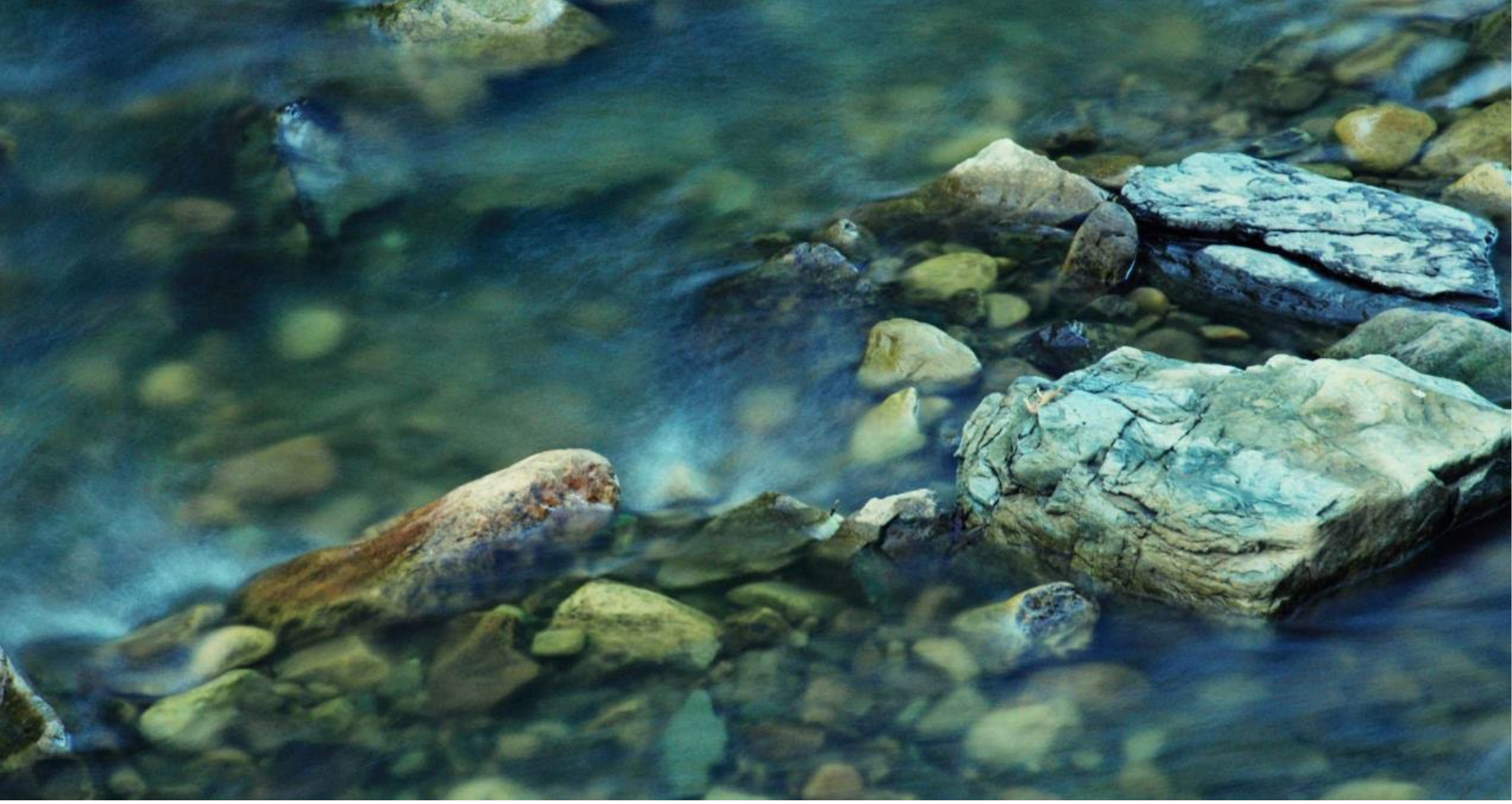
Appendix A
Water Surface Elevation Monitoring



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.

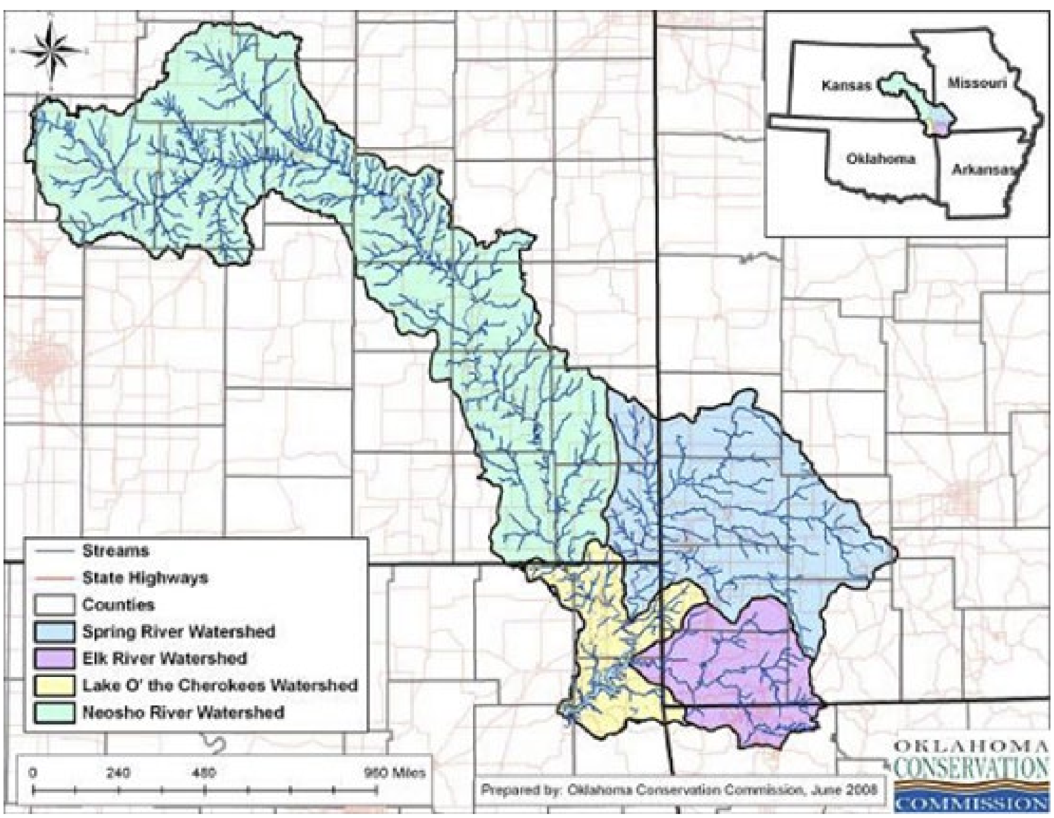
The purpose of this water level study is to provide continuous water level data for a time period of five years at locations distributed through the Grand Lake watershed. This water level data will be used to calibrate and validate hydraulic models of the watershed, understand the nature of flooding 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.

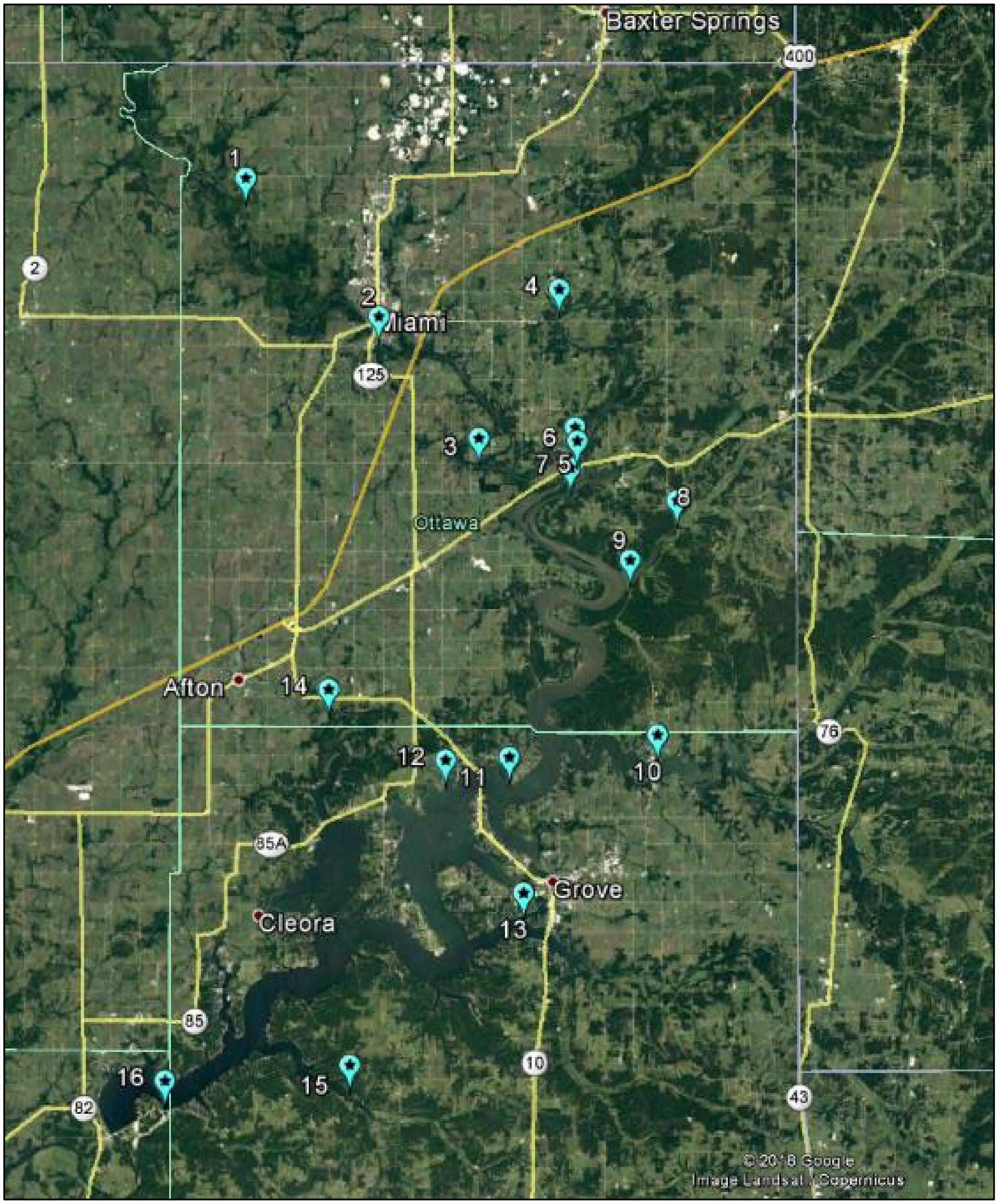


Table 1
Location of HOBO data loggers in the Grand Lake watershed

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

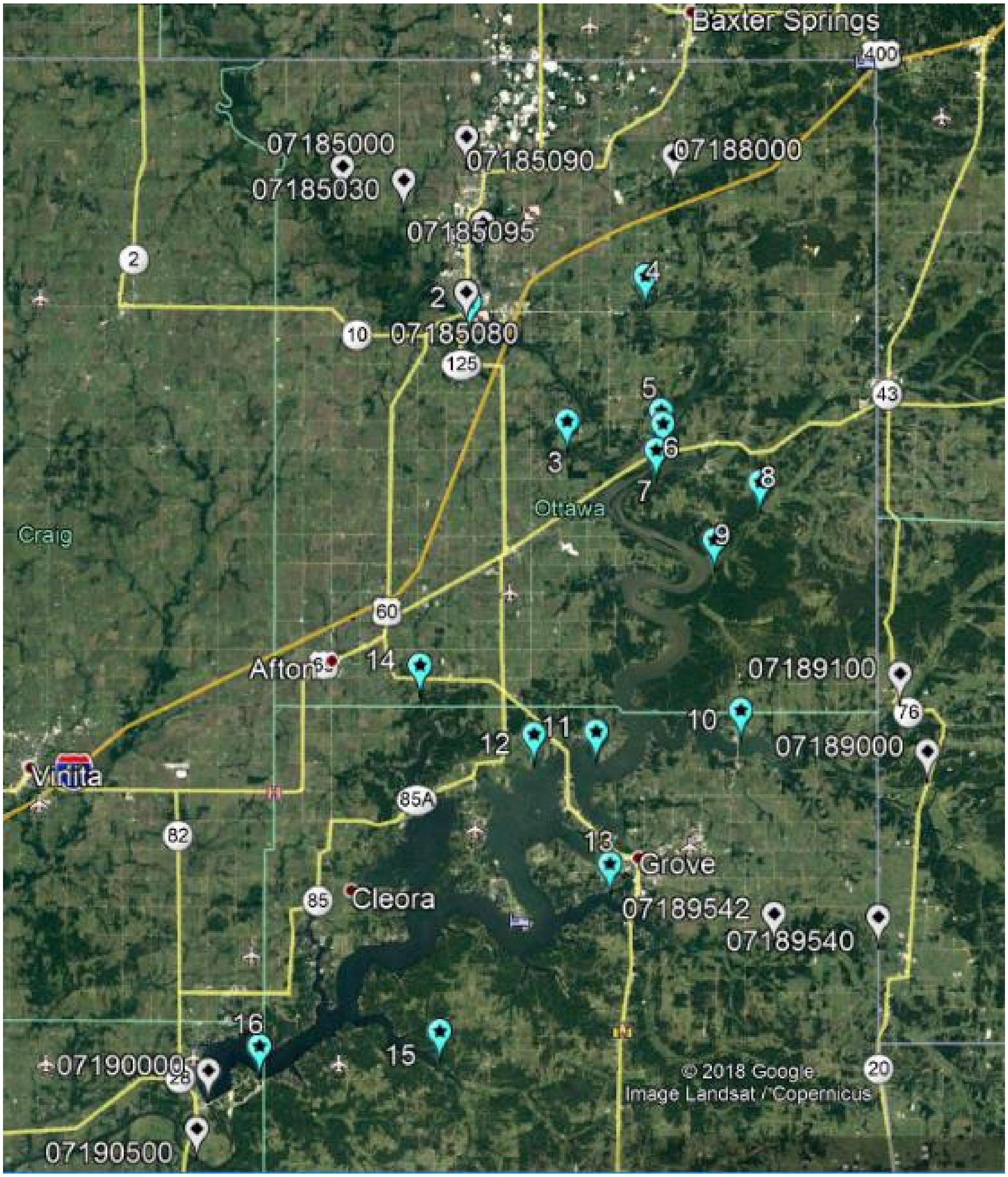
Grand Lake has been extensively studied and has several existing data sources. USGS gages are present throughout the watershed and are located near HOBO loggers at locations 1 and 16 (Table 2). Those USGS gages were used to verify water level measurements from the HOBO loggers. Station 1 is located on 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.

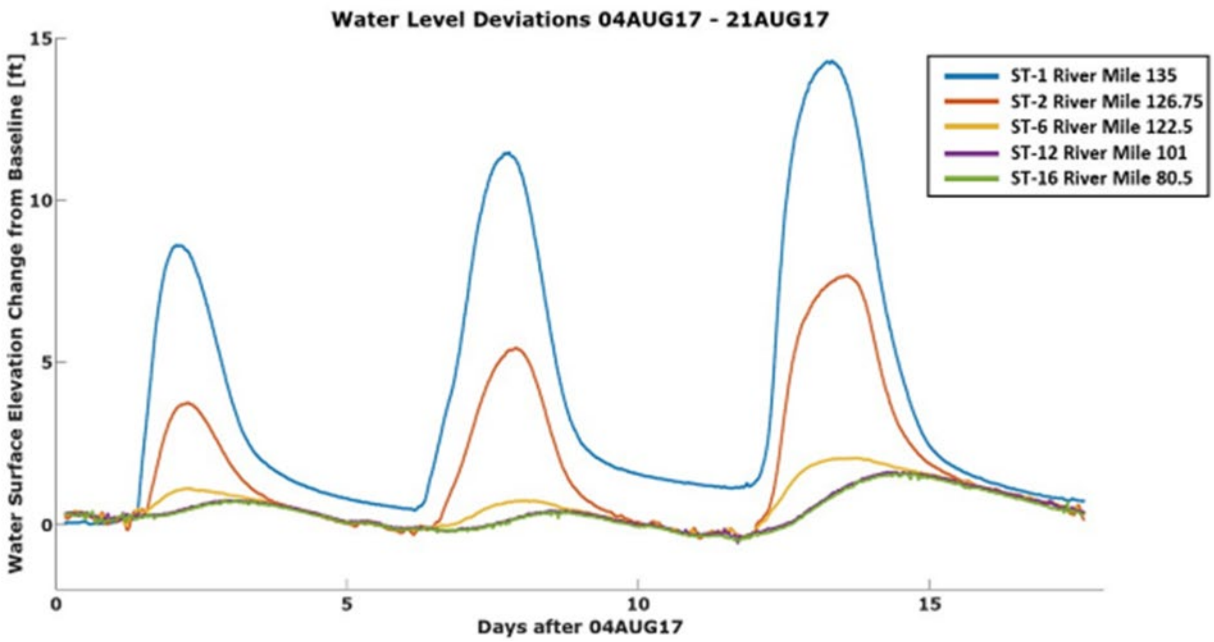


Table 4
Key parameters of the August 2017 floods shown in Figure 5

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

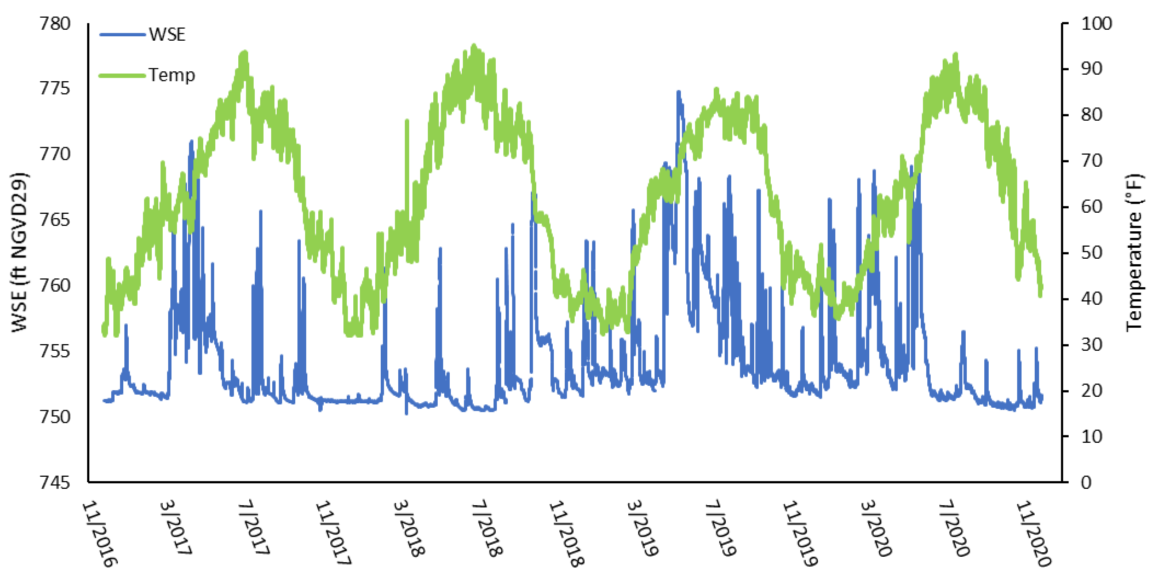


Figure A2
Station 2: Neosho River at Riverview Park, Miami, OK

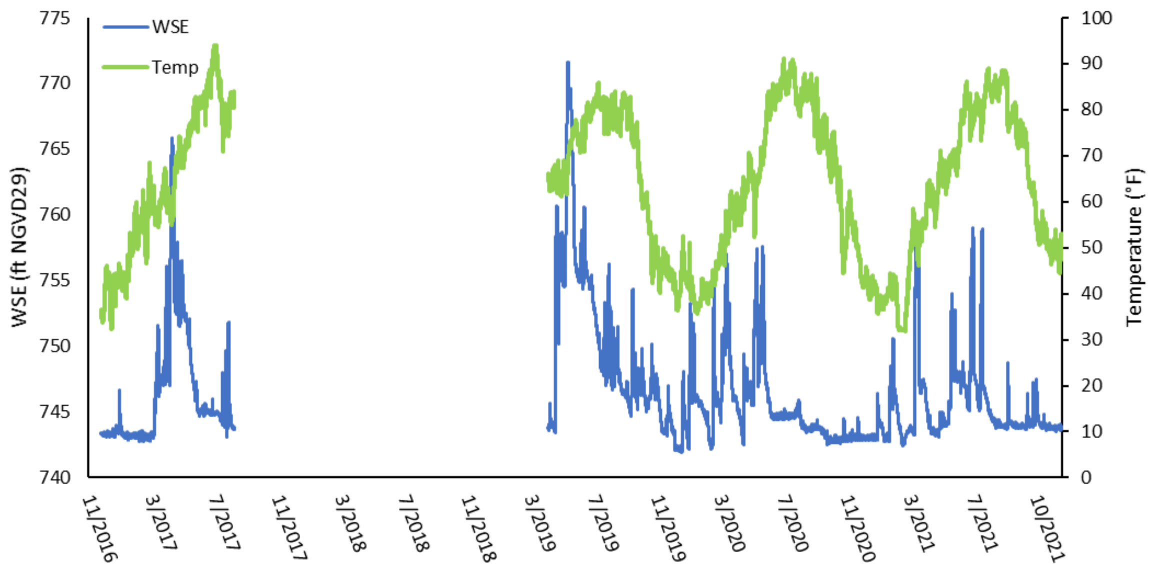


Figure A3
Station 3: Neosho River at Connors Bridge at S 590 Rd.

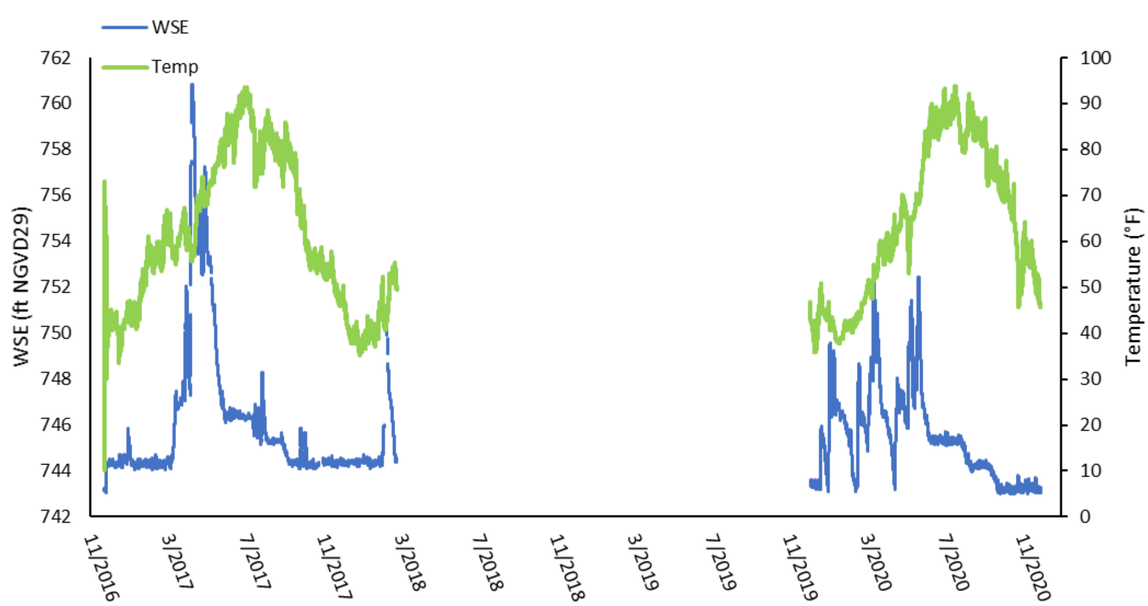


Figure A4
Station 4: Spring River upstream of Hwy 10 bridge

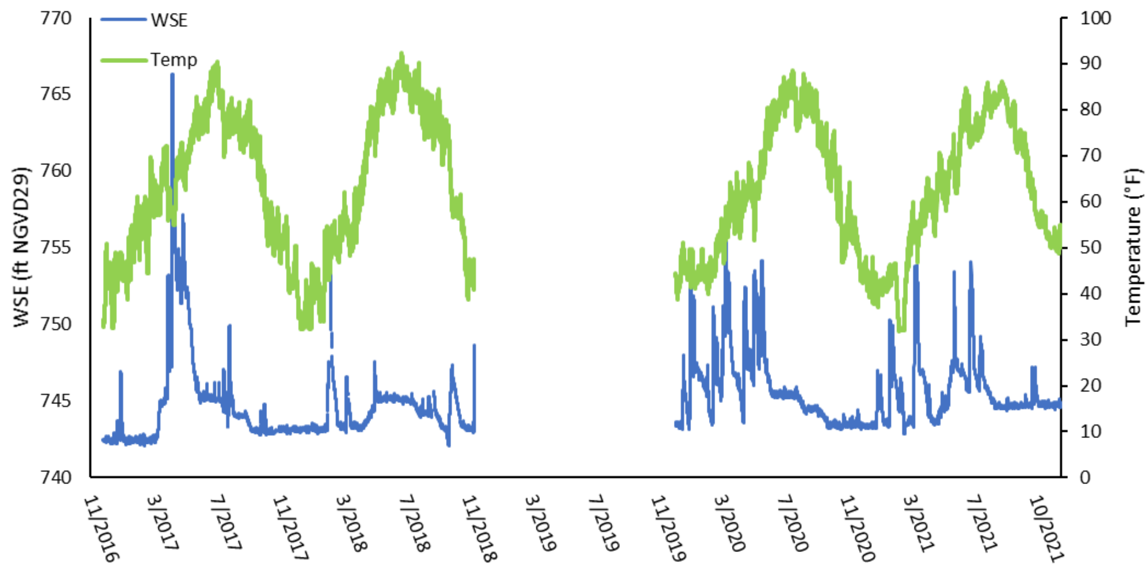


Figure A5
Station 5: Spring River at Twin Bridges Area at Grand Lake State Park boat launch

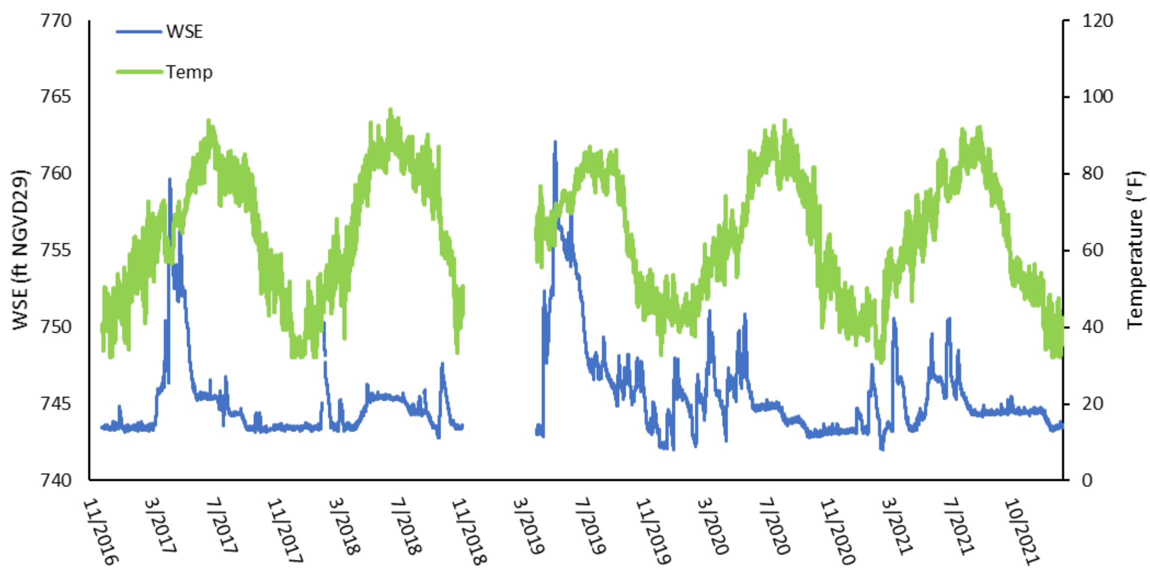


Figure A6
Station 6: Confluence of Neosho and Spring Rivers at Twin Bridges Area at Grand Lake State Park

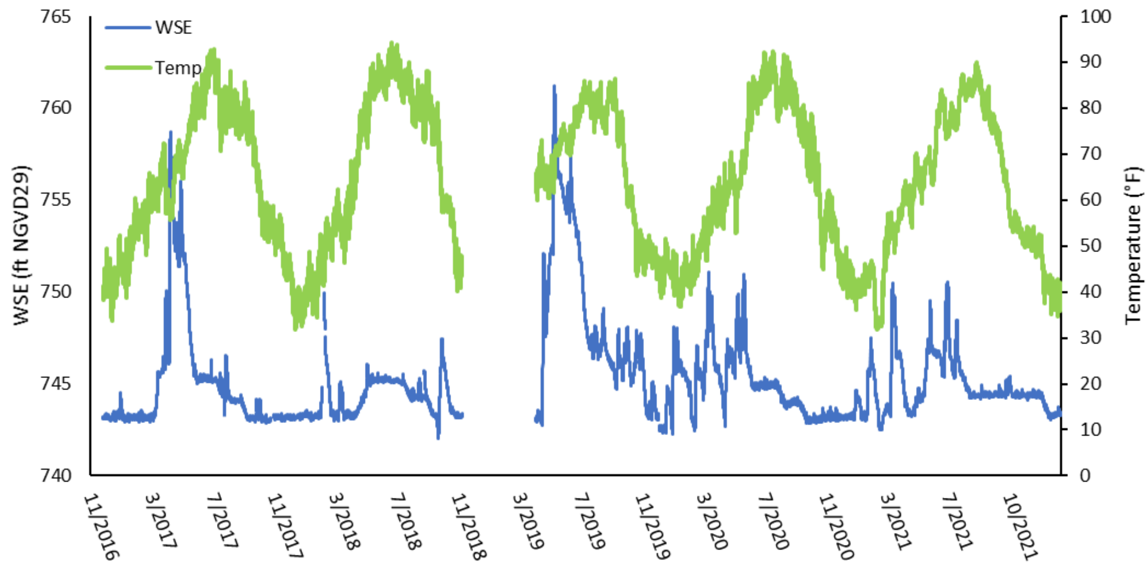


Figure A7
Station 7: Neosho River off E157 Road downstream of railroad bridge

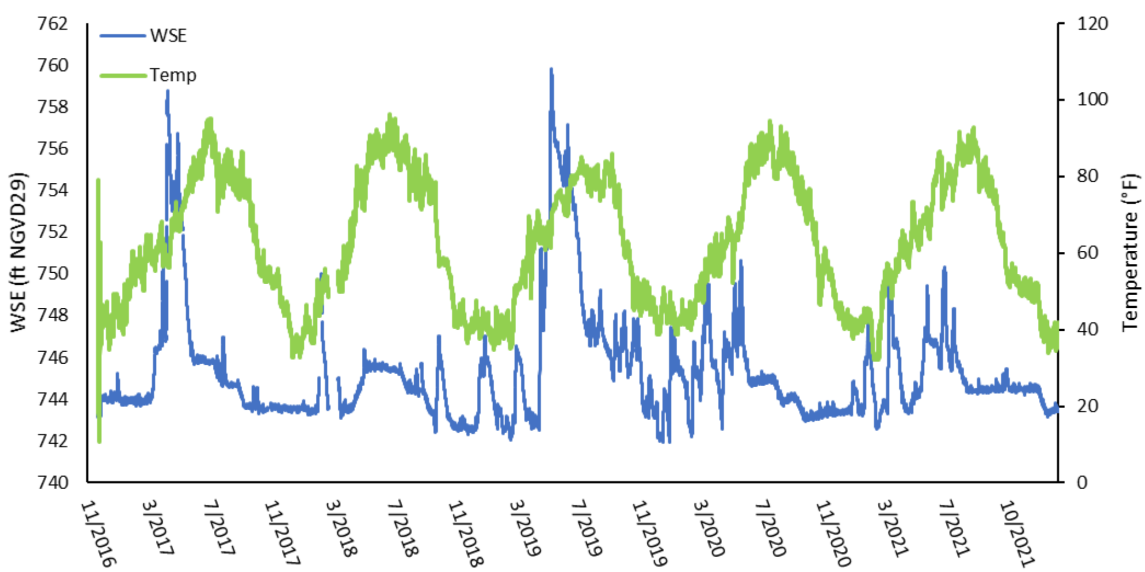


Figure A8
Station 8: Sycamore Creek at Hwy 10 bridge

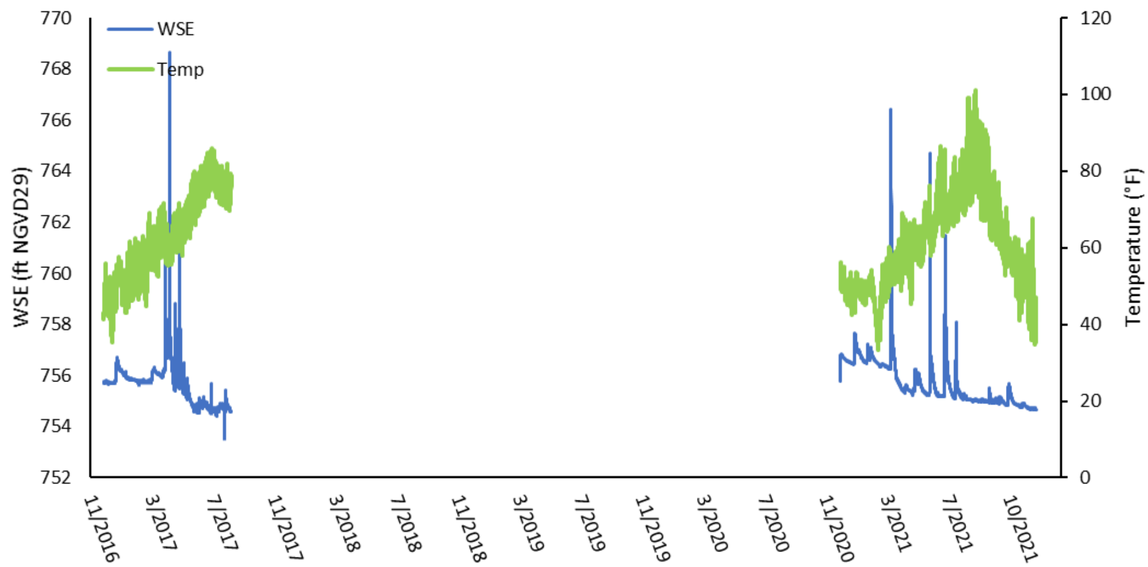


Figure A9
Station 10: Grand Lake/Elk River upstream of Hwy 10 bridge north of Grove, OK

