OPS-1 WATER CONVEYANCE ASSESSMENT INTERIM TECHNICAL MEMORANDUM

KERN RIVER NO. 3 HYDROELECTRIC PROJECT
FERC PROJECT NO. 2290

PREPARED FOR:

KERNVILLE, CALIFORNIA

October 2023

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LIST OF ACRONYMS AND ABBREVIATIONS

cfs	cubic feet per second
FERC	Federal Energy Regulatory Commission
KR3	Kern River No. 3
Project	Kern River No. 3 Hydroelectric Project (FERC Project No. 2290)
RSP	Revised Study Plan
SCE	Southern California Edison
SPD	Study Plan Determination

1.0 INTRODUCTION

This interim Technical Memorandum provides the methods and findings of the desktop analysis associated with the *OPS-1 Water Conveyance Assessment Study Plan* in support of Southern California Edison's (SCE) Kern River No. 3 (KR3) Hydroelectric Project (Project) relicensing, Federal Energy Regulatory Commission (FERC) Project No. 2290. The OPS-1 Study Plan was included in SCE's Revised Study Plan (RSP) submitted on July 1, 2022 (SCE, 2022). In the October 12, 2022 Study Plan Determination (SPD) (FERC, 2022), FERC approved the OPS-1 Study Plan with modifications. Specifically, FERC recommended SCE evaluate a full range operational flows (no flow to full tunnel flows) with the goal of determining what flows are necessary for maintaining Project safety and tunnel integrity in addition to reviewing any available construction documents or reports associated with previous tunnel rehabilitation projects.

Data review and analysis efforts associated with characterization of the hydraulics (hydraulic assessment) for the full range of tunnel flows were initiated in 2023 and summarized below. SCE will complete additional work associated with the structural integrity analysis of the unlined and concrete-lined conveyance tunnel (structural integrity assessment), with results included as part of the Draft License Application and Updated Study Report.

The OPS-1 Study was conducted with support from engineering firms MarshWagner and Kleinschmidt Associates, who have documented expertise in hydropower, hydraulic analyses, and tunnels / underground structures. MarshWagner led the evaluation of tunnel and lining integrity based on their desktop review of documentation available on the tunnel design and construction and supported by tunnel hydraulic characteristics developed by Kleinschmidt Associates. Note that a site visit was not conducted and that all analyses were based on available information on the geology, tunnel design and construction, and hydraulic flow data.

2.0 STUDY GOALS AND OBJECTIVES

The objectives of the study, as outlined in OPS-1 Study Plan (SCE, 2022), include:

- Conduct an engineering review and evaluation of current water conveyance conditions (e.g., hydrostatic pressure, flow depth) under varying flow conditions.
- Identify guidelines for future operational conditions using current Project information and industry best practices to maintain water conveyance system integrity.

3.0 STUDY AREA AND STUDY SITES

The study area includes the approximately 13 miles of water conveyance infrastructure that runs along the eastern hillslope above the North Fork Kern River between Fairview Dam and the KR3 Forebay. The water conveyance infrastructure included with the analysis and described herein was limited to tunnels, open and covered aboveground flumes, a steel siphon, and a regulated pressure flume.

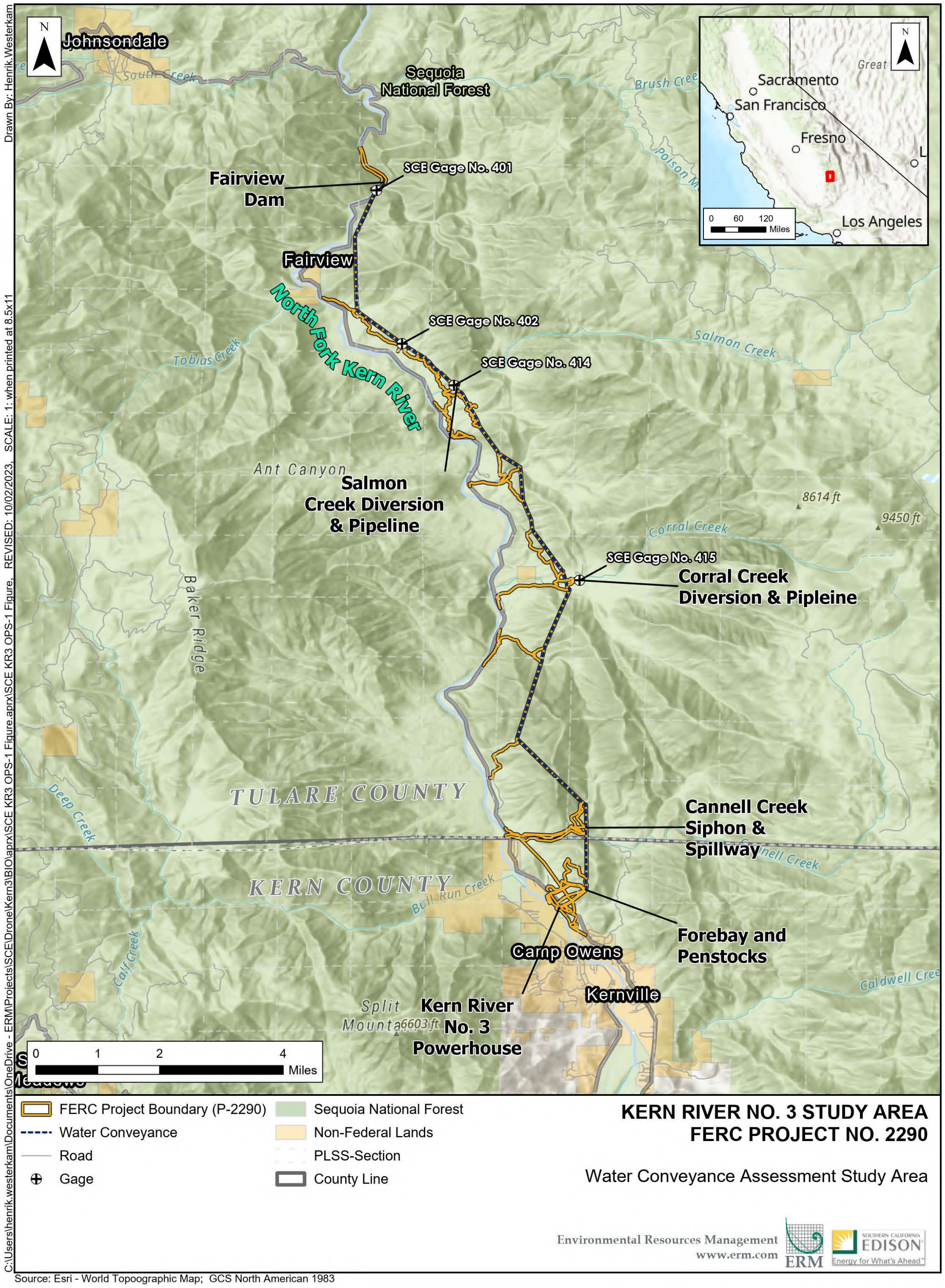


Figure 3-1. Water Conveyance Assessment Study Area.

4.0 METHODS

Study implementation followed the methods described in SCE's RSP Package (SCE, 2022), and as amended by FERC in their SPD (FERC, 2022).

Study Plan Variances

There are no variances from the OPS-1 Study approved in the FERC SPD (FERC, 2022) issued in October 2022.

4.1. PHASE 1: SUMMARY OF EXISTING INFORMATION

The information sources used in this study for the hydraulic assessment include Project drawings to define tunnel alignment, profile, and cross-sections; correspondence with SCE staff regarding observed flow conditions in the tunnel; recorded flow data in the tunnel to correlate to observed flow conditions; and HEC-RAS reference manual (USACE, 2022). Specific references are listed below, which are also presented in the attached technical memorandum on the hydraulic assessment (see Appendix A, filed as CEII).

