FA-01b WATER QUALITY MODEL DEVELOPMENT STUDY REPORT

SKAGIT RIVER HYDROELECTRIC PROJECT
FERC NO. 553

Seattle City Light

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Updated Study Report

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List of Acronyms and Abbreviations

°C ....degrees Celsius
1Dmax........................1-day maximum
7DADMax..................7-day average of daily maximum
C-CAP........................Coast Change Analysis Program
cfs...............................cubic feet pers second
City Light...................Seattle City Light
CoSD..........................City of Seattle datum
DEM...........................digital elevation model
DO..............................dissolved oxygen
Ecology ....Washington State Department of Ecology
FERC..........................Federal Energy Regulatory Commission
ft ....feet/foot
GIS ....Geographic Information System
ISR ....Initial Study Report
LiDAR........................Light Detection and Ranging
LP...............................licensing participant
m ....meter
MAE...........................mean absolute error
MAF...........................mean absolute value
m^2/s ....meter squared per second
m^3/s ....cubic meters per second
msl.............................mean sea level
NAVD 88...................North American Vertical Datum of 1988
NSE............................Nash Sutcliffe model efficiency coefficient
NPS ....National Park Service
PBIAS ....percent bias
PRM...........................Project River Mile
Project ....Skagit River Hydroelectric Project
QAPP ....Quality Assurance Program Plan
RAWS........................Remote Automatic Weather Stations
RSME.........................root mean square error

RSP ....Revised Study Plan
SA ....sensitivity analysis
SPD ....Study Plan Determination
SR...............................State Route
SRF ....Shade Reduction Factor
USGS .........................U.S. Geological Survey
USFWS ......................U.S. Fish Wildlife Service
USR............................Updated Study Report
W/m^2 ....watt per square meter
WDFW.......................Washington Department of Fish and Wildlife
WQ.............................water quality
WY ....water year

Glossary of Modeling Terms Used in this Report

Branch	The term used in CE-QUAL-W2 for a subset of a waterbody that consists of an area of coherent flow direction and consistent water-surface slope (e.g., the main stem, side arm, or other region within a reservoir or a defined reach of a river).
Cell	The unique combination of a layer and a segment, each spanning the full width of a branch (i.e., width averaged).
CE-QUAL-W2	The specific computer model selected for simulating temperature and water quality in Project reservoirs and the Skagit River downstream.
Lateral Dimension	The distance in a long and narrow water body from one bank to another approximately orthogonal to the direction of flow.
Layer	Divisions along the vertical dimension.
Longitudinal Dimension	The distance in a long and narrow water body from its upstream end to its downstream end with or against the direction of flow.
Mean Sea Level	A local tidal datum defined by the arithmetic mean of hourly height observations.
Model	A computer simulation of a real-world physical system.
Orientation	The direction of the flow in a segment relative to true north.
Segment	Divisions of a branch along the longitudinal dimension.
Vertical Dimension	The distance in a water body from its surface to its bed with or against the force of gravity.
Waterbody	The term used in CE-QUAL-W2 for a simulated body of water.

1.0 INTRODUCTION

The FA-01b Water Quality Model Development Study (WQ Model Development Study) is being conducted in support of the relicensing of the Skagit River Hydroelectric Project (Project), Federal Energy Regulatory Commission (FERC) No. 553. This study is one component of the overall FA-01 Water Quality Study, which also includes the FA-01a Water Quality Monitoring Study (FA-01a WQ Monitoring Study), which is addressed in a companion report (City Light 2023a). On June 9, 2021, Seattle City Light (City Light) filed a "Notice of Certain Agreements on Study Plans for the Skagit Relicensing" (June 9, 2021 Notice)[1] that detailed additional modifications to the Revised Study Plan (RSP) submitted by City Light on April 7, 2021 (City Light 2021a). The modifications in the June 9, 2021 Notice were agreed to between City Light and supporting licensing participants (LP) (which include the Swinomish Indian Tribal Community, Upper Skagit Indian Tribe, National Marine Fisheries Service, National Park Service [NPS], U.S. Fish and Wildlife Service [USFWS], Washington State Department of Ecology [Ecology], and Washington Department of Fish and Wildlife [WDFW]). The June 9, 2021 Notice included City Light's intent to conduct water quality modeling using CE-QUAL-W2.

In its Study Plan Determination (SPD), FERC approved City Light's proposal in the June 9, 2021 Notice to develop a hydrodynamic water quality model (CE-QUAL-W2) to evaluate water temperatures, specifically the effects of cold-water releases from the reservoirs on water temperatures in the Skagit River downstream of Gorge Dam. FERC also noted that City Light proposed to, after completion of the water temperature model, develop a nutrient and productivity component for the water quality model. In its SPD, FERC states, "…we do not recommend requiring City Light to conduct a future nutrient sampling program and develop a nutrient model for the Project reservoirs, major tributaries, and Skagit River from Gorge Dam to the Skagit estuary..." Notwithstanding, City Light is implementing the WQ Model Development Study as agreed to in the June 9, 2021 Notice as described in Section 2 of this study report.

On March 8, 2022, City Light filed its Initial Study Report (ISR). WDFW, NPS, USFWS, and Upper Skagit Indian Tribe filed requests for study modification. FERC's August 8, 2022 Determination on Requests for Study Modification required no modifications to the WQ Model Development Study.

The WQ Model Development Study is substantially complete and documents hydrodynamic and temperature model development, calibration, and results. City Light will continue data collection and water quality model development and calibration through spring 2023, pursuant to its commitments under the June 9, 2021 Notice. City Light is filing this report of the study efforts with FERC as part of its Updated Study Report (USR) and will supplement results reported herein in a subsequent addendum.

1 Referred to by FERC in its July 16, 2021 Study Plan Determination as the "updated RSP."

2.0 STUDY GOALS AND OBJECTIVES

The goal of this study is to develop a set of hydrodynamic, temperature, and water quality (i.e., nutrients, algae, and dissolved oxygen [DO]) models in the CE-QUAL-W2 modeling platform (Wells 2021a). These models will act as a tool in scenario analyses to evaluate impacts from the Project on aquatic resources. These models will be used to simulate:

- Temperature, nutrients, DO, and algae concentrations within the Project reservoirs and downstream from Gorge Dam.
- The effects of different flow management scenarios on the above variables within the Project reservoirs and downstream in the Skagit River. Scenarios will be developed collaboratively with City Light and the LPs beginning in 2022.

The models simulate water surface elevation in the reservoirs and the river downstream of the Project as a prerequisite to simulating hydrodynamics and temperature. When the CE-QUAL-W2 modeled river reaches for which surface elevations were modeled by the FA-02 Instream Flow Model Development Study (City Light 2023b) and the OM-01 Operations Model Study (City Light 2023d), water elevations were compared to ensure consistency among the models. The models will also simulate several additional variables related to algal growth and nutrient dynamics in the Project.

The June 9, 2021 Notice commitments incorporated within this WQ Model Development Study are identified below.

- City Light will modify the FA-01 Water Quality Study to include development of a CE-QUAL-W2 model to evaluate temperature impacts from the Project on aquatic resources. City Light will seek and incorporate the input of Scott Wells in the development of the CE-QUAL-W2 model. The CE-QUAL-W2 model will be used to evaluate, among other things, the impact of cold-water releases from Ross reservoir on fishery resources. City Light will schedule one or more workshops with the LPs, as needed, to collaboratively develop this model.
- City Light will also modify the study plan to initiate modeling of nutrient and productivity components after (1) the CE-QUAL-W2 model for temperature is developed; and (2) data sources and years available are evaluated against the objectives of the LPs. Concurrently, City Light would continue to collect proposed water quality parameter data and develop the CE-QUAL-W2 framework and integration with the OM-01 Operations Model Study and other modeling tools in order to perform a sensitivity analysis to determine the accuracy and sensitivity of the tool (and data needs) for illustrating nutrient dynamics under alternative operational scenarios.
- City Light will convene a workshop with concerned LPs to discuss parameters, frequency, monitoring locations, and temporal overlap with existing data. The workshop will also identify the parameters to be modeled by CE-QUAL-W2, potential gaps in the model, and the approach to filling the gaps.

This report focuses on the development of the CE-QUAL-W2 models of hydrodynamics and temperature in the Project reservoirs and the Skagit River downstream of the Gorge Development under existing conditions. Water quality variables are in the process of being added to these models, and data collection is underway through spring 2023 to provide the full dataset needed to develop and calibrate the water quality models.

3.0 STUDY AREA

The hydrodynamic and temperature models developed for the Project are limited to the full-pool areas of the three Project reservoirs—Ross Lake, Diablo Lake, and Gorge Lake—including the flowing upper portions of Diablo Lake and Gorge Lake (Figure 3.0-1). Tributary inflows to the reservoirs were not modeled. Instead, they were estimated (described below) and used as inputs to the reservoir models. The Skagit River downstream of Gorge Dam was modeled within its main river channel (i.e., its bankfull width, not its floodplain) to Project River Mile (PRM) 54.6, which is at the Concrete-Sauk Valley Road bridge crossing just below its confluence with the Baker River in Concrete, Washington. The downstream boundary of the model was extended from PRM 65, near the confluence with the Sauk River, to Concrete in January 2022. Characteristics of the three reservoirs and Skagit River downstream to Concrete are summarized in Table 3.0-1.

Table 3.0-1. Study area summary characteristics.

Attribute	Ross Lake	Diablo Lake	Gorge Lake	Skagit River: Gorge Dam to Concrete
Drainage Area (sq. miles)	1,008	1,135	1,172	2,737
Length (miles)	24	4.5	4.5	43.0
Normal Maximum Water Surface Elevation (feet [ft])[1]	1,608.76 (1,602.5)	1,211.36 (1,205)	881.51 (875)	--
Surface Area at Normal Maximum Water Surface Elevation (acres)	11,725	905	235	--
Usable Storage (acre-ft)	1,063,000	6,200	1,600	--
Spillways	2	2	1	--
Spillway Crest Elevation (ft)[1]	1,588.2 (1,582)	1,193.65 (1,187)	831.3 (825)	--
Dam Crest Elevation (ft)[1]	1,621.2 (1,615)	1,224.65 (1,218)	886.8 (880.5)	--

1 All elevations in the table are North American Vertical Datum 1988 (NAVD 88) with the City of Seattle Datum (CoSD) value in parentheses. As described in Section 2.3.1 of the RSP, the CoSD requires a conversion to NAVD 88 in order to be comparable with elevations measured and presented elsewhere in analyses and discussions surrounding Project relicensing.

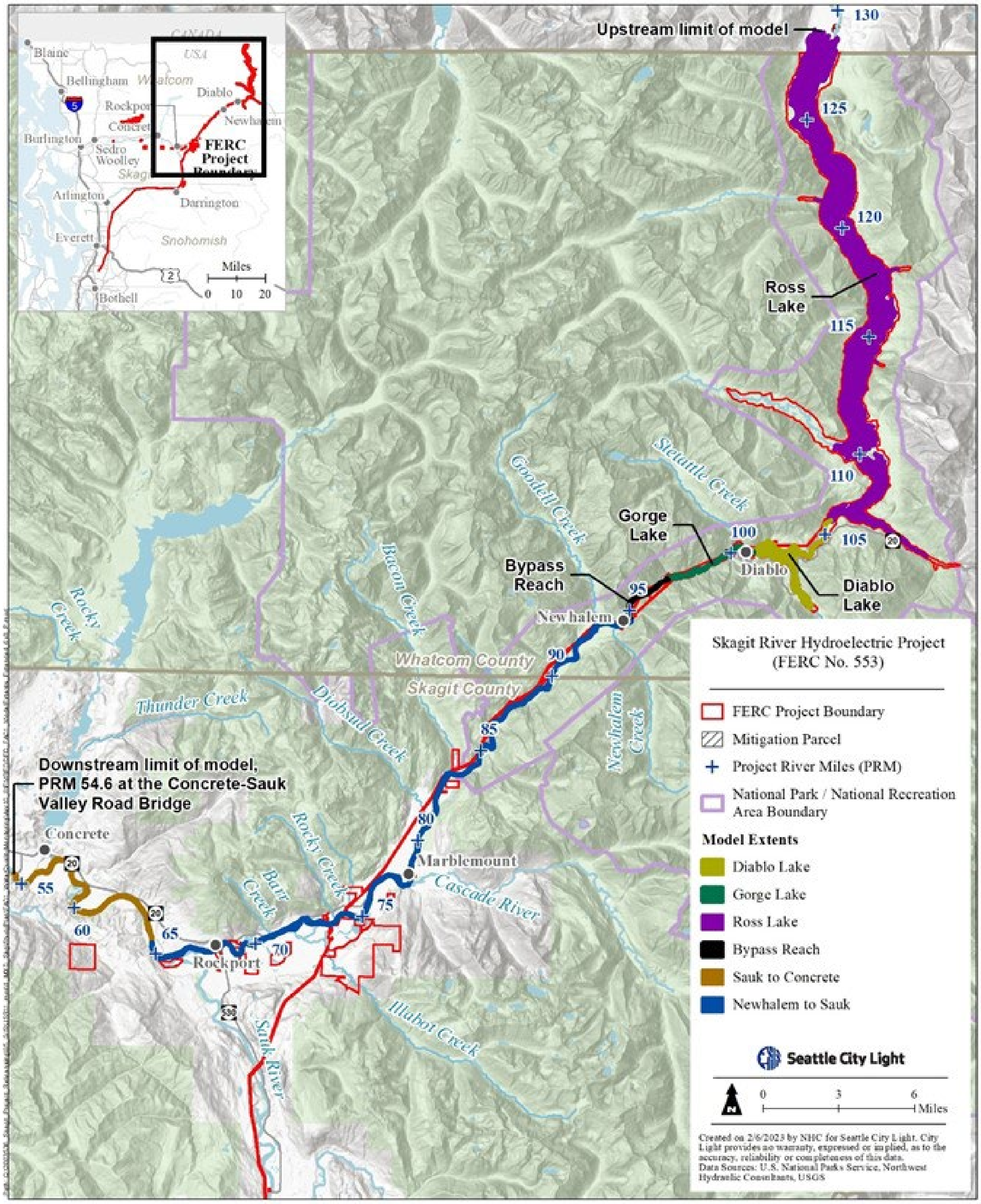

Figure 3.0-1. The study area simulated in the CE-QUAL-W2 models.

4.0 METHODS

4.1 Modeling Quality Assurance Project Plan

The Quality Assurance Program Plan (QAPP) serves as a roadmap to ensure success of this WQ Model Development Study. It is described first in this section of methods because it influences the model development methodology that follows below. This document is required for environmental studies involving Ecology, and a modeling QAPP outlines the procedures and methods to be implemented to ensure study goals and objectives are met specifically for environmental modeling studies. The QAPP is developed during the initial planning stages of the study, can evolve over time, and remains relevant in final documentation.

The modeling QAPP for this WQ Model Development Study was completed in March 2022 (NHC and Geosyntec 2022). An outline of the QAPP is provided below:

- Introduction;
- Problem Definition and Management Objectives;
- Issue/Need Definition;
- Study Goals and Objectives;
- Study Area;
- Key Processes and Variables;
- Technical Approach;
- Model Selection and Limitations;
- Model Development;
- Data Quality Objectives and Criteria;
- Documentation in Model Reports;
- Peer Review;
- Management Scenarios;
- Project Organization;
- Recordkeeping and Archiving
- Implementation and Adaptive Management; and
- References

4.2 Model Development

4.2.1 Overview

The Project and the Skagit River downstream were simulated using CE-QUAL-W2, a two-dimensional, laterally averaged, hydrodynamic and water quality model originally developed by the U.S. Army Corps of Engineers and maintained by Portland State University. The latest available version, which has been used in this modeling effort, is version 4.5 (Wells 2021a).

The two-dimensions of a CE-QUAL-W2 model are: (1) depth; and (2) longitudinal distance in the path of a river channel's flow (i.e., upstream to downstream). CE-QUAL-W2 achieves substantial reductions in required computing resources and model run time by averaging across the lateral dimension of a narrow body of water (i.e., the width or distance from one shoreline to another). In other words, when considering horizontal variation, this modeling software resolves differences in the upstream or downstream directions, but it assumes that a waterbody is uniform across its width. Thus, CE-QUAL-W2 is well-suited for reservoirs like Ross Lake, Diablo Lake, and Gorge Lake, which fill narrow river valleys where lateral averaging is a reasonable assumption. CE-QUAL-W2 is limited in its ability to describe circular or wide lakes where wind blowing across the lake can be more important for circulation than flow from a coherent upstream inflow or a downstream outflow. Similarly, CE-QUAL-W2 is an excellent choice for the Skagit River, which exhibits unidirectional flow downstream and does not spread across a wide floodplain under a wide range of flow regimes.

In CE-QUAL-W2, a simulated body of water is termed a "waterbody." Waterbodies are composed of "branches," which are areas of coherent flow direction (i.e., separate arms of a reservoir) or consistent water-surface slope (i.e., reaches of a river). Water is routed from a given branch into a downstream branch or to the downstream terminus of the model.

Development of a CE-QUAL-W2 model for a waterbody involves development of supporting input files and specifications of values within a control file. Input files include, but are not limited to:

- Bathymetry;
- Meteorology;
- Flow in tributaries;
- Temperature in tributaries; and
- Minor input files.

The development of these files and the control file is described in this section. Although a single model can simulate multiple waterbodies, it is often convenient and efficient to use separate models for separate waterbodies. This study used six separate CE-QUAL-W2 models: one for each reservoir, one for the Gorge bypass reach, and two for the Skagit River downstream of Newhalem. For convenience, the Skagit River downstream of Gorge Dam is described here as a single model because the simulation of different river reaches involved similar activities that were distinct from the simulations of the Project reservoirs. The following sections describe the development of these models separately where activities for each differ.

4.2.2 Bathymetry

This section introduces key concepts of a CE-QUAL-W2 bathymetry file. Subsections below describe the development of specific bathymetry files for Ross Lake, Diablo Lake, Gorge Lake, and the Skagit River downstream of Gorge Dam to Concrete, Washington. Creation of a CE-QUAL-W2 bathymetric file is necessary for model calibration because it determines the appropriate volume-elevation curve for the waterbody, which, in turn, allows the accurate simulation of water level and water residence time. A bathymetry input file in CE-QUAL-W2 specifies, in order, six key pieces of information about the simulated waterbody:

(1) The length of a model "segment." Segments are divisions of the distance from the inflow of the waterbody to its downstream boundary (e.g., a dam or other downstream study limit). Segment length varies between reservoir and river models (see subsections below); segment boundaries are designed to trace curving shoreline features. Figure 4.2-1 shows the relationship between segments and layers within a branch.[2]

(2) The initial elevation of the water surface in each model segment.

(3) The orientation of the segment relative to true north. Description of segments relative to true north and relative to one another allows for the accurate representation of mechanical mixing due to wind.

(4) The friction of the channel bed of the segment. Model segments with flow in their bottom layers are common in rivers, and thus the specification of bed friction in each segment is required. This specification is not generally important for models of deep waterbodies like reservoirs or lakes, so model default values are used (see subsections below).

(5) The thickness of each "layer" within a segment. Layers are vertical divisions of the water column in a CE-QUAL-W2 model that can be conceptualized as horizontal planes within the waterbody. The unique combination of a specific layer and a specific segment is known as a model "cell." Layer thicknesses differ for the river and reservoir models (see subsections below).

(6) The width of each model cell. This specification of a width for model cells of specified length and thickness (i.e., depth) determines their volume, which, in turn, determines the volume for the waterbody. At the surface of a waterbody, the width of a cell is the bankfull width of that river or reservoir. At depth, the width of a cell is the width of the river or reservoir channel a short distance above its bed (Figure 4.2-1).

[2] Branch is the term used in CE-QUAL-W2 for a subset of a waterbody that consists of an area of coherent flow direction and consistent water-surface slope (e.g., the main stem, side arm, or other region within a reservoir or a defined reach of a river).

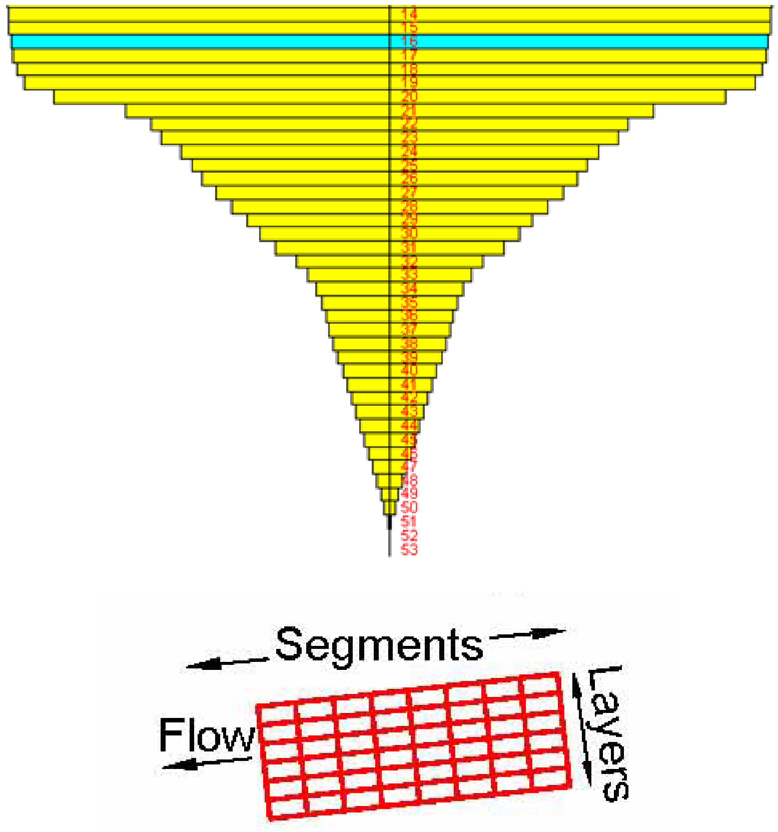

Figure 4.2-1. End-View (top) and side-view (bottom) of typical CE-QUAL-W2 model grid.