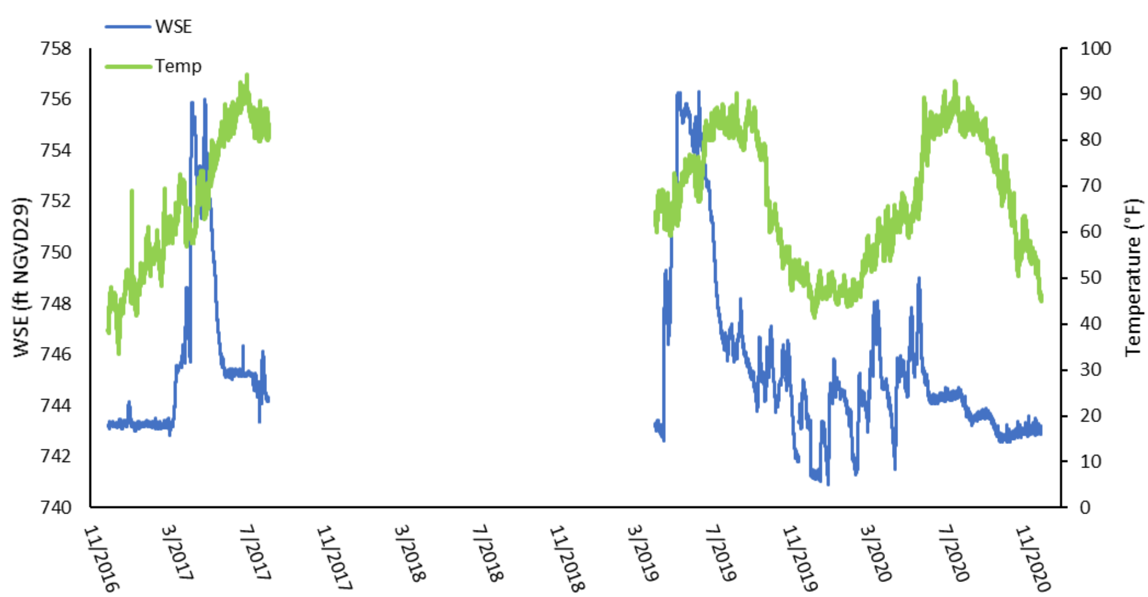


Figure A10
Station 11: Grand Lake at Hickory Point, upstream of Hwy 59 bridge

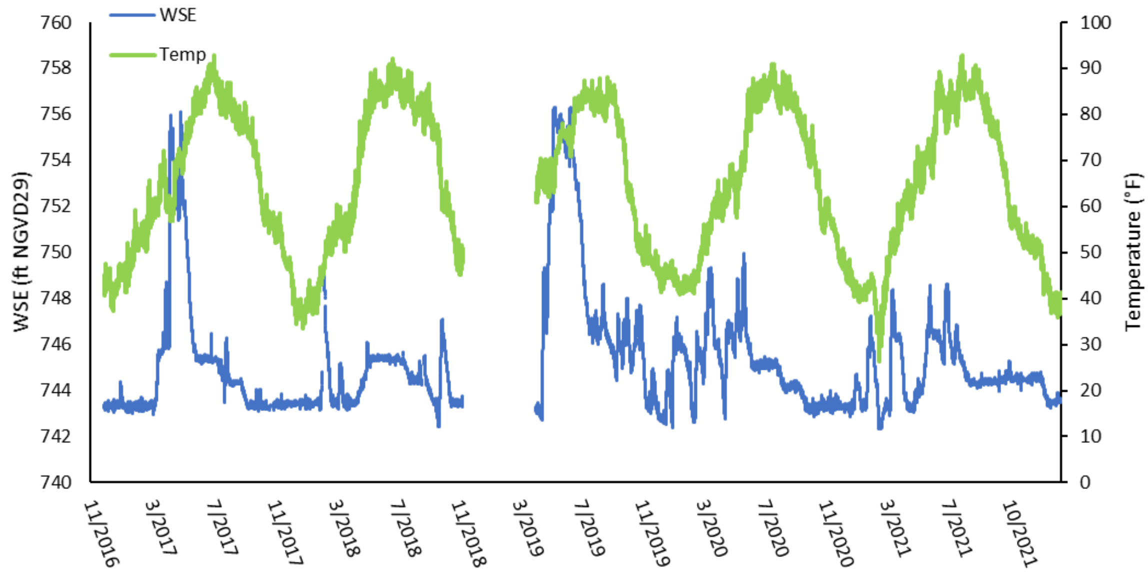


Figure A11
Station 12: Grand Lake at public access off S. 580 Rd, downstream of Hwy 59 bridge

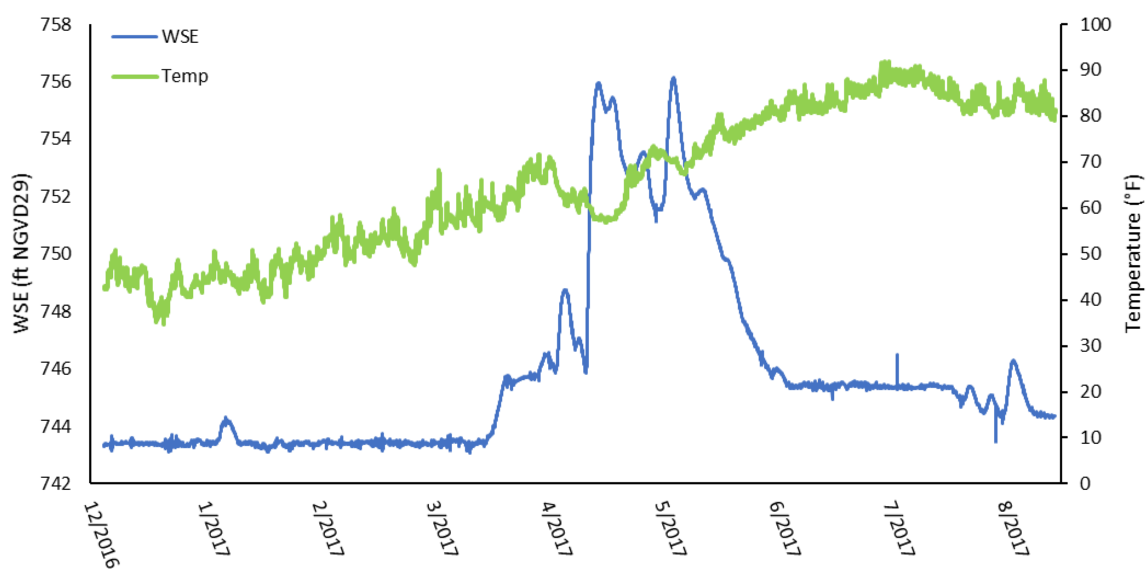


Figure A12
Station 13: Grand Lake at Honey Creek State Park

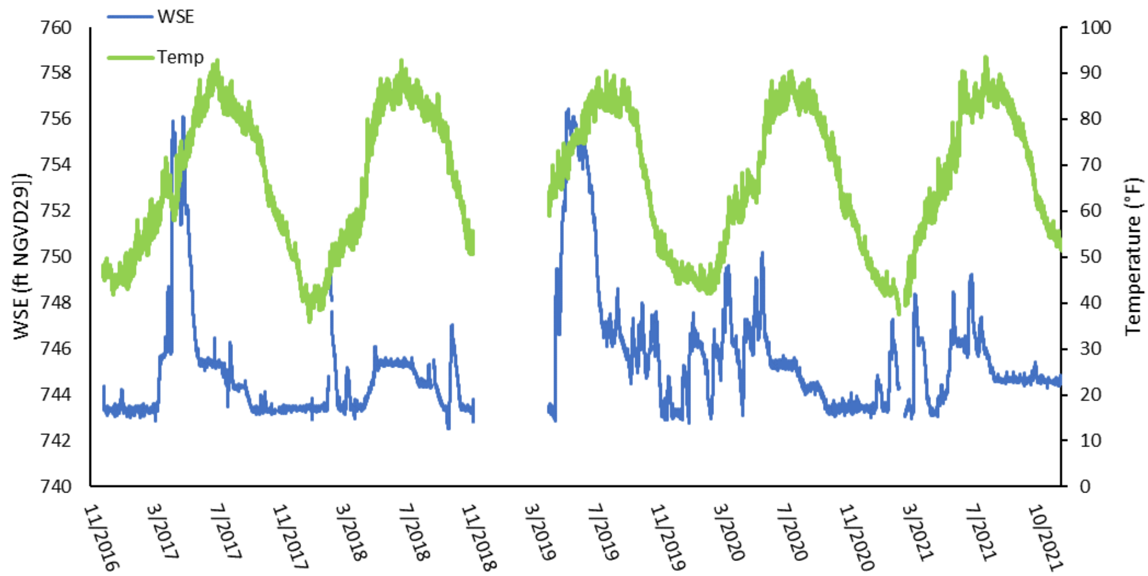


Figure A13
Station 14: Horse Creek off E 249 Rd

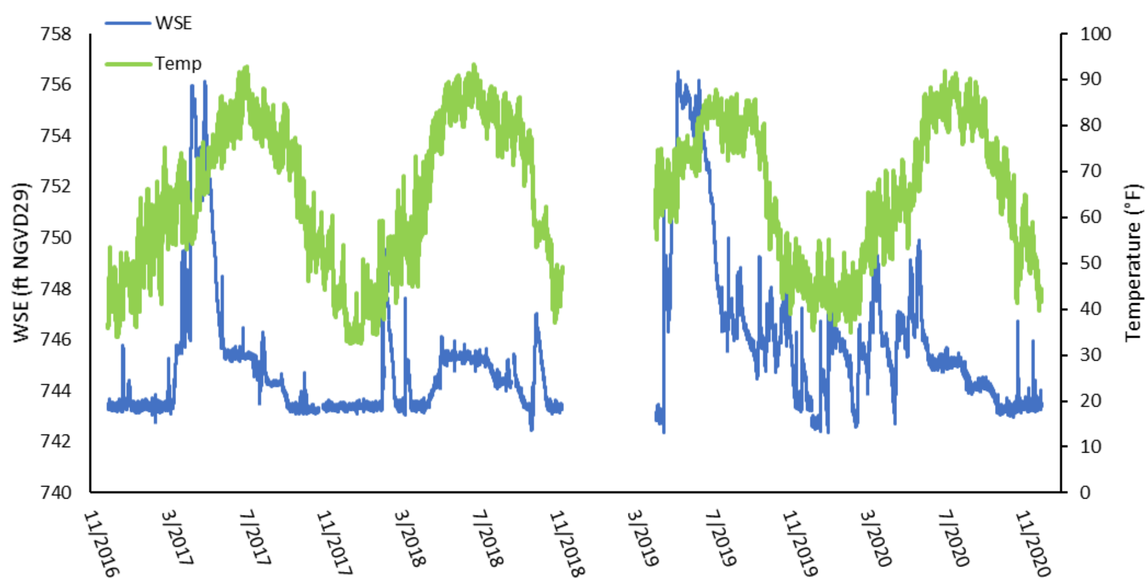


Figure A14
Station 15: Grand Lake near Woods Spring Branch off S 560 Rd & E 360 Rd

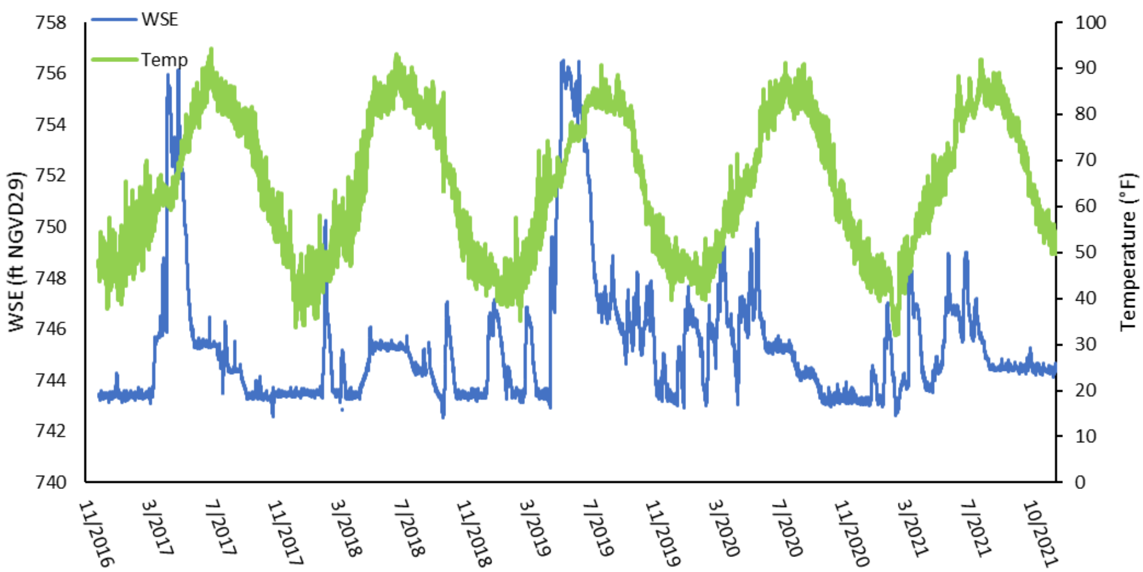
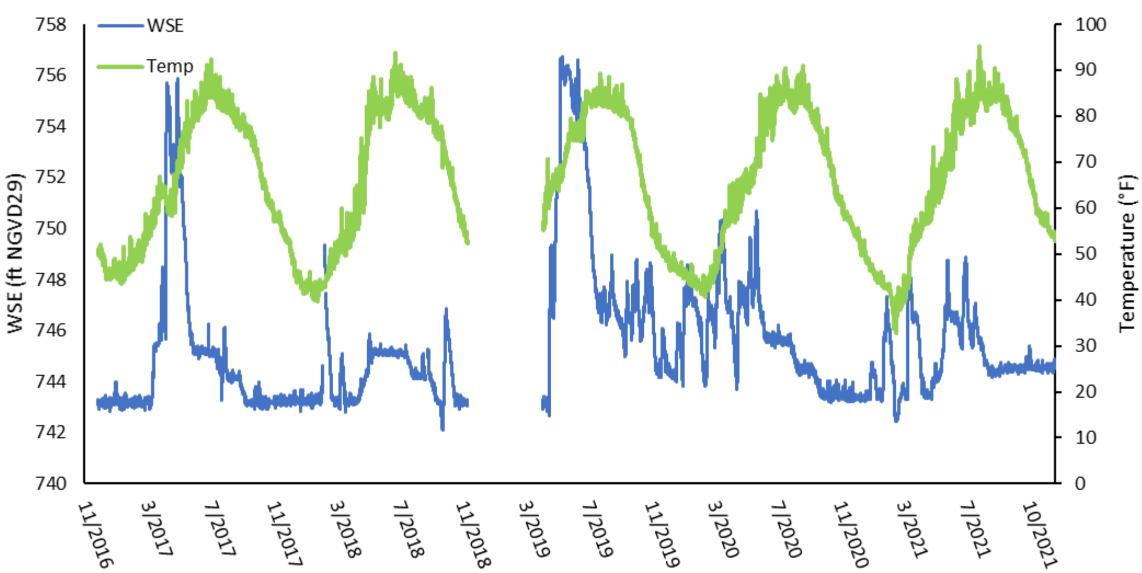
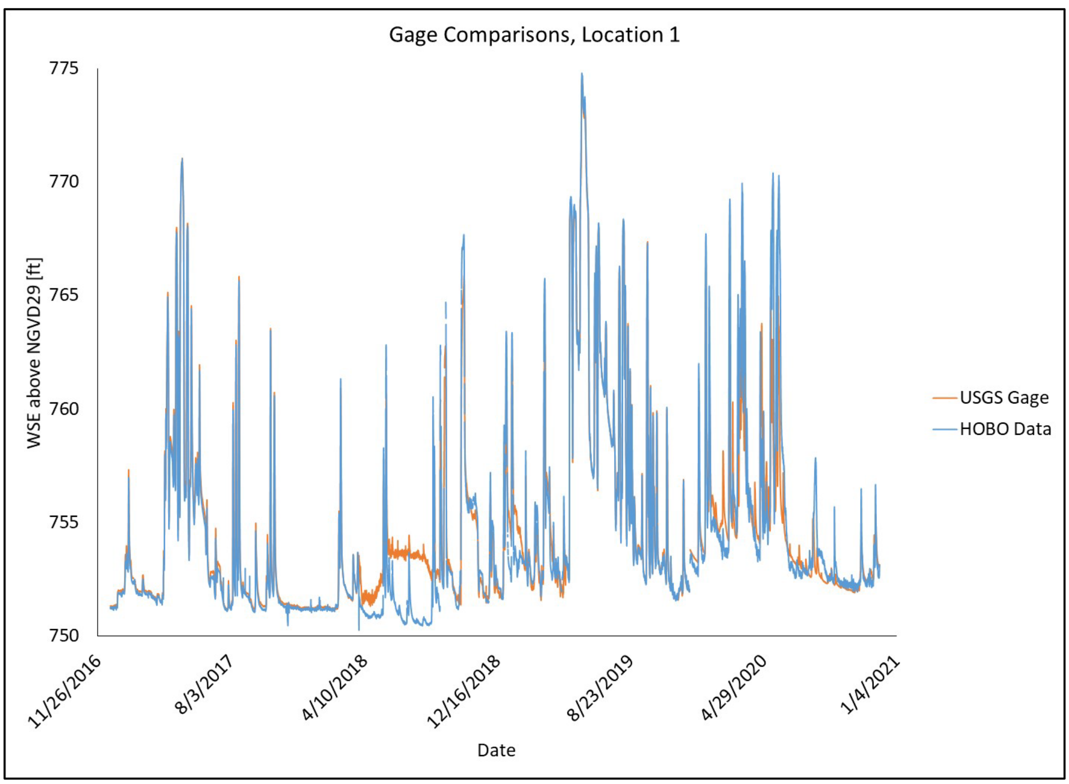


Figure A15
Station 16: Grand Lake at Cherokee State Park Boat Ramp, Disney, OK



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).

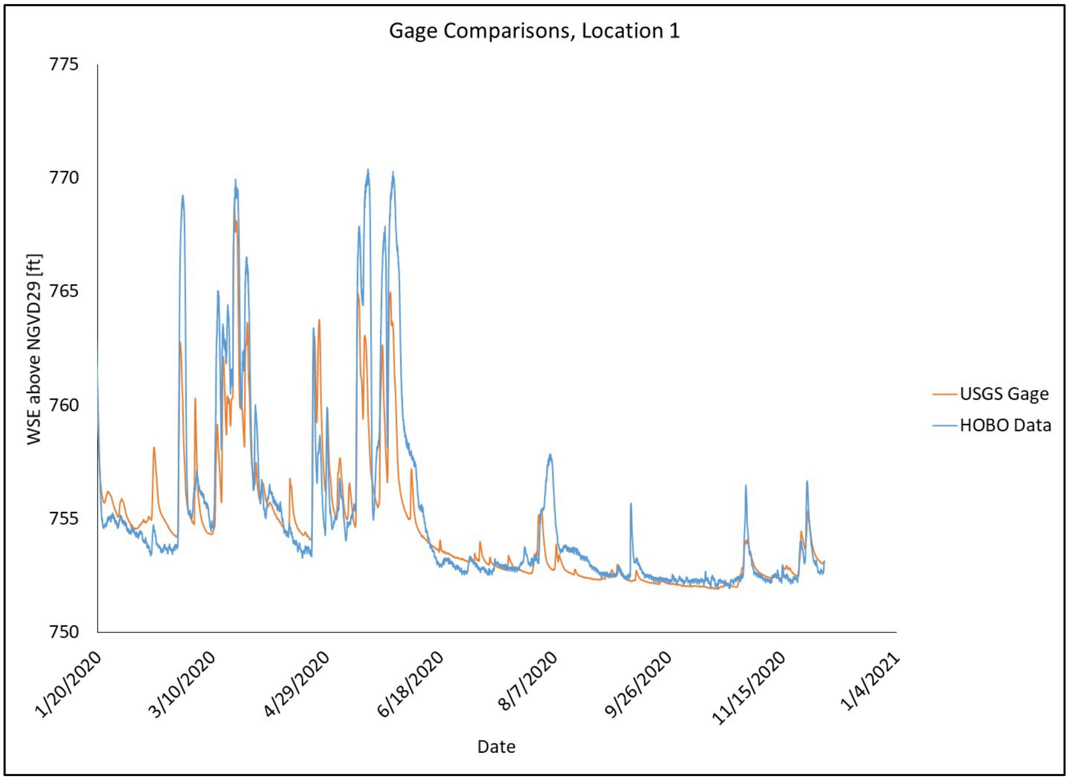
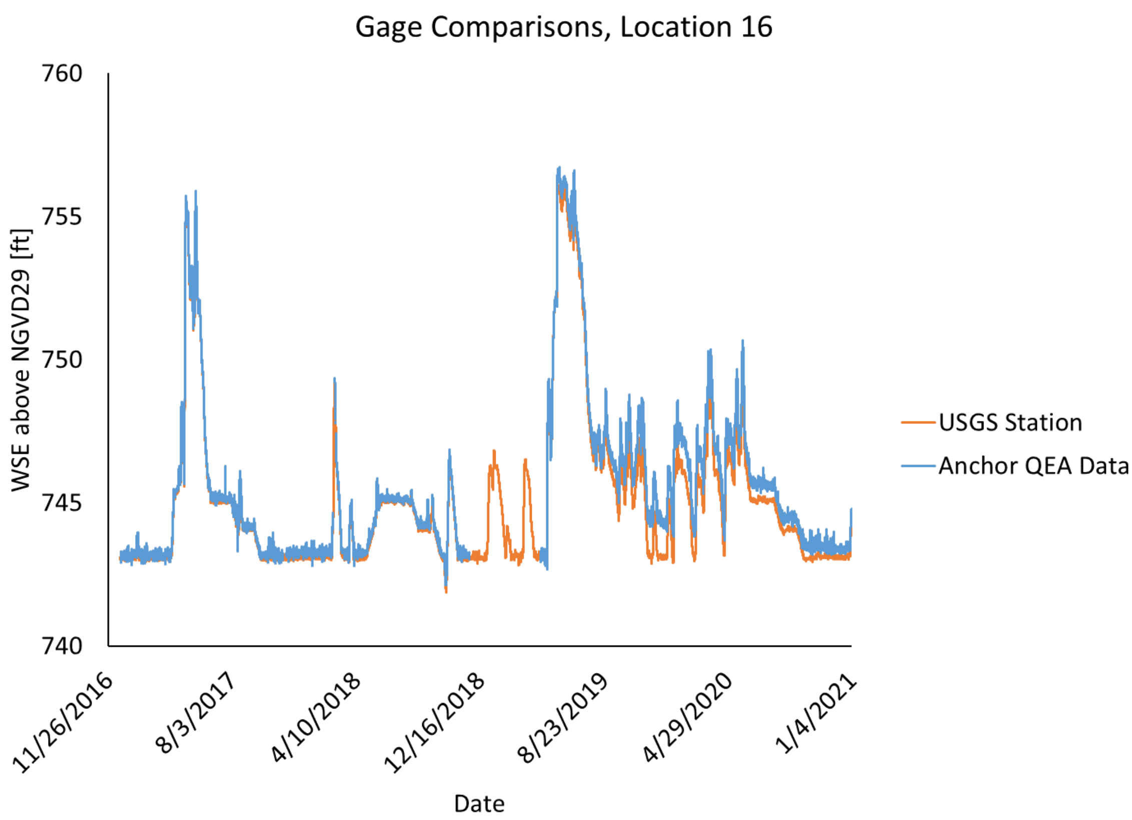


Figure A18
Station 16 compared to USGS Gage 07190000 (Lake O' the Cherokees at Langley, OK).



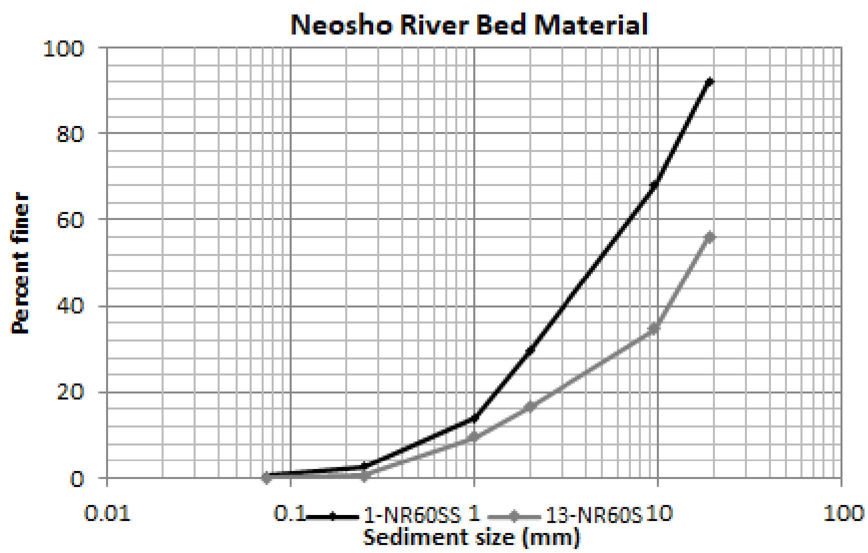
Appendix B
Sediment Grab Sampling

Particle Size Distribution Results

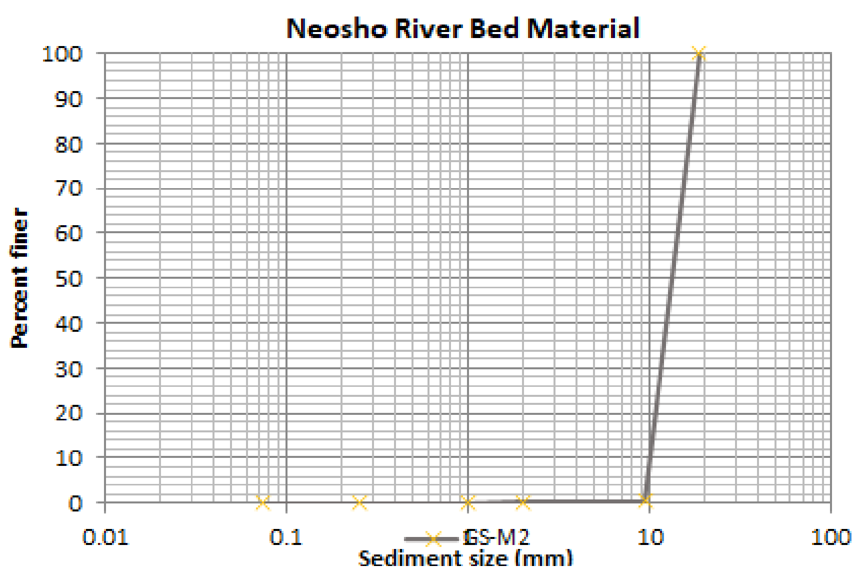
Note: Graphs are provided for each stream in an upstream to downstream direction showing HEC-RAS River Mile for each sample. Core sample particle size distributions are also included with other samples to provide context and completeness. Unless otherwise noted, samples are from the riverbed.

Neosho River above Tar Creek

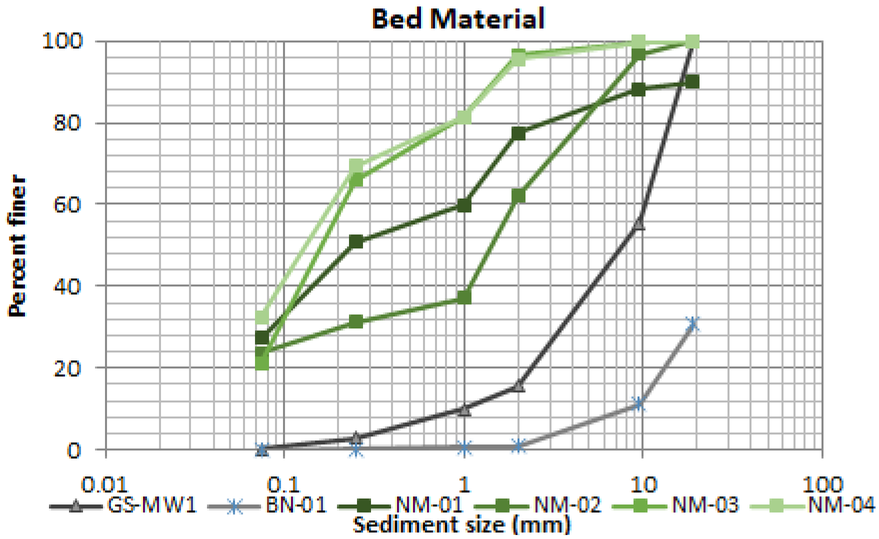
River Mile 145.5



River Mile 135.95

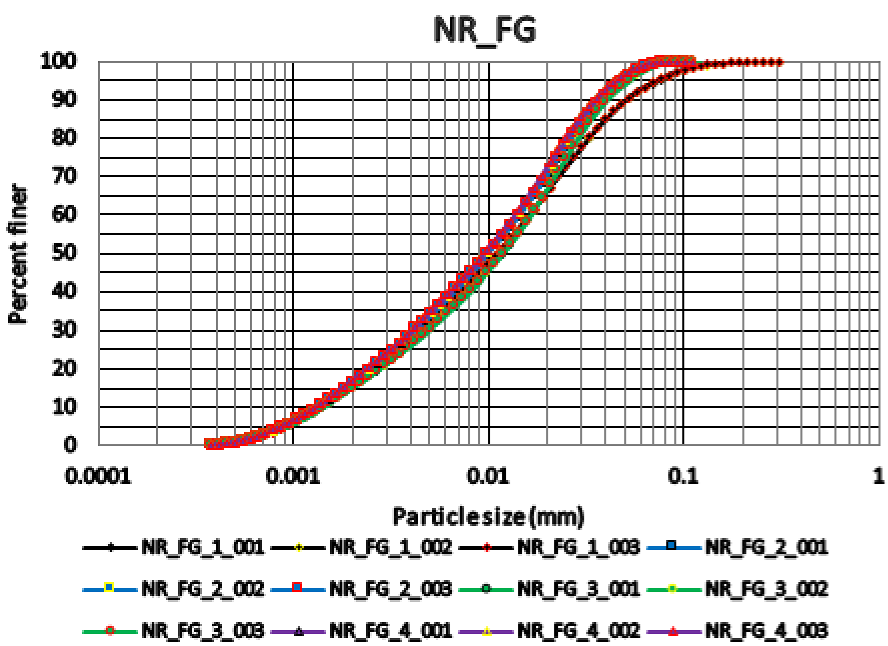


River Mile 134.6–135.46

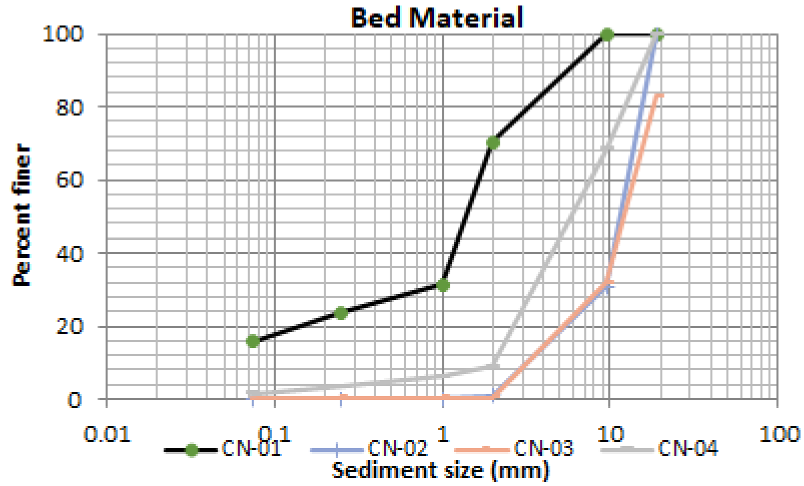


Note: NM-01 – left bank surface, NM-02 – floodplain surface, NM-04 – right bank surface

