Kaweah Project, FERC Project No. 298

AQ 4 – Water Temperature
Final Technical Study Report

December 2019

Southern California Edison Company
Regulatory Support Services
1515 Walnut Grove Avenue, Rosemead, CA 91770

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List of Acronyms

AQ 4 – TSP	AQ 4 – Water Temperature Technical Study Plan
DEM	Digital Elevation Model
DRG	Digital Raster Graphic
FERC	Federal Energy Regulatory Commission
GIS	Geographic Information System
HEC-DSS	Hydrologic Engineering Center Data Storage System
HGR	High-Gradient Riffles
LGR	Low-Gradient Riffles
MAE	Mean Absolute Error
PSP	Proposed Study Plan
RMSE	Root Mean Squared Error
RSP	Revised Study Plan
SCE	Southern California Edison
TSR	Technical Study Report
USGS	United States Geological Survey

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1 INTRODUCTION

This Technical Study Report (TSR) describes the data and findings developed by Southern California Edison (SCE) in association with implementation of the AQ 4 – Water Temperature Technical Study Plan (AQ 4 – TSP) for the Kaweah Project (Project). The AQ 4 – TSP was included in SCE's Revised Study Plan (RSP)[1] (SCE 2017a) and was approved by the Federal Energy Regulatory Commission (FERC) on October 24, 2017, as part of its Study Plan Determination for the Project (FERC 2017). Specifically, this report provides a description of the methods and results of temperature monitoring and modeling for the Kaweah River and East Fork Kaweah River in the project area. These activities were completed in 2018 and 2019.

2 STUDY OBJECTIVES

The AQ 4 – TSP included three study objectives, as follows:

- Characterize the relationship between flow and water temperature in bypass river reaches using an appropriate model supported by existing water temperature data;
- Assess the potential effects of increased air temperature due to global warming on water temperatures over the term of the new Federal Energy Regulatory Commission (FERC) license; and
- Document the availability of cold-water temperature refugia in bypass river reaches.

3 EXTENT OF STUDY AREA

The study area for water temperature modeling includes the Kaweah River and the East Fork Kaweah River bypass river reaches as well as the Kaweah No. 1 and No. 2 flowlines described in Table AQ 4-1 (Map AQ 4-1)

4 STUDY APPROACH

The following sections describe the approaches used to develop the: (1) water temperature model; (2) unimpaired flow scenario; (3) climate change scenarios; and (4) cold water thermal refugia assessment.

4.1 Water Temperature Model

The following describes the general approach and methodology for: (1) model selection; (2) model development; (3) model parameter calibration; and (4) model calibration assessment.

4.1.1 Model Selection

The appropriate water temperature model with dynamic flow routing capability and within-day temperature modeling capability was selected in collaboration with stakeholders. Initial modeling options reviewed were HEC-RAS (Brunner 2010) or RMA-2 and RMA-11 (King 1994; King 1997). The RMA-2 (hydraulics) and RMA-11 (water quality) models were selected for this application.

[1] SCE filed a Proposed Study Plan (PSP) on May 24, 2017 (SCE 2017b). Three comments were filed on the PSP, however, they did not result in revisions to any of the study plans. Therefore, SCE filed a Revised Study Plan (RSP) on September 19, 2017 which stated that the PSP, without revision, constituted its RSP. The FERC subsequently issued a Study Plan Determination on October 24, 2017 approving all study plans for the Kaweah Project.

4.1.2 Model Development

The water temperature model was developed to simulate hourly water temperature from which average, maximum, and minimum daily water temperatures were derived for the summer months when water temperature is of most concern to aquatic species. Modeling development steps completed include the collection/development of model inputs including (1) channel geometry data; (2) topographic solar shading information; (3) meteorological data (air temperature, wind speed, relative humidity, solar radiation); (4) flow data; (5) and water temperature data for the modeled river reaches. These steps are described in the following sections.

4.1.2.1 Geometry

Development of channel slopes and stream geometry used several sources of information including the United States Geological Survey (USGS) Digital Elevation Model (DEM) data and channel habitat surveys. Specific geometry details of the river models are outlined below. Geometric data required for each river reach include:

- stream line work with channel elevation (stream course and gradient);
- channel geometry data by habitat type (e.g., cross-section data);
- channel roughness; and
- channel slope.

Stream Line Work

Geographic Information System (GIS) based line work for the river reaches was digitized from orthophotos[2] with the bed elevation data generated by overlaying the stream line work onto georeferenced, digital raster graphics (DRGs) of U.S. Geological Survey (USGS) 7.5-minute quadrangle maps and digitizing the contour line intersections. Distance and river miles along the river line were calculated using ESRI ArcGIS software.

The stream line work data were then used to develop the initial, one-dimensional numerical grid for the models, which comprised a system of elements.

Habitat Types

Habitat types throughout the Kaweah River and East Fork Kaweah River sub-reaches were categorized as high-gradient riffles (HGR), low-gradient riffles (LGR), runs, and pools. Once the grid was constructed, habitat types were assigned to each element throughout the Kaweah and East Fork Kaweah Rivers consistent with field observations identified in the AQ 1 – TSR (SCE 2019a; SD A).

Channel Cross-Sections

Following the definition of the stream course and gradient, the channel morphology was characterized using cross sections at each model node. Development of cross sections required assigning a habitat type to each element in the model grid. Subsequently, a representative cross section for each habitat type, based on individual sub-reaches, was assigned to the corresponding node (location) for each element in the model grid. The geometry data were derived from the cross-sections and instream flow modelling developed in the AQ 1 – TSR (SCE 2019a; SD A).

[2] The orthophoto product was obtained from Eagle Aerial, Hexagon Imagery Program, 2016. Photos were collected on 7/1/2016.

4.1.2.2 Shading

Daily and seasonal topographic solar shading was generated using Information System (GIS) algorithms and USGS DEM data. This solar shading was then applied to the solar inputs to RMA-11.

4.1.2.3 Meteorological Data

Meteorological data, including air temperature, wet bulb temperature (or dew point temperature), solar radiation, cloud cover, wind speed, and barometric pressure were required for heat budget calculations within the numerical models. Several meteorological stations are located throughout the Project study area. Primary meteorological stations were selected based on their proximity to the project area and the quality of the collected data. Other nearby stations were selected to be used as secondary stations when data gaps needed to be filled. Data from the primary and secondary stations was downloaded and analyzed for quality control. Outliers were removed and small data gaps (of less than a few hours) were filled by linear interpolation. Larger gaps in the primary meteorological station's datasets were filled by using data from secondary stations.

4.1.2.4 Flow Data

Hydrology data were generated from the operating USGS and SCE flow gages during the study period. Daily average flows were used in all of the bypass reaches for the hourly temperature model (i.e., daily average flows were input as hourly flows).

4.1.2.5 Water Temperature Data

Water temperature data for inflows, outflows, and facility operations were required for temperature RMA-11 modeling. Water temperature data were collected as part of the water temperature monitoring program for the river reaches and flowlines.

4.1.3 Model Calibration and Validation

The hydrodynamics and heat budget portions of the water temperature models were calibrated and validated with empirical water temperature and meteorological data. The hydrodynamic model was calibrated using travel time and the diurnal signal in water temperature as a proxy.

4.1.3.1 Model Parameter Calibration

Following model implementation and general model testing, the river model parameters were adjusted (calibrated) using the 2018 empirical flow and water temperature data by adjusting a number of default values assigned to model parameters in the implementation stage.

Flow Calibration Parameters

Initial channel roughness and slope factors were assigned to each element based on habitat type. Roughness values are represented by Manning roughness coefficients and initial values were set to represent mountain streams. Calibration of the RMA-2 river flow models included adjusting the element slope factor and Manning's n values by habitat type so the modeled hydrology matched realistic stream travel times through the river reaches. This was further confirmed by examining the phase of simulated and observed water temperatures.

Water Temperature Calibration Parameters

The RMA-11 water temperature model was calibrated by adjusting parameters for each river reach including wind speed coefficients (King 2003; Deas and Lowney 2000), topographic shading, dead pool area, topographic emissivity and terrestrial long-wave radiation contribution fraction (Bartholow 1989, PCWA 2010), bed temperature, and bed heat exchange coefficient (Hauser and Schohl 2003; Meier et al. 2003).

4.1.4 Model Calibration Assessment

Model calibration results were presented in two ways: graphically and statistically. The hourly time series data at each location were graphically examined for the 2018 calendar year as well as shorter time periods (3-month periods). Statistics were completed for hourly, daily mean, and daily maximum temperatures. Summary statistics were Mean Bias, mean absolute error (MAE), and root-mean squared error (RMSE).

$$\text{Mean Bias, } \varepsilon = \frac{1}{n}\sum_{i=1}^{n}(Xsim_i - Xmeas_i)$$

$$\text{MAE} = \frac{1}{n}\sum_{i=1}^{n}|Xsim_i - Xmeas_i|$$

$$\text{RMSE} = \sqrt{\frac{\sum_{i=1}^{n}(Xsim_i - Xmeas_i)^2}{n}}$$

Mean bias was used to indicate the amount the models, on average, over or underestimated temperature. Equal overestimation and underestimation of temperature in a time series, however, could result in a Mean Bias of zero. MAE and RMSE quantify the absolute error (negative and positive errors do not cancel each other in these estimators as in the Mean Bias). Both MAE and RMSE indicate the magnitude of the average error; however, RMSE is more sensitive to outliers in the data than the MAE because the errors are squared and summed (large errors become larger) prior to taking the square root. The two error estimates can be used together to diagnose the variation in the errors in a set of simulations. The RMSE will always be larger or equal to the MAE. The greater difference between them, the greater the variance in the individual errors in the sample. If RMSE is approximately equal to MAE, then all the errors are of the same magnitude (low variance).

4.2 Existing and Unimpaired Flow Scenarios

Unimpaired 2018 hydrology was calculated from existing 2018 hydrology by summing diversion flow and impaired river flow below the diversions for both the Kaweah River and the East Fork Kaweah River. Unimpaired 2018 hydrology was then run through the calibrated water temperature model along with 2018 meteorology and the results were compared to the results of the impaired hydrology calibration run.

4.3 Climate Change Scenarios

Available predictions of changes in air temperature as a result of global warming were incorporated into two model runs (simulating 2030 and 2070 conditions) to evaluate the resulting impact on water temperature over the anticipated term of the new FERC license period (30-50 years). The following sections describe the development of (1) climate change meteorological data; (2) inflow temperatures; and (3) final scenario set-up.

4.3.1 Meteorological Data

Results from the WSIP (Water Storage Investment Program) climate change model were used to apply a correction to 2018 air temperature and dew point temperature data used for the calibration period to simulate anticipated climate change in 2030 and 2070. Three datasets were downloaded from the California Natural Resources Agency (CNRA 2018): (1) 1995 historical air temperature – detrended, (2) 2030 future conditions and (3) 2070 future conditions. The model grid point that was closest to the Project area was identified by latitude and longitude. The data/climate model results from 1995, 2030, and 2070 for that location were imported into Excel and the monthly average temperature was calculated using monthly minimum and maximum temperatures. The difference in monthly temperatures between the 1995 historical air temperature and the two climate change runs (2030, 2070) was then calculated. Since the calibration dataset used 2018 meteorological data, the relative monthly difference in air temperature between 2018 and the 2030 and 2070 climate change estimates was calculated by linear interpolation.

The original calibration meteorological dataset was adjusted for climate change by adding the difference in monthly average temperature to the hourly temperatures for the 2030 and 2070 climate change scenarios. The difference was interpolated between the mid-point of each month.

In addition to adding a climate change correction to air temperature, the dew point temperature was also recalculated based on the updated air temperature. This was done using a formula that that links air temperature, dew point, and relative humidity[3].

No models are currently available that estimate the impact of climate change on relative humidity, wind speed, wind direction, solar radiation, cloud cover or barometric pressure. These parameters were not changed for either the 2030 or 2070 climate change scenario runs.

4.3.2 Inflow Temperature Development

To represent water temperature for the headwater boundary on the Kaweah and East Fork Kaweah Rivers, an equilibrium temperature (Teq) approach was applied. The approach depends upon hourly meteorological data and daily flow data.

Equilibrium water temperature is the theoretical water temperature when all heat fluxes (e.g., long wave radiation, shortwave radiation, conduction, evaporation, etc.) sum to zero. In effect, this approach allows a water body to emit as much energy as it absorbs, i.e., the water temperature is in equilibrium with meteorological conditions. The important assumption when determining theoretical equilibrium temperature is that the value is independent of initial water temperature, volume of water, and time of exposure.

By incorporating initial water temperature and stream attributes (e.g., the ratio of stream surface area to volume) representative hourly water temperatures can be estimated akin to a natural system where water temperatures vary over a day in response to dynamic meteorological conditions.

4.3.3 Climate Change Water Temperature Scenario

Two climate change meteorological scenarios were assessed (2030 and 2070) and compared at the Kaweah River below Powerhouse 2 and at the East Fork Kaweah above the confluence.

4.4 Cold Water Thermal Refugia Assessment

4.4.1 Tributary Refugia

The East Fork Kaweah River is the only significant summer inflow tributary of the Kaweah River within the project area. No summer inflow tributaries to the East Fork Kaweah River exist in the project area. The monthly average water temperature of the East Fork Kaweah River above the confluence with the Kaweah River was compared with the temperature of the Kaweah River upstream and downstream of the confluence to determine if the East Fork Kaweah River provides cold water refugia for trout.

4.4.2 Deep Pool Refugia

In the Kaweah River and East Fork Kaweah River water temperature data were collected in deep pools to identify the potential availability of water temperature refugia at the bottom of pools for trout. Four deep pools were measured in the Kaweah River. One upstream and three downstream of the East Fork Kaweah River confluence. Two deep pools were measured in the East Fork Kaweah River downstream of the first fish passage barrier. Water temperature loggers were installed to collect surface and bottom temperature at a frequency of 10 minutes for 2 days (August 27–29, 2019) in order to examine potential thermal

3 Dew Point Temperature is calculated using the relationship outlined in Singh (1992) Elementary Hydrology

$$RH = \left[\frac{112 - 0.1T + T_d}{112 + 0.9T}\right]^8$$

stratification. Vertical water temperature profiles were also measured using a YSI temperature probe (model 6920 V2-2) at noon, 2pm, 4pm, and 6pm on one day (either August 27 or 28).

5 STUDY RESULTS

5.1 Water Temperature Model

5.1.1 Model Selection

The models RMA-2 and RMA-11 (King 2013; King 2014) were selected as appropriate river flow and water temperature models with seasonal, daily, and sub-day temperature modeling capability, as necessary for specific study reaches. Both have dynamic simulation capability to capture a wide range of varying conditions (flow, meteorology). A review of available models and their attributes is provided in Appendix A.

RMA-2 is a finite-element, hydrodynamic model capable of modeling highly dynamic flow regimes over short spatial scales and time steps. Output from RMA-2 (including velocity, depth, and representative surface and bed areas) is passed to the water quality model, RMA-11. RMA-11 is a finite-element water quality model that simulates the fate and transport of a wide range of physical, chemical, and biological constituents. For this application RMA-11 is used to simulate water temperature, including the heat exchange at the air-water and bed water interfaces as well as the effect of stream inputs and diversions. These linked river models were applied on hourly or sub-hourly time steps to capture short-term water temperature response (e.g., diurnal range, maximum daily temperature). The RMA models were applied in one-dimension and represented hydrodynamic and temperature variations along the longitudinal axis of the river (i.e., laterally and vertically averaged) (Saviz et al. 1995; UC Davis 1998; PacifiCorp 2005; Jayasundara et al. 2010).

The river models were also capable of incorporating attributes of the Kaweah Project such as steep riverine reaches; the range of natural flow fluctuations, including low summer flows in certain reaches; topographic shading due to the mountainous terrain; as well as other features. While not all attributes were applied in this project, this model flexibility provided a comprehensive analysis of the Kaweah Project and its effect on water temperatures in the river systems.

5.1.2 Model Development

5.1.2.1 Geometry

A summary of the RMA-2 model elements for the Kaweah River and East Fork Kaweah River are provided in Table AQ 4-2. The following sections provide additional details about the development of those model elements.

Stream Line Work

The stream line data were used to develop the initial, one-dimensional numerical grid for the models, which comprised a system of elements. Specifically, the river was divided into 0.02-mile (approximately 32-meter (m)) increments represented by model elements. Each element consisted of three discrete points, termed nodes, an upstream, downstream, and mid-element node spaced at 0.01-miles (approximately 16-m) (Figure AQ 4-1). The model grid extends over all the project study reaches (Table AQ 4-1).

Habitat Types

The proportions of different habitat types in each modeled stream reach are shown in Table AQ 4-3 based on the proportion of each habitat type mapped in each of the sub-reaches, AQ 1 – TSR (SCE 2019a; SD A). A conceptual example is shown in Figure AQ 4-2. The model used linear interpolation to construct the transition between the different habitat types in adjacent elements.

Channel Cross-Sections

Habitat type specific relationships between stage and flow, velocity, and area for each sub-reach were developed via hydraulic modeling in a separate analysis (AQ-1 TSR) (SCE 2019a; SD A). Thus, once elements were assigned habitat types, representative stage versus wetted width and stage versus wetted area relationships were developed for each node on a sub-reach basis for the Kaweah and East Fork Kaweah rivers (Appendix B).

Two additional factors were considered in characterizing cross-sections in the models: low flow channel configurations and dead pool (flow at zero stage). The first factor considered was modeling low flow conditions using fitted relationships (see Appendix B). Streams typically have discrete low flow channels that are not well represented using power functions developed over a large range of flows. In this case, the relationships were developed over a range of flows from 0 cfs to 2000 cfs for the Kaweah River and 0 cfs to 250 cfs for the East Fork Kaweah River. At low flows these relationships can result in artificially wide and shallow flows, leading to simulated temperatures that are unrealistically high. To address this condition, the width at the lowest stages of flow in a cross section (e.g., the lowest 3 ft) was reduced to represent a narrow low flow channel. For larger flows, this modification had no impact on simulated temperatures, but proved important when modeling temperatures during the lowest flows of the year.

The second factor addressed the condition that the wetted width and wetted area versus stage curves were typically greater than zero at the stage of zero flow for some pool habitat types (e.g., no flow in the channel, only standing water). The width/area below the stage of zero flow is considered dead pool volume. Only pools were assumed to have potentially significant dead pool volumes. The amount of dead pool volume affected diurnal variations in temperature and was used as a calibration parameter in selected river reaches (Table AQ 4-4).

5.1.2.2 Shading

While topographic shading was initially deemed useful to represent, after model testing, the topographic shade did not materially impact water temperatures due to limited topographical shading opportunities (a function of aspect and local topography), seasonal hydrology and meteorology, and solar altitude. Coupled with these conditions were the short travel times in winter (rainfall) and spring (snowmelt), when flows were higher than in summer and fall. During summer, when flows abate and travel times are longer, high solar altitude limits impacts of topographic shading on water temperature.

5.1.2.3 Meteorological Data

Meteorological data from four meteorological stations were used, the locations and features of which are described in Table AQ 4-5. Data from nearby meteorological stations were used to “fill in” for the reaches where only a partial data record was available at the primary meteorological station (Table AQ 4-6). The locations of the meteorological stations are shown on Map AQ 4-2. A summary of the meteorological data collected in 2018 is provided in Appendix C.

5.1.2.4 Flow Data

Gage locations used to generate existing and unimpaired hydrology flow data are shown in Map AQ 4-3.

- **Rivers** – A summary of the headwater and downstream boundary conditions, tributary inflows, and accretion inputs for each river reach represented in the model is provided in Table AQ 4-2, along with the associated model nodes and element numbers that correspond with specific locations. In locations where the hydrology combined inflows from two sources into a single node, the flow from each source was determined and the flow from one source was shifted downstream by one element in RMA-2 to clearly identify where all flows originated.

- **Accretion Flows** – No accretions or depletions were included in the model. During winter periods, when seasonal creeks may provide minor inflows, these flows are typically negligible when compared to Kaweah River stream flows. During summer periods many of these tributaries cease to flow or they are negligible compared to Kaweah River stream flows. In general, tributary inflows have minimal impacts on overall longitudinal stream temperature conditions and, as such, were not included in the modeling assessment.

5.1.2.5 Water Temperature Data

A summary of the water temperature monitoring sites on the Kaweah River, East Fork Kaweah River, and diversion flow lines during 2018 is shown in Table AQ 4-7 and Map AQ 4-4. A copy of the water temperature data collected at these sites is provided in Appendix D. Water temperature data from water temperature monitoring stations were used for river boundary conditions located at each headwater location (Table AQ 4-8) as well as where powerhouse returns entered the Kaweah River. Further, water temperatures from within the modeling domain were used to calibrate the model. Water temperature data were also collected for the Kaweah No. 1, 2, and 3 Flowlines and return flow temperatures from powerhouses. These data were used in modeling.

5.1.3 Model Calibration and Validation

Temperature model accuracy was evaluated by comparing modeled and measured hourly temperature time series at multiple locations along the river reach. The monitoring locations where observed data were used to calibrate the model for each reach are shown on Map AQ 4-4.

5.1.3.1 Model Parameter Calibration

During the calibration stage of model development, selected model parameters were adjusted to improve model performance, as measured by comparing simulation results with observed data at multiple locations using the aforementioned calibration assessment statistics (i.e., ε, MAE, RMSE). For the Kaweah River the calibration locations were upstream of East Fork Kaweah River confluence, upstream of Kaweah No. 1 Powerhouse, upstream of Kaweah No. 2 Powerhouse, and downstream of Kaweah No. 2 Powerhouse. The East Fork Kaweah River calibration location was located just upstream of the confluence with the Kaweah River. The models were run in series, with the East Fork Kaweah River results at the mouth forming an inflow to the Kaweah River.

Flow Calibration Parameters

The final calibrated Manning's n and slope flow parameters are presented in Table AQ 4-9. Flows in 2018 in the project area ranged from a minimum of approximately 10 cfs to over 2,500 cfs.

Water Temperature Calibration Parameters

The final calibrated water temperature parameters are presented in Table AQ 4-10.

5.1.4 Model Calibration Assessment

5.1.4.1 Kaweah River

Simulated hourly water temperature for the Kaweah River for the 2018 calendar year had a mean bias that ranged from -0.06ºC to 0.16°C for all four locations, and MAE and RMSE ranged from 0.45°C to 0.78°C and 0.60°C to 1.03°C, respectively. Daily average statistics for mean bias ranged from -0.06°C to 0.16°C for all four locations, and MAE and RMSE ranged from 0.25°C to 0.55°C and 0.33°C to 0.79°C, respectively. MAE and RMSE are notably lower for the daily average statistics. Calibration results for the Kaweah River for the aforementioned locations are shown graphically in Figure AQ 4-3 and summarized in Table AQ 4-11. Review of graphical and statistical performance indicate that the model performs well, representing water temperature response to seasonal short-term, and diurnal variations in meteorological conditions. Further, the model replicates the temperature regime associated with the snowmelt runoff that occurs during the mid-March through May period. Specifically, during these high flow, cold water events the river experiences a suppressed diurnal range in response to the large volumes of cold water passing through the system. After the snowmelt hydrograph abates in mid-June, water temperatures increase notably, as does the diurnal range. All aspects are captured by the model. Modeling very low flows in the fall is a challenge as estimates of the low flow channel and interactions with the bed (e.g., hyporheic flow and bed conduction in large substrate channels) present complex temperature interactions. Nonetheless, the model performs well throughout the year.

5.1.4.2 East Fork Kaweah River

Simulated hourly water temperature for the East Fork Kaweah River for the 2018 calendar year had a mean bias that was less than -1.02°C for the East Fork Kaweah River above the Kaweah River, and MAE and RMSE were 1.32°C and 1.60°C, respectively. Daily average statistics for mean bias was -0.15°C for the East Fork Kaweah River above the Kaweah River, and MAE and RMSE were 0.64°C and 0.82°C, respectively. Mean Bias, MAE, and RMSE are notably lower for the daily average statistics. Calibration results for the East Fork Kaweah River above the Kaweah River are shown graphically in Figure AQ 4-4 and summarized in Table AQ 4-11. Review of graphical and statistical performance indicate that the model performs well, representing water temperature response to seasonal short-term and diurnal variations in meteorological conditions. Further, as with the Kaweah River, the model replicates the temperature regime associated with the snowmelt runoff that occurs during the mid-March through May period. Specifically, during these high flow, cold water events the river experiences a suppressed diurnal range in response to the large volumes of cold water passing through the system. After the snowmelt hydrograph abates in mid-June, water temperatures increase notably, as does the diurnal range. All aspects are captured by the model. Modeling very low flows in the fall is a challenge as estimates of the low flow channel and interactions with the bed (e.g., hyporheic flow and bed conduction in large substrate channels) present complex temperature interactions. The model systematically slightly under predicted during the snowmelt period – both daily maximum and minimum – and also slightly under predicted maximum daily temperatures in the summer, leading to a higher mean bias than the Kaweah River. Daily average statistics were similar to the Kaweah River. Overall, the model performs well throughout the year.

5.1.4.3 Model Sensitivity Analysis

During the calibration process, the models were also assessed for sensitivity. Overall, only a few model parameters were sensitive. For rivers (RMA-2), flow hydrodynamics were sensitive to channel roughness and slope. Increasing channel roughness decreased stream velocity, increased depth, and increased travel time. Increasing the slope factor (reducing the local gradient of the river), similarly decreased stream velocity, increased depth, and increased travel time. Ultimately a balance of roughness and slope factor were used. No single parameter of the temperature models (RMA-11) was highly sensitive;

simulated temperatures were moderately sensitive to several parameters (evaporation coefficients, shade, bed temperature, bed heat exchange coefficient). In summary:

- Increasing evaporation coefficients increases net heat loss from the system, typically shifting the simulated trace downward.
- Shade reduces incoming solar radiation during daylight hours and is most effective when the sun is at a high solar altitude (e.g., during mid-day hours). While topographic shade may have a notable impact in spring, flows associated with snowmelt runoff are high at this time and the impact of shade is moderated. In mid-summer, the solar altitude is high and topographic shade has minimal effect. Finally, late in the summer and into fall, when annual flows are at the minimum, the stream can experience local, small-scale shading as the flow drops into a low flow channel that can be shaded by boulders and stream banks. Riparian shade was not included in the modeling assessment, but modest local shade was included.
- Bed temperature can be a factor in low flow conditions with large substrate. Bed conduction (and heat exchange) was moderately sensitive, which is logical given the bedrock nature of the stream systems.

Several other parameters were not modified in calibration, but relied on previous application of similar models to steep mountain streams (PCWA 2010). A summary of model parameters and their sensitivity is provided in Table AQ 4-12. Appendix E includes additional summary statistics tables and time series plots for 3-month periods during 2018 to provide more detail.

5.2 Existing and Unimpaired Flow Scenarios

Existing and unimpaired 2018 hydrology was calculated using gages summarized in Table AQ 4-13.

5.2.1 Kaweah River

Using the calibrated model, a comparative analysis was completed using the baseline (existing flow conditions for 2018) and an unimpaired (no diversion) flow regime also based on 2018 hydrology. Graphical and statistical summaries for the Kaweah River are presented in Figure AQ 4-5 and Table AQ 4-14, respectively. Apparent in these results are that the unimpaired flows differ predominantly in the winter and spring months. In 2018, most hydropower diversions were terminated after the spring snowmelt flows abated. Temperature differences during winter and early spring were modest. During summer and fall, when diversions for hydropower were offline, water temperatures were the same for both historical and unimpaired conditions. The difference in monthly average temperature ranged from -0.6°C (June) to 0°C (several months), with the unimpaired flow regime resulting in monthly average water temperatures slightly lower or equal to the baseline case (Figure AQ 4-6). Appendix F includes additional summary statistics tables and figures, including longitudinal profiles comparing conditions for the 15th of March, June, September, and December, and time series plots for 3-month periods during 2018 to provide more detail.

5.2.2 East Fork Kaweah River

Graphical and statistical summaries for the East Fork Kaweah River are presented in Figure AQ 4-7 and Table AQ 4-14, respectively. Similar to the Kaweah River, unimpaired flows differ predominantly in the winter and spring months. In 2018, most hydropower diversions were terminated after the spring snowmelt flows abated. Temperature differences during winter were modest. Snowmelt runoff on the East Fork Kaweah River was sufficient to offset the slight increases in flow under the unimpaired flow – decreases in water temperature under the unimpaired case were small, 0.1ºC or less. During summer and fall, when diversions for hydropower were offline, water temperatures were the same for both historical and unimpaired conditions. Monthly average water temperatures in the East Fork of the Kaweah at the Confluence ranged from 6.0°C to 23.3°C under baseline (historic) flow regime (Table AQ 4-15). The difference in monthly temperature ranged from -0.2°C (February/March) to 0.0°C (several months), with the unimpaired flow regime resulting in monthly average water temperatures slightly lower or equal to the baseline case (Figure AQ 4-8). Appendix F includes additional summary statistics tables and figures, including longitudinal profiles comparing conditions for the 15th of March, June, September, and December, and time series plots for 3-month periods during 2018 to provide more detail.

5.3 Climate Change Scenarios

5.3.1 Meteorological Data

The difference in estimated monthly average air temperatures between 2018 and the two climate change scenarios 2030 and 2070 is shown in Table AQ 4-16. The final adjusted air temperature and dew point temperature is provided in Appendix C.

5.3.2 Inflow Temperature Development

Inflow temperature was developed using an equilibrium water temperature model. For equilibrium water temperature model runs, depth was used as a proxy for the stream surface area to volume ratio. Depth was approximated using discharge-stage equations for representative high gradient reaches in the headwaters of the Kaweah River (stage (ft) = $0.734(\text{flow (cfs)})^{0.292}$) and East Fork Kaweah River (stage (ft) = $0.937(\text{flow (cfs)})^{0.251}$). Because depth is a proxy for the stream surface area to volume ratio, a factor is applied to calibrate the water temperature to reproduce the approximate diurnal range (1.2 for the Kaweah River and 1.7 for the East Fork Kaweah River). Comparisons of calculated equilibrium temperature and observed water temperature at the headwater of the Kaweah and East Fork Kaweah Rivers are shown in Figure AQ 4-9 top left and top right, respectively, for 2018 flow conditions.

During the spring snowmelt runoff period for both streams the equilibrium temperature is markedly higher than observed river temperatures. High flows, short travel times, and larger thermal masses associated with snowmelt result in water temperatures for these headwater locations that are well below equilibrium. That is, high elevation cold waters travel quickly downstream and have not attained equilibrium with the atmosphere during this time of year. After snowmelt abates in late June, low, relatively shallow flows with longer transit times allow streams to attain equilibrium.

Climate change meteorology was subsequently applied to the equilibrium temperature calculation to reflect warmer conditions for a 2030 and 2070 condition. The snowmelt period inflow water temperature remained unchanged from historic conditions, however, the calculated equilibrium temperature was used for the remainder of the year to reflect warmer conditions. The snowmelt period was assumed unchanged because even under warmer conditions snowmelt waters would still consist of high elevation cold waters that would arrive prior to equilibrium temperature being attained. No adjustment was made for the possibility that the hydrograph magnitude or duration could change under climate change conditions. The calculated water headwater temperatures for the Kaweah River and East Fork Kaweah River for 2030 and 2070 climate change are shown in Figure AQ 4-9, bottom left and bottom right, respectively. These headwater inflow temperatures were applied to the climate change simulations for the Kaweah and East Fork Kaweah Rivers.

5.3.3 Climate Change Water Temperature Scenario

The following sections describe the water temperature results for the 2030 and 2070 climate change scenarios compared to the baseline 2018 calibration run for the Kaweah River and the East Fork Kaweah River.

5.3.3.1 Kaweah River

Monthly average water temperatures in the Kaweah River below Kaweah No. 2 Powerhouse both increased and decreased under both 2030 and 2070 climate change regimes compared to the baseline (historic) flow regime. Under the baseline (historic) flow regime, the monthly average water temperature ranged from 7.8°C to 24.2°C. Under the 2030 climate change regime, the changes in the monthly average water temperatures ranged from -0.3°C to 1.0°C. Under the 2070 climate change regime, the changes in monthly average water temperature ranged from 0.0°C to 1.7°C. The maximum monthly temperature ranged from 8.7°C to 26.4°C under baseline (historic) flow regime and changes ranged from -0.3°C to 1.0°C and 0.1°C to 1.7°C under the 2030 and 2070 climate change regimes, respectively. The minor decrease in the 2030 climate change scenario for both monthly average and monthly maximum temperature change is due to the assumptions in estimating the upstream boundary condition temperature (see section 5.2) and assumed future meteorology. Results for the Kaweah River for the 2030 and 2070 climate change regime are shown in Figure AQ 4-10 and Figure AQ 4-11. Statistical comparisons between the 2018 baseline run and the 2030 and 2070 climate change runs are provided in Table AQ 4-17 and Table AQ 4-18, respectively. Tabulated results are included in Table AQ 4-19 and Table AQ 4-20.

Appendix G includes additional summary statistics tables and figures, including longitudinal profiles comparing conditions for the 15th of March, June, September, and December, and time series plots for 3-month periods to provide more detail for the 2030 and 2070 climate change assessments.

5.3.3.2 East Fork Kaweah River

Monthly average water temperatures in the East Fork of the Kaweah River at the confluence generally increased under climate change regimes compared to the baseline (historic) flow regime. Under baseline (historic) flow regime, the monthly average water temperature ranged from 6.0°C to 23.3°C. Under the 2030 climate change regime, the monthly average water temperatures increased between 0.0°C to 1.1°C. Under the 2070 climate change regime, the monthly average water temperature increased between 0.1°C to 1.7°C. The maximum monthly temperature ranged from 8.5°C to 26.2°C under baseline (historic) flow regime and increased between 0.0°C to 1.8°C and 0.1°C to 2.6°C under the 2030 and 2070 climate change regimes, respectively. Results for the East Fork Kaweah River are shown in Figure AQ 4-12 and Figure AQ 4-13. Statistical comparisons between the 2018 baseline run and the 2030 and 2070 climate change runs are provided in Table AQ 4-17 and Table AQ 4-18, respectively. Tabulated results are included in Table AQ 4-19 and Table AQ 4-20.

Appendix G includes additional summary statistics tables and figures, including longitudinal profiles comparing conditions for the 15th of March, June, September, and December, and time series plots for 3-month periods to provide more detail for the 2030 and 2070 climate change assessments.

5.4 Cold Water Thermal Refugia Assessment

5.4.1 Tributary Refugia

Comparison of water temperatures in the East Fork Kaweah River above the Confluence with the Kaweah River with temperatures in the Kaweah River upstream of the Confluence showed that the East Fork Kaweah River does provide limited cold water refugia during some months of the year. The East Fork is colder than the main stem Kaweah River in the months of August through November by an average of between 0.49°C and 1.59 °C (Table AQ 4-21). In other months of the year, the East Fork Kaweah River is either the same temperature or slightly warmer than the main stem Kaweah River (Figure AQ 4-14).

5.4.2 Deep Pool Refugia

Comparison of bottom versus surface water temperatures using temperature loggers at four pools in the Kaweah River (Figure AQ 4-15) and two pools in the East Fork Kaweah River (Figure AQ 4-16) did not detect any water temperature stratification over a two day period (August 27 – August 29) (see Map AQ 4-5). Vertical temperature profiles taken at noon, 2pm, 4pm, and 6pm on one day, either August 27 or August 28, also detected no temperature stratification in the Kaweah River (Figure AQ 4-17) and the East Fork Kaweah River (Figure AQ 4-18). Very few deep slow velocity pools exist in the Project study area and the flow magnitude and turbulence in the rivers likely does not allow for any significant temperature stratification to occur in either the Kaweah River or East Fork Kaweah River.

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TABLES

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Table AQ 4-1. Summary of Model Bypass Reaches Modeled in AQ-4 TSR

Study Reach	Site ID	Bypass Reaches	Comparison Reaches (upstream or downstream of the Project)
Kaweah River Upstream of Kaweah No. 3 Powerhouse	KR US PH3		X
Kaweah River Downstream of Kaweah No. 3 Powerhouse and Upstream of the East Fork Kaweah River Confluence	KR DS PH3	X	
Kaweah River Downstream of East Fork Kaweah Confluence and Upstream of Kaweah No. 1 Powerhouse	KR US PH1	X	
Kaweah River Downstream of Kaweah No. 1 Powerhouse and Upstream of Kaweah No. 2 Powerhouse	KR US PH2	X	
Kaweah River Downstream of Kaweah No. 2 Powerhouse	KR DS PH2		X
East Fork Kaweah River Upstream of the Kaweah No. 1 Diversion	EF US K1 Div		X
East Fork Kaweah River Downstream of the Kaweah No. 1 Diversion	EF DS K1 Div	X	
East Fork Kaweah River Upstream of Confluence with Kaweah River	EF US Confl	X	

Table AQ 4-2. RMA-2 Model Summary of River Reaches.

Reach Elements	River Reaches							
	Kaweah River					East Fork Kaweah River		
	KR US PH3	KR DS PH3	KR US PH1	KR US PH2	KR DS PH2	EF US K1 Div	EF DS K1 Div	EF US Confl
Length (km)	---	0.93	3.06	2.59	2.72	---	6.87	0.76
Number of Nodes	---	60	189	160	170	---	424	49
Number of Elements	---	30	95	80	85	---	214	25
Maximum Elevation (m)	---	417.6	386.8	328.3	283.6	---	788.8	422.1
Minimum Elevation (m)	---	386.8	328.3	283.6	244.9	---	422.1	387.1
Boundary Condition Model Elements (Nodes)								
Headwater Boundary Condition	1	---	---	---	---	---	1	---
Tributaries[1]	---	---	30 (60)	---	---	---	---	---
Accretion Inputs[2]	---	---	---	124 (249)	205 (409)	---	---	---
Downstream Boundary Condition[3]	---	---	---	---	289 (579)	---		236 (473)

[1] East Fork Kaweah River

[2] PH #1 return (124) and PH #2 return (205)

[3] Stage boundary condition

Table AQ 4-3. Proportion of Habitat for Modeled Bypass Reaches

Study Reach	Instream Flow Modeling							Temperature Modeling		
	HGR	LGR	Run	Pool	Cascade	RM Start	RM End	RM Start	RM End	Comment
Kaweah River										
Kaweah River Upstream of Kaweah No. 3 Powerhouse (US PH3)	30.0%	2.0%	4.0%	64.0%	0.0%	8.97	9.94	8.95	9.95	Reach ends one mile above start.
Kaweah River Downstream of Kaweah No. 3 Powerhouse and Upstream of the East Fork Kaweah River Confluence (DS PH3)	19.6%	5.1%	27.0%	40.7%	7.7%	8.35	8.93	8.37	8.95	
Kaweah River Downstream of East Fork Kaweah Confluence and Upstream of Kaweah No. 1 Powerhouse (US PH1)	13.3%	46.2%	14.8%	23.0%	2.7%	6.47	8.35	6.47	8.37	
Kaweah River Downstream of Kaweah No. 1 Powerhouse and Upstream of Kaweah No. 2 Powerhouse (US PH2)	38.1%	32.1%	3.6%	25.6%	0.6%	4.86	6.47	4.86	6.47	
Kaweah River Downstream of Kaweah No. 2 Powerhouse (DS PH2)	17.0%	24.8%	28.8%	27.6%	1.8%	3.17	4.86	3.17	4.86	Reach starts at conf. with NF Kaweah River
East Fork Kaweah River										
East Fork Kaweah River Upstream of the Kaweah No. 1 Diversion (EF Ref)	33.0%	7.0%	0.0%	54.0%	6.0%	4.74	5.71	4.74	5.74	Reach ends one mile above start.
East Fork Kaweah River Downstream of the Kaweah No. 1 Diversion (EF DS K1)	39.2%	0.0%	15.6%	30.9%	14.3%	0.47	4.72	0.47	4.74	
East Fork Kaweah River Upstream of Confluence with Kaweah River (EF US Confl)	8.6%	22.6%	6.3%	47.5%	15.1%	0.00	0.47	0.00	0.47	

Table AQ 4-4. Average Pool Volumes at Dead Pool

Pool #	Xsect	XS Area at szf (ft^2)	Average Area (ft^2)	Pool Length (ft)*	Est. Pool Volume ft^3
Kaweah River Upstream of Confluence with the East Fork Kaweah River					
1	T5	20.1	98.5	168.0	16540.8
	T6	176.8			
2	T10	92.6	64.1	150.0	9613.3
	T11	35.6			
3	T12	32.1	58.0	75.0	4351.0
	T13	83.9			
4	T16	53.0	69.0	130.0	8966.3
	T17	85.0			
Kaweah River Upstream of Powerhouse 1					
1	T1	34.8	201.2	225.0	45275.4
	T2	367.6			
Kaweah River Upstream of Powerhouse 2					
1	T2	25.6	201.8	310	62551.3
	T3	366.7			
	T4	213.1			
East Fork Kaweah River Upstream of the Confluence with the Kaweah River					
1	T1	6.3	32.4	85	2756.0
	T2	53.4			
	T3	37.6			
2	T16	66.4	60.0	165	9904.7
	T17	64.0			
	T18	57.1			
	T19	52.5			

Table AQ 4-5. Summary of Meteorological Stations in Vicinity of Project Area

Station Name	Station Code	Latitude	Longitude	Elevation (ft)	Parameters	Period of Record	Operator	Source
Powerhouse No. 1 Met Station (CARDNO)	NA	36.46513	-118.86147	1145	Air Temperature, Dew Point Temperature, Relative Humidity, Wind Speed, Wind Direction, Precipitation	2/2/2018 to 12/12/2018	Cardno	Cardno
East Fork Met Station (CARDNO)*	NA	36.44942	-118.79134	2562	Air Temperature, Dew Point Temperature, Relative Humidity, Wind Speed, Wind Direction, Precipitation	2/2/2018 to 6/20/2018	Cardno	Cardno
		36.44956	-118.78889	2805		7/5/2018 to 12/12/2018		
Lindcove	CIMIS #86	36.3605	-119.05935	480	Air Temperature, Dew Point Temperature, Relative Humidity, Wind Speed, Wind Direction, Precipitation	11/12/2002 to present	University of California citrus research facility	CIMIS
Case Mountain*	CDEC CMA	36.411	-118.809	6450	Air Temperature, Relative Humidity, Solar Radiation, Wind Speed, Wind Direction, Precipitation	8/01/2002 to present	US Bureau of Land Management	CDEC
Three Rivers Museum	DW0117	36.44829	-118.90016	860	Air Temperature, Dew Point Temperature, Relative Humidity, Wind Speed, Wind Direction, Precipitation	01/01/2009 to present	NOAA	Mesowest
Three Rivers	CW4177	36.4775	-118.8445	1240	Air Temperature, Dew Point Temperature, Relative Humidity, Wind Speed, Wind Direction, Precipitation	8/3/2005 to present	Private	Mesowest

* Station used for purposes of comparison only

Table AQ 4-6. Meteorological Stations and Associated Information Used for Each Model Reach.

Meteorological Elements	Data Source	
	Primary Meteorological Station	Backup Meteorological Station
Solar radiation	PH No. 1	CIMIS 86
Air temperature	PH No. 1	D0117
Relative Humidity/Dew Point	C4177	D0117
Wind speed	PH No. 1	D0117
Wind direction	PH No. 1	D0117
Atmospheric pressure[2]	PH No. 1	D0117

Table AQ 4-7. Data Used for Water Temperature Analyses on the Kaweah and the East Fork Kaweah Rivers.

Monitoring Sites	Site ID	Number of Monitoring Loggers	Sampling Location		Bypass Reaches	Comparison Reaches (upstream or downstream of the Project)
			River Mile	GPS Location		
Water Temperature Monitoring Sites						
Kaweah River						
Kaweah River Upstream of Kaweah No. 3 Powerhouse	KR US PH3	2	8.96	36.48635136, -118.8361886		X
Kaweah River Downstream of Kaweah No. 3 Powerhouse	KR DS PH3	2	8.79 8.82	36.48439526, -118.8357774 36.48405746, -118.8359942	X	
Kaweah No. 3 Powerhouse Tailrace	No. 3 Flowline	2	8.95	36.48620181, -118.8357265	X	
Kaweah River Upstream of the Confluence with East Fork Kaweah River	KR US Conf EF	2	8.44	36.47956494, -118.8380172	X	
Kaweah River Downstream of the Confluence with East Fork Kaweah River	KR DS Conf EF	2	8.3	36.4794382, -118.8402536	X	
Kaweah River Upstream of Kaweah No. 1 Powerhouse	KR US PH1	2	6.51 6.52	36.46579943, -118.862146 36.46593544, -118.8620571	X	
Kaweah River Downstream of Kaweah No. 1 Powerhouse	KR DS PH1	2	6.45	36.46562639, -118.863133	X	
Kaweah No. 1 Powerhouse Tailrace	No. 1 Flowline	2	6.49	36.4653658, -118.8620713	X	
Kaweah River Upstream of Kaweah No. 2 Powerhouse	KR US PH2	2	5.04	36.46071055, -118.8796395	X	
Kaweah River Downstream of Kaweah No. 2 Powerhouse	KR DS PH2	3	4.81	36.4613941, -118.8834057		X
Kaweah No. 2 Powerhouse Tailrace	No. 2 Flowline	2	4.95	36.46186337, -118.8806466	X	
East Fork Kaweah River						
East Fork Kaweah River Downstream of the Kaweah No. 1 Diversion Dam	EF DS K1 Div	2	4.68	36.45138042, -118.7899557	X	
East Fork Kaweah River Upstream of the Confluence with Kaweah River	EF US Confl KR	2	0.09	36.47896325, -118.8374857	X	

Monitoring Sites	Site ID	Number of Monitoring Loggers	Sampling Location		Bypass Reaches	Comparison Reaches (upstream or downstream of the Project)
			River Mile	GPS Location		
Air Temperature Monitoring Sites						
Kaweah No. 3 Powerhouse Air Temp		2	8.93	36.48592359, -118.8364717		
Kaweah No. 1 Diversion Dam Air Temp		2	4.48	36.44906467, -118.7916033		
Weather Station Monitoring Sites						
Kaweah No. 1 Powerhouse Weather Station		1	6.49	36.465126, -118.861466		

Table AQ 4-8. Water Temperature Sources for Kaweah Project RMA-11 River Reach Modeling.

Inflows	Application	Data Type	Monitoring Location/ Data Used
Kaweah River Reach 1 (KR DS PH3)			
Kaweah River Temperature	boundary condition	measured time series	KR US PH3
Kaweah River Reach 2 (KR US PH1)			
Kaweah River Temperature	boundary condition	simulated time series	Outflow from Kaweah Reach 1
East Fork Kaweah Temperature	tributary inflow	simulated time series	Outflow from East Fork Reach 2
Kaweah River Reach 3 (KR US PH2)			
Kaweah River Temperature	boundary condition	simulated time series	Outflow from Kaweah Reach 2
East Fork conduit	tributary inflow	measured time series	K1 Flowline Below PH1 Div.
Kaweah River Reach 4 (KR DS PH2)			
Kaweah River Temperature	boundary condition	simulated time series	Outflow from Kaweah Reach 3
PH2 conduit	tributary inflow	measured time series	K2 Flowline Above PH2
East Fork Kaweah River Reach 1 (EF DS K1 Div)			
East Fork Kaweah Temperature	boundary condition	measured time series	EF US of PH1 Div EF DS of PH1 Div
East Fork Kaweah River Reach 2 (EF US Confl)			
East Fork Kaweah Temperature	boundary condition	simulated time series	Outflow from East Fork Reach 1

[1] Interpolated water temperature data between the dates given were used.

Table AQ 4-9. Calibrated RMA-2 Model Roughness and Slope Factors for Each River Reach by Habitat Type.

RMA-2 Model Factors	Habitat Type[1]	Kaweah River					East Fork Kaweah River		
		KR US PH3	KR DS PH3	KR US PH1	KR US PH2	KR DS PH2	EF US K1 Div	EF DS K1 Div	EF US Confl
Roughness Factor (Manning's *n*)	POOL	0.070	0.070	0.070	0.070	0.070	0.070	0.070	0.070
	RUN	0.070	0.070	0.070	0.070	0.070	0.070	0.070	0.070
	HGR	0.070	0.070	0.070	0.070	0.070	0.070	0.070	0.070
	LGR	0.070	0.070	0.070	0.070	0.070	0.070	0.070	0.070
Slope Factor	POOL	0.95	0.95	0.95	0.95	0.95	0.85	0.85	0.85
	RUN	0.90	0.90	0.90	0.90	0.90	0.80	0.80	0.80
	HGR	0.85	0.85	0.85	0.85	0.85	0.80	0.80	0.80
	LGR	0.85	0.85	0.85	0.85	0.85	0.80	0.80	0.80

[1] HGR = high gradient riffle, LGR = low gradient riffle

Table AQ 4-10. RMA-11 Water Temperature Model Parameter Values for River Reaches.

Calibrated Parameter	Kaweah River					East Fork Kaweah River		
	KR US PH3	KR DS PH3	KR US PH1	KR US PH2	KR DS PH2	EF US K1 Div	EF DS K1 Div	EF US Confl
a (coefficient in evaporation equation)	0.0000122	0.0000122	0.0000122	0.0000122	0.0000122	0.0000122	0.0000122	0.0000122
b (coefficient in evaporation equation)	0.0000115	0.0000115	0.0000115	0.0000115	0.0000115	0.0000115	0.0000115	0.0000115
Topographic shading	None	None	None	None	None	Yes	Yes	Yes
Local shading modified*	0.80-0.72	0.80-0.72	0.80-0.72	0.80-0.72	0.80-0.72	None	None	None
Dead pool area (POOL)[1], m2	20	20	20	20	20	None	None	None
Topographic emissivity	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98
Terrestrial long wave radiation contribution fraction	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Bed temperature °C	9.0-23.0	9.0-23.0	9.0-23.0	9.0-23.0	9.0-23.0	6.0-25.0	6.0-25.0	6.0-25.0
Bed heat exchange coefficient W m^{-2} $^{0}C^{-1}$	-80.00	-80.00	-80.00	-80.00	-80.00	-80.00	-80.00	-80.00

[1] Dead pool area was modified during calibration.

* Transmittance = 0.80-0.72

Table AQ 4-11. Calibration Statistics for the 2018 Simulations in the Kaweah and East Fork Kaweah Rivers.

Location	Hourly			Daily Average		
	Mean Bias	MAE	RMSE[1]	Mean Bias	MAE	RMSE
Kaweah River						
US of East Fork	-0.06	0.45	0.60	-0.06	0.25	0.33
US of PH#1	0.16	0.50	0.67	0.16	0.39	0.51
US of PH#2	-0.01	0.72	0.91	-0.01	0.53	0.69
DS of PH#2	0.14	0.78	1.03	0.14	0.55	0.79
East Fork Kaweah River						
US of Confluence	-1.02	1.32	1.60	-0.15	0.64	0.82

MAE = Mean absolute error

Mean Bias = average of simulated minus observed

RMSE = Root mean square error

Table AQ 4-12. Sensitivity of River Model Parameters.

Parameters	Calibration Parameter	Sensitivity	Notes
Flow	Manning n	High	Affects travel time, can affect phase of diurnal cycle/variation of water temperature.
	Slope Factor	High	Affects travel time, can affect phase of diurnal cycle/variation of water temperature.
Temperature	a & b coefficients in evaporation equation	Medium	Affects evaporative cooling. In this application, these coefficients had a modest impact on temperature.
	Topographic Shade	Low	Reduces solar radiation, a principal component of the heat budget. The topographic relief was not globally sufficient for this parameter to have a large effect.
	Local Shade	Medium	Reduces solar radiation, a principal component of the heat budget. Local shade was not significant and had a minimal effect on water temperature.
	Dead Pool Area (m^2)	Low	Affects diurnal variation of water temperature.
	Terrestrial Long Wave (%)	Low	Contributes slightly to heat budget.
	Terrestrial Emissivity	Low	Contributes slightly to heat budget.
	Bed Temperature (°C)	Medium	A moderately sensitive parameter that affects both mean temperature and diurnal range. Seasonal values used in several reaches.
	Bed Heat Exchange Coefficient ($W/m^2/°C$)	Medium	A moderately sensitive parameter that affects both mean temperature and diurnal range. Seasonal values used in several reaches.

Table AQ 4-13. Flow Gages used to Calculate Unimpaired Flow

Gage Name	SCE Gage Number	USGS Station Number	Lat, Long
Kaweah River Gages (Sum of Gages = Unimpaired Flow)			
Kaweah River below Conduit No. 2 near Hammond, CA	203	USGS 1128600	36°29'04", 118°50'06"
Kaweah River Conduit No. 2 near Hammond, CA	204a	-	36°29'10", 118°50'09"
East Fork Kaweah River Gages (Sum of Gages = Unimpaired Flow)			
East Fork Kaweah River near Three Rivers, CA	201a		36°27'05", 118°47'15"
East Fork Kaweah River Conduit No. 1 near Three Rivers, CA	202		36°27'05", 118°47'19"

Table AQ 4-14. Summary Statistics Comparison of 2018 Baseline (Existing) and Unimpaired Simulations in the Kaweah River and East Fork Kaweah River.

Location	Hourly			Daily Average		
	Mean Bias[1]	MAE	RMSE	Mean Bias	MAE	RMSE
Kaweah River						
US East Fork Conf	0.05	0.05	0.09	0.05	0.05	0.08
US No. 1 PH	0.15	0.16	0.26	0.15	0.15	0.24
US No. 2 PH	0.15	0.16	0.23	0.15	0.15	0.21
US North Fork	0.13	0.3	0.44	0.13	0.28	0.41
East Fork Kaweah River						
US Confluence	0.07	0.09	0.17	0.07	0.08	0.15

MAE = Mean absolute error

Mean Bias = average of baseline (historic) minus unimpaired

RMSE = Root mean square error

Table AQ 4-15. Monthly Average Water Temperature for the Baseline (Existing) and Unimpaired Flows in the Kaweah River Below Powerhouse 2 and East Fork of the Kaweah River at the Confluence.

Scenario	Monthly Average Water Temperature (°C)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Kaweah												
Baseline	8.6	8.9	9.1	10.2	14.1	19	24.1	24.2	22	15.6	10.9	7.8
Unimpaired	8.3	8.9	8.9	10.1	13.9	18.4	23.7	24.2	22	15.6	10.9	8.3
Difference	-0.2	0	-0.2	-0.1	-0.3	-0.6	-0.4	0	0	0	0	0.5
East Fork												
Baseline	6.4	6	8	9.3	12	17.1	23.3	22.5	19.6	13.5	9.1	7
Unimpaired	6.3	5.8	7.8	9.3	11.9	16.9	23.3	22.5	19.5	13.5	9	7
Difference	-0.1	-0.2	-0.2	-0.1	0	-0.1	0	0	0	0	0	0

Table AQ 4-16. Monthly Average Adjustment to 2018 Air Temperatures for 2030 and 2070 Climate Change Scenarios

Month	Average Monthly Air Temperature Adjustment to 2018 Data (°C)	
	2030 Climate Change Scenario	2070 Climate Change Scenario
January	0.40	1.74
February	0.37	1.62
March	0.37	1.59
April	0.36	1.85
May	0.48	2.07
June	0.56	2.57
July	0.63	2.77
August	0.72	2.95
September	0.61	2.69
October	0.49	2.50
November	0.33	2.04
December	0.36	1.93

Table AQ 4-17. Summary Statistics for the 2018 Baseline (Historic) and Climate Change 2030 Simulations in the Kaweah and East Fork Kaweah Rivers.

Location	Hourly			Daily Average		
	Mean Bias	MAE	RMSE	Mean Bias	MAE	RMSE
Kaweah River						
US East Fork Conf	-0.37	0.88	1.32	-0.37	0.86	1.29
US No. 1 PH	-0.27	0.48	0.78	-0.27	0.46	0.76
US No. 2 PH	-0.24	0.37	0.64	-0.24	0.35	0.62
US North Fork	-0.22	0.33	0.57	-0.22	0.32	0.57
East Fork Kaweah River						
US Confluence	-0.37	0.39	0.67	-0.37	0.38	0.66

MAE = Mean absolute error

Mean Bias = average of baseline (historic) minus climate change 2030

RMSE = Root mean square error

Table AQ 4-18. Summary Statistics for the 2018 Baseline (Historic) and Climate Change 2070 Simulations in the Kaweah and East Fork Kaweah Rivers.

Location	Hourly			Daily Average		
	Mean Bias	MAE	RMSE	Mean Bias	MAE	RMSE
Kaweah River						
US East Fork	-1.22	1.28	1.88	-1.22	1.27	1.86
US No. 1 PH	-0.84	0.86	1.23	-0.84	0.85	1.22
US No. 2 PH	-0.75	0.76	1.07	-0.75	0.76	1.06
US North Fork	-0.76	0.76	1.02	-0.76	0.76	1.01
East Fork Kaweah River						
US Confluence	-0.84	0.84	1.12	-0.84	0.84	1.11

MAE = Mean absolute error

Mean Bias = average of baseline (historic) minus climate change 2070

RMSE = Root mean square error

Table AQ 4-19. Monthly Statistics for the 2018 Baseline (Historic) and Climate Change 2030 Simulations in the Kaweah and East Fork Kaweah Rivers.

Scenario	Monthly Average Water Temperature (°C)											
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Baseline (Historic)	8.6	8.9	9.1	10.2	14.1	19	24.1	24.2	22	15.6	10.9	7.8
Climate Change 2030	9.6	9	9	10.2	14.2	19.9	24.4	24.2	22	15.7	10.6	8.3
Climate Change 2070	10.3	9.3	9.1	10.3	14.3	20.5	25.3	24.9	22.5	16.3	11.3	9.1
Difference (2030-baseline)	*1.0*	*0.1*	*-0.1*	*0.0*	*0.1*	*0.9*	*0.3*	*0.0*	*0.0*	*0.1*	*-0.3*	*0.5*
Difference (2070-baseline)	*1.7*	*0.4*	*0.0*	*0.1*	*0.2*	*1.5*	*1.2*	*0.7*	*0.5*	*0.7*	*0.4*	*1.3*
Monthly Maximum Water Temperature (°C)												
Baseline (Historic)	9.8	10.6	10.3	11.3	15.2	20.5	26	26.4	24.3	17.5	12.4	8.7
Climate Change 2030	10.7	10.7	10.2	11.4	15.4	21.5	26.4	26.4	24.2	17.6	12.1	9.2
Climate Change 2070	11.4	11	10.4	11.5	15.6	22.3	27.3	27.2	24.9	18.3	12.8	10
Difference (2030-baseline)	*0.9*	*0.1*	*-0.1*	*0.1*	*0.2*	*1.0*	*0.4*	*0.0*	*-0.1*	*0.1*	*-0.3*	*0.5*
Difference (2070-baseline)	*1.6*	*0.4*	*0.1*	*0.2*	*0.4*	*1.8*	*1.3*	*0.8*	*0.6*	*0.8*	*0.4*	*1.3*

Table AQ 4-20. Monthly Statistics for the 2018 Baseline (Historic) and Climate Change 2070 Simulations in the Kaweah and East Fork Kaweah Rivers.

Scenario	Monthly Average Water Temperature (°C)											
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Baseline (Historic)	6.4	6	8	9.3	12	17.1	23.3	22.5	19.6	13.5	9.1	7
Climate Change 2030	7.3	6.3	8	9.3	12	17.8	23.6	22.5	19.7	14	9.4	8.1
Climate Change 2070	7.8	6.6	8.1	9.4	12.1	18.5	24.5	23.2	20.2	14.7	9.9	8.7
Difference (2030-baseline)	*0.9*	*0.3*	*0.0*	*0.0*	*0.0*	*0.7*	*0.3*	*0.0*	*0.1*	*0.5*	*0.3*	*1.1*
Difference (2070-baseline)	*1.4*	*0.6*	*0.1*	*0.1*	*0.1*	*1.4*	*1.2*	*0.7*	*0.6*	*1.2*	*0.8*	*1.7*
Monthly Maximum Water Temperature (°C)												
Baseline (Historic)	8.7	8.9	12.3	13.6	15.8	22.5	26.2	25.5	23.6	19.4	13.8	8.5
Climate Change 2030	10.5	9.1	12.3	13.7	15.9	22.9	26.5	25.6	23.8	19.8	14	10
Climate Change 2070	11.3	9.6	12.5	13.7	16	23.5	27.4	26.4	24.5	20.7	14.5	10.7
Difference (2030-baseline)	*1.8*	*0.2*	*0.0*	*0.1*	*0.1*	*0.4*	*0.3*	*0.1*	*0.2*	*0.4*	*0.2*	*1.5*
Difference (2070-baseline)	*2.6*	*0.7*	*0.2*	*0.1*	*0.2*	*1.0*	*1.2*	*0.9*	*0.9*	*1.3*	*0.7*	*2.2*

Table AQ 4-21. Monthly Average Water Temperatures in Kaweah River and East Fork Kaweah River Upstream of Confluence

Month	Kaweah River (US Conf. with EF) °C	East Fork Kaweah River (US Conf. with KR) °C	Difference (KR – EF) °C
February	5.84	5.23	0.61
March	7.41	7.64	-0.24
April	9.65	9.60	0.05
May	12.66	12.76	-0.09
June	17.33	17.97	-0.65
July	23.22	23.38	-0.16
August	23.13	22.64	0.49
September	20.84	19.24	1.59
October	15.03	13.58	1.45
November	10.01	8.94	1.07
December	6.46	6.44	0.02

FIGURES

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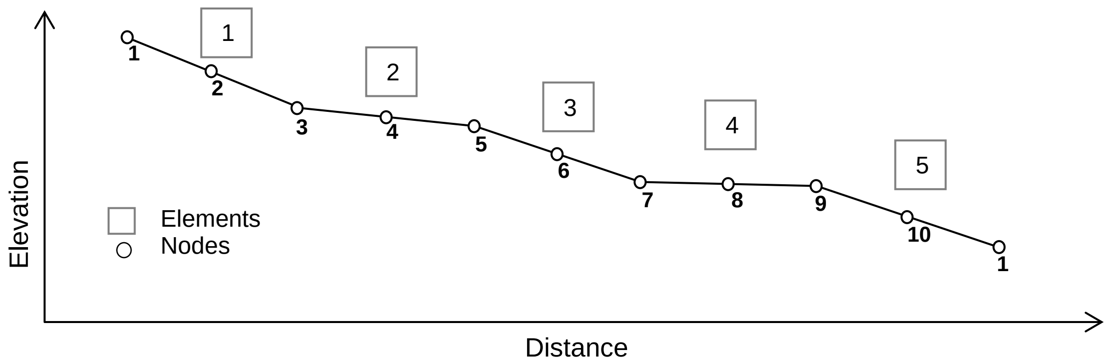


Figure AQ 4-1. Conceptualization of river representation in the stream models (RMA-2 and RMA-11) showing river profile representation of elements and nodes.

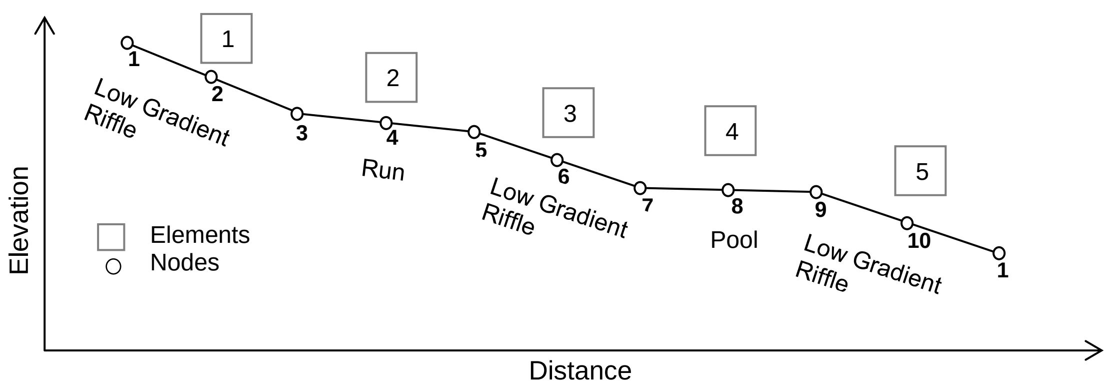


Figure AQ 4-2. Conceptualization of river representation in the stream models (RMA-2 and RMA-11) showing river profile representation of elements and nodes with associated habitat type assignment by element type.

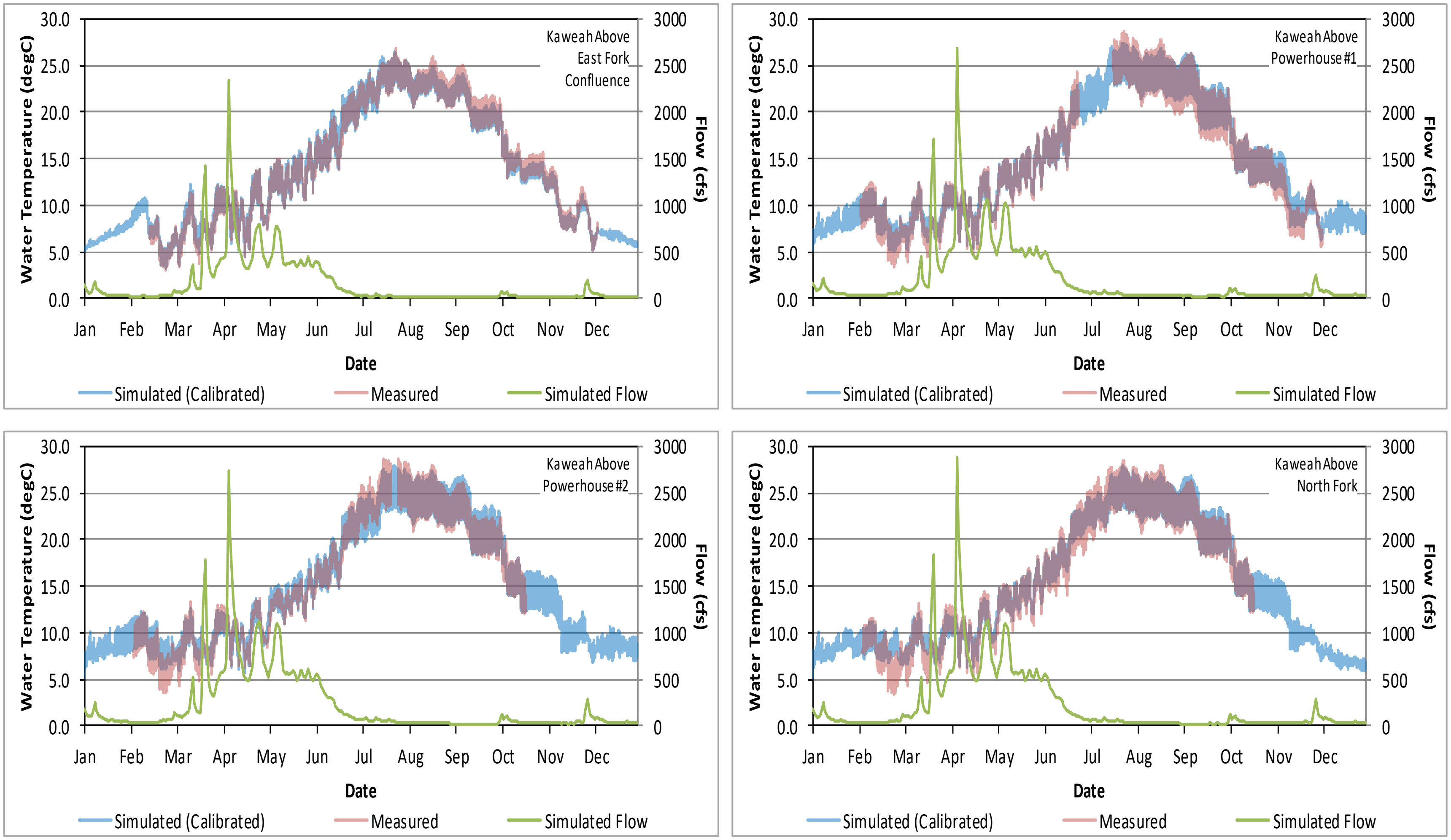


Figure AQ 4-3. Water Temperature Model Calibration Results for Kaweah River Upstream of the Confluence with the East Fork for January 1 – December 31, 2018.

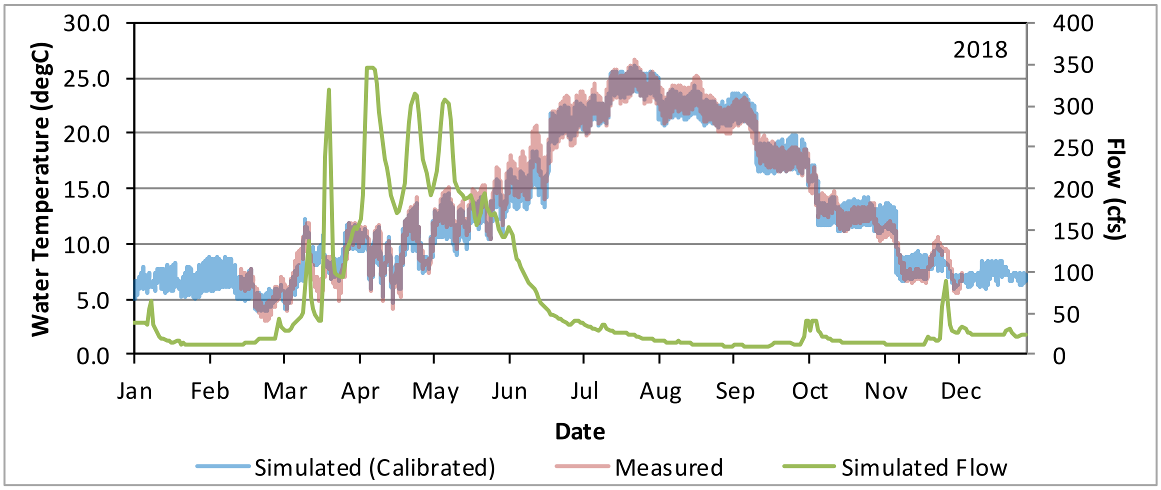


Figure AQ 4-4. Water Temperature Model Calibration Results for East Fork Kaweah River Upstream of Kaweah River for January 1 – December 31, 2018.

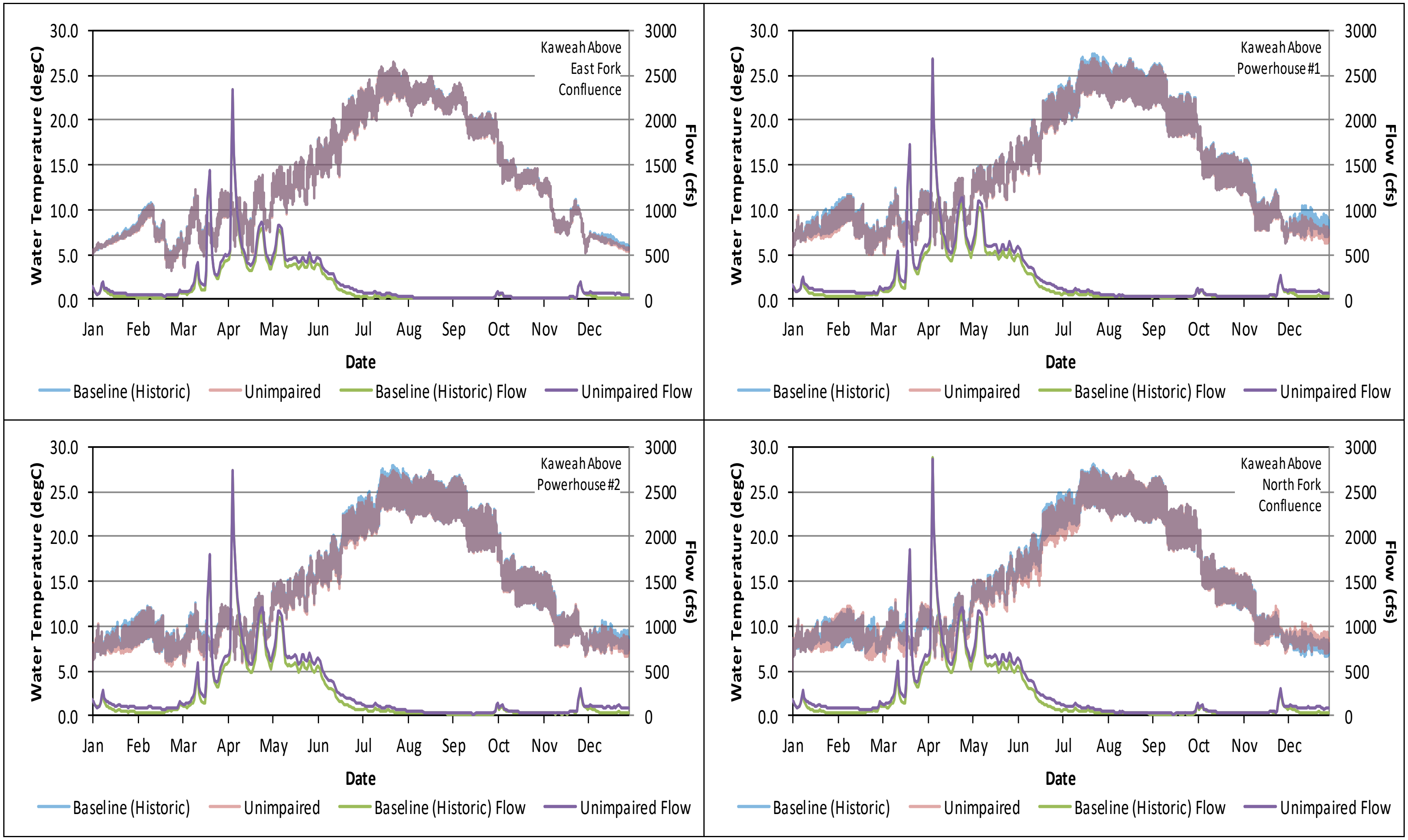


Figure AQ 4-5. Hourly Water Temperature and Daily Average Flow Results for the Baseline (Historic) and Unimpaired Simulations for Kaweah River Upstream of the Confluence with the East Fork, January 1 – December 31, 2018.

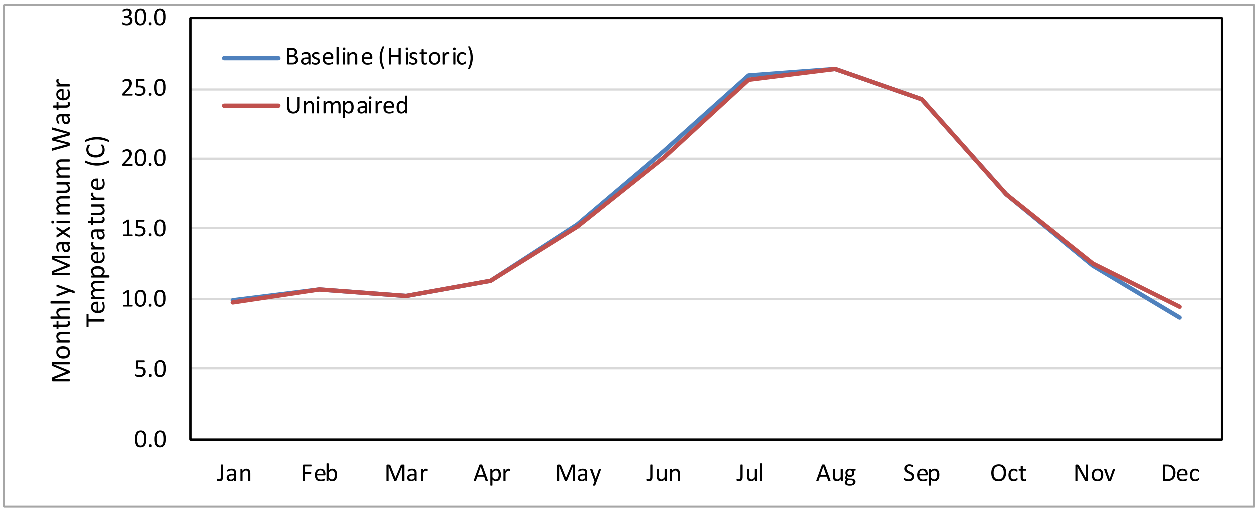


Figure AQ 4-6. Monthly Average Maximum Water Temperatures in the Kaweah River Downstream of Powerhouse 2 for the Baseline (Historic) and Unimpaired Flows.

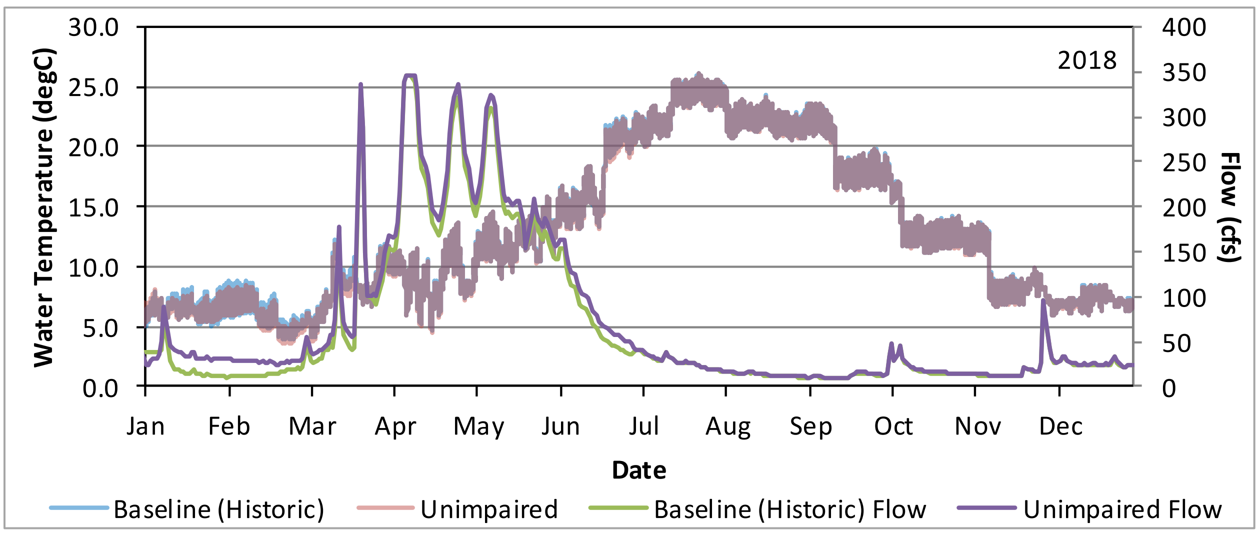


Figure AQ 4-7. Hourly Water Temperature and Daily Average Flow Results for the Baseline (Historic) and Unimpaired Simulations for the East Fork of the Kaweah River Upstream of the Confluence with the Kaweah River, January 1 – December 31, 2018.

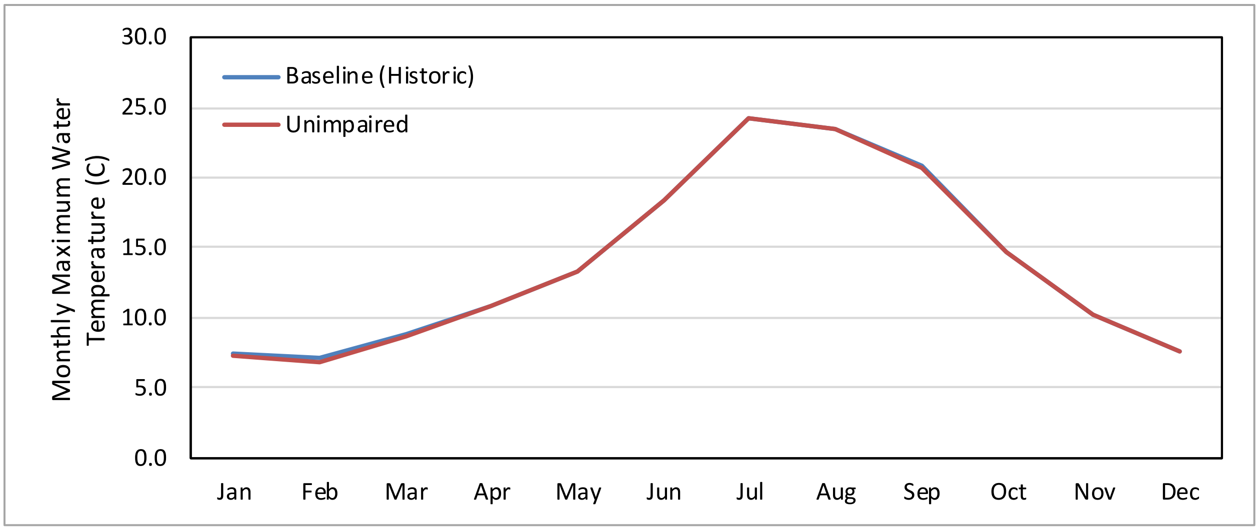


Figure AQ 4-8. Monthly Average Maximum Water Temperatures in the East Fork Kaweah River at the Confluence for the Baseline (Historic) and Unimpaired Flows

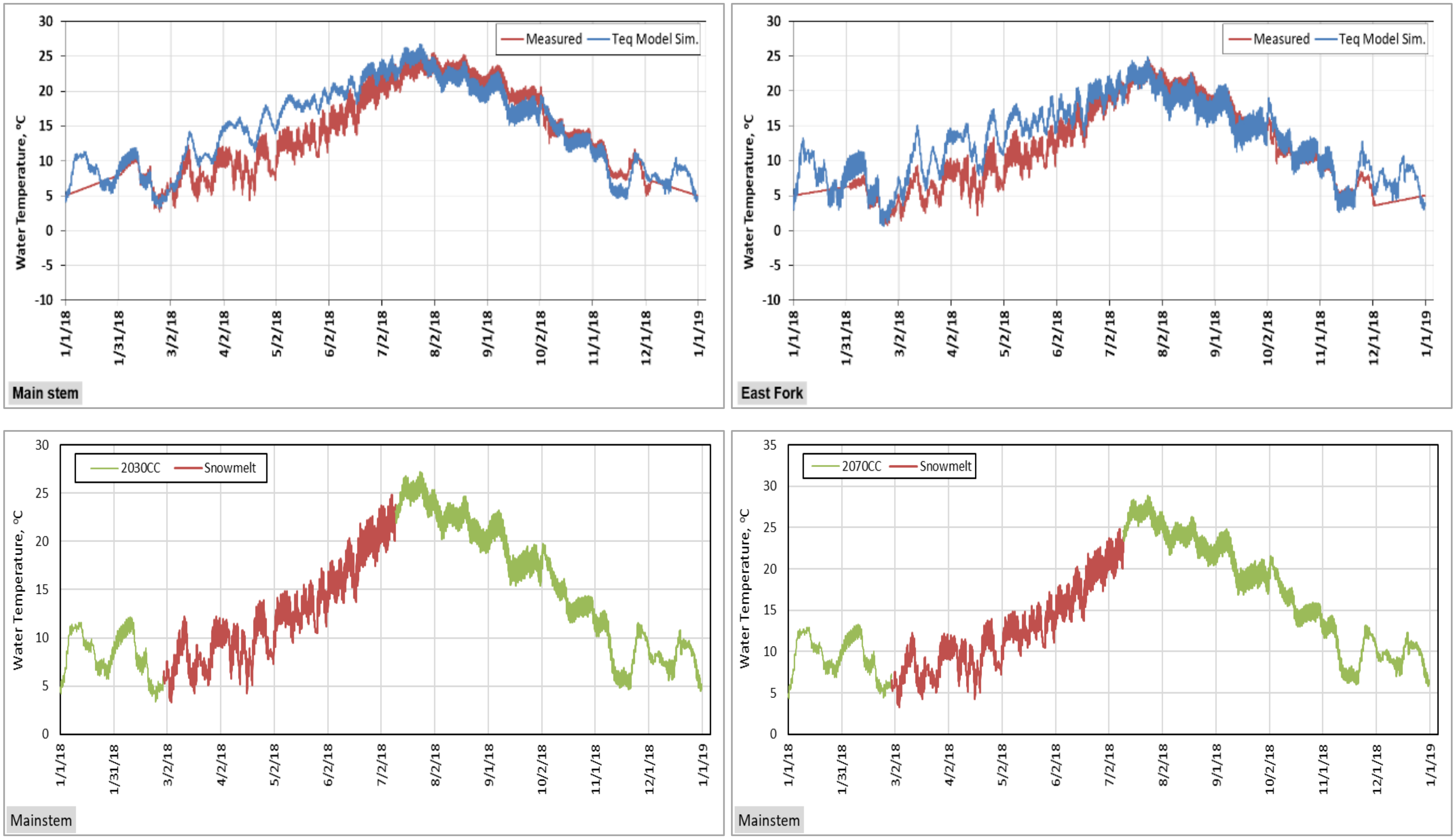


Figure AQ 4-9. Kaweah River at headwater: observed and estimated equilibrium water temperature: 2018 (Top left); East Fork Kaweah River at headwater: observed and estimated equilibrium water temperature: 2018. (Top Right); Calculated water headwater temperatures for the Kaweah River for 2030 climate conditions. (Bottom Left); Calculated water headwater temperatures for the Kaweah River for 2070 climate conditions. (Bottom Right)

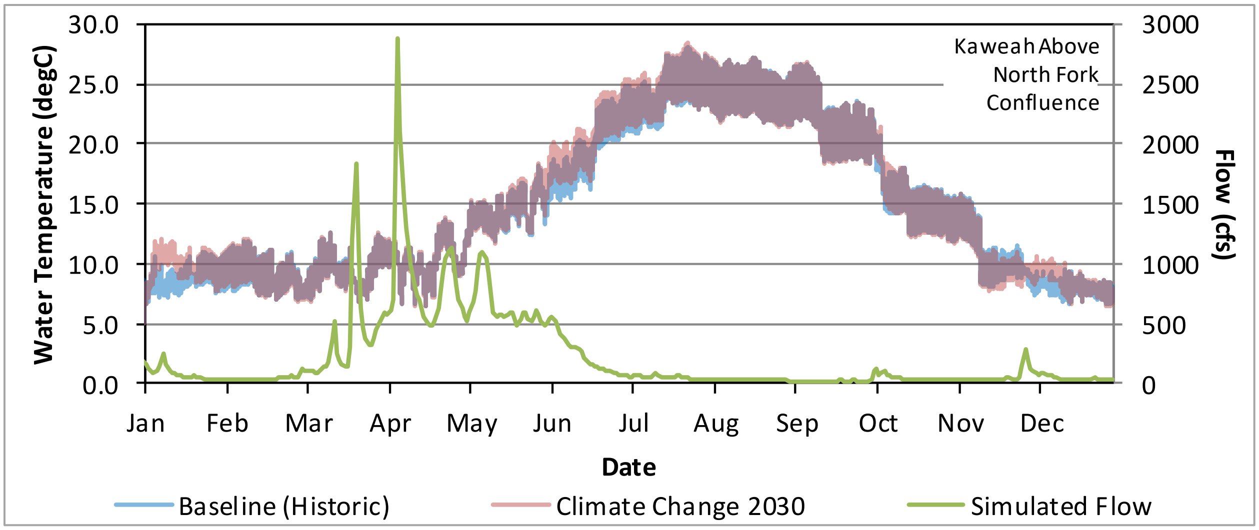


Figure AQ 4-10. Hourly Water Temperature and Daily Average Flow Model Results for the Baseline (Existing) and Climate Change 2030 for Kaweah River Upstream of the Confluence with the North Fork, January 1 – December 31, 2018.

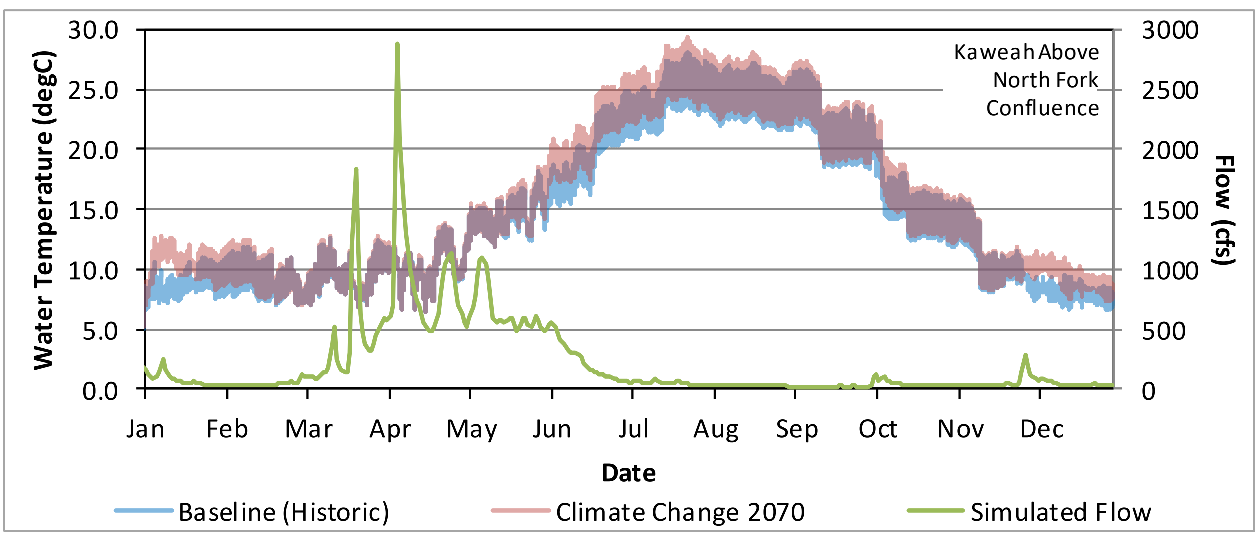


Figure AQ 4-11. Hourly Water Temperature and Daily Average Flow Model Results for the Baseline (Existing) and Climate Change 2070 for Kaweah River Upstream of the Confluence with the North Fork, January 1 – December 31, 2018.

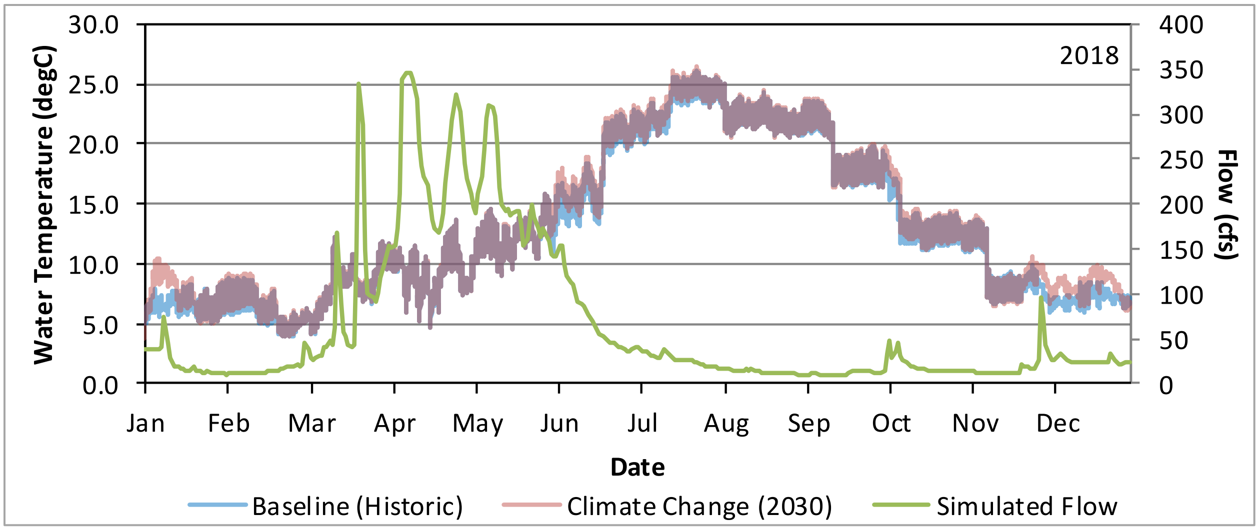


Figure AQ 4-12. Hourly Water Temperature Model Results Baseline (Existing) and Climate Change 2030 for East Fork of the Kaweah River Upstream of the Confluence with the Kaweah River for January 1 – December 31, 2018.

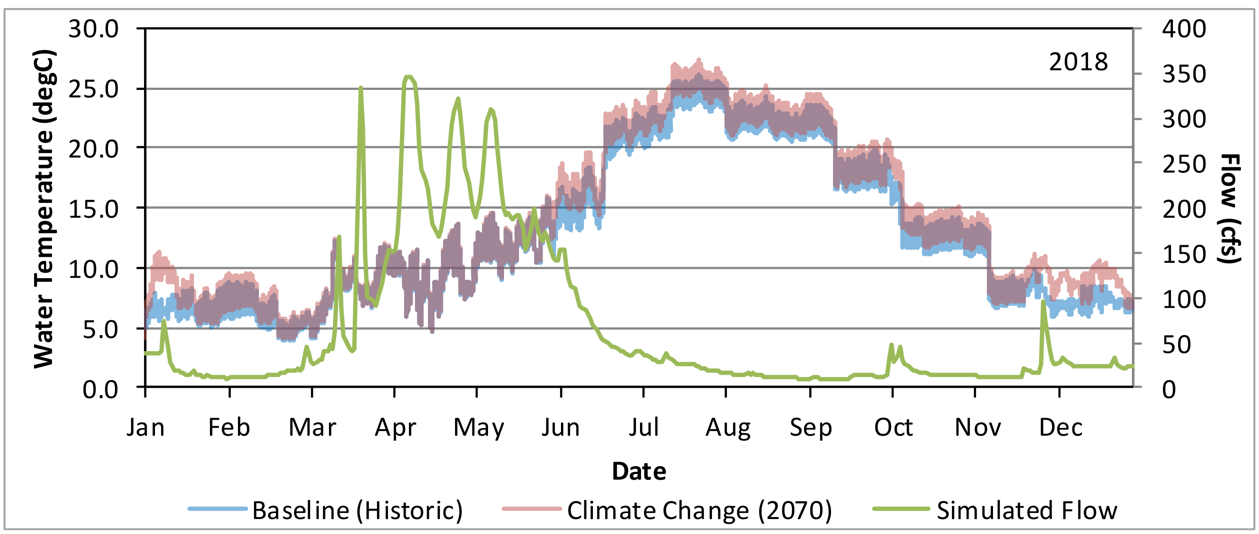


Figure AQ 4-13. Hourly Water Temperature Model Results Baseline (Historic) and Climate Change 2070 for East Fork of the Kaweah River Upstream of the Confluence with the Kaweah River for January 1 – December 31, 2018.

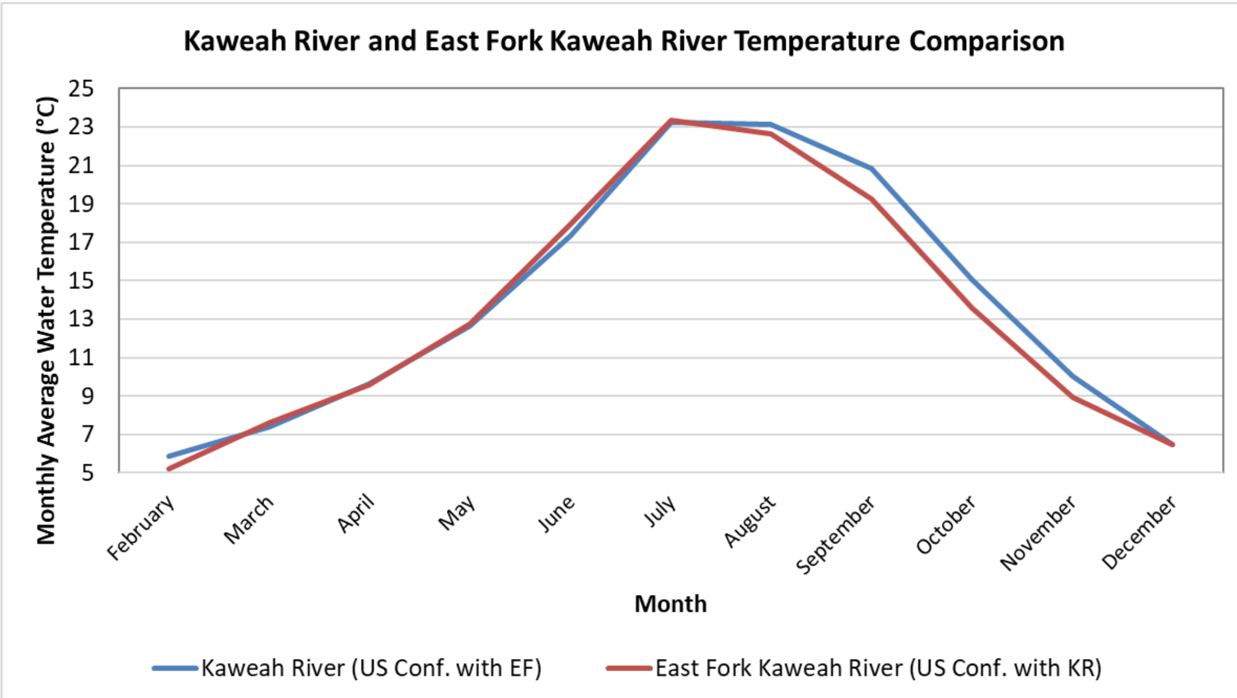


Figure AQ 4-14. Comparison of Monthly Average Water Temperatures on the Kaweah River Upstream of Conf. with the East Fork and the East Fork River Upstream of the Conf. with the Kaweah River.

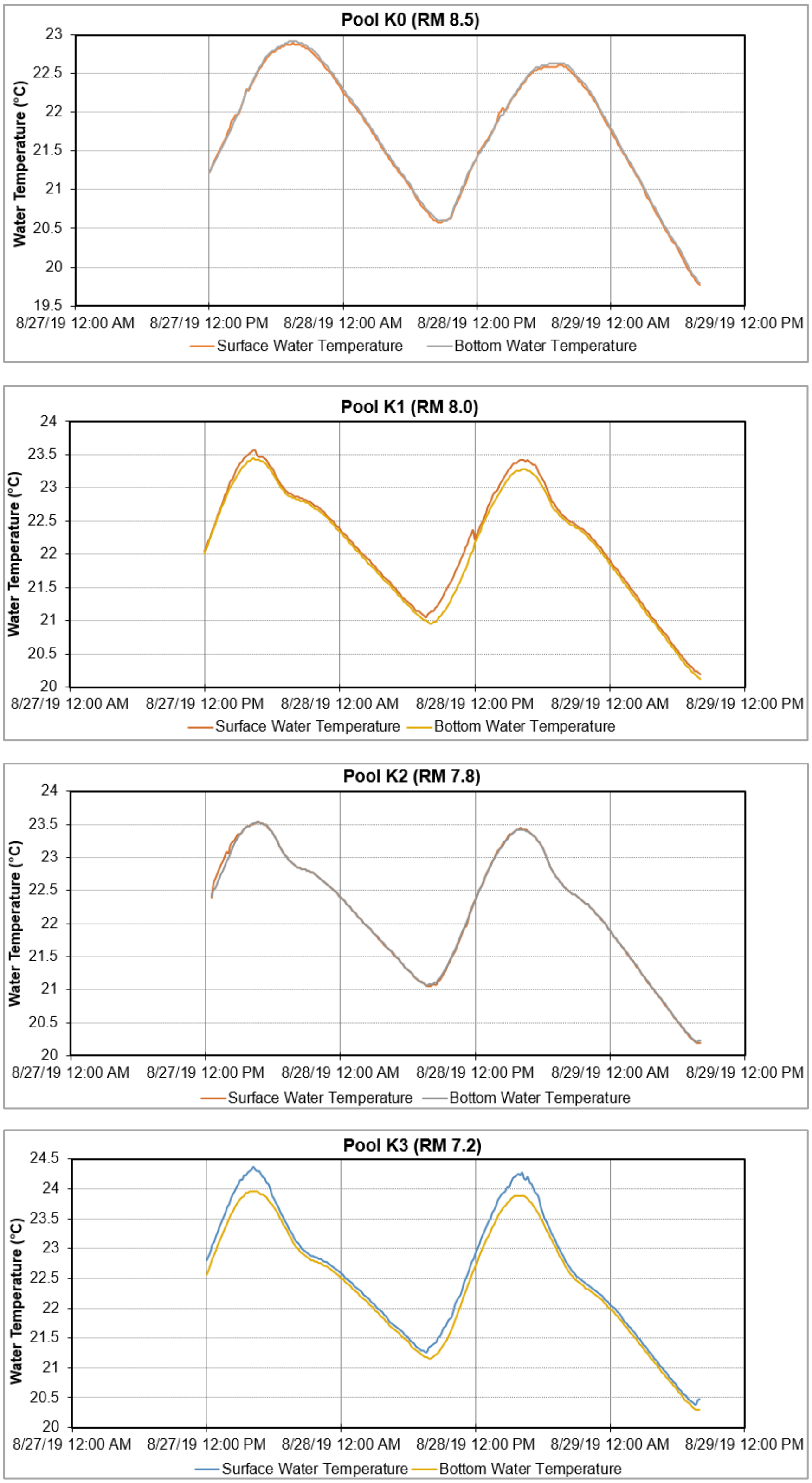


Figure AQ 4-15. Kaweah River Pool Water Temperature, Surface and Bottom, Time Series on August 27 – August 29, 2019.

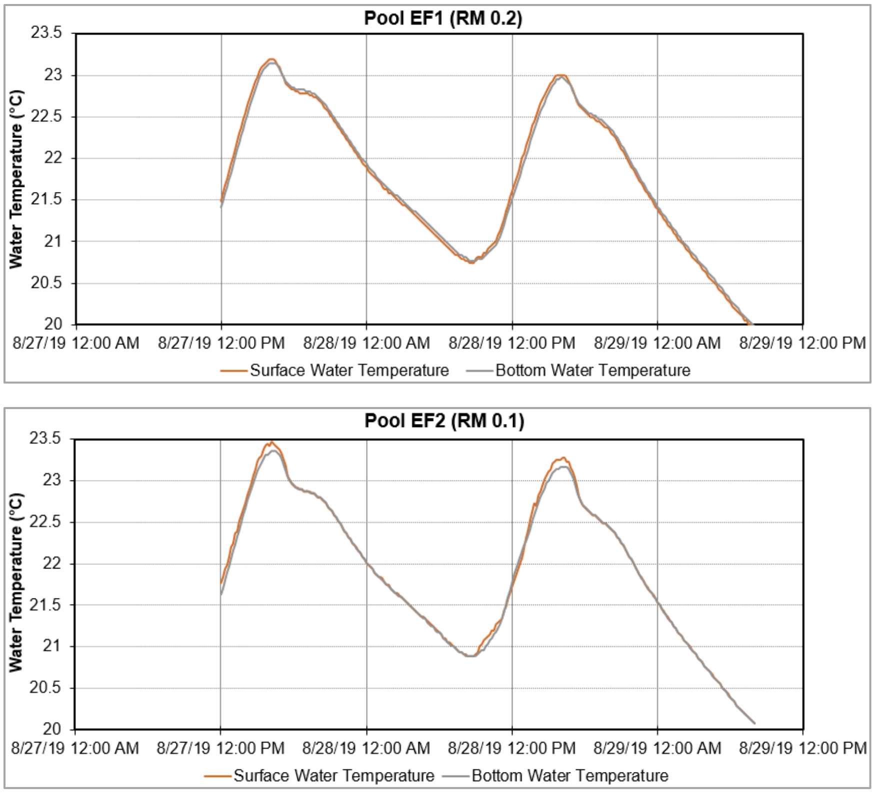


Figure AQ 4-16. East Fork Kaweah River Pool Water Temperature, Surface and Bottom, Time Series on August 27 – August 29, 2019.

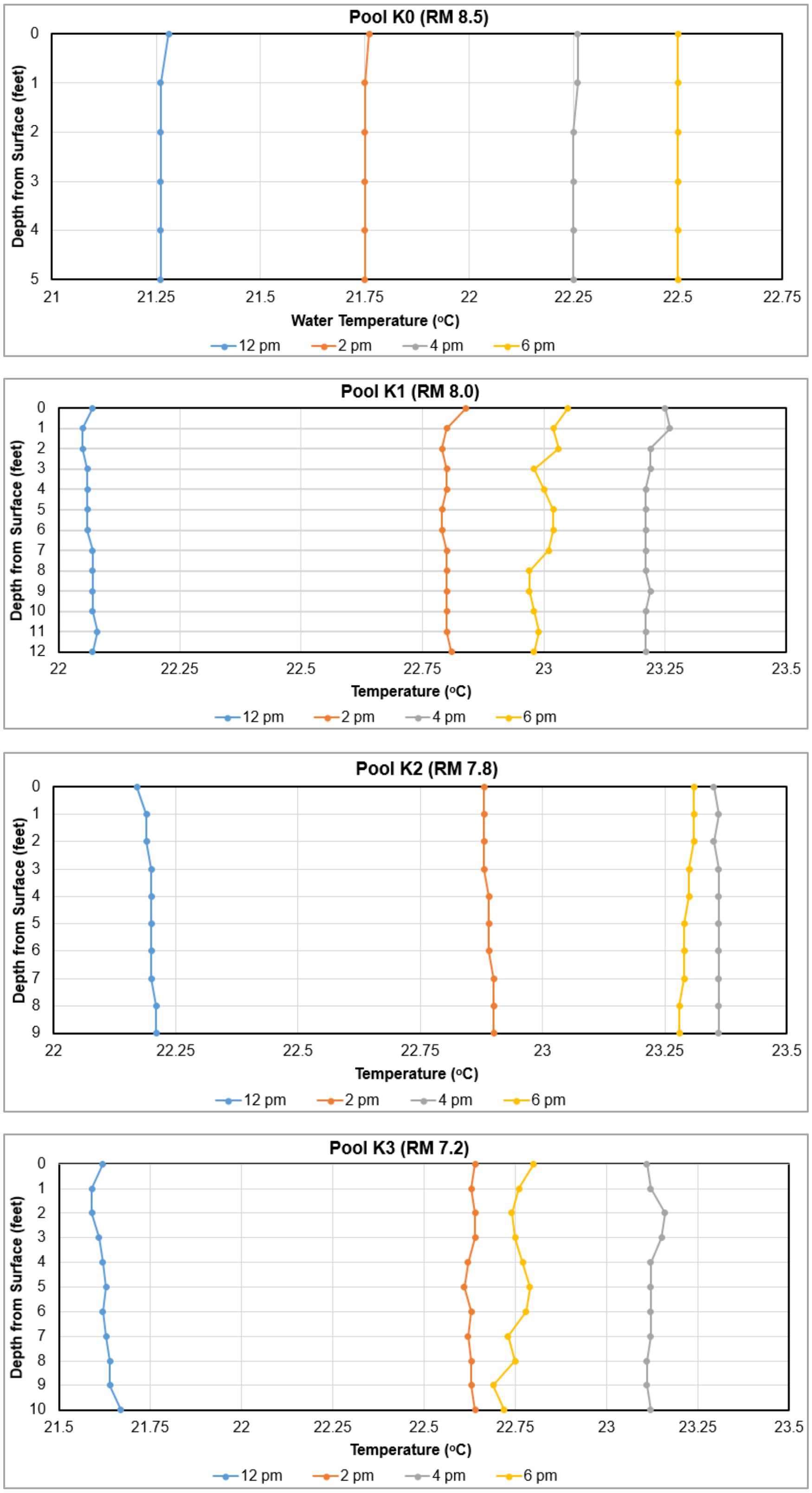
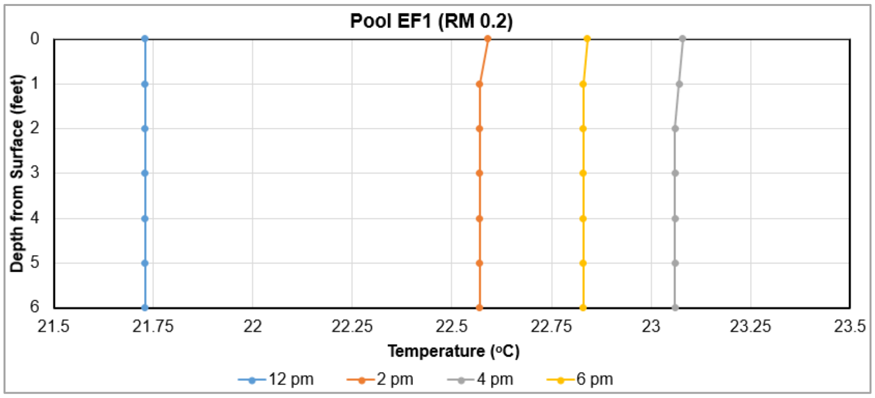


Figure AQ 4-17. Kaweah River Pool Water Temperature Profiles on August 27 or August 28, 2019.



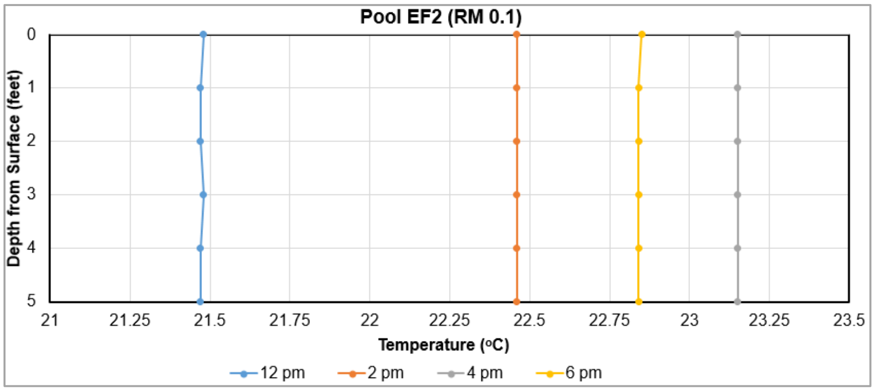


Figure AQ 4-18. East Fork Kaweah River Pool Water Temperature Profiles on August 27, 2019.

