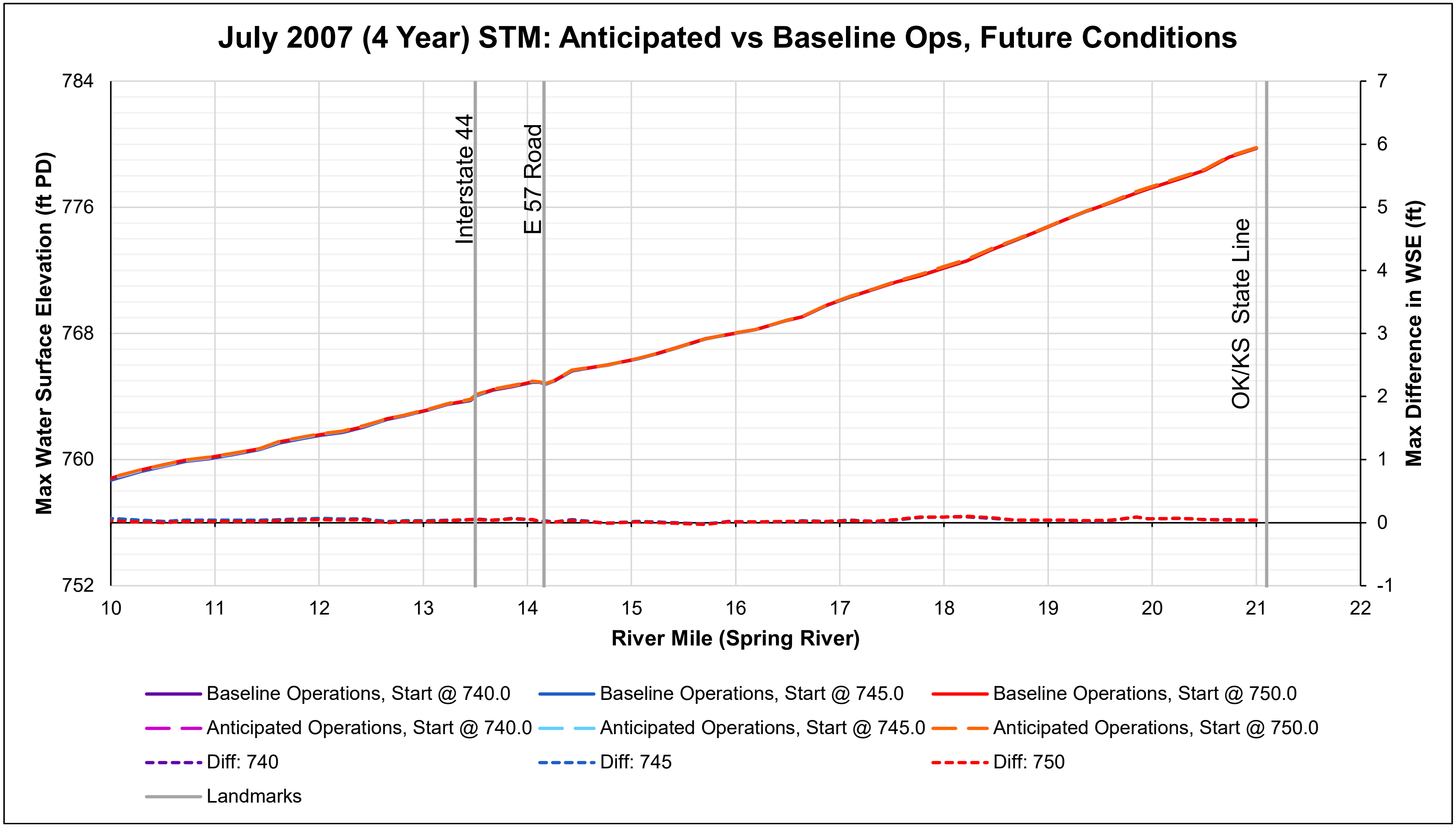
July 2007 (4 Year) STM: Anticipated vs Baseline Ops, Future Conditions
Max Water Surface Elevation (ft PD)
Max Difference in WSE (ft)
River Mile (Neosho River)
774
770
766
762
758
7
6
5
4
3
2
1
0
-1
130
131
132
133
134
135
136
137
138
139
140
Interstate 44
Tar Creek
Abandoned RR
Highway 125
BN RR
Old Highway 69
Baseline Operations, Start @ 740.0
Baseline Operations, Start @ 745.0
Baseline Operations, Start @ 750.0
Anticipated Operations, Start @ 740.0
Anticipated Operations, Start @ 745.0
Anticipated Operations, Start @ 750.0
Diff: 740
Diff: 745
Diff: 750
Landmarks



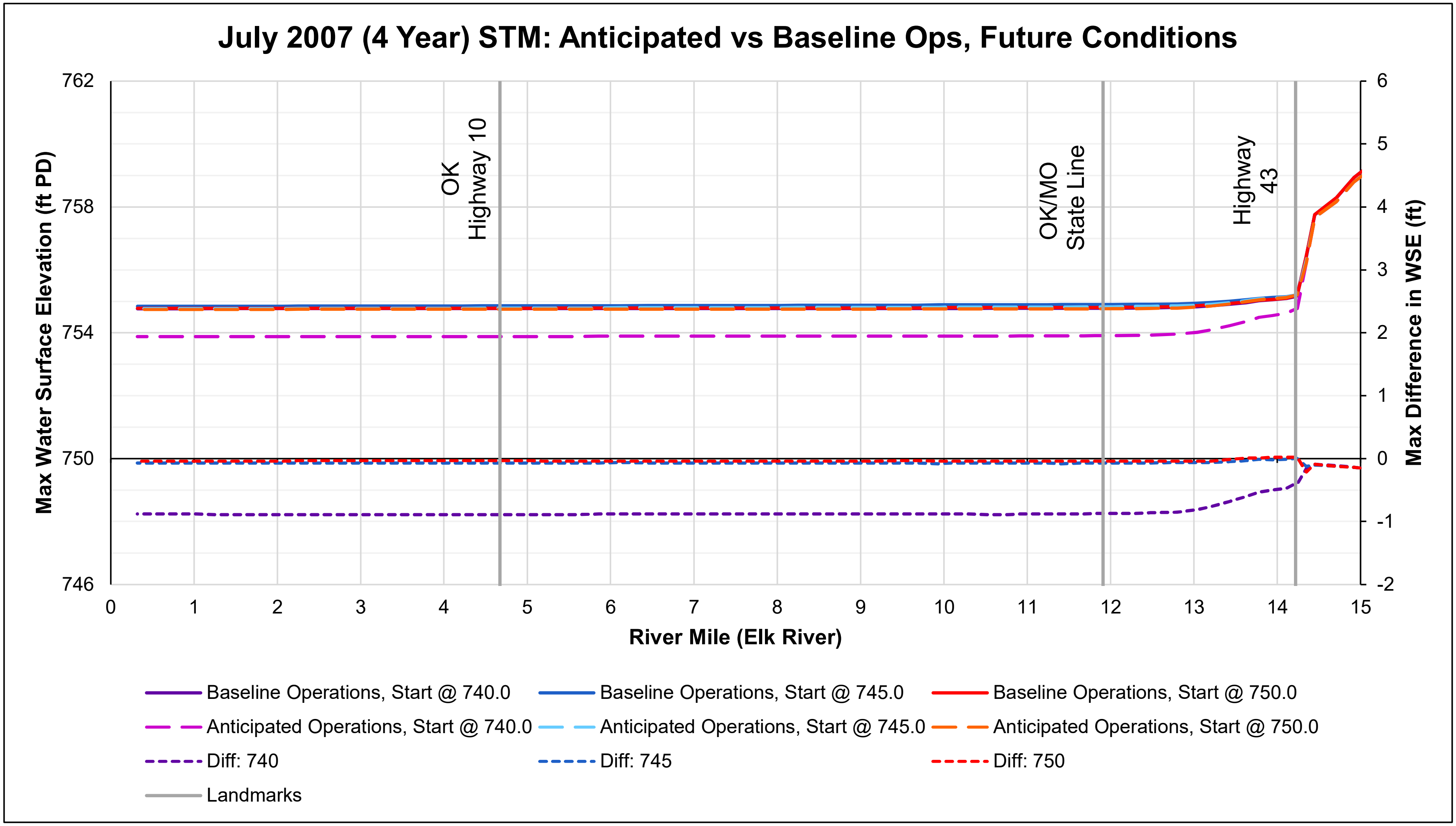
July 2007 (4 Year) STM: Anticipated vs Baseline Ops, Future Conditions
Max Water Surface Elevation (ft PD)
Max Difference in WSE (ft)
River Mile (Neosho River)
E 60 Road
784
780
776
772
768
7
6
5
4
3
2
1
0
-1
140
141
142
143
144
145
146
147
148
149
150
151
152
153
154
Baseline Operations, Start @ 740.0
Baseline Operations, Start @ 745.0
Baseline Operations, Start @ 750.0
Anticipated Operations, Start @ 740.0
Anticipated Operations, Start @ 745.0
Anticipated Operations, Start @ 750.0
Diff: 740
Diff: 745
Diff: 750
Landmarks



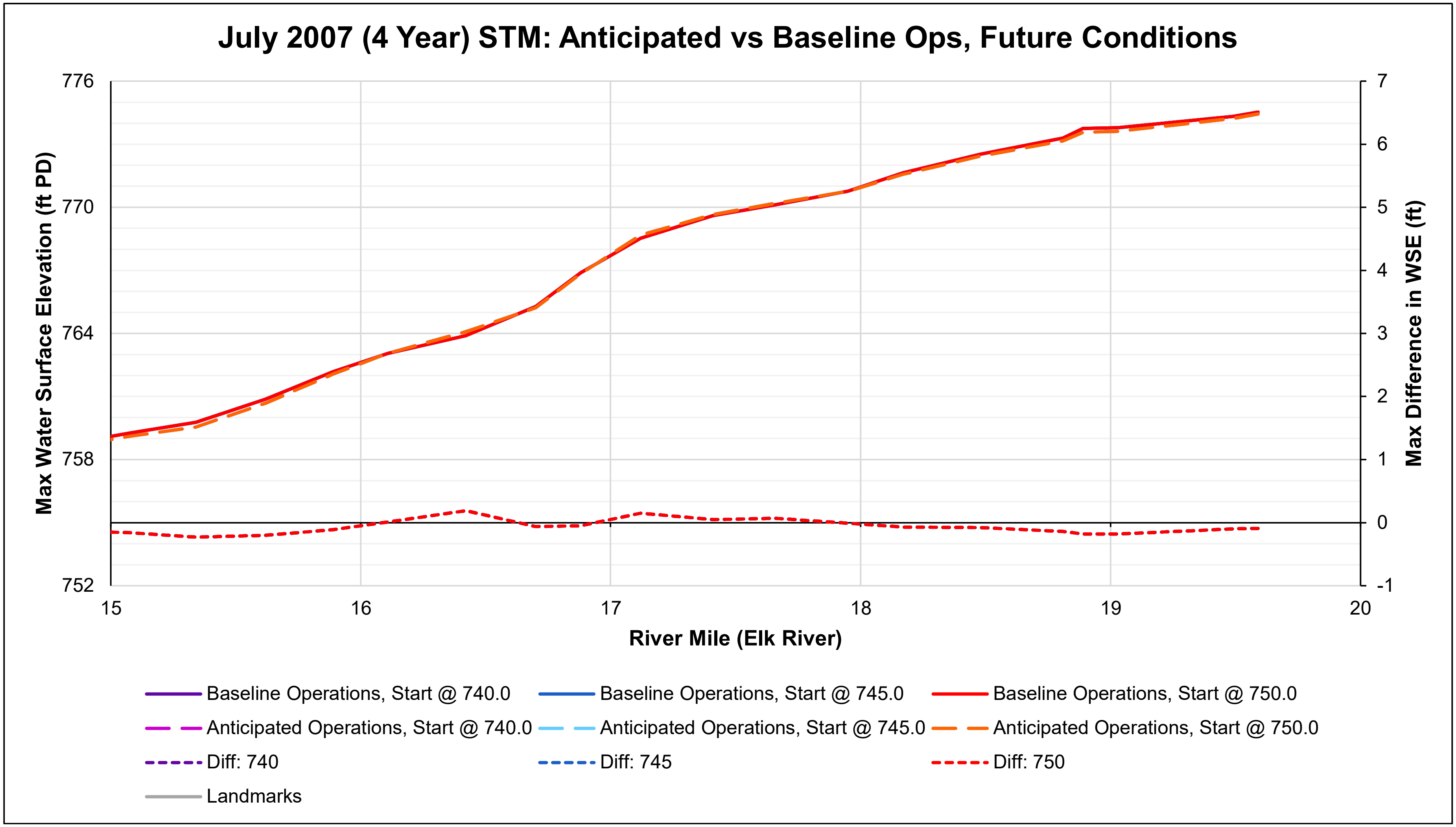
July 2007 (4 Year) STM: Anticipated vs Baseline Ops, Future Conditions
Max Water Surface Elevation (ft PD)
762
758
754
750
746
Max Difference in WSE (ft)
6
5
4
3
2
1
0
-1
-2
0
1
2
3
4
5
6
7
8
9
10
River Mile (Spring River)
Highway 60
OK Highway 10
Baseline Operations, Start @ 740.0
Baseline Operations, Start @ 745.0
Baseline Operations, Start @ 750.0
Anticipated Operations, Start @ 740.0
Anticipated Operations, Start @ 745.0
Anticipated Operations, Start @ 750.0
Diff: 740
Diff: 745
Diff: 750
Landmarks



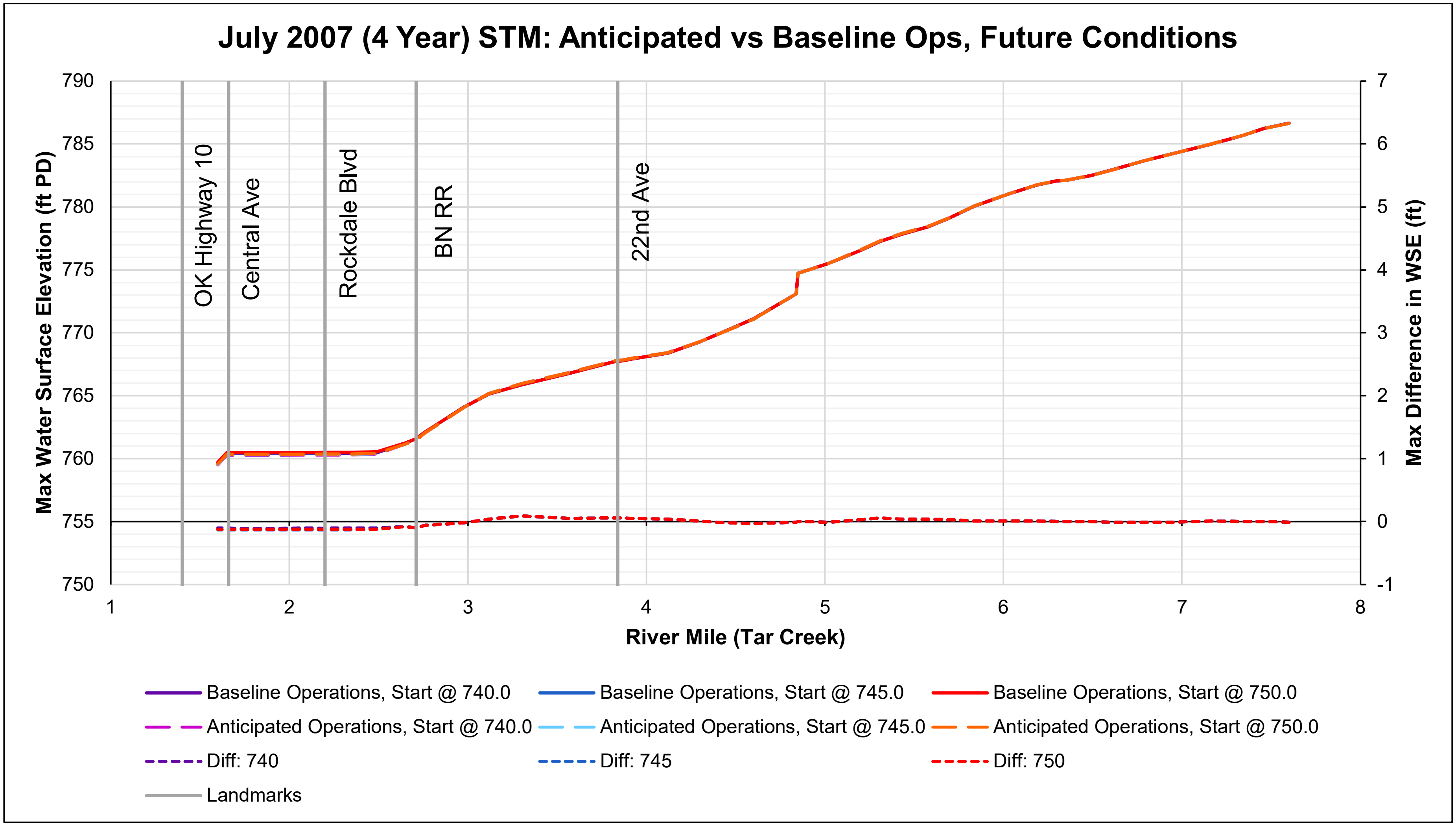
July 2007 (4 Year) STM: Anticipated vs Baseline Ops, Future Conditions
Max Water Surface Elevation (ft PD)
784
776
768
760
752
Max Difference in WSE (ft)
7
6
5
4
3
2
1
0
-1
Interstate 44
E 57 Road
OK/KS State Line
10
11
12
13
14
15
16
17
18
19
20
21
22
River Mile (Spring River)
Baseline Operations, Start @ 740.0
Baseline Operations, Start @ 745.0
Baseline Operations, Start @ 750.0
Anticipated Operations, Start @ 740.0
Anticipated Operations, Start @ 745.0
Anticipated Operations, Start @ 750.0
Diff: 740
Diff: 745
Diff: 750
Landmarks



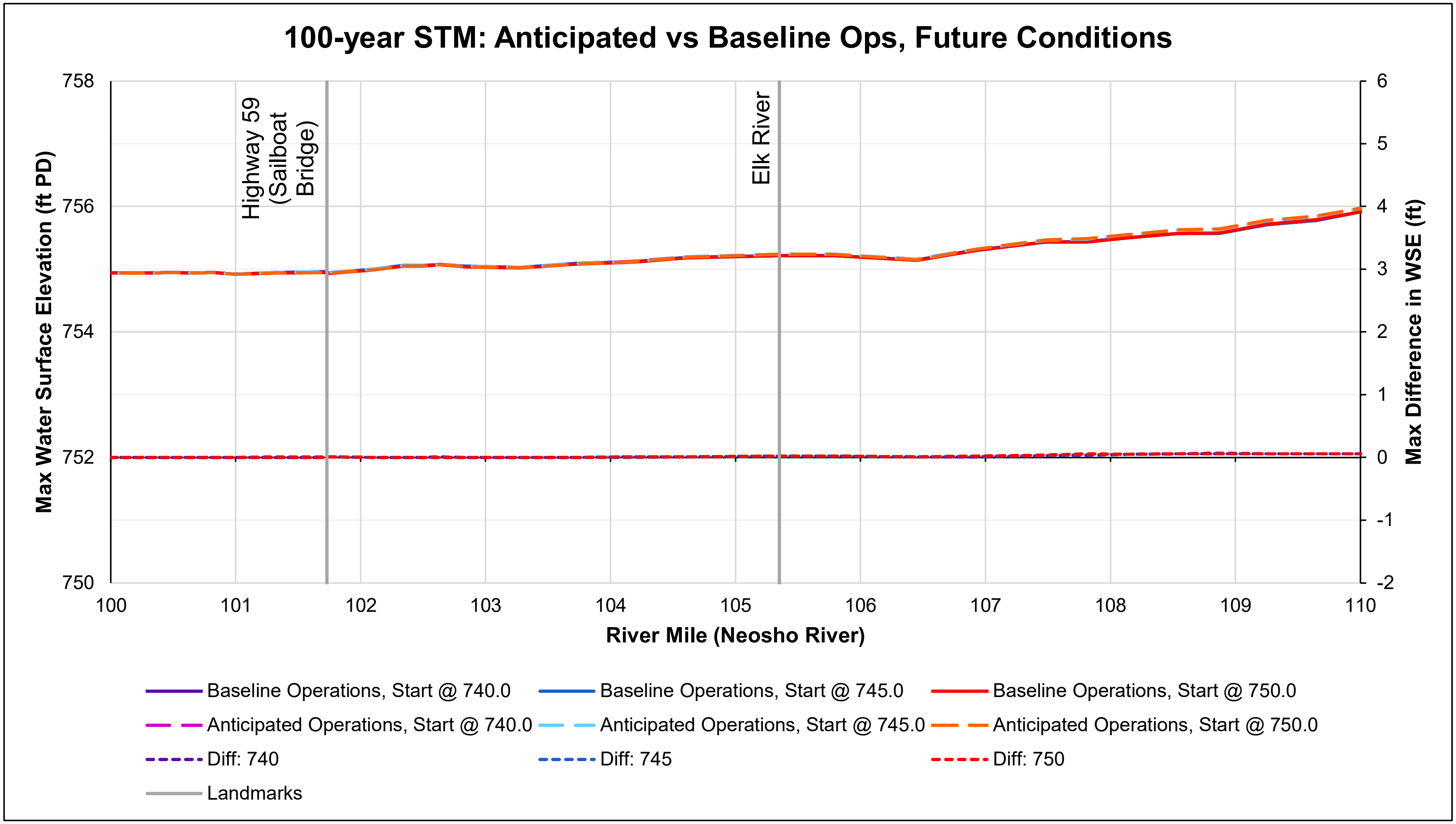
July 2007 (4 Year) STM: Anticipated vs Baseline Ops, Future Conditions
Max Water Surface Elevation (ft PD)
Max Difference in WSE (ft)
River Mile (Elk River)
762
758
754
750
746
6
5
4
3
2
1
0
-1
-2
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
OK
Highway 10
OK/MO
State Line
Highway
43
Baseline Operations, Start @ 740.0
Baseline Operations, Start @ 745.0
Baseline Operations, Start @ 750.0
Anticipated Operations, Start @ 740.0
Anticipated Operations, Start @ 745.0
Anticipated Operations, Start @ 750.0
Diff: 740
Diff: 745
Diff: 750
Landmarks



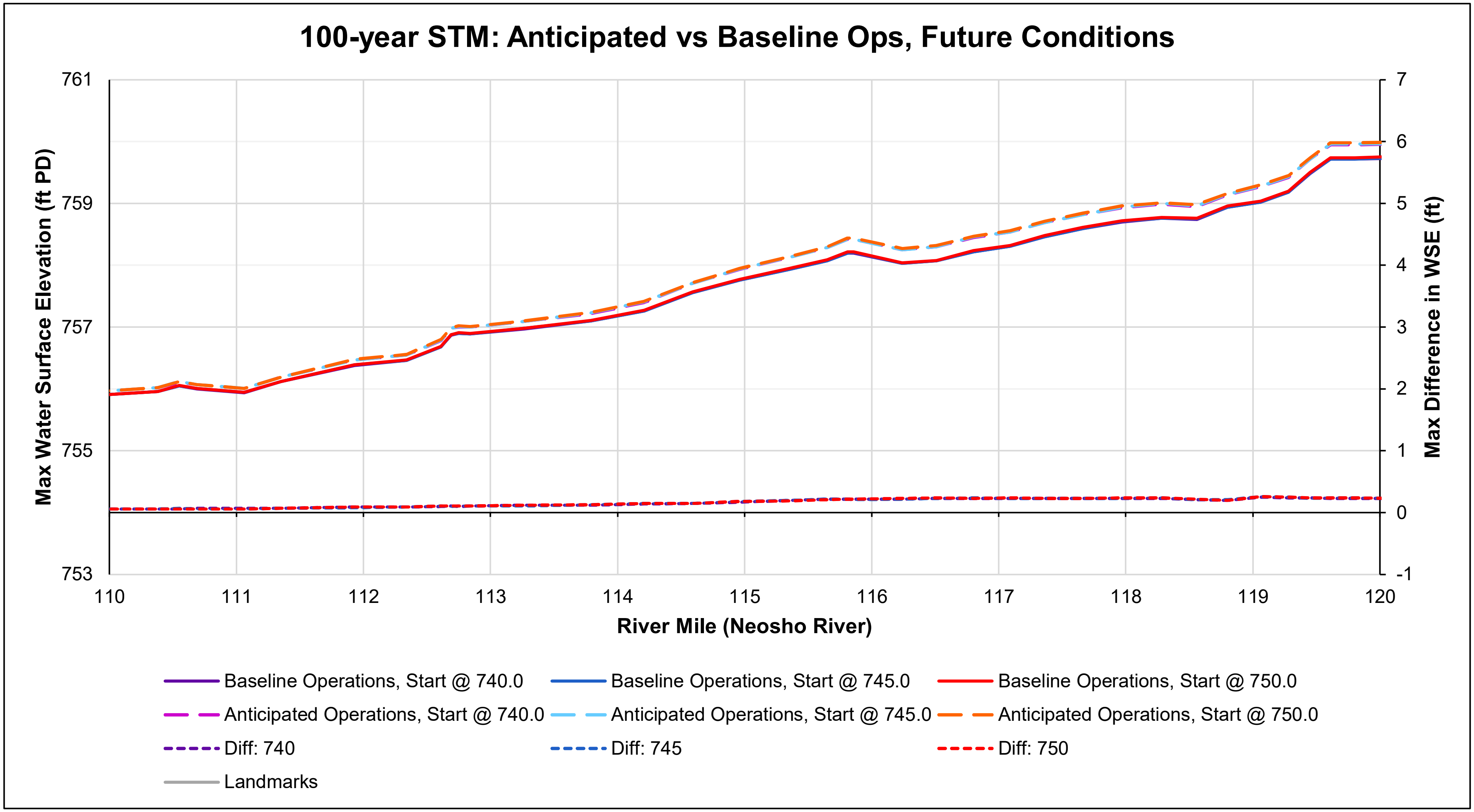
July 2007 (4 Year) STM: Anticipated vs Baseline Ops, Future Conditions
Max Water Surface Elevation (ft PD)
776
770
764
758
752
Max Difference in WSE (ft)
7
6
5
4
3
2
1
0
-1
15
16
17
18
19
20
River Mile (Elk River)
Baseline Operations, Start @ 740.0
Baseline Operations, Start @ 745.0
Baseline Operations, Start @ 750.0
Anticipated Operations, Start @ 740.0
Anticipated Operations, Start @ 745.0
Anticipated Operations, Start @ 750.0
Diff: 740
Diff: 745
Diff: 750
Landmarks

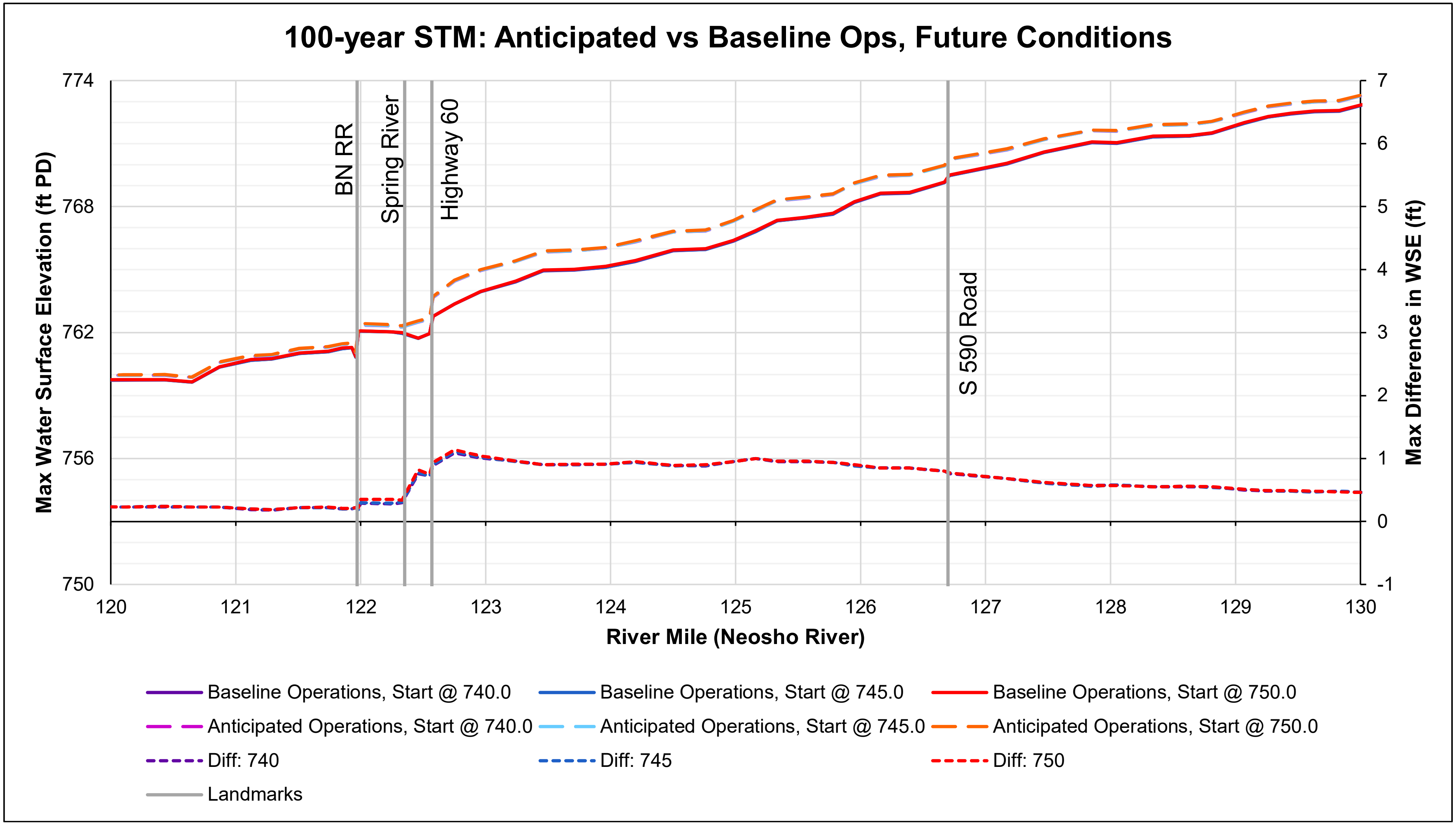


July 2007 (4 Year) STM: Anticipated vs Baseline Ops, Future Conditions
Max Water Surface Elevation (ft PD)
Max Difference in WSE (ft)
River Mile (Tar Creek)
790
785
780
775
770
765
760
755
750
7
6
5
4
3
2
1
0
-1
1
2
3
4
5
6
7
8
OK Highway 10
Central Ave
Rockdale Blvd
BN RR
22nd Ave
Baseline Operations, Start @ 740.0
Baseline Operations, Start @ 745.0
Baseline Operations, Start @ 750.0
Anticipated Operations, Start @ 740.0
Anticipated Operations, Start @ 745.0
Anticipated Operations, Start @ 750.0
Diff: 740
Diff: 745
Diff: 750
Landmarks

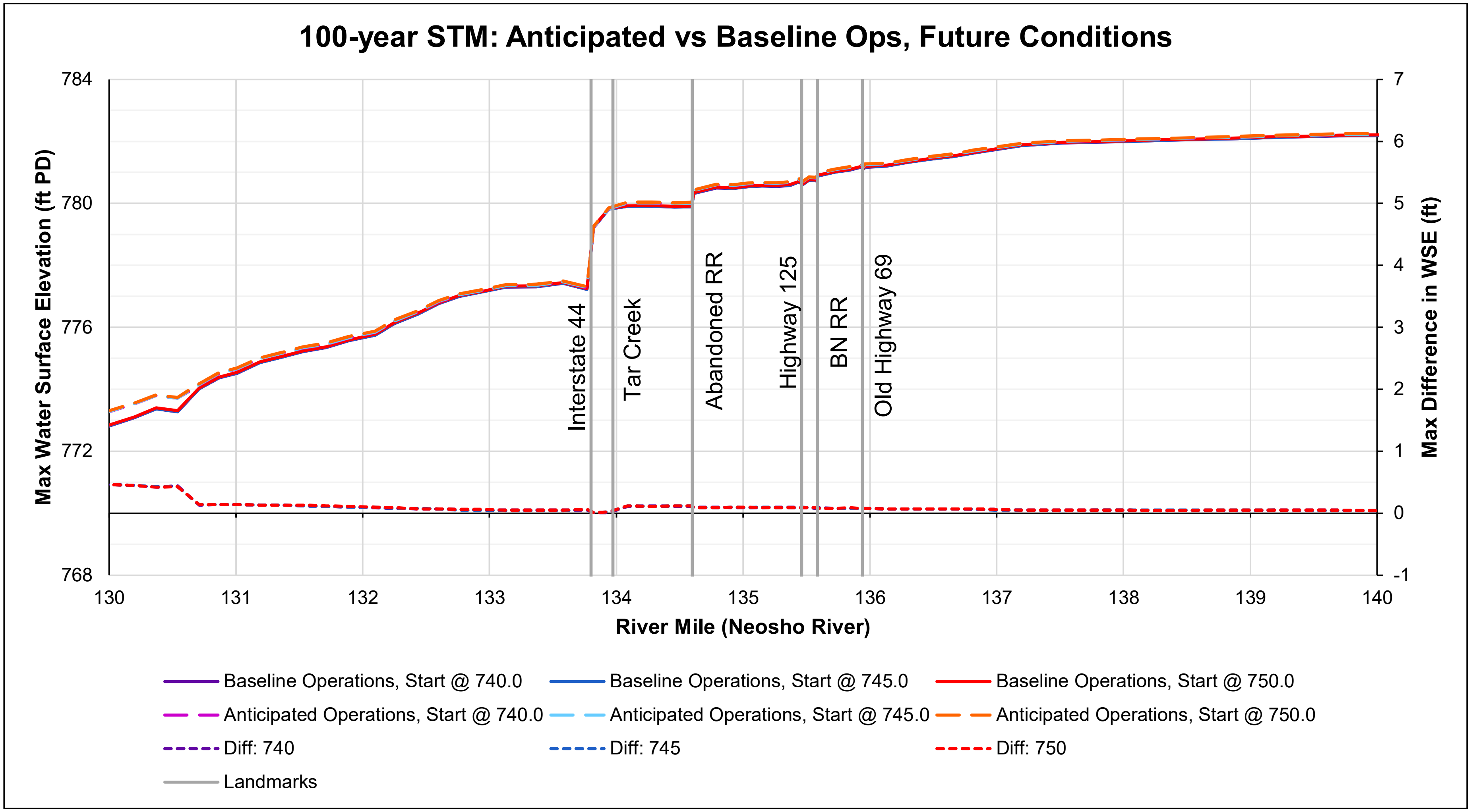


100-year STM: Anticipated vs Baseline Ops, Future Conditions
Max Water Surface Elevation (ft PD)
Max Difference in WSE (ft)
River Mile (Neosho River)
Highway 59 (Sailboat Bridge)
Elk River
758
756
754
752
750
6
5
4
3
2
1
0
-1
-2
100
101
102
103
104
105
106
107
108
109
110
Baseline Operations, Start @ 740.0
Baseline Operations, Start @ 745.0
Baseline Operations, Start @ 750.0
Anticipated Operations, Start @ 740.0
Anticipated Operations, Start @ 745.0
Anticipated Operations, Start @ 750.0
Diff: 740
Diff: 745
Diff: 750
Landmarks

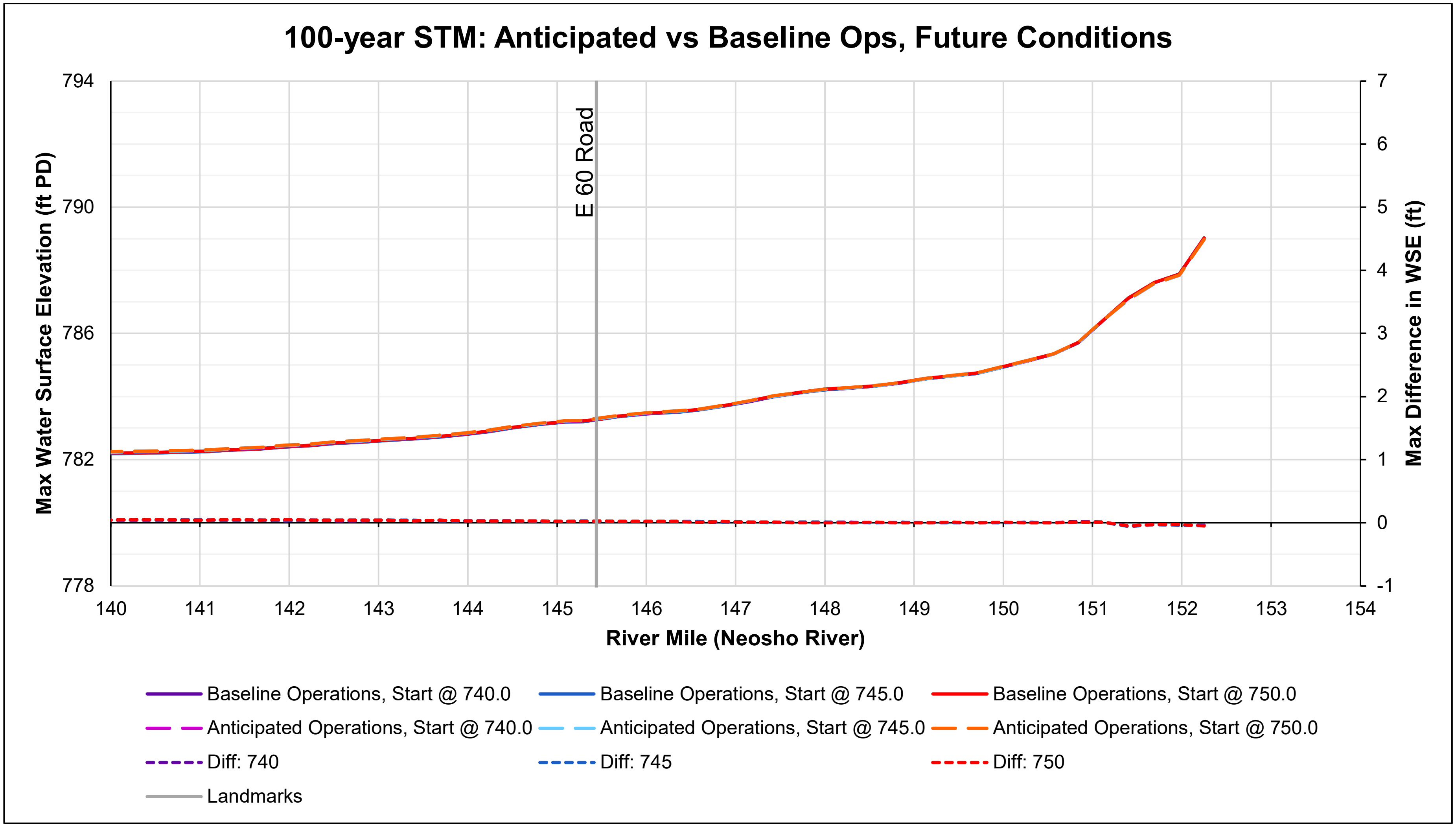

100-year STM: Anticipated vs Baseline Ops, Future Conditions
Max Water Surface Elevation (ft PD)
Max Difference in WSE (ft)
River Mile (Neosho River)
761
759
757
755
753
7
6
5
4
3
2
1
0
-1
110
111
112
113
114
115
116
117
118
119
120
Baseline Operations, Start @ 740.0
Baseline Operations, Start @ 745.0
Baseline Operations, Start @ 750.0
Anticipated Operations, Start @ 740.0
Anticipated Operations, Start @ 745.0
Anticipated Operations, Start @ 750.0
Diff: 740
Diff: 745
Diff: 750
Landmarks

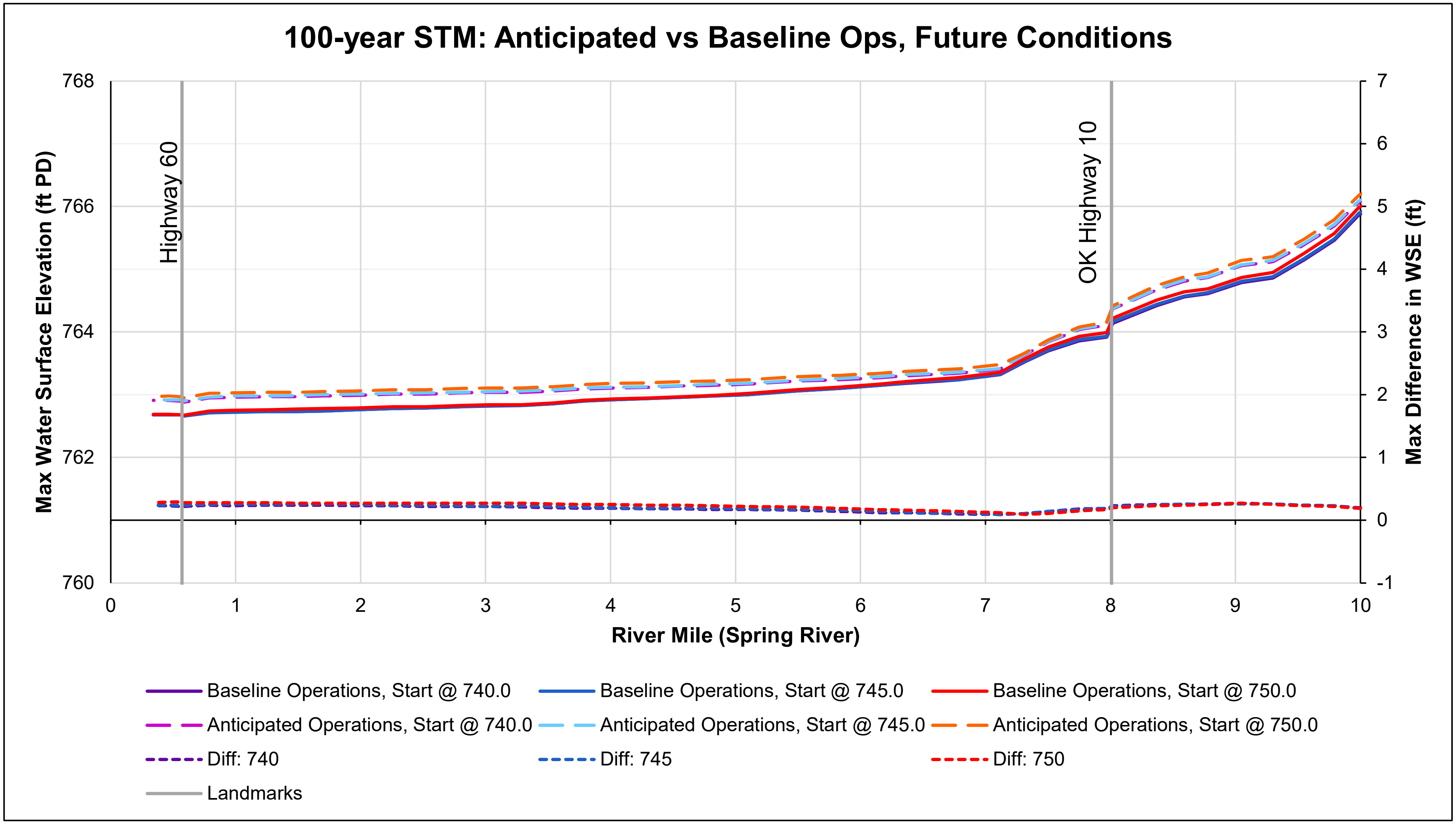


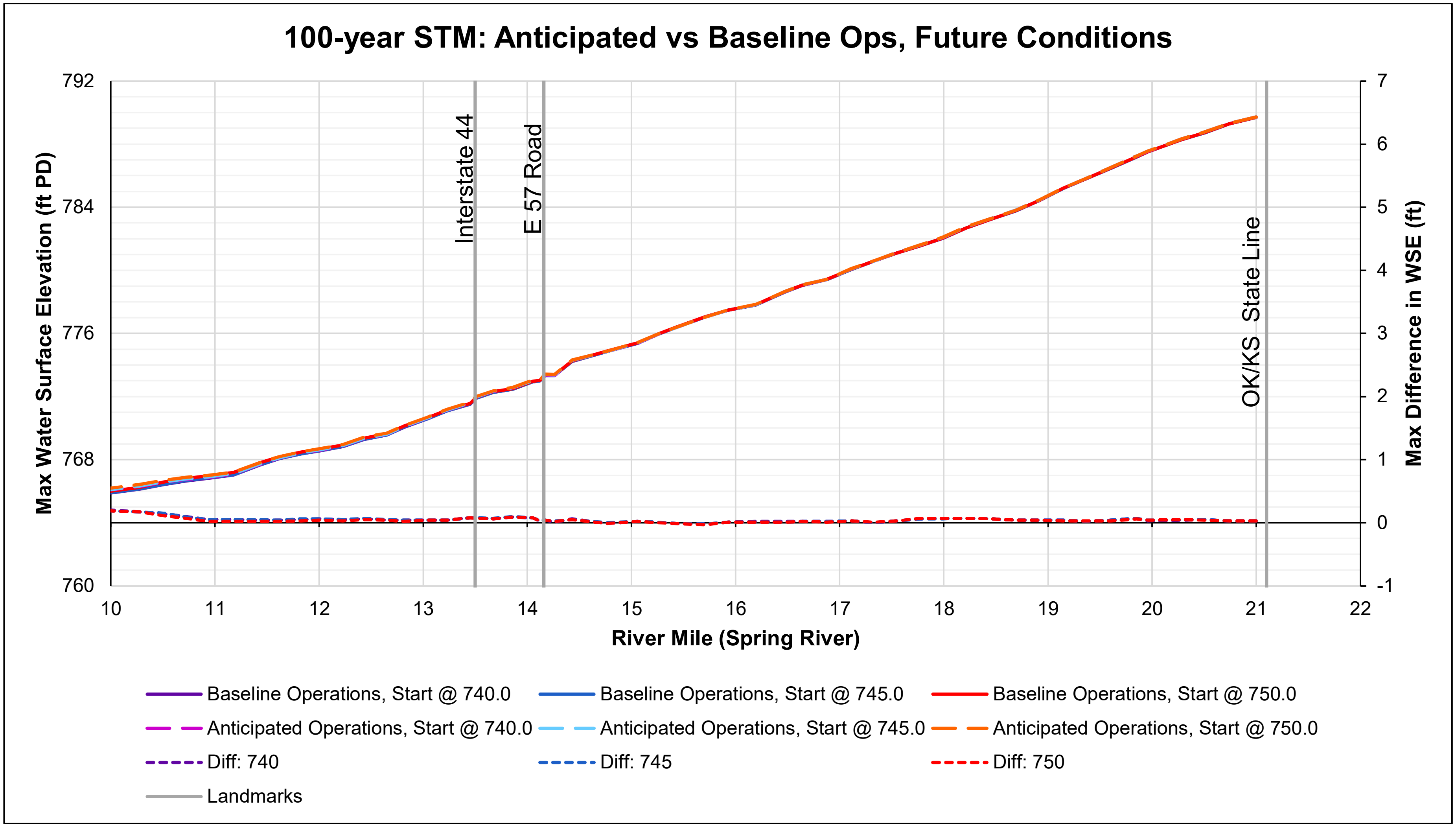
100-year STM: Anticipated vs Baseline Ops, Future Conditions
Max Water Surface Elevation (ft PD)
Max Difference in WSE (ft)
River Mile (Neosho River)
774
768
762
756
750
7
6
5
4
3
2
1
0
-1
120
121
122
123
124
125
126
127
128
129
130
BN RR
Spring River
Highway 60
S 590 Road
Baseline Operations, Start @ 740.0
Baseline Operations, Start @ 745.0
Baseline Operations, Start @ 750.0
Anticipated Operations, Start @ 740.0
Anticipated Operations, Start @ 745.0
Anticipated Operations, Start @ 750.0
Diff: 740
Diff: 745
Diff: 750
Landmarks

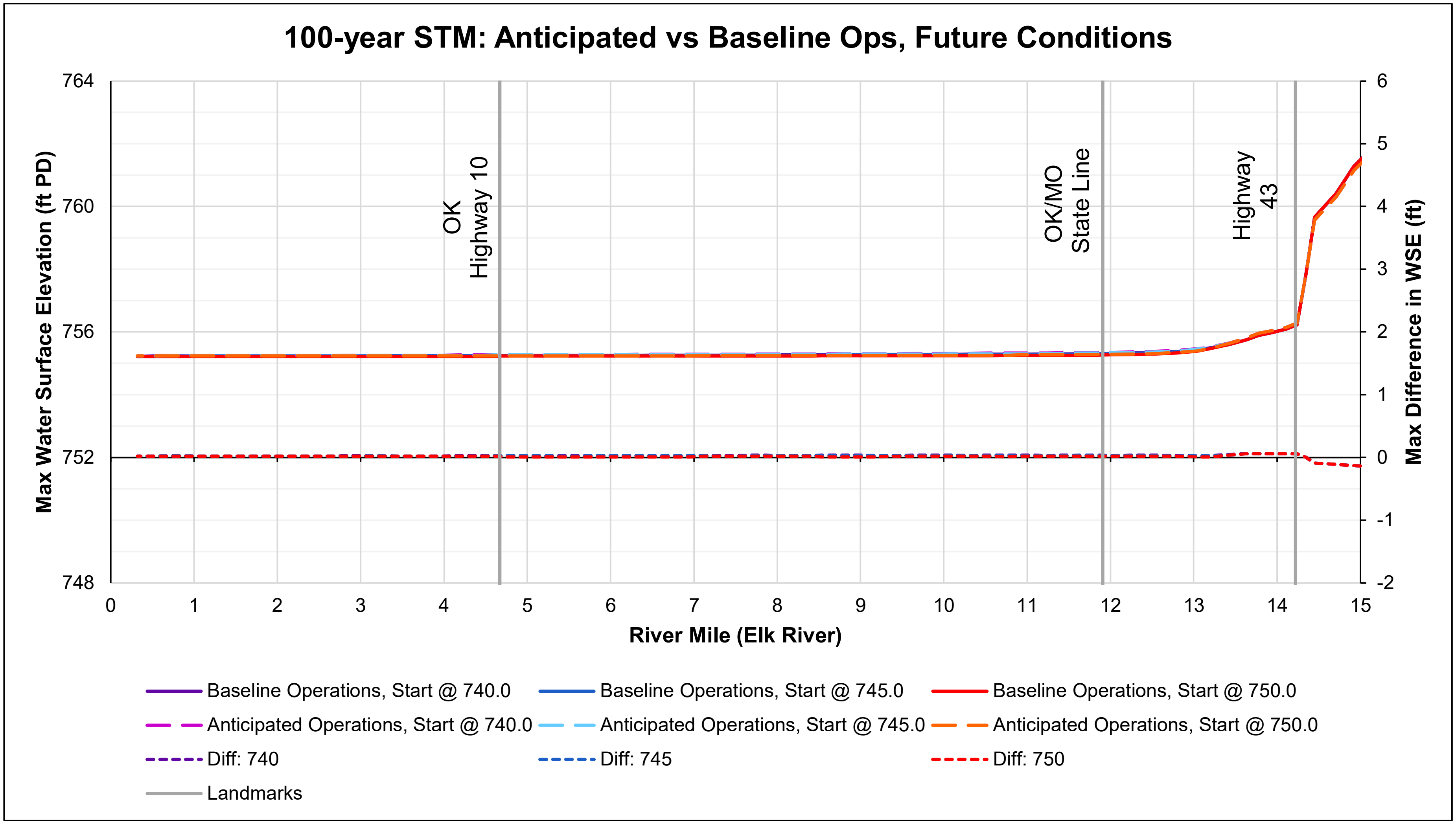


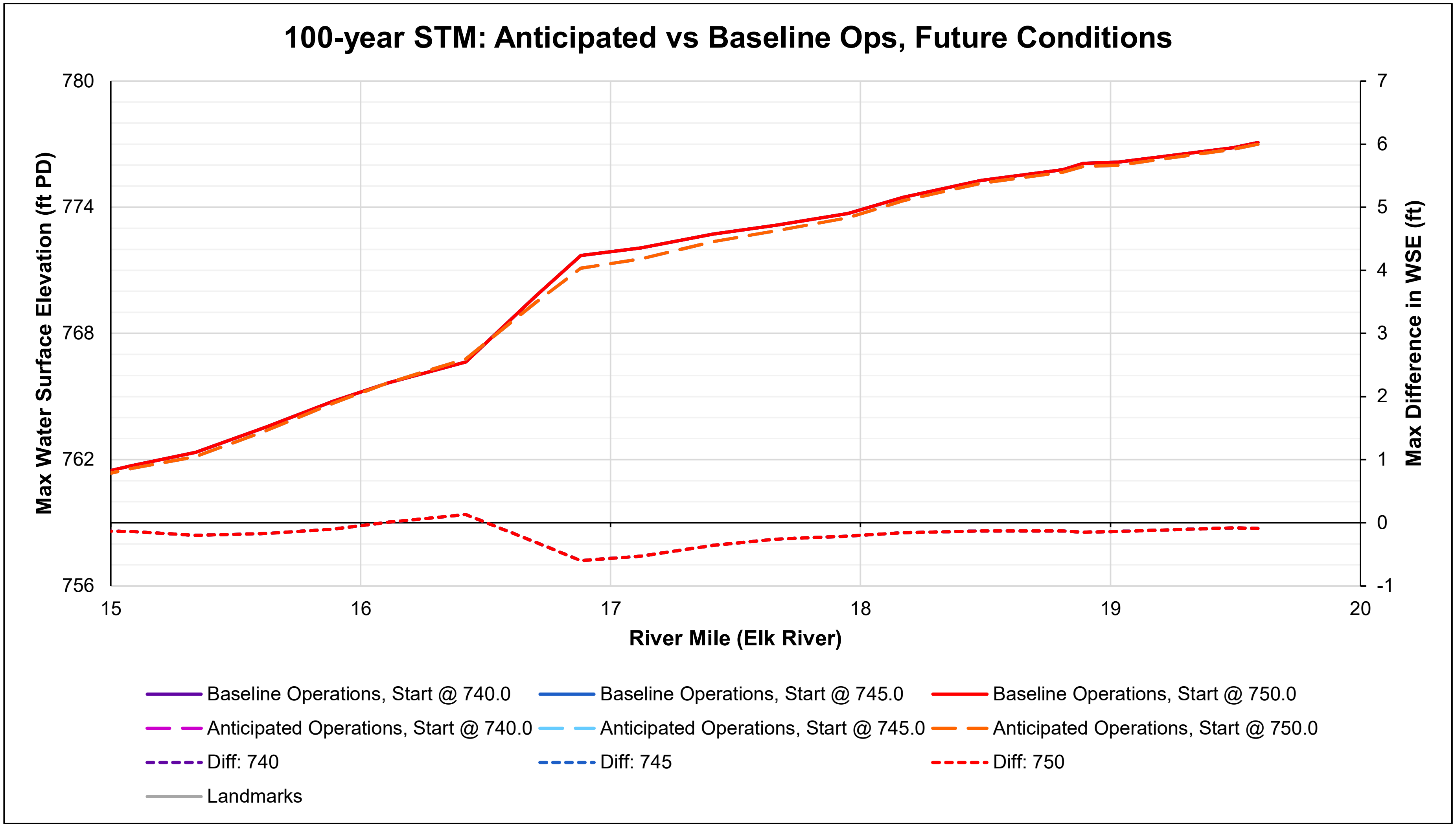
100-year STM: Anticipated vs Baseline Ops, Future Conditions
Max Water Surface Elevation (ft PD)
784
780
776
772
768
Max Difference in WSE (ft)
7
6
5
4
3
2
1
0
-1
130
131
132
133
134
135
136
137
138
139
140
River Mile (Neosho River)
Interstate 44
Tar Creek
Abandoned RR
Highway 125
BN RR
Old Highway 69
Baseline Operations, Start @ 740.0
Baseline Operations, Start @ 745.0
Baseline Operations, Start @ 750.0
Anticipated Operations, Start @ 740.0
Anticipated Operations, Start @ 745.0
Anticipated Operations, Start @ 750.0
Diff: 740
Diff: 745
Diff: 750
Landmarks


100-year STM: Anticipated vs Baseline Ops, Future Conditions
Max Water Surface Elevation (ft PD)
794
790
786
782
778
Max Difference in WSE (ft)
7
6
5
4
3
2
1
0
-1
E 60 Road
140
141
142
143
144
145
146
147
148
149
150
151
152
153
154
River Mile (Neosho River)
Baseline Operations, Start @ 740.0
Baseline Operations, Start @ 745.0
Baseline Operations, Start @ 750.0
Anticipated Operations, Start @ 740.0
Anticipated Operations, Start @ 745.0
Anticipated Operations, Start @ 750.0
Diff: 740
Diff: 745
Diff: 750
Landmarks

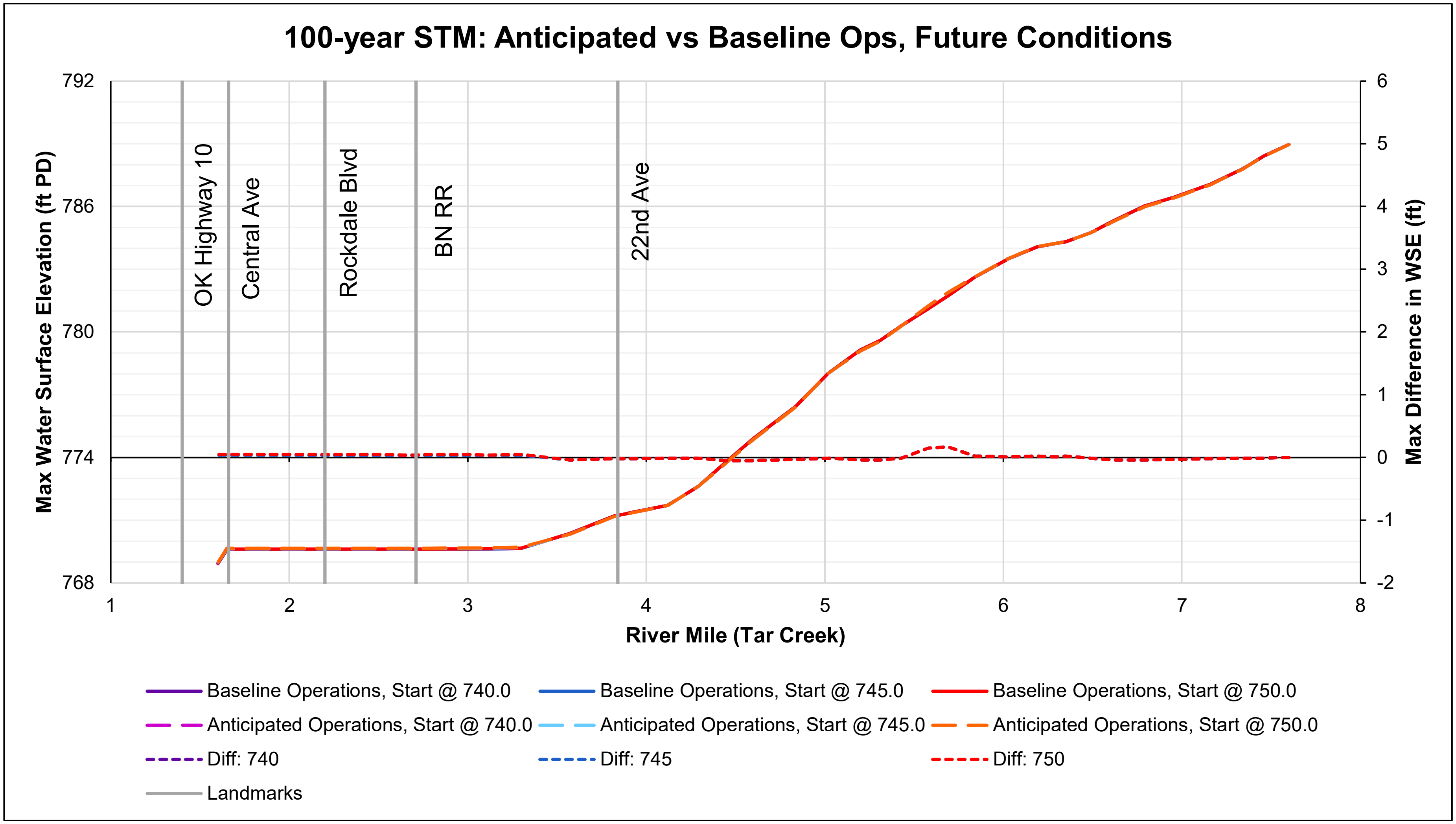

100-year STM: Anticipated vs Baseline Ops, Future Conditions
Max Water Surface Elevation (ft PD)
Max Difference in WSE (ft)
River Mile (Spring River)
Highway 60
OK Highway 10
768
766
764
762
760
7
6
5
4
3
2
1
0
-1
0
1
2
3
4
5
6
7
8
9
10
Baseline Operations, Start @ 740.0
Baseline Operations, Start @ 745.0
Baseline Operations, Start @ 750.0
Anticipated Operations, Start @ 740.0
Anticipated Operations, Start @ 745.0
Anticipated Operations, Start @ 750.0
Diff: 740
Diff: 745
Diff: 750
Landmarks


100-year STM: Anticipated vs Baseline Ops, Future Conditions
Max Water Surface Elevation (ft PD)
Max Difference in WSE (ft)
River Mile (Spring River)
Interstate 44
E 57 Road
OK/KS State Line
792
784
776
768
760
7
6
5
4
3
2
1
0
-1
10
11
12
13
14
15
16
17
18
19
20
21
22
Baseline Operations, Start @ 740.0
Baseline Operations, Start @ 745.0
Baseline Operations, Start @ 750.0
Anticipated Operations, Start @ 740.0
Anticipated Operations, Start @ 745.0
Anticipated Operations, Start @ 750.0
Diff: 740
Diff: 745
Diff: 750
Landmarks


100-year STM: Anticipated vs Baseline Ops, Future Conditions
Max Water Surface Elevation (ft PD)
Max Difference in WSE (ft)
River Mile (Elk River)
764
760
756
752
748
6
5
4
3
2
1
0
-1
-2
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
OK Highway 10
OK/MO State Line
Highway 43
Baseline Operations, Start @ 740.0
Baseline Operations, Start @ 745.0
Baseline Operations, Start @ 750.0
Anticipated Operations, Start @ 740.0
Anticipated Operations, Start @ 745.0
Anticipated Operations, Start @ 750.0
Diff: 740
Diff: 745
Diff: 750
Landmarks



100-year STM: Anticipated vs Baseline Ops, Future Conditions
Max Water Surface Elevation (ft PD)
780
774
768
762
756
Max Difference in WSE (ft)
7
6
5
4
3
2
1
0
-1
15
16
17
18
19
20
River Mile (Elk River)
Baseline Operations, Start @ 740.0
Baseline Operations, Start @ 745.0
Baseline Operations, Start @ 750.0
Anticipated Operations, Start @ 740.0
Anticipated Operations, Start @ 745.0
Anticipated Operations, Start @ 750.0
Diff: 740
Diff: 745
Diff: 750
Landmarks



100-year STM: Anticipated vs Baseline Ops, Future Conditions
Max Water Surface Elevation (ft PD)
792
786
780
774
768
Max Difference in WSE (ft)
6
5
4
3
2
1
0
-1
-2
River Mile (Tar Creek)
1
2
3
4
5
6
7
8
OK Highway 10
Central Ave
Rockdale Blvd
BN RR
22nd Ave
Baseline Operations, Start @ 740.0
Baseline Operations, Start @ 745.0
Baseline Operations, Start @ 750.0
Anticipated Operations, Start @ 740.0
Anticipated Operations, Start @ 745.0
Anticipated Operations, Start @ 750.0
Diff: 740
Diff: 745
Diff: 750
Landmarks

APPENDIX E-9 Grand Lake Bathymetric Map

U.S. Department of the Interior
U.S. Geological Survey

Prepared in cooperation with the
Grand River Dam Authority

Scientific Investigations Map 3467
Sheet 1 of 2

Acknowledgments

The authors would like to thank Darrell Townsend, Brian Edwards, and the Grand River Dam Authority Police Department for their assistance in boat storage and logistics. This bathymetric survey could not have been accomplished without their assistance. The authors would also like to thank Mike Williams for his assistance with lodging and hospitality throughout the project.

The authors also thank U.S. Geological Survey colleagues for their contributions to this bathymetric survey. Richard Huizinga and Jarrett Ellis provided advice in processing such a large dataset. Billy Heard, Marty Phillips, and Levi Close helped with data collection and surveying. James Hanlon was instrumental in custom fabrication and boat preparation regarding instrument deployment.

Abstract

The U.S. Geological Survey (USGS), in cooperation with the Grand River Dam Authority, completed a high-resolution multibeam bathymetric survey to compute a new area and capacity table for Grand Lake O' the Cherokees in northeastern Oklahoma. Area and capacity tables identify the relation between the elevation of the water surface and the volume of water that can be impounded at each water-surface elevation. The area and capacity of Grand Lake O' the Cherokees were computed from a triangular irregular network surface created in Global Mapper Version 21.0.1. The triangular irregular network surface was created from three datasets: (1) a multibeam mapping system bathymetric survey of Grand Lake O' the Cherokees completed during April–July 2019, (2) a previous bathymetric survey of the Neosho, Spring, and Elk Rivers, and (3) a 2010 USGS lidar-derived digital elevation model. The digital elevation model data were used in areas with land-surface elevations greater than 744 feet above the North American Vertical Datum of 1988 where the multibeam sonar data could not be collected. The 2019 multibeam sonar data were the predominant data used to compute the new area and capacity table for Grand Lake O' the Cherokees.

Introduction[1]

In February 2017, the Grand River Dam Authority (GRDA) filed a Pre-Application Document and Notice of Intent for relicensing the Pensacola Hydroelectric Project with the Federal Energy Regulatory Commission (FERC). The predominant feature of the Pensacola Hydroelectric Project (FERC license number 1494; GRDA, 2017) is Pensacola Dam, which impounds Grand Lake O' the Cherokees (known locally and hereinafter referred to as "Grand Lake") in northeastern Oklahoma. Identification of information gaps and assessment of project effects on stakeholders are central aspects of the FERC relicensing process (FERC, 2012). One of the information gaps is that a complete area and capacity table has not been produced since 1940. Area and capacity tables identify the relations between the elevation of the water surface and the volume of water that can be impounded at each water-surface elevation.

In the 80-year history of Grand Lake, only four area and capacity tables have been developed. The first area and capacity table was developed in 1940 by the U.S. Army Corps of Engineers (USACE) when the Pensacola Dam was built, spanning water-surface elevations from 612.33 to 758.33 feet (ft) (values adjusted to feet above the North American Vertical Datum of 1988) (NAVD 88) (Hunter and others, 2020). An updated area and capacity table was published in 1949, spanning water-surface elevations from 714.33 to 754.43 ft above NAVD 88 (Hunter and Labriola, 2019). In 2009, the Oklahoma Water Resources Board (OWRB) calculated a third area and capacity table, spanning water-surface elevations from 613.46 to 746.46 ft above NAVD 88 (OWRB, 2009). The fourth and most recent area and capacity table (Hunter and Labriola, 2019) was produced in 2019 by combining the bathymetric survey of Grand Lake (OWRB, 2009, 2016) and the 2017 U.S. Geological Survey (USGS) bathymetric survey of the Neosho, Spring, and Elk Rivers (Hunter and others, 2017; Smith and others, 2017). The area and capacity table for the 2019 study spanned water-surface elevations from 612 to 759 ft above NAVD 88. Although the Hunter and Labriola (2019) area and capacity table was published in 2019, it was produced by combining data obtained during 2009 and 2017, with most of the bathymetry data collected in 2009. Because the majority of the data used to compute the area and capacity table in Hunter and Labriola (2019) were more than 10 years old, it was determined that an up-to-date area and capacity table was needed and that the best way to achieve this goal was to complete a new bathymetric survey.

Over time, the capacity of reservoirs to store water decreases as the sediment load carried by the impounded river(s) is deposited on the lakebed and as the water-surface elevation associated with a given surface area of the reservoir changes (OWRB, 2009; Hunter and others, 2017). Because of this natural phenomenon, updated area and capacity tables are periodically needed to identify the volume of water that a reservoir can hold at any given elevation. Stakeholders need an updated version of the area and capacity table for Grand Lake to assist in making informed decisions for project operations and floodplain management. The stakeholders in the study area include the GRDA, USACE, and citizens living on property bordering Grand Lake and its tributaries. The data from USGS streamgage 07190000, Lake O' the Cherokees at Langley, Okla. (USGS, 2019), along with the updated area and capacity values presented in this report, can be used by the GRDA and USACE when making decisions about the management of the lake.

Purpose and Scope

This report presents an updated area and capacity table for Grand Lake featuring bathymetric data collected in 2019 and augmented by previously collected data. Descriptions of the equipment and methods that were used are included. The updated area and capacity values are summarized and depicted in the report and are available in complete digital form in an associated data release (Hunter and others, 2020). The results of this bathymetric survey are compared with previous bathymetric surveys of Grand Lake.

Description of the Study Area[1]

Grand Lake spans parts of Craig, Delaware, Mayes, and Ottawa Counties in northeastern Oklahoma and is the third largest reservoir in terms of surface area and capacity in the State (OWRB, 2015). Three major rivers in Oklahoma flow into Grand Lake: the Neosho, Spring, and Elk Rivers (fig. 1). The Neosho River and its tributaries are impounded by Pensacola Dam to form Grand Lake. Pensacola Dam spans 1 mile between the communities of Langley and Disney, Okla. (fig. 1). The hydroelectric energy produced by the lake is distributed to citizens in 75 of the 77 counties in Oklahoma (GRDA, 2015). Elevation data compiled by Grand Lake project engineers are referenced to a local datum established by the USACE for the Pensacola Dam referred to as the "Pensacola Datum" (PD). The PD has been used since the construction of the dam in March 1940 and can be converted to National Geodetic Vertical Datum of 1929 (NGVD 29) by adding 1.07 ft (USACE, 2018a) and to NAVD 88 by adding 1.40 ft (National Geodetic Survey [NGS], National Oceanic and Atmospheric Administration [NOAA], 2018) (fig. 2).

Grand Lake has seasonal conservation pool elevations. Pending environmental conditions, elevations of the top of the conservation pool (referenced to the PD) are as follows:

- May 1–31 (start of the annual season), 742.0 to 744.0 ft;
- June 1–July 31, 744.0 ft;
- August 1–15, 744.0 to 743.0 ft;
- August 16–September 15, 743.0 ft;
- September 16–30, 743.0 to 742.0 ft;
- October 1–April 30 (winter conservation pool elevation), 742.0 ft.

The top of the dam is 757.00 ft above PD or 758.40 ft above NAVD 88 (USACE, 2018b) (fig. 2).

Methods of Bathymetric Survey and Data Analysis

A bathymetric survey of Grand Lake was completed between April 1 and July 31, 2019. The methods and tools used in this study were similar to those described in Richards and others (2019) and Huizinga and others (2019). During data collection, the water-surface elevation of the lake ranged from a minimum elevation of 741.79 ft above PD on April 30, 2019, to a maximum elevation of 755.08 ft above PD on June 24, 2019, which was only 0.19 ft less than the peak of record for the lake (07190000; USGS, 2019). The extreme high-water-surface elevations in Grand Lake culminating with the maximum elevation of 755.08 ft in June 2019 facilitated the collection of a more extensive set of multi-beam bathymetric data than would have been possible if the lake had been at more typical water-surface elevations during the survey.

Bathymetric Data Collection

The multibeam mapping system (MBMS) used for sonar data collection of depths and positions (fig. 3; see sheet 2) consists of several different components that work together to output a high-resolution point-cloud dataset: the multibeam echosounder (MBES), an inertial navigation system (INS), and a data-collection and data-processing computer. The MBES used in this survey was a 400-kilohertz NORBIT iWBMSh mounted on a manned boat (NORBIT, 2014a). The iWBMSh has a curved array that allows data to be collected in a swath out to 210 degrees, meaning from nadir (directly below the MBES) to 105 degrees to either side. During this survey, most data were collected by using a swath of 140 degrees, but shallow areas were surveyed with 150-degree swaths. Even though most data were collected at 140- and 150-degree swaths, the iWBMSh can collect quality data from swaths as large as 160 degrees, although limiting the beam width reduced noise on the outer edges of the swath in some instances. The NORBIT iWBMSh swath also can electronically tilt the curved array allowing the user to accurately survey sloped banks or shallow areas up to the water surface in some instances.

The next component in the MBMS was the INS. The INS used in this survey was the Applanix OceanMaster (Applanix Corporation, 2017). The INS provides the position location of the survey vessel in three-dimensional space. The INS simultaneously measures heave, pitch, roll, and heading of the watercraft during the survey.

The MBES data were collected and stored by using HYPACK/HYSWEEP software (HYPACK, Inc., 2019). The MBES was mounted to a NORBIT Portus Pole made of flex-free carbon fiber (NORBIT, 2014b). The flex-free carbon fiber pole limited expansion and contraction, which provided repeatable offsets between the multibeam head and the global positioning system antennas during the survey.

Real-time navigation was guided by using global navigation satellite systems (GNSS) with two GNSS antennas mounted on the Portus Pole. These data were collected in real time on the boat and then were postprocessed using the POSPac Mobile Mapping Suite (MMS) software (Applanix Corporation, 2020). POSPac MMS is software that identifies and corrects sensor and environmental errors that occur during data collection. POSPac software blended the raw data with values collected by Applanix SmartBase (ASB) postprocessed virtual reference stations through a subroutine known as Applanix PP-RTX (Applanix Corporation, 2019). Once the data were blended, POSPac output a "smoothed best estimate of trajectory," or "SBET" file. This SBET file was then used as the navigation data from each day to provide the best possible trajectory of the boat. The SBET file was coupled with the depth data from the MBES to correctly position the MBES data in three-dimensional space.

In a bathymetric survey, the velocity of sound in water must be known in order to accurately calculate depth based on acoustic wave two-way travel time. For this survey, a series of sound velocity casts were collected by using an AML Oceanographic Base X_2 sound velocity profiler (SVP) (AML Oceanographic, 2020). Casts were collected once an hour at different locations to determine the velocity of sound throughout the water column at various locations. These data were then applied to the MBES data during postprocessing.

The bathymetric survey preparation and data collection were completed using HYPACK/HYSWEEP software (HYPACK, Inc., 2019). Once data collection was completed, data were visualized in HYPACK/HYSWEEP as a point cloud. This point cloud was georeferenced using the SBET file provided by POSPac. After the data were georeferenced, they were further corrected by the removal of extreme outliers (data spikes) and the application of sound velocity and patch test corrections (Huizinga, 2017). The georeferenced data were output to a comma-delimited file (CSV) where the data were filtered and reduced to a 3.28-ft data resolution, which were used for bathymetric surface and contour map creation. The georeferenced data, associated metadata, and shapefiles (Blue Marble Geographics, 2019) are provided in Hunter and others (2020).

Surveying revealed several interesting features on the lakebed, including what appeared to be several sunken boats. During the 1930s, several small communities were evacuated in order to create this lake; the displaced populace left behind homes, businesses, and other structures. The foundations of many of those structures were evident in the MBES data. A notable finding was a large cavity in the lakebed close to the entrance of Duck Creek (fig. 1). This cavity measured about 10 ft wide, 25 ft long, and 90 ft deep. When the lake is at summer conservation pool elevation of 744.00 ft, the total depth over this cavity exceeds 130 ft.

Bathymetric Surface and Contour Map Creation

A bathymetric surface was derived from a triangulated irregular network (TIN) created in Global Mapper Version 21.0.1 (Blue Marble Geographics, 2019) using multibeam sonar data collected during this study, a 4-ft-resolution single-beam sonar elevation raster for the Spring and Neosho Rivers and a 2-ft resolution for the Elk River (Hunter and others, 2017), a 1/9 arc-second light detection and ranging (lidar) digital elevation model (DEM) completed in 2010 near Grand Lake (USGS, 2012), and a lidar dataset in the LASer (LAS) data format used for three-dimensional point lidar cloud data (USGS, 2014; Arms and others, 2020). The LAS dataset was used to supplement points along Pensacola Dam to better define elevations. Centroids from the single-beam sonar rasters and the lidar DEM were extracted and used to supplement the creation of the bathymetric surface. For this survey, the vertical datum was the NAVD 88 using the geoid model GEOID12b (National Geodetic Survey, 2017), and the horizontal datum was the North American Datum of 1983 (NAD 83). The DEM data were used in areas with land-surface elevations above 744 ft above NAVD 88 where the multibeam data could not be collected. With the 2019 multibeam sonar data representing the predominant source of data, the area and capacity data documented by this report reflect lake conditions during 2019 when the multibeam data were collected.

Linear enforcement (Wilson and Richards, 2006) was used to define areas with steep topography, areas with V-shaped stream channels bordering the lake, and areas with gaps between the lidar data and multibeam data. Linear enforcement was primarily used along gaps between the multibeam sonar data and the lidar data to enforce steep topography that would otherwise be interpolated as flat by the TIN algorithm. Linear enforcement entailed generating linear vectors and linearly interpolating points along those vectors. End points of each linear vector were used to extract elevation values from either the multibeam data or lidar data. Elevations were interpolated from the minimum elevation to the maximum elevation. These points were then used to calculate the bathymetric surface.

Contour lines were generated at 2-ft intervals from the bathymetric TIN surface. Contour lines were then filtered to remove small, closed contour lines that did not affect the lake capacity depicted by the contour map and only distracted from the visual appearance of the map. Small, closed contours of less than 1,000 ft in length were removed from the contour lines for the multibeam data below 743 ft. For the lidar data, contour lines above 743 ft in elevation and less than 300 ft in length were also removed. Contours were filtered to improve the visual appearance of contour lines without affecting the lake capacity depicted by the contour map (fig. 3; see sheet 2).

Bathymetric Data-Collection Quality Assurance

The bathymetric data-collection quality was assessed in real time while collecting data. The MBMS chief operator continually monitored the data as it was being collected. The operator monitored the MBES screen as well as the INS screen looking for inconsistencies and alarms that would reveal bad data collection or loss of satellite connection. The overlapping transects were also monitored for inconsistencies. The real-time quality assurance was part of the data screening in addition to collection of beam-angle checks and patch tests to maintain data integrity. Uncertainty estimations were also computed from those data that were collected to help quantify the accuracy of the survey results.

Beam-Angle Check

The beam-angle check is required to verify that the MBES is operating within the USACE-approved standards, particularly in the outer beams (greater than 25 degrees from nadir [vertical]) of the MBES. The beam-angle check was done at the beginning of this project and was completed following guidance set by the USACE; the results were within the recommended performance standards described by the USACE (USACE, 2013).

Patch Tests

For this bathymetric survey, patch tests were conducted on the first and last day of data collection. A patch test is a calibration test that is used to identify and correct for systematic errors that might be created by the mounting angle, timing, or position of the MBES with respect to the INS. After the initial offsets from a patch test are determined, they usually remain consistent, with the exception of an event that would change how the system is mounted, such as striking underwater or floating debris (Huizinga, 2017). The offsets provided by the patch test are used during post processing of the data. Proper calibration will yield consistent bathymetric results despite varying boat orientation, speed, and motion. The patch tests from the beginning and end of this survey were consistent, showing no systematic changes.

Uncertainty Estimations

Uncertainty associated with this bathymetry survey was estimated by computing the total propagated uncertainty (TPU) as described in Huizinga (2010, 2017). The TPU was calculated for each 3.28-ft (1 meter) survey-grid cell by using the Combined Uncertainty and Bathymetry Estimator (CUBE) method (Calder and Mayer, 2003; Richards and Huizinga, 2018). The CUBE method allows all random system component uncertainties and resolution effects to be combined and propagated through the data processing steps, thereby providing a robust estimate of the spatial distribution of possible uncertainty within the survey area. Thus, when all relevant error sources are considered, the TPU of a point is an estimate of the accuracy to be expected for such a point (Czuba and others, 2011; Richards and Huizinga, 2018). More than 95 percent of the TPU values were less than 0.30 ft, which is within the most stringent specifications for an International Hydrographic Organization (IHO) Special Order survey (IHO, 2008). The median TPU value of the data was about 0.07 ft. The largest TPU in this survey was 2.48 ft (fig. 4). The higher uncertainties were located near high relief features or along edges of transects where MBES side-lobe data were collected, which typically are sources of noisier data (Richards and Huizinga, 2018).

The process to create a raster dataset from various inputs with different resolutions requires resampling to incorporate all of the data into a single file with a single resolution. This process will create minor differences between the input and output raster datasets, which typically resulted in reduced resolution (larger cell size) compared to higher resolution (smaller cell size) raster datasets (Lowell and Jaton, 2020). Information provided in the data release associated with this publication helps illustrate some of the resampling differences between the raster dataset in this data release (Hunter and others, 2020) and the raster datasets used as inputs to generate a bathymetric surface along the Neosho, Elk, and Spring Rivers (Hunter and others, 2017).

Bathymetric Surface and Contour Quality Assurance

A quality-assurance (QA) dataset was created from the multibeam dataset generated from random points distributed throughout the survey area. These data were removed from the multibeam dataset and compared to data from the final TIN for QA and accuracy. The QA dataset consisted of about 4.2 percent (about 6.8 million points) of the total multibeam dataset. The QA data points were then used to extract elevation values from the TIN to compare the difference between the QA dataset and the TIN. Calculated error was about 0.47 ft at the 95th-percentile value for the approximately 6.8 million points in the QA dataset (Hyndman and Fan, 1996; Huizinga and others, 2019). A 1-ft buffer was generated around each contour line, and QA multibeam points were extracted from this buffer. The contour elevations were used to compare elevations to the QA dataset. Calculated error was 1.77 ft at the 95th-percentile value for the approximately 6.8-million-point QA dataset (Hyndman and Fan, 1996; Huizinga and others, 2019).

Bathymetry, Surface Area, and Capacity Results

The surface area and capacity data calculated in this study are reported in table 1, and the previous calculated capacities are graphed in figure 5, along with the capacities calculated as part of this study, for comparison. These newly calculated capacities are slightly less than those derived from the previous area and capacity tables (OWRB, 2009; Hunter and Labriola, 2019). At the conservation pool elevation of 743.40 ft above NAVD 88, the area and capacity table from 1940 gives the interpolated capacity of 1,584,600 acre-feet (acre-ft) (Hunter and others, 2020). The more recent hybrid 2009/2017 table gives a capacity of 1,424,400 acre-ft (Hunter and Labriola, 2019), and the calculated capacity table for this study gives a capacity of 1,307,300 acre-ft. At the top of the dam elevation of 758.40 ft above NAVD 88, the capacities were 2,387,400 acre-ft in 1940 (Hunter and others, 2020), 2,183,200 acre-ft in the hybrid 2009/2017 study (Hunter and Labriola, 2019), and 2,067,600 acre-ft for this study.

The capacity in Grand Lake has gradually decreased over time. Total capacity between the hybrid 2009/2017 capacity table that mostly consisted of data collected in 2009 and the capacity table from this study decreased by about 117,100 acre-ft (about −8.2 percent) at the conservation pool elevation of 743.40 ft above NAVD 88 and decreased by about 115,600 acre-ft (about −5.3 percent) at the top of the dam elevation of 758.40 ft above NAVD 88 (fig. 5). The interpolated 1940 capacity is 2,387,400 acre-ft at an elevation of 758.40 ft above NAVD 88, whereas the 2019 capacity is 2,067,600 acre-ft at an elevation of 758.40 ft above NAVD 88. The capacity of Grand Lake at conservation pool elevation has decreased about 277,300 acre-ft since 1940, and the capacity at the top of dam elevation has decreased about 319,800 acre-ft since 1940.

As explained in the Introduction of this report, reservoirs slowly impound sediment carried by the rivers that drain into them, thus losing capacity over time. Although the methods used to collect data in 1940 are unknown (Hunter and Labriola, 2019), the multibeam data collected in the 2019 survey of Grand Lake are likely of much higher resolution and accuracy than previously collected bathymetry data (OWRB, 2009) because of technological advancements in the tools and methods used to collect bathymetric data. In addition, differences in data collection methods among 1940 (unknown), 2009 (single-beam sonar), 2009/2017 hybrid (single-beam sonar), and 2019 (multi-beam sonar) may have contributed to perceived changes in the capacity of Grand Lake. The single-beam sonar data collected in 2009 were collected along transects spaced about 300 ft apart, but the data density of the multi-beam sonar data was far greater in most areas. The multi-beam survey used a POS MV Ocean Master to correct for pitch, roll, and yaw of the survey boat (Applanix 2017). Failure to dynamically correct for these variables during data collection activities in previous surveys would increase calculated depths relative to this survey because any movement of the survey boat will cause the sonar beam to deviate from vertical, increasing the beam travel distance and thus overestimating depth for a surface with relatively flat topography (L-3 Communications SeaBeam Instruments, 2000). The Grand Lake lakebed consists of mostly flat topography (as illustrated by widely spaced contours [fig. 3; see sheet 2]). Previous surveys likely did not correct for boat movement to the same precision as this survey, and some of the reduced capacity could be attributed to this difference in data-collection techniques.

[1]This section is modified from Hunter and Labriola (2019).

References

AML Oceanographic, 2020, AML Base X2 SVP: Victoria, British Columbia, AML Oceanographic web page, accessed February 10, 2020, at https://amloceanographic.com/product/base-x2-svp/.

Applanix Corporation, 2017, POS MV OceanMaster specifications: Richmond Hill, Ontario, Canada, Applanix Corporation web page, 2 p., accessed January 27, 2020, at https://www.applanix.com/downloads/products/specs/posmv/POSMV_OCEANMASTER.pdf.

Applanix Corporation, 2019, Applanix PP-RTX in hydrographic survey: Richmond Hill, Ontario, Canada, Applanix Corporation web page, 2 p., accessed January 27, 2020, at https://www.applanix.com/downloads/case_studies/Applanix_PP-RTX_in_Hydrographic_Survey.pdf.

Applanix Corporation, 2020, POSPac MMS: Richmond Hill, Ontario, Canada, Applanix Corporation website, accessed January 27, 2020, at https://www.applanix.com/.

Arms, C.A., Fleischhauer, C., and Murray, K., 2020, Sustainability of digital formats—Planning for Library of Congress collections: U.S. Library of Congress web page, accessed July 24, 2020, at https://www.loc.gov/preservation/digital/formats/fdd/fdd000418.shtml.

Blue Marble Geographics, 2019, Create contours from TIN areas: Blue Marble Geographics Global Mapper web page, accessed January 27, 2020, at https://www.bluemarblegeo.com/knowledgebase/global-mapper-21-1/Generate_Contours.htm?Highlight=triangulated%20irregular%20network#TIN.

Calder, B.R., and Mayer, L.A., 2003, Automatic processing of high-rate, high-density multibeam echosounder data: Geochemistry, Geophysics, Geosystems, v. 4, no. 6, 22 p., accessed January 27, 2020, at https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2002GC000486.

Czuba, J.A., Best, J.L., Oberg, K.A., Parsons, D.R., Jackson, P.R., Garcia, M.H., and Ashmore, P., 2011, Bed morphology, flow structure, and sediment transport at the outlet of Lake Huron and in the upper St. Clair River: Journal of Great Lakes Research, v. 37, no. 3, p. 480–493, accessed January 27, 2020, at https://doi.org/10.1016/j.jglr.2011.05.011.

Federal Energy Regulatory Commission [FERC], 2012, A guide to understanding and applying the integrated licensing process study criteria: Federal Energy Regulatory Commission, 33 p., accessed May 26, 2017, at https://www.ferc.gov/industries/hydropower/gen-info/guidelines/guide-study-criteria.pdf.

Grand River Dam Authority [GRDA], 2015, The economic impact of the Grand River Dam Authority, accessed September 17, 2020, at http://www.grda.com/wp-content/uploads/2015/04/2015-GRDA-Economic-Impact.pdf.

Grand River Dam Authority [GRDA], 2017, Pensacola Hydroelectric Project—Scoping document 2 for the Pensacola Hydroelectric Project: Grand River Authority, Federal Energy Regulatory Commission report no. 1494–438, 566 p., accessed September 17, 2020, at https://www.grda.com/wp-content/uploads/2019/04/Pensacola-P-1494-NOI-PAD-02-01-17-FINAL.pdf.

Huizinga, R.J., 2010, Bathymetric surveys at highway bridges crossing the Missouri River in Kansas City, Missouri, using a multibeam echo sounder, 2010: U.S. Geological Survey Scientific Investigations Report 2010–5207, 61 p., accessed January 27, 2020, at https://doi.org/10.3133/sir20105207.

Huizinga, R.J., 2017, Bathymetric and velocimetric surveys at highway bridges crossing the Missouri and Mississippi Rivers near St. Louis, Missouri, May 23–27, 2016: U.S. Geological Survey Scientific Investigations Report 2017–5076, 102 p., accessed January 27, 2020, at https://doi.org/10.3133/sir20175076.

Huizinga, R.J., Ellis, J.T., Sharpe, J.B., LeRoy, J.Z., and Richards, J.M., 2019, Bathymetric map and surface area and capacity table for Beaver Lake near Rogers, Arkansas, 2018: U.S. Geological Survey Scientific Investigations Map 3445, 2 sheets, accessed January 27, 2020, at https://doi.org/10.3133/sim3445.

Hunter, S.L., Ashworth, C.E., and Smith, S.J., 2017, Bathymetric surveys of the Neosho River, Spring River, and Elk River, northeastern Oklahoma and southwestern Missouri, 2016–17: U.S. Geological Survey Scientific Investigations Report 2017–5101, 59 p., accessed January 27, 2020, at https://doi.org/10.3133/sir20175101.

Hunter, S.L., and Labriola, L.G., 2019, Area and capacity of Grand Lake O' the Cherokees, northeastern Oklahoma, 2009: U.S. Geological Survey Scientific Investigations Report 2019–5040, 18 p., accessed January 27, 2020, at https://doi.org/10.3133/sir20195040.

Hunter, S.L., Trevisan, A.R., and Villa, J., 2020, Data release of bathymetric map, surface area, and capacity of Grand Lake O' the Cherokees, northeastern Oklahoma, 2019: U.S. Geological Survey data release, https://doi.org/10.5066/P9KA2T3Z.

Hyndman, R.J., and Fan, Y., 1996, Sample quantiles in statistical packages: American Statistician, v. 50, no. 4, p. 361–365, accessed July 28, 2020, at https://doi.org/10.2307/2684934.

HYPACK, Inc., 2019, HYPACK user manual: Middletown, Conn., HYPACK, Inc., 2,556 p., accessed January 23, 2020, at http://www.hypack.com/File%20Library/Resource%20Library/Manuals/2019/2019-HYPACK-User-Manual.pdf.

International Hydrographic Organization [IHO], 2008, IHO standards for hydrographic surveys (5th ed.): International Hydrographic Organization Special Publication no. 44, 28 p., accessed July 24, 2020, at https://iho.int/uploads/user/pubs/standards/s-44/S-44_5E.pdf.

L-3 Communications SeaBeam Instruments, 2000, Multibeam Sonar Theory of Operation, 107 p., accessed October 14, 2020, at https://www3.mbari.org/data/mbsystem/sonarfunction/SeaBeamMultibeamTheoryOperation.pdf.

Lowell, K., and Jaton, A., 2000, Spatial accuracy assessment—Land information uncertainty in natural resources (1st ed.): Boca Raton, Fla., CRC Press, 450 p., accessed September 22, 2020, at https://doi.org/10.1201/9781482279573.

National Geodetic Survey, 2017, GEOID12b: National Oceanic and Atmospheric Administration, National Geodetic Survey web page, accessed July 29, 2020, at https://www.ngs.noaa.gov/GEOID/GEOID12/.

National Geodetic Survey [NGS], National Oceanic and Atmospheric Administration [NOAA], 2018, VERTCON—North American Vertical Datum conversion: National Oceanic and Atmospheric Administration, National Geodetic Survey web page, accessed October 25, 2018, at https://www.ngs.noaa.gov/TOOLS/Vertcon/vertcon.html.

NORBIT, 2014a, Datasheet: Trondheim, Norway, NORBIT Subsea Accessed September 21, 2020, at https://norbit.com/media/PS-150010-10_iWBMSh_Pn_12007-AACDB4_A4.pdf.

NORBIT, 2014b, NORBIT carbon fibre "Portus" mounting pole: Trondheim, Norway, 1 p., accessed January 27, 2020, at https://norbit.com/media/PS-190002-1_Carbon-Fiber-PORTUS-Pole_A4.pdf.

Oklahoma Water Resources Board [OWRB], 2009, Hydrographic survey of Grand Lake: Oklahoma Water Resources Board, 27 p., accessed January 27, 2017, at https://www.owrb.ok.gov/studies/reports/reports_pdf/GrandLake--hydrologicsurvey.pdf.

Oklahoma Water Resources Board [OWRB], 2015, Lakes of Oklahoma (3d ed.): Oklahoma Water Resources Board web page, accessed December 17, 2018, at http://www.owrb.ok.gov/news/publications/lok/lok.php.

Oklahoma Water Resources Board [OWRB], 2016, Bathymetric lake studies: Oklahoma Water Resources Board web page, accessed January 27, 2020, at http://www.owrb.ok.gov/maps/pmg/owrbdata_Bathy.html.

Richards, J.M., and Huizinga, R.J., 2018, Bathymetric contour map, surface area and capacity table, and bathymetric difference map for Clearwater Lake near Piedmont, Missouri, 2017: U.S. Geological Survey Scientific Investigations Map 3409, 1 sheet, accessed January 27, 2020, at https://doi.org/10.3133/sim3409.

Richards, J.M., Huizinga, R.J., and Ellis, J.T., 2019, Bathymetric contour map, surface area and capacity table, and bathymetric change map for Sugar Creek Lake near Moberly, Missouri, 2018: U.S. Geological Survey Scientific Investigations Map 3431, 1 sheet, accessed January 27, 2020, at https://doi.org/10.3133/sim3431.

Smith, S.J., Ashworth, C.E., and Smith, K.A., 2017, Bathymetry and capacity of Shawnee Reservoir, Oklahoma, 2016: U.S. Geological Survey data release, accessed January 16, 2017, at https://doi.org/10.5066/F72805SC.

U.S. Army Corps of Engineers [USACE], 2013, Engineering and design—Hydrographic surveying: Washington, D.C., U.S. Army Corps of Engineers manual no. EM 1110–2–1003, 560 p., accessed January 27, 2020, at https://www.publications.usace.army.mil/Portals/76/Publications/EngineerManuals/EM_1110-2-1003.pdf?ver=2014-01-06-155809-307.

U.S. Army Corps of Engineers [USACE], 2018a, Pensacola Lake, monthly lake report, Apr 96: U.S. Army Corps of Engineers web page, accessed October 25, 2018, at http://www.swt-wc.usace.army.mil/chartbin/PENSApr96.html.

U.S. Army Corps of Engineers [USACE], 2018b, PENO2—Pensacola (Grand Lake), OK: U.S. Army Corps of Engineers web page, accessed October 25, 2018, at http://www.swt-wc.usace.army.mil/PENS.lakepage.html.

U.S. Geological Survey [USGS], 2012, National Elevation Dataset (NED) 1/9 arc-second DEM: U.S. Geological Survey database, accessed January 28, 2020, at https://viewer.nationalmap.gov/basic/?basemap=b1&category=ned&q=&zoom=10&bbox=-95.1059,37.0359,-94.5016,36.4268&preview=&avail=DEM%201/9%20arc-second.

U.S. Geological Survey [USGS], 2014, National Elevation Dataset (NED) lidar point cloud (LPC): U.S. Geological Survey database, accessed June 23, 2020, at https://viewer.nationalmap.gov/basic/?basemap=b1&category=nedsrc&q=&zoom=15&bbox=-95.04525661,36.46319398,-94.99749184,36.48990336&preview=&avail=&refpoly=.

U.S. Geological Survey [USGS], 2019, USGS water data for the Nation: U.S. Geological Survey National Water Information System database, accessed June 1, 2020, at https://doi.org/10.5066/F7P55KJN.

Wilson, G.L., and Richards, J.M., 2006, Procedural documentation and accuracy assessment of bathymetric maps and area/capacity tables for small reservoirs: U.S. Geological Survey Scientific Investigations Report 2006–5208, 24 p., accessed January 27, 2020, at https://doi.org/10.3133/sir20065208.

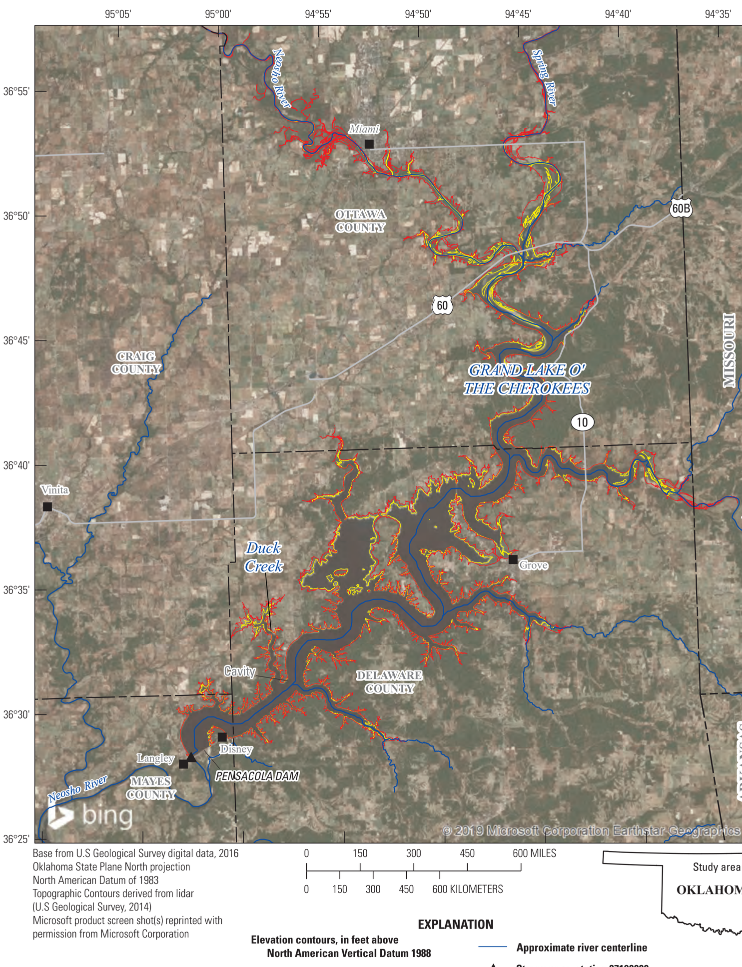


Figure 1. Elevation contours for the top of the conservation pool and top of the dam, Grand Lake O' the Cherokees, northeastern Oklahoma. Modified from figure 1 in Hunter and Labriola (2019).

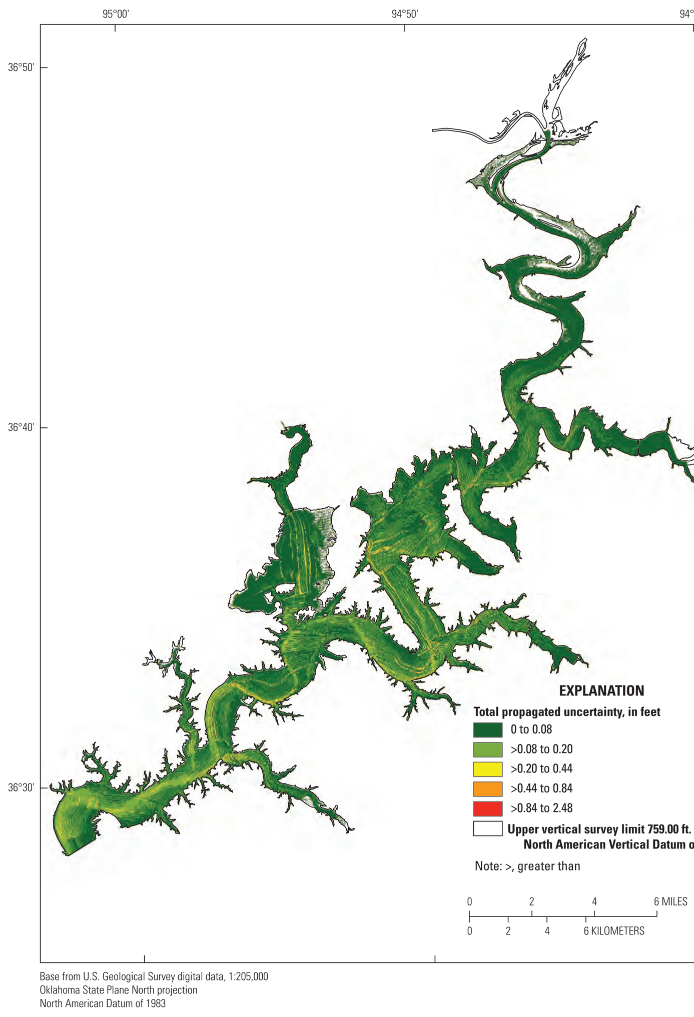
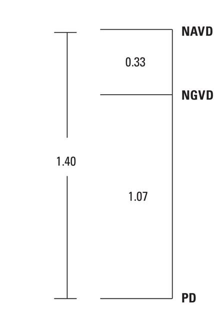


Figure 4. Extent of multibeam bathymetric data collected in 2019 and the total propagated uncertainty pertaining to the collected data, Grand Lake O' the Cherokees, northeastern Oklahoma.



	Elevations, in feet		
	NAVD 88	NGVD 29	PD
Conservation pool	743.40	743.07	742.00
Top of the dam	758.40	758.07	757.00

Figure 2. Datum transformations and conversions for the North American Vertical Datum of 1988 (NAVD 88), National Geodetic Vertical Datum of 1929 (NGVD 29), and Pensacola Datum (PD) used in the computation of area and capacity for Grand Lake O' the Cherokees, northeastern Oklahoma. Reprinted from Hunter and Labriola (2019).

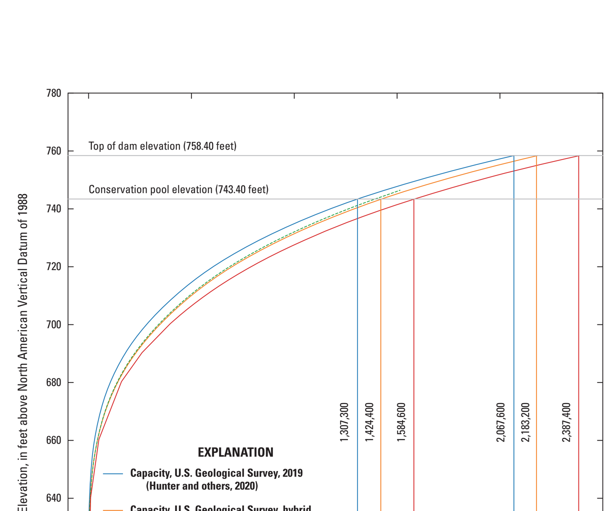


Figure 5. Capacity of Grand Lake O' the Cherokees as calculated with elevation data from 1940, from the Oklahoma Water Resources Board (2009), from the U.S. Geological Survey hybrid 2009/17 study (Hunter and Labriola, 2019), and from bathymetric data collected in 2019 and compiled for this study. Modified from figure 4 in Hunter and Labriola (2019).

Table 1. Surface area and capacity at specified water-surface elevations for Grand Lake O' the Cherokees in northeastern Oklahoma from a bathymetric survey completed during April 1–July 31, 2019, augmented with previously collected single-beam sonar data and lidar point-cloud data.

[ft, feet; NAVD 88, North American Vertical Datum of 1988; winter conservation pool elevation is 742.0 ft above Pensacola Datum, 743.4 ft above NAVD 88, and the top of dam elevation is 757.0 ft above Pensicola Datum, 758.4 ft above NAVD 88]

Water-surface elevation,[1] in ft	Water-surface elevation,[2] in ft	Capacity,[3] in acre-ft	Surface area, in acres	Water-surface elevation,[1] in ft	Water-surface elevation,[2] in ft	Capacity,[3] in acre-ft	Surface area, in acres	Water-surface elevation,[1] in ft	Water-surface elevation,[2] in ft	Capacity,[3] in acre-ft	Surface area, in acres
626.00	624.60	100	60	672.00	670.60	65,400	4,040	718.00	716.60	563,900	19,960
628.00	626.60	300	110	674.00	672.60	73,900	4,470	720.00	718.60	605,100	21,260
630.00	628.60	500	170	676.00	674.60	83,300	4,960	722.00	720.60	649,000	22,660
632.00	630.60	1,000	270	678.00	676.60	93,700	5,420	724.00	722.60	695,700	24,020
634.00	632.60	1,600	360	680.00	678.60	105,100	5,930	726.00	724.60	745,100	25,330
636.00	634.60	2,400	430	682.00	680.60	117,400	6,420	728.00	726.60	797,100	26,730
638.00	636.60	3,300	500	684.00	682.60	130,800	6,950	730.00	728.60	852,100	28,220
640.00	638.60	4,400	580	686.00	684.60	145,200	7,460	732.00	730.60	910,100	29,760
642.00	640.60	5,600	640	688.00	686.60	160,600	7,990	734.00	732.60	971,000	31,260
644.00	642.60	7,000	710	690.00	688.60	177,100	8,570	736.00	734.60	1,035,300	33,010
646.00	644.60	8,500	840	692.00	690.60	195,000	9,300	738.00	736.60	1,103,200	34,900
648.00	646.60	10,300	950	694.00	692.60	214,400	10,050	740.00	738.60	1,174,900	36,860
650.00	648.60	12,300	1,070	696.00	694.60	235,100	10,760	742.00	740.60	1,250,900	39,240
652.00	650.60	14,600	1,210	698.00	696.60	257,400	11,490	**743.40**	**742.00**	**1,307,300**	**41,580**
654.00	652.60	17,200	1,410	700.00	698.60	281,100	12,190	744.00	742.60	1,332,500	42,390
656.00	654.60	20,300	1,690	702.00	700.60	306,200	12,930	746.00	744.60	1,419,400	44,580
658.00	656.60	24,000	1,970	704.00	702.60	332,900	13,710	748.00	746.60	1,510,900	46,850
660.00	658.60	28,200	2,270	706.00	704.60	361,000	14,460	750.00	748.60	1,606,900	49,190
662.00	660.60	33,000	2,530	708.00	706.60	390,600	15,160	752.00	750.60	1,707,800	51,690
664.00	662.60	38,400	2,800	710.00	708.60	421,700	15,910	754.00	752.60	1,813,800	54,390
666.00	664.60	44,200	3,070	712.00	710.60	454,300	16,740	756.00	754.60	1,925,500	57,300
668.00	666.60	50,700	3,360	714.00	712.60	488,800	17,720	758.00	756.60	2,043,300	60,520
670.00	668.60	57,700	3,680	716.00	714.60	525,200	18,750	**758.40**	**757.00**	**2,067,700**	**61,180**

[1]Elevations are referenced to the North American Vertical Datum of 1988.

[2]Elevations are referenced to the Pensacola Datum, a local datum established in 1940 by the U.S. Army Corps of Engineers for the Penscola Dam impounding Grand Lake O' the Cherokees. Pensacola Datum is calculated by subtracting 1.40 ft from NAVD 88.

[3]Capacities were computed from a surface triangulated irregular network that was computed at about 0.47 ft at the 95th-percentile value for the approximately 6.8-million-point quality-assurance dataset. The explanation of the vertical accuracy calculation is in the "Bathymetric Surface and Contour Quality Assurance" section of this report. Capacities have been rounded to the nearest hundred.

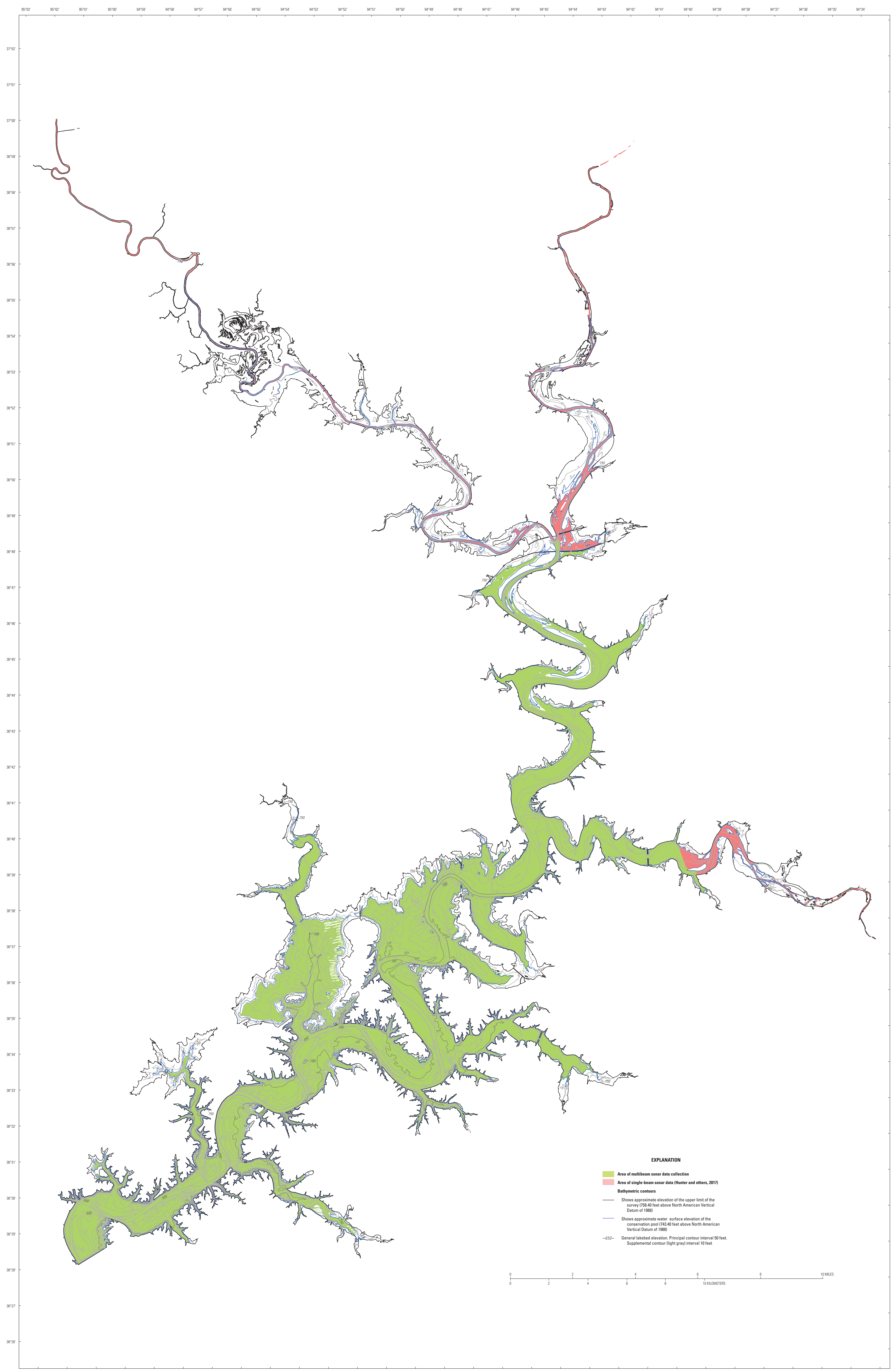
Bathymetric Map, Surface Area, and Capacity of Grand Lake O' the Cherokees, Northeastern Oklahoma, 2019

By

Shelby L. Hunter, Adam R. Trevisan, Jennifer Villa, and Kevin A. Smith

2020

Prepared in cooperation with the
Grand River Dam Authority



Base from U.S. Geological Survey digital data,1:80,000
Oklahoma State Plane North projection
North American Datum of 1983

Figure 3. Bathymetric contours for Grand Lake O' the Cherokees obtained from the multibeam mapping system survey completed in 2019 and augmented with previously collected single-beam sonar data (Hunter and others, 2017) and lidar point-cloud data (U.S. Geological Survey, 2014).

Bathymetric Map, Surface Area, and Capacity of Grand Lake O' the Cherokees, Northeastern Oklahoma, 2019

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For sale by U.S. Geological Survey, Information Services, Box 25286, Federal Center, Denver, CO 80225, 1–888–ASK–USGS

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APPENDIX E-10 Historical Flooding, Flood Control, and Hydropower Report

A History of Flooding, Flood Control, and Hydropower on the Neosho (Grand) River

Submitted to: Grand River Dam Authority

Grand River Dam Authority

Submitted by:

Historical Research Associates, Inc.

Heather Lee Miller, PhD

Seattle, WA

May 2023

Historical Research Associates, Inc.

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Introduction

The Neosho (Grand) River moves from north to south through Morris, Marion, Lyon, Coffey, Woodson, Allen, Neosho, Labette, and Cherokee Counties in Kansas, and Craig, Ottawa, Delaware, Mayes, Wagoner/Cherokee, and Muskogee Counties in Oklahoma (Figure 1). The river is commonly known as the Neosho River in Kansas and the Grand River (not to be confused with other Grand Rivers in Iowa, Michigan, Missouri, South Dakota, or Wisconsin) in Oklahoma. The official division between the two is where the Spring River merges with the Neosho River upstream from Pensacola Dam near Wyandotte, Oklahoma; downstream from this junction, the river is more commonly known as the Grand. For consistency, we use the term *Neosho River* throughout this report unless a historical document uses or quotes the term as *Grand River*.

The Neosho River is 460 miles long, with 297 of those miles in Kansas and the other 163 in Oklahoma.[1] The Neosho River floodplain "embraces about 264,300 acres, of which about 223,100 are in the reach above the Pensacola Dam site (mile 77) and 41,200 below that locality."[2] All major tributaries of the Neosho are upstream of the Pensacola Dam. From north to south, they are as follows: "Cottonwood River (mile 380), with a drainage area of 1,830 square miles in Kansas; Lightning Creek (mile 185), with 230 square miles in Kansas; Spring River (mile 131), with 2,655 square miles in Missouri, Kansas, Arkansas, and Oklahoma; and Elk River (mile 114), with 1,015 square miles in Missouri, Arkansas, and Oklahoma." Minor tributaries between Pensacola and the Fort Gibson Dam are "Cabin Creek (mile 68), with a drainage area of 490 square miles in Oklahoma; Spavinaw Creek (mile 61), with 400 square miles in Arkansas and Oklahoma; and Pryor Creek (mile 40), with 270 square miles in Oklahoma."[3] Only the last 2 miles of the Neosho River above its junction with the Arkansas are considered by the U.S. Army Corps of Engineers (USACE; the Corps) to be navigable.[4]

This report outlines two historical threads related to the Neosho River: the sheer number of floods that have occurred on the river since before non-Indigenous people arrived in the watershed and the development of the river for power production and flood control. The contours of the story are captured in three parts: Part 1 provides a detailed chronology from 1826 through 1919 of flooding on the Neosho River from its headwaters in Kansas to its junction with the Arkansas River. Part 2 tracks the parallel flood control efforts that people made at the state level in Kansas, at the territorial and then state level in Indian Territory/Oklahoma, and at the federal level in Washington, DC, and various regional agency or district offices prior to the creation of the Grand River Dam Authority in 1935. Part 3 traces the early history of attempts to develop power production on the Neosho River and how those efforts ultimately led to the creation of the Grand River Dam Authority (GRDA) and construction of the Pensacola Dam and Reservoir. Woven into the narrative of Part 3 is the complicated interplay between local, state, and federal entities as pertained to hydroelectric development versus flood control on the river, as embodied in the Pensacola Dam and

Reservoir (and subsequent dams and reservoirs on the Neosho and within the greater Neosho watershed). The planning, construction, and subsequent operation of the Pensacola Dam occurred during not only a time of great national economic, social, and political flux but also during a sea change in federal policies that would ultimately cement the role of the U.S. Army Corps of Engineers as primary overseer of all flood control efforts in the nation.

Despite a long history of flooding on the Neosho River in both Kansas and Oklahoma, the original designers and promoters of what would become the Pensacola Project were pushing for its use as a purely power-generating facility with the potential for only ancillary flood control benefits. By the late 1920, decades of attempts to construct a private power-producing facility on the Neosho River at the Pensacola site had failed; and although the Corps had determined that the plans were viable, it refused to vet the project on grounds that it was economically infeasible and thus not in the national interest. By the mid-1930s, however, in the depths of the Depression, the newly formed GRDA received financial support for the Pensacola project from the Public Works Administration (PWA) as a local New Deal–era relief program. In an apparent about-face regarding the Neosho River, the Corps had simultaneously (and surprisingly) begun to make its own plans for using the dam and its reservoir for flood control. This reversal created a bifurcation (and ultimate conflict) between the power- and jobs-producing role GRDA, PWA, Federal Power Commission (FPC), and later Department of Interior saw for Pensacola and the flood-control role the Corps wanted. Modifications to the final FPC license for the Grand River Dam and Reservoir created a "compromise" that allowed GRDA to move forward and complete construction and fill the reservoir.

The purely coincidental timing of when GRDA went officially online in early 1941 with the onset of World War II later in the year exacerbated the tensions that already existed among GRDA, PWA, FPC, the Corps, and Interior over whether Pensacola's primary purpose would be power or flood control and whether it was best operated by a private, state, or federal entity. The reluctant compromise these entities had struck during licensing of the Pensacola Project in 1939 to allow both power generation and flood control on the Neosho River led to a series of federal enactments that ultimately gave the Corps full responsibility for and authority over flood control operations at the Pensacola Dam. The reverberations of these decisions are still felt today.

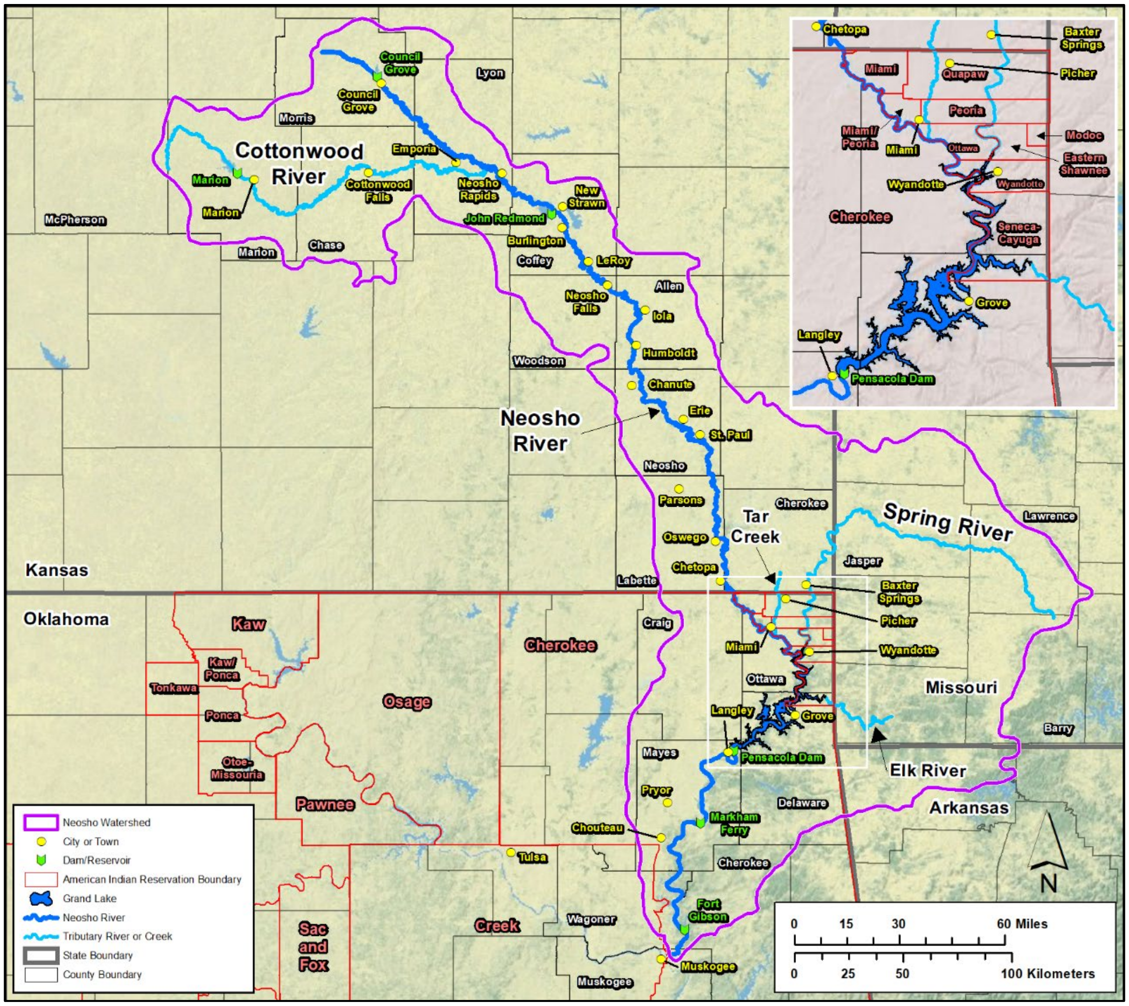


Figure 1. Topographical map of the Neosho River watershed in Kansas and Oklahoma, with major tributaries.