- SCE (Southern California Edison). 1990a. *Exhibit F General Design Drawings Kern River No. 3 Project*. Rosemead, CA
- SCE (Southern California Edison). 1990b. *Exhibit G Plan View of Kern River No. 3 Project.* Rosemead, CA.
- SCE (Southern California Edison). 2023a. North Fork Kern River time series table (preliminary data). Accessed: June 28, 2023. Retrieved from: https://www.sutronwin.com/scedison/tw/jsp/
- SCE (Southern California Edison). 2023b. RE: Exposed Tunnel Photos. Email Received: June 19, 2023.
- USACE (U.S. Army Corps of Engineers). 2022. *HEC-RAS River Analysis System Hydraulic Reference Manual,* Version 6.3.1. U.S. Army Corps of Engineers Hydrologic Engineering Center.
- WCC (Woodward – Clyde Consultants). 1998. *Reconnaissance Inspection and Evaluation of Kern River No. 3 Tunnels.* Prepared for SCE.
- Project documents, including as-built drawings, hydraulic information, descriptions of recent refurbishment work conducted on the tunnels, and any recent inspection reports.
- Interviews with SCE's Project Operators and review of Station Orders or other documents describing SCE's current operational practices when cycling conveyance flows in accordance with license requirements, or during tunnel dewatering events for maintenance outages.

- Geologic maps and other published information.
- Literature review of studies on tunnel structural integrity, tunnel operation and long-term effects of cycling tunnel flows and industry best practices.

4.2. PHASE 2: PROJECT CONVEYANCE FLOWLINE ASSESSMENT

4.2.1. HYDRAULIC ASSESSMENT

The following provides a brief summary of the hydraulic assessment methodology. Additional details are presented in a separate hydraulic assessment technical memorandum (Appendix A).

A 1D quasi-steady-state HEC-RAS hydraulic model was created to model flow conditions in the KR3 power conveyance tunnel (USACE, 2022). Although pressurized flow in the tunnel was not expected, the HEC-RAS model was set up with a Preissmann slot to accommodate pressurized flow conditions using open channel flow equations.

Flows modeled included constant flows of 100, 200, 300, 400, 500, and 600 cubic feet per second (cfs). The upstream boundary of the model is the tunnel entrance (Sta 10+57.69), just downstream from the sediment settling basin, and the downstream boundary is where the tunnel transitions to the concrete pressure pipe (Sta 643+44.21). The upstream boundary condition was set as a constant flow and the downstream boundary was modeled as a set water surface elevation of 3,505 feet, which represents the normal pond elevation of the forebay downstream of the concrete pressure pipe.

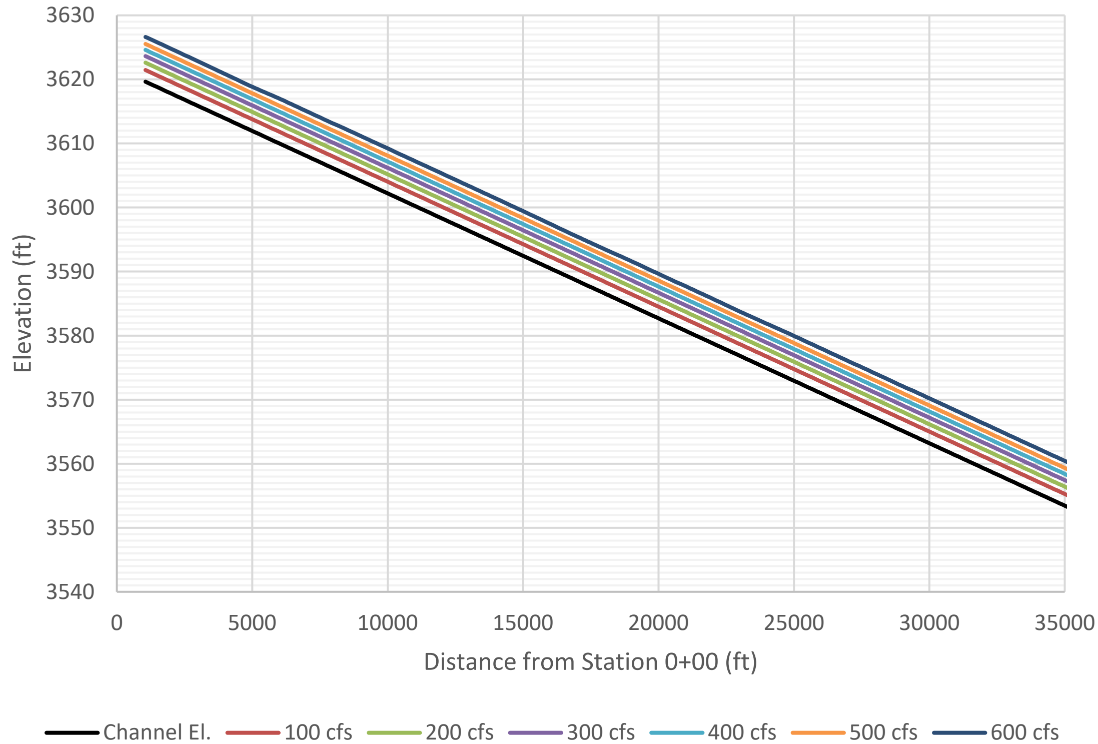
The results were used to inform potential conveyance lining abrasion and lining stability assessments along the tunnel segments of the conveyance flowline.

5.0 DATA SUMMARY

5.1. HYDRAULIC ASSESSMENT

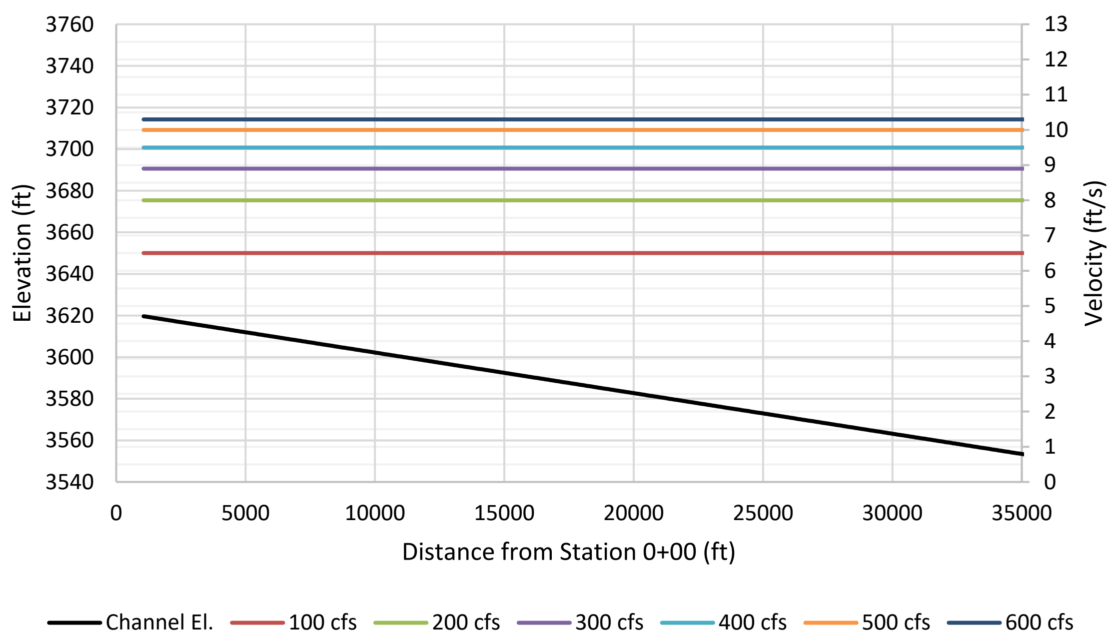
The following provides a brief summary of the hydraulic assessment results. Additional details are presented in a separate hydraulic assessment technical memorandum (Appendix A).