A waterbody in CE-QUAL-W2 is described by one bathymetry file. A single waterbody can include multiple branches and separate branches can have unique slopes that are represented in the bathymetry file. Activities specific to the development of the bathymetry files for each model are described below. Digital Elevation Models (DEM) of bathymetry for each of the CE-QUAL-W2 models have been developed from the best available data for each. The data sources are discussed in the sections that follow.[3]

4.2.2.1 Ross Lake

Segmentation

Ross Lake was divided into 178 segments for the Skagit River (main) branch and 34 segments for the Ruby Arm branch. The Skagit River branch segments have a mean length of 713.28 ft with a range of 214.00-1,517.81 ft; the Ruby Arm segments have a mean length of 543.47 ft with a range of 246.58-1,193.80 ft. Segment lengths were determined such that the sides of segments traced major shoreline features of the reservoir. To adequately represent the geomorphic features of the river, and thus the bathymetry, shorter segment lengths were assigned in sections with more shoreline curvature. This resulted in a larger number of segments in meandering parts of the reservoir. Longer segments were defined in relatively straight parts of the reservoir, resulting in

[3] Collection of bathymetry data by City Light is ongoing. These data will not be incorporated into the models discussed herein.

fewer segments in those areas. Thus, a balance was achieved between reducing the computational burden of excess model segments while accounting for the geomorphic variability of the reservoir.

The development of model segments was configured using an automated process[4] followed by manual refinement to ensure that the model segmentations accurately cover the shapes of the waterbodies. Inputs to the software tool consisted of the boundary outline of the reservoir, which was developed in Geographic Information System (GIS), and the specification of an approximate segment length of 820 ft (250 m). Accompanying parameter values in the boundary coordinate shapefile indicated points representing the four corners of the pseudo-rectangular, curvilinear segments. The segment shapes were then defined by the length of the waterbody divided by the segment length as the initial length of each segment. The resulting segments were exported to shapefiles for further manual refinements that focused on angular sections of shoreline and the confluence of the Ruby Arm with the Skagit River branch (e.g., Figure 4.2-2).

Initial Water Surface Elevation

The initial water surface elevation was set at 1,569.99 ft NAVD 88 (1,563.73 ft CoSD) based on the observed water level on the first day of the simulation.

Segment Orientation

Segment orientation was produced by the automated methods described above and spot checked manually to verify quality.

Bed Friction

The Chézy bed friction factor was set at 70 for the reservoir model segments. This is an accepted default value for CE-QUAL-W2 models (Wells 2021b). Although hundreds of submerged trees exist in Ross Lake, the default value is appropriate because we assume that flow velocities at the bottom of Ross Lake have a negligible effect on the overall hydrodynamics of this large lacustrine waterbody. Even in its riverine and transition zones, the rapid increase in width and depth relative to the inflowing river will slow water velocities notably such that model performance is not sensitive to bed friction.

Layer Thickness

Layer thickness was set at 3.28 ft (1 m), which was selected as a compromise between the large layer thicknesses that would decrease computation time (by decreasing the number of cells) and smaller layer thicknesses that would allow for finer resolution of vertical variation in model results (e.g., thermal stratification). The current vertical layers of 3.28 ft are well suited for capturing thermal stratification in the Project reservoirs.

Cell Widths

Cell widths in the bathymetry file were determined from volume-elevation curves developed from the DEM created to represent the reservoir bathymetry. With the cell length and height fixed following the steps described above, the width of each cell is determined by dividing the volume

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4 In the automated process, the model grid shapefiles were developed using Python libraries called "pygridtools" (Hobson 2018) and "pygridgen" (Hetland 2018). Pygridtools is a high-level interface for curvilinear-orthogonal grid generation, manipulation, and visualization, which depends on pygridgen for the generation of new grids.

at a given elevation by that height (1 m) and the cell length. This requires a volume-elevation curve for each segment of the reservoir. These volume-elevation curves were constructed from a DEM of the terrain beneath Ross Lake and near its shoreline to an elevation higher than its full-pool elevation (Figure 4.2-3).

The DEM of the Ross Lake bathymetry was created by merging 40-ft bathymetry contour maps from the 1960s (U.S. Geological Survey [USGS] 1963a; USGS 1969a; USGS 1969b) and Light Detection and Ranging (LiDAR) (topobathymetry) data collected on behalf of City Light in 2018 (Quantum Spatial Inc. 2018a) and reprocessed by HDR Engineering, Inc. (HDR) in 2020 (HDR 2020) when the reservoir was drawn down to an elevation of approximately 1,499.3 ft NAVD 88 (1,493.04 ft CoSD). In areas where the USGS contour data (USGS 1963a; USGS 1969a; USGS 1969b) and the LiDAR data (Quantum Spatial Inc. 2018a; HDR 2020) overlap, the elevation values were expected to differ due to the different data collection methods. This difference was not evaluated, as the LiDAR data are considered more accurate than the USGS contour data. In these areas, the LiDAR data were used wherever possible. However, because the LiDAR surveys did not collect information below the water surface, information was only available for portions of Ross Lake that were exposed when the reservoir was drawn down. Therefore, the LiDAR data were used at elevations above 1,499.3 ft NAVD 88 (1,493.04 ft CoSD), and the USGS contour data were used at elevations below this level. USGS contour data were hand digitized as line shapefiles (Figure 4.2-4) and densified to 3-ft contour intervals to match the resolution of the LiDAR DEMs. To be able to combine the contour data with the LiDAR data, the contour data were interpolated onto a grid with a 3-ft horizontal resolution.

The vertical datum for the contour data was set as the mean sea level (msl), in ft. The vertical datum for the LiDAR, however, was NAVD 88, in ft. The relationship between msl and NAVD 88 at Seattle was used to convert msl to NAVD 88 for the contour DEM. Mean sea level is 4.3 ft above NAVD 88 at Seattle, so 4.3 ft was added to the contour DEM. The lowest elevation for the collected LiDAR for Ross Lake was approximately 1,485 ft. Values above 1,490 ft in the contour DEM and values below 1,500 ft in the LiDAR DEM were set to no data. The 10 ft vertical gap between the two datasets provided a buffer to account for uncertainties in the contour DEM. The two DEMs were merged, and the gaps were filled via numerical interpolation.

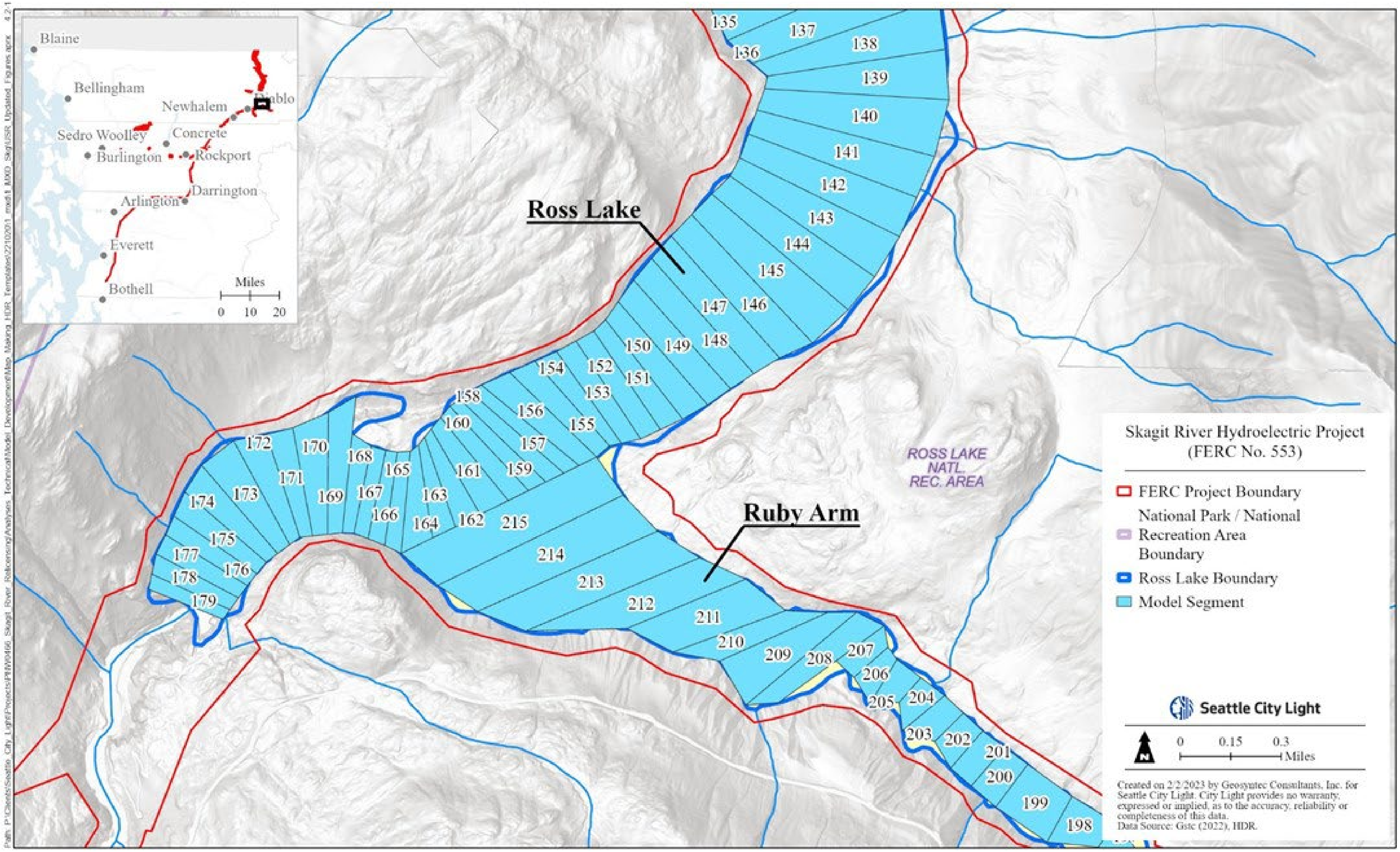


Figure 4.2-2. Example of segmentation of Ross Lake. View is scaled so that individual segments can be identified clearly in the downstream portion of the reservoir.

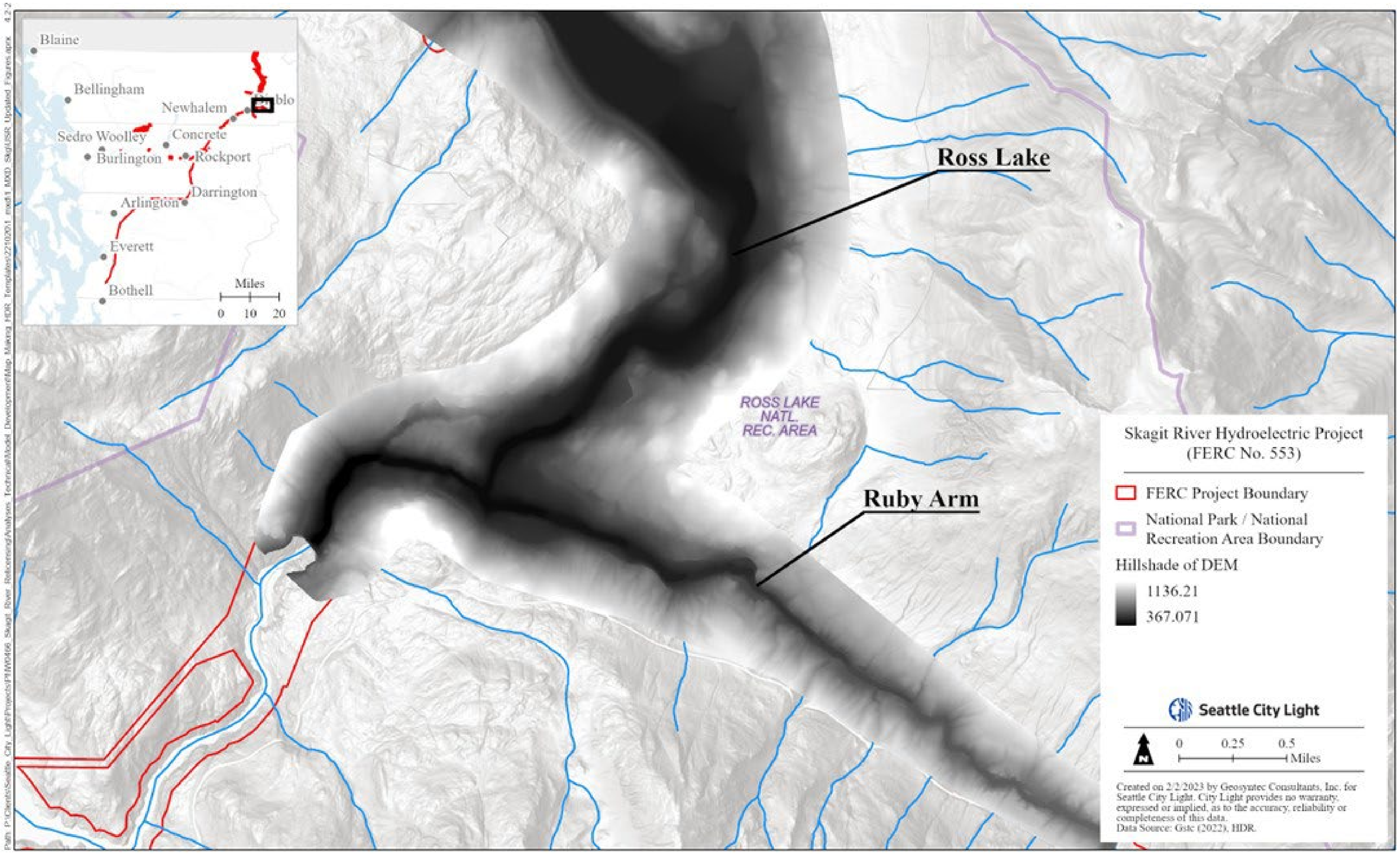


Figure 4.2-3. Example of hill shade visualization of final DEM for central Ross Lake.

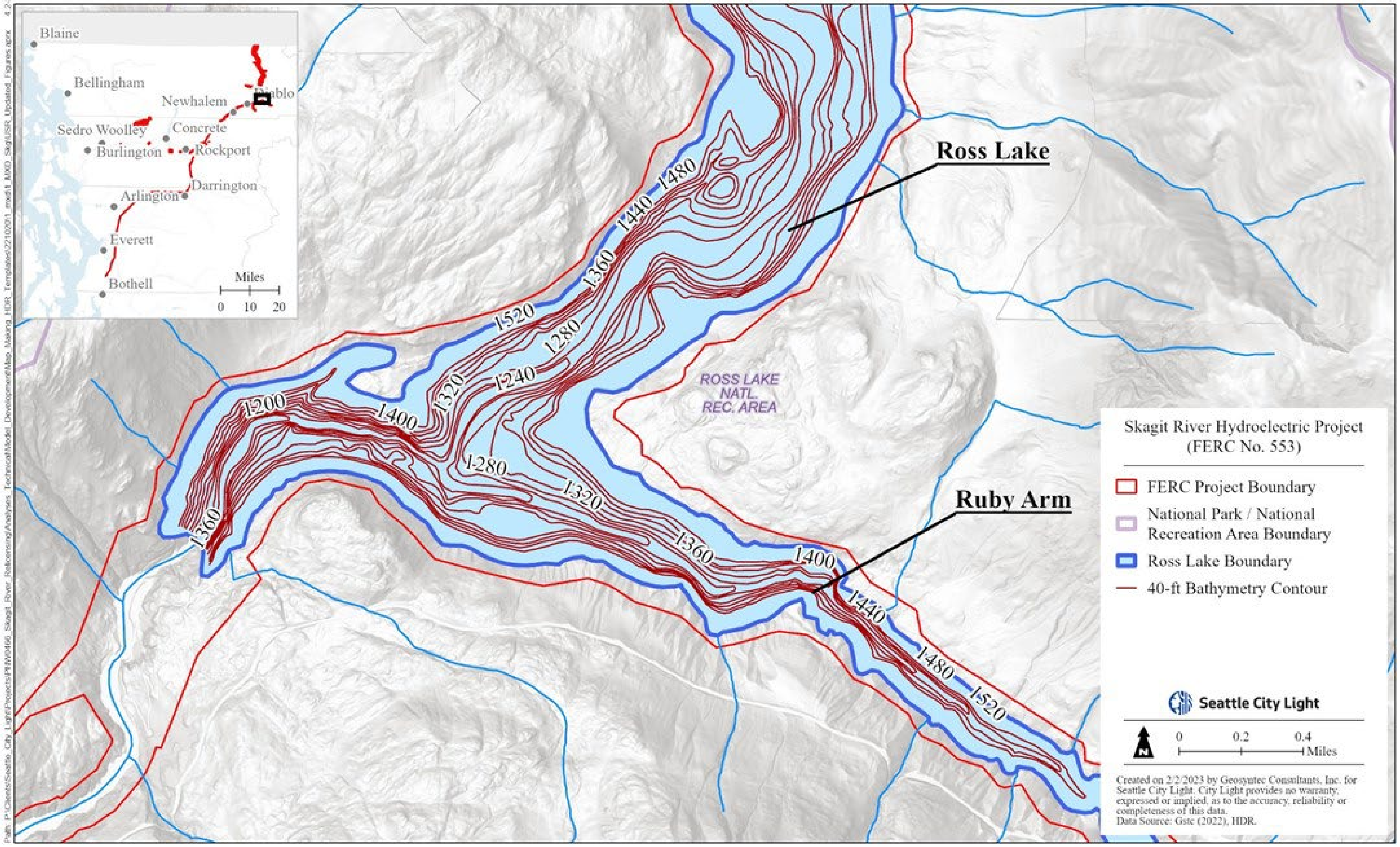


Figure 4.2-4. Example of digitized contours for central Ross Lake.

4.2.2.2 Diablo Lake

Segmentation

Diablo Lake was divided into 60 segments for the Skagit River (main) branch and 24 segments for the Thunder Arm branch. The Skagit River branch segments have a mean length of 396.62 ft with a range of 100.52-877.76 ft; the Thunder Arm branch segments have a mean length of 509.60 ft with a range of 317.65-816.04 ft. Segments were developed in the same manner described above for Ross Lake.

Initial Water Surface Elevation

The initial elevation of the water surface was set at 1,207.71 ft NAVD 88 (1,201.35 ft CoSD) based on the water level observed on the first day of the simulation.

Segment Orientation

Segment orientation was produced by the automated methods described above for Ross Lake and spot checked manually to verify quality.

Bed Friction

The Chézy bed friction factor was set at 70 for the model segments (Wells 2021b).

Layer Thickness

Layer thicknesses were set at 3.28 ft (1 m), as in Ross Lake, described above.

Cell Widths

Initially, cell widths were determined as described above for Ross Lake. Diablo Lake bathymetric and topographic data consist of LiDAR data collected in 2018 and 2016 (Quantum Spatial Inc. 2018b; Quantum Spatial 2017b) and reprocessed by HDR Engineering, Inc. (HDR 2020) and USGS contour bathymetry data from the 1960s (USGS 1963a; USGS 1963b). The 2018 LiDAR for Diablo Lake consisted of LiDAR collected for Thunder Arm only and this was used in its entirety. The 2016 LiDAR and contour DEM were used for coverage over the rest of the reservoir. Elevation data for the 2016 LiDAR data below 1,254 ft NAVD 88 (approximately 1,248 ft CoSD) were set to no data. Likewise, elevations for the contour DEM above 1,204 ft NAVD 88 (approximately 1,198 ft CoSD) were set to no data. The larger vertical gap, 50 ft, was used to accommodate more uncertainty with the contour DEM associated with steeper terrain around Diablo Lake than around Ross Lake. The two LiDAR datasets were merged, and then the resulting LiDAR dataset was merged with the contour DEM. In the final merged DEM, the 2018 LiDAR took first priority, the 2016 LiDAR took second priority, and the contour data took third priority. A 100-ft horizontal buffer was used between the two LiDAR datasets to allow for smooth interpolation between the two datasets.

During the water balance process, the bathymetry was modified further to remove model instabilities and to allow for modeled reservoir water levels to adequately match observed data. Initial water balance results showed significant time step violations in model cells adjacent to large jumps in the channel bottom depth, which were found to be artefacts of the cell width estimation process described above. These jumps were largely caused by gaps in the contour DEM in the deepest parts of the reservoir. A manual revision effort was undertaken to smooth out these gaps by examining historical survey records of the Skagit River before the construction of the Diablo Development. Several model segments were deepened to elevations matching the channel bottom elevations of the historical surveys. Similarly, the model representation of Thunder Arm was shallower than the profiling data that were available for calibration, and so this region was deepened as well. The overall stage-storage curve for the modeled reservoir was then compared to those included in FERC licensing documents, and manual adjustments were made to ensure that the cumulative storage of the modeled reservoir conformed to previously estimated values.

4.2.2.3 Gorge Lake

Segmentation

The Gorge Lake model consists of five branches and 64 segments that are tabulated in Table 4.2-1 and described as follows:

- Branch 1 – Diablo Stetattle: represents the area extending from Diablo Dam to upstream of Stetattle Creek;
- Branch 2 – Stetattle Creek: represents the area extending from upstream of Stetattle Creek to Gorge Lake Campground to account for notable changes in bed slope within the more riverine Stetattle reach;
- Branch 3 – Gorge Lake: represents the area extending from Gorge Lake Campground to Gorge Dam;
- Branch 4 –State Route (SR) 20 Bridge right bank refinement area: provides enhanced lateral definition of region downstream of SR 20. This area is adjacent and contiguous to the main reservoir flow path but was defined as a separate branch to allow any variation in flow patterns and mixing to be captured by the model.
- Branch 5 – Boat Launch refinement area: represents the side channel region near the boat launch by Gorge Lake Campground; and

The current model segmentation for Gorge Lake is shown in Figure 4.2-5.

Table 4.2-1. Branches and segments in the Gorge Lake model.

Waterbody / Branch	Upstream-Downstream PRM	Segment Identifiers	Branch Slope	Landmark
1 – 1	101.51 – 100.44	2 – 15	0	Diablo Powerhouse
1 – 2	100.44 – 100.31	18 – 21	0.005	Stetattle Creek
1 – 3	100.31 – 97.35	24 – 55	0	Gorge Lake
1 – 4	100.31 – 100.24	58 – 59	0	SR 20 Bridge
1 – 5	99.91 – 99.74	62 – 63	0	Boat Launch

Initial Water Surface Elevation

The initial water surface elevation for the model segments in the Gorge Lake pool region of the model (branch 3) was set to the water surface elevation reported at the USGS Gorge Lake near Newhalem gage (12177700), at the date and time when each model run began. The reaches at the upstream end of the model (branches 1 and 2) begin each model simulation wet with a shallow water depth approximately 1m higher than the forebay.