Part 1: Historical Flooding on the Neosho River

Introduction

Along its entire course and over likely millennia, the Neosho River has overflowed its banks countless times. Both the archaeological and historical records document these events and their ongoing damage in detail. Furthermore, the river has continued to flood despite the many interventions that people have made to minimize its damage, especially once non-Indigenous settlers entered the area and decided to establish homesteads and farms and locate growing communities along the riverbanks.

In a 1931 assessment, the Corps estimated that floods on the Neosho River above the mouth of the Spring occurred "with an average frequency of one major flood every 7 years; one moderate flood every 2 years; and one minor flood per year."[5] As one person explained, the area around Miami had "been inundated by every major flood on the Neosho River before [Pensacola Dam] was built."[6] By comparison, the Neosho below the Spring (technically, the Grand River) only experienced about "one major flood every 10 years, one moderate flood every 4 years, and one minor flood every 2 years."[7] Weather patterns in the watershed and the geology of the riverbed and its surrounding environs both contribute to the regular flooding. The Corps later described the area as "subject to intense single storms over limited areas, as well as to general storms over large portions of the watershed."[8] Both types of storms can cause overflow on limited reaches of the river or flood conditions over extensive portions of the river valley. As a result, a flood or floods occurred somewhere on the Neosho or one of its tributaries most years on record. These floods varied in location and magnitude. Various Corps reports noted the difference in flood frequencies in the Neosho River watershed between the reaches above and below the mouth of the Spring River just south of Miami, Oklahoma. As the Corps explained in their 1931 report—ten years before construction of the Pensacola Dam—this difference was due to two conditions. One was "the fact that due to the large amount of channel storage in the Kansas [and far northeastern corner of Oklahoma] area[s], flood flows in the upper reach are reduced in peak flow with consequent increase in duration."[9] The other was "the large channel capacity in the main stem below the mouth of Spring River," which made it "capable of carrying any flood from the Kansas area without overflow except when augmented by a considerable flow from Spring and Elk Rivers and other tributaries in Oklahoma."[10]

Archaeological documentation makes clear that the Neosho River has cycled through flooding and drought for millennia. The archaeological record of Indigenous peoples who lived in the watershed in Kansas (which includes the tributary Cottonwood River) indicates that many groups moved seasonally from semipermanent settlements in the floodplain to higher locations, depending on the season and level of the river.[11] As growing numbers of non-Indigenous people forced Indigenous peoples off their traditional lands and onto reservations over the course of the nineteenth century, people of mostly European descent entered and occupied the area that would become Kansas and Oklahoma. Many settled permanently in the Neosho floodplain to take advantage of the rich agricultural and grazing lands they found there; others populated growing communities and towns where they established or worked for the businesses, schools, churches, and other organizations that supported their economy.

Western concepts of land use and property laws, which focused on individual or familial ownership on delineated parcels of land, were not conducive to the seasonal migrations that Indigenous peoples long employed to cope with floods and drought. Thus, along the entire course of the Neosho River and its many tributaries, non-Indigenous farmers, industrialists, and townspeople alike found themselves occupying land subject to almost annual flooding—sometimes, multiple times per year—that varied from nuisance water on fields or in basements to floods of epic and disastrous proportions. Anecdotes from the nineteenth century indicate that the Indigenous peoples of Kansas had warned non-Indigenous people against permanent occupation of lands in the floodplain. As one observer from Council Grove reported after the 1903 flood swept away the Main Street Bridge,

> The tradition of the Kaws, who lived here from 1817 till 1873, that "once the valley was washed from hills to hills" was verified, but no one dreamed of a wave of water high enough to carry off this strong structure and to flood every business house in the city. The Kaws used to tell of this tradition, and say, "White man heap big fool to build big house near river," and for a time last spring we thought they were correct.[12]

So too, these people grappled with periods of extreme drought in which rivers, creeks, and smaller waterbodies would dry up, creating shortages of fresh water because the remaining water was often polluted with raw sewage and other waste. Although extreme weather events compelled some people to give up and move away, most non-Indigenous people who settled along the Neosho and its tributaries resigned themselves to coexisting with the cycle of flooding and drought. Individuals, local groups, municipalities, state officials, and eventually, federal agencies participated in flood-control measures in the area that became Kansas and Oklahoma. Indeed, flood control became (and remains) a ubiquitous feature of life for those living and working along the Neosho.

Documents from the time of early non-Indigenous settlement of the area indicate that the Neosho River has experienced "seasons of flood" along its course almost every year since early non-Indigenous visitors and settlers people started keeping track.[13] Research indicates that especially disastrous floods occurred at various locations in the Neosho River watershed in 1826, 1844, 1885, 1895, 1902, 1903, 1904, 1909, 1927, 1941, 1943, 1948, 1951, 1986, and 1993. Specifically in the two southernmost Kansas counties (Neosho and Labette) and two northernmost Oklahoma counties (Ottawa and Delaware), the worst years were 1826, 1844, 1895, 1902–1904, 1917–1918, 1922, 1928, 1941, 1943, 1948, 1951, 1986, 1993, and 2007. (See Appendix A for photographs of Neosho River and tributary floods between 1885 and 2019; see Appendix B for a chronological timeline of flooding in the larger watershed between 1826 and 2019.)

Less is known about the exact locations of the 1826 and 1844 floods than later ones, but by all accounts, they were of epic proportions. A Commissioner of Indian Affairs 1826 annual report and a later chronicle of the history of what is now Neosho County indicate that the flood that year likely caused the greatest damage in present-day southeastern Kansas and northeastern Oklahoma, although at least one author reported that the Neosho did not flood in 1844.[14] Other reports, however, locate the 1844 flooding variously in today's Woodson, Coffey, and Neosho Counties (through all of which the Neosho runs) and indicate that Neosho County was hard hit. According to Superintendent Thomas Harvey, when he arrived at the Osage Subagency on May 22, 1844, the Neosho was "'very high, having overflowed its banks and covered the bottoms to a considerable depth, which [made] the river in most places more than a mile wide'"[15]

Early Non-Indigenous Settlement: 1857–1885

Between the epic flood events of 1844 and 1885, a series of floods varying in size and damage, occurred on the Neosho River and its tributaries in 1854,[16] 1855,[17] 1856,[18] 1857, 1858,[19] 1866, 1867,[20] 1868,[21] 1869, 1870,[22] 1871,[23] 1873,[24] 1875,[25] 1876,[26] 1877,[27] 1878,[28] 1881,[29] 1883,[30] and 1884.[31] Of these episodes, a few stand out.[32] The flood of 1857 "swept down the Neosho, carrying with it wigwams, houses, and crops."[33] Again in 1866, after an "extremely wet" summer, "the streams rose higher than they had been known to rise, by the Indians, for fifteen years."[34] According to Neosho Indian agent G. C. Snow, the Quapaws had suffered "severely [in 1866] for food and clothing. Their crops were quite all destroyed last year by the floods, and they have no annuities from the government."[35] The year 1869 again saw flooding on the Neosho, with a small flood in February followed by a much larger deluge in June, during which the river "rose twenty feet in nine hours," rushed "along over a stretch of a mile in width between its ordinary banks and the western limits of [St. Paul]," and "washed the ferry boats away."[36]

In 1885, the Neosho experienced one of its worst flood years up to that time. Citing the *Monthly Weather Review*, a 1908 report described the "unusually high and destructive flood" of 1885 on the Neosho, especially in Neosho Falls (Woodson County), Humboldt (Allen County), and Parsons (Labette County).[37] Another report described the 1885 flood as "the largest prior to that of 1904."[38] Neosho County endured three large floods in 1885: one "very high" on February 11, a series of floods between May 15 and May 29 that washed out the "nearly completed bridge south of

St. Francis church" and "forty feet of the Erie mill dam," and a "record breaker" on July 4.[39] The July flood "spread over more territory and did more damage in the way of carrying away harvested crops and destroying growing crops" than had the 1869 flood in Neosho County.[40] Because the flood took out a half mile of railroad track, a steamer was needed to "convey passengers across the waters."[41] At Burlington, Rock Creek flooded into Neosho River, which achieved a crest of 35.2 feet on "present gage zero datum, making it one of the greatest on record at that place." At Oswego that year, the crest reached 25.2, "also close to the highest water ever known there."[42] Tragically, at least nine people lost their lives in the floodwaters, according to reports that three bodies had been found at Parsons, three more at Chanute, and three more at Neosho, with others still missing.[43]

1886-1904

Starting with the "unusually high and destructive" 1885 flood, reporting on Neosho River floods began to increase considerably.[44] After the 1885 flood, federal and state flood reports and state and local news coverage reveal the sheer volume of overflows that people in the watershed endured. Year after year, floods in the Neosho River watershed inundated towns, farms, homes, and businesses; destroyed roads, railroads, bridges, and other infrastructure; and caused countless dollars in damages, in addition to the death of people and countless numbers of animals and livestock. Between 1886 and 1894, the Neosho River flooded in 1888,[45] 1889,[46] 1890,[47] 1891,[48] 1892,[49] and 1894.[50]

In 1895, the Neosho River experienced two major floods. The September flood hit Neosho Falls (Woodson County), Emporia (Lyon County), and Strawn (Coffey County), Kansas, especially hard. According to the September 1895 *Monthly Weather Review*, for example, the Neosho Valley was flooded "for ten miles above Emporia."[51] The December flood wreaked particular havoc and "was confined largely to the Grand (Neosho) River Valley in Oklahoma" and Chetopa (Labette County), Kansas, immediately north of the Kansas–Oklahoma state line.[52] According to Corps engineer Major General J. L. Schley, the December flood (which he called "the greatest of record" prior to 1939, when he was writing), was "estimated to have had a peak discharge at Grove, Oklahoma, 29 miles above the Pensacola Dam site, of 250,000 cubic feet per second."[53] At Chetopa, around 15 miles upstream from Miami, the Neosho River was reported to be "six miles wide"; with the Neosho and its tributary, Labette Creek, "out of their banks," many residents were "preparing to leave."[54]

In the six years between the 1895 floods and those that began in 1902, flooding occurred in all but two. In May 1896, the Neosho River flooded Neosho, Coffey, and Allen Counties in Kansas.[55] From May 5 to 12, 1898, people along the Neosho River in Coffey and Neosho Counties experienced an "average size flood."[56] Neosho County experienced four separate floods in 1899, one each in June, July, August, and September. During the July flood, the Neosho River at Chanute was "out of its banks . . . and steadily rising." The water had "nearly reached" the high-water mark from 1885, levees were "broken at several points," and "bottom lands for miles up and down the river are flooded. . . . Thousands of dollars worth of wheat is floating down the river with barns and outbuildings."[57] In 1900, only small floods occurred in Coffey and Neosho Counties in September.[58] In April 1901, the Cottonwood south of Emporia was a mile wide and the Neosho was up 22 feet.[59]

The years from 1902 through 1904 saw a series of disastrous floods along the Neosho and its tributaries from one end to the other, as well as along many other Kansas rivers. Floods were rampant in 1902. In late May and early June, "almost incessant rain for 10 days raised the Cottonwood River higher than it [had] been for several years," and by June 12, both the Cottonwood and Neosho floodwaters had "stalled" six Santa Fe trains at Emporia (Lyon County).[60] Neosho County again endured four separate floods that year.[61] In late May, the Neosho in Miami was to the top of its banks and filled with driftwood, a situation that had led to the drowning of a local man, Al Crooks.[62] According to press coverage, the "record-breaking" 1902 flood was the worst since 1885.[63] However, superlatives given to the 1902 floods would soon be surpassed in 1903 and 1904, two of the worst flood years on the Neosho River to that date.

Due to "almost continuous rains" over the region in May 1903, the entirety of the Neosho River flooded in late May and June 1903.[64] Council Grove endured one of its "most destructive" floods when "in one wild night the Neosho drew the curtain of distress over our city that surpassed all former records." Floodwaters destroyed the telephone and telegraph systems the Main Street Bridge and rendered the municipal waterworks inoperable and unable "to furnish relief and water for the thirsty hundreds." Additionally, "hundreds of small buildings and thousands of head of stock were swept down the river, a large number . . . being killed or drowned." On top of the flood damage, numerous fires broke out, furthering the damage.[65] The gage at Iola recorded the "largest flood in total volume" at that location, with unofficial records showing that the river was "above flood stage 10 successive days and almost bankfull the preceding 6 days."[66] Parts of Neosho County were inundated three separate times, with each flood worse than the one preceding it.[67] At Chanute, the river overtopped the levees and covered a gas field, spreading oil from leaking tanks across the region.[68] Indian Territory was similarly hard hit by flooding in 1903. One account from June described the Neosho River as "three miles wide" with farms "covered with water [up] to ten feet deep. The Neosho river above Miami, I.T. has covered the prairie farms for miles south of the river's main channel."[69] As one reporter summed it up, the 1903 flood was the "greatest flood ever known in Oklahoma and Kansas."[70]

If Kansans and those living along the Neosho River in Indian Territory thought 1903 was a bad flood year, they must have felt overwhelmed when almost exactly one year later, they experienced even worse flooding. According to one report, the 1904 floods were "greater in number, height, and destructiveness than ever known before" on the Neosho River. Although there were no official records of the height that the floods in April, June, and July reached, there were "quite a number of well-defined flood marks" along the river that showed the crest of the flood of July 10, 1904, "reached a height of about 1 foot greater than that of the 1885 flood."[71] One estimate valued 1904 property losses in the Neosho River basin at $1,200,000. Again, the floodwaters stretched along the entirety of the Neosho River and its tributaries. At Cottonwood Falls, for example, the water "was between four and five feet deep on the floor of the bridge."[72] On July 14, 1904, the "second disastrous flood of the year [in Chase County had] come and gone and left in its wake devastated fields, dead stock, and houses filled with mud and slime."[73] In early June, at Emporia, the Neosho and Cottonwood Rivers were reported as "rising a foot an hour."[74] At Strawn and Burlington, where for the third year in a row, the Neosho was "out of its banks [and] flooding all the bottom land," reports indicated that the "principal damage" would be to "growing crops."[75] A later report noted that both Neosho Rapids and Iola, Kansas, experienced record floods in July.[76] "According to the memory of the oldest inhabitant," on July 9, 1904, the Neosho River stood at the highest mark ever in Iola.[77]

Farther downstream in Kansas, Neosho County was also hit hard. Heavy rain in late April turned the Neosho River at St. Paul into "an inland sea, caused by the most phenomenal rise ever made in this section. Twenty-four hours ago, the river was scarcely a foot above the ordinary depth, but now traffic on both the Santa Fe and Katy railroads is paralyzed, and levees are broken, causing thousands of acres of rich farming land to be inundated."[78] On June 11, 1904, the Neosho River at Chanute and Erie was "the highest ever recorded. All of the oil country is under water. . . . In some places the Neosho river is six miles wide." Because the April flood had already breached local dikes, they "furnished no protection for the lowlands."[79] Four days later, the newspaper proclaimed that the Neosho had yet again made "a new record" and was a foot higher at Chanute than ever before. The floods washed out railroad tracks and "wiped out many of the levees" (presumably, different ones from those that were breached in April).[80] In June, the water was up again in St. Paul, with thirteen days of "the worst flood in its history." Water in the main channel rose "nine inches higher than in 1885," and one mile of the M.K. & T. railroad track was "underwater, preventing trains from passing over."[81] On July 9, Chanute experienced a fourth overflow, promising to be "the biggest of all in the history of Chanute." Again, water was "spreading over the Chanute oil fields," and the surrounding area "probably never contained more water than it does tonight."[82] In July, St. Paul also endured the fourth flood of the season, which reached "fourteen inches higher than the flood of 1885." Again, a large section of railroad track was washed out.[83]

The Neosho River flooded Indian Territory extensively in 1904, too. Early June saw flooding at Miami, where on June 7, the Neosho River "covered the new . . . 600 feet [*sic*] toll bridge with three feet of water," "ruined a thousand acres of corn," and prevented "rural mail wagons" from reaching the post office.[84] Ten days later, news reports described the Neosho as "higher than ever before known here." The river had risen "five feet in twenty four hours and is still rising. The water is now three feet deep on the new [$10,000?] toll bridge, and there is little hope of saving it. Three miles above town, the river is six miles wide," a thousand acres of corn were "completely ruined," and the water was "now within two feet of the [St. Louis–San Francisco Railway] Frisco bridge."[85]

1905-1941

Historical documents compiled to date indicate that the Neosho River (and/or its tributaries) flooded all but nine of the sixty years from 1905 to 1965. Accounts of the rise and fall of the Neosho and its tributaries in southeastern Kansas and northeastern Oklahoma repeat the superlatives of similar events and damages incurred between 1885 and 1904. The Spring River was out of its banks in both July and August 1905, when the Neosho joined the Spring in flooding.[86] June proved once again to be the month for floods in 1906 when "heavy rains of the early portion of the month . . . caused flood stages in a considerable portion" of the Neosho.[87] Flooding was reported from Chase County, Kansas, to what is now Delaware County, Oklahoma, where the Neosho "was bank full and slushing over into many bottom pieces of corn."[88] On May 25, near Miami, the Neosho River was "out of its banks and many farms are covered with water."[89] The July 1909 flood of the Cottonwood and Neosho in Kansas, for example, was "as high as ever reported," and the second flood that year, in November, broke "all previous records" for the fall season.[90] In January 1910, another unseasonable flood occurred along the Cottonwood and Neosho Rivers. Although floodwaters caused damages during the January flood, ice posed more of a danger. The Cottonwood flooded and then froze in the streets of Marion, Kansas. The Neosho River flooded at the same time, breaking "all records" at Strawn. According to press coverage, there was an ice dam at Strawn and one between Strawn and Hartford. The one at Strawn began "a short distance below the river bridge and extend[ed] about two and one-half miles down the river. Dynamite was used but the ice dam [was] still holding. Water [was] in the ditches in the streets of town. The river below the ice dam [was] considerably lower than the level above the dam."[91] In Lyon County, the January event was the "greatest flood known so early in the season" and "most of the damage done was to buildings and fences by floating ice blocks."[92]

Spring rains caused flooding on the Neosho and Spring Rivers in April and May 1912. Neosho County encountered a "small flood" on April 4. From April 25 through 28, "high run-off resulted in severe flooding in the lower reaches of the river" and the "peak stage at Wyandotte, Oklahoma, was 30.0 feet on April 30," 5 feet above flood stage for that location.[93] According to the *Monthly Weather Review*, the Neosho "was at flood stage April 29 and 30 from Oswego southward, causing damage to crops and enforced suspension of business. The loss is estimated at $40,000."[94] The flood on the Spring River overtopped the Lowell Dam in Galena, Kansas, which on April 29 was "5 inches under water" despite "all flood gates at the dam and bypass bridge, a half mile up stream, open." Additionally, the "Badger Dike was two feet under water and mines [were] flooded."[95] In May 1912, the "lower" Neosho flooded, doing about $15,000 in damage mostly to agricultural lands.[96]

Substantial flooding occurred on the Neosho River in Kansas and Oklahoma in 1915. A "small flood" on April 22 in Neosho County started the flood season off that year.[97] But the worst of the 1915 floods happened in late May/early June and September. The spring flooding affected Lyon, Coffey, and Neosho Counties in Kansas and Ottawa County in Oklahoma (and likely Allen County in Kansas, since it sits between Coffey and Neosho).[98] The area around and including Miami suffered massive wind and storm damage, witnessing a "down pour of rain [that] was the greatest in years." The rain had completely saturated the ground, which was "covered with water, resembling streams. The rivers and creeks [were] bank full and overflowing in many places."[99] Reportedly, although the Neosho did not reach flood stage at Wyandotte, it "overflowed its banks above and below that [gaging] station."[100] The flooding situation only got worse from there. In Miami, the local paper reported that the Neosho River had "been on a week's spree, a wild and reckless rampage, spreading ruin in its wake, overflowing its banks and surrounding territory." The city park was "completely inundated," the river reached "within three or four feet of the wagon bridge floor" and blocked travel westward out of town for days because the west approach of the highway bridge was six or eight feet underwater, and "all growing crops and pasture along the river [were] destroyed by this overflow."[101] Fall flooding on the Neosho in 1915 occurred in September, exceeding flood stages for at least a full week in both Kansas and Oklahoma. The *Monthly Weather Review* reported that the flood at Iola (the highest recorded there since 1904) had required the rescue of 600 families. "While the damage from flooded conditions was greatest in Allen, Neosho, and Labette Counties, the river rose above flood stages along the course from Iola south to the Kansas-Oklahoma State Line."[102] The flooding caused "great losses" (and estimated $2,460,000 worth) to railroads, bridges, crops, levees, and livestock.[103] At Miami, flooding once again prevented motorists from crossing the highway bridge, requiring stranded travelers to set up a "city of tents" in which to shelter until the water receded.[104]

In June 1917, Tar Creek went on a "rampage" and flooded Picher, Oklahoma. November the next year witnessed the Neosho River and Tar Creek again overflowing their banks, spilling water into Miami, and "completely" submerging Picher.[105] The Neosho and Spring Rivers and Tar Creek again flooded in Oklahoma in March and May/June 1920. Heavy rain March 19 and 20 led to all three of these watercourses being "extremely high," having "inundated the lowlands." The local newspaper reported that in Picher, Cardin, and other towns near Miami, "cellars and basements were flooded as there are no sewer facilities available to carry off the heavy storm waters."[106] A few days later, the Neosho rose above flood stage at Fort Gibson.[107] In late May/early June, heavy rains caused "more flooding in basements in Miami."[108]

In spring 1927, the river was out of its banks in both Oklahoma and Kansas, with "mad flood waters" inundating the bottomlands of most of the watershed from Iola to Miami. The flooding marooned "scores of motorists" trying to cross the Neosho River at Miami, where the bridge was covered in water that had "attained [its] highest level in 23 years."[109] Another flood in June 1928 covered large portions of Miami.[110]

1941–2019

Disastrous floods on the Neosho River have continued since construction of the Pensacola Dam. Indeed, immediately after the project became operational, three major floods occurred in 1941 and 1943. In 1941, flooding caused heavy losses along the river's entire course. As one report described, floods were "the rule, rather than the exception" from April to October that year, with flood stage being "reached or exceeded" in every month except May.[111] Two floods in October 1941 saw the Neosho "on spree again." In early October, floodwaters all but surrounded Wyandotte, Oklahoma, cutting it off from the rest of Ottawa County; later October found the Neosho River, Spring River, and others "spreading havoc" across Oklahoma.[112] Both the Spring and Neosho Rivers flooded again in May 1943. At 23.95 inches of rain that month, Miami experienced the "greatest monthly amount recorded at any station in the state."[113] The Miami Public Utility Board (PUB) superintendent noted that the water level, which reached the racetrack, exhibit building, and swimming pool, was "the highest of any record."[114] Federal operation of the Pensacola Dam during the May flood was "credited with saving" the "big war plant" at the Oklahoma Ordnance Works immediately downstream.[115] Some people blamed dam operators at the time for the "flood troubles" Miami and Wyandotte had suffered, "where waters from the Grand river dam reservoir backed up into the outskirts."[116] Later review of the issue partially contradicted this narrative, indicating that any effects Grand Lake might have had on upriver flooding in May 1943 were "below Miami."[117]

News coverage in 1944 proclaimed that flooding in April had broken "all known records at Chanute, Erie, and St. Paul, and at the highway bridge east of Parsons, with the Neosho, "one vast sea, in some places, four or five miles wide."[118] Farther downstream, Wyandotte was "menaced by rampaging Neosho."[119] Late that year, a second round of flooding that was "extraordinarily high for December" was caused by a "combination of rain falling on frozen ground with high base flows already prevalent."[120] Flooding along the Neosho and its tributaries in June 1948 again submerged substantial portions of the town of Picher on Tar Creek and the lowlands in Kansas and Oklahoma. But the floods of July 1948 caused the most damage in Ottawa County.[121] According to local news reports, "a new all-time high water mark reportedly was established at a point [Commerce] 12 miles north of Miami," a measurement that surpassed the previous record from spring 1943.[122] Other reports indicated that the Commerce gaging station recorded the third- and fourth-highest known floods in terms of magnitude (prior to 1969) that year.[123]

Still the largest on record, the historical flood of July 1951 swelled countless rivers and streams and wreaked havoc across the Midwest.[124] Residents in Kansas and Oklahoma suffered greatly during this flood on a number of watercourses; heavy storms caused the Neosho, in particular, to reach "flood heights far in excess of any previously known." Miami "suffered extensive damage," with approximately a quarter of the city underwater and damages estimated "as high as several million dollars."[125] In 1954, "major flooding" of the Neosho and Tar Creek "caused extensive damage to Miami development."[126] News reports from 1957 depicted the Neosho River bridge at Commerce (to which the gage was affixed) close to being overtopped and water extending far past the river banks on either side.[127] In 1961, the Commerce gage recorded the fifth-highest flood (prior to 1969) on the Neosho.[128]

In 1964, 1965, and 1968, respectively, the Corps completed the long-anticipated Council Grove, John Redmond (Strawn), and Marion dam and reservoir projects on the Neosho River in Kansas. Later reports indicated that these structures did indeed succeed as proponents had hoped in diminishing downstream flood damage.[129] However, Neosho River floods did not and would seemingly never disappear. A 1964 flood pushed the Neosho again out of its banks at Miami, where it flooded the fairgrounds for several days, a scene that was repeated in 1969, when Riverview Park was again flooded and the park road closed.[130] In the 1970s, floods of various sizes occurred every year in both Kansas and Oklahoma, with the Neosho on yet another "rampage" in Neosho County in 1970 and doing "the expected" by overflowing in Labette County in 1973.[131] Miami was especially hard hit in 1974, when combined high-water levels on the Neosho and Tar Creek caused flooding to both the west and east sides of town. Descriptions of the flood noted that Miami's fairgrounds, the "scene of many a western sporting event, could have accommodated a water polo match last week, or a racing meet for sea horses."[132]

The litany of Neosho River floods in Kansas and Oklahoma continued throughout the 1980s and 1990s. In southeastern Kansas, the river was out of its banks in one or all of Neosho, Labette, and Allen Counties in 1980, 1982, 1985, 1986, 1988, 1989, 1993, and 1998.[133] During the same two decades in northeastern Oklahoma, the story was much the same. In 1985, Ottawa and two other Oklahoma counties received disaster declarations. At Miami, the Neosho "crested 13 feet above flood stage. . . , damaging 300 homes and dozens of businesses."[134] Both Tar Creek and the Neosho caused floods in Miami in 1987; the Neosho flooded again in 1990, 1992, 1994, 1995, and 1997, each time either flooding the fairground, closing roads, or forcing home evacuations (or all three at once).[135]

Two major floods occurred during the last two decades of the 1900s in Miami—one in 1986 and one in 1993. As described in a pamphlet the Miami Kiwanis Club published in 1986, two storm systems resulted in rainfall amounting to 25 to 30 inches of rain between September 27 and October 3 that year.

> The first two days of rain saturated the ground and raised rivers and creeks to near flood levels as upstream from Miami, heavy thunderstorms in eastern Kansas fell into the Neosho and Tar Creek Basins. A second storm system struck on Tuesday, September 30th, bringing additional rainfall of 5 to 10 inches, causing severe flash flooding, twenty-six homes were evacuated in Sky Ranch West as the rapidly rising Tar creek swept out of its banks. The continued rainfall caused the Neosho River to rise above flood stage on Thursday, October 2nd, flooding rural areas from southeastern Kansas to the headwaters of Grand Lake and threatening all homes and

> businesses in low lying areas of Miami. Evacuations, sandbagging and other precautions to protect lives property continued throughout the remainder of the week. More than 400 volunteers worked around the clock each day, helping those that were threatened by projected crest levels of 766 feet.

Ultimately, the Oklahoma National Guard (ONG) deployed to assist emergency operations in Miami.[136] Miami residents again evacuated their homes and businesses and received help from the ONG in the 1993 flood, which also affected Wyandotte. According to State Emergency Director Tom Feuerborn, "We have extensive flooding on the Spring River, Tar Creek and the Neosho River. Most of the water is coming from Kansas where they had rains of 12 to 15 inches."[137]

The first two decades of the twenty-first century have also witnessed flooding of the Neosho River in Kansas and Oklahoma. Floods occurred in Oklahoma, specifically, in 2000, 2002, 2004, 2007, 2015, and 2019.[138] The 2007 Neosho and Tar Creek overflows "engulfed" Miami, flooding over 600 homes in that town.[139] The "record-breaking" May 2019 Neosho flood caused "major damage" in Miami, forcing "closures and major remodels" of some businesses. According to the National Weather Service both the Neosho and Spring reached "historic levels" during this flood with the Commerce gage recording its "fifth highest crest on record over the past 79 years" and the Spring reaching its "eighth highest crest since 1940."[140]

Flooding continued off and on into the twenty-first century and to the present at various locations in the Neosho River watershed, despite many efforts made over the course of the twentieth century to prevent such flooding. As evidenced through the litany of flood events presented in this section, everything from minor to major floods have occurred at almost every point along the Neosho River in Kansas and Oklahoma from as early as anyone could remember or document. As discussed in the next section, even once flood-control prevention measures—from early levees in Kansas to the multipurpose Pensacola Dam and Reservoir to other dams and reservoirs in both Kansas and Oklahoma—were constructed, floods continued to break records. Unfortunately for the people living in the vicinity of Neosho River and its tributaries, if current weather conditions continue, the likelihood of Kansans and Oklahomans living along the Neosho River experiencing record-breaking floods will likely continue.

Part 2: Controlling the Neosho River: Early Efforts at Flood Control before Creation of the GRDA

Introduction

Non-Indigenous peoples' attempts to harness the Neosho River and its tributaries began almost as soon as they began to occupy the area. Individuals living in the watershed, especially those immediately adjacent to the river, became active first in utilizing waterpower for mills and other industries along the riverbanks and then in flood control efforts in the nineteenth century.[141] Although federal and state agencies got involved in flood control earlier in Kansas than they did in Indian Territory (later Oklahoma), by the early 1900s, private, local, state, and federal agencies in different combinations and permutations all along the Neosho River and its tributaries sought cost-effective means to protect valuable agricultural land, domestic and commercial buildings and property, infrastructure, and human and animal lives from floodwaters.

Between the early 1890s and the mid-1930s, Kansans and those living in the Indian Territory/Oklahoma experimented with various forms of flood control along the Neosho River. People in Neosho County, Kansas, for example, built the first system of levees on the river in the 1890s, setting the stage for Kansas officials to begin creating a series of commissions and conservancy organizations to study the causes of and address flooding along the Neosho River and the state more generally. Officials in what would become the state of Oklahoma in 1907 also began to form water-related committees and supported private and public studies of flooding and flood prevention and control on the Neosho River. In both Kansas and Oklahoma, flood-control advocates engaged in early debates over the efficacy of everything from clearing streambanks of debris and clearing rivers of snags to straightening rivers to levees to reservoirs.

In towns like Miami, Oklahoma, flooding from the Neosho River led to ongoing battles against high water in the town. Platted along the eastern bank of the river, Miami's main business area sat close to the river, which created a natural barrier between the town and lands west of the river on which people had settled. Thus, the first matter of business for the town, even before Oklahoma achieved statehood, was providing reliable crossing for wagons and pedestrians, and then gas-powered vehicles, over the unpredictable Neosho. Although bridges were more reliable than ferries, the City (and then Ottawa County) found itself repairing flood damages to bridges sometimes multiple times per year. Adding to Miami's water problem was a nonexistent and then deficient early stormwater and sewer system, which was often overwhelmed by sheer volume of rain so many storms brought. Once Miami completed its first storm sewer system in the 1920s, some in-town flooding diminished, although the City continued to expand the system over time in response to ongoing complaints of flooding in various areas of town, including along Tar Creek, which runs north–south through Miami east of the Neosho. To address the ongoing issues, especially constant flooding of the city's public park along the eastern bank of the Neosho River and over a low dam the City had built across the river for the park, Miami created a public utilities board (PUB) in 1927. The PUB would continue to address flooding and stormwater issues throughout the creation of a municipal zoning ordinance in 1930 and beyond.

By the early 1900s, the federal government was playing a more engaged role in flood control around the country, especially after a series of disastrous floods on the Mississippi and other large rivers around the country. However, the U.S. government (primarily the Corps) took a hands-off approach to flood control on the Neosho River until the later 1930s, when the Corps set its sights on using the Pensacola Dam and Reservoir Project in Oklahoma for flood control. This reversal would lead to Congress including money for Neosho River projects in the 1936 Flood Control Act.

In addition to flood-control efforts on the Neosho River, also beginning in the 1890s, interest grew rapidly around developing hydropower on the Neosho River at a larger scale. As Part 3 explores in more depth, in northeastern Oklahoma (and far southeastern Kansas), Henry Holderman was the first to conduct private surveys of the Neosho River and envision developing a power-generating dam on it. Holderman and others worked tirelessly into the 1930s surveying potential dam sites and modeling the power that specific dam designs and pool levels could produce.

Although mostly downplaying the Neosho River for flood control, the Corps had received authorization and appropriations from Congress in the 1927 River and Harbor Act to begin studying the power potential of rivers around the country, including the Neosho. This study resulted in what was known as a 308 report for the Neosho River, which outlined the Corps' proposed approach in 1935 to a power-generating dam akin to Pensacola and also explored what kind of benefit the dam (or a series of dams) might have on downstream flood control. The 308 report for the Neosho River stated that power-producing dams were feasible on the lower reach and that had Pensacola Dam (with some flood-control capacity) existed in 1927, it would have mitigated at least some of the disastrous downstream flooding that had occurred that year. Still, the Corps determined that federal funding for neither power production nor flood control on the Neosho River was economically justified at the time the study was released in summer 1935. The seeming fact that the Corps reportedly saw no utility in supporting power generation or flood control on the Neosho River coincided with the PWA's interest in developing economic relief projects around the country. Thus, when the State of Oklahoma created the Grand River Dam Authority in 1935 and took solid steps toward executing plans to build the long-awaited Pensacola Dam, it received federal funding and support not through the Corps but instead through the PWA for a power-focused project.

Early Flood-Control Efforts in Kansas

The First Levees: Neosho County

After destructive floods in 1889 and 1891, private parties got serious about building levees along the Neosho River in Neosho County.[142] Landowners near Erie concluded in 1890 "that by filling up the low places that permitted the water to overflow the lands, they could protect their lands from overflow from the ordinary flood." They then held a meeting at which they decided to assess "each owner of land who would be benefitted . . . thirty cents per acre for each acre to be benefitted." The landowners used that money to complete the "filling" work, which "was found to be of great benefit."[143] Although the makeshift levee seemed to work and inspired other locals to plan their own flood-control structures, arguments soon arose over who should pay the costs versus who received the benefits of future levees. Neosho County residents quickly realized that "individual action could not be depended upon, nor would it be safe to build private levees for the reason that some parts would be neglected and there would be no power to compel the proper building of the levee or to keep it in repair."[144]

On April 2, 1892, Neosho County residents gathered at a meeting in Chanute and adopted resolutions stating that Neosho River flooding was exacerbated by extant dams (such as the Erie mill dam, which had been washed out in 1885 and rebuilt), railroad trestles, and thick vegetation along the riverbanks that they believed were impeding water flow. Attendees called for a "mass convention" to take place May 7, 1893, and invited "owners of bottom land" affected by flooding to not only attend the meeting but spread the word to anyone else who might be interested. The stated goal of the May meeting was to devise plans "for securing definite, accurate, and reliable information" as to the causes of the recent floods and "to agree upon whatever action may be necessary to prevent the further recurrence of same." In the meantime, R. N. Allen (convener and secretary of the April 1892 meeting), J. L. Barnes, and D. C. Newman formed a committee "to further investigate the causes of the overflow." Additionally, J. M. Allen, Marion Johnson (one of the landowners involved in building the first levee near Erie), and Dr. W. E. Baker were tasked with determining what kinds of legislation would be needed "to prevent or remove obstructions in the river or to levy the same."[145]

During the 1893 legislative session, Arthur Lodge, a local landowner whose property was "subject to overflow," gathered money from other Neosho County residents and hired an attorney to draft a levee bill. Senator J. C. Carpenter made some "slight changes" to the bill and then "pressed its passage through the senate" after which Representative J. M. Dunsmore "obtained its passage" in the House.[146]

The 1893 law created levee districts and gave the Neosho County commissioners power over the entire levee-building process from planning to construction. The law also appointed an overseer for each levee district, to be paid by the district, "whose duty it is to note any defect or injury that may appear in any part of the levee" and keep it "in good repair."[147] That same year, the first county-approved levee, the Baughman levee, was constructed near Shaw, followed by the Dutton levee just west of Erie. By 1902, Neosho County could claim 80 miles of levees along the Neosho River. Although "now and then loss has occurred by the breaking of a part of a levee" due to damage or shoddy design or workmanship, locals crowed about the overall "success" of the levees when "properly constructed."[148] The levees protected and benefited 18,529 acres of land, the value of which had doubled since they had been constructed. Furthermore, the levees had "added to the material wealth" of the county. And that wasn't all. "Their benefit from a sanitary point of view is inestimable."[149] By 1904, nineteen levee districts existed in Neosho County.[150]

Preventing Destructive Floods in Kansas

After the disastrous flood years of 1903 and 1904, beleaguered residents in the watershed had urgently demanded answers, a request that in 1905 was "brought to the attention" of the drainage investigations unit of the U.S. Office of Experiment Stations.[151] Although Neosho County residents had been constructing levees for at least a decade, no other county had developed such a system and levees (or any other kind of flood-control structures) were few to nonexistent along the Neosho River in Kansas. The people in these counties had suffered immense damage from flooding. Based on field investigations completed in 1906 and 1907, James Wright and Charles Elliott reported in their 1908 *Prevention of Injury by Floods in the Neosho Valley, Kansas*, that farmers' refusal to clean out snags and trash on their portions of riverfront obstructed waterflow and exacerbated flooding. "An immense amount of good would be accomplished by clearing out the snags, removing the bars, and cutting the timber on each side" of the river, they argued.[152] Ultimately, they suggested five main actions: remove obstructions from bottom and banks of channels, build "substantial levees" 900 feet apart on the lower section of the river and "return levees on each side of the channels of the larger tributaries," remove brush and trees from land lying between the levees, create interior drainage "by means of ditches with outlets through the levees into the channels by means of sluice gates," and cut a few bends in the upper section of the river to increase velocity.[153] The large-scale straightening of the "very crooked" Neosho that some people advocated, however, was infeasible both financially and logistically.[154] Additionally, Wright and Elliott assumed that all lands bordering the Neosho River would be "organized into drainage districts under the drainage law enacted by the [Kansas] legislature in 1905."[155]

In 1911, the Kansas legislature enacted a statute that permitted drainage districts to encompass more than one county. The law allowed districts on the more logical watershed basis. Several such districts were established: by one estimate, more than fifty drainage and levee districts had been created in Kansas by the early 1950s. But one observer remarked, "their contribution to effective flood control was reliably reported to have been practically valueless."[156] Still, at least some of the levees worked. In 1915, an article in the *Farmers Mail and Breeze*, called the Deming Ranch in Oswego, with its 11-mile-long levee, "a fine example of what can be done in reclaiming land." A "system of dykes and tiles drainage" kept the ranch "protected from excessive rainfall" and made it so that "all the bottoms can be flooded above and below the farm, and still the water is kept off the Deming property."[157]

Commissions and Conservancy

Kansas Flood and Water Congress and State Drainage and Conservation Association

Flood control in Kansas gained momentum during the 1910s, largely through the efforts of state officials. On July 9, 1915, "in response to a general call issued by Governor [Arthur] Capper, there convened at Topeka a meeting of representative citizens from all parts of the state to discuss flood protection." The gathering resulted in the creation of the Kansas Flood and Water Congress. A year later, the engineering subcommittee of the flood and water congress outlined its four primary findings: federal cooperation and aid were necessary to "working out a comprehensive and satisfactory system for flood abatement in Kansas," a permanent state flood committee was required to serve as the official acting body for the state, the state needed to reestablish stream gages that the U.S. Geological Survey (USGS) formerly maintained, and immediate enactment of "adequate state legislation" that would empower the state "to make a comprehensive study of the Kansas flood conditions."[158] The next year, in June, representatives of twenty-two drainage boards, county commissioners, and mayors of cities affected by floods met to initiate "a concentrated, energetic campaign to reduce Kansas' annual loss of millions from floods." Governor Capper and others achieved their overall goal—the creation of the Kansas State Drainage and Conservation Association—that would work toward securing "better drainage legislation" and be empowered "to condemn property for flood protection." Some experts at the meeting believed that an effective drainage system would do more to address flooding than "dikes or levees."[159] To that end, attendees proposed to create a Neosho River drainage district as one of four in the state. The new association was to cooperate with the state flood and water congress "to bring about better protection against floods." Additionally, the group advocated creating a legislative committee to consider how to achieve the legislation they sought, including giving drainage boards authority to condemn property and enlarge districts. They also called for a centralized body to organize the drainage boards and ensure communication and coordination.[160]

Kansas Water Commission

The call for a centralized body was answered on March 13, 1917, when the Kansas legislature passed the Kansas Water Commission Law and created the Kansas Water Commission

(KWC).[161] The move was likely (at least in part) a response to the federal River and Harbors Act of July 27, 1916, and Flood Control Act of March 1, 1917.[162] The 1916 act authorized the War Department to conduct both a physical survey of the territory and an analysis of data "already gathered by governmental, state, private efforts, and by the Board of Engineers of the War Department," with the goal of devising a "general plan" that would "best guard against the recurrence of floods and diminish their damaging effects upon the lower valleys of the Kansas, Arkansas, Missouri, and the Mississippi rivers." In light of the importance of these rivers both to the "lives and welfare" of Kansans and also to downstream navigability, the Corps felt that thorough reconnaissance of the watersheds of each river was of "sufficient national importance to warrant" a federal survey.[163] The investigation, however, was contingent "upon action by the state of Kansas" that guaranteed state cooperation with the federal government and revision of state water laws in order to "bring them into harmony" with and to facilitate "the adoption and execution of" any plans that came out of the Corps' investigation.[164] Although the 1917 Flood Control Act focused only on the Mississippi and Sacramento Rivers, Kansans undoubtedly hoped their rivers might receive federal attention next.

With that in mind, the law tasked the KWC with investigating and securing "the most advantageous adjustment of the interest involved in matters of floods, drainage, irrigation, water power and navigation."[165] The commission was composed of the governor (ex officio chairman) and two civil engineers.[166] As soon as it was official, the KWC turned its attention to studying flooding in eastern Kansas and initiating "hydrometric investigations . . . without delay."[167] To that end, the commission entered into a cooperative agreement with the USGS for stream gaging. Another cooperative agreement was executed with the U.S. Weather Bureau.[168] Originally, funds for the KWC were slated to come through proceeds generated from the so-called Kansas sand law, as compensation for sand, oil, gas, gravel, minerals, or other natural products taken from navigable streams. At the time the Water Commission Law passed, however, the sand law had been rendered "inoperative" by litigation still pending before the Supreme Court of Kansas. Without a secure funding source, the state was forced to make small appropriations from its general fund for the balance of fiscal year 1917 and for fiscal years 1918 and 1919 to support field investigations for stream gaging. The lack of funding eliminated the compensation KWC commissioners had been promised in the bill and required the commission to rely on already-employed state engineers to shoulder the additional responsibilities of the commission, also without compensation.[169]

Inadequate funding hamstrung the KWC the entire decade it existed. In its first biennial report, the KWC was already noting that it could not conduct requested special investigations due to limited funds. However, the commissioners made plans for the next biennium to conduct river surveys ($8,000 from 1921 budget) and to analyze and recommend ways to enact "more effective water laws" ($1,000 from 1921 budget). The KWC recommended that once it received permanent financing, it receive authority to approve all plans and generally take over supervision of the drainage districts (akin to how the state oversaw local highway matters). It also called on the legislature to provide flood relief that would assist in clearing the banks of the Neosho and other rivers in the state.[170]

The KWC carried on with little money over the next eight years. Early on, the commissioners "realized the impossibility" of fulfilling, "in its entirety, the broad program" that its founding legislation had outlined for it.[171] Every biennial report made clear that the economic situation would limit what it could accomplish. With this in mind, the KWC chose to focus the most attention on the stream-gaging program.[172] To the KWC commissioners, the importance of the program could "scarcely be exaggerated," as the data the gages gathered was "the basis for all calculations for flood prevention, water supplies, sanitation, drainage, water power, navigation, and irrigation."[173] In addition to the privileges the KWC garnered by cooperating with the USGS for the gaging program (for example, the U.S. Postal Service provided free office space to the team), affiliation with USGS for the gaging program would ensure not only consistency of the readings being gathered but also the "unqualified acceptance" of the data by courts and "leading hydraulic authorities in the country."[174] By 1924, the KWC was proud to report that it was operating thirty-two stations (a 100 percent increase over the 1921–1922 biennium), which were "well distributed over the principal watersheds of the state."[175] Eight of the gaging stations extant in 1924 were in the Neosho River watershed. Originally installed by the USGS in 1895 and cooperatively run with the U.S. Weather Bureau since 1904, the station at Iola was the oldest on the Neosho River and one of the first group of gages installed in Kansas. In 1904, the agencies established one gage at Neosho Rapids and one at Oswego. Over time, gages were added at LeRoy and Cottonwood River at Emporia (1908, both maintained by the Weather Service), another gage "near Iola" (1917, USGS), Parsons (1921, USGS), and Cottonwood River at Elmdale (1922, USGS).[176] However, of these, only four remained in operation in 1935—the two at or near Iola, Parsons, and Cottonwood Falls—for unknown reasons.[177]

Another stride the KWC made was to study the existing state water laws. In their second biennial report, the commissioners recommended that revisions be made to streamline jurisdictional borders to enable greater efficiencies in service, to require state inspection and approval of engineering plans related to the "regulation of uncontrolled flood waters" or "drainage of overflowed lands," and to strengthen and extend state and local cooperation around control and use of water resources to help these organizations function more effectively.[178] Additionally, the KWC suggested that the state create a uniform filing system, develop a statewide water code, engage in further flood studies, extend the stream-gaging program, and consider irrigation an integral part of the21rogramm.[179]

After several disastrous floods swept the Arkansas valley in 1923, Kansas state water commissioner H. A. Rice was called to a flood-control conference with the Arkansas Valley Improvement Association, two U.S. congressmen, and close to fifty representatives of the flood-damaged counties. Attendees made permanent the Arkansas Valley Improvement Association. The organization would prove influential in future flood-control efforts on the Neosho, as part of the larger Arkansas River watershed.[180]

Kansas Division of Water Resources

The KWC continued its work through 1927, when the state legislature created the Kansas Division of Water Resources (DWR) under the Kansas State Board of Agriculture. The DWR took over "all of the authority, powers and duties theretofore conferred and imposed by law upon the Kansas Water Commission and the state irrigation commissioner" and abolished both the KWC and Division of Irrigation. The legislation thus "brought together into one department all state activities relating to irrigation, drainage, flood control and the conservation and utilization of the waters of the state."[181] The new body met in May 1927 to formalize its goals, but unfortunately, the DWR was "vested with much power" and "endowed with but little money," much like the KWC, its predecessor. As one newspaper reported, the legislature had given the division "words of encouragement as a substitute for funds." The new commissioners planned to conduct an extensive survey of conditions as soon as possible. Local media forewarned, however, that scant funds would "cramp" its activities and the DWR would not accomplish more than "a survey with a view to urging legislative action at the 1929 session."[182] During the meeting, the DWR discussed and approved plans for the building of artificial lakes and ponds, along with levees and dikes. However, it also pointed out to attendees that individuals and local benefit/taxing districts would need to fund and undertake those projects for themselves because, much like the federal government, the state could not fund or participate in the construction of works that benefited one locale over another. Agricultural board secretary Jacob C. Mohler reassured people that the body would not sit idle and that DWR chief engineer George Knapp would use his connections with county, railroad, utility, and irrigation engineers to gather data for future use as soon as funds became available.[183]

Conservancy Legislation and Appeals to Congress

The year 1927 proved to be a disastrous one across the United States, with Kansas suffering almost $15,500,000 in flood damage. Notably, most of the losses occurred in the Neosho River watershed, whose residents suffered estimated damages of $6,568,810.[184] In response, the DWR ramped up its flood-control efforts. Governor Ben Paulen and the DWR held a statewide flood-control and water-conservation conference in December. Soon thereafter, the governor appointed Knapp to the seven-person Flood Control and Water Conservation Committee (FCWCC), charged with working out a "comprehensive plan for flood control legislation to be presented to the 1929 legislature."[185] The FCWCC began meeting in February 1928 to address four main areas: controlling floods by drainage and levee districts, reducing floods through stream cleaning and maintenance, equalizing stream flow, and conserving water by building dams. At that time, the state constitution prohibited "the state from engaging in works of internal improvement, except the building of roads,

[and] creation of drainage and levee districts, which in effect [were] local benefit districts," so the FCWCC set out to study the drainage and levee districts and laws pertaining to them. Over the course of the year, the committee had meetings about the districts and low-water flow and conducted two trips to view rivers and meet with locals in various areas.[186]

In late 1928, the Kansas FCWCC issued its recommendation for legal reform. First was enacting a conservancy district law patterned after Ohio's Miami Conservancy District and requiring all drainage, levee, or irrigation plans to be approved by the DWR chief engineer. As part of this first recommendation, the committee supported retaining current drainage and levee district laws but repealing the irrigation district act. Second was enacting a maintenance law for streams and tributaries to be overseen by the counties (like roads), and to be funded in part by a levy on the entire county and in part by an additional levy on floodplain property. DWR would do the surveys and oversee application of the act. Third, the committee sought an amendment of the current act to provide greater compensation for reservoirs built with DWR approval. Last, FCWCC members advocated repealing a law that required the designer of a dam to give bond for its safety, instead placing the responsibility on DWR, whose chief would give approval before construction.[187]

Parallel to developments at the state level, Kansans made their voices heard in Congress. Debate during January 1928 hearings of the House Committee on Flood Control both presaged the increased role the federal government would take regarding flood control on the Neosho River in Kansas and Oklahoma under the Flood Control Act of 1936 and reflected the resistance of many in Congress to funding measures they perceived to provide greater local than national benefits.[188] The tragedies Americans experienced across multiple states during the 1927 floods pushed many senators and representatives to rethink the role the federal government should play regarding funding for flood prevention and relief to states and localities. U.S. Senator Arthur Capper, the former Kansas governor, went "on record as being in the strongest possible way" in favor of direct federal flood relief monies for victims of the 1927 floods on the Mississippi River. He also advocated for a federal flood-control program that would "recognize [flooding] as a national problem."[189] Like many of his colleagues, however, Capper was neither convinced nor ready to assert that the federal government should assume all costs for flood control and intimated that some form of local contribution would be required. Echoing estimates of flood damage in the Neosho River watershed, Kansas House Representative William Sproul explained that his district was "the worst flood region" of Kansas, where all the rivers (including the Neosho) had been "frequently overflowing, to the great detriment of the farming country and the cities near the streams." Sproul agreed with Capper in his opinion that the federal government should assume all obligation for flood relief on the Mississippi, but "with reference to the control of the floods in the tributary territories" like the area of the Neosho River watershed, he felt it would be "equitable and just" to divide costs among the federal government, states, and benefiting districts.[190]

In response to the FCWCC's recommendations, the 1929 Kansas legislature passed several acts relating to the creation of conservation districts, flood control, drainage, and the building of dams and required that the chief engineer of the DWR review and approve all such plans.[191] The DWR also received "authority over the placing of obstructions in the rivers and streams" and decision-making power over "changes made in the course, current, or cross section of any stream in the state." By 1931, sixteen sets of flood-protection or drainage plans had been submitted to DWR, of which the chief engineer approved fifteen. Additional approval was given for repairs on more than fifty levee systems and to thirteen of fifteen plans for dams. However, DWR still had made no progress in preparing general plans for state watersheds, with which the Water Commission Act had tasked it. Once again, a failure to obtain appropriations from the 1929 legislature meant that DWR could only await "the results of the flood-control surveys and plans now being made on Kansas streams by the War Department."[192]

Almost immediately following passage of the 1929 Conservancy Act, which the Kansas legislature modeled essentially word-for-word on the Ohio act, residents in the Neosho and Verdigris River valleys mobilized to create conservancy districts under the law.[193] As it was designed and approved by the DWR, the Neosho River district would span portions of nine counties and follow "a strip of land two or three miles wide from Council Grove on the Neosho River and Cedar Point on the Cottonwood River nearly 150 miles to the state line."[194] Locals knew it would be an arduous process to finalize the district. The surveys the new law required would take at least a year to complete, and courts had to approve the resulting appraisals before the districts could petition for federal approval. Even if the districts secured court and Congressional approval, federal funding was in no way guaranteed. Knapp was optimistic, however, that Congress would affirm such funding because land in Kansas was "worth just as much" as anywhere else and Americans living in Kansas suffered as much from flooding as did those living in the Mississippi River valley.[195]

Optimism about the proposed Neosho River conservancy district was dashed in 1930, when the Kansas Supreme Court ruled the law unconstitutional on grounds that the legislature had "exceeded its powers in delegating to the district courts its authority to establish political subdivisions such as conservancy districts." Although the state planning board wrote that this objection could "easily be overcome by the legislative establishment of a predetermined number of conservancy districts having definite boundaries, with boards of directors appointed by the governor by and with the consent of the legislature," no such action appears to have been taken. Despite ongoing recommendations from the board to revive the Conservancy Law, by 1936, the idea appeared dead.[196]

The Deming levee described so enthusiastically in 1915 might be seen as the exception that proved the rule where levees were concerned in Kansas. By 1928, almost every private levee built along the Neosho River had failed during floods and they all required constant repair or wholesale rebuilding.[197] During the late 1920s and into the 1930s, engineers like Knapp and other Kansans were beginning to doubt the efficacy of widespread leveeing of rivers for some different reasons, including a lack of comprehensive flood-control laws and fighting instead of cooperation among the extant levee districts. Knapp reassured the committee that Kansans were interested "in any manner" of flood control but emphasized to the committee his personal interest in building reservoirs.[198] When asked if he thought building reservoirs in Kansas could also help with downstream flooding in Oklahoma and Arkansas, Knapp replied that they would be more helpful than continuing to follow the current policy "of attempting to control [water flow] values by cutting off bends and building levees."[199] In fact, Knapp explained, levees and straightening efforts might be creating worse flood conditions elsewhere on a river depending on its profile. He backed this up with an example in Salina, where after an engineer had raised the levee and straightened a portion of the Smoky Hill River through the city, flood flows downstream from the town increased significantly.[200] Ultimately, Knapp was "convinced" that the reservoir system had "merit" and expressed his "personal opinion" that Kansans would "be entirely willing to bear their portion of any work from which they will receive benefit."[201]

Despite massive and widespread levee failures and changing theories about the most effective ways to minimize flood damage along the Neosho River, faith in levees remained strong through the 1930s among laypeople and engineers alike. By the early 1930s, fifty-one levees or levee systems could be found along the Neosho.[202] In 1931, the Corps designed and estimated the costs of constructing twenty-nine additional levees from the headwaters of the Neosho to locations in Ottawa County, Oklahoma.[203] Although the completion of these proposed projects was not guaranteed, the stage was set for the federal government to get involved in flood control in Kansas.

Early Flood-Control Efforts along the Neosho River in Indian Territory and Oklahoma

Flooding occurred equally as often and as damagingly along the entire course of the Neosho River, both north and south of the Kansas–Indian Territory and then Kansas–Oklahoma border. However, local and state efforts in Indian Territory (IT) and then Oklahoma to curb flood damages progressed more slowly than they did in Kansas. Having achieved statehood in 1861, by the late nineteenth century, Kansas was a "mature" political entity comprising relatively well-organized local governments that could more actively respond to non-Indigenous demands to help Kansans prevent, minimize, or mitigate flood damages along the Neosho. Although the Indian Service attempted to ameliorate flood impacts in northeastern IT prior to statehood, these meager efforts were not undertaken in a concerted fashion. Once Oklahoma became a state in 1907, both Indigenous and non-Indigenous people were better able to influence local and state officials to focus on flood control. By the 1920s, Oklahoma's efforts looked very similar to those in Kansas. Oklahomans appointed committees on both local and state levels to investigate their options for flood control; enacted a state water resources division; sent both elected officials and nonelected representatives to Washington, DC, to lobby for federal action; and grew increasingly divided regarding the costs versus benefits of local flood control measures as they related to different regions of the state.

Reservoirs versus Levees

Levees were not nearly as common in Oklahoma as they were in Kansas. In 1912, Tulsa city engineer T. C. Hughes advocated building a system of reservoirs on Oklahoma rivers for not only flood control but also irrigation. Although he did not refer to the Neosho River by name, Hughes echoed a similar if slow-growing pro-reservoir movement among people living along the Neosho in Kansas. Indeed, despite laudatory descriptions of levees like the one at the Deming farm in Kansas, engineers and laypeople alike debated the efficacy of levees almost as soon as they built them. As early as 1907, a commentator attending a January flood control conference in Iola reported that among Kansans in Neosho County who had built the first system of levees on the river in the 1890s, there was a "decided sentiment against levees." However, he noted, "levees continued to be built" despite the fact that "each big flood destroyed at least part of them."[204] Whether Hughes was privy to this sentiment among Kansans in 1907, he himself did not actively support building levees in Oklahoma—at least not northeastern Oklahoma where he resided. Rather, Hughes argued in 1912 that the State of Oklahoma should "issue seventy-five or one hundred million dollars in bonds, to thoroughly survey every foot of our territory and to construct great lakes and reservoirs and control absolutely all water that falls within our borders." Not only would the waterbodies prevent reoccurring floods in "hundreds of thousands of acres of bottom land the richest in the state," which was currently "valueless for agricultural purposes," but the land would also "immediately take on its proper value and be worth millions of dollars for home building purposes and will offer an attractive inducement for immigration and capital to invest when they see it is placed in a safe condition."[205] Perhaps ironically, the federal government continued to advocate for levees at various locations along the Neosho River well into the 1930s—an idea to which the Corps would return in the 1990s. Levee advocates and reservoir supporters would continue to debate each other throughout the twentieth century.

Commissions and Conservancy

Conservancy Legislation and the Oklahoma Flood Control Legislative Committee

In February 1921, the Oklahoma House considered and moved forward Bill No. 169, known as the "conservancy measure," modeled after the Miami (Ohio) Conservancy Act. The Oklahoma bill provided "that all territory subject to damage from floods be allowed to form a tentative drainage district, regardless of county lines." If people in counties where the districts might be located voted in favor of forming such an entity, then the district would "legally incorporate . . . and vote conservation bonds." Property "benefited by the protection offered from floods would be assessed a sum determined by the measure of relief offered." Monies raised would go toward paying the bond interest. The bill was controversial because Oklahoma statutes at the time neither allowed the organization of such entities "irrespective of county boundaries" nor the issuance of bonds. The fact that the bill's backers were Oklahoma legislators hailing from regions near the Canadian River had generated some resistance from legislators from other parts of the state. Opposition came from people who worried that such a law might benefit some Oklahomans over others.[206]

According to one commentator, many legislators dropped their opposition to the bill once they were convinced that "it was not special legislation for the three counties most affected, and that the other counties would not be called upon to help finance the drainage project except in the ratio of the benefit they received by being protected from floods."[207] However, the 1921 conservancy bill seems not to have ultimately passed, as drafting state conservation legislation was the subject of discussion at a November 27, 1923, meeting of the Oklahoma state flood control legislative committee. Samuel H. McCrory, chief of the U.S. Department of Agriculture (USDA) Engineering Department, attended the meeting and recommended that Oklahoma legislators once again draft a conservancy law based on Ohio's. McCrory "pledged" that the federal government (through USDA) would support such an effort "both in an advisory capacity in the passage of an adequate law, and also in the matter of aiding the investigation of, and recommending the solution for, Oklahoma flood control problems." Whether he had Congressional authority to make this "pledge" is unknown.[208]

Perhaps the committee believed that federal presence at the meeting would lend more weight to such legislation and convince those who voted against it in 1921. Indeed, committee members approved a motion to add McCrory's language to the draft bill. Furthermore, they determined that since the rivers in question crossed state lines, an interstate commission was more appropriate than a state commission and vowed to work toward a multistate organization. They then read the proposed language of the bill, which declared its passage was an emergency and "immediately necessary for the preservation of the public peace, health, and safety"; agreed to some amendments to the bill; and created a permanent Flood Control Legislative Committee with J. F. Owens as chairman.[209] Immediately after the meeting adjourned, the committee delegates (led by Ernest E. Blake and including McCrory) marched to the statehouse and presented the proposed law to Governor Martin Trapp. In addition to support for the bill itself, the committee requested the governor press for a $100,000 appropriation for "preliminary investigation of flood control" in the state.[210]

The next year, in February 1924, the Conservancy Act (Senate Bill 63) was before both houses of the Oklahoma Legislature. According to one political commentator, the state's flood loss in 1923 alone—approximately $100,000,000 with 600,000 acres of land (representing $12,000,000 in lost taxes)—rendered passage of the bill "a matter of great importance to the people of the state." Because current law still limited operation of drainage districts to counties, it was "impossible to drain, or protect these rivers" on a larger, more logical scale. The proposed 1924 act, however, would allow drainage (or levee) districts to be as large geographically as was the area needing flood-control measures—more of a watershed approach. This arrangement would thus reduce the overall cost to any of the benefited parties while spreading the benefits more widely. Backers also noted that the USDA was insisting that if the State of Oklahoma wanted federal assistance, then the state "must hold back these waters, impound them in the natural reservoirs, and use them where possible for irrigation, power, or other available uses." War Department engineers preferred that that streams "be consistently handled as a whole and not here and there a part of them." The Corps estimated that the costs of enacting flood-control in Oklahoma on a watershed basis at less than half of the cost of damage in 1923. Additionally, the Corps asserted appropriate placement of reservoirs could impound enough water to irrigate "as much as five million acres of land, which would return at least one hundred million dollars, for water rights, or more than the entire costs of the Conservancy Districts."[211] By June, Chairman Owens had invited members of the committee to a meeting at which the question of flood control would be "brought to the fore" and informed them that "the Flood Control proposition is moving along nicely."[212]

Drainage, Irrigation, and Reclamation Commission and Interstate Cooperation

In July 1924, Blake, who was a member of the Oklahoma Drainage and Irrigation Commission, was advocating for both irrigation and flood control. He recounted how two floods and one drought in 1923 had led Oklahomans to take the "broader view . . . that floods were the common interest of all, the water the common hope of all, and its proper handling the duty of all." The Oklahoma government should "take up the cause for the public good," presumably with federal support, Blake believed; "such is the wealth of good deeds, thus accomplishing both reliefs gives two benefits, and gives four resources for the expense: income from improved lands in the west [parts of Oklahoma], and from protected lands, counties, cities, railroads and properties in the middle and east. Being thus divided, the costs become slight to everyone, burdensome to none, and of benefit to all."[213] Although Blake did not mention Neosho River in particular, his thoughts presumably applied to all rivers in the state. In 1925, Oklahoma re-formed the state Drainage and Irrigation Commission into the Drainage, Irrigation, and Reclamation Commission (DIRC) with Blake at the helm. By statute, the commission's charge was to promote flood control, diminish flood destruction, and "promote the conservation and use of waters in the State," not only to protect public and private property but also to aid in agricultural and industrial development[214]

Members of the new DIRC involved themselves in matters of importance to both Oklahomans and others affected by downriver flooding. In June 1925, Oklahoma joined the new nine-state Interstate Commission (Alabama, Arkansas, Colorado, Kansas, Louisiana, Mississippi, New Mexico, Texas, and Oklahoma), whose purpose was to prevent flooding downstream from the Arkansas and Red Rivers (and later, the White River). Members of the DIRC attended the inaugural meeting of the Interstate Commission alongside representatives from New Mexico, Texas, and Kansas, and a volunteer delegate from Colorado. In January 1926, attendees from Arkansas, New Mexico, Texas, Oklahoma, Louisiana, and Colorado, and a delegate from Kansas met once again. According to Blake's reporting of the events, commissioners agreed that interstate agreements related to flooding would result in more economic control, greater benefits, and wider distribution of costs among the states involved. This in turn would lessen the financial burden to each person who benefited while enhancing multistate control of "entire stream systems, as units, under interstate agreements." The Chief of Engineers agreed.[215] After the meeting, the commissioners returned to their respective states to ascertain what measures and procedures would "encourage comprehensive development" and to gather all available and relevant information about flooding in each state. They also tasked themselves with developing a "feasible plan for the regulation and conservation of the waters of the Arkansas River and its tributaries, (a) to regulate and conserve the water supply, (b) to prevent devastation by floods, (c) the extent of federal interest and co-operation without impairing control by a State within a State of her natural resources and her state jurisdiction and sovereignty."[216]

On behalf of the DIRC, Blake submitted a report to Governor Trapp on October 26, 1926. The study revealed that flood protection efforts in the state like "channel straightening, ditching, and levee protection" had proven to be not only "a failure and a disappointment" but also "very destructive to the properties both above and below the improvement, and generally to those who thought to benefit by them." Additionally, he noted that the geological nature of streams in Oklahoma and the volatility of the weather contributed to ongoing flood problems.[217]

Blake and other DIRC commissioners believed that the most economical approach to flood control in Oklahoma was to build reservoirs at key sites on tributaries. Because the state had neither installed enough gages to track nor kept good data about flood destruction on the Neosho River or elsewhere (except for a USGS gaging station installed in 1899 on the Neosho River at Fort Gibson[218]), Blake's study was necessarily incomplete. Despite data gaps, the commissioners had compiled as many damage reports as they could and checked tax rolls, public records, and expert opinions. They concluded that since 1907, floods had caused an average of $10,000,000 annually in Oklahoma. As they described it,

> the year 1923 was exceptional in that the flood loss to the State that year approximated one hundred million dollars. . . . 1926 has already far exceeded the average, already reaching probably fifteen million dollars. The agricultural lands of

> the State subject to flood damage will aggregate, we think, when completely tabulated, two million acres, of which about one million is practically destroyed and rendered unproductive, one-half million is damaged approximately 50%, and one-half million damaged approximately 25%. . . . We have no doubt that the taxable valuation of the State is reduced at least $100,000,000.00 by reason of our floods, and we have found some counties where the tax burden is more than double what it would be if they were protected from the floods.[219]

While the DIRC focused on flood control and minimizing flood damage, they also addressed using the state's water supply for irrigation/agriculture; power generation, industrial development, municipal water, and downstream navigation.[220] The DIRC report lauded the fact that an interstate district was under consideration for the Neosho and Verdigris Rivers. Knowing that water could be stored in Oklahoma more cheaply than anywhere else in the United States and that storing such water would accrue benefits to states other than Oklahoma, they believed that an interstate compact would "divide the cost and greatly reduce the expense" for the State of Oklahoma. Furthermore, it was "only proper" that downstream beneficiaries pay their fair share.[221] For example, the DIRC had proposed to foot a substantial portion of construction costs to withhold one-third of Arkansas River floodwaters, even though doing so would benefit Arkansas and other downstream states as much as (if not more than) Oklahoma itself. The proposal was met with compliments from members of Congress, Commerce secretary Herbert Hoover, Interior secretary Hubert Work, and the Army Engineers Board.[222]

Like Kansans involved in flood control efforts, Oklahoma DIRC members understood that in order to obtain federal monetary assistance for flood control, the committee and legislators needed to convince the federal government that state efforts would protect and promote matters about which the federal government was concerned, which included "improving navigation and protecting government river control works, protecting and cheapening interstate commerce, assuring regularity to the transportation of mail and messages, and assuring permanence of lines of military transportation." For Blake, Oklahoma waters, if used properly, "would equal the value of our coal, or oil, or any one of our major agricultural crops." To lower flood-control costs, the commission suggested that the state shift from accepting petitions for small districts to imposing larger districts across the state—possibly even just one statewide district. Larger districts would be able to "deal more effectively with the Federal government and co-operating States."[223] Once the districts were established and plans for projects drawn up and priced, then the state could figure out how best to allocate the benefits and costs among the beneficiaries.

Blake and the other DIRC commissioners understood that Oklahomans, too, were potential downstream beneficiaries of other states' flood-control efforts—Kansas, in particular. During a two-day meeting at Chanute, Kansas, in October 1926, Blake and Cyrus Avery (chair of the Oklahoma State Highway Commission), Kansas senator Arthur Capper, and representatives from nine southeast Kansas counties discussed how reservoirs in Kansas could prevent flood damage in Oklahoma and how better roads would help "expedite crop movements."[224] As Blake explained to attendees, "A single flood has cost this section of the state $6,529,000, while the entire prevention program might be carried out for $5,350,000." He went on to say that the Neosho River "could be curbed by 21 reservoirs at an estimated cost of $2,688,000" and discussed possible locations for flood-control reservoirs. This kind of flood control, Blake asserted, would undoubtedly help Oklahoma.[225]

Oklahoma Flood Control Commission and Appeals to Congress

After yet another "season of floods" in Oklahoma, talk turned once again to how best to control flooding in the state. According to an editorial in the *Oklahoma News*, the "disastrous" floods of 1923 had pushed Oklahomans "to demand, and get, a flood control law'" passed but that the law "or its operation was defective" and farmers were "incensed" by it. Facing threats of a call for its repeal, the Eleventh Legislature, which convened from January to March 1927, amended the law and approved the four-state flood control compact. At the same time, Governor Henry Johnston named a new Flood Control Commission.[226] Some Oklahomans were calling on Oklahoma legislators to ratify the flood control compact that Governor Johnston had successfully negotiated with Texas and New Mexico. Oklahoma City political commentator Victor Harlow believed that Kansas, Colorado, and Arkansas might also join the compact, which called for reservoir construction (primarily on the Canadian River) and would include the federal government paying half the cost of the proposed projects. To Harlow, because Oklahoma would benefit greatly from the compact, it behooved state representatives to "rise above the entanglement of small struggles and personal desires which has marred this session and to grasp and act upon a matter of great public moment."[227]

Harlow called on the legislature to meet in April and May so that the problems of flood control would receive more attention. He wrote, "the terrible disaster overwhelming the Mississippi lowlands should only serve to emphasize to us the massiveness of our own problem in the valleys of the Arkansas and the two Canadians. . . . Apparently the last legislature merely accomplished the destruction of the law which the state had. . . . Oklahoma has no flood control law susceptible of being practically applied, and of course can have none until the next legislature meets."[228] DIRC chairman Thomas C. Harrell acknowledged that Oklahomans faced "a real flood problem" and assured the public that the commission would encourage any "reasonable proposition for artificial storage of water, for irrigation or other purposes." The details of whether the flood solution would consist of a few large reservoirs, many small reservoirs, or a system of temporary reservoirs could be worked out later.[229]

In May 1928, Blake returned from Washington, DC, to Oklahoma "with a record of achievement that has hardly been paralleled in Oklahoma activity in Washington. Single-handed, with the opposition of powerful Oklahoma elements which should have been his coadjutors, he has been able so to impress his views and his plans upon the President and the Congress that the whole idea which he represented [a reservoir plan] has been embodied in the Flood Control Bill recently passed." Political commentor Harlow praised Blake for his "persistence, energy, and ability" in pressing his cause for many years. "Rarely is it given to any man to formulate alone and unaided an important constructive idea . . . and then practically single-handed to drive it into the national legislative system."[230]

In August 1928, the Oklahoma DIRC came out even more firmly in favor of using reservoirs for flood control and "charted a complete system of reservoirs to be constructed at strategic points for the controlling of flood waters" in the state. The plan mirrored the one that Blake had presented to Congress in May and which Tulsa congressman Everette B. Howard supported. The plan called for three reservoirs on the Neosho River and others on the Verdigris, Cimarron, North and South Canadian, Arkansas, and Little Caney Rivers. Howard asserted that had these reservoirs been in place in 1927, none of the rivers would have flooded that year. Approval and construction of the proposed reservoirs was "another forward step towards progress for Oklahoma and the stabilization in value of some of her best lands which are at present subject to annual inundation by floods."[231]

Later in 1928, Blake expressed frustration that the Corps' flood control surveys were moving too slowly despite "official approval" of DIRC chairman Harrell. While efforts had been more fruitful for the Red River survey, which federal engineer George E. Clements headed, the Arkansas River survey was nowhere near complete. Frank B. King, associate engineer in charge of the survey, had hired more staff to help, but at the time employed only four engineers, studying power, run-off and stream control, economics, and irrigation, respectively—nowhere near the staff needed for a survey the magnitude of which the Arkansas Basin required.[232] Two years later, the DIRC was mapping all rivers and creeks in Oklahoma in order to "work out a system of flood control."[233]

Blake and the DIRC commissioners seeking federal support for flood control were stymied in 1933 for several reasons, including the fact that Oklahoma was competing with every other state for money. To make matters worse, evidentiary documents for the flood-control plan that Blake and the commission had been working on and had presented to Congress unsuccessfully for years "vanished."[234] Apparently, the plans' absence was discovered when the Public Works Administration finally got interested enough to request the plan and supporting documents during yet another meeting with the Oklahoma contingent in Washington, DC. Blake insisted that when he left his office as head of the DIRC, he handed over all field notes and received a receipt from them, but the documents were nowhere to be found.[235] A "frantic telegraphic search" ensued and failed. As one commentator noted, if the plans could not be found, "years of effort" and $50,000 in state monies might "all have been wasted." "If these records should actually be lost," it might mean the collapse of a program which would have meant at least $45,000,000 more to the State. Oklahoma's share in the estimated $100,000,000 cost of controlling floods in the Arkansas Basin.[236] When Blake returned to Oklahoma, he downplayed the "misplacement of the field notes of the interstate engineers" as "not as serious a matter as has been pictured." Blake was sure the notes would turn up, but at the very least, he had in his possession all the blueprints and plans that had been made from those notes.[237]

Regarding other disagreements among Oklahomans in DC around plans being formulated among the Corps and interstate commissions, Blake reported that "the point of conflict" was the Corps' determination that none of the recommended reservoirs (except one in Colorado and one at Fort Reno) would "afford protection enough below to justify their being built." Blake also noted that Oklahomans disagreed with the Corps' proposal "to catch the flood waters further down the rivers," a plan that did nothing to diminish flood damage in Oklahoma. The Oklahoma delegation was "split," with the "east side gentlemen" (i.e., the Tulsa contingent and presumably GRDA proponents who would benefit from federal funding should the Corps determine the project was economically justified) pushing an Arkansas Basin–specific program that would provide no relief to western Oklahoma.[238] Additionally, Oklahomans from the eastern part of the state wanted to challenge the Memphis District engineers' report to show that the engineers had inaccurately estimated the cost-benefit ratio of the proposed dams and to convince the secretary of interior to overrule the engineers' report in their favor. Others, including two Tulsans and Senator Wesley Disney from Oklahoma's First District, also wanted water requirements for navigation of the Arkansas River below Tulsa "reduced from a 9 foot stage of slack water to a 6 foot stage of slack water and the cost re-calculated on that basis."[239] Although most of the Oklahoma delegation returned to Oklahoma, Disney remained in DC to promote flood-control projects with the assistance of Tulsans Colonel Clarence B. Douglas, Eugene Lorton, and Newton R. Graham; N. D. Welty of Bartlesville; H. B. Cobban of Miami; and other "prominent" Oklahomans.[240]

By the early to mid-1930s, before passage of the 1936 Flood Control Act, many Oklahomans felt strongly that a series of three dams and reservoirs (not levees) was the most effective way to minimize flood damage along the Neosho River both in Oklahoma and downstream states. Additionally, having power-generating capacity at each of the dams would be of benefit to Oklahomans, specifically. The federal government, however, saw it differently. The Corps' studies had determined that levees, especially above the mouth of the Spring River, were the best means of flood control on the Neosho. While most of those proposed levees would be in Kansas, three were proposed for Ottawa County, Oklahoma: one west of Miami (5.3 miles long, average 9 feet tall), one northwest of Miami (9.8 miles long, average 9 feet tall), and one straddling the state line in Ottawa and Cherokee Counties (12.9 miles long, average 8 feet tall). Despite the detailed plans and cost estimates the Corps made for this system of levees on the Neosho above the Spring, they could find no economic justification for expending federal monies on them at that time.[241]

The Corps was similarly reluctant to recommend congressional support for the proposed series of three dams and reservoirs below the mouth of the Spring at Pensacola, Markham Ferry, and Fort Gibson. Even though the Corps' own studies showed that not only would the combined storage and power dam at Pensacola and smaller low-head dams at Markham Ferry and Fort Gibson have minimized downstream damage of the April 1927 floods, but these facilities also could "be developed at a price which is normally considered reasonable." As with the proposed levees in Oklahoma, however, the Corps concluded that, "in the absence of a market, there can be no economic justification for such construction."[242] The federal government would not be involving itself in flood control on the Neosho River in Oklahoma at that time.

Miami, Oklahoma, Flood Control

As with almost every town located along the Neosho River, Indigenous and non-Indigenous residents in and around what is currently Miami, Oklahoma, had endured ongoing floods for as long as anyone could remember. Not surprisingly, then, the people who first platted the town in 1891, immediately adjacent to the river, continued to experience flooding and the damages it caused.[243] Scant evidence exists about early flood control efforts in the town, but the river—and its floods—has played a prominent role in Miamians' lives. Perhaps the most important concern of early Miamians was how to cross the river safely from the east bank, where the town was sited, to the west bank. Private ferries conveyed people and goods across the Neosho from 1891 until 1901, when a group of four local men received a charter for and eventually built a wagon toll bridge across the Neosho River at Miami. While some lauded the proposed bridge as a "valuable adjunct to the prosperity of our thriving progressive town," not everyone was so enthusiastic.[244] Unsurprisingly, resistance came from an owner of the ferry charter, next to whose facility the bridge was proposed to be constructed at the foot of what is now Main Street.[245] In 1905, purported "enemies of Miami" argued against the town as the seat of proposed Quapaw County because the bridge was still tolled, putting an unfair burden on county residents west of the river trying to access county services. Hands tied, supporters of Miami's county-seat bid reminded detractors that the City still had a year before it could exercise its option under the original charter to purchase the bridge but assured them that the town would find a solution to the problem.[246] When exactly the City eliminated the issue is unknown, but Miami did become the seat of Ottawa County in 1907, and the County ultimately took over the bridge as part of a county highway.

Also in 1901, the St. Louis–San Francisco "Frisco" Railway was building its own bridge across the Neosho River just south of Miami. Workers building the bridge had been discouraged from starting the job until "after the usual floods accompanying [the heavy June rains] had come and gone," but as soon as they got underway, they completed the bridge in record time. By October, the entire rail line was complete, replete with "a gold spike being driven in Miami as the finishing touch to the line that was to give Miami through train service and lift it from the position of being 'the end of the earth.'"[247]

By 1900, Miami had begun building water-related infrastructure in the form of culverts, but appears not to have had a storm sewer system until October 1917, when Miami City Ordinance No. 308 authorized an $80,000 bond measure to build a storm sewer system in the town.[248] Contracts were let for their construction the following spring.[249] Two years later, Ordinance No. 438 approved an additional $150,000 in bonds to expand the system and by August 9, 1921, the "Neosho River line" (storm sewer) was officially complete.[250] Engineers completed additional lines and outfall sewers in early January 1922 (one to Tar Creek and apparently a second to Neosho River).[251] However by November 1922, the river was already creating problems with the new sewer system, and Miami commissioners were discussing condemnation of "a narrow strip of land paralleling the Neosho river for the purpose of building up the banks to prevent the river from washing away under the city sewer line, which also parallels the river west of the city." At the time, no action was taken.[252]

On June 9, 1921, Miami Ordinance No. 490 created the Public Municipal Park (adjacent to which a low dam across the Neosho River would eventually be constructed); three months later, the Board of Park Commissioners was formed by Ordinance No. 497.[253] Almost immediately, Miamians and others in Ottawa County realized that flooding was going to be a problem at what was named Riverview Park. Two successive floods in March 1922 not only inundated the park but also created a worrisome log jam at the county bridge immediately upstream. By March 29, county commissioner Jim Jarrett had given up trying to clear the jam, and the commissioners began discussing instead a plan to build a levee to prevent flooding in Riverview Park. Jarrett finally got behind a plan that had been "suggested repeatedly and may be the feasible one to follow. . . . It would be necessary to construct an eight-foot levy at the lower section of the park to prevent the backwater from overflowing the park. The greater portion of the water now in the park came in over the river bank about 100 yards below the bridge."[254] The County ultimately decided to build a rock wall at the ends of the bridge in Miami "to withstand future floods" and prevent future damage.[255] In July 1922, the City made plans to raise the "lower" end of the park to match the "higher" north end. According to Charles Ellis, superintendent of the municipal light and water plant, the City had already been contemplating this leveling even before the recent spring and early summer floods, and that "the present rise could have been prevented if the work had been completed" when it was originally proposed.[256]

On July 30, 1923, the Miami board of commissioners approved construction of 6-foot-tall dam across the Neosho at the city park.[257] Whether the larger city commission envisioned a dual role for the dam as both a flood-control structure and park enhancement is unclear, but the Parks Department had grand plans for a beach, bathhouse, camping shelters, and even locks through the dam, which they believed would be a "desirable acquisition to the splendid resort."[258] The City intended to charge $1 per passage through the proposed locks.[259] Multiple spring floods delayed construction and damaged the dam as it was being built. In April 1924, for example, city crews were working on various projects around Riverview Park, including "constructing the concrete apron on the east dam, where floods played havoc with the bank during the fall and winter, even cutting under the end of the dancing pavilion and causing the floor of one corner of the building to fall into the water."[260] In May, Miamians attended the grand opening of Riverview Park and the newly formed Lake Miami, on which boating was predicted to be a "chief attraction"; "fishing at the dam is good," proclaimed the local newspaper.[261] Although the park was officially open, work on the dam continued after the celebration.[262] In October 1929, the City acquired more land for the park, expanding it two blocks east of Main Street and three blocks south of Ninth Avenue.[263]

Dealing with storm runoff and drainage was an ongoing struggle for the City of Miami, which on February 28, 1927, voted to amend the city charter and create the public utilities board (PUB).[264] On May 7, the newly formed PUB held its first meeting, at which members agreed to the board's rules and regulations and elected G. W. Sapp head of the sewer division.[265] In April 1929, the Miami PUB was once again discussing "improper drainage" of stormwater. At the meeting on April 19 that year, the board directed PUB superintendent H. G. Freehauf to come up with an estimate for what it would cost to construct a "proper drainage system" for the flooding problem on B, C, and D Streets NW (now P, O, and N Streets NW[266]) immediately adjacent to the Neosho River in the city.[267] Later minutes did not record what exactly Freehauf presented to the PUB. However, he likely in part proposed creating a storm drainage sewer district, which the board discussed at the June 7 meeting and then asked the city attorney to investigate.[268] In early September 1929, the PUB discussed creating a sewer district and 500-foot sewer line in the southwest portion of the city.[269] The next month, the City of Miami started the process of creating a comprehensive zoning ordinance.[270] On June 30, 1930, Miami commissioners passed Ordinance No. 588, which finalized it.[271]

Floods continued to wreak havoc at Riverview Park. In 1933, "high water and powerful eddies" resulting from a spring flood washed out the west bank of the river near the dam at Riverview Park.[272] That July, the Miami PUB, which had taken over the Parks Department, drafted a budget to repair the dam itself and construct a "wing wall" to protect it on the west side of the river.[273] The final structure was a concrete retaining wall 400 feet long and 20 feet tall.[274] In June 1944, on the heels of a large flood in May 1943, the City condemned more land for the park, blaming GRDA for past flooding of this part of the park and in anticipation of potential future overflows.[275]

Federal Involvement in Flood Control and Power Development Nationally and on the Neosho River prior to 1935

Although the Constitution implicitly reserved to the federal government control over navigable rivers and streams and their tributaries (a stipulation often referred to as the commerce clause), states exercised the most control over watercourses through most of the nineteenth century. It would take almost 150 years for Congress to pass legislation specific to flood control (1917) or hydropower development (1920). Federal officials, most notably staff of what would become the Army Corps of Engineers, were not completely out of the loop, however. By the 1820s, under the guise of improving interstate navigability under the commerce clause, Corps engineers were performing surveys and river projects that "everyone in Congress knew . . . [were] also for flood control."[276] For nearly a century, the Corps' river improvement efforts were often caught between a fight that, as one historian described it, "pitted one locality and region against another amid cries of 'pork barrel' spending and 'log-rolling.'"[277]

Between 1849 and 1912, early federal flood-control measures evolved in the wake of several disastrous floods (most occurring on or along the Mississippi River) that spurred Congressional action. Flooding in 1849, for example, led to the passage of the 1849 and 1850 Swamp Lands Acts, which "encouraged the reclamation of millions of acres of flood-prone wetlands" most notably in the lower Mississippi Valley. After another Mississippi flood in 1874, Congress created the Mississippi River Commission in 1879.[278]

In 1884, a slow evolution toward more active involvement in flood control began when Congress passed the Rivers and Harbors Act that year, authorizing "the Secretary of War to remove unauthorized obstructions, including dams, bridges, and causeways."[279] The 1890 Rivers and Harbors Act took this authority further and outlawed creating unauthorized obstructions to navigable water over which the United States had jurisdiction.[280] The next year, the federal government "granted free rights of way through the public lands and reservations for canals, ditches, and reservoirs," extending this in 1896 to "any citizen or association of citizens . . . for the purpose of generating, manufacturing, or distributing electric power."[281] Under the 1899 Rivers and Harbors Act, anyone proposing to build a bridge, dam, dike, or causeway over navigable waters of the United States was required to submit plans for consent of Congress and approval of the Corps of Engineers and secretary of war before construction.[282]

One of the first pieces of federal legislation specific to developing power sites on the nation's river was the General Dam Act of 1906. The act "empowered the federal government to compel dam owners to construct, operate, and maintain navigation facilities without compensation whenever necessary at hydroelectric power sites." Still, the government was not in the power business, and private interests almost exclusively developed most power projects before World War I.[283]

Thus, at the same time Kansans and then Oklahomans sought relief from the almost annual floods to which they were subjected, the federal government had few means by which to directly intervene or assist with flood control on the Neosho River. Historian Joseph Arnold explained that this was due to a lack of federal resources, the "formidable engineering and economic obstacles to flood control by methods other than levees, such as reservoirs," the relatively slow growth of large population centers along the river through the end of the nineteenth century, and the resistance of many politicians who believed it was unconstitutional to provide federal aid for flood-control projects that would ostensibly benefit local interests more than the nation as a whole.[284] Conversely, the lack of true federal oversight of hydropower facilities until passage of the 1920 Federal Water Power Act caused later consternation among private and then state interests that had been developing plans to site a hydroelectric plant on the Neosho River since the early 1890s.[285] The shifting federal role in both flood control and power development on the Neosho River—from mostly hands off until 1936 to mostly hands on by 1941—created complicated public and private dynamics within both Kansas and Oklahoma. The repercussions of the shift continue to this day.

This was the milieu in which Neosho County, Kansas, residents found themselves in the 1890s, when private parties started building the first flood-control levees on the Neosho River near Erie.[286] Citizens knew that if they could engage the federal government in providing both monetary and engineering assistance, their efforts might be more successful. To that end, in 1894, locals in Osage Mission (present-day St. Paul) formed the Neosho Land and Improvement Company with furthering its flood control goals at either or both a local and federal level as its primary focus. The group was soon able to influence U.S. Representative Snyder S. Kirkpatrick (a resident of nearby Wilson County) to pass a bill in 1896 to have the Corps conduct a survey of the Neosho River.[287] That year, Corps engineer J. R. Van Frank conducted a survey of the Neosho from the north line of Neosho County to the south line of Labette County.[288] Still ostensibly focused on navigability, his superior, Captain William Sibert reported to the secretary of war that the "extremely small low-water discharge makes it impracticable to improve this stream for navigation purposes . . . . It is not . . . worthy of improvement by the United States."[289] This early Corps survey did not result in immediate federal aid to Kansans in Neosho and Labette Counties. However, Congress soon passed the Rivers and Harbors Appropriation Act of 1899, paving the way for the federal government to involve itself in planning and funding flood-control projects around the nation.[290]

Although continual flooding on the Neosho River was not enough to pressure federal agencies to get involved in Kansas or Oklahoma, over the first three decades of the twentieth century, national concern about flood control generally intensified alongside national debate over the utility of levees versus reservoirs as preventive or mitigating measures against flood damage. The early 1900s saw disastrous flooding on rivers in Kansas with serious impacts on large population centers of Kansas City and Topeka, whose citizens began pressing their representatives in Congress to take action. In 1912 and 1913, "two terrifying floods . . . devastated" the Mississippi River valley, highlighting the "inadequacy of the levee system."[291] On the heels of these floods came another in 1916. In the aftermath, Congress established the House Committee on Flood Control in 1916 and passed the Flood Control Act in 1917, the "first act aimed exclusively at controlling floods."[292] Although, as noted above, the 1917 legislation only addressed flooding on the Mississippi and Sacramento Rivers, "the door had been opened," if ever so slightly, to a nationwide program of flood control.[293]

After World War I, Congress opened the door wide to developing hydropower resources on rivers in which it had showed little interest in investing money for "comprehensive waterways development."[294] In 1920, Congress passed the Water Power Act of 1920, which created the FPC and solidified federal control over power dams on nonnavigable rivers.[295] The subsequent passage of the River and Harbor Act of March 3, 1925 (43 Stat 1186), which ordered the Corps of Engineers to determine the cost to do surveys of the nation's rivers and recommend ways to improve them, would perhaps ironically lead to the "most detailed and comprehensive flood control studies and plans ever."[296] In April 1926, the Corps' estimate to survey over 180 rivers and tributaries for $7,300,000 became enshrined in House Document 308 of the sixty-ninth Congress. Under the 1927 River and Harbor Act, Congress began funding the studies, which would result in what became known collectively as the 308 reports.[297]

Although Congress's focus with the 308 surveys may have been on developing hydropower sites around the country, the Corps fully understood the addition influence it might have on pressing forward with a national flood-control program. As Chief of Engineers Major General Harry Taylor noted, the program would "have a far-reaching influence in controlling and coordinating all works in connection with the diverse beneficial uses which may be made of the streams under federal jurisdiction."[298] Although he called out neither power nor flooding in this statement, he certainly meant both—and his prediction could not have been more accurate. Indeed, the results of the 308 survey that included the Neosho River set the stage for future debates over and the ultimate construction of Pensacola and later the Fort Gibson and Markham Ferry dams in Oklahoma.

The River and Harbors Act of January 21, 1927, and Flood Control Act of May 15, 1928, authorized the Corps specifically to report on all tributaries to the Mississippi as regards flood control in the larger watershed. This included the Neosho River, as tributary to the Arkansas. The surveys resulted in several documents published between 1931 and the final *Arkansas River and Tributaries* (dated August 24, 1935; formally printed in 1936), all with slightly varied but similar results and recommendations.[299]

The Corps-led 308 studies were underway by summer 1929, when the *Miami Daily News-Record* noted that surveyors had "swarmed" the area. On the morning of July 1, government engineers were in Miami, Oklahoma, where, according to the news, surveyors were "mapping out purely visionary dams and supplementary channels on the streams tributary to the Arkansas and Mississippi rivers for the purpose of submitting accurate figures to the consulting engineers." The Corps believed these maps would be comprehensive enough to provide estimates of the "exact acreage" that reservoirs would cover if the hydropower dams were built.[300] In addition to reservoir sites, the engineers were surveying for locations at which to build more levees. The district engineer's June 1931 report on the Neosho River summarized the "most practical plan" for flood control as building levees (in a prioritized, three-stage approach) in the overflow areas along the main stem of the Neosho above the mouth of the Spring.[301] As noted above, survey results led the

Corps to propose constructing three levees in Oklahoma (one straddling the state line) on the Neosho and another forty-nine in Kansas, which already had fifty-one levees or drainage districts at that time.[302] Two of the proposed levees were near Miami in Ottawa County; one straddled the state border between Ottawa and Cherokee Counties (Kansas), and two more would have been located in southern Cherokee County near Chetopa and Oswego. The latter two would likely have had some mitigatory influence on flooding in northeastern Oklahoma.[303] These levees would protect an estimated 133,840 acres, according to Corps calculations; however, none of the proposed construction was "economically justifiable" at that time.[304] Interestingly, the report stated that if reservoirs (not levees) had been extant on the Neosho, the April 1927 floods would not have done such damage on the Mississippi. Still, the cost of reservoirs compared to the damage benefits they might afford did not pencil out in 1931, and the Corps also determined that reservoir building on the Neosho for flood control reasons was not economically justifiable.[305] No evidence exists that any of the fifty-plus levees proposed in 1931 were built as designed; it would take three more decades to get the reservoirs built.

In sum, the district engineer recommended in 1931 a three-pronged plan for the "most efficient development of the water resources of the Grand" watershed.[306] First was to develop waterpower on the lower reaches of the Grand in Oklahoma.[307] Second, was the recommended levee-building plan.[308] Last, a reservoir at Council Grove, Kansas, would improve municipal water supply and quality (but nothing specific to flood control).[309] Despite the so-called practicality of these three measures, the Corps concluded that none of the proposed reservoirs in Oklahoma reservoirs or levees in Kansas was "economically justifiable at the present time" due to "excessive" cost (although it recognized that later economic conditions might change this cost-benefit analysis).[310] Furthermore, the federal government determined that costs associated with building reservoirs to either generate power or provide municipal water "should be left to private initiative."[311]

By February 1934, when the Corps issued yet another "Report on the Grand (Neosho River)," the Corps had reduced the number of levees proposed in 1931 for Oklahoma to two (again with one straddling the state line) and for Kansas to twenty-two. This iteration of the report deemed the two Ottawa County levees as having the least economic merit of all the proposed projects.[312] Unlike in the previous report, the Corps assessed specific cost-benefit ratios for the Pensacola, Markham Ferry, and Fort Gibson (both individually and as a group of three) and a reservoir at Council Grove. Yet again, however, they were placed at the bottom of the priority list, likely because the Corps did not yet see these as providing enough preventative benefit where flood-control damages were concerned and being focused on private development of power and municipal water sources, which the Corps did not see as its purview.[313]

The 1935, final iteration of the 308 report on the Arkansas River and tributaries served as the basis for both the flood-control and hydroelectric projects the Flood Control Act of 1936 authorized (and subsequent acts appropriated funds for). By that time, the Corps had whittled down the original list of proposed levees substantially. The act only authorized projects in Kansas and required local entities to provide free easements and rights-of-way, release the U.S. government from any future damages claims; and maintain and operate the structures after their completion.[314] The levees authorized were planned for the cities of Florence, Cottonwood Falls, Emporia, Neosho Rapids, Hartford, Burlington, LeRoy, Neosho Falls, Iola, Humboldt, and Chetopa; and in Cherokee, Chetopa, and Lyon Counties. Ultimately, however, with the exception of the City of Iola, which did ultimately build its levee, "local interests did not desire the construction of the proposed levees and would not provide the necessary rights of way."[315] Public hearings, for example at Burlington, Kansas, elicited such statements as, "the people of Burlington do not want levees," and that the general preference was for a system of reservoirs on the Cottonwood and Neosho Rivers instead.[316]

Regarding the Neosho River as a whole, the Corps determined that while it did indeed overflow a "considerable area," no economic justification existed at the time for the federal government to pursue large flood control projects on it. The Corps did note that future economic conditions might justify a storage reservoir on the Spring River above its confluence with the Neosho but that at the time, financial concerns were local not federal in nature.[317] Improving the river for navigability made no sense for the Corps. While the Corps found no economical sites for power production along the Neosho in Kansas, the Pensacola, Markham Ferry, and Fort Gibson sites were viable. Still, with an air of finality, the Corps stated that there was "no Federal interest involved on this stream."[318]

Some combination of the results of the Corps 308 reports completed in 1935 and 1936 and the series of "disastrous" floods that swept the nation those same years compelled Congress to pass first the Rivers and Harbors Act of August 30, 1935, and then the Flood Control Act of June 26, 1936.[319] Adding to the momentum, President Herbert Hoover in the late 1920s and Franklin D. Roosevelt from 1933 onward pushed for flood control through various means. Early in the Depression, Hoover advocated using flood-control projects on the Mississippi River as an "unemployment relief measure," presaging the widespread New Deal programs Roosevelt would implement.[320] The 1935 act took things further, reflecting the ongoing trend toward planning and funding multipurpose dams for "controlling floods, improving navigation, regulating the flow of the streams of the United States, providing for storage and for the delivery of the stored waters thereof, for the reclamation of public lands and Indian reservations, and other beneficial uses, and for the generation of electric energy as a means of financially aiding and assisting such undertakings."[321] Roosevelt furthered Hoover's drive to unite work relief with flood control and hydropower development "in a manner that the New Deal was to continue doing throughout the 1930s and that became one of the rationales" for federal funding of projects like Pensacola through the PWA and passage of the 1936 act, which focused on flood control through the Corps.[322]

As discussed in this section, prior either to creation of the GRDA or to passage of the Flood Control Act of 1936, individuals, municipalities, and the States of Kansas and Oklahoma marshaled numerous efforts to effect some form of flood control on the Neosho River and its tributaries. Levees, clearing banks and the watercourse, and even straightening sections of rivers and streams served to provide some measure of relief, but in no way prevented flooding from causing damage along the Neosho. Although the Corps was mostly hands-off where navigability and flood control on the Neosho River was concerned up until the mid-1930s, the FPC involved itself with power production on the nation's rivers after passage of the 1920 Federal Water Power Act. After the Depression hit, the PWA was tasked with funding local projects for economic relief, which dovetailed nicely with more local attempts to develop power, such as the efforts that individuals and then GRDA were making to construct the Pensacola Project.

As the next section outlines, in 1935, the State of Oklahoma created the GRDA and began moving forward in earnest with securing an FPC license and agreement with the PWA to develop the Pensacola Dam to generate hydroelectricity. Soon after, the Corps reversed gears where flood control was concerned on many rivers, including the Neosho. This sea change, as codified in the 1936 Flood Control Act and cemented in subsequent revisions and amendments to the act as well as other enactments, opened the door wide to the Corps' direct involvement and oversight of operation of the Pensacola Dam and Reservoir. These two developments set the stage for what has come close to a century of debate over power generation and flood control on the Neosho.

Part 3: Managing the Neosho River: Flood Control and Power Production after the Creation of the GRDA

Introduction

Many people have written about the history of the development of the Neosho River for power production and flood control. What follows is a summary leading up to creation of the Grand River Dam Authority in 1935, debates around and eventual issuance of and modifications to the FPC license in 1939, federal operations of the dam during World War, the return of Pensacola Dam operations to GRDA in 1946, and ongoing jockeying for control that would play out during that period (and arguably, up to the present).

As discussed in part 2, the Corps had shown an early interest in rivers like the Neosho, which although nonnavigable could yield viable sites like Pensacola for power-generating facilities and dams that could have a positive effect on downstream navigation and stream flow. Still, for decades, the Corps had concluded that the potential combined benefits of the Pensacola project for multiple purposes (power generation, navigability, and flood control) did not outweigh the estimated costs to the federal government. Because it was focused on larger issues of downstream navigability and flooding, the Corps came late to the table where the Pensacola Dam was concerned for power production or any kind of flood control upstream of the proposed dam. Additionally, by the time the Corps decided it wanted more authority at Pensacola, most of the planning and design was done, and the Public Works Administration (PWA) had determined to use federal New Deal grant and loan funds to assist in its completion. PWA envisioned the Pensacola Dam as an important Depression-era relief measure for the region (primarily to create jobs and generate power for rural electrification projects and economic development), and GRDA was thrilled to have found federal support for their project—one that many people in Oklahoma and nearby states had wanted for decades.

By the time GRDA and PWA sealed the deal, however, the Corps had its own plans for Pensacola. Under the 1920 Federal Water Power Act, the FPC had assumed responsibility for licensing power dams on rivers like the Neosho. However, in June 1938, Congress had passed an amendment to the Flood Control Act that conveyed to the Corps complete authority over flood control on the nation's rivers to include the power to dictate how FPC-licensed hydroelectric dams would operate as regarded flood control. The act also charged the Corps with responsibility to secure (and pay for) rights and title to land, legal settlements, or flowage easements necessary to constructing the dam and reservoir. Under this authority, the Corps weighed in on the license for the Pensacola project. During this phase, PWA, GRDA, the FPC, and the Corps engaged in long debates around the proper pool levels for power generation versus flood control and who would control the dam to manage these pool levels. The exact elevation of the power pool versus the flood poll was key to determining which agency was responsible and who would pay. Negotiations ultimately resulted in a 1939 FPC order outlining a compromise. Neither party was thrilled with the terms but both parties appreciated that the compromise would allow the stalled project finally to move forward. No one could have known the lasting effects the compromise would have on how the project was run after it was completed and commenced commercial operations in spring 1941.

Under the final license, GRDA was responsible for acquiring land and easements up to elevation 750 (with some exceptions related specifically to the two railroads within the project area) and the federal government for the land between elevations 750 and 755. According to the license, the federal government was responsible for acquiring those lands and easements before GRDA could (under the terms of its license) operate the dam above elevation 750. GRDA/PWA would also need to enter into settlement agreements with various parties regarding known, predictable damages to municipal infrastructure (for example, the Miami storm sewers) and roads and bridges (for example, with Ottawa County). To expedite the process for GRDA, Congress passed a law giving GRDA the right to acquire Indian land below elevation 750 without congressional approval at a fair price or, if an Indian refused to sell, the authority to condemn the land.

On the heels of Pensacola Dam's grand opening in spring 1941, additional changes to federal policies outlined in ever-greater detail the Corps' role in managing flood control on the Neosho River and therefore, how much control it could exercise over GRDA operations under its FPC license and PWA contract. The Flood Control Acts of 1941 and 1944 further cemented the Corps' flood-control authority. Two years after Executive Order No. 8944 transferred wartime operation of the Pensacola Dam to the FWA in November 1941, Executive Order No. 9373 transferred this role from the FWA to Department of Interior, which in turn created the Southwestern Power Administration. After the war ended, Interior and GRDA agreed to a plan that returned operations of the Pensacola Dam to GRDA (according to its license and with Corps oversight) on September 1, 1946.

Floods in 1941 and spring 1943 would test the operations arrangement between GRDA/PWA and the Corps almost immediately after the Pensacola Project began commercial operations in spring 1941. Heavy flooding occurred after two big storms in 1941—one in April and a much larger one that lasted from September through November. Following the rules of the license, GRDA notified the Corps when the pool reached elevation 745 in April and followed Corps directions thereafter. When the Corps directed GRDA to allow the pool to rise to elevation 750 (at the dam), GRDA complied, but not without notifying the Corps that potential upstream flooding might occur. The Corps ignored this warning, and upstream lands did indeed flood.

After the spring 1941 flood, the Corps and GRDA codified rules and regulations around operating the dam during flood conditions and the War Department hastened to acquire land and flowage easements between elevations 750 and 755. In May 1943, another large flood hit the Neosho River and led again to Corps takeover of Pensacola operations. Because the United States had not yet acquired all the land to elevation 755, Federal Works Agency (FWA) administrator Douglas Wright used his emergency powers and an appropriation from Congress to quickly complete the process ahead of any potential flood damage claims they might face. He also made decisions that many believed protected the downstream Oklahoma Ordnance Works from major damage and work stoppages, but others criticized his actions and blamed him for both upstream and downstream flooding.

Between June 1943 and September 1, 1946, when the federal government handed the Pensacola Project back to GRDA, no further flood events caused damages attributable to dam operations on the Neosho River. The Department of the Interior created the Southwestern Power Administration (SWPA) in September 1943 and granted that agency control over Pensacola Dam. SWPA quickly moved to acquire land and easements up to elevation 760 to allow for flexibility in dam operations in unusual or emergency flood situations.

The history of the planning, construction, and operation of the dam and reservoir at Pensacola reveals divides that existed, grew, were bridged, and widened again among those entities focused on power and those focused on flood control. In some cases, the means and goals of these entities dovetailed neatly, but in many cases, their objectives diverged, and they actively competed against one another. The results of the competing interest of power versus flood control could be seen at local, state, regional, and federal levels into the second decade of the twenty-first century. Through a series of enactments, the roles of GRDA and the Corps were clarified and codified such that the Corps controls operations of the Pensacola "flood pool" (i.e., reservoir elevations at 745 feet and above) whereas GRDA (under its FERC license) controls operations for power generation in the "conservation pool" below that.

Private Hydropower Development on the Neosho (Grand) River before GRDA

The State of Oklahoma formally created the Grand River Dam Authority with passage of the Grand River Dam Authority Enabling Act on April 26, 1935. However, private attempts to locate and build a hydropower dam on the Neosho River had begun as early as the 1890s. The first person to see the river's power potential was a Cherokee citizen, Henry Holderman, who grew up in Indian Territory, attended the Wyandotte Indian School, and became fascinated with waterpower at an early age. According to various sources, Holderman, like many of his generation, saw electricity as the harbinger of progress and prosperity, things he desired for members of the Cherokee Nation.[323]

Hoping to facilitate construction of a hydropower dam on the Neosho River, Holderman organized and executed a river survey between Iola, Kansas, and the Arkansas River; they located three possible sites during the journey. By the late 1890s, Holderman was solidly on the path he would follow until he died: trying to attract financial backing to construct his proposed dam. Having sold his family's land holdings to purchase "the prospective sites and the riverbed from the Cherokee Nation," Holderman worked diligently through the first three decades of the twentieth century to draw investors—from cotton manufacturers to railroad operators to miners—to his project.[324] Holderman (and his wife) teamed with various investors and incorporated a number of entities to develop waterpower on the Neosho. With three backers, he formed the Grand River Power Company under the U.S. Court of Appeals for the Indian Territory in 1907. The company reportedly initiated condemnation proceedings on land for the pool, but no record exists of any corporate activity thereafter. In 1913, Holderman, his wife, Maude Holderman, and Strang banker E. L Stegall, formed the Grand River Power and Electric Company (GRPEC) under what was now Oklahoma state law. The company existed just over twenty years but lost it charter in 1934 for nonpayment of license fees.[325]

Plans for hydropower on the Neosho gained momentum after 1917, when Holderman and others incorporated the Grand River Hydro-Electric Company (GRHEC). Engineer Royal D. Salisbury developed plans and a cost estimate for a dam in 1920; the plans were either made public or leaked in 1921, as the *Miami Daily Record-Herald* reported with concern in late December that year that the company was ready to begin construction. The article provided no specifics about the size or location of the proposed dam, but noted that as designed, it would create a "tremendous overflow" on the Spring River to a point "almost midway" between Baxter Springs, Kansas, and Wyandotte, Oklahoma, and on the Neosho to a point "some miles northwest of Miami."[326] In 1922, GRHEC applied for and received a permit from the Oklahoma state engineer "to appropriate the entire flow of Grand River, at the approximate location of Pensacola Dam, for the purpose of generating electric power and energy."[327] Whether it submitted the exact plans on which the *Daily Record-Herald* reported is unknown.

In a parallel process to the GRHEC's attempt to build a state-permitted dam on the Neosho River, the Public Service Company of Oklahoma (PSCO) initiated the process of securing a preliminary federal permit from the newly created FPC at its own site near the one GRHEC proposed. To that end, on May 25, 1923, PSCO president Fred W. Insull filed a declaration of intention to the FPC for a project on the Neosho River.[328] According to its declaration, PSCO was already "serving electricity" in the northeast Oklahoma cities of Tulsa, Nowata, Broken Arrow, Garnett, and Dawson and was in negotiations to expand its grid to include Pryor, Vinita, Big Cabin, and Adair. PSCO asserted that the "constantly increasing demand for additional electric power" made it immediately "necessary" to receive the permit and develop the dam. A couple weeks later, the FPC requested that the Corps report on the appropriate jurisdiction for such a project.[329] In response, Memphis District commander Donald H. Connelly noted that although the Neosho

River was not navigable above Fort Gibson, the section between Fort Gibson and the Neosho's confluence with the Arkansas was both navigable and overseen by the Corps. Connelly expressed some concern that if the proposed project was "freed" from U.S. control, adverse effects to navigability on the lower reaches of the Neosho or the Arkansas might occur.[330] He thus recommended that "provision for passing 375 [cubic feet per second] over or through the dam at all times is necessary to protect the interests of interstate and foreign commerce."[331] Based on Donnelly's findings, Corps acting chief Harry Taylor recommended that the FPC was the appropriate jurisdictional agency for the proposed project.[332]

On April 12, 1924, PSCO submitted its application for a preliminary permit.[333] On July 16, 1924, Oklahoma state attorney general George F. Short submitted a protest on behalf of the State of Oklahoma against the FPC's issuance of PSCO's preliminary permit for the Grand River Dam. The State's argument was that the Neosho was nonnavigable and therefore not subject to FPC authority (or any federal authority, for that matter) and that the State had already granted prior rights to the beneficial use of the water to the GRHEC. Call informed Short that his protest was baseless because fluctuations in stream flow due to operations of a dam on the Neosho River could have an adverse effect on navigability on the Arkansas River to which the Neosho was tributary.[334] A year later, with the State's protest apparently dropped, the FPC moved ahead and finalized a preliminary permit a year later on July 25, 1925. The permit covered initial studies in support of an application to license FPC Project No. 498, "a concrete dam in the Grand River, a power house, and appurtenant works," near Bernice in Delaware and Ottawa Counties.[335] The proposed location was upstream from where GRDA ultimately built the Pensacola Dam on a bend of the river that headed northwest just past the protrusion of land on which the Shangri La Resort currently stands.[336]

The preliminary FPC permit gave PSCO three years' priority over other applicants in submitting a license application, which was to include the results of all engineer studies and cost estimates, installation of a stream gage at or near the proposed dam site, boring and stability analyses at the dam site, and gathering and submitting market data to support the economic feasibility of the project.[337] If the fifty-year license were to be granted, the permit specified that it would include a number of conditions. Specifically related to the dam's potential role in flood control, was the stipulation that operations affecting "use, storage, and discharge from storage" were to "be controlled by such reasonable rules and regulations as the Secretary of War may prescribe in the interests of navigation and as the Federal Power Commission may prescribe in the interest of flood control and of the fullest practicable utilization of the waters of said river for power purposes."[338]

While PSCO was securing a preliminary permit from the FPC, in 1924, GRHEC transferred its rights to the Oklahoma Hydro-Electric Company (OHEC), and the new company received state permits for the three other proposed dam sites on the Neosho.[339] OEHC then hired Tulsan Victor Cochrane to report on the feasibility of Neosho River power projects and acquired some land a short distance downstream of the current Pensacola Dam site. Additionally, they secured interest in the dam from Miami mining magnate J. F. Robinson, who sought cheap electricity for the local, booming lead and zinc industry in which he was heavily invested. In 1925, Cochrane and W. R. Holway (who later played a prominent role in designing and constructing the Pensacola Dam) conducted surveys regarding the "economical height to which a dam should be built (for the development of power) at the Pensacola site."[340]

Jockeying for position, OEHC and PSCO both applied to the DIRC in late 1925 for state permits for their projects. By that time, what was now the OHEC had failed to begin construction on their proposed 159-foot dam near Ketchum and thus their permit had expired due to a "two and one-half year statutory limitation requiring completion of one-fifth of the work on such a project within this period." Perhaps hedging their bets with their preliminary FPC permit, PSCO applied for a state permit to build a "40-foot dam above the other site." The DIRC determined that the smaller dam would "be a waste" considering OEHC's plan to develop the entire river, but it issued neither an extension to OEHC nor a permit to PSCO at that time.[341]

In March 1926, Robinson applied to the DIRC to construct four dams on Neosho River. Approval came in October; however, by that time, Robinson's failing health led him to assign his rights to Tulsan Wash E. Hudson, who in turn assigned his rights to Grand-Hydro, yet another new corporation formed on November 6, 1929, in Oklahoma (with Hudson as one of its incorporators).[342] The DIRC proclaimed that work on the first of four hydroelectric dams was slated to begin on December 1, 1930, and that letting of contracts would start within twenty days.[343]

Almost simultaneous with this announcement, Oklahoma courts decided that House Bill No. 4 (the so-called Revocable Permit Bill) was unconstitutional. Despite this adverse ruling, "the Tulsa interests, headed by Wash Hudson" proceeded in their negotiations for the Neosho River project.[344] Hudson had transferred the permit they had just received to an eastern corporation but retained interest as president with the backing of "several capitalists of St. Louis and Chicago as well as a small local group." Some doubted the financial viability of the project, but Hudson assured everyone that all was well, and that the money was available to begin construction on the first of the four proposed dams for an estimated cost of $26,000,000. Backers claimed that the project would produce enough cheap electricity to supply all northeastern Oklahoma with power and that electricity use would be "vastly increased" in that region. "Farms will be electrified, and new industries established, to utilize this cheap and convenient power," proponents proclaimed. The City of Tulsa was especially keen that the plant "be completed before the present electric franchise of that city expires, and a cheaper service may be available through it."[345] As it would turn out, despite earlier protests to the contrary, Insull from PSCO was a financial backer of the new Grand-Hydro Corporation (and likely had been since the Tulsa contingent had taken over). However, despite the permit enthusiasm and by that time having acquired approximately 2,100 acres of land for the dam and reservoir, "the Insull empire collapsed."[346]

Grand-Hydro's final attempt to dam the Neosho River came in summer 1931, when it applied again to the DIRC—this time to build a 50-foot dam 6 or 7 miles above the current Pensacola Dam site with a "14-foot equalizing dam" located close to the current dam. The original application has not been found; but based on minutes from the conservation commission's discussion of the application, Grand-Hydro's proposal focused on power generation not flood control (although the equalizing dam may have served somehow in that capacity).[347]

In October 1931, E. R. Englebrecht sued Ottawa County for $977 for the purported value of gravel that Ottawa County had taken from the Neosho River along his farm. The case needed to be resolved "so that the Grand River Power company [*sic*] will know who to get its title from for a damsite down near Ketchum."[348] The suit harkened back to treaties the United States made with the Seneca and Cherokee in 1831 and after. The first treaty with the Senecas forced them onto land east of the Neosho River and "north of the line which now is two miles south of the [Ottawa] county line." A later treaty forced the Cherokee onto lands west of the river. In 1831, a government survey had fixed the limits of that tract. Englebrecht's argument was that the river had changed course over the past hundred years since the treaties were signed and the boundaries surveyed and that he could prove it by "structural traces" and testimony of an "old inhabitant" who remembered "he cut wood formerly, where the gravel bar now stands." Also in question was whether the Seneca and Cherokee titles "each extended to the middle of the river, or to their respective banks; and if the latter, the riverbed would still be government property unassigned." Another potentiality was that it remained unassigned tribal land due to the riverbed not being included when the allotments were made (the same allotments that Holderman likely bought in his initial attempts to build a dam). The outcome of the suit would be directly influenced by the outcome of a case the Cherokee Tribe had pending against Grand-Hydro (related to their proposed dam and reservoir site) wherein the Cherokee were arguing that the riverbed was tribal property.[349] The outcome of this case is unknown; however, although the commission had approved the application, Grand-Hydro never made any use of the waters of the Neosho River.[350]

Grand River Dam Authority and the Pensacola Dam

Creation of the Grand River Dam Authority

As private efforts to develop a power dam on the Neosho River died at the beginning of the Depression, public agencies' focus on the potential for flood control on the Neosho had begun to grow. Oklahoma politicians at the state and federal level pushed to consolidate their efforts to develop hydropower on the Neosho River under the auspices of a state entity. The fact that the Corps had determined that Neosho River power projects at Pensacola, Markham Ferry, and Fort Gibson were feasible (even if not in the interest of the federal government at that time) bolstered the resolve of supporters of state involvement. Additionally, favorable reports on Neosho River projects had emanated from both the President's Committee on Water Flow (primarily focused on flood control benefits) and the Mississippi Valley Committee of the Public Works Administration (primarily focused on power and recreation benefits) in the first half of the 1930s.[351] Especially based on the latter two reports, Oklahomans believed creating an official entity with which the federal government could negotiate and share costs might attract New Deal program relief to the state. The Pensacola Project seemed like a ready-made opportunity to put unemployed Oklahomans to work and to spur the economic development that cheap electricity and recreational opportunities might bring.

By 1935, the proposed Pensacola Dam had already been heavily researched and engineered. Although it was not quite shovel ready, numerous studies conducted over the previous four decades had located the best site, estimated the land needed for the pool, and made preliminary estimates of how various dam and reservoir designs would affect power production and flood control. U.S. Senator Elmer Thomas had been focusing for several years at that point on securing federal funding for flood control for Oklahoma.[352] Elected to Congress in 1931, U.S. Representative Wesley E. Disney had taken up the charge of securing an interstate compact and federal funding for projects that would make the Arkansas navigable to Tulsa, facilitate building the Pensacola Dam (along with another dam at Flat Rock, Missouri, on the White River), and bring "cheap power and water rates" to Oklahoma, Kansas, and Texas.[353] Despite these efforts and the increasing volume of Oklahomans' calls for federal support of hydropower development of the Neosho River, neither Thomas nor Disney had been successful to that point. As one historian explained it, however, these failures had left the door open for the Neosho River project to "rest on its merits as a power site approved by the state."[354]

At his inauguration in January 1935, newly elected Governor Ernest Marland (a staunch Roosevelt Democrat dedicated to bringing New Deal money to his state) pledged to create a well-funded Oklahoma Planning Board and Flood Control Board in order to negotiate access to New Deal recovery money.[355] Oklahomans thus began a full-court press at the state level to finally build the dams they had long desired.[356]

Oklahoma legislators, led by Senator Jack Rorschach of Vinita drafted a bill in March 1935 to create a Grand River Dam Authority, which was passed by both houses but "forced into conference" to address competing interests and opposition within the Senate. Among other things, two senators wanted state authorities to build dams in their regions, others worried that the bill presaged federal entry into and competition with private companies in the power business, and at least one believed it was unconstitutional.[357] Additional opposition came from coal miners in Oklahoma and Arkansas, who sent petitions to Congress arguing that a GRDA hydroelectric facility would "put the coal mining industry in Oklahoma out of business and cut off or greatly reduce the earning power of about 7,000 coal miners in Oklahoma."[358] In support of the bill, Rorschach declared that creating GRDA would furnish an opportunity to finally build the long-desired Pensacola Dam and that Disney had intimated to him that federal funds would likely be available if the authority was created. The bill ultimately passed with a controversial caveat.

Governor Marland signed Senate Bill Number 395 creating the Grand River Dam Authority into law on April 26, 1935.[359] GRDA was tasked with overseeing "a conservation and reclamation district" that ultimately included Adair, Cherokee, Craig, Creek, Delaware, Mayes, Macintosh, Muskogee, Nowata, Okmulgee, Ottawa, Sequoyah, Tulsa, and Wagoner Counties in northeastern Oklahoma.[360] The Authority was empowered as a governmental agency to "control, store, and preserve" the waters of the Neosho River and its tributaries "for any useful purpose." Useful purposes included developing waterpower and electric energy, preventing flood damage, reforesting the watershed to prevent soil erosion and floods, acquiring lands or easements (by purchase or condemnation) related to its purposes, and to "construct, extend, improve, maintain, and reconstruct . . . any and all facilities of any kind necessary or convenient to the exercise of such powers, rights, privileges, and function."[361] The act also authorized GRDA to borrow money for projects through bonding. A nine-member board of directors was appointed to oversee GRDA; the governor, attorney general, and commissioner of labor each got to choose three of the nine. Originally, GRDA's term was set to expire July 1, 1937 (unless extended) and would be headquartered in Vinita (subject to change by the board).[362]

Much to the chagrin of the bill's supporters (and Marland himself), the bill as passed contained language that prohibited GRDA from selling power directly via its own transmission lines and forced it instead to sell to local power companies that could then charge retail prices to consumers. Marland knew the bill he signed had been a compromise. During an address later that spring to several representatives of eastern Oklahoma cities, he expressed his frustration with the "power trust," which he blamed for adding the Kirkpatrick amendment and "hamstringing" the bill. He reiterated his deep desire to see the Pensacola plan implemented and his belief that federal support via some form of New Deal relief program was imminent.[363] Members of the GRDA board and other backers of the Pensacola Dam were similarly incensed with the Kirkpatrick amendment, most notably because PWA, from which GRDA hoped to receive funding, refused to consider the project with the amendment in place.[364] Although not everyone was thrilled with the way it was created, GRDA was officially born.