MAPS

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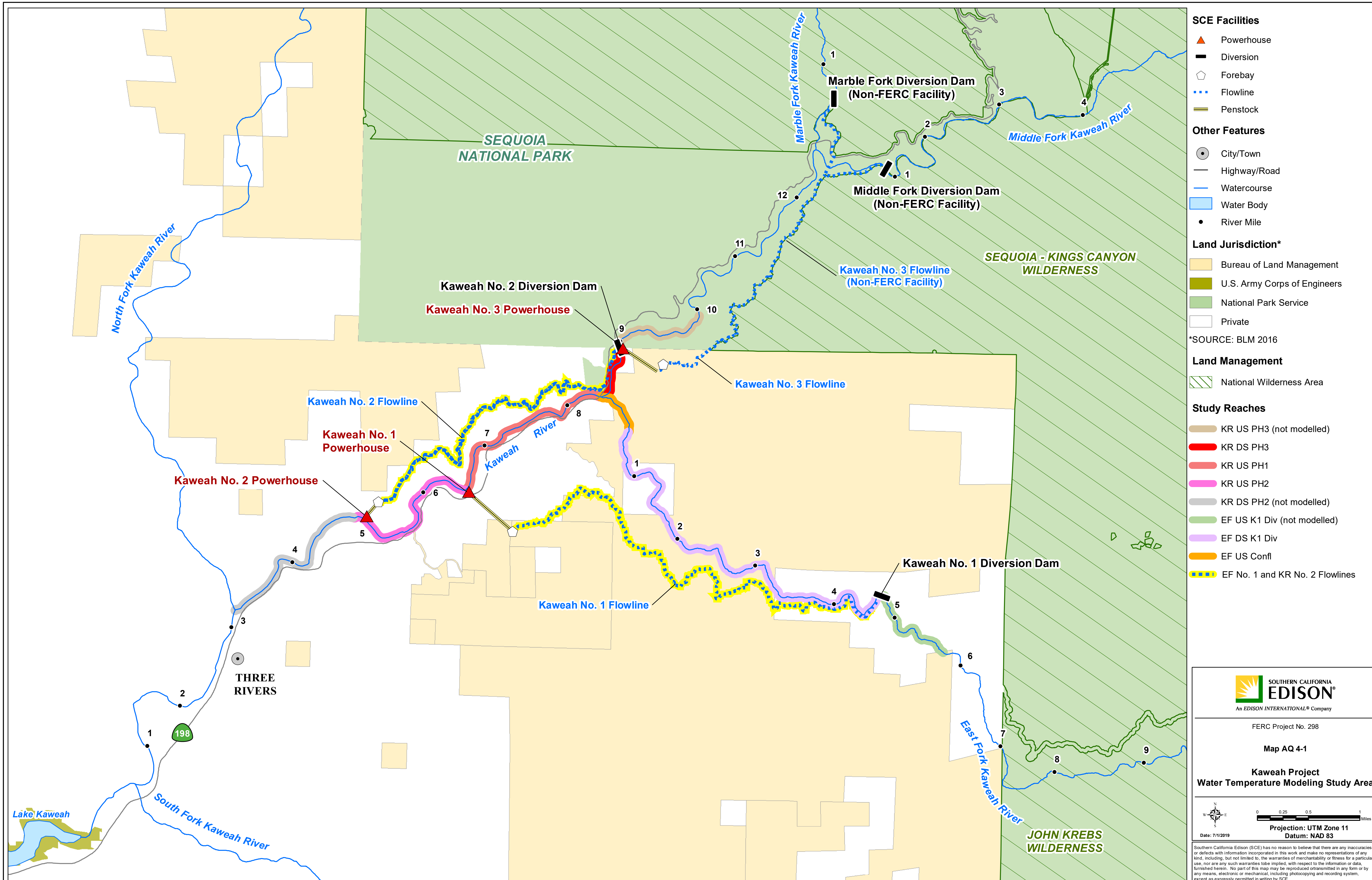

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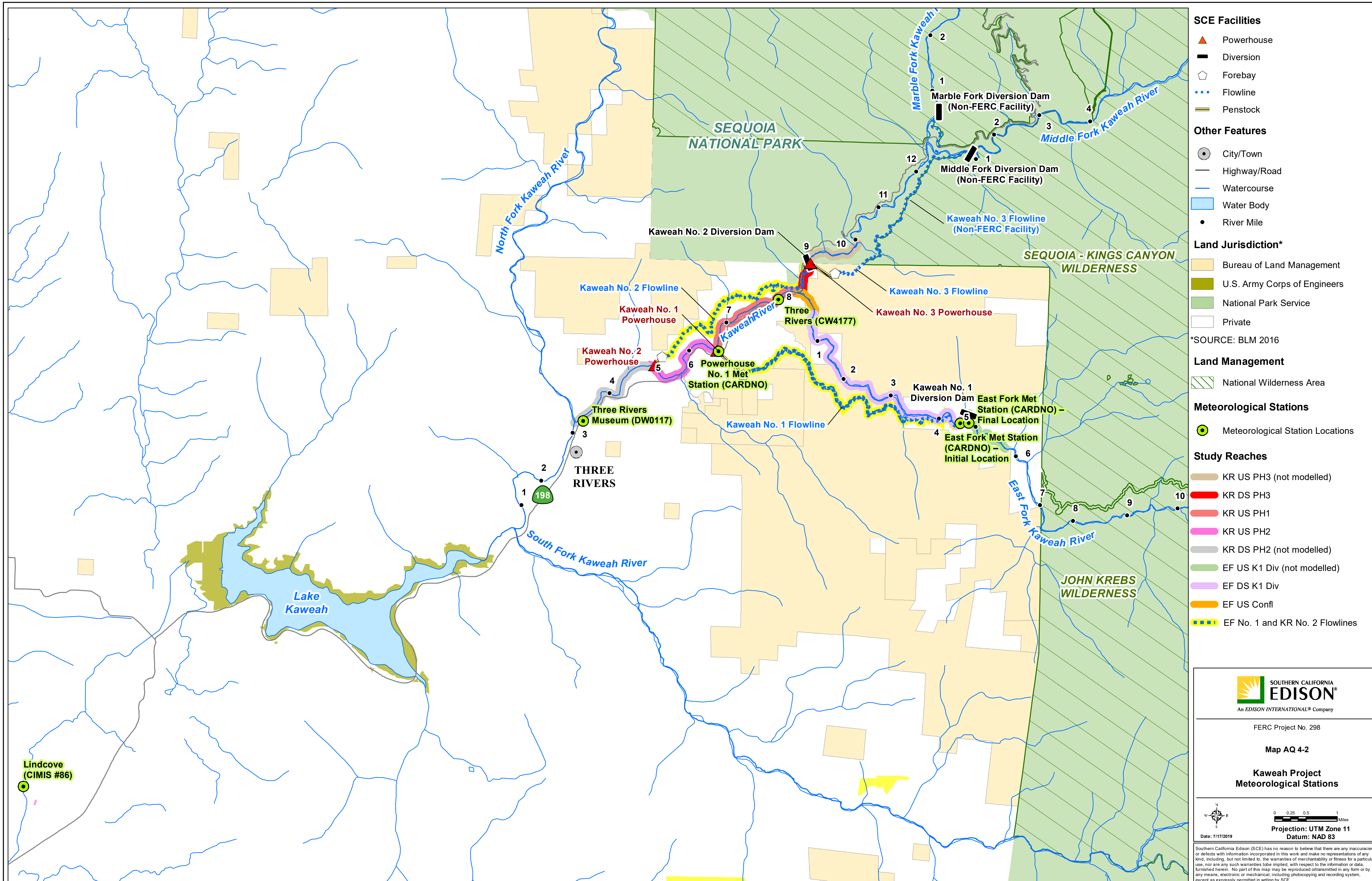

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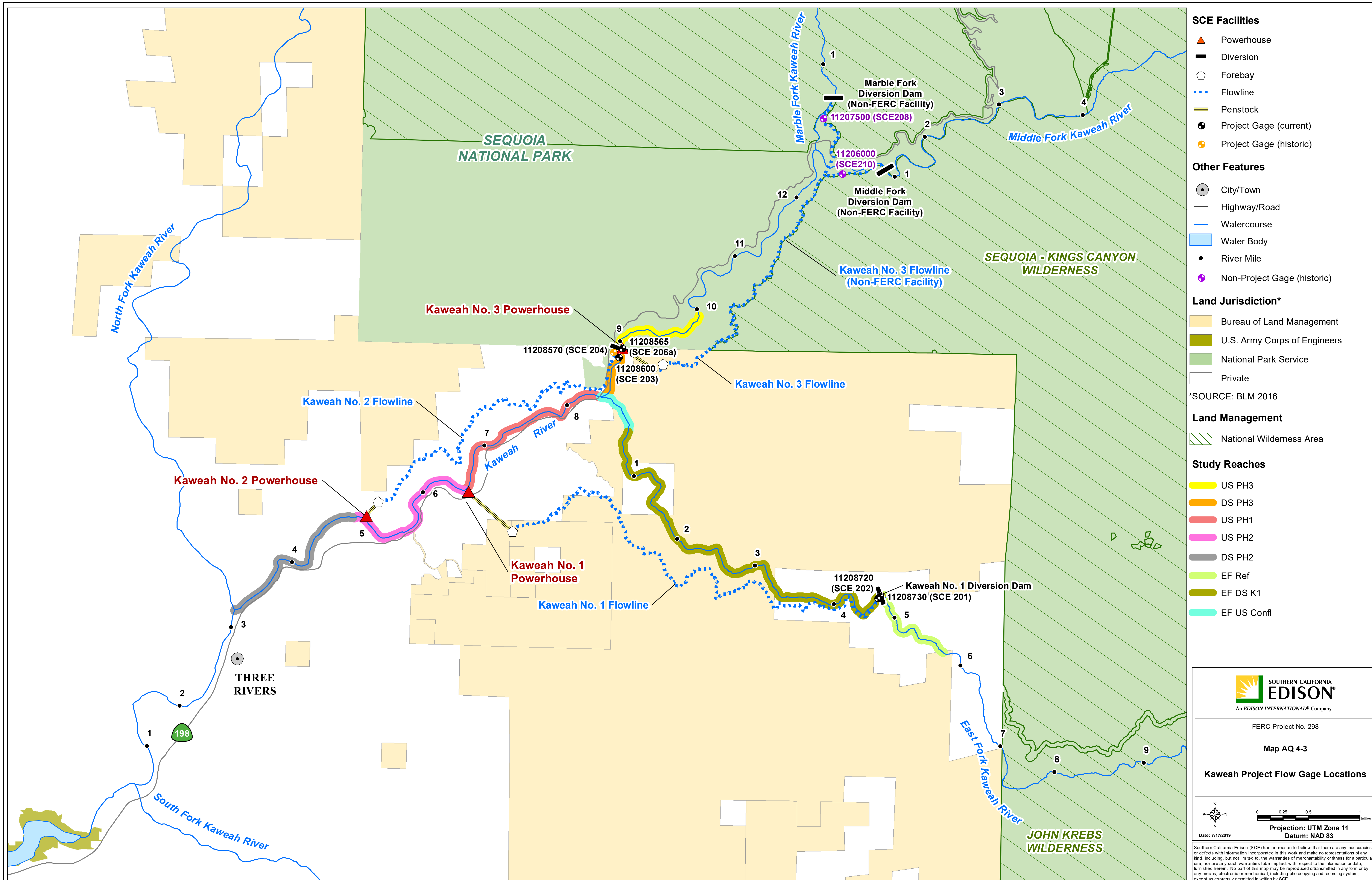

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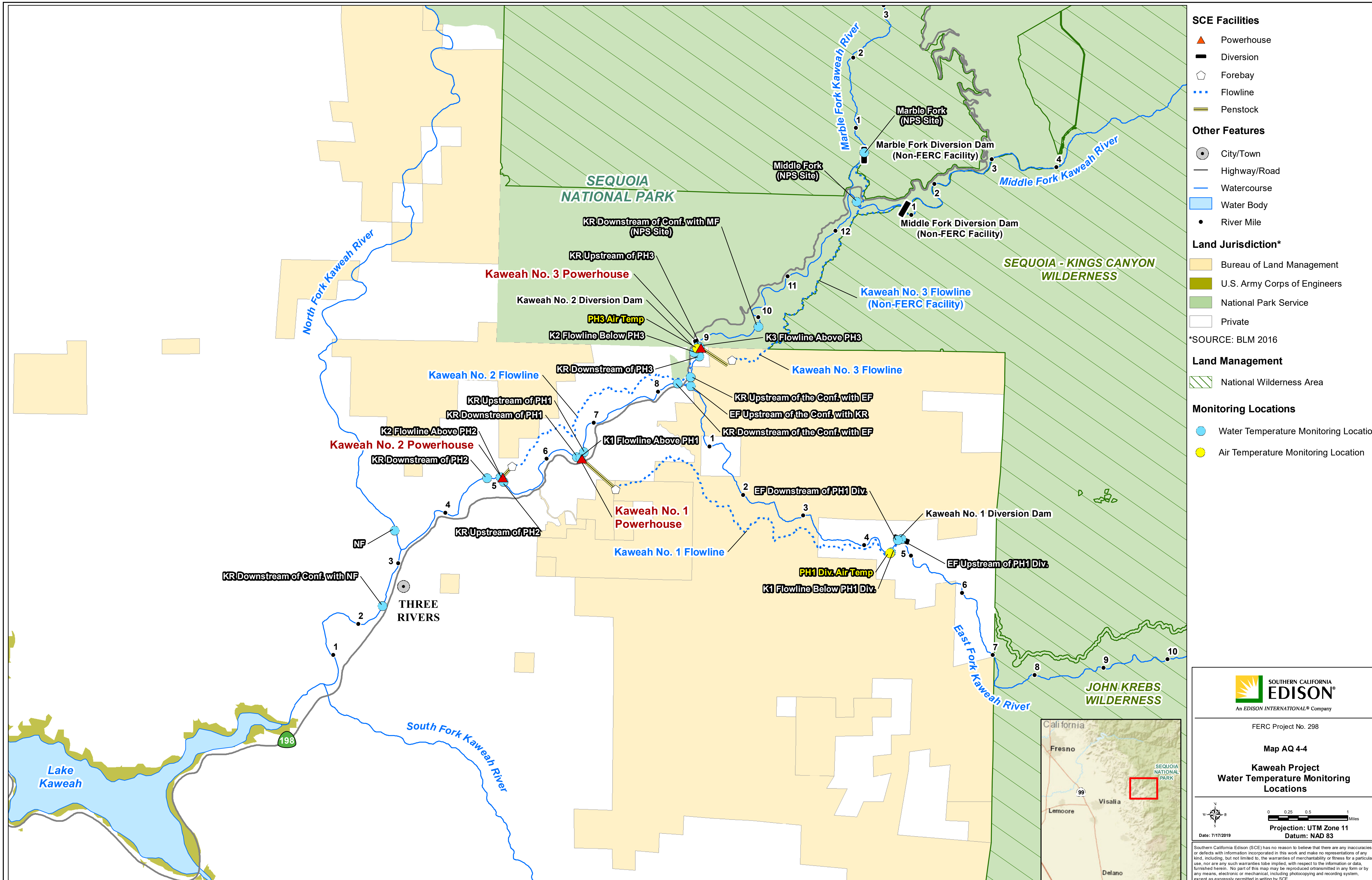

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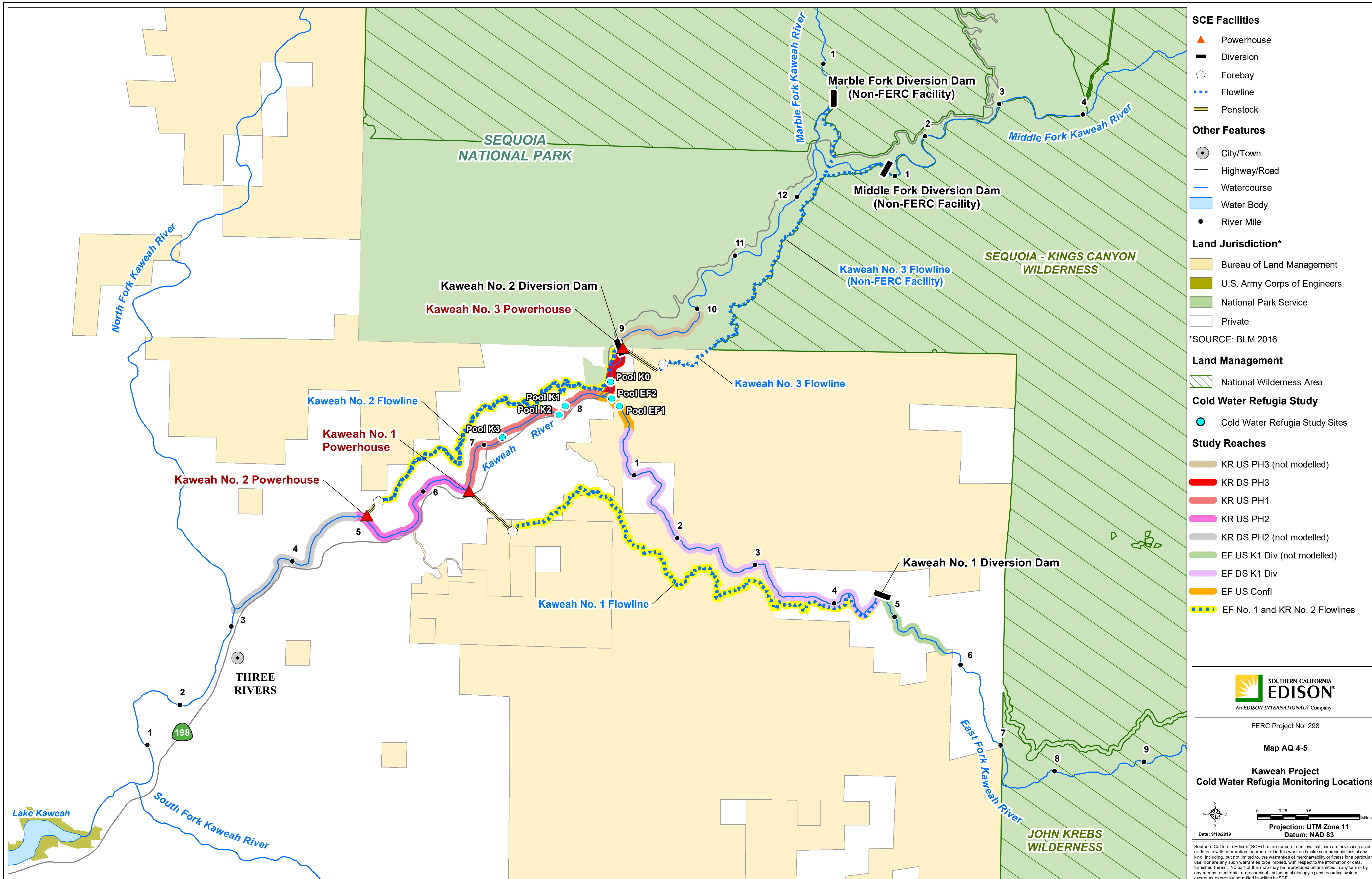

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APPENDIX A

Attributes of Prospective Water Temperature Models

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A review of applicable river flow and temperature models was completed to aid model selection for the Kaweah River Project. A wide range of model attributes was examined for nine river models (Table A-1). A few critical attributes used to assess the models included documentation, active support, open source codes, and pre-and post-processors. Specific to river models, attributes of particular concern included:

- longitudinal temperature gradients;
- replication of dynamic flow conditions on a short time step (e.g., one-hour) to assess potential implications of hydropower operations, i.e., robust hydrodynamics;
- sub-daily temperatures/maximum daily temperatures; and
- topographic and riparian shading.

There were several models potentially applicable to the Project. Discussions with the stakeholders, resource availability, schedule, and system attributes were considered when selecting a final model. Ultimately the suite of RMA-2 and RMA-11 models was selected for modeling water temperature for the Kaweah River Project.

Table A-1. General Model Attributes Considered during Model Selection.

		Model								
		TVA	QUAL-2K	WASP	HEC- RAS (Temp)	HSPF	Heat Source	SNTEMP	RMA2/ RMA11	CE-QUAL-RIV1
Attribute	Author/ Sponsor	Tennessee Valley Authority	EPA[e]	EPA	U.S. Army Corps	USGS[e]	Oregon Dept of Envir. Quality	USGS	RMA[e]	U.S. Army Corps
	System	River	River	River	River	River	River	River	River	River
	Dimension	1	1	1,2,3	1	1	1	1	1,2	1
	Dynamic Flow Model	Yes	No	Yes[a]	Yes	No	Yes	No	Yes	Yes
	Boundary Condition	P,NP	P,NP	P,NP	P,NP	P,NP	P,NP	P	P,NP	P,NP
	Topographic Shade	No	No	No	No	Yes	Yes	Yes	Yes	No
	Riparian Shade[b]	Yes	No	No	No	Yes	Yes	Yes	Yes	No
	Steep River Logic[c]	No	No	No	No	Yes	No	n/a	Yes	No
	Bed Conduction	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	No
	Hyporheic Flow	No	No	No	No	No	No	No	No	No
	Time Step	SD	SD	SD	SD	SD	SD	D	SD	SD
	Actively Supported	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	Pre-Processor	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
	Post Processor	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
	Open Source Code	Yes	Yes	Yes	Yes[d]	Yes	Yes	Yes	Yes	Yes
	Documentation	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Boundary Conditions: P – Point, and NP – Nonpoint

Time Step: SD – sub-daily, and D - Daily

[a] Requires a hydrodynamic model (e.g., Dynhyd).

[b] Solar radiation can be pre-processed for all models. There is a version of RMA-11 that includes riparian vegetation shading for the one-dimensional formulation.

[c] Steep river logic in HSPF includes representing reaches as pools with weirs, a cumbersome but potentially viable approach.

[d] HEC_RAS temperature model was in beta version when this process commenced. Status of source code is currently unknown.

[e] EPA = Environmental Protection Agency, USFS = United States Geological Survey, RMA = Resource Management Associates.

APPENDIX B

Channel Geometry

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List of Tables

List of Figures

Table B-1a. Kaweah River Downstream of Kaweah No. 3 Powerhouse and Upstream of the East Fork Kaweah River Confluence Pool Habitat Cross-Section Representation.

Relative Elevation, ft	Calibrated Flow, cfs	Wetted Area, ft^2	Wetted Width, ft
0.00	0.00	53.28	33.39
1.27	7.00	92.95	50.04
1.41	10.00	99.40	51.38
1.64	16.50	110.27	53.46
1.73	20.00	115.10	54.33
1.85	25.00	121.21	55.37
1.96	30.00	126.65	56.26
2.05	35.00	131.59	57.05
2.13	40.00	136.14	57.75
2.21	45.00	140.37	58.38
2.31	52.10	145.93	59.20
2.57	75.00	161.35	61.33
2.80	100.00	175.33	63.14
2.99	125.00	187.40	64.63
3.16	150.00	198.14	65.90
3.31	175.00	207.89	67.01
3.44	200.00	216.87	68.01
3.56	225.00	225.21	68.91
3.68	250.00	233.04	69.74
3.77	271.50	239.42	70.40
3.88	300.00	247.44	71.21
4.07	350.00	260.51	72.51
4.23	400.00	272.54	73.67
4.51	497.00	293.61	75.62
4.77	600.00	313.53	77.40
5.00	700.00	331.04	78.90
5.20	800.00	347.17	80.25
5.39	900.00	362.17	81.47
5.56	1000.00	376.23	82.59
5.87	1200.00	402.10	84.59
6.14	1400.00	425.58	86.34

Table B-1b. Kaweah River Downstream of Kaweah No. 3 Powerhouse and Upstream of the East Fork Kaweah River Confluence Run Habitat Cross-Section Representation.

Relative Elevation, ft	Calibrated Flow, cfs	Wetted Area, ft^2	Wetted Width, ft
0.00	0.00	16.35	1.34
0.93	7.00	39.72	34.77
1.06	10.00	44.44	36.98
1.26	16.50	52.72	40.32
1.35	20.00	56.51	41.69
1.46	25.00	61.41	43.33
1.56	30.00	65.85	44.72
1.65	35.00	69.95	45.94
1.73	40.00	73.77	47.02
1.80	45.00	77.36	47.99
1.89	52.10	82.15	49.23
2.16	75.00	95.75	52.45
2.39	100.00	108.44	55.16
2.58	125.00	119.67	57.35
2.75	150.00	129.86	59.21
2.91	175.00	139.25	60.83
3.05	200.00	148.01	62.26
3.18	225.00	156.25	63.56
3.30	250.00	164.06	64.75
3.40	271.50	170.48	65.69
3.52	300.00	178.62	66.85
3.72	350.00	192.04	68.68
3.90	400.00	204.56	70.31
4.21	497.00	226.86	73.05
4.50	600.00	248.33	75.50
4.75	700.00	267.52	77.58
4.98	800.00	285.42	79.42
5.19	900.00	302.27	81.09
5.39	1000.00	318.23	82.60
5.75	1200.00	347.99	85.30
6.07	1400.00	375.42	87.65

Table B-1c. Kaweah River Downstream of Kaweah No. 3 Powerhouse and Upstream of the East Fork Kaweah River Confluence Low Gradient Riffle (LGR) Habitat Cross-Section Representation.

Relative Elevation, ft	Calibrated Flow, cfs	Wetted Area, ft^2	Wetted Width, ft
0.00	0.00	0.00	0.00
1.33	7.00	12.09	22.92
1.45	10.00	14.59	25.05
1.63	16.50	19.00	28.36
1.71	20.00	21.02	29.75
1.80	25.00	23.64	31.44
1.89	30.00	26.03	32.90
1.96	35.00	28.23	34.18
2.02	40.00	30.28	35.34
2.08	45.00	32.22	36.39
2.15	52.10	34.81	37.73
2.35	75.00	42.17	41.31
2.52	100.00	49.07	44.36
2.65	125.00	55.19	46.89
2.77	150.00	60.75	49.06
2.88	175.00	65.89	50.98
2.97	200.00	70.69	52.69
3.05	225.00	75.22	54.26
3.13	250.00	79.51	55.70
3.20	271.50	83.04	56.85
3.27	300.00	87.52	58.28
3.40	350.00	94.93	60.55
3.51	400.00	101.84	62.59
3.69	497.00	114.18	66.06
3.86	600.00	126.09	69.22
4.01	700.00	136.75	71.92
4.14	800.00	146.72	74.34
4.26	900.00	156.11	76.55
4.37	1000.00	165.02	78.58
4.56	1200.00	181.65	82.22
4.73	1400.00	197.01	85.43

Table B-1d. Kaweah River Downstream of Kaweah No. 3 Powerhouse and Upstream of the East Fork Kaweah River Confluence High Gradient Riffle (HGR) Habitat Cross-Section Representation.

Relative Elevation, ft	Calibrated Flow, cfs	Wetted Area, ft^2	Wetted Width, ft
0.00	0.00	0.00	0.00
1.30	7.00	15.24	24.79
1.44	10.00	18.40	26.66
1.67	16.50	23.98	29.52
1.76	20.00	26.55	30.71
1.88	25.00	29.88	32.13
1.99	30.00	32.90	33.35
2.08	35.00	35.69	34.42
2.16	40.00	38.31	35.37
2.24	45.00	40.77	36.23
2.33	52.10	44.05	37.33
2.60	75.00	53.42	40.20
2.82	100.00	62.19	42.63
3.01	125.00	69.98	44.62
3.18	150.00	77.07	46.31
3.32	175.00	83.62	47.79
3.46	200.00	89.73	49.11
3.58	225.00	95.50	50.30
3.69	250.00	100.98	51.39
3.78	271.50	105.48	52.26
3.89	300.00	111.20	53.34
4.07	350.00	120.64	55.04
4.23	400.00	129.47	56.56
4.51	497.00	145.23	59.12
4.77	600.00	160.44	61.44
4.99	700.00	174.07	63.40
5.18	800.00	186.81	65.15
5.37	900.00	198.81	66.73
5.53	1000.00	210.21	68.18
5.84	1200.00	231.49	70.76
6.11	1400.00	251.15	73.02

Table B-2a. Kaweah River Downstream of East Fork Kaweah Confluence and Upstream of Kaweah No. 1 Powerhouse Pool Habitat Cross-Section Representation.

Relative Elevation, ft	Calibrated Flow, cfs	Wetted Area, ft^2	Wetted Width, ft
0.00	0.00	223.41	48.49
0.72	7.00	238.50	58.07
0.82	10.00	242.45	59.63
1.00	16.50	249.82	62.27
1.07	20.00	253.36	63.44
1.17	25.00	258.06	64.93
1.26	30.00	262.44	66.25
1.33	35.00	266.57	67.45
1.41	40.00	270.51	68.56
1.47	45.00	274.27	69.59
1.56	52.10	279.38	70.94
1.79	75.00	294.42	74.69
2.00	100.00	309.10	78.10
2.19	125.00	322.54	81.04
2.35	150.00	335.08	83.65
2.49	175.00	346.91	86.03
2.62	200.00	358.16	88.22
2.74	225.00	368.94	90.26
2.86	250.00	379.30	92.17
2.95	271.50	387.94	93.72
3.07	300.00	399.02	95.68
3.26	350.00	417.62	98.87
3.43	400.00	435.32	101.81
3.73	497.00	467.61	106.96
4.01	600.00	499.58	111.82
4.26	700.00	528.83	116.11
4.48	800.00	556.67	120.05
4.69	900.00	583.32	123.72
4.89	1000.00	608.96	127.16
5.25	1200.00	657.72	133.49
5.57	1400.00	703.72	139.23

Table B-2b. Kaweah River Downstream of East Fork Kaweah Confluence and Upstream of Kaweah No. 1 Powerhouse Run Habitat Cross-Section Representation.

Relative Elevation, ft	Calibrated Flow, cfs	Wetted Area, ft^2	Wetted Width, ft
0.00	0.00	42.67	18.98
0.53	7.00	73.84	80.85
0.61	10.00	79.92	84.35
0.73	16.50	90.51	89.61
0.78	20.00	95.34	91.74
0.85	25.00	101.55	94.29
0.91	30.00	107.17	96.44
0.96	35.00	112.33	98.30
1.01	40.00	117.13	99.95
1.06	45.00	121.65	101.44
1.12	52.10	127.65	103.32
1.28	75.00	144.61	108.20
1.42	100.00	160.37	112.25
1.54	125.00	174.25	115.52
1.65	150.00	186.80	118.28
1.74	175.00	198.33	120.67
1.83	200.00	209.07	122.79
1.91	225.00	219.16	124.69
1.99	250.00	228.70	126.43
2.05	271.50	236.53	127.80
2.13	300.00	246.44	129.49
2.25	350.00	262.75	132.15
2.36	400.00	277.94	134.51
2.56	497.00	304.90	138.45
2.74	600.00	330.77	141.97
2.90	700.00	353.84	144.93
3.05	800.00	375.30	147.56
3.18	900.00	395.47	149.92
3.31	1000.00	414.53	152.06
3.54	1200.00	450.00	155.86
3.75	1400.00	482.61	159.16

Table B-2c. Kaweah River Downstream of East Fork Kaweah Confluence and Upstream of Kaweah No. 1 Powerhouse Low Gradient Riffle (LGR) Habitat Cross-Section Representation.

Relative Elevation, ft	Calibrated Flow, cfs	Wetted Area, ft^2	Wetted Width, ft
0.00	0.00	0.00	0.00
1.34	7.00	23.97	41.43
1.48	10.00	28.71	44.23
1.69	16.50	37.01	48.48
1.78	20.00	40.80	50.22
1.89	25.00	45.68	52.31
1.99	30.00	50.10	54.09
2.07	35.00	54.17	55.64
2.15	40.00	57.97	57.02
2.22	45.00	61.53	58.26
2.31	52.10	66.27	59.84
2.55	75.00	79.71	63.97
2.75	100.00	92.22	67.43
2.93	125.00	103.26	70.25
3.07	150.00	113.25	72.63
3.20	175.00	122.45	74.71
3.32	200.00	131.03	76.56
3.43	225.00	139.08	78.23
3.53	250.00	146.71	79.76
3.61	271.50	152.98	80.97
3.71	300.00	160.91	82.47
3.86	350.00	173.99	84.83
4.01	400.00	186.17	86.93
4.25	497.00	207.82	90.45
4.47	600.00	228.63	93.63
4.66	700.00	247.20	96.31
4.83	800.00	264.51	98.70
4.99	900.00	280.78	100.85
5.13	1000.00	296.18	102.81
5.39	1200.00	324.84	106.30
5.62	1400.00	351.24	109.35

Table B-2d. Kaweah River Downstream of East Fork Kaweah Confluence and Upstream of Kaweah No. 1 Powerhouse High Gradient Riffle (HGR) Habitat Cross-Section Representation.

Relative Elevation, ft	Calibrated Flow, cfs	Wetted Area, ft^2	Wetted Width, ft
0.00	0.00	1.41	18.72
1.44	7.00	15.44	26.51
1.58	10.00	18.46	27.78
1.81	16.50	23.82	29.93
1.90	20.00	26.30	30.89
2.01	25.00	29.53	32.10
2.11	30.00	32.47	33.18
2.20	35.00	35.20	34.16
2.28	40.00	37.75	35.06
2.35	45.00	40.16	35.90
2.44	52.10	43.39	37.00
2.69	75.00	52.63	40.06
2.90	100.00	61.34	42.84
3.07	125.00	69.11	45.24
3.22	150.00	76.20	47.38
3.36	175.00	82.76	49.32
3.48	200.00	88.92	51.11
3.58	225.00	94.73	52.77
3.69	250.00	100.25	54.33
3.77	271.50	104.81	55.60
3.87	300.00	110.60	57.20
4.03	350.00	120.19	59.81
4.17	400.00	129.17	62.21
4.41	497.00	145.26	66.41
4.64	600.00	160.84	70.39
4.83	700.00	174.84	73.89
5.00	800.00	187.96	77.11
5.16	900.00	200.35	80.11
5.30	1000.00	212.13	82.92
5.56	1200.00	234.19	88.10
5.79	1400.00	254.63	92.80

Table B-3a. Kaweah River Downstream of Kaweah No. 1 Powerhouse and Upstream of Kaweah No. 2 Powerhouse Pool Habitat Cross-Section Representation.

Relative Elevation, ft	Calibrated Flow, cfs	Wetted Area, ft^2	Wetted Width, ft
0.00	0.00	189.79	51.35
1.07	7.00	223.75	55.62
1.19	10.00	229.30	56.34
1.38	16.50	238.66	57.55
1.46	20.00	242.82	58.09
1.56	25.00	248.09	58.78
1.64	30.00	252.78	59.39
1.72	35.00	257.04	59.95
1.79	40.00	260.97	60.46
1.85	45.00	264.61	60.94
1.93	52.10	269.42	61.58
2.15	75.00	282.73	63.33
2.34	100.00	294.81	64.93
2.50	125.00	305.24	66.32
2.64	150.00	314.53	67.55
2.76	175.00	322.96	68.68
2.87	200.00	330.73	69.71
2.97	225.00	337.96	70.68
3.07	250.00	344.73	71.59
3.14	271.50	350.26	72.33
3.23	300.00	357.20	73.26
3.38	350.00	368.52	74.78
3.52	400.00	378.95	76.18
3.75	497.00	397.21	78.64
3.97	600.00	414.47	80.97
4.15	700.00	429.67	83.03
4.32	800.00	443.66	84.92
4.47	900.00	456.67	86.69
4.61	1000.00	468.88	88.35
4.86	1200.00	491.34	91.40
5.09	1400.00	511.73	94.18

Table B-3b. Kaweah River Downstream of Kaweah No. 1 Powerhouse and Upstream of Kaweah No. 2 Powerhouse Run Habitat Cross-Section Representation.

Relative Elevation, ft	Calibrated Flow, cfs	Wetted Area, ft^2	Wetted Width, ft
0.00	0.00	0.00	0.00
1.32	7.00	26.48	36.12
1.45	10.00	31.24	38.95
1.65	16.50	39.39	43.31
1.73	20.00	43.05	45.10
1.83	25.00	47.74	47.28
1.92	30.00	51.94	49.14
1.99	35.00	55.78	50.77
2.06	40.00	59.34	52.22
2.12	45.00	62.67	53.54
2.20	52.10	67.06	55.23
2.42	75.00	79.38	59.65
2.60	100.00	90.69	63.39
2.75	125.00	100.56	66.45
2.88	150.00	109.41	69.07
2.99	175.00	117.50	71.35
3.10	200.00	124.99	73.40
3.19	225.00	132.00	75.25
3.28	250.00	138.59	76.94
3.35	271.50	143.99	78.30
3.43	300.00	150.80	79.97
3.57	350.00	161.95	82.62
3.69	400.00	172.28	84.99
3.90	497.00	190.49	88.98
4.09	600.00	207.84	92.59
4.26	700.00	223.21	95.66
4.40	800.00	237.44	98.40
4.54	900.00	250.75	100.88
4.66	1000.00	263.28	103.16
4.88	1200.00	286.46	107.21
5.07	1400.00	307.65	110.77

Table B-3c. Kaweah River Downstream of Kaweah No. 1 Powerhouse and Upstream of Kaweah No. 2 Powerhouse Low Gradient Riffle (LGR) Habitat Cross-Section Representation.

Relative Elevation, ft	Calibrated Flow, cfs	Wetted Area, ft^2	Wetted Width, ft
0.00	0.00	0.53	17.98
1.10	7.00	15.31	31.61
1.22	10.00	18.60	33.49
1.41	16.50	24.51	36.59
1.49	20.00	27.27	37.94
1.59	25.00	30.86	39.62
1.68	30.00	34.15	41.10
1.76	35.00	37.20	42.44
1.83	40.00	40.08	43.65
1.89	45.00	42.80	44.77
1.97	52.10	46.45	46.24
2.20	75.00	56.94	50.24
2.39	100.00	66.89	53.79
2.55	125.00	75.81	56.82
2.69	150.00	83.97	59.48
2.82	175.00	91.56	61.87
2.93	200.00	98.70	64.05
3.03	225.00	105.45	66.06
3.13	250.00	111.89	67.94
3.20	271.50	117.20	69.46
3.30	300.00	123.97	71.36
3.45	350.00	135.20	74.43
3.59	400.00	145.75	77.24
3.82	497.00	164.70	82.10
4.04	600.00	183.13	86.64
4.23	700.00	199.74	90.60
4.40	800.00	215.35	94.21
4.55	900.00	230.13	97.54
4.69	1000.00	244.21	100.65
4.95	1200.00	270.65	106.31
5.18	1400.00	295.22	111.39

Table B-3d. Kaweah River Downstream of Kaweah No. 1 Powerhouse and Upstream of Kaweah No. 2 Powerhouse High Gradient Riffle (HGR) Habitat Cross-Section Representation.

Relative Elevation, ft	Calibrated Flow, cfs	Wetted Area, ft^2	Wetted Width, ft
0.00	0.00	2.65	23.99
1.01	7.00	11.92	28.27
1.12	10.00	14.08	29.15
1.30	16.50	17.99	30.69
1.38	20.00	19.82	31.40
1.47	25.00	22.23	32.32
1.55	30.00	24.44	33.15
1.62	35.00	26.50	33.92
1.68	40.00	28.45	34.64
1.74	45.00	30.29	35.31
1.82	52.10	32.78	36.22
2.02	75.00	39.96	38.78
2.20	100.00	46.83	41.18
2.34	125.00	53.01	43.31
2.47	150.00	58.70	45.24
2.58	175.00	64.01	47.02
2.69	200.00	69.02	48.68
2.78	225.00	73.77	50.25
2.87	250.00	78.31	51.74
2.94	271.50	82.06	52.96
3.02	300.00	86.85	54.51
3.16	350.00	94.83	57.07
3.29	400.00	102.35	59.46
3.50	497.00	115.90	63.73
3.70	600.00	129.14	67.84
3.87	700.00	141.12	71.52
4.02	800.00	152.41	74.95
4.16	900.00	163.13	78.19
4.29	1000.00	173.37	81.26
4.52	1200.00	192.66	86.99
4.73	1400.00	210.66	92.27

Table B-4a. East Fork Kaweah River Downstream of the Kaweah No. 1 Diversion and Upstream of Confluence with Kaweah River Pool Habitat Cross-Section Representation.

Relative Elevation, ft	Calibrated Flow, cfs	Wetted Area, ft^2	Wetted Width, ft
0.00	0.00	44.66	28.30
1.17	7.00	65.09	36.85
1.31	10.00	69.47	38.12
1.54	16.50	77.25	40.21
1.64	20.00	80.84	41.13
1.76	25.00	85.52	42.29
1.87	30.00	89.78	43.31
1.96	35.00	93.73	44.23
2.05	40.00	97.43	45.08
2.13	45.00	100.92	45.86
2.23	52.10	105.60	46.88
2.51	75.00	118.96	49.69
2.75	100.00	131.56	52.21
2.96	125.00	142.79	54.36
3.14	150.00	153.03	56.27
3.30	175.00	162.51	57.99
3.44	200.00	171.40	59.56
3.58	225.00	179.79	61.01
3.70	250.00	187.77	62.37
3.80	271.50	194.34	63.48
3.92	300.00	202.70	64.86
4.12	350.00	216.54	67.11
4.31	400.00	229.50	69.16
4.62	497.00	252.69	72.74
4.91	600.00	275.16	76.10
5.16	700.00	295.34	79.03
5.38	800.00	314.24	81.72
5.59	900.00	332.09	84.21
5.78	1000.00	349.06	86.54
6.13	1200.00	380.83	90.79
6.45	1400.00	410.26	94.62

Table B-4b. East Fork Kaweah River Downstream of the Kaweah No. 1 Diversion and Upstream of Confluence with Kaweah River Run Habitat Cross-Section Representation.

Relative Elevation, ft	Calibrated Flow, cfs	Wetted Area, ft^2	Wetted Width, ft
0.00	0.00	0.00	0.00
1.49	7.00	18.83	30.76
1.65	10.00	23.11	33.16
1.91	16.50	30.81	36.84
2.02	20.00	34.41	38.36
2.15	25.00	39.12	40.20
2.27	30.00	43.44	41.77
2.37	35.00	47.46	43.15
2.46	40.00	51.25	44.38
2.54	45.00	54.83	45.49
2.65	52.10	59.65	46.92
2.94	75.00	73.54	50.65
3.20	100.00	86.75	53.81
3.41	125.00	98.62	56.40
3.59	150.00	109.51	58.60
3.75	175.00	119.66	60.53
3.90	200.00	129.20	62.26
4.03	225.00	138.24	63.82
4.16	250.00	146.87	65.25
4.25	271.50	154.00	66.39
4.38	300.00	163.09	67.80
4.58	350.00	178.19	70.03
4.75	400.00	192.40	72.03
5.06	497.00	217.97	75.39
5.34	600.00	242.88	78.44
5.58	700.00	265.37	81.02
5.80	800.00	286.53	83.33
6.00	900.00	306.59	85.42
6.18	1000.00	325.72	87.33
6.51	1200.00	361.69	90.75
6.80	1400.00	395.19	93.74

Table B-4c. East Fork Kaweah River Downstream of the Kaweah No. 1 Diversion and Upstream of Confluence with Kaweah River Low Gradient Riffle (LGR) Habitat Cross-Section Representation.

Relative Elevation, ft	Calibrated Flow, cfs	Wetted Area, ft^2	Wetted Width, ft
0.00	0.00	0.00	0.00
1.27	7.00	8.45	16.15
1.39	10.00	10.38	17.85
1.58	16.50	13.86	20.53
1.66	20.00	15.49	21.66
1.76	25.00	17.62	23.06
1.85	30.00	19.58	24.26
1.93	35.00	21.40	25.33
1.99	40.00	23.12	26.29
2.06	45.00	24.74	27.17
2.14	52.10	26.93	28.31
2.35	75.00	33.23	31.35
2.53	100.00	39.24	33.97
2.69	125.00	44.63	36.16
2.82	150.00	49.59	38.05
2.93	175.00	54.20	39.72
3.04	200.00	58.55	41.24
3.13	225.00	62.67	42.62
3.22	250.00	66.60	43.89
3.29	271.50	69.85	44.91
3.38	300.00	73.99	46.18
3.51	350.00	80.88	48.22
3.64	400.00	87.37	50.05
3.85	497.00	99.04	53.18
4.04	600.00	110.41	56.06
4.21	700.00	120.69	58.53
4.36	800.00	130.37	60.75
4.50	900.00	139.54	62.79
4.62	1000.00	148.30	64.66
4.85	1200.00	164.76	68.05
5.05	1400.00	180.10	71.04

Table B-4d. East Fork Kaweah River Downstream of the Kaweah No. 1 Diversion and Upstream of Confluence with Kaweah River High Gradient Riffle (HGR) Habitat Cross-Section Representation.

Relative Elevation, ft	Calibrated Flow, cfs	Wetted Area, ft^2	Wetted Width, ft
0.00	0.00	0.00	0.00
1.53	7.00	19.02	26.95
1.67	10.00	22.70	28.60
1.90	16.50	29.12	31.08
1.99	20.00	32.04	32.09
2.10	25.00	35.80	33.30
2.20	30.00	39.20	34.33
2.29	35.00	42.32	35.22
2.37	40.00	45.23	36.01
2.44	45.00	47.95	36.72
2.53	52.10	51.58	37.63
2.77	75.00	61.82	39.97
2.98	100.00	71.32	41.93
3.15	125.00	79.69	43.52
3.30	150.00	87.25	44.85
3.43	175.00	94.20	46.02
3.55	200.00	100.66	47.05
3.66	225.00	106.73	47.98
3.75	250.00	112.47	48.83
3.83	271.50	117.18	49.50
3.93	300.00	123.14	50.33
4.09	350.00	132.95	51.64
4.22	400.00	142.07	52.80
4.46	497.00	158.26	54.74
4.68	600.00	173.79	56.48
4.86	700.00	187.64	57.94
5.03	800.00	200.51	59.24
5.18	900.00	212.60	60.41
5.32	1000.00	224.04	61.48
5.57	1200.00	245.29	63.37
5.79	1400.00	264.82	65.02

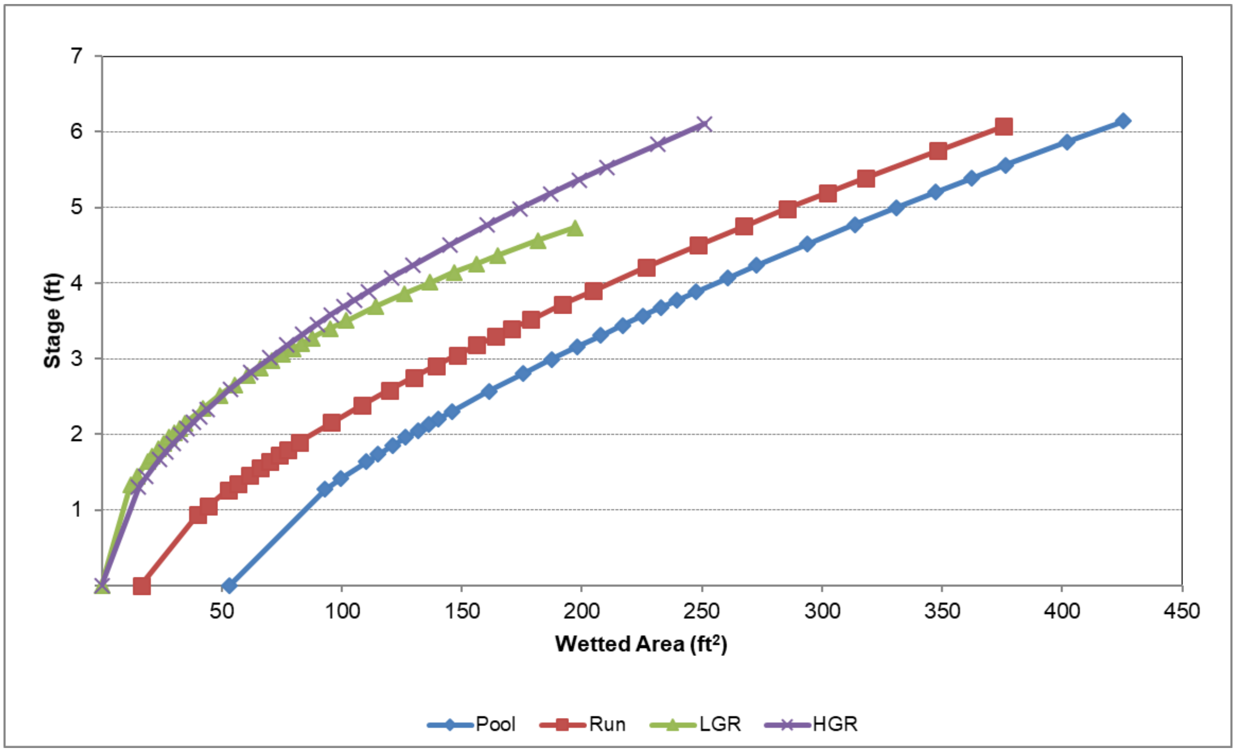

Figure B-1a. Stage-Wetted Area Relationships for Habitat Types in the Kaweah River Downstream of Kaweah No. 3 Powerhouse and Upstream of the East Fork Kaweah River Confluence

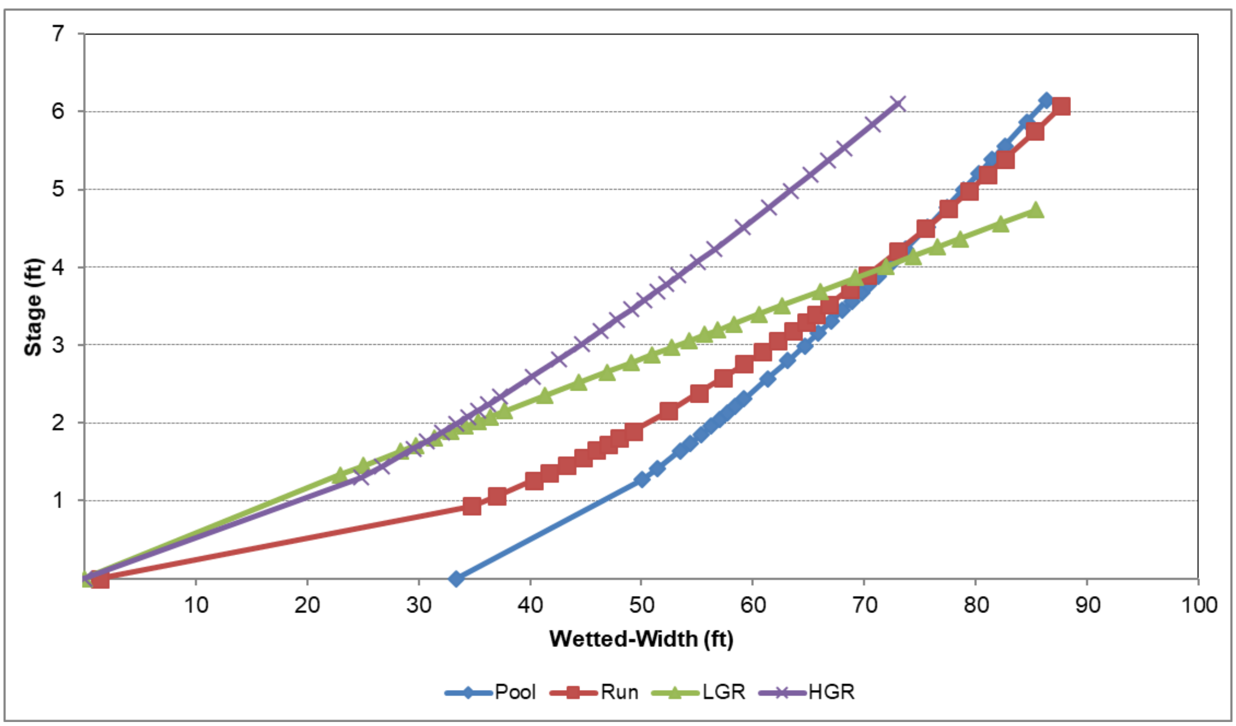

Figure B-1b. Stage-Wetted Width Relationships for Habitat Types in the Kaweah River Downstream of Kaweah No. 3 Powerhouse and Upstream of the East Fork Kaweah River Confluence

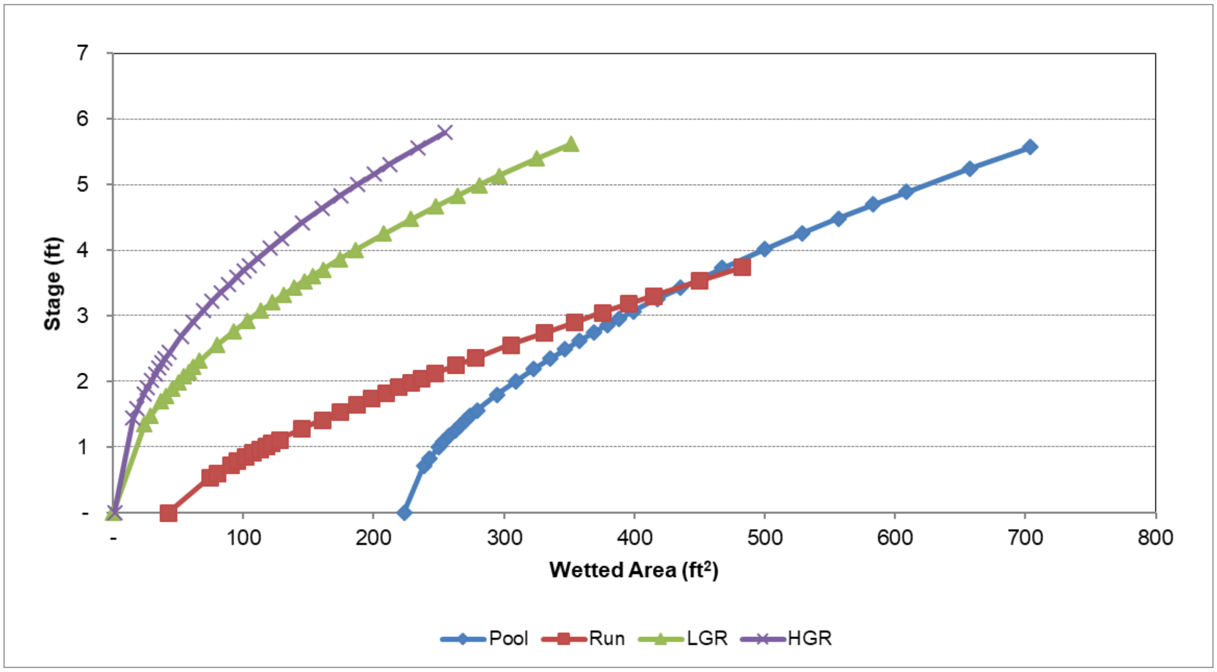

Figure B-2a. Stage-Wetted Area Relationships for Habitat Types in the Kaweah River Downstream of East Fork Kaweah Confluence and Upstream of Kaweah No. 1 Powerhouse.

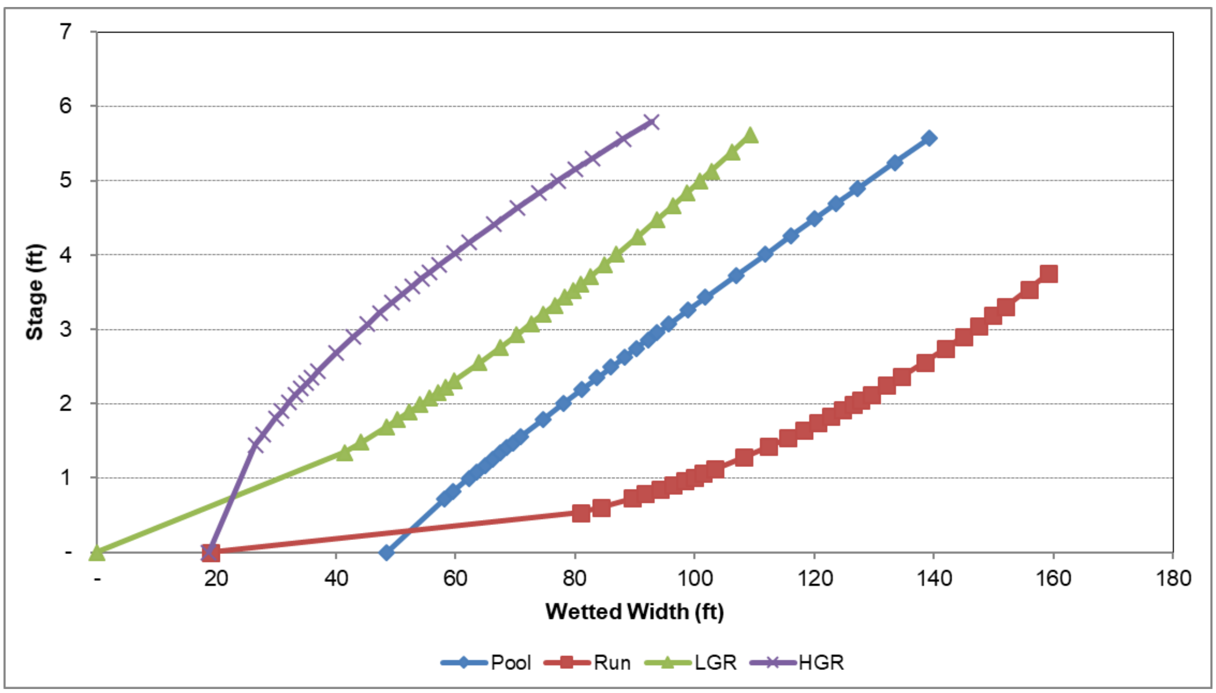

Figure B-2b. Stage-Wetted Width Relationships for Habitat Types in the Kaweah River Downstream of East Fork Kaweah Confluence and Upstream of Kaweah No. 1 Powerhouse.

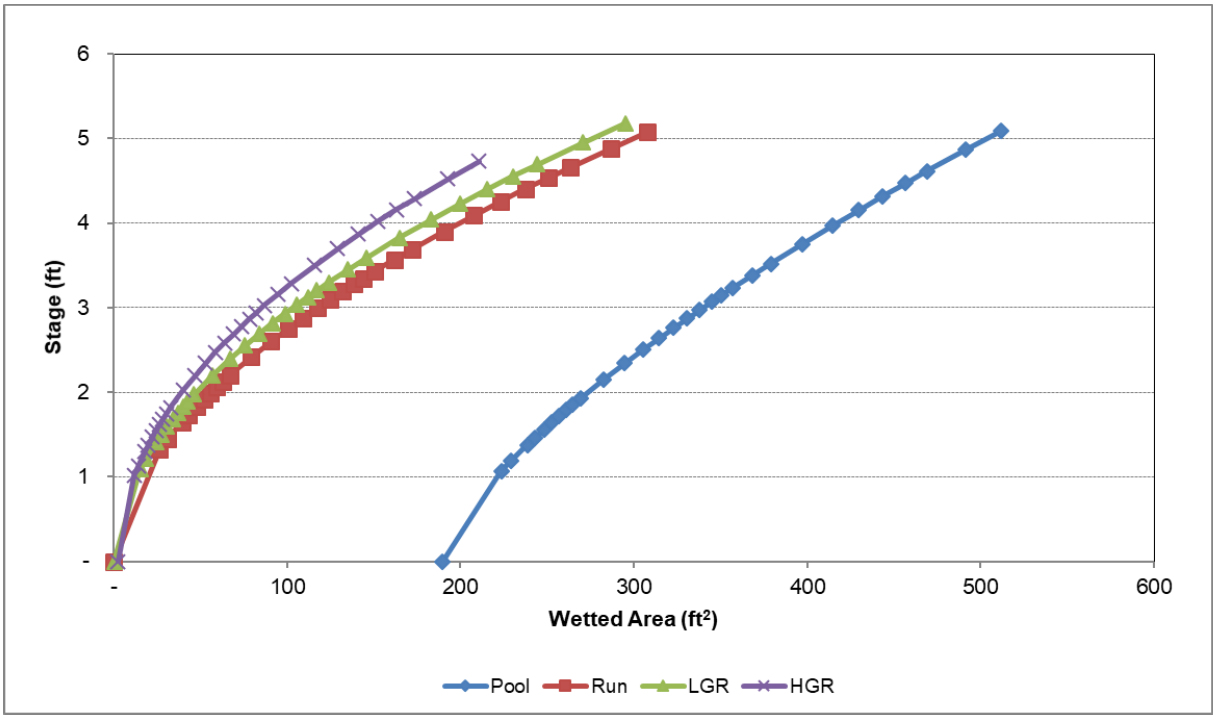

Figure B-3a. Stage-Wetted Area Relationships for Habitat Types in the Kaweah River Downstream of Kaweah No. 1 Powerhouse and Upstream of Kaweah No. 2 Powerhouse

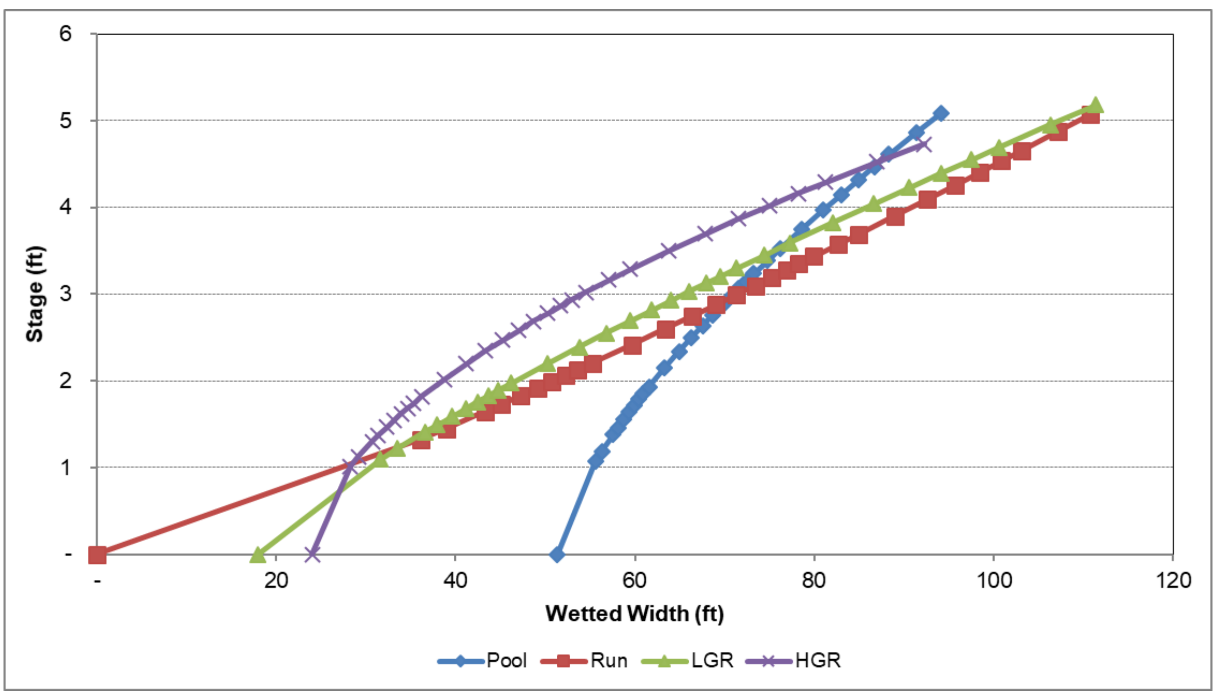

Figure B-3b. Stage-Wetted Width Relationships for Habitat Types in the Kaweah River Downstream of Kaweah No. 1 Powerhouse and Upstream of Kaweah No. 2 Powerhouse

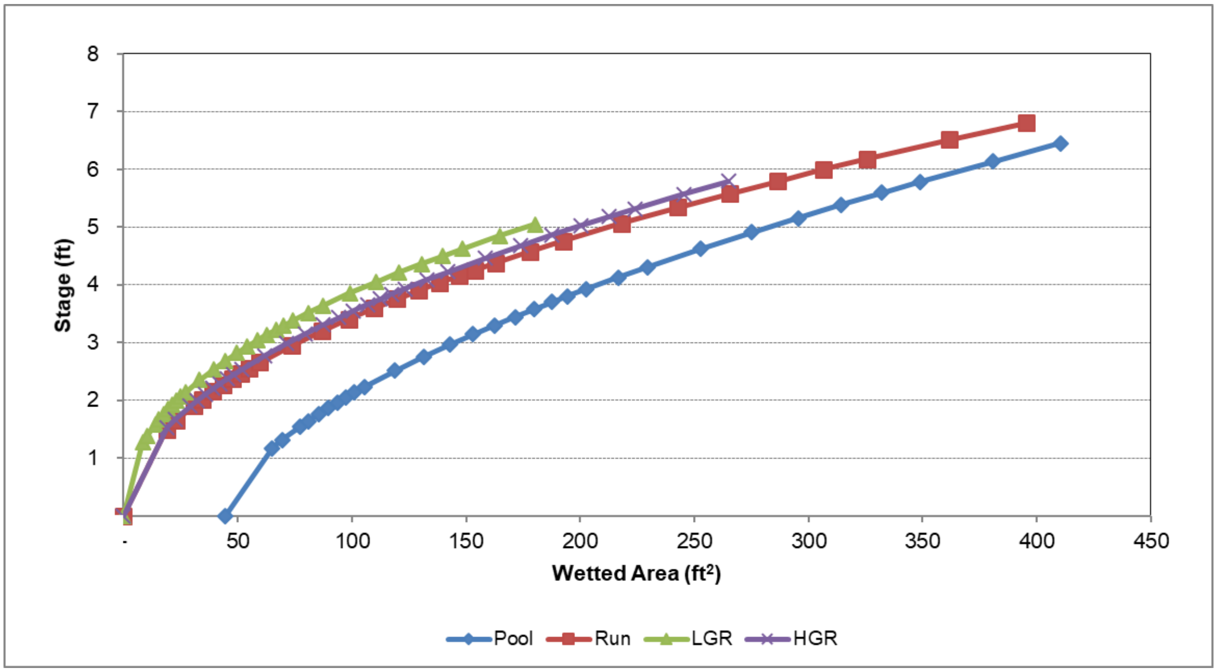

Figure B-4a. Stage-Wetted Area Relationships for Habitat Types in the East Fork Kaweah River Downstream of the Kaweah No. 1 Diversion and Upstream of Confluence with Kaweah River

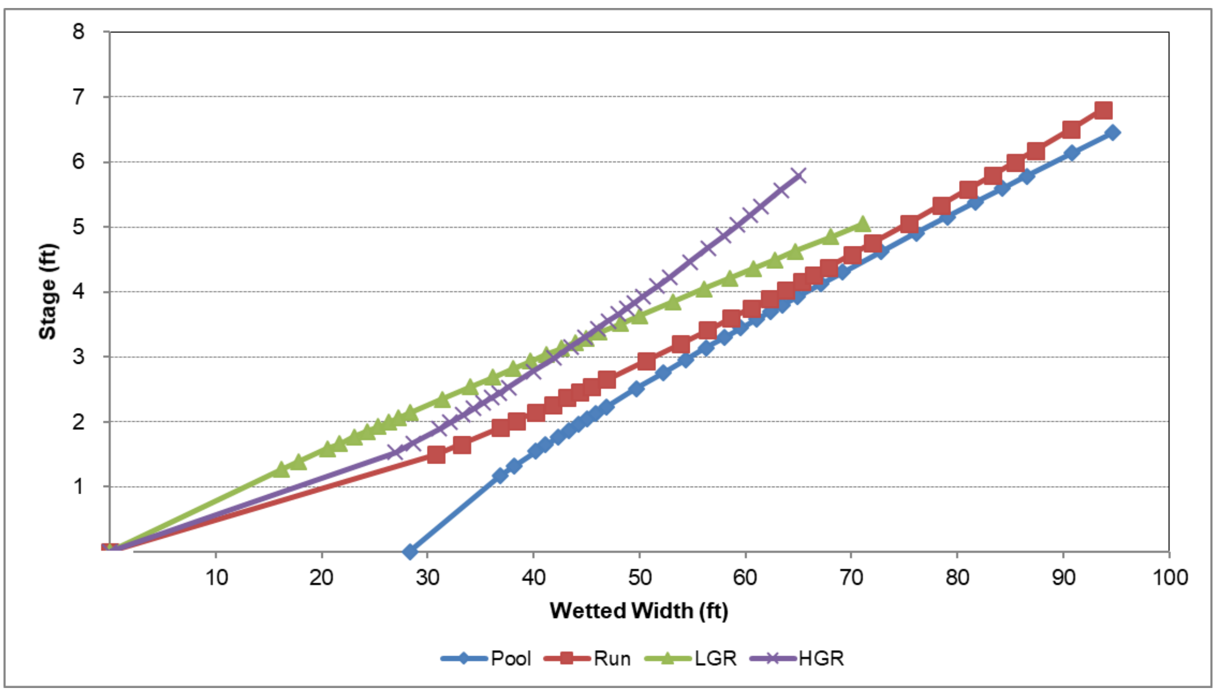

Figure B-4b. Stage-Wetted Width Relationships for Habitat Types in the East Fork Kaweah River Downstream of the Kaweah No. 1 Diversion and Upstream of Confluence with Kaweah River

APPENDIX C

Meteorological Data
(See Attached Electronic Media)

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Datasets of meteorological data by monitoring station (see Map AQ 4-2), the combined final 2018 calibration period, and the 2030 and 2070 climate change scenarios organized by tab in spreadsheet AQ4-C_Data.xlsx.

Full Stations

Capable of measuring six parameters: (1) air temperature, (2) relative humidity, (3) solar radiation, (4) wind speed, (5) wind direction and (6) barometric pressure.

PCWA Maintained

Powerhouse No. 1 Met Station ....Tab: Powerhouse 1

Other Agency Maintained

Lindcove CIMIS #86* ....Tab: CIMIS 86

Three Rivers Museum DW0117..Tab: DW0117

Three Rivers CW4177.. Tab: C4177

*Barometric pressure was not available for this station

Combined Dataset for 2018 Calibartion Run

The final combined dataset (with data gaps filled) used for the 2018 calibration period is provided on the following tab:

Combined Hourly Data

Climate Change Data

Spreadsheet AQ4-C_Data.xlsx also contains the final meterological data used for the 2030 and 2070 climate change scenarios. These data can be found on the following tabs:

- 2030 Climate Change
- 2070 Climate Change

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APPENDIX D

Measured Water Temperature Data
(See Attached Electronic Media)

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The following are a list of sites of Measured Water Temperature by Reach and Monitoring Station (see Map AQ 4-4) contained in the file AQ4-D_Data.xlsx. Each tab contains data from one site.

Main Stem Kaweah River and Tributaries

- Marble Fork (NPS) – Marble Fork Kaweah River
- Middle Fork (NPS) – Middle Fork Kaweah River
- KR DS Conf with MF (NPS) – Kaweah River Downstream with Confluence with Middle Fork Kaweah River
- KR US PH3 – Kaweah River Upstream of Powerhouse 3
- KR DS PH3 – Kaweah River Downstream of Powerhouse 3
- KR US Conf with EF – Kaweah River Upstream of Confluence with East Fork Kaweah River
- KR DS Conf with EF – Kaweah River Downstream of Confluence with East Fork Kaweah River
- KR US PH1 – Kaweah River Upstream of Powerhouse 1
- KR DS PH1 – Kaweah River Downstream of Powerhouse 1
- KR DS PH2 – Kaweah River Downstream of Powerhouse 2
- NF – North Fork Kaweah River
- KR DS Conf. with NF – Kaweah River Downstream of Confluence with North Fork Kaweah River

East Fork Kaweah River

- EF US of PH1 Div. – East Fork Kaweah River Upstream of Powerhouse 1 Diversion
- EF DS of PH1 Div. – East Fork Kaweah River Downstream of Powerhouse 1 Diversion
- EF US Conf with KR – East Fork Kaweah River Upstream of Confluence with Kaweah River

Flowlines

- K1 Flowline Below PH1 Div. – K1 Flowline Below Powerhouse 1 Diversion
- K1 Flowline Above PH1 – K1 Flowline Above Powerhouse 1
- K2 Flowline Below PH3 – K2 Flowline Below Powerhouse 3
- K2 Flowline Above PH2 – K2 Flowline Above Powerhouse 2
- K3 Flowline Above PH3 (Tailrace) – K3 Flowline Above Powerhouse 3 Trailrace
- K3 Flowline Below PH3 – K3 Flowline Below Powerhouse 3

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APPENDIX E

River Temperature Calibration Results

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Table E- 1. Calibration Statistics for the 2018 Simulations in the Kaweah River from Upstream of the East Fork to Downstream of Powerhouse #2.

Location	Hourly			Daily Average		
	Mean Bias[1]	MAE[1]	RMSE[1]	Mean Bias[1]	MAE[1]	RMSE[1]
US of East Fork	-0.06	0.45	0.60	-0.06	0.25	0.33
US of PH#1	0.16	0.50	0.67	0.16	0.39	0.51
US of PH#2	-0.01	0.72	0.91	-0.01	0.53	0.69
DS of PH#2	0.14	0.78	1.03	0.14	0.55	0.79

[1]Mean Bias = average of simulated minus observed, MAE = Mean absolute error, RMSE = Root mean square error

Table E- 2. Calibration Statistics for the 2018 Simulations in the East Fork of the Kaweah River Upstream of the Confluence with the Kaweah River.

Location	Hourly			Daily Average		
	Mean Bias[1]	MAE[1]	RMSE[1]	Mean Bias[1]	MAE[1]	RMSE[1]
US of Confluence	-1.02	1.32	1.60	-0.15	0.64	0.82

[1]Mean Bias = average of simulated minus observed, MAE = Mean absolute error, RMSE = Root mean square error

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Kaweah River

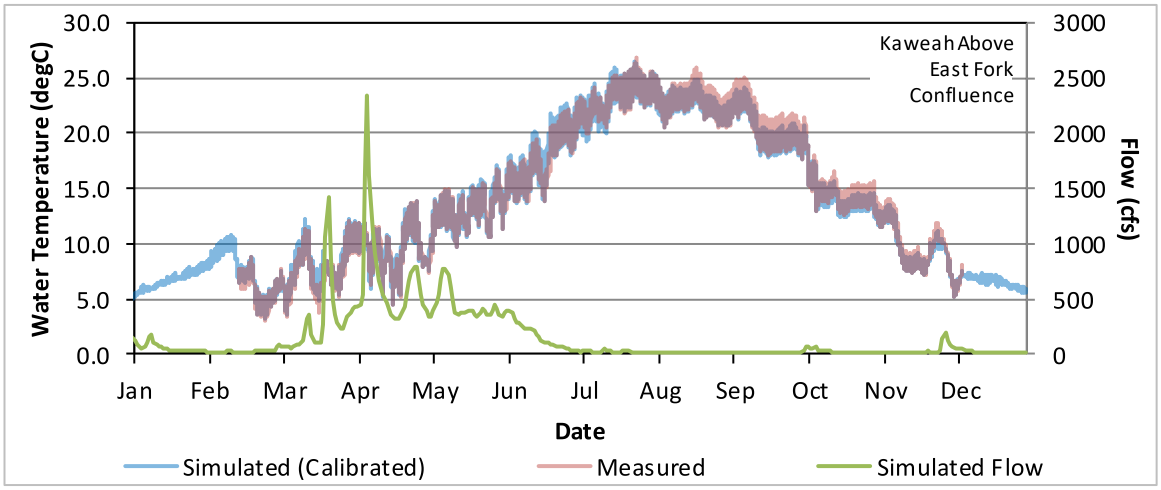

Figure E-1. Water Temperature Model Calibration Results for Kaweah River Upstream of the Confluence with the East Fork for January 1 – December 31, 2018.

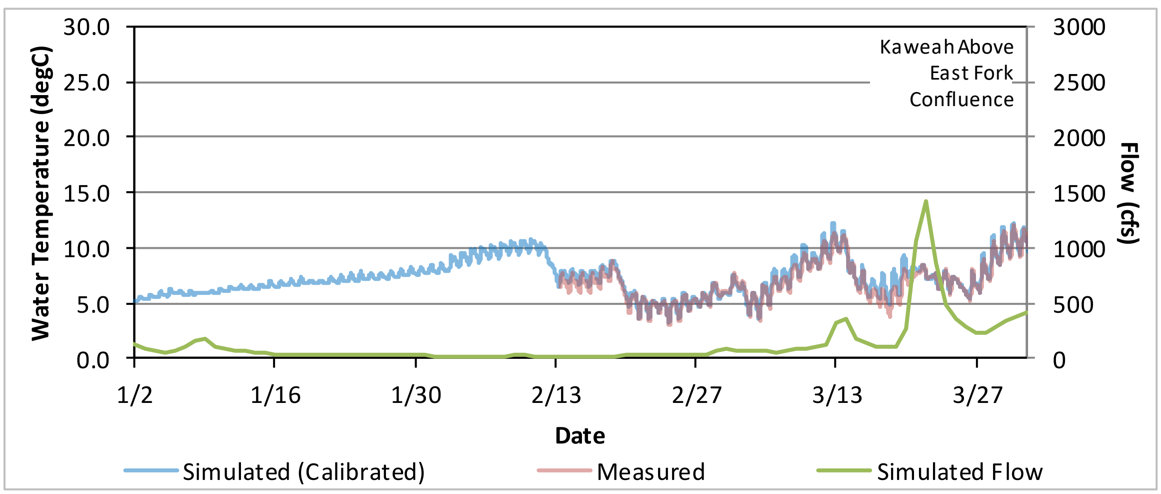

Figure E-2. Water Temperature Model Calibration Results for Kaweah River Upstream of the Confluence with the East Fork for January 1 – March 31, 2018.

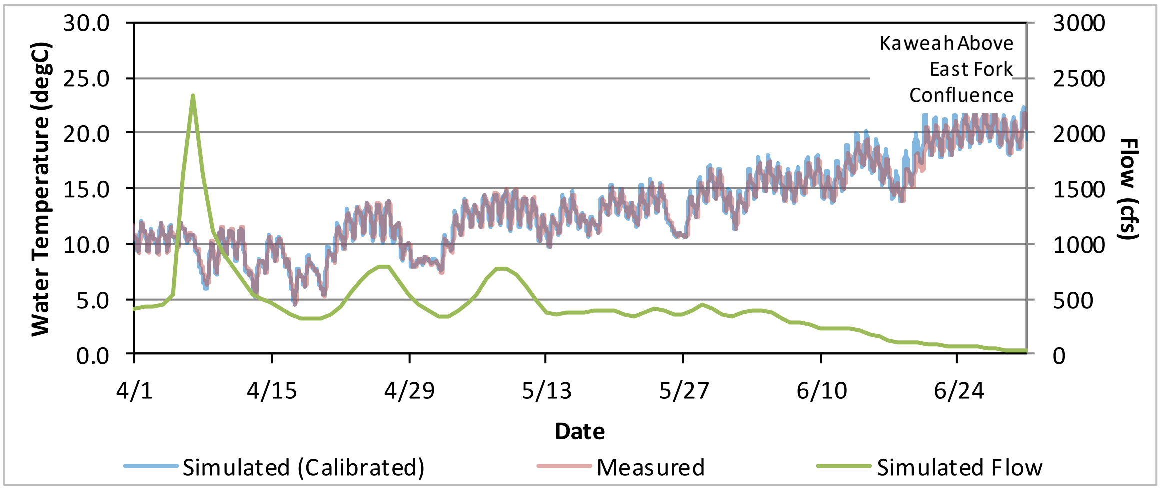

Figure E- 3. **Water Temperature Model Calibration Results for Kaweah River Upstream of the Confluence with the East Fork for April 1 – June 30, 2018.**

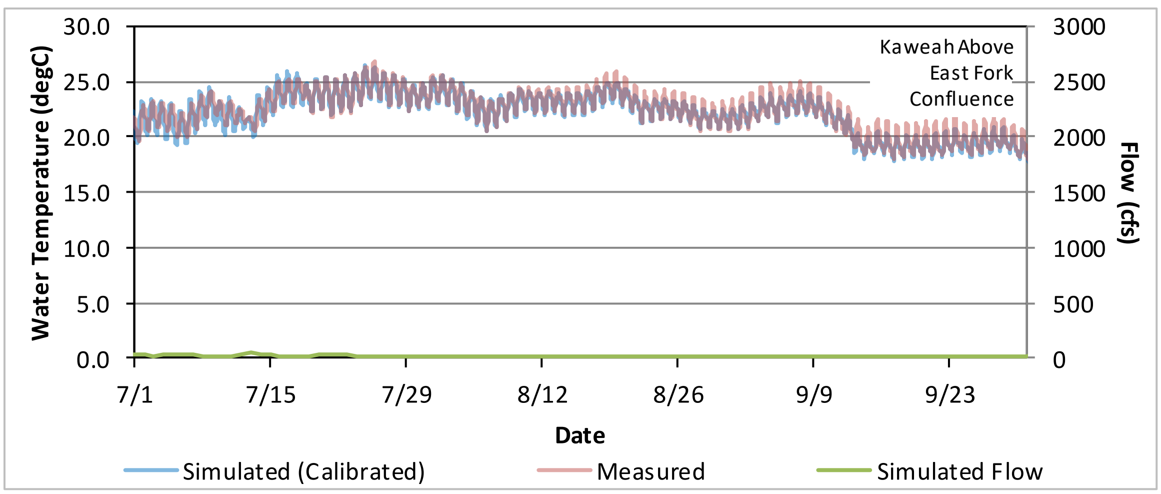

Figure E- 4. **Water Temperature Model Calibration Results for Kaweah River Upstream of the Confluence with the East Fork for July 1 – September 30, 2018.**

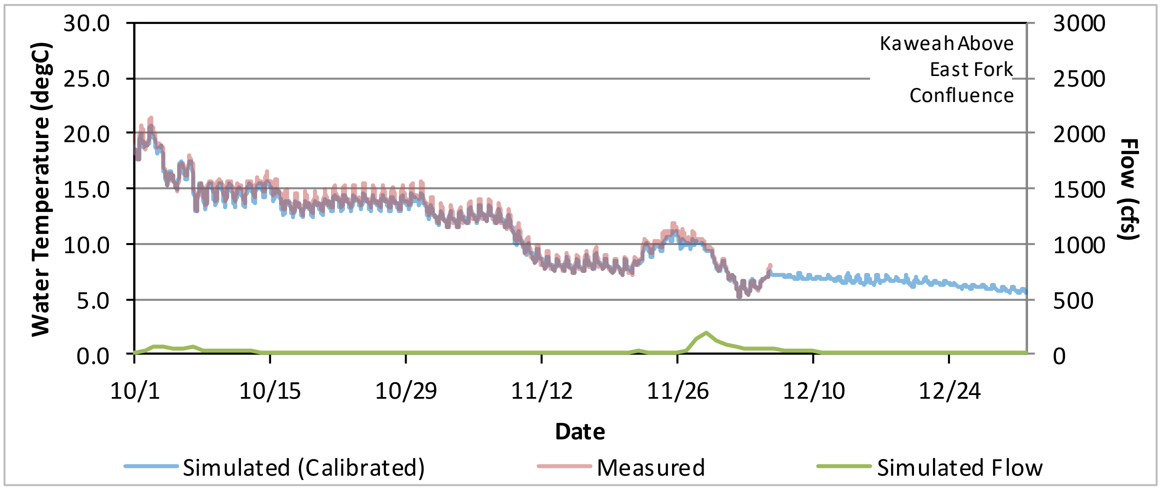

Figure E- 5. **Water Temperature Model Calibration Results for Kaweah River Upstream of the Confluence with the East Fork for October 1 – December 31, 2018.**

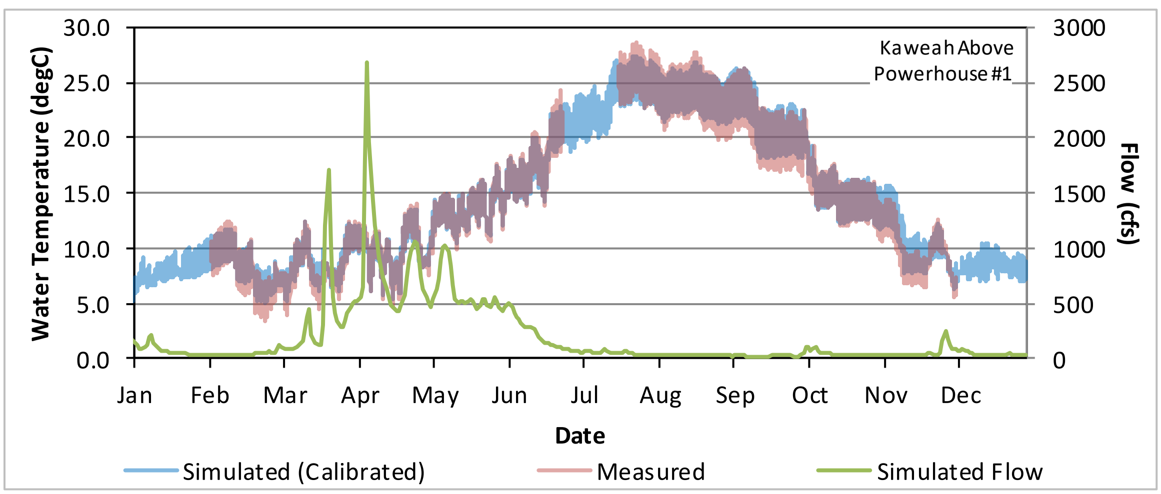

Figure E- 6. **Water Temperature Model Calibration Results for Kaweah River Upstream of Powerhouse #1 for January 1 – December 31, 2018.**

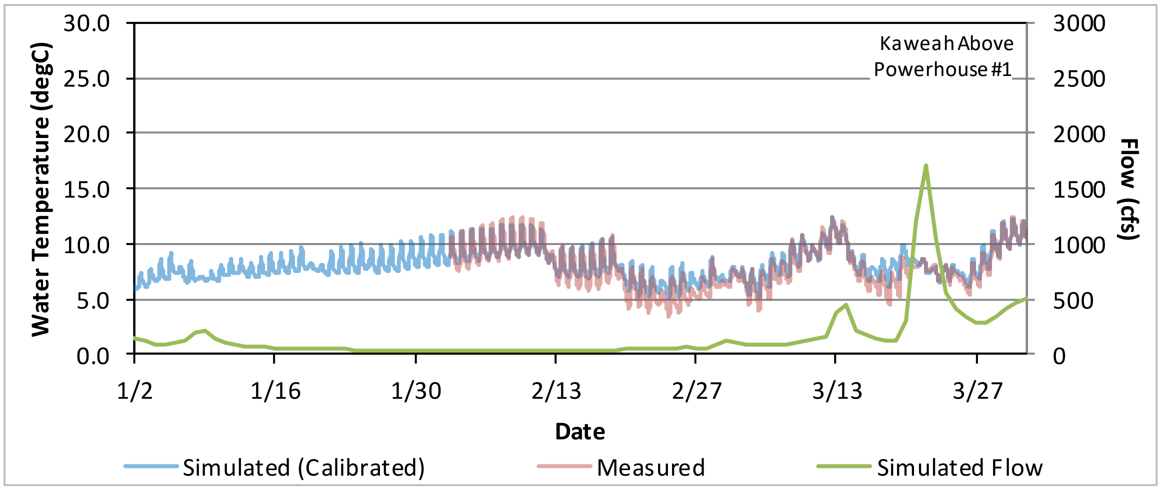

Figure E- 7. Water Temperature Model Calibration Results for Kaweah River Upstream of Powerhouse #1 for January 1 – March 31, 2018.

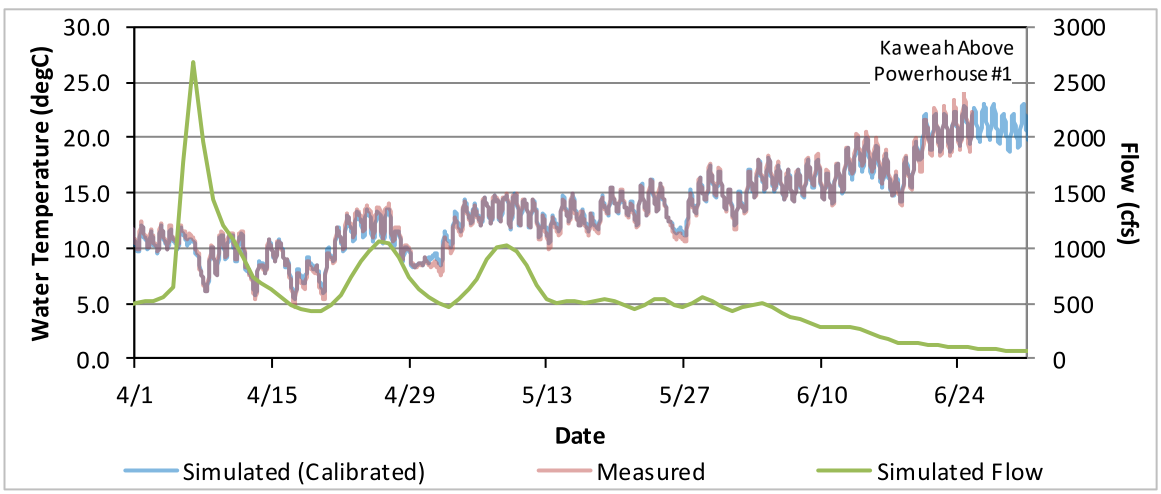

Figure E- 8. Water Temperature Model Calibration Results for Kaweah River Upstream of Powerhouse #1 for April 1 – June 30, 2018.

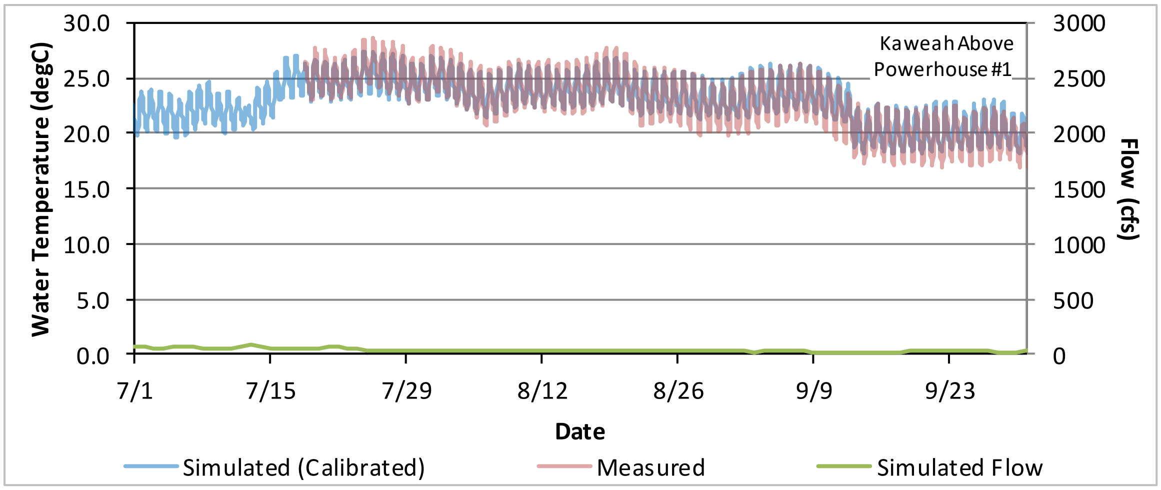

Figure E- 9. **Water Temperature Model Calibration Results for Kaweah River Upstream of Powerhouse #1 for July 1 – September 30, 2018.**

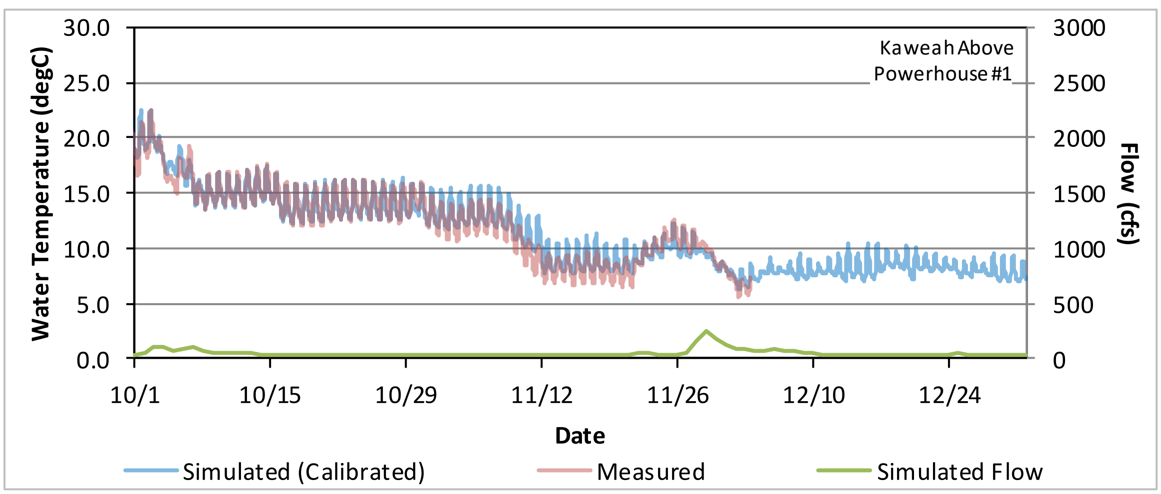

Figure E- 10. **Water Temperature Model Calibration Results for Kaweah River Upstream of Powerhouse #1 for October 1 – December 31, 2018.**

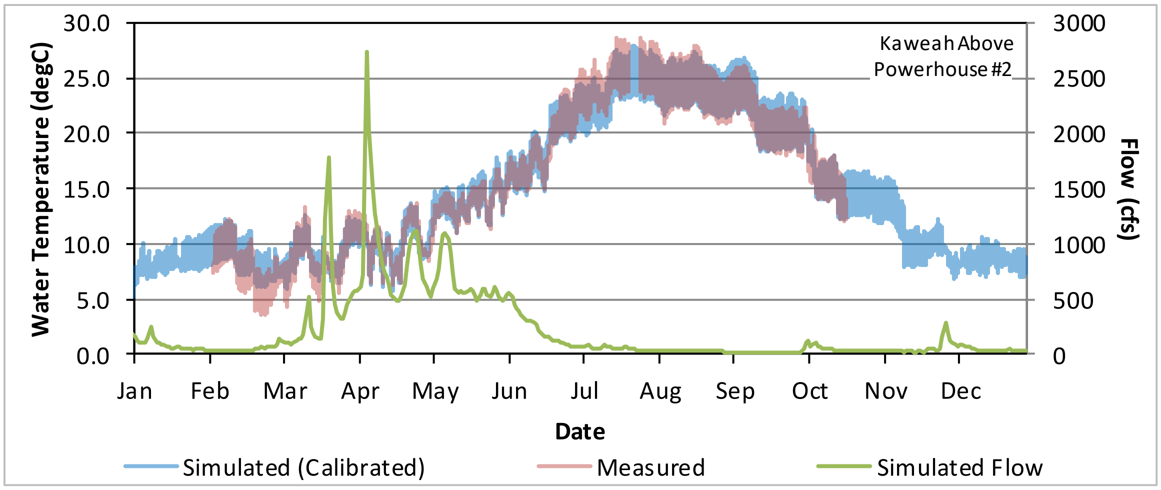

Figure E- 11. **Water Temperature Model Calibration Results for Kaweah River Upstream of Powerhouse #2 for January 1 – December 31, 2018.**

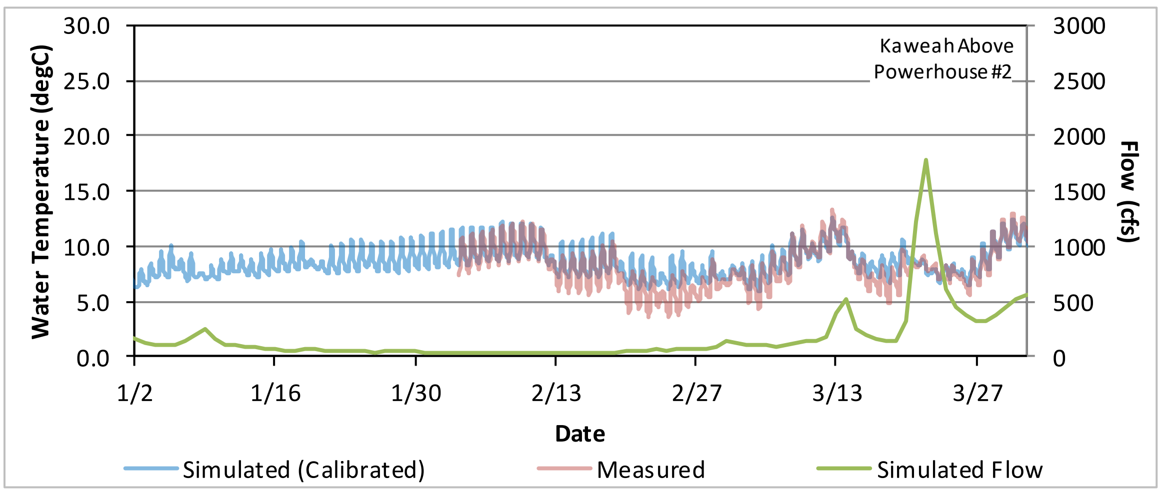

Figure E- 12. **Water Temperature Model Calibration Results for Kaweah River Upstream of Powerhouse #2 for January 1 – March 31, 2018.**

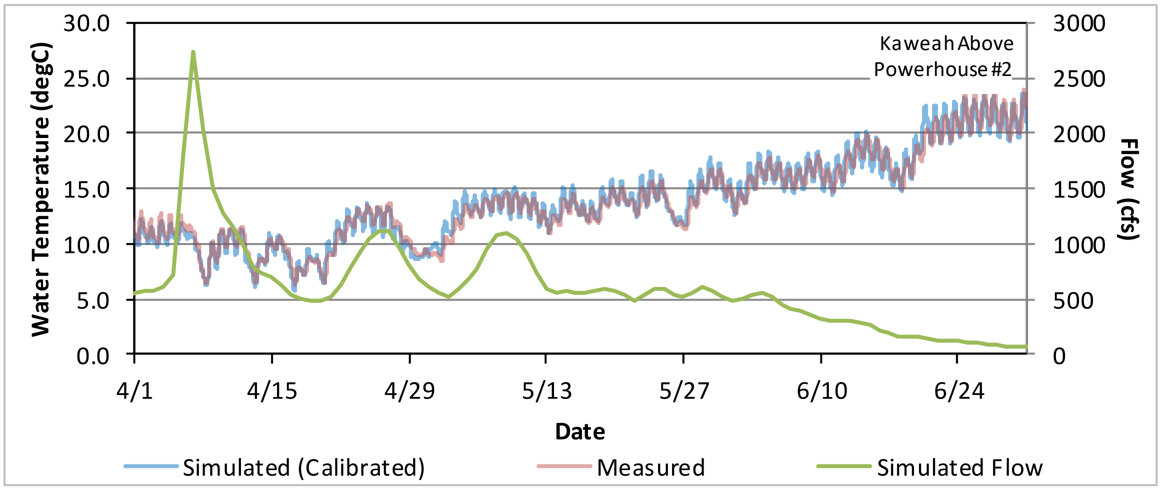

Figure E- 13. Water Temperature Model Calibration Results for Kaweah River Upstream of Powerhouse #2 for April 1 – June 30, 2018.

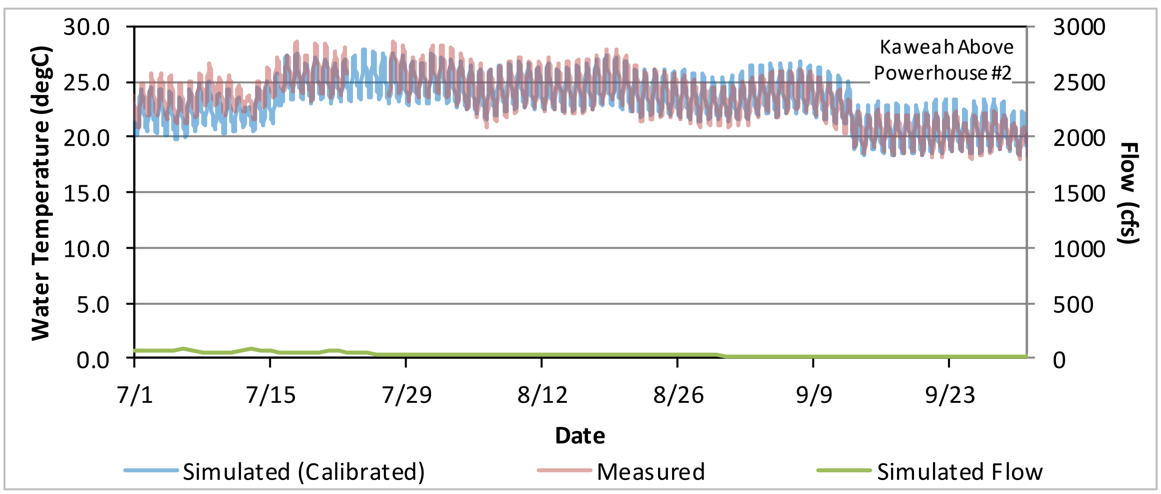

Figure E- 14. Water Temperature Model Calibration Results for Kaweah River Upstream of Powerhouse #2 for July 1 – September 30, 2018.

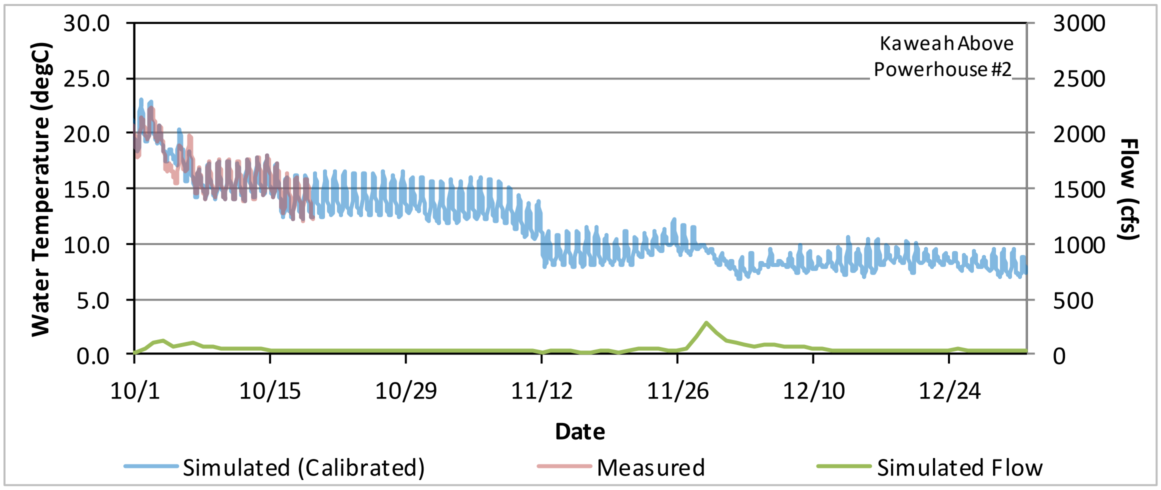

Figure E- 15. **Water Temperature Model Calibration Results for Kaweah River Upstream of Powerhouse #2 for October 1 – December 31, 2018.**

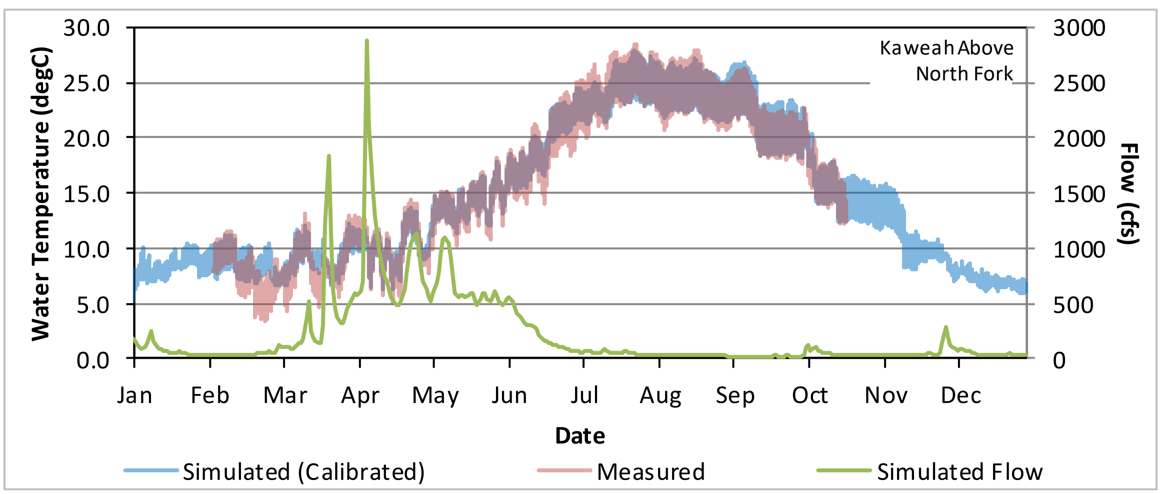

Figure E- 16. **Water Temperature Model Calibration Results for Kaweah River Downstream of Powerhouse #2 for January 1 – December 31, 2018.**

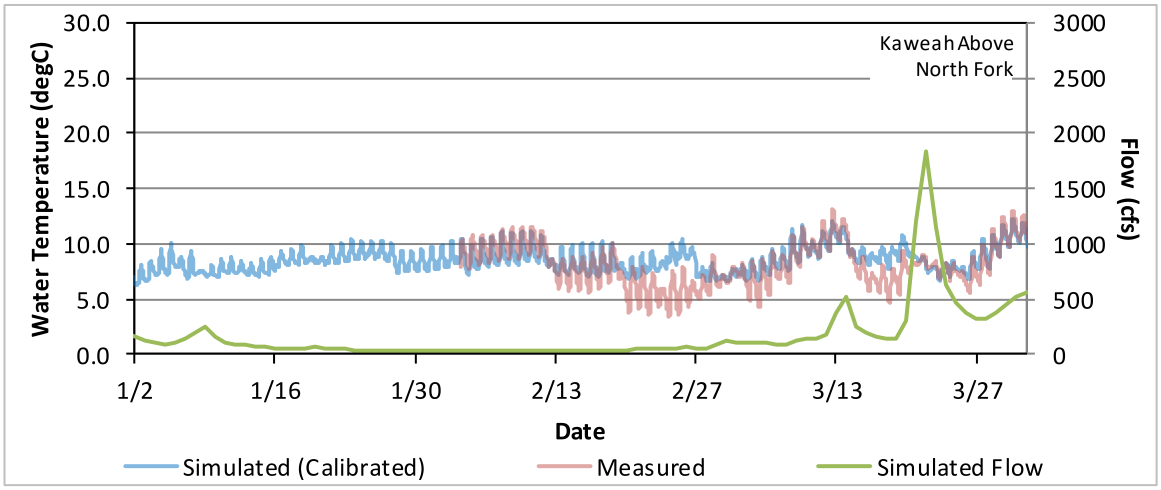

Figure E- 17. Water Temperature Model Calibration Results for Kaweah River Downstream of Powerhouse #2 for January 1 – March 31, 2018.

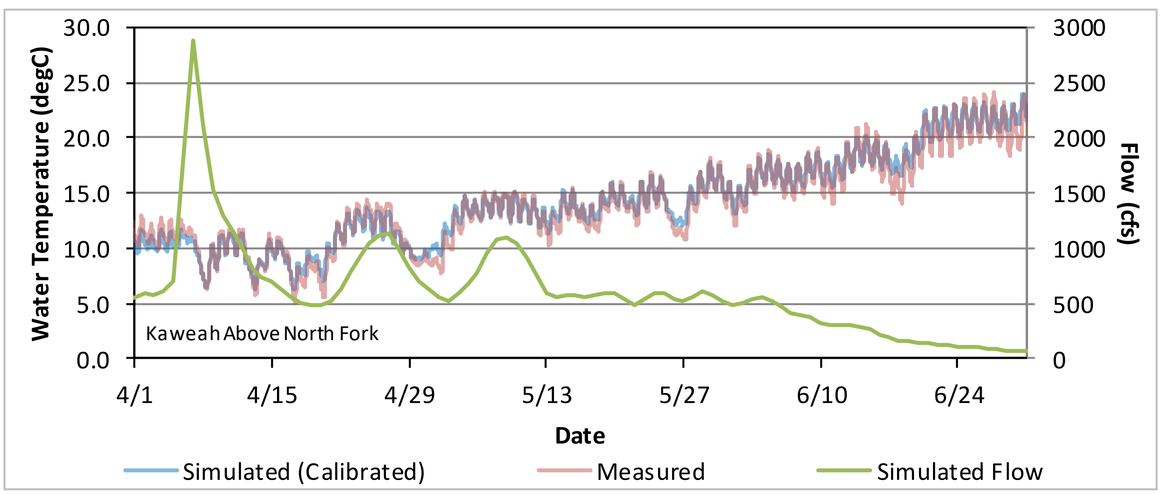

Figure E- 18. Water Temperature Model Calibration Results for Kaweah River Downstream of Powerhouse #2 for April 1 – June 30, 2018.

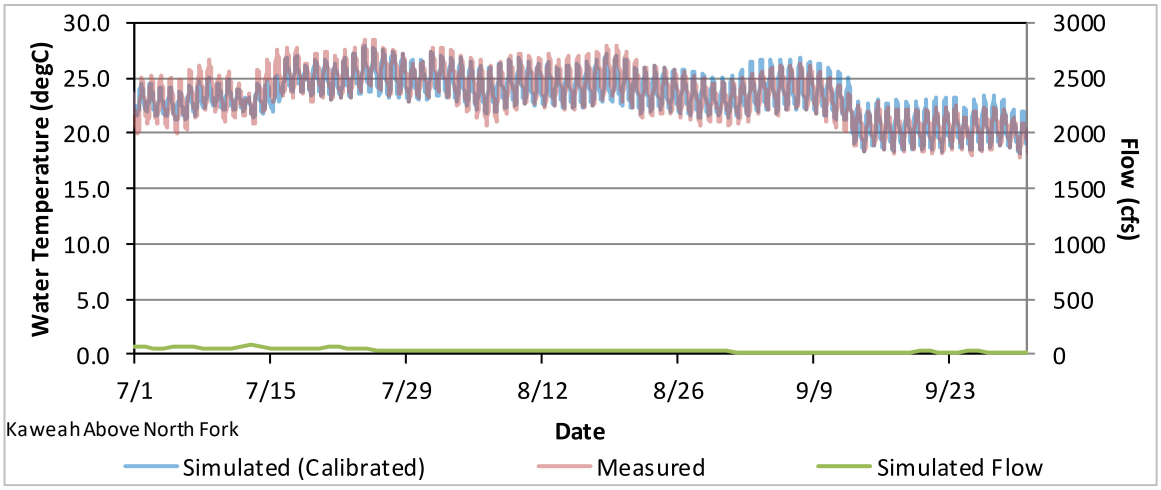

Figure E- 19. Water Temperature Model Calibration Results for Kaweah River Downstream of Powerhouse #2 for July 1 – September 30, 2018.