Water surface profiles and average flow velocity along the length of tunnel are presented in Figures 5.1-1 through 5.1-4 for the modeled flows ranging from 100 cfs to 600 cfs. Typical corresponding flow depth and velocity rating curves for each modeled flow are presented in Figures 5.1-5 and 5.1-6.



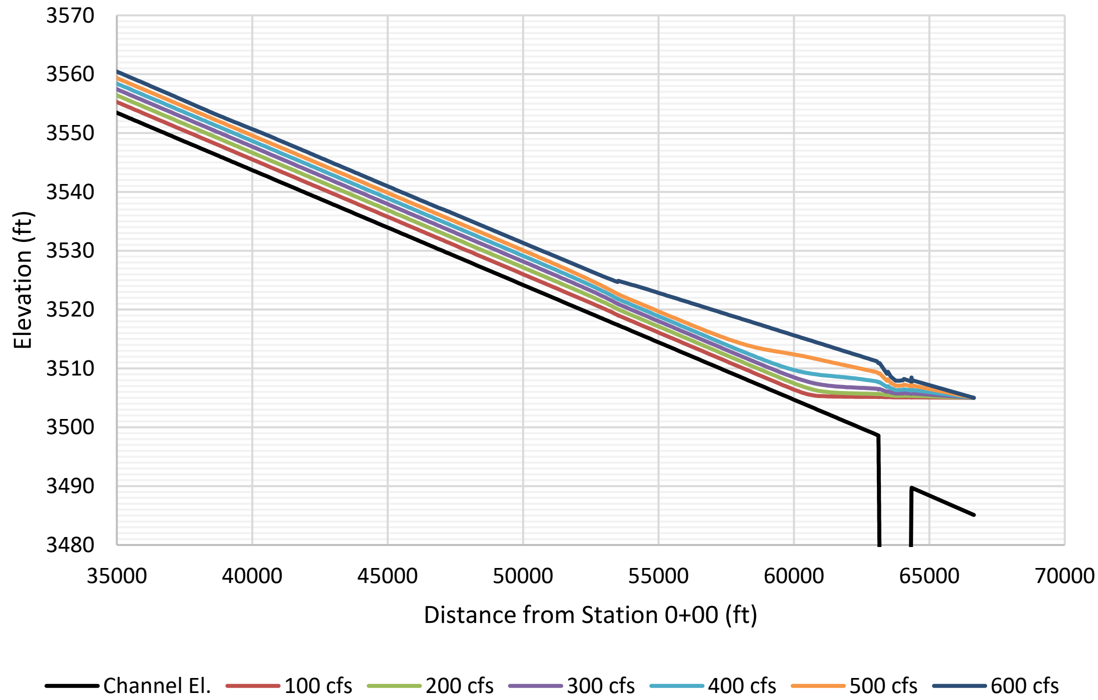
cfs = cubic feet per second; ft = foot

Figure 5.1-1. Estimated Water Surface Profiles in Tunnel STA 000+00 to 350+00.



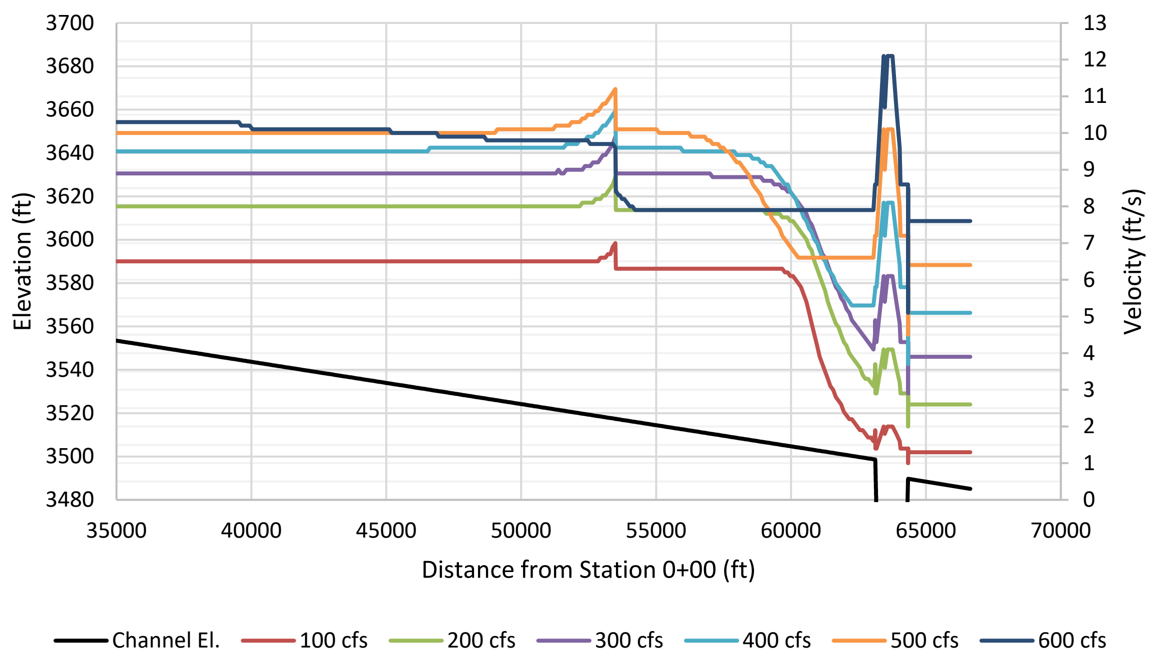
ft = foot; ft/s = feet per second

Figure 5.1-2. Estimated Velocity in Tunnel STA 000+00 to 350+00.



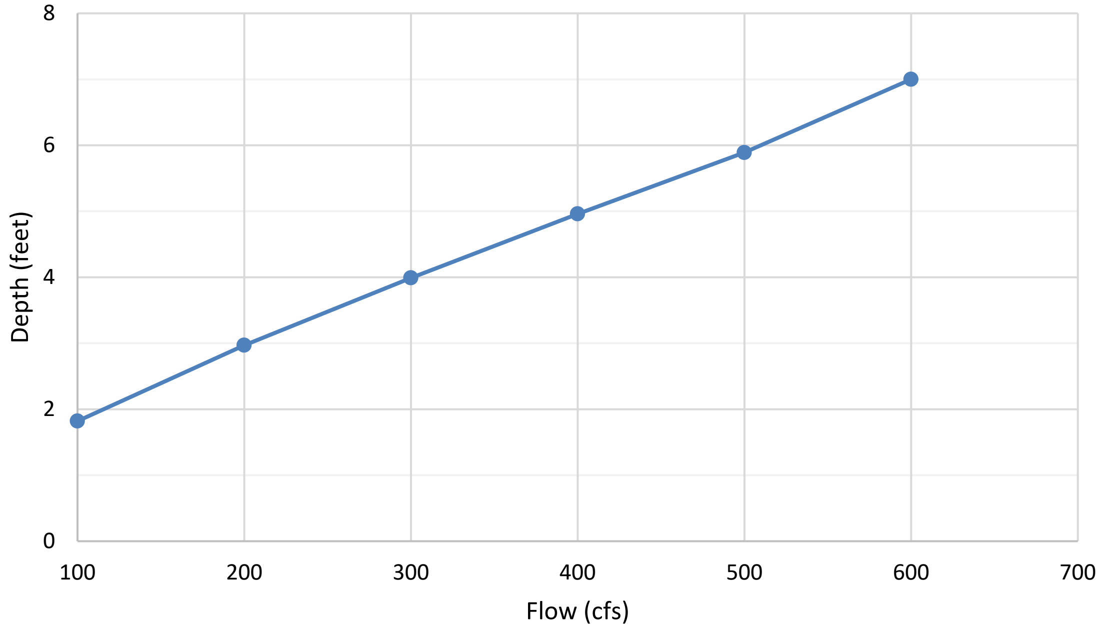
cfs = cubic feet per second; ft = foot

Figure 5.1-3. Estimated Water Surface Profiles in Tunnel STA 350+00 to 666+44.21.