River Mile 135.04

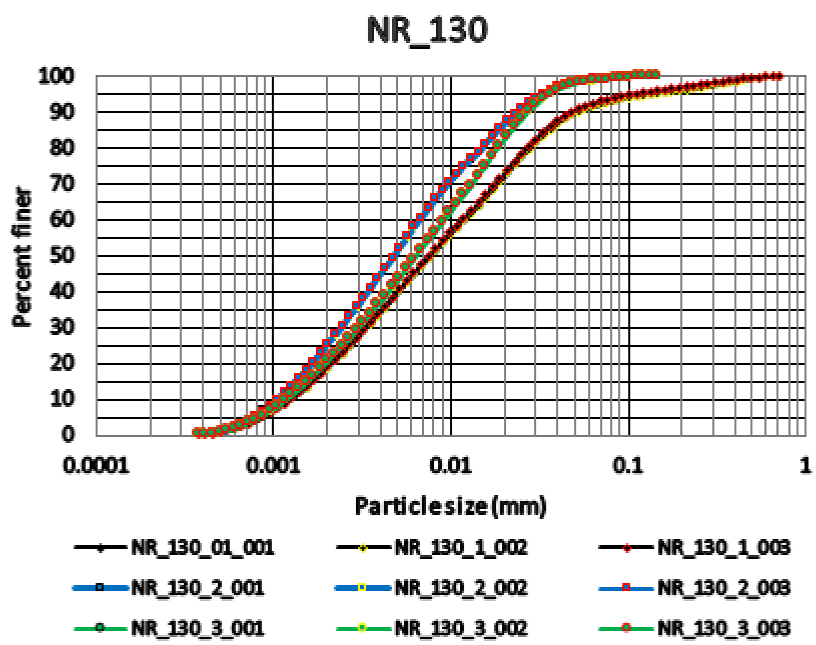


River Mile 128.81–130.37

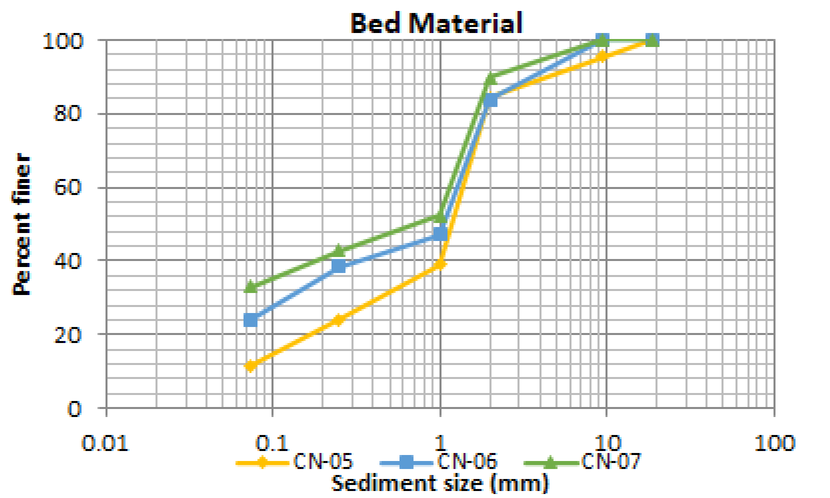


Note: CN-01 – bank

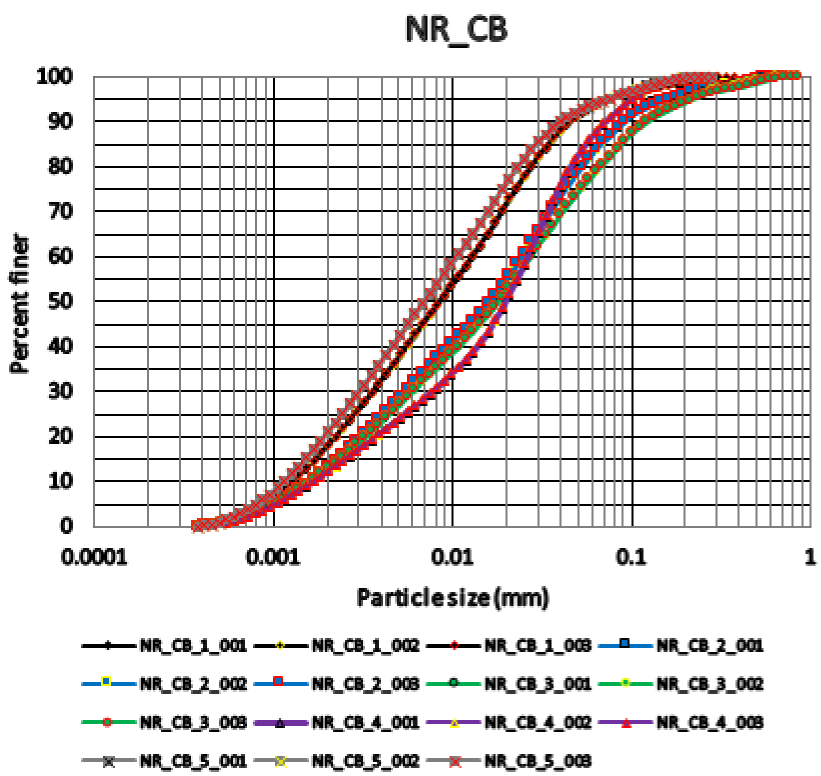
River Mile 130.37



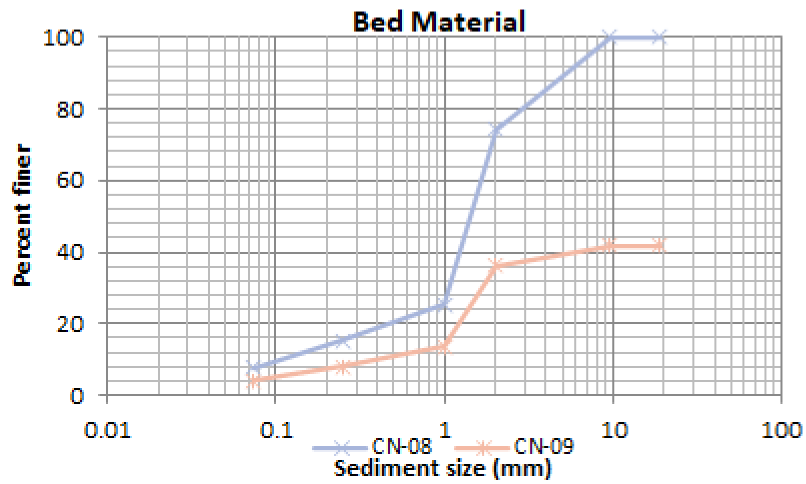
River Mile 126.69–127.85



River Mile 126.69

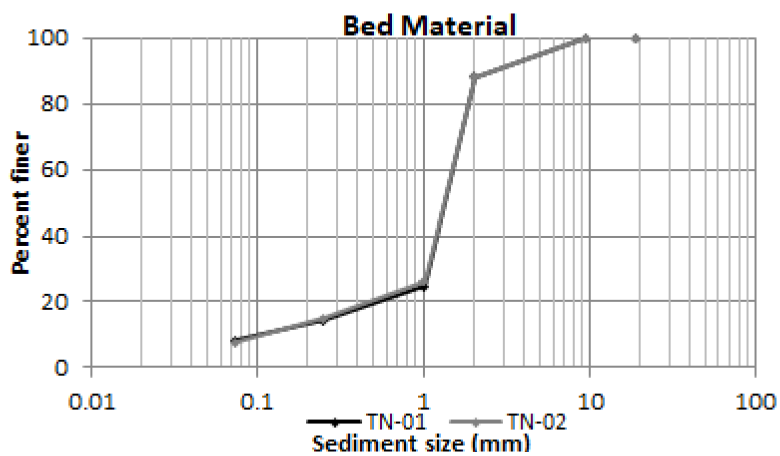


River Mile 124.2–125.33



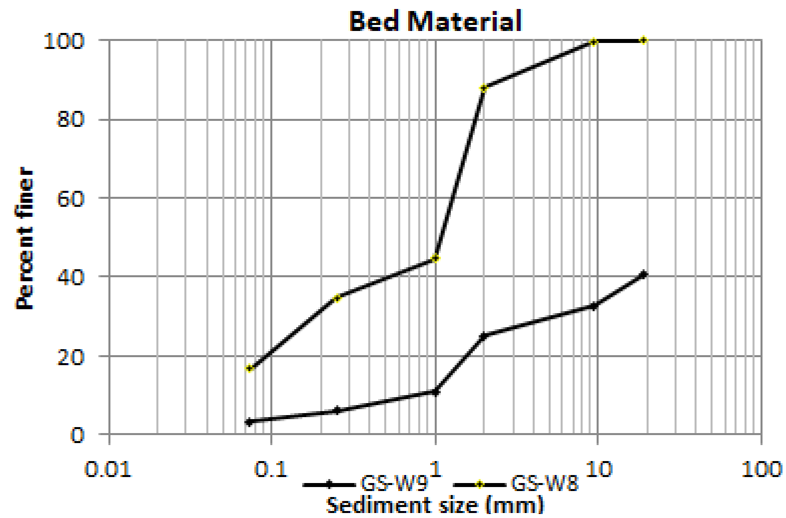
Note: CN-08 – left bank

River Mile 122.57–123.24

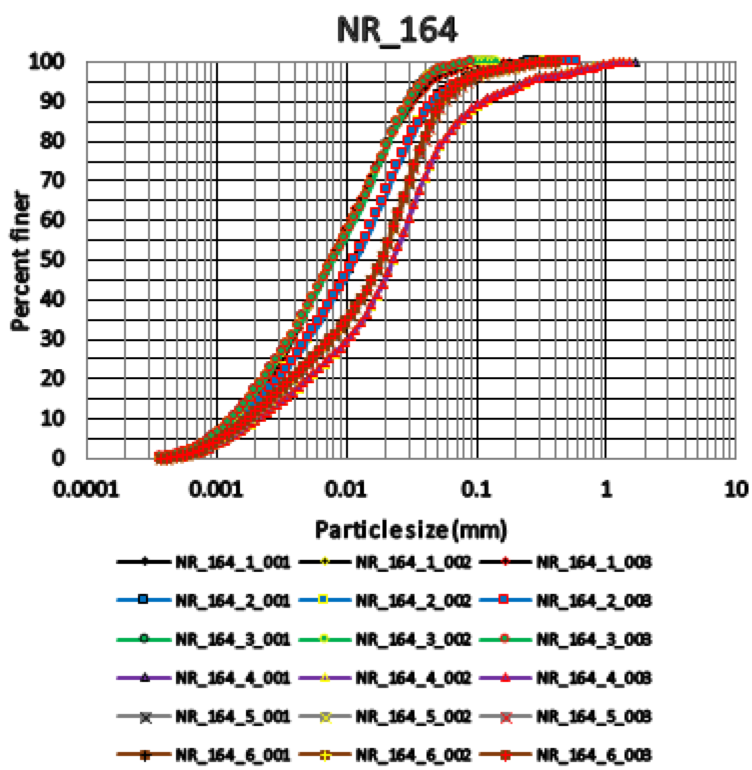


Neosho River – Grand Lake

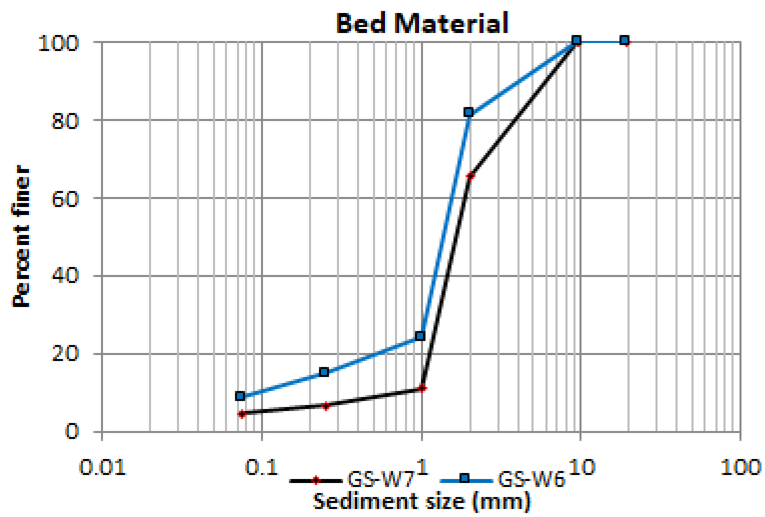
River Mile 120.1–122.25



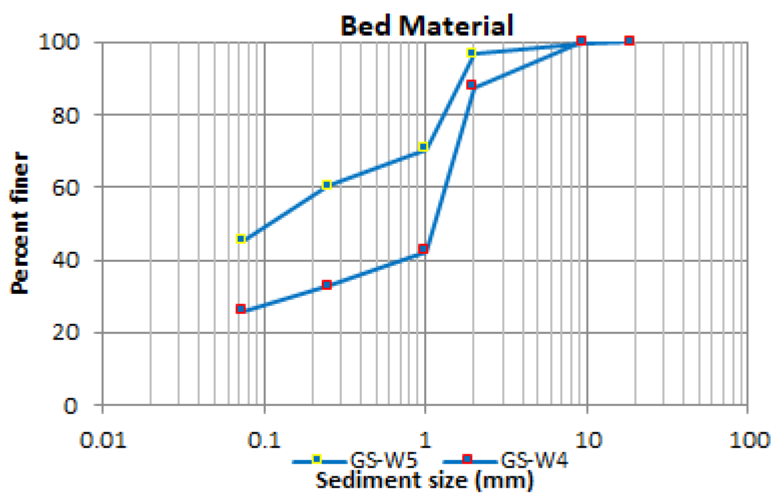
River Mile 120.1–120.43



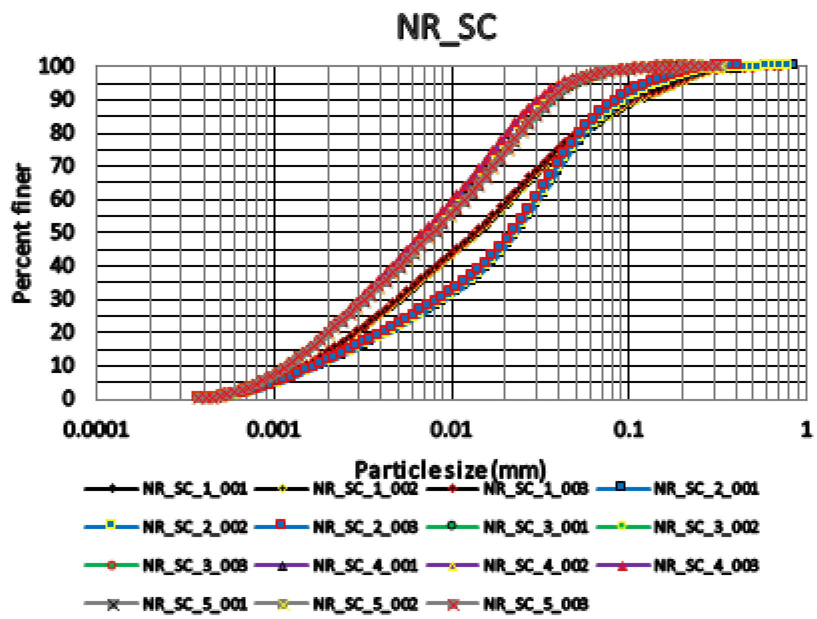
River Mile 117.66–119.06



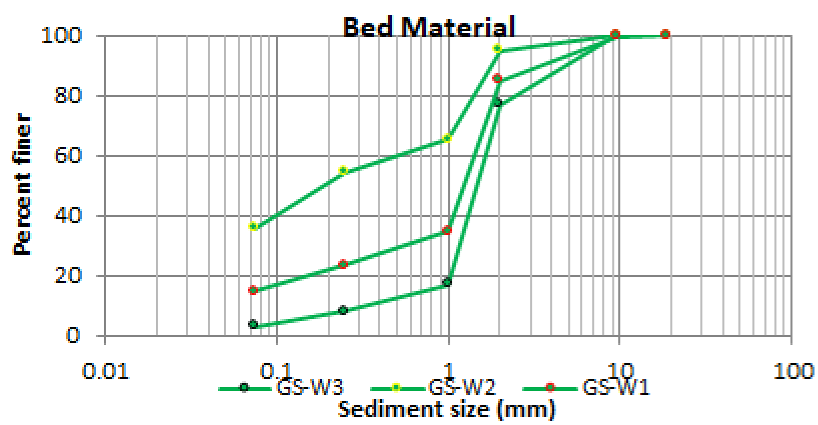
River Station 115.65–115.86



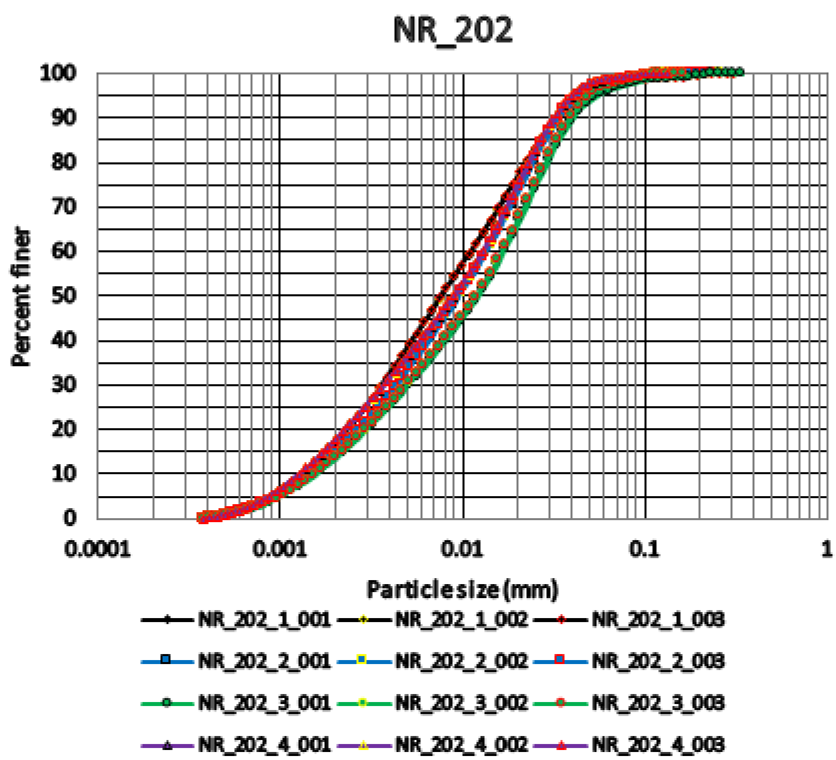
River Station 115.65–115.86



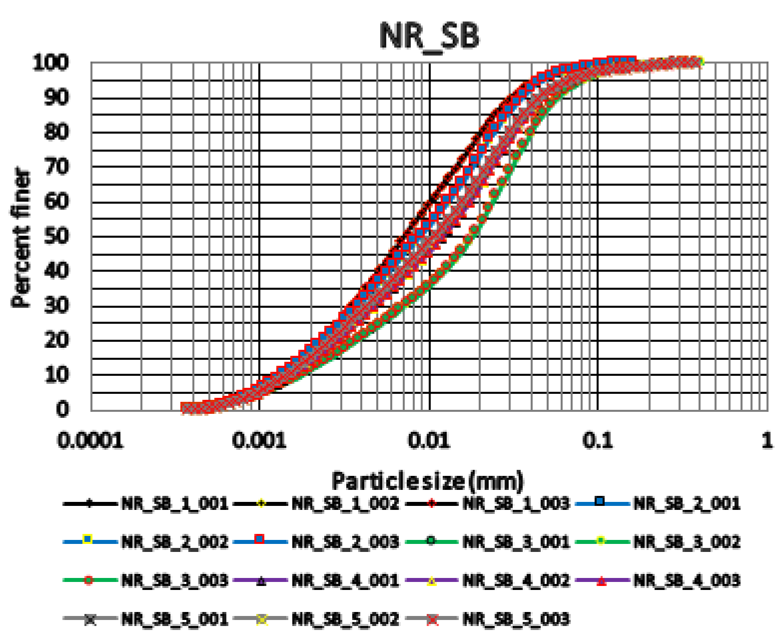
River Mile 112.34–114.21



River Mile 112.34–112.61

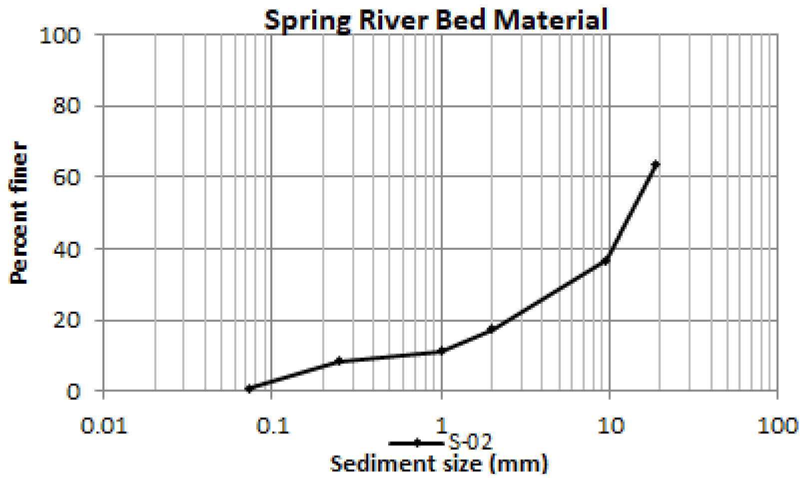


River Mile 108.87–109.25

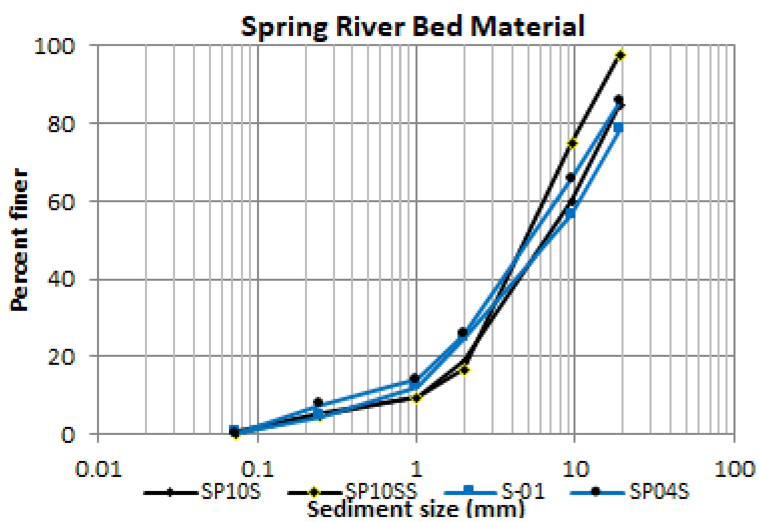


Spring River

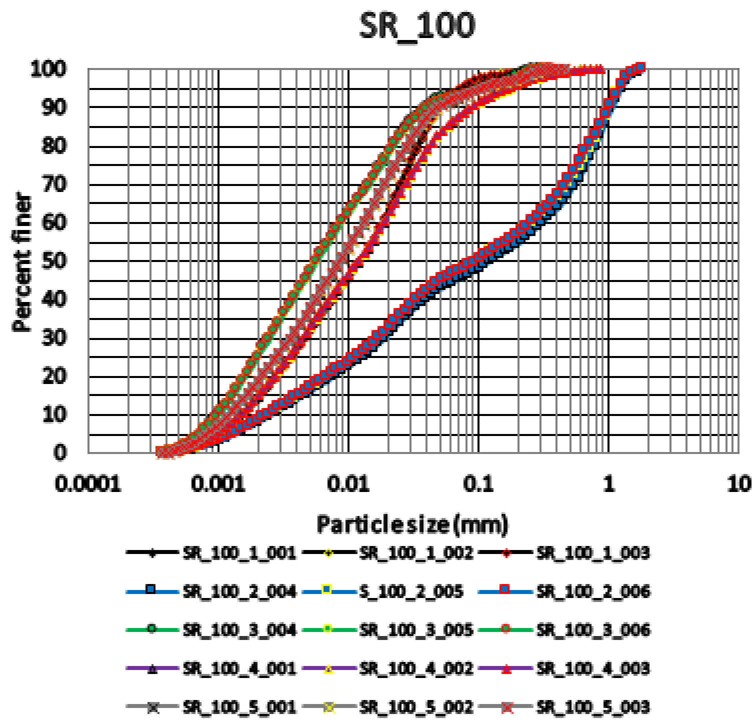
River Mile 14.16



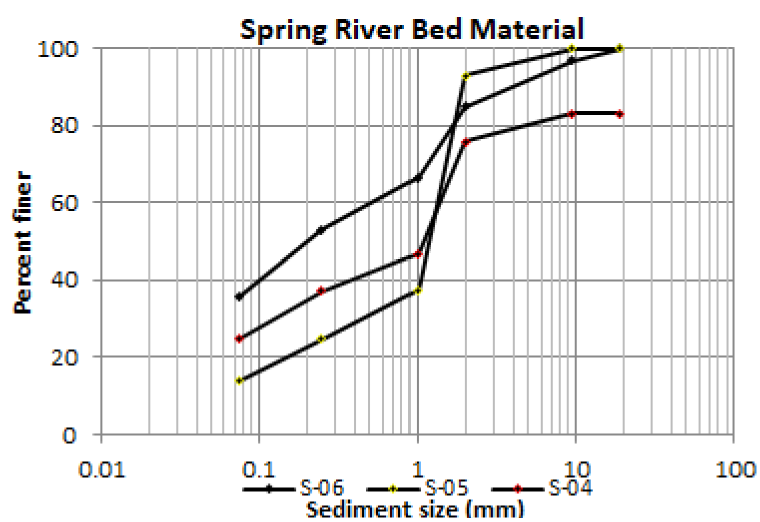
River Mile 8.01



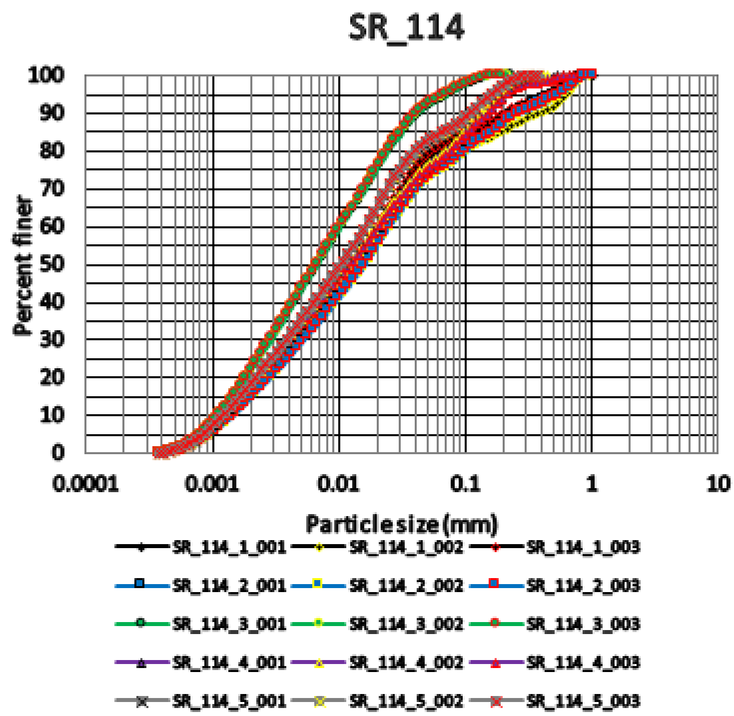
River Mile 7.5



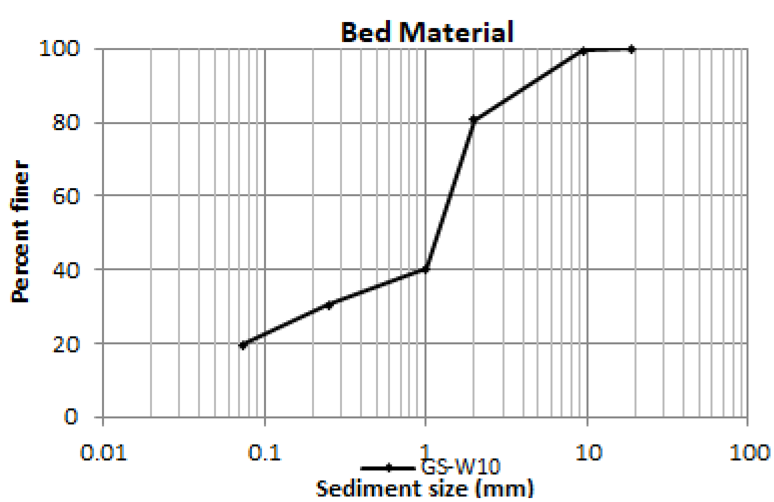
River Mile 2.26–5.1



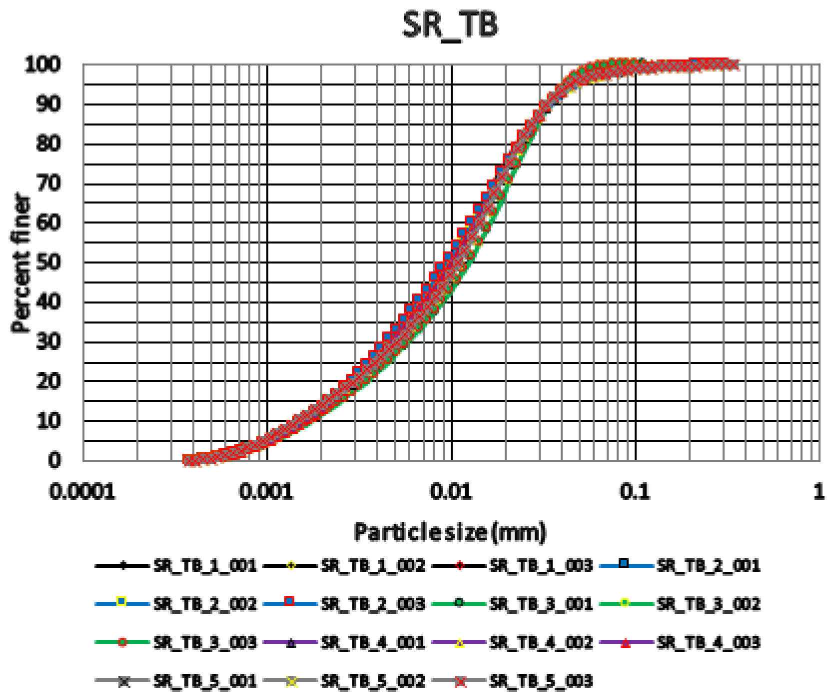
River Mile 4.82



River Mile 0.57–0.69

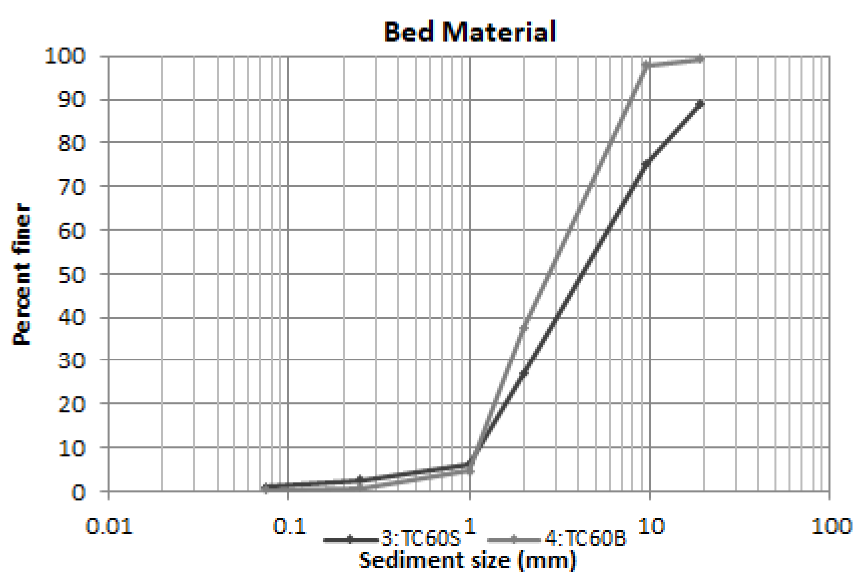


River Mile 0.79–0.99

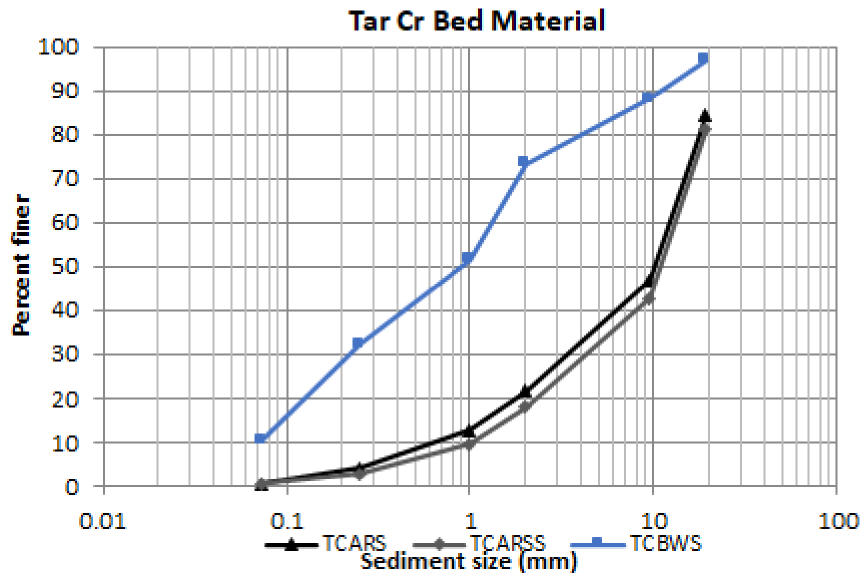


Tar Creek

River Mile 6.33

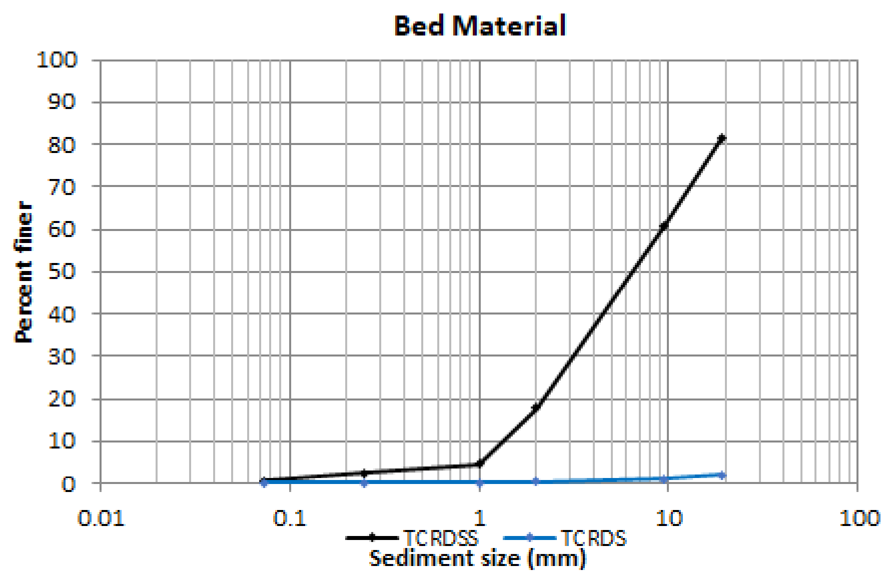


River Mile 2.74–2.98

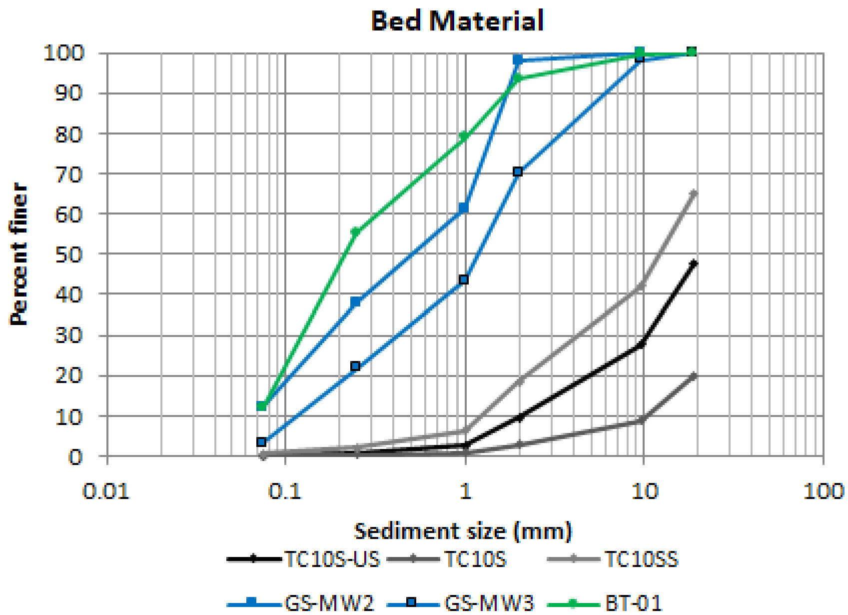


Note: BW: backwater

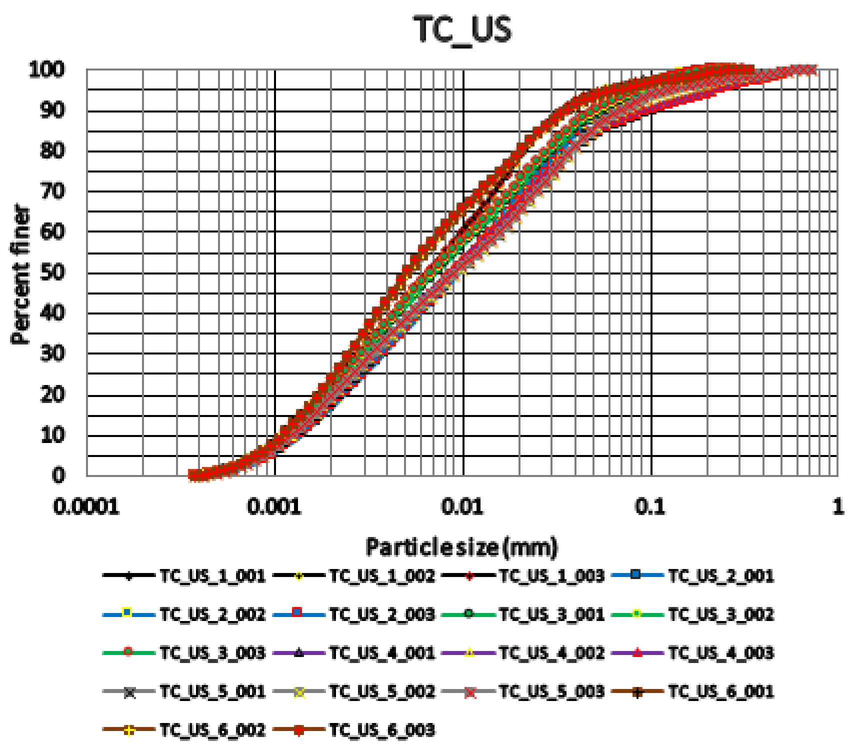
River Mile 2.23



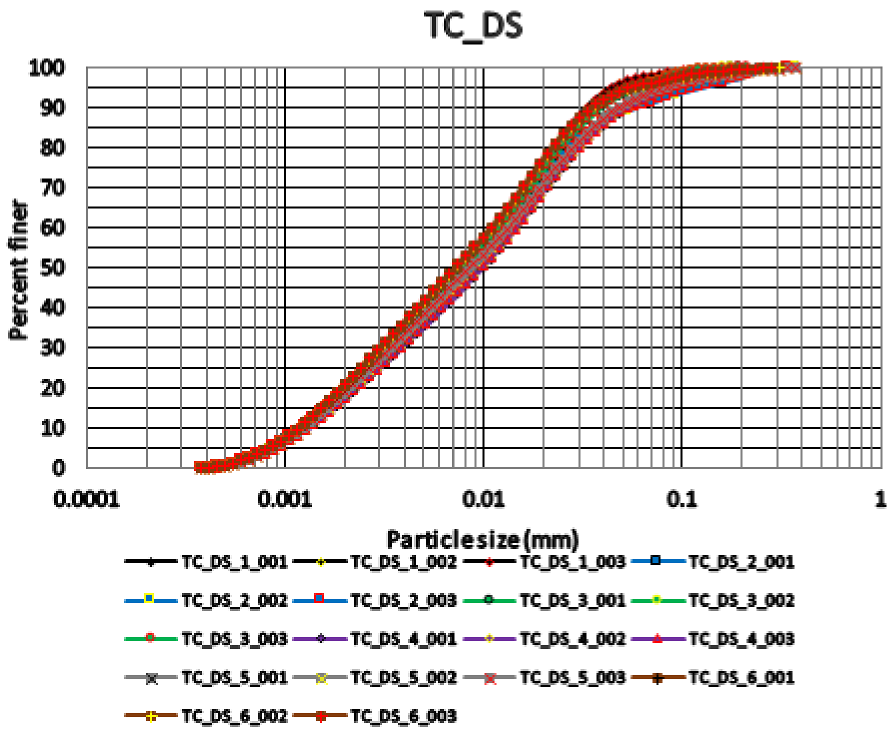
River Mile 1.6



River Mile 1.6

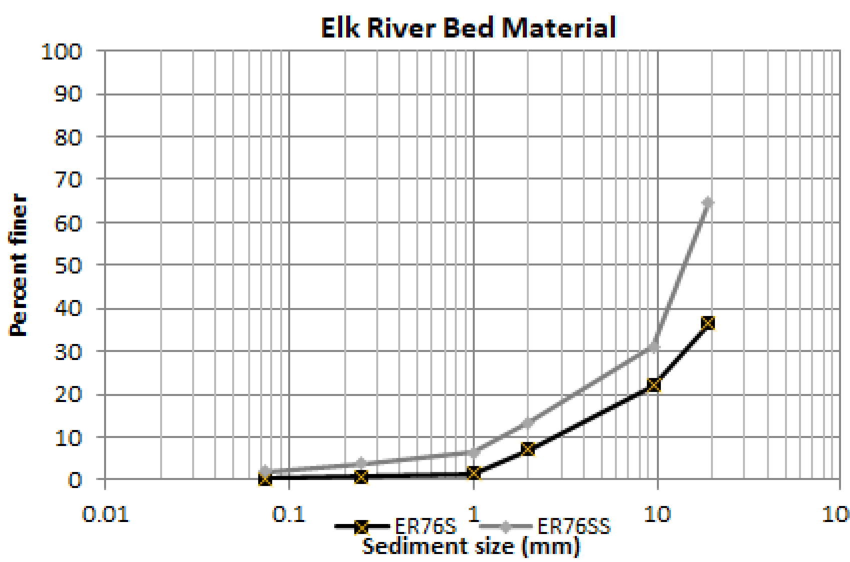


River Mile 1.6

