PREPARED BY

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Updated Study Report

Hydrologic and Hydraulic Modeling: Downstream Hydraulic Model

Pensacola Hydroelectric Project
Project No. 1494

September 30, 2022

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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 exclusively by the United States Army Corps of Engineers (USACE). This Updated Study Report (USR) 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 (also referred to as the Markham Ferry Hydroelectric Project), 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). Five historical flow events and one synthetic event were analyzed for a range of starting pool elevations at Pensacola Dam. An additional suite of simulations was computed to analyze an alternate operational scenario anticipated by GRDA for 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 within GRDA's anticipated and extreme, hypothetical operational ranges 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).

However, comparing anticipated operations to baseline operations for a suite of simulations that spanned the FERC-requested range of starting pool elevations and inflow event magnitudes, the results of the DHM demonstrate that anticipated operations have an immaterial impact on downstream WSELs and inundation as compared to baseline operations.

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
USR .... Updated Study Report
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.
5. On September 30, 2021, GRDA filed its Initial Study Report (ISR).
6. On February 24, 2022, the FERC issued its Determination on Requests for Study Modifications and New Studies for the Project.
7. On September 30, 2022, GRDA filed this report, the Updated Study Report (USR).

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).

GRDA's ISR was a continuation of the MISR and incorporated comments provided on the MISR. The ISR documented the development of the DHM and findings from the analyses of historical and synthetic flow events with different initial starting stages at Pensacola Dam. GRDA's ISR concluded that initial stages at Pensacola Dam have an impact on downstream WSELs and out-of-bank inundation.

FERC's February 2022 Determination recommended the following modifications to the DHM as part of the H&H modeling study:

1. Run scenarios with a starting elevation at Pensacola Dam of 734 feet PD and extending up to and including an elevation of 757 feet PD.
2. Report the frequency, timing, amplitude (i.e., elevation), and duration of inundation for each of the simulated inflow events with starting elevations between 734 and 757 feet PD.

As documented in this USR, GRDA has completed FERC's requested modifications as follows:

1. GRDA simulated scenarios with starting reservoir elevations at Pensacola Dam ranging from 734 feet PD up to and including 757 feet PD.
2. GRDA reported the frequency, timing, amplitude, and duration of flow events as follows:
    a. Frequency of the inflow events (*i.e.*, estimated return period) is reported in this document and its appendices.
    b. The term "timing" originates in the RSP and refers to seasonality of inflow to Pensacola Dam and inundation from the Upstream Hydraulic Model (UHM). Timing is discussed in Section 11 of the USR for the UHM. GRDA used the UHM to analyze the seasonality of normal (median) operational levels and inflows as it impacts the Aquatic Species Study, the Terrestrial Species Study, and the Wetlands and Riparian Habitat Study.
    c. Amplitude (*i.e.*, elevation) is reported as WSEL in this document and its appendices.
    d. Duration of inundation is reported in this document and its appendices.

The DHM and this report were updated during the second season according to FERC's February 2022 Determination. 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.

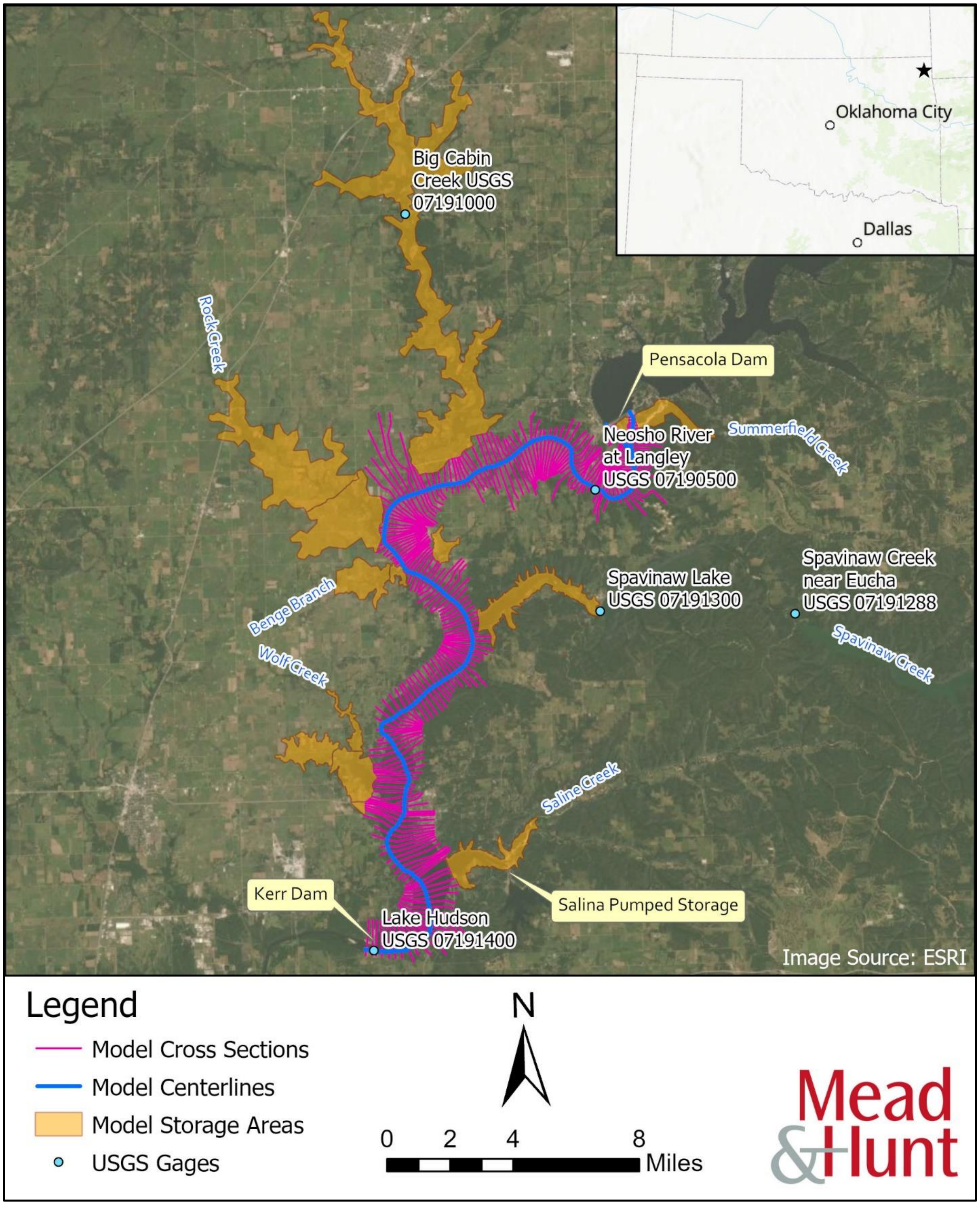
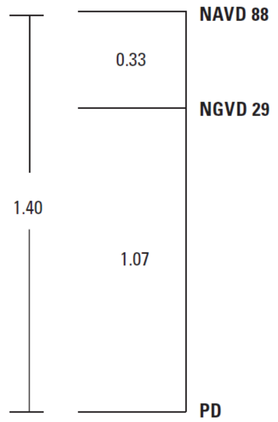


FIGURE 1. DOWNSTREAM HYDRAULIC MODEL STUDY AREA.

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).

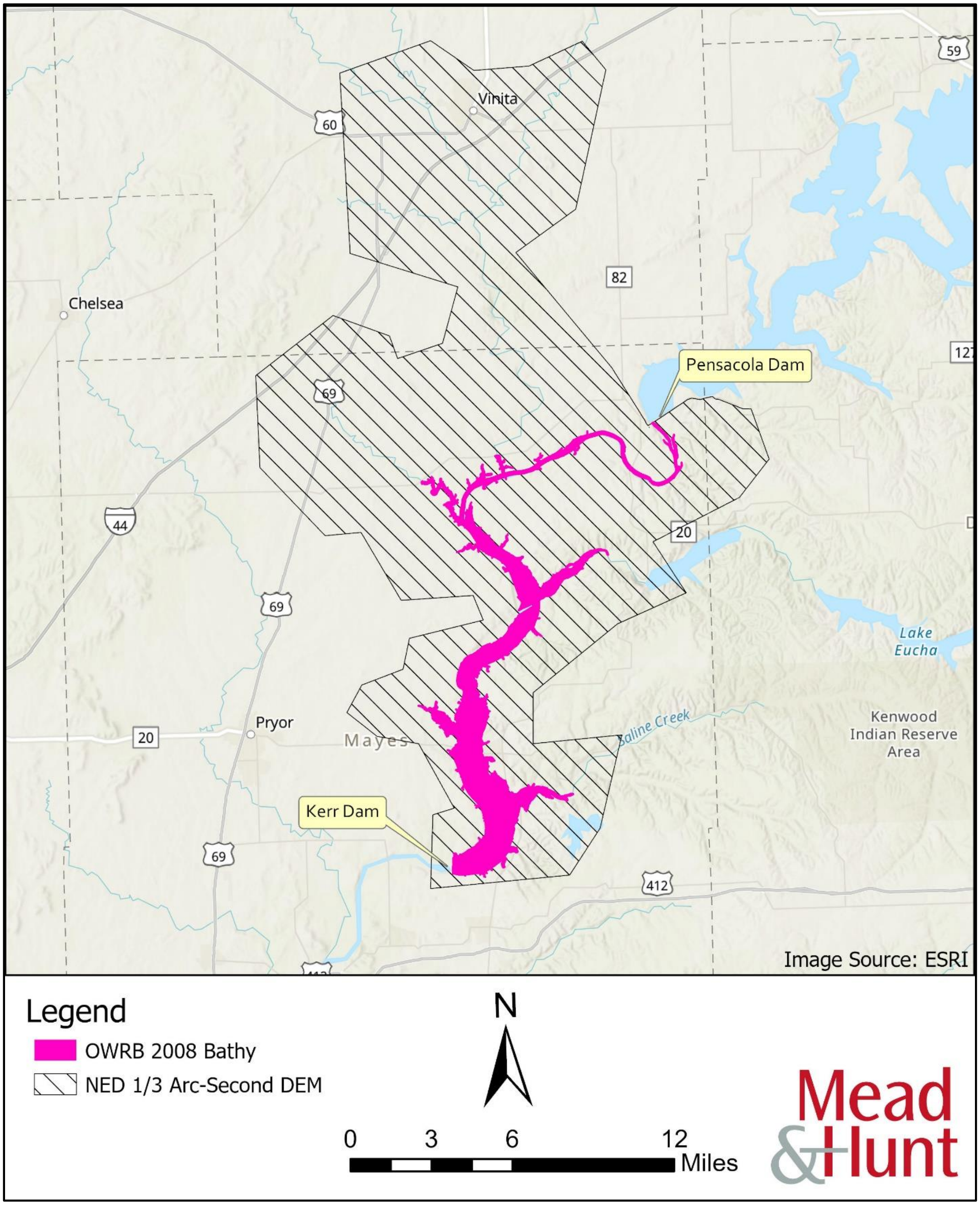


FIGURE 3. TOPOGRAPHIC AND BATHYMETRIC DATA EXTENTS.

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.

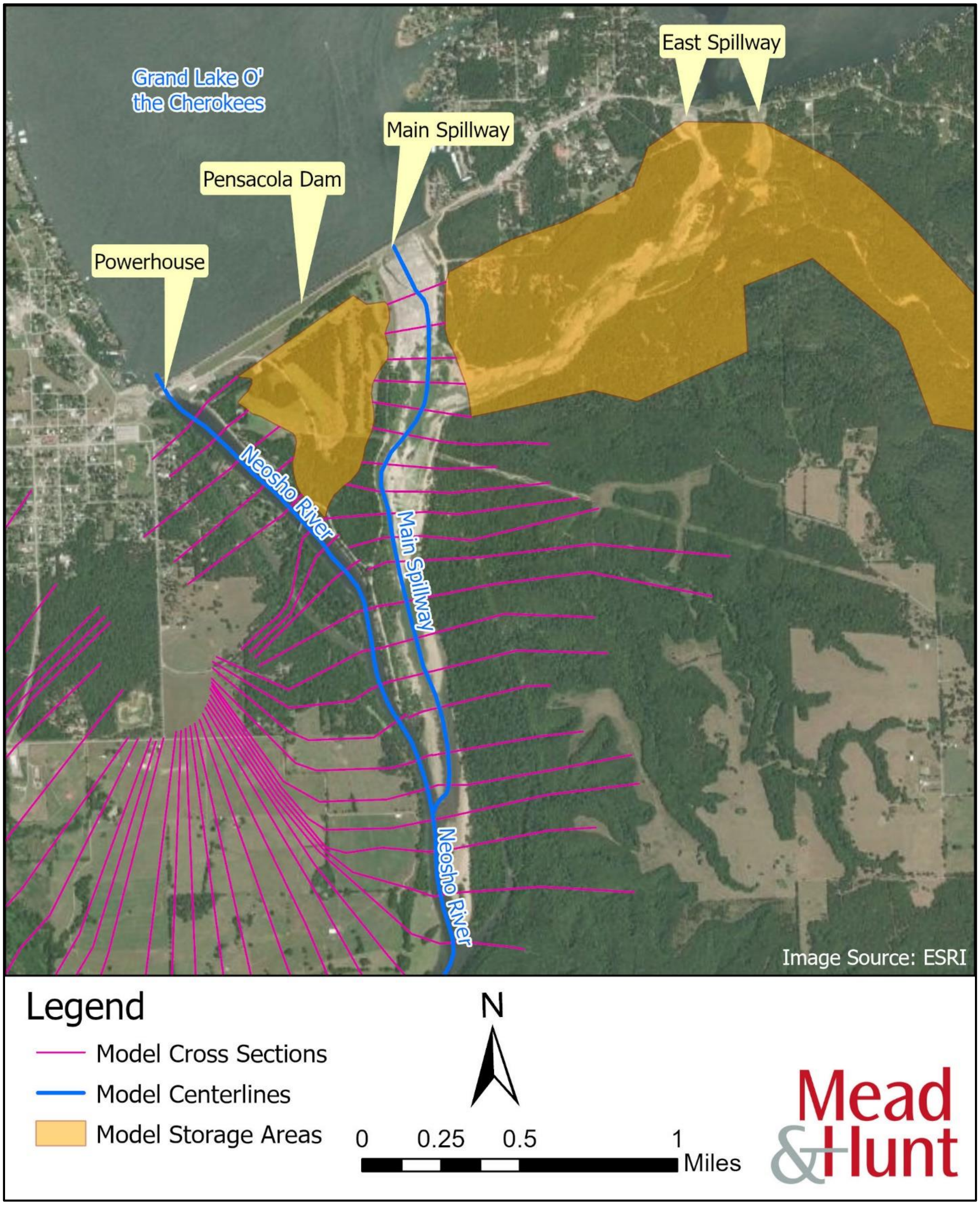


FIGURE 4. MODEL CONFIGURATION JUST DOWNSTREAM OF PENSACOLA DAM.

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

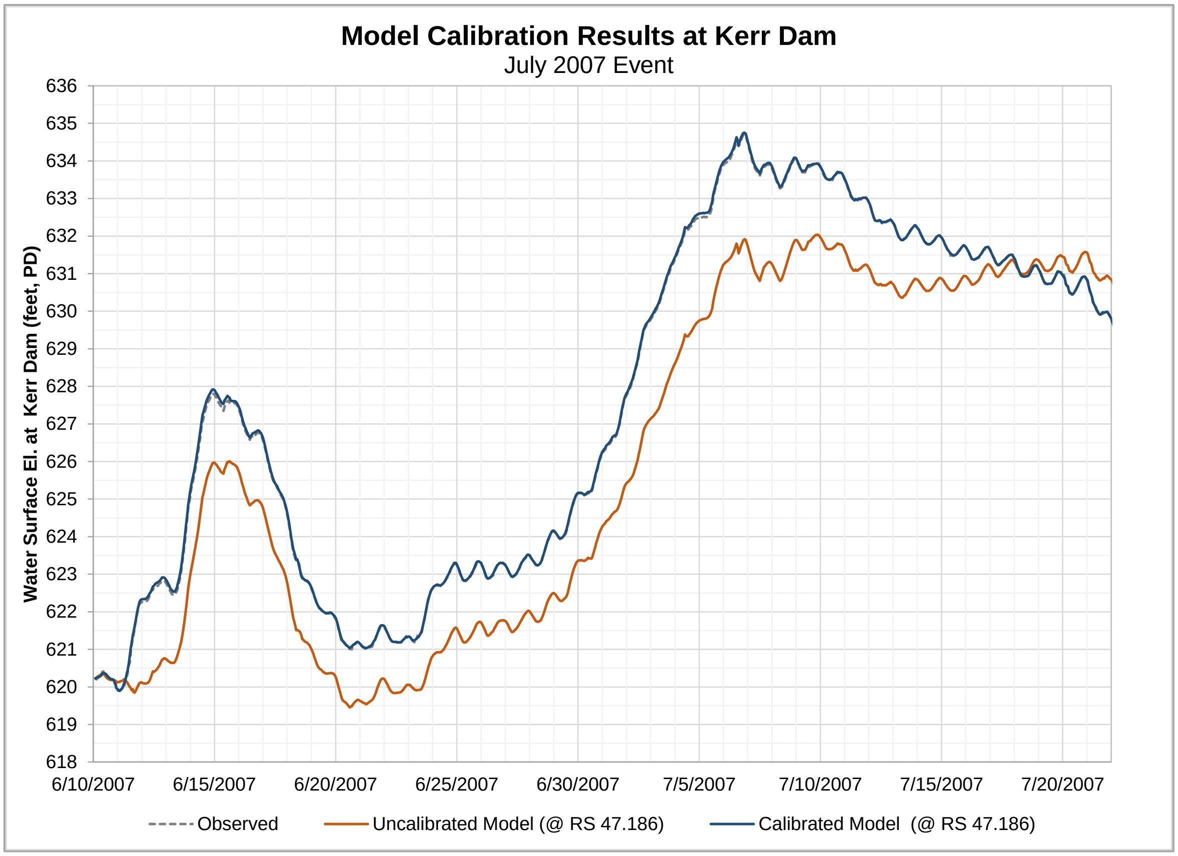


FIGURE 5. JULY 2007 EVENT STAGE HYDROGRAPHS AT KERR DAM.

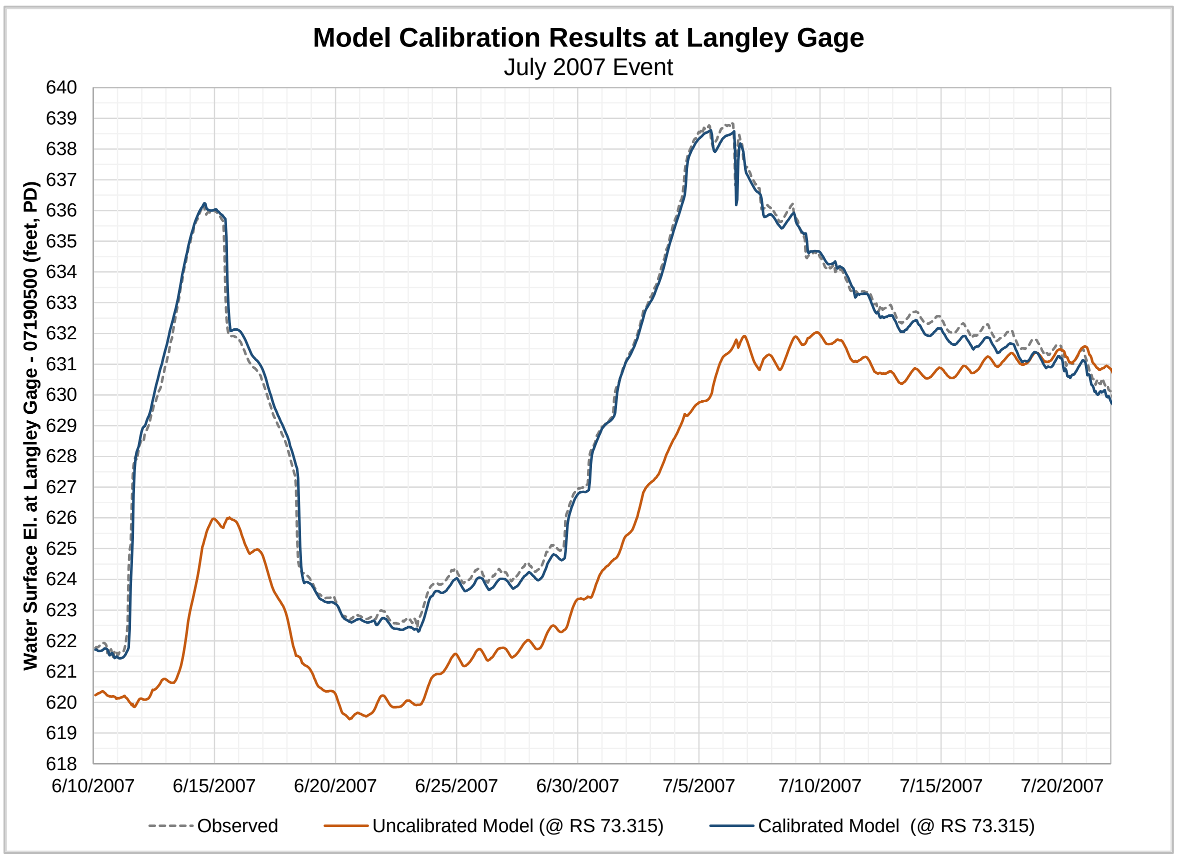


FIGURE 6. JULY 2007 EVENT STAGE HYDROGRAPHS AT LANGLEY GAGE.

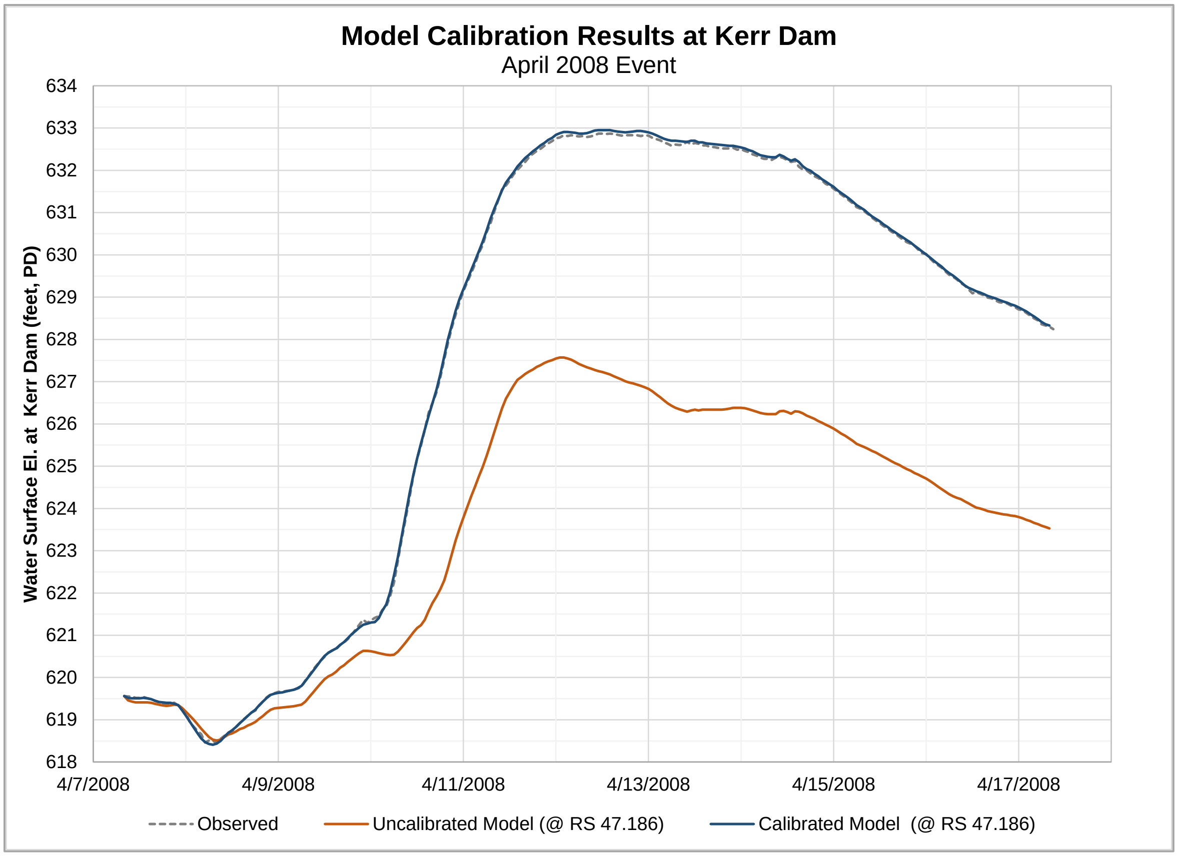


FIGURE 7. APRIL 2008 EVENT STAGE HYDROGRAPHS AT KERR DAM.

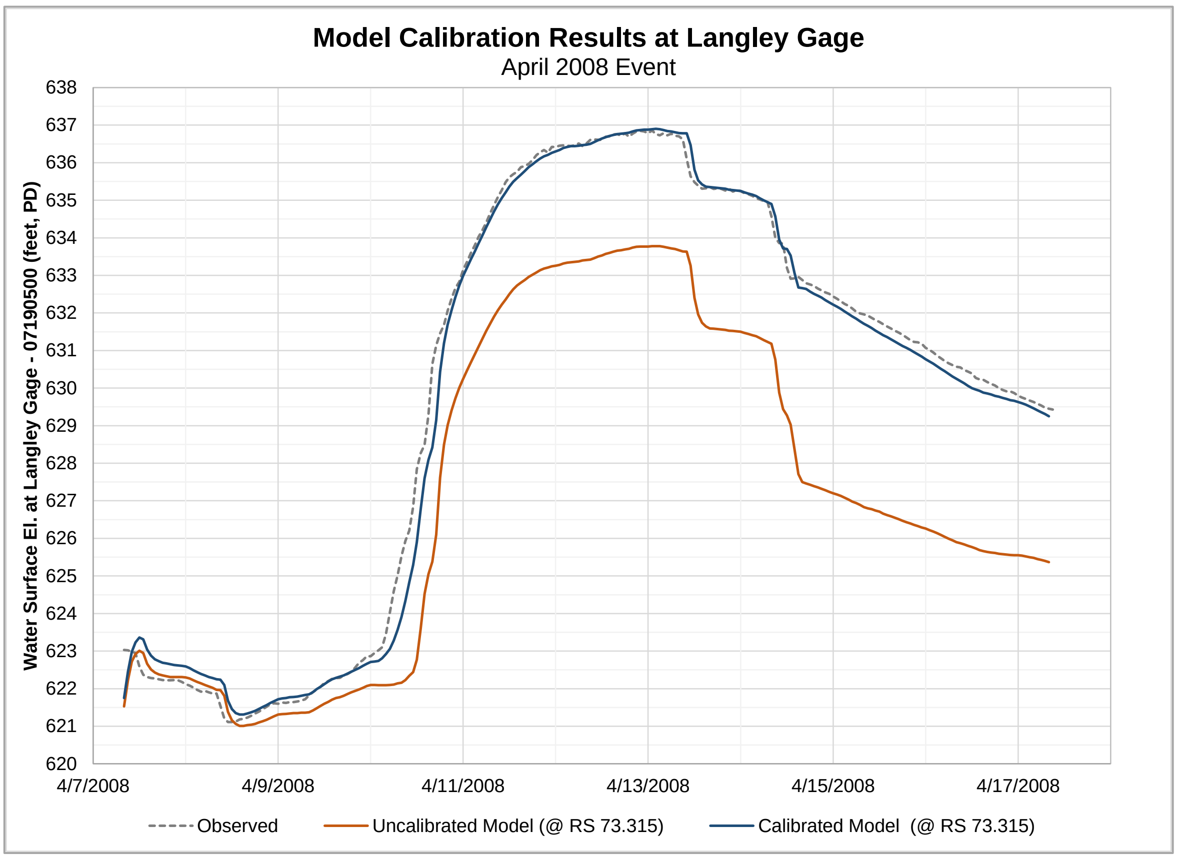


FIGURE 8. APRIL 2008 EVENT STAGE HYDROGRAPHS AT LANGLEY GAGE.

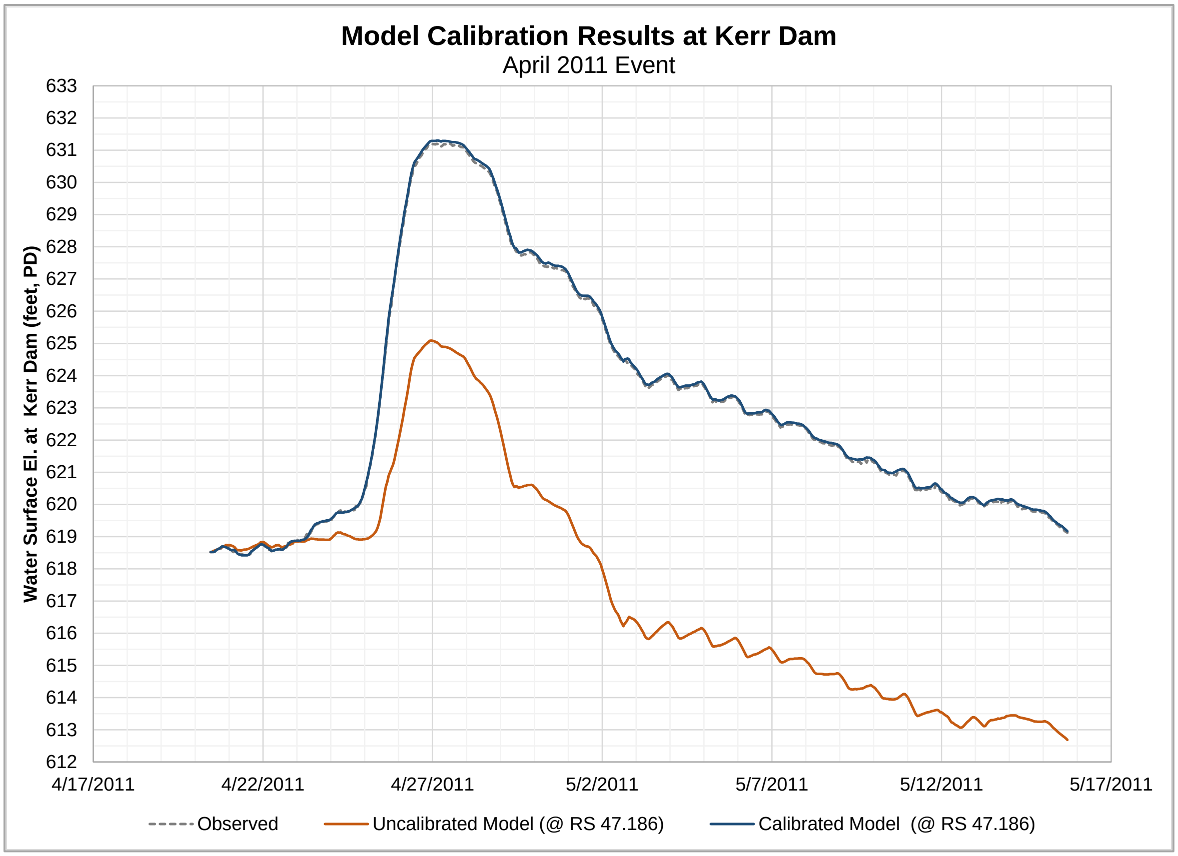


FIGURE 9. APRIL 2011 EVENT STAGE HYDROGRAPHS AT KERR DAM.

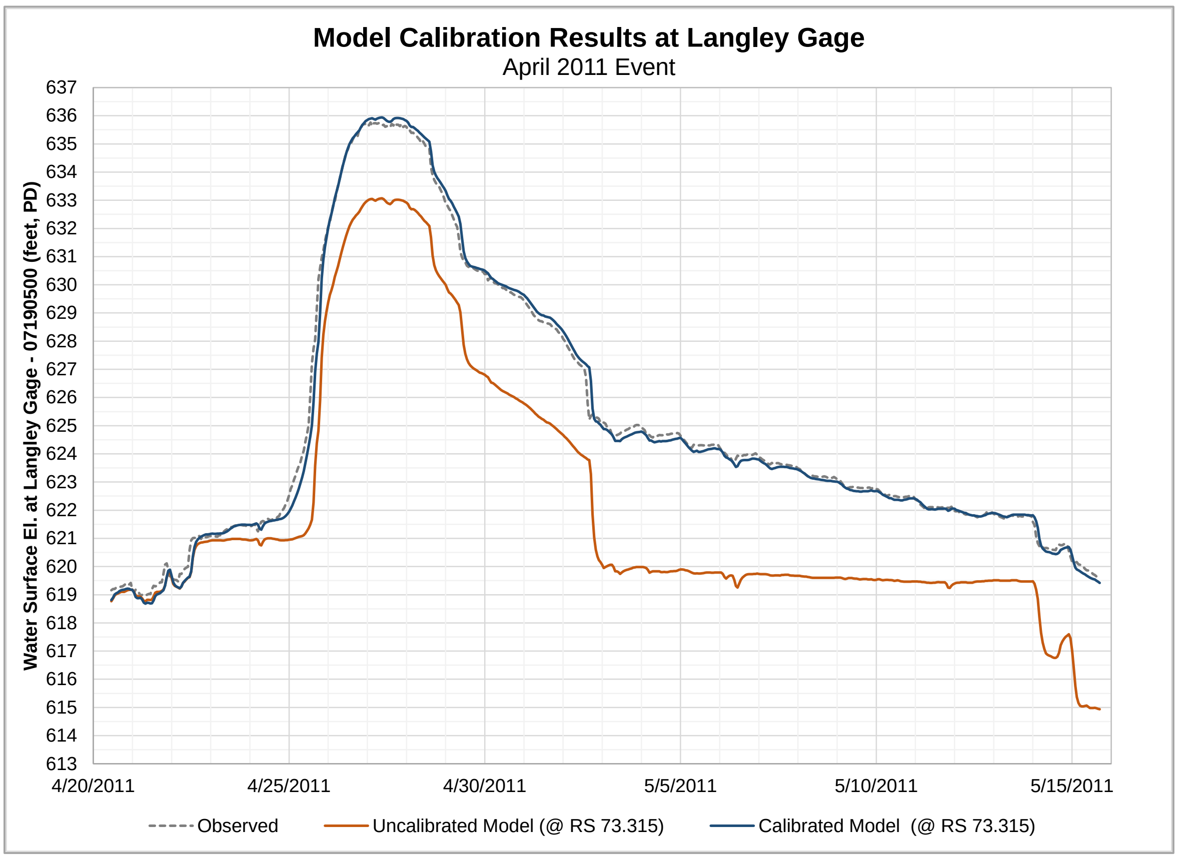


FIGURE 10. APRIL 2011 EVENT STAGE HYDROGRAPHS AT LANGLEY GAGE.

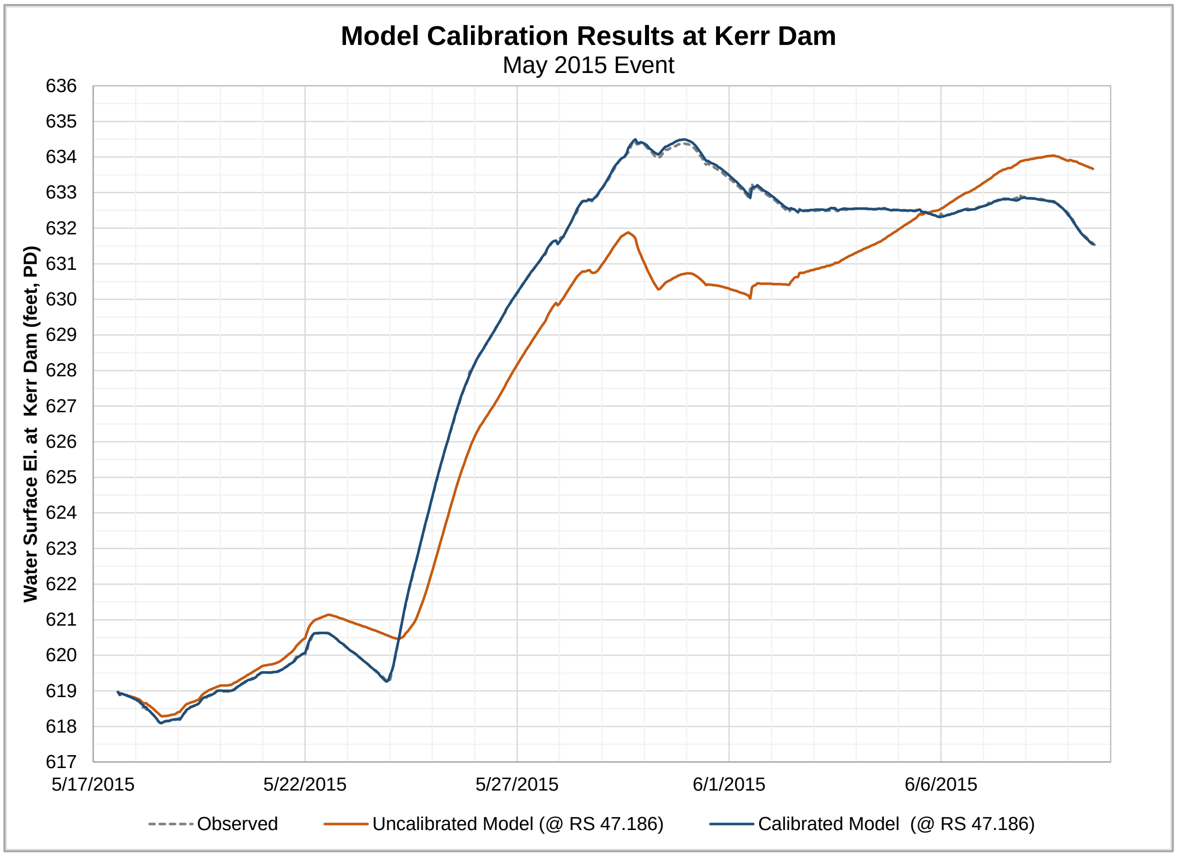


FIGURE 11. MAY 2015 EVENT STAGE HYDROGRAPHS AT KERR DAM.

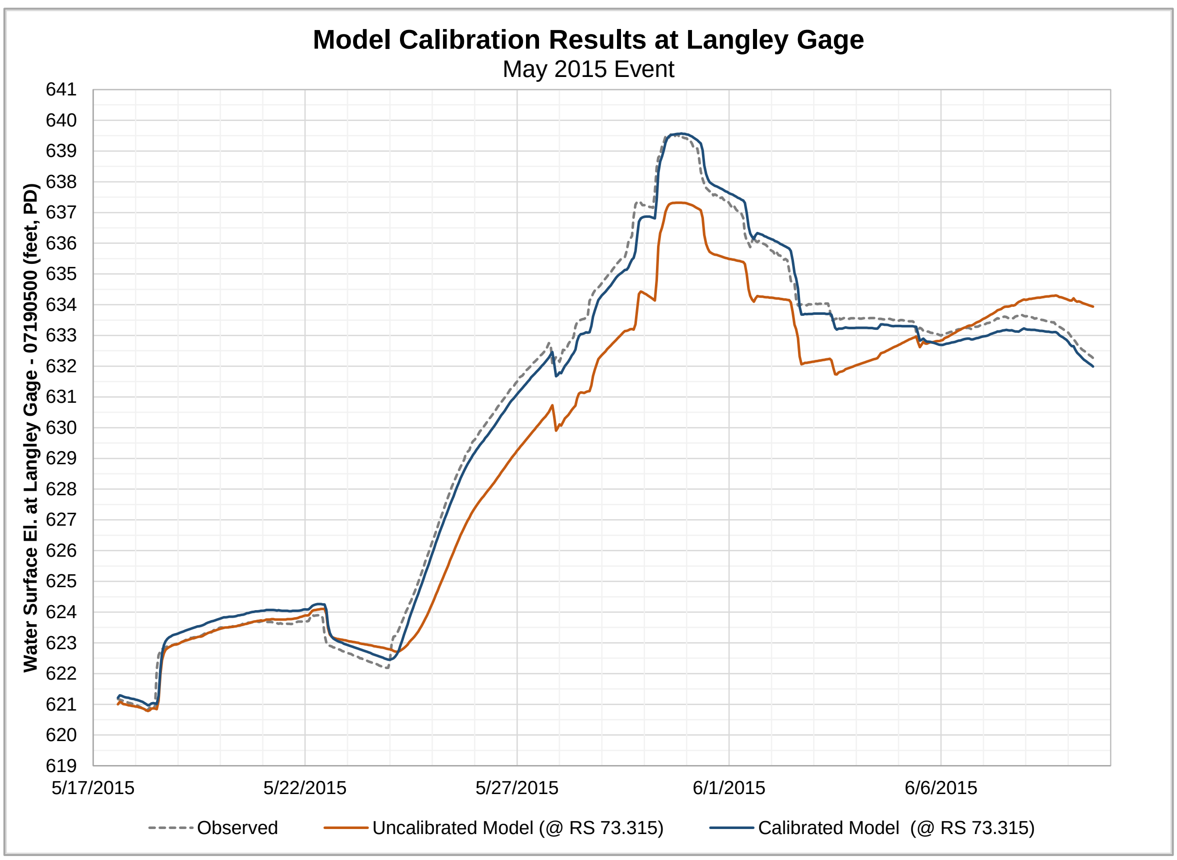


FIGURE 12. MAY 2015 EVENT STAGE HYDROGRAPHS AT LANGLEY GAGE.

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 Operations Model (OM), which was updated according to FERC's February 2022 Determination. 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**.

Each flow event was analyzed assuming starting pools at Pensacola Dam equal to the historical starting stage. In addition to the historical pool elevation, eleven other starting pool elevations were simulated. Starting pool elevations at Pensacola Dam were divided into two categories:

1. Starting reservoir elevations within GRDA's anticipated operational range of 742 to 745 feet PD.
2. Extreme, hypothetical values of starting reservoir elevations outside of GRDA's anticipated operational range. These extreme, hypothetical values below and above GRDA's anticipated operational range were included in the H&H Study based on FERC's February 2022 Determination.

TABLE 6. SUMMARY OF FLOW EVENTS ANALYZED.

Event	Type	Estimated Return Period[1]	Pensacola Dam Historical Pool Elev. At Simulation Start (ft, PD)	Simulation Time Window
September 1993	Historical	21 years	743.85	Sept. 24, 1993 – Oct. 17, 1993
June 2004	Historical	1 year	743.42	June 13, 2004 – June 26, 2004
July 2007	Historical	4 years	745.69	June 28, 2007 – July 25, 2007
October 2009	Historical	3 years	740.98	Oct. 8, 2009 – Oct. 22, 2009
December 2015	Historical	15 years	742.86	Dec. 26, 2015 – Jan. 17, 2016
100-year	Synthetic	100 years	N/A	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 14 days.

Table 7 lists the non-historical Pensacola Dam starting pool elevations analyzed. The OM, which was updated according to FERC's February 2022 Determination, was used to compute the boundary conditions used in the DHM for the various starting pool elevations at Pensacola Dam. The model inputs for each event are discussed in more detail in **Section 3.3**.

TABLE 7. LIST OF ADDITIONAL PENSACOLA DAM INITIAL POOL ELEVATIONS SIMULATED.

Inflow Event	Pensacola Dam Pool Elevation at Simulation Start (ft, PD)	
	Anticipated Operational Range	Extreme, Hypothetical Range
Sept. 1993 (21 year)	742.0, 742.5, 743.0, 743.5, 744.0, 744.5, 745.0	734.0, 749.0, 753.0, 757.0
June 2004 (1 year)	742.0, 742.5, 743.0, 743.5, 744.0, 744.5, 745.0	734.0, 749.0, 753.0, 757.0
July 2007 (4 year)	742.0, 742.5, 743.0, 743.5, 744.0, 744.5, 745.0	734.0, 749.0, 753.0, 757.0
Oct. 2009 (3 year)	742.0, 742.5, 743.0, 743.5, 744.0, 744.5, 745.0	734.0, 749.0, 753.0, 757.0
Dec. 2015 (15 year)	742.0, 742.5, 743.0, 743.5, 744.0, 744.5, 745.0	734.0, 749.0, 753.0, 757.0
100-year	742.0, 742.5, 743.0, 743.5, 744.0, 744.5, 745.0	734.0, 749.0, 753.0, 757.0

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 8**. Hydrograph plots showing results from the OM that were used as inputs to the HEC-RAS model are included in **Appendix A**.

TABLE 8. SUMMARY OF OPERATIONS MODEL RESULTS USED FOR HEC-RAS SIMULATIONS.

Event	Pensacola Starting Stage Category	Pensacola Starting Stage (ft, PD)	Pensacola Dam Peak Outflow[2] (cfs)	Kerr Dam Peak Stage (ft, PD)
September 1993 (21 Year)[1]	Historical	743.85	198,000	634.83
	Anticipated Operational Range	742	150,000	634.71
		742.5	150,000	634.71
		743	152,000	634.71
		743.5	162,000	634.71
		744	173,000	634.72
		744.5	184,000	634.72
		745	198,000	634.83
	Extreme Hypothetical Operational Range	734	124,000	630.83
		749	210,000	635.12
		753	215,000	635.17
		757	250,000	635.20
June 2004 (1 Year)[1]	Historical	743.42	45,000	619.48
	Anticipated Operational Range	742	15,000	619.09
		742.5	28,000	619.09
		743	22,000	619.09
		743.5	25,000	619.09
		744	21,000	619.09
		744.5	32,000	619.34
		745	45,000	620.36
	Extreme Hypothetical Operational Range	734	14,000	619.09
		749	50,000	624.42
		753	101,000	631.51
		757	124,000	632.20
July 2007 (4 Year)[1]	Historical	745.69	117,000	634.81
	Anticipated Operational Range	742	101,000	634.59
		742.5	117,000	634.62
		743	117,000	634.62
		743.5	117,000	634.62
		744	99,000	634.61
		744.5	117,000	634.62
		745	117,000	634.81
	Extreme Hypothetical Operational Range	734	100,000	634.55
		749	117,000	634.81
		753	125,000	634.81
		757	141,000	634.81
October 2009 (3 year)[1]	Historical	740.98	86,000	632.99
	Anticipated Operational Range	742	100,000	633.51
		742.5	81,000	630.93
		743	99,000	633.51
		743.5	76,000	629.70

Event	Pensacola Starting Stage Category	Pensacola Starting Stage (ft, PD)	Pensacola Dam Peak Outflow[2] (cfs)	Kerr Dam Peak Stage (ft, PD)
		744	79,000	630.62
		744.5	78,000	629.61
		745	98,000	632.99
	Extreme Hypothetical Operational Range	734	65,000	628.73
		749	91,000	634.39
		753	102,000	634.55
		757	113,000	634.56
December 2015 (15 year)[1]	Historical	742.86	195,000	634.82
	Anticipated Operational Range	742	195,000	634.82
		742.5	195,000	634.82
		743	195,000	634.82
		743.5	195,000	634.82
		744	195,000	634.82
		744.5	195,000	634.82
		745	195,000	634.82
	Extreme Hypothetical Operational Range	734	100,000	634.56
		749	195,000	634.86
		753	195,000	634.85
		757	232,000	634.89
100-year	Anticipated Operational Range	742	322,000	634.94
		742.5	322,000	634.92
		743	322,000	634.92
		743.5	322,000	634.92
		744	322,000	634.92
		744.5	322,000	634.92
		745	322,000	634.92
	Extreme Hypothetical Operational Range	734	322,000	634.93
		749	322,000	634.92
		753	322,000	634.92
		757	322,000	634.92

[1] Return period for peak inflow at 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 9**. 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 9. 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 computed 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 USR for the 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 USR 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 10** 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 9**.

TABLE 10. 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 downstream WSELs for the various starting stages at Pensacola Dam (**Tables C.1** through **C.6**). These tables include two calculations of maximum difference in peak WSEL:

1. Maximum difference for simulations with starting stages at Pensacola Dam within GRDA's anticipated operational range (742 to 745 feet PD).
2. Maximum difference for simulations with starting stages at Pensacola Dam at extreme, hypothetical values (734 to 757 feet PD) which are outside GRDA's anticipated operational range.

A separate table was created for comparing the maximum downstream 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 downstream WSELs. The water surface profile plots are included in **Appendix D**. Similar to the tabular data, plots were developed for each flow event to compare the maximum downstream WSELs for the various starting stages at Pensacola Dam (**Figures D.1** through **D.6**). The plots include two profiles of calculated maximum difference in peak WSEL:

1. Maximum difference for simulations with starting stages at Pensacola Dam within GRDA's anticipated operational range (742 to 745 feet PD).
2. Maximum difference for simulations with starting stages at Pensacola Dam at extreme, hypothetical values (734 to 757 feet PD) which are outside GRDA's anticipated operational range.

A separate plot was developed to show the maximum downstream 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 downstream 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 downstream inundation extents for each flow event using the various starting stages at Pensacola Dam (**Appendix E.1** through **E.6**), and a separate map set was developed to compare the maximum downstream 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 11 presents a summary of smallest and largest downstream inundation areas, as well as the percentage difference between them, for simulated starting pool elevations at Pensacola Dam within GRDA's anticipated operational range. The first six rows in the table present smallest and largest maximum inundation areas for simulations with various starting pool elevations at Pensacola Dam within GRDA's anticipated operational range 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. Stated another way, the first six rows in the table characterize the impact of GRDA's anticipated operations and the last row characterizes the impact of nature. The maximum downstream inundation area differences for a given event due to a change in starting stage within GRDA's anticipated operational range 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 11. SUMMARY OF MINIMUM AND MAXIMUM DOWNSTREAM INUNDATION AREAS FOR STARTING POOL ELEVATIONS AT PENSACOLA DAM WITHIN GRDA'S ANTICIPATED OPERATIONAL RANGE.

Event	Area of Inundation (acres)		Difference (%)
	Smallest	Largest	
Sept. 1993 (21 year)	18,623	19,065	2.3%
June 2004 (1 year)	12,210	12,838	4.9%
July 2007 (4 year)	17,986	18,397	2.2%
Oct. 2009 (3 year)	15,759	17,504	10.0%
Dec. 2015 (15 year)	19,061	19,070	0.0%
100-year	20,721	20,736	0.1%
Historical Starting Stage (impact of nature)	12,593	19,069	34.0%

Table 12 presents a summary of smallest and largest downstream inundation areas for all simulated starting pool elevations at Pensacola Dam (734 to 757 feet PD), including extreme, hypothetical values outside GRDA's anticipated operational range. Except for the June 2004 event, the maximum inundation area differences for a given event due to change in starting stage are much smaller than the maximum differences when inflow events are compared against each other, and the historical starting stage is used.

TABLE 12. SUMMARY OF MINIMUM AND MAXIMUM DOWNSTREAM INUNDATION AREAS FOR ALL STARTING POOL ELEVATIONS AT PENSACOLA DAM, INCLUDING EXTREME, HYPOTHETICAL VALUES OUTSIDE GRDA'S ANTICIPATED OPERATIONAL RANGE.

Event	Area of Inundation (acres)		Difference (%)
	Smallest	Largest	
Sept. 1993 (21 year)	16,739	19,560	14.4%
June 2004 (1 year)	12,127	17,263	29.8%
July 2007 (4 year)	17,976	18,605	3.4%
Oct. 2009 (3 year)	15,215	17,994	15.4%
Dec. 2015 (15 year)	18,015	19,507	7.6%
100-year	20,720	20,757	0.2%
Historical Starting Stage (impact of nature)	12,593	19,069	34.0%

Tabulated results of downstream inundation duration are presented in **Appendix F**. Downstream inundation duration was defined as the time of inundation above the defined flowage easement for the Markham Ferry Hydroelectric Project. As defined in the Water Control Manual for Markham Ferry Reservoir (USACE, 1992), the flowage easement elevation varies from 637.5 feet NGVD29 to 658.0 feet NGVD29 and is based on a water surface profile computed by the USACE for a flow of 300,000 cfs through Markham Ferry Reservoir (Lake Hudson) with 230,000 cfs coming from Pensacola Dam.

In **Appendix F.1** through **Appendix F.6**, tables are organized by flow event. For example, the set of tables in **Appendix F.1** report downstream inundation duration for the September 1993 inflow event.

Each table in **Appendix F.1** through **Appendix F.6** includes two calculations of difference in inundation duration:

1. Inundation duration difference for simulations with starting pool elevations at Pensacola Dam within GRDA's anticipated operational range (742 to 745 feet PD).
2. Inundation duration difference for simulations with starting pool elevations at Pensacola Dam at extreme, hypothetical values (734 to 757 feet PD) outside GRDA's anticipated operational range.

Appendix F.7 presents a set of inundation duration tables for simulations that used historical starting pool elevations at Pensacola Dam where inundation durations are compared for the various inflow events. Of the flow events analyzed, the 100-year event is the only event to exceed the flowage easement for Lake Hudson. The maximum difference in duration of downstream inundation is 3 hours for 100-year scenarios with starting stages at Pensacola Dam within GRDA's anticipated operational range. The maximum difference in duration of downstream inundation is 22 hours for 100-year scenarios with starting stages at Pensacola Dam that include extreme, hypothetical values.