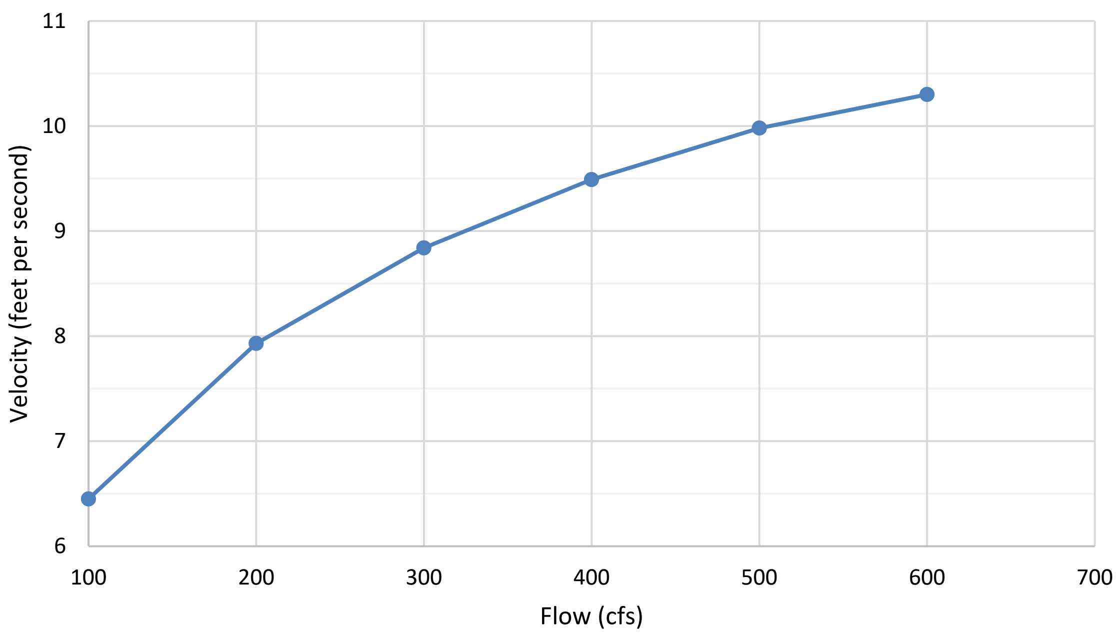
ft = foot; ft/s = feet per second

Figure 5.1-4. Estimated Velocity in Tunnel STA 350+00 to 666+44.21.



cfs = cubic feet per second; ft = foot

Figure 5.1-5. Typical Depth to Flow Relationship in Concrete-lined Tunnel Sections.



cfs = cubic feet per second

Figure 5.1-6. Typical Velocity to Flow Relationship in Concrete-lined Tunnel Sections.

6.0 STUDY SPECIFIC CONSULTATION

No study-specific consultation is required for this study, and no consultation has been conducted to date.

7.0 OUTSTANDING STUDY PLAN ELEMENTS

Date	Activity
Fall/Winter 2023-2024	Complete Coneyance Flowline Structural Integrity Assessment
Fall 2024	Provide results in the Updated Study Report

8.0 REFERENCES

FERC (Federal Energy Regulatory Commission). 2022. *Study Plan Determination for the Kern River No. 3 Hydroelectric Project.* Accession No. 20221012-3024. October 12.

SCE (Southern California Edison). 1990a. *Exhibit F General Design Drawings Kern River No. 3 Project*. Rosemead, CA

_____. 1990b. *Exhibit G Plan View of Kern River No. 3 Project*. Rosemead, CA.

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_____. 2023b. RE: Exposed Tunnel Photos. Email Received: June 19, 2023.

_____. 2022. *Kern River No. 3 Hydroelectric Project, Revised Study Plan*. Filed with FERC on July 1. Accessed: August 2023. Retrieved from: sce.com/sites/default/files/custom-files/Web files/Revised_Study_Plan_KR3_20220701.pdf

USACE (U.S. Army Corps of Engineers). 2022. *HEC-RAS River Analysis System Hydraulic Reference Manual*, Version 6.3.1. U.S. Army Corps of Engineers Hydrologic Engineering Center.

WCC (Woodward – Clyde Consultants). 1998. *Reconnaissance Inspection and Evaluation of Kern River No. 3 Tunnels.* Prepared for SCE.

APPENDIX A
KERN RIVER NO. 3 – STUDY OPS-1: WATER CONVEYANCE ASSESSMENT
POWER TUNNEL HYDRAULIC MODEL RESULTS (FILED AS CEII)

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MEMORANDUM

To: Jillian Roach (ERM)

From: Cheyenne Kinn, EIT; Carl Mannheim, PE

Cc: Carlos Jaramillo, PE (MarshWagner)

Date: October 5, 2023 (REV 1)

Re: Kern River No. 3 – Study OPS-1: Water Conveyance Assessment Power Tunnel Hydraulic Model Results (REDACTED – PUBLIC VERSION)

INTRODUCTION

The Kern River No. 3 Hydroelectric Project (KR3) power conveyance tunnel segments may be affected by rapid flow cycling (i.e., decreases or increases in flow rates and corresponding decreases or increases in water levels in the conveyance). Current operating conditions include flows ranging from as little as 2-3 cubic feet per second (cfs) up to the maximum capacity of approximately 600 cfs. As part of Southern California Edison's (SCE) relicensing efforts for KR3, Federal Energy Regulatory Commission (FERC) has accepted a water conveyance assessment study (Study OPS 1: Water Conveyance Assessment) to evaluate the effects on conveyance tunnel lining stability for different flow rates by conducting an engineering review and evaluation of current water conveyance conditions (i.e., hydrostatic pressure, flow depth, and velocity) under varying flow conditions (up to 600 cfs), and to identify guidelines for future operation conditions using current project information and industry best practices to maintain water conveyance system (lining) integrity.

The purpose of this memorandum is to support the evaluation of lining stability in the tunnel segments by MarshWagner by providing a steady-state characterization of the flow conditions in the tunnel segments for a range of flows up to 600 cfs.

All elevations are reported in the KR3 Plant Datum.

BACKGROUND

The power conveyance comprises approximately 13 miles of water tunnels, open and covered aboveground flumes, a steel inverted siphon, flume overflow sections, and a forebay from which two penstocks connect to the powerhouse. The project FERC Exhibits F and G provided profile elevations (referenced to the Kern River No. 3 Plant datum), as well as tunnel and siphon geometry. The overall conveyance includes a combination of arched (D-shaped) tunnels, covered flumes, aboveground open flumes, an inverted siphon, and a concrete pressure pipe.

Figure 1 shows a plan and profile of the conveyance, based on known elevations at the tunnel entrance and at the siphon entrance but with assumed intermediate elevations. Per the referenced FERC exhibits, stationing is in the downstream direction starting at 0+00 at the diversion structure.