Funding the Pensacola Dam

Throughout 1935 and 1936, "a small group of men worked incessantly" to keep GRDA's vision of a Neosho River dam or dams alive and top of mind with state and federal officials.[365] They traveled on their own dime (or with the support of contributions primarily from citizens of Grove, Miami, Pryor, and Vinita) to meet with the governor and representatives of state agencies and journeyed multiple times to DC and elsewhere around the country advocating the cause. At the federal level, Senator Thomas and Representative Disney lobbied for GRDA often and forcefully. Although they encountered multiple roadblocks along the way during 1935 and 1936, their tireless efforts (especially Disney's) eventually paid off when Roosevelt called in 1936 for a thorough survey of the Pensacola Dam project.[366] In the meantime, back in Oklahoma, local supporters of the Pensacola Dam project were applying pressure to their representative in the Oklahoma legislature.[367] Finally, in early 1937, state legislators removed the Kirkpatrick amendment from the enabling act.[368] Securing federal funding through PWA was once again on the table.

Once the Kirkpatrick amendment to the GRDA act was repealed, the political wheels spun quickly in GRDA's favor at both a local and federal level. In March 1937, the Oklahoma legislature renewed GRDA's charter through June 1939 in anticipation of construction, which everyone hoped would be imminent.[369] Army engineers conducted more detailed studies of the Pensacola, Markham Ferry, and Fort Gibson sites in conjunction with the larger Arkansas River Basin flood control program. In June 1937, Senator Thomas was able to secure $16,000,000 for the project as an amendment to a War Department appropriation bill. Funding, however, ultimately came under the purview of PWA (which was overseen at that time by the Interior Department) when Congress appropriated PWA funds for the Pensacola Project. Secretary of Interior Harold Ickes, a former detractor of the project, recommended that it receive $20,000,000 based on correspondence he received from the Corps of Engineers on June 8, 1937.[370] President Roosevelt approved the $20,000,000 allocation for the Pensacola Project on September 18, 1937; PWA followed up, offering GRDA a loan of $11,563,000 (to issue bonds that would then be sold to PWA) and grant of $8,437,000 to fund the project.[371]

The public reaction was jubilant. "A large celebration" took place in Vinita with local cities like Miami entering floats into the parade and appearances by Marland, Disney, Thomas, Holderman, Reybold, and many other long-time supporters and early financial backers of the project.[372] According to one account, Reybold "remarked that 'people up here' had worked hard for the project and deserved it."' Pensacola's tireless advocate, Representative Disney, noted with some irony, "'this is the first time I've ever been happy at a Grand River meeting. Usually I've been mad. I'm proud of the project. . . . Why, we would have had the dam two years ago, if the Senate had passed the authorization which I had put through the House twice.'"[373]

The GRDA board approved PWA's offer during its October 16, 1937, meeting and appointed R. L. Davidson general counsel.[374] In short succession, GRDA hired the Tulsa-based company Holway and Neuffer as the project engineers and appointed general manager Robert Van Lear Wright, whom PWA backed and who was close with Ickes.[375] After forty years of envisioning, the Neosho River Dam development was officially underway.

Designing the Pensacola Dam: The Pool Controversy

In fall 1937, William Rea (W. R.) Holway, assisted by engineer Victor Cochrane, began formulating their plans for the Pensacola Dam. Both Holway and Cochrane were intimately familiar with the project, as they had worked closely together in the 1920s in determining "the economical height to which a dam should be built (for the development of power)" at the Pensacola site. (Holway would play a prominent engineering role at the Pensacola Dam for many years to come.) In addition to their own studies of the site, Holway and Cochrane reviewed the Corps' 1935 308 report and investigations that Grand-Hydro and its predecessors had completed between 1918 and 1930. Armed with several models and designs but with no contractual requirements or guidance as to the dam design and the size of the pool, the first question the engineers needed answered was exactly how much power production and flood control PWA was contemplating at Pensacola. On November 10, 1937, PWA power division director Clark Foreman explained that the Pensacola Project allotment had been made to cover construction of a project "embodying the engineering features" the Corps chief had presented in a letter to the PWA assistant administrator on June 8, 1937 (a statement Ickes reiterated to Chief of Engineers M. C. Tyler in a letter the next day).[376] The Corps design to which Foreman referred called for the top of the dam to be at elevation 765, the maximum pool for dual purposes at 760, and the maximum pool for power use at 735. Additionally, its spillway was to be uncontrolled.[377]

Neither Holway nor Cochrane understood the basis of the directions the Corps (via PWA) had given them. Although their primary focus was on power generation, they had always planned to include some form of flood control in the design. As Holway explained, engineers knew from the beginning that "a gated spillway would be necessary on any dam on the Grand River in order to have any control over floods." Not only had he and Cochrane "spent considerable time and money preparing theoretical hydrographs showing the amount of flood control that could be obtained by gates which we proposed to install," but they also felt strongly that the power pool elevation needed to be 745 not 735 to generate "enough revenue from power production to pay off the bonds, which would be issued against the project by the Authority." In early 1938, Holway and Cochrane presented the results of their studies to Little Rock District engineer Colonel Eugene Reybold to press for gates on the spillway. In a surprise turn of events, Reybold said that despite the June 8 letter, the Corps "had never contemplated an 'uncontrolled' spillway and did not want one." Holway and Cochrane then raised two more concerns: first, that the June 8 letter had not provided enough spillway capacity, and second, that the proposed power pool elevation of 735 needed to be raised 745 to "obtain enough revenue from power production to pay off the bonds" that GRDA would be issuing for the project. Reybold "protested" that Secretary Ickes had assured the Corps that they would receive "adequate flood control in the project."[378] However, Reybold had to concede that the flood control that an uncontrolled spillway would have provided (and as the Corps had proposed it in the June 8 letter) "was practically none."[379]

Holway and Cochrane were working during a period when the Corps was moving away from earlier assessments that there was no federal interest in the Neosho River for flood control to instead authorizing preliminary examinations in Oklahoma of the Pensacola, Markham Ferry, and Fort Gibson reservoir sites for multipurpose dams.[380] To many, this appeared to be a confusing about-face. As Holway explained, "up to and in the year 1935, the Corps of Engineers had found that flood control on Grand River was . . . merely a 'local' problem."[381] Indeed, the Corps' 1935 308 report about the Arkansas and tributaries specifically noted that there was "no plan for flood control in the river below the mouth of Spring River that is practical from both an engineering and economic standpoint" and that to use the river "to its best advantage," the focus should be on developing water power. Doing so would eliminate all "flood problems, as practically the entire reach will be occupied by water-power reservoirs."[382]

Thus, in 1937, when GRDA received funding from PWA (and significantly, not the War Department), Holway and Cochrane were focused on designing a hydropower project that could meet the stipulations of its PWA grant and loan contract, which required it to be self-liquidating. After their meeting with Reybold regarding the dam's design, the engineers moved forward with the plans that best supported both GRDA's financial obligations while still incorporating some flood control. On February 11, 1938, GRDA filed with the FPC its declaration of intent to seek a license for the Pensacola Project.[383] On April 22, 1938, Holway and Cochrane submitted to the GRDA board a plan that provided for a gated spillway that could accommodate 535,000 cubic feet per second (cfs) with the dam crest at 757, maximum pool level at 755, power pool level at 745, and spillway crest at 730. The board immediately approved the plans and then submitted them to both PWA and Corps, whose approval was needed to secure the FPC license.[384]

Several months of debate over the power pool level ensued. In a meeting soon after the Corps received the plans, Reybold once again "contended" for the 735 power level, which GRDA representatives refused to concede. Reybold "agreed" that as designed, the dam "could be operated their way or our way," he ultimately indicated that the Corps "would approve the structural features of the project." The plans moved up the chain of command. In May and June 1938, GRDA engineers and officials visited DC several times to discuss their plans with the FPC and Corps. According to a later account by Holway, Chief of Engineers Tyler listened to the GRDA engineers explain that the specifications outlined in the Corps' June 8 letter were untenable for GRDA and in reality, counter to the Corps' hopes for some flood control at the dam. After hearing the problems with the Corps' call for an uncontrolled spillway; the Corps' proposed elevation of 760, which GRDA knew from its own modeling would flood Grove and Miami; and the Corps' request for an entirely inadequate 5,000 acres of flood control at the project, Tyler admitted that the Corps had "made a mistake" and asked what remedy GRDA sought. When the engineers responded by saying the best option for GRDA would be for the Corps to vet the plans with the 745 pool level, Tyler approved the plans so that GRDA could move ahead with taking bids but punted the elevation question to "a later determination."[385]

Almost immediately thereafter, the FPC conveyed to GRDA "certain criticisms" the Corps had made on the design Tyler had approved. GRDA engineers reviewed the comments and responded that they had found mistakes in the Corps' computations. In response, the FPC sent an engineer to Vinita to facilitate a compromise. The FPC explained to GRDA that the Corps would "waive their criticisms of design" in exchange for a power pool elevation of 735. Once again, GRDA refused to compromise and stood by its original design.

In the middle of the debate over the Pensacola design, Congress passed the Flood Control Act of 1938 on June 28. The legislation clarified language in the 1936 act and solidified the Corps' jurisdiction over federal "investigations and improvements of rivers and other waterways for flood control." Furthermore, the act required the Corps to acquire with federally appropriated funds "title to all lands, easements, and rights-of-way" for any dam and reservoir project (as well as channel improvements) previously authorized by either the 1928 or 1936 Flood Control Acts (with some exceptions).[386] Although the act didn't call out the Pensacola Project by name, a May 1938 House report from the Flood Control Committee on the proposed legislation confirmed that although the Pensacola Dam project was under the umbrella of the Arkansas River Basin plan, the Works Progress Administration had authorized and appropriated funds for its construction.[387]

The inability to reach a compromise precipitated a hearing in Fort Smith, Arkansas, with the Corps, FPC, and GRDA on December 7, 1938. Also in attendance were members of the Arkansas Valley Association (hailing from as far north as Tulsa to as far south as Pine Bluff), who urged that the power pool be lowered to 735 for flood control. As Holway later described, one of the representatives made "a long, impassioned plea for less power and more flood control," and continually referred to the Corps' 308 report as "the B-I-B-L-E" regarding flood control in the Arkansas River Basin. Holway countered, noting that this so-called Bible had recommended that the "there was no Federal interest in such a development." GRDA was chagrined to hear at this meeting that "the Army now had a plan to build a dam at Pensacola to provide 960,000 acre-feet of flood storage and had complained that the Authority was proposing to give them only 520,000 acre-feet." Not only did such a plan go completely against the 308 report but, as Holway pointed out, despite various unofficial statements forecasting the Corps' growing interest in Pensacola for flood control, there was "no *published* report" by the Corps of such a plan."[388] Additionally, lowering the power pool elevation to 735 would reduce GRDA's firm power generation at Pensacola by 20 percent, thereby incurring a 20 percent increase in its rates to consumers. An increase in this size would bring GRDA's electricity rates almost in line with the rates local utilities were charging, greatly diminishing any economic benefit the project was supposed to bring to Oklahomans under the goals of New Deal relief programs—a consequence of which the Corps was aware.[389]

Federal Power Commission License and Continuing Pool Controversies

Despite ongoing controversies over the pool level, on January 27, 1939, the FPC issued a license for Project No. 1494 to GRDA for the Pensacola Dam and Reservoir. The license authorized GRDA to operate the reservoir at 745 feet for power production but specified that GRDA was

> not to utilize storage space above said elevation 745 for power production purposes except during periods when the reservoir is being operated for the control of floods. The storage capacity between elevations 745 and 755 shall be expressly reserved for the control of floods. The Licensee shall impound flood waters in the storage space between elevations 745 and 755, and release flood waters therefrom, when, as, and in the manner directed by the Secretary of War, or his authorized representative: provided, that the Licensee shall not be required to impound any water above elevation 750 until the United States has acquired the necessary flowage rights above that elevation.[390]

General counsel Davidson undoubtedly echoed the sentiments of everyone at GRDA (and PWA) when he wrote to Oklahoma State Representative Lincoln Battlefield from Mayes County that the FPC's decision to uphold GRDA's preferred power pool level at 745 was "a distinct victory for the Authority in its controversy with the Army Engineers over the storage capacity . . . between power development and flood control."[391]

Despite Davidson's sense of victory, GRDA general manager Wright was not thrilled about paragraphs 4, 5, and 6 of the license. In mid-February 1939, Wright wrote to the FPC, recognizing the commission's "evident intent" to help GRDA meet its financial obligations to PWA by fixing the power pool at 745. However, as he explained to the FPC in mid-February 1939, the wording in the paragraphs he questioned instituted "a definite and fixed division" in the reservoir's storage capacity between power generation and flood control and required GRDA to defer to the secretary of war regarding operations between elevations 745 and 755. The order created "a condition not previously contemplated" in their plans that would increase costs by approximately $1,000,000. GRDA would "no longer [be] able to anticipate the frequency" of the use of this part of the pool. This was a problem because the GRDA engineers' power-generation models had been based on a plan that the Pensacola pool would be "normally and habitually used to elevation 750" and that GRDA would only be responsible for purchasing land and preventing damages to that contour. Wright asserted to the FPC that "the equivalent of the maximum flood record could be controlled under elevation 750 and that flooding between 750 and 755 would be necessary only as the result of rainfall, the volume and frequency of which could not be clearly predicted from available records, but which should not occur more than once in fifty years." As a result, Wright did not consider it "economically feasible" at that time "to buy and clear this additional land and permanently protect the structures of others." The GRDA engineers' models suggested that GRDA could operate the Pensacola Reservoir in a way that would "anticipate the necessity of flood storage space in the minimum amount of 520,000 acre feet, with normal flood restricted to 750, and still discharge under all conditions within the bank-full capacity of Grand River below the Pensacola site." He summed up by asking the FPC to consider the effect to GRDA's ability to be self-liquidating (and thereby repay its loan to PWA) and modify the license to "effectuate" this ability.[392]

Further discussion in spring 1939 revealed a fundamental divide between how GRDA and the Corps had been planning to use the pool level to address flood control. As Holway explained it, the difference was directly related to how each entity proposed to operate the dam. GRDA proposed to lower the normally 745 power pool in advance of a flood to 735 or 740 so that they could ensure enough spillage to never top 750, even in flood conditions. "With the maximum flood for which the spillways are designed, 525,000 sec ft, the pool level" might reach elevation 755, but such a flood would "probably never occur and probably only once in fifty years will 220,000 sec ft be exceeded." The Army's plan was "to maintain the pool level at 735 for power purposes with the gates open and to close the gates and stop the flow of water entirely in the Grand River to keep it out of the Mississippi when a high crest was expected at the mouth of the Arkansas, with no relation to the size of the flood coming down the Grand River." As he summed up, the Corps' approach to flood control at that point was "to hold back floods and to release them when desired, unless the storage has been filled and the waters must be released from the reservoir as fast as they come in, which could well be at a time when the largest peak of that particular flood was coming down the river." Holway feared that this approach might actually prove to be "harmful rather than helpful, due to the possibility of having to let a large amount of water down just at the wrong time."[393]

The pool level controversy that continued to rage into early summer 1939 precipitated a few changes over the next few months to the first iteration of the license.[394] By early July, however, GRDA, had "hurdled . . . a major obstacle" in its path and reached a compromise with the FPC and Corps, which had agreed to take responsibility for purchasing all land and easements between elevations 750 and 755.[395] In its final form, officially authorized in late July 1939, the license authorized "a dam approximately 147 feet in height and 5,595 feet long . . . consisting of a reinforced concrete, multiple arch, non-overflow section 4,284 feet long, a concrete gravity spillway section 861 feet long, with crest gates of the Taintor type, and a concrete gravity, non-overflow section 451 feet long." An auxiliary spillway about "one mile east of the main dam, [would consist] of two detached gravity concrete sections, about 800 feet in total length," also with gates. The reservoir would extend "approximately 55 miles upstream from the dam, having a storage capacity of 1,680,000 acre-feet at elevation 745 feet amsl, which is the maximum power pool level, and provision for flood control storage to elevation 755, at which level the total storage capacity will be about 2,200,000 acre-feet."[396] Perhaps the most important sections of the license related to the pool controversy were Articles 13 and 14, which authorized GRDA

> to operate the reservoir in such manner as to utilize storage space below elevation 745 for power production purposes but not to utilize any storage space above said elevation 745 for power production purposes except during periods when the reservoir is being operated for the control of floods. The storage capacity between elevations 745 and 755 shall be expressly reserved for the control of floods. The Licensee shall impound flood waters in the storage space between elevations 745 and 755 and release flood waters therefrom when, as, and in the manner directed by the Secretary of War, or his authorized representative: provided, that the Licensee shall not be required to impound any water above elevation 750 until the United States has acquired the necessary flowage rights above that elevation. . . . Subject to the provisions of Article 13, the operation of the project by the licensee, [Article 14 commanded that] so far as such operation may affect the use, storage, and discharge from storage, of waters, shall at all times be subject to the control of the Secretary of War under such rules and regulations as he may prescribe in the interests of navigation and flood control, and subject to the control of the Commission under such rules and regulations as it may prescribe for the safety of the dam and for the protection of life, health, and property.[397]

Although the matter of the pool elevation seemed to be resolved, the pool controversy would continue well into the 1940s and beyond.

Land Acquisition, Flowage Easements, and Damages Settlements

Although GRDA had been steadily acquiring land and easements for the reservoir that would form behind the dam since executing its contract with PWA, once GRDA received its final license in July 1939, the pressure was on to complete the process, which had already proven to be contentious, tedious, and far more expensive than originally estimated. Although it was obligated to acquire land up to elevation 750, Holway urged GRDA in October 1939 at the very least to secure land acquisitions to the 730-foot contour—the lowest level at which the dam could begin generating power. However, even below that lower contour line, Holway explained, only 334 of the needed 837 tracts had yet been acquired.[398] As one news outlet described it, "scarcely a week passes" that GRDA "does not strike a snag of some kind in its efforts to acquire land needed for the project."[399] By mid-December, with the project nearing completion, GRDA was under tremendous pressure to purchase or start condemnation proceedings immediately in the remaining 4,836 acres left to acquire—a seemingly unsurmountable hurdle.[400] A further sense of urgency was created by the fact that GRDA was working on a January 29, 1940, construction deadline, which was itself already an extension from the original July 1, 1939, deadline.[401]

To make matters even more complicated during this period, ongoing internal discord between the GRDA board and General Manager Wright reached a crisis point in November 1939 when the GRDA board asked Wright to resign under charges that Wright had "proved inefficient."[402] Many at GRDA had viewed Wright as an outsider since the day he was appointed. Indeed, friction had grown to such a point that in March 1939, the Seventeenth Legislature rewrote the GRDA enabling act, which reduced the board membership to five people whom only the governor would appoint.[403] Thus by late 1939, with anti–New Deal governor Phillips and his five appointees in charge, some of the pressure to oust Wright may have been due as much to political differences as Wright's performance. Although it was "conceded on all sides" that GRDA could fire Wright "regardless of the attitude of the PWA," PWA had to approve a replacement and could "refuse to approve administrative acts of the Authority and can delay or refuse to advance further funds for the project."[404] With that in mind, GRDA "filed formal charges" and removed Wright from his position in late November 1939.[405]

Early in 1940, tensions between GRDA and PWA over filling the general manager role "eased" after PWA granted a three-month extension for completion of the project, extended Davidson's interim appointment for another few days, and agreed to review a new set of candidates and make a recommendation.[406] Among GRDA supporters, however, Wright's firing had taken on an even more ominous political hue. Democratic U.S. Senator Josh Lee "charged that 'powerful forces' were seeking to stop construction of the Grand river dam in an effort 'to prevent the government from selling cheap electricity to the people.'" He also inferred that Governor Phillips "had obtained power over the GRDA at the last legislature in order to gain control of the project." Lee noted that the general manager situation was "'not a fight of personalities but one over fundamental issues as to whether the people of Oklahoma will have a right to cheap electricity.'" Whether true or not, Lee believed that Phillips and the new GRDA board intended to block construction.[407] GRDA and PWA had agreed to hire former Muskogee city manager, T. P. Clonts, as general manager by March 1, 1940.[408]

On November 4, 1939, 5,000 people attended the dedication of Pensacola Dam. With the water already rising, attendees "witnessed the greatest massing of water craft ever conducted in Oklahoma," watched "motorboat races and water skiing" and a "parade across the dam," and listened to Governor Turner's dedication speech.[409] The celebration belied the frantic land negotiations that had been going on and would continue for years to come. Between receiving the license in July 1939 and spring 1941, when full commercial operations commenced, GRDA settled its suit with Grand-Hydro over ownership of and a price for the dam site, dealt with hundreds of individual condemnation cases, negotiated with the state over highways and railroad companies over their lines, entered into settlement agreements with the City of Miami and Ottawa County, and sought and received title from the federal government to all Indian lands within its jurisdiction.

Individual Parcels

A thorn in GRDA's side throughout the land acquisitions period was the process of setting the value of the land to be acquired or condemned. At the outset of the process, GRDA had pledged to make "every effort . . . to acquire the property without resorting to condemnation suits." However, local people also expected "a great real estate boom to result from the expenditure of $1,250,000 for 46,500 acres of land to be inundated."[410] Although local landowners and commentators like Victor Harlow may have anticipated the potential of increasing land values, no one at GRDA seems to have expected the "unexpected high appraisements and damage awards" that district court juries would uphold.[411] GRDA appraisers had based their $1,250,000 estimate on "the price the property would bring at a free voluntary sale" (whether a dam was to be built or not).[412] However, landowners and court appraisers were basing their estimates, which district judges were upholding, on the value of the land as part of the dam and reservoir site—land that GRDA was required by its PWA contract and its FPC license to secure before operations could commence.

Discrepancies also existed between the federal agencies and both GRDA and private owners. For example, in the Grand-Hydro case, negotiations had broken off in February 1939 between GRDA and Grand-Hydro over the value of the 395-acre dam site and 1,705 acres directly upstream, which Grand-Hydro legally owned and which GRDA had to secure before it could move forward with the project. According to one report, Grand-Hydro valued the land at $243,000, PWA appraisers at $193,000, and GRDA at $75,000. In response to the impasse, GRDA planned "immediate condemnation proceedings to obtain title to the property."[413] Although GRDA's federal license now enabled it to condemn land valued at more than $3,000 in federal instead of state courts, that decision only held for new cases. Indeed, GRDA "received a severe set back . . . when appraisers appointed by the Mayes County District Court" fixed the value of Grand-Hydro's land at $314,755, an even higher value than Grand-Hydro had originally estimated.[414] Staring down the construction deadline, PWA approved and released the payment in January 1940.[415]

In late November 1939, GRDA "filed formal charges" to disqualify District Judge W. M. Thomas from Miami from all future land-condemnation suits related to the Pensacola Dam—"suits which in the past in the three-county area have gone against the Authority with considerable regularity."[416] GRDA also believed that Thomas should recuse himself because he owned land that GRDA needed to partially condemn.[417] GRDA pleaded for removal of cases from Delaware County, charging that the citizens of the county "have made an organized effort to force payments far in excess of the fair value for needed land." Thomas refused to disqualify himself and "overruled the motion," to which GRDA responded by filing a mandamus action with the Oklahoma Supreme Court "in an effort to force his disqualification." GRDA assistant counsel Gayle Pickens asserted that in early 1938, "landowners assumed a hostile attitude and made an organized effort to force the Grand River Dam [A]uthority to pay far in excess of the fair value of lands needed."[418] He recounted how these landowners had met to form an organization "to prejudice the citizenry against

Grand River Dam Authority . . . [and] intimidate county officials, jurors and court-appointed appraisers." GRDA believed that "the citizenry as a whole has been intimidated" and that "either through friendship with their neighbors of fear of losing that friendship, hesitates to arrive at a true land value." Furthermore, GRDA had been having a hard time finding witnesses in Delaware and Ottawa Counties "due to this intimidation."[419] In Thomas's defense, attorney J. G. Austin of Miami argued that "some Delaware County jurors have held a 'distorted view' of land values in the area because of high prices set in the early days by appraisers," but Thomas was "not responsible for this attitude or disqualified in any way."[420]

State Highways

In early October 1939, GRDA asked for a six-month extension on the January 29, 1940, completion deadline. At that time, Oklahoma governor Leon C. Phillips, along with the state highway department, were "deadlocked in negotiations over payment of costs of removal of state roads in the area." Phillips had originally pushed for $1,600,000 but they reduced that amount to $900,000 "in an effort to make an amicable settlement."[421] According to earlier news coverage of the matter, GRDA only had $323,000 for the expense.[422] By October 1940, Davidson wrote to the GRDA board that "no settlement of this controversy has been reached as yet, but no suit has been filed by the State or the State Highway Commission for recovery of damages against the Authority" either.[423]

Railroads

Construction of the dam and the reservoir to fill behind it would inundate parts of the tracks of the two railroads that crossed the area, the St. Louis–San Francisco "Frisco" Railway and the Kansas, Oklahoma & Gulf Railway (KO&G). To mitigate these damages, in early July 1939, the FPC modified GRDA's license for the Pensacola project and required the Authority to "acquire all necessary lands, easements, and rights of way up to elevation 750; and raise all railroads affected by the project to such elevation above elevation 755 as may be necessary to provide for operation of the railroads when the reservoir is raised to elevation 755"[424] GRDA engineers moved quickly to complete this work. By December 1939, Holway conveyed the news that the relocation of railroads within the reservoir pool was complete.[425] Later reports described that GRDA relocated and raised the Frisco tracks to the required elevation, except a small section of east of Wyandotte, "because the railroad company did not deem it necessary." As for the KO&G, GRDA obtained flowage rights instead of relocating or raising it, however, that process occurred during federal control.[426]

After GRDA retook control of Pensacola Dam in 1946, there was some confusion among GRDA staff as to whether the federal government had indeed completed the land acquisition process. Although GRDA counsel Q. B. Boydstun believed that GRDA and the federal government had acquired all "necessary flowage rights" for the railroads, he explained in a May 1947 letter to

Tulsa District Engineer Col. C. H. Chorpening that GRDA had not yet received the official documents to prove this and would need to confirm with SWPA (which presumably possessed them).[427] By March 1948, GRDA general manager France Paris was able to confirm that either tracks had been raised or flowage easements secured up to 755' regarding the Frisco and KO&G railroads.[428]

City of Miami

As the pool controversy continued among GRDA, PWA, and the Corps in 1937 and 1938, the City of Miami had its own concerns about possible damages the town and its citizens might endure once the Pensacola Dam was complete and the lake at full pool behind it. According to the City, the lake would "reach the City . . . when the lake is full and when the lake recedes it will leave mud flats near the City." The solution as the city commissioners saw it was to build a low water dam south of the city. To that end, the City passed a resolution on November 7, 1938, calling on U.S. Senator Thomas "to have a survey made by some competent engineer of this project in order to ascertain the probable cost" of such a dam.[429] Whether Senator Thomas had any influence is unknown, but in April 1939, the Oklahoma State senate passed a bill in support of acquiring land for city park purposes (whether the 5 to 10 acre parcel the City needed to build the dam would actually be a park was unclear). Mayor Dobson proclaimed that the construction of a low-water dam near the "Connor Bridge," 9 miles southeast of town was the city's "No. 1 project." Rough plans estimated the dam would be 15 to 18 feet tall and 900 feet long, have a lock and a lock keeper's house, and would maintain a "constant water level" once Grand Lake was filled. GRDA would provide the easement and title (if it could secure them). The City had applied for funding through the Works Progress Administration (WPA), and Miami's share of the estimated $175,000 project would be $35,000 to $40,000.[430]

In June 1939, the Miami PUB contracted engineer Eugene Wood to survey and make recommendations regarding what it would cost to build a low-water dam south of town.[431] In July, for unknown reasons, the City of Miami abruptly canceled the low-water dam project.[432]

Between 1938 and 1940, both GRDA and the City of Miami were in discussions about assorted items related to the Pensacola Project, including estimating how much GRDA electricity the City might use and what rates they could expect to pay.[433] They also embarked on extensive investigations and discussions about what kinds of damages city infrastructure might experience. On October 20, 1939, the Miami PUB was anticipating C. E. Bardsley's report regarding a recent survey and estimate of damages he had made about potential damages to the disposal plant and sewer outfalls. At the same meeting, the PUB superintendent reported that in a different survey he had participated in, the finding was that the extant outfalls would be 1 to 5 feet below the 745 feet amsl.[434]

Miami mayor W. W. Dobson, city attorney E. C. Fitzgerald, PUB superintendent Freehauf, and GRDA engineer Holway met at Vinita on January 30, 1940, to discuss the potential damages. On February 1, 1940, GRDA engineer Holway wrote to Dobson regarding the meeting in Vinita two days' prior between Holway, Dobson, and Fitzgerald regarding potential damages.[435] In response to what he learned at the meeting, Holway wrote to Dobson two days later "to correct the impression prevalent in the City of Miami, among the citizens," that GRDA had "ignored Miami and its rights." He wanted Miamians to understand what Dobson, Fitzgerald, and Freehauf already knew—that GRDA had been studying the "situation" for months at the City's behest. GRDA's studies (which Holway said were documented in numerous field survey books) had determined that Miami would suffer no possible damages with the lake level at 730 or 735, which GRDA needed to hold the lake at to allow time for highways to be relocated, and that "any damage which might be done to the property of the City of Miami would be when the lake reached its final level of 745 or 750, in flood times." Additionally, Holway stated that GRDA had not yet negotiated with Miami over potential liability because other places, "such as Vinita and Grove Water Supplies and the railroads and etc." would be flooded "by even the 730 lake level, and, therefore, had to be taken care of before the lake was filled." Since no damage could "accrue" to the City of Miami until the lake reached "a high level," GRDA had delayed the conversation, "while other more pressing matters have been taken care of." Still, Holway promised to bring Miami's concerns to the GRDA board and reassured the mayor and commissioners that GRDA would "very shortly make some definite move towards settling this matter."[436] After hearing what had transpired at the January 30 meeting (and presumably reading Holway's letter), the PUB board collectively agreed that GRDA should settle damages with the City of Miami "before closing the gates at the dam."[437]

On March 1, 1940, the mayor and Miami PUB met with a contingent of GRDA representatives that included Clonts, Davidson, Holway, and Supervisor of Power, Sales, and Distribution Carl L. Gearhardt to again discuss potential damage to outfall sewers. After the discussion, the PUB made a motion to "immediately" conduct another survey that would show "the elevation of the sewer line, the type of soil intervening the line and all other data which may be compiled to determine the probable effect of maintaining an average water level of 745 feet." Additionally, the study should recommend "the probable cost of obtaining easement rights and construction of [a] new line without prejudice of the City to take any action which may be deemed necessary."[438] A month later, the mayor and PUB met once again with the independent surveyors and GRDA. Fitzgerald "presented the plans and profiles" of the extant Neosho River and Tar Creek outfall sewer system and its proposed new location and then the group discussed potential damage to the Neosho River bridge (at Main Street) and Riverview Park. The group also contemplated the fact that flowage rights and park damage "would have to be referred" to the "governmental department" (presumably the city attorney and mayor). Ultimately, the Miami officials asked GRDA "to relocate the sewers," which Clonts promised to refer to the GRDA board.[439]

On April 23, at a special session with both the PUB and city commissioners to discuss outfalls, Clonts presented GRDA's opinion that the Authority should not be "stuck with the Tar Creek outfall and that the City shouldn't ask them to throw away the entire sewer system and build a complete new one." Furthermore, GRDA believed that without Tar Creek on the table, the City could build a new sewer for $50,000 and that "by working up a P.W.A. Project the City would be able to build the sewer cheaper than the proposed estimate." Clonts continued that he would recommend to the GRDA board that the City receive $30,000 in damages for the Neosho River outfall sewers and $5,000 for the bridge.[440] Over the course of May and into June, the debate continued, with Clonts also taking up the matter of damages with PWA. As Clonts reported to Freehauf in early June, Clonts had asked PWA about settling damages to the Miami sewers and whether PWA would "be agreeable to settle these damages and then hold in abeyance the alleged damages to the bridge and park." PWA responded that it would not "approve any settlement which does not liquidate all of the alleged damages.'"[441]

By October 1940, Davidson reported to the GRDA board that the City of Miami and GRDA had settled on a $50,000 damage claim "for flooding a portion of the sewer system of the City of Miami and a part of a public park and for anticipated injuries to a certain highway bridge within the corporate limits of the City."[442] The next month, PWA approved the proposed settlement, which specified that in exchange for the $50,000, the City of Miami would "release and discharge the Authority from any and all claims for damages caused by the construction, maintenance and operation of the project or by the overflowing and inundating of lands and properties of the City located in the basin area and lying below elevation 750" and that the City would convey to GRDA flowage easements for "all of the City's lands and properties located in the basin area and lying below elevation 750." The settlement was executed on November 14, 1940. Mayor Dobson signed for the City and Ray McNaughton signed on behalf of the GRDA board.[443] The full city commission approved and the mayor signed the release of the flowage easement at the December 2, 1940, meeting.[444] On the same day, the City of Miami passed a resolution related to the flowage easement through the Park of the Grand River Lake."[445]

Ottawa County

Ottawa County also sought damages from GRDA related to the Pensacola Project. In September 1939, GRDA general manager Wright, counsel Davidson, and engineer Holway opined to the GRDA board that $40,000 was a fair sum to pay Ottawa County for damages related to the reservoir's projected inundation of county roads and bridges.[446] On November 6, 1939, the Ottawa County Commissioners passed a resolution requiring GRDA to raise certain county bridges to 760 feet amsl, and in January 1940, the commissioners passed a resolution "authorizing and directing Frank Nesbitt to prosecute mandamus proceedings against the GRDA in protection of the interest of Ottawa County regarding certain roads and bridges."[447] Originally estimating damages to county roads and bridges at $350,000, the County had reduced to $152,500 the amount it was seeking.[448] Clonts, Davidson, and Holway told the GRDA board on August 3 that they saw no justification for that sum and recommended sticking to their $40,000 recommendation.[449] As of October 1940, with the construction deadline looming, no agreement had yet been reached between GRDA and Ottawa County, although GRDA recognized its liability "for actual damages sustained by the County."[450]

In December 1940, Clonts read to the GRDA board a letter from Ottawa County attorney Nesbitt stating that the board of commissioners would "compromise and settle Ottawa County's claim for damages for the destruction of or injury to the Bee Creek, Spring River, and Conner Bridges and approaches for the sum of" $55,000.[451] The county commissioners passed a resolution on December 28, 1940, accepting the settlement terms and the GRDA board Resolution No. 2070 approving the agreement on January 6, 1941.[452] A few weeks later, a PWA official pointed out that PWA was fine with the agreement terms but that the commissioners had not entered an official resolution appropriately in the Commissioners Journal. This error was corrected in the February 5, 1941, corrected resolution.[453] On March 8, 1941, Ottawa County Commissioners passed an additional resolution regarding GRDA damages—accepting payment and vacating roads and bridges under 750 feet amsl.[454] In January 1945, Ottawa County passed a resolution releasing SWPA/GRDA from further liability on rebuilt roads and bridges.[455]

Indian Lands

In addition to the city, county, private, and state lands or flowage easements that GRDA needed to acquire for the Pensacola Dam, "a considerable quantity of Indian land in Ottawa, Delaware, Craig, and Mayes Counties" (both allotments and trust lands) within the proposed power pool contour (up elevation 750) for which GRDA was responsible.[456] In comments on House Committee of Indian Affairs' Report No. 7901, regarding a bill that would assist in this process, Acting Secretary of the Interior E. K. Burlew suggested to committee chairman Representative Will Rogers (from Oklahoma) a few revisions but granted overall approval from Interior. Burlew agreed that if GRDA took responsibility for acquiring and paying a fair price for Indian lands, the federal government would grant all rights and easements related thereto.[457]

On June 11, 1940, Congress passed the Act to Transfer Certain Lands to the Grand River Dam Authority, and for Other Purposes. The law authorized GRDA to acquire, without congressional approval, "all the right, title, and interest held by the United States and by individual Indians and tribes of Indians in Indian Lands located in Ottawa, Delaware, Craig, and Mayes Counties, Oklahoma, lying below an elevation of [750 feet amsl], which may be required for the Grand River Dam Reservoir." This grant was subject to individual Indian owner consent and Interior's approval of a map of each parcel and determination of appropriate compensation. If any individual or Tribe refused consent, the act authorized GRDA to initiate condemnation proceedings in federal district court. The act outlined specific caveats, including a requirement that only the "principal Chief" of the Cherokee Nation appointed "under section 6 of the Act of April 26, 1906 (34 Stat. 137, 139)" could give consent for the Cherokee Nation, and that "as to the lands of the Seneca Indian School, the interest conveyed hereby shall be a flowage easement only."[458]

One question that surrounded acquiring and paying for Indian land revolved around whether GRDA would purchase the land outright or exchange it for other parcels. GRDA general counsel R. L. Davidson was "of the opinion" that GRDA "could not purchase land above the 750 ft. contour line and exchange the same but that the only way the Authority could dispose of such land acquired would be by sale for cash."[459] However, the secretary of interior was allowed to use his discretion in using any compensation received "in the purchase of lieu lands," under 47 Stat. 474 (June 30, 1932), which provided that "whenever any nontaxable land of a restricted Indian is condemned or sold the proceeds may be reinvested in other land, to be likewise restricted and nontaxable."[460]

Operating the Dam

GRDA Operations: April 1941–November 20, 1941

In March 1940, GRDA closed the gates of the Pensacola Dam, behind which water began to pool; GRDA officially commenced operations almost exactly a year later. As outlined above, under the terms of its PWA contract and FPC license, GRDA controlled dam operations up to elevation 745 (and had purchased land and flowage easements to the 750 contour line), but the War Department took over during flood situations to manage pool operations above that elevation (and was responsible for acquiring land above elevation 750).

Almost immediately after GRDA opened the project, a flood elevated Grand Lake in mid-April 1941, precipitating the Corps' takeover of operations. Later reports suggested that this first attempt to coordinate between GRDA and the Corps might not have been the smoothest process. On April 17, the pool was at 741.05 feet and climbing. The Corps directed GRDA to discharge 30,000 cfs until 10 p.m. that night, but GRDA did not heed the directive and continued to spill into April 18. The problem was that the "overburden in the spillway get-away channel had not been excavated" because the designing engineer had assumed that pilot channels excavated in the bedrock would "cause the hydraulic removal of the entire overburden . . . before it became necessary to utilize the full discharge capacity of the spillway." GRDA's continued spill in contradiction to the Corps' directions was a direct result of the GRDA engineers' fears that the powerhouse might be severely damaged. The Corps sent observers to the dam on April 18, and the pool reached a height of 748.14 feet on April 19, whereafter the spillway get-away channel began to give way as designed and was fully open by April 20.[461] (See more in next section about 1941 flood damages.)

The interagency dynamics experienced during the April 1941 flood led the Corps to devise a set of rules and regulations around flood-control operations at the Pensacola Dam, as follows:

1. Whenever the elevation of the reservoir exceeds elevation 745, the discharge facilities shall be operated so as (a) to reduce as much practicable the flood damage below the reservoir and (b) to limit the elevation of the reservoir to elevation 750.
2. The District Engineer . . . shall advise the Authority when inflow rates are anticipated which may raise the elevation of the pool above elevation 745, and the maximum rate of release allowable. The Authority shall then take such measures to increase the storage capacity of the reservoir available for the control of floods as are not inconsistent with the development of power.
3. The Authority shall inform the District Engineer daily, promptly after taking the morning observations, as to the elevation of the reservoir pool and the tail water, and the rates of release for the preceding 24 hours. Whenever the pool is above elevation 745, the Authority shall submit these reports by telegraph or telephone as directed by the District Engineer, supplemented by such additional telegraphic or telephonic reports as may be required by the District Engineer in the interest of flood control.[462]

When an even larger flood hit in September and October 1941, GRDA and the Corps both appeared to have adhered closely to these rules.[463]

In August 1941, Congress amended the Flood Control Act of 1938 to specifically include the Neosho River reservoirs under the Arkansas River Basin general comprehensive flood control plan. Additionally, the 1941 Flood Control Act appropriated an additional $29,000,000 to achieve the goals of the plan.[464] By including the Pensacola Project under the Arkansas River Basin plan, the 1941 law implicitly obligated the Corps to acquire land, easements, and rights-of-way above elevation 750 for flood control.

Federal Operations: November 21, 1941–August 31, 1946

Undoubtedly in anticipation of entering the war that had been raging in Europe since the late 1930s, Franklin D. Roosevelt signed Executive Order No. 8944, "Directing the Federal Works Administration to Take Possession of and Operate a Certain project of the Grand River Dam Authority," on November 19, 1941.[465] Roosevelt did this under Section 16 of the Federal Water Power Act of 1920, which allowed the president to take possession of any or all of a private operation for war purposes but ensured that the federal government would then pay "just and fair compensation" at an amount set by the FPC when it returned the operation.[466] The executive order directed the FWA administrator to take over Pensacola Dam for the war effort as of November 21, 1941, with Douglas G. Wright appointed as special representative to the administrator to administer the project.[467] Wright "immediately initiated appropriate action necessary for the completion of the project so as to make it usable" for wartime needs. Some wrangling regarding power distribution ensued, but by August 1942, "the majority of the war load deliveries" was being made. GRDA, which had initially had trouble finding a market for its power, was now solidly on the positive side of the balance sheet. As of September 1945, the project was essentially complete, with the fifth generator in the process of being installed (GRDA had contracted but not completed the work before government takeover) and scheduled to be operational by early 1946.[468]

In December 1941 (pursuant to the 1941 Flood Control Act), the War Department began acquiring the necessary lands and easements to permit storage of floodwaters in Pensacola Reservoir between elevations 750 and 755. By a directive of February 19, 1943, President Roosevelt put FWA in charge of acquiring land and easements; Executive Order No. 9366, dated July 30, 1943, and Executive Order No. 9373, dated August 30, 1943, which went into effect September 1, 1943, transferred administration of the Pensacola Project, including additional land acquisition, from FWA to Interior. Also on September 1, Interior created the SWPA to oversee the operations of Pensacola, Denison, and Norfork Dams in Oklahoma, Texas, and Arkansas.[469] From then until GRDA regained control of the operation in late summer 1946, SWPA administered the project.[470]

Floods and Flood Damage in 1941 and 1943

The years during which the Pensacola Dam was being planned and constructed coincided with some of the worst drought years experienced in that part of the country for decades. The stream gage on the Neosho River near Parsons, Kansas (approximately 50 river miles above Miami and 80 river miles above the Pensacola Dam), for example, recorded flows as low as 0 cfs for considerable periods in 1934, 1936, and 1939.[471] Historical data for the stream gage at Grove, Oklahoma, indicate that between 1925 and 1939, 1927 (15,750 cfs), 1928 (10,500 cfs), 1929 (11,970 cfs), and 1935 (9,660) recorded the highest annual cfs, and 1931 (2,533 cfs), 1934 (1,750 cfs), 1936 (2,845), and 1939 (2,188 cfs) recorded the lowest averages (the filling of Grand Lake rendered the gage inoperable). The gage at Commerce, Oklahoma, established in 1940, registered an annual average cfs in 1940 (566.8), one of only eight years with under 1,000 cfs between 1940 and 2022. By comparison, the four highest annual cfs recorded at Commerce were in 1951 (8,821 cfs), 1993 (11,140 cfs), 1999 (9,330 cfs), and 2019 (11,070 cfs).[472] As Holway later wrote, "it is interesting to note that of the six largest floods [prior to 1948], four occurred in the first three years of operation; and that also the driest period on record for the river was in 1939–40, during the peak of construction."[473] The first few years of Pensacola operations just happened to coincide with a run of wet years after the Dust Bowl era. GRDA and the Corps were forced to closely coordinate their efforts during three significant flood events in April and September–November 1941 and May 1943.

1941 Floods and Damage

As noted above, a flood in April 1941 led to the first instance of the Corps operating the Pensacola Dam and Reservoir under flood conditions, which resulted in the promulgation of rules and regulations that each entity agreed to follow the next time such an occasion arose. Just five months later, the opportunity arrived when the area experienced almost two full months of flooding.

According to plan, GRDA handed over control to the Corps when flood stage was reached. Between September 9 and November 6, 1941, GRDA followed the Corps directives to the letter, always attempting to keep the lake level at or under elevation 750.[474] As GRDA engineer Walter C. Burnham later explained, "during the 1941 floods, the reservoir was filled to 749.7 with the first flood waters before the crest flows of the tributaries entered. This resulted in having a full pool to elevation 750 when the maximum inflow from Neosho and Spring Rivers reached the reservoir and caused the greatest possible backwater in the lower reaches of these streams [in some cases, causing damage] . . . above contour 750."[475]

As early as November 12, 1941, GRDA general counsel Marshall expressed his concern to acting general manager C. A. West about potential GRDA liability for damages associated with holding the reservoir at 750 feet during the October 1941 floods. Marshall wanted to find out whether GRDA might be "clothed with any semblance of immunity" against damage claims arising from the flood—damages that stemmed directly from GRDA executing War Department orders. Marshall sought to find agreement about the government's obligation regarding anticipated litigation against GRDA, what recognition the government would give "if any, to the matter of its duty to indemnify the Authority against liability in these damage cases," and what policy the government would institute regarding reimbursement to GRDA for judgments rendered for damages. Marshall urged that this be done as soon as feasible.[476]

In December 1941, Wright assured Tulsa District engineer H. A. Montgomery that while GRDA recognized its responsibility for operating the dam "for national defense and national safety," GRDA felt it was "necessary to increase the storage of water in the reservoir to a normal operating level of 747.5 at this time. It is our plan to cooperate with your office as much as possible in the operation of the project during the flood condition . . . . However, final decision as to project operation will be made by this office . . . unless contrary instructions are issued by the Administrator or the President. It is the very definite policy of this office that under no flood conditions shall the level of the reservoir be again raised, as it was in the last flood, to a height which will back water in the reservoir above the 750 contour. This project is faced with a large number of damage suits from the requirement in the last flood of raising the level of the reservoir at the dam to such a point that the back water level in the upper reaches of the reservoir was approximately ½ feet above the 750 contour line which is the property line of the project."[477]

Also in December, Marshall wrote to Tulsa District engineer Montgomery, listed the flood claims already made against GRDA as result of 1941 flooding, and noted that they were expecting other damage claims "on account of alleged flooding of lands in the upper part of the reservoir area above the 750 contour." Marshall asserted GRDA's position that all the damage the claims outlined had resulted from the Corps' management of the flood-control pool. He further explained that while Article 13 of the license provided "that the Licensee shall not be required to impound any water above elevation 750 until the United States shall have acquired necessary flowage rights above that elevation, it would appear that the office of the District Representative of the Secretary of War has interpreted the language of the license to mean 750 at the dam." Thus GRDA believed that it "should be protected against any liability that may result, as well as against the expense involved in defending itself against it on this account."[478] Montgomery responded that the chief of engineers did not consider the War Department liable for any damages during the 1941 floods.[479] Marshall conveyed this response to the Board, noting that it appeared GRDA would bear the "burden of the investigation and defense of these claims." In the meantime, FWA special assistant general counsel R. L. Davidson (later GRDA counsel) would keep track of all expenditures associated with defending GRDA against these claims in case they could recoup them in the future.[480]

Which entity bore ultimate liability for damages incurred during the fall 1941 floods would come down to the definition of the 750 elevation and what it meant in relation to land and easements that GRDA was responsible for securing up to 750 and land between 750 and 755 for which the federal government was responsible. As Marshall explained in a letter to the FPC, he thought Montgomery was interpreting License Article 13 "as requiring the Authority's operating force to impound waters in the reservoir up to elevation 750 at the dam, and it is my information that the resultant backwater curve resulted in bringing the level of the reservoir near the headwaters of the lake to a point above elevation 750." Wright, Davidson, and Marshall found this position to be "wholly unjustified." Marshall then requested that the FPC amend Article 13 to relieve GRDA from any such liability and instead assign to the Corps "full and complete responsibility for any and all injuries sustained or damages suffered in consequence of the manner and method of the control of reservoir operations above said elevation."[481] Once GRDA's adversary, Judge Thomas now found himself in support of GRDA's position, writing to Montgomery about the several lawsuits already pending in his district and an estimated 2,000 more that might be coming. He had heard reports that the United States was planning to acquire land and easements for the five feet between 750 and 755, "and possibly more" to address "the slope" on the upper reaches of the during floods. Thomas remarked that he had spoken with not only the GRDA attorneys but also landowners, and that they were "all very anxious to know" whether the Corps intended to acquire that land in "the near future." Thomas felt that if the Corps did plan to buy the land, then all pending litigation was "quite useless" and that "most of the party litigants" agreed. If the Corps did not intend to acquire the land soon, though, litigation would proceed.[482]

The FPC did not respond as hoped to GRDA's request to render the Corps, not GRDA, liable for damages incurred by the Corps' operations of the Pensacola Dam during flood times. The FPC's Leon Fuquay directed Marshall's attention "to the fact that the Authority has failed to file maps showing the completed project boundary in accordance with Article 9, although repeated requests have been made by the Commission." Until this was done, the FPC could not determine whether GRDA had acquired sufficient land to fulfill the article. He also pointed out that "It is a known fact that backwater effects result from the impounding of waters and failure to take such effects into consideration in acquiring sufficient lands cannot create a liability against the United States." He added that license Articles 12 and 13 "confirm this interpretation." Fuquay directed GRDA to Article 17, which stated "that in no event shall the United States be liable for damages occasioned to the property of others by the construction, operation, or maintenance of the project. As to claims for damages for flood waters below the dam there appears no necessity for comment." In a parting shot, Fuquay said that both the FPC and the War Department "hitherto have been extremely lenient with respect to the provisions for flood control" and that the Authority's desire to file a formal license amendment appeared "unwarranted."[483]

Not to be deterred, Marshall retorted, "As you know, the Authority is and has been without means since November 21, 1941, to provide preparation of maps indicating the boundaries of the project." But, he continued, that was beside the point of his March 24 letter, which was specifically arguing that because the Authority was required by its license to maintain flood-water storage to elevation 750, he had to "reject" the FPC's view that the Authority should "assume moral or legal responsibility for damage caused by back-water to lands above elevation 750." Furthermore, Marshall rejected the idea that either License Article 12 or 13 "contemplates the acquisition by the Authority of lands near the headwaters of the lake above elevation 750 to enable flood-storage waters to be held at the dam at such an elevation as would involve the flooding of lands above elevation 750 in the upper reaches of the reservoir. It is the Authority's view that Article 12 of the license distinctly contemplates that the United States shall acquire necessary flowage rights above elevation 750 to permit the use of any part of the reservoir area for flood-control purposes above that elevation." Additionally, Marshall pointed out that the Federal Emergency Administration of Public Works (FEAPW) program under which the original project was built "contemplated that no lands would be acquired (except in exceptional instances . . .) with funds lent or granted by the Government for construction purposes, above elevation 750. Thus, it would have been impossible for the Authority to have acquired land above elevation 750 in the upper reservoir area to provide for flowage of the waters of the reservoir to a point above that elevation." In closing, Marshall rejected the idea that Article 17 rendered the Authority responsible for actions they took at the dam under the Corps' direction.[484]

Marshall took GRDA's case to Special Representative to the Administrator Wright, asking him to try to change the FPC's "attitude."[485] Wright wrote to the FPC on June 15, 1942, that after conferring with FWA's legal department, he believed that while GRDA remained under federal control, it was "not subject" to the FPC license provisions. He asserted that in his opinion, the FPC's only jurisdiction (while the project was under federal control) was over what the fair and just compensation would be to GRDA once the project reverted to them. "In other words, the operation of the license issued to the Authority is suspended until possession of the project is restored to the Authority in accordance with the Executive Order of the President." Wright stated that since the Administrator took over control of the project on November 21, 1941, GRDA had "refused" to take actions that would flood "land above elevation 750 at any point on the reservoir. Despite this stance, GRDA was "cooperating . . . as fully as possible" with Corps directives regarding operations for flood control. Wright noted that the controversy between GRDA and the FPC did not affect his operation of the project but that he was "in sympathy" with GRDA.[486]

Write reiterated Articles 12 and 13 of the license, noting that "there is nothing in the license that fixes the elevation of 750 at the dam" and explained that he believed that neither GRDA nor the FPC (or PWA or the Corps, for that matter) had taken into consideration the potential "backwater curve incident to the inflow, but that each had in mind, both in the acquisition of lands and the impounding of water, a uniform level of 750 over the entire reservoir." All agreed that GRDA was not required to impound water "at any point on the reservoir above elevation 750 [i.e., the contour line]," until the United States had acquired the land and flowage rights above that elevation. Wright echoed Marshall in requesting that before the project reverted to GRDA, "the license should be amended so as to eliminate this controversy. The license should recognize the existence of the backwater curve and make specific provisions with respect to it; it is contemplated that the United States will acquire the necessary flowage rights above elevation 750 to provide five (5) feet of additional storage above elevation 750, and if this is done before the project is returned to the Authority, the controversy maybe entirely eliminated so far as future operations are concerned." He was adamant that whatever the final solution was, it would "not require the Authority to acquire any lands or flowage rights above elevation 750 at any point on the reservoir."[487]

Fuquay was adamant that from its inception, federal authorities had regarded the Pensacola Project as desirable for flood control purposes. While this characterization of early federal interest in Pensacola was false, he was correct in pointing out that the conflict between the power generation and flood control had "for many years . . . delayed actual construction at this site." He defended the FPC, noting that the commission had tried to create license conditions that would balance power with flood control, as "only in this way can the full public benefits be derived, that justify use of this site." According to Fuquay (also somewhat inaccurate), "the original assumption upon which approval was given for construction of this development was that flood control storage of approximately 960,000 acre feet would be provided" by using the storage capacity between 735 and 755. However, after GRDA made "urgent representations" that it could not operate economically otherwise, the FPC ultimately authorized (in its January 27, 1939, license draft) a 745 power pool level with flood control storage between 745 and 755. "Subsequent" to receiving the January 27, 1939, license, GRDA proposed to the FPC that it should only be required to acquire land and easements up to elevation 750. "This proposal was made in spite of the fact that the application had proposed 'a reservoir containing at maximum power pool level 1,680,000 acre feet of water and at flood pool level 2,200,000 acre feet.'" In other words, to Fuquay, the FPC license as originally issued anticipated that GRDA would acquire all land up to elevation 755. In his estimation, if the FPC had authorized a maximum power pool to elevation 755 for a power-only facility, then the commission would have "expected" GRDA to "acquire those rights to lands lying above this elevation which would be affected by the backwater from the reservoir." But because the FPC license "relieved" GRDA "of the considerable expense of purchasing lands within the upper five feet of the storage reservoir," Fuquay saw "no sound reason" that GRDA "should not acquire those rights which may be affected by backwater from this reservoir when it is operated up to elevation 750 for flood control purposes. The only other alternative would be operation of the reservoir to a lower elevation than 750 and operation of the reservoir to a lower elevation would not be in harmony with the letter and spirit of the license and would thwart one of the principal purposes for which the project was authorized"—power generation.[488]

1943 Floods and Damages

The May 1943 flood raised different concerns about the role the Pensacola Dam should play in flood control on the Neosho River. Whereas upstream flooding was the primary issue with the 1941 floods, both upstream and downstream flooding were at issue in 1943. The flood also brought into stark contrast the catch-22 GRDA faced in trying to balance dam operations to minimize potential damages to both upstream and downstream lands.

Comprising two separate events between May 7 and 26, 1943, the floods (especially the second) created "record-high discharges" on the Spring River—even higher than that stream recorded in 1951. The lower basin of the Neosho River also "flooded severely" from around Iola, Kansas, to Oklahoma.[489] According to a later account, "the largest previous flood on the Grand River had a peak of 235,000 second-feet; this one had a peak of 347,000 . . . the largest in about a 100-year record . . . almost 60 percent larger, both in peak and quantity, than any known flood on the Grand River."[490] On May 10, 1943, the reservoir reached 749.05 feet and spill was increased to such a level as to seriously threaten the newly constructed Oklahoma Ordnance Works (OOW), approximately 30 miles downstream. Given the situation and the OOW's importance to the war effort, Wright authorized raising the pool above 750 feet (and as far as 752 feet) in order to protect the plant.[491] Although no one could have predicted that things would get even worse, the *Tulsa Tribune* was somewhat premature in an article published that day crediting the Pensacola Dam with "saving" the OOW.[492] The next day, the elevation reached 751.32 feet, on which news reports blamed "flood troubles" at Miami and its outskirts.[493]

After a few more days of heavy rain, Wright gave directions to raise the pool as high as 755 feet, "five feet above the property line," an area "in the process of obtaining flowage easements." By the morning of May 19, the pool was at 753 feet. After that, GRDA sent out warnings to city and county officials below the dam "that releases would be made and that the river would be several feet above the 1941 record." Essentially, the "flood volume of the May 1943 [flood] exceeded any other major storm and entered the reservoir in a much shorter time." The pool level apparently reached its highest elevation at 754.58 feet.[494]

The Fallout of Balancing Upstream and Downstream Needs

Immediately after the flood, GRDA and FWA received strong criticism from various quarters for its operations of Pensacola during the flood. Especially vocal was Tulsan Newton Graham, chair of the board of the Southwest Valley Association and Tulsa Chamber of Commerce member, whose focus was on flooding downstream of Pensacola on the Neosho River and beyond. According to Graham, "every person who advocated the building of this [Pensacola] dam [was] promised flood control and that promise is not being kept," the blame for which he placed squarely in GRDA's lap. Graham believed that GRDA could have prevented the death and estimated million dollars' worth of destruction to residences, private property, livestock, and crops. And while he acknowledged the importance of electricity (and presumably, protection of the OOW) to the war effort, "potatoes, corn and livestock" were just as crucial.[495] In response, Wright explained how even at 735 feet, downstream flooding would have been an issue that could have only been solved if the Markham Ferry and Fort Gibson Dams would have been in place. Put simply, "the Grand River valley was completely full of water from the Grand River Dam to the end of the watershed." The only way Wright could see to have prevented the downstream flooding on the Neosho and Arkansas Rivers would have been if the Fort Gibson Dam had been constructed already. It was impossible that one dam could "control a flood that fills the entire river valley from its mouth to the headwaters." Furthermore, it was "ridiculous to expect to secure flood control on the Arkansas River system by control works on the Grand River alone when the floods contributed by other streams are equally devastating and severe."[496]

Supporters of GRDA and Wright's actions pointed out that unpredictable weather contributed as much as or more to the flooding (upstream and downstream) than dam operations. A May 19 editorial in the *Tulsa Tribune* noted that before they "kicked around" the management of the dam, critics "had better take a look at the rainfall reports" and recognize that May was historically a relatively dry month and that GRDA had been operating based on weather reports that everyone had access to and which predicted clearing skies, not the epic rainfall that actually occurred. The real blame, the editorial proclaimed, was really Congress, which had thus far underfunded flood-control efforts in the Neosho River valley.[497]

Wright then remarked that "flood control works on the Grand River without question destroy potential power producing capacity on one of the best power producing streams in the area." Why, he wondered, did people not focus more intently on a more "sensible plan of flood control for the Arkansas River basin" that included building "as much flood control works as possible on streams that do not have potential power producing capacity and the utilization to as great a degree as possible of the potential power capacity of rivers like the Grand?" "Let's not criticize one dam for not controlling a flood in the Arkansas river system when all studies show that a large number of dams are necessary to accomplish this purpose."[498]

The fallout of the 1943 flood resulted in GRDA and Wright being called to testify almost a year later in 1944 in front of the appropriations subcommittee for the Department of the Interior. Wright responded to allegations that "maladministration" of the Pensacola Dam and Reservoir caused damage during the two May 1943 floods. Wright explained that the FPC license set the power pool elevation of the Neosho River Dam at 745 feet. The first flood raised the reservoir almost to elevation 745. The "second flood made the first one look like a baby" and filled the reservoir to 754.58 feet. Wright noted that he took matters into his own hands and "did something . . . a little bit unusual." Facing the seeming inevitability of either "wiping out" the OOW downstream or inundating 5 extra feet of land that neither GRDA nor the federal government yet owned, Wright pushed forward with FWA approval to purchase the land with a congressional appropriation he had just received. As he explained, this enable him to use "5 feet more storage than there would have been available had I not taken that emergency action."[499]

Wright summed up that he thought the 1943 flood should have made it exceedingly clear to people that what was needed on the Neosho River was a "comprehensive plan" for flood control—one that included the Markham Ferry and Fort Gibson Dams—"or you are not going to get very much out of it." Wright was proud of the flood protection GRDA's operation of the Pensacola Dam and his quick moves to acquire land and easement had provided. He noted how much worse things could have been, including losing the $75,000,000 OOW. Instead, GRDA's actions allowed the OOW operators enough time to "build dikes and sandbag their works before the peak got there."[500] Rather than cast blame on GRDA, he felt strongly that the Authority had done its best under the conditions.

Although he thought it was obvious, Wright reiterated to the committee that the Pensacola Dam had been built as a "50-50 compromise" between power production and flood control. Although the Army had always wanted more flood-control storage in the reservoir, the State of Oklahoma (supported by the PWA contract and FPC license) had always seen its main purpose as providing power to Oklahomans and later the war effort (indeed, OOW had been sited specifically to access inexpensive GRDA power). The upshot, Wright concluded, was that the Corps had realized after a few years of Pensacola being in service that it needed to revise the original Fort Gibson Dam plans. The Corps was convinced that in order to effectuate more consistent flood control both upstream and downstream of Pensacola on the Neosho, the Corps needed to increase the size of the Fort Gibson reservoir and focus on better coordination of operations between Pensacola and the planned Markham Ferry and Fort Gibson Dams. Doing so would reduce at least some of the pressure that had been on a single dam to do the work that GRDA had originally planned in its first designs of the Markham Ferry and Fort Gibson facilities that the Corps itself had argued until the late 1930s were neither economically feasible nor desirable as federal projects.

Thankfully, Wright noted, by the time of the March 1944 hearings, Congress had finally authorized and appropriated the last of the three planned dams, Fort Gibson.[501]

Damages Claims, Land Condemnations, and Securing Additional Land and Flowage Easements

Oklahomans upstream of the Pensacola Dam sought to file damages claims for the May 1943 floods almost immediately after floodwaters had receded. By June, FWA was attempting to test a case already in court to "amend one land condemnation suit to cover personal property" retroactively to cover May damages to personal property.[502] Additionally, because flood victims had "no recourse" and were unable to sue the U.S. government under the laws at that time, District Judge Thomas was pushing for legislation to make it possible to do so. Thomas argued that it was "against the constitution to take or damage private property without just compensation" and furthermore unfair that the FWA alone had the power to determine the amount of damages they would pay.[503]

Thomas described in detail the damage he predicted future dam/pool elevation increases would cause, noting that "the inhabited section of Miami starts at about 750 feet above sea level" and that the sewer discharge was at about 751 feet. Tar Creek and Spring River would also be affected. He may have based his comments on engineering surveys by Black & Veatch, a firm the Corps employed to make initial studies of potential upstream damage if Grand Lake were raised 5 feet. Thomas requested that the Corps make the study findings public and pressed for its inclusion in the record of future House Flood Committee hearings. That way, "Miami city officials and property owners above the dam, who contend that damage will extend far beyond the proposed reservoir line, will be able to go into court, or before a damage commission and cite expert engineering testimony to offset the testimony of FWA engineers who disagree."[504]

During the June 17, 1943, meeting of the Miami PUB, commissioners discussed correspondence Miami mayor F. E. Millner had received from Judge Thomas regarding flood damages, which made recommendations regarding how Miamians could best advocate for themselves regarding flood damage. Thomas urged the City and parties to act quickly and gather proof of claims to submit to FWA representatives, who would be holding hearings "as to the correct flood curve line as shown by the May Flood of this year," in order to pressure FWA to adopt a "fair" flood curve that would reimburse flood victims retroactively and protect them against future floods. Thomas also thought the City should press for public statements from FWA "that if they cannot negotiate damage settlements to that line, that they will condemn to that line" and "that they will stipulate in all condemnation proceedings above the dam that the damages caused by the May Flood may be litigated and evidence introduced in reference thereto as a part of the condemnation proceedings on a cross-petition to be filed by the property owner."[505] Thomas furthermore warned the City of Miami and anyone in the general area damaged by floods to "stay out of any entangling associations with affected communities below the dam." Because there was a "conflict in interests between our community and those communities," Thomas believed that "any collaboration with them will prove detrimental to the interest of the City of Miami and other property owners affected in this community." The PUB determined that Thomas, Freehauf, and Nesbitt should go to Tulsa and Kansas City and "obtain what information" they could.[506]

Thomas, Freehauf, and Nesbitt had met unsuccessfully with Black & Veatch to solicit its engineering services (possibly due to a perceived conflict since they were in the Corps' employ). Next steps were reaching out next to Burns & McDonnell and paying someone to review the local newspapers for relevant flood-control data.[507] On July 7, 1943, a special session of the PUB met to discuss flood control and damages with a Burns & McDonnell engineer. The PUB determined that a special study would need to be made but tabled the discussion.[508] The City appears to have reached out to GRDA immediately, indicating that they might be moving ahead with litigation. GRDA general counsel Marshall replied with a reiteration of the terms of Miami's November 14, 1941, settlement agreement.[509]

On August 1, 1943, Wright told the Miami newspaper that GRDA planned to purchase more land in order to be able to elevate the pool to 755 feet (at the dam), a move that "may have been influenced by flood stages beyond that point last May." Wright reported that the "taking line" was still being determined between Wyandotte and Miami, but he thought that "purchases to the 770 line would be necessary . . . to prevent recurrent flooding of privately-owned lands." Wright was not ready to go "public" with any further details due to the ever-changing nature of the process.[510] The process that Wright was referring to in part was likely the impending formalization of SWPA under the Department of Interior, which would take over from FWA on September 1, 1943.

In meetings of the Miami PUB on August 3 and 19 that were attended by Holway, chief of land acquisitions Grover Spade, chief counsel Davidson (representing the nascent SWPA), and Miami's mayor and city attorney. Attendees discussed the "contemplated flowage easement" that SWPA wanted to raise from the 755 elevation (which had been acquired through Wright's emergency condemnations in May 1943) to 760 feet and how best to achieve that goal.[511] Despite "cheery talk" by property owners in the area about the potential high prices they might receive during the new phase of land and easement acquisitions, Wright (on behalf of the federal government) made it clear that "land values [had] not increased because it was now lake-front property" and that "although federal juries returned oversized awards to landowners in [past] GRDA cases," federal attorneys did not anticipate "a repeat performance."[512] The process was still ongoing on November 29, 1943, when Wright proclaimed that the lake level at the dam would only reach 755 feet in flood conditions but that SWPA would continue to operate the dam at elevation 745 under normal conditions. Still, he assured locals that SWPA was seeking to "make it possible to raise the water level for flood control" from elevation 755, by which he was likely referring to SWPA's decision to acquire land and easements up to elevation 760.[513]

In mid-March 1944, the PUB discussed how the SWPA condemnation suits continued to "inch toward Miami." Miami attorney and PUB member Nesbitt explained that the petitions that had been filed thus far were to secure flowage easements around Grand Lake "up to the 758 foot level" and that the government was not seeking fee simple—just easements—so the land owner would continue to pay taxes. According to Nesbitt, as SWPA acquired easements, "the elevation is graduated toward Miami and at the time the city is affected, it is anticipated the elevation here will be 760 feet or more."[514] When the Oklahoma Planning and Resources Board asked GRDA to produce documentation of all land and easements SWPA had secured in early 1945, Marshall responded SWPA's administrator had possession and GRDA had no means of procuring the requested documentation due to staff shortages. However, he reported that GRDA itself had acquired close to 50,000 acres of land below elevation 750 and had prepared "several thousand tract maps" which were being printed and to be filed soon with the FPC.[515] Marshall also confirmed that SWPA had "for some time" been acquiring "past lands in fee and flowage easements above the Authority's taking line, that is, above elevation 750, and these lands constitute a part of the reservoir area, with particular reference to the accommodation of flood control."[516]

On December 22, 1944, Congress passed the 1944 Flood Control Act. Section 7 of the law specified, "Hereafter, it shall be the duty of the Secretary of War to prescribe regulations for the use of storage allocated for flood control or navigation at all reservoirs constructed wholly or in part with Federal funds provided on the basis of such purposes, and the operation of any such project shall be in accordance with such regulations."[517] Although SWPA was technically overseeing power production at Pensacola by late 1944, the Corps was firmly in charge of flood control on the Neosho River.

GRDA Operations Resume, September 1, 1946

With World War II winding down, GRDA began its push to regain control over its power operations on the Neosho River. In June 1946, Oklahoma governor Robert S. Kerr unsuccessfully requested of President Harry S. Truman that the Pensacola Dam be restored to GRDA.[518] Truman regretted that he was unable to effectuate the transfer at that time, explaining that he wanted to safeguard the process and ensure that the federal government had accomplished all of the necessary milestones before returning Pensacola operations to GRDA. These milestones included determining exactly which properties would be returned, "including improvements and construction work completed," auditing mutual accounts, and renegotiating the loan and grant arrangements—all in concert with Interior and other related agencies.[519] Although hopes were high that GRDA would regain control by the beginning of 1946, negotiations were ongoing throughout the first half of 1946. The House Flood Control Committee and Interior approved proposed legislation for the return in early summer and the Corps reported favorably on the Senate version of the bill later in June.[520]

On August 1, 1946, GRDA and the United States of America issued a settlement agreement formalizing the transfer.[521] Under the terms of the agreement, GRDA would receive $5,000,000 in compensation for federal use of the project and the return of all properties that the government had acquired originally from GRDA or constructed since it took over operations.[522] Additionally, the government would "grant, transfer, convey and deliver . . . all flowage rights" below elevation 750 to GRDA.[523] In return, GRDA would "grant, transfer, convey, and deliver . . . flowage rights . . . above elevation 750."[524] Last, GRDA agreed to hold the United States of America harmless "from any and all claims, damages, causes of action, debts, contracts, and demands whatsoever" relating to any period during which GRDA was receiving PWA loan and grant money, operating under its contract with FWA, or was under federal control.[525] On August 9, 1946, Congress passed An Act to Authorize the Use of Certain Lands of the United States for Flowage in Connection with Providing Additional Storage Space in the Pensacola Reservoir of the Grand River Dam Project in Oklahoma, and for Other Purposes.[526]

Final paperwork was signed in Kansas City and Tulsa on August 21, 1946, effecting the return of Pensacola Dam to GRDA and retiring old and issuing new bonds with a lower interest rate. GRDA general manager France Paris noted that this momentous event "would mark the start of its 'fullest possible development as a source of low-cost power and as a recreational facility unexcelled in the southwest.'" The Tulsa offices of GRDA were also returned to Vinita.[527] SWPA assured the Corps that SWPA was ensuring that all contractual items were complete and anticipated the final close date for the agreement would be August 31, 1946.[528]

When GRDA retook control over power generation at the Pensacola Project, sufficient flowage easements had been acquired to "protect all interests of the Government from liability and damage resulting from major floods comparable to the great flood of May 1943" (and were therefore conveyed to GRDA through the settlement agreement). Flowage rights applied to flood flows of 10,000 cfs to about 80,000 cfs on the Neosho River above Miami along with small areas along the Spring and Elk Rivers and possibly a few small tributaries. As Burnham explained the situation after the transfer, the "main body of land" on which flowage rights had been acquired was "the valley storage lake above Miami," which had been "inundated by every major flood on the Neosho River before the reservoir was built."[529] Burnham provided a description of where floodwaters went at that time in the Miami area.

> This valley storage lake is about four miles wide north and south and over five miles wide east and west. The overflow area is approximately 13,500 acres. The area inundated as shown on the old 308 report maps and the overflow area in the 1943 flood are about the same. The outlet of the lake is approximately mile 145.2. . . . The inlet of Neosho River at the upper end and near the northwest corner of the lake at

> mile 156.5. . . . The length of the river channel between these two points and sections is 11.3 miles or 59,700 feet. . . . The first overflow during a flood occurs at the bend adjacent to Mud Creek near mile 156.5, and meets the water retarded by the bottleneck at mile 145.2. This action is entirely independent of the reservoir at any elevation. . . . Water elevation at low water at mile [1]56.5 is about 754 and at mile 145.2 is about 738—a difference of sixteen feet in 11.3 miles or a fall of 1.41 feet per mile.[530]

Burnham provided this detailed description because the valley storage lake seemed "to have been overlooked when the data for the envelope curves were calculated" and that "streams flowing into the valley lake upset calculations of backwater curves."[531] Although Burnham did not specify, it seems he was referring to the 1942 report Black & Veatch had prepared for the Corps, which modeled a number of different curve envelopes associated with lake levels at the dam.[532] Black & Veatch based their backwater curve models on an estimated mean flood stage for Miami based on data from the Parsons gaging station and an estimated cfs at Miami based on data from the Commerce gaging station. Furthermore, "streams flowing into the valley lake upset calculations of backwater curves."[533] Burnham believed their models to be inaccurate due to the presence of the valley storage lake upstream from Miami, which created conditions different from those at Parsons or Commerce, thus skewing the results. According to Burnham, "correction of these elevations will change the points of intersection and reduce the heighth [*sic*] of the calculated backwater curve above section 25, assuming the envelope curve below section 25 is correct."[534]

In sum, Burnham calculated that "all lands under the 755 backwater envelope curve are inundated by major floods," but that "the reservoir operated at any elevation to 755 does not damage these lands." Furthermore, any effects of the "backwater curve resulting from the May 1943 flood were below Miami." To Burnham, "any money paid for inundating lands above Miami will not compensate for damages as lands have been inundated by every major flood independent of the reservoir." To protect "nearly all the good land," he suggested constructing a levee "on the left bank starting at the Commerce gage and following contour 765 for about a mile and then follow near the 760 contour to a point just north of Miami."[535] No such levee appears ever to have been built.

Post-1946 Flood Control on the Neosho River

By the time GRDA regained control of the Pensacola Project, Markham Ferry and Fort Gibson Dams had been authorized as part of the Arkansas River Basin plan and received appropriations for construction under the 1941 Flood Control Act. The stage was finally set for completion of those two projects, and the Corps began construction on Fort Gibson Dam in 1942.[536] Despite the crucial role most people agreed it should play in flood control on the Neosho, the project was not complete until 1953.[537] GRDA began construction on the Markham Ferry Dam (now known as the Robert S. Kerr Dam, which impounds Lake Hudson) in 1958 and completed it in 1964.[538]

Although some public Kansas entities and private corporations and individuals had built dams that created reservoirs to provide both flood control and water, typically on smaller tributaries, by the beginning of World War II, only a few of the 1930s-era flood-control projects the Corps had proposed and authorized along the Neosho River in Kansas and Oklahoma had come to fruition by 1946. The lack of follow through on these recommended projects, despite the promise of some federal funding, stemmed mostly from localities' refusal or inability to meet the level of cooperation and cost-sharing required for federal assistance.[539] Still, at the time GRDA took the Pensacola Project back from the federal government, concern about flooding remained an issue, and federal, state, and local officials and the public continued to debate the best means of flood-control on the upper Neosho.[540] In 1949, Kansans lobbied Congress for the construction of a series of four dams and reservoirs (that would be coupled with soil conservation efforts) along the Neosho.[541] Congress authorized three of the projects in the Flood Control Act of 1950. The disastrous flood of 1951 emphasized how essential these dams were for flood control in the Neosho River watershed.

Despite the impetus the disastrous 1951 flood provided to make progress on the the Kansas reservoir projects, it would take more than a decade for each to be completed: Council Grove in 1964, John Redmond (formerly known as Strawn Dam) in 1965, and Marion in 1968.[542] Later reports indicated that the Kansas reservoir system on the Cottonwood and Neosho reduced flood stages "significantly" at Miami.[543] According to one study of the John Redmond Dam, "controlled releases from the dam [had] decreased the magnitudes of peak discharges and increased the magnitudes of low discharges" downstream from the dam.[544]

Since the late 1960s, efforts to control flooding on Neosho River and its tributaries and the damages those floods cause have continued with local insurance studies, municipal planning and zoning, and local floodplain management programs coordinated through the Federal Emergency Management Agency (FEMA) in support of the National Flood Insurance Act of 1968 and Flood Disaster Protection Act of 1973.

In 1979, the City of Miami hired a consultant to draft a zoning ordinance to address flooding and other issues in the City. According to the draft ordinance, the certain areas within the town were

> subject to periodic inundation, which results in loss of life and property, health and safety hazards, disruption of commerce and governmental services, and extraordinary public expenditures for flood protection and relief, all of which adversely affect the public health, safety, and general welfare. . . . These flood losses are created by the cumulative effect of obstructions in flood plains, which cause an increase in flood heights and velocities, and by the occupancy of flood hazard areas

> by uses vulnerable to floods and hazardous to other lands because they are inadequately elevated, floodproofed, or otherwise protected from flood damage.[545]

The next year, FEMA published a study of "the existence and severity of flood hazards" along the Neosho and other streams in and around Miami to support the town's conversion to "the regular program of flood insurance by the Federal Insurance Administration (FIA)" and "promote sound flood plain management."[546] The 1980 study emphasized that the Neosho was the "primary source of flooding," in Miami, which had been originally sited along the river's left bank and developed most extensively in that area.[547] Although "most" residences and businesses were "above flooding elevations" some areas on the Neosho, Tar Creek, and other small streams had been "inundated by past floods."[548] FEMA concluded that "continuous heavy rains" and "intense local thunderstorms moving in a northeasterly direction across northeastern Oklahoma and southeastern Kansas." Much like part 1 of this study shows, FEMA's review of historical documents and interviews with locals documented "numerous flooding instances on the Neosho River and Tar Creek" over time.[549]

The 1980 FEMA study, which was updated in 1988 to include an evaluation of flooding on Little Elm Creek, specifically considered contributing factors to damage at Miami from the two largest floods on record—1943 and 1951. In 1954, heavy, sustained rains (especially at Joplin, Missouri) combined with ground saturation led to high flood crests (25.12) and large peak discharges (105,000 cfs) at the Commerce gage and subsequent filling of the Pensacola Reservoir (although the FEMA report made no association between the reservoir level and flooding at Miami).[550] The 1951 flood was caused by a "sequence of significant rainfall" over the Neosho River Basin from late April 1951, which

> culminated in the critical storm of July 9–13. Rainfall in May was considerably above normal, and the June rainfall was more than twice the normal. There were three (3) storm periods, June 20–24, June 28–30, and July 9–13. The 1951 flood actually began in June when the Neosho River became bankfull on June 24 and gradually rose to about 5 feet over bankfull by July 1. The storms moved from north to south so that the rainfall followed the floods downstream. . . . the occurrence of these storms in such rapid succession not only produced flooding, but saturated the soil and accounted for the phenomenal rates of runoff in the latter parts of the storm. Rainfall during the period July 9–13 consisted of a series of intense thunderstorms over the upper Neosho River watershed. . . . A total of 17.4 inches for the storm period was unofficially recorded south of Emporia, Kansas.[551]

During the July 1951 flood, the report estimated that "velocities in the channel of Neosho River in the vicinity of Miami ranged up to 10 feet per second. Overbank velocities ranged up to 7 feet per second." Compared to the 1943 flood, 1951 was a monster with the crest stage at the Commerce gage standing at 34.03 feet and the estimated peak discharge at 267,000 cfs.[552]

The FEMA report further noted that bridges in Miami did not prove to be significant obstructions to the floodwaters and their effect on the "head loss" of the river in 1951 was "negligible." The authors concluded that flooding on Tar Creek, however, was "often elevated downstream of the St. Louis–San Francisco Railway Bridge from the Neosho River," due to "backwater effects" upstream of the bridge.[553] Again, no mention was made to the Pensacola Reservoir contributing to the epic flooding in Miami in 1951.

After a major flood in fall 1986 caused $11,000,000 in damages in Miami, Oklahoma, and the surrounding area, "several communities" inquired about what kind of help the Corps could provide in solving the flood problems. "Local interests" sought to understand the cause of the frequent flooding and "suggested potential solutions, including dredging, flood control reservoirs, channel improvement, levee protection, reservoir storage reallocations of the existing Neosho River lakes, and other measures." In May 1987, Miami's mayor wrote to the Oklahoma governor, requesting "assistance in obtaining a Federal study to examine the flood situation and the flood control operation of Grand Lake."[554] Soon after, the Corps received funds to conduct a reconnaissance study of potential flood measures on the Neosho River between the John Redmond Dam near New Strawn, Kansas, and Miami. After examining "structural and non-structural solutions" for Miami specifically, the Corps recommended in March 1989 that a levee protection project was the economically feasible solution.[555] The Corps reported that spring that it expected to finalize a cost-sharing agreement with the City of Miami—a policy of which the mayor and city commissioners were aware—by fall 1989.[556] However, in June 1990, Miami's Board of Commissioners voted not to initiate feasibility studies and the Corps discontinued the studies.[557]

In 2016, confusion questions remained about ownership within the FERC boundary for the Grand River Dam Project. To simplify the regulatory framework, Congress included clarifying language in 2016 Water Infrastructure Improvements for the Nation Act. The act conveyed "by quitclaim deed and without consideration, to the Grand River Dam Authority, an agency of the State of Oklahoma, for flood control purposes, all right, title, and interest of the United States in and to real property under the administrative jurisdiction of the Secretary acquired in connection with the Pensacola Dam project, together with any improvements on the property."[558] This change would have no effect on the authority invested in either FERC to license the project or on the Corps' jurisdiction over flood control.

Congress outlined further clarification and instruction regarding the roles of FERC and the Corps related to the Grand River Dam in the 2019 National Defense Authorization Act for Fiscal Year 2020. Section 7612 clearly defined the conservation pool and the flood pool and established the Corps' "exclusive jurisdiction and responsibility for management of the flood pool for flood control operations at Grand Lake O' the Cherokees." Congress further clarified that FERC's jurisdiction "shall not extend to any land or water outside the project boundary," established that "any land, water, or physical infrastructure or other improvement outside the project boundary shall not be considered to be part of the project"; and forbade FERC from making any changes to the project boundary without GRDA's "expressed written agreement." Furthermore, the law prohibited FERC or any other federal or state agency from imposing license conditions relating to water surface elevations at the Pensacola Project, except with respect to FERC's "rules and regulations for project safety and protection of human health" and eliminated federal land management agencies' authority to impose mandatory license conditions under FPA Section 4(e). Last, Congress directed the Corps to complete a "study of infrastructure and lands upstream from the project to evaluate resiliency to flooding."[559]

Thus, as of the 2023 relicensing process (and this writing), the Corps remains firmly in control of flood control operations at the Pensacola Dam over elevation 750 while GRDA (under its FERC license and within the FERC boundary) holds responsibility for the power pool up to elevation 750.

Conclusion

Several narratives are drawn through this study of flooding, flood control, and the development of hydropower on the Neosho River. First is the sheer volume of water that the river has both carried within and spilled outside its banks from proverbially time immemorial. Archaeological evidence, ethnographic accounts, early military and settler reports, newspapers, photographs, interviews, and countless other documents attest to this fact. The Neosho is not and has never been unique as the mainstem river within a watershed in the middle of the North American continent, where geological conditions and topography, climatic patterns, and soil conditions create conditions ideal for extremes of both drought and deluge.

The second narrative relates to how flooding has had an often-disastrous impact on the humans who have populated the Neosho River watershed and others like it in the region. Whereas Native people sought to adapt to the vagaries of their environment, moving between higher ground during floods and lower ground when the rivers and streams were within their banks, people of mostly European descent (and the enslaved people they brought West with them) adhered to a more settled interaction with single plots of land on which they constructed homes and outbuildings, planted crops, grazed animals, extracted mineral resources, and so on. River bottoms have the distinct advantage of providing fertile soil and easy access to water for drinking, irrigation, transportation, and power production; river bottoms are also highly susceptible to floods and the death and destruction floodwaters leave behind. Many non-Indigenous people (especially those moving west in pursuit of "proving up" land that would become legally theirs under the various Homestead Acts) believed in the land ownership model and in settling at one location. This desire for rootedness did not allow for the ease of movement Indigenous people had based on seasonal rounds or climactic vagaries. Thus, non-Indigenous people settled along a river that flooded—often multiple times per year--wiping out crops, destroying buildings, killing livestock, and sometimes taking human lives.

Thus, as non-Indigenous people chose and Indigenous people were forced to move to the territory that become Kansas and Oklahoma along the Neosho River, efforts expanded to control flooding and minimize its risks while also taking advantage of the benefits proximity to water imparted. The narrative of trying to control flooding on the river played itself out at the private, local, state, territorial, and ultimately, federal levels in various combinations over time in the region. The contours of these efforts sat solidly within the context of the expanding United States—from removal of Native people to Indian Territory, through the Civil War and Kansas statehood, through Oklahoma statehood, expanding federal involvement in navigation and flood control, the Depression, two world wars, the Cold War, and beyond.

Alongside flood control developed the narrative of increased demand for electric power as the nineteenth century turned into the twentieth. People had been harnessing waterpower on river and streams via mechanical waterwheels for centuries, but late nineteenth- and early twentieth-century advances in generating and transmitting electricity led to ever-greater interest in siting hydroelectric facilities on the nation's waterways. People living along the Neosho River were as excited as other people around the country to develop rivers and streams for power. This enthusiasm was evidenced by the tireless efforts of Henry Holderman and others to site a hydroelectric dam on the Neosho River in Oklahoma over the course of the 1890s through 1930s.

The narrative threads of power production and flood control both ran parallel and intersected. Although the federal government advanced haltingly into widespread flood-control efforts during the early twentieth century, the astounding successes of such private hydroelectric facilities as Niagara Falls in New York State or Snoqualmie Falls outside Seattle sparked the passage of the Federal Power Act in 1920, creating the Federal Power Commission to oversee, license, and regulate the ever-growing number of facilities. Into the mix stepped any number of private, municipal, state, and soon federal attempts to site, design, and develop power projects.

Into this milieu stepped the State of Oklahoma, which was determined by the early 1930s to develop hydroelectricity on the Neosho River—the outgrowth of what had begun with Holderman's early surveys of the river. When the Grand River Dam Authority came to be in 1935, the Corps was (at least on paper) resolutely disinterested in supporting federal development of specifically the Neosho River for either power or flood control purposes. However, the State of Oklahoma and two federal agencies (the FPC and Public Works Administration) perceived in the Pensacola project a terrific opportunity to provide desperately needed jobs during the Depression and affordable electricity for local communities and industries.

Whether anyone in the FPC or PWA was aware or not, a sea change was underway within the Corps. The agency was steadily moving away from its original position that nonnavigable rivers like the Neosho were not worth federal investment and toward a much stronger interest in controlling these tributaries to larger, more problematic rivers downstream that had by then been experiencing decades of disastrous floods. As hydroelectric power production grew rapidly over the first three decades of the twentieth century, the U.S. Army Corps of Engineers, which had previously maintained a mostly hands-off approach to flood control (especially on nonnavigable rivers)—became increasingly concerned about the effects of floods on safety, navigation, and commerce on the nation's rivers. A series of disastrous floods across the United States spurred a movement toward Corps' responsibility for and authority over flood control. This role at times pitted the Corps' flood-control mandate against the various goals of individuals, power generators, manufacturing and mining companies, municipalities, states, regions, and even other federal agencies.

The siting, designing, licensing, construction, operation, and relicensing of the Pensacola Dam provide a fascinating window onto the dynamics that surrounded the often-conflicting goals between those who prioritized power generation (and in the case of GRDA, the need to generate enough revenue through power generation to comply with its self-liquidizing agreement with the PWA) and those who prioritized flood control. The two were never mutually exclusive, but different emphases and compromises made during the initial licensing created an at-times confusing regulatory and operational framework where power versus flood control was concerned.

The purely coincidental timing of when GRDA went officially online in early 1941 with the onset of World War II later that year exacerbated the lack of clarity among GRDA, PWA, FPC, the Corps, and Interior over whether Pensacola's primary purpose would be power or flood control and whether it was best operated by a private, state, or federal entity. Unfortunately, this opacity led to early tensions and accusations of malintent (mostly around responsibility for flooding upstream of the dam and liability for flood damages and prevention). Everything from mild annoyance to outright hostility among the parties involved in or living near the Pensacola has been rooted in the initial debates surrounding the reservoir pool level and associated land acquisitions and flowage easements and how these were resolved by compromise in the original license. Fortunately, a series of congressional acts and related reports and enactments codified and clarified the roles of GRDA, FERC, and the Corps where the operation, oversight, and ownership of the Pensacola project is now concerned. The past almost century of interplay between power production and flood control combined with the ever-present specter of flooding of the Neosho River and its tributaries comprise the final, overarching narrative of tension that remains among people living in the watershed today.

Endnotes

[1] Unless otherwise noted, physical description provided here come from various portions (including transmittal letters with earlier dates) of *Report on Survey of Pensacola, Markham Ferry, and Fort Gibson Reservoir Sites, Grand (Neosho) River, Okla.*, October 29, 1938, House Document No. 107, *U.S. Congressional Serial Set* (1939), esp. 2–20. See also H.R.Doc. No. 308, 74th Cong., 1st Session, maps, 1931, Box 3, Folder 4: Grand (Neosho) River, Native American Lands Maps Collection, 1993-060, Oklahoma State University, Archives, Stillwater (OSU Archives); maps, graphs, plans in Folder: Grand (Neosho) River, Okla, Preliminary Report Pensacola, Markham Ferry, Ft. Gibson Reservoirs, Appendices I and II, to Accompany Oct 29, 1938, Plats 1938, RG77, Corps of Engineers, Southwestern Division, Rivers and Harbors Studies and Reports, 1928–1942, Eagletown–Guadalupe, HM2000, Box 2, E. SW7, National Archives and Records Administration, Fort Worth, TX (NARA-FW).

[2] *Report on Survey . . . Grand (Neosho) River, Okla.*, October 29, 1938, 19.

[3] *Report on Survey . . . Grand (Neosho) River, Okla.*, October 29, 1938, 10.

[4] *Report on Survey . . . Grand (Neosho) River, Okla.*, October 29, 1938, 5, 9, 20.

[5] Synopsis of District Engineer's Report on Grand (Neosho) River, Kansas, Missouri, Arkansas, and Oklahoma, June 19, 1931, 9, Folder: Grand (Neosho) River—KS, MO, AR, OK, RG77, Corps of Engineers, Southwestern Division, Engineering Files—Harbors and Rivers, 1920–1940, Galveston–Grand (Neosho) River, HM2000, Box 21, NARA-FW.

[6] Walter C. Burnham to Douglas G. Wright, Administrator, July 28, 1947, Operation Grand River Dam Project, Grand River Dam Authority, Headquarters, Chouteau, OK (GRDA-HQ).

[7] Synopsis of District Engineer's Report, June 19, 1931, 9; *Report on Survey . . . Grand (Neosho) River, Okla.*, October 29, 1938, 17; and *Arkansas River and Tributaries*, 1231.

[8] *Grand (Neosho) River and Its Tributaries*, *Oklahoma*, *Kansas*, *Missouri*, *and Arkansas*, February 19, 1946, reprinted with correspondence in *U.S. Congressional Serial Set* (Washington, DC: GPO, 1948): 1–71, quotation on 23. According to this report, "a total of 62 storms having an average rainfall over a major division of the watershed of 3 inches or more in the period January 1900 through June 1944, with 53 of these storms having an average rainfall over the entire watershed of 3 inches or more" (19–20).

[9] *Arkansas River and Tributaries*, *3 Vols*., *Report of Corps of Engineers*, part 10, House Document No. 308, reprinted with illustrations in *U.S. Congressional Serial Set* (Washington, DC: GPO, 1936): 1215–341, quotation on 1231. Although the report refers to valley storage in "Kansas" and does not specify the small section of watershed in northeastern Oklahoma above the Spring River, the division of the river into two distinct reaches divided at the mouth of the Spring in the report and the similarity in topography around the Grand River between southeast Kansas and northeast indicates that this description of "Kansas" should include the small section of the river in Oklahoma north of the Spring.

[10] *Report on Survey . . . Grand (Neosho) River, Okla.*, October 29, 1938, 17; and *Arkansas River and Tributaries*, 1230–31.

[11] Arthur H. Rohn and Alice E. Emerson, "Great Bend Sites at Marion, Kansas," *Wichita State University Publications in Anthropology* No. 1, 1984, quotation on 15, on file at Iola (Kansas) Public Library.

[12] George P. Morehouse, "A Famous Old Crossing on the Santa Fe Trail," address to Kansas State Historical Society, December 1, 1903, reprinted in *Transactions of the Kansas State Historical Society, 1903–1904* (Topeka: Clark, 1904), 137.

[13] Quotation from Defence of Western Frontier, Letter from the Secretary of War, in Reply to the Resolution of the House of Representatives of the 24th Ultimo, Relative to the Plan Proposed for the Defence of the Western Frontier; also, What Tribes of Indians Inhabit the Country Immediately West of Arkansas and Missouri, April 1, 1840, 2, Referred to the Committee on Military Affairs, April 1, 1840, 26th Cong., 1st Sess., *U.S. Congressional Serial Set* Vol. No. 366, Session Vol. No. 4, H.R.Doc. No. 161. See also Grand (Neosho) River, Okla., Watershed, Adjacent Area, and Details of Lower Grand River Valley," map, October 1938, Appendix 1, *Report on Survey . . . Grand (Neosho) River, Okla.*, October 29, 1938. General statements about flooding frequency in this paragraph are based on reviewing and cataloging numerous sources (including historical society manuscript and photograph collections, newspapers, federal and state agency reports, and other relevant documents) gathered in Kansas and Oklahoma, as well as through databases and online sources such as newspapers.com, HathiTrust, *Congressional Record*, and so on. All documents available upon request.

[14] U.S. Office of Indian Affairs Annual Report of the Commissioner of Indian Affairs, for the Years 1826–1839, 1834, Report No. 474, Regulating the Indian Department, esp. 114, retrieved from https://search.library.wisc.edu/digital/A3YVW4ZRARQT7J8S; and William W. Graves, *The First Protestant Osage Missions, 1820–1837* (Oswego, KS: Carpenter, 1949). See also James O. Wright and Charles G. Elliott, *The Prevention of Injury by Floods in the Neosho Valley, Kansas*, U.S. Office of Experiment Stations Bulletin No. 198 (Washington, DC: GPO, 1908); U.S. Army Corps of Engineers [USACE], Tulsa District, *Flood Plain Information: Neosho River and Tar Creek, Miami, Oklahoma* (Tulsa, OK: District, 1969); and Kansas State Board of Agriculture (KSBA), *Twenty-First Biennial Report, for the Years 1917 and 1918* (Topeka: KSBA, 1919). Accounts conflict on whether the 1844 flood was actually on the Grand River; according to Snowden D. Flora, "There are no records of a flood in 1844 along the Neosho or Arkansas Rivers" ("Climate of Kansas," in KSBA, *Report of the Kansas State Board of Agriculture* 67, no. 285 [June 1948]: 280).

[15] In 1844, the Osage Subagency was located on the Neosho River in southeastern Kansas likely near what is now St. Paul (once Osage Mission), Kansas, in Neosho County. Harvey quoted in Louise Barry, comp., *The Beginning of the West: Annals of the Kansas Gateway to the American West, 1540–1854* (Topeka: Kansas State Historical Society [KSHS], 1972), 513. See also Edward Charles Murphy and Others, *Destructive Floods in the United States in 1904*, U.S. Geological Survey (USGS) Water Supply and Irrigation Paper No. 147, Series M, General Hydrographic Investigations, 15, 58th Cong., 3d Sess., *U.S. Congressional Serial Set* Vol. No. 4877, Sess. Vol. No. 98, H.R.Doc. No. 464 (Washington, DC: GPO, 1905); H. A. Rice and Roger C. Rice, "The Relation of the Kansas Water Commission to the Flood Problem of Kansas," paper read before the Kansas Engineering Society, Tenth Annual Meeting, January 15–16, 1918, Lawrence, Kansas (Topeka: Smith, 1918), 7; Flood Control and Water Conservation Committee (FCWCC), *Report of the Flood Control and Water Conservation Committee to the Governor of the State of Kansas*, December 27, 1928 (Topeka: State Printer, 1928); "Flooding of the Neosho River," comp. Erin Burdick, undated typescript [ca. 2019], on file at Coffey County Historical Society, Burlington, KS; KSBA, *Twenty-First Biennial Report*; William W. Graves, *Annals of Osage Mission* (??; repr., St. Paul, KS: Graves Memorial Library, 1987); "The Neosho River Watershed—Center of Worst Kansas Flood—That of 1844—1951 Flood Losses," in Ralph Richards, *What Are We Going to Do About It?* (n.p.: s.p.?, [1952]), 16–17; and USACE Tulsa District, *Flood Plain Information*.

[16] "The old timer, whose crop for that year went down to the Mississippi and whose fences also kept them company, will never forget the flood of 1869. The [Osage] Mission folks reported it the worst flood since 1854, when it seems there was a record breaker" (L. Wallace Duncan, *History of Neosho and Wilson Counties, Kansas* [Fort Scott, KS: Monitor, 1902], 33).

[17] See, for example, James H. Holmes, testimony given on December 8, 1856, to Thaddeus Hyatt, Item Number: 2593, 2, Thaddeus Hyatt Coll. #401, Box 1 Folder 5, www.kansasmemory.org; and S. D. Flora, "The Climate of Kansas," in KSBA, *Twenty-First Biennial Report*, 342.

[18] See, for example, Mary Lou DeLong Atherly, *Yesterday's Tomorrow: A History of Strawn, Kansas, and Surrounding Territory* (self-pub., 1982), 3, quoting Frank W. Blackmar, *Kansas* (Chicago: n.p., 1912), 54, on file at Coffey County Historical Society. Although the river remains unspecified, according to the Indian commissioner that year, "the Osages have not, in a manner, raised anything, their corn having been destroyed by overflows of the streams early in the summer" (although the "streams" remain unnamed, the Osage still resided in the Neosho River basin in the 1850s). See also Andrew J. Dorn, United States, Office of Indian Affairs, Annual Report of the Commissioner of Indian Affairs, for the Year 1856, Southern Superintendency, Report No. 44, 131–72, quotation on 134, https://digicoll.library.wisc.edu/cgi-bin/History/History-idx?type=browse&scope=HISTORY.COMMREP.

[19] On the Cottonwood River in 1858, heavy rain brought the stream out of its banks and "washed away" wheat "on the bottom lands" (D. A. Ellsworth, comp., *History of Chase County*, 5, book out of binding, missing title page, and contained in blue ring binder, Chase County Historical Society, Cottonwood Falls, KS).

[20] "Overflow about the first of July [1867] on the Grand in Neosho County" (W. W. Graves, *History of Neosho County*, Vol. 1 [1949; repr., St. Paul, KS: Osage Mission Historical Society, 1986], 435).

[21] Neosho River "overflowed for several days during the first part of September [1868]" (Graves, *History of Neosho County*, 1:435).

[22] "Small flood last part of October [1870]" (Graves, *History of Neosho County*, 1:435).

[23] "July 1, [1871,] Neosho valley flooded" (Graves, *History of Neosho County*, 1:435).

[24] "January 22, [1873,] small flood; June 1, Neosho river very high; Osage Mission fair grounds flooded" (Graves, *History of Neosho County*, 1:435).

[25] "August 5, [1875,] small flood" (Graves, *History of Neosho County*, 1:435).

[26] "May 3, [1876,] small flood" (Graves, *History of Neosho County*, 1:435).

[27] "June 13, [1877,] big flood; washed out railroad track at Osage Mission" (Graves, *History of Neosho County*, 1:435). The 1877 flood on the Cottonwood River was reportedly one that "makes the traditional oldest inhabitant shrug his shoulders and scratch his head, and reluctantly admit that he 'never did saw anything like it in these parts afore.' . . . The only rival this flood has had in the annals of Kansas worthy of the name was in 1868, we believe, but this recent overflow was from one to two feet deeper than that one, in the Cottonwood valley" ("The Flood Here and Elsewhere," *Marion County Record*, May 25, 1877, unattributed and undated clipping, Binder: Floods and Natural Disasters, 11, Marion County Historical Society, Marion, KS).

[28] "May 22, [1878,] railroad track washed out again" (Graves, *History of Neosho County*, 1:435).

[29] "May 25, [1881,] small flood" (Graves, *History of Neosho County*, 1:435).

[30] In 1883, the Spring River flooded. Writing to the Indian Agent at Quapaw Agency, Charley Quapaw remarked, "We the Chief and head men wants to let you know that we do want to go working at the [farms?], you know that the rails are on the east side of the Spring River, river has been up all the Blessed Time we can't get over the river" (Charley Quapaw to Sir, August 11, 1883, Roll QA11, Quapaw Agency Records, Oklahoma History Center, Oklahoma City, OK [OKHC]).

[31] "May 7, [1884,] big flood; no mail for four days; October 1, another flood" (Graves, *History of Neosho County*, 1:435).

[32] Dependable records of flooding in the Neosho River watershed that date from the first half of the nineteenth century, especially for former Indian Territory/Oklahoma, are few, and diverse sources (especially county annals) provide varying lists of notable flood dates in specific locales. HRA relied on these kinds of sources for flood facts during most of the second half of the late nineteenth century due to a lack of time available to access original newspapers and the fact that many of the smaller newspapers (most of which covered Kansas during that period) are hard to locate and often in poor shape in county historical societies. In some cases, historical societies have compiled clippings files for flooding, but these kinds of collections were neither consistently comprehensive in scope nor uniformly collected. Exponential growth of local newspapers by the mid- to late 1880s led to more uniform coverage of Neosho River overflows in Kansas, which had been a state with official counties, county seats, and municipalities since 1861. Weather and flood reporting from Indian Territory was sparser until the 1890s when non-Indigenous people who were settling the area founded newspapers. News coverage in Oklahoma became more uniform and comparable to Kansas once it became a state in 1907. Additionally, HRA relied on the U.S. Signal Corps' *Monthly Weather Review* (which began publication in summer 1872 and was taken over by the U.S. Weather Bureau in 1891) for flood information from approximately 1889 forward.

[33] Laura M. French, *History of Emporia and Lyon County, Kansas* (Emporia, KS: Emporia Gazette, 1929).

[34] A. T. Dickerman, "The Early White Settlers among the Osages," presentation to Labette County Historical Society, November 13, 1878, reprinted in *Oswego Independent*, November 23, 1878, 28, Labette County Clippings, Vol. 1, KSHS. See also Graves, *History of Neosho County*, 1:434; and French, *History of Emporia and Lyon County*, 189.

[35] G. C. Snow, United States, Office of Indian Affairs, Annual Report of the Commissioner of Indian Affairs, for the Year 1867, Southern Superintendency, Report No. 113, 315–31, 324, https://digicoll.library.wisc.edu/cgi-bin/History/History-idx?type=browse&scope=HISTORY.COMMREP.

[36] Quotations from Graves, *History of Neosho County*, 1:435; and Duncan, *History of Neosho and Wilson Counties*, 97.

[37] Wright and Elliott, *Prevention of Injury by Floods*, 11.

[38] Murphy et al., *Destructive Floods in the United States in 1904*, 78.

[39] Graves, *History of Neosho County*, 1:435; and Graves, *Annals of Osage Mission*, 360.

[40] Duncan, *History of Neosho and Wilson Counties*, 33. See also "The Flood," [*(Iola) Register*], July 3, 1885, unattributed clipping, Folder: Floods, 1885-1904-1927-1951, clippings, Allen County Historical Society, Iola, KS; "The Neosho River Floods," typed manuscript and images, Folder: Strawn Area Photos, Binder Vol. 1, Neosho River and Churches, Coffey County Historical Society; and Wanda Christy, comp., *Coffey County*, Vol. 1, *A Glimpse into Its Past, Present, and Future!* ([Burlington, KS]: Coffey County Today, 1987).

[41] Graves, *Annals of Osage Mission*, 362.

[42] Flora, "Climate of Kansas," *Report of the Kansas State Board of Agriculture*, 280. See also "A Flood," *Kansas City Evening Star*, July 2, 1885, 1; and "Kansas Flood," *Dallas (TX) Weekly Herald*, July 9, 1885, 6.

[43] "Bodies Taken from the Water," *Aberdeen (SD) Weekly News*, July 17, 1885, 2.

[44] Wright and Elliott, *Prevention of Injury by Floods*, 11.

[45] Stoelzing reported that Chanute, Kansas, was flooded on June 26, 1888 ("First One in 28 Years").

[46] Between June 15 and June 20, 1889, portions of both Allen and Neosho Counties, Kansas, were once again underwater. According to the *Monthly Weather Review*, Allen County had "suffered severely from floods in the Neosho River and its tributaries. Crops have been badly damaged. There is a serious washout on the Saint Louis, Wichita, and Western Railroad" (*Monthly Weather Review* 17 [June 1889]: 155). In Neosho County, the flood stage on the Neosho River was "only two feet below that of 1885" (Graves, *History of Neosho County*, 1:435). Stoelzing, from Chanute, reported that a flood lasting five days began on June 15, 1889 ("First One in 28 Years"). See also "At Council Grove," *Tacoma (Washington) Daily Ledger*, May 18, 1889, 1.

[47] Stoelzing reported Chanute floods on May 9, October 12, and November 14, the latter of which he described as the highest ("First One in 28 Years").

[48] On June 27, 1891, in Lyon County, the water was within three inches of the 1877 high mark (French, *History of Emporia and Lyon County*). The Neosho flooded again on May 29 in Chanute (Stoelzing, "First One in 28 Years") and between June 19 and June 25, 1891. According to Graves, the June flood in Neosho County was "moderate" (Graves, *History of Neosho County*, 1:435).

[49] May and June 1892 were again flood months on the Neosho River in Kansas. Stoelzing reported a flood that began in Chanute on May 14 and lasted four days ("First One in 28 Years"). According to Graves, by May 19, the Neosho River had "been out of its banks for the past week, and within two feet of the 1885 marks" in Neosho County, destroying "much wheat" (*Annals of Osage Mission*, 448). Three separate flooding incidents occurred: a "high flood" on May 17, the second on May 31, and the third in early June when Graves reported that the Neosho was again out of its banks at St. Paul (Graves, *History of Neosho County*, 1:435; and Graves, *Annals of Osage Mission*, 449).

[50] On March 24, 1894, the *Terral (OK) Times* reported that "the Neosho River has been very high" (1), presaging the almost annual June floods, which reportedly took place between June 20 (the date on which Stoelzing reported flooding in Chanute ["First One in 28 Years"]) and June 28, the date on which Graves reported a "big flood" in Neosho County (Graves, *History of Neosho County*, 1:435).

[51] A. J. Henry, "Local Storms," *Monthly Weather Review* (September 1895): 327–29, quotation on 328. See also "Neosho River Floods," Coffey County Historical Society.

[52] *Report on Survey . . . Grand (Neosho) River, Okla.*, October 29, 1938, 2. See also *Grand (Neosho) River and Its Tributaries*, 27.

[53] J. L. Schley, Major General, Chief of Engineers, to Congress, Re: Grand (Neosho) River, Oklahoma, Markham Ferry and Fort Gibson Reservoirs, January 12, 1939, in *Report on Survey . . . Grand (Neosho) River, Okla.*, October 29, 1938. See also J. L. Schley, Chief of Engineers, to Secretary of War, January 4, 1939, RG0980 [GRDA], Box 3, Folder 11, Federal Power Commission corr. re: Pensacola Dam, 1 of 2, 1937–1939, Oklahoma State Department of Libraries and Archives, Oklahoma City, OK (OSDLA); and S. L. Scott, Lt. Col., Corps of Engineers, [Little Rock] District Engineer, *Preliminary Examination of Pensacola, Markham Ferry, and Fort Gibson Reservoir Sites, Grand (Neosho) River, Oklahoma*, September 21, 1937 (and September 1937 map), Folder: Grand (Neosho) River, Okla, Preliminary Report Pensacola, Markham Ferry, Ft. Gibson Reservoirs, RG77, Corps of Engineers, Southwestern Division, Rivers and Harbors Studies and Reports, 1928–1942, Eagletown–Guadalupe, HM2000, Box 2, NARA-FW.

[54] "Neosho River Six Miles Wide," and "High Water at Chetopa," both in *(Oklahoma City) Daily Times-Journal*, December 21, 1895, 4. Between approximately 1895 through 1907 (the year of Oklahoma statehood), Oklahoma newspapers did not report on flooding at the same rate as did Kansas newspapers. Later accounts, however, indicated that flooding on Grand (Neosho) River occurred as often in Oklahoma as it did in Kansas (and, in fact, individual Kansans and the Weather Bureau often warned Oklahomans of flood crests that were moving downstream toward them). Presuming weather patterns and flooding have changed little over time, HRA attributes the dearth of flood coverage in Oklahoma to the fact that population centers were smaller and less developed and that newspapers were neither widespread nor comprehensive in their coverage of such goings on in Indian Territory. The Oklahoma City article is an exception that indicates the gravity of the December 1895 flood.

[55] Graves, *History of Neosho County*, 1:436; Burdick, "Flooding of the Neosho River"; Stoelzing "First One in 28 Years"; and "A Flood at Huntington, Kan.," *Tecumsah (OK) Herald*, May 30, 1896.

[56] Quotation from Graves, *History of Neosho County*, 1:436. See also Burdick, "Flooding of the Neosho River."

[57] Graves, *History of Neosho County*, 1:436. Quotations from "High Water in the Neosho Bottom Lands in Southern Kansas Are Flooded," *Kansas City Star*, July 5, 1899, 1; and "Chanute, KS, July 5," *Garfield County Democrat*, July 13, 1899.

[58] Burdick, "Flooding of the Neosho River;" Graves, *History of Neosho County*, 1:436; and Stoelzing "First One in 28 Years."

[59] French, *History of Emporia and Lyon County*, 190.

[60] Quotations, respectively, from *History of Chase County, Kansas* (Abstracts of *Leader News*), 1899–1999, comp. Patty J. Donelson, trans. Lorna Marvin, http://www.ksgenweb.org/chase/historyPat.html; and "Stalled by High Water," *Kiel (OK) Press*, June 12, 1902.

[61] Graves, *History of Neosho County*, 1:436.

[62] "Al Crooks Drowns," *Miami Record*, May 30, 1902, 1.

[63] "A Record-Breaking Flood," *Oklahoma City Weekly Times-Journal*, June 13, 1902. See also "The Flood in the Neosho River," *Norman (OK) Democrat-Topic*, June 13, 1902, 1.

[64] USACE Tulsa District, Survey Report on Flood Control, Morris County on Grand (Neosho) River in Kansas, Grand (Neosho) River and Its Tributaries, Oklahoma, Kansas, Missouri, and Arkansas, and Review Report on Flood Control, Lightning Creek, Labette Creek, and Flat Rock Creek, Tributaries to the Neosho River in Kansas, September 4, 1941, 35, Appendix II—Hydrology and Related Data, Appendix III—Geology and Soil Investigations, Appendix IV—Economic Data, Appendix V—Physical Data, Costs, Etc., Folder: Grand (Neosho) River, Survey Report, Tulsa District, Sept 4, 1941 [1 of 3 folders with same title in box], RG77, Corps of Engineers, Southwestern Division, Engineering Files—Harbors and Rivers, 1920–1940, Grand (Neosho) River–Gulf Intercoastal Water Way, HM2000, Box 22, NARA-FW.

[65] "Flood," undated typescript, and "Desolation and Destruction by Flood and Flames at Night," *Council Grove Republican*, June 5, 1903, both in Folder: 1903 Flood; and "Flood and Fire," [*Council Grove Republican*], v. 20, [June 5, 1903], unattributed clipping in Folder: Flood 1951, all at Morris County Historical Society, Council Grove, KS.

[66] USACE Tulsa District, *Survey Report on Flood Control*, 35.

[67] Graves, *History of Neosho County*, 1:436.

[68] "Water Covers Gas Field; Neosho River the Latest Stream to Overflow and Terrorize the People; Immense Damage Will Result," *O'Keene (I.T.) Eagle*, June 12, 1903, 3.

[69] "Railroad Traffic Delayed," *Guthrie (OK) Daily Leader*, June 1, 1903.

[70] Jack L. Cross, ed., "Thomas J. Palmer, Frontier Publicist," reprinted in part, *Chronicles of Oklahoma* 28, no. 4 (1950): 452–??, esp. 480. For more on the 1903 floods, see also "Other Kansas Towns Tell the Same Story; Streams out of Banks; Crops Ruined; People Leaving Homes; Many Drowned, . . . Neosho and Cottonwood Rivers Highest Ever Known," *Topeka Journal*, May 29, 1903, "Ruination and Sorrow . . . Cottonwood and Neosho Valleys Storm Swept," *Topeka Journal*, May 30, 1903, "Emporia and the Neosho Valley in Bad Shape," *Topeka Journal*, June 1, 1903, all in Floods in Kansas, Clippings, Vol. 1, KSHS; "Cottonwood and Neosho," and "Kansas Is Flooded . . . Chase County Has the Greatest Flood in Its History," both in [*Chase County Leader*], June 4, 1903, unattributed clippings, Folder: Floods, Chase County Historical Society; French, *History of Emporia and Lyon County*, 191; Burdick, "Flooding of the Neosho River"; Murphy et al., *Destructive Floods in the United States in 1904*, 90–91; Rice and Rice, "Relation of the Kansas Water Commission," 6; Flora, "Climate of Kansas," in KSBA, *Twenty-First Biennial Report*, 342; and FCWCC, *Report*, 5.

[71] Murphy et al., *Destructive Floods in the United States in 1904*, quotation on 78, see also 92.

[72] Proceedings and Debates of the First Session of the Sixty-Fourth Congress, Cong. Rec. 53 (May 13, 1916): 7900–3, quotation on 7902.

[73] "Chase County Flooded; The Cottonwood Bottoms Covered with Water from Bluff to Bluff," [*Chase County Leader*], June 9, 1904, and "The Flood," [*Chase County Leader*], July 14, 1904, unattributed clippings, Folder: Floods, Chase County Historical Society.

[74] "Terrifying Downpour; Central Kansas Is Completely Flooded," *Oklahoma State Capital*, June 3, 1904. See also "Neosho Valley Flooded: Hundreds Are Homeless; Neosho River Rose a Foot Every Hour Last Night," *Topeka Capital*, June 3, 1904, High Waters of 1904, Scrap Book, Vol. 5, KSHS.

[75] "Neosho River Floods," Coffey County Historical Society; quotation from "The Neosho River out of Its Banks," *Weekly Examiner* (Bartlesville, I.T), June 4, 1904, 3.

[76] Bennett Swenson reported that in 1944, July 1904 still held the record for the highest stage achieved at Neosho Rapids and Iola, Kansas (Swenson, "River Stages and Floods," *Monthly Weather Review* [May 1944]: 119–23).

[77] "Neosho Is Still Rising; It Is Higher than Ever Before at Iola and the Worst Is Feared," *Kansas City Journal*, July 9, 1904, High Waters of 1904, Scrap Book, Vol. 5, KSHS.

[78] "Neosho River an Inland Sea," *Canadian Valley News* (Jones City, OK), 3, no. 50, (Ed. 1), April 29, 1904, 4.

[79] "Kansas Flood Situation," *Anadarko (AR) Life*, June 11, 1904, 1.

[80] Graves, *History of Neosho County*, 1:441.

[81] William W. Graves, comp., *The Annals of St. Paul: A Third of a Century. From the Change of Name in 1895 to January 1929* (1942; repr., St. Paul, KS: Journal Press, 1976), 183.

[82] Quotation from "Oil Fields are Flooded; Phenomenal Rise in the Neosho River Causes It to Overflow at Chanute," *Kansas City Journal*, July 7, 1904. See also "Neosho Makes a New Record," *Abilene Reflector*, July 11, 1904, both in High Waters of 1904, Scrap Book, Vol. 5, KSHS.

[83] Graves, *Annals of St. Paul*, 185.

[84] "Neosho Is High," *Hennessey (OK) Eagle*, June 16, 1904, 2. See also "The Neosho River," *Vinita (OK) Daily Chieftain*, June 7, 1904, 3.

[85] "Toll Bridge in Danger," *Norman (OK) Democrat-Topic*, June 17, 1904, 2. See also USACE Tulsa District, *Flood Plain Information*. For more on the 1904 floods, see also "Neosho River Floods," Coffey County Historical Society; Burdick, "Flooding of the Neosho River"; Wright and Elliott, *Prevention of Injury by Floods*; Rice and Rice, "Relation of the Kansas Water Commission," 6; Flora, "Climate of Kansas," in KSBA, *Twenty-First Biennial Report*, 342; FCWCC, *Report*, 5; French, *History of Emporia and Lyon County*, 191; Christy, comp., *Coffey County*; "Some Water Marks," *Weekly Examiner* (Bartlesville, I.T.), June 11, 1904, 1; "Devastation in Its Path," *O'Keene (I.T.) Eagle*, July 15, 1904, 3; and "Flood Situation Improving," *Anadarko (AR) Life*, July 16, 1904, 1

[86] "Rivers and Floods," *Monthly Weather Review* (July 1905): 288; and "R.F.D. No. 1," *Miami Record-Herald*, August 25, 1905, 8.

[87] H. C. Frankenfield, "Rivers and Floods," *Monthly Weather Review* (June 1906): 283.

[88] *History of Chase County, Kansas*, http://www.ksgenweb.org/chase/historyPat.html; and quotation from "Neosho River Flooding," *Grove (OK) Sun*, June 8, 1906.

[89] "Death and Ruin by Oklahoma Flood," *Oregonian* (Portland, OR), May 25, 1909, 3.

[90] Quotations from, respectively, "Cottonwood and Neosho Rivers Flood Valleys," *Topeka Capital*, July 10, 1909, and "Neosho and Cottonwood Rivers Raise 18 Feet," *Topeka Capital*, November 15, 1909, both in [Collection:] Floods in Kansas, Clippings, Vol. 7, KSHS. See also E. H. Bowie, "Rivers and Floods," *Monthly Weather Review* (July 1909): 399; and O. C. Burrows, "The Floods from Kansas City to St. Louis, MO," *Monthly Weather Review* (July 1909): 399.

[91] *Daily Republican* cited in Atherly, *Yesterday's Tomorrow*, quotations on 98–99.

[92] French, *History of Emporia and Lyon County*, quotations on 191–92.

[93] USACE Tulsa District, *Survey Report on Flood Control*, quotations on 25, 37.

[94] Graves, *History of Neosho County*, 1; and Isaac M. Cline, "Climatological Data for April, 1912: District No. 7, Lower Mississippi Valley," *Monthly Weather Review* (April 1912): 571–72, quotation on 572.

[95] "Flood Almost Equals that of 1895," *Galena (KS) Evening Times*, April 29, 1912, 1. See also "Spring River Flood Is Now Slowly Falling at Lowell," *Galena (KS) Evening Times*, April 30, 1912, 1.

[96] H. C. Frankenfield, "Rivers and Floods, May 1912," *Monthly Weather Review* (May 1912): 804. What Frankenfield meant by the term *lower Grand River* here is unclear, but typically when referring to the Grand, *lower* refers either to the entirety of the Grand River in Oklahoma or the section downstream from the confluence of the Grand and Spring Rivers.

[97] Graves, History of Neosho County, 1:436.

[98] French, *History of Emporia and Lyon County*, 192; "Neosho River Floods," Coffey County Historical Society; and Graves, *History of Neosho County*, 1:436.

[99] "Terrific Storms Sweep Country," *Miami Record-Herald*, May 28, 1915, 1.

[100] Alfred J. Henry, "Rivers and Floods, May 1915," *Monthly Weather Review* (May 1915): 239.

[101] "Neosho River Went on Week's Rampage; Receding," *Miami Record-Herald*, June 4, 1915, 1.

[102] Alfred J. Henry, "Rivers and Floods, September 1915," *Monthly Weather Review* (September 1915): 474–75, quotation on 474.

[103] Henry, "Rivers and Floods, September 1915," 475.

[104] "Cross Country Travel Held Up at Neosho River Bridge," *Miami Record-Herald*, supp., September 24, 1915, 1.

[105] Quotations from, respectively, "Rains Cause Washout on O.K.&M.," *Miami Record-Herald*, June 8, 1917; and Rainfall Wednesday Greatest in Years; 4.30 Inches, Reports," *Miami Daily Record-Herald*, November 7, 1918, 1. See also Alfred J. Henry, "Rivers and Floods, November 1918," *Monthly Weather Review* (November 1918): 525.