5. Discussion of Results

Maximum WSELs, maximum inundation extents, and inundation durations 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 (21 Year) Flow Event

As shown in **Table 8**, when compared to all the flow events analyzed as part of this study, the September 1993 event represents the second largest in regard to releases from Pensacola Dam. According to the results of the OM, for this event, the maximum releases from Pensacola Dam are dependent on the starting stage of Pensacola Dam. For the scenarios analyzed, the peak stages at Kerr Dam follow a similar trend to the releases 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 within GRDA's anticipated operational range between 742 and 745 feet PD (maximum difference in peak stage of 0.12 feet). The peak stages at Kerr Dam differ by a maximum of 4.4 feet between scenarios that include starting stages at Pensacola Dam that include extreme, hypothetical values (734 to 757 feet PD).

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 1.1 to 3.4 feet for simulations with starting stages at Pensacola Dam within GRDA's anticipated operational range, and 6.6 to 10 feet for simulations with starting stages that include extreme, hypothetical values. 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 0.10 to 0.24 feet for starting stages at Pensacola Dam within GRDA's anticipated operational range, and 4.3 to 4.9 feet for starting stages that include extreme, hypothetical values. As shown in **Appendix E.1**, the differences in maximum inundation extent through the downstream portion of the DHM are not appreciable.

The flowage easement for Lake Hudson is not exceeded for any of the September 1993 event simulations, including those with extreme value, hypothetical starting stages at Pensacola Dam. Therefore, as shown in **Table F.1**, the duration of downstream inundation at every location for all the September 1993 simulations is zero (0).

5.2 June 2004 (1 Year) Event

As shown in **Table 8**, 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 results of the OM for the scenarios analyzed, the peak stages at Kerr Dam follow a similar trend to the releases from Pensacola Dam. As shown in **Table C.2** and **Figure D.2**, the peak stages at Kerr Dam for starting stages within GRDA's anticipated operational range (742 to 745 feet PD) differ by 1.3 feet. The peak stages at Kerr Dam differ by 13 feet when comparing simulations that include extreme, hypothetical values of starting stages at Pensacola Dam (734 to 757 feet PD).

For the June 2004 event, the variability in releases from Pensacola Dam due to the different starting stages leads to differences in the downstream maximum WSELs and maximum inundation extents (shown in **Appendix E.2**). These differences are most pronounced upstream of the Big Cabin Creek confluence (RM 66.78). For the simulations with starting stages at Pensacola Dam within GRDA's anticipated operational range (742 to 745 feet PD), the differences in maximum WSEL through this portion of the DHM range from 1.8 to 7.3 feet. For simulations with starting stages at Pensacola Dam that include extreme, hypothetical values the differences in maximum WSEL through this same portion of the DHM range from 14 feet to 20 feet. Because the portion of the DHM upstream of Big Cabin Creek 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.

The flowage easement for Lake Hudson is not exceeded for any of the June 2004 event simulations, including those with extreme, hypothetical value starting stages at Pensacola Dam. Therefore, as shown in **Table F.2**, the duration of downstream inundation at every location for all the June 2004 simulations is zero (0).

5.3 July 2007 (4 Year) Event

As shown in **Table 8**, 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 results of the OM and as shown in **Table C.3** and **Figure D.3**, the peak stages at Kerr Dam only differ slightly between the scenarios using starting stages at Pensacola Dam within GRDA's anticipated operational range of 742 to 745 feet PD (maximum difference in peak stage of 0.22 feet). The same can be said when comparing peak stages at Kerr Dam for scenarios with starting stages that include extreme, hypothetical values of 734 to 757 feet PD (maximum difference in peak stage of 0.26 feet).

For the July 2007 event, the variability in releases from Pensacola Dam due to the different starting stages leads to differences in the maximum downstream WSELs and inundation extents. As shown in **Table C.3**, these differences are most pronounced upstream of the Big Cabin Creek confluence where differences in maximum WSEL range from 0.69 to 1.9 feet for simulations with starting stages at Pensacola Dam within GRDA's anticipated operational range, and 0.96 to 3.8 feet for starting stages that include extreme, hypothetical values.

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.3**, downstream of the Strang Road Bridge (RM 63.32), the differences in maximum WSEL are consistent at approximately 0.20 feet for starting stages at Pensacola Dam within GRDA's anticipated operational range, and range from 0.20 to 0.35 feet for starting stages that include extreme, hypothetical values. As shown in **Appendix E.3**, the differences in maximum inundation extent through the downstream portion of the DHM are not appreciable, while the differences in maximum inundation extent through the upstream portion of the DHM are more pronounced.

The flowage easement for Lake Hudson is not exceeded for any of the July 2007 event simulations, including those with extreme, hypothetical value starting stages at Pensacola Dam. Therefore, as shown in **Table F.3**, the duration of downstream inundation at every location for all the July 2007 simulations is zero (0).

5.4 October 2009 (3 Year) Event

As shown in **Table 8**, 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 results of the OM for the scenarios analyzed, the peak stages at Kerr Dam follow a similar trend to the releases from Pensacola Dam. As shown in **Table C.4** and **Figure D.4**, the peak stages at Kerr Dam differ by 3.9 feet between the scenarios using starting stages at Pensacola Dam within GRDA's anticipated operational range (742 to 745 feet PD). The peak stages at Kerr Dam differ by approximately 5.8 feet between the scenarios using starting stages at Pensacola Dam that include extreme, hypothetical values (734 to 757 feet PD).

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**, for the scenarios using starting stages at Pensacola Dam within GRDA's anticipated operational range the differences in downstream maximum WSEL range from approximately 3.5 feet just downstream of Pensacola Dam, to approximately 4.0 feet near Spavinaw Creek (RM 60.2). For the scenarios using starting stages at Pensacola Dam that include extreme, hypothetical values, the differences in maximum downstream WSEL range from approximately 5.8 feet at Kerr Dam, to approximately 6.6 feet just downstream of Pensacola 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.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.

The flowage easement for Lake Hudson is not exceeded for any of the October 2009 event simulations, including those with extreme, hypothetical value starting stages at Pensacola Dam. Therefore, as shown in **Table F.4**, the duration of downstream inundation at every location for all the October 2009 simulations is zero (0).

5.5 December 2015 (15 Year) Event

As shown in **Table 8**, when compared to all the flow events analyzed as part of this study, the December 2015 event represents the third largest releases from Pensacola Dam. For this event, the maximum releases from Pensacola Dam are not dependent on the starting stage of Pensacola Dam for scenarios with starting stages at Pensacola Dam within GRDA's anticipated operational range (742 to 745 feet PD). This is because, according to the results of the OM, the peak outflows from Pensacola Dam are nearly identical for all starting stages within GRDA's anticipated operational range. Therefore, as shown in **Table C.5**, the peak stages at Kerr Dam are also identical for all scenarios with starting stages within GRDA's anticipated operational range.

For scenarios with starting stages at Pensacola Dam that include extreme, hypothetical values (734 to 757 feet PD), maximum releases from Pensacola Dam are dependent on the starting stage at Pensacola Dam. However, as shown in **Table C.5**, the peak stages at Kerr Dam only differ by a maximum of approximately 0.3 feet between the scenarios with starting stages at Pensacola Dam that include extreme, hypothetical values.

Because the peak releases from Pensacola Dam are identical for all starting stage combinations within GRDA's anticipated operational range, as shown in **Table C.5** the differences in the maximum WSELs are small throughout the DHM (maximum difference of 0.05 feet). For scenarios with starting stages that include extreme, hypothetical values, the differences in maximum downstream WSEL are less pronounced through Lake Hudson and range from 0.33 feet at Kerr Dam to 1.2 feet at RM 62. In the upstream portions of the DHM, the maximum differences in WSEL range from 1.5 feet just upstream of Strang Road Bridge (RM 63.3) to 9.9 feet just downstream of Pensacola Dam.

As shown in **Appendix E.5**, the maximum downstream inundation extents are identical for all scenarios with starting stages at Pensacola Dam within GRDA's anticipated operational range. Downstream of Strang Road Bridge, the inundation extents are nearly identical, including the scenarios with starting stages at Pensacola Dam that include extreme, hypothetical values. Upstream of Strang Road Bridge, the differences in inundation extents for the scenarios with starting stages that include extreme, hypothetical values are more pronounced.

The flowage easement for Lake Hudson is not exceeded for any of the December 2015 event simulations, including those with extreme, hypothetical value starting stages at Pensacola Dam. Therefore, as shown in **Table F.5**, the duration of downstream inundation at every location for all the December 2015 simulations is zero (0).

5.6 100-year Event

As shown in **Table 8**, 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. As shown in **Table C.6**, the differences in peak stage at Kerr Dam are negligible when comparing all the simulations (0.02 feet), including the simulations with starting stages at Pensacola Dam with extreme, hypothetical values (734 to 757 feet PD).

As shown in **Table C.6** and on **Figure D.6**, the maximum WSELs for the 100-year event for all starting stages at Pensacola Dam, even those with extreme, hypothetical values, are nearly identical. The maximum difference in downstream WSEL for scenarios with starting stages at Pensacola Dam within GRDA's anticipated operational range (742 to 745 feet PD) is 0.03 feet, and the maximum difference in WSEL for scenarios with starting stages that include extreme, hypothetical values is 0.05 feet. As such, the maximum downstream inundation extents shown in **Appendix E.6** are also nearly identical.

Of the flow events analyzed, the 100-year event is the only event to exceed the flowage easement for Lake Hudson. As shown in **Table F.6**, the flowage easement is only exceeded between approximately RM 69.7 and RM 73.3. At these locations, the maximum difference in duration of downstream inundation is 3 hours for scenarios with starting stages at Pensacola Dam within GRDA's anticipated operational range. The maximum difference in duration of downstream inundation is 22 hours for scenarios with starting stages at Pensacola Dam that include extreme, hypothetical values. Refer to Section 6 for a comparison between baseline and anticipated operations.

5.7 Comparison of Historical Starting Stages

As shown in **Table 8**, 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. 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 feet.

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 approximately 17 feet at the confluence to approximately 19 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 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 the inundation extents for the September 1993 and December 2015 events being nearly identical. 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 event resulting in a much smaller inundation extent compared to the other four events.

The flowage easement for Lake Hudson is not exceeded for any of the events simulated with historical starting stages at Pensacola. Therefore, as shown in **Table F.7**, the duration of downstream inundation at every location for all the events simulated with historical starting stages at Pensacola Dam is zero (0).

6. Anticipated Operations Analysis

As proposed in Section 2.6.5 of the H&H Study RSP, "an additional suite of model runs following the same parameters" was run for the operational scenario anticipated by GRDA for Pensacola Dam. As discussed in Section 1.6.2 of GRDA's December 29, 2021 filing with FERC, GRDA anticipates the following operational parameters will apply for Pensacola Dam during the new license term:

1. GRDA will no longer utilize a rule curve with seasonal target elevations.
2. GRDA will maintain the reservoir between elevations 742 and 745 feet PD for purposes of normal hydropower operations. While hydropower operations may occur when the water surface elevations are outside this range (e.g. maintenance drawdowns and high-flow events), GRDA expects to generally maintain water surface elevations between 742 and 745 feet PD during normal Project operations.
3. Instead of managing the Project to target a specified seasonal elevation, GRDA's anticipated operations may fluctuate reservoir levels within the elevational range of 742 and 745 feet PD, for purposes of responding to grid demands, market conditions, and the public interest, such as environmental and recreational considerations.
4. GRDA will continue to adhere to the USACE's direction on flood control operations in accordance with the Water Control Manual.

This operational scenario is henceforth referred to as "anticipated operations". To characterize the impact of anticipated operations on the range of flow events and Pensacola Dam starting pool elevations studied, the following scenarios were simulated:

1. June 2004 (1 year) inflow event, starting pool elevation of 734.0 feet PD,
2. June 2004 (1 year) inflow event, starting pool elevation of 757.0 feet PD,
3. July 2007 (4 year) inflow event, using the OM period of record starting pool elevation,
4. 100-year inflow event, starting pool elevation of 734.0 feet PD, and
5. 100-year inflow event, starting pool elevation of 757.0 feet PD.

These 5 scenarios were simulated with (1) baseline operations and (2) anticipated operations for a total of 10 simulations. The suite of simulations represents:

1. The minimum and maximum starting pool elevations requested by FERC,
2. The smallest and largest inflow events requested by FERC, and
3. An event of historical importance to communities upstream of Pensacola Dam that is within the studied range of starting pool elevations and within the studied range of inflow magnitudes. The starting pool elevation at Pensacola Dam for this event was not arbitrary, but came out of the operational simulations, making it the most integrous comparison of the effects of anticipated operations versus baseline operations on maximum WSEL in this study.

Results from the analysis are presented in **Appendix G**. The input hydrographs to the DHM for this suite of simulations is included in **Appendix G.1**. Tabulated results of maximum downstream WSEL are included in **Appendix G.2**. Plots of maximum downstream WSEL profiles are included in **Appendix G.3**. Tabulated results of downstream inundation duration are presented in **Appendix G.4**.

Table 13 presents a summary of maximum increases in peak WSEL in the DHM for anticipated operations as compared to baseline operations. The following findings can be concluded from these results:

1. For the June 2004 (1 year) event, there are increases in peak downstream WSEL for a starting stage at Pensacola Dam of 734 feet PD. The increases occur through the upstream portion of the DHM (upstream of RM 69), with the largest increase being 0.53 feet. These increases are due to slight variations in the pattern of powerhouse releases at Pensacola Dam for the anticipated operations, but flows are contained within the riverbanks. No spillway releases from Pensacola Dam occur for this scenario.
2. For the June 2004 (1 year) flow event, there are no increases in peak downstream WSEL for a starting stage at Pensacola Dam of 757 feet PD.
3. For the July 2007 (4 year) flow event, there are no increases in peak downstream WSEL for the OM period of record starting stages at Pensacola Dam.
4. For the 100-year event, the maximum increase in peak downstream WSEL for a starting stage at Pensacola Dam of 734 feet PD is 0.01 feet.
5. For the 100-year inflow event, there are no increases in peak downstream WSEL for a starting stage at Pensacola Dam of 757 feet PD.

TABLE 13. SUMMARY OF INCREASES IN DOWNSTREAM WSEL DUE TO ANTICIPATED OPERATIONS AS COMPARED TO BASELINE OPERATIONS.

Simulation	Maximum Increase in Peak WSEL Due to Anticipated Operations (ft)
June 2004 (1 year) event, starting pool elevation of 734.0 feet PD	0.53*
June 2004 (1 year) event, starting pool elevation of 757.0 feet PD	0.00
July 2007 (4 year) event, period of record starting pool elevation	0.00
100-year event, starting pool elevation of 734.0 feet PD	0.01
100-year event, starting pool elevation of 757.0 feet PD	0.00

**Flows contained within riverbanks, no spillway releases from Pensacola Dam.*

The results show that anticipated operations have an immaterial impact on downstream WSELs as compared to baseline operations.

Plots of maximum downstream WSEL profiles from the analysis of anticipated operations are included in **Appendix G.3**. For the June 2004 (1 year) event and the 100-year event, the plots show peak water surface elevation profiles for the simulations with starting stages at Pensacola Dam of 734 and 757 feet PD (the minimum and maximum starting stages requested by FERC) for both baseline and anticipated operations. The dotted lines plot the increase in WSEL due to anticipated operations as compared to baseline operations and are plotted on the secondary y-axis. In some cases, the dotted line is not visible because the increase in peak WSEL due to anticipated operations is zero. Similarly, a plot is also included in **Appendix G.3** to show the maximum downstream WSEL profiles for baseline and anticipated operations for the July 2007 (4 year) event. The plots show how anticipated operations have an immaterial impact on downstream WSELs as compared to baseline operations for a suite of simulations that spans the FERC-requested range of starting pool elevations at Pensacola Dam and flow event magnitudes.

As shown in **Appendix G.4**, the maximum difference in duration of downstream inundation is 1 hour when comparing baseline operations to anticipated operations. This difference only occurs for the 100-year event as it is the only flow event to exceed the flowage easements.

Inundation maps are presented in **Appendix E**. Based on the maximum downstream WSELs, no additional inundation maps were created for this suite of analyses. While the results do show an increase in Max WSEL of up to 0.53 feet for the June 2004 (1 year) event with a starting stage of 734 feet PD, the increase is contained within the river channel and therefore the difference would not effectively be displayed on an inundation map. For the other scenarios, the maximum difference in WSEL is 0.01 feet and also cannot be effectively displayed on an inundation map. Therefore, for the purposes of this study, the extent of downstream inundation for anticipated operations is virtually identical to the extent of downstream inundation for baseline operations.

7. Conclusions

The results of the DHM demonstrate that initial stages at the Project within GRDA's anticipated and extreme, hypothetical operational ranges 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).

However, comparing anticipated operations to baseline operations for a suite of simulations that spanned the FERC-requested range of starting pool elevations and inflow event magnitudes, the results of the DHM demonstrate that anticipated operations have an immaterial impact as compared to baseline operations.

8. References

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APPENDIX A:
SIMULATED HYDROGRAPHS

APPENDIX A.1:

SEPTEMBER 1993 (21 YEAR) EVENT SIMULATED HYDROGRAPHS

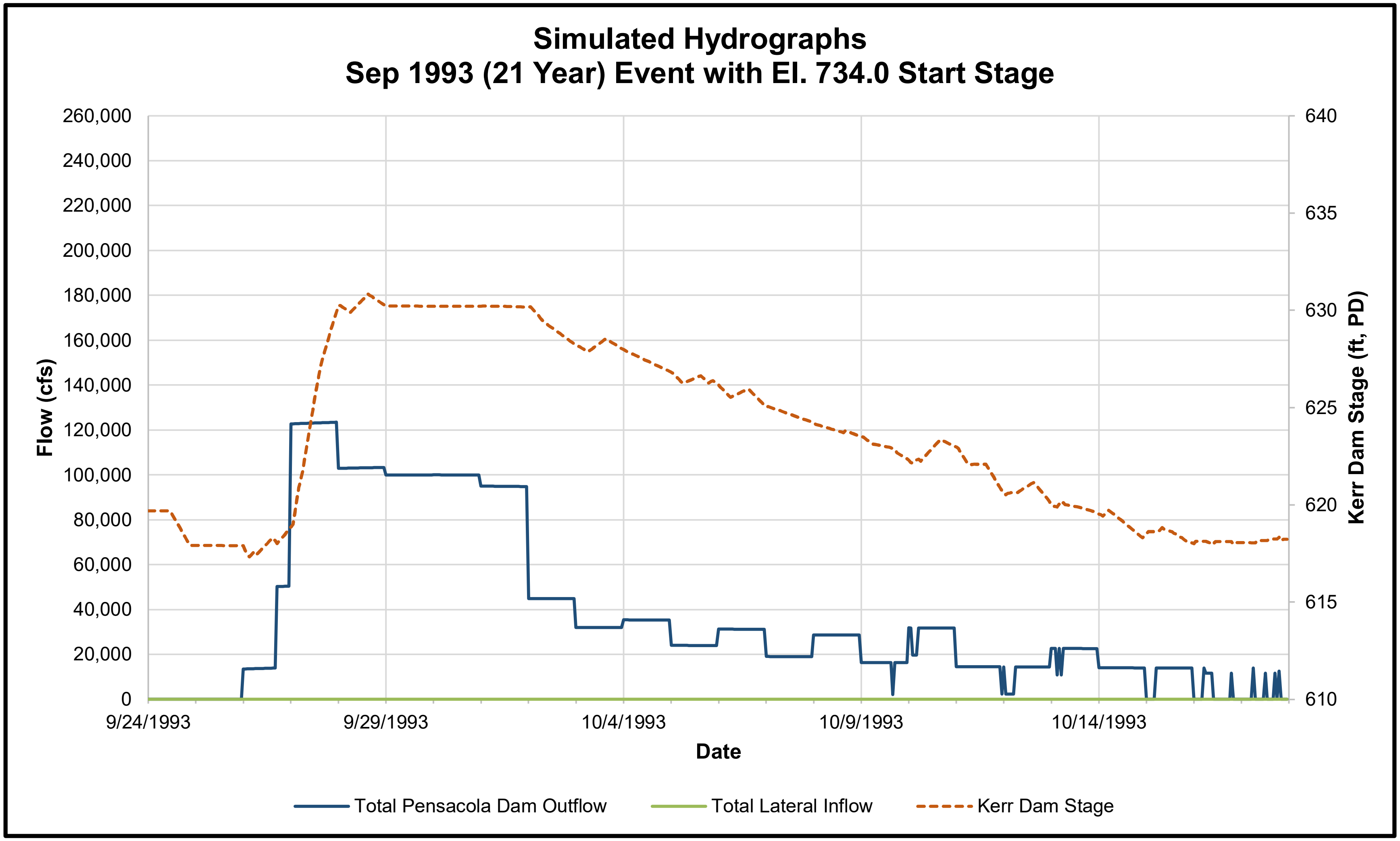


Figure A.1. Simulated hydrograph for the September 1993 (21 year) event with El. 734.0 starting stage at Pensacola Dam.

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 (21 year) event.*

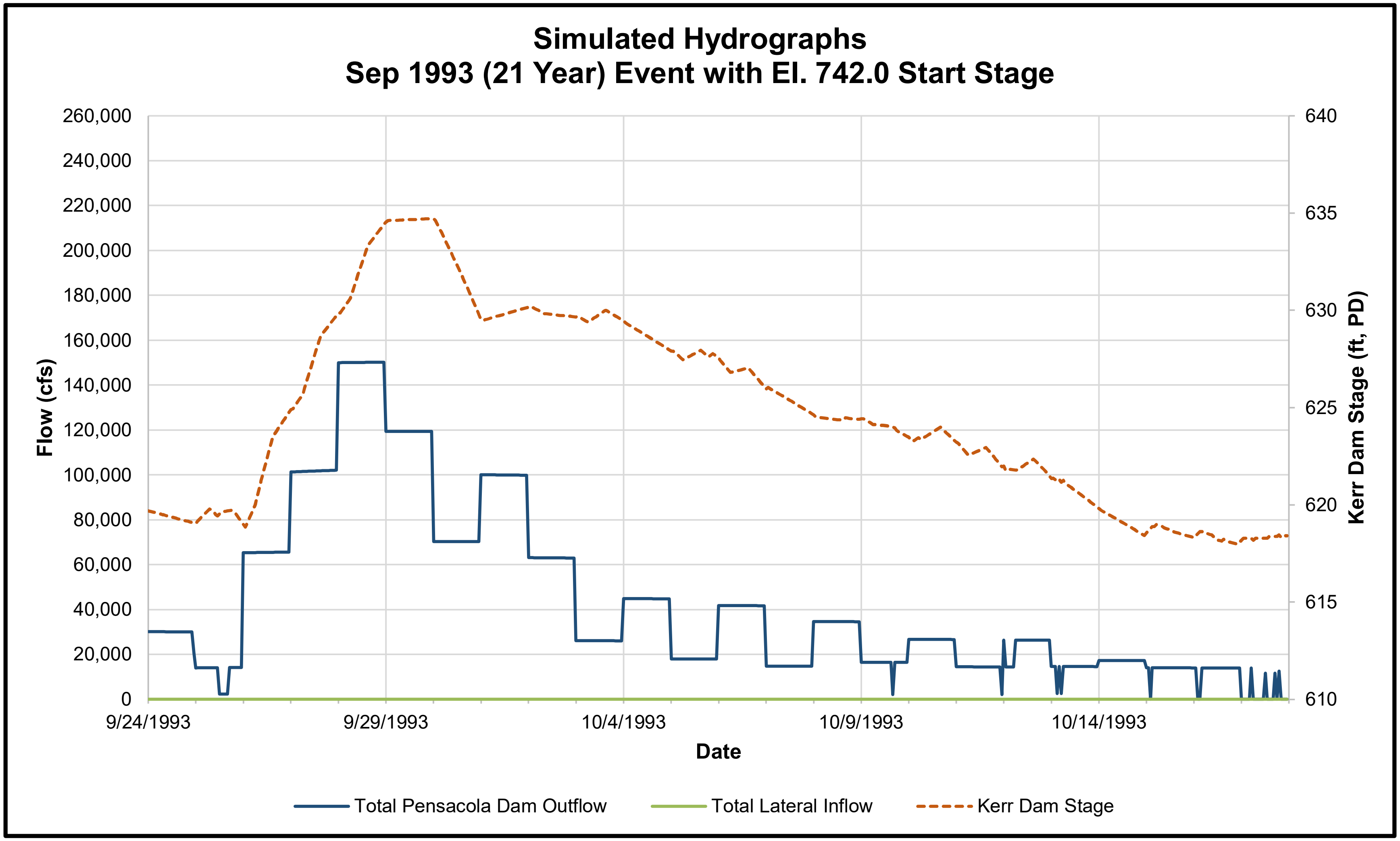


Figure A.2. Simulated hydrograph for the September 1993 (21 year) event with El. 742.0 starting stage at Pensacola Dam.

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 (21 year) event.*

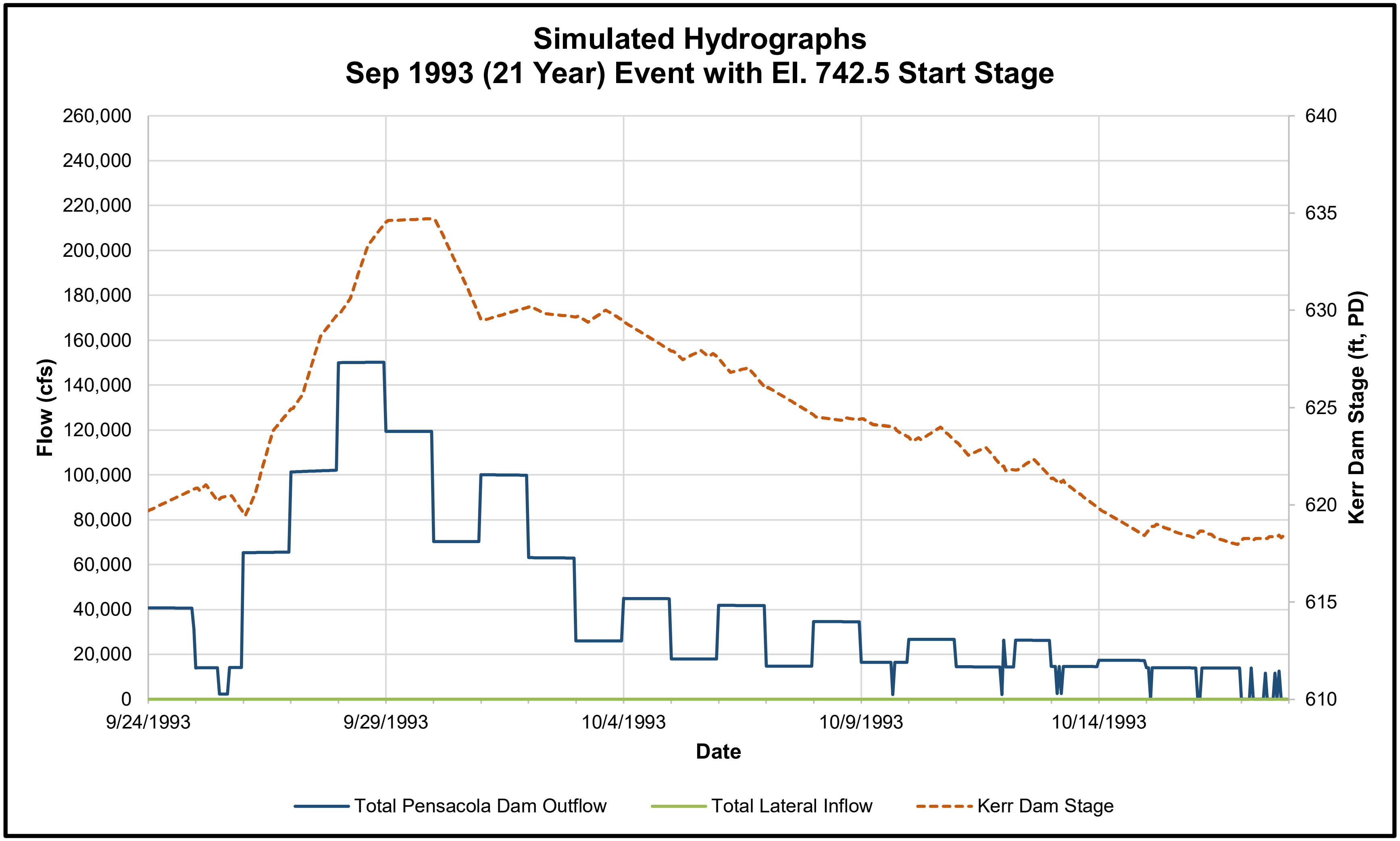


Figure A.3. Simulated hydrograph for the September 1993 (21 year) event with El. 742.5 starting stage at Pensacola Dam.

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 (21 year) event.*

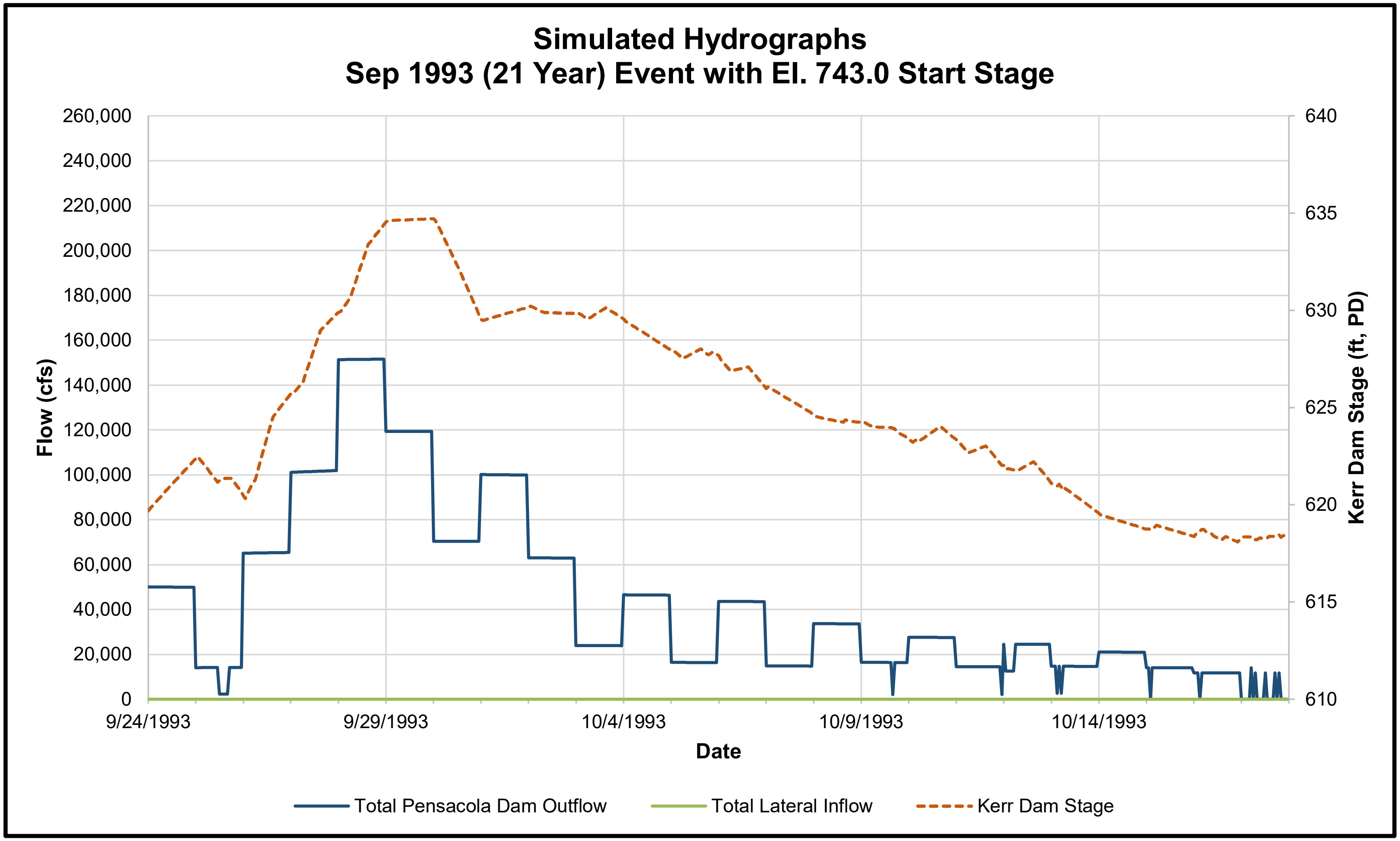


Figure A.4. Simulated hydrograph for the September 1993 (21 year) event with El. 743.0 starting stage at Pensacola Dam.

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 (21 year) event.*

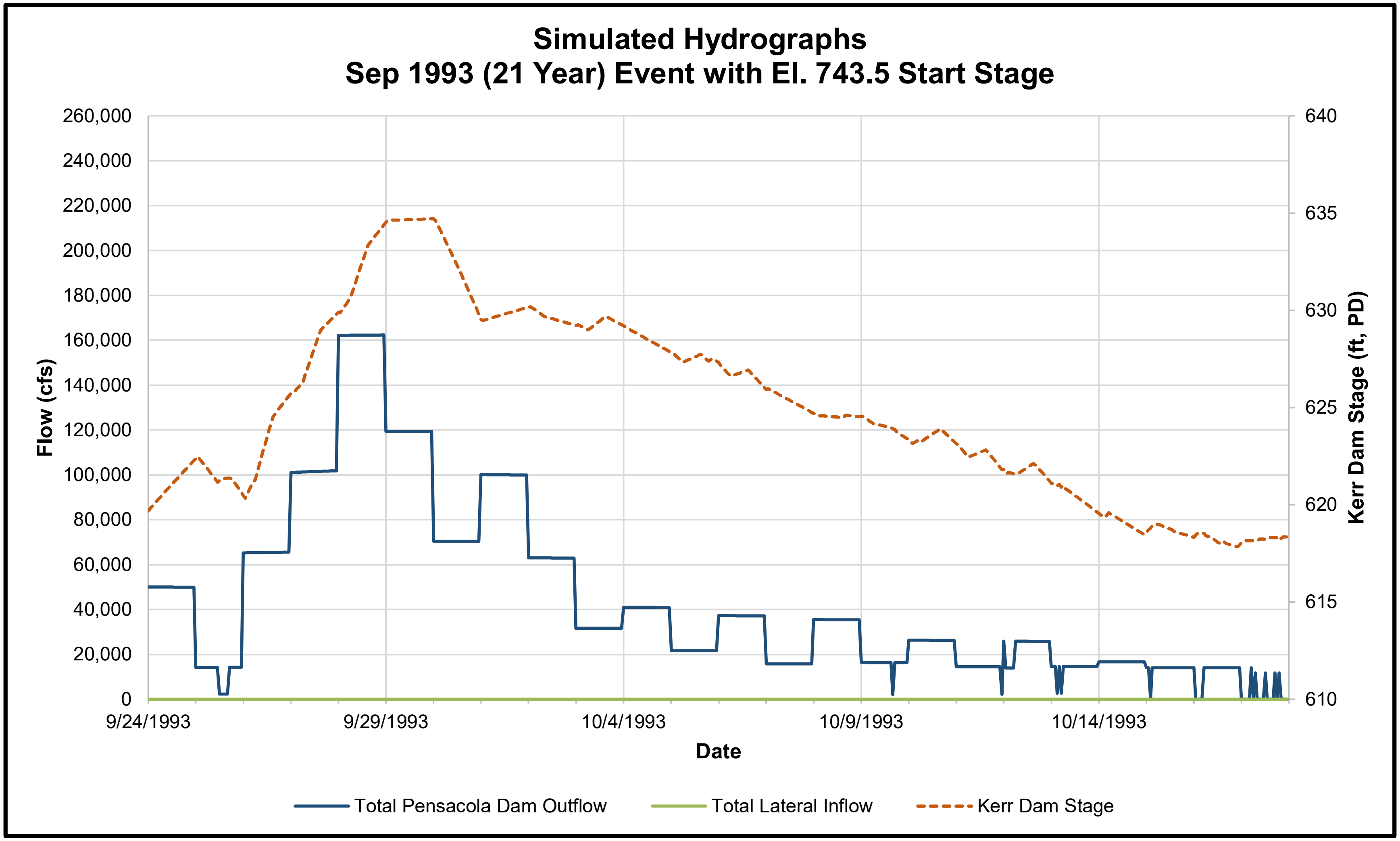


Figure A.5. Simulated hydrograph for the September 1993 (21 year) event with El. 743.5 starting stage at Pensacola Dam.

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 (21 year) event.*

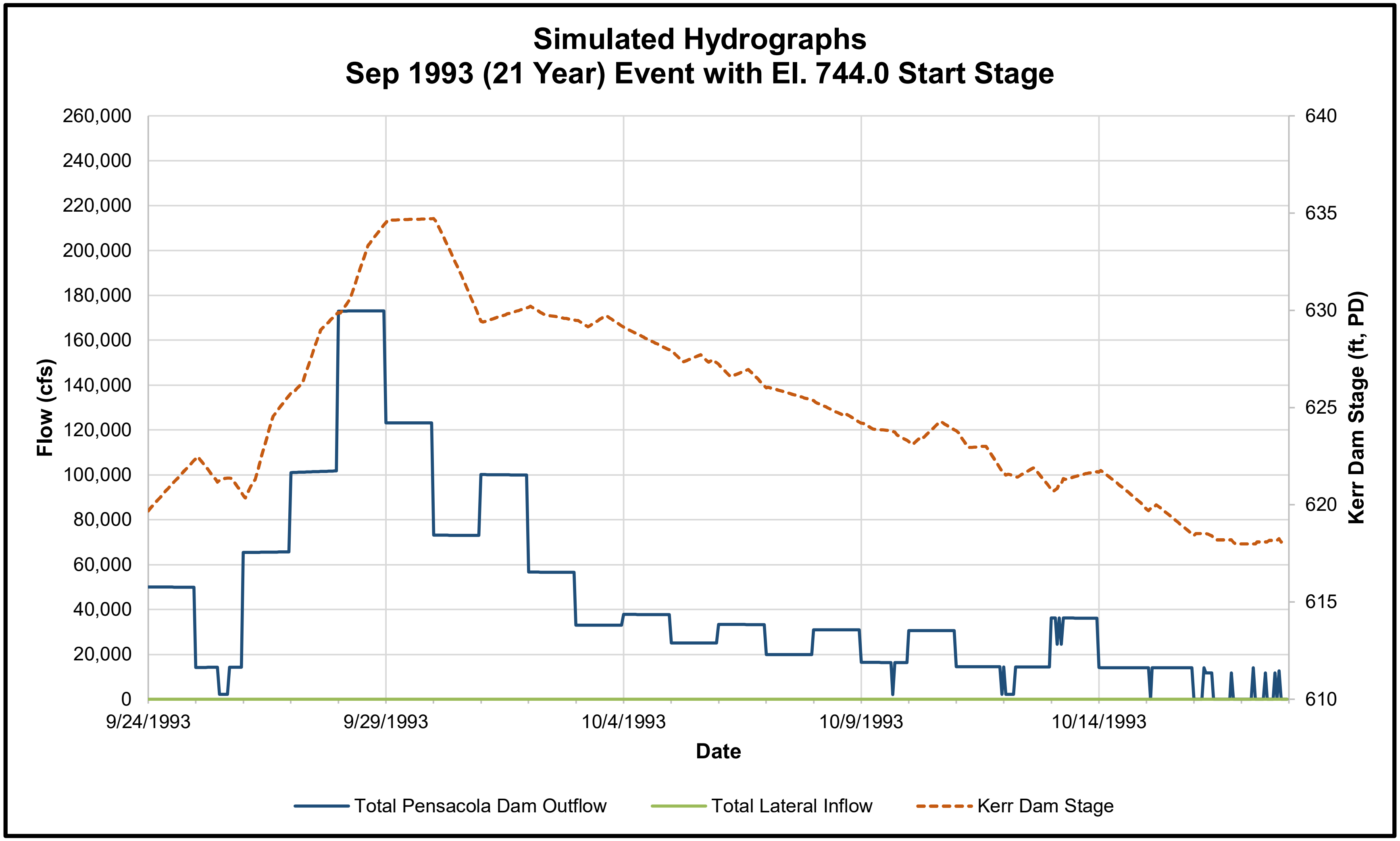


Figure A.6. Simulated hydrograph for the September 1993 (21 year) event with El. 744.0 starting stage at Pensacola Dam.

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 (21 year) event.*

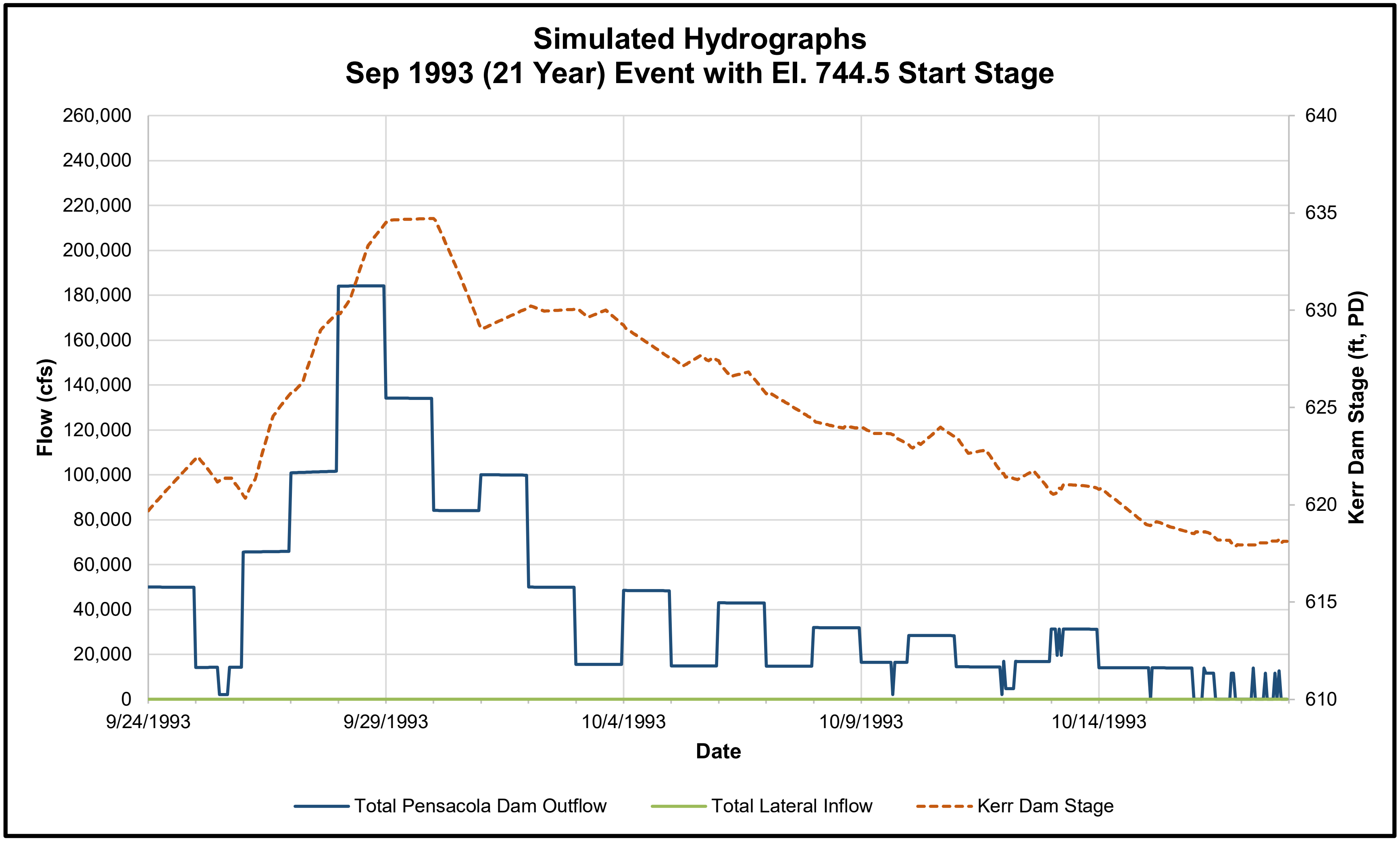


Figure A.7. Simulated hydrograph for the September 1993 (21 year) event with El. 744.5 starting stage at Pensacola Dam.

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 (21 year) event.*

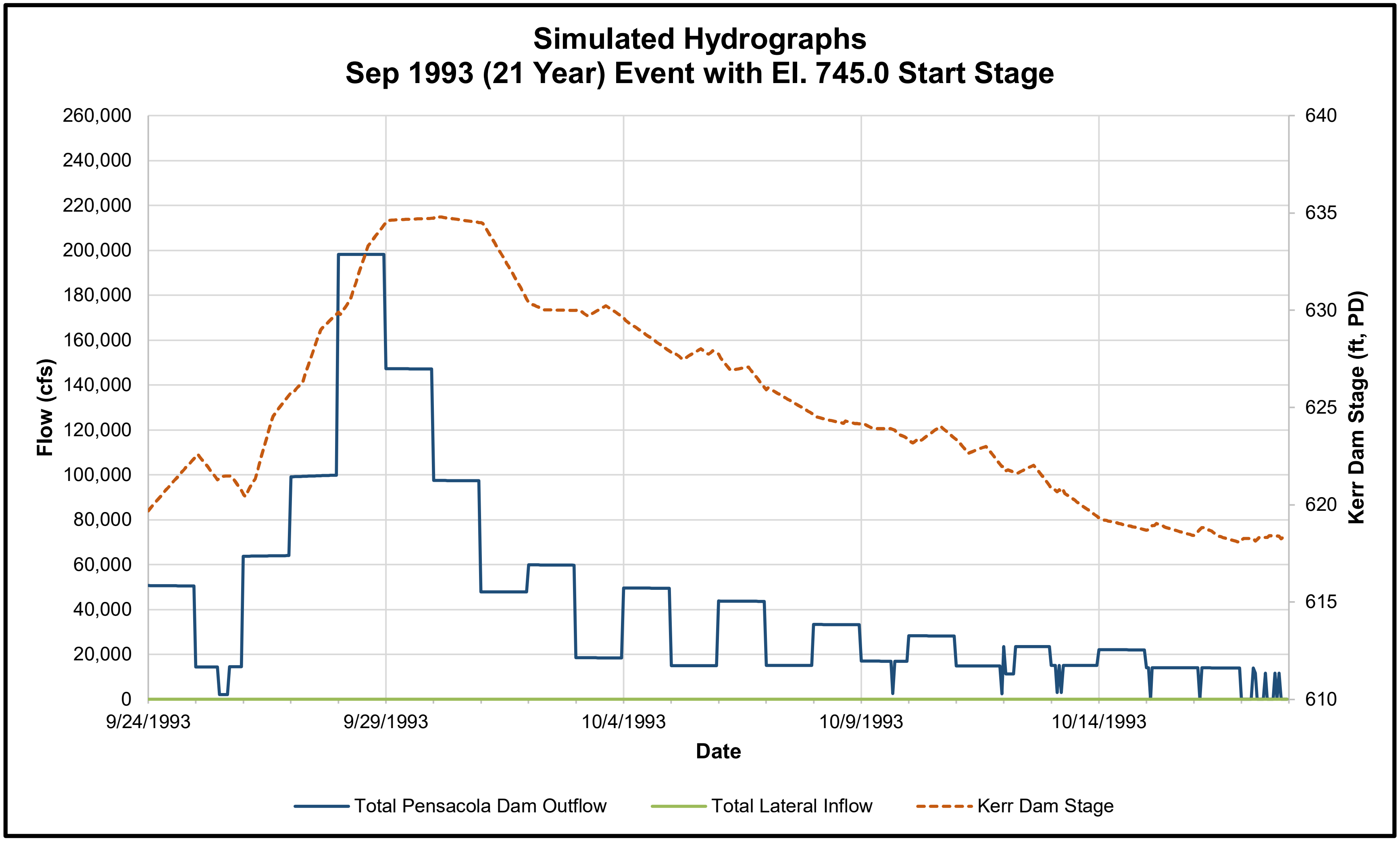


Figure A.8. Simulated hydrograph for the September 1993 (21 year) event with El. 745.0 starting stage at Pensacola Dam.

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 (21 year) event.*

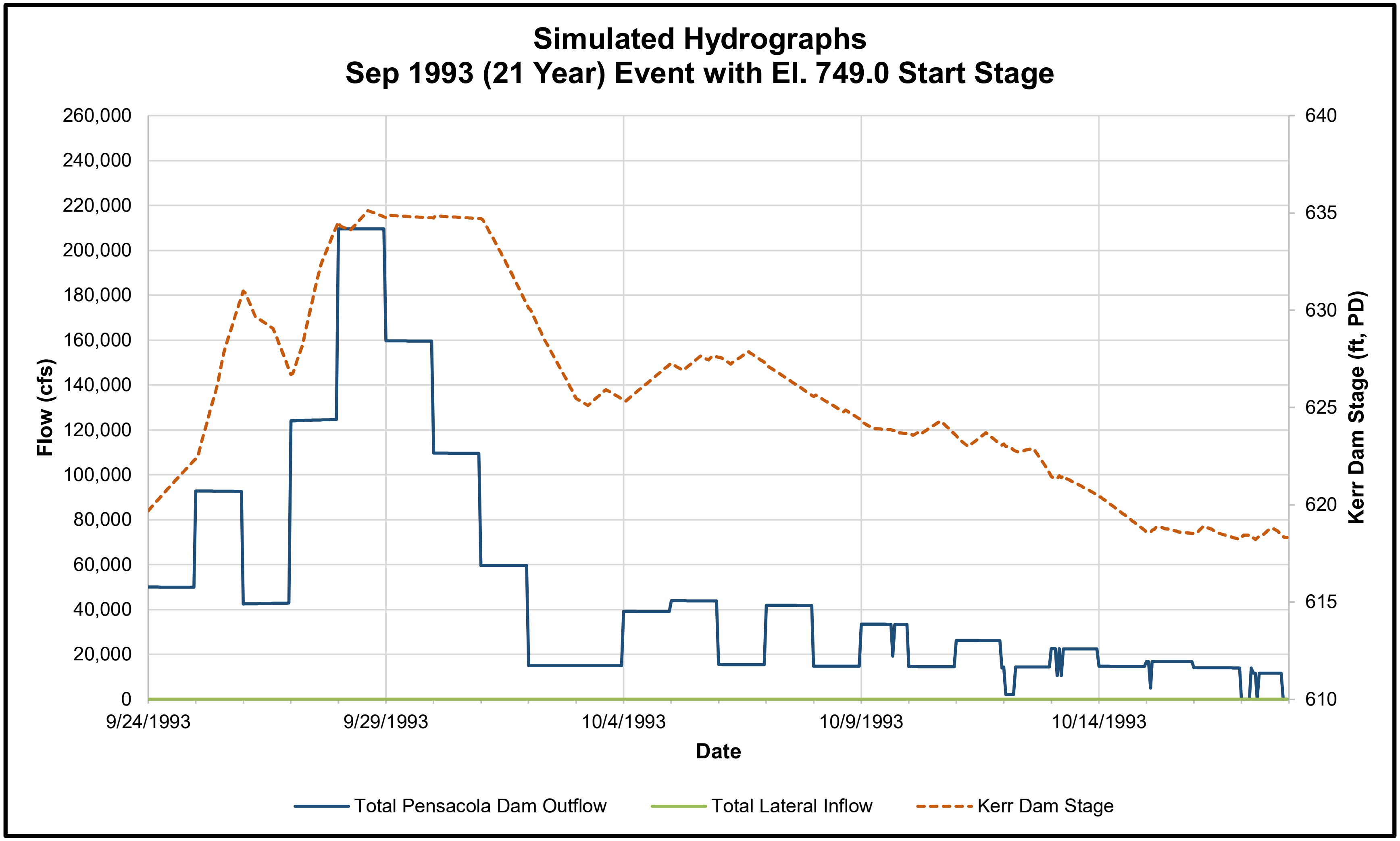


Figure A.9. Simulated hydrograph for the September 1993 (21 year) event with El. 749.0 starting stage at Pensacola Dam.