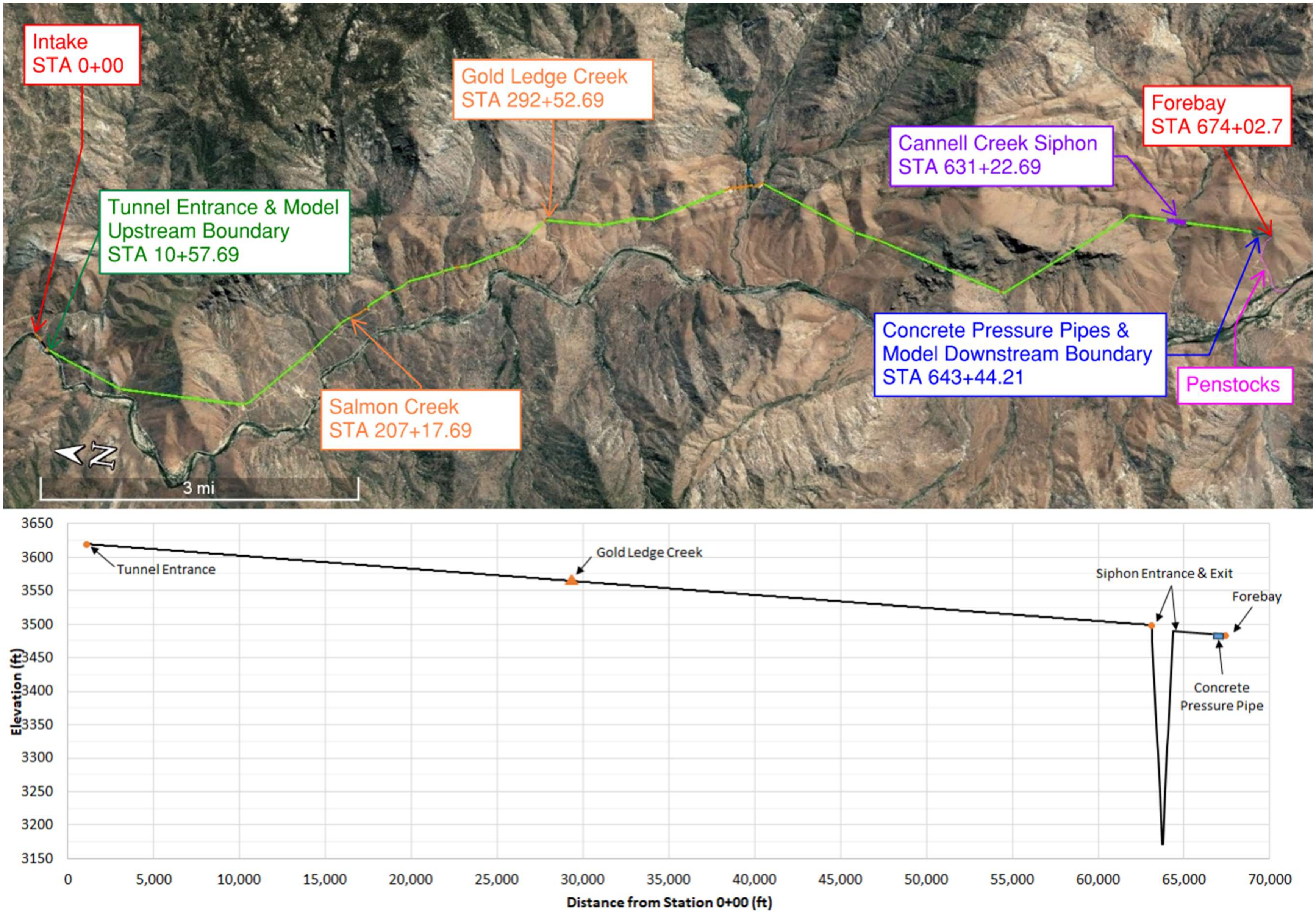

Figure 1. Plan and Profile of the KR3 Power Conveyance

Hydraulic Model

A 1D quasi-steady-state HEC-RAS hydraulic model was created to model flow conditions in the KR3 power conveyance tunnel (USACE 2022). Although pressurized flow in the tunnel was not expected, the HEC-RAS model was set up to with a Preissmann slot to accommodate pressurized flow conditions using open channel flow equations.

Flows modeled include constant flows of 100 cfs, 200 cfs, 300 cfs, 400 cfs, 500 cfs, and 600 cfs. The upstream boundary of the model is the tunnel entrance, just downstream from the sediment settling basin, and the downstream boundary is where the tunnel transitions to the concrete pressure pipe. The upstream boundary condition was set as a constant flow (e.g., 600 cfs), and the downstream boundary was modeled as a set water surface elevation of 3,505 feet, which represents the normal pond elevation of the forebay downstream of the concrete pressure pipe. Figure 2 shows the elevation profile used for the tunnel, and Table 1 provides the elevations used to linearly interpolate the cross-section elevations.

All stationing refers to the approximate FERC Exhibit stationing, unless otherwise specified.

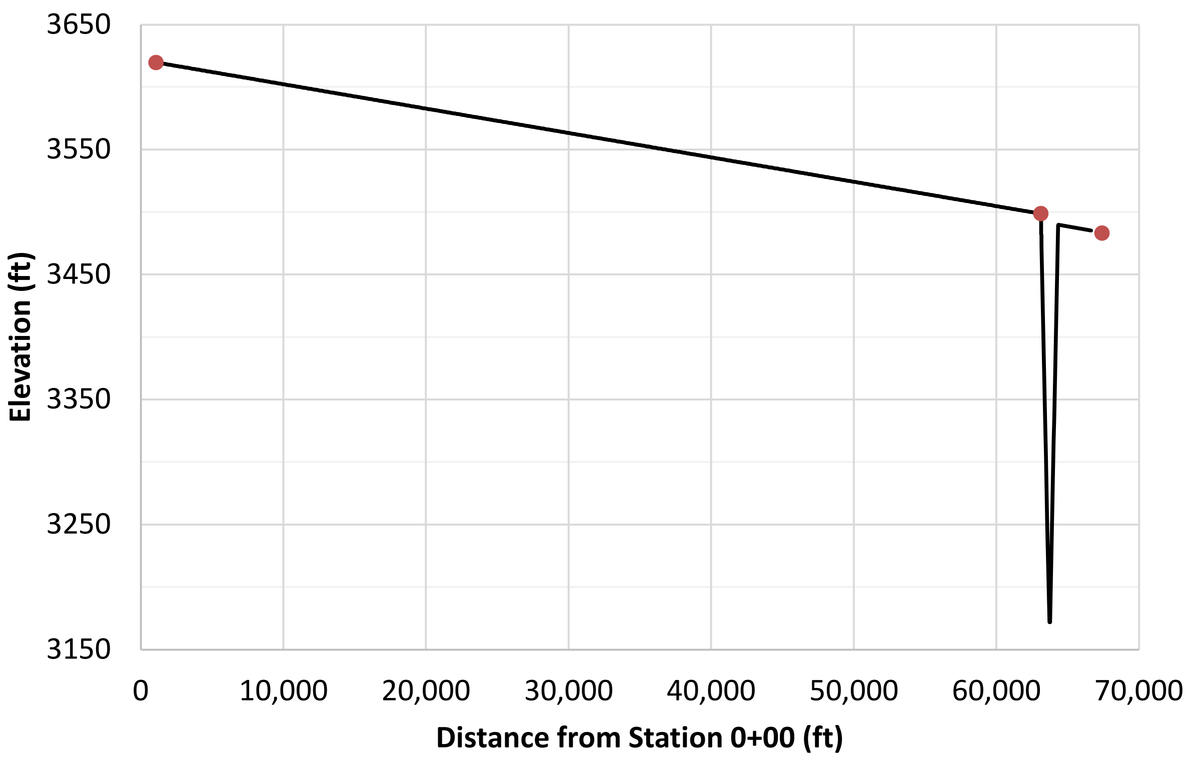

Figure 2. Elevation Profile Used for the 1D HEC-RAS Model of KR3 Project.