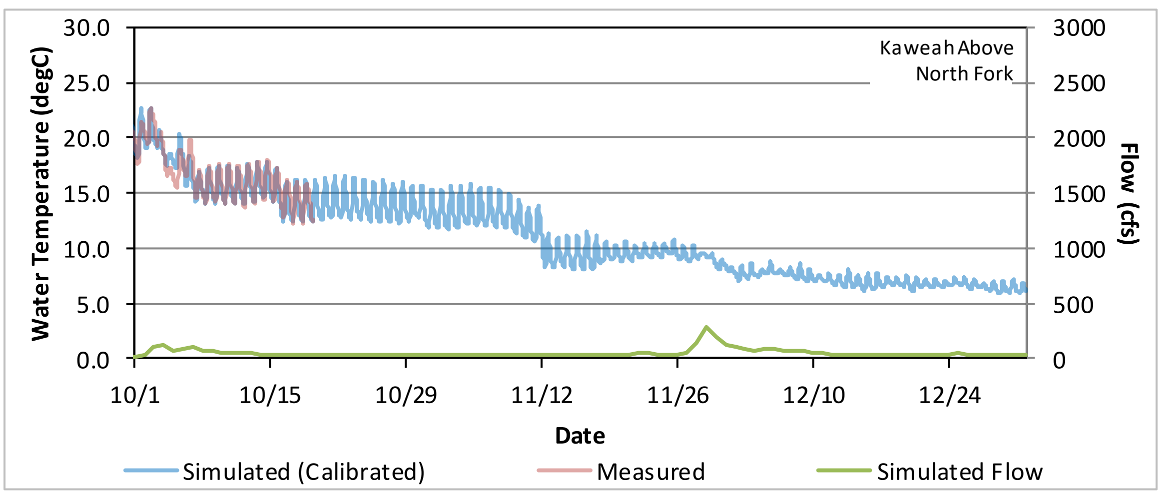

Figure E- 20. Water Temperature Model Calibration Results for Kaweah River Downstream of Powerhouse #2 for October 1 – December 31, 2018.

East Fork of the Kaweah River

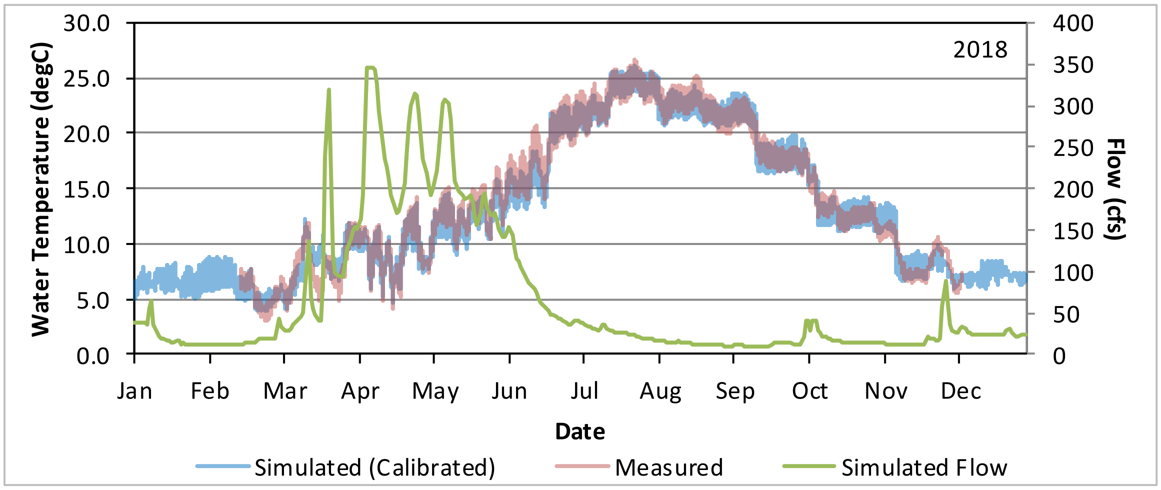

Figure E- 21. Water Temperature Model Calibration Results for East Fork of the Kaweah River Upstream of the Confluence with the Kaweah River for January 1 – December 31, 2018.

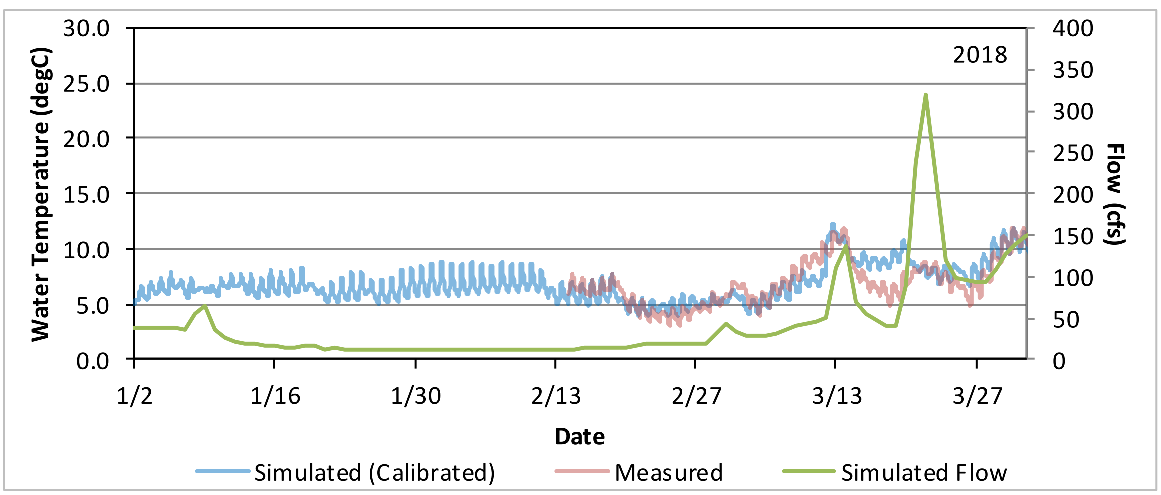

Figure E- 22. Water Temperature Model Calibration Results for East Fork of the Kaweah River Upstream of the Confluence with the Kaweah River for January 1 – March 31, 2018.

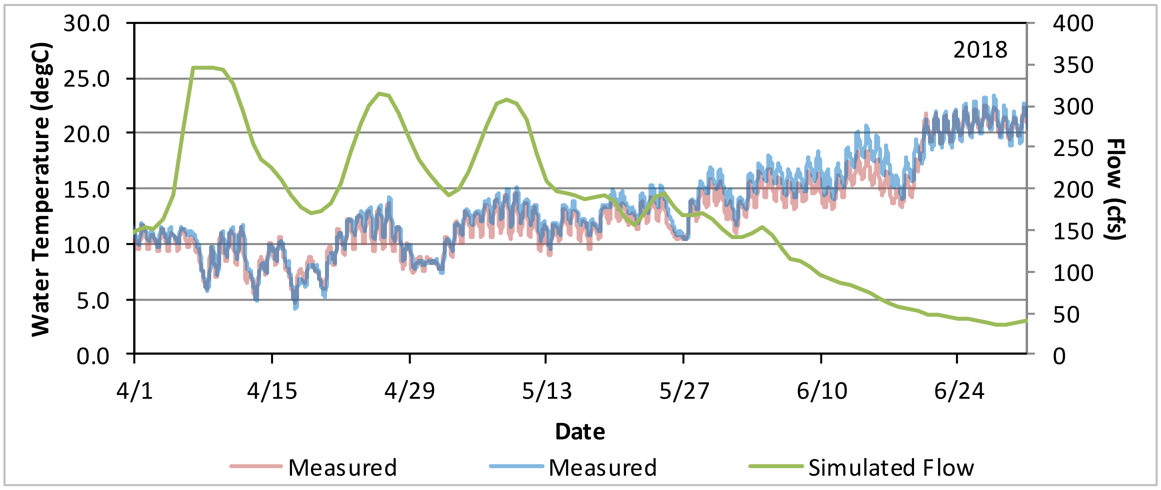

Figure E- 23. **Water Temperature Model Calibration Results for East Fork of the Kaweah River Upstream of the Confluence with the Kaweah River for April 1 – June 30, 2018.**

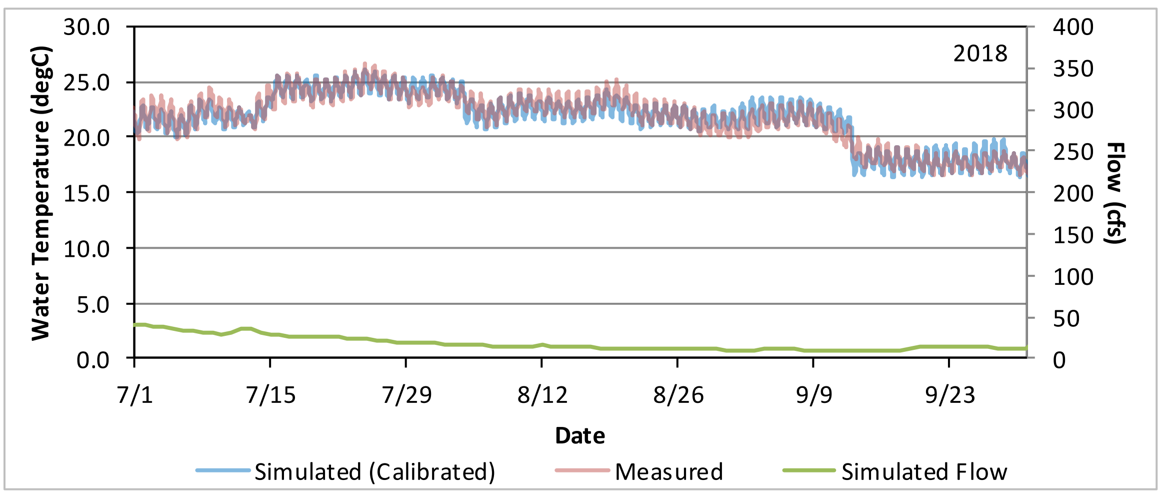

Figure E- 24. **Water Temperature Model Calibration Results for East Fork of the Kaweah River Upstream of the Confluence with the Kaweah River for July 1 – September 30, 2018.**

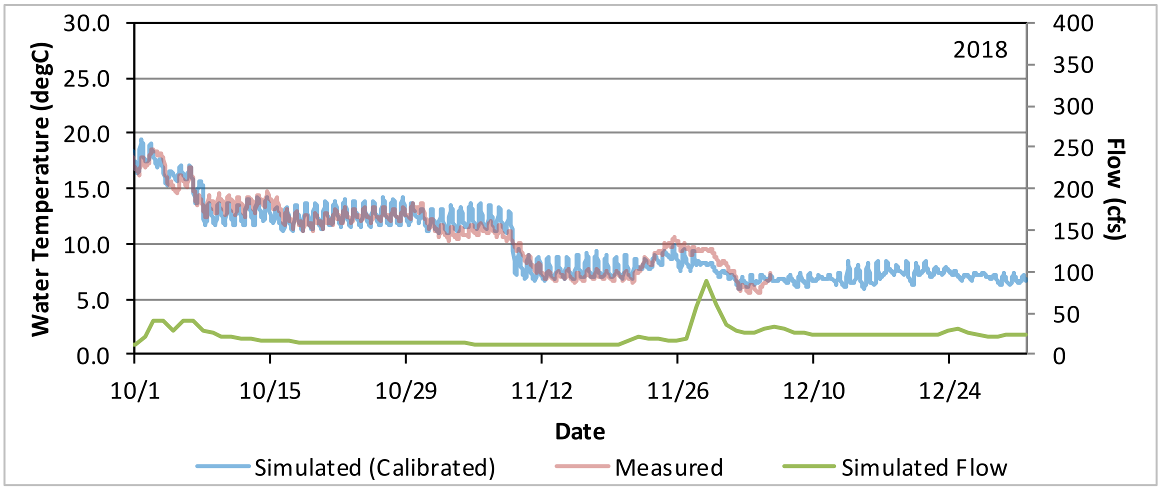

Figure E- 25. Water Temperature Model Calibration Results for East Fork of the Kaweah River Upstream of the Confluence with the Kaweah River for October 1 – December 31, 2018.

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APPENDIX F

Modeled Longitudinal and Temporal Water Temperature Profiles for Baseline (Historic) and Unimpaired Flows

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Table F - 1. Summary Statistics for the 2018 Baseline (Historic) and Unimpaired Simulations in the Kaweah River from Upstream of the East Fork to Upstream of the North Fork.

Location	Hourly			Daily Average		
	Mean Bias[1]	MAE[1]	RMSE[1]	Mean Bias[1]	MAE[1]	RMSE[1]
US East Fork	0.05	0.05	0.09	0.05	0.05	0.08
US PH#1	0.15	0.16	0.26	0.15	0.15	0.24
US PH#2	0.15	0.16	0.23	0.15	0.15	0.21
US North Fork	0.13	0.30	0.44	0.13	0.28	0.41

[1]Mean Bias = average of baseline (historic) minus unimpaired, MAE = Mean absolute error, RMSE = Root mean square error

Table F - 2. Summary Statistics for the 2018 Baseline (Historic) and Unimpaired Simulations in the East Fork of the Kaweah River Upstream of the Confluence with the Kaweah River.

Location	Hourly			Daily Average		
	Mean Bias[1]	MAE[1]	RMSE[1]	Mean Bias[1]	MAE[1]	RMSE[1]
US Confluence	0.07	0.09	0.17	0.07	0.08	0.15

[1]Mean Bias = average of baseline (historic) minus unimpaired, MAE = Mean absolute error, RMSE = Root mean square error

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Kaweah River: Longitudinal Water Temperature Profiles

Figure F - 1. **March 15, 2018 Baseline (Historic) Maximum, Average, and Minimum Longitudinal Water Temperature Profiles in the Kaweah River from Upstream of the Confluence with the East Fork (RM8.95) to Upstream of the Confluence with the North Fork (RM3.17).**

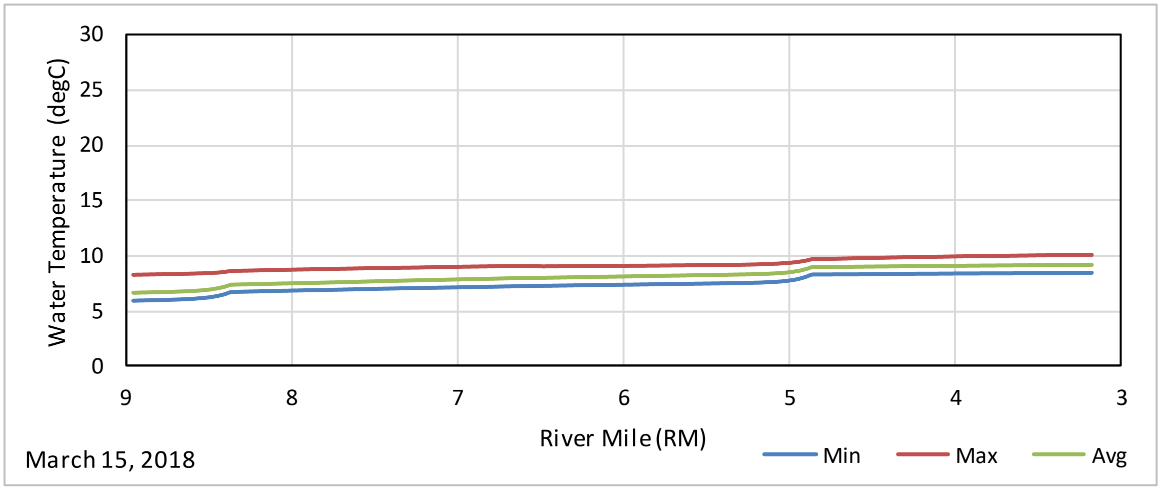


Figure F - 2. **March 15, 2018 Unimpaired Maximum, Average, and Minimum Longitudinal Water Temperature Profiles in the Kaweah River from Upstream of the Confluence with the East Fork (RM8.95) to Upstream of the Confluence with the North Fork (RM3.17).**

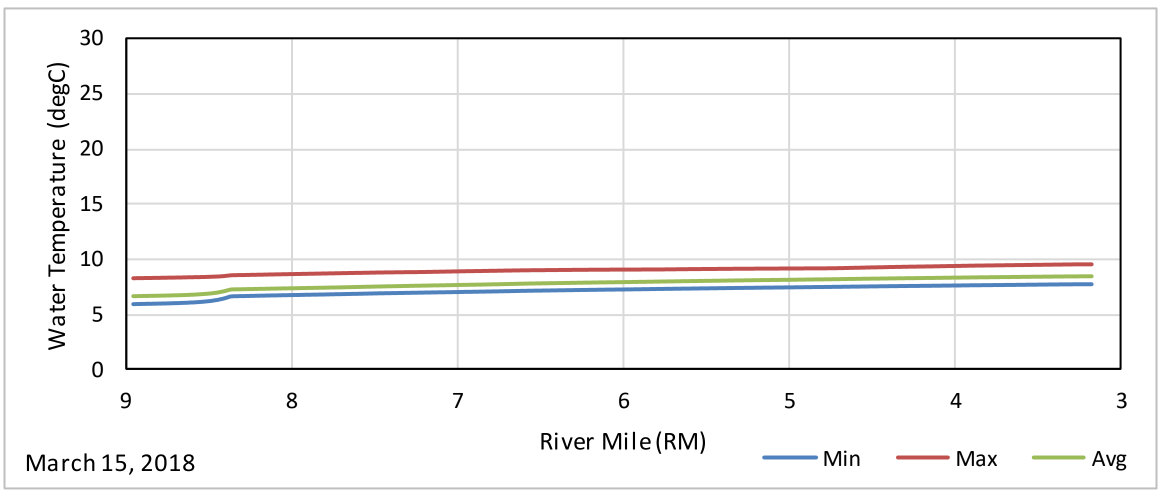


Figure F - 3. **March 15, 2018 Average Longitudinal Water Temperature Profile in the Kaweah River Upstream of the Confluence with the East Fork (RM8.95) to Upstream of the Confluence with the North Fork (RM3.17) for the Baseline (Historic) and Unimpaired Simulations.**

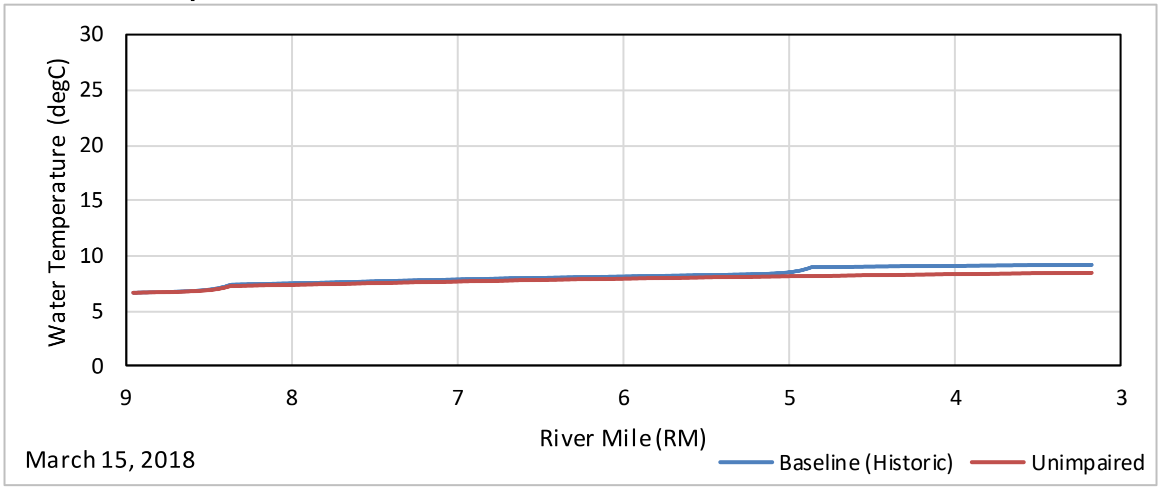


Figure F - 4. **June 15, 2018 Baseline (Historic) Maximum, Average, and Minimum Longitudinal Water Temperature Profiles in the Kaweah River from Upstream of the Confluence with the East Fork (RM8.95) to Upstream of the Confluence with the North Fork (RM3.17).**

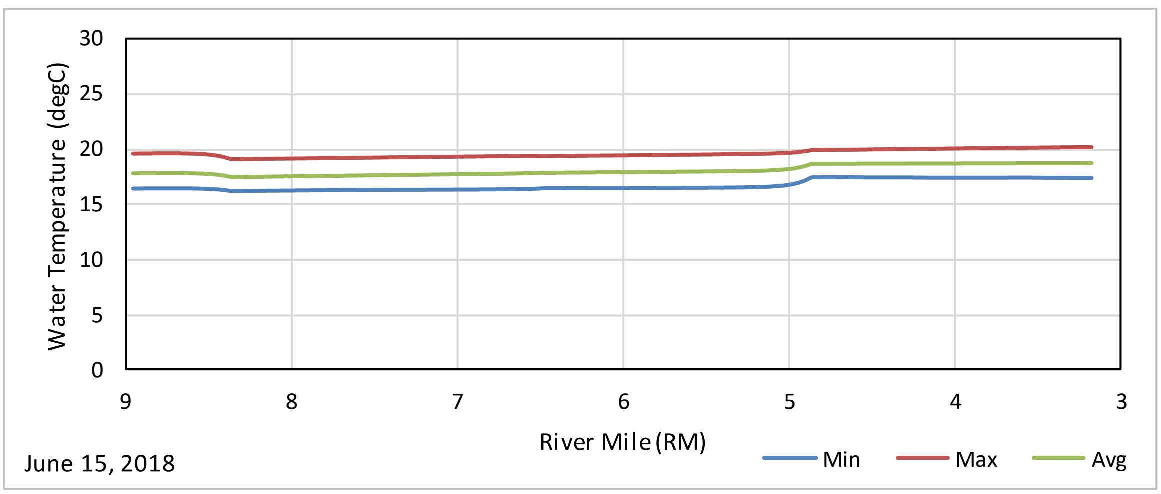


Figure F - 5. June 15, 2018 Unimpaired Maximum, Average, and Minimum Longitudinal Water Temperature Profiles in the Kaweah River from Upstream of the Confluence with the East Fork (RM8.95) to Upstream of the Confluence with the North Fork (RM3.17).

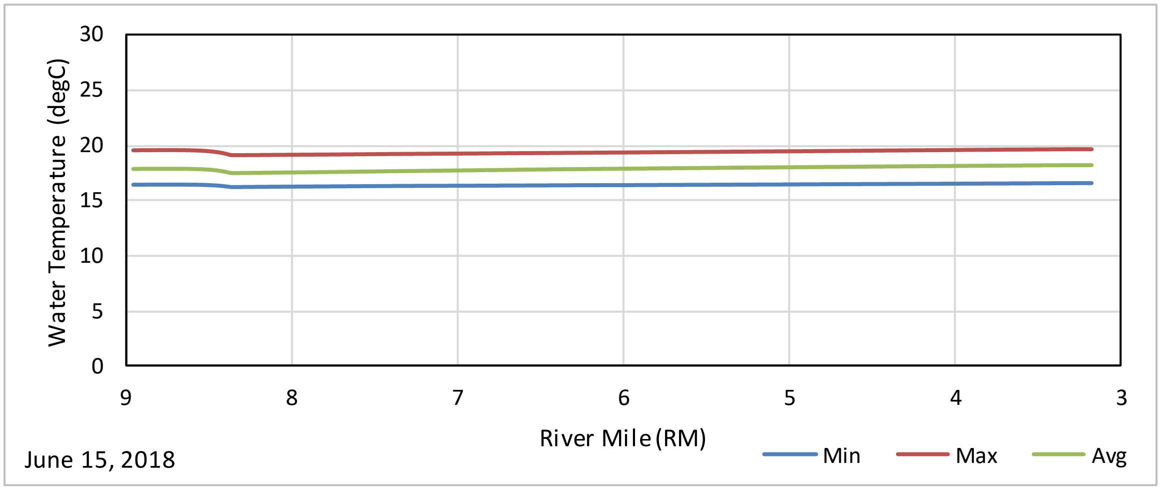
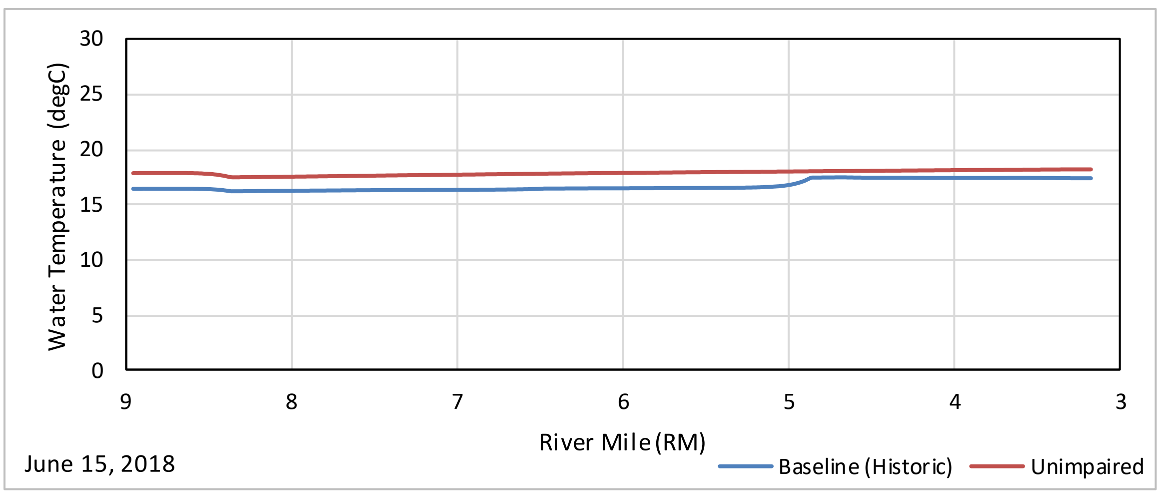


Figure F - 6. June 15, 2018 Average Longitudinal Water Temperature Profile in the Kaweah River from Upstream of the Confluence with the East Fork (RM8.95) to Upstream of the Confluence with the North Fork (RM3.17) for the Baseline (Historic) and Unimpaired Simulations.



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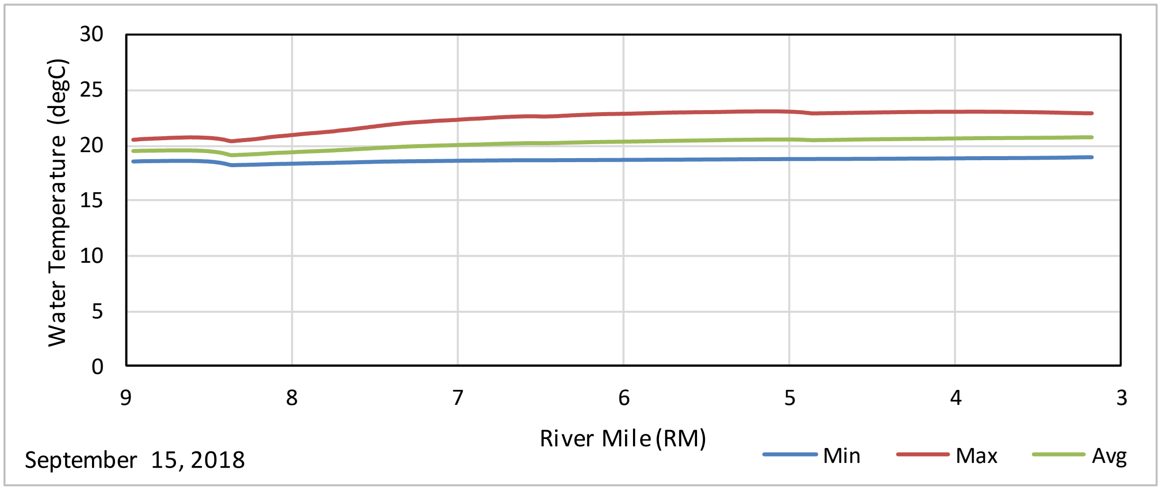


Figure F - 8. September 15, 2018 Unimpaired Maximum, Average, and Minimum Longitudinal Water Temperature Profiles in the Kaweah River from Upstream of the Confluence with the East Fork (RM8.95) to Upstream of the Confluence with the North Fork (RM3.17).

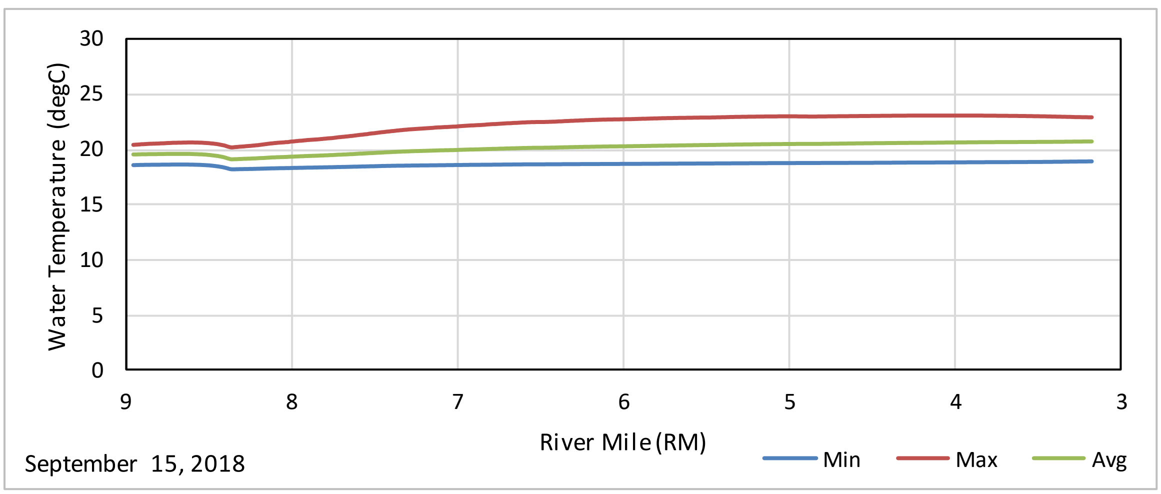
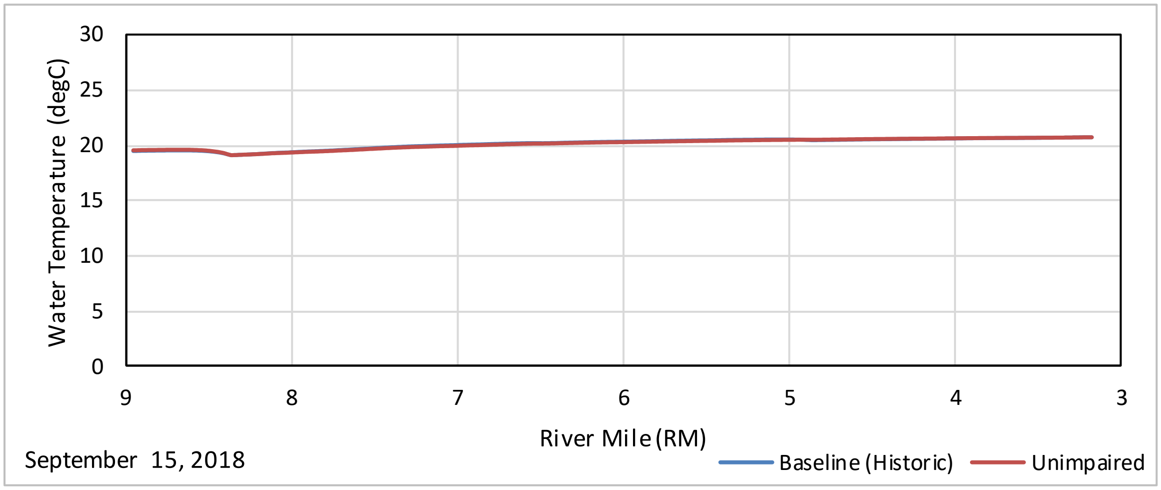


Figure F - 9. September 15, 2018 Average Longitudinal Water Temperature Profile in the Kaweah River from Upstream of the Confluence with the East Fork (RM8.95) to Upstream of the Confluence with the North Fork (RM3.17) for the Baseline (Historic) and Unimpaired Simulations.



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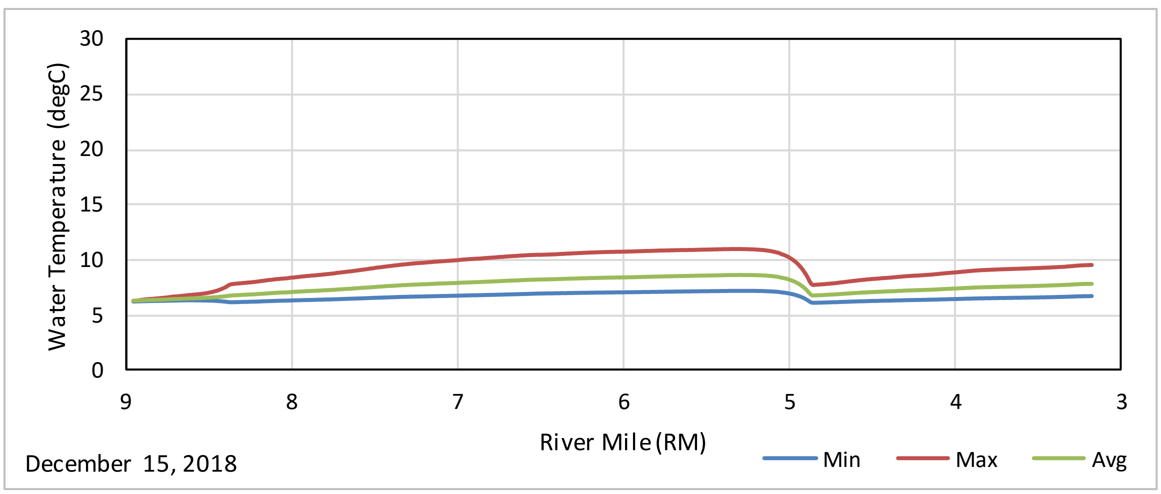


Figure F - 11. December 15, 2018 Unimpaired Maximum, Average, and Minimum Longitudinal Water Temperature Profiles in the Kaweah River from Upstream of the Confluence with the East Fork (RM8.95) to Upstream of the Confluence with the North Fork (RM3.17).

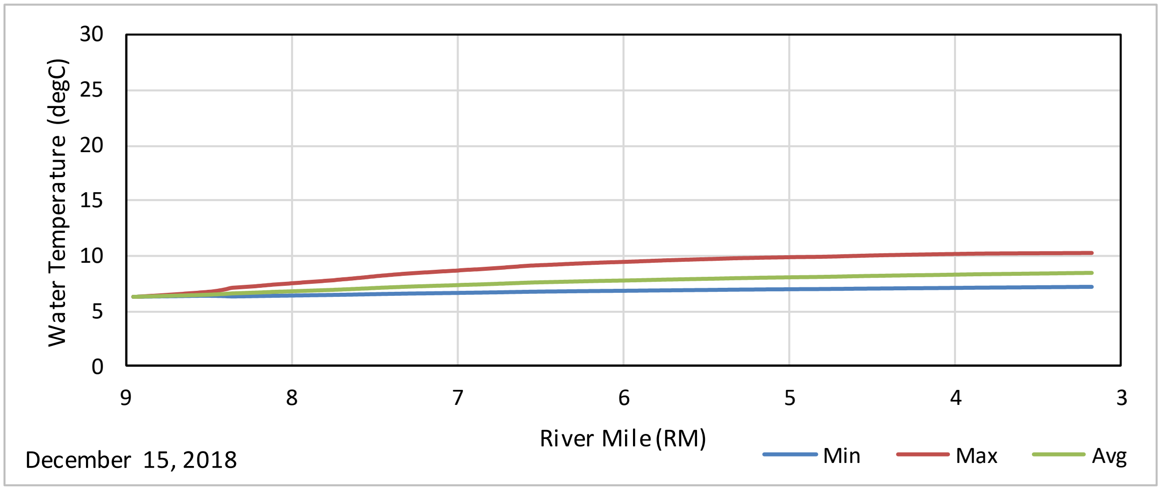
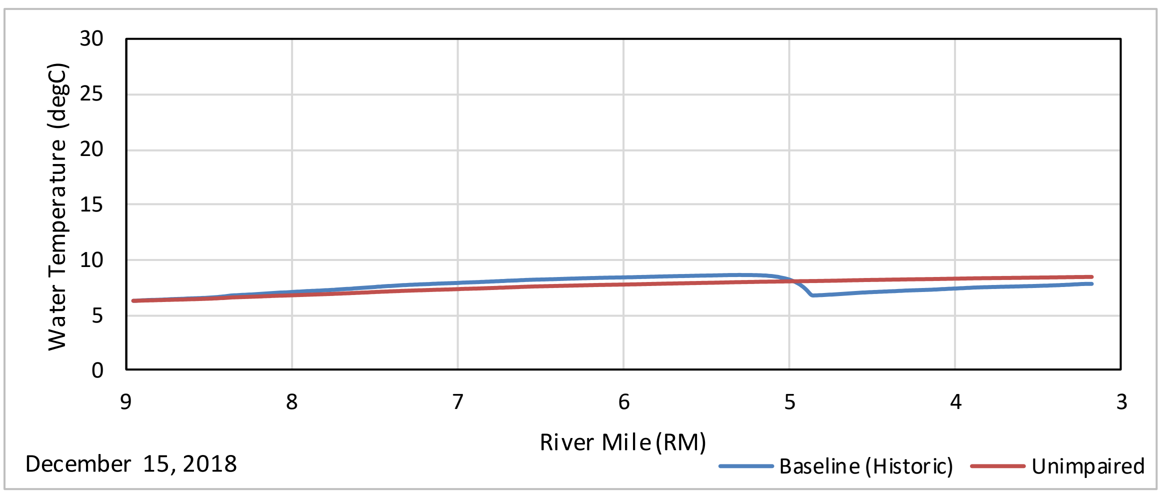
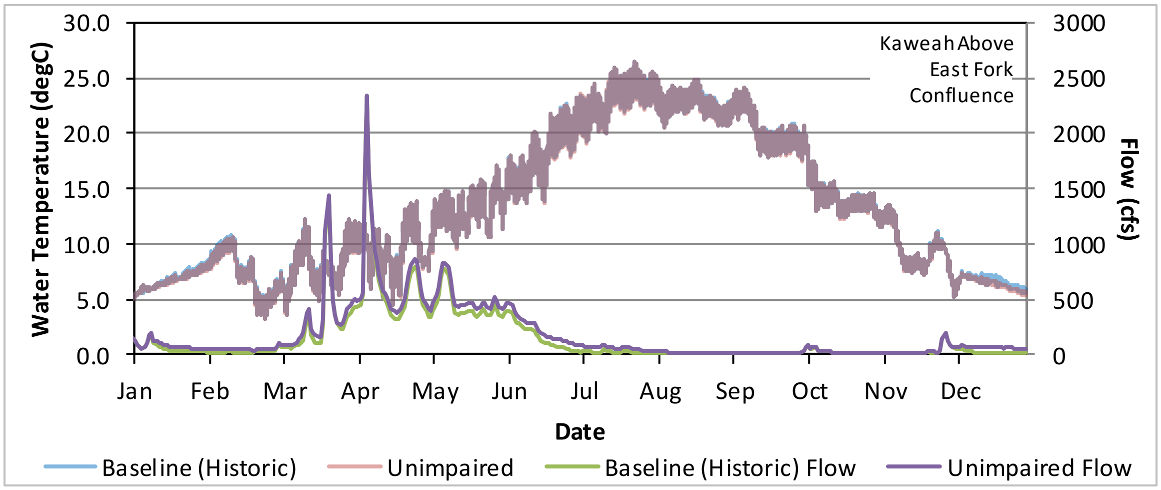


Figure F - 12. December 15, 2018 Average Longitudinal Water Temperature Profile in the Kaweah River from Upstream of the Confluence with the East Fork (RM8.95) to Upstream of the Confluence with the North Fork (RM3.17) for the Baseline (Historic) and Unimpaired Simulations.



Kaweah River: Temporal Water Temperature Profiles

Figure F - 13. Hourly Water Temperature and Daily Average Flow Results for the Baseline (Historic) and Unimpaired Simulations for Kaweah River Upstream of the Confluence with the East Fork, January 1 – December 31, 2018.



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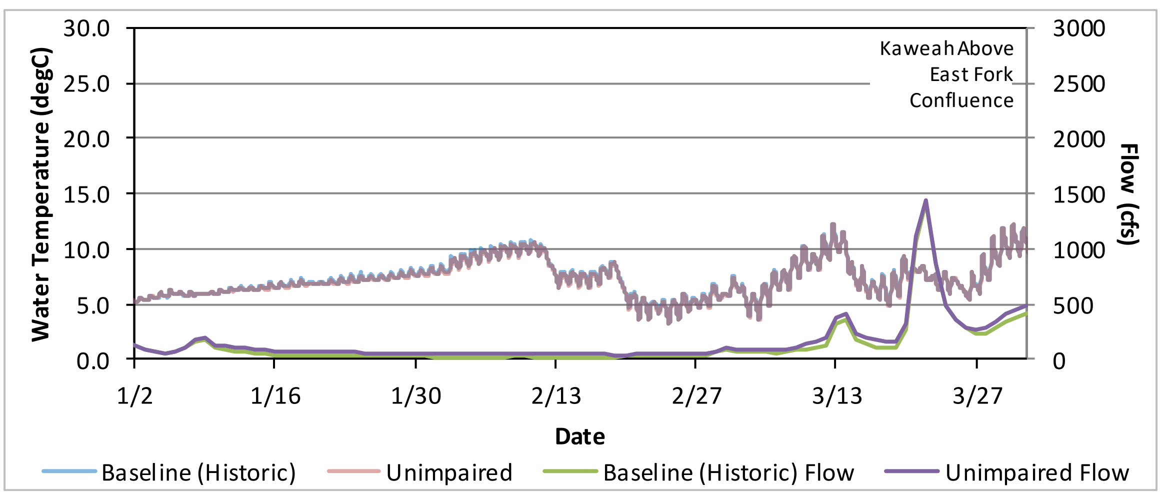
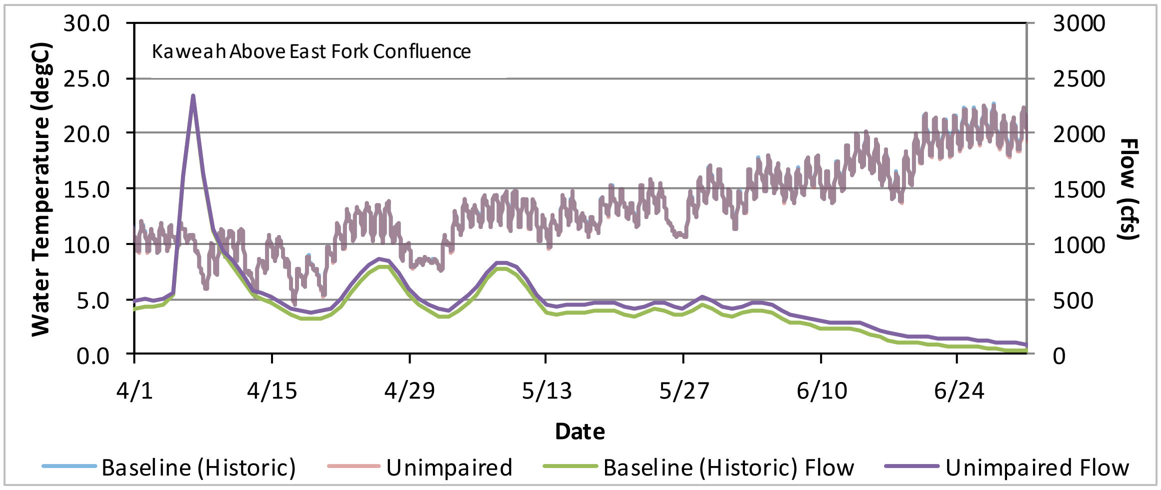


Figure F - 15. Hourly Water Temperature and Daily Average Flow Results for the Baseline (Historic) and Unimpaired Simulations for Kaweah River Upstream of the Confluence with the East Fork, April 1 – June 30, 2018.



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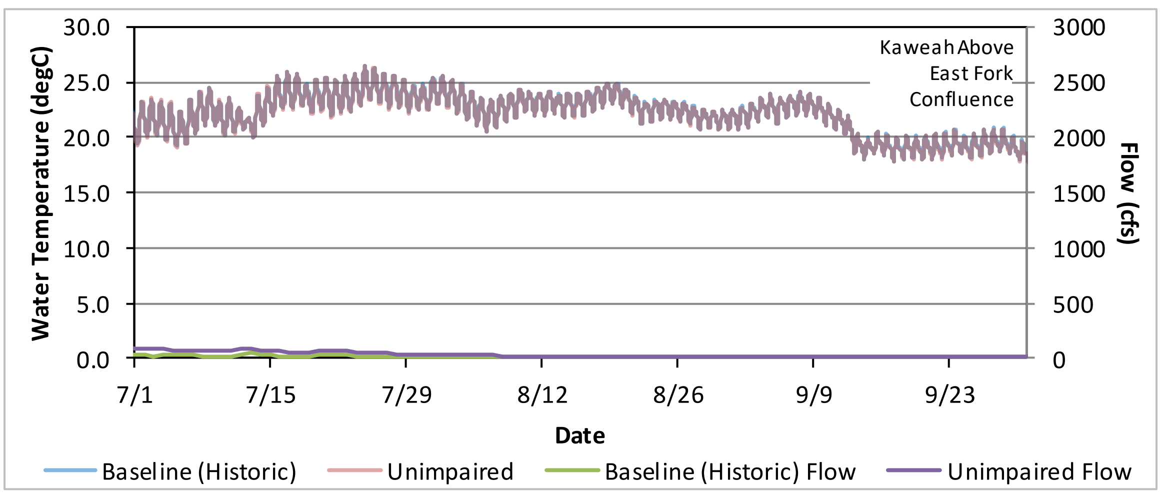

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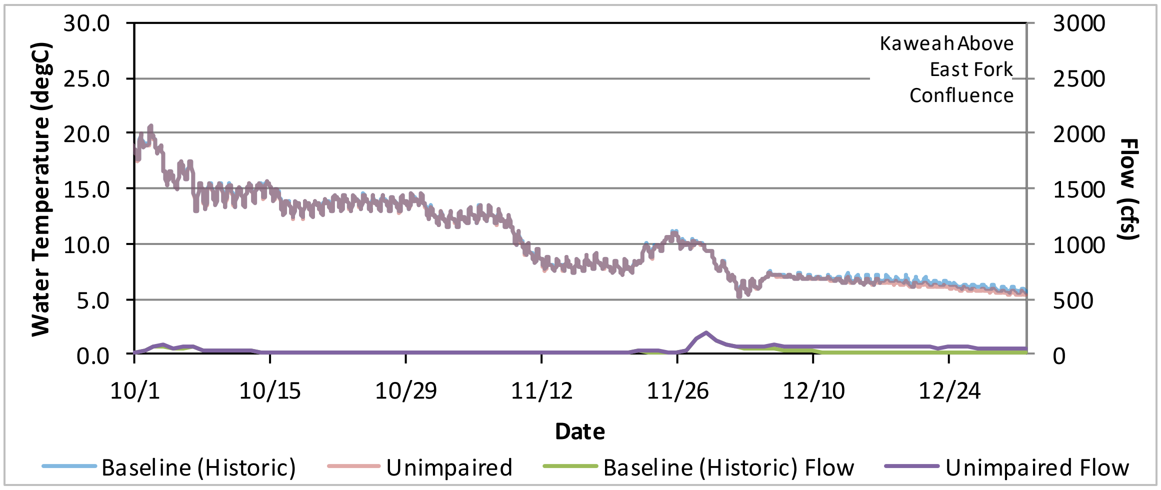


Figure F - 18. Hourly Water Temperature and Daily Average Flow Results for the Baseline (Historic) and Unimpaired Simulations for Kaweah River Upstream of Powerhouse #1, January 1 – December 31, 2018.

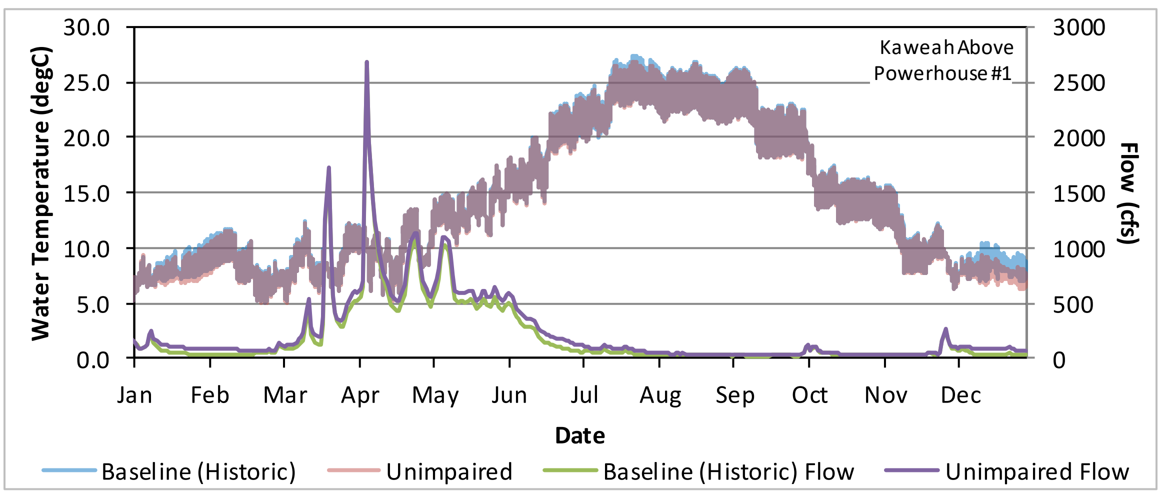


Figure F - 19. Hourly Water Temperature and Daily Average Flow Results for the Baseline (Historic) and Unimpaired Simulations for Kaweah River Upstream of Powerhouse #1, January 1 – March 31, 2018.

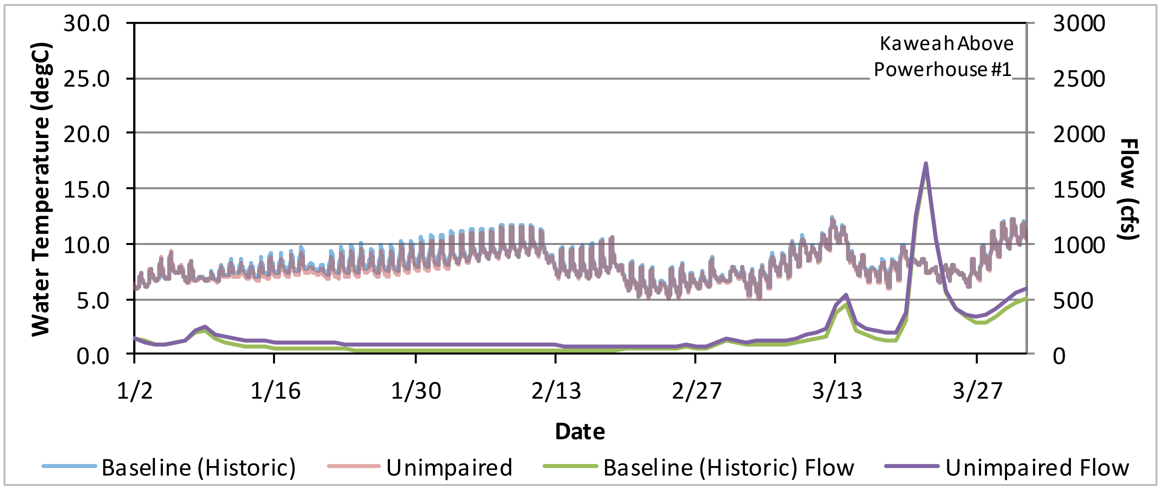


Figure F - 20. Hourly Water Temperature and Daily Average Flow Results for the Baseline (Historic) and Unimpaired Simulations for Kaweah River Upstream of Powerhouse #1, April 1 – June 30, 2018.

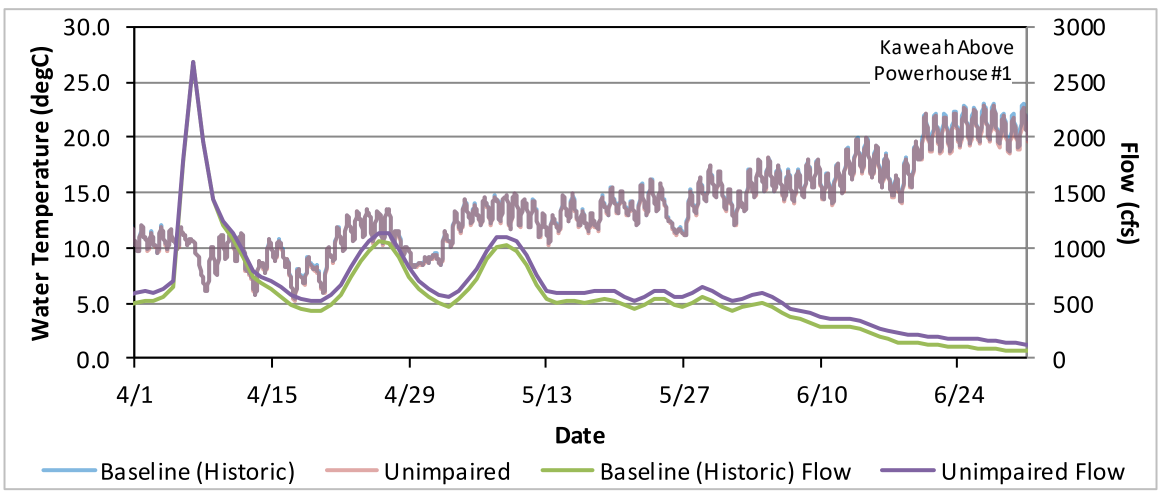


Figure F - 21. Hourly Water Temperature and Daily Average Flow Results for the Baseline (Historic) and Unimpaired Simulations for Kaweah River Upstream of Powerhouse #1, July 1 – September 30, 2018.

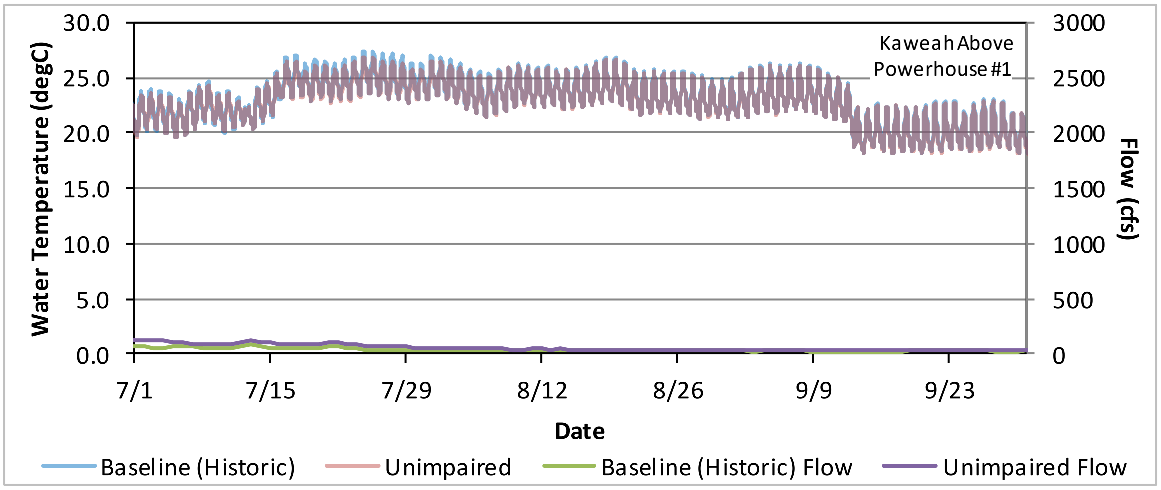


Figure F - 22. Hourly Water Temperature and Daily Average Flow Results for the Baseline (Historic) and Unimpaired Simulations for Kaweah River Upstream of Powerhouse #1, October 1 – December 31, 2018.

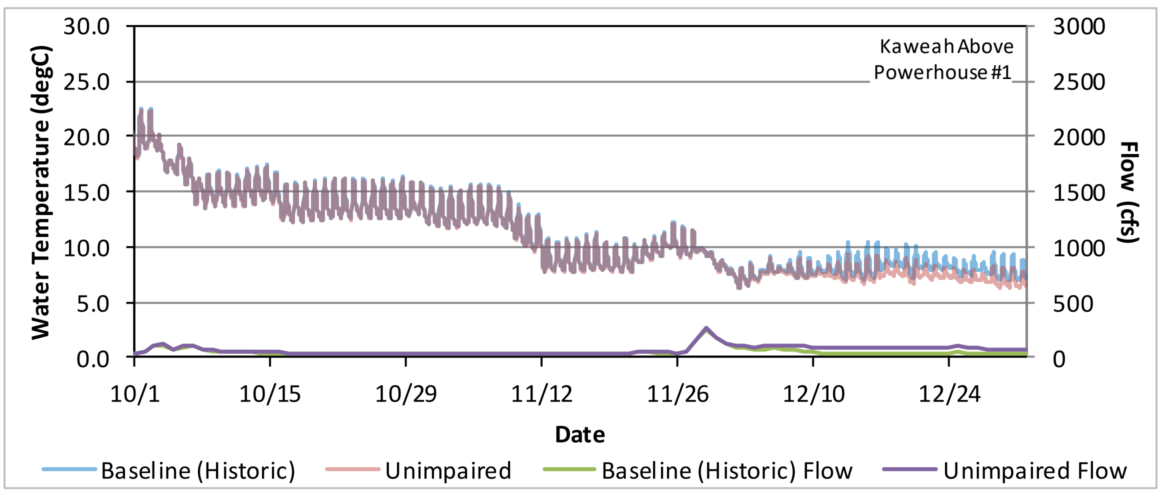


Figure F -23. Hourly Water Temperature and Daily Average Flow Results for the Baseline (Historic) and Unimpaired Simulations for Kaweah River Upstream of Powerhouse #2, January 1 – December 31, 2018.

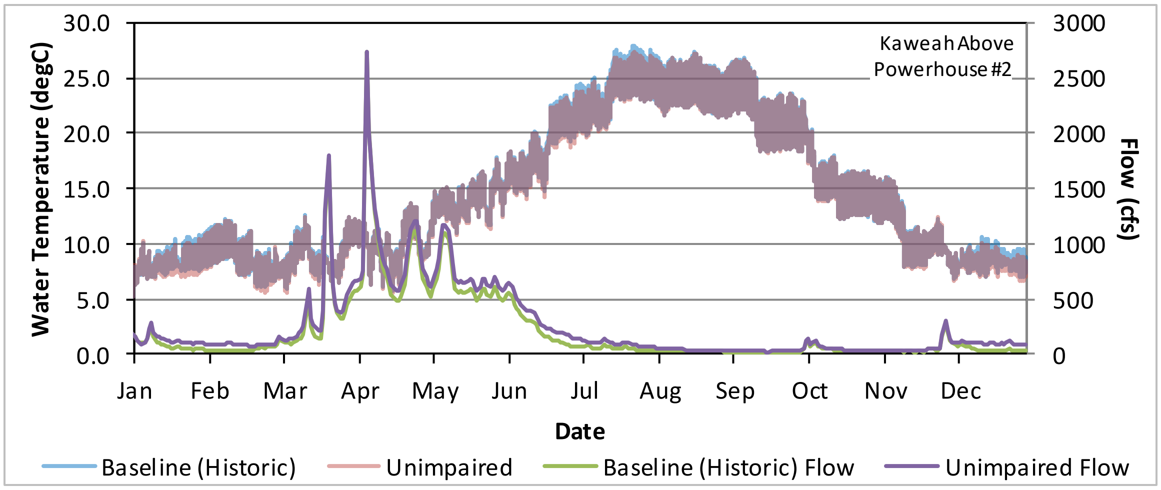


Figure F - 24. Hourly Water Temperature and Daily Average Flow Results for the Baseline (Historic) and Unimpaired Simulations for Kaweah River Upstream of Powerhouse #2, January 1 – March 31, 2018.

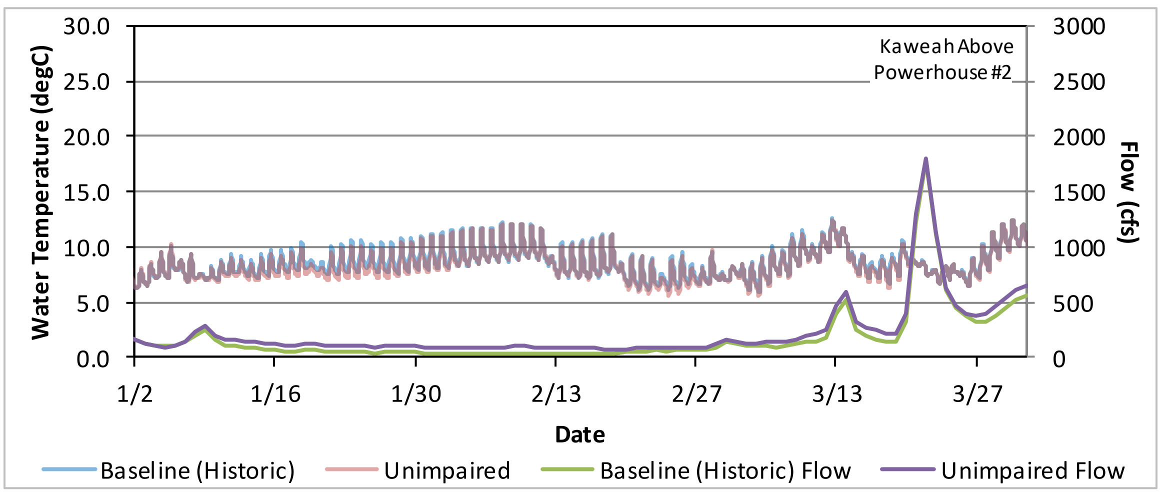


Figure F - 25. Hourly Water Temperature and Daily Average Flow Results for the Baseline (Historic) and Unimpaired Simulations for Kaweah River Upstream of Powerhouse #2, April 1 – June 30, 2018.

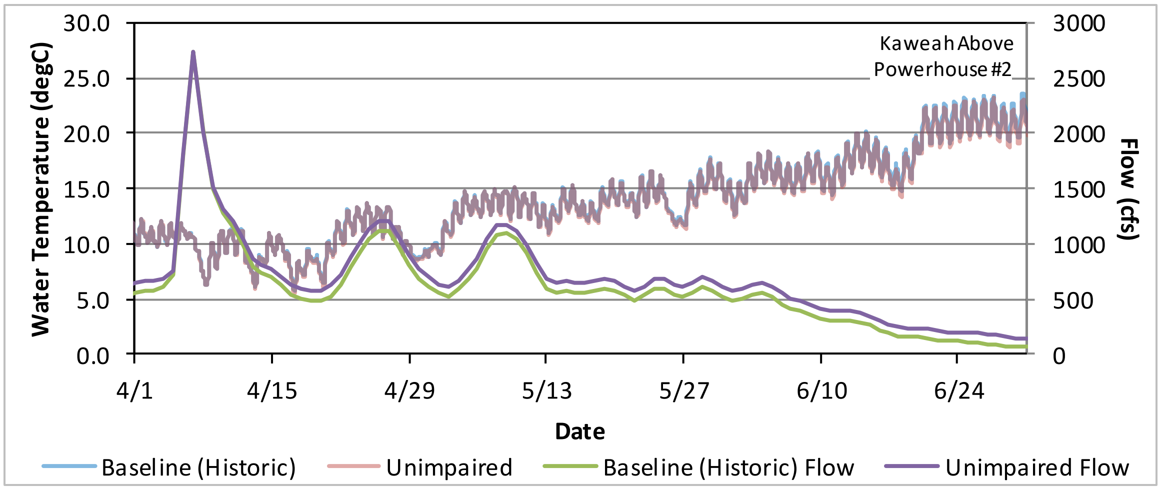


Figure F - 26. Hourly Water Temperature and Daily Average Flow Results for the Baseline (Historic) and Unimpaired Simulations for Kaweah River Upstream of Powerhouse #2, July 1 – September 30, 2018.

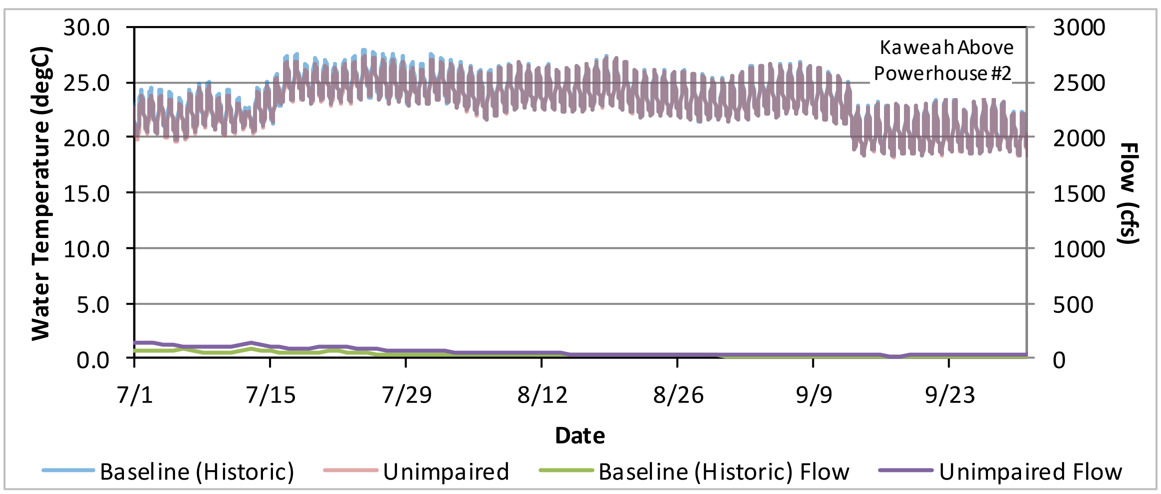


Figure F - 27. Hourly Water Temperature and Daily Average Flow Results for the Baseline (Historic) and Unimpaired Simulations for Kaweah River Upstream of Powerhouse #2, October 1 – December 31, 2018.

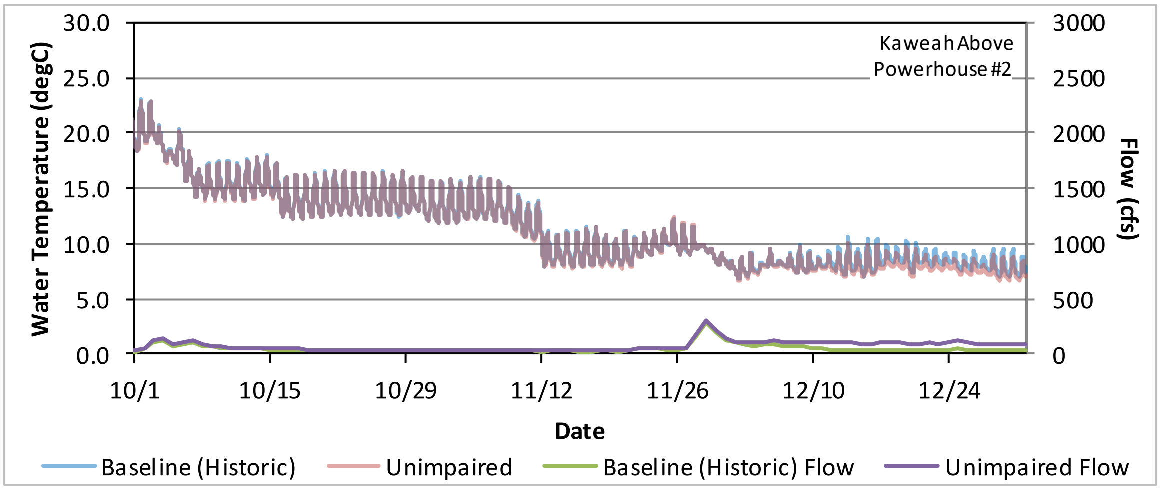
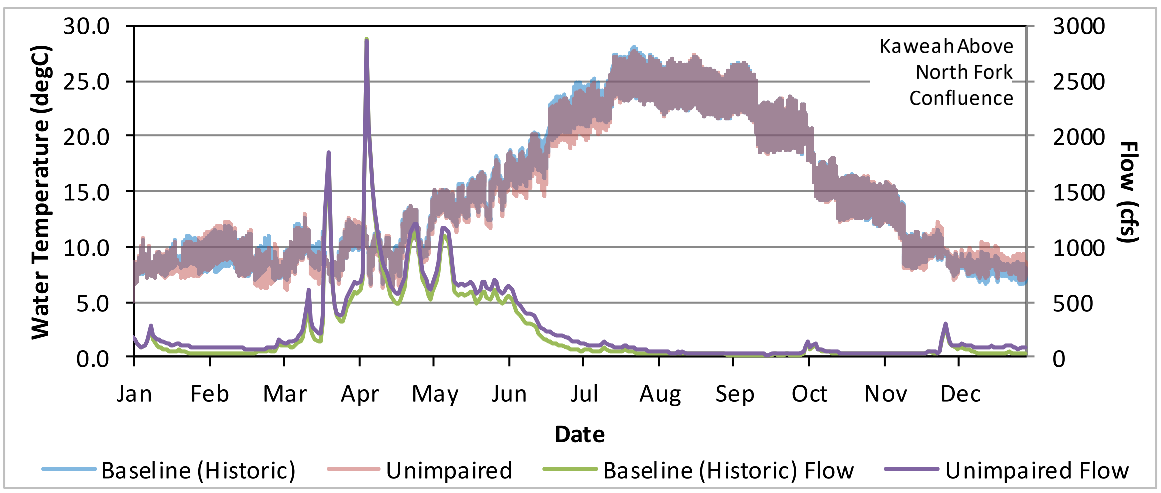


Figure F - 28. Hourly Water Temperature and Daily Average Flow Results for the Baseline (Historic) and Unimpaired Simulations for Kaweah River Upstream of the Confluence with the North Fork, January 1 – December 31, 2018.



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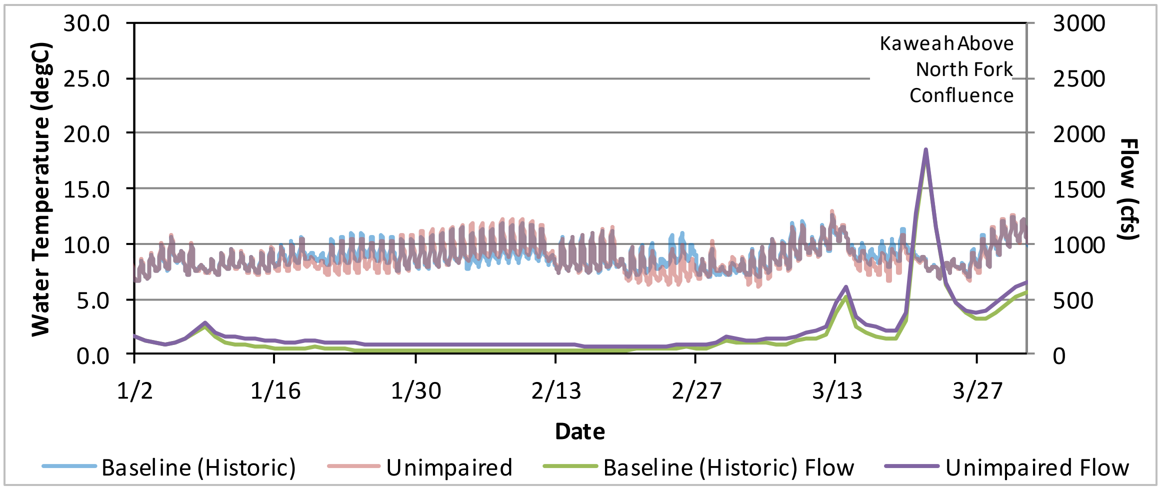

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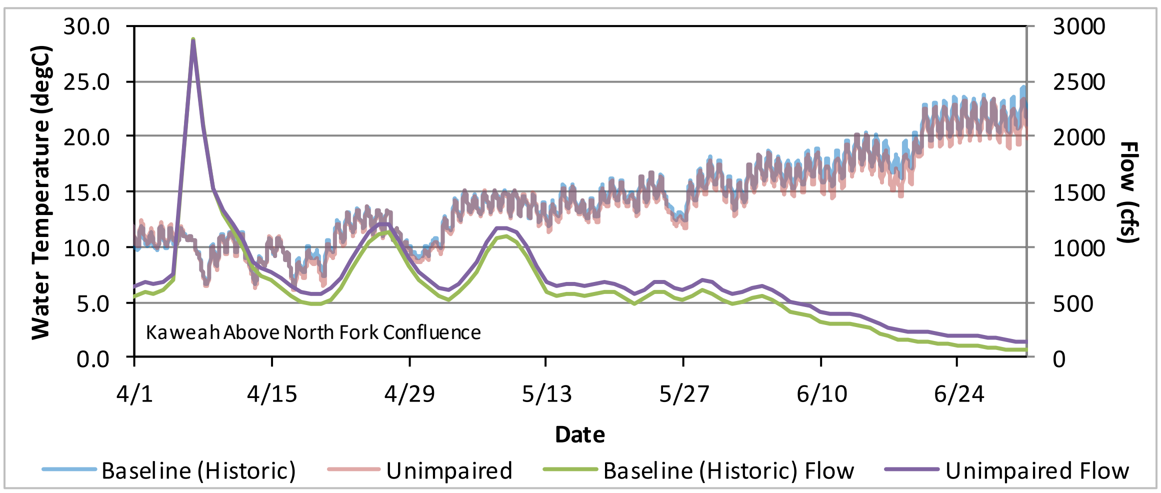

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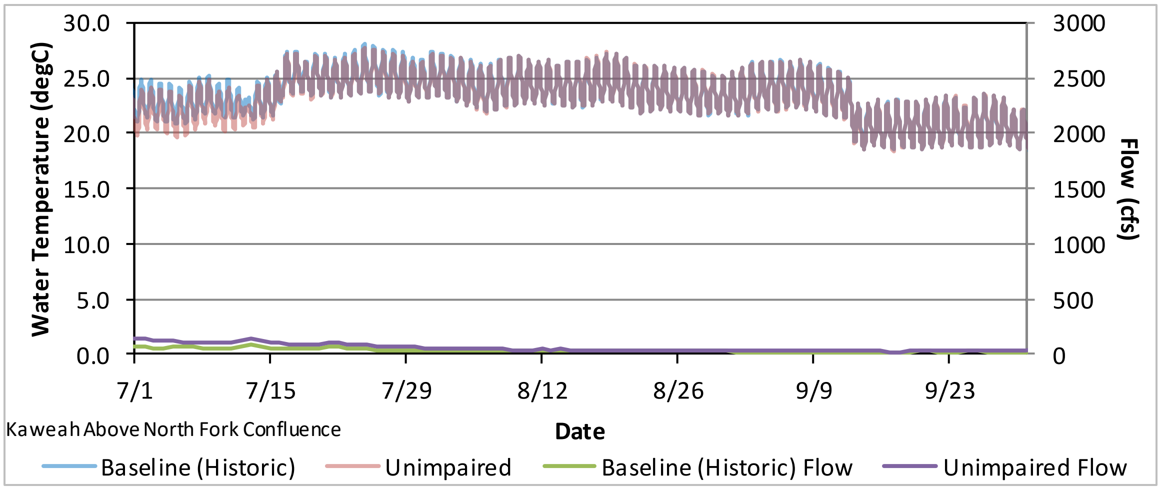
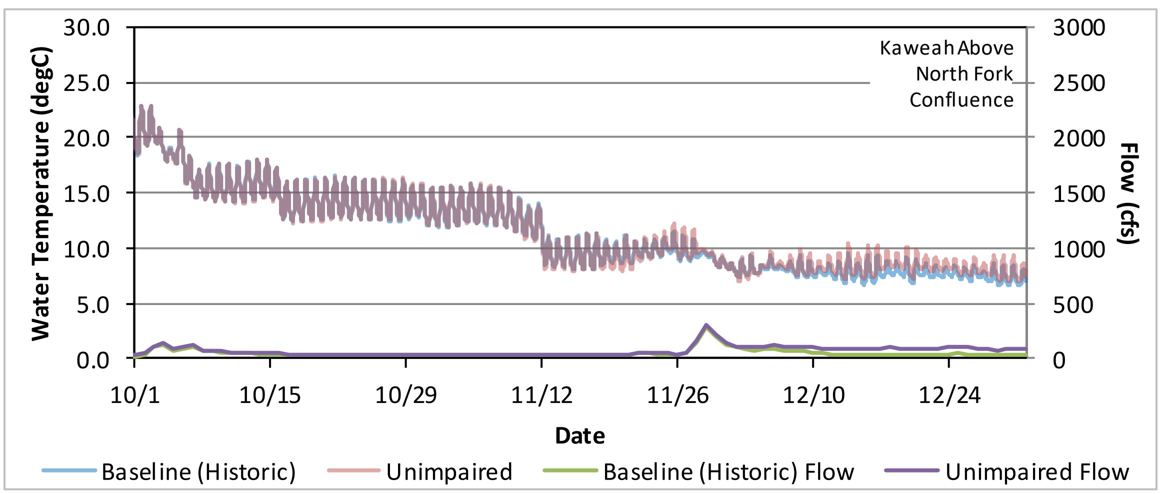


Figure F - 32. Hourly Water Temperature and Daily Average Flow Results for the Baseline (Historic) and Unimpaired Simulations for Kaweah River Upstream of the Confluence with the North Fork, October 1 – December 31, 2018.



East Fork of the Kaweah River

Figure F - 33. March 15, 2018 Baseline (Historic) Maximum, Average, and Minimum Longitudinal Water Temperature Profiles in the East Fork of the Kaweah River Upstream of the Confluence with the Kaweah River.

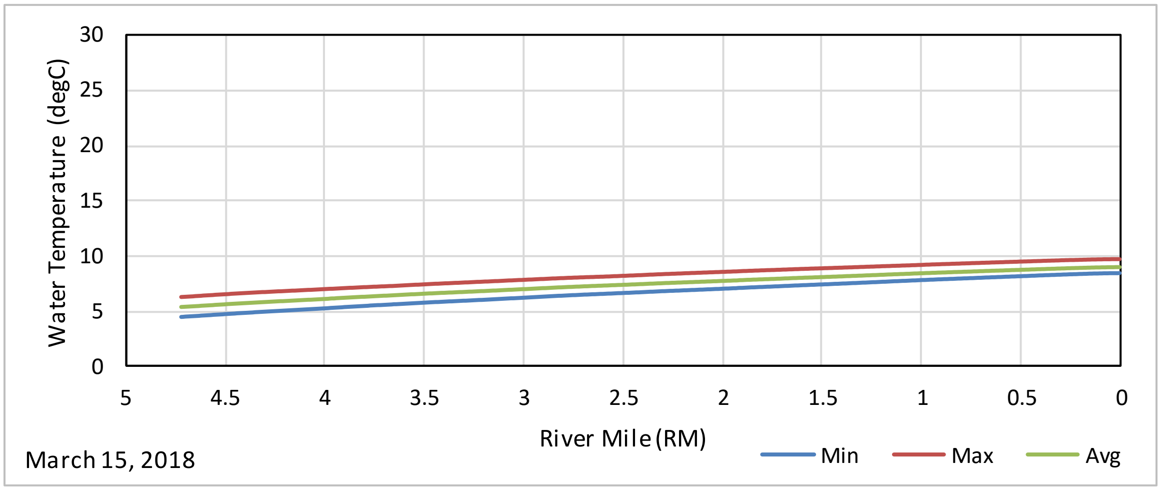
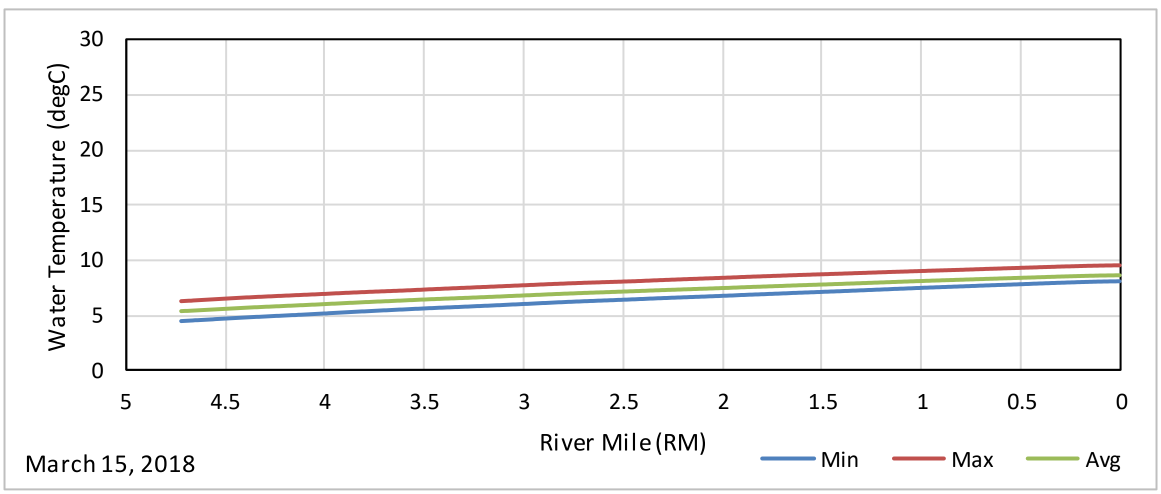


Figure F - 34. March 15, 2018 Unimpaired Maximum, Average, and Minimum Longitudinal Water Temperature Profiles in the East Fork of the Kaweah River Upstream of the Confluence with the Kaweah River.



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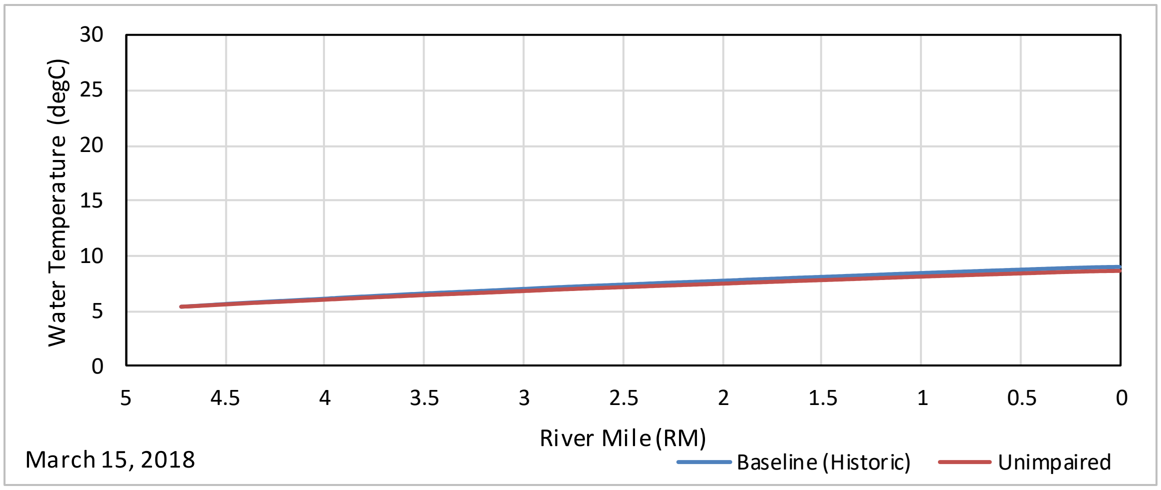


Figure F - 36. June 15, 2018 Baseline (Historic) Maximum, Average, and Minimum Longitudinal Water Temperature Profiles in the East Fork of the Kaweah River Upstream of the Confluence with the Kaweah River.

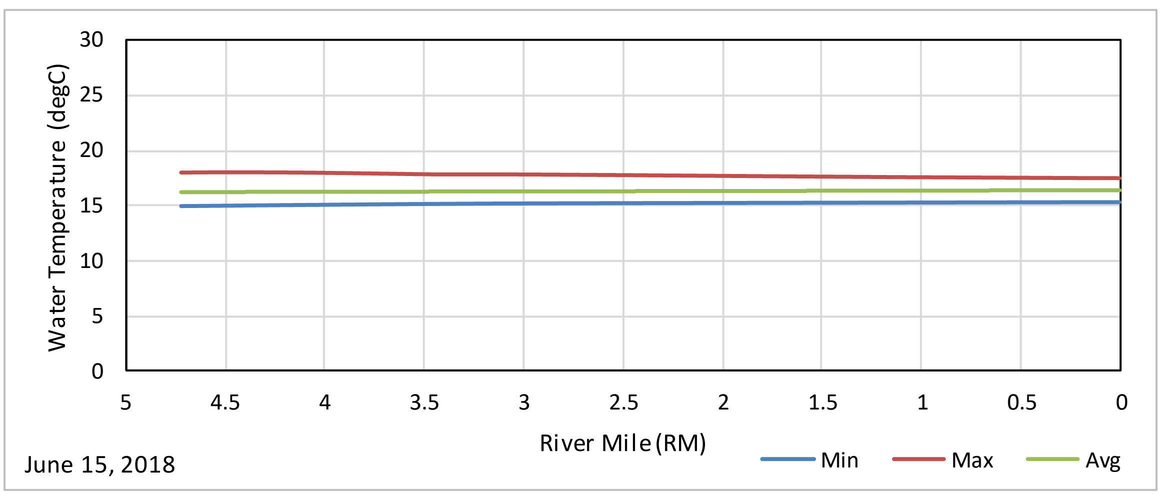
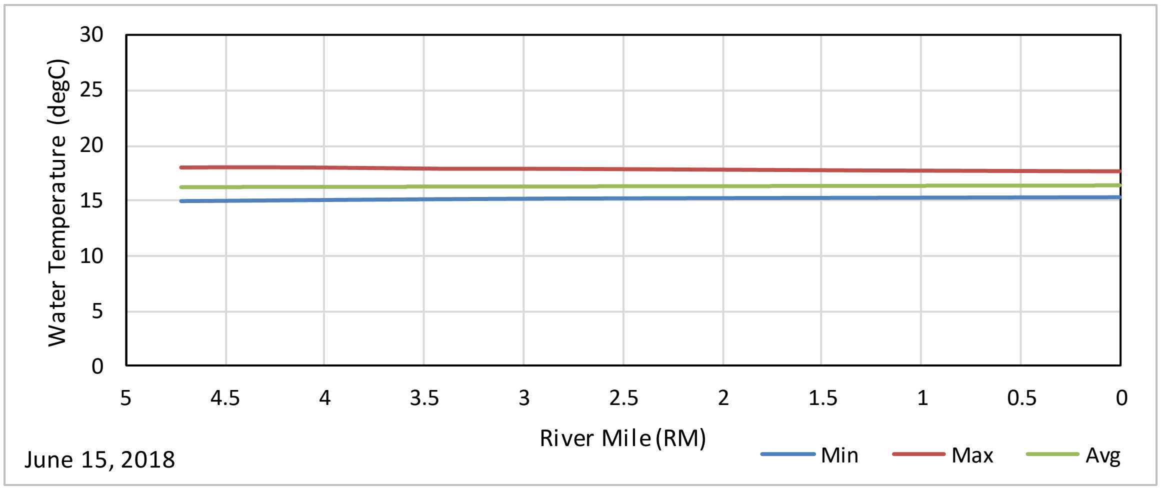


Figure F - 37. June 15, 2018 Unimpaired Maximum, Average, and Minimum Longitudinal Water Temperature Profiles in the East Fork of the Kaweah River Upstream of the Confluence with the Kaweah River.



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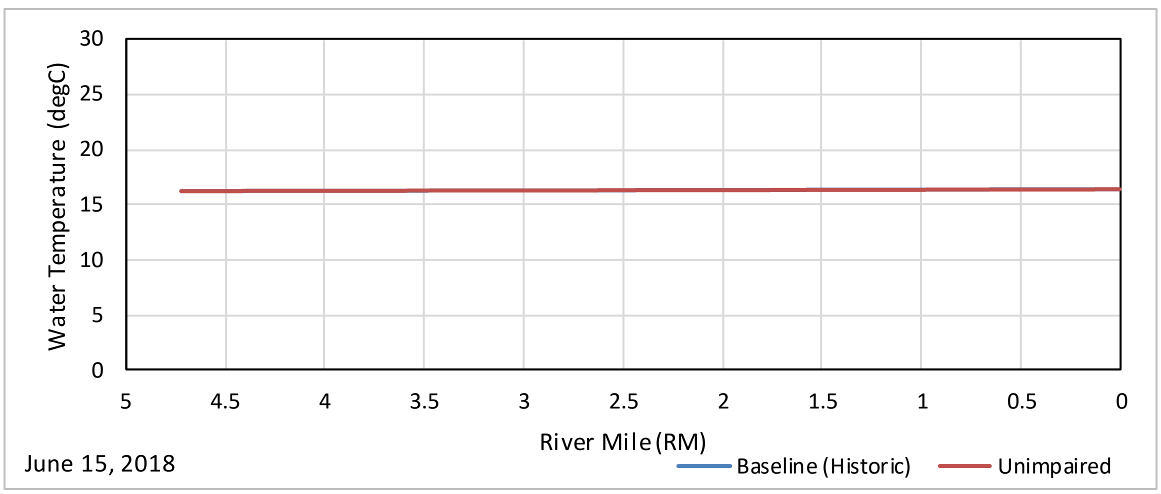


Figure F - 39. September 15, 2018 Baseline (Historic) Maximum, Average, and Minimum Longitudinal Water Temperature Profiles in the East Fork of the Kaweah River Upstream of the Confluence with the Kaweah River.

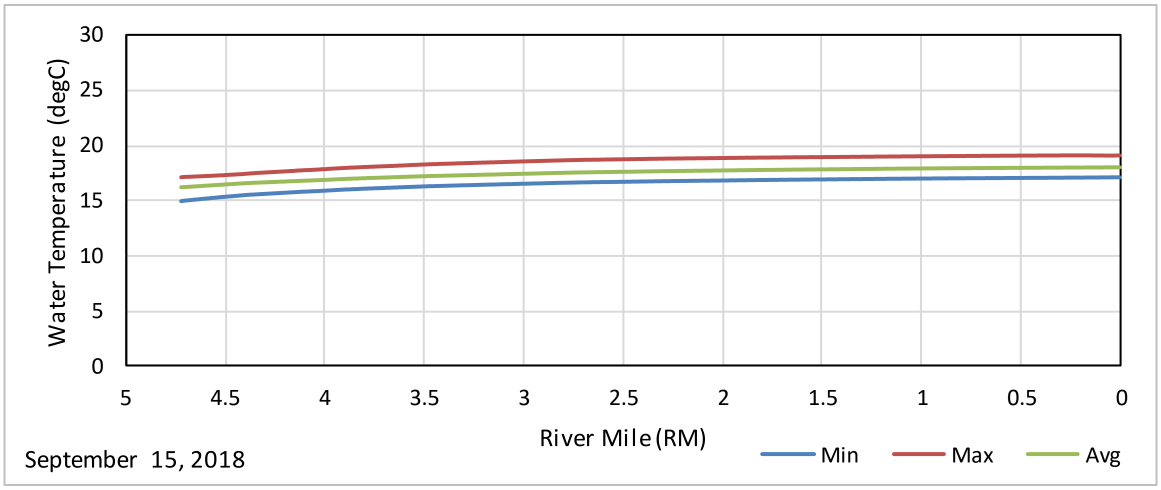
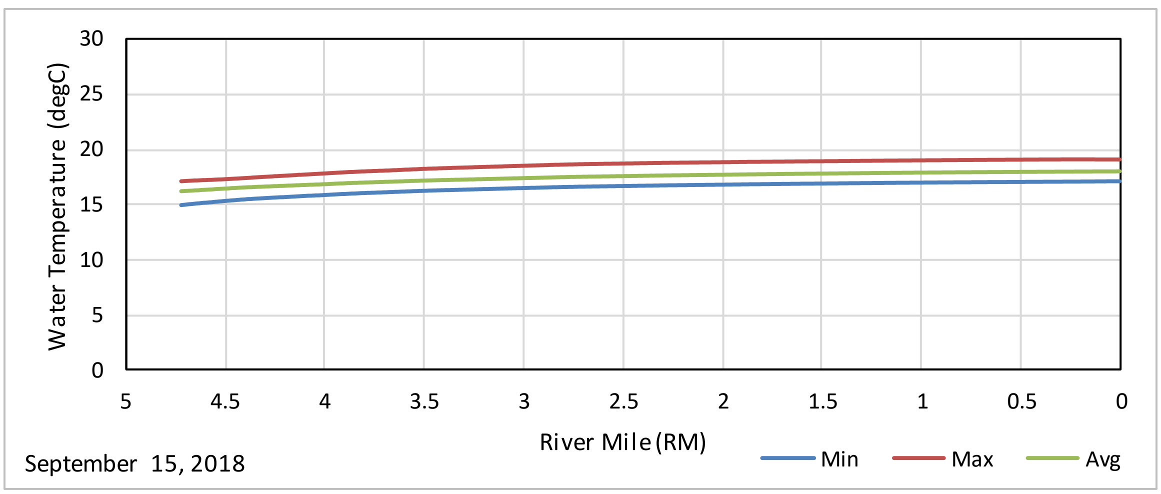


Figure F - 40. September 15, 2018 Unimpaired Maximum, Average, and Minimum Longitudinal Water Temperature Profiles in the East Fork of the Kaweah River Upstream of the Confluence with the Kaweah River.



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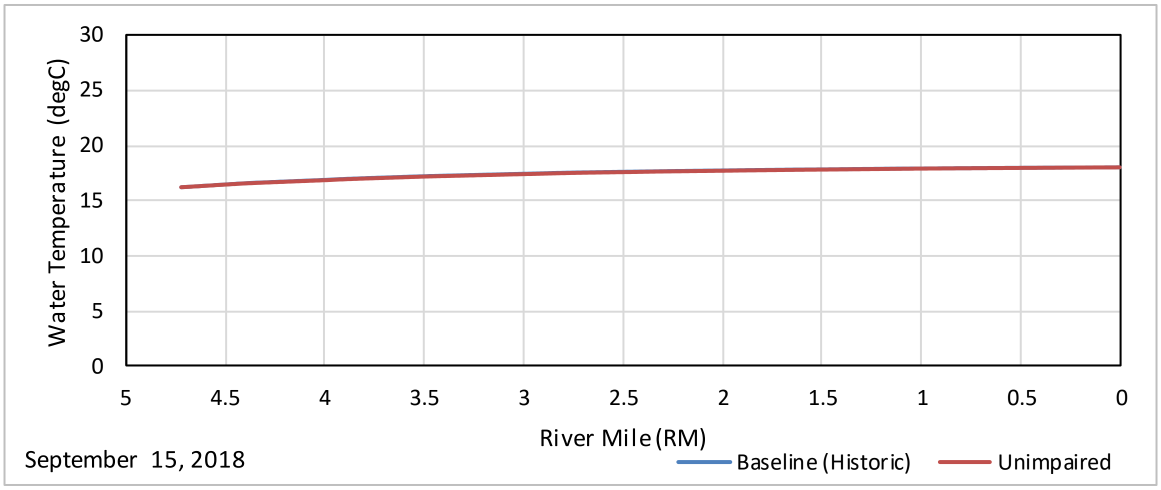

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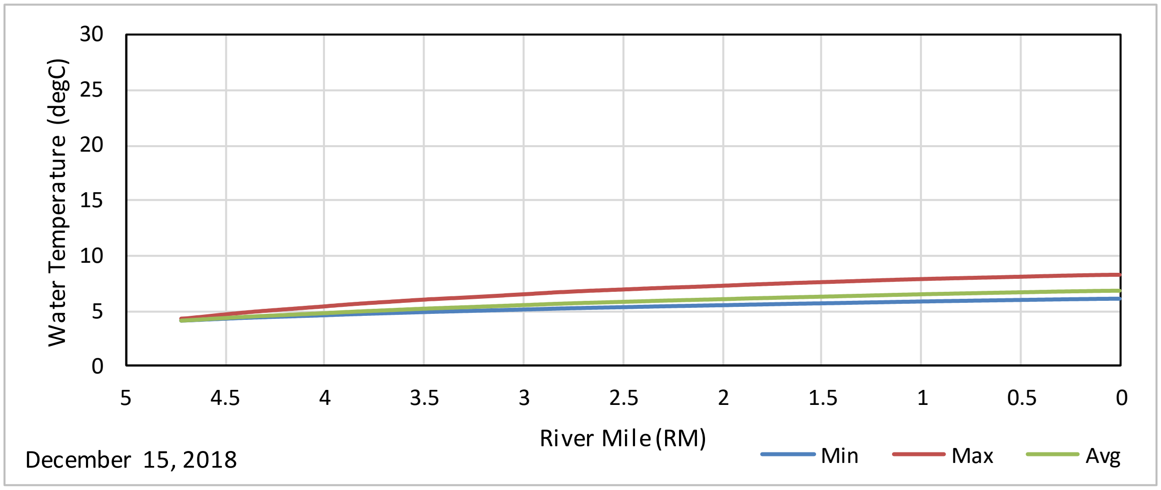
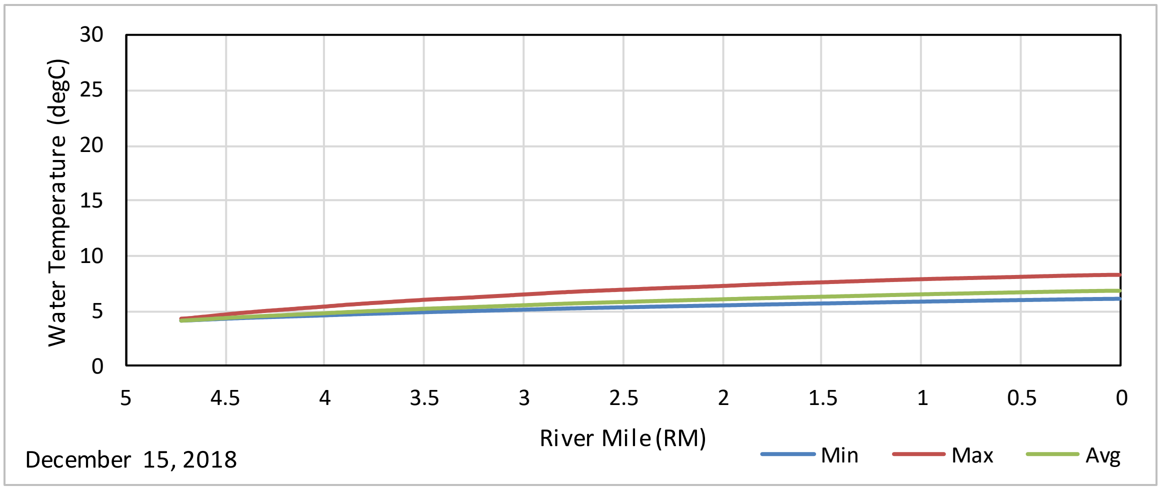


Figure F - 43. December 15, 2018 Unimpaired Maximum, Average, and Minimum Longitudinal Water Temperature Profiles in the East Fork of the Kaweah River Upstream of the Confluence with the Kaweah River.



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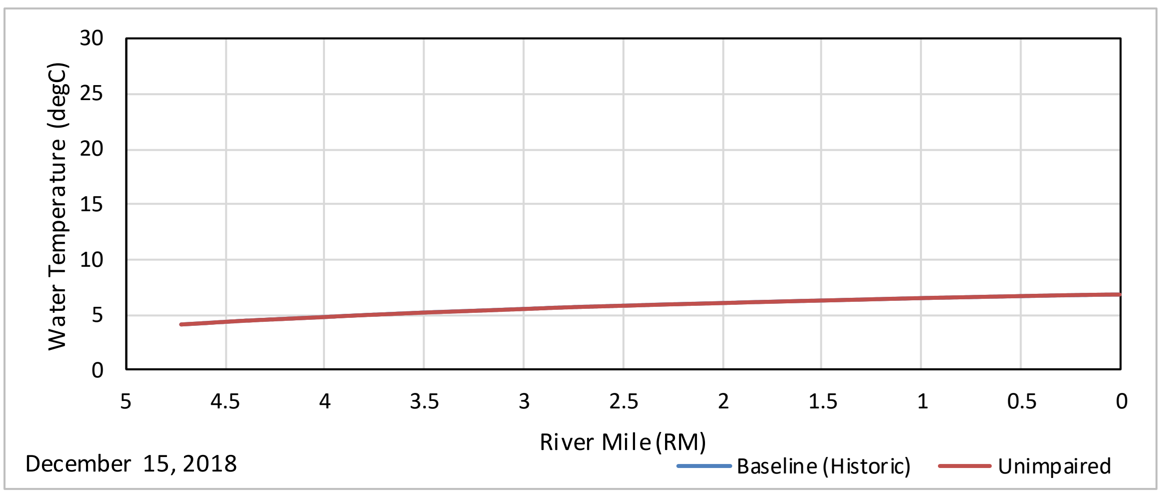


East Fork of the Kaweah River: Temporal Water Temperature Profiles

Figure F - 45. Hourly Water Temperature and Daily Average Flow Results for the Baseline (Historic) and Unimpaired Simulations for the East Fork of the Kaweah River Upstream of the Confluence with the Kaweah River, January 1 – December 31, 2018.

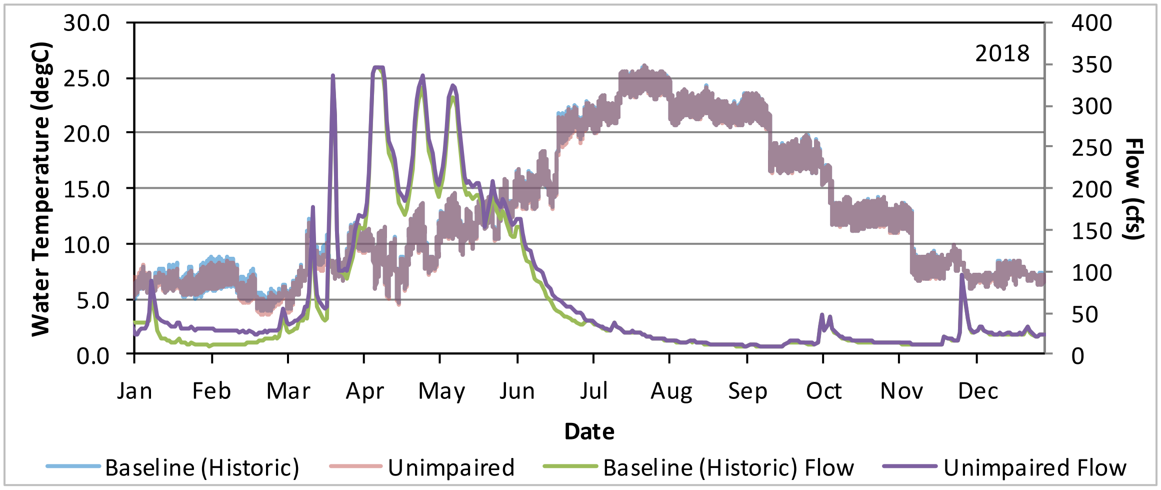


Figure F - 46. Hourly Water Temperature and Daily Average Flow Results for the Baseline (Historic) and Unimpaired Simulations for the East Fork of the Kaweah River Upstream of the Confluence with the Kaweah River, January 1 – March 31, 2018.

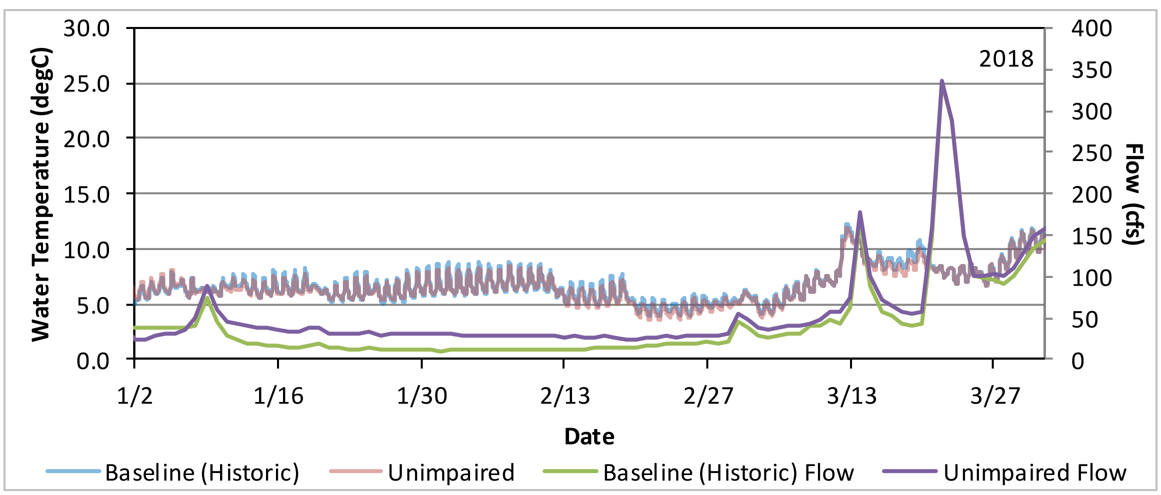


Figure F - 47. **Hourly Water Temperature and Daily Average Flow Results for the Baseline (Historic) and Unimpaired Simulations for the East Fork of the Kaweah River Upstream of the Confluence with the Kaweah River, April 1 – June 30, 2018.**

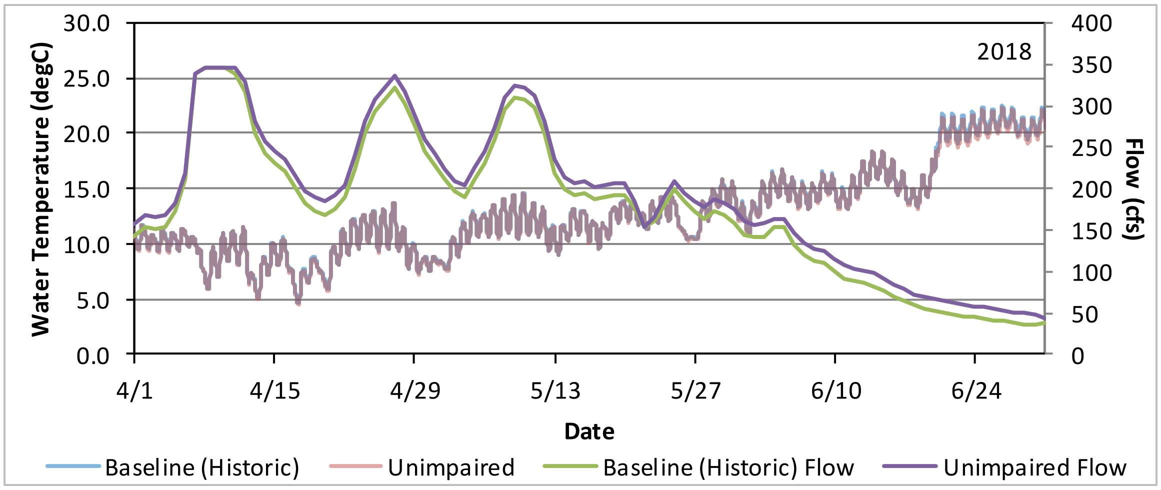
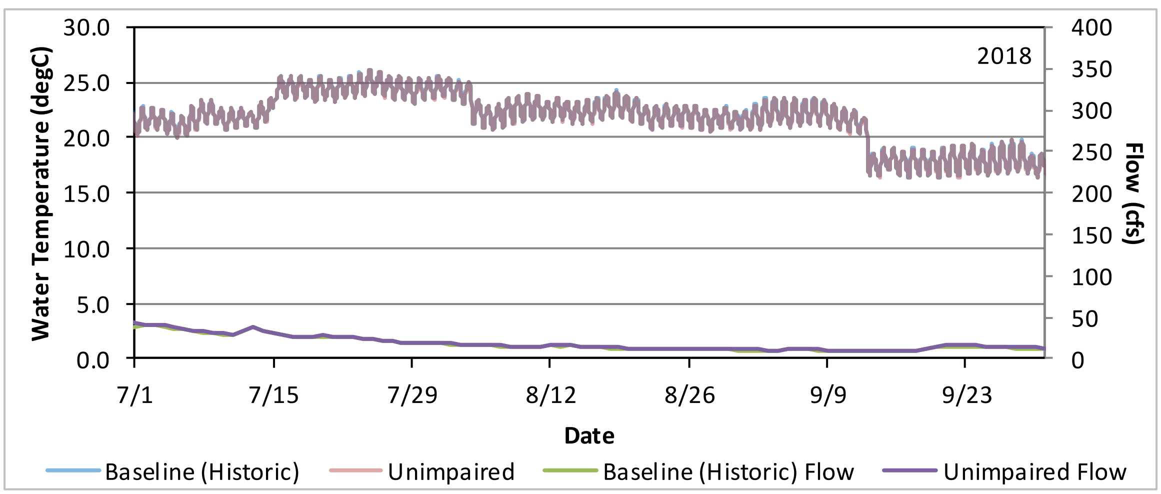


Figure F - 48. **Hourly Water Temperature and Daily Average Flow Results for the Baseline (Historic) and Unimpaired Simulations for the East Fork of the Kaweah River Upstream of the Confluence with the Kaweah River, July 1 – September 30, 2018.**



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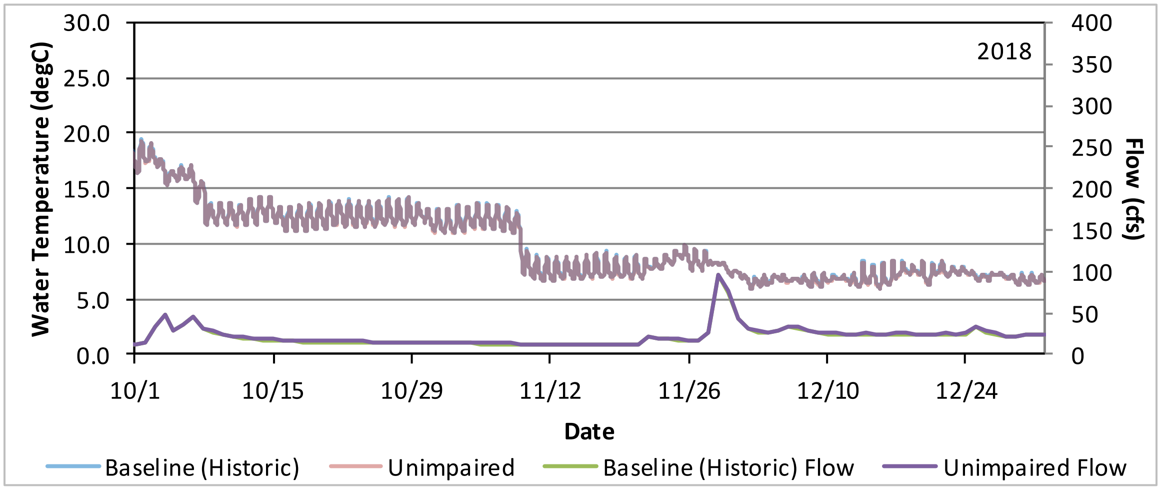

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APPENDIX G

Modeled Longitudinal and Temporal Water Temperature Profiles for Baseline (Historic) and Climate Change Flows

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Location	Hourly			Daily Average			Daily Min			Daily Max		
	Mean Bias[1]	MAE[1]	RMSE[1]	Mean Bias[1]	MAE[1]	RMSE[1]	Mean Bias[1]	MAE[1]	RMSE[1]	Mean Bias[1]	MAE[1]	RMSE[1]
US East Fork	-0.37	0.88	1.32	-0.37	0.86	1.29	-0.37	0.77	1.23	-0.32	0.97	1.38
US PH#1	-0.27	0.48	0.78	-0.27	0.46	0.76	-0.32	0.46	0.74	-0.20	0.51	0.79
US PH #2	-0.24	0.37	0.64	-0.24	0.35	0.62	-0.28	0.37	0.62	-0.19	0.38	0.64
US North Fork	-0.22	0.33	0.57	-0.22	0.32	0.57	-0.24	0.34	0.57	-0.19	0.33	0.57

[1]Mean Bias = average of baseline (historic) minus climate change 2030, MAE = Mean absolute error, RMSE = Root mean square error

Table G - 2. Summary Statistics for the 2018 Baseline (Historic) and Climate Change 2070 Simulations in the Kaweah River.