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 (21 year) event.*

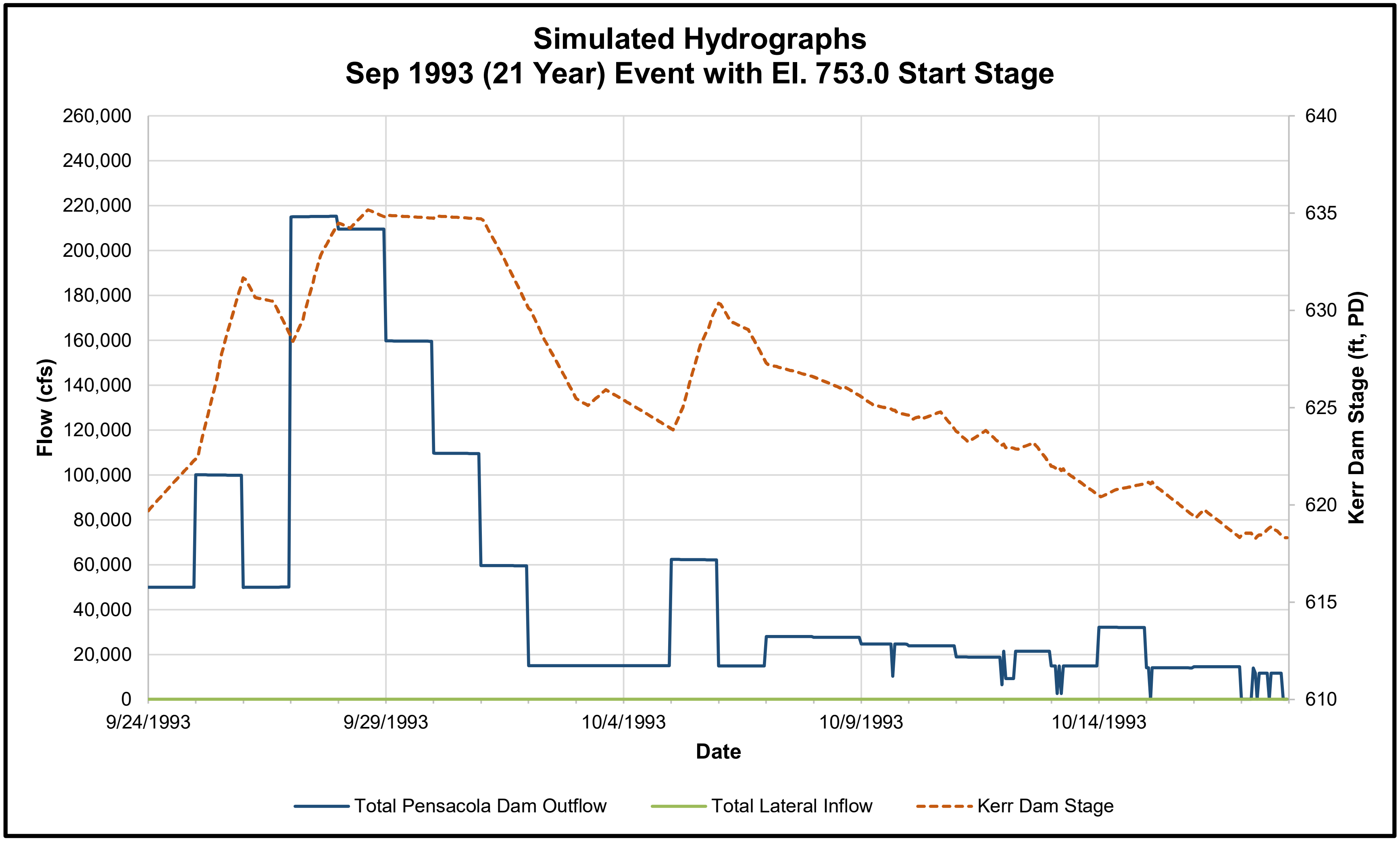


Figure A.10. Simulated hydrograph for the September 1993 (21 year) event with El. 753.0 starting stage at Pensacola Dam.

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 (21 year) event.*

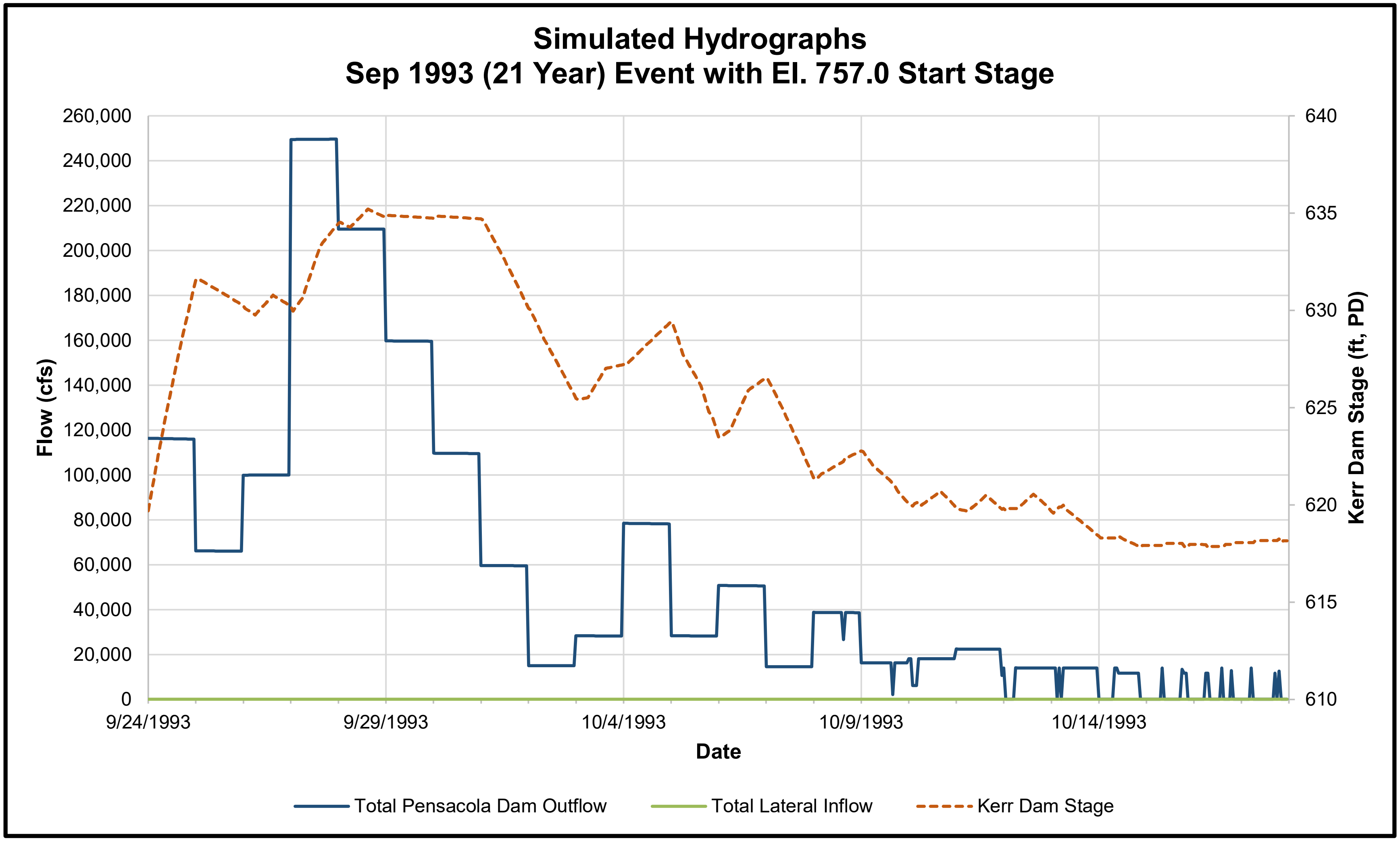


Figure A.11. Simulated hydrograph for the September 1993 (21 year) event with El. 757.0 starting stage at Pensacola Dam.

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 (21 year) event.*

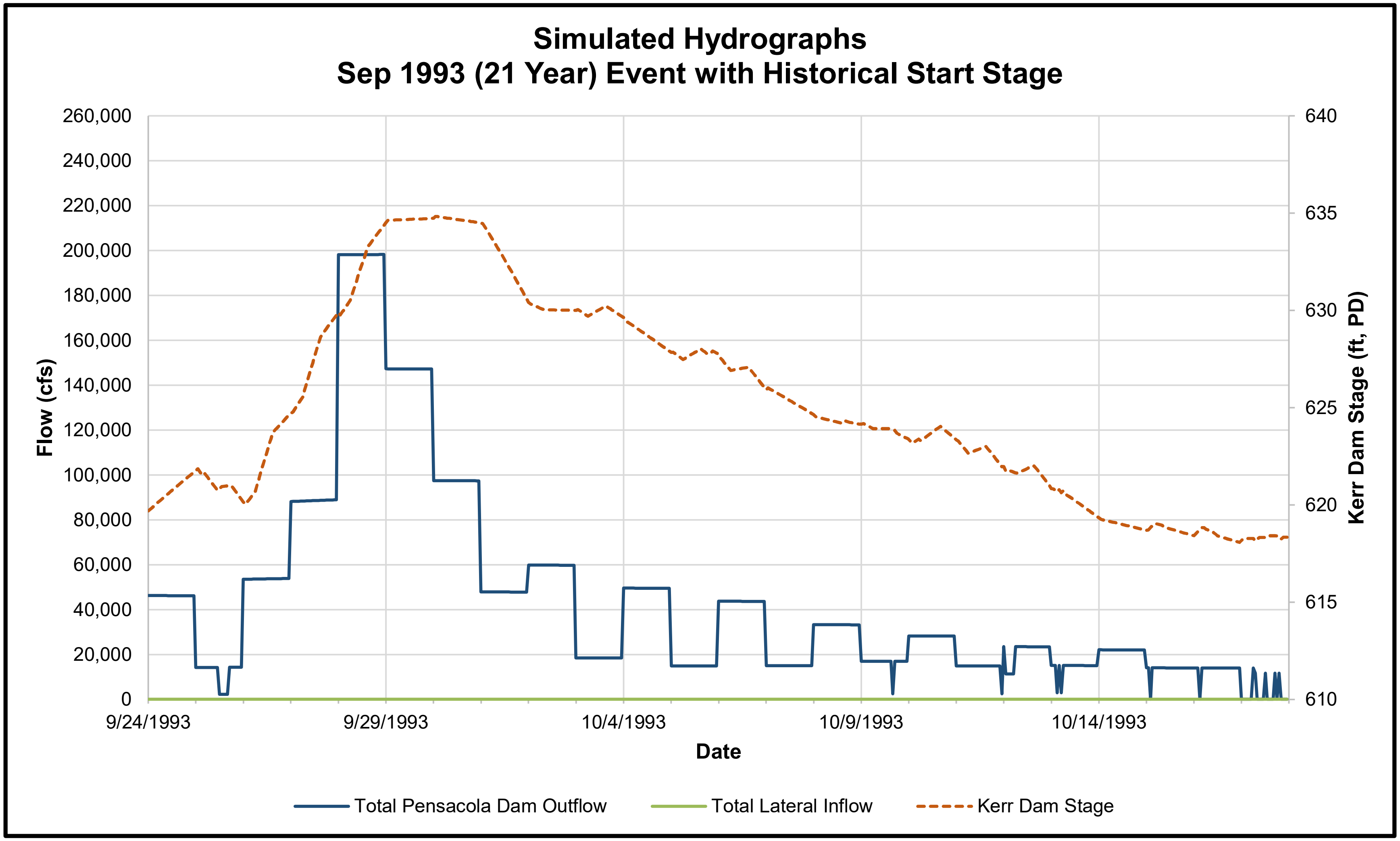


Figure A.12. Simulated hydrograph for the September 1993 (21 year) event with historical starting stage at Pensacola Dam.

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 (21 year) event.*

APPENDIX A.2:
JUNE 2004 (1 YEAR) EVENT SIMULATED HYDROGRAPHS

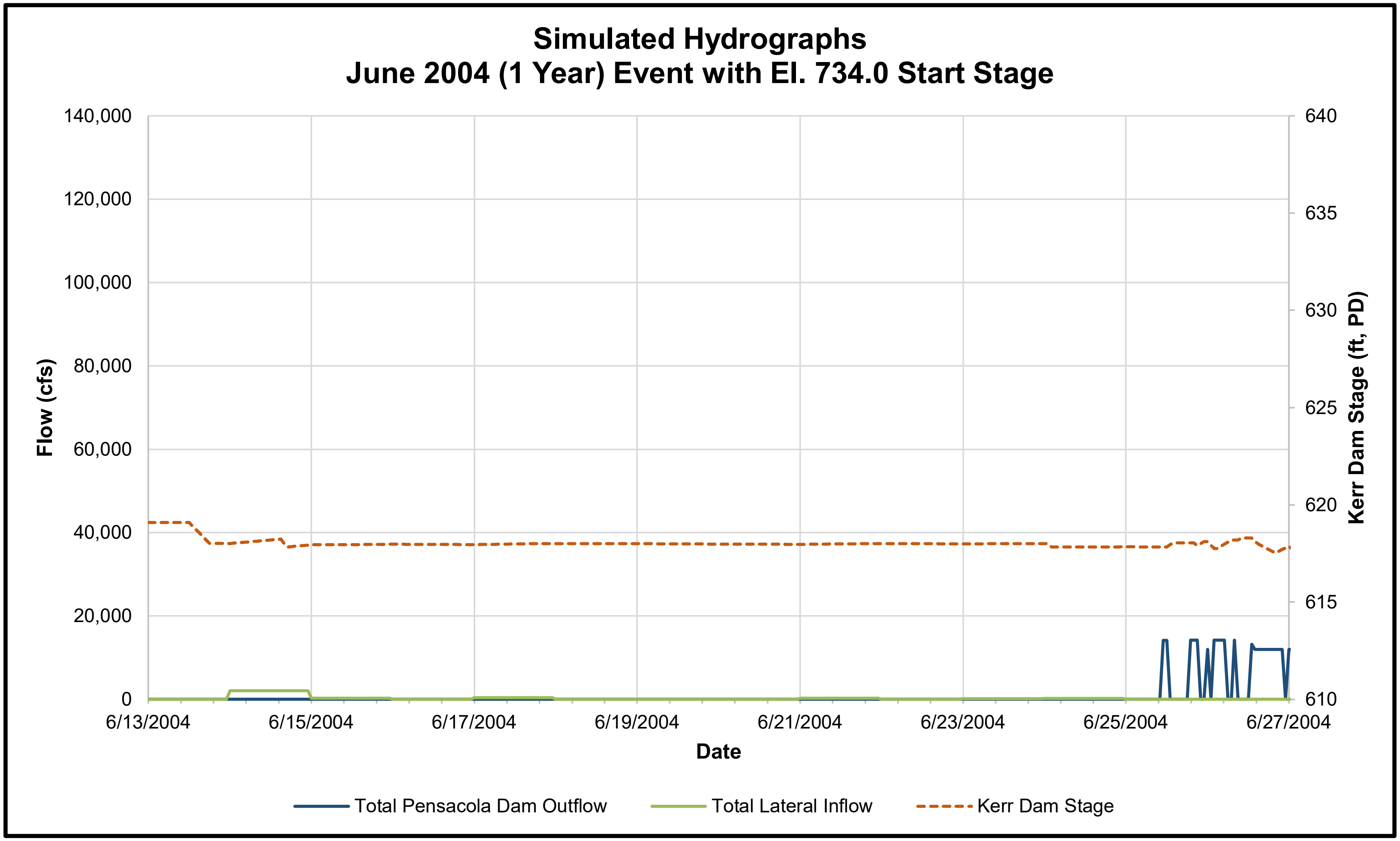


Figure A.13. Simulated hydrograph for the June 2004 (1 year) event with El. 734.0 starting stage at Pensacola Dam.

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.

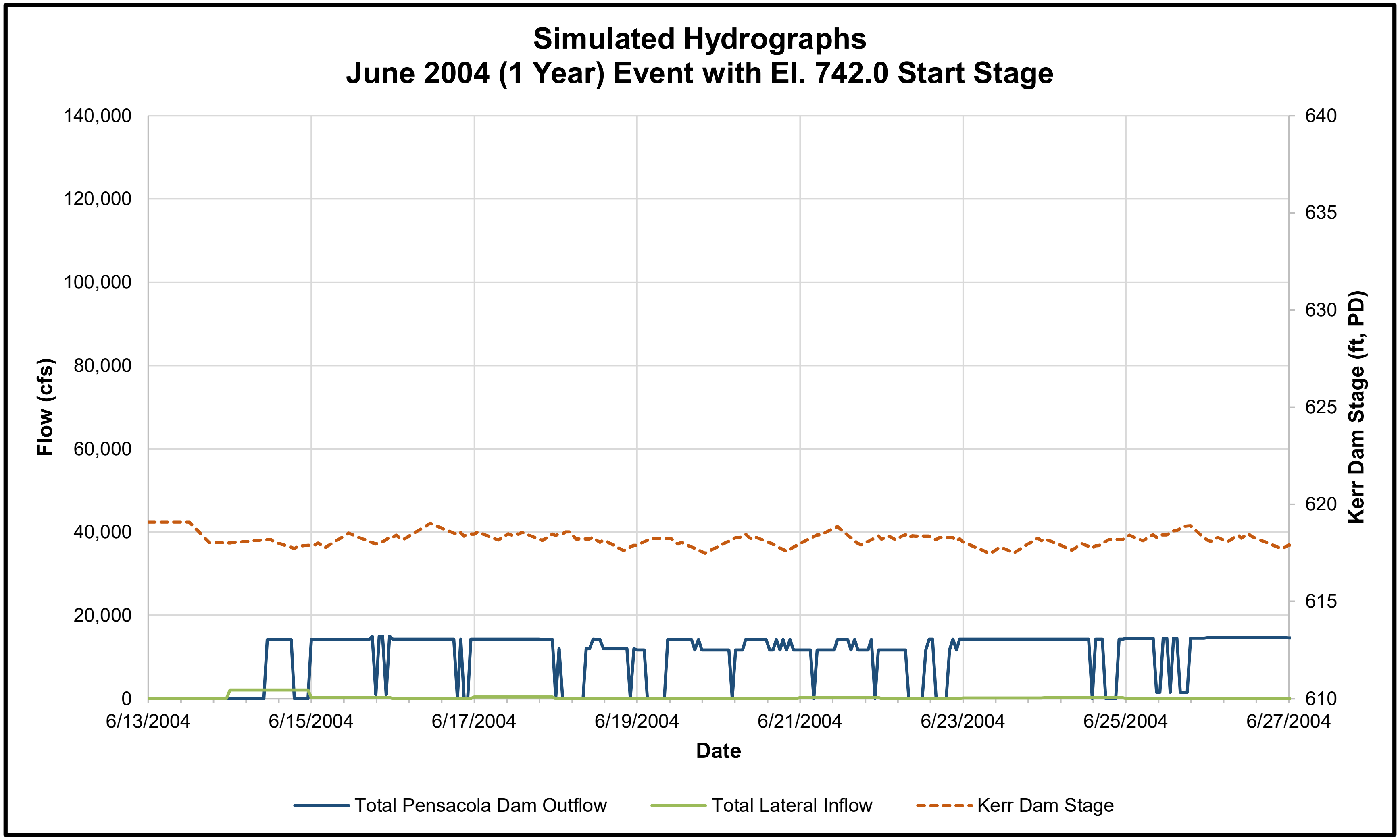


Figure A.14. Simulated hydrograph for the June 2004 (1 year) event with El. 742.0 starting stage at Pensacola Dam.

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.

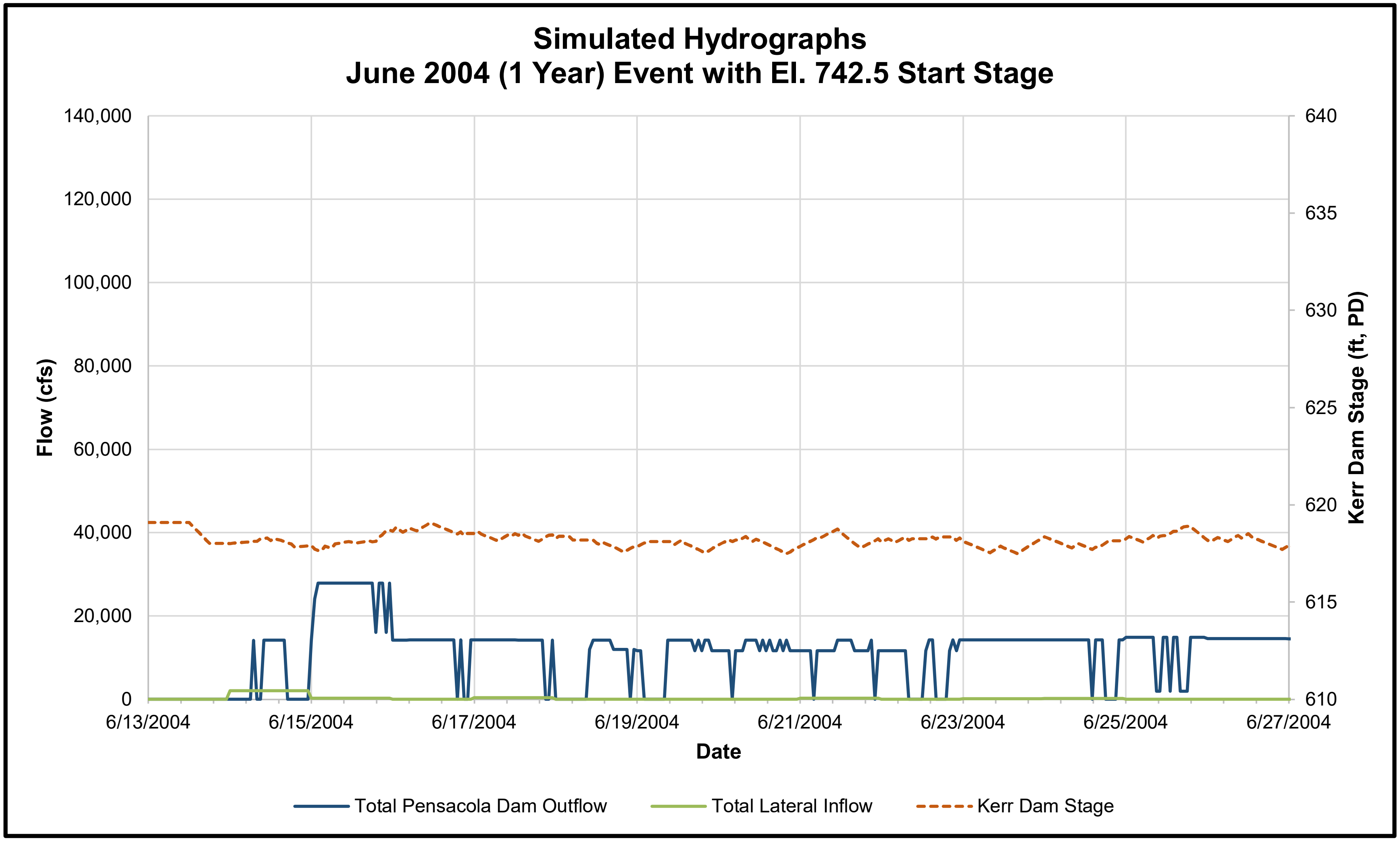


Figure A.15. Simulated hydrograph for the June 2004 (1 year) event with El. 742.5 starting stage at Pensacola Dam.

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.

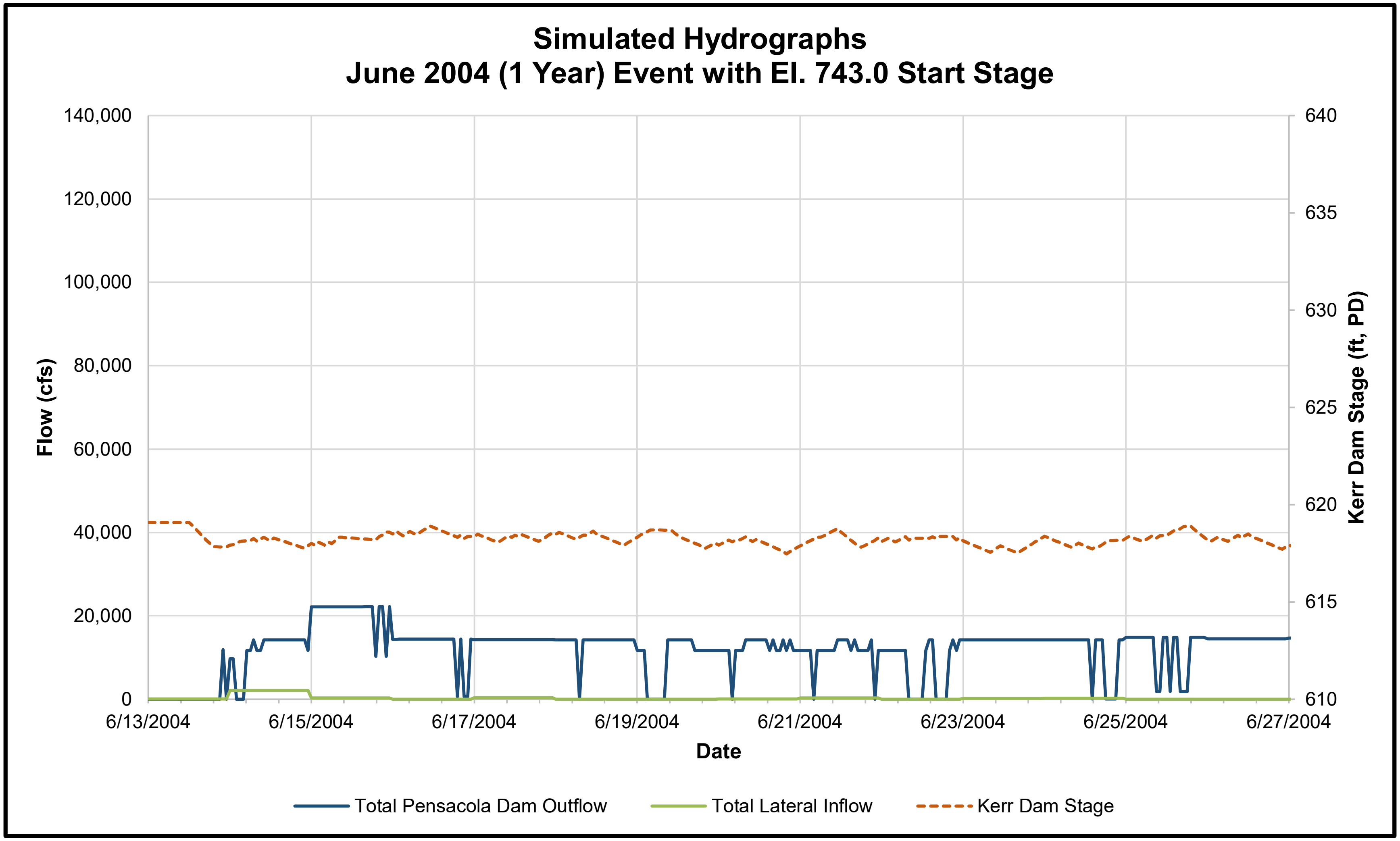


Figure A.16. Simulated hydrograph for the June 2004 (1 year) event with El. 743.0 starting stage at Pensacola Dam.

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.

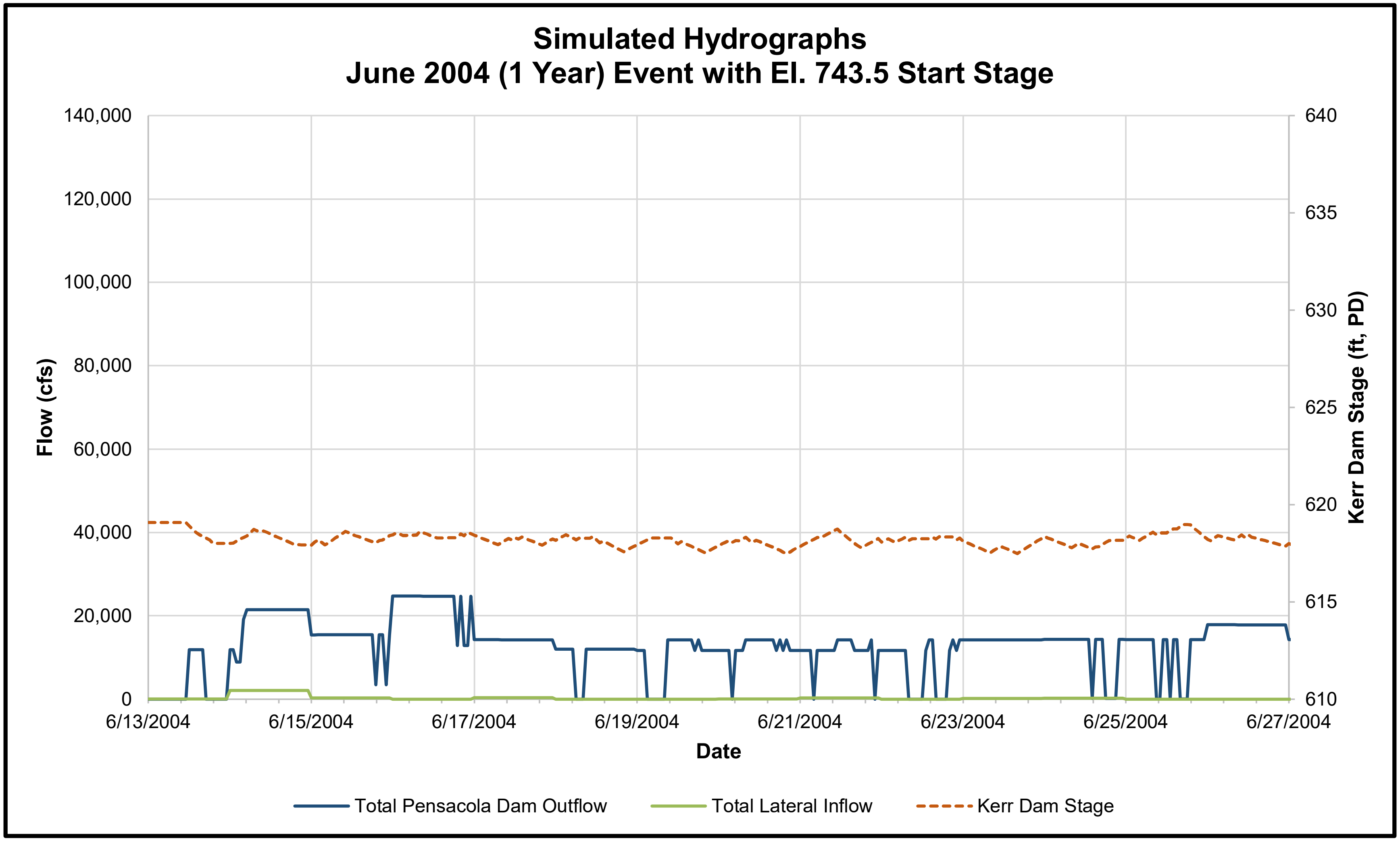


Figure A.17. Simulated hydrograph for the June 2004 (1 year) event with El. 743.5 starting stage at Pensacola Dam.

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.

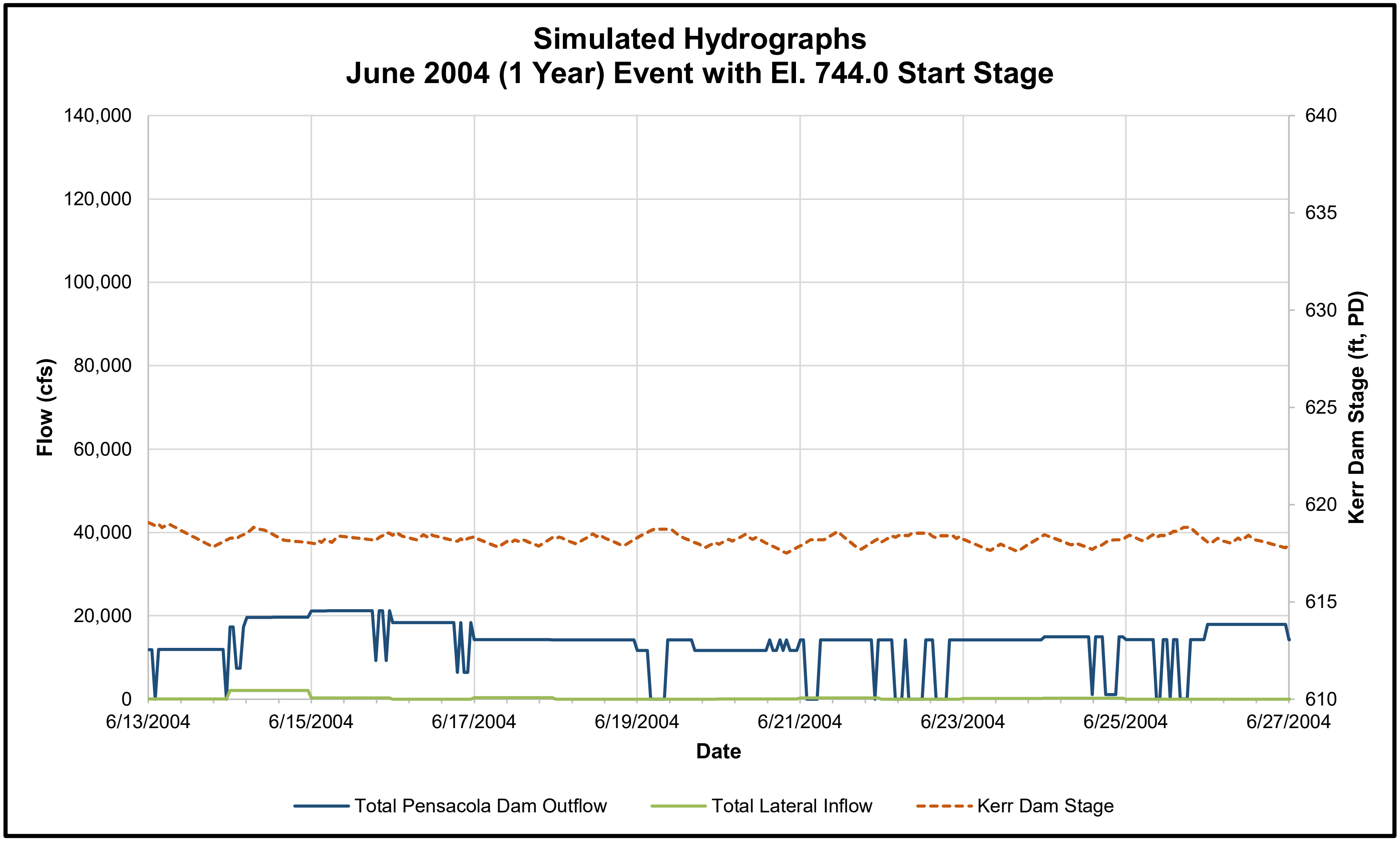


Figure A.18. Simulated hydrograph for the June 2004 (1 year) event with El. 744.0 starting stage at Pensacola Dam.

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.

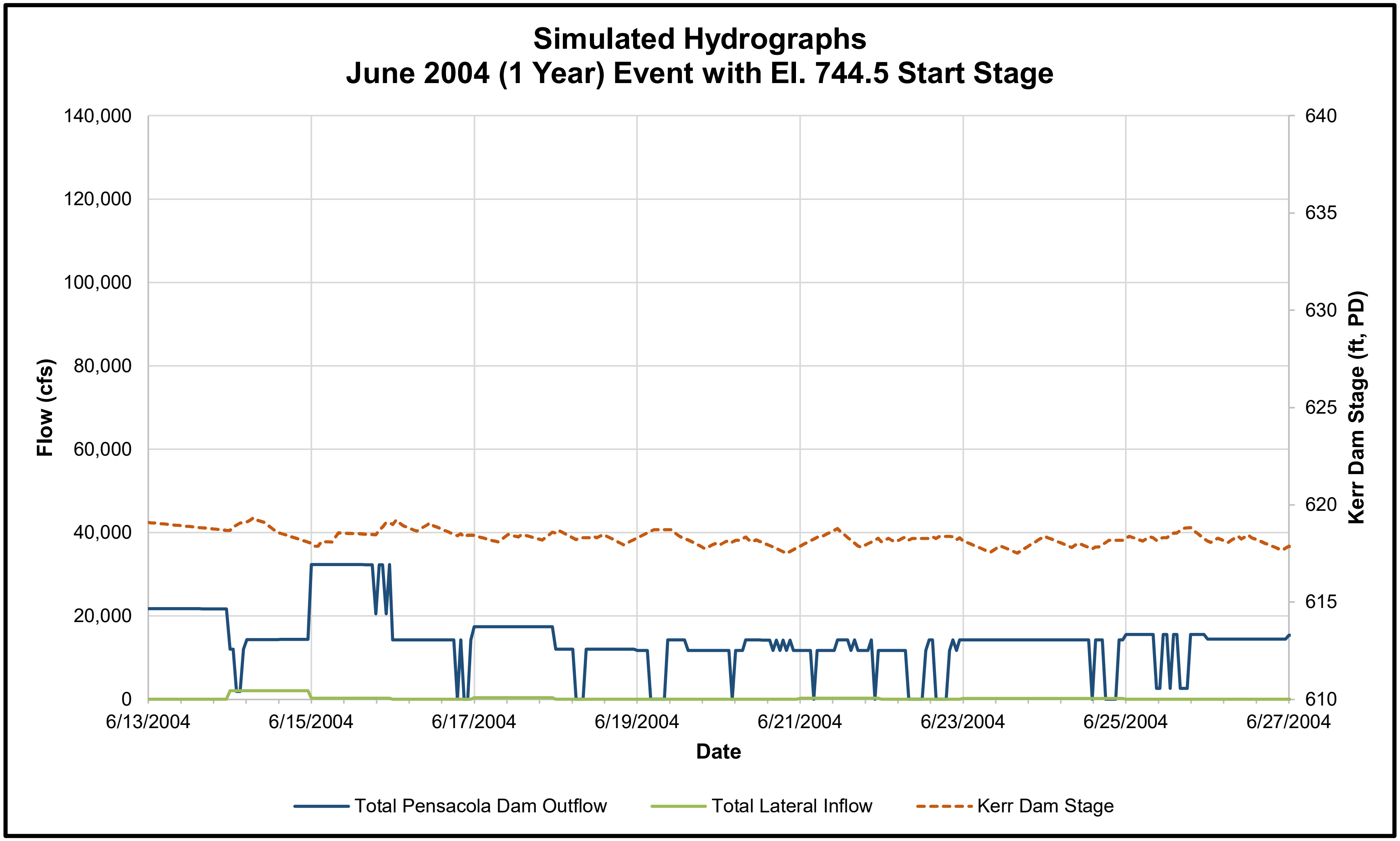


Figure A.19. Simulated hydrograph for the June 2004 (1 year) event with El. 744.5 starting stage at Pensacola Dam.

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.

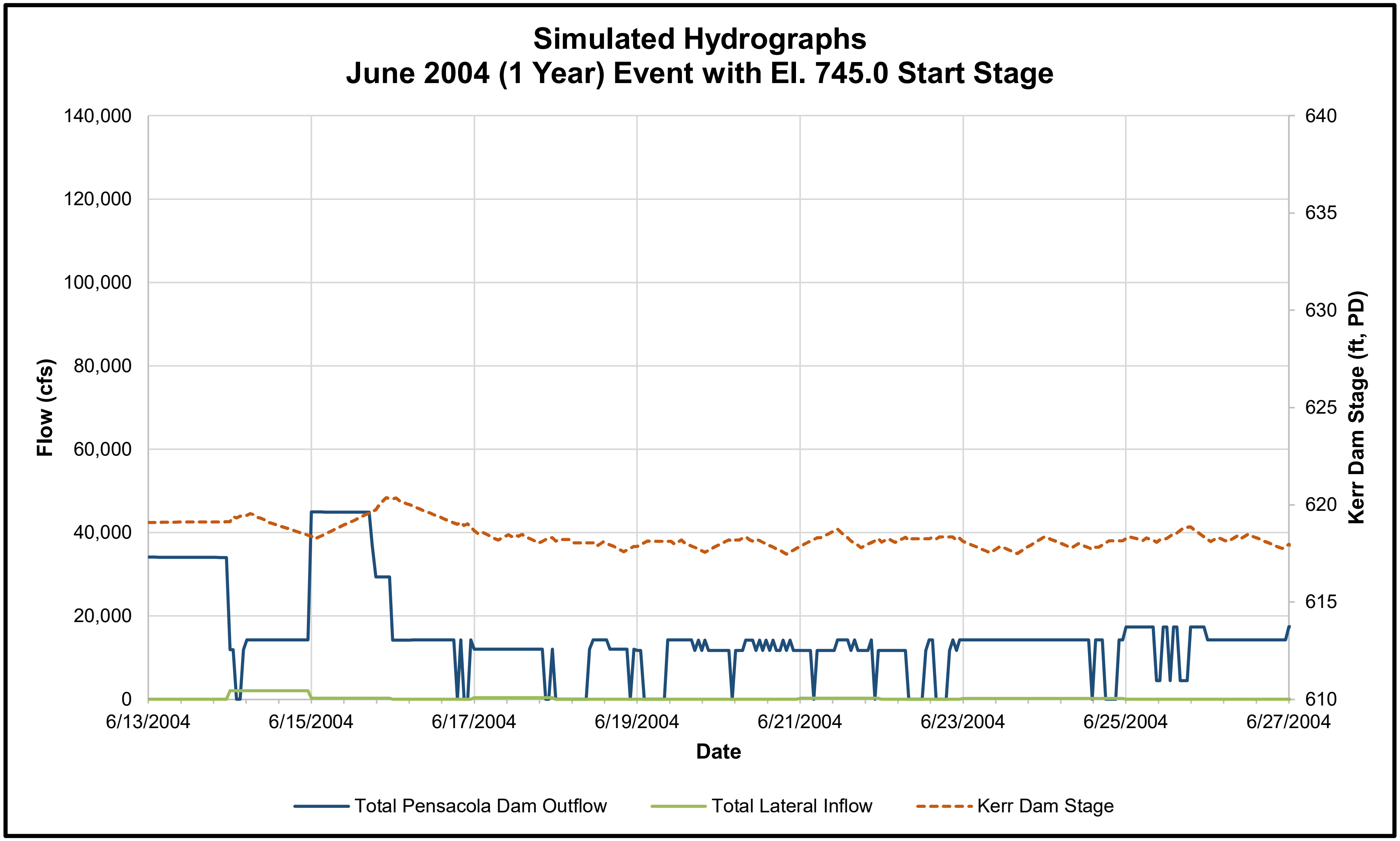


Figure A.20. Simulated hydrograph for the June 2004 (1 year) event with El. 745.0 starting stage at Pensacola Dam.

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.

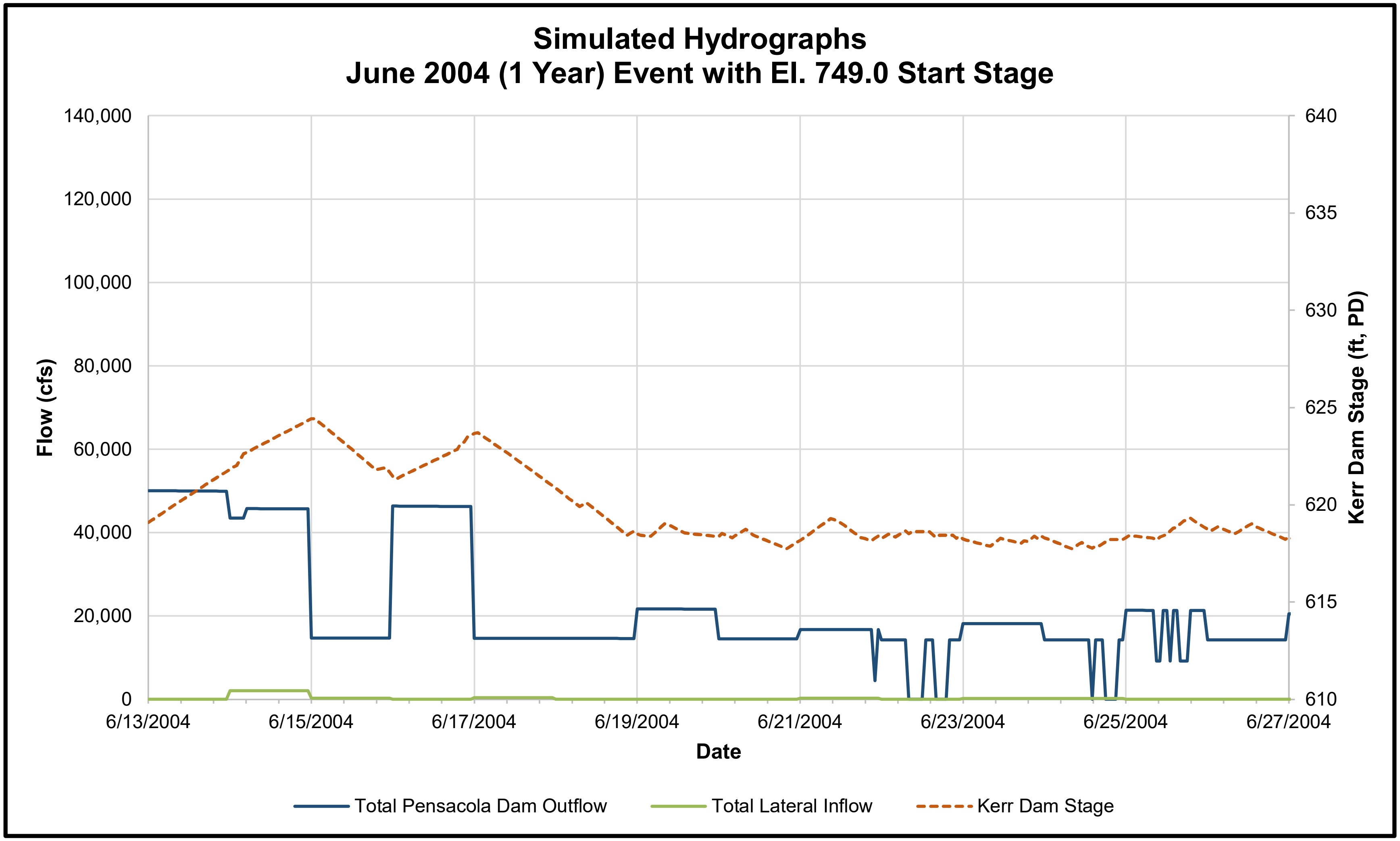


Figure A.21. Simulated hydrograph for the June 2004 (1 year) event with El. 749.0 starting stage at Pensacola Dam.

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.

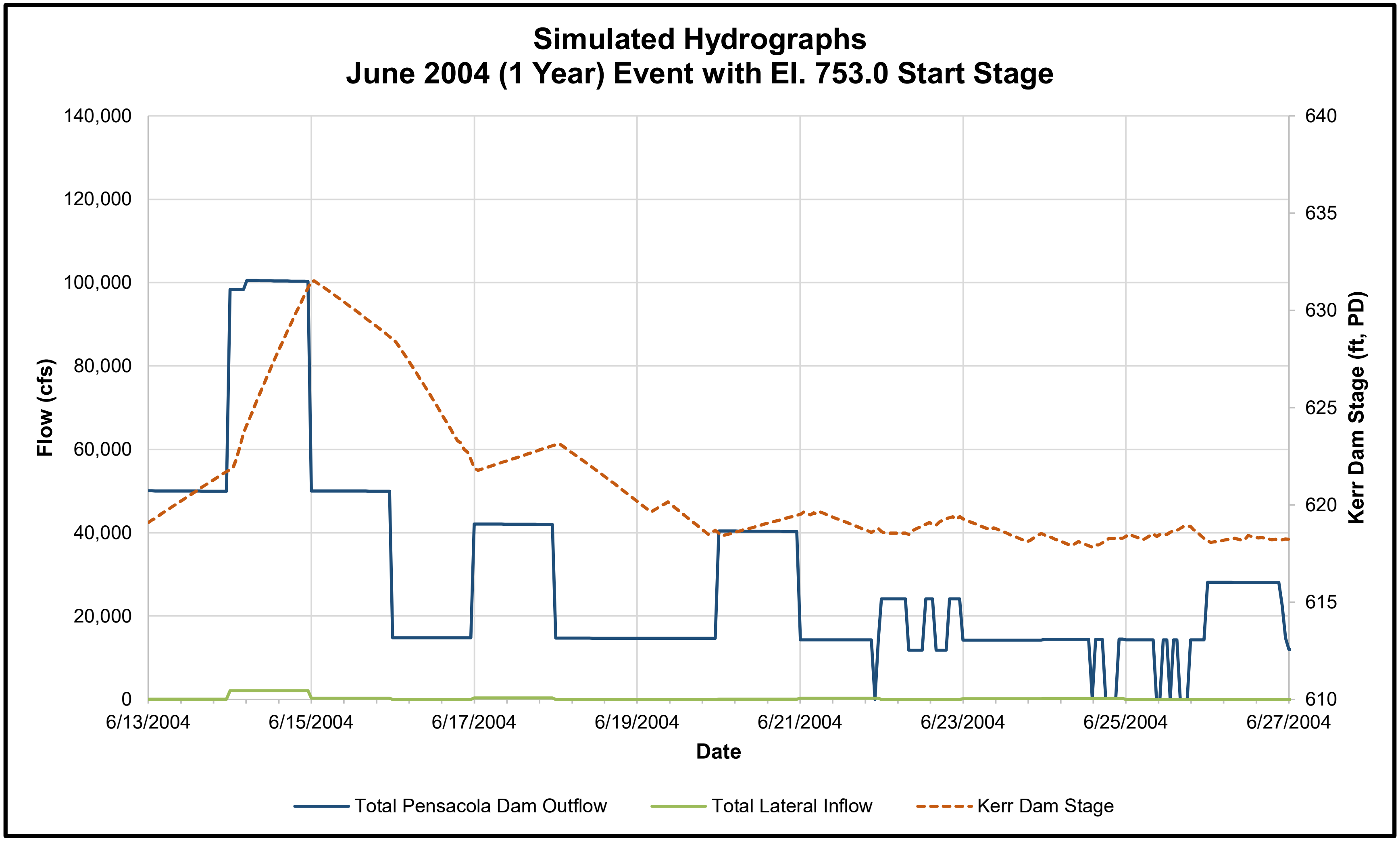


Figure A.22. Simulated hydrograph for the June 2004 (1 year) event with El. 753.0 starting stage at Pensacola Dam.

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.

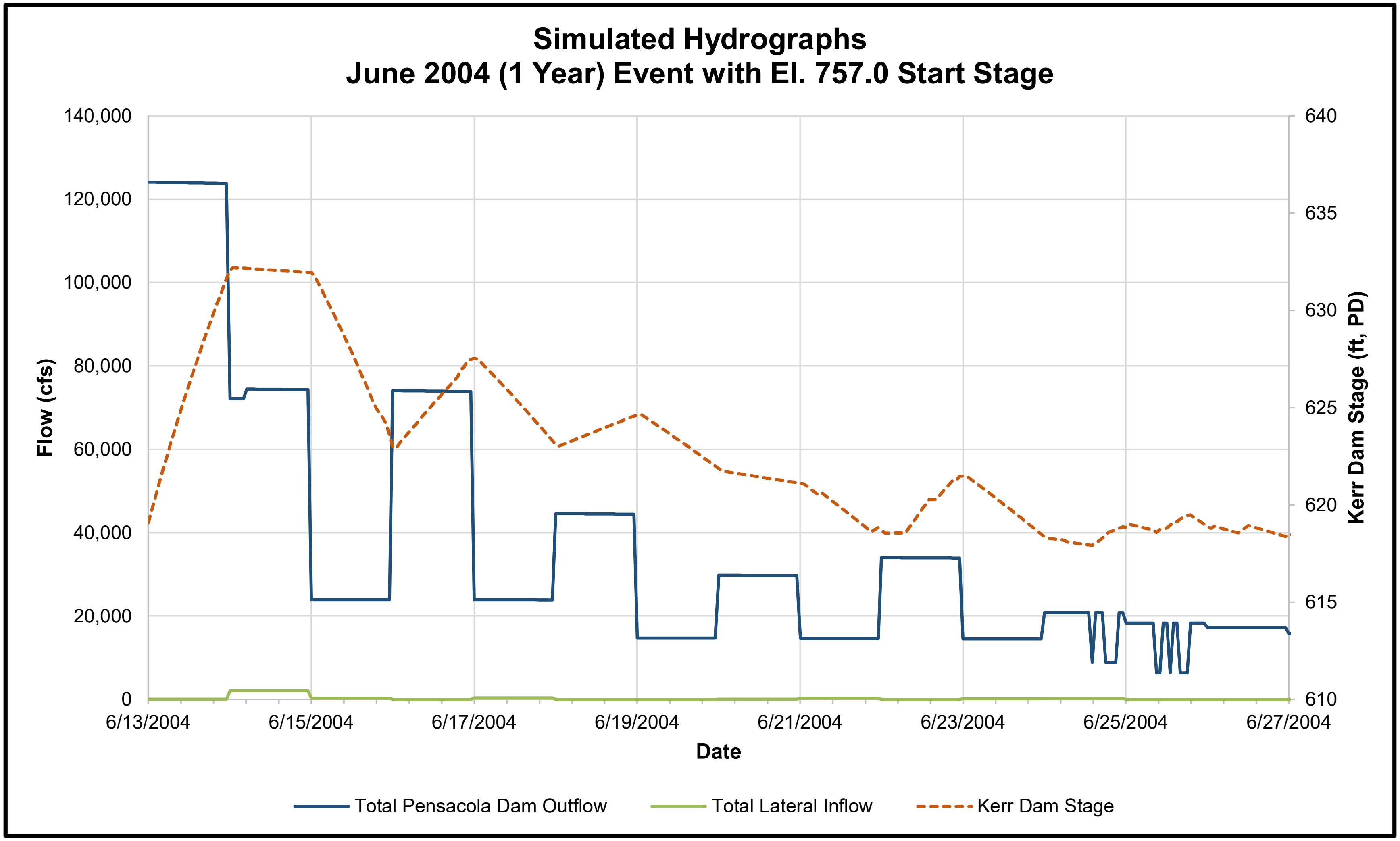


Figure A.23. Simulated hydrograph for the June 2004 (1 year) event with El. 757.0 starting stage at Pensacola Dam.

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.