[106] "6 Inches of Rain in Last 24 Hours Gauge Here Shows; Heavy Downpour Which is General over Wide Section Does Damage over District; Creeks are Flooded," *Miami Record-Herald*, March 20, 1920, 1.

[107] Table I, Flood Stages March 1920, *Monthly Weather Review* (March 1920): 177.

[108] "1.60 Inches of Rain Fell Here Late Friday," *Miami Record-Herald*, June 4, 1920, 5; and "May an Unusually Wet Month with 6.08 Inches of Rain," *Miami Record-Herald*, June 11, 1920, 4.

[109] Quotations from, respectively, "Flood in Kansas . . . Neosho River State at Oswego Up to 22 Feet," *Topeka Journal*, April 9, 1927, 1926, Floods in Kansas, Clippings, Vol. 7, KSHS; and "Highway Traffic out of Miami on No. 7 Is Resumed," *Chickasha (OK) Daily Express*, April 18, 1927, 1. See also "River over Highway 7 Southwest of Miami," and "Like Flood of 1922," both in *Miami Record-Herald*, April 11, 1927, 1–2; "Flood at Standstill Here; Death Toll from Storms in Other Sections Passes 100," and "Neosho Believed to Be at Crest of 24-Foot Rise," both in *Miami News-Record*, April 15, 1927, 1; and "Report on Grand (Neosho) River, Kansas, Missouri, Arkansas, and Oklahoma," June 4, 1931, Appendix 3, Folder: Grand (Neosho) River, Volume 2, Appendix 1–3, June 1931, 2 of 2, RG77, Corps of Engineers, Southwestern Division, Engineering Files—Harbors and Rivers, 1920–1940, Galveston–Grand (Neosho) River, HM2000, Box 21, E. SW8, NARA-FW.

[110] "Airplane Views of Neosho River Flood in Vicinity of Miami," and "Reporter in Airplane, Finds Floods over Wide Territory; Fairground Under Water and Miami Packing Company's Plant is Endangered," *Miami Daily News-Record*, June 26, 1928, 1, clippings in Folder: Floods, Ottawa County Historical Society, Dobson Museum, Miami, OK (Dobson Museum). Note that these images were printed a week after the flood itself.

[111] Bennett Swenson, "River Stages and Floods," *Monthly Weather Review* (October 1941): 313–15, quotations on 314.

[112] "Water Forces Wyandotte's Schools Shut," *Miami Daily News-Record*, October 30, 1941, 1–2; quotation from "Floods Spreading Havoc over State," *Miami Daily News-Record*, October 30, 1941, 1.

[113] "Rainfall," typescript, May 1943, Folder: "History of the Grand River Dam Project with Reference to Reports of U.S. Army Engineers to Congress Prior to the Creation of the Grand River Dam Authority with Other Reports during the Construction of the Project," ca. second half of 1943, Box 30, Alva J. Hickerson Papers, Identifier: 1983-002, OSU Archives. See also M. V. Marcher, J. F. Kenny, and Others, *Hydrology of Area 40, Western Region, Interior Coal Province Kansas, Oklahoma, and Missouri: Neosho River, Verdigris River, Caney River, Spring River, Bird Creek*, USGS Water-Resources Investigations Open-File Report 83–266 (1984), 46, KSHS.

[114] Minutes of the Public Utility Board of the City of Miami, OK, May 21, 1943, Book 2, p. 1511, City Hall, Miami, OK (hereafter Miami PUB Minutes).

[115] "Dam Credited with Saving Big War Plant," *Tulsa Tribune*, May 11, 1943, Folder: Tables, Plates and Exhibits to Accompany Letter to Chief of Engineers, Dated May 29, 1943, from District Engineer, Tulsa District, Re: Flood of May 1943, Box 13, Hickerson Papers, OSU Archives.

[116] "Grand Lake Backs Up," *Tulsa World*, May 12, 1943, Folder: Tables, Plates and Exhibits to Accompany Letter to Chief of Engineers, Dated May 29, 1943, from District Engineer, Tulsa District, Re: Flood of May 1943, Box 13, Hickerson Papers, OSU Archives.

[117] Burnham to Wright, July 28, 1947. In this report, Burnham referenced a letter from R. C. Crawford, Brig. Gen., Acting Chief of Engineers, to Arthur Goldschmidt, July 2, 1947 [copy not found at GRDA-HQ].

[118] *Parsons Sun*, April 27, 1944, quoted in KSBA, Division of Water Resources, *Report of the Kansas State Board of Agriculture, December, 1944: River Basin Problems and Proposed Reservoir Projects for a State Plan of Water Resources Development* (Topeka: KSBA, 1945), 57.

[119] "Wyandotte Is Menaced by Rampaging Neosho Today," *Miami Daily News-Record*, April 13, 1944, 1.

[120] [“River Stages and Floods,”] *Monthly Weather Review* (December 1944): 2[49]–50.

[121] “Picher Business Area under Water, *Miami Daily News-Record*, June 22, 1948, 1; and “River near Crest, Flood Expected to Ease Grip on Area,” *Miami Daily News-Record*, June 24, 1948, 1.

[122] “Rampaging Neosho Nears Crest,” *Miami Daily News-Record*, July 28, 1948, 1. See also “Neosho Leaves Banks in Wide Kansas Region,” *Miami Daily News-Record*, July 20, 1948, 1; “Neosho River at New Peak, Lake’s Rising,” *Miami Daily News-Record*, July 21, 1948, 1; “Five-Foot Rise since Monday; Families Flee,” *Miami Daily News-Record*, July 27, 1948; and “Waters Recede in Miami after Neosho Crests,’ *Miami Daily News-Record*, July 29, 1948, 1. Other sources place the gage 9 miles north of Miami (see Federal Emergency Management Agency [FEMA], Federal Insurance Administration, “Flood Insurance Study, City of Miami, Oklahoma, Ottawa County,” June 1980, accessed February 27, 2022, https://hdl.handle.net/2027/txa.ark:/81423/m3m022).

[123] USACE Tulsa District, *Flood Plain Information*, 18.

[124] Scores of reports and articles have been written about the July 1951 floods. See, for example, USGS and Canada—Department of Resources and Development, Water Resources Division, [“The Kansas Floods of 1951”], *Water Resources Review*, August 9, 1951, and USACE, “Floods of June–July 1951, Kansas and Oklahoma, presentation at ASCE Meeting, Oklahoma City, OK, September 21, 1951, both in Folder: July 1951 Flood, Box 13, Hickerson Papers, OSU Archives.

[125] [“The Kansas Floods of 1951”], 3.

[126] Erling Helland Associates, “Report on the Miami Area Comprehensive Plan, Miami, Ottawa County, Oklahoma,” April 16, 1979. Prepared for the City Planning Commission, Miami, OK, OSDLA.

[127] “Neosho Overflow,” aerial photograph, [*Miami News-Record*], May 26, 1957, clipping in Dobson Museum.

[128] USACE Tulsa District, *Flood Plain Information*, 18.

[129] FEMA, “Flood Insurance Study,” June 1980.

[130] “River Drop,” and “The Wide Neosho (photograph),” both in *Miami News-Record*, June 17, 1964, 1; and “Floods Begin to Recede in Northeast,” *Daily Oklahoman*, June 30, 1969, 40.

[131] “Neosho Rampage,” *Parsons Sun*, April 20, 1970, 2; and “New Flood on Neosho,” *Parsons Sun*, October 15, 1973, 1.

[132] “Miami Schools Dismiss; Some Evacuate Here; Crest on Wednesday,” *Miami News-Record*, March 12, 1974, 1; quotation from Neosho River flood, photograph, [*Miami News-Record*], March 17, 1974, clipping, Dobson Museum.

[133] “Neosho Takes Generous Swath of Land near Chanute,” *Wichita Eagle*, April 1, 1980, 13; Martin Thomas, “Rains Douse Area,” *Parsons Sun*, May 31, 1982, 1; “River Here Expected to Crest Seven Feet above Flood Level,” *Iola Register*, November 16, 1985, 1; “High Water Leaves Mark on City of Chanute,” [*Chanute Tribune*, October 6, 1986], and “Overflowing River Floods Countryside,” [*Chanute Tribune*, April 4, 1988], clippings, both in Folder: Chanute Flood, Genealogy Room, Chanute Public Library, Chanute, KS; “Storms Cause Flooding in Area,” *Parsons Sun*, June 12, 1989, 1; “500 Leave Homes as Two Oklahoma Rivers Flood,” *New York Times*, September 28, 1993; and “Flooding Toll Still Unknown,” *Iola Register*, October 7, 1998, 2. Flooding immediately south of the Kansas border in Ottawa County, Oklahoma, suggests that the Neosho may also have flooded (depending on the point source of the flood) at upstream locations in southeastern Kansas in 1987, 1990, 1992, 1994, 1995, and 1997. See next note.

[134] “3 Flooded Counties Now Disaster Areas,” *Daily Oklahoman/Times*, March 7, 1985, 33.

[135] Carla Hinton, “Records Fall; Water Rises,” *Daily Oklahoman*, Mary 31, 1990, 1; “Strong Winds, Rains Pummel Parts of State,” *Daily Oklahoman*, July 14, 1992, 6; “Heavy Rains, Floods Cripple Parts of State,” *Tulsa World*, April 12, 1994, 1; “Floodwaters,” photograph, *Grove Sun*, May 19, 1995; and “Blackwell Driver Dies in Flood,” *Daily Oklahoman*, April 14, 1997, 81.

[136] Miami Kiwanis Club, *The Flood of ‘86: A Pictorial Study*. [Miami, OK: Kiwanis, 1986], OSDLA. See also, “Oklahoma Floods Force Thousands to Evacuate,” *New York Times*, October 5, 1986, 26.

[137] "Flooding Forces Evacuation in Northeast Oklahoma," *UPI*, September 27, 1993, https://www.upi.com/Archives/1993/09/27/Flooding-forces-evacuation-in-northeast-Oklahoma/1678749102400/

[138] "Northeast Oklahoma Sustains More Flooding," *Iola Register*, May 10, 2000, 11; Oklahoma Climatological Survey, Oklahoma Monthly Climate Summary, May 2002, https://climate.ok.gov/summaries/monthly/2002/MCS_May_2002.pdf; Sheila Stogsdill, "Heavy Rains Bring Flood Warnings," *Oklahoman*, April 25, 2004; Oklahoma Farm Bureau, "Miami Flooding," *Oklahoma Country* (Fall 2007): 22; National Weather Service, *Monthly Report of River and Flood Conditions, December 2015*, https://www.weather.gov/media/tsa/e5/e5dec15.pdf; and Kimberly Barker, "Retreating Floodwaters Reveal Major Damage in Miami," *Joplin (MO) Globe*, June 12, 2019, https://www.joplinglobe.com/news/local_news/retreating-floodwaters-reveal-major-damage-in-miami/article_85748c11-e963-5335-b18c-a4bbf4c35e94.html.

[139] Oklahoma Farm Bureau, "Miami Flooding," *Oklahoma Country* (Fall 2007): 22. See also Sheila Stogsdill, "Rising Water Leaves Miami 'Indescribable,'" *Oklahoman*, July 5, 2007, https://www.oklahoman.com/story/news/2007/07/05/rising-water-leaves-miami-indescribable/61760229007/.

[140] Kimberly Barker, "Retreating Floodwaters Reveal Major Damage in Miami," *Joplin (MO) Globe*, June 12, 2019.

[141] Early attempts to control water flow on the Neosho River were the low dams people built across the river to harness power for adjacent industrial operations, notably mills. Examples were at Cottonwood Falls, Emporia, and Erie, Kansas, the latter of which the flood of 1885 destroyed forty feet. See Carrie Breese Chandler, "A History of the Old Mill at Cottonwood Falls," originally published in the *Chase County Leader*, February 7, 1934, in *Chase County Historical Sketches*, Vol. 1 (Cottonwood Falls, KS: Chase County Historical Society, 1940), 61–63; Murphy et al., *Destructive Floods in the United States in 1904*, 15; Graves, *Annals of Osage Mission*, 360; and "Neosho River," USGS, *Twenty-First Annual Report, 1899–1900*, Part IV—Hydrography (Washington, DC: GPO, 1901), 245–53.

[142] Different accounts conflict on when the first levee was constructed. According to Duncan's 1905 *History of Neosho and Wilson Counties* (105) and Graves's 1949 *History of Neosho County* (1:441), the year was 1890. According to Murphy et al., *Destructive Floods in the United States in 1904* (92), the year was 1892. See also Wright and Elliott, *Prevention of Injury by Floods*.

[143] Duncan, *History of Neosho and Wilson Counties*, 105.

[144] Duncan, *History of Neosho and Wilson Counties*, 106.

[145] Graves, *Annals of Osage Mission*, 445, quoting the *Journal*.

[146] Duncan, *History of Neosho and Wilson Counties*, 106.

[147] Duncan, *History of Neosho and Wilson Counties*, 106–7, quotation on 107. See also Graves, *History of Neosho County*, 1:439.

[148] Duncan, *History of Neosho and Wilson Counties*, 106.

[149] Duncan, *History of Neosho and Wilson Counties*, 107.

[150] Murphy et al., *Destructive Floods in the United States in 1904*, 92–93.

[151] Wright and Elliott, *Prevention of Injury by Floods*, 3, quotation on 7. See also "Yearbook of Department of Agriculture, 1908," *U.S. Congressional Serial Set* (1908): 1–822 (Washington, DC: GPO, 1909).

[152] Wright and Elliott, *Prevention of Injury by Floods*, 10.

[153] "Investigation of the Neosho Valley Floods by Drainage Engineers of the U.S. Office of Experiment Stations," *Kansas Farmer* 46, no. 14 (April 2, 1908): 419–20, quotations on 419; and Wright and Elliott, *Prevention of Injury by Floods*, 23–24.

[154] Wright and Elliott, *Prevention of Injury by Floods*, 22–23.

[155] Wright and Elliott, *Prevention of Injury by Floods*, 28.

[156] "Dams and Reservoirs—Their Uses—Proper Sizes," in Richards, *What Are We Going to Do About It?* 18–20, esp. 19.

[157] F. B. Nichols, "No Floods for Oswego; Livestock Is Featured behind High Levees on the Deming Ranch," *Farmers Mail and Breeze* (Topeka) 45, no. 7 (February 13, 1915): 1.

[158] Rice and Rice, "Relation of the Kansas Water Commission," 17.

[159] "Drainage Men Will Ask for Powers of Condemnation," *Topeka Capital*, June 22, 1916, Dams and Flood Control, Clippings, Vol. 1, KSHS.

[160] "Drainage Boards Organize, Adjourn," *Topeka Capital*, June 23, 1916, Dams and Flood Control, Clippings, Vol. 1, KSHS.

[161] Kansas Water Commission (KWC), *First Biennial Report, 1917–1918*, by H. A. Rice and Roger C. Rice (Topeka: Smith, 1919), 7–9; and Session Laws of Kansas, 1917, chapter 172, p. 218, in State of Kansas, *Session Laws, 1917, Passed at the Thirty-Seventh Regular Session—The Same Being the Twentieth Biennial Session—of the Legislature of the State of Kansas*, May 26, 1917 (Topeka: Smith, 1917).

[162] River and Harbor Act of 1916, July 27, 1916, ch. 260, 39 Stat. 391 (note: unable to locate actual text, only citation); and An Act to Provide for the Control of the Floods of the Mississippi River and of the Sacramento River, California, and for Other Purposes, States at Large, 64th Cong., 2d Sess., Ch. 144, March 1, 1917.

[163] "Floods in Kansas," H.R.Doc. No. 321, 65th Cong., 1st Sess., quoted in KWC, *Second Biennial Report, 1919–1920* (Topeka: Zumwalt, 1921), 9.

[164] "Floods in Kansas," quoted in KWC, *Second Biennial Report*, 10.

[165] KWC, *First Biennial Report*, 1917–1918, 8.

[166] KWC, *First Biennial Report, 1917–1918*, 9. The engineers were required to be qualified as at least associate members of the American Society of Civil Engineers.

[167] KWC, *First Biennial Report*, 1917–1918, 9.

[168] KWC, *First Biennial Report*, 1917–1918, 14, 19.

[169] KWC, *First Biennial Report*, 1917–1918, 9–10.

[170] KWC, *First Biennial Report*, 1917–1918, 29.

[171] KWC, *Fourth Biennial Report, 1923–1924* (Topeka: Walker, 1924), 3, 7.

[172] KWC, *Second Biennial Report*, 1919–1920, 11.

[173] KWC, *Fourth Biennial Report*, 1923–1924, 7.

[174] KWC, *Fourth Biennial Report*, 1923–1924, 6.

[175] KWC, *Fourth Biennial Report*, 1923–1924, 3.

[176] Compare KWC, *Surface Waters of Kansas, 1895–1919, Prepared in Cooperation with the U.S. Geological Survey* (Topeka: Walker, 1921), 17–18; KWC, *Surface Waters of Kansas, 1919–1924, Prepared in Cooperation with the U.S. Geological Survey* (Topeka: Walker, 1925), 12–13; and J. B. Spiegel, "Surface Waters of Kansas, 1924–1928," in KSBA, *Report of Division of Water Resources for the Biennium July 1, 1926, to June 30, 1928* (Topeka: KSBA, 1930), 18–19. Records from a gage "near Iola" covered August 1, 1895, through November 30, 1903, and October 12, 1917, through September 30, 1924. From 1895–1903, the gage was located at a city water and powerhouse four miles upstream from the gage that was extant in 1924. The U.S. Weather Bureau kept gaging records at Iola from December 1, 1903–October 11, 1917. Apparently, there were two gages, one "at Iola" and one "near Iola," beginning in 1917. See KSBA, *Report of the Kansas State Board of Agriculture, Division of Water Resources for the Quarter Ending June, 1936, Containing Stream-Flow Data for the Period from October 1, 1928, to September 30, 1935* (Topeka: Austin, 1937), 529.

[177] KSBA, *Report of the Kansas State Board of Agriculture, Division of Water Resources . . . Ending June, 1936*, 12.

[178] KWC, *Second Biennial Report*, 1919–1920, 5.

[179] KWC, *Second Biennial Report*, 1919–1920, 18–19.

[180] KWC, *Fourth Biennial Report, 1923–1924*, 8–9. The *Fourth Biennial Report* was the last that KWC published separately. The report for the commission's fifth biennium (which would prove to be its last and was sparse) was included in KSBA, *Twenty-Fifth Biennial Report, for the Years 1925 and 1926* (Topeka: KSBA, 1927).

[181] "Report of Division of Water Resources," KSBA, *Twenty-Sixth Biennial Report, 1927 and 1928* (Topeka: Walker, 1929), 216.

[182] "To Make Surveys in Kansas," *Topeka Journal*, May 17, 1927, Floods in Kansas, Clippings, Vol. 7, KSHS.

[183] "Artificial Lake and Dike Plans Given Approval; Actual Work, However, Must be Done Locally, Water Resources Committee Points Out," *Topeka Capital*, May 18, 1927, Floods in Kansas, Clippings, Vol. 7, KSHS. Knapp held the post of state irrigation engineer until becoming the first DWR chief engineer (also known as the State Engineer), a position he held until 1951. See Ken Kopp, "DWR Engineer Passes the Torch," *Kansas Lifeline* (March 2020): 100–3, https://krwa.net/portals/krwa/lifeline/2003/DWRChief.pdf.

[184] FCWCC, *Report*, 6.

[185] "Report of Division of Water Resources," *Twenty-Sixth Biennial Report, 1927 and 1928*, quotation on 216; and FCWCC, *Report*, 7–9.

[186] FCWCC, *Report*, 7–9.

[187] FCWCC, *Report*, 32–34.

[188] An Act Authorizing the Construction of Certain Public Works on Rivers and Harbors for Flood Control, and for Other Purposes, June 22, 1936, H.R. 8455, P.L. No. 738, 74th Congress, Sess. II, 1578–79, 1594, 1596 (hereafter, Flood Control Act of 1936).

[189] "Flood Control," *Hearings before the Committee on Flood Control, House of Representatives*, January 18–26, 1928, 70th Congress, 1st Sess., "On the Control of the Destructive Flood Waters of the United States," Part 5, Mississippi River and Its Tributaries (Washington, DC: GPO, 1928), quotations on 3035a–3035b.

[190] "Flood Control," *Hearings*, quotations on 3039–40.

[191] "Knapp Explains Kansas Flood Control Bills," *Topeka Capital*, August 8, 1929, Kansas Board of Agriculture, Clippings, Vol. 1, 1872–1955, KSHS; and KSBA, *Twenty-Seventh Biennial Report, for the Years 1929 and 1930* (Topeka: KSBA, 1931), 280. The *Twenty-Seventh Biennial Report* made no mention of the Conservancy Act, which had been ruled unconstitutional in 1930 before the report went to press.

[192] KSBA, *Twenty-Seventh Biennial Report*, 280.

[193] "First Action Is Taken in Flood Invested Areas;" and Kansas State Planning Board, *Water: It's Use and Control in Kansas, an Outline* (Topeka: State Planning Board, October 1936), 10, 17–18.

[194] "First Action Is Taken in Flood Invested Areas."

[195] "First Action."

[196] Kansas State Planning Board, *Water . . . Use and Control*, 10.

[197] FCWCC, *Report*, 13.

[198] "Flood Control on the Mississippi River and Its Tributaries," *Hearings before the Committee on Flood Control*, H.R., April 29–May 2, 1930, 71st Cong., 2d Sess., Pt. 3 (Washington, DC: GPO, 1930), 837.

[199] "Flood Control on the Mississippi River and Its Tributaries," *Hearings*, 846.

[200] "Flood Control on the Mississippi River and Its Tributaries," *Hearings*, 846.

[201] "Flood Control on the Mississippi River and Its Tributaries," *Hearings*, 847.

[202] *Arkansas River and Tributaries*, 1243. See also Kansas State Planning Board, *Neosho-Verdigris Drainage Basin Report* (Topeka: Planning Board, 1936), 16.

[203] Levee Project Estimates ca. 1931, Folder: Grand (Neosho) River, Memphis District—Volume 3, Appendix 4–6, June 1931, RG77, Corps of Engineers, Southwestern Division, Engineering Files—Harbors and Rivers, 1920–1940, Grand (Neosho) River–Gulf Intercoastal Water Way, HM2000, Box 22, NARA-FW. See also "Report on the Grand (Neosho) River, A Tributary of the Arkansas River," Submitted in Compliance with Letter, Chief of Engineers, February 15, 1934, Folder: Grand (Neosho) River, Feb. 15, 1934, RG77, Corps of Engineers, Southwestern Division, Engineering Files—Harbors and Rivers, 1920–1940, Galveston–Grand (Neosho) River, HM2000, Box 21, NARA-FW.

[204] Graves, *History of Neosho County*, 1:441–42.

[205] T. C. Hughes, City Engineer, Tulsa, "Oklahoma's Natural Water Supply: Its Conservation, and Effect on Climate, on Agriculture, and on Manufactures," 1912, Folder: Water, Flood Control, Cement, and Crops 1907–1923, Joseph Thoburn Collection, 1986.001, Box 10, Conservation, Flood Control, and Farming, OKHC.

[206] "Flood Bill through House," *Harlow's Weekly* 20, no. 8 (February 25, 1921): 3.

[207] "Flood Bill through House," 3.

[208] Minutes of Meeting of State Flood Control Legislative Committee, November 27, 1923, 2, Folder: Flood Control 1923–1927, Thoburn Collection, Box 10, OKHC.

[209] Quotations, respectively, from A Bill Entitled an Act to Provide for the Creation and Organization of a State Conservation Commission and Prescribing the Duties and Defining the Powers Thereof," draft, ca. November 27, 1923 ["1924" handwritten on document], sec. 7, p. 2, Folder: Flood Control 1923–1927, Thoburn Collection, Box 10, OKHC; and Minutes . . . State Flood Control Legislative Committee, November 27, 1923, 3.

[210] Minutes . . . State Flood Control Legislative Committee, November 27, 1923, 4.

[211] See "Oklahoma State Chamber of Commerce to Citizens of Oklahoma Who Are Interested in Flood Control," [1924], Folder: Water, Flood Control, Cement, and Crops 1907–1923, Thoburn Collection, Box 10, OKHC; and E. E. Blake, "Flood Control Law Advocated for Oklahoma," *Harlow's Weekly*, February 9, 1924, 12, 14 (essentially, the same document).

[212] J. F. Owens to J. B. Thoburn, June 19, 1924, Folder: Flood Control 1923–1927, Thoburn Collection, Box 10, OKHC.

[213] E. E. Blake, "Flood Control and Irrigation," *Harlow's Weekly* 23, no. 28 (July 12, 1924): 11, 13–14, quotations on 11.

[214] E. E. Blake, Commissioner of Drainage, Irrigation, and Reclamation Commission, to Governor M. E. Trapp, October 26, 1926, State of Oklahoma Commission of Drainage, Irrigation, and Reclamation Collection, Box 1, OSDLA. See also E. E. Blake, Misc. correspondence, Folder: 1927–28 Flood Control Correspondence, E. E. Blake, E. E. Blake Papers, 2006.03, Box 1 [of 1], OKHC. Note: Blake was heavily involved in debates 1927/1928 about the utility of levees (preferred by "civilian engineers") versus reservoirs for flood control (preferred by Army engineers and Blake himself).

[215] Blake to Trapp, October 26, 1926, 2.

[216] Blake to Trapp, October 26, 1926, 2–3.

[217] Blake to Trapp, October 26, 1926, 3.

[218] See USGS, Water Resources Research, for Oklahoma Planning and Resources Board, *Oklahoma Water: Quantity, Occurrence, and Quality of Surface and Ground Water*, March 1, 1945, 29, Industrial Development and Parks Department, Box 6, OSDLA; and "Rivers and Floods," *Monthly Weather Review* (September 1904): 402–3.

[219] Blake to Trapp, October 26, 1926, 4.

[220] Blake to Trapp, October 26, 1926, 5.

[221] Blake to Trapp, October 26, 1926, 8–9, quotation on 9.

[222] Blake to Trapp, October 26, 1926, 10–11, quotation on 10.

[223] Blake to Trapp, October 26, 1926, 12.

[224] As reported in "Flood Prevention Possible; Oklahoma Irrigation Commissioner Says Reservoir System Would Prevent Recurrence of Floods," *Topeka Capital*, October 15, 1926, Floods in Kansas, Clippings, Vol. 7, KSHS.

[225] "Flood Prevention Possible."

[226] Victor E. Harlow, "Floods Bring Renewed Talk of Control," *Harlow's Weekly* 26, no. 16 (April 16, 1927): 4–5, 16, quotation on 5.

[227] Victor E. Harlow, "Ratify the Flood Control Compact," editorial, *Harlow's Weekly* 26, no. 11 (March 12, 1927): 3.

[228] Victor E. Harlow, "The Flood Control Problem," editorial, *Harlow's Weekly* 26, no. 17 (April 23, 1927): n.p.

[229] "Board Espouses Water Storage," *Miami News-Record*, June 1, 1927, 8.

[230] Victor E. Harlow, "Ave, Blake!" editorial, *Harlow's Weekly* 27, no. 2[?] (May 26, 1928): n.p.

[231] "Reservoir System Planned for Control of Floods," *Harlow's Weekly* 27, no. 32 (August 11, 1928): 10.

[232] "The Status of Flood Control," *Harlow's Weekly* 27, no. 4[?] (November 3, 1928): quotation on 7, 14.

[233] "The Oklahoma Conservation Commission," *Miami News-Record*, June 24, 1930, 2. Reporters that referred to the "conservation commission" were referring to the DIRC.

[234] D. P. and Times Bound files, *Times*, August 18, 1933, 2, cited in Amelia Harris, "Has Anyone Seen the State Flood Plan?" Folder: Water—Bibliography, 1941, Box 80, Water, Federal Writers Project Coll. 1935–1942, 1981.105, OKHC. See also "Oklahoma at Washington," *Harlow's Weekly* (August 26, 1933): 3–4.

[235] "Oklahoma at Washington," 3.

[236] D. P. and Times Bound files, 2.

[237] "Oklahoma at Washington," 3.

[238] D. P. and Times Bound files, 2.

[239] "Oklahoma at Washington," 3.

[240] "Oklahoma at Washington," 3.

[241] Levee Project Estimates ca. 1931; and "Report on the Grand (Neosho) River," February 15, 1934.

[242] Synopsis of District Engineer's Report, June 19, 1931, 15. See also "Confidential: Flood Control Act of 1936," Hearings before the Committee on Commerce, Senate, March 30, 1936, 74th Cong., 2d Sess., on H.R. 8455, An Act Authorizing the Construction of Certain Public Works on Rivers and Harbors for Flood Control and for Other Purposes, Pt. 2 (Washington, DC: GPO, 1936), esp. 68–69, 73–74, 107.

[243] See Map of Miami, Indian Territory, platted May 19, 1891, redrawn by City of Miami Engineering Department, 1991; and Map of Miami, Indian Territory, Ottawa Reservation, [August 14, 1899?], both at City Hall, Miami, OK.

[244] "The Bridge Charter," *Miami Republican*, March 22, 1901; quotation from "The Bridge" *Miami Republican*, April 5, 1901.

[245] "The Wagon Bridge," *Miami Republican*, May 10, 1901; and "The Wagon Bridge Is a Certainty," *Miami Republican*, May 10, 1901.

[246] "That Bridge Bugaboo," *Miami Record-Herald*, October 20, 1925, 1.

[247] As reported in "Building of Miami Railroad Bridge Established New Fast Record," *Miami Daily Record-Herald*, July 13, 1919, 4.

[248] On August 15, 1900, Miami street commissioner Thomas McBee reported that he had "put in 15 single culberts [*sic*], 3 double, and repaired 3 old ones" (August 15, 1900, City of Miami, Board of Commissioners Minutes [hereafter Miami Commissioners' Minutes], Book 1, 30, City Hall, Miami, OK. See also October 22, 1917, Miami Commissioners' Minutes, Book 7/12/15–4/9/19, 97–101.

[249] March 29, 1918, and April 16, 1918, Miami Commissioners' Minutes, Minute Record D, 5/3/15–4/30/19, 345 and page number unknown, respectively.

[250] April 12, 1920, Miami Commissioners' Minutes, 8/3/19–5/2/21, 324–25; and August 9, 1921, Miami Commissioners' Minutes, Minute Record F, 5/9/21–3/15/26, 36.

[251] January 9, 1922, Miami Commissioners' Minutes, Minute Record F, 5/9/21–3/15/26, 70.

[252] "Only 17 Arrests Made by Police Last Month," *Miami Record-Herald*, November 24, 1922, 1.

[253] June 9, 1921, n.p., and September 6, 1921, 43, both in Miami Commissioners' Minutes, Minute Record F, 5/9/21–3/15/26.

[254] "Proposal Made to Build Levee at Riverview Park Following Second Flooding in Two Weeks," *Miami Daily Record-Herald*, March 29, 1922, 1.

[255] "Wall Will Be Built to Protect Bridge," *Miami Daily Record-Herald*, April 30, 1922, 1.

[256] "City Plans to Keep River out of Park," *Miami Daily Record-Herald*, July 18, 1922, 1.

[257] July 30, 1923, Miami Commissioners' Minutes, Minute Record F, 5/9/21–3/15/26, 185.

[258] "Crews Busy on Park Projects," *Miami News-Record*, April 27, 1924, 1. See also "River Rise Causes Damage at Dam," *Miami News-Record*, April 30, 1924, 1; "River Falls Rapidly Following Overflow," *Miami News-Record*, May 2, 1924, 1; "High Water Continues to Delay Work at Dam, *Miami News-Record*, May 8, 1924, 2; and "Workmen Rebuild River Cofferdam," *Miami News-Record*, May 11, 1924, 1.

[259] Project at Dam Is near Final Stages," *Miami News-Record*, May 25, 1924, 1. For a good overview photograph of the dam as it appeared in 1954 (with what appears to be a lock), see Neosho River, Miami, Low Water, Sept. 1954, courtesy Dobson Museum, accessed February 13, 2023, https://www.facebook.com/photo?fbid=559731372855295&set=pcb.559732412855191. Only small pieces of the ends of the dam exist at Riverview Park today.

[260] "Crews Busy on Park Projects," 1.

[261] "Concert to Mark Riverview Park's Official Opening," *Miami News-Record*, May 10, 1925, 1.

[262] "Workmen Rebuild Cofferdam," *Miami News-Record*, May 11, 1924, 1; and "Project at Dam Is near Final Stages," *Miami News-Record*, May 25, 1924, 1.

[263] October 10, 1929, Miami Commissioners' Minutes, Minute Record F-1, 3/22/26–5/4/31, 293. In 1891, the Miami Tollbridge Company Ferry joined Miami on the east side of the Neosho River at the foot of Ninth Avenue. Today, the highway bridge meets Miami at Eighth Ave. and Ninth Ave. is a park road running south of the municipal pool. Maps indicate that none of the blocks associated with this purchase (164, 165, 170, 171, 172, and 173) had been developed residentially. Compare Map of Miami, Indian Territory, Ottawa Reservation, [August 14, 1899?], and Map of Miami, Indian Territory, platted May 19, 1891, redrawn by City of Miami Engineering Department, 1991, both at City Hall, Miami, OK; and current tax parcel map on the Ottawa County Assessor's website, accessed January 11, 2023, http://lmweb.dyndns.org:6580/MapView-Ottawa/.

[264] February 28, 1927, Miami Commissioners' Minutes, Minute Record F-1, 3/22/26–5/4/31, 83.

[265] May 7, 1927, Miami PUB Minutes, Book 1, 2, City Hall, Miami, OK.

[266] See Map of Miami, Indian Territory, Ottawa Reservation, [August 14, 1899?], and Map of Miami, Indian Territory, platted May 19, 1891, redrawn by City of Miami Engineering Department, 1991, both at City Hall, Miami, OK.

[267] April 19, 1929, Miami PUB Minutes, Book 1, 101.

[268] June 7, 1929, Miami PUB Minutes, Book 1, 108.

[269] September 10, 1929, Miami PUB Minutes, Book 1, 120.

[270] October 10, 1929, 293; October 19, 1929, 297–98; and October 28, 1929, 300–2, all in Miami Commissioners' Minutes, Minute Record F-1, 3/22/26–5/4/31.

[271] June 30, 1930, Miami Commissioners' Minutes, Minute Record F-1, 3/22/26–5/4/31, 377–79.

[272] "Work Begun at Dam," *Miami Daily News-Record*, July 25, 1933, 1.

[273] July 17, 1933, Miami Commissioners' Minutes, Minute Record F-2, 5/6/31–10/3/38, 204. See also July 10, 1933, 351, and July 21, 1933, 353, both in Miami PUB Minutes, Book 1.

[274] "Repair of Dam Nearing Finish," *Miami Daily News-Record*, August 13, 1933, 1.

[275] Resolution, June 5, 1944, Brown Binder, City Hall, Miami, OK. See also Miami PUB Minutes, Book 2, n.p.

[276] Joseph L. Arnold, *The Evolution of the 1936 Flood Control Act* (Fort Belvoir, VA: USACE, Office of History, 1988), 4–5, quotation on 5.

[277] Arnold, *Evolution of the 1936 Flood Control Act*, 5.

[278] Arnold, *Evolution of the 1936 Flood Control Act*, 3.

[279] 23 Stat. 133, 1884, quoted in Gifford Pinchot, "The Long Struggle for Effective Federal Water Power Legislation," *George Washington Law Review* 14, no. 1 (December 1945): 9–20, quotation on 10.

[280] 26 Stat. 426, 454, 1890, cited in Pinchot, "Long Struggle," 10.

[281] 26 Stat. 1101 (1891) and 29 Stat. 120 (1896) quoted in Pinchot, "Long Struggle," 10.

[282] 30 Stat., 1121, 1151, cited in Pinchot, "Long Struggle," 10; and USACE, "Multipurpose Waterway Development," accessed December 29, 2022, https://www.usace.army.mil/About/History/Brief-History-of-the-Corps/Multipurpose-Waterway-Development/.

[283] USACE, "Multipurpose Waterway Development." The Corps of Engineers did install a power station substructure at Lock and Dam #1 on the upper Mississippi River. The government later leased the power facility to the Ford Motor Company. In 1919, the Corps began construction of Dam #2 later renamed Wilson Dam as a hydroelectric facility at Muscle Shoals on the Tennessee River. Support for the facility, which was intended to supply power for nitrate production, declined with the end of World War I, and its completion was threatened. However, by 1925 that project was substantially finished.

[284] Arnold, *Evolution of the 1936 Flood Control Act*, 4, 5.

[285] "An Act to Create a Federal Power Commission; to Provide for the Improvement of Navigation; Development of Water Power; the Use of Public Lands in Relation Thereto . . . and for Other Purposes," June 10, 1920, ch. 285, 41 Stat. 1063 (Federal Water Power Act of 1920). For a version with explanatory notes on later modifications, see https://www.energy.gov/sites/prod/files/2015/06/f22/FWPA1920.pdf.

[286] Graves, *History of Neosho County*, 1:441; and Duncan, *History of Neosho and Wilson Counties*, 105–7.

[287] Graves, *History of Neosho County*, 1:441.

[288] Floods in Kansas, letter from the Secretary of War, transmitting, with a letter from the Chief of Engineers, R*eport on Preliminary Examination of Floods in the State of Kansas*, August 7, 1917, referred to the Committee on Flood Control and ordered to be printed, with illustrations, August 7, 1917, 65th Cong., 1st Sess., H.R.Doc. No. 321, *U.S. Congressional Serial Set* (Washington, DC: GPO, 1917).

[289] J. R. Van Frank, "Preliminary Examination of Neosho River, Kansas, from the North Line of Neosho County to the South Line of Labette County," October 19, 1896, Letter from Capt. William L. Sibert, November 24, 1896 and Letter from the Secretary of War, Transmitting, with a Letter from the Chief of Engineers, Report of Examination of Neosho River, Kansas, etc.), December 14, 1896, Referred to the Committee on Rivers and Harbors and Ordered to be Printed, December 14, 1896, 54th Cong., 2d Sess., Serial Set Vol. No. 3505, Session Vol. No. 29, H.R.Doc. 83. See also Graves, *History of Neosho County*, 1:441; and "Provisions for Western Rivers," *Guthrie (OK) Daily Leader*, April 5, 1896, 1.

[290] Rivers and Harbors Appropriation Act of 1899, March 3, 1899, Ch. 425, Sec. 9, 30 Stat. 1151. 33 U.S.C. § 401 et seq.

[291] U.S. Army Corps of Engineers, "Multipurpose Waterway Development."

[292] An Act to Provide for the Control of the Floods of the Mississippi River and of the Sacramento River, California, and for Other Purposes, States at Large, 64th Cong., 2d Sess., Ch. 144, March 1, 1917. For a history of the act, see Matthew T. Pearcy, "A History of the Ransdell-Humphreys Flood Control Act of 1917, *Louisiana History* 41, no. 2 (Spring 2000): 133–59. Quotation from Arnold, *Evolution of the 1936 Flood Control Act*, 3.

[293] Arnold, *Evolution of the 1936 Flood Control Act*, 15.

[294] Arnold, *Evolution of the 1936 Flood Control Act*, 16.

[295] Federal Water Power Act of 1920.

[296] Rivers and Harbors Act of March 3, 1925 (43 Stat 1186). Quotation from Arnold, *Evolution of the 1936 Flood Control Act*, 16.

[297] Arnold, *Evolution of the 1936 Flood Control Act*, 16–17.

[298] Taylor quoted in Arnold, *Evolution of the 1936 Flood Control Act*, 16.

[299] *Arkansas River and Tributaries*, 1215–341.

[300] "Flood Survey Started Here; Government Engineers in Miami to Map Neosho River for Control Job," *Miami Daily News-Record*, July 1, 1929, 1. See also "Grove News," *Miami News-Record*, June 23, 1929, 6.

[301] Synopsis of District Engineer's Report, June 19, 1931, 11.

[302] See Levee Project Estimates, ca. 1931; and Synopsis of District Engineer's Report, June 19, 1931.

[303] Levee Project Estimates ca. 1931. The information in this document was included in the later "Report on the Grand (Neosho) River," February 15, 1934.

[304] Synopsis, June 19, 1931, 10.

[305] Synopsis, June 19, 1931, 11.

[306] Synopsis, June 19, 1931, 12.

[307] Synopsis, June 19, 1931, 12.

[308] Synopsis, June 19, 1931, 12–13.

[309] Synopsis, June 19, 1931, 13.

[310] Synopsis, June 19, 1931, 11, 12–13.

[311] Synopsis, June 19, 1931, 13.

[312] "Report on the Grand (Neosho) River," February 15, 1934, 5–6.

[313] "Report on the Grand (Neosho) River," February 15, 1934, Appendices 25–29.

[314] Flood Control Act of 1936, 1571.

[315] R. V. Smrha, "Kansas Plan for Neosho River Basin Development," *Journal of the American Water Works Association* 39, no. 7 (July 1, 1947): 673–79, quotation on 674.

[316] KSBA, Division of Water Resources, *Progress on a State Plan of Water Resources Development, during the Period July 1, 1941, to September 30, 1942* (Topeka: KSBA, December 1942), 22, Folder: Grand Neosho River, T.D. [Tulsa District], Report of the Kansas State Board of Agriculture, 1942, RG77, Corps of Engineers, Southwestern Division, Survey Reports, 1937–1965, Grand Neosho River–Guadalupe River, HM2000, Box 17, NARA-FW.

[317] Secretary of War to Congress, July 29, 1935, quoted in KSBA, *Report . . . July 1, 1941, to September 30, 1942*, 21.

[318] *Arkansas River and Tributaries*, 1215–17, quotation on 1217.

[319] Arnold, *Evolution of the 1936 Flood Control Act*, 3.

[320] Arnold, *Evolution of the 1936 Flood Control Act*, 22.

[321] An Act Authorizing the Construction, Repair, and Preservation of Certain Public Works on Rivers and Harbors, and for Other Purposes, August 30, 1935, Chap. 831, §5, 49 Stat. 1048, quotation on 1039–40.

[322] Arnold, *Evolution of the 1936 Flood Control Act*, 22.

[323] Bill Caldwell, "Henry Holderman Was a Determined Visionary," *Joplin (MO) Globe*, October 31, 2020. See also W. R. Holway, "Dams on the Grand River," *Chronicles of Oklahoma* 26, no. 8 (Autumn 1948): 329–34; and W. R. Holway, *A History of the Grand River Dam Authority, State of Oklahoma, 1935–1968*, 2 Vols. (Tulsa: GRDA, 1968–1969), esp. 1:1–4, on which most of this section is based. See also Henry C. Holderman, interview by James R. Carselowey, September 15, 1937, transcript, *Indian-Pioneer History* 29, Grant Foreman Collection, Folder: Rivers, Okla, Grand River Dam, Okla, OKHC.

[324] Caldwell, "Henry Holderman."

[325] Holway, "Dams on the Grand River," 329; and Holway, *History of the Grand River Dam Authority*, 1:2.

[326] "Construction Expected to Begin Soon on Grand River Dam Project, Labeled One of Biggest Power Undertakings in U.S.," *Miami Daily Record-Herald*, December 20, 1921, 6.

[327] C. Orville Elliott, "An Analysis of the Production and Distribution of Electric Power by the Grand River Dam Authority" (PhD. diss., University of Oklahoma, 1958), 16.

[328] Fred W. Insull, PSCO, to Federal Power Commission, Declaration of Intention, May 25, 1923, 1, Folder: Power Projects: Grand River, OK, RG77, Corps of Engineers, Southwestern Division, Engineering Files—Harbors and Rivers, 1920–1940, Power Projects: Dixie Power–White River, HM2000, Box 56, E. SW8, NARA-FW.

[329] William V. King, Acting Executive Secretary, Federal Power Commission, to General Beach, re: Declaration of Intention, Public Service Company of Oklahoma, June 8, 1923, Folder: Power Projects: Grand River, OK, Box 56, NARA-FW.

[330] Donald H. Connelly, District Engineer, Memphis District, to Chief of Engineers, U.S. Army, October 16, 1923, 3, Folder: Power Projects: Grand River, OK, Box 56, NARA-FW.

[331] Connelly to Chief of Engineers, October 16, 1923, 4.

[332] H. Taylor, Acting Chief of Engineers, to Chief of Engineers, U.S. Army, October 22, 1923, Folder: Power Projects: Grand River, OK, Box 56, NARA-FW.

[333] April 12 date comes from the permit itself—application is not in folder, although the April 3 map is. See Federal Power Commission, Preliminary Permit, Project No. 498, Public Service Company of Oklahoma, July 25, 1925; and Public Service Company of Oklahoma, Application for Proposed Permit, Project No. 498, Map, April 3, 1924; both in Folder: Power Projects: Grand River, OK, Box 56, NARA-FW.

[334] Lewis W. Call, Acting Executive Secretary, Federal Power Commission, to George F. Short, Attorney General, State of Oklahoma, July 17, 1924, Folder: Power Projects: Grand River, OK, Box 56, NARA-FW.

[335] FPC, Preliminary Permit, July 25, 1925, 1, 3.

[336] PSCO, Application for Proposed Permit, Map, April 3, 1924.

[337] FPC, Preliminary Permit, July 25, 1925, 3–4.

[338] FPC, Preliminary Permit, July 25, 1925, 6.

[339] Holway, "Dams on the Grand River," 330; and Holway, *History of the Grand River Dam Authority*, 1:3.

[340] Holway, *History of the Grand River Dam Authority*, 2, sec. 6:1.

[341] All quotations from Elliott, "Grand River Dam Authority," 17.

[342] Holway, "Dams on the Grand River," 330; Elliott, "Grand River Dam Authority," 18; and Holway, *History of the Grand River Dam Authority*, 1:4.

[343] "Grand River Dam Job Set for Dec. 1," *Miami Daily News-Record*, October 29, 1930, 1.

[344] "Grand River Electric Project," *Harlow's Weekly* (November 16, 1929): 5, 16.

[345] "Grand River Electric Project," 16.

[346] *Tulsa World*, February 4, 1940, quoted in Elliott, "Grand River Dam Authority," 18.

[347] Conservation Commission, Minutes, re: "Application of Grand Hydro for Appropriation of Waters of Grand River," August 29, 1931, Soil Conservation Board, Box 2, OSDLA.

[348] "Ownership of River Beds at Issue in Suit against Ottawa County," *Miami Daily News-Record*, October 11, 1931, 1.

[349] "Riverbed Suit," *Harlow's Weekly* (October 17, 1931): 10.

[350] Holway, "Dams on the Grand River," 330; and Holway, *History of the Grand River Dam Authority*, 1:4.

[351] Elliott, "Grand River Dam Authority," 20–21.

[352] Richard Lowitt, "Developing the Grand River Dam Authority, Part 1, 1935–1944," *Chronicles of Oklahoma* 87, no. 2 (Summer 2009): 132–65.

[353] "Disney Water Proposals," *Harlow's Weekly* (December 1, 1934): 6.

[354]Lowitt, "Developing the Grand River Dam Authority, Part 1, 1935–1944," 132–65.

[355] O. D. Hall, "Inauguration Day and the Legislature," *Harlow's Weekly* (January 19, 1935): 4–5

[356] Lowitt, "Developing the Grand River Dam Authority, Part 1," 134.

[357] "Grand River Dam Project," *Harlow's Weekly* (March 4, 1935): 8–9, quotation on 8.

[358] "Grand River Dam Project," 9.

[359] Holway, *History of the Grand River Dam Authority*, 2:1.

[360] Unless otherwise noted, this paragraph is based on Holway, "Dams on the Grand River," 331; the text of the enabling act, transcribed in Holway, *History of the Grand River Dam Authority*, 2:1–4; and Lowitt, "Developing the Grand River Dam Authority, Part 1," 134–35.

[361] Holway, *History of the Grand River Dam Authority*, 2, sec. 2:1–2.

[362] See Holway, *History of the Grand River Dam Authority*, 2, sec. 2:6–7; and Elliott, "Grand River Dam Authority," 23.

[363] "Governor at Vinita," *Harlow's Weekly* (May 25, 1935): 11.

[364] Holway, *History of the Grand River Dam Authority*, 2:4.

[365] Holway, *History of the Grand River Dam Authority*, 2:9

[366] Lowitt, "Developing the Grand River Dam Authority, Part 1," 136; Holway, "Dams on the Grand River," 331; and Holway, *History of the Grand River Dam Authority*, 2, sec. 2:9–10.

[367] Holway, "Dams on the Grand River," 331; and Holway, *History of the Grand River Dam Authority*, 2, sec. 2:4. See also "No Grand River Legislation Soon," *Harlow's Weekly* (November 28, 1936): 11; and "Grand River Dam to Get Support," *Harlow's Weekly* (December 12, 1936): 3.

[368] Holway, "Dams on the Grand River," 331; and Holway, *History of the Grand River Dam Authority*, 2, sec. 2:4. See also "Grand River Again," *Harlow's Weekly* (January 16, 1937): 7.

[369] Lowitt, "Developing the Grand River Dam Authority, Part 1," 140.

[370] Holway, *History of the Grand River Dam Authority*, 2, sec. 2:10–11 and Lowitt, "Developing the Grand River Dam Authority, Part 1," 138–40.

[371] Lowitt, "Developing the Grand River Dam Authority, Part 1," 140. See also U. S. Russell, "Grand River Hydro-Electric Project Is Approved," *Harlow's Weekly* (September 18, 1937): 5–6.

[372] Compare descriptions of the celebration (with different dates) in Holway, *History of the Grand River Dam Authority*, 2, sec. 3:1; and Thelma K. Shumake, "Grand River Dam," May 2, 1939, Folder: Rivers, Okla, Grand River Dam, Okla, OKHC.

[373] Shumake, quoting the *Phoenix* and *Oklahoman*, in "Grand River Dam," May 2, 1939, 2–5, 7.

[374] Holway, *History of the Grand River Dam Authority*, 2, sec. 3:6; and Lowitt, "Developing the Grand River Dam Authority, Part 1," 140. See also "Choosing Key Officials for Dam Project a Big Task," *Harlow's Weekly* (October 30, 1937): 8.

[375] Holway, *History of the Grand River Dam Authority*, 2, sec. 3:9, 6–7, and sec. 6:1; and Lowitt, "Developing the Grand River Dam Authority, Part 1," 140.

[376] Quotation from Holway, *History of the Grand River Dam Authority*, 2, sec. 6:1; and see E. M. Markham, Maj. Gen., Chief of Engineers, to Col. Horatio B. Hackett, Asst. Admin. Federal Emergency Administration of Public Works, June 8, 1937; and Harold L. Ickes, Administrator [FEAPW], to Brig. Gen. M. C. Tyler, Acting Chief of Engineers, November 17, 1937, both in unlabeled folder, Box 3373 Legal, Misc. Legal Files 1937–1976, GRDA-HQ. See also "Brief Terms in Grand River Dam Contract," *Harlow's Weekly* (October 23, 1937): 14.

[377] Holway, *History of the Grand River Dam Authority*, 2, sec. 6:1.

[378] Unless otherwise noted, all quotations in this paragraph are from Holway, *History of the Grand River Dam Authority*, 2, sec. 6:2. The exact date of Holway and Cochrane's meeting with Reybold is unknown, but it must have pre-dated the April 22, 1938, plans the engineers ultimately submitted to and received approval on from the Corps.

[379] Holway, *History of the Grand River Dam Authority*, 2, sec. 6:3.

[380] Flood Control Act of 1936, 1578–79, 1596.

[381] W. R. Holway, Consulting Engineer, to Edward P. Marshall, GRDA General Counsel, April 20, 1945, conveying [Don McBride], "Statement on the Part of the Grand River Dam Authority," undated typescript, 2, [Master Files], GRDA-HQ

[382] *Arkansas and Its Tributaries*, 1250.

[383] Federal Power Commission, Docket No. DI–141, Declaration of Intent, February 11, 1938, also includes license articles, etc., Envelope: 1941–1946, Miscellaneous, Box 5095 Pensacola Misc. Records, 1940–1946, GRDA-HQ.

[384] Holway, *History of the Grand River Dam Authority*, 2, sec. 6:3–4.

[385] Holway, *History of the Grand River Dam Authority*, 2, sec. 6:4–5, quotations on 4.

[386] An Act Authorizing the Construction of Certain Public Works on Rivers and Harbors for Flood Control, and for Other Purposes, June 28, 1938, H.R. 10618, P.L. No. 761, 75th Cong., Sess. 3, 1215–26, quotations on 1215 (hereafter, Flood Control Act of 1938).

[387] "Comprehensive Flood-Control Plans and Works for Reservoirs, Levees, and Floodwalls," H.R. Rep. No. 2353 to Accompany H.R. 10618, 75th Cong., 3d Sess., *U.S. Congressional Serial Set* (1938): 1–38, esp. 20.

[388] All quotations in this paragraph are from Holway, *History of the Grand River Dam Authority*, 2, sec. 6:5. The Corps and other entities, however, had completed preliminary reporting.

[389] Holway, *History of the Grand River Dam Authority*, 2, sec. 6:5. According to Holway, a January 4, 1939, Corps report, advocated for reservoir construction on the Grand for flood control and noted that it would "yield a considerable economic benefit" especially downstream along the lower Mississippi and Arkansas Rivers. However, the Corps also found that building reservoirs for flood control alone "'would adversely affect hydroelectric development on the Grand River in Oklahoma, a condition not in accord with public interest" (cited in W. R. Holway, Consulting Engineer, to Edward P. Marshall, GRDA General Counsel, April 20, 1945; and [Don McBride], "Statement on the Part of the Grand River Dam Authority," undated typescript, [Master Files], GRDA-HQ).

[390] Federal Power Commission, Order Authorizing Issuance of License for Major Project, Project No. 1494, January 27, 1939, RG0980 [GRDA], box 3, folder 11, Federal Power Commission corr. re: Pensacola Dam, 1 of 2, 1937–1939, OSDLA. See also Oklahoma Planning and Resources Board, Division of Industrial and State Planning, Grand River Dam Authority and Pensacola Dam, confidential memorandum, ca. September 1945 (cover letter, Don McBride, OK Planning and Resources Board, to Hon. Robert S. Kerr, Governor of Oklahoma, September 8, 1945), 39 Box 5094 Legal, Pensacola & Kerr Misc. Records, 1940–1964, GRDA-HQ.

[391] R. L. Davidson, GRDA General Counsel, to Representative Lincoln Battenfield, January 31, 1939, Folder: Legislation, Box 3399 Pensacola/Hydro, Legislation and Legal Cases from 1940s, GRDA-HQ.

[392] R. V. L. Wright, GRDA General Manager, to Federal Power Commission, February 17, 1939, RG0980 [GRDA], box 3, folder 11, Federal Power Commission corr. re: Pensacola Dam, 1 of 2, 1937–1939, OSDLA.

[393] W. R. H[olway] to R. V. L. Wright, re: Flood Control Policy, April 4, 1939, Folder: Holway & Neuffer, General Mgr. Files [1930s], Box 2893 Dalrymple v. GRDA, 1940–1941 Originals, GRDA-HQ.

[394] Federal Power Commission, Order Modifying Authorization for Issuance of License, Project No. 1494, April 28, 1939; and Federal Power Commission, Order Further Modifying Authorization for Issuance of License, Project No. 1494, July 5, 1939, both in RG0980 [GRDA], box 3, folder 11, Federal Power Commission corr. re: Pensacola Dam, 1 of 2, 1937–1939, OSDLA. See also Holway, *History of the Grand River Dam Authority*, 2, sec. 6:5–6.

[395] GRDA Board, Resolution No. 299, July 11, 1939, RG0980 [GRDA], box 3, folder 11, Federal Power Commission corr. re: Pensacola Dam, 1 of 2, 1937–1939, OSDLA; Federal Power Commission, Washington, DC, License for Major Project, Project No. 1494, Oklahoma–Missouri Grand River Dam Authority, July 12, 1939, [Master Files], GRDA-HQ (document scanned at GRDA was both incomplete and dated July 12, 1939, so is therefore not the final license, which HRA was unable to locate as of this writing; and quotation from "Grand River Dam Authority Gets Federal Power License," *Harlow's Weekly* 51, no. 27 (July 8, 1939): 3. See also "Army Engineers Enter Grand River Dam Case," Harlow's Weekly (July 1, 1939): 3.

[396] License for Project No. 1494.

[397] License for Project No. 1494.

[398] Holway cited in "Grand River Dam Authority Faces Delay in Power Sale," *Harlow's Weekly* 51, no. 43 (October 28, 1939): 2.

[399] "Grand River Dam Authority Gets Rebuff in Land Case," *Harlow's Weekly* (October 21, 1939): 4.

[400] "Grand River Dam Authority Developments Come Fast," (2) and "Land Acquisition Speed Is Needed," (3) both in *Harlow's Weekly* 51, no. 50 (December 16, 1939).

[401] "Brief Terms in Grand River Dam Contract," *Harlow's Weekly* (October 23, 1937): 14; and "Grand River Dam Authority to Ask for Time Extension," *Harlow's Weekly* (October 14, 1939): 4.

[402] "Washington Conference Fails to Solve Grand River Matter," *Harlow's Weekly* (November 18, 1939): 4.

[403] "State Senate Passes Bill Giving Governor Full Control of GRDA While Board Ponders Empty Till," *Miami Daily News-Record*, March 7, 1939, 1; and "Grand River Dam Fight Breaks on Two Fronts," *Harlow's Weekly* (November 25, 1939): 3.

[404] "Washington Conference Fails to Solve Grand River Matter," *Harlow's Weekly* (November 18, 1939): 4.

[405] "Grand River Dam Fight Breaks," 3.

[406] "PWA Ready to Name Manager for Grand River Project," *Harlow's Weekly* 52, no. 1 (January 1, 1940): 2.

[407] "Lee Makes Charges in Grand River Dam Case," *Harlow's Weekly* 52, no. 1 (January 1, 1940): 2.

[408] Formal documentation of his exact hire date has not been found, however, Miami PUB minutes from March 1, 1940, indicate that Clonts was present and serving as general manager at a meeting that day (Miami PUB Minutes, March 1, 1940, 1014).

[409] "Grand Lake's Dam Dedicated by Turner," November 4, 1939, Photograph 2012.201.OVZ001.6516, Gateway to Oklahoma History, https://gateway.okhistory.org/ark:/67531/metadc1702369/?q=%22Grand%20River%22%20flood.

[410] Curtis Ward, "Celebration Follows Court Dam Decision," *Harlow's Weekly* (January 5, 1938): 14–15, quotations on 15.

[411] "Grand River Dam Authority Again Faces Fund Shortage," *Harlow's Weekly* (April 29, 1939): 4.

[412] Memorandum Brief, GRDA, a Public Corporation, vs. Grand-Hydro, a Corporation, et al., in the District Court of Mayes County, State of Oklahoma, No. 6375, Box 3362 Legal Pensacola Years, 1941–?, GRDA-HQ.

[413] "Grand River Dam Authority Land Purchase Efforts Fail," *Harlow's Weekly* (February 18, 1939): 5.

[414] "Grand River Dam Authority Gets Federal Power License," *Harlow's Weekly* 51, no. 27 (July 8, 1939): 3.

[415] "Grand River Dam Authority Fights for Site Title," *Harlow's Weekly* (October 7, 1939): 6; and "Grand River Dam Authority Moves to Acquire Dam Site," *Harlow's Weekly* (January 27, 1940): 2. For more on the Grand-Hydro suit, see R. L. Davidson, General Counsel to GRDA Board of Directors, October 14, 1940, Folder: Miscellaneous No. 2—1940, Box 3312 Pensacola 1940; Memorandum Brief, GRDA, a Public Corporation, vs. Grand-Hydro, a Corporation, et al., in the District Court of Mayes County, State of Oklahoma, No. 6375, Box 3362 Legal Pensacola Years, 1941–?; and Settlement Agreement between Grand River Dam Authority, a Public Corporation, and United States of America, August 1, 1946, 7, Box 2893 Dalrymple v. GRDA, 1940–1941 Originals, all at GRDA-HQ.

[416] "Grand River Dam Fight Breaks," 3.

[417] "Grand River Dam Fight Breaks," 3.

[418] "Organized Efforts to Force High Land Payments Charged," *Harlow's Weekly* (November 25, 1939): 3–4, quotation on 3.

[419] "Organized Efforts," 4.

[420] "Efforts Continued to Disqualify Judge," *Harlow's Weekly* (December 2, 1939): 4.

[421] R. L. Davidson, General Counsel, to GRDA Board of Directors, October 14, 1940, Folder: Miscellaneous No. 2—1940, Box 3312 Pensacola 1940, GRDA-HQ.

[422] "Grand River Dam Authority to Ask for Time Extension," *Harlow's Weekly* (October 14, 1939): 4.

[423] Davidson to GRDA Board of Directors, October 14, 1940, 2.

[424] Order Further Modifying Authorization for Issuance of License, Project No. 1494, July 5, 1939, [Master Files], GRDA-HQ.

[425] "Holway's Monthly Report Reveals Job's Progress," *Harlow's Weekly* 51, no. 50 (December 16, 1939): 2–3, quotation on 2.

[426] Q. B. Boydstun to Col. C. H. Chorpening, Tulsa District Engineer, May 15, 1947, 1, [Master Files], GRDA-HQ.

[427] Boydstun to Chorpening, May 15, 1947, 2.

[428] France Paris, GRDA GM, to Federal Power Commission, March 17, 1948, Folder: Master File 45, Box 2893 Dalrymple v. GRDA, 1940–1941 Originals, GRDA-HQ.

[429] City of Miami Resolution, November 7, 1938, Brown Binder, unpaginated, City Hall, Miami, OK.

[430] "Neosho Dam Is Labeled City's No. 1 Project," [*Miami News-Record*], April 21, 1939, accessed February 13, 2023, https://www.facebook.com/photo?fbid=559731689521930&set=pcb.559732412855191.

[431] First discussion of hiring Wood occurred on May 29, 1939, Book 2, 906–7; the contract was executed on June 2, 1939, Book 2, 909–11, both in Miami PUB Minutes. The PUB referred to a map accompanying the June 2, 1939, report that marked the proposed spot for the low-water dam, but neither the report nor the map has been found.

[432] Miami PUB Minutes, July 28, 1939, Book 2, 927–28. (Note: document missing in HRA's collection; description taken from research log.)

[433] Miami PUB Minutes, October 3, 5, 1939, Book 2, 942–44. Miami PUB included GRDA reports on Miami power plant operations in the meeting minutes. See also Minutes, February 8, 1940, Book 2, 994–1006, and February 16, 1940, Book 2, 1009.

[434] Miami PUB Minutes, October 20, 1939, Book 2, 939.

[435] Miami PUB Minutes, February 2, 1940, Book 2, 992.

[436] All quotations from W. R. Holway to Mayor W. W. Dobson and City of Miami, February 1, 1940, Folder: Correspondence—Engineers, Holway & Neuffer, Box 2902 Dalrymple v. GRDA, Box 2—Discovery Material, 1938–1939 Eng. Originals, GRDA-HQ. Note: mention is made in this letter of a "Miami sewer" survey (Contract 13-A, Book F 98), but this document has yet to be found.

[437] Minutes, February 16, 1940, Book 2, 1009.

[438] Miami PUB Minutes, March 1, 1940, Book 2, 1014.

[439] Miami PUB Minutes, April 9, 1940, Book 2, 1052.

[440] Miami PUB Minutes, April 23, 1940, 1063. GRDA also presented a proposal for power rates and charges (minutes, 1064–75).

[441] Miami PUB Minutes, May, June 1940, Book 2, 1105, quotations on 1109.

[442] R. L. Davidson, General Counsel to GRDA Board of Directors, October 14, 1940, Folder: Miscellaneous No. 2—1940, Box 3312 Pensacola 1940, GRDA-HQ.

[443] T. P. Clonts to Frank Nesbitt, Miami PUB, letter re: settlement of damages to City of Miami, November 12, 1940, transcribed in Minute Book 2, quotation on 1167, terms of agreement on 1169–73. See also Minutes of a Recessed Meeting of the Board of Directors of the Grand River Dam Authority, Held at Vinita, Oklahoma, November 12, 1940, on file at GRDA-HQ; and City of Miami Resolution No. A48, December 2, 1940, Brown Binder, City Hall, Miami, OK.

[444] December 2, 1940, resolution, release, and full text of the flowage easement transcribed in Minute Book 2, 1176–81. Fitzgerald followed up with a letter to GRDA assistant counsel Boydstun that the final resolution did not include one piece of language that GRDA had requested "because it would be incorrect." Fitzgerald noted that "the sum paid would not be nearly sufficient to locate and reconstruct the sewer system and water system and it was the understanding at the time we talked about that matter that we would use that sum in a WPA project; it being probably sufficient for the sponsor's part" (E. C. Fitzgerald to Q. B. Boydstun, December 3, 1940, transcribed in Minute Book 2, 1182).

[445] Cited to Minute Book G, Page 122, in Black Binder, W. C. Glenn, "A resumé of principal official acts of government of the City of Miami, Oklahoma, from August 16, 1899, to January 1, 1946, as compiled from the records of said City," City Hall, Miami, OK.

[446] R. V. L. Wright, R. L. Davidson, and W. R. Holway to GRDA Board of Directors, September 29, 1939, Folder: Non-Contract Construction, Grand River Project—Relocation of Utilities and Highways, Highways and Roads, Box 2893 Dalrymple v. GRDA, 1940–1941 Originals, GRDA-HQ.

[447] Ottawa County, Commissioners' Journal, No. 6, Beginning February 10, 1936, November 6, 1939, 239–40, and January 2, 1940, 249, Ottawa County Clerk's Office, Miami, OK.

[448] R. L. Davidson, General Counsel to GRDA Board of Directors, October 14, 1940, Folder: Miscellaneous No. 2—1940, Box 3312 Pensacola 1940, GRDA-HQ.

[449] T. P. Clonts, R. L. Davidson, and W. R. Holway to GRDA Board of Directors, August 3, 1940, Folder: Non-Contract Construction, Grand River Project—Relocation of Utilities and Highways, Highways and Roads, Box 2893. See also W. R. Holway to H. H. Ferguson, PWA Project Engineer, December 22, 1939, Folder: Correspondence—Engineers, Holway & Neuffer, Box 2902 Dalrymple v. GRDA, Box 2—Discovery Material, 1938–1939 Eng. Originals, both at GRDA-HQ.

[450] Davidson to GRDA Board, October 14, 1940.

[451] Minutes of a Recessed Meeting of the Board of Directors of the Grand River Dam Authority, Held at Vinita, Oklahoma, December 10, 1940, 8, on file at GRDA-HQ.

[452] Ottawa County, Commissioners' Journal, No. 6, December 28, 1940, 298–99; and Minutes of the Regular Monthly Meeting of the Board of Directors of the Grand River Dam Authority, Held at Vinita, Oklahoma, January 6, 1941, GRDA-HQ. See also Resolution No. 3, [Ottawa County Commissioners], December 28, 1940, Folder: Ottawa County, Box 2902 Dalrymple v. GRDA, Box 2—Discovery Material, 1938–1939 Eng. Originals, GRDA-HQ.

[453] See Lester M. Mark, Project Engineer, PWA, to T. P. Clonts, GRDA General Manager, January 16, 1941, Folder: Ottawa County, Box 2902 Dalrymple v. GRDA, Box 2—Discovery Material, 1938–1939 Eng. Originals, GRDA-HQ; Minutes of a Recessed Meeting of the Board of Directors of the Grand River Dam Authority, Held at Vinita, Oklahoma, January 21, 1941, GRDA-HQ; and Resolution No. 3 ("the correct resolution"), Ottawa County, Commissioners' Journal, No. 6, 309.

[454] Ottawa County, Commissioners' Journal, No. 6, March 8, 1941, 314–16.

[455] Ottawa County, Commissioners' Journal, No. 6, January 27, 1945, 532.

[456] E. K. Burlew, Acting Secretary of the Interior to Will Rogers, Chairman, House Committee on Indian Affairs, "Transferring Indian Lands to Grand River Dam Authority," April 20, 1940, printed in S.Rep. No. 1633, leg. day April 24, 1940, 76th Cong., 3d Sess., *U.S. Congressional Serial Set* (1940): 1–2, quotation on 1. See also H.R.Rep. No. 1940, "Transferring Indian Lands to Grand River Dam Authority," April 9, 1940, n.p., in the same volume.

[457] Committee on Indian Affairs, "Transferring Indian Lands to Grand River Dam Authority," *U.S. Congressional Serial Set* (1940): 1–2.

[458] An Act to Transfer Certain Indian Lands to the Grand River Dam Authority, and for Other Purposes, Public Law No. 597, 76th Cong., Chapter 322, 3d Sess., H.R. 7901, approved June 11, 1940, Folder: Misc., RG75, Records of the Bureau of Indian Affairs, Records of the Miami Indian Agency, Records of the Administrative Division, Records Relating to Land, Appraisal Records, Correspondence, 1930–1943, Miscellaneous, Box No. 5, E.107, NARA-FW.

[459] See Clyde W. Finn, Land Field Agent, to J. M. Stewart, Director of Lands, Office of Indian Affairs, March 8, 1939; H. A. Andrews, Superintendent, Quapaw Indian Agency, to Rex H. Barnes, Asst. Land Field Agent, February 28[?illegible], 1939; and quotation from Clyde W. Finn, Land Field Agent, to H. A. Andrews, Superintendent, Quapaw Indian Agency, February 24, 1939, all in Folder: Land Acquisition (Miscellaneous), RG75, Records of the Bureau of Indian Affairs, Records of the Miami Indian Agency, Records of the Administrative Division, Records Relating to Land, General, Land Transaction Files, 1938–1959, Box No. 2, E.93, E.94, NARA-FW.

[460] Burlew to Rogers, April 20, 1940.

[461] All quotations from U.S. Engineer Office, Tulsa, Oklahoma, "Operation of Pensacola Reservoir during Flood of April 1941, Grand (Neosho) River, Arkansas River Basin," May 1942, Folder: Pensacola Reservoir (Grand [Neosho] River), OK, T.D. [Tulsa District], 1942, RG77, Corps of Engineers, Southwestern Division, Reports and Studies on Waterways, 1936-1943, Tulsa District: Pensacola-Washita River, HM2000, Box 7, E. SW12, NARA-FW. See also W. C. Burnham, Hydraulic Engineer, to Edward P. Marshall, General Counsel, November 17, 1941, memorandum on Regulation of Flood Water Storage by District Engineer, Corps of Engineers, above Elevation 745, [Master Files], GRDA-HQ.

[462] Full original document is Brig. Gen. John J. Kingman, Acting Chief of Engineers, to Secretary of War, Rules and Regulations for the Operation of the Pensacola Dam, Grand River, Oklahoma, in the Interest of Flood Control," File No. 7495 (Grand River Dam Authority) 60, June 21, 1941, Folder: No. 16,098, District Court of Ottawa County, Board of Education of the Town of Wyandotte, etc. vs. Grand River Dam Authority [ca. 1941–1943], Box 2893 Dalrymple v. GRDA, 1940–1941 Originals, GRDA-HQ. A partial transcription of the original is in Burnham to Marshall, November 17, 1941, memorandum, 2–3.

[463] See, for example, Telegrams, Board of Education of the Town of Wyandotte, etc. vs. Grand River Dam Authority, Folder: No. 16,098, District Court of Ottawa County, Board of Education of the Town of Wyandotte, etc. vs. Grand River Dam Authority [ca. 1941–1943], Box 2893 Dalrymple v. GRDA, 1940–1941 Originals, GRDA-HQ.

[464] An Act Authorizing the Construction of Certain Public Works on Rivers and Harbors for Flood Control, and for Other Purposes, August 18, 1941, H.R. 4911, P.L. No. 228, 77th Cong., Sess. 1, 638–51, esp. 645 (hereafter, Flood Control Act of 1941).

[465] Franklin D. Roosevelt, "Executive Order, Directing the Federal Works Administration to Take Possession of and Operate a Certain project of the Grand River Dam Authority," Executive Order No. 8944, November 19, 1941, *Federal Register* 6, no. 228 (November 25, 1941): 5947.

[466] Quoted in [Q. B. Boydstun],"Suggested Proposal of Secretary of the Interior for Settlement of Affairs between Grand River Dam Authority and the United States," draft [ca. June 1945?], "Synopsis of the History of Grand River Dam Authority," undated typescript [June 1945?], [Master Files], GRDA-HQ. See also Douglas G. Wright, Special Representative for the Administrator, to FPC, June 15, 1942, [Master Files], GRDA-HQ.

[467] Grand (Neosho) River and Its Tributaries, Oklahoma, Kansas, Missouri, and Arkansas, February 19, 1946, H.R.Doc. No. 442, reprinted with correspondence in *U.S. Congressional Serial Set* (Washington, DC: GPO, 1948): 1–71, esp. 35.

[468] "History of the Grand River Dam Project, November 21, 1941, to September 30, 1945," 4.

[469] "Southwestern Power Administration," *Official Congressional Directory*, corrected to February 14, 1947 (Washington, DC: GPO, 1947): 605.

[470] Grand (Neosho) River and Its Tributaries, Oklahoma, Kansas, Missouri, and Arkansas, February 19, 1946, H.R.Doc. No. 442, reprinted with correspondence in *U.S. Congressional Serial Set* (Washington, DC: GPO, 1948): 1–71, esp. 35.

[471] KSBA, *Progress on a State Plan of Water Resources Development . . . September 30, 1942*, 18.

[472] Gaging data from USGS 07185000 Neosho River near Commerce, OK (1940–2022) and USGS 07189500 Neosho River near Grove, OK (1925–1939), accessed February 7, 2023, waterdata.usgs.gov.

[473] Holway, "Dams on the Grand River," 332.

[474] Telegrams, Board of Education of the Town of Wyandotte, etc. vs. Grand River Dam Authority, Folder: No. 16,098, District Court of Ottawa County, Board of Education of the Town of Wyandotte, etc. vs. Grand River Dam Authority [ca. 1941–1943], Box 2893 Dalrymple v. GRDA, 1940–1941 Originals, GRDA-HQ. Note: there is a full list of the directions the Corps gave GRDA from April 17–November 17, 1941, in Master Files, GRDA-HQ.

[475] W. C. Burnham, Hydraulic Engineer, to Douglas G. Wright, Special Representative for the Administrator, February 4, 1943, Summary with Data of Reservoir Operations, 1942, 1 [Master Files], GRDA-HQ.

[476] Edward P. Marshall, GRDA General Counsel, to C. A. West, GRDA Acting General Manager, Re: Potential Liability Resulting from Flooding of Uncontrolled Lands, November 12, 1941, quotation on 2, Folder: Miscellaneous—No. 3—1941, Box 2897 Dalrymple v. GRDA, 1940–1941 Originals, GRDA-HQ.

[477] Douglas G. Wright, Special Representative for the Administrator, to H. A. Montgomery, U.S. District Engineer, Tulsa, December 16, 1941, Folder: Tables, Plates and Exhibits to Accompany Letter to Chief of Engineers, Dated May 29, 1943, from District Engineer, Tulsa District, Re: Flood of May 1943, Box 13, Alva J. Hickerson Papers, Identifier: 1983-002, OSU Archives.

[478] Edward P. Marshall, General Counsel, to Lt. Col. H. A. Montgomery, December 18, 1941, re: Flood Damage Claims c. GRDA, [Master Files], GRDA-HQ.

[479] Lt. Col. H. A. Montgomery, Tulsa District, to Edward P. Marshall, GRDA General Counsel, February 19, 1942, in [Master Files], GRDA-HQ.

[480] Edward P. Marshall, GRDA General Counsel, to GRDA Board, February 24, 1942, [Master Files], GRDA-HQ.

[481] Edward P. Marshall, GRDA General Counsel, to FPC, March 24, 1942, [Master Files], GRDA-HQ.

[482] Judge William M. Thomas to Col. A. J. Montgomery, Tulsa District Engineer, May 13, 1942, [Master Files], GRDA-HQ.

[483] Leon M. Fuquay, FPC, to Edward P. Marshall, GRDA General Counsel, May 18, 1942, [Master Files], GRDA-HQ.

[484] Edward P. Marshall, GRDA General Counsel, to Leon M. Fuquay, FPC, June 5, 1942, [Master Files], GRDA-HQ.

[485] Edward P. Marshall, GRDA General Counsel, to Douglas G. Wright, Special Representative for the Administrator, June 5, 1942, [Master Files], GRDA-HQ.

[486] Douglas G. Wright, Special Representative for the Administrator, to FPC, June 15, 1942, [Master Files], GRDA-HQ.

[487] Wright to FPC, June 15, 1942.

[488] [Leon M. Fuquay], FPC, to Douglas G. Wright, Special Representative for the Administrator, July 3, 1942, [Master Files], GRDA-HQ.

[489] Kansas Water Resources Board, State Water Plan Studies—Part A: Preliminary Appraisal of Kansas Water Problems, Section 7, Neosho Unit, June 1961, 51, KSHS.

[490] "Statement of Douglas G. Wright, Administrator, Southwestern Power Administration, Accompanied by Arthur Goldschmidt, Director, Division of Power, Department of the Interior," March 1, 1944, in *Interior Department Appropriation Bill for 1945, Hearings Conducted by the Subcommittee [on Interior Department Appropriations]*, Part 1 (Washington, DC: GPO, 1944), 177.

[491] W. C. Burnham, Hydraulic Engineer, to Douglas G. Wright, Special Representative for the Administrator, June 5, 1943, Memorandum re Reservoir Operations through Flood Period—May 1943, 2, [Master Files], GRDA Headquarters, Choteau, Oklahoma.

[492] "Dam Credited with Saving Big War Plant," *Tulsa Tribune*, May 11, 1943.

[493] Pool level from Burnham to Wright, June 5, 1943, 2; and quotation from "Grand Lake Backs Up," *Tulsa World*, May 12, 1943.

[494] Wright, statement, 176.

[495] Graham quoted in Lowitt, “Developing the Grand River Dam Authority, Part 1,” 154. See also Resolution, Pryor Chamber of Commerce, May 21, 1943; N. R. Graham to Tulsa Chamber of Commerce, May 18, 1943; Record of Grand River Dams, [1943]; “C. of C. Asks GRD Inquiry,” *Tulsa Tribune*, May 18, 1943; “GRD Operation Criticized,” *Tulsa World*, May 19, 1943; “3-Dam Control ‘Flood Answer,’” *Tulsa Tribune*, May 19, 1943; Muskogee Chamber of Commerce, “Petition to the Oklahoma Delegation in Congress,” May 24, 1943; “GRDA Policy Disregards Other Areas, Graham Says,” *Tulsa World*, May 30, 1943; “GRDA Policy Disregards Other Areas, Graham Says,” *Tulsa World*, May 30, 1943; “Grand River Dam Inquiry Essential,” *Tulsa World*, May 31, 1943; “Wright Answers Graham’s Charge,” *Tulsa World*, June 2, 1943; “Graham Pens New Reply to Wright,” *Tulsa World*, June 3, 1943; “Wright Declares GRD Co-Operated,” *Tulsa World*, June 5, 1943; “GRDA Made Dam, ‘Power Project,’ Engineer Admits,” *Tulsa World*, June 9, 1943; “E. H. Moore Cites First GRD Plans,” *Tulsa World*, June 19, 1943; “Holway Answers Moore’s Charges,” *Tulsa World*, June 23, 1943, Folder N. R. Graham Report, Grand River, 1943 Flood; and additional documents compiled in Folder: Tables, Plates and Exhibits to Accompany Letter to Chief of Engineers, Dated May 29, 1943, from District Engineer, Tulsa District, Re: Flood of May 1943, all in Box 13, Alva J. Hickerson Papers, Identifier: 1983-002, OSU Archives.

[496] Douglas G. Wright, Special Representative for the Administrator, to Western Power Office, May 25, 1943, Memorandum on Protest of the Operating Policy of Pensacola Reservoir during the Flood of May 8 to May 24, 1943, quotations on 2, [Master Files], GRDA-HQ.

[497] “Grand River Dam,” editorial, May 19, 1943.

[498] Wright, Memorandum on Protest,” 3.

[499] Wright, statement, 177.

[500] Wright, statement, 178.

[501] Wright, statement, 178. See also W. C. Burnham, Hydraulic Engineer, to Douglas G. Wright, Administrator, June 28, 1946, Folder: Tables, Plates and Exhibits to Accompany Letter to Chief of Engineers, Dated May 29, 1943, from District Engineer, Tulsa District, Re: Flood of May 1943, Box 13, Alva J. Hickerson Papers, Identifier: 1983-002, OSU Archives.

[502] “FWA Would Pay for Personal Losses in Flood,” [*Tulsa Tribune*?], [June?] 1943, RG0980 [GRDA], box 3, Folder GRDA-Newspaper clippings + a Few Photo, 1938–1964, OSDLA.

[503] “Thomas Pushes Legislation to Help This Area,” *Miami Daily News-Record*, June 13, 1943, 1, 7, quotation on 7.

[504] “Thomas Pushes Legislation,” 7.

[505] Miami PUB Minutes, June 18, 1943, Book 2, 1515–16.

[506] Miami PUB Minutes, June 18, 1943, Book 2, 1516.

[507] Miami PUB Minutes, July 2, 1943, Book 2, 1521.

[508] Miami PUB Minutes, July 7, 1943, Book 2, 1524. Whether the City completed the survey is unclear; in November when Burns & McDonnell checked on whether Miami still needed their services, the City noted that it was “still not ready to move ahead” perhaps because it was waiting for the results of the SWPA’s land and easement acquisition and settlement of pending damage claims and condemnation suits (Miami PUB Minutes, November 3, 1943, Book 2, 1562–63).

[509] Edward P. Marshall, GRDA General Counsel, to Perry Porter, Attorney, July 21, 1943, [Master Files], GRDA-HQ.

[510] “GRD’s Director Discloses Plan to Buy Acreage,” and “Ickes Named by FDR to Sell GRD Power,” *Miami Daily News-Record*, August 1, 1943, 1.

[511] Miami PUB Minutes, August 3, 1944, Book 2, 1665–69, quotation on 1666.

[512] “U.S. Puts Crimp in Hopes for Grand Lake Boom,” [*Tulsa Tribune*?], August 10, 1943, clipping, Folder GRDA-Newspaper Clippings + A Few Photos, 1938–1964, Box 3, RG0980 [GRDA], OSDLA.

[513] “Lake Elevation to 755 Only in Time of Flood,” *Miami Daily News-Record*, November 28, 1943, 10.

[514] "U.S. Sues for Land in County," *Miami Daily News-Record*, March 14, 1944, 1.

[515] Edward P. Marshall, GRDA General Counsel, to Don McBride, Oklahoma Planning and Resources Board, February 24, 1945, 1, Folder (MC) Miscellaneous, Box 5095 Pensacola Misc. Records, 1940–1946, GRDA-HQ.

[516] Marshall to McBride, February 24, 1945, 2.

[517] An Act Authorizing the Construction of Certain Public Works on Rivers and Harbors for Flood Control, and for Other Purposes, December 22, 1944, H.R. 4485, P.L. No. 534, 78th Cong., 2d sess., 887–907, quotation on 890 (hereafter, Flood Control Act of 1944).

[518] Oklahoma Planning and Resources Board, confidential memorandum, ca. September 1945, GRDA-HQ.

[519] "Synopsis of the History of Grand River Dam Authority," undated typescript [June 1945?], 3–5.

[520] "Action to Return GRDA to State Is Passed by Solons," *Miami Daily News-Record*, May 23, 1946, 5; "Authorizing Return of Grand River Dam Project to Grand River Dam Authority of Oklahoma," House Report No. 2107, May 23, 1946, and "Authorizing Return of Grand River Dam Project to Grand River Dam Authority of Oklahoma," Senate Report No. 1500, June 13, 1946, *U.S. Congressional Serial Set* (1946): 1–4; and Flood Control, Hearings before the Committee on Commerce, Senate, on H.R. 6597, An Act Authorizing the Construction of Certain Public Works on Rivers and Harbors for Flood Control, and for Other Purposes, June 24–26, 1946, 79th Cong., 2d sess. (Washington, DC: GPO, 1946).

[521] Settlement Agreement between Grand River Dam Authority, a Public Corporation, and United States of America, August 1, 1946, Box 2893 Dalrymple v. GRDA, 1940–1941 Originals, GRDA-HQ.

[522] Settlement Agreement, August 1, 1946, 14, 18.

[523] Settlement Agreement, August 1, 1946, 14.

[524] Settlement Agreement, August 1, 1946, 18.

[525] Settlement Agreement, August 1, 1946, 27.

[526] An Act to Authorize the Use of Certain Lands of the United States for Flowage in Connection with Providing Additional Storage Space in the Pensacola Reservoir of the Grand River Dam Project in Oklahoma, and for Other Purposes, August 9, 1946, Public Law 79-712, Chapter 944, 79th Cong., 2d Sess., *U.S. Statutes at Large* 60, Main Section (1946): 974–75.

[527] "U.S. Returns Grand River Dam to State: Transfer Effected at Twin Conferences in Tulsa and Kansas City," [*Tulsa Tribune*?], [August 21, 1946], n.p., Folder GRDA-Newspaper Clippings + A Few Photos, 1938–1964, OSDLA. See also "Grand River Transfer Effected Here Today," [*Tulsa Tribune?*], [August 21, 1946], in same folder.

[528] Douglas G. Wright, Administrator, Southwestern Power Administration, to Col. C. H. Chorpening, Tulsa District Engineer, August 21, 1946; Col. C. H. Chorpening to GRDA, August 23, 1946; and Douglas G. Wright, Administrator, Southwestern Power Administration, to John L. Saunders, USGS, August 28, 1946, [Master Files], GRDA-HQ.

[529] W. C. Burnham, Hydraulic Engineer, to Douglas G. Wright, Administrator, July 28, 1947, 1, regarding sufficient flowage easements and referring to Brig. Gen. R. C. Crawford, Acting Chief of Engineers, to Arthur Goldschmidt, July 2, 1947, 1, [Master Files], GRDA.

[530] Burnham to Wright, July 28, 1947, 1.

[531] Burnham to Wright, July 28, 1947, 2.

[532] Black & Veatch, "Report on Pensacola Reservoir Backwater Effect on Sanitary and Storm Sewer Systems at Miami, Oklahoma," December 1942, and cover letter from Bert F. Steves to District Engineer, U.S. Engineer Corps, Tulsa, December 28, 1942, Folder: Pensacola Reservoir (Grand [Neosho] River), OK, T.D. [Tulsa District], 800.922, 1942, RG77, Corps of Engineers, Southwestern Division, Reports and Studies on Waterways, 1936–1943, Tulsa District: Pensacola-Washita River, HM2000, Box 7, NARA-FW.

533 Burnham to Wright, July 28, 1947, 2.

534 Burnham to Wright, July 28, 1947, 3.

535 Burnham to Wright, July 28, 1947, 5.

536 *Annual Report of the Chief of Engineers, United States Army*, 2 parts, House Document No. 658 (Washington, DC: GPO, 1942), 1:982–84.

537 USACE, "History of Fort Gibson Lake," accessed December 2, 2022, https://www.swt.usace.army.mil/Locations/Tulsa-District-Lakes/Oklahoma/Fort-Gibson-Lake/History/#:~:text=Abandoned%20by%20the%20government%20in,of%20the%20first%20log%20fort.

538 Glen Roberson, "Grand River Dam Authority," *Encyclopedia of Oklahoma History and Culture*, accessed December 2, 2022, https://www.okhistory.org/publications/enc/entry.php?entry=GR006.

539 *Grand (Neosho) River and Its Tributaries*, 38.

540 *Grand (Neosho) River and Its Tributaries*, 41. Public hearings revealed that most local entities and private individuals wanted the proposed projects but neither wanted to pay for them nor met the basic requirements that federal assistance required. The first hurdle was the fact that Kansas had not created a legal mechanism by which to create public entities within the state with which the government could contract and that could also guarantee the government against future claims for damages on account of construction and operation of the project. Even with the creation of such entities, it was almost impossible to secure enough local support or funds to purchase the land and flowage rights, secure rights-of-way, etc., shared costs of planning and construction, and bear all costs of operation and maintenance once the structure was built. As one report noted, "Were all costs to be borne by the federal government, there appears to be little doubt the attitude expressed at these hearings would be entirely different. However, the belief has grown that ultimately the federal government will assume all costs in connection with the protection of cities and agricultural lands from flood damage." What people misunderstood was that the goals of the federal government in most cases was improving streams as they related to navigable waters downstream—a priority that was often in direct conflict with state and local interest in domestic and industrial water supply, urban and rural flood control, irrigation, pollution, and other primarily local concerns. See Kansas State Planning Board, *Water Resources of Kansas*, Kansas Legislative Council Publication No. 66, November 1937, KSHS, 6–7.

541 Christy, comp., *Coffey County*, 72.

542 Flood Control Act of May 17, 1950, Public Law 516, 81st Cong., 2nd Sess., Chapter 188. See also USACE, "History of Council Grove Lake," https://www.swt.usace.army.mil/Locations/Tulsa-District-Lakes/Kansas/Council-Grove-Lake/History/; "History of Marion Reservoir," https://www.swt.usace.army.mil/Locations/Tulsa-District-Lakes/Kansas/Marion-Reservoir/History/; and "History of John Redmond Reservoir," https://www.swt.usace.army.mil/Locations/Tulsa-District-Lakes/Kansas/John-Redmond-Reservoir/History/, all accessed December 1, 2022.

543 FEMA, "Flood Insurance Study," June 1980.

544 Seth E. Studley, *Changes in High-Flow Frequency and Channel Geometry of the Neosho River Downstream from John Redmond Dam, Southeastern Kansas*, U.S. Geological Survey Water-Resources Investigations Report 96-4243 (1996), 1.

545 Erling Helland Associates, "Zoning Ordinance for the City of Miami, Oklahoma," June 18, 1979, 45, prepared for the City Planning Commission, Miami, OK, OSDLA.

546 FEMA, "Flood Insurance Study," June 1980, 1.

547 FEMA, "Flood Insurance Study," June 1980, 4, 6, quotation on 2.

548 FEMA, "Flood Insurance Study," June 1980, 6.

549 FEMA, "Flood Insurance Study," June 1980, 7.

[550] FEMA, "Flood Insurance Study," June 1980, 8. See also Federal Emergency Management Agency, "Flood Insurance Study, City of Miami, Oklahoma, Ottawa County," September 30, 1988, accessed February 27, 2022, https://hdl.handle.net/2027/txa.ark:/81423/m3m022, which is almost exactly the same as the 1980 report.

[551] FEMA, "Flood Insurance Study," June 1980, 8–9.

[552] FEMA, "Flood Insurance Study," June 1980, 8.

[553] FEMA, "Flood Insurance Study," June 1980, 16.

[554] Army Corps of Engineers, "Southwestern Division Report," Energy and Water Development Appropriations for 1990, *Hearings before a Subcommittee of the Committee on Appropriations, House of Representatives*, February 1, 1989, 101st Congress, 1st Sess. (Washington, DC: GPO, 1989), 918.

[555] Army Corps of Engineers, "Status Report, Southwestern Division," *Hearings before a Subcommittee of the Committee on Appropriations, House of Representatives*, July 21, 1991, 102d Congress, 1st Sess. (Washington, DC: GPO, 1991), 565.

[556] "Southwestern Division Report," February 1, 1989, 871.

[557] "Status Report, Southwestern Division," July 21, 1991, 565.

[558] An Act to Provide for Improvements to the Rivers and Harbors of the United States, to Provide for the Conservation and Development of Water and Related Resources, and for Other Purposes, December 16, 2016, S. 612, PL 322, 114th Cong., 130 Stat. 1631, n,p., https://www.congress.gov/114/plaws/publ322/PLAW-114publ322.pdf.

[559] An Act to Authorize Appropriations for Fiscal Year 2020 for Military Activities of the Department of Defense, for Military Construction, and for Defense Activities of the Department of Energy, to Prescribe Military Personnel Strengths for Such Fiscal Year, and for Other Purposes, December 20, 2018, S. 1790, PL 92, 116th Cong., 1333 Stat. 1198, n.p., https://www.congress.gov/116/plaws/publ92/PLAW-116publ92.pdf.

Appendix A: Photographic Chronology of Flooding in the Neosho (Grand) River Watershed

1885

Figure 1. Neosho River flood, Burlington, Coffey County, Kansas, July 4, 1885.

Source: Wanda Christy, comp., *Coffey County*, Vol. 1, *A Glimpse into Its Past, Present, and Future!*

Pre-1892

Figure 2. Neosho River flood, Burlington, Coffey County, Kansas, n.d. [pre-1892].

Source: Coffey County Historical Society, Burlington, KS.

1898

Figure 3. Neosho River flood, near Council Grove, Morris County, Kansas, 1898.
Source: Kansas State Historical Society, Digital Collection, Image 622748.

1902

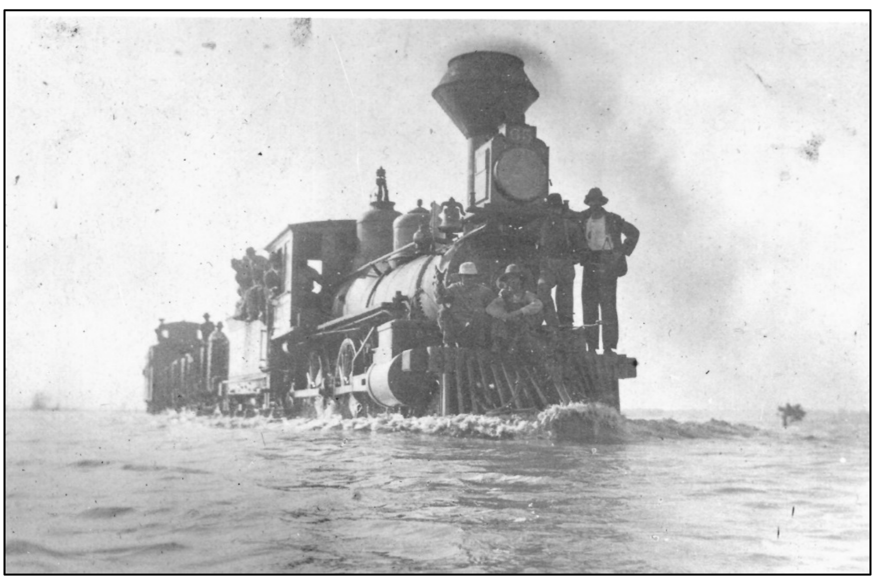


Figure 4. Neosho River flood, Hartford, Lyon County, Kansas, ca. 1902.
Source: Lyon County Historical Society, Emporia, KS.

Figure 5. Neosho River flood, Burlington, Coffey County, Kansas, June 8, 1902.
Source: Coffey County Historical Society, Burlington, KS.

Figure 6. Cottonwood River flood, Marion, Marion County, Kansas, June 3, 1902.
Source: Marion County Historical Society, Marion, KS.

Figure 7. Neosho River flood, Iola, Allen County, Kansas, ca. 1902.
Source: Allen County Historical Society, Iola, KS.

1903

Figure 8. Cottonwood River flood, Marion, Marion County, Kansas, May 29, 1903.
Source: Marion County Historical Society, Marion, KS.

Figure 9. Aftermath of May 28, 1903, Neosho River flood. Council Grove, Morris County, Kansas, photo dated June 4, 1903.

Source: Morris County Historical Society, Council Grove, KS.

1904

Figure 10. Neosho River flood, Strawn, Coffey County, Kansas, July 7, 1904.

Source: Coffey County Historical Society, Burlington, KS.

Figure 11. Neosho River flood, Iola, Allen County, Kansas, ca. 1904.
Source: Allen County Historical Society, Iola, KS

1909

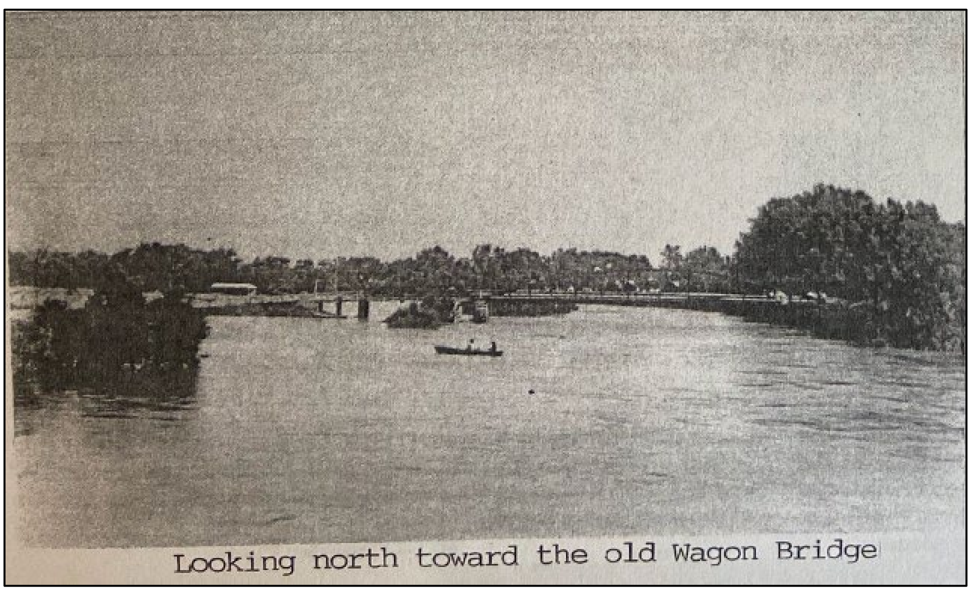


Figure 12. Neosho River flood, LeRoy, Coffey County, Kansas, July 11, 1909.
Source: Wanda Houck Christy and Della Becker Meyer, comps., "LeRoy, Kansas: The Birth of a Small Town," typed manuscript, 2014, Coffey County Historical Society, Burlington, KS.

1910

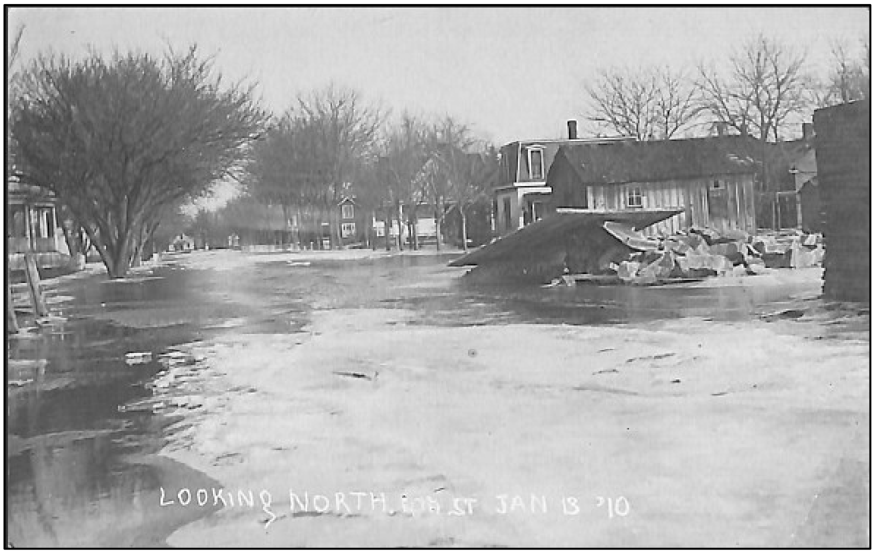


Figure 13. Cottonwood River flood, Marion, Marion County, Kansas, January 13, 1910.

Source: Marion County Historical Society, Marion, KS.

1916

Figure 14. Cottonwood River flood, Marion, Marion County, Kansas, June 11, 1916.

Source: Marion County Historical Society, Marion, KS.

1922

Figure 15. Rock Creek (Neosho River tributary) flood, Burlington, Coffey County, Kansas, April 8, 1922.

Source: Kansas Water Commission, *Third Biennial Report, 1921–1922* (Topeka, KS: Walker, 1922). On file at Kansas State Historical Society, Topeka.

Figure 16. Neosho River flood, Miami, Ottawa County, Oklahoma, April 9, 1922.[1]

Source: Dobson Museum, Ottawa County Historical Society, Miami, OK.

[1] Velma Nieberding reprinted this image in her book and noted that it was taken at the south end of Main Street showing the former entrance to the park. She refers to an "X" on the photo in her book, which is barely visible on the pillar at the left (just above the horses' rumps), and notes that this structure "is believed to be the old low-water bridge replaced in 1967" (*History of Ottawa County* [Marceline, MO: Walsworth, 1983], 193).

1923

Figure 17. Cottonwood River flood, exact location unknown, June 10, 1923.
Source: Chase County Historical Society, Cottonwood Falls, KS.

Figure 18. Neosho River flood, Council Grove, Morris County, Kansas, July 4, 1923.
Source: Morris County Historical Society, Council Grove, KS.

Figure 19. Tar Creek (Neosho River tributary) flood, Picher, Ottawa County, Oklahoma, June 14, 1923.

Source: Garnet L. Hood, scrapbook, n.d., Oklahoma History Center, Oklahoma City.

1926

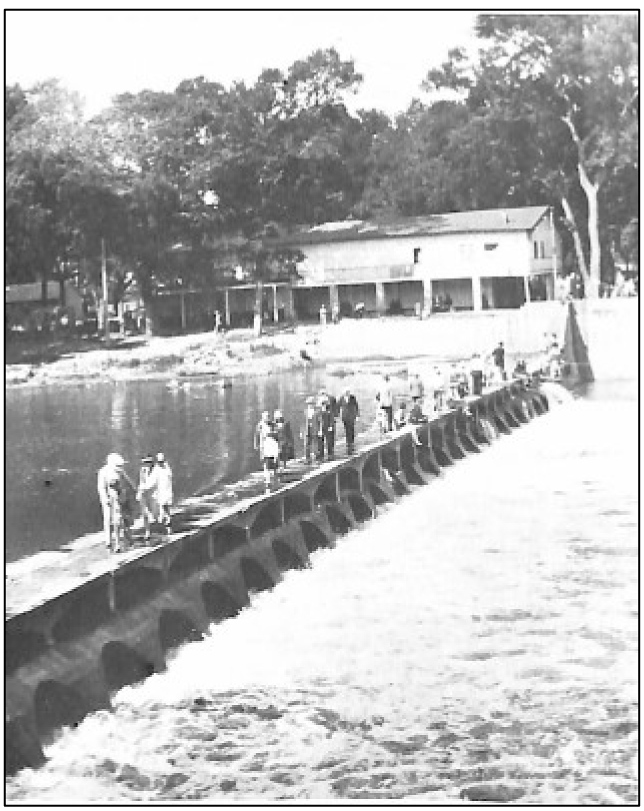


Figure 20. Low-water dam, Riverview Park, Miami, Ottawa County, Oklahoma, May 16, 1926.

Source: George and Frances Webb, eds., *Reflections, Miami, Oklahoma, 1891–1991* ([Miami, OK?]: Sooner Printing, 1991), 43. On file at Dobson Museum/Ottawa County Historical Society, Miami, OK.

Figure 21. Neosho River flood, Burlington, Coffey County, Kansas, September 12, 1926.
Source: Coffey County Historical Society, Burlington, KS.

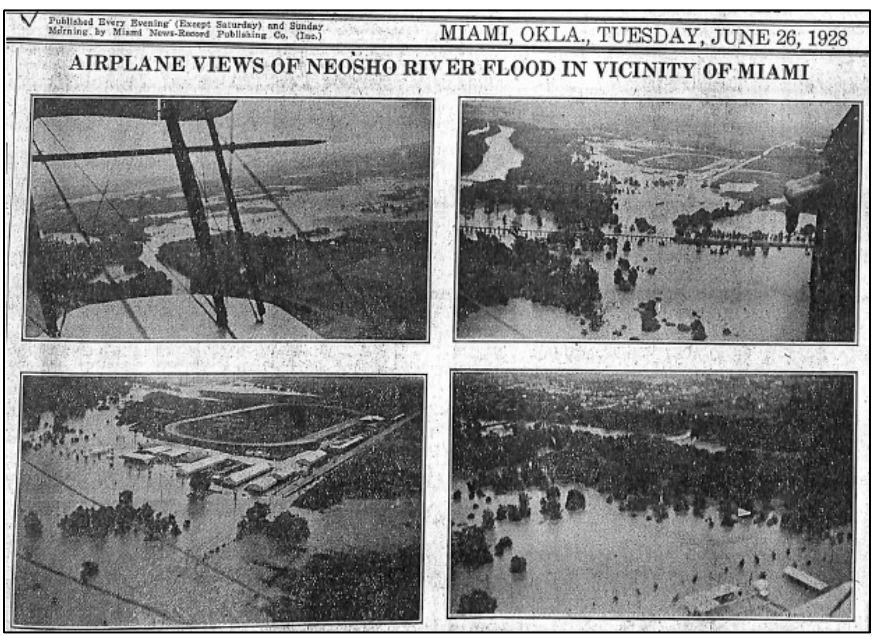
1927

Figure 22. Neosho River flood, Council Grove, Morris County, Kansas, June 17, 1927.
Source: Morris County Historical Society, Council Grove, KS.

Figure 23. Cottonwood River flood, Cottonwood Falls, Kansas, ca. 1927.

Source: Chase County Historical Society, Cottonwood Falls, KS.

1928



Published Every Evening (Except Saturday) and Sunday Morning by Miami News-Record Publishing Co. (Inc.)

MIAMI, OKLA., TUESDAY, JUNE 26, 1928

AIRPLANE VIEWS OF NEOSHO RIVER FLOOD IN VICINITY OF MIAMI

Figure 24. Neosho River flood, Miami, Ottawa County, Oklahoma, June 26, 1928.

Source: *Miami News-Record*, June 26, 1928, on file at Dobson Museum, Ottawa County Historical Society, Miami, OK.

1929

Figure 25. Neosho River flood, Council Grove, Morris County, Kansas, ca. 1929. Compare with Figure 29.

Source: Morris County Historical Society, Council Grove, KS.

1935

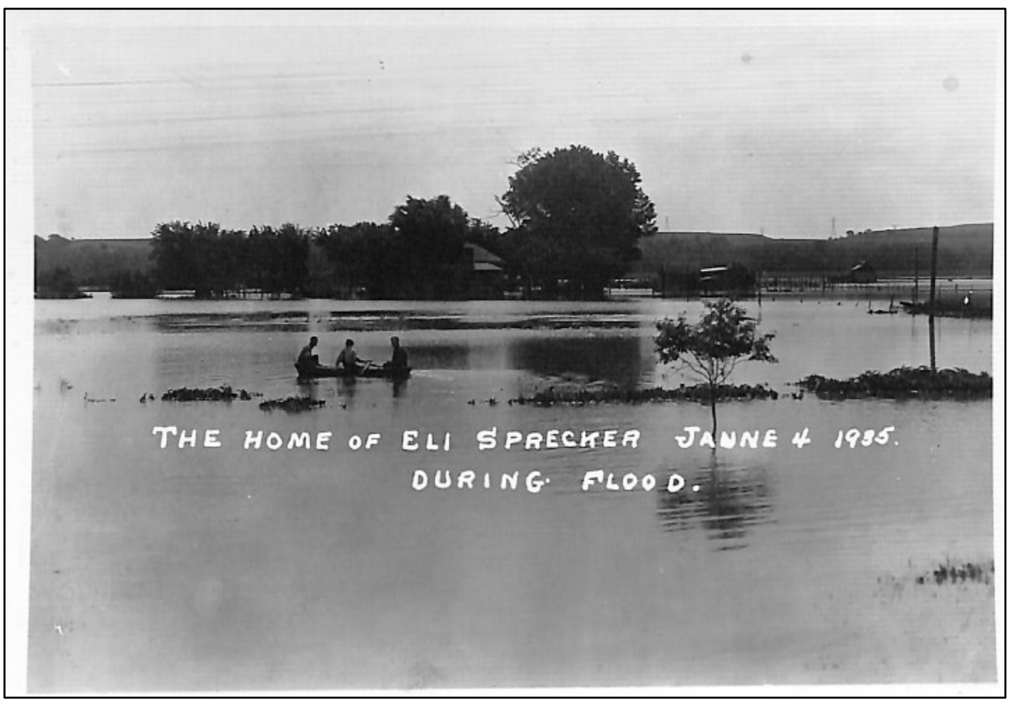
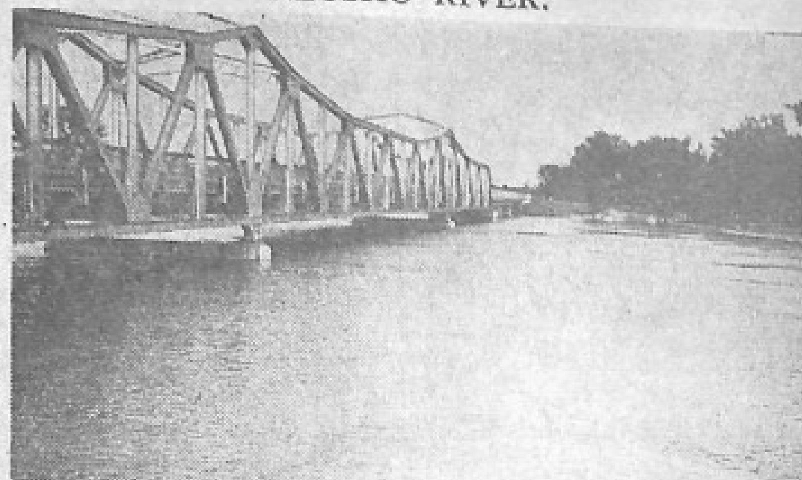


Figure 26. Neosho River flood, vicinity of Council Grove, Morris County, Kansas, June 4, 1935.

Source: Morris County Historical Society, Council Grove, KS.

1938

KANSAS FLOOD GLIMPSES ALONG THE NEOSHO RIVER.



RISING RIVER—The Neosho river, which has been at flood stage more than a week, is shown yesterday as it reached a new high point, running only a few feet under a bridge on highway 166 near Chetopa, Kas., just north of the Oklahoma state line.

HIGHWAY RESEMBLES A CANAL—At this point on highway 166 near Chetopa the only "traffic" now is by boat. Notice the highway sign at the extreme right. The roadway lies under the floodwaters. In the boat (left to right) are Mrs. Emma Logan, R. W. Cook and Miss Dora Ross.

Figure 27. Neosho River flood, near Chetopa, Labette County, Kansas, June 1, 1938.

Source: *Kansas City Star*, Flood Clippings, Vol. 8, Kansas State Historical Society, Topeka.

1941

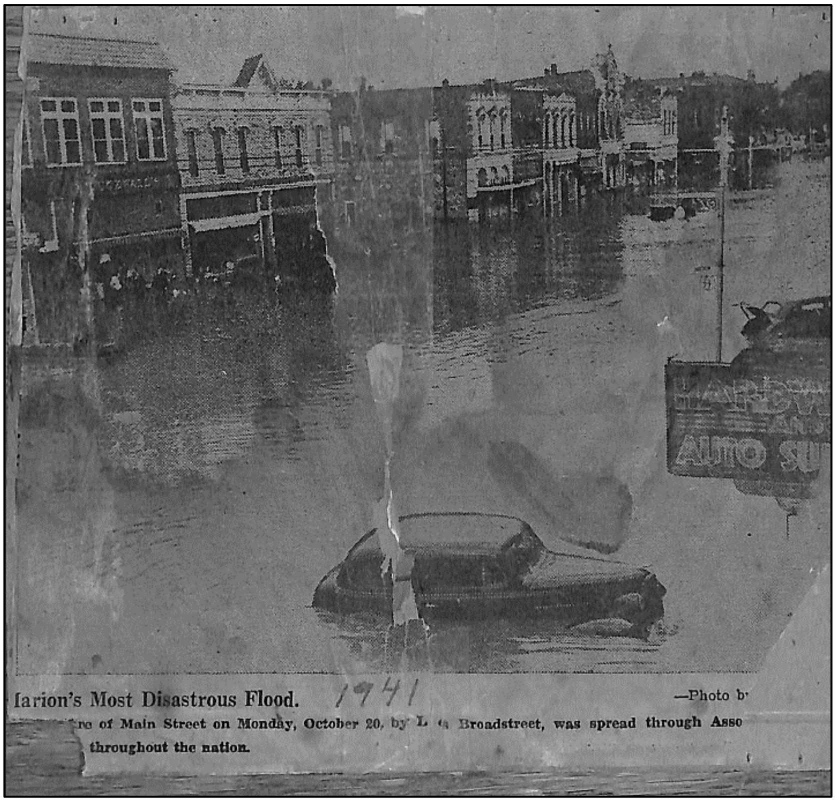


Figure 28. Cottonwood River flood, Marion, Marion County, Kansas, October 20, 1941.

Source: Marion County Historical Society, Marion, KS.

Figure 29. Neosho River flood, Council Grove, Morris County, Kansas, October 20, 1941. Compare flood level on buildings with Figure 25.

Source: Morris County Historical Society, Council Grove, KS.

1943

Figure 30. Spring River flood, Baxter Springs, Cherokee County, Kansas, May 1943. Source: Baxter Springs Historical Society, Baxter Springs, KS.

1944

FIG. 11.—Height of April, 1944, flood on the Cottonwood river at Strong City.

Figure 31. Cottonwood River flood, Strong City, Chase County, Kansas, April 1944.

Source: Kansas State Board of Agriculture, Division of Water Resources, *Report of the Kansas State Board of Agriculture, December, 1944: River Basin Problems and Proposed Reservoir Projects for a State Plan of Water Resources Development* (Topeka: Kansas State Board of Agriculture, 1945), 55.

FIG. 15.—Levee break south of Erie during April, 1944, flood.

Figure 32. Neosho River flood, Erie, Neosho County, Kansas, April 1944.

Source: Kansas State Board of Agriculture, Division of Water Resources, *Report of the Kansas State Board of Agriculture, December, 1944: River Basin Problems and Proposed Reservoir Projects for a State Plan of Water Resources Development* (Topeka: Kansas State Board of Agriculture, 1945), 60.

FIG. 16.—Breaks in levees west of St. Paul during the 1944 flood.

Figure 33. Neosho River flood, St. Paul, Neosho County, Kansas, April 1944.

Source: Kansas State Board of Agriculture, Division of Water Resources, *Report of the Kansas State Board of Agriculture, December, 1944: River Basin Problems and Proposed Reservoir Projects for a State Plan of Water Resources Development* (Topeka: Kansas State Board of Agriculture, 1945), 61.

1945

Figure 34. Neosho River flood, Burlington, Coffey County, Kansas, April 17, 1945.

Source: Coffey County Historical Society, Burlington, KS.

1948

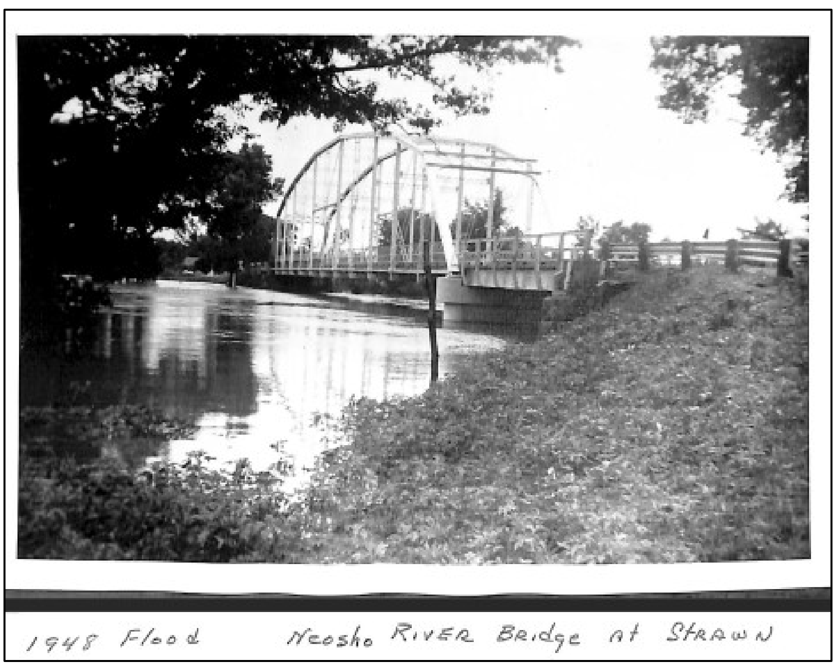
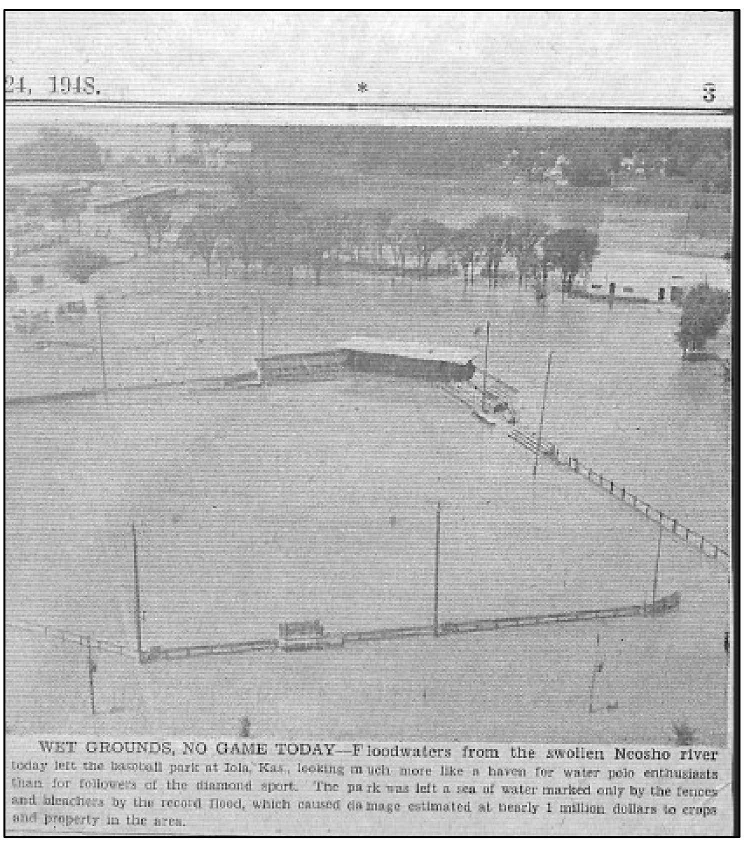


Figure 35. Neosho River flood, Strawn, Coffey County, Kansas, [July?], 1948.

Source: Coffey County Historical Society, Burlington, KS

Figure 36. Neosho River flood, Burlington, Coffey County, Kansas, July 22, 1948. Compare flood level on buildings with Figure 42.

Source: Coffey County Historical Society, Burlington, KS.



24, 1948. 3

WET GROUNDS, NO GAME TODAY—Floodwaters from the swollen Neosho river today left the baseball park at Iola, Kas., looking much more like a haven for water polo enthusiasts than for followers of the diamond sport. The park was left a sea of water marked only by the fences and bleachers by the record flood, which caused damage estimated at nearly 1 million dollars to crops and property in the area.

Figure 37. Neosho River flood, Iola, Allen County, Kansas, July 24, 1948.

Source: Allen County Historical Society, Iola, KS.

Figure 38. Neosho River flood, Kansas Gas & Electric plant, east of Parsons, Labette County, Kansas, July 25, 1948.

Source: Labette County Historical Museum, Parsons, KS.

1949

Figure 39. Neosho River floodwaters turned into ice floes, Council Grove, Morris County, Kansas, February 12, 1949.

Source: Morris County Historical Society, Council Grove, KS.

1951

Figure 40. Cottonwood River flood, Marion, Marion County, Kansas, [July] 1951.

Source: Marion County Historical Society, Marion, KS.

Figure 41. Neosho River flood, Council Grove, Morris County, Kansas, July 11, 1951.

Source: Morris County Historical Society, Council Grove, KS.

Figure 42. Neosho River flood, Burlington, Coffey County, Kansas, July 1951. Compare flood level on buildings with Figure 36.

Source: Coffey County Historical Society, Burlington, KS.