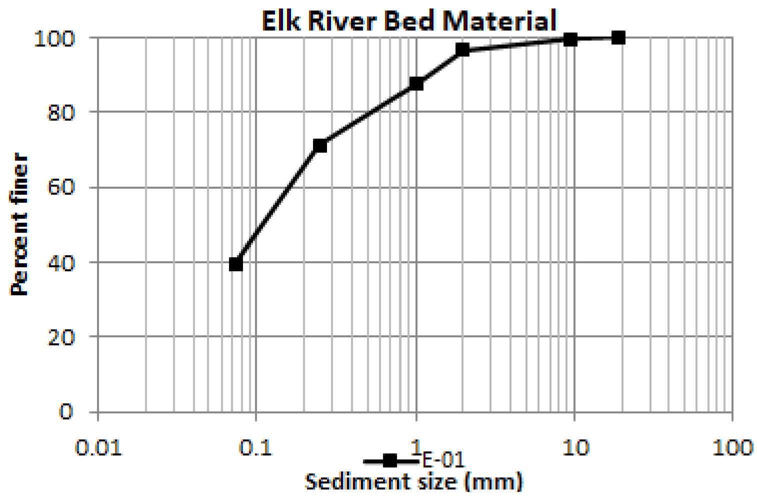


Elk River

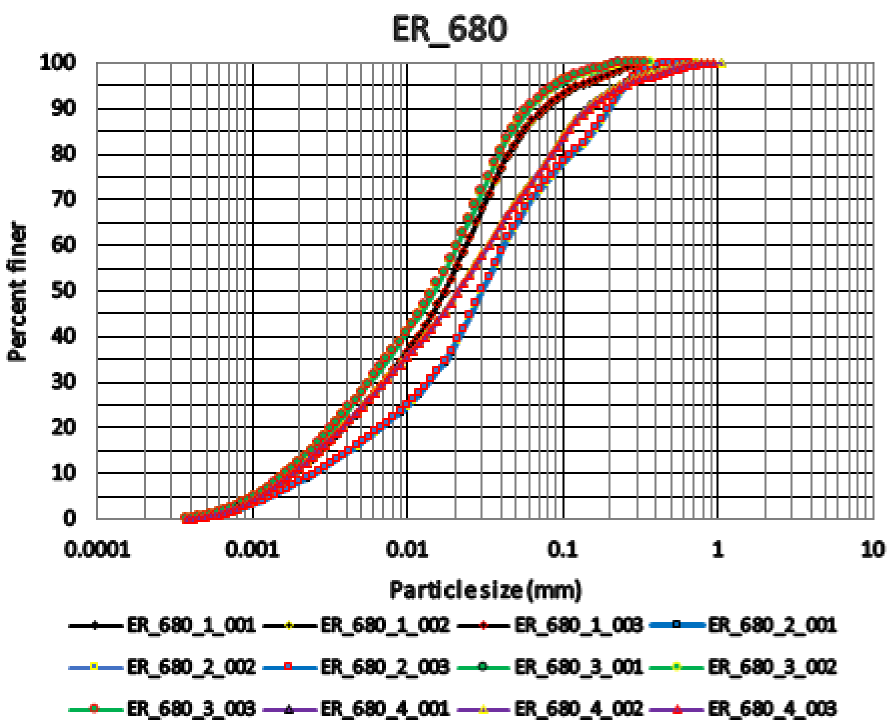
River Mile 14.22



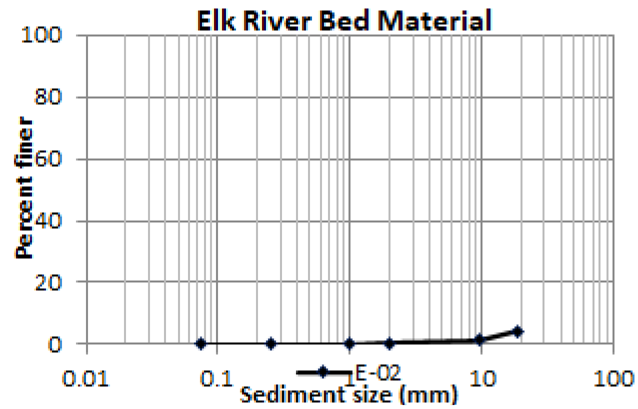
River Mile 8.8



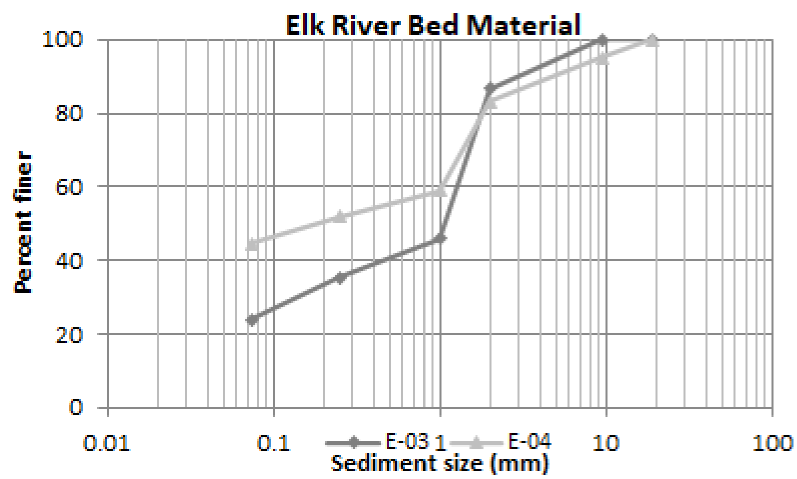
River Mile 8.8



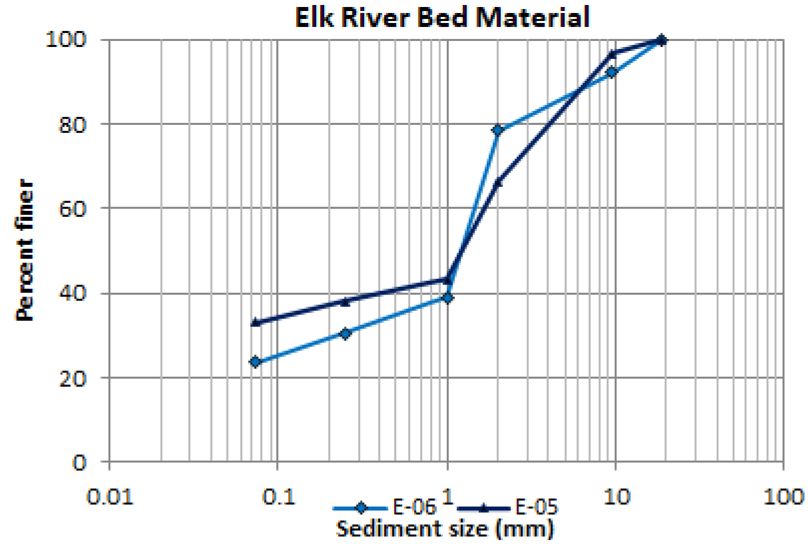
River Mile 7.5-7.79



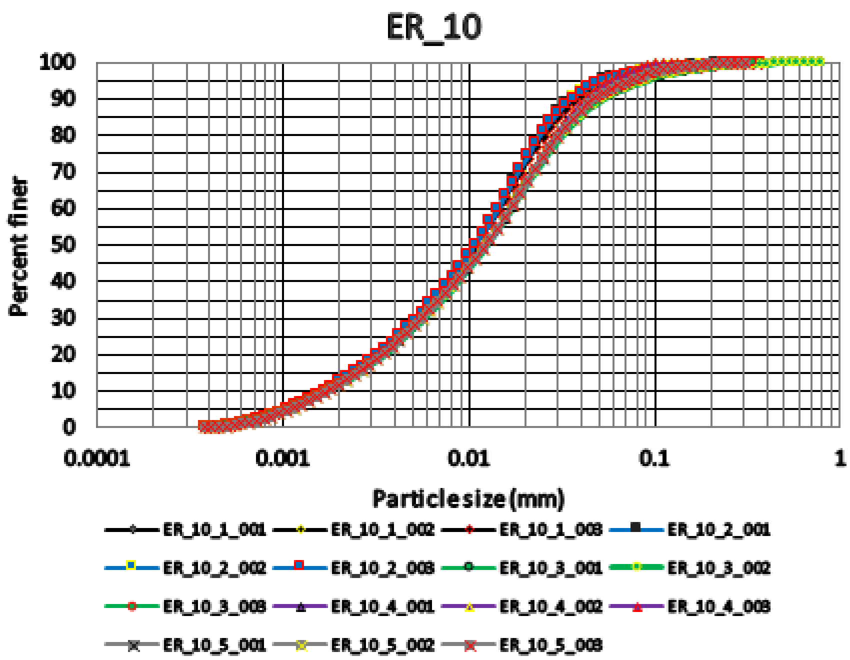
River Mile 5.86–6.57



River Mile 4.67–4.9 (E-05 and ER_10)



River Mile 3.2–3.43 E-06



Sediment Grab Sampling

FRESHWATER ENGINEERING

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

FreshWater Engineering

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

FRESHWATER ENGINEERING

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

FreshWater Engineering

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

FRESHWATER ENGINEERING

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

FRESHWATER ENGINEERING

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

FreshWater Engineering

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

FreshWater Engineering

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

FRESHWATER ENGINEERING

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

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

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

FreshWater Engineering

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

FreshWater Engineering

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

FRESHWATER ENGINEERING

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

FRESHWATER ENGINEERING

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

FRESHWATER ENGINEERING

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

FreshWater Engineering

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

FRESHWATER ENGINEERING

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

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:

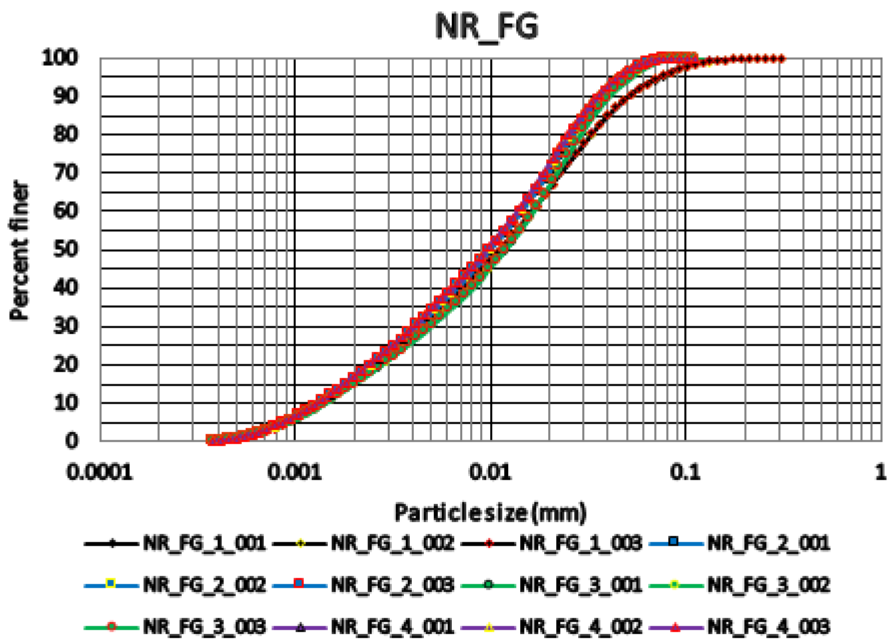
- GrabSampleLocations.csv

Appendix C
SEDflume Core Sampling

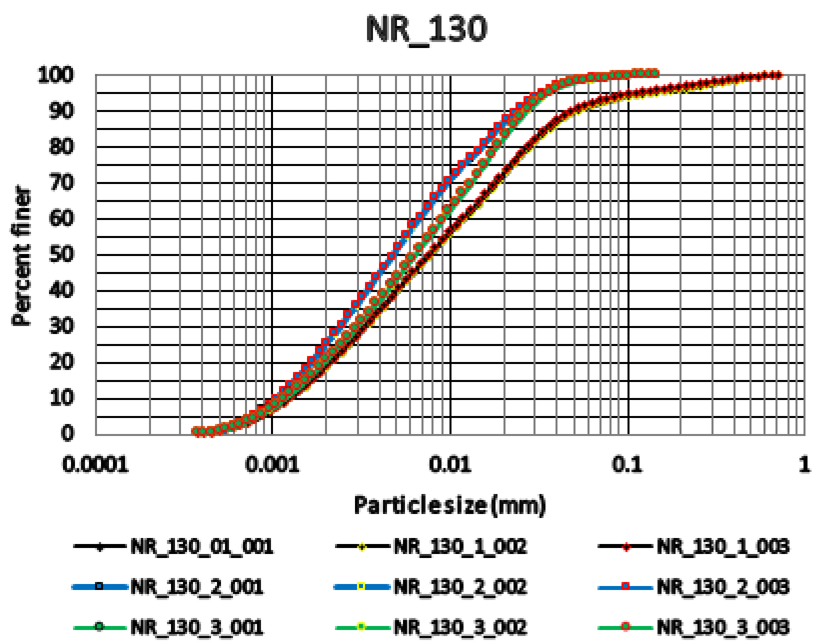
Particle Size Distribution Results

Neosho River above Tar Creek

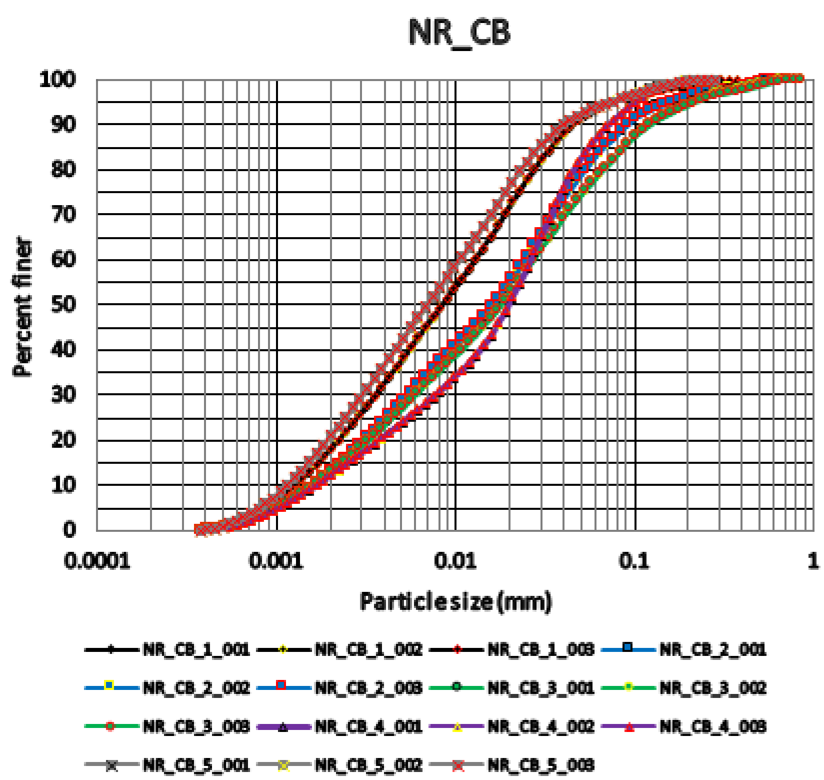
River Mile 135.15



River Mile 130.54

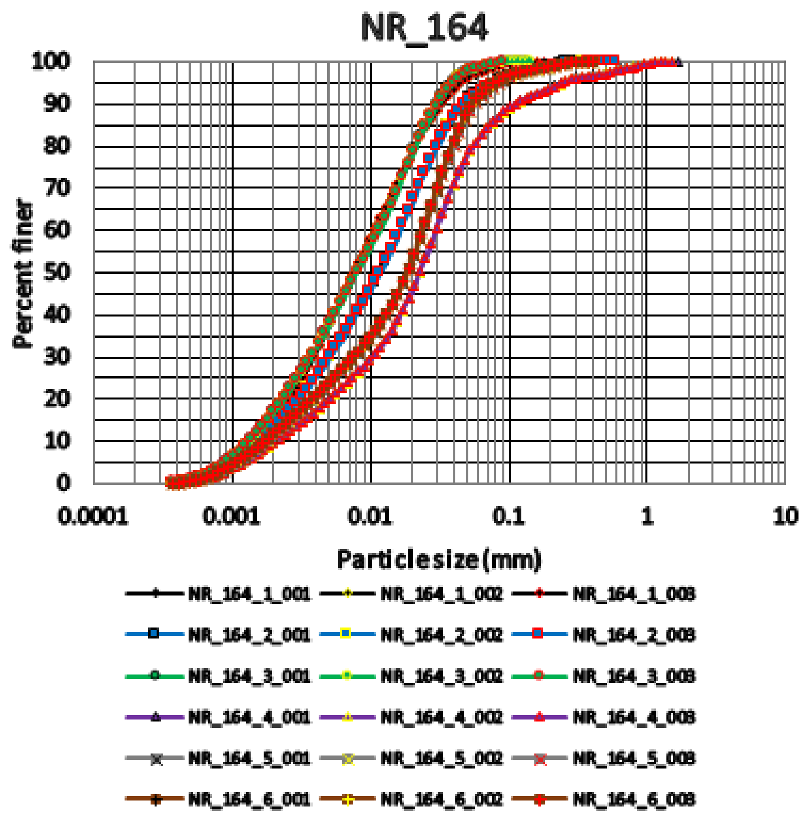


River Mile 126.69

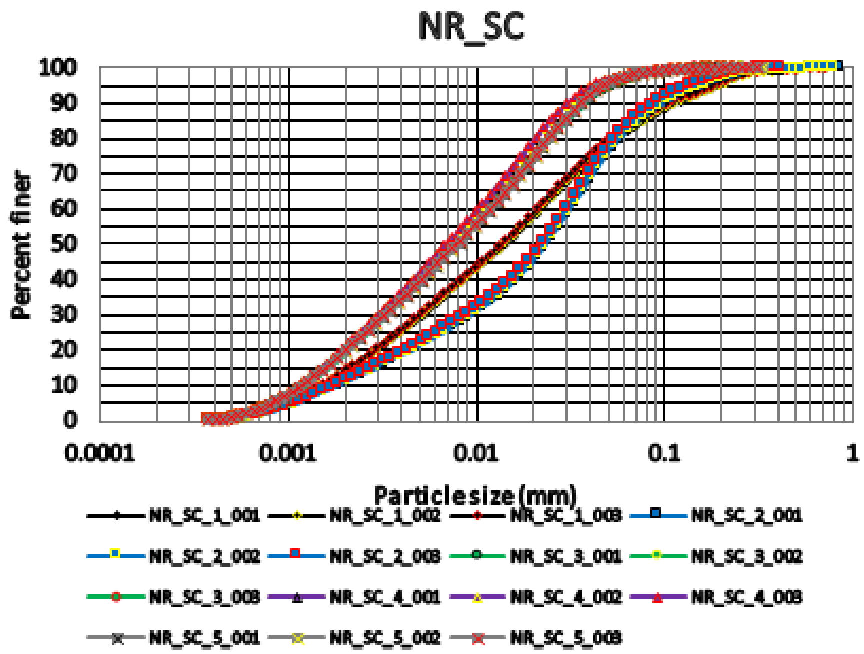


Neosho River – Grand Lake

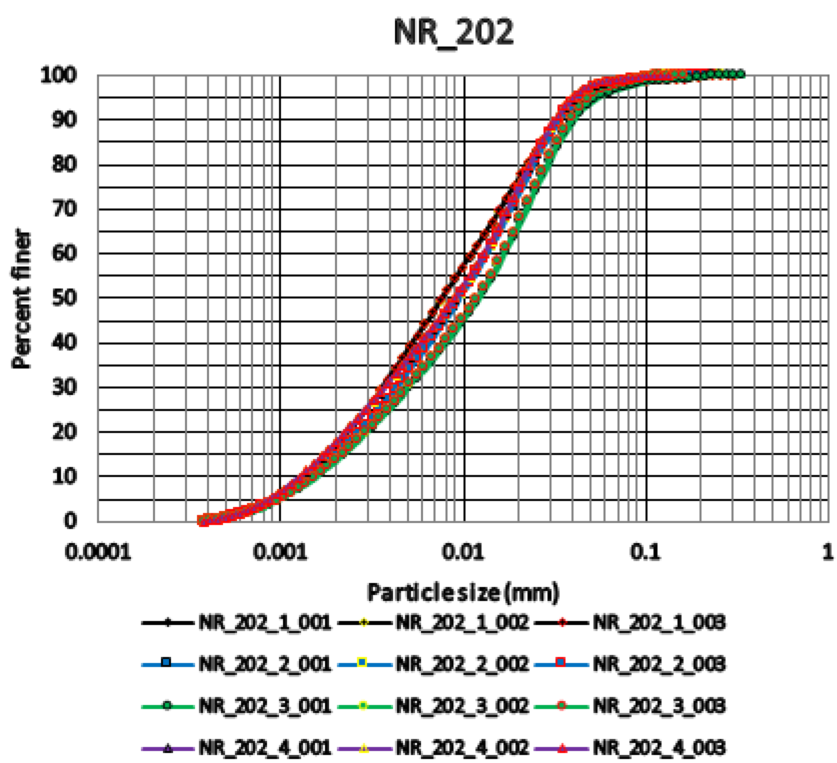
River Mile 120.43



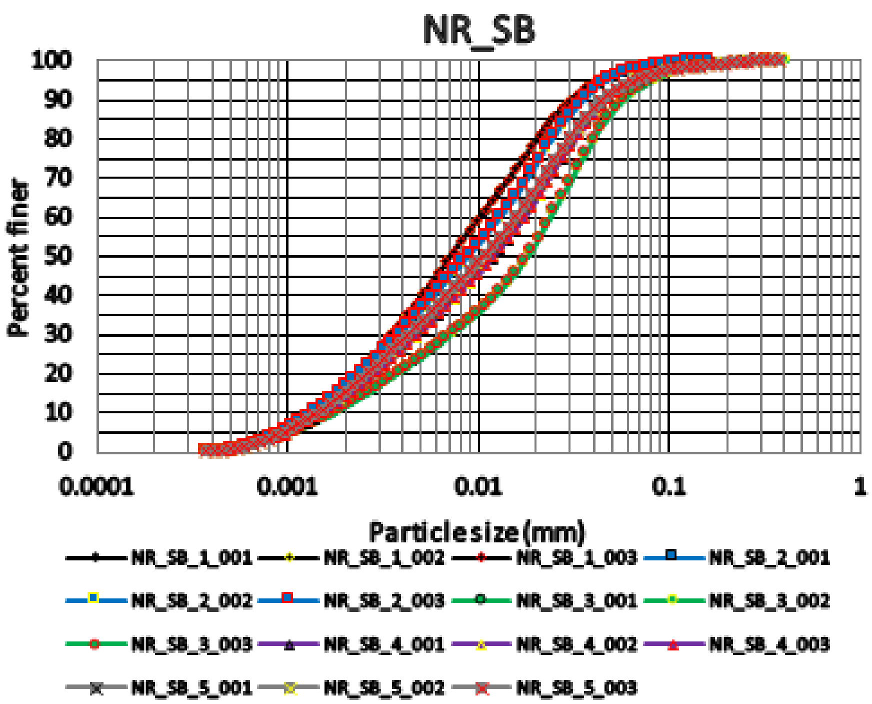
River Mile 115.81



River Mile 112.69

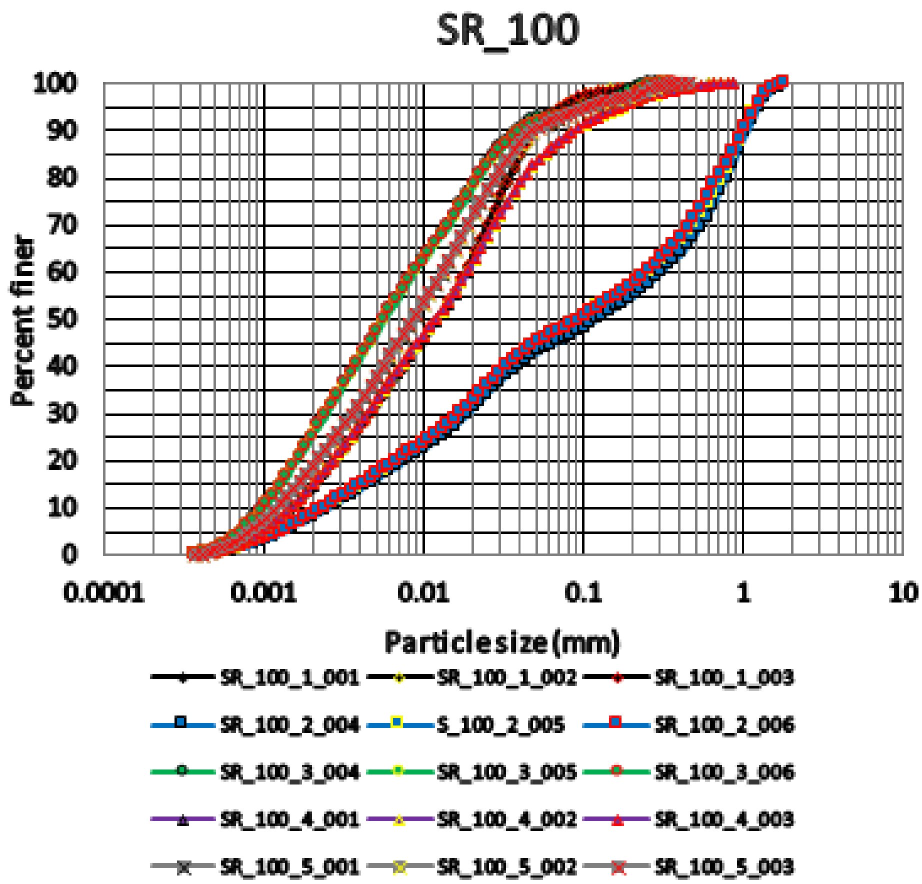


River Station 109.65

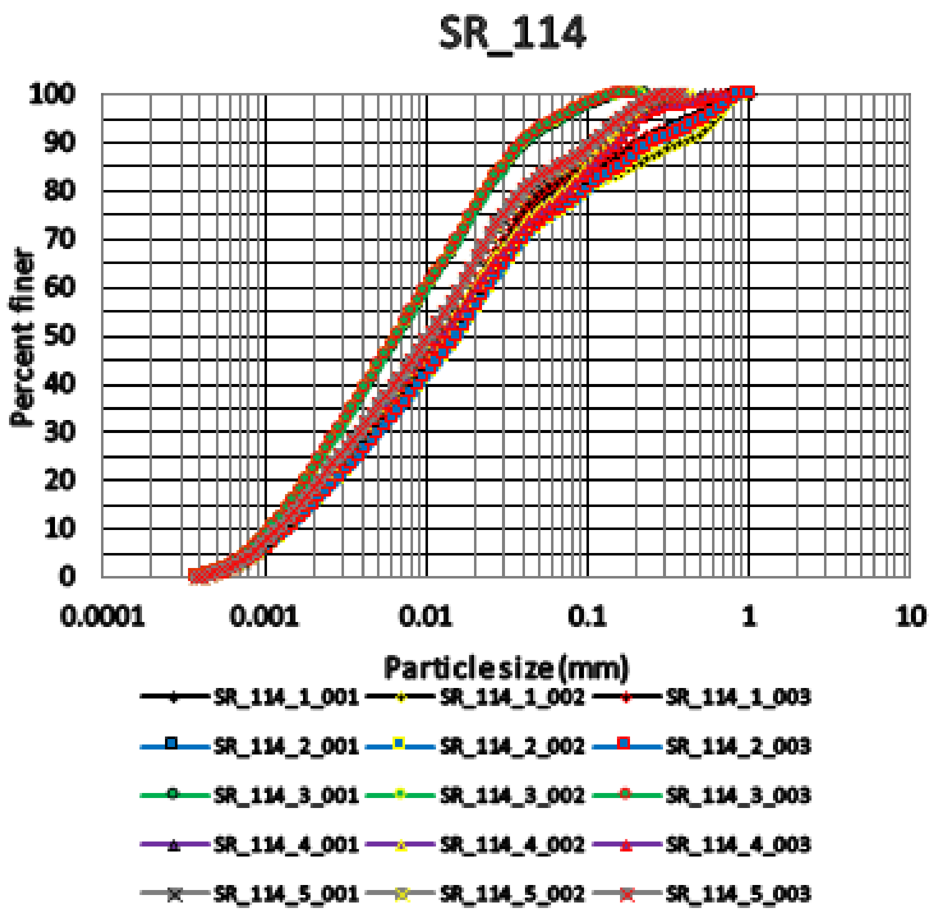


Spring River

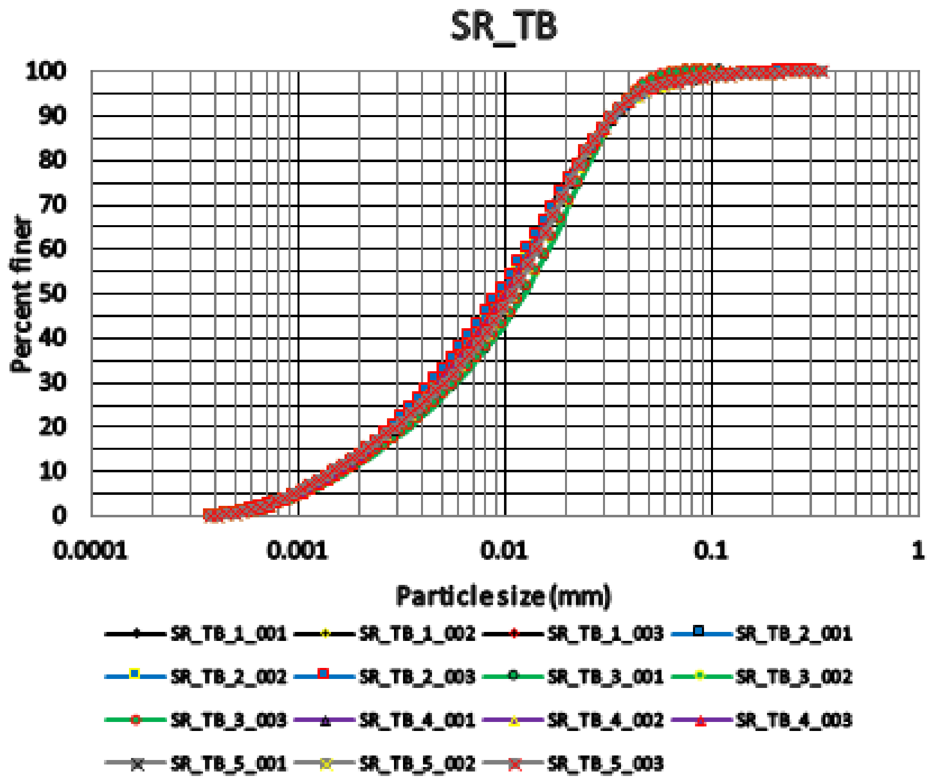
River Mile 7.5



River Mile 4.82

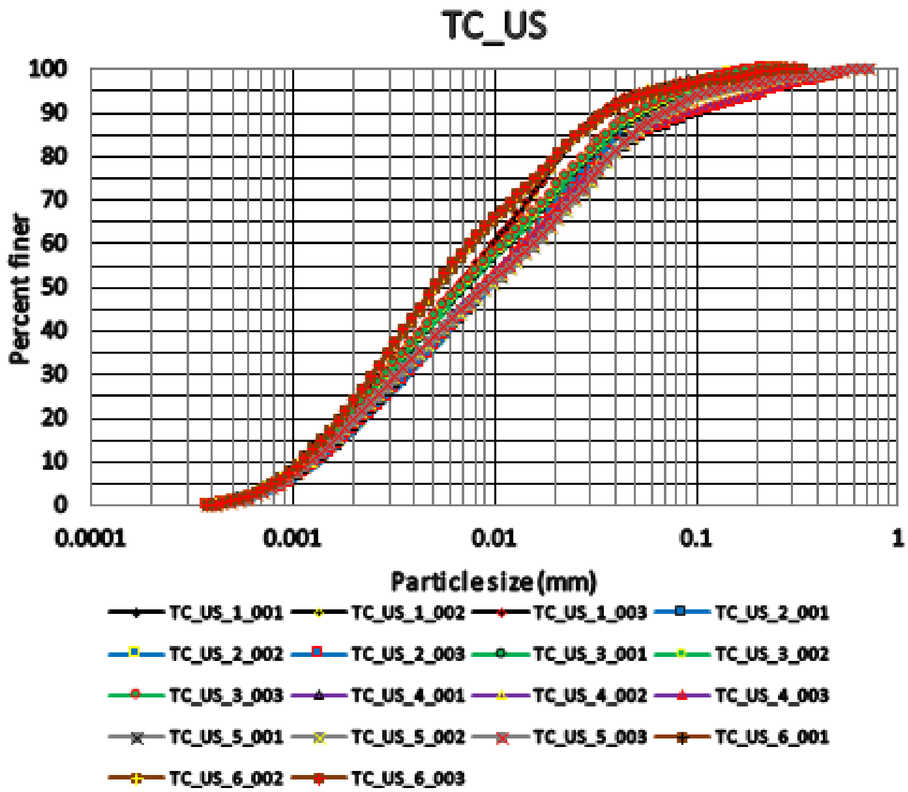


River Mile 0.79



Tar Creek

Downstream of River Mile 1.6



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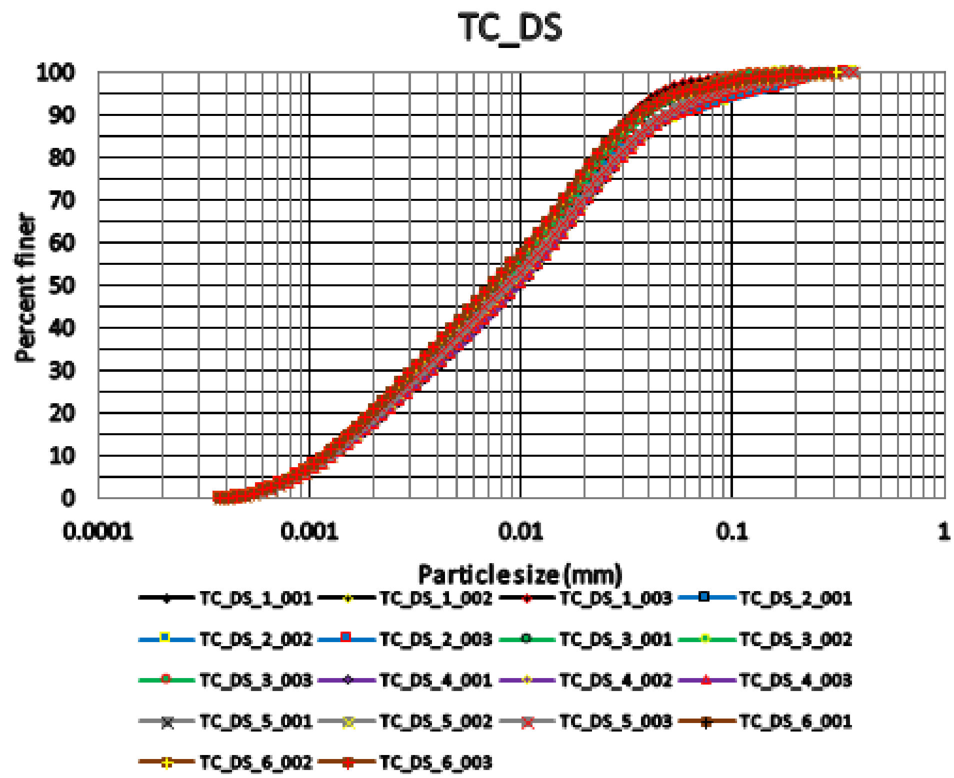
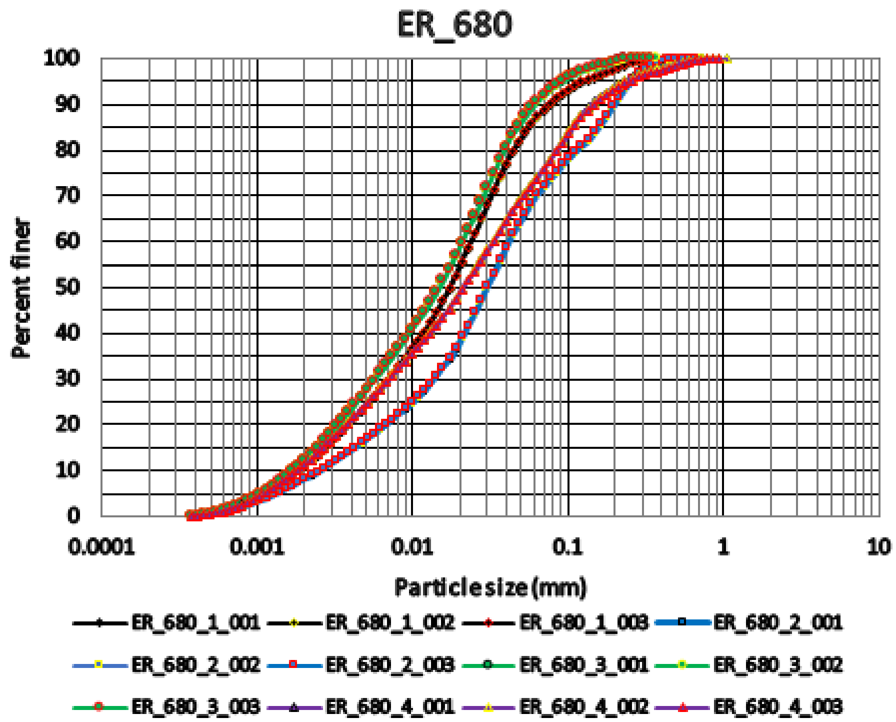
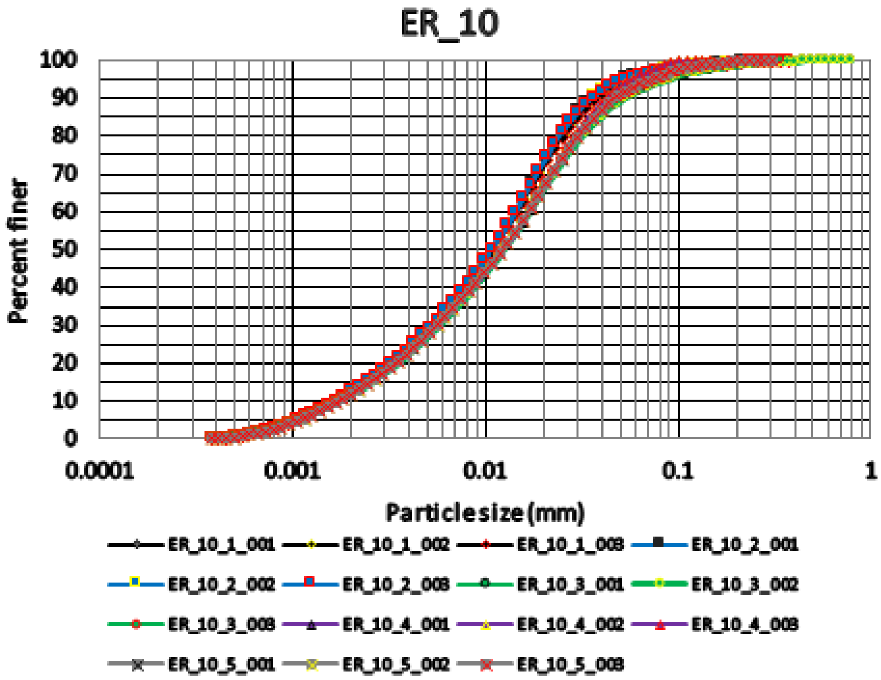


Elk River

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.

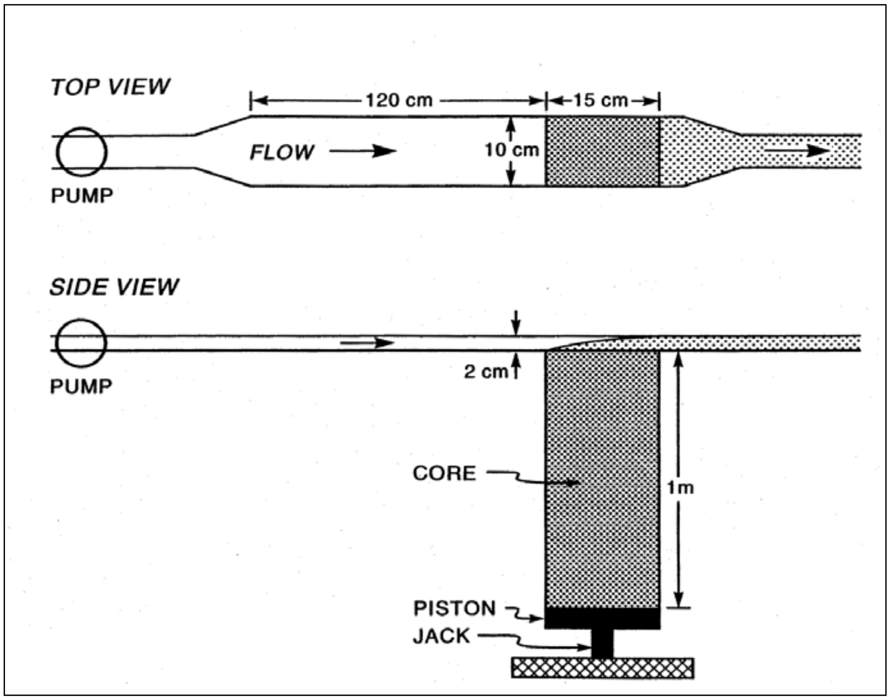

Figure 1. Schematic of SEDflume setup showing top and side views

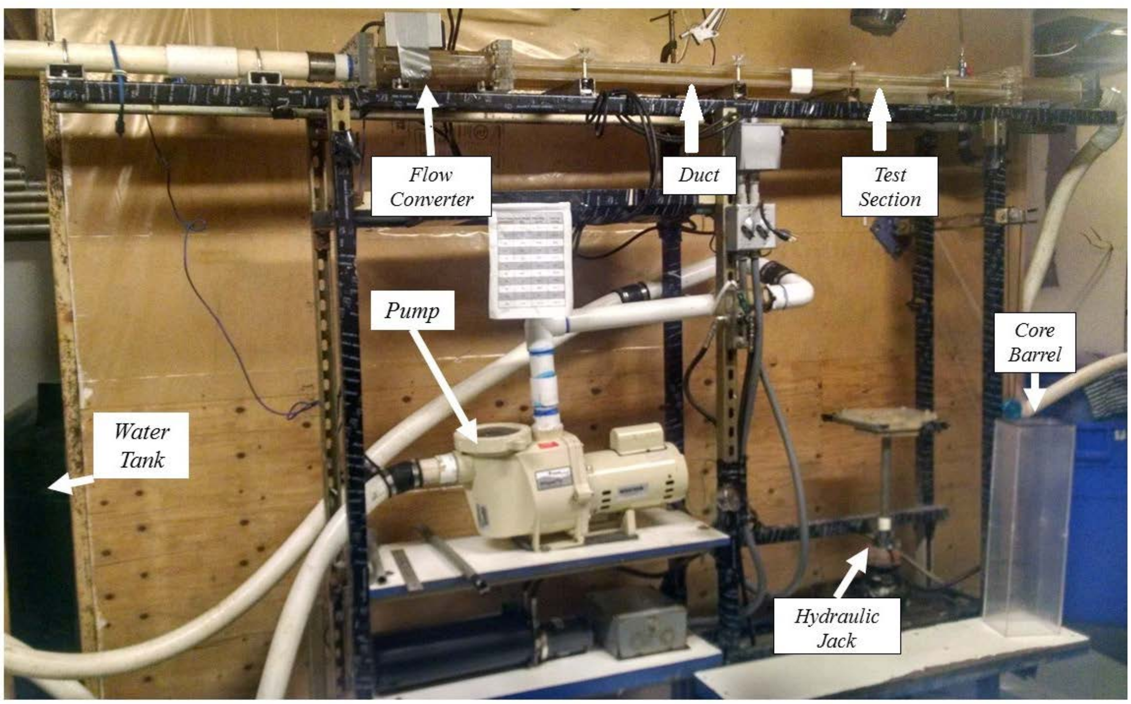

Figure 2. SEDflume in Integral's laboratory, Santa Cruz, California

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:

$$E = \frac{\Delta z}{T} \qquad [1]$$

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]

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[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:

$$E = A\tau^n \rho^m \quad [2]$$

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:

$$E = A\tau^n \quad [3]$$

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.

$$\rho_{wet} = \frac{(100 * \rho_s)}{100 + (W + IG)(\rho_s - 1)} \quad [5]$$

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

$$MC = \frac{M_w - M_d}{M_d} \quad [6]$$

This formulation represents the ratio of water to solids. Using the moisture content value, dry bulk densities were calculated using the following relationship:

$$\rho_{dry} = \frac{\rho_{wet}}{1 + MC} \quad [7]$$

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/cm^3	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/cm^3	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/cm^3)
ρs = density of sediment particle (assumed 2.65 g/cm^3)

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.

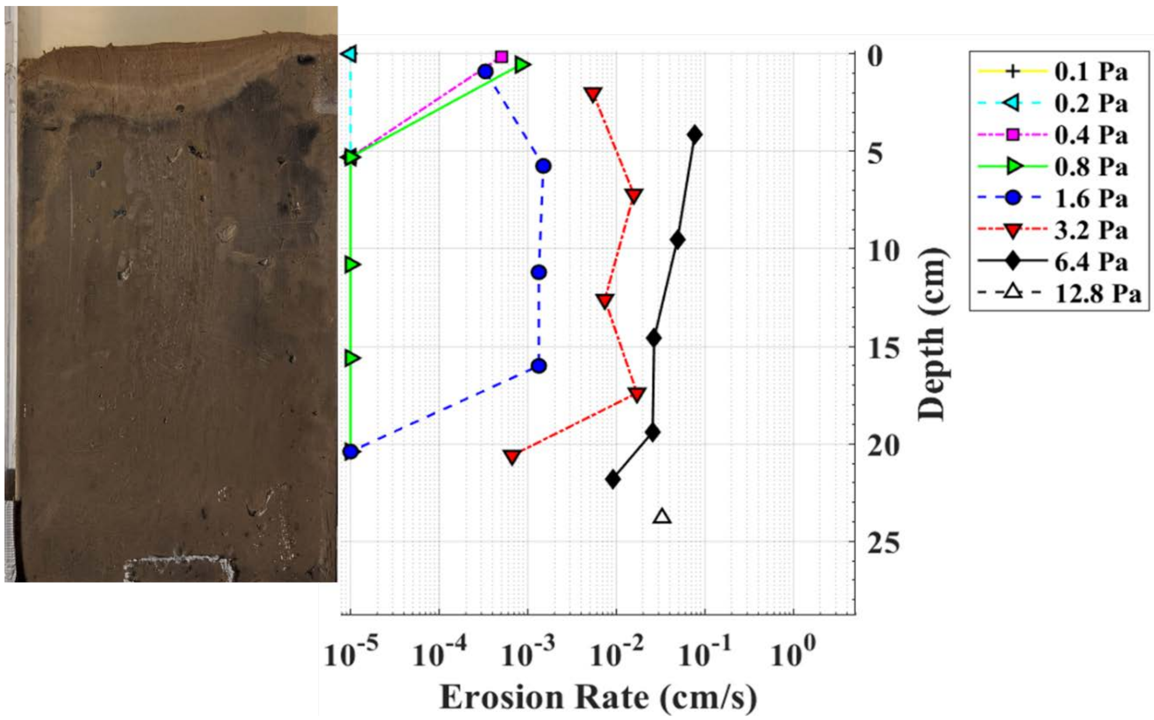

Figure 3. Photograph of Core ER-10 aligned with applied shear stresses and associated erosion rates

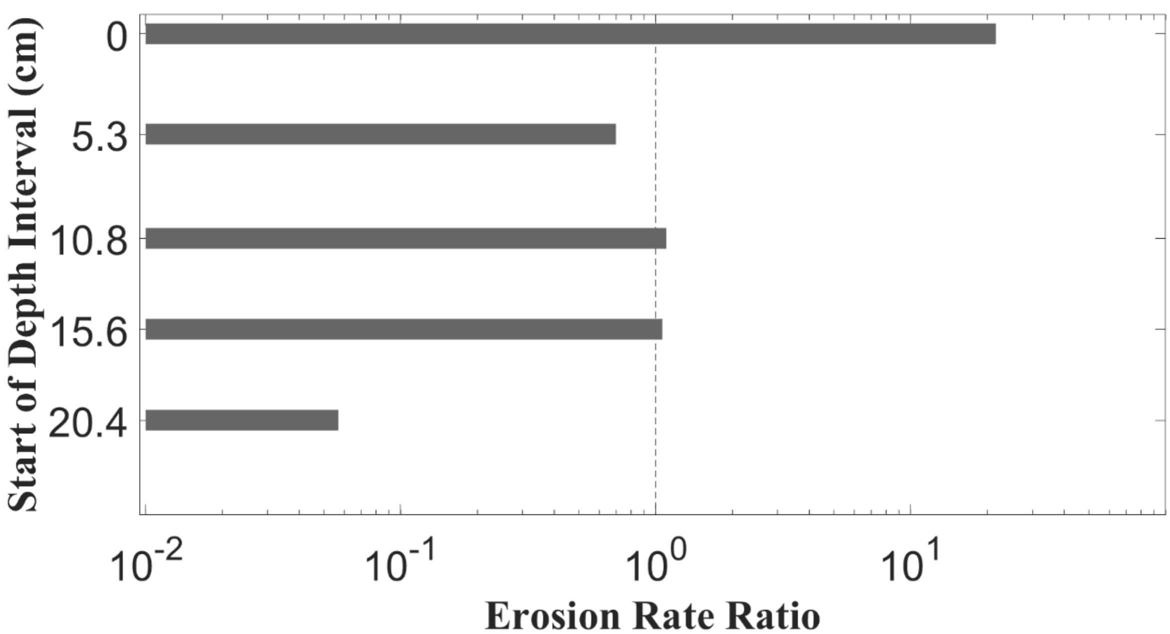

Figure 4. Intracore erosion rates of ER-10

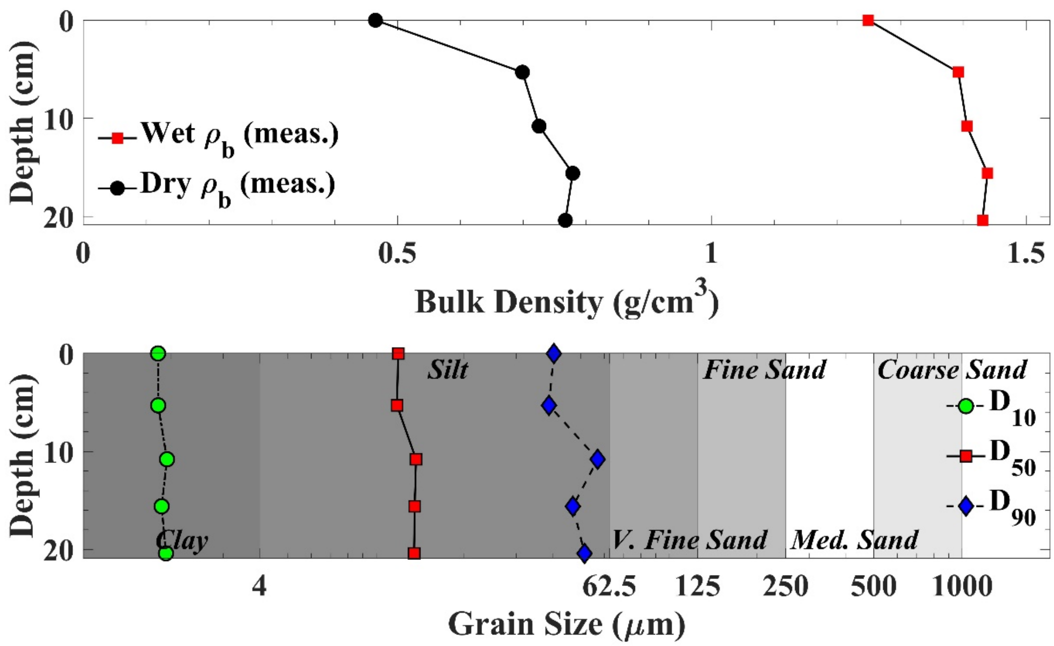

Figure 5. Physical properties of ER-10 with depth

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.

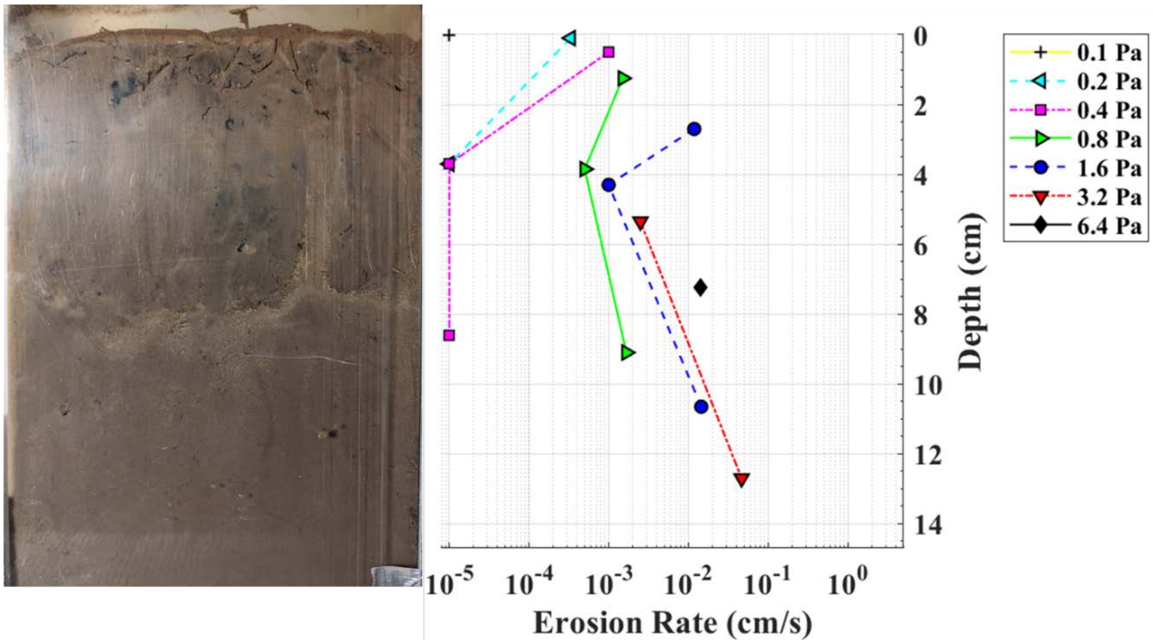

Figure 6. Photograph of Core ER-680 aligned with applied shear stresses and associated erosion rates

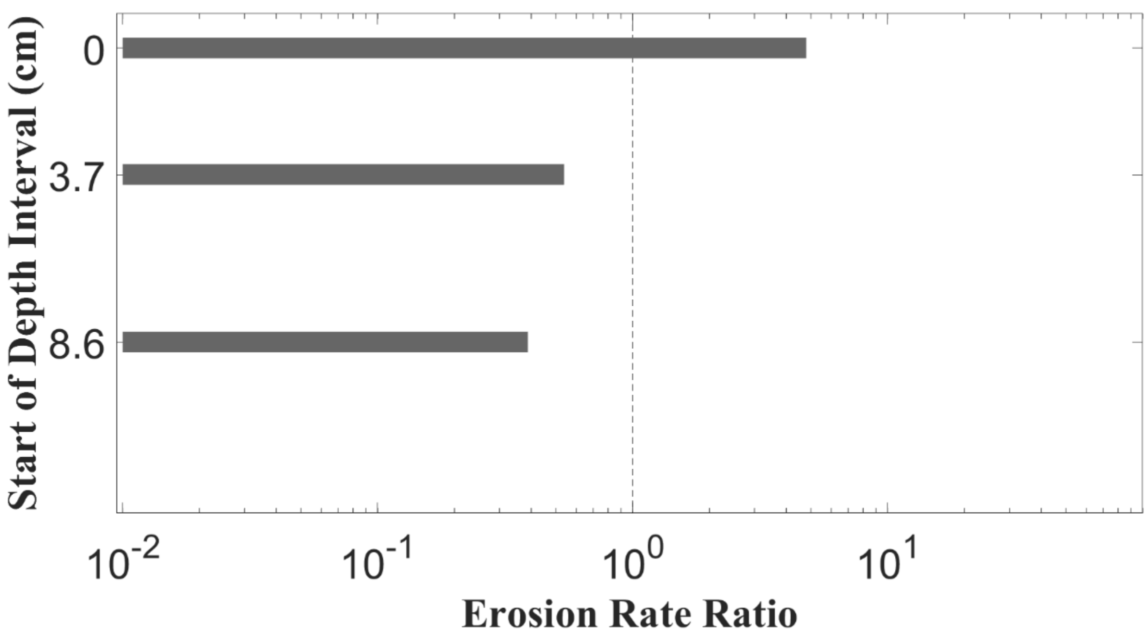

Figure 7. Intracore erosion rates in ER-680

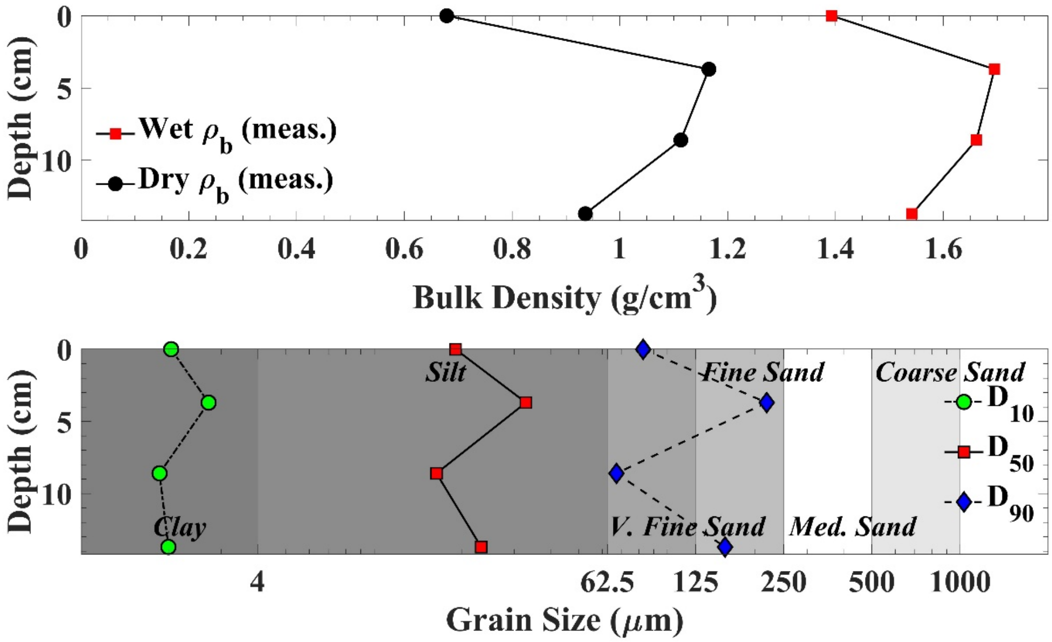

Figure 8. Physical properties of ER-680 with depth

Table 5. Physical properties and derived critical shear stresses of ER-680

Sample Depth (cm)	Median Grain Size (µm)	Wet Bulk Density (g/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	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.