Table 1. Elevations Used for Linear Interpolation of Cross-section Elevations

Location	Approximate FERC Exhibit F/G Station	Elevation (ft)
Tunnel Entrance	10+57.7	3,619.6
Siphon Entrance	631+22.7	3,498.6
Forebay	674+02.7	3,483.1

The siphon was modeled with cross-sections ranging from a diameter of 8 feet at the narrowest up to 9.5 feet at the widest, with transitions between these sizes determined from Exhibit F drawings. Figure 3 shows a typical siphon section.

The locations and lengths of different cross-section types (open flume, lined/unlined tunnel, covered flumes, siphon) were determined using Exhibits F and G for the KR3 Project. The approximate shape of the arched tunnel sections was also based on these Exhibits. The tunnel segments are 8.5 feet wide by 8 feet high north of Station 533+63 and 9.5 feet wide by 8 feet high south of Station 533+63, with arched tops. Figure 4 shows a typical arched tunnel section. For modeling simplicity, the tunnel cross-sections were approximated as rectangles, with the height of the tunnel being the highest point of the arch. This approximation slightly increases the model tunnel capacity at very high flows but does not affect the results with lower flows.

The approximately 1,000 feet of aboveground flumes were modeled as 8.5 feet wide and 8.25 feet high. See Figures 5 and 6 below for typical covered and open flume sections, respectively.

FIGURE REDACTED
CONTAINS CRITICAL ENERGY INFRASTRUCTURE INFORMATION (CEII)

Figure 3. Typical Siphon Section (SCE 1990).

FIGURE REDACTED
CONTAINS CRITICAL ENERGY INFRASTRUCTURE
INFORMATION (CEII)

Figure 4. Typical Arched Tunnel Section (SCE 1990).

FIGURE REDACTED
CONTAINS CRITICAL ENERGY INFRASTRUCTURE
INFORMATION (CEII)

Figure 6. Typical Open Flume Section (SCE 1990).

FIGURE REDACTED
CONTAINS CRITICAL ENERGY INFRASTRUCTURE
INFORMATION (CEII)

Figure 5. Typical Covered Flume Section (SCE 1990).

A single Manning's n roughness coefficient of 0.012 was assigned to the concrete-lined tunnels, flumes, covered flumes, and the riveted steel pipe siphon. This is a slightly lower than typical value used for concrete but within a normal range. See Model Validation below.

MODEL VALIDATION

ERM provided observations (Appendix A) of flume water levels at two locations along the conveyance (SCE 2023a): 1) at Gold Ledge; and 2) at Corral Creek. The flow at the time of these observations was obtained from SCE's online hourly flow log and ranged from 550 cfs to 585 cfs. Manning's roughness coefficient (n) was adjusted in the HEC-RAS model, and a final value of 0.012 was selected, resulting in a very close match of model results to those observed conditions. This Manning's n value is in the lower range of what is typical for the materials described in the tunnels as well as the corrugated metal pipe siphon. Table 2 below presents the model validation results, which confirms a very good match of model results the with observed flow conditions.

Table 2. HEC-RAS Model Validation Results

Location	Flow (cfs)[a]	Observed Approximate Depth (ft)[b]	Modeled Depth (ft)	Difference (ft)
Gold Ledge	585	6.75	6.76	0.01
Corral Creek 17	550	6.25	6.35	0.10
Corral Creek 18	550	6.25	6.35	0.10

cfs = cubic feet per second, ft = feet

[a] Obtained from preliminary hourly data (SCE 2023a)

[b] Estimated depth based on observation of distance of water surface below top of flume walls (SCE 2023b)

RESULTS

Figures 7a through 7d present the final water surface elevations, flow depths, velocities, and invert elevations through the length of the tunnel.

Upstream of the siphon, flow depths and velocities in the tunnel range from 1.7 ft and 1.6 fps for 100 cfs to 8.3 ft and 10.3 fps for 600 cfs. The model results indicate that the conveyance is pressurized for varying distances upstream of the siphon for all flows. The model indicates that the conveyance is fully pressurized downstream of the siphon for all flows due to the elevation of the forebay water surface elevation. Consistent with observations of historic power flows, no overtopping of the flume is indicated by the model for any of the modeled flows up to and including 600 cfs.

In Figure 7b, the velocity for a flow of 600 cfs is less consistent than the other flow velocities. The variation is likely a computational artifact of the quasi steady-state HEC-RAS model, since it varies less than 0.25 feet per second throughout the region of the tunnel depicted in Figure 7b.

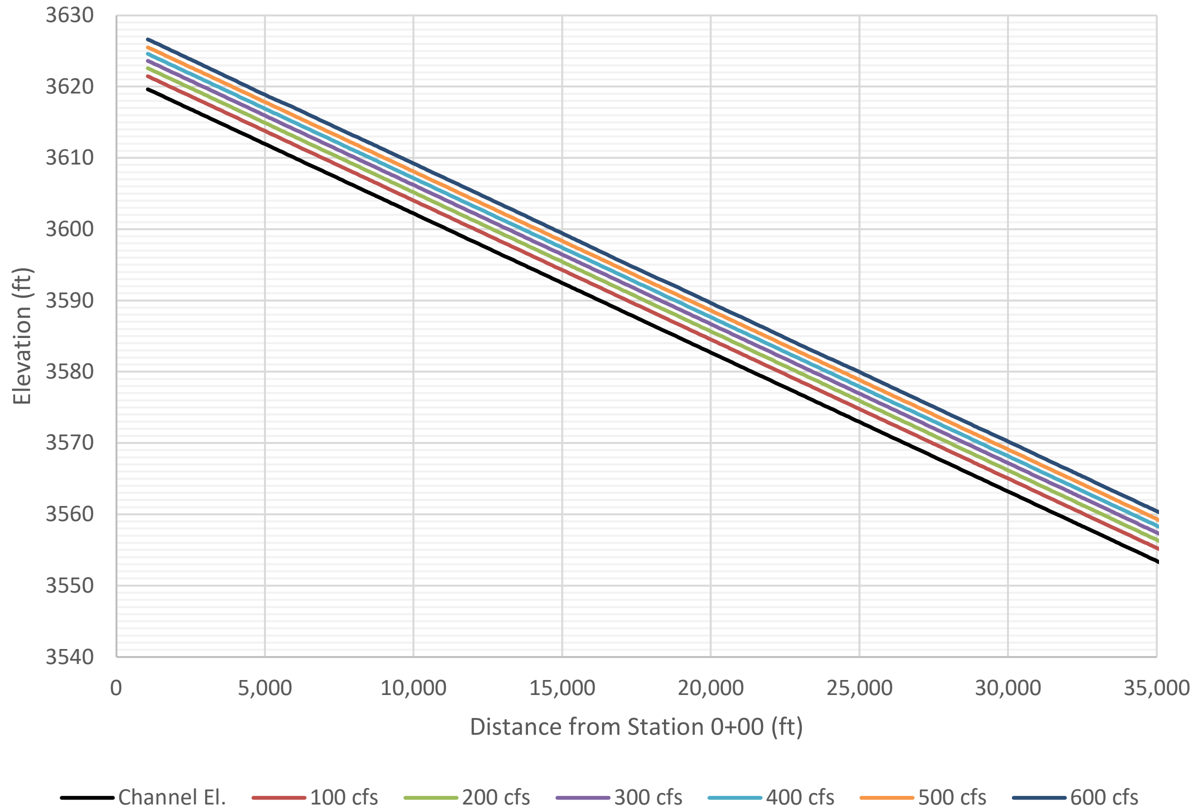

Figure 7a. Estimated Water Surface Elevation Results in Tunnel STA 000+00 to 350+00.