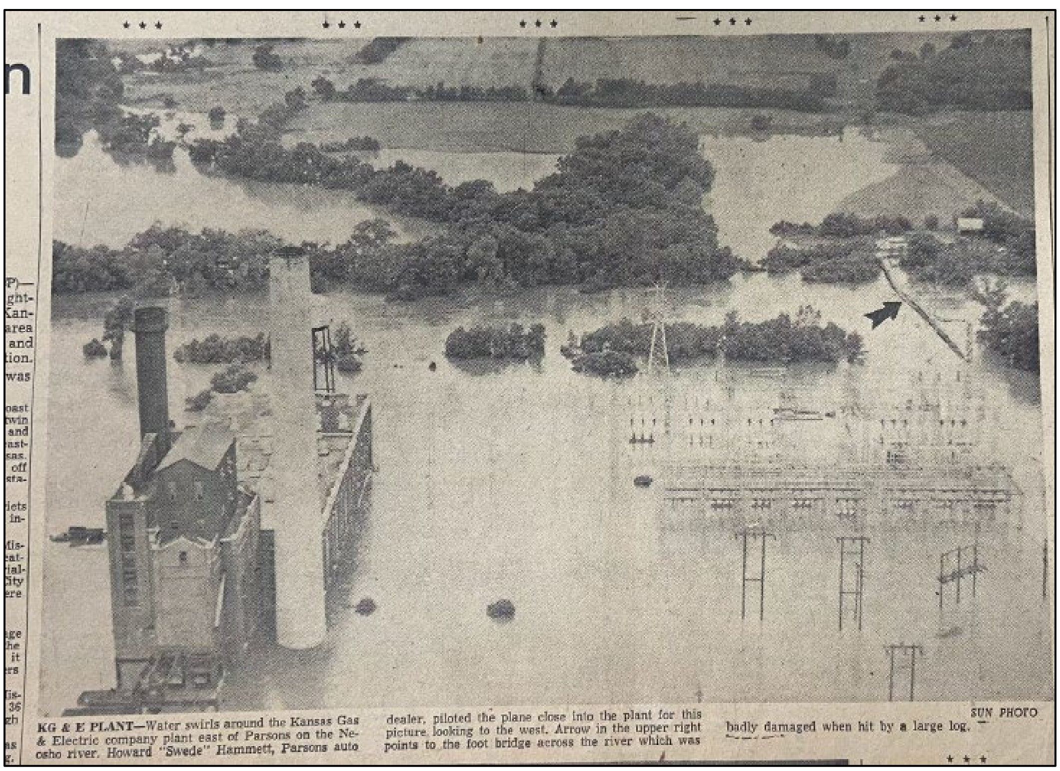


Figure 43. Neosho River flood, Kansas Gas & Electric plant east of Parsons, Labette County, Kansas, July 14, 1951.

Source: Labette County Historical Museum, Parsons, KS.

Figure 44. Neosho River flood, Miami, Ottawa County, Oklahoma, July 1951. Source Dobson Museum, Ottawa County Historical Society, Miami, OK.

1957


SUNDAY, MAY 26, 1957

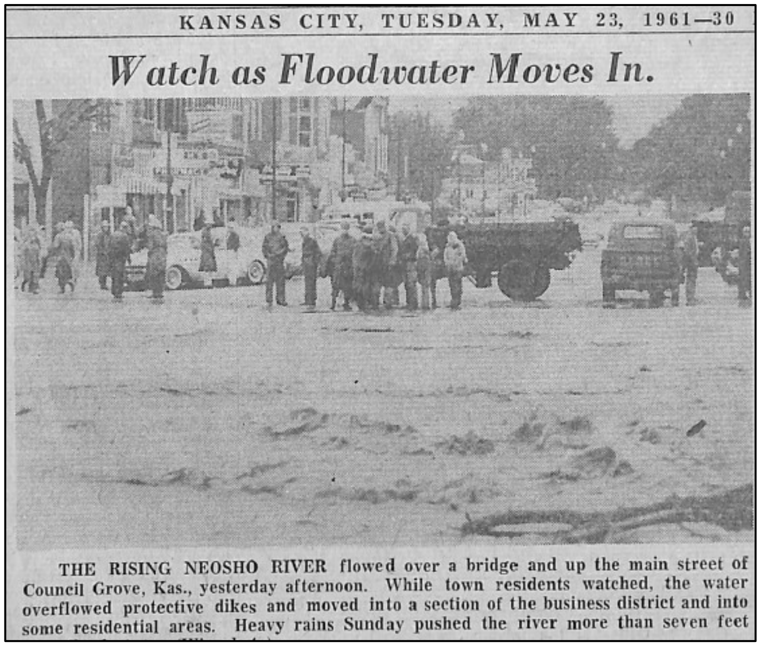
This was a new bridge in 1957

NEOSHO OVERFLOW—Swollen Neosho river waters spread over farm lands and roads leading to the Stepp's Ford bridge, west of Commerce. The aerial picture was taken by Orrick Sparlin. The GRDA's "Commerce" gauge is located at the bridge. It showed a level of 19.5 feet at noon Saturday. Flood stage is 15 feet.

Figure 45. Neosho River flood, Commerce, Ottawa County, Oklahoma, May 26, 1957.

Source: Dobson Museum, Ottawa County Historical Society, Miami, OK.

1961


KANSAS CITY, TUESDAY, MAY 23, 1961—30

Watch as Floodwater Moves In.

THE RISING NEOSHO RIVER flowed over a bridge and up the main street of Council Grove, Kas., yesterday afternoon. While town residents watched, the water overflowed protective dikes and moved into a section of the business district and into some residential areas. Heavy rains Sunday pushed the river more than seven feet

Figure 46. Neosho River flood, Council Grove, Morris County, Kansas, May 23, 1961.

Source: Morris County Historical Society, Council Grove, KS.

1964

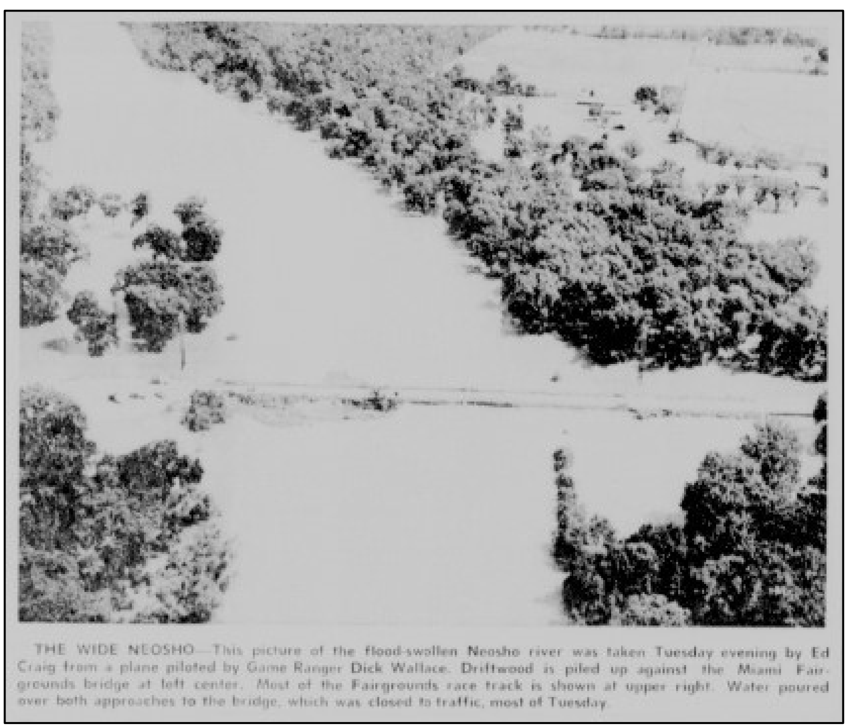
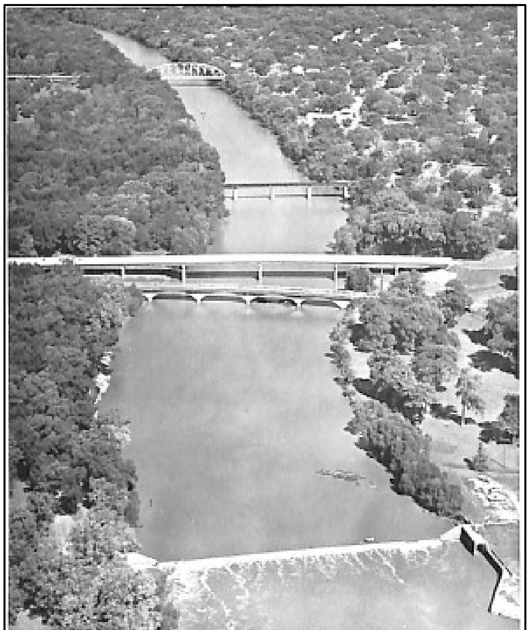

THE WIDE NEOSHO—This picture of the flood-swollen Neosho river was taken Tuesday evening by Ed Craig from a plane piloted by Game Ranger Dick Wallace. Driftwood is piled up against the Miami Fairgrounds bridge at left center. Most of the Fairgrounds race track is shown at upper right. Water poured over both approaches to the bridge, which was closed to traffic, most of Tuesday.

Figure 47. Neosho River Flood, Miami, Ottawa County, Oklahoma, June 17, 1964.

Source: *Miami News-Record*, June 17, 1964.

1967



The white ribbon in the center of this photo was in 1967 the new bridge over the Neosho River in southern Miami. It was just upstream from the old fairgrounds bridge it replaced. Further upstream is the railroad bridge and further still the U.S. 69 span. In foreground, water pours over the low-water bridge in Riverview Park.
(Ed Craig)

Figure 48. Bridges and low-water dam on the Grand (Neosho) River, Miami, Ottawa County, Oklahoma, ca. 1967.

Source: George and Frances Webb, Eds., *Reflections, Miami, Oklahoma, 1891–1991* ([Miami, OK?]: Sooner Printing, 1991), 107. On file at Dobson Museum/Ottawa County Historical Society, Miami, OK.

1974

THE MAIL GOES THROUGH—Neither rain, snow, sleet nor Neosho flood waters stopped postman B.G. (Bill) Hampton from his appointed rounds this morning. Here he utilizes the last bit of dry land to reach the front steps at 119 Fifth southwest.

Figure 49. Neosho River flood, Miami, Ottawa County, Oklahoma, March 12, 1974.

Source: *Miami News-Record*, March 12, 1974.

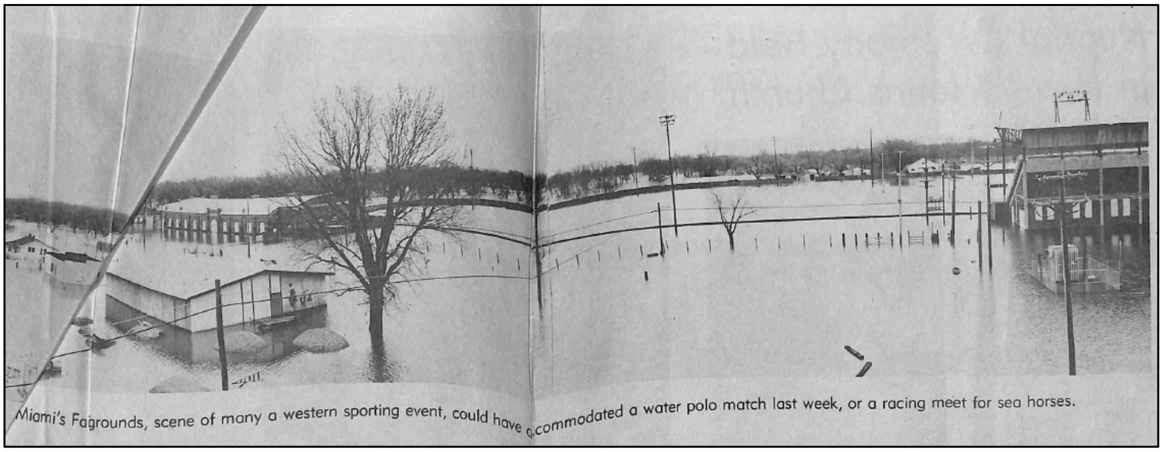


Figure 50. Neosho River flood, Miami, Ottawa County, Oklahoma, ca. March 12, 1974.

Source Ottawa County Historical Society, Dobson Museum, Miami, OK.

1986

Figures 51. Neosho River flood, Miami, Ottawa County, Oklahoma, October 1986.

Source: Miami Kiwanis Club, comp., *The Flood of '86* (Miami, OK: [Kiwanis, 1987?]). On file at Dobson Museum/Ottawa County Historical Society, Miami, OK.

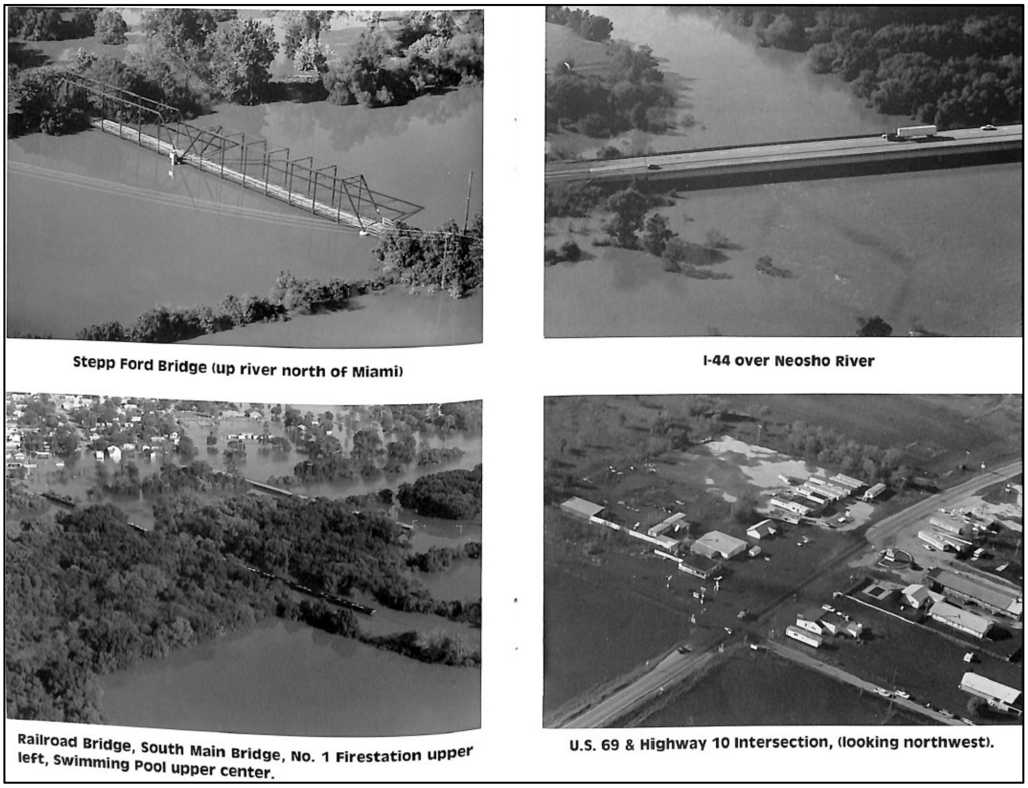


Figure 52. Neosho River flood, Miami, Ottawa County, Oklahoma, October 1986.

Source: Miami Kiwanis Club, comp., *The Flood of '86* (Miami, OK: [Kiwanis, 1987?]). On file at Dobson Museum/Ottawa County Historical Society, Miami, OK.

2007

Figure 53. Neosho River and Tar Creek flood, Miami, Ottawa County, Oklahoma, July 2007. Note the Miami softball complex (blue roofs, *left*) and fairgrounds (long buildings, *middle*).

Source: *Oklahoma Country*, Fall 2007.

2019

Figure 54. Neosho River and Tar Creek flood, Miami, Ottawa County, Oklahoma, June 2019.
Source: Laurie Sisk, *Joplin Globe*.

Appendix B. Chronology of Flooding in the Neosho (Grand) River Watershed

Neosho River Watershed Flooding Chronology

Year	Event
1826	Kansas climatologist T. B. Jennings described flooding on the Neosho in 1826 as "**carrying away wigwams, houses, and gathered and ungathered crops**."
1836	According to accounts gathered in the Coffey County Historical Society,(CCHS) Sac and Fox chief Soconut, "**swam his horse from bluff to bluff** (Indian Hill to Ottumwa Hill)" during the 1836 Neosho flood.
1844	Superintendent Thomas H. Harvey arrived at the Osage Sub Agency on May 22, 1844, where he found the Neosho, "very high, having overflowed its banks and covered the bottoms to a considerable depth, . . . **in most places more than a mile wide**."
1854	According to residents of Osage Mission (later St. Paul), the flood that year was a "**record breaker**."
ca. 1855-1856	"Spring rains sent the Neosho River out of its banks, flooding lowlands all through the area that was to be colonized [by a group of vegetarians." (*Iola Register*)
1857	A compilation of historical information from Emporia and Lyon Counties, Kansas, reported, "**A destructive flood swept down the Neosho**, carrying with it wigwams, houses and crops."
1865	*Neosho County Journal (NCJ)* described the Neosho as "very high."
1866	Neosho Indian Agent, G. C. Snow, reported that the Quapaws had suffered "severely" in 1866 "for food and clothing. Their crops were quite **all destroyed last year by the floods**"
1867	Neosho "overflow" in early July. *(NCJ)*
1868	Neosho "**overflowed for several days** during the first part of September." *(NCJ)*
1869	Neosho"**rose twenty feet in nine hours** and washed the ferry boats away." July saw the region "**submerged with the highest water in fifteen years**," with the Neosho "**rushing along over a stretch a mile in width**." *(NCJ)*
1870	A "small flood" occurred in late October. *(NCJ)*
1871	In July, the Neosho valley was flooded. *(NCJ)*
1873	Neosho was "very high" and had flooded the Osage Mission fairgrounds. *(NCJ)*
1875	A "small flood" occurred in August. *(NCJ)*
1876	Another "small flood" occurred in May. *(NCJ)*
1877	May 1877 flood was one "which makes the traditional oldest inhabitant shrug his shoulders and scratch his head, and reluctantly admit that he '**never did saw anything like it in these parts afore**.'" *(Marion County Record)*
1878	The Neosho **washed out the railroad track** "again." *(NCJ)*
1881	Another flood on the Neosho. *(NCJ)*
1884	"Big flood; no mail for four days" in May and another Neosho overflow in October. *(NCJ)*
1885	A 1948 Kansas State Board of Agriculture climate report noted that the July 1885 flooding of the Neosho was "**one of the greatest on record**" at Burlington and "**also close to the highest water ever known**" at Oswego.
1888	Chanute resident and weather watcher, Henry Stoelzing, reported a Neosho flood that year.
1889	Neosho "**was five miles wide at Humboldt**" during the 1889 flood. *(Spirit of Kansas)*

Neosho River Watershed Flooding Chronology

Year	Event
1890	Three separate Neosho floods at Chanute in 1890, with the highest in November. (Stoelzing)
1891	***City of Miami founded within Indian Territory.***
1891	According to a history of Emporia and Lyon Counties, in June 1891, the water was **within three inches of the 1877 high mark**.
1892	***First levees built on the Neosho in Neosho County.***
1892	Neosho had "**been out of its banks for the past week, and within two feet of the 1885 marks**. Much wheat has been destroyed." *(NCJ)*
1894	Neosho was "very high" that spring. *(Terral Times)*
1895	The U.S. Army Corps of Engineers (Corps) called the 1895 flood, "**one of the greatest floods**" in the history of the Neosho River valley. Originating in southern Kansas, the flood "was constantly augmented in crest flow as it traveled downstream throughout the Oklahoma reach, where it caused exceptionally high stages at Wyandotte as well as at Wagoner." **The Corps estimated the peak discharge at Grove at 250,000 cfs**.
1896	"Rising" Neosho was expected to cause "much damage" at Humboldt in late May. *(Tecumsah Herald)*
1898	"Average-size flood" lasted approximately a week in May. *(NCJ)*
1899	Neosho was "out of its banks . . . and steadily rising," with levees breached "in several places," the bottom lands flooded "for miles up and down the river," and the water **nearly reaching the height of the 1885 flood**. *(Kansas City Star)*
1900	Flood in Chanute lasted seven days in September. (Stoelzing)
1901	***St. Louis–San Francisco Railway ("Frisco") railroad truss bridge constructed over the Neosho in Miami.***
1901	As reported in a local history, on April 13 the Cottonwood River south of Emporia was a mile wide and **the Neosho up 22 feet**.
1902	Neosho "reached the highest mark this morning and is still rising. . . . The river is a **mile wide**." *(Oklahoma City Weekly Times Journal)*
1903	"Floods in Indian territory have delayed traffic on the railroads seriously." Neosho was **three miles wide** in some locations and "covered with water [up] to ten feet deep. The Neosho river above Miami, I.T. has covered the prairie farms for miles south of the river's main channel." *(Guthrie Daily Leader)*
1904	Neosho inundated the new Miami toll bridge with "three feet of water. The freshet **ruined a thousand acres of corn**. Rural mail wagons cannot get one mile from the post office. The water reached within two feet of the Frisco bridge." *(Norman Democrat Topic)*
1905	"One of the heaviest rains known to the oldest settlers visited this section of the country Friday night. As a result, both the Neosho and Spring rivers were out of their banks." *(Miami Record-Herald [MRH])*
1906	Heavy rains "caused flood stages in a considerable portion of the Neosho River." *(Monthly Weather Review [MWR])*
1907	Neosho overflowed from January 18–24, 1907. *(NCJ)*
1908	**Flood stages at almost every location on the Neosho between Iola and Fort Gibson**. *(MWR)*
1909	Neosho and Cottonwood Rivers "**broke all previous records**" for flooding during the winter season. *(Topeka Capital)*

Neosho River Watershed Flooding Chronology

Year	Event
1910	January floods again "**broke all records**" for winter flooding with ice dams causing flooding in the streets of Strawn. *(CCHS)*
1911	Flood at Lowell on the Spring River "**was worst ever experienced** at that place with the water nearly running over the dam." *(Galena Evening Times)*
1912	Neosho at flood stage "from Oswego southward, causing damage to crops and enforced suspension of business," and an estimated loss of $40,000. *(MWR)*
1912	***Missouri, Oklahoma & Gulf railroad bridge constructed over the Neosho.***
1915	Neosho on a "week's spree, a wild and reckless rampage, spreading ruin in its wake, overflowing its banks and surrounding territory. . . . **The city park is completely inundated**." *(MRH)*
1916	In June, the Neosho had been "in flood throughout its entire course in Kansas during the month. **In duration the flood was one of the longest on record**." *(MWR)*
1917	Tar Creek "on a rampage." *(MRH)*
1918	Heavy rain caused flooding in low places in the city, "and in many sections yards and streets were submerged. Water flowed over sidewalks in streams even in the high residence sections." *(MRH)*
1919	Workers building a new railroad bridge at Miami were discouraged from starting the job until "after the usual floods . . . had come and gone." *(MRH)*
1920	Neosho and Spring Rivers and Tar Creek, "[were] extremely high and [had] inundated the lowlands." *(MRH)*
1921	At their own peril, "hundreds of people" gathered at the South Main St. bridge to watch water "**14 feet above normal**" and a log jam wash out the approaches to the new bridge over the Neosho. *(MRH)*
1922	Due to heavy rains and flooding in Kansas, the Neosho was once again out of its banks at Miami where water "**entirely covered Riverview Park . . . and was flowing approximately two feet deep through the auditorium**." *(MRH)*
1923	1923 was a year of "outstanding floods" on the Neosho in both Kansas and Oklahoma brought on by "**four weeks of almost continuous and frequently excessive rains**" and with crest stages "**higher than any previously recorded**." *(MWR)*
1924	***Low dam at Riverview Park in Miami completed.***
1924	Crews repairing damages caused by fall and winter floods to the low dam and dance pavilion at Riverview Park were again facing setbacks due to the Neosho's rapid rise that spring. *(Miami News-Record [MNR])*
1926	"**Disastrous floods**" on the Neosho. *(MWR)*
1927	In April, the Neosho **rose 24 feet in the Miami area**, inundating highways and railroads, **causing 22 deaths**, and leading to an estimated half million dollars in damage. *(MNR)*
1928	Neosho was out of its banks in Iola and "from two to three feet over its banks in Coffey county, Parsons, and south to the Oklahoma line." *(Topeka Journal)*
1929	Neosho "flooding most of the bottom farms and causing considerable damage to growing crops." *(MNR)*
1930	June saw flood stages on the Neosho at Oswego and Fort Gibson. *(MWR)*
1931	Late fall rains caused "moderate" floods on the Neosho, which achieved flood stages at Le Roy, Iola, Chanute, Parsons, and Oswego. *(MWR)*
1932	"Young men with a knack for doing dangerous tricks" were riding logs on the Neosho over the "inundated" low dam in Miami "during its perilous flood stage." *(Miami Daily News-Record [MDNR])*

Neosho River Watershed Flooding Chronology

Year	Event
1933	Neosho flood waters had blocked highways in the Miami area in three directions; Ottawa County was expected to experience "**its highest water in several years**." *(MDNR)*
1935	***State of Oklahoma created the Grand River Dam Authority (GRDA).***
1935	***In 1935, the "largest truss span in Oklahoma" at the time, according to a history of Ottawa County, was completed over the Neosho at Miami (location of current Rte. 66 bridge at approximate corner of E and 3rd Streets SW).***
1935	"Disastrous floods" occurred on the Neosho. (Kansas State Planning Board)
1936	***Congress enacted the Flood Control Act of 1936, which authorized several levee projects along stretches of the Neosho in Kansas, as well as "preliminary examinations and surveys for flood control" at "Pensacola Reservoir, Oklahoma."***
1937	Two "moderate overflows" of the Neosho. *(MWR)*
1938	***Congress enacted the Flood Control Act of 1938, which authorized many projects, arguably including the Pensacola Dam, and required the Secretary of War to acquire title to all lands necessary for the authorized dam and reservoir projects.***
1938	"Big flood" of the Neosho reported in numerous news outlets in Kansas and Oklahoma.
1939	***The Federal Power Commission issued the original license for the Pensacola Project to GRDA.***
1939	***Iola levee operational.***
1940	***Congress enacted a special statute that granted GRDA title to all federal and Native American–owned lands in the Project area, up to elevation 750 feet.***
1940	***Pensacola Dam completed.***
1941	**Floods were "the rule, rather than the exception," in the Neosho watershed** from April to October, where flood stages were "reached or exceeded . . . every month during this period except in May." *(MWR)*
1941	***Congress enacted the Flood Control Act of 1941, which directed the Corps to provide flood control at Pensacola Dam.***
1941	***FDR's Executive Order 8944 directed FWA administrator to take over Pensacola Dam for the war effort.***
1942	On the Cottonwood and Neosho, "crest stages were generally 3 to 5 feet above bankfull" in June "with the **overflow lasting about a week**." *(MWR)*
1943	***1901 Frisco railroad truss bridge replaced with another with no trusses.***
1943	According to FEMA, the Neosho "rose to its crest stage above bankfull in 76 hours at an average rate of 0.13 foot per hour with a maximum rate of 0.6 foot per hour and remained above bankfull stage for about 11 days."
1944	Flooding broke "all known records at Chanute, Erie, and St. Paul, and at the highway bridge east of Parsons," with the Neosho "**one vast sea, in some places four or five miles wide**."*(Parsons Sun)*
1944	***Congress enacted the Flood Control Act of 1944, which again granted the Corps all flood-control responsibilities at the Project.***
1945	"Big flood" washed out a railroad track near St. Paul and water from the Neosho overtopped levees. *(NCJ)*
1946	Neosho reached flood stage at Oswego in January. *(MWR)*
1946	***Congress enacted special legislation that returned the Pensacola Hydroelectric Project to GRDA following World War II, and in doing so, confirmed ownership responsibilities related to the conservation and flood pools.***

Neosho River Watershed Flooding Chronology

Year	Event
1948	According to gaging information, the two crests that occurred at Commerce in 1948 were the **third- and fourth-highest known floods**, respectively, in order of magnitude at that location (prior to 1969).
1949	"Minor flooding along the Neosho at various locations." *(MWR)*
1950	The Corps reported that heavy rainfall caused a spring flood on the Neosho.
1951	U.S. Geological Survey reported that the Neosho "reached **flood heights far in excess of any previously known** as result of heavy storms."
1954	According to a 1979 consultant's report on the Miami Area Comprehensive Plan, "major floods causing **extensive damage to Miami development** occurred."
1955	Gaging information recorded the Neosho at Commerce above the 15-foot flood stage.
1957	"Swollen Neosho river waters spread over farmlands and roads." (*MNR*).
1958	"Neosho was flooding from Burlington, KS, to its mouth, with four to five feet of flooding lowlands in Miami." *(Tulsa Tribune)*
1959	Flooding on the Neosho. (CCHS)
1960	Another Neosho flood. (CCHS)
1961	Gaging information recorded that the crest at Commerce was the **fifth-highest known flood in order of magnitude** at Commerce (prior to 1969).
1962	Four separate floods on the Neosho. (CCHS)
1964	***Council Grove Dam/Reservoir completed.***
1964	High floodwaters at the Third Ave. bridge and **Miami fairgrounds had been flooding for a few days**. *(MNR)*
1965	***John Redmond (Strawn) Dam/Reservoir completed.***
1965	Another Neosho flood. (CCHS)
1967	***New "fairgrounds" bridge constructed over Neosho at Miami immediately upstream from the 1921 concrete arch bridge, which it replaced.***
1967	Neosho crested near Commerce above flood stage. *(MNR)*
1968	***Marion Dam/Reservoir completed.***
1969	In Miami, the Neosho **flooded Riverview Park and closed the park road**. *(Daily Oklahoman)*
1970	"Neosho rampage." *(Parsons Sun)*
1971	"Minor flooding" on Neosho. *(Tulsa World)*
1972	Neosho 2 feet over flood stage at Commerce. *(Daily Oklahoman)*
1973	Neosho "did the expected" and overflowed into Labette County lowlands. *(Parsons Sun)*
1974	Due to flooding, "Miami's Fairground . . . could have accommodated a water polo match last week, or a racing meet for sea horses." (clipping, Dobson Museum)
1975	Neosho receding after a "hit-run" flood of from 3 to 4 feet. *(Parsons Sun)*
1976	"**At least 3 bridges across Neosho and Spring in Ottawa County were blocked**" due to flooding. *(Tulsa World)*
1977	"High water brought a halt" to construction near the Miami fairgrounds. *(MNR)*
1978	Neosho 3 feet over flood stage at Commerce and expected to crest at 5 feet over flood stage. *(Tulsa World)*

Neosho River Watershed Flooding Chronology

Year	Event
1979	Neosho "spilling out of its banks . . . gorged by rain concentrations." *(Parsons Sun)*
1980	Neosho "takes generous swath of land near Chanute." *(Wichita Eagle)*
1982	"Pumped up by heavy rains," the Neosho overflowed in Labette and Neosho Counties; more flooding expected into NE Oklahoma. *(Parsons Sun)*
1985	Ottawa County declared a disaster area due to flooding. Neosho **crested 13 feet above flood stage at Miami, damaging 300 homes and dozens of businesses**. *(Daily Oklahoman/Times)*
1986	"**One of the worst floods ever experienced in Miami** resulted from days of record-setting rainfall." (Miami Kiwanis Club pamphlet)
1987	***Congress enacted Public Law No. 100-202, which directed the Corps to investigate solutions to flooding problems in the City of Miami, including the adequacy of the United States' easements for flood control at the Pensacola Project.***
1987	Runoff from Tar Creek flooded streets and "at least 10 houses" in Miami and the Neosho was expected also to flood. *(Tulsa World)*
1988	Neosho crested at Chanute 7.9 feet above flood stage. *(Chanute Tribune)*
1989	Neosho flooding near Parsons and at Oswego; at Chetopa, "**most of the city park near the banks of the Neosho was standing under water**." *(Parsons Sun)*
1990	Neosho caused the flooding of Miami's Riverview Park. *(Daily Oklahoman)*
1992	Rain "forced the Neosho River from its banks, causing flooding" and closing streets in Miami. *(Daily Oklahoman)*
1992	***FERC relicensed the Pensacola Project for a new 30-year term, maintaining that "The Grand Lake flood pool . . . is controlled by the Corps for flood control storage, as mandated by the Flood Control Act of 1944, and not subject to Commission authority."***
1993	Neosho crested 9.5 feet above flood stage at Miami, **covering nearly two dozen city streets with water**." *(Daily Oklahoman)*
1994	"In Miami, **30–35 homes were evacuated** as the Neosho River inched out of its banks . . . eight months ago, a flood prompted the evacuation of the same homes." *(Tulsa World)*
1995	Neosho floodwaters **closed State Highway 125 near Miami fairgrounds**. *(Grove Sun)*
1996	***Congress enacted the Water Resources Development Act of 1996, which directed the Corps to undertake a real estate adequacy analysis at the Pensacola Project and authorized the Corps to acquire additional acreage from willing sellers.***
1997	"Neosho River spilling out of its banks near Commerce." *(Daily Oklahoman)*
1998	"**Major flooding** along the Neosho River near Oswego." *(Iola Register)*
2000	***Congress enacted the Water Resources Development Act of 2000, which directed the Corps to purchase easements for lands adversely affected by backwater flooding at the Pensacola Project.***
2000	"Neosho "**came within a foot of homes" in Miami**. *(Iola Register)*
2002	"A two-day total of 2.84 inches of rain at Miami helped push the Neosho River out of its banks, sending it six feet above flood stage." (Oklahoma Climatological Survey)
2004	Neosho and Spring both above flood levels, "cutting off access to low-lying areas." *(Oklahoman)*
2007	Neosho **overflow "engulfed" Miami, flooding over 600 homes in Miami alone**. (Oklahoma Farm Bureau)

Neosho River Watershed Flooding Chronology

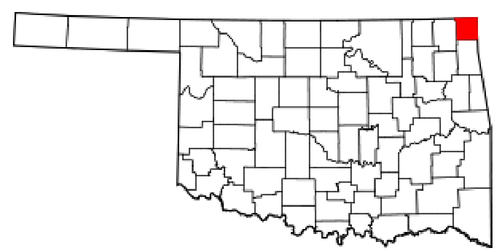
Year	Event
2015	"Moderate" flooding of Neosho near Commerce. (National Weather Service)
2018	***Congress enacted the Water Infrastructure Improvements for the Nation Act, which directed the Corps to convey to GRDA all property interests of the United States at the Pensacola Project, while retaining the Corps' exclusive jurisdiction over flood control.***
2019	Neosho had its eighth-highest crest at Commerce since 1940 with **Miami hit hard by a "record-breaking" flood**. *(Joplin Globe)*
2019	***Congress enacted the National Defense Authorization Act for Fiscal Year 2020, which Congress confirmed the Corps' exclusive jurisdiction over flood control at the Pensacola Project, prohibited other agencies from regulating water surface elevations, and defined the FERC-licensed project to consist only of lands within the then-current Project boundary.***

APPENDIX E-11 Ottawa County Flood Insurance Studies

FLOOD INSURANCE STUDY

OTTAWA COUNTY, OKLAHOMA
AND INCORPORATED AREAS

Community Name	Community Number
AFTON, TOWN OF	400155
COMMERCE, CITY OF	400156
FAIRLAND, TOWN OF	400377
MIAMI, CITY OF	400157
NORTH MIAMI, TOWN OF	400426
PEORIA, TOWN OF	400158
PICHER, CITY OF	400159
QUAPAW, TOWN OF	400436
WYANDOTTE, TOWN OF	400161
OTTAWA COUNTY, UNINCORPORATED AREAS	400154



EFFECTIVE: AUGUST 5, 2010

Federal Emergency Management Agency

FLOOD INSURANCE STUDY NUMBER
40115CV000A

NOTICE TO
FLOOD INSURANCE STUDY USERS

Communities participating in the National Flood Insurance Program have established repositories of flood hazard data for floodplain management and flood insurance purposes. This Flood Insurance Study may not contain all data available within the repository. It is advisable to contact the community repository for any additional data.

Selected Flood Insurance Rate Map panels for the community contain information that was previously shown separately on the corresponding Flood Boundary and Floodway Map panels (e.g., floodways, cross sections). In addition, former flood hazard zone designations have been changed as follows:

Old Zone	New Zone
A1 through A30	AE
V1 through V30	VE
B	X
C	X

Part or all of this Flood Insurance Study may be revised and republished at any time. In addition, part of this Flood Insurance Study may be revised by the Letter of Map Revision process, which does not involve republication or redistribution of the Flood Insurance Study. It is, therefore, the responsibility of the user to consult with community officials and to check the community repository to obtain the most current Flood Insurance Study components. A listing of the Community Map Repositories can be found on the Index Map.

Initial Countywide FIS Effective Date: August 5, 2010

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FLOOD INSURANCE STUDY
OTTAWA COUNTY, OKLAHOMA AND INCORPORATED AREAS

1.0 INTRODUCTION

1.1 Purpose of Study

This Flood Insurance Study (FIS) revises and updates information about the existence and severity of flood hazards in the geographic area of Ottawa County, including the Cities of Commerce, Miami, and Picher; the Towns of Afton, Fairland, North Miami, Peoria, Quapaw, and Wyandotte; and the unincorporated areas of Ottawa County (referred to collectively herein as Ottawa County), and aids in the administration of the National Flood Insurance Act of 1968 and the Flood Disaster Protection Act of 1973. This study has developed flood-risk data for various areas of the community that will be used to establish actuarial flood insurance rates and to assist the community in its efforts to promote sound floodplain management. Minimum floodplain management requirements for participation in the National Flood Insurance Program (NFIP) are set forth in the Code of Federal Regulations at 44 CFR, 60.3.

Please note that the Towns of North Miami, Peoria, and Quapaw are currently non-participating communities. The Flood Hazard areas shown for these communities are for information only.

In some States or communities, floodplain management criteria or regulations may exist that are more restrictive or comprehensive than the minimum Federal requirements. In such cases, the more restrictive criteria take precedence, and the State (or other jurisdictional agency) will be able to explain them.

1.2 Authority and Acknowledgments

The sources of authority for this FIS report are the National Flood Insurance Act of 1968 and the Flood Disaster Protection Act of 1973.

The new hydrologic and hydraulic analyses for this study were performed by Watershed VI Alliance, for the Federal Emergency Management Agency (FEMA), under Contract No. EMT-2002-CO-0048, Project Order No. J034. This study was completed in June 2008. The histories of the individual communities before the first countywide FIS are presented below.

City of Miami
The hydrologic and hydraulic analyses for the original FIS for the City of Miami represent a revision of the original analyses prepared by Benham-Blair Affiliates, Inc., for FEMA under Contract No. H-4642. That work was completed in June 1979 (Reference 1).

The hydrologic and hydraulic analyses for the revised FIS was based were prepared by the Tulsa District of the U.S. Army Corps of Engineers (USACE). That work was completed in September 1986 (Reference 1).

Town of Wyandotte
The hydrologic and hydraulic analyses for the original FIS for the Town of Wyandotte

were prepared by the USACE, Tulsa District, for FEMA under Inter-Agency Agreement No. EMW-84-E-1506, Project Order No. 1, Amendment No. 32 and 32b. That work was completed in June 1986 (Reference 2).

The FIS for the Town of Wyandotte was revised on December 19, 1997 to incorporate the results of a reevaluation of the flood hazards along Wyandotte Ditch and the adequacy of a levee protecting a school from flooding from Grand Lake O' the Cherokees (Grand Lake).

A reevaluation was performed by the USACE, Tulsa District, under Contract No. EMW-93-E-4119, and by Michael Baker Jr., Inc., under a Technical Evaluation Contract. That work was completed on February 11, 1997 (Reference 2).

Unincorporated Areas of Ottawa County
The hydrologic and hydraulic analyses for the unincorporated areas of Ottawa County were prepared by the Tulsa District of the USACE for FEMA, under Inter-Agency Agreement No. EMW-84-E-1506, Project Order No. 1, Amendment No. 29 and 29b. That work was completed in September 1986 (Reference 3).

1.3 Coordination

The initial Consultation Coordination Officer (CCO) meeting was held on April 10, 2007, and attended by representatives of the Cities of Commerce and Miami; the Towns of Afton, Fairland, and Wyandotte; Ottawa County; the Oklahoma Water Resources Board (OWRB); FEMA; and Watershed VI Alliance (the study contractor).

The results of the study were reviewed at the final CCO meeting held on December 8, 2008, and attended by representatives of the Cities of Commerce, Miami, and Wyandotte, the Seneca Tribe, the Eastern Shawnee Tribe, FEMA, and the study contractor. All problems raised at that meeting have been addressed in this study.

The history of the coordination activities for the individual communities before the first countywide meeting is presented below.

City of Miami
On March 14, 1978, an initial CCO meeting was held with representatives of FEMA, the City of Miami, and Benham-Blair & Affiliates, Inc. (the study contractor) to explain the nature and purpose of the FIS. A legal notice announcing the initiation of the study and stating its objectives was placed in the local newspaper. Contact was maintained during the course of that study with the Tulsa District of the USACE, the Ottawa County Soil Conservation Service, and the City of Miami for general community information.

On January 10, 1980, the results of that study were reviewed at a final CCO meeting attended by representatives of FEMA, the City, and the study contractor.

Town of Wyandotte
On February 13, 1984, an initial CCO meeting was held with representatives from FEMA, the Town of Wyandotte, and the Tulsa District of the USACE (the study contractor) to determine the streams to be studied by detailed methods. Coordination between town officials and Federal, State, and regional agencies produced a variety of information pertaining to floodplain regulations, available community maps, flood history, and other hydrologic data.

The U.S. Geological Survey (USGS), the Bureau of Reclamation, the National Weather Service, the Soil Conservation Service, the State Conservationist, and the OWRB were contacted for information related to the study.

On December 8, 1986, a final CCO meeting was held with representatives from FEMA, the Town, and the study contractor to review the results of the study.

The results of the revision to Wyandotte Ditch were reviewed at a final CCO meeting held on February 11, 1997, and attended by representatives of FEMA and the Town of Wyandotte. All problems raised at that meeting were addressed in the 1997 FIS.

Unincorporated Areas of Ottawa County

On February 14, 1984, an initial CCO meeting was held with representatives of FEMA, Ottawa County, and the USACE (the study contractor) to determine the streams to be studied by detailed methods. Coordination between county officials and Federal, State, and regional agencies produced a variety of information pertaining to floodplain regulations, available community maps, flood history, and other hydrologic data.

Agencies that contributed significant data to this study were the USGS, the Oklahoma Department of Transportation, the National Weather Service, the Soil Conservation Service, and the Oklahoma Water Resources Board.

Contact between Ottawa County and the Tulsa District of the USACE was maintained during the course of this study for general community information.

On January 12, 1988, a final CCO meeting was held with representatives of FEMA, the County, and the study contractor to review the results of the study.

2.0 AREA STUDIED

2.1 Scope of Study

This FIS report covers the geographic area of Ottawa County, Oklahoma, including the incorporated communities listed in Section 1.1.

The areas studied by detailed methods were studied in a previous study. The detail studied streams in this revision were digitally converted from the previous study. The previous study selected streams with priority given to all known flood hazards and areas of projected development or proposed construction through September 1991. Approximate analyses were used to study those areas having a low development potential or minimal flood hazards. The scope and methods of study were proposed to, and agreed upon, by FEMA and Watershed VI Alliance. "Streams Digitally Converted" are presented in Table 1.

Table 1: Streams Digitally Converted

Flooding Source	Reach Length (miles)	Study Area
Belmont Run	2.99	From its confluence with Tar Creek to a point approximately 0.23 mile upstream of Newman Road
Fairgrounds Branch	1.71	From its confluence with the Neosho River to a point approximately 1.15 miles upstream of US Highway 125
Little Elm Creek	3.28	From its confluence with the Neosho River to a point approximately 0.20 mile upstream of State Route 10
Lost Creek (Lower Reach)	1.66	From its confluence with Grand Lake to a point approximately 2.70 miles upstream
Lost Creek (Upper Reach)	1.30	From a point approximately 0.60 mile downstream of Burlington Northern Railroad to the upstream county boundary
Neosho River	3.86	From a point approximately 1.12 miles downstream of the confluence of Little Elm Creek to a point approximately 0.52 mile upstream of the confluence of Tar Creek
Quail Creek	0.98	From its confluence with the Neosho River to P street NW in the City of Miami
Tar Creek	6.92	From its confluence with the Neosho River to a point approximately 1.24 miles upstream of D Street
Warren Branch	1.90	From a point approximately 0.32 mile downstream of the downstream Town of Peoria corporate limits to a point approximately 0.58 mile upstream of the upstream Town of Peoria corporate limits
Wyandotte Ditch (including the effects of Grand Lake)	1.05	Entire length within the Town of Wyandotte

Approximate methods of analysis were used to study all remaining areas having a potential flood hazard that did not have available scientific or technical data. The following streams and their tributaries were studied by approximate methods: Garrett Creek; Sycamore Creek; the Spring River; Brush Creek; Roark Creek; Mud Creek; Fourmile Creek; Hudson Creek; Horse Creek; Little Horse Creek; Ogeechee Creek; Winds Creek; Fivemile Creek; Little Fivemile Creek; Wolf Creek; Coal Creek; Slow Creek; Squaw Creek; Cow Creek; Lytle Creek; Flint Branch; Devils Hollow; Grand Lake; Bee Creek; Hickory Creek; Council Hollow; and portions of Little Elm Creek, Lost Creek (Lower Reach), Lost Creek (Upper Reach), Neosho River, Tar Creek, and Warren Branch.

Mapping for Ottawa County, Oklahoma, and Incorporated Areas has been prepared using digital data. Previously published Flood Insurance Rate Map (FIRM) and Flood

Boundary and Floodway Map data produced manually have been converted to vector digital data by a digitizing process.

2.2 Community Description

Ottawa County is located in the extreme northeast corner of the State of Oklahoma. It is bordered by Cherokee County to the north; Newton County, Missouri to the east; McDonald County, Missouri to the southeast; Delaware County to the south; and Craig County to the west. The county encompasses an area of 485 square miles, with 471 square miles on land. There are nine incorporated towns and cities in Ottawa County, with the City of Miami as the largest city and county seat.

Ottawa County is a mostly rural agricultural area with small areas of residential and industrial development associated with its cities. There are also mining operations along Tar Creek. The year 2000 population of the county was 33,194, an increase of approximately nine percent over the 1990 population of 30,561 (Reference 4). The population was estimated at 33,026 in 2006. There is a tremendous amount of new housing and commercial development in the floodplain of the Neosho River. The county is served by several Federal, State, and local roads, with Interstate Route 44 (Will Rogers Turnpike) being the most widely traveled. The turnpike runs from southwest to northeast. Other highways serving Ottawa County are: U.S. Routes 59, 60, and 69, and State Route 10.

The climate of Oklahoma is continental, with long hot summers and winters that are shorter and milder than those of more northern Plains states. Ottawa County is characterized by a wide range of temperatures across the county, ranging from near 59 degrees in southern parts to less than 56 degrees in the northeast (Reference 5). Daily temperatures range from an average of 92 degrees Fahrenheit (°F) in July to an average of 22°F in January. The mean annual temperature of the area is 59°F. Winds from the south are dominant, averaging less than eight miles-per-hour. Annual average precipitation for the county is 44.85 inches. May and September are the wettest months on average, but abundant rain falls from March through November. Most winters have at least one inch of snow, with about one year in four having ten or more inches.

The terrain in Ottawa County consists of rolling hills with moderate slopes. In the Neosho River drainage basin, rolling uplands with elevations above 1,500 feet quickly descend 150 feet to a broad valley, generally 1 to 5 miles back from the river. The floodplains of the Neosho River, Tar Creek, and their tributaries are associated with the Lightning soil series, which is described as deep, poorly drained, nearly level soils formed from alluvium washed from soils of the prairies. The native vegetation in the floodplains is mainly tall grass prairie, due to the availability of water, but includes some hardwood trees.

Most of the area of Ottawa County is divided between the Neosho River basin and the Spring River basin. The major tributaries to the Neosho River are Tar Creek and Little Elm Creek, but the small tributary Fairgrounds Branch is also included in this study. The major tributaries to Spring River that are included in this study are Lost Creek with its tributary Wyandotte Ditch in the south central portion of the county and Warren Branch in the northeastern part of the county.

The Neosho River flows from the northwest to the southeast across the county through a wide floodplain. The river begins in the Flint Hills region of Morris County, Kansas, and flows southeast more than 300 river miles in Kansas. It then flows south approximately

164 river miles across northeastern Oklahoma to its confluence with the Arkansas River near Muskogee, Oklahoma. About 10 miles downstream of the City of Miami, the Neosho River joins the Spring River and is impounded to form the Grand Lake O' the Cherokees. This 46,500-acre reservoir was created by the construction of the Pensacola Dam in 1940 as a source for hydroelectric power.

The Neosho River channel is well defined and very crooked. It varies in width from approximately 100 feet near Council Grove, Kansas, to approximately 300 feet near the City of Miami, Oklahoma, and is occasionally obstructed by snags, trash heaps, and gravel bars. Throughout its course, the river occupies a bed of gravel, boulders, and rock ledges. The banks are generally stable, varying in height from 15 to 30 feet and are covered with brush and trees above the lower water line. The total fall of the Neosho River from its headwaters to its junction with the Arkansas River is 1,000 feet. Throughout most of its length, excluding the upper reach, the average fall of the streambed is slightly over 1 foot per mile.

Fairgrounds Branch is a small tributary of the Neosho River in the City of Miami. Its basin is approximately 2 square miles in drainage area, which is devoted mainly to agricultural usage. There are small residential developments adjacent to Highway 125, which is on the ridge line for the Fairgrounds Branch basin.

Tar Creek originates in Cherokee County, Kansas, and flows from north to south through the central part of Ottawa County to its confluence with the Neosho River just upstream of Highway 44 above Little Elm Creek. Most of the total drainage area of 53.3 square mile lies within Ottawa County. The creek flows near the City of Commerce and through the City of Miami, so the floodplain is the most developed of any stream in the study area. Tar Creek flows reasonably straight through a channel in a floodplain varying from approximately 1,800 feet to approximately 3,800 feet in width. The average slope is approximately 10.4 feet per mile.

Two tributaries of Tar Creek are included in this study: Belmont Run and Quail Creek. Belmont Run is the most significant tributary within the Miami corporate limits. It has a drainage area of 3.1 square miles, mostly on the west side of Miami which includes the industrial park development and commercial districts. Quail Creek intercepts Tar Creek upstream of Rockdale Bridge. Its watershed is 2.8 square miles of mostly residential development and the local country club. Quail Creek has a greater average stream slope of approximately 22 feet per mile than Belmont Run's 12.5 feet per mile.

Little Elm Creek runs through the central portion of the county from north to south and empties into the Neosho River. The river is just east of Miami and its floodplain is currently all agricultural and residential.

Lost Creek runs in most of the southeastern part of the county before emptying into Grand Lake. This creek crosses the northern edge of the Town of Wyandotte in a western direction and has a drainage area of approximately 95 square miles that is approximately 20 miles long. The average slope of the Lost Creek streambed is approximately 17 feet per mile.

Wyandotte Ditch is the local name for a drainage channel that runs from east to west on the south side of Wyandotte before emptying into Lost Creek. Wyandotte Ditch has a drainage area of approximately 1.0 square mile. The average stream slope is a steep 75 feet per mile; however, through the community, the streambed slope is approximately 35 feet per mile.

Warren Branch flows through the Town of Peoria, in the northeastern part of the county. This area floods regularly, mainly due to heavy rains and fast runoff from the high hills. There is little overall new development expected in this area.

City of Miami

The City of Miami is located in the northwestern portion of Ottawa County, only 95 miles northeast of Tulsa and 15 miles southwest of Joplin, Missouri. It is bordered by the City of Commerce to the north and the unincorporated areas of Ottawa County to the east, south, and west. With a year 2000 population of 13,704, Miami is by far the largest city in the county (Reference 4). The other cities and towns in Ottawa County have populations of 2,700 or less. The City of Miami does not exercise its extraterritorial jurisdiction at the present time.

The topography of Miami and its general vicinity is gently rolling, with no areas over 3 to 5 percent slopes. Much of the City lies on the northern bank of the Neosho River and along Tar Creek, but the Fairgrounds and newer residential areas are expanding on the south side of the Neosho River. While most residential properties and the larger part of Miami's business district are above flooding elevations, existing residential, commercial, and industrial areas have been inundated by past floods. U.S. Highway 66 and 69 and Oklahoma State Highway 10 cross the Neosho River on a common bridge from the west and the Main Street Bridge crosses at a southwestern area of the City. Both of these bridges were overtopped by the July 1951 flood.

A near record flood occurred on the Neosho River in June of 2007. Significant property damage was reported in the City of Miami. Approximately 2,500 residents were evacuated and 574 structures were inundated with water. Some buildings had up to 3 feet of water in them and approximately 148 homes and businesses were damaged to the degree that they were not given permission to renovate. All highways except for one and approximately 40 streets in Miami were closed due to high water causing limited access into and out of the city (Reference 6).

Town of Wyandotte

The Town of Wyandotte is located in the southeastern portion of Ottawa County and is completely bordered by unincorporated areas. In 2000, the population of the town was approximately 363 (Reference 4).

The topography of the town and its surrounding area can be described as gently rolling. Wyandotte is adjacent to the Spring River arm of Grand Lake and includes Lost Creek and Wyandotte Ditch.

2.3 Principal Flood Problems

Floods can occur in Ottawa County during any season but are most frequent during May and September. Autumn floods are often associated with widespread heavy rains north of a stalled cold front, or the interaction between a surface front and remnants of a tropical storm. Springtime floods usually occur in the warm sector of a slow-moving cyclone (Reference 5). Major flooding during the spring and summer months can also be produced by the intense rainfall associated with intense localized thunderstorms (Reference 3).

Major flood problems in Ottawa County have occurred in all of the floodplains of the streams studied in this report.

Major floods of record occurred on the Neosho River and Tar Creek in July 1951, May 1943, April 1944, July 1948, February 1985, October 1986, and July 2007. The July 1951 flood is believed to be the greatest flood known to have occurred in this area, with the Neosho River cresting at 34.03 in nearby Commerce. Newspapers pointed out the hazard to life and the substantial damage to property occasioned by this flood, which left 3,000 persons homeless (Reference 1). The July 2007 flood is believed to be the second highest flood in the City of Miami, with the Neosho River cresting at 29.25 feet. Over 200 homes were destroyed and 266 more homes suffered major damage in this flood (Reference 7). The May 1943 flood was the highest flood on the upper reaches of Tar Creek and the third highest flood on the Neosho River at Miami. The February 1985 flood, according to surveyed high water-marks, was between a 10- and 50-year flood for the Neosho River and Tar Creek (Reference 1).

Past flood records on Little Elm Creek, Lost Creek, and Warren Branch are scarce. The February 1985 flood is the only record of flooding in these areas. Surveyed high-water marks indicate that this flood was less than a 10-year flood on Little Elm Creek, Lost Creek, and Warren Branch (Reference 2).

Officials for the Town of Wyandotte have indicated that overland flooding has occurred along Wyandotte Ditch, while most flooding is the result of the backwater effects of Grand Lake or from a combination of surface runoff and poor drainage.

2.4 Flood Protection Measures

There are three USACE flood control reservoirs operating in the Neosho River Basin above the City of Miami in the State of Kansas: Council Grove, Marion, and John Redmond Reservoirs. These reservoirs, which were completed since the July 1951 flood, reduce flood stages significantly at Miami. In addition, the Natural Resources Conservation Service has six watershed programs in various stages of development in the basin above Miami. However, these programs have very little effect on the Neosho River flooding in the Miami area.

The National Weather Service (NWS) of the National Oceanic and Atmospheric Administration provides flood warning service to the City of Miami for crests on the Neosho River. These warnings are related to the river gage near Commerce, approximately 9 miles upstream. When flooding is expected at the Commerce gage, the police dispatcher at Miami is notified by telephone from the Tulsa River Forecast Center. The police dispatcher is asked to relay this information to the Miami City Engineer and the Ottawa County Civil Defense Office. These warnings are also published on http://www.weather.gov/alerts for further dissemination by news media.

Specific river and flood forecasts and warnings are not provided for Tar Creek or its tributaries, since economic restraints do not permit NWS funding of the relatively dense networks of the river and rainfall stations required to produce accurate forecasts for this area. At present, the principal service the NWS can provide the Tar Creek area is a general alert to the danger of flash flooding by means of forecasts of approaching storm systems and/or radar indications of imminent or occurring heavy rainfall. Warnings of this type are published on the Internet.

There is currently a flood control project being planned for Tar Creek that would alleviate a large amount of local flooding now being experienced. There are no other flood protection measures known to exist or to be planned in the near future on Little Elm Creek, Tar Creek, Lost Creek, or Warren Branch.

There was a provisionally accredited levee (PAL) in the northwestern part of the Town of Wyandotte which was certified to protect the school and surrounding area from the 1-percent-annual-chance flood resulting from backwater (elevation 756) from Grand Lake. Information about this PAL was available in the revised Wyandotte FIS dated December 19, 1997. The ground behind the PAL, however, has been filled in and has ceased to act as a levee; therefore it has been removed from the FIRM. The previous PAL was not certified to protect from the 0.2-percent-annual-chance flood.

There are no other known structural flood control measures that affect the study area.

3.0 ENGINEERING METHODS

For the flooding sources studied by detailed methods in the community, standard hydrologic and hydraulic study methods were used to determine the flood-hazard data required for this study. Flood events of a magnitude that is expected to be equaled or exceeded once on the average during any 10-, 50-, 100-, or 500-year period (recurrence interval) have been selected as having special significance for floodplain management and for flood insurance rates. These events, commonly termed the 10-, 50-, 100-, and 500-year floods, have a 10-, 2-, 1-, and 0.2-percent chance, respectively, of being equaled or exceeded during any year. Although the recurrence interval represents the long-term, average period between floods of a specific magnitude, rare floods could occur at short intervals or even within the same year. The risk of experiencing a rare flood increases when periods greater than 1 year are considered. For example, the risk of having a flood that equals or exceeds the 1-percent-annual-chance flood in any 50-year period is approximately 40 percent (4 in 10); for any 90-year period, the risk increases to approximately 60 percent (6 in 10). The analyses reported herein reflect flooding potentials based on conditions existing in the community at the time of completion of this study. Maps and flood elevations will be amended periodically to reflect future changes.

3.1 Hydrologic Analyses

Hydrologic analyses were carried out to establish peak discharge-frequency relationships for each flooding source studied by detailed methods affecting the community.

The upper reaches of the Neosho River basin are presently regulated by the John Redmond, Council Grove, and Marion Flood Control Reservoirs. Accordingly, the annual peak discharge-frequency curve at the USGS stream gage near Commerce was derived using a graphical analysis of output from the Southwestern Division Reservoir Regulation Simulation Model of the Arkansas River Basin, Run No. 85-01. This simulation used present regulation criteria and the existing basin conditions for the hydrologic period of record from January 1940 through December 1974. The set of frequency data obtained from this exercise was the natural (without flood control reservoirs) annual peak discharge-frequency curve, which was used as a guide for extrapolation of the frequency interval (Reference 7) (Reference 8). To estimate frequency flows for the study reach, which is approximately 11 miles downstream from the gage, the frequency flows at the Commerce gage were increased using a drainage area ratio to the 0.7 power to account for the 195 square miles of tributary drainage area between the Commerce gage and the downstream study limit. The hydrologic analysis of the Neosho River was reevaluated for comparison with the discharges developed by the USACE Flood Plain Information report (Reference 9)

As part of the Tar Creek Feasibility Investigation under the authority of the OWRB, a hydrologic model for the Tar Creek basin was developed by the SCS (Reference 8). Discharge estimates from this model were used in the design of channels to divert surface water away from mining subsidence areas and into the Tar Creek drainage system.

Frequency discharges for Little Elm Creek were estimated using the USACE HEC-1 watershed modeling of the basin (Reference 10). Based on Snyder's unit hydrograph method (Reference 11), the coefficients for this hydrograph were determined by the Tulsa District USACE regional relationships (Reference 12). Typical precipitation losses of 1.0 inch initial and 0.05 inch constant were assumed.

For Belmont Run, Quail Creek, and Fairgrounds Branch, hydrological and meteorological data were examined from the U.S. Weather Service Bureau Paper and climatological bulletins. Mean annual precipitation figures from USGS Water Resources Investigations 77-54 were used in conjunction with the regression formulas for rural and urbanized areas for establishing the peak discharges for the selected recurrence intervals (Reference 13).

Frequency discharges for the upper and lower reaches of Lost Creek, Wyandotte Ditch, and Warren Branch were also estimated using the USACE HEC-1 watershed modeling (Reference 10). Coefficients for the Lost Creek and Warren Branch hydrographs were determined by the Tulsa District USACE regional relationships (Reference 12) based on Snyder's unit hydrograph method (Reference 11). Lost Creek was based on 1.05 inches initial loss (Reference 13) and an SCS curve number 72 (Reference 15) while Warren Branch was based on 1.0 inch initial loss and 0.05 inch constant. The 10-, 2-, and 1-percent-annual-chance rainfall for Wyandotte Ditch was based on extrapolated data from the National Weather Service Technical Paper No. 40 (Reference 7).

Above the confluence of Lost Creek (Upper Reach) and Little Lost Creek, there are presently three SCS floodwater retarding structures and three debris basins, each having ultimate, base flood storage. A summary of stillwater elevations is provided in Table 3. To account for the operation of these structures, the total contributing drainage area was reduced by an amount equal to the area above the six SCS structures. Then, a TP-40, 1-percent-annual-chance, 48-hour storm rainfall was applied to each HEC-1 model to estimate the respective 1-percent-annual-chance peak discharges (Reference 16). To determine the proper slope for the discharge-frequency curves, two reference discharge-frequency relationships were developed using data from the Shoal Creek gage near Big Cabin with the Flood Flow Frequency Analysis program (Reference 17). The reference discharge-frequency relationships were combined to obtain an intermediate slope for the discharge-frequency curves for each basin; the curves were then plotted through their respective 1-percent-annual-chance discharge points.

Peak discharge-drainage area relationships for streams studied by detailed methods are shown in Table 2, "Summary of Discharges."

Table 2: Summary of Discharges

Flooding Source and Location	Drainage Area (Square miles)	Peak Discharges (Cubic Feet per Second) 10-percent	2-percent	1-percent	0.2-percent
BELMONT RUN					
At its confluence with Tar Creek	3.12	1,791	2,649	3,072	4,059
Upstream of Main Street	2.09	1,368	2,017	2,333	3,072
Upstream of 22nd Avenue Northeast	1.70	1,191	1,753	2,024	2,661
Upstream of Highland Avenue	1.24	963	1,415	1,630	2,137
FAIRGROUNDS BRANCH					
At its confluence with the Neosho River	2.04	1,111	1,775	2,109	2,898
Upstream of confluence of South Tributary	1.43	872	1,389	1,645	2,252
Upstream of South Main Street	1.08	721	1,145	1,351	1,845
LITTLE ELM CREEK					
At its confluence with the Neosho River	12.65	3,700	6,990	8,720	13,700
LOST CREEK (LOWER REACH)					
Approximately 4,600 feet above its confluence with Grand Lake	95.19	13,800	22,700	27,400	38,300
At its confluence with Grand Lake	91.90	13,800	22,700	27,400	38,300
LOST CREEK (UPPER REACH)					
Approximately 5,000 feet above its confluence with Grand Lake	59.84	8,200	15,500	19,310	30,400

Table 2: Summary of Discharges (Cont'd)

Flooding Source and Location	Drainage Area (Square miles)	Peak Discharges (Cubic Feet per Second) 10-percent	2-percent	1-percent	0.2-percent
NEOSHO RIVER					
Entire reach within City of Miami	6,057	86,300	147,000	177,000	260,000
Approximately 50,000 feet above its confluence with Spring River	6,071	69,600	139,100	175,000	279,500
QUAIL CREEK					
Entire reach within City of Miami	2.79	1,351	2,161	2,576	3,547
TAR CREEK					
At its confluence with the Neosho River	50.5	8,470	12,200	14,300	19,440
Upstream of 22nd Avenue Northeast	47.23	8,200	11,860	13,920	18,950
Upstream of private road	43.29	7,930	11,560	13,580	18,500
Below D Street bridge	37.68	7,220	10,610	12,480	17,020
Below U.S. Route 69 bridge	34.23	6,910	10,190	11,990	16,370
WARREN BRANCH					
Approximately 20,000 feet above its confluence with Spring River	18.86	4,830	9,100	11,330	17,900
WYANDOTTE DITCH					
At its confluence with Grand Lake	0.86	*	*	1,650	*

* Data Not Available

Table 3: Summary of Stillwater Elevations

Flooding Source and Location	Elevation (Feet) 10-percent	2-percent	1-percent	0.2-percent
GRAND LAKE O' THE CHEROKEES				
Just downstream of the confluence of Council Hollow	*	*	755.0	*
LOST CREEK				
Approximately 250 feet upstream of Lost Creek County Highway	755.8	757.3	758.0	760.0

* Not determined

3.2 Hydraulic Analyses

Analyses of the hydraulic characteristics of flooding from the sources studied were carried out to provide estimates of the elevations of floods of the selected recurrence intervals. Users should be aware that flood elevations shown on the Flood Insurance Rate Map represent rounded whole-foot elevations and may not exactly reflect the elevations shown on the Flood Profiles or in the Floodway Data tables in the FIS report. Flood elevations shown on the FIRM are primarily intended for flood insurance rating purposes. For construction and/or floodplain management purposes, users are cautioned to use the flood elevation data presented in this FIS in conjunction with the data shown on the FIRM.

Cross-sectional data for the backwater analyses of the Neosho River, Little Elm Creek, Tar Creek, and Fairgrounds Branch were obtained from topographic maps compiled from aerial photographs (Reference 18). All bridges and culverts were surveyed to obtain elevation data and structural geometry. Within the City of Miami, cross sections for the backwater analyses for the Neosho River were obtained from the 1969 USACE study in conjunction with field checks at all structures on the reach (Reference 9). Dimensions for the new structure on Main Street were obtained from Oklahoma State Highway Department, and structural plans for the railway bridge upstream of Main Street were provided by the St. Louis-San Francisco Railway. The cross sections for Tar Creek were obtained by the USACE in September 1986. The field cross sections for Belmont Run, Quail Creek, and Fairgrounds Branch were obtained by the study contractor in March 1979.

Water-surface elevations of floods of the selected recurrence intervals were computed using the USACE HEC-2 step-backwater computer program (Reference 19). The HEC-2 model was calibrated for all the streams studied using flows from the February 22-24, 1985 storm. High-water marks from the February 1985 flood were matched to within 1 foot. Flood profiles were drawn showing computed water-surface elevations for floods of the selected recurrence intervals. Starting water surface elevations for all sources studied in detail were determined using the slope/area method. Within the City of Miami, starting water-surface elevations for the Neosho River were calculated using known high-water marks. Starting water-surface elevations for Belmont Run and Quail Creek were coincident with flood elevations on Tar Creek since coincident floods on the tributaries and main stream of Tar Creek are probable.

Comparisons of the results for the Neosho River and Tar Creek were analyzed with results of the 1969 USACE study on the Neosho River and Tar Creek. Adjustments to the model reflect additional residential development and commercial growth. The final comparisons on the Neosho River resulted in differences of 0.5-foot or less. The present model flood levels were shown in this study as it reflects the Main Street Bridge and rebuilt Frisco Railroad Bridge.

The acceptability of all assumed hydraulic factors, cross sections, and hydraulic structure data was checked by computations that duplicated historic floodwater profiles on the Neosho River and Tar Creek study reaches. For Belmont Run, Quail Creek, and Fairgrounds Branch, there are no historic flood profiles available.

Cross-sectional data for the backwater analyses for Lost Creek and Warren Branch were obtained from topographic maps compiled from aerial photographs (Reference 18). All bridges and culverts were surveyed to obtain elevation data and structural geometry.

Water-surface elevations of floods of the selected recurrence intervals in Lost Creek and Warren Branch were computed using the USACE HEC-2 step-backwater computer program (Reference 19). The HEC-2 model was calibrated for these streams studied using flows from the February 22-24, 1985 storm. High-water marks from the February 1985 flood were matched to within 1 foot. Flood profiles were drawn showing computed water-surface elevations for floods of the selected recurrence intervals. Starting water surface elevations for all sources studied in detail were determined using the slope/area method.

The original analysis on Wyandotte Ditch indicated a sheet flow situation. Cross sections were developed from the 2 foot contour interval maps perpendicular to the sheet flow. Normal depth computations resulted in an average 1 percent annual chance recurrence interval flood depth of approximately 1 foot. Grand Lake was examined for its effects on the Town of Wyandotte. It has an elevation of approximately 755 feet for a 10 percent annual chance frequency storm and a Government Flowage Easement of approximately 760 feet. (Reference 20). The original hydraulic model for Wyandotte Ditch was modified to incorporate overflow from Wyandotte Ditch that flows to the north. Revised hydraulic analyses for the 1-percent-annual-chance flood event for Wyandotte Ditch were performed using the USACE HEC-2 computer program (Reference 21). Cross sections were compiled based on topographic mapping and linear interpolation between contours. The slope-area method was used to determine the starting water-surface elevation (Reference 22). Channel roughness factors (Manning's "n" values) used in the hydraulic computations were chosen by engineering judgment after field reconnaissance of the watershed. Channel and over bank "n" values for the streams studied by detailed methods are shown in 4, “Summary of Roughness Coefficients.”

Table 4: Summary of Roughness Coefficients

Flooding Source	Roughness Coefficients	
	Channel	Overbanks
Belmont Run (within the City of Miami)	0.035–0.095*	0.045–0.095
Fairgrounds Branch (within the City of Miami)	0.035–0.095*	0.045–0.095
Little Elm Creek (within the City of Miami)	0.035–0.095*	0.045–0.095
Little Elm Creek (all other reaches)	0.035–0.045	0.08–0.12
Lost Creek (Lower Reach)	0.045–0.060	0.07
Lost Creek (Upper Reach)	0.045–0.050	0.08–0.12
Neosho River (within the City of Miami)**	0.040–0.045	0.045–0.060
Neosho River (all other reaches)	0.030	0.04–0.95
Quail Creek (within the City of Miami)	0.035–0.095*	0.045–0.095
Tar Creek (within the City of Miami)	0.035–0.095*	0.045–0.095
Tar Creek (all other reaches)	0.050–0.060	0.08–0.14
Warren Branch	0.050–0.075	0.06–0.10
Wyandotte Ditch	0.040	0.065–0.070

* Through culverts, values were reduced to 0.018–0.024

** Occasional obstructions of snags and trash heaps on the upstream side of bridge piers were not considered.

Locations of selected cross sections used in the hydraulic analyses are shown on the Flood Profiles (Exhibit 1). For stream segments for which a floodway was computed (Section 4.2), selected cross-section locations are also shown on the FIRM (Exhibit 2).

The hydraulic analyses for this study were based on unobstructed flow. The flood elevations shown on the Flood Profiles (Exhibit 1) are thus considered valid only if hydraulic structures remain unobstructed, operate properly, and do not fail.

3.3 Vertical Datum

All FIS reports and FIRMs are referenced to a specific vertical datum. The vertical datum provides a starting point against which flood, ground, and structure elevations can be referenced and compared. Until recently, the standard vertical datum used for newly created or revised FIS reports and FIRMs was the National Geodetic Vertical Datum of 1929 (NGVD). With the completion of the North American Vertical Datum of 1988 (NAVD), many FIS reports and FIRMs are now prepared using NAVD as the referenced vertical datum.

Flood elevations shown in this FIS report and on the FIRM are referenced to the NAVD88. These flood elevations must be compared to structure and ground elevations referenced to the same vertical datum. Some of the data used in this revision were taken from the prior effective FIS reports and FIRMs and adjusted to NAVD88. The datum conversion factor from NGVD29 to NAVD88 in Ottawa County is +0.353 feet.

For information regarding conversion between the NGVD and NAVD, visit the National Geodetic Survey website at www.ngs.noaa.gov, or contact the National Geodetic Survey at the following address:

NGS Information Services
NOAA, N/NGS12
National Geodetic Survey
SSMC-3, #9202
1315 East-West Highway
Silver Spring, Maryland 20910-3282
(301) 713-3242

Temporary vertical monuments are often established during the preparation of a flood hazard analysis for the purpose of establishing local vertical control. Although these monuments are not shown on the FIRM, they may be found in the Technical Support Data Notebook associated with the FIS report and FIRM for this community. Interested individuals may contact FEMA to access these data.

To obtain current elevation, description, and/or location information for benchmarks shown on this map, please contact the Information Services Branch of the NGS at (301) 713-3242, or visit their Web site at www.ngs.noaa.gov.

4.0 FLOODPLAIN MANAGEMENT APPLICATIONS

The NFIP encourages State and local governments to adopt sound floodplain management programs. To assist in this endeavor, each FIS report provides 1-percent-annual-chance floodplain data, which may include a combination of the following: 10-, 2-, 1-, and 0.2-percent-annual-chance flood elevations; delineations of the 1- and 0.2-percent-annual-chance floodplains; and a 1-percent-annual-chance floodway. This information is presented on the FIRM and in many components of the FIS report, including Flood Profiles, Floodway Data tables, and Summary of Stillwater Elevation tables. Users should reference the data presented in the FIS report as well as additional information that may be available at the local community map repository before making flood elevation and/or floodplain boundary determinations.

4.1 Floodplain Boundaries

To provide a national standard without regional discrimination, the 1-percent-annual-chance flood has been adopted by FEMA as the base flood for floodplain management purposes. The 0.2-percent-annual-chance flood is employed to indicate additional areas of flood risk in the community. For each stream studied by detailed methods, the 1- and 0.2-percent-annual-chance floodplain boundaries have been delineated using the flood elevations determined at each cross section.

Between cross sections, the boundaries were interpolated using topographic maps for the original studies and restudies as follows:

City of Miami
Topographic maps at a scale of 1:24,000 with a contour interval of 10 feet (Reference 22).

Town of Wyandotte
Topographic maps at a scale of 1:2,400 with a contour interval of 2 feet (Reference 23).

Unincorporated Areas of Ottawa County
Topographic maps at a scale of 1:7,200 with a contour interval of 2 feet (Reference 18).

The 1- and 0.2-percent-annual-chance floodplain boundaries are shown on the FIRM. On this map, the 1-percent-annual-chance floodplain boundary corresponds to the boundary of the areas of special flood hazards (Zones A and AE), and the 0.2-percent-annual-chance floodplain boundary corresponds to the boundary of areas of moderate flood hazards. In cases where the 1- and 0.2-percent-annual-chance floodplain boundaries are close together, only the 1-percent-annual-chance floodplain boundary has been shown. Small areas within the floodplain boundaries may lie above the flood elevations, but cannot be shown due to limitations of the map scale and/or lack of detailed topographic data.

For the streams studied by approximate methods, only the 1-percent-annual-chance floodplain boundary is shown on the FIRM.

4.2 Floodways

Encroachment on floodplains, such as structures and fill, reduces flood-carrying capacity, increases flood heights and velocities, and increases flood hazards in areas beyond the encroachment itself. One aspect of floodplain management involves balancing the economic gain from floodplain development against the resulting increase in flood hazard. For purposes of the NFIP, a floodway is used as a tool to assist local communities in this aspect of floodplain management. Under this concept, the area of the 1-percent-annual-chance floodplain is divided into a floodway and a floodway fringe. The floodway is the channel of a stream, plus any adjacent floodplain areas, that must be kept free of encroachment so that the base flood can be carried without substantial increases in flood heights. Minimum Federal standards limit such increases to 1 foot, provided that hazardous velocities are not produced. The floodways in this study are presented to local agencies as minimum standards that can be adopted directly or that can be used as a basis for additional floodway studies.

The floodways presented in this study were computed for certain stream segments on the basis of equal-conveyance reduction from each side of the floodplain. Floodway widths were computed at cross sections. Between cross sections, the floodway boundaries were interpolated. The results of the floodway computations are tabulated for selected cross sections (see Table 5, “Floodway Data Table” of this FIS report). In cases where the floodway and 1-percent-annual-chance floodplain boundaries are either close together or collinear, only the floodway boundary is shown.

A floodway was not determined for the Neosho River; however, results of the hydraulic analysis are shown in Table 5. Portions of the floodway widths for the Neosho River, Tar Creek, and Warren Branch extend beyond the county boundary.

Near the confluence of streams studied in detail, floodway computations are made without regard to flood elevations on the receiving water body. Therefore, "Without Floodway" elevations presented in Table 5 for certain downstream cross sections of Tar Creek and Quail Creek are lower than the regulatory flood elevations in that area, which must take into account the 1-percent-annual-chance flooding due to backwater from other sources.

No floodways were computed for Wyandotte Ditch as part of this restudy; however, a floodway along Lost Creek (Lower Reach) has been annexed at the Main Street right-of-way crossing of Lost Creek.

The area between the floodway and 1-percent-annual-chance floodplain boundaries is termed the floodway fringe. The floodway fringe encompasses the portion of the floodplain that could be completely obstructed without increasing the water-surface elevation (WSEL) of the base flood more than 1 foot at any point. Typical relationships between the floodway and the floodway fringe and their significance to floodplain development are shown in Figure 1.

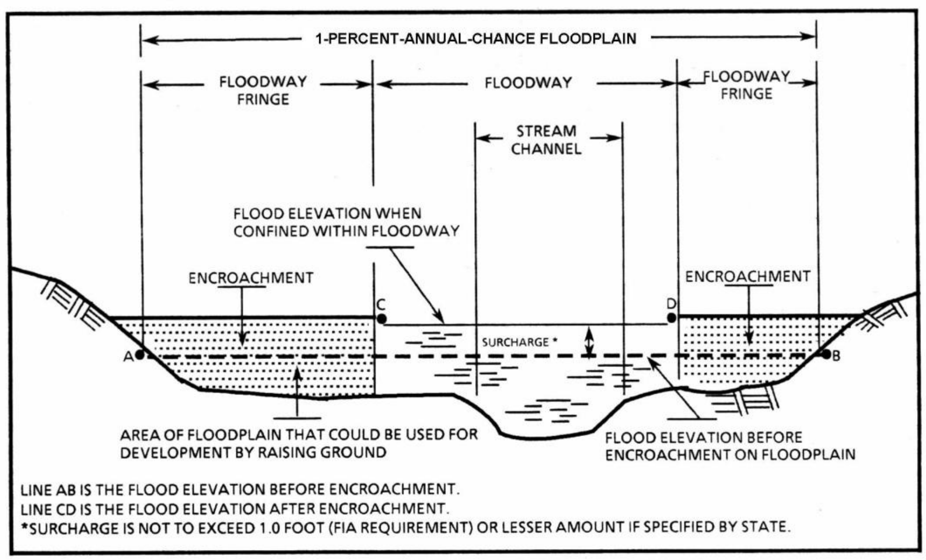


Figure 1: Floodway Schematic

FLOODING SOURCE		FLOODWAY			1-PERCENT-ANNUAL-CHANCE-FLOOD WATER SURFACE ELEVATION			
CROSS SECTION	DISTANCE[1]	WIDTH (FEET)	SECTION AREA (SQUARE FEET)	MEAN VELOCITY (FEET PER SECOND)	REGULATORY (FEET NAVD)	WITHOUT FLOODWAY (FEET NAVD)	WITH FLOODWAY (FEET NAVD)	INCREASE (FEET)
BELMONT RUN								
A	1,474	157	630	4.9	775.1	775.1	776.0	0.9
B	1,626	310	1,311	2.3	776.0	776.0	777.0	1.0
C	2,015	297	1,196	2.6	777.0	777.0	777.7	0.7
D	2,433	124	511	6.0	781.6	781.6	782.4	0.8
E	2,717	259	1,335	2.3	782.8	782.8	783.6	0.8
F	5,125	439	1,413	1.7	786.0	786.0	786.9	0.9
G	6,917	700	3,495	0.6	791.8	791.8	792.5	0.7
H	8,550	678	1,576	1.3	792.6	792.6	793.1	0.5
I	10,126	380	4,239	0.5	798.1	798.1	798.8	0.7
J	10,718	357	1,945	1.0	798.4	798.4	799.0	0.6
K	12,018	282	1,486	1.4	798.7	798.7	799.3	0.6
L	13,569	206	1,228	1.3	801.7	801.7	802.5	0.8
M	14,619	120	625	2.6	802.3	802.3	802.9	0.6
N	15,819	211	972	1.7	803.7	803.7	804.3	0.6
O	17,000	192	770	2.1	804.6	804.6	805.2	0.6

[1]Feet above confluence with Tar Creek

TABLE 5

FEDERAL EMERGENCY MANAGEMENT AGENCY

OTTAWA COUNTY, OK
AND INCORPORATED AREAS

FLOODWAY DATA

BELMONT RUN

FLOODING SOURCE		FLOODWAY			1-PERCENT-ANNUAL-CHANCE-FLOOD WATER SURFACE ELEVATION			
CROSS SECTION	DISTANCE[1]	WIDTH (FEET)	SECTION AREA (SQUARE FEET)	MEAN VELOCITY (FEET PER SECOND)	REGULATORY (FEET NAVD)	WITHOUT FLOODWAY (FEET NAVD)	WITH FLOODWAY (FEET NAVD)	INCREASE (FEET)
FAIRGROUNDS BRANCH								
A	7,250	100	474	2.9	775.3	775.3	776.1	0.8
B	8,250	51	177	4.5	781.7	781.7	782.6	0.9
C	9,250	145	302	2.7	790.0	790.0	790.7	0.7

[1]Feet above confluence with Neosho River

FEDERAL EMERGENCY MANAGEMENT AGENCY

OTTAWA COUNTY, OK
AND INCORPORATED AREAS

FLOODWAY DATA

FAIRGROUNDS BRANCH

TABLE 5

FLOODING SOURCE		FLOODWAY			1-PERCENT-ANNUAL-CHANCE-FLOOD WATER SURFACE ELEVATION			
CROSS SECTION	DISTANCE[1]	WIDTH (FEET)	SECTION AREA (SQUARE FEET)	MEAN VELOCITY (FEET PER SECOND)	REGULATORY (FEET NAVD)	WITHOUT FLOODWAY (FEET NAVD)	WITH FLOODWAY (FEET NAVD)	INCREASE (FEET)
LITTLE ELM CREEK								
A	3,053	320	3,126	2.8	772.3	755.3[2]	756.2[2]	0.9
B	4,343	258	1,978	4.4	772.3	757.2[2]	758.1[2]	0.9
C	5,668	349	2,001	4.4	772.3	761.7[2]	762.7[2]	1.0
D	6,250	276	1,830	4.8	772.3	764.0[2]	765.0[2]	1.0
E	7,340	393	2,795	3.1	772.3	766.9[2]	767.8[2]	0.9
F	7,808	261	1,522	5.7	772.3	769.3[2]	770.0[2]	0.7
G	9,478	650	3,354	2.6	774.2	774.2	775.2	1.0
H	10,319	373	2,059	4.2	775.7	775.7	776.6	0.9
I	11,280	573	3,132	2.8	778.0	778.0	778.9	0.9
J	12,363	466	2,351	3.7	780.4	780.4	781.2	0.8
K	14,842	494	2,864	3.8	785.2	785.2	786.2	1.0
L	15,718	514	3,829	2.3	786.1	786.1	787.1	1.0
M	16,100	501	3,273	2.7	787.5	787.5	788.5	1.0
N	16,460	727	5,026	1.7	787.9	787.9	788.9	1.0
O	16,652	542	3,434	2.5	788.1	788.1	789.1	1.0
P	18,300	402	2,459	3.5	789.8	789.8	790.8	1.0

[1]Feet above confluence with Neosho River
[2]Elevation computed without consideration of backwater effects from the Neosho River

TABLE 5

FEDERAL EMERGENCY MANAGEMENT AGENCY

OTTAWA COUNTY, OK
AND INCORPORATED AREAS

FLOODWAY DATA

LITTLE ELM CREEK

FLOODING SOURCE		FLOODWAY			1-PERCENT-ANNUAL-CHANCE-FLOOD WATER SURFACE ELEVATION			
CROSS SECTION	DISTANCE[1]	WIDTH (FEET)	SECTION AREA (SQUARE FEET)	MEAN VELOCITY (FEET PER SECOND)	REGULATORY (FEET NAVD)	WITHOUT FLOODWAY (FEET NAVD)	WITH FLOODWAY (FEET NAVD)	INCREASE (FEET)
LOST CREEK (LOWER REACH)								
A	5,090	497	4,128	6.6	755.9	755.9	756.9	1.0
B	7,040	1,431	14,046	2.0	758.9	758.9	759.7	0.8
C	8,000	1,494	10,886	2.5	759.2	759.2	760.2	1.0
D	10,000	1,513	6,840	4.0	761.6	761.6	762.6	1.0
E	11,960	959	9,040	3.0	764.6	764.6	765.6	1.0
F	12,840	735	4,945	5.5	765.6	765.6	766.6	1.0
G	13,700	590	4,861	5.6	768.4	768.4	769.4	1.0

[1]Feet above confluence with Grand Lake O' the Cherokees

TABLE 5

FEDERAL EMERGENCY MANAGEMENT AGENCY

OTTAWA COUNTY, OK
AND INCORPORATED AREAS

FLOODWAY DATA

LOST CREEK (LOWER REACH)

FLOODING SOURCE		FLOODWAY			1-PERCENT-ANNUAL-CHANCE-FLOOD WATER SURFACE ELEVATION			
CROSS SECTION	DISTANCE[1]	WIDTH (FEET)	SECTION AREA (SQUARE FEET)	MEAN VELOCITY (FEET PER SECOND)	REGULATORY (FEET NAVD)	WITHOUT FLOODWAY (FEET NAVD)	WITH FLOODWAY (FEET NAVD)	INCREASE (FEET)
LOST CREEK (UPPER REACH)								
A	45,800	787	6,115	3.2	829.4	829.4	830.4	1.0
B	46,240	618	3,750	5.1	830.3	830.3	831.3	1.0
C	47,295	1,073	6,074	3.2	833.6	833.6	834.6	1.0
D	48,315	770	4,183	5.6	835.6	835.6	836.5	0.9
E	48,705	605	3,823	5.1	836.7	836.7	837.7	1.0
F	49,065	353	2,237	8.6	838.5	838.5	838.7	0.2
G	49,755	410	2,661	7.3	841.9	841.9	842.2	0.3
H	49,970	407	3,104	6.2	843.5	843.5	844.4	0.9
I	50,465	730	6,421	3.0	845.5	845.5	846.1	0.6
J	50,900	803	8,395	2.3	845.9	845.9	846.5	0.6
K	51,800	850	7,120	2.7	846.4	846.4	847.2	0.8
L	52,845	850	7,127	2.7	847.6	847.6	848.6	1.0
M	52,890	850	6,880	2.8	847.6	847.6	848.6	1.0

[1]Feet above confluence with Grand Lake O' the Cherokees

TABLE 5

FEDERAL EMERGENCY MANAGEMENT AGENCY

OTTAWA COUNTY, OK
AND INCORPORATED AREAS

FLOODWAY DATA

LOST CREEK (UPPER REACH)

FLOODING SOURCE		FLOODWAY			1-PERCENT-ANNUAL-CHANCE-FLOOD WATER SURFACE ELEVATION			
CROSS SECTION	DISTANCE[1]	WIDTH (FEET)	SECTION AREA (SQUARE FEET)	MEAN VELOCITY (FEET PER SECOND)	REGULATORY (FEET NAVD)	WITHOUT FLOODWAY (FEET NAVD)	WITH FLOODWAY (FEET NAVD)	INCREASE (FEET)
NEOSHO RIVER								
A	51,080	1,846	32,453	5.4	770.1	770.1	771.1	1.0
B	53,210	1,900	35,431	4.9	771.1	771.1	771.9	0.8
C	54,266	1,920	38,645	4.5	771.7	771.7	772.5	0.8
D	55,820	2,480	46,866	3.7	772.1	772.1	773.0	0.9
E	58,520	1,280	33,895	5.2	772.6	772.6	773.6	1.0
F	58,640	1,250	33,921	5.2	772.7	772.7	773.7	1.0
G	60,315	2,990	70,260	2.5	773.7	773.7	774.6	0.9
H	62,265	2,590	43,130	4.1	774.0	774.0	774.6	0.6
I	62,787	*	*	*	773.2	773.2	*	*
J	67,381	*	*	*	774.9	774.9	*	*
K	67,979	*	*	*	775.2	775.2	*	*
L	69,939	*	*	*	775.8	775.8	*	*
M	74,652	*	*	*	776.4	776.4	*	*

[1]Feet above confluence with Spring River
*Floodway not computed

TABLE 5

FEDERAL EMERGENCY MANAGEMENT AGENCY

OTTAWA COUNTY, OK
AND INCORPORATED AREAS

FLOODWAY DATA

NEOSHO RIVER

FLOODING SOURCE		FLOODWAY			1-PERCENT-ANNUAL-CHANCE-FLOOD WATER SURFACE ELEVATION			
CROSS SECTION	DISTANCE[1]	WIDTH (FEET)	SECTION AREA (SQUARE FEET)	MEAN VELOCITY (FEET PER SECOND)	REGULATORY (FEET NAVD)	WITHOUT FLOODWAY (FEET NAVD)	WITH FLOODWAY (FEET NAVD)	INCREASE (FEET)
QUAIL CREEK								
A[2]	375	655	5,408	2.6	774.0	768.4[4]	769.3[4]	0.9
B[3]	850	1,130	8,602	2.7	774.0	769.6[4]	770.5[4]	0.9
C	1,950	84	316	8.1	774.0	769.2[4]	769.2[4]	0.0
D	3,450	354	1,064	2.4	774.0	773.2[4]	773.8[4]	0.6
E	4,513	77	405	6.4	775.4	775.4	775.6	0.2
F	4,637	137	407	6.3	776.3	776.3	776.4	0.1
G	5,012	136	614	4.2	777.6	777.6	778.5	0.9
H	5,612	107	451	5.7	779.4	779.4	780.3	0.9

[1]Feet above confluence with Tar Creek
[2]Mapped coincident with cross-section B on Tar Creek
[3]Mapped coincident with cross-section C on Tar Creek
[4]Elevation computed without consideration of backwater effects from the Neosho River

TABLE 5

FEDERAL EMERGENCY MANAGEMENT AGENCY

OTTAWA COUNTY, OK
AND INCORPORATED AREAS

FLOODWAY DATA

QUAIL CREEK

FLOODING SOURCE		FLOODWAY			1-PERCENT-ANNUAL-CHANCE-FLOOD WATER SURFACE ELEVATION			
CROSS SECTION	DISTANCE[1]	WIDTH (FEET)	SECTION AREA (SQUARE FEET)	MEAN VELOCITY (FEET PER SECOND)	REGULATORY (FEET NAVD)	WITHOUT FLOODWAY (FEET NAVD)	WITH FLOODWAY (FEET NAVD)	INCREASE (FEET)
TAR CREEK								
A	11,250	1,046	6,474	2.2	774.0	766.0[4]	767.0[4]	1.0
B[2]	12,100	655	5,408	2.6	774.0	768.4[4]	769.3[4]	0.9
C[3]	12,900	1,130	8,602	1.7	774.0	769.6[4]	770.5[4]	0.9
D	13,800	1,130	7,180	2.0	774.0	770.5[4]	771.3[4]	0.8
E	14,500	470	2,682	5.3	774.0	774.0	774.0	0.0
F	14,970	900	6,739	2.1	775.1	775.1	775.6	0.5
G	15,720	790	7,114	2.0	775.5	775.5	776.3	0.8
H	16,950	895	5,665	2.5	776.3	776.3	777.3	1.0
I	18,205	1,190	7,710	1.8	777.8	777.8	778.8	1.0
J	19,400	1,221	7,746	1.8	778.3	778.3	779.2	0.9
K	19,918	1,046	7,222	1.9	778.6	778.6	779.5	0.9
L	20,250	1,007	6,503	2.1	779.0	779.0	779.9	0.9
M	21,255	974	6,130	2.3	779.9	779.9	780.8	0.9
N	22,465	1,513	8,804	1.6	780.8	780.8	781.7	0.9
O	23,760	1,200	7,322	1.9	781.6	781.6	782.6	1.0
P	24,625	1,490	10,022	1.4	782.1	782.1	783.1	1.0
Q	25,020	1,340	7,762	1.7	782.2	782.2	783.2	1.0
R	25,210	1,350	8,024	1.7	782.5	782.5	783.4	0.9
S	25,910	1,585	9,131	1.5	782.8	782.8	783.7	0.9

[1]Feet above confluence with Neosho River
[2]Mapped coincident with cross-section A on Quail Creek
[3]Mapped coincident with cross-section B on Quail Creek
[4]Elevation computed without consideration of backwater effects from the Neosho River

TABLE 5

FEDERAL EMERGENCY MANAGEMENT AGENCY

OTTAWA COUNTY, OK
AND INCORPORATED AREAS

FLOODWAY DATA

TAR CREEK

FLOODING SOURCE		FLOODWAY			1-PERCENT-ANNUAL-CHANCE-FLOOD WATER SURFACE ELEVATION			
CROSS SECTION	DISTANCE[1]	WIDTH (FEET)	SECTION AREA (SQUARE FEET)	MEAN VELOCITY (FEET PER SECOND)	REGULATORY (FEET NAVD)	WITHOUT FLOODWAY (FEET NAVD)	WITH FLOODWAY (FEET NAVD)	INCREASE (FEET)
TAR CREEK (CONTINUED)								
T	27,500	1,420	6,700	2.0	783.6	783.6	784.6	1.0
U	28,910	756	3,977	3.3	785.8	785.8	786.8	1.0
V	31,135	1,500	10,360	1.2	788.5	788.5	789.5	1.0
W	32,830	983	6,774	1.8	789.5	789.5	790.4	0.9
X	33,180	1,030	5651	2.2	790.1	790.1	791.1	1.0
Y	33,520	880	4236	2.9	790.6	790.6	791.4	0.8
Z	34,660	725	4,150	3.0	793.2	793.2	793.4	0.2
AA	35,720	840	6,174	2.0	793.9	793.9	794.7	0.8
AB	36,630	890	7,598	1.6	794.3	794.3	795.1	0.8
AC	37,640	758	6,216	2.0	794.8	794.8	795.6	0.8
AD	38,885	757	8,162	1.5	795.3	795.3	796.2	0.9
AE	39,525	812	7,238	1.7	795.6	795.6	796.5	0.9

[1]Feet above confluence with Neosho River

TABLE 5

FEDERAL EMERGENCY MANAGEMENT AGENCY

OTTAWA COUNTY, OK
AND INCORPORATED AREAS

FLOODWAY DATA

TAR CREEK

FLOODING SOURCE		FLOODWAY			1-PERCENT-ANNUAL-CHANCE-FLOOD WATER SURFACE ELEVATION			
CROSS SECTION	DISTANCE[1]	WIDTH (FEET)	SECTION AREA (SQUARE FEET)	MEAN VELOCITY (FEET PER SECOND)	REGULATORY (FEET NAVD)	WITHOUT FLOODWAY (FEET NAVD)	WITH FLOODWAY (FEET NAVD)	INCREASE (FEET)
WARREN BRANCH								
A	19,600	137	1,706	6.6	855.4	855.4	856.4	1.0
B	20,285	130	1,611	7.0	858.3	858.3	859.3	1.0
C	20,805	140	1,756	6.5	861.3	861.3	861.9	0.6
D	21,015	186	2,740	4.1	868.8	868.8	869.1	0.3
E	24,230	464	2,760	4.1	878.9	878.9	879.9	1.0
F	25,165	349	1,706	6.6	885.2	885.2	886.2	1.0
G	25,800	320	2,246	5.0	890.3	890.3	891.2	0.9
H	27,000	492	3,205	3.5	895.8	895.8	896.8	1.0

[1]Feet above confluence with Spring River

TABLE 5

FEDERAL EMERGENCY MANAGEMENT AGENCY

OTTAWA COUNTY, OK
AND INCORPORATED AREAS

FLOODWAY DATA

WARREN BRANCH

5.0 INSURANCE APPLICATION

For flood insurance rating purposes, flood insurance zone designations are assigned to a community based on the results of the engineering analyses. These zones are as follows:

Zone A

Zone A is the flood insurance rate zone that corresponds to the 1-percent-annual-chance floodplains that are determined in the FIS report by approximate methods. Because detailed hydraulic analyses are not performed for such areas, no base (1-percent-annual-chance) flood elevations (BFEs) or depths are shown within this zone.

Zone AE

Zone AE is the flood insurance rate zone that corresponds to the 1-percent-annual-chance floodplains that are determined in the FIS report by detailed methods. Whole-foot BFEs derived from the detailed hydraulic analyses are shown at selected intervals within this zone.

Zone X

Zone X is the flood insurance rate zone that corresponds to areas outside the 0.2-percent-annual-chance floodplain, areas within the 0.2-percent-annual-chance floodplain, areas of 1-percent-annual-chance flooding where average depths are less than 1 foot, areas of 1-percent-annual-chance flooding where the contributing drainage area is less than 1 square mile (sq. mi.), and areas protected from the base flood by levees. No BFEs or depths are shown within this zone.

6.0 FLOOD INSURANCE RATE MAP

The FIRM is designed for flood insurance and floodplain management applications.

For flood insurance applications, the map designates flood insurance rate zones as described in Section 5.0 and, in the 1-percent-annual-chance floodplains that were studied by detailed methods, shows selected whole-foot BFEs or average depths. Insurance agents use zones and BFEs in conjunction with information on structures and their contents to assign premium rates for flood insurance policies.

For floodplain management applications, the map shows by tints, screens, and symbols, the 1- and 0.2-percent-annual-chance floodplains, floodways, and the locations of selected cross sections used in the hydraulic analyses and floodway computations.

The countywide FIRM presents flooding information for the entire geographic area of Ottawa County. Previously, FIRMs were prepared for each incorporated community and the unincorporated areas of the County identified as flood-prone. This countywide FIRM also includes flood-hazard information that was presented separately on Flood Boundary and Floodway Maps (FBFMs), where applicable. Historical data relating to the maps prepared for each community are presented in Table 6, “Community Map History.”

COMMUNITY NAME	INITIAL IDENTIFICATION	FLOOD HAZARD BOUNDARY MAP REVISIONS DATE	FIRM EFFECTIVE DATE	FIRM REVISIONS DATE
Afton, Town of	February 7, 1975	None	January 3, 1986	None
Commerce, City of	June 4, 1976	None	July 18, 1985	None
Fairland, Town of	April 9, 1976	None	January 1, 1992	None
Miami, City of	February 1, 1974	December 5, 1975	December 16, 1980	April 19, 1983 September 30, 1988 September 3, 1997
North Miami, Town of	April 9, 1976	None	August 5, 2010	None
Ottawa County (Unincorporated Areas)	May 20, 1977	None	December 2, 1988	December 19, 1997
Peoria, Town of	November 22, 1974	None	August 5, 2010	None
Picher, City of	July 23, 1976	None	September 21, 1982	None
Quapaw, Town of	August 13, 1976	None	August 5, 2010	None
Wyandotte, Town of	June 28, 1974	December 12, 1975 December 10, 1976	December 17, 1987	December 19, 1997

TABLE 6

FEDERAL EMERGENCY MANAGEMENT AGENCY

OTTAWA COUNTY, OK

AND INCORPORATED AREAS

COMMUNITY MAP HISTORY

7.0 OTHER STUDIES

In June 1969, the USACE published a Flood Plain Information report for the Neosho River and Tar Creek (Reference 10). The USACE presented the 1-percent-annual-chance Standard Project Flood and July 1951 flood elevations for these streams. The study updated Manning's coefficients, bridge structural changes, and residential development since 1969. Comparisons of the results of the backwater analysis by the study contractor with the USACE flood levels resulted in differences not greater than 0.5 foot; therefore, the study flood levels were used in this study to show the latest topographic development.

A FIS for the City of Seneca, Missouri, has been published (Reference 22). The results of this study are in exact agreement with the results of that study.

FIS reports have been prepared for the City of Miami (Reference 1) and the Town of Wyandotte (Reference 2) as well as the unincorporated areas of Ottawa County (Reference 3). This FIS report either supersedes or is compatible with all previous studies published on streams studied in this report and should be considered authoritative for the purposes of the NFIP.

8.0 LOCATION OF DATA

Information concerning the pertinent data used in the preparation of this study can be obtained by contacting FEMA Region VI, Federal Insurance and Mitigation Division, 800 North Loop 288, Denton, Texas 76209.

9.0 BIBLIOGRAPHY AND REFERENCES

1. Federal Emergency Management Agency. Flood Insurance Study, City of Miami, Ottawa County, Oklahoma. Washington, D.C., September 30, 1988.

2. Federal Emergency Management Agency. Flood Insurance Study, City of Wyandotte, Ottawa County, Oklahoma. Washington, D.C., December 19, 1997.

3. Federal Emergency Management Agency. Flood Insurance Study, Ottawa County, Unincorporated Areas. Washington, D.C., March 31, 1997.

4. U.S. Department of Commerce, Bureau of the Census. *"State & County Quickfacts, Oklahoma Quicklinks"*. [Online] 2007. Available http://www.census.gov/census2000/states/ok.html.

5. Oklahoma Climatological Survey. *"Climatological Information for Ottawa County, OK"*. [Online] 2007. Available http://climate.ocs.ou.edu/county/ottawa.html.

6. National Climatic Data Center. *Event Record Details - 01 Jul 2007 Flood - Commerce, OK.* [Online. http://www4.ncdc.noaa.gov/cgi-win/wwcgi.dll?wwevent~ShowEvent~676070] July 2007.

7. Miami News Record. Preliminary damage assessment continues after Oklahoma Floods. *Miami News Record.* [Online] July 9, 2007. http://www.miaminewsrecord.com/archives.

8. U.S. Department of Agriculture, Soil Conservation Service. Tar Creek Feasibility Investigation, Task II.3.E.f: Assessment of Changes in Drainage Patterns Resulting from Proposed Diversion and Diking. Stillwater, Oklahoma, December 1983.

9. U.S. Department of the Army, Corps of Engineers, Tulsa District. Flood Plain Information, Neosho River and Tar Creek, Miami, Oklahoma. Tulsa, Oklahoma, June 1969.

10. U.S. Department of the Army, Corps of Engineers, Hydrologic Engineering Center. *HEC-1 Flood Hydrograph Package: Computer Program.* Davis, California, January 1985.

11. Snyder, Franklin F. "Synthetic Unit Hydrographs" in. *Transactions of the American Geophysical Union.* Vols. 19, Part 1, pp. 447-454.

12. U.S. Department of the Army, Corps of Engineers. Regional Relationships for Unit Hydrograph Coefficients, Natural and Urbanized Basins. Tulsa, Oklahoma, May 1980.

13. U.S. Department of the Army, Corps of Engineers, Hydrologic Engineering Center. *HEC-2 Water Surface Profiles, Generalized Computer Program.* Davis, California, October 1973.

14. U.S. Department of the Army, Corps of Engineers. Detailed Project Report: Lost and Little Creeks, Seneca, Missouri. January 1976.

15. U.S. Department of Agriculture, Soil Conservation Service. Technical Release No. 55: Urban Hydrology for Small Watersheds. Washington, D.C., January 1975.

16. U.S. Department of Commerce, Weather Bureau. Technical Paper No. 40: Rainfall Frequency Atlas of the United States. Washington, D.C., 1961, Revised 1963.

17. U.S. Department of the Army, Corps of Engineers, Hydrologic Engineering Center. *Flood Flow Frequency Analysis, Computer Program 723-X6-L7550.* Davis, California, February 1982.

18. Aerial Data Service. Photogrammetric Topographic Survey, Scale 1:2,400, Contour Interval 2 Feet: Ottawa County, Oklahoma. Tulsa, Oklahoma, April 1984.

19. U.S. Army Corps of Engineers, Hydrologic Engineering Center. *HEC-2 Water Surface Profiles, Generalized Computer Program.* Davis, California, April 1984.

20. U.S. Department of the Army, Corps of Engineers, Tulsa District. Civil Works Project Maps. Tulsa, Oklahoma, September 30, 1979.

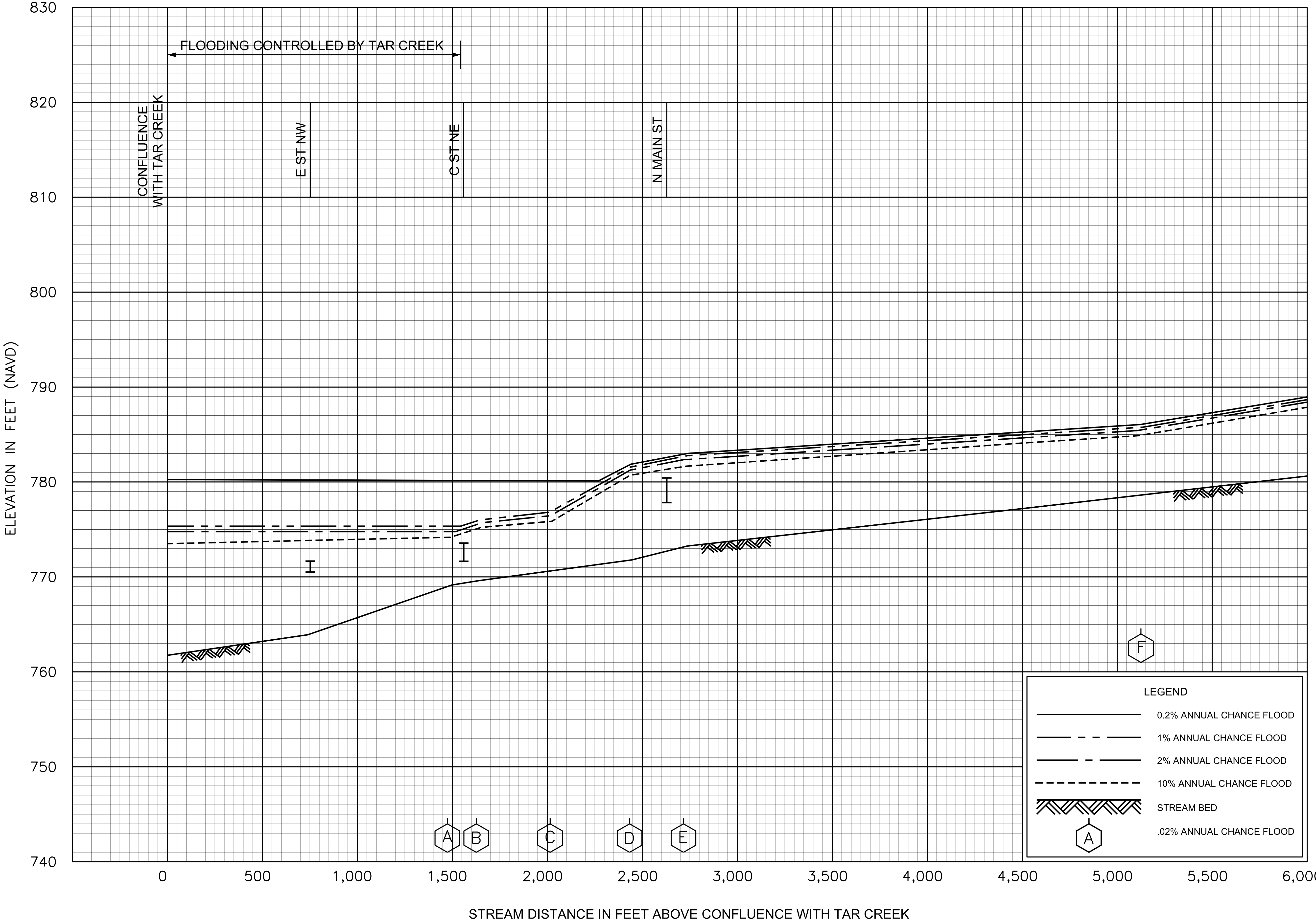
21. U.S. Department of the Army, Corps of Engineers, Hydrologic Engineering Center. *HEC-2 Water Surface Profiles, Generalized Computer Program, Version 4.6.2.* Davis, California, May 1991.

22. Federal Emergency Management Agency. Flood Insurance Study, City of Seneca, Newton County, Missouri. Washington, D.C., June 29, 1982.

23. U.S. Department of the Army, Corps of Engineers, Hydrologic Engineering Center. Report on Reservoir System Operation for Flood Control, Neosho River Basin, Kansas-Oklahoma. Davis, California, October 1973.

24. U.S. Department of the Interior, Geological Survey. 7.5-Minutes Series of Topographic Maps, Scale 1:24,000, Contour Interval 10 Feet: Miami, SE, Oklahoma, 1961; Miami SW, Oklahoma, 1961; Picher, Oklahoma, 1961; Miami NW, Oklahoma-Kansas. 1961.

25. Aerial Data Service, Inc. Topographic Maps, Scale 1:2,400, Contour Interval 2 Feet, Wyandotte, Oklahoma. , April 1984.