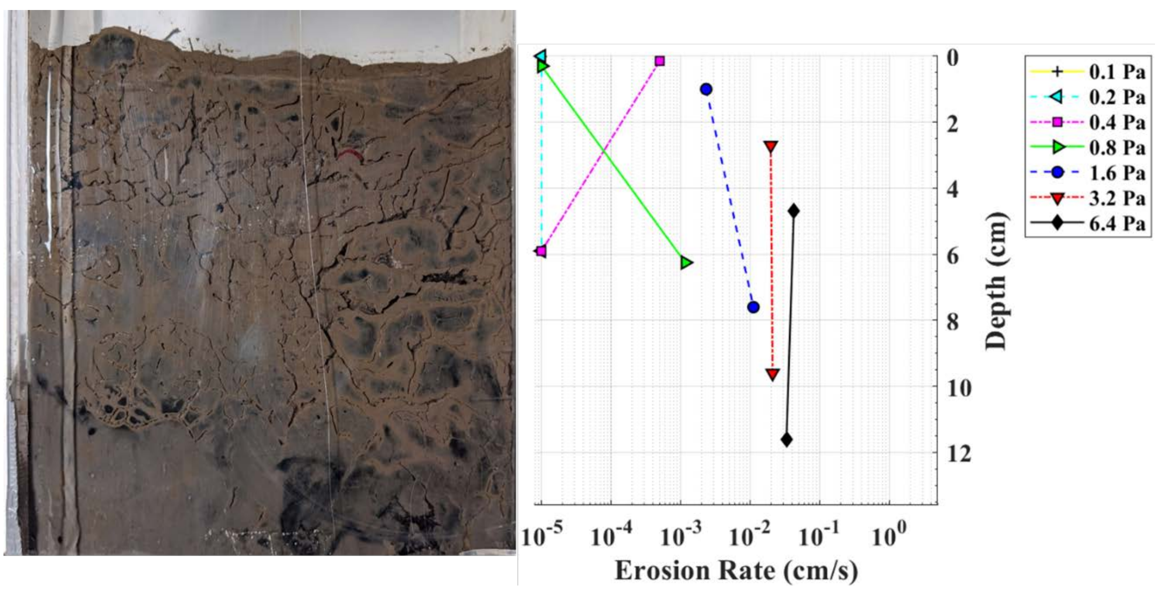

Figure 9. Photograph of Core NR-130 aligned with applied shear stresses and associated erosion rates

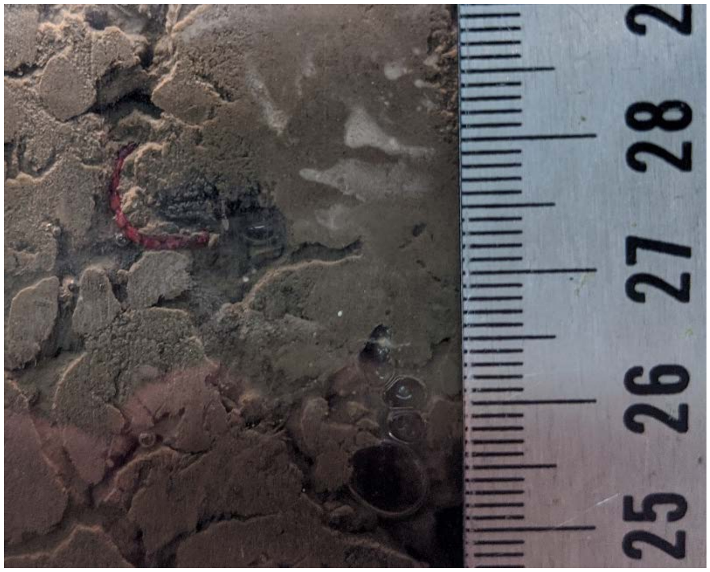

Figure 10. Invertebrate in burrow in NR-130

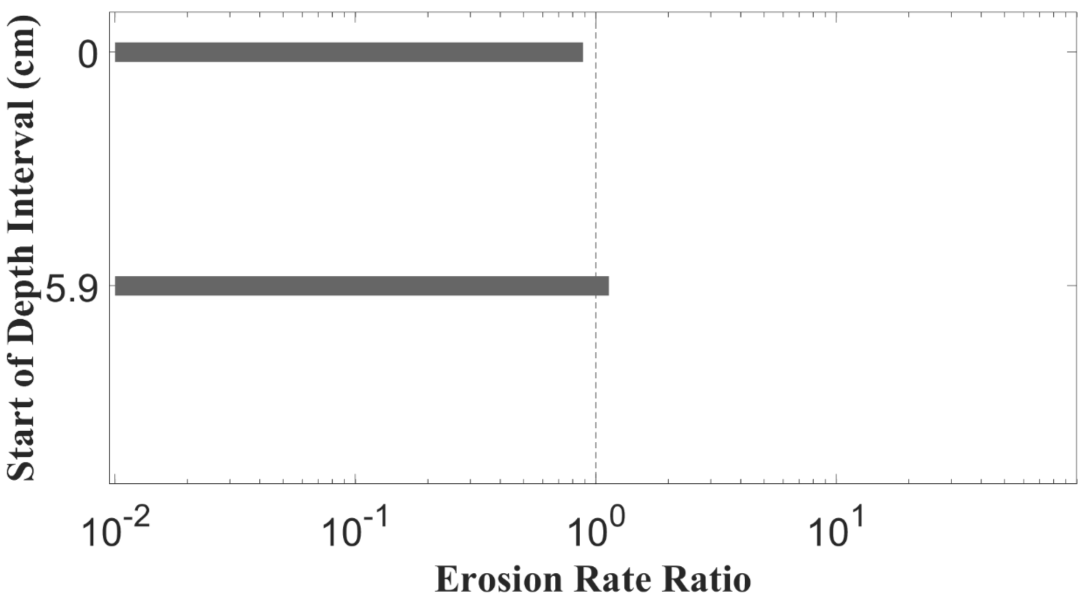

Figure 11. Intracore erosion rates in NR-130

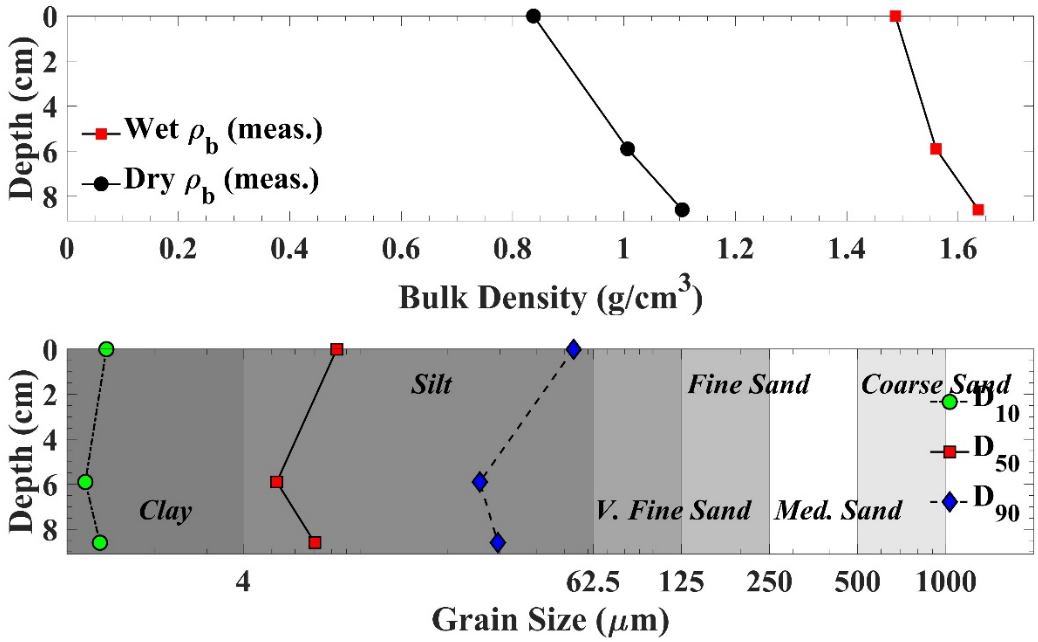

Figure 12. Physical properties of NR-130 with depth

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).

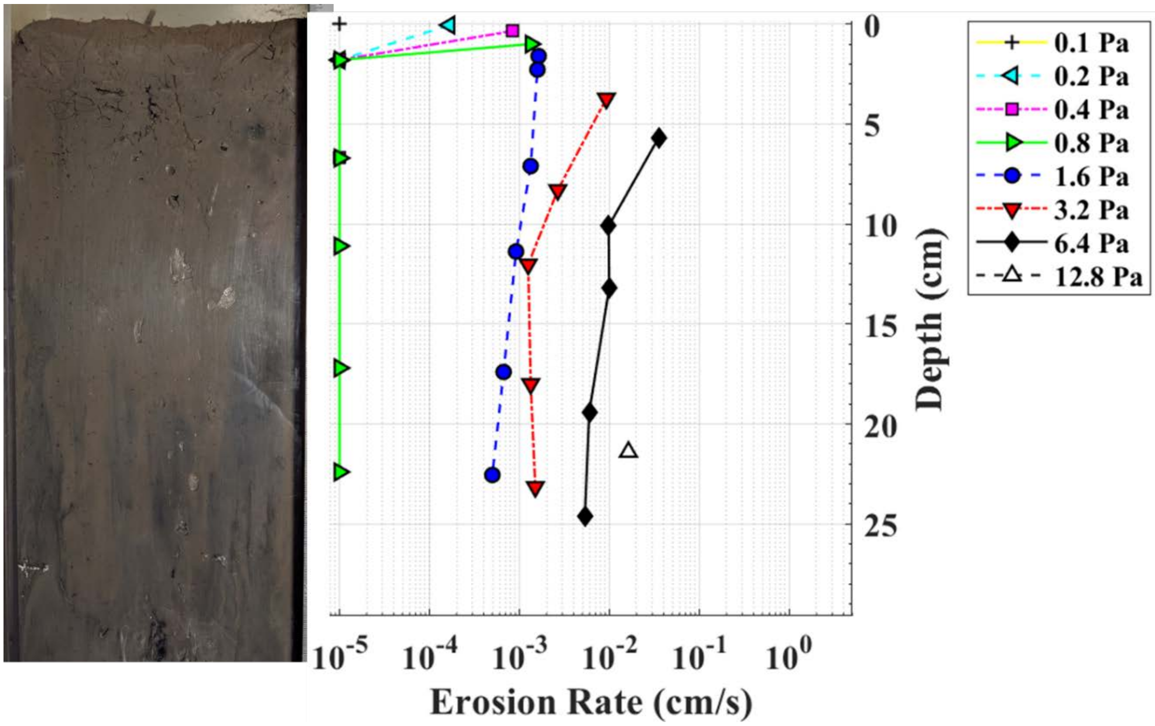

Figure 13. Photograph of Core NR-164 aligned with applied shear stresses and associated erosion rates

Figure 14. Grouping of invertebrates in NR-164

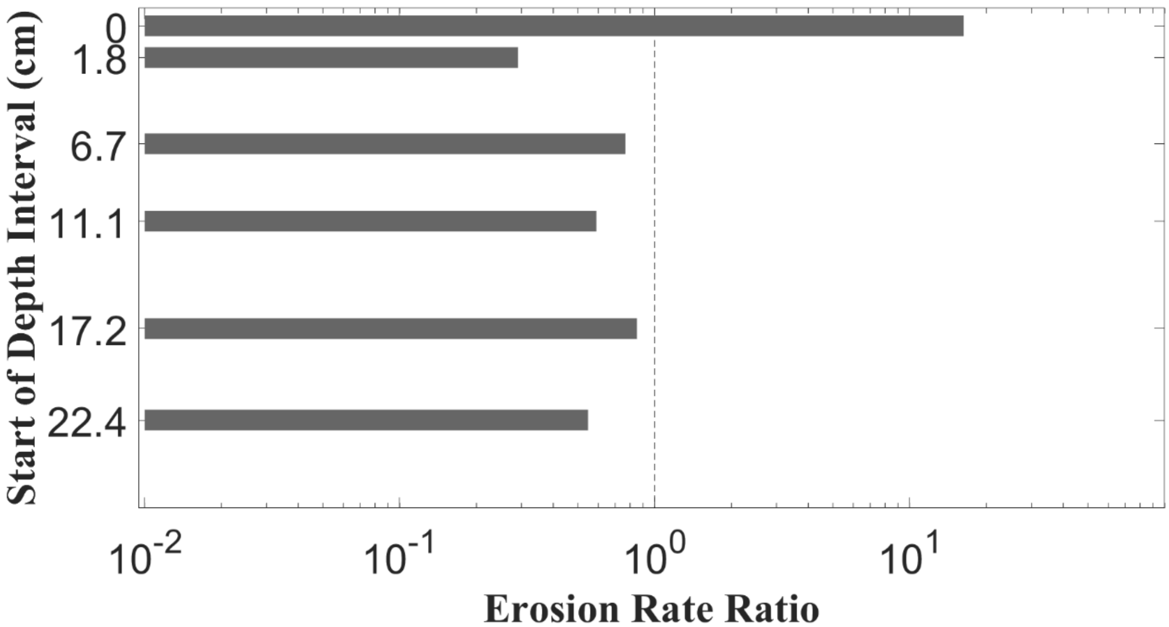

Figure 15. Intracore erosion rates in NR-164

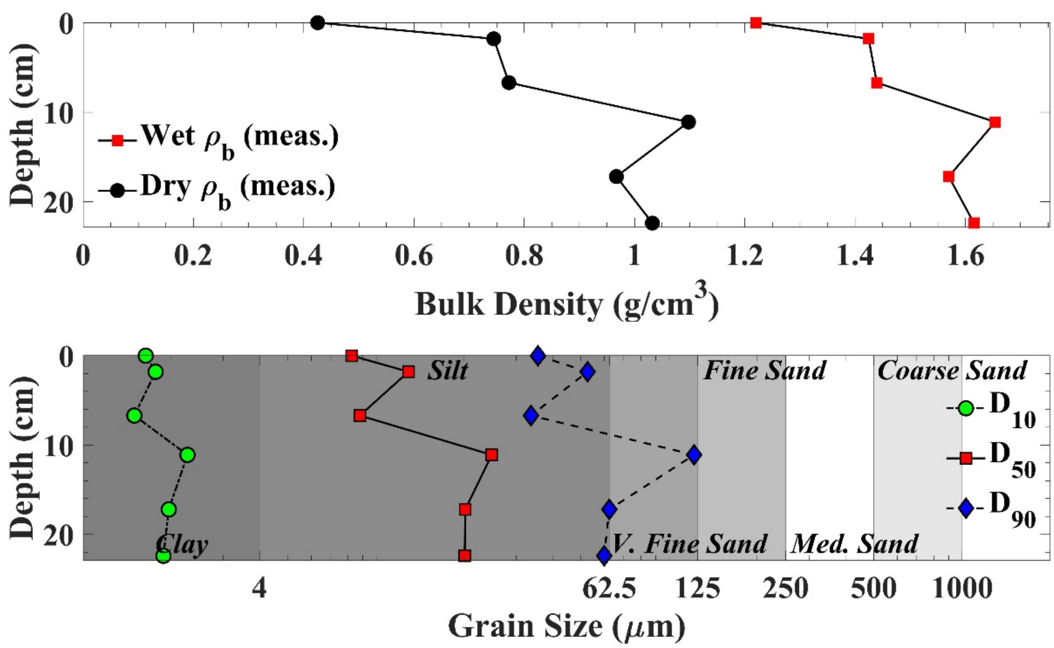

Figure 16. Physical properties of NR-164 with depth

Table 9. Physical properties and derived critical shear stresses of NR-164

Sample Depth (cm)	Median Grain Size (µm)	Wet Bulk Density (g/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	8.25	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.

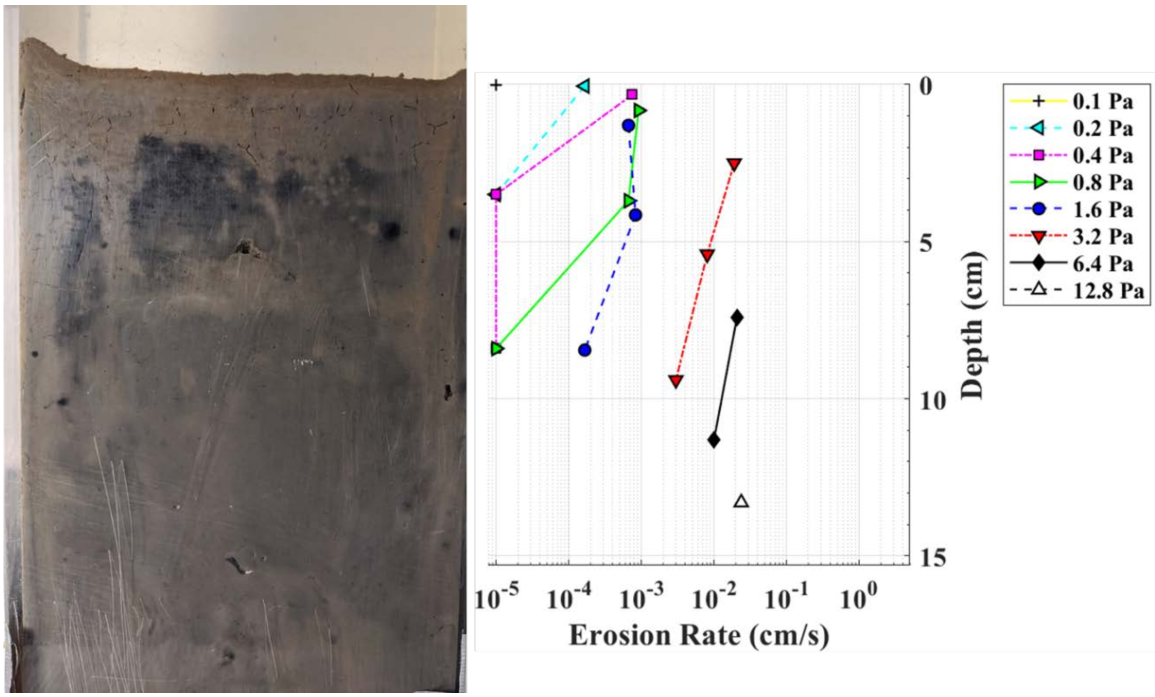

Figure 17. Photograph of Core NR-202 aligned with applied shear stresses and associated erosion rates

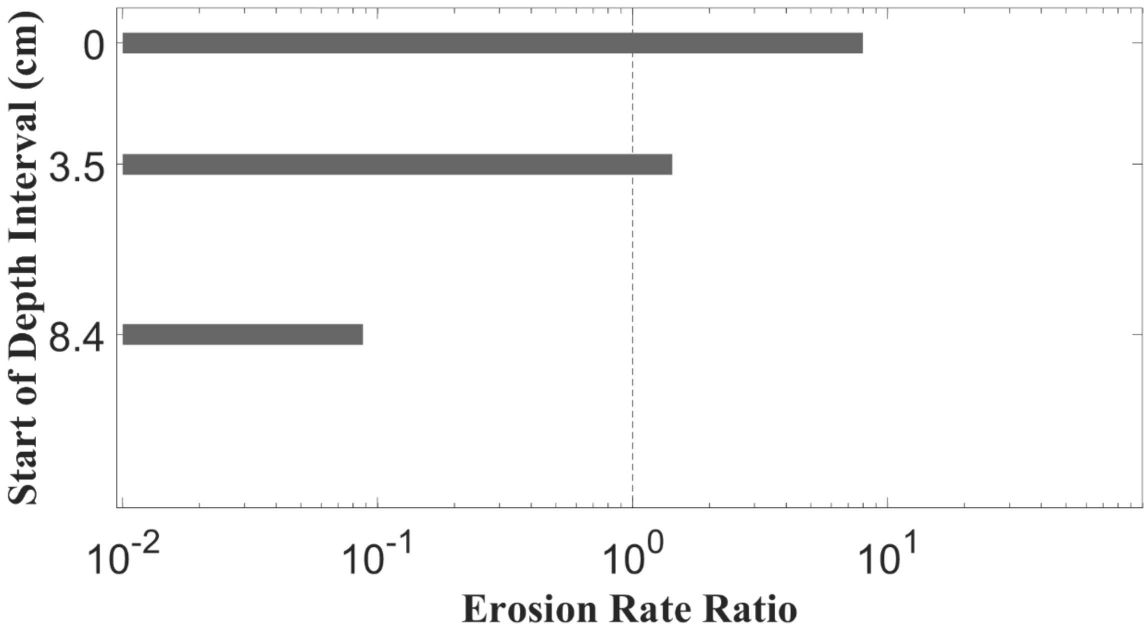

Figure 18. Intracore erosion rates in NR-202

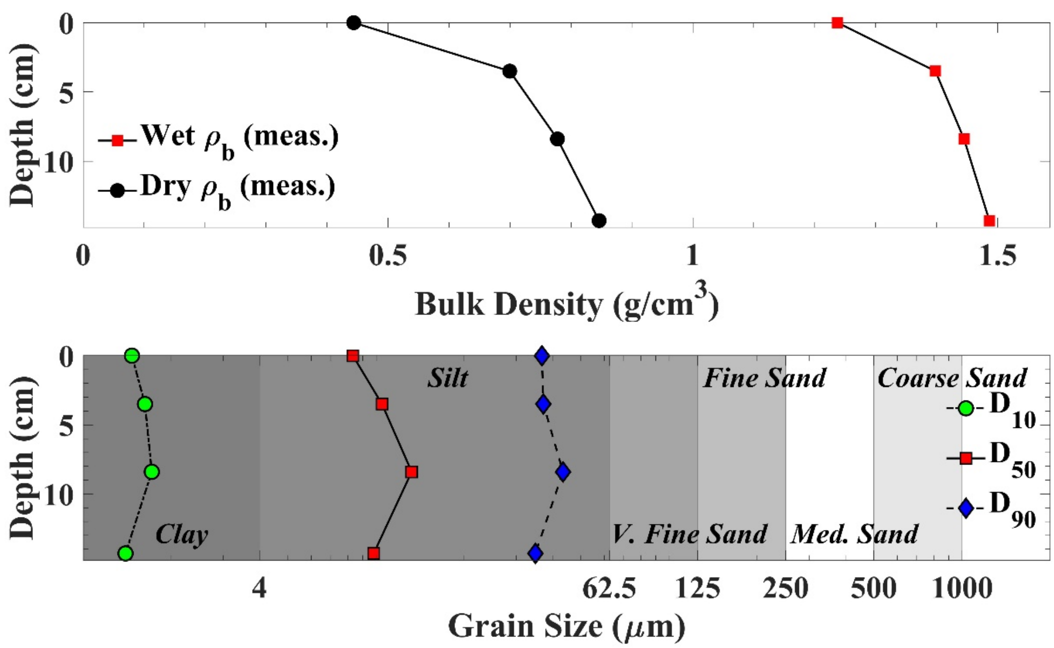

Figure 19. Physical properties of NR-202 with depth

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).

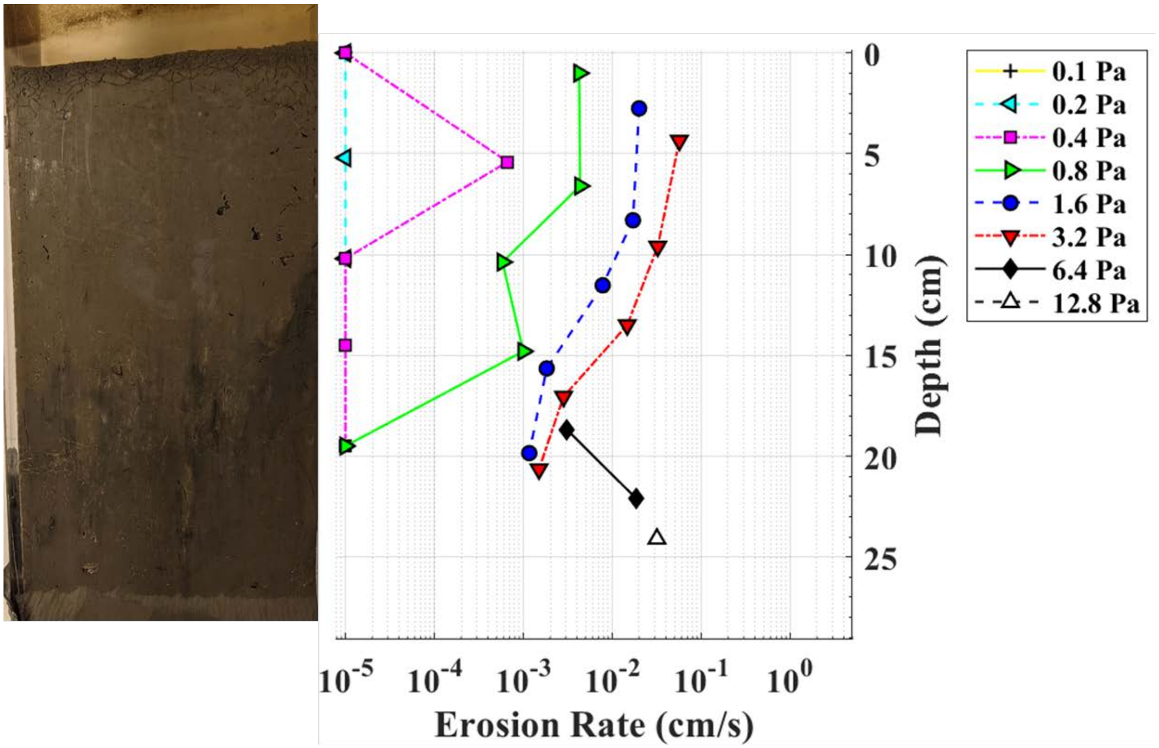

Figure 20. Photograph of Core NR-CB aligned with applied shear stresses and associated erosion rates

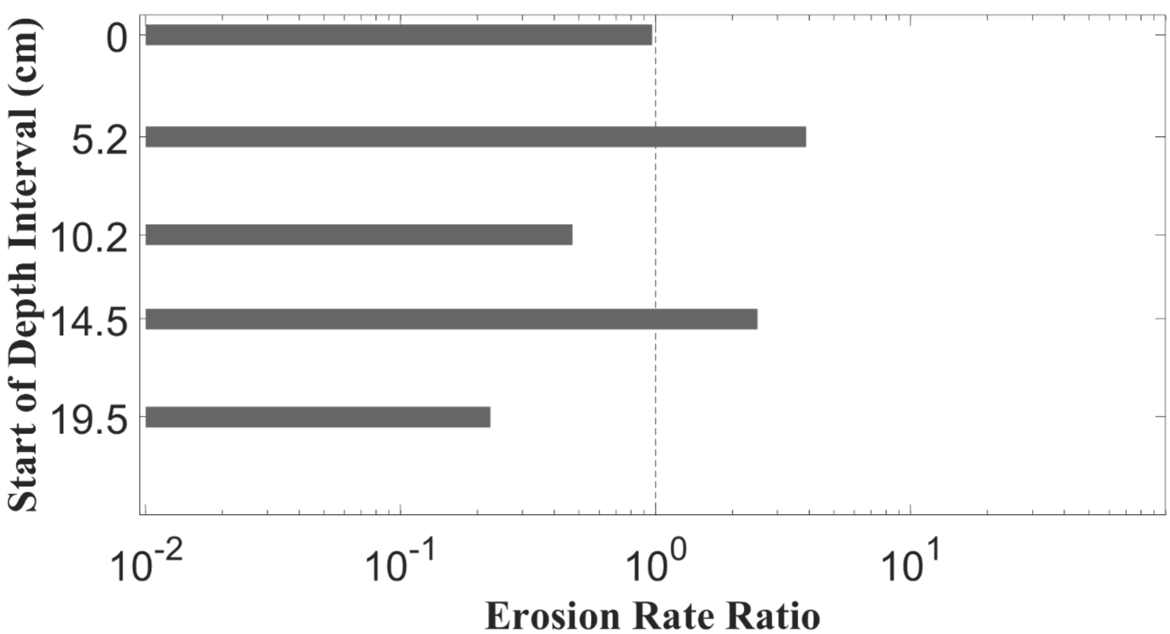

Figure 21. Intracore erosion rates in NR-CB

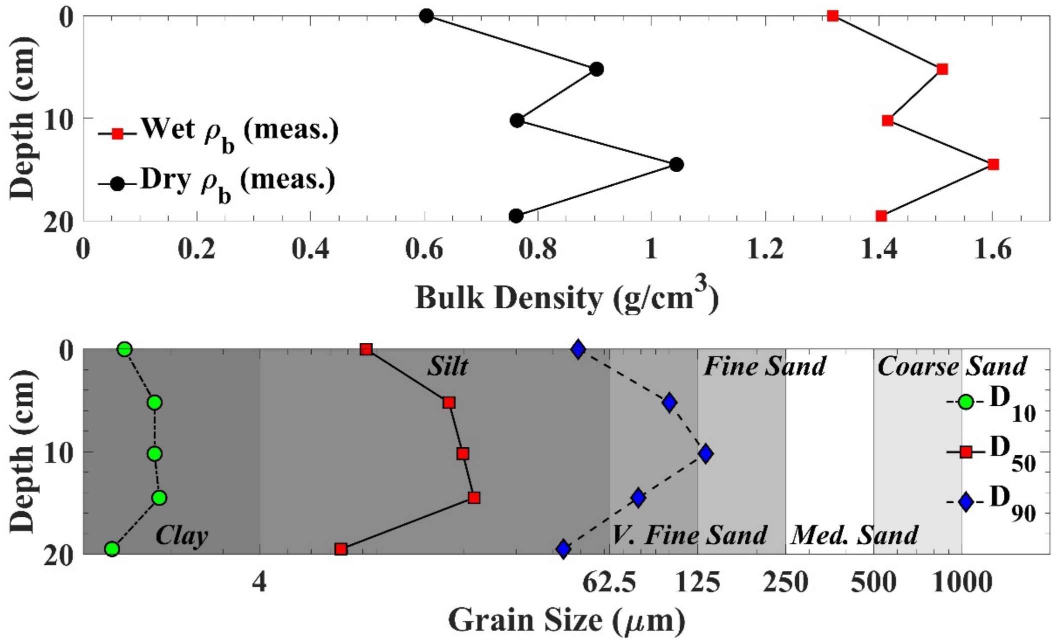

Figure 22. Physical properties of NR-CB with depth

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.