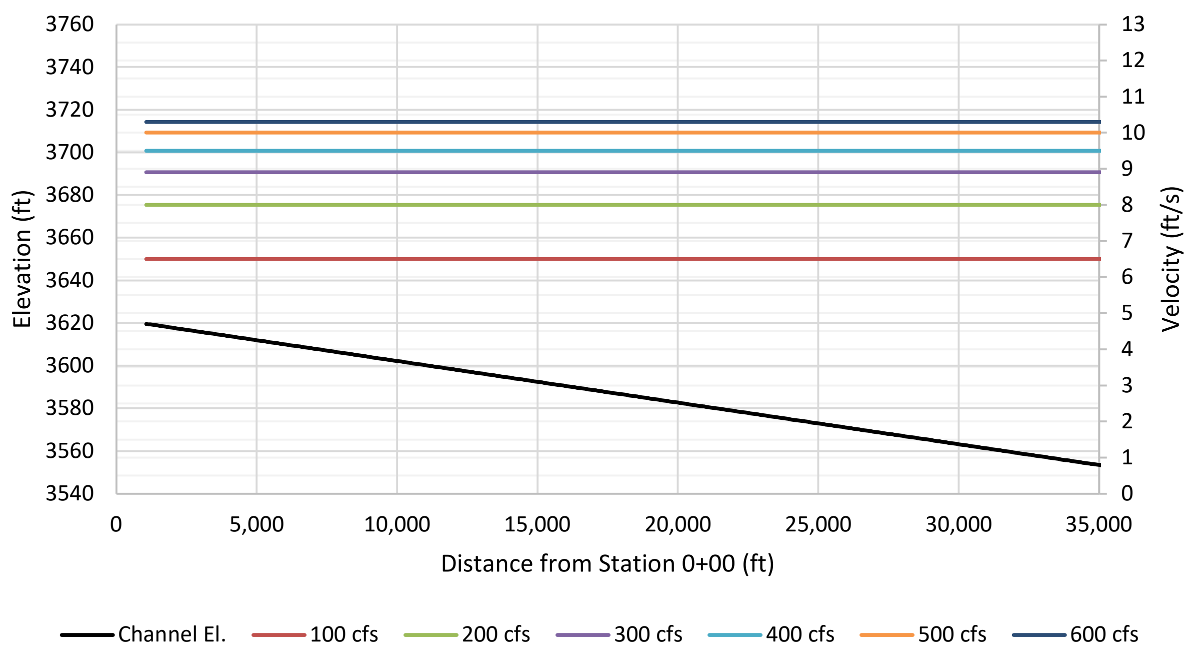

Figure 7b. Estimated Velocity Results in Tunnel STA 000+00 to 350+00.

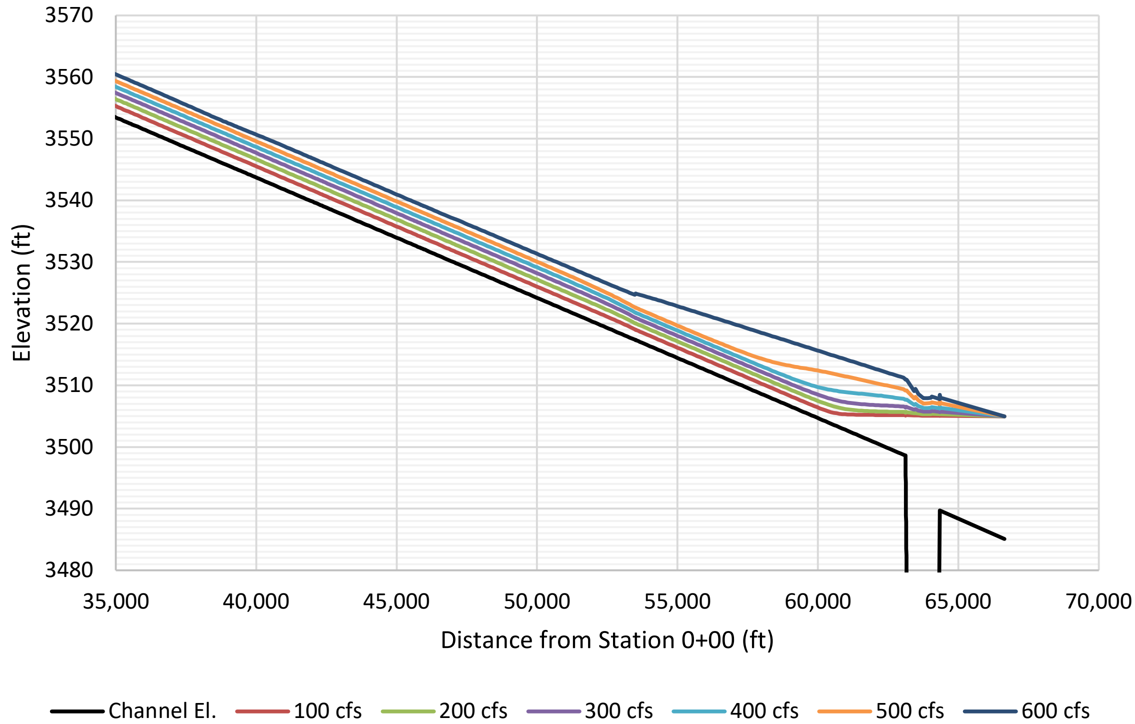

Figure 7c. Estimated Water Surface Elevation Results in Tunnel STA 350+00 to 666+44.21.

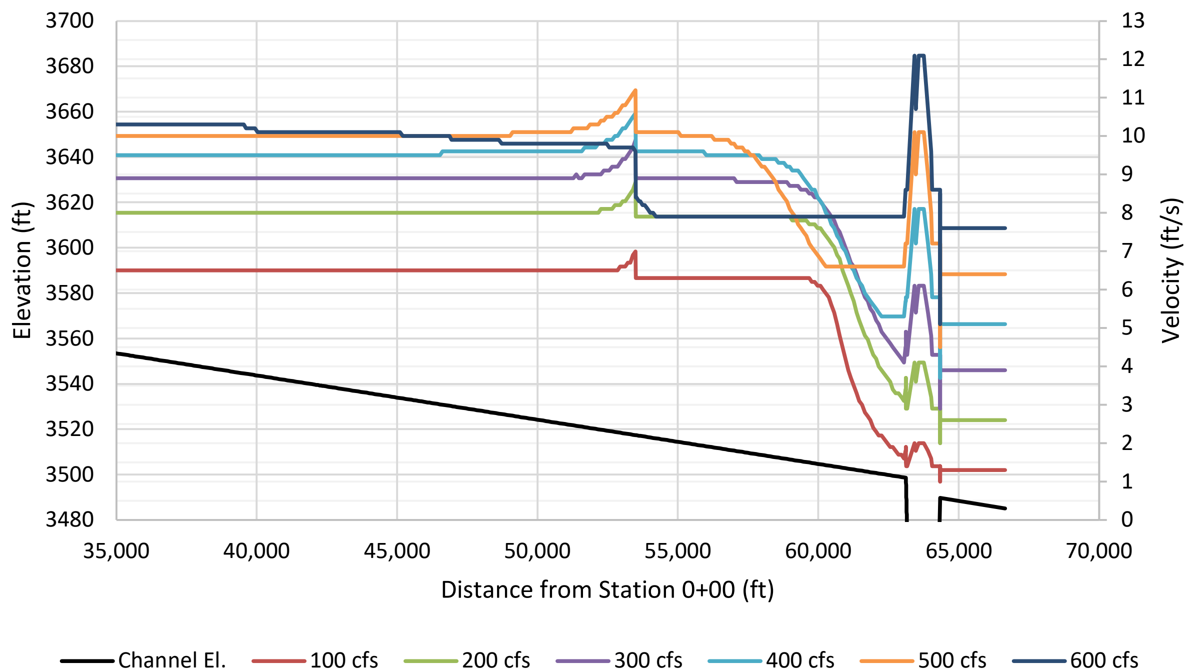

Figure 7d. Estimated Velocity Results in Tunnel STA 350+00 to 666+44.21.

In Figure 7d, the velocity for a flow of 600 cfs does not follow the same general pattern seen with the other flows, especially lacking a spike in velocity around Station 533+63. At this station, the width of the tunnel expands from 8.5 feet to 9.5 feet, causing an increased velocity for flows from 100 cfs to 500 cfs. At 600 cfs, the spike does not occur because the tunnel is pressurized through Station 533+63 and diminishing the effect of expansion on the velocity.

Additionally, in Figure 7d, all model runs have a spike in velocity, with the highest velocity occurring at the lowest elevation of the siphon. These increases and decreases in velocity are caused by the changing diameters through the siphon. The highest velocity in the siphon corresponds to the smallest diameter in the siphon.

SUMMARY OF RESULTS

The KR3 conveyance tunnel was modeled using HEC-RAS for flows ranging from 100 cfs to 600 cfs. It used validation data provided by ERM to confirm water surface elevations at select locations in the tunnel. The final model results closely represent the observed water surface elevations with final Manning's n values that are on the lower end of the range of what would be considered typical values for the tunnel lining and siphon piping materials.

The results indicate that flow depths and velocities in the concrete-lined tunnel segments range from 1.7 ft and 6.3 feet per second (fps) for 100 cfs to 8.0 ft and 10.1 fps for 600 cfs, per Figures 8 and 9 and Table 3 below.

The results of this analysis will be used to support further research on the stability of the tunnel concrete lining under varying flow conditions.

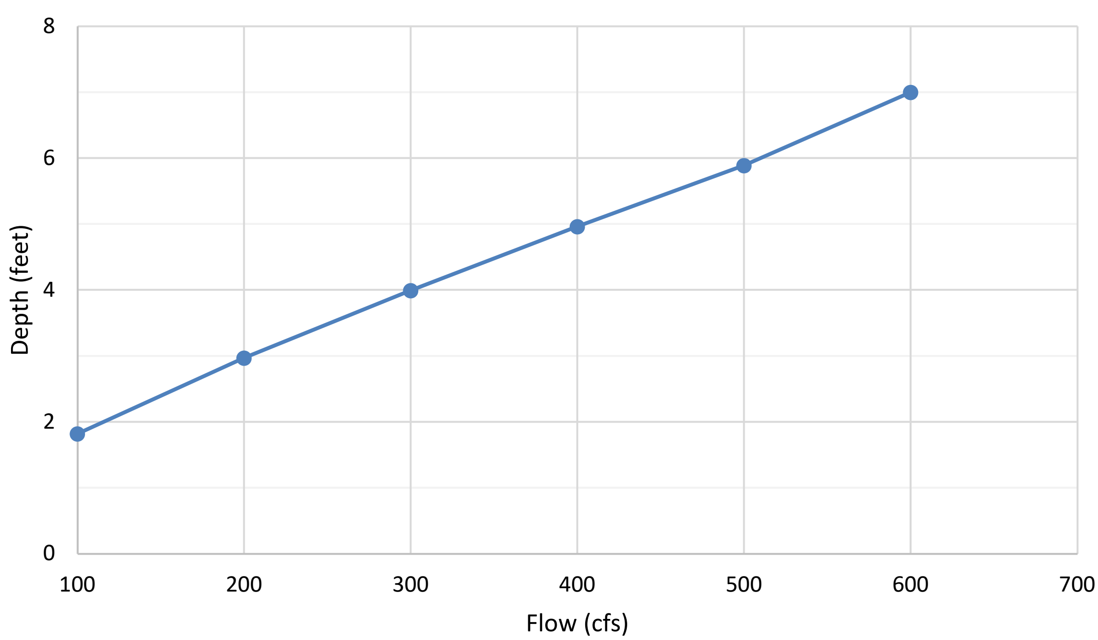

FIGURE 8. Typical Depth to Flow Relationship in Concrete-lined Tunnel Sections.

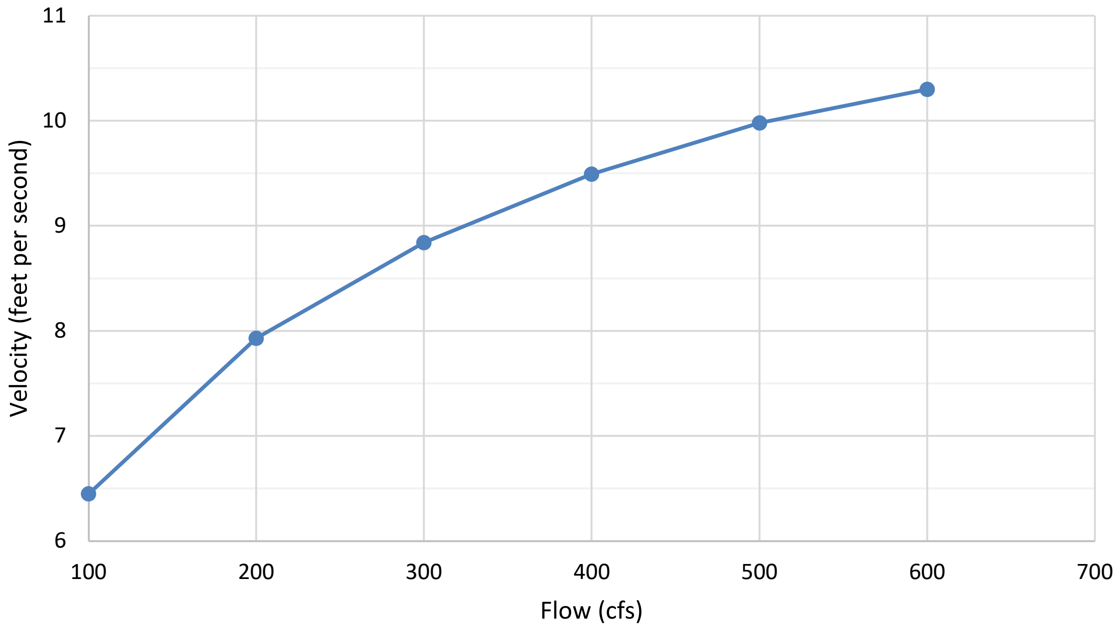

FIGURE 9. Typical Velocity to Flow Relationship in Concrete-lined Tunnel Sections.

Table 3. Typical Depth and Velocity in Concrete-lined Tunnel Sections

Flow (cfs)	STA 313+76.39 (Width = 8.5 ft)	
	Depth (ft)	Velocity (fps)
100	1.8	6.5
200	3.0	7.9
300	4.0	8.8
400	5.0	9.5
500	5.9	10.0
600	7.0	10.3

cfs = cubic feet per second, ft = feet, fps = feet per second

References

SCE (Southern California Edison). 1990. *Exhibit F General Design Drawings Kern River No. 3 Project.* Rosemead, CA.

SCE (Southern California Edison). 1990. *Exhibit G Plan View of Kern River No. 3 Project.* Rosemead, CA.

SCE (Southern California Edison). 2023a. North Fork Kern River time series table (preliminary data). Accessed: June 28, 2023. Retrieved from: https://www.sutronwin.com/scedison/tw/jsp/

SCE (Southern California Edison). 2023b. RE: Exposed Tunnel Photos. Email Received: June 19, 2023.

USACE (United States Army Corps of Engineers). 2022. *HEC-RAS River Analysis System Hydraulic Reference Manual Version 6.3.1*. United States Army Corps of Engineers Hydrologic Engineering Center.

Appendix A

Tunnel/Flume Flow Depth Field Observations

Tunnel at 14 Goldledge .jpg

Tunnel at 17Corral Creek North (002).jpg

Tunnel at 18 Corral Creek Access (002).jpg