FLOOD PROFILES

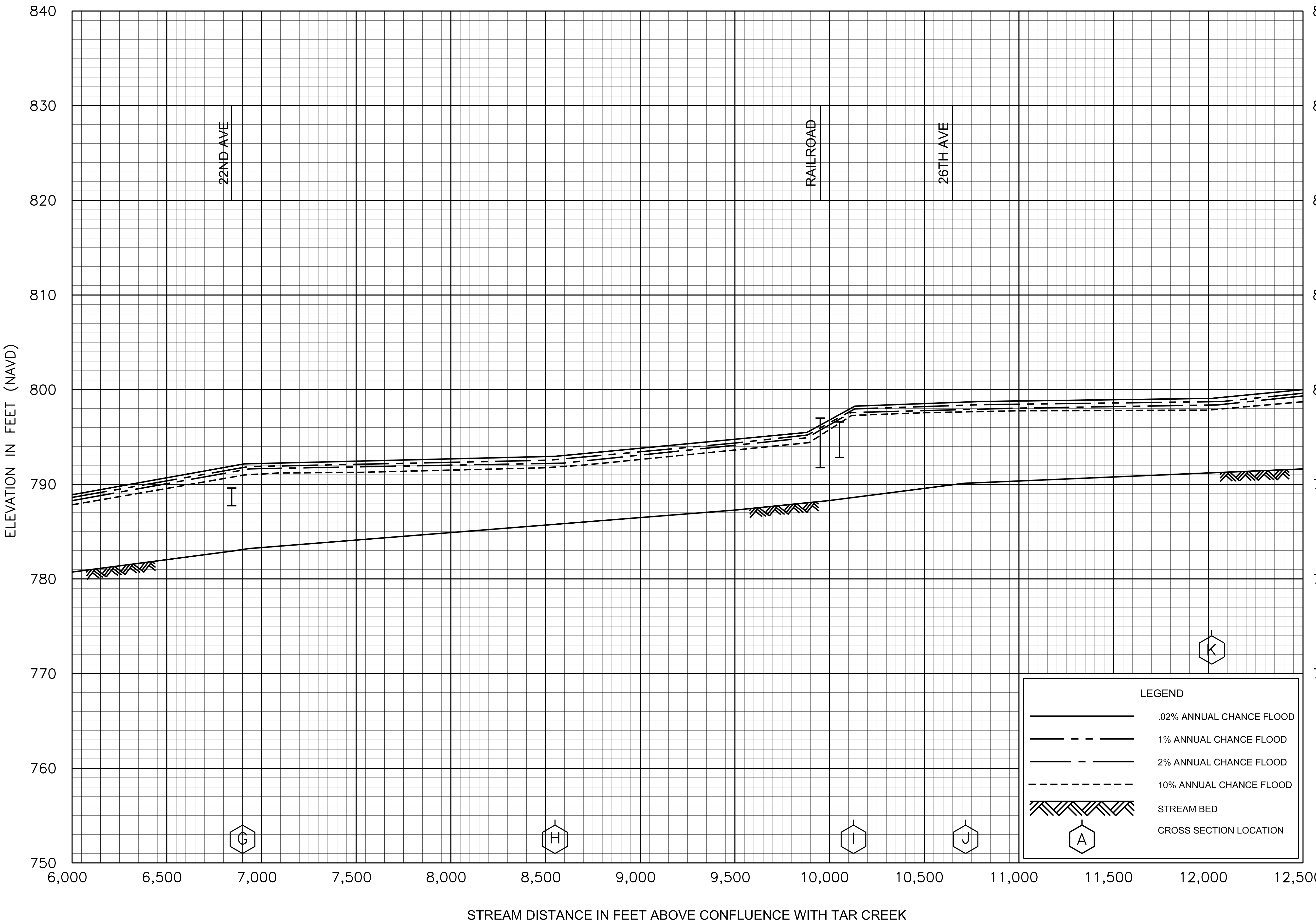
BELMONT RUN

FEDERAL EMERGENCY MANAGEMENT AGENCY

OTTAWA COUNTY, OK

AND INCORPORATED AREAS

01P



FLOOD PROFILES

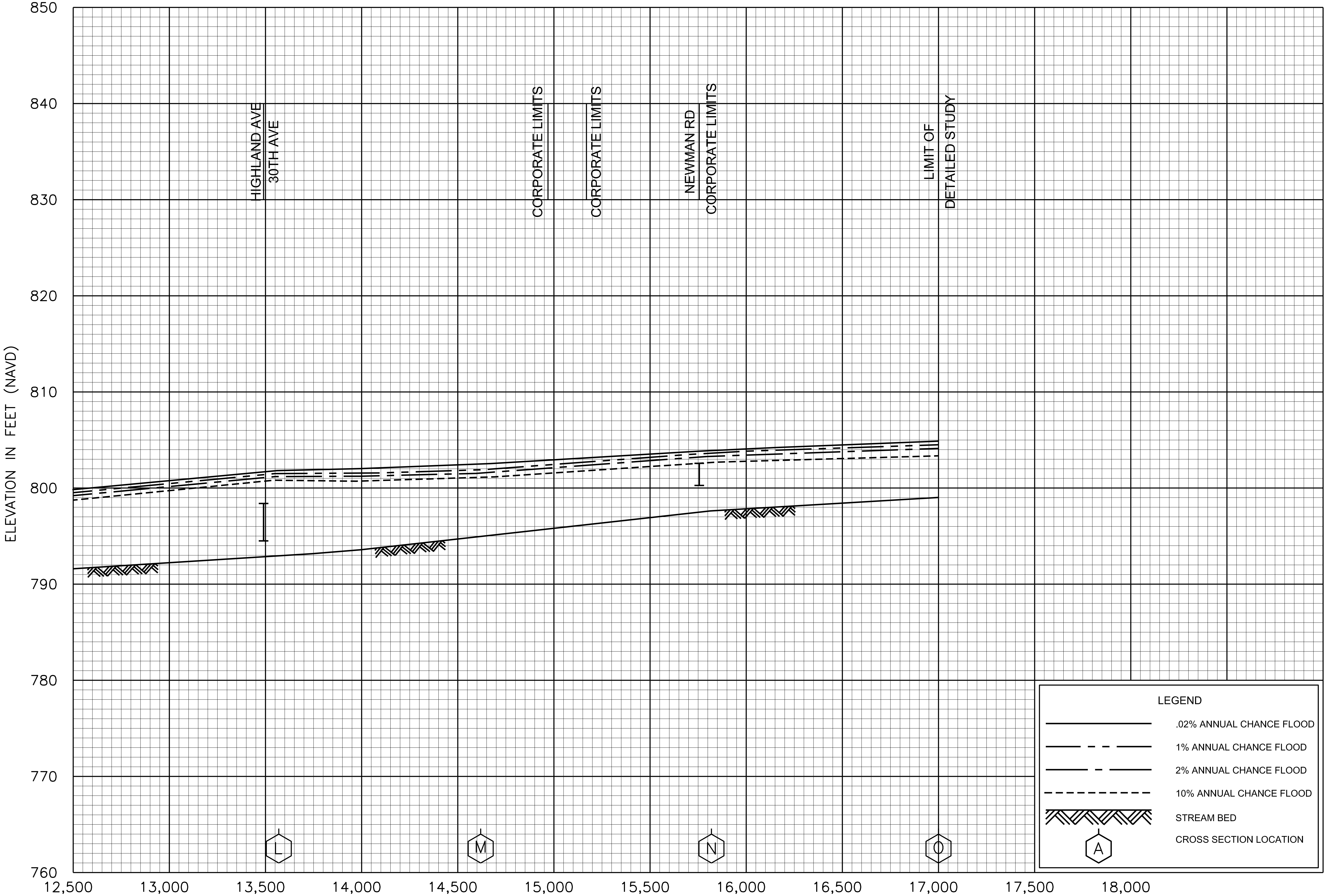
BELMONT RUN

FEDERAL EMERGENCY MANAGEMENT AGENCY

OTTAWA COUNTY, OK

AND INCORPORATED AREAS

02P



FLOOD PROFILES

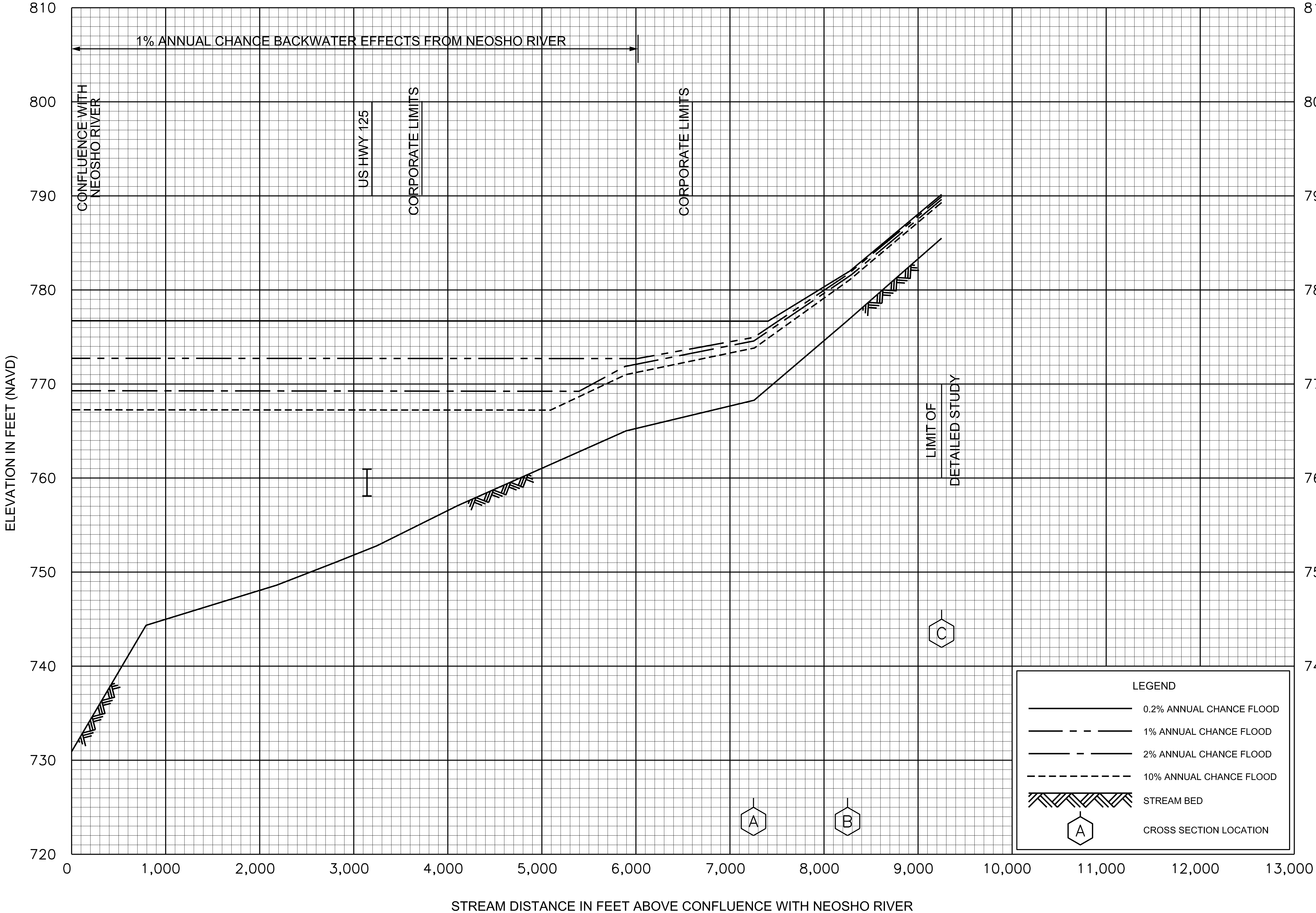
BELMONT RUN

FEDERAL EMERGENCY MANAGEMENT AGENCY

OTTAWA COUNTY, OK

AND INCORPORATED AREAS

03P



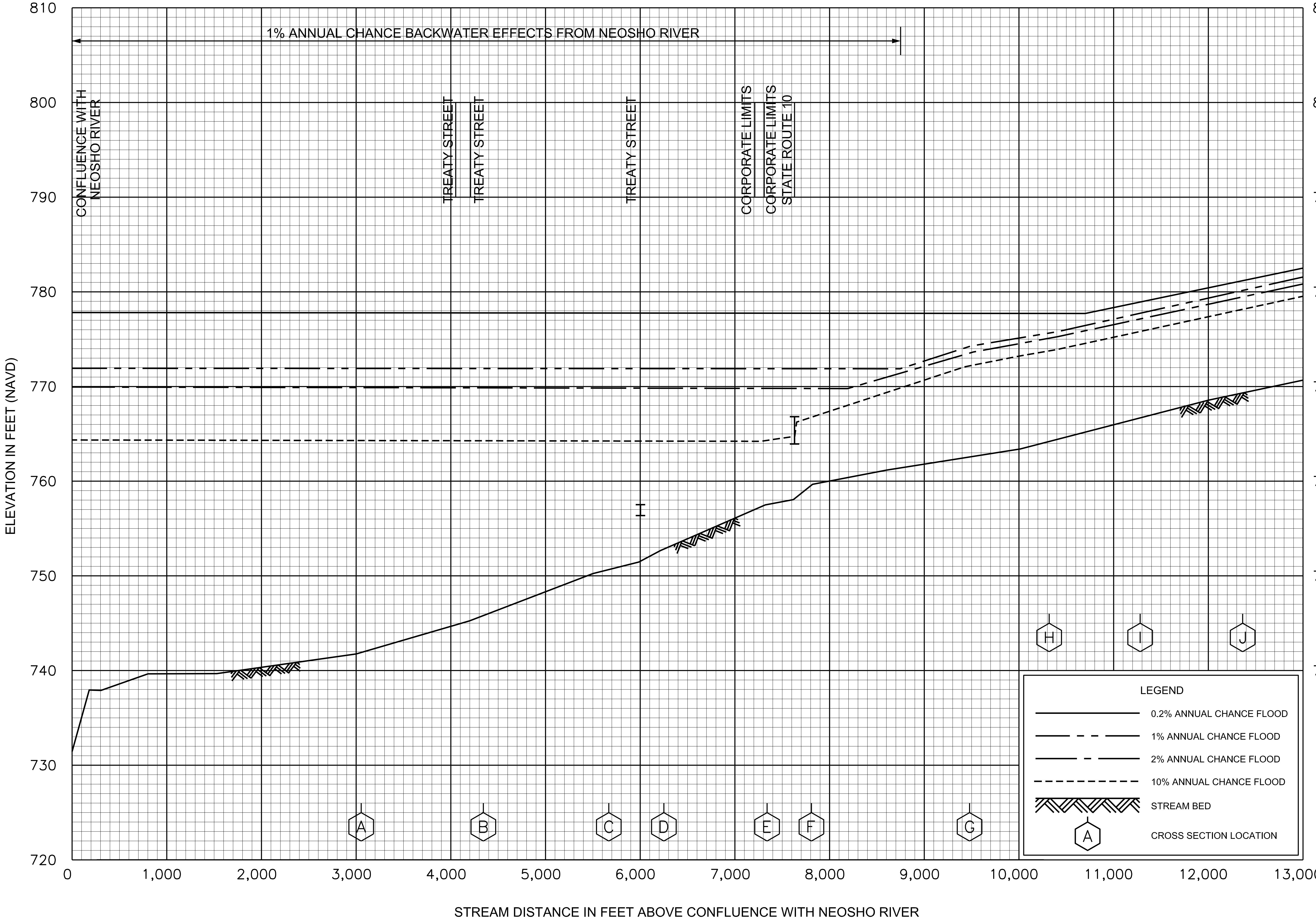
FLOOD PROFILES

FAIRGROUNDS BRANCH

FEDERAL EMERGENCY MANAGEMENT AGENCY

OTTAWA COUNTY, OK
AND INCORPORATED AREAS

04P

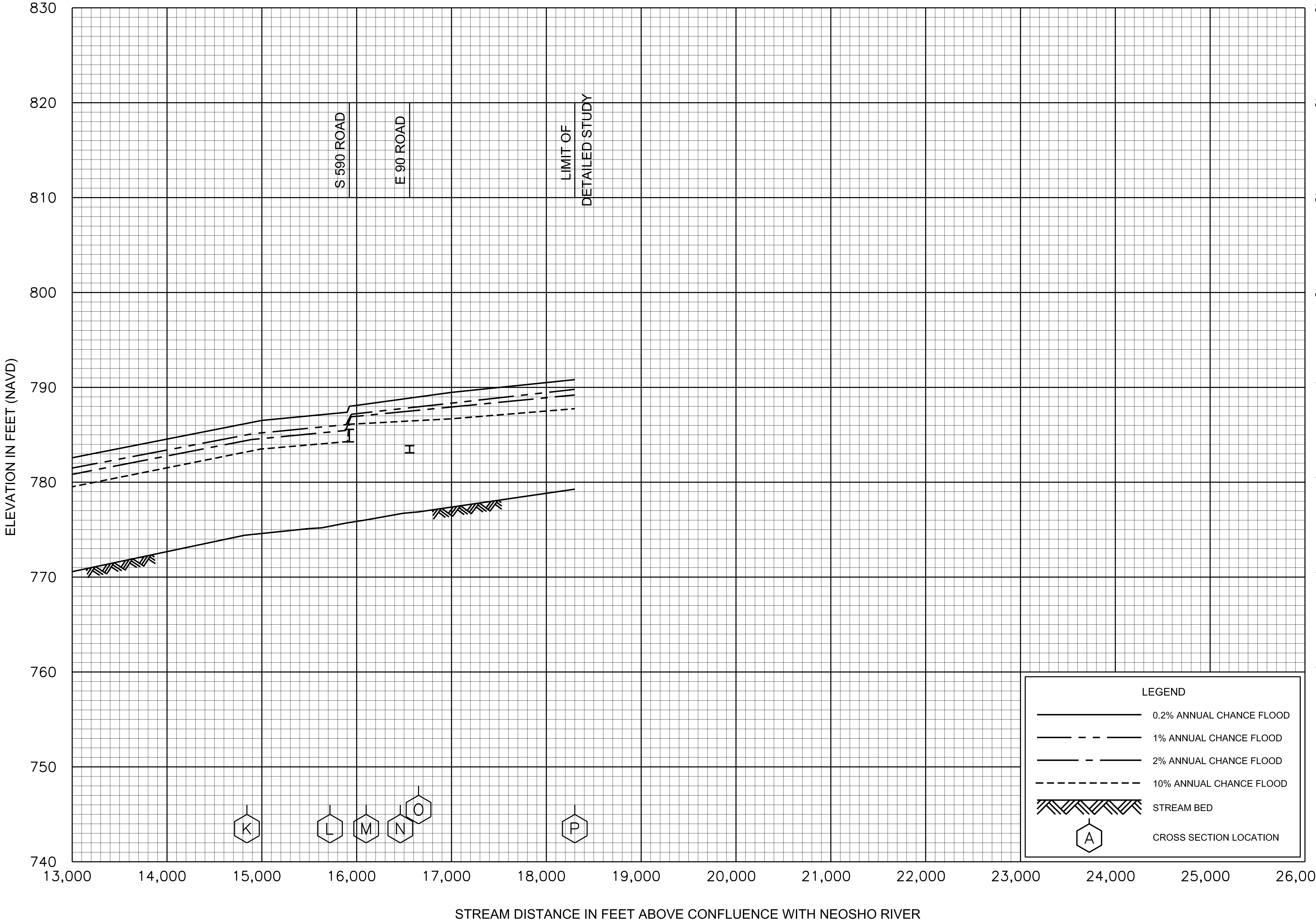


FLOOD PROFILES

LITTLE ELM CREEK

FEDERAL EMERGENCY MANAGEMENT AGENCY

OTTAWA COUNTY, OK
AND INCORPORATED AREAS



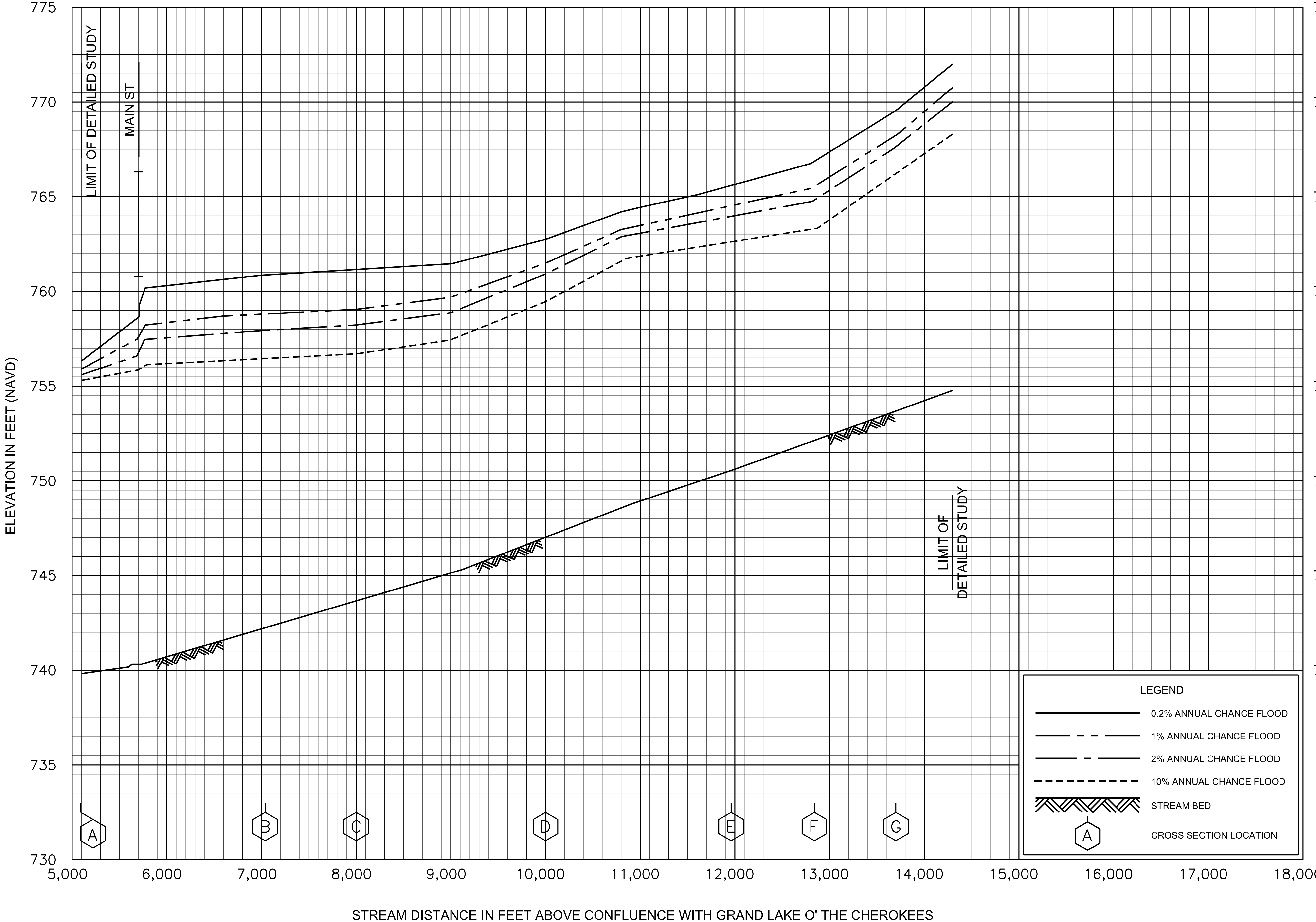
FLOOD PROFILES

LITTLE ELM CREEK

FEDERAL EMERGENCY MANAGEMENT AGENCY

OTTAWA COUNTY, OK

AND INCORPORATED AREAS



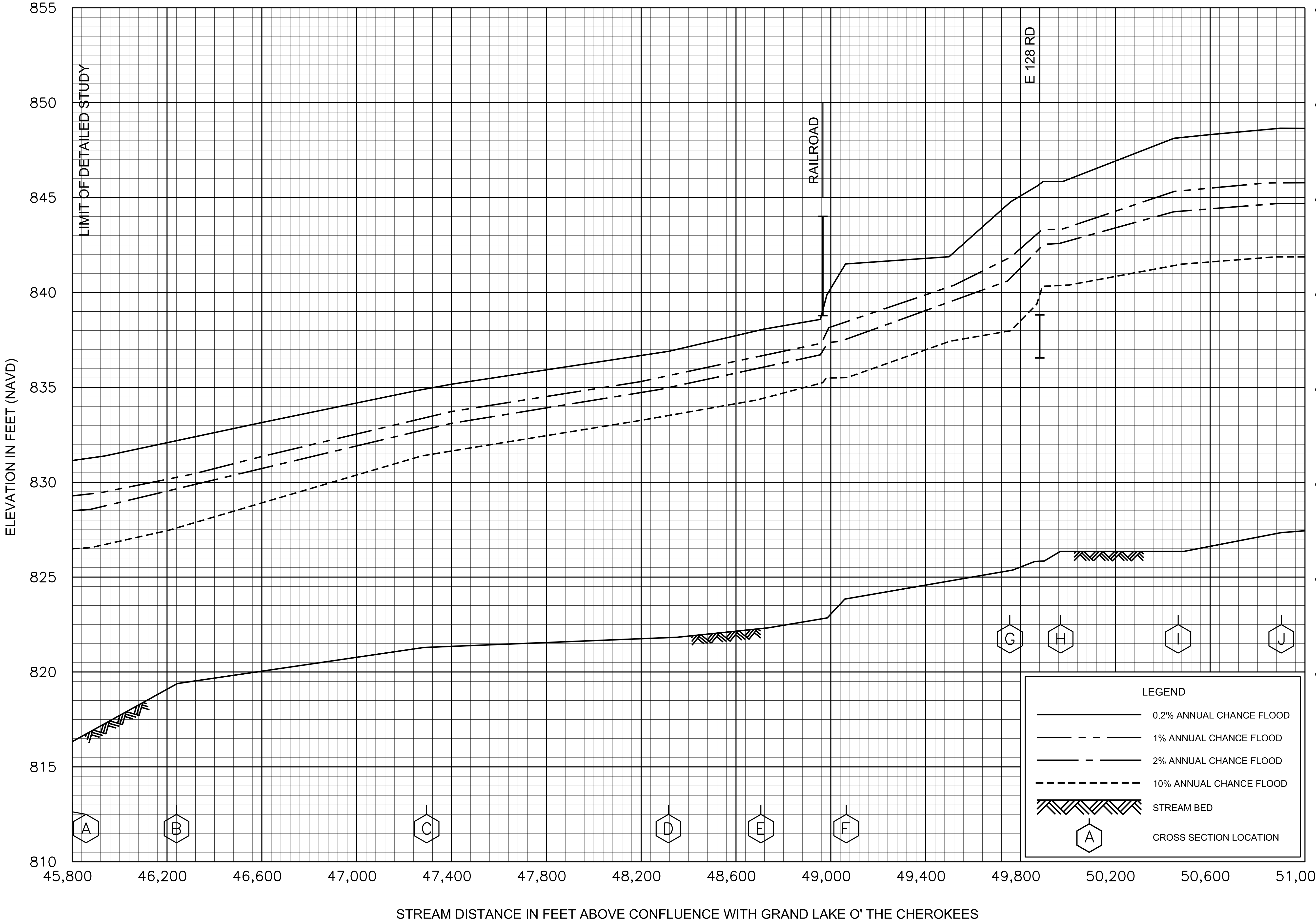
FLOOD PROFILES

LOST CREEK (LOWER REACH)

FEDERAL EMERGENCY MANAGEMENT AGENCY

OTTAWA COUNTY, OK
AND INCORPORATED AREAS

07P



FLOOD PROFILES

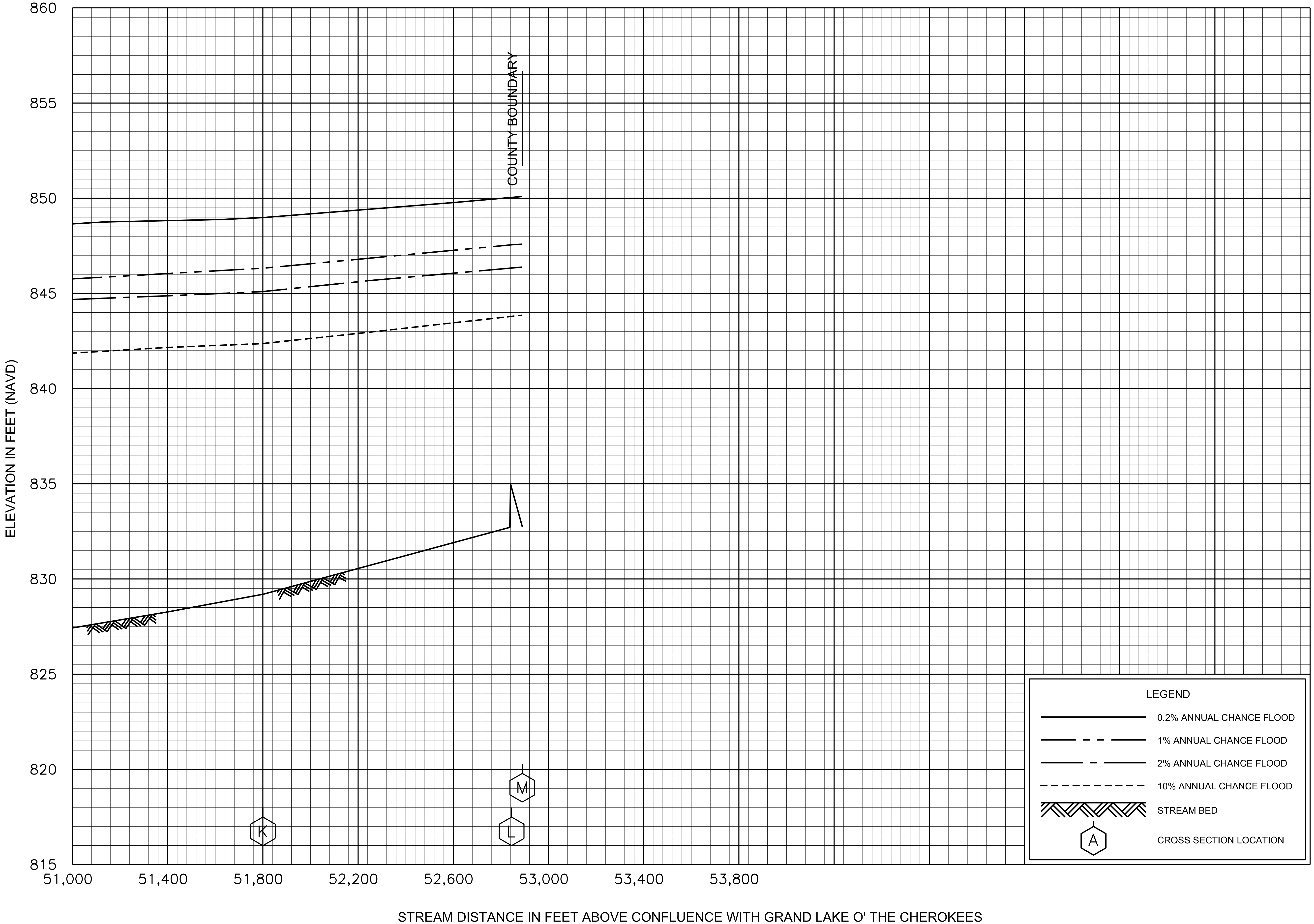
LOST CREEK (UPPER REACH)

FEDERAL EMERGENCY MANAGEMENT AGENCY

OTTAWA COUNTY, OK

AND INCORPORATED AREAS

08P



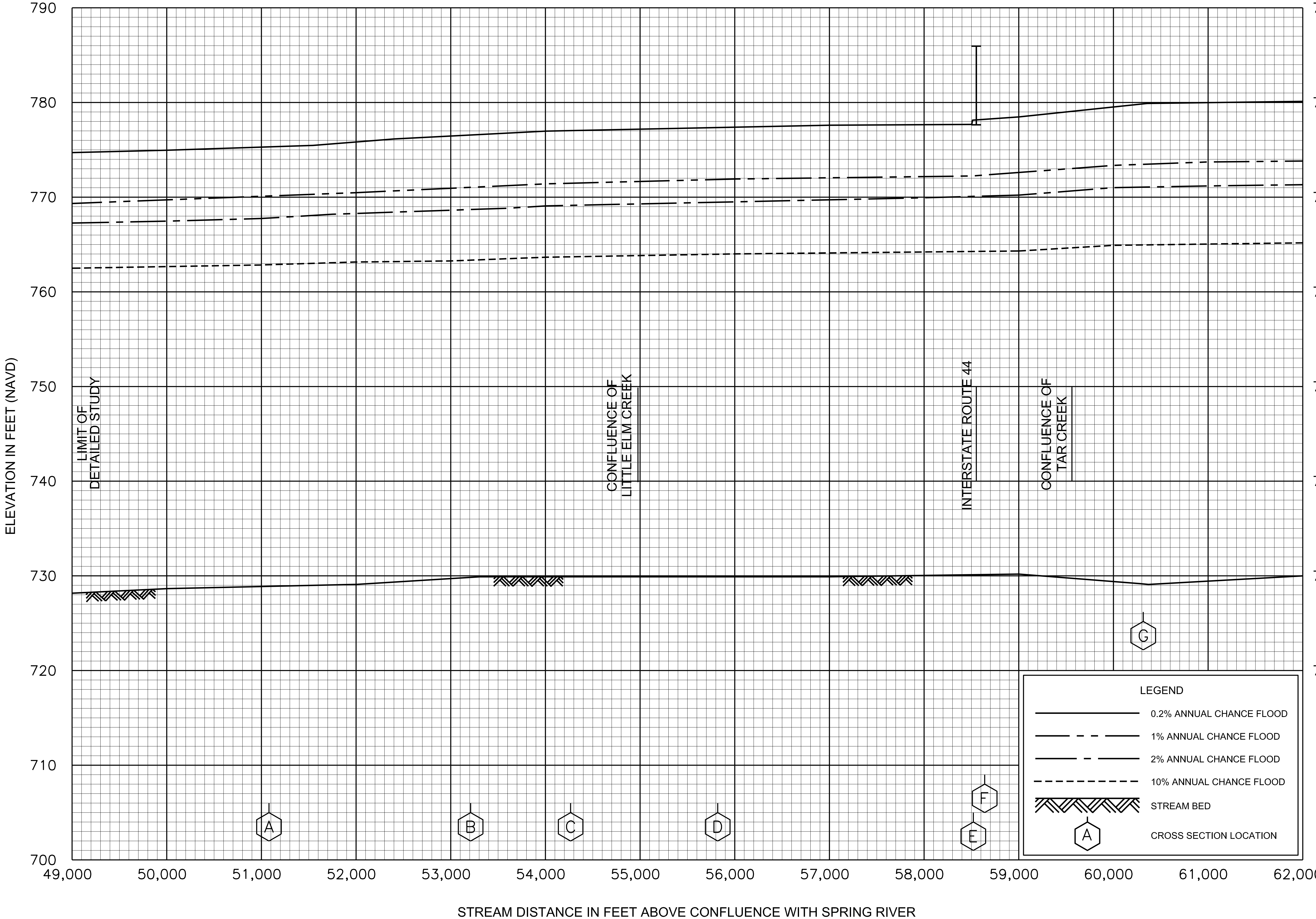
FLOOD PROFILES

LOST CREEK (UPPER REACH)

FEDERAL EMERGENCY MANAGEMENT AGENCY

OTTAWA COUNTY, OK

AND INCORPORATED AREAS

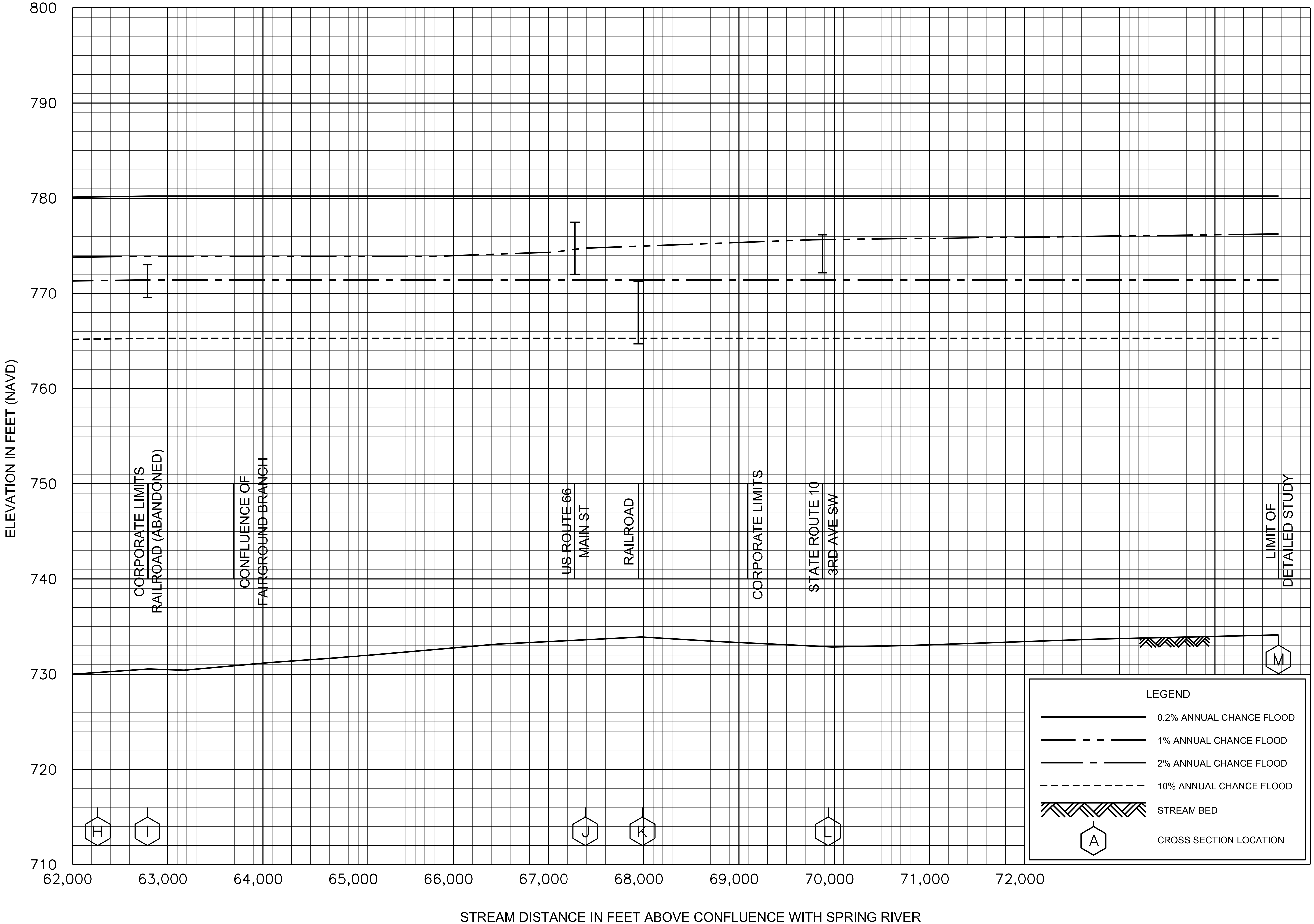


FLOOD PROFILES

NEOSHO RIVER

FEDERAL EMERGENCY MANAGEMENT AGENCY

OTTAWA COUNTY, OK
AND INCORPORATED AREAS



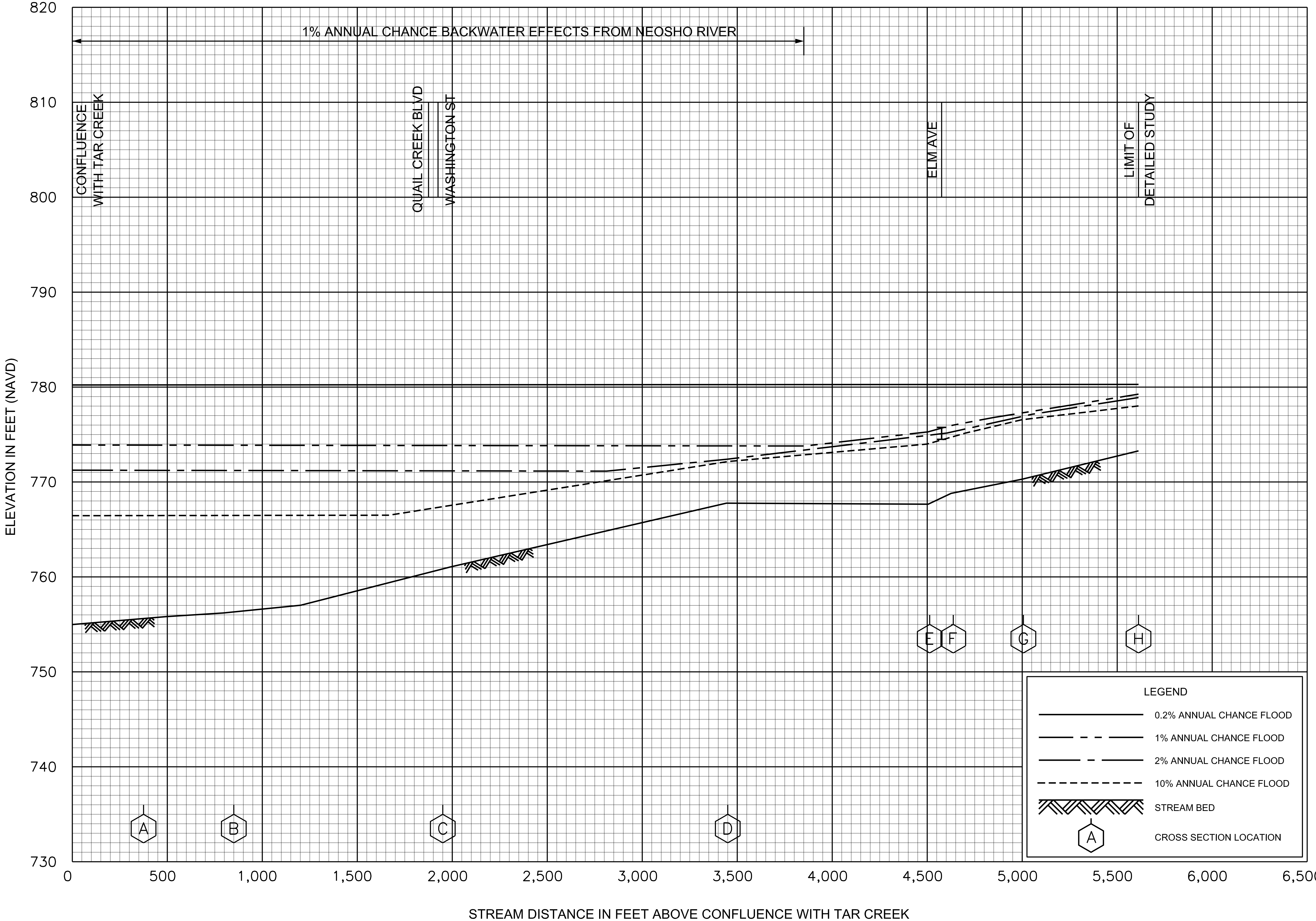
FLOOD PROFILES

NEOSHO RIVER

FEDERAL EMERGENCY MANAGEMENT AGENCY

OTTAWA COUNTY, OK

AND INCORPORATED AREAS



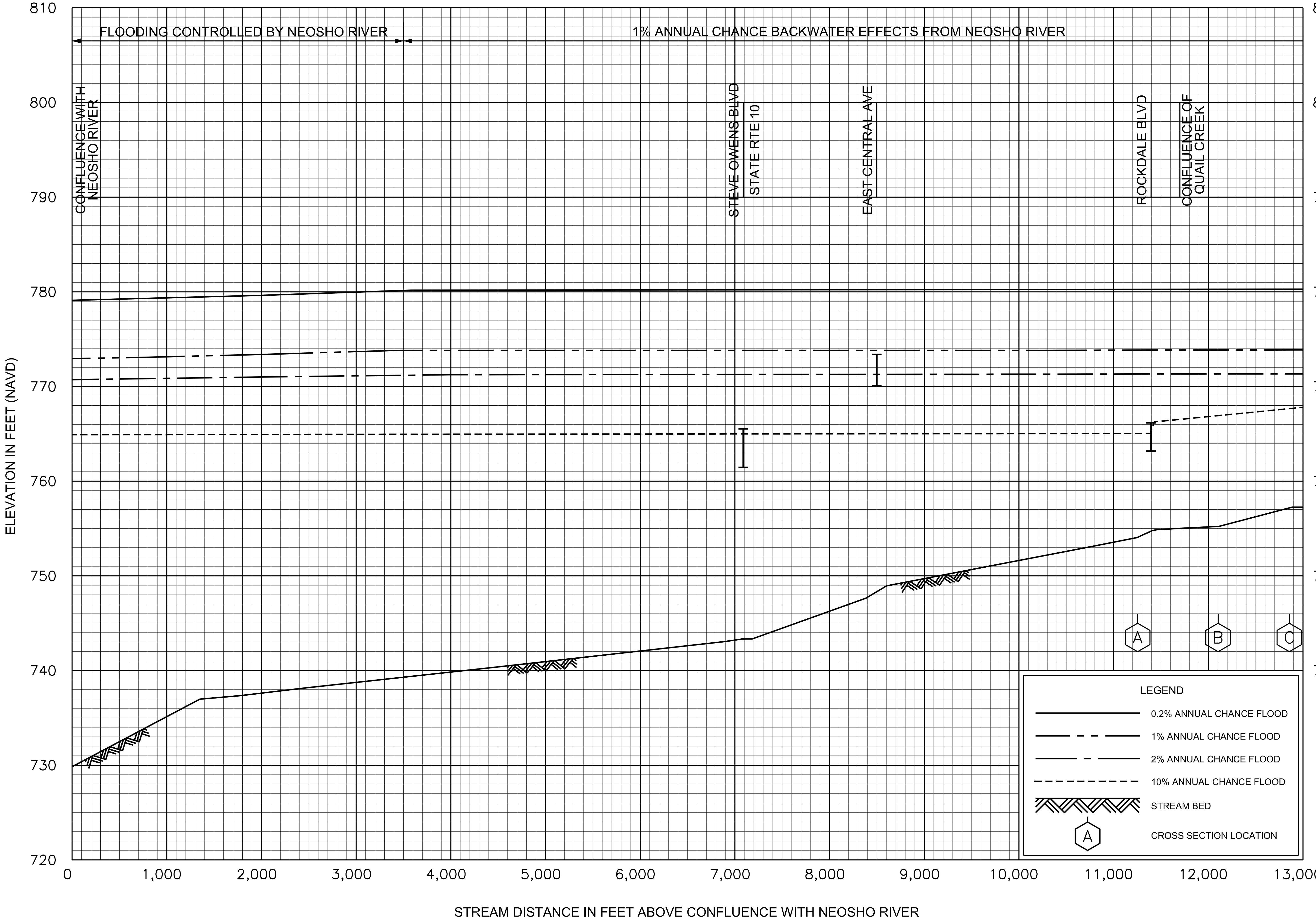
FLOOD PROFILES

QUAIL CREEK

FEDERAL EMERGENCY MANAGEMENT AGENCY

OTTAWA COUNTY, OK

AND INCORPORATED AREAS



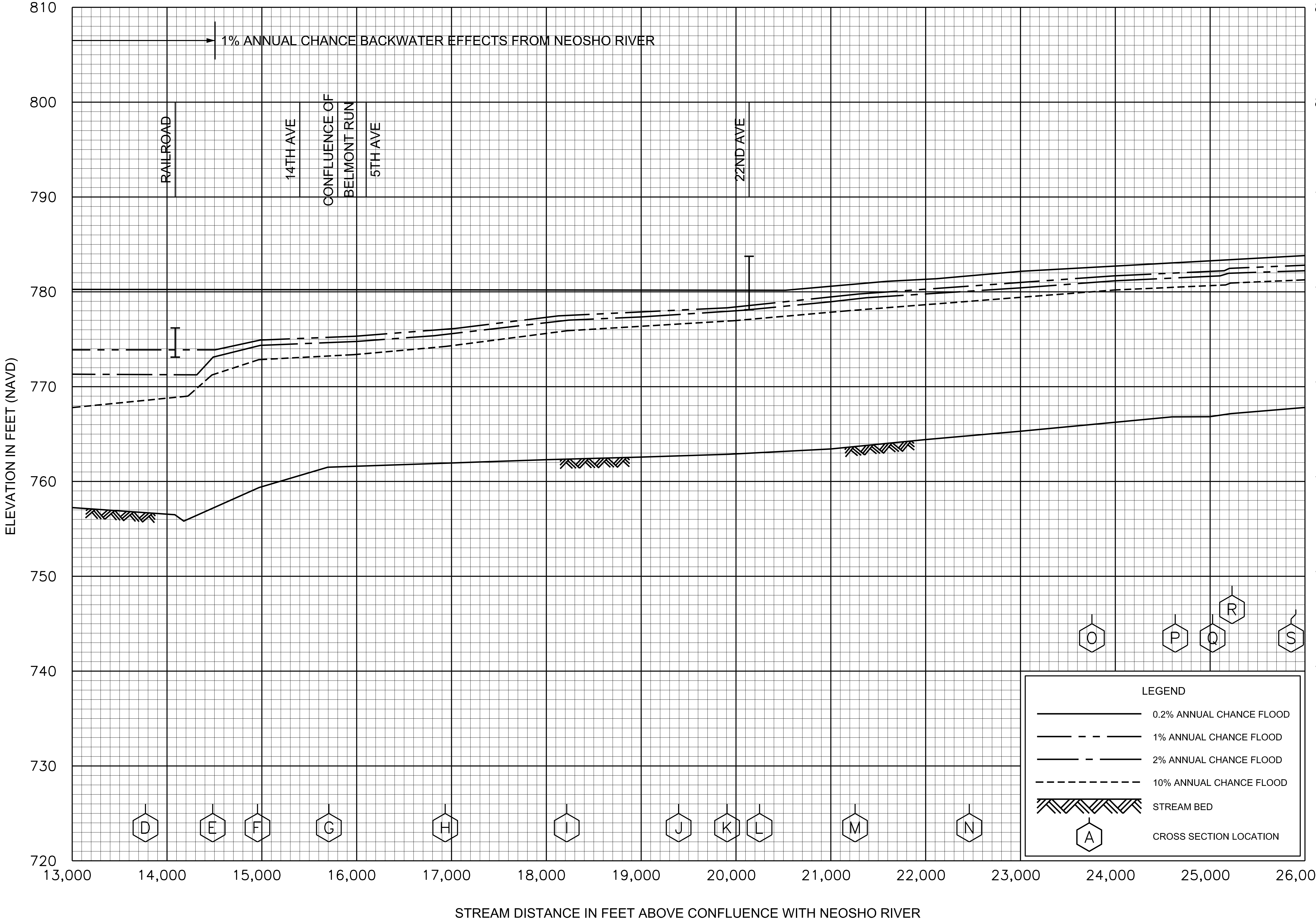
FLOOD PROFILES

TAR CREEK

FEDERAL EMERGENCY MANAGEMENT AGENCY

OTTAWA COUNTY, OK

AND INCORPORATED AREAS

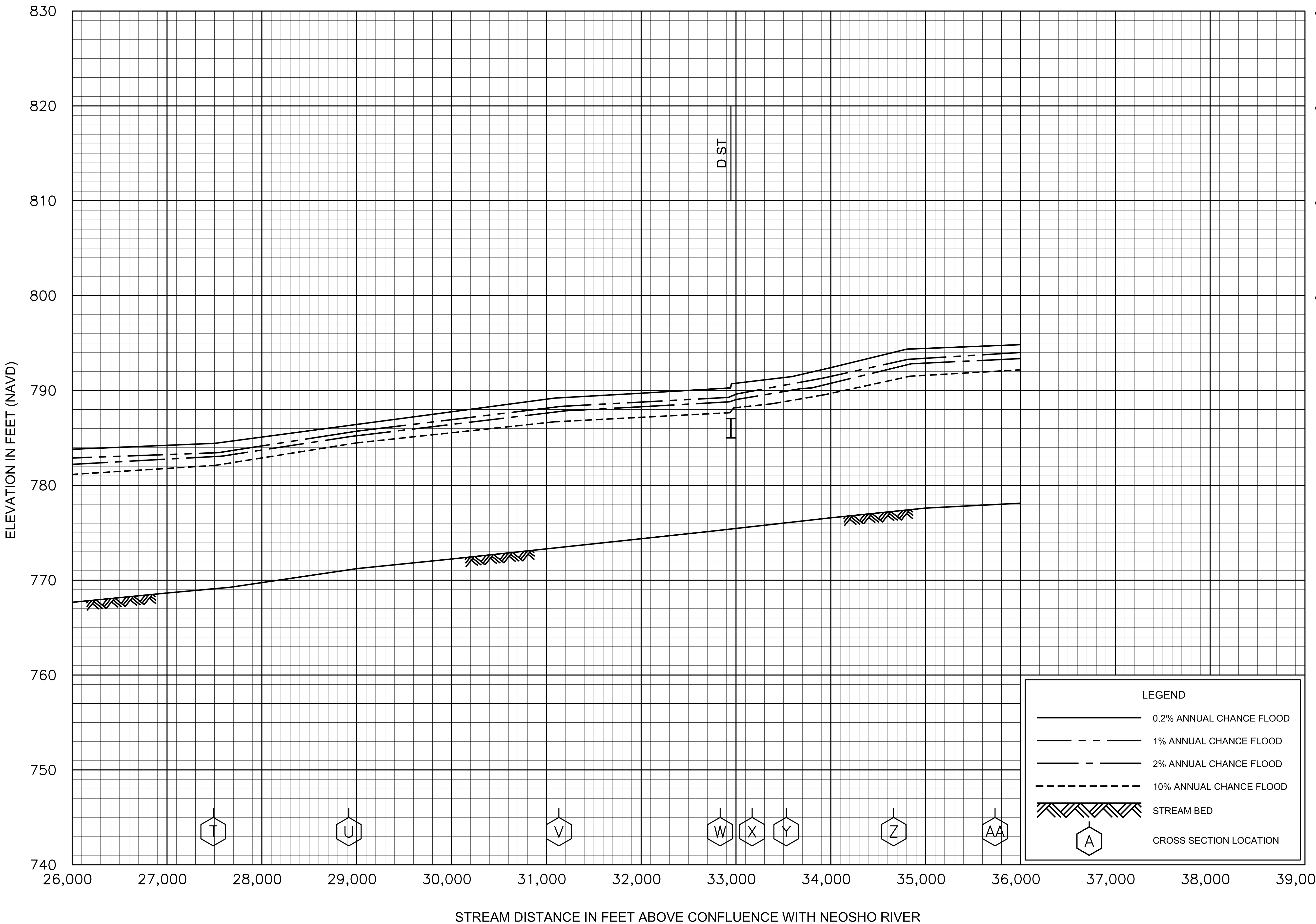


FLOOD PROFILES

TAR CREEK

FEDERAL EMERGENCY MANAGEMENT AGENCY

OTTAWA COUNTY, OK
AND INCORPORATED AREAS

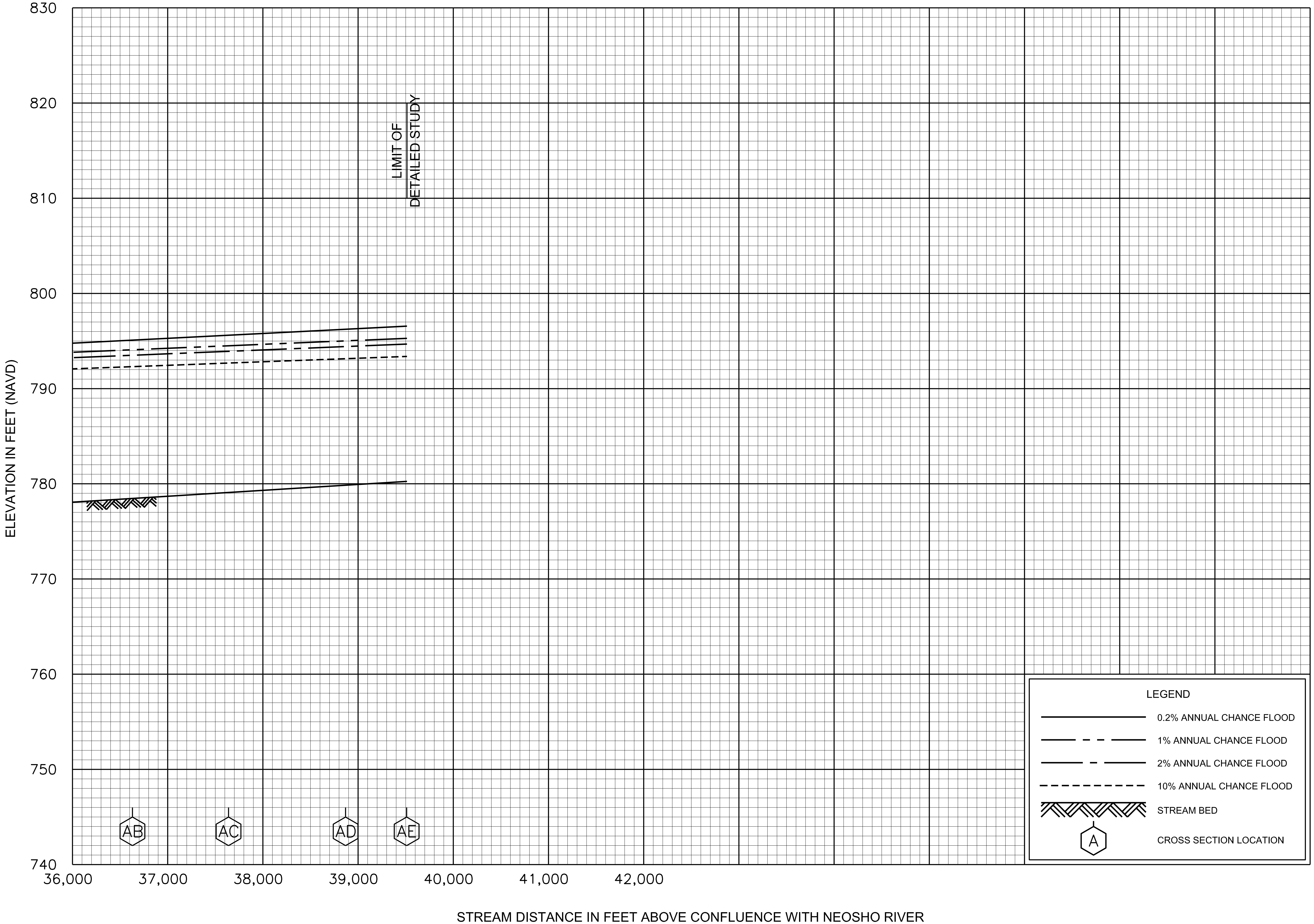


FLOOD PROFILES

TAR CREEK

FEDERAL EMERGENCY MANAGEMENT AGENCY

OTTAWA COUNTY, OK
AND INCORPORATED AREAS



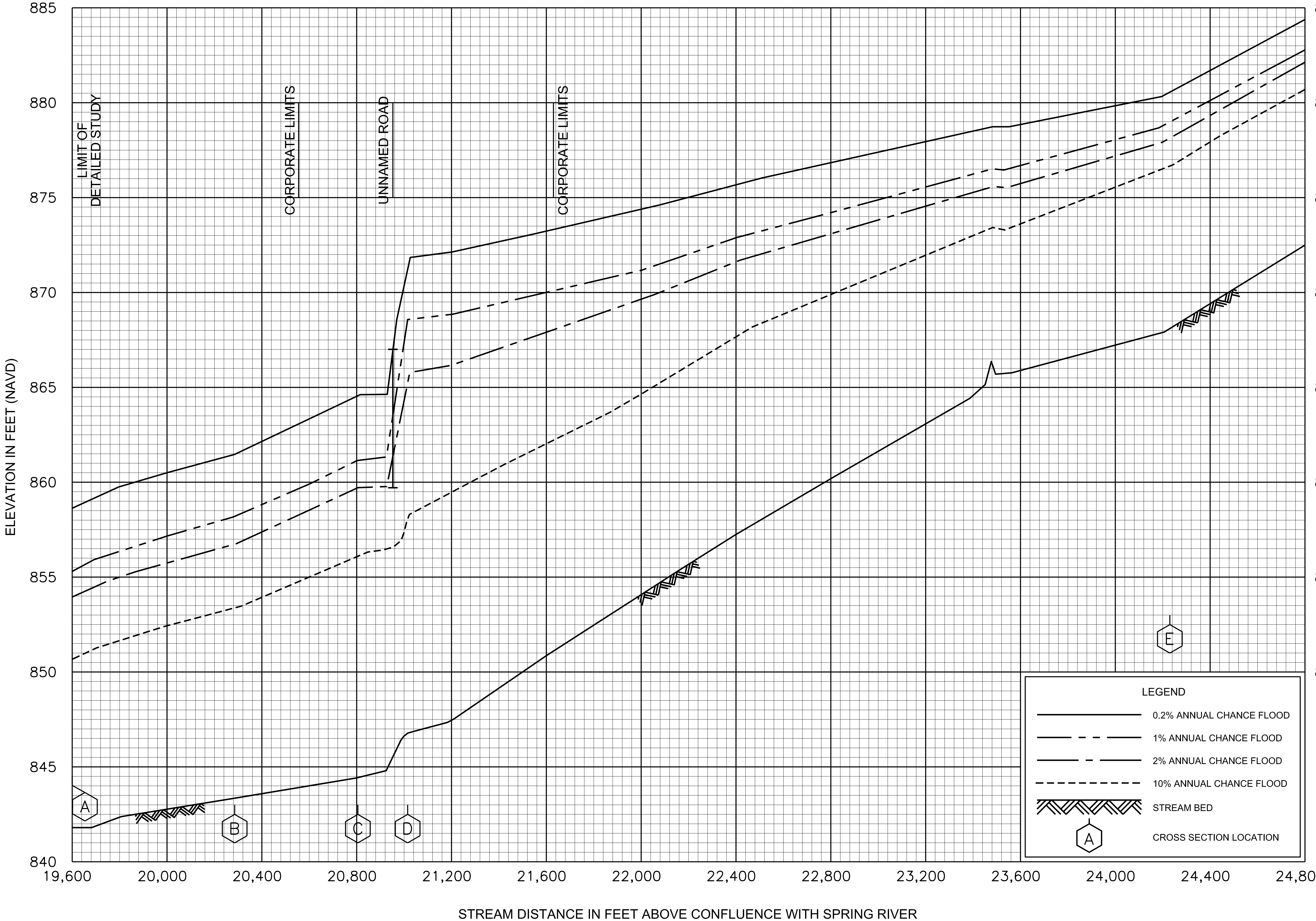
FLOOD PROFILES

TAR CREEK

FEDERAL EMERGENCY MANAGEMENT AGENCY

OTTAWA COUNTY, OK

AND INCORPORATED AREAS

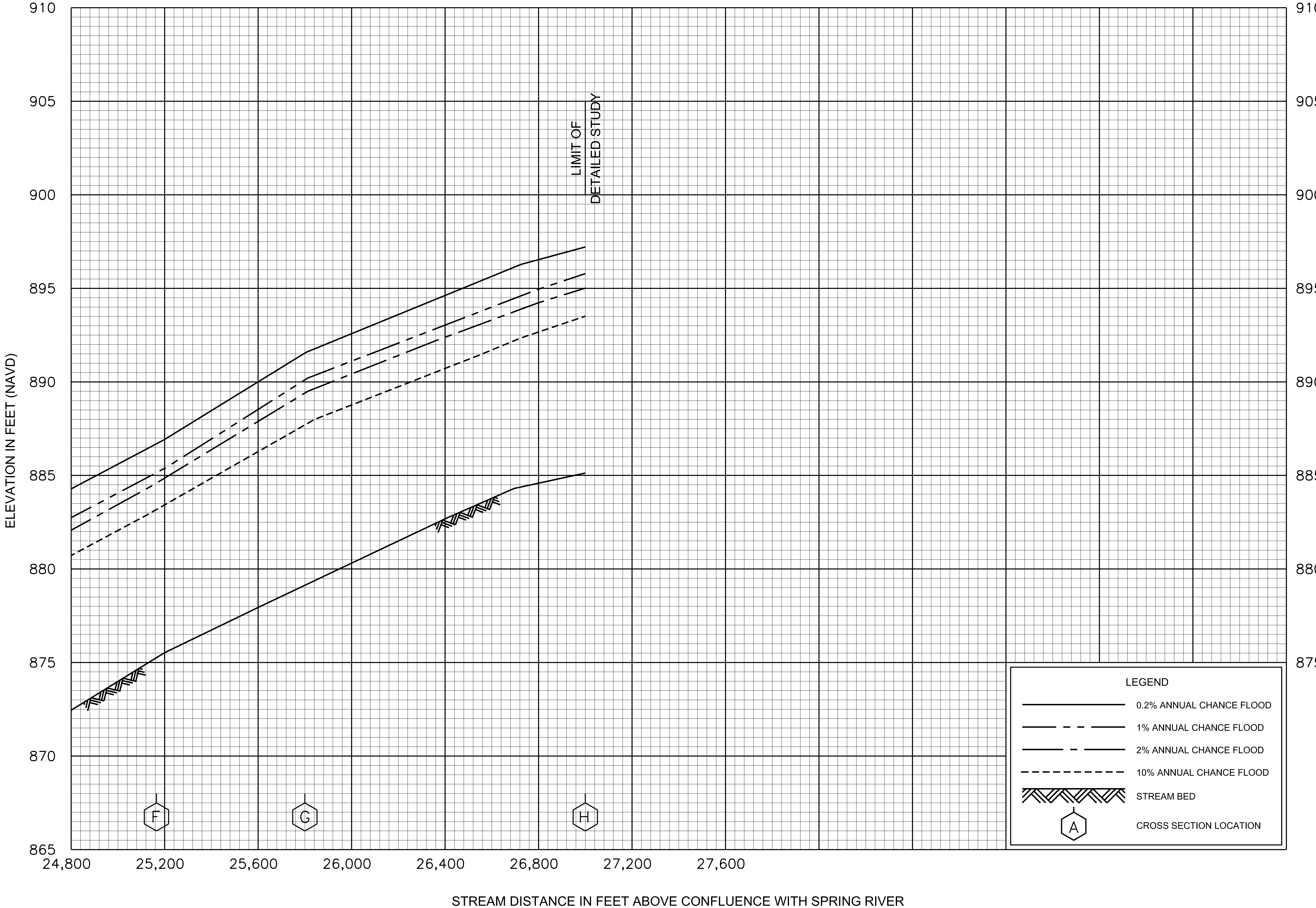


FLOOD PROFILES

WARREN BRANCH

FEDERAL EMERGENCY MANAGEMENT AGENCY

OTTAWA COUNTY, OK
AND INCORPORATED AREAS

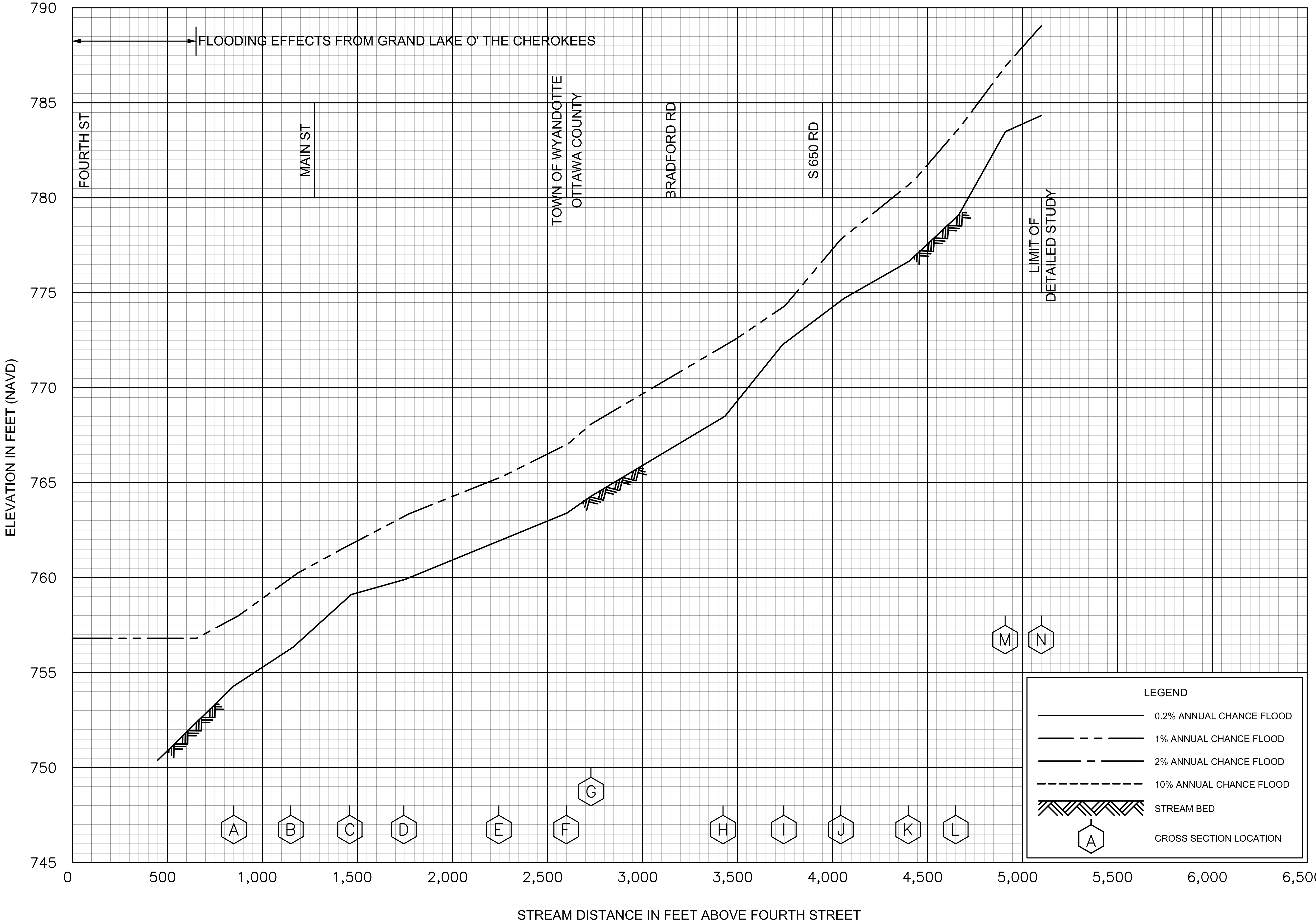


FLOOD PROFILES

WARREN BRANCH

FEDERAL EMERGENCY MANAGEMENT AGENCY

OTTAWA COUNTY, OK
AND INCORPORATED AREAS



FLOOD PROFILES

WYANDOTTE DITCH

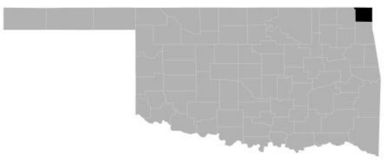
FEDERAL EMERGENCY MANAGEMENT AGENCY

OTTAWA COUNTY, OK
AND INCORPORATED AREAS

FLOOD INSURANCE STUDY

FEDERAL EMERGENCY MANAGEMENT AGENCY

VOLUME 1 OF 1



OTTAWA COUNTY, OKLAHOMA

AND INCORPORATED AREAS

COMMUNITY NAME	COMMUNITY NUMBER
AFTON, TOWN OF	400155
COMMERCE, CITY OF	400156
FAIRLAND, TOWN OF	400377
MIAMI, CITY OF	400157
NORTH MIAMI, TOWN OF*	400426
OTTAWA COUNTY, UNINCORPORATED AREAS	400154
PEORIA, TOWN OF	400158
QUAPAW, TOWN OF	400436
WYANDOTTE, TOWN OF	400161
WYANDOTTE NATION	405451

*No Special Flood Hazard Areas Identified

FEMA

REVISED:

SEPTEMBER 13, 2019

FLOOD INSURANCE STUDY NUMBER
40115CV000B

Version Number 2.3.3.2

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Flood Insurance Rate Map (FIRM)

FLOOD INSURANCE STUDY REPORT
OTTAWA COUNTY, OKLAHOMA

SECTION 1.0 – INTRODUCTION

1.1 The National Flood Insurance Program

The National Flood Insurance Program (NFIP) is a voluntary Federal program that enables property owners in participating communities to purchase insurance protection against losses from flooding. This insurance is designed to provide an alternative to disaster assistance to meet the escalating costs of repairing damage to buildings and their contents caused by floods.

For decades, the national response to flood disasters was generally limited to constructing flood-control works such as dams, levees, sea-walls, and the like, and providing disaster relief to flood victims. This approach did not reduce losses nor did it discourage unwise development. In some instances, it may have actually encouraged additional development. To compound the problem, the public generally could not buy flood coverage from insurance companies, and building techniques to reduce flood damage were often overlooked.

In the face of mounting flood losses and escalating costs of disaster relief to the general taxpayers, the U.S. Congress created the NFIP. The intent was to reduce future flood damage through community floodplain management ordinances, and provide protection for property owners against potential losses through an insurance mechanism that requires a premium to be paid for the protection.

The U.S. Congress established the NFIP on August 1, 1968, with the passage of the National Flood Insurance Act of 1968. The NFIP was broadened and modified with the passage of the Flood Disaster Protection Act of 1973 and other legislative measures. It was further modified by the National Flood Insurance Reform Act of 1994 and the Flood Insurance Reform Act of 2004. The NFIP is administered by the Federal Emergency Management Agency (FEMA), which is a component of the Department of Homeland Security (DHS).

Participation in the NFIP is based on an agreement between local communities and the Federal Government. If a community adopts and enforces floodplain management regulations to reduce future flood risks to new construction and substantially improved structures in Special Flood Hazard Areas (SFHAs), the Federal Government will make flood insurance available within the community as a financial protection against flood losses. The community's floodplain management regulations must meet or exceed criteria established in accordance with Title 44 Code of Federal Regulations (CFR) Part 60, *Criteria for Land Management and Use*.

SFHAs are delineated on the community's Flood Insurance Rate Maps (FIRMs). Under the NFIP, buildings that were built before the flood hazard was identified on the community's FIRMs are generally referred to as "Pre-FIRM" buildings. When the NFIP was created, the U.S. Congress recognized that insurance for Pre-FIRM buildings would be prohibitively expensive if the premiums were not subsidized by the Federal

Government. Congress also recognized that most of these floodprone buildings were built by individuals who did not have sufficient knowledge of the flood hazard to make informed decisions. The NFIP requires that full actuarial rates reflecting the complete flood risk be charged on all buildings constructed or substantially improved on or after the effective date of the initial FIRM for the community or after December 31, 1974, whichever is later. These buildings are generally referred to as “Post-FIRM” buildings.

1.2 Purpose of this Flood Insurance Study Report

This Flood Insurance Study (FIS) Report revises and updates information on the existence and severity of flood hazards for the study area. The studies described in this report developed flood hazard data that will be used to establish actuarial flood insurance rates and to assist communities in efforts to implement sound floodplain management.

In some states or communities, floodplain management criteria or regulations may exist that are more restrictive than the minimum Federal requirements. Contact your State NFIP Coordinator to ensure that any higher State standards are included in the community’s regulations.

1.3 Jurisdictions Included in the Flood Insurance Study Project

This FIS Report covers the entire geographic area of Ottawa County, Oklahoma.

The jurisdictions that are included in this project area, along with the Community Identification Number (CID) for each community and the United States Geological Survey (USGS) 8-digit Hydrologic Unit Code (HUC-8) sub-basins affecting each, are shown in Table 1. The FIRM panel numbers that affect each community are listed. If the flood hazard data for the community is not included in this FIS Report, the location of that data is identified.

Jurisdictions that have no identified SFHAs as of the effective date of this study are indicated in the table. Changed conditions in these communities (such as urbanization or annexation) or the availability of new scientific or technical data about flood hazards could make it necessary to determine SFHAs in these jurisdictions in the future.

Table 1: Listing of NFIP Jurisdictions

Community	CID	HUC-8 Sub-Basin(s)	Located on FIRM Panel(s)	If Not Included, Location of Flood Hazard Data
Afton, Town of	400155	11070206	40115C0228G 40115C0229G 40115C0235G 40115C0236G 40115C0237G	
Commerce, City of	400156	11070206	40115C0035G 40115C0045G 40115C0055G 40115C0065G	

Table 1: Listing of NFIP Jurisdictions, continued

Community	CID	HUC-8 Sub-Basin(s)	Located on FIRM Panel(s)	If Not Included, Location of Flood Hazard Data
Fairland, Town of	400377	11070206	40115C0165G 40115C0255G	
Miami, City of	400157	11070206	40115C0045G 40115C0065G 40115C0135G 40115C0155G	
North Miami, Town of[1]	400426	11070206	40115C0045G	
Ottawa County Unincorporated Areas	400154	11070205, 11070206, 11070207, 11070208, 11070209	40115C0025G 40115C0035G 40115C0045G 40115C0050G 40115C0055G 40115C0065G 40115C0075G 40115C0095F 40115C0100F 40115C0125F 40115C0135G 40115C0150G 40115C0155G 40115C0165G 40115C0175G 40115C0180G 40115C0185G 40115C0190G 40115C0195G 40115C0205G 40115C0215F 40115C0228G 40115C0229G 40115C0230G 40115C0235G 40115C0236G 40115C0237G 40115C0245G 40115C0255G 40115C0275G 40115C0300G 40115C0325F[2]	
Peoria, Town of	400158	11070207	40115C0095F	

Table 1: Listing of NFIP Jurisdictions, continued

Community	CID	HUC-8 Sub-Basin(s)	Located on FIRM Panel(s)	If Not Included, Location of Flood Hazard Data
Quapaw, Town of	400436	11070206, 11070207	40115C0075G	
Wyandotte, Town of	400161	11070206	40115C0190G	
Wyandotte Nation	405451	11070206, 11070207	40115C0175G 40115C0180G 40115C0185G 40115C0190G 40115C0195G	

[1]No Special Flood Hazard Areas Identified

[2]Panel Not Printed

1.4 Considerations for using this Flood Insurance Study Report

The NFIP encourages State and local governments to implement sound floodplain management programs. To assist in this endeavor, each FIS Report provides floodplain data, which may include a combination of the following: 10-, 4-, 2-, 1-, and 0.2-percent annual chance flood elevations (the 1% annual chance flood elevation is also referred to as the Base Flood Elevation (BFE)); delineations of the 1% annual chance and 0.2% annual chance floodplains; and 1% annual chance floodway. This information is presented on the FIRM and/or in many components of the FIS Report, including Flood Profiles, Floodway Data tables, Summary of Non-Coastal Stillwater Elevations tables, and Coastal Transect Parameters tables (not all components may be provided for a specific FIS).

This section presents important considerations for using the information contained in this FIS Report and the FIRM, including changes in format and content. Figures 1, 2, and 3 present information that applies to using the FIRM with the FIS Report.

- Part or all of this FIS Report may be revised and republished at any time. In addition, part of this FIS Report may be revised by a Letter of Map Revision (LOMR), which does not involve republication or redistribution of the FIS Report. Refer to Section 6.5 of this FIS Report for information about the process to revise the FIS Report and/or FIRM.

  It is, therefore, the responsibility of the user to consult with community officials by contacting the community repository to obtain the most current FIS Report components. Communities participating in the NFIP have established repositories of flood hazard data for floodplain management and flood insurance purposes. Community map repository addresses are provided in Table 30, "Map Repositories," within this FIS Report.

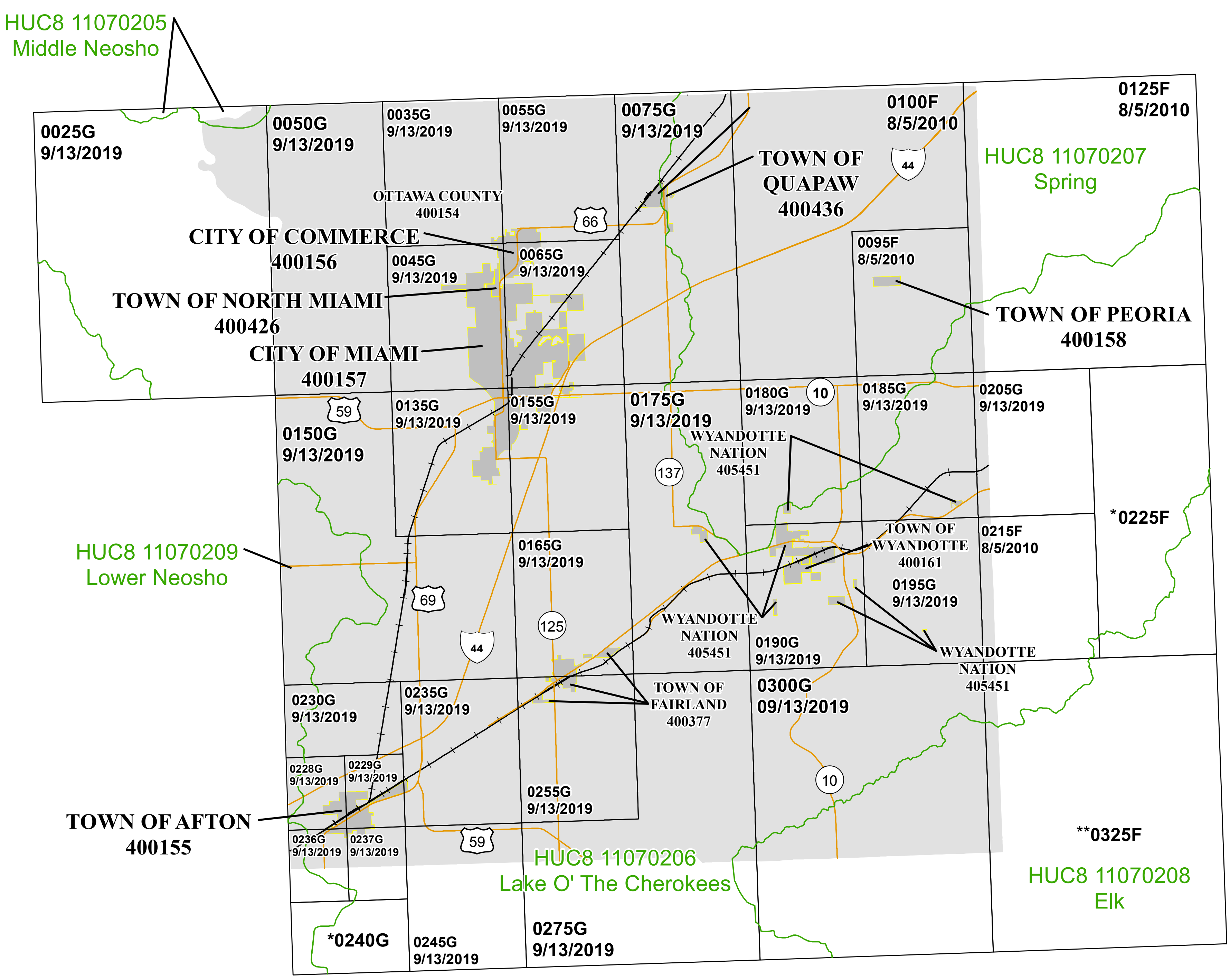
- New FIS Reports are frequently developed for multiple communities, such as entire counties. A countywide FIS Report incorporates previous FIS Reports for individual communities and the unincorporated area of the county (if not jurisdictional) into a single document and supersedes those documents for the purposes of the NFIP.

The initial Countywide FIS Report for Ottawa County became effective on August 5, 2010. Refer to Table 27 for information about subsequent revisions to the FIRMs.

- FEMA has developed a *Guide to Flood Maps* (FEMA 258) and online tutorials to assist users in accessing the information contained on the FIRM. These include how to read panels and step-by-step instructions to obtain specific information. To obtain this guide and other assistance in using the FIRM, visit the FEMA Web site at www.fema.gov/online-tutorials.

The FIRM Index in Figure 1 shows the overall FIRM panel layout within Ottawa County, and also displays the panel number and effective date for each FIRM panel in the county. Other information shown on the FIRM Index includes community boundaries, watershed boundaries, and USGS HUC-8 codes.

Figure 1: FIRM Panel Index



ATTENTION: The corporate limits shown on this FIRM Index are based on the best information available at the time of publication. As such, they may be more current than those shown on FIRM panels issued before September 13, 2019

N

1 inch = 20,833 feet 1:250,000

Feet
0 11,250 22,500 45,000

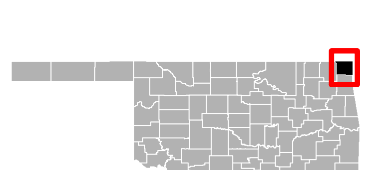
Map Projection:
Lambert Conformal Conic, State Plane Oklahoma North Zone FIPS 3501; North American Datum 1983

THE INFORMATION DEPICTED ON THIS MAP AND SUPPORTING DOCUMENTATION ARE ALSO AVAILABLE IN DIGITAL FORMAT AT
HTTP://MSC.FEMA.GOV

SEE FLOOD INSURANCE STUDY FOR ADDITIONAL INFORMATION

*PANEL NOT PRINTED - AREA OUTSIDE COUNTY BOUNDARY
**PANEL NOT PRINTED - NO SPECIAL FLOOD HAZARD AREAS

COUNTY LOCATOR



NATIONAL FLOOD INSURANCE PROGRAM
FLOOD INSURANCE RATE MAP PANEL INDEX

OTTAWA COUNTY, OKLAHOMA And Incorporated Areas

PANELS PRINTED:

0025, 0035, 0045, 0050, 0055. 0065, 0075, 0095, 0100, 0125, 0135, 0150, 0155, 0165, 0175, 0180, 0185, 0190, 0195, 0205, 0215, 0228, 0229, 0230, 0235, 0236, 0237, 0245, 0255, 0275, 0300

FEMA

MAP NUMBER
40115CIND0B

MAP REVISED
SEPTEMBER 13, 2019

Each FIRM panel may contain specific notes to the user that provide additional information regarding the flood hazard data shown on that map. However, the FIRM panel does not contain enough space to show all the notes that may be relevant in helping to better understand the information on the panel. Figure 2 contains the full list of these notes.

Figure 2: FIRM Notes to Users

NOTES TO USERS

For information and questions about this map, available products associated with this FIRM including historic versions of this FIRM, how to order products, or the National Flood Insurance Program in general, please call the FEMA Map Information eXchange at 1-877-FEMA-MAP (1-877-336-2627) or visit the FEMA Flood Map Service Center website at msc.fema.gov. Available products may include previously issued Letters of Map Change, a Flood Insurance Study Report, and/or digital versions of this map. Many of these products can be ordered or obtained directly from the website. Users may determine the current map date for each FIRM panel by visiting the FEMA Flood Map Service Center website or by calling the FEMA Map Information eXchange.

Communities annexing land on adjacent FIRM panels must obtain a current copy of the adjacent panel as well as the current FIRM Index. These may be ordered directly from the Flood Map Service Center at the number listed above.

For community and countywide map dates, refer to Table 27 in this FIS Report.

To determine if flood insurance is available in the community, contact your insurance agent or call the National Flood Insurance Program at 1-800-638-6620.

The map is for use in administering the NFIP. It may not identify all areas subject to flooding, particularly from local drainage sources of small size. Consult the community map repository to find updated or additional flood hazard information.

BASE FLOOD ELEVATIONS: For more detailed information in areas where Base Flood Elevations (BFEs) and/or floodways have been determined, consult the Flood Profiles and Floodway Data and/or Summary of Non-Coastal Stillwater Elevations tables within this FIS Report. Use the flood elevation data within the FIS Report in conjunction with the FIRM for construction and/or floodplain management.

FLOODWAY INFORMATION: Boundaries of the floodways were computed at cross sections and interpolated between cross sections. The floodways were based on hydraulic considerations with regard to requirements of the National Flood Insurance Program. Floodway widths and other pertinent floodway data are provided in the FIS Report for this jurisdiction.

FLOOD CONTROL STRUCTURE INFORMATION: Certain areas not in Special Flood Hazard Areas may be protected by flood control structures. Refer to Section 4.3 "Non-Levee Flood Protection Measures" of this FIS Report for information on flood control structures for this jurisdiction.

Figure 2. FIRM Notes to Users, continued

PROJECTION INFORMATION: The projection used in the preparation of the map was State Plane Lambert Conformal Conic, Oklahoma North Zone FIPS 3501. The horizontal datum was the North American Datum of 1983 NAD83, GRS1980 spheroid. Differences in datum, spheroid, projection or State Plane zones used in the production of FIRMs for adjacent jurisdictions may result in slight positional differences in map features across jurisdiction boundaries. These differences do not affect the accuracy of the FIRM.

ELEVATION DATUM: Flood elevations on the FIRM are referenced to the North American Vertical Datum of 1988. These flood elevations must be compared to structure and ground elevations referenced to the same vertical datum. For information regarding conversion between the National Geodetic Vertical Datum of 1929 and the North American Vertical Datum of 1988, visit the National Geodetic Survey website at www.ngs.noaa.gov.

Local vertical monuments may have been used to create the map. To obtain current monument information, please contact the appropriate local community listed in Table 30 of this FIS Report.

BASE MAP INFORMATION: Base map information shown on this FIRM was provided by United States Census Bureau, dated 2016; Wyandotte Nation, dated 2009; United States Bureau of Land Management, dated 2006; United States Geologic Survey, dated 2005; and digital orthophotography was collected by the U.S. Department of Agriculture Farm Service Agency. This imagery was flown in 2015 and was produced with a 1-meter ground sample distance. For information about base maps, refer to Section 6.2 "Base Map" in this FIS Report.

The map reflects more detailed and up-to-date stream channel configurations than those shown on the previous FIRM for this jurisdiction. The floodplains and floodways that were transferred from the previous FIRM may have been adjusted to conform to these new stream channel configurations. As a result, the Flood Profiles and Floodway Data tables may reflect stream channel distances that differ from what is shown on the map.

Corporate limits shown on the map are based on the best data available at the time of publication. Because changes due to annexations or de-annexations may have occurred after the map was published, map users should contact appropriate community officials to verify current corporate limit locations.

NOTES FOR FIRM INDEX

REVISIONS TO INDEX: As new studies are performed and FIRM panels are updated within Ottawa County, Oklahoma, corresponding revisions to the FIRM Index will be incorporated within the FIS Report to reflect the effective dates of those panels. Please refer to Table 27 of this FIS Report to determine the most recent FIRM revision date for each community. The most recent FIRM panel effective date will correspond to the most recent index date.

ATTENTION: The corporate limits shown on this FIRM Index are based on the best information available at the time of publication. As such, they may be more current than those shown on FIRM panels issued before September 13, 2019.

SPECIAL NOTES FOR SPECIFIC FIRM PANELS

This Notes to Users section was created specifically for Ottawa County, Oklahoma, effective September 13, 2019.

Figure 2. FIRM Notes to Users, continued

FLOOD RISK REPORT: A Flood Risk Report (FRR) may be available for many of the flooding sources and communities referenced in this FIS Report. The FRR is provided to increase public awareness of flood risk by helping communities identify the areas within their jurisdictions that have the greatest risks. Although non-regulatory, the information provided within the FRR can assist communities in assessing and evaluating mitigation opportunities to reduce these risks. It can also be used by communities developing or updating flood risk mitigation plans. These plans allow communities to identify and evaluate opportunities to reduce potential loss of life and property. However, the FRR is not intended to be the final authoritative source of all flood risk data for a project area; rather, it should be used with other data sources to paint a comprehensive picture of flood risk.

Each FIRM panel contains an abbreviated legend for the features shown on the maps. However, the FIRM panel does not contain enough space to show the legend for all map features. Figure 3 shows the full legend of all map features. Note that not all of these features may appear on the FIRM panels in Ottawa County.

Figure 3: Map Legend for FIRM

SPECIAL FLOOD HAZARD AREAS: *The 1% annual chance flood, also known as the base flood or 100-year flood, has a 1% chance of happening or being exceeded each year. Special Flood Hazard Areas are subject to flooding by the 1% annual chance flood. The Base Flood Elevation is the water surface elevation of the 1% annual chance flood. The floodway is the channel of a stream plus any adjacent floodplain areas that must be kept free of encroachment so that the 1% annual chance flood can be carried without substantial increases in flood heights. See note for specific types. If the floodway is too narrow to be shown, a note is shown.*

	Special Flood Hazard Areas subject to inundation by the 1% annual chance flood (Zones A, AE, AH, AO, AR, A99, V and VE)
Zone A	The flood insurance rate zone that corresponds to the 1% annual chance floodplains. No base (1% annual chance) flood elevations (BFEs) or depths are shown within this zone.
Zone AE	The flood insurance rate zone that corresponds to the 1% annual chance floodplains. Base flood elevations derived from the hydraulic analyses are shown within this zone.
Zone AH	The flood insurance rate zone that corresponds to the areas of 1% annual chance shallow flooding (usually areas of ponding) where average depths are between 1 and 3 feet. Whole-foot BFEs derived from the hydraulic analyses are shown at selected intervals within this zone.
Zone AO	The flood insurance rate zone that corresponds to the areas of 1% annual chance shallow flooding (usually sheet flow on sloping terrain) where average depths are between 1 and 3 feet. Average whole-foot depths derived from the hydraulic analyses are shown within this zone.
Zone AR	The flood insurance rate zone that corresponds to areas that were formerly protected from the 1% annual chance flood by a flood control system that was subsequently decertified. Zone AR indicates that the former flood control system is being restored to provide protection from the 1% annual chance or greater flood.
Zone A99	The flood insurance rate zone that corresponds to areas of the 1% annual chance floodplain that will be protected by a Federal flood protection system where construction has reached specified statutory milestones. No base flood elevations or flood depths are shown within this zone.
Zone V	The flood insurance rate zone that corresponds to the 1% annual chance coastal floodplains that have additional hazards associated with storm waves. Base flood elevations are not shown within this zone.
Zone VE	Zone VE is the flood insurance rate zone that corresponds to the 1% annual chance coastal floodplains that have additional hazards associated with storm waves. Base flood elevations derived from the coastal analyses are shown within this zone as static whole-foot elevations that apply throughout the zone.

Figure 3: Map Legend for FIRM, continued

	Regulatory Floodway determined in Zone AE.
OTHER AREAS OF FLOOD HAZARD	
	Shaded Zone X: Areas of 0.2% annual chance flood hazards and areas of 1% annual chance flood hazards with average depths of less than 1 foot or with drainage areas less than 1 square mile.
	Future Conditions 1% Annual Chance Flood Hazard – Zone X: The flood insurance rate zone that corresponds to the 1% annual chance floodplains that are determined based on future-conditions hydrology. No base flood elevations or flood depths are shown within this zone.
	Area with Reduced Flood Risk due to Levee: Areas where an accredited levee, dike, or other flood control structure has reduced the flood risk from the 1% annual chance flood.
	Area with Flood Risk due to Levee: Areas where a non-accredited levee, dike, or other flood control structure is shown as providing protection to less than the 1% annual chance flood.
OTHER AREAS	
	Zone D (Areas of Undetermined Flood Hazard): The flood insurance rate zone that corresponds to unstudied areas where flood hazards are undetermined, but possible.
NO SCREEN	Unshaded Zone X: Areas of minimal flood hazard.
FLOOD HAZARD AND OTHER BOUNDARY LINES	
(ortho) (vector)	Flood Zone Boundary (white line on ortho-photography-based mapping; gray line on vector-based mapping)
	Limit of Study
	Jurisdiction Boundary
	Limit of Moderate Wave Action (LiMWA): Indicates the inland limit of the area affected by waves greater than 1.5 feet
GENERAL STRUCTURES	
Aqueduct Channel Culvert Storm Sewer	Channel, Culvert, Aqueduct, or Storm Sewer
Dam Jetty Weir	Dam, Jetty, Weir

Figure 3: Map Legend for FIRM, continued

	Levee, Dike, or Floodwall
Bridge	Bridge
REFERENCE MARKERS	
22.0	River mile Markers
CROSS SECTION & TRANSECT INFORMATION	
B 20.2	Lettered Cross Section with Regulatory Water Surface Elevation (BFE)
5280 21.1	Numbered Cross Section with Regulatory Water Surface Elevation (BFE)
17.5	Unlettered Cross Section with Regulatory Water Surface Elevation (BFE)
8	Coastal Transect
	Profile Baseline: Indicates the modeled flow path of a stream and is shown on FIRM panels for all valid studies with profiles or otherwise established base flood elevation.
	Coastal Transect Baseline: Used in the coastal flood hazard model to represent the 0.0-foot elevation contour and the starting point for the transect and the measuring point for the coastal mapping.
513	Base Flood Elevation Line
ZONE AE (EL 16)	Static Base Flood Elevation value (shown under zone label)
ZONE AO (DEPTH 2)	Zone designation with Depth
ZONE AO (DEPTH 2) (VEL 15 FPS)	Zone designation with Depth and Velocity
BASE MAP FEATURES	
Missouri Creek	River, Stream or Other Hydrographic Feature
234	Interstate Highway
234	U.S. Highway

Figure 3: Map Legend for FIRM, continued

(234)	State Highway
234	County Highway
MAPLE LANE	Street, Road, Avenue Name, or Private Drive if shown on Flood Profile
RAILROAD	Railroad
	Horizontal Reference Grid Line
—	Horizontal Reference Grid Ticks
+	Secondary Grid Crosshairs
Land Grant	Name of Land Grant
7	Section Number
R. 43 W. T. 22 N.	Range, Township Number
$^{42}76^{000m}$E	Horizontal Reference Grid Coordinates (UTM)
365000 FT	Horizontal Reference Grid Coordinates (State Plane)
80° 16’ 52.5”	Corner Coordinates (Latitude, Longitude)

SECTION 2.0 – FLOODPLAIN MANAGEMENT APPLICATIONS

2.1 Floodplain Boundaries

To provide a national standard without regional discrimination, the 1% annual chance (100-year) flood has been adopted by FEMA as the base flood for floodplain management purposes. The 0.2% annual chance (500-year) flood is employed to indicate additional areas of flood hazard in the community.

Each flooding source included in the project scope has been studied and mapped using professional engineering and mapping methodologies that were agreed upon by FEMA and Ottawa County as appropriate to the risk level. Flood risk is evaluated based on factors such as known flood hazards and projected impact on the built environment. Engineering analyses were performed for each studied flooding source to calculate its 1% annual chance flood elevations; elevations corresponding to other floods (e.g. 10-, 4-, 2-, 0.2-percent annual chance, etc.) may have also been computed for certain flooding sources. Engineering models and methods are described in detail in Section 5.0 of this FIS Report. The modeled elevations at cross sections were used to delineate the floodplain boundaries on the FIRM; between cross sections, the boundaries were interpolated using elevation data from various sources. More information on specific mapping methods is provided in Section 6.0 of this FIS Report.

Depending on the accuracy of available topographic data (Table 22), study methodologies employed (Section 5.0), and flood risk, certain flooding sources may be mapped to show both the 1% and 0.2% annual chance floodplain boundaries, regulatory water surface elevations (BFEs), and/or a regulatory floodway. Similarly, other flooding sources may be mapped to show only the 1% annual chance floodplain boundary on the FIRM, without published water surface elevations. In cases where the 1% and 0.2% annual chance floodplain boundaries are close together, only the 1% annual chance floodplain boundary is shown on the FIRM. Figure 3, “Map Legend for FIRM”, describes the flood zones that are used on the FIRMs to account for the varying levels of flood risk that exist along flooding sources within the project area. Table 2 and Table 3 indicate the flood zone designations for each flooding source and each community within Ottawa County, respectively.

Table 2, “Flooding Sources Included in this FIS Report,” lists each flooding source, including its study limits, affected communities, mapped zone on the FIRM, and the completion date of its engineering analysis from which the flood elevations on the FIRM and in the FIS Report were derived. Descriptions and dates for the latest hydrologic and hydraulic analyses of the flooding sources are shown in Table 12. Floodplain boundaries for these flooding sources are shown on the FIRM (published separately) using the symbology described in Figure 3. On the map, the 1% annual chance floodplain corresponds to the SFHAs. The 0.2% annual chance floodplain shows areas that, although out of the regulatory floodplain, are still subject to flood hazards.

Small areas within the floodplain boundaries may lie above the flood elevations but cannot be shown due to limitations of the map scale and/or lack of detailed topographic data. The procedures to remove these areas from the SFHA are described in Section 6.5 of this FIS Report.

Table 2: Flooding Sources Included in this FIS Report

Flooding Source	Community	Downstream Limit	Upstream Limit	HUC-8 Sub-Basin(s)	Length (mi) (streams or coastlines)	Area (mi^2) (estuaries or ponding)	Floodway (Y/N)	Zone shown on FIRM	Date of Analysis
Bee Creek and Zone A tributaries	Ottawa County, Unincorporated Areas	N/A	N/A	11070206	5.7		N	A	2016
Belmont Run	Miami, City of; Ottawa County, Unincorporated Areas	At confluence with Tar Creek (at Miami)	Just downstream of U.S. Highway 60	11070206	3.5		Y	AE	2016
Coal Creek and Zone A tributaries	Ottawa County, Unincorporated Areas	N/A	N/A	11070206	25.4		N	A	2016
Council Hollow Creek and Zone A tributaries	Ottawa County, Unincorporated Areas	N/A	N/A	11070206	2.6		N	A	2016
Cow Creek	Ottawa County, Unincorporated Areas	At confluence with Neosho River	Ottawa county line	11070206	7.9		N	A	2016
Elm Creek and Zone A tributaries	Ottawa County, Unincorporated Areas	N/A	N/A	11070206	26.2		N	A	2016
Fairgrounds Branch	Miami, City of; Ottawa County, Unincorporated Areas	At confluence with the Neosho River	Approximately 2.7 miles upstream of confluence with Neosho River	11070206	2.8		Y	AE	2016
Garrett Creek and Zone A tributaries	Miami, City of; Ottawa County, Unincorporated Areas	N/A	N/A	11070206	7		N	A	2016
Grand Lake O' The Cherokees	Ottawa County, Unincorporated Areas	N/A	N/A			0.4	N	AE	2016
Grand Lake Tributary 2 and Zone A tributaries	Ottawa County, Unincorporated Areas	N/A	N/A	11070206	4.5		N	A	2016
Hickory Creek and Zone A tributaries	Ottawa County, Unincorporated Areas	N/A	N/A	11070206	4.2		N	A	2016

Table 2: Flooding Sources Included in this FIS Report, continued

Flooding Source	Community	Downstream Limit	Upstream Limit	HUC-8 Sub-Basin(s)	Length (mi) (streams or coastlines)	Area (mi^2) (estuaries or ponding)	Floodway (Y/N)	Zone shown on FIRM	Date of Analysis
Horse Creek and Zone A tributaries	Afton, Town of; Ottawa County, Unincorporated Areas	N/A	N/A	11070206	26.8		N	A	2016
Horse Creek	Afton, Town of; Ottawa County, Unincorporated Areas	Approximately 0.36 mile upstream of confluence of Horse Creek Tributary 1	Approximately 0.2 mile downstream of confluence with Horse Creek Tributary 5	11070206	3.4		N	AE	2016
Horse Creek Tributary 3	Afton, Town of; Ottawa County, Unincorporated Areas	At confluence with Horse Creek	Approximately 1.08 miles upstream of confluence with Horse Creek Tributary 3-2	11070206	2		N	AE	2016
Horse Creek Tributary 3-1	Afton, Town of; Ottawa County, Unincorporated Areas	At confluence with Horse Creek Tributary 3	Approximately 0.9 mile upstream of confluence with Horse Creek Tributary 3	11070206	0.9		N	AE	2016
Horse Creek Tributary 3-2	Afton, Town of; Ottawa County, Unincorporated Areas	At confluence with Horse Creek Tributary 3	Approximately 1,700 feet upstream from South Main Avenue	11070206	1.4		N	AE	2016
Horse Creek Tributary 3-2-1	Afton, Town of; Ottawa County, Unincorporated Areas	At confluence with Horse Creek Tributary 3-2	Approximately 2.12 miles upstream of confluence with Horse Creek Tributary 3-2	11070206	2.1		N	AE	2016
Hudson Creek and Zone A tributaries	Fairland, Town of; Ottawa County, Unincorporated Areas	N/A	N/A	11070206	38		N	A	2016
Little Elm Creek and Zone A tributaries	Ottawa County, Unincorporated Areas	N/A	N/A	11070206	18.3		N	A	2016

Table 2: Flooding Sources Included in this FIS Report, continued

Flooding Source	Community	Downstream Limit	Upstream Limit	HUC-8 Sub-Basin(s)	Length (mi) (streams or coastlines)	Area (mi^2) (estuaries or ponding)	Floodway (Y/N)	Zone shown on FIRM	Date of Analysis
Little Elm Creek	Miami, City of; Ottawa County, Unincorporated Areas	At confluence with the Neosho River	At confluence with Little Elm Creek Tributary 2	11070206	3.5		Y	AE	2008
Little Horse Creek and Zone A tributaries	Fairland, Town of; Ottawa County, Unincorporated Areas	N/A	N/A	11070206	27.3		N	A	2016
Lost Creek and Zone A tributaries	Ottawa County, Unincorporated Areas; Wyandotte Nation of Oklahoma; Wyandotte, Town of	N/A	N/A	11070206	8.4		N	A	2016
Lost Creek (at Wyandotte)	Ottawa County, Unincorporated Areas; Wyandotte Nation of Oklahoma; Wyandotte, Town of	At confluence with Grand Lake O' The Cherokees	Approximately 1.0 miles upstream of confluence with Lost Creek Tributary 2	11070206	2.8		Y	AE	2016
Lost Creek (Upper Reach)	Ottawa County, Unincorporated Areas; Wyandotte Nation of Oklahoma; Wyandotte, Town of	Approximately 6.9 miles upstream of confluence with Lost Creek Tributary 2	Approximately 8.2 miles upstream of confluence with Lost Creek Tributary 2	11070206	1.3		Y	AE	2008
Lytle Creek and Zone A tributaries	Ottawa County, Unincorporated Areas;	N/A	N/A	11070206	8.6		N	A	2016
Mud Creek	Ottawa County, Unincorporated Areas	At confluence with Neosho River	Ottawa county line	11070206	0.4		N	A	2016
Neosho River	Miami, City of; Ottawa County, Unincorporated Areas	Approximately 1,000 feet upstream of US Highway 60	Approximately 1,400 upstream of E 60 Road	11070206	23		Y	AE	2016
Neosho River	Ottawa County, Unincorporated Areas	Ottawa County line	Approximately 1,000 feet upstream of US Highway 60	11070206	16.4		N	AE	2016
Neosho River and Zone A tributaries	Ottawa County, Unincorporated Areas	N/A	N/A	11070206	27.7		N	A	2016

Table 2: Flooding Sources Included in this FIS Report, continued

Flooding Source	Community	Downstream Limit	Upstream Limit	HUC-8 Sub-Basin(s)	Length (mi) (streams or coastlines)	Area (mi^2) (estuaries or ponding)	Floodway (Y/N)	Zone shown on FIRM	Date of Analysis
Ogeechee Creek and Zone A tributaries	Fairland, Town of; Ottawa County, Unincorporated Areas	N/A	N/A	11070206	13.8		N	A	2016
Quail Creek and Zone A tributaries	Miami, City of; Ottawa County, Unincorporated Areas	N/A	N/A	11070206	2.4		N	A	2016
Quail Creek	Miami, City of; Ottawa County, Unincorporated Areas	At confluence with Tar Creek (at Miami)	At confluence with Quail Creek Tributary 1	11070206	2.8		Y	AE	2016
Tar Creek and Zone A tributaries	Commerce, City of; Miami, City of; Ottawa County, Unincorporated Areas;	N/A	N/A	11070206	21		N	A	2016
Tar Creek (at Miami)	Commerce, City of; Miami, City of; Ottawa County, Unincorporated Areas;	At confluence with Neosho River	Approximately 0.3 miles of upstream of confluence with Tar Creek Tributary 2	11070206	7.6		Y	AE	2016
Unnamed Creek 1 and Zone A tributaries	Ottawa County, Unincorporated Areas	N/A	N/A	11070206	5.5		N	A	2016
Unnamed Creek 2	Ottawa County, Unincorporated Areas	N/A	N/A	11070206	1.6		N	A	2016
Warren Branch	Ottawa County, Unincorporated Areas; Peoria, Town of	Approximately 0.32 mile downstream of the downstream Town of Peoria corporate limits	Approximately 0.58 mile upstream of the upstream Town of Peoria corporate Limits	11070207	1.9		Y	AE	1986
Windy Creek	Ottawa County, Unincorporated Areas	At confluence with Cow Creek	Ottawa county line	11070206	5.8		N	A	2016
Wyandotte Ditch	Ottawa County, Unincorporated Areas; Wyandotte, Town of	Approximately 3,300 feet upstream of the confluence with Lost Creek	Approximately 950 feet upstream of S 650 Road	11070206	0.96		N	AE	2016

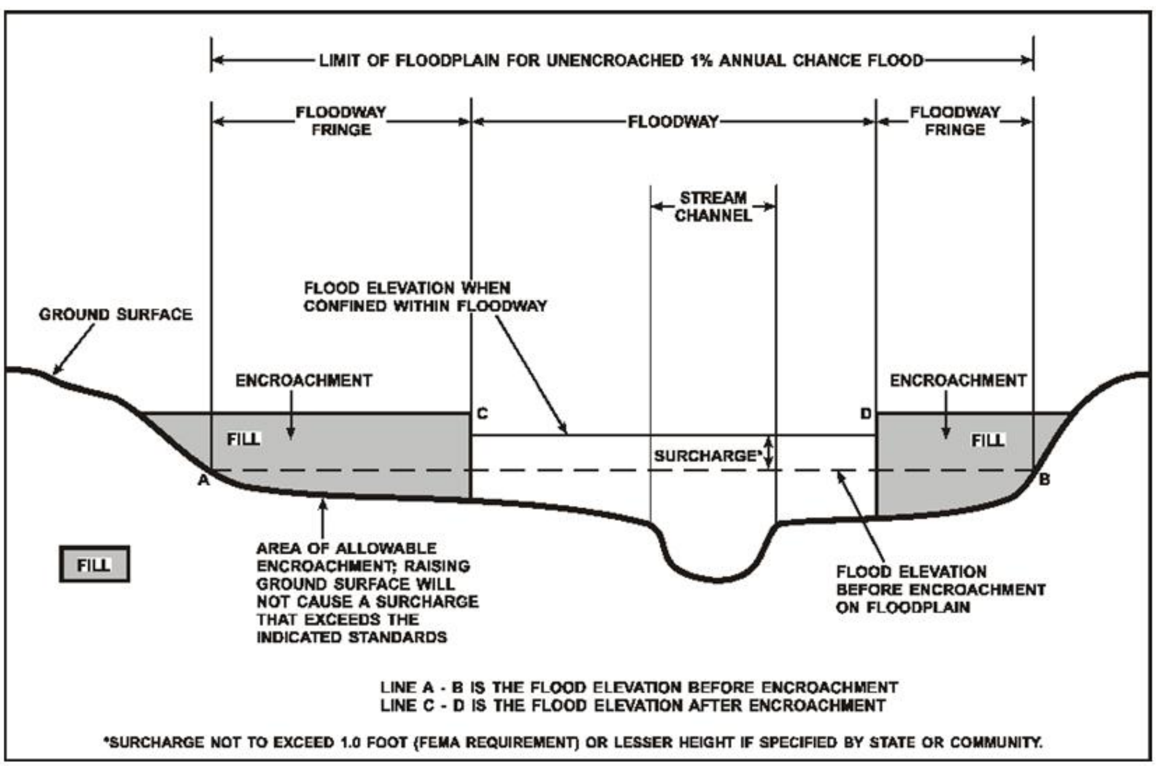
2.2 Floodways

Encroachment on floodplains, such as structures and fill, reduces flood-carrying capacity, increases flood heights and velocities, and increases flood hazards in areas beyond the encroachment itself. One aspect of floodplain management involves balancing the economic gain from floodplain development against the resulting increase in flood hazard.

For purposes of the NFIP, a floodway is used as a tool to assist local communities in balancing floodplain development against increasing flood hazard. With this approach, the area of the 1% annual chance floodplain on a river is divided into a floodway and a floodway fringe based on hydraulic modeling. The floodway is the channel of a stream, plus any adjacent floodplain areas, that must be kept free of encroachment in order to carry the 1% annual chance flood. The floodway fringe is the area between the floodway and the 1% annual chance floodplain boundaries where encroachment is permitted. The floodway must be wide enough so that the floodway fringe could be completely obstructed without increasing the water surface elevation of the 1% annual chance flood more than 1 foot at any point. Typical relationships between the floodway and the floodway fringe and their significance to floodplain development are shown in Figure 4.

To participate in the NFIP, Federal regulations require communities to limit increases caused by encroachment to 1.0 foot, provided that hazardous velocities are not produced. The floodways in this project are presented to local agencies as minimum standards that can be adopted directly or that can be used as a basis for additional floodway projects.

Figure 4: Floodway Schematic



Floodway widths presented in this FIS Report and on the FIRM were computed at cross sections. Between cross sections, the floodway boundaries were interpolated. For certain stream segments, floodways were adjusted so that the amount of floodwaters conveyed on each side of the floodplain would be reduced equally. The results of the floodway computations have been tabulated for selected cross sections and are shown in Table 23, "Floodway Data."

All floodways that were developed for this Flood Risk Project are shown on the FIRM using the symbology described in Figure 3. In cases where the floodway and 1% annual chance floodplain boundaries are either close together or collinear, only the floodway boundary has been shown on the FIRM. For information about the delineation of floodways on the FIRM, refer to Section 6.3.

2.3 Base Flood Elevations

The hydraulic characteristics of flooding sources were analyzed to provide estimates of the elevations of floods of the selected recurrence intervals. The Base Flood Elevation (BFE) is the elevation of the 1% annual chance flood. These BFEs are most commonly rounded to the whole foot, as shown on the FIRM, but in certain circumstances or locations they may be rounded to 0.1 foot. Cross section lines shown on the FIRM may also be labeled with the BFE rounded to 0.1 foot. Whole-foot BFEs derived from engineering analyses that apply to coastal areas, areas of ponding, or other static areas with little elevation change may also be shown at selected intervals on the FIRM.

Cross sections with BFEs shown on the FIRM correspond to the cross sections shown in the Floodway Data table and Flood Profiles in this FIS Report. BFEs are primarily intended for flood insurance rating purposes. For construction and/or floodplain management purposes, users are cautioned to use the flood elevation data presented in this FIS Report in conjunction with the data shown on the FIRM.

2.4 Non-Encroachment Zones

This section is not applicable to this Flood Risk Project.

2.5 Coastal Flood Hazard Areas

This section is not applicable to this Flood Risk Project.

2.5.1 Water Elevations and the Effects of Waves

This section is not applicable to this Flood Risk Project.

Figure 5: Wave Runup Transect Schematic

[Not Applicable to this Flood Risk Project]

2.5.2 Floodplain Boundaries and BFEs for Coastal Areas

This section is not applicable to this Flood Risk Project.

2.5.3 Coastal High Hazard Areas

This section is not applicable to this Flood Risk Project.

Figure 6: Coastal Transect Schematic

[Not Applicable to this Flood Risk Project]

2.5.4 Limit of Moderate Wave Action

This section is not applicable to this Flood Risk Project.

SECTION 3.0 – INSURANCE APPLICATIONS

3.1 National Flood Insurance Program Insurance Zones

For flood insurance applications, the FIRM designates flood insurance rate zones as described in Figure 3, “Map Legend for FIRM.” Flood insurance zone designations are assigned to flooding sources based on the results of the hydraulic or coastal analyses. Insurance agents use the zones shown on the FIRM and depths and base flood elevations in this FIS Report in conjunction with information on structures and their contents to assign premium rates for flood insurance policies.

The 1% annual chance floodplain boundary corresponds to the boundary of the areas of special flood hazards (e.g. Zones A, AE, V, VE, etc.), and the 0.2% annual chance floodplain boundary corresponds to the boundary of areas of additional flood hazards.

Table 3 lists the flood insurance zones in Ottawa County.

Table 3: Flood Zone Designations by Community

Community	Flood Zone(s)
Afton, Town of	AE, A, X
Commerce, City of	AE, A, X
Fairland, Town of	A, X
Miami, City of	AE, A, X
North Miami, Town of	X
Ottawa County, Unincorporated Areas	AE, A, X
Peoria, Town of	AE, A, X
Quapaw, Town of	A, X
Wyandotte, Town of	AE, A, X
Wyandotte Nation	AE, A, X

SECTION 4.0 – AREA STUDIED

4.1 Basin Description

Table 4 contains a description of the characteristics of the HUC-8 sub-basins within which each community falls. The table includes the main flooding sources within each basin, a brief description of the basin, and its drainage area.

Table 4: Basin Characteristics

HUC-8 Sub-Basin Name	HUC-8 Sub-Basin Number	Primary Flooding Source	Description of Affected Area	Drainage Area (square miles)
Elk	11070208	Elk River	Begins at the southeast portion of Ottawa County, continuing into McDonald County, Missouri, also covering portions of Newton and Barry counties in Missouri and Benton County, Arkansas.	1,026
Lake O' The Cherokees	11070206	Grand Lake O' The Cherokees	Begins at the Oklahoma State line in Craig and Ottawa Counties and continues south into Delaware and Mayes counties. The basin also extends into Newton and McDonald counties, Missouri and Benton County, Arkansas.	909
Lower Neosho	11070209	Neosho River	Begins south of the Pensacola Dam at the downstream end of the Grand Lake O' The Cherokees in Mayes County. The basin contains Big Cabin Creek in Craig County and also contains portions of Cherokee, Delaware, Ottawa, Rogers and Wagoner counties.	2,225
Middle Neosho	11070205	Neosho River	Begins at the confluence of Neosho River and Big Creek in Neosho County, Kansas and flows south, including Allen, Bourbon, Cherokee, and Crawford Counties in Kansas and Ottawa and Craig Counties, Oklahoma.	1,425
Spring	11070207	Spring River	Is located within the northeast corner of Ottawa County heading east. Also covers the eastern half of Cherokee and Crawford Counties in Kansas and all or portions of Barry, Barton, Christian, Jasper and Newton Counties in Missouri, ending in Lawrence County, Missouri.	2,591

4.2 Principal Flood Problems

Table 5 contains a description of the principal flood problems that have been noted for Ottawa County by flooding source.

Table 5: Principal Flood Problems

Flooding Source	Description of Flood Problems
All major streams	Flooding is most frequent in May and September due to intense localized thunderstorms, slow-moving cyclones, or weather fronts. Major flood problems have occurred in all of the floodplains of the studied streams.

Table 6 contains information about historic flood elevations in the communities within Ottawa County.

Table 6: Historic Flooding Elevations

Flooding Source	Location	Historic Peak (Feet NAVD88)	Event Date	Approximate Recurrence Interval (years)	Source of Data
Neosho River	2nd Street, Miami, City of	772.46	1993	100	USACE, HWM
Neosho River	M Street NW, Miami, City of	772.96	1994	100	USACE, HWM
Neosho River	I-44, Miami, City of	766.96	1994	100	USACE, HWM

4.3 Non-Levee Flood Protection Measures

Table 7 contains information about non-levee flood protection measures within Ottawa County such as dams, jetties, and or dikes. Levees are addressed in Section 4.4 of this FIS Report.

Table 7: Non-Levee Flood Protection Measures

Flooding Source	Structure Name	Type of Measure	Location	Description of Measure
Grand Lake O' The Cherokees	Pensacola Dam	Dam	Downstream end of Grand Lake O' The Cherokees in Mayes County	Hydroelectric dam that created the 46,500 acre reservoir

4.4 Levees

This section is not applicable to this flood risk project.

Table 8: Levees

[Not Applicable to this Flood Risk Project]

SECTION 5.0 – ENGINEERING METHODS

For the flooding sources in the community, standard hydrologic and hydraulic study methods were used to determine the flood hazard data required for this study. Flood events of a magnitude that are expected to be equaled or exceeded at least once on the average during any 10-, 25-, 50-, 100-, or 500-year period (recurrence interval) have been selected as having special significance for floodplain management and for flood insurance rates. These events, commonly termed the 10-, 25-, 50-, 100-, and 500-year floods, have a 10-, 4-, 2-, 1-, and 0.2% annual chance, respectively, of being equaled or exceeded during any year.

Although the recurrence interval represents the long-term, average period between floods of a specific magnitude, rare floods could occur at short intervals or even within the same year. The risk of experiencing a rare flood increases when periods greater than 1 year are considered. For example, the risk of having a flood that equals or exceeds the 100-year flood (1-percent chance of annual exceedance) during the term of a 30-year mortgage is approximately 26 percent (about 3 in 10); for any 90-year period, the risk increases to approximately 60 percent (6 in 10). The analyses reported herein reflect flooding potentials based on conditions existing in the community at the time of completion of this study. Maps and flood elevations will be amended periodically to reflect future changes.

5.1 Hydrologic Analyses

Hydrologic analyses were carried out to establish the peak elevation-frequency relationships for floods of the selected recurrence intervals for each flooding source studied. Hydrologic analyses are typically performed at the watershed level. Depending on factors such as watershed size and shape, land use and urbanization, and natural or man-made storage, various models or methodologies may be applied. A summary of the hydrologic methods applied to develop the discharges used in the hydraulic analyses for each stream is provided in Table 12. Greater detail (including assumptions, analysis, and results) is available in the archived project documentation.

A summary of the discharges is provided in Table 9. A summary of stillwater elevations developed for non-coastal flooding sources is provided in Table 10. Stream gage information is provided in Table 11.

Table 9: Summary of Discharges

Flooding Source	Location	Drainage Area (Square Miles)	Peak Discharge (cfs)				
			10% Annual Chance	4% Annual Chance	2% Annual Chance	1% Annual Chance	0.2% Annual Chance
Belmont Run	27 ft upstream of confluence with Tar Creek (at Miami)	2.49	1,776	2,394	2,854	3,384	4,794
Belmont Run	489 ft upstream of confluence with Tar Creek (at Miami)	2.48	1,730	2,327	2,779	3,294	4,674
Belmont Run	654 ft upstream of confluence with Tar Creek (at Miami)	1.68	1,374	1,852	2,208	2,625	3,730
Belmont Run	1,301 ft upstream of confluence with Tar Creek (at Miami)	1.65	1,359	1,832	2,184	2,596	3,689
Belmont Run	1,951 ft upstream of confluence with Tar Creek (at Miami)	1.63	1,336	1,801	2,148	2,553	3,630
Belmont Run	2,218 ft upstream of confluence with Tar Creek (at Miami)	1.61	1,315	1,771	2,114	2,513	3,574
Belmont Run	2,052 ft downstream of confluence with Belmont Creek	1.25	1,115	1,502	1,795	2,134	3,041
Belmont Run	3,616 ft upstream of confluence with Tar Creek (at Miami)	1.24	1,111	1,497	1,786	2,127	3,031

Table 9: Summary of Discharges, continued

Flooding Source	Location	Drainage Area (Square Miles)	Peak Discharge (cfs)				
			10% Annual Chance	4% Annual Chance	2% Annual Chance	1% Annual Chance	0.2% Annual Chance
Belmont Run	4,625 ft upstream of confluence with Tar Creek (at Miami)	1.19	870	1,217	1,482	1,798	2,657
Belmont Run	5,401 ft upstream of confluence with Tar Creek (at Miami)	1.13	850	1,189	1,447	1,756	2,595
Belmont Run	6,738 ft upstream of confluence with Tar Creek (at Miami)	0.96	756	1,057	1,287	1,564	2,316
Belmont Run	7,694 ft upstream of confluence with Tar Creek (at Miami)	0.87	737	1,035	1,256	1,528	2,258
Belmont Run	8,705 ft upstream of confluence with Tar Creek (at Miami)	0.86	745	1,047	1,270	1,545	2,279
Belmont Run	10,143 ft upstream of confluence with Tar Creek (at Miami)	0.79	693	973	1,181	1,438	2,126
Belmont Run	11,526 ft upstream of confluence with Tar Creek (at Miami)	0.62	445	660	825	1,031	1,600
Belmont Run	11,970 ft upstream of confluence with Tar Creek (at Miami)	0.59	441	655	817	1,022	1,585
Belmont Run	13,747 ft upstream of confluence with Tar Creek (at Miami)	0.42	375	561	695	872	1,348

Table 9: Summary of Discharges, continued

Flooding Source	Location	Drainage Area (Square Miles)	Peak Discharge (cfs)				
			10% Annual Chance	4% Annual Chance	2% Annual Chance	1% Annual Chance	0.2% Annual Chance
Fairgrounds Branch	At confluence with Neosho River	1.89	1,159	1,754	2,146	2,653	3,988
Fairgrounds Branch	1,137 ft upstream of confluence with Neosho River	1.34	938	1,422	1,737	2,155	3,246
Fairgrounds Branch	1,751 ft upstream of confluence with Neosho River	1.23	895	1,357	1,657	2,058	3,099
Fairgrounds Branch	2,883 ft upstream of confluence with Neosho River	1.2	893	1,357	1,654	2,055	3,091
Fairgrounds Branch	3,240 ft upstream of confluence with Neosho River	1.08	833	1,266	1,544	1,919	2,890
Fairgrounds Branch	4,177 ft upstream of confluence with Neosho River	1.04	814	1,237	1,508	1,875	2,825
Fairgrounds Branch	6,317 ft upstream of confluence with Neosho River	0.9	952	1,365	1,629	1,983	2,876
Fairgrounds Branch	6,996 ft upstream of confluence with Neosho River	0.87	942	1,352	1,611	1,962	2,844
Fairgrounds Branch	7,632 ft upstream of confluence with Neosho River	0.56	573	875	1,061	1,328	2,002

Table 9: Summary of Discharges, continued

Flooding Source	Location	Drainage Area (Square Miles)	Peak Discharge (cfs)				
			10% Annual Chance	4% Annual Chance	2% Annual Chance	1% Annual Chance	0.2% Annual Chance
Fairgrounds Branch	8,315 ft upstream of confluence with Neosho River	0.49	531	812	983	1,232	1,858
Fairgrounds Branch	9,032 ft upstream of confluence with Neosho River	0.46	519	795	961	1,205	1,814
Fairgrounds Branch	9,483 ft upstream of confluence with Neosho River	0.43	509	782	943	1,183	1,779
Fairgrounds Branch	10,090 ft upstream of confluence with Neosho River	0.36	462	711	855	1,075	1,615
Fairgrounds Branch	10,598 ft upstream of confluence with Neosho River	0.22	352	544	652	824	1,239
Fairgrounds Branch	10,957 ft upstream of confluence with Neosho River	0.21	347	539	643	813	1,219
Fairgrounds Branch	11,859 ft upstream of confluence with Neosho River	0.13	274	428	508	645	967
Grand Lake O' The Cherokees	At station 138,727 of Neosho River study	10,351	87,598	124,837	159,203	197,642	307,356
Horse Creek	At confluence with Horse Creek Tributary 2	23.52	4,468	6,614	8,344	10,090	15,282
Horse Creek	3,179 ft downstream of confluence with Horse Creek Tributary 3	23.06	4,442	6,579	8,295	10,033	15,188

Table 9: Summary of Discharges, continued

Flooding Source	Location	Drainage Area (Square Miles)	Peak Discharge (cfs)				
			10% Annual Chance	4% Annual Chance	2% Annual Chance	1% Annual Chance	0.2% Annual Chance
Horse Creek	167 ft downstream of confluence with Horse Creek	22.75	4,437	6,573	8,286	10,022	15,169
Horse Creek	At confluence with Horse Creek Tributary 3	16.58	3,651	5,418	6,818	8,274	12,542
Horse Creek	At confluence with Horse Creek Tributary 4	15.01	3,439	5,105	6,423	7,801	11,835
Horse Creek Tributary 3	At confluence with Horse Creek	5.69	2,007	3,008	3,748	4,597	6,973
Horse Creek Tributary 3	2,393 ft downstream of confluence with Horse Creek Tributary 3-1	5.66	2,006	3,007	3,747	4,595	6,970
Horse Creek Tributary 3	1,500 ft downstream of confluence with Horse Creek Tributary 3-1	5.62	2,000	2,999	3,736	4,582	6,950
Horse Creek Tributary 3	433 ft downstream of confluence with Horse Creek Tributary 3-1	5.59	1,996	2,993	3,728	4,573	6,935
Horse Creek Tributary 3	At confluence with Horse Creek Tributary 3-1	3.75	1,538	2,307	2,873	3,538	5,385
Horse Creek Tributary 3	At confluence with Horse Creek 3-2	3.00	1,315	1,971	2,457	30,302	4,630
Horse Creek Tributary 3	915 ft upstream of confluence with Horse Creek Tributary 3-2	1.56	866	1,300	1,618	2,010	3,084

Table 9: Summary of Discharges, continued

Flooding Source	Location	Drainage Area (Square Miles)	Peak Discharge (cfs)				
			10% Annual Chance	4% Annual Chance	2% Annual Chance	1% Annual Chance	0.2% Annual Chance
Horse Creek Tributary 3	2,210 ft upstream of confluence with Horse Creek Tributary 3-2	1.41	816	1,226	1,524	1,896	2,911
Horse Creek Tributary 3	3,394 ft upstream of confluence with Horse Creek Tributary 3-2	1.33	791	1,189	1,477	1,838	2,822
Horse Creek Tributary 3-1	At confluence with Horse Creek Tributary 3	1.75	879	1,311	1,641	2,037	3,141
Horse Creek Tributary 3-1	1,316 ft upstream of confluence with Horse Creek Tributary 3	1.68	841	1,252	1,570	1,949	3,012
Horse Creek Tributary 3-1	2,412 ft upstream of confluence with Horse Creek Tributary 3	1.57	819	1,223	1,530	1,901	2,934
Horse Creek Tributary 3-1	3,776 ft upstream of confluence with Horse Creek Tributary 3	1.3	743	1,112	1,388	1,728	2,665
Horse Creek Tributary 3-2	At confluence with Horse Creek Tributary 3	0.54	621	890	1,069	1,310	1,929
Horse Creek Tributary 3-2	1,132 ft upstream of confluence with Horse Creek Tributary 3	0.45	561	805	966	1,186	1,746
Horse Creek Tributary 3-2	1,692 ft upstream of confluence with Horse Creek Tributary 3	0.43	557	801	960	1,179	1,734

Table 9: Summary of Discharges, continued

Flooding Source	Location	Drainage Area (Square Miles)	Peak Discharge (cfs)				
			10% Annual Chance	4% Annual Chance	2% Annual Chance	1% Annual Chance	0.2% Annual Chance
Horse Creek Tributary 3-2	2,093 ft upstream of confluence with Horse Creek Tributary 3	0.36	401	612	748	943	1,443
Horse Creek Tributary 3-2	2,916 ft upstream of confluence with Horse Creek Tributary 3	0.35	393	602	734	926	1,415
Horse Creek Tributary 3-2	1,032 ft upstream of confluence with Horse Creek Tributary 3	0.23	308	473	576	729	1,116
Horse Creek Tributary 3-2	4,264 ft upstream of confluence with Horse Creek Tributary 3	0.21	299	460	559	709	1,083
Horse Creek Tributary 3-2	4,890 ft upstream of confluence with Horse Creek Tributary 3	0.13	224	346	418	533	815
Horse Creek Tributary 3-2	3,590 ft upstream of confluence with Horse Creek Tributary 3	0.04	99	153	185	238	368
Horse Creek Tributary 3-2-1	764 ft upstream of confluence with Horse Creek Tributary 3-2	1.42	895	1,355	1,671	2,078	3,165
Horse Creek Tributary 3-2-1	1,842 ft upstream of confluence with Horse Creek Tributary 3-2	1.36	890	1,351	1,663	2,068	3,144
Horse Creek Tributary 3-2-1	3,123 ft upstream of confluence with Horse Creek Tributary 3-2	1.33	880	1,336	1,643	2,044	3,106

Table 9: Summary of Discharges, continued

Flooding Source	Location	Drainage Area (Square Miles)	Peak Discharge (cfs)				
			10% Annual Chance	4% Annual Chance	2% Annual Chance	1% Annual Chance	0.2% Annual Chance
Horse Creek Tributary 3-2-1	4,139 ft upstream of confluence with Horse Creek Tributary 3-2	1.13	801	1,218	1,496	1,865	2,835
Little Elm Creek	32 ft upstream of confluence with Neosho River	12.78	3,700	5,133	6,990	8,720	13,700
Little Elm Creek	At confluence with Little Elm Creek Tributary 1	7.53	2,640	3,667	4,988	6,255	9,869
Lost Creek (at Wyandotte)	At confluence with Grand Lake O' The Cherokees	91.74	13,770	17,641	22,664	27,360	38,263
Lost Creek (at Wyandotte)	788 ft upstream of confluence with Grand Lake O' The Cherokees	91.69	13,762	17,632	22,654	27,349	38,253
Lost Creek (at Wyandotte)	1,737 ft upstream of confluence with Grand Lake	91.66	13,757	17,626	22,648	27,342	38,247
Lost Creek (at Wyandotte)	174 ft downstream of confluence with Lost Creek Tributary 1	91.61	13,746	17,615	22,635	27,328	38,234
Lost Creek (at Wyandotte)	At confluence with Lost Creek Tributary 1	90.19	13,489	17,336	22,324	26,983	37,914
Lost Creek (at Wyandotte)	903 ft upstream of confluence with Lost Creek Tributary 1	90.06	13,465	17,309	22,295	26,951	37,884

Table 9: Summary of Discharges, continued

Flooding Source	Location	Drainage Area (Square Miles)	Peak Discharge (cfs)				
			10% Annual Chance	4% Annual Chance	2% Annual Chance	1% Annual Chance	0.2% Annual Chance
Lost Creek (at Wyandotte)	At confluence with Lost Creek Tributary 2	88.8	13,237	17,062	22,018	26,644	37,599
Lost Creek (at Wyandotte)	1,323 ft upstream of confluence with Lost Creek Tributary 2	88.48	13,180	16,999	21,947	26,566	37,526
Lost Creek (at Wyandotte)	3,103 ft upstream of Confluence with Lost Creek Tributary 2	88.14	13,117	16,931	21,872	26,481	37,447
Lost Creek (at Wyandotte)	5,158 ft upstream of confluence with Lost Creek Tributary 2	87.74	13,046	16,853	21,784	26,385	37,357
Lost Creek (Upper Reach)	Approximately 5,000 feet above its confluence with Grand Lake O' The Cherokees	59.84	8,200	*	15,500	19,310	30,400
Neosho River	Station 232,186	8,726	89,236	129,519	170,004	212,405	322,521
Neosho River	Station 305,167	6,136	51,980	88,681	117,066	146,597	222,987
Neosho River	At gage 07185000, station 353626	5,927	62,110	101,223	132,595	165,272	247,751
Tar Creek (at Miami)	71 ft upstream of confluence with Neosho River	54.71	8,884	10,550	12,743	14,930	20,290
Tar Creek (at Miami)	1,856 ft upstream of confluence with Neosho River	54.51	8,866	10,530	12,720	14,904	20,255

Table 9: Summary of Discharges, continued

Flooding Source	Location	Drainage Area (Square Miles)	Peak Discharge (cfs)				
			10% Annual Chance	4% Annual Chance	2% Annual Chance	1% Annual Chance	0.2% Annual Chance
Tar Creek (at Miami)	3,949 ft upstream of confluence with Neosho River	54.34	8,851	10,513	12,702	14,882	20,226
Tar Creek (at Miami)	4,885 ft upstream of confluence with Neosho River	53.84	8,807	10,465	12,646	14,818	20,141
Tar Creek (at Miami)	5,947 ft downstream of confluence with Quail Creek	53.8	8,804	10,461	12,641	14,813	20,134
Tar Creek (at Miami)	4,914 ft downstream of confluence with Quail Creek	53.61	8,788	10,443	12,621	14,789	20,103
Tar Creek (at Miami)	4,603 ft downstream of confluence with Quail Creek	53.23	8,754	10,405	12,578	14,740	20,037
Tar Creek (at Miami)	3,300 ft downstream of confluence with Quail Creek	53.1	8,742	10,392	12,563	14,723	20,015
Tar Creek (at Miami)	3,057 ft downstream of confluence with Quail Creek	52.91	8,726	10,374	12,542	14,699	19,983
Tar Creek (at Miami)	1,685 ft downstream of confluence with Quail Creek	52.66	8,704	10,349	12,514	14,667	19,940
Tar Creek (at Miami)	968 ft downstream of confluence with Quail Creek	52.43	8,683	10,327	12,488	14,637	19,900

Table 9: Summary of Discharges, continued

Flooding Source	Location	Drainage Area (Square Miles)	Peak Discharge (cfs)				
			10% Annual Chance	4% Annual Chance	2% Annual Chance	1% Annual Chance	0.2% Annual Chance
Tar Creek (at Miami)	359 ft downstream of confluence with Quail Creek	52.27	8,669	10,310	12,469	14,615	19,872
Tar Creek (at Miami)	108 ft upstream of confluence with Quail Creek	49.68	8,435	10,050	12,172	14,274	19,417
Tar Creek (at Miami)	1,452 ft upstream of confluence with Quail Creek	49.14	8,386	9,995	12,110	14,202	19,322
Tar Creek (at Miami)	2,052 ft downstream of confluence with Belmont Creek	49.13	8,385	9,994	12,109	14,201	19,320
Tar Creek (at Miami)	1,013 ft downstream of confluence with Belmont Creek	49.01	8,374	9,982	12,094	14,185	19,298
Tar Creek (at Miami)	387 ft downstream of confluence with Belmont Run	48.84	8,359	9,965	12,075	14,162	19,269
Tar Creek (at Miami)	5 ft upstream of confluence with Belmont Run	46.35	8,127	9,705	11,778	13,821	18,814
Tar Creek (at Miami)	1,348 ft upstream of confluence with Belmont Run	46.27	8,120	9,697	11,769	13,810	18,800
Tar Creek (at Miami)	2,839 ft upstream of confluence with Belmont Run	46.08	8,102	9,677	11,745	16,784	18,765

Table 9: Summary of Discharges, continued

Flooding Source	Location	Drainage Area (Square Miles)	Peak Discharge (cfs)				
			10% Annual Chance	4% Annual Chance	2% Annual Chance	1% Annual Chance	0.2% Annual Chance
Tar Creek (at Miami)	3,686 ft upstream of confluence with Belmont Run	46.07	8,100	9,675	11,744	13,781	18,762
Tar Creek (at Miami)	3,910 ft upstream of confluence with Belmont Run	45.61	8,057	9,627	11,688	13,717	18,676
Tar Creek (at Miami)	7,131 ft downstream of confluence with Garrett Creek	45.37	8,034	9,601	11,659	13,684	18,632
Tar Creek (at Miami)	3,754 ft downstream of confluence with Garrett Creek	44.54	7,955	9,513	11,558	13,568	18,477
Tar Creek (at Miami)	2,706 ft downstream of confluence with Garrett Creek	43.12	7,817	9,359	11,380	13,364	18,205
Tar Creek (at Miami)	600 ft upstream of confluence with Garrett Creek	39.03	7,410	8,901	10,855	12,759	17,398
Tar Creek (at Miami)	2,592 ft upstream of confluence with Garrett Creek	38.8	7,387	8,875	10,825	12,724	17,352
Tar Creek (at Miami)	1,817 ft downstream of confluence with Tar Creek Tributary 1	38.77	7,383	8,871	10,820	12,719	17,345
Tar Creek (at Miami)	53 ft upstream of confluence with Tar Creek Tributary 1	37.27	7,229	8,697	10,619	12,488	17,037

Table 9: Summary of Discharges, continued

Flooding Source	Location	Drainage Area (Square Miles)	Peak Discharge (cfs)				
			10% Annual Chance	4% Annual Chance	2% Annual Chance	1% Annual Chance	0.2% Annual Chance
Tar Creek (at Miami)	61 ft upstream of confluence with Tar Creek Tributary 2	35.91	7,086	8,536	10,434	12,274	16,751
Tar Creek (at Miami)	1,942 ft upstream of confluence with Tar Creek Tributary 2	35.7	7,063	8,510	10,404	12,240	16,706
Tar Creek (at Miami)	73 ft upstream of confluence with Tar Creek Tributary 3	29.49	6,374	7,730	9,501	11,198	15,314
Tar Creek (at Miami)	85 ft upstream of confluence with Lytle Creek	16.83	4,715	5,828	7,278	8,625	11,862
Tar Creek (at Miami)	39 ft upstream of confluence with Tar Creek Tributary 4	16.04	4,595	5,689	7,114	8,434	11,605
Tar Creek (at Miami)	1,427 ft upstream of confluence with Tar Creek Tributary 4	15.12	4,452	5,524	6,919	8,207	11,300
Tar Creek (at Miami)	65 ft upstream of confluence with Tar Creek Tributary 5	14.3	4,320	5,370	6,737	7,996	11,015
Tar Creek (at Miami)	1,740 ft upstream of confluence with Tar Creek Tributary 5	13.93	4,261	5,301	6,655	7,900	10,887
Tar Creek (at Miami)	1,178 ft downstream of confluence with Tar Creek Tributary 6	13.24	4,145	5,166	6,494	7,714	10,635

Table 9: Summary of Discharges, continued

Flooding Source	Location	Drainage Area (Square Miles)	Peak Discharge (cfs)				
			10% Annual Chance	4% Annual Chance	2% Annual Chance	1% Annual Chance	0.2% Annual Chance
Warren Branch	Approximately 20,000 feet above its confluence with Spring River	18.86	4,830	*	9,100	11,330	17,900
Wyandotte Ditch	At confluence with Grand Lake O' The Cherokees	0.50	553	854	1,033	1,650	1,957

Figure 7: Frequency Discharge-Drainage Area Curves

[Not Applicable to this Flood Risk Project]

Table 10: Summary of Non-Coastal Stillwater Elevations

		Elevations (feet NAVD88)				
Flooding Source	Location	10% Annual Chance	4% Annual Chance	2% Annual Chance	1% Annual Chance	0.2% Annual Chance
Grand Lake O' The Cherokees	Ottawa County, Unincorporated Areas Wyandotte, Town of	755.6	756.3	756.4	756.5	756.7

Table 11: Stream Gage Information used to Determine Discharges

Flooding Source	Gage Identifier	Agency that Maintains Gage	Site Name	Drainage Area (Square Miles)	Period of Record	
					From	To
Neosho River	07185000	USGS	Neosho River near Commerce, OK	5,926	01/06/1904	05/02/2012
Neosho River[1]	07189500	USGS	Neosho River near Grove, OK	9,969	10/01/1924	09/30/1939

[1]Prior to dam construction and used only for flow verifications

5.2 Hydraulic Analyses

Analyses of the hydraulic characteristics of flooding from the sources studied were carried out to provide estimates of the elevations of floods of the selected recurrence intervals. Base flood elevations on the FIRM represent the elevations shown on the Flood Profiles and in the Floodway Data tables in the FIS Report. Rounded whole-foot elevations may be shown on the FIRM in coastal areas, areas of ponding, and other areas with static base flood elevations. These whole-foot elevations may not exactly reflect the elevations derived from the hydraulic analyses. Flood elevations shown on the FIRM are primarily intended for flood insurance rating purposes. For construction and/or floodplain management purposes, users are cautioned to use the flood elevation data presented in this FIS Report in conjunction with the data shown on the FIRM.