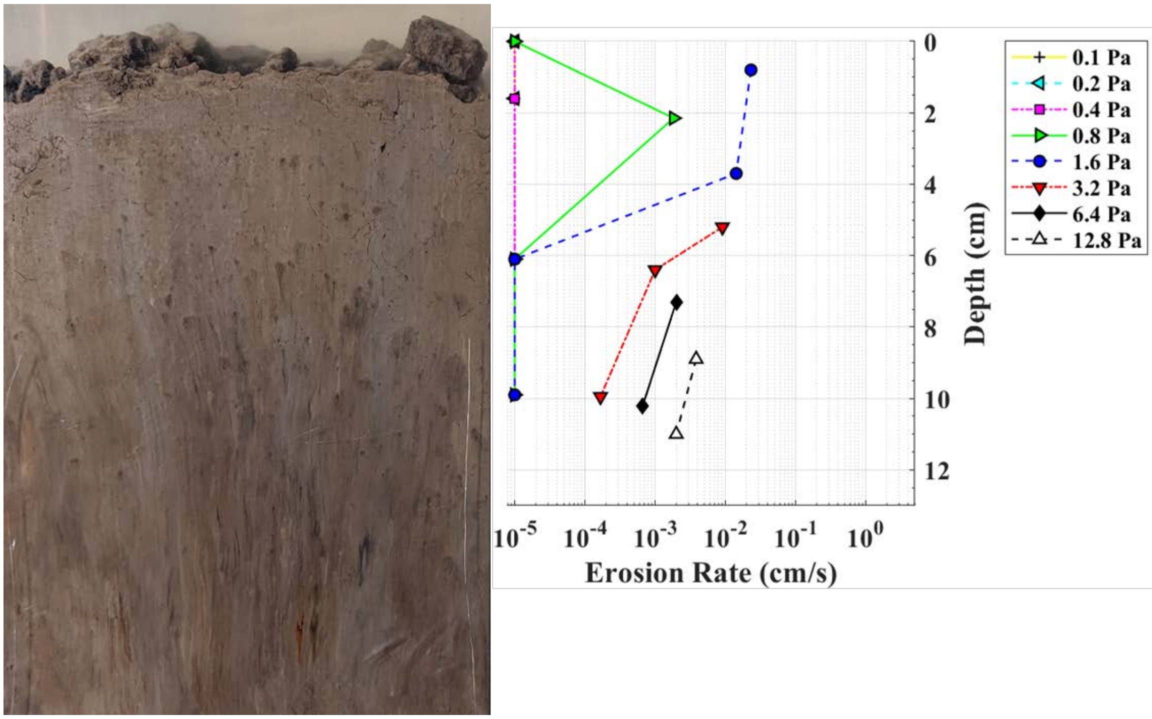

Figure 23. Photograph of Core NR-FG aligned with applied shear stresses and associated erosion rates

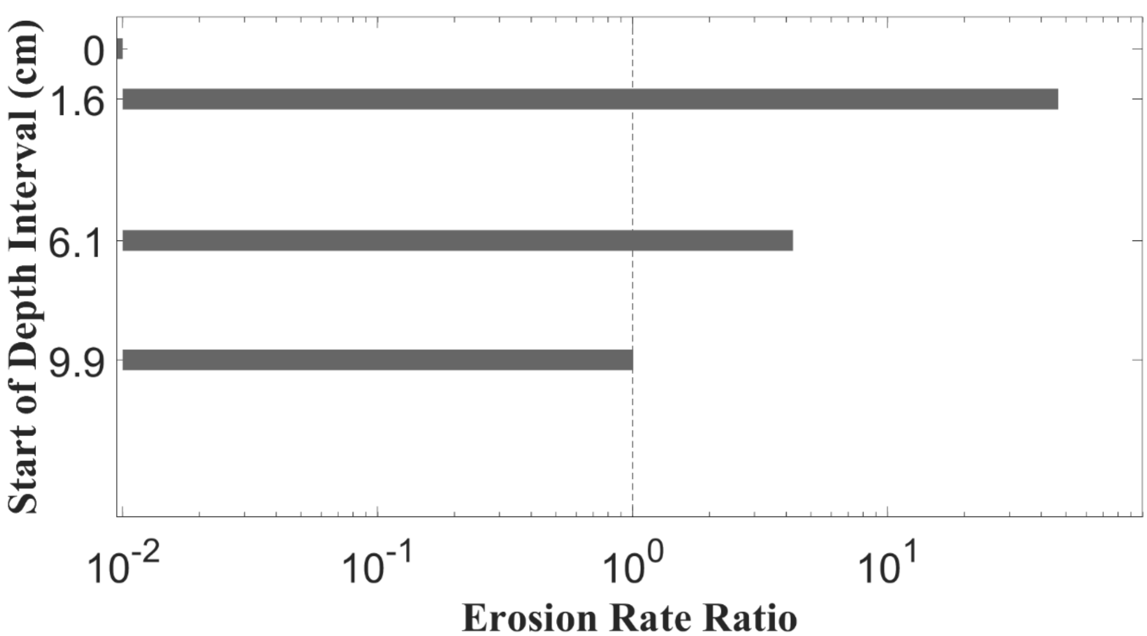

Figure 24. Intracore erosion rates in NR-FG

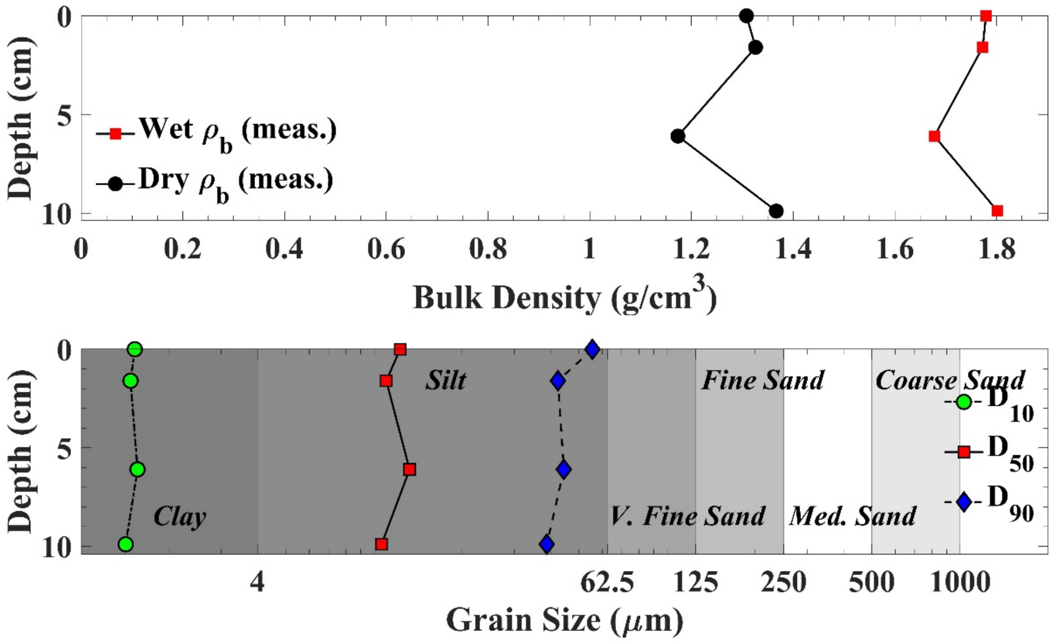

Figure 25. Physical properties of NR-FG with depth

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).

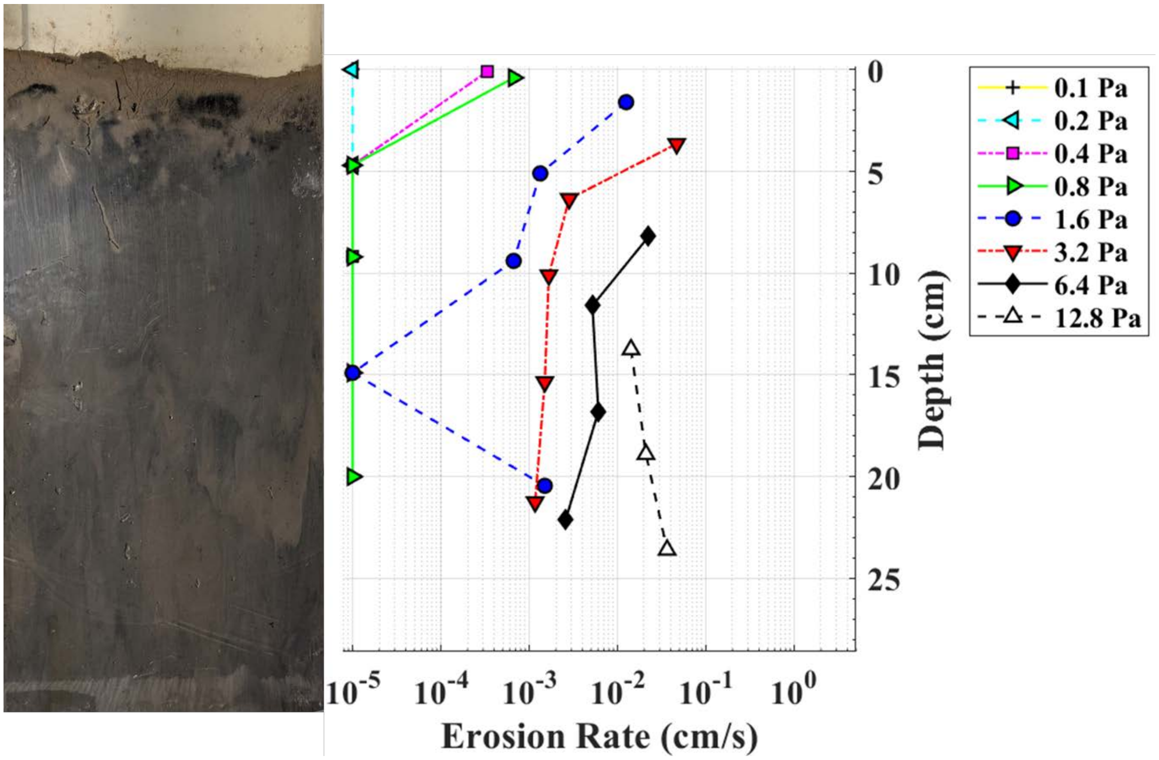

Figure 26. Photograph of Core NR-SB aligned with applied shear stresses and associated erosion rates

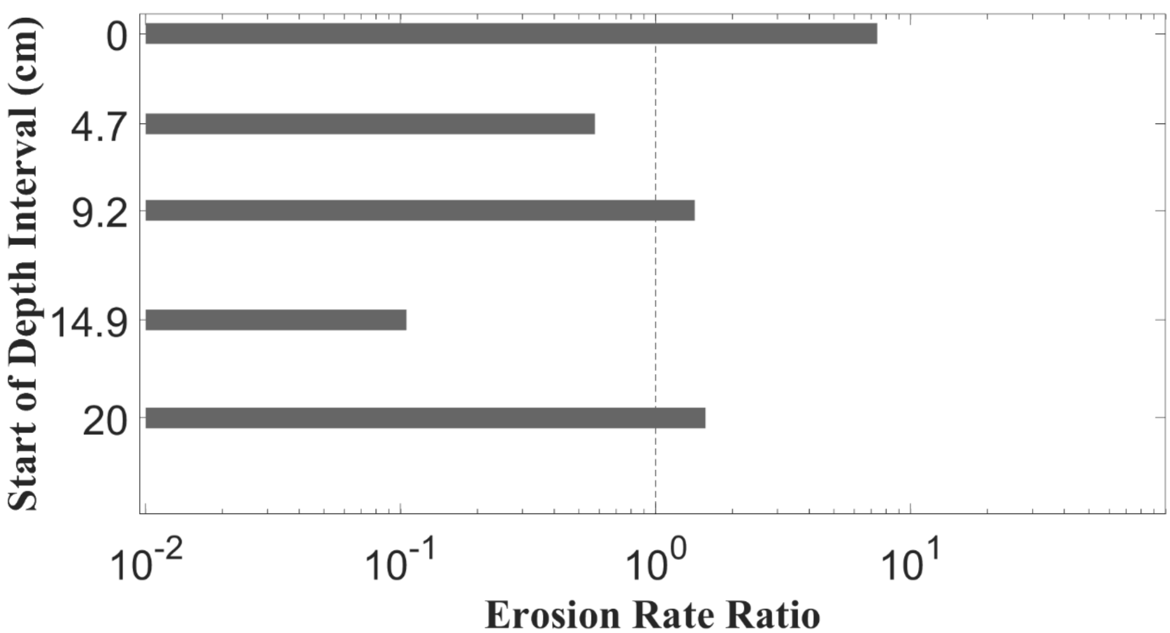

Figure 27. Intracore erosion rates for NR-SB

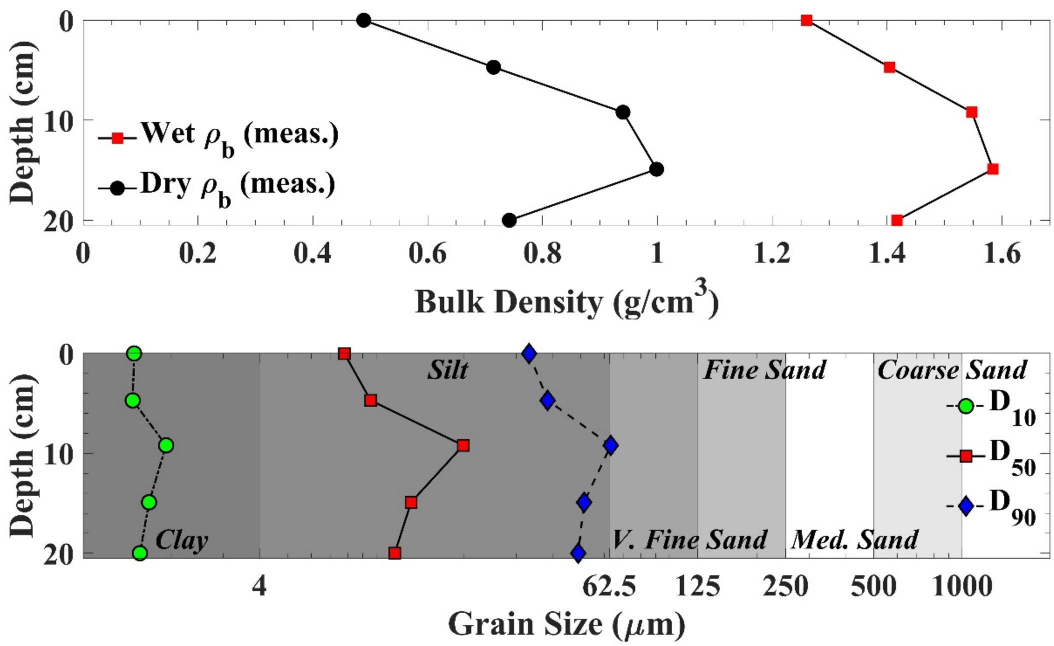

Figure 28. Physical properties of NR-SB with depth

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).

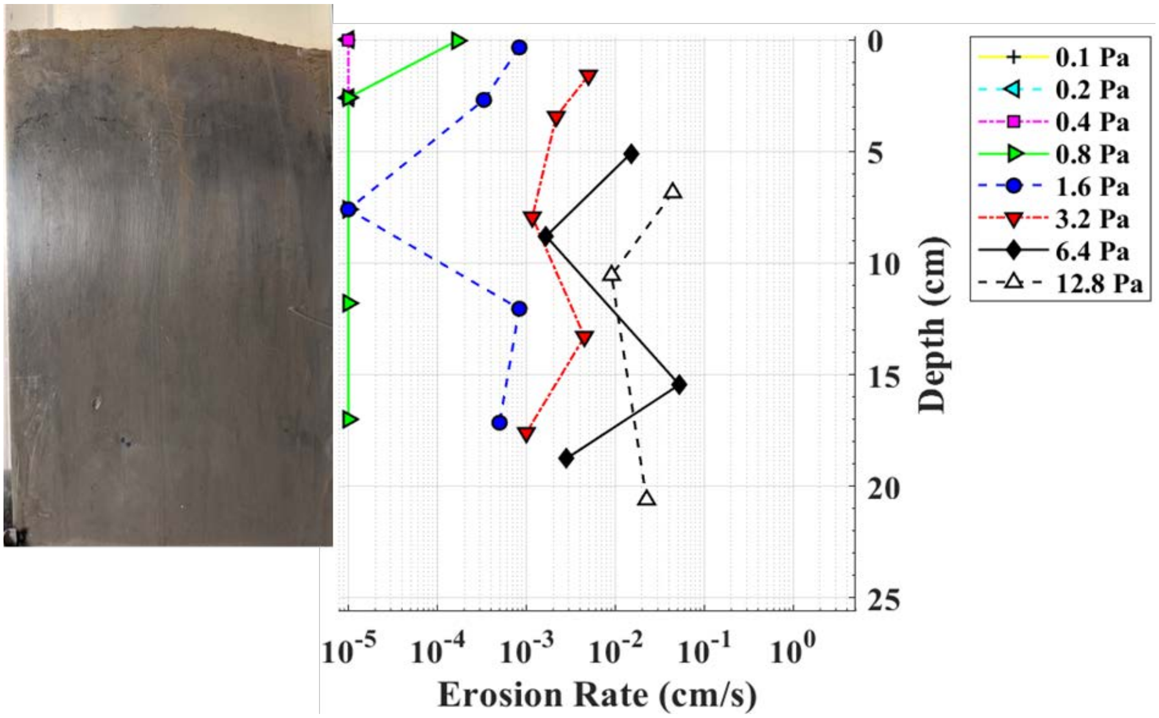

Figure 29. Photograph of Core NR-SC aligned with applied shear stresses and associated erosion rates

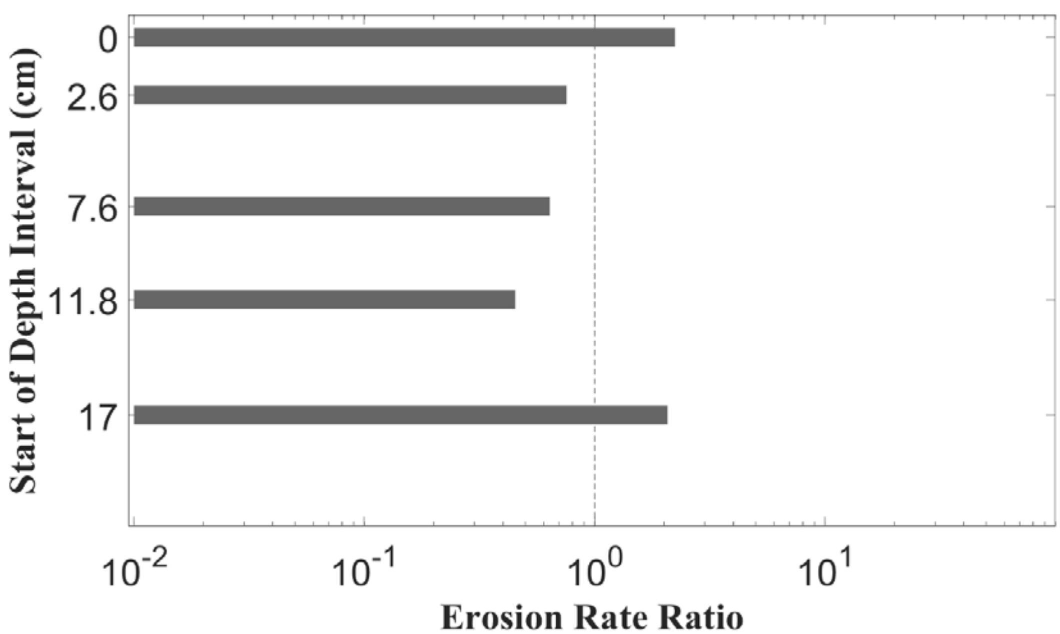

Figure 30. Intracore erosion rates of NR-SC

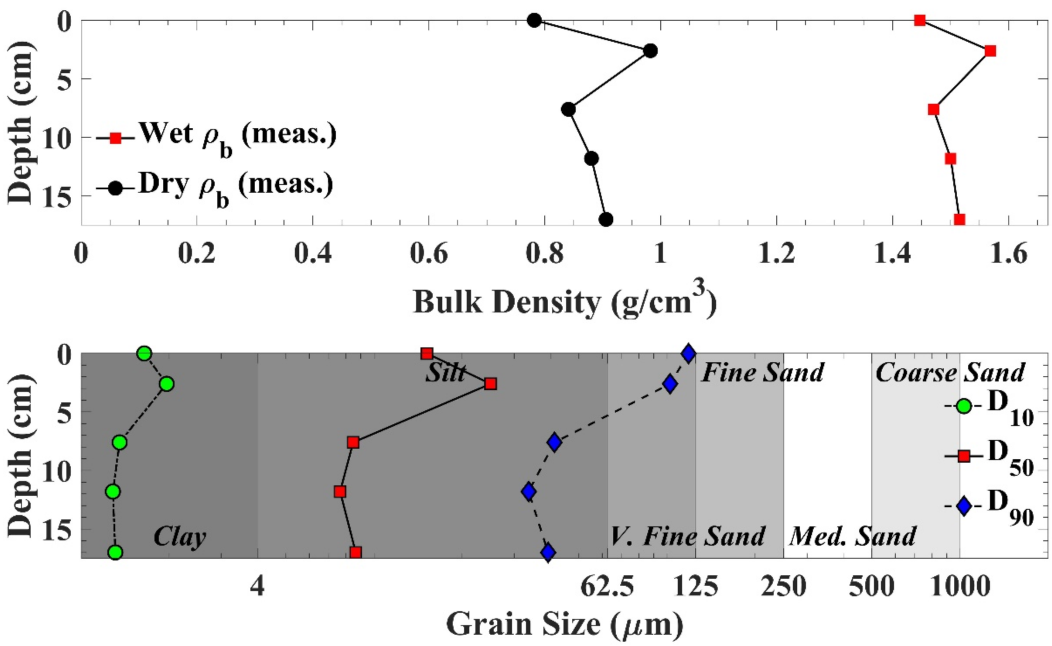

Figure 31. Physical properties of NR-SC with depth

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).

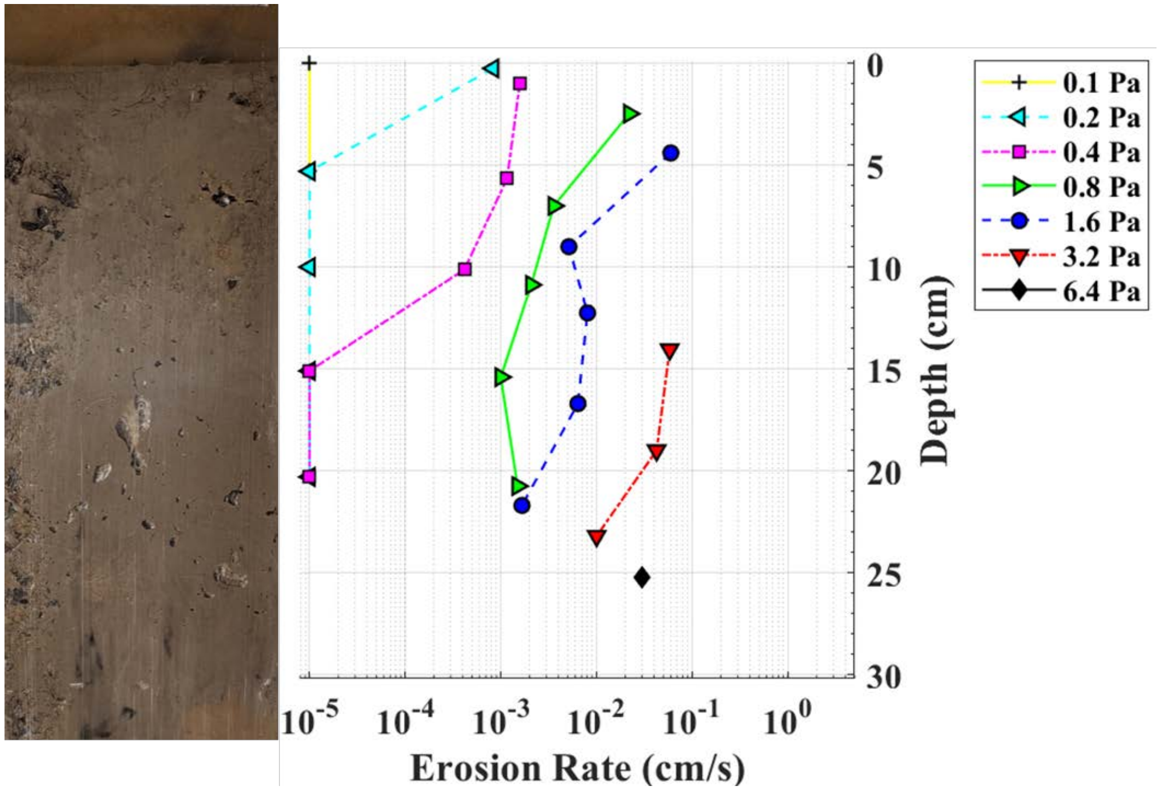

Figure 32. Photograph of Core SR-100 aligned with applied shear stresses and associated erosion rates

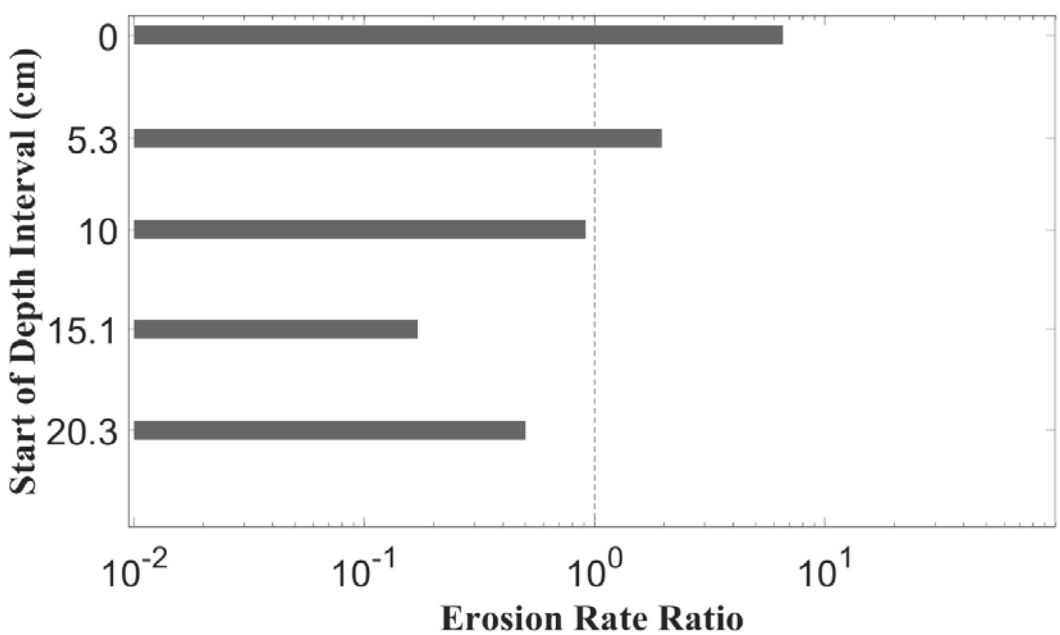

Figure 33. Intracore erosion rates for SR-100

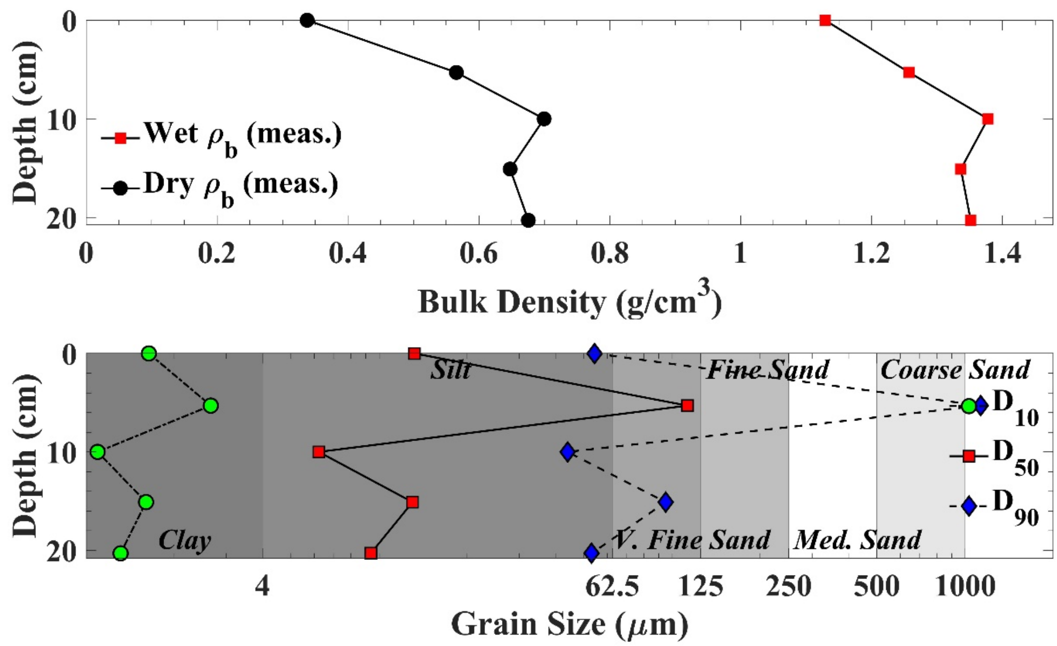

Figure 34. Physical properties of SR-100 with depth

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).

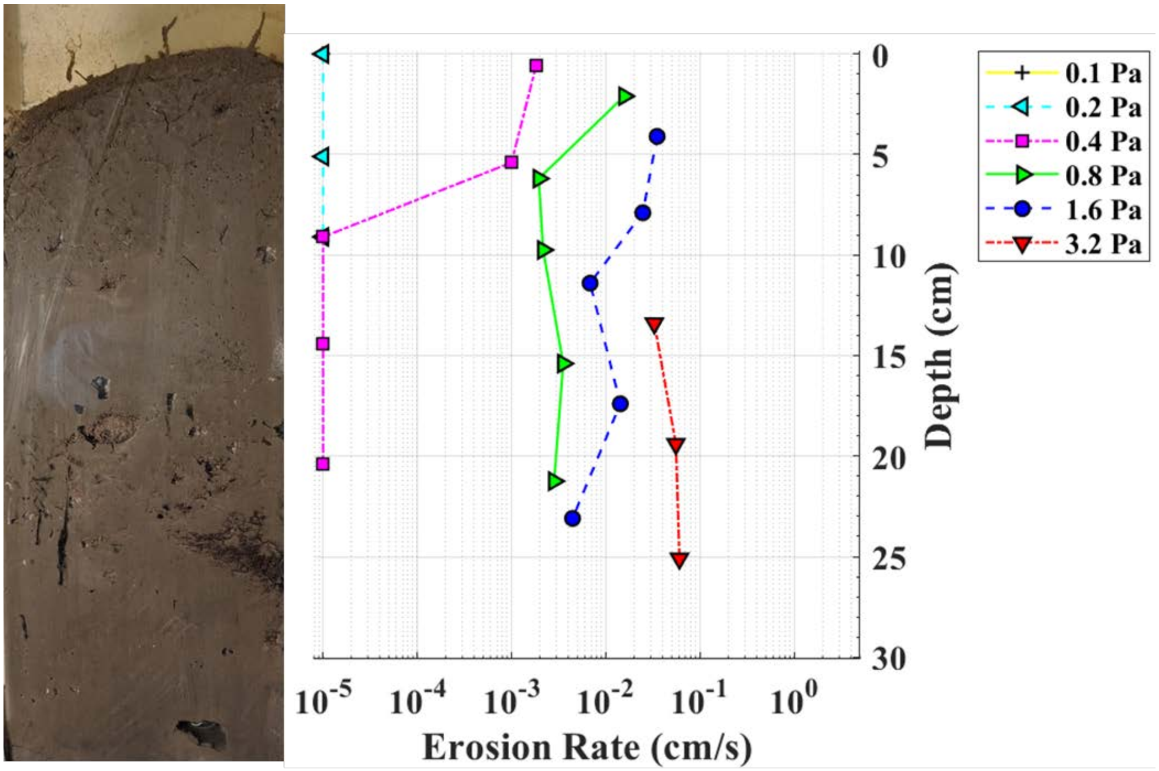

Figure 35. Photograph of Core SR-114 aligned with applied shear stresses and associated erosion rates

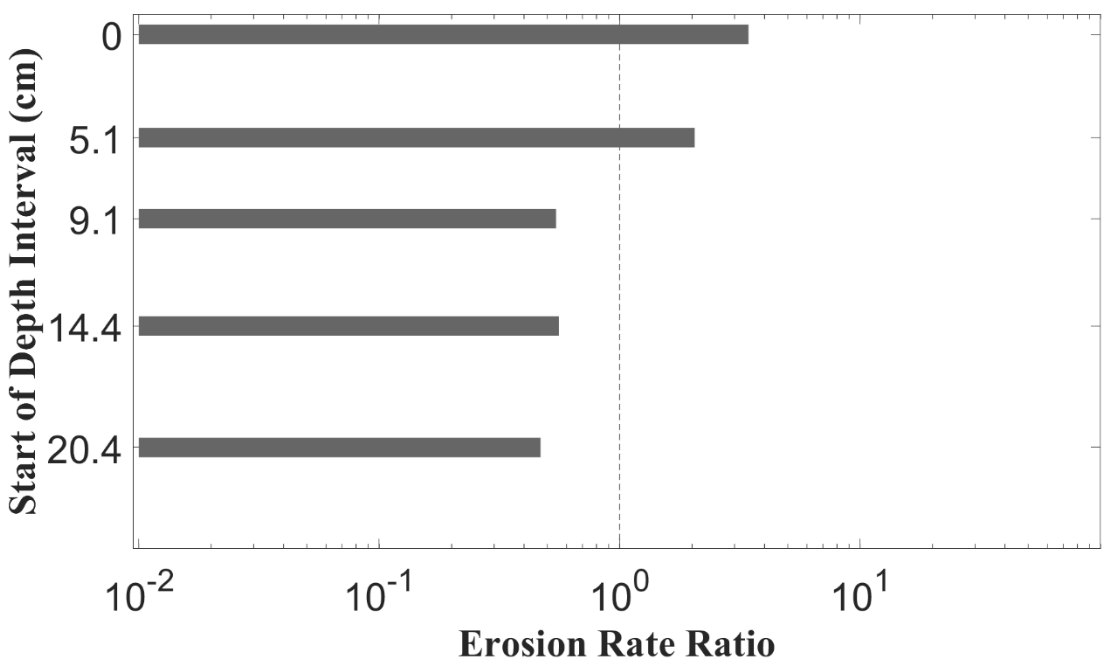

Figure 36. Intracore erosion rates of SR-114

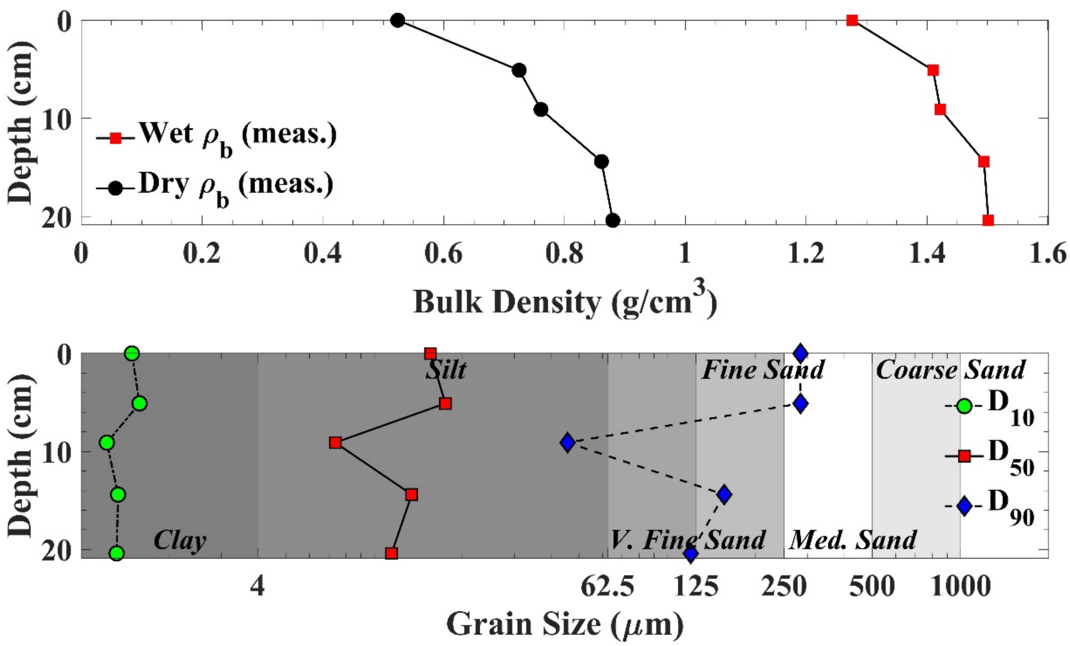

Figure 37. Physical properties of SR-114 with depth

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

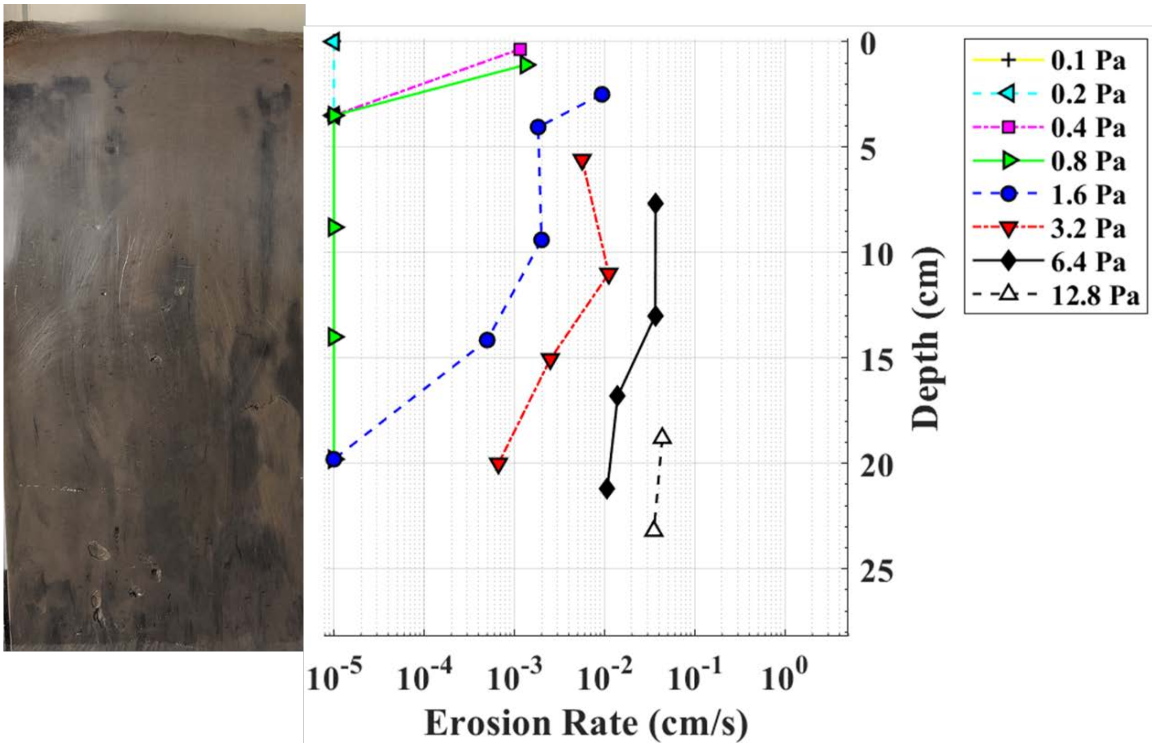

Figure 40. Photograph of Core SR-TB aligned with applied shear stresses and associated erosion rates