Location	Hourly			Daily Average			Daily Min			Daily Max		
	Mean Bias[1]	MAE[1]	RMSE[1]	Mean Bias[1]	MAE[1]	RMSE[1]	Mean Bias[1]	MAE[1]	RMSE[1]	Mean Bias[1]	MAE[1]	RMSE[1]
US East Fork	-1.22	1.28	1.88	-1.22	1.27	1.86	-1.24	1.28	1.83	-1.15	1.25	1.88
US PH#1	-0.84	0.86	1.23	-0.84	0.85	1.22	-0.93	0.93	1.26	-0.74	0.78	1.18
US PH #2	-0.75	0.76	1.07	-0.75	0.76	1.06	-0.84	0.84	1.10	-0.67	0.69	1.02
US North Fork	-0.76	0.76	1.02	-0.76	0.76	1.01	-0.80	0.81	1.05	-0.69	0.70	0.97

[1]Mean Bias = average of baseline (historic) minus climate change 2070, MAE = Mean absolute error, RMSE = Root mean square error

Table G - 3. Summary Statistics for the 2018 Baseline (Historic) and Climate Change 2030 Simulations in the East Fork of the Kaweah River above the Confluence with the Kaweah River.

Location	Hourly			Daily Average			Daily Min			Daily Max		
	Mean Bias[1]	MAE[1]	RMSE[1]	Mean Bias[1]	MAE[1]	RMSE[1]	Mean Bias[1]	MAE[1]	RMSE[1]	Mean Bias[1]	MAE[1]	RMSE[1]
US Confluence	-0.37	0.39	0.67	-0.37	0.38	0.66	-0.33	0.35	0.62	-0.35	0.37	0.67

[1]Mean Bias = average of baseline (historic) minus climate change 2030, MAE = Mean absolute error, RMSE = Root mean square error

Table G -4. Summary Statistics for the 2018 Baseline (Historic) and Climate Change 2070 Simulations in the East Fork of the Kaweah River above the Confluence with the Kaweah River.

Location	Hourly			Daily Average			Daily Min			Daily Max		
	Mean Bias[1]	MAE[1]	RMSE[1]	Mean Bias[1]	MAE[1]	RMSE[1]	Mean Bias[1]	MAE[1]	RMSE[1]	Mean Bias[1]	MAE[1]	RMSE[1]
US Confluence	-0.84	0.84	1.12	-0.84	0.84	1.11	-0.85	0.85	1.10	-0.78	0.79	1.07

[1]Mean Bias = average of baseline (historic) minus climate change 2070, MAE = Mean absolute error, RMSE = Root mean square error

Kaweah River: Longitudinal Water Temperature Profiles

Figure G - 1. March 15, 2018 Baseline (Historic) Maximum, Average, and Minimum Longitudinal Water Temperature Profiles in the Kaweah River Upstream of the Confluence with the East Fork.

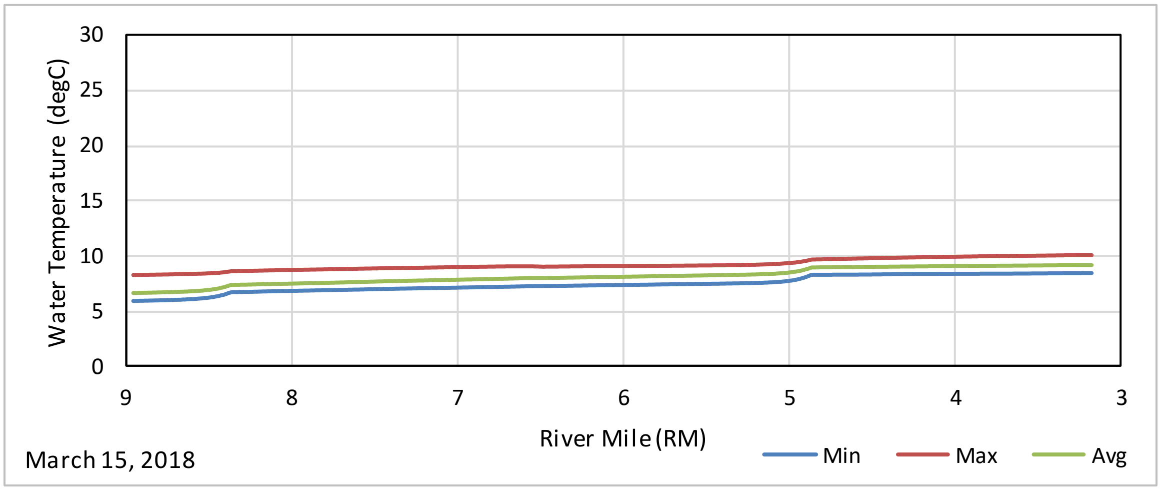


Figure G - 2. March 15, 2018 Climate Change 2030 Maximum, Average, and Minimum Longitudinal Water Temperature Profiles in the Kaweah River Upstream of the Confluence with the East Fork.

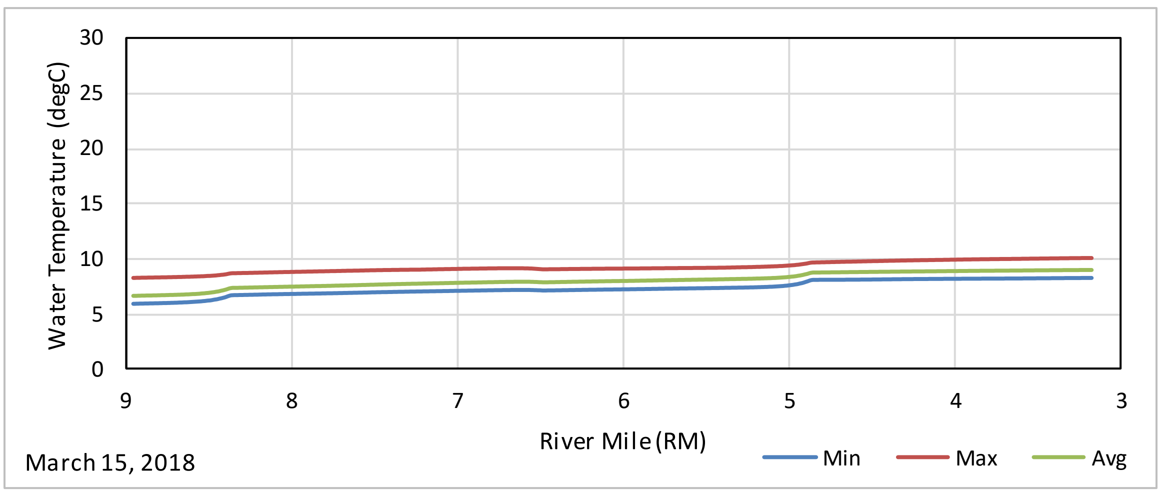


Figure G - 3. March 15, 2018 Climate Change 2070 Maximum, Average, and Minimum Longitudinal Water Temperature Profiles in the Kaweah River Upstream of the Confluence with the East Fork.

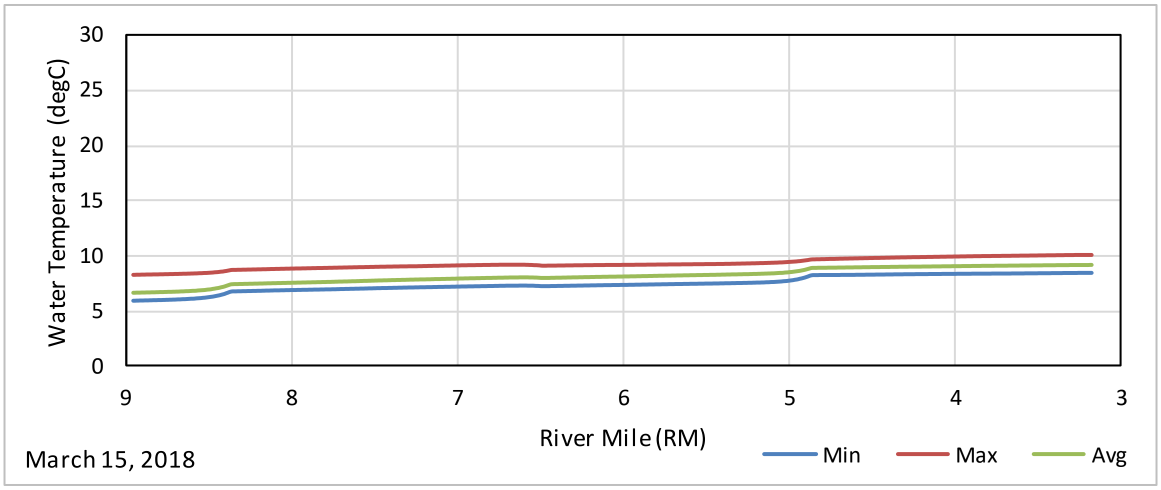


Figure G - 4. March 15, 2018 Average Longitudinal Water Temperature Profile in the Kaweah River Upstream of the Confluence with the East Fork.

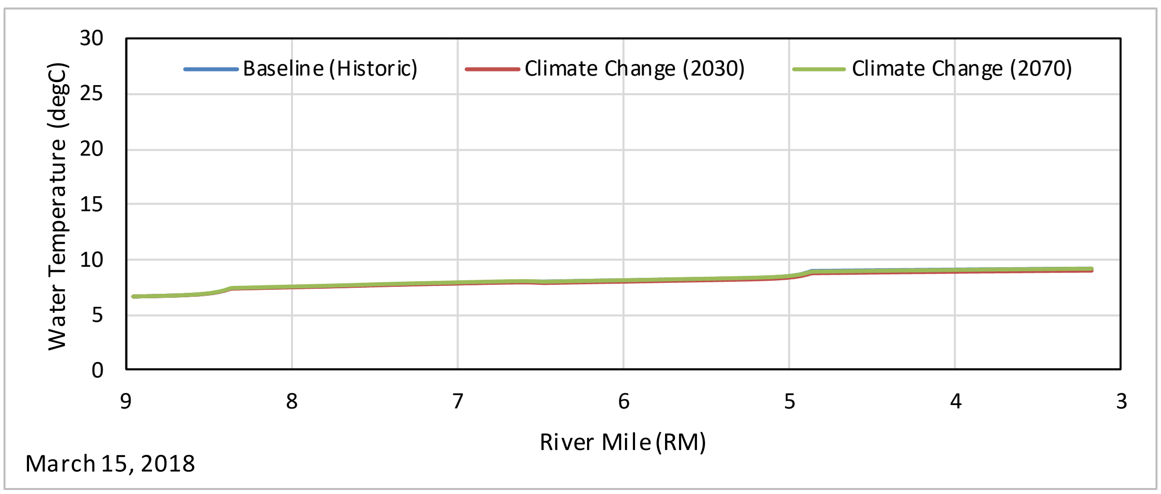


Figure G - 5. **June 15, 2018 Baseline (Historic) Maximum, Average, and Minimum Longitudinal Water Temperature Profiles in the Kaweah River Upstream of Powerhouse #1.**

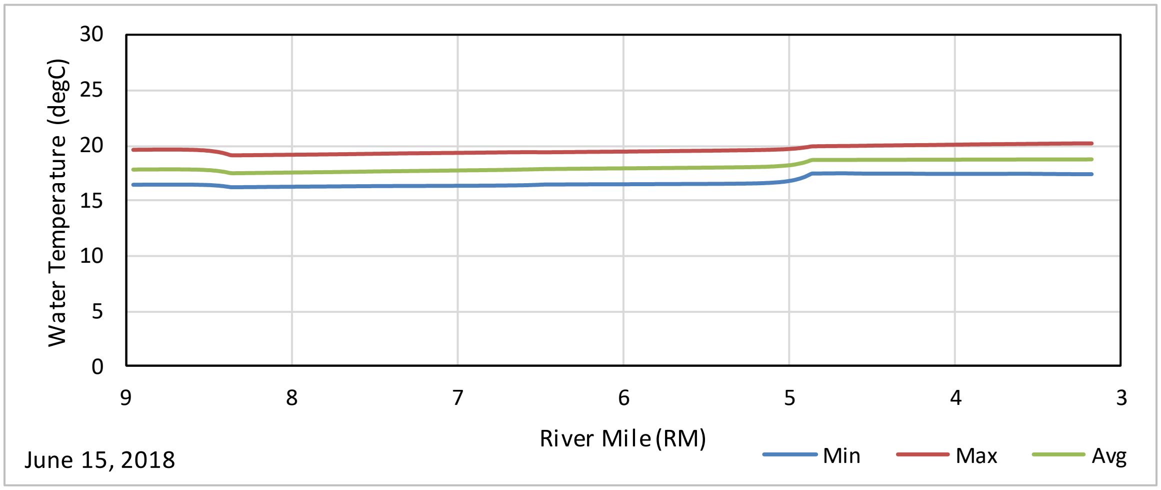


Figure G - 6. **June 15, 2018 Climate Change 2030 Maximum, Average, and Minimum Longitudinal Water Temperature Profiles in the Kaweah River Upstream of Powerhouse #1.**

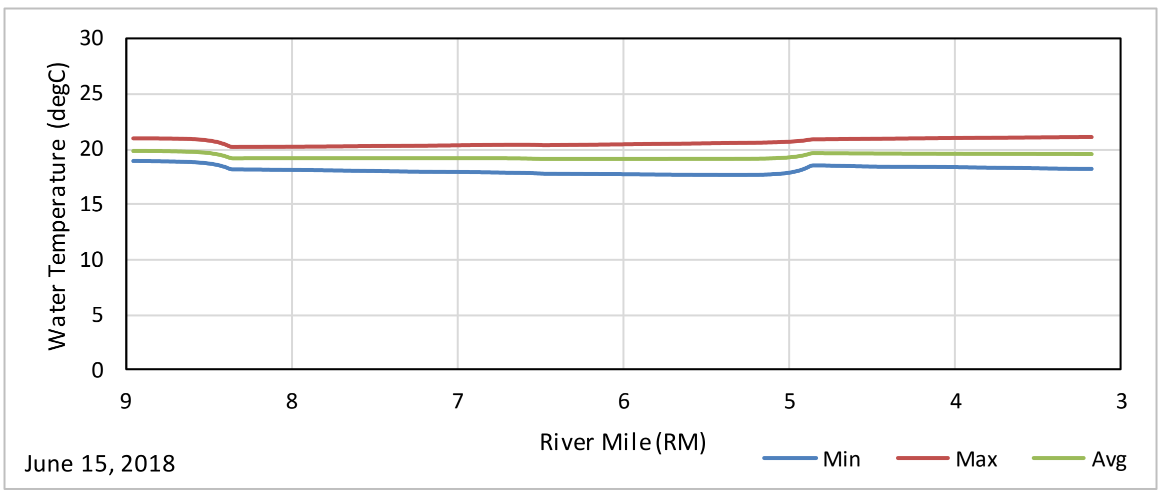


Figure G - 7. June 15, 2018 Climate Change 2070 Maximum, Average, and Minimum Longitudinal Water Temperature Profiles in the Kaweah River Upstream of Powerhouse #1.

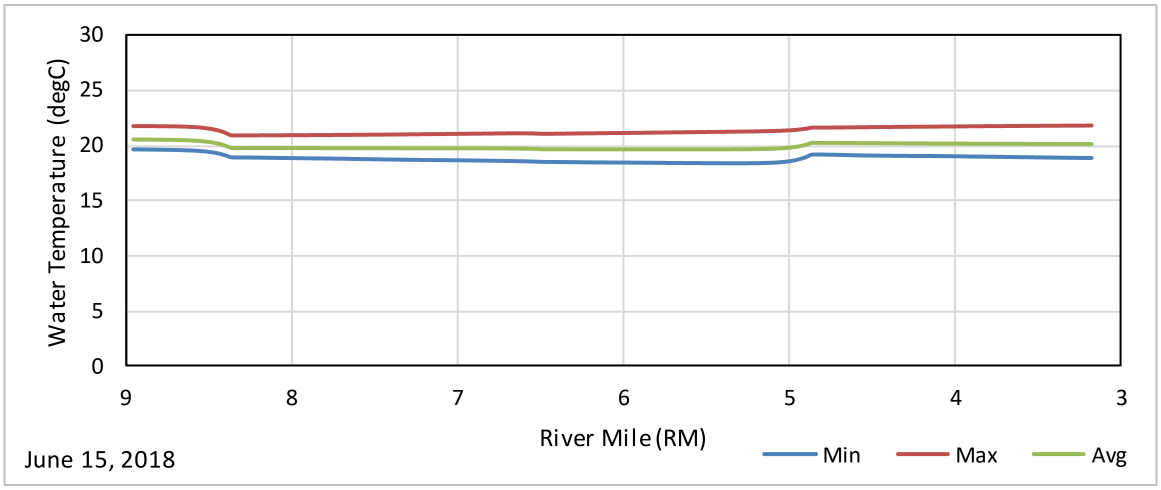


Figure G - 8. June 15, 2018 Average Longitudinal Water Temperature Profile in the Kaweah River Upstream of Powerhouse #1.

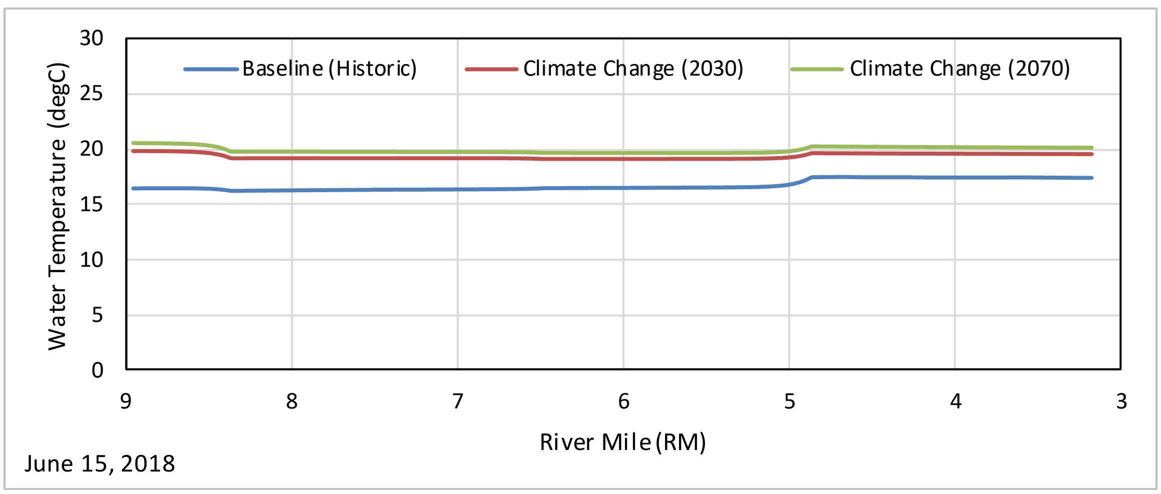


Figure G - 9. September 15, 2018 Baseline (Historic) Maximum, Average, and Minimum Longitudinal Water Temperature Profiles in the Kaweah River Upstream of Powerhouse #2.

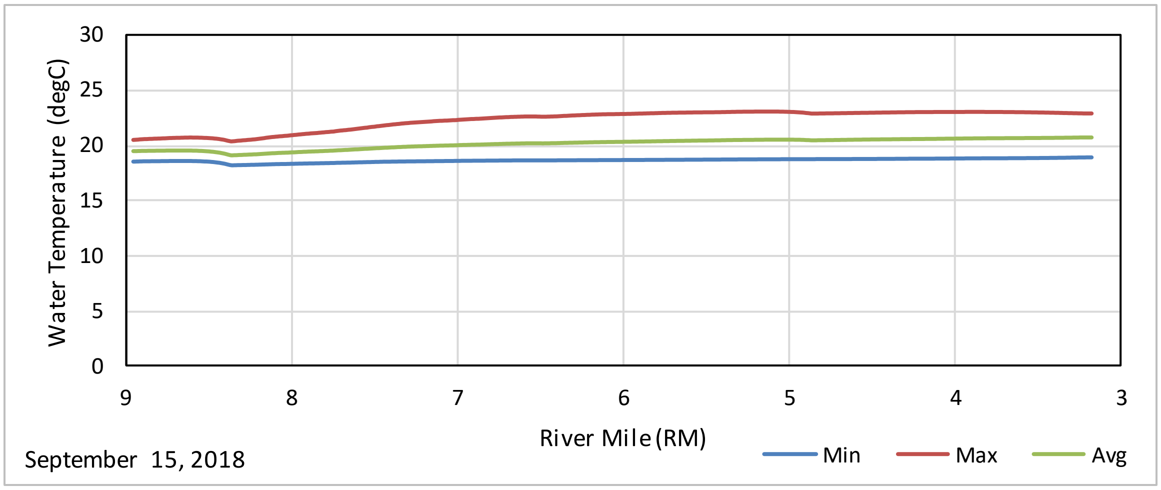


Figure G - 10. September 15, 2018 Climate Change 2030 Maximum, Average, and Minimum Longitudinal Water Temperature Profiles in the Kaweah River Upstream of Powerhouse #2.

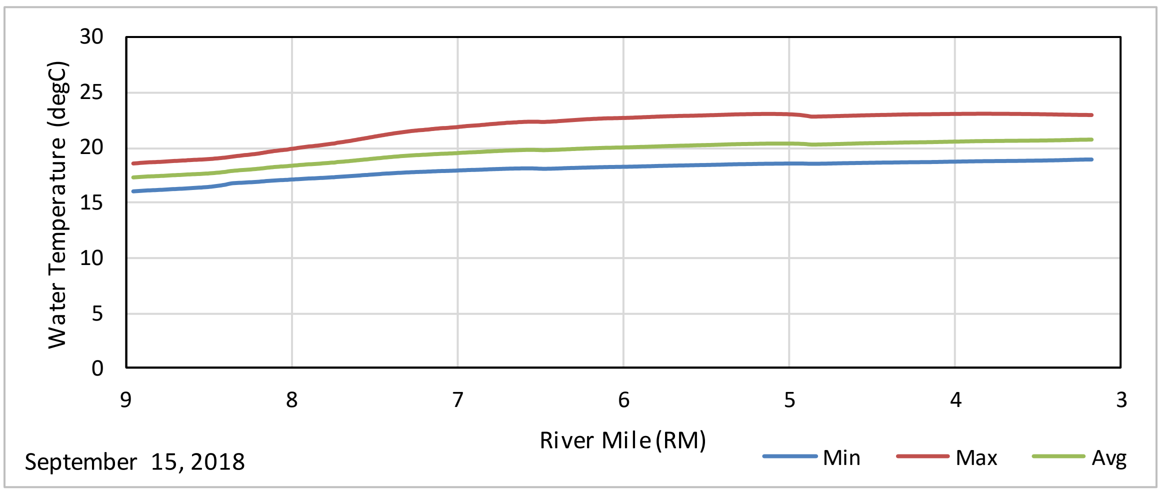


Figure G - 11. September 15, 2018 Climate Change 2070 Maximum, Average, and Minimum Longitudinal Water Temperature Profiles in the Kaweah River Upstream of Powerhouse #2.

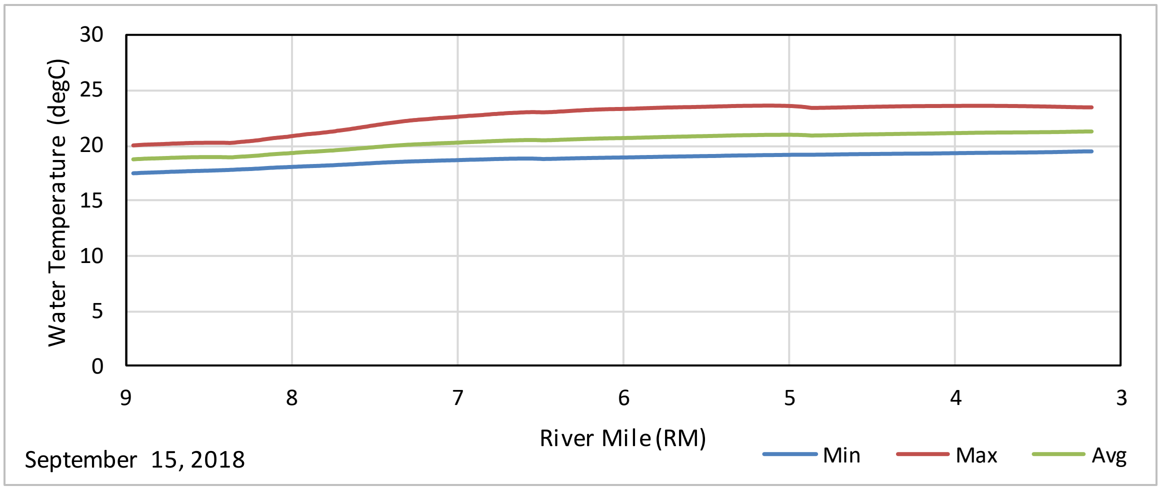


Figure G - 12. September 15, 2018 Average Longitudinal Water Temperature Profile in the Kaweah River Upstream of Powerhouse #2.

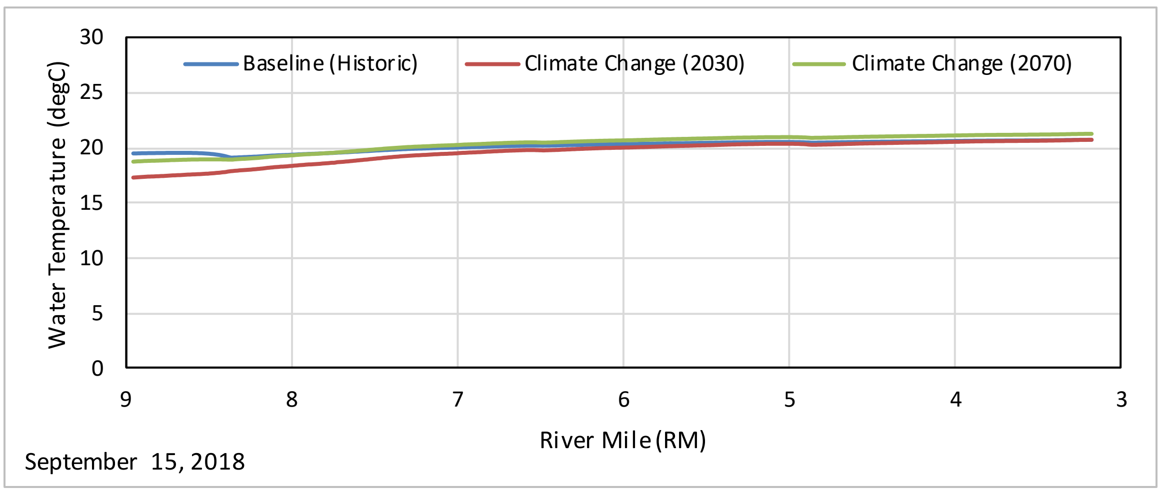


Figure G - 13. December 15, 2018 Baseline (Historic) Maximum, Average, and Minimum Longitudinal Water Temperature Profiles in the Kaweah River Upstream of the Confluence with the North Fork.

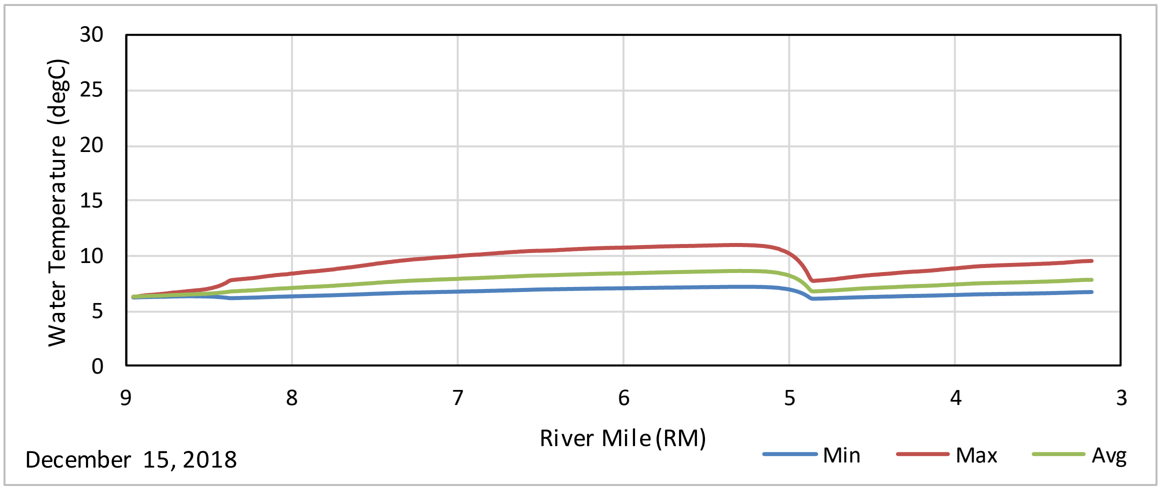


Figure G - 14. December 15, 2018 Climate Change 2030 Maximum, Average, and Minimum Longitudinal Water Temperature Profiles in the Kaweah River Upstream of the Confluence with the North Fork.

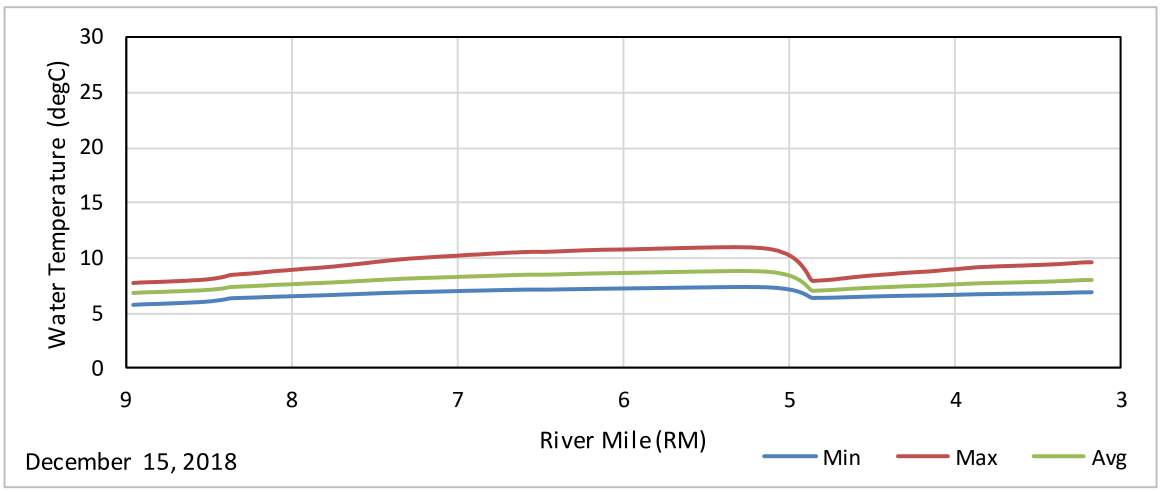


Figure G - 15. December 15, 2018 Climate Change 2070 Maximum, Average, and Minimum Longitudinal Water Temperature Profiles in the Kaweah River Upstream of the Confluence with the North Fork.

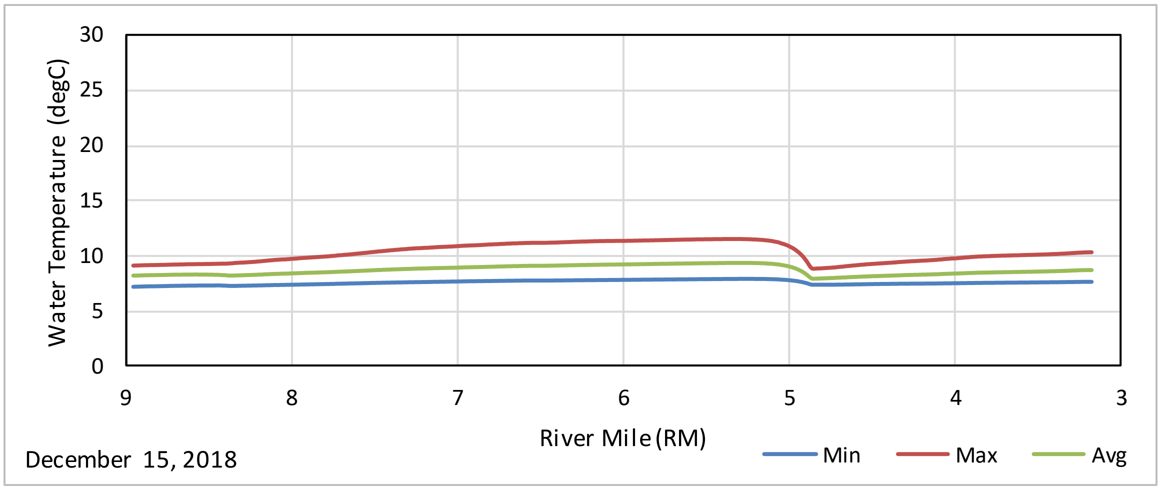
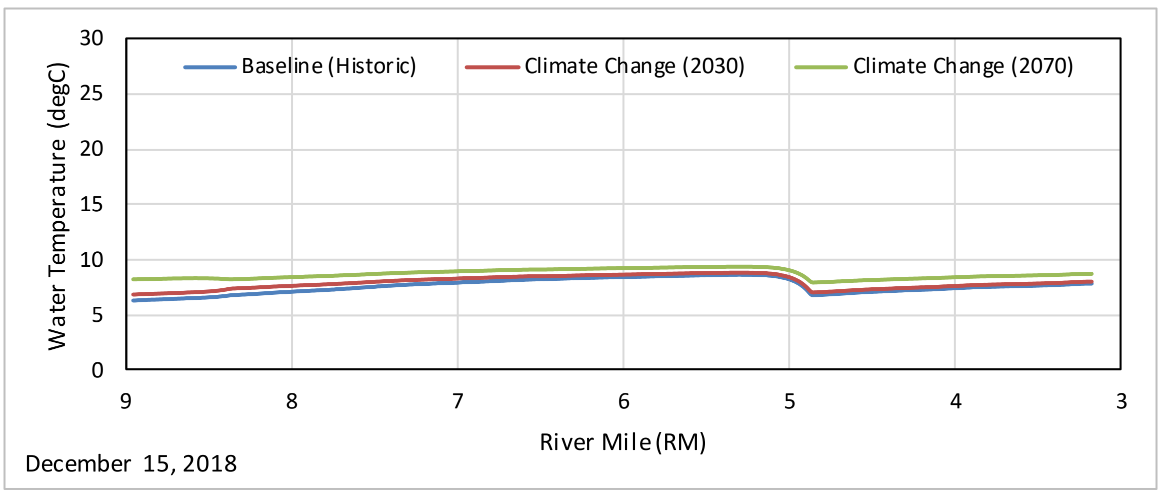


Figure G - 16. December 15, 2018 Average Longitudinal Water Temperature Profile in the Kaweah River Upstream of the Confluence with the North Fork.



Kaweah River: Temporal Water Temperature Profiles

Figure G - 17. Hourly Water Temperature and Daily Average Flow Model Results for the Baseline (Historic) and Climate Change 2030 for Kaweah River Upstream of the Confluence with the East Fork, January 1 – December 31, 2018.

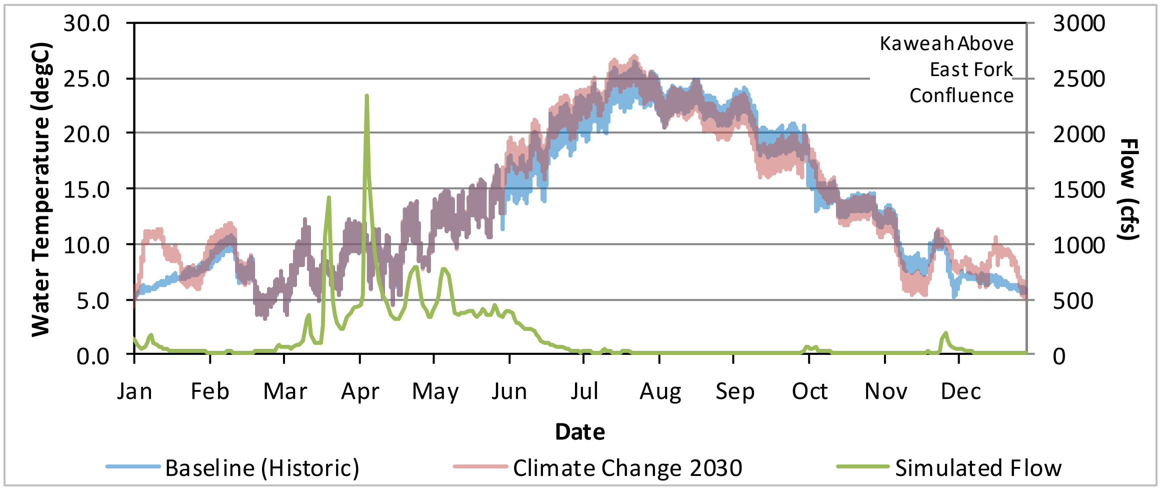


Figure G - 18. Hourly Water Temperature and Daily Average Flow Model Results for the Baseline (Historic) and Climate Change 2030 for Kaweah River Upstream of the Confluence with the East Fork, January 1 – March 31, 2018.

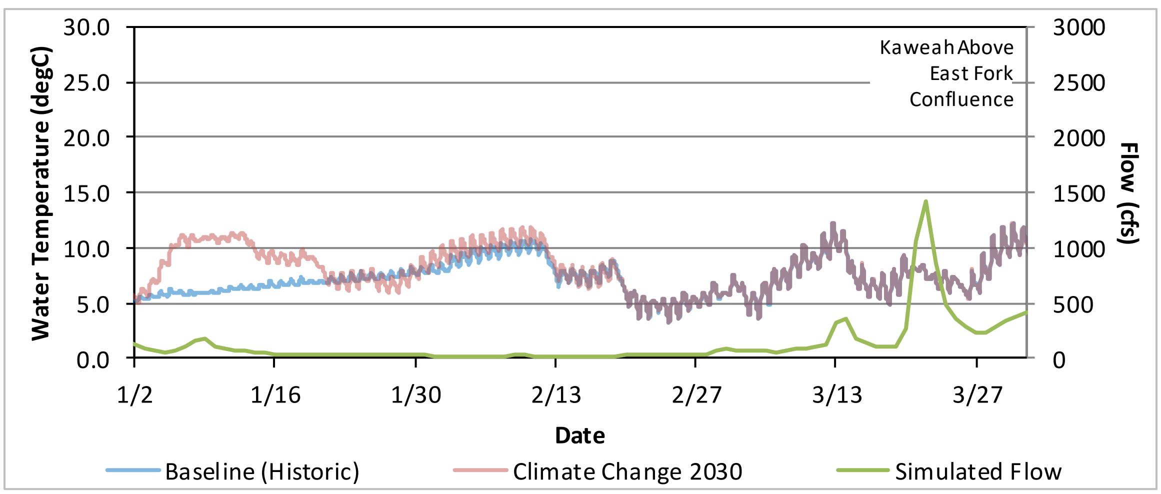


Figure G - 19. Hourly Water Temperature and Daily Average Flow Model Results for the Baseline (Historic) and Climate Change 2030 for Kaweah River Upstream of the Confluence with the East Fork, April 1 – June 30, 2018.

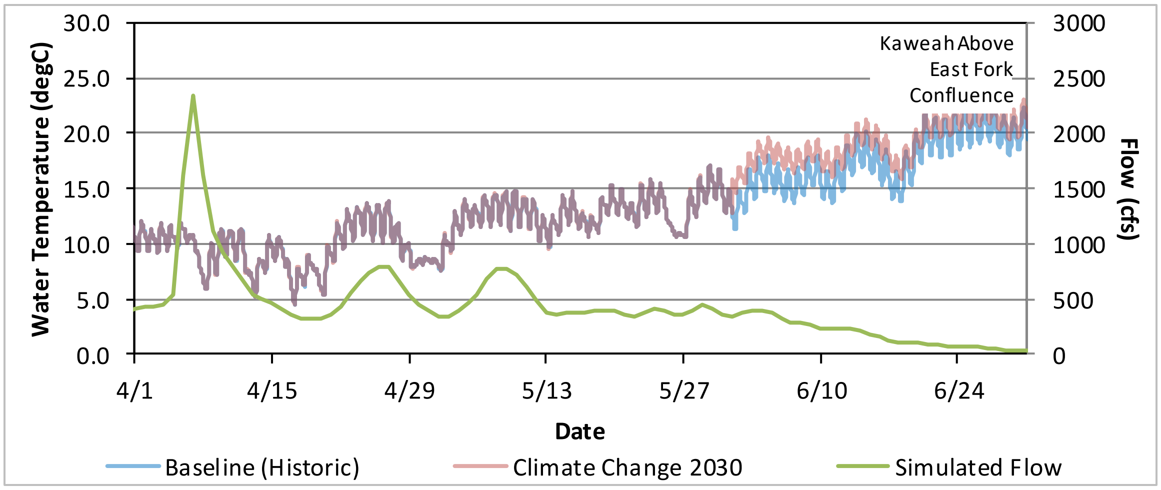


Figure G - 20. Hourly Water Temperature and Daily Average Flow Model Results for the Baseline (Historic) and Climate Change 2030 for Kaweah River Upstream of the Confluence with the East Fork, July 1 – September 30, 2018.

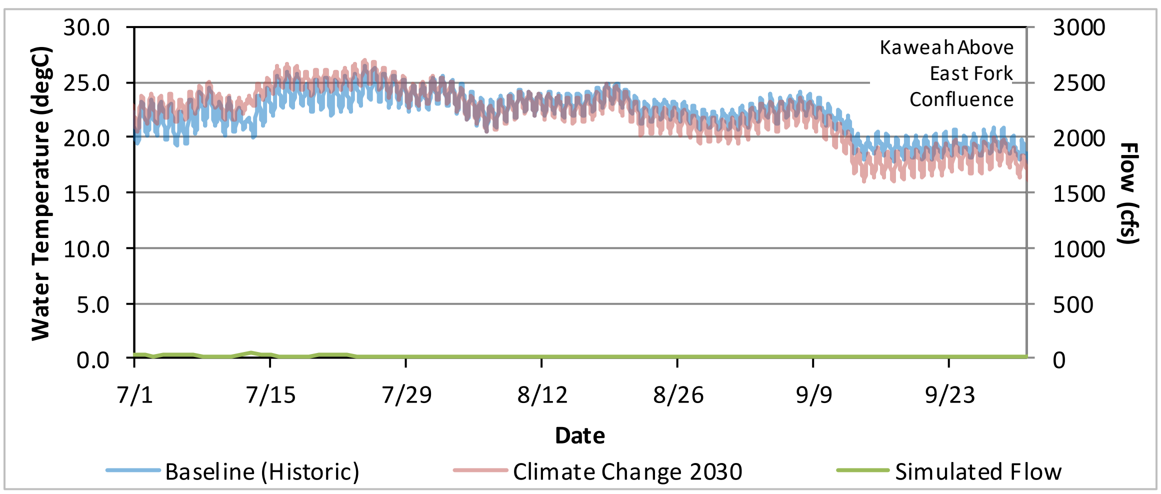


Figure G - 21. Hourly Water Temperature and Daily Average Flow Model Results for the Baseline (Historic) and Climate Change 2030 for Kaweah River Upstream of the Confluence with the East Fork, October 1 – December 31, 2018.

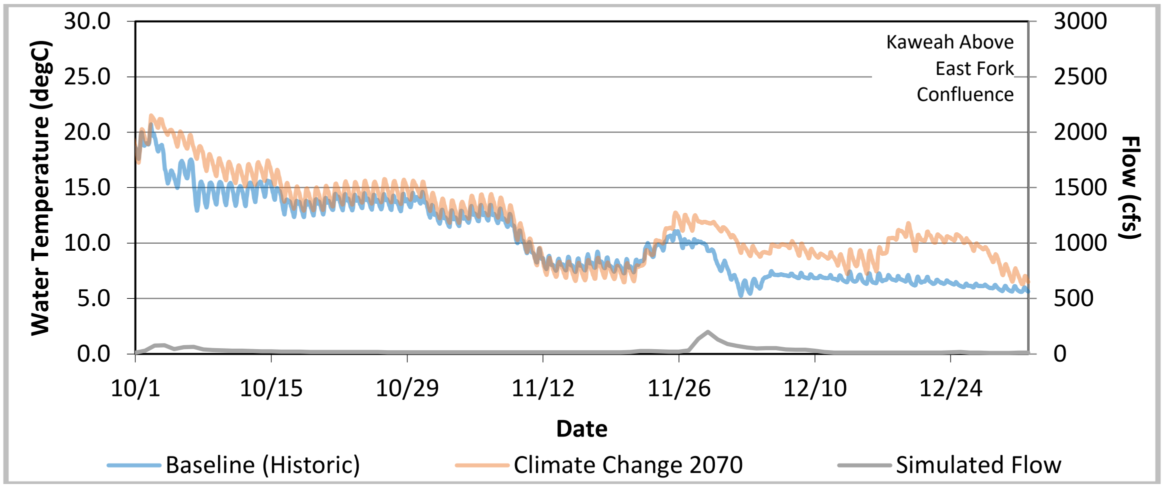


Figure G - 22. Hourly Water Temperature and Daily Average Flow Model Results for the Baseline (Historic) and Climate Change 2030 for Kaweah River Upstream of Powerhouse #1, January 1 – December 31, 2018.

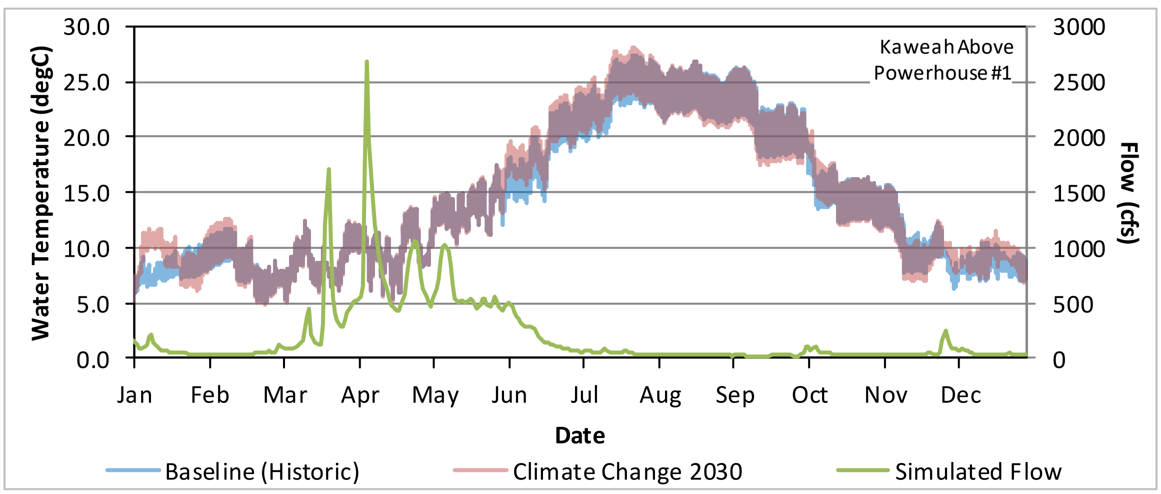


Figure G - 23. Hourly Water Temperature and Daily Average Flow Model Results for the Baseline (Historic) and Climate Change 2030 for Kaweah River Upstream of Powerhouse #1, January 1 – March 31, 2018.

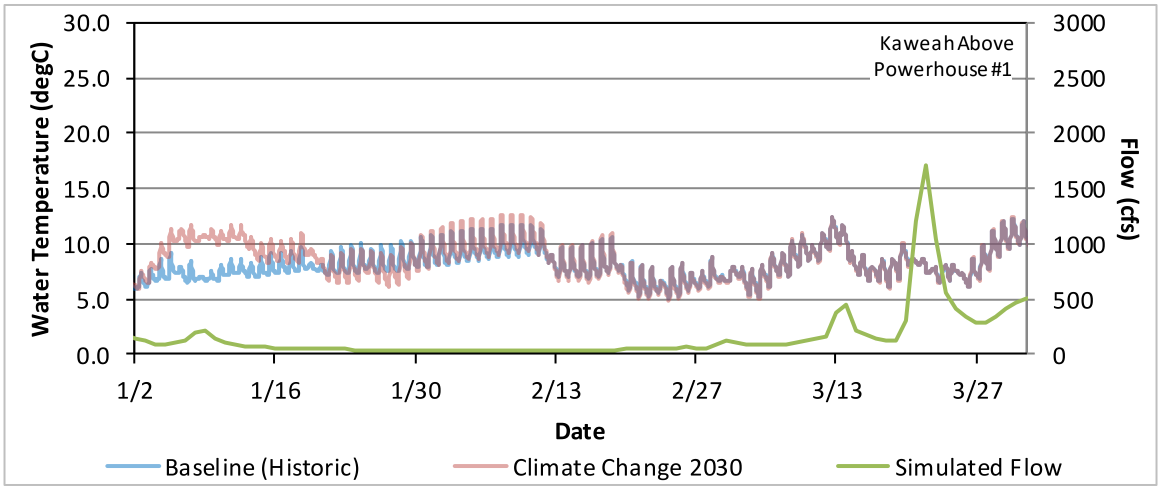


Figure G - 24. Hourly Water Temperature and Daily Average Flow Model Results for the Baseline (Historic) and Climate Change 2030 for Kaweah River Upstream of Powerhouse #1, April 1 – June 30, 2018.

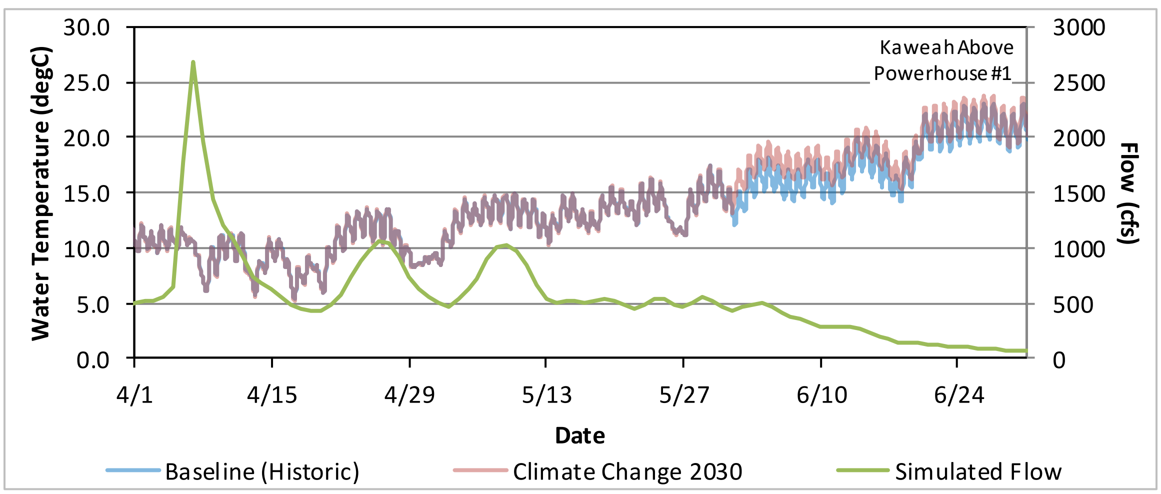


Figure G - 25. **Hourly Water Temperature and Daily Average Flow Model Results for the Baseline (Historic) and Climate Change 2030 for Kaweah River Upstream of Powerhouse #1, July 1 – September 30, 2018.**

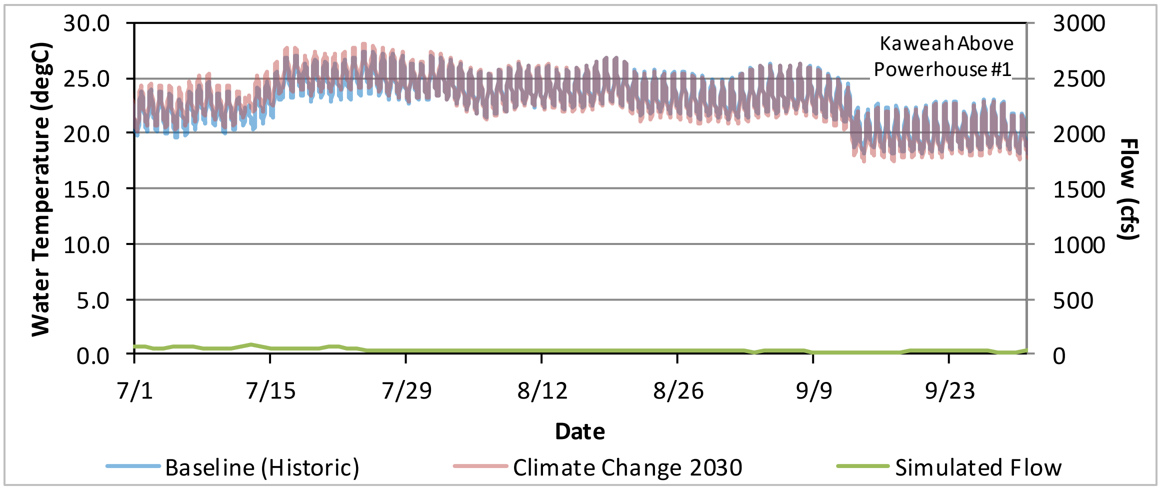


Figure G - 26. **Hourly Water Temperature and Daily Average Flow Model Results for the Baseline (Historic) and Climate Change 2030 for Kaweah River Upstream of Powerhouse #1, October 1 – December 31, 2018.**

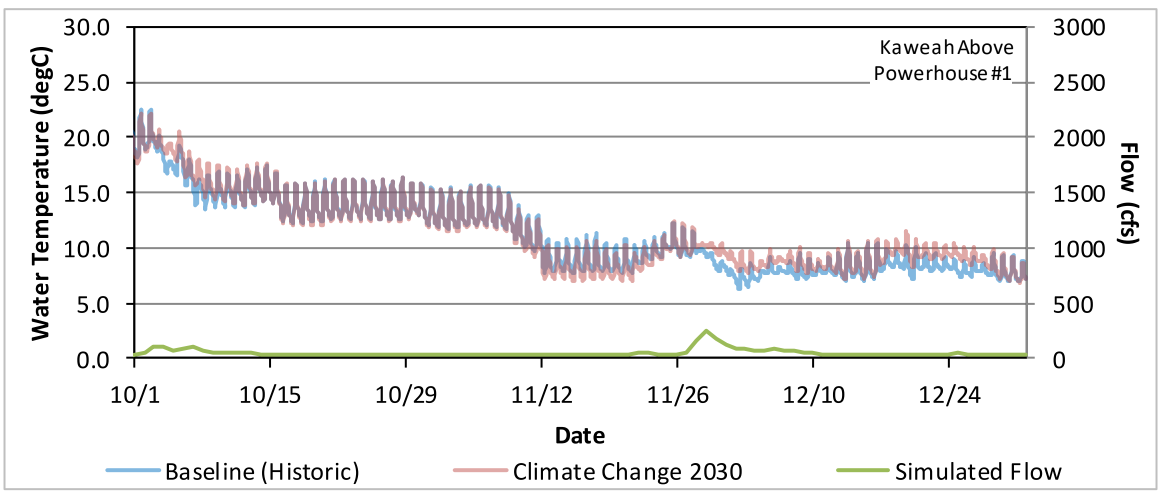


Figure G - 27. Hourly Water Temperature and Daily Average Flow Model Results for the Baseline (Historic) and Climate Change 2030 for Kaweah River Upstream of Powerhouse #2, January 1 – December 31, 2018.

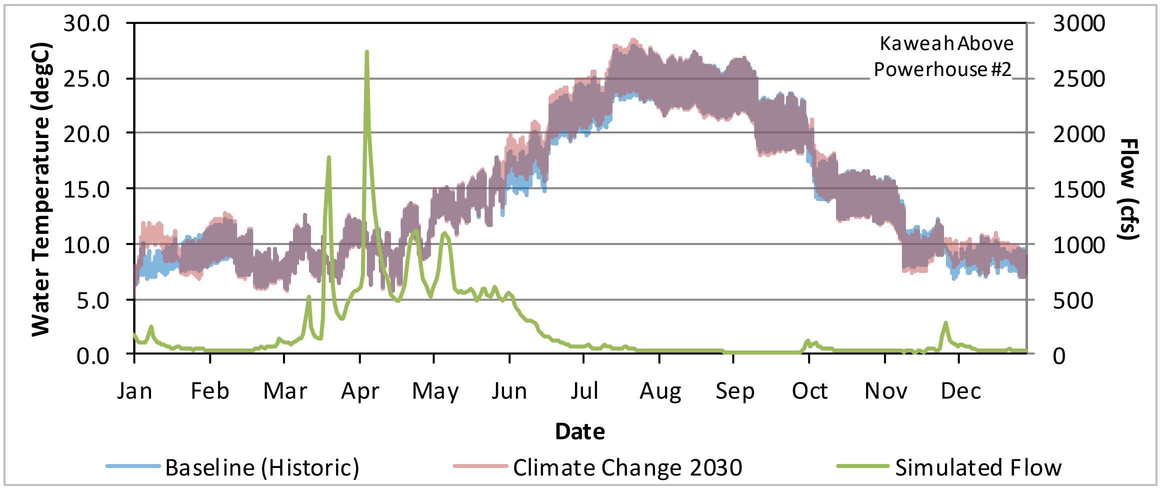


Figure G - 28. Hourly Water Temperature and Daily Average Flow Model Results for the Baseline (Historic) and Climate Change 2030 for Kaweah River Upstream of Powerhouse #2, January 1 – March 31, 2018.

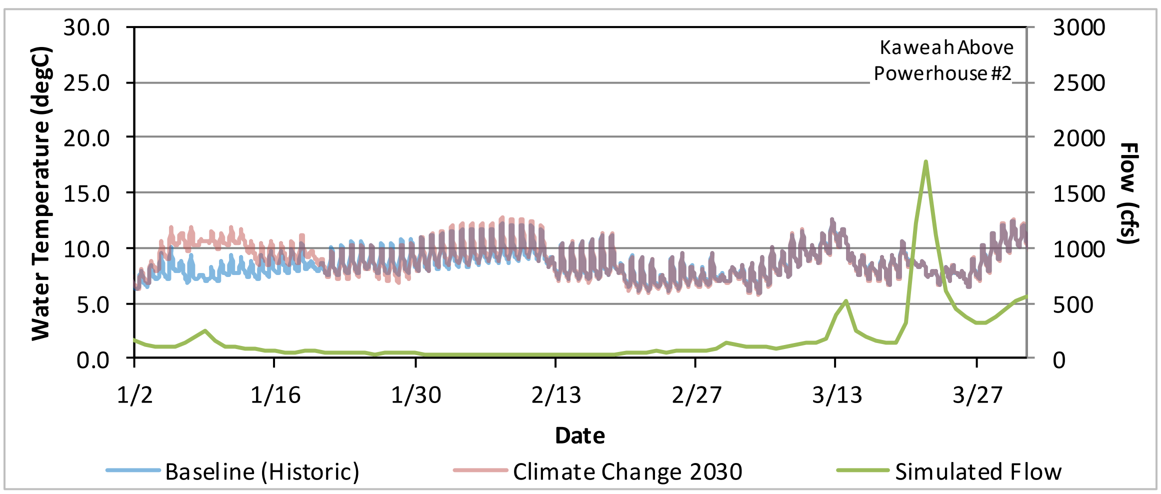


Figure G - 29. Hourly Water Temperature and Daily Average Flow Model Results for the Baseline (Historic) and Climate Change 2030 for Kaweah River Upstream of Powerhouse #2, April 1 – June 30, 2018.

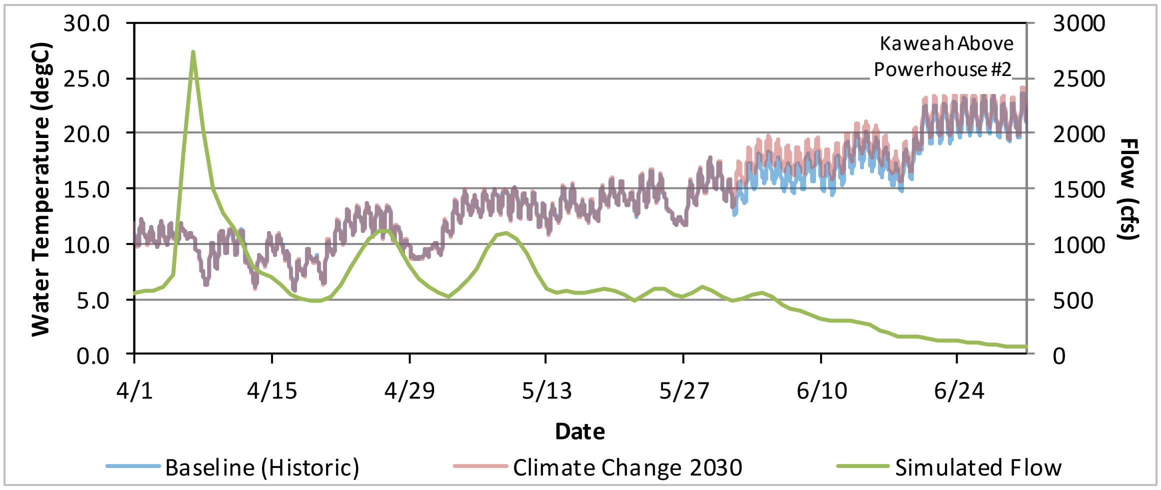


Figure G - 30. Hourly Water Temperature and Daily Average Flow Model Results for the Baseline (Historic) and Climate Change 2030 for Kaweah River Upstream of Powerhouse #2, July 1 – September 30, 2018.

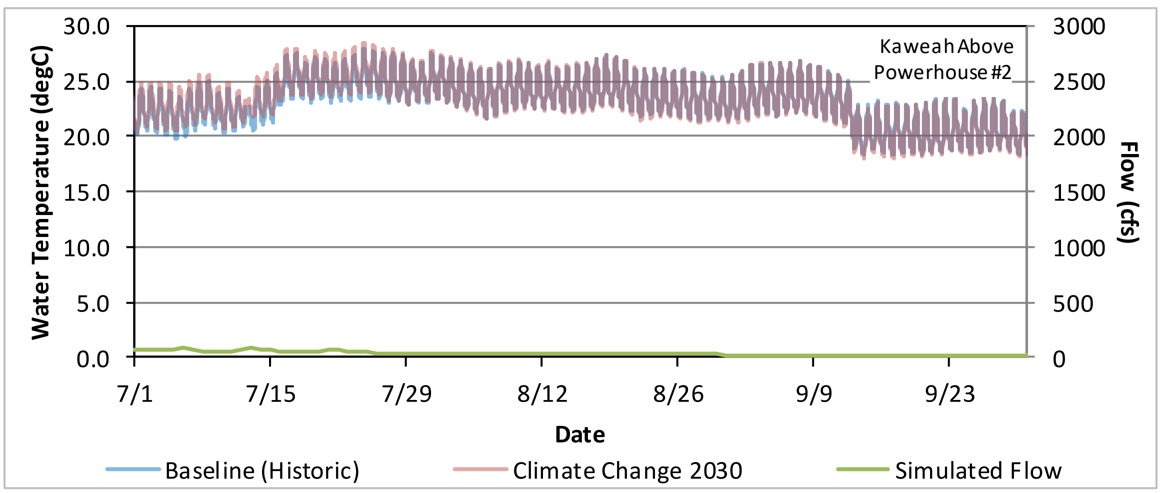


Figure G - 31. Hourly Water Temperature and Daily Average Flow Model Results for the Baseline (Historic) and Climate Change 2030 for Kaweah River Upstream of Powerhouse #2, October 1 – December 31, 2018.

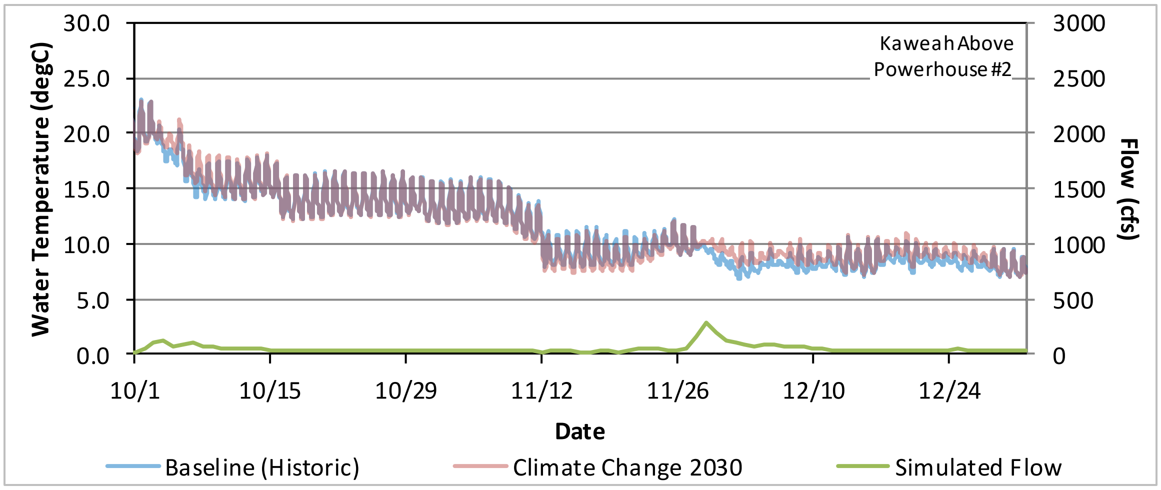


Figure G - 32. Hourly Water Temperature and Daily Average Flow Model Results for the Baseline (Historic) and Climate Change 2030 for Kaweah River Upstream of the Confluence with the North Fork, January 1 – December 31, 2018.

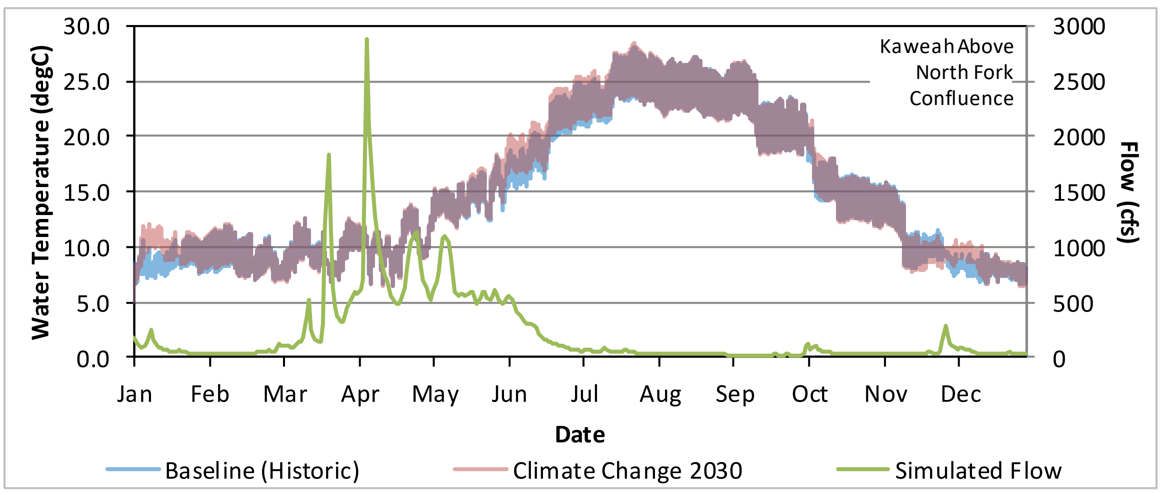


Figure G - 33. Hourly Water Temperature and Daily Average Flow Model Results for the Baseline (Historic) and Climate Change 2030 for Kaweah River Upstream of the Confluence with the North Fork, January 1 – March 31, 2018.

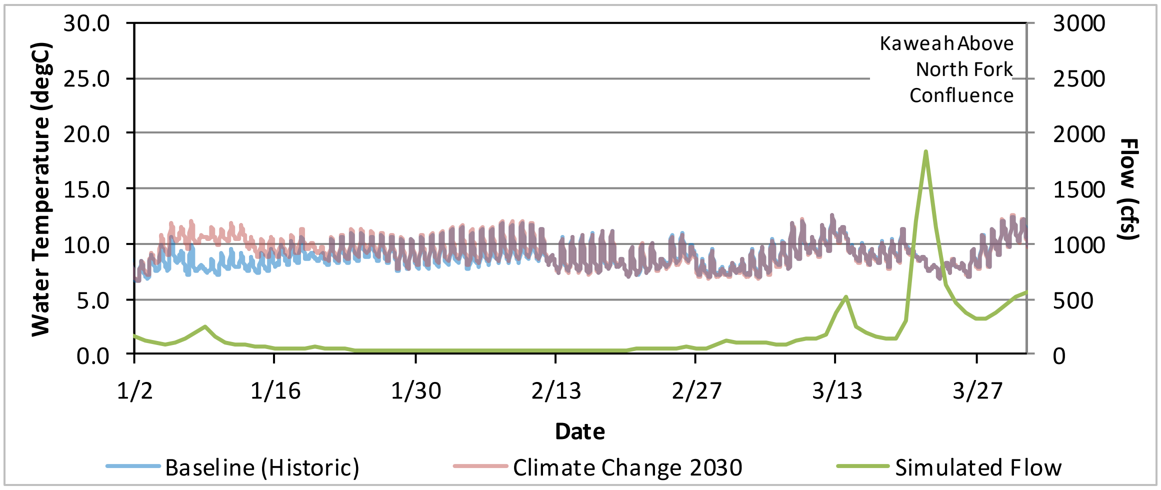


Figure G - 34. Hourly Water Temperature and Daily Average Flow Model Results for the Baseline (Historic) and Climate Change 2030 for Kaweah River Upstream of the Confluence with the North Fork, April 1 – June 30, 2018.

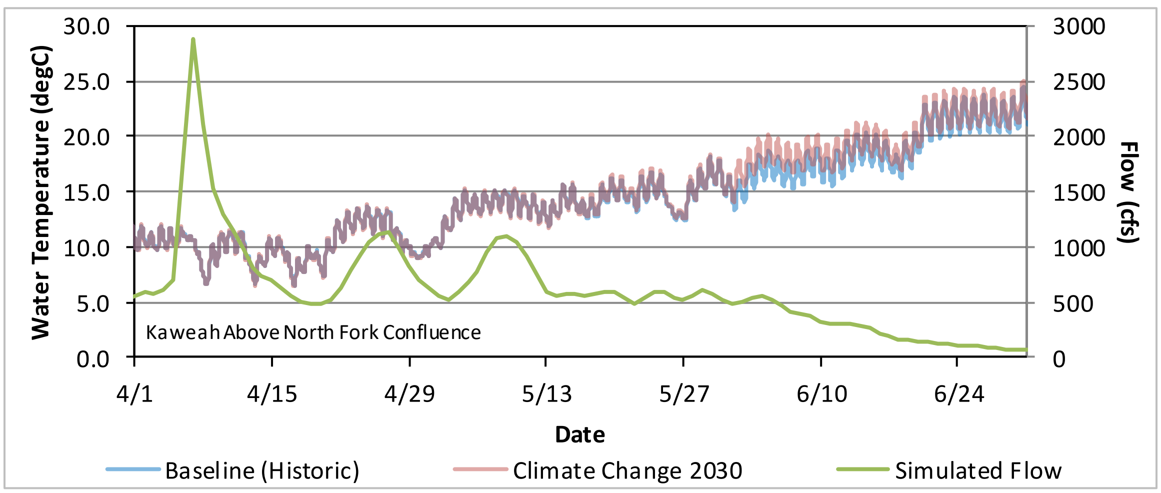


Figure G - 35. Hourly Water Temperature and Daily Average Flow Model Results for the Baseline (Historic) and Climate Change 2030 for Kaweah River Upstream of the Confluence with the North Fork, July 1 – September 30, 2018.

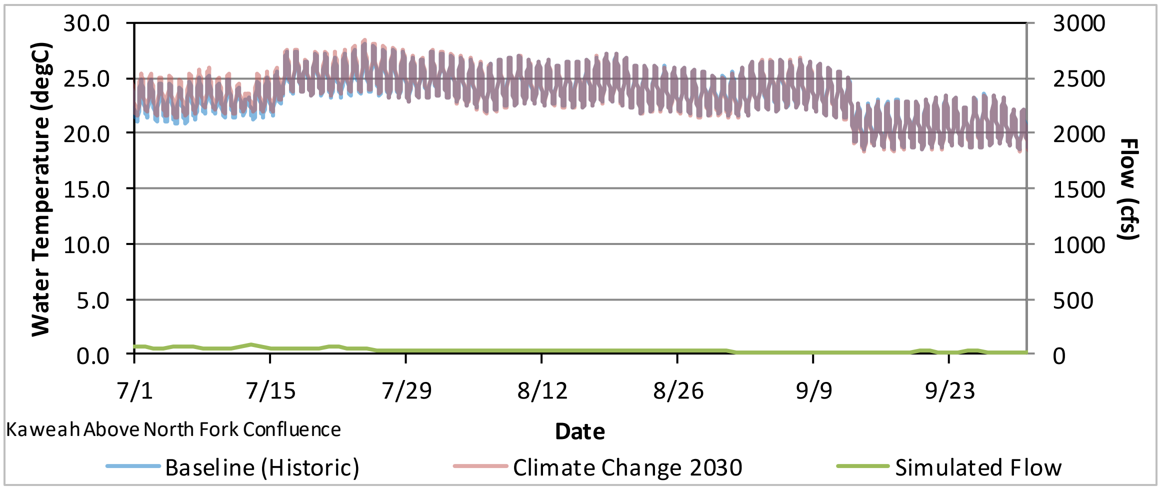


Figure G - 36. Hourly Water Temperature and Daily Average Flow Model Results for the Baseline (Historic) and Climate Change 2030 for Kaweah River Upstream of the Confluence with the North Fork, October 1 – December 31, 2018.

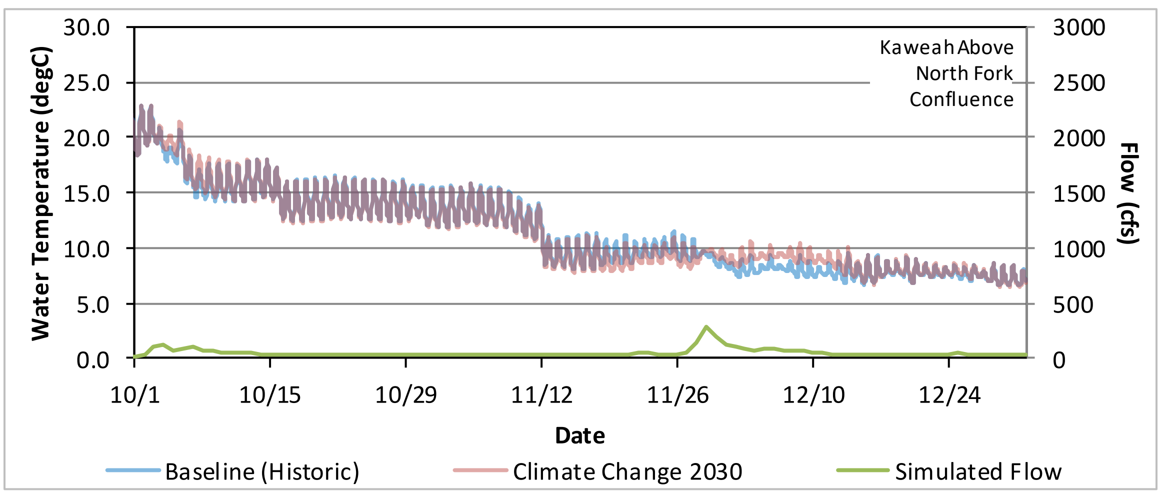


Figure G - 37. Hourly Water Temperature and Daily Average Flow Model Results for the Baseline (Historic) and Climate Change 2070 for Kaweah River Upstream of the Confluence with the East Fork, January 1 – December 31, 2018.

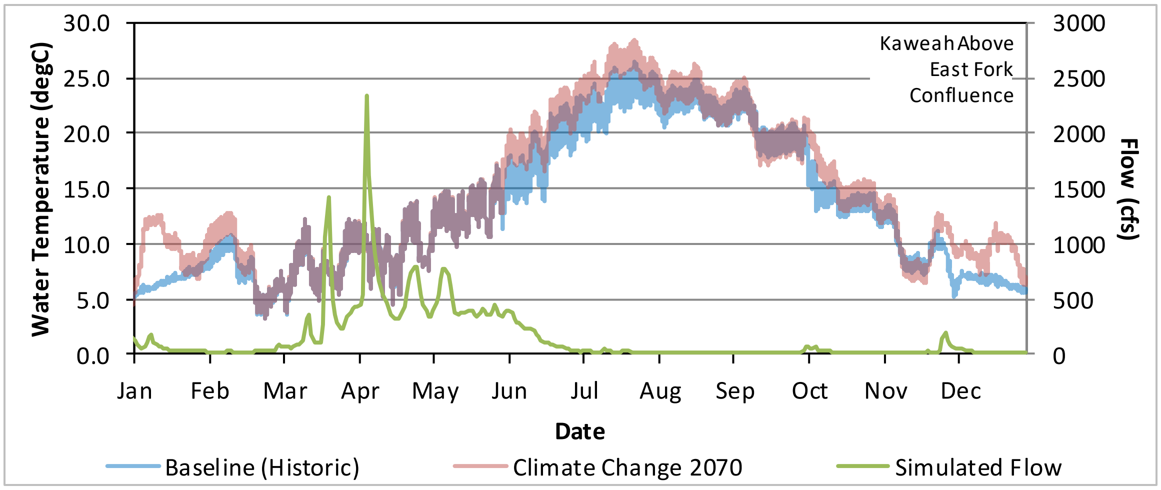


Figure G - 38. Hourly Water Temperature and Daily Average Flow Model Results for the Baseline (Historic) and Climate Change 2070 for Kaweah River Upstream of the Confluence with the East Fork, January 1 – March 31, 2018.

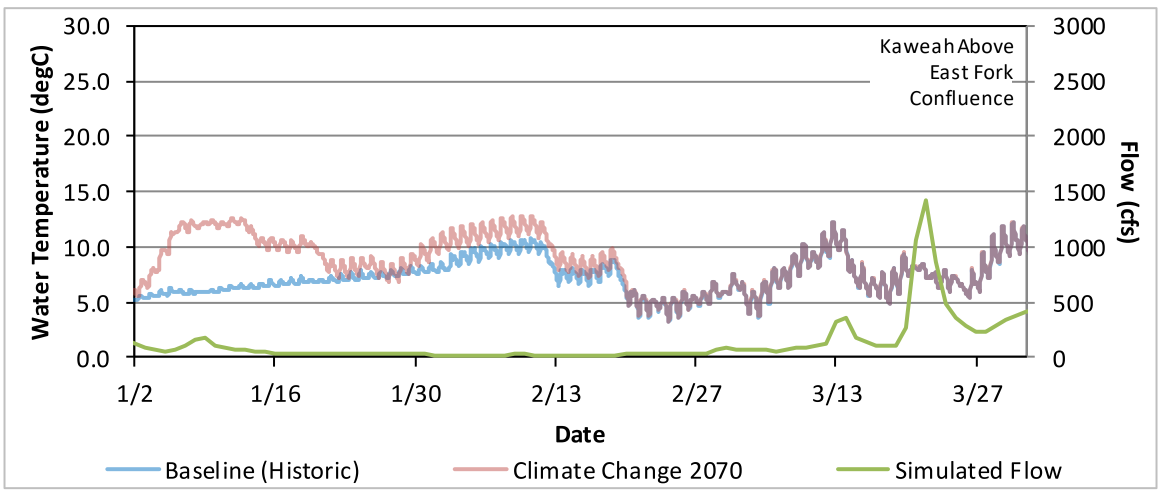


Figure G - 39. Hourly Water Temperature and Daily Average Flow Model Results for the Baseline (Historic) and Climate Change 2070 for Kaweah River Upstream of the Confluence with the East Fork, April 1 – June 30, 2018.

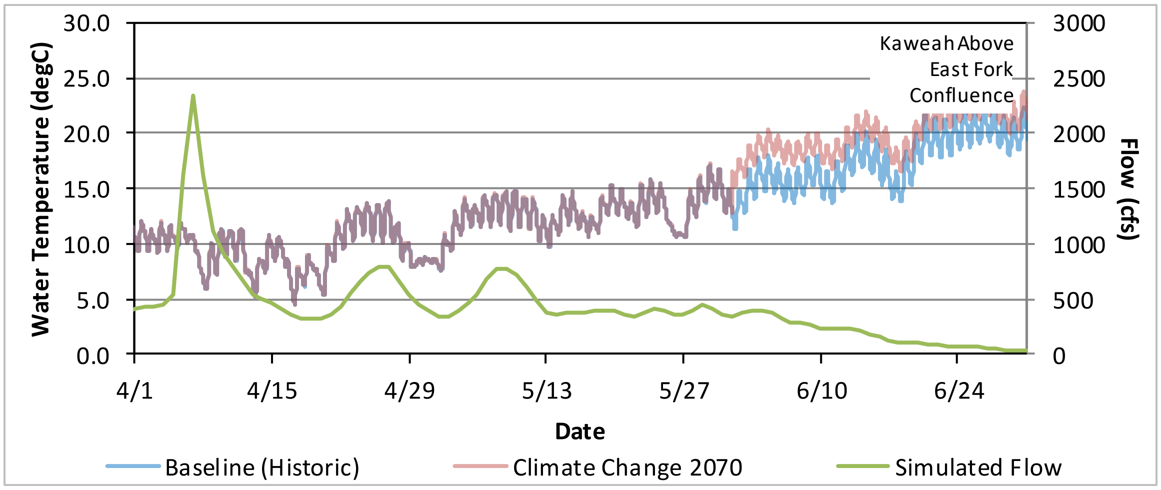


Figure G - 40. Hourly Water Temperature and Daily Average Flow Model Results for the Baseline (Historic) and Climate Change 2070 for Kaweah River Upstream of the Confluence with the East Fork, July 1 – September 30, 2018.

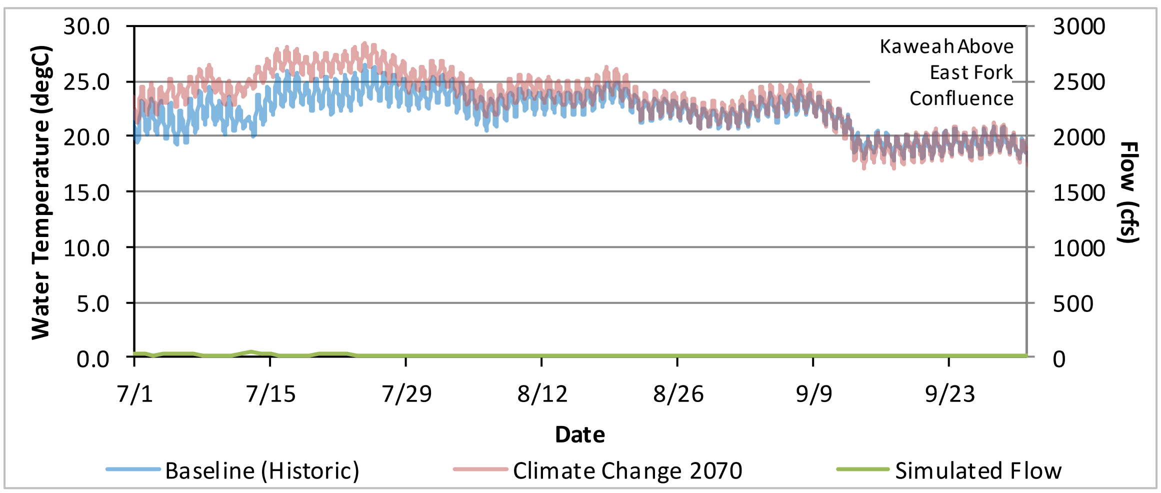


Figure G - 41. Hourly Water Temperature and Daily Average Flow Model Results for the Baseline (Historic) and Climate Change 2070 for Kaweah River Upstream of the Confluence with the East Fork, October 1 – December 31, 2018.

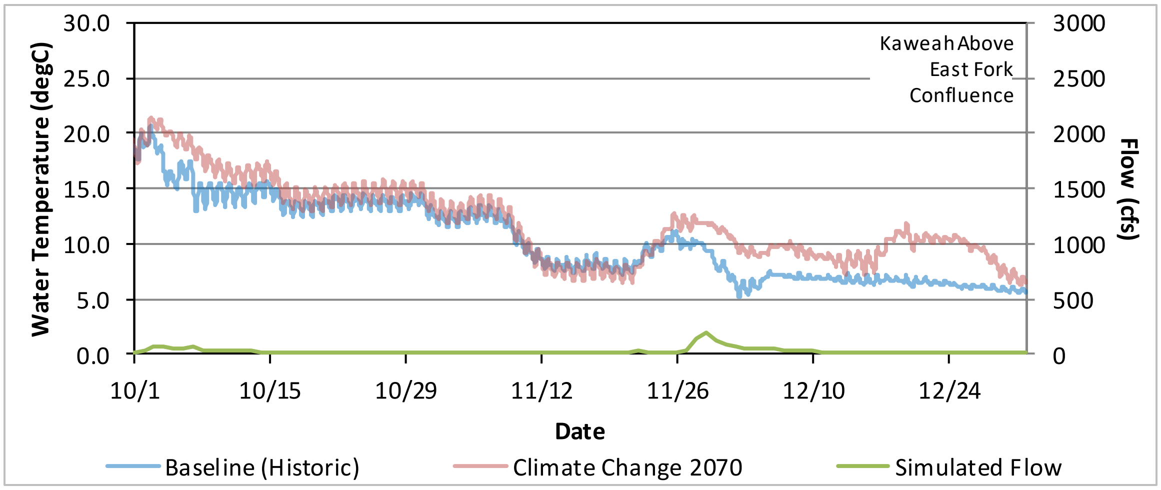


Figure G - 42. Hourly Water Temperature and Daily Average Flow Model Results for the Baseline (Historic) and Climate Change 2070 for Kaweah River Upstream of Powerhouse #1, January 1 – December 31, 2018.

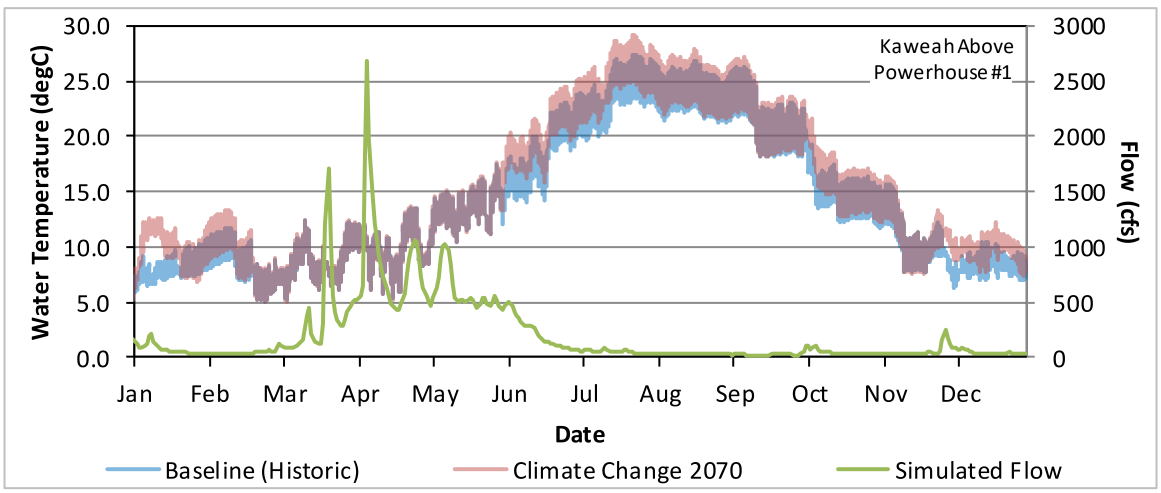


Figure G - 43. Hourly Water Temperature and Daily Average Flow Model Results for the Baseline (Historic) and Climate Change 2070 for Kaweah River Upstream of Powerhouse #1, January 1 – March 31, 2018.

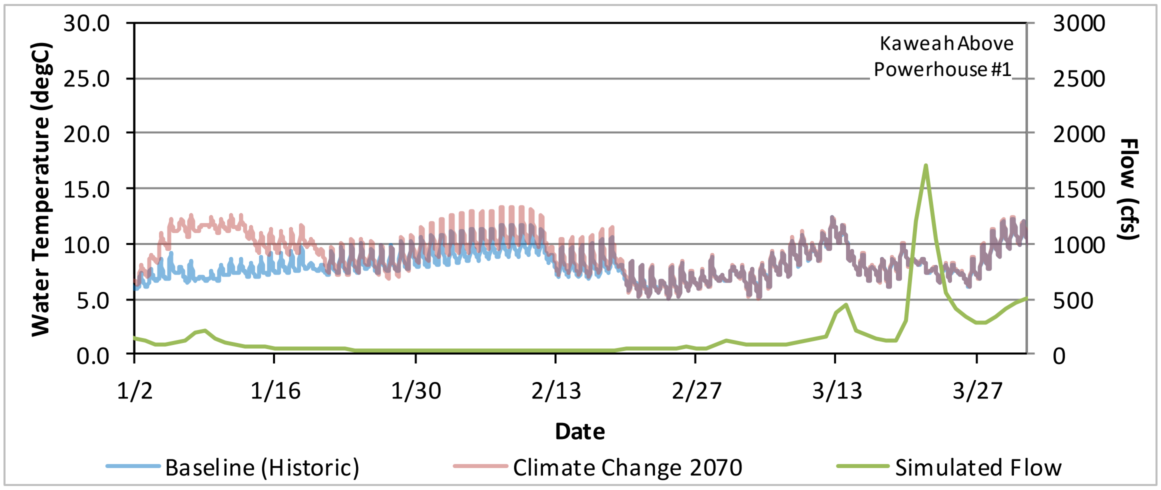


Figure G - 44. Hourly Water Temperature and Daily Average Flow Model Results for the Baseline (Historic) and Climate Change 2070 for Kaweah River Upstream of Powerhouse #1, April 1 – June 30, 2018.

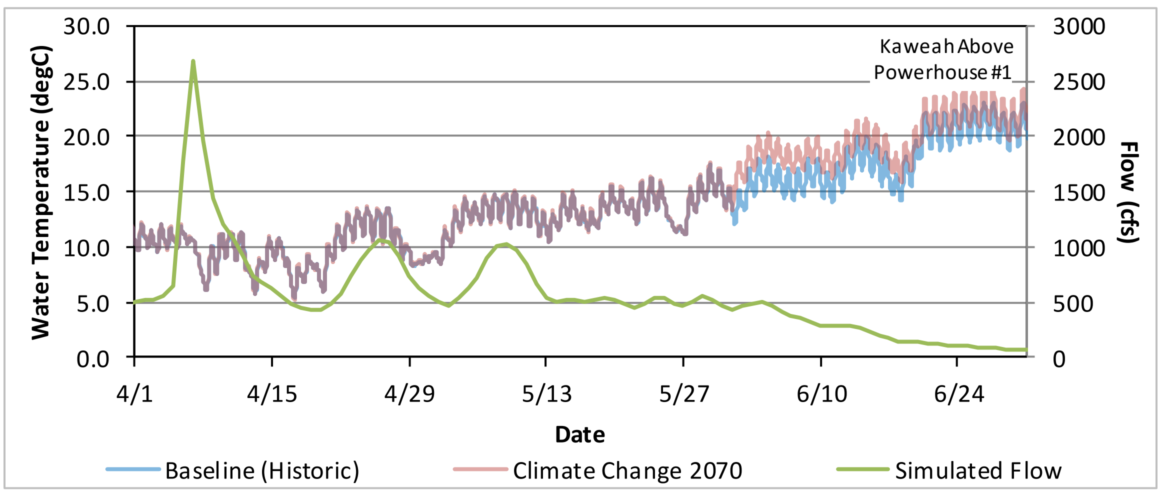


Figure G - 45. Hourly Water Temperature and Daily Average Flow Model Results for the Baseline (Historic) and Climate Change 2070 for Kaweah River Upstream of Powerhouse #1, July 1 – September 30, 2018.

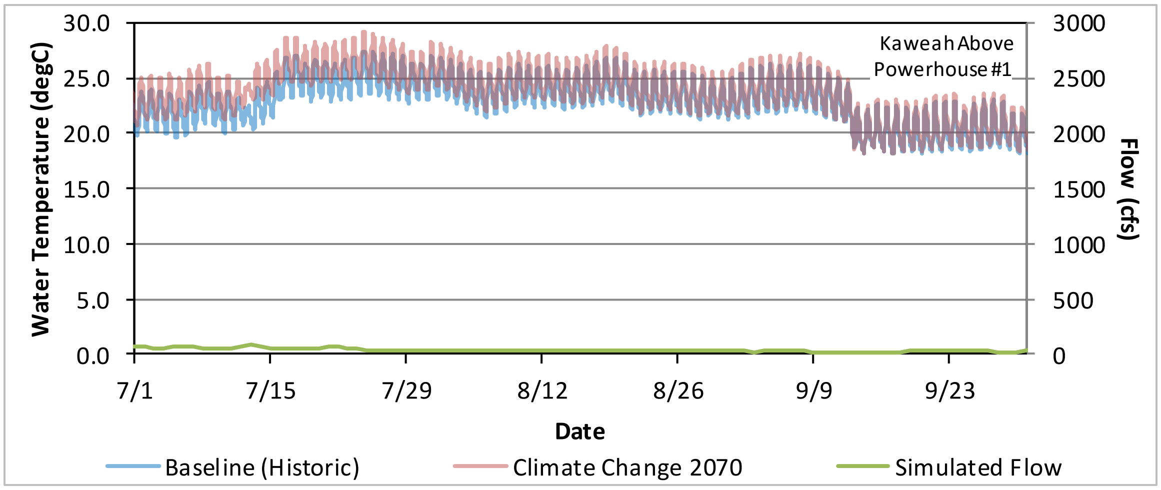


Figure G - 46. Hourly Water Temperature and Daily Average Flow Model Results for the Baseline (Historic) and Climate Change 2070 for Kaweah River Upstream of Powerhouse #1, October 1 – December 31, 2018.

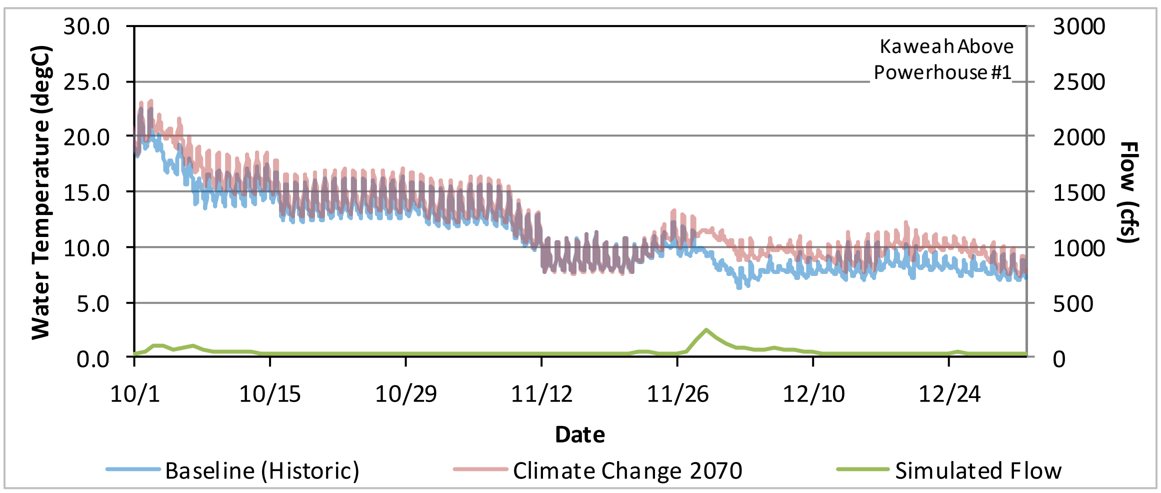


Figure G - 47. Hourly Water Temperature and Daily Average Flow Model Results for the Baseline (Historic) and Climate Change 2070 for Kaweah River Upstream of Powerhouse #2, January 1 – December 31, 2018.

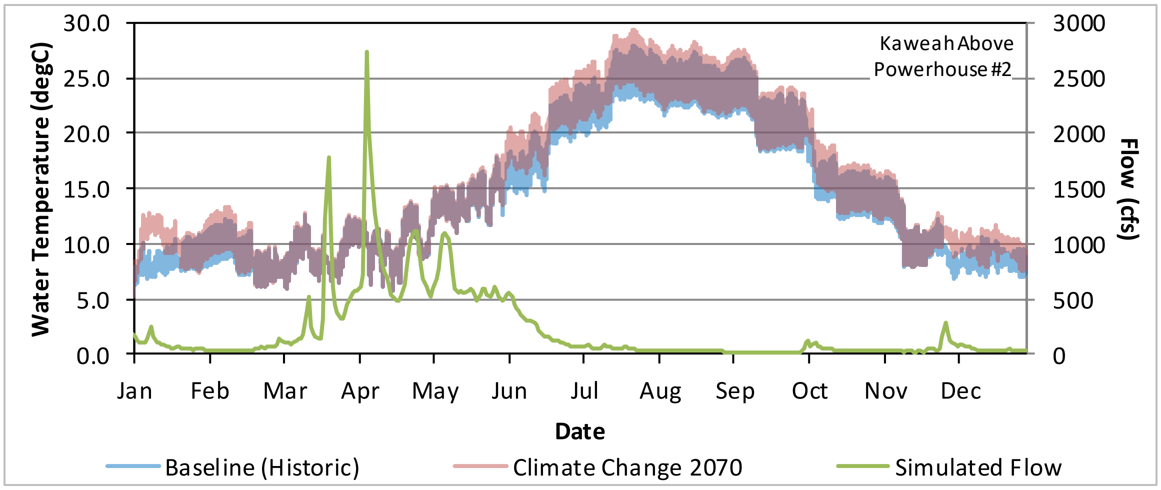
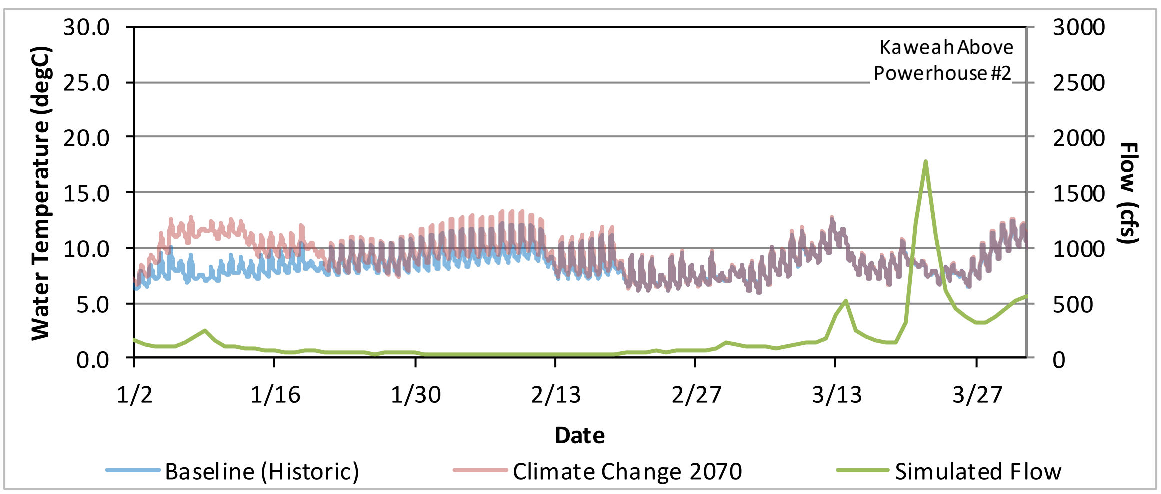


Figure G - 48. Hourly Water Temperature and Daily Average Flow Model Results for the Baseline (Historic) and Climate Change 2070 for Kaweah River Upstream of Powerhouse #2, January 1 – March 31, 2018.