For streams for which hydraulic analyses were based on cross sections, locations of selected cross sections are shown on the Flood Profiles (Exhibit 1). For stream segments for which a floodway was computed (Section 6.3), selected cross sections are also listed in Table 23, "Floodway Data."

A summary of the methods used in hydraulic analyses performed for this project is provided in Table 12. Roughness coefficients are provided in Table 13. Roughness coefficients are values representing the frictional resistance water experiences when passing overland or through a channel. They are used in the calculations to determine water surface elevations. Greater detail (including assumptions, analysis, and results) is available in the archived project documentation.

Table 12: Summary of Hydrologic and Hydraulic Analyses

Flooding Source	Study Limits Downstream Limit	Study Limits Upstream Limit	Hydrologic Model or Method Used	Hydraulic Model or Method Used	Date Analyses Completed	Flood Zone on FIRM	Special Considerations
Bee Creek and Zone A tributaries	N/A	N/A	USGS Gage Analyses/ Regression Equations	HEC-RAS Version 4.1	2016	A	
Belmont Run	At confluence with Tar Creek (at Miami)	Just downstream of U.S. Highway 60	Regression Equations	HEC-RAS Version 4.1	2016	AE w/ Floodway	
Coal Creek and Zone A tributaries	N/A	N/A	USGS Gage Analyses/ Regression Equations	HEC-RAS Version 4.1	2016	A	
Council Hollow Creek and Zone A tributaries	N/A	N/A	USGS Gage Analyses/ Regression Equations	HEC-RAS Version 4.1	2016	A	
Cow Creek	At confluence with Neosho River	Ottawa county line	USGS Gage Analyses/ Regression Equations	HEC-RAS Version 4.1	2016	A	
Elm Creek and Zone A tributaries	N/A	N/A	USGS Gage Analyses/ Regression Equations	HEC-RAS Version 4.1	2016	A	
Fairgrounds Branch	At confluence with the Neosho River	Approximately 2.7 miles upstream of confluence with Neosho River	Regression Equations	HEC-RAS Version 4.1	2016	AE w/ Floodway	

Table 12: Summary of Hydrologic and Hydraulic Analyses, continued

Flooding Source	Study Limits Downstream Limit	Study Limits Upstream Limit	Hydrologic Model or Method Used	Hydraulic Model or Method Used	Date Analyses Completed	Flood Zone on FIRM	Special Considerations
Garrett Creek and Zone A tributaries	N/A	N/A	USGS Gage Analyses/ Regression Equations	HEC-RAS Version 4.1	2016	A	
Grand Lake O' The Cherokees	N/A	N/A	USGS Gage Analyses/ Regression Equations	HEC-RAS Version 4.1	2016	AE	
Grand Lake Tributary 2 and Zone A tributaries	N/A	N/A	USGS Gage Analyses/ Regression Equations	HEC-RAS Version 4.1	2016	A	
Hickory Creek and Zone A tributaries	N/A	N/A	USGS Gage Analyses/ Regression Equations	HEC-RAS Version 4.1	2016	A	
Horse Creek	Approximately 0.36 mile upstream of confluence of Horse Creek Tributary 1	Approximately 0.2 mile downstream of confluence with Horse Creek Tributary 5	Regression Equations	HEC-RAS Version 4.1	2016	AE	
Horse Creek Tributary 3	At confluence with Horse Creek	Approximately 1.08 miles upstream of confluence with Horse Creek Tributary 3-2	Regression Equations	HEC-RAS Version 4.1	2016	AE	

Table 12: Summary of Hydrologic and Hydraulic Analyses, continued

Flooding Source	Study Limits Downstream Limit	Study Limits Upstream Limit	Hydrologic Model or Method Used	Hydraulic Model or Method Used	Date Analyses Completed	Flood Zone on FIRM	Special Considerations
Horse Creek Tributary 3-1	At confluence with Horse Creek Tributary 3	Approximately 0.9 mile upstream of confluence with Horse Creek Tributary 3	Regression Equations	HEC-RAS Version 4.1	2016	AE	
Horse Creek Tributary 3-2	At confluence with Horse Creek Tributary 3	Approximately 1,700 feet upstream from South Main Avenue	Regression Equations	HEC-RAS Version 4.1	2016	AE	
Horse Creek Tributary 3-2-1	At confluence with Horse Creek Tributary 3-2	Approximately 2.12 miles upstream of confluence with Horse Creek Tributary 3-2	Regression Equations	HEC-RAS Version 4.1	2016	AE	
Hudson Creek and Zone A tributaries	N/A	N/A	USGS Gage Analyses/ Regression Equations	HEC-RAS Version 4.1	2016	A	
Little Elm Creek and Zone A Tributaries	N/A	N/A	USGS Gage Analyses/ Regression Equations	HEC-RAS Version 4.1	2016	A	
Little Elm Creek	At confluence with the Neosho River	At confluence with Little Elm Creek Tributary 2	Various	HEC-2	2008	AE	Redelineated in 2015

Table 12: Summary of Hydrologic and Hydraulic Analyses, continued

Flooding Source	Study Limits Downstream Limit	Study Limits Upstream Limit	Hydrologic Model or Method Used	Hydraulic Model or Method Used	Date Analyses Completed	Flood Zone on FIRM	Special Considerations
Little Horse Creek and Zone A tributaries	N/A	N/A	USGS Gage Analyses/ Regression Equations	HEC-RAS Version 4.1	2016	A	
Lost Creek and Zone A tributaries	N/A	N/A	USGS Gage Analyses/ Regression Equations	HEC-RAS Version 4.1	2016	A	
Lost Creek (at Wyandotte)	At confluence with Grand Lake O' The Cherokees	Approximately 1.0 miles upstream of confluence with Lost Creek Tributary 2	Various	HEC-RAS Version 4.1	2016	AE w/ Floodway	
Lost Creek (Upper Reach)	Approximately 6.9 miles upstream of confluence with Lost Creek Tributary 2	Approximately 8.2 miles upstream of confluence with Lost Creek Tributary 2	COE HEC-1	HEC-2	2008	AE w/ Floodway	Redelineated in 2015
Lytle Creek and Zone A tributaries	N/A	N/A	USGS Gage Analyses/ Regression Equations	HEC-RAS Version 4.1	2016	A	
Mud Creek	At confluence with Neosho River	Ottawa county line	USGS Gage Analyses/ Regression Equations	HEC-RAS Version 4.1	2016	A	
Neosho River	Approximately 1,000 feet upstream of US Highway 60	Approximately 1,400 upstream of E 60 Road	USGS Gage Analysis	HEC_RAS Version 4.1	2016	AE w/ Floodway	Only portion with floodway

Table 12: Summary of Hydrologic and Hydraulic Analyses, continued

Flooding Source	Study Limits Downstream Limit	Study Limits Upstream Limit	Hydrologic Model or Method Used	Hydraulic Model or Method Used	Date Analyses Completed	Flood Zone on FIRM	Special Considerations
Neosho River	Ottawa County line	Approximately 1,000 feet upstream of US Highway 60	Regression Equations	HEC-RAS Version 4.1	2016	AE	Limited Detail Study
Neosho River and Zone A tributaries	N/A	N/A	USGS Gage Analyses/ Regression Equations	HEC-RAS Version 4.1	2016	A	
Ogeechee Creek and Zone A tributaries	N/A	N/A	USGS Gage Analyses/ Regression Equations	HEC-RAS Version 4.1	2016	A	
Quail Creek and Zone A tributaries	N/A	N/A	USGS Gage Analyses/ Regression Equations	HEC-RAS Version 4.1	2016	A	
Quail Creek	At confluence with Tar Creek (at Miami)	At confluence with Quail Creek Tributary 1	Regression Equations	HEC-RAS Version 4.1	2016	AE w/ Floodway	
Tar Creek and Zone A tributaries	N/A	N/A	USGS Gage Analyses/ Regression Equations	HEC-RAS Version 4.1	2016	A	
Tar Creek (at Miami)	At confluence with Neosho River	Approximately 0.3 miles of upstream of confluence with Tar Creek Tributary 2	Effective Study/Curve Fitting	HEC-RAS Version 4.1	2016	AE w/ Floodway	

Table 12: Summary of Hydrologic and Hydraulic Analyses, continued

Flooding Source	Study Limits Downstream Limit	Study Limits Upstream Limit	Hydrologic Model or Method Used	Hydraulic Model or Method Used	Date Analyses Completed	Flood Zone on FIRM	Special Considerations
Unnamed Creek 1 and Zone A tributaries	N/A	N/A	USGS Gage Analyses/ Regression Equations	HEC-RAS Version 4.1	2016	A	
Unnamed Creek 2	N/A	N/A	USGS Gage Analyses/ Regression Equations	HEC-RAS Version 4.1	2016	A	
Warren Branch	Approximately 0.32 mile downstream of the downstream Town of Peoria corporate limits	Approximately 0.58 mile upstream of the upstream Town of Peoria corporate Limits	USACE HEC-1	USACE HEC-2	1986	AE w/ Floodway	
Windy Creek	At confluence with Cow Creek	Ottawa county line	USGS Gage Analyses/ Regression Equations	HEC-RAS Version 4.1	2016	A	
Wyandotte Ditch	Approximately 3,300 feet upstream of the confluence with Lost Creek	Approximately 950 feet upstream of S 650 Road	Various	HEC-RAS Version 4.1	2016	AE	

Table 13: Roughness Coefficients

Flooding Source	Channel "n"	Overbank "n"
Belmont Run	0.05 – 0.06	0.05 – 0.13
Fairground Branch	0.05 – 0.055	0.06 – 0.13
Grand Lake O' The Cherokees	0.035	0.06 – 0.12
Horse Creek	0.045	0.06 – 0.12
Horse Creek Tributary 3	0.045	0.06 – 0.12
Horse Creek Tributary 3-1	0.04	0.06 – 0.12
Horse Creek Tributary 3-2	0.04	0.06 – 0.12
Horse Creek Tributary 3-2-1	0.04 – 0.045	0.06 – 0.12
Little Elm Creek (within the City of Miami)	0.035 – 0.095[1]	0.045 – 0.095
Little Elm Creek (all other reaches)	0.035 – 0.045	0.08 – 0.12
Lost Creek (at Wyandotte)	0.04 – 0.05	0.06 – 0.13
Lost Creek (Upper Reach)	0.045 - 0.050	0.08 – 0.12
Neosho River	0.02 - 0.055	0.04 – 0.15
Quail Creek	0.04 – 0.05	0.06 – 0.13
Tar Creek (at Miami)	0.045 – 0.05	0.05 – 0.13
Warren Branch	0.050 – 0.075	0.06 – 0.10
Wyandotte Ditch	0.040	0.065 – 0.070

[1]Through culverts, values were reduced to 0.018-0.024

5.3 Coastal Analyses

This section is not applicable to this flood risk project.

Table 14: Summary of Coastal Analyses

[Not Applicable to this Flood Risk Project]

5.3.1 Total Stillwater Elevations

This section is not applicable to this flood risk project.

Figure 8: 1% Annual Chance Total Stillwater Elevations for Coastal Areas

[Not Applicable to this Flood Risk Project]

Table 15: Tide Gage Analysis Specifics

[Not Applicable to this Flood Risk Project]

5.3.2 Waves

This section is not applicable to this flood risk project.

5.3.3 Coastal Erosion

This section is not applicable to this flood risk project.

5.3.4 Wave Hazard Analyses

This section is not applicable to this flood risk project.

Figure 9: Transect Location Map

[Not Applicable to this Flood Risk Project]

5.4 Alluvial Fan Analyses

This section is not applicable to this flood risk project.

Table 16: Coastal Transect Parameters

[Not Applicable to this Flood Risk Project]

Table 17: Summary of Alluvial Fan Analyses

[Not Applicable to this Flood Risk Project]

Table 18: Results of Alluvial Fan Analyses

[Not Applicable to this Flood Risk Project]

SECTION 6.0 – MAPPING METHODS

6.1 Vertical and Horizontal Control

All FIS Reports and FIRMs are referenced to a specific vertical datum. The vertical datum provides a starting point against which flood, ground, and structure elevations can be referenced and compared. Until recently, the standard vertical datum used for newly created or revised FIS Reports and FIRMs was the National Geodetic Vertical Datum of 1929 (NGVD29). With the completion of the North American Vertical Datum of 1988 (NAVD88), many FIS Reports and FIRMs are now prepared using NAVD88 as the referenced vertical datum.

Flood elevations shown in this FIS Report and on the FIRMs are referenced to NAVD88. These flood elevations must be compared to structure and ground elevations referenced to the same vertical datum. For information regarding conversion between NGVD29 and NAVD88 or other datum conversion, visit the National Geodetic Survey website at www.ngs.noaa.gov.

Temporary vertical monuments are often established during the preparation of a flood hazard analysis for the purpose of establishing local vertical control. Although these monuments are not shown on the FIRM, they may be found in the archived project documentation associated with the FIS Report and the FIRMs for this community. Interested individuals may contact FEMA to access these data.

To obtain current elevation, description, and/or location information for benchmarks in the area, please visit the NGS website at www.ngs.noaa.gov.

The countywide conversion factor of +0.353 feet was calculated for Ottawa County.

Table 19: Countywide Vertical Datum Conversion

[Not Applicable to this Flood Risk Project]

Table 20: Stream-Based Vertical Datum Conversion

[Not Applicable to this Flood Risk Project]

6.2 Base Map

The FIRMs and FIS Report for this project have been produced in a digital format. The flood hazard information was converted to a Geographic Information System (GIS) format that meets FEMA's FIRM Database specifications and geographic information standards. This information is provided in a digital format so that it can be incorporated into a local GIS and be accessed more easily by the community. The FIRM Database includes most of the tabular information contained in the FIS Report in such a way that the data can be associated with pertinent spatial features. For example, the information contained in the Floodway Data table and Flood Profiles can be linked to the cross sections that are shown on the FIRMs. Additional information about the FIRM Database and its contents can be found in FEMA's *Guidelines and Standards for Flood Risk Analysis and Mapping*, www.fema.gov/guidelines-and-standards-flood-risk-analysis-and-mapping.

Base map information shown on the FIRM was derived from the sources described in Table 21.

Table 21: Base Map Sources

Data Type	Data Provider	Data Date	Data Scale	Data Description
Digital Orthoimagery	USDA/FSA	2015	1:12,000	NAIP 2015 Color orthoimagery
Political Boundaries	Wyandotte Nation	2009	1:24,000	Community boundaries
Public Land Survey System (PLSS)	Bureau of Land Management	2006	1:24,000	PLSS quadrangles
Surface Water Features	United States Geological Survey	2005	1:24,000	Streams, rivers, and lakes were derived from NHD data
Transportation Features	U.S. Census Bureau	2016	1:24,000	Ottawa County roads and railroads from TIGER/Line Shapefile.

6.3 Floodplain and Floodway Delineation

The FIRM shows tints, screens, and symbols to indicate floodplains and floodways as well as the locations of selected cross sections used in the hydraulic analyses and floodway computations.

For riverine flooding sources, the mapped floodplain boundaries shown on the FIRM have been delineated using the flood elevations determined at each cross section; between cross sections, the boundaries were interpolated using the topographic elevation data described in Table 22.

In cases where the 1% and 0.2% annual chance floodplain boundaries are close together, only the 1% annual chance floodplain boundary has been shown. Small areas within the floodplain boundaries may lie above the flood elevations but cannot be shown due to limitations of the map scale and/or lack of detailed topographic data.

The floodway widths presented in this FIS Report and on the FIRM were computed for certain stream segments on the basis of equal conveyance reduction from each side of the floodplain. Floodway widths were computed at cross sections. Between cross sections, the floodway boundaries were interpolated. Table 2 indicates the flooding sources for which floodways have been determined. The results of the floodway computations for those flooding sources have been tabulated for selected cross sections and are shown in Table 23, "Floodway Data."

Table 22: Summary of Topographic Elevation Data used in Mapping

Community	Flooding Source	Source for Topographic Elevation Data			
		Description	Vertical Accuracy	Horizontal Accuracy	Citation
Afton, Town of	All within 11070206	Light Detection and Ranging data (LiDAR)	0.06 meter RMSEz	2 centimeters at 95% confidence level	RAMPP, 2013
Commerce, City of	All within 11070206	Light Detection and Ranging data (LiDAR)	0.06 meter RMSEz	2 centimeters at 95% confidence level	RAMPP, 2013
Fairland, Town of	All within 11070206	Light Detection and Ranging data (LiDAR)	0.06 meter RMSEz	2 centimeters at 95% confidence level	RAMPP, 2013
Miami, City of	All within 11070206	Light Detection and Ranging data (LiDAR)	0.06 meter RMSEz	2 centimeters at 95% confidence level	RAMPP, 2013
North Miami, Town of	All within 11070206	Light Detection and Ranging data (LiDAR)	0.06 meter RMSEz	2 centimeters at 95% confidence level	RAMPP, 2013
Ottawa County, Unincorporated Areas	All within 11070206	Light Detection and Ranging data (LiDAR)	0.06 meter RMSEz	2 centimeters at 95% confidence level	RAMPP, 2013
Peoria, Town of	Warren Branch	Topographic Maps	10 Ft	1:24,000	USGS 1961
Quapaw, Town of	All within 11070206	Light Detection and Ranging data (LiDAR)	0.06 meter RMSEz	2 centimeters at 95% confidence level	RAMPP, 2013
Wyandotte, Town of	All within 11070206	Light Detection and Ranging data (LiDAR)	0.06 meter RMSEz	2 centimeters at 95% confidence level	RAMPP, 2013
Wyandotte Nation	All within 11070206	Light Detection and Ranging data (LiDAR)	0.06 meter RMSEz	2 centimeters at 95% confidence level	RAMPP, 2013

BFEs shown at cross sections on the FIRM represent the 1% annual chance water surface elevations shown on the Flood Profiles and in the Floodway Data tables in the FIS Report.

Table 23: Floodway Data

LOCATION		FLOODWAY			1% ANNUAL CHANCE FLOOD WATER SURFACE ELEVATION (FEET NAVD88)			
CROSS SECTION	DISTANCE[1]	WIDTH (FEET)	SECTION AREA (SQ. FEET)	MEAN VELOCITY (FEET/ SEC)	REGULATORY	WITHOUT FLOODWAY	WITH FLOODWAY	INCREASE
A	1,705	189	658	3.1	778.8	776.8[2]	777.6	0.8
B	2,455	166	601	3.3	781.5	781.5	782.2	0.7
C	3,081	184	880	2.2	782.6	782.6	783.5	0.9
D	3,653	282	1,402	1.2	783.3	783.3	784.3	1.0
E	4,147	281	1,017	1.6	783.9	783.9	784.6	0.7
F	4,777	408	1,380	1.2	784.8	784.8	785.2	0.4
G	5,624	127	471	3.5	786.2	786.2	786.3	0.1
H	7,172	247	1,030	1.5	791.1	791.1	792.1	1.0
I	7,588	356	1,437	1.1	791.5	791.5	792.5	1.0
J	8,159	286	672	2.0	792.5	792.5	793.0	0.5
K	8,627	267	518	2.6	793.7	793.7	794.0	0.3
L	9,133	641	1,485	0.9	794.6	794.6	795.0	0.4
M	10,625	181	1,026	1.3	797.5	797.5	798.2	0.7
N	11,830	132	920	1.4	799.4	799.4	799.9	0.5
O	12,143	156	968	1.3	799.6	799.6	800.1	0.5
P	13,267	86	581	1.8	800.5	800.5	800.9	0.4

[1]Feet above confluence with Tar Creek (at Miami)

[2]Elevation computed without consideration of backwater effects

TABLE 23

FEDERAL EMERGENCY MANAGEMENT AGENCY

OTTAWA COUNTY, OKLAHOMA

AND INCORPORATED AREAS

FLOODWAY DATA

FLOODING SOURCE: BELMONT RUN

LOCATION		FLOODWAY			1% ANNUAL CHANCE FLOOD WATER SURFACE ELEVATION (FEET NAVD88)			
CROSS SECTION	DISTANCE[1]	WIDTH (FEET)	SECTION AREA (SQ. FEET)	MEAN VELOCITY (FEET/SEC)	REGULATORY	WITHOUT FLOODWAY	WITH FLOODWAY	INCREASE
Q	13,663	97	625	1.6	800.8	800.8	801.3	0.5
R	14,056	102	642	1.6	801.0	801.0	801.7	0.7
S	14,571	127	687	1.5	801.3	801.3	802.1	0.8
T	15,653	140	767	1.1	803.4	803.4	804.3	0.9
U	16,221	114	531	1.6	803.9	803.9	804.6	0.7
V	16,694	128	559	1.6	804.5	804.5	805.2	0.7
W	17,136	97	389	2.2	805.2	805.2	806.1	0.9
X	17,679	86	392	2.2	806.9	806.9	807.8	0.9
Y	18,200	117	479	1.8	807.9	807.9	808.8	0.9
Z	18,716	50	142	6.2	809.3	809.3	810.0	0.7

[1]Feet above confluence with Tar Creek (at Miami)

TABLE 23

FEDERAL EMERGENCY MANAGEMENT AGENCY

OTTAWA COUNTY, OKLAHOMA

AND INCORPORATED AREAS

FLOODWAY DATA

FLOODING SOURCE: BELMONT RUN

LOCATION		FLOODWAY			1% ANNUAL CHANCE FLOOD WATER SURFACE ELEVATION (FEET NAVD88)			
CROSS SECTION	DISTANCE[1]	WIDTH (FEET)	SECTION AREA (SQ. FEET)	MEAN VELOCITY (FEET/SEC)	REGULATORY	WITHOUT FLOODWAY	WITH FLOODWAY	INCREASE
A	6,214	149	635	3.0	779.5	770.1[2]	770.4	0.3
B	6,824	158	606	3.1	779.5	772.9[2]	773.2	0.3
C	7,665	231	824	2.1	779.5	776.1[2]	776.5	0.4
D	8,835	175	447	3.9	780.4	780.4	781.1	0.7
E	9,811	164	508	2.4	785.8	785.8	786.7	0.9
F	10,239	97	376	3.3	789.0	789.0	789.8	0.8
G - P[3]								

[1]Feet above confluence with Neosho River
[2]Elevation computed without consideration of backwater effects
[3]Floodway not computed

TABLE 23

FEDERAL EMERGENCY MANAGEMENT AGENCY

OTTAWA COUNTY, OKLAHOMA

AND INCORPORATED AREAS

FLOODWAY DATA

FLOODING SOURCE: FAIRGROUNDS BRANCH

LOCATION		FLOODWAY			1% ANNUAL CHANCE FLOOD WATER SURFACE ELEVATION (FEET NAVD88)			
CROSS SECTION	DISTANCE[1]	WIDTH (FEET)	SECTION AREA (SQ. FEET)	MEAN VELOCITY (FEET/SEC)	REGULATORY	WITHOUT FLOODWAY	WITH FLOODWAY	INCREASE
A	3,053	320	3,126	2.8	777.4	755.3[2]	756.2	0.9
B	4,343	258	1,978	4.4	777.4	757.2[2]	758.1	0.9
C	5,668	349	2,001	4.4	777.4	761.7[2]	762.7	1.0
D	6,250	276	1,830	4.8	777.4	764.0[2]	765.0	1.0
E	7,340	393	2,795	3.1	777.4	766.9[2]	767.8	0.9
F	7,808	261	1,522	5.7	777.4	769.3[2]	770.0	0.7
G	9,478	650	3,354	2.6	777.4	774.2[2]	775.2	1.0
H	10,319	373	2,059	4.2	777.4	775.7[2]	775.7	0.9
I	11,280	573	3,132	2.8	778.0	778.0	778.9	0.9
J	12,362	466	2,351	3.7	780.4	780.4	781.2	0.8
K	14,842	494	2,864	3.8	785.2	785.2	786.2	1.0
L	15,718	514	3,829	2.3	786.1	786.1	787.1	1.0
M	16,100	501	3,273	2.7	787.5	787.5	788.5	1.0
N	16,460	727	5,026	1.7	787.9	787.9	788.9	1.0
O	16,652	542	3,434	2.5	788.1	788.1	789.1	1.0
P	18,300	402	2,459	3.5	789.8	789.8	790.8	1.0

[1]Feet above confluence with Neosho River
[2]Elevation computed without consideration of backwater effects

TABLE 23	FEDERAL EMERGENCY MANAGEMENT AGENCY **OTTAWA COUNTY, OKLAHOMA** AND INCORPORATED AREAS	**FLOODWAY DATA** **FLOODING SOURCE: LITTLE ELM CREEK**

LOCATION		FLOODWAY			1% ANNUAL CHANCE FLOOD WATER SURFACE ELEVATION (FEET NAVD88)			
CROSS SECTION	DISTANCE[1]	WIDTH (FEET)	SECTION AREA (SQ. FEET)	MEAN VELOCITY (FEET/SEC)	REGULATORY	WITHOUT FLOODWAY	WITH FLOODWAY	INCREASE
A	4,432	948	9,832	2.8	758.4	754.7[2]	755.6	0.9
B	4,922	746	6,936	3.9	758.4	755.2[2]	755.9	0.7
C	5,561	417	4,801	5.7	758.4	756.2[2]	757.1	0.9
D	5,698	439	5,342	5.1	758.4	757.2[2]	757.9	0.7
E	6,099	1,141	12,810	2.1	758.7	758.7	759.4	0.7
F	6,659	1,640	16,340	1.7	758.9	758.9	759.7	0.8
G	6,928	1,950	17,577	1.5	759.0	759.0	759.9	0.9
H	7,564	1,950	15,762	1.7	759.4	759.4	760.3	0.9
I	8,864	1,750	12,951	2.1	759.9	759.9	760.7	0.8
J	9,337	1,480	10,311	2.6	760.6	760.6	761.5	0.9
K	9,855	1,219	7,017	3.8	761.1	761.1	762.0	0.9
L	10,393	1,153	7,593	3.5	762.2	762.2	763.1	0.9
M	10,849	1,128	7,967	3.3	763.1	763.1	763.9	0.8
N	11,165	1,053	7,946	3.3	764.1	764.1	764.8	0.7
O	12,005	1,110	8,446	3.1	765.1	765.1	765.9	0.8
P	12,499	1,073	7,715	3.4	765.8	765.8	766.6	0.8

[1]Feet above confluence with Neosho River

[2]Elevation computed without consideration of backwater effects

TABLE 23

FEDERAL EMERGENCY MANAGEMENT AGENCY

OTTAWA COUNTY, OKLAHOMA

AND INCORPORATED AREAS

FLOODWAY DATA

FLOODING SOURCE: LOST CREEK (AT WYANDOTTE)

LOCATION		FLOODWAY			1% ANNUAL CHANCE FLOOD WATER SURFACE ELEVATION (FEET NAVD88)			
CROSS SECTION	DISTANCE[1]	WIDTH (FEET)	SECTION AREA (SQ. FEET)	MEAN VELOCITY (FEET/SEC)	REGULATORY	WITHOUT FLOODWAY	WITH FLOODWAY	INCREASE
Q	12,878	994	7,239	3.7	766.4	766.4	767.2	0.8
R	13,403	963	6,699	4.0	767.4	767.4	768.0	0.6
S	13,854	697	5,441	4.9	768.8	768.8	769.2	0.4
T	14,310	501	4,552	5.8	770.8	770.8	771.6	0.8
U	14,829	266	3,271	8.1	772.3	772.3	773.2	0.9

[1]Feet above confluence with Neosho River

TABLE 23

FEDERAL EMERGENCY MANAGEMENT AGENCY

OTTAWA COUNTY, OKLAHOMA

AND INCORPORATED AREAS

FLOODWAY DATA

FLOODING SOURCE: LOST CREEK (AT WYANDOTTE)

LOCATION		FLOODWAY			1% ANNUAL CHANCE FLOOD WATER SURFACE ELEVATION (FEET NAVD88)			
CROSS SECTION	DISTANCE[1]	WIDTH (FEET)	SECTION AREA (SQ. FEET)	MEAN VELOCITY (FEET/SEC)	REGULATORY	WITHOUT FLOODWAY	WITH FLOODWAY	INCREASE
A	45,800	787	6,115	3.2	829.4	829.4	830.4	1.0
B	46,240	618	3,750	5.1	830.3	830.3	831.3	1.0
C	47,295	1,073	6,074	3.2	833.6	833.6	834.6	1.0
D	48,315	770	4,183	5.6	835.6	835.6	836.5	0.9
E	48,705	605	3,823	5.1	836.7	836.7	837.7	1.0
F	49,065	353	2,237	8.6	838.5	838.5	838.7	0.2
G	49,755	410	2,661	7.3	841.9	841.9	842.2	0.3
H	49,970	407	3,104	6.2	843.5	843.5	844.4	0.9
I	50,465	730	6,421	3.0	845.5	845.5	846.1	0.6
J	50,900	803	8,395	2.3	845.9	845.9	846.5	0.6
K	51,800	850	7,120	2.7	846.4	846.4	847.2	0.8
L	52,845	850	7,127	2.7	847.6	847.6	848.6	1.0
M	52,890	850	6,880	2.8	847.6	847.6	848.6	1.0

[1]Feet above confluence with Grand Lake O' The Cherokees

TABLE 23

FEDERAL EMERGENCY MANAGEMENT AGENCY

OTTAWA COUNTY, OKLAHOMA

AND INCORPORATED AREAS

FLOODWAY DATA

FLOODING SOURCE: LOST CREEK (UPPER REACH)

LOCATION		FLOODWAY			1% ANNUAL CHANCE FLOOD WATER SURFACE ELEVATION (FEET NAVD88)			
CROSS SECTION	DISTANCE[1]	WIDTH (FEET)	SECTION AREA (SQ. FEET)	MEAN VELOCITY (FEET/ SEC)	REGULATORY	WITHOUT FLOODWAY	WITH FLOODWAY	INCREASE
A - L[2]								
M	284,443	3,700	74,848	1.9	776.9	776.9	776.9	0.0
N	293,841	3,600	76,820	1.9	778.9	778.9	779.4	0.5
O	298,512	4,029	85,698	1.7	779.5	779.5	780.5	1.0
P	300,747	5,165	92,095	1.6	779.9	779.9	780.9	1.0
Q	310,110	13,550	281,551	0.5	780.4	780.4	781.4	1.0
R	314,238	16,000	368,018	0.4	780.5	780.5	781.5	1.0
S - X[2]								

[1]Feet above Pensacola Dam

[2]Floodway not computed

TABLE 23

FEDERAL EMERGENCY MANAGEMENT AGENCY

OTTAWA COUNTY, OKLAHOMA

AND INCORPORATED AREAS

FLOODWAY DATA

FLOODING SOURCE: NEOSHO RIVER

LOCATION		FLOODWAY			1% ANNUAL CHANCE FLOOD WATER SURFACE ELEVATION (FEET NAVD88)			
CROSS SECTION	DISTANCE[1]	WIDTH (FEET)	SECTION AREA (SQ. FEET)	MEAN VELOCITY (FEET/SEC)	REGULATORY	WITHOUT FLOODWAY	WITH FLOODWAY	INCREASE
A	4,337	250	1,142	2.5	778.8	778.0[2]	778.9	0.9
B – Q[3]								

[1]Feet above confluence with Tar Creek (at Miami)

[2]Elevation is computed without consideration of backwater effects

[3]Floodway is not computed

TABLE 23

FEDERAL EMERGENCY MANAGEMENT AGENCY

OTTAWA COUNTY, OKLAHOMA

AND INCORPORATED AREAS

FLOODWAY DATA

FLOODING SOURCE: QUAIL CREEK

LOCATION		FLOODWAY			1% ANNUAL CHANCE FLOOD WATER SURFACE ELEVATION (FEET NAVD88)			
CROSS SECTION	DISTANCE[1]	WIDTH (FEET)	SECTION AREA (SQ. FEET)	MEAN VELOCITY (FEET/SEC)	REGULATORY	WITHOUT FLOODWAY	WITH FLOODWAY	INCREASE
A	16,488	1,048	6,723	2.1	778.8	774.2[2]	775.2	1.0
B	18,840	1,314	8,415	1.6	778.8	777.6[2]	778.4	0.8
C	20,151	1,108	7,830	1.8	778.8	778.5[2]	779.3	0.8
D	21,760	1,107	7,468	1.8	780.7	780.7	781.4	0.7
E	22,672	1,485	7,875	1.7	781.5	781.5	782.1	0.6
F	24,295	1,583	9,018	1.5	782.5	782.5	783.2	0.7
G	26,488	1,748	9,091	1.5	783.8	783.8	784.7	0.9
H	28,040	1,375	7,314	1.8	784.8	784.8	785.5	0.7
I	29,452	1,365	7,060	1.9	786.2	786.2	786.9	0.7
J	30,833	1,228	7,245	1.8	787.7	787.7	788.5	0.8
K	31,828	1,121	6,593	1.9	788.9	788.9	789.6	0.7
L	33,639	1,005	5,906	2.2	790.6	790.6	791.4	0.8
M	34,912	565	3,728	3.4	791.7	791.7	792.4	0.7
N	35,842	1,024	7,849	1.6	793.0	793.0	793.7	0.7
O	36,724	1,483	10,468	1.2	793.4	793.4	794.1	0.7
P	37,806	913	6,365	2.0	793.8	793.8	794.4	0.6

[1]Feet above confluence with Neosho River

[2]Elevation computed without consideration of backwater effects

TABLE 23

FEDERAL EMERGENCY MANAGEMENT AGENCY

OTTAWA COUNTY, OKLAHOMA

AND INCORPORATED AREAS

FLOODWAY DATA

FLOODING SOURCE: TAR CREEK (AT MIAMI)

LOCATION		FLOODWAY			1% ANNUAL CHANCE FLOOD WATER SURFACE ELEVATION (FEET NAVD88)			
CROSS SECTION	DISTANCE[1]	WIDTH (FEET)	SECTION AREA (SQ. FEET)	MEAN VELOCITY (FEET/SEC)	REGULATORY	WITHOUT FLOODWAY	WITH FLOODWAY	INCREASE
Q	38,764	923	6,139	2.0	794.5	794.5	795.1	0.6
R	39,414	758	5,548	2.2	794.9	794.9	795.6	0.7
S	40,104	707	6,032	2.0	795.8	795.8	796.6	0.8

[1]Feet above confluence with Neosho River

TABLE 23

FEDERAL EMERGENCY MANAGEMENT AGENCY

OTTAWA COUNTY, OKLAHOMA

AND INCORPORATED AREAS

FLOODWAY DATA

FLOODING SOURCE: TAR CREEK (AT MIAMI)

LOCATION		FLOODWAY			1% ANNUAL CHANCE FLOOD WATER SURFACE ELEVATION (FEET NAVD88)			
CROSS SECTION	DISTANCE[1]	WIDTH (FEET)	SECTION AREA (SQ. FEET)	MEAN VELOCITY (FEET/SEC)	REGULATORY	WITHOUT FLOODWAY	WITH FLOODWAY	INCREASE
A	19,600	137	1,706	6.6	855.4	855.4	856.4	1.0
B	20,285	130	1,611	7.0	858.3	858.3	859.3	1.0
C	20,805	140	1,756	6.5	861.3	861.3	861.9	0.6
D	21,015	186	2,740	4.1	868.8	868.8	869.1	0.3
E	24,230	464	2,760	4.1	878.9	878.9	879.9	1.0
F	25,165	349	1,706	6.6	885.2	885.2	886.2	1.0
G	25,800	320	2,246	5.0	890.3	890.3	891.2	0.9
H	27,000	492	3,205	3.5	895.8	895.8	896.8	1.0

[1]Feet above confluence with Spring River

TABLE 23

FEDERAL EMERGENCY MANAGEMENT AGENCY

OTTAWA COUNTY, OKLAHOMA

AND INCORPORATED AREAS

FLOODWAY DATA

FLOODING SOURCE: WARREN BRANCH

Table 24: Flood Hazard and Non-Encroachment Data for Selected Streams

[Not Applicable to this Flood Risk Project]

6.4 Coastal Flood Hazard Mapping

This section is not applicable to this flood risk project.

Table 25: Summary of Coastal Transect Mapping Considerations

[Not Applicable to this Flood Risk Project]

6.5 FIRM Revisions

This FIS Report and the FIRM are based on the most up-to-date information available to FEMA at the time of its publication; however, flood hazard conditions change over time. Communities or private parties may request flood map revisions at any time. Certain types of requests require submission of supporting data. FEMA may also initiate a revision. Revisions may take several forms, including Letters of Map Amendment (LOMAs), Letters of Map Revision Based on Fill (LOMR-Fs), Letters of Map Revision (LOMRs) (referred to collectively as Letters of Map Change (LOMCs)), Physical Map Revisions (PMRs), and FEMA-contracted restudies. These types of revisions are further described below. Some of these types of revisions do not result in the republishing of the FIS Report. To assure that any user is aware of all revisions, it is advisable to contact the community repository of flood-hazard data (shown in Table 30, "Map Repositories").

6.5.1 Letters of Map Amendment

A LOMA is an official revision by letter to an effective NFIP map. A LOMA results from an administrative process that involves the review of scientific or technical data submitted by the owner or lessee of property who believes the property has incorrectly been included in a designated SFHA. A LOMA amends the currently effective FEMA map and establishes that a specific property is not located in a SFHA.

To obtain an application for a LOMA, visit www.fema.gov/floodplain-management/letter-map-amendment-loma and download the form "MT-1 Application Forms and Instructions for Conditional and Final Letters of Map Amendment and Letters of Map Revision Based on Fill". Visit the "Flood Map-Related Fees" section to determine the cost, if any, of applying for a LOMA.

FEMA offers a tutorial on how to apply for a LOMA. The LOMA Tutorial Series can be accessed at www.fema.gov/online-tutorials.

For more information about how to apply for a LOMA, call the FEMA Map Information eXchange; toll free, at 1-877-FEMA MAP (1-877-336-2627).

6.5.2 Letters of Map Revision Based on Fill

A LOMR-F is an official revision by letter to an effective NFIP map. A LOMR-F states FEMA's determination concerning whether a structure or parcel has been elevated on fill above the base flood elevation and is, therefore, excluded from the SFHA.

Information about obtaining an application for a LOMR-F can be obtained in the same manner as that for a LOMA, by visiting www.fema.gov/floodplain-management/letter-map-amendment-loma for the "MT-1 Application Forms and Instructions for Conditional and Final Letters of Map Amendment and Letters of Map Revision Based on Fill" or by calling the FEMA Map Information eXchange, toll free, at 1-877-FEMA MAP (1-877-336-2627). Fees for applying for a LOMR-F, if any, are listed in the "Flood Map-Related Fees" section.

A tutorial for LOMR-F is available at www.fema.gov/online-tutorials.

6.5.3 Letters of Map Revision

A LOMR is an official revision to the currently effective FEMA map. It is used to change flood zones, floodplain and floodway delineations, flood elevations and planimetric features. All requests for LOMRs should be made to FEMA through the chief executive officer of the community, since it is the community that must adopt any changes and revisions to the map. If the request for a LOMR is not submitted through the chief executive officer of the community, evidence must be submitted that the community has been notified of the request.

To obtain an application for a LOMR, visit www.fema.gov/national-flood-insurance-program-flood-hazard-mapping/mt-2-application-forms-and-instructions and download the form "MT-2 Application Forms and Instructions for Conditional Letters of Map Revision and Letters of Map Revision". Visit the "Flood Map-Related Fees" section to determine the cost of applying for a LOMR. For more information about how to apply for a LOMR, call the FEMA Map Information eXchange; toll free, at 1-877-FEMA MAP (1-877-336-2627) to speak to a Map Specialist.

Previously issued mappable LOMCs (including LOMRs) that have been incorporated into the Ottawa County FIRM are listed in Table 26.

Table 26: Incorporated Letters of Map Change

[Not Applicable to this Flood Risk Project]

6.5.4 Physical Map Revisions

A Physical Map Revisions (PMR) is an official republication of a community's NFIP map to effect changes to base flood elevations, floodplain boundary delineations, regulatory floodways and planimetric features. These changes typically occur as a result of structural works or improvements, annexations resulting in additional flood hazard areas or correction to base flood elevations or SFHAs.

The community's chief executive officer must submit scientific and technical data to FEMA to support the request for a PMR. The data will be analyzed and the map will be revised if warranted. The community is provided with copies of the revised information and is afforded a review period. When the base flood elevations are changed, a 90-day appeal period is provided. A 6-month adoption period for formal approval of the revised map(s) is also provided.

For more information about the PMR process, please visit www.fema.gov and visit the “Flood Map Revision Processes” section.

6.5.5 Contracted Restudies

The NFIP provides for a periodic review and restudy of flood hazards within a given community. FEMA accomplishes this through a national watershed-based mapping needs assessment strategy, known as the Coordinated Needs Management Strategy (CNMS). The CNMS is used by FEMA to assign priorities and allocate funding for new flood hazard analyses used to update the FIS Report and FIRM. The goal of CNMS is to define the validity of the engineering study data within a mapped inventory. The CNMS is used to track the assessment process, document engineering gaps and their resolution, and aid in prioritization for using flood risk as a key factor for areas identified for flood map updates. Visit www.fema.gov to learn more about the CNMS or contact the FEMA Regional Office listed in Section 8 of this FIS Report.

6.5.6 Community Map History

The current FIRM presents flooding information for the entire geographic area of Ottawa County. Previously, separate FIRMs, Flood Hazard Boundary Maps (FHBMs) and/or Flood Boundary and Floodway Maps (FBFMs) may have been prepared for the incorporated communities and the unincorporated areas in the county that had identified SFHAs. Current and historical data relating to the maps prepared for the project area are presented in Table 27, “Community Map History.” A description of each of the column headings and the source of the date is also listed below.

- *Community Name* includes communities falling within the geographic area shown on the FIRM, including those that fall on the boundary line, nonparticipating communities, and communities with maps that have been rescinded. Communities with No Special Flood Hazards are indicated by a footnote. If all maps (FHBM, FBFM, and FIRM) were rescinded for a community, it is not listed in this table unless SFHAs have been identified in this community.

- *Initial Identification Date (First NFIP Map Published)* is the date of the first NFIP map that identified flood hazards in the community. If the FHBM has been converted to a FIRM, the initial FHBM date is shown. If the community has never been mapped, the upcoming effective date or “pending” (for Preliminary FIS Reports) is shown. If the community is listed in Table 27 but not identified on the map, the community is treated as if it were unmapped.

- *Initial FHBM Effective Date* is the effective date of the first FHBM. This date may be the same date as the Initial NFIP Map Date.

- *FHBM Revision Date(s)* is the date(s) that the FHBM was revised, if applicable.

- *Initial FIRM Effective Date* is the date of the first effective FIRM for the community.

- *FIRM Revision Date(s)* is the date(s) the FIRM was revised, if applicable. This is the revised date that is shown on the FIRM panel, if applicable. As countywide studies are completed or revised, each community listed should have its FIRM dates updated accordingly to reflect the date of the countywide study. Once the FIRMs exist in countywide format, as PMRs of FIRM panels within the county are completed, the FIRM Revision Dates in the table for each community affected by the PMR are updated with the date of the PMR, even if the PMR did not revise all the panels within that community.

The initial effective date for the Ottawa County FIRMs in countywide format was 08/05/2010.

Table 27: Community Map History

Community Name	Initial Identification Date	Initial FHBM Effective Date	FHBM Revision Date(s)	Initial FIRM Effective Date	FIRM Revision Date(s)
Afton, Town of	02/07/1975	2/07/1975	None	01/03/1986	09/13/2019 08/05/2010
Commerce, City of	06/04/1976	06/04/1976	None	07/18/1985	09/13/2019 08/05/2010
Fairland, Town of	04/09/1976	04/09/1976	None	01/01/1992	09/13/2019 08/05/2010
Miami, City of	01/25/1974	01/25/1974	12/05/1975	12/16/1980	09/13/2019 08/05/2010 09/03/1997 09/30/1988 04/19/1983
North Miami, Town of[1]	04/09/1976	04/09/1976	None	08/05/2010	09/13/2019
Ottawa County, Unincorporated Areas	05/20/1977	05/20/1977	None	12/02/1988	09/13/2019 08/05/2010 12/19/1997
Peoria, Town of	11/22/1974	11/22/1974	None	08/05/2010	N/A
Quapaw, Town of	08/13/1976	08/13/1976	None	08/05/2010	09/13/2019
Wyandotte, Town of	06/28/1974	06/28/1974	12/10/1976 12/12/1975	12/17/1987	09/13/2019 08/05/2010 12/19/1997

Community Name	Initial Identification Date	Initial FHBM Effective Date	FHBM Revision Date(s)	Initial FIRM Effective Date	FIRM Revision Date(s)
Wyandotte Nation[2]	5/20/1977	5/20/1977	N/A	12/02/1988	09/13/2019 08/05/2010 12/19/1997

[1]No Special Flood Hazard Areas Identified

[2]Dates for this community were taken from Ottawa County, Unincorporated Areas

SECTION 7.0 – CONTRACTED STUDIES AND COMMUNITY COORDINATION

7.1 Contracted Studies

Table 28 provides a summary of the contracted studies, by flooding source, that are included in this FIS Report

Table 28: Summary of Contracted Studies Included in this FIS Report

Flooding Source	FIS Report Dated	Contractor	Number	Work Completed Date	Affected Communities
Bee Creek and Zone A Tributaries	09/13/2019	RAMPP	HSFE06-11-J-0001	September 2016	Ottawa County, Unincorporated Areas
Belmont Run	09/13/2019	RAMPP	HSFE06-11-J-0001	September 2016	Miami, City of; Ottawa County, Unincorporated Areas; North Miami, Town of
Coal Creek and Zone A tributaries	09/13/2019	RAMPP	HSFE06-11-J-0001	September 2016	Ottawa County, Unincorporated Areas
Council Hollow Creek and Zone A tributaries	09/13/2019	RAMPP	HSFE06-11-J-0001	September 2016	Ottawa County, Unincorporated Areas
Cow Creek	09/13/2019	RAMPP	HSFE06-11-J-0001	September 2016	Ottawa County, Unincorporated Areas
Elm Creek and Zone A tributaries	09/13/2019	RAMPP	HSFE06-11-J-0001	September 2016	Ottawa County, Unincorporated Areas
Fairgrounds Branch	09/13/2019	RAMPP	HSFE06-11-J-0001	September 2016	Miami, City of; Ottawa County, Unincorporated Areas

Table 28: Summary of Contracted Studies Included in this FIS Report, continued

Flooding Source	FIS Report Dated	Contractor	Number	Work Completed Date	Affected Communities
Garrett Creek and Zone A tributaries	09/13/2019	RAMPP	HSFE06-11-J-0001	September 2016	Miami, City of; Ottawa County, Unincorporated Areas
Grand Lake O The Cherokees	09/13/2019	RAMPP	HSFE06-11-J-0001	September 2016	Ottawa County, Unincorporated Areas; Wyandotte, Town of
Grand Lake Tributary 2 and Zone A tributaries	09/13/2019	RAMPP	HSFE06-11-J-0001	September 2016	Ottawa County, Unincorporated Areas
Hickory Creek and Zone A tributaries	09/13/2019	RAMPP	HSFE06-11-J-0001	September 2016	Ottawa County, Unincorporated Areas
Horse Creek and Zone A tributaries	09/13/2019	RAMPP	HSFE06-11-J-0001	September 2016	Afton, Town of; Ottawa County, Unincorporated Areas
Horse Creek	09/13/2019	RAMPP	HSFE06-11-J-0001	September 2016	Afton, Town of; Ottawa County, Unincorporated Areas
Horse Creek Tributary 3	09/13/2019	RAMPP	HSFE06-11-J-0001	September 2016	Afton, Town of; Ottawa County, Unincorporated Areas
Horse Creek Tributary 3-1	09/13/2019	RAMPP	HSFE06-11-J-0001	September 2016	Afton, Town of; Ottawa County, Unincorporated Areas
Horse Creek Tributary 3-2	09/13/2019	RAMPP	HSFE06-11-J-0001	September 2016	Afton, Town of; Ottawa County, Unincorporated Areas
Horse Creek Tributary 3-2-1	09/13/2019	RAMPP	HSFE06-11-J-0001	September 2016	Afton, Town of; Ottawa County, Unincorporated Areas
Hudson Creek and Zone A Tributaries	09/13/2019	RAMPP	HSFE06-11-J-0001	September 2016	Fairland, Town of; Ottawa County, Unincorporated Areas
Little Elm Creek and Zone A tributaries	09/13/2019	RAMPP	HSFE06-11-J-0001	September 2016	Miami, City of; Ottawa County, Unincorporated Areas

Table 28: Summary of Contracted Studies Included in this FIS Report, continued

Flooding Source	FIS Report Dated	Contractor	Number	Work Completed Date	Affected Communities
Little Elm Creek	12/19/1997	Coe	EMW-84-1506	September 1986	Miami, City of; Ottawa County, Unincorporated Areas
Little Horse Creek and Zone A tributaries	09/13/2019	RAMPP	HSFE06-11-J-0001	September 2016	Fairland, Town of; Ottawa County, Unincorporated Areas
Lost Creek and Zone A tributaries	09/13/2019	RAMPP	HSFE06-11-J-0001	September 2016	Ottawa County, Unincorporated Areas; Wyandotte Nation; Wyandotte, Town of
Lost Creek (at Wyandotte)	09/13/2019	RAMPP	HSFE06-11-J-0001	September 2016	Ottawa County, Unincorporated Areas; Wyandotte, Town of; Wyandotte Nation
Lost Creek (Upper Reach)	12/19/1997	Coe	EMW-84-E-1506	September 1986	Ottawa County, Unincorporated Areas; Wyandotte, Town of; Wyandotte Nation
Lytle Creek and Zone A tributaries	09/13/2019	RAMPP	HSFE06-11-J-0001	September 2016	Ottawa County, Unincorporated Areas;
Mud Creek	09/13/2019	RAMPP	HSFE06-11-J-0001	September 2016	Ottawa County, Unincorporated Areas
Neosho River	09/13/2019	RAMPP	HSFE06-11-J-0001	September 2016	Miami, City of; Ottawa County, Unincorporated Areas
Neosho River	09/13/2019	RAMPP	HSFE06-11-J-0001	September 2016	Ottawa County, Unincorporated Areas
Neosho River and Zone A tributaries	09/13/2019	RAMPP	HSFE06-11-J-0001	September 2016	Miami, City of; Ottawa County, Unincorporated Areas
Ogeechee Creek and Zone A tributaries	09/13/2019	RAMPP	HSFE06-11-J-0001	September 2016	Fairland, Town of; Ottawa County, Unincorporated Areas

Table 28: Summary of Contracted Studies Included in this FIS Report, continued

Flooding Source	FIS Report Dated	Contractor	Number	Work Completed Date	Affected Communities
Quail Creek and Zone A tributaries	09/13/2019	RAMPP	HSFE06-11-J-0001	September 2016	Miami, City of; Ottawa County, Unincorporated Areas
Quail Creek	09/13/2019	RAMPP	HSFE06-11-J-0001	September 2016	Miami, City of; Ottawa County, Unincorporated Areas
Tar Creek (at Miami)	09/13/2019	RAMPP	HSFE06-11-J-0001	September 2016	Commerce, City of; Miami, City of; Ottawa County, Unincorporated Areas;
Unnamed Creek 1 and Zone A tributaries	09/13/2019	RAMPP	HSFE06-11-J-0001	September 2016	Ottawa County, Unincorporated Areas
Unnamed Creek 2	09/13/2019	RAMPP	HSFE06-11-J-0001	September 2016	Ottawa County, Unincorporated Areas
Warren Branch	12/19/1997	Coe	EMW-84-1506	September 1986	Ottawa County, Unincorporated Areas; Peoria, Town of
Windy Creek	09/13/2019	RAMPP	HSFE06-11-J-0001	September 2016	Ottawa County Unincorporated Areas
Wyandotte Ditch	12/19/1997	Coe	EMW-84-1506	September 1986	Ottawa County, Unincorporated Areas; Wyandotte, Town of

7.2 Community Meetings

The dates of the community meetings held for this Flood Risk Project and previous Flood Risk Projects are shown in Table 29. These meetings may have previously been referred to by a variety of names (Community Coordination Officer (CCO), Scoping, Discovery, etc.), but all meetings represent opportunities for FEMA, community officials, study contractors, and other invited guests to discuss the planning for and results of the project.

Table 29: Community Meetings

Community	FIS Report Dated	Date of Meeting	Meeting Type	Attended By
Afton, Town of	09/13/2019	9/14/2011	Discovery	The Town of Afton, FEMA and RAMPP
		1/20/2016	Flood Risk Review	The Town of Afton, FEMA and RAMPP
		08/24/2016	Flood Risk Review	The Town of Afton, FEMA and RAMPP
		11/30/2017	Final CCO	Representatives of Ottawa County, Wyandotte Nation and the City of Miami
Commerce, City of	09/13/2019	9/14/2011	Flood Risk Review	The City of Commerce, FEMA and RAMPP
		1/20/2016	Flood Risk Review	The City of Commerce, FEMA and RAMPP
		08/24/2016	Flood Risk Review	The City of Commerce, FEMA and RAMPP
		11/30/2017	Final CCO	Representatives of Ottawa County, Wyandotte Nation and the City of Miami

Table 29: Community Meetings, continued

Community	FIS Report Dated	Date of Meeting	Meeting Type	Attended By
Fairland, Town of	09/13/2019	9/14/2011	Flood Risk Review	The City of Fairland, FEMA and RAMPP
		1/20/2016	Flood Risk Review	The City of Fairland, FEMA and RAMPP
		08/24/2016	Flood Risk Review	The City of Fairland, FEMA and RAMPP
		11/30/2017	Final CCO	Representatives of Ottawa County, Wyandotte Nation and the City of Miami
Miami, City of	09/13/2019	9/14/2011	Flood Risk Review	The City of Miami, FEMA and RAMPP
		1/20/2016	Flood Risk Review	The City of Miami, FEMA and RAMPP
		08/24/2016	Flood Risk Review	The City of Miami, FEMA and RAMPP
		11/30/2017	Final CCO	Representatives of Ottawa County, Wyandotte Nation and the City of Miami
North Miami, Town of	09/13/2019	9/14/2011	Flood Risk Review	The Town of North Miami, FEMA and RAMPP
		1/20/2016	Flood Risk Review	The Town of North Miami, FEMA and RAMPP

Table 29: Community Meetings, continued

Community	FIS Report Dated	Date of Meeting	Meeting Type	Attended By
North Miami, Town of (continued)	9/13/2019	08/24/2016	Flood Risk Review	The Town of North Miami, FEMA and RAMPP
		11/30/2017	Final CCO	Representatives of Ottawa County, Wyandotte Nation and the City of Miami
Ottawa County, Unincorporated Areas	09/13/2019	9/14/2011	Flood Risk Review	Ottawa County, FEMA and RAMPP
		1/20/2016	Flood Risk Review	Ottawa County, FEMA and RAMPP
		08/24/2016	Flood Risk Review	Ottawa County, FEMA and RAMPP
		11/30/2017	Final CCO	Representatives of Ottawa County, Wyandotte Nation and the City of Miami
Peoria, Town of	08/05/2010	04/10/2007	Initial CCO	Cities of Commerce and Miami; the Towns of Afton, Fairland, and Wyandotte; Ottawa County, The Oklahoma Water Resources Board; FEMA; and Watershed VI Alliance
		12/08/2008	Final CCO	Cities of Commerce, Miami, and Wyandotte, the Seneca Tribe, the Eastern Shawnee tribe, FEMA and Watershed VI Alliance
Quapaw, Town of	09/13/2019	9/14/2011	Flood Risk Review	The Town of Quapaw, FEMA and RAMPP
		1/20/2016	Flood Risk Review	The Town of Quapaw, FEMA and RAMPP
		08/24/2016	Flood Risk Review	The Town of Quapaw, FEMA and RAMPP
		11/30/2017	Final CCO	Representatives of Ottawa County, Wyandotte Nation and the City of Miami

Table 29: Community Meetings, continued

Community	FIS Report Dated	Date of Meeting	Meeting Type	Attended By
Wyandotte, Town of	09/13/2019	9/14/2011	Flood Risk Review	The Town of Wyandotte, FEMA and RAMPP
		1/20/2016	Flood Risk Review	The Town of Wyandotte, FEMA and RAMPP
		08/24/2016	Flood Risk Review	The Town of Wyandotte, FEMA and RAMPP
		11/30/2017	Final CCO	Representatives of Ottawa County, Wyandotte Nation and the City of Miami
Wyandotte Nation	09/13/2019	9/14/2011	Flood Risk Review	The Town of Wyandotte, FEMA and RAMPP
		1/20/2016	Flood Risk Review	The Town of Wyandotte, FEMA and RAMPP
		08/24/2016	Flood Risk Review	The Town of Wyandotte, FEMA and RAMPP
		11/30/2017	Final CCO	Representatives of Ottawa County, Wyandotte Nation and the City of Miami

SECTION 8.0 – ADDITIONAL INFORMATION

Information concerning the pertinent data used in the preparation of this FIS Report can be obtained by submitting an order with any required payment to the FEMA Engineering Library. For more information on this process, see www.fema.gov.

The additional data that was used for this project includes the FIS Report and FIRM that were previously prepared for Ottawa County (FEMA 2010).

Table 30 is a list of the locations where FIRMs for Ottawa County can be viewed. Please note that the maps at these locations are for reference only and are not for distribution. Also, please note that only the maps for the community listed in the table are available at that particular repository. A user may need to visit another repository to view maps from an adjacent community.

Table 30: Map Repositories

Community	Address	City	State	Zip Code
Afton, Town of	Town Hall 201 Southwest 1st Street	Afton	OK	74331
Commerce, City of	City Hall 618 Commerce Street	Commerce	OK	74339
Fairland, Town of	Town Hall 28 North Main Street	Fairland	OK	74343
Miami, City of	Civic Center 129 5th Avenue Northwest	Miami	OK	74355
North Miami, Town of[1]	Town Hall 309 Pine Street	North Miami	OK	74358
Ottawa County, Unincorporated Areas	Ottawa County Courthouse Annex 123 East Central Boulevard Suite 103	Miami	OK	74354
Peoria, Town of	Courthouse Annex 123 East Central Boulevard Suite 103	Miami	OK	74354
Quapaw, Town of	Town Hall 410 South Main Street	Quapaw	OK	74363
Wyandotte, Town of	Town Hall 212 South Main Street	Wyandotte	OK	74370
Wyandotte Nation	Tribal Administration 64700 East Highway 60	Wyandotte	OK	74370

[1]No Special Flood Hazard Areas identified

The National Flood Hazard Layer (NFHL) dataset is a compilation of effective FIRM Databases and LOMCs. Together they create a GIS data layer for a State or Territory. The NFHL is updated as studies become effective and extracts are made available to the public monthly. NFHL data can be viewed or ordered from the website shown in Table 31.

Table 31 contains useful contact information regarding the FIS Report, the FIRM, and other relevant flood hazard and GIS data. In addition, information about the State NFIP Coordinator and GIS Coordinator is shown in this table. At the request of FEMA, each Governor has designated an agency of State or territorial government to coordinate that State's or territory's NFIP activities. These agencies often assist communities in developing and adopting necessary floodplain management measures. State GIS Coordinators are knowledgeable about the availability and location of State and local GIS data in their state.

Table 31: Additional Information

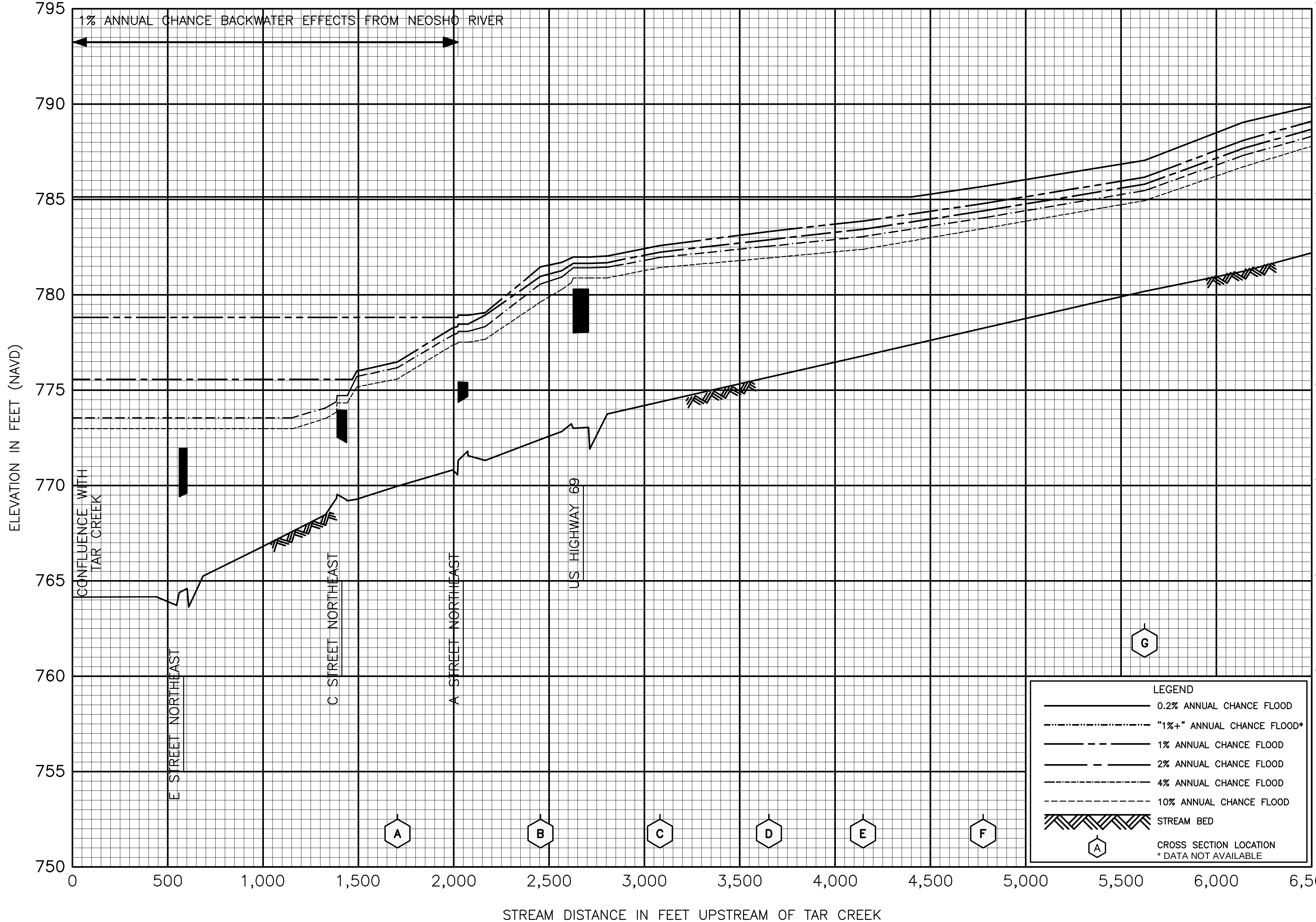
FEMA and the NFIP	
FEMA and FEMA Engineering Library website	www.fema.gov/national-flood-insurance-program-flood-hazard-mapping/engineering-library
NFIP website	www.fema.gov/national-flood-insurance-program
NFHL Dataset	msc.fema.gov
FEMA Region VI	Jennifer Knecht FEMA Region Representative FEMA Region VI 800 North Loop 288 Denton, TX 76209 (940) 898-5553 Jennifer.Knecht@fema.dhs.gov
Other Federal Agencies	
USGS website	www.usgs.gov
Hydraulic Engineering Center website	www.hec.usace.army.mil
State Agencies and Organizations	
State NFIP Coordinator	Yohanes Sugeng, PE, CFM Oklahoma Water Resources Board 3800 North Classen Boulevard Oklahoma City, Oklahoma 73118 (405) 530-8800 yohanes.sugeng@owrb.ok.gov
State GIS Coordinator	Mike Sharp Acting State Geographic Information Coordinator Lincoln Plaza Office Building 4545 N. Lincoln Blvd, Suite 11A Oklahoma City, OK 73105 Phone: (405) 521-4813 mike.sharp@conservaton.ok.gov

SECTION 9.0 – BIBLIOGRAPHY AND REFERENCES

Table 32 includes sources used in the preparation of and cited in this FIS Report as well as additional studies that have been conducted in the study area.

Table 32: Bibliography and References

Citation in this FIS	Publisher/ Issuer	*Publication Title,* "Article," Volume, Number, etc.	Author/Editor	Place of Publication	Publication Date/ Date of Issuance	Link
RAMPP, 2013	Federal Emergency Management Agency	*Light Detection and Ranging data (LiDAR) 0.06 meter RMSEz, 2 cm at 95% confidence*	RAMPP	Denton, TX	September 30, 2013	
USACE, HWM	U.S. Department of the Army, Corps of Engineers	*High Water Marks of the Neosho River*	U.S. Department of the Army, Corps of Engineers	Davis, CA		
USGS, 1961	United States Geologic Survey	*7.5-Minutes Series of Topographic Maps, Scale 1:24,000, Contour Interval 10 Feet: Miami, SE, Oklahoma, 1961; Miami SW, Oklahoma, 1961; Picher, Oklahoma, 1961; Miami NW, Oklahoma-Kansas.*	U.S. Department of the Interior, Geological Survey	N/A	1961	



FLOOD PROFILES

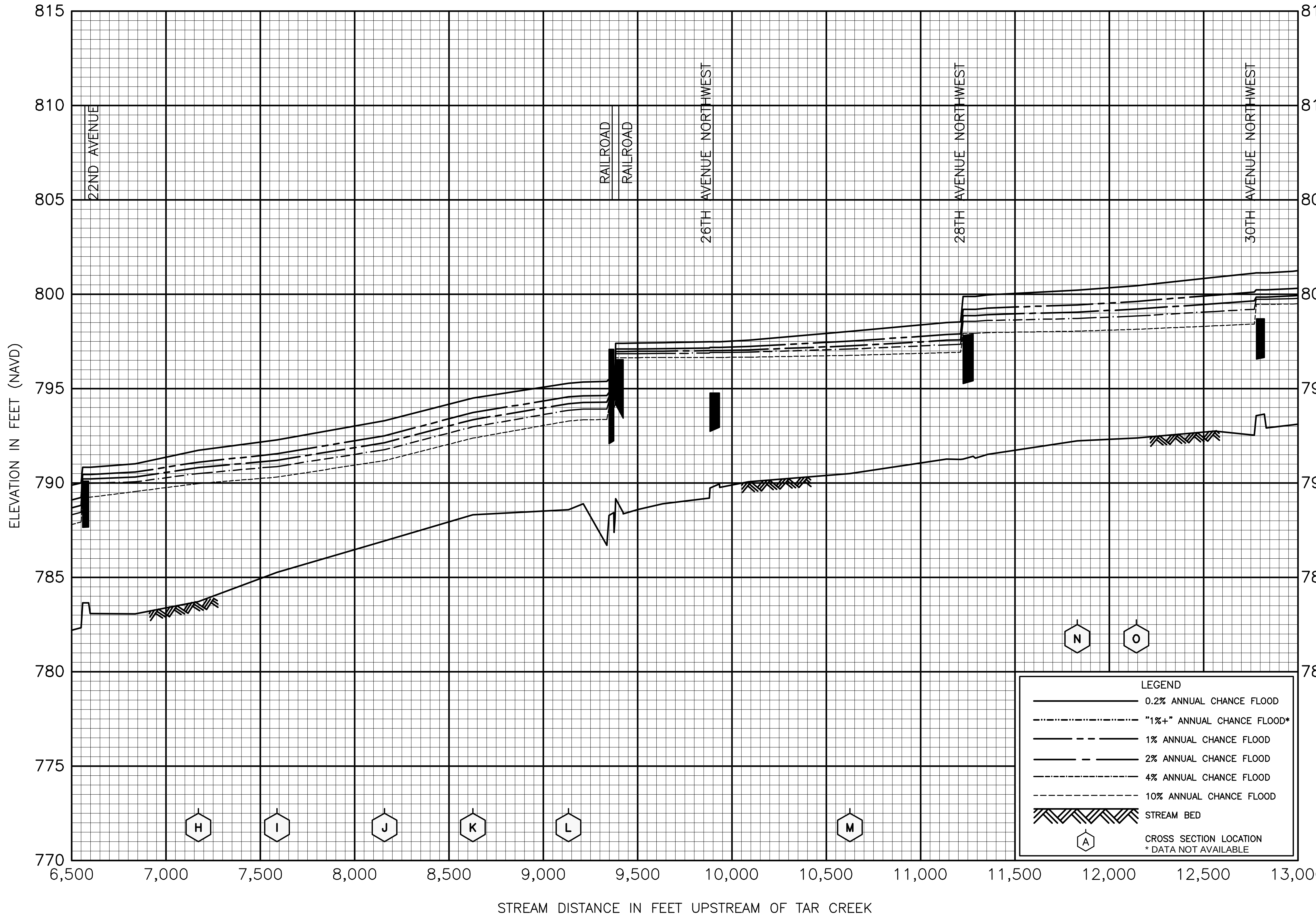
BELMONT RUN

FEDERAL EMERGENCY MANAGEMENT AGENCY

OTTAWA COUNTY, OK

AND INCORPORATED AREAS

01P



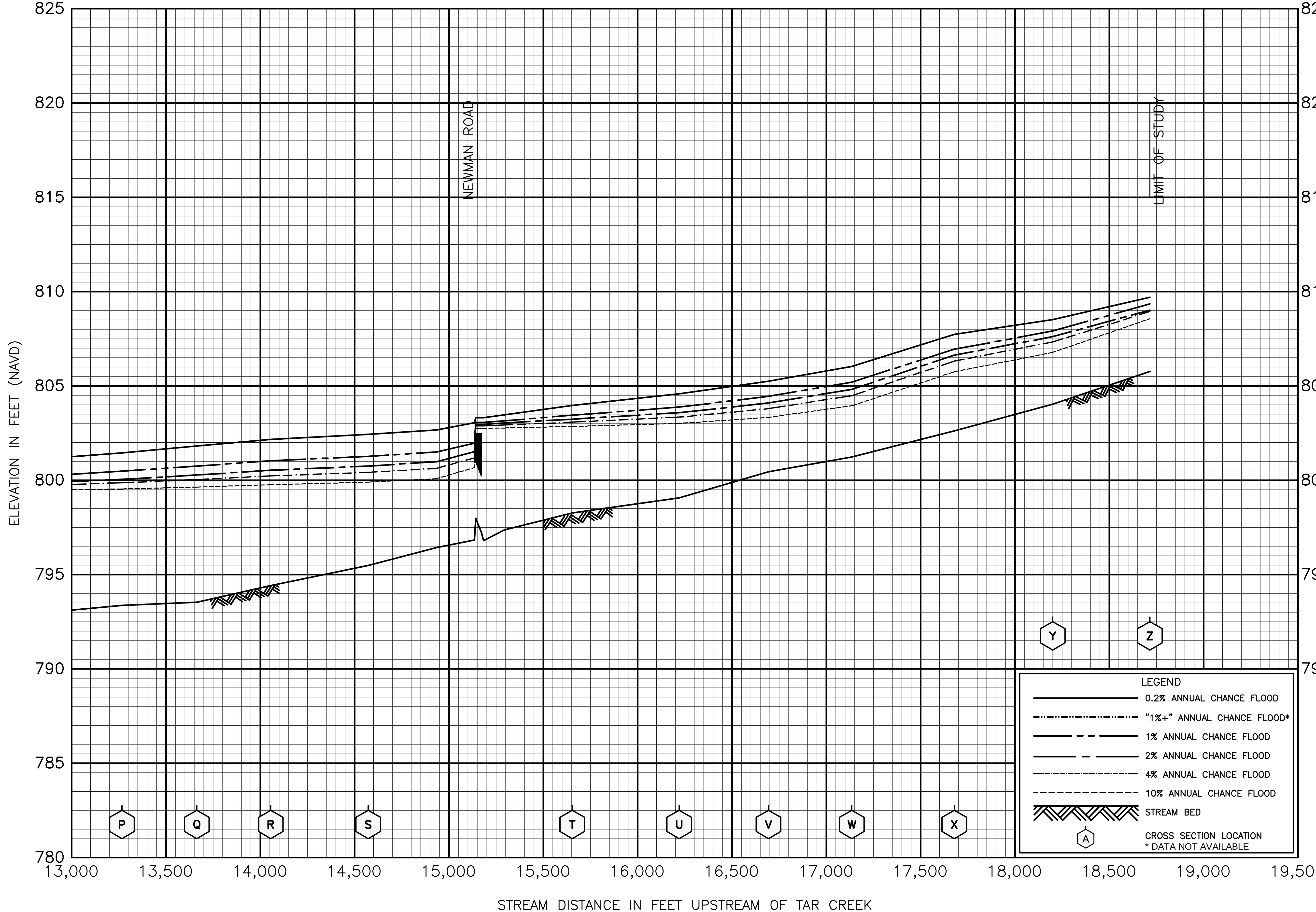
FLOOD PROFILES

BELMONT RUN

FEDERAL EMERGENCY MANAGEMENT AGENCY

OTTAWA COUNTY, OK

AND INCORPORATED AREAS



FLOOD PROFILES

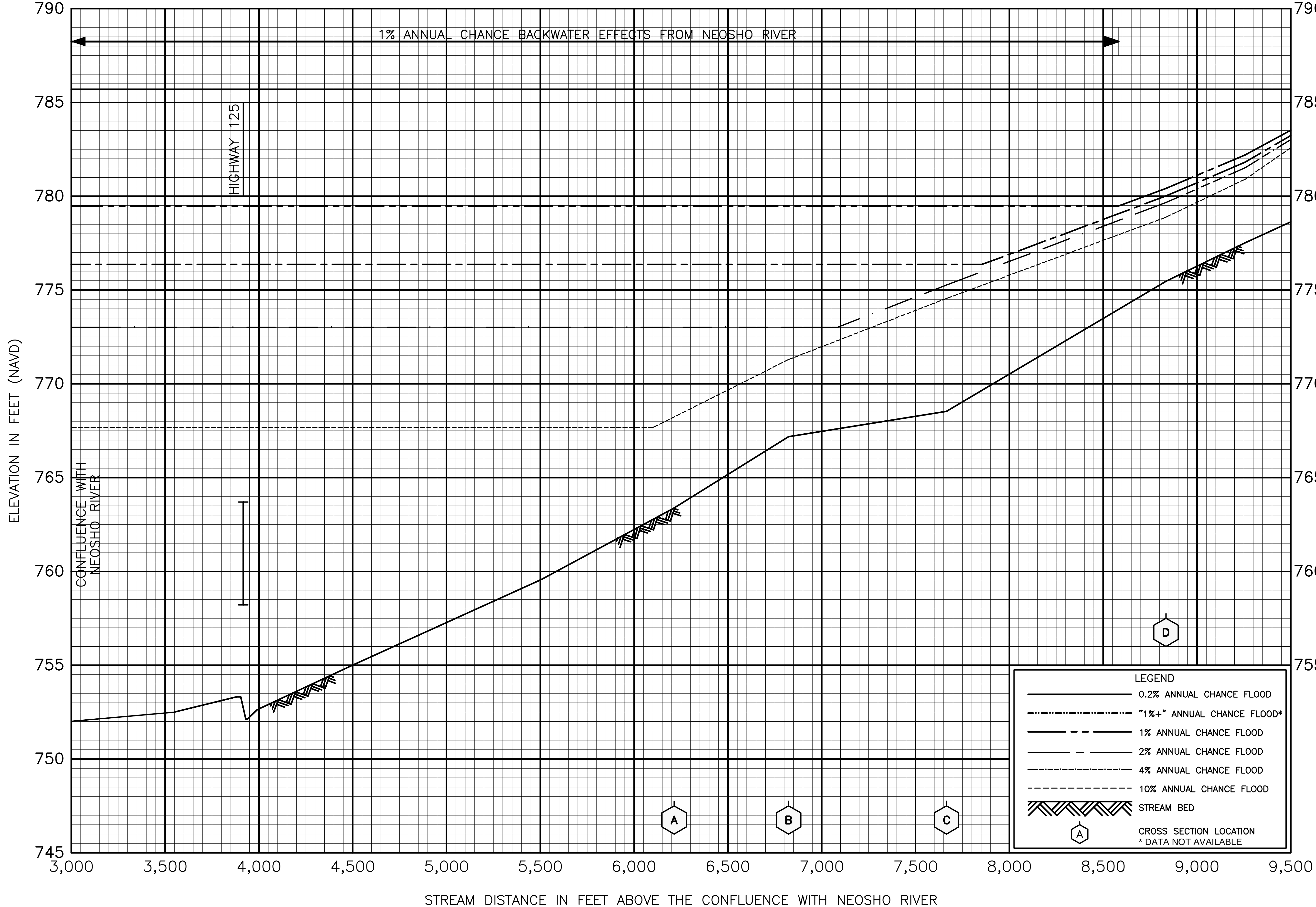
BELMONT RUN

FEDERAL EMERGENCY MANAGEMENT AGENCY

OTTAWA COUNTY, OK

AND INCORPORATED AREAS

03P



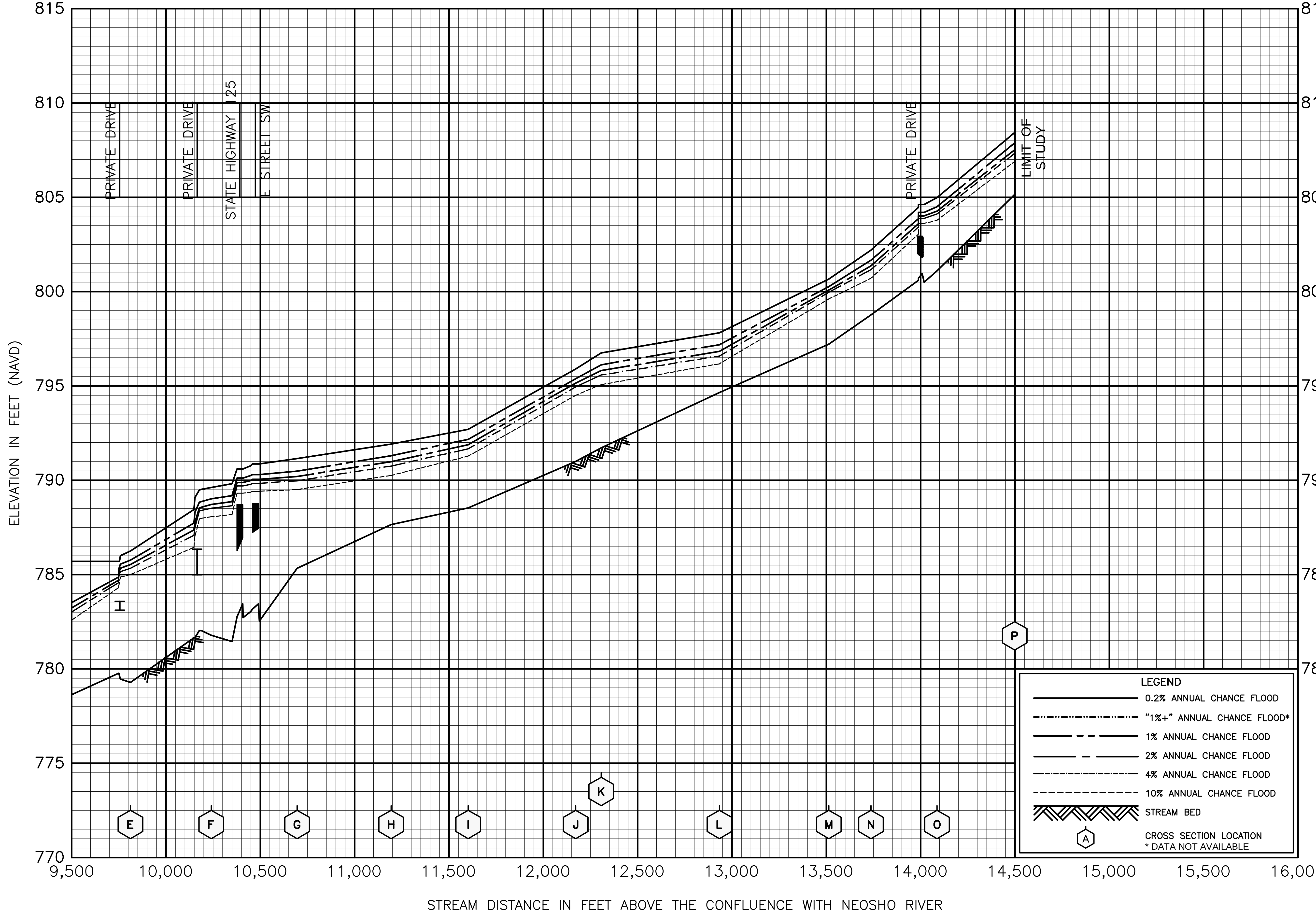
FLOOD PROFILES

FAIRGROUNDS BRANCH

FEDERAL EMERGENCY MANAGEMENT AGENCY

OTTAWA COUNTY, OK

AND INCORPORATED AREAS



FLOOD PROFILES

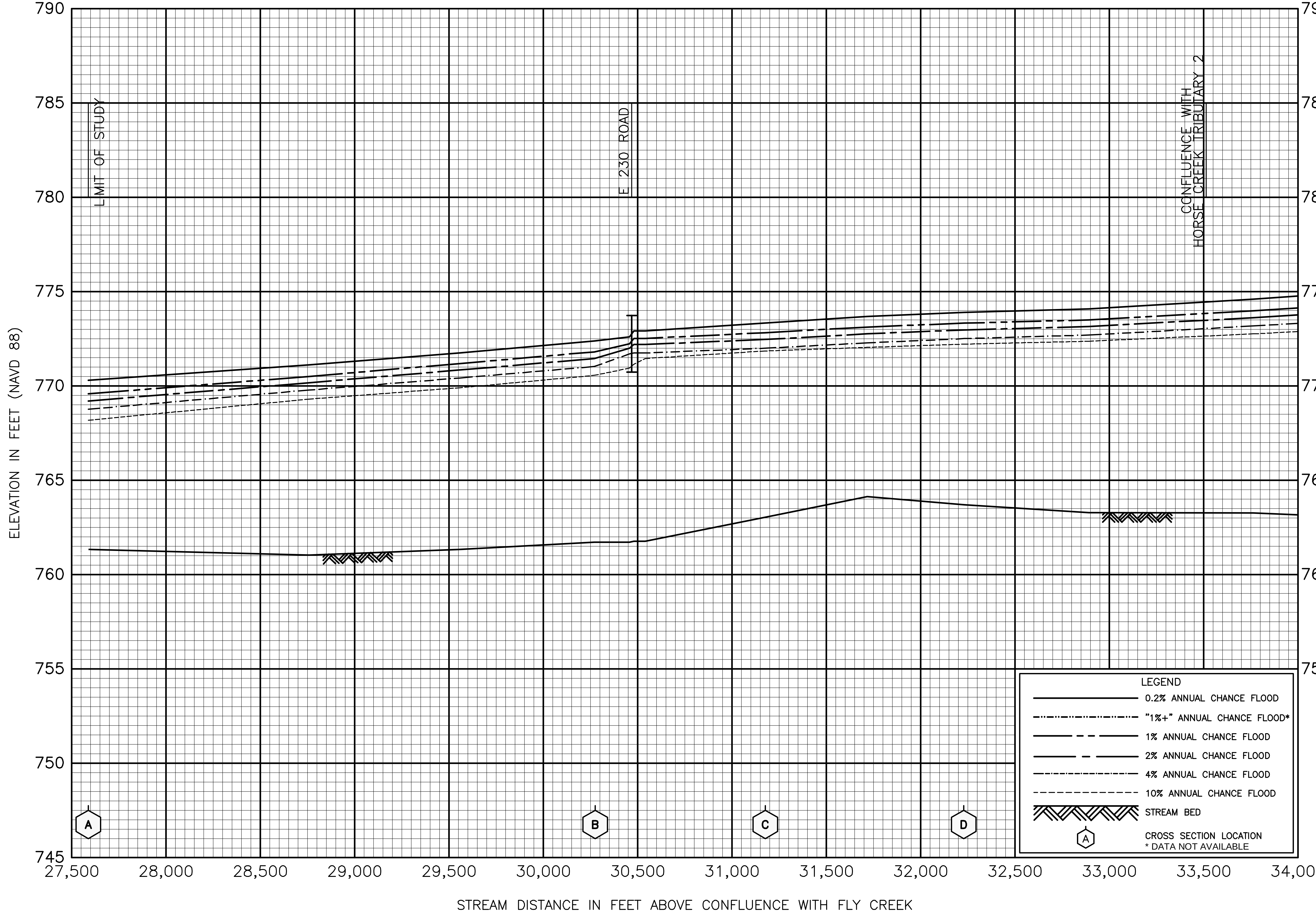
FAIRGROUNDS BRANCH

FEDERAL EMERGENCY MANAGEMENT AGENCY

OTTAWA COUNTY, OK

AND INCORPORATED AREAS

05P



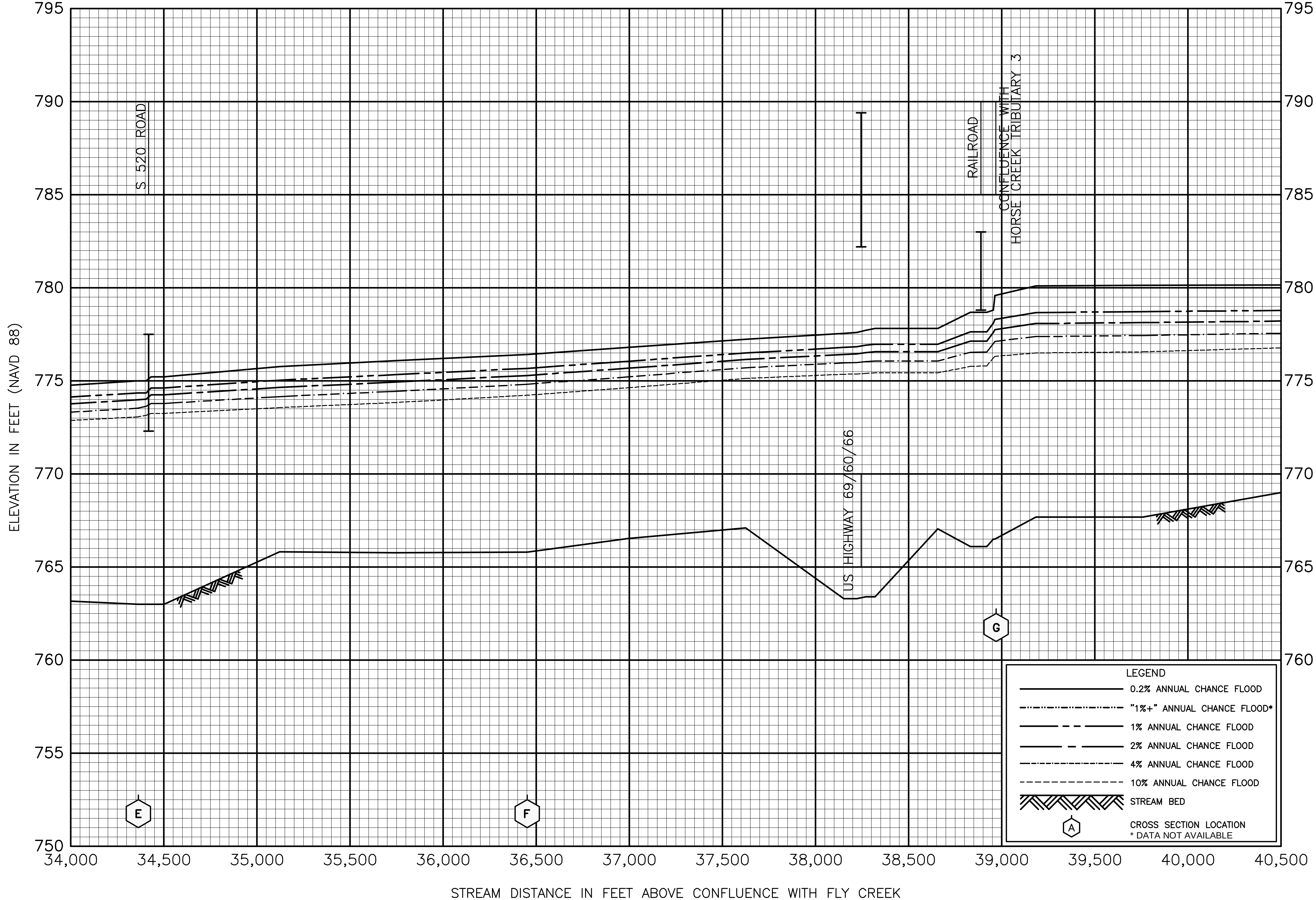
FLOOD PROFILES

HORSE CREEK

FEDERAL EMERGENCY MANAGEMENT AGENCY

OTTAWA COUNTY, OK

AND INCORPORATED AREAS



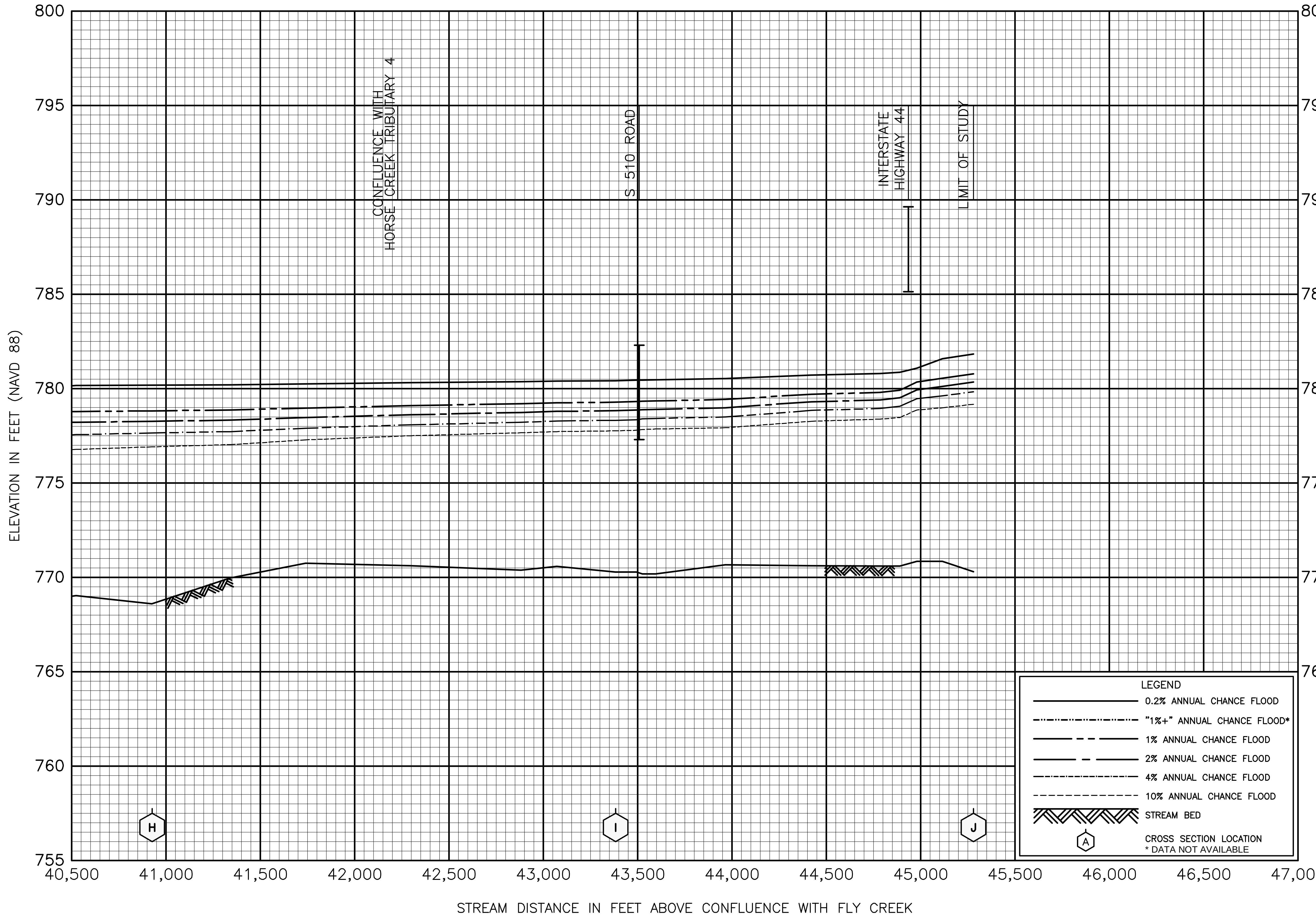
FLOOD PROFILES

HORSE CREEK

FEDERAL EMERGENCY MANAGEMENT AGENCY

OTTAWA COUNTY, OK

AND INCORPORATED AREAS



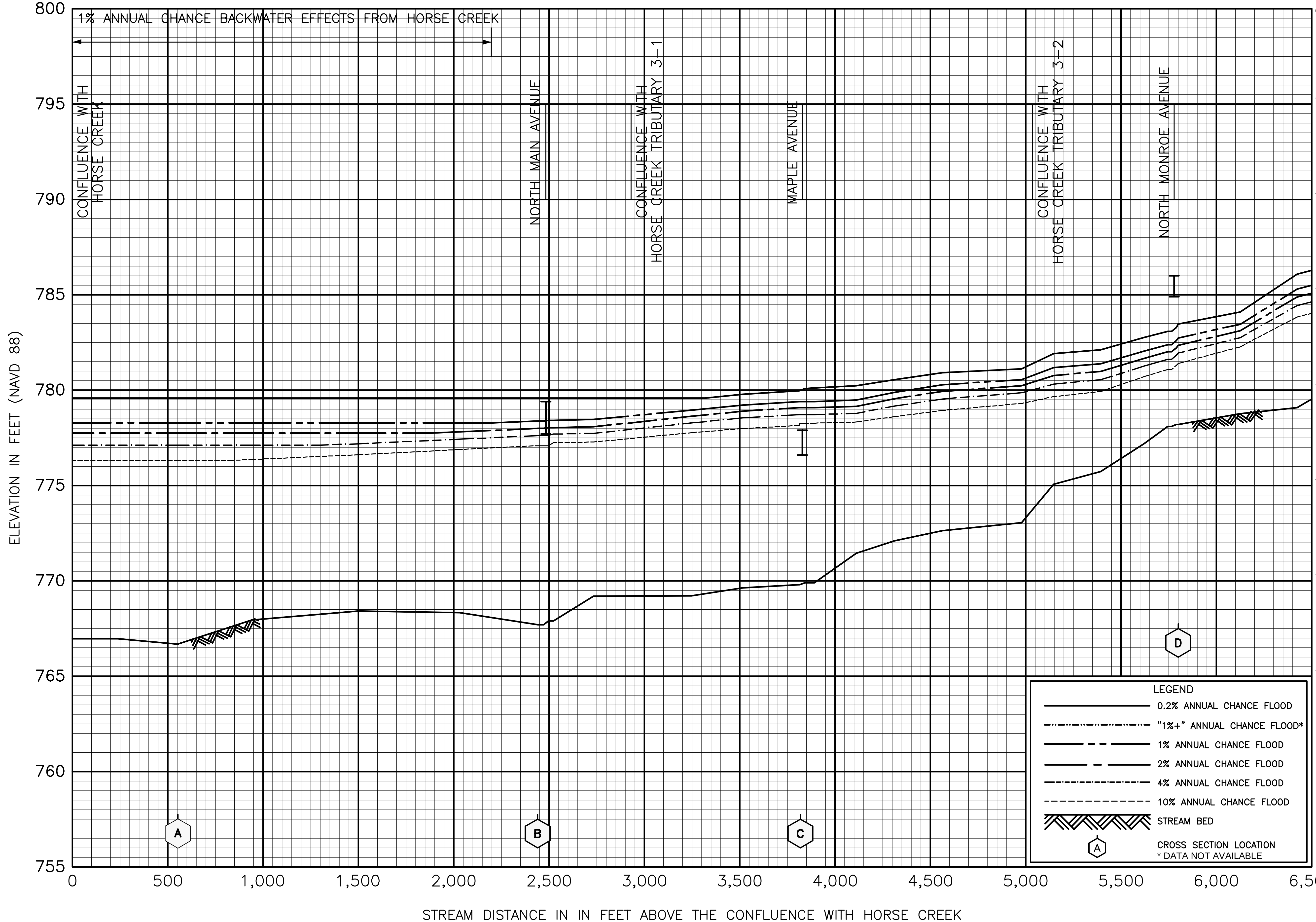
FLOOD PROFILES

HORSE CREEK

FEDERAL EMERGENCY MANAGEMENT AGENCY

OTTAWA COUNTY, OK

AND INCORPORATED AREAS



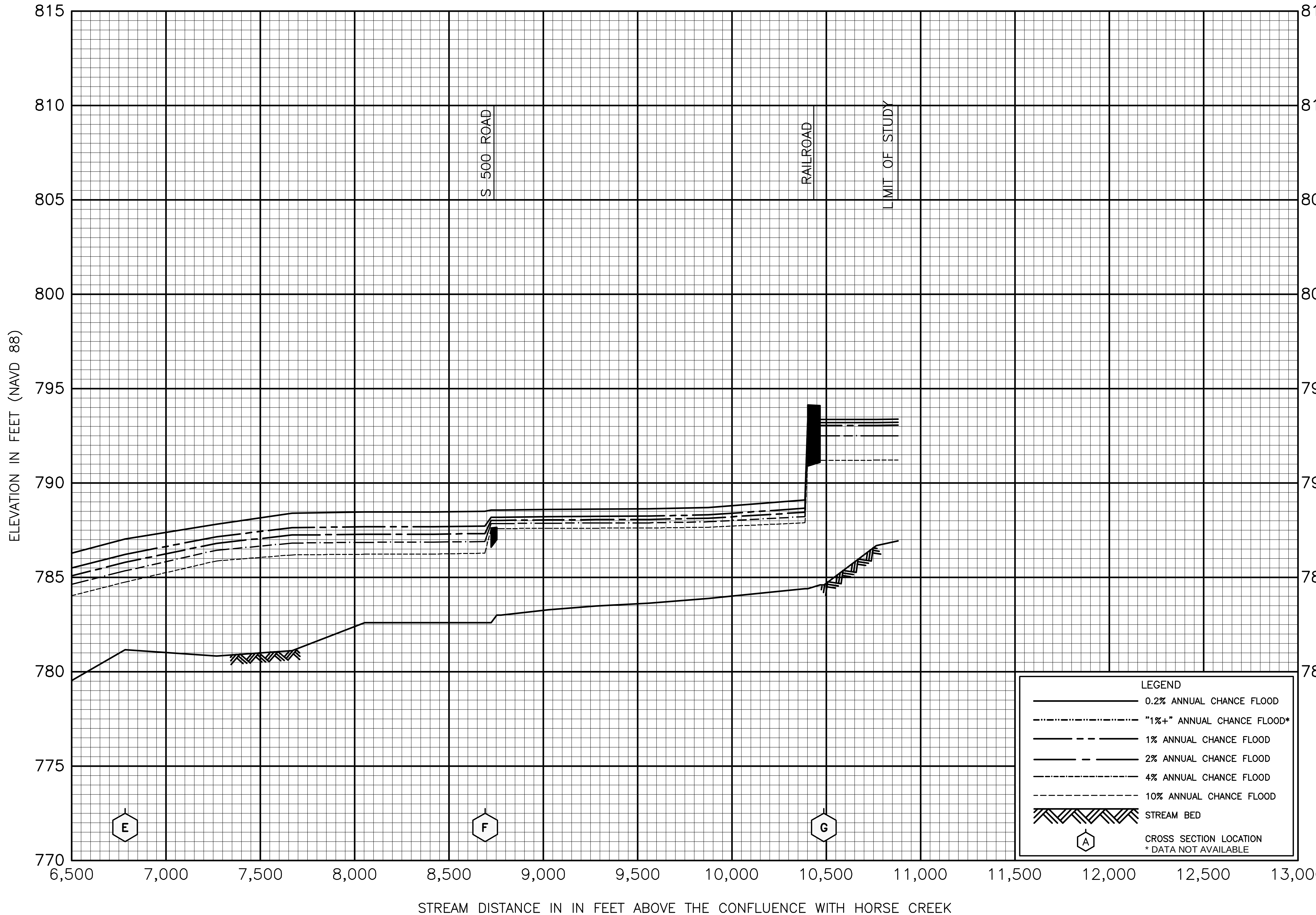
FLOOD PROFILES

HORSE CREEK TRIBUTARY 3

FEDERAL EMERGENCY MANAGEMENT AGENCY

OTTAWA COUNTY, OK

AND INCORPORATED AREAS



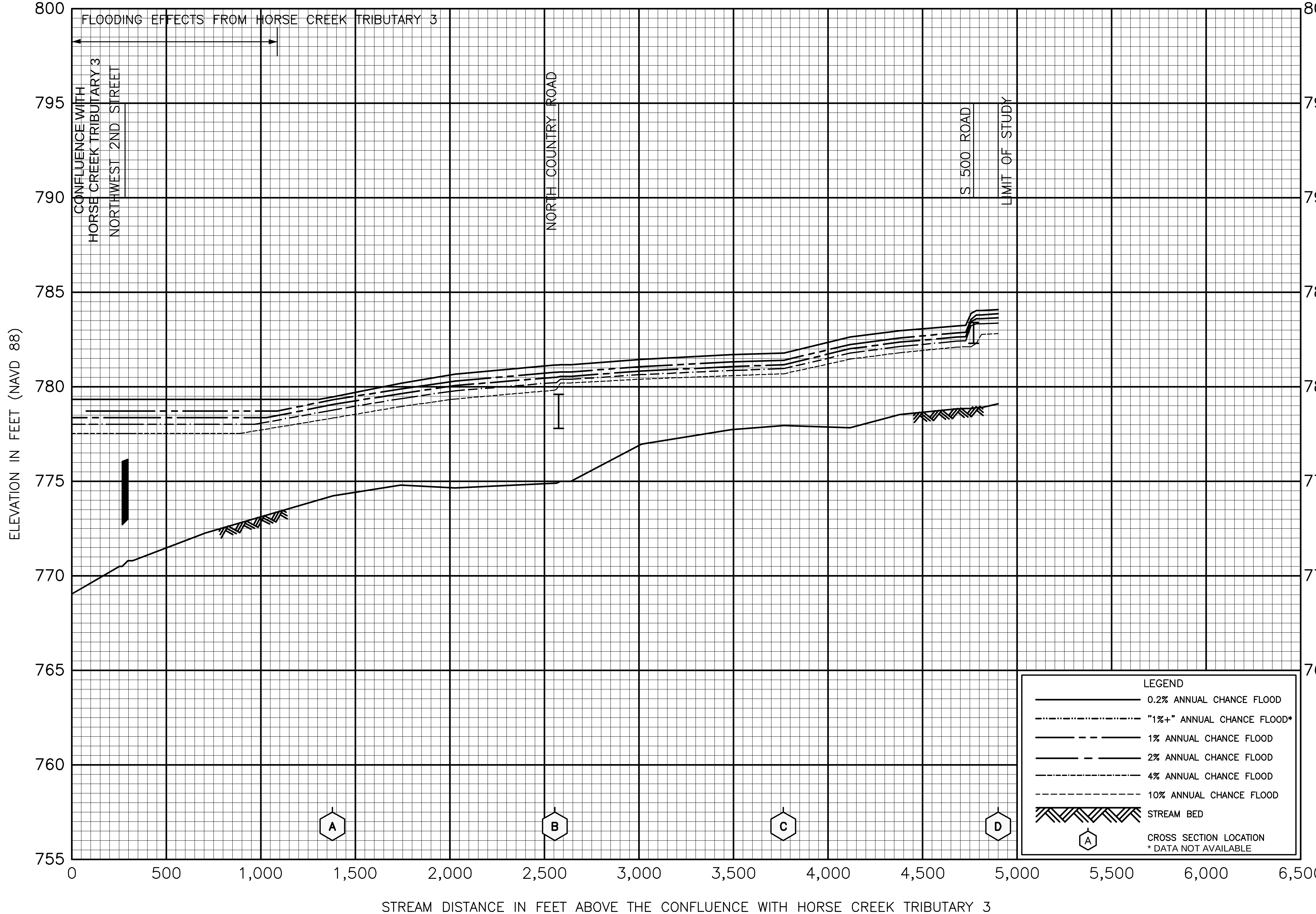
FLOOD PROFILES

HORSE CREEK TRIBUTARY 3

FEDERAL EMERGENCY MANAGEMENT AGENCY

OTTAWA COUNTY, OK

AND INCORPORATED AREAS



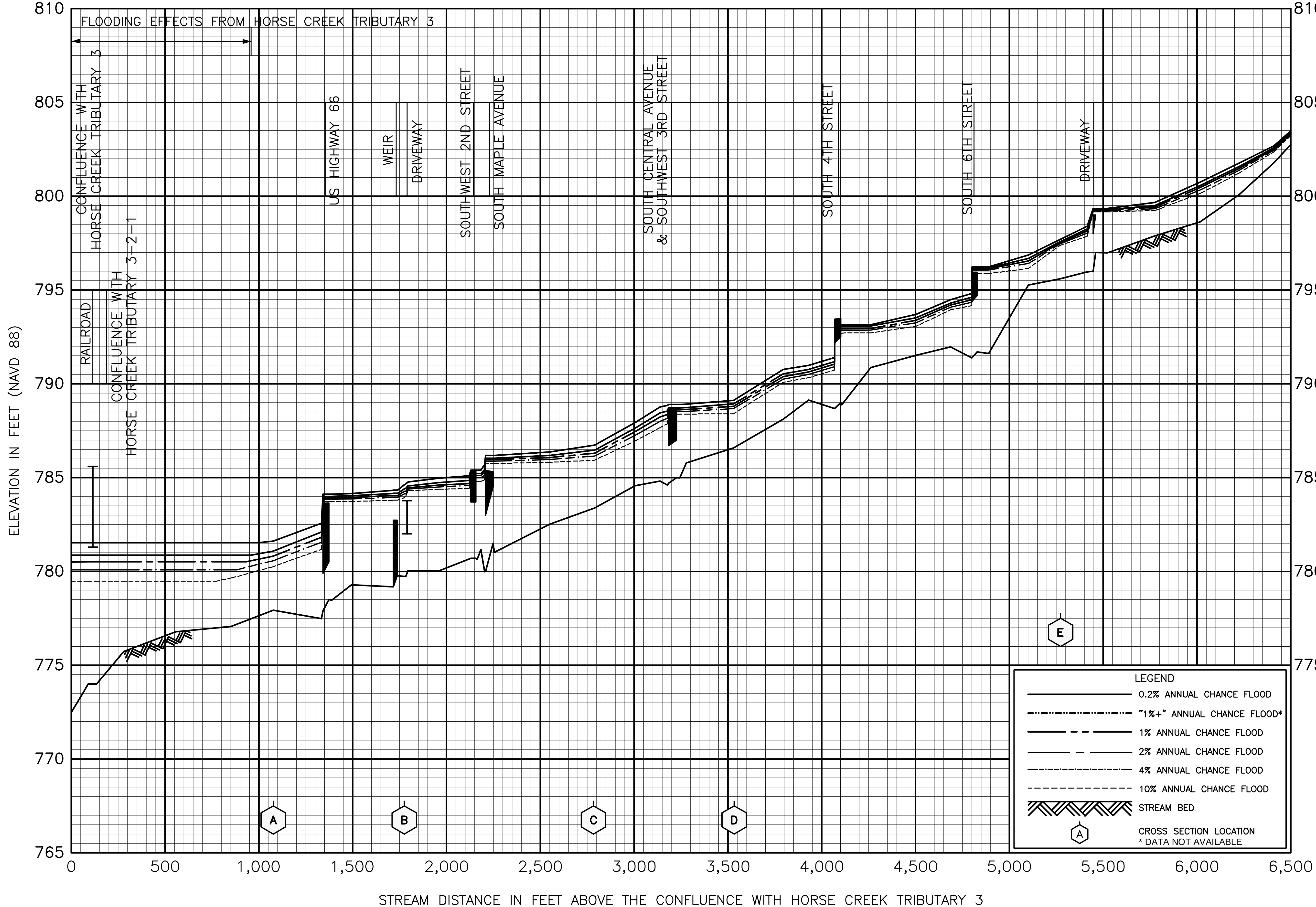
FLOOD PROFILES

HORSE CREEK TRIBUTARY 3-1

FEDERAL EMERGENCY MANAGEMENT AGENCY

OTTAWA COUNTY, OK

AND INCORPORATED AREAS



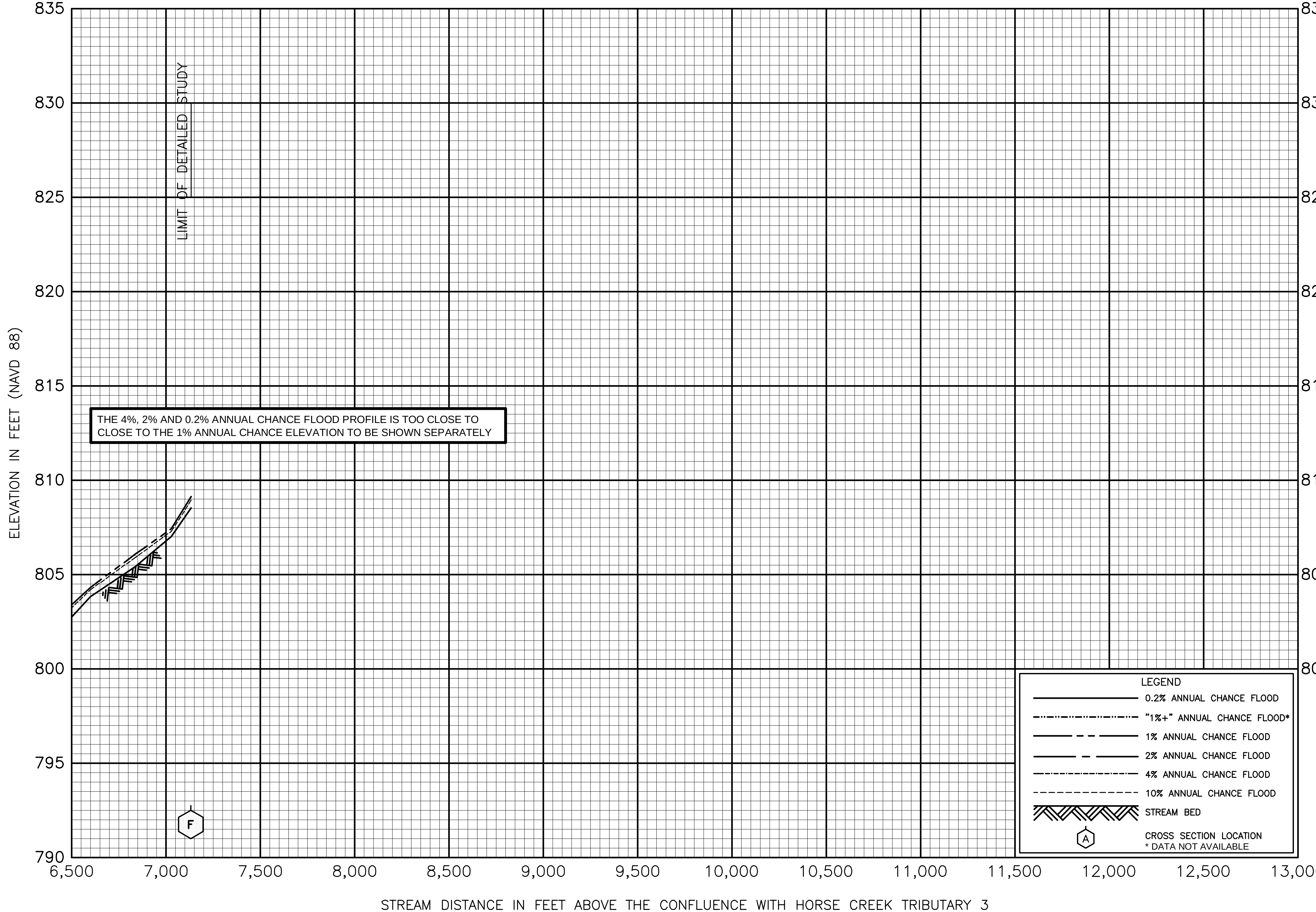
FLOOD PROFILES

HORSE CREEK TRIBUTARY 3-2

FEDERAL EMERGENCY MANAGEMENT AGENCY

OTTAWA COUNTY, OK

AND INCORPORATED AREAS



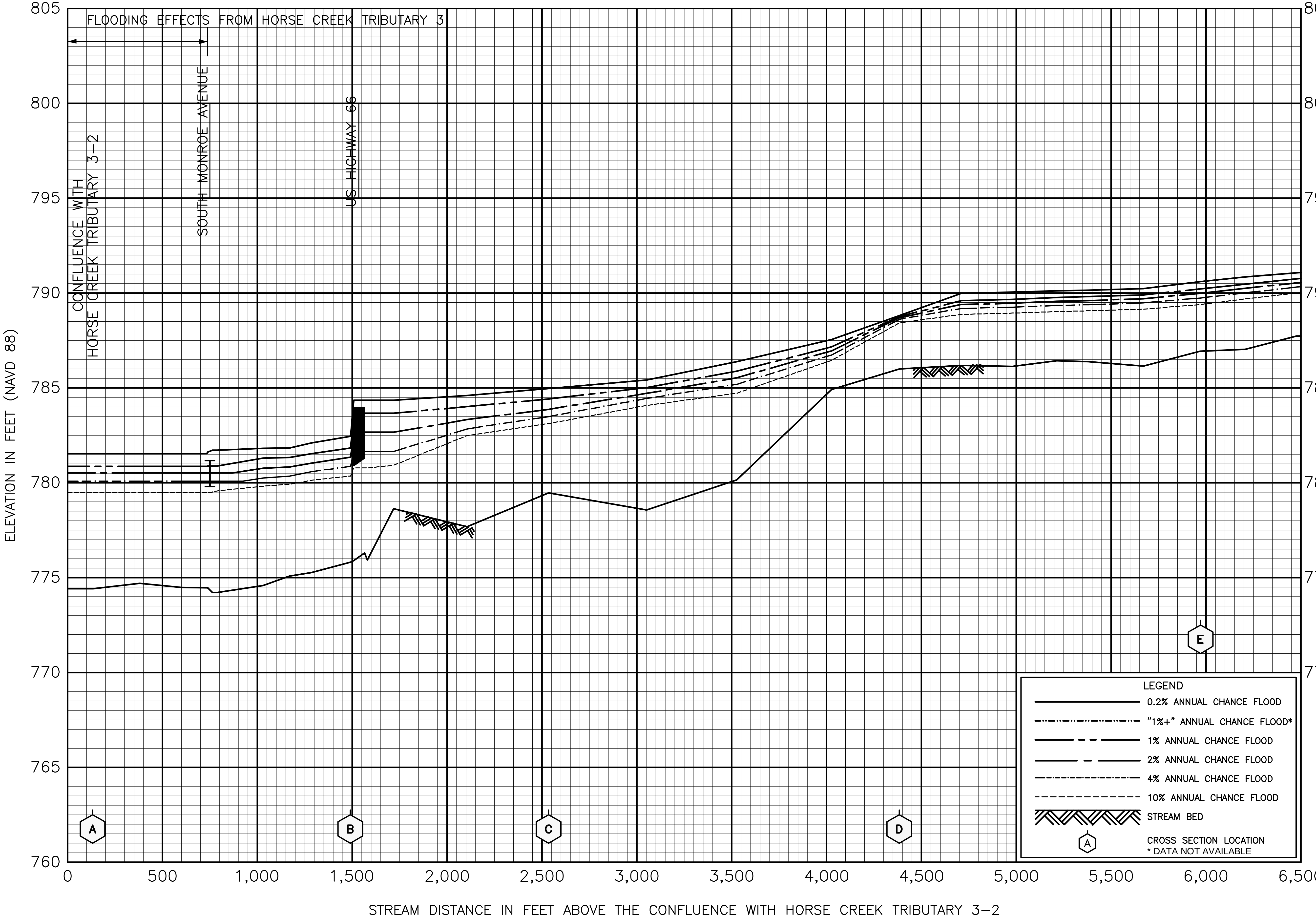
FLOOD PROFILES

HORSE CREEK TRIBUTARY 3-2

FEDERAL EMERGENCY MANAGEMENT AGENCY

OTTAWA COUNTY, OK

AND INCORPORATED AREAS



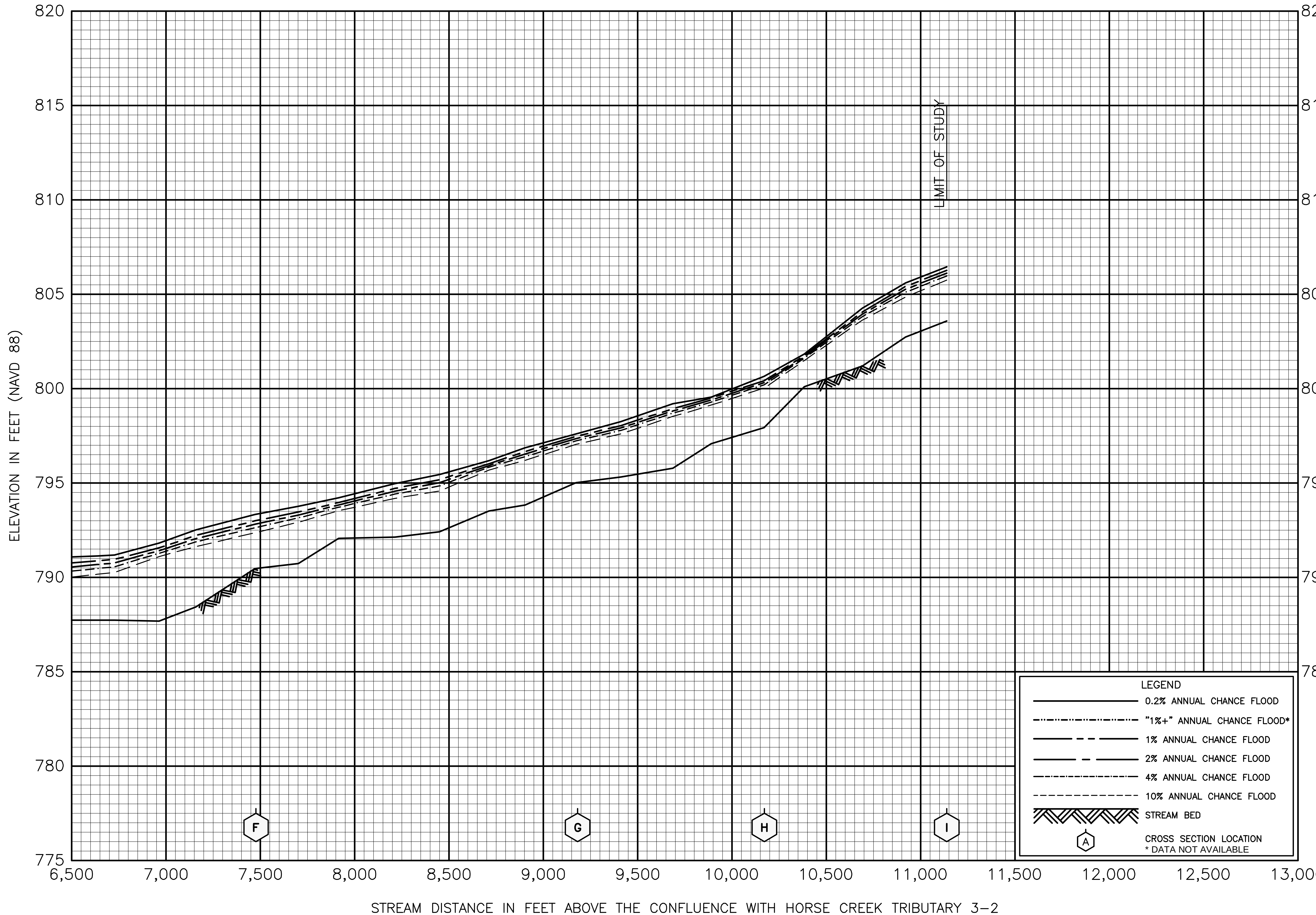
FLOOD PROFILES

HORSE CREEK TRIBUTARY 3-2-1

FEDERAL EMERGENCY MANAGEMENT AGENCY

OTTAWA COUNTY, OK

AND INCORPORATED AREAS



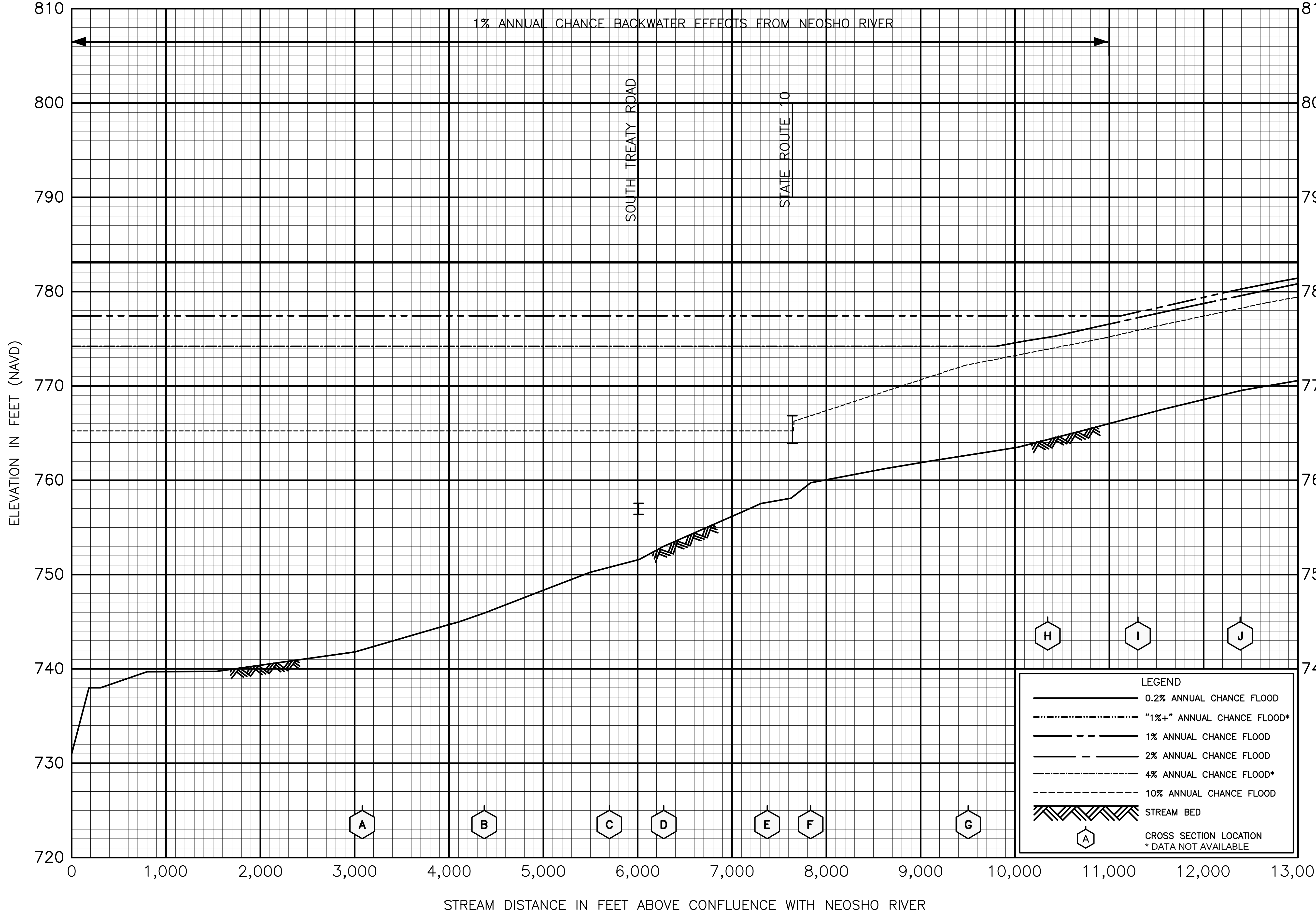
FLOOD PROFILES

HORSE CREEK TRIBUTARY 3-2-1

FEDERAL EMERGENCY MANAGEMENT AGENCY

OTTAWA COUNTY, OK

AND INCORPORATED AREAS



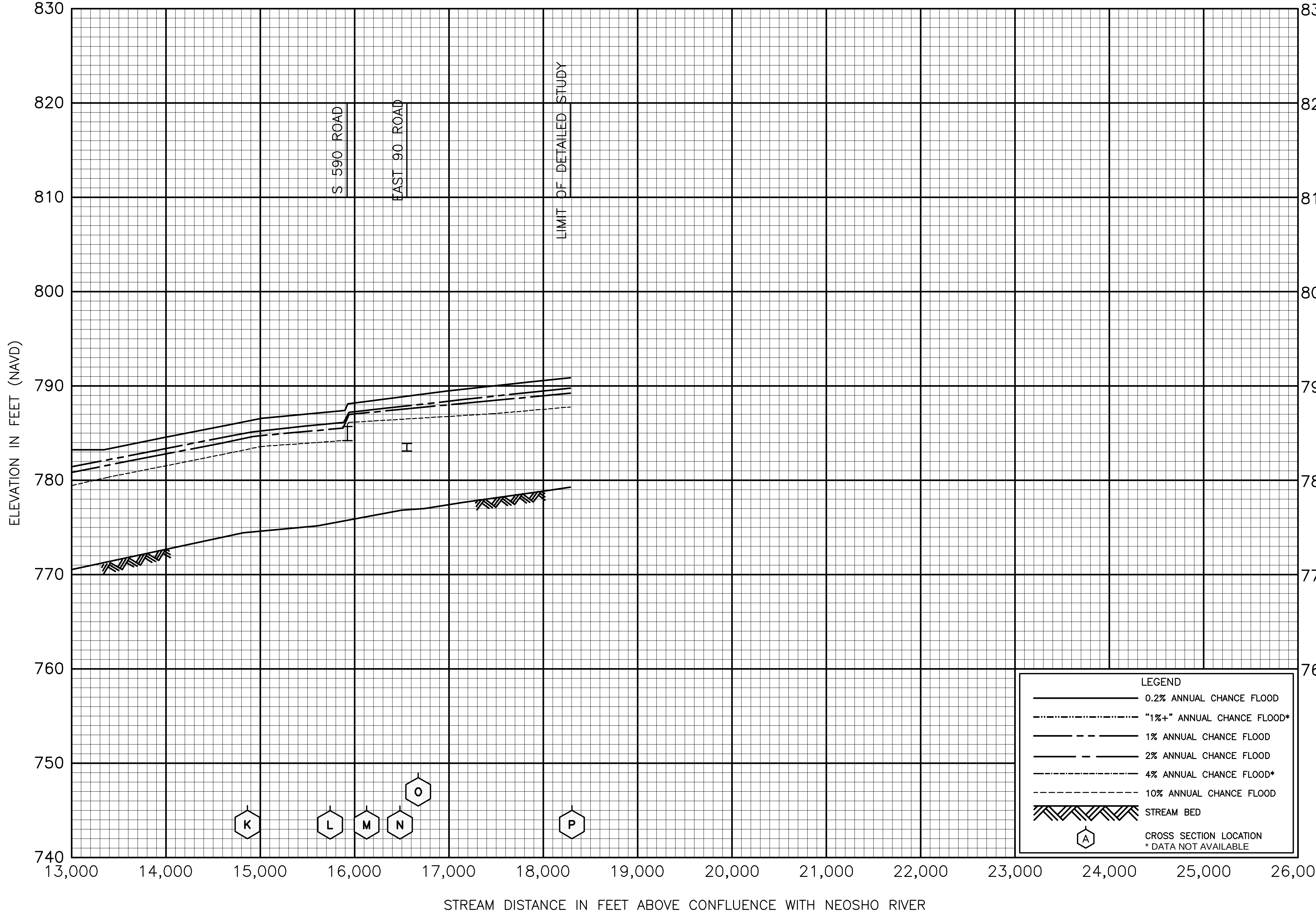
FLOOD PROFILES

LITTLE ELM CREEK

FEDERAL EMERGENCY MANAGEMENT AGENCY

OTTAWA COUNTY, OK

AND INCORPORATED AREAS



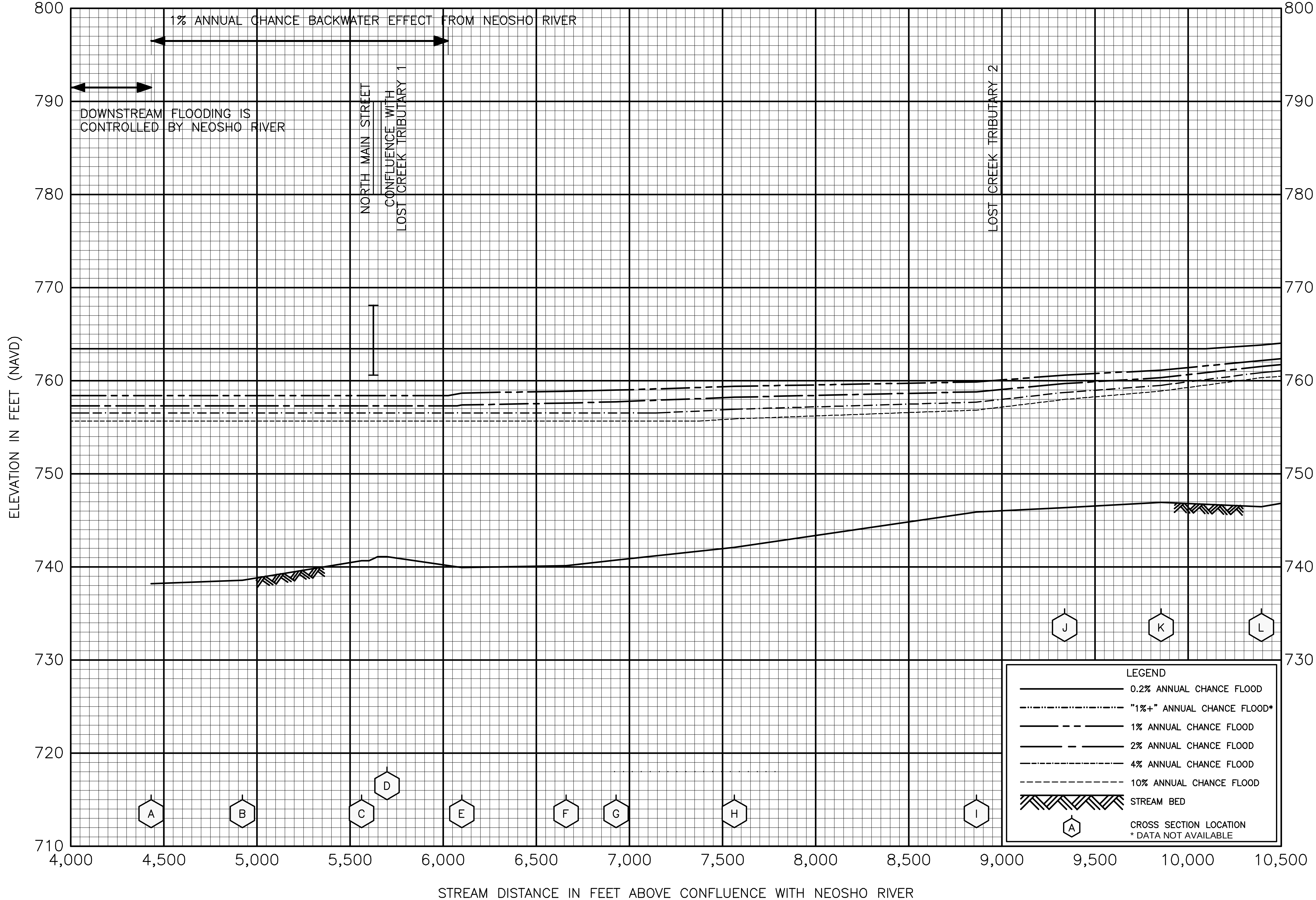
FLOOD PROFILES

LITTLE ELM CREEK

FEDERAL EMERGENCY MANAGEMENT AGENCY

OTTAWA COUNTY, OK

AND INCORPORATED AREAS



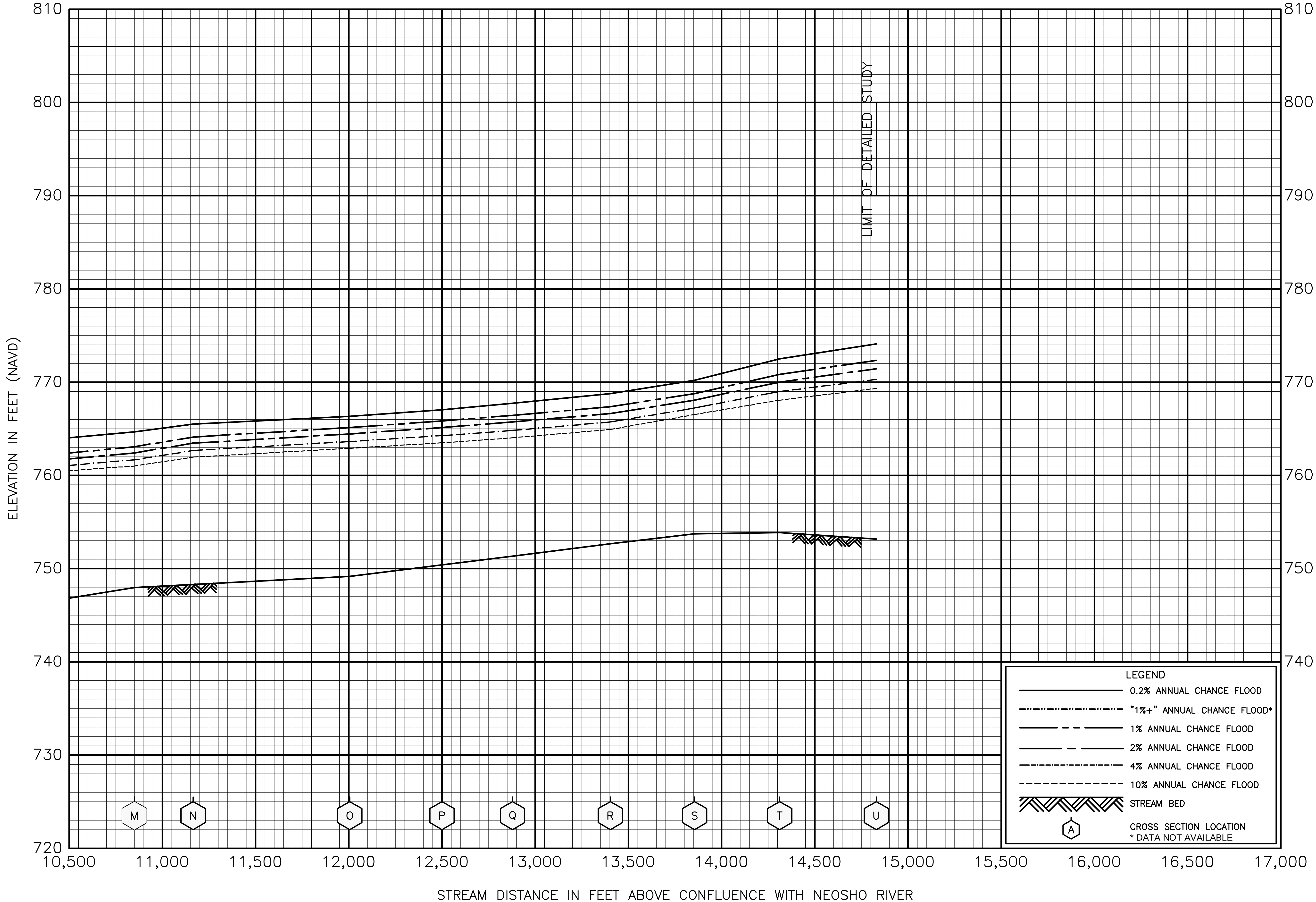
FLOOD PROFILES

LOST CREEK (AT WYANDOTTE)

FEDERAL EMERGENCY MANAGEMENT AGENCY

OTTAWA COUNTY, OK

AND INCORPORATED AREAS



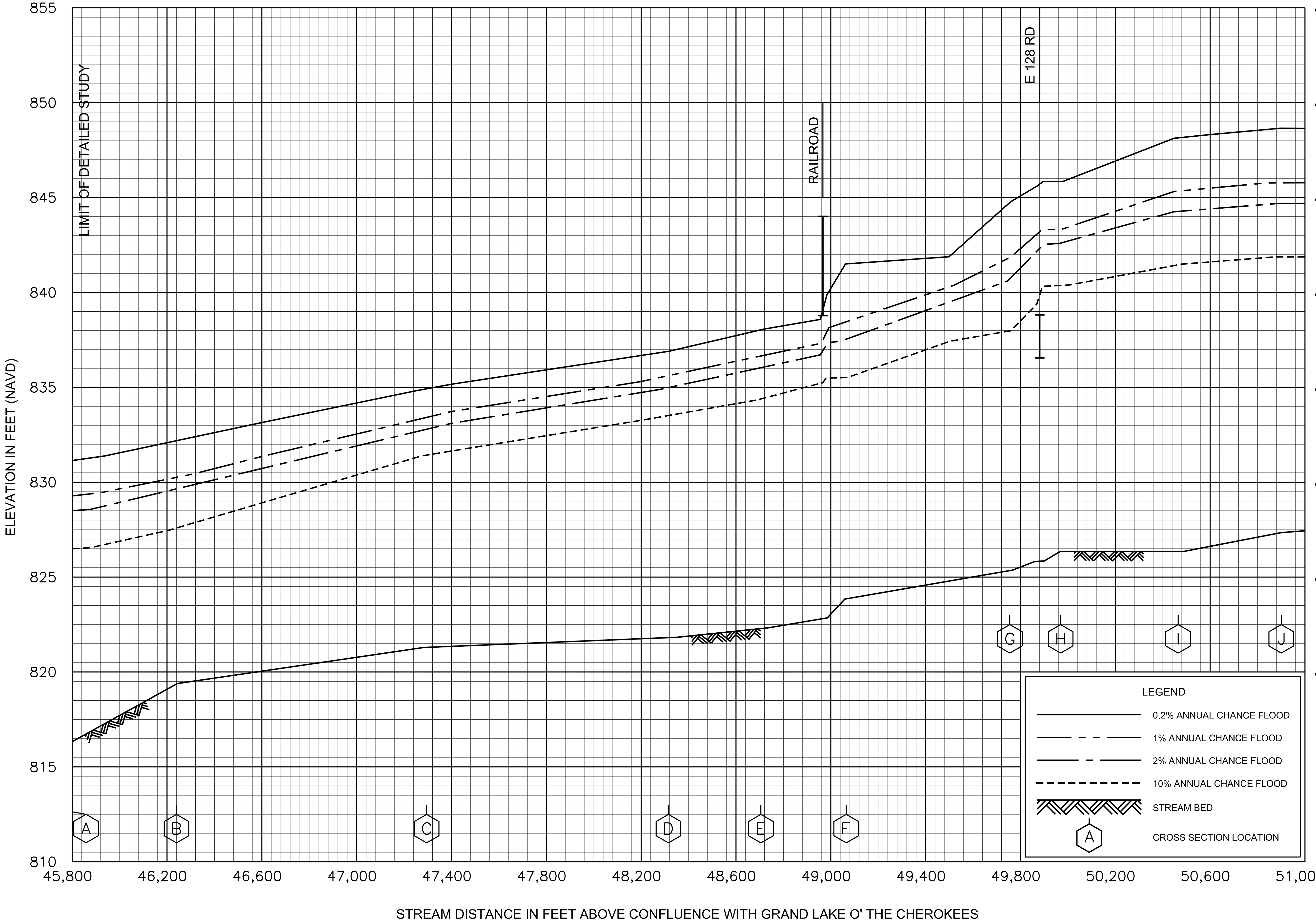
FLOOD PROFILES

LOST CREEK (AT WYANDOTTE)

FEDERAL EMERGENCY MANAGEMENT AGENCY

OTTAWA COUNTY, OK

AND INCORPORATED AREAS



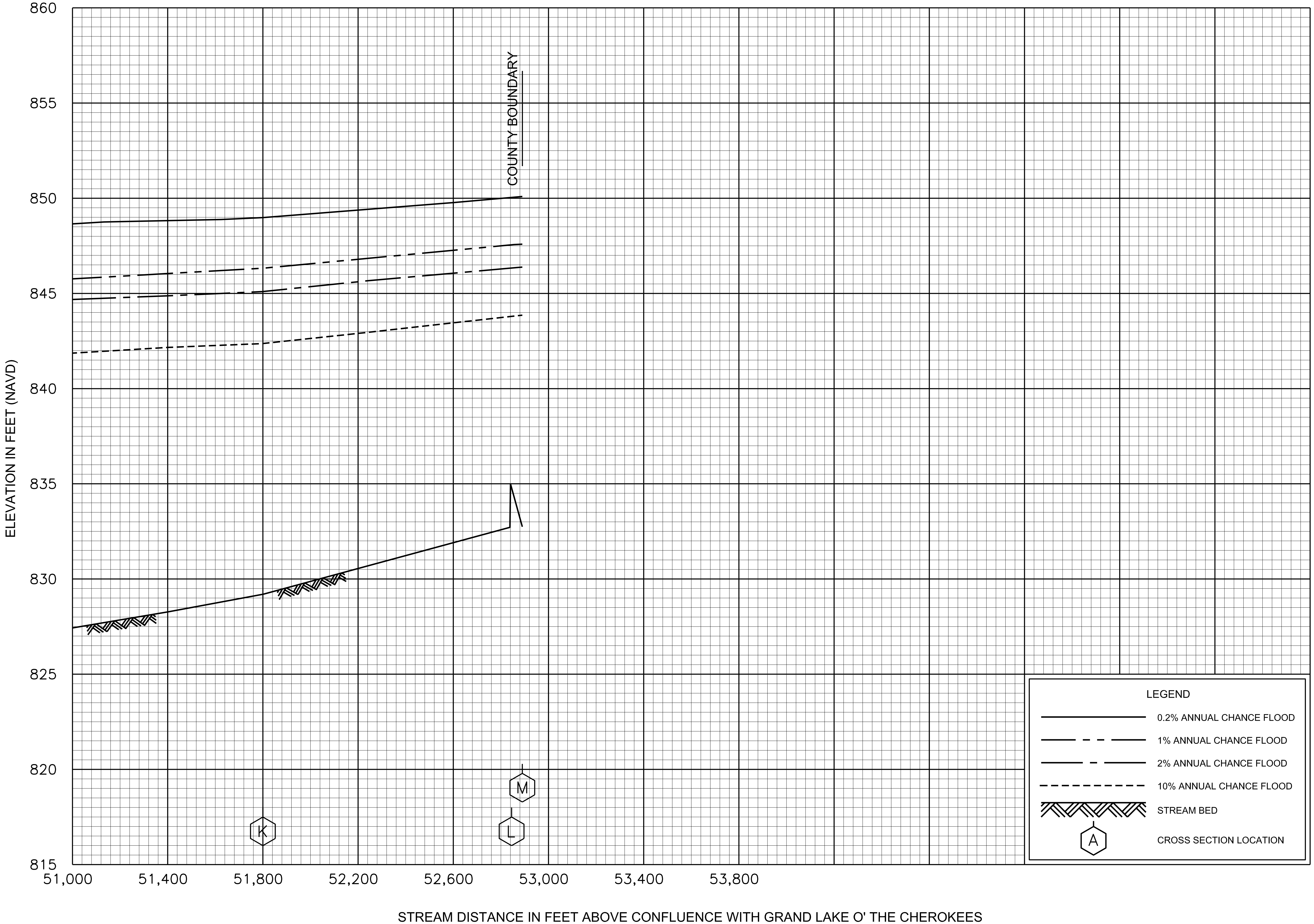
FLOOD PROFILES

LOST CREEK (UPPER REACH)

FEDERAL EMERGENCY MANAGEMENT AGENCY

OTTAWA COUNTY, OK

AND INCORPORATED AREAS



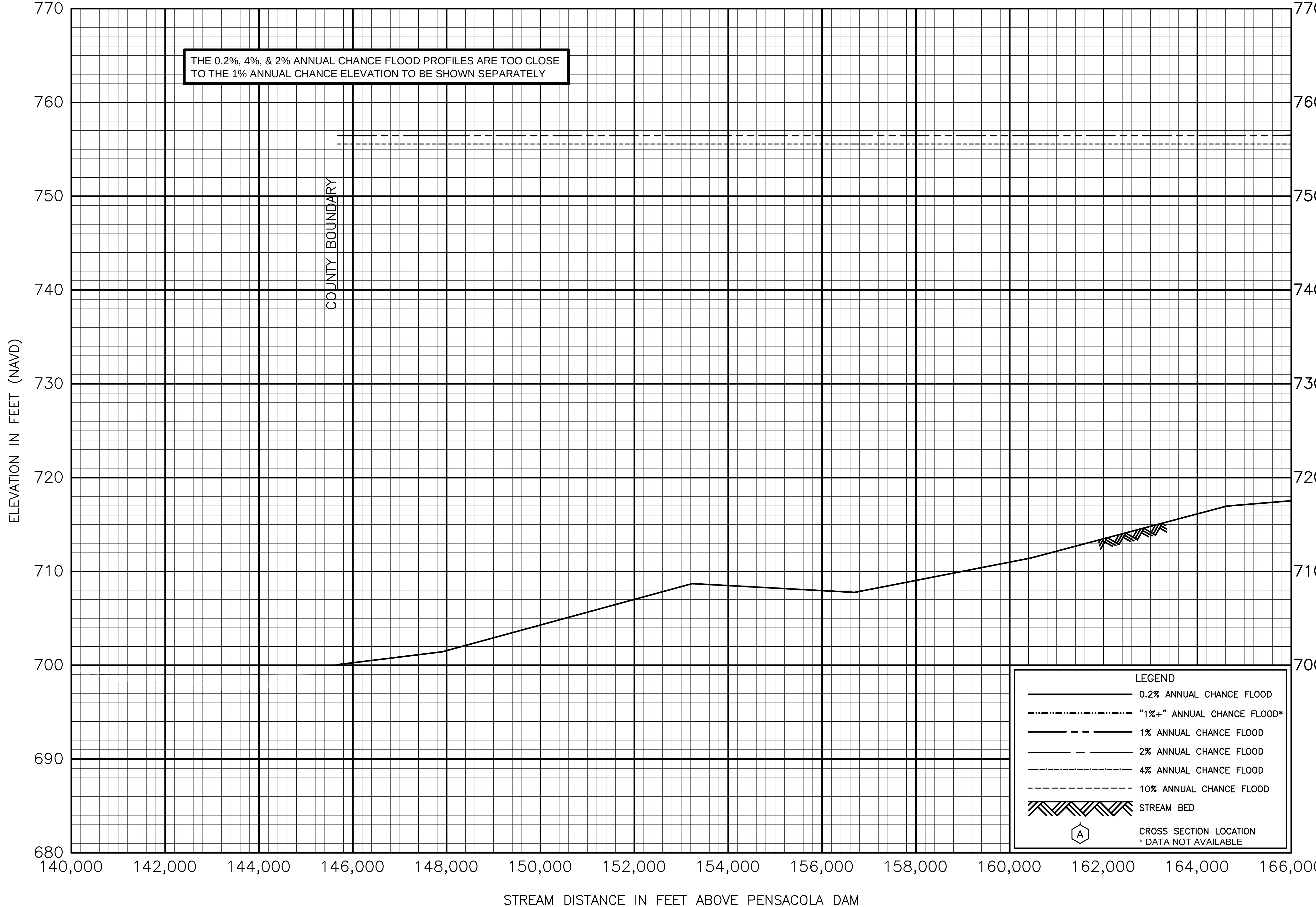
FLOOD PROFILES

LOST CREEK (UPPER REACH)

FEDERAL EMERGENCY MANAGEMENT AGENCY

OTTAWA COUNTY, OK

AND INCORPORATED AREAS



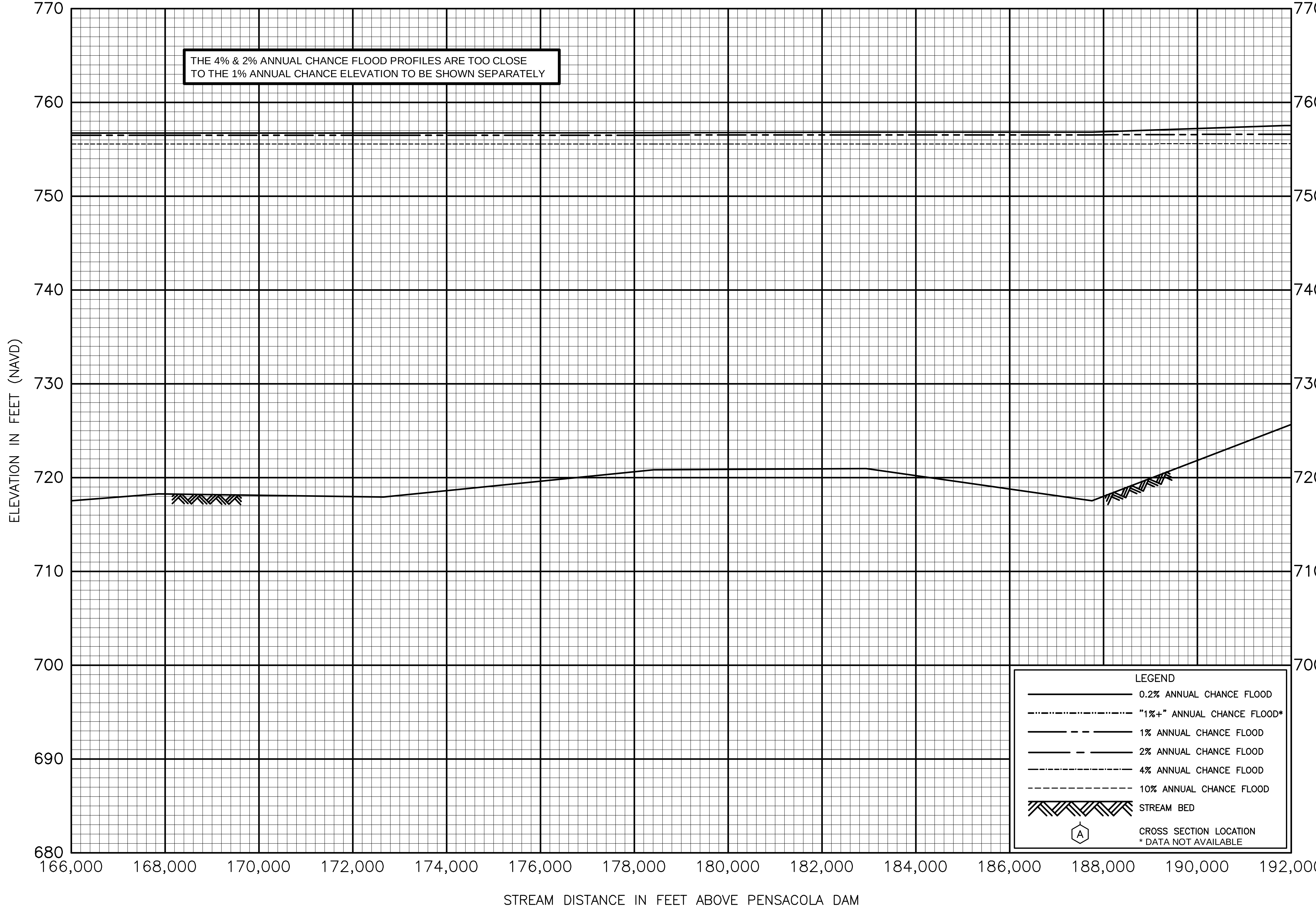
FLOOD PROFILES

NEOSHO RIVER

FEDERAL EMERGENCY MANAGEMENT AGENCY

OTTAWA COUNTY, OK

AND INCORPORATED AREAS



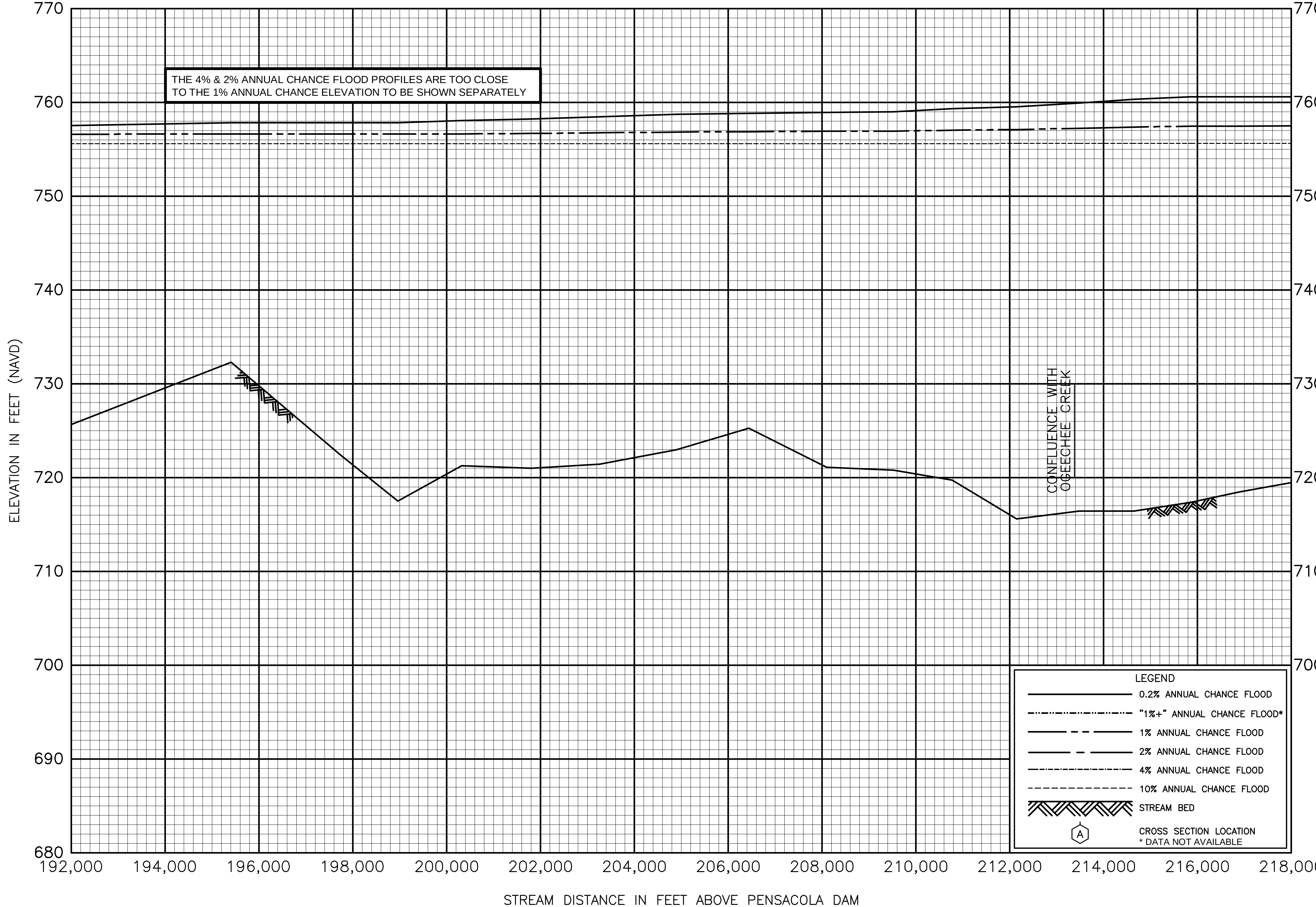
FLOOD PROFILES

NEOSHO RIVER

FEDERAL EMERGENCY MANAGEMENT AGENCY

OTTAWA COUNTY, OK

AND INCORPORATED AREAS



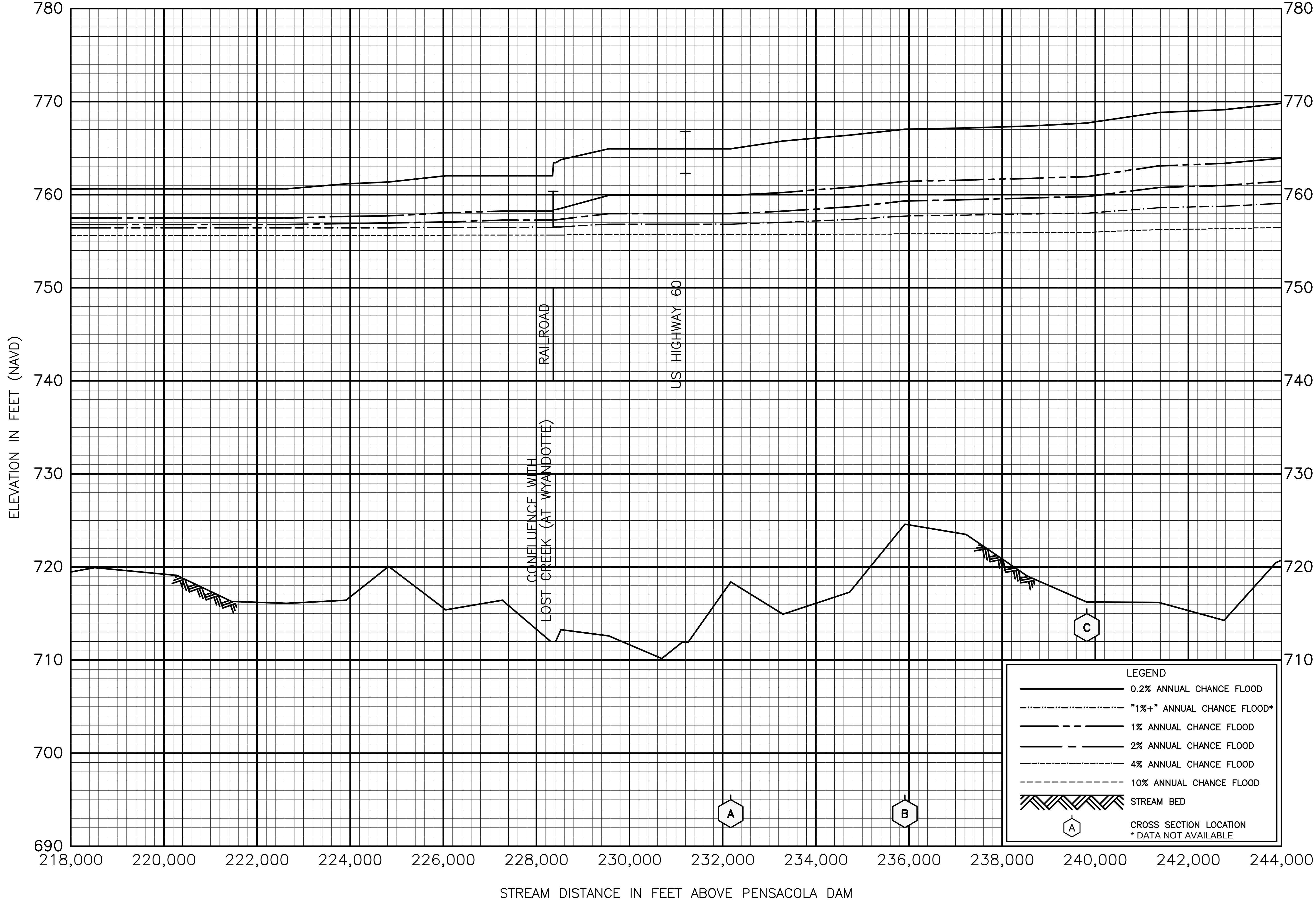
FLOOD PROFILES

NEOSHO RIVER

FEDERAL EMERGENCY MANAGEMENT AGENCY

OTTAWA COUNTY, OK

AND INCORPORATED AREAS



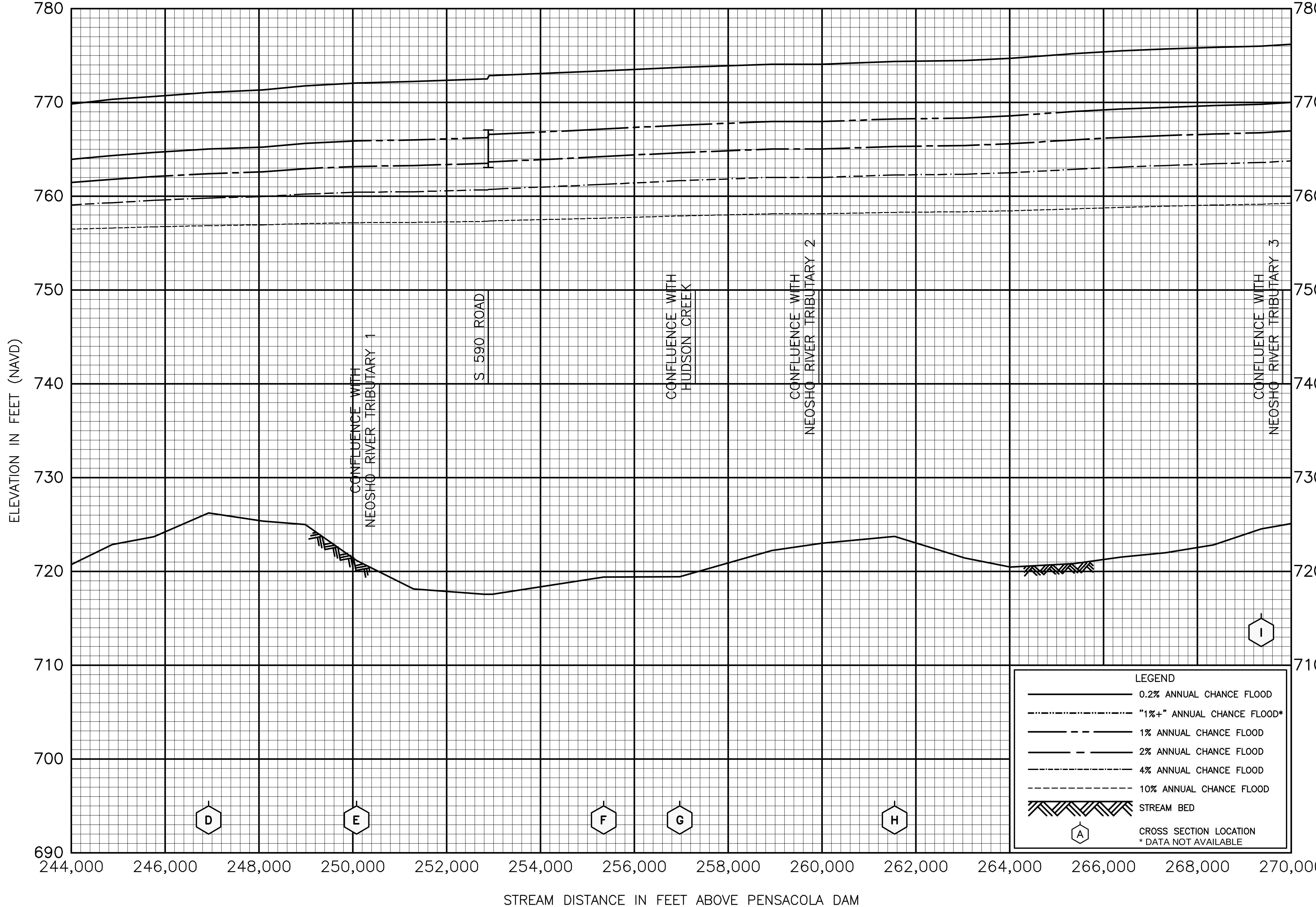
FLOOD PROFILES

NEOSHO RIVER

FEDERAL EMERGENCY MANAGEMENT AGENCY

OTTAWA COUNTY, OK

AND INCORPORATED AREAS



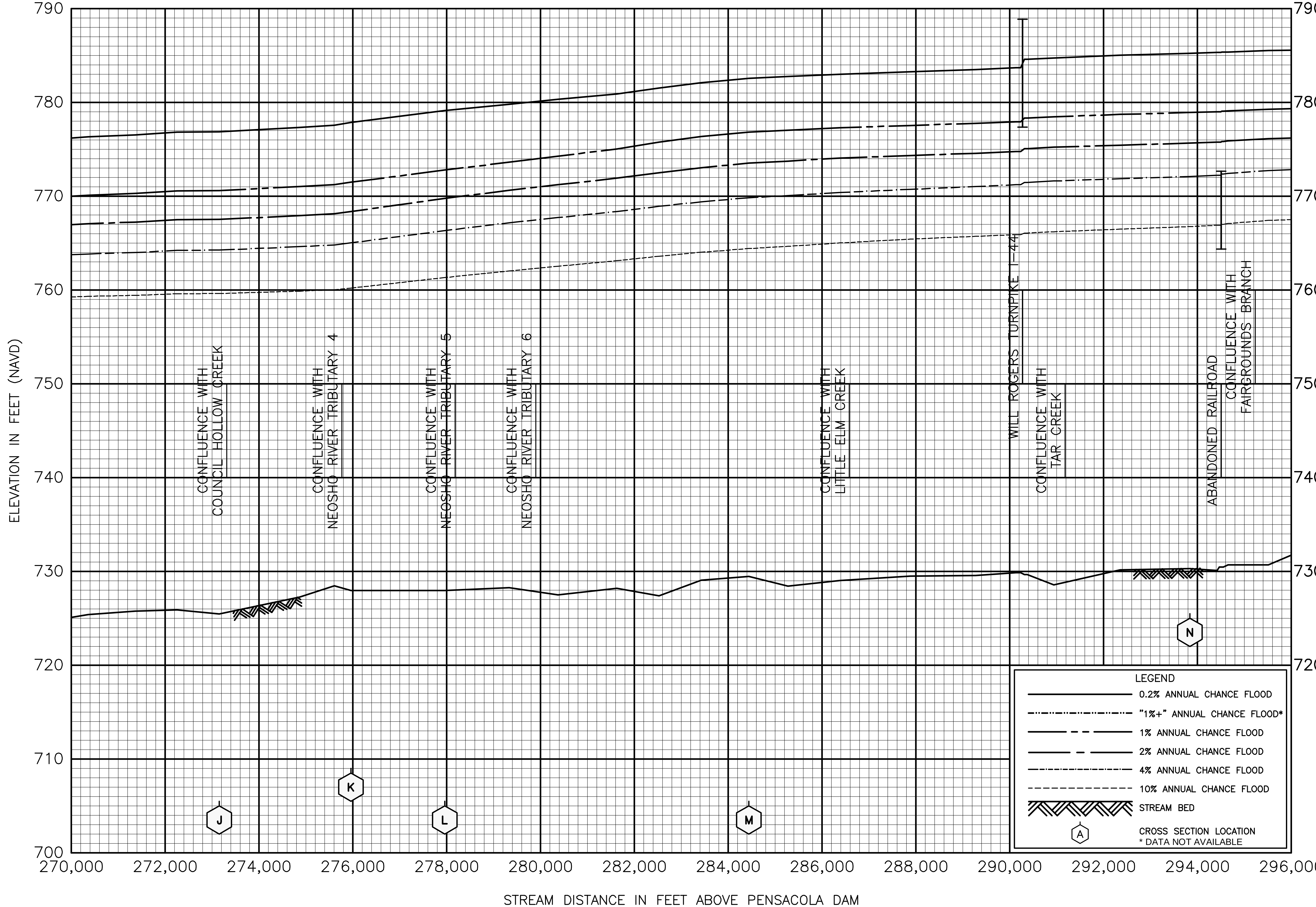
FLOOD PROFILES

NEOSHO RIVER

FEDERAL EMERGENCY MANAGEMENT AGENCY

OTTAWA COUNTY, OK

AND INCORPORATED AREAS



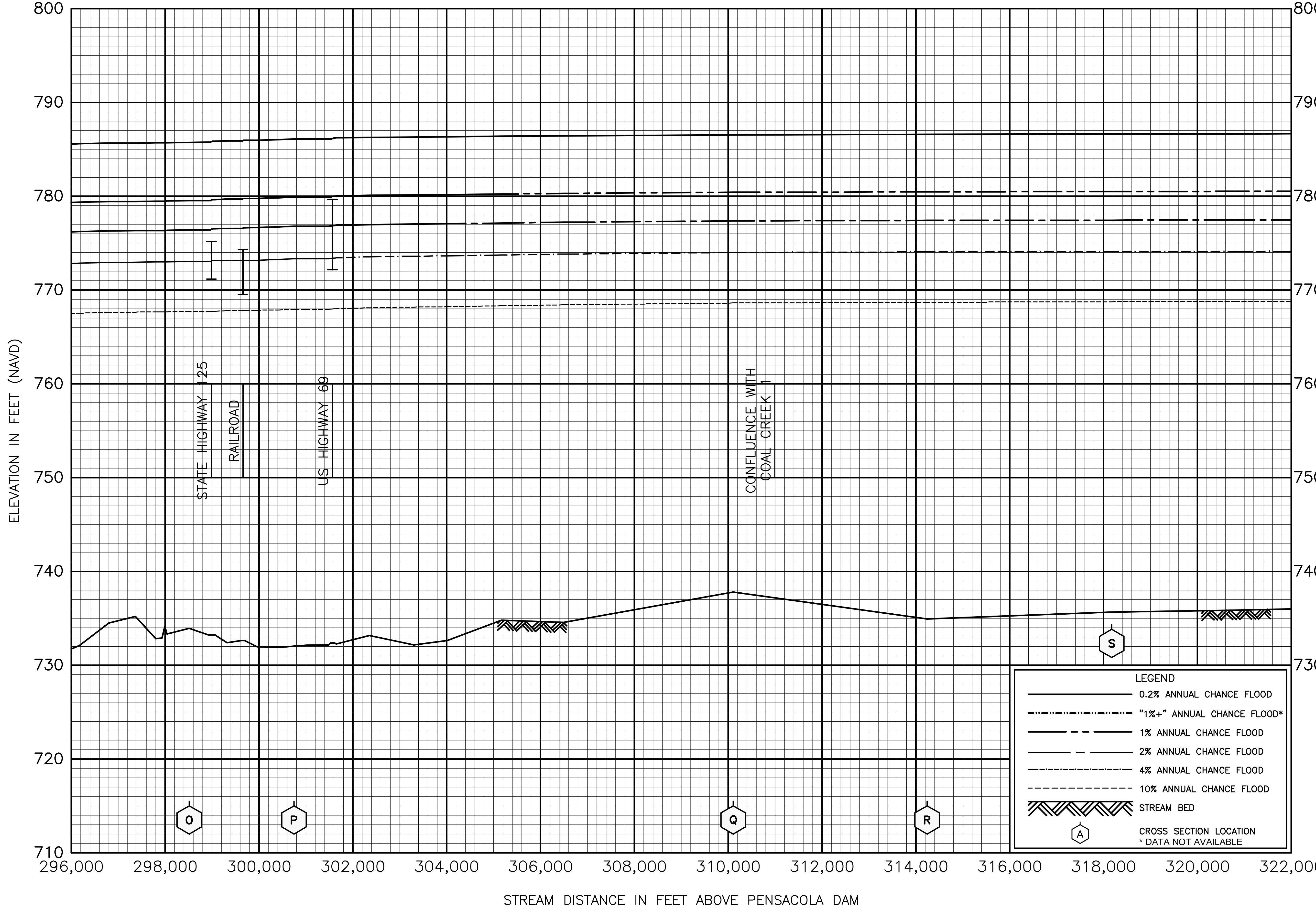
FLOOD PROFILES

NEOSHO RIVER

FEDERAL EMERGENCY MANAGEMENT AGENCY

OTTAWA COUNTY, OK

AND INCORPORATED AREAS



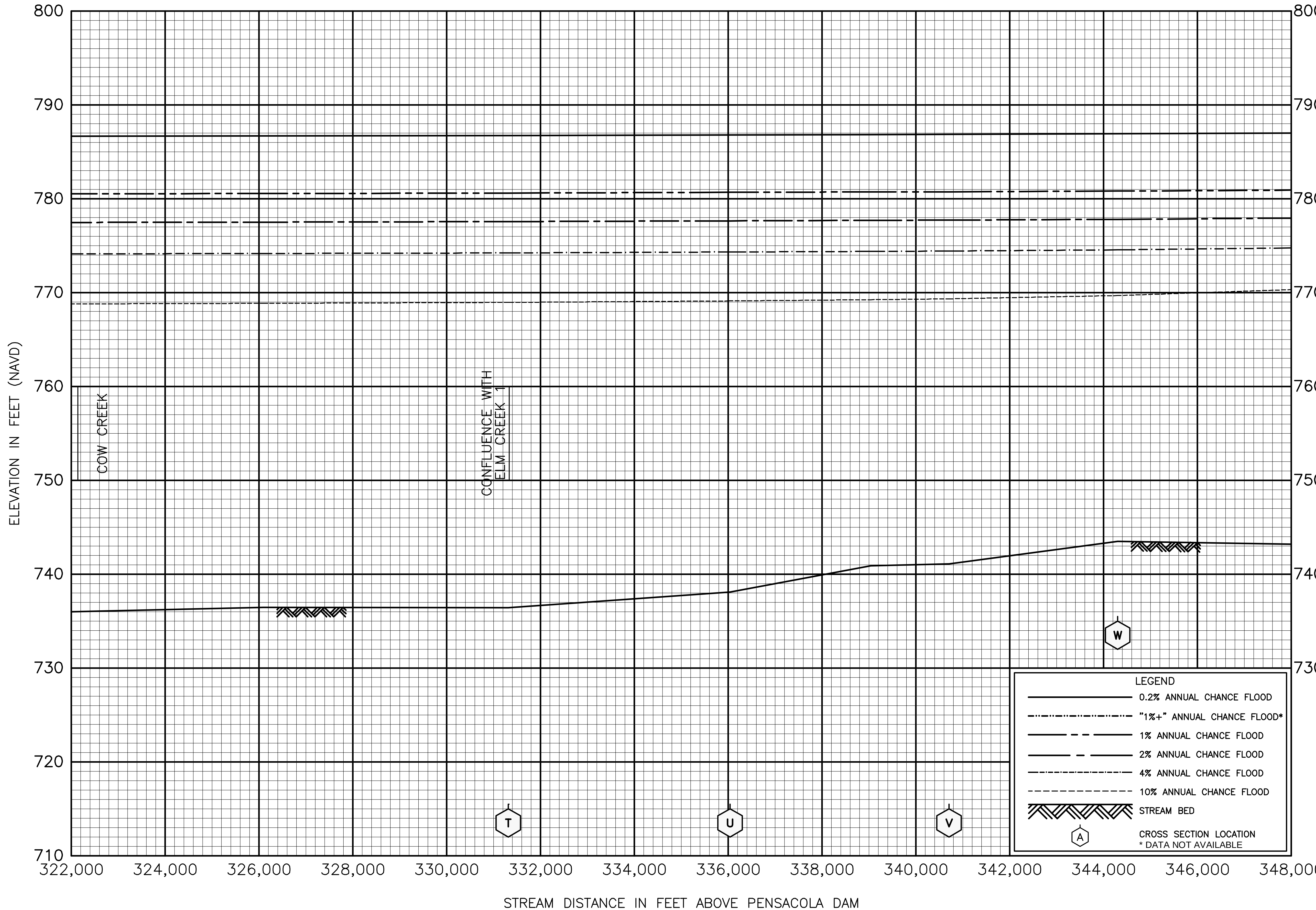
FLOOD PROFILES

NEOSHO RIVER

FEDERAL EMERGENCY MANAGEMENT AGENCY

OTTAWA COUNTY, OK

AND INCORPORATED AREAS



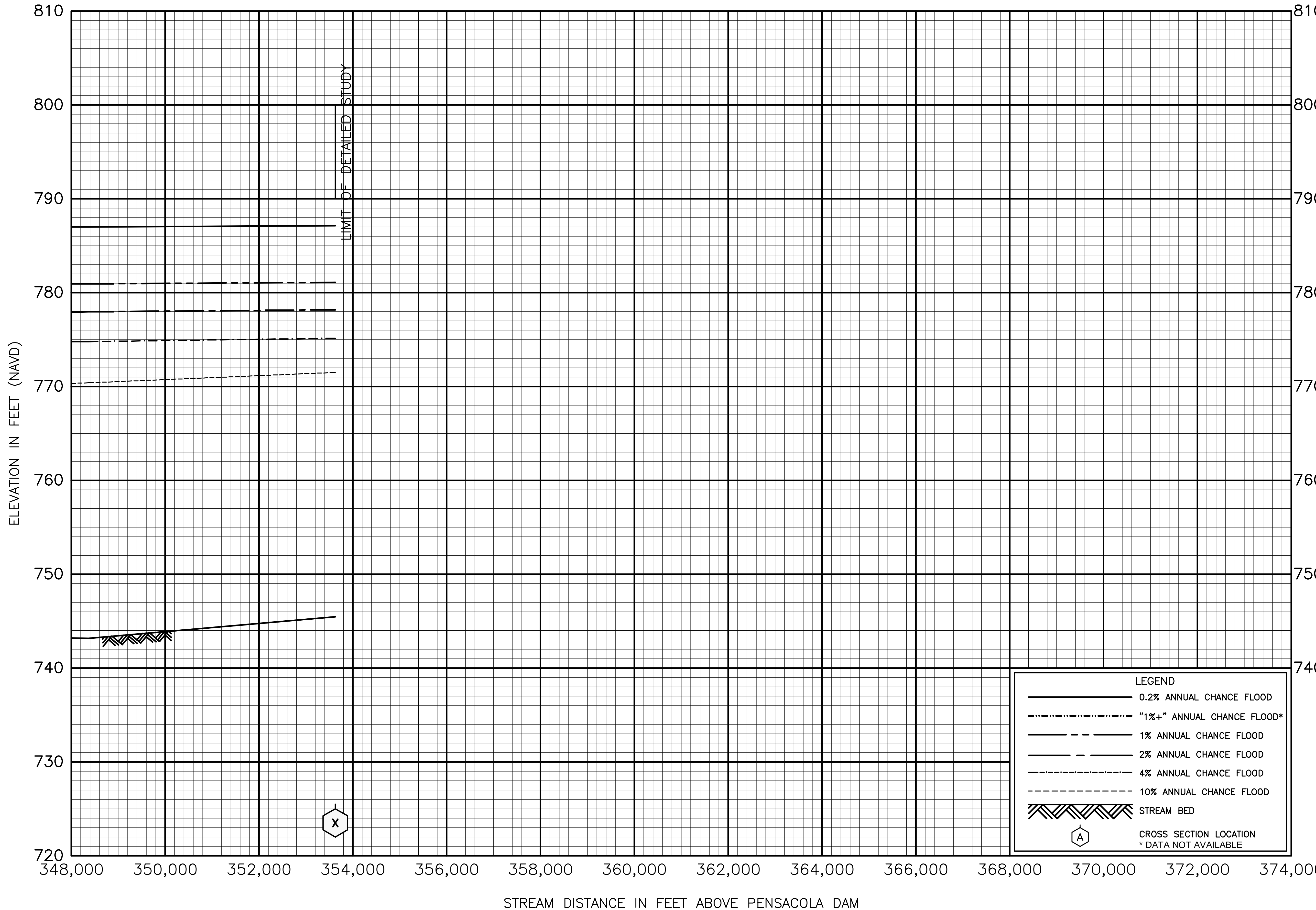
FLOOD PROFILES

NEOSHO RIVER

FEDERAL EMERGENCY MANAGEMENT AGENCY

OTTAWA COUNTY, OK

AND INCORPORATED AREAS



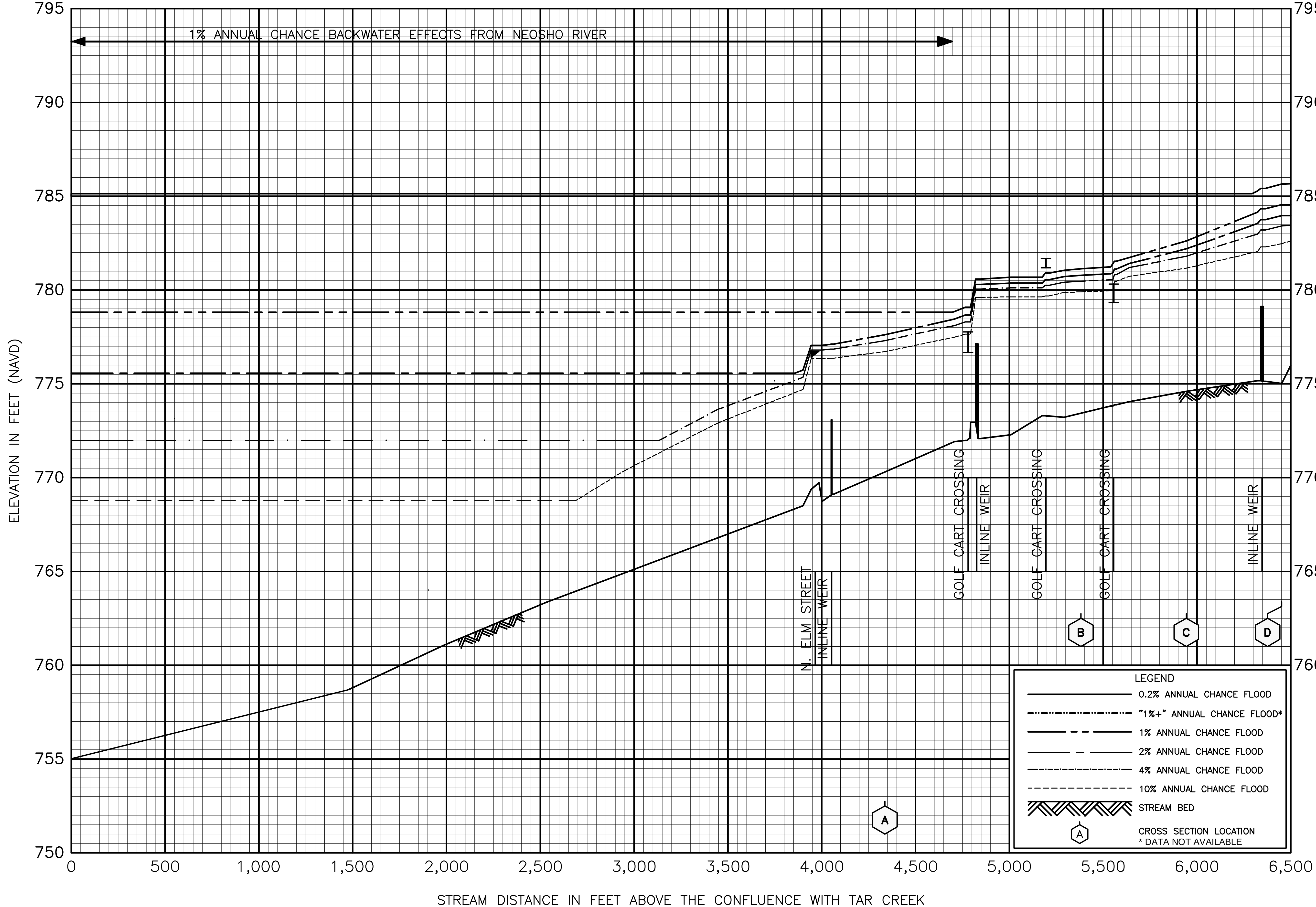
FLOOD PROFILES

NEOSHO RIVER

FEDERAL EMERGENCY MANAGEMENT AGENCY

OTTAWA COUNTY, OK

AND INCORPORATED AREAS



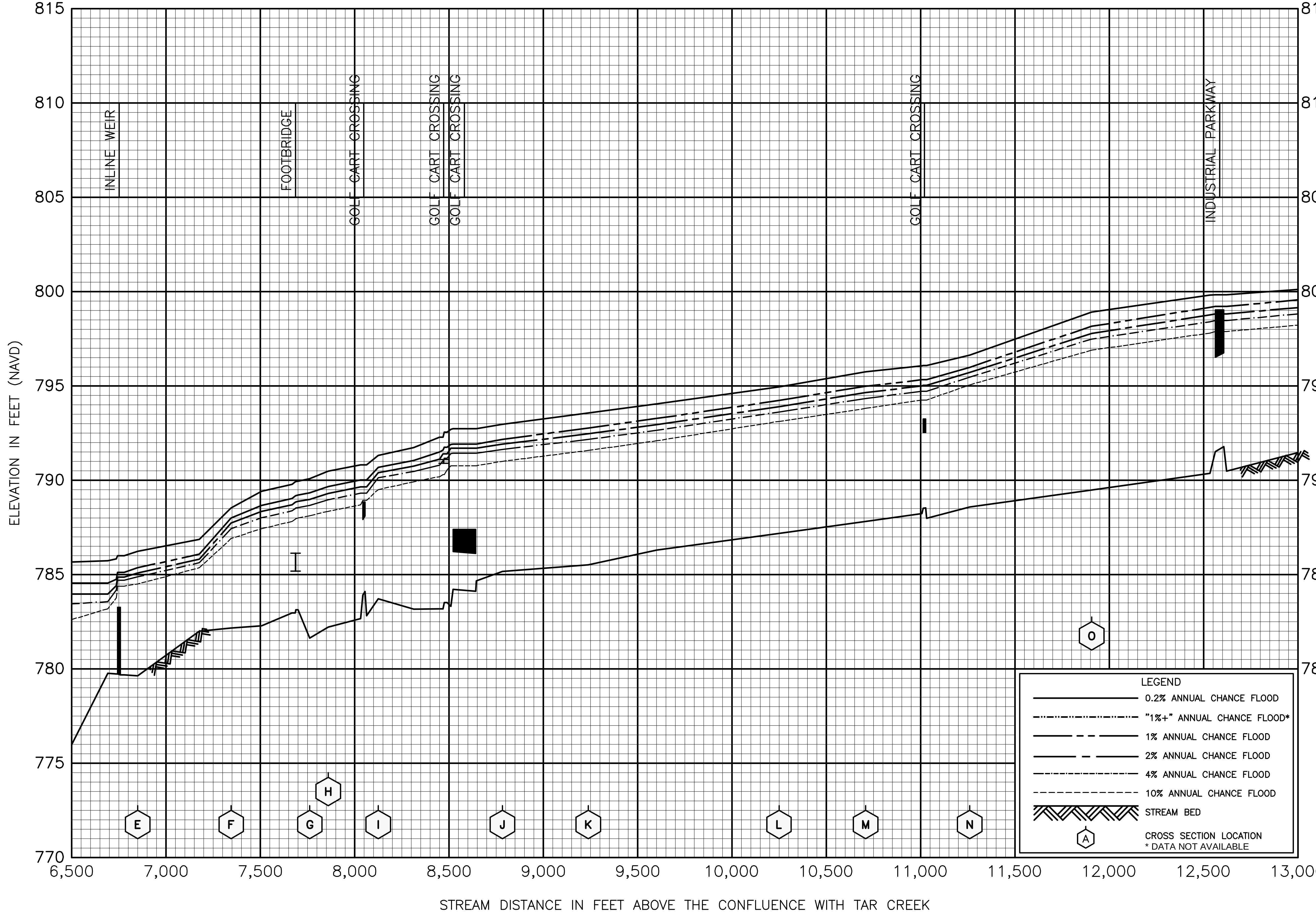
FLOOD PROFILES

QUAIL CREEK

FEDERAL EMERGENCY MANAGEMENT AGENCY

OTTAWA COUNTY, OK

AND INCORPORATED AREAS



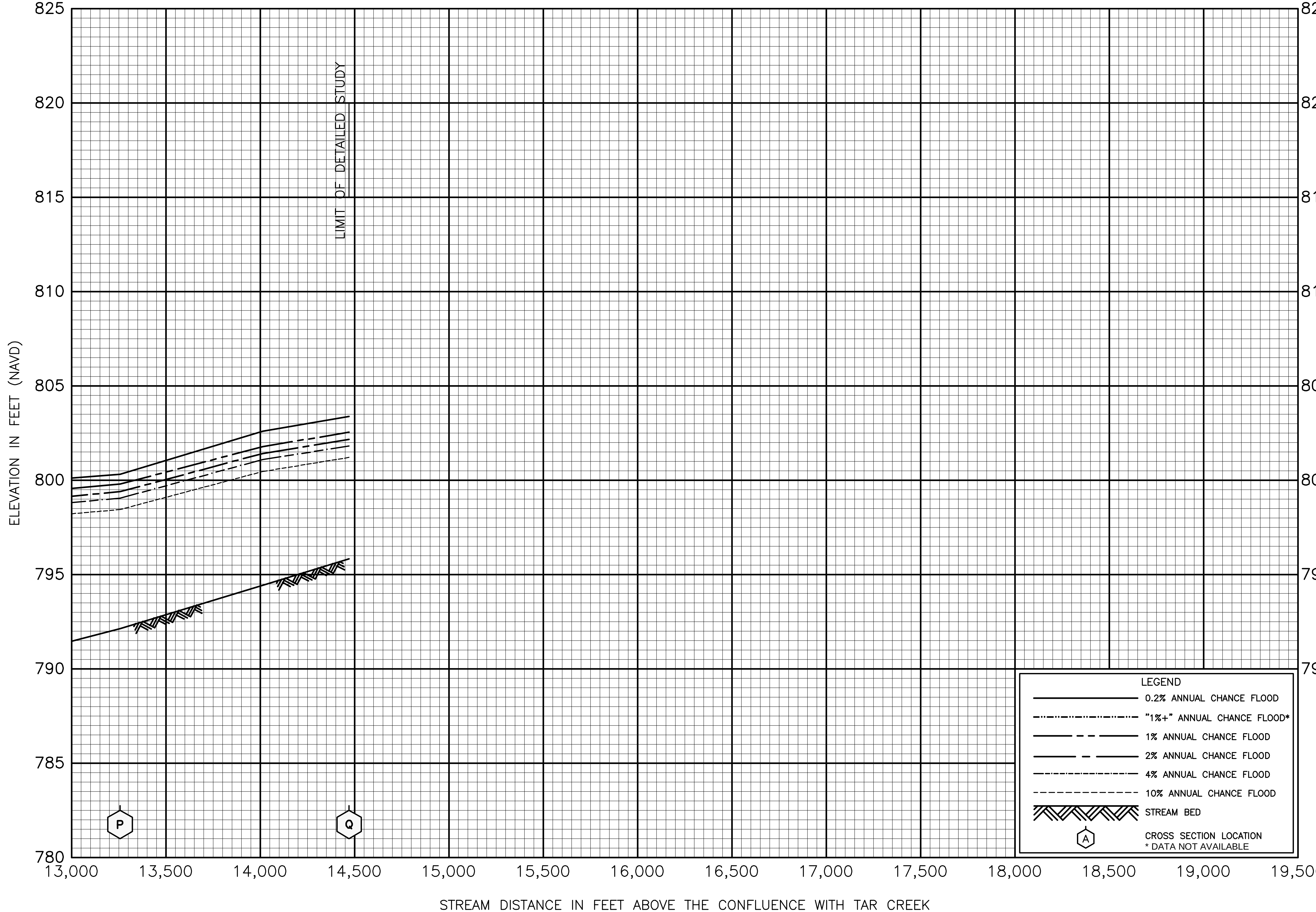
FLOOD PROFILES

QUAIL CREEK

FEDERAL EMERGENCY MANAGEMENT AGENCY

OTTAWA COUNTY, OK

AND INCORPORATED AREAS



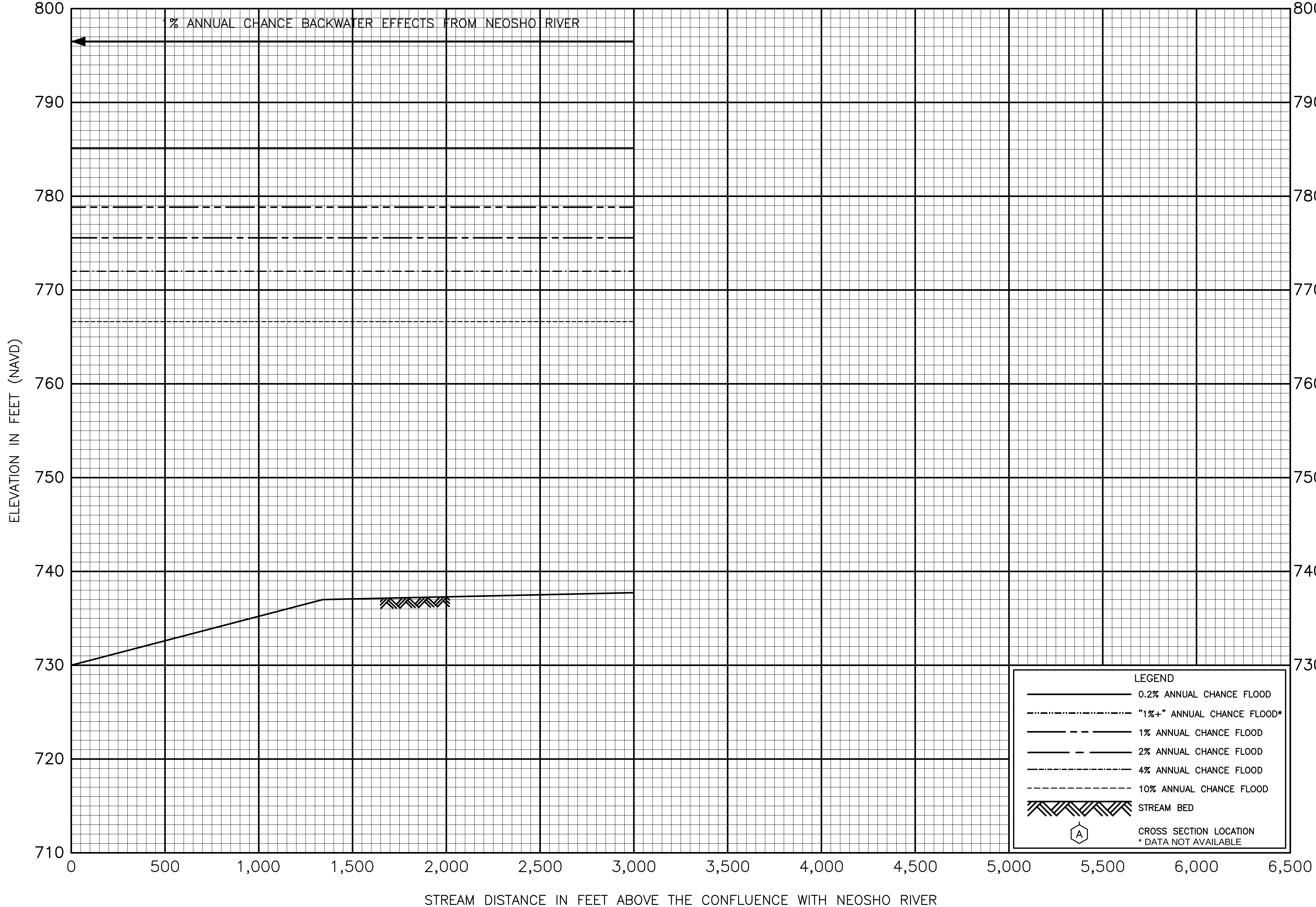
FLOOD PROFILES

QUAIL CREEK

FEDERAL EMERGENCY MANAGEMENT AGENCY

OTTAWA COUNTY, OK

AND INCORPORATED AREAS



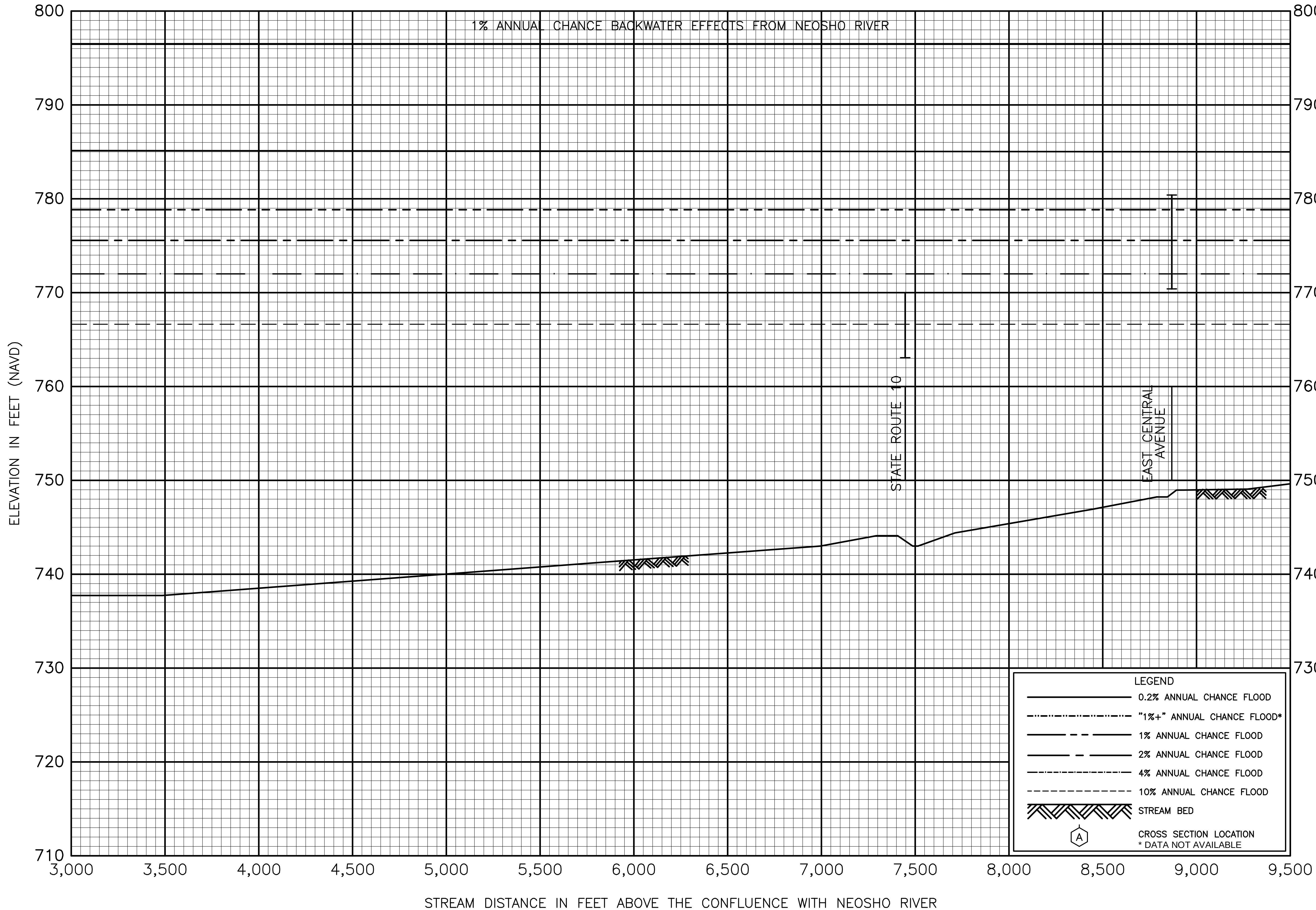
FLOOD PROFILES

TAR CREEK (AT MIAMI)

FEDERAL EMERGENCY MANAGEMENT AGENCY

OTTAWA COUNTY, OK

AND INCORPORATED AREAS



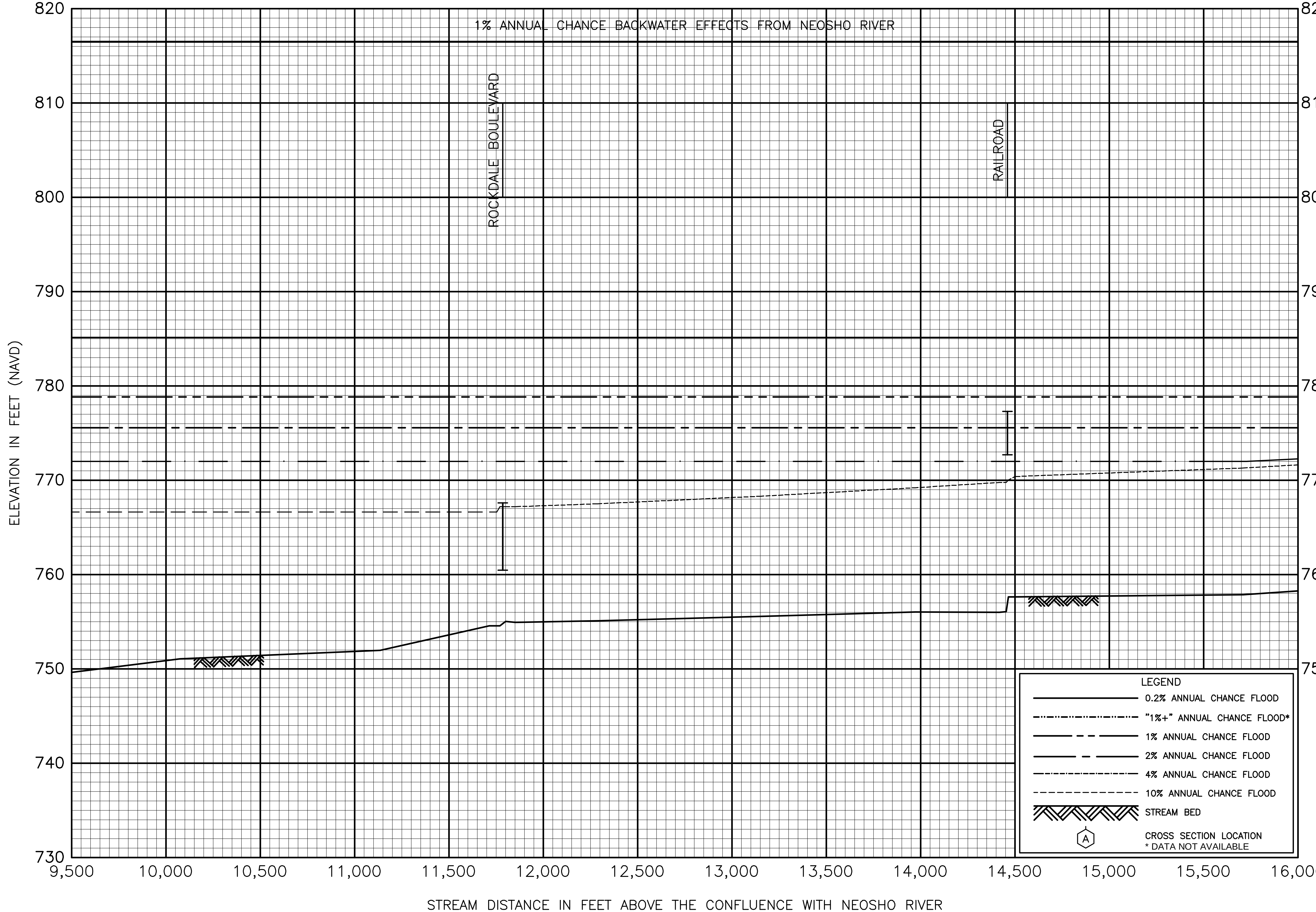
FLOOD PROFILES

TAR CREEK (AT MIAMI)

FEDERAL EMERGENCY MANAGEMENT AGENCY

OTTAWA COUNTY, OK

AND INCORPORATED AREAS



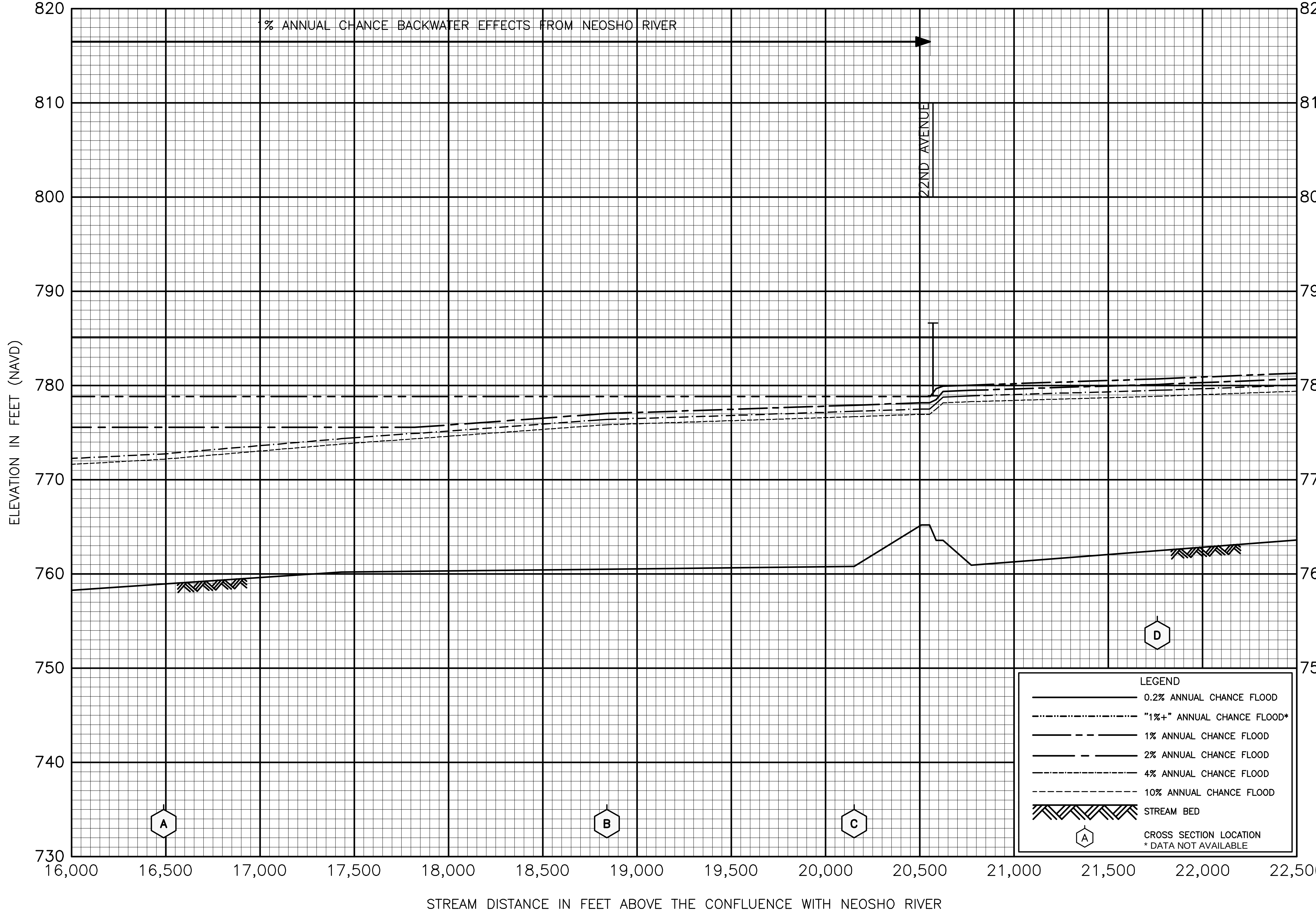
FLOOD PROFILES

TAR CREEK (AT MIAMI)

FEDERAL EMERGENCY MANAGEMENT AGENCY

OTTAWA COUNTY, OK

AND INCORPORATED AREAS



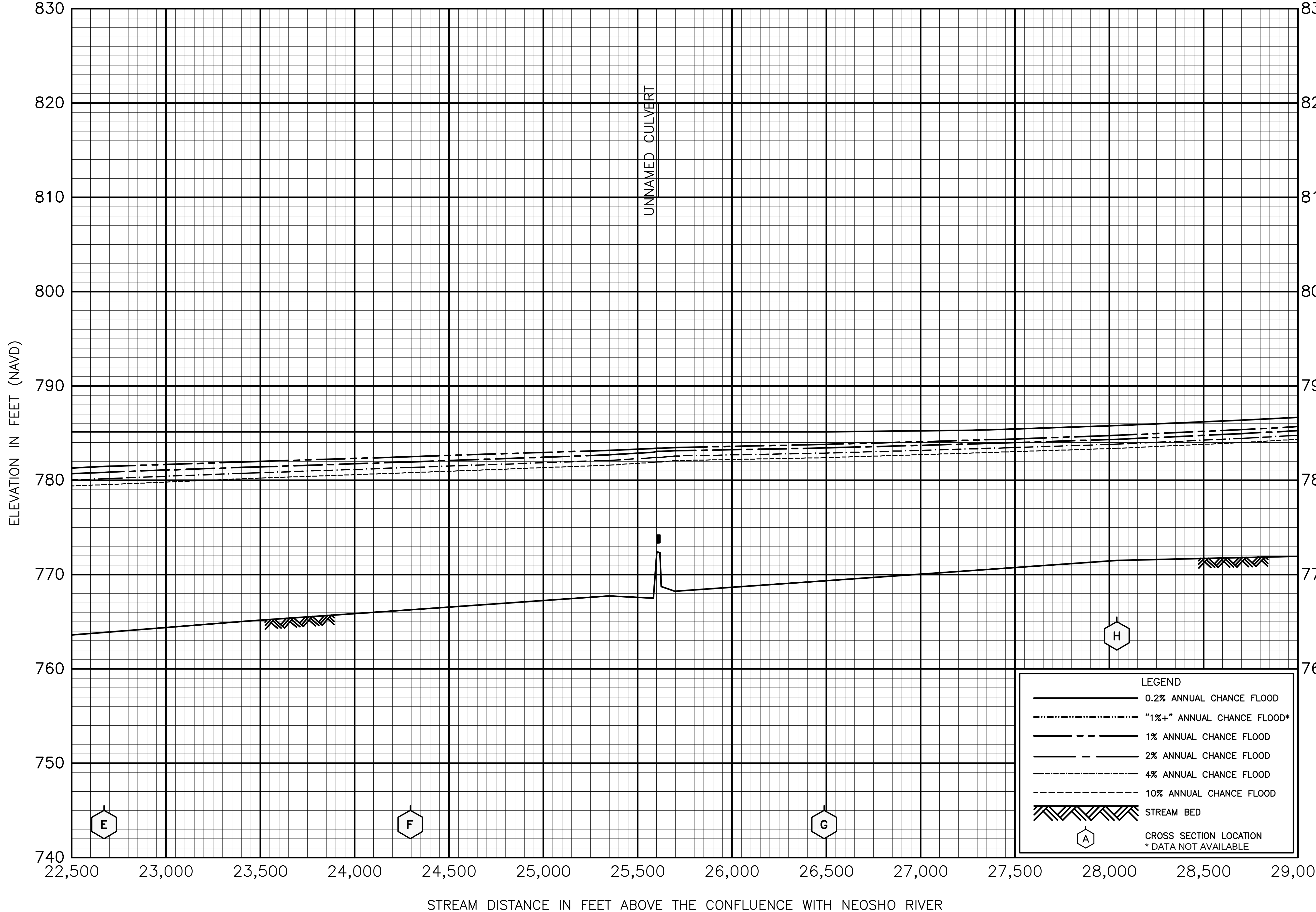
FLOOD PROFILES

TAR CREEK (AT MIAMI)

FEDERAL EMERGENCY MANAGEMENT AGENCY

OTTAWA COUNTY, OK

AND INCORPORATED AREAS



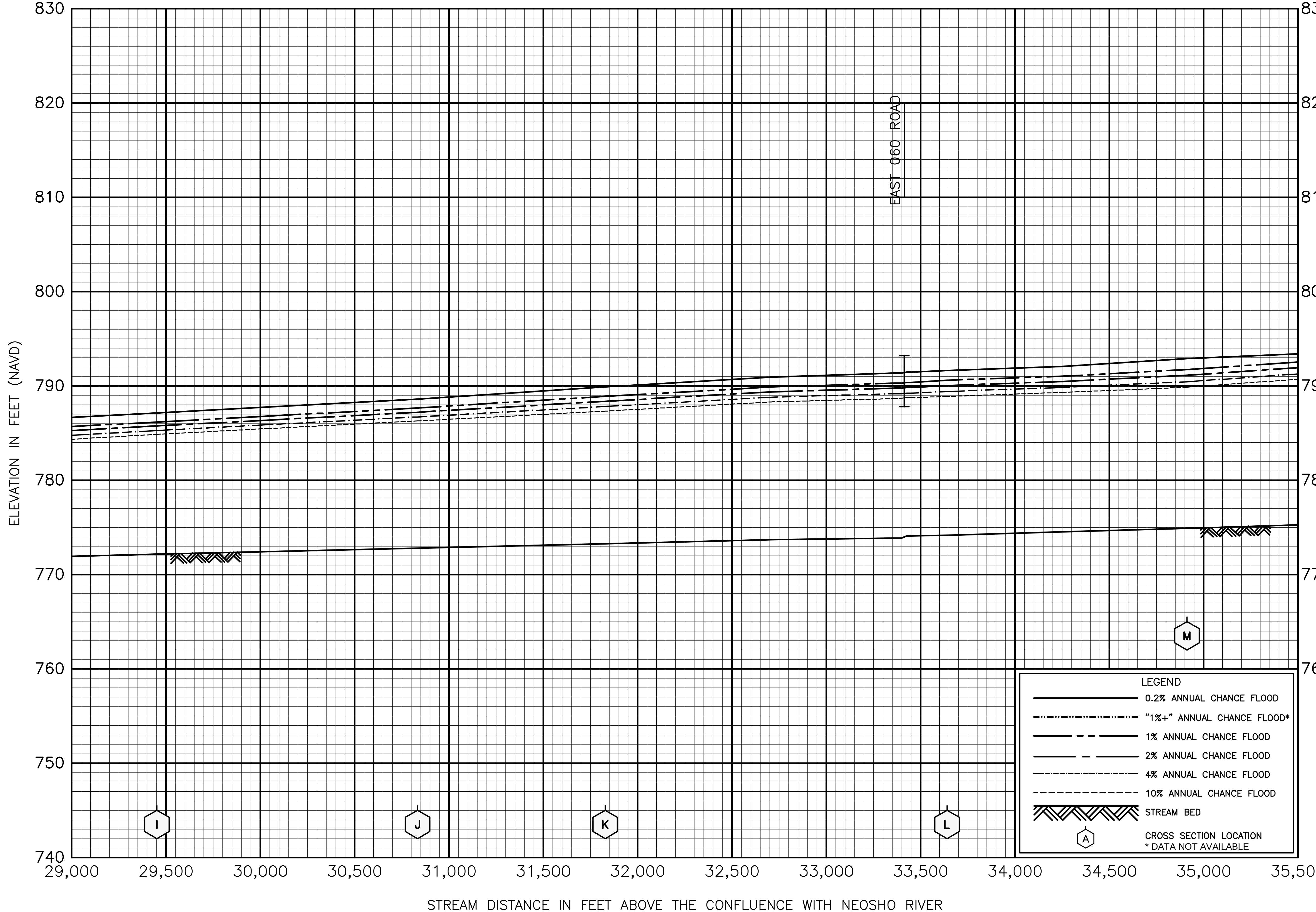
FLOOD PROFILES

TAR CREEK (AT MIAMI)

FEDERAL EMERGENCY MANAGEMENT AGENCY

OTTAWA COUNTY, OK

AND INCORPORATED AREAS



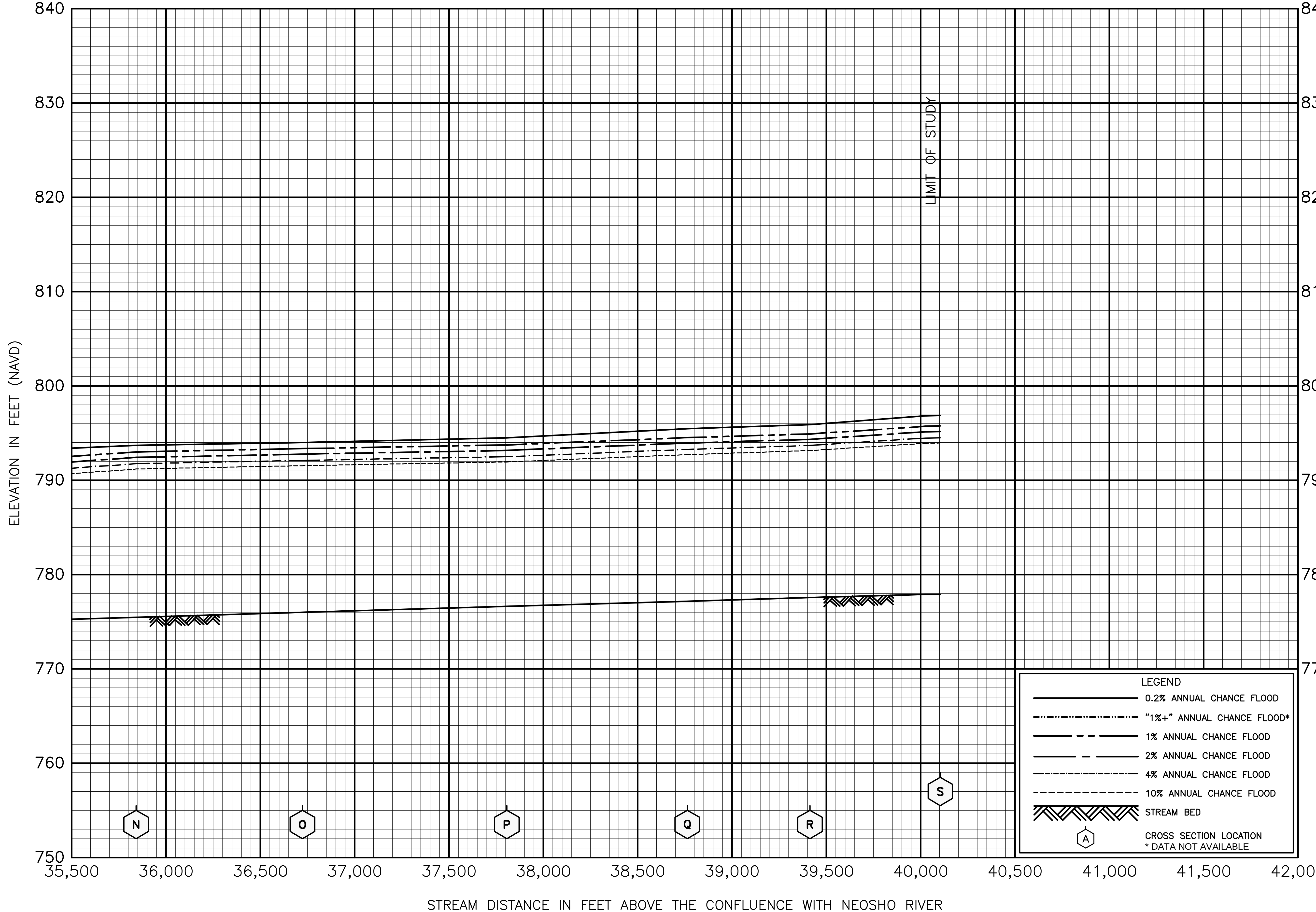
FLOOD PROFILES

TAR CREEK (AT MIAMI)

FEDERAL EMERGENCY MANAGEMENT AGENCY

OTTAWA COUNTY, OK

AND INCORPORATED AREAS

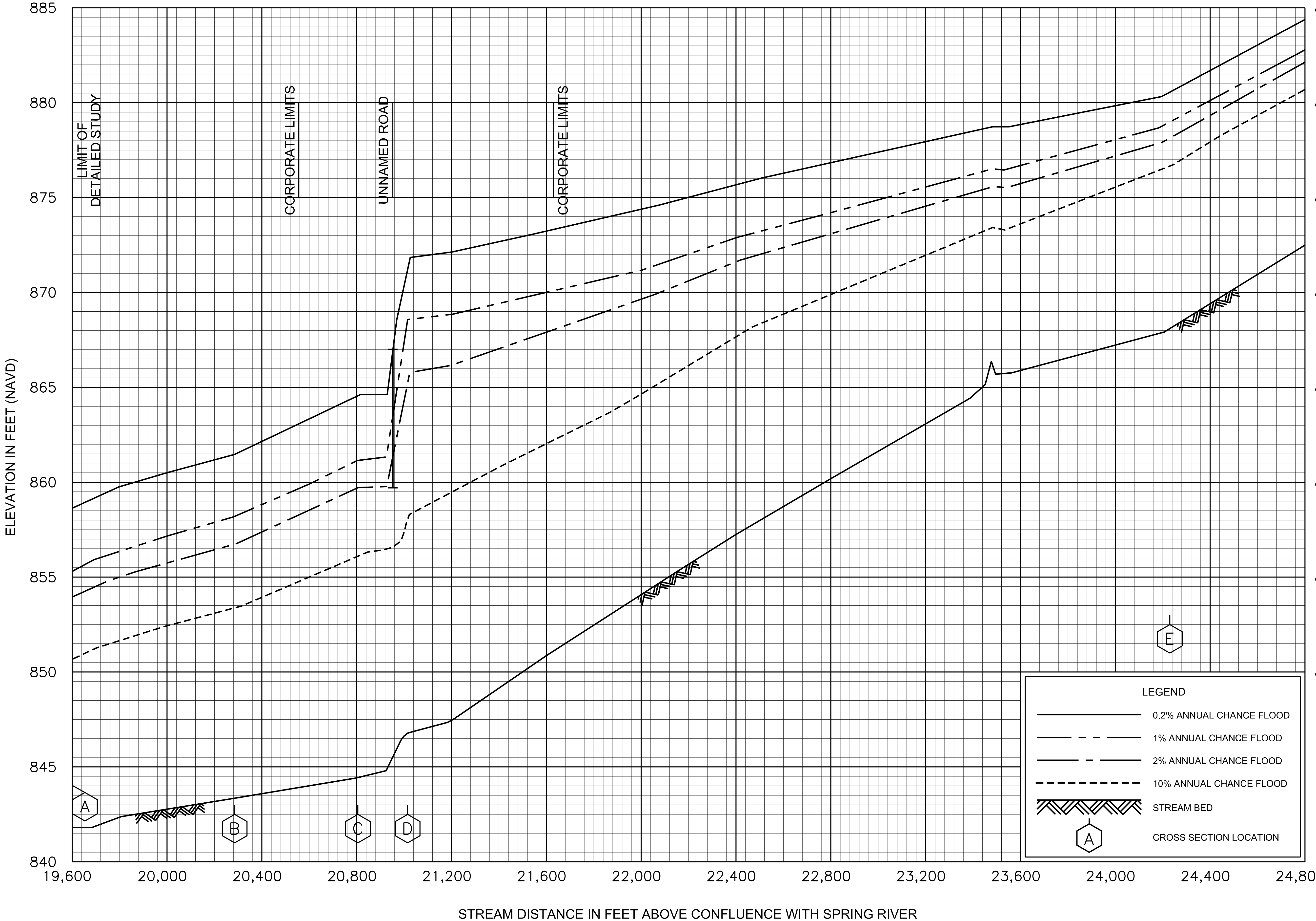


FLOOD PROFILES

TAR CREEK (AT MIAMI)

FEDERAL EMERGENCY MANAGEMENT AGENCY

OTTAWA COUNTY, OK
AND INCORPORATED AREAS



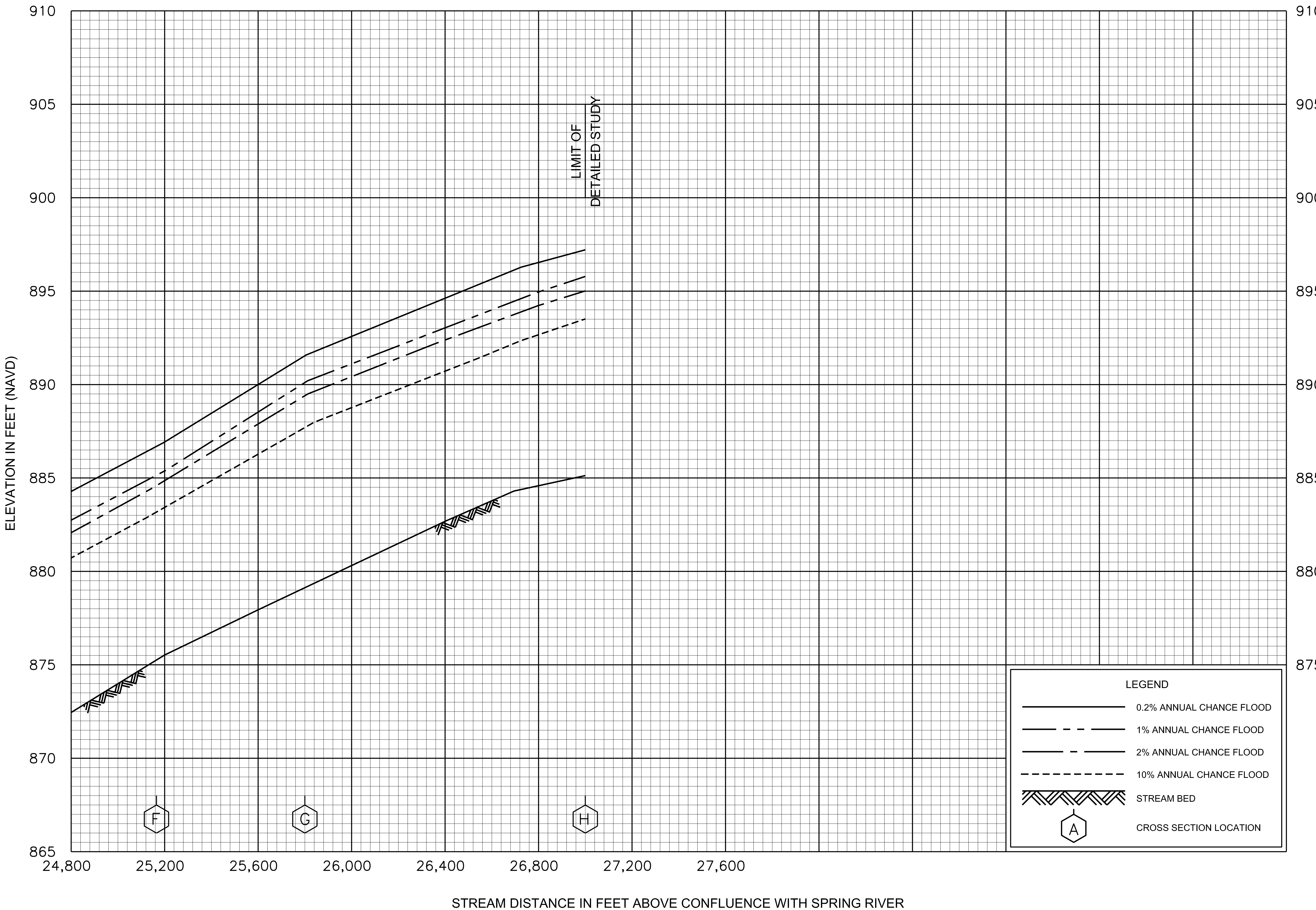
FLOOD PROFILES

WARREN BRANCH

FEDERAL EMERGENCY MANAGEMENT AGENCY

OTTAWA COUNTY, OK

AND INCORPORATED AREAS



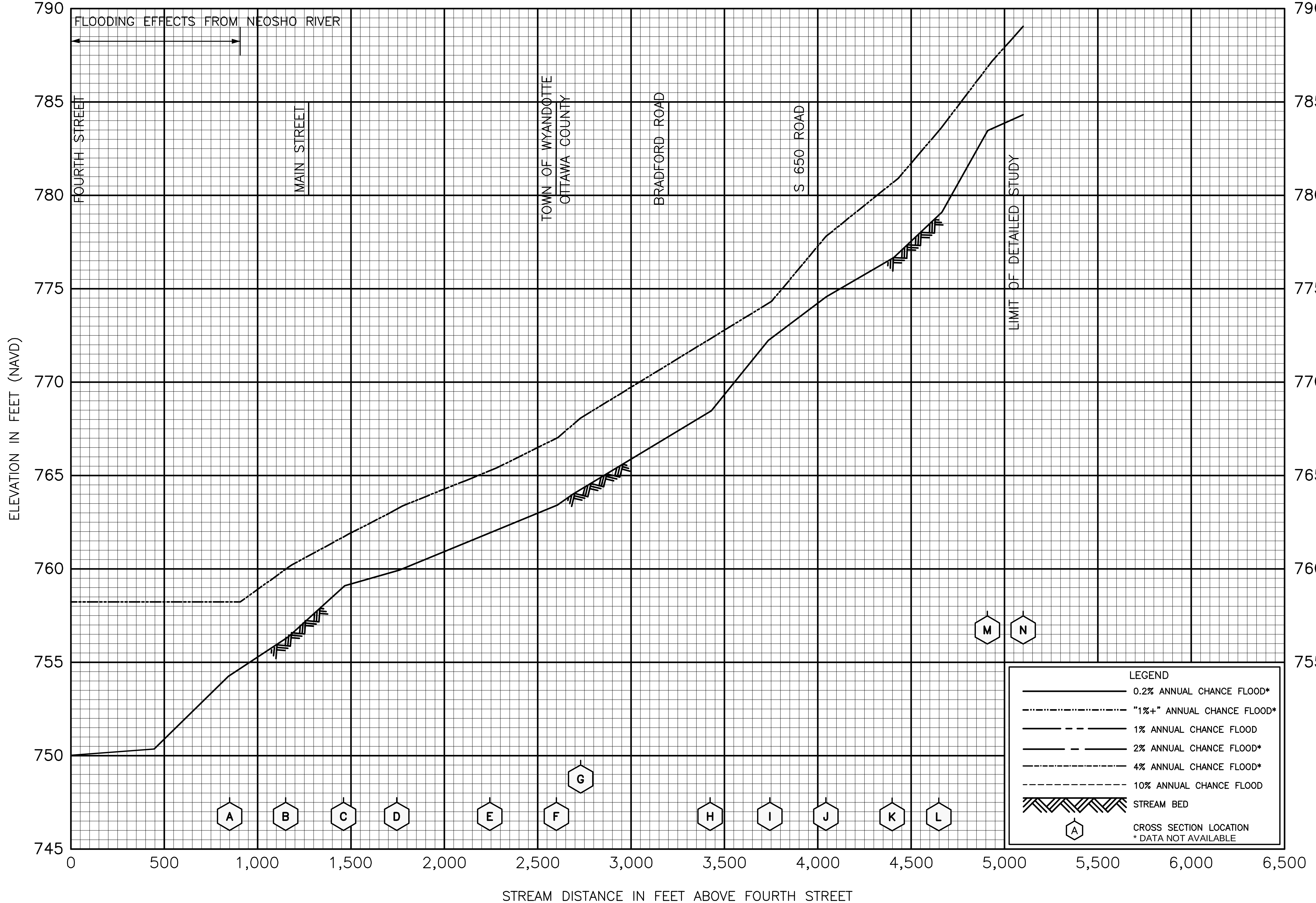
FLOOD PROFILES

WARREN BRANCH

FEDERAL EMERGENCY MANAGEMENT AGENCY

OTTAWA COUNTY, OK

AND INCORPORATED AREAS



FLOOD PROFILES

WYANDOTTE DITCH

FEDERAL EMERGENCY MANAGEMENT AGENCY

OTTAWA COUNTY, OK
AND INCORPORATED AREAS