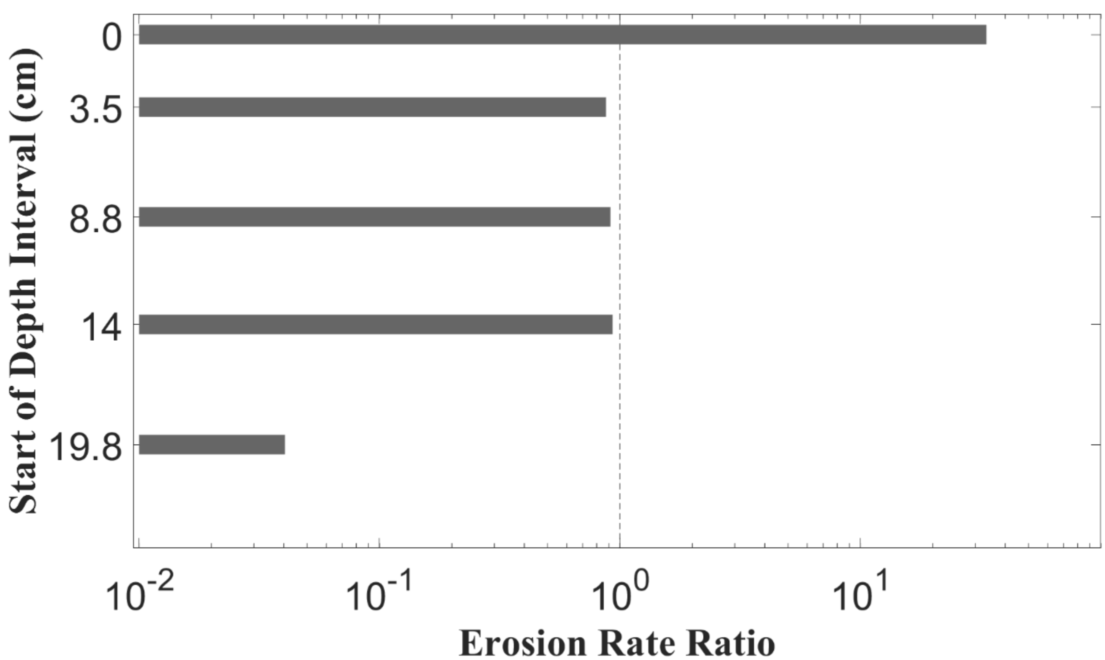

Figure 41. Intracore erosion rate of SR-TB

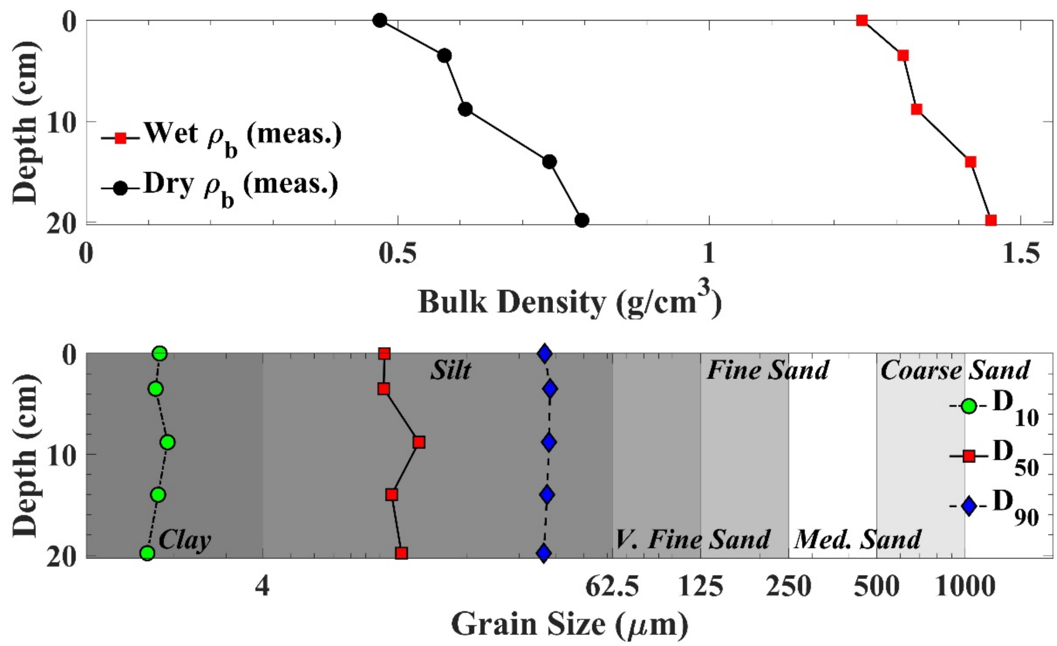

Figure 42. Physical properties of SR-TB with depth

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).

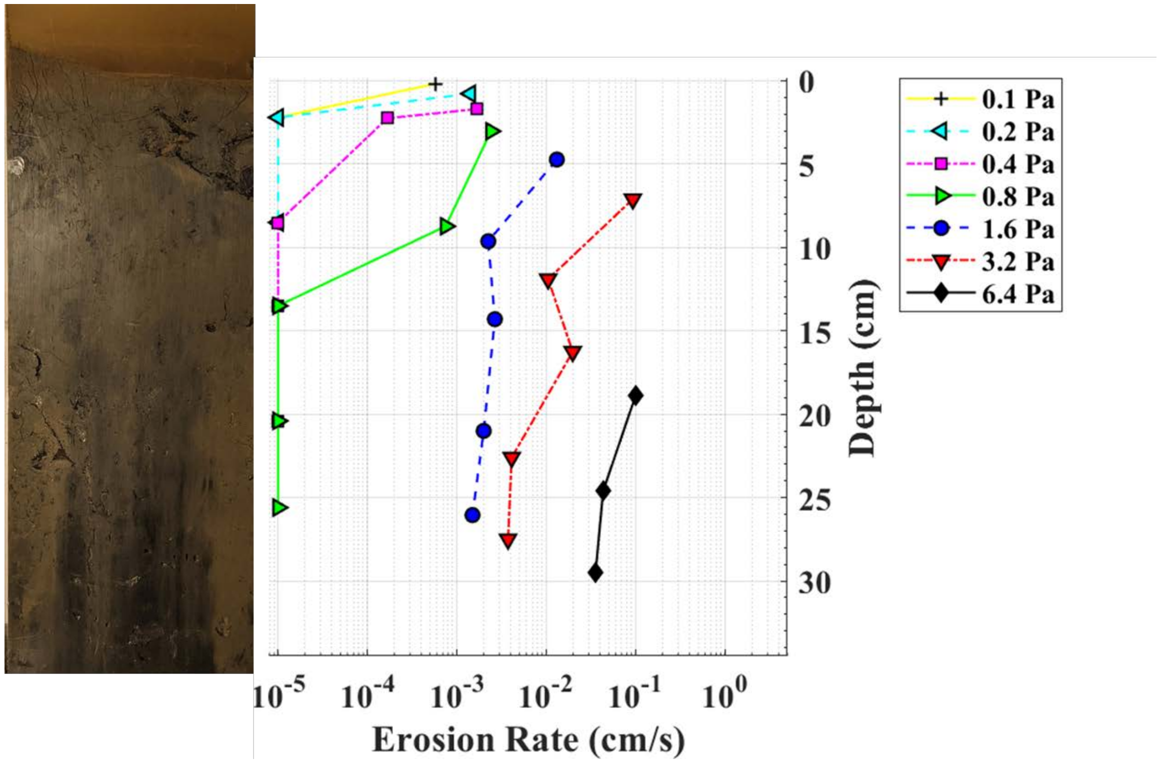

Figure 43. Photograph of Core TC-DS aligned with applied shear stresses and associated erosion rates

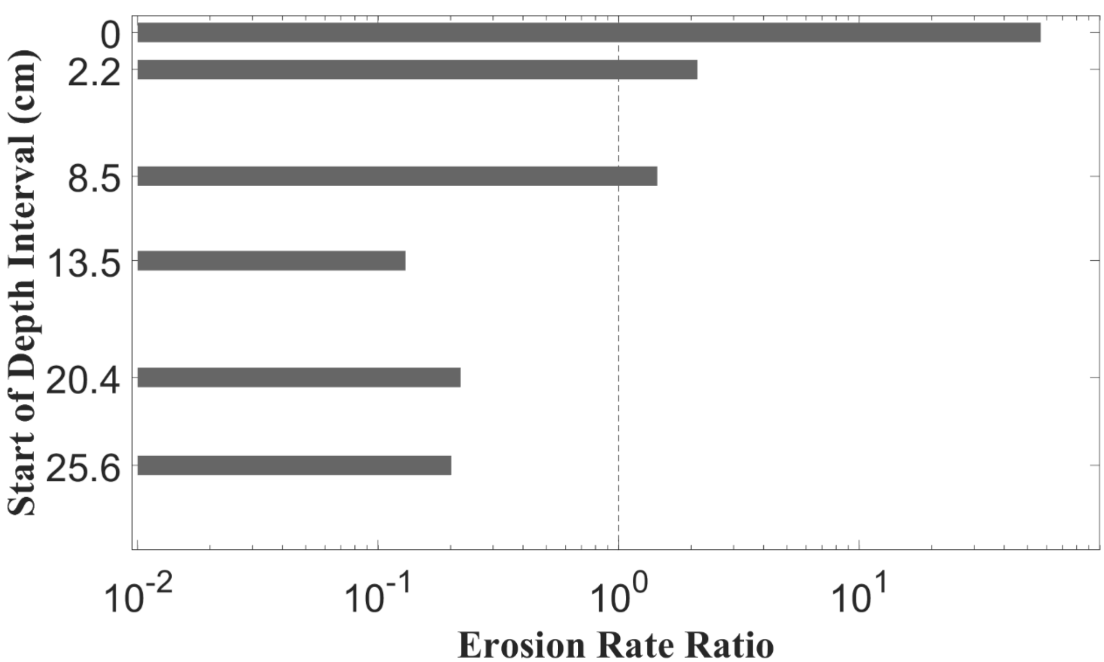

Figure 44. Intracore erosion rates of TC-DS

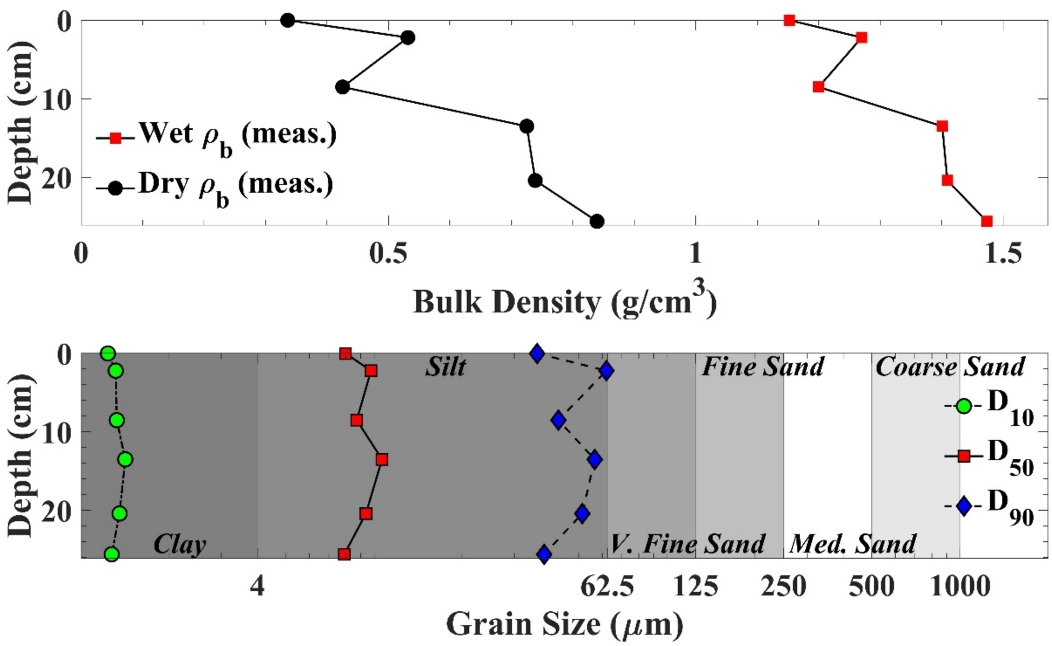

Figure 45. Physical properties of TC-DS with depth

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).

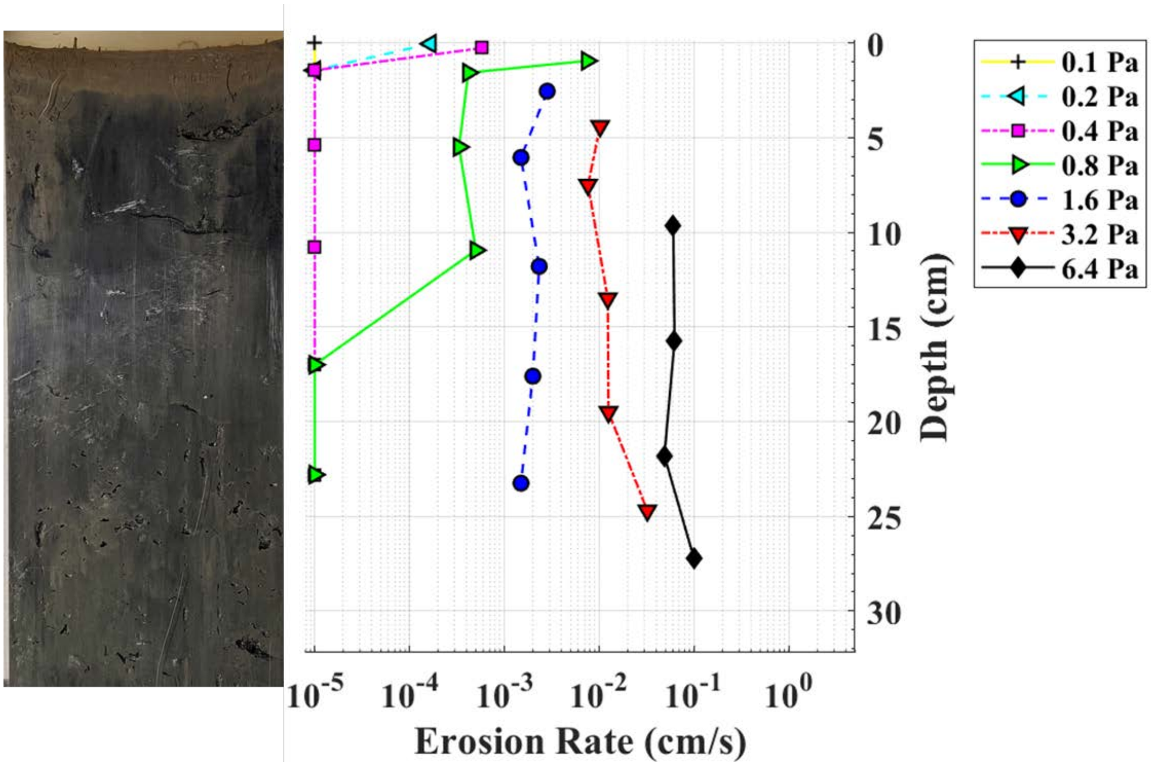

Figure 46. Photograph of Core TC-US aligned with applied shear stresses and associated erosion rates

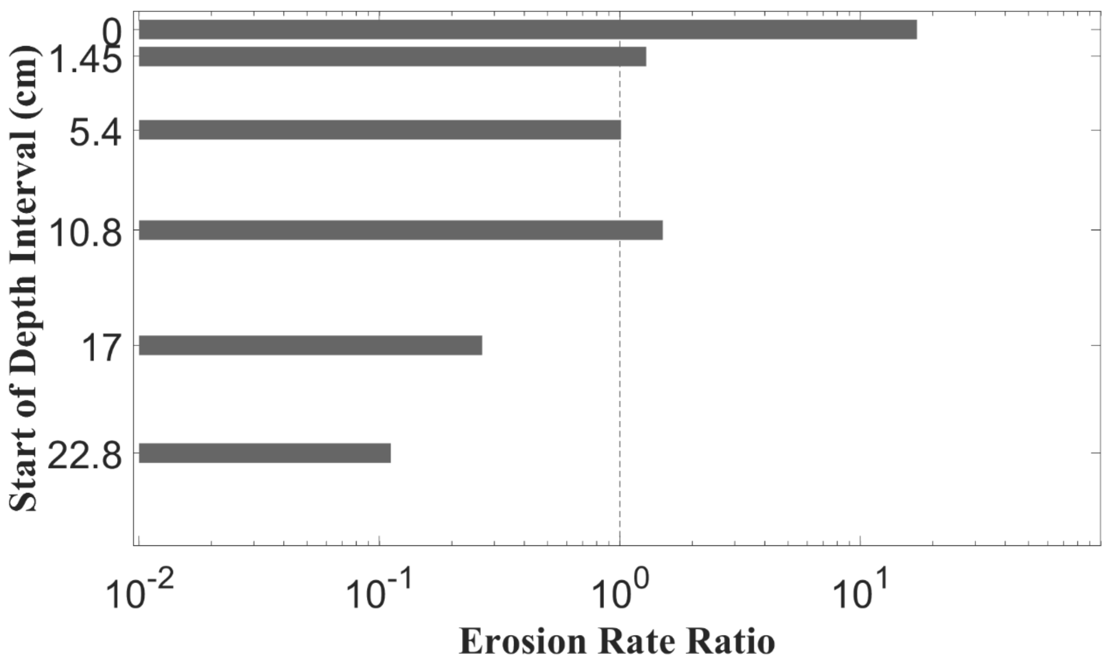

Figure 47. Intracore erosion rates for TC-US

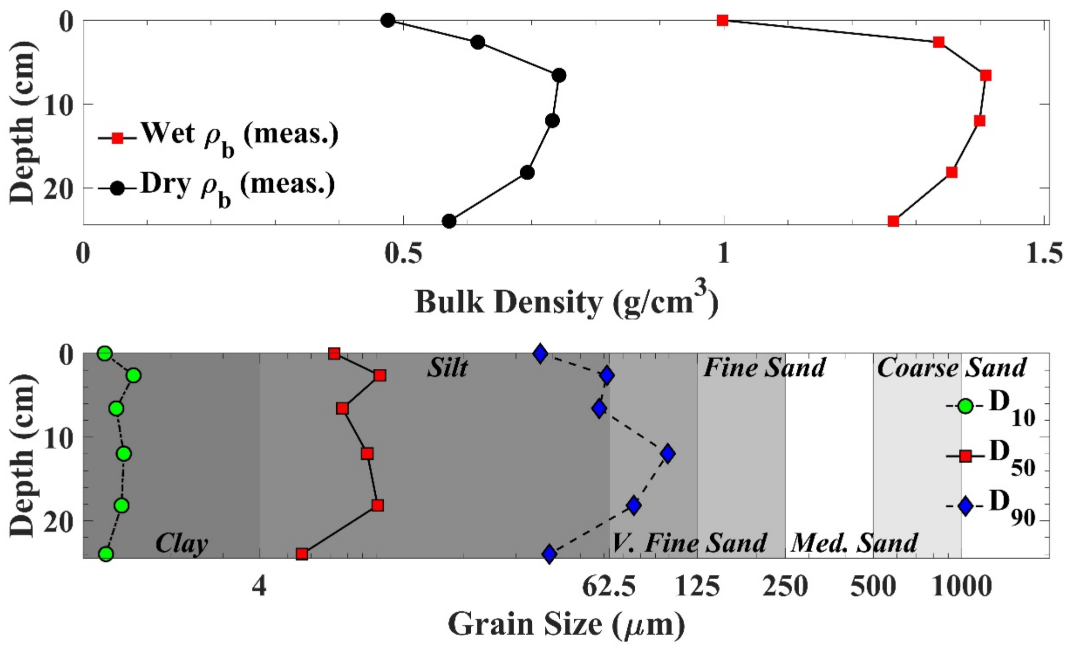

Figure 48. Physical properties of TC-US with depth

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.

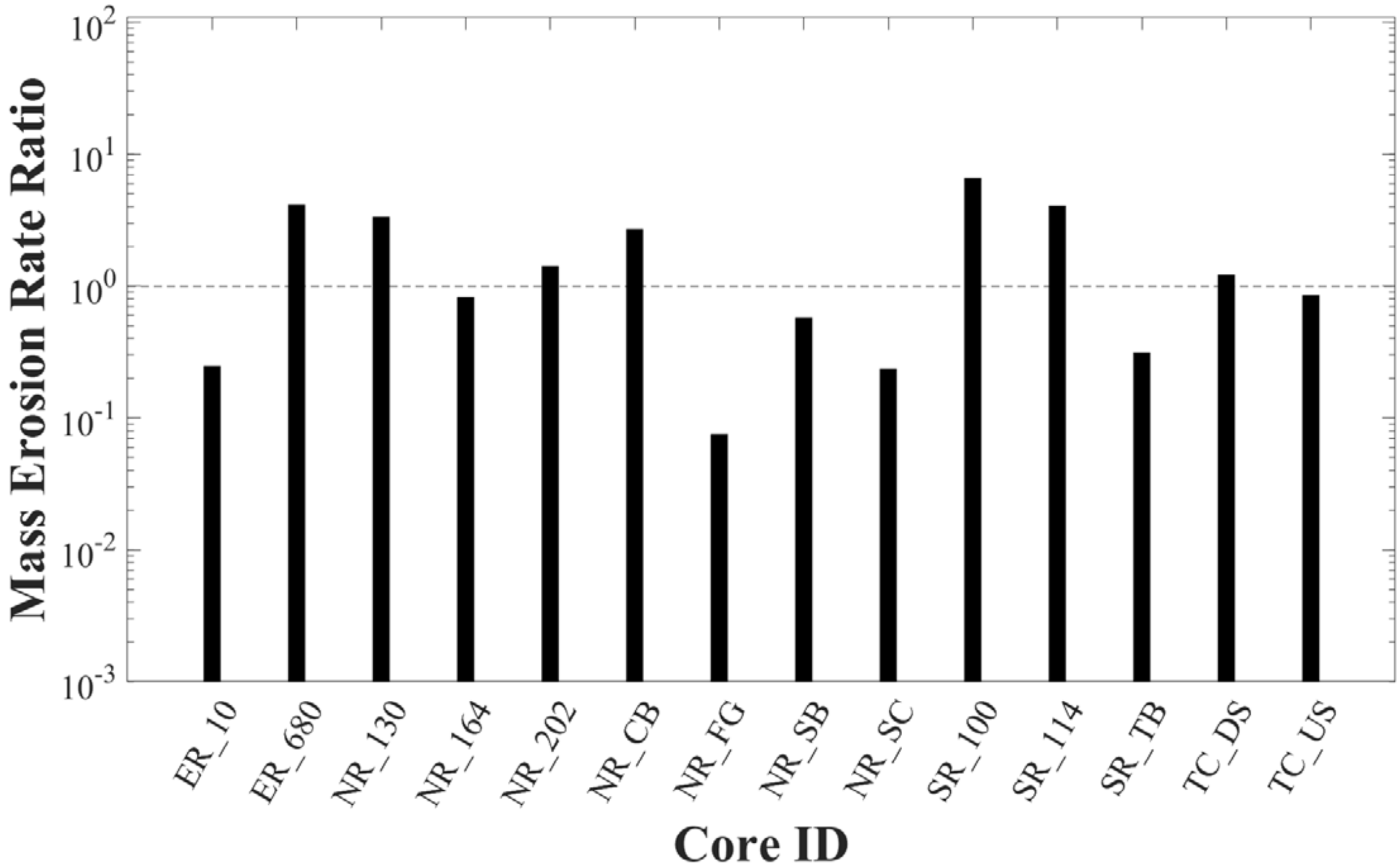

Figure 49. Intercore erosion rate ratios: Depth-averaged core erosion rates compared to the site-wide average erosion rates.

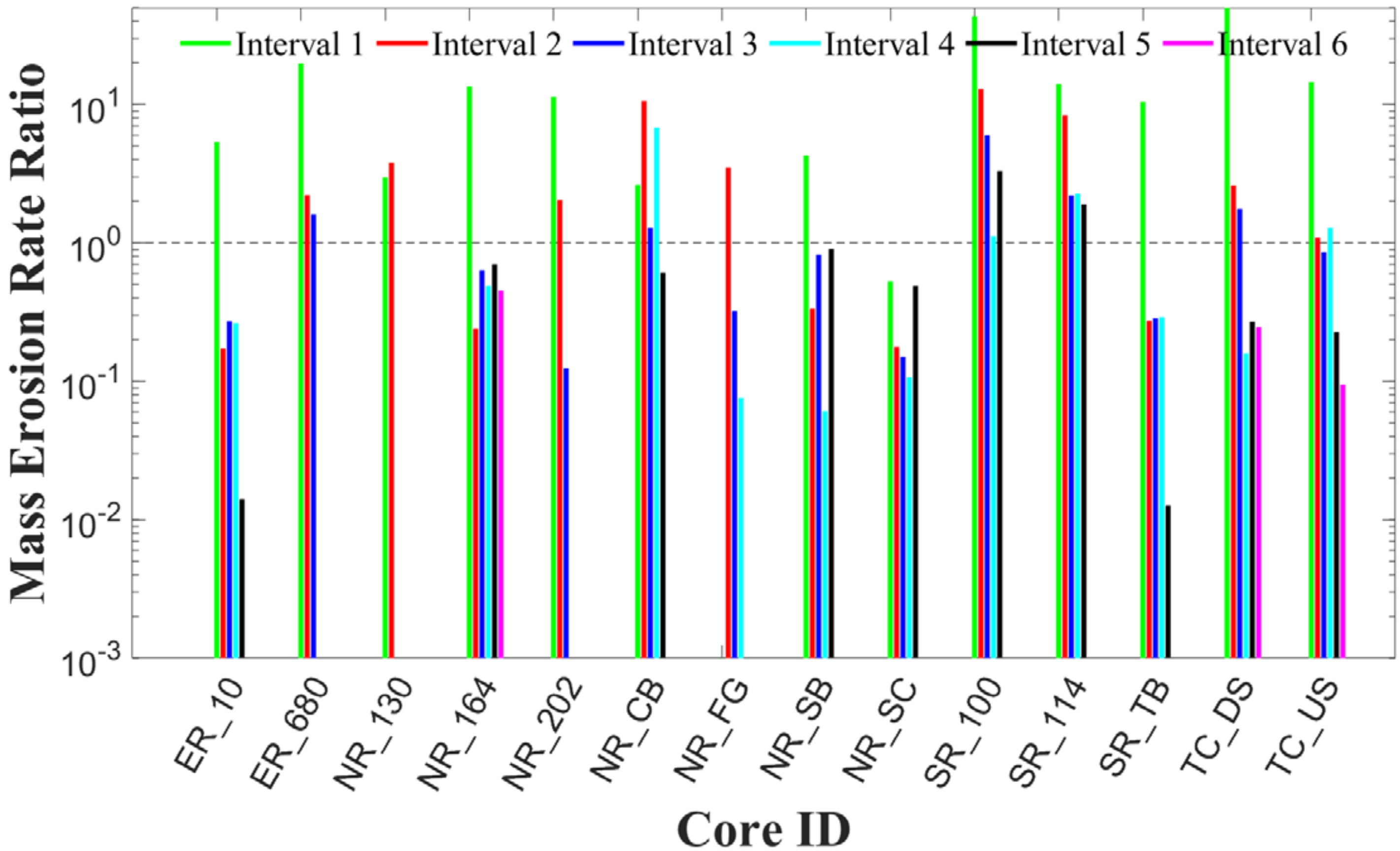

Figure 50. Intracore erosion rate by interval for each core.

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Appendix D
Suspended Sediment Concentration Measurements

SSC/Bedload Sampling

FRESHWATER ENGINEERING

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*,   Bridge   ~10 feet below gage

238, 266, 294, 322, 350*, 378, 406, 434, 462, 490*, 518, 546

Notes: (SEWI, *=MEWI x 5)

Sample times 1-10 min; Collected few grains of sand, occasional gravel; not measurable

General Remarks:

SSC/Bedload Sampling

FRESHWATER ENGINEERING

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

FRESHWATER ENGINEERING

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: ______

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

FRESHWATER ENGINEERING

Site: Elk River at Hwy 43

Staff: TJK, BLD, LLR, EAF Date: 5/17/2020 Time: 16:15

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

FreshWater Engineering

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*, 255, 285, 315, 345, 375*, 405, 435, 465, 495, 525*, 555, 585   Bridge   ~10 feet below gage

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, 147, 161, 175*, 189, 203, 217, 231, 245*, 259, 273

Bridge   ~10 feet below gage

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

General Remarks:

SSC/Bedload Sampling

Site: Spring River at E 57 Rd

Staff: TJK, BLD Date: 7/31/2020 Time: 10:30

FRESHWATER ENGINEERING

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, 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, organic debris; not measurable

General Remarks:

SSC/Bedload Sampling

FRESHWATER ENGINEERING

Site: Tar Creek at HWY 69

Staff: TJK, BLD Date: 7/31/2020 Time: 15:00

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*, Bridge ~10 feet below gage

14, 15, 16, 17, 18*, 19, 20

Notes:

(SEWI, *=MEWI x 5)

Sample times 1-10 min; No sediment collected in mesh bag; not measurable

General Remarks:

SSC/Bedload Sampling

FreshWater Engineering

Site: Neosho River @ E 60 Rd

Staff: TJK, BLD Date: 4/30/2021 Time: 15:30

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, 238, 263, 288, 313*, 338, 363, 388, 413, 438*, 463, 488 Bridge ~10 feet below gage

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: 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*,   Bridge   ~10 feet below gage

272, 304, 336, 368, 400*, 432, 464, 496, 528, 560*, 592, 624

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

FRESHWATER ENGINEERING

Site: Spring River @ E 57 Rd

Staff: TJK, BLD   Date: 5/28/2021   Time: 9:28

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, 147, 161, 175*, 189, 203, 217, 231, 245*, 259, 268   Bridge   ~10 feet below gage

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

FreshWater Engineering

Site: Tar Creek @ HWY 69

Staff: TJK, BLD   Date: 5/28/2021   Time: 12:01

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, 92, 100*, 108, 116, 124, 132, 140*, 148, 156   Bridge   ~10 feet below gage

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, 158, 173, 188*, 203, 218, 233, 248, 263*, 278, 293

Bridge ~10 feet below gage

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

FRESHWATER ENGINEERING

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

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"

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:

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: