PREPARED BY

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Initial Study Report

Hydrologic and Hydraulic Modeling: Downstream Hydraulic Model

Pensacola Hydroelectric Project
Project No. 1494

September 30, 2021

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Executive Summary

Mead & Hunt is assisting Grand River Dam Authority (GRDA) with its intent to relicense the Pensacola Hydroelectric Project (Project), which is regulated by the Federal Energy Regulatory Commission (FERC). Flood control operations at the Project are regulated by the United States Army Corps of Engineers (USACE). This Initial Study Report (ISR) documents the findings of the Hydrologic and Hydraulic (H&H) modeling downstream of the Project.

The Proposed Study Plan (PSP) and Revised Study Plan (RSP) recommended the development of a Comprehensive Hydraulic Model (CHM). The model downstream of the Project is referred to as the Downstream Hydraulic Model (DHM). Mead & Hunt developed a one-dimensional (1D) Hydrologic Engineering Center River Analysis System (HEC-RAS) model extending from just downstream of Pensacola Dam and through Lake Hudson to the Robert S. Kerr Dam, where flood control operations are also regulated by USACE. The model geometry was developed from the best available topographic and bathymetric data. Bridge structures within the model were represented based on record drawings obtained from various agencies. The model was calibrated to four historical events based on measurements at the United States Geological Survey (USGS) stream gage near Langley, OK (USGS Gage No. 07190500) and observed water surface elevations (WSEL) at Kerr Dam.

The calibrated HEC-RAS model was used to analyze a range of operating conditions at Pensacola Dam utilizing results from the Operations Model (OM). Six historical flow events and one synthetic event were analyzed for a range of starting pool elevations at Pensacola Dam. Inflows to Lake Hudson for the synthetic 100-year event were derived from a statistical analysis of historical inflow volumes. Maximum WSEL values and inundation extents were extracted from HEC-RAS and analyzed.

The results of the DHM demonstrate that initial stages at the Project have an impact on downstream WSELs and out-of-bank inundation. As the analysis shows, downstream WSELs, stages at Kerr Dam, and inundation extents are dependent on the magnitude and volume of releases from the Project, which in turn are dependent on initial stage at the Project. Out-of-bank inundation downstream of the Project is the result of spillway releases which are directed by the USACE. Under authority of Section 7 of the 1944 Flood Control Act, the Tulsa District of the USACE is responsible for prescribing and directing the flood control operations of the Project. The USACE is also responsible for directing spillway releases in accordance with the procedures for system balancing of flood storage outlined in the Arkansas River Basin Water Control Master Manual (USACE, 1980). This authority is reinforced by Section 7612 (c) of the National Defense Authorization Act (NDAA) of Fiscal Year 2020 which states that “The Secretary [of the Army] shall have exclusive jurisdiction and responsibility for management of the flood pool for flood control operations at Grand Lake O' the Cherokees” (116th Congress, 2019).

Use of the DHM to analyze different operational scenarios for the Project is entirely dependent on results from the OM due to the relatively flat gradient along Lake Hudson. As discussed in the ISR for the OM, there are currently some known limitations and planned improvements for the next phase of the study. Following these improvements, more consistent predictions of peak stages versus initial stages are expected.

List of Abbreviations and Terms

1D ... One-Dimensional
CFS ... Cubic Feet Per Second
CHM ... Comprehensive Hydraulic Model
DEM ... Digital Elevation Model
DHM ... Downstream Hydraulic Model
FERC ... Federal Energy Regulatory Commission
FRM ... Flood Routing Model
GEV ... Generalized Extreme Value
GRDA ... Grand River Dam Authority
H&H ... Hydrologic and Hydraulic
HEC-RAS ... Hydrologic Engineering Center River Analysis System
ISR ... Initial Study Report
MISR ... Model Input Status Report
NAVD88 ... North American Vertical Datum of 1988
NED ... National Elevation Dataset
NDAA ... National Defense Authorization Act
NGVD29 ... National Geodetic Vertical Datum of 1929
OM ... Operations Model
OWRB ... Oklahoma Water Resources Board
PD ... Pensacola Datum
PSP ... Proposed Study Plan
RM ... River Mile
RSP ... Revised Study Plan
RWM ... RiverWare Model
SPD ... Study Plan Determination
UHM ... Upstream Hydraulic Model
USACE ... United States Army Corps of Engineers
USGS ... United States Geological Survey
WSEL ... Water Surface Elevation

1. Introduction and Background

1.1 Project Description

The Pensacola Hydroelectric Project is owned and operated by GRDA and regulated by the FERC. The Pensacola Dam is in Mayes County, Oklahoma on the Grand-Neosho River. Pensacola Dam impounds Grand Lake. Construction of Pensacola Dam was completed in 1940. **Figure 1** displays the study area. Downstream of Pensacola Dam, GRDA also owns and operates the Robert S. Kerr Dam as the Markham Ferry Hydroelectric Project. Kerr Dam is also in Mayes County and impounds Lake Hudson, also known as Markham Ferry Reservoir. Flood control operations at both Pensacola Dam and Kerr Dam are regulated by USACE.

1.2 Study Plan Proposals and Determination

GRDA is currently relicensing the Project. The timeline of study plan proposals and determination is as follows:

1. On April 27, 2018, GRDA filed its PSP to address hydrologic and hydraulic modeling in support of its intent to relicense the Project.
2. On September 24, 2018, GRDA filed its RSP.
3. On November 8, 2018, the FERC issued its Study Plan Determination (SPD) for the Project.
4. On January 23, 2020, the FERC issued an Order on Request for Clarification and Rehearing, which clarified the timeline for certain milestones applicable to the relicensing study plan.

The PSP and RSP recommended the development of a CHM as part of the H&H modeling study. This report discusses the DHM. As stated in the RSP, the objectives of the H&H modeling study are:

1. Determine the duration and extent of inundation under the current license operations of the Project during several measured inflow events.
2. Determine the duration and extent of inundation under any proposed change in these operations that occurs during several measured or synthetic inflow events.
3. Provide the model results in a format that can inform other analyses (to be completed separately) of Project effects, if any, in several resource areas.
4. Determine the feasibility of implementing alternative operations scenarios, if applicable, that may be proposed by GRDA as part of the relicensing effort.

The FERC's SPD and Order on Request for Clarification and Rehearing included direction to provide a model input status report by March 30, 2021 and hold a conference call on model inputs and calibration within 30 days of the input status report. The Downstream Hydraulic Model Input Status Report (Mead & Hunt, 2021) was filed with FERC and shared with stakeholders on March 30, 2021, and a Technical Conference was held on April 21, 2021, to allow relicensing participants to ask questions regarding the Model Input Status Report (MISR).

The study's purpose is to analyze the influence Project operations have on inundation downstream of the Project through Lake Hudson. This report documents the development of the DHM and findings from the analyses of several historical and synthetic flow events under different operational scenarios at Pensacola Dam.

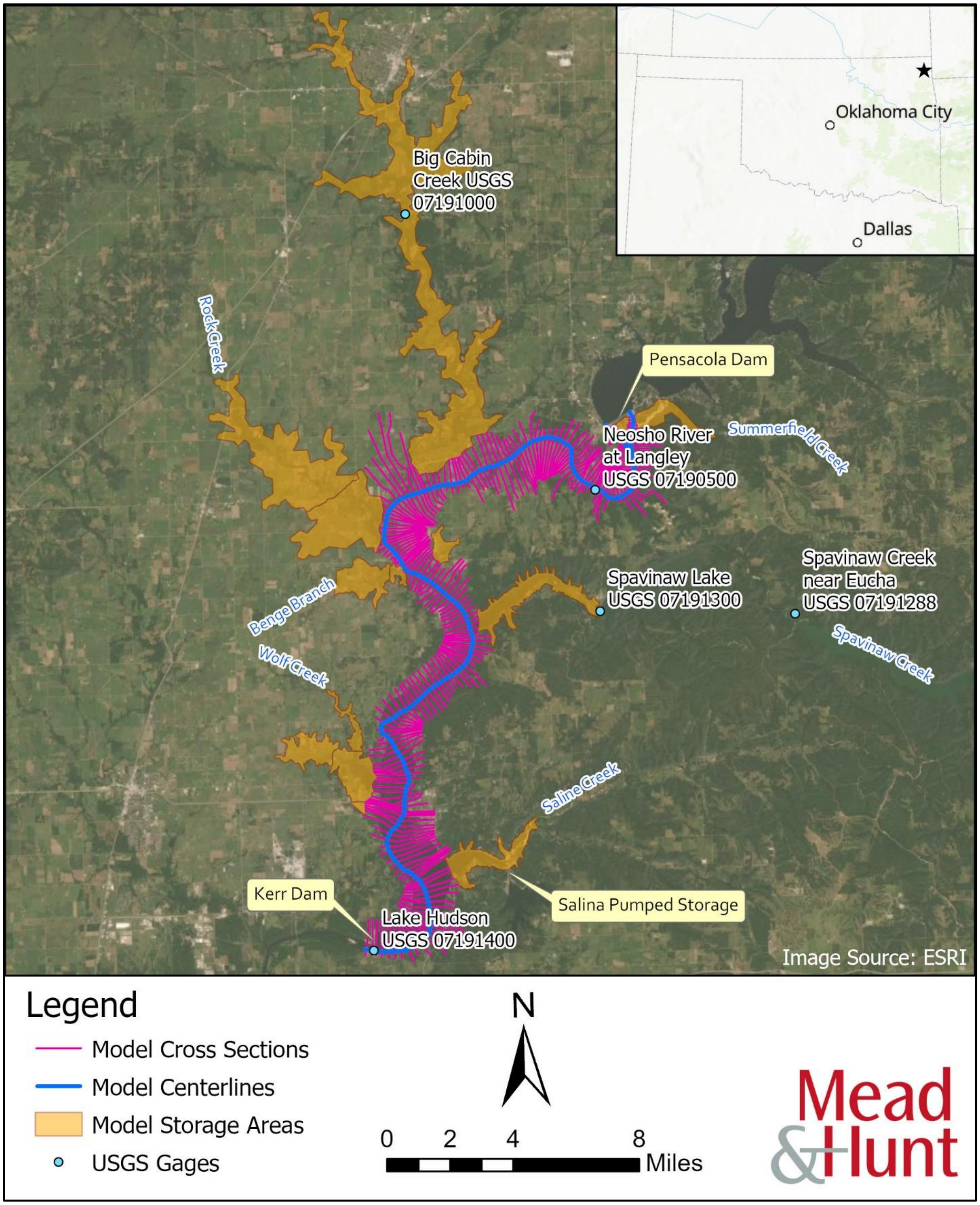
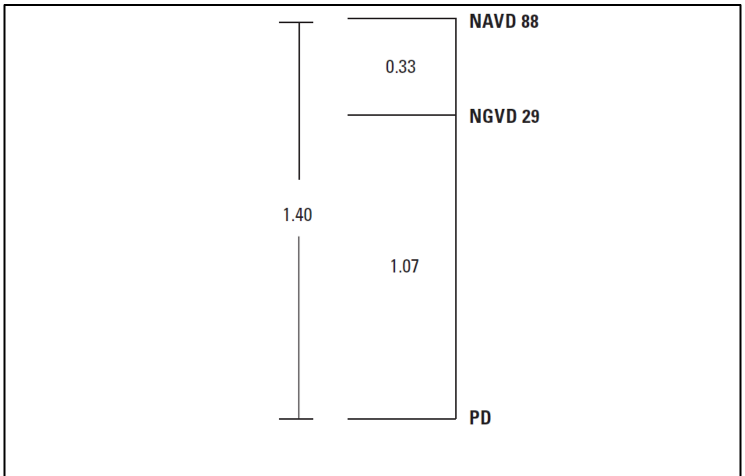


Figure 1. Downstream Hydraulic Model Study Area.

1.3 Vertical Datums

Data sources for this study use a variety of vertical datums. Unless otherwise noted, data are presented in the Pensacola Datum (PD). To convert from PD to the National Geodetic Vertical Datum of 1929 (NGVD29), add 1.07 feet. To convert from NGVD29 to the North American Vertical Datum of 1988 (NAVD88), add 0.33 feet. **Figure 2** displays datum transformations and conversions (Hunter, Trevisan, Villa, & Smith, 2020). The HEC-RAS model discussed in this report was developed in NGVD29.



	Elevations, in feet		
	NAVD 88	NGVD 29	PD
Conservation pool	743.40	743.07	742.00
Top of the dam	758.40	758.07	757.00

Figure 2. Datum Transformations and Conversions.
Source: (HUNTER, TREVISAN, VILLA, & SMITH, 2020)

2. Model Development and Calibration

The DHM was developed using HEC-RAS Version 5.0.7 and is a 1D, unsteady-state model. The various model components along with model calibration are discussed in the following sections.

2.1 Topographic and Bathymetric Data

Topographic and bathymetric data used to develop the DHM consisted of a single Digital Elevation Model (DEM) to represent the bathymetry of the Neosho River, Lake Hudson, and overbank areas, as shown in **Figure 3**. The DEM was developed using the following data sources, listed in descending order of priority:

1. Oklahoma Water Resources Board (OWRB) bathymetry, representing the Neosho River and Lake Hudson from just downstream of Pensacola Dam to just upstream of Kerr Dam (Oklahoma Water Resources Board, 2008).
2. USGS National Elevation Dataset (NED) 1/3 arc-second elevation layer, representing the overbank areas (USGS, 2017a).

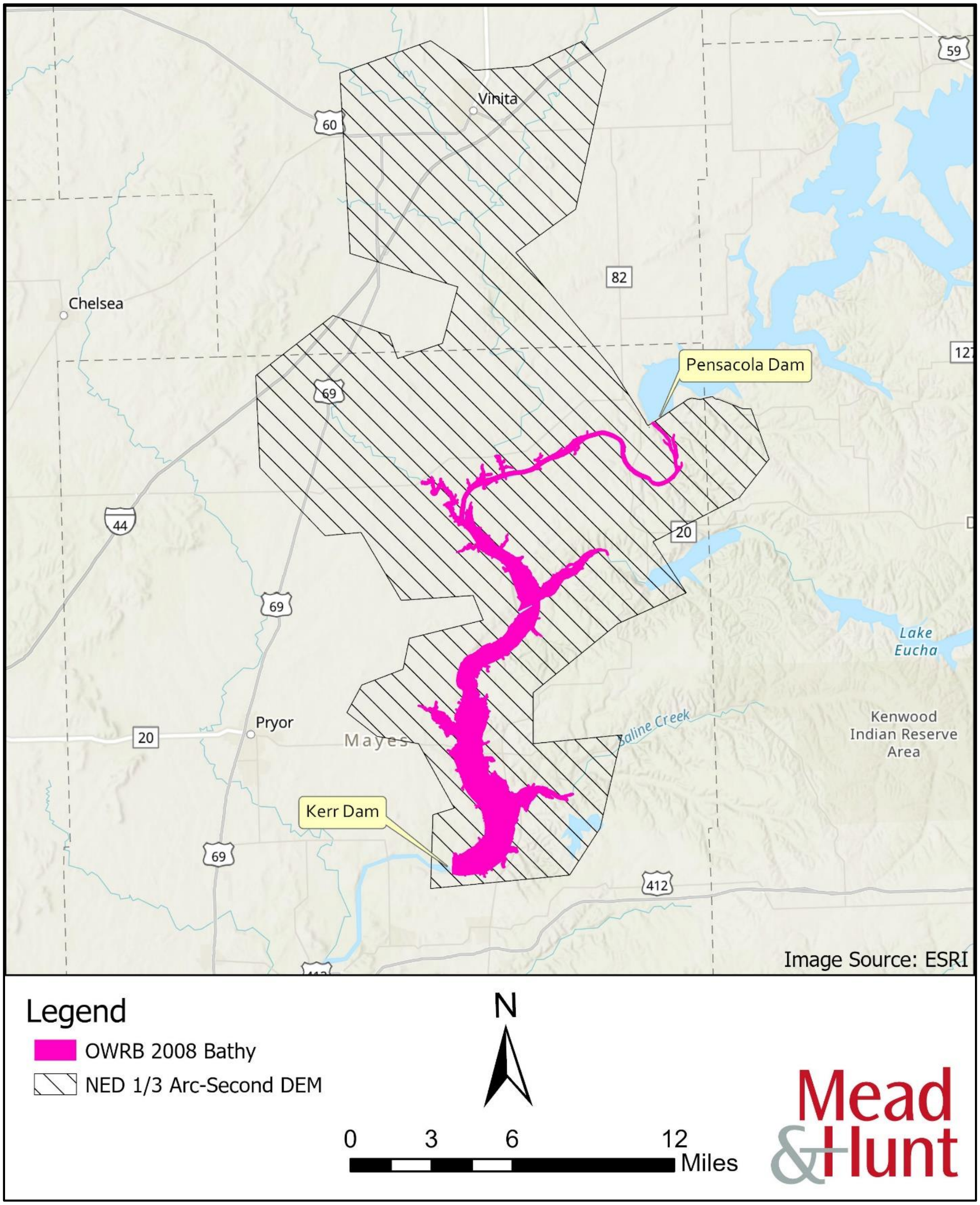


Figure 3. Topographic and Bathymetric Data Extents.

2.2 Model Geometry

The model geometry was originally created using HEC-GeoRAS, a toolset used for processing geospatial data in ArcGIS for use in HEC-RAS. Cross-sections were defined for the Neosho River channel just downstream of Pensacola Dam to just downstream of Kerr Dam. As shown in **Figure 4,** separate parallel reaches were defined for the Neosho River channel just below Pensacola Dam and the main spillway channel below Pensacola Dam, with these reaches joining each other approximately 1.6 miles downstream of Pensacola Dam. A single reach then represents the remainder of the Neosho River and Lake Hudson to just downstream of Kerr Dam.

Storage areas were developed in the model at various tributaries to the Neosho River and Lake Hudson to represent the available storage volumes outside the main flow path of the reservoir. A storage area was also used to represent the east spillway channel downstream of the Project from just downstream of Pensacola Dam, to where it joins the main spillway channel. An additional storage area was used to represent the potential flow exchange between the river channel and the main spillway channel below the Project. Lateral structures were used to connect the storage areas to their respective cross-sections.

Four bridges that cross the Neosho River and Lake Hudson within the study area were included in the DHM. The bridges were defined within the model geometry based on record drawings obtained from the Oklahoma Department of Transportation and GRDA. For calibration purposes, Kerr Dam was represented by an inline structure near the downstream end of the model to assign a flow hydrograph boundary condition based on recorded discharges through the dam.

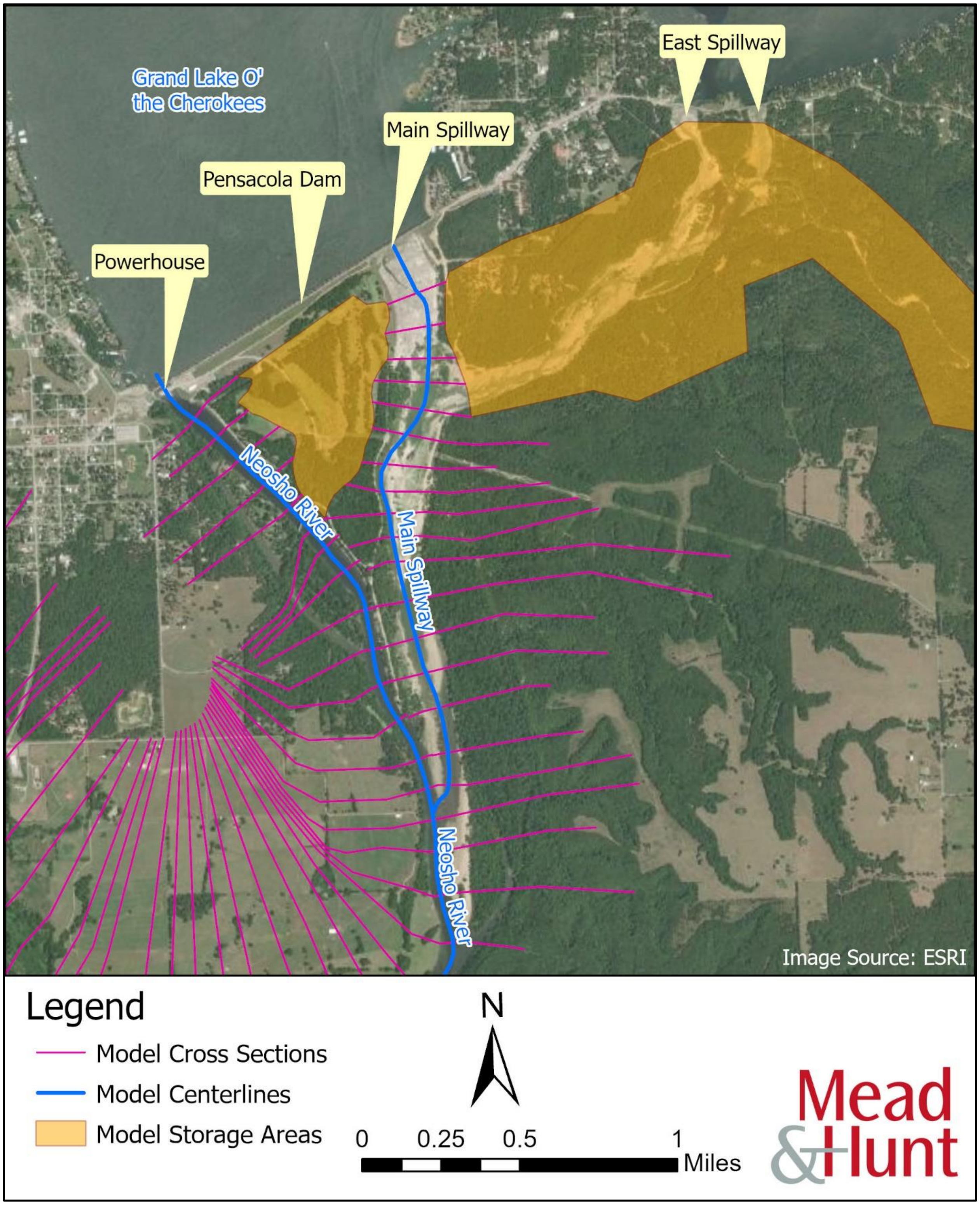


Figure 4. Model configuration just downstream of Pensacola Dam.

2.3 Manning’s n-values

Manning’s n-values for the DHM were delineated based on land cover type, vegetation density, and development visible in aerial imagery. The n-values were established based on guidance provided in the HEC-RAS Hydraulic Reference Manual (USACE, 2016). **Table 1** provides the land use categories and their respective n-values prior to calibration.

Table 1. Manning's n-values Prior to Calibration.

Land Use Category	n-value
Channel	0.030
Pasture high grass or mature row crops	0.035
Mature field crops	0.040
Light brush and trees	0.060
Urban or residential	0.070
Dense urban or residential	0.090
Medium to dense brush	0.100

2.4 Boundary Conditions for Calibration

The boundary conditions used for model calibration were comprised of multiple boundary condition types including inflow hydrographs, lateral inflow hydrographs, outflow hydrographs, and a normal depth boundary condition at the downstream end of the model. A uniform lateral inflow hydrograph boundary condition was also included in the model to represent ungaged tributaries along the reservoir and is discussed further in **Section 2.5**. Where available, observed time series data were obtained from USGS stream gages within the study area (USGS, 2017b), (USGS, 2017c), (USGS, 2017d), (USGS, 2017e) and used to develop the inflow boundary conditions and aid in model calibration. The applicable USGS stream gages are listed in **Table 2** and their locations are displayed in **Figure 1**. USGS stream gage No. 07191400 reports storage (in acre-feet) for Lake Hudson and is included in **Figure 1** for context but was not used for model calibration and therefore not included in **Table 2**.

Table 2. USGS Stream Gage Stations.

USGS Gage No.	Station Name
07190500	Neosho River near Langley, OK
07191000	Big Cabin Creek near Big Cabin, OK
07191288	Spavinaw Creek near Eucha, OK
07191300	Spavinaw Lake at Spavinaw, OK

For calibration, outflows from Pensacola Dam were included as inflow hydrographs to the 1D reaches using time series data provided by GRDA. GRDA sends this data to USACE monthly. Flows were split between powerhouse discharges and main spillway discharges accordingly and assigned to the Neosho River channel and the main spillway channel, respectively.

Lateral inflow hydrographs were used to represent discharge from the east spillways at Pensacola Dam and flows from Big Cabin Creek, Lake Spavinaw, and Salina Pumped Storage Project. Discharges from the east spillways at Pensacola Dam were derived from USACE time series operations data. The gage locations for Big Cabin Creek and Lake Spavinaw are a considerable distance from the inflow locations represented in the model. Hydrologic routing parameters were obtained from the USACE Tulsa District's HEC-HMS model of the Lower Grand Neosho River Watershed and used to route the gaged flows to the lateral inflow locations used in the HEC-RAS model. Flows from Lake Spavinaw were computed by using gaged outflows from upstream Lake Eucha (USGS Gage No. 07191288), and calculating the outflow from Lake Spavinaw using routing parameters obtained from the USACE HEC-HMS model. Flows from the Salina Pumped Storage Project were derived from power consumption and generation time series data obtained from GRDA. This data was converted from megawatts to cubic feet per second (cfs) using separate conversion factors for pumping mode and generating mode, with positive flow rates representing inflows from power generation and negative flow rates representing withdrawals from pumping.

For calibration, outflows through Kerr Dam were represented with an outflow hydrograph assigned to the inline structure in the model using observed time series data obtained from GRDA and USACE. A normal depth boundary condition is assigned to the furthest downstream cross-section of the model. The model results for the study area upstream of Kerr Dam for calibration are not sensitive to the assumed normal depth slope because the flow hydrograph assigned at Kerr Dam allows the model to compute WSELs upstream of the dam independent of the computed water levels downstream of the dam.

2.5 Model Calibration

The DHM was calibrated using four historical events which were chosen because they represent flow events for which suitable time series data were available with reasonable consistency. The four events used for calibration are summarized in **Table 3**.

Table 3. Summary of Calibration Events.

Event	Simulation Start/End Date	Pensacola Dam Peak Outflow (cfs)	Kerr Dam Peak Outflow (cfs)
July 2007	June 10, 2007 - July 23, 2007	106,941	99,034
April 2008	April 7, 2008 - April 17, 2008	82,340	91,287
April 2011	April 20, 2011 - May 15, 2011	80,559	91,852
May 2015	May 17, 2015 - June 9, 2015	107,246	121,400

The HEC-RAS model was calibrated based on measurements at the USGS stream gage along the Neosho River near Langley (USGS No. 07190500). The boundary conditions described in **Section 2.4** were used during calibration, with time series data specific to each event.

Initial model runs revealed discrepancies between the recorded data and actual data related to volume conservation errors, which caused modeled WSELs at Kerr Dam to vary significantly from the observed elevations through the course of the simulation. The most likely reason for the volume conservation errors is due to missing inflow from the ungaged tributaries and direct rainfall on Lake Hudson. The largest ungaged tributaries include Summerfield Creek, the lower portion of Big Cabin Creek, Rock Creek, Benge Branch, Wolf Creek, and Saline Creek. To correct for the volume conservation errors, a uniform lateral inflow hydrograph was used as an additional boundary condition in the model to distribute the missing inflow along the length of Lake Hudson. The lateral inflow hydrograph was computed for each event to minimize the difference between simulated and measured WSELs at Kerr Dam.

Manning's n-values were adjusted within the model in conjunction with the lateral inflow adjustments to provide a better match to the observed elevations at the Langley gage near the upstream end of the model. The goal of the Manning's n-value adjustment was to match the peak WSELs closely for all the calibration events using a single model geometry. The final calibrated model included an 8% increase to each of the initially selected Manning's n-values (presented in **Table 1**). Calibrated Manning's n-values are provided in **Table 4**.

Table 4. Calibrated Manning's n-values.

Land Use Category	Calibrated n-value
Channel	0.0324
Pasture high grass or mature row crops	0.0378
Mature field crops	0.0432
Light brush and trees	0.0648
Urban or residential	0.0756
Dense urban or residential	0.0972
Medium to dense brush	0.1080

A summary of peak WSELs from the calibrated model and observed elevations at the Langley gage are provided in **Table 5**. The eight figures that follow show the computed stage hydrographs versus the observed stages for each of the four calibration events at Kerr Dam (**Figure 5**, **Figure 7**, **Figure 9**, and **Figure 11**) and at the Langley Gage (**Figure 6**, **Figure 8**, **Figure 10**, and **Figure 12**). The stage hydrographs show a close match to the observed stages throughout each of the four events.

Table 5. Calibration Results at Langley Gage.

Event	Observed Peak WSEL at Langley Gage (No. 07190500) (feet, PD)	Modeled Peak WSEL at Langley Gage (RS 73.315) (feet, PD)	Over/Under Prediction (feet)
July 2007	638.9	638.6	-0.3
April 2008	636.9	636.9	0.0
April 2011	635.8	635.9	0.1
May 2015	639.5	639.6	0.1

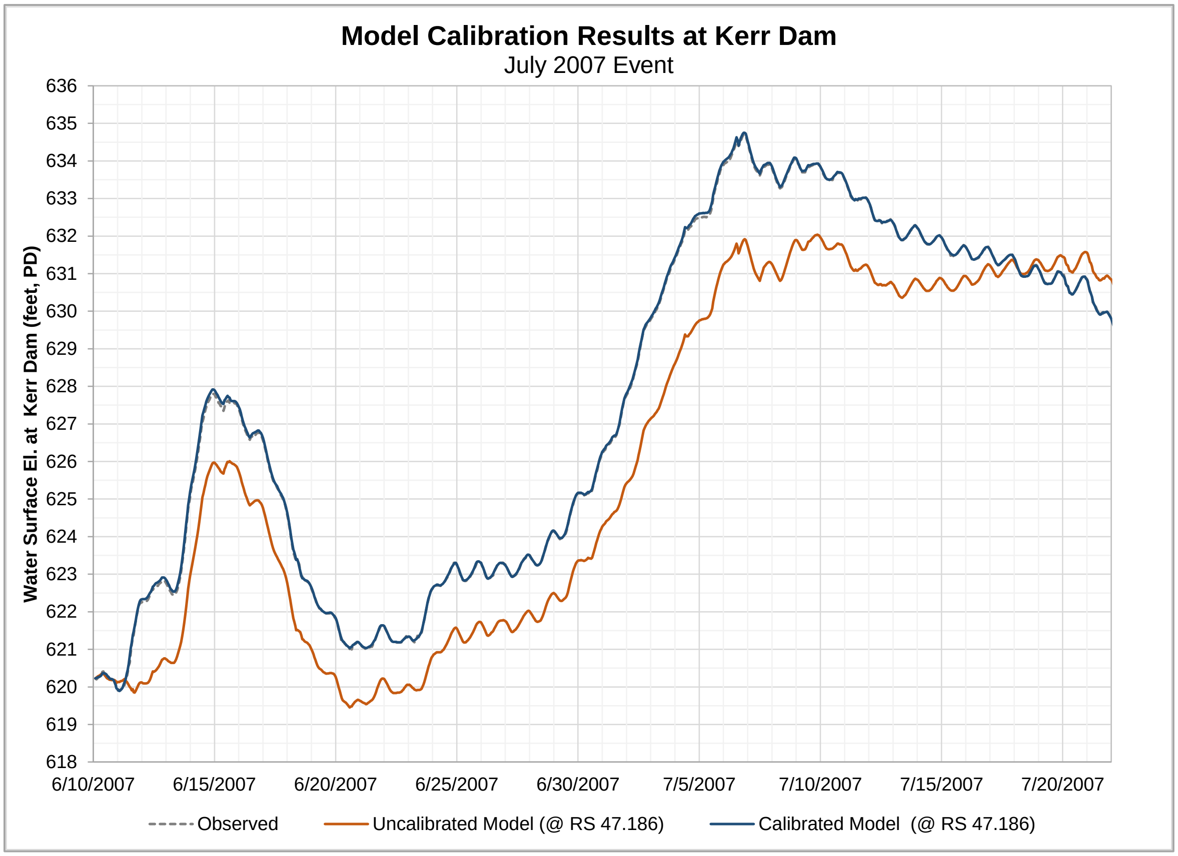


Figure 5. July 2007 Event Stage Hydrographs at Kerr Dam.

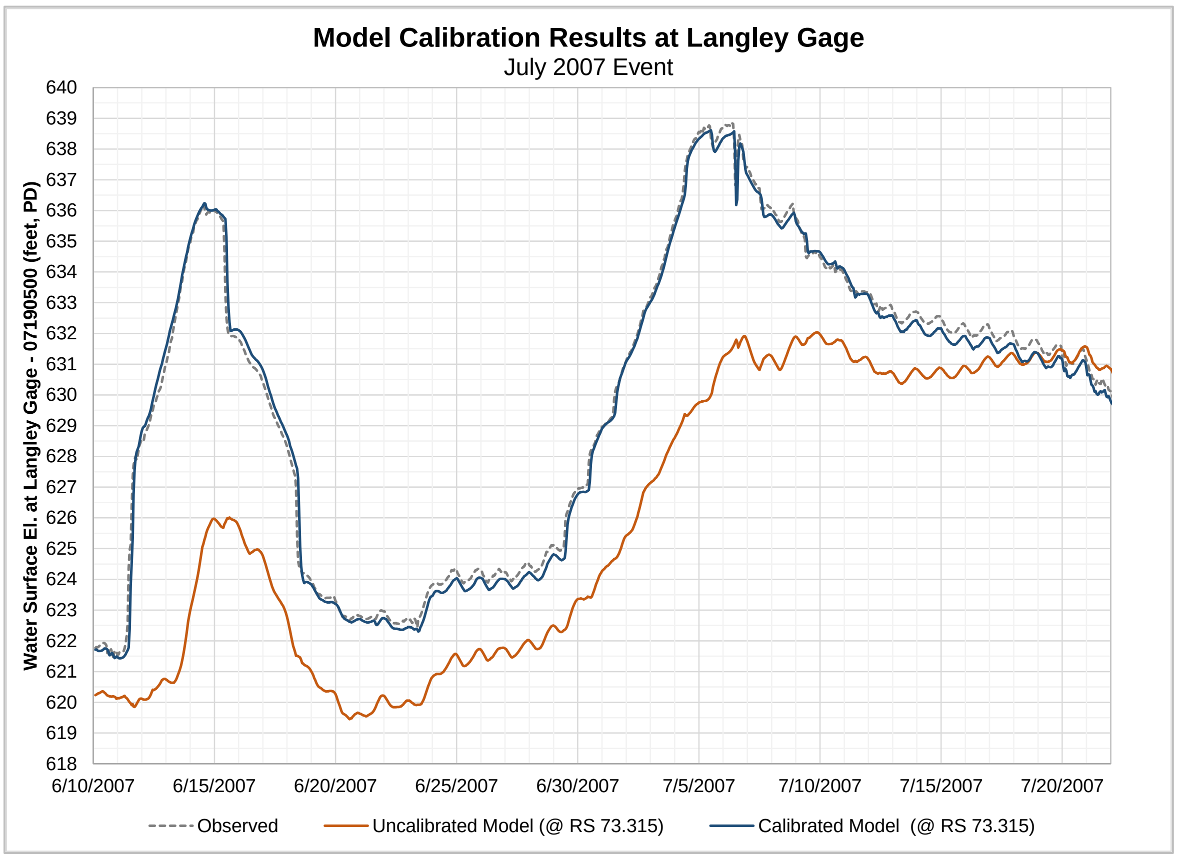


Figure 6. July 2007 Event Stage Hydrographs at Langley Gage.

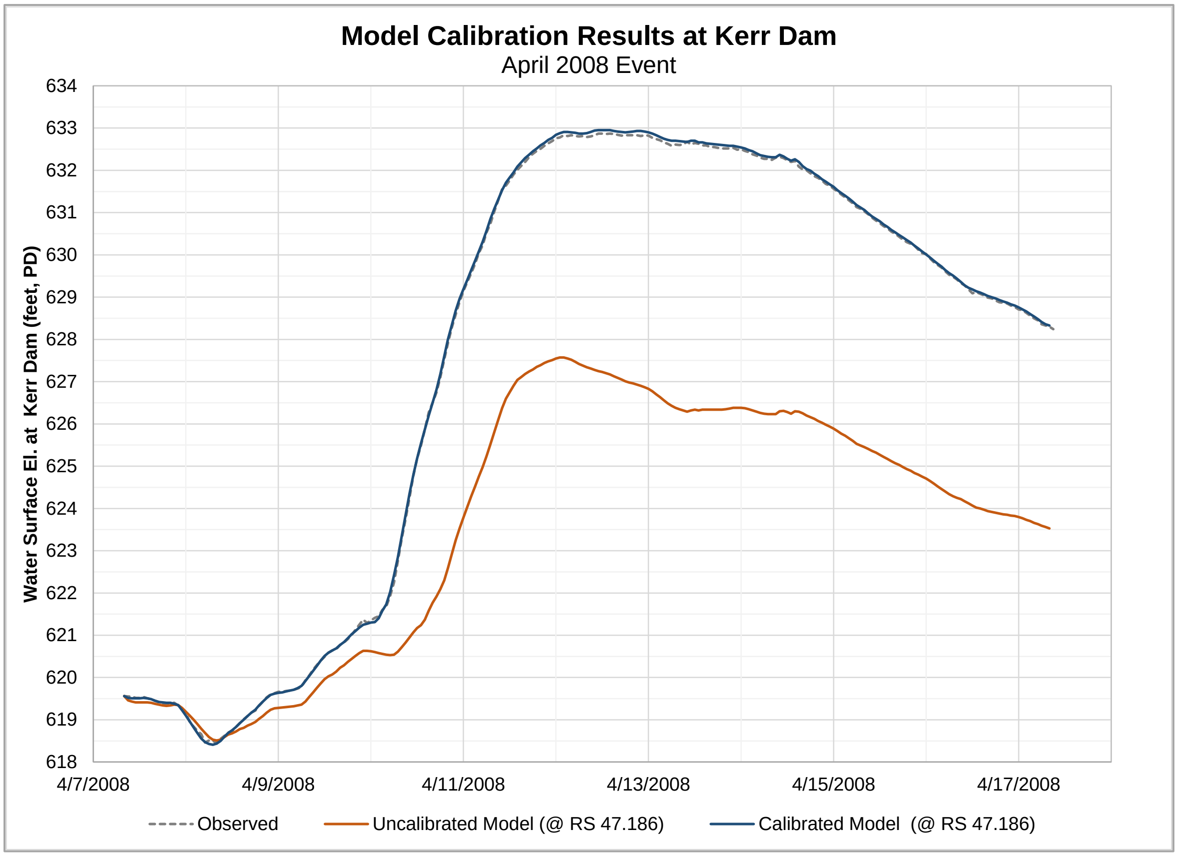


Figure 7. April 2008 Event Stage Hydrographs at Kerr Dam.

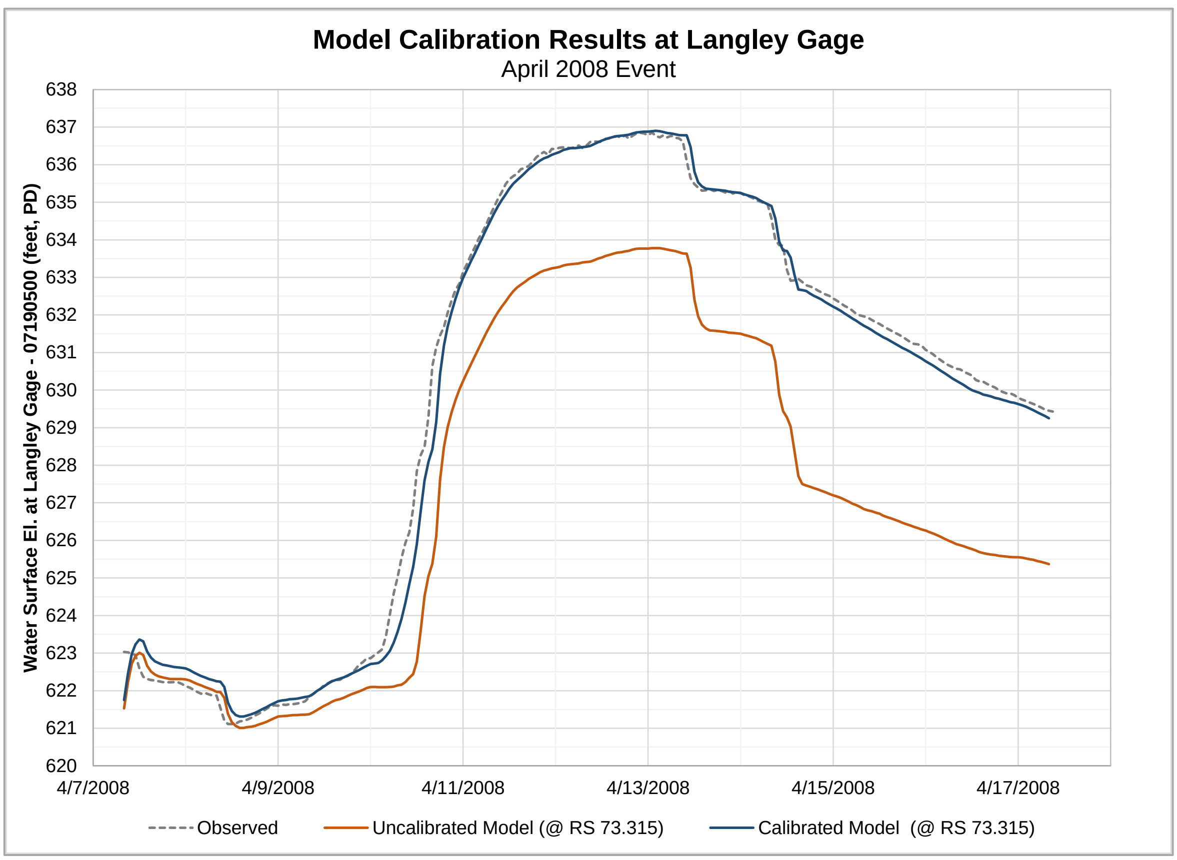


Figure 8. April 2008 Event Stage Hydrographs at Langley Gage.

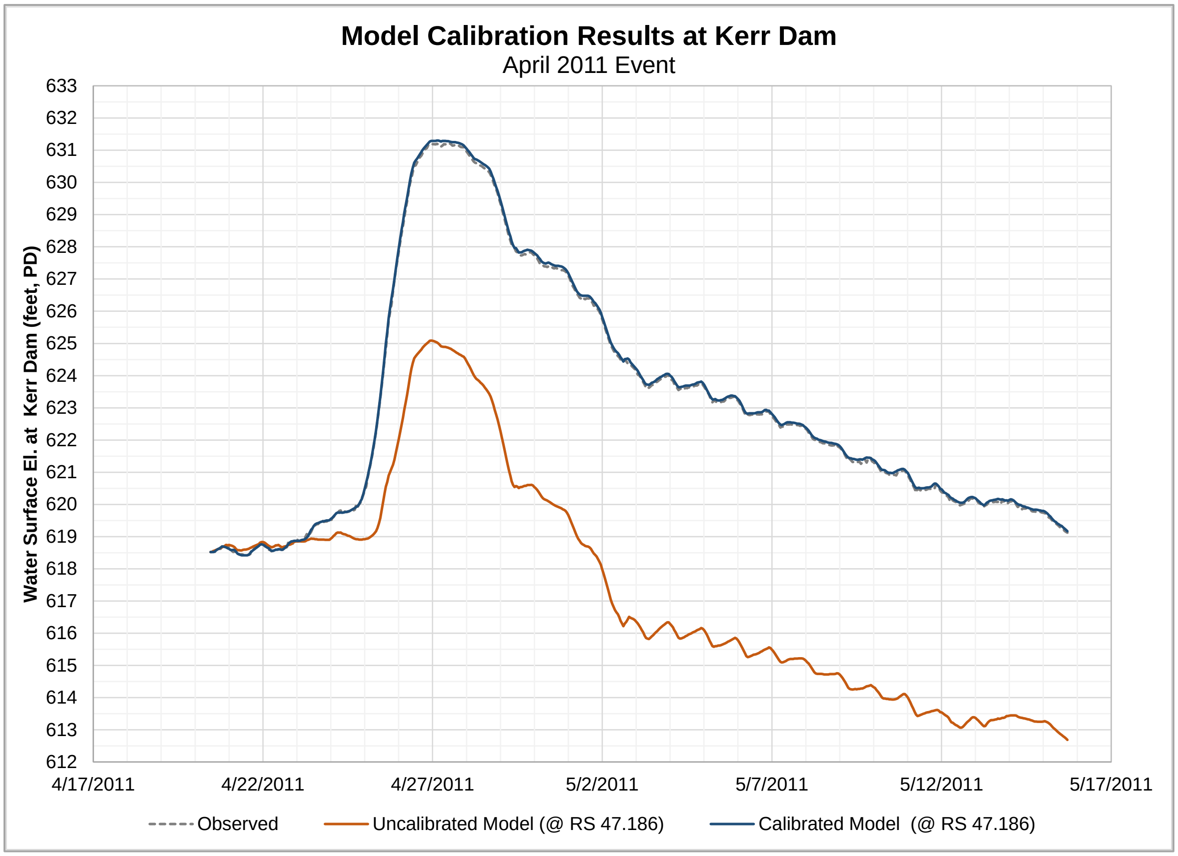


Figure 9. April 2011 Event Stage Hydrographs at Kerr Dam.

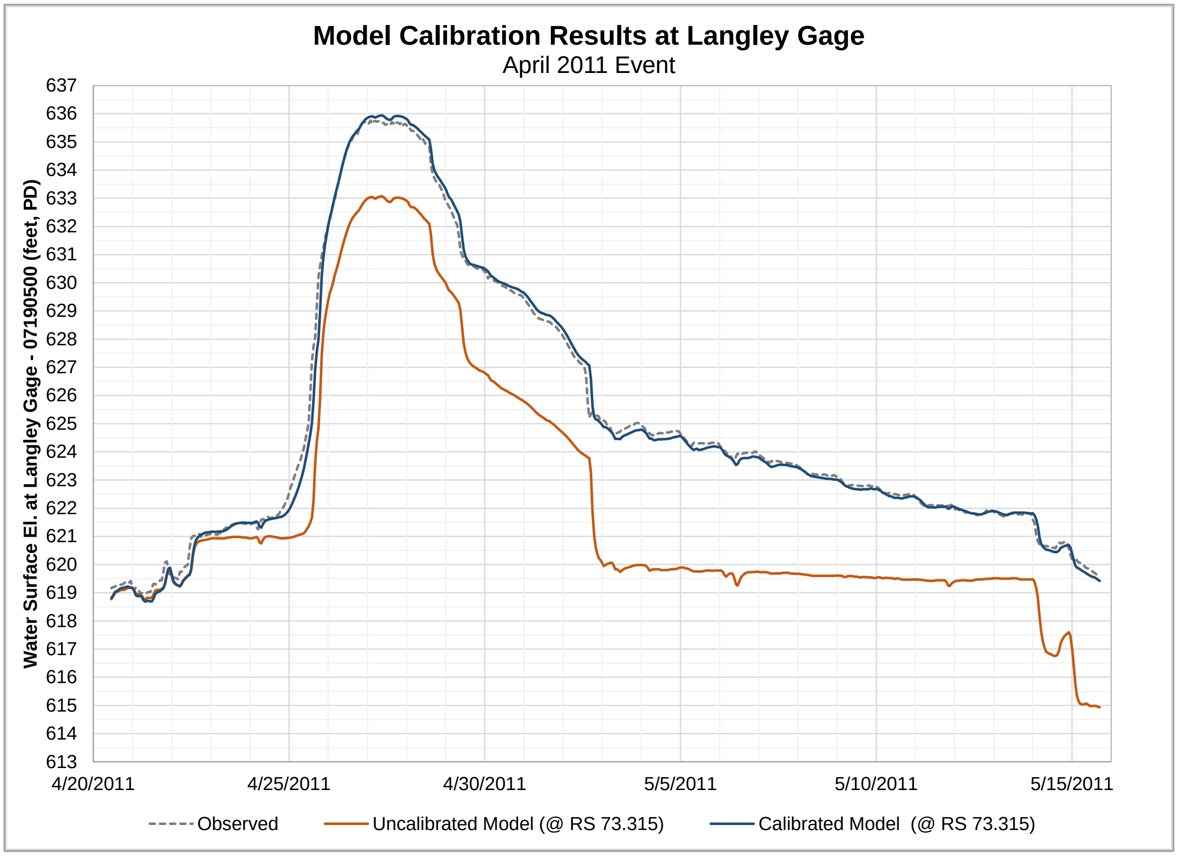


Figure 10. April 2011 Event Stage Hydrographs at Langley Gage.

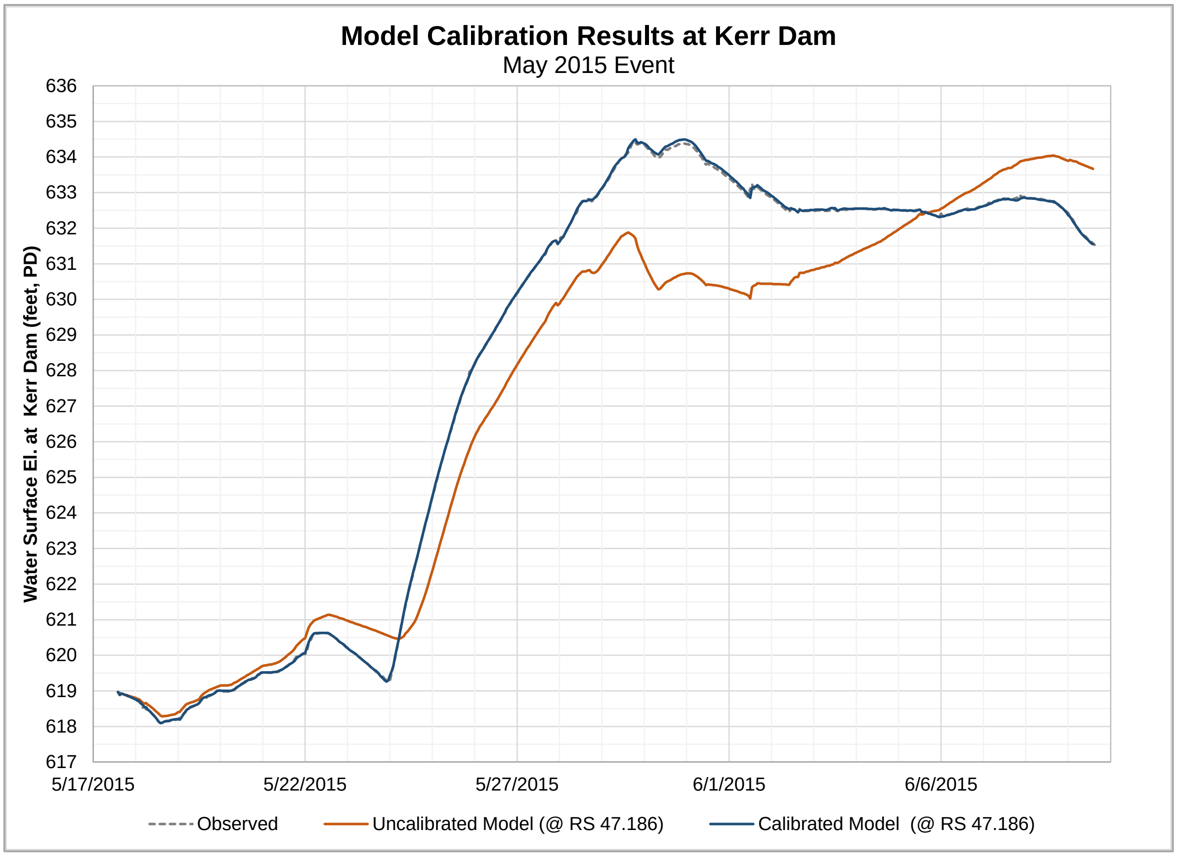


Figure 11. May 2015 Event Stage Hydrographs at Kerr Dam.

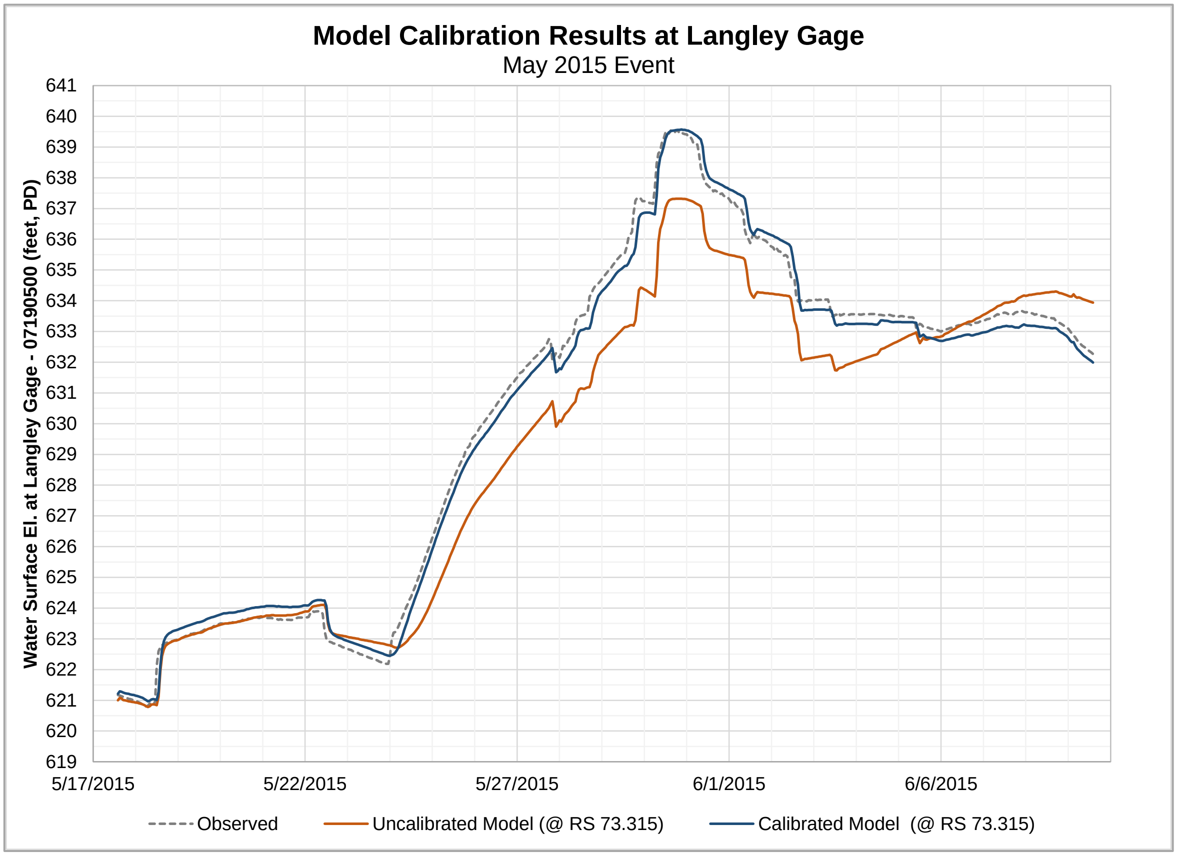


Figure 12. May 2015 Event Stage Hydrographs at Langley Gage.

3. Modeled Scenarios

The calibrated HEC-RAS model was used to analyze a variety of historical and synthetic flow events under a range of initial stages at Pensacola Dam. Inputs to the HEC-RAS model were developed using results generated from the OM. The various model simulations are discussed below.

3.1 Scenarios Summary

For this study, five historical flow events and one synthetic flow event were analyzed for a range of initial stages at Pensacola Dam. The flow events are summarized in **Table 6**. Development of the 100-year event hydrograph is discussed in **Section 3.3**.

Table 6. Summary of flow events analyzed.

Event	Type	Estimated Return Period[1]	Simulation Time Window
September 1993	Historical	21 years	Sept. 24, 1993 – Oct. 17, 1993
June 2004	Historical	1 year	June 13, 2004 – June 24, 2004
July 2007	Historical	4 years	June 28, 2007 – July 29, 2007
October 2009	Historical	3 years	Oct. 8, 2009 – Oct. 22, 2009
December 2015	Historical	15 years	Dec. 26, 2015 – Jan. 17, 2016
100-year	Synthetic	100 years	N/A[2]

1 Return period for peak inflow at Pensacola Dam.

2 Because the 100-year event is synthetic, there is no historical start or end date. The duration of the simulation is 24 days.

Each flow event was analyzed assuming starting pools at Pensacola Dam equal to the historical starting stage and representing elevations within the conservation pool of 742-, 743-, 744-, and 745-feet PD. The model inputs for each event are discussed in more detail in **Section 3.3**.

3.2 Modified Model Geometry

Modifications were made to the calibrated HEC-RAS model geometry to be used for simulating the various Pensacola Dam initial stage and flow event scenarios based on the OM output. The downstream end of the calibrated model geometry was truncated to just upstream of Kerr Dam to allow the use of a downstream stage boundary condition. This involved removing the inline structure used to represent Kerr Dam, and removing the two model cross sections downstream of Kerr Dam from the calibrated model geometry.

3.3 Boundary Conditions

Results from the OM were used as boundary conditions to the HEC-RAS model to simulate the various flow events and initial stages at Pensacola Dam. A summary of the OM results used in the HEC-RAS model simulations is provided in **Table 7**. Hydrograph plots showing results from the OM that were used as inputs to the HEC-RAS model are included in **Appendix A**.

Table 7. Summary of operations model results used for HEC-RAS simulations.

Event	Pensacola Starting Stage (ft, PD)	Pensacola Dam Peak Outflow[2] (cfs)	Kerr Dam Peak Stage (ft, PD)
September 1993	743.85[1]	174,000	634.84
	742	157,000	634.80
	743	157,000	634.86
	744	177,000	634.82
	745	198,000	634.94
June 2004	743.42[1]	23,000	619.09
	742	14,000	619.09
	743	21,000	619.09
	744	21,000	619.09
	745	46,000	621.14
July 2007	745.69[1]	117,000	634.60
	742	100,000	633.19
	743	117,000	633.19
	744	108,000	632.11
	745	117,000	634.48
October 2009	740.98[1]	100,000	633.85
	742	100,000	634.37
	743	100,000	634.37
	744	81,000	630.96
	745	99,000	633.36
December 2015	742.86[1]	195,000	634.59
	742	195,000	635.55
	743	195,000	635.55
	744	195,000	635.42
	745	195,000	634.21
100-year	742	322,000	630.56
	743	322,000	630.56
	744	322,000	631.92
	745	322,000	633.20

1 Historical pool elevation of Pensacola Dam.

2 Values rounded to the nearest 1,000 cfs.

A stage hydrograph boundary condition was used at the downstream-most cross section of the model to represent stages at Kerr Dam. Outflows from the powerhouse at Pensacola Dam were input as inflow hydrograph boundary conditions. The OM reports spillway flows at Pensacola Dam for each time step as a single value; flows between the main spillway and east spillways are not divided. For input into the HEC-RAS model, the reported spillway flows from the OM for Pensacola Dam were divided between the main and east spillways using a ratio of the maximum discharge capacities of each spillway. Based on that ratio, 69 percent of the total spillway flow was modeled as an inflow boundary condition at the upstream end of the main spillway channel, and 31 percent of the total spillway flow was modeled as lateral inflow boundary condition at the east spillway storage area.

Lateral inflows to the Neosho River and Lake Hudson between Pensacola Dam and Kerr Dam are also reported as a single value for each time step in the OM. These lateral inflows are simply passed through the OM from the USACE RiverWare model (RWM) output; the OM does not modify the lateral inflow values. For input into the HEC-RAS model, the lateral inflows were divided between tributary inflows and local inflows based on drainage area ratios computed for each contributing source. The drainage area ratios used for subdividing the reported lateral inflows from the OM are provided in **Table 8**. Tributary inflows from Summerfield Creek, Big Cabin Creek, Spavinaw Creek, and Saline Creek were represented in the HEC-RAS model as lateral inflow hydrographs. A uniform lateral inflow hydrograph distributed along the length of Lake Hudson was used to represent local inflow to the reservoir via direct rainfall on the reservoir, local runoff from the adjacent hillsides, and inflows from smaller incoming streams.

Table 8. Ratios used to subdivide lateral inflows.

Lateral Inflow Component	Ratio
Summerfield Creek	0.02
Big Cabin Creek	0.41
Saline Creek	0.10
Spavinaw Creek	0.33
Local inflow	0.14

For the synthetic 100-year event, a statistical analysis of historical inflow volume was conducted to correlate lateral inflow volumes at Lake Hudson against the peak inflows to Pensacola Dam. The statistical model was developed based on a coefficient of determination (R^2) best-fit calculation assuming the Generalized Extreme Value (GEV) distribution (Bolívar et al., 2010; Takara, 2009). The GEV distribution is a family of distributions (Gumbel, Frechét, and Weibull) commonly used to model infrequent (extreme) random variables, including wind speed, precipitation, and stream flow. The ISR for the Upstream Hydraulic Model (UHM) provides details on the statistical analysis of historical inflow volumes and peak flows at Pensacola Dam, and the development of the synthetic 100-year inflow hydrograph at Pensacola Dam.

Lake Hudson lateral inflow for 24-hour periods was extracted from the RWM output. Lateral inflow by 24-hour duration was converted to volume. Volumes were placed into bins with D+0 representing the day when the peak inflow at Pensacola Dam occurred, D-1 representing the day before the peak, D+1 representing the day after the peak, and so on. The outermost bins included the average over three days: D-8 to D-10, and D+7 to D+9. Thus, the full set of bins is as follows: D-8 to D-10, D-7, D-6, D-5, D-4, D-3, D-2, D-1, D+0, D+1, D+2, D+3, D+4, D+5, D+6, and D+7 to D+9.

As discussed in the ISR for the UHM, sets of bins were calculated for the day within each USGS water year, centered around the date on which the annual maximum inflow at Pensacola Dam occurred (one set of bins per USGS water year). Bins were then ordered according to the maximum inflow at Pensacola Dam and used to calculate the Generalized Extreme Value (GEV) distribution parameters. The 100-year inflow at Pensacola Dam was predicted using the GEV distribution parameters and the annual peak inflow values from the RWM output. The reduced variate was calculated for each ordered peak inflow value, and the shape parameter was adjusted to maximize the R^2 correlation of the GEV-linearized discharges (annual peak inflows vs. reduced variate of peak inflows at Pensacola Dam). This resulted in a 100-year inflow at Pensacola Dam within 3 percent of the value calculated in Mead & Hunt's inflow frequency analysis. The shape parameter was then adjusted to match the 100-year inflow at Pensacola Dam based on the Grand Lake inflow frequency analysis, resulting in a shape parameter of -0.02 and a reduced variate of 4.41 for the Pensacola Dam 100-year peak inflow. Daily lateral inflows to Lake Hudson corresponding to the day of the peak inflow at Pensacola Dam were also plotted against the reduced variates for the corresponding peak inflow at Pensacola Dam.

For each lateral inflow volume bin (D-8 to D-10, D-7… D+0… D+6, and D+7 to D+9), the binned daily volumes were plotted as a function of the reduced variates for the corresponding peak inflow values at Pensacola Dam, using the same adjusted shape parameter (k) used to predict the 100-year inflow at Pensacola Dam. A linear trend line for each volume bin (e.g., D+0) was calculated to obtain the scale parameter σ (linear slope, m) and a location parameter μ (linear intercept, b) for each volume bin. The R^2 values computed based on the linear trend lines fit through the data show a poor correlation between the peak inflows at Pensacola Dam and lateral inflows into Lake Hudson. This is due to the watersheds being mostly hydrologically independent from one another, and the relatively long average travel time for rainfall to reach Pensacola Dam as inflow. However, there is still a positive correlation between increasing peak inflow at Pensacola Dam and increasing lateral inflow into Lake Hudson, so the statistical model is useful for predicting lateral inflows into Lake Hudson expected to be coincident with a 100-year inflow event at Pensacola Dam.

The reduced variate for the 100-year peak inflow at Pensacola Dam (4.41), along with the scale and location parameters for each lateral inflow volume bin were then used to calculate the daily Lake Hudson lateral inflow volumes that are predicted to correspond to a 100-year peak inflow event at Pensacola Dam. **Table 9** displays the results of the statistical analysis, and plots from the analysis are shown in **Appendix B**. The resulting lateral inflow volume curve was used to develop a lateral inflow hydrograph for Lake Hudson. For use as boundary conditions in the HEC-RAS model for the 100-year event, the lateral inflow hydrograph was then divided into tributary and local inflow hydrographs using the ratios given in **Table 8**.

Table 9. Results of historical lateral inflow volume statistical analysis.

Volume Bin	Scale Parameter, σ (m)	Location Parameter, μ (b)	100-year Lake Hudson Lateral Inflow Volume (acre-feet)
D-8 to D-10 avg.	3,314	1,647	16,274
D-7	2,143	1,643	11,100
D-6	746	3,876	7,167
D-5	1,711	3,473	11,023
D-4	1,429	3,636	9,944
D-3	4,368	5,550	24,827
D-2	6,910	11,586	42,081
D-1	12,884	18,908	75,769
D+0	14,562	25,031	89,297
D+1	12,974	15,212	72,470
D+2	8,690	6,955	45,306
D+3	3,856	4,816	21,833
D+4	1,950	3,996	12,601
D+5	1,778	4,478	12,325
D+6	1,037	3,948	8,525
D+7 to D+9 avg.	1,568	3,626	10,547

4. Study Results

The HEC-RAS model results were used to extract the maximum WSELs throughout the DHM for each modeled flow event and scenario. The resulting maximum WSELs are documented in the tables provided in **Appendix C**. Tables are provided for each flow event comparing the maximum WSELs for starting stages at Pensacola Dam of 742-, 743-, 744-, and 745-feet PD (**Tables C.1** through **C.6**). These tables also include the maximum difference in WSELs between the four starting stage scenarios. A separate table was created for comparing the maximum WSELs for each of the flow events using the historical starting stage at Pensacola Dam (**Table C.7**).

Graphical water surface profiles were also developed from the HEC-RAS model results showing the computed maximum WSELs. The water surface profile plots are included in **Appendix D**. Similar to the tabular data, plots were developed to compare the maximum WSELs for the conservation pool starting stages at Pensacola Dam of 742-, 743-, 744-, and 745-feet PD for each flow event (**Figures D.1** through **D.6**), and a separate plot was developed to show the maximum WSELs for each of the flow events using a historical starting stage at Pensacola Dam (**Figure D.7**).

In addition, the HEC-RAS model results were used to develop maps showing the inundation extents resulting from the computed WSELs. The inundation maps are included in **Appendix E**. A series of 10 maps at a scale of 1:24,000 (1 inch = 2,000 feet) cover the downstream model area. Like the tabular and graphical results, separate map sets were developed to compare the maximum inundation extents for each flow event using starting conservation pool stages at Pensacola Dam of 742-, 743-, 744-, and 745-feet PD (**Appendix E.1** through **E.6**), and a separate map set was developed to compare the maximum inundation extents for all the flow events using a historical starting stage at Pensacola Dam (**Appendix E.7**). The inundation extents shown on the maps were developed using the RAS Mapper application and are based on the topographic data discussed in **Section 2.1**.

Table 10 presents a summary of smallest and largest inundation areas, as well as the percentage difference between them. The first six rows in the table present smallest and largest maximum inundation areas for the 742-, 743-, 744-, and 745-feet PD Pensacola Dam conservation pool starting stages for a given flow event. The last row in the table presents the smallest and largest maximum inundation areas for the various flow events using the historical starting stage elevations. The maximum inundation area differences for a given event due to a change in starting stage are an order of magnitude smaller than the maximum differences when inflow events are compared against each other, and the historical starting stage is used.

Table 10. Summary of minimum and maximum inundation areas.

Event	Area of Inundation (acres)		Difference (%)
	Smallest	Largest	
September 1993	18,679	19,013	1.8%
June 2004	12,202	13,005	6.4%
July 2007	17,277	18,327	5.9%
October 2009	16,276	17,851	9.3%
December 2015	18,806	19,243	2.3%
100-year	19,166	19,803	3.3%
Historical Starting Stage	12,246	19,411	45.3%

5. Discussion of Results

Maximum WSELs and maximum inundation extents were analyzed to assess the downstream influence of various initial stages at Pensacola Dam. The following subsections provide a discussion of the results from the hydraulic modeling for each flow event analyzed.

5.1 September 1993 Flow Event

As shown in **Table 7**, when compared to all the flow events analyzed as part of this study, the September 1993 event represents the third largest in regard to releases from Pensacola Dam. For this event, the maximum releases from Pensacola Dam are dependent on the starting stage of Pensacola Dam. According to the results of the OM, the largest release from Pensacola Dam occurs with a starting stage of 745 feet (approximately 198,000 cfs). Conversely, the smallest release occurs at a starting stage of 742 feet (approximately 157,000 cfs). For the scenarios analyzed, the peak stages at Kerr Dam follow a similar trend to the releases from Pensacola Dam. The highest peak stage at Kerr Dam is associated with the largest release from Pensacola Dam. As shown in **Figure D.1**, the peak stages at Kerr Dam only differ slightly between the scenarios using starting stages at Pensacola Dam between 742 and 745 feet (maximum difference of 0.14 feet).

For the September 1993 event, the variability in releases from Pensacola Dam due to the different starting stages leads to differences in the maximum WSELs and inundation extents in the upstream portion of the DHM. These differences are most pronounced upstream of the Big Cabin Creek confluence (River Mile (RM) 66.78) where differences in maximum WSEL range from 0.87 to 2.90 feet. This portion of the DHM is more riverine in nature and is upstream of the main body of Lake Hudson where peak stages at Kerr Dam have a greater influence on maximum WSELs. Therefore, for this event, variations in the releases from Pensacola Dam have an influence on the computed maximum WSELs and inundation extents through the upper portion of the DHM.

The differences in maximum WSEL and inundation extents due to the different starting stages are much smaller in the downstream portion of the DHM through Lake Hudson. As shown in **Table C.1**, downstream of the Strang Road bridge (RM 63.32), the differences in maximum WSEL range from 0.13 to 0.18 feet. As shown in **Appendix E.1**, the differences in maximum inundation extent through the downstream portion of the DHM are not appreciable.

5.2 June 2004 Event

As shown in **Table 7**, when compared to all the flow events analyzed as part of this study, the June 2004 event represents the smallest releases from Pensacola Dam. For this event, the maximum releases from Pensacola Dam are dependent on the starting stage of Pensacola Dam. According to the results of the OM, the largest release from Pensacola Dam occurs with a starting stage of 745 feet (approximately 46,000 cfs). Conversely, the smallest release occurs at a starting stage of 742 feet (approximately 14,000 cfs). For the scenarios analyzed, the peak stages at Kerr Dam follow a similar trend to the releases from Pensacola Dam. The highest peak stage at Kerr Dam is associated with the largest release from Pensacola Dam. However, as shown in **Table C.2**, the peak stages at Kerr Dam for the 742-, 743-, and 744-feet starting stages are identical at 619.09 feet. As shown in **Figure D.2**, the maximum WSELs for the scenarios with 742-, 743-, and 744-feet starting stages converge to an elevation of approximately 619 feet just upstream of Strang Rd. Bridge to Kerr Dam. However, the scenario with a starting stage of 745 feet is approximately 2 feet higher.

For the June 2004 event, the variability in releases from Pensacola Dam due to the different starting stages leads to differences in the maximum WSELs and maximum inundation extents (shown in **Appendix E.2**) primarily in the upstream portion of the DHM. These differences are most pronounced upstream of the Big Cabin Creek confluence (RM 66.78) where the differences in maximum WSEL range from 2.61 feet at the confluence to 6.95 feet just downstream of Pensacola Dam. Because this portion of the DHM is more riverine and is upstream of the main body of Lake Hudson where peak stages at Kerr Dam have the greatest influence on maximum WSELs, the variations in the releases from Pensacola Dam have an influence on the computed maximum WSELs and maximum inundation extents through the upper portion of the DHM.

5.3 July 2007 Event

As shown in **Table 7**, when compared to all the flow events analyzed as part of this study, the July 2007 event represents the third smallest releases from Pensacola Dam. For this event, the maximum releases from Pensacola Dam are dependent on the starting stage of Pensacola Dam. According to the results of the OM, the largest release from Pensacola Dam occurs with a starting stage of 745 feet (approximately 117,00 cfs). Conversely, the smallest release occurs at a starting stage of 742 feet (approximately 100,000 cfs). For the scenarios analyzed, the highest stage at Kerr Dam is associated with the highest release from Pensacola Dam; however, the peak stages at Kerr Dam do not follow a trend similar to the releases from Pensacola Dam. For example, the 742-foot starting stage produces a peak outflow from Pensacola Dam of approximately 100,000 cfs and results in a peak stage at Kerr Dam of 633.19 feet, while the 744-foot starting stage produces a peak outflow from Pensacola Dam of approximately 108,000 cfs and results in a peak stage of 632.11. The greater peak outflows at Pensacola Dam do not necessarily correspond to higher peak stages at Kerr Dam.

For the July 2007 event, the variability in releases from Pensacola Dam due to the different starting stages in combination with the variability in peak stages at Kerr Dam leads to nearly uniform differences in the maximum WSELs throughout the DHM. As shown in **Table C.3**, the differences in maximum WSEL range from approximately 2.3 feet just downstream of Pensacola Dam, to approximately 2.0 feet near RM 70, and up to approximately 2.4 feet at Kerr Dam.

While the differences in maximum WSEL due to different starting elevations are nearly uniform through the DHM, the differences in maximum inundation extent are not. As shown in **Appendix E.3**, the differences in maximum inundation extent through the upper portion of the DHM (upstream of RM 62) are more pronounced due to the riverine-like conditions and flatter floodplain, whereas the differences in inundation extent through the lower portion of Lake Hudson (downstream of RM 62) are generally less pronounced due to the steeper valley walls.

5.4 October 2009 Event

As shown in **Table 7**, when compared to all the flow events analyzed as part of this study, the October 2009 event represents the second smallest releases from Pensacola Dam. For this event, the maximum releases from Pensacola Dam are dependent on the starting stage of Pensacola Dam. According to the results of the OM, the largest release from Pensacola Dam occurs with a starting stage of 742 feet (approximately 100,000 cfs). Conversely, the smallest release occurs at a starting stage of 744 feet (approximately 81,000 cfs). For the scenarios analyzed, the peak stages at Kerr Dam follow a similar trend to the releases from Pensacola Dam. The highest stage at Kerr Dam is associated with the highest release from Pensacola Dam. As shown in **Figure D.4**, the peak stages at Kerr Dam differ by approximately 3.4 feet between the scenarios using starting stages at Pensacola Dam of 744 versus 742 feet.

For the October 2009 event, the variability in releases from Pensacola Dam due to the different starting stages in combination with the variability in the peak stages at Kerr Dam leads to nearly uniform differences in the maximum WSELs throughout the DHM. As shown in **Table C.4**, the differences in maximum WSEL range from approximately 3.1 feet just downstream of Pensacola Dam, to approximately 3.7 feet near RM 70.

While the differences in maximum WSEL due to different starting elevations are nearly uniform through the DHM, the differences in maximum inundation extent are not. As shown in **Appendix E.4**, the differences in maximum inundation extent through the upper portion of the DHM (upstream of RM 62) are more pronounced due to the riverine-like conditions and flatter floodplain, whereas the differences in inundation extent through the lower portion of Lake Hudson (downstream of RM 62) are less pronounced due to the steeper valley walls.

5.5 December 2015 Event

As shown in **Table 7**, when compared to all the flow events analyzed as part of this study, the December 2015 event represents the second largest releases from Pensacola Dam. For this event, the maximum releases from Pensacola Dam are not dependent on the starting stage of Pensacola Dam because, according to the results of the OM, the peak outflows from Pensacola Dam are nearly identical for all starting stages. However, as shown in **Table C.5**, the peak stages at Kerr Dam differ by a maximum of approximately 1.3 feet between the scenarios with varying starting stages, with starting stages of 742 and 743 feet producing the highest peak stages at Kerr Dam compared to the other scenarios. This apparent inconsistency could be due to limitations with the OM. Refer to the OM ISR for a discussion of the known limitations and planned improvements to the OM.

Because the peak releases from Pensacola Dam are identical for all starting stage combinations, the differences in the maximum WSELs are small in the uppermost portion of the DHM upstream of the OK-82 Bridge (RM 72.822). As shown in **Table C.5**, the differences in maximum WSELs become more pronounced downstream of the OK-82 Bridge and range from approximately 0.4 feet at the OK-82 Bridge up to approximately 1.3 feet just upstream of Kerr Dam.

As shown in **Appendix E.5**, the maximum inundation extents are nearly identical for all but the 745-foot starting stage which has the smallest maximum inundation extent. The differences in maximum inundation extents do not vary significantly between the upper and lower portions of the DHM.

5.6 100-year Event

As shown in **Table 7**, when compared to all the flow events analyzed as part of this study, the 100-year event represents the largest releases from Pensacola Dam. For this event, the maximum releases from Pensacola Dam are not dependent on the starting stage of Pensacola Dam because, according to the results of the OM, the peak outflows from Pensacola Dam are identical for all starting stages. However, as shown in **Table C.6**, the peak stages at Kerr Dam differ by a maximum of approximately 2.6 feet between the scenarios with varying starting stages, with a starting stage of 745 feet producing the highest peak stage at Kerr Dam and a starting stage of 742 feet producing the lowest peak stage, as would be expected.

Because the peak releases from Pensacola Dam are identical for all starting stage combinations, the differences in maximum WSELs are small in the uppermost portion of the DHM upstream of the OK-82 Bridge (RM 72.822). As shown in **Table C.6** the differences in maximum WSELs become more pronounced downstream of the OK-82 Bridge and range from approximately 0.2 feet at the OK-82 Bridge to approximately 2.6 feet just upstream of Kerr Dam.

As shown in **Appendix E.6**, the maximum inundation extents are nearly identical for all but the 745-foot starting stage which has the largest inundation extent. The differences in inundation extents vary the most in the upstream portion of the DHM, particularly between RM 61 and RM 67.

5.7 Comparison of Historical Starting Stages

As shown in **Table 7**, the peak outflows from Pensacola Dam vary significantly between all five events analyzed with a starting stage at Pensacola Dam equal to the historical pool elevation. The outflows from Pensacola Dam for the simulations with a historical starting stage at Pensacola Dam range from approximately 23,000 cfs for the June 2004 event, to 195,000 cfs for the December 2015 event. As shown in **Table C.7** and **Figure D.7**, the variability in peak outflows from Pensacola Dam for the historical starting stage simulations results in large differences between the maximum WSELs throughout the DHM. The peak stages at Kerr Dam differ by a maximum of approximately 15.8 feet, with the peak stages at Kerr Dam for the September 1993, October 2009, July 2007, and December 2015 events being similar and the June 2004 resulting in a much lower WSEL profile compared to the other four events.

Because the peak releases from Pensacola Dam differ greatly between each of the flow events using a historical starting stage at Pensacola Dam, the differences in maximum WSELs also differ greatly throughout the DHM. As shown in **Table C.7**, the differences in maximum WSEL become more pronounced upstream of Big Cabin Creek confluence (RM 66.78) where the differences in maximum WSEL range from 17.81 feet at the confluence to 23.72 feet at the N 4475 Road Bridge. Because this portion of the DHM is more riverine and is upstream of the main body of Lake Hudson where peak stages at Kerr Dam have the greatest influence on maximum WSELs, the variations in the releases from Pensacola Dam between each of the events have an influence on the computed maximum WSELs.

As shown in **Appendix E.7,** when comparing the flow events with historical starting stage at Pensacola Dam, the differences in maximum WSEL throughout the DHM translate into differences in the maximum inundation extents. The differences in maximum inundation extents are most pronounced upstream of the Big Cabin Creek confluence, with variation in the inundation extents between all the flow events. Downstream of the Big Cabin Creek confluence, the maximum inundation extents for the September 1993, October 2009, July 2007, and December 2015 events are all similar, with the June 2004 resulting in a much smaller inundation extent compared to the other four events.

6. Conclusions

The results of the DHM demonstrate that initial stages at the Project have an influence on downstream WSELs and out-of-bank inundation. As the analysis shows, downstream WSELs, stages at Kerr Dam, and inundation extents are dependent on the magnitude and volume of releases from the Project, which in turn are dependent on initial stage at the Project. Out-of-bank inundation downstream of the Project is the result of spillway releases which are directed by the USACE. Under authority of Section 7 of the 1944 Flood Control Act, the Tulsa District of the USACE is responsible for prescribing and directing the flood control operations of the Project. The USACE is also responsible for directing spillway releases in accordance with the procedures for system balancing of flood storage outlined in the Arkansas River Basin Water Control Master Manual (USACE, 1980). This authority is reinforced by Section 7612 (c) of the NDAA of Fiscal Year 2020 which states that “The Secretary [of the Army] shall have exclusive jurisdiction and responsibility for management of the flood pool for flood control operations at Grand Lake O' the Cherokees” (116th Congress, 2019).

Use of the DHM to analyze different operational scenarios for the Project is entirely dependent on results from the OM due to the relatively flat gradient along Lake Hudson. As discussed in the ISR for the OM, there are currently some known limitations and planned improvements for the next phase of the study. Following these improvements, more consistent predictions of peak stages versus initial stages are expected.

7. References

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APPENDIX A:
SIMULATED HYDROGRAPHS

APPENDIX A.1:
SEPTEMBER 1993 EVENT SIMULATED HYDROGRAPHS

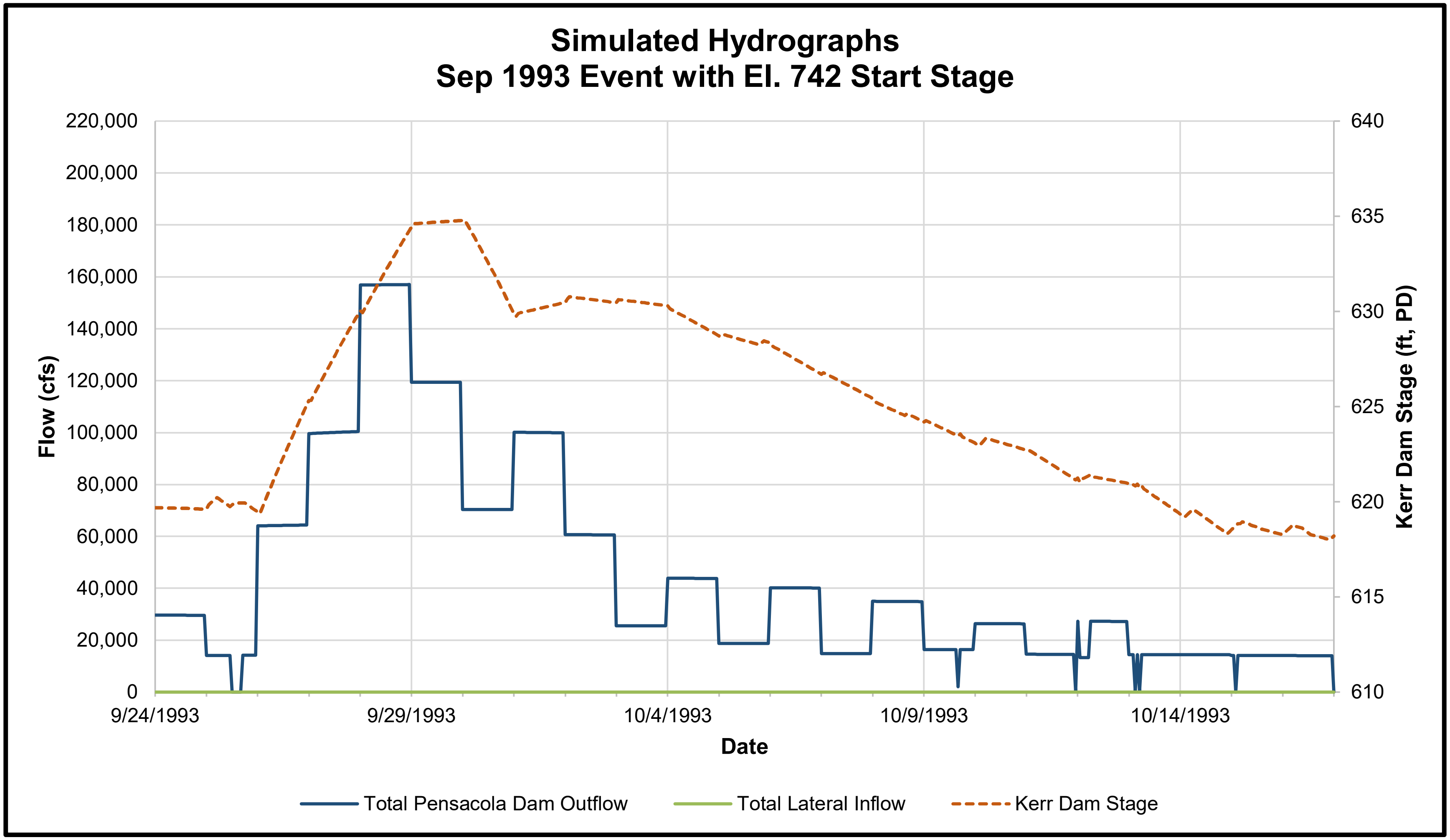


Figure A.1. Simulated hydrograph for the September 1993 event with El. 742 starting stage at Pensacola Dam.

Notes:

1. *The solid blue and green lines are plotted against the left y-axis and represent the Total Pensacola Dam Outflow and Total Lateral Inflow respectively.*
2. *The dashed line is plotted against the right y-axis and represents the stage at Kerr Dam.*
3. *Total Lateral Inflow is 0 cfs throughout the duration of the September 1993 event.*

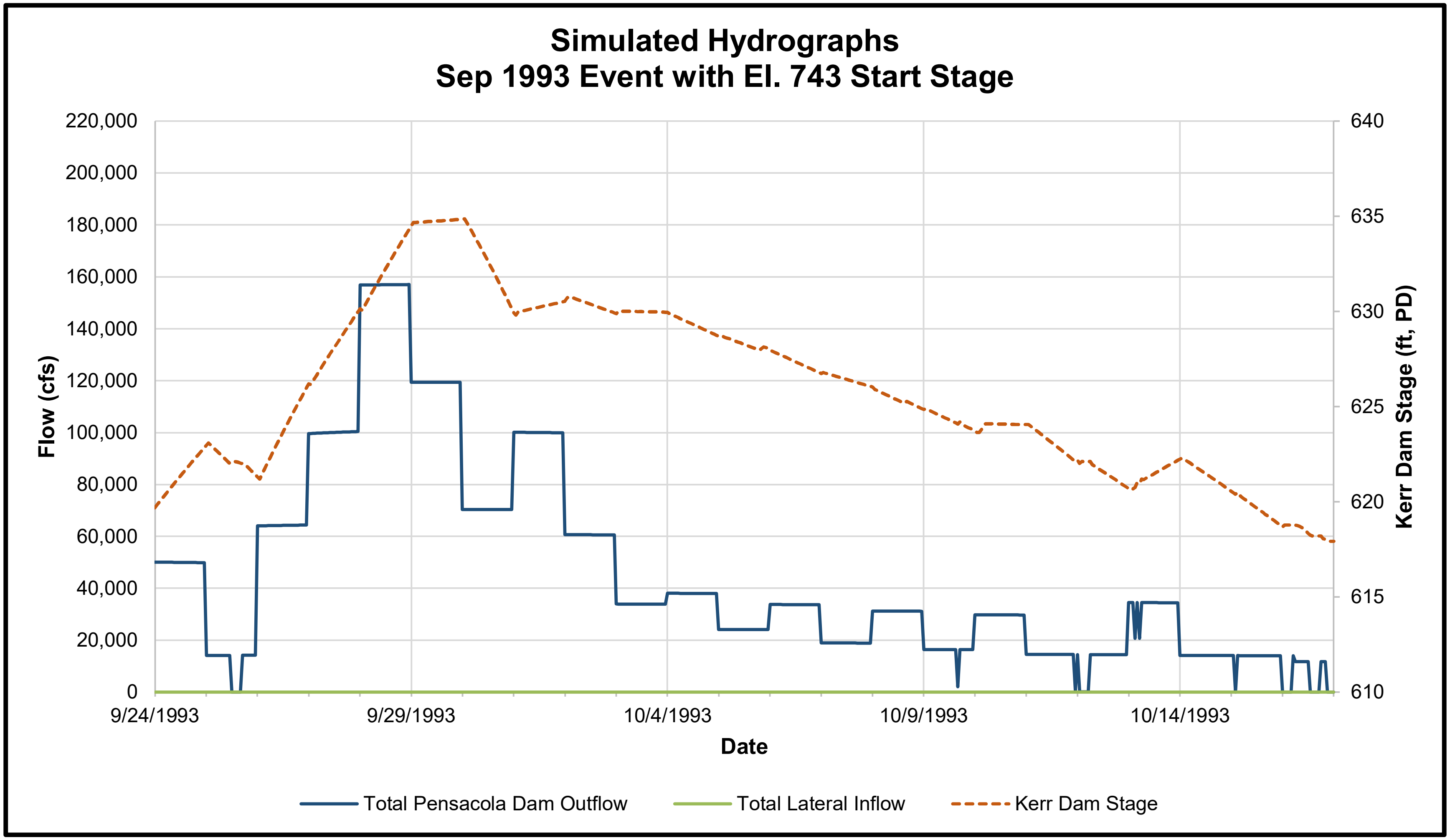


Figure A.2. Simulated hydrograph for the September 1993 event with El. 743 starting stage at Pensacola Dam.

Notes: 1. The solid blue and green lines are plotted against the left y-axis and represent the Total Pensacola Dam Outflow and Total Lateral Inflow respectively.

2. The dashed line is plotted against the right y-axis and represents the stage at Kerr Dam.

3. Total Lateral Inflow is 0 cfs throughout the duration of the September 1993 event.

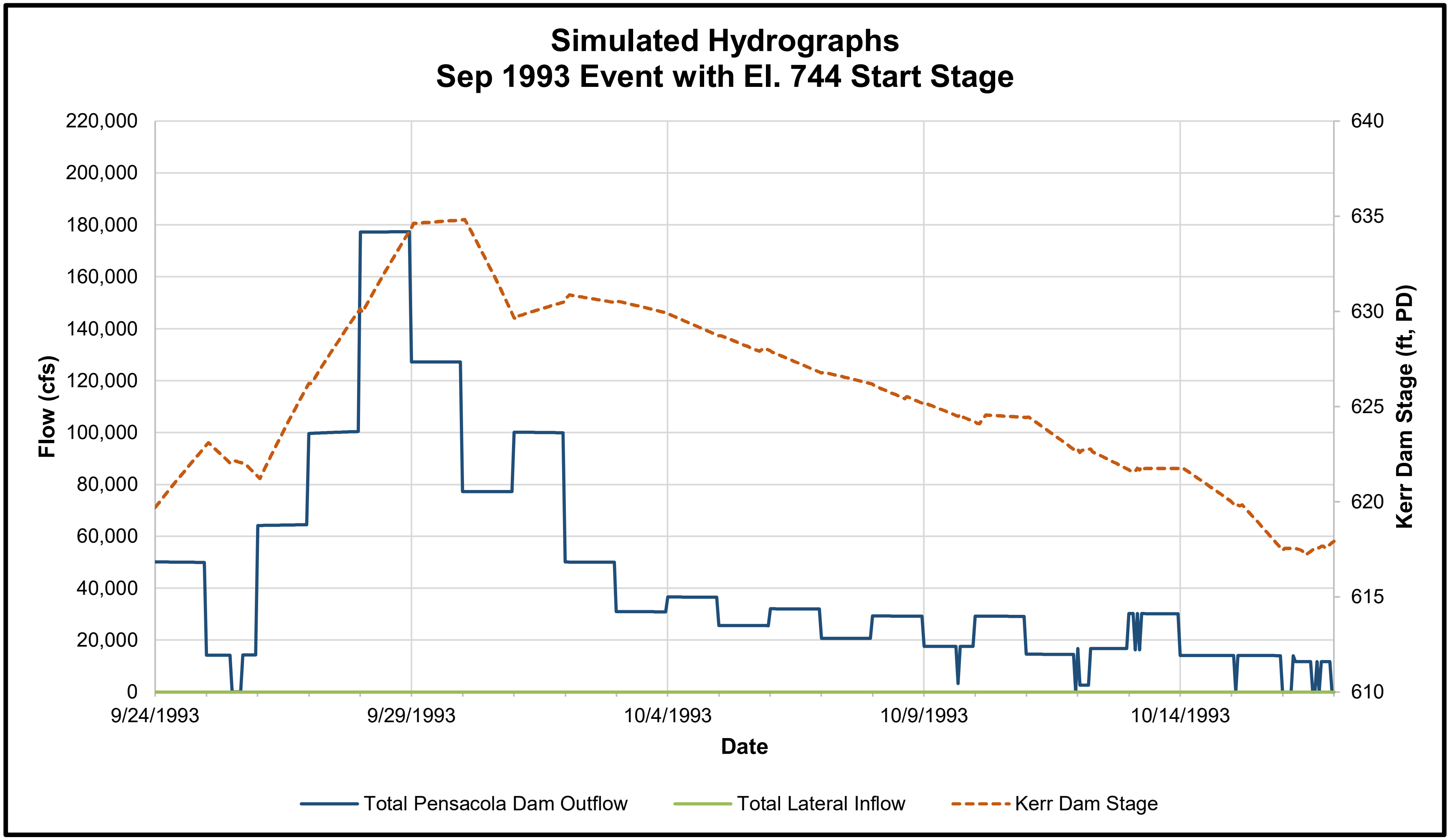


Figure A.3. Simulated hydrograph for the September 1993 event with El. 744 starting stage at Pensacola Dam.

Notes:
1. *The solid blue and green lines are plotted against the left y-axis and represent the Total Pensacola Dam Outflow and Total Lateral Inflow respectively.*
2. *The dashed line is plotted against the right y-axis and represents the stage at Kerr Dam.*
3. *Total Lateral Inflow is 0 cfs throughout the duration of the September 1993 event.*

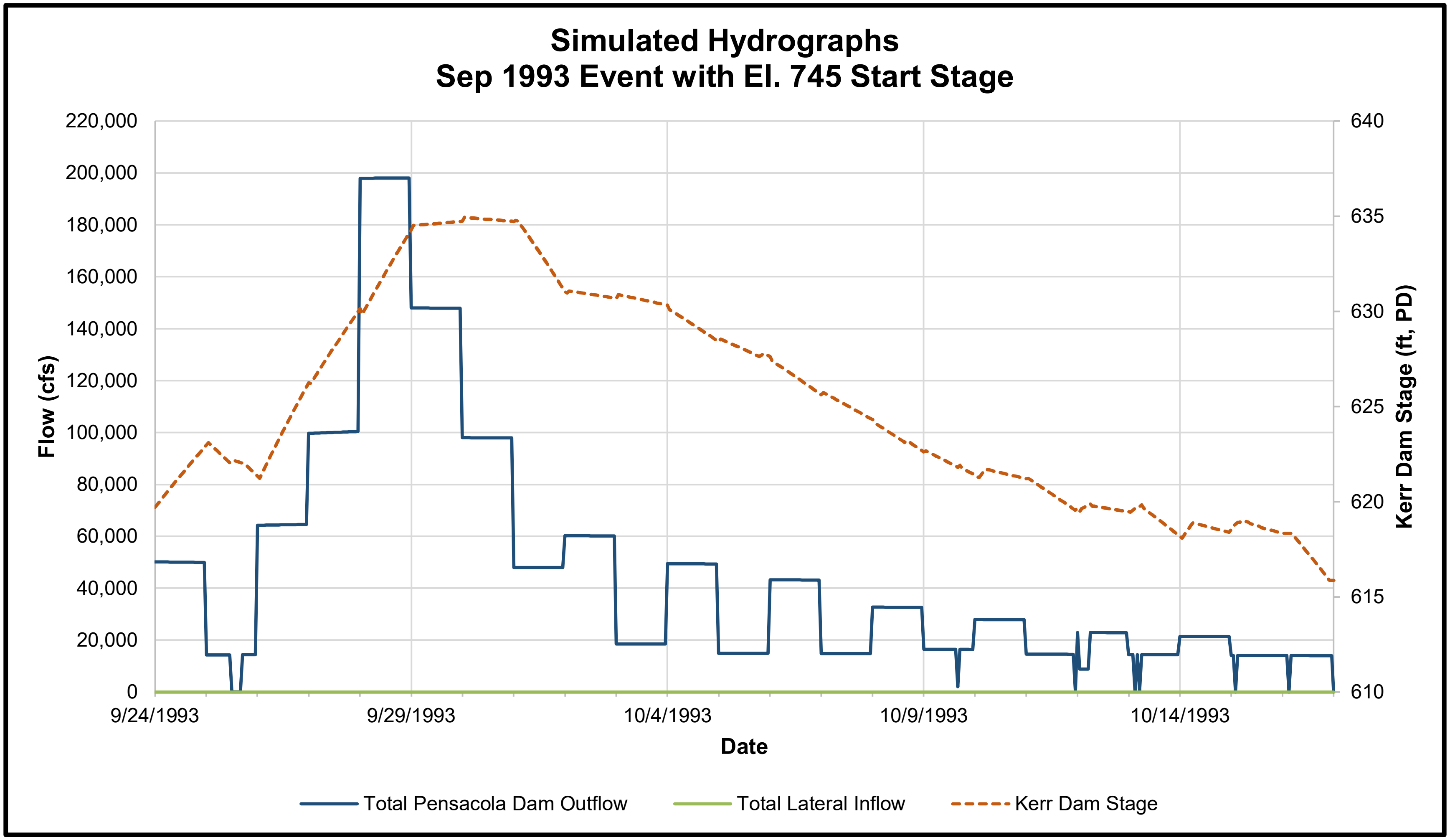


Figure A.4. Simulated hydrograph for the September 1993 event with El. 745 starting stage at Pensacola Dam.

Notes:

1. The solid blue and green lines are plotted against the left y-axis and represent the Total Pensacola Dam Outflow and Total Lateral Inflow respectively.

2. The dashed line is plotted against the right y-axis and represents the stage at Kerr Dam.

3. Total Lateral Inflow is 0 cfs throughout the duration of the September 1993 event.

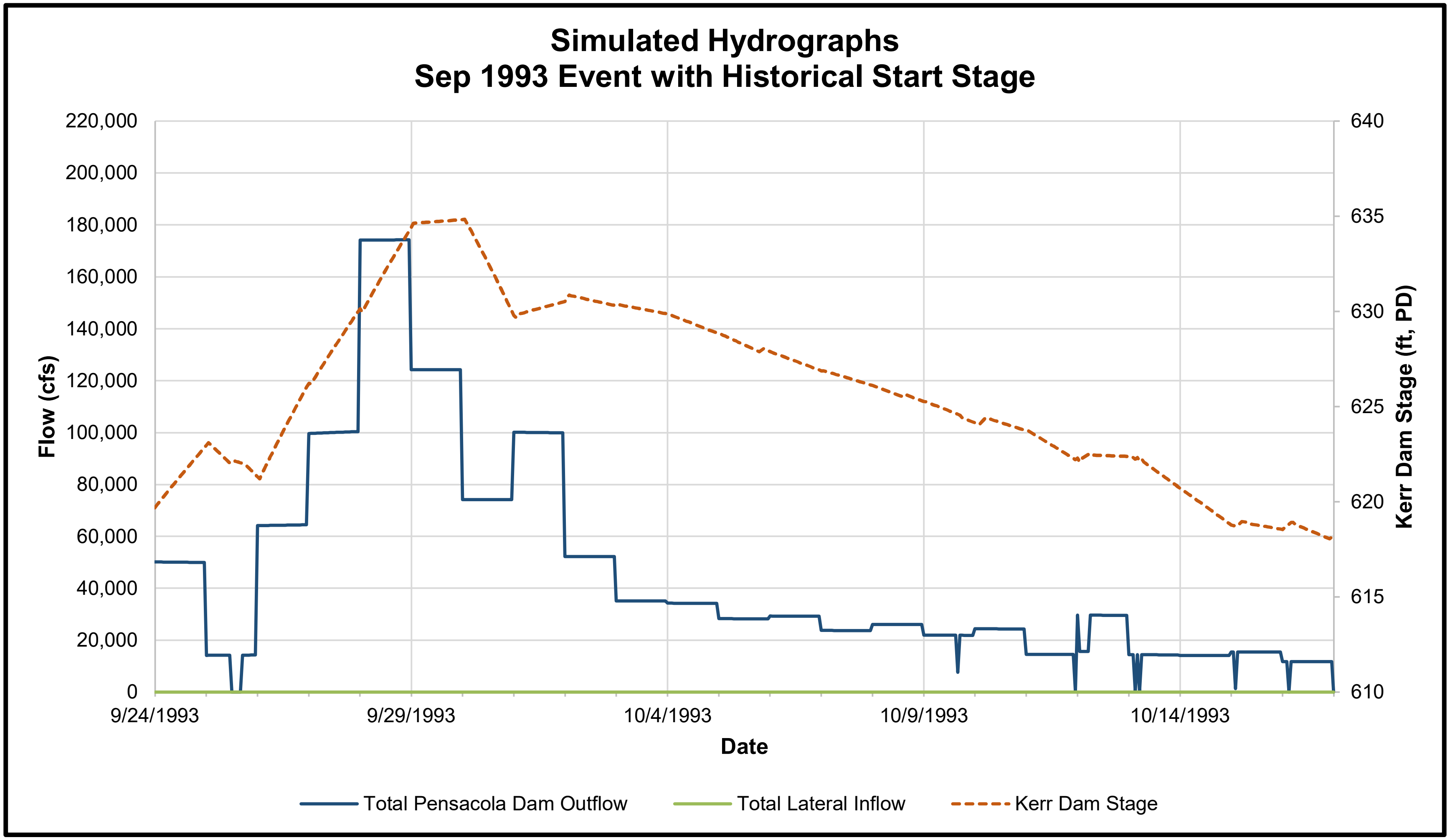


Figure A.5. Simulated hydrograph for the September 1993 event with historical starting stage at Pensacola Dam.

Notes:

1. *The solid blue and green lines are plotted against the left y-axis and represent the Total Pensacola Dam Outflow and Total Lateral Inflow respectively.*
2. *The dashed line is plotted against the right y-axis and represents the stage at Kerr Dam.*
3. *Total Lateral Inflow is 0 cfs throughout the duration of the September 1993 event.*

APPENDIX A.2:

JUNE 2004 EVENT SIMULATED HYDROGRAPHS

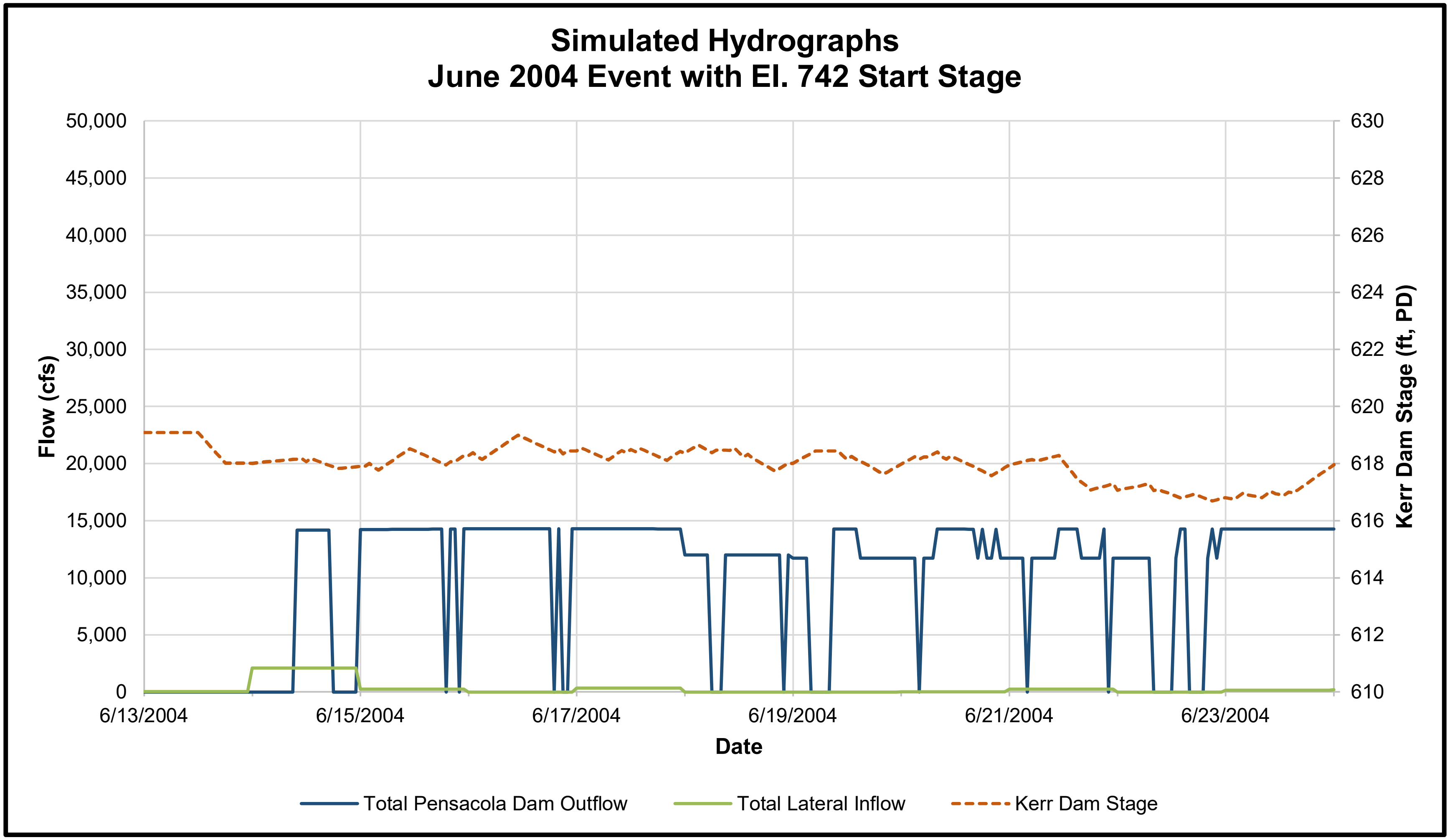


Figure A.6. Simulated hydrograph for the June 2004 event with El. 742 starting stage at Pensacola Dam.

Notes: 1. The solid blue and green lines are plotted against the left y-axis and represent the Total Pensacola Dam Outflow and Total Lateral Inflow respectively.
2. The dashed line is plotted against the right y-axis and represents the stage at Kerr Dam.

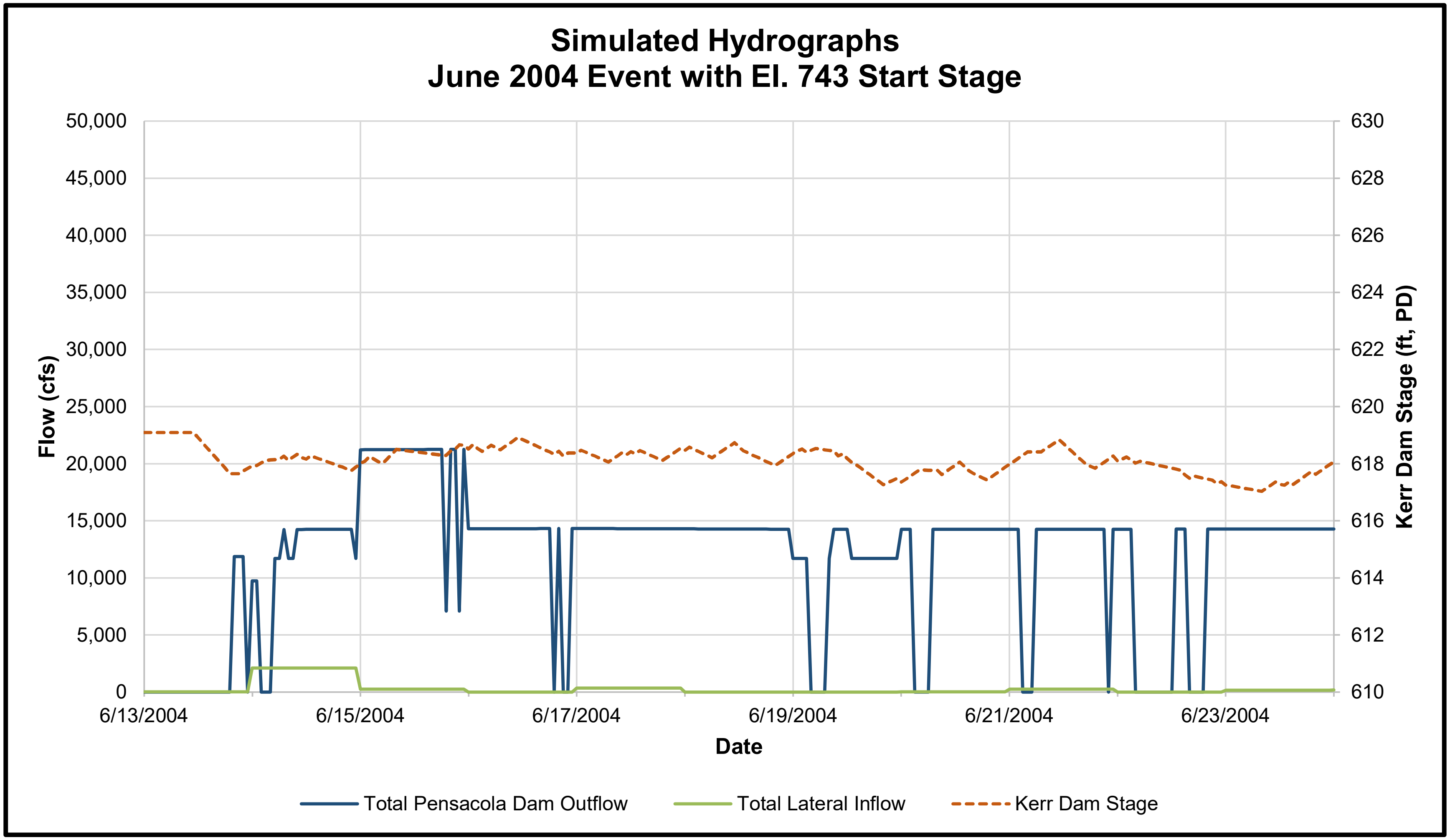


Figure A.7. Simulated hydrograph for the June 2004 event with El. 743 starting stage at Pensacola Dam.

Notes: 1. The solid blue and green lines are plotted against the left y-axis and represent the Total Pensacola Dam Outflow and Total Lateral Inflow respectively.

2. The dashed line is plotted against the right y-axis and represents the stage at Kerr Dam.

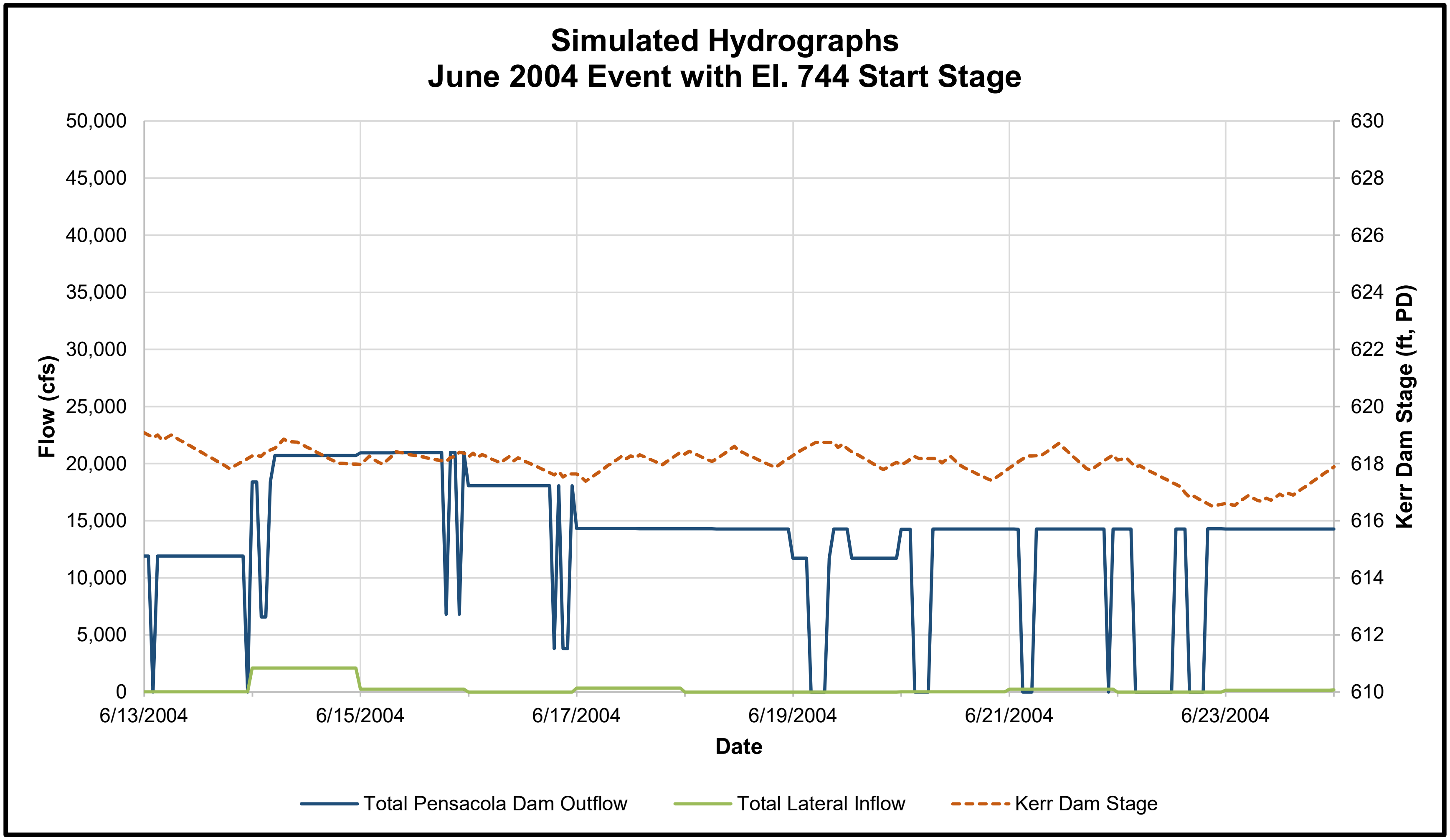


Figure A.8. Simulated hydrograph for the June 2004 event with El. 744 starting stage at Pensacola Dam.

Notes: 1. *The solid blue and green lines are plotted against the left y-axis and represent the Total Pensacola Dam Outflow and Total Lateral Inflow respectively.*
2. *The dashed line is plotted against the right y-axis and represents the stage at Kerr Dam.*

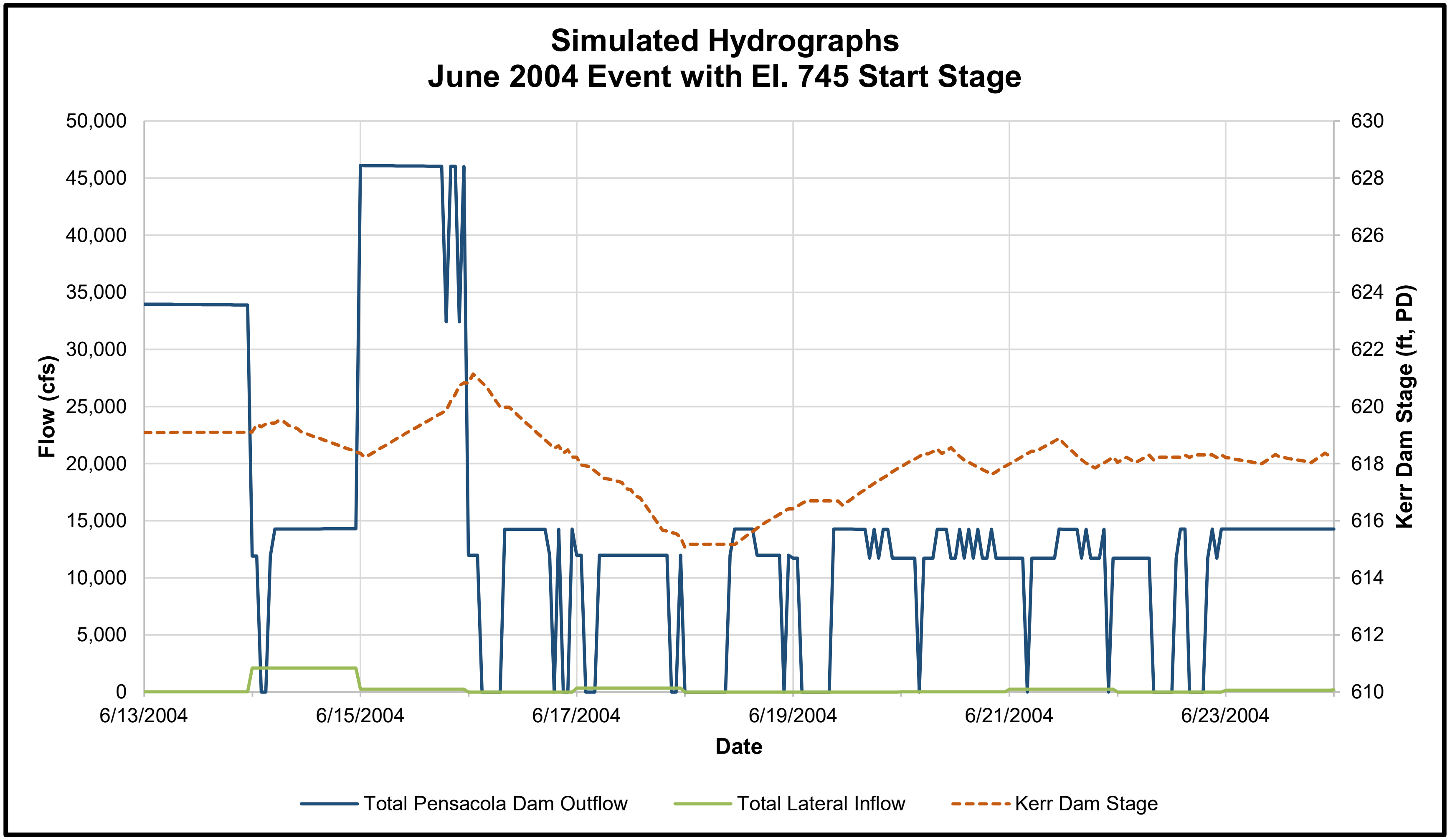


Figure A.9. Simulated hydrograph for the June 2004 event with El. 745 starting stage at Pensacola Dam.

Notes: 1. *The solid blue and green lines are plotted against the left y-axis and represent the Total Pensacola Dam Outflow and Total Lateral Inflow respectively.*
2. *The dashed line is plotted against the right y-axis and represents the stage at Kerr Dam.*

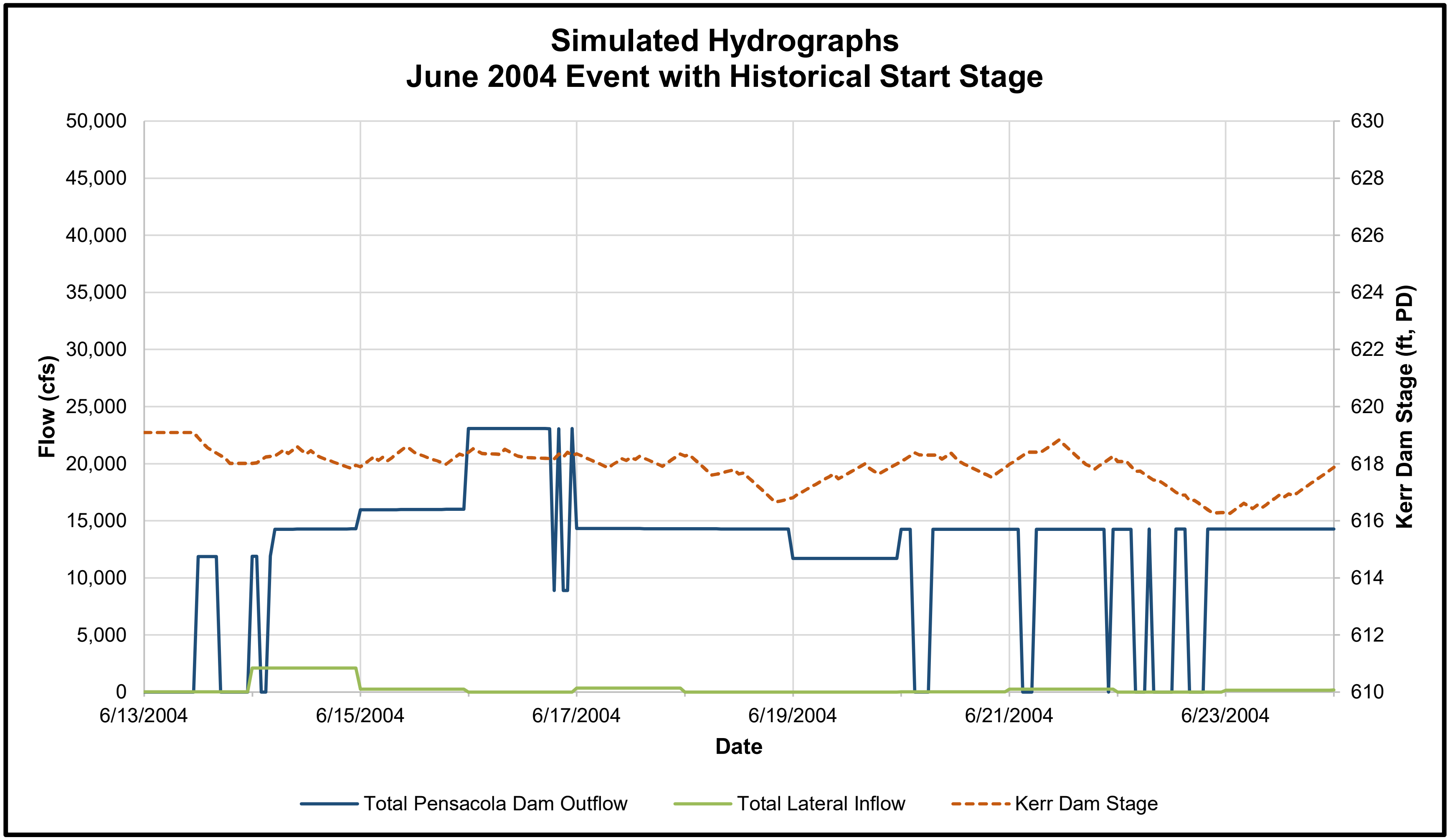


Figure A.10. Simulated hydrograph for the June 2004 event with historical starting stage at Pensacola Dam.

Notes:
1. *The solid blue and green lines are plotted against the left y-axis and represent the Total Pensacola Dam Outflow and Total Lateral Inflow respectively.*
2. *The dashed line is plotted against the right y-axis and represents the stage at Kerr Dam.*

APPENDIX A.3:
JULY 2007 EVENT SIMULATED HYDROGRAPHS

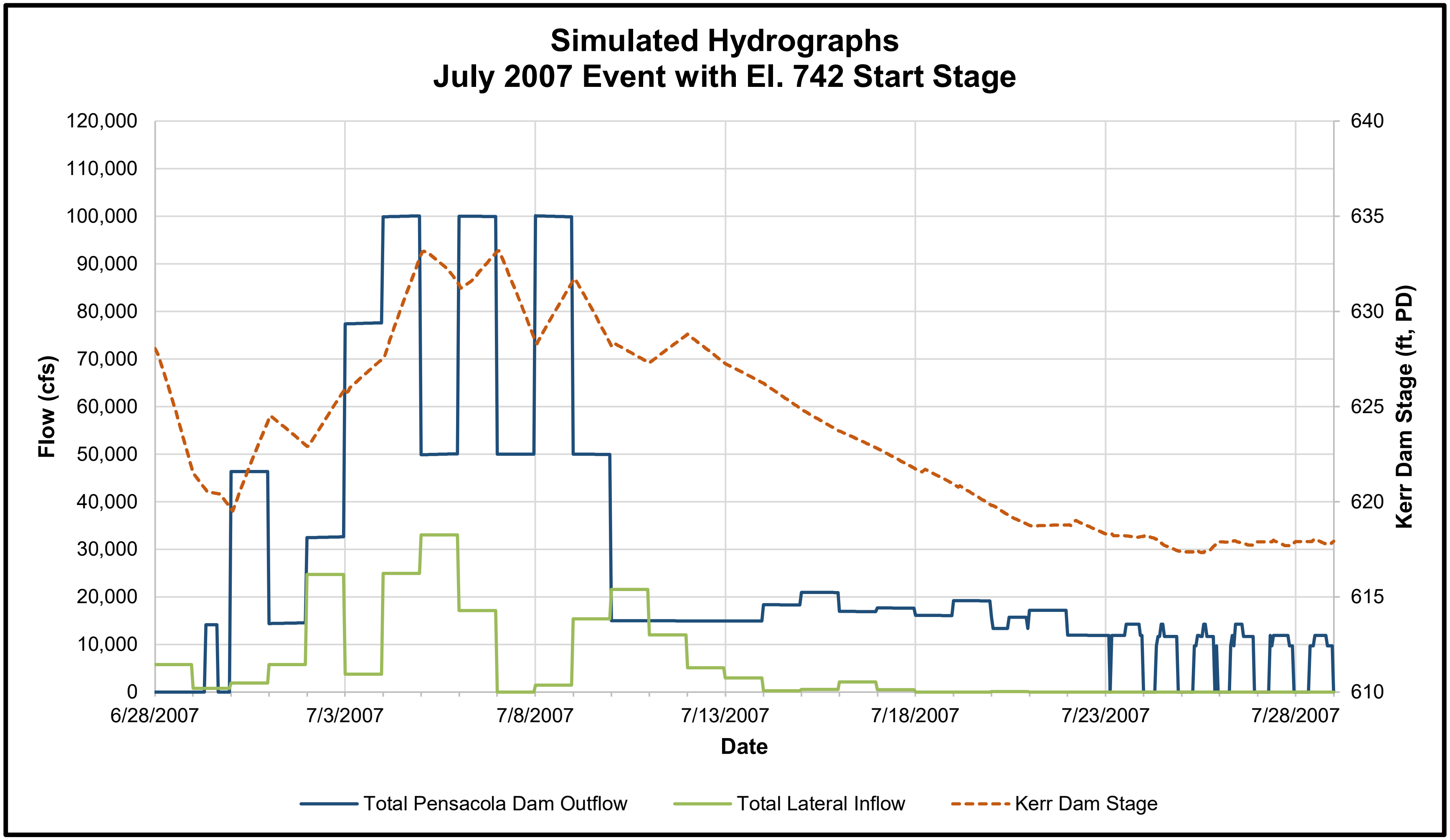


Figure A.11. Simulated hydrograph for the July 2007 event with El. 742 starting stage at Pensacola Dam.

Notes:

1. *The solid blue and green lines are plotted against the left y-axis and represent the Total Pensacola Dam Outflow and Total Lateral Inflow respectively.*
2. *The dashed line is plotted against the right y-axis and represents the stage at Kerr Dam.*

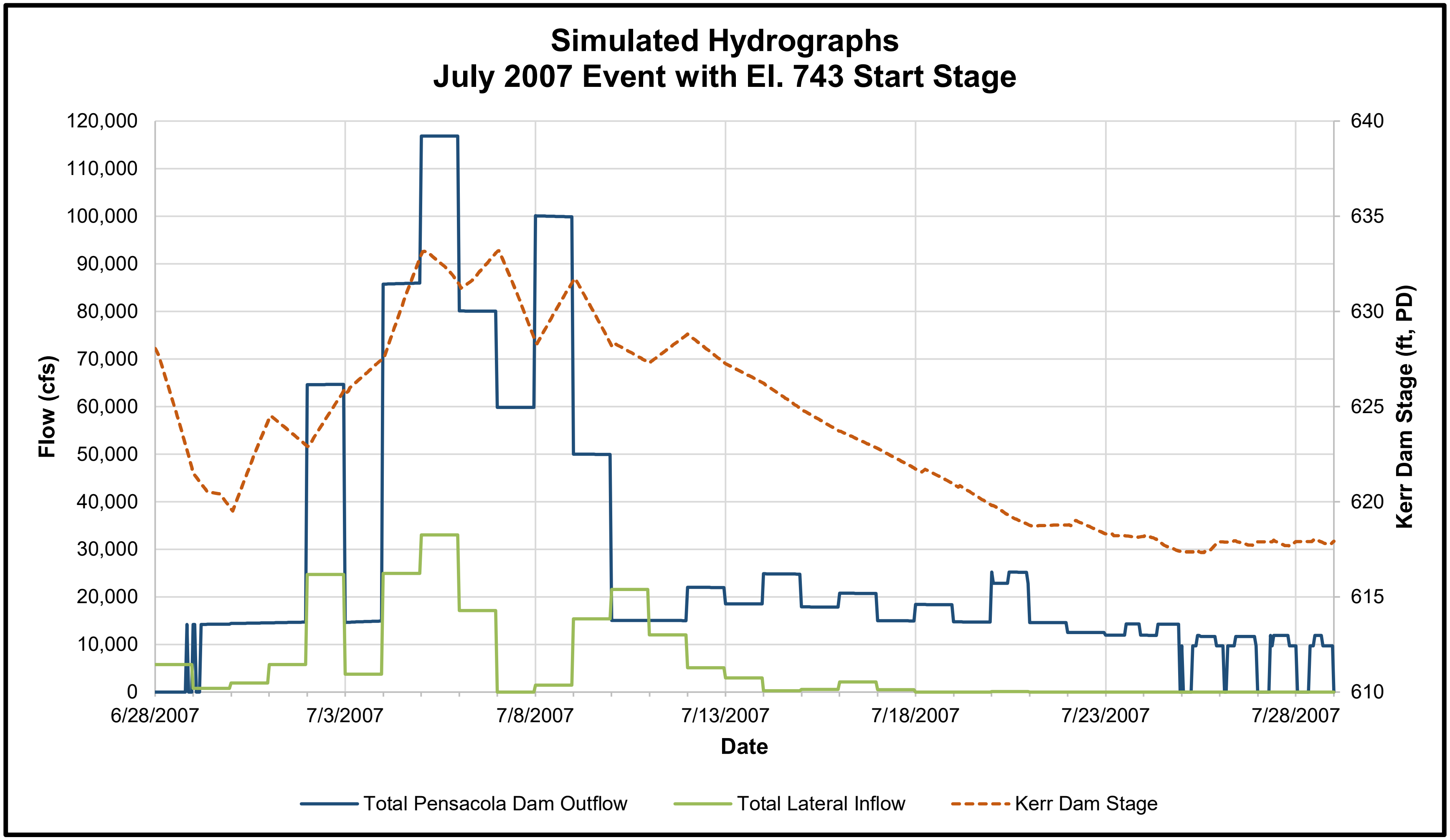


Figure A.12. Simulated hydrograph for the July 2007 event with El. 743 starting stage at Pensacola Dam.

Notes: 1. The solid blue and green lines are plotted against the left y-axis and represent the Total Pensacola Dam Outflow and Total Lateral Inflow respectively.

2. The dashed line is plotted against the right y-axis and represents the stage at Kerr Dam.

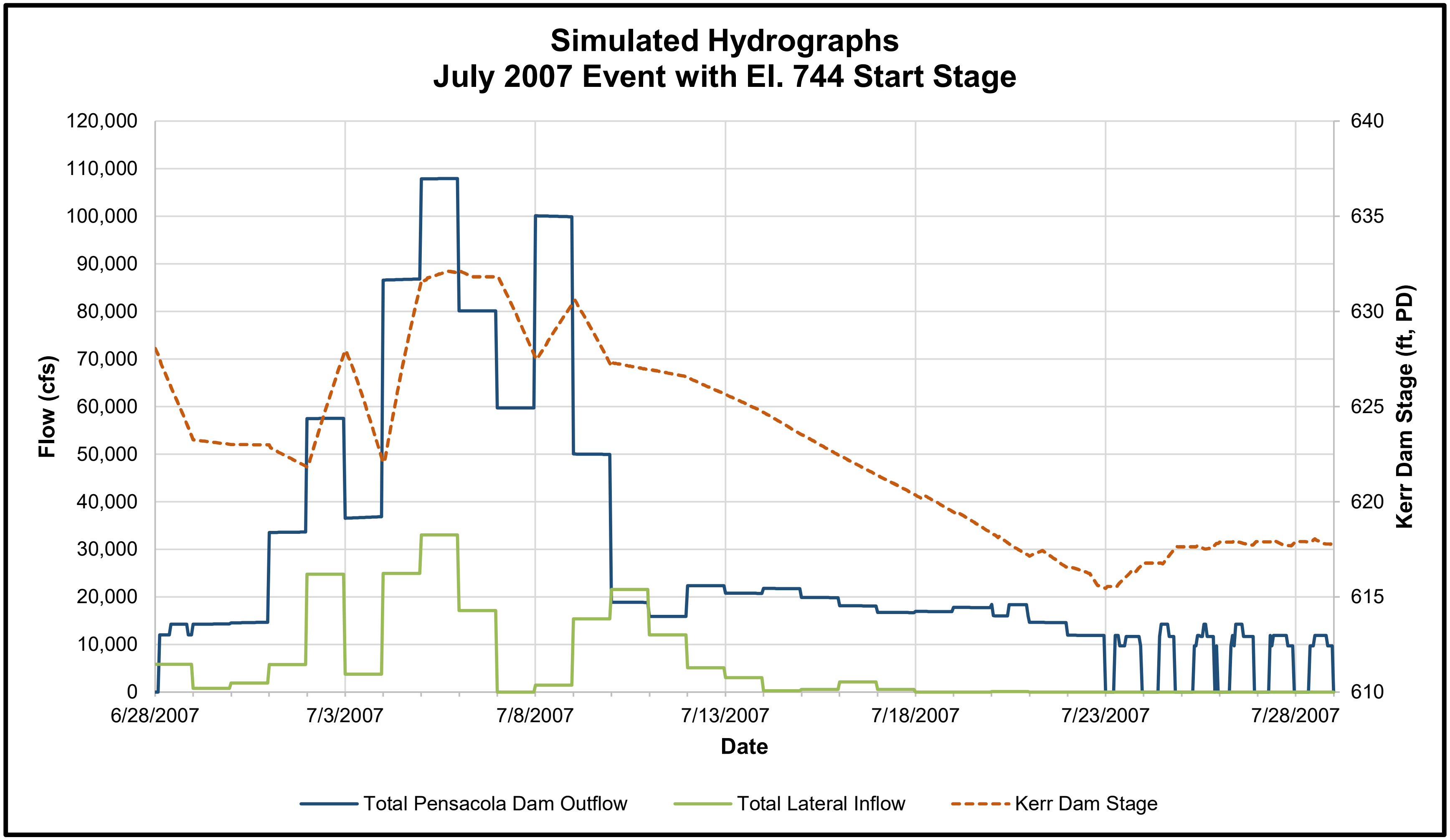


Figure A.13. Simulated hydrograph for the July 2007 event with El. 744 starting stage at Pensacola Dam.

Notes: 1. The solid blue and green lines are plotted against the left y-axis and represent the Total Pensacola Dam Outflow and Total Lateral Inflow respectively.
2. The dashed line is plotted against the right y-axis and represents the stage at Kerr Dam.

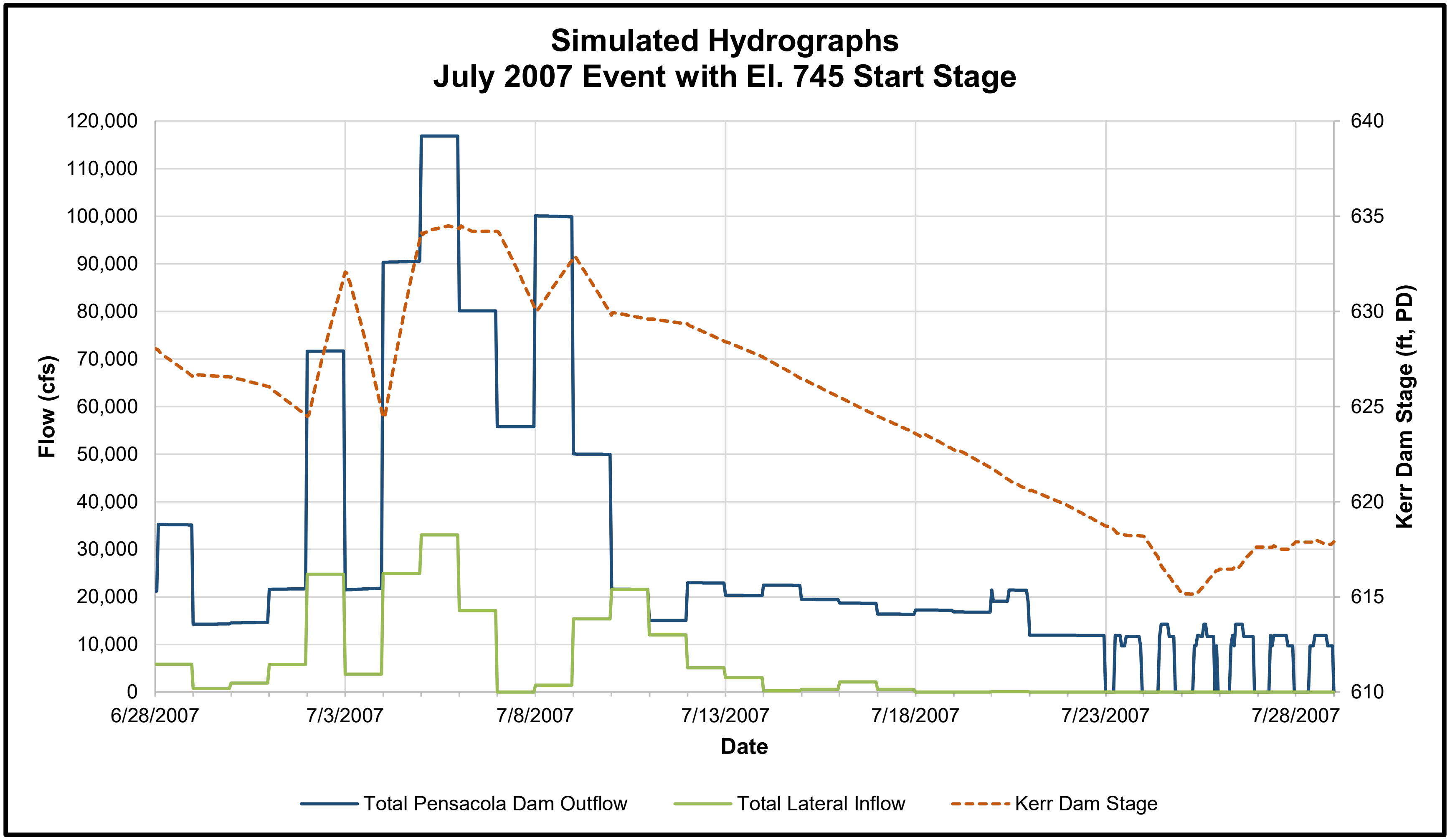


Figure A.14. Simulated hydrograph for the July 2007 event with El. 745 starting stage at Pensacola Dam.

Notes: 1. The solid blue and green lines are plotted against the left y-axis and represent the Total Pensacola Dam Outflow and Total Lateral Inflow respectively.

2. The dashed line is plotted against the right y-axis and represents the stage at Kerr Dam.

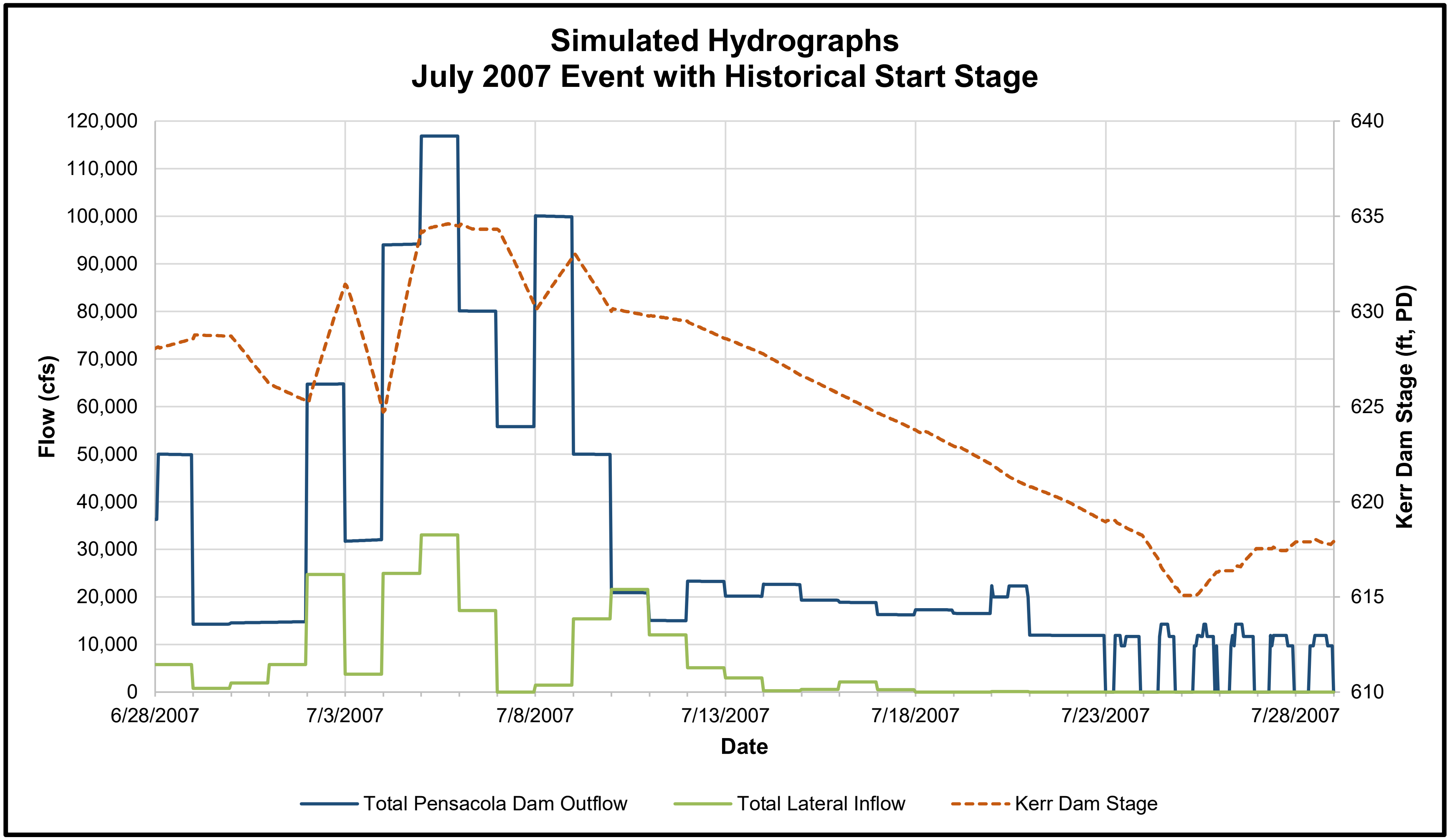


Figure A.15. Simulated hydrograph for the July 2007 event with historical starting stage at Pensacola Dam.

Notes: 1. *The solid blue and green lines are plotted against the left y-axis and represent the Total Pensacola Dam Outflow and Total Lateral Inflow respectively.*
2. *The dashed line is plotted against the right y-axis and represents the stage at Kerr Dam.*

APPENDIX A.4:

OCTOBER 2009 EVENT SIMULATED HYDROGRAPHS

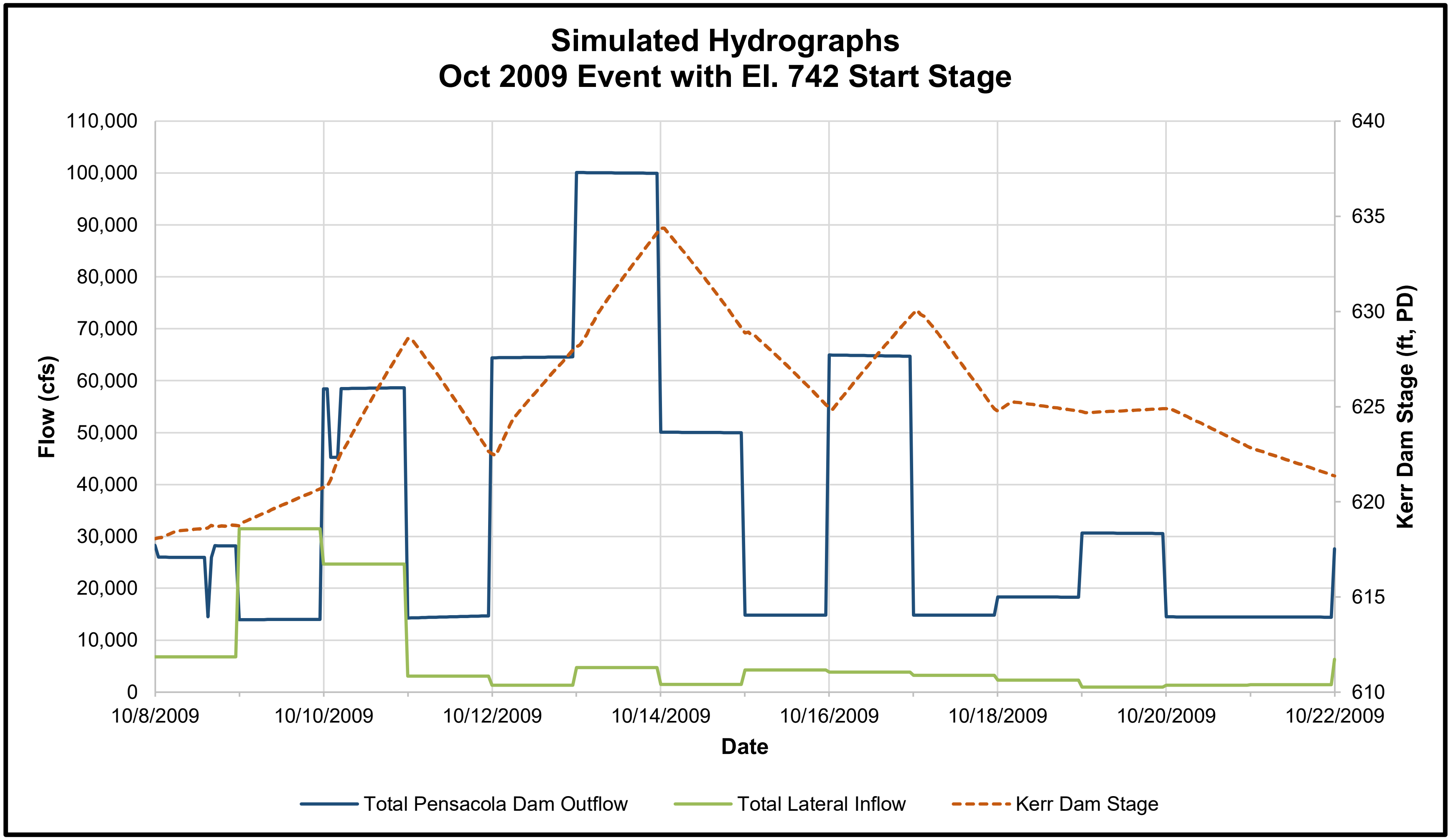


Figure A.16. Simulated hydrograph for the October 2009 event with El. 742 starting stage at Pensacola Dam.

Notes: 1. The solid blue and green lines are plotted against the left y-axis and represent the Total Pensacola Dam Outflow and Total Lateral Inflow respectively.

2. The dashed line is plotted against the right y-axis and represents the stage at Kerr Dam.

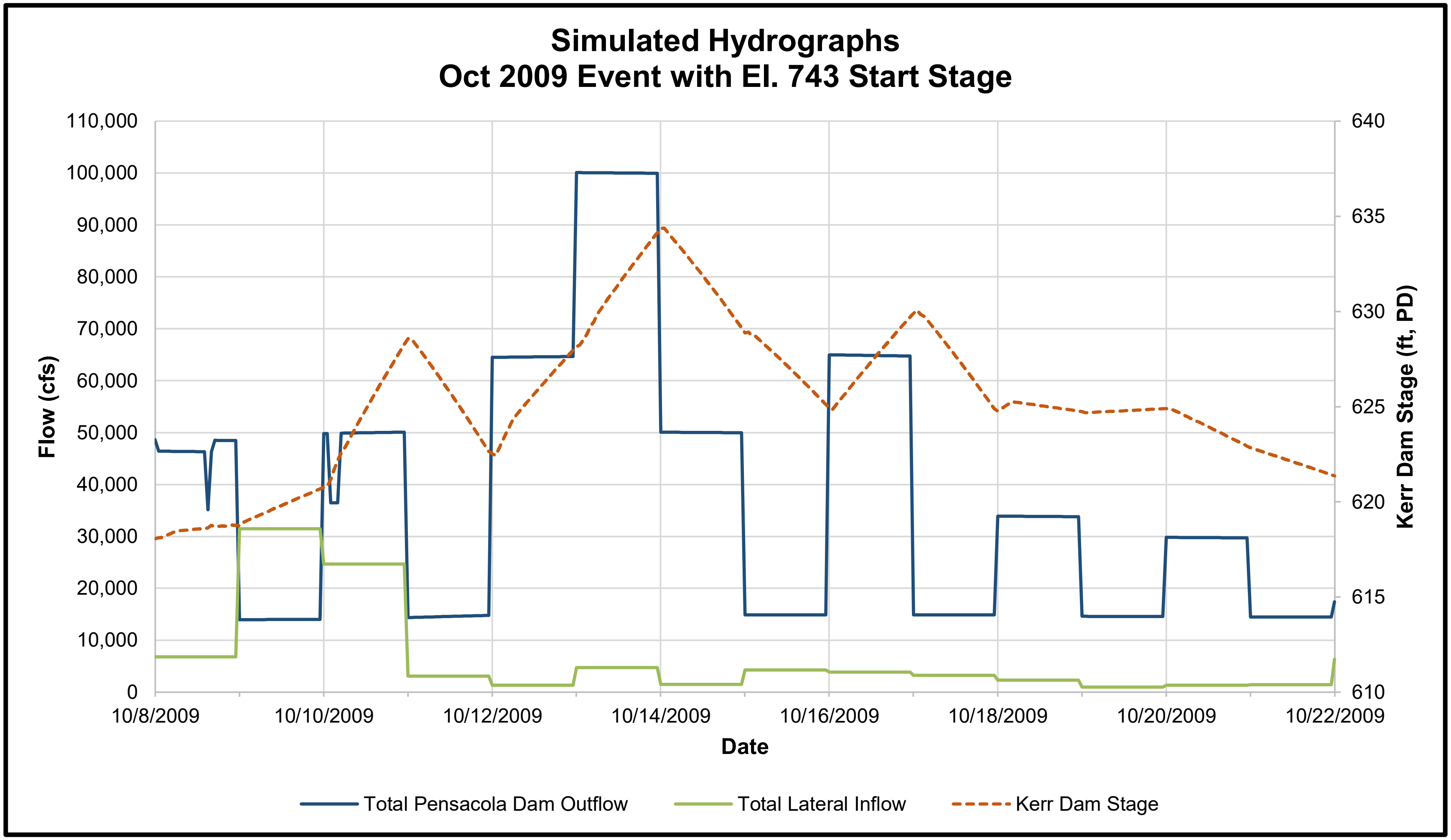


Figure A.17. Simulated hydrograph for the October 2009 event with El. 743 starting stage at Pensacola Dam.

Notes: 1. The solid blue and green lines are plotted against the left y-axis and represent the Total Pensacola Dam Outflow and Total Lateral Inflow respectively.
2. The dashed line is plotted against the right y-axis and represents the stage at Kerr Dam.

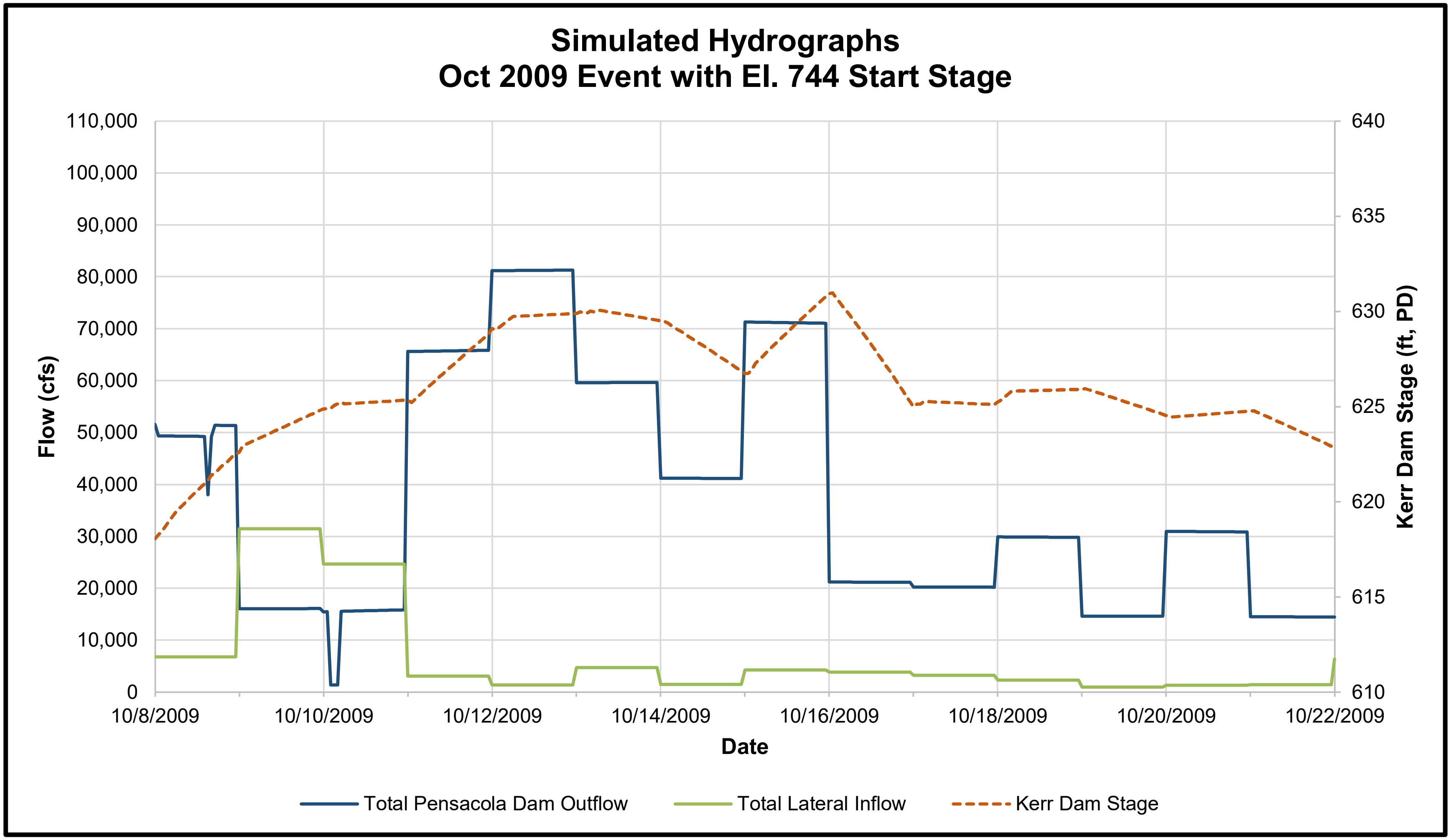


Figure A.18. Simulated hydrograph for the October 2009 event with El. 744 starting stage at Pensacola Dam.

Notes:

1. The solid blue and green lines are plotted against the left y-axis and represent the Total Pensacola Dam Outflow and Total Lateral Inflow respectively.

2. The dashed line is plotted against the right y-axis and represents the stage at Kerr Dam.

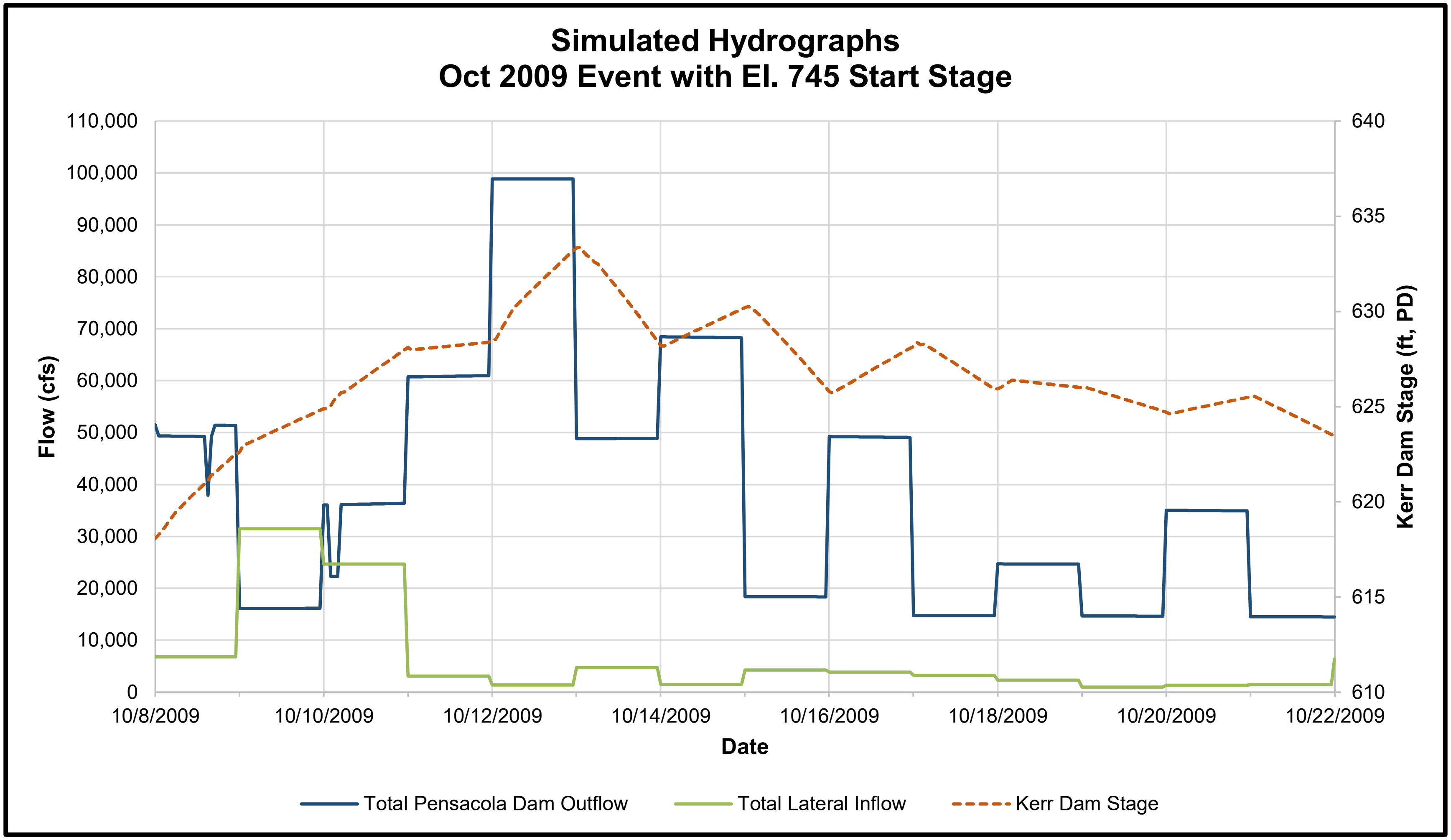


Figure A.19. Simulated hydrograph for the October 2009 event with El. 745 starting stage at Pensacola Dam.

Notes: *1. The solid blue and green lines are plotted against the left y-axis and represent the Total Pensacola Dam Outflow and Total Lateral Inflow respectively.*

2. The dashed line is plotted against the right y-axis and represents the stage at Kerr Dam.

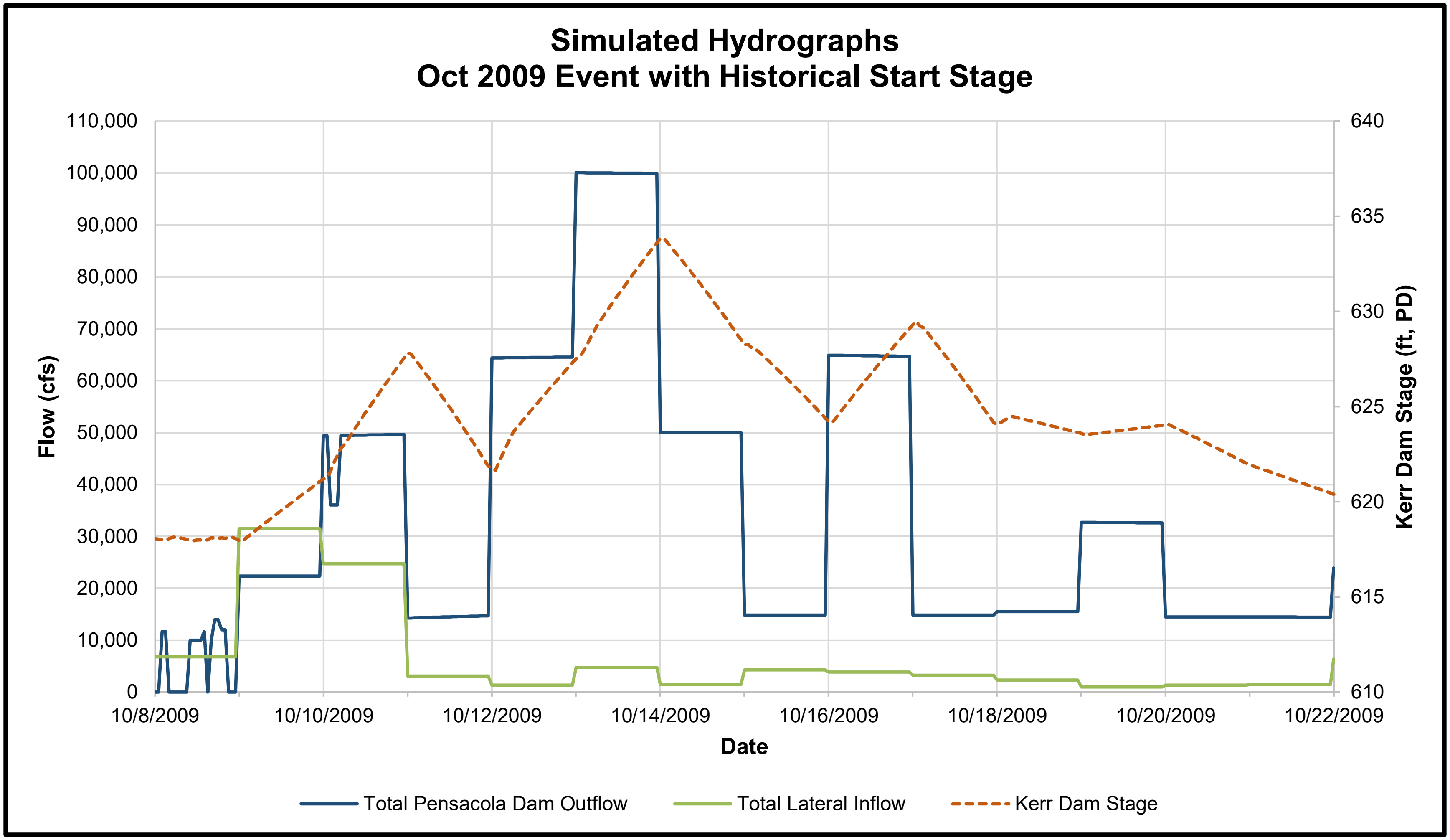


Figure A.20. Simulated hydrograph for the October 2009 event with historical starting stage at Pensacola Dam.

Notes: 1. The solid blue and green lines are plotted against the left y-axis and represent the Total Pensacola Dam Outflow and Total Lateral Inflow respectively.

2. The dashed line is plotted against the right y-axis and represents the stage at Kerr Dam.

APPENDIX A.5:
DECEMBER 2015 EVENT SIMULATED HYDROGRAPHS

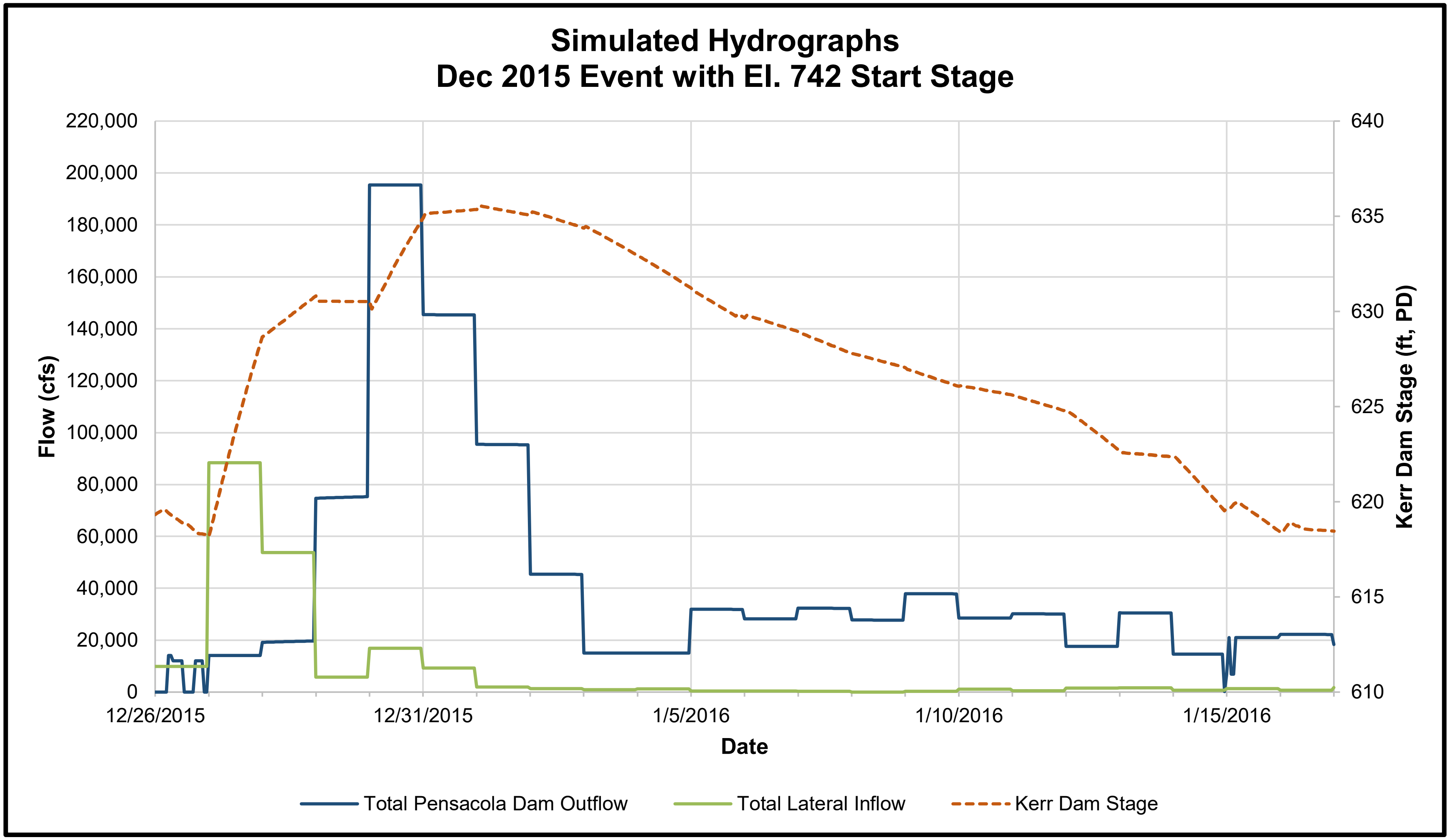


Figure A.21. Simulated hydrograph for the December 2015 event with El. 742 starting stage at Pensacola Dam.

Notes: 1. *The solid blue and green lines are plotted against the left y-axis and represent the Total Pensacola Dam Outflow and Total Lateral Inflow respectively.*
2. *The dashed line is plotted against the right y-axis and represents the stage at Kerr Dam.*

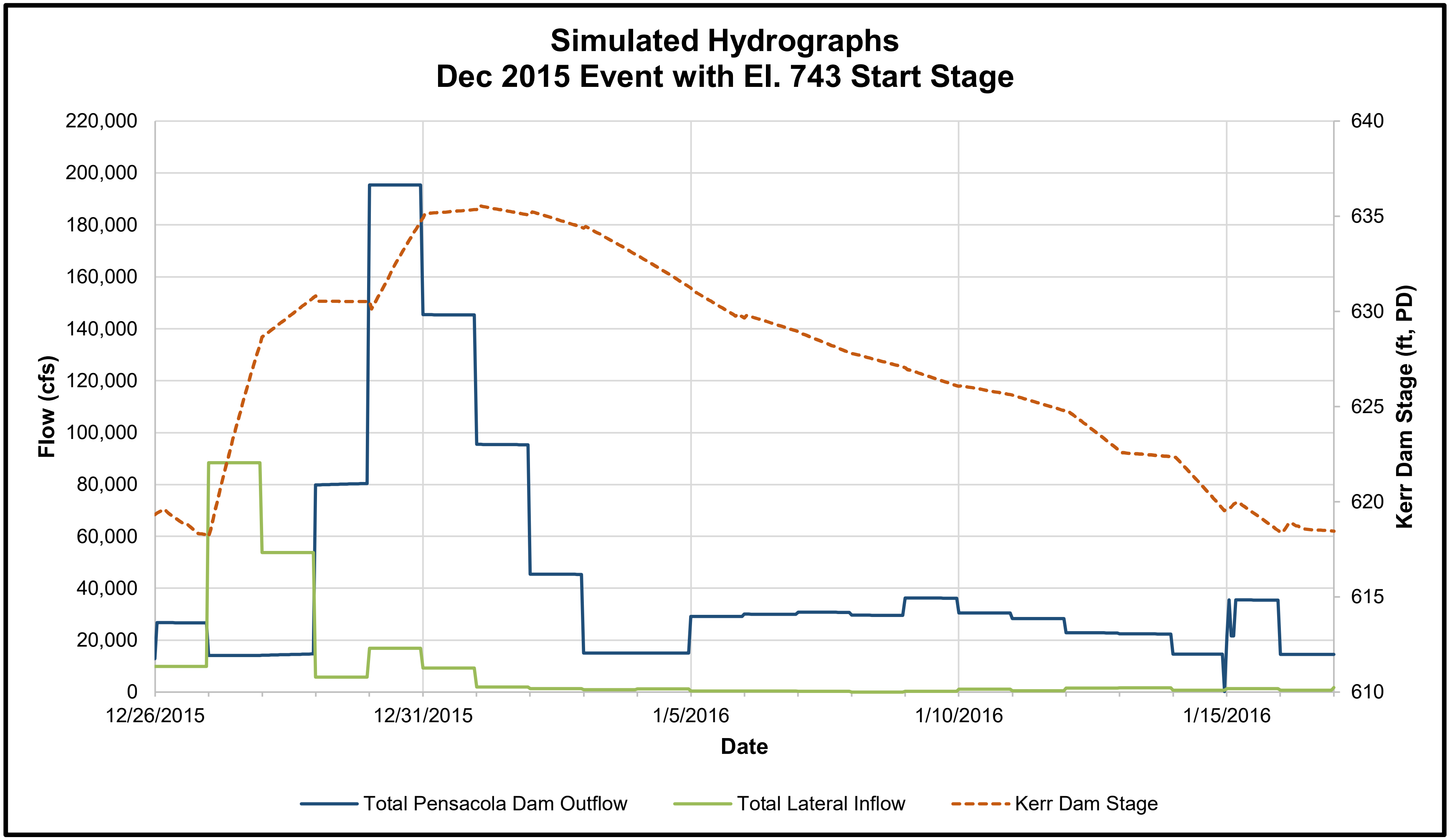


Figure A.22. Simulated hydrograph for the December 2015 event with El. 743 starting stage at Pensacola Dam.

Notes: 1. The solid blue and green lines are plotted against the left y-axis and represent the Total Pensacola Dam Outflow and Total Lateral Inflow respectively.

2. The dashed line is plotted against the right y-axis and represents the stage at Kerr Dam.

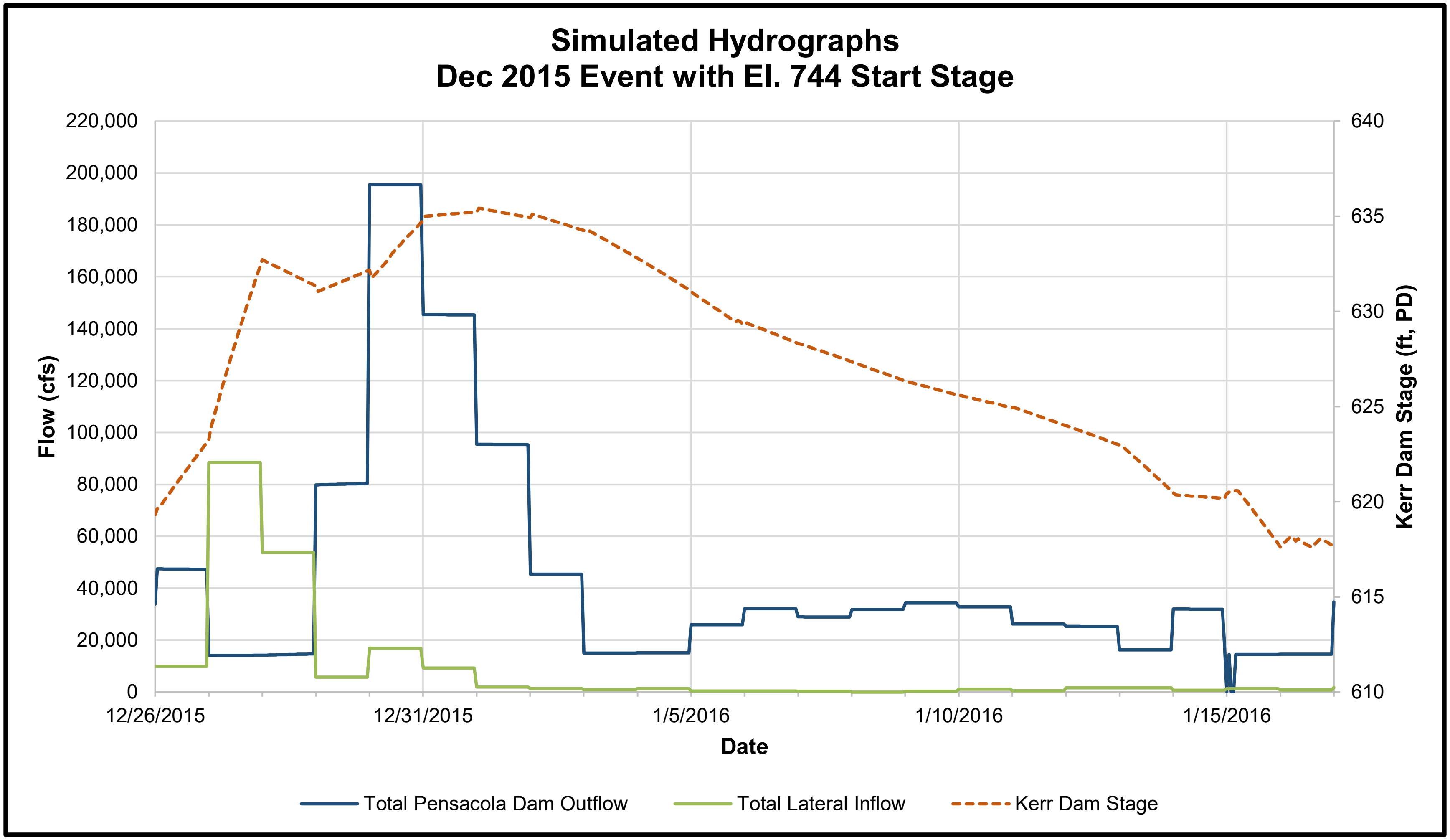


Figure A.23. Simulated hydrograph for the December 2015 event with El. 744 starting stage at Pensacola Dam.

Notes: 1. The solid blue and green lines are plotted against the left y-axis and represent the Total Pensacola Dam Outflow and Total Lateral Inflow respectively.

2. The dashed line is plotted against the right y-axis and represents the stage at Kerr Dam.

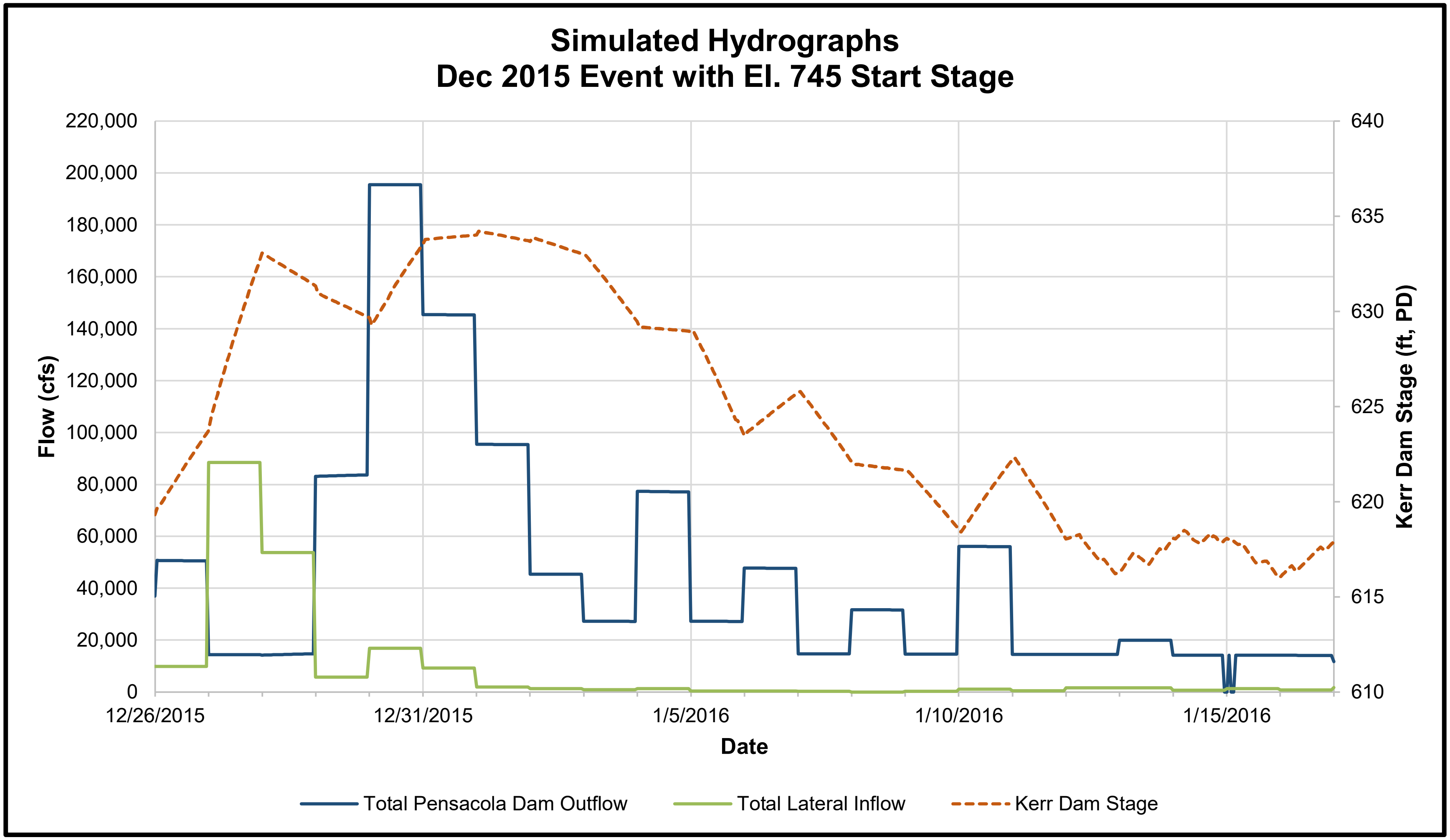


Figure A.24. Simulated hydrograph for the December 2015 event with El. 745 starting stage at Pensacola Dam.

Notes: 1. The solid blue and green lines are plotted against the left y-axis and represent the Total Pensacola Dam Outflow and Total Lateral Inflow respectively.
2. The dashed line is plotted against the right y-axis and represents the stage at Kerr Dam.

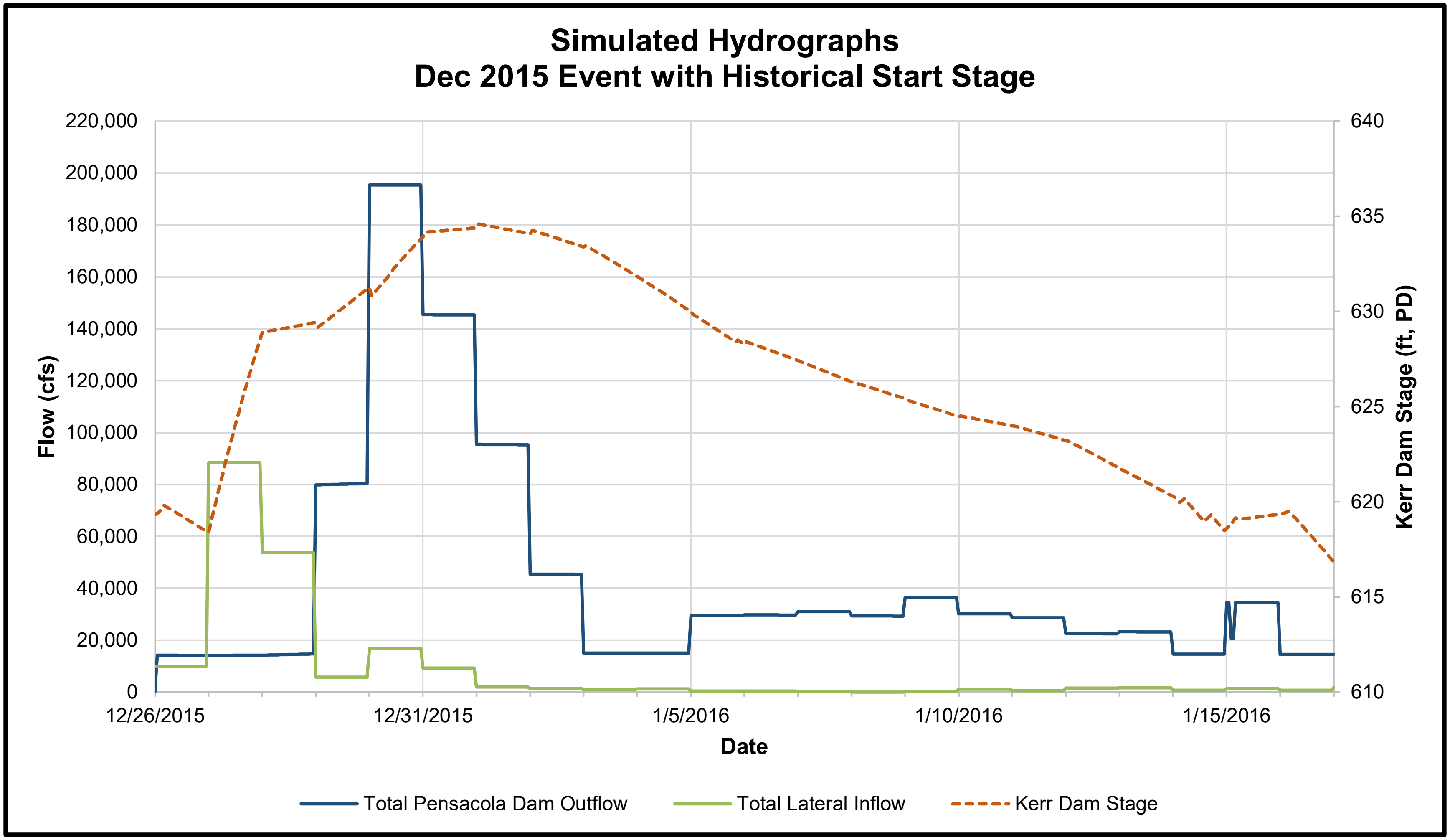


Figure A.25. Simulated hydrograph for the December 2015 event with historical starting stage at Pensacola Dam.

Notes: 1. The solid blue and green lines are plotted against the left y-axis and represent the Total Pensacola Dam Outflow and Total Lateral Inflow respectively.

2. The dashed line is plotted against the right y-axis and represents the stage at Kerr Dam.

APPENDIX A.6:
100-YEAR EVENT SIMULATED HYDROGRAPHS

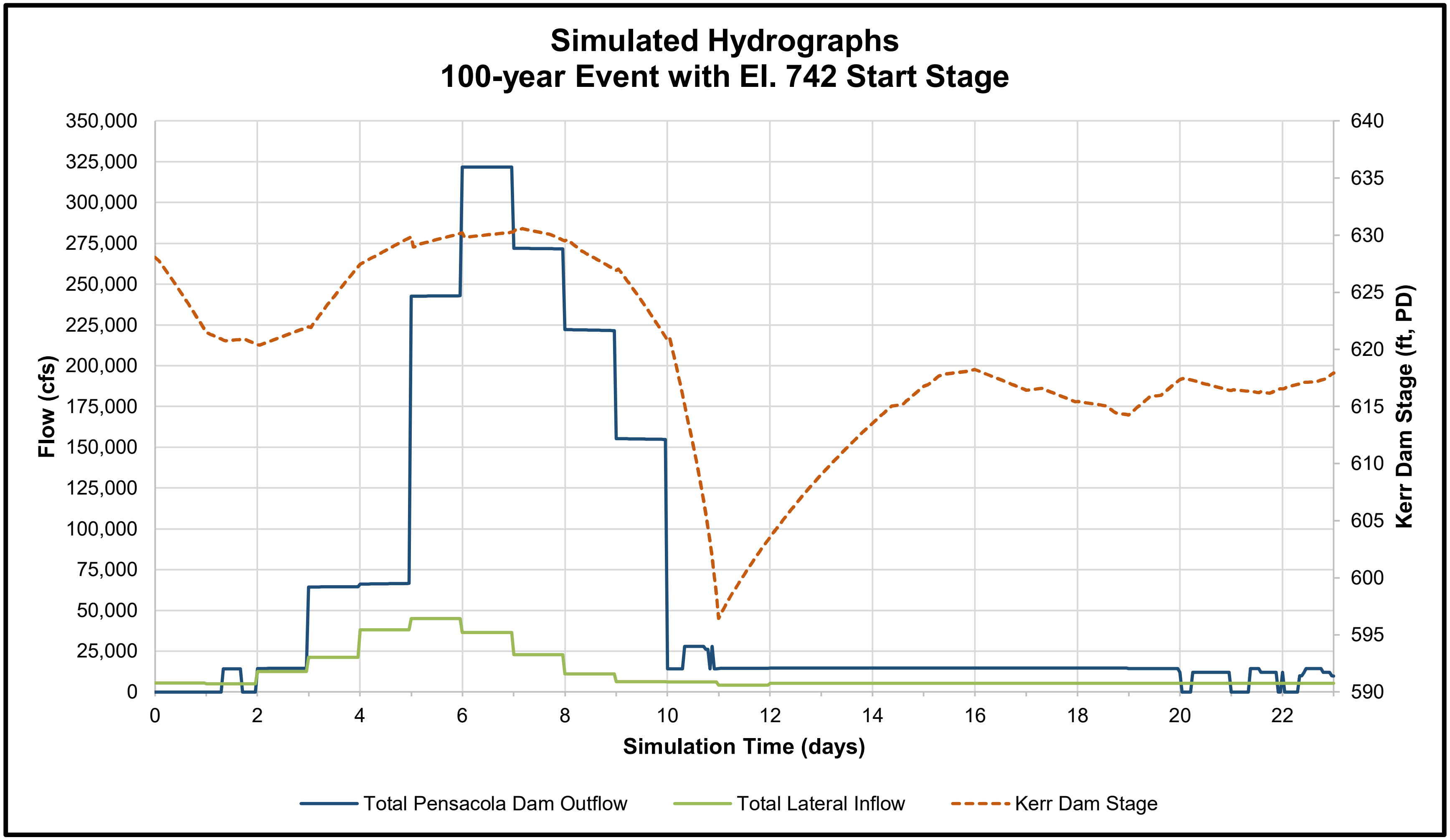


Figure A.26. Simulated hydrograph for the 100-year event with El. 742 starting stage at Pensacola Dam.

Notes: 1. *The solid blue and green lines are plotted against the left y-axis and represent the Total Pensacola Dam Outflow and Total Lateral Inflow respectively.*
2. *The dashed line is plotted against the right y-axis and represents the stage at Kerr Dam.*

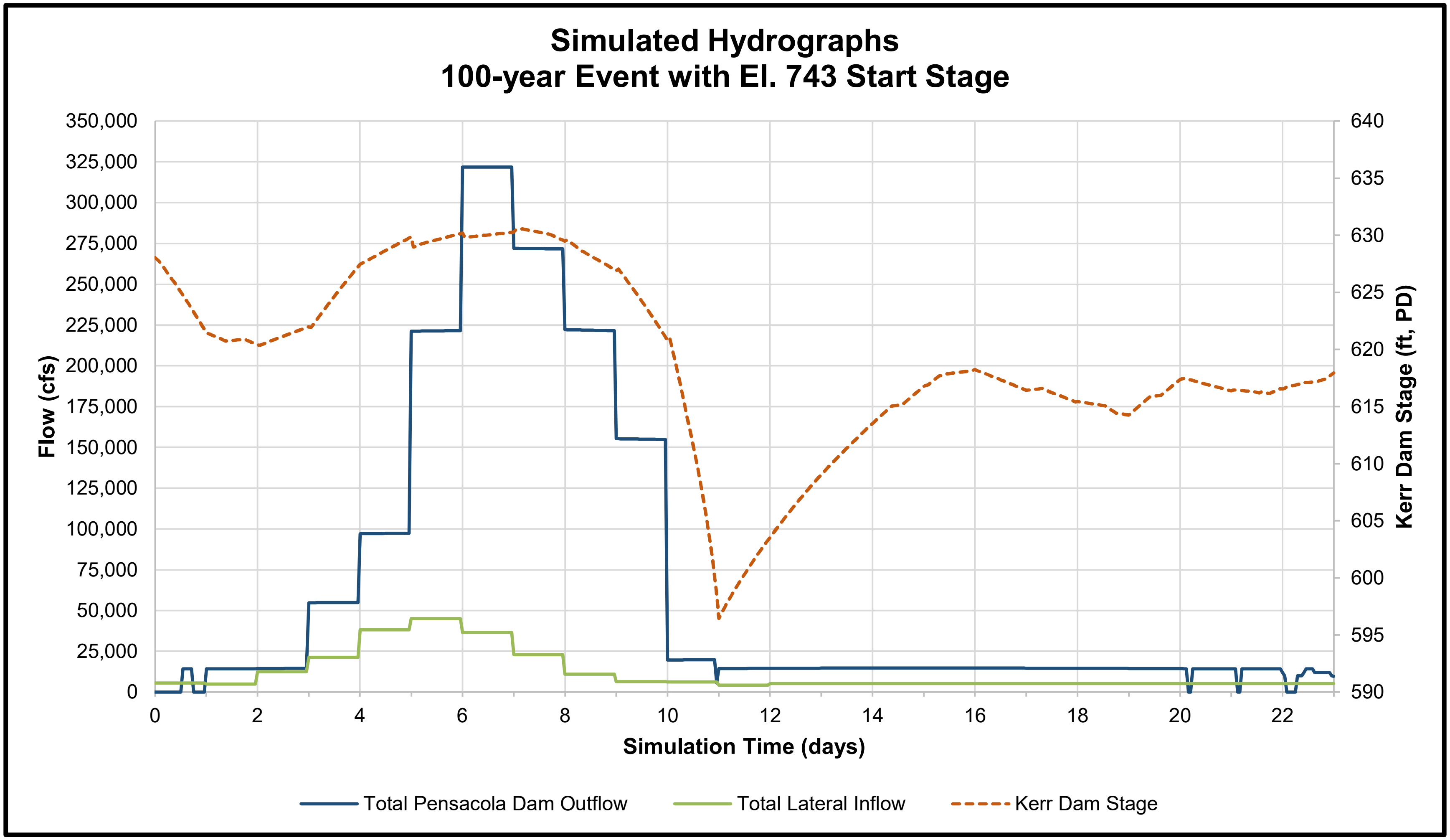


Figure A.27. Simulated hydrograph for the 100-year event with El. 743 starting stage at Pensacola Dam.

Notes: 1. The solid blue and green lines are plotted against the left y-axis and represent the Total Pensacola Dam Outflow and Total Lateral Inflow respectively.
2. The dashed line is plotted against the right y-axis and represents the stage at Kerr Dam.

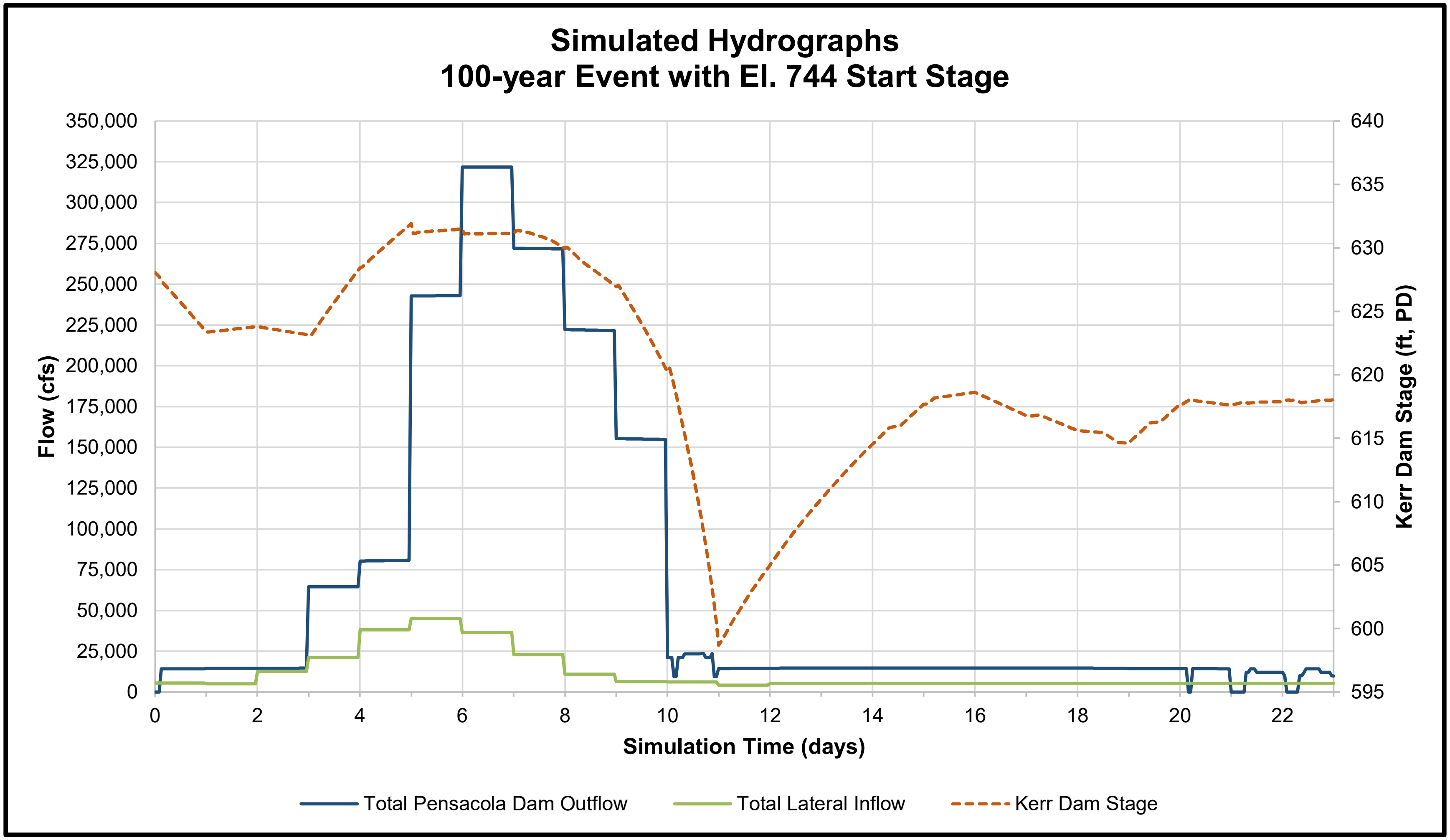


Figure A.28. Simulated hydrograph for the 100-year event with El. 744 starting stage at Pensacola Dam.

Notes: 1. The solid blue and green lines are plotted against the left y-axis and represent the Total Pensacola Dam Outflow and Total Lateral Inflow respectively.
2. The dashed line is plotted against the right y-axis and represents the stage at Kerr Dam.

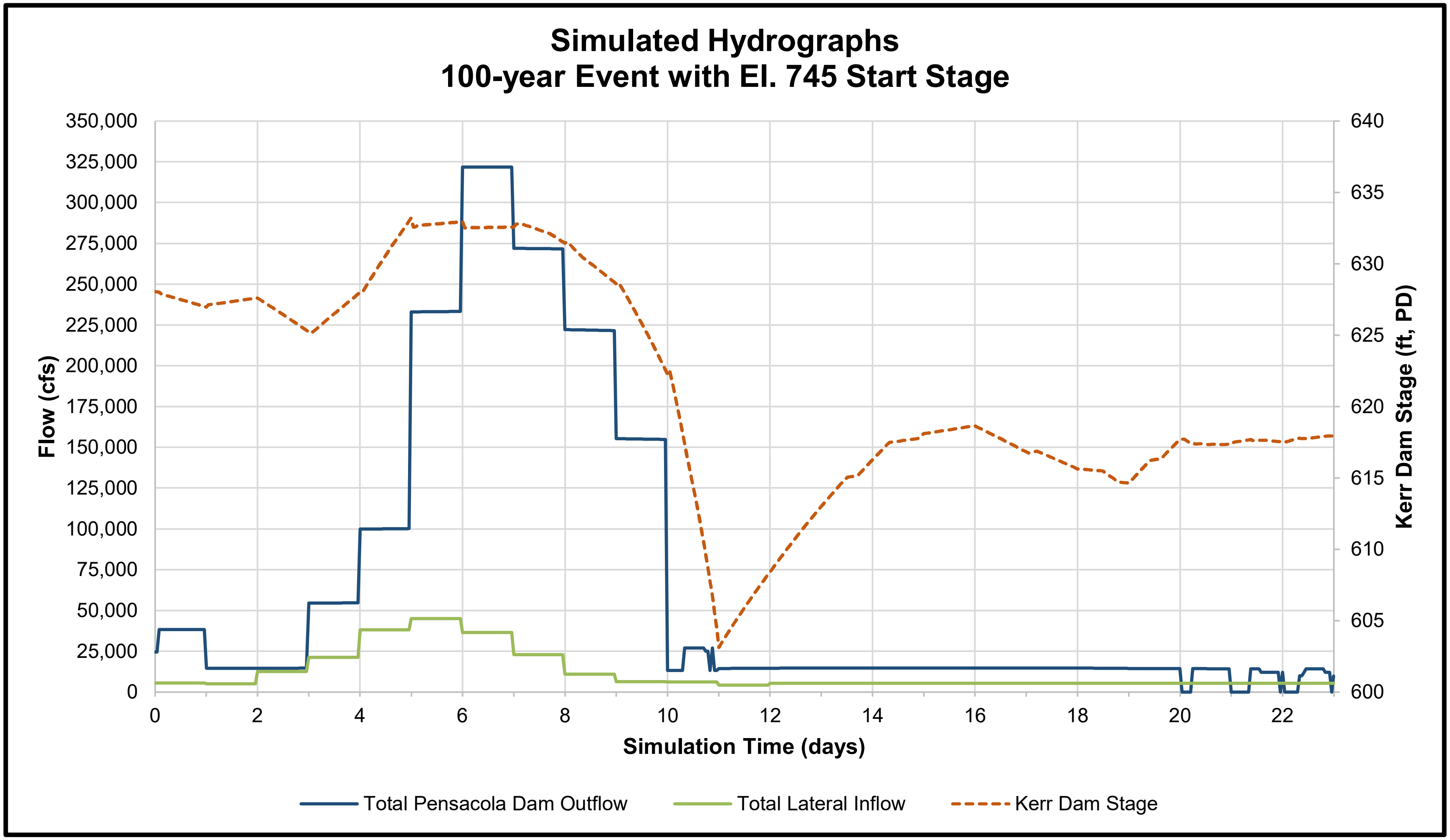
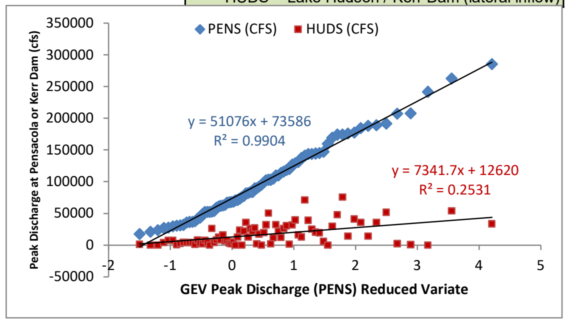


Figure A.29. Simulated hydrograph for the 100-year event with El. 745 starting stage at Pensacola Dam.

Notes: 1. The solid blue and green lines are plotted against the left y-axis and represent the Total Pensacola Dam Outflow and Total Lateral Inflow respectively.
2. The dashed line is plotted against the right y-axis and represents the stage at Kerr Dam.

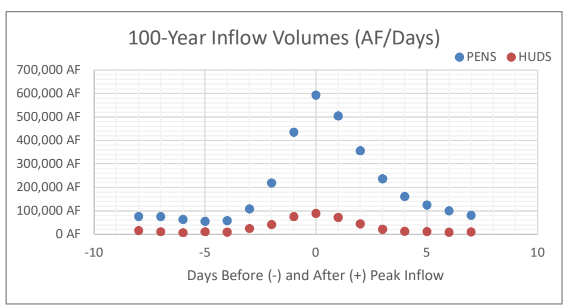
APPENDIX B:
HISTORICAL INFLOW VOLUME STATISTICAL ANALYSIS

PENS = Pensacola Dam / Grand Lake (total inflow)
HUDS = Lake Hudson / Kerr Dam (lateral inflow)

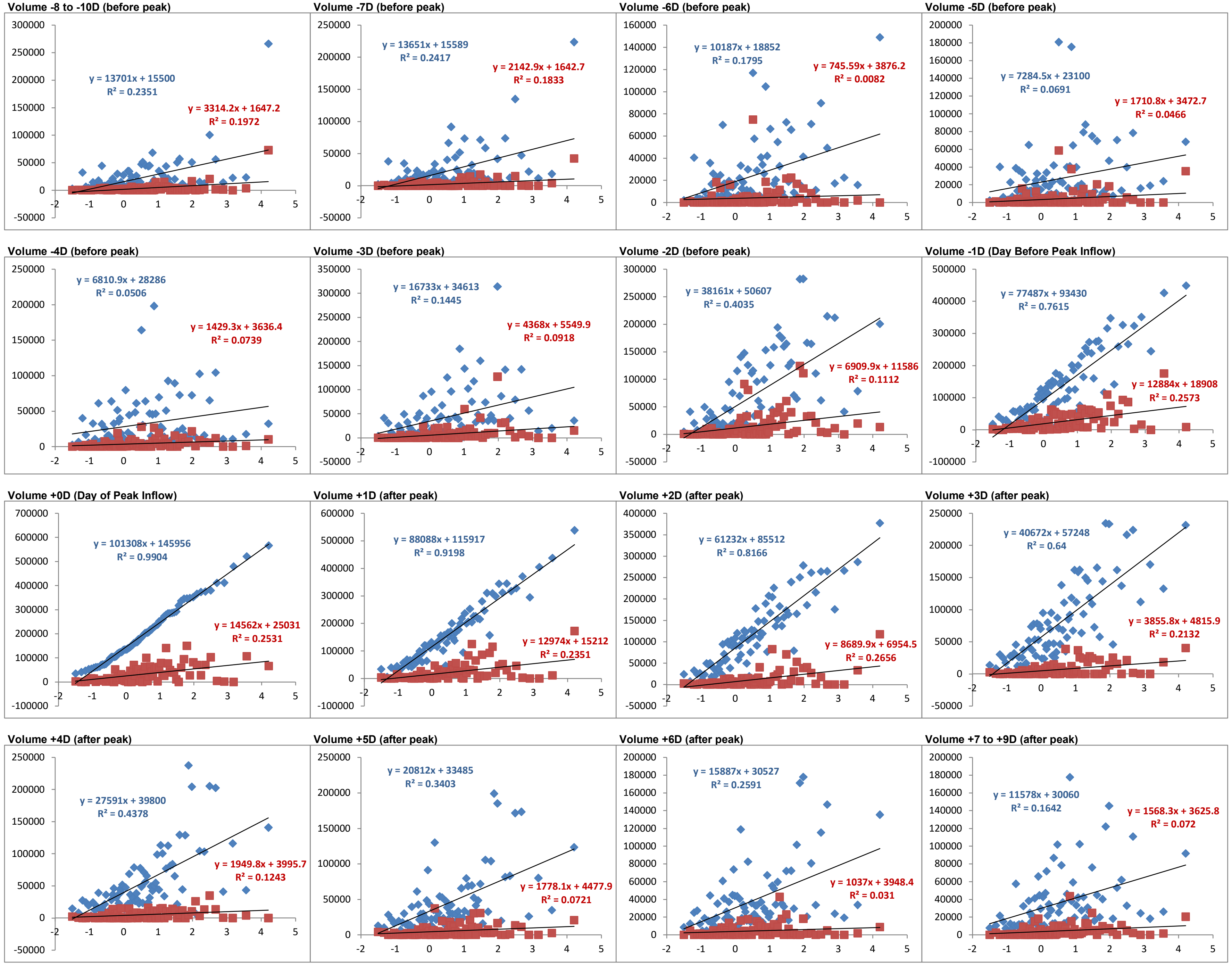


reduced variate for 100-year event, y = 4.41

	scale, σ (m)	location, μ (b)	100-year
PENS (CFS)	51076	73586	299,000 cfs
HUDS (CFS)	7342	12620	45,021 cfs
PENS D–8 to –10 (AF)	13701	15500	75,966 AF
PENS D–7 (AF)	13651	15589	75,835 AF
PENS D–6 (AF)	10187	18852	63,810 AF
PENS D–5 (AF)	7285	23100	55,249 AF
PENS D–4 (AF)	6811	28286	58,344 AF
PENS D–3 (AF)	16733	34613	108,461 AF
PENS D–2 (AF)	38161	50607	219,023 AF
PENS D–1 (AF)	77487	93430	435,403 AF
PENS D+0 (AF)	101308	145956	593,058 AF
PENS D+1 (AF)	88088	115917	504,675 AF
PENS D+2 (AF)	61232	85512	355,747 AF
PENS D+3 (AF)	40672	57248	236,745 AF
PENS D+4 (AF)	27591	39800	161,567 AF
PENS D+5 (AF)	20812	33485	125,334 AF
PENS D+6 (AF)	15887	30527	100,641 AF
PENS D+7 to +9 (AF)	11578	30060	81,157 AF
HUDS D–8 to –10 (AF)	3314	1647	16,274 AF
HUDS D–7 (AF)	2143	1643	11,100 AF
HUDS D–6 (AF)	746	3876	7,167 AF
HUDS D–5 (AF)	1711	3473	11,023 AF
HUDS D–4 (AF)	1429	3636	9,944 AF
HUDS D–3 (AF)	4368	5550	24,827 AF
HUDS D–2 (AF)	6910	11586	42,081 AF
HUDS D–1 (AF)	12884	18908	75,769 AF
HUDS D+0 (AF)	14562	25031	89,297 AF
HUDS D+1 (AF)	12974	15212	72,470 AF
HUDS D+2 (AF)	8690	6955	45,306 AF
HUDS D+3 (AF)	3856	4816	21,833 AF
HUDS D+4 (AF)	1950	3996	12,601 AF
HUDS D+5 (AF)	1778	4478	12,325 AF
HUDS D+6 (AF)	1037	3948	8,525 AF
HUDS D+7 to +9 (AF)	1568	3626	10,547 AF



Average Daily Volume (AF) vs GEV Peak Discharge (PENS) Reduced Variate Correlation Plots



APPENDIX C:
MAX WATER SURFACE ELEVATIONS

PENSACOLA DAM **TABLE C.1**

GRAND RIVER DAM AUTHORITY DOWNSTREAM MODEL MAX WSELs - SEPTEMBER 1993 EVENT

River Mile	Bed El. (ft, PD)	Pensacola Dam Starting Stage (ft, PD)				Max WSEL Difference El. 742 to 745* (ft)
		El. 742 Max WSEL (ft, PD)	El. 743 Max WSEL (ft, PD)	El. 744 Max WSEL (ft, PD)	El. 745 Max WSEL (ft, PD)	
77.000	Pensacola Dam					
76.880	608.88	646.24	646.25	647.77	649.14	2.90
76.463	607.35	646.19	646.21	647.72	649.09	2.90
76.414	N 4475 Rd. Bridge					
76.362	607.61	646.17	646.18	647.69	649.06	2.89
75.317	606.30	645.35	645.37	646.81	648.10	2.75
74.300	605.42	643.64	643.65	644.99	646.16	2.52
73.315	600.08	642.48	642.50	643.75	644.84	2.36
72.884	606.92	641.78	641.80	643.00	644.03	2.25
72.822	OK-82 Bridge					
72.772	604.91	641.43	641.45	642.57	643.65	2.22
71.645	603.05	640.67	640.70	641.79	642.80	2.13
70.910	601.50	639.26	639.29	640.23	641.19	1.93
69.686	599.92	638.38	638.41	639.24	640.13	1.75
68.685	597.81	637.34	637.38	638.03	638.75	1.41
67.715	594.14	636.62	636.66	637.15	637.72	1.10
66.855	592.57	636.14	636.19	636.56	637.01	0.87
66.780	Big Cabin Creek					
65.712	590.99	635.72	635.77	636.03	636.36	0.64
64.435	588.21	635.32	635.38	635.43	635.59	0.27
63.369	585.72	635.05	635.11	635.12	635.19	0.14
63.322	Strang Rd. Bridge					
63.299	587.89	634.99	635.05	635.05	635.12	0.13
62.325	582.59	635.05	635.11	635.12	635.19	0.14
61.308	584.75	635.01	635.07	635.07	635.15	0.14
60.263	582.15	634.98	635.04	635.04	635.13	0.15
60.200	Spavinaw Creek					
59.019	582.85	634.94	635.00	634.99	635.09	0.15
57.950	582.47	634.90	634.96	634.95	635.06	0.16
56.927	576.95	634.87	634.93	634.92	635.04	0.17
55.890	577.05	634.86	634.92	634.91	635.04	0.18
54.456	577.89	634.85	634.91	634.89	635.02	0.17
52.988	572.13	634.78	634.84	634.80	634.95	0.17
52.954	OK-20 Bridge					
52.922	569.25	634.77	634.83	634.79	634.94	0.17
50.500	Saline Creek					
50.396	569.69	634.81	634.87	634.83	634.97	0.16
49.110	562.60	634.81	634.87	634.83	634.96	0.15
48.118	558.27	634.80	634.86	634.82	634.95	0.15
47.186	553.07	634.80	634.86	634.82	634.94	0.14
47.120	Kerr Dam					

*Difference between the highest and lowest Max WSELs from the simulations with El. 742 to El. 745 Pensacola Dam starting stages.

PENSACOLA DAM **TABLE C.2**

GRAND RIVER DAM AUTHORITY DOWNSTREAM MODEL MAX WSELs - JUNE 2004 EVENT

River Mile	Bed El. (ft, PD)	Pensacola Dam Starting Stage (ft, PD)				Max WSEL Difference El. 742 to 745* (ft)
		El. 742 Max WSEL (ft, PD)	El. 743 Max WSEL (ft, PD)	El. 744 Max WSEL (ft, PD)	El. 745 Max WSEL (ft, PD)	
77.000	Pensacola Dam					
76.880	608.88	623.62	625.14	625.06	630.57	6.95
76.463	607.35	623.35	624.95	624.87	630.50	7.15
76.414	N 4475 Rd. Bridge					
76.362	607.61	623.08	624.77	624.70	630.45	7.37
75.317	606.30	622.20	623.99	623.92	629.75	7.55
74.300	605.42	621.70	623.29	623.24	628.72	7.02
73.315	600.08	621.36	622.75	622.72	627.80	6.44
72.884	606.92	621.08	622.33	622.31	627.16	6.08
72.822	OK-82 Bridge					
72.772	604.91	621.00	622.20	622.18	626.96	5.96
71.645	603.05	620.11	620.82	620.91	625.43	5.32
70.910	601.50	619.84	620.30	620.44	624.43	4.59
69.686	599.92	619.52	619.64	619.87	623.20	3.68
68.685	597.81	619.35	619.27	619.53	622.39	3.12
67.715	594.14	619.28	619.20	619.40	622.05	2.85
66.855	592.57	619.23	619.15	619.29	621.76	2.61
66.780	Big Cabin Creek					
65.712	590.99	619.19	619.11	619.21	621.58	2.47
64.435	588.21	619.14	619.09	619.15	621.27	2.18
63.369	585.72	619.12	619.09	619.13	621.26	2.17
63.322	Strang Rd. Bridge					
63.299	587.89	619.12	619.09	619.13	621.26	2.17
62.325	582.59	619.11	619.09	619.12	621.25	2.16
61.308	584.75	619.09	619.09	619.12	621.25	2.16
60.263	582.15	619.09	619.09	619.11	621.24	2.15
60.200	Spavinaw Creek					
59.019	582.85	619.09	619.09	619.10	621.22	2.13
57.950	582.47	619.09	619.09	619.10	621.21	2.12
56.927	576.95	619.09	619.09	619.10	621.21	2.12
55.890	577.05	619.09	619.09	619.10	621.21	2.12
54.456	577.89	619.09	619.09	619.10	621.21	2.12
52.988	572.13	619.09	619.09	619.09	621.20	2.11
52.954	OK-20 Bridge					
52.922	569.25	619.09	619.09	619.09	621.20	2.11
50.500	Saline Creek					
50.396	569.69	619.09	619.09	619.09	621.18	2.09
49.110	562.60	619.09	619.09	619.09	621.16	2.07
48.118	558.27	619.09	619.09	619.09	621.15	2.06
47.186	553.07	619.09	619.09	619.09	621.14	2.05
47.120	Kerr Dam					

*Difference between the highest and lowest Max WSELs from the simulations with El. 742 to El. 745 Pensacola Dam starting stages.

PENSACOLA DAM **TABLE C.3**

GRAND RIVER DAM AUTHORITY DOWNSTREAM MODEL MAX WSELs - JULY 2007 EVENT

River Mile	Bed El. (ft, PD)	Pensacola Dam Starting Stage (ft, PD)				Max WSEL Difference El. 742 to 745* (ft)
		El. 742 Max WSEL (ft, PD)	El. 743 Max WSEL (ft, PD)	El. 744 Max WSEL (ft, PD)	El. 745 Max WSEL (ft, PD)	
77.000	Pensacola Dam					
76.880	608.88	640.98	642.81	641.69	643.23	2.25
76.463	607.35	640.95	642.78	641.65	643.19	2.24
76.414	N 4475 Rd. Bridge					
76.362	607.61	640.93	642.75	641.63	643.16	2.23
75.317	606.30	640.33	642.08	640.98	642.52	2.19
74.300	605.42	639.10	640.66	639.61	641.19	2.09
73.315	600.08	638.30	639.76	638.73	640.35	2.05
72.884	606.92	637.73	639.09	638.08	639.74	2.01
72.822	OK-82 Bridge					
72.772	604.91	637.56	638.89	637.88	639.56	2.00
71.645	603.05	636.95	638.25	637.20	639.00	2.05
70.910	601.50	636.09	637.19	636.19	638.04	1.95
69.686	599.92	635.44	636.44	635.41	637.42	2.01
68.685	597.81	634.83	635.68	634.67	636.75	2.08
67.715	594.14	634.43	635.18	634.18	636.30	2.12
66.855	592.57	634.14	634.81	633.81	635.99	2.18
66.780	Big Cabin Creek					
65.712	590.99	633.87	634.39	633.38	635.61	2.23
64.435	588.21	633.56	633.95	632.91	635.21	2.30
63.369	585.72	633.32	633.63	632.54	634.86	2.32
63.322	Strang Rd. Bridge					
63.299	587.89	633.31	633.61	632.53	634.82	2.29
62.325	582.59	633.35	633.64	632.57	634.89	2.32
61.308	584.75	633.31	633.58	632.50	634.83	2.33
60.263	582.15	633.30	633.54	632.46	634.80	2.34
60.200	Spavinaw Creek					
59.019	582.85	633.26	633.46	632.38	634.73	2.35
57.950	582.47	633.24	633.41	632.32	634.67	2.35
56.927	576.95	633.22	633.36	632.27	634.63	2.36
55.890	577.05	633.22	633.34	632.25	634.61	2.36
54.456	577.89	633.21	633.30	632.22	634.59	2.37
52.988	572.13	633.17	633.21	632.11	634.47	2.36
52.954	OK-20 Bridge					
52.922	569.25	633.16	633.20	632.09	634.46	2.37
50.500	Saline Creek					
50.396	569.69	633.19	633.21	632.14	634.51	2.37
49.110	562.60	633.19	633.19	632.13	634.50	2.37
48.118	558.27	633.19	633.19	632.12	634.49	2.37
47.186	553.07	633.19	633.19	632.11	634.48	2.37
47.120	Kerr Dam					

*Difference between the highest and lowest Max WSELs from the simulations with El. 742 to El. 745 Pensacola Dam starting stages.

River Mile	Bed El. (ft, PD)	Pensacola Dam Starting Stage (ft, PD)				Max WSEL Difference El. 742 to 745* (ft)
		El. 742 Max WSEL (ft, PD)	El. 743 Max WSEL (ft, PD)	El. 744 Max WSEL (ft, PD)	El. 745 Max WSEL (ft, PD)	
77.000	Pensacola Dam					
76.880	608.88	641.13	641.13	638.02	640.75	3.11
76.463	607.35	641.10	641.10	637.99	640.72	3.11
76.414	N 4475 Rd. Bridge					
76.362	607.61	641.08	641.08	637.97	640.70	3.11
75.317	606.30	640.50	640.50	637.39	640.10	3.11
74.300	605.42	639.32	639.32	636.27	638.88	3.05
73.315	600.08	638.58	638.58	635.33	638.08	3.25
72.884	606.92	638.04	638.04	634.76	637.51	3.28
72.822	OK-82 Bridge					
72.772	604.91	637.88	637.88	634.60	637.34	3.28
71.645	603.05	637.34	637.34	633.82	636.73	3.52
70.910	601.50	636.56	636.56	632.98	635.89	3.58
69.686	599.92	636.01	636.01	632.32	635.26	3.69
68.685	597.81	635.49	635.49	631.86	634.68	3.63
67.715	594.14	635.17	635.17	631.61	634.32	3.56
66.855	592.57	634.97	634.97	631.43	634.09	3.54
66.780	Big Cabin Creek					
65.712	590.99	634.81	634.81	631.30	633.89	3.51
64.435	588.21	634.64	634.64	631.15	633.68	3.49
63.369	585.72	634.53	634.53	631.06	633.53	3.47
63.322	Strang Rd. Bridge					
63.299	587.89	634.52	634.52	631.05	633.52	3.47
62.325	582.59	634.56	634.56	631.08	633.56	3.48
61.308	584.75	634.55	634.55	631.07	633.54	3.48
60.263	582.15	634.54	634.54	631.07	633.53	3.47
60.200	Spavinaw Creek					
59.019	582.85	634.52	634.52	631.06	633.50	3.46
57.950	582.47	634.50	634.50	631.05	633.48	3.45
56.927	576.95	634.48	634.48	631.04	633.46	3.44
55.890	577.05	634.48	634.48	631.03	633.45	3.45
54.456	577.89	634.46	634.46	631.02	633.44	3.44
52.988	572.13	634.42	634.42	630.99	633.39	3.43
52.954	OK-20 Bridge					
52.922	569.25	634.41	634.41	630.98	633.38	3.43
50.500	Saline Creek					
50.396	569.69	634.40	634.40	630.98	633.38	3.42
49.110	562.60	634.39	634.39	630.97	633.37	3.42
48.118	558.27	634.38	634.38	630.96	633.36	3.42
47.186	553.07	634.37	634.37	630.96	633.36	3.41
47.120	Kerr Dam					

*Difference between the highest and lowest Max WSELs from the simulations with El. 742 to El. 745 Pensacola Dam starting stages.

PENSACOLA DAM **TABLE C.5**

GRAND RIVER DAM AUTHORITY DOWNSTREAM MODEL MAX WSELs - DECEMBER 2015 EVENT

River Mile	Bed El. (ft, PD)	Pensacola Dam Starting Stage (ft, PD)				Max WSEL Difference El. 742 to 745* (ft)
		El. 742 Max WSEL (ft, PD)	El. 743 Max WSEL (ft, PD)	El. 744 Max WSEL (ft, PD)	El. 745 Max WSEL (ft, PD)	
77.000	Pensacola Dam					
76.880	608.88	649.09	649.09	649.11	648.98	0.13
76.463	607.35	649.04	649.04	649.06	648.92	0.14
76.414	N 4475 Rd. Bridge					
76.362	607.61	649.01	649.01	649.03	648.89	0.14
75.317	606.30	648.07	648.07	648.09	647.94	0.15
74.300	605.42	646.18	646.18	646.21	646.01	0.20
73.315	600.08	644.90	644.90	644.93	644.69	0.24
72.884	606.92	644.12	644.12	644.15	643.88	0.27
72.822	OK-82 Bridge					
72.772	604.91	643.81	643.81	643.86	643.42	0.44
71.645	603.05	642.96	642.96	643.00	642.62	0.38
70.910	601.50	641.47	641.47	641.52	640.97	0.55
69.686	599.92	640.52	640.52	640.56	639.89	0.67
68.685	597.81	639.23	639.23	639.27	638.48	0.79
67.715	594.14	638.29	638.29	638.32	637.42	0.90
66.855	592.57	637.65	637.65	637.66	636.67	0.99
66.780	Big Cabin Creek					
65.712	590.99	636.99	636.99	636.97	635.91	1.08
64.435	588.21	636.27	636.27	636.20	635.01	1.26
63.369	585.72	635.90	635.90	635.75	634.42	1.48
63.322	Strang Rd. Bridge					
63.299	587.89	635.72	635.72	635.58	634.41	1.31
62.325	582.59	635.80	635.80	635.67	634.48	1.32
61.308	584.75	635.74	635.74	635.61	634.43	1.31
60.263	582.15	635.72	635.72	635.59	634.41	1.31
60.200	Spavinaw Creek					
59.019	582.85	635.69	635.69	635.56	634.37	1.32
57.950	582.47	635.66	635.66	635.53	634.34	1.32
56.927	576.95	635.64	635.64	635.51	634.31	1.33
55.890	577.05	635.63	635.63	635.51	634.31	1.32
54.456	577.89	635.62	635.62	635.50	634.29	1.33
52.988	572.13	635.55	635.55	635.42	634.22	1.33
52.954	OK-20 Bridge					
52.922	569.25	635.54	635.54	635.41	634.20	1.34
50.500	Saline Creek					
50.396	569.69	635.57	635.57	635.45	634.24	1.33
49.110	562.60	635.57	635.57	635.44	634.23	1.34
48.118	558.27	635.56	635.56	635.43	634.22	1.34
47.186	553.07	635.55	635.55	635.42	634.21	1.34
47.120	Kerr Dam					

*Difference between the highest and lowest Max WSELs from the simulations with El. 742 to El. 745 Pensacola Dam starting stages.

River Mile	Bed El. (ft, PD)	Pensacola Dam Starting Stage (ft, PD)				Max WSEL Difference El. 742 to 745* (ft)
		El. 742 Max WSEL (ft, PD)	El. 743 Max WSEL (ft, PD)	El. 744 Max WSEL (ft, PD)	El. 745 Max WSEL (ft, PD)	
77.000	Pensacola Dam					
76.880	608.88	656.13	656.13	656.16	656.22	0.09
76.463	607.35	656.07	656.07	656.10	656.15	0.08
76.414	N 4475 Rd. Bridge					
76.362	607.61	656.03	656.03	656.06	656.11	0.08
75.317	606.30	654.70	654.70	654.73	654.79	0.09
74.300	605.42	652.36	652.36	652.40	652.49	0.13
73.315	600.08	650.70	650.70	650.76	650.87	0.17
72.884	606.92	649.89	649.89	649.95	650.07	0.18
72.822	OK-82 Bridge					
72.772	604.91	649.05	649.05	649.13	649.28	0.23
71.645	603.05	648.05	648.05	648.15	648.33	0.28
70.910	601.50	646.56	646.56	646.69	646.94	0.38
69.686	599.92	645.33	645.33	645.49	645.79	0.46
68.685	597.81	643.22	643.22	643.43	643.80	0.58
67.715	594.14	641.43	641.43	641.69	642.15	0.72
66.855	592.57	640.01	640.01	640.32	640.88	0.87
66.780	Big Cabin Creek					
65.712	590.99	638.21	638.21	638.58	639.25	1.04
64.435	588.21	635.83	635.83	636.35	637.26	1.43
63.369	585.72	633.26	633.26	633.87	635.33	2.07
63.322	Strang Rd. Bridge					
63.299	587.89	633.09	633.09	633.72	634.72	1.63
62.325	582.59	633.55	633.55	634.20	635.30	1.75
61.308	584.75	633.07	633.07	633.76	634.86	1.79
60.263	582.15	632.78	632.78	633.50	634.64	1.86
60.200	Spavinaw Creek					
59.019	582.85	632.24	632.24	632.99	634.20	1.96
57.950	582.47	631.83	631.83	632.59	633.85	2.02
56.927	576.95	631.52	631.52	632.30	633.61	2.09
55.890	577.05	631.42	631.42	632.21	633.53	2.11
54.456	577.89	631.22	631.22	632.03	633.38	2.16
52.988	572.13	630.53	630.53	631.95	633.24	2.71
52.954	OK-20 Bridge					
52.922	569.25	630.42	630.42	631.94	633.22	2.80
50.500	Saline Creek					
50.396	569.69	630.70	630.70	631.95	633.23	2.53
49.110	562.60	630.65	630.65	631.94	633.22	2.57
48.118	558.27	630.61	630.61	631.93	633.21	2.60
47.186	553.07	630.56	630.56	631.92	633.20	2.64
47.120	Kerr Dam					

*Difference between the highest and lowest Max WSELs from the simulations with El. 742 to El. 745 Pensacola Dam starting stages.

River Mile	Bed El. (ft, PD)	Historical Inflow Event					Max WSEL Difference* (ft)
		Sep 1993 Max WSEL (ft, PD)	June 2004 Max WSEL (ft, PD)	July 2007 Max WSEL (ft, PD)	Oct 2009 Max WSEL (ft, PD)	Dec 2015 Max WSEL (ft, PD)	
77.000	Pensacola Dam						
76.880	608.88	647.55	625.56	643.26	640.95	649.03	23.47
76.463	607.35	647.50	625.39	643.23	640.92	648.97	23.58
76.414	N 4475 Rd. Bridge						
76.362	607.61	647.47	625.23	643.20	640.90	648.95	23.72
75.317	606.30	646.60	624.46	642.56	640.30	648.00	23.54
74.300	605.42	644.79	623.73	641.24	639.09	646.08	22.35
73.315	600.08	643.57	623.15	640.41	638.32	644.78	21.63
72.884	606.92	642.82	622.69	639.80	637.76	643.98	21.29
72.822	OK-82 Bridge						
72.772	604.91	642.41	622.56	639.62	637.59	643.58	21.02
71.645	603.05	641.63	621.11	639.07	637.01	642.76	21.65
70.910	601.50	640.09	620.52	638.12	636.20	641.17	20.65
69.686	599.92	639.12	619.77	637.50	635.60	640.13	20.36
68.685	597.81	637.93	619.33	636.85	635.05	638.76	19.43
67.715	594.14	637.07	619.24	636.40	634.70	637.73	18.49
66.855	592.57	636.50	619.20	636.10	634.48	637.01	17.81
66.780	Big Cabin Creek						
65.712	590.99	635.99	619.16	635.72	634.31	636.26	17.10
64.435	588.21	635.40	619.11	635.33	634.14	635.39	16.29
63.369	585.72	635.12	619.09	634.99	634.02	634.79	16.03
63.322	Strang Rd. Bridge						
63.299	587.89	635.05	619.09	634.93	634.01	634.77	15.96
62.325	582.59	635.11	619.09	635.00	634.05	634.84	16.02
61.308	584.75	635.06	619.09	634.95	634.04	634.80	15.97
60.263	582.15	635.04	619.09	634.91	634.03	634.78	15.95
60.200	Spavinaw Creek						
59.019	582.85	634.99	619.09	634.84	634.01	634.74	15.90
57.950	582.47	634.95	619.09	634.79	633.99	634.71	15.86
56.927	576.95	634.92	619.09	634.74	633.97	634.69	15.83
55.890	577.05	634.91	619.09	634.73	633.96	634.68	15.82
54.456	577.89	634.89	619.09	634.70	633.94	634.67	15.80
52.988	572.13	634.82	619.09	634.59	633.90	634.59	15.73

*Difference between the highest and lowest Max WSELs from the simulations with historical starting stages.

River Mile	Bed El. (ft, PD)	Historical Inflow Event					Max WSEL Difference* (ft)
		Sep 1993	June 2004	July 2007	Oct 2009	Dec 2015	
		Max WSEL (ft, PD)	Max WSEL (ft, PD)	Max WSEL (ft, PD)	Max WSEL (ft, PD)	Max WSEL (ft, PD)	
52.954	OK-20 Bridge						
52.922	569.25	634.80	619.09	634.57	633.89	634.58	15.71
50.500	Saline Creek						
50.396	569.69	634.85	619.09	634.63	633.88	634.62	15.76
49.110	562.60	634.85	619.09	634.62	633.87	634.61	15.76
48.118	558.27	634.84	619.09	634.61	633.86	634.60	15.75
47.186	553.07	634.84	619.09	634.60	633.85	634.59	15.75
47.120	Kerr Dam						

*Difference between the highest and lowest Max WSELs from the simulations with historical starting stages.

APPENDIX D:
WATER SURFACE ELEVATION PROFILES

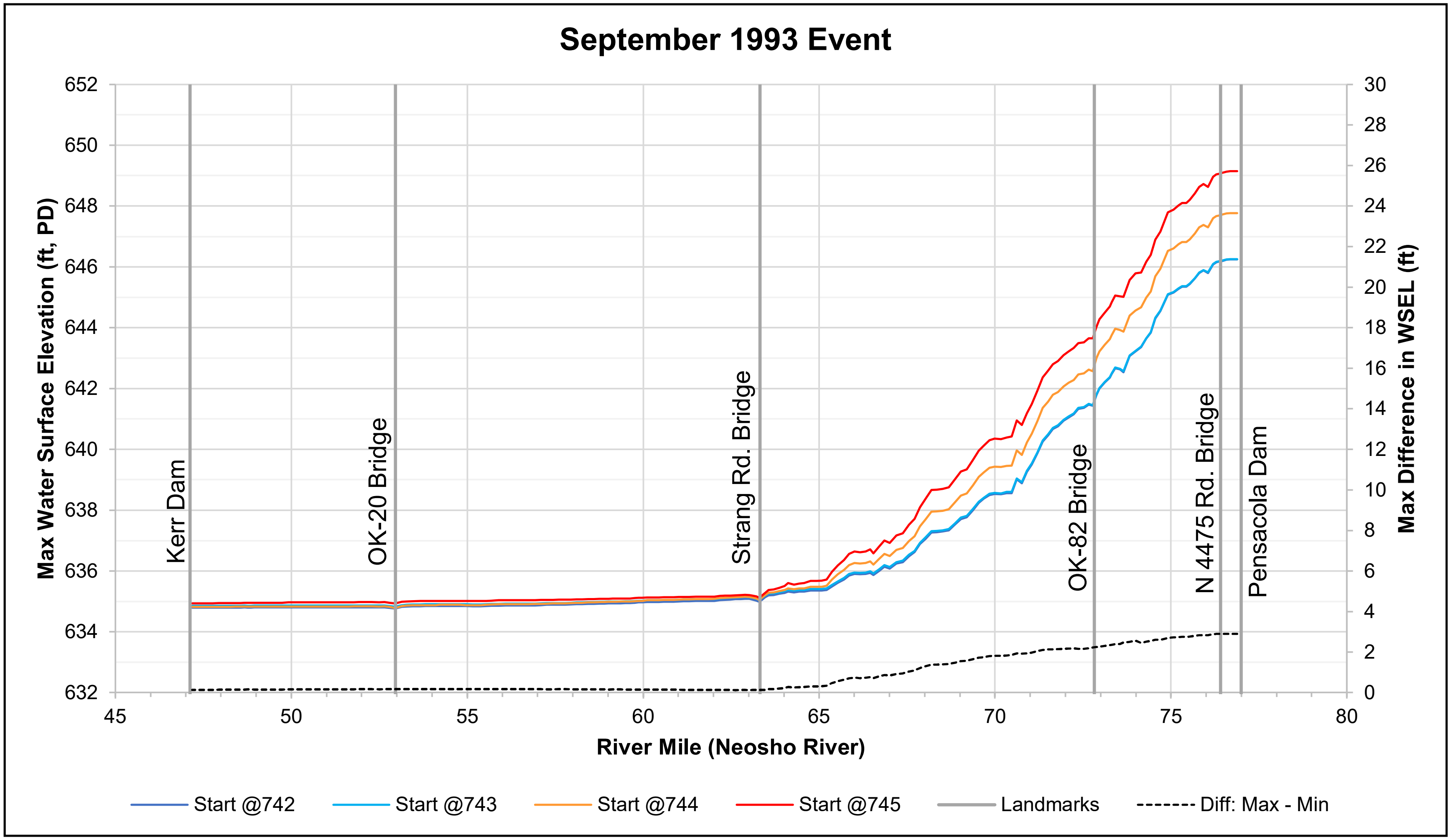


Figure D.1. Water surface elevations for the September 1993 event downstream of Pensacola Dam along the Neosho River profile.

Notes:

1. In the legend, the first set of series names refers to pool elevation at Pensacola Dam at the start of the simulation. For example, "Start @ 742" means a starting pool elevation of 742 ft PD.

2. The dashed line is plotted against the right y-axis and represents the difference between the highest and lowest max WSEL displayed on the figure.

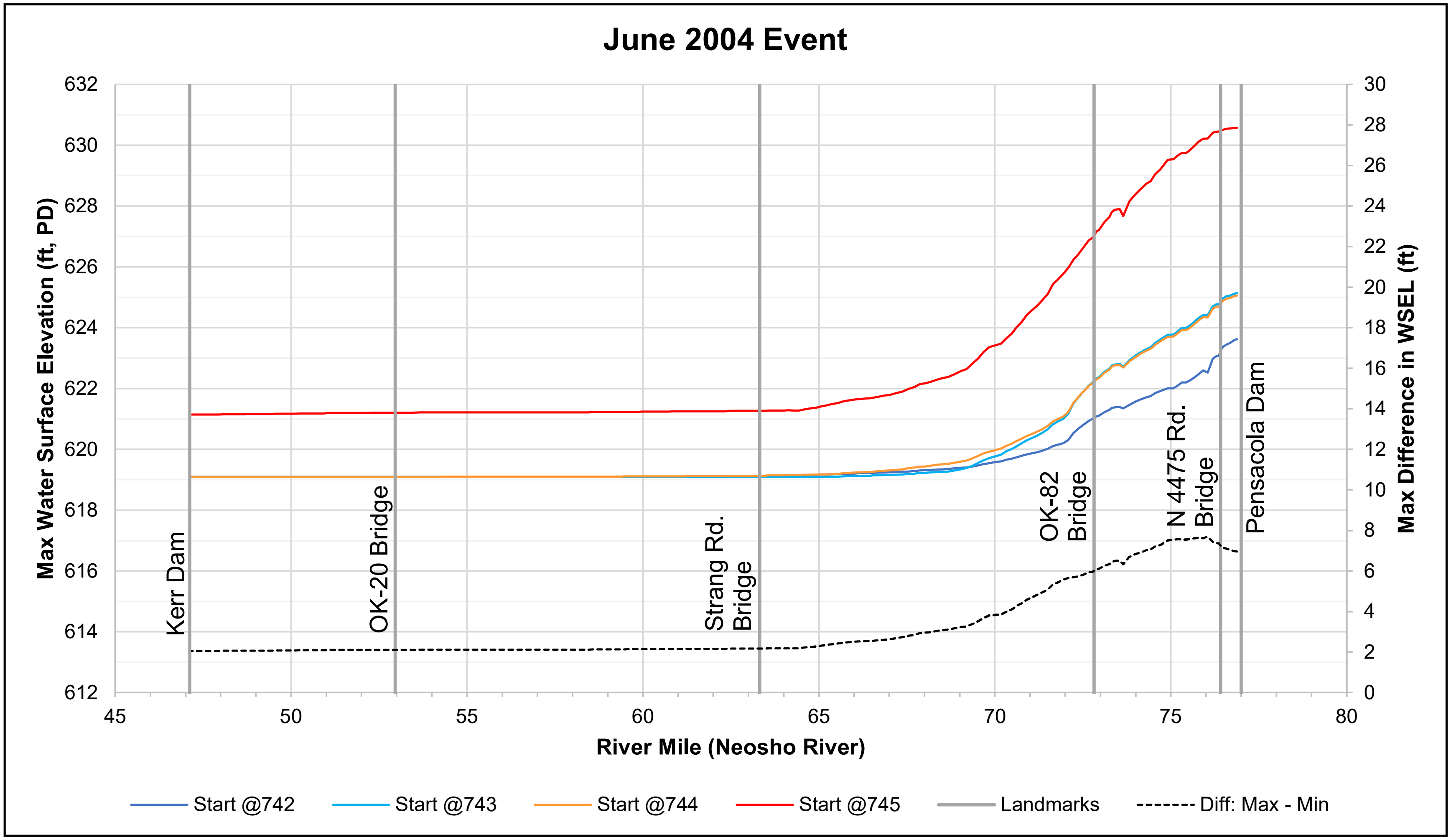


Figure D.2. Water surface elevations for the June 2004 event downstream of Pensacola Dam along the Neosho River profile.

Notes: 1. In the legend, the first set of series names refers to pool elevation at Pensacola Dam at the start of the simulation. For example, "Start @ 742" means a starting pool elevation of 742 ft PD.

2. The dashed line is plotted against the right y-axis and represents the difference between the highest and lowest max WSEL displayed on the figure.

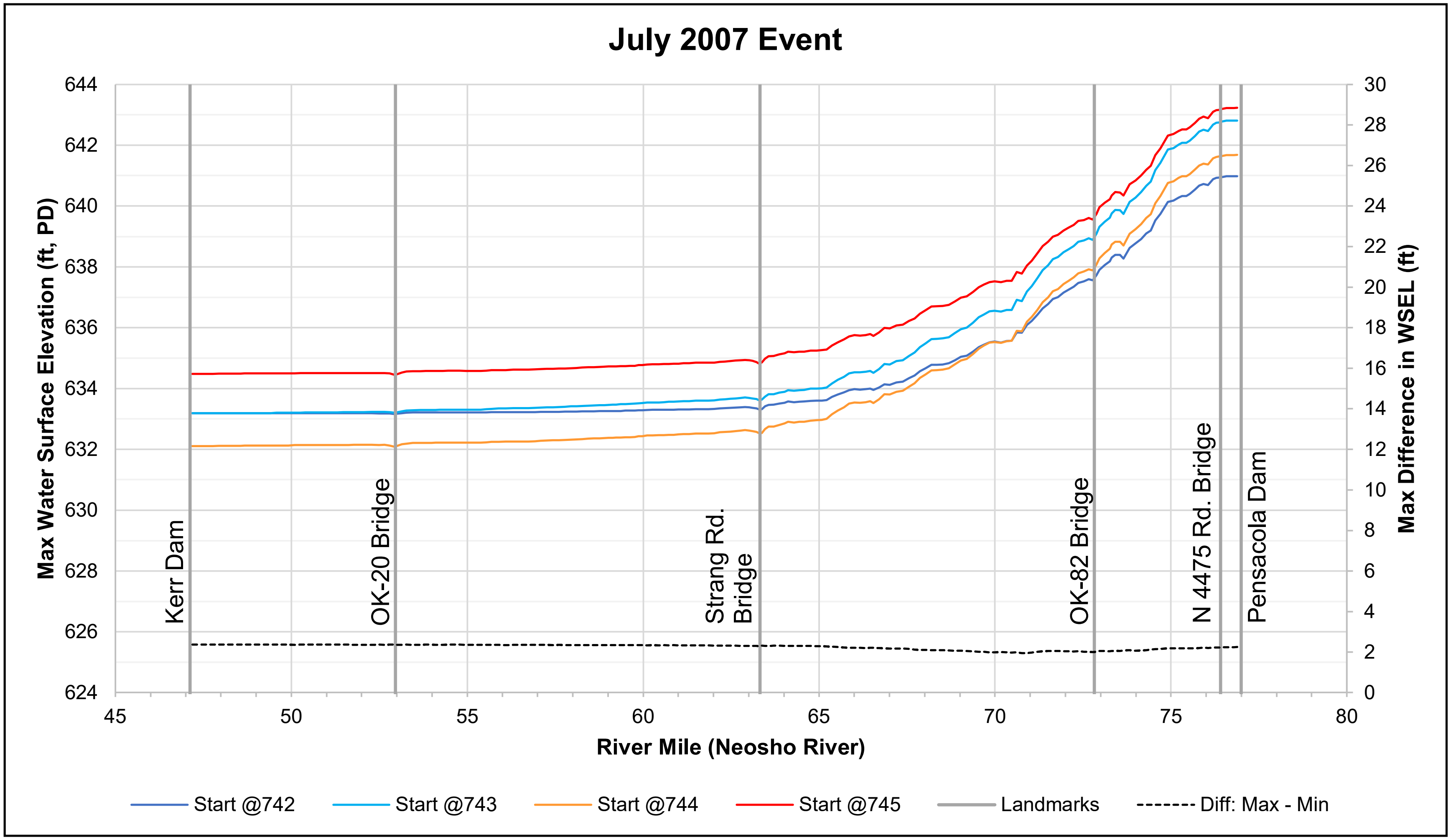


Figure D.3. Water surface elevations for the July 2007 event downstream of Pensacola Dam along the Neosho River profile.

Notes: 1. In the legend, the first set of series names refers to pool elevation at Pensacola Dam at the start of the simulation. For example, "Start @ 742" means a starting pool elevation of 742 ft PD.

2. The dashed line is plotted against the right y-axis and represents the difference between the highest and lowest max WSEL displayed on the figure.

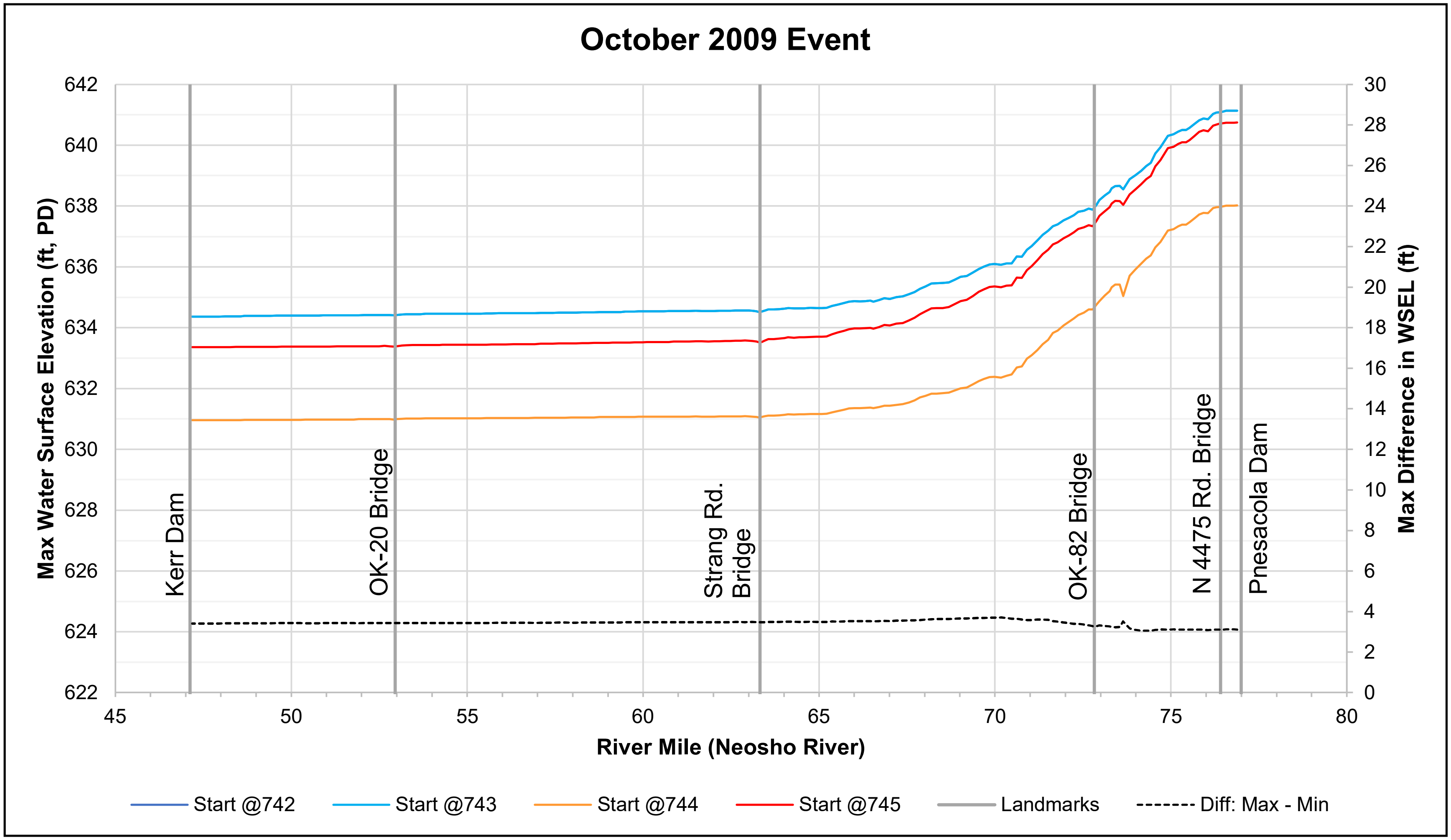


Figure D.4. Water surface elevations for the October 2009 event downstream of Pensacola Dam along the Neosho River profile.

Notes: 1. In the legend, the first set of series names refers to pool elevation at Pensacola Dam at the start of the simulation. For example, "Start @ 742" means a starting pool elevation of 742 ft PD.

2. The dashed line is plotted against the right y-axis and represents the difference between the highest and lowest max WSEL displayed on the figure.

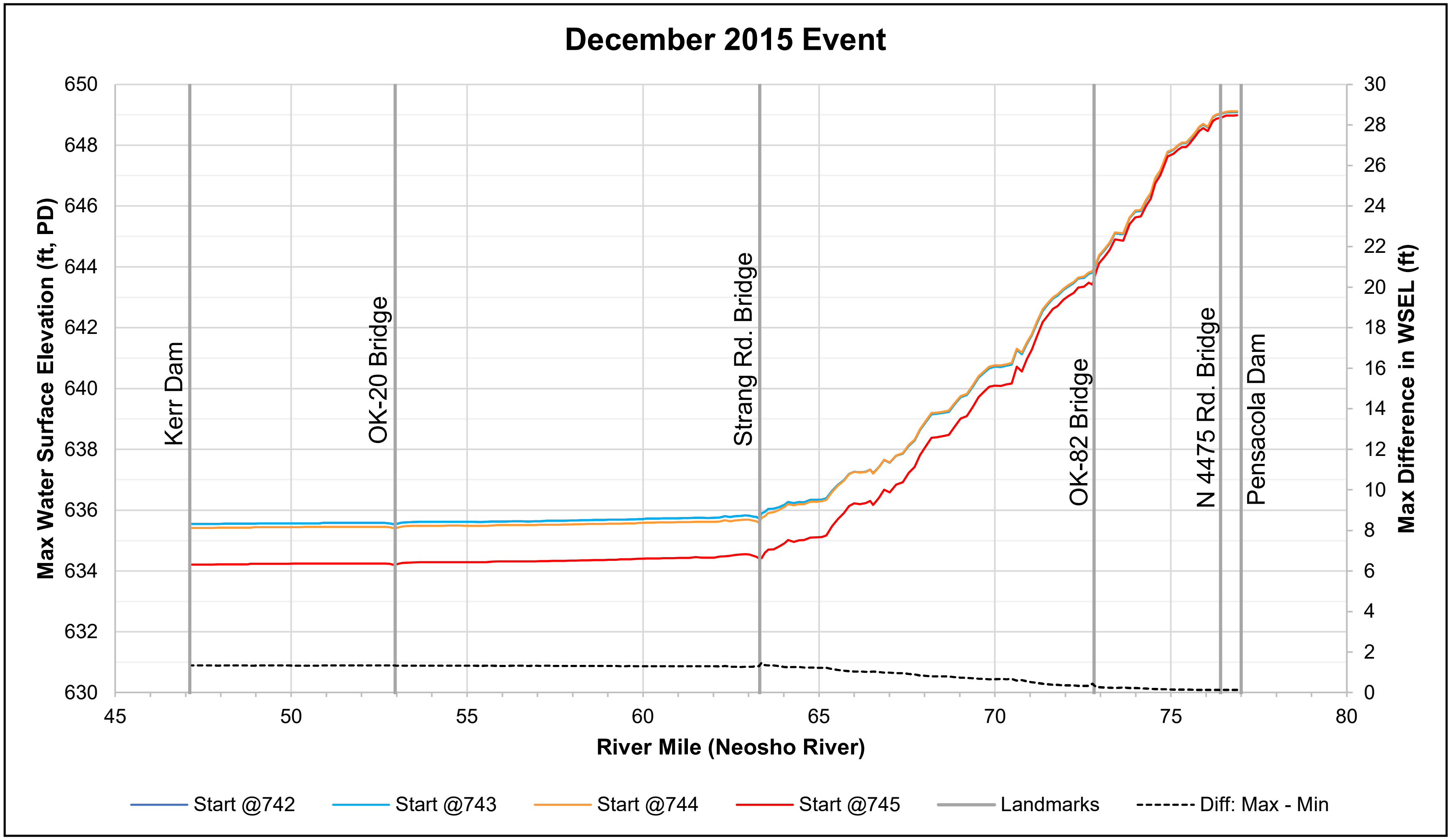


Figure D.5. Water surface elevations for the December 2015 event downstream of Pensacola Dam along the Neosho River profile.

Notes: 1. In the legend, the first set of series names refers to pool elevation at Pensacola Dam at the start of the simulation. For example, "Start @ 742" means a starting pool elevation of 742 ft PD.

2. The dashed line is plotted against the right y-axis and represents the difference between the highest and lowest max WSEL displayed on the figure.

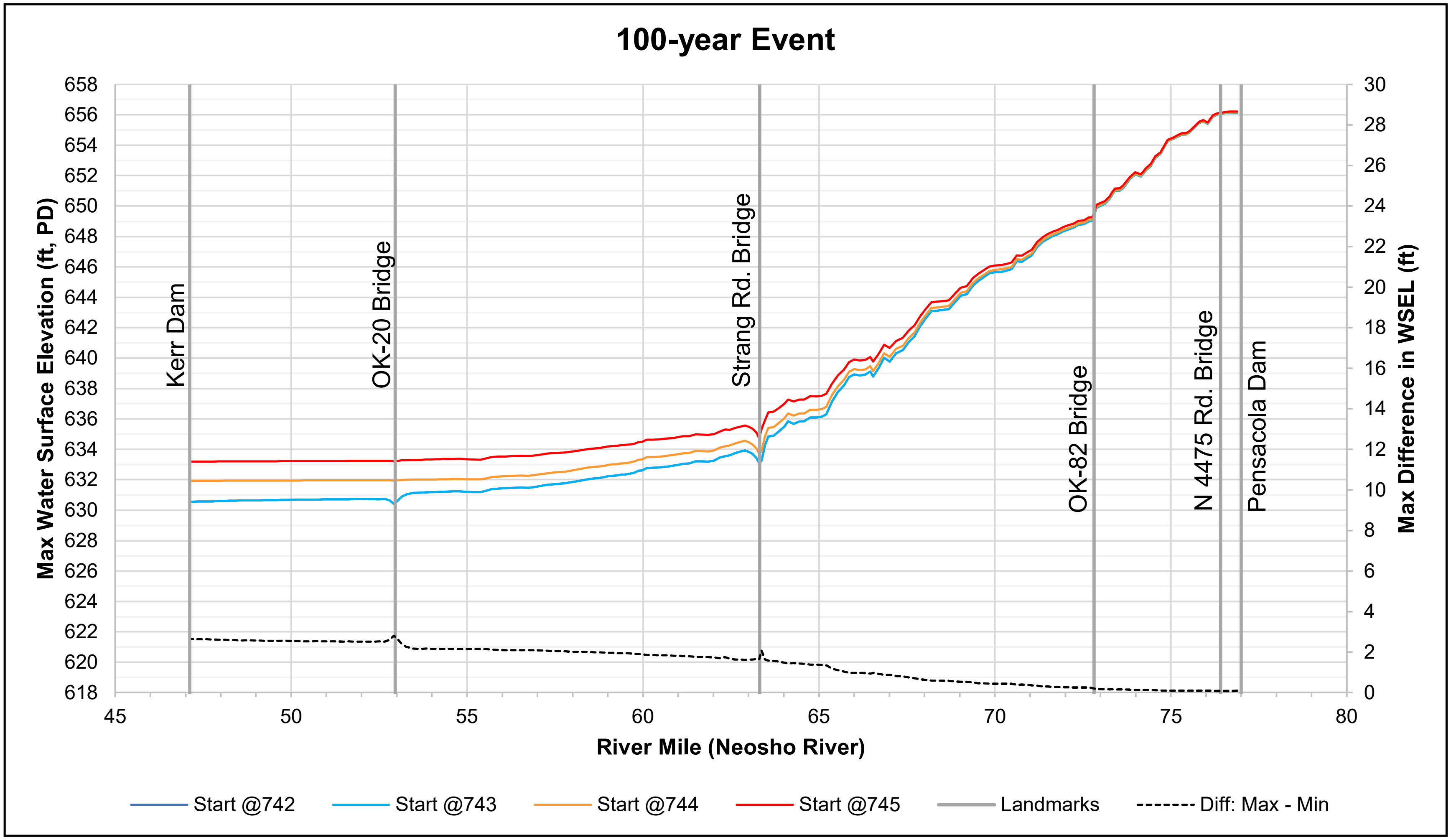


Figure D.6. Water surface elevations for the 100-year event downstream of Pensacola Dam along the Neosho River profile.

Notes:

1. In the legend, the first set of series names refers to pool elevation at Pensacola Dam at the start of the simulation. For example, "Start @ 742" means a starting pool elevation of 742 ft PD.

2. The dashed line is plotted against the right y-axis and represents the difference between the highest and lowest max WSEL displayed on the figure.

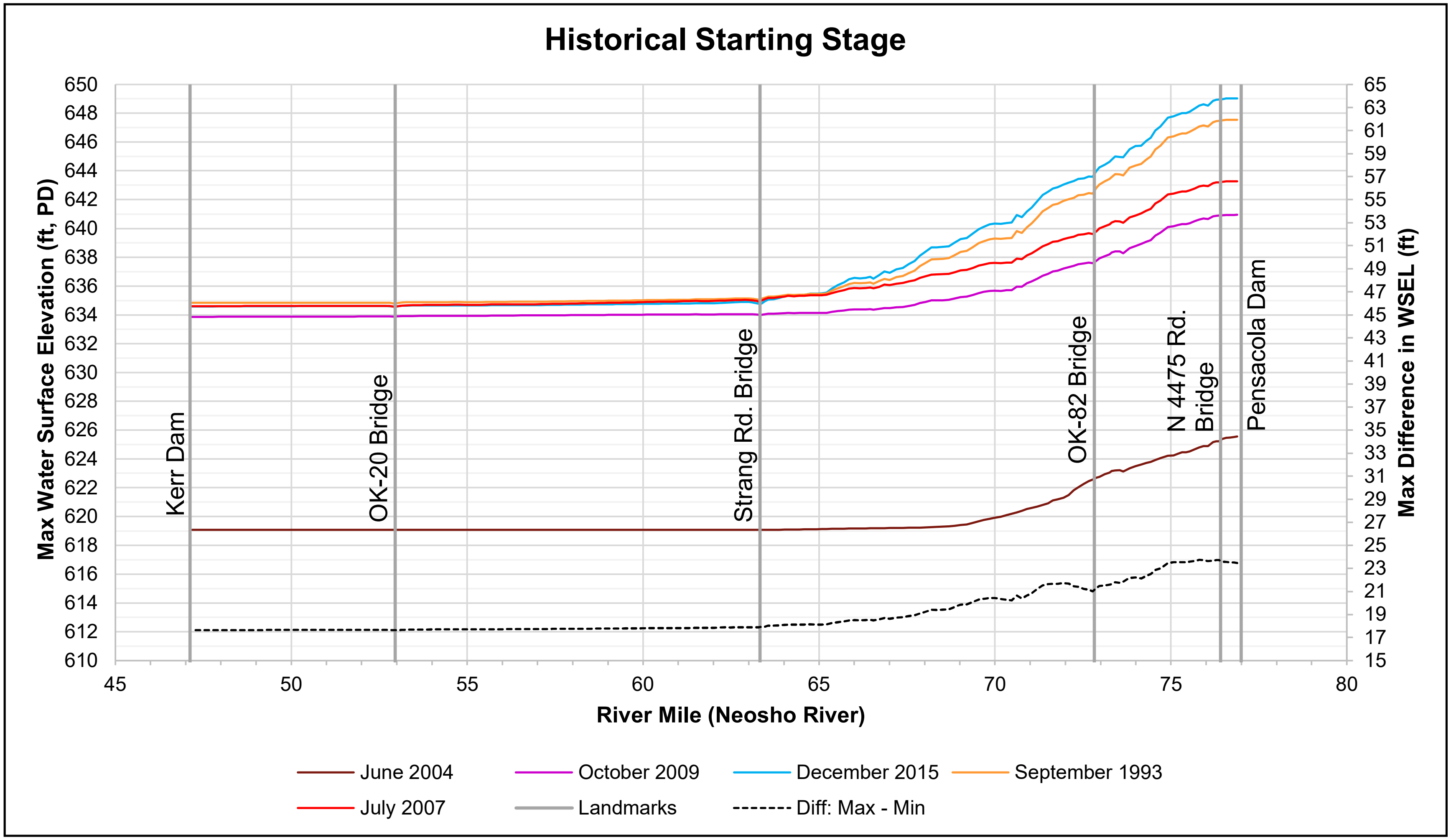


Figure D.7. Water surface elevations for events with historical starting stages downstream of Pensacola Dam along the Neosho River profile.

Note: The dashed line is plotted against the right y-axis and represents the difference between the highest and lowest max WSEL displayed on the figure.

APPENDIX E:
INUNDATION MAPS

Due to the size of the inundation map files, the maps are included as separate PDF files.