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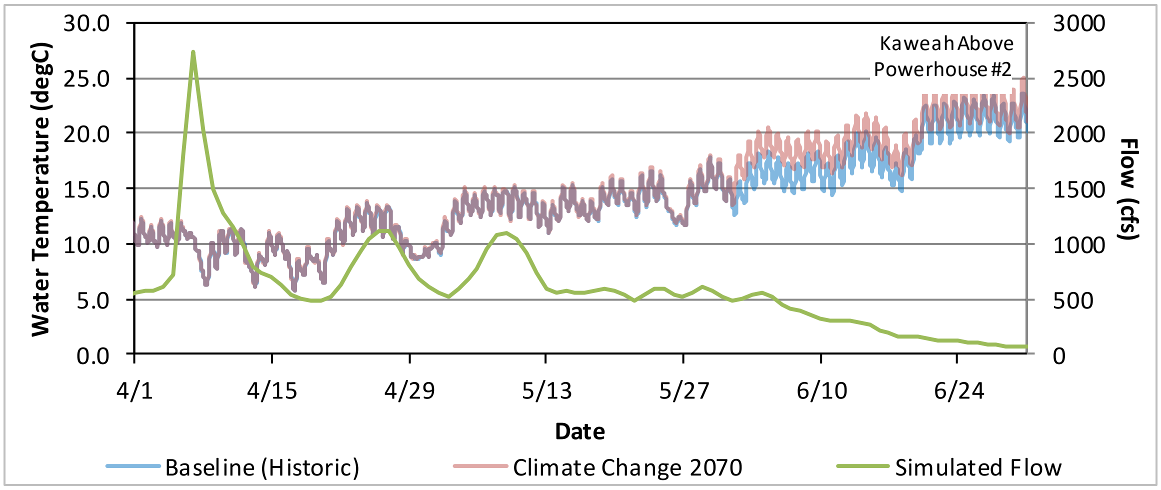

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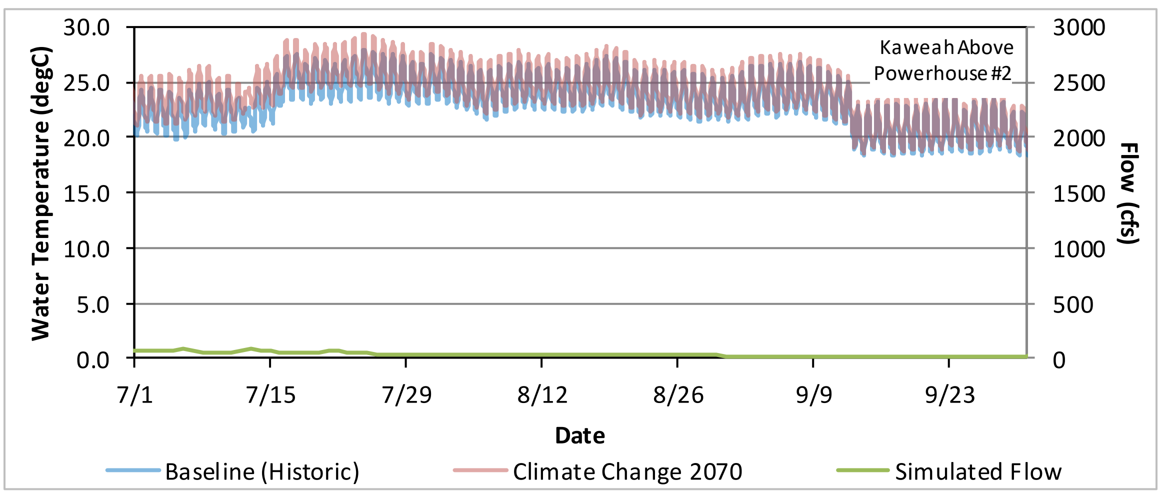

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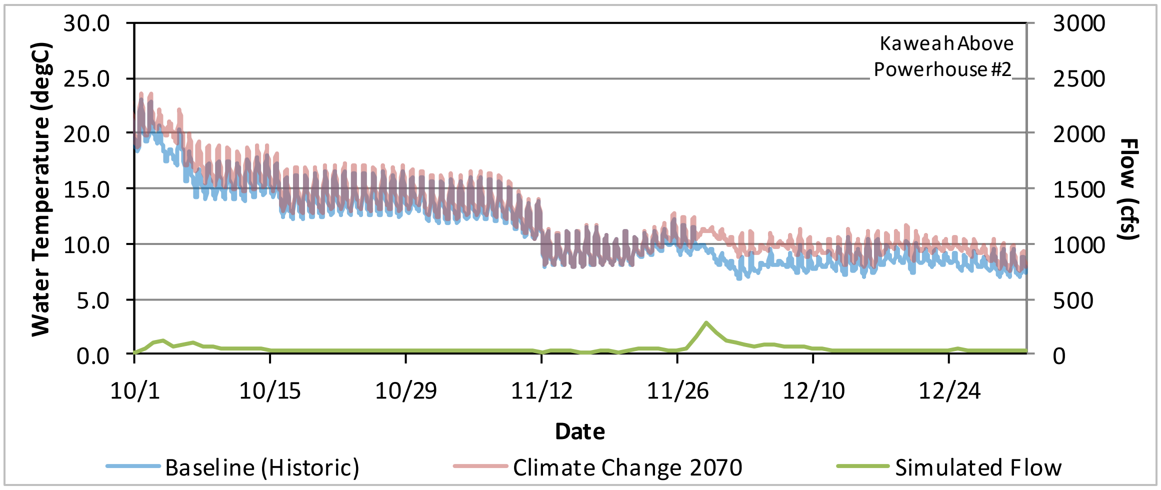

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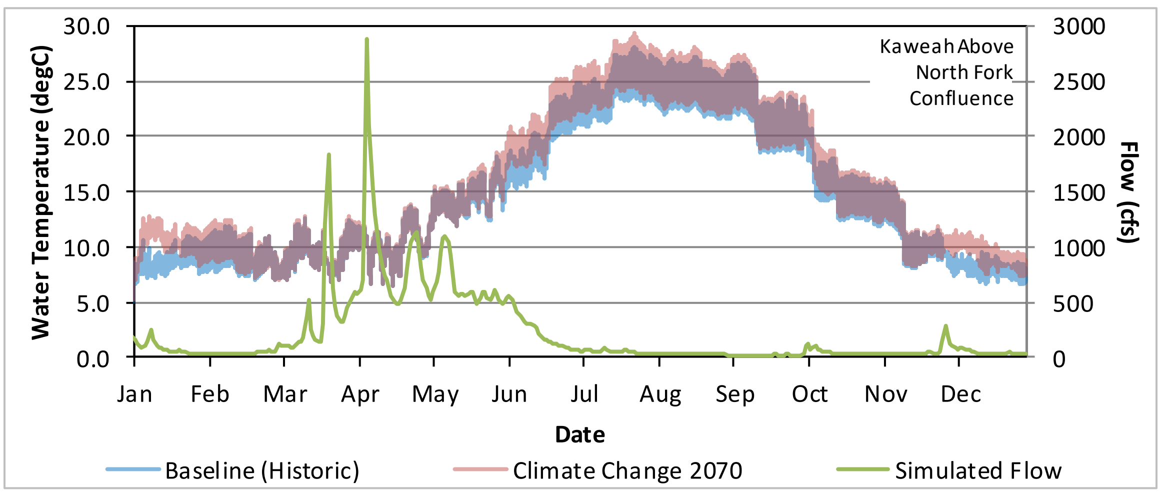

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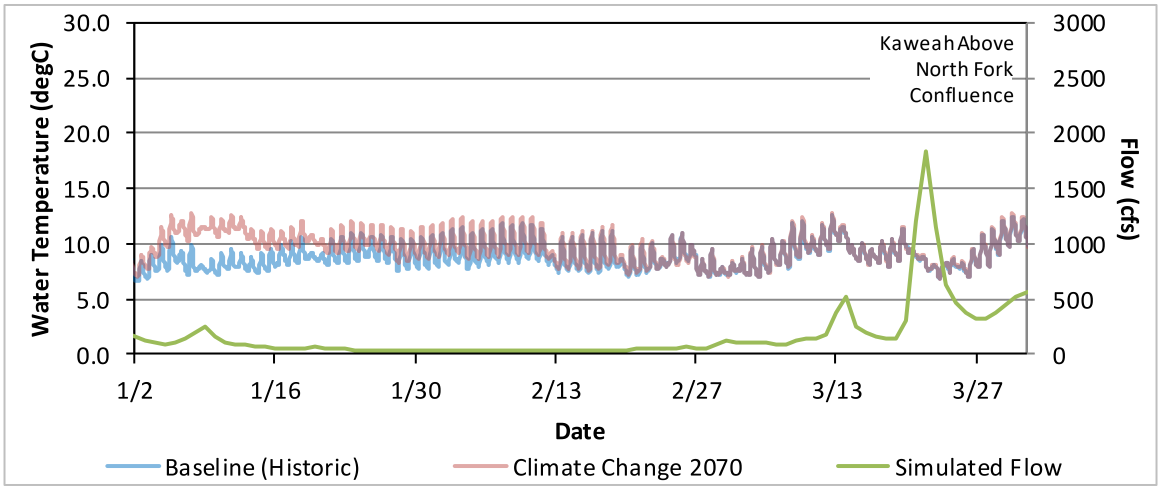

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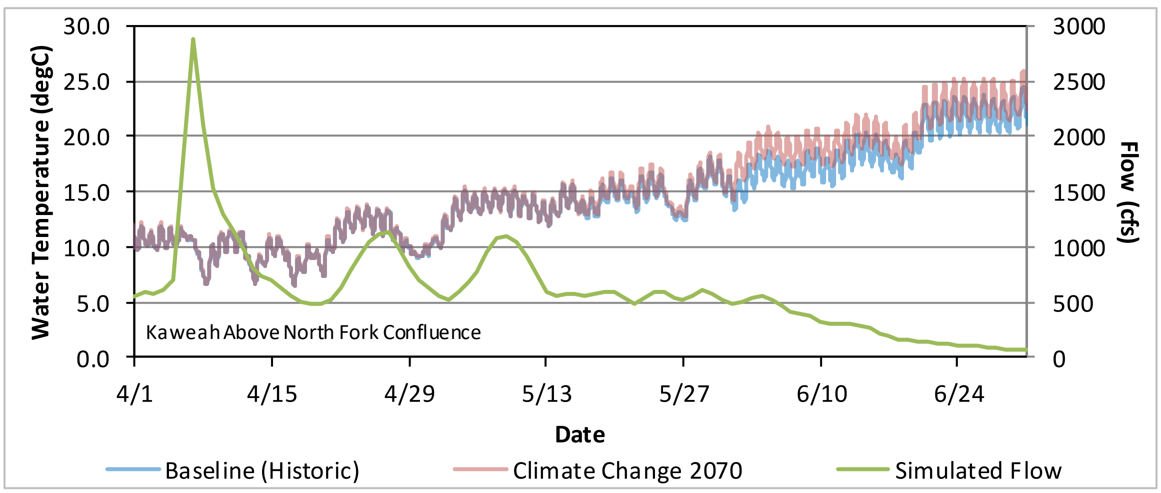

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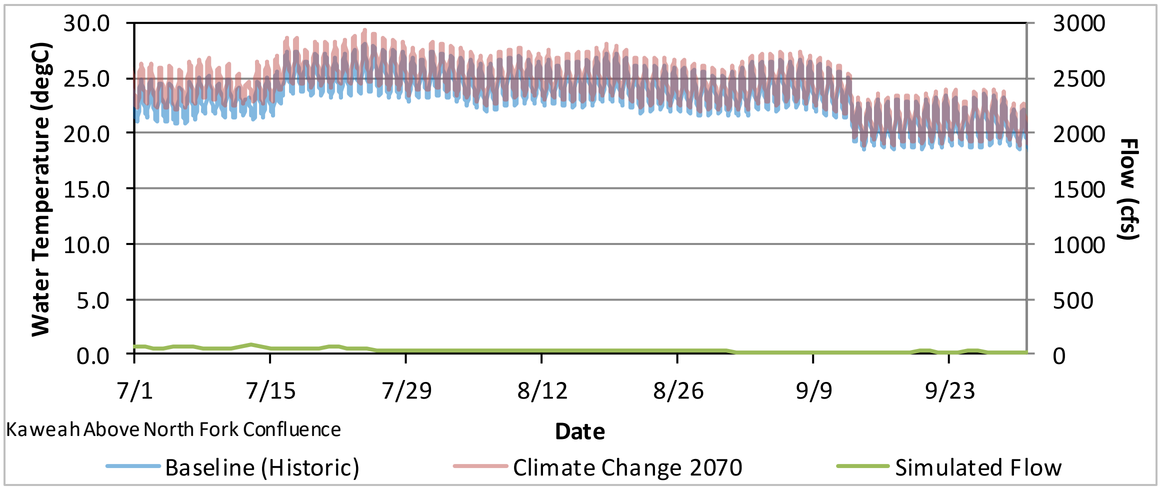

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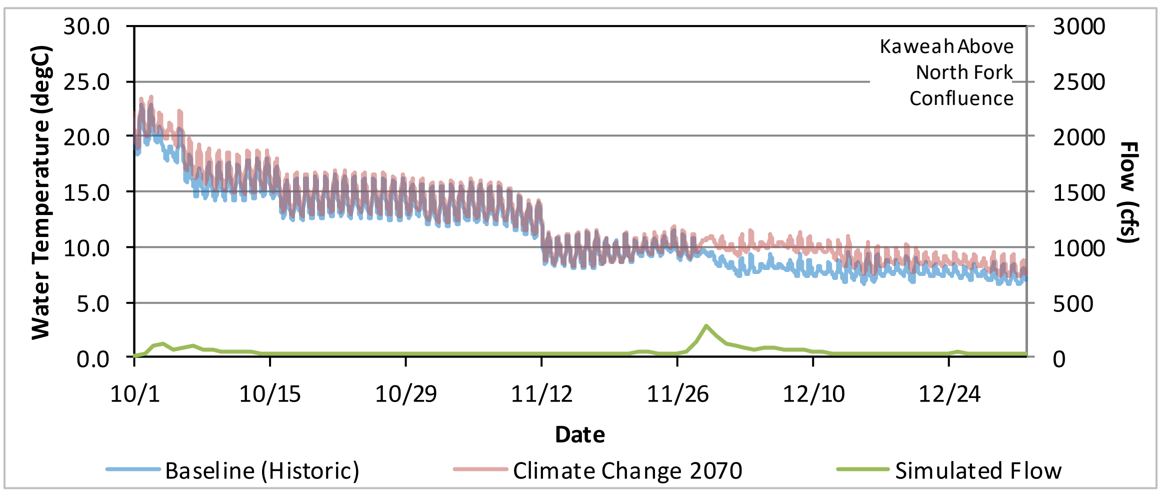

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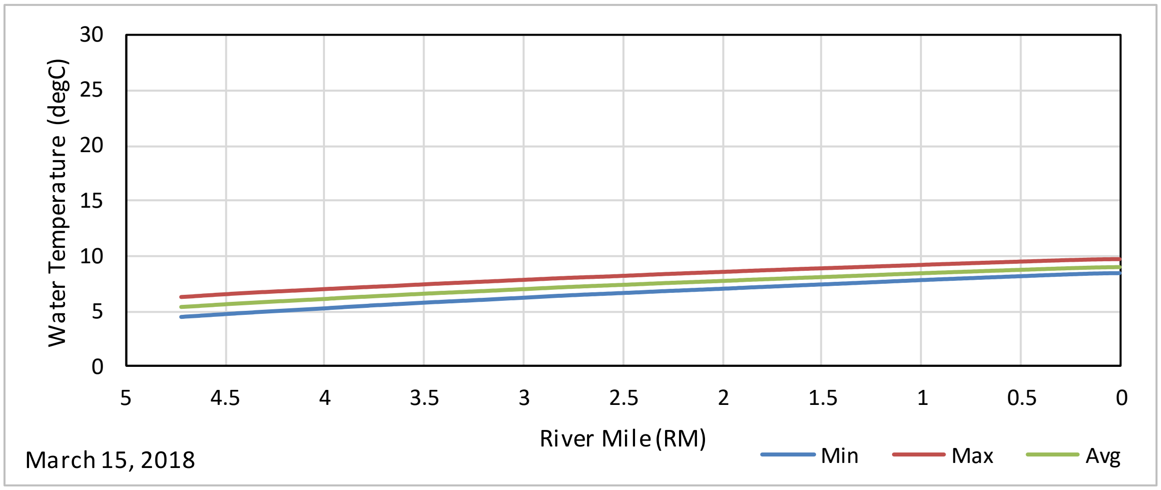

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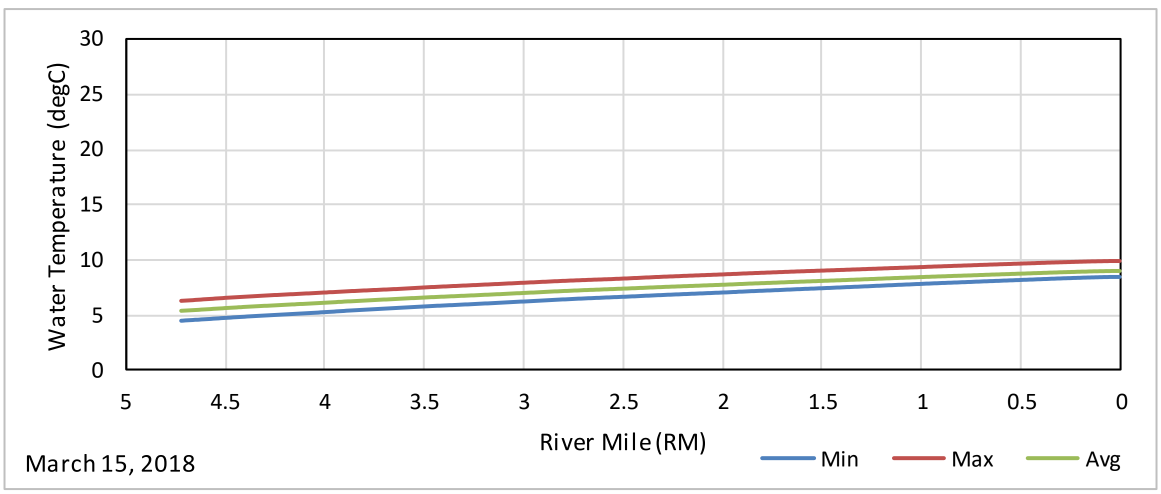

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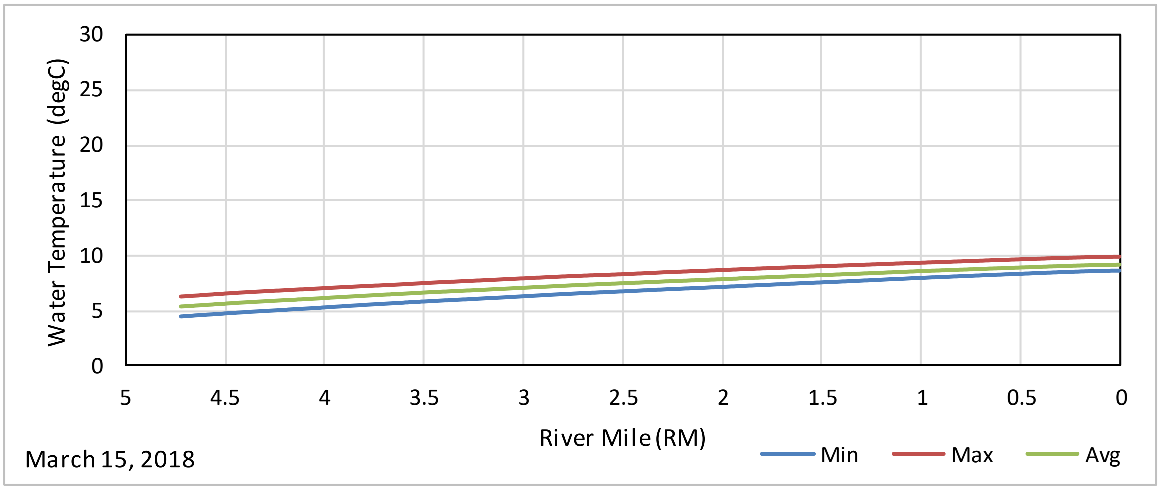

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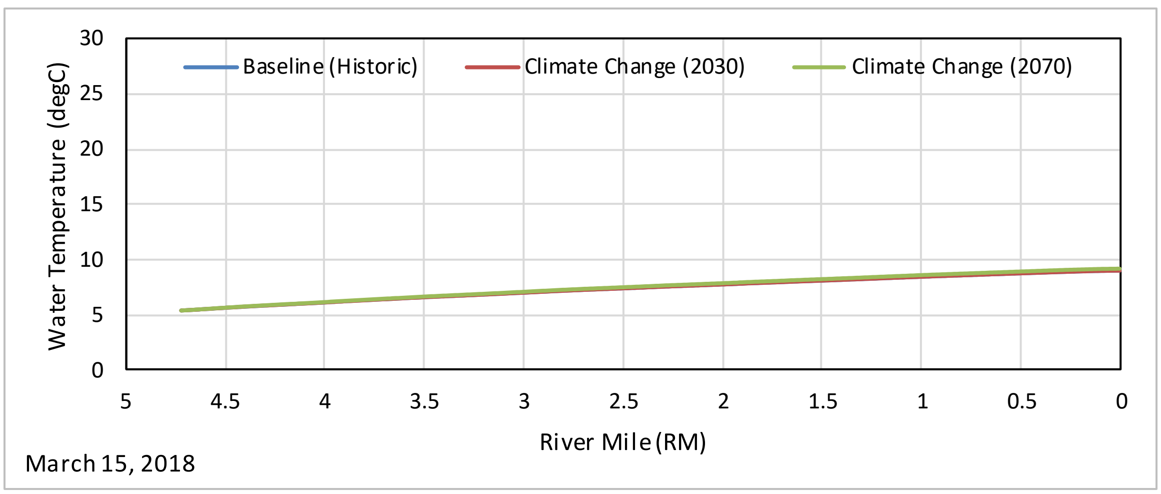

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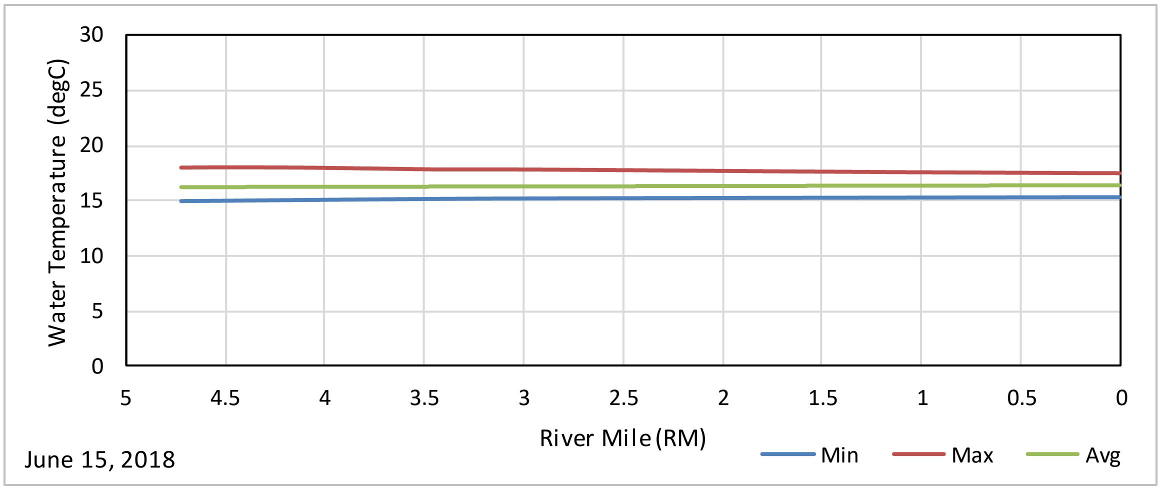

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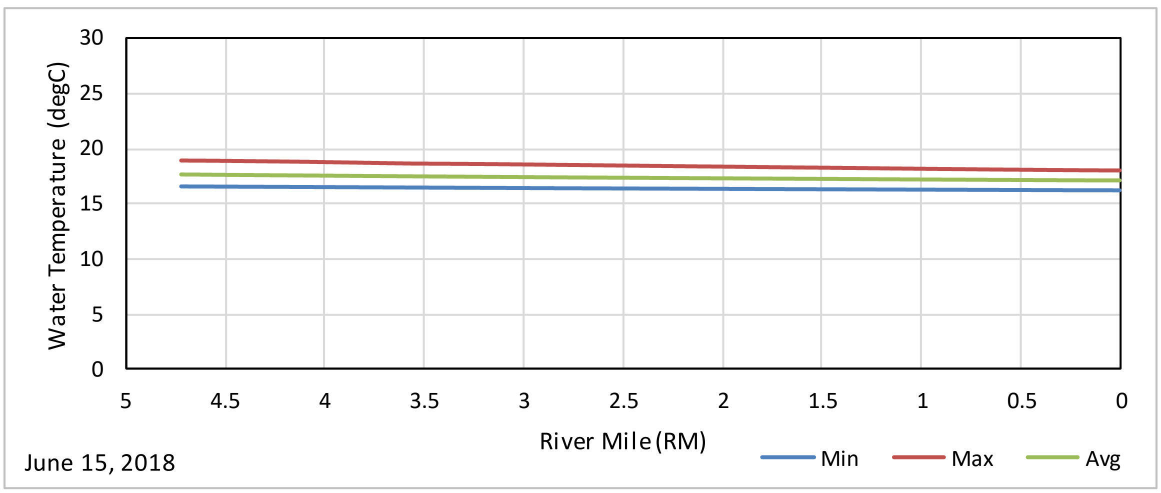

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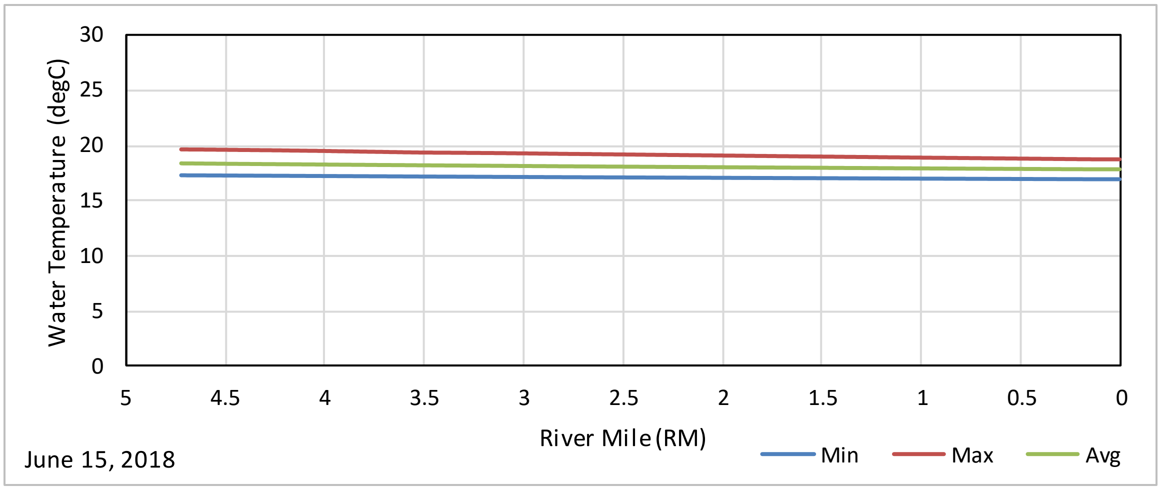

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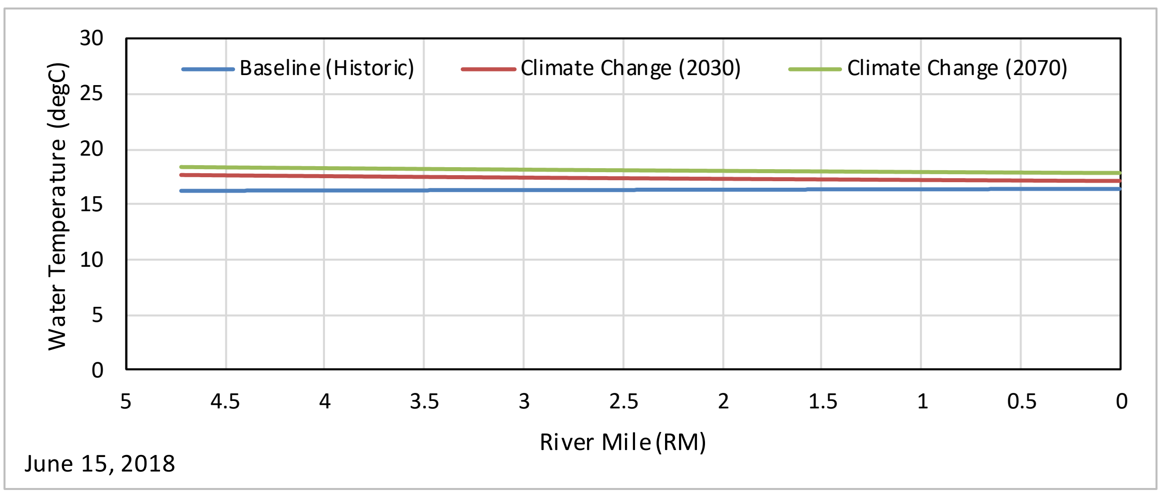

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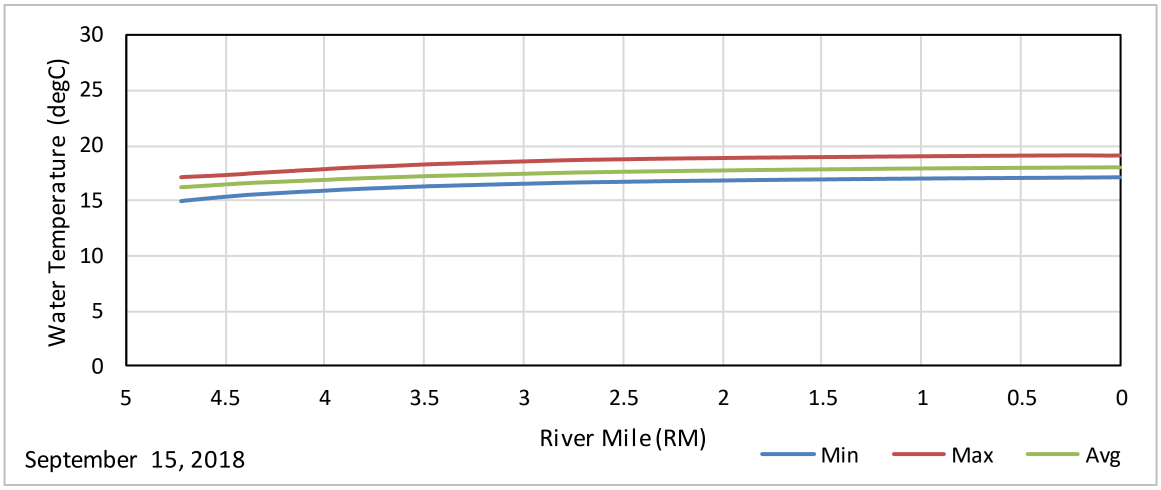

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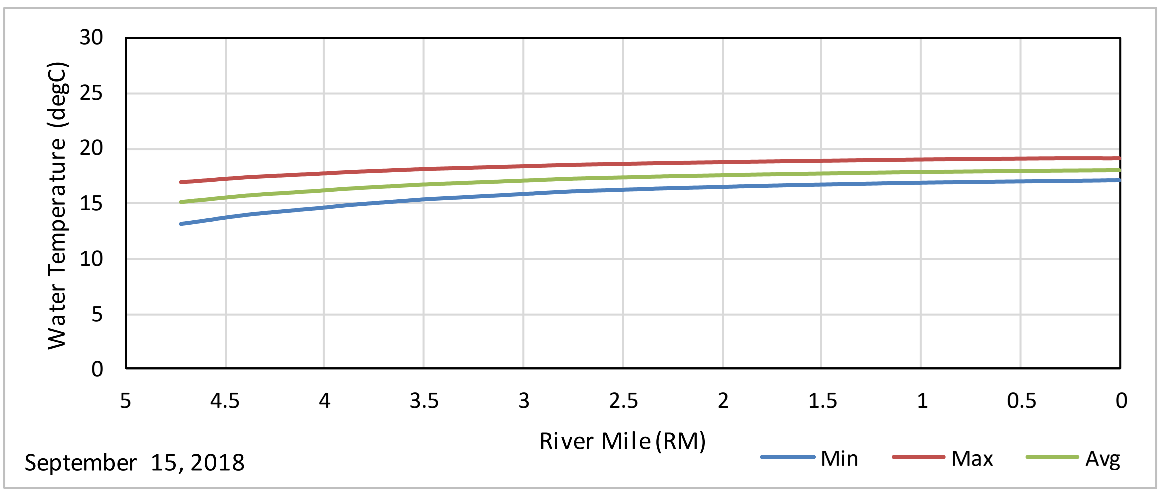

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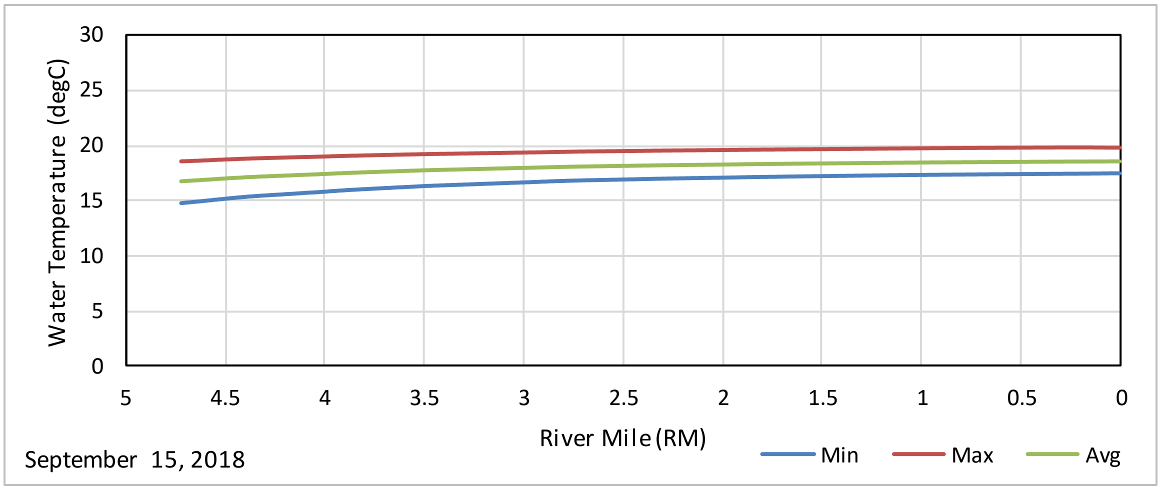

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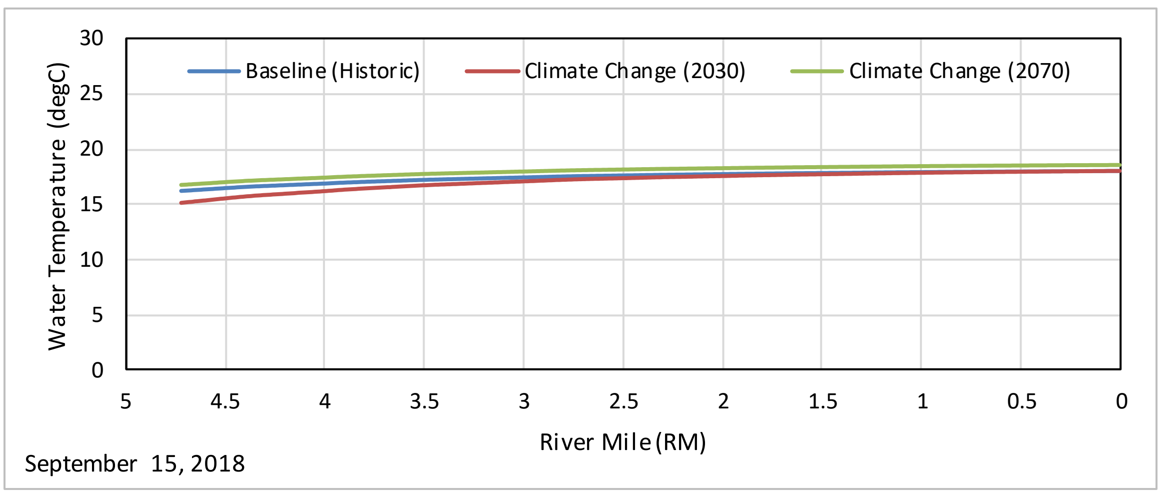

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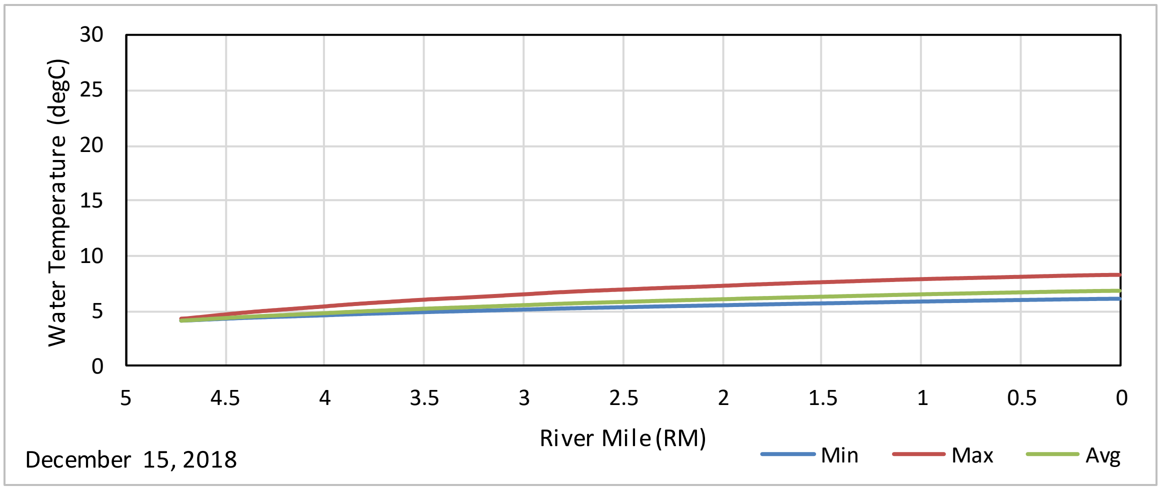

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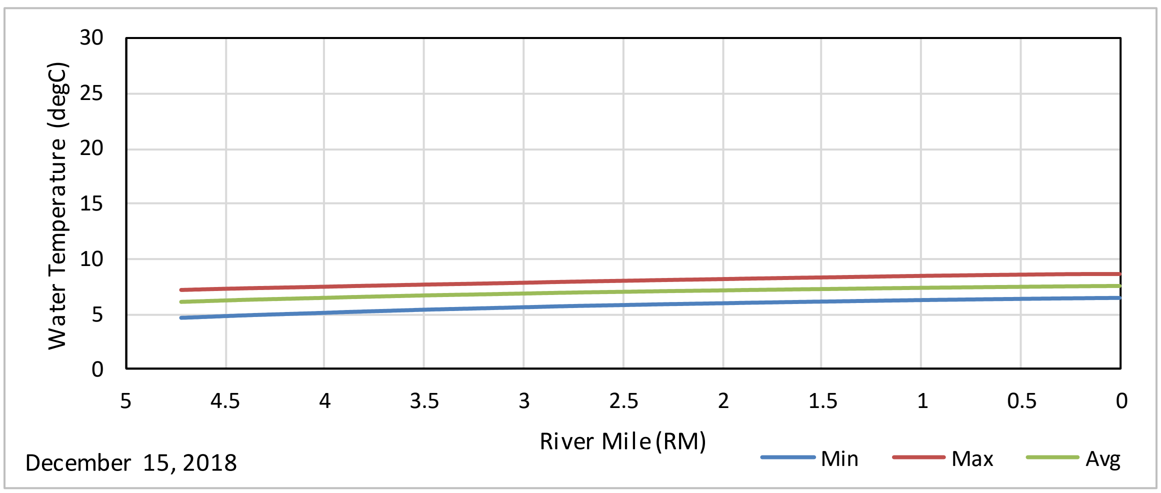

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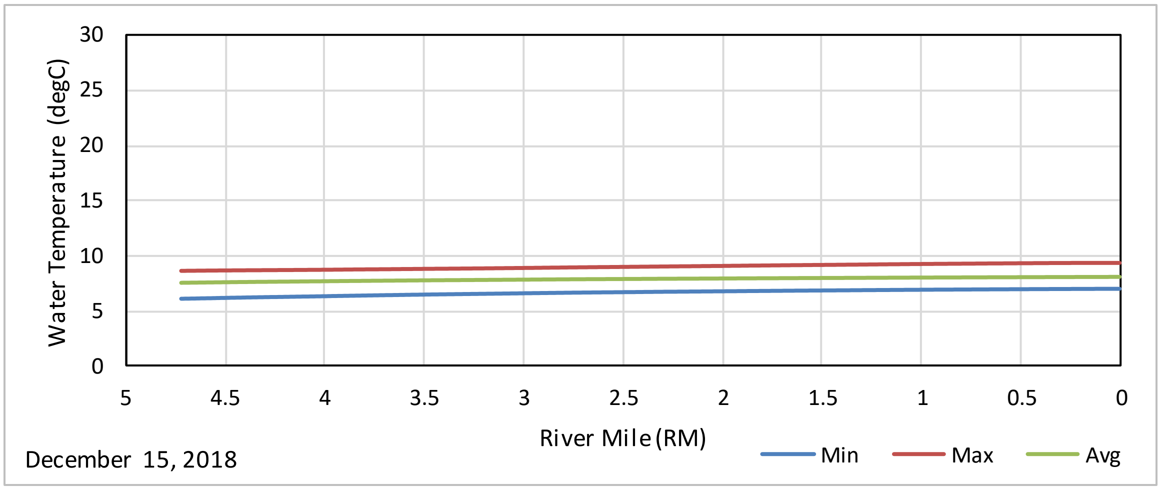

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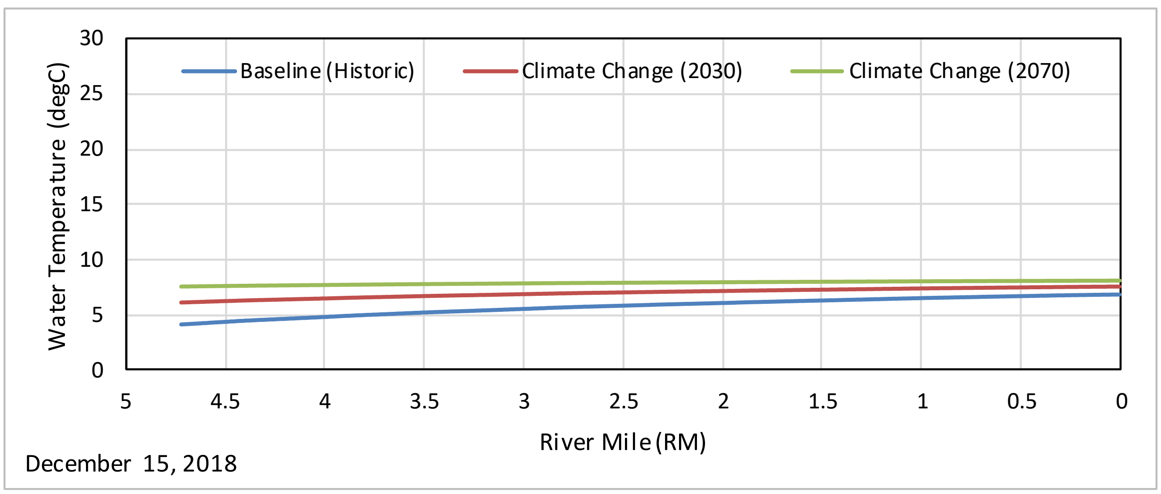

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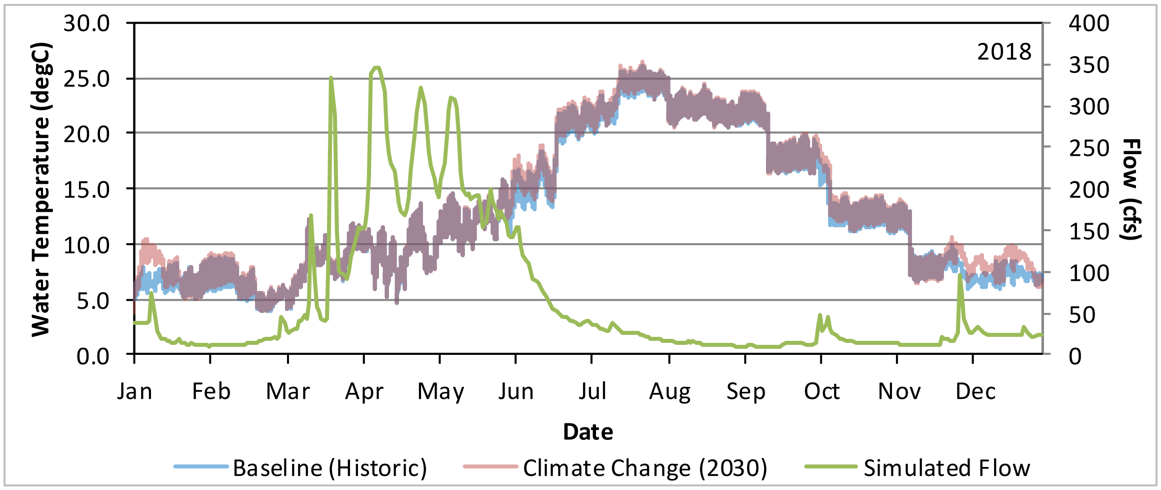

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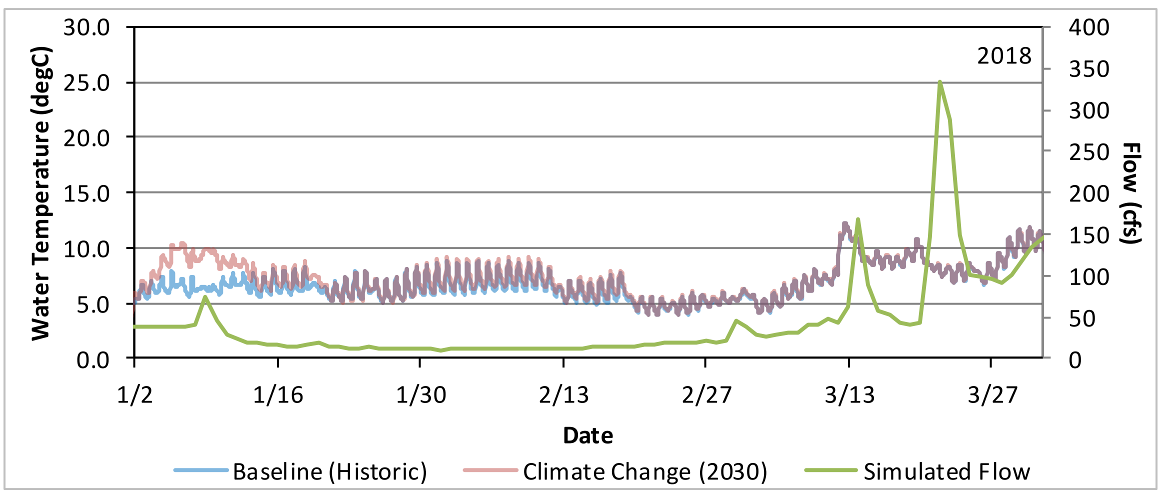

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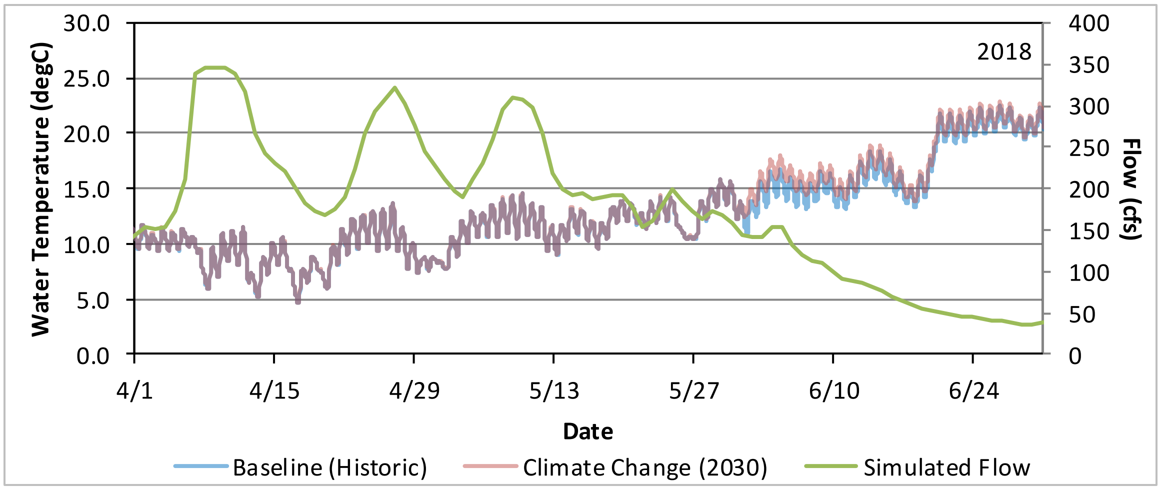

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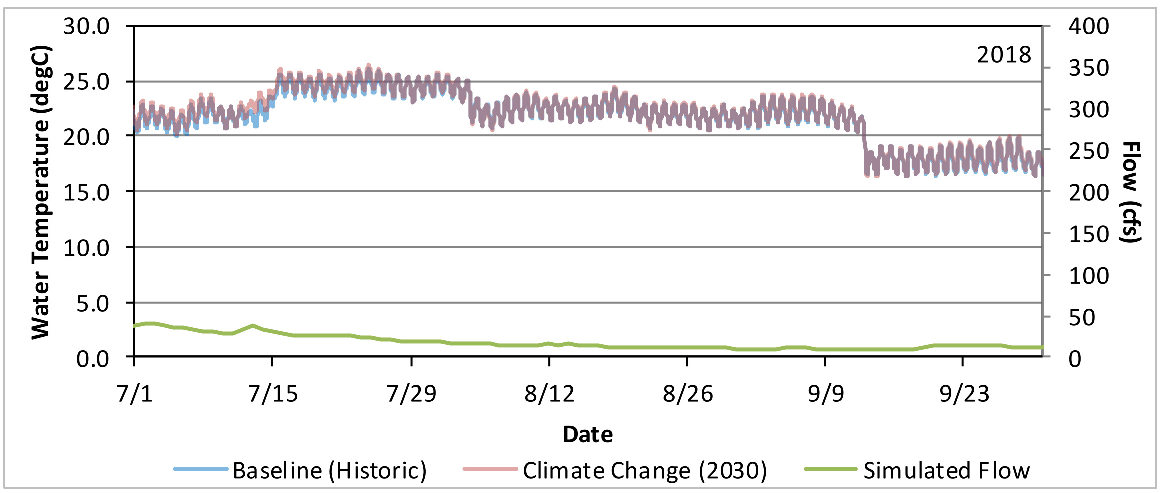

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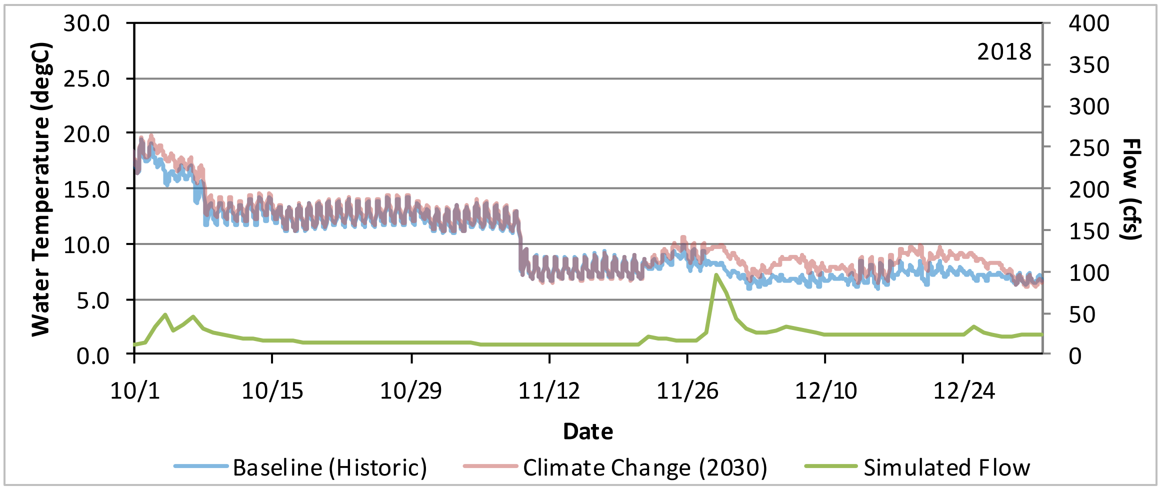

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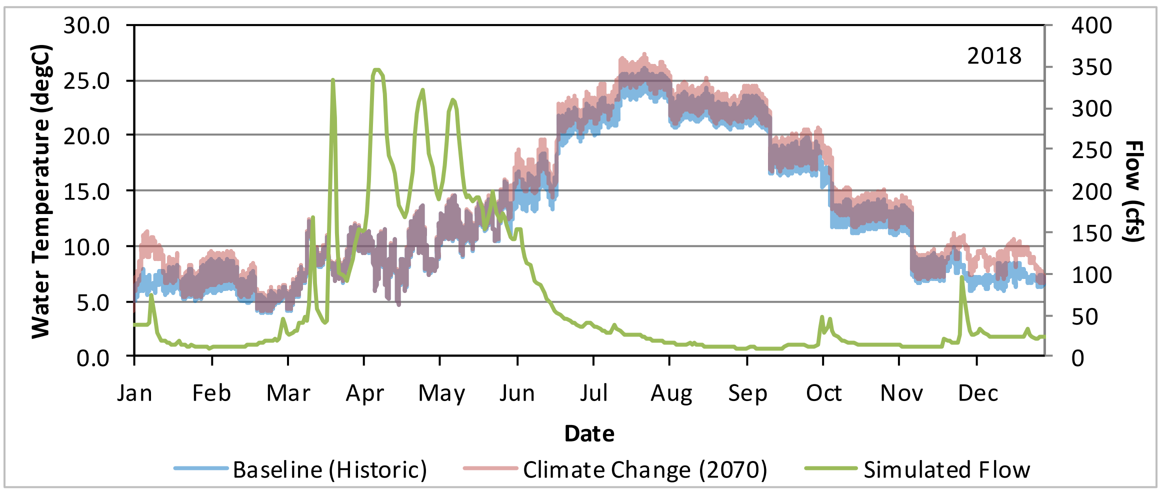

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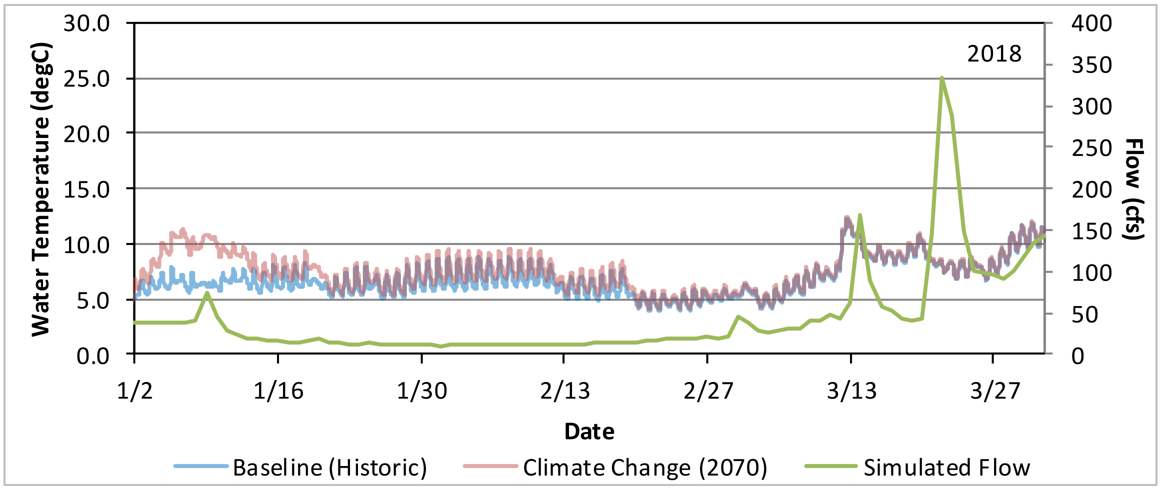

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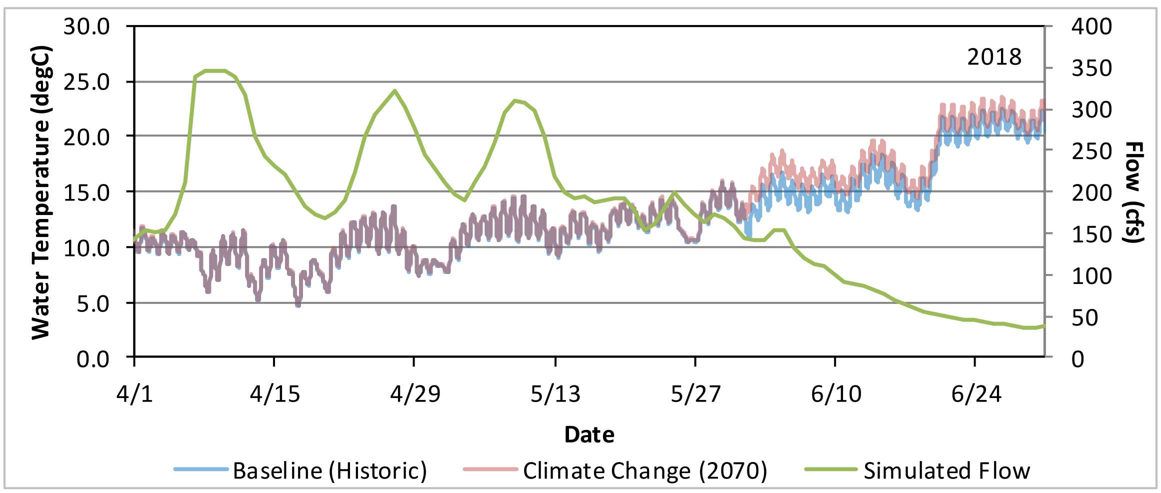

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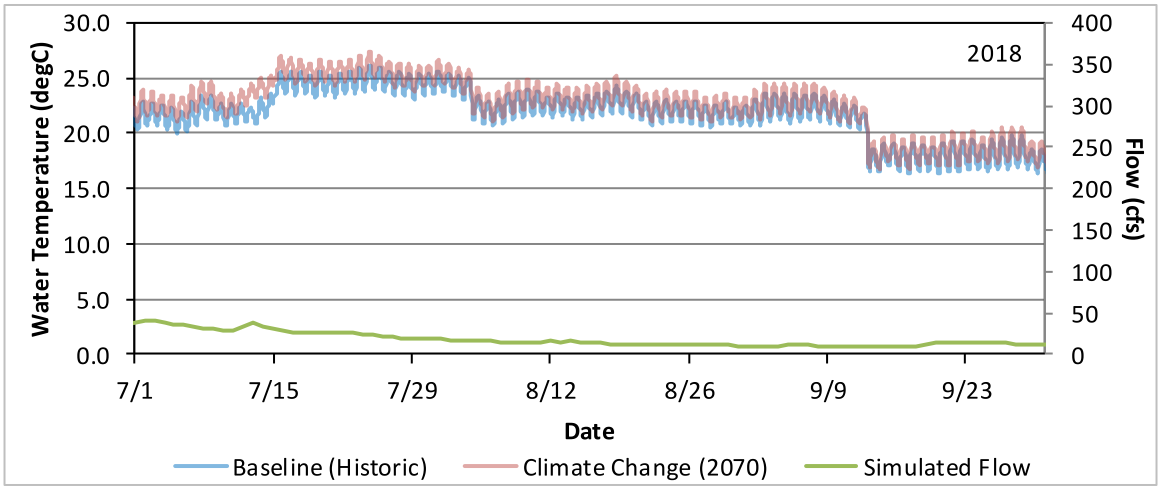

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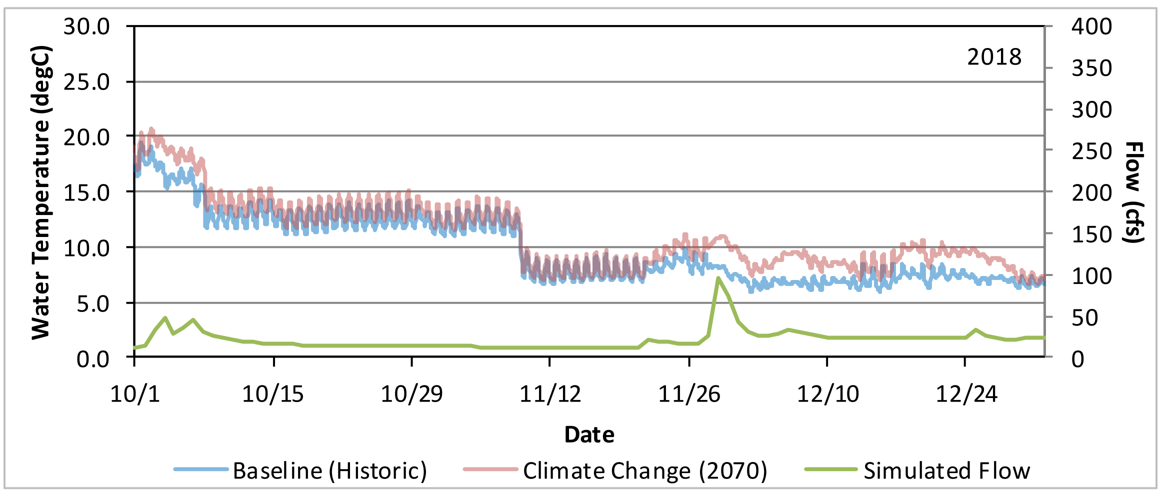

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Kaweah Project, FERC Project No. 298

AQ 5 – Geomorphology
Final Technical Study Report

December 2019

SOUTHERN CALIFORNIA EDISON®
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Regulatory Support Services
1515 Walnut Grove Avenue, Rosemead, CA 91770

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List of Acronyms

ac-ft	acre foot/feet
BLM	U.S. Bureau of Land Management
cfs	cubic foot/feet per second
FD	fluid drag
FERC	Federal Energy Regulatory Commission
gsC	gravelly-sandy-cobble
mm	millimeter
NPS	National Park Service
Project	Kaweah Project
RM	river mile
RSP	Revised Study Plan
SCE	Southern California Edison Company
SNP	Sequoia National Park
TSP	Technical Study Plan
TSR	Technical Study Report
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
WY	Water Year

1 INTRODUCTION

This Technical Study Report (TSR) describes the data and findings developed by Southern California Edison Company (SCE) in association with implementation of the AQ 5 – Geomorphology Technical Study Plan (AQ 5 – TSP) for the Kaweah Project (Project). The AQ 5 – TSP was included in SCE's Revised Study Plan (RSP)[1] (SCE 2017a) and was approved by the Federal Energy Regulatory Commission (FERC) on October 24, 2017, as part of its Study Plan Determination for the Project (FERC 2017). Specifically, this report provides a description of the methods and results of AQ 5 – TSP completed in 2018.

2 STUDY OBJECTIVES

The AQ 5 – TSP included four study objectives, as follows:

- Document sediment conditions in the bypass reaches.
- Characterize sediment capture in diversion pools.
- Develop information to assist in the identification of flows necessary to maintain geomorphic processes in the bypass reaches.
- Identify sources of sediment (major gullies, areas of vegetation and soil loss, and hillslope destabilization and erosion), including documentation of erosion resulting from spills from Project forebays and historic flume failures.

3 EXTENT OF STUDY AREA

- The Study Area included the bypass reaches, comparison reaches, and Project flowlines/flumes and Project forebay spill channels (Table AQ 5-1).
- It should be noted that the majority of lands along the bypass reaches are privately owned and outside the FERC Project boundary. For the purposes of the geomorphic studies described herein, SCE, as appropriate, took the following steps to obtain approval to conduct field studies on private property:
  - Provided notification to landowner of Project relicensing and requested authorization to enter property to conduct field studies.
  - If authorization was obtained, SCE completed field studies as described in the technical study plan.
  - If authorization was not obtained, SCE limited field studies to those lands where landowners provided access.

[1] SCE filed a Proposed Study Plan (PSP) on May 24, 2017 (SCE 2017b). Three comments were filed on the PSP; however, they did not result in revisions to any of the study plans. Therefore, SCE filed a Revised Study Plan (RSP) on September 19, 2017, which stated that the PSP, without revision, constituted its RSP. The FERC subsequently issued a Study Plan Determination on October 24, 2017, approving all study plans for the Kaweah Project.

4 STUDY APPROACH

4.1 Sediment Conditions in the Bypass Reaches

The amount of fine sediment in pools and the particle size composition and fine sediment content of spawning gravels was determined in the bypass reaches, as described below.

4.1.1 Fine Sediment in Pools

Analysis of residual fine sediment in pools, V* (Hilton and Lisle 1993), was conducted in 5 to 10 pools at each of the sampling locations in the bypass and comparison reaches (Table AQ 5-1). Pools with V* values that were relatively low (less than 0.1) were approximated by visual estimation using a snorkel and mask (Hilton and Lisle 1993). In cases where V* was likely higher than 0.1, a more rigorous, quantitative approach was taken to estimate the fraction of fine sediment (Hilton and Lisle 1993). Estimates of V* were made for each of the sampled pools and a weighted average V* of the pools within each study reach was calculated (weighted by total pool volume).

4.1.2 Particle Size Composition and Fine Sediment Content of Spawning Gravels

4.1.2.1 Field Methods

Bulk sediment samples were collected from sites in each of the study reaches (Table AQ 5-1) to determine a quantitative measure of the particle size distribution and fine sediment content in spawning gravels

The bulk sampling sites were selected at locations containing gravels in typical trout spawning habitat (i.e., pool tail-out, pocket gravel, or riffles). Thirty-two bulk samples were collected as summarized in Table AQ 5-1. The sampling sites are also shown on Map AQ 5-1. One side-by-side replicate pair of bulk samples were collected at each study site. The replicate samples provide a measure of the natural variability in particle size composition within the same gravel deposit.

The bulk sediment samples were collected following standard sedimentological practices (McNeil and Ahnell 1960) using a modified McNeil sampler (a bottomless 2-gallon bucket). Bulk samples were collected to depths approximating that of the trout egg pocket in a redd by manually pushing the sampler into the bed to a depth of at least 3 to 5 inches. Samples were collected during the low-flow summer season of 2018.

The coarser sediments collected (≥16 millimeters [mm]) were air dried, sieved, and weighed on site. The finer sediments were packaged and transported from the field and later air dried, sieved, and weighed. Samples were processed using a standard set of wire mesh sieves (approved by the American Society of Testing Materials), representing one-half phi interval size classes ranging from 256 to 1 millimeter (mm).

4.1.2.2 Analytical Methods

The dry weight of each sieved size class in the bulk sample at each spawning site was recorded, and graphically plotted as a cumulative particle size distribution curve and plotted by size class frequencies (histograms). Particle size statistics were developed from the distribution curves and histograms (e.g., D_{50}, D_{16}, and D_{84} size classes).

Fisheries literature indicates that most trout (rainbow and brown) spawning occurs in medium to coarse gravel (based on the Udden-Wentworth scale) of 8–64 mm (Kondolf and Wolman 1993, Reiser and Bjornn 1979, Grost et al. 1991). Fine sediment (<1 mm and <6.4 mm) in the gravel can affect egg incubation (e.g., reduce water flow and dissolved oxygen delivery to eggs) and fry emergence. Gravel within a constructed redd typically has less fine sediment than it did before redd construction (Kondolf 2000) because the process of redd construction winnows fine sediments from the unspawned gravel deposit. To account for this cleaning effect, the amount of fine sediment content in the bulk samples was adjusted using regression equations developed by Kondolf (2000):

- Percent of fine sediment <1 mm in winnowed gravels = 0.67 x Initial gravel percent <1 mm particle size
- Percent of fine sediment <6.4 mm in winnowed gravels = 0.58 x Initial gravel percent <6.4 mm particle size

The criteria developed by Kondolf (1988, 2000) were used for this study to determine if gravels would support high spawning success:

- Percentage finer than 1 mm should be less than 14%; and
- Percentage finer than 6.4 mm should be less than 30%.

The fine sediment content at each potential spawning gravel site prior to spawning, and as predicted after redd construction, were analyzed.

4.2 Sediment Capture in Project Diversions

4.2.1 Kaweah No. 1 Diversion

The sediment trapped in the Kaweah No. 1 Diversion Pool was too coarse to be practically sampled using bulk collection methods, so polygons of sediment facies were mapped onto an air photo of the site to characterize the general sedimentological character of the bed material. Sediment patches with similar particle size distributions were classified by their dominant and subdominant particles sizes (Buffington and Montgomery 1999). For example, a patch dominated by small cobbles, then coarse gravel, and then by sand would was classified as gravelly-sandy-cobble (gsC). The facies polygons mapped in the field were digitized to create quantitative amounts of sediment surface area. The amount of sediment in the diversion pool was estimated using the mapped area of sediment facies and the height of the diversion dam to approximate the depth of the deposit.

4.2.2 Kaweah No. 2 Diversion

For the Kaweah No. 2 Diversion Pool, particle size composition of captured sediments was determined using standard sedimentological practices at two sampling locations. A 3-foot-by-3-foot patch of the armored surface layer was scraped away to reveal the subsurface bulk material representative of the coarse bedload. This material was then excavated to the depth of the largest particle size in the sample (Bunte and Abt 2001). The coarser sediment collected (16 mm or larger) were air dried, sieved, and weighed on site. The finer sediments were packaged and transported from the field and later air dried, sieved, and weighed. Samples were processed using a standard set of wire mesh sieves representing one-half phi interval size classes ranging from 256 to 1 mm. Particles greater than 512 mm were measured with a ruler and weighed individually. Particle size composition of the bulk samples collected at the Kaweah No. 2 Diversion Pool was plotted as cumulative distribution curves and histograms and summary statistics of particle size composition (e.g., geometric mean, D_{50}, D_{16}, and D_{84}) were estimated.

A facies map was also made for the Kaweah No. 2 Diversion Pool. An estimate of the total volume of sediment impounded behind the diversion was generated using the facies polygon areas and the height of the diversion dam.

4.2.3 Historical Sediment Removal

SCE operators were interviewed regarding sediment removal at the Kaweah No.1 and No. 2 diversion pools to identify the amount of historical sediment removal that has occurred, if any.

4.3 Flows to Maintain Geomorphic Processes in Bypass Reaches

Sediment transport conditions under existing and unimpaired hydrologic regimes were evaluated in the bypass reaches.

4.3.1 Existing and Unimpaired Hydrologic Regimes

A comparison of existing and unimpaired hydrologic regimes (high flow magnitude, duration, and frequency) in bypass and comparison reaches was developed. The magnitude and frequency of annual instantaneous peak flows were analyzed using the methods published in Guidelines for Determining Flood Flow Frequency – Bulletin 17C (England et al. 2018). Flood frequency estimates were generated using the U.S. Geological Survey (USGS) software PeakFQ, following methods detailed in the User's Manual for Program PeakFQ Annual Flood - Frequency Analysis Using Bulletin 17B Guidelines (Flynn et al. 2006, Veilleux et al. 2014). Flood frequency model parameters (skew and variance) for the Kaweah River Basin used in the PeakFQ model were published in Regional Skew for California, and Flood Frequency for Selected Sites in the Sacramento–San Joaquin River Basin (Parrett et al. 2011). Existing and unimpaired flood frequency curves were plotted together to facilitate comparison of changes in peak discharge (existing versus unimpaired) for recurrence intervals ranging from 1.005 to 100 years.

Existing annual instantaneous peak flow records were obtained from USGS and SCE gage data (Table AQ 5-2). Unimpaired annual instantaneous peak flow was developed by adding the appropriate flowline diversion or powerhouse inflow, at the time of the instantaneous peak, to the existing values. Existing and unimpaired annual peak discharge comparisons were developed at each study reach (eight total) (Table AQ 5-1) for water years (WY) 1994 through WY 2018. The mass balance approach for each of the eight reaches is shown in Table AQ 5-3.

The frequency and duration of average daily flows for existing and unimpaired conditions was also compared for each reach. The duration of flows (i.e., number of days) equaling or exceeding the 1.5-year unimpaired annual peak daily average flow magnitude were tallied for each water year in the available gaging records. The 1.5-year annual peak daily average flow recurrence interval was selected as the threshold for comparing flow durations because it is a commonly recurring annual high flow event, and because it is typically considered to be a geomorphically significant flow (near bankfull flow) that moves sediment and structures channels.

4.3.2 Sediment Transport Conditions under Existing and Unimpaired Flows

The flow required to initiate sediment movement was determined by calculating the discharges required to initiate sand, gravel, and/or cobble transport at the instream flow modeling transects (AQ 1 – Instream Flow Study). Initiation of motion was determined using the hydraulic model estimates of bed shear stress (τ) and the Shield's criterion that defines the critical shear stress (τ^*_{ci}) at which incipient motion occurs. Wilcock's (1996) method was used to calculate bed shear stress and the Wilcock and Crowe (2003) method was used to calculate the critical shear stress needed to initiate sediment movement for mixed-size sediment. Calculation of bed shear stress and initiation of motion are described in more detail in Appendix A.

At each study transect, hydraulic modeling was performed for 30 different discharges (low to high flow). Flow depth, velocity, and substrate size at each cell along the transects (i.e., cells were typically less than a few feet wide) were used to calculate sediment movement. The discharge at which initiation of motion occurred for 10% of the sand (0.1–0.2 inch), gravel (0.2–3 inches), or cobble (3–12 inches) substrate size classes within the wetted portion of the cross-section in each reach was used as the "initiation of motion" threshold for each substrate size.

4.4 Sources of Sediment and Project-Related Erosion

The location and relative volume of hillslope mass wasting and bank erosion in the bypass reaches was documented via aerial reconnaissance, ground surveys, and aerial photography. Initial surveys were completed in 2017, as part of the Pre-Application Document (SCE 2016), which included foot traverses of spill channels for the Kaweah No. 2 and Kaweah No. 3 forebays, as well as aerial surveys in the bypass reaches. Follow-up aerial surveys in the bypass reaches were completed in summer 2018. Historical sediment removal and disposal from forebays or diversion facilities, as part of routine operation and maintenance, was documented via interviews with Project operators.

5 STUDY RESULTS

5.1 Sediment Conditions in the Bypass Reaches

The Kaweah River and East Fork Kaweah River in the Study Area are steep, coarse substrate rivers (e.g., abundant large cobbles, boulders, very large boulders, and bedrock) (Figure AQ 5-1). Very little gravel exists in the system and finer substrate (sand) exists in the pools or in the velocity shadow of large substrate. Sediment transport and deposition dynamics in boulder, bedrock-dominated system are mediated by the resistant channel boundary. The bypass reach downstream of the Kaweah No. 2 Diversion has a 3% gradient and consists of boulder and cobble step pool sequences punctuated by bedrock pools. The bypass reaches in the Kaweah River downstream of the confluence with the East Fork River is somewhat lower gradient (1.9% to 2.0%) and exhibits plane-bed and pool-riffle morphology with abundant large substrates. The bypass reach in the East Fork Kaweah downstream of the Kaweah No. 1 Diversion is predominately a steep (5% to 6% gradient) bedrock, plunge pool channel punctuated by coarse sediment aggregations in lower gradient sections. The exception is the lower 0.5 mile of stream near the confluence with the Middle Fork Kaweah (4% gradient), which includes large boulder substrates in combination with lower-gradient pools and runs with expansive sand deposits.

The entire system is sediment supply-limited and seasonally-transported bedload (e.g., gravel, cobble) is found in relatively rare, discrete deposits mantling the coarse (boulder, bedrock) and much less frequently transported channel. Coarse, granitic sand is present throughout the river system, with deposits in some low gradient areas that are expansive and deep. The sand is mobile, as can easily be observed in the field during any modest flow, and larger episodes of sand transport are likely semi-annual.

5.1.1 Fine Sediment in Pools

Fine sediment in pools was limited to a small proportion of the residual pool volume. In 48 of the 60 sampling sites V* values were less than 0.10. Twelve sampling sites had V* values greater than 0.10, with the highest value of 0.18. The results of the V* measurements are provided in Table AQ 5-4, which summarizes the residual pool measurements, the average volume of fine sediment stored in each pool, and the calculated V*. Map AQ 5-1 depicts the locations where the pools were sampled.

Based on visual observations of the pool substrate, the majority of the pools contained bedrock or boulders. Cobble and/or coarse gravels were also often, though not always, observed within each of the pools surveyed. In most cases, the fine sediment was a thin coating (less than 0.1 feet thick) located within the interstitial spaces of the coarse bed material. At pool locations where thicker fine sediment deposits were present, the deposits were located primarily along the margins of the residual pool in slack water areas, or in the velocity shadow of larger boulders. In some cases, the primary sediment deposits consisted of a large, discrete mantle of fine gravel and coarse sand more than a foot thick overlying bedrock in an otherwise sediment-free pool.

The volume weighted average V* for each reach (Table AQ 5-4) was 0.1 or less, except in the comparison reach upstream of the East Fork Kaweah No. 1 Diversion (V* = 0.14) and in the lowest gradient reach, Kaweah River downstream of Kaweah No. 1 Powerhouse and upstream of Kaweah No. 2 Powerhouse (V* was 0.12).

5.1.2 Particle Size Composition and Fine Sediment Content of Spawning Gravels

The D_{50} of the 32 bulk samples at the sampling locations were within the typical size range of spawning material used by trout (8 to 64 mm) except for four samples in the Kaweah River downstream of the East Fork Kaweah River Confluence and upstream of the Kaweah No. 1 Powerhouse and four samples in the East Fork Kaweah upstream of the confluence with the Kaweah River. The spawning gravel samples at the sites that were not in the typical spawning size range were all smaller than those typically used by trout. Larger sized gravels were not present at those sites.

Fine sediment within potential spawning gravels was generally within the criteria to support high reproductive success; however, spawning gravels were generally very limited in the river due to the high gradient of the rivers. The statistical results from the analyses of bulk sediment samples are presented in Table AQ 5-5. Histogram and cumulative particle size distribution curves from each bulk sample are available in Appendix B. The amount of fine sediment within the potential spawning gravel sample is shown in Table AQ 5-6.

Fine sediment < 1 mm was relatively low in all of the all gravel samples. After accounting for winnowing during spawning, all 32 gravel samples had <1 mm fine sediment concentrations less than the Kondolf (1988, 2000) 14% value (sample range 0.0–9.8%) (Table AQ 5-6). Fine sediment content < 6.4 mm for 25 of the 32 of the gravel samples was within the Kondolf (1988, 2000) < 30% criteria after accounting for winnowing during spawning (Table AQ 5-6). Three of the eight samples in the Kaweah River downstream of the East Fork Kaweah Confluence and upstream of the Kaweah No. 1 Powerhouse slightly exceeded the 6.4 mm <30% criteria (37.6%, 31.4%, and 31.6%). All four of the gravel samples in the East Fork Kaweah River Upstream of the Confluence with the Kaweah River exceeded the 6.4 mm fine sediment criteria (31.8%, 45.2%, 57.95%, 58.0%).

5.2 Sediment Capture in Project Diversions

5.2.1 Kaweah No. 1 Diversion

The Kaweah No. 1 Diversion Dam is a 6-foot high overflow concrete gravity dam, with a crest length of 20 feet. The diversion impounds a small open water pool with a sandy gravel deposit and upstream of the small pool is a cobbley-boulder veneer that is deposited atop the bedrock channel boundary (Map AQ 5-2 and Figure AQ 5-2a). The total distance of influence of the diversion dam is approximately 140 feet and the area of influence is approximately 0.1 acre. It is likely that the small deposit of sandy gravel near the diversion is transported and replaced seasonally. The cobbley-boulder veneer is imbricated and likely only moves episodically during large floods. The volume of sediment upstream of the diversion is <1,155 yd^3 (Table AQ 5-7a).

5.2.2 Kaweah No. 2 Diversion

The Kaweah No. 2 Diversion Dam is an approximately 7-foot high masonry overflow gravity dam, with an overall crest of 161 feet. The diversion maintains an open pool immediately upstream of the diversion dam and in front of the diversion structure (right side of the river looking downstream). Upstream of the open water that is near the structure, the diversion pool is mostly filled with coarse sediment (Map AQ 5-2 and Figure AQ 5-2b)

Two bulk sediment samples were collected from the subsurface of the 0.6-acre deposit of sediment trapped by the Kaweah No. 2 Diversion. The samples were collected atop the exposed portion of the sediment deposit just upstream of the Kaweah No. 3 Powerhouse. The D_{50} ranged from 79.6 to 97.1 mm, and the geometric mean ranged from 29.8 to 78.1 mm (see Appendix C and Table AQ 5-8).

The sediment facies were dominated by gravelly cobble with small deposit of cobbley boulder near the diversion intake and large deposit of coarse sand at the upstream end of the pool deposit overlying the bedrock pool bottom. Overall, the deposit was loosely bedded and appeared to be mobile during bankfull or larger floods.

A simple estimate of the volume of the deposit was made by multiplying the area (0.6 acre, e.g., 2,855 square yards [yds^2]) by an estimate of the average sediment depth (~2 yards, e.g., 6 feet) based the height of the Kaweah No. 2 Diversion Dam (~7 feet), yielding a volume of approximately 5,700 cubic yards (yds^3) (Table AQ 5-7b).

5.2.3 Historical Sediment Removal

No sediment management activities have occurred since issuance of the current license at the Kaweah No. 1 Diversion Pool and Kaweah No. 2 Diversion Pool. However, at Kaweah No. 2 Diversion Pool a small amount of sediment blocking the intake structure has been removed periodically.

5.3 Flows to Maintain Geomorphic Processes in Bypass Reaches

5.3.1 Existing and Unimpaired Hydrologic Regimes

Annual instantaneous peak flow exceedance plots for each bypass reach under existing and unimpaired conditions show that the existing and unimpaired instantaneous peak stream flows are similar and within the analysis error range (95% confidence limits). The annual instantaneous peak flood frequency analysis for recurrence intervals from 1.005 year up to 100 years is summarized in Figures AQ 5-3a-d and in Appendix D, Table D-1. The lack of difference in annual peak flood recurrence intervals between existing and unimpaired indicates that annual peak flows have not been substantially altered by Project operations in the bypass reaches.

The difference in the frequency (duration) of days that flows equaled or exceed the unimpaired 1.5-year annual daily average flow magnitude for each bypass reach is shown in Table AQ 5-9. Under existing conditions, the average number of days each year that exceed the unimpaired 1.5-year flow event ranged from 1.2 to 2.6 days less than under unimpaired conditions (Table AQ 5-9). The frequency of existing daily flows exceeding the 1.5-year unimpaired flow event was 87 to 93% of what would occur under unimpaired flows.

5.3.2 Sediment Transport Conditions under Existing and Unimpaired Flows

Estimates of the flow required to initiate motion of sand, gravel substrate were modeled at a total of 61 transects within the four AQ 1 – Instream Flow Study modeling sites. Table AQ 5-10 depicts the modeled discharge at which 10% of the particles of each size class (sand, gravel, and cobble) within the wetted channel in each reach moved. As expected, the smaller substrates (sand, gravel) move at lower flows and the matrix substrate of the channel (e.g., cobbles) moved at higher flows. Cobbles move near the average daily Q 1.5 year flow. There is little difference between the existing and unimpaired average daily Q 1.5 flows (Table AQ 5-10); therefore, little difference would exist between the frequency of cobble transport under existing conditions versus unimpaired conditions.

Figures AQ 5-4a-d depict existing and unimpaired daily discharge exceedance plots (all daily flows WY 1994 – WY 2018) for each reach with superimposed discharges for the modeled sand, gravel, and cobble transport (10% of the sediment). The plots also include the average daily Q 1.5 year and instantaneous peak Q 1.5 year flow values. Differences between the existing versus unimpaired percent exceedance values for each of the transport flows (sand, gravel, cobble, average daily Q 1.5 year, instantaneous peak Q 1.5 year values) can be seen on the plots. Table AQ 5-11 shows the percent exceedance differences. For the sand transport (lowest flow) the existing versus unimpaired differences range from 1.5 to 12%, for gravel transport the differences range from <1.1 to 5.5%, and for cobble the differences range from <1.1 to 1.4%. In general, the exceedance plots show limited effect of existing conditions on sediment transport as compared to unimpaired conditions.

5.4 Sources of Sediment and Project-Related Erosion

5.4.1 Sediment Supply

Mass Wasting

The National Park Service (NPS) conducted an assessment of mass wasting in the Kaweah Watershed (Watershed), including areas susceptible to large mass wasting events. Portions of the watersheds upstream of the bypass reaches (Marble, Middle, and East forks of the Kaweah River) were identified as areas where large mass wasting events have the potential to occur. Specifically, areas in the upper Watershed that are steep (>40% slope) with poor vegetative cover have the highest susceptibility for the occurrence of a large mass wasting event (Austin 2013).

Surveys completed by SCE in the Project vicinity in July 2015 did not identify evidence of any recent hillslope mass wasting events adjacent to the bypass reaches. An aerial survey in summer 2018 also did not find any evidence of mass wasting into the bypass reaches. The potential for large mass wasting events on the hillslopes adjacent to the bypass reaches is relatively low. In summer 2018, a rock fall above Kaweah No. 1 Flowline damaged the flume, however, the event did not supply sediment to the channel. There have been no recent fires (since 2005) (USDA-FS 2015) and the hillslopes are well vegetated, which reduces the potential for mass wasting.

Streambank Erosion

In the upper 3.2-mile portion of the Kaweah River in the Study Area (river mile [RM] 5.8 to RM 9.0) and in the entire East Fork Kaweah River upstream of its confluence with the mainstem to Kaweah No. 1 Diversion (RM 0.0 to RM 4.7), the potential for bank erosion is very low due to the presence of bedrock and coarse boulder substrates that stabilize the streambed and banks. In the lower 1-mile segment of the Kaweah River in the Study Area (RM 5.8 to RM 4.85), the potential for excessive bank erosion is also generally low because the streambanks are well vegetated with riparian trees and shrubs, and various grasses.

5.4.2 Project Roads

All of the Project trails and most of the Project roads are unpaved and therefore susceptible to erosion. Erosion of the roads and trails is controlled by directing runoff along the road through drainage features such as ditches or water bars, or under the road via culverts and downdrains. However, erosion of the trail or road surface can occur when the amount of runoff exceeds the capacity of the erosion control features, or when these features are damaged or blocked by debris. In addition, erosion can occur where concentrated runoff has been directed down natural slopes.

To minimize the potential for erosion, SCE regularly inspects the Project access roads and trails, including erosion control features, during normal Project activities, and makes repairs, as necessary. Minor repairs are conducted on an as-needed basis and major repairs are implemented annually in consultation with the appropriate resource agencies. In general, SCE regrades the Project roads and maintains the adjacent ditches annually (FERC 1991).

5.4.3 Flowlines

The flowlines are narrow and essentially contour the hillsides, so there are limited areas of cut and fill that could be subject to erosion or slope instability (FERC 1991). Slope runoff above the flowlines is channeled through culverts and overflow chutes.

Breaks in the flowlines have the potential to cause erosion. Historically, these breaks caused substantial local erosion in the vicinity of the break, creating gullies and channels up to 40 feet wide and 10 to 15 feet deep. These channels have since been revegetated by native grasses and scattered brush. In 1992, SCE implemented a plan to limit the potential for erosion from flowline breaks. The plan specified actions that were to be implemented in the event of a break, including shutting off the flow within 2 hours (Sholes 1989, SCE 1992).

5.4.4 Intake Structures

Kaweah No. 1 Intake Structure

The Kaweah No. 1 Intake incudes a concrete sandbox upstream of the flowline. A low-level outlet at the downstream end of the sandbox is routinely opened during high flows to flush sand and gravel sediment into the active stream channel. If larger substrate becomes trapped in the sandbox, it is typically removed by hand and placed back into the active channel during the fall maintenance outage.

Kaweah No. 2 Diversion Pool/Intake

The Kaweah No. 2 Diversion Pool is 0.6 acre and has a design capacity of approximately 1–2 acre feet (ac-ft). Over time, the diversion pool has filled in with sediment and it currently has a capacity of approximately 0.2 ac-ft. No sediment management activities have occurred since issuance of the current license other than removal of a small amount of sediment blocking the intake structure.

5.4.5 Forebays

Water in the flowlines at times spills at the forebays into adjacent natural drainage channels (e.g., when powerhouse units trip or during draining forebays for maintenance). Periodic spills have occurred into these drainage channels for decades. The spills generally last for less than a day. The locations of the natural drainage channels are shown on Maps AQ 5-3, AQ 5-4, and AQ 5-5 and a general description of each is provided below.

5.4.5.1 Kaweah No. 1 Forebay Tank

Spills

Overflow from the Kaweah No. 1 Forebay Tank is directed through a spill flume into a natural drainage channel located adjacent to the penstock (Map AQ 5-3). There is also drain and pipe from the bottom of the tank directed approximately 50 feet downslope adjacent to the penstock. Once in the natural channel, the water travels approximately 0.72 mile downslope before flowing into the Kaweah River just south of the Kaweah No. 1 Powerhouse Campus. This drainage channel is very steep and heavily vegetated. In aerial photographs of the area there is extensive bedrock in the vicinity of the channel and there is no evidence of extensive erosion, rather the channel appears similar to adjacent natural drainage channels on the hillside. Field verification of the upper portion of the channel has not been attempted due to safety concerns. At the bottom 0.25 mile of channel, near the river, the channel is dominated by coarse boulders, cobbles, and bedrock and there is no evidence of excessive erosion due to Project-related spills (Figures AQ 5-5a-c).

Sediment Removal

A low-level outlet in the forebay tank is routinely opened during normal operations to flush sand and fine sediment from the bottom of the tank into an adjacent natural drainage channel. Any large material remaining in the bottom of the tank is removed by hand during the fall maintenance outage.

5.4.5.2 Kaweah No. 2 Forebay

Spills

At the Kaweah No. 2 Forebay, up to 87 cubic feet per second (cfs) can spill into three concrete-lined spillway chutes, which discharge into natural drainage channels (Map AQ 5-4). The primary spillway drainage channel is located adjacent to the forebay and receives spill flows up to 40 cfs. The drainage channel is approximately 0.23-mile long and flows into the Kaweah No. 2 Tailrace. The two smaller drainages converge approximately 220 feet downslope and then continue downslope to the Kaweah River, discharging approximately 0.16 mile upstream of the Kaweah No. 2 Powerhouse. The upper sections of the three spillway drainage channels are very steep, with slopes exceeding 50%. Figure AQ 5-6a shows the primary drainage channel with approximately 10 cfs of water.

The three spillway drainage channels show evidence of historical incision through the unconsolidated decomposed granite to the underlying granitic bedrock (Figure AQ 5-6b). Most of the vertical erosion occurred several decades ago based on the size of the trees currently established along the channel margins. The side slopes of the upper sections of the drainages are generally comprised of bedrock or coarse boulders or decomposed granite, with relatively minimal vegetative cover. Some ongoing instability occurs in the upper portion of the primary channel where the unconsolidated decomposed granite/soil horizon overlays the bedrock (Figure AQ 5-6c). The other bedrock or large boulder sections are stable (Figure AQ 5-6d). The lower portions of the drainage channels are lower gradient and well vegetated, which reduces the erosion potential.

Sediment Removal

The forebay has several low-level outlets which are routinely opened during normal operations to flush some accumulation of sand and fine sediment from the bottom of the forebay into natural drainages. Any large build-up of material is removed by hand during the fall maintenance outage.

5.4.5.3 Kaweah No. 3 Forebay

Spills

At Kaweah No. 3 Forebay, up to 97 cfs of flow can spill into an approximate 75-foot long concrete-lined spillway chute that begins at the upstream end of the forebay (Map AQ 5-5). The chute discharges into an adjacent natural drainage channel that flows approximately 0.3 mile downslope into the Kaweah River. Spills occur periodically and generally last for less than a day. The drainage is very narrow and steep (approximately 38% gradient), and is primarily comprised of large boulders and bedrock and is well vegetated (Figures AQ 5-7a-d). The large substrate/bedrock acts as rip-rap and well-vegetated side slopes limit the potential for down cutting and erosion of the side slopes. At the confluence with the Kaweah River, the drainage is vegetated, with no large sediment deposits at the margins of the channel. There is no evidence of excessive erosion due spills (Figure AQ 5-7e).

A forebay drainage channel exists on the downstream side of the forebay. During sediment removal activities (see below) or other activities where the forebay is drained, water is released from the low-level outlet and enters a short concrete chute. The chute discharges into a natural drainage channel that flows approximately 0.5 mile downslope into the Kaweah River within the Sequoia National Park (SNP) (Map AQ 5-5). From aerial photographs, the drainage is very narrow and steep, well vegetated, and appears to be primarily comprised of large boulders and bedrock. There is no evidence of excessive erosion due to spills.

Sediment Removal

Active sediment removal in the forebay occurs approximately every 5 years. Heavy equipment is used to remove the sediment. The majority of the sediment removed is composed of sand. Prior to sediment removal, water in the forebay is lowered, first by passing water via the penstock through the Kaweah No. 3 Powerhouse. As the forebay water level approaches the elevation of the intake structure, diversion through the powerhouse is discontinued and the remainder of the water is released through the forebay's low-level outlet. Water released from the low-level outlet enters a short concrete chute. The chute discharges into a natural drainage channel that flows approximately 0.5 mile downslope into the Kaweah River within the SNP (Map AQ 5-5). Sediment removal with heavy equipment occurs once the sediment in the bottom of the forebay dries. Most recently, in the summer of 2018, approximately 2,500 cubic yards of sediment was removed from the forebay. The forebay is located on lands managed by the U.S. Bureau of Land Management (BLM). SCE consults with BLM on the disposition of the material prior to initiation of sediment removal activities.

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TABLES

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Table AQ 5-1. V*, Bulk Spawning Gravel, and Sediment Transport Hydraulic Model Locations

River/Reach	Site ID	Bypassed Reach	Reaches Upstream of Project Facilities or Comparison Reaches	Initiation of Motion Sediment Transport Modeling Site	Number of Bulk Spawning Gravel Samples	Number of V* Pools
Kaweah River						
Kaweah River Upstream of Kaweah No. 3 Powerhouse	K9.5		X	Yes	4	10
Kaweah River Downstream of Kaweah No. 3 Powerhouse and Upstream of the East Fork Kaweah River Confluence	K8.7	X		Yes	4	10
Kaweah River Downstream of East Fork Kaweah Confluence and Upstream of Kaweah No. 1 Powerhouse	K7.3	X		Yes	8	5
Kaweah River Downstream of Kaweah No. 1 Powerhouse and Upstream of Kaweah No. 2 Powerhouse	K6.9	X		Yes	0	5
Kaweah River Downstream of Kaweah No. 2 Powerhouse	K4.3	X		Yes	4	10
East Fork Kaweah River						
East Fork Kaweah River Upstream of the Kaweah No. 1 Diversion	EFK5.2		X	Yes	4	10
East Fork Kaweah River Downstream of the Kaweah No. 1 Diversion	EFK3.8	X		Yes	4	5
East Fork Kaweah River Upstream of Confluence with Kaweah River	EFK0.7	X		Yes	4	5

Table AQ 5-2. Project Flow Gages Used in Existing and Unimpaired Hydrology Comparison

Gage Name	SCE Gage Number	USGS Station Number	Period of Record	Latitude, Longitude
East Fork Kaweah River				
East Fork Kaweah River near Three Rivers, CA	201	USGS 11208730	06/01/1952-present	36°27'05", 118°47'15"
	201a		10/01/1995-present	36°27'05", 118°47'15"
East Fork Kaweah River Conduit 1 near Three Rivers, CA	202		10/01/2002-present	36°27'05", 118°47'19"
East Fork Kaweah River Conduit 1 at Power Plant near Hammond, CA	200a	USGS 11208800	10/01/2002-present	36°27'55", 118°51'43"
Kaweah River				
Marble Fork Kaweah River below No. 3 Conduit near Potwisha, CA	208	USGS 11207500	10/01/1975-09/30/2002	36°31'10", 118°48'00"
Middle Fork Kaweah River below No. 3 Conduit near Hammond, CA	206a	USGS 11208565	10/01/2001-present	36°29'10", 118°50'08"
Kaweah River below Conduit No. 2 near Hammond, CA	203	USGS 11208600	10/01/1993-present	36°29'04", 118°50'06"
Kaweah River Conduit No. 2 near Hammond, CA	204a		12/08/2005-present	36°29'10", 118°50'09"
Kaweah River Conduit No. 2 at Powerhouse near Hammond, CA	205a	USGS 11208818	10/01/2002-present	36°27'42", 118°52'46"
Middle Fork Kaweah River Conduit No. 3 A Power Plant near Hammond, CA	206a	USGS 11208565	10/01/2002-present	36°29'10", 118°50'08"

Table AQ 5-3. Mass Balance Approach and USGS and SCE Gages Used for Determining Existing and Unimpaired Flow in Study Reaches

Existing Flow	Unimpaired Flow
Kaweah River Upstream of Kaweah No. 3 Powerhouse	
1994-2002: Sum of Kaweah No. 2 Flowline (USGS 11208570 [SCE 204a]) and the main Kaweah River downstream of the Kaweah No. 2 Diversion (USGS 11208600 [SCE 203]) minus the discharge of the Kaweah No. 3 Powerhouse (Sum of SCE 210 & SCE 208 gages). 2002-2018: Sum of Kaweah No. 2 Flowline (USGS 11208570 [SCE 204a]) and the main Kaweah River downstream of the Kaweah No. 2 Diversion (USGS 11208600 [SCE 203]) minus the discharge of the Kaweah No. 3 Powerhouse (SCE 206a).	1994-2002: Sum of Kaweah No. 2 Flowline (USGS 11208570 [SCE 204a]), the main Kaweah River downstream of the Kaweah No. 2 Diversion (USGS 11208600 [SCE 203]), and the discharge of the Kaweah No. 3 Powerhouse (Sum of SCE 210 & SCE 208 gages). 2002-2018: Sum of Kaweah No. 2 Flowline (USGS 11208570 [SCE 204a]), the main Kaweah River downstream of the Kaweah No. 2 Diversion (USGS 11208600 [SCE 203]), and the discharge of the Kaweah No. 3 Powerhouse (SCE 206a).
Kaweah River Downstream of Kaweah No. 3 Powerhouse and Upstream of the East Fork Kaweah River Confluence	
1994-2018: Main Kaweah River downstream of the Kaweah No. 2 Diversion (USGS 11208600 [SCE 203]).	1994-2018: The discharge of Kaweah No. 2 Flowline (USGS 1208570 [SCE 204a]) and the main Kaweah River downstream of the Kaweah No. 2 Diversion (USGS 11208600 [SCE 203]).
Kaweah River Downstream of East Fork Kaweah Confluence and Upstream of Kaweah No. 1 Powerhouse	
1994-2018: Sum of main Kaweah River downstream of the Kaweah No. 2 Diversion (USGS 11208600 [SCE 203]) and the East Fork Kaweah River downstream of the Kaweah No. 1 Diversion (11208730 [SCE 201]).	1994-2002: Sum of Flowline 2 (USGS 11208570 [SCE 204a]), the main Kaweah River downstream of the Kaweah No. 2 Diversion (USGS 11208600 [SCE 203]), East Fork Kaweah River downstream of the Kaweah No. 1 Diversion (11208730 [SCE 201]), and the Kaweah No. 1 Flowline (USGS 11208720 [SCE 202]). 2002-2018: Sum of Flowline 2 (USGS 11208570 [SCE 204a]), the main Kaweah River downstream of the Kaweah No. 2 Diversion (USGS 11208600 [SCE 203]), East Fork Kaweah River downstream of the Kaweah No. 1 Diversion (11208730 [SCE 201]), and the Kaweah No. 1 Flowline (USGS 11208720 [SCE 202]).

Existing Flow	Unimpaired Flow
Kaweah River Downstream of Kaweah No. 1 Powerhouse and Upstream of Kaweah No. 2 Powerhouse	
1994-2018: Sum main Kaweah River downstream of the Kaweah No. 2 Diversion (USGS 11208600 [SCE 203]), the East Fork Kaweah River downstream of the Kaweah No. 1 Diversion (11208730 [SCE 201]), and the Kaweah No. 1 Flowline (USGS 11208720 [SCE 202]).	1994-2002: Sum of Flowline 2 (USGS 11208570 [SCE 204a]), the main Kaweah River downstream of the Kaweah No. 2 Diversion (USGS 11208600 [SCE 203]), East Fork Kaweah River downstream of the Kaweah No. 1 Diversion (11208730 [SCE 201]), and the Kaweah No. 1 Flowline (USGS 11208720 [SCE 202]). 2002-2018: Sum of Flowline 2 (USGS 11208570 [SCE 204a]), the main Kaweah River downstream of the Kaweah No. 2 Diversion (USGS 11208600 [SCE 203]), East Fork Kaweah River downstream of the Kaweah No. 1 Diversion (11208730 [SCE 201]), and the Kaweah No. 1 Flowline (USGS 11208720 [SCE 202]).
Kaweah River Downstream of Kaweah No. 2 Powerhouse	
1994-2018: Same as unimpaired flow upstream of Powerhouse No. 2 (see above).	1994-2018: Same as unimpaired flow upstream of Powerhouse No. 2 (see above).
East Fork Kaweah River Upstream of the Kaweah No. 1 Diversion	
1994-2018: Sum of East Fork Kaweah River downstream of the Kaweah No. 1 Diversion (11208730 [SCE 201]) and the Kaweah No. 1 Flowline (USGS 11208720 [SCE 202]).	1994-2002: Sum of East Fork Kaweah River downstream of the Kaweah No. 1 Diversion (11208730 [SCE 201]) and the Kaweah No. 1 Flowline (USGS 11208720 [SCE 202]). 2002-2018: Sum of East Fork Kaweah River downstream of the Kaweah No. 1 Diversion (11208730 [SCE 201]) and the Kaweah No. 1 Flowline (USGS 11208720 [SCE 202]).
East Fork Kaweah River Downstream of the Kaweah No. 1 Diversion	
1994-2018: East Fork Kaweah River downstream of the Kaweah No. 1 Diversion (11208730 [SCE 201]).	1994-2002: Sum of East Fork Kaweah River downstream of the Kaweah No. 1 Diversion (11208730 [SCE 201]) and the Kaweah No. 1 Flowline (USGS 11208720 [SCE 202]). 2002-2018: Sum of East Fork Kaweah River downstream of the Kaweah No. 1 Diversion (11208730 [SCE 201]) and the Kaweah No. 1 Flowline (USGS 11208720 [SCE 202]).
East Fork Kaweah River Upstream of Confluence with Kaweah River	
1994-2018: East Fork Kaweah River downstream of the Kaweah No. 1 Diversion (11208730 [SCE 201]).	1994-2002: Sum of East Fork Kaweah River downstream of the Kaweah No. 1 Diversion (11208730 [SCE 201]) and the Kaweah No. 1 Flowline (USGS 11208720 [SCE 202]). 2002-2018: Sum of East Fork Kaweah River downstream of the Kaweah No. 1 Diversion (11208730 [SCE 201]) and the Kaweah No. 1 Flowline (USGS 11208720 [SCE 202]).

Table AQ 5-4. V* Measurement Results 2018

River/Reach	Pool Number	River Mile	Avg. Length (ft)	Avg. Width (ft)	Pool Bed Surface Area (ft^2)	Avg. Residual Pool Volume (ft^3)	Avg. Fines Thickness (ft)	Avg. Fines Surface Area (ft^2)	Avg. Volume Fine Sediment (ft^3)	Calculated V*
Kaweah River										
Kaweah River Upstream of Kaweah No. 3 Powerhouse	1	9.73	33.00	20.00	660.00	2,145.00	trace[1]	--	--	<0.001
	2	9.76	84.00	32.00	2,688.00	53.76	trace[1]	--	--	<0.001
	3	9.74	45.00	42.00	1,890.00	3,402.00	trace[1]	--	---	<0.001
	4	9.79	45.00	46.00	2,070.00	3,105.00	trace[1]	--	--	<0.001
	5	9.81	111.00	38.00	4,218.00	5,483.40	trace[1]	--	--	<0.001
	6	9.84	90.00	33.00	2,970.00	5,049.00	trace[1]	--	--	<0.001
	7	9.86	45.00	60.00	2,700.00	2,700.00	trace[1]	--	--	<0.001
	8	9.89	60.00	35.00	2,100.00	2,625.00	trace[1]	--	--	<0.001
	9	9.94	117.00	46.00	5,382.00	5,382.00	trace[1]	--	--	<0.001
	10	10.01	75.00	60.00	4,500.00	13,500.00	trace[1]	--	--	<0.001
									Weighted Average V*	**<0.001**
Kaweah River Downstream of Kaweah No. 3 Powerhouse and Upstream of the East Fork Kaweah River Confluence	1	8.80	59.00	21.00	1,239.00	1,239.00	trace[1]	--	--	<0.001
	2	8.78	68.00	33.00	2,244.00	2,244.00	0.70	648.00	479.52	0.09
	3	8.76	93.00	39.00	3,627.00	3,627.00	0.75	368.30	282.51	0.02
	4	8.71	87.00	24.00	2,088.00	2,088.00	trace[1]	--	--	<0.001
	5	8.69	81.00	45.00	3,645.00	3,645.00	trace[1]	--	--	<0.001
	6	8.68	60.00	39.00	2,340.00	1,872.00	0.50	93.50	44.88	0.01
	7	8.67	84.00	48.00	4,032.00	6,048.00	1.30	428.91	603.55	0.10
	8	8.58	96.00	48.00	4,608.00	4,608.00	trace[1]	--	--	<0.001
	9	8.56	153.00	60.00	9,180.00	13,770.00	1.10	1,346.40	1,454.42	0.18
									Weighted Average V*	**0.07**

River/Reach	Pool Number	River Mile	Avg. Length (ft)	Avg. Width (ft)	Pool Bed Surface Area (ft^2)	Avg. Residual Pool Volume (ft^3)	Avg. Fines Thickness (ft)	Avg. Fines Surface Area (ft^2)	Avg. Volume Fine Sediment (ft^3)	Calculated V*
Kaweah River Downstream of East Fork Kaweah Confluence and Upstream of Kaweah No. 1 Powerhouse	1	6.91	222.00	45.00	9,990.00	16,983.00	0.11	7,055.09	758.42	0.04
	2	8.00	330.00	42.00	13,860.00	13,860.00	0.23	16,995.37	3,903.63	0.15
	3	6.86	90.00	31.00	2,790.00	5,859.00	0.08	2,328.00	196.43	0.17
	4	7.09	123.00	59.00	7,257.00	13,062.60	0.06	5,689.98	355.62	0.03
	5	7.85	276.00	65.10	1,7967.60	32,341.68	0.25	17,165.51	4,205.55	0.09
									Weighted Average V*	**0.10**
Kaweah River Downstream of Kaweah No. 1 Powerhouse and Upstream of Kaweah No. 2 Powerhouse	1	5.05	372.00	54.00	20,088.00	24,105.60	0.29	19,974.78	5,742.75	0.09
	2	5.13	159.00	41.00	6,519.00	11,734.20	0.18	4,987.12	903.92	0.12
	3	5.20	195.00	50.60	9,867.00	17,760.60	0.24	10,320.92	2,488.08	0.12
	4	5.25	180.00	38.00	6,840.00	13,680.00	0.12	5,097.60	597.38	0.14
	5	6.40	54.00	33.00	1,782.00	2,494.80	0.09	1,301.40	122.01	0.05
									Weighted Average V*	**0.12**
Kaweah River Downstream of Kaweah No. 2 Powerhouse	1	3.51	285.00	25.00	7,125.00	6,412.50	0.09	5,700.00	498.75	0.10
	2	3.71	450.00	60.00	27,000.00	27,000.00	0.11	21,380.28	2,371.88	0.07
	3	3.76	99.00	51.00	5,049.00	13,127.40	0.60	375.00	225.00	0.08
	4	3.81	237.00	55.00	13,035.00	20,856.00	0.18	10,238.40	1,855.71	0.08
	5	3.91	54.00	32.00	1,728.00	2,592.00	0.03	1,473.19	49.11	0.04
	6	3.98	285.00	18.00	5,130.00	7,695.00	0.80	499.38	399.50	0.03
	7	4.08	144.00	12.00	1,728.00	2,592.00	trace[1]	--	--	<0.001
	8	4.14	348.00	57.00	19,836.00	37,688.40	trace[1]	--	--	<0.001
	9	4.20	285.00	225.00	64,125.00	96,187.50	1.00	1,500.00	1,500.00	0.02
	10	4.34	291.00	51.00	14,841.00	22,261.50	trace[1]	--	--	<0.001
									Weighted Average V*	**0.03**

River/Reach	Pool Number	River Mile	Avg. Length (ft)	Avg. Width (ft)	Pool Bed Surface Area (ft^2)	Avg. Residual Pool Volume (ft^3)	Avg. Fines Thickness (ft)	Avg. Fines Surface Area (ft^2)	Avg. Volume Fine Sediment (ft^3)	Calculated V*
East Fork Kaweah River										
East Fork Kaweah River Upstream of the Kaweah No. 1 Diversion	1a	5.51	45.00	30.00	1,350.00	1,350.00	0.10	1,298.64	124.45	0.09
	2a	5.46	57.00	52.00	2,964.00	3,556.80	0.19	2,453.66	465.17	0.15
	3a	5.45	66.00	47.00	3,102.00	3,102.00	0.02	2,450.25	40.84	0.01
	4a	5.42	75.00	47.00	3,525.00	5,640.00	0.08	4,080.00	306.00	0.06
	1b	5.52	45.00	46.00	2,070.00	2,691.00	0.31	1,603.80	501.19	0.24
	2b	5.56	120.00	39.00	4,680.00	4,680.00	0.25	3,982.65	975.75	0.15
	3b	5.60	75.00	37.00	2,775.00	2,775.00	0.45	2,480.98	1,108.69	0.37
	4b	5.64	57.00	23.00	1,311.00	1,704.30	0.20	976.05	193.18	0.21
	5b	5.68	144.00	35.30	5,083.20	6,099.84	0.42	3,698.82	1,554.66	0.10
									Weighted Average V*	**0.14**
East Fork Kaweah River Downstream of the Kaweah No.1 Diversion	1	4.60	105.00	28.50	2,992.50	2,993.00	trace[1]	--	--	<0.001
	2	4.64	105.00	20.00	2,100.00	2,100.00	trace[1]	--	--	<0.001
	3	4.67	54.00	22.00	1,188.00	1,188.00	trace[1]	--	--	<0.001
	4	4.40	103.00	22.00	2,266.00	2,266.00	trace[1]	--	--	<0.001
	5	4.41	80.00	16.00	1,280.00	1,280.00	trace[1]	--	--	<0.001
									Weighted Average V*	**<0.001**
East Fork Kaweah River Upstream of Confluence with Kaweah River	1	0.11	126.00	45.00	5,670.00	4,536.00	0.40	5,670.00	559.08	0.06
	2	0.12	42.00	47.00	1,974.00	1,974.00	0.12	1,566.00	182.70	0.11
	3	0.19	93.00	37.00	3,441.00	3,096.90	0.14	2,437.15	345.26	0.08
	4	0.22	201.00	38.00	7,638.00	11,457.00	0.12	1,566.00	182.70	0.11
	5	0.25	42.00	42.00	1,764.00	529.20	trace[1]	--	--	<0.001
									Weighted Average V*	**0.06**

[1] A visual estimate was conducted in which little or no fine sediment was observed.

Table AQ 5-5. Sediment Statistics of Spawning Gravel Samples

Sample	Habitat Type	River Mile	Geometric Mean (mm)	D_{84} (mm)	D_{50} (mm)	D_{16} (mm)
Kaweah River						
Kaweah River Upstream of Kaweah No. 3 Powerhouse						
Sample 1.1	MCP	8.97	9.70	54.40	15.49	1.73
Sample 1.2	MCP	8.97	12.59	75.20	25.23	2.11
Sample 2.1	MCP	8.97	8.85	41.85	16.34	1.87
Sample 2.2	MCP	8.97	10.91	70.73	15.00	1.68
Kaweah River Downstream of Kaweah No. 3 Powerhouse and Upstream of the East Fork Kaweah River Confluence						
Sample 1.1	HGR	8.85	13.36	68.37	36.81	2.61
Sample 1.2	HGR	8.85	11.20	60.50	33.86	2.07
Sample 2.1	HGR	8.51	7.42	36.75	10.40	1.50
Sample 2.2	HGR	8.51	8.32	39.17	14.02	1.77
Kaweah River Downstream of East Fork Kaweah Confluence and Upstream of Kaweah No. 1 Powerhouse						
Sample 1.1	SRN	8.37	8.87	46.57	19.95	1.69
Sample 1.2	SRN	8.37	8.71	56.48	11.08	1.34
Sample 2.1	SRN	8.37	10.33	97.24	8.12	1.10
Sample 2.2	SRN	8.37	7.77	45.34	13.52	1.33
Sample 1.1	MCP	7.84	4.41	17.57	3.02	1.11
Sample 1.2	MCP	7.84	6.34	30.54	5.33	1.32
Sample 2.1	MCP	7.84	8.45	54.94	6.19	1.30
Sample 2.2	MCP	7.84	8.46	59.17	4.43	1.21
Kaweah River Downstream of Kaweah No. 1 Powerhouse and Upstream of Kaweah No. 2 Powerhouse						
No Samples Collected						
Kaweah River Downstream of Kaweah No. 2 Powerhouse						
Sample 1.1	LGR	4.68	9.83	41.54	17.56	2.33
Sample 1.2	LGR	4.68	7.66	36.86	14.65	1.59
Sample 2.1	LGR	4.68	10.84	47.98	14.82	2.45
Sample 2.2	LGR	4.68	7.69	34.70	11.54	1.71

Sample	Habitat Type	River Mile	Geometric Mean (mm)	D_{84} (mm)	D_{50} (mm)	D_{16} (mm)
East Fork Kaweah River						
East Fork Kaweah River Upstream of the Kaweah No. 1 Diversion						
Sample 1.1	MCP	4.79	23.56	93.50	51.46	5.93
Sample 1.2	MCP	4.79	18.32	75.19	34.01	4.47
Sample 2.1	MCP	4.79	10.24	37.81	12.20	2.78
Sample 2.2	MCP	4.79	25.52	104.76	56.27	6.22
East Fork Kaweah River Downstream of the Kaweah No. 1 Diversion						
Sample 1.1	HGR	4.64	8.42	39.09	9.07	1.81
Sample 1.2	HGR	4.64	5.82	17.18	7.84	1.97
Sample 2.1	STP	4.69	20.15	36.03	20.05	11.27
Sample 2.2	STP	4.69	15.54	32.84	15.07	7.35
East Fork Kaweah River Upstream of Confluence with Kaweah River						
Sample 1.1	MCP	0.1	4.64	12.07	5.87	1.78
Sample 1.2	MCP	0.1	3.07	7.67	3.03	1.23
Sample 2.1	MCP	0.1	1.77	2.88	1.63	1.08
Sample 2.2	MCP	0.1	1.45	2.08	1.43	1.01

Table AQ 5-6. Fine Sediment Content of Spawning Gravel Samples

Location	Habitat Type	River Mile	Gravel Prior to Cleaning		Gravel Following Winnowing of Fine Sediment	
			Cumulative % Finer Than 1 mm	Cumulative % Finer Than 6.4 mm	Cumulative % Finer Than 1 mm	Cumulative % Finer Than 6.4 mm
Kaweah River						
Kaweah River Upstream of Kaweah No. 3 Powerhouse						
Sample 1.1	MCP	8.97	7.07	30.26	4.73	17.55
Sample 1.2	MCP	8.97	5.27	27.10	3.53	15.72
Sample 2.1	MCP	8.97	6.43	28.76	4.31	16.68
Sample 2.2	MCP	8.97	6.17	32.29	4.13	18.73
Kaweah River Downstream of Kaweah No. 3 Powerhouse and Upstream of the East Fork Kaweah River Confluence						
Sample 1.1	RUN	8.85	6.07	24.01	4.07	13.92
Sample 1.2	RUN	8.85	7.61	25.98	5.10	15.07
Sample 2.1	HGR	8.51	9.39	36.17	6.29	20.98
Sample 2.2	HGR	8.51	6.76	33.03	4.53	19.16
Kaweah River Downstream of East Fork Kaweah Confluence and Upstream of Kaweah No. 1 Powerhouse						
Sample 1.1	SRN	8.37	6.32	33.73	4.23	19.56
Sample 1.2	SRN	8.37	8.00	42.55	5.36	24.68
Sample 2.1	SRN	8.37	13.09	46.72	8.77	27.10
Sample 2.2	SRN	8.37	10.76	37.04	7.21	21.48
Sample 1.1	MCP	7.84	11.83	64.75	7.93	37.55
Sample 1.2	MCP	7.84	7.51	54.07	5.03	31.36
Sample 2.1	MCP	7.84	7.58	50.74	5.08	29.43
Sample 2.2	MCP	7.84	9.37	54.50	6.28	31.61
Kaweah River Downstream of Kaweah No. 1 Powerhouse and Upstream of Kaweah No. 2 Powerhouse						
No Samples Collected						
Kaweah River Downstream of Kaweah No. 2 Powerhouse						
Sample 1.1	LGR	4.68	5.03	25.46	3.37	14.77
Sample 1.2	LGR	4.68	7.99	32.85	5.35	19.05
Sample 2.1	LGR	4.68	5.30	27.34	3.55	15.85
Sample 2.2	LGR	4.68	7.30	33.54	4.90	19.45

East Fork Kaweah River						
East Fork Kaweah River Upstream of the Kaweah No. 1 Diversion						
Sample 1.1	MCP	0.1	2.67	17.05	1.79	9.89
Sample 1.2	MCP	0.1	3.01	18.93	2.02	10.98
Sample 2.1	MCP	0.1	5.43	27.74	3.64	16.09
Sample 2.2	MCP	0.1	2.53	16.48	1.70	9.56
East Fork Kaweah River Downstream of the Kaweah No. 1 Diversion						
Sample 1.1	HGR	4.64	6.37	38.10	4.27	22.10
Sample 1.2	HGR	4.64	4.34	38.80	2.91	22.50
Sample 2.1	STP	4.69	0.00	1.93	0.00	1.12
Sample 2.2	STP	4.69	1.07	10.10	0.72	5.86
East Fork Kaweah River Upstream of Confluence with Kaweah River						
Sample 1.1	MCP	4.79	4.68	54.84	3.13	31.81
Sample 1.2	MCP	4.79	9.94	77.90	6.66	45.18
Sample 2.1	MCP	4.79	9.23	99.92	6.18	57.95
Sample 2.2	MCP	4.79	14.58	99.98	9.77	57.99

Table AQ 5-7a. Sediment Facies, Area, and Volume of the Sediment trapped in the Kaweah No. 1 Diversion Pool

Facies Type	Area (ft^2)
Sandy Gravel	89
Bedrock	777
Sandy Gravel	306
Sandy Bouldery Cobble	904
Cobbley Boulder	3,124
Sandy Gravel	89
Total Area (ft^2)	**5,199**
Total Area (ac)	**0.1**
Volume (yds^3)	**1,155**

Table AQ 5-7b. Sediment Facies, Area, and Volume of the Sediment trapped in the Kaweah No. 2 Diversion Pool

Facies Type	Area (ft^2)
Cobbley Boulder	3,139
Sandy Gravelly Cobble	2,606
Gravelly Cobble	12,907
Gravelly Cobbley Boulder	803
Sand	6,227
Cobbley Boulder	3,139
Total Area (ft^2)	**25,682**
Total Area (ac)	**0.6**
Volume (yds^3)	**6,658**

Table AQ 5-8. Sediment Statistics of Bulk Samples From Kaweah No. 2 Diversion Pool

Sample	D16	D50	D84	Geometric Mean
1	32.1	97.1	190.3	78.1
2	6.5	79.6	135.4	29.8

Table AQ 5-9. Summaries of Existing and Unimpaired Daily and Peak Q 1.5 Flows and Average Annual Days Exceeding Each for the Study Reaches

Study Reach	Site ID	Existing Average Daily Q 1.5	Unimpaired Average Daily Q 1.5	Existing Average Annual Days > Unimpaired Daily Q 1.5	Unimpaired Average Annual Days > Unimpaired Daily Q 1.5	Difference in Annual Days > Daily Q 1.5	Existing Percent of Unimpaired (%)
Kaweah River Downstream of Kaweah No. 3 Powerhouse and Upstream of the East Fork Kaweah River Confluence	DS PH3	985	1,069	17.2	19.8	2.6	87
Kaweah River Downstream of East Fork Confluence and Upstream of Kaweah No. 1 Powerhouse	US PH1	1,618	1,658	12.8	14.6	2.0	88
Kaweah River Downstream of Kaweah No. 1 Powerhouse and Upstream of Kaweah No. 2 Powerhouse	US PH2	1,583	1,658	14.0	16.1	2.0	87
East Fork Kaweah River Downstream of the Kaweah No. 1 Diversion	EF DS Div 1	431	454	17.2	18.4	1.2	93

Table AQ 5-10. Summaries of Discharge (Q) at 10% Incipient Motion for Sand, Gravel, and Cobble in Bypass Reaches with Existing and Unimpaired Q values at a 1.5 Recurrence Interval

Study Reach	Site ID	Q 10% (cfs)			Existing Average Daily Q 1.5 (Peak Q 1.5) (cfs)	Unimpaired Average Daily Q 1.5 (Peak Q 1.5) (cfs)
		Sand	Gravel	Cobble		
Kaweah River Downstream of Kaweah No. 3 Powerhouse and Upstream of the East Fork Kaweah River Confluence	DS PH3	112	277	848	985 (1,632)	1,069 (1,684)
Kaweah River Downstream of East Fork Confluence and Upstream of Kaweah No. 1 Powerhouse	US PH1	567	751	>1,900[1]	1,618 (2,365)	1,658 (2,451)
Kaweah River Downstream of Kaweah No. 1 Powerhouse and Upstream of Kaweah No. 2 Powerhouse	US PH2	295	482	1,677	1,583 (2,434)	1,658 (2,451)
East Fork Kaweah River Upstream of Confluence with Kaweah River	EF US Confl	207	>240[2]	>240[2]	431 (717)	454 (737)

1 Less than 10% of the cobbles moved at the highest flow modeled in the AQ 1 – Instream Flow Study, 1,900 cfs.

2 No gravel or cobble moved in this reach at flows less than the highest flow modeled in the AQ – 1 Instream Flow Study, 240 cfs. Gravel and cobble were only present in the margin of the channel and much higher flows were needed to initiate movement.

Table AQ 5-11. Percent Change in Exceedance of the Q 10% Flow for Existing and Unimpaired Flows by Sediment Type in Study Reaches

Reach	Percent Change in Exceedance (%)				
	Sand	Gravel	Cobble	Average Q 1.5	Peak Q 1.5
Kaweah River Downstream of Kaweah No. 3 Powerhouse and Upstream of the East Fork Kaweah River Confluence	12	5.5	1.4	7.9	3.1
Kaweah River Downstream of East Fork Confluence and Upstream of Kaweah No. 1 Powerhouse	3.9	2.7	<0.3	2.4	3.5
Kaweah River Downstream of Kaweah No. 1 Powerhouse and Upstream of Kaweah No. 2 Powerhouse	5.7	5.5	0.6	4.5	0.7
East Fork Kaweah River Downstream of the Kaweah No. 1 Diversion	1.5	<1.1	<1.1	5.1	2.7

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FIGURES

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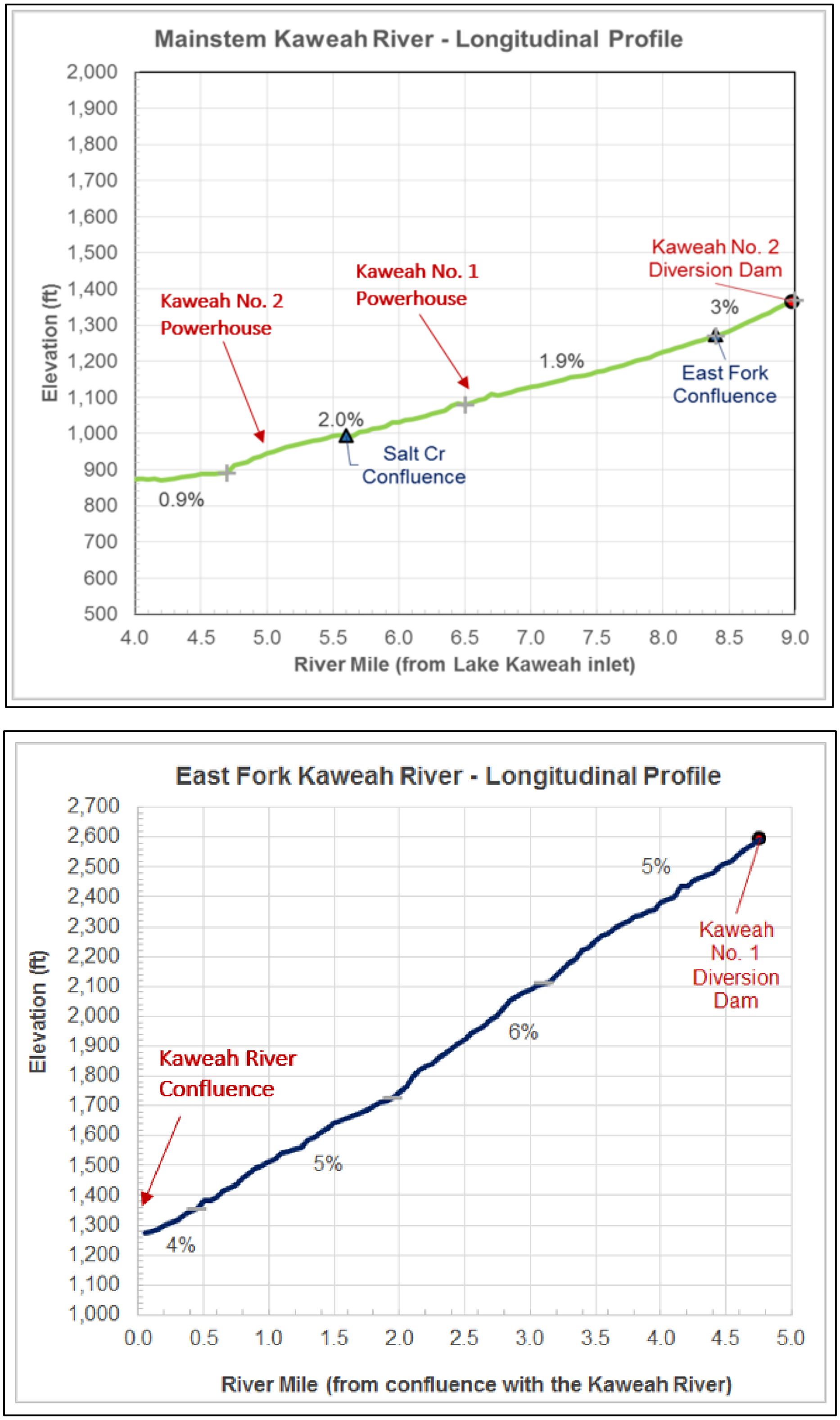

Figure AQ 5-1. **Longitudinal Profiles for the Kaweah River (top) and East Fork Kaweah River (bottom) Bypass Reaches (Longitudinal profiles developed from 10 m DEM data. Gray lines indicate gradient breaks).**

Figure AQ 5-2a. **An image of the Kaweah No. 1 Diversion pool sediment deposit, from river left. The diversion dam is visible in the left of the image. Flow is right to left.**

Figure AQ 5-2b. **An image of the Kaweah No. 2 Diversion pool sediment deposit (Google Earth image).**

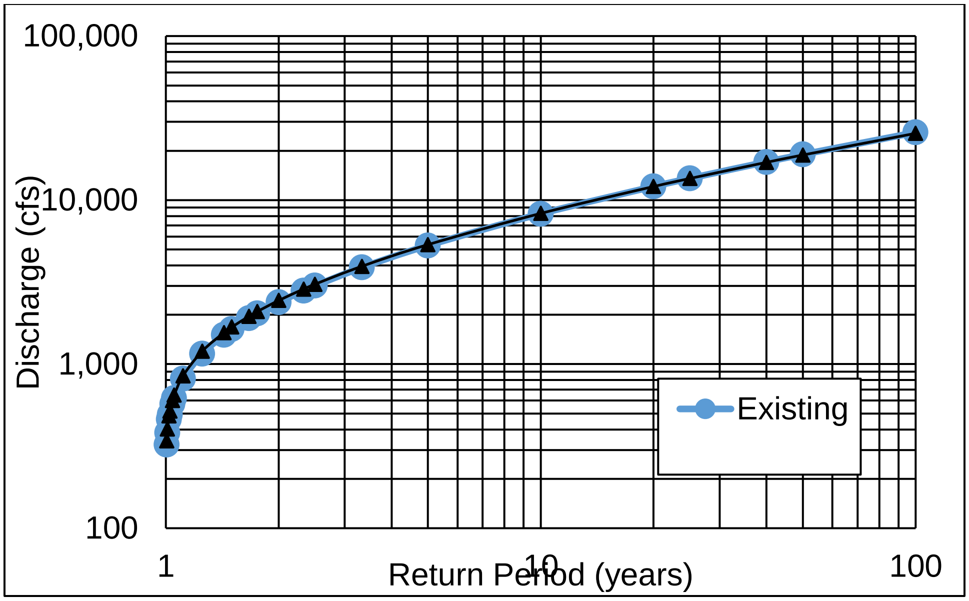

Figure AQ 5-3a. Flood Frequency for Existing and Unimpaired Flows in the Kaweah River Downstream of Kaweah No. 3 Powerhouse and Upstream of the East Fork Kaweah River Confluence.

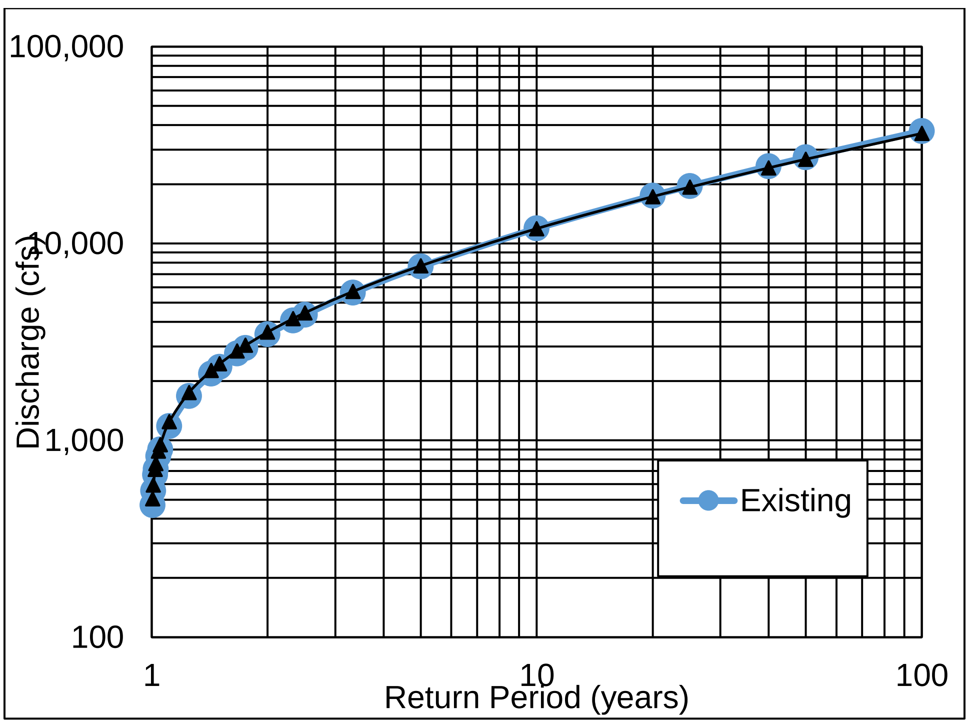

Figure AQ 5-3b. Flood Frequency for Existing and Unimpaired Flows in the Kaweah River Downstream of East Fork Kaweah Confluence and Upstream of Kaweah No. 1 Powerhouse.

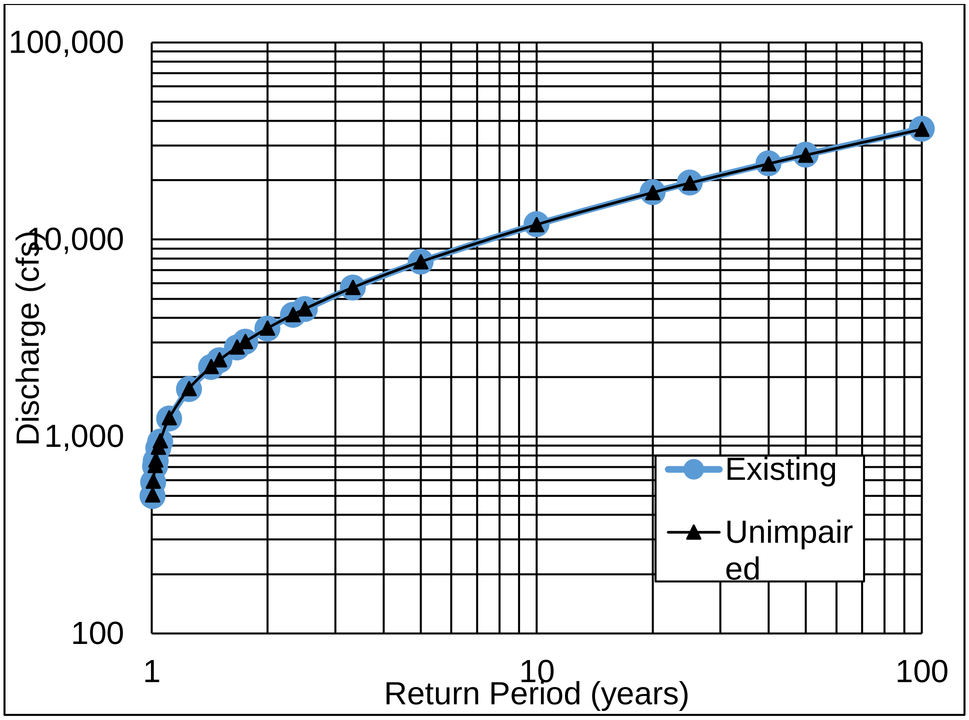

Figure AQ 5-3c. Flood Frequency for Existing and Unimpaired Flows in the Kaweah River Downstream of Kaweah No. 1 Powerhouse and Upstream of Kaweah No. 2 Powerhouse.

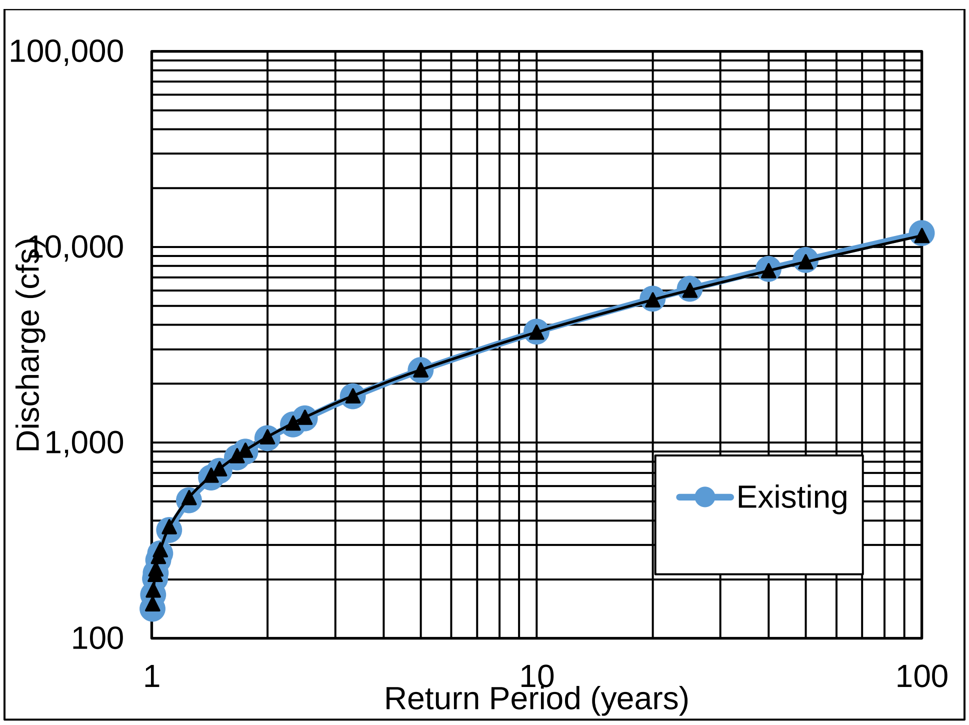

Figure AQ 5-3d. Flood Frequency for Existing and Unimpaired Flows in the East Fork Kaweah River Downstream of the Kaweah No. 1 Diversion

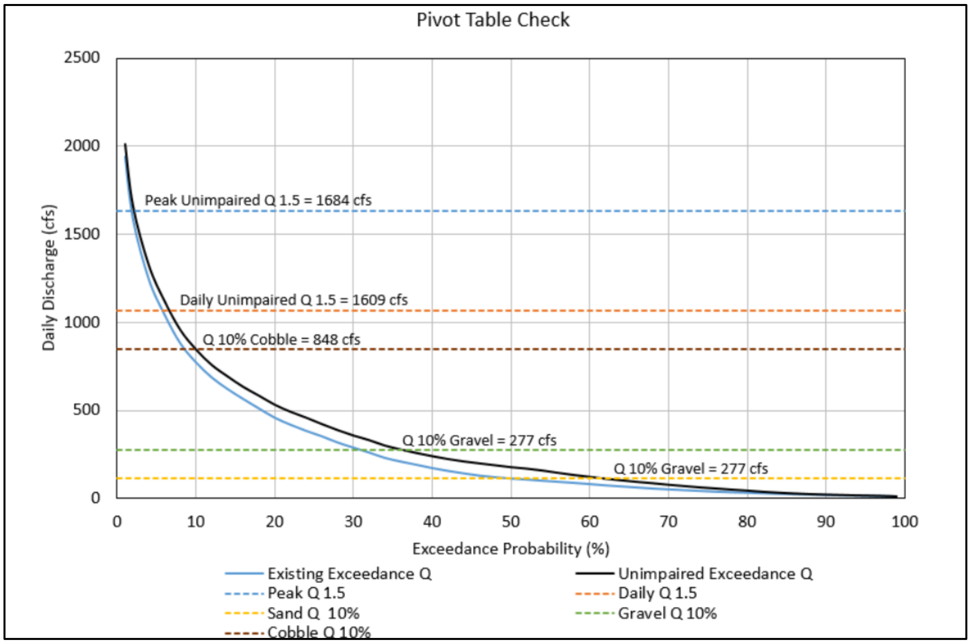

Figure AQ 5-4a. **Daily Discharge and Exceedance Probability with associated Q Values for the Kaweah River Downstream of Kaweah No. 3 Powerhouse and Upstream of the East Fork Kaweah River Confluence**

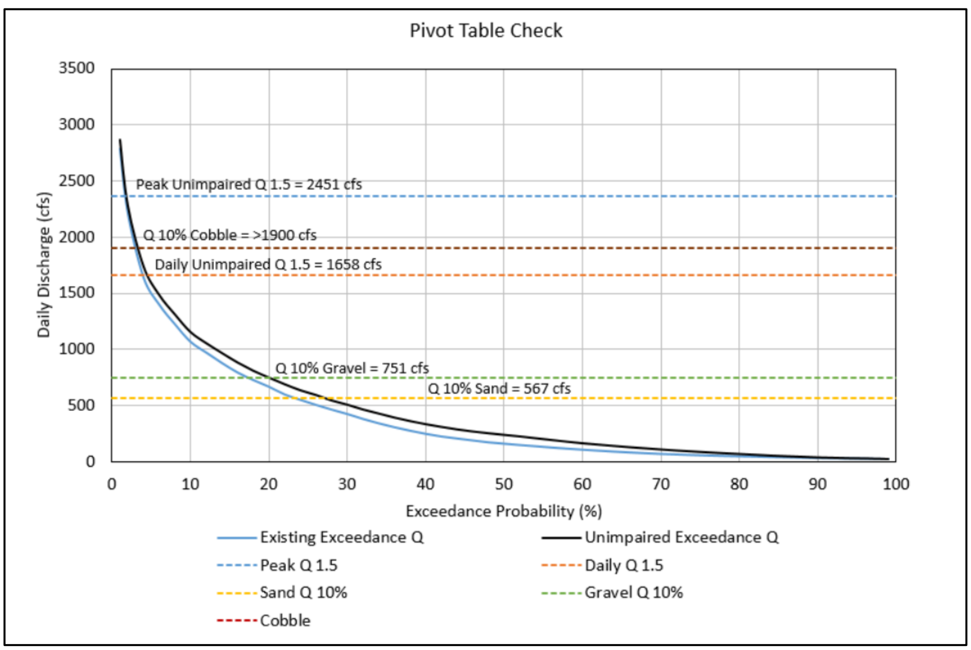

Figure AQ 5-4b. **Daily Discharge and Exceedance Probability with associated Q Values for the Kaweah River Downstream of the East Fork Kaweah Confluence and Upstream of the Kaweah No. 1 Powerhouse**

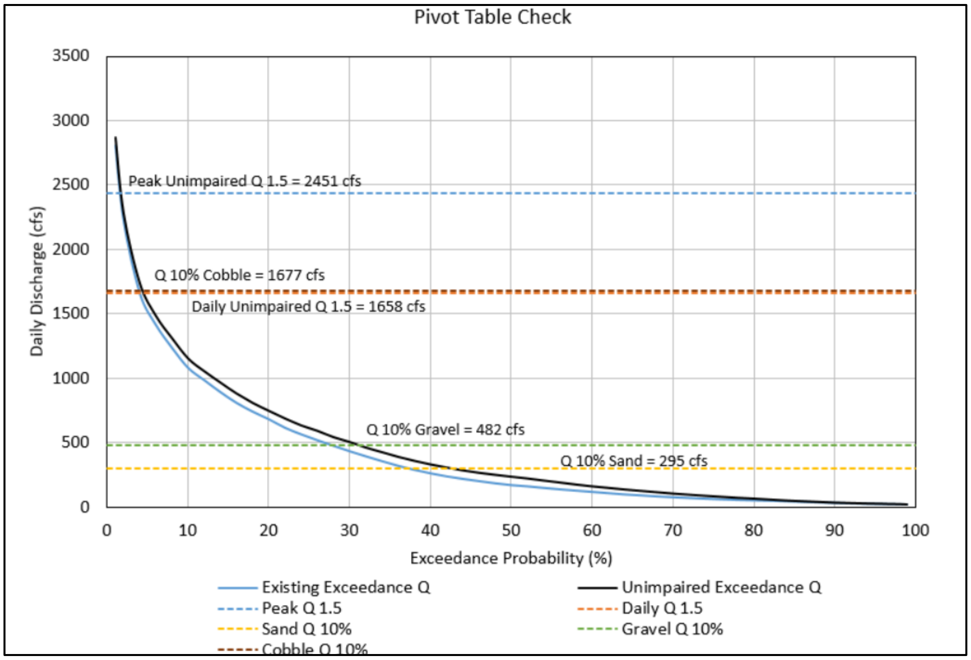

Figure AQ 5-4c. Daily Discharge and Exceedance Probability with associated Q Values for the Kaweah River Downstream of the Kaweah No. 1 Powerhouse and Upstream of Kaweah No. 2 Powerhouse

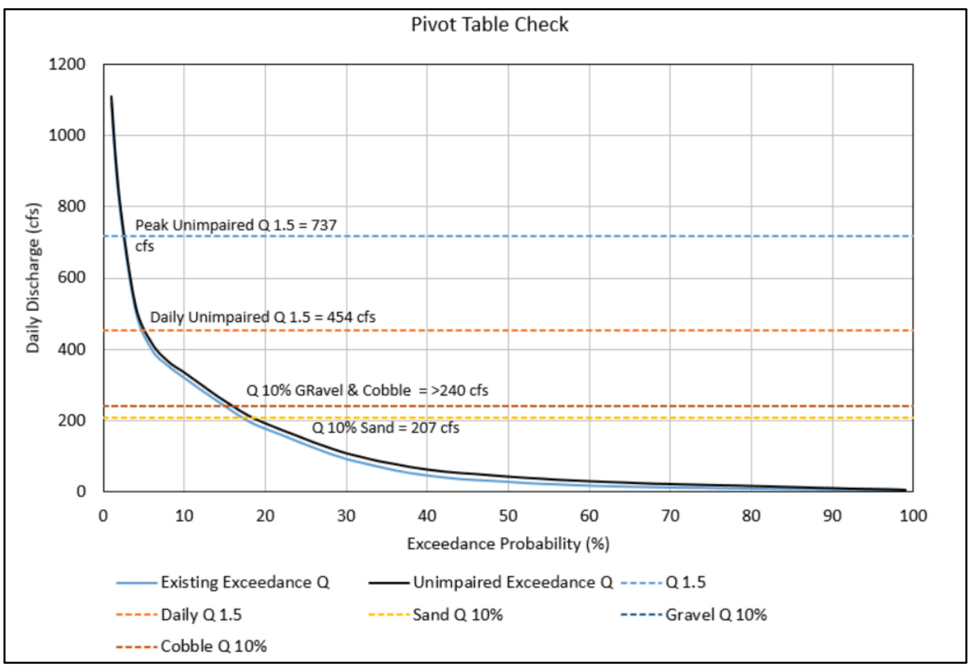

Figure AQ 5-4d. Daily Discharge and Exceedance Probability with associated Q Values for East Fork Kaweah River Upstream of Confluence with Kaweah River

Figure AQ 5-5a. Representative photograph of the portion of the natural drainage channel which receives flow from the Kaweah No. 1 Forebay tank.

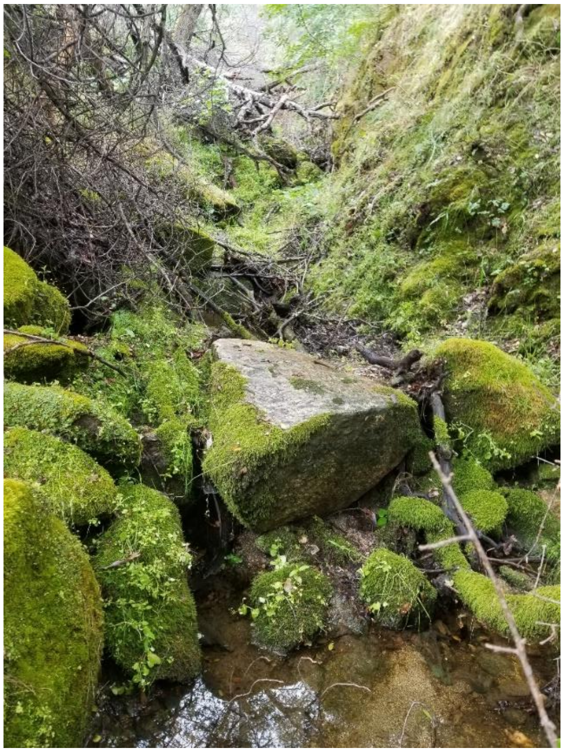

Figure AQ 5-5b. Representative photograph of the portion of the natural drainage channel which receives flow from the Kaweah No. 1 Forebay tank.

Figure AQ 5-5c. **Representative photograph of the portion of the natural drainage channel which receives flow from the Kaweah No. 1 Forebay tank.**

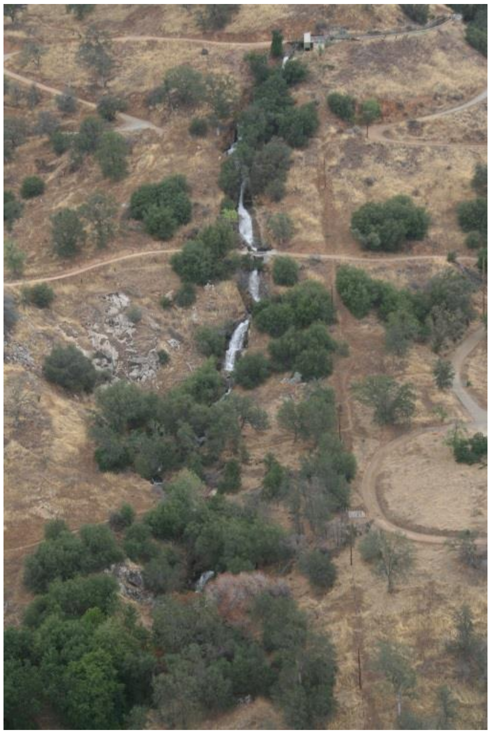

Figure AQ 5-6a. Representative photograph of the portion of the natural drainage channel which receives flow from the Kaweah No. 2 Forebay.

Figure AQ 5-6b. Representative photograph of a down cut section in the natural drainage channel which receives flow from the Kaweah No. 2 Forebay.

Figure AQ 5-6c. Recent erosion on the side slope of the natural drainage channel which receives flow from the Kaweah No. 2 Forebay.

Figure AQ 5-6d. Representative photograph of a stable section of the natural drainage channel which receives flow from the Kaweah No. 2 Forebay.

Figure AQ 5-7a. Representative photograph of the upper portion of the drainage chute and natural drainage channel that receives flow from the Kaweah No. 3 Forebay.

Figure AQ 5-7b. Representative section of the natural drainage channel that receives flow from the Kaweah No. 3 Forebay illustrating the steep, bedrock/boulder nature of this drainage.

Figure AQ 5-7c. Representative section of the natural drainage channel that receives flow from the Kaweah No. 3 Forebay showing boulders along the side slopes of the drainage.

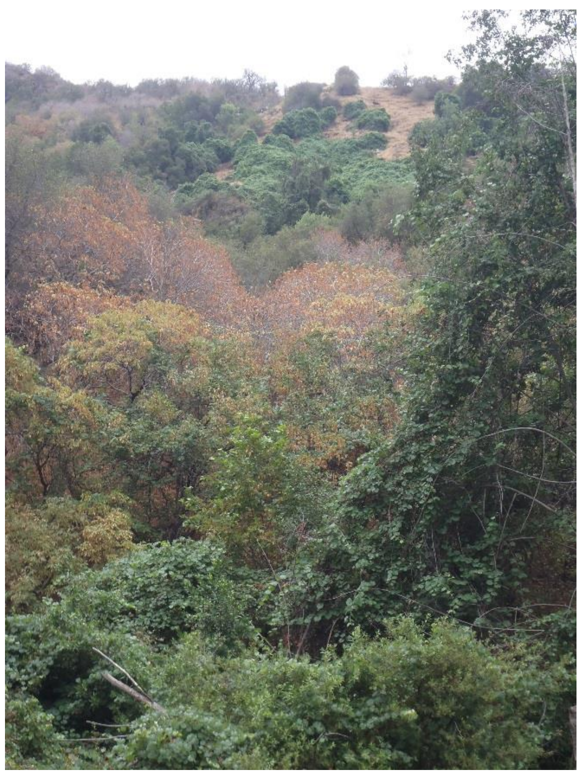

Figure AQ 5-7d. View of the natural drainage channel that receives flow from the Kaweah No. 3 Forebay from the bottom.

Figure AQ 5-7e. Outlet of the natural drainage channel that receives flow from the Kaweah No. 3 Forebay at the Kaweah River.

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MAPS

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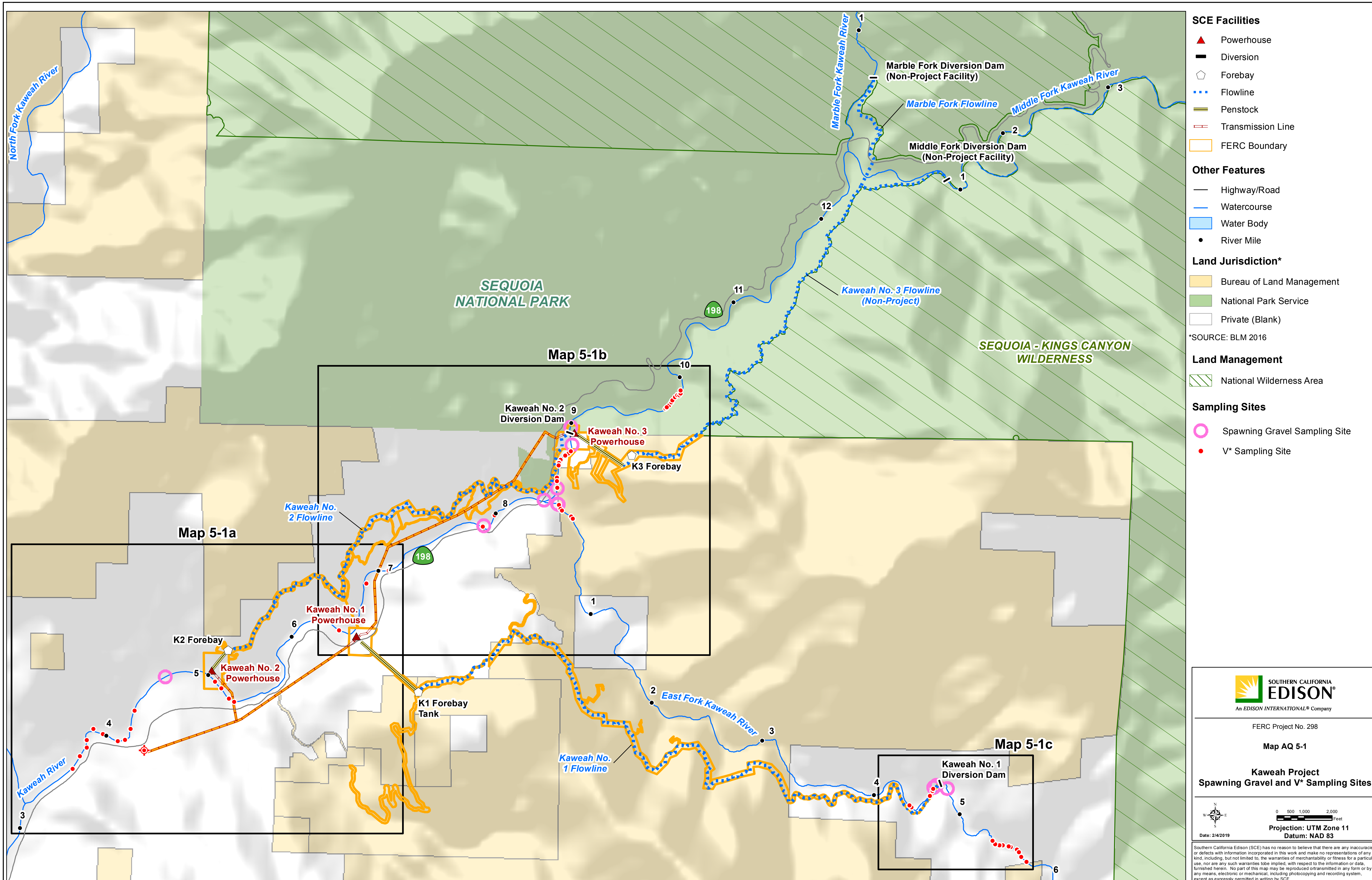

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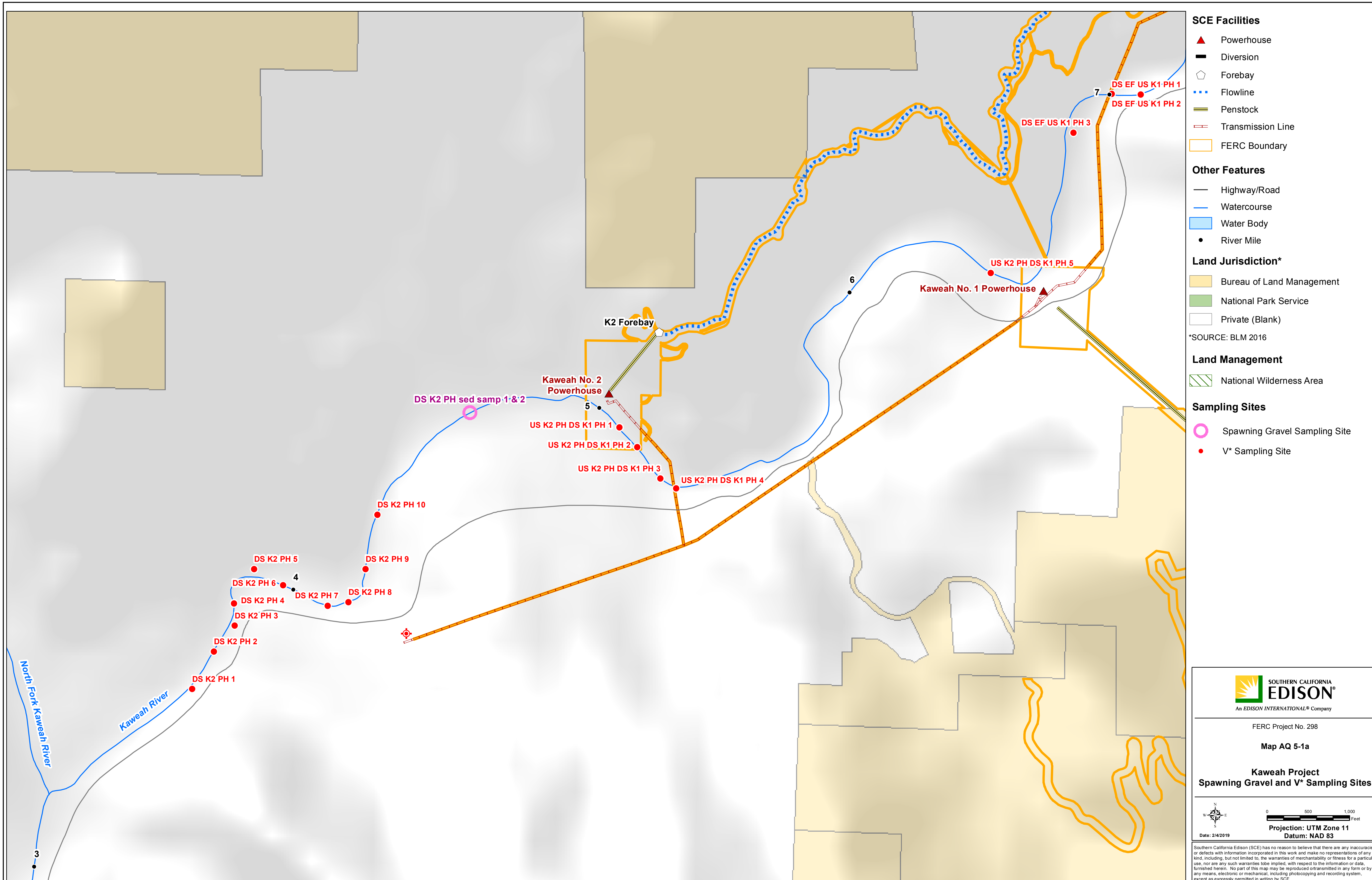

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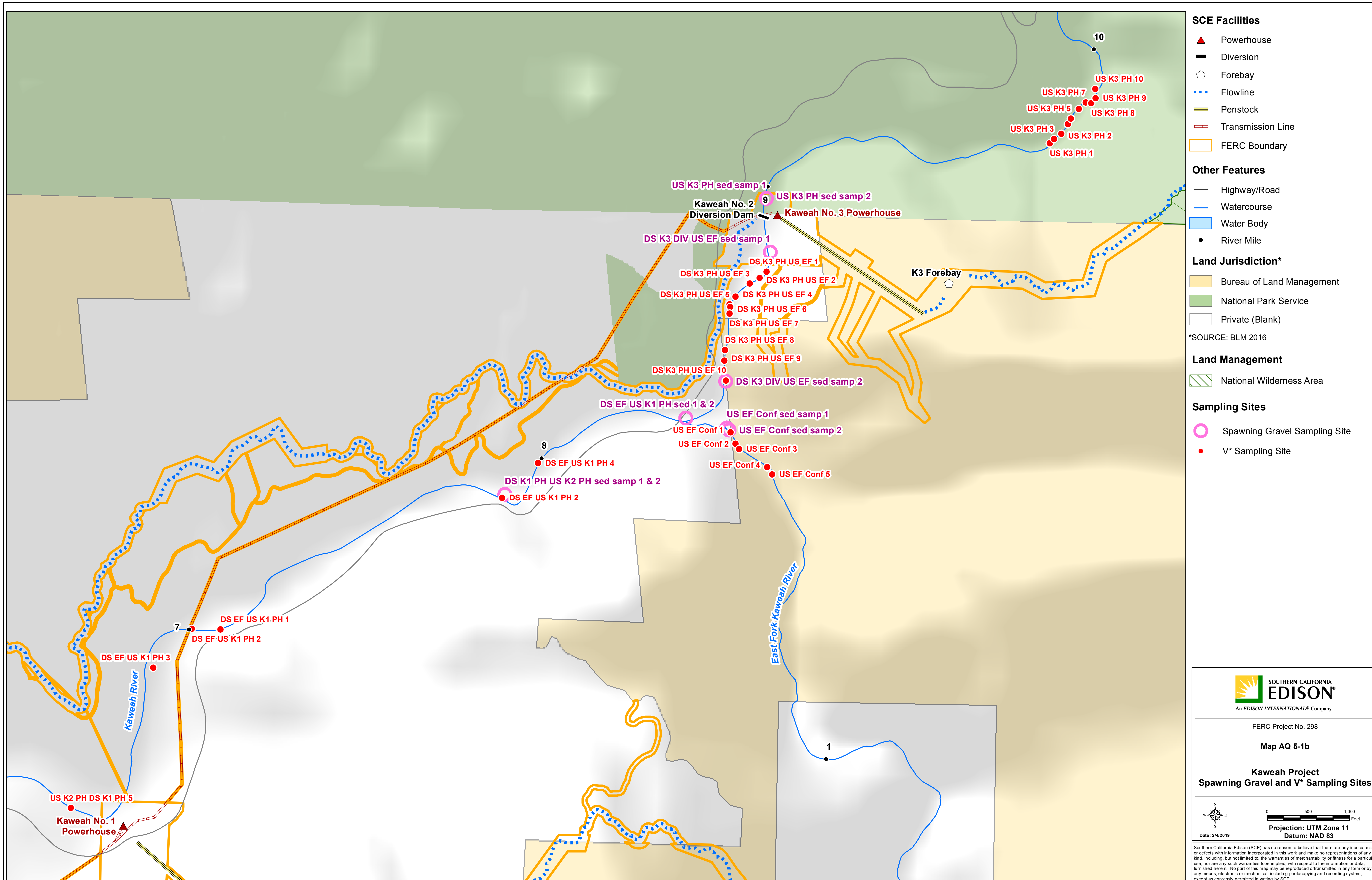

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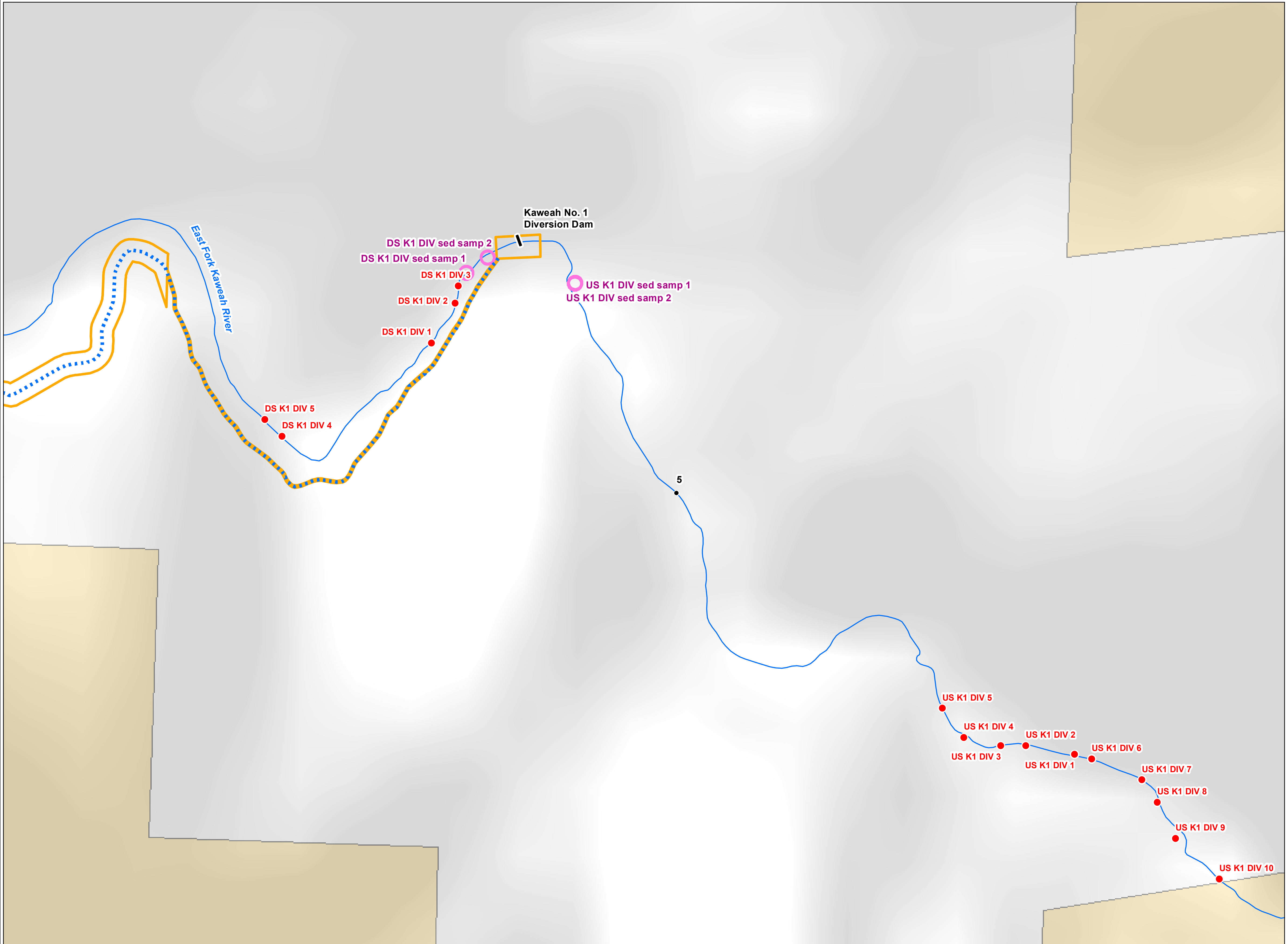

SCE Facilities

- Powerhouse
- Diversion
- Forebay
- Flowline
- Penstock
- Transmission Line
- FERC Boundary

Other Features

- Highway/Road
- Watercourse
- Water Body
- River Mile

Land Jurisdiction*

- Bureau of Land Management
- National Park Service
- Private (Blank)

*SOURCE: BLM 2016

Land Management

- National Wilderness Area

Sampling Sites

- Spawning Gravel Sampling Site
- V* Sampling Site

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FERC Project No. 298

Map AQ 5-1c

Kaweah Project
Spawning Gravel and V* Sampling Sites

N W E S
0 250 500 Feet

Date: 2/4/2019

Projection: UTM Zone 11
Datum: NAD 83

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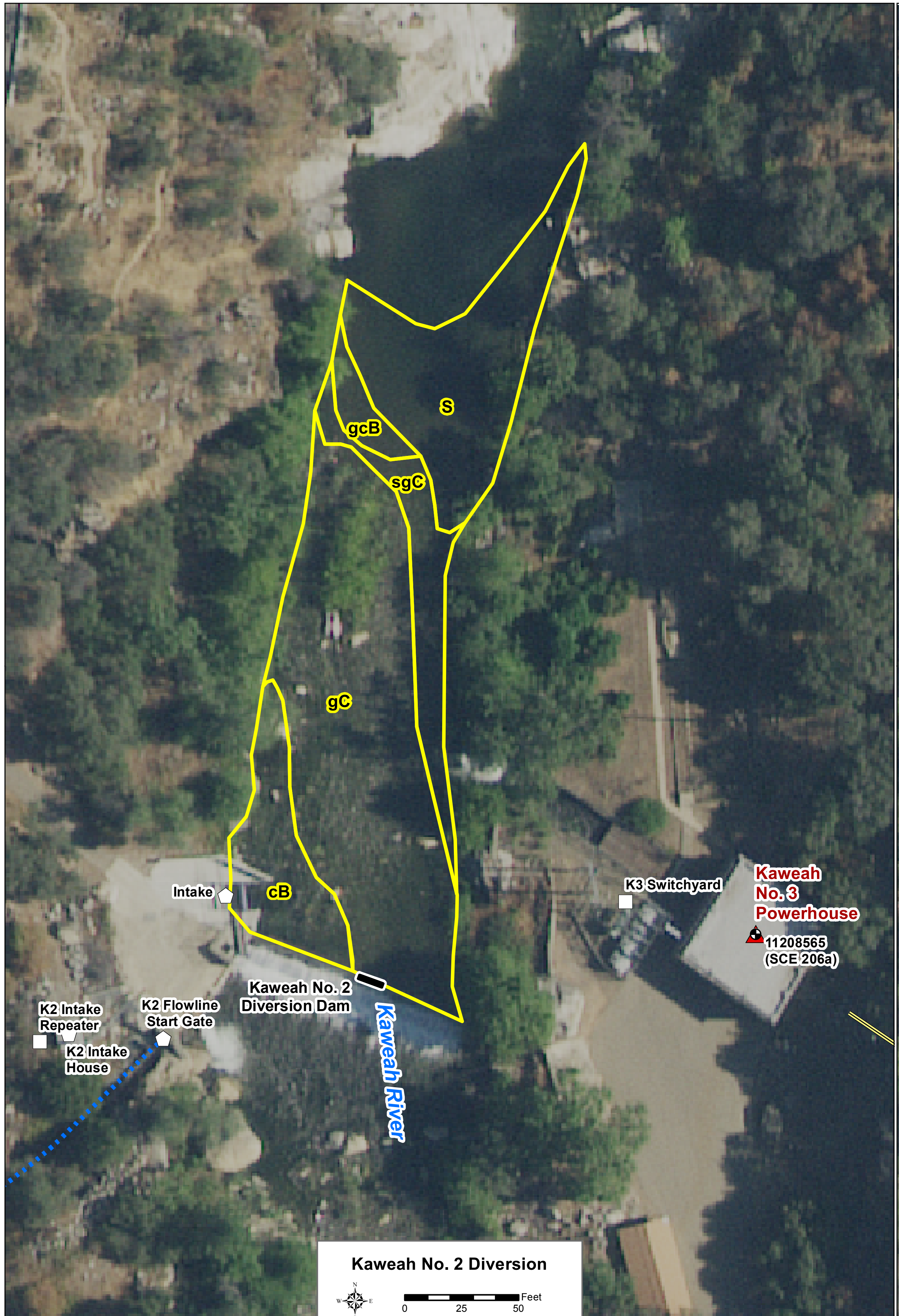

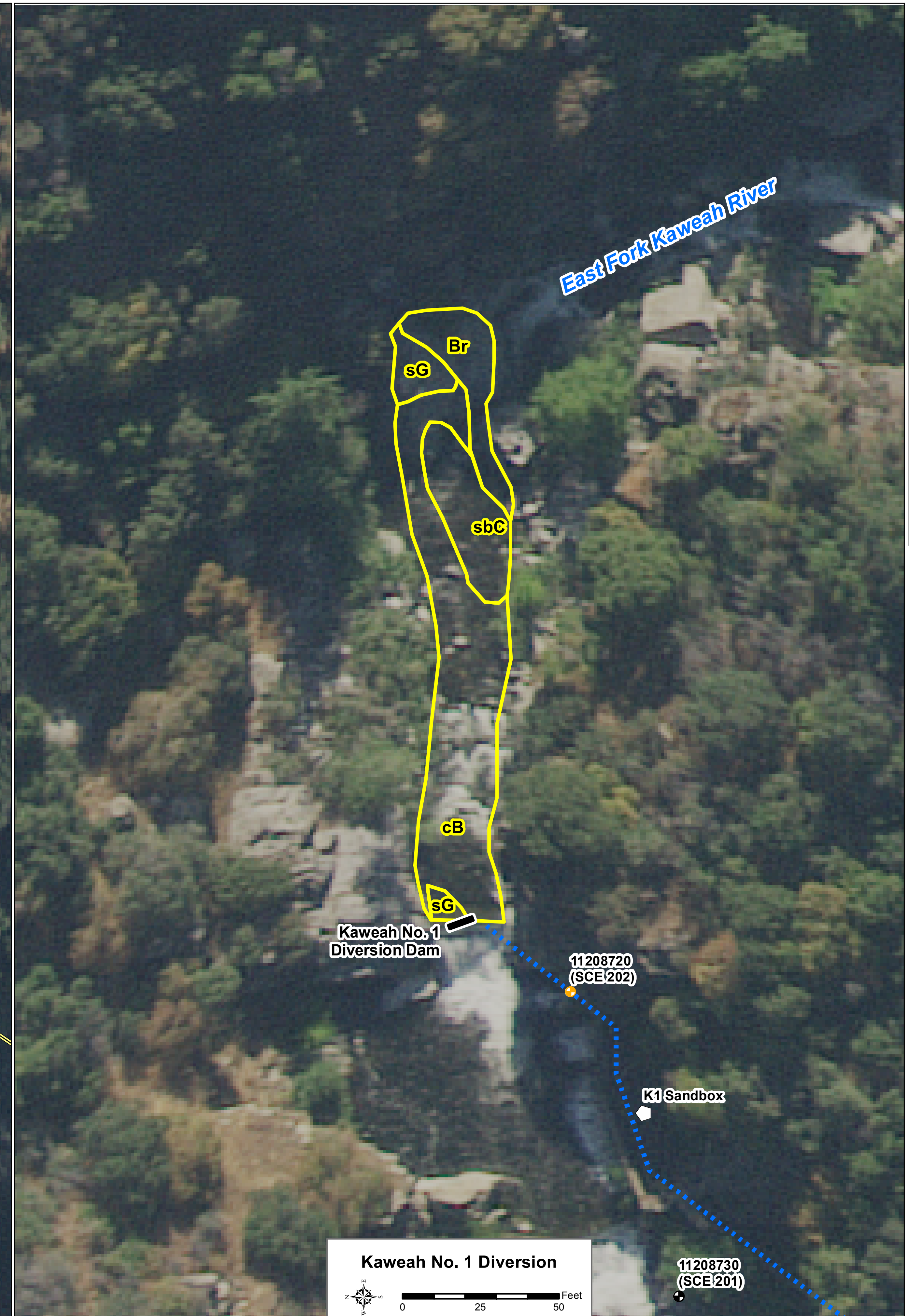

SCE Facilities

- Powerhouse
- Diversion
- Water Conveyance Facility
- Flowline
- Penstock
- Ancillary Facility
- Project Gage (current)
- Project Gage (historic)

Facies Survey Data

- Delineated Facies Types
- Br Bedrock
- cB Cobbly Boulder
- gC Gravelly Cobble
- gcB Gravelly Cobbly Boulder
- S Sand
- sbC Sandy Bouldery Cobble
- sG Sandy Gravel
- sgC Sandy Gravelly Cobble

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Map AQ5-2

Kaweah Project
Facies types Upstream of
Kaweah Nos. 1 and 2 Diversions

Date: 2/5/2019

Projection: UTM Zone 11
Datum: NAD 83

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SCE Facilities

- Powerhouse
- Diversion
- Utility
- Forebay
- Flowline
- Penstock
- Transmission Line

Other Features

- Project Road
- Non-Project General Access Road
- River/Stream

Survey Features

- K1 Forebay Tank Spill Drainage*

*NOTE: Location of natural drainage channels are approximate based on topography

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Map AQ5-3

Kaweah No. 1 Forebay Tank and Associated Natural Drainage Channels

N S W E

0 50 100 200 Feet

Projection: UTM Zone 11
Datum: NAD 83

Date: 5/30/2019

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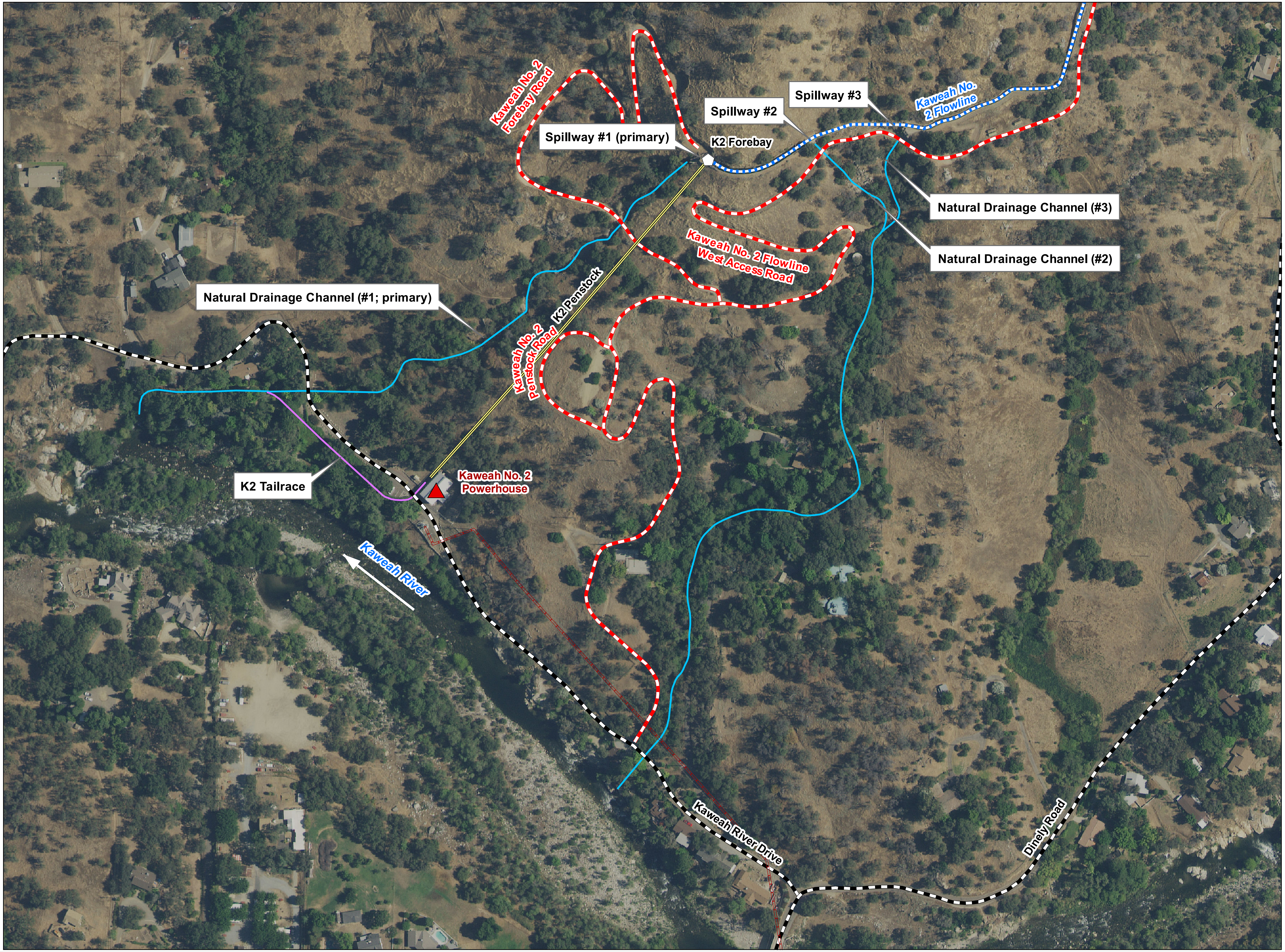

SCE Facilities

- Powerhouse
- Diversion
- Utility
- Forebay
- Flowline
- Tailrace
- Penstock
- Transmission Line

Other Features

- Project Road
- Non-Project General Access Road
- River/Stream

Survey Features

- K2 Forebay Spill Drainage*

*NOTE: Location of natural drainage channels are approximate based on topography

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Map AQ5-4

Kaweah No. 2 Forebay and Associated Natural Drainage Channels

0 50 100 200 Feet

Projection: UTM Zone 11
Datum: NAD 83

Date: 5/30/2019

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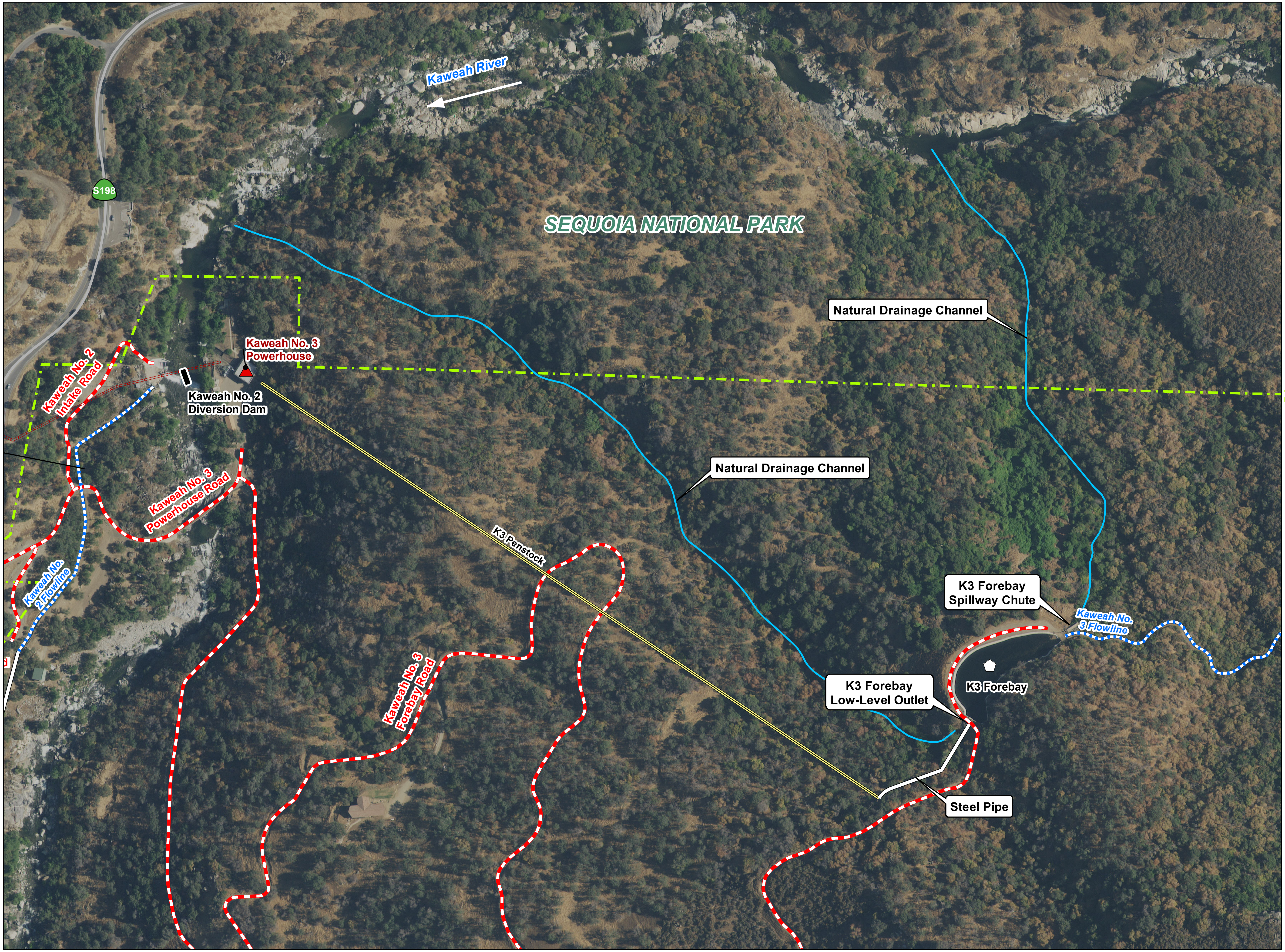

SCE Facilities

- Powerhouse
- Diversion
- Utility
- Forebay
- Flowline
- Steel Pipe
- Penstock
- Transmission Line

Other Features

- Project Road
- Non-Project General Access Road
- River/Stream

Survey Features

- K3 Forebay Spill Drainage*

*NOTE: Location of natural drainage channels are approximate based on topography

Land Jurisdiction

- National Park Service Boundary

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Map AQ5-5

Kaweah No. 3 Forebay and Associated Natural Drainage Channels

N S W E

0 50 100 200 Feet

Projection: UTM Zone 11
Datum: NAD 83

Date: 5/30/2019

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APPENDIX A

Evaluation of Sediment Transport Conditions

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Appendix A
Evaluation of Sediment Transport Conditions

A.1 Shear Stress Calculation

Calculation of the stream's bed shear stress (τ_0), or tangential force per unit bed area, is necessary to understand flow intensity and its ability to mobilize and transport sediment particles resting on the bed. Bedload transport rates (e.g., gravel transport) are steep and non-linear, which means relatively small changes in shear stress can create large changes in sediment transport. Therefore, obtaining accurate shear stress estimates is critical in calculating sediment transport.

For steady, uniform flow the momentum equation states a balance must exist between shear forces (resisting forces) and gravity component (driving forces)

$$\tau_0 P_w \Delta s = \rho g A \Delta s S$$

or

$$\tau_0 = \rho g R S$$

where τ_0 is bottom shear stress, P_w is wetted perimeter, Δs is length of control volume, ρ is fluid density, g is gravity acceleration, A is cross-section area, S is the bed slope, and R is the hydraulic radius.

To calculate bed shear stress for steady, gradually varied flow conditions common to most streams, the friction slope S_f is often substituted for the bed slope S. And for relatively wide channels where the hydraulic radius and mean flow depth are approximately similar, the "depth*slope" product is used to calculate the mean cross-sectionally averaged boundary shear stress

$$\tau_0 = \rho g H S_f$$

where *H* is mean flow depth.

The mean boundary shear stress, however, includes forces acting on debris jams, vegetation, channel banks, bar forms, and other features that add resistance and increase flow depth. Research has shown that the actual bed shear stress available for sediment transport (effective shear stress) is often a third to a half the mean boundary shear stress (Dietrich 1987). To gain a better estimate of only the portion of the shear stress that is acting on the sediment grains and available to transport sediment, a local estimate of shear stress directly above the area of the bed of interest is required. This local estimate is often referred to as a grain stress.

The following section describes the method used in this study to calculate local bed shear stress.

Time averaged fluid shear stress in a streamflow is defined as the rate of change of downstream momentum per unit cross-sectional area

$$\tau = -\rho \overline{u'v'}$$

where τ is turbulent shear stress, ρ is fluid density, u' is downstream velocity, and v' is vertical velocity.

Determining the vertical variation in flow velocity in turbulent flow requires knowledge of the mixing length *l*, or the vertical distance over which a fluid parcel's momentum changes. By equating the mixing length to

$$u' = -l\left(\frac{d\bar{u}}{d\bar{y}}\right) \quad \text{and} \quad v' = l\left(\frac{d\bar{u}}{d\bar{y}}\right)$$

then turbulent shear stress is

$$\tau = -\rho\overline{u'v'} = \rho l^2\left(\frac{d\bar{u}}{dy}\right)^2$$

By assuming that: (1) the fluid shear is approximately equal to the bed shear near the streambed; and (2) mixing length increases linearly with distance from the bed, the law of the wall equation for determining the velocity gradient near the streambed (i.e., "wall") is calculated from

$$\frac{\bar{u}}{u*} = \frac{1}{\kappa}\ln\left(\frac{y}{y_0}\right)$$

where κ is Von Karman's constant (commonly set at 0.41), $\bar{u}$ is time averaged velocity at flow depth y above the bed, and y_0 is the flow depth where flow velocity equals zero. The shear velocity, $u*$, is a measure of the velocity gradient near the bed, from which local bed shear stress can be calculated

$$\tau_0 = u*^2\,\rho$$

In reality, flow velocity is only zero where $y = 0$. Therefore, in order to solve the equation for hydraulically rough flows, y_0 is related to the equivalent roughness height, k_s, by

$$y_0 = \frac{k_s}{30}$$

And k_s is based on the dominant coarse bed substrate, such as the D_{84} (the particle size in which 84% of the bed surface is finer).

Integration of the law of the wall equation above over the entire flow depth (h) shows that the mean flow velocity occurs at a distance of 0.368h from the bed. By inserting the 0.368h and k_s values into the law of the wall equation above, the local shear velocity, and thus local shear stress related to grain-induced resistance can be determined from mean channel velocity (U) using Keulegan's (1938) resistance law for rough flow:

$$\frac{U}{u*} = \frac{1}{\kappa}\ln\left(\frac{h}{k_s}\right) + 6$$

This equation, or variations of it, is commonly used to calculate local shear stress values for use in incipient motion and sediment transport analysis.

The following equation (from Wilcock 1996) was used to calculate local grain stress in this study:

$$\frac{U}{u*} = \frac{1}{\kappa}\ln\left(\frac{h}{ez_0}\right)$$

where z_0 (the bed roughness length where flow velocity (u) is 0) is calculated from

$$z_o = \frac{3D_{84}}{30}$$

A.2 Initiation of Motion Calculation

Whether or not a particle on the stream bed will be entrained by the flow or remain in place depends on: (1) randomness (grain placement and turbulence); and (2) balance of driving fluid drag (F_D) and resisting gravity forces (F_G)

$$F_D \propto \tau_0 D^2, \text{ and } F_G \propto (\rho_s - \rho) g D^3$$

and

$$\frac{F_D}{F_G} \propto \frac{\tau_0}{(\rho_s - \rho) g D} = \Theta = \tau^*$$

where D is grain diameter and ρ_s is sediment density. The dimensionless bed shear stress (Θ, commonly called the Shields number, or τ^*) is a measure of sediment mobility. If τ^* is greater than the threshold required for sediment motion (τ^*_c, critical dimensionless bed shear stress), then sediment motion is predicted to occur.

Much research continues in the field of sediment movement initiation and the selection of appropriate τ^*_c. Figure A-1 shows initiation of motion curves from which τ^*_c is determined from the particle Reynolds number (R_{ep}). If the τ^*_c value plots above the curve, then sediment motion is predicted to occur; whereas if the value is under the curve, then no motion is predicted to occur. Both curves show that as particle size increases from coarse sand to gravel, the increased resistance to movement from the weight of the particle exceeds the additional drag exerted on the particle, and thus the critical dimensionless shear stress required for movement increases. The curves flatten out at as particle size approaches coarse gravel (32-64 mm) and coarser particles. Several researchers have shown the original Shields curve (in blue) values for initiation of motion are too high, and thus predict too much shear stress is required for sediment movement. Therefore, Figure A-1 shows a modified curve (in red) in which the initiation of motion curve flattens out around 0.045 instead of 0.06.

The same two original and modified Shields curves are plotted in dimensional units in Figure A-2. From this plot, the amount of shear stress (Pascal units) needed to initiate motion of a given particle size (mm units) can be determined.

A.3 Initiation of Motion for Sediment Mixtures

The initiation of motion curves in Figures A-1 and A-2 represent critical shear stress values needed to mobilize sediment of a uniform size resting on a nearly flat channel bed. The curves do not consider how the relative variability of grain sizes in a sediment mixture influence initiation of motion values for individual particle sizes (D_i) within the mixture. For sediment mixtures of coarse and fine particles, the coarser particles (e.g., gravel) in the mixture can be relatively easier to mobilize than if all the sediment was the same size because the coarser grains protrude higher into the flow where flow velocities are greater, and they have relatively lower pivoting angles. By contrast, the smaller particles in the sediment mixture have higher pivot angles, and are shielded from the higher flow velocities by the larger particles. Therefore, the finer (e.g., sand) particles in a mixture can be relatively harder to mobilize than if all the sediment was the same size.

Additionally, research has shown the importance of the percentage of sand in a sediment mixture on the critical shear stress needed to mobilize both sand and gravel particles (Wilcock 1998; Wilcock and Crowe 2003). As the sand content increases on the bed to larger percentages, the gravel particles become less constrained by other gravel particles, and thus more of the particle is exposed to fluid drag since it is becoming larger than its surroundings. Once the gravel particle is entrained, it moves faster over the relatively smooth, mobile bed created by the sand than it would over other gravel particles, and it may move a greater distance because potential resting areas are filled with sand. At even higher percentages of sand, gravel particles can be mobilized through undercutting of the underlying sand, and once mobilized the gravel keeps going over the relatively smooth sand bed. Figure A-3[2] shows how variations in bed surface sand content influence the critical dimensionless shear stress needed to initiate motion of a sediment mixtures mean particle size (D_m) (Wilcock and Crowe 2003). Figure A-4 is the same plot but with dimensional critical shear stress values for different D_m values. The plots show that as surface sand content increases from 0 to 20%, the shear stress needed to mobilize the D_m decreases. Sand content increases greater than 20% have little influence on the critical shear stress needed for sediment initiation.

The Wilcock and Crowe (2003) method for calculating the critical shear stress needed to initiate sediment movement for mixed-size sediment was used for this study. This method was chosen since it considers how relative particle size variation within the sediment mixture and sand content influence sediment mobility.

A.4 References

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Keulegan, G. H. 1938. Laws of turbulent flow in open channels. J ournal of Research of the National Bureau of Standards 21(Paper RP1151): 707-741.

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Wilcock, P. R. 1998. Two-fraction model of initial sediment motion in gravel-bed rivers. Science 280: 410-412.

Wilcock, P. R. and J. C. Crowe. 2003. Surface-based transport model for mixed-size sediment. Journal of Hydraulic Engineering 129(2): 120-128.

[2] The reference shear stress values presented in Wilcock and Crowe (2003) were converted to critical shear stress values by reducing the reference shear stress by 10%, per Wilcock 1998.

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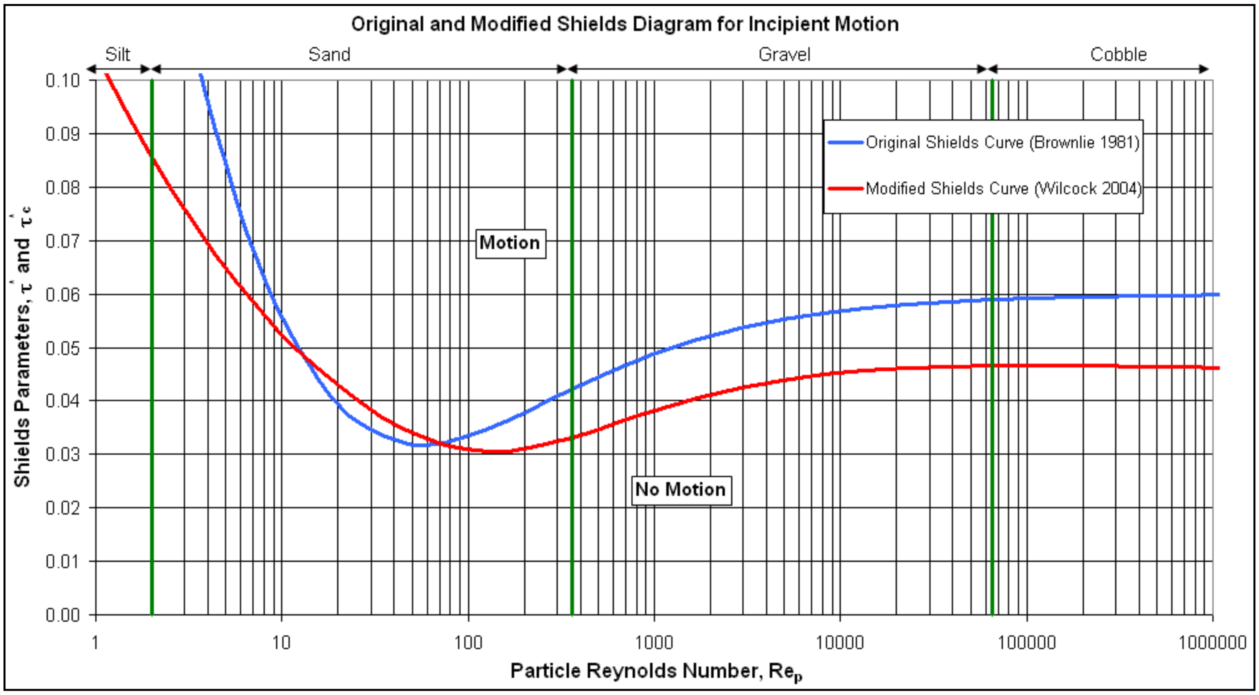
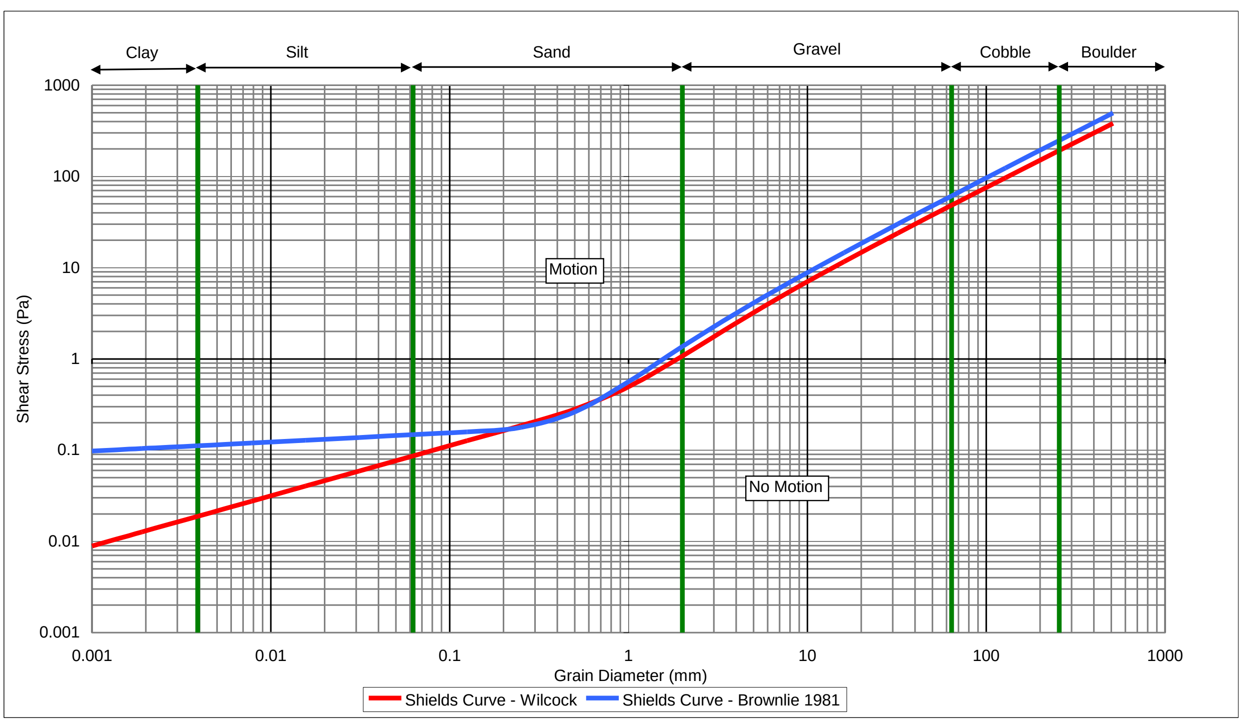


Figure A-1. Dimensionless initiation of motion curves.



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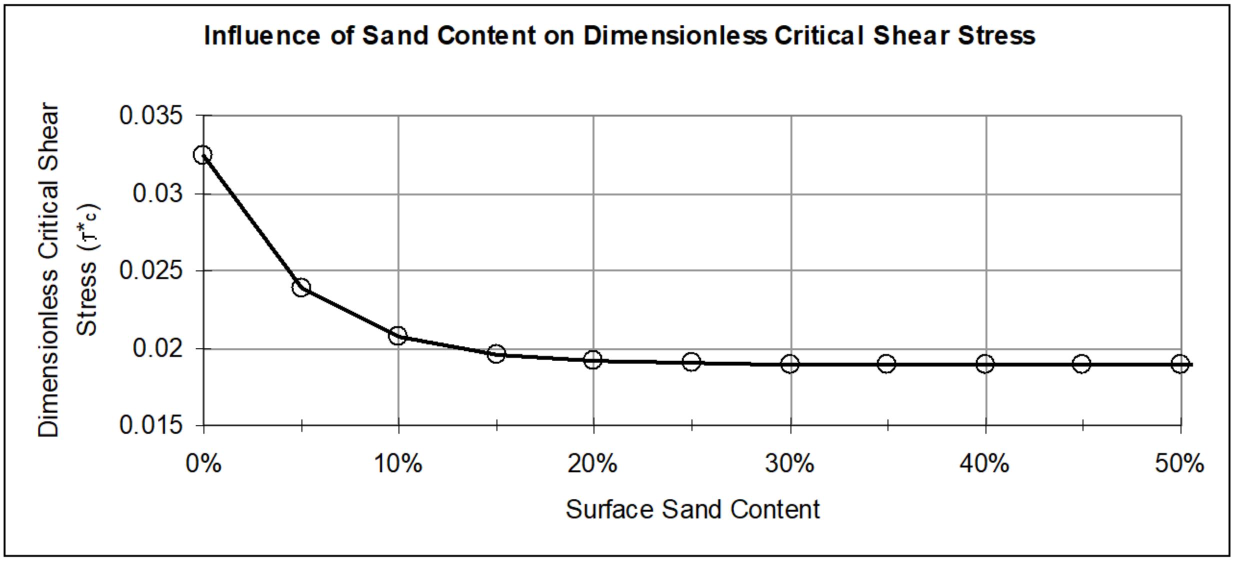

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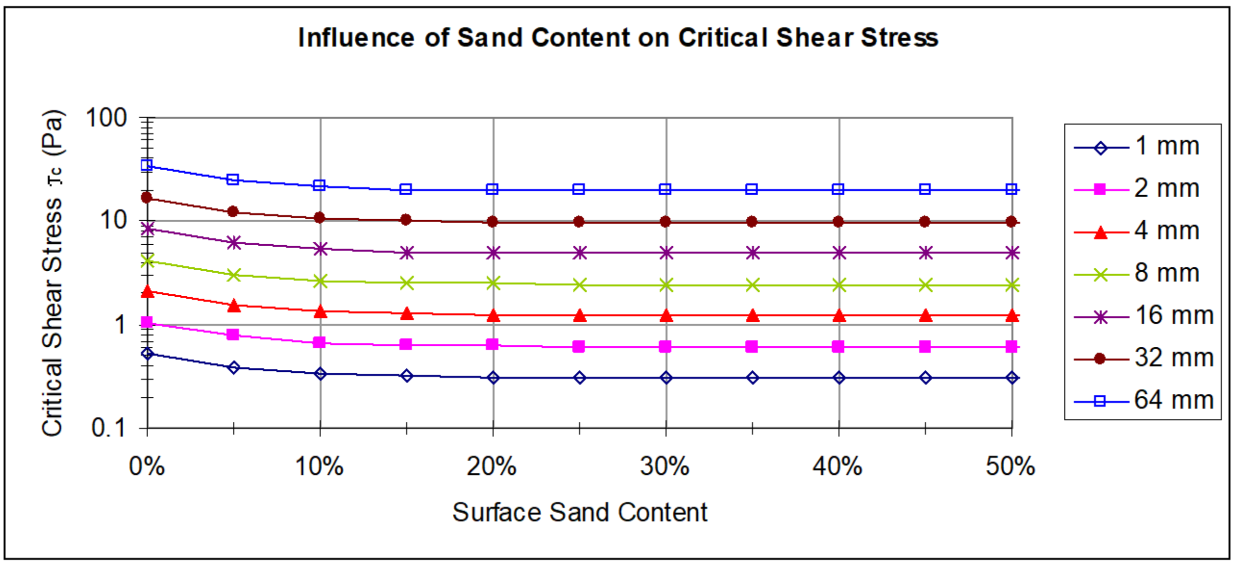

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APPENDIX B

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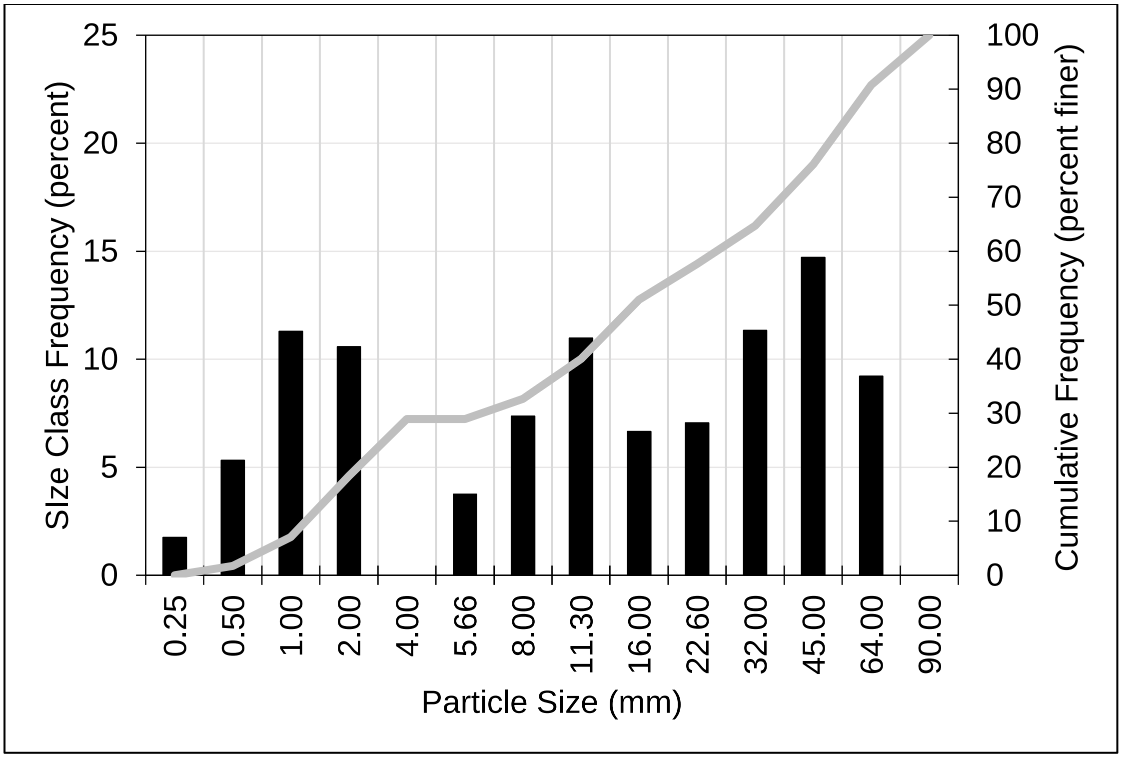
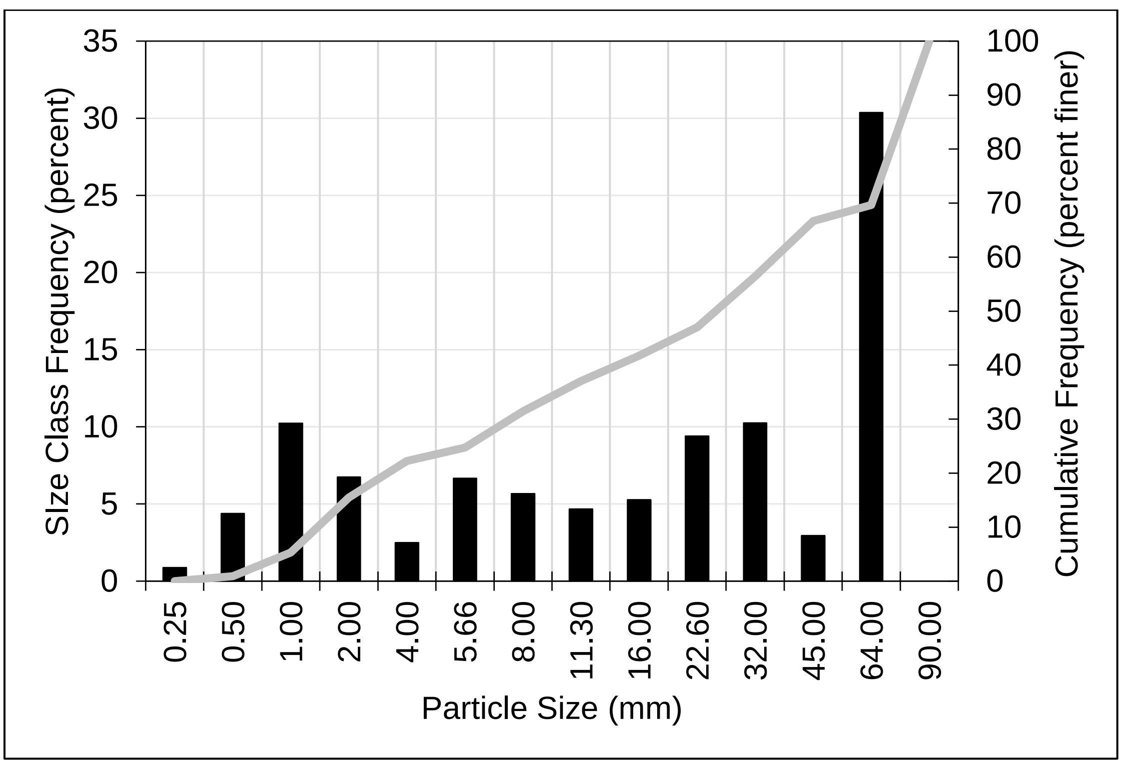


Figure B-1. Kaweah River Upstream of Kaweah No. 3 Powerhouse Spawning Gravel: Histogram and Cumulative Particle Size Distribution, Sample 1 Subsample 1.



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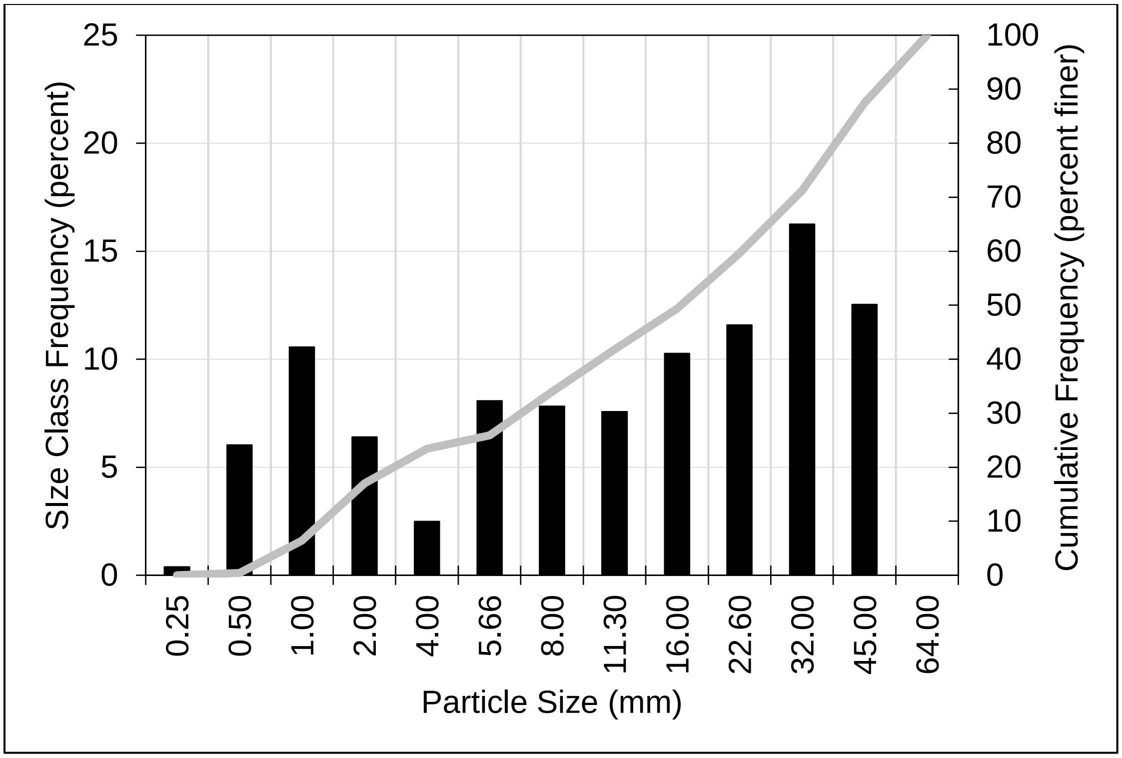

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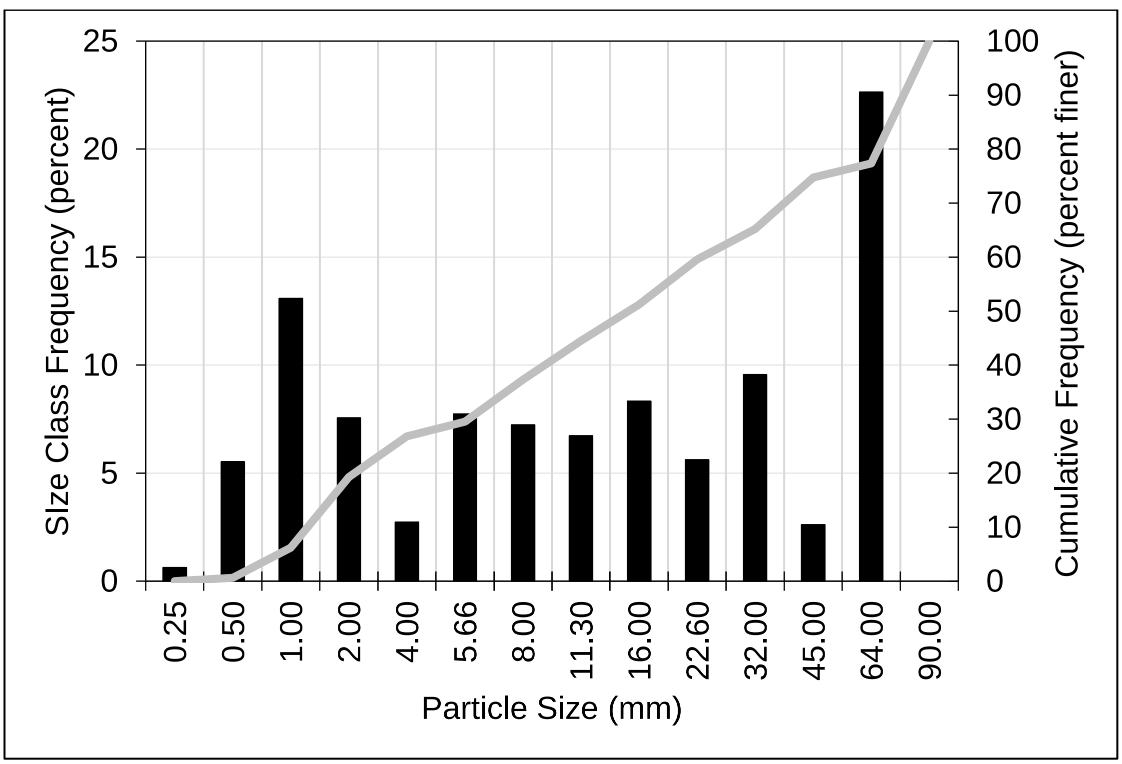

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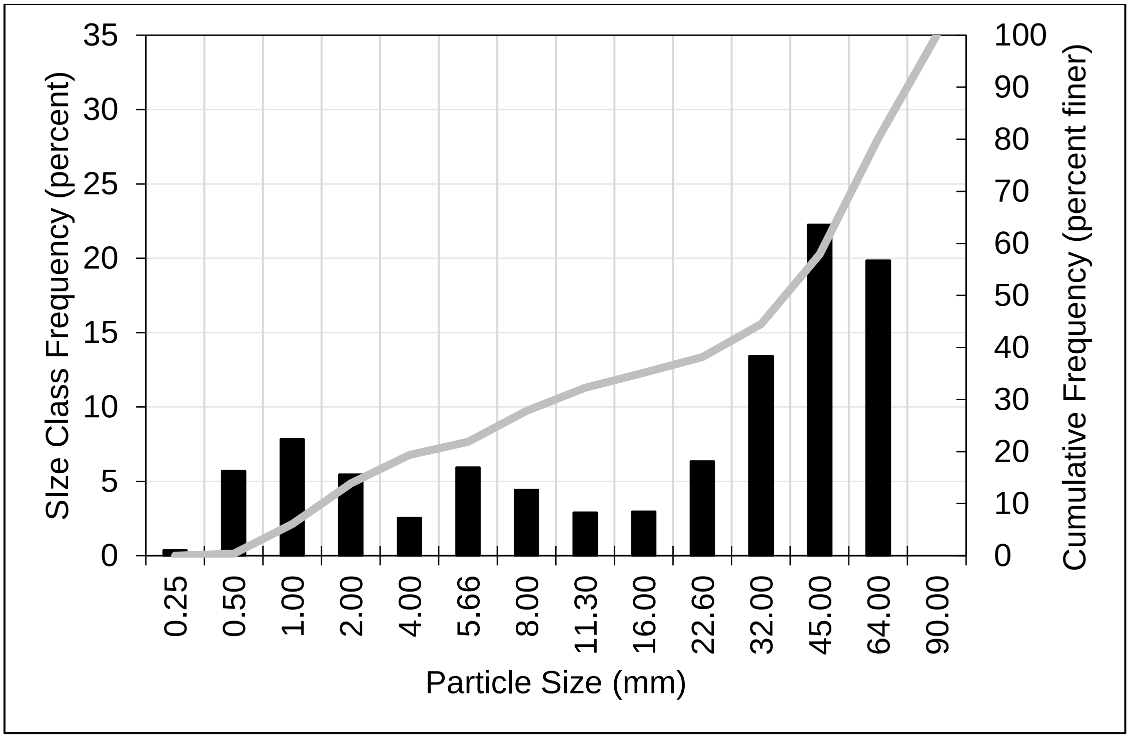


Figure B-5. Kaweah River Downstream of Kaweah No. 3 Powerhouse and Upstream of the East Fork Kaweah River Confluence Spawning Gravel: Histogram and Cumulative Particle Size Distribution, Sample 1 Subsample 1.

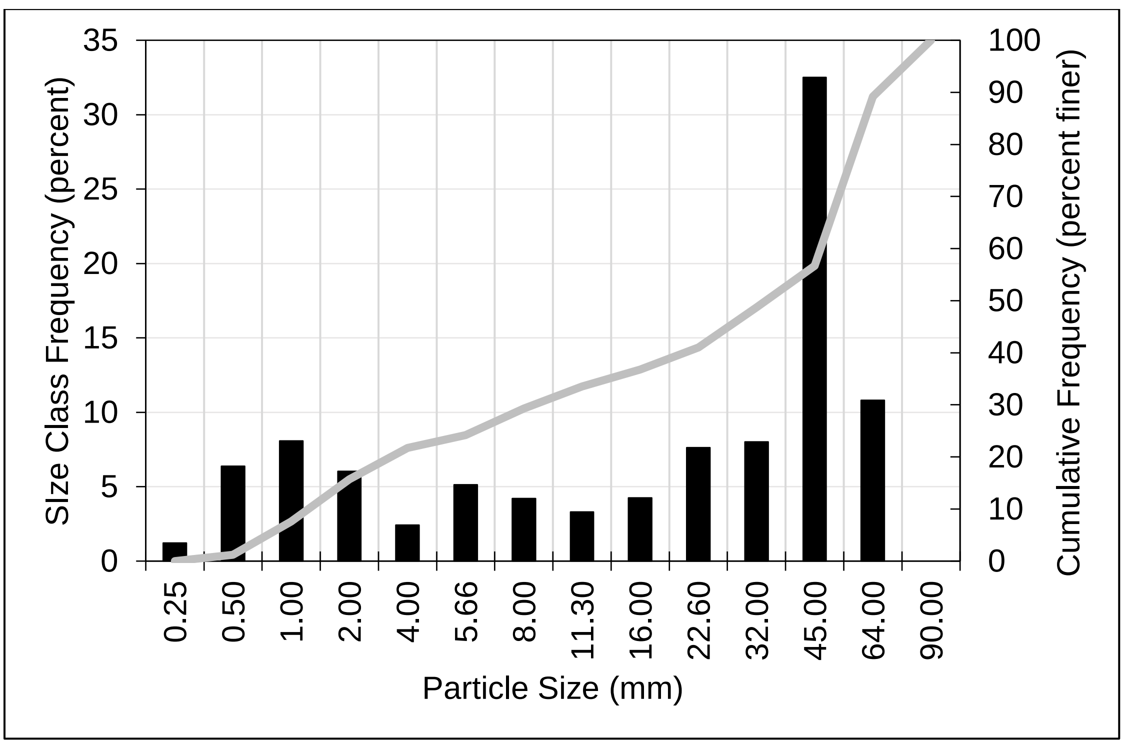


Figure B-6. Kaweah River Downstream of Kaweah No. 3 Powerhouse and Upstream of the East Fork Kaweah River Confluence Spawning Gravel: Histogram and Cumulative Particle Size Distribution, Sample 1 Subsample 2.

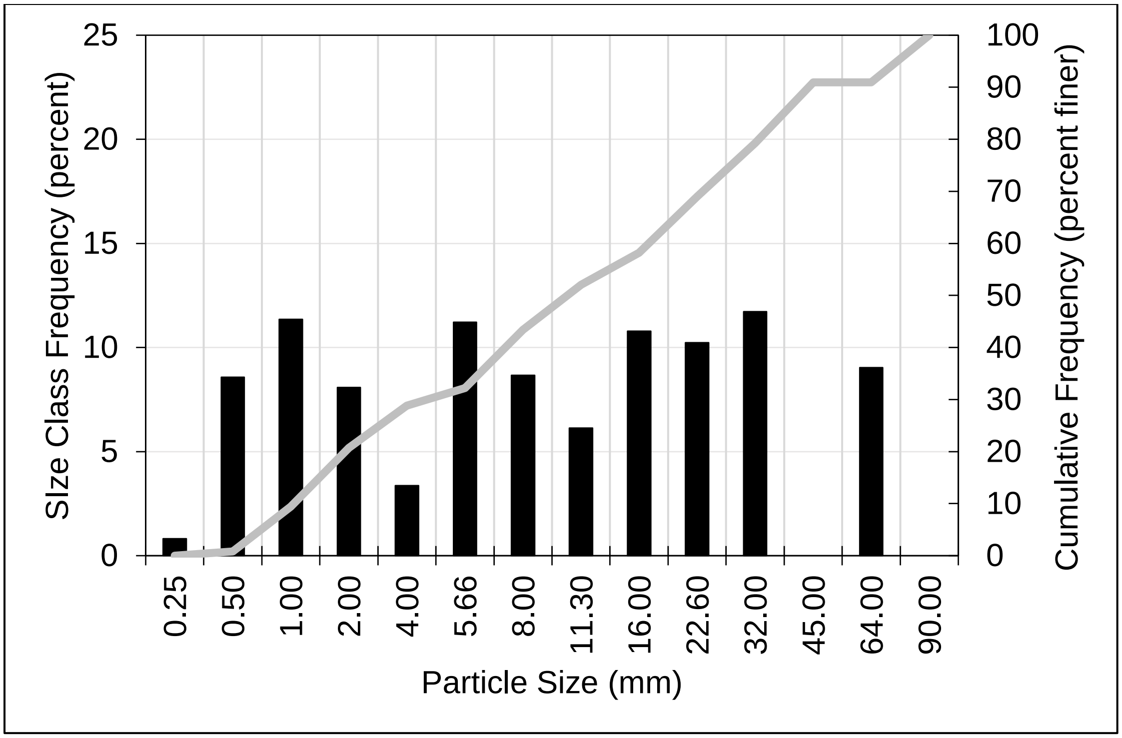
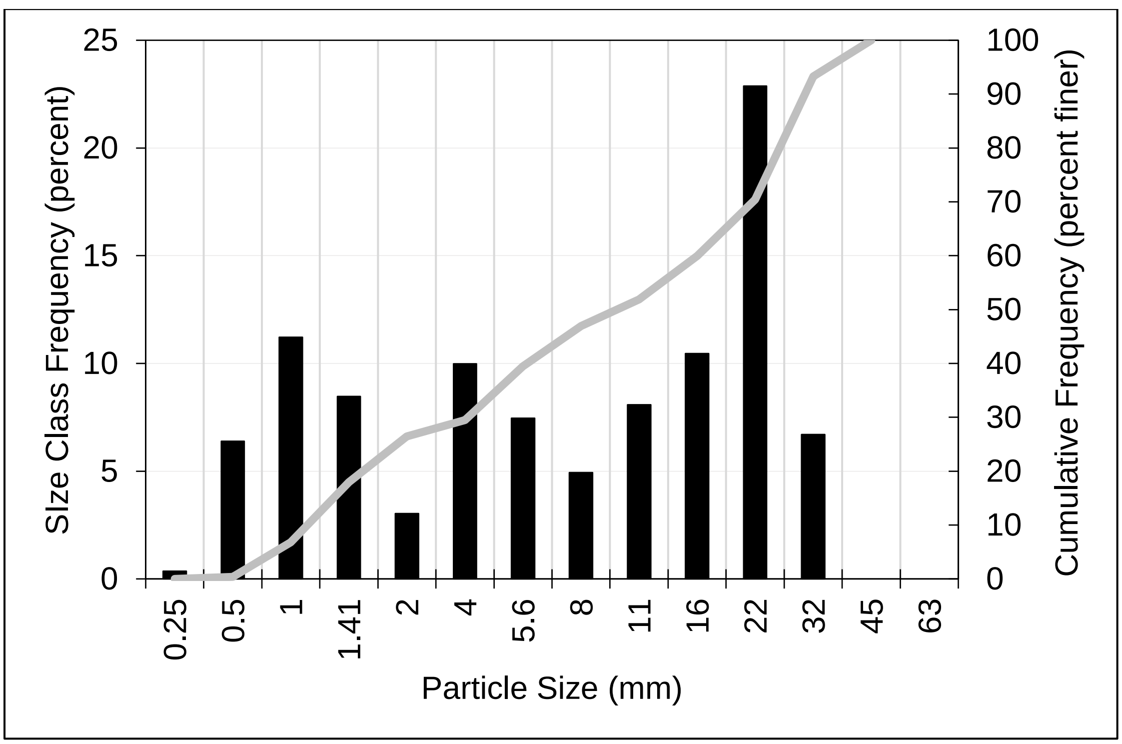


Figure B-7. **Kaweah River Downstream of Kaweah No. 3 Powerhouse and Upstream of the East Fork Kaweah River Confluence Spawning Gravel: Histogram and Cumulative Particle Size Distribution, Sample 2 Subsample 1.**



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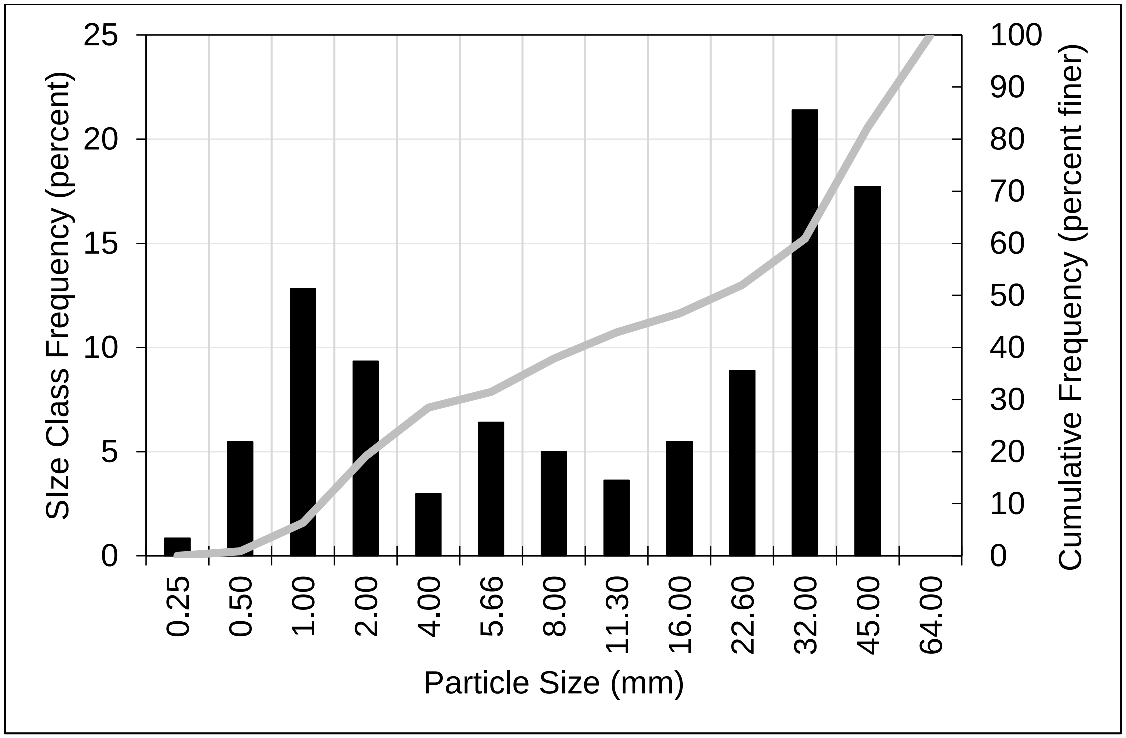


Figure B-9. Kaweah River Downstream of East Fork Kaweah Confluence and Upstream of Kaweah No. 1 Powerhouse: Histogram and Cumulative Particle Size Distribution, Sample 1 Subsample 1.

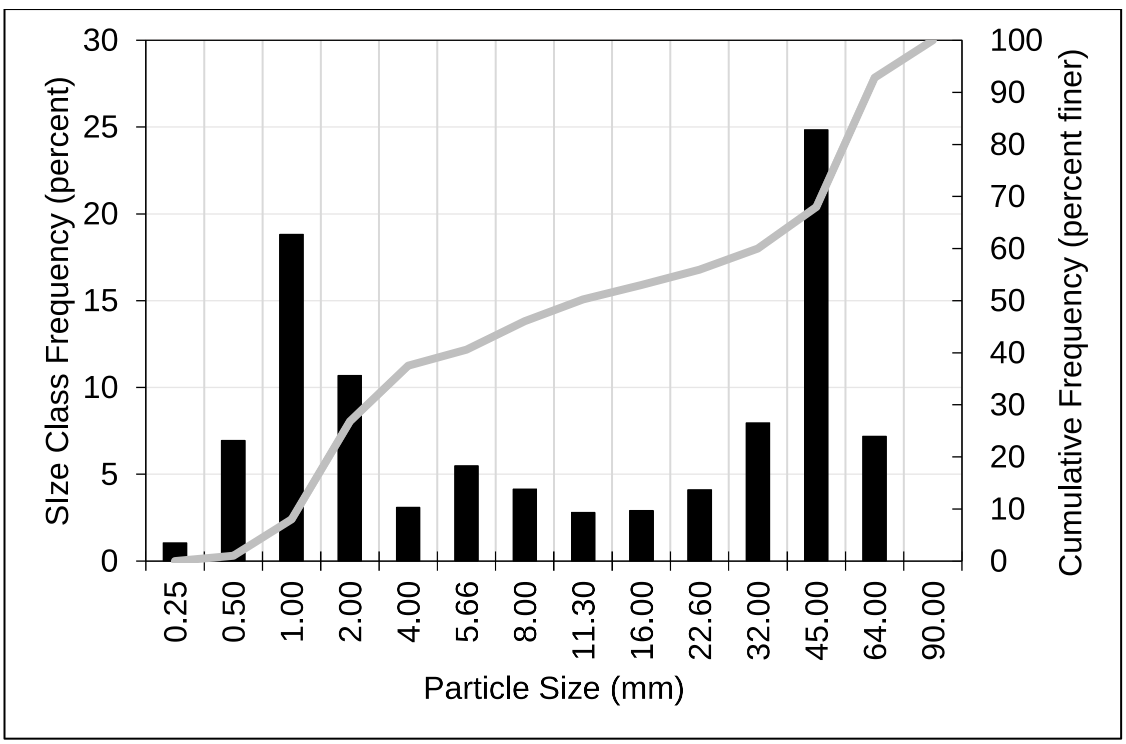
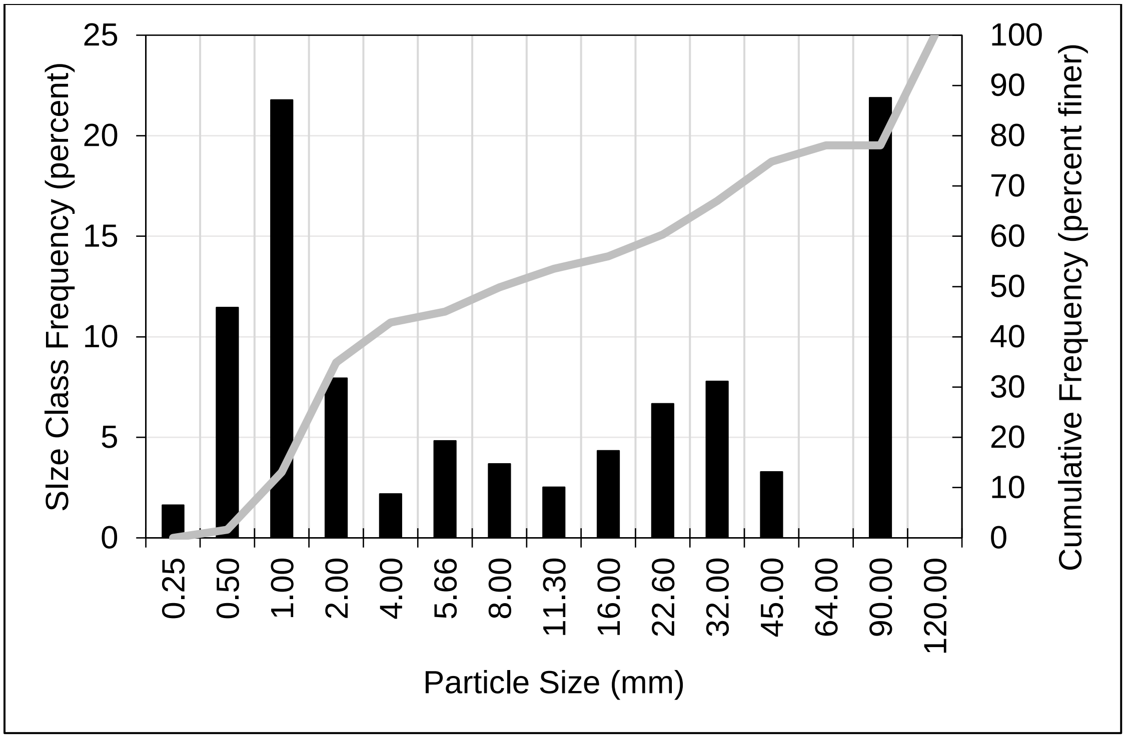


Figure B-10. Kaweah River Downstream of East Fork Kaweah Confluence and Upstream of Kaweah No. 1 Powerhouse: Histogram and Cumulative Particle Size Distribution, Sample 1 Subsample 2.



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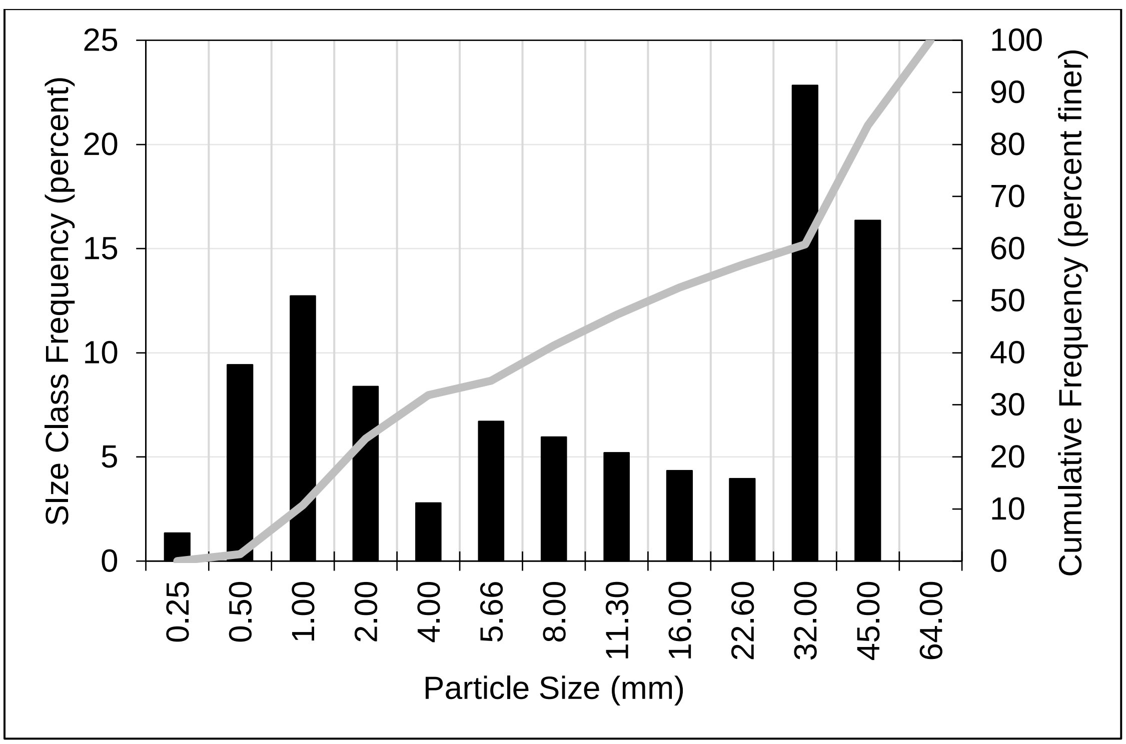

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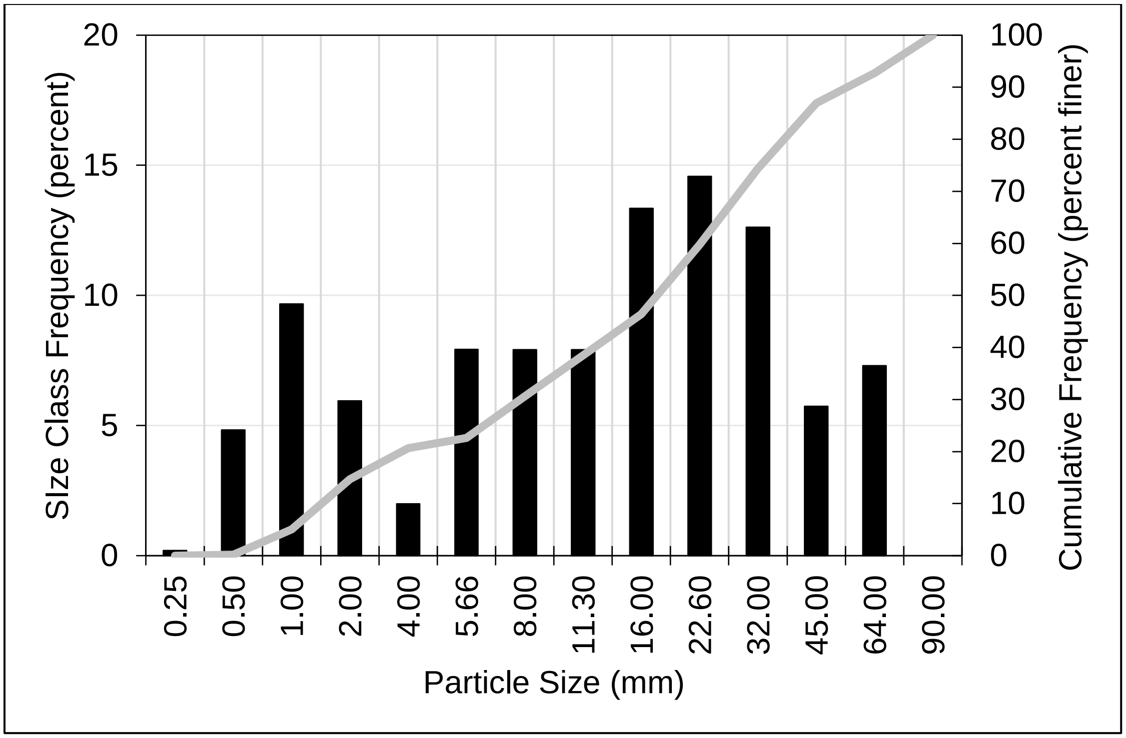
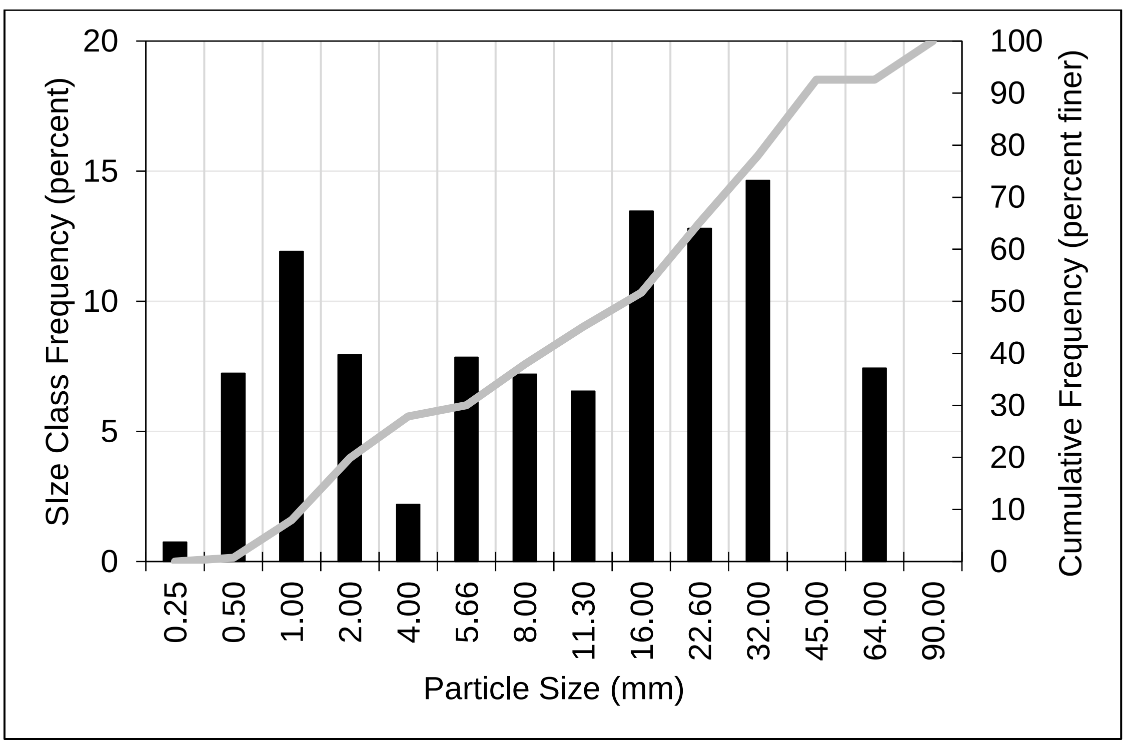


Figure B-13. Kaweah River Downstream of Kaweah No. 2 Powerhouse: Histogram and Cumulative Particle Size Distribution, Sample 1 Subsample 1.



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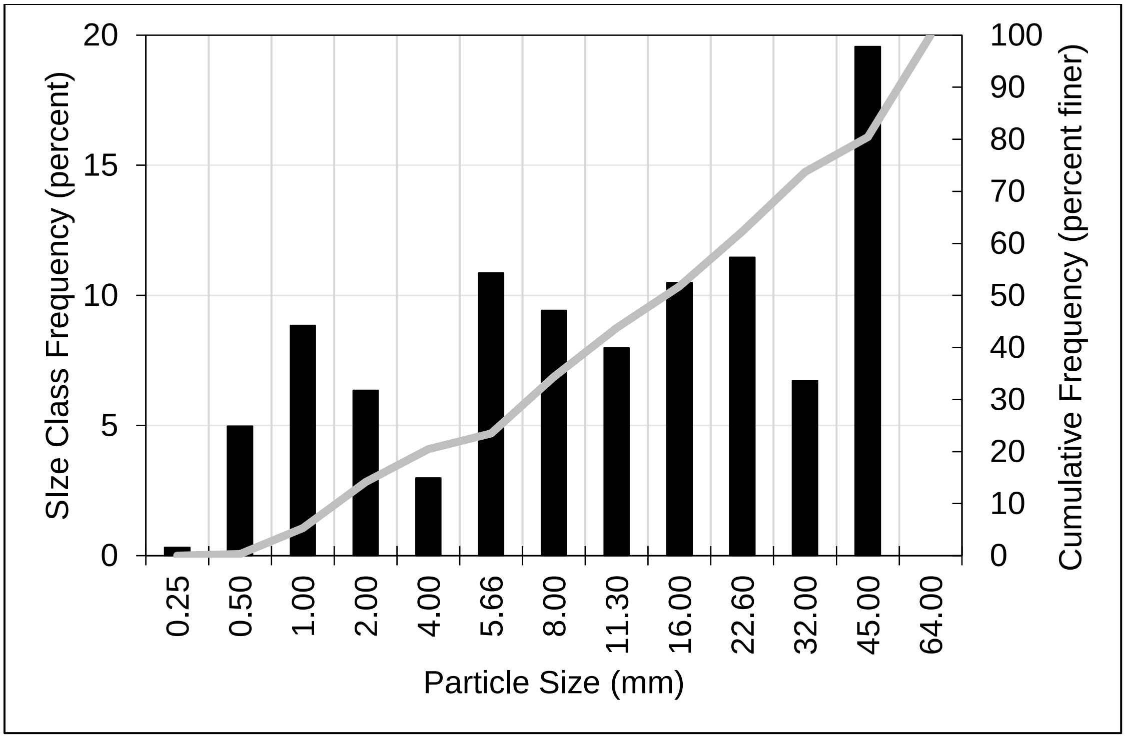

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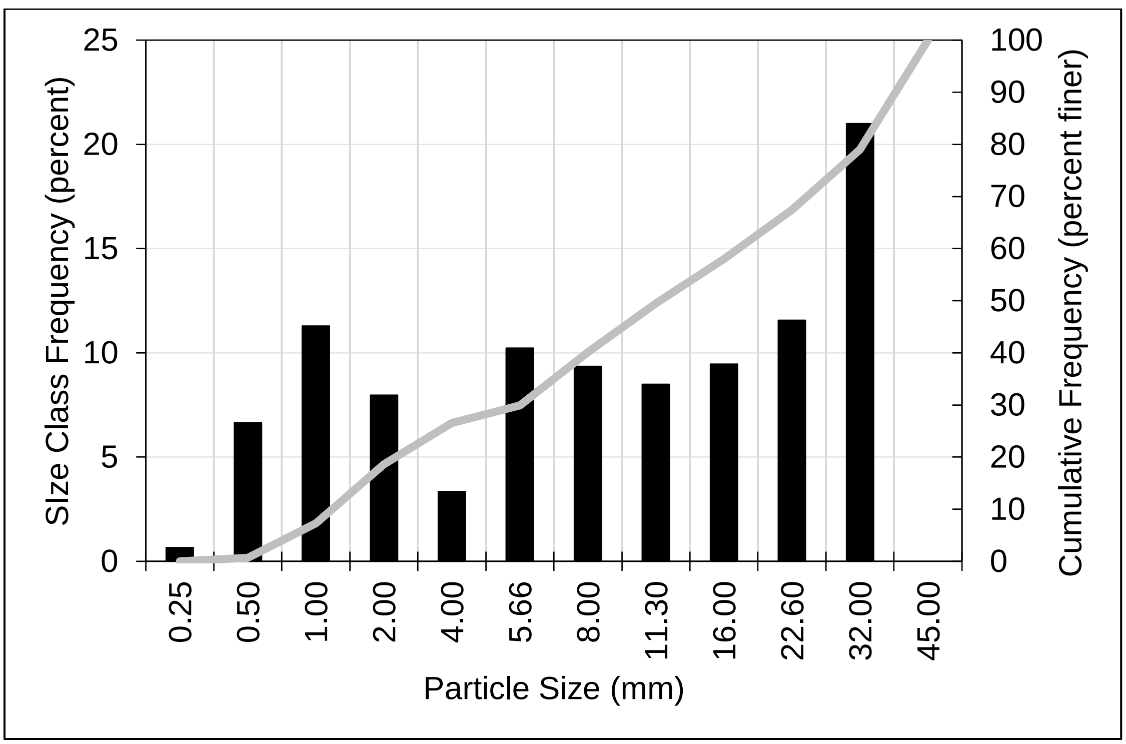

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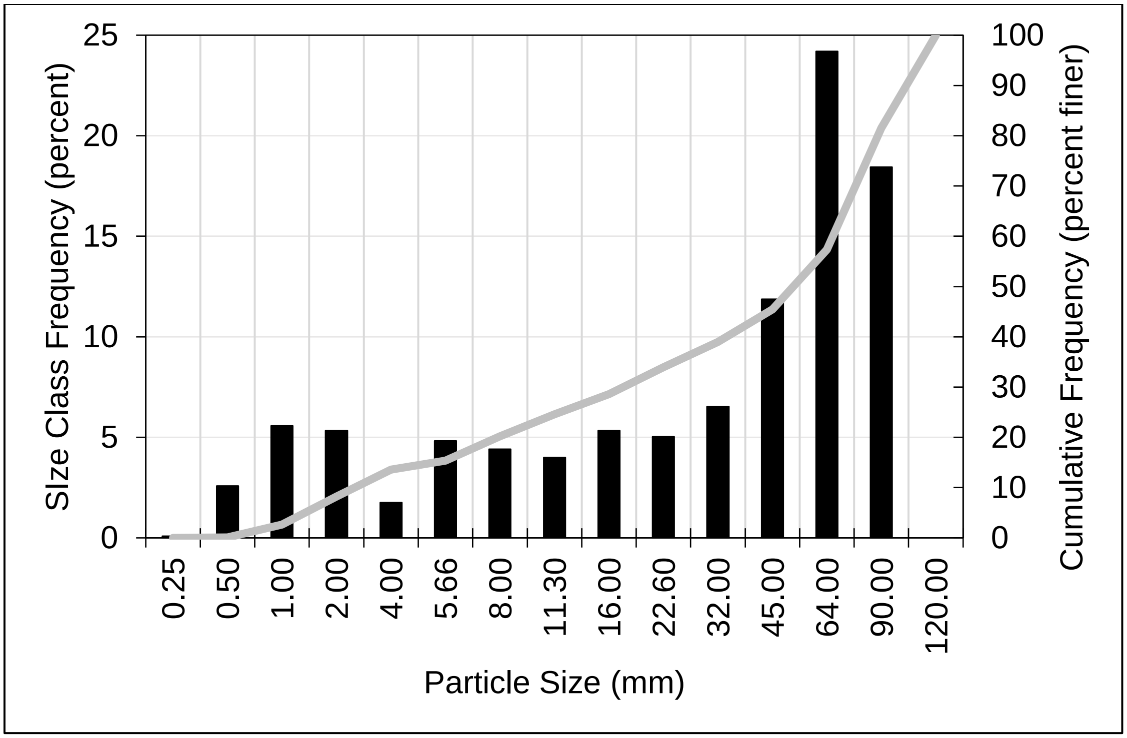

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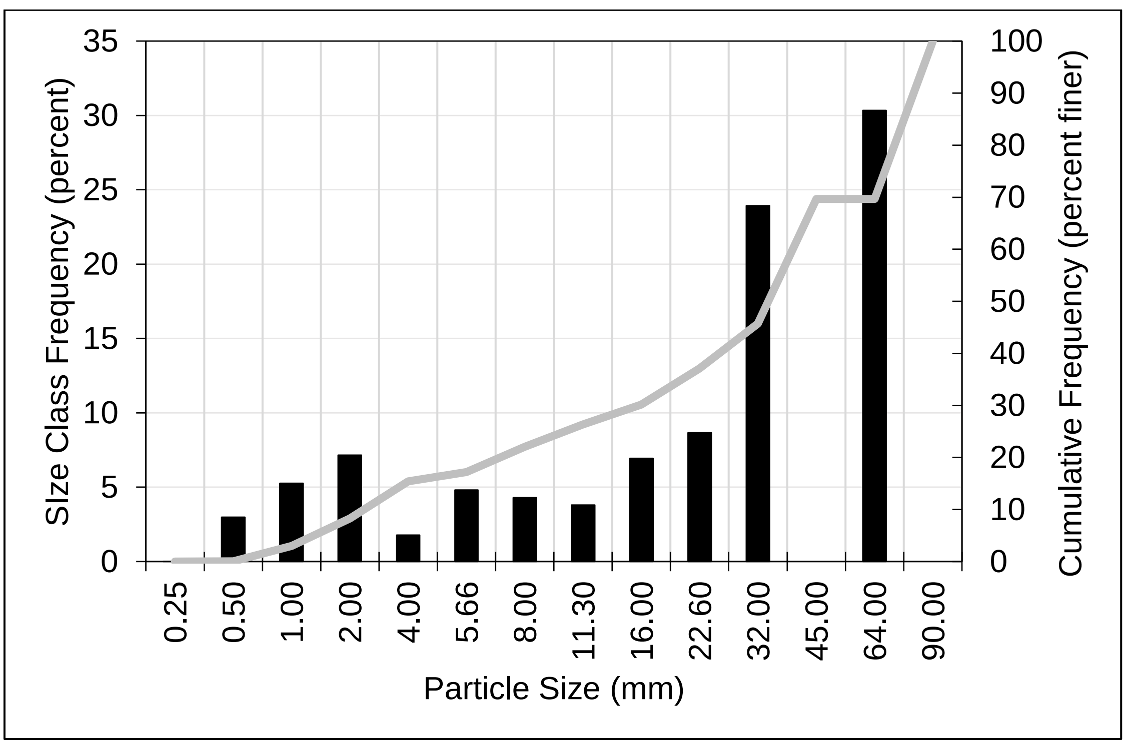

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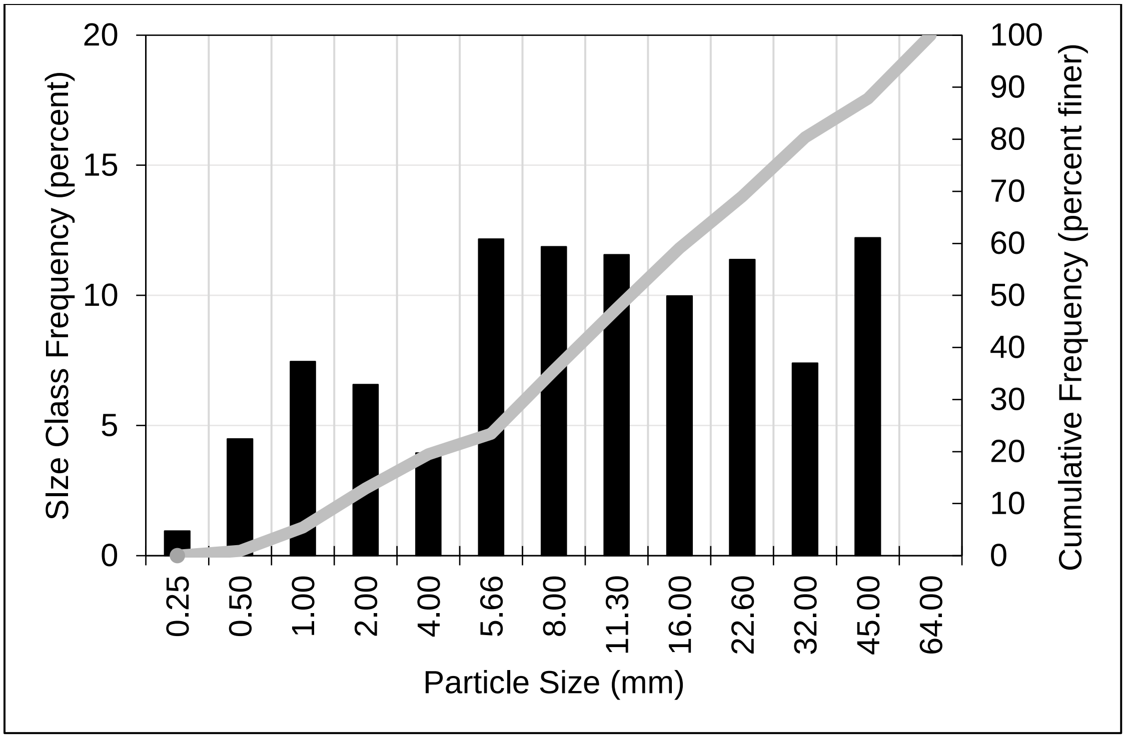

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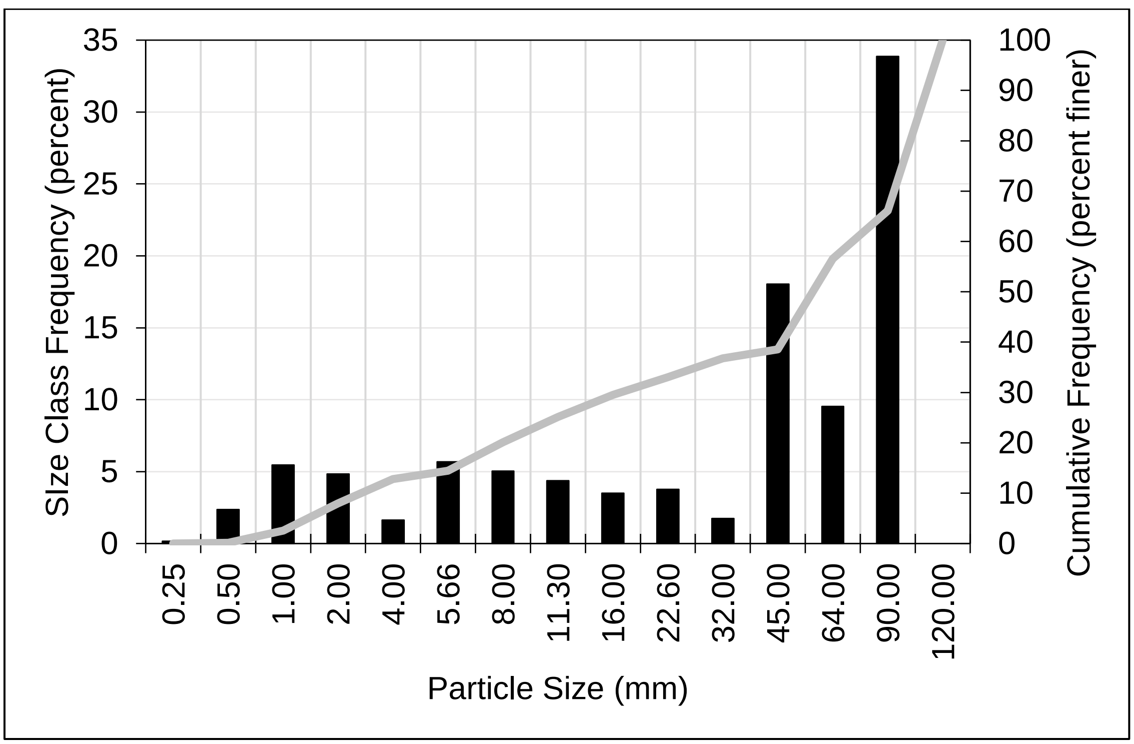

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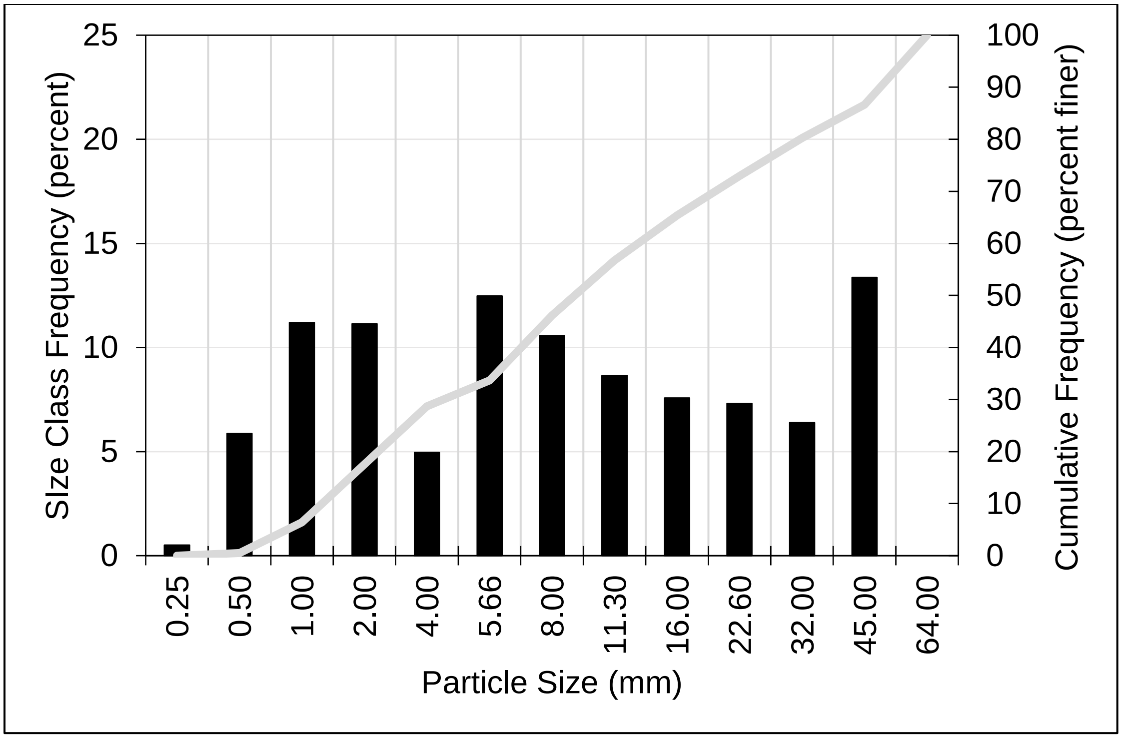
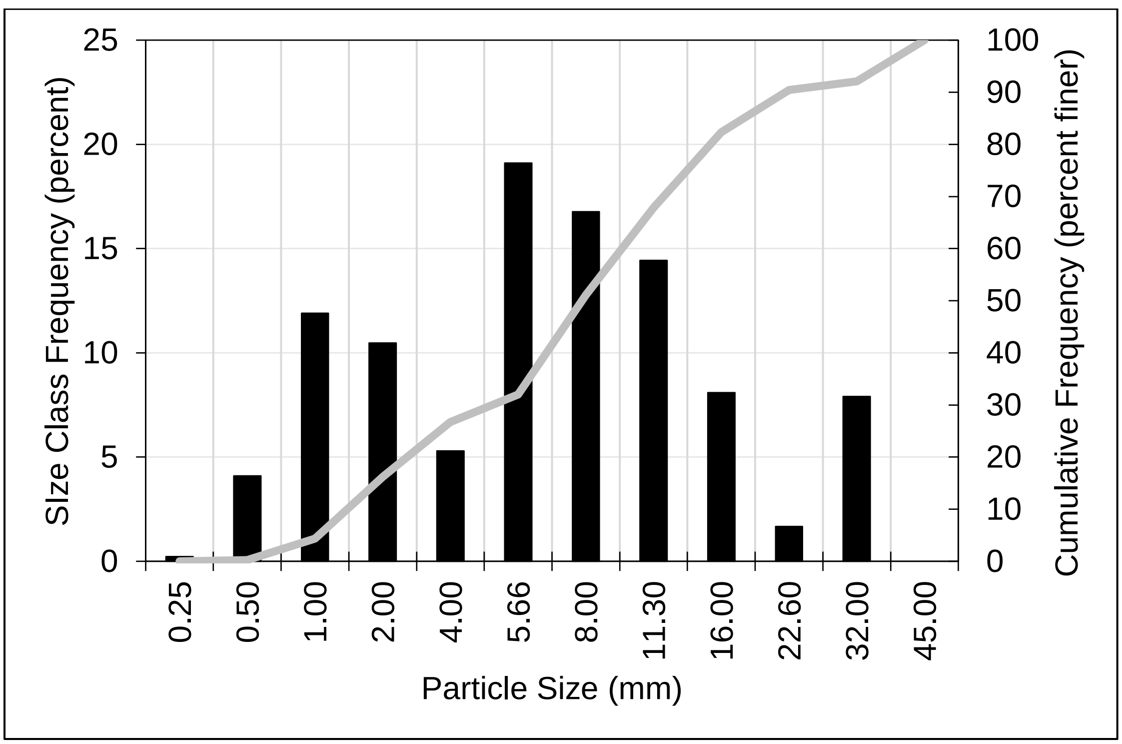


Figure B-21. East Fork Kaweah River Downstream of the Kaweah No. 1 Diversion: Histogram and Cumulative Particle Size Distribution, Sample 1 Subsample 1.



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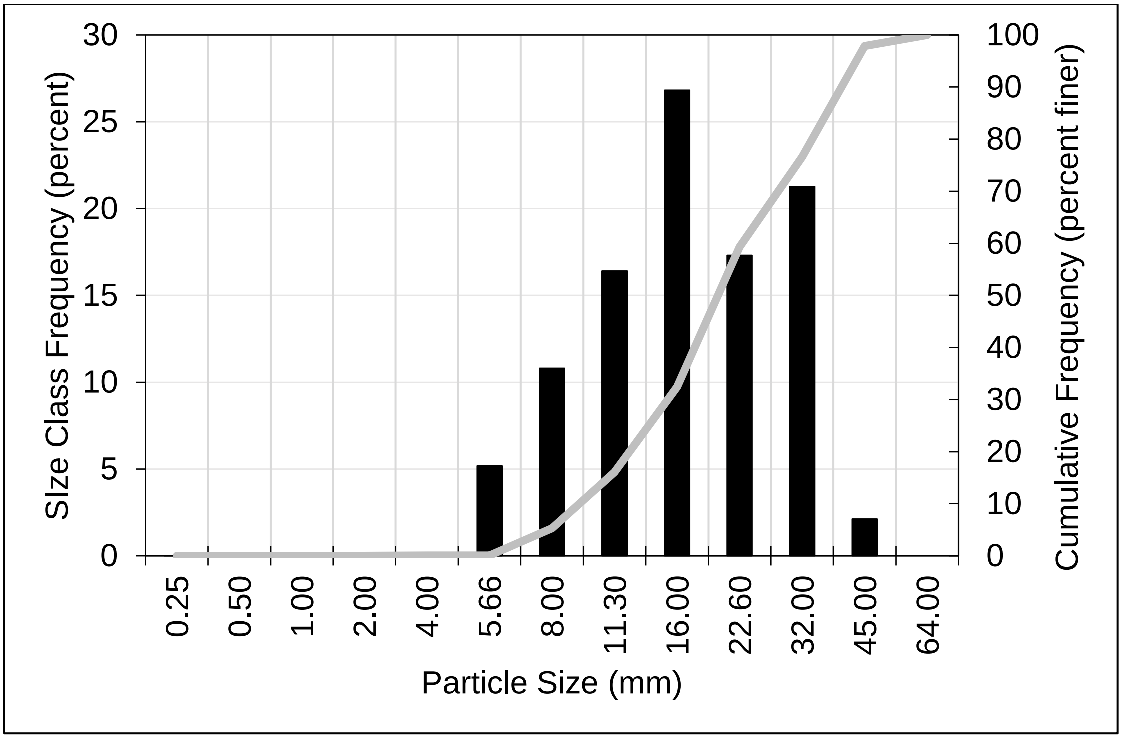
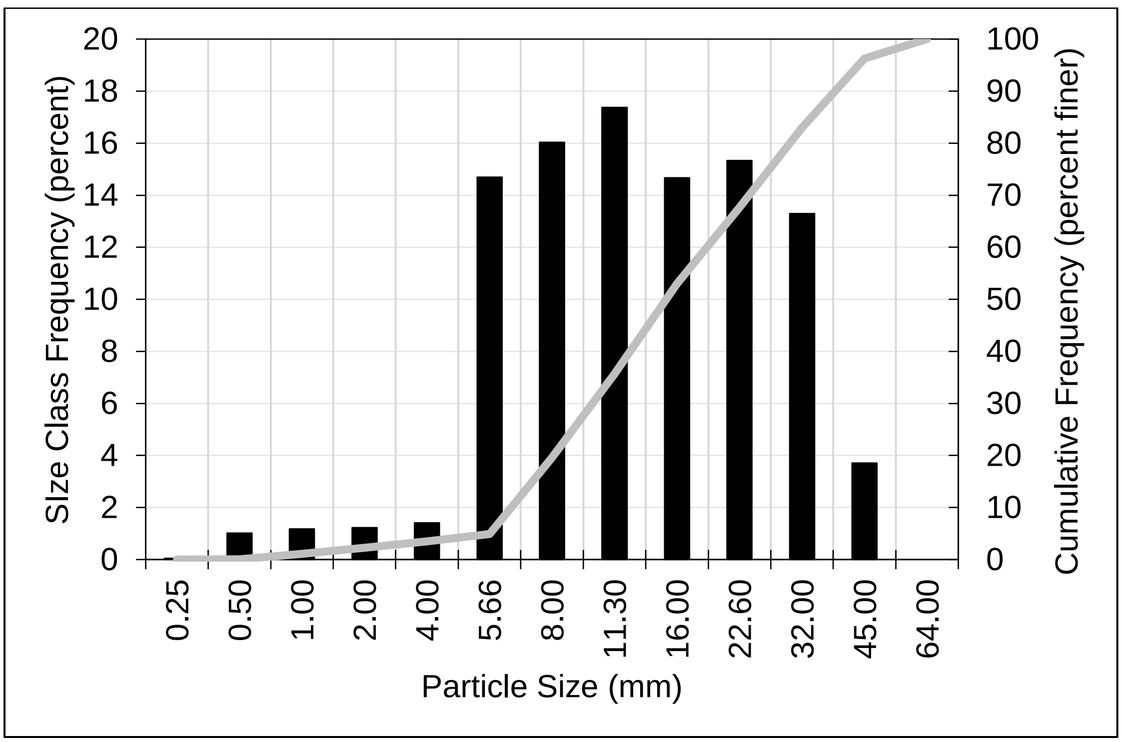


Figure B-23. East Fork Kaweah River Downstream of the Kaweah No. 1 Diversion: Histogram and Cumulative Particle Size Distribution, Sample 2 Subsample 1.



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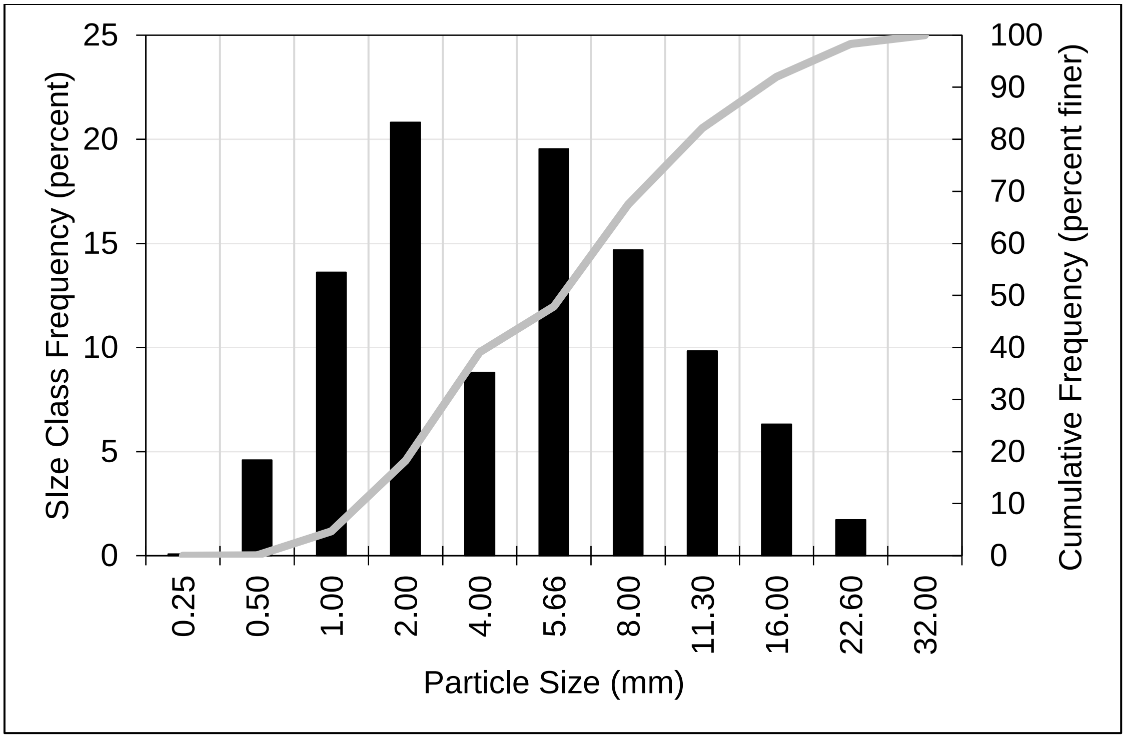
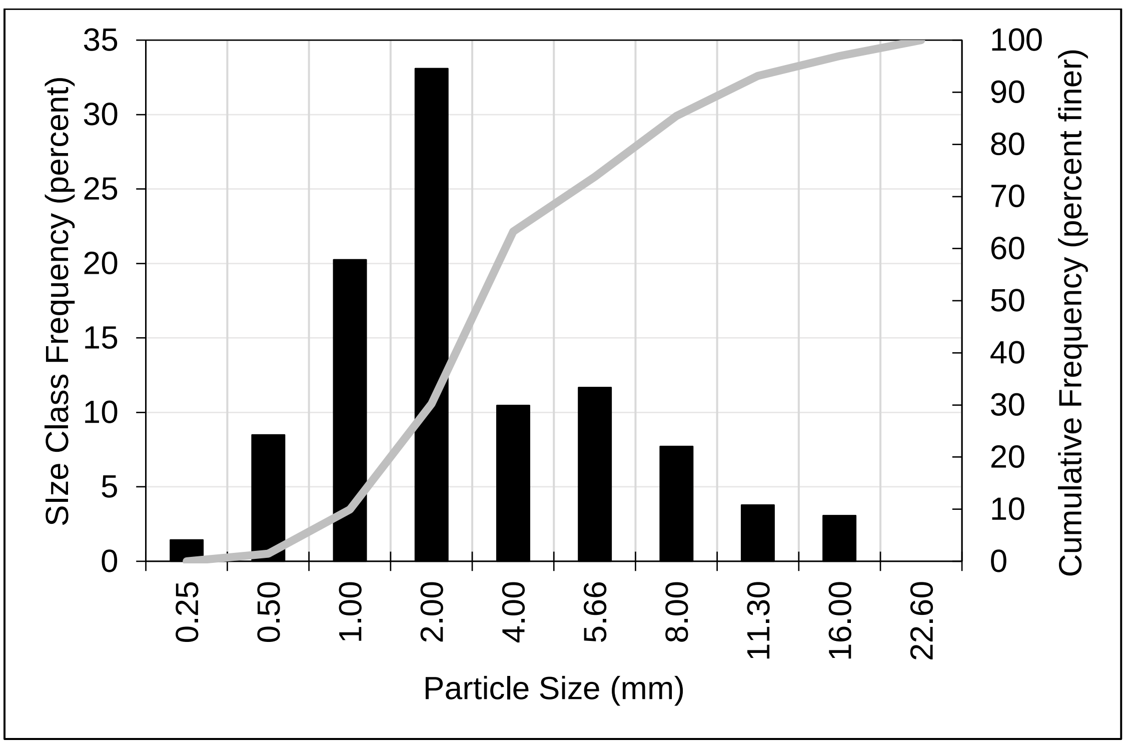


Figure B-25. East Fork Kaweah River Upstream of Confluence with Kaweah River: Histogram and Cumulative Particle Size Distribution, Sample 1 Subsample 1.



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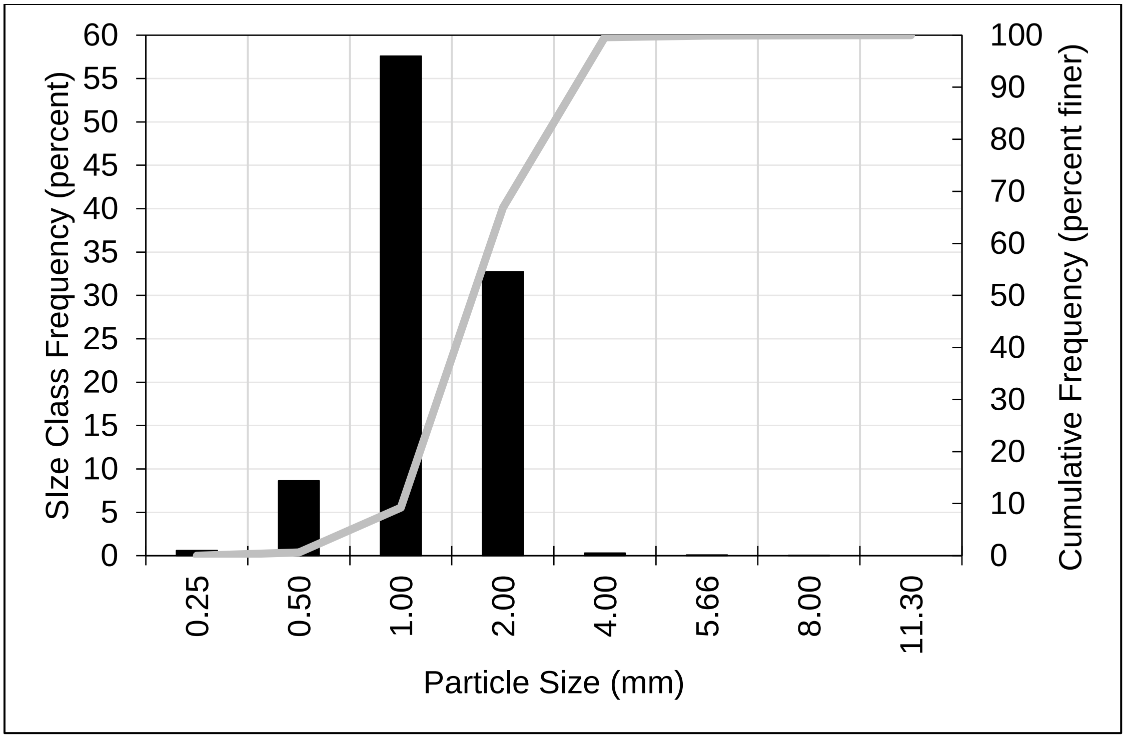

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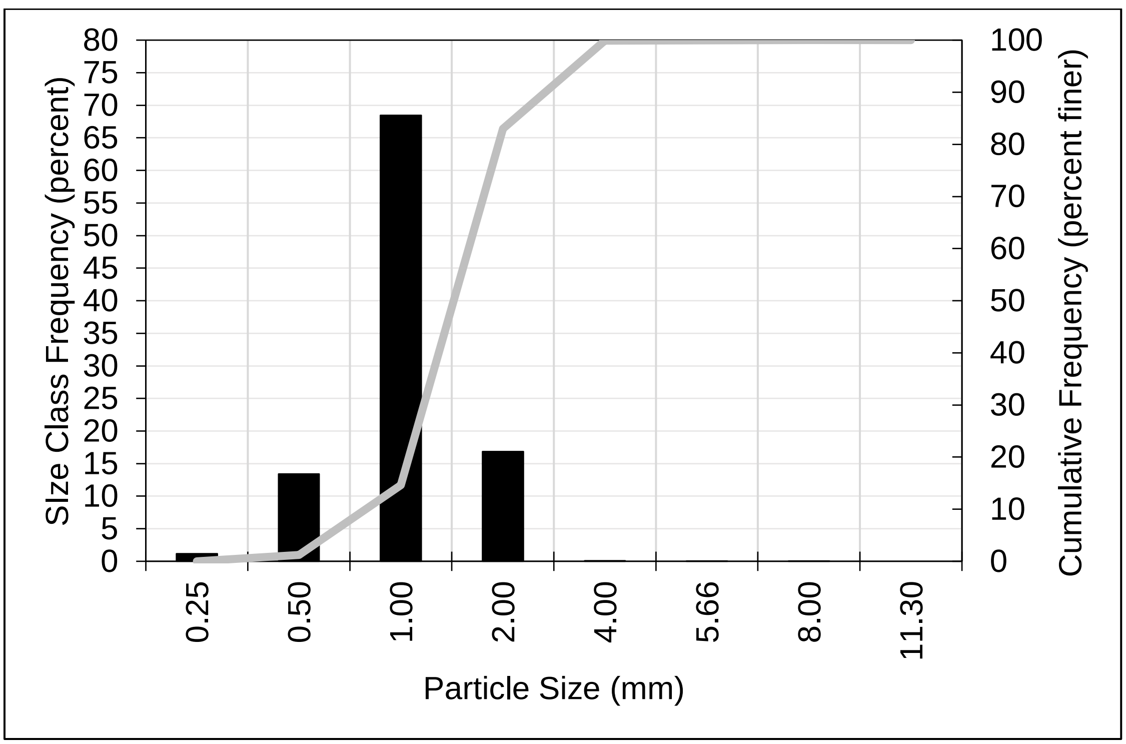

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APPENDIX C

Kaweah No. 2 Diversion Pool Bulk Sample Frequency Distributions

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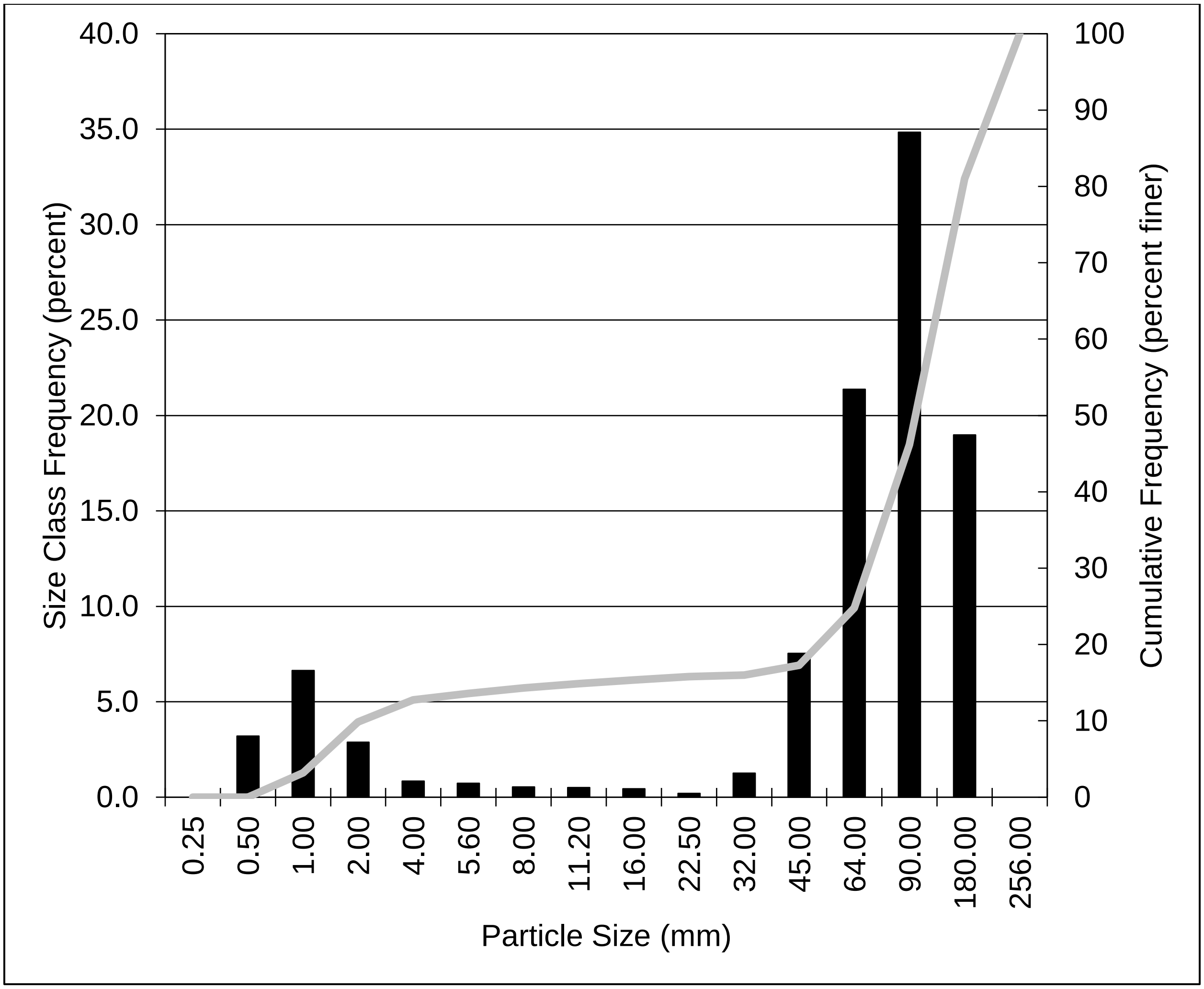

Figure C-1. Kaweah River Upstream of Kaweah No. 2 Diversion: Histogram and Cumulative Particle Size Distribution, Sample 1, Subsample 1.

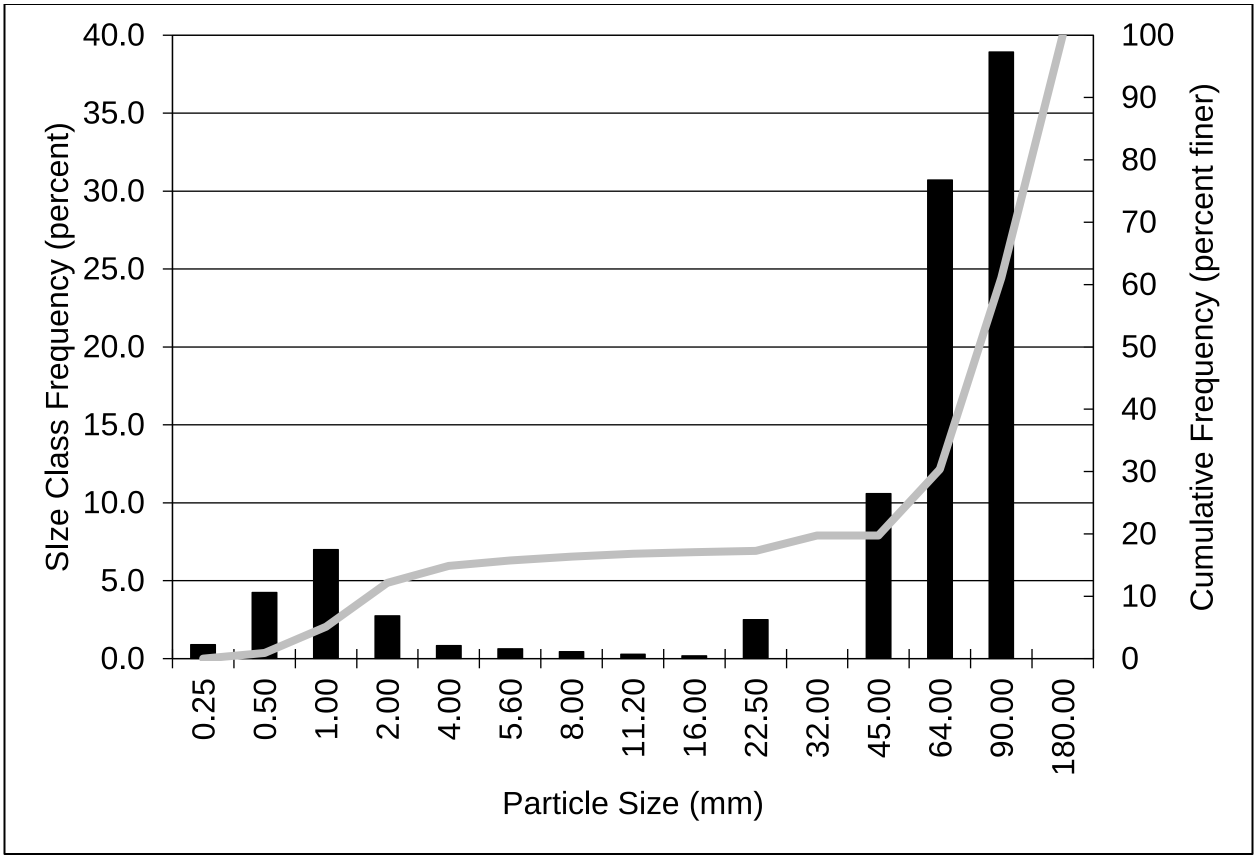

Figure C-2. Kaweah River Upstream of Kaweah No. 2 Diversion: Histogram and Cumulative Particle Size Distribution, Sample 1, Subsample 2.

APPENDIX D

Flood Recurrence Statistics for Bypass Reaches

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Table D-1. Peak Flow of Existing and Unimpaired Hydrologic Regimes for all Study Reaches

Annual Exceedance	Recurrence Interval	Study Reach: Kaweah River Upstream of Kaweah No. 3 Powerhouse		Kaweah River Downstream of Kaweah No. 3 Powerhouse and Upstream of the East Fork Kaweah River Confluence		Kaweah River Downstream of East Fork Kaweah Confluence and Upstream of Kaweah No. 1 Powerhouse		Kaweah River Downstream of Kaweah No. 1 Powerhouse and Upstream of Kaweah No. 2 Powerhouse		Kaweah River Downstream of Kaweah No. 2 Powerhouse		East Fork Kaweah River Upstream of the Kaweah No. 1 Diversion		East Fork Kaweah River Downstream of the Kaweah No. 1 Diversion		East Fork Kaweah River Upstream of Confluence with Kaweah River	
		Existing	Unimpaired	Existing	Unimpaired	Existing	Unimpaired	Existing	Unimpaired	Existing	Unimpaired	Existing	Unimpaired	Existing	Unimpaired	Existing	Unimpaired
1.00	1.01	291.3	341.8	323.0	341.8	469.3	504.8	497.3	504.8	504.8	504.8	149.8	149.8	141.4	149.8	141.4	149.8
0.99	1.01	345.9	402.6	381.5	402.6	554.1	593.7	585.3	593.7	593.7	593.7	176.3	176.3	166.9	176.3	166.9	176.3
0.98	1.02	420.0	484.5	460.4	484.5	668.6	713.3	703.9	713.3	713.3	713.3	212.0	212.0	201.5	212.0	201.5	212.0
0.98	1.03	449.8	517.2	492.0	517.2	714.4	761.0	751.2	761.0	761.0	761.0	226.2	226.2	215.3	226.2	215.3	226.2
0.96	1.04	525.6	600.0	572.2	600.0	830.5	881.7	871.0	881.7	881.7	881.7	262.3	262.3	250.4	262.3	250.4	262.3
0.95	1.05	569.6	647.8	618.5	647.8	897.7	951.3	940.1	951.3	951.3	951.3	283.2	283.2	270.7	283.2	270.7	283.2
0.90	1.11	756.8	849.5	814.7	849.5	1182.0	1245.0	1231.0	1245.0	1245.0	1245.0	371.2	371.2	356.7	371.2	356.7	371.2
0.80	1.25	1087.0	1199.0	1157.0	1199.0	1677.0	1752.0	1736.0	1752.0	1752.0	1752.0	524.3	524.3	507.2	524.3	507.2	524.3
0.70	1.43	1428.0	1556.0	1507.0	1556.0	2183.0	2267.0	2250.0	2267.0	2267.0	2267.0	680.6	680.6	661.7	680.6	661.7	680.6
0.67	**1.50**	**1550.0**	**1684.0**	**1632.0**	**1684.0**	**2365.0**	**2451.0**	**2434.0**	**2451.0**	**2451.0**	**2451.0**	**736.5**	**736.5**	**717.2**	**736.5**	**717.2**	**736.5**
0.60	1.67	1818.0	1959.0	1904.0	1959.0	2758.0	2848.0	2830.0	2848.0	2848.0	2848.0	857.5	857.5	837.5	857.5	837.5	857.5
0.57	1.75	1947.0	2092.0	2036.0	2092.0	2948.0	3040.0	3022.0	3040.0	3040.0	3040.0	916.1	916.1	895.9	916.1	895.9	916.1
0.50	2.00	2293.0	2445.0	2385.0	2445.0	3453.0	3549.0	3530.0	3549.0	3549.0	3549.0	1072.0	1072.0	1051.0	1072.0	1051.0	1072.0
0.43	2.33	2712.0	2870.0	2806.0	2870.0	4062.0	4158.0	4140.0	4158.0	4158.0	4158.0	1259.0	1259.0	1238.0	1259.0	1238.0	1259.0
0.40	2.50	2913.0	3072.0	3008.0	3072.0	4353.0	4449.0	4430.0	4449.0	4449.0	4449.0	1348.0	1348.0	1328.0	1348.0	1328.0	1348.0
0.30	3.33	3792.0	3950.0	3883.0	3950.0	5617.0	5708.0	5691.0	5708.0	5708.0	5708.0	1736.0	1736.0	1719.0	1736.0	1719.0	1736.0
0.20	5.00	5214.0	5352.0	5287.0	5352.0	7643.0	7712.0	7701.0	7712.0	7712.0	7712.0	2357.0	2357.0	2348.0	2357.0	2348.0	2357.0
0.10	10.00	8258.0	8299.0	8255.0	8299.0	11920.0	11910.0	11920.0	11910.0	11910.0	11910.0	3669.0	3669.0	3686.0	3669.0	3686.0	3669.0
0.05	20.00	12270.0	12100.0	12110.0	12100.0	17490.0	17310.0	17360.0	17310.0	17310.0	17310.0	5371.0	5371.0	5437.0	5371.0	5437.0	5371.0
0.04	25.00	13810.0	13550.0	13580.0	13550.0	19600.0	19360.0	19420.0	19360.0	19360.0	19360.0	6019.0	6019.0	6105.0	6019.0	6105.0	6019.0
0.03	40.00	17500.0	16990.0	17090.0	16990.0	24660.0	24220.0	24320.0	24220.0	24220.0	24220.0	7565.0	7565.0	7709.0	7565.0	7709.0	7565.0
0.02	50.00	19500.0	18830.0	18980.0	18830.0	27370.0	26820.0	26950.0	26820.0	26820.0	26820.0	8395.0	8395.0	8572.0	8395.0	8572.0	8395.0
0.01	100.00	26830.0	25530.0	25860.0	25530.0	37270.0	36270.0	36500.0	36270.0	36270.0	36270.0	11430.0	11430.0	11740.0	11430.0	11740.0	11430.0
0.01	200.00	36210.0	33980.0	34570.0	33980.0	49810.0	48150.0	48520.0	48150.0	48150.0	48150.0	15260.0	15260.0	15760.0	15260.0	15760.0	15260.0
0.002	500.00	52560.0	48480.0	49610.0	48480.0	71430.0	68490.0	69130.0	68490.0	68490.0	68490.0	21880.0	21880.0	22760.0	21880.0	22760.0	21880.0

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Kaweah Project, FERC Project No. 298

AQ 6 – Water Quality
Final Technical Study Report

December 2019

Southern California Edison Company
Regulatory Support Services
1515 Walnut Grove Avenue, Rosemead, CA 91770

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°C	degrees Celsius
°F	degrees Fahrenheit
µS/cm	microSiemens per centimeter
AQ 6 – TSP	AQ 6 – Water Quality Technical Study Plan
Basin Plan	Water Quality Control Plan for the Tulare Lake Basin
cfs	cubic feet per second
CTR	California Toxics Rule
DO	dissolved oxygen
EPA	Environmental Protection Agency
FERC	Federal Energy Regulatory Commission
GPS	Global Positioning System
MDL	method detection limit
mg/L	milligram per liter
mL	milliliter
MRL	method reporting limit
NTU	Nephelometric Turbidity Unit
PDF	Portable Document Format
PQL	practical quantitation limit
Project	Kaweah Project
PSP	Proposed Study Plan
QA	quality assurance
QA/QC	quality assurance/quality control
RL	reporting limit
RSP	Revised Study Plan
SCE	Southern California Edison Company

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1 INTRODUCTION

This Technical Study Report describes the data and findings developed by Southern California Edison Company (SCE) in association with implementation of the AQ 6 – Water Quality Technical Study Plan (AQ 6 – TSP) for the Kaweah Project (Project). The AQ 6 – TSP was included in SCE's Revised Study Plan (RSP)[1] (SCE 2017a) and was approved by the Federal Energy Regulatory Commission (FERC) on October 24, 2017, as part of its Study Plan Determination for the Project (FERC 2017). Specifically, this report provides a description of the methods and results of the water quality sampling completed in 2018.

2 STUDY OBJECTIVES

The AQ 6 – TSP included one study objective, as follows:

- Characterize physical, chemical, and bacterial water quality conditions in the bypass[2] river reaches and comparison reaches, and compare to the Water Quality Control Plan for the Tulare Lake Basin (Basin Plan; CRWQCB 2018) objectives and water quality standards and other applicable Environmental Protection Agency (EPA) national or California Toxics Rule (CTR) standards.

3 EXTENT OF STUDY AREA

The study area included the bypass river reaches associated with the Project and comparison river reaches upstream and downstream of the bypass reaches (Table AQ 6-1, Map AQ 6-1).

It should be noted that the majority of lands along the bypass reaches are privately owned and outside the FERC Project boundary. Prior to beginning the water quality study in 2018, SCE provided notification to landowners about Project relicensing and requested authorization to enter property to conduct the field study. If authorization was obtained, SCE completed sampling as described in the AQ 6 – TSP. If authorization was not obtained, SCE sampled from the nearest location within the reach where permission was granted.

4 STUDY APPROACH

The following describes the water quality sampling field program, which included *in-situ* water quality measurements, general water quality sampling, coliform sampling, and laboratory analysis and reporting. The results from the water quality sampling program were documented in tables and then compared to the Basin Plan (CRWQCB 2018) water quality objectives, the CTR, and applicable EPA national water quality criteria.

4.1 *In-situ* Field Measurements

In-situ water quality measurements (water temperature, dissolved oxygen [DO], turbidity, conductivity, and pH) were collected at sampling locations listed in Table AQ 6-1 using a YSI® meter. Samples were collected during the spring runoff (May 7 to 9 and May 30 to 31, 2018), and during the summer low-flow or base-flow period (August 20 to 24, 2018). Pre- and post-sampling calibration of *in-situ* instrumentation was conducted following the manufacturer's instructions.

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1 SCE filed a Proposed Study Plan (PSP) on May 24, 2017 (SCE 2017b). Three comments were filed on the PSP, however, they did not result in revisions to any of the study plans. Therefore, SCE filed an RSP on September 19, 2017 which stated that the PSP, without revision, constituted its RSP. The FERC subsequently issued a Study Plan Determination on October 24, 2017, approving all study plans for the Kaweah Project.

2 A bypass reach is a segment of a river downstream of a diversion facility where Project operations result in the diversion of a portion of the water from that reach. Typically the diverted water re-enters the river through a powerhouse at the downstream end of the bypass reach.

The results of the *in-situ* monitoring were documented on field data sheets and then entered into Excel spreadsheets. Quality Assurance/Quality Control (QA/QC) of the data entry was subsequently performed by a separate individual.

4.2 General Water Quality Sampling

General water quality samples (e.g., calcium, chloride, hardness, dissolved metals, etc.) were collected at sampling locations listed in Table AQ 6-1 and depicted on Map AQ 6-1. Samples were collected twice: once during the spring runoff and once during the summer low-flow period to screen for potential water quality issues. Samples were collected using methods consistent with the EPA 1669 (EPA 1996) sampling protocol Sampling Ambient Water for Trace Metals at EPA Water Quality Criteria. Water quality samples collected from streams were analyzed for the parameters listed in Table AQ 6-2, which include general parameters, a suite of dissolved metals, total mercury, and bacteria.

Water quality samples were decanted into laboratory-supplied sample containers. The sample containers were labeled with the date and time that the sample was collected and the sampling site or identification label. The sample container was preserved (as appropriate), stored, and delivered to a State-certified water quality laboratory for analyses in accordance with maximum holding periods. A chain-of-custody record was maintained with the samples at all times. The sampling site locations were recorded using a Global Positioning System (GPS) unit and the coordinates were recorded on field data sheets.

The results of the analyses were provided by the laboratory in either Portable Document Format (PDF) files or Excel spreadsheets. The PDF results were then entered into an Excel spreadsheet and QA/QC of the data entry was performed by a separate individual.

4.3 Coliform Sampling

Total and fecal coliform, specifically *Escherichia coli* (*E. coli*), sampling was conducted to determine if study waters met objectives for contact recreational activities identified by EPA (2012). The Basin Plan includes the older fecal coliform standard, rather than the newer recommended *E. coli* standard (CRWQCB 2018). Samples were collected at a near-shore location immediately above and below the river access area near Kaweah No. 2 Powerhouse (“Edison Beach”) where contact recreation (e.g., swimming) occurs. Coliform samples were collected five times between July 5 and July 31, 2018, which is within the thirty-day period mandated by the Basin Plan. Samples were generally collected in the afternoon when the access area was open (Monday – Thursday; 8 am – 7 pm).

Samples were decanted into laboratory supplied sample vials that contained preservative. The samples were placed on ice and delivered to the laboratory immediately after sampling.

The results of the analyses were provided by the laboratory in PDF files. The PDF results were then entered into an Excel spreadsheet and QA/QC of the data entry was performed by a separate individual.

4.4 Laboratory Analysis and Reporting

Water quality samples collected during the field program were analyzed by State-certified laboratories approved by the State Water Resources Control Board for chemical analysis. The laboratories attempted to attain reporting and detection limits that were at or below the applicable regulatory criteria. The parameters analyzed by the laboratories are provided in Table AQ 6-2 and described in Appendix A. The laboratories reported each chemical parameter with an associated method detection limit (MDL), method reporting limit (MRL or RL), and/or practical quantitation limit (PQL). The MDL is the minimum measured concentration of a substance that can be reported with 99 percent confidence that the measured concentration is distinguishable from method blank result (EPA 2016). MRL and PQL are laboratory specific measures of the lowest concentration the laboratory could reliably reproduce (usually 3 to 10 times the MDL). One laboratory used MRL and PQL interchangeably and the other laboratories reported a MRL (or RL). A detailed definition of MDL, MRL, and PQL is provided in Appendix B along with a glossary of laboratory terminology, the units of measure used by the laboratories, and water quality criteria calculation methods.

4.5 Quality Assurance/ Quality Control Procedures

Water quality samples were collected using methods consistent with the EPA 1669 (EPA 1996) sampling protocol Sampling Ambient Water for Trace Metals at EPA Water Quality Criteria. At each station, all samples were collected by the same person, wearing ultra-trace sampling gloves. In-stream water samples were collected just below the water surface in areas of steady flow. Water quality samples were collected using the designated collection bottle supplied by the appropriate laboratory. Upon collection, each sample was immediately labeled with the date and time and logged on a chain-of-custody form and placed into a cooler filled with ice. Sampling equipment was cleaned with a cleaning solution and distilled water prior to sample collection.

Water quality samples were delivered to the analytical laboratory within the appropriate holding times. Coliform samples were delivered to the laboratory on the same day of collection, while all other samples were delivered between 24 to 48 hours of the sample collection time by courier. A chain-of-custody form accompanied all samples from the time of collection to delivery and submittal to the analytical laboratory.

Standard quality assurance (QA) procedures were performed by the laboratories during analyses of water samples. These included matrix and laboratory spikes and spike duplicates, matrix duplicates, and method blanks as appropriate. A summary of the QA measures were included with each certified laboratory report. A QA/QC screening level review was conducted on all of the laboratory analytical reports.

5 STUDY RESULTS

Results of the spring and summer 2018 *in-situ* field measurements, general water quality sampling, and coliform sampling are discussed below. A summary of the water quality tests performed, analysis methods, detection and reporting limits, water quality criteria, and holding time and preservative requirements is included in Table AQ 6-2. Sampling occurred from May 7 to 9 and May 30 to 31, 2018, for the spring sampling period and from August 20 to 23, 2018, for the summer sampling period. A description of the sampling locations, GPS coordinates, and sampling dates is included in Table AQ 6-1. Table AQ 6-3 shows that most results met the Basin Plan water quality objectives, the CTR, and EPA national water quality criteria. All *in-situ* field measurements and coliform parameters are discussed below, but only two general water quality parameters (ammonia and alkalinity) that had unique issues related to Basin Plan water quality objectives, the CTR, and/or the EPA national water quality criteria are discussed. Results of the QA/QC of the laboratory reports are also discussed at the end of this section.

5.1 Water Quality Objectives and Criteria

The Basin Plan identifies specific water quality objectives of allowable limits or levels of water quality constituents. These objectives are established for the protection of beneficial uses of the waters in the Tulare Lake Basin, which is comprised of the drainage area of the San Joaquin Valley south of the San Joaquin River and includes the Kaweah River upstream of Lake Kaweah (CRWQCB 2018). If water quality is maintained at levels that meet these objectives, the beneficial uses of the waters are considered to be protected. The beneficial uses identified in the Basin Plan for the Kaweah River upstream of Lake Kaweah include: (1) municipal and domestic supply; (2) hydropower generation; (3) water contact recreation; (4) non-contact water recreation; (5) warm freshwater habitat; (6) cold freshwater habitat; (7) wildlife habitat; (8) rare, threatened, or endangered species; (9) spawning, reproduction, and / or early development; (10) freshwater replenishment. The definition of each of these beneficial uses is provided in Table AQ 6-4.

Water quality objectives include both numeric and narrative objectives (Table AQ 6-2). The Basin Plan provides specific numeric objectives for *in-situ* measurements, chemical constituents, metals, and bacteria. The Basin Plan water quality objectives for chemical constituents are derived from the maximum contaminant levels that are provided in Title 22 of the California Code of Regulations. Table AQ 6-2 also includes the CTR and EPA national water quality criteria (65 FR 31682, EPA 2019). The most stringent objectives were used for this study.

Several of the parameters analyzed do not have established water quality criteria. Various literature sources were reviewed for each parameter to identify guidelines or ranges that might be expected for the Project area. The ranges are described in Appendix A.

5.2 *In-Situ* Field Measurements

In-situ field measurements are presented in Table AQ 6-5 for the spring sampling period and in Table AQ 6-6 for the summer sampling period. Each *in-situ* parameter is discussed below.

5.2.1 Water Temperature

The Basin Plan water quality objective for water temperature states that elevated temperature wastes shall not cause the temperature of waters designated COLD[3] or WARM[4] to increase by more than 5 degrees Fahrenheit (°F) (2.78 degrees Celsius [°C]) above natural receiving water temperature (CRWQCB 2018). There are no water temperature criteria in the CTR or in the EPA's national water quality criteria.

During the spring 2018 sampling period (May 7 to 9 and May 30 to 31, 2018) water temperatures ranged from 9.31°C to 16.56°C and during the summer sampling period (August 20 to 23, 2018) water temperatures ranged from 18.19°C to 26.90°C. *In-situ* field measurements consisted of a single point measurement taken at each site during each site visit, and the time of day at which measurements were taken varied across sites. Both temperature and streamflow can fluctuate over the course of a day and both (temperature and flow) fluctuated during the sampling periods. Figure AQ 6-1 shows continuous flow and water temperature data in the bypass reaches. The continuous water temperature data was collected as part of the AQ 4 Water Temperature Modeling Technical Study. Tables AQ 6-5 and AQ 6-6 also show the flow in the flowlines or stream reaches when the *in situ* sampling was conducted.

During the spring sampling period, water temperature in all locations was less than 17°C and significant flow existed in the river reaches and the flowlines (Figure AQ 6-1). During the summer sampling period some high water temperatures were present (>25°C), but these were natural occurrences in the system. No significant Project flow diversions were occurring. The powerhouses were not operating during the summer low flow period. Kaweah No. 1 Flowline was diverting only 0.48 to 0.56 cubic feet per second (cfs) (for water delivery requirements), Kaweah No. 2 Flowline was diverting 2.6 cfs (for water delivery requirements), and Kaweah No. 3 Flowline was not diverting water.

The AQ 4 Water Temperature Modeling Technical Study includes continuous water temperature data collected in the bypass reaches and water temperature modeling that will be used to identify if there are

[3] The Basin Plan defines the beneficial use Cold Freshwater Habitat (COLD) as uses of water that support cold water ecosystems, including, but not limited to, preservation or enhancement of aquatic habitats, vegetation, fish, or wildlife, including invertebrates. The Basin Plan indicates that waters designated as COLD are present in Kaweah River above Lake Kaweah and notes that the beneficial uses of any specifically identified water body generally apply to its tributary streams. In some cases a beneficial use may not be applicable to the entire body of water, and in these cases the Regional Water Board's judgement will be applied.

[4] The Basin Plan defines the beneficial use Warm Freshwater Habitat (WARM) as uses of water that support warm water ecosystems, including, but not limited to, preservation or enhancement of aquatic habitats, vegetation, fish, or wildlife, including invertebrates. WARM includes support for reproduction and early development of warm water fish. The Basin Plan indicates that waters designated as WARM are present in Kaweah River above Lake Kaweah and notes that the beneficial uses of any specifically identified water body generally apply to its tributary streams. In some cases a beneficial use may not be applicable to the entire body of water, and in these cases the Regional Water Board's judgement will be applied.

potential effects of the Project on water temperature during the late spring or early summer period in year types when the hydrology provides enough water for the Project powerhouses to operate.

5.2.2 Dissolved Oxygen

The Basin Plan water quality objectives for DO are a minimum of 5.0 milligrams per liter (mg/L) for water designated WARM and a minimum of 7.0 mg/L for waters designated COLD or SPWN[5] (CRWQCB 2018). The EPA's DO criterion was established in the 1986 Gold Book, which recommends a 1-day minimum DO value of 8.0 mg/L in cold waters for early life stages of fish (EPA 1986). There are no water temperature criteria in the CTR.

During the *in situ* water sampling, DO exceeded the minimum criteria in the Basin Plan and the EPA's 1986 Gold Book during both the spring and summer 2018 sampling periods: during the spring 2018 sampling period DO ranged from 9.1 to 10.05 mg/L and during the summer 2018 sampling period DO ranged from 8.3 to 9.61 mg/L.

5.2.3 Turbidity

The Basin Plan water quality objective for turbidity states that, "where natural turbidity is between 0 and 5 Nephelometric Turbidity Units (NTUs), increases shall not exceed 1 NTU. Where natural turbidity is between 5 and 50 NTUs, increases shall not exceed 20 percent. Where natural turbidity is equal to or between 50 and 100 NTUs, increases shall not exceed 10 NTUs. Where natural turbidity is greater than 100 NTUs, increases shall not exceed 10 percent" (CRWQCB 2018). There are no turbidity criteria in the CTR or in the EPA's national water quality criteria.

For the *in situ* sampling, turbidity measured using a YSI meter ranged from 0.1 to 5.5 NTUs during the spring 2018 sampling period and from 1.2 to 4.0 NTUs during the summer 2018 sampling period. Turbidity was also measured in the laboratory as part of the general water quality parameters. Turbidity measured in the laboratory ranged from 0.42 to 2.7 NTUs during the spring 2018 sampling period and from 0.31 to 0.53 NTUs during the summer 2018 sampling period. Turbidity measured in the study area was very low. The Project consists of concrete diversions and lined flowlines and is unlikely to alter turbidity as a result of normal Project operations.

5.2.4 Conductivity

The Basin Plan water quality objective for conductivity is a maximum of 175 microsiemens per centimeter (µS/cm) (CRWQCB 2018). There are no conductivity criteria in the CTR or in the EPA's national water quality criteria. Conductivity was below the maximum criterion during both the spring and summer 2018 sampling periods: conductivity ranged from 15 to 50 µS/cm during the spring 2018 sampling period and from 92 to 139 µS/cm during the summer 2018 sampling period (Tables AQ 6-5 and AQ 6-6).

5.2.5 pH

The Basin Plan water quality objective for pH states that, "the pH of water shall not be depressed below 6.5, raised above 8.3, or changed at any time more than 0.3 units from normal ambient pH" (CRWQCB 2018). The national EPA pH criterion is 6.5 to 9 for chronic exposure in fresh water (EPA 2019). There is no pH criterion in the CTR.

During the spring sampling period (May 7 to 9 and May 30 to 31, 2018), pH values ranged from 7.32 to 7.88 and during the summer sampling period (August 20 to 23, 2018), pH values were generally higher,

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5 The Basin Plan defines the beneficial use Spawning, Reproduction, and/or Early Development (SPWN) as uses of water that support high quality aquatic habitats suitable for reproduction and early development of fish. SPWN is limited to cold water fisheries. The Basin Plan indicates that waters designated as SPWN are present in Kaweah River above Lake Kaweah and notes that the beneficial uses of any specifically identified water body generally apply to its tributary streams. In some cases a beneficial use may not be applicable to the entire body of water, and in these cases the Regional Water Board's judgement will be applied.

ranging from 7.82 to 8.57. All sites were within the EPA pH criteria. A single site, K2 Flowline Above PH2, had a pH of 8.57, slightly outside of the 6.5 to 8.3 "depression range" identified in the Basin Plan (Tables AQ 6-5 and AQ 6-6). Flow in the K2 Flowline in August was very low (2.6 cfs) as water was only being diverted to meet consumptive water deliveries for water users and not for hydropower generation (Table AQ 6-6). Likely the combination of low flow and daytime photosynthesis by attached algae in the flowline and the general low alkalinity (soft water) in the Kaweah River watershed resulted in the slightly higher pH value. During the day, photosynthesis results in the removal of CO_2 and/or HCO_3^- from the water and consequently pH values increase, particularly in waters with low alkalinity (low buffering capacity) (e.g., Hem 1989; Boyd 2015). Because the flow in the flowline was being used by consumptive water users, very little would have potentially returned to the Kaweah River and, therefore, the slightly elevated pH water would not have affected the Kaweah River.

5.3 General Water Quality Sampling

Results of the general water quality sampling are presented in Table AQ 6-7 for spring and in Table AQ 6-8 for summer. Table AQ 6-9 and Table AQ 6-10 contain the calculated criteria and results for ammonia, which has criteria based on temperature and pH and therefore must be calculated on a location-by-location basis. Table AQ 6-11 and Table AQ 6-12 contain calculated criteria and results for cadmium, copper, lead, and nickel, which have hardness-based criteria. For each of these metals, the water quality criterion decreases with decreasing water hardness (see Appendix B for equations). All general water quality sampling parameters were within the Basin Plan water quality objectives and the CTR and EPA national water quality criteria. With respect to ammonia, 4 of 29 samples were greater than the Basin Plan ammonia "waste discharge" objective. The samples were not "waste discharge," they were natural conditions; nevertheless, ammonia is discussed below. Also, because of the naturally low alkalinity in the Kaweah River watershed, 9 of 29 samples were below the EPA total alkalinity criterion. The EPA criterion also has an "unless the low alkalinity is natural," which is the case for the Kaweah River samples; nevertheless, alkalinity is also discussed below. General water quality sampling parameters that were within the Basin Plan water quality objectives and CTR and EPA national water quality criteria or that have no criteria defined are not discussed below.

5.3.1 Ammonia

The Basin Plan water quality objective for ammonia is that discharge of waste shall not cause concentrations of ammonia to exceed 0.025 mg/L (CRWQCB 2018). The national EPA ammonia criteria are dependent on ambient pH and temperature conditions and were calculated using both the acute and chronic criterion calculations (see Appendix B for equations) in the EPA's Aquatic Life Ambient Water Quality Criteria for Ammonia – Freshwater (EPA 2013). There are no ammonia criteria in the CTR.

The calculated ammonia criteria and laboratory ammonia concentration results are presented in Table AQ 6-9 for the spring sampling period and Table AQ 6-10 for the summer sampling period. Ammonia was detected in four samples: K2 Flowline Below PH3 during the spring 2018 sampling period; and KR Upstream of PH1, KR Upstream of PH2, and KR Downstream of PH2 during the summer sampling period. The ammonia concentration in two samples (KR Upstream of PH1 and KR Upstream of PH2) fell below the PQL and above the MDL, and therefore the ammonia concentration values at these sites are considered estimates. All four samples are above the "waste discharge" values in the Basin Plan; however, Project operations do not produce any "waste discharge." One sample (KR Downstream of PH2 during the summer 2018 sampling period) exceeded the EPA calculated ammonia chronic criterion, but not the acute criterion.

There are no known Project related activities, facilities, or operations that have the potential to affect ammonia concentrations and cause the slightly elevated ammonia levels at a few places in the Project area. Ammonia can be produced from septic systems (decomposing organic matter) and there are many homes and the Sequoia National Park Visitor Center that are adjacent to the Kaweah River and could potentially be a source for ammonia.

5.3.2 Total Alkalinity

The EPA national water quality criterion for total alkalinity states that a continuous concentration, "of 20 mg/L is a minimum value except where alkalinity is naturally lower, in which case the criterion cannot be lower than 25 percent of the natural level" (EPA 2019). There is no alkalinity criterion in the Basin Plan water quality objectives or in the CTR.

During the spring sampling period, alkalinity was below 20 mg/L at 9 of the 16 sites (Table AQ 6-7). All of the other sites also had relatively low alkalinity (<24.1 mg/L) except for one likely anomalous measurement (369 mg/L, KR Downstream of the Conf. with EF). Low alkalinity is a natural condition of the Kaweah River watershed during spring high flow conditions. Snowmelt and rainfall runoff have little opportunity to pick up calcium carbonate from the basin geology. During the summer, low flow sampling period, alkalinity was higher (ranging from 38.8 to 63.5 mg/L at 12 of the 13 sites sampled) (Table AQ 6-8). During the summer there was also one site that had an apparently anomalous high reading (645 mg/L, EF Upstream of K1 Div.). There are no known mechanisms through which the Project would affect alkalinity. Alkalinity of natural waters in the range observed in the Kaweah River is considered low (Boyd 2015), but is generally a product of the underlying geology and land use of a watershed.

5.4 Coliform Sampling

The Basin Plan water quality objective for bacteria states that, "in water designated REC-1[6], the fecal coliform concentration based on a minimum of not less than five samples for any 30-day period shall not exceed a geometric mean of 200/100 milliliters (mL), nor shall more than ten percent of the total number of samples taken during any 30-day period exceed 400/100 mL" (CRWQCB 2018). *E. coli* is a species of fecal coliform bacteria that is specific to fecal material from humans and other warm-blooded animals. EPA now recommends *E. coli* as the best indicator of health risk from water contact in recreational waters rather than fecal coliform (i.e., fecal coliform concentrations are composed of some species of bacteria that are not necessarily fecal in origin). The EPA's criterion for *E. coli* is that it should not exceed a geometric mean of 126/100 mL, nor more than ten percent of samples exceed 410/100 mL in waters used for freshwater contact recreation (EPA 2012). The State Water Resources Control Board in 2018[7] updated the statewide Water Quality Control Plan for Inland Surface Waters, Enclosed Bays, and Estuaries of California to include a REC-1 bacterial water quality criteria for *E. coli* of a six week rolling average of 100/100 mL with not more than 10% of the samples to exceed 320/100 ml that is intended to supersede bacterial REC-1 numeric criteria that is contained in a Basin Plan. Neither the Basin Plan nor the EPA have criteria for total coliform.

Water samples were collected five times between July 5 and July 31, 2018, at one location upstream of Edison Beach, a public recreational beach, and one location downstream of the beach (Map AQ 6-2). The samples were processed at the laboratory for total coliform and *E. coli*. The samples, inadvertently, were not also processed for fecal coliform concentration. The results of the total coliform and *E. coli* analysis are presented in Table AQ 6-13. *E. coli* concentrations ranged from 14.5 to 69.7/100mL upstream of Edison Beach and from 14.8 to 76.9/100mL downstream of Edison Beach. All samples were less than the EPA criteria for human health risk for contact recreation and the updated State Water Resources Control Board bacterial criteria of *E. coli* concentration of 100/100mL. Because the samples were not processed for the less specific fecal coliform test, the fecal coliform concentration is unknown.

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[6] The Basin Plan defines the beneficial use Water Contact Recreation (REC-1) as uses of water for recreational activities involving body contact with water, where ingestion of water is reasonably possible. These include, not are not limited to, swimming, wading, water skiing, skin and scuba diving, surfacing, white water activities, fishing, or use of natural hot springs. The Basin Plan indicates that waters designated as REC-1 are present in Kaweah River above Lake Kaweah and notes that the beneficial uses of any specifically identified water body generally apply to its tributary streams. In some cases a beneficial use may not be applicable to the entire body of water, and in these cases the Regional Water Board's judgement will be applied.

[7] https://www.waterboards.ca.gov/board_decisions/adopted_orders/resolutions/2018/final_iswebe_bacteria_provisions.pdf

Total coliform was greater than 2,419.6/100mL in all samples collected. There is no contact recreation criteria for total coliform, because much of total coliform can be from natural sources (total coliform is primarily used in drinking water analyses to indicate the potential contamination from outside water sources).

5.5 Laboratory Analysis and Reporting

Eighteen analytes were tested by APPL Labs, three analytes were tested by BSK Associates Labs, and nine analytes were tested by Brooks Applied Labs. The laboratories provided reports of each parameter analyzed and the associated MDL, MRL, and/or PQL. All of the laboratory reports are available upon request.

5.6 Quality Assurance/ Quality Control Procedures

Appendix C contains a detailed QA/QC summary of the reports received from the water quality testing laboratories. The QA/QC review of reports from APPL Labs, BSK Associates Labs, and Brooks Applied Labs indicated that most of the samples were acceptable (i.e., holding times, preservation, sample containers, etc. were appropriate). The labs flagged four samples with qualifiers: (1) Sample 21 Total Kjeldahl Nitrogen and; (2) Sample 12 Total Alkalinity the analyte was found in a method blank as well as in the sample; (3) Sample 28 Total Organic Carbon was received without chemical preservation; (4) and Sample 21 Turbidity was subcontracted to BSK Associates Labs after equipment failure at APPL Labs prevented analysis of the sample, and the sample was received at BSK Associates Labs past the holding time limit and above the mandated temperature.

Numerous samples had results that were less than or equal to the MDL, and therefore were considered non-detects, or were greater than the MDL but less than or equal to the PQL/MRL, and therefore were considered estimates (see Appendix B for a discussion of MDL, PQL and MRL). Samples with analyte concentrations that were less than or equal to the MDL were included as "<MDL" in Tables AQ 6-7 through AQ 6-12. Samples with analyte concentrations that were greater than the MDL but less than or equal to the PQL or MRL are reported in Tables AQ 6-7 through AQ 6-12 and flagged with footnotes indicating that they should be considered estimates.

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TABLES

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Table AQ 6-1. Water Quality Monitoring and Sampling Locations.

Sampling Location	Sampling Location Description	Sample ID	GPS Coordinates		Sampled in Spring? (May 7 – 31, 2018)	Sampled in Summer? (Aug 20 – 23, 2018)
			UTM11_ NAD 83 E	UTM11_ NAD 83 N		
Kaweah River						
K3 Flowline Above PH3	Kaweah No. 3 Flowline Upstream of the Kaweah No. 3 Powerhouse	6, 19	336315	4039197	Y	N[1]
KR Upstream of PH3	Kaweah River Upstream of the Kaweah No. 3 Powerhouse	8, 25	335524	4039460	Y	Y
K2 Flowline Below PH3	Kaweah No. 2 Flowline Downstream of the Kaweah No. 3 Powerhouse	9	335446	4039333	Y	N[1]
KR Downstream of PH3	Kaweah River Downstream of the Kaweah No. 3 Powerhouse	7, 26	335549	4039215	Y	Y
KR Upstream of the Conf. with EF	Kaweah River Upstream of the East Fork Kaweah River Confluence	10, 27	335382	4038784	Y	Y
KR Downstream of the Conf. with EF	Kaweah River Downstream of the East Fork Kaweah Confluence	11, 32	335161	4038695	Y	Y
KR Upstream of PH1	Kaweah River Upstream of the Kaweah No. 1 Powerhouse	14, 23, 34	333144	4037224	Y	Y
K1 Flowline Above PH1	Kaweah No. 1 Flowline Upstream of the Kaweah No. 1 Powerhouse	12, 16	333867	4036565	Y	N[2]
KR Downstream of PH1	Kaweah River Downstream of the Kaweah No. 1 Powerhouse	13, 22, 33	333049	4037206	Y	Y
K2 Flowline Above PH2	Kaweah No. 2 Flowline Upstream of the Kaweah No. 2 Powerhouse	5, 18, 36	331832	4037037	Y	Y
KR Upstream of PH2	Kaweah River Downstream of the Kaweah No. 1 Powerhouse and Upstream of the Kaweah No. 2 Powerhouse	4, 17, 35	331593	4036687	Y	Y
KR Downstream of PH2	Kaweah River Downstream of the Kaweah No. 2 Powerhouse	15, 24, 37	331240	4036770	Y	Y
East Fork Kaweah River						
EF Upstream of K1 Div.	East Fork Kaweah River Upstream of the Kaweah No. 1 Diversion	2, 28	339661	4035539	Y	Y
EF Downstream of K1 Div.	East Fork Kaweah River Downstream of the Kaweah No. 1 Diversion	3, 20, 29	339590	4035507	Y	Y
K1 Flowline Below K1 Div.	Kaweah No. 1 Flowline Downstream of the Kaweah No. 1 Diversion	1, 30	339450	4035266	Y	Y
EF Upstream of the Conf. with KR	East Fork Kaweah River Upstream of the Confluence with Kaweah River	21, 31	335383	4038647	Y	Y

Notes:

[1] The water level in the K3 Flowline above PH3 and the K2 Flowline below PH3 was so low during the summer sampling period that it could not be reached without entering the flowlines. Since entering the flowlines is prohibited, water quality samples could not be collected.

[2] The K1 Flowline above PH1 was dry during the summer sampling period and therefore water quality samples could not be collected.

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Table AQ 6-2. Summary of Water Quality Analytical Tests, Including Laboratory Methods and Detection Limits, and Chemical Water Quality Objectives.

Analyte	Units[1]	Analysis Method[2]	Method Detection Limit (MDL)	Practical Quantitation Limit (PQL)/ Method Reporting Limit (MRL)	Water Quality Criteria			Sample Container	Hold Time	Preservative/ Comment
					Basin Plan[3]	CA Toxics Rule (CTR)[4]	EPA Criteria[5]			
***In-Situ* Measurements**				**PQL/MRL**						
Water Temperature	Celsius (°C)	Water Quality Meter	Not Applicable	Not Applicable	≤ +5°F[6]	NS	NS	Not Applicable	Not Applicable	None
Dissolved Oxygen (DO)	mg/L	Water Quality Meter	Not Applicable	Not Applicable	5.0 - 7.0[7]	NS	3.0 - 8.0[8]	Not Applicable	Not Applicable	None
Turbidity	NTU	Water Quality Meter	Not Applicable	Not Applicable	Depends on natural turbidity[9]	NS	NS	Not Applicable	Not Applicable	None
Conductivity	µS/cm at 25°C	Water Quality Meter	Not Applicable	Not Applicable	175	NS	NS	Not Applicable	Not Applicable	None
pH	unitless	Water Quality Meter	Not Applicable	Not Applicable	6.5 – 8.3[10]	NS	6.5 – 9.0	Not Applicable	Not Applicable	None
General Parameters				**PQL/MRL**						
Calcium	µg/L	EPA 200.7	10.79	50.0	NS	NS	NS	500mL plastic	180 days	HNO_3, maintain at ≤6°C
Chloride	mg/L	EPA 300.0	0.08	1.0	250[11]	NS	230/860[12]	250mL plastic	28 days	Maintain at ≤6°C
Hardness (as $CaCO_3$)	mg/L	EPA 200.7/SM 2340B	1.00	1.0	NS	NS	NS	500mL plastic	180 days	HNO_3, maintain at ≤6°C
Magnesium	µg/L	EPA 200.7	3.48	25.0	NS	NS	NS	500mL plastic	180 days	HNO_3, maintain at ≤6°C
Nitrate	mg/L	EPA 300.0	0.01	0.2	10	NS	NS	500mL plastic	48 hours	H_2SO_4, maintain at ≤6°C
Nitrite	mg/L	EPA 300.0	0.01	0.1	1	NS	NS	500mL plastic	48 hours	H_2SO_4, maintain at ≤6°C
Nitrate/Nitrite (NO_3)	mg/L	EPA 353.2	0.028	0.10	10	NS	NS	500mL plastic	48 hours	H_2SO_4, maintain at ≤6°C
Ammonia as N	mg/L	EPA 350.1	0.012	0.5	0.025	NS	Depends on pH & temperature	500mL plastic	28 days	H_2SO_4, maintain at ≤6°C
Total Kjeldahl Nitrogen (TKN)	mg/L	EPA 351.2	0.267	0.50	NS	NS	NS	500mL plastic	28 days	H_2SO_4, maintain at ≤6°C
Total Phosphorus	µg/L	SM 4500	24.0	100	NS	NS	NS	500mL plastic	28 days	H_2SO_4, maintain at ≤6°C
Ortho-phosphate	mg/L	SM 4500-P E	0.016	0.05	NS	NS	NS	500mL amber glass	48 hours	Maintain at ≤6°C
Potassium	µg/L	EPA 200.7	93.9	500	NS	NS	NS	500mL plastic	180 days	HNO_3, maintain at ≤6°C
Sodium	µg/L	EPA 200.7	82.9	500	NS	NS	NS	500mL plastic	180 days	HNO_3, maintain at ≤6°C
Sulfate (SO_4)	mg/L	EPA 300.0	0.09	1.0	250[11]	NS	NS	250mL plastic	180 days	Maintain at ≤6°C
Total Dissolved Solids	mg/L	SM 2540C	4.4	10	500[11]	NS	NS	500mL plastic	7 days	Maintain at ≤6°C
Total Suspended Solids	mg/L	SM 2540D	5.6	10	NS	NS	NS	500mL plastic	7 days	Maintain at ≤6°C
Turbidity	NTU	EPA 180.1/SM 2130B	0.035	0.10	Depends on natural turbidity[9]	NS	NS	1L amber glass	Not Applicable	Maintain at ≤6°C
Organic Carbon, Total (TOC)	mg/L	SM 5310C	Not Applicable	0.2	NS	NS	NS	250mL amber glass	28 days	H_2SO_4, maintain at ≤6°C
Total Alkalinity	mg/L	SM 2320B	0.85	2.0	NS	NS	>20[13]	250mL plastic	14 days	Maintain at ≤6°C
Metals-Dissolved				**MRL**						
Arsenic	µg/L	EPA 1638	0.056	0.204	10	150/340[12]	150/340[12], 0.018[14], 0.14[15]	125mL plastic	48 hours	Maintain at ≤6°C
Cadmium	µg/L	EPA 1638	0.031	0.092	5	2.2/4.3[12, 16]	0.72/1.8[12, 16]	125mL plastic	48 hours	Maintain at ≤6°C
Copper	µg/L	EPA 1638	0.112	0.337	1,000[11]	9.0/13[12, 16], 1,300[14]	9.0/13[12, 16, 17]	125mL plastic	48 hours	Maintain at ≤6°C

Analyte	Units[1]	Analysis Method[2]	Method Detection Limit (MDL)	Practical Quantitation Limit (PQL)/ Method Reporting Limit (MRL)	Water Quality Criteria: Basin Plan[3]	Water Quality Criteria: CA Toxics Rule (CTR)[4]	Water Quality Criteria: EPA Criteria[5]	Sample Container	Hold Time	Preservative/ Comment
Iron	µg/L	EPA 1638	1.43	4.34	300[11]	NS	1,000[18], 300[19]	125mL plastic	48 hours	Maintain at ≤6°C
Lead	µg/L	EPA 1638	0.026	0.077	15	2.5/65[12, 16]	2.5/65[12, 16]	125mL plastic	48 hours	Maintain at ≤6°C
Manganese	µg/L	EPA 1638	0.107	0.321	50[11]	NS	50[20]	125mL plastic	48 hours	Maintain at ≤6°C
Nickel	µg/L	EPA 1638	0.117	0.352	100	52/470[12, 16], 610[14], 4,600[15]	52/470[12, 16], 610[14], 4,600[15]	125mL plastic	48 hours	Maintain at ≤6°C
Chromium-Total	µg/L	EPA 1638	0.128	0.383	50	NS	NS	125mL plastic	48 hours	Maintain at ≤6°C
Metals-Total				**MRL**						
Mercury	ng/L	EPA 1631E	0.13	0.40	2,000	50[14], 51[15]	770/1,400[12]	125mL plastic	48 hours	Maintain at ≤6°C
Bacteria				**MRL**						
Total Coliform	MPN/100 mL	EPA SM9223B	Not Applicable	1	NS	NS	NS	100 mL plastic	24 hours	Maintain at ≤6°C
E. coli	MPN/100 mL	EPA SM9223B	Not Applicable	1	NS	NS	126	100 mL plastic	24 hours	Maintain at ≤6°C

Notes:

MDL - Method Detection Limit: The minimum measured concentration of a substance that can be reported with 99 percent confidence that the measured concentration is distinguishable from method blank results.

MPN - Most probable number of bacterial colonies per 100 mL of water.

MRL - Method Reporting Limit: The lowest concentration of a substance that can be reliably reported under current laboratory operating conditions.

NS - no standard available

PQL - Practical Quantitation Limit: The concentration that can be reliably measured within specified limits and accuracy during routine laboratory operating conditions.

Footnotes:

1 Units follow listed criterion standards. If standards were not available, laboratory supplied units were used. (Note: µg/L-ppb and mg/L=ppm)

2 Analysis methods are periodically updated by the EPA. The most recent methods available were used for the water quality analysis.

3 The Water Quality Control Plan for the Tulare Lake Basin Second Edition relies on California primary and secondary Maximum Concentration Level objectives as criteria for water quality to be used as a municipal and domestic supply for human consumption.

4 California Toxics Rule (CTR) criteria are based primarily on EPA standards developed under the Clean Water Act for human consumption of water and aquatic organisms with an adult risk for carcinogens estimated to be one in one million as contained in the Integrated Risk Information System (IRIS) as of October 1, 1996.

5 Federal water quality criteria are from the EPA's website unless otherwise noted in the footnotes.
Aquatic Life Criteria: https://www.epa.gov/wqc/national-recommended-water-quality-criteria-aquatic-life-criteria-table#table
Human Health Criteria: https://www.epa.gov/wqc/national-recommended-water-quality-criteria-human-health-criteria-table

6 Elevated temperature wastes shall not cause the temperature of waters designated COLD or WARM to increase by more than 5°F above natural receiving water temperature.

7 5.0 mg/L for waters designated WARM, 7.0 mg/L for waters designated COLD or SPWN.

8 The 1-day minimum warmwater criteria are 5.0 mg/L for early life stages, which includes all embryonic and larval stages and all juveniles forms to 30 days following hatching, and 3.0 mg/L for other life stages. The 1-day minimum coldwater criteria are 8.0 mg/L to achieve required intergravel DO concentrations for early life stages, 5.0 mg/L for early life stages exposed directly to the water column, and 4.0 mg/L for other life stages (EPA's 1986 'Gold Book').

9 Where natural turbidity is between 0 and 5 NTUs, increases shall not exceed 1 NTU. Where natural turbidity is between 5 and 50 NTUs, increases shall not exceed 20 percent. Where natural turbidity is equal to or between 50 and 100 NTUs, increases shall not exceed 10 NTUs. Where natural turbidity is greater than 100 NTUs, increases shall not exceed 10 percent.

10 pH shall not be depressed below 6.5, raised above 8.3, or changed at any time more than 0.3 units from normal ambient pH.

11 The criteria listed are secondary Maximum Concentration Levels for California drinking water quality objectives that do not necessarily indicate a toxic amount of contaminate. Rather these standards dictate water quality objectives designed to preserve taste, odor, or appearance of drinking water.

12 Freshwater aquatic life protection, continuous concentration (4-day average)/maximum concentration (1-hour average).

13 The CCC of 20 mg/L is a minimum value except where alkalinity is naturally lower, in which case the criterion cannot be lower than 25 percent of the natural level.

14 Human health criterion (30-day average) for drinking water sources (consumption of water and aquatic organisms).

15 Human health criterion (30-day average) for other waters (consumption of aquatic organisms only).

16 Criterion is hardness dependent which is expressed as a function of hardness and decreases as hardness decreases. The actual criteria are calculated based on the hardness (as $CaCO_3$) of the sample water. Values displayed above correspond to a total hardness of 100mg/L.

17 Criteria values are from the EPA's 2004 National Recommended Water Quality Criteria.

18 Criterion for freshwater aquatic life protection (EPA's 1986 'Gold Book').

19 Criterion for domestic water supplies (EPA's 1986 'Gold Book').

Table AQ 6-3. Results that Met Water Quality Criteria.

Analyte	Result Completely Consistent With Criteria[1]
***In-Situ* Measurements**	
Water Temperature	Yes
Dissolved Oxygen (DO)	Yes
Turbidity	Yes
Conductivity	Yes
pH	No (Discussed in Text)
General Parameters	
Calcium	No Standard Available (NS)
Chloride	Yes
Hardness (as $CaCO_3$)	NS
Magnesium	NS
Nitrate	Yes
Nitrite	Yes
Nitrate/Nitrite (NO_3)	Yes
Ammonia as N	No (Discussed in Text)
Total Kjeldahl Nitrogen (TKN)	NS
Total Phosphorus	NS
Ortho-phosphate	NS
Potassium	NS
Sodium	NS
Sulfate (SO_4)	Yes
Total Dissolved Solids	Yes
Total Suspended Solids	NS
Turbidity	Yes
Organic Carbon, Total (TOC)	NS
Total Alkalinity	No (Discussed in Text)
Metals-Dissolved	
Arsenic	Yes
Cadmium	Yes
Copper	Yes
Iron	Yes
Lead	Yes
Manganese	Yes
Nickel	Yes
Chromium-Total	Yes

Analyte	Result Completely Consistent With Criteria[1]
Metals-Total	
Mercury	Yes
Bacteria	
Total Coliform	NS
E. coli	Yes

Notes:

NS - No standard available

[1] Applicable water quality criteria come from The Water Quality Control Plan for the Tulare Lake Basin Second Edition, the California Toxics Rule, and the EPA's Federal water quality criteria.

Table AQ 6-4. Water Quality Control Plan for the Tulare Lake Basin - Beneficial Uses Above Lake Kaweah.

Beneficial Use	Definition
Municipal and Domestic Supply (MUN)	Uses of water for community, military, or individual water supply systems including, but not limited to, drinking water supply.
Hydropower Generation (POW)	Uses of water for hydropower generation.
Water Contact Recreation (REC-1)	Uses of water for recreational activities involving body contact with water, where ingestion of water is reasonably possible. These uses include, but are not limited to, swimming, wading, water-skiing, skin and scuba diving, surfing, white water activities, fishing, or use of natural hot springs.
Non-contact Water Recreation (REC-2)	Uses of water for recreational activities involving proximity to water, but where there is generally no body contact with water, nor any likelihood of ingestion of water. These uses include, but are not limited to, picnicking, sunbathing, hiking, beachcombing, camping, boating, tidepool and marine life study, hunting, sightseeing, or aesthetic enjoyment in conjunction with the above activities.
Warm Freshwater Habitat (WARM)	Uses of water that support warm water ecosystems, including, but not limited to, preservation or enhancement of aquatic habitats, vegetation, fish, or wildlife, including invertebrates. WARM includes support for reproduction and early development of warm water fish.
Cold Freshwater Habitat (COLD)	Uses of water that support cold water ecosystems including, but not limited to, preservation or enhancement of aquatic habitats, vegetation, fish, or wildlife, including invertebrates.
Wildlife Habitat (WILD)	Uses of water that support terrestrial or wetland ecosystems, including, but not limited to, preservation and enhancement of terrestrial habitats or wetlands, vegetation, wildlife (e.g., mammals, birds, reptiles, amphibians, invertebrates), or wildlife water and food sources.
Rare, Threatened, or Endangered Species (RARE)	Uses of water that support habitats necessary, at least in part, for the survival and successful maintenance of plant or animal species established under state or federal law as rare, threatened or endangered.
Spawning, Reproduction and/or Early Development (SPWN)	Uses of water that support high quality aquatic habitats suitable for reproduction and early development of fish. SPWN shall be limited to cold water fisheries.
Freshwater Replenishment (FRSH)	Uses of water for natural or artificial maintenance of surface water quantity or quality.

Source: Water Quality Control Plan for the Tulare Lake Basin Second Edition revised May 2018.

Table AQ 6-5. Summary of *In-Situ* Water Quality Measurements, Spring 2018.

Sampling Location	Sample ID	Date	Time	Flow (cfs)	Water Temperature (°C)	Dissolved Oxygen (mg/L)	Turbidity (NTU)	Conductivity (µS/cm)	pH
K3 Flowline Above PH3	6	5/8/2018	825	90	10.82	9.33	3.7	15	7.32
	19	5/30/2018	1145	88	13.53	10.05	1.8	17	7.68
KR Upstream of PH3	8	5/8/2018	1000	841	11.88	9.44	2.0	16	7.35
K2 Flowline Below PH3	9	5/8/2018	1045	68	12.16	9.31	3.1	16	7.36
KR Downstream of PH3	7	5/8/2018	930	773	11.75	9.46	2.2	15	7.35
KR Upstream of the Conf. with EF	10	5/8/2018	1200	773	12.75	9.1	2.3	16	7.4
KR Downstream of the Conf. with EF	11	5/8/2018	1310	1073	13.49	9.21	2.9	23	7.55
KR Upstream of PH1	14	5/9/2018	1110	1088	12.1	9.48	3.6	22	7.51
	23	5/31/2018	845	531	13.56	9.77	0.9	28	7.64
K1 Flowline Above PH1	12	5/9/2018	830	16	9.38	9.3	5.5	38	7.69
	16	5/30/2018	835	16	14.02	9.22	0.5	49	7.46
KR Downstream of PH1	13	5/9/2018	1000	1104	12.05	9.26	3.9	23	7.5
	22	5/31/2018	820	547	13.51	10.04	0.1	29	7.51
K2 Flowline Above PH2	5	5/7/2018	1405	65	14.78	9.35	1.7	19	7.75
	18	5/30/2018	1035	69	15.37	9.87	0.8	18	7.75
KR Upstream of PH2	4	5/7/2018	1250	880	14.05	9.27	2.5	26	7.56
	17	5/30/2018	1015	627	15.37	9.55	1.1	27	7.6
KR Downstream of PH2	15	5/9/2018	1150	1171	13.12	9.15	3.8	23	7.51
	24	5/31/2018	930	616	13.95	9.9	2.8	29	7.76
EF Upstream of K1 Div.	2	5/7/2018	1015	276	9.34	9.57	1.5	41	7.74
EF Downstream of K1 Div.	3	5/7/2018	1100	258	9.59	9.8	2.0	40	7.7
	20	5/30/2018	1300	158	13.63	9.39	0.8	50	7.88
K1 Flowline Below K1 Div.	1	5/7/2018	840	18	9.31	9.71	2.1	40	7.7
EF Upstream of the Conf. with KR	21	5/30/2018	1430	158	16.56	9.31	0.6	50	7.84

Table AQ 6-6. Summary of *In-Situ* Water Quality Measurements, Summer 2018.

Sampling Location	Sample ID	Date	Time	Flow (cfs)	Water Temperature (°C)	Dissolved Oxygen (mg/L)	Turbidity (NTU)	Conductivity (µS/cm)	pH
KR Upstream of PH3	25	8/20/2018	1100	23.6	23.07	8.51	4.0	93	7.86
KR Downstream of PH3	26	8/20/2018	1315	21	24.03	8.43	3.5	92	8.07
KR Upstream of the Conf. with EF	27	8/20/2018	1400	21	25.03	8.44	2.5	92	8.16
KR Downstream of the Conf. with EF	32	8/23/2018	1031	29.2	21.93	8.9	2.2	110	8.04
KR Upstream of PH1	34	8/23/2018	1155	29.2	23.03	8.9	2.4	110	8.14
KR Downstream of PH1	33	8/23/2018	1123	29.68	22.42	8.71	2.3	110	8.12
K2 Flowline Above PH2	36	8/23/2018	1254	2.6	26.9	9.61	2.1	95	8.57
KR Upstream of PH2	35	8/23/2018	1325	29.68	23.8	8.3	1.3	113	8.21
KR Downstream of PH2	37	8/23/2018	1400	32.28	24.64	8.69	1.2	113	8.17
EF Downstream of K1 Div.	29	8/22/2018	900	9.1	18.19	8.97	3.2	136	7.84
EF Upstream of the Conf. with KR	31	8/23/2018	938*	9.2	21.04	8.85	1.9	139	7.82

Notes:

* *In-situ* water quality measurements were taken in the morning and water quality samples were collected in the afternoon.

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Table AQ 6-7. Summary of Analytical Results for Water Quality Samples Collected during the Spring 2018 Sampling Event.

					Sample ID	6, 19	8	9	7	10	11	14, 23	12, 16	13, 22	5, 18	4, 17	15, 24	2	3, 20	1	21
					Sample Location	K3 Flowline Above PH3	KR Upstream of PH3	K2 Flowline Below PH3	KR Downstream of PH3	KR Upstream of the Conf. with EF	KR Downstream of the Conf. with EF	KR Upstream of PH1	K1 Flowline Above PH1	KR Downstream of PH1	K2 Flowline Above PH2	KR Upstream of PH2	KR Downstream of PH2	EF Upstream of K1 Div.	EF Downstream of K1 Div.	K1 Flowline Below K1 Div.	EF Upstream of the Conf. with KR
					Date	5/8/2018[1], 5/30/2018[1]	5/8/2018	5/8/2018	5/8/2018	5/8/2018	5/8/2018	5/9/2018[1], 5/31/2018[1]	5/9/2018[1], 5/30/2018[1]	5/9/2018[1], 5/31/2018[1]	5/7/2018[1], 5/30/2018[1]	5/7/2018[1], 5/30/2018[1]	5/9/2018[1], 5/31/2018[1]	5/7/2018	5/7/2018[1], 5/30/2018[1]	5/7/2018	5/30/2018
					Time	0825, 1145	1000	1045	0930	1200	1310	1110, 0845	0830, 0835	1000, 0820	1405, 1035	1250, 1015	1150, 0930	1015	1100, 1300	0840	1430
General Parameters	**Units**	**MDL**	**PQL/MRL**	**WQ Criteria**																	
Calcium	µg/L	10.79	50.0	NS		1740	2040	2010	1930	2040	3120	3300	6410	3260	2850	3660	3190	6660	6270	6590	7350
Chloride	mg/L	0.08	1.0	250[2]		0.6[J]	0.7[J]	0.7[J]	0.7[J]	0.7[J]	0.7[J]	<MDL	0.7[J]	<MDL	0.7[J]	0.8[J]	<MDL	0.8[J]	0.7[J]	0.7[J]	0.8[J]
Hardness (as $CaCO_3$)	mg/L	1.00	1.0	NS		5.4	6.4	6.4	6.1	6.3	9.2	9.7	17.9	9.6	8.6	10.8	9.4	18.6	17.5	18.5	20.5
Magnesium	µg/L	3.48	25.0	NS		266	316	341	303	298	334	346	468	343	366	400	346	487	456	485	519
Nitrate	mg/L	0.01	0.2	10[2]		<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL
Nitrite	mg/L	0.01	0.1	1[2]		<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL
Nitrate/Nitrite (NO_3)	mg/L	0.028	0.10	10[2]		<MDL	<MDL	<MDL	<MDL	<MDL	0.16	0.34	0.36	0.24	<MDL	<MDL	0.08[J]	<MDL	<MDL	<MDL	1.50
Ammonia as N	mg/L	0.012	0.5	0.025[3]		<MDL	<MDL	**1.6**	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL
Total Kjeldahl Nitrogen (TKN)	mg/L	0.267	0.50	NS		<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	0.41[B,J]
Total Phosphorus	µg/L	24.0	100	NS		<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	39[J]	<MDL	<MDL	49[J]	<MDL	<MDL	<MDL	<MDL	53[J]	<MDL
Ortho-phosphate	mg/L	0.016	0.05	NS		<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL
Potassium	µg/L	93.9	500	NS		370[J]	413[J]	418[J]	401[J]	401[J]	420[J]	415[J]	493[J]	434[J]	419[J]	463[J]	408[J]	504	468[J]	484[J]	473[J]
Sodium	µg/L	82.9	500	NS		884	1060	1020	999	1050	1120	1230	1420	1200	1220	1390	1200	1570	1490	1570	1740
Sulfate (SO_4)	mg/L	0.09	1.0	250[2]		0.7[J]	0.7[J]	0.8[J]	0.7[J]	0.8[J]	1.0	1.1	1.7	1.1	0.8[J]	1.1	1.1	1.9	1.8	1.8	2.0
Total Dissolved Solids	mg/L	4.4	10	500[2]		30	33	34	25	26	35	33	49	41	36	40	35	51	49	48	58
Total Suspended Solids	mg/L	5.6	10	NS		9[J]	11	10	14	11	10	<MDL	<MDL	<MDL	7[J]	7[J]	<MDL	11	8[J]	16	<MDL
Turbidity	NTU	0.035	0.10	Depends on natural turbidity[4]		1.30	1.40	1.40	1.10	0.80	1.00	2.10	2.70	2.10	0.42	0.60	1.40	1.10	0.77	0.72	0.61[H,T]
Organic Carbon, Total (TOC)	mg/L	Not Applicable	0.2	NS		1.6	1.5	1.5	1.5	1.6	1.7	1.6	2.1	1.7	1.5[B]	1.8[B]	1.6	2.2[B]	2.1[B]	2.1[B]	1.6
Total Alkalinity	mg/L	0.85	2.0	>20[5]		5.9	6.6	1.0[J]	6.5	2.8	369	9.4	22.4[B]	11.6	7.8	20.3	9.7	23.6	23.7	24.1	20.4

					Sample ID	6, 19	8	9	7	10	11	14, 23	12, 16	13, 22	5, 18	4, 17	15, 24	2	3, 20	1	21
					Sample Location	K3 Flowline Above PH3	KR Upstream of PH3	K2 Flowline Below PH3	KR Downstream of PH3	KR Upstream of the Conf. with EF	KR Downstream of the Conf. with EF	KR Upstream of PH1	K1 Flowline Above PH1	KR Downstream of PH1	K2 Flowline Above PH2	KR Upstream of PH2	KR Downstream of PH2	EF Upstream of K1 Div.	EF Downstream of K1 Div.	K1 Flowline Below K1 Div.	EF Upstream of the Conf. with KR
					Date	5/8/2018[1], 5/30/2018[1]	5/8/2018	5/8/2018	5/8/2018	5/8/2018	5/8/2018	5/9/2018[1], 5/31/2018[1]	5/9/2018[1], 5/30/2018[1]	5/9/2018[1], 5/31/2018[1]	5/7/2018[1], 5/30/2018[1]	5/7/2018[1], 5/30/2018[1]	5/9/2018[1], 5/31/2018[1]	5/7/2018	5/7/2018[1], 5/30/2018[1]	5/7/2018	5/30/2018
					Time	0825, 1145	1000	1045	0930	1200	1310	1110, 0845	0830, 0835	1000, 0820	1405, 1035	1250, 1015	1150, 0930	1015	1100, 1300	0840	1430
Metals-Dissolved	**Units**	**MDL**	**MRL**	**WQ Criteria**																	
Arsenic	µg/L	0.056	0.204	10[2]		0.124[J]	0.223[J]	0.210	0.215	0.233	0.435	0.564	1.250	0.589	0.269, 0.305	0.566	0.585	0.894	1.200	0.951	1.365
Cadmium	µg/L	0.031	0.092	Hardness dependent[6]		<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL
Copper	µg/L	0.112	0.337	Hardness dependent[6]		0.239[J]	0.261[J]	0.290[J]	0.299[J]	0.283[J]	0.383	0.260[J]	0.573	0.228[J]	0.268[J], 0.271[J]	0.254[J]	0.236[J]	0.224[J]	0.192[J]	0.322[J]	0.233[J]
Iron	µg/L	1.43	4.34	300[2]		65.5	50.7	47.1	45.4	48.2	55.5	37.7	44.0	47.2	166.7, 29.3	48.1	38.6	40.1	47.3	38.4	71.1
Lead	µg/L	0.026	0.077	Hardness dependent[6]		0.041[J]	0.044[J]	0.031[J]	0.028[J]	0.027[J]	0.046[J]	<MDL	0.032[J]	0.029[J]	<MDL	0.028[J]	<MDL	<MDL	0.037[J]	<MDL	0.062[J]
Manganese	µg/L	0.107	0.321	50[2]		2.30	1.74	1.74	1.65	1.95	2.32	1.60	2.05	1.96	3.29, 1.19	2.06	1.80	1.57	2.21	1.65	3.21
Nickel	µg/L	0.117	0.352	Hardness dependent[6]		<MDL	<MDL	<MDL	<MDL	<MDL	0.133[J]	<MDL	0.120[J]	<MDL	<MDL, 0.236[J]	<MDL	<MDL	0.206[J]	<MDL	0.187[J]	<MDL
Chromium-Total	µg/L	0.128	0.383	50[2]		<MDL	0.132[J]	<MDL	0.134[J]	<MDL	0.136[J]	<MDL	0.151[J]	<MDL	<MDL, 0.464	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL
Metals-Total	**Units**	**MDL**	**MRL**	**WQ Criteria**																	
Mercury	ng/L	0.13	0.40	1,400[7]		0.66	0.97	1.12	1.04	0.94	0.94	0.65	0.81	0.70	0.84, 0.72	0.95	0.67	1.29	1.29	1.35	1.28

Note: Bold results do not meet the listed criteria

Acronyms

MRL (Method Reporting Limit): The lowest concentration of a substance that can be reliably reported under current laboratory operating conditions.

PQL (Practical Quantitation Limit): The concentration that can be reliably measured within specified limits and accuracy during routine laboratory operating conditions.

<MDL: Analyte was not detected above the method detection limit and is therefore considered a non-detect.

NS: No standard

Footnotes

[B] The analyte was found in a method blank, as well as in the sample.

[J] Detected by the instrument, the result is greater than the method detection limit but less than or equal to the method reporting limit. Result is reported and considered an estimate.

[H] Holding time exceeded. Due to equipment failure at the primary lab, the sample was subcontracted to another lab and the analysis was completed one day past holding time.

[T] Sample was received above the mandated temperature. Due to equipment failure at the primary lab, the sample was subcontracted to another lab and was received above the mandated temperature. The lab did not indicate by how much temperature was exceeded.

[1] Some locations were sampled twice because samples were missed or because holding times were exceeded during the first sampling effort. Sample results where holding times were exceeded were omitted from this results table except one instance (see "H" flag) where holding time was exceeded due to lab equipment failure.

[2] Water quality objective from the 2018 Water Quality Control Plan for the Tulare Lake Basin Second Edition.

[3] Basin Plan water quality objective is 0.025 mg/L. EPA criterion is pH, temperature, and life cycle dependent. See Table AQ 6-9 for EPA criteria and results.

[4] Where natural turbidity is between 0 and 5 NTUs, increases shall not exceed 1 NTU. Where natural turbidity is between 5 and 50 NTUs, increases shall not exceed 20 percent. Where natural turbidity is equal to or between 50 and 100 NTUs, increases shall not exceed 10 NTUs. Where natural turbidity is greater than 100 NTUs, increases shall not exceed 10 percent.

[5] EPA criterion. The CCC of 20 mg/L is a minimum value except where alkalinity is naturally lower, in which case the criterion cannot be lower than 25 percent of the natural level.

[6] Criterion is hardness dependent which is expressed as a function of hardness and decreases as hardness decreases. The actual criterion is calculated based on the hardness (as CaCO3) of the sample water. Refer to Table AQ 6-11 for sample site criteria and results.

[7] EPA maximum concentration (1-hour average) criterion for freshwater aquatic life protection. Basin Plan water quality objective is less stringent (2,000 ng/L).

Table AQ 6-8. Summary of Analytical Results for Water Quality Samples Collected during the Summer 2018 Sampling Event.

					Sample ID	25	26	27	32	34	33	36	35	37	28	29	30	31
					Sample Location	KR Upstream of PH3	KR Downstream of PH3	KR Upstream of the Conf. with EF	KR Downstream of the Conf. with EF	KR Upstream of PH1	KR Downstream of PH1	K2 Flowline Above PH2	KR Upstream of PH2	KR Downstream of PH2	EF Upstream of K1 Div.	EF Downstream of K1 Div.	K1 Flowline Below K1 Div.	EF Upstream of the Conf. with KR
					Date	8/20/2018	8/20/2018	8/23/2018	8/23/2018	8/23/2018	8/23/2018	8/23/2018	8/23/2018	8/23/2018	8/21/2018	8/21/2018	8/21/2018	8/23/2018
					Time	1100	1315	1400	1031	1155	1123	1254	1325	1400	1250	0900	1415	0938
General Parameters	**Units**	**MDL**	**PQL**	**WQ Criteria**														
Calcium	µg/L	10.79	50.0	NS		8350	8690	9670	13700	13100	14200	10000	14100	13500	21200	21000	20800	21100
Chloride	mg/L	0.08	1.0	250[1]		3.0	3.0	3.0	2.8	2.9	2.7	3.2	3.3	3.4	1.4	1.4	1.3	1.8
Hardness (as $CaCO_3$)	mg/L	1.00	1.0	NS		26.7	27.9	31.0	41.2	39.3	42.6	32.0	42.2	40.7	59.2	58.9	58.2	59.5
Magnesium	µg/L	3.48	25.0	NS		1430	1500	1670	1680	1620	1730	1690	1730	1680	1540	1540	1550	1650
Nitrate	mg/L	0.01	0.2	10[1]		<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL
Nitrite	mg/L	0.01	0.1	1[1]		<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL
Nitrate/Nitrite (NO_3)	mg/L	0.028	0.10	10[1]		<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL
Ammonia as N	mg/L	0.012	0.5	0.025[2]		<MDL	<MDL	<MDL	<MDL	**0.3[J]**	<MDL	<MDL	**0.1[J]**	**0.9**	<MDL	<MDL	<MDL	<MDL
Total Kjeldahl Nitrogen (TKN)	mg/L	0.267	0.50	NS		<MDL	<MDL	<MDL	0.50	<MDL	0.27[J]	0.44[J]	0.72	<MDL	<MDL	<MDL	<MDL	<MDL
Total Phosphorus	µg/L	24.0	100	NS		<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL
Ortho-phosphate	mg/L	0.016	0.05	NS		<MDL	<MDL	0.03[J]	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL
Potassium	µg/L	93.9	500	NS		1180	1210	1360	1320	1310	1430	1410	1470	1400	1230	1270	1270	1350
Sodium	µg/L	82.9	500	NS		5340	5580	6160	6280	6030	6520	6400	6830	6650	5240	5200	5180	6220
Sulfate (SO_4)	mg/L	0.09	1.0	250[1]		2.0	2.0	2.0	3.0	3.0	3.0	2.1	2.9	2.9	4.6	4.7	4.6	4.7
Total Dissolved Solids	mg/L	4.4	10	500[1]		66	66	70	83	87	77	66	78	75	89	90	91	105
Total Suspended Solids	mg/L	5.6	10	NS		<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL
Turbidity	NTU	0.035	0.10	Depends on natural turbidity[3]		0.37	0.39	0.36	0.32	0.31	0.35	0.38	0.40	0.33	0.37	0.41	0.34	0.53
Organic Carbon, Total (TOC)	mg/L	Not Applicable	0.2	NS		1.2	1.3	1.3	1.2	1.2	1.2	1.5	1.2	1.2	0.9[C]	0.9	1.1	1.2
Total Alkalinity	mg/L	0.85	2.0	>20[4]		38.8	40.5	41.0	49.4	49.1	49.6	39.2	49.2	48.8	645	62.9	63.2	63.5
Metals-Dissolved	**Units**	**MDL**	**MRL**	**WQ Criteria**														
Arsenic	µg/L	0.056	0.204	10[1]		3.265	3.190	3.210	3.340	3.120	3.215	3.330	2.950	2.995	2.442	2.450	2.465	3.475
Cadmium	µg/L	0.031	0.092	Hardness dependent[5]		<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL
Copper	µg/L	0.112	0.337	Hardness dependent[5]		0.150[J]	0.174[J]	0.182[J]	0.171[J]	0.280[J]	0.154[J]	0.208[J]	0.141[J]	0.137[J]	0.120[J]	0.125[J]	0.125[J]	0.137[J]
Iron	µg/L	1.43	4.34	300[1]		26.7	27.2	28.1	35.1	36.0	37.0	35.7	47.4	48.8	30.2	33.5	30.7	40.7
Lead	µg/L	0.026	0.077	Hardness dependent[5]		<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL

					Sample ID	25	26	27	32	34	33	36	35	37	28	29	30	31
					Sample Location	KR Upstream of PH3	KR Downstream of PH3	KR Upstream of the Conf. with EF	KR Downstream of the Conf. with EF	KR Upstream of PH1	KR Downstream of PH1	K2 Flowline Above PH2	KR Upstream of PH2	KR Downstream of PH2	EF Upstream of K1 Div.	EF Downstream of K1 Div.	K1 Flowline Below K1 Div.	EF Upstream of the Conf. with KR
					Date	8/20/2018	8/20/2018	8/23/2018	8/23/2018	8/23/2018	8/23/2018	8/23/2018	8/23/2018	8/23/2018	8/21/2018	8/21/2018	8/21/2018	8/23/2018
					Time	1100	1315	1400	1031	1155	1123	1254	1325	1400	1250	0900	1415	0938
Manganese	µg/L	0.107	0.321	50[1]		1.34	1.2	1.10	1.82	1.51	1.55	1.36	2.245	2.25	3.415	3.75	3.26	2.92
Nickel	µg/L	0.117	0.352	Hardness dependent[5]		0.140[J]	<MDL	0.123[J]	0.121[J]	0.121[J]	<MDL	0.120[J]	0.121[J]	0.119[J]	0.122[J]	0.138[J]	0.142[J]	0.124[J]
Chromium-Total	µg/L	0.128	0.383	50[1]		<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL
Metals-Total	**Units**	**MDL**	**MRL**	**WQ Criteria**														
Mercury	ng/L	0.13	0.40	1,400[6]		0.30[J]	0.26[J]	0.31[J]	0.30[J]	0.31[J]	0.30[J]	0.33[J]	0.25[J]	0.28[J]	0.43	0.45	0.46	0.50

Notes: Bold results do not meet the listed criteria

Acronyms:

<MDL: Analyte was not detected above the method detection limit and is therefore considered a non-detect.

MRL (Method Reporting Limit): The lowest concentration of a substance that can be reliably reported under current laboratory operating conditions.

NS: No standard

PQL (Practical Quantitation Limit): The concentration that can be reliably measured within specified limits and accuracy during routine laboratory operating conditions.

Footnotes:

[C] Sample was received without chemical preservation.

[J] Detected by the instrument, the result is greater than the method detection limit but less than or equal to the method reporting limit. Result is reported and considered an estimate.

[1] Water quality objective from the 2018 Water Quality Control Plan for the Tulare Lake Basin Second Edition.

[2] Basin Plan water quality objective is 0.025 mg/L. EPA criterion is pH, temperature, and life cycle dependent. See Table AQ 6-10 for EPA criteria and results.

[3] Where natural turbidity is between 0 and 5 NTUs, increases shall not exceed 1 NTU. Where natural turbidity is between 5 and 50 NTUs, increases shall not exceed 20 percent. Where natural turbidity is equal to or between 50 and 100 NTUs, increases shall not exceed 10 NTUs. Where natural turbidity is greater than 100 NTUs, increases shall not exceed 10 percent.

[4] EPA criterion. The CCC of 20 mg/L is a minimum value except where alkalinity is naturally lower, in which case the criterion cannot be lower than 25 percent of the natural level.

[5] Criterion is hardness dependent which is expressed as a function of hardness and decreases as hardness decreases. The actual criterion is calculated based on the hardness (as CaCO3) of the sample water. Refer to Table AQ 6-12 for sample site criteria and results.

[6] EPA maximum concentration (1-hour average) criterion for freshwater aquatic life protection. Basin Plan water quality objective is less stringent (2,000 ng/L).

Table AQ 6-9. Basin Plan Ammonia Waste Discharge Exceedance Criteria and Calculated Ammonia Concentration Criteria for the Spring 2018 Sampling Event.

Sample Site, Date, Time, and Parameters						Basin Plan Waste Discharge Exceedance Criteria	EPA Ammonia Chronic Criteria[1]	EPA Ammonia Acute Criteria[1]	Ammonia Concentration
Sample ID	**Location Name**	**Date**	**Time**	**pH**	**Temperature (°C)**	**mg/L**	**mg/L**	**mg/L**	**mg/L**
6	K3 Flowline Above PH3	5/08/2018	0825	7.3	10.82	0.025	2.89	17.07	<MDL
8	KR Upstream of PH3	5/08/2018	1000	7.4	11.88	0.025	2.65	16.41	<MDL
9	K2 Flowline Below PH3	5/08/2018	1045	7.4	12.16	0.025	2.58	16.20	**1.6**
7	KR Downstream of PH3	5/08/2018	0930	7.4	11.75	0.025	2.67	16.41	<MDL
10	KR Upstream of the Conf. with EF	5/08/2018	1200	7.4	12.75	0.025	2.41	15.34	<MDL
11	KR Downstream of the Conf. with EF	5/08/2018	1310	7.6	13.49	0.025	2.03	12.31	<MDL
14	KR Upstream of PH1	5/09/2018	1110	7.5	12.1	0.025	2.30	13.09	<MDL
12	K1 Flowline Above PH1	5/09/2018	0830	7.7	9.38	0.025	2.29	9.81	<MDL
13	KR Downstream of PH1	5/09/2018	1000	7.5	12.05	0.025	2.33	13.28	<MDL
5	K2 Flowline Above PH2	5/07/2018	1405	7.8	14.78	0.025	1.51	8.85	<MDL
4	KR Upstream of PH2	5/07/2018	1250	7.6	14.05	0.025	1.94	12.12	<MDL
15	KR Downstream of PH2	5/09/2018	1150	7.5	13.12	0.025	2.15	13.09	<MDL
2	EF Upstream of K1 Div.	5/07/2018	1015	7.7	9.34	0.025	2.17	9.01	<MDL
3	EF Downstream of K1 Div.	5/07/2018	1100	7.7	9.59	0.025	2.24	9.64	<MDL
1	K1 Flowline Below K1 Div.	5/07/2018	0840	7.7	9.31	0.025	2.28	9.64	<MDL
21	EF Upstream of the Conf. with KR	5/30/2018	1430	7.8	16.56	0.025	1.21	6.98	<MDL

Notes: Bold results do not meet the listed criterion.

<MDL: Analyte was not detected above the method detection limit (MDL) and is therefore considered a non-detect. The MDL for ammonia is 0.012 mg/L.

[1] Ammonia criterion calculated using guidelines from the EPA's 2013 Aquatic Life Ambient Water Quality Criteria for Ammonia - Freshwater, which is based on ambient pH and temperature conditions.

Table AQ 6-10. Basin Plan Ammonia Waste Discharge Exceedance Criteria and Calculated EPA Ammonia Concentration Criteria for the Summer 2018 Sampling Event.

Sample Site, Date, and Parameters						Basin Plan Waste Discharge Exceedance Criteria	EPA Ammonia Chronic Criteria[1]	EPA Ammonia Acute Criteria[1]	Ammonia Concentration
Sample ID	Location Name	Date	Time	pH	Temperature (°C)	mg/L	mg/L	mg/L	mg/L
25	KR Upstream of PH3	8/20/2018	1100	7.86	23.07	0.025	0.77	3.92	<MDL
26	KR Downstream of PH3	8/20/2018	1315	8.07	24.03	0.025	0.54	2.45	<MDL
27	KR Upstream of the Conf. with EF	8/20/2018	1400	8.16	25.03	0.025	0.44	1.89	<MDL
32	KR Downstream of the Conf. with EF	8/23/2018	1031	8.04	21.93	0.025	0.65	3.08	<MDL
34	KR Upstream of PH1	8/23/2018	1155	8.14	23.03	0.025	0.52	2.32	0.3[J]
33	KR Downstream of PH1	8/23/2018	1123	8.12	22.42	0.025	0.56	2.54	<MDL
36	K2 Flowline Above PH2	8/23/2018	1254	8.57	26.9	0.025	0.20	0.74	<MDL
35	KR Upstream of PH2	8/23/2018	1325	8.21	23.8	0.025	0.44	1.90	0.1[J]
37	KR Downstream of PH2	8/23/2018	1400	8.17	24.64	0.025	0.45	1.92	**0.9**
28	EF Upstream of K1 Div.	8/22/2018	0900	7.83[2]	18.08[3]	0.025	1.11	6.26	<MDL
29	EF Downstream of K1 Div.	8/22/2018	0900	7.84	18.19	0.025	1.09	6.10	<MDL
30	K1 Flowline Below K1 Div.	8/22/2018	0900	7.83[2]	18.15[3]	0.025	1.10	6.23	<MDL
31	EF Upstream of the Conf. with KR	8/23/2018	0938	7.82	21.04	0.025	0.93	4.99	<MDL

Notes: Bold results do not meet the listed criterion.

<MDL: Analyte was not detected above the method detection limit (MDL) and is therefore considered a non-detect. The MDL for ammonia is 0.012 mg/L.

[1] Ammonia criterion calculated using guidelines from the EPA's 2013 Aquatic Life Ambient Water Quality Criteria for Ammonia - Freshwater, which is based on ambient pH and temperature conditions.

[2] pH was not measured at this site on this date. The pH value was estimated by averaging the pH values at the other sites on the East Fork Kaweah River (EF Downstream of K1 Div. and EF Upstream of the Conf with KR).

[3] Temperature was not measured with a YSI at this site on this date. Temperature values were obtained from the temperature logger reading at this site at 0900 on 8/22/2018.

[J] Detected by the instrument, the result is greater than the method detection limit but less than or equal to the reporting limit (RL). Result is reported and considered an estimate. The RL for ammonia is 0.5 mg/L.

Table AQ 6-11. Hardness-based Water Quality Criteria for Cadmium, Copper, Lead, and Nickel for the Spring 2018 Sampling Event.

Sample ID	**6, 19**	**8**	**9**	**7**	**10**	**11**	**14, 23**	**12, 16**	**13, 22**	**5, 18**	**4, 17**	**15, 24**	**2**	**3, 20**	**1**	**21**
Sample Location	**K3** **Flowline Above PH3**	**KR** **Upstream of PH3**	**K2** **Flowline Below PH3**	**KR** **Downstream of PH3**	**KR** **Upstream of the Conf. with EF**	**KR** **Downstream of the Conf. with EF**	**KR** **Upstream of PH1**	**K1** **Flowline Above PH1**	**KR** **Downstream of PH1**	**K2** **Flowline Above PH2**	**KR** **Upstream of PH2**	**KR** **Downstream of PH2**	**EF** **Upstream of K1 Div.**	**EF** **Downstream of K1 Div.**	**K1** **Flowline Below K1 Div.**	**EF** **Upstream of the Conf. with KR**
Date Sampled	**5/08/2018 5/30/2018**	**5/08/2018**	**50/8/2018**	**5/08/2018**	**5/08/2018**	**5/08/2018**	**5/09/2018 5/31/2018**	**5/09/2018 5/30/2018**	**5/09/2018 5/31/2018**	**5/07/2018 5/30/2018**	**5/07/2018 5/30/2018**	**5/09/2018 5/31/2018**	**5/07/2018**	**5/07/2018 5/30/2018**	**5/07/2018**	**5/30/2018**
Time Sampled	**0825, 1145**	**1000**	**1045**	**0930**	**1200**	**1310**	**1110, 0845**	**0830, 0835**	**1000, 0820**	**1405, 1035**	**1250, 1015**	**1150, 0930**	**1015**	**1100, 1300**	**0840**	**1430**
Hardness ($CaCO_3$) (mg/L)	**5.4**	**6.4**	**6.4**	**6.1**	**6.3**	**9.2**	**9.7**	**17.9**	**9.6**	**8.6**	**10.8**	**9.4**	**18.6**	**17.5**	**18.5**	**20.5**
Cadmium (Cd)																
Laboratory Result (µg/L)	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL
Maximum Criterion (µg/L)	0.12	0.14	0.14	0.13	0.13	0.19	0.20	0.36	0.20	0.18	0.22	0.20	0.37	0.35	0.37	0.41
Continuous Criterion (µg/L)	0.08	0.09	0.09	0.09	0.09	0.12	0.12	0.20	0.12	0.11	0.13	0.12	0.20	0.19	0.20	0.22
Copper (Cu)																
Laboratory Result (µg/L)	0.239[J]	0.261[J]	0.290[J]	0.299[J]	0.283[J]	0.383	0.260[J]	0.573	0.228[J]	0.268[J], 0.271[J]	0.254[J]	0.236[J]	0.224[J]	0.192[J]	0.322[J]	0.233[J]
Maximum Criterion (µg/L)	0.86	1.01	1.01	0.96	0.99	1.42	1.49	2.66	1.48	1.33	1.65	1.45	2.75	2.60	2.74	3.02
Continuous Criterion (µg/L)	0.74	0.86	0.86	0.82	0.84	1.17	1.22	2.06	1.21	1.10	1.34	1.19	2.13	2.02	2.12	2.31
Lead (Pb)																
Laboratory Result (µg/L)	0.041[J]	0.044[J]	0.031[J]	0.028[J]	0.027[J]	0.046[J]	<MDL	0.032[J]	0.029[J]	<MDL	0.028[J]	<MDL	<MDL	0.037[J]	<MDL	0.062[J]
Maximum Criterion (µg/L)	2.42	2.94	2.94	2.78	2.89	4.46	4.74	9.52	4.68	4.13	5.36	4.57	9.94	9.28	9.88	11.10
Continuous Criterion (µg/L)	0.09	0.11	0.11	0.11	0.11	0.17	0.18	0.37	0.18	0.16	0.21	0.18	0.39	0.36	0.39	0.43
Nickel (Ni)																
Laboratory Result (µg/L)	<MDL	<MDL	<MDL	<MDL	<MDL	0.133[J]	<MDL	0.120[J]	<MDL	<MDL, 0.236[J]	<MDL	<MDL	0.206[J]	<MDL	0.187[J]	<MDL
Maximum Criterion (µg/L)	39.63	45.76	45.76	43.94	45.16	62.21	65.05	109.24	64.49	58.76	71.24	63.35	112.84	107.17	112.33	122.52
Continuous Criterion (µg/L)	4.40	5.08	5.08	4.88	5.02	6.91	7.23	12.13	7.16	6.53	7.91	7.04	12.53	11.90	12.48	13.61

Notes: Bold results do not meet the calculated criteria

<MDL: Analyte was not detected above the method detection limit (MDL) and is therefore considered a non-detect. The MDL for cadmium is 0.031 µg/L, the MDL for lead is 0.026 µg/L, and the MDL for nickel is 0.117 µg/L.

[J] Detected by the instrument, the result is greater than the MDL but less than or equal to the method reporting limit (MRL). Result is reported and considered an estimate. The MRL for copper is 0.337 µg/L, the MRL for lead is 0.077 µg/L, and the MRL for nickel is 0.352 µg/L.

California Toxics Rule (CTR) and EPA standard was used for Cu, Pb, and Ni. EPA standard was used for Cd as it is more stringent than the CTR standard.

Formulas used are provided in Appendix B.

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Table AQ 6-12. Hardness-based Water Quality Criteria for Cadmium, Copper, Lead, and Nickel for the Summer 2018 Sampling Event.

Sample ID	25	26	27	32	34	33	36	35	37	28	29	30	31
Sample Location	**KR Upstream of PH3**	**KR Downstream of PH3**	**KR Upstream of the Conf. with EF**	**KR Downstream of the Conf. with EF**	**KR Upstream of PH1**	**KR Downstream of PH1**	**K2 Flowline Above PH2**	**KR Upstream of PH2**	**KR Downstream of PH2**	**EF Upstream of K1 Div.**	**EF Downstream of K1 Div.**	**K1 Flowline Below K1 Div.**	**EF Upstream of the Conf. with KR**
Date Sampled	**8/20/2018**	**8/20/2018**	**8/23/2018**	**8/23/2018**	**8/23/2018**	**8/23/2018**	**8/23/2018**	**8/23/2018**	**8/23/2018**	**8/21/2018**	**8/21/2018**	**8/21/2018**	**8/23/2018**
Time Sampled	**1100**	**1315**	**1400**	**1031**	**1155**	**1123**	**1254**	**1325**	**1400**	**1250**	**0900**	**1415**	**0938**
Hardness (CaCO3) (mg/L)	**26.7**	**27.9**	**31**	**41.2**	**39.3**	**42.6**	**32**	**42.2**	**40.7**	**59.2**	**58.9**	**58.2**	**59.5**
Cadmium (Cd)													
Laboratory Result (µg/L)	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL
Maximum Criterion (µg/L)	0.52	0.54	0.60	0.78	0.75	0.81	0.62	0.80	0.77	1.10	1.09	1.08	1.10
Continuous Criterion (µg/L)	0.27	0.27	0.30	0.37	0.36	0.38	0.30	0.38	0.37	0.48	0.48	0.48	0.49
Copper (Cu)													
Laboratory Result (µg/L)	0.150[J]	0.174[J]	0.182[J]	0.171[J]	0.280[J]	0.154[J]	0.208[J]	0.141[J]	0.137[J]	0.120[J]	0.125[J]	0.125[J]	0.137[J]
Maximum Criterion (µg/L)	3.87	4.04	4.46	5.83	5.57	6.01	4.59	5.96	5.76	8.20	8.16	8.07	8.24
Continuous Criterion (µg/L)	2.90	3.01	3.29	4.20	4.03	4.32	3.38	4.28	4.15	5.72	5.70	5.64	5.75
Lead (Pb)													
Laboratory Result (µg/L)	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL
Maximum Criterion (µg/L)	14.95	15.71	17.68	24.30	23.05	25.22	18.32	24.96	23.97	36.33	36.13	35.66	36.54
Continuous Criterion (µg/L)	0.58	0.61	0.69	0.95	0.90	0.98	0.71	0.97	0.93	1.42	1.41	1.39	1.42
Nickel (Ni)													
Laboratory Result (µg/L)	0.140[J]	<MDL	0.123[J]	0.121[J]	0.121[J]	<MDL	0.120[J]	0.121[J]	0.119[J]	0.122[J]	0.138[J]	0.142[J]	0.124[J]
Maximum Criterion (µg/L)	153.21	159.02	173.84	221.14	212.48	227.48	178.58	225.67	218.87	300.50	299.21	296.20	301.79
Continuous Criterion (µg/L)	17.02	17.66	19.31	24.56	23.60	25.27	19.83	25.07	24.31	33.38	33.23	32.90	33.52

Notes: Bold results do not meet the calculated criteria

<MDL: Analyte was not detected above the method detection limit (MDL) and is therefore considered a non-detect. The MDL for cadmium is 0.031 µg/L, the MDL for lead is 0.026 µg/L, and the MDL for nickel is 0.117 µg/L.

[J] Detected by the instrument, the result is greater than the MDL but less than or equal to the method reporting limit (MRL). Result is reported and considered an estimate. The MRL for copper is 0.337 µg/L and the MRL for nickel is 0.352 µg/L.

California Toxics Rule (CTR) and EPA standard was used for Cu, Pb, and Ni. EPA standard was used for Cd as it is more stringent than the CTR standard.

Formulas used are provided in Appendix B.

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Table AQ 6-13. Edison Beach Coliform Sampling Upstream/Downstream Comparison.

Sample Location	Test	Sample Date				
		7/05/2018	7/12/2018	7/19/2018	7/26/2018	7/31/2018
Upstream of Edison Beach	Total Coliform (MPN/100mL)	>2419.6	>2419.6	>2419.6	>2419.6	>2419.6
	E. coli (MPN/100mL)	69.7	52.9	41.4	14.5	14.5
Downstream of Edison Beach	Total Coliform (MPN/100mL)	>2419.6	>2419.6	>2419.6	>2419.6	>2419.6
	E. coli (MPN/100mL)	30.1	76.9	45.7	18.7	14.8

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FIGURES

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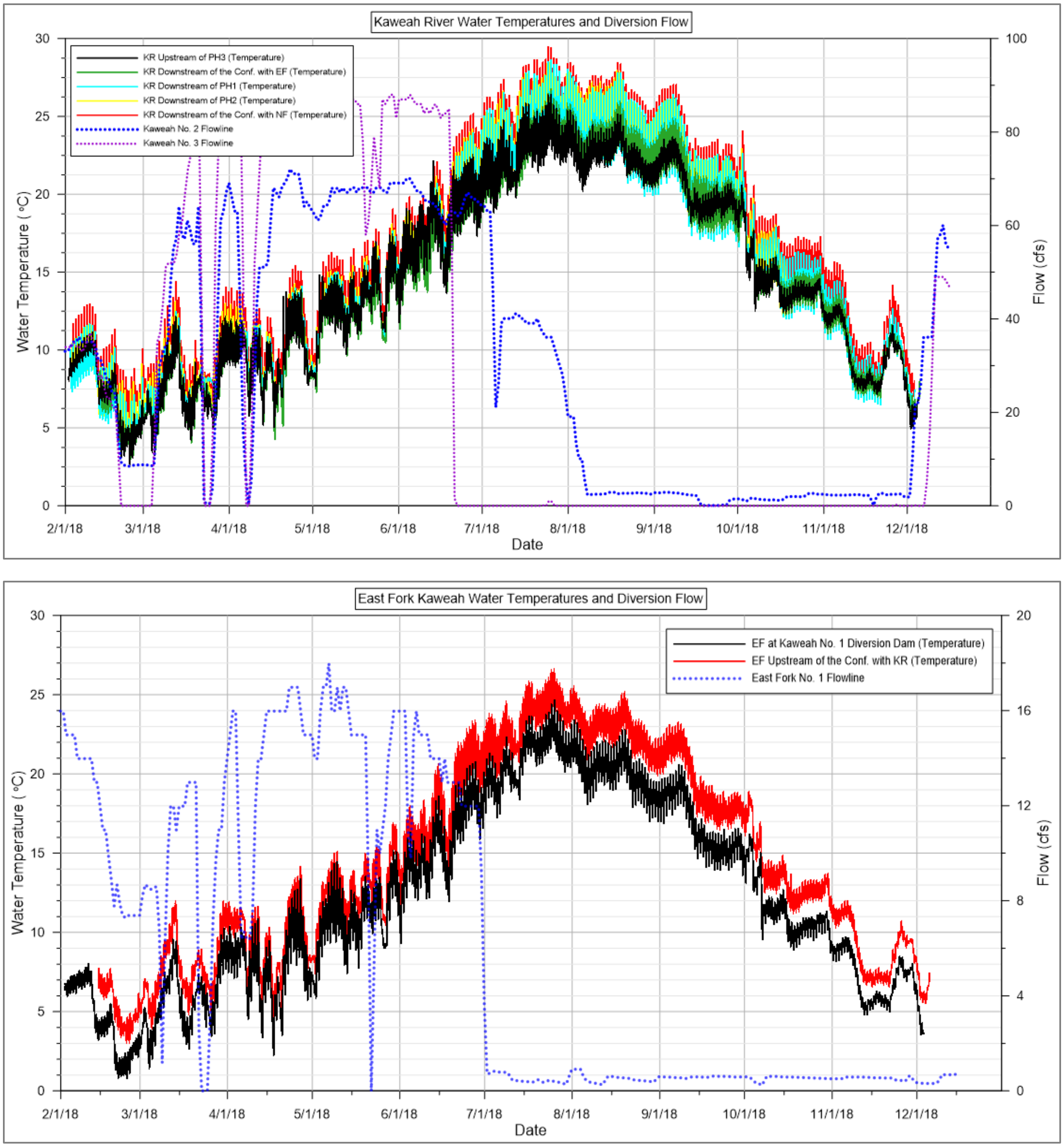

Figure AQ 6-1. 2018 Water Temperature and Flow in Kaweah River and East Fork Kaweah River.

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MAPS

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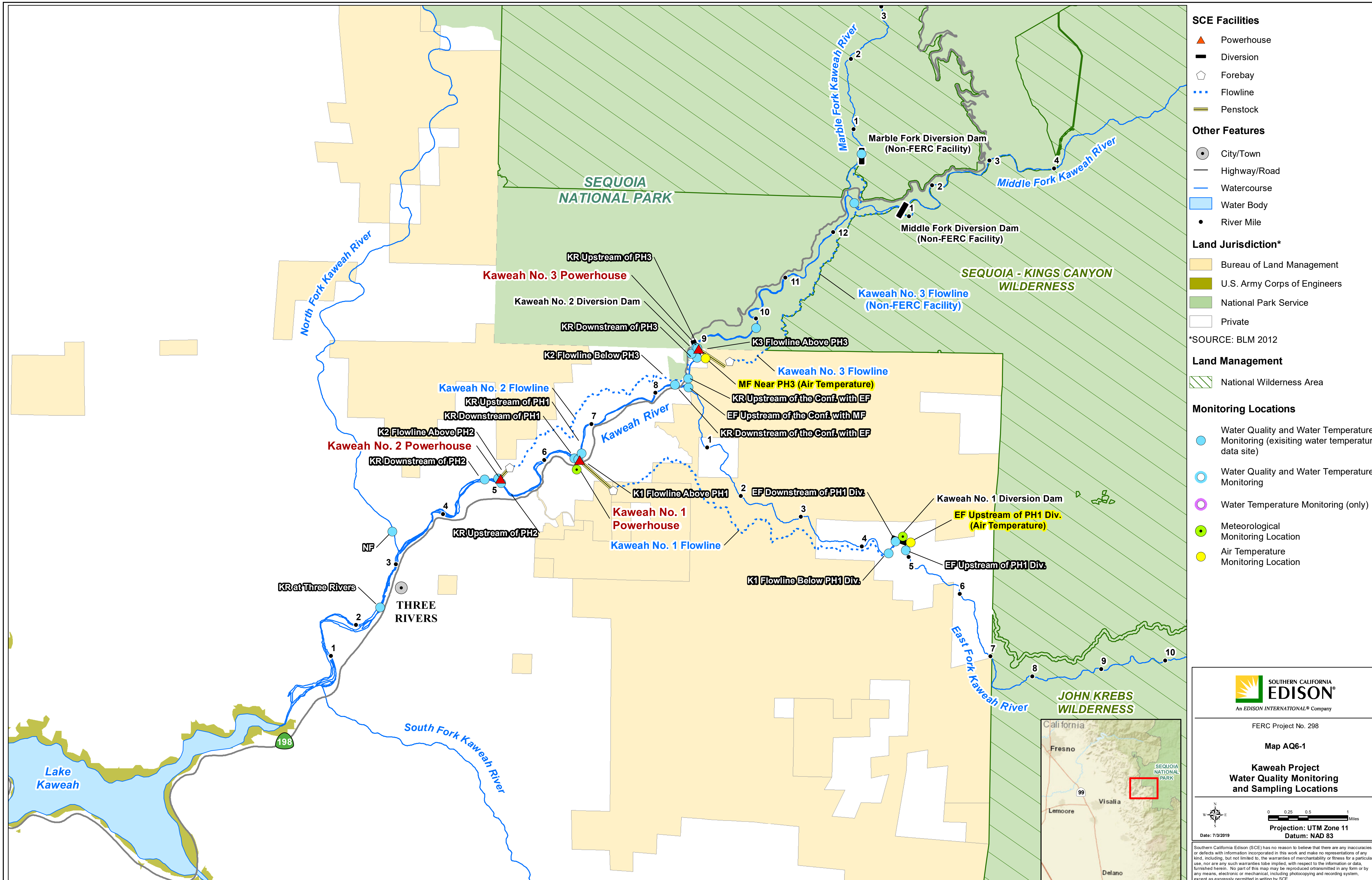

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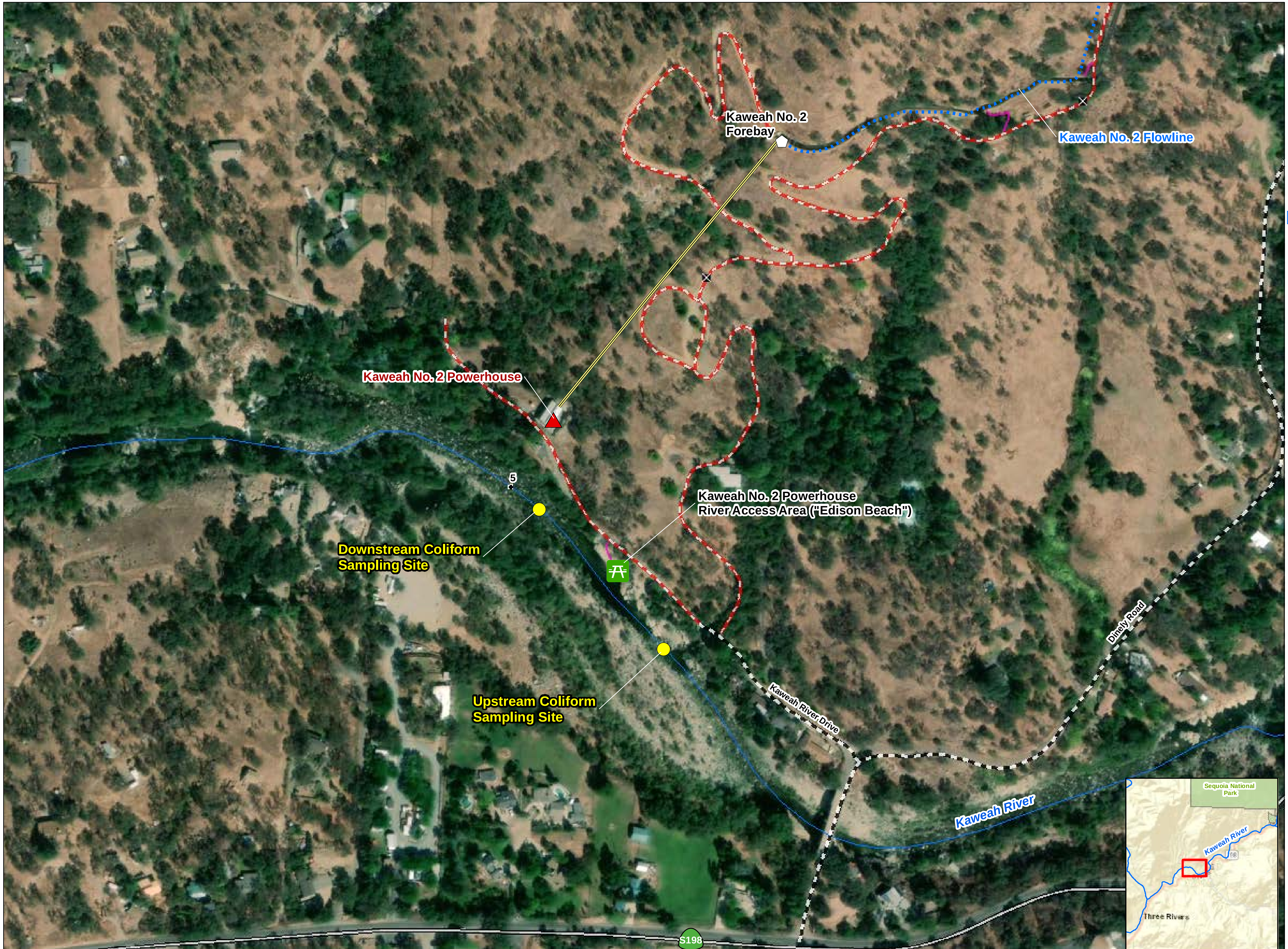

SCE Facilities
- Powerhouse
- Diversion
- Forebay
- Flowline
- Penstock

Other Features
- City/Town
- Highway/Road
- Watercourse
- Water Body
- River Mile

Transportation
- Project Road
- Project Trail
- Non-Project General Access Road
- Gate

Monitoring Locations
- Coliform Sampling Sites

SOUTHERN CALIFORNIA EDISON®
An EDISON INTERNATIONAL® Company

FERC Project No. 298

Map AQ 6-2

Kaweah Project
Edison Beach Coliform
Sampling Locations

N W E S

0 50 100 200 300 Feet

Date: 1/31/2019

Projection: UTM Zone 11
Datum: NAD 83

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APPENDIX A

Overview of Water Quality Parameters

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A.1 Water Quality Monitoring Parameter

A.1.1 *In-situ* Measurements

Temperature

Ambient water temperature is a measurement of the intensity of heat stored in a volume of water and is generally reported in degrees Celsius (°C) or Fahrenheit (°F). Natural heat sources include solar radiation, air transfer, condensation of water vapor at the water surface, sediments, precipitation, surface runoff, and groundwater. Anthropogenic sources of heat include industrial effluents, agriculture, forest harvesting, decreases in streamside vegetation coverage, urban development, and mining.

Water temperature has important effects on aquatic biota. Increased water temperature reduces oxygen solubility while elevating metabolic oxygen demand. This causes lower oxygen concentrations that may be detrimental to some aquatic organisms. Reproductive and other biological activities, such as migration, spawning, egg incubation, and fry rearing, are often triggered by water temperature. A rise in water temperature can also provide conditions for the growth of disease-causing organisms. Temperature also influences the solubility of many chemical compounds, thus affecting their toxicity to aquatic life (EPA 1986, MELP 1998).

Dissolved Oxygen (DO)

Dissolved oxygen (DO) is a measure of the amount of oxygen dissolved in water. Values for DO in water analyses are commonly provided in mg/L, although a percentage of saturation may also be used. The concentration of DO in surface water is usually less than 10 mg/L (MELP 1998). The actual concentration will vary with other parameters such as temperature, elevation, photosynthetic activity, biotic activity, stream discharge, and the concentration of other solutes (Hem 1989, Michaud 1994). The maximum solubility of oxygen (fully saturated) at sea level is 12.75 mg/L at 5ºC and 8 mg/L at 25ºC. DO concentrations decrease within increasing temperatures or elevation (MELP 1998).

Dissolved oxygen is derived from the atmosphere and photosynthetic production by aquatic plants. Atmospheric oxygen is changed to dissolved oxygen when it enters the water, with more mixing occurring in turbulent waters. Dissolved oxygen is essential for the respiration of fish and other aquatic organisms (Michaud 1994). As water moves past their breathing apparatus (such as gills in fish), oxygen gas bubbles in the water (DO) are transferred from the water to their blood. The transfusion is efficient only above certain concentrations. Oxygen is also used for the decomposition of organic matter and other biological and chemical processes. Anoxic waters have obvious detrimental effects on aerobic organisms. These conditions can also lead to the accumulation of chemically reduced compounds, such as ammonium and hydrogen sulfide, in the bottom sediments that can be toxic to benthic organisms (Michaud 1994).

Nutrient solubility and availability rely partly on DO levels, and thus DO also affects the productivity of aquatic ecosystems. In streams, DO concentrations tend to be higher in faster moving waters. During the summer, in particular, when discharges and velocities decrease in streams, DO concentrations can be quite low. Pollution can cause decreases in average DO concentrations by contributing organic matter that uses oxygen or nutrients and stimulates the growth of algae.

Conductivity

Conductivity is a measurement of the ability of water to conduct an electric current and provides an estimate of the concentration of dissolved solids. This property is related to water temperature and total ion content (e.g. chloride, sulfate, sodium, and calcium), and depends on the concentration of dissolved metals and other dissolved materials. Water carries more current with increased ion content in the water. Conductivity is lower in cooler waters. Conductivity is measured in terms of resistance and reported in microsiemens per centimeter (μm/cm) at 25ºC. Water source and geologic composition of the watershed are important controlling factors of conductivity. Streams that flow through granite bedrock, for example, have lower conductivity than those that flow through limestone or clay soils. The conductivity of pure waters is 0.055 μS/cm. The conductivity of freshwater at 25ºC varies between 50 and 1,500 μm/cm (Hem 1989, MELP 1998). Conductivity measurements in streams flowing through granitic, siliceous, or other igneous rocks usually range between 10 and 50 μS/cm. In comparison, it generally ranges between 150 and 500 μS/cm in streams that are flowing through limestones. Conductivity itself is not an aquatic health concern, but serves as an indicator of other water quality concerns.

pH

A pH value is a measure of the activity of hydrogen ions in a water sample. Various types of chemical reactions that occur in natural waters produce hydrogen ions, which are then consumed by participating in subsequent chemical reactions in the system. These interrelated chemical reactions that produce and consume hydrogen ions control the pH value of a water body. It is a useful index of the status of equilibrium reactions in which the water participates. A pH of 7 is considered neutral, values less than 7 are acidic, and values greater than 7 are basic. The units of pH are logarithmic; so a difference of one unit represents a 10-fold change in hydrogen ion concentration. The higher the pH, the fewer free hydrogen ions are present in the water. The pH of natural fresh waters ranges from 4.0 to 10.0, with most waters falling between 6.5 and 8.5 (EPA 1986, Hem 1989, MELP 1998).

The pH of water determines the solubility (the amount that can be dissolved in water) and biological availability (the amount that can be used by aquatic biota) of chemical constituents, such as nutrients (e.g. carbon, nitrogen and phosphorus) and heavy metals (e.g. lead, copper). Unusually high or low pH can have adverse effects on aquatic biota. Values above 9.5 and below 4.5 are considered lethal to aquatic organisms (EPA 1996, MELP 1998). For heavy metals, the degree to which they are soluble determines their toxicity. They tend to be more toxic when pH is lower because they are more soluble and bioavailable.

The pH of water is naturally variable, although the amount of change in natural waters tends to be very small due to many chemical reactions. This ability of the water to maintain a stable pH is called buffering capacity. The initial pH of water is influenced by the geology of the watershed and the original source of the water. In particular, alkalinity, which is typically low in granitic drainages, is usually the primary factor that influences pH values. This causes the waters to be more acidic (pH <7.0) in these types of watersheds (Wetzel 2001). The greatest natural cause for variation is the daily and seasonal changes in photosynthesis. Photosynthesis uses up hydrogen molecules and therefore increases the pH. The pH increases during the day (with maximum values up to 9.0) and decreases at night. Respiration and decomposition processes lower pH. The pH also tends to be higher during the growing season when photosynthesis is greater. As a result, most streams that drain coniferous forests tend to be slight acidic (6.5 to 6.8) (Hem 1989, Michaud 1994, Wetzel 2001).

A.2 Laboratory Analysis Parameter

A.2.1 <u>General Parameters</u>

Calcium

Calcium (Ca) is the most abundant of the alkaline-earth metals and is a major constituent of many common rock minerals and of the solutes present in the water (Hem 1989). It is generally the main cation in surface waters. It is most commonly present as the calcium ion (Ca^{2+}) and is generally derived from weathering or dissolution of minerals in soil and rocks. Under conditions of high bicarbonate or sulfate concentration, calcium bicarbonate or calcium sulfate may exist (Hem 1989). It contributes to the total hardness of water. Calcium is reported in µg/L. Water bodies with less than 10,000 µg/L are considered calcium poor, whereas greater than 20,000 µg/L are considered calcium rich. Average dissolved concentration in river waters ranges from 13,400 µg/L to 15,000 µg/L, but can vary substantially due to geology and climate (Hem 1989). Although calcium is an important constituent of igneous rocks, its concentration in associated water bodies is generally low (Hem 1989) (39 µg/L for granitic watersheds, Wetzel 2001) due to slow decomposition rates of igneous rock materials (Hem 1989).

Calcium is an essential element for metabolism in most plants and animals (Hem 1989). The distribution of many freshwater species, particularly invertebrates, is related to calcium concentration. Significant changes in calcium concentration in a water body can influence the presence or absence of these organisms. Most calcium in surface waters is derived from waters flowing over limestone, dolomite, gypsum, and other calcium-containing sedimentary rocks and minerals.

Chloride

Chloride (Cl-) is among the important anions found in natural waters (Hem 1989). Chloride is reported in mg/L. It originates from the dissociation of salts, such as sodium chloride or calcium chloride, in water. Concentrations tend to be low in fresh waters (8.3 mg/L, on average) (Schlesinger 1997, MELP 1998), and essentially zero in granite drainages (Wetzel 2001). Water will taste salty when the chloride concentrations are greater than 250 to 400 mg/L.

Chloride influences osmotic salinity balance and ion exchange in aquatic organisms, thus making it an important ion for metabolic processes. Increased chloride levels may reduce the toxicity of nitrite to aquatic life (MELP 1998). Fish and invertebrates appear to be more sensitive to increases in chloride levels than aquatic plants. High chloride content can adversely affect plant growth. Fairly low concentrations can be lethal to fish (EPA 1986). Chloride is common in areas with limestone deposits. It is uncommon in most other soils, rocks, or minerals (Hem 1989). Anthropogenic sources of chloride include municipal water supplies, sewage plant effluents, urban development, rock salt, agricultural runoff, and industrial effluents (MELP 1998).

Hardness

The hardness of water is based on its content of calcium and magnesium salts, combined with bicarbonate and carbonate (temporary hardness) and with sulfates, chlorides, and other anions of mineral acids (permanent harness) (MELP 1989). Hardness is expressed in degrees of hardness or mg/L of calcium carbonate ($CaCO_3$). Values greater than 120 mg/L are considered hard, while values less than 60 mg/L are considered soft (Hem 1989, MELP 1989). The EPA (1986) utilizes the following hardness classification:

Concentration $CaCO_3$ (mg/L)	**Description**
<75	Soft Water
75-150	Moderately Hard Water
150-300	Hard Water
>300	Very Hard Water

Water hardness can have indirect effects on aquatic biota, primarily affecting the toxicity of certain metals (MELP 1989). The binding activity of major ions such as calcium and magnesium with metals such as copper, lead, and zinc, will lower the toxicity of these metals by decreasing the bioavailability. Therefore, when water hardness is low, the toxic effects of these metals may increase.

Hardness is influenced by the underlying rock-types, such as limestone. Anthropogenic sources of hardness include the inorganic chemical industry and mines (EPA 1986). The effects of hardness on freshwater fish and other aquatic life appear to be related to the ions causing the hardness rather than hardness (EPA 1986). For this reason, technical guidance groups recommend providing the concentrations of specific ions, rather than using hardness.

Magnesium

Magnesium (Mg) is a common alkaline-earth metal found in igneous, sedimentary, and other rock types. It contributes to the total hardness of water. Magnesium concentration is reported in mg/L or µg/L. It is much more soluble than calcium, with an average concentration of 5,000 µg/L in North American rivers (Schlesinger 1997) and 31 µg/L in granite drainage basins (Wetzel 2001).

Magnesium is an essential nutrient in the metabolic activity of plants and animals. It is commonly present as an ion (Mg^{2+}) and is typically derived from weathering of ferromagnesian minerals in soil and rocks or dissolution of limestone. Similar to calcium, magnesium may exist as magnesium bicarbonate or magnesium sulfate under certain conditions. Magnesium concentrations are not strongly influenced by anthropogenic activities (Hem 1989).

Nitrate/Nitrite

Nitrate (NO_3^-) and nitrite (NO_2^-) ions are produced during nitrification of reduced and organic forms of nitrogen. Nitrate and nitrite are typically reported in mg/L or µg/L. Nitrite is usually present in only minute quantities in water (<0.001 mg/L) because it in an intermediate, unstable form of nitrogen within the nitrogen cycle (MELP 1998). It is formed from nitrate or ammonium ions by certain microorganisms found in soil and water (EPA 1986). Nitrate is formed by the complete oxidation of ammonium by microorganism in the soil and water. It is the most oxidized and stable form of nitrogen in water, and therefore is the principle form of combined nitrogen. Most surface waters contain less than 0.01 mg/L of nitrite and less than 0.2 mg/L nitrate (MELP 1998, Wetzel 2001).

Nitrate is the primary form of nitrogen used during plant growth. Excessive amounts of nitrate may cause phytoplankton or macrophyte outbreaks. Nitrite is toxic to aquatic life at relatively low concentrations (MELP 1998). Although it is an essential plant nutrient, excessive nitrogen can cause proliferation of algae and macrophytes, resulting in eutrophic water conditions. Eutrophication causes decreased oxygen levels which may cause stress or mortality of fish and invertebrates (EPA 1986). Sources of elevated nitrate and nitrite come from municipal and industrial wastewaters, agricultural runoff, urban development, and automobile exhausts.

Ammonia

Ammonia is found in two forms, ammonium (NH_4^+) that is not toxic and NH_3, which is (EPA 1986). Ammonium is readily adsorbed onto mineral surfaces (Hem 1989). It is reported as mg/L or µg/L, with typical surface water values less than 0.1 mg/L (MELP 1998, Wetzel 2001). Ammonia as NH_3 is reported to be toxic to various aquatic organisms over a range of concentrations (0.53 to 22.8 mg/L) (Oram 2007).

Complex nitrogen cycling and processes occur within aquatic systems. Nitrogen is an essential plant nutrient which contributes to the productivity of a water body. However, excessive ammonia over-stimulates the growth of algae and other plants, leading to eutrophication of a water body. The resulting decrease of oxygen levels may cause stress and mortality of fish and invertebrates (EPA 1986). High ammonia concentrations are also toxic to aquatic life. The specific concentration at which ammonia is harmful to organism depends upon the temperature and pH of the water. At higher temperatures and pH, a greater proportion of the total ammonia is present as NH_3, increasing the toxicity of the water (EPA 1986). The distribution of ammonia in surface waters varies spatially and seasonally depending upon productivity and the amount of organic matter. Anthropogenic sources of ammonia include fertilizers, livestock wastes, residential effluents (e.g. cleaning products), mining, sewage treatments plans, and effluent from various types of industries (Oram 2007).

Total Kjeldahl Nitrogen

Total Kjeldahl nitrogen (TKN) is a measure of both the ammonia and organic forms of nitrogen. Organic nitrogen includes organic compounds, such as proteins, polypeptides, amino acids, and urea. TKN is reported in mg/L or μg/L (MELP 1998). In Sierra Nevadan rivers and streams, TKN values typically range between 0.025 and 0.65 mg/L (EPA 2000).

High ammonia concentrations can be deleterious to aquatic life, as it contributes to the eutrophication of water bodies. Organic nitrogen is not biologically available. As a result, it does not influence plant growth or water quality condition until it is transformed to the inorganic forms of nitrogen (MELP 1998). Natural sources of TKN include decaying organic material such as plants and animals wastes. Some species of streamside vegetation, such as alders, are nitrogen fixers. Elevated nitrogen concentrations have been measured in waters with decaying alder leaves (Wetzel 2001). Anthropogenic sources of TKN include effluents from sewage treatment plants and industry, agriculture (fertilizers), urban developments, paper plants, recreation, and mining.

Total Phosphorus

Phosphorus (P) is a nutrient that is essential for growth, and is a measure of both organic and inorganic forms of phosphorus. It can be measured as total phosphorus or ortho-phosphate. Total phosphorus is the total amount of phosphorus in the sample. Ortho-phosphate is the portion that is available to organisms for growth. Total phosphorus measurements include phosphorus that is in biological tissue, as well as the insoluble mineral particles (Michaud 1994, MELP 1998). Phosphorus is fairly abundant in sediments, but concentrations are usually less than a few tenths of a milligram per liter in surface waters (Hem 1989). Total phosphorus concentrations in the rivers and streams in the Sierra Nevada typically range between 2.5 and 485 μg/L (EPA 2000). It is usually reported in μg/L or mg/L.

Phosphorus is essential for plant growth and is often the most limiting nutrient for plant growth in surface waters. As a result, inputs of phosphorus into surface waters can cause algal blooms. Anthropogenic sources of phosphorus include effluents from sewage treatment plants and industry, agriculture, and urban developments (EPA 1986, Hem 1989, MELP 1998).

Ortho-phosphate

Ortho-phosphate (PO_4) is a measure of the inorganic oxidized form of soluble phosphorus. It is generally reported in mg/L or μg/L. Background concentrations of orthophosphate in surface waters generally average 0.01 mg/L (Hem 1989).

Along with nitrogen, phosphorus is a necessary nutrient for plant growth. Ortho-phosphate is the most readily available form of phosphorus for uptake during photosynthesis. Animals obtain phosphorus through the consumption of plant materials. Excess ortho-phosphate causes prolific algal growth, causing the same detrimental water conditions as described for nitrogen and total phosphorus (MELP 1998). Since phosphorus is typically the most limiting nutrient for plant growth in fresh water, additions of this element are often the primary causes of eutrophication of water bodies. Phosphate ions readily and strongly adsorb onto soils, suspended solids, and streambed sediments. As a result, soil erosion can be a source of ortho-phosphate. Other sources include agricultural, urban, and industrial wastewater effluents.

Potassium

Potassium (K) is a common element in most rock types, but occurs in generally lower concentrations and is less soluble than calcium and magnesium (Hem 1989). Potassium is reported in mg/L or μg/L, with an average concentration of 1,400 µg/L in North American rivers and 8 µg/L in granite drainage basins (Wetzel 2001).

Potassium is important in the cellular ion transport and exchange processes of plants and animals, especially for algae growth (Wetzel 2001). Potassium is derived during the weathering of feldspar and mica minerals from rocks and soil. Another potential source of potassium is release through the decay of plant materials (Hem 1989). The alteration of potassium concentration in natural waters is not common, except when effluent from industrial, agricultural, or urban sources exist or runoff from road salts reaches a water body (Wetzel 2001). This type of pollution can cause significant alteration in the ionic composition of water bodies and ultimately change the balance of plant and animal productivity.

Sodium

Sodium (Na) is the most abundant of the alkaline-earth metals and is commonly found in solution (Hem 1989). It generally has lower water concentrations than calcium, except in igneous dominated watersheds (Wetzel 2001). Sodium is typically reported in mg/L, with concentrations that range from less than 1 mg/L to more than 500 mg/L. An average sodium concentration of 9.0 mg/L is found in North American rivers (Schlesinger 1997) and 0.088 mg/L in granite drainage basins (Wetzel 2001).

Sodium is important in the cellular ion transport and exchange processes of plants and animals (Wetzel 2001). Certain species of cyanobacteria require high amounts of sodium for photosynthesis, metabolism, and nitrogen fixation. The enrichment of water with high levels of sodium and phosphorus from domestic effluents can result in large cyanobacteria populations (Wetzel 2001). Sodium is typically present as an ion (Na^+) and is commonly derived from the weathering of rocks and soil or the dissolution of sodium salts (Hem 1989). Similar to potassium, sodium concentrations in natural water bodies are not easily altered, except by pollutants such as road salts, industrial effluent, and agricultural runoff (Hem 1989, Wetzel 2001).

Sulfate

Sulfate (SO_4^{2-}) is a relatively common anion produced during geochemical weathering of sulfides (reduced form) from igneous and sedimentary rocks and soils (Hem 1989, Wetzel 2001). Sulfate is reported in mg/L or μg/L, with an average concentration of 20 mg/L in North American rivers (Schlesinger 1997) and 0.031 mg/L in granite drainage basins (Wetzel 2001).

Sulfur is essential for proper metabolic functioning of all organisms. The primary sources of sulfur compounds to water bodies is atmospheric precipitation, which is largely due to the combustion of fossil fuels, oxidation of metallic sulfides, and smelting of ores (Hem 1989, Wetzel 2001). Sulfate is naturally released from volcanic regions, during rock weathering, and through sulfur-reducing bacterial activity (Hem 1989, Wetzel 2001). The most extensive natural occurrence of sulfate is in evaporate sediments and rocks. Sulfate tends to form complex ions with sodium and calcium (Hem 1989). Strong acids associated with sulfate are major contributors to acidifications of lakes and rivers (Hem 1989, Wetzel 2001).

Total Dissolved Solids

Total dissolved solids (TDS) is a measure of the concentration of inorganic salts (e.g. sodium, chloride, potassium, calcium, magnesium, and sulfate), small amounts of organic material, and dissolved materials in the water column and is reported in mg/L. The value of TDS in fresh water naturally ranges from 0 to 1,000 mg/L (EPA 1986, MELP 1998). Concentrations tend to be comparatively low in streams in granitic and sandstone-dominated watersheds than watersheds with abundant limestone.

The effect of elevated TDS levels on aquatic biota depends on the ionic composition of the dissolved material and the extent of the increase in concentration. Under natural conditions, all aquatic life must be able to survive a range of TDS concentrations (EPA 1986). Sources of total dissolved solids include sewage, stormwater and agricultural runoff, salts from roads, and industrial and water treatment plant wastewater discharges. Total dissolved solids can also be derived from natural sources, including carbonate and salt deposits and mineral springs.

Total Suspended Solids

Total suspended solids (TSS) is a measurement of particulate matter suspended in the water column and is typically reported in mg/L (MELP 1998). Nephelometric Turbidity Units (NTUs) correspond approximately to TSS concentrations. Total suspended solids fluctuate with stream flow and may increase significantly during snowmelt and runoff from rain events. Streams in forested watersheds tend to have low TSS concentrations, usually less than 50 mg/L, although concentrations can be naturally much higher in some streams and rivers (Windell 1992). Waters with TSS concentrations less than 20 mg/L are usually considered to be clear. Concentrations between 40 and 80 mg/L are considered to be cloudy. Waters with concentrations greater than 150 mg/L appear dirty.

High TSS concentrations can increase turbidity, resulting in reduced light penetration, reduced primary productivity, damage to fish gills, and impaired fish feeding ability. Once the suspended solids settle on the stream or lake bottom, invertebrate and other benthic organisms and fish spawning can be adversely affected (EPA 1986).

The freshwater aquatic life criterion for TSS set forth in the EPA's *Quality Criteria for Water* (1976) states that 'settable and suspended solids should not reduce the depth of the composition point for photosynthetic activity by more than 10 percent from the seasonally established norm for aquatic life.' In other words, light penetration should not be decreased more than 10 percent.

Turbidity

Turbidity is a measurement of the amount of light that is scattered or absorbed from a water sample. It is an indicator of suspended particulate matter in a water body. More suspended particles in the water cause greater scattering. Materials that contribute to turbidity include silt, clay, finely divided organic material, soluble organic compounds, and microorganisms (Michaud 1994, MELP 1998). Turbidity values are reported in NTUs. In general, turbidity values of 10 NTU or less represent very clear water; 50 NTU is cloudy; and 100 to 500 NTU is very cloudy or muddy. Rivers and streams in the Sierra Nevada are typically very clear, with turbidity measurements ranging between 1.65 and 5.73 NTU (EPA 2000).

High turbidity levels can have adverse effects in aquatic ecosystems. High turbidity reduces light penetration, which impairs photosynthesis of submerged vegetation and algae (MELP 1998, Michaud 1994). A reduction in plant growth will reduce the production of aquatic invertebrates and fish species. In addition, as particulates settle, they can adversely affect larvae by filling in the spaces between the rocks that may be used as habitat. High turbidity also affects the ability of fish to find and capture food and can impair gill function in some fish under chronically high levels (Michaud 1994). High turbidity also increases the total available surface area of suspended solids upon which metals and other pollutants can attach and bacteria can grow.

Turbidity values can be naturally variable. Waters are often more turbid following rain events, which may increase erosion and urban runoff. Turbidity increases can also be caused by effluents from wastewater and septic systems, decaying plants and animals, and bottom-feeding fish.

Total Organic Carbon

Total Organic Carbon (TOC) is a measure of the dissolved and particulate organic carbon in water, which is primarily composed of humic substances and decomposing plant and animal materials. Total organic carbon is reported as mg/L. Values in natural waters are usually between 1 and 30 mg/L (Hem 1989, MELP 1998). In small streams, the proportion of dissolved organic carbon relative to particulate organic carbon increases downstream as particles are broken down and decomposed. In slower moving larger rivers, TOC can also be derived from phytoplankton growth and rooted plants (Schlesinger 1997).

Carbon is required for biological processes. Dissolved oxygen concentrations are inversely related to organic carbon concentrations. The amount of TOC in the water varies with flow with generally higher concentrations at higher flows (Schlesinger 1997). Natural sources include decomposing leaves and roots that may enter directly into a stream or waterbody, particularly from the adjacent riparian zone and floodplain. Dissolved sources include soluble carbohydrates and amino acids that are leached from decomposing leaves and roots and humic acids from soil organic matter (Schlesinger 1997). Sources of TOC include agriculture and municipal and industrial water discharges (MELP 1998).

Total Alkalinity (as $CaCO_3$)

Alkalinity is a measurement of the ability of water to neutralize acids (buffering capacity). Alkalinity is the concentration of bases in dissolved in water. These bases are usually carbonate and bicarbonate, but can also be hydroxides. These buffers are important because they slow the rate at which the pH changes. The pH can change naturally as a result of photosynthetic activity of the aquatic vegetation. When the pH is very high (greater than 9) hydroxide ions may also be present. In addition, carbonate and bicarbonate reduce the toxicity of some toxic heavy metals (EPA 1986, Hem 1989, Wetzel 2001). Alkalinity is typically expressed as an equivalent amount of calcium carbonate ($CaCO_3$) in mg/L and generally ranges from 0 to 500 mg/L in fresh waters (MELP 1998). Alkalinity levels up to 400 mg/L are not considered to be detrimental to human health (EPA 1986). Alkalinity values less than 10 mg/L are considered very low and the pH of these waters is very susceptible to acid inputs. Alkalinity values are often very low in granitic drainages (Wetzel 2001). Values between 10 and 20 mg/L are considered moderately susceptible to acid inputs.

In general, very low or high alkalinity itself does not cause detrimental effects to aquatic organisms. However, the concentration of the dissolved materials (alkalinity) and their ratio to one another determines the actual pH and buffering capacity in a given water system (EPA 1986, Wetzel 2001). Waters with very low alkalinity values have little capacity to buffer acid inputs and are thus susceptible to acidification (MELP 1998). As previously discussed, extreme pH values can adversely affect aquatic biota, particularly in low pH (acidic) waters. Acidified drainage basins are known to possess increased sulfate and dissolved aluminum concentrations, as well as significant changes in the ion species and ratios (Wetzel 2001). In some inland waters of extremely high salinity, hydroxide, borate, silicate, phosphate, and sulfide may be the major sources of alkalinity (Wetzel 2001). Relatively few aquatic organisms are adapted to these unusual conditions.

A.2.2 Metals Dissolved

Arsenic

Arsenic (As) is a widely distributed element in the Earth's crust (ATSDR 2007). It is highly volatile and is an important component in many biochemical processes (Hem 1989). In its elemental form, it appears as a metal-like substance but it is usually found in compounds with other elements and appears as white or colorless powder. Inorganic arsenic results from compounds with elements such as oxygen, chlorine, or sulfur. Organic arsenic results from compounds with hydrogen and carbon. Organic arsenic is generally less harmful than inorganic arsenic (ATSDR 2007). Arsenic is measured in μg/L or mg/L. Natural surface water normally contains an arsenic concentration of about 1 μg/L.

Arsenic can be highly toxic to most organisms in excess concentrations. Concentrations above 5 μg/L have been shown to reduce growth and reproduction in aquatic invertebrates and algae (MELP 1998). Concentrations of 550 μg/L have produced mortality in fish (MELP 1998). In addition, organic arsenic can bioaccumulate in fish and shellfish (ATSDR 2007). Concentrations above 25 μg/L can have negative effects on livestock and, therefore, are potentially toxic to wildlife (MELP 1998). Arsenic is used as a preservative for wood, and is used in pesticides, metal alloys (especially in automobile batteries), and semiconductors and light diodes. Anthropogenic sources of arsenic include coal-fired power plants, industrial water discharge, and agricultural runoff (Hem 1989). It occurs naturally in soil and can enter water from wind-blown dust, runoff, and leaching. Volcanoes are another natural source of arsenic (ATSDR 2007).

Cadmium

Cadmium (Cd) is an element that occurs naturally in the environment. It is usually found combined with other elements, such as zinc and lead, rather than occurring as a pure metal (MELP 1998, ATSDR 1999). It can be measured in either the dissolved (as in this study) or in the total state in water. It dissolves in water at varying degrees depending on which other elements it is combined. Cadmium most easily dissolves in water when it is in a compound with chlorides and sulfates. These compounds are usually present only in small amounts in the environment (ATSDR 1999). It is reported in mg/L or μg/L. It usually found in very small concentrations (less than 0.1 μg/L) (Wetzel 2001).

Cadmium has highly toxic effects on aquatic plants and animals in all chemical forms. It is extremely toxic to fish and zooplankton, and has been found to accumulate in plant cells and some aquatic organisms. It also diminishes plant growth. Its toxicity increases with the presence of other metals, including zinc and copper (MELP 1998, Oram 2007). The majority of cadmium is released into the environment from natural sources, primarily from the weather of rocks that naturally contain various amounts of cadmium. In addition, it can be releases into the environment by forest fires and volcanoes. Anthropogenic sources of cadmium include industrial effluents, fossil fuels burning, and mining (ATSDR 1999).

Copper

Copper (Cu) is a metallic element, which can occur as a free native metal or combined with ionic metals (Hem 1989). It is measured in either the total or dissolved state in water samples, and reported in μg/L or mg/L. Copper is typically found in trace concentrations from 1 to 10 μg/L (MELP 1998) and levels near 10 μg/L are common in river water (Hem 1989). The fresh water aquatic life criterion for copper depends on the hardness of the water body being tested. Copper toxicity decreases with increasing hardness and increases with increasing pH (EPA 1986, Wetzel 2001).

Copper is an essential element in plant and animal metabolism, but quantities above normal trace concentrations are highly toxic to most aquatic life forms (MELP 1998). Many of the deleterious effects of copper, such as inhibition of phosphorus uptake in green algae, are highly variable depending on other environmental conditions such as pH, alkalinity, total organic carbon, and water hardness (EPA 1986, Wetzel 2001). Copper may be released during industrial, agricultural, and mining activities. Other common sources include copper plumbing and equipment (Hem 1989, MELP 1998).

Iron

Iron (Fe) is the second most abundant metallic element in the Earth's outer crust, but concentrations in water tend to be small (Hem 1989). Iron can be measured in either the total or dissolved state and reported as μg/L or mg/L. Average iron concentrations of 40 μg/L are found in the world's lake and rivers. The typical amount found in neutral and alkaline surface waters ranges from 0.05 to 0.20 mg/L (Wetzel 2001), with an average of 0.16 mg/L in surface waters in North America (Schlesinger 1997). High concentrations of iron are generally only found in acidic waters (pH less than 3 to 4), such as in runoff of streams from strip mines (Wetzel 2001). Concentrations of iron above 0.3 mg/L cause undesirable taste, and when precipitated out of solution due to oxidation, cause a reddish brown color to the water.

Iron is an essential element in plant and animal respiration and its availability in lakes and streams can limit photosynthetic productivity (Wetzel 2001). The chemical behavior of iron is highly dependent on oxidation intensity and is a function of pH and temperatures (Hem 1989, Wetzel 2001). Iron is released in sediment when igneous rock minerals are broken down by water. Iron is also present in organic matter in soils and can be processed into surface water through oxidation and reduction activities that often involve microorganism (Hem 1989). Industrial effluent, acid mine drainage, and smelters are also sources of iron (MELP 1998).

Lead

Lead (Pb) is a metallic element, which is widely dispersed in sedimentary rocks, but has low natural mobility due to low solubility (Hem 1989). The criterion for lead is expressed in terms of dissolved metal in the water column (MELP 1998). Lead concentration is reported in μg/L. The relative abundances of different species of lead are pH dependent and solubility increases with increasing alkalinity (EPA 1986). The freshwater aquatic life criterion for lead depends on the hardness of the water body being tested. The toxic effects of lead decreases as DO and hardness concentrations increase (MELP 1998).

Lead is toxic to all animals (MELP 1998) and is particularly toxic to aquatic organism at relatively low concentrations (Wetzel 2001). Fossil fuel combustion, especially of leaded gasoline, contributed greatly to the deposition of lead in waterways in the twentieth century. Other sources of lead include industrial effluent, smelting and refining, batteries, and lead pipe used to transport drinking water (Wetzel 2001).

Manganese

Manganese (Mn) is one of the more abundant metallic elements, although there is only one-fiftieth the amount of manganese in the Earth's crust as there is iron (Hem 1989). It does not naturally occur as a metal, but is found in association with various salts and minerals, often with iron compounds (EPA 1986). Its chemical reactivity is very similar to that of iron and they behave much the same way in freshwater systems (Wetzel 2001). It is a minor constituent of many igneous and metamorphic minerals (Hem 1989). It can substitute for iron, magnesium, or calcium in silicate structures, but it is not an essential element of silicate rock minerals (Hem 1989). Small amounts of manganese are often present in dolomite or limestone as a substitute for calcium. The average concentration of manganese in surface waters is about 35 μg/L (Wetzel 2001). It is rarely found in surface waters at concentrations greater than 1 mg/L (EPA 1986).

Manganese is an essential nutrient for microflora, plants, and animals as an enzyme catalyst and as an important component of photosynthesis and nitrogen fixation (EPA 1986, Hem 1989). High concentrations of manganese can have an inhibitory effect on cyanobacteria and green algae and tend to favor diatom growth (Wetzel 2001). Divalent manganese is released into aqueous solution during weathering of rock and through organic processes (Hem 1989).

Nickel

Nickel (Ni) is one of the five ferromagnetic elements. It only occurs as a very small fraction (0.018 percent) in the Earth's crust (HSDB 2007). It can be combined with various other metals, including iron, copper, chromium, and zinc, and may substitute for iron in igneous rocks. Nickel also may be precipitated with iron oxides and manganese oxides (Hem 1989, ATSDR 2005). In addition, nickel can also be combined with other elements, most commonly sulfur, and oxygen. Many of the compounds containing nickel easily dissolve in water (ATSDR 2005). Concentrations in natural surface waters are usually low (10 μg/L, Hem 1989).

Nickel is an essential element in some enzymes found in bacteria and plants. It is an important component in nitrogen fixation and some enzymes (Wetzel 2001). However, when it occurs in large quantities and is combined with some elements, for example nitrate, sulfur, and chloride, nickel can be very toxic to aquatic biota. It may accumulate in some plants (ATSDR 2005). The toxicity of nickel to aquatic biota is dependent on hardness. Toxicity is greater when the water is softer compared to harder water conditions. It can also be released from volcanoes. Nickel is naturally found in all soils, and strongly attaches to particles that contain iron or magnesium. When this occurs, it is not readily available for uptake by plants and animals. Nickel is found in surface waters as a result of weathering of rocks containing nickel. Anthropogenic sources of nickel include industrial effluent, oil-burning and coal-burning power plants, mining, and trash incinerators (ATSDR 2005).

Chromium

Chromium (Cr) is naturally present in the environment and has a number of oxidation states. The most common forms are chromium (0), trivalent (chromium (III)), and hexavalent (chromium (VI)). Hexavalent chromium (chromium VI) compounds are the most toxic state. It is usually measured as total chromium. Naturally, chromium concentrations in surface water are usually less than 10 μg/L (Hem 1989).

Chromium (VI) compounds adversely affect all aquatic biota, including algae. It does not appear to bioaccumulate in plants and animals. It is also a known human carcinogen (EPA 1986). The toxicity of chromium (VI) increases as hardness and pH increase. Chromium (III) is more toxic in soft waters. Chromium naturally occurs in rocks and soil, but in very small amounts. It is also released during volcanic eruptions. Anthropogenic sources of chromium (0), (III) and (VI) include emissions from coal and oil burning and industrial effluents (ATSDR 2000).

A.2.3 Metals - Total

Mercury

Mercury (Hg) is a trace element in the Earth's crust that normally occurs in quantities of only 1 to 2 ng/L in natural waters (MELP 1998). It may be present in the environment as elemental mercury (Hg^0), inorganic mercury (Hg^{2+}), or organic mercury (primarily methyl mercury, MeHg). Elemental mercury was commonly used in thermometers. Methyl mercury is the most toxic of these mercury compounds (EPA 1986). It is a serious neuron-toxin and has been found in high concentrations in lakes far removed from sources of mercury (EPA 1986). Methyl mercury bioaccumulates, which is the process by which organisms that are exposed to chemicals either from their diet, water, or other sources accumulate and retain the chemicals. Inorganic mercury does not accumulate in aquatic organisms. Various chemical and biological processes can readily convert the various forms of mercury. Anaerobic bacteria in sediments readily convert inorganic mercury into methyl mercury. With the exception of gold mining areas where elemental mercury is used, mercury is typically present in surface waters, sediment, or soils as inorganic mercury.

Mercury is highly toxic and has a long retention time in animal cells. Rates of methyl mercury production and bioaccumulation depend not only on the abundance of inorganic mercury but also on a complex assortment of environmental variables which affect the activities and species composition of the bacteria and the availability of the inorganic mercury for methylation (USGS 2003, HSDB 2007). These variables include, but are not limited to, pH of the water, the length of the food chain, dissolved organic matter, soil type, and the proportion of wetlands in the watershed. Once converted to methyl mercury by bacteria, it can bioaccumulate in aquatic organisms and be passed up the food chain (Hem 1989). Temperature, pH, alkalinity, suspended sediment load, and the geomorphology of the watershed are known to affect the accumulation of mercury in fish (Klasing et al. 2006). In addition to bioaccumulating, methyl mercury also biomagnifies (higher concentrations at higher levels in the food chain) (USGS 2003). Because bacteria mediate the rate of methyl mercury formation, fish living in even mildly contaminated waters are not safe to eat.

Detectible levels of mercury are found in almost all fish, with more than 95 percent of it occurring as methyl mercury (Klasing et al. 2006). People primarily become exposed to methyl mercury by consuming fish (Klasing et al. 2006). Fish at the highest trophic levels (higher up the food chain) tend to have higher levels of methyl mercury than those lower in the food chain. Larger and older fish of a given species also tend to have higher methyl mercury levels than smaller and younger fish of the same species. It is particularly toxic to the fetus and young children and can cause serious neurological abnormalities to a fetus even without symptoms in the mother. Recent studies indicate that the fetus is more sensitive to methyl mercury than adults. As a result, the Office of Environmental Health Hazard Assessment has established separate 'reference doses', which is "the daily exposure likely to be without significant risk of deleterious health effects during a lifetime". The reference dose for women of childbearing age and children aged 17 and younger is $1x10^{-4}$ mg/kg-day. For men and women beyond childbearing age, the reference dose is $3x10^{-4}$ mg/kg-day (Klasing et al. 2006).

Mercury contamination can occur from both natural processes and human activities. Mercury is highly volatile and thus, atmospheric deposition is a major pathway into aquatic systems (Hem 1989, MELP 1998). Impounded water and flooding also cause the release of sedimentary mercury (MELP 1998). Sources of mercury contamination include coal combustion, waste incineration, mining and smelting, and production of fertilizers (MELP 1998, USGS 2003). Mercury is typically measured as the total mercury in water, soil, or tissue samples. Water samples containing just 5 to 10 ng/L are considered polluted (MELP 1998).

A.2.4 Bacteria

Total Coliform

Coliform bacteria are a group of several genera of relatively harmless microorganisms that live in soil, water, and the intestines of cold- and warm-blooded animals including humans (Murphy 2007). Total coliform concentrations are reported as the most probable number of bacteria colonies present per 100 milliliter (mL) of sample water (Michaud 1994).

Total coliform bacteria occur naturally in surface and shallow ground waters and are essential in the breakdown or organic matter in water. Oxygen is not a requirement for these bacteria, but they can use it. They produce acid and gas from the fermentation of lactose. Coliform bacteria are not pathogenic and are only mildly infectious. The total coliform group is relatively easy to culture in the lab, and therefore, has been selected as the primary indicatory bacteria for the presence of disease-causing organisms. If large numbers of coliform bacteria are found in water, there is a high probability that pathogenic bacteria or organisms, such as Giardia may be present. Coliform bacteria, rather than actual pathogens, are used to assess water quality because they are easier to isolate and identify (Murphy 2007).

E. coli

Escherichia coli (*E. coli*) is the most common organism in the fecal coliform group, a subgroup of coliform bacteria that live in the intestinal tract and feces of warm-blooded animals (Murphy 2007). *E. coli* concentrations are reported as the most probable number of bacteria colonies present per 100 mL of sample water. The EPA conducted studies in the 1970s and 1980s evaluating fecal coliform, *E. coli*, and enterococci as indicators of fecal contamination and found that *E. coli* is a good predictor of gastrointestinal illness in fresh waters (EPA 2012).

Fecal coliform species by themselves are not usually harmful, although some strains of *E. coli*, such as *E. coli* O157:H7, which is found in the digestive tract of cattle, can cause intestinal illness. The presence of *E. coli* indicates contamination from the feces of humans or other animals, which can contain pathogenic organisms such as bacteria, viruses, and parasites that cause gastrointestinal illness (Windell 1992, Murphy 2007). The major sources of *E. coli* entering freshwater are wastewater treatment plant effluent, failing septic systems, storm water runoff, animal carcasses, and animal and human wastes, including runoff from animal manure and manure storage areas. Human and animal wastes can be washed into storm drains, streams, and lakes during storms (Michaud 1994, Murphy 2007; EPA 2015).

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APPENDIX B

Glossary of Analytical Laboratory Terminology, Units of Measurements, and Calculations

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B.1 Glossary

Method Detection Limit (MDL)

A measure of the method sensitivity. The MDL is the lowest concentration that can be detected by an instrument with correction for the effects of sample matrix and method-specified parameters such as sample preparation. It is defined as, "the minimum measured concentration of a substance that can be reported with 99 percent confidence that the measured concentration is distinguishable from method blank results" (EPA 2016).

Method Reporting Limit (MRL) or Reporting Limit (RL)

The lowest concentration of a substance that can be reliably reported under current laboratory operating conditions. Sometimes referred to as the reporting limit (RL). The MRL is based on the level of the low standard used in the instrument calibration and the volumes/weights used in the analysis of samples (BAL 2016). The MRL cannot be less than the MDL and is typically 3 to 10 times the MDL (BAL 2016). Different labs and agencies may use the terms MRL and Practical Quantitation Limit (PQL) slightly differently, and MRL and/or PQL values are calculated by each lab based on their unique set of instruments and experience. APPL Labs uses PQL and RL interchangeably, BSK Associates Labs uses RL, and Brooks Applied Labs uses MRL.

Practical Quantitation Limit (PQL)

The concentration that can be reliably measured within specified limits and accuracy during routine laboratory operating conditions. It is typically determined by a combination of the instrument detection limit (IDL, the lowest the instrument is capable of seeing with specified confidence limits) and the lowest calibration standard used. The calibration level is selected (usually greater than the IDL) based upon the needs of the specified batch of samples being run. Different labs and agencies may use the terms MRL and PQL slightly differently, and MRL and/or PQL values are calculated by each lab based on their unique set of instruments and experience. APPL Labs uses PQL and RL interchangeably, BSK Associates Labs uses RL, and Brooks Applied Labs uses MRL.

B.2 Units of Measure

The following table summarizes the units used by the laboratories, the Basin Plan (CRWQCB 2018), and the EPA (65 FR 31682, EPA 2019). The laboratory/field units were used throughout the report, and the table below summarizes the conversions from the Basin Plan and EPA units to the units used in the report.

Water Quality Analyte	Laboratory/ Field Unit	Basin Plan Unit	EPA Unit	Conversion to Standard Unit for Report
***In-Situ* Measurements**				
Water Temperature	Celsius (°C)	Fahrenheit (°F)	--	$T_{(°C)} = (T_{(°F)} - 32) / 1.8$
Dissolved Oxygen (DO)	mg/L	mg/L	mg/L	No conversion
Turbidity	NTU	NTU	--	No conversion
Conductivity	µS/cm at 25°C	∝mhos/cm	--	1 ∝mhos/cm = 1 µS/cm at 25°C
pH	unitless	unitless	unitless	No conversion
General Parameters				
Calcium	µg/L	--	--	No conversion
Chloride	mg/L	mg/L	µg/L	Divide µg/L by 1,000
Hardness (as $CaCO_3$)	mg/L	--	--	No conversion
Magnesium	µg/L	--	--	No conversion
Nitrate	mg/L	mg/L	--	No conversion
Nitrite	mg/L	mg/L	--	No conversion
Nitrate/Nitrite (NO_3)	mg/L	mg/L	--	No conversion
Ammonia as N	mg/L	mg/L	mg/L	No conversion
Total Kjeldahl Nitrogen (TKN)	mg/L	--	--	No conversion
Total Phosphorus	µg/L	--	--	No conversion
Ortho-phosphate	mg/L	--	--	No conversion
Potassium	µg/L	--	--	No conversion
Sodium	µg/L	--	--	No conversion
Sulfate (SO_4)	mg/L	mg/L	--	No conversion
Total Dissolved Solids	mg/L	mg/L	--	No conversion
Total Suspended Solids	mg/L	--	--	No conversion
Turbidity	NTU	NTU	--	No conversion
Organic Carbon, Total (TOC)	mg/L	--	--	No conversion
Total Alkalinity (as $CaCO_3$)	mg/L	--	mg/L	No conversion
Metals-Dissolved				
Arsenic	µg/L	mg/L	µg/L	Multiply mg/L by 1,000
Cadmium	µg/L	mg/L	µg/L	Multiply mg/L by 1,000
Copper	µg/L	mg/L	µg/L	Multiply mg/L by 1,000
Iron	µg/L	mg/L	µg/L	Multiply mg/L by 1,000
Lead	µg/L	mg/L	µg/L	Multiply mg/L by 1,000
Manganese	µg/L	mg/L	µg/L	Multiply mg/L by 1,000
Nickel	µg/L	mg/L	µg/L	Multiply mg/L by 1,000
Chromium-Total	µg/L	mg/L	--	Multiply mg/L by 1,000

Water Quality Analyte	Laboratory/ Field Unit	Basin Plan Unit	EPA Unit	Conversion to Standard Unit for Report
Metals-Total				
Mercury	ng/L	mg/L	µg/L	Multiply mg/L by 1,000,000 Multiply µg/L by 1,000
Bacteria				
Total Coliform	MPN/100 mL	--	--	No conversion
E. coli	MPN/100 mL	--	MPN/100 mL	No conversion

B.3 Calculations

Several criteria must be calculated on a site-by-site basis. The following equations apply to those analytes.

Ammonia

Criteria are temperature and pH dependent. Equations are from the EPA's Aquatic Life Ambient Water Quality Criteria for Ammonia – Freshwater (EPA 2013). The Criteria Continuous Concentration (CCC) is a 30-day rolling average concentration of total ammonia nitrogen (milligrams per liter [mg/L]) that cannot be exceeded more than once every three years on average. The Criteria Maximum Concentration (CMC) is the one-hour average concentration of total ammonia nitrogen (mg/L) that cannot be exceeded more than once every three years on average where *Oncorhynchus* species are present. In these equations, temperature should be in degrees Celsius (°C).

$$CCC = 0.8876 \times \left(\frac{0.0278}{1+10^{7.688-pH}} + \frac{1.1994}{1+10^{pH-7.688}}\right) \times \left(2.126 \times 10^{0.028\times(20-MAX(T,7))}\right)$$

$$CMC = MIN\left(\left(\frac{0.275}{1+10^{7.204-pH}} + \frac{39.0}{1+10^{pH-7.204}}\right), \left(0.7249 \times \left(\frac{0.0114}{1+10^{7.204-pH}} + \frac{1.6181}{1+10^{pH-7.204}}\right) \times \left(23.12 \times 10^{0.036\times(20-T)}\right)\right)\right)$$

Cadmium (Cd)

Criteria are hardness dependent. The EPA's national water quality criteria equations for cadmium are more stringent than the California Toxics Rule (CTR) criteria equations (65 FR 31682), so the national water quality criteria equations are used (EPA 2019). These equations calculate the freshwater CCC and CMC for cadmium. Hardness should be in mg/L.

$$CCC\ (in\ \mu g/L) = (1.101672 - [\ln(hardness) * 0.041838]) * e^{0.7977 * \ln(hardness) - 3.909}$$

$$CMC\ (in\ \mu g/L) = (1.136672 - [\ln\ (hardness) * 0.041838]) * e^{0.9789 * \ln(hardness) - 3.866}$$

Copper (Cu):

Criteria are hardness dependent. The EPA's national water quality criteria equations for copper are the same as the equations in the CTR (65 FR 31682, EPA 2019). These equations calculate the freshwater CCC and CMC for copper. Hardness should be in mg/L.

$$CCC\ (in\ \mu g/L) = 0.96 * e^{0.8545 * \ln(hardness) - 1.702}$$

$$CMC\ (in\ \mu g/L) = 0.96 * e^{0.9422 * \ln(hardness) - 1.7}$$

Lead (Pb)

Criteria are hardness dependent. The EPA's national water quality criteria equations for lead are the same as the equations in the CTR (65 FR 31682, EPA 2019). These equations calculate the freshwater CCC and CMC for lead. Hardness should be in mg/L.

$$CCC\ (in\ \mu g/L) = (1.46203 - [\ln(hardness) * 0.145712]) * e^{1.273 * \ln(hardness) - 4.705}$$

$$CMC\ (in\ \mu g/L) = (1.46203 - [\ln(hardness) * 0.145712]) * e^{1.273 * \ln(hardness) - 1.46}$$

Nickel (Ni)

Criteria are hardness dependent. The EPA's national water quality criteria equations for nickel are the same as the equations in the CTR (65 FR 31682, EPA 2019). These equations calculate the freshwater CCC and CMC for nickel. Hardness should be in mg/L.

$$CCC\ (in\ \mu g/L) = 0.997 * e^{0.846 * \ln(hardness) + 0.0584}$$

$$CMC\ (in\ \mu g/L) = 0.998 * e^{0.846 * \ln(hardness) + 2.255}$$

B.4 Sources Cited in this Appendix

65 FR 31682. Water Quality Standards; Establishment of Numeric Criteria for Priority Toxic Pollutants for the State of California. Federal Register. Vol. 65, No. 97. Thursday, May 18, 2000. Rules and Regulations.

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EPA (Environmental Protection Agency). 2013. Aquatic Life Ambient Water Quality Criteria for Ammonia – Freshwater. April.

EPA (Environmental Protection Agency). 2016. Definition and Procedure for the Determination of the Method Detection Limit, Revision 2. EPA 821-R-16-006. December.

EPA (Environmental Protection Agency). 2019. National Recommended Water Quality Criteria – Aquatic Life Criteria Table. Retrieved January 8, 2019, from https://www.epa.gov/wqc/national-recommended-water-quality-criteria-aquatic-life-criteria-table

APPENDIX C

Quality Assurance / Quality Control Laboratory Review

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A quality assurance/quality control (QA/QC) review was performed on the laboratory reports received from APPL Labs, BSK Associates Labs, and Brooks Applied Labs. The review consisted of (1) checking that the sample identification numbers, sample dates and times, and analytes requested on the chain of custody forms matched the sample identification numbers, sample dates and times, and analytes measured in the laboratory reports; (2) checking that the sample identification numbers were consistent throughout the laboratory reports; (3) identifying any samples that did not meet the required holding times; and (4) noting which samples were flagged with quality control data issues by the laboratories. The results of this QA/QC review are summarized for the spring 2018 sampling period in Table C-1 and for the summer 2018 sampling period in Table C-2.

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Table C-1. Quality Assurance/Quality Control Review of Spring 2018 Sample Laboratory Analyses.

Report ID	APPL: 85715	BSK: A8E1235	APPL: 85726	BSK: A8E1690	APPL: 85743	BSK: A8E1691	BAL: 1819010	APPL: 85929	BSK: A8E3998	BSK: A8F0101	BAL: 1822029
Sample Locations	K1 Flowline Below K1 Div. EF Upstream of K1 Div. EF Downstream of K1 Div. KR Upstream of PH2 K2 Flowline Above PH2	K1 Flowline Below K1 Div. EF Upstream of K1 Div. EF Downstream of K1 Div. KR Upstream of PH2 K2 Flowline Above PH2	K3 Flowline Above PH3 KR Downstream of PH3 KR Upstream of PH3 K2 Flowline Below PH3 KR Upstream of the Conf. with EF KR Downstream of the Conf. with EF	K3 Flowline Above PH3 KR Downstream of PH3 KR Upstream of PH3 K2 Flowline Below PH3 KR Upstream of the Conf. with EF KR Downstream of the Conf. with EF	K1 Flowline Above PH1 KR Downstream of PH1 KR Upstream of PH1 KR Downstream of PH2	K1 Flowline Above PH1 KR Downstream of PH1 KR Upstream of PH1 KR Downstream of PH2	K1 Flowline Below K1 Div. EF Upstream of K1 Div. EF Downstream of K1 Div. KR Upstream of PH2 K2 Flowline Above PH2 K3 Flowline Above PH3 KR Downstream of PH3 KR Upstream of PH3 K2 Flowline Below PH3 KR Upstream of the Conf. with EF KR Downstream of the Conf. with EF K1 Flowline Above PH1 KR Downstream of PH1 KR Upstream of PH1 KR Downstream of PH2	EF Upstream of the Conf. with KR	EF Upstream of the Conf. with KR	EF Upstream of the Conf. with KR	K1 Flowline Above PH1 KR Upstream of PH2 K2 Flowline Above PH2 K3 Flowline Above PH3 EF Downstream of K1 Div. EF Upstream of the Conf. with KR KR Downstream of PH1 KR Upstream of PH1 KR Downstream of PH2
Sample ID Numbers	1 2 3 4 5	1 2 3 4 5	6 7 8 9 10 11	6 7 8 9 10 11	12 13 14 15	12 13 14 15	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15	21	21	21	16 17 18 19 20 21 22 23 24
Date Sampled	5/7/2018	5/7/2018	5/8/2018	5/8/2018	5/9/2018	5/9/2018	5/7/2018 - 5/9/2018	5/30/2018	5/30/2018	5/30/2018	5/30/2018 - 5/31/2018
Analysis	General Parameters	General Parameters (TOC)	General Parameters	General Parameters (TOC)	General Parameters	General Parameters (TOC)	Metals (Dissolved and Total)	General Parameters	General Parameters (TOC)	General Parameters (Turbidity)	Metals (Dissolved and Total)
Do all samples match COC?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Is sample ID consistent throughout report?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Were all sample holding times met?	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	No	Yes
Were there any quality control data issues?	No	Yes B2.0: TOC for all samples	No	No	Yes B: Total Alkalinity for Sample 12	No	Yes H: As Cd Cr Cu Fe Mn Ni and Pb for Samples 12 13 14 and 15. These samples were excluded from the report.	Yes B: Total Kjeldahl Nitrogen for Sample 21	No	Yes HT1.0: Turbidity for Sample 21 SC1.1: Turbidity for Sample 21	No

Notes:
APPL = APPL Labs
BAL = Brooks Applied Labs
BSK = BSK Associates Laboratory
TOC = Total Organic Carbon

APPL Labs QC Code:
B: The analyte was found in a method blank, as well as in the sample.

Brooks Applied Labs (BAL) QC Code:
H: Holding time and/or preservation requirements not met.

BSK Associates Laboratory QC Code:
B2.0: Analyte present in the method blank above the method detection limit (MDL). Laboratory does not determine batch acceptance on detections below the reporting limit (RL).
HT1.0: Holding time exceeded. Sample was received at the lab past holding time.
SC1.1: Sample was received above the mandated temperature.

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Table C-2. Quality Assurance/Quality Control Review of Summer 2018 Sample Laboratory Analyses.

Report ID	APPL: 86644	BSK: A8H2862	BSK: A8H3259	APPL: 86653	BSK: A8H3117	APPL: 86677	BSK: A8H3462	BAL: 1834011
Sample Locations	KR Upstream of PH3, KR Downstream of PH3, KR Upstream of the Conf. with EF	KR Upstream of PH3, KR Downstream of PH3, KR Upstream of the Conf. with EF	KR Upstream of PH3, KR Downstream of PH3, KR Upstream of the Conf. with EF	EF Upstream of K1 Div., EF Downstream of K1 Div., K2 Flowline Below K1 Div.	EF Upstream of K1 Div., EF Downstream of K1 Div., K2 Flowline Below K1 Div.	KR Upstream of the Conf. with EF, EF Upstream of the Conf. with KR, KR Downstream of the Conf. with EF, KR Downstream of PH1, KR Upstream of PH1, KR Upstream of PH2, K2 Flowline Above PH2, KR Downstream of PH2	EF Upstream of the Conf. with KR, KR Downstream of the Conf. with EF, KR Downstream of PH1, KR Upstream of PH1, KR Upstream of PH2, K2 Flowline Above PH2, KR Downstream of PH2	KR Upstream of PH3, KR Downstream of PH3, KR Upstream of the Conf. with EF, EF Upstream of K1 Div., EF Downstream of K1 Div., K2 Flowline Below K1 Div., EF Upstream of the Conf. with KR, KR Downstream of the Conf. with EF, KR Downstream of PH1, KR Upstream of PH1, KR Upstream of PH2, K2 Flowline Above PH2, KR Downstream of PH2
Sample ID Numbers	25, 26, 27	25, 26, 27	25, 26, 27	28, 29, 30	28, 29, 30	27, 31, 32, 33, 34, 35, 36, 37	31, 32, 33, 34, 35, 36, 37	25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37
Date Sampled	8/20/2018	8/20/2018	8/20/2018	8/21/2018	8/21/2018	8/23/2018	8/23/2018	8/20/2018 - 8/23/2018
Analysis	General Parameters	General Parameters (Turbidity)	General Parameters (TOC)	General Parameters	General Parameters (TOC, Turbidity)	General Parameters	General Parameters (TOC, Turbidity)	Metals (Dissolved and Total)
Do all samples match COC?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Is sample ID consistent throughout report?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Were all sample holding times met?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Were there any quality control data issues?	No	No	No	No	Yes SC1.4: TOC for Samples 28 and 29	Yes B: Total Alkalinity for Sample 36 (Sample was rerun by lab. Rerun sample was 1 day outside of holding time limit.)	No	No

Notes:

APPL = APPL Labs

BAL = Brooks Applied Labs

BSK = BSK Associates Laboratory

TOC = Total Organic Carbon

APPL Labs QC Code:
B: The analyte was found in a method blank, as well as in the sample.

BSK Associates Laboratory QC Code:
SC1.4: Sample was received without chemical preservation.

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