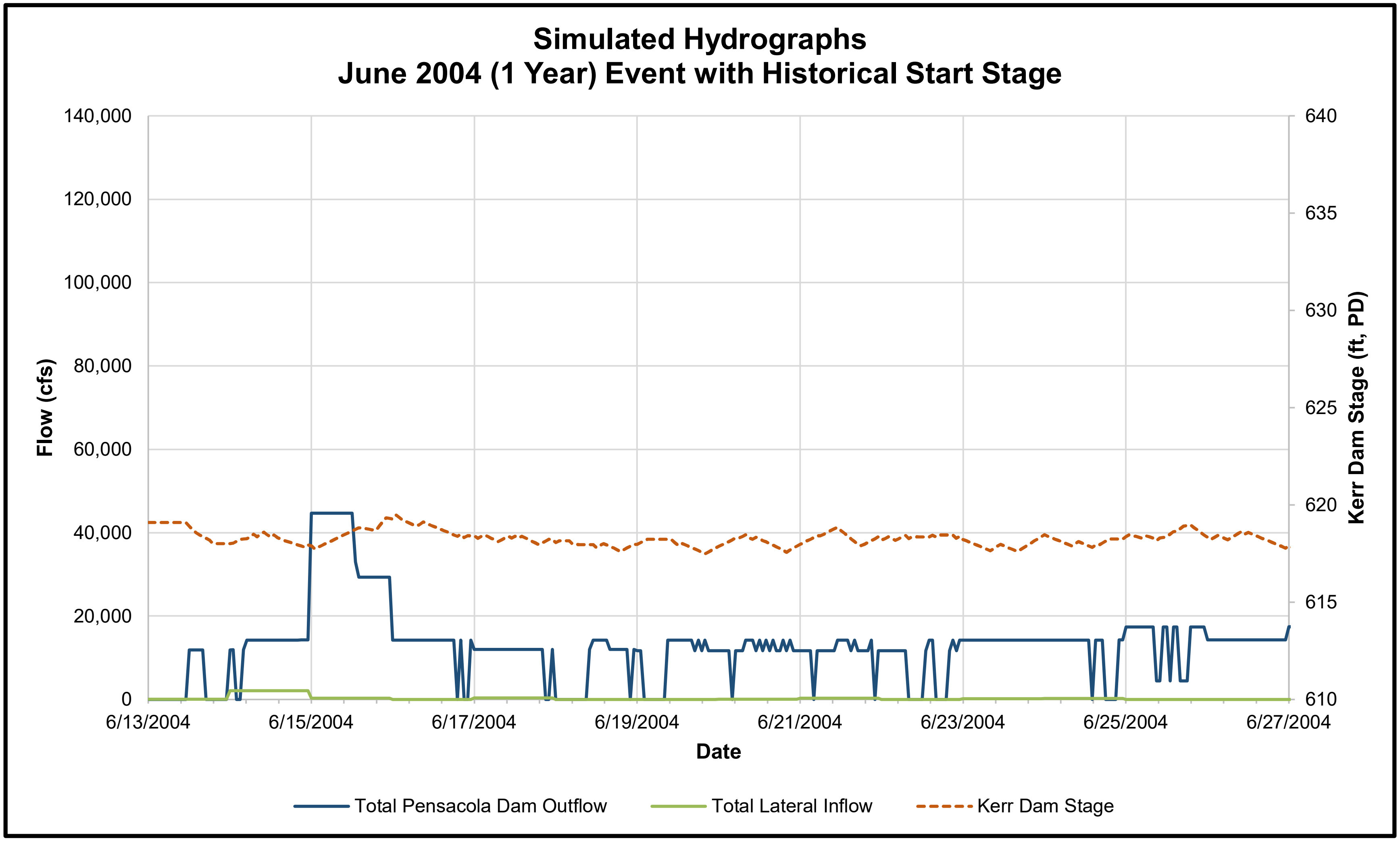


Figure A.24. Simulated hydrograph for the June 2004 (1 year) event with historical starting stage at Pensacola Dam.

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 (4 YEAR) EVENT SIMULATED HYDROGRAPHS

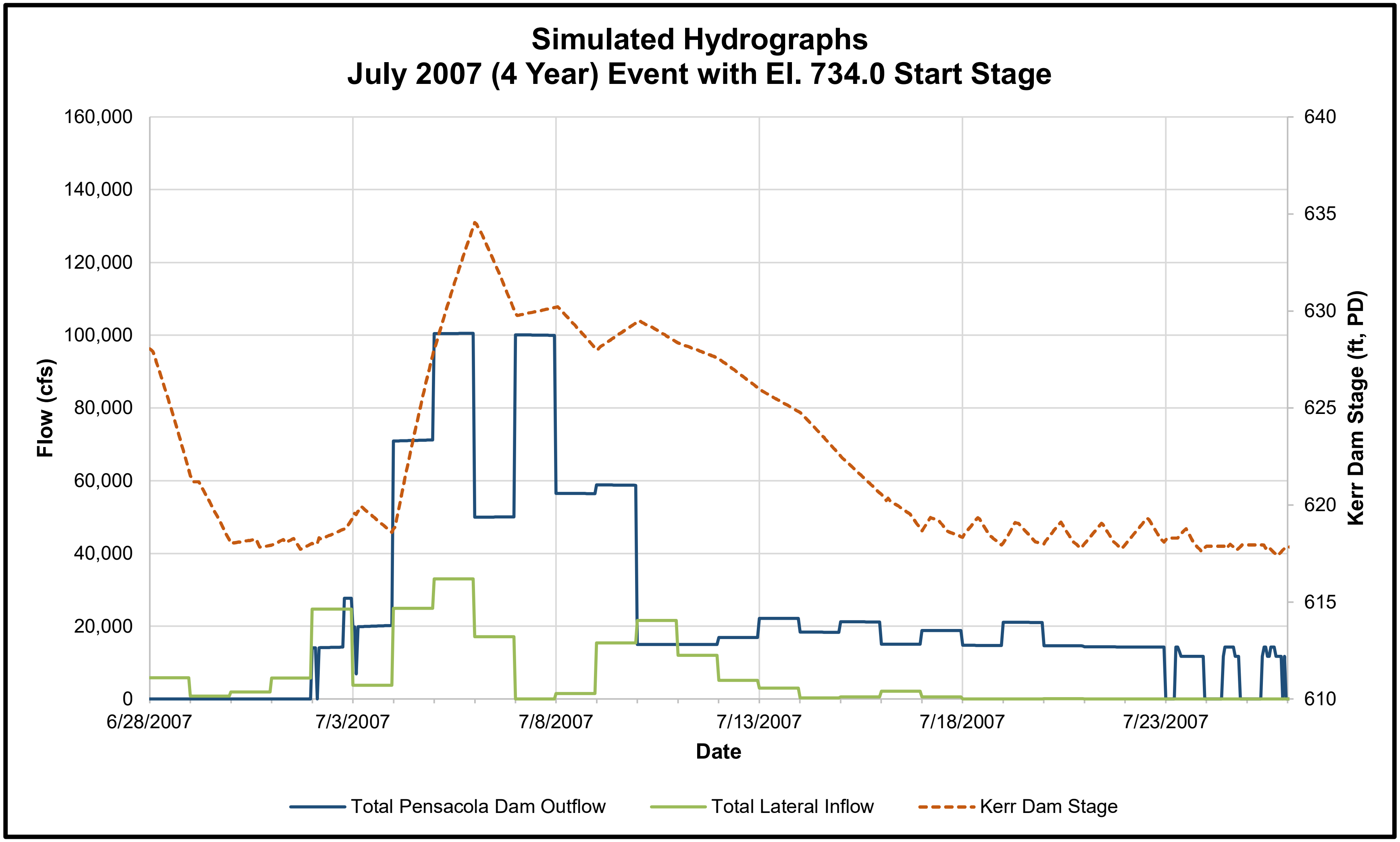


Figure A.25. Simulated hydrograph for the July 2007 (4 year) event with El. 734.0 starting stage at Pensacola Dam.

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.

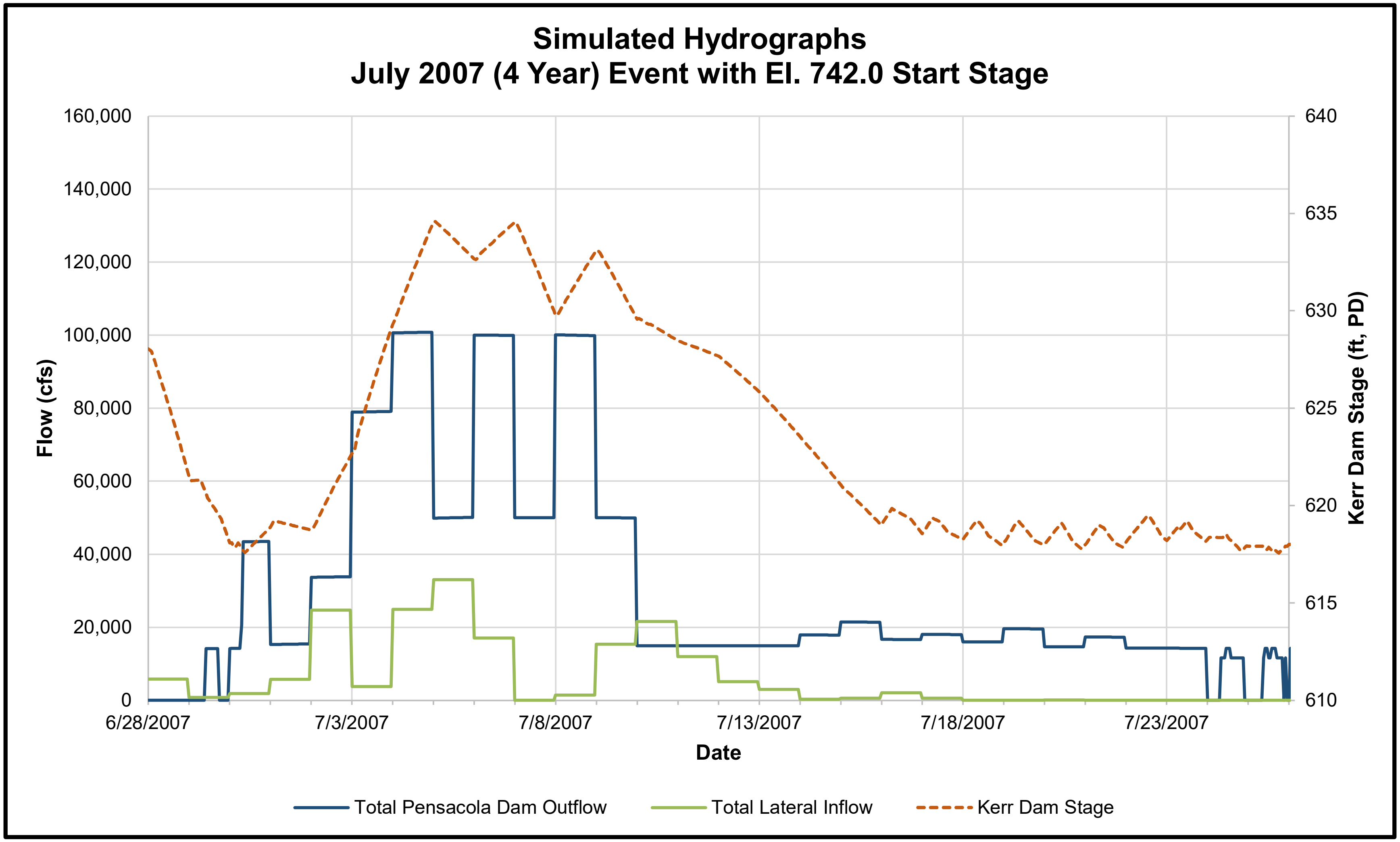


Figure A.26. Simulated hydrograph for the July 2007 (4 year) event with El. 742.0 starting stage at Pensacola Dam.

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.

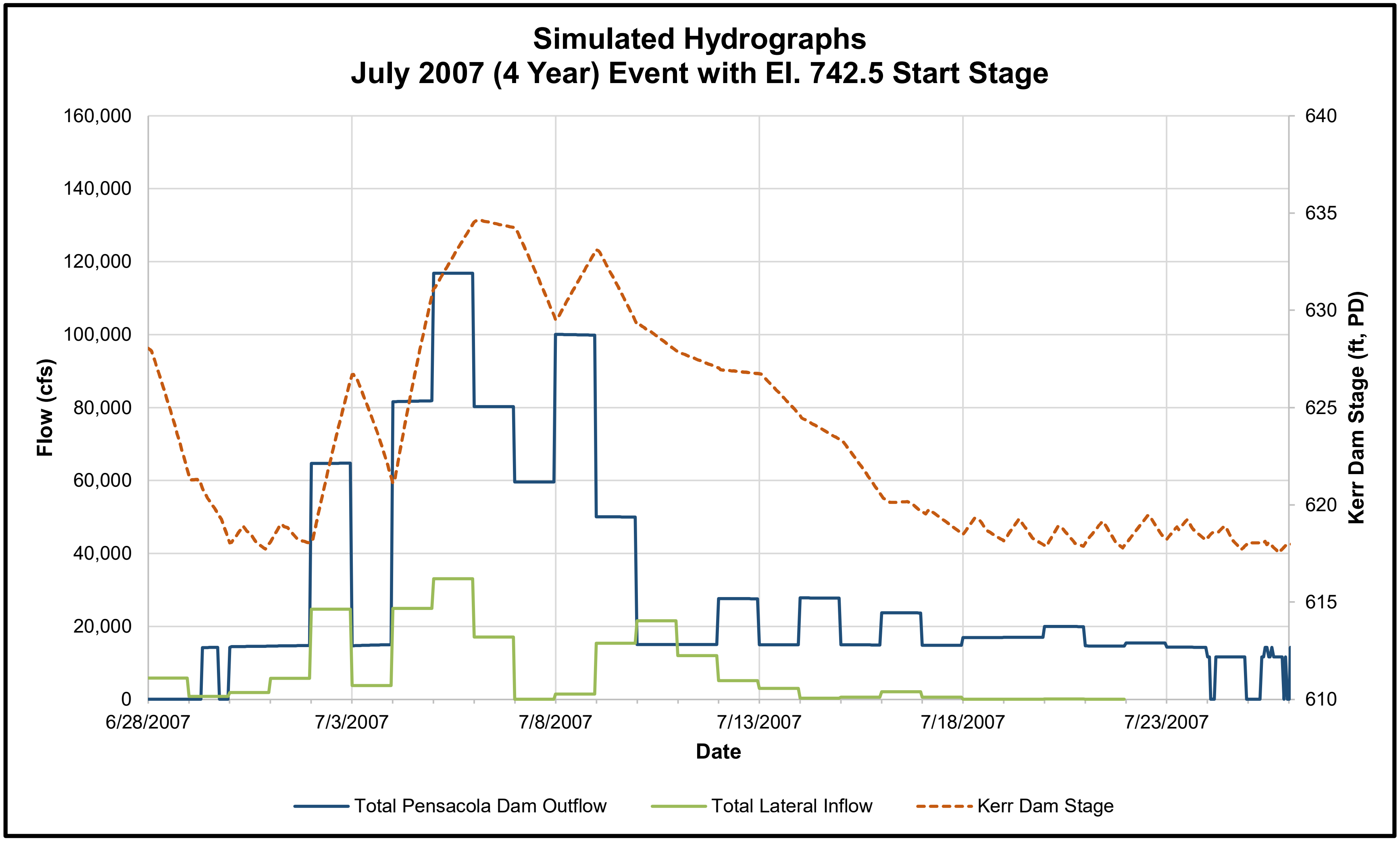


Figure A.27. Simulated hydrograph for the July 2007 (4 year) event with El. 742.5 starting stage at Pensacola Dam.

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.

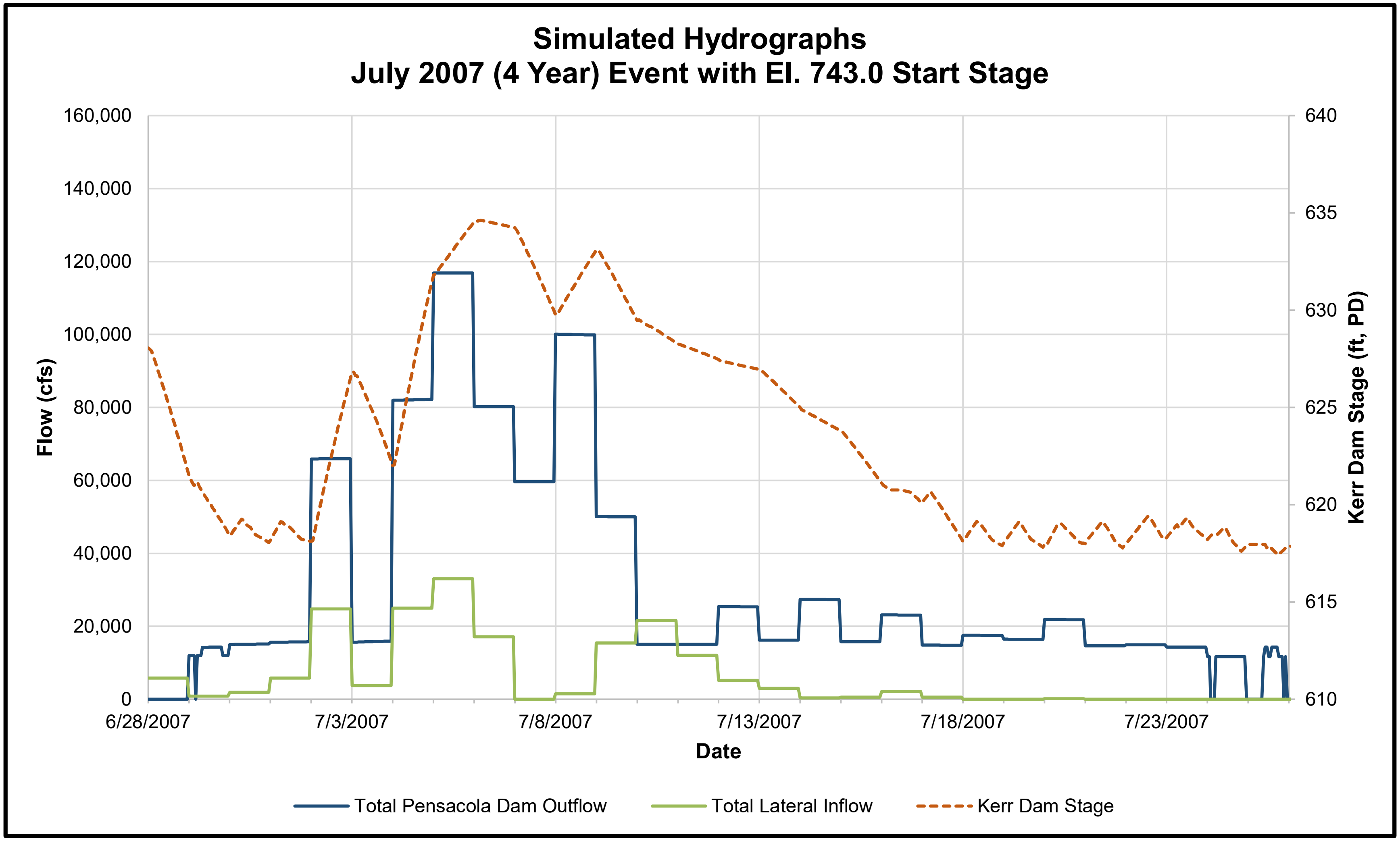


Figure A.28. Simulated hydrograph for the July 2007 (4 year) event with El. 743.0 starting stage at Pensacola Dam.

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.*

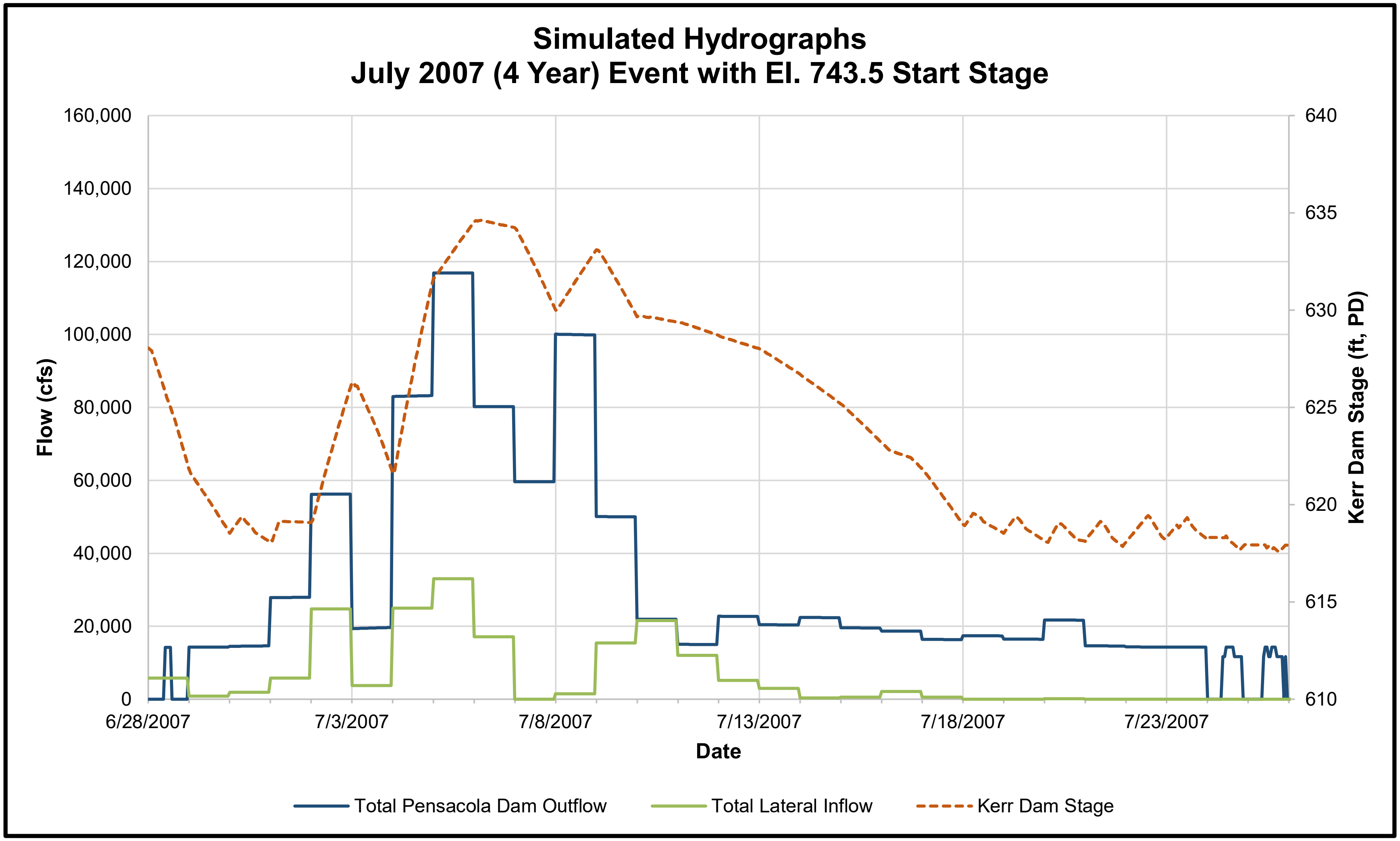


Figure A.29. Simulated hydrograph for the July 2007 (4 year) event with El. 743.5 starting stage at Pensacola Dam.

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.

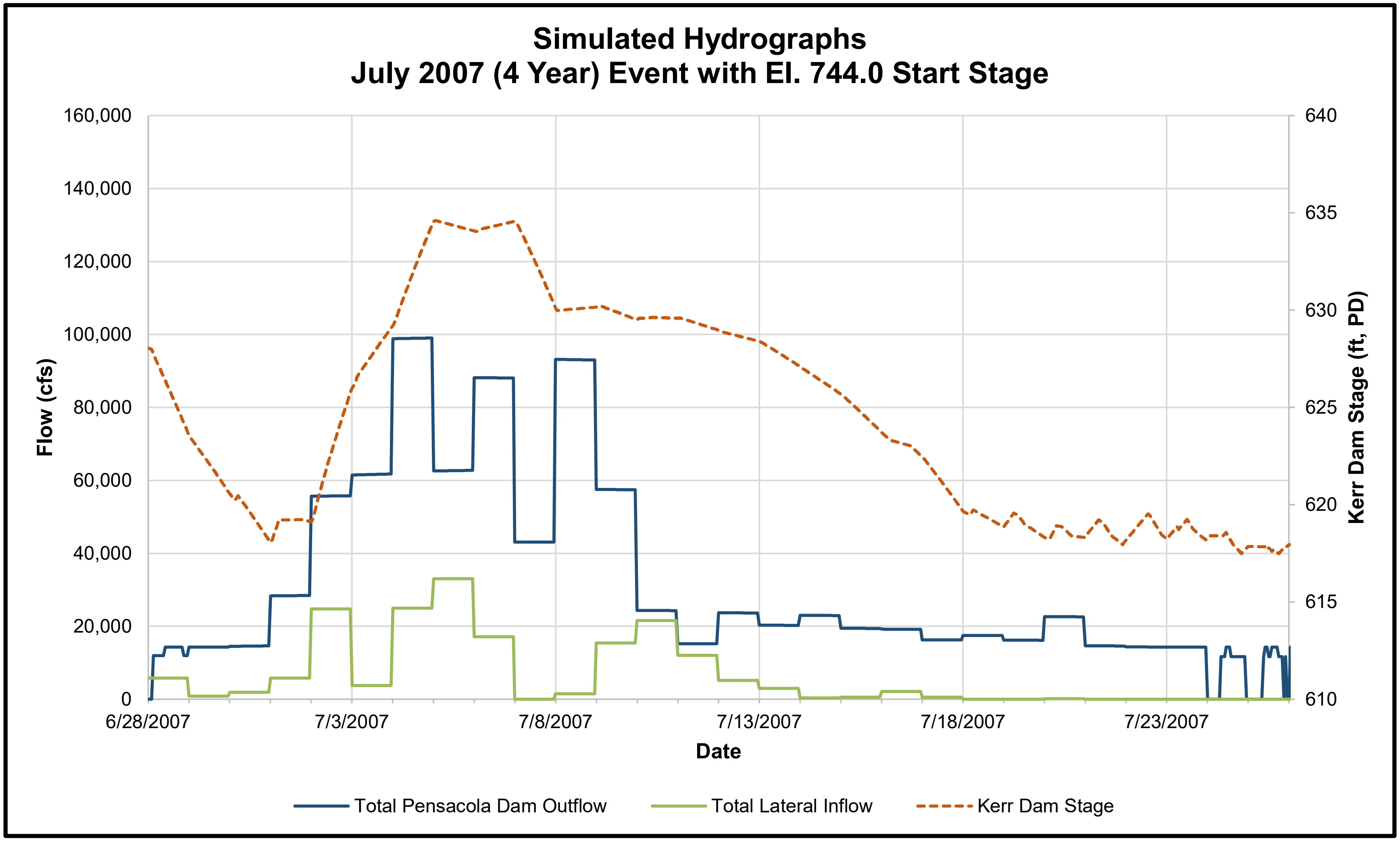


Figure A.30. Simulated hydrograph for the July 2007 (4 year) event with El. 744.0 starting stage at Pensacola Dam.

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.

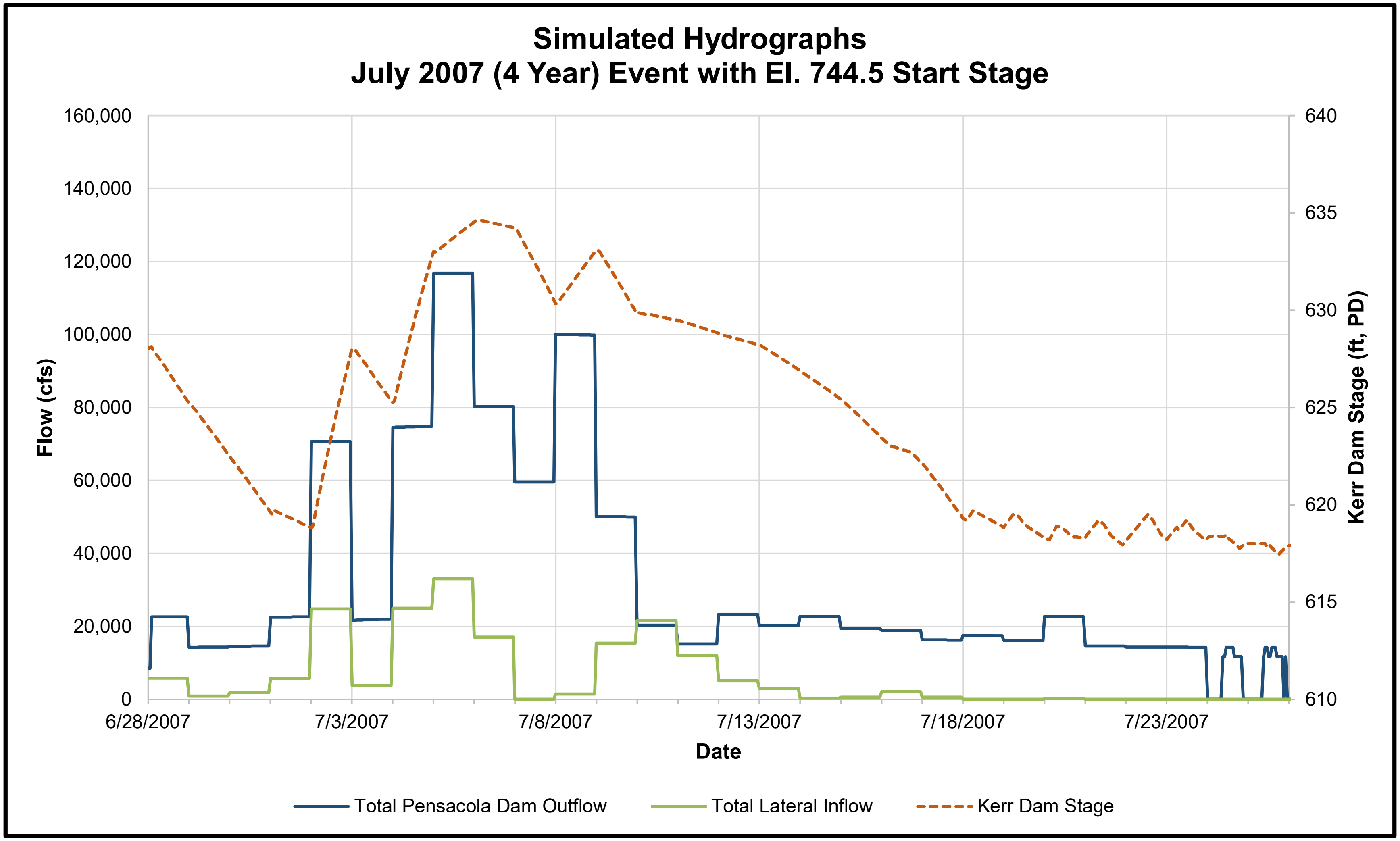


Figure A.31. Simulated hydrograph for the July 2007 (4 year) event with El. 744.5 starting stage at Pensacola Dam.

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.

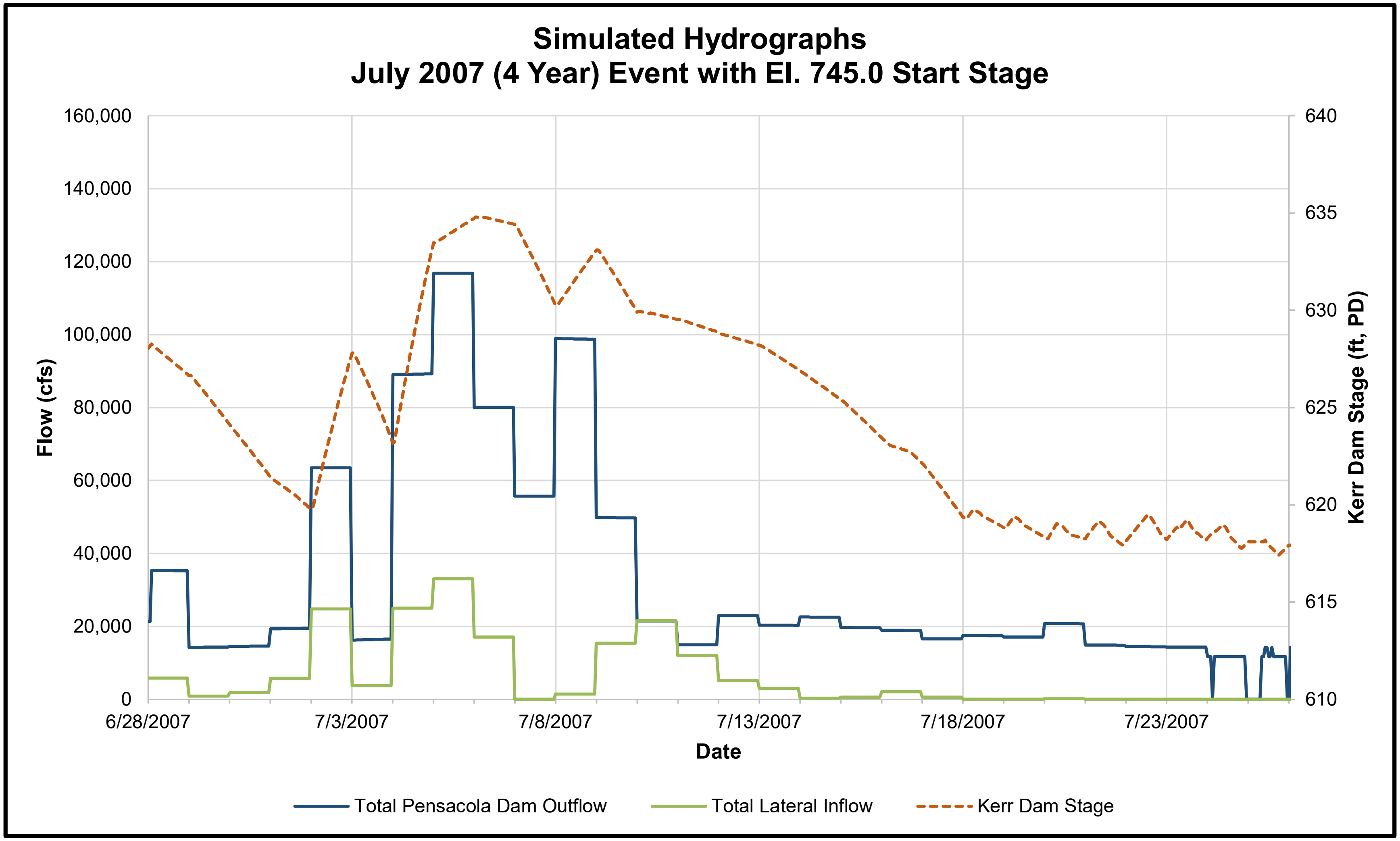


Figure A.32. Simulated hydrograph for the July 2007 (4 year) event with El. 745.0 starting stage at Pensacola Dam.

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.

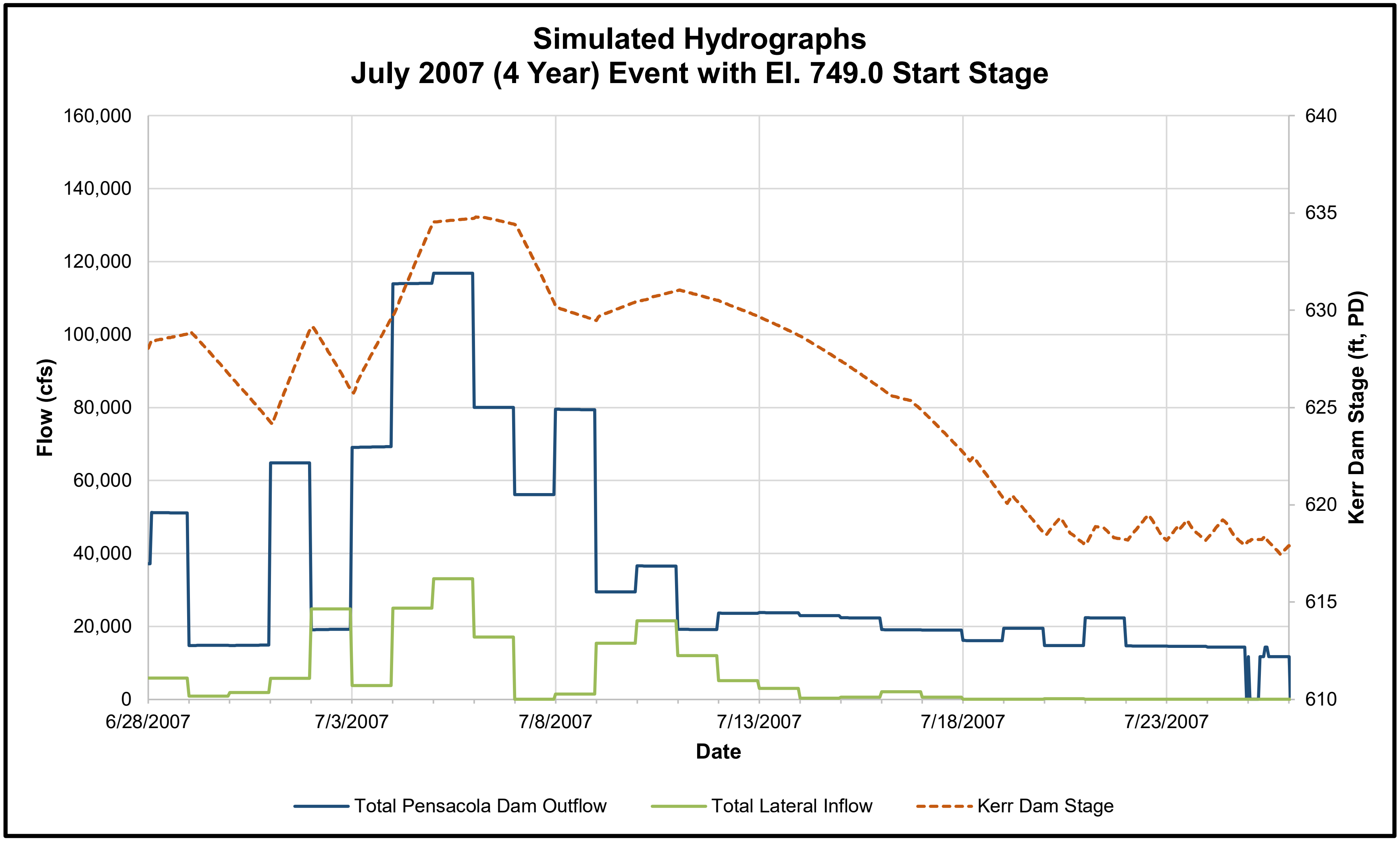


Figure A.33. Simulated hydrograph for the July 2007 (4 year) event with El. 749.0 starting stage at Pensacola Dam.

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.*

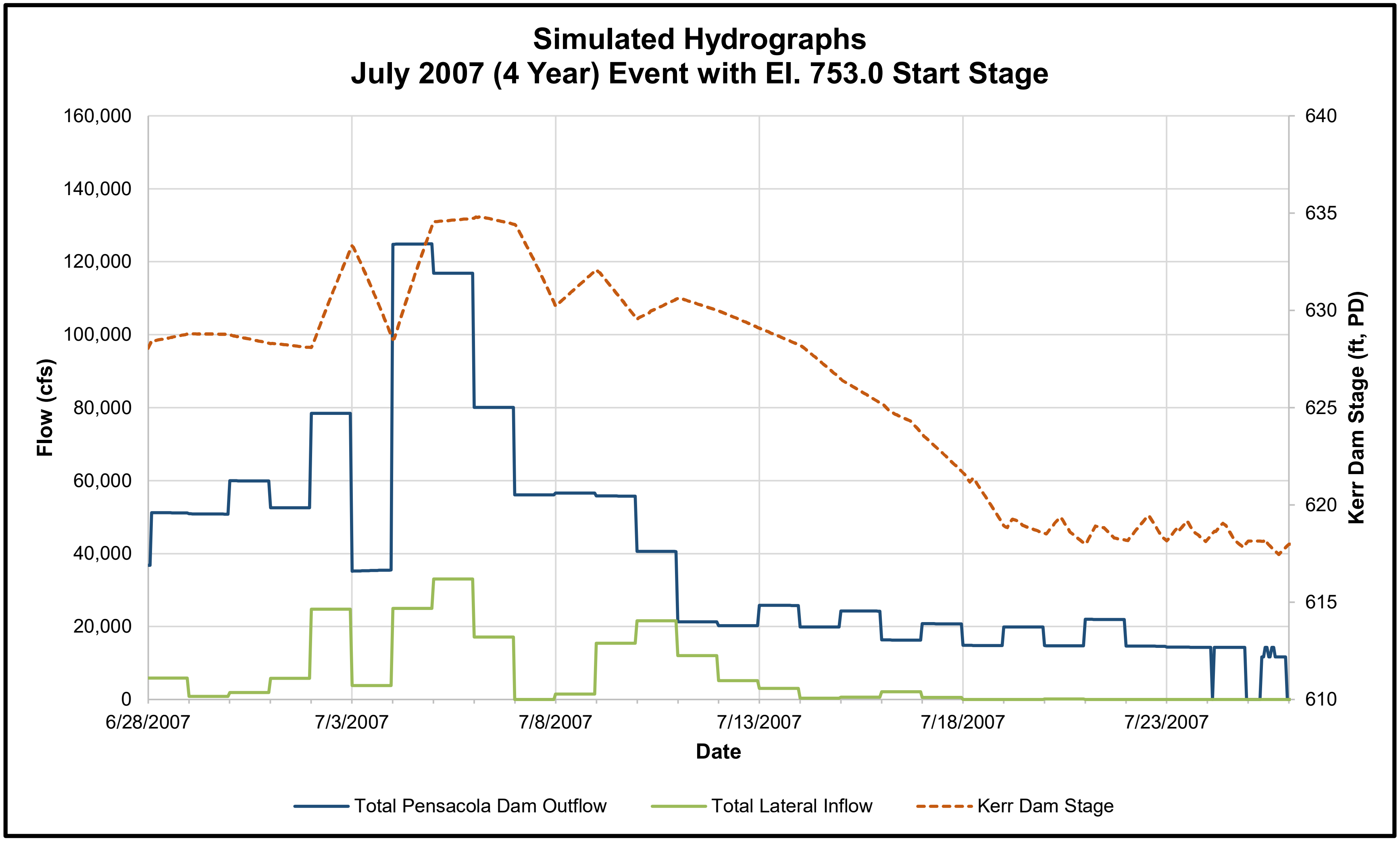


Figure A.34. Simulated hydrograph for the July 2007 (4 year) event with El. 753.0 starting stage at Pensacola Dam.

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.*

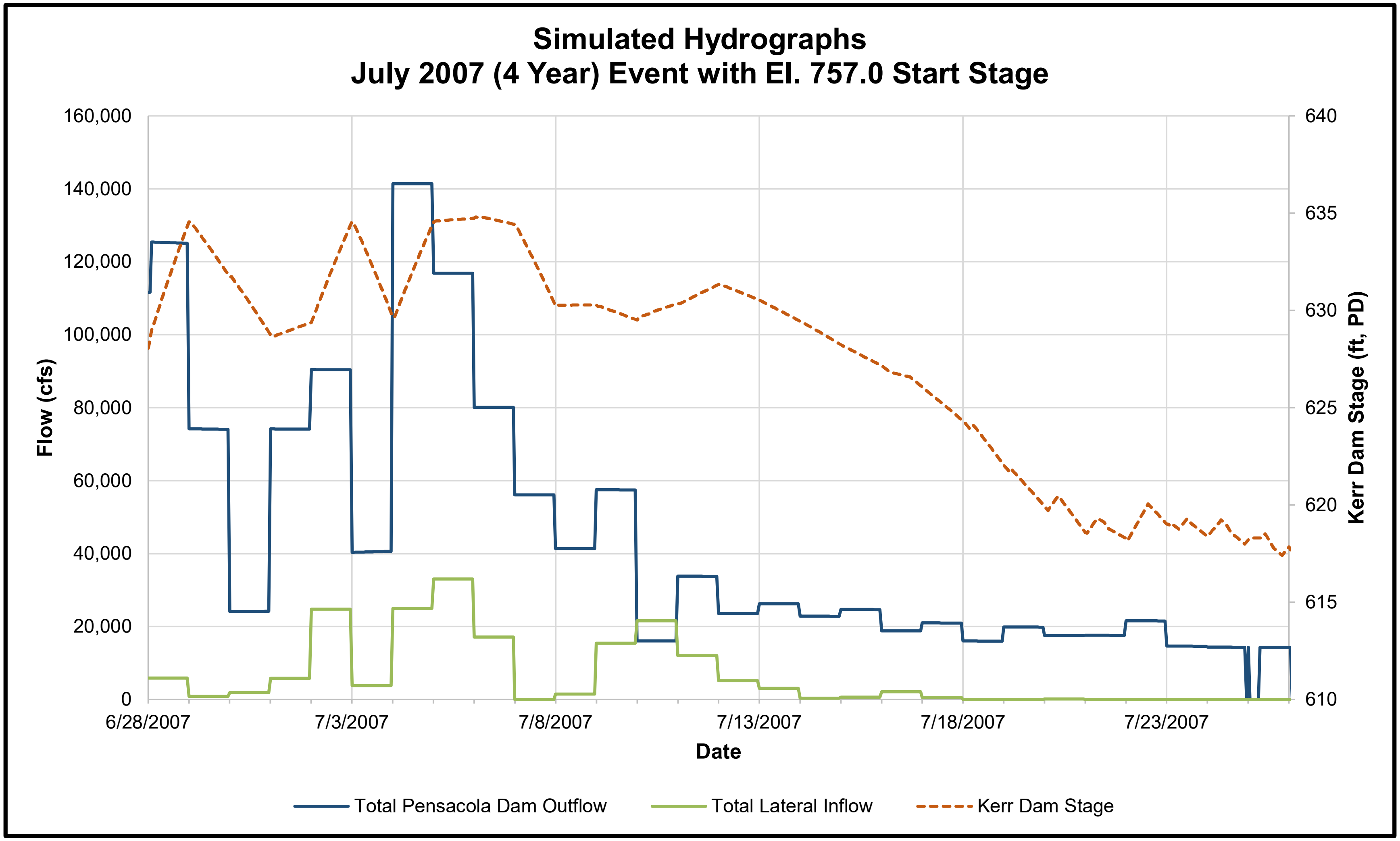


Figure A.35. Simulated hydrograph for the July 2007 (4 year) event with El. 757.0 starting stage at Pensacola Dam.

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.

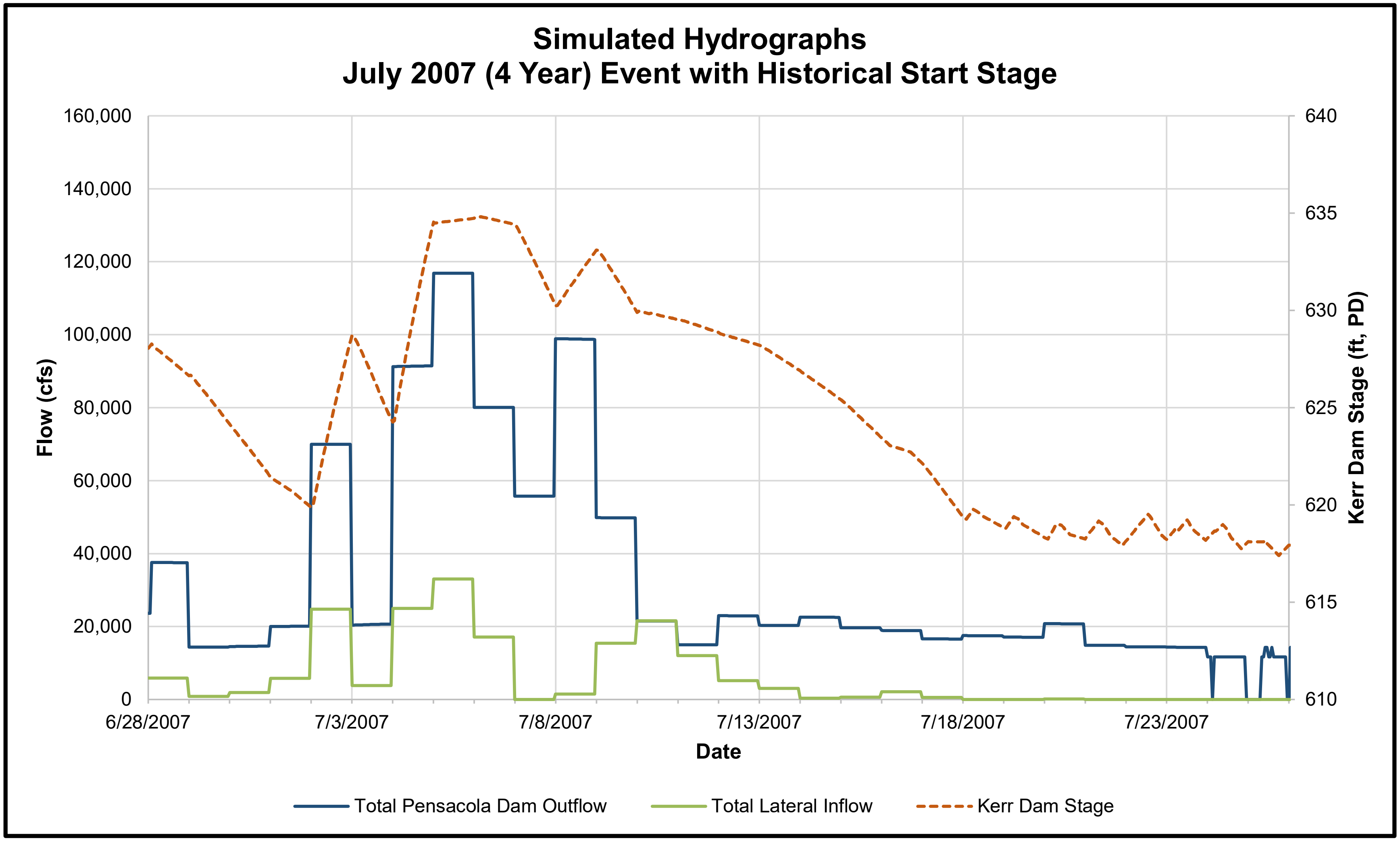


Figure A.36. Simulated hydrograph for the July 2007 (4 year) event with historical starting stage at Pensacola Dam.

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 (3 YEAR) EVENT SIMULATED HYDROGRAPHS

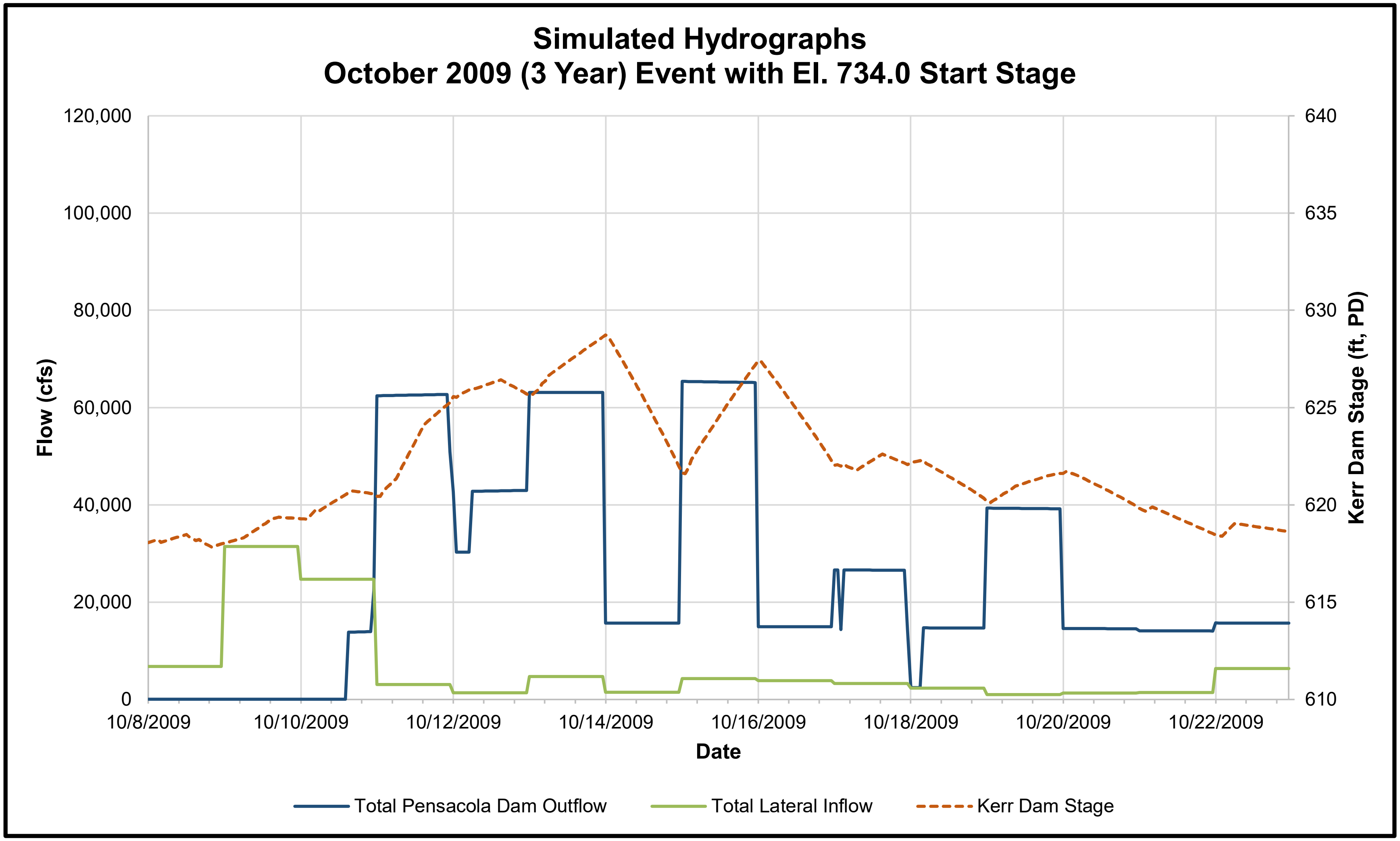


Figure A.37. Simulated hydrograph for the October 2009 (3 year) event with El. 734.0 starting stage at Pensacola Dam.

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.

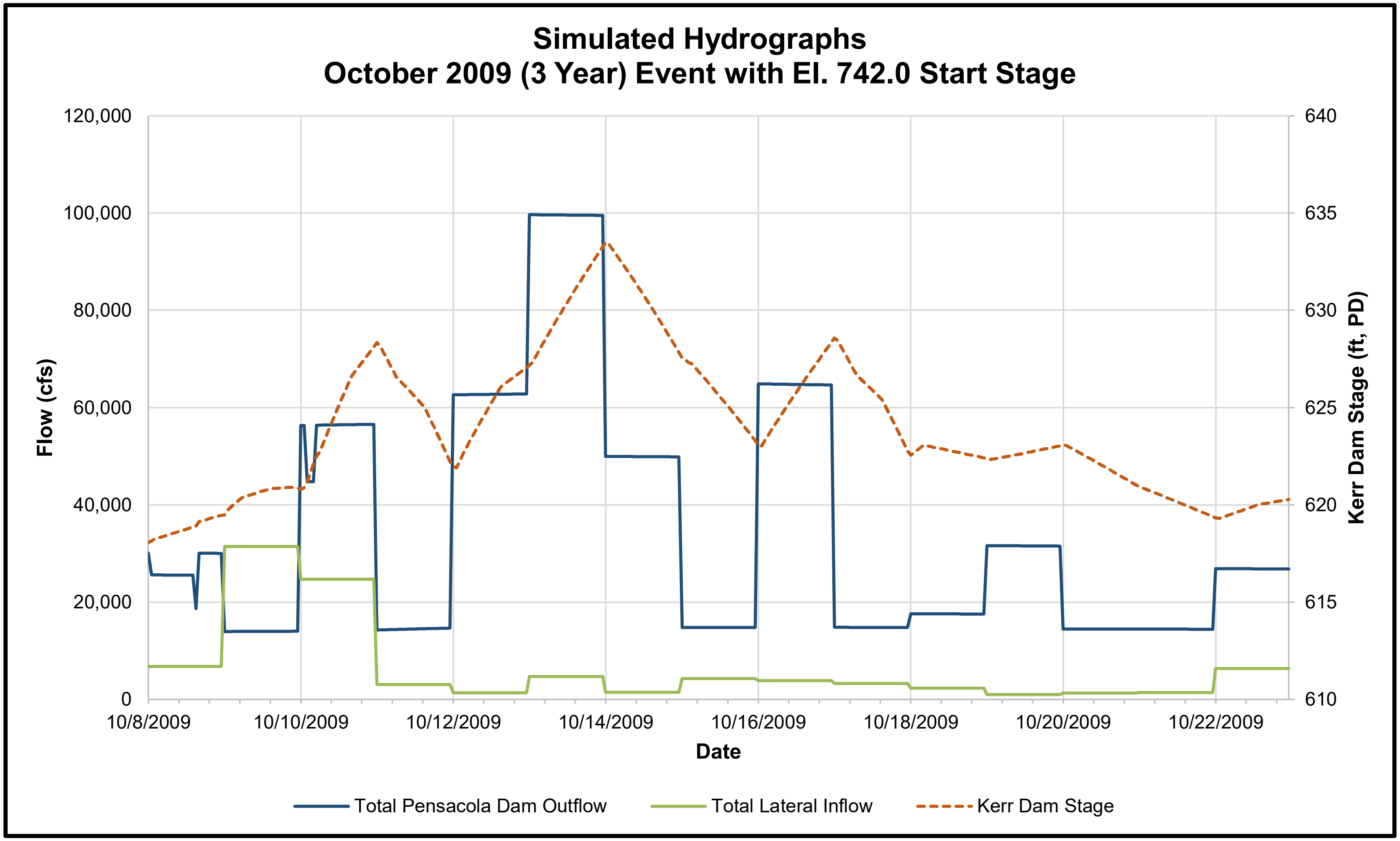


Figure A.38. Simulated hydrograph for the October 2009 (3 year) event with El. 742.0 starting stage at Pensacola Dam.

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.

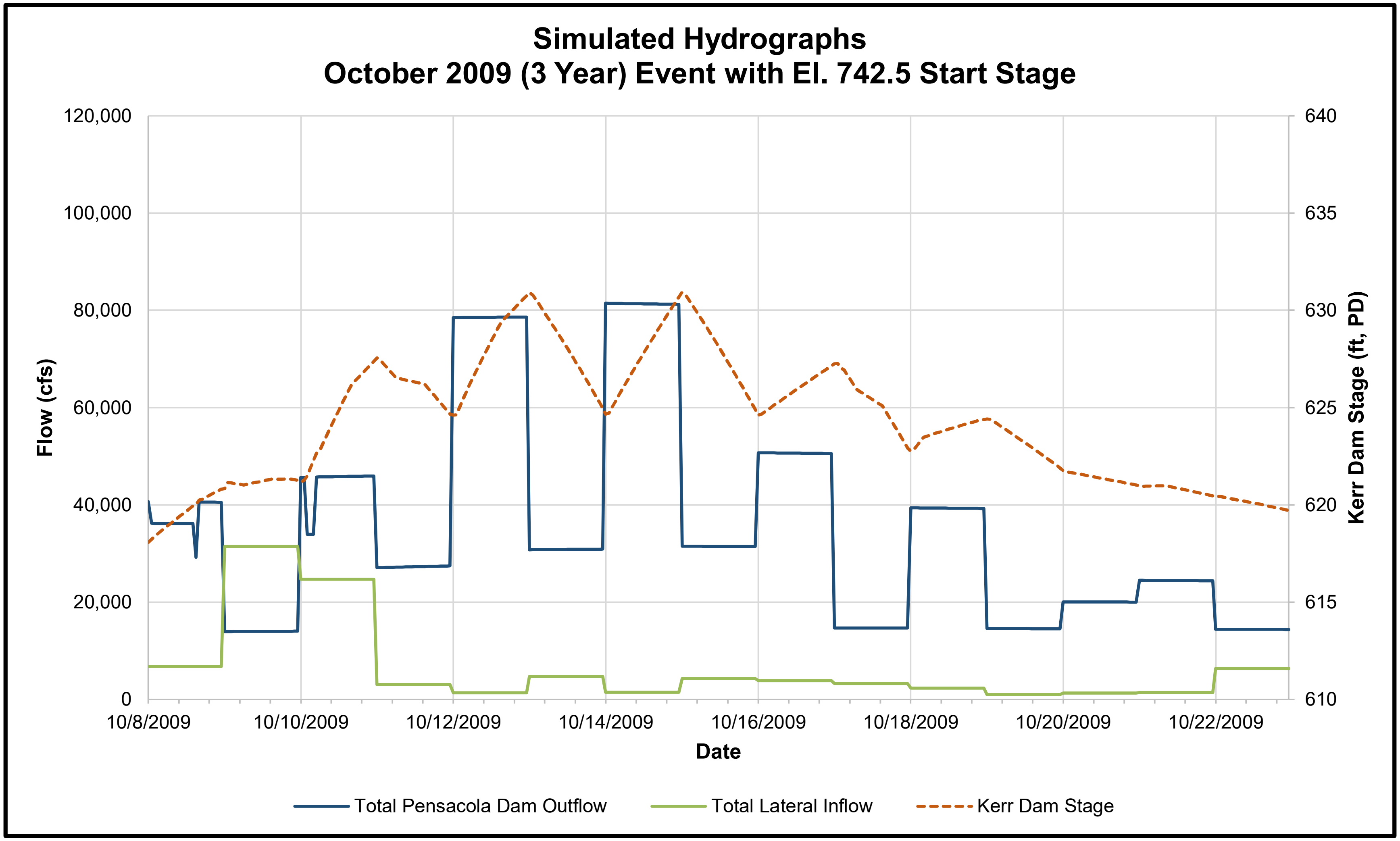


Figure A.39. Simulated hydrograph for the October 2009 (3 year) event with El. 742.5 starting stage at Pensacola Dam.

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.

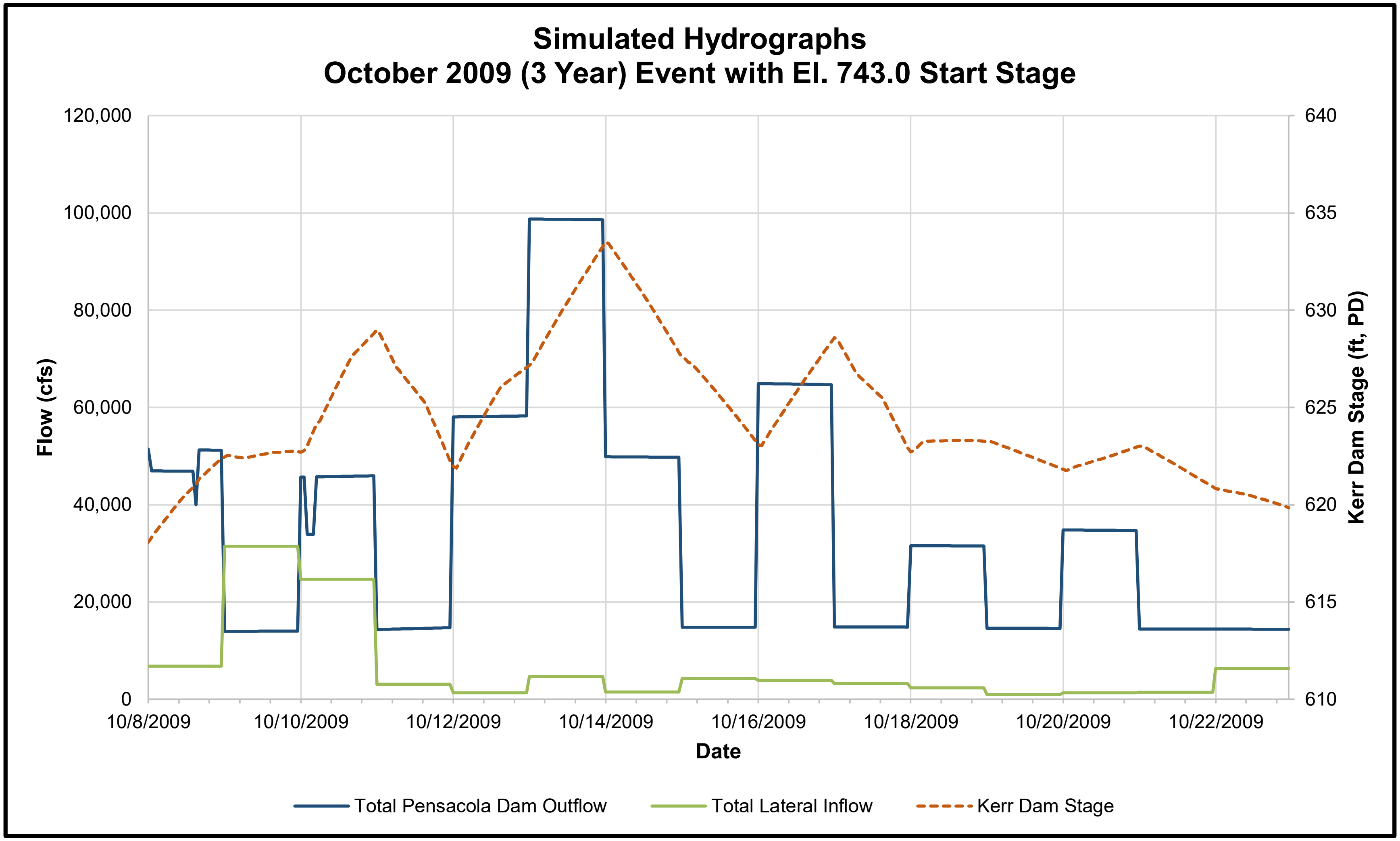


Figure A.40. Simulated hydrograph for the October 2009 (3 year) event with El. 743.0 starting stage at Pensacola Dam.

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.

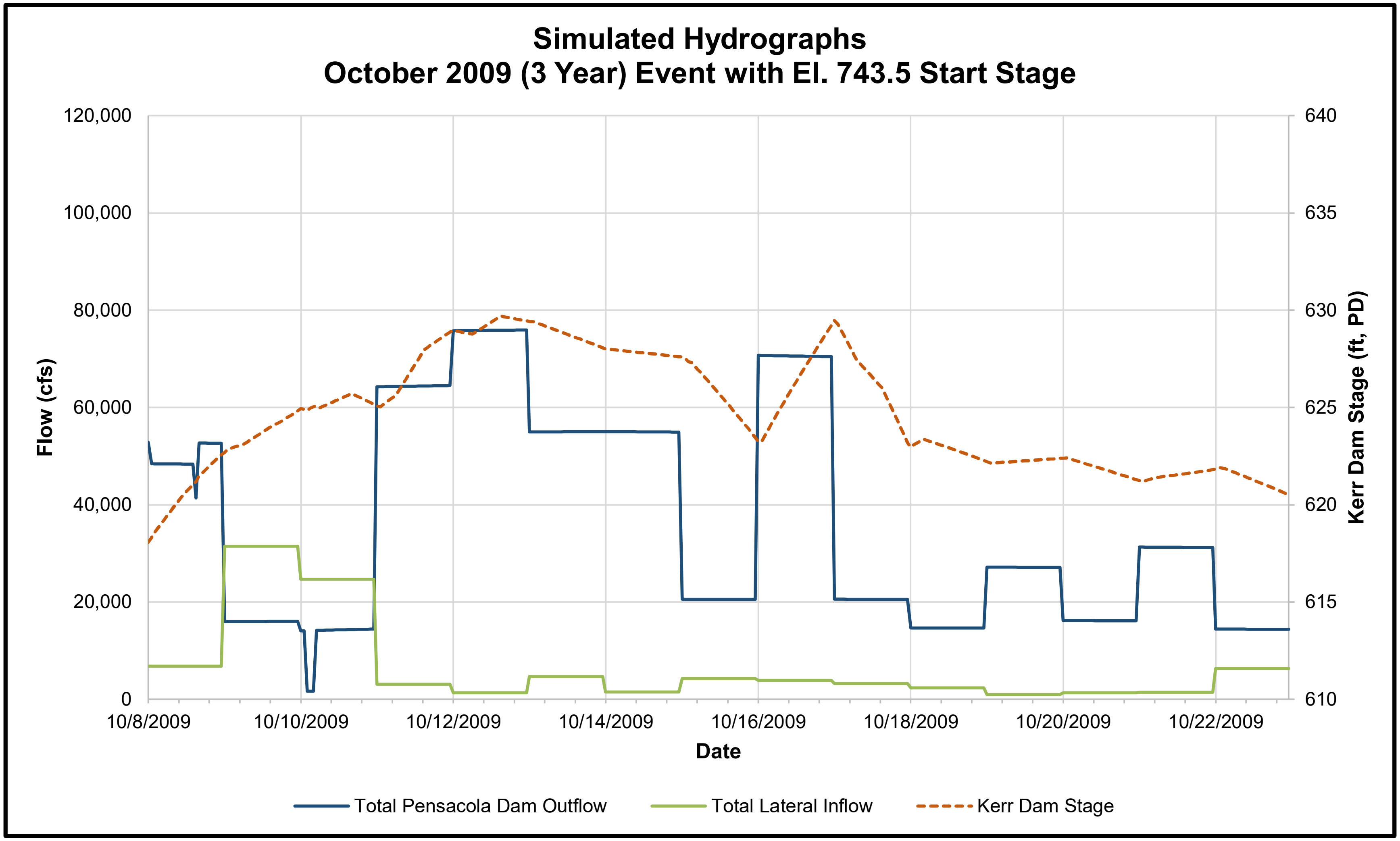


Figure A.41. Simulated hydrograph for the October 2009 (3 year) event with El. 743.5 starting stage at Pensacola Dam.

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.

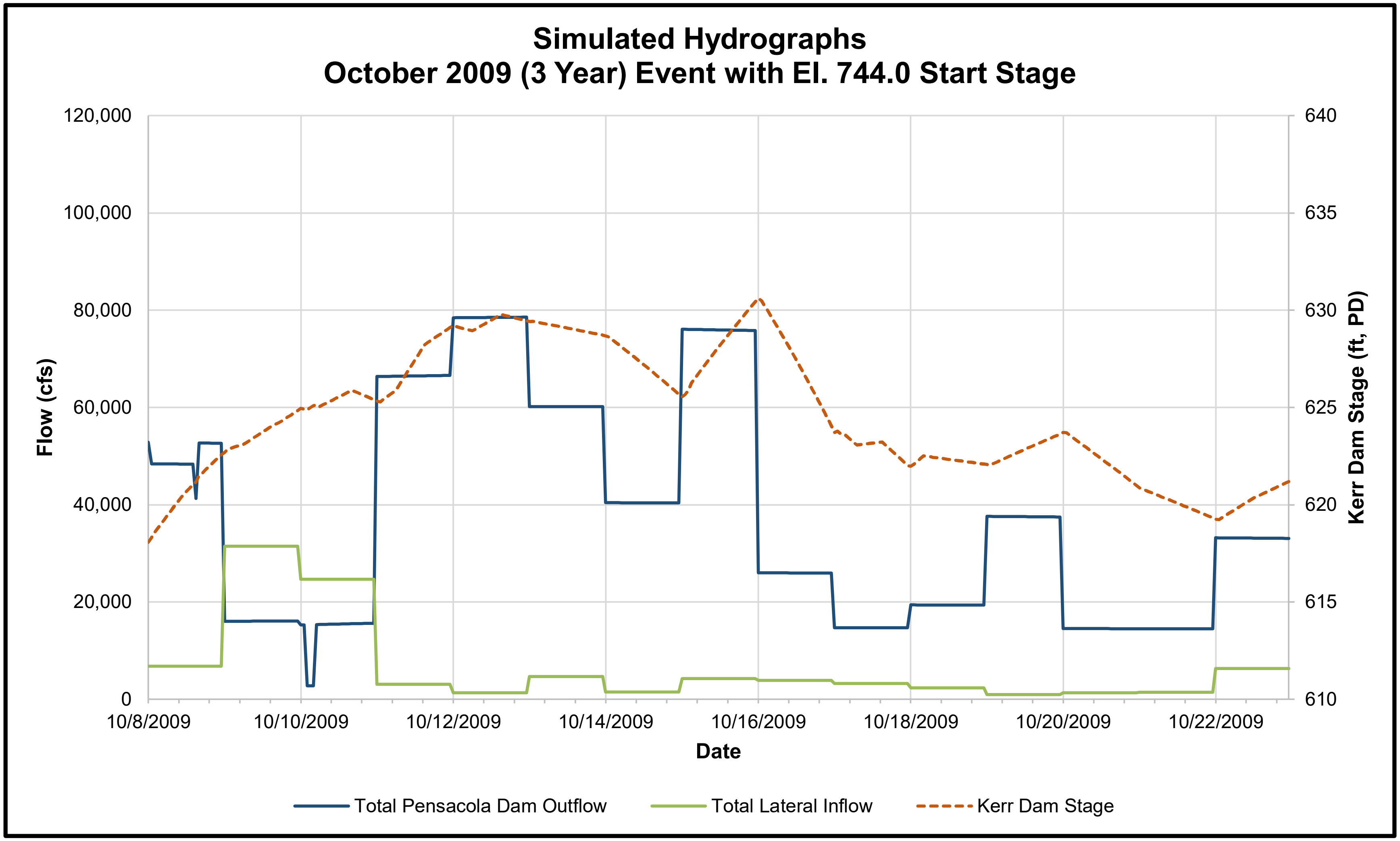


Figure A.42. Simulated hydrograph for the October 2009 (3 year) event with El. 744.0 starting stage at Pensacola Dam.

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.

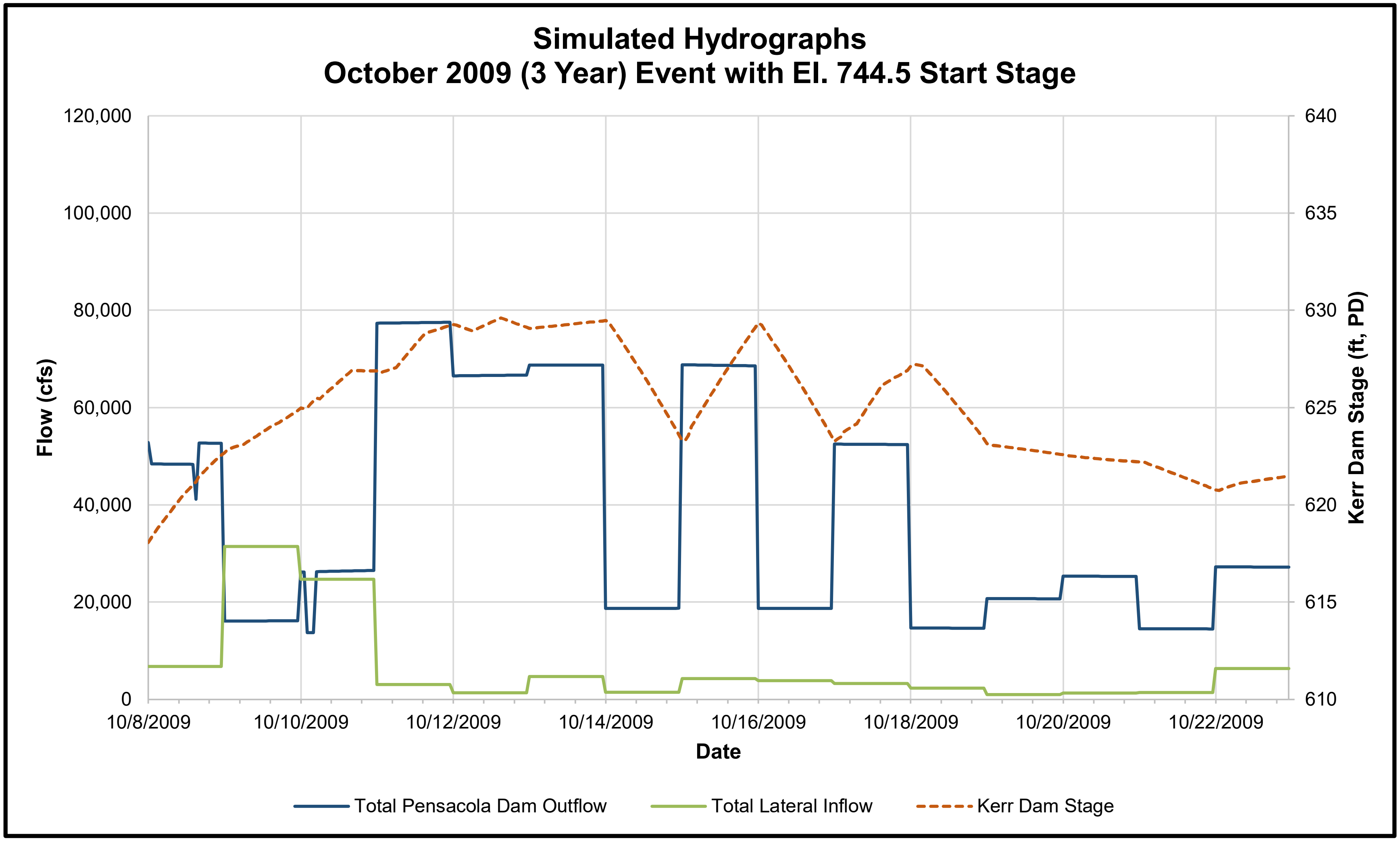


Figure A.43. Simulated hydrograph for the October 2009 (3 year) event with El. 744.5 starting stage at Pensacola Dam.

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.*

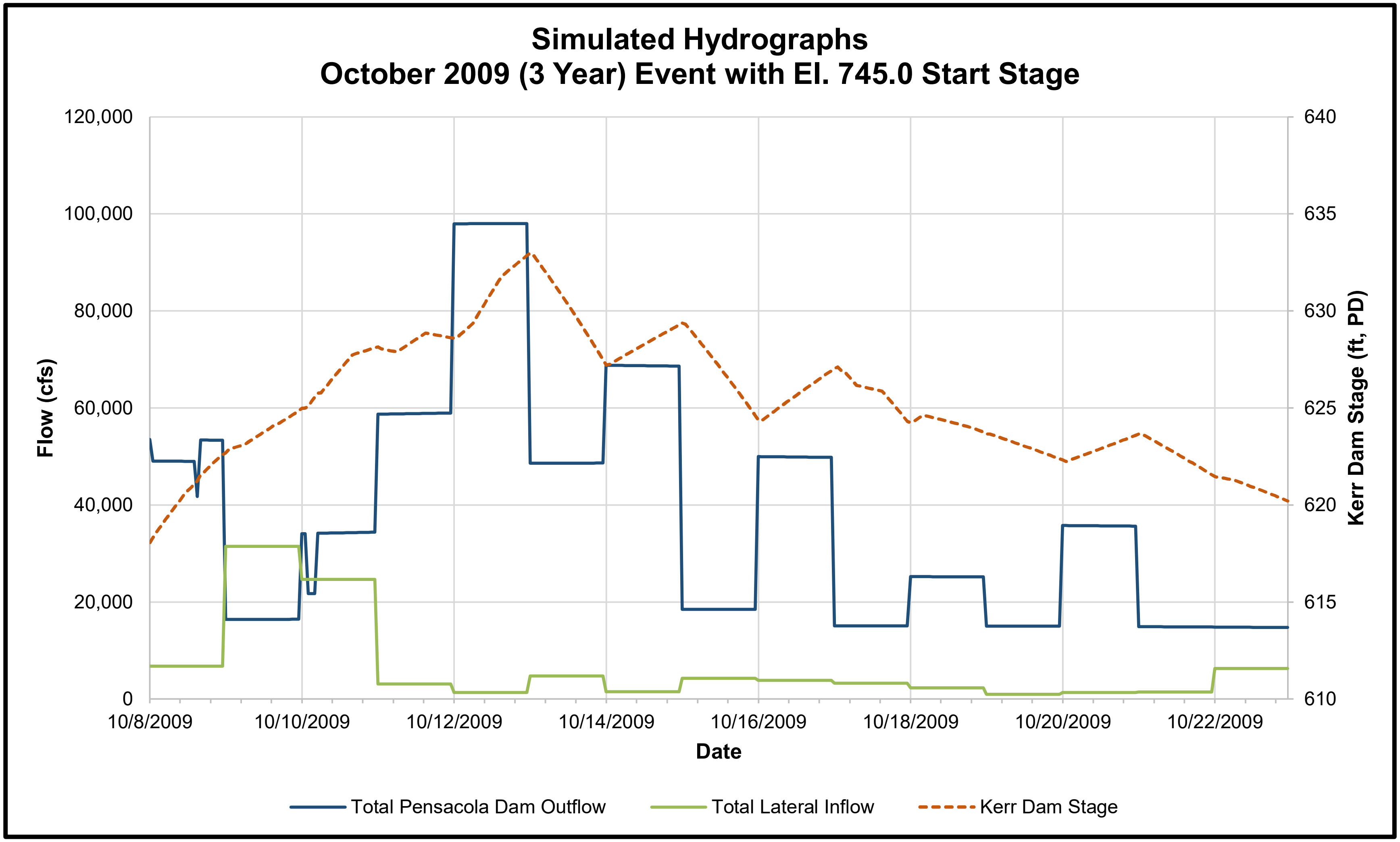


Figure A.44. Simulated hydrograph for the October 2009 (3 year) event with El. 745.0 starting stage at Pensacola Dam.

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.

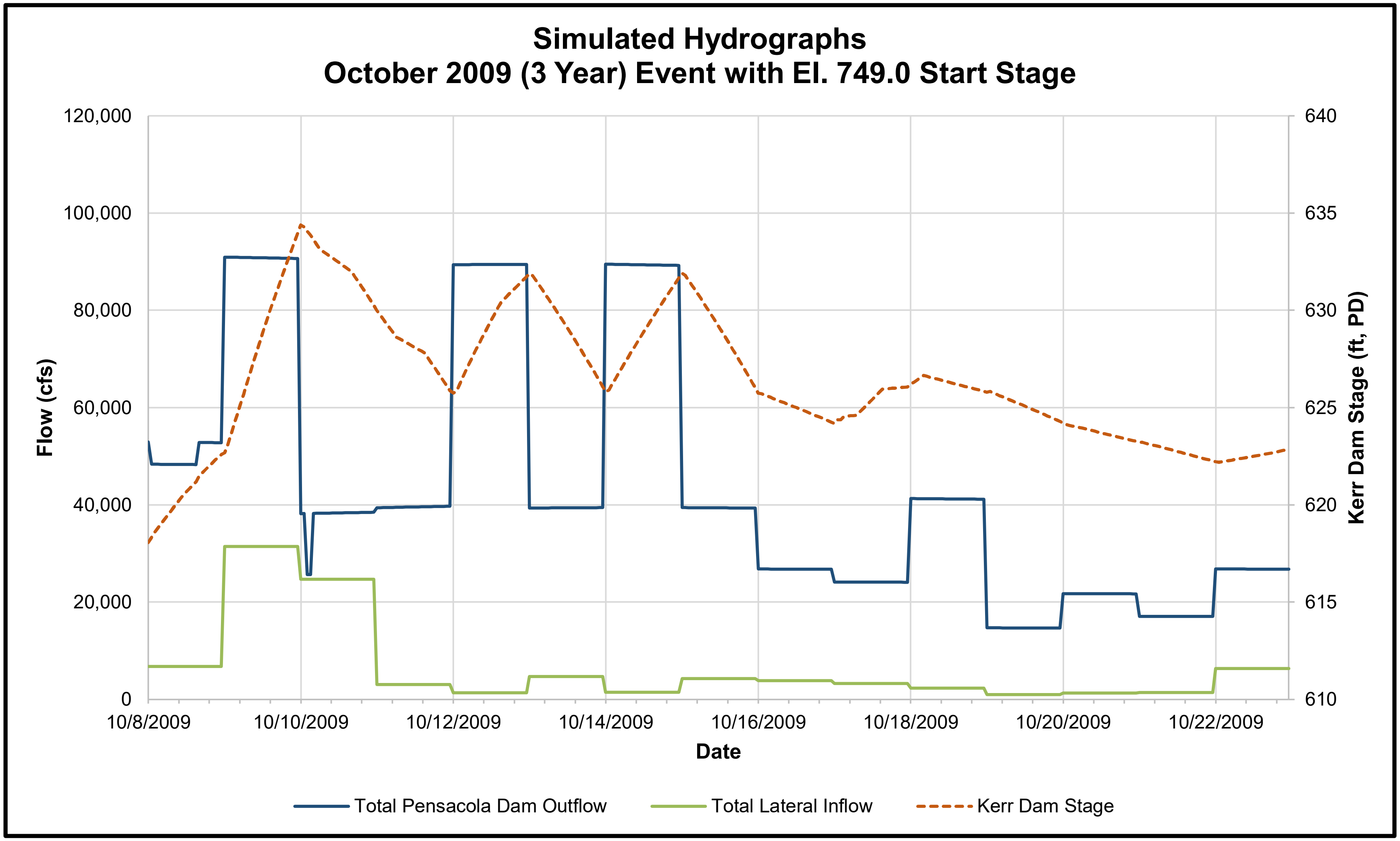


Figure A.45. Simulated hydrograph for the October 2009 (3 year) event with El. 749.0 starting stage at Pensacola Dam.

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.

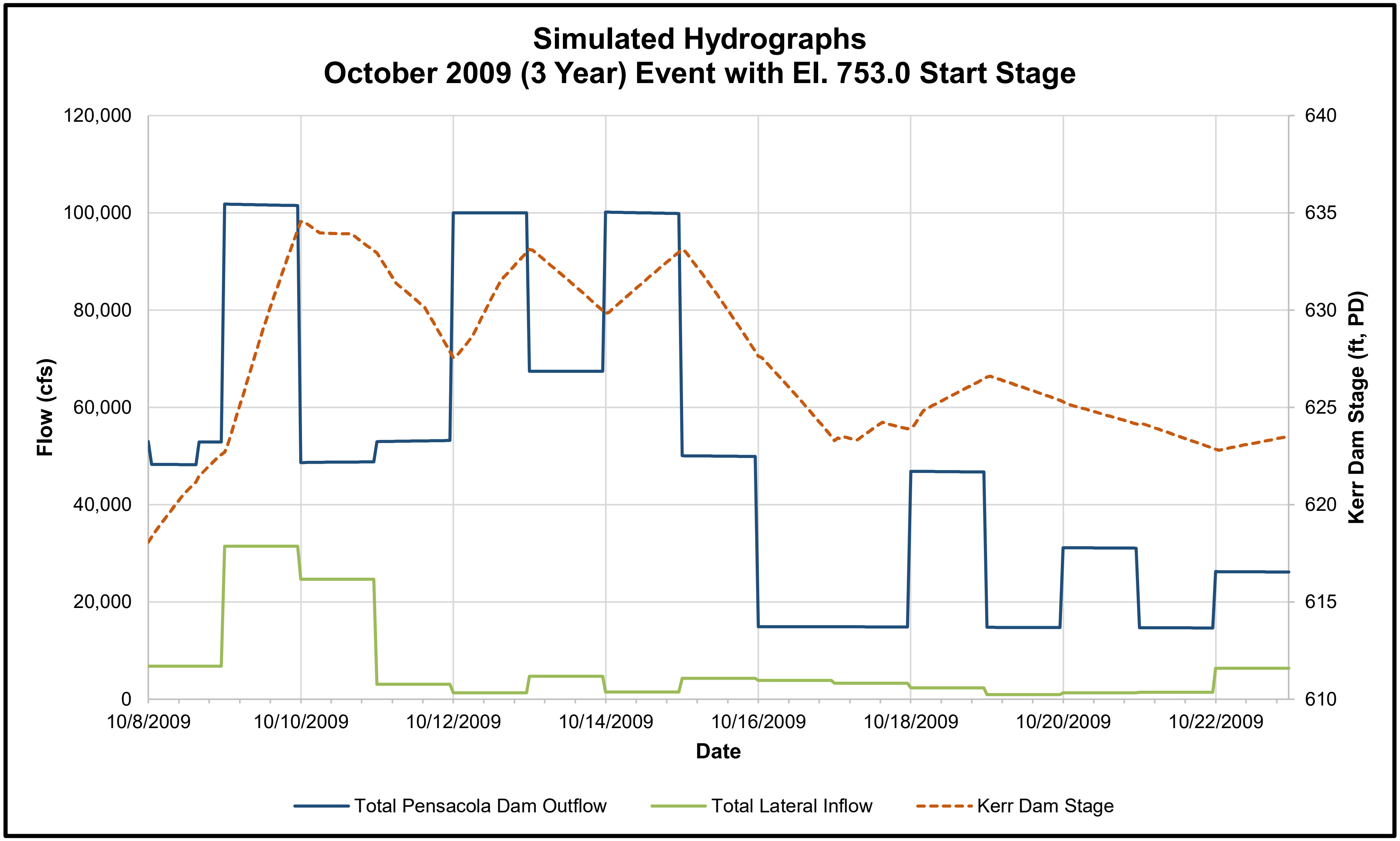


Figure A.46. Simulated hydrograph for the October 2009 (3 year) event with El. 753.0 starting stage at Pensacola Dam.

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.

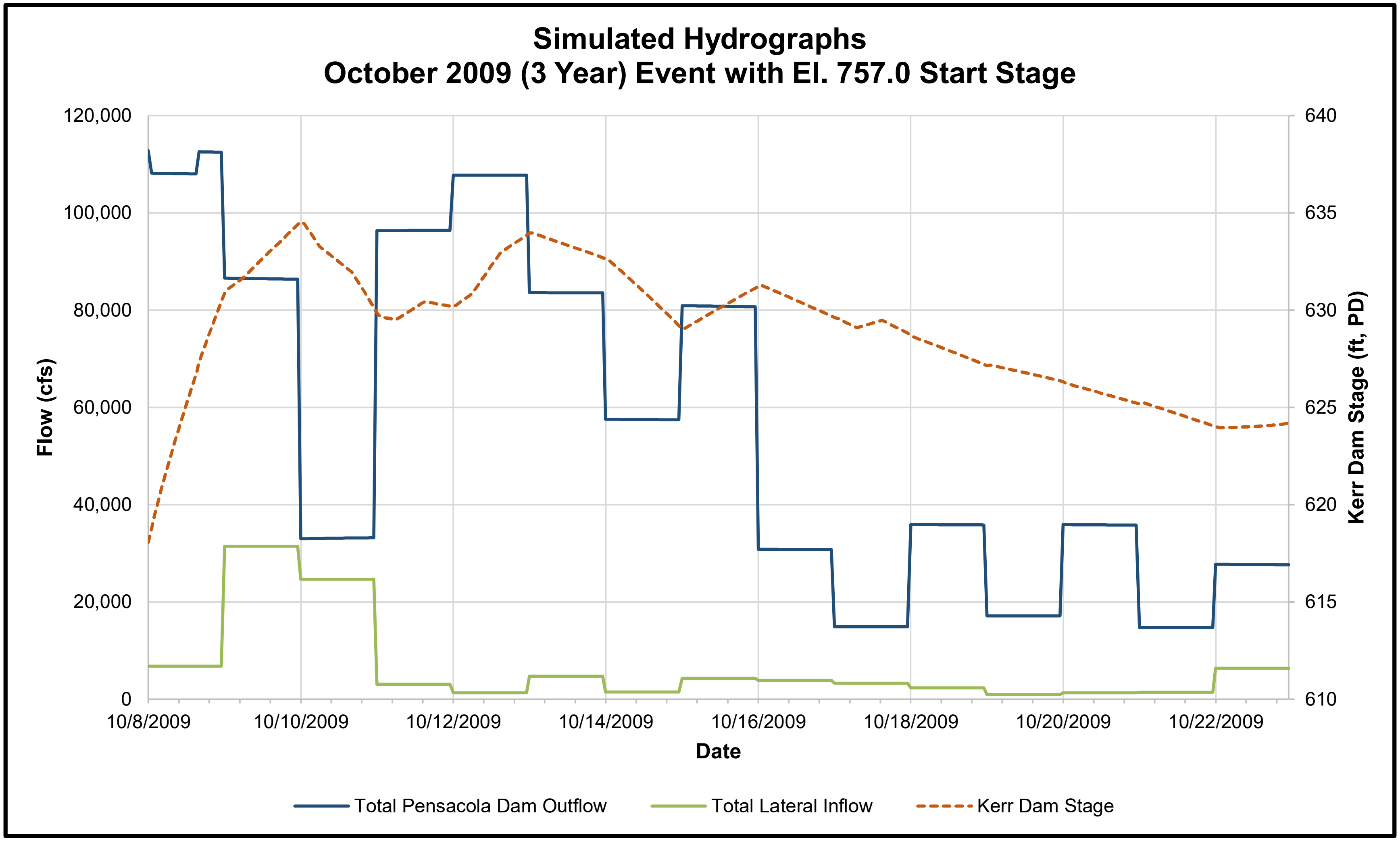


Figure A.47. Simulated hydrograph for the October 2009 (3 year) event with El. 757.0 starting stage at Pensacola Dam.

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.

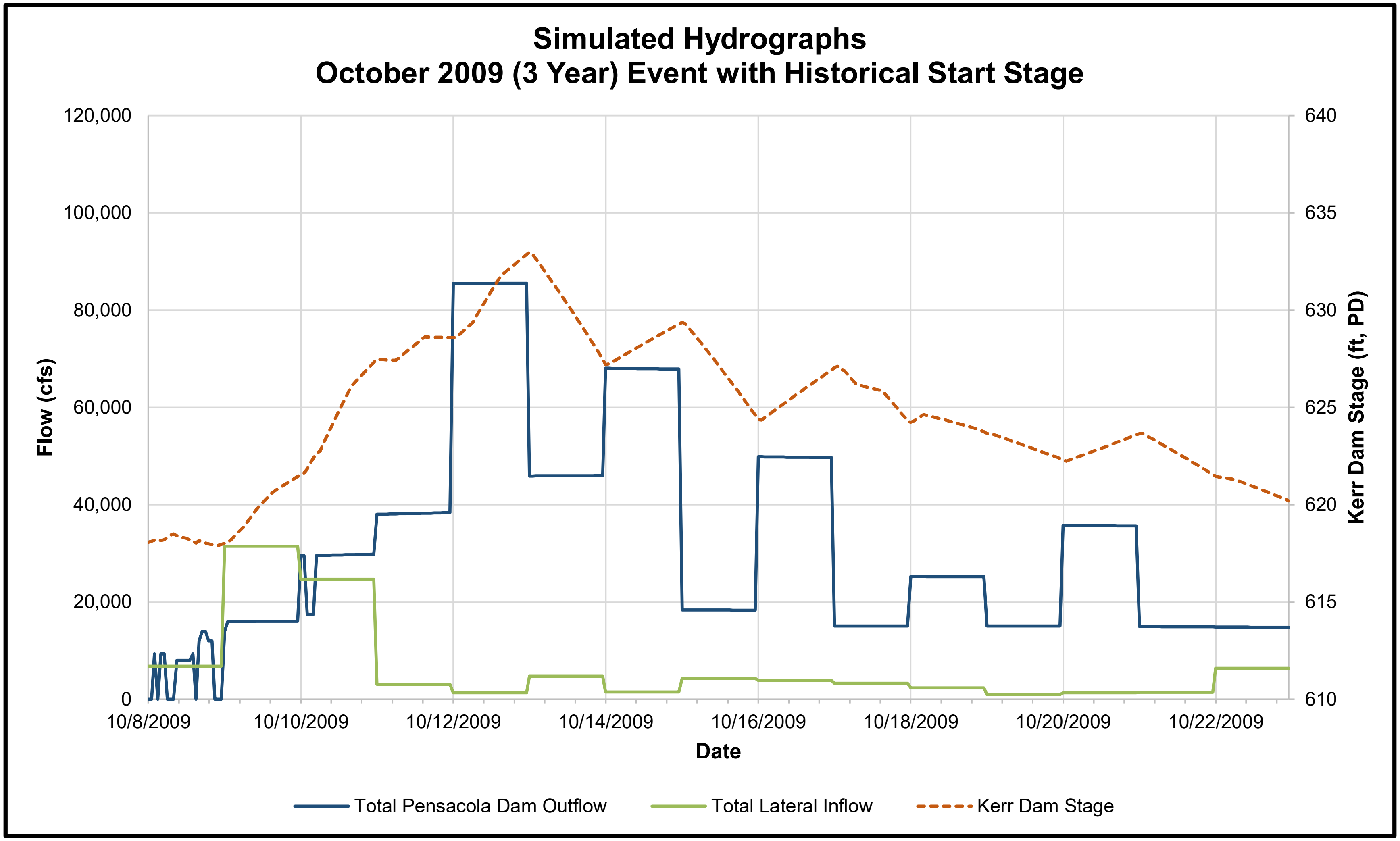


Figure A.48. Simulated hydrograph for the October 2009 (3 year) event with historical starting stage at Pensacola Dam.

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 (15 YEAR) EVENT SIMULATED HYDROGRAPHS

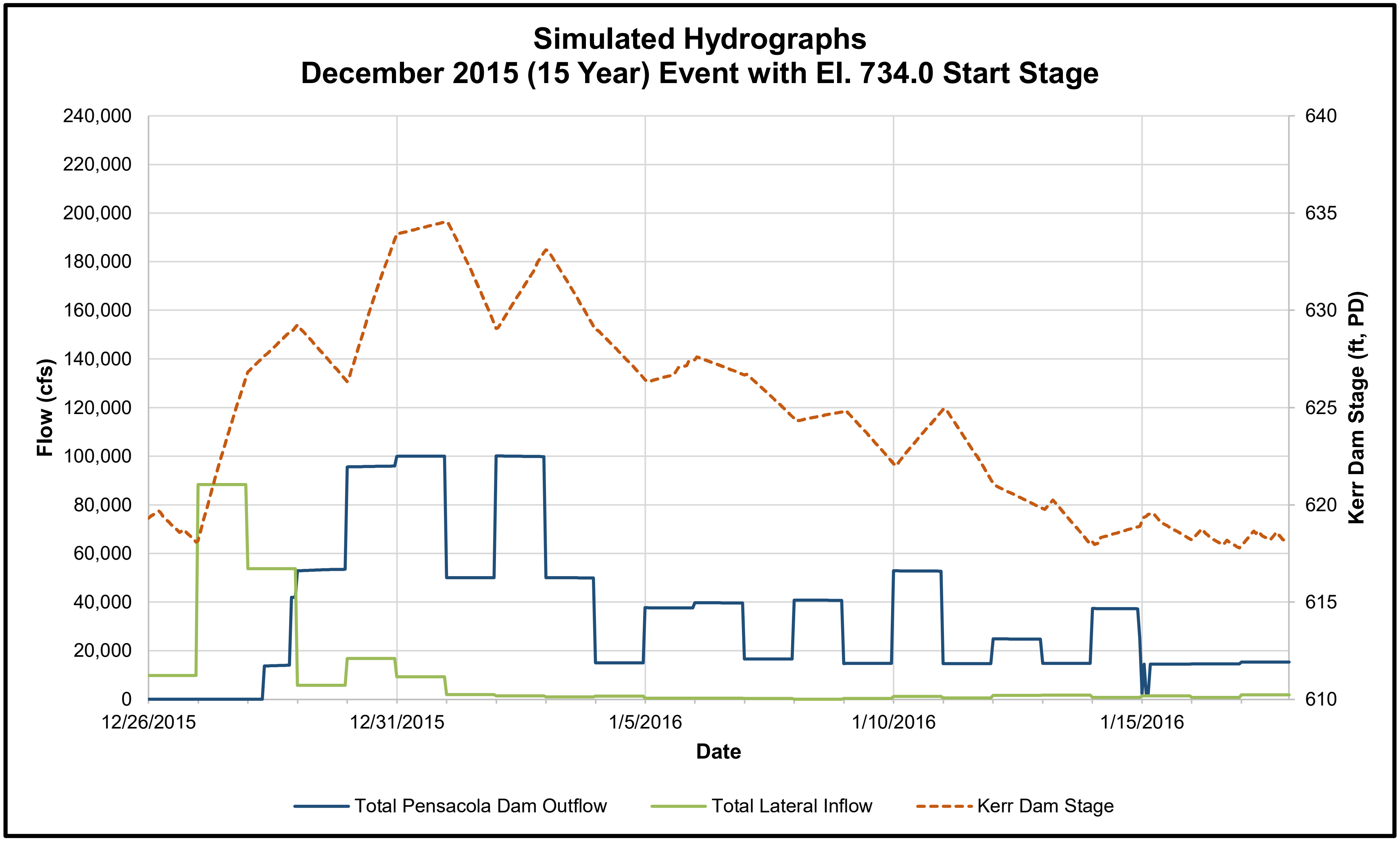


Figure A.49. Simulated hydrograph for the December 2015 (15 year) event with El. 734.0 starting stage at Pensacola Dam.

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.

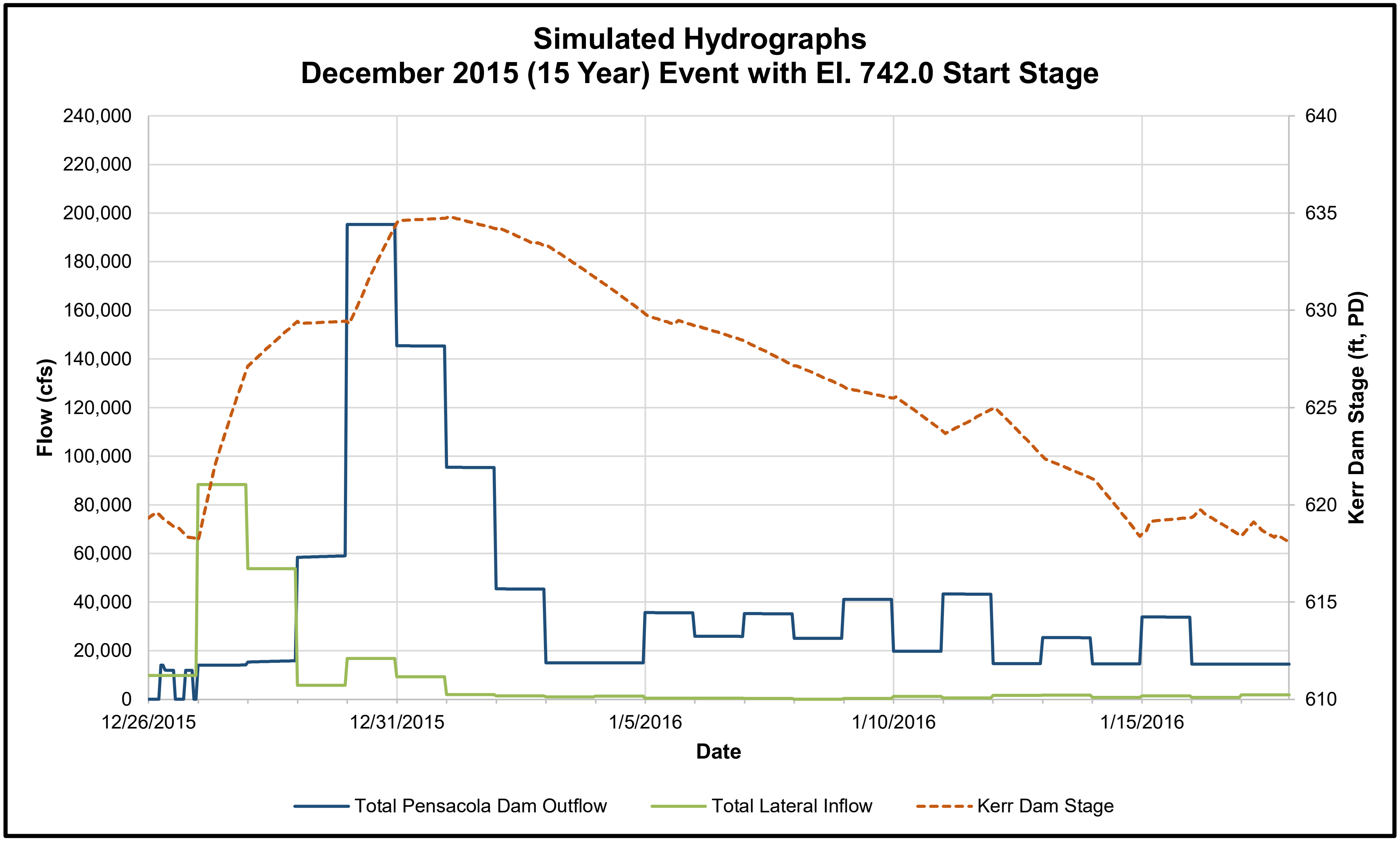


Figure A.50. Simulated hydrograph for the December 2015 (15 year) event with El. 742.0 starting stage at Pensacola Dam.

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.

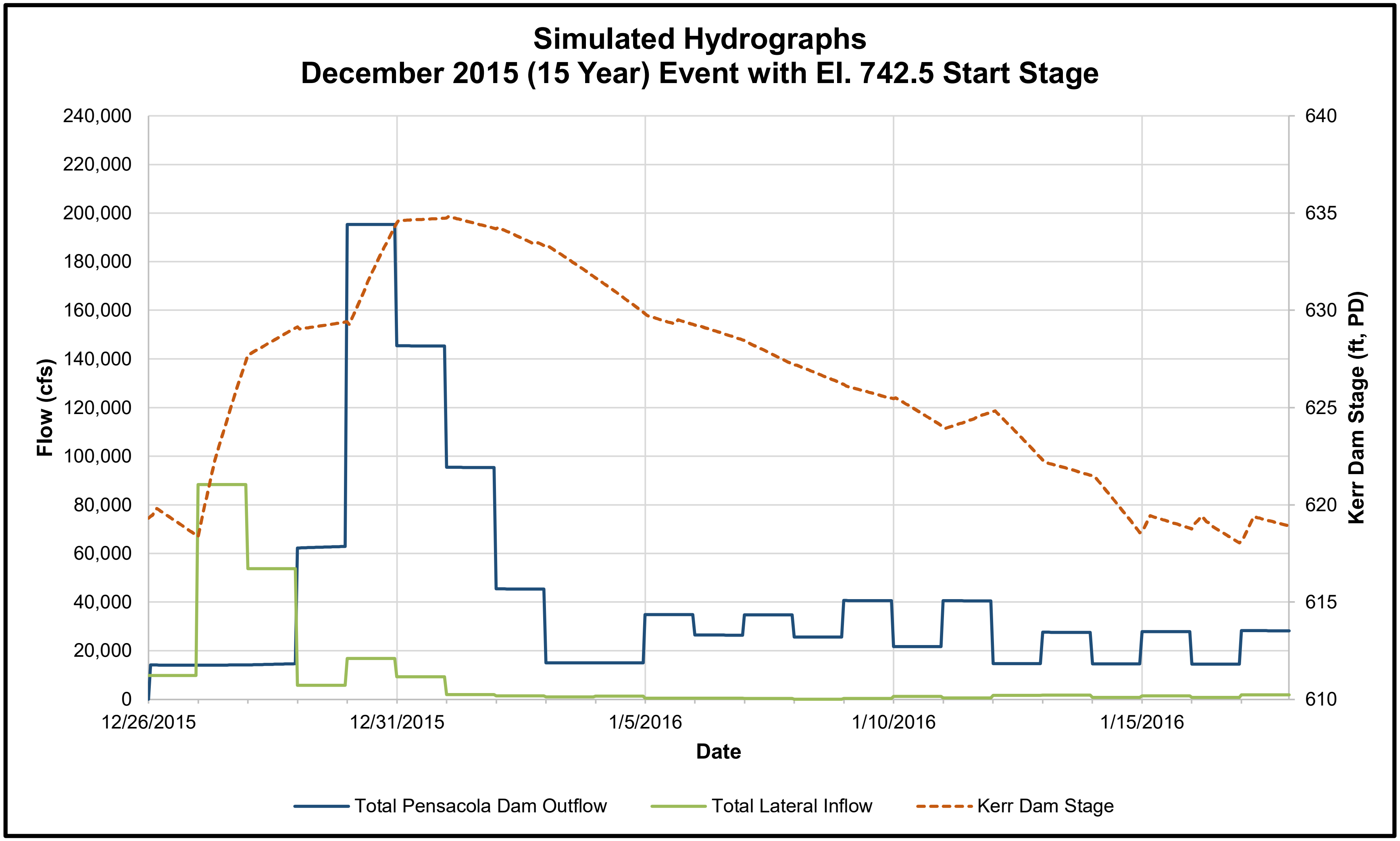


Figure A.51. Simulated hydrograph for the December 2015 (15 year) event with El. 742.5 starting stage at Pensacola Dam.

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.*

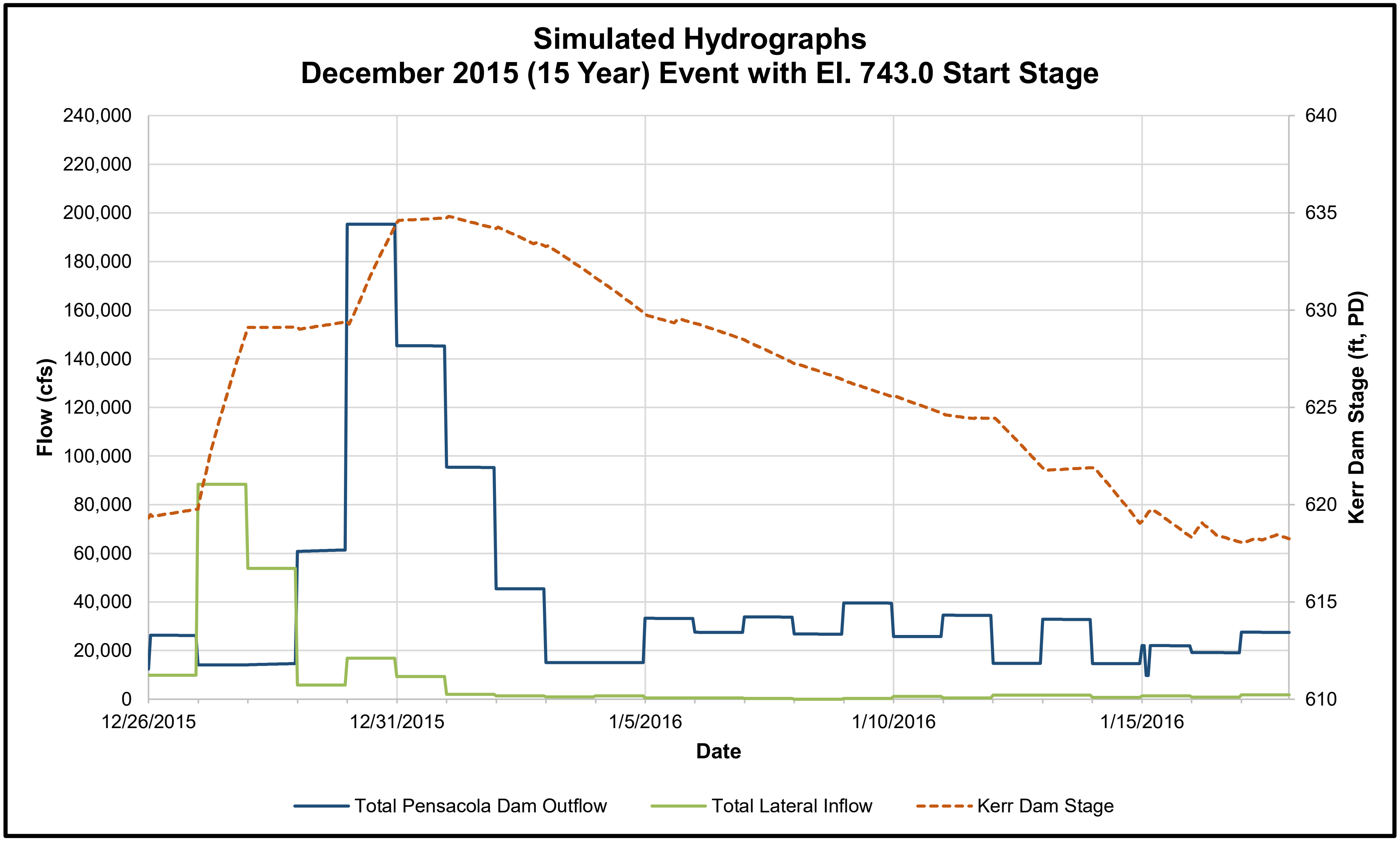


Figure A.52. Simulated hydrograph for the December 2015 (15 year) event with El. 743.0 starting stage at Pensacola Dam.

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.

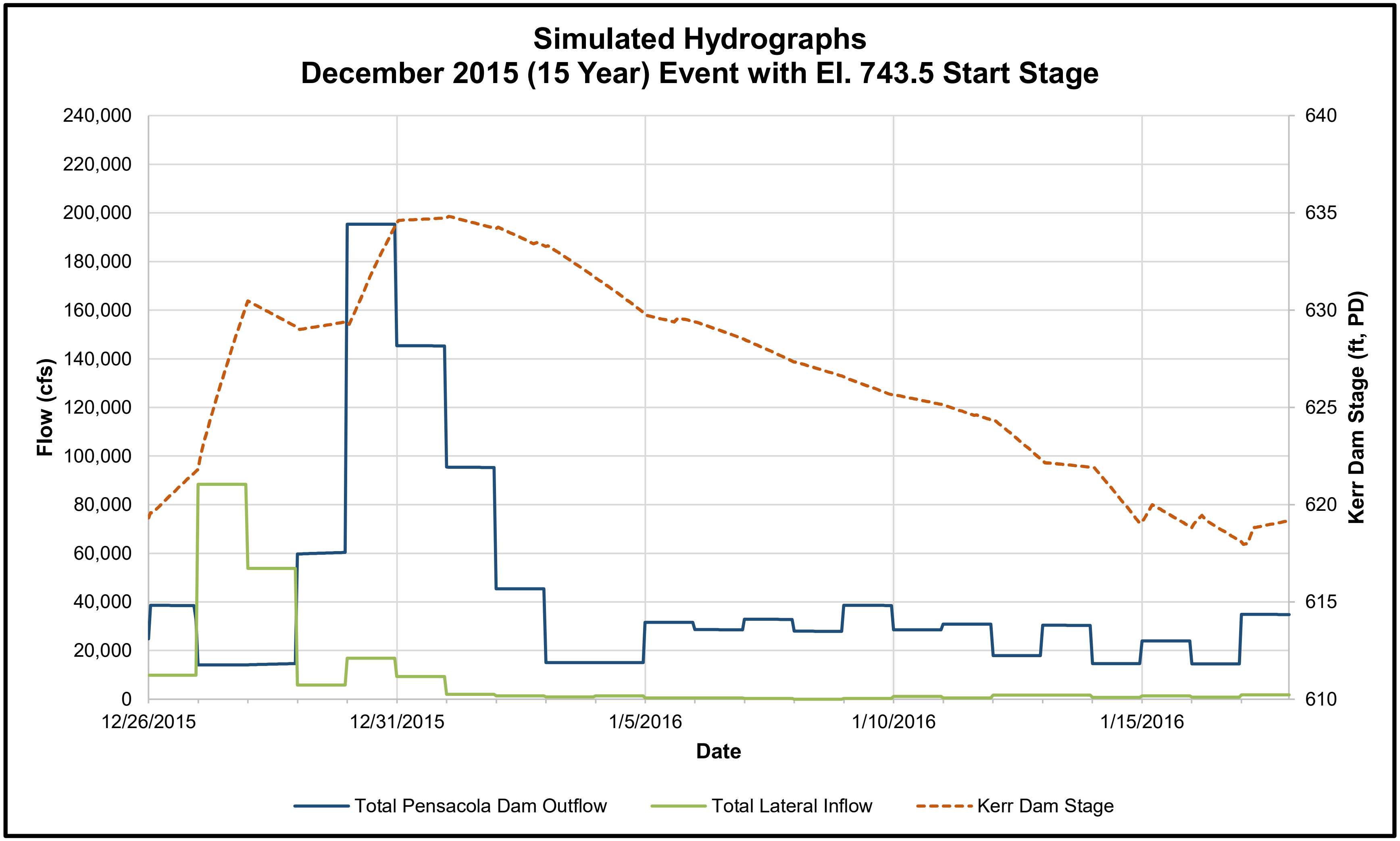


Figure A.53. Simulated hydrograph for the December 2015 (15 year) event with El. 743.5 starting stage at Pensacola Dam.

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.

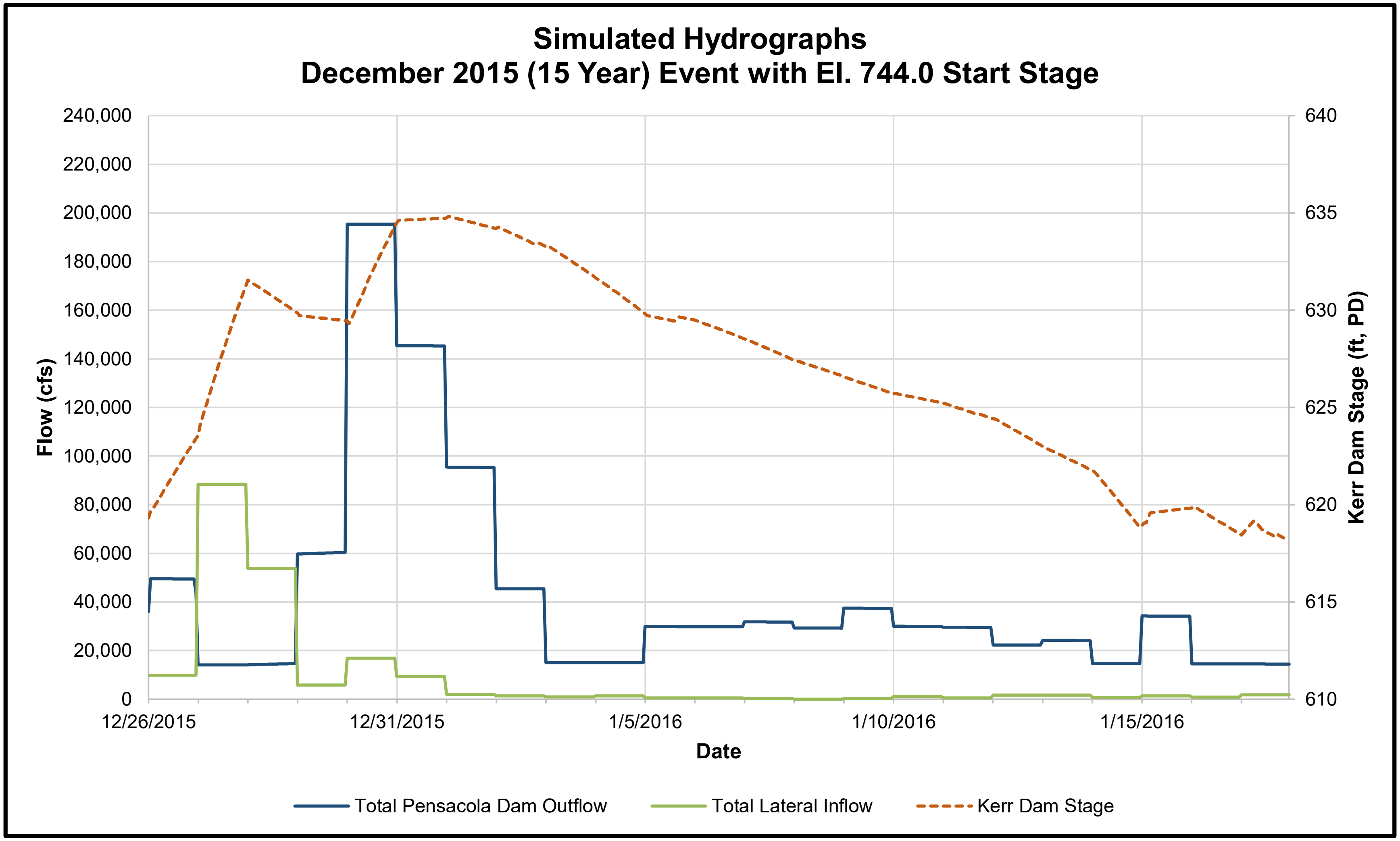


Figure A.54. Simulated hydrograph for the December 2015 (15 year) event with El. 744.0 starting stage at Pensacola Dam.

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.

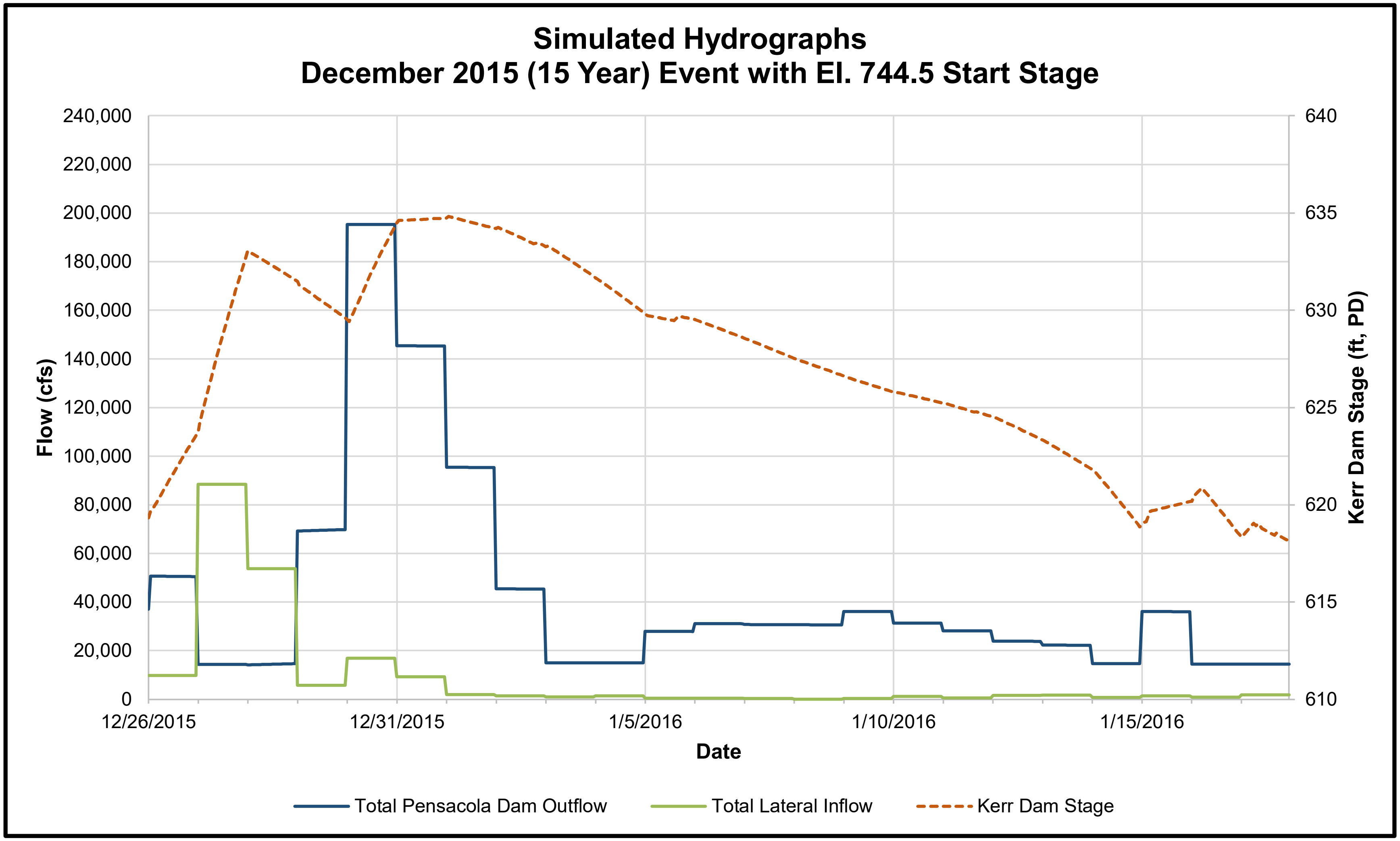


Figure A.55. Simulated hydrograph for the December 2015 (15 year) event with El. 744.5 starting stage at Pensacola Dam.

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.

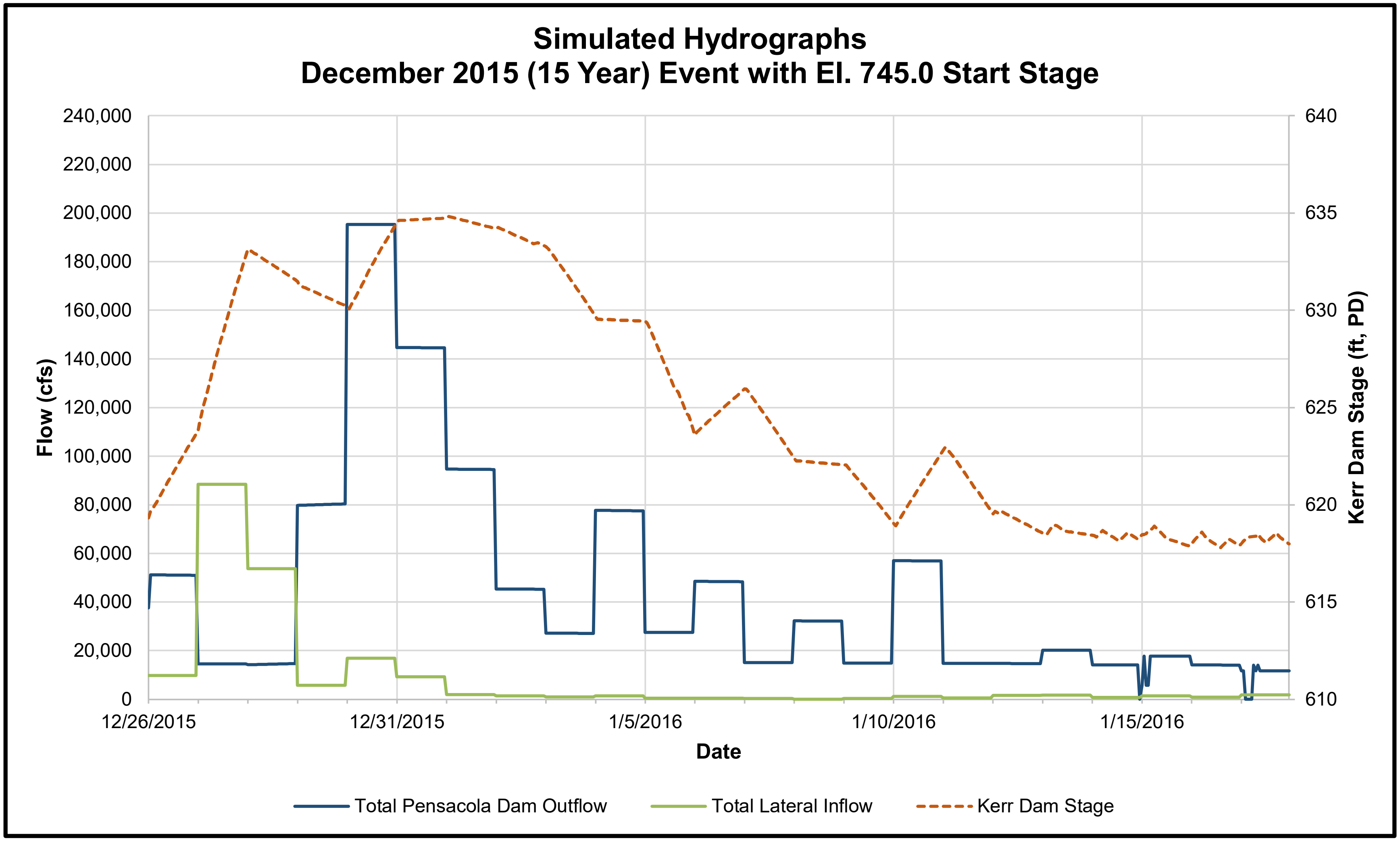


Figure A.56. Simulated hydrograph for the December 2015 (15 year) event with El. 745.0 starting stage at Pensacola Dam.

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.*

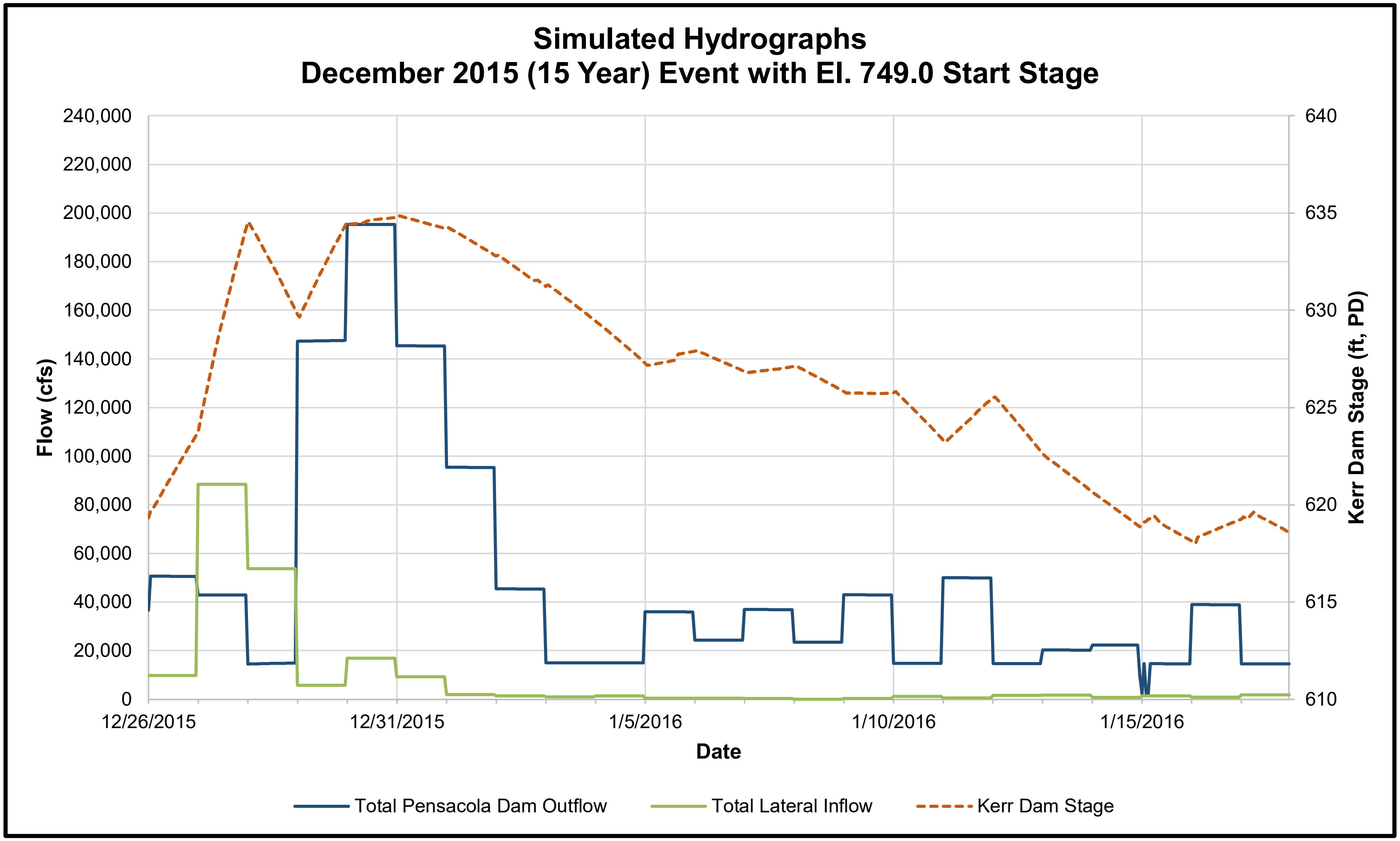


Figure A.57. Simulated hydrograph for the December 2015 (15 year) event with El. 749.0 starting stage at Pensacola Dam.

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.*

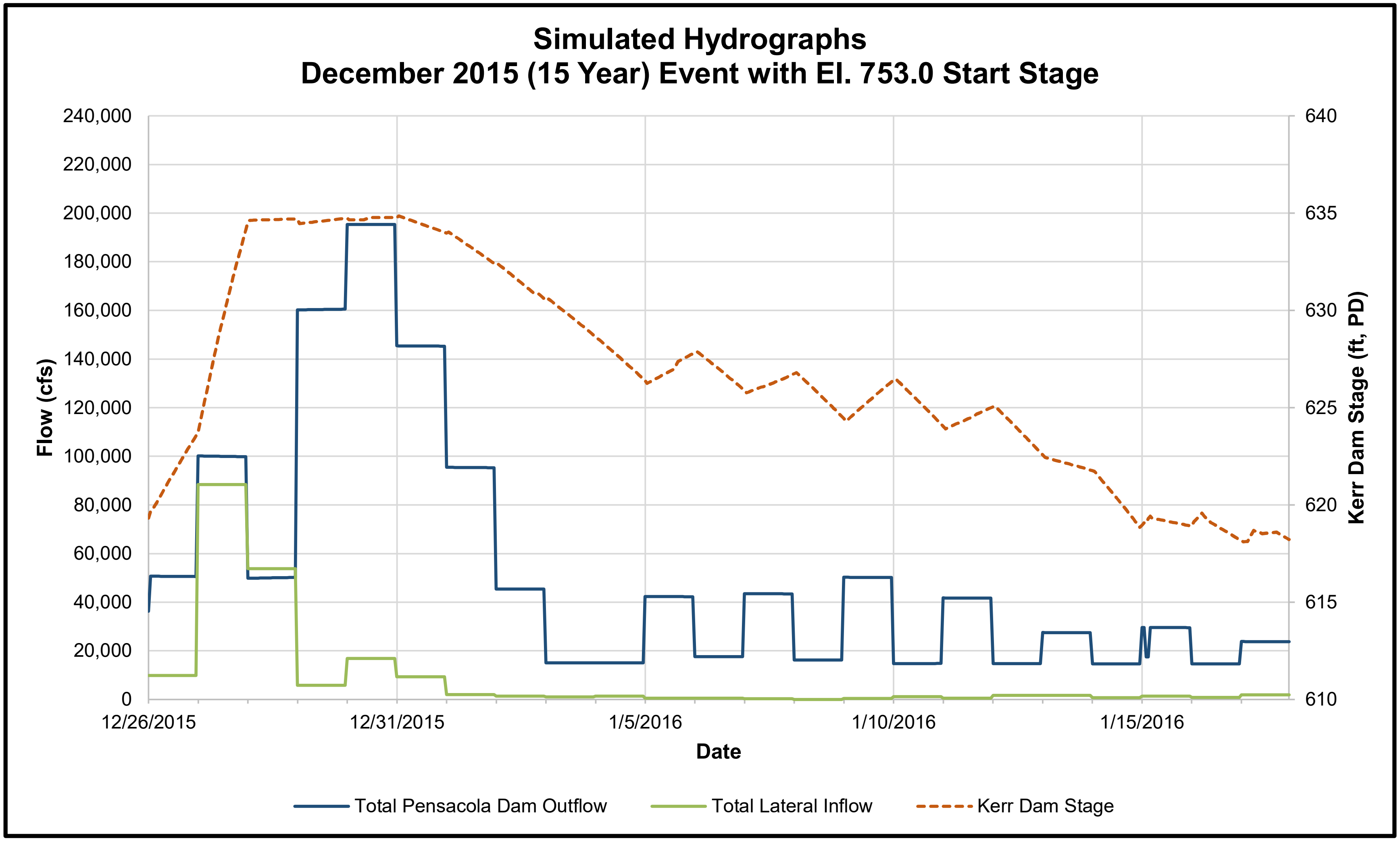


Figure A.58. Simulated hydrograph for the December 2015 (15 year) event with El. 753.0 starting stage at Pensacola Dam.

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.

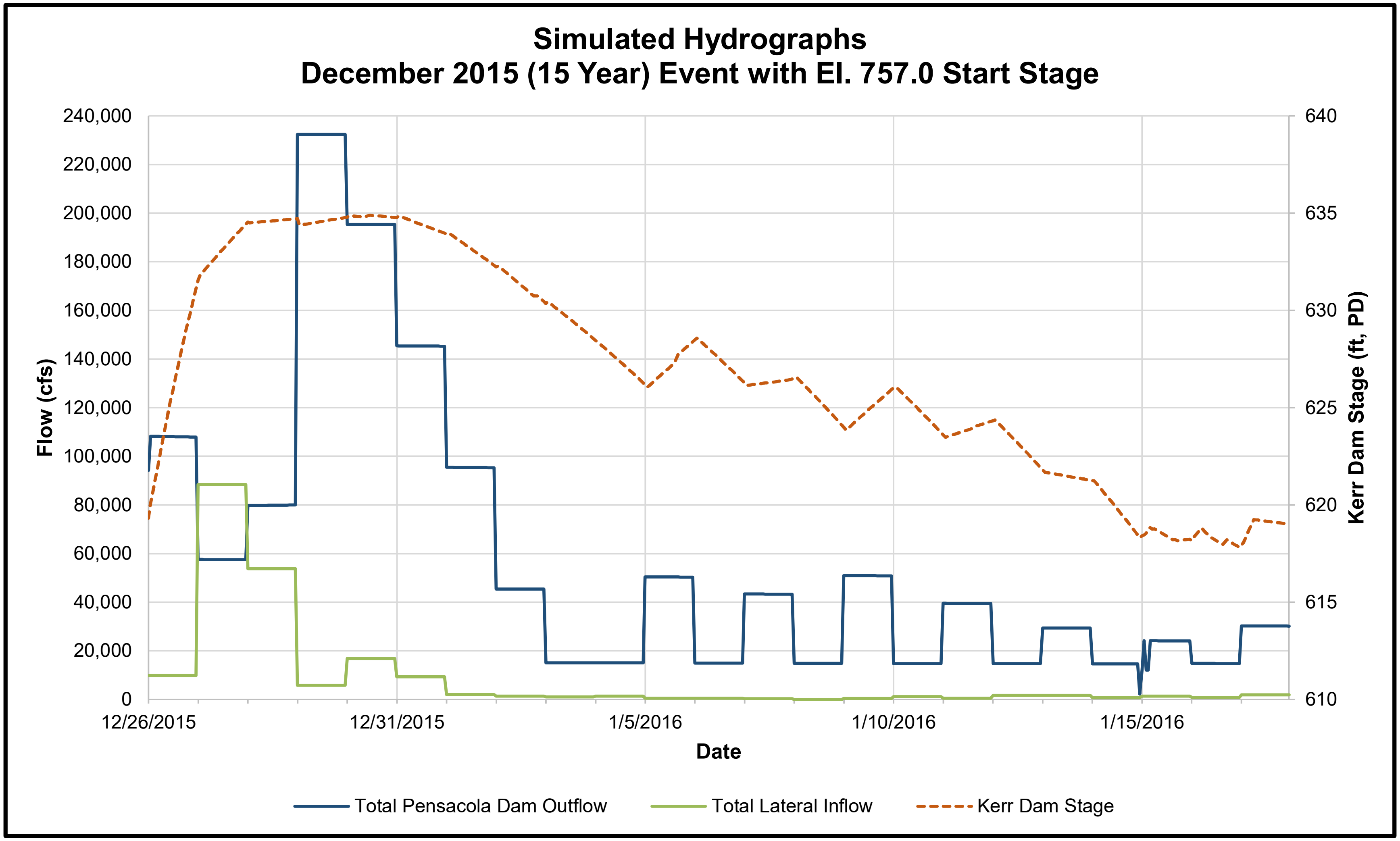


Figure A.59. Simulated hydrograph for the December 2015 (15 year) event with El. 757.0 starting stage at Pensacola Dam.

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.

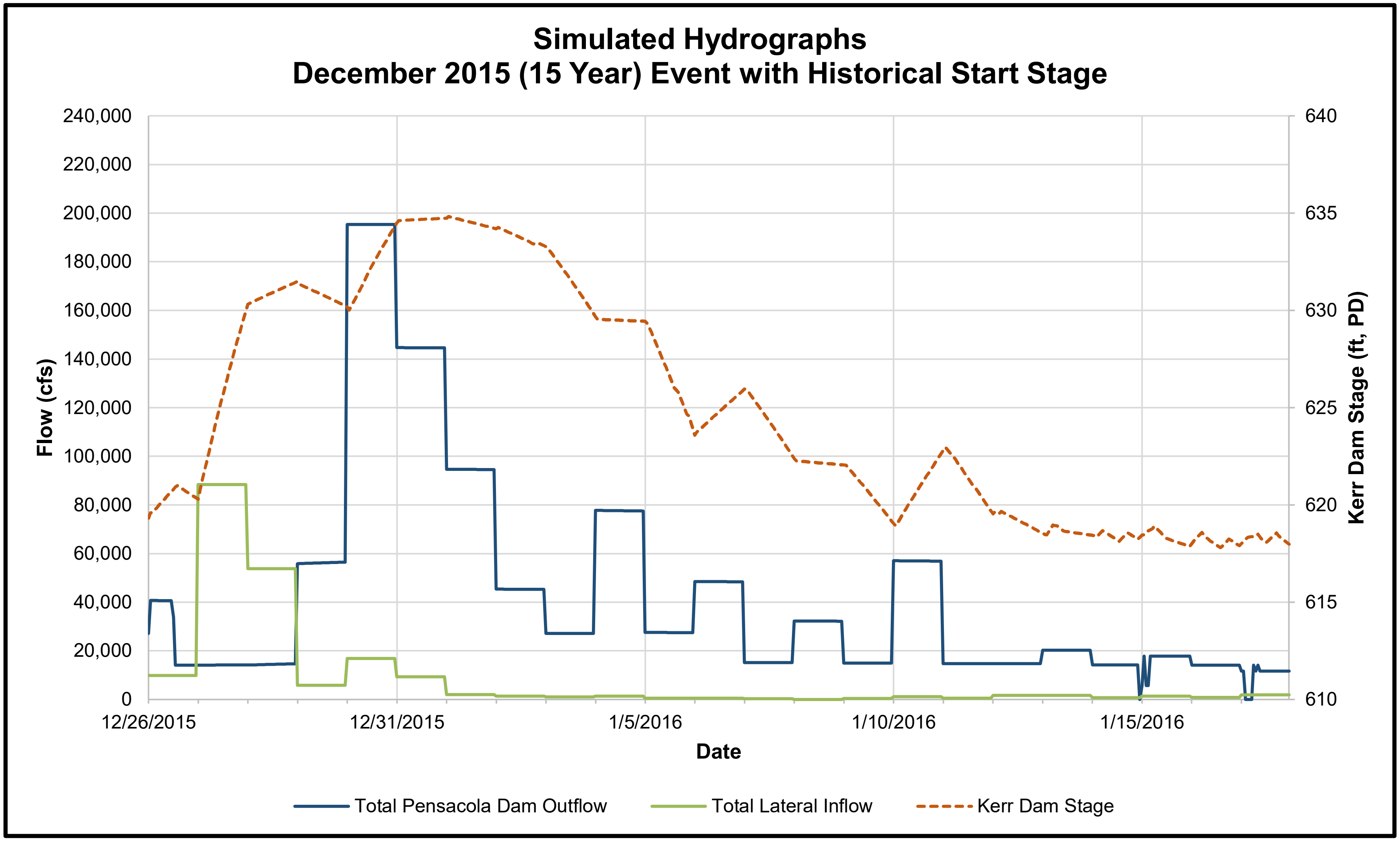


Figure A.60. Simulated hydrograph for the December 2015 (15 year) event with historical starting stage at Pensacola Dam.

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

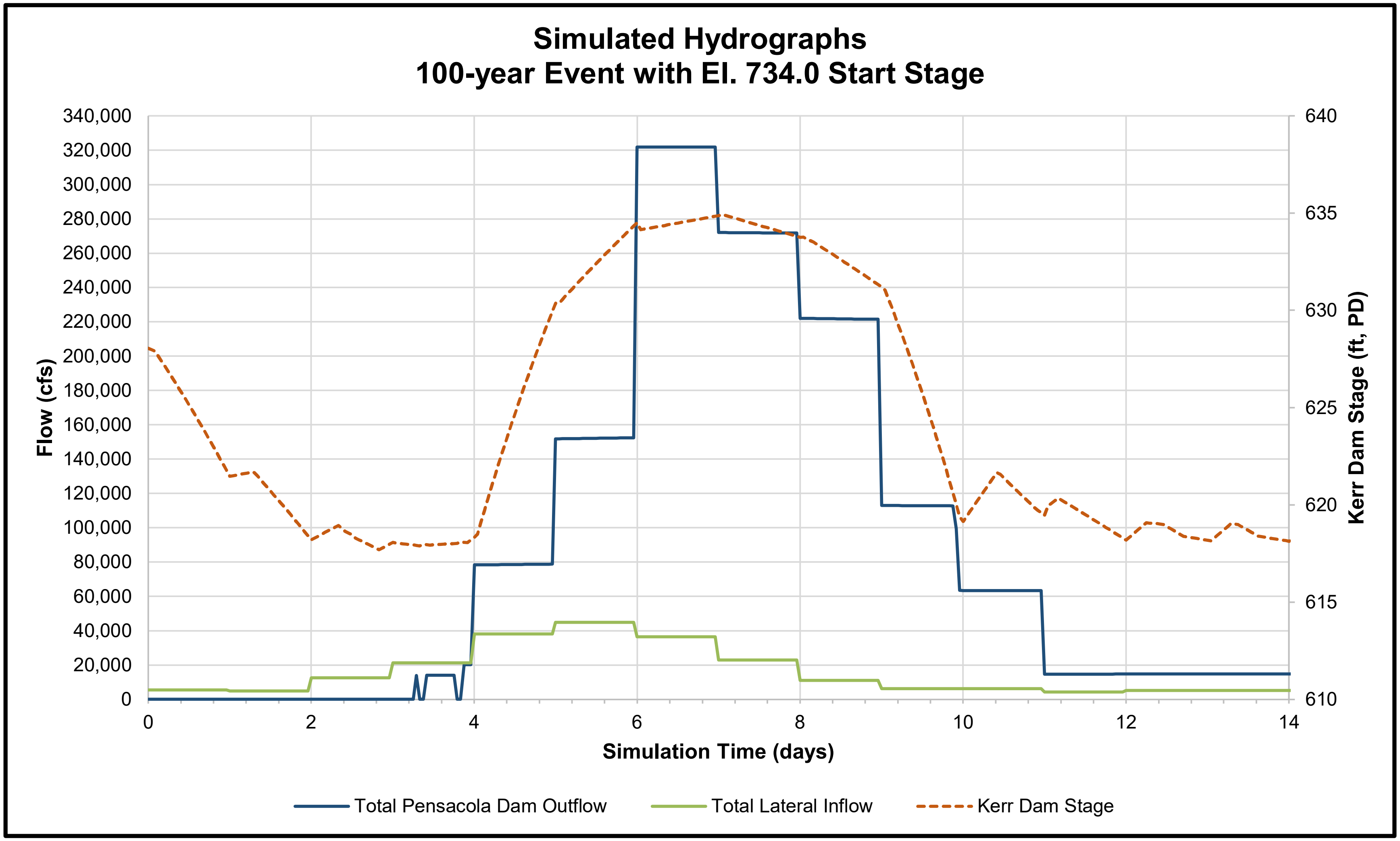


Figure A.61. Simulated hydrograph for the 100-year event with El. 734.0 starting stage at Pensacola Dam.

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.

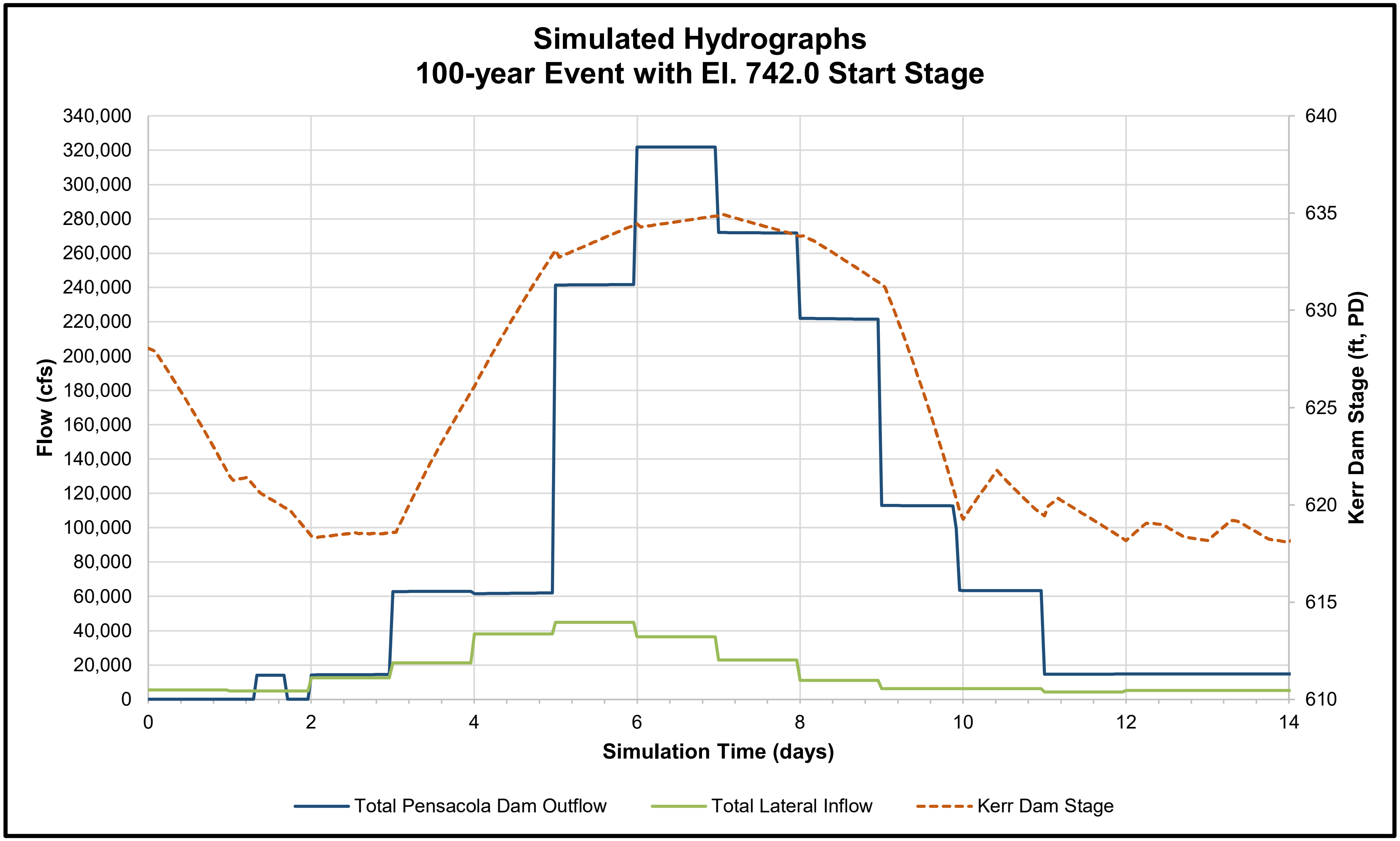


Figure A.62. Simulated hydrograph for the 100-year event with El. 742.0 starting stage at Pensacola Dam.

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.*

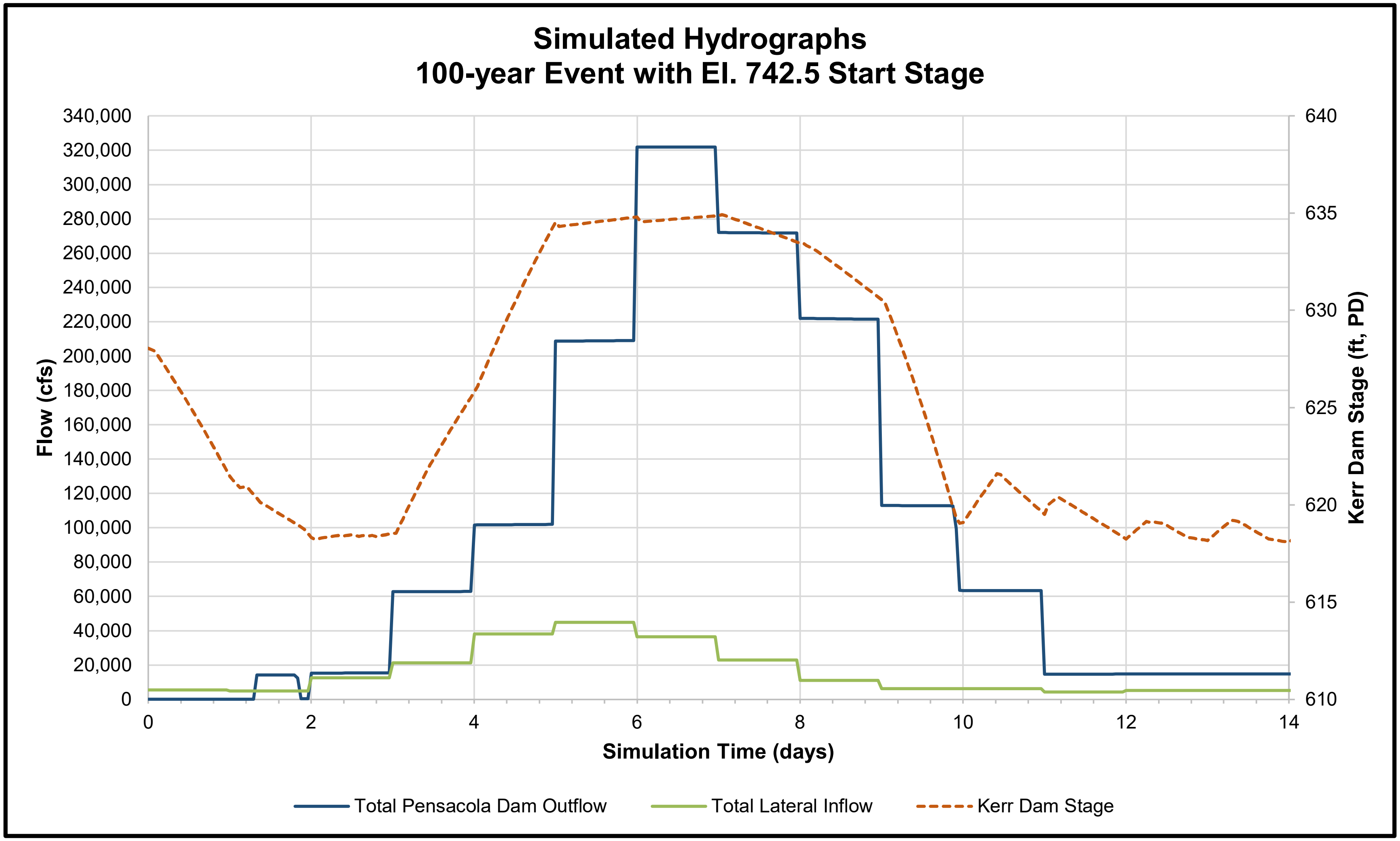


Figure A.63. Simulated hydrograph for the 100-year event with El. 742.5 starting stage at Pensacola Dam.

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.

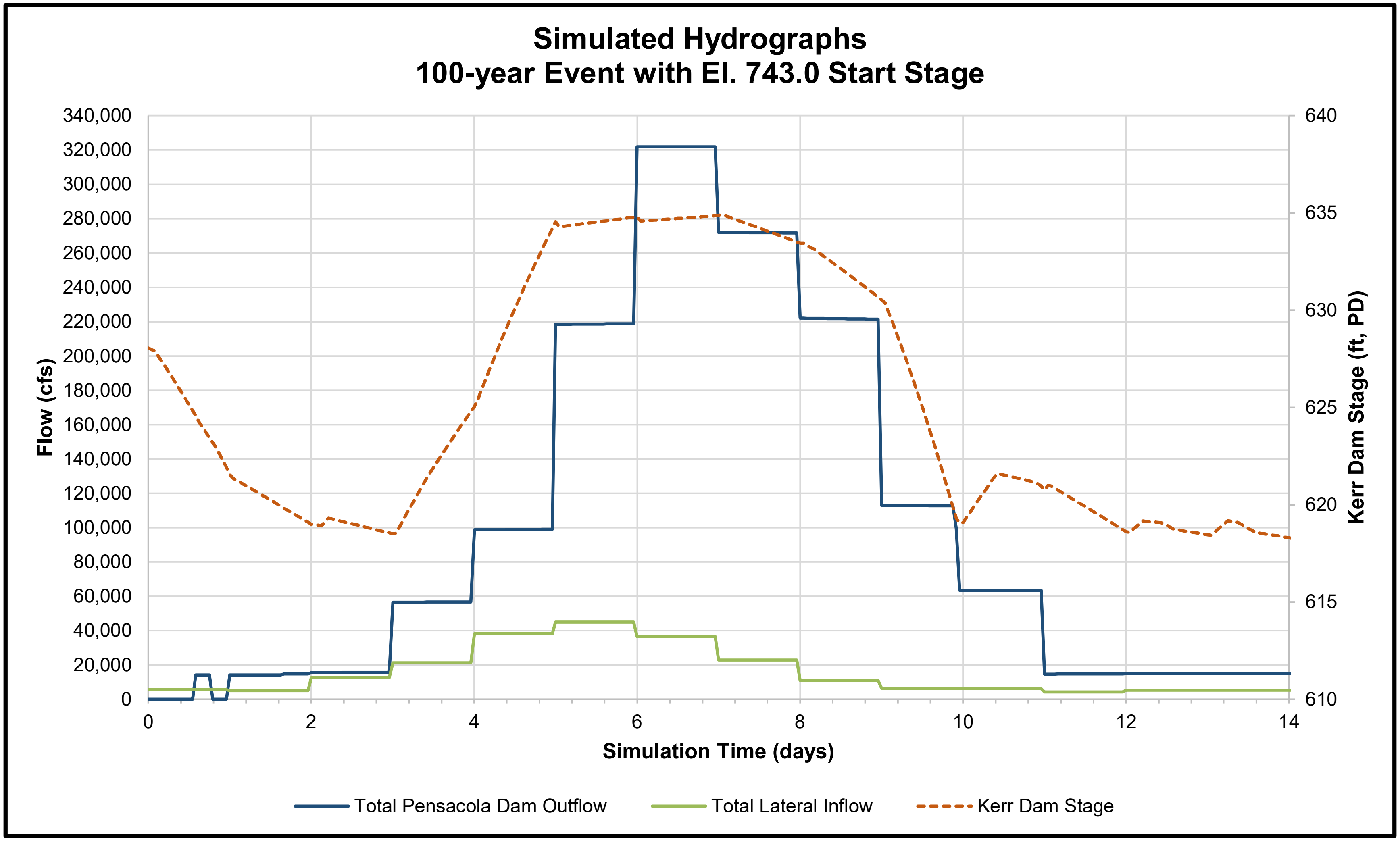


Figure A.64. Simulated hydrograph for the 100-year event with El. 743.0 starting stage at Pensacola Dam.

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.

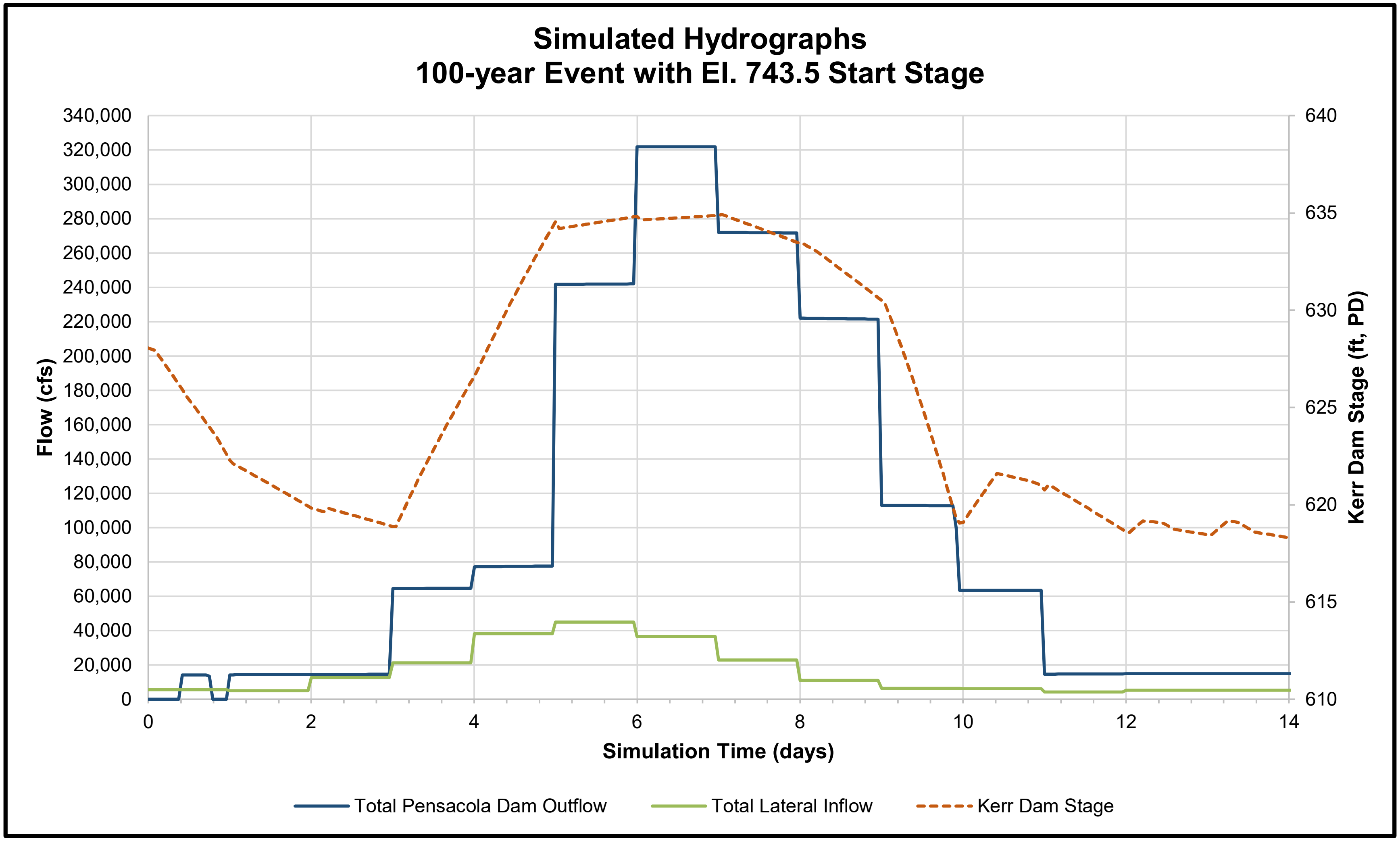


Figure A.65. Simulated hydrograph for the 100-year event with El. 743.5 starting stage at Pensacola Dam.

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.

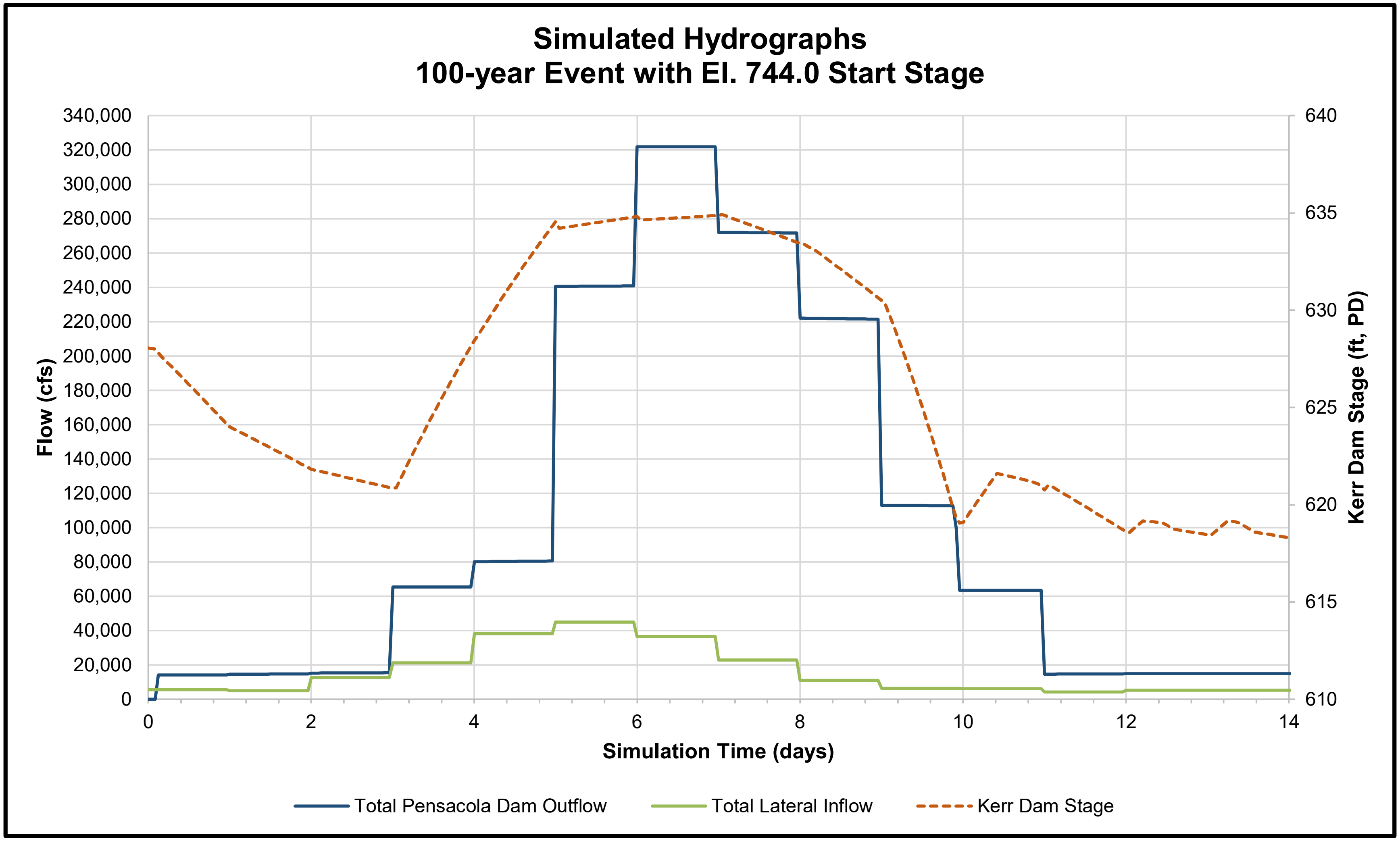


Figure A.66. Simulated hydrograph for the 100-year event with El. 744.0 starting stage at Pensacola Dam.

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.

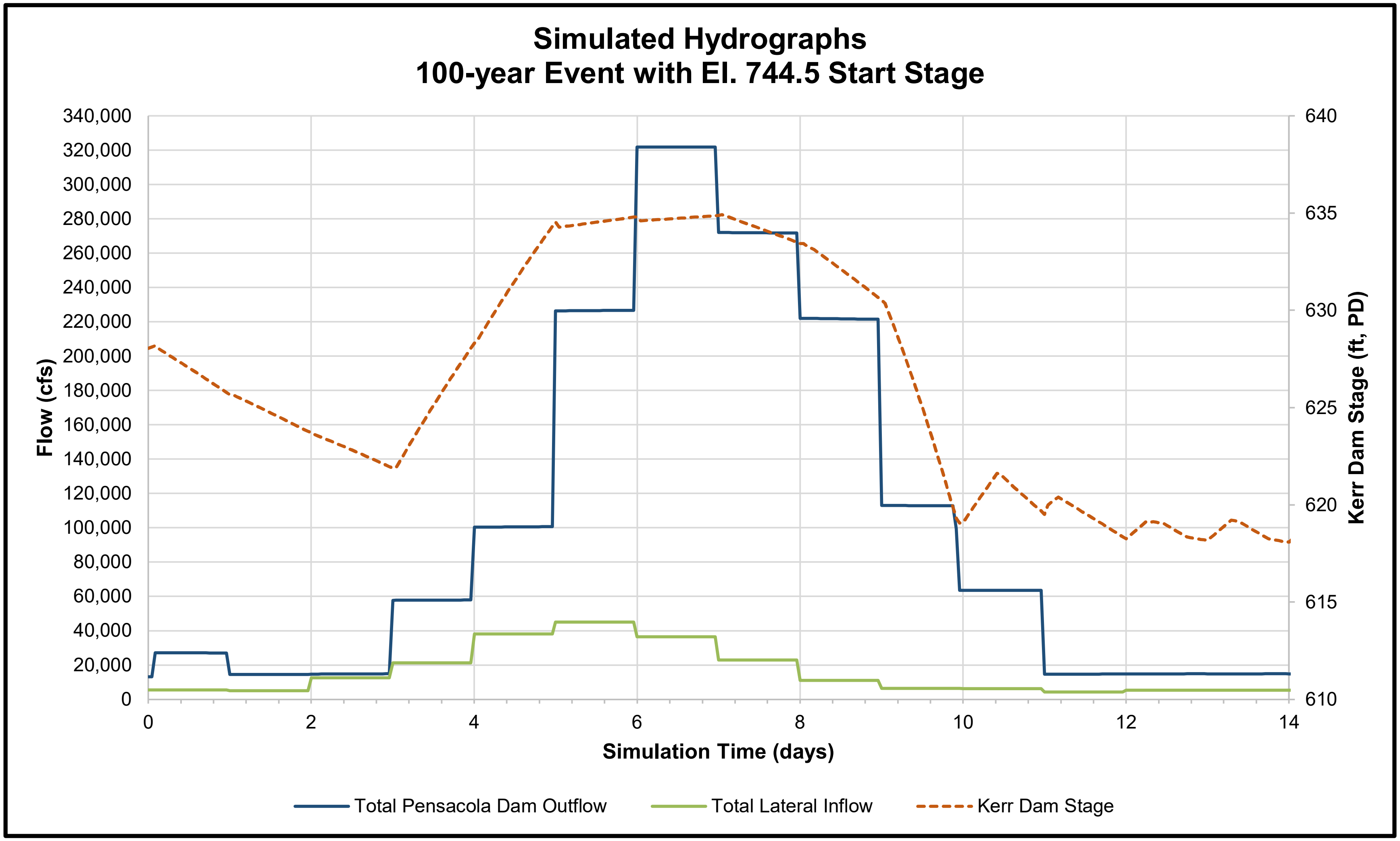


Figure A.67. Simulated hydrograph for the 100-year event with El. 744.5 starting stage at Pensacola Dam.

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.

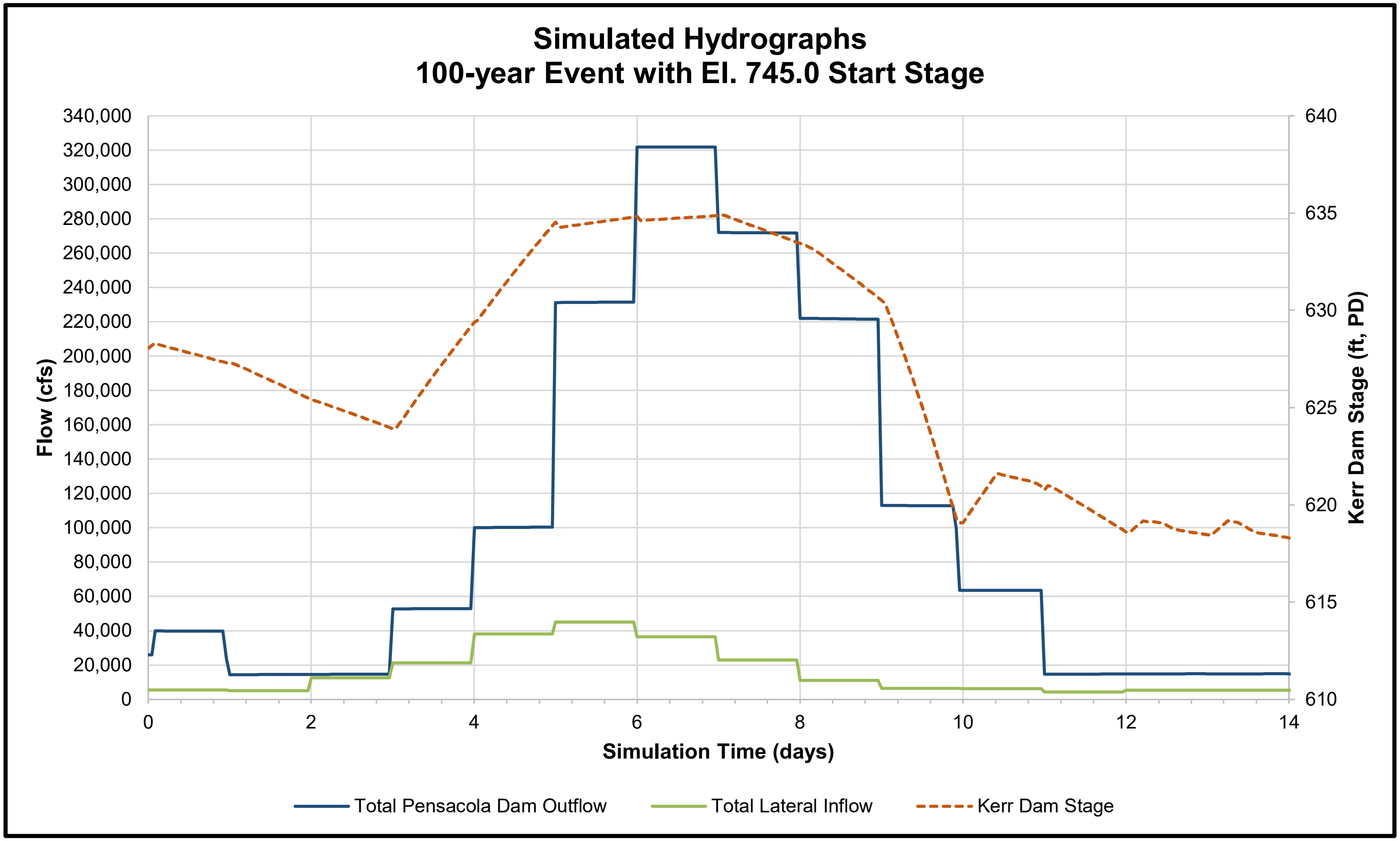


Figure A.68. Simulated hydrograph for the 100-year event with El. 745.0 starting stage at Pensacola Dam.

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.*

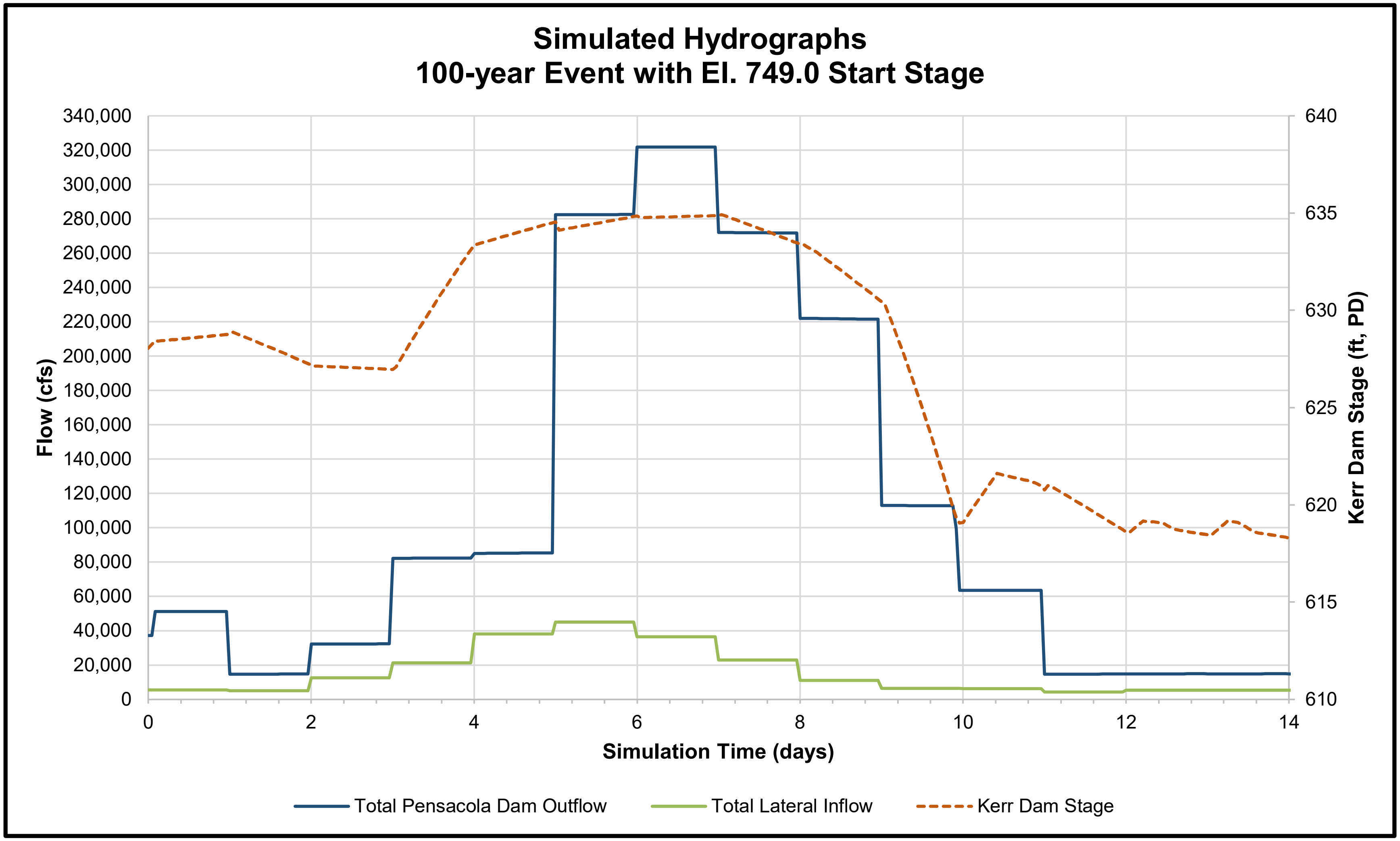


Figure A.69. Simulated hydrograph for the 100-year event with El. 749.0 starting stage at Pensacola Dam.

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.

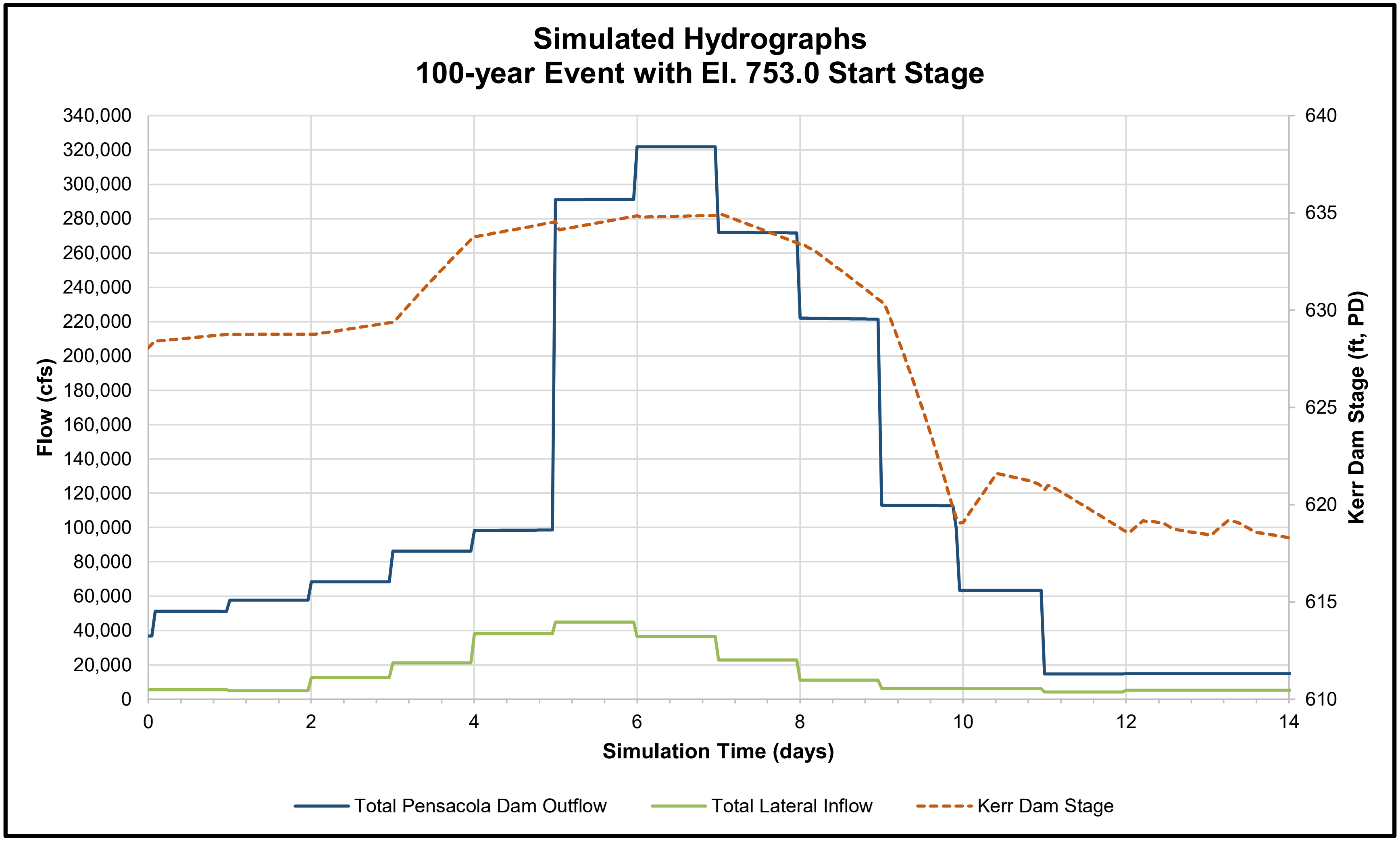


Figure A.70. Simulated hydrograph for the 100-year event with El. 753.0 starting stage at Pensacola Dam.

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.

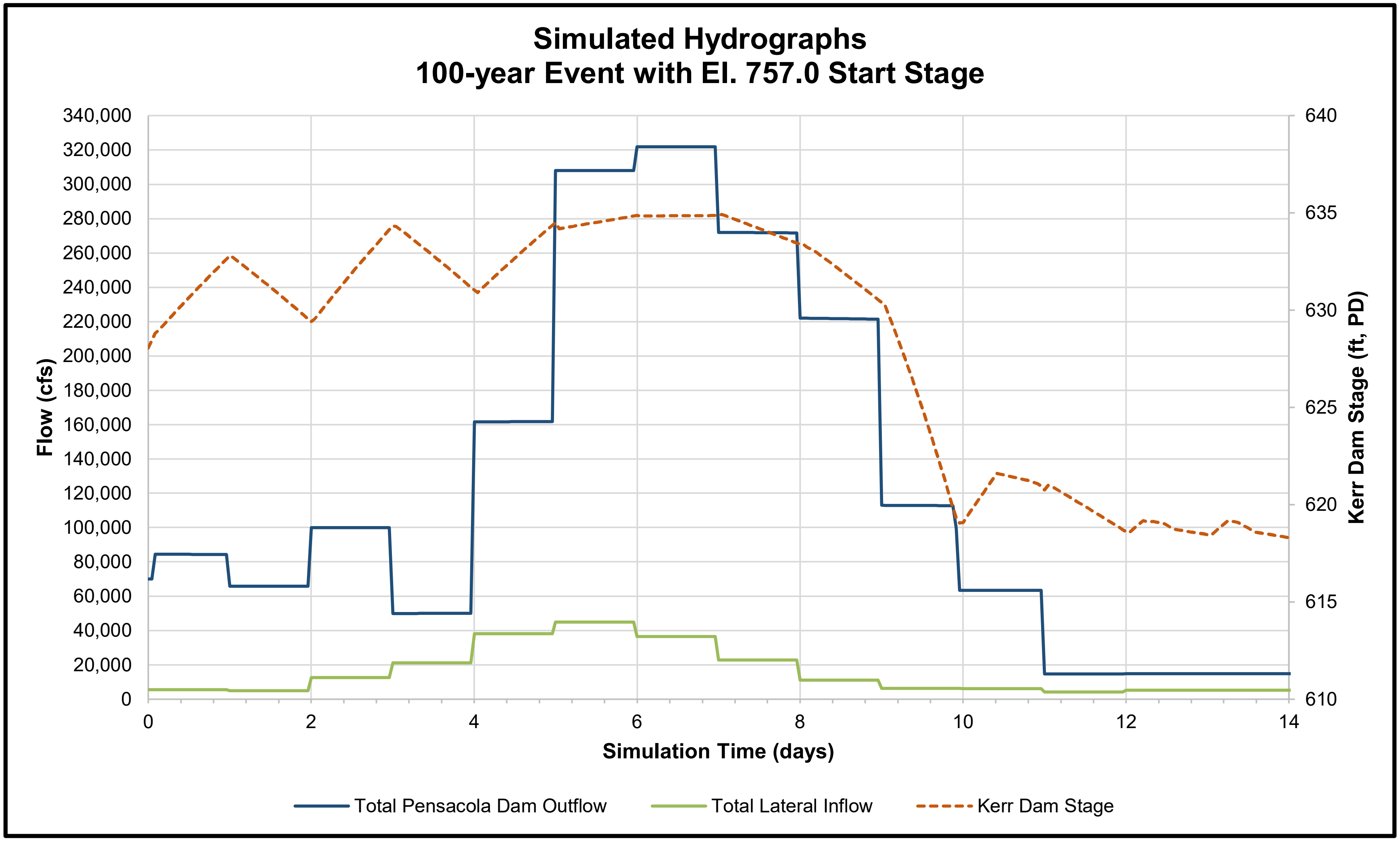
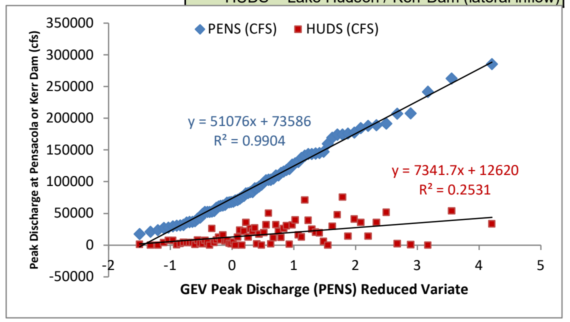


Figure A.71. Simulated hydrograph for the 100-year event with El. 757.0 starting stage at Pensacola Dam.

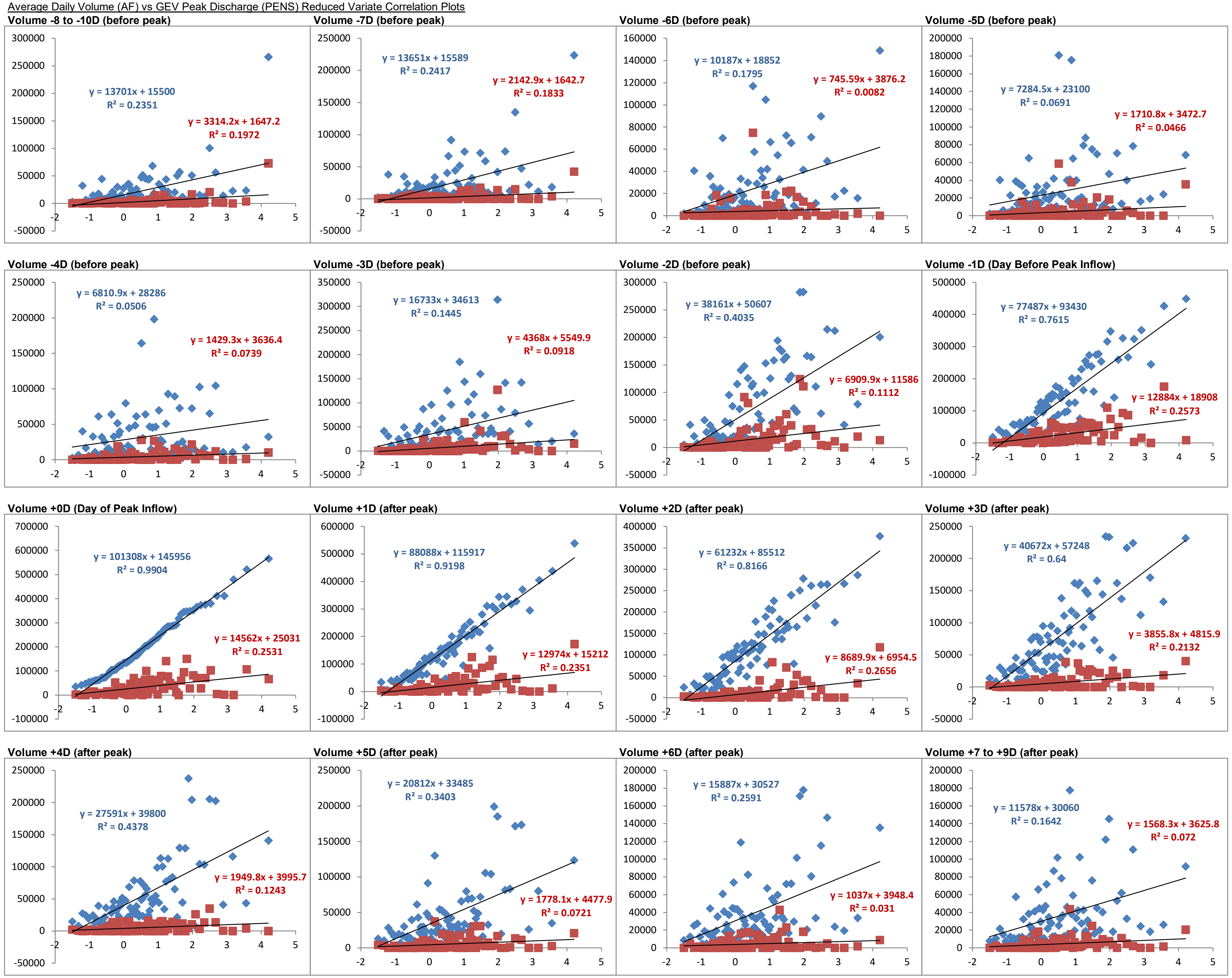
Notes: 1. *The solid blue and green lines are plotted against the left y-axis and represent the Total Pensacola Dam Outflow and Total Lateral Inflow respectively.*
2. *The dashed line is plotted against the right y-axis and represents the stage at Kerr Dam.*

APPENDIX B:
HISTORICAL INFLOW VOLUME STATISTICAL ANALYSIS

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

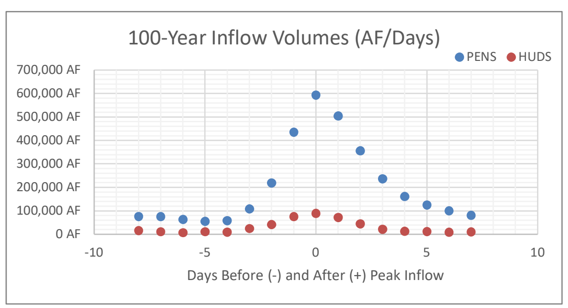


Average Daily Volume (AF) vs GEV Peak Discharge (PENS) Reduced Variate Correlation Plots



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



APPENDIX C:
MAX WATER SURFACE ELEVATIONS

River Mile	Bed El. (ft, PD)	Pensacola Dam Starting Stage (ft, PD)											Anticipated Operational Range WSE Difference[1] (ft)	Extreme Hypothetical Range WSE Difference[2] (ft)
		El. 734.0	El. 742.0	El. 742.5	El. 743.0	El. 743.5	El. 744.0	El. 744.5	El. 745.0	El. 749.0	El. 753.0	El. 757.0		
		Max WSE (ft, PD)	Max WSE (ft, PD)	Max WSE (ft, PD)	Max WSE (ft, PD)	Max WSE (ft, PD)	Max WSE (ft, PD)	Max WSE (ft, PD)	Max WSE (ft, PD)	Max WSE (ft, PD)	Max WSE (ft, PD)	Max WSE (ft, PD)		
77.000	Pensacola Dam													
76.880	608.88	642.40	645.76	645.76	645.88	646.72	647.53	648.30	649.20	650.09	650.27	652.40	3.44	10.00
76.463	607.35	642.36	645.72	645.72	645.83	646.67	647.47	648.24	649.14	650.04	650.21	652.33	3.42	9.97
76.414	N 4475 Rd. Bridge													
76.362	607.61	642.34	645.69	645.69	645.80	646.64	647.45	648.21	649.11	650.01	650.18	652.29	3.42	9.95
75.317	606.30	641.56	644.90	644.90	645.01	645.81	646.58	647.31	648.16	649.03	649.17	651.19	3.26	9.63
74.300	605.42	639.88	643.24	643.24	643.34	644.08	644.80	645.47	646.24	647.11	647.17	649.10	3.00	9.22
73.315	600.08	638.77	642.14	642.14	642.23	642.91	643.58	644.21	644.93	645.81	645.82	647.64	2.79	8.87
72.884	606.92	637.93	641.46	641.46	641.55	642.21	642.85	643.45	644.12	645.14	645.15	646.90	2.66	8.97
72.822	OK-82 Bridge													
72.772	604.91	637.67	641.15	641.15	641.23	641.84	642.44	643.01	643.81	644.68	644.70	646.17	2.66	8.50
71.645	603.05	636.74	640.41	640.41	640.49	641.09	641.68	642.24	642.92	643.80	643.81	645.30	2.51	8.56
70.910	601.50	635.36	639.08	639.08	639.14	639.65	640.17	640.69	641.36	642.34	642.36	643.77	2.28	8.41
69.686	599.92	634.18	638.24	638.24	638.30	638.75	639.22	639.71	640.34	641.37	641.39	642.69	2.10	8.51
68.685	597.81	633.10	637.27	637.27	637.32	637.68	638.06	638.45	638.97	639.99	640.02	640.99	1.70	7.89
67.715	594.14	632.57	636.59	636.60	636.63	636.91	637.21	637.53	637.96	638.97	639.00	639.70	1.37	7.13
66.855	592.57	632.16	636.15	636.15	636.18	636.40	636.65	636.91	637.27	638.25	638.29	638.76	1.12	6.60
66.780	Big Cabin Creek													
65.712	590.99	631.85	635.76	635.76	635.78	635.95	636.13	636.34	636.62	637.56	637.59	637.84	0.86	5.99
64.435	588.21	631.44	635.31	635.31	635.32	635.42	635.53	635.67	635.85	636.74	636.78	636.80	0.54	5.36
63.369	585.72	631.17	634.98	634.98	634.98	634.99	635.04	635.12	635.24	636.22	636.26	636.28	0.26	5.11
63.322	Strang Rd. Bridge													
63.299	587.89	631.15	634.93	634.93	634.93	634.93	634.95	635.00	635.07	635.80	635.86	635.89	0.14	4.74
62.325	582.59	631.17	634.99	634.99	634.99	635.02	635.06	635.12	635.23	635.99	636.04	636.07	0.24	4.90
61.308	584.75	631.12	634.95	634.95	634.95	634.95	634.99	635.04	635.12	635.80	635.85	635.88	0.17	4.76
60.263	582.15	631.08	634.92	634.92	634.92	634.92	634.95	635.00	635.07	635.73	635.78	635.80	0.15	4.72
60.200	Spavinaw Creek													
59.019	582.85	631.02	634.87	634.87	634.87	634.87	634.89	634.93	634.98	635.60	635.65	635.68	0.11	4.66
57.950	582.47	630.98	634.84	634.84	634.84	634.84	634.85	634.88	634.94	635.49	635.54	635.57	0.10	4.59
56.927	576.95	630.95	634.81	634.81	634.81	634.81	634.82	634.84	634.92	635.41	635.46	635.49	0.11	4.54
55.890	577.05	630.94	634.80	634.80	634.80	634.80	634.81	634.83	634.92	635.38	635.43	635.46	0.12	4.52
54.456	577.89	630.91	634.78	634.78	634.78	634.78	634.79	634.81	634.90	635.33	635.38	635.41	0.12	4.50
52.988	572.13	630.85	634.70	634.70	634.70	634.70	634.71	634.71	634.82	635.12	635.16	635.19	0.12	4.34
52.954	OK-20 Bridge													

1 Max difference in Max WSEL from simulations with Pensacola Dam starting stages of El. 742.0 to El. 745.0 ft.
2 Max difference in Max WSEL from simulations with Pensacola Dam starting stages of El. 734.0 to El. 757.0 ft.

PENSACOLA DAM **TABLE C.1**

GRAND RIVER DAM AUTHORITY DOWNSTREAM MODEL MAX WSELs - SEPTEMBER 1993 (21 YEAR) EVENT

River Mile	Bed El. (ft, PD)	Pensacola Dam Starting Stage (ft, PD)											Anticipated Operational Range WSE Difference[1] (ft)	Extreme Hypothetical Range WSE Difference[2] (ft)
		El. 734.0	El. 742.0	El. 742.5	El. 743.0	El. 743.5	El. 744.0	El. 744.5	El. 745.0	El. 749.0	El. 753.0	El. 757.0		
		Max WSE (ft, PD)	Max WSE (ft, PD)	Max WSE (ft, PD)	Max WSE (ft, PD)	Max WSE (ft, PD)	Max WSE (ft, PD)	Max WSE (ft, PD)	Max WSE (ft, PD)	Max WSE (ft, PD)	Max WSE (ft, PD)	Max WSE (ft, PD)		
52.922	569.25	630.84	634.69	634.69	634.69	634.69	634.70	634.69	634.80	635.08	635.13	635.16	0.11	4.32
50.500	Saline Creek													
50.396	569.69	630.85	634.73	634.73	634.73	634.73	634.74	634.74	634.85	635.17	635.22	635.25	0.12	4.40
49.110	562.60	630.84	634.72	634.72	634.72	634.72	634.73	634.73	634.84	635.15	635.21	635.23	0.12	4.39
48.118	558.27	630.84	634.72	634.72	634.72	634.72	634.73	634.73	634.84	635.14	635.19	635.22	0.12	4.38
47.186	553.07	630.83	634.71	634.71	634.71	634.71	634.72	634.72	634.83	635.12	635.17	635.20	0.12	4.37
47.120	Kerr Dam													

1 Max difference in Max WSEL from simulations with Pensacola Dam starting stages of El. 742.0 to El. 745.0 ft.
2 Max difference in Max WSEL from simulations with Pensacola Dam starting stages of El. 734.0 to El. 757.0 ft.

River Mile	Bed El. (ft, PD)	Pensacola Dam Starting Stage (ft, PD)											Anticipated Operational Range WSE Difference[1] (ft)	Extreme Hypothetical Range WSE Difference[2] (ft)
		El. 734.0	El. 742.0	El. 742.5	El. 743.0	El. 743.5	El. 744.0	El. 744.5	El. 745.0	El. 749.0	El. 753.0	El. 757.0		
		Max WSE (ft, PD)	Max WSE (ft, PD)	Max WSE (ft, PD)	Max WSE (ft, PD)	Max WSE (ft, PD)	Max WSE (ft, PD)	Max WSE (ft, PD)	Max WSE (ft, PD)	Max WSE (ft, PD)	Max WSE (ft, PD)	Max WSE (ft, PD)		
77.000	Pensacola Dam													
76.880	608.88	623.14	623.62	626.61	625.32	625.96	625.11	627.66	630.33	631.47	640.28	642.63	6.71	19.49
76.463	607.35	622.84	623.35	626.48	625.14	625.80	624.93	627.55	630.27	631.43	640.26	642.59	6.92	19.75
76.414	N 4475 Rd. Bridge													
76.362	607.61	622.54	623.09	626.36	624.98	625.66	624.75	627.45	630.21	631.40	640.24	642.57	7.12	20.03
75.317	606.30	621.46	622.21	625.60	624.19	624.91	623.96	626.73	629.51	630.75	639.59	641.82	7.30	20.36
74.300	605.42	620.92	621.71	624.78	623.48	624.15	623.26	625.85	628.49	629.79	638.26	640.20	6.78	19.28
73.315	600.08	620.58	621.37	624.09	622.91	623.54	622.72	625.10	627.57	629.05	637.18	639.15	6.20	18.57
72.884	606.92	620.29	621.09	623.56	622.46	623.07	622.29	624.54	626.94	628.57	636.52	638.36	5.85	18.07
72.822	OK-82 Bridge													
72.772	604.91	620.20	621.01	623.40	622.33	622.92	622.16	624.37	626.74	628.42	636.32	638.12	5.73	17.92
71.645	603.05	619.18	620.13	621.75	620.88	621.46	620.77	622.78	625.20	627.46	635.54	637.30	5.07	18.12
70.910	601.50	619.09	619.86	620.99	620.31	620.84	620.30	621.96	624.20	626.81	634.55	636.03	4.34	16.94
69.686	599.92	619.09	619.55	620.01	619.59	620.03	619.76	620.87	622.84	626.08	633.73	635.06	3.29	15.97
68.685	597.81	619.09	619.38	619.56	619.25	619.54	619.46	620.18	621.69	625.52	633.01	634.14	2.44	15.05
67.715	594.14	619.09	619.31	619.37	619.18	619.34	619.34	619.95	621.21	625.24	632.58	633.58	2.03	14.49
66.855	592.57	619.09	619.26	619.31	619.13	619.22	619.24	619.75	620.97	625.01	632.30	633.23	1.84	14.14
66.780	Big Cabin Creek													
65.712	590.99	619.09	619.22	619.27	619.10	619.16	619.19	619.63	620.86	624.88	632.10	632.99	1.76	13.90
64.435	588.21	619.09	619.17	619.22	619.09	619.12	619.15	619.50	620.68	624.63	631.91	632.73	1.59	13.64
63.369	585.72	619.09	619.15	619.20	619.09	619.09	619.13	619.48	620.61	624.56	631.79	632.52	1.52	13.43
63.322	Strang Rd. Bridge													
63.299	587.89	619.09	619.15	619.19	619.09	619.09	619.13	619.47	620.60	624.56	631.78	632.51	1.51	13.42
62.325	582.59	619.09	619.14	619.18	619.09	619.09	619.12	619.46	620.58	624.55	631.81	632.54	1.49	13.45
61.308	584.75	619.09	619.12	619.17	619.09	619.09	619.12	619.45	620.55	624.53	631.79	632.50	1.46	13.41
60.263	582.15	619.09	619.11	619.16	619.09	619.09	619.11	619.44	620.52	624.52	631.77	632.48	1.43	13.39
60.200	Spavinaw Creek													
59.019	582.85	619.09	619.10	619.16	619.09	619.09	619.10	619.42	620.49	624.51	631.74	632.42	1.40	13.33
57.950	582.47	619.09	619.09	619.15	619.09	619.09	619.10	619.41	620.48	624.50	631.71	632.38	1.39	13.29
56.927	576.95	619.09	619.09	619.14	619.09	619.09	619.10	619.40	620.46	624.48	631.68	632.34	1.37	13.25
55.890	577.05	619.09	619.09	619.14	619.09	619.09	619.10	619.40	620.45	624.48	631.67	632.32	1.36	13.23
54.456	577.89	619.09	619.09	619.13	619.09	619.09	619.10	619.39	620.44	624.47	631.64	632.29	1.35	13.20
52.988	572.13	619.09	619.09	619.12	619.09	619.09	619.09	619.37	620.42	624.45	631.59	632.23	1.33	13.14
52.954	OK-20 Bridge													

1 Max difference in Max WSEL from simulations with Pensacola Dam starting stages of El. 742.0 to El. 745.0 ft.
2 Max difference in Max WSEL from simulations with Pensacola Dam starting stages of El. 734.0 to El. 757.0 ft.

River Mile	Bed El. (ft, PD)	Pensacola Dam Starting Stage (ft, PD)											Anticipated Operational Range WSE Difference[1] (ft)	Extreme Hypothetical Range WSE Difference[2] (ft)
		El. 734.0	El. 742.0	El. 742.5	El. 743.0	El. 743.5	El. 744.0	El. 744.5	El. 745.0	El. 749.0	El. 753.0	El. 757.0		
		Max WSE (ft, PD)	Max WSE (ft, PD)	Max WSE (ft, PD)	Max WSE (ft, PD)	Max WSE (ft, PD)	Max WSE (ft, PD)	Max WSE (ft, PD)	Max WSE (ft, PD)	Max WSE (ft, PD)	Max WSE (ft, PD)	Max WSE (ft, PD)		
52.922	569.25	619.09	619.09	619.12	619.09	619.09	619.09	619.37	620.41	624.44	631.59	632.22	1.32	13.13
50.500	Saline Creek													
50.396	569.69	619.09	619.09	619.10	619.09	619.09	619.09	619.36	620.39	624.44	631.56	632.23	1.30	13.14
49.110	562.60	619.09	619.09	619.09	619.09	619.09	619.09	619.35	620.38	624.43	631.54	632.22	1.29	13.13
48.118	558.27	619.09	619.09	619.09	619.09	619.09	619.09	619.34	620.37	624.43	631.52	632.21	1.28	13.12
47.186	553.07	619.09	619.09	619.09	619.09	619.09	619.09	619.34	620.36	624.42	631.51	632.20	1.27	13.11
47.120	Kerr Dam													

1 Max difference in Max WSEL from simulations with Pensacola Dam starting stages of El. 742.0 to El. 745.0 ft.
2 Max difference in Max WSEL from simulations with Pensacola Dam starting stages of El. 734.0 to El. 757.0 ft.

River Mile	Bed El. (ft, PD)	Pensacola Dam Starting Stage (ft, PD)											Anticipated Operational Range WSE Difference[1] (ft)	Extreme Hypothetical Range WSE Difference[2] (ft)
		El. 734.0	El. 742.0	El. 742.5	El. 743.0	El. 743.5	El. 744.0	El. 744.5	El. 745.0	El. 749.0	El. 753.0	El. 757.0		
		Max WSE (ft, PD)	Max WSE (ft, PD)	Max WSE (ft, PD)	Max WSE (ft, PD)	Max WSE (ft, PD)	Max WSE (ft, PD)	Max WSE (ft, PD)	Max WSE (ft, PD)	Max WSE (ft, PD)	Max WSE (ft, PD)	Max WSE (ft, PD)		
77.000	Pensacola Dam													
76.880	608.88	641.40	641.50	643.06	643.10	643.09	641.27	643.16	643.24	643.30	643.62	645.09	1.97	3.82
76.463	607.35	641.37	641.47	643.03	643.06	643.05	641.24	643.12	643.20	643.27	643.58	645.04	1.96	3.80
76.414	N 4475 Rd. Bridge													
76.362	607.61	641.34	641.45	643.00	643.03	643.03	641.22	643.09	643.17	643.24	643.56	645.02	1.95	3.80
75.317	606.30	640.77	640.88	642.35	642.39	642.38	640.65	642.45	642.53	642.61	642.87	644.27	1.88	3.62
74.300	605.42	639.60	639.73	641.00	641.04	641.03	639.50	641.11	641.21	641.29	641.41	642.67	1.71	3.17
73.315	600.08	638.87	639.01	640.15	640.20	640.19	638.78	640.27	640.38	640.46	640.50	641.64	1.60	2.86
72.884	606.92	638.35	638.49	639.52	639.57	639.56	638.27	639.65	639.77	639.86	639.86	640.92	1.50	2.65
72.822	OK-82 Bridge													
72.772	604.91	638.19	638.34	639.34	639.39	639.37	638.11	639.46	639.59	639.69	639.69	640.69	1.48	2.58
71.645	603.05	637.68	637.83	638.78	638.83	638.82	637.61	638.91	639.04	639.14	639.14	640.01	1.43	2.40
70.910	601.50	636.91	637.06	637.82	637.87	637.86	636.85	637.95	638.10	638.20	638.20	638.78	1.25	1.93
69.686	599.92	636.39	636.52	637.19	637.24	637.23	636.35	637.33	637.50	637.60	637.60	638.02	1.15	1.67
68.685	597.81	635.88	635.99	636.53	636.57	636.56	635.87	636.66	636.84	636.95	636.95	637.18	0.97	1.31
67.715	594.14	635.55	635.64	636.08	636.12	636.11	635.59	636.21	636.40	636.51	636.51	636.63	0.81	1.08
66.855	592.57	635.33	635.43	635.77	635.81	635.80	635.41	635.90	636.10	636.21	636.21	636.29	0.69	0.96
66.780	Big Cabin Creek													
65.712	590.99	635.09	635.19	635.43	635.46	635.46	635.19	635.53	635.74	635.83	635.83	635.87	0.55	0.78
64.435	588.21	634.88	634.98	635.08	635.10	635.10	635.00	635.16	635.37	635.45	635.45	635.45	0.39	0.57
63.369	585.72	634.73	634.82	634.80	634.79	634.79	634.84	634.82	635.06	635.13	635.13	635.13	0.27	0.40
63.322	Strang Rd. Bridge													
63.299	587.89	634.72	634.80	634.78	634.77	634.77	634.83	634.79	634.99	635.05	635.05	635.05	0.22	0.33
62.325	582.59	634.77	634.85	634.84	634.84	634.84	634.87	634.86	635.06	635.12	635.12	635.12	0.22	0.35
61.308	584.75	634.76	634.83	634.81	634.80	634.80	634.84	634.81	635.01	635.07	635.07	635.07	0.21	0.31
60.263	582.15	634.75	634.81	634.79	634.78	634.78	634.82	634.78	634.97	635.03	635.03	635.03	0.19	0.28
60.200	Spavinaw Creek													
59.019	582.85	634.72	634.77	634.74	634.74	634.74	634.78	634.73	634.92	634.96	634.97	634.97	0.19	0.25
57.950	582.47	634.69	634.74	634.71	634.70	634.70	634.75	634.70	634.89	634.91	634.91	634.91	0.19	0.22
56.927	576.95	634.67	634.71	634.69	634.69	634.69	634.72	634.69	634.87	634.87	634.87	634.87	0.18	0.20
55.890	577.05	634.67	634.70	634.68	634.68	634.68	634.71	634.68	634.87	634.87	634.87	634.87	0.19	0.20
54.456	577.89	634.65	634.68	634.67	634.67	634.67	634.68	634.67	634.85	634.85	634.85	634.85	0.18	0.20
52.988	572.13	634.59	634.61	634.62	634.62	634.62	634.62	634.62	634.81	634.81	634.81	634.81	0.20	0.22
52.954	OK-20 Bridge													

1 Max difference in Max WSEL from simulations with Pensacola Dam starting stages of El. 742.0 to El. 745.0 ft.
2 Max difference in Max WSEL from simulations with Pensacola Dam starting stages of El. 734.0 to El. 757.0 ft.

River Mile	Bed El. (ft, PD)	Pensacola Dam Starting Stage (ft, PD)											Anticipated Operational Range WSE Difference[1] (ft)	Extreme Hypothetical Range WSE Difference[2] (ft)
		El. 734.0	El. 742.0	El. 742.5	El. 743.0	El. 743.5	El. 744.0	El. 744.5	El. 745.0	El. 749.0	El. 753.0	El. 757.0		
		Max WSE (ft, PD)	Max WSE (ft, PD)	Max WSE (ft, PD)	Max WSE (ft, PD)	Max WSE (ft, PD)	Max WSE (ft, PD)	Max WSE (ft, PD)	Max WSE (ft, PD)	Max WSE (ft, PD)	Max WSE (ft, PD)	Max WSE (ft, PD)		
52.922	569.25	634.58	634.60	634.61	634.61	634.61	634.61	634.61	634.80	634.80	634.80	634.80	0.20	0.22
50.500	Saline Creek													
50.396	569.69	634.58	634.61	634.63	634.63	634.63	634.63	634.63	634.82	634.82	634.82	634.82	0.21	0.24
49.110	562.60	634.57	634.60	634.63	634.63	634.63	634.62	634.63	634.82	634.82	634.82	634.82	0.22	0.25
48.118	558.27	634.56	634.60	634.62	634.62	634.62	634.62	634.62	634.81	634.81	634.81	634.81	0.21	0.25
47.186	553.07	634.55	634.59	634.62	634.62	634.62	634.61	634.62	634.81	634.81	634.81	634.81	0.22	0.26
47.120	Kerr Dam													

1 Max difference in Max WSEL from simulations with Pensacola Dam starting stages of El. 742.0 to El. 745.0 ft.
2 Max difference in Max WSEL from simulations with Pensacola Dam starting stages of El. 734.0 to El. 757.0 ft.

PENSACOLA DAM **TABLE C.4**

GRAND RIVER DAM AUTHORITY DOWNSTREAM MODEL MAX WSELs - OCTOBER 2009 (3 YEAR) EVENT

River Mile	Bed El. (ft, PD)	Pensacola Dam Starting Stage (ft, PD)											Anticipated Operational Range WSE Difference[1] (ft)	Extreme Hypothetical Range WSE Difference[2] (ft)
		El. 734.0	El. 742.0	El. 742.5	El. 743.0	El. 743.5	El. 744.0	El. 744.5	El. 745.0	El. 749.0	El. 753.0	El. 757.0		
		Max WSE (ft, PD)	Max WSE (ft, PD)	Max WSE (ft, PD)	Max WSE (ft, PD)	Max WSE (ft, PD)	Max WSE (ft, PD)	Max WSE (ft, PD)	Max WSE (ft, PD)	Max WSE (ft, PD)	Max WSE (ft, PD)	Max WSE (ft, PD)		
77.000	Pensacola Dam													
76.880	608.88	635.28	640.79	638.05	640.70	637.31	637.66	637.34	640.60	640.15	641.24	641.90	3.48	6.62
76.463	607.35	635.24	640.76	638.03	640.67	637.29	637.63	637.32	640.57	640.12	641.20	641.86	3.47	6.62
76.414	N 4475 Rd. Bridge													
76.362	607.61	635.22	640.74	638.01	640.65	637.27	637.61	637.29	640.55	640.10	641.18	641.84	3.47	6.62
75.317	606.30	634.68	640.14	637.44	640.06	636.70	637.04	636.71	639.95	639.57	640.60	641.21	3.44	6.53
74.300	605.42	633.76	638.92	636.34	638.85	635.64	635.95	635.60	638.73	638.51	639.39	639.92	3.32	6.16
73.315	600.08	632.98	638.12	635.44	638.05	634.76	635.04	634.68	637.91	637.82	638.65	639.10	3.44	6.12
72.884	606.92	632.52	637.55	634.91	637.49	634.23	634.49	634.12	637.33	637.35	638.10	638.50	3.43	5.98
72.822	OK-82 Bridge													
72.772	604.91	632.37	637.38	634.74	637.33	634.07	634.32	633.95	637.16	637.21	637.95	638.32	3.43	5.95
71.645	603.05	631.61	636.78	634.03	636.73	633.31	633.57	633.14	636.53	636.73	637.42	637.73	3.64	6.12
70.910	601.50	630.95	635.95	633.26	635.90	632.54	632.86	632.31	635.68	636.08	636.65	636.82	3.64	5.87
69.686	599.92	630.33	635.33	632.60	635.30	631.83	632.23	631.53	635.03	635.64	636.13	636.17	3.80	5.84
68.685	597.81	629.82	634.76	632.05	634.73	631.23	631.71	630.87	634.42	635.25	635.65	635.65	3.89	5.83
67.715	594.14	629.53	634.40	631.74	634.39	630.87	631.41	630.54	634.05	635.02	635.37	635.40	3.86	5.87
66.855	592.57	629.31	634.17	631.53	634.16	630.59	631.20	630.32	633.80	634.90	635.21	635.23	3.85	5.92
66.780	Big Cabin Creek													
65.712	590.99	629.16	634.00	631.37	633.99	630.39	631.04	630.15	633.59	634.77	635.05	635.03	3.85	5.89
64.435	588.21	628.97	633.82	631.21	633.81	630.12	630.86	629.94	633.36	634.71	634.96	634.85	3.88	5.99
63.369	585.72	628.86	633.70	631.13	633.70	629.95	630.77	629.81	633.18	634.65	634.86	634.70	3.89	6.00
63.322	Strang Rd. Bridge													
63.299	587.89	628.85	633.69	631.12	633.69	629.94	630.76	629.80	633.17	634.64	634.85	634.69	3.89	6.00
62.325	582.59	628.86	633.73	631.15	633.73	629.95	630.79	629.80	633.21	634.68	634.88	634.73	3.93	6.02
61.308	584.75	628.84	633.72	631.14	633.72	629.91	630.79	629.77	633.19	634.67	634.87	634.73	3.95	6.03
60.263	582.15	628.84	633.71	631.13	633.71	629.88	630.78	629.75	633.18	634.66	634.85	634.72	3.96	6.01
60.200	Spavinaw Creek													
59.019	582.85	628.82	633.68	631.11	633.68	629.84	630.76	629.72	633.15	634.63	634.81	634.70	3.96	5.99
57.950	582.47	628.81	633.66	631.09	633.66	629.82	630.75	629.70	633.12	634.60	634.78	634.68	3.96	5.97
56.927	576.95	628.80	633.64	631.07	633.64	629.79	630.73	629.68	633.10	634.58	634.76	634.66	3.96	5.96
55.890	577.05	628.79	633.63	631.06	633.63	629.78	630.72	629.67	633.09	634.57	634.74	634.65	3.96	5.95
54.456	577.89	628.78	633.61	631.04	633.61	629.77	630.71	629.66	633.07	634.54	634.72	634.64	3.95	5.94
52.988	572.13	628.75	633.56	631.00	633.56	629.73	630.67	629.63	633.02	634.49	634.66	634.59	3.93	5.91
52.954	OK-20 Bridge													

1 Max difference in Max WSEL from simulations with Pensacola Dam starting stages of El. 742.0 to El. 745.0 ft.
2 Max difference in Max WSEL from simulations with Pensacola Dam starting stages of El. 734.0 to El. 757.0 ft.

PENSACOLA DAM **TABLE C.4**

GRAND RIVER DAM AUTHORITY — DOWNSTREAM MODEL MAX WSELs - OCTOBER 2009 (3 YEAR) EVENT

River Mile	Bed El. (ft, PD)	Pensacola Dam Starting Stage (ft, PD)											Anticipated Operational Range WSE Difference[1] (ft)	Extreme Hypothetical Range WSE Difference[2] (ft)
		El. 734.0	El. 742.0	El. 742.5	El. 743.0	El. 743.5	El. 744.0	El. 744.5	El. 745.0	El. 749.0	El. 753.0	El. 757.0		
		Max WSE (ft, PD)	Max WSE (ft, PD)	Max WSE (ft, PD)	Max WSE (ft, PD)	Max WSE (ft, PD)	Max WSE (ft, PD)	Max WSE (ft, PD)	Max WSE (ft, PD)	Max WSE (ft, PD)	Max WSE (ft, PD)	Max WSE (ft, PD)		
52.922	569.25	628.75	633.56	630.99	633.56	629.72	630.66	629.62	633.01	634.49	634.65	634.58	3.94	5.90
50.500	Saline Creek													
50.396	569.69	628.74	633.54	630.97	633.54	629.72	630.65	629.63	633.02	634.45	634.62	634.59	3.91	5.88
49.110	562.60	628.74	633.53	630.95	633.53	629.71	630.64	629.62	633.01	634.43	634.60	634.58	3.91	5.86
48.118	558.27	628.73	633.52	630.94	633.52	629.71	630.63	629.61	633.00	634.40	634.58	634.57	3.91	5.85
47.186	553.07	628.73	633.51	630.93	633.51	629.70	630.62	629.61	632.99	634.39	634.55	634.56	3.90	5.83
47.120	Kerr Dam													

1 Max difference in Max WSEL from simulations with Pensacola Dam starting stages of El. 742.0 to El. 745.0 ft.
2 Max difference in Max WSEL from simulations with Pensacola Dam starting stages of El. 734.0 to El. 757.0 ft.

River Mile	Bed El. (ft, PD)	Pensacola Dam Starting Stage (ft, PD)											Anticipated Operational Range WSE Difference[1] (ft)	Extreme Hypothetical Range WSE Difference[2] (ft)
		El. 734.0	El. 742.0	El. 742.5	El. 743.0	El. 743.5	El. 744.0	El. 744.5	El. 745.0	El. 749.0	El. 753.0	El. 757.0		
		Max WSE (ft, PD)	Max WSE (ft, PD)	Max WSE (ft, PD)	Max WSE (ft, PD)	Max WSE (ft, PD)	Max WSE (ft, PD)	Max WSE (ft, PD)	Max WSE (ft, PD)	Max WSE (ft, PD)	Max WSE (ft, PD)	Max WSE (ft, PD)		
77.000	Pensacola Dam													
76.880	608.88	641.54	649.04	649.04	649.04	649.04	649.04	649.04	649.06	649.18	649.19	651.50	0.02	9.96
76.463	607.35	641.51	648.99	648.99	648.99	648.99	648.99	648.99	649.00	649.12	649.13	651.44	0.01	9.93
76.414	N 4475 Rd. Bridge													
76.362	607.61	641.49	648.96	648.96	648.96	648.96	648.96	648.96	648.97	649.09	649.10	651.40	0.01	9.91
75.317	606.30	640.92	648.02	648.01	648.01	648.01	648.02	648.02	648.03	648.16	648.17	650.36	0.02	9.44
74.300	605.42	639.77	646.11	646.11	646.11	646.11	646.11	646.11	646.13	646.30	646.31	648.35	0.02	8.58
73.315	600.08	639.05	644.81	644.81	644.81	644.81	644.81	644.82	644.84	645.04	645.05	646.98	0.03	7.93
72.884	606.92	638.53	644.02	644.02	644.02	644.02	644.02	644.02	644.04	644.26	644.27	646.27	0.02	7.74
72.822	OK-82 Bridge													
72.772	604.91	638.38	643.65	643.65	643.65	643.65	643.65	643.66	643.69	644.02	644.04	645.61	0.04	7.23
71.645	603.05	637.87	642.82	642.82	642.82	642.82	642.82	642.83	642.85	643.15	643.17	644.78	0.03	6.91
70.910	601.50	637.09	641.28	641.28	641.28	641.28	641.28	641.28	641.32	641.72	641.73	643.31	0.04	6.22
69.686	599.92	636.55	640.28	640.27	640.27	640.27	640.28	640.28	640.32	640.78	640.80	642.30	0.05	5.75
68.685	597.81	636.02	638.95	638.95	638.95	638.95	638.95	638.96	639.00	639.50	639.52	640.76	0.05	4.74
67.715	594.14	635.67	637.97	637.97	637.97	637.97	637.97	637.98	638.02	638.56	638.58	639.61	0.05	3.94
66.855	592.57	635.43	637.30	637.30	637.30	637.30	637.30	637.31	637.35	637.90	637.92	638.80	0.05	3.37
66.780	Big Cabin Creek													
65.712	590.99	635.21	636.61	636.61	636.61	636.61	636.61	636.62	636.66	637.18	637.21	637.92	0.05	2.71
64.435	588.21	634.96	635.85	635.85	635.85	635.85	635.85	635.86	635.88	636.37	636.39	636.92	0.03	1.96
63.369	585.72	634.74	635.28	635.28	635.28	635.28	635.28	635.28	635.28	635.79	635.81	636.26	0.00	1.52
63.322	Strang Rd. Bridge													
63.299	587.89	634.72	635.09	635.09	635.09	635.09	635.09	635.09	635.09	635.40	635.41	635.64	0.00	0.92
62.325	582.59	634.77	635.26	635.26	635.26	635.26	635.26	635.26	635.25	635.63	635.65	635.95	0.01	1.18
61.308	584.75	634.73	635.15	635.15	635.15	635.15	635.15	635.15	635.14	635.46	635.47	635.71	0.01	0.98
60.263	582.15	634.71	635.09	635.09	635.09	635.09	635.09	635.09	635.09	635.38	635.40	635.62	0.00	0.91
60.200	Spavinaw Creek													
59.019	582.85	634.68	635.00	635.00	635.00	635.00	635.00	635.00	635.00	635.25	635.26	635.46	0.00	0.78
57.950	582.47	634.65	634.94	634.94	634.94	634.94	634.94	634.94	634.93	635.14	635.15	635.33	0.01	0.68
56.927	576.95	634.63	634.91	634.91	634.91	634.91	634.91	634.91	634.90	635.08	635.07	635.22	0.01	0.59
55.890	577.05	634.62	634.90	634.90	634.90	634.90	634.90	634.90	634.90	635.06	635.05	635.19	0.00	0.57
54.456	577.89	634.61	634.89	634.89	634.89	634.89	634.89	634.89	634.89	635.02	635.01	635.13	0.00	0.52
52.988	572.13	634.55	634.80	634.80	634.80	634.80	634.80	634.80	634.80	634.83	634.82	634.87	0.00	0.32
52.954	OK-20 Bridge													

1 Max difference in Max WSEL from simulations with Pensacola Dam starting stages of El. 742.0 to El. 745.0 ft.
2 Max difference in Max WSEL from simulations with Pensacola Dam starting stages of El. 734.0 to El. 757.0 ft.

PENSACOLA DAM **TABLE C.5**

GRAND RIVER DAM AUTHORITY DOWNSTREAM MODEL MAX WSELs - DECEMBER 2015 (15 YEAR) EVENT

River Mile	Bed El. (ft, PD)	Pensacola Dam Starting Stage (ft, PD)											Anticipated Operational Range WSE Difference[1] (ft)	Extreme Hypothetical Range WSE Difference[2] (ft)
		El. 734.0	El. 742.0	El. 742.5	El. 743.0	El. 743.5	El. 744.0	El. 744.5	El. 745.0	El. 749.0	El. 753.0	El. 757.0		
		Max WSE (ft, PD)	Max WSE (ft, PD)	Max WSE (ft, PD)	Max WSE (ft, PD)	Max WSE (ft, PD)	Max WSE (ft, PD)	Max WSE (ft, PD)	Max WSE (ft, PD)	Max WSE (ft, PD)	Max WSE (ft, PD)	Max WSE (ft, PD)		
52.922	569.25	634.54	634.79	634.79	634.79	634.79	634.79	634.79	634.79	634.80	634.79	634.83	0.00	0.29
50.500	Saline Creek													
50.396	569.69	634.57	634.84	634.84	634.84	634.84	634.84	634.84	634.84	634.90	634.89	634.94	0.00	0.37
49.110	562.60	634.57	634.83	634.83	634.83	634.83	634.83	634.83	634.83	634.89	634.88	634.92	0.00	0.35
48.118	558.27	634.56	634.83	634.83	634.83	634.83	634.83	634.83	634.83	634.88	634.87	634.91	0.00	0.35
47.186	553.07	634.56	634.82	634.82	634.82	634.82	634.82	634.82	634.82	634.86	634.85	634.89	0.00	0.33
47.120	Kerr Dam													

1 Max difference in Max WSEL from simulations with Pensacola Dam starting stages of El. 742.0 to El. 745.0 ft.

2 Max difference in Max WSEL from simulations with Pensacola Dam starting stages of El. 734.0 to El. 757.0 ft.

River Mile	Bed El. (ft, PD)	Pensacola Dam Starting Stage (ft, PD)											Anticipated Operational Range WSE Difference[1] (ft)	Extreme Hypothetical Range WSE Difference[2] (ft)
		El. 734.0	El. 742.0	El. 742.5	El. 743.0	El. 743.5	El. 744.0	El. 744.5	El. 745.0	El. 749.0	El. 753.0	El. 757.0		
		Max WSE (ft, PD)	Max WSE (ft, PD)	Max WSE (ft, PD)	Max WSE (ft, PD)	Max WSE (ft, PD)	Max WSE (ft, PD)	Max WSE (ft, PD)	Max WSE (ft, PD)	Max WSE (ft, PD)	Max WSE (ft, PD)	Max WSE (ft, PD)		
77.000	Pensacola Dam													
76.880	608.88	656.34	656.35	656.35	656.35	656.35	656.35	656.35	656.35	656.35	656.35	656.35	0.00	0.01
76.463	607.35	656.28	656.28	656.28	656.28	656.28	656.28	656.28	656.28	656.29	656.29	656.29	0.00	0.01
76.414	N 4475 Rd. Bridge													
76.362	607.61	656.24	656.24	656.24	656.24	656.24	656.24	656.24	656.24	656.25	656.25	656.25	0.00	0.01
75.317	606.30	654.94	654.94	654.94	654.94	654.94	654.94	654.94	654.94	654.94	654.94	654.95	0.00	0.01
74.300	605.42	652.68	652.68	652.68	652.68	652.69	652.69	652.68	652.69	652.69	652.69	652.69	0.01	0.01
73.315	600.08	651.10	651.11	651.11	651.11	651.11	651.11	651.11	651.11	651.11	651.11	651.11	0.00	0.01
72.884	606.92	650.34	650.34	650.34	650.34	650.34	650.34	650.34	650.34	650.35	650.35	650.35	0.00	0.01
72.822	OK-82 Bridge													
72.772	604.91	649.64	649.65	649.66	649.66	649.66	649.66	649.66	649.66	649.66	649.66	649.66	0.01	0.02
71.645	603.05	648.74	648.75	648.75	648.75	648.76	648.76	648.75	648.76	648.76	648.76	648.76	0.01	0.02
70.910	601.50	647.48	647.48	647.49	647.49	647.49	647.49	647.49	647.49	647.50	647.50	647.50	0.01	0.02
69.686	599.92	646.43	646.43	646.44	646.44	646.45	646.45	646.44	646.44	646.45	646.45	646.45	0.02	0.02
68.685	597.81	644.60	644.61	644.62	644.62	644.62	644.62	644.62	644.62	644.63	644.63	644.63	0.01	0.03
67.715	594.14	643.11	643.12	643.13	643.14	643.14	643.14	643.14	643.14	643.14	643.14	643.15	0.02	0.04
66.855	592.57	642.00	642.01	642.03	642.03	642.03	642.03	642.03	642.03	642.03	642.04	642.04	0.02	0.04
66.780	Big Cabin Creek													
65.712	590.99	640.58	640.59	640.61	640.61	640.61	640.61	640.61	640.61	640.61	640.62	640.62	0.02	0.04
64.435	588.21	638.99	639.00	639.01	639.01	639.02	639.02	639.01	639.02	639.02	639.02	639.02	0.02	0.03
63.369	585.72	638.03	638.04	638.05	638.05	638.05	638.05	638.05	638.05	638.06	638.06	638.06	0.01	0.03
63.322	Strang Rd. Bridge													
63.299	587.89	637.08	637.09	637.11	637.11	637.12	637.12	637.11	637.11	637.12	637.12	637.13	0.03	0.05
62.325	582.59	637.19	637.20	637.22	637.22	637.23	637.23	637.23	637.23	637.24	637.24	637.24	0.03	0.05
61.308	584.75	636.69	636.70	636.72	636.72	636.73	636.73	636.73	636.73	636.73	636.74	636.74	0.03	0.05
60.263	582.15	636.52	636.52	636.54	636.54	636.55	636.55	636.55	636.55	636.56	636.56	636.57	0.03	0.05
60.200	Spavinaw Creek													
59.019	582.85	636.17	636.17	636.19	636.19	636.20	636.20	636.20	636.20	636.20	636.21	636.21	0.03	0.04
57.950	582.47	635.88	635.88	635.90	635.90	635.91	635.91	635.91	635.91	635.91	635.92	635.92	0.03	0.04
56.927	576.95	635.64	635.64	635.66	635.66	635.67	635.67	635.67	635.67	635.67	635.68	635.68	0.03	0.04
55.890	577.05	635.57	635.58	635.58	635.59	635.59	635.59	635.59	635.59	635.60	635.60	635.61	0.01	0.04
54.456	577.89	635.45	635.46	635.44	635.45	635.45	635.45	635.45	635.45	635.45	635.46	635.46	0.02	0.02
52.988	572.13	634.85	634.86	634.83	634.83	634.83	634.83	634.83	634.83	634.83	634.83	634.83	0.03	0.03
52.954	OK-20 Bridge													

1 Max difference in Max WSEL from simulations with Pensacola Dam starting stages of El. 742.0 to El. 745.0 ft.
2 Max difference in Max WSEL from simulations with Pensacola Dam starting stages of El. 734.0 to El. 757.0 ft.

PENSACOLA DAM | **TABLE C.6**

GRAND RIVER DAM AUTHORITY | DOWNSTREAM MODEL MAX WSELs - 100-YEAR EVENT

River Mile	Bed El. (ft, PD)	Pensacola Dam Starting Stage (ft, PD)											Anticipated Operational Range WSE Difference[1] (ft)	Extreme Hypothetical Range WSE Difference[2] (ft)
		El. 734.0	El. 742.0	El. 742.5	El. 743.0	El. 743.5	El. 744.0	El. 744.5	El. 745.0	El. 749.0	El. 753.0	El. 757.0		
		Max WSE (ft, PD)	Max WSE (ft, PD)	Max WSE (ft, PD)	Max WSE (ft, PD)	Max WSE (ft, PD)	Max WSE (ft, PD)	Max WSE (ft, PD)	Max WSE (ft, PD)	Max WSE (ft, PD)	Max WSE (ft, PD)	Max WSE (ft, PD)		
52.922	569.25	634.74	634.75	634.73	634.73	634.73	634.73	634.73	634.73	634.73	634.73	634.73	0.02	0.02
50.500	Saline Creek													
50.396	569.69	635.06	635.07	635.05	635.05	635.05	635.05	635.05	635.05	635.05	635.05	635.05	0.02	0.02
49.110	562.60	635.02	635.03	635.01	635.01	635.01	635.01	635.01	635.01	635.01	635.01	635.01	0.02	0.02
48.118	558.27	634.98	634.99	634.97	634.97	634.97	634.97	634.97	634.97	634.97	634.97	634.97	0.02	0.02
47.186	553.07	634.93	634.94	634.92	634.92	634.92	634.92	634.92	634.92	634.92	634.92	634.92	0.02	0.02
47.120	Kerr Dam													

1 Max difference in Max WSEL from simulations with Pensacola Dam starting stages of El. 742.0 to El. 745.0 ft.
2 Max difference in Max WSEL from simulations with Pensacola Dam starting stages of El. 734.0 to El. 757.0 ft.

River Mile	Bed El. (ft, PD)	Historical Inflow Event					Max WSEL Difference* (ft)
		Sept 1993	June 2004	July 2007	Oct 2009	Dec 2015	
		Max WSE (ft, PD)	Max WSE (ft, PD)	Max WSE (ft, PD)	Max WSE (ft, PD)	Max WSE (ft, PD)	
77.000	Pensacola Dam						
76.880	608.88	649.20	630.19	643.30	639.39	649.06	19.01
76.463	607.35	649.14	630.12	643.26	639.36	649.00	19.02
76.414	N 4475 Rd. Bridge						
76.362	607.61	649.11	630.06	643.24	639.35	648.97	19.05
75.317	606.30	648.16	629.35	642.60	638.82	648.03	18.81
74.300	605.42	646.24	628.31	641.28	637.79	646.13	17.93
73.315	600.08	644.93	627.37	640.46	636.97	644.83	17.56
72.884	606.92	644.12	626.71	639.86	636.48	644.04	17.41
72.822	OK-82 Bridge						
72.772	604.91	643.80	626.51	639.68	636.34	643.69	17.29
71.645	603.05	642.92	624.86	639.13	635.78	642.85	18.06
70.910	601.50	641.36	623.80	638.19	635.08	641.32	17.56
69.686	599.92	640.33	622.31	637.59	634.55	640.32	18.02
68.685	597.81	638.97	621.03	636.94	634.07	639.00	17.97
67.715	594.14	637.96	620.50	636.50	633.78	638.02	17.52
66.855	592.57	637.27	620.06	636.20	633.59	637.34	17.28
66.780	Big Cabin Creek						
65.712	590.99	636.61	619.91	635.82	633.43	636.65	16.74
64.435	588.21	635.85	619.71	635.44	633.26	635.88	16.17
63.369	585.72	635.24	619.64	635.12	633.14	635.28	15.64
63.322	Strang Rd. Bridge						
63.299	587.89	635.06	619.63	635.04	633.13	635.09	15.46
62.325	582.59	635.23	619.60	635.11	633.16	635.25	15.65
61.308	584.75	635.12	619.57	635.06	633.15	635.14	15.57
60.263	582.15	635.07	619.55	635.02	633.14	635.09	15.54
60.200	Spavinaw Creek						
59.019	582.85	634.98	619.53	634.96	633.12	635.00	15.47
57.950	582.47	634.94	619.52	634.90	633.10	634.93	15.42
56.927	576.95	634.92	619.52	634.87	633.08	634.90	15.40
55.890	577.05	634.91	619.52	634.87	633.08	634.90	15.39
54.456	577.89	634.90	619.52	634.85	633.06	634.89	15.38
52.988	572.13	634.82	619.51	634.81	633.02	634.80	15.31

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

TABLE C.7
DOWNSTREAM MODEL MAX WSELs - HISTORICAL EVENTS

River Mile	Bed El. (ft, PD)	Historical Inflow Event					Max WSEL Difference* (ft)
		Sept 1993	June 2004	July 2007	Oct 2009	Dec 2015	
		Max WSE (ft, PD)	Max WSE (ft, PD)	Max WSE (ft, PD)	Max WSE (ft, PD)	Max WSE (ft, PD)	
52.954	OK-20 Bridge						
52.922	569.25	634.80	619.51	634.80	633.01	634.79	15.29
50.500	Saline Creek						
50.396	569.69	634.85	619.50	634.82	633.01	634.84	15.35
49.110	562.60	634.84	619.49	634.82	633.00	634.83	15.35
48.118	558.27	634.84	619.48	634.81	633.00	634.83	15.36
47.186	553.07	634.83	619.48	634.81	632.99	634.82	15.35
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

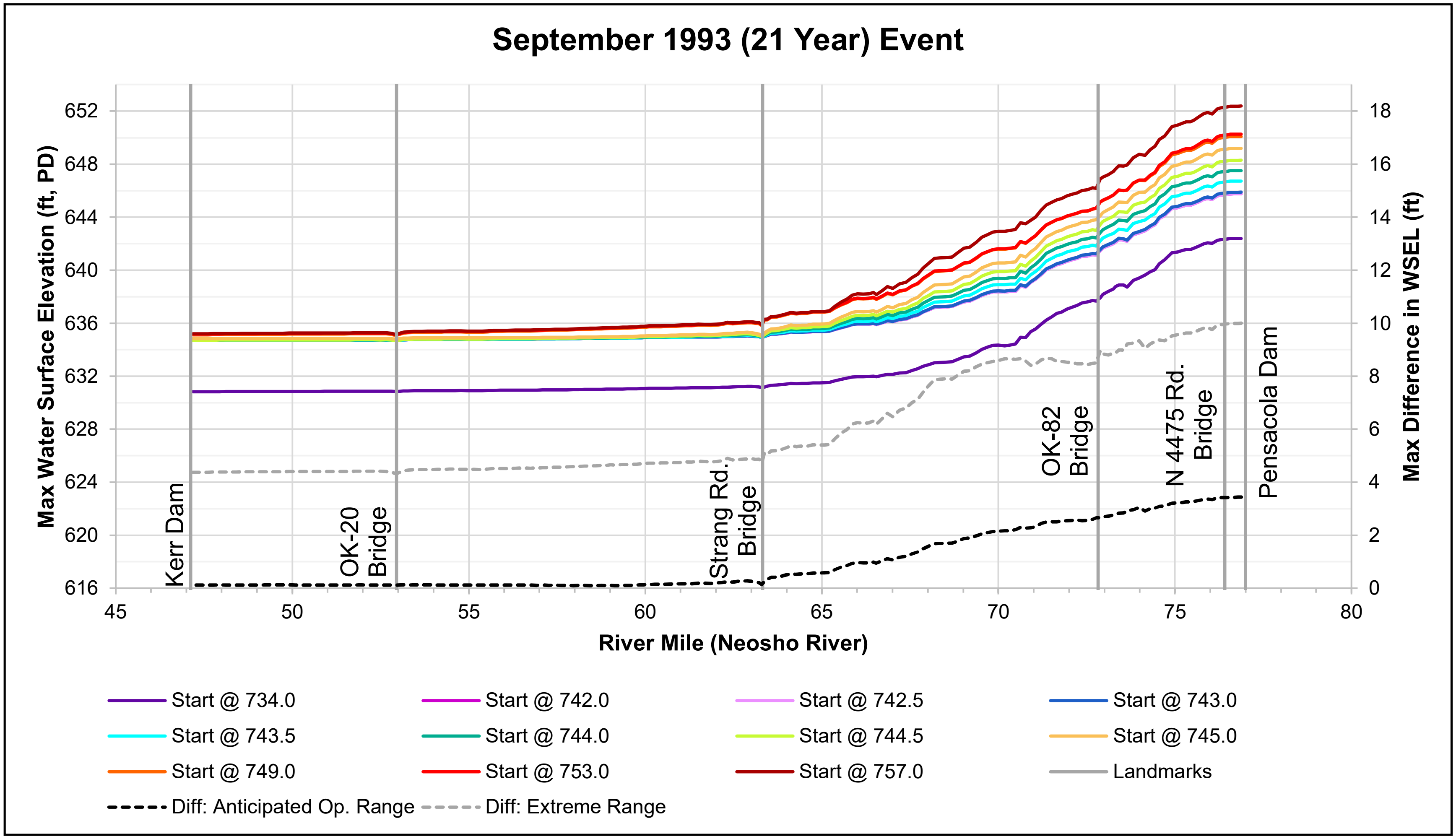


Figure D.1. Water surface elevations for the September 1993 (21 year) event downstream of Pensacola Dam along the Neosho River profile.

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 @ 742.0" means a starting pool elevation of 742.0 ft PD.

2. The black dashed line plotted against the right y-axis represents the maximum difference in WSEL for simulations with starting stages within GRDA's anticipated operational range (742 to 745 feet PD). The gray dashed line represents the maximum difference in WSEL for simulations with starting stages at extreme, hypothetical values (734 to 757 feet PD) outside GRDA's anticipated operational range.

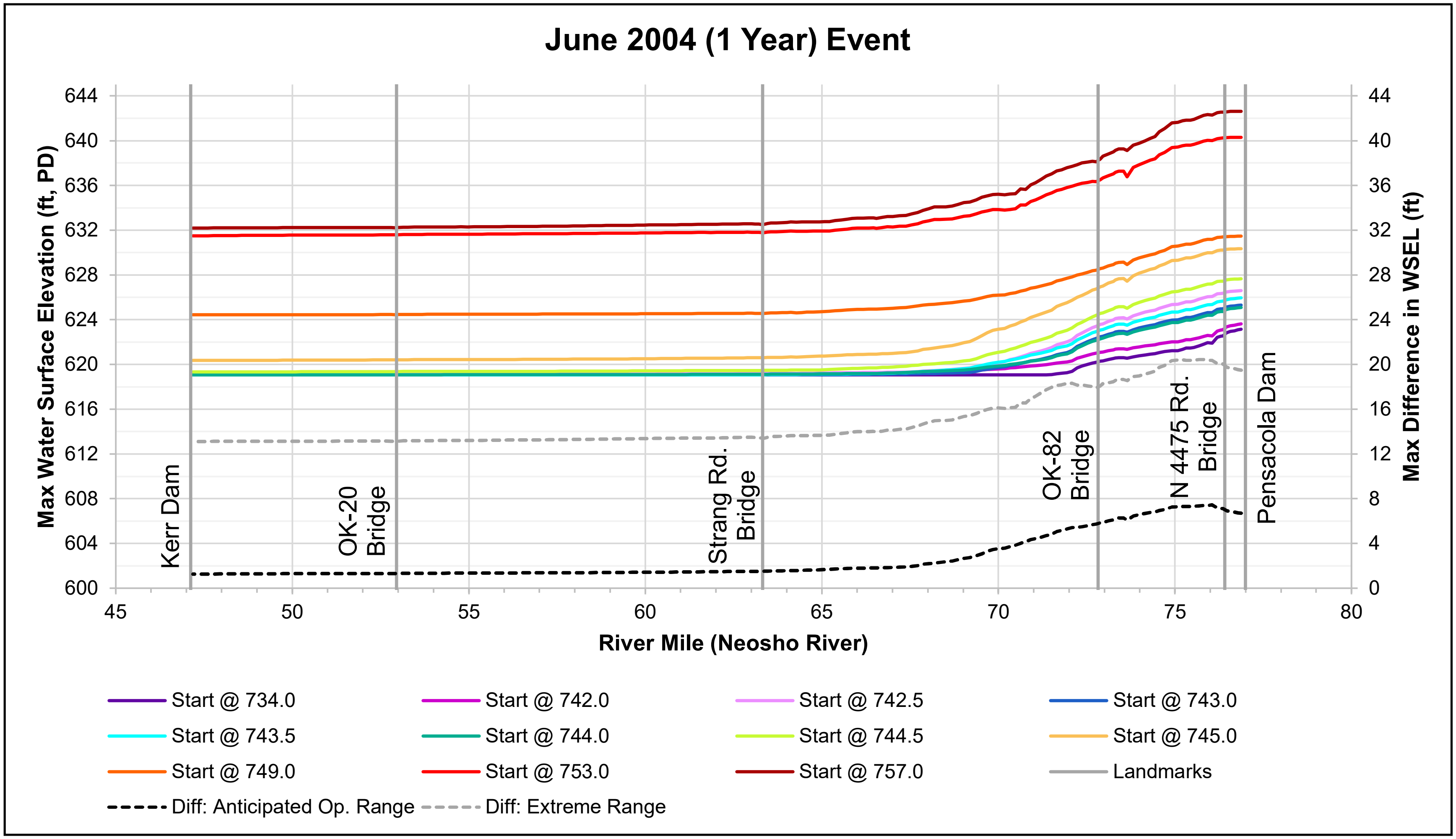


Figure D.2. Water surface elevations for the June 2004 (1 year) event downstream of Pensacola Dam along the Neosho River profile.

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 @ 742.0" means a starting pool elevation of 742.0 ft PD.

2. The black dashed line plotted against the right y-axis represents the maximum difference in WSEL for simulations with starting stages within GRDA's anticipated operational range (742 to 745 feet PD). The gray dashed line represents the maximum difference in WSEL for simulations with starting stages at extreme, hypothetical values (734 to 757 feet PD) outside GRDA's anticipated operational range.

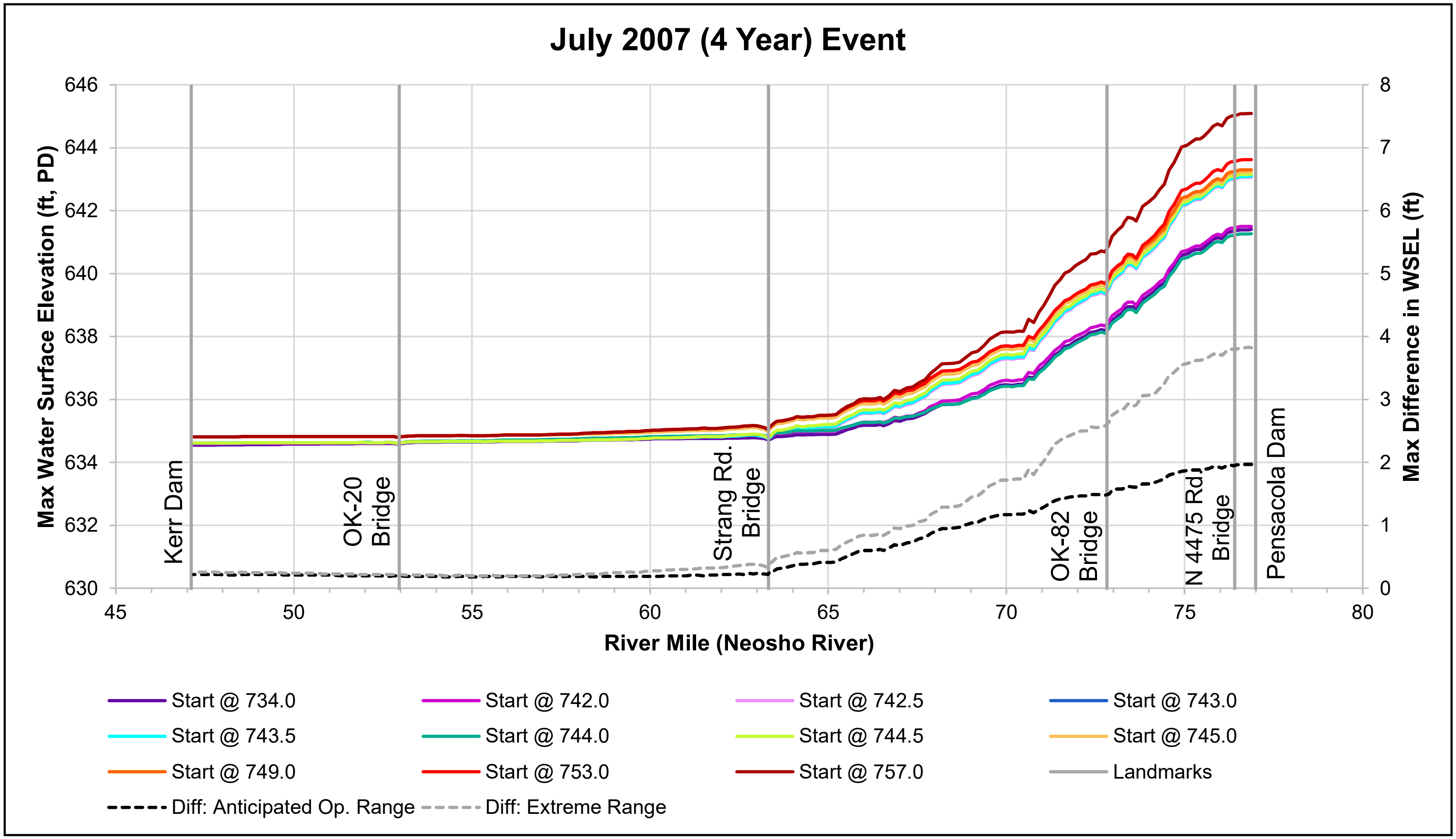


Figure D.3. Water surface elevations for the July 2007 (4 year) event downstream of Pensacola Dam along the Neosho River profile.

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 @ 742.0" means a starting pool elevation of 742.0 ft PD.

2. The black dashed line plotted against the right y-axis represents the maximum difference in WSEL for simulations with starting stages within GRDA's anticipated operational range (742 to 745 feet PD). The gray dashed line represents the maximum difference in WSEL for simulations with starting stages at extreme, hypothetical values (734 to 757 feet PD) outside GRDA's anticipated operational range.

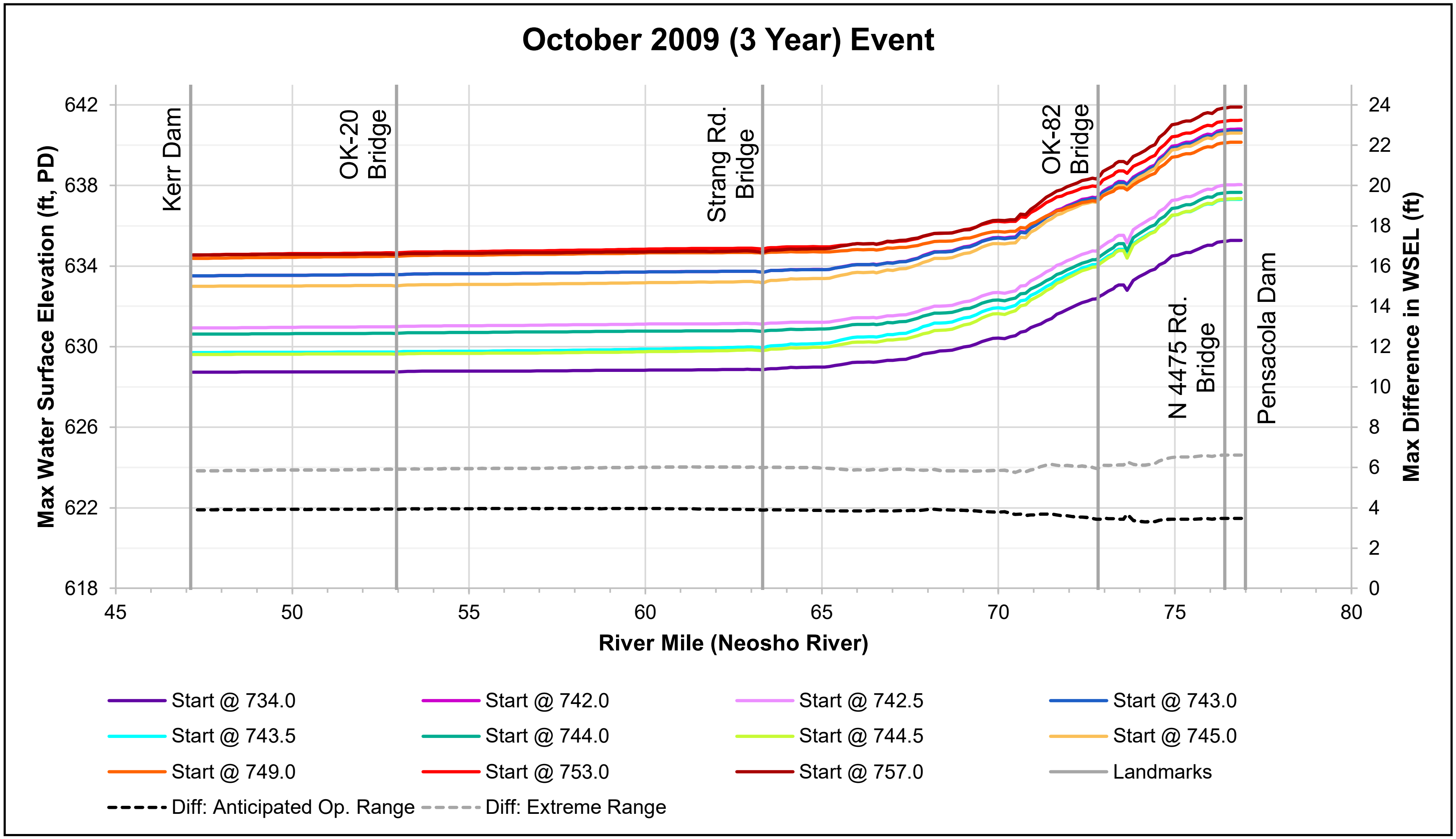


Figure D.4. Water surface elevations for the October 2009 (3 year) event downstream of Pensacola Dam along the Neosho River profile.

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 @ 742.0" means a starting pool elevation of 742.0 ft PD.

2. The black dashed line plotted against the right y-axis represents the maximum difference in WSEL for simulations with starting stages within GRDA's anticipated operational range (742 to 745 feet PD). The gray dashed line represents the maximum difference in WSEL for simulations with starting stages at extreme, hypothetical values (734 to 757 feet PD) outside GRDA's anticipated operational range.

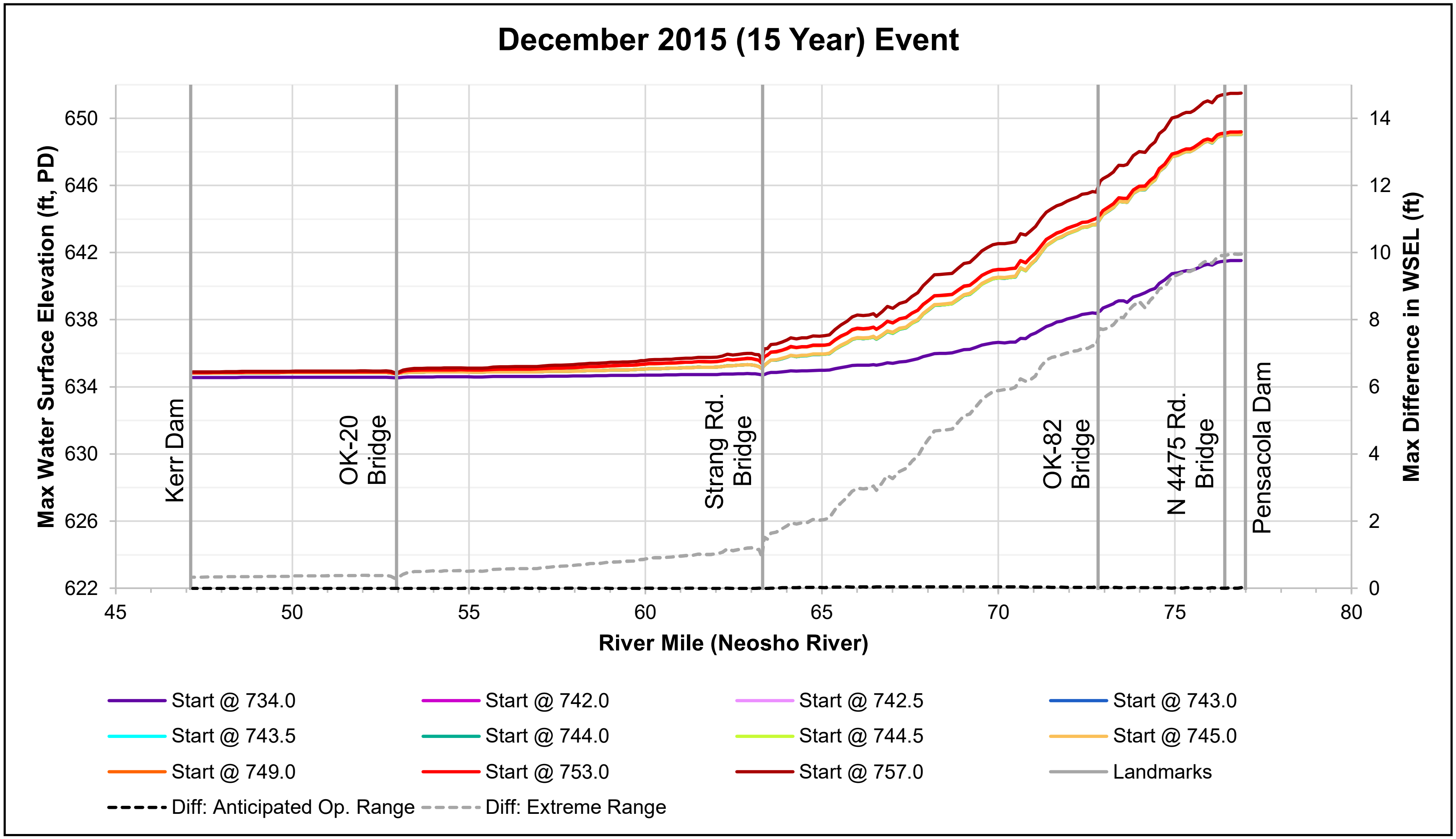


Figure D.5. Water surface elevations for the December 2015 (15 year) event downstream of Pensacola Dam along the Neosho River profile.

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 @ 742.0" means a starting pool elevation of 742.0 ft PD.

2. The black dashed line plotted against the right y-axis represents the maximum difference in WSEL for simulations with starting stages within GRDA's anticipated operational range (742 to 745 feet PD). The gray dashed line represents the maximum difference in WSEL for simulations with starting stages at extreme, hypothetical values (734 to 757 feet PD) outside GRDA's anticipated operational range.

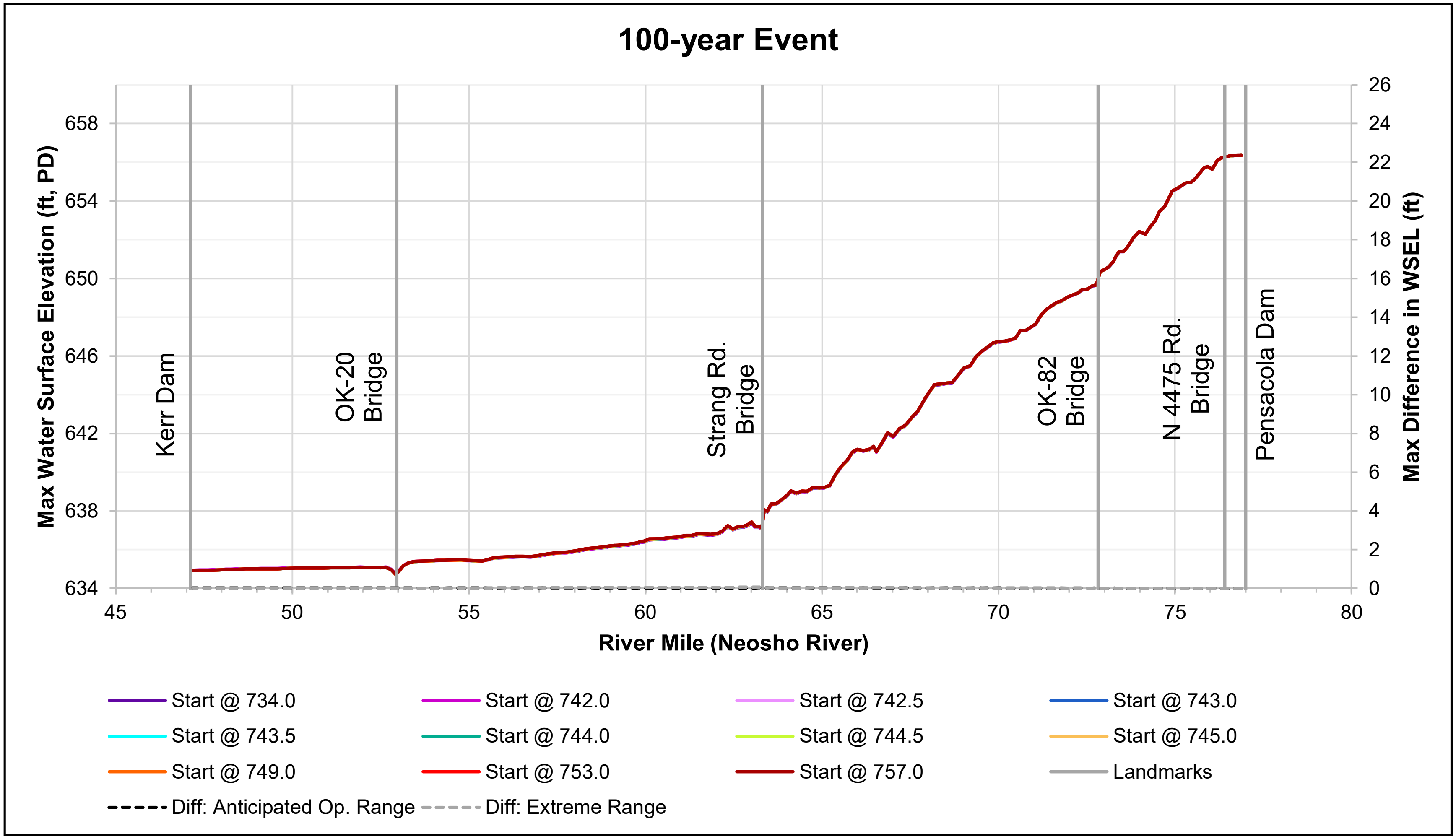


Figure D.6. Water surface elevations for the 100-year event downstream of Pensacola Dam along the Neosho River profile.

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 @ 742.0" means a starting pool elevation of 742.0 ft PD.

2. The black dashed line plotted against the right y-axis represents the maximum difference in WSEL for simulations with starting stages within GRDA's anticipated operational range (742 to 745 feet PD). The gray dashed line represents the maximum difference in WSEL for simulations with starting stages at extreme, hypothetical values (734 to 757 feet PD) outside GRDA's anticipated operational range.

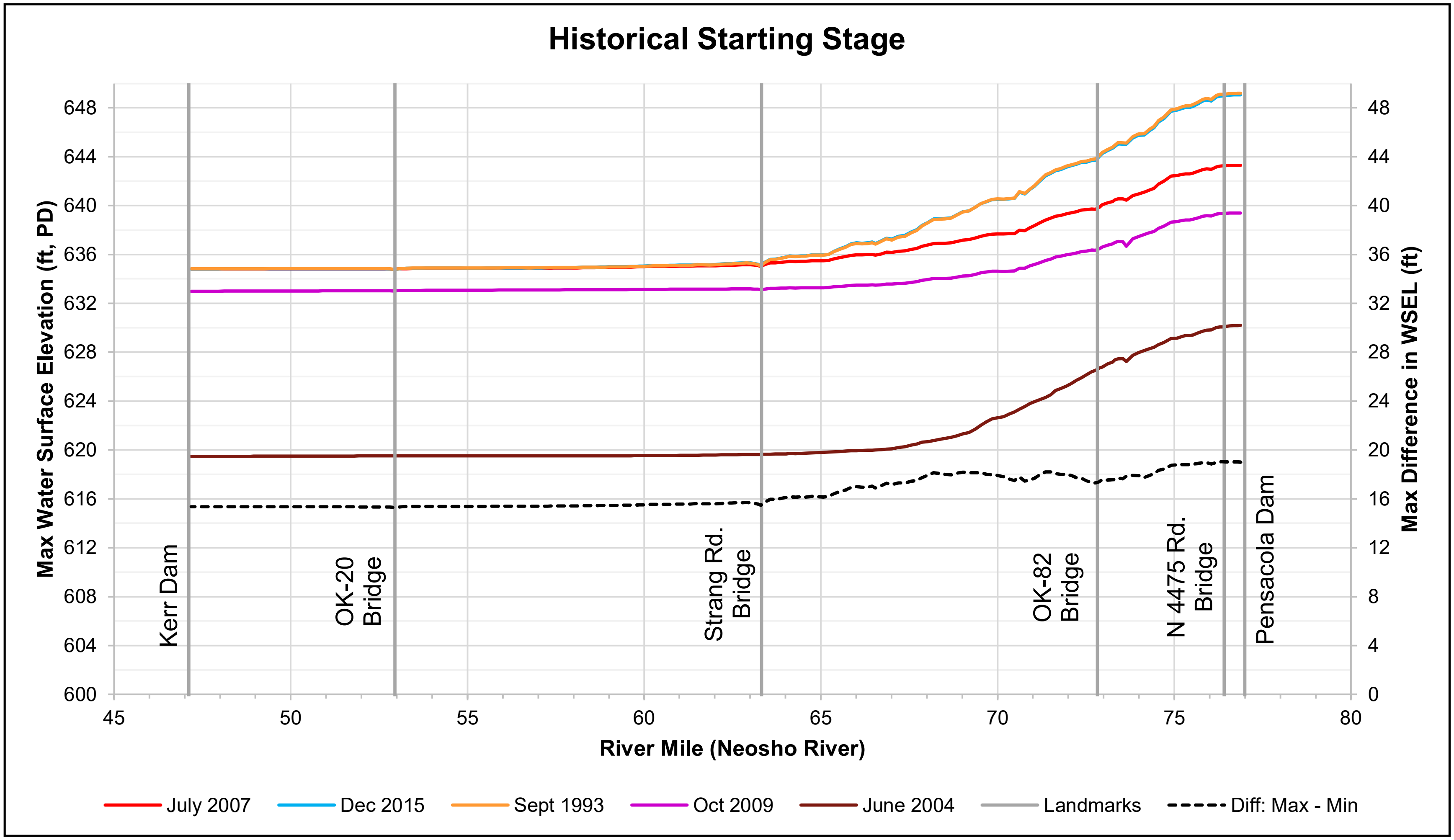


Figure D.7. Water surface elevations for events with historical starting stages downstream of Pensacola Dam along the Neosho River profile.

Note: 1. 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 file size limits, the inundation maps, duration of inundation tables, and anticipated operations analysis are included as separate PDFs.