Segment Orientation

Segment orientation was produced by automated methods.

Bed Friction

Although CE-QUAL-W2 allows the use of either the Chézy or Manning's bed friction coefficient (n), which are related to one another through hydraulic radius, Manning's coefficient tends to be used more often in riverine environments and was therefore used in the Skagit River model discussed in Section 4.2.2.4. For consistency with the Skagit River model, the Manning's n friction factor was also used to define channel roughness within Gorge Lake, a run-of-river reservoir with riverine characteristics. A Manning's n friction factor of 0.035 was therefore applied to all model segments within the Gorge Lake model.

Layer Thickness

The vertical layer thicknesses were set at 3.28 ft (1 m).

Cell Widths

Cell widths for each segment at each layer height were produced by automated methods based on a DEM of Gorge Lake bathymetry developed from multiple data sources. The 2018 topobathymetric LiDAR dataset (Quantum Spatial 2018b), which was applied to the DEM where it was available, generally covers segments 2 through 20 within the Reflector Bar and Stetattle reaches and also covers shallow and dry-ground areas within the remainder of the reservoir. It is common for topobathymetric LiDAR datasets to contain areas where the LiDAR system failed to acquire data (returns) from wetted channel areas. Returns are the reflected laser pulses sensed by the LiDAR system that are used to map topographic surfaces, and bathymetric channel bed returns are limited by turbidity, depth, obstructions, and bottom surface reflectivity. A void is an area where no returns were detected. The spatial location of voids is a product that accompanies the LiDAR data. There are voids in the 2018 topobathymetric LiDAR where depths exceed the limit of the technology, approximately 10 to 15 ft in this dataset. The depth limit of topobathymetric LiDAR typically corresponds to approximately 1.5 Secchi disk depths but is also limited by other factors including boulders, surface turbulence, and tree cover. A limited 2016 standard LiDAR dataset (Quantum Spatial 2017b) was also used to extend the bathymetry DEM landward to include the surrounding terrain.

Within Stetattle reach segments 6 through 18, single beam bathymetric data from a 2017 survey (True North Surveying, Inc. 2017) was used to fill the voids. A few small voids in segments 2 through 6 where the 2017 survey data were not available were interpolated (i.e., filled based on values at the edges of the voids in the topobathymetric LiDAR data).

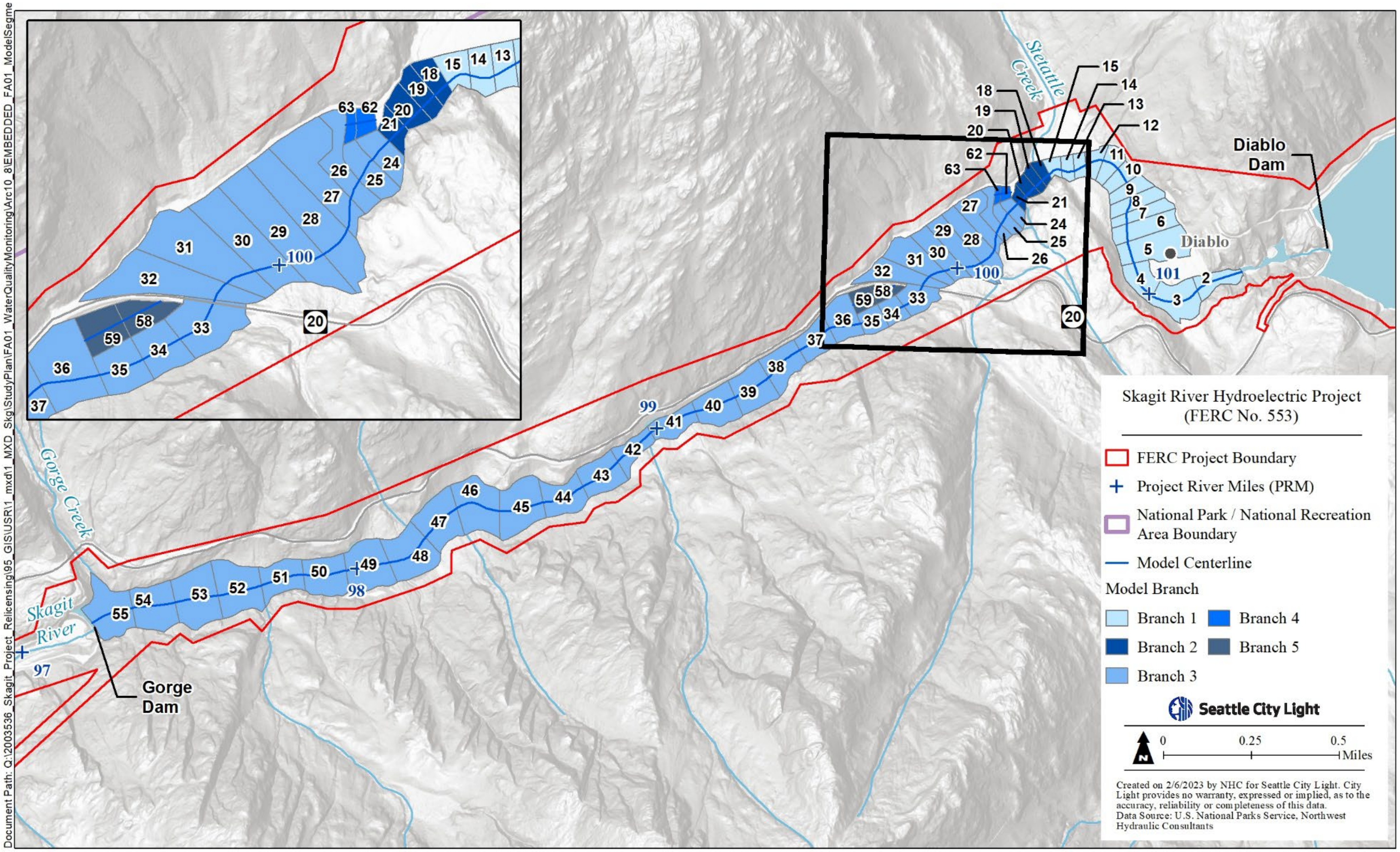


Figure 4.2-5. Current model segmentation for existing conditions Gorge Lake model.

Bathymetry for the region between SR 20 Bridge and Gorge Dam was defined using historical topographic map contours. The 1960s contour data used for Diablo and Ross lakes were not used for Gorge Lake because the 40-ft contour interval data are not of an adequate resolution to define the reservoir's shallower topography. Instead, digitized 5-ft contour mapping conducted in 1915, before the construction of Gorge Dam, was used. A sample of these data, taken from record file "USGS 1915 Skagit River Profile Survey_Plate3.JPG," is provided below as Figure 4.2-6.

Because the vertical datum of the 1915 data was not easily verified, it was shifted vertically to tie into the higher accuracy LiDAR data where the two datasets overlap. It is recognized that two major construction efforts on Gorge Dam in 1921 and 1961 may have modified this topography to some extent and that 100 years of dam operations have likely resulted in some localized sedimentation effects. As mentioned previously in Section 4.2.2, it is expected that newer bathymetry of the reservoir will be collected and used to define the grid as part of subsequent modeling effort of this reservoir. The mean top width for all Gorge Lake model segments is 601 ft (183 m); widths ranged from 200-1,263 ft (61-385 m).

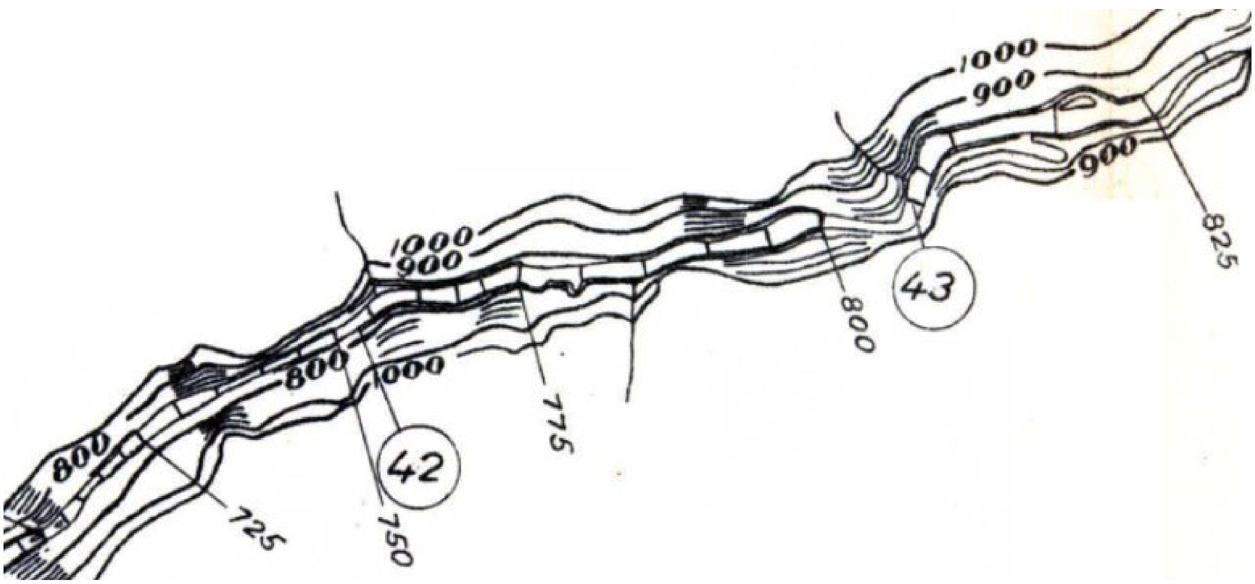


Figure 4.2-6. Example of 1915 5-ft contours used for Gorge Lake bathymetry.

Lateral Flow Connections between Parallel Model Branches

As noted previously, additional definition was added to the Gorge Lake model using two parallel branches adjacent to the main flow path of Gorge Lake, one located downstream of the SR 20 Bridge and the other located downstream of Stetattle Creek by the boat launch. The lateral movement of flow between the main flow path of Gorge Lake and these parallel branches was characterized using four lateral flow connections within the model. Two lateral flow connections were used to define the movement of flow to each side channel. Relevant parameters used for the lateral flow connections are summarized in Table 4.2-2.

Table 4.2-2. Gorge Lake lateral flow connections between parallel branches.

Parallel Branch	Location	Typical Flow Direction	Upstream Segment[1]	Downstream Segment[1]	Crest Elevation (m)
SR 20 Bridge	Right bank	From river	34	58	266.66
SR 20 Bridge	Right bank	From river	35	59	266.66
Boat launch	Right bank	From river	24	62	273
Boat launch	Right bank	From river	25	63	271

1 Lateral flow connections have upstream and downstream segments defined in the model, but flows can move in either direction across the connections. Figure 4.2-5 shows the spatial positions of each segment in the Gorge Lake model.

The spillway and intake were implemented at the downstream end of the model as outlet structures by Gorge Dam. Relevant parameters used are summarized in Table 4.2-3.

Table 4.2-3. Outlet structure parameters.

Structure	Withdrawn type	Centerline Elevation (m)	Width (m)
Spillway	Line	253.63	28.65
Intake	Point	246.68	N/A

4.2.2.4 Skagit River: Gorge Dam to Concrete

Segmentation

The Skagit River model is divided into three reaches: Gorge bypass reach, Newhalem to Sauk (N2S) reach, and Sauk to Concrete (S2C) reach. The segmentation details of the three reaches are as follows:

- Gorge bypass reach: The Gorge bypass reach starts below the Gorge Lake dam plunge pool and ends at the Gorge Powerhouse upstream of Newhalem. It consists of 1 waterbody, two branches, and 17 segments.
- Newhalem to Sauk (N2S) reach: The N2S reach encompasses five waterbodies, eight branches (including two side channels), and 187 segments.
- Sauk to Concrete (S2C) reach: The S2C reach consists of five waterbodies, seven branches (two defining side channel 58.5-L), and 68 segments.

Table 4.2-4 and Figure 4.2-7 describe the waterbody characteristics of the Skagit River model in detail. The segment identifier column in the table lists the active segments in each branch. A GIS mapbook showing the segment layout of the N2S and S2C reaches of the Skagit River model is provided as Attachment A (Skagit River CE-QUAL-W2 Model Segments, Relative Floodplain Elevations, and Side-channels, from Newhalem to Concrete).

Table 4.2-4. Branches and segments in the Skagit River model.

Waterbody / Branch	Upstream PRM	Segment Identifiers[1]	Branch Slope (%)	Landmark
Gorge bypass reach				
1 – 1	97.039	2 – 11	2.25	Below Gorge Dam plunge pool
1 – 2	95.248	14 – 16	0.63	
N2S reach				
1 – 1	94.696	2 – 18	0.34	Newhalem / Gorge Powerhouse inflow
1 – 2	91.615	21 – 44	0.24	
2 – 3	87.773	47 – 55	0.27	
3 – 4	86.170	58 – 125	0.15	
3 – 5	74.508	128 – 144	0.18	
3 – 6	70.510	147 – 174	0.12	Sauk River confluence
4 – 7	91.083	177 – 182	0.24	Side Channel 90.7-L
5 – 8	68.403	185 – 186	0.13	Side Channel 68.3-R
S2C reach				
1 – 1	64.504	2 – 22	0.09	
2 – 2	60.587	25 – 28	0.09	
3 – 3	59.814	31 – 40	0.09	
3 – 4	57.590	43 – 45	0.20	
3 – 5	56.935	48 – 59	0.05	Concrete, WA
4/5 – 6/7	59.778	62 – 69	0.08	Side Channel 58.5-L

1 Two inactive segments are included between each branch.

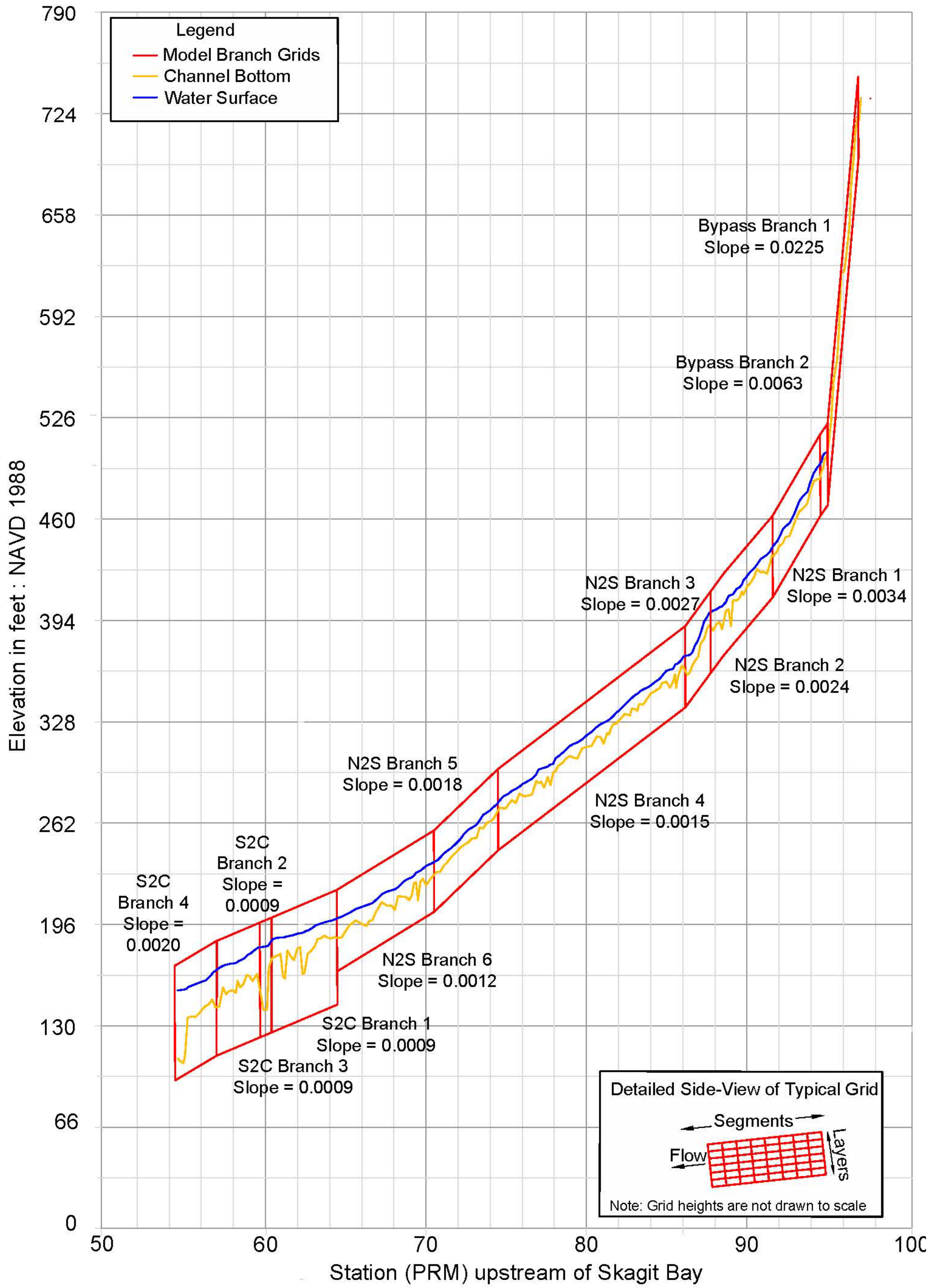


Figure 4.2-7. Profile plot of the Skagit River between Gorge Dam and Concrete. Sixteen branches are currently defined in the three Skagit River models to account for notable changes in hydraulic slope and side channel areas.

Initial Water Surface Elevation

The initial water surface elevation in the Skagit River model varies. An initial discharge was specified for the segments, and an initial depth as assumed such that all model segments begin wet.

Segment Orientation

Segment orientation was produced by automated methods and spot checked manually to verify quality.

Bed Friction

The Manning's bed friction factor was set to 0.057 for the model segments in the Gorge bypass reach, between 0.028-0.059 in the N2S reach, and between 0.035-0.048 in the S2C reach based on relative reach roughness used for the FA-02 Instream Flow Model Development Study's hydraulic modeling effort (City Light 2023b), while also matching available water level observations.

Layer Thickness

The vertical layer thicknesses were selected as 3.28 ft (1 m) in the Gorge bypass reach and 0.82 ft (0.25 m) in the N2S and S2C reaches. Thicker layers were selected for the Gorge bypass reach model because they provide improved model numerical stability within this higher slope reach.

While vertical stratification is not a concern in the riverine reaches, which are well mixed, variation in vertical layer width is also used to define the channel geometry (i.e., side slope). A single rectangular layer, similar to a flume, could be used but it would not accurately represent the wetted channel width at varying flows. As a result, layer thicknesses of less than 3.28 ft (1 m) were used as needed to define the channel geometry. The quality of the channel geometry definition was confirmed by comparing simulated to observed wetted top widths as part of the grid refinement process.

Cell Widths

Cell widths for each segment at each layer height in the Skagit River were also produced by automated methods based on DEMs of each reach. The DEMs of the Gorge bypass reach and N2S reaches, which span from Gorge Dam to approximately 1.5 miles (0.9 km) downstream of the Sauk River confluence (approximately 32 river miles), were developed from a combination of standard and topobathymetric LiDAR (Quantum Spatial Inc. 2017a and 2018b), boat-based bathymetric (sonar) surveys, and terrain data from an existing hydraulic model of the Barnaby reach of the Skagit River. Like the 2018 topobathymetric LiDAR data set used for the reservoirs, the 2017 topobathymetric LiDAR dataset covering the river also contain voids. The 2017 and 2018 topobathymetric LiDAR includes approximately 105 acres of voids within the main channel, which account for approximately 10 percent of the main channel area.

To address the data gaps (i.e., voids) and to replace suspect surface values, two bathymetric survey efforts were conducted: the first over two separate weeks in October 2020 and March 2021 for voids in the 2017 and 2018 surfaces between Gorge Powerhouse and PRM 73.4; and the second over a week in September 2021 for voids within the Barnaby Reach surface between PRM 73.4 and the confluence with the Sauk River. Detailed documentation of the bathymetric void infilling is covered in Attachment C to the FA-02 Upper Skagit Hydraulic Model Calibration Report (Attachment A to the FA-02 Instream Flow Model Development Study [City Light 2023b]).

Elevations for the Gorge bypass reach, located between Gorge Dam and Gorge Powerhouse, were applied directly from LiDAR data (Quantum Spatial 2017a), and voids were filled using a 2017 single beam bathymetric survey covering the Gorge Dam plunge pool (True North Surveying, Inc. 2017). One channel bed feature within the Gorge bypass reach, referred to as “Existing Feature 2” by the FA-05 Bypass Instream Flow Model Development Study (City Light 2023c), has slopes exceeding 25 percent, which cause numerical instabilities with the CE-QUAL-W2 modeling framework. To address this, the slopes of this feature were artificially reduced. This modification is not expected to affect temperature or other simulation results.

For the S2C reach downstream of the confluence of the Sauk River, a DEM was developed from a combination of standard and topobathymetric LiDAR (Quantum Spatial Inc. 2017a and NV5 Geospatial 2022). Although the 2022 topobathymetric LiDAR dataset covers the entire Skagit River reach between Gorge Dam and Concrete, the 2022 data were only applied downstream of the Sauk River confluence. Like the 2017 and 2018 topobathymetric LiDAR data sets used for the river upstream of the Sauk River confluence and reservoirs, the 2022 topobathymetric LiDAR dataset also contains voids. These voids were filled with a combination of legacy 1990s cross-section data collected by the U.S. Army Corps of Engineers and assumptions based on typical scour hole depths in similar positions in the river.

Lateral Flow Connections between Mainstem and Side Channels

Three Skagit River side channels were defined within the model: side channels 90L and 68R upstream of the Sauk River and 58L downstream. Nine internal lateral flow connections defined along locations of high ground that control the movement of flow between the mainstem of the river and the side channels were calculated from the terrain data and simulated mainstem river water levels as summarized in Table 4.2-5. The 90L and 58L side channels each include six segments and the 68R side channel includes two segments. A schematic view of the side channel segment configuration over the terrain DEM for each area is provided as Figure 4.2-8.

Table 4.2-5. Skagit River lateral flow connections between mainstem and side-channel.

Side-Channel	Location	Typical Flow Direction	Upstream Segment	Downstream Segment	Crest Elev. (m)
N2S 90L	Left bank	To channel	25	179	132.3
N2S 90L	Left bank	To channel	26	180	132.1
N2S 90L	Left bank	To channel	27	181	130.9
N2S 90L	Left bank	To river	28	182	130.3
N2S 68R	Right bank	To channel	158	185	66.5
S2C 58L	Left bank	To channel	31	62	54.0
S2C 58L	Left bank	To channel	32	64	53.0
S2C 58L	Left bank	To river	33	65	53.0
S2C 58L	Left bank	To river	63	69	53.5
S2C 58L	Left bank	Between channels	64	68	53.5
S2C 58L	Left bank	Between channels	65	68	53.5

1 Lateral flow connections have upstream and downstream segments defined in the model, but flows can move in either direction across the connections. Figure 4.2-8 shows the spatial positions of each side-channel segment in the N2S and S2C Skagit River models.

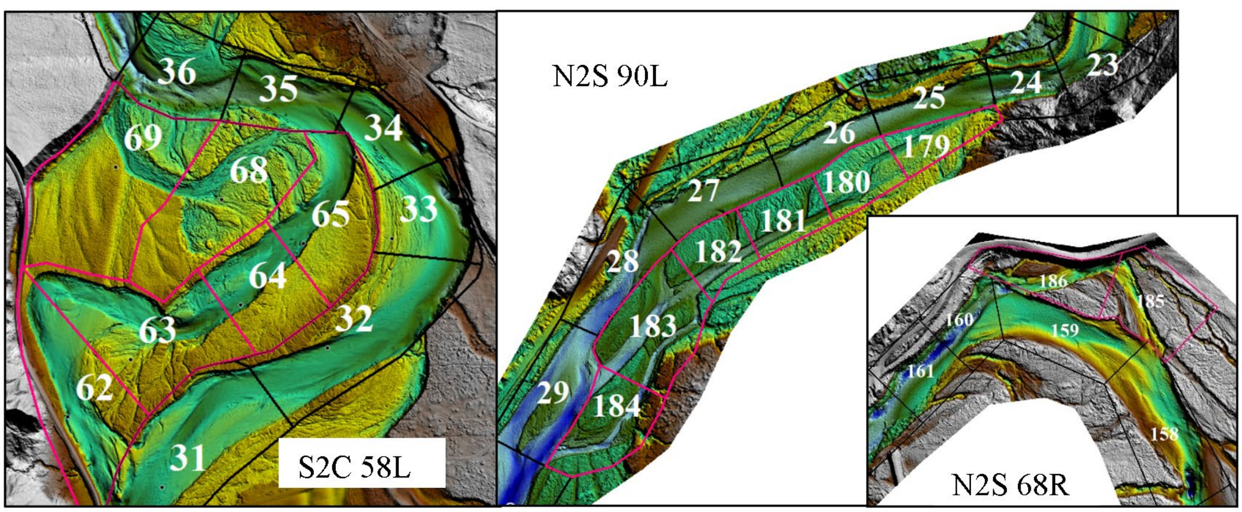


Figure 4.2-8. Schematic of CE-QUAL-W2 model segment configuration of Skagit River side channels 90L (center), 68R (right), and 58L (left).

4.2.3 Meteorology

Reservoir and riverine models require meteorological input files. In CE-QUAL-W2, this consists of a time series of:

- Air temperature;
- Dew point temperature;
- Wind speed;
- Wind direction;
- Cloud cover; and
- Incident short wave solar radiation.

The separate waterbodies simulated in each of the four models required independent meteorology input files (Table 4.2-6). NPS provided a list of 22 active climate stations inside North Cascades National Park and Ross Lake National Recreation Area and 24 active climate stations outside the parks. These have start dates ranging from 1931 to 2014, and they measure different combinations of air temperature, precipitation, relative humidity, soil temperature, soil moisture, wind speed, wind direction, snow depth, snow-water equivalent, and solar radiation. Two stations from the Remote Automatic Weather Stations (RAWS) program, Hozomeen and Marblemount, were selected based on their temporal coverage and available measurements. Data were downloaded from the Western Regional Climate Center (2021), and data were processed for recent durations during which data were most complete (Table 4.2-6).

Table 4.2-6. Meteorology stations.

Model	Station	Program	Coordinates	Elevation[1] (ft)	Duration[2]
Ross Lake	Hozomeen and Marblemount	RAWS	49.1083 -121.1833	1,704 (1,698)	Feb. 2018 – Oct. 2021; Jan. 2011 – Oct. 2021
Diablo Lake	Marblemount	RAWS	48.5944 -121.5611	361 (355)	Jan. 2011 – Oct. 2021
Gorge Lake	Marblemount	RAWS	48.5944 -121.5611	361 (355)	Jan. 2011 – Oct. 2021
Skagit River	Marblemount	RAWS	48.5944 -121.5611	361 (355)	Jan. 2011 – Oct. 2021

1 Elevations shown relative to NAVD 88, with elevations relative to CoSD in parentheses. All elevations are rounded to the nearest foot.

2 Data are available as early as 2004 and 2003 for Hozomeen and Marblemount Stations, respectively. However, filling large data gaps would have required substantial effort to estimate values of meteorological variables prior to the duration shown.

For the Hozomeen site, the data coverage completeness was around 98 percent between January 1, 2020 and October 31, 2021, with a maximum of 33 hours of continuous missing data. For the Marblemount site, the data coverage completeness was greater than 99 percent between January 1, 2020 and October 31, 2021, with a maximum of 9 hours of continuous missing data. Missing data were filled using linear interpolation for short time period gaps (i.e., less than 6 hours) and, for gaps of a few days, available data from a few days before and after the missing hours were used to preserve the temporal variation of the variables. Most of the meteorological variables required by the CE-QUAL-W2 model were available at the RAWS stations except dewpoint temperature and cloud cover, which were calculated using measured variables.

The dewpoint temperature was computed based on relative humidity and air temperature by rearranging Equation 4.1-1 (Singh 1992):

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

Eq. 4.1-1

Where: RH is the measured relative humidity at the two stations (dimensionless);
T is the air temperature in Celsius (°C); and
T_d is the dewpoint temperature (°C).

Cloud cover is used to compute the long-wave atmospheric radiation in the CE-QUAL-W2 model (Wells 2021b). The cloud cover was computed based on net and clear-sky short wave solar radiation by rearranging Equation 4.1-2 (Wunderlich 1972):

$$\phi_{s\_net} = \phi_{s\_clearsky}(1 - 0.65C^2)$$

Eq. 4.1-2

Where: $\Phi_{s\text{-}net}$ is the measured net short wave solar radiation in watts per square m (W/m^2);
$\Phi_{s\text{-}clearsky}$ is the clear-sky short wave solar radiation (W/m^2); and
C is the cloud cover fraction between 0 and 1 (dimensionless).

The clear-sky solar radiation was estimated using a method developed by Annear and Wells (2007) that estimates the clear-sky short wave solar radiation using five different models. These were calibrated using the short-wave solar radiation measured in clear-sky days at the Marblemount monitoring site, and the best-fit model was used to compute cloud cover fraction for the entire simulation period using Equation 4.1-2. Because solar radiation values are zero overnight, cloud cover was linearly interpolated between values at the beginning and end of each night. Solar radiation at the Hozomeen meteorological station was judged to be unreliable because it is surrounded by forest that shades it during much of the day, so solar radiation data were not used.

4.2.4 Flow Input Files

Reservoir and riverine models require input files containing time series of flow into the simulated waterbody via each tributary and out of the waterbody via its downstream boundary and other withdrawals. These files are created in two major steps. First, the inflows[5] and outflows that need to be included in the model must be defined. Second, existing data must be used to develop time

[5] CE-QUAL-W2 divides inflows to a waterbody as "branch inputs" if they enter the main branches of a model (i.e., the main arms of a reservoir) in the longitudinal direction and "tributaries" if they are minor streams that enter a segment of the model in the lateral direction. Some tributaries mentioned in this passage are classified as branch inputs when implemented in CE-QUAL-W2, but this distinction is not relevant for comprehension by the non-modeler, so the inflows are termed "tributaries" in this report.

series for these inflows and outflows. These two tasks are connected; often, available data influence the inflows that can be included in the model.

4.2.4.1 Ross Lake

As a mountain reservoir at a northern temperate latitude, Ross Lake is fed by numerous streams of varying sizes. Of these, the Skagit River, Big Beaver Creek, and Ruby Creek are gaged by the USGS. These gaged flows were used without modification as inputs to the Ross Lake model.

The inflows to the reservoirs via the 26 ungaged, named tributaries cannot be neglected, yet these tributaries are too numerous to estimate the flow in each individually. Consequently, tributary inflow regions were developed around Ross Lake to define catchment areas that, for the purposes of developing model input files, would be considered as contributing runoff into a single inflow to the waterbodies (Figure 4.2-9). This delineation of catchment areas defined the number of tributaries and, in turn, inflow time series that were developed for the Ross Lake model.

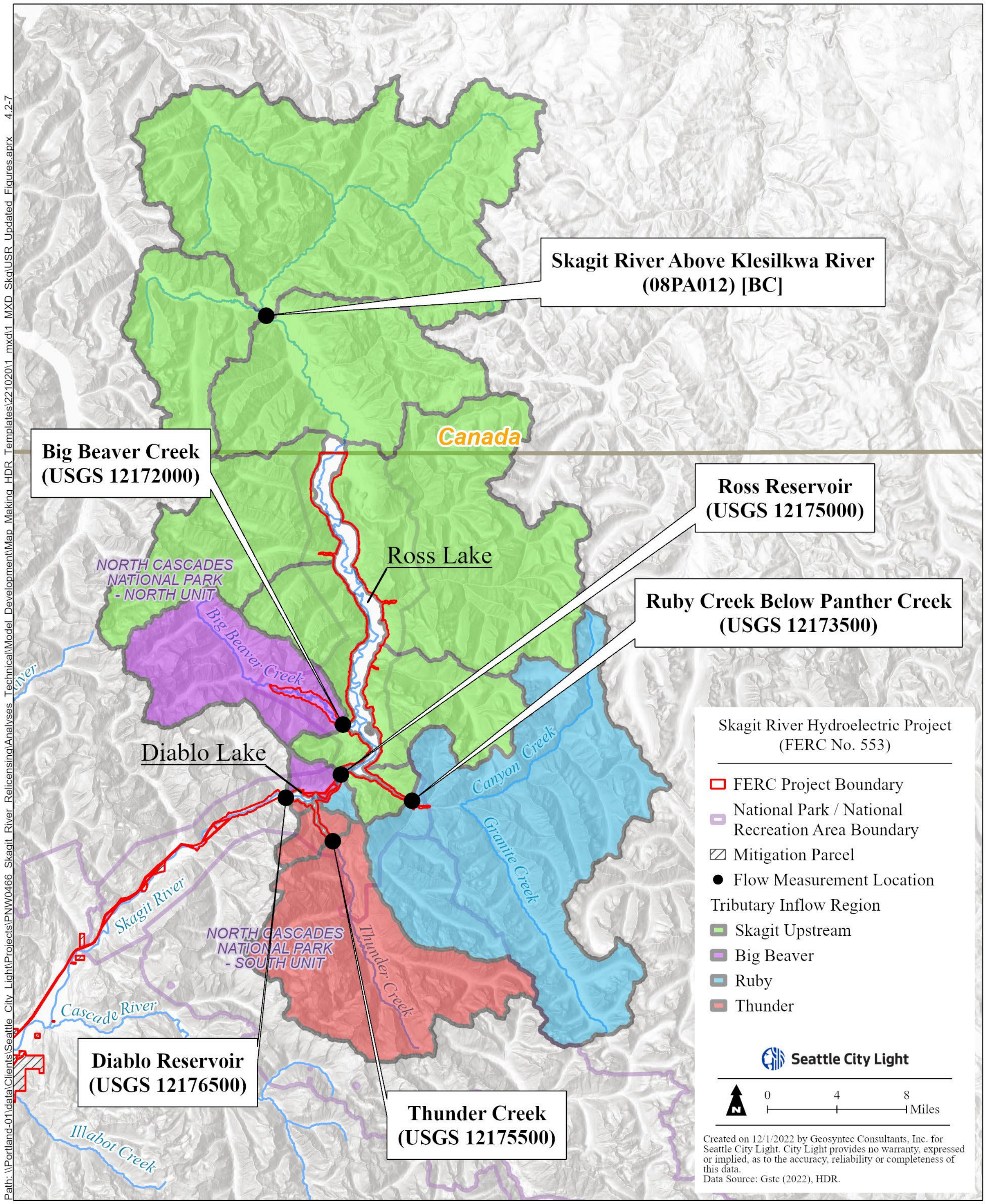


Figure 4.2-9. Tributary inflow regions surrounding Ross Lake.

For gaged tributaries—Big Beaver Creek and Ruby Creek—inflow regions corresponded to the watersheds of these creeks upstream of the USGS gages. These watersheds were determined by beginning with the 1/3 arc-second n49w123 1 x 1 degree DEM created by the USGS and the Canada three-dimensional DEM created by Natural Resources Canada (Natural Resources Canada 2020). These DEMs were pre-processed, merged, projected into Universal Transverse Mercator Zone 10 using ArcGIS 10.7, and inspected for any gaps or errors. Watersheds were delineated in ArcGIS (ArcMap 10.7) following the Watershed Delineation with ArcGIS 10.2.x guideline from Trent University (Trent University 2014), which uses these steps:

(1) Create a Depression-less DEM. The Fill tool in Hydrology toolbox in ArcGIS 10.7 was used to remove any cells in the final DEM raster that did not have an associated drainage value. These cells in the DEM are commonly known as imperfections or sinks. The result is a DEM surface raster without any small imperfections.

(2) Create a Flow Direction Grid. A flow direction raster was created from the DEM surface raster in Step 1 using the D8 method (Greenlee 1987) of the Flow Direction Tool in Hydrology toolbox in ArcGIS 10.7. The D8 method assigns an integer between 1 and 255 to each grid of the DEMs raster with respect to the location of the steepest downslope neighbor cells. The final product in Step 2 is an integer raster with values ranging from 1 to 255.

(3) Create a Flow Accumulation Grid. The number of upstream cells flowing into each of the grids was calculated using the Flow Accumulation tool in the Hydrology Toolbox in ArcGIS 10.7. The final product is a raster surface where the higher values represent areas of lower elevation into which water flows naturally.

(4) Snap Watershed Outlet (Pour) Points. Tributaries of the Skagit River were identified, and a point shapefile of the discharged location was created. Then, the Snap Pour Point tool in ArcGIS 10.7 was used to snap the outlet of each tributary to its most downstream grid (i.e., highest value) in the flow accumulation raster surface in Step 3. Finally, the pour points were inspected and adjusted to ensure the most downstream grid of each tributary is selected.

(5) Delineate Watershed. The Watershed Tool in the Hydrology Toolbox was used to delineate the drainage area of the tributaries using the Flow Direction and the Pour Points rasters in Steps 2 and 4. Then, drainage areas raster was simplified and converted to a vector drainage area file for further geoprocessing using the Raster to Polygon tool in ArcGIS 10.7.

For ungaged tributaries, the above process was repeated. It led to the delineation of 763 watersheds, far too many to effectively characterize within the CE-QUAL-W2 modeling framework. Many of the watersheds, therefore, were consolidated into larger inflow regions and assigned a single outflow location into Ross. The practical effect of this is the assignment of, for example, the total volumetric flow in Hozomeen Creek, Lightning Creek, and other small tributaries that enter the northeastern portion of Ross Lake into Hozomeen Creek alone, which was assigned to flow into a specific segment of the Ross Lake model. This led to 10 individual inflow segments to the Ross Lake model (Figures 4.2-10 and 4.2-11).

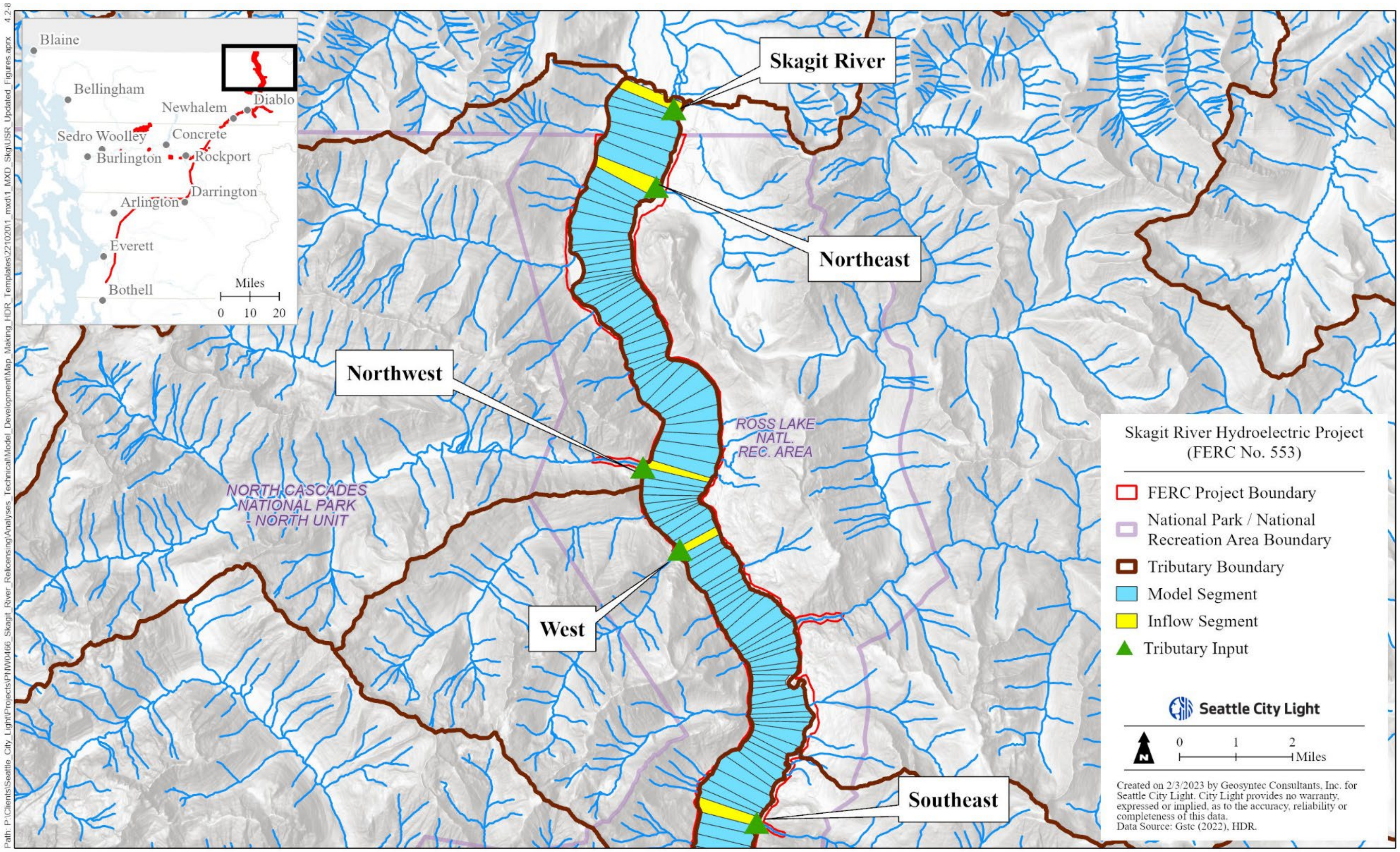


Figure 4.2-10. Entry points of tributary inflow regions (inflow segments) into northern Ross Lake.

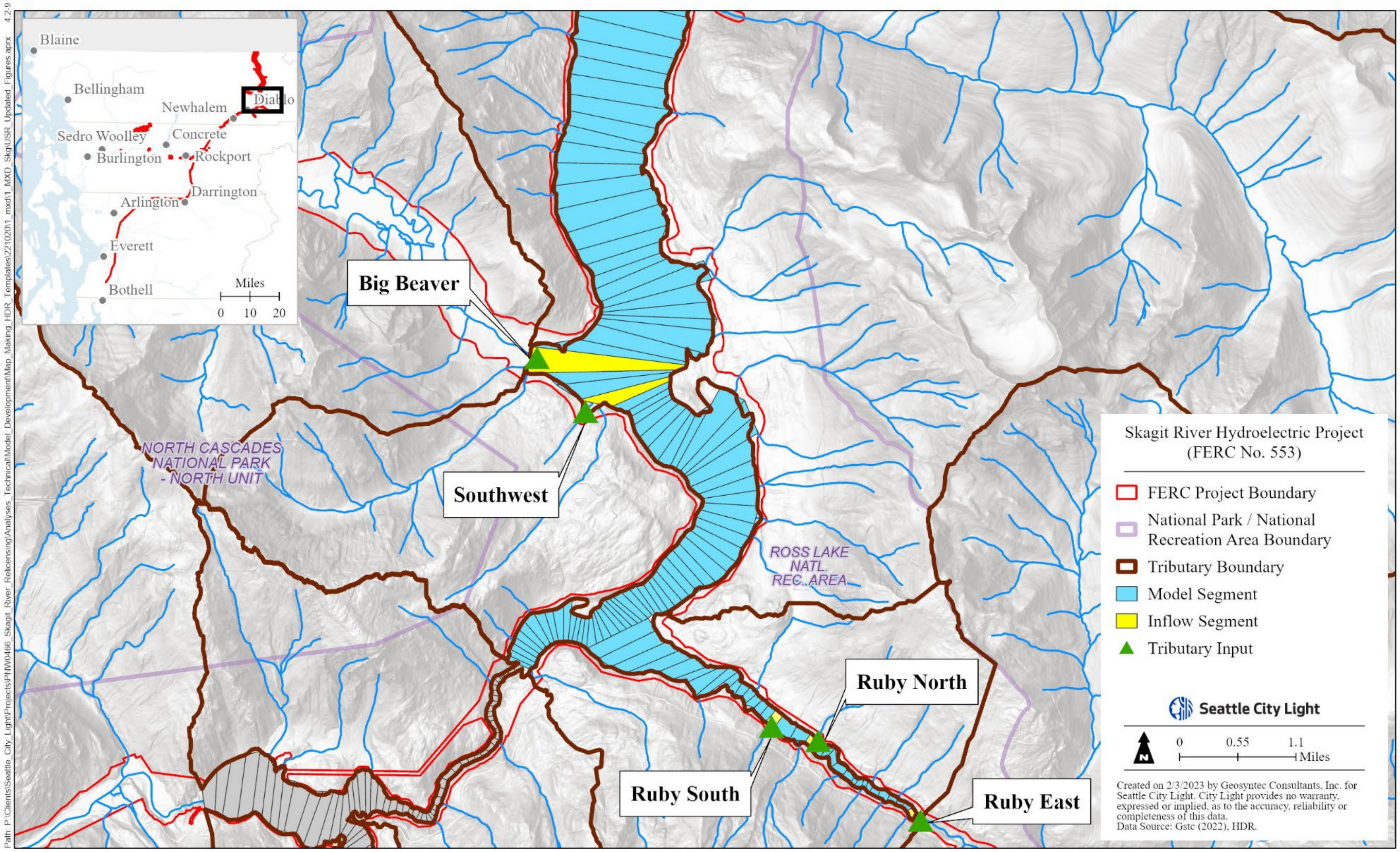


Figure 4.2-11. Entry points of tributary inflow regions (inflow segments) into southern Ross Lake.

Once the inflow regions were defined, their areas were calculated in GIS and then the flow in each was estimated from the flow at a nearby flow gage and the ratio of the drainage areas between the gaged watershed and the ungaged watershed of interest (Table 4.2-7). The upper Skagit River gage (Water Survey of Canada gage 08PA012) is located immediately upstream of the Skagit River's confluence with the Klesilkwa River, which joins the Skagit River from the west after draining a significant area. Consequently, the Klesilkwa River flow and the flow into the Skagit River between its confluence with the Klesilkwa River and the upstream end of Ross Lake were both estimated based on the gaged Skagit River flow. These three flows were summed to create an estimate of the Skagit River inflow to Ross Lake.

Error in these estimates comes from the variability of precipitation volumes between watersheds in mountainous terrain as well as the elevation of these watersheds, which will influence the fraction of precipitation that falls as snow throughout the year. However, error in these flow estimates cannot be quantified because no data are available in the ungaged streams for comparison. Error was thus accommodated by the addition of a "distributed tributary" to the model, which adjusted the total inflow to Ross Lake by an amount required to achieve a water balance calibration (discussed below).

Dam outflows were taken from City Light dam operations data. These were adjusted at a daily time step in the dam operations model, which was developed as part of the OM-01 Operations Model Study (City Light 2023d), and then they were downscaled to hourly flow rates for use in CE-QUAL-W2.

During the water balance process for Ross Lake, a closer match between observed water levels and model output was observed when changing the estimation method for ungaged inflow regions from the nearest gaged tributary to the upper Skagit River gage (Water Survey of Canada gage 08PA012). Although the upper Skagit River gage is farther from most ungaged inflow regions than the gages on Big Beaver Creek and Ruby Creek, an assessment of topography in each basin indicated that the Big Beaver and Ruby Creek basins have higher average elevations than the ungaged tributary areas. These higher elevations may result in larger snowpacks that would lead to seasonal runoff patterns that are not representative of the lower elevation ungaged basins. The average elevation of the upstream Skagit River was found to be more representative of these ungaged tributary areas.

Table 4.2-7. Sources of flow data for Ross Lake tributary inflow regions.

Inflow Region	Area (mi²)	Gage	Estimation	Inflow Location
Skagit River	391.73	Skagit	Sum of gaged values and prorated[1] estimates of Klesilkwa flows and inflows between Klesilkwa and Ross Lake	Skagit River inflow to Ross Lake
Northwest	81.71	Skagit	Prorated by watershed area relative to upstream Skagit River	Silver Creek
West	32.13	Skagit		No Name Creek
Southwest	7.44	Skagit		S. of Pierce Creek
Big Beaver	65.18	Big Beaver	None (USGS values used)	Big Beaver Creek
Northeast	161.71	Skagit	Prorated by watershed area relative to upstream Skagit River	Hozomeen Creek
Southeast	45.28	Skagit		Devils Creek
Ruby East	212.94	Ruby	None (USGS values used)	Ruby Creek
Ruby North	3.56	Skagit	Prorated by watershed area relative to upstream Skagit River	Lone Tree Creek
Ruby South	5.89	Skagit		Lillian Creek

1 Flows in ungaged basins were estimated by prorating gaged flow by the ratio of the area of the watersheds of ungaged and gaged basins.

4.2.4.2 Diablo Lake

Development of inflow files for the Diablo Lake model followed the procedure described for Ross Lake. The main inflow to Diablo Lake is Ross Dam, and Thunder Creek is the only gaged tributary. Inflow regions around Diablo Lake were smaller than those around Ross Lake, and flow in ungaged tributaries was based on gaged flows in Ruby Creek, Big Beaver Creek, and Thunder Creek (Table 4.2-8). These flows were assigned to specific segments of the Diablo Lake model (Figure 4.2-12).

Table 4.2-8. Sources of flow data for Diablo Lake tributary inflow regions.

Inflow Region	Area (mi²)	Gage	Estimation	Inflow Location
Ross Lake	1,008	Ross Dam	Sum of powerhouse and spillway flows	Ross Dam outflow to Diablo Lake
East	2.37	Ruby	Prorated by watershed area relative to Ruby	Horsetail Creek
North	5.46	Big Beaver	Prorated by watershed area relative to Big Beaver	Sourdough Creek
South	0.66	Thunder	Prorated by watershed area relative to Thunder	None; center of inflow region used
Thunder South	110.36	Thunder	None (USGS values used)	Thunder Creek
Thunder West	5.48	Thunder	Prorated by watershed area relative to Thunder	Colonial Creek
Thunder East	2.95	Thunder		None; center of inflow region used

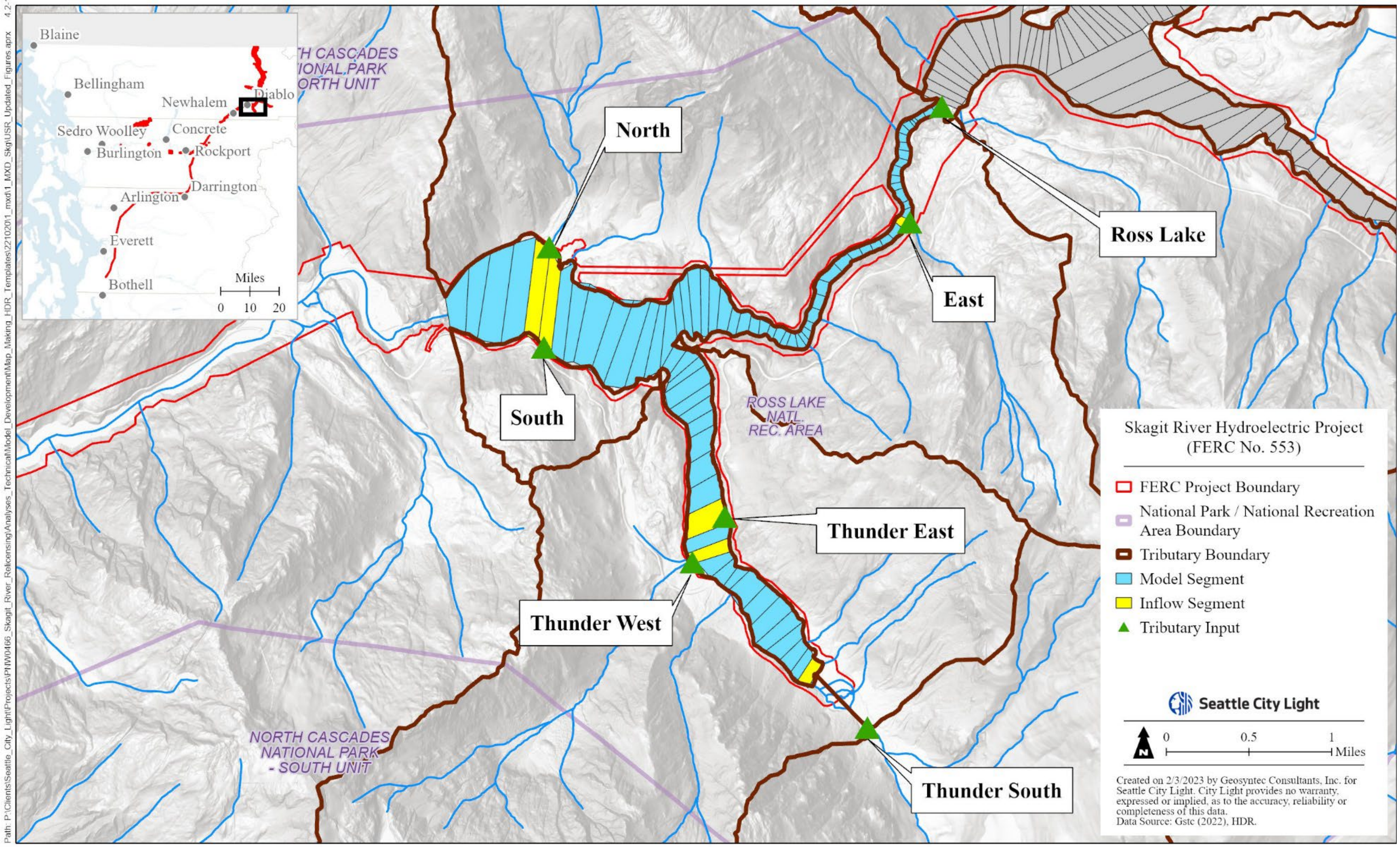


Figure 4.2-12. Entry points of tributary inflow regions into Diablo Lake.

4.2.4.3 Gorge Lake

The primary inflow to Gorge Lake is the powerhouse outflow from Diablo Dam, which enters from the right bank in the middle of the Diablo Stetattle reach (i.e., not the head of the waterbody which begins at Diablo Dam). One major stream, Stetattle Creek, which has a basin area of approximately 22.8 square miles, is represented as a lumped tributary input to the reservoir model (Figure 4.2-13). All other inflow to the reservoir is lumped as distributed inflow, calculated as part of the water balance being performed to match USGS water level records.

Flows into the model were developed following methodology described in the document "USGS Based Hydrology Calculation Summary" (Appendix 1 of Attachment A to the OM-01 Operations Model Study Report [City Light 2023d]) (Table 4.2-9). Additional adjustments were conducted based on hourly water level observations at Gorge Lake to account for changes in storage as well as spill flow information from City Light. Flows out of the model include Gorge Dam spillway flow and powerhouse flow.

Table 4.2-9. Sources of inflow data for Gorge Lake.

Inflow Region	Area (sq. miles)	Gage	Estimation	Inflow Location
Diablo Lake (spill to Reflector Bar)	1,135	Diablo Dam	Diablo spillway flows	Diablo Dam
Diablo Lake (powerhouse to Stetattle Reach)	1,135	Diablo Dam	Diablo Powerhouse flows + estimation of baseflow	Diablo Powerhouse
Stetattle Reach	27.5	Big Beaver, Newhalem, or Thunder	Prorated by watershed area relative to Big Beaver, Newhalem, or Thunder Creek	Stetattle Creek
West Zone (Gorge Lake Local and Gorge Creek)	9.7	-	Based on water-balance to observed USGS water level record	Distributed

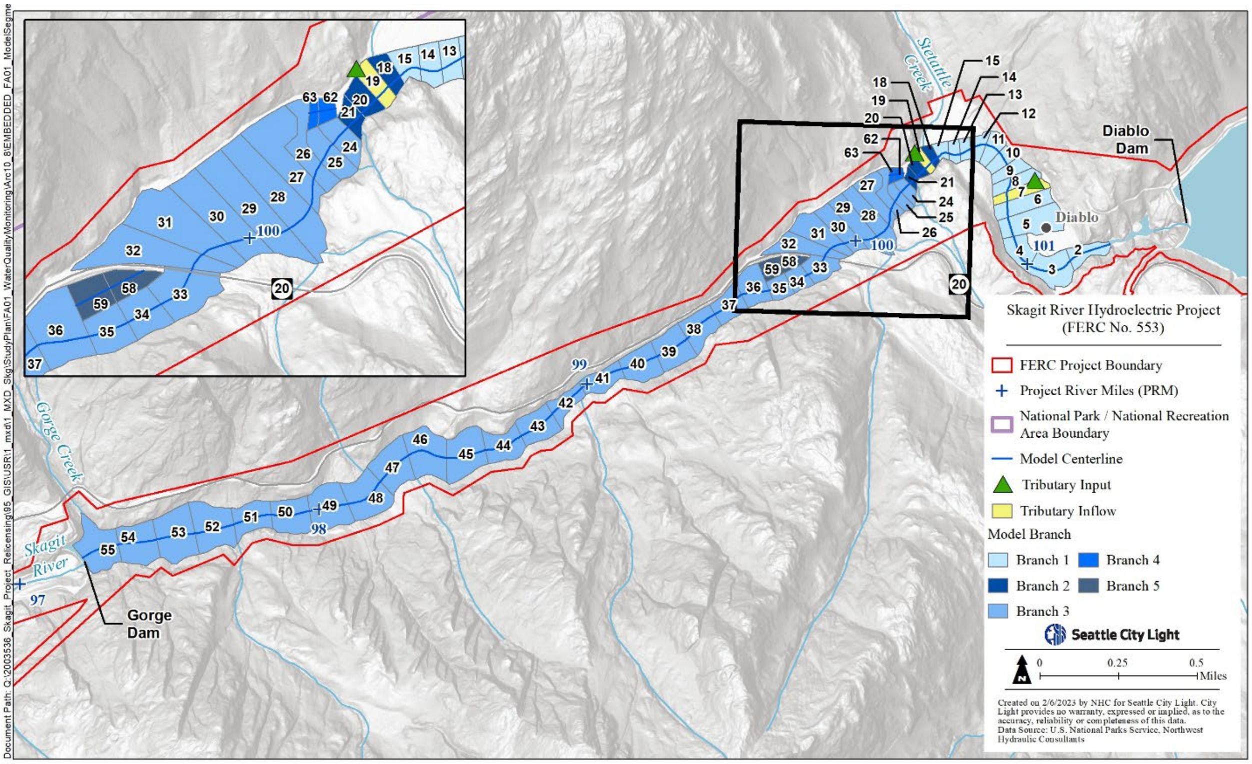


Figure 4.2-13. Entry points of tributary inflow regions into Gorge Lake.

4.2.4.4 Gorge Bypass Reach

The primary hydrologic input to the Gorge bypass reach is flow released as spill from Gorge Dam. Flow records for Gorge Dam spillway operations were provided by City Light, and stage and discharge records for the USGS Skagit River at Newhalem gage (12178000) were obtained online.[6] Discharges from Gorge Powerhouse were determined by computing the difference between releases from Gorge Dam and corresponding discharges at the USGS Skagit River at Newhalem gage. Tributary inflows between Gorge Dam and the Gorge Powerhouse (the beginning of the Skagit River N2S model) include Afternoon Creek (ungaged). Spill releases from Gorge Dam are typically limited to fewer than ten releases per year, which account for less than 5 percent of the annual hydrograph. Because CE-QUAL-W2 is susceptible to instabilities during zero flow conditions, and sensitivity tests of simulated temperature in the reach show small changes (typically less than a 0.05 ºC change in the daily maximum [+ or -] between Gorge Dam and Newhalem) in simulated temperature between Gorge Dam and Newhalem, the Gorge bypass reach model was not run for the Existing Conditions simulations. Instead, Gorge Powerhouse, spill releases, and Afternoon Creek flows were routed to the Skagit River N2S model directly at Newhalem for the existing conditions simulations discussed in Section 5. The Gorge bypass reach model was only used to simulate steady state flow conditions as part of the hydrodynamic calibration and model testing process.

6 USGS data are available online at https://waterdata.usgs.gov/nwis.

4.2.4.5 Skagit River from Newhalem to PRM 54.6

Inflows to the Skagit River mainstem models between Gorge Dam and the Concrete-Sauk Valley Road Bridge at Concrete include the outflows from Gorge Dam and multiple tributary inputs (see Table 4.2-10 and Figure 4.2-14). The relative contribution of flows from the Project varies along the reach, with non-Project discharges contributing approximately 10 percent of annual average flows at Newhalem and increasing downstream to as much as 37 percent of the annual average flow downstream of the Cascade River and 62 percent downstream of the Sauk River confluence (City Light 2021b). The methodology used to develop hourly inflows for the 19 tributaries defined in the Skagit River models between Gorge Dam and Concrete is described in the NHC (2023) memo titled "Hydrology Datasets, Newhalem to Mount Vernon" and is briefly summarized here.

After considering several approaches involving the use of hydrologic models, streamflow observations, or some combination of both, it was decided that hourly flows would be developed exclusively using published USGS streamflow data based on the relative completeness of the published streamflow records and consistency with prior hydrology efforts for the relicensing study (Appendix 1 of Attachment A to the OM-01 Operations Model Study Report [City Light 2023d]). The hourly flows were developed using sub-daily and daily streamflow data from 11 USGS gages. Hourly flows for five gaged tributaries (Newhalem Creek, Bacon Creek, Cascade River, Sauk River, and Baker River) were developed by scaling the hourly data at the gage based on drainage area to estimate the flows at the mouth of each tributary. Hourly flows for six tributary areas between Newhalem and Marblemount were estimated based on flow differencing of these respective mainstem gages and the Newhalem Creek and Bacon Creek tributary gages to maintain the observed mainstem flows at Marblemount. Within the Gorge bypass reach (Gorge Dam to Newhalem) and for tributary areas between Marblemount and Mount Vernon, hourly flows were estimated by scaling a reference tributary gage based on drainage area and annual water yield.

Table 4.2-10. Sources of hourly flow data for the Skagit River models between Gorge Dam and Concrete.

Inflow Region	Area (sq. miles)	Estimation	Inflow Location
Skagit River: Gorge Dam to Gorge Powerhouse			
Gorge Lake (spill to Gorge bypass reach)	1,172	Gorge spillway flows	Gorge Dam
Gorge bypass reach	4.0	Prorated by watershed area relative to Newhalem Creek USGS gage (12178100)	Afternoon Creek (PRM 95.7)
Gorge Lake (powerhouse to Newhalem reach)	1,184	Gorge Dam spillway flows	Gorge Dam powerhouse outflow to Skagit River
Skagit River: Newhalem to Sauk River Confluence			
Skagit River at Newhalem	1,184	Skagit River at Newhalem USGS gage flow observations (12178000)	Newhalem USGS gage (PRM 94.2)
Newhalem Creek	28.1	Prorated by watershed area relative to Newhalem Creek USGS gage (12178100)	Newhalem Creek (PRM 93.8)
Goodell and Martin Creeks	42.1	Flow differencing of Newhalem and Marblemount mainstem gages and Newhalem Creek and Bacon Creek tributary gages	Goodell Creek (PRM 93.3)

Inflow Region	Area (sq. miles)	Estimation	Inflow Location
Thornton and Babcock Creeks	9.7	Flow differencing of Newhalem and Marblemount mainstem gages and Newhalem Creek and Bacon Creek tributary gages	Thornton Creek (PRM 90.5)
Sky and Damnation Creeks	20.1	Flow differencing of Newhalem and Marblemount mainstem gages and Newhalem Creek and Bacon Creek tributary gages	Damnation Creek (PRM 88.0)
Alma Creek	8.4	Flow differencing of Newhalem and Marblemount mainstem gages and Newhalem Creek and Bacon Creek tributary gages	Alma Creek (PRM 85.5)
Copper Creek	6.0	Flow differencing of Newhalem and Marblemount mainstem gages and Newhalem Creek and Bacon Creek tributary gages	Copper Creek (PRM 84.4)
Bacon Creek	51.2	Prorated by watershed area relative to Bacon Creek USGS gage (12179900)	Bacon Creek (PRM 83.2)
Diobsud and Taylor Creeks	35.8	Flow differencing of Newhalem and Marblemount mainstem gages and Newhalem Creek and Bacon Creek tributary gages	Diobsud Creek (PRM 81.0)
Cascade River	185.4	Prorated by watershed area relative to Cascade River USGS gage (12182500)	Cascade River (PRM 77.2)
Olson, Corkindale, and O'Brien Creeks	19.5	Prorated by watershed area and annual water yield relative to Newhalem Creek USGS gage (12178100)	Corkindale Creek (PRM 74.3)
Rocky Creek	10.9	Prorated by watershed area and annual water yield relative to Newhalem Creek USGS gage (12178100)	Rocky Creek (PRM 73.8)
Illabot Creek	47.3	Prorated by watershed area and annual water yield relative to Newhalem Creek USGS gage (12178100)	Illabot Creek (PRM 73.0)
Sutter and Barr Creeks	4.0	Prorated by watershed area and annual water yield relative to Newhalem Creek USGS gage (12178100)	Barr Creek (PRM 70.8)
Sauk Mountain and Barnaby Sloughs	14.5	Prorated by watershed area and annual water yield relative to Newhalem Creek USGS gage (12178100)	Near Rockport (PRM 67.8)
Sauk River	732.8	Sauk River USGS flow observations (12189500)	Sauk River (PRM 66.8)
Skagit River: Sauk River confluence to Concrete			
Skagit River Below Sauk River confluence	2,382	Simulated outflow from Newhalem to Sauk Skagit River model	Skagit River Below Sauk River Confluence (PRM 66.7)
Miller and Aldon Creeks	18.2	Prorated by watershed area and annual water yield relative to Newhalem Creek USGS gage (12178100)	Miller Creek (PRM 64.6)
Jackman Creek	27.9	Prorated by watershed area and annual water yield relative to Newhalem Creek USGS gage (12178100)	Jackman Creek (PRM 58.4)
Baker River	299.2	Baker River USGS flow observations (12193400/12193500)	Baker River (PRM 56.8)

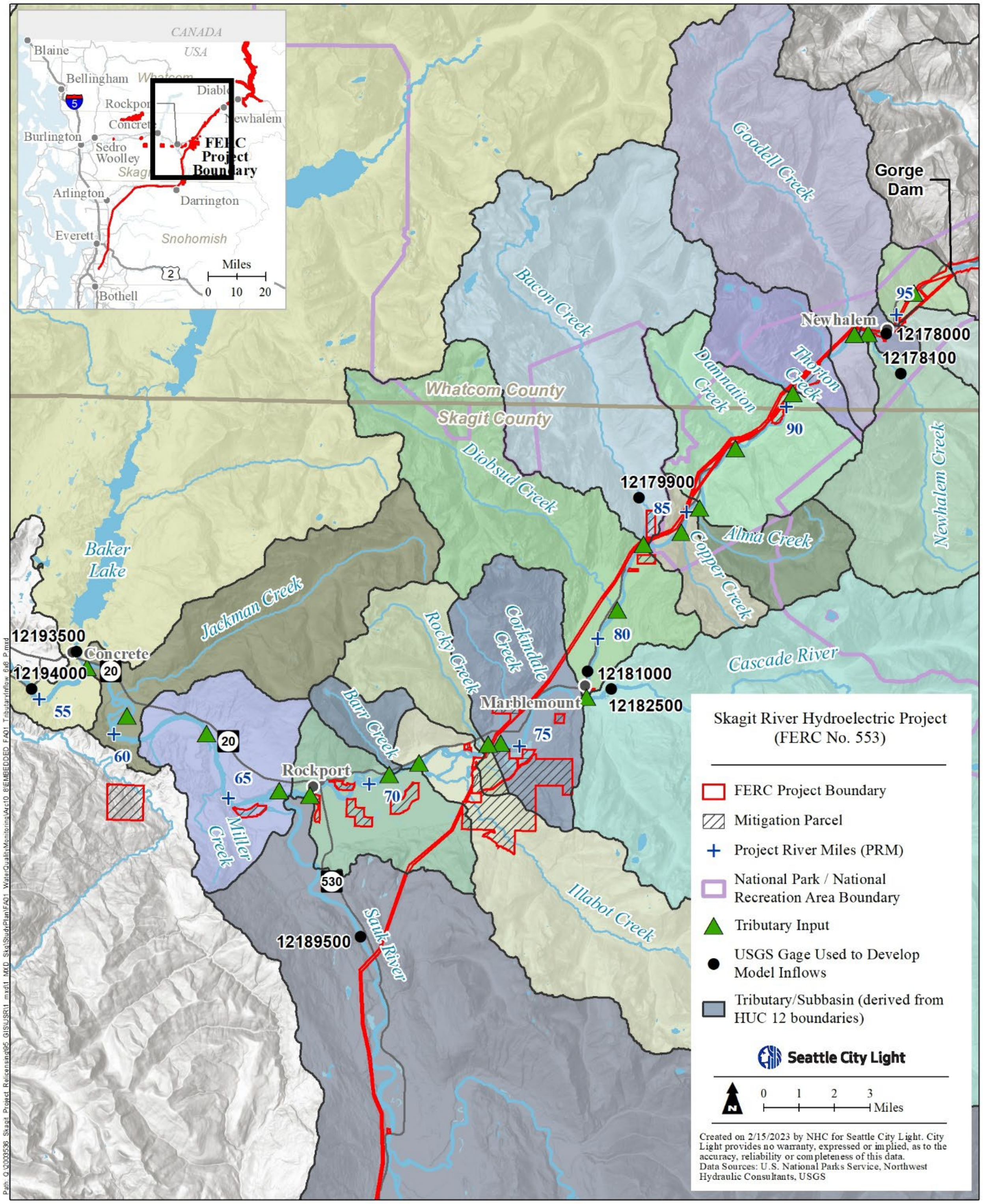


Figure 4.2-14. Inflow locations to the Skagit River models between Gorge Dam and Concrete.

4.2.4.6 Flow Data Availability

The duration of available inflow data is a major constraint on the duration of model simulations. Flow data availability are summarized in Table 4.2-11. Limited data exist from time periods decades ago (e.g., the 1950s), but these are not useful for development of a model that represents present conditions.

Table 4.2-11. Availability of flow data.

Gage	Number[1]	Record Start	Record End
Ross Lake Inflows			
Skagit River above Klesilkwa	08PA012	Mid-2019	Present
Big Beaver Creek	12172000	June 27, 2018	Present
Ruby Creek	12173500	April 30, 2018	Present
Diablo Lake Inflows			
Ross Dam	None	January 1, 1997	Present
Thunder Creek	12175500	October 1, 1989	Present
Gorge Lake Inflows			
Diablo Dam	None	January 1, 1997	Present
Skagit River Gages and Inflows			
Gorge Dam	None	January 1,1997	Present
Skagit River at Newhalem	12178000	October 5, 1987	Present
Newhalem Creek	12178100	October 1, 1989	Present
Skagit River below Babcock Creek	12178600	November 10, 2020	Present
Skagit River below Damnation Creek	12178900	September 26, 2020	Present
Skagit River above Alma Creek	12179000	June 11, 2020	Present
Bacon Creek	12179900	November 3, 1998	Present
Skagit River above Diobsud Creek	12180300	June 9, 2020	Present
Skagit River at Marblemount	12181000	October 1, 1987	Present
Cascade River	12182500	June 7, 2006	Present
Skagit River at Corkindale	12183900	June 9, 2020	Present
Skagit River near Rockport	12184700	October 1, 2015	Present

1 The Skagit River above Klesilkwa is operated by the Water Survey of Canada. The other gages are USGS gages.

4.2.5 Temperature Input Files

In addition to input files describing flow of water into and out of simulated waterbodies, reservoir and riverine models require input files that contain time series of water quality constituents that will be modeled. Insofar as the models simulated water temperature, temperature time series were required in the same tributaries for which inflows were specified. Substantial temperature monitoring efforts in recent years have created a robust inventory of temperature data in tributaries around Ross Lake, Diablo Lake, Gorge Lake, and the Skagit River, as described in the FA-01a WQ Monitoring Study Interim Report, Attachment D (City Light 2022a). Using those data, input files of tributary temperature were developed as indicated in Table 4.2-12. When data were not available in an inflow region, a nearby record was used directly or filled via regression analysis. Therefore, some temperature records are used to provide temperature inputs for multiple inflow regions. The temperature monitoring sites used for developing temperature input files for the Skagit River models between Gorge Dam and Concrete are shown in Figure 4.2-15.

Table 4.2-12. Sources of tributary temperature data.

Inflow Region	Water Temperature Record Used
Ross Lake Tributaries	
Skagit River	Skagit River at Swing Bridge
Northwest	Silver Creek NPS sensor
West	Silver Creek NPS sensor
Southwest	Big Beaver USGS gage
Big Beaver	Big Beaver USGS gage
Northeast	Hozomeen Creek
Southeast	Big Beaver USGS gage
Ruby East	Ruby Creek USGS gage
Ruby North	Granite Creek
Ruby South	Granite Creek
Diablo Lake Tributaries	
Ross Lake	Ross Dam log boom
East	Granite Creek
North	Granite Creek
South	Granite Creek
Thunder South	Thunder Creek USGS gage
Thunder West	Thunder Creek USGS gage
Thunder East	Thunder Creek USGS gage
Gorge Lake Tributaries	
Diablo Lake (spill to Reflector Bar or powerhouse to Stetattle upper reach)	Diablo Dam log boom
Stetattle Reach	Stetattle Creek City Light and Stream Temperature Study sensor
Skagit River Tributaries	
Skagit River at Newhalem	Skagit River at Newhalem USGS gage (12178000)
Newhalem Creek	Newhalem Creek USGS gage (12178100)
Bacon Creek	Bacon Creek USGS gage (12179900)
Cascade River	Cascade River USGS gage (12182500)
Sauk River	Sauk River USGS gage (12189500)
Baker River[1]	Baker River Puget Sound Energy sensor

1 Available observed stream temperature data for the Baker River below the Baker River Hydroelectric Project (FERC No. 2150) is limited to one winter season in 2018, four summer seasons between 2018 and 2021, and summer/fall 2022. Gaps in the Lower Baker River temperature record were filled with two separate regressions that vary seasonally: 1) December to July 15 is based on the USGS Skagit River at Newhalem gage as Baker River temperature = 0.9174x + 1.0152 (‘x’ is the observed source stream temperature), R2 value of 0.78; 2) July 16 to November is based on Baker River temperature calculated as a 30 day moving average of the Upper Baker River NPS sensor with a lag and shift applied.

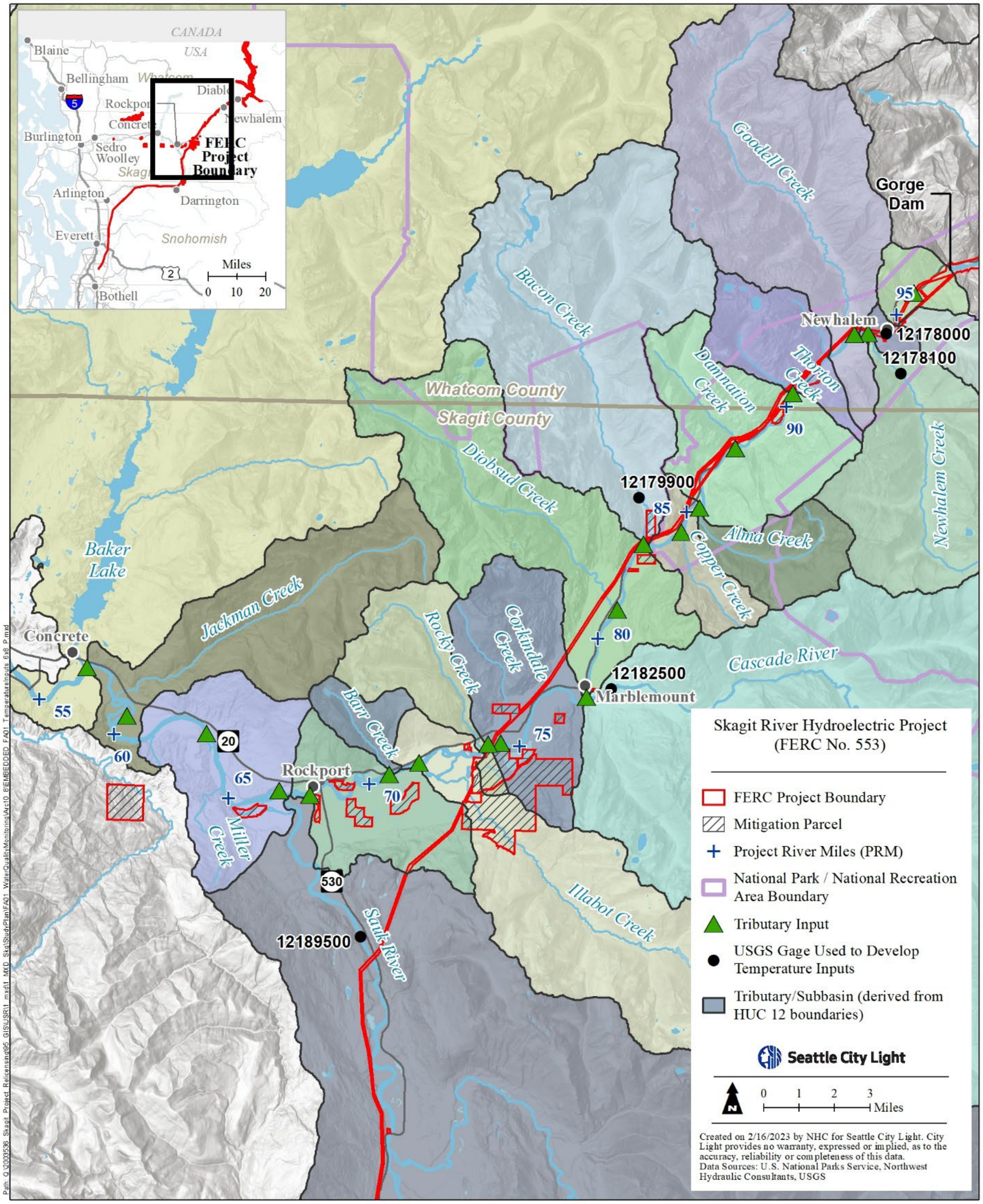


Figure 4.2-15. Temperature monitoring sites used to develop inputs for the Skagit River models between Gorge Dam and Concrete.

A CE-QUAL-W2 model calculates temperatures at the outflows of dams or at the downstream extent of the modeled river reach. However, time series of temperatures in outflows from Ross Dam, Diablo Dam, and Gorge Dam are required as upstream inputs to Diablo Lake, Gorge Lake, and the Skagit River, respectively. Additionally, these time series can be useful for calibrating the Ross Lake, Diablo Lake, and Gorge Lake models, respectively. Because water temperature is not measured continuously in dam outflows, temperature time series of dam outflows were created using the time series measured by thermistors downstream of the dams near the outflows from each powerhouse. Observed water temperatures used for calibration of the Skagit River model were applied using the USGS Skagit River at Newhalem gage (12178000) temperature record.

4.2.6 Topographic Shading

An additional input file required by CE-QUAL-W2 is the topographic shade file. This file describes the extent to which topography might shade the waterbodies with enough frequency to reduce the incident short-wave solar radiation on the water surface. A file of dynamic shading coefficients was assembled for each reservoir. These files allow the models to calculate the shading in each segment of each reservoir based on the angle of the sun, the height of the nearby mountains, and the height and proximity of vegetation near the water.

Topographic shading angles were calculated with an automated process that used the elevation and distance of topography on radial transects extending from the center of each model segment. These measurements were used to calculate the inclination angle at each point along the transect, and the maximum angle in each transect was used as the inclination angle in the shade file. An example for a segment within the Skagit River model is shown in Figure 4.2-16, which shows radial transects (for clarity, they are shown every 20°C) and locations of maximum inclination angle along those transects.

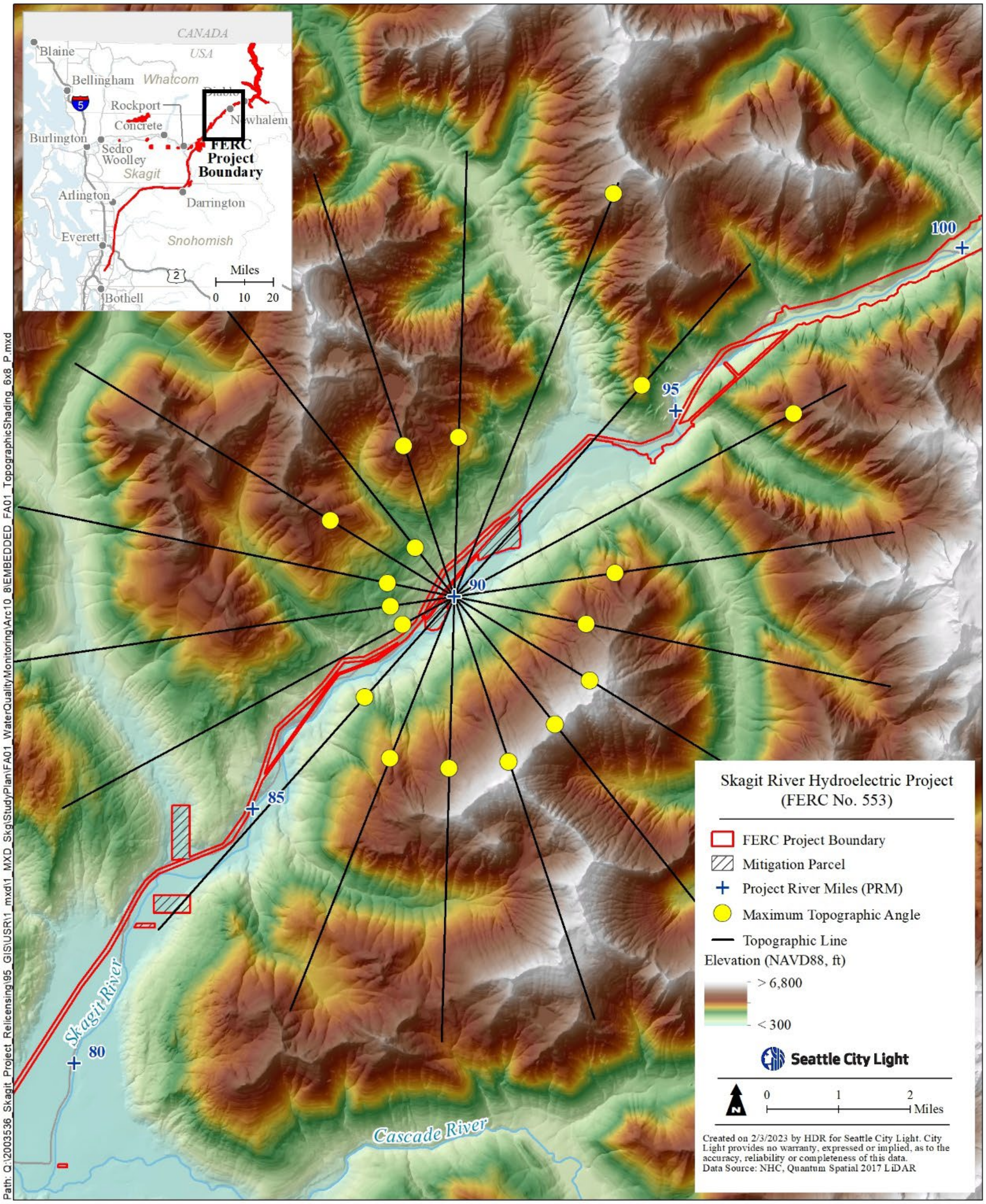


Figure 4.2-16. Maximum inclination angles along radial transects originating from a segment located between Newhalem and Marblemount within the Skagit River model.

4.2.7 Vegetative Shading

In the Skagit River downstream of Gorge Dam to PRM 54.6, shading of the river from vegetation was also included in the model input parameters. Vegetative shading was not considered for the three reservoir models, as vegetation does not shade a significant portion of their surface area. These inputs include the maximum inclination angle to shade-controlling vegetation on both the left and right banks of the river and the CE-QUAL-W2 Shade Reduction Factors (SRF), which reduce the incident solar radiation when the angle above the horizon is lower than the shade-controlling vegetation angle based on the density of the riparian vegetation. SRF values range from zero to 1.0; a dense cluster of trees or a building providing complete blockage of sunlight would be assigned a SRF value approaching 1.0 and a sparse tree cluster would be assigned a smaller value on the order of 0.15. The density of vegetation in the Skagit River riparian corridor is used for SRF factor determination and was assigned based on a National Oceanic and Atmospheric Administration (NOAA) Coastal Change Analysis Program (C-CAP) land cover dataset (NOAA 2016) that was available for the study area. Riparian vegetation density values were assigned to C-CAP land cover classes using values similar to those used by past riverine CE-QUAL-W2 modeling studies within Washington State and those identified by King County (2005) as part of a detailed riparian characterization in the Green-Duwamish watershed that included both air photo and hemispherical photo analysis to define shade values. Those values, which range from 25 percent to 90 percent, are listed in Table 4.2-13. Maximum inclination angle to shade controlling vegetation was captured throughout the reach when sampled within 3,280 ft (1,000 m) of the stream channel, and vegetation density was sampled across a 328 ft (100 m) riparian corridor (Figure 4.2-17).

Table 4.2-13. Vegetation density values applied to landcover mapping categories for SRF calculations.

NOAA CCAP Land Cover Class Names[1]	Density (%)
Developed	25
Open Space	25
Grassland	25
Deciduous Forest	75
Evergreen Forest	90
Mixed Forest	75
Scrub/Shrub	50
Palustrine Forested Wetland	75
Palustrine Scrub/Shrub Wetland	50
Emergent Wetland	25
Unconsolidated Shore	25
Bare Land	25
Water	75
Aquatic Bed	75
Snow/Ice	25

1 C-CAP classes have been combined or eliminated if not present in the study area.

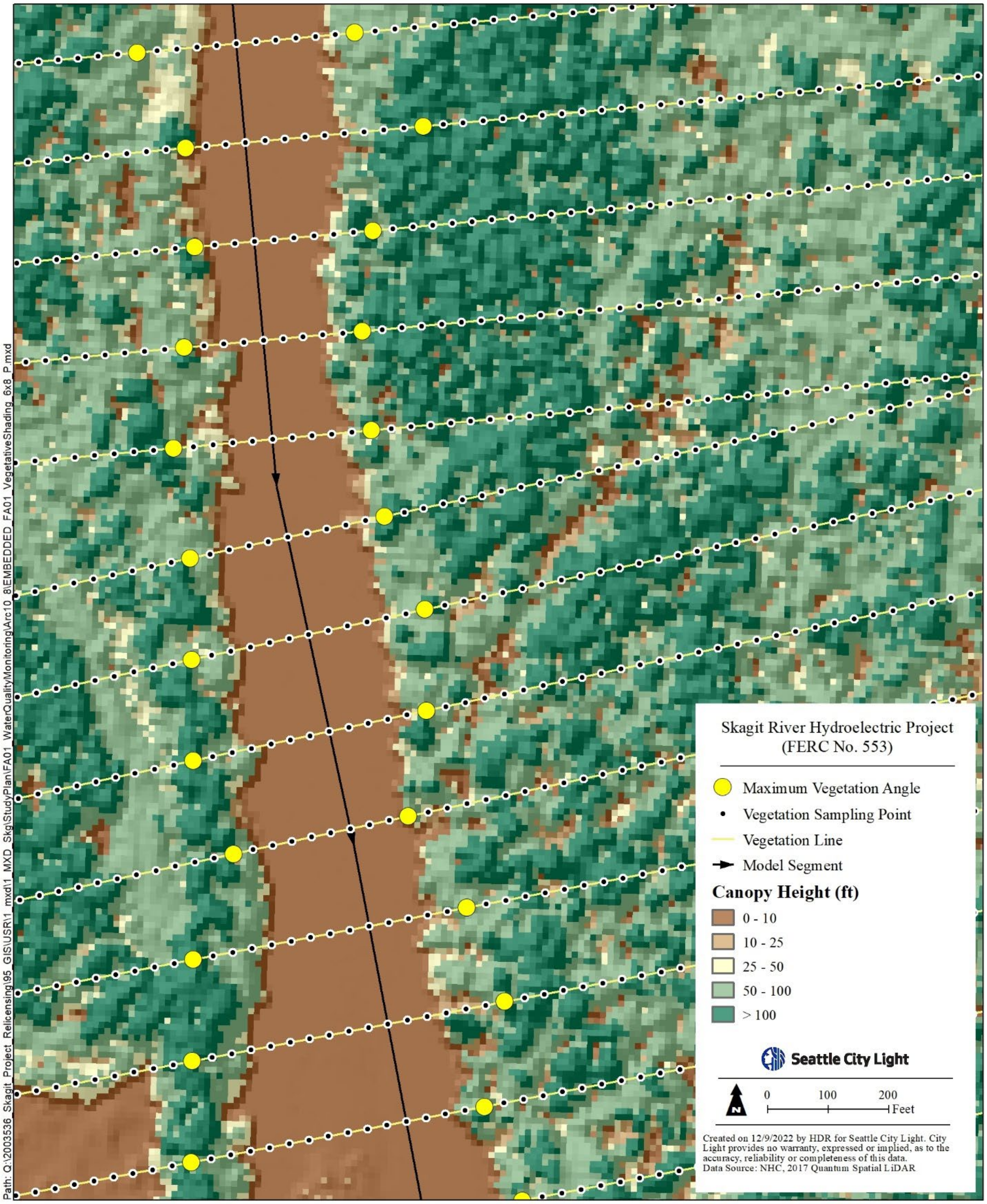


Figure 4.2-17. Shade controlling vegetation lines sampled along the Skagit River downstream of Gorge Dam.

4.2.8 Wind Sheltering File

The wind sheltering file describes the extent to which the effective wind speed on the water surface may be altered to account for differences between measurements at the meteorological station used for input data and the waterbody being modeled. It contains coefficients known as “wind sheltering coefficients,” with one value assigned to each model segment. These values can vary over time as desired. Wind sheltering coefficients are scalar multipliers of wind speed. These coefficients are named with the assumption that they will generally be less than 1 and thus reduce wind speeds to account for topographic sheltering in individual model segments.

During the process of calibrating the models, Geosyntec met with CE-QUAL-W2 modeling expert Dr. Scott Wells. Due to the distance between the Marblemount RAWS station and the reservoirs, Dr. Wells expected that large modifications to wind data would be required and advised using broad corrections to wind data that varied seasonally (Wells 2022). This suggestion was implemented in the development of the wind sheltering file. Early model calibration runs indicated that wind speeds on Ross Lake were too low, and so wind sheltering coefficients in the model on the order of 2.6 seemed acceptable to Dr. Wells (Wells 2022). Thus, in this modeling, the wind sheltering coefficients act to increase wind speeds observed at the Marblemount RAWS station, not to represent a sheltering effect of mountains.

4.2.9 Model Control File

Key parameters of the model control file are:

- Latitude and longitude: The center of Ross and Diablo lakes and the downstream end of Gorge Lake and the modeled reach of the Skagit River were used.
- Elevation of the bottom of the waterbody: The elevation of the base of a dam or of the riverbed downstream of the Concrete Sauk Valley Road Bridge in Concrete, WA.
- Longitudinal eddy viscosity and diffusivity: Set to 1 m squared per second (m^2/s) for all three reservoir models (the default value) and 0.1 m^2/s for the Skagit River model (based on prior river model calibrations).
- Bottom heat exchange: Set to the default value of 0.3 watts W/m^2 per degree Celsius.
- Sediment temperature coefficient controlling heat lost to sediments that is added back to water column: Set to 1.0 in the reservoir models and 0.75 in the Skagit River models.
- Sediment temperature: Set to the long-term average air temperature stated in the meteorological input file.
- Light extinction: Set to the recommended default value of 0.45 inverse m.
- Maximum vertical eddy viscosity: Set to the default value of 1 m^2/s.
- Number of outlet structures: Each dam has two outlet structures, the spillway and the penstocks. Elevations and widths of each were taken from the latest available documentation of the Project.

4.3 Debugging and Calibration

4.3.1 Debugging Approach

Model debugging is the process of iteratively running the model and resolving syntax or logical errors that may have occurred when developing input files or specifying parameters in the control file. When modeling with CE-QUAL-W2, the preprocessor utility is used to test the model for errors before running the model. The model was debugged until preprocessor errors were eliminated and preprocessor warnings were eliminated or deemed acceptable. This debugging practice is consistent with industry standards.

4.3.2 Calibration Approach

4.3.2.1 Calibration Targets

The QAPP for this modeling study describes calibration targets (Northwest Hydraulic Consultants and Geosyntec Consultants 2022), reviewed briefly here before specific calibration approaches are discussed below. The quality of calibration was evaluated qualitatively and quantitatively. Qualitative evaluations consist of careful examination of figures that show comparisons between observed data and model output for the same times and locations, usually as vertical profiles in a deep water column or as time series for an extended period at one location and one depth. These figures are particularly useful because they allow the modeler to check the quality of calibration carefully at key locations, depths, or times and to evaluate agreement between model output and data at multiple locations or times simultaneously.

Quantitatively, the match between simulated and observed water levels in the Skagit River should produce a mean absolute error statistic of less than 0.2 m and 15 percent of the long-term average discharge (evaluated with hourly model output). Temperature simulations in the river aim for mean absolute error statistics of less than 0.4°C. In the reservoir models, the agreement of water level should produce a root mean squared error of 0.05 m or less, and the agreement between observed and simulated temperatures should produce a mean absolute error of less than 1°C in vertical profiles.

4.3.2.2 Hydrodynamic Calibration

For each model, an initial hydrodynamic calibration was performed to fit simulated water surface elevation levels to water levels that have been observed at the dams, at gages on the Skagit River, and to new water level data collected for the study. The customary method of achieving a “water balance” for a reservoir model is to use the CE-QUAL-W2 water balance utility to calculate the difference in inflows at each time step during the simulation that would be required to resolve the difference in water levels. Then, those flows are added to the waterbody via a “distributed tributary,” which is a conceptual tributary whose flow is divided evenly among the cells. This is meant to resolve small errors in inflows.

For the Skagit River models, both steady and unsteady flow simulations were performed as part of the hydrodynamic calibration. Several steady-state (constant inflow) simulations were first conducted to match simulated water surface elevation profiles to observations collected between 2020 and 2022. Continuous water surface profiles corresponding to flows of 2,350, 4,200, and 6,700 cubic feet per second (cfs) at Newhalem were collected during several boat surveys between Newhalem and the Sauk River in 2020 and 2021 (NHC 2022a, 2022b, 2022c). Water levels were also surveyed at three locations between the Sauk River confluence and Concrete in May and August of 2022. In addition, an unsteady flow simulation was conducted for water year (WY) 2021, and simulated flow and water level time series were compared to observations at three USGS gages (Skagit River at Marblemount, above Alma Creek, and near Concrete). The Skagit River monitoring sites used for hydrodynamic calibration are summarized in Table 4.3-1 and shown in Figure 4.3-1.

Table 4.3-1. Skagit River hydrodynamic and temperature calibration monitoring sites.

PRM	Location Description	Owner	Station ID	Variables	Start Date	End Date
91.6		City Light	SKAGIT2	Temperature	September 2020	September 2021
86.0	Above Alma Creek	USGS	12179000	Flow Water level	October 2020	September 2021
85.9		City Light	SKAGIT3	Temperature	September 2020	September 2021
79.0	Marblemount	USGS	12181000	Flow Water level Temperature	October 2020	September 2021
75.6		City Light	SKAGIT4	Temperature	September 2020	September 2021
69.3		City Light	SKAGIT5	Temperature	June 2021	September 2021
62.4		City Light		Water level	May 26, 2022 and August 19, 2022	May 26, 2022 and August 19, 2022
60.8		City Light	SKAGIT6	Temperature	June 2021	September 2021
60.0		City Light		Water level	May 26, 2022 and August 19, 2022	May 26, 2022 and August 19, 2022
56.8	Baker River Confluence	City Light		Water level	May 26, 2022 and August 19, 2022	May 26, 2022 and August 19, 2022
54.6	Concrete	USGS	12194000	Flow Water level	October 2020	September 2021
54.5	Concrete	City Light	SKAGIT7	Temperature	June 2021	September 2021

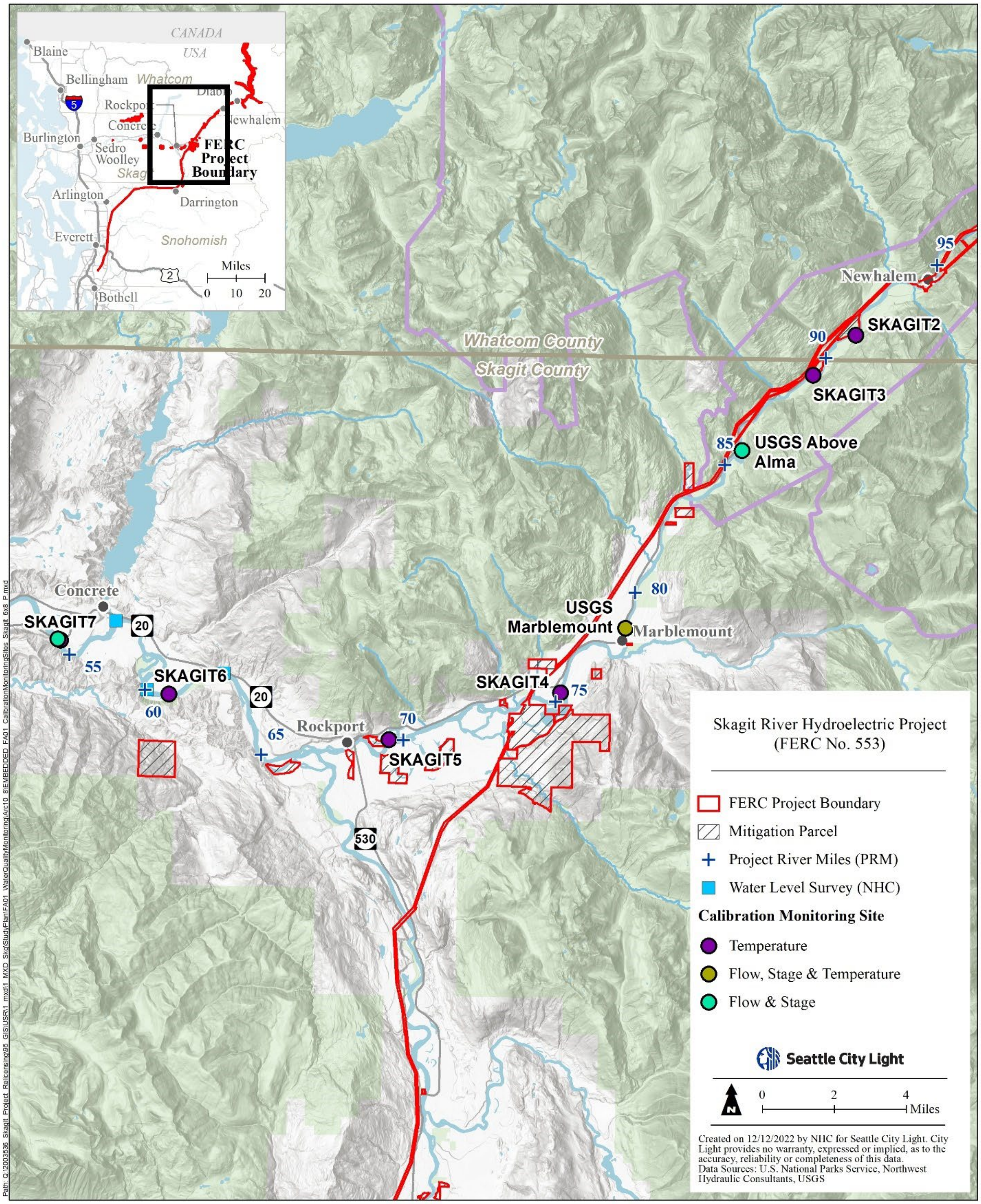


Figure 4.3-1. Skagit River hydrodynamic and temperature calibration monitoring sites.

4.3.2.3 Temperature Calibration

Following the hydrodynamic calibration, a second calibration process was performed to improve the accuracy of simulated temperatures. Temperature calibration involved comparison of temperature profiles and time series simulated by the models to vertical profiles and thermistor chain data collected in the reservoirs and temperature measurements recorded in the Skagit River downstream of Gorge Powerhouse. Usable portions of the temperature datasets were constrained by quality control flags, as detailed in Attachment D to the FA-01a WQ Monitoring Study Interim Study Report (City Light 2022a).

For the Ross Lake model, the distance between the Marblemount meteorological station and Ross Lake combined with the mountainous topography of the region imply that the meteorological data collected from Marblemount are not necessarily representative of conditions on the Project reservoirs. The Hozomeen meteorological station was also not representative of Ross Lake wind and sunshine because it is located in forest. Consequently, for Ross Lake, temperature calibration largely focused on varying meteorological parameters such as wind sheltering and air temperature. A spatially variable initial conditions file was also developed from monitoring data.

Ross Lake temperature data exist as synoptic vertical profiles collected monthly by NPS from the Little Beaver, Skymo, and Pumpkin Mountain locations and as time series from thermistor chains deployed successively by City Light at three locations near Ross Dam (Table 4.3-2, Figure 4.3-2). All useable profile data were used for calibration; data were sampled from thermistor chains at noon at two-week intervals and used for calibration. In each case, model results from the hour nearest to the time of data collection were compared to data. As a check on the vertical calibration, the simulated temperature of water released from Ross Dam was compared to continuous temperature data collected downstream of Ross Powerhouse.

Table 4.3-2. Vertical profile and thermistor chain data in Ross Lake.

	Vertical Profiles			Thermistor Chains		
Month	Little Beaver	Skymo	Pumpkin Mountain	Log Boom	Dam Face	Spillway Boom
May 2019			x			
June 2019	x	x	x	x		
July 2019	x	x	x	x		
August 2019	x	x	x	x		
September 2019	x	x	x	x	x	
October 2019	x	x	x	x	x	
November 2019	x	x	x		x	
December 2019					x	x
January 2020						x
February 2020						x
March 2020						x
April 2020						x
May 2020			x			x
June 2020	x	x	x			x
July 2020	x	x	x			x
August 2020	x	x	x			x
September 2020	x	x	x			x
October 2020	x	x	x			x
November 2020		x	x			x

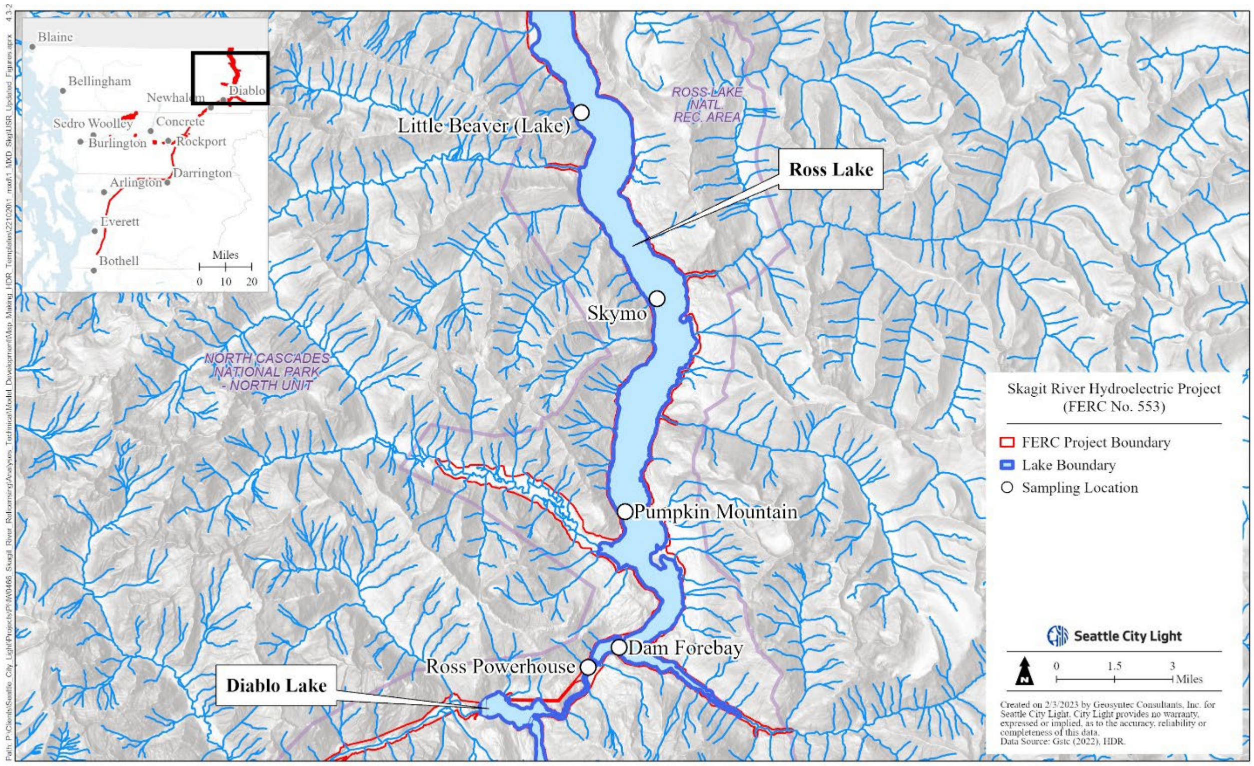


Figure 4.3-2. Locations of calibration data on Ross Lake. The "Dam Forebay" area includes the three locations called "Log Boom," "Dam Face," and "Spillway Boom."

For the Diablo Lake model, the Marblemount meteorological station is also far from Diablo Lake so meteorological parameters were adjusted in the Diablo model as well. Additionally, Secchi disc data collected on Diablo Lake by City Light were used to estimate light extinction coefficients, but a diagnostic analysis indicated that temperature results were not particularly sensitive to this parameter, which was left a moderate value.

The Diablo Lake model was calibrated using three profiling events in 2019 and six events in 2020 at the buoy in Thunder Arm and near Diablo Dam (Table 4.3-3, Figure 4.3-3). Similar to Ross Dam, simulated temperature of water released from Diablo Dam was compared to time series data collected at the Diablo Powerhouse location downstream of Diablo Dam.

Table 4.3-3. Vertical profile data in Diablo Lake.

Month	Vertical Profiles			Thermistor Chains	
	Thunder Arm Bridge	Temp Buoy	Dam	Buster Brown Bay	Diablo Boom
June 2019	x	x	x	x	x
July 2019				x	x
August 2019	x	x	x	x	x
October 2019	x	x	x	x	x
November 2019				x	x
December 2019				x	x
May 2020		x	x		
July 2020		x	x		
August 2020		x	x		
September 2020		x	x		
October 2020		x	x		
November 2020		x	x		

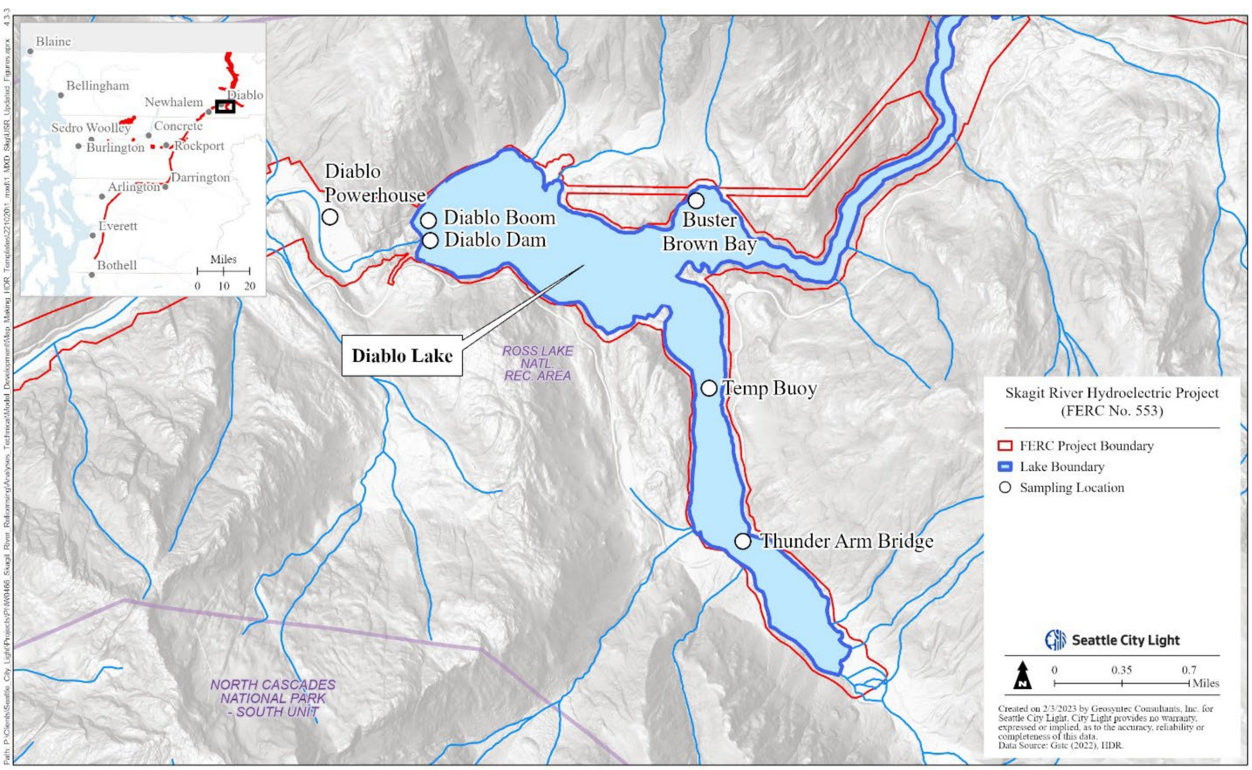


Figure 4.3-3. Locations of calibration data on Diablo Lake.

For the Gorge Lake model, wind speed and direction from the Marblemount meteorological station were adjusted to account for the land-over water and topographic sheltering effect. The Gorge Lake model was calibrated against stage and temperature data summarized in Table 4.3-4 and shown in Figure 4.3-4 (the USGS Skagit River at Newhalem gage [12178000], is not shown in the figure).

Table 4.3-4. Thermistor data used for Gorge Lake calibration.

Location	Calibration Data	Start Date	End Date
Log Boom	Temperature thermistor chain	January 2019	January 2021
Powerline	Temperature time series	January 2019	January 2021
Midway	Temperature time series	January 2019	January 2021
USGS Skagit River at Newhalem gage (12178000)	Temperature time series	January 2019	January 2021

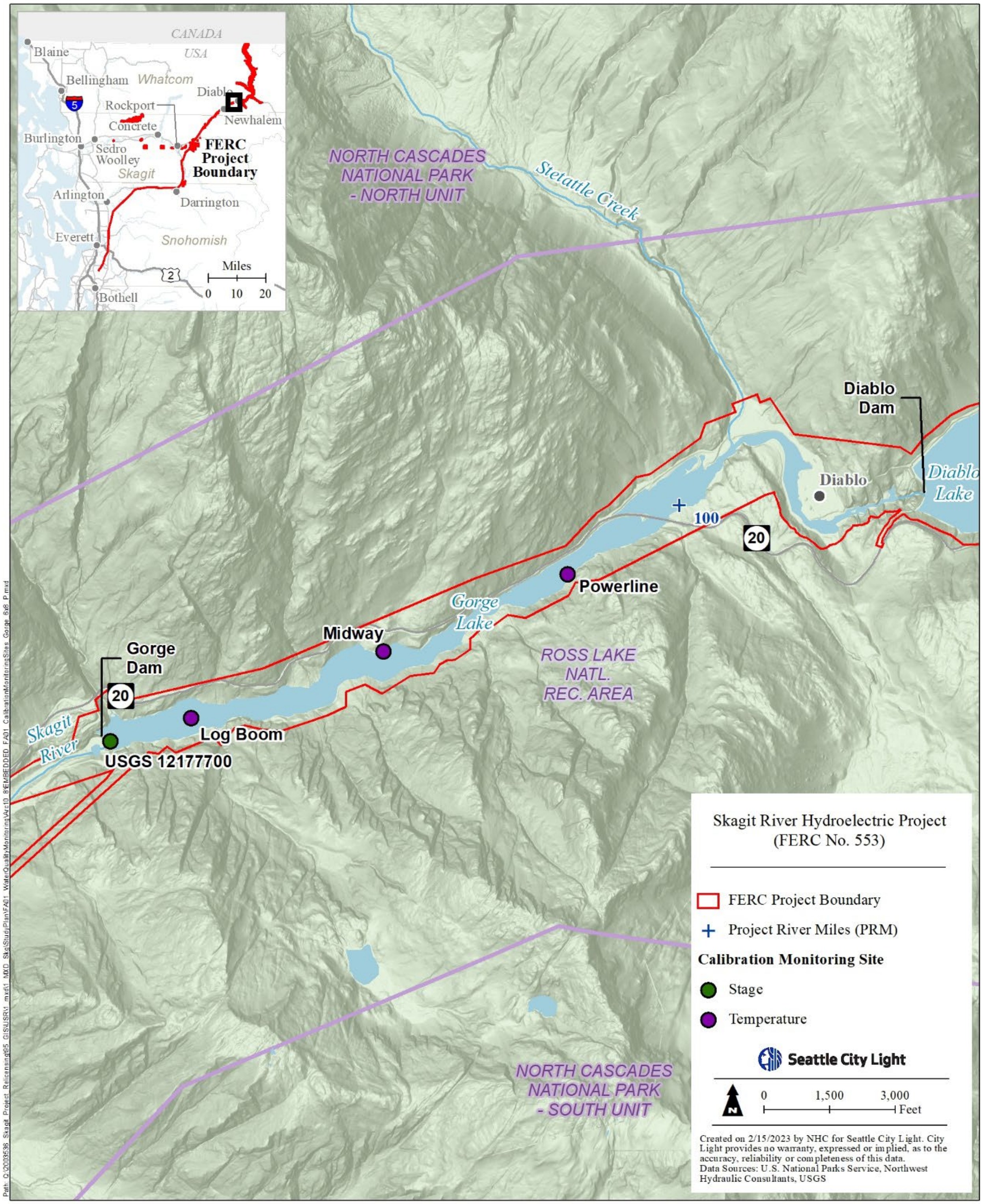


Figure 4.3-4. Locations of calibration data on Gorge Lake.

For the Skagit River models, temperature calibration was conducted for WY 2021 using seven continuous temperature monitoring sites (six City Light stations and the USGS Marblemount gage) between PRM 91.6 (downstream of Newhalem) and PRM 54.5 (downstream of Concrete). No temperature calibration of the Gorge bypass reach model was possible due to a lack of observed temperature data collected during times of continuous flow that aligned with the simulated time period. The Skagit River monitoring sites used for temperature calibration are summarized in Table 4.3-1 and shown in Figure 4.3-1.

4.3.3 Calibration Statistics and Figures

Water level calibration was assessed qualitatively by creating time series figures of simulated and observed water levels and calculating the statistics described in Section 4.3.2.1. Temperature calibration was assessed qualitatively in river reaches by creating time series figures that compare model output for the same depths and times as those observed by temperature gages in the field and, in reservoirs, by creating vertical profile figures that compare model output with vertical profile data over many depths for a given time and location. Error statistics in vertical profiles required interpolation of data or model output to match their depths. This was performed using the Scipy interp1d function, which uses the points on either side of the desired point, (X1, Y1) and (X2, Y2), to determine the point (X, Y) using Equation 4.3-1.

$$Y = Y1 + \frac{(X - X1)}{(X2 - X1)} * (Y2 - Y1)$$

Eq. 4.3-1

Calculated error statistics including and in addition to those specified in the modeling QAPP were used to evaluate temperature calibrations qualitatively. These statistics were the root mean squared error (RMSE) (Equation 4.3-2), the mean absolute error (MAE) (Equation 4.3-3), the percent bias (PBIAS) (Equation 4.3-4), and the Nash Sutcliffe model efficiency coefficient (NSE) (Equation 4.3-5).

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N}(Modeled_i - Observed_i)^2}{N}}$$

Eq. 4.3-2

Where: N is the number of samples;
$Modeled_i$ is the modeled value of the i^{th} sample; and
$Observed_i$ is the observed value of the i^{th} sample.

$$\mathrm{MAE} = \frac{1}{n}\sum_{j=1}^{n}|y_j - \hat{y}_j|$$

Eq. 4.3-3

Where: n is the number of samples;
y_j is the observed value of the j^{th} sample; and
$\hat{y}_j$ is the modeled value of the j^{th} sample.

$$PBIAS = 100\frac{\sum_{i=1}^{N}(M_i - O_i)}{\sum_{i=1}^{N} O_i}$$

Eq. 4.3-4

Where: N is the number of samples;
M_i is the modeled value of the i^{th} sample; and
O_i is the observed value of the i^{th} sample.

$$NSE = 1 - \frac{\sum_{i=1}^{n}(OBS_i - MOD_i)^2}{\sum_{i=1}^{n}(OBS_i - \overline{OBS})^2}$$

Eq. 4.3-5

Where: n is the number of samples;
OBS_i is the observed value;
MOD_i is the modeled value; and
$\overline{OBS}$ is the average of the observed values.

4.3.4 Calibration Results

4.3.4.1 Ross Lake

The water balance calibration process resulted in changes to the input flow estimation process for Ross Lake (estimating several tributary area inflows using upper Skagit River flows instead of adjacent flow gages, fully described in Section 4.2.2.1). Following this change, iterative adjustments to distributed tributary flows achieved a water level calibration with an RMSE of 0.7 ft (0.02 m) (Figure 4.3-5). This fell below the target RMSE of 1.8 ft (0.05 m). Distributed inflows usually ranged between 0 and 700 cfs (0-20 m^3/s) with occasional excursions that are likely associated with significant inflow (i.e., storm) events. This magnitude of flow seems reasonable for the number of small tributaries that enter Ross Lake, the size of the Ross Lake watershed, and the uncertainty of estimates of both ungaged modeled tributaries and dam releases. The small range into which most distributed flow values fall suggests no unreasonable bias in the flows of the modeled tributaries and dam outflows for the Ross Lake model.

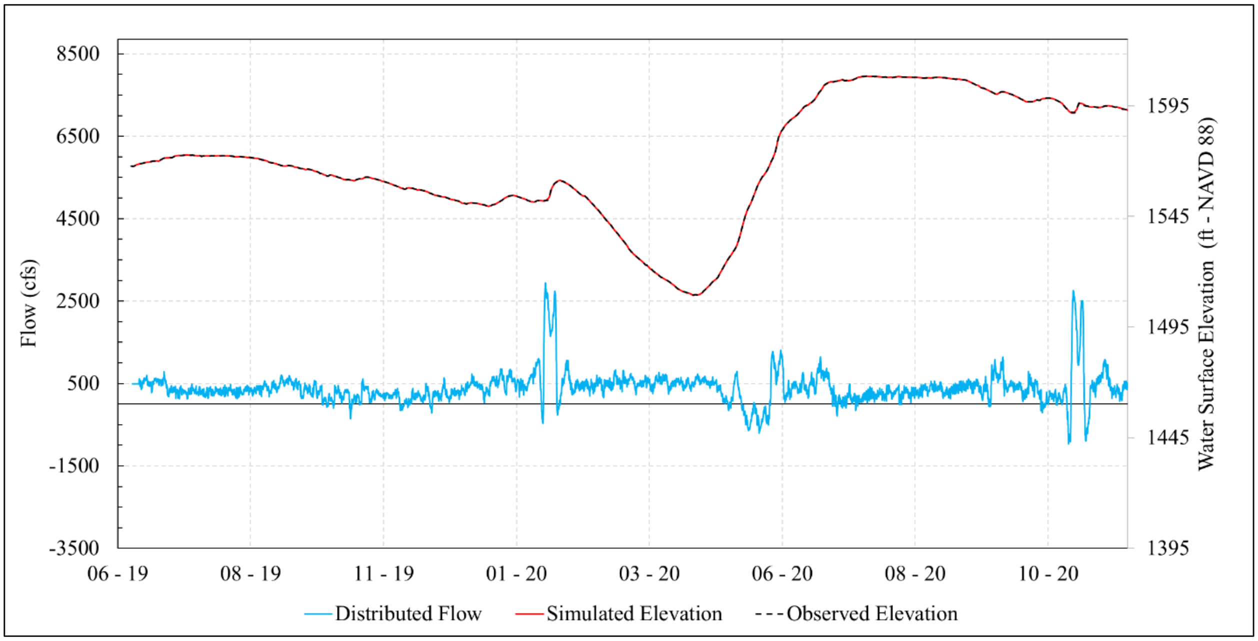


Figure 4.3-5. Ross Lake distributed tributary inflow and water balance calibration shown by nearly identical observed water surface elevation and simulated water surface elevation (ft NAVD 88).

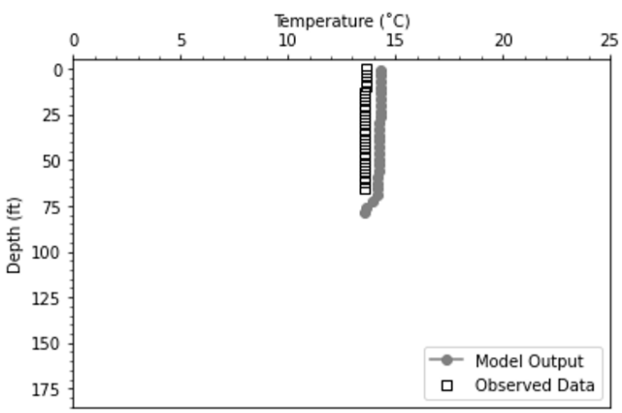
Achieving an adequate calibration of modeled temperature in Ross Lake required four changes to the model after the initial inputs and parameterizations described above:

- The wind sheltering coefficient was set to values of 2.0-2.8 that varied both across the reservoir and throughout the simulation. This change magnified the wind speed measured in Marblemount, where the wind was consistently light and variable.
- The model used the air temperature and dewpoint temperature from the Marblemount meteorological station from November 25, 2019, through April 20, 2020 and the air temperature and dewpoint temperature of the Hozomeen meteorological station otherwise (i.e., in summer and autumn). The temperatures at Marblemount were notably warmer than those at Hozomeen in 2019 and 2020, so this change allows the use of temperatures from near the reservoir as much as possible while shifting in winter to address a cold bias in surface and mid-depth temperatures near the dam.
- The dewpoint temperature was set to the air temperature between November 25, 2019, and March 15, 2020. This was necessary to address an initial winter cold bias, and it is reasonable because the Marblemount meteorological station does not represent conditions on Ross Lake and the wet (i.e., actual) adiabatic lapse rate[7] is likely to vary between these two locations.

[7] The wet, or actual, adiabatic lapse rate describes the decrease in air temperature with rising altitude from Earth's surface at a given humidity level.

- The Skagit River inflow temperature was increased by up to 0.5°C during spring 2020. This was based on past periods when data existed at both the monitoring location above the confluence with the Klesilkwa River (the only location with data during the simulation period) and data at Swing Bridge, the monitoring station nearest to the upstream end of Ross Lake.

Seasonally, calibration of the Ross Lake model showed qualitative agreement in autumn 2019 in all four monitoring locations (Little Beaver, Skymo, Pumpkin Mountain, and the dam forebay; an example is included as Figure 4.3-6, and a full set of calibration figures is available in Attachment B). In winter 2020, which was characterized by isothermal conditions, vertical profile plots usually showed close matches between model output and data closely, but data were only available near the dam (Figure 4.3-7). In early summer (i.e., June) 2020, a qualitative evaluation of calibration showed disagreement between model output and data at depth at locations nearer the upper end of the reservoir, with model output underestimating lake temperatures, but this disagreement did not occur near the dam. This disagreement can be attributed to uncertainty about meteorology and a lack of monitoring data for the previous several months (Figure 4.3-8). In summer and autumn 2020, modeled temperature profiles generally represented observed data but did not match field profiles precisely (Figure 4.3-9). This is due to a compromise between efforts to tune model parameters (primarily the wind sheltering coefficient) to improve model calibration and a desire to avoid parameter refinements that are so numerous and detailed that they become applicable only to the precise time and location at which the monitoring data were collected. The quality of calibration was generally consistent between monitoring locations and between depths, and it is also consistent with that of other seasonally stratified reservoirs of this depth with a similar amount of monitoring and input data.



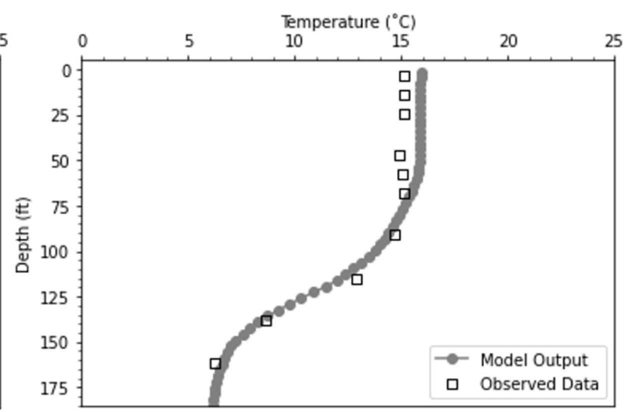


Figure 4.3-6. Model calibration for Ross Lake at the Skymo (left panel) and Log Boom (right panel) locations on October 10, 2019.

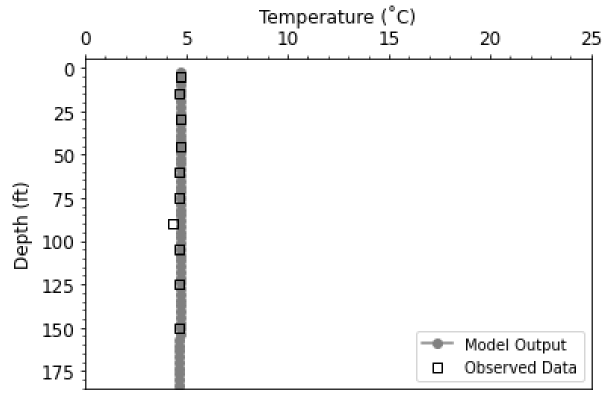


Figure 4.3-7. Model calibration for Ross Lake at the Spillway Boom location on January 18, 2020. No monitoring data are available from an additional location further upstream in the reservoir on this date.

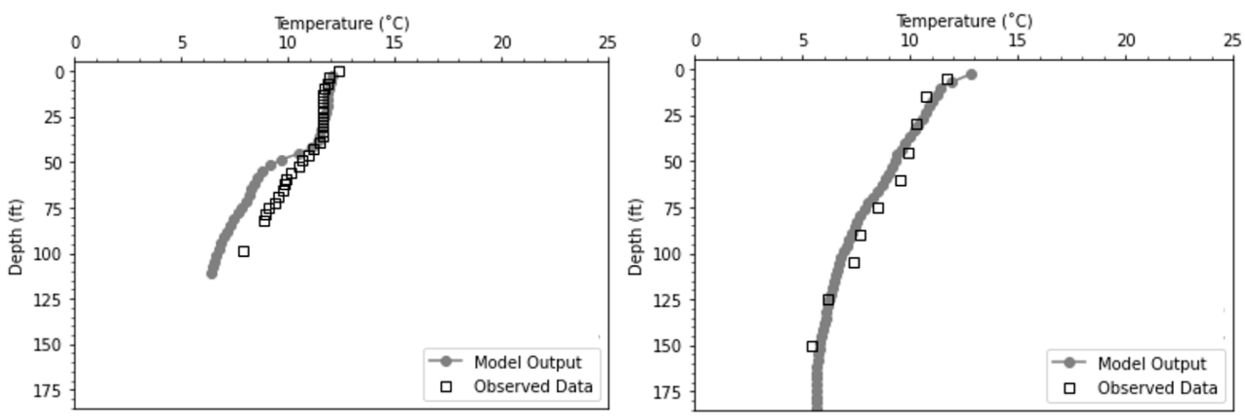


Figure 4.3-8. Model calibration for Ross Lake at the Skymo (left panel) and Spillway Boom (right panel) locations on June 16, 2020.

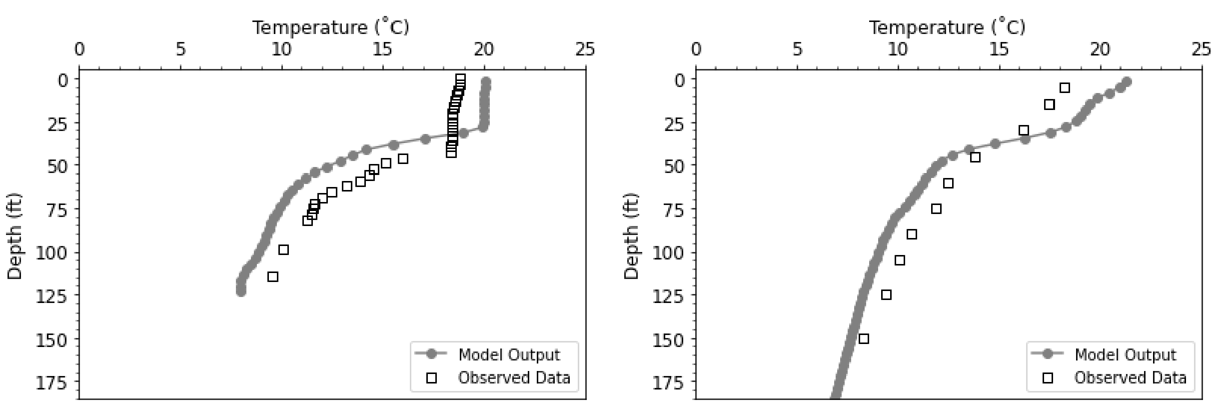


Figure 4.3-9. Model calibration for Ross Lake at the Skymo location (left panel) and the Spillway Boom location (right panel) on August 13, 2020.

Error statistics (RMSE, MAE, and PBIAS) were calculated for the comparisons of modeled profiles with the calibration data described above (Section 4.3.3). The 75th percentile value of the MAE across 68 calibration comparisons was 1.0°C, indicating that the calibration was acceptable for 75 percent of the profiles evaluated. Additionally, the 95th percentile of RMSE and MAE were both under 2°C, indicating that the discrepancies in calibration profiles with a lesser degree of fit is not extreme. The median PBIAS was 0.0 percent (Table 4.3-5; full statistics appear in Attachment B). This neutral bias resulted in part from a calibration that represents a middle ground between cold and warm biases, each of which are discussed below.

Table 4.3-5. Summary of temperature error statistics from Ross Lake calibration comparisons.

Percentile	RMSE (°C)[1]	MAE (°C)[1]	PBIAS (%)[1]
95th	1.9	1.8	6.1
75th	1.1	1.0	2.8
Median	0.8	0.7	0.0
25th	0.5	0.4	-5.1
5th	0.3	0.2	-11.1

1 RMSE: root mean squared error; MAE: mean absolute error, and PBIAS: percent bias.

When model output is colder than observed temperatures, the bias is larger than when model output is too warm (i.e., for PBIAS in Table 4.3-5, the magnitudes of the 25th and 5th percentiles are larger than the magnitudes of the 75th and 95th percentiles). There are two primary reasons for the bias under cold conditions. First, model output is too cold at Little Beaver, the most upstream monitoring location, in late 2019 and most of 2020 (e.g., Figure 4.3-8). The modeled temperatures in this region are influenced by inflows, which were measured reliably, and meteorology, and thus the bias may be due to imprecise wind and solar radiation data in this part of the reservoir. This bias is considered acceptable for model performance because this bias is generally resolved by the time the water reaches Ross Dam. Second, cold bias occurs near the dam in February 2020 because the model simulates a late-January cold event that is not reflected in reservoir monitoring data. This may be due to mountain microclimates that create temporary, yet notably different, weather conditions during winter.

When the model is biased warm, it is usually due to mismatches between summer and autumn thermocline depths and temperatures in the surface mixed layer (Figure 4.3-9). This is likely due to the use of meteorological variables as broadly applied calibration parameters.

Dam withdrawals vary between 60 and 160 ft (18-49 m) deep, depending on water level, with shallowest dam withdrawals occurring in spring when the water level is lowest and deepest dam withdrawals occurring in summer, when the reservoir is at normal maximum water surface elevation. In some months, simulated temperatures are slightly lower than observed data at these depths. This is reflected in a comparison of temperatures measured downstream of Ross Powerhouse to and modeled outflow temperatures (Figure 4.3-10). Comparing dam withdrawals to observed temperatures at the Ross Powerhouse resulted in an RMSE of 1.47°C, MAE of 1.02°C, and NSE of 0.72. Differences occur primarily in late summer, when measured temperatures exceeded model estimates by as much as 7°C. These higher observed values can vary hourly or sub-hourly and appear to be associated with low flow out of Ross Dam (Figure 4.3-11). This indicates that they do not reflect changes in the deep-water temperature in Ross Lake, and so the model was not adjusted to address this discrepancy. The observed increase in temperature is most consistent when flow out Ross Lake is 0 cfs, indicating that this is not a heating process inside the dam penstocks or turbines. Instead, these data must represent heating that occurs in the dam tailrace due to summertime meteorological conditions that is most prevalent during low flow. Therefore, the disagreement between model output and data does not necessitate a revision to the model. Furthermore, this suggests that the model output of Ross Dam temperatures is a better input for the upstream boundary of the Diablo model than data from Ross Powerhouse. This use of Ross model output as Diablo model input is presented in Section 5.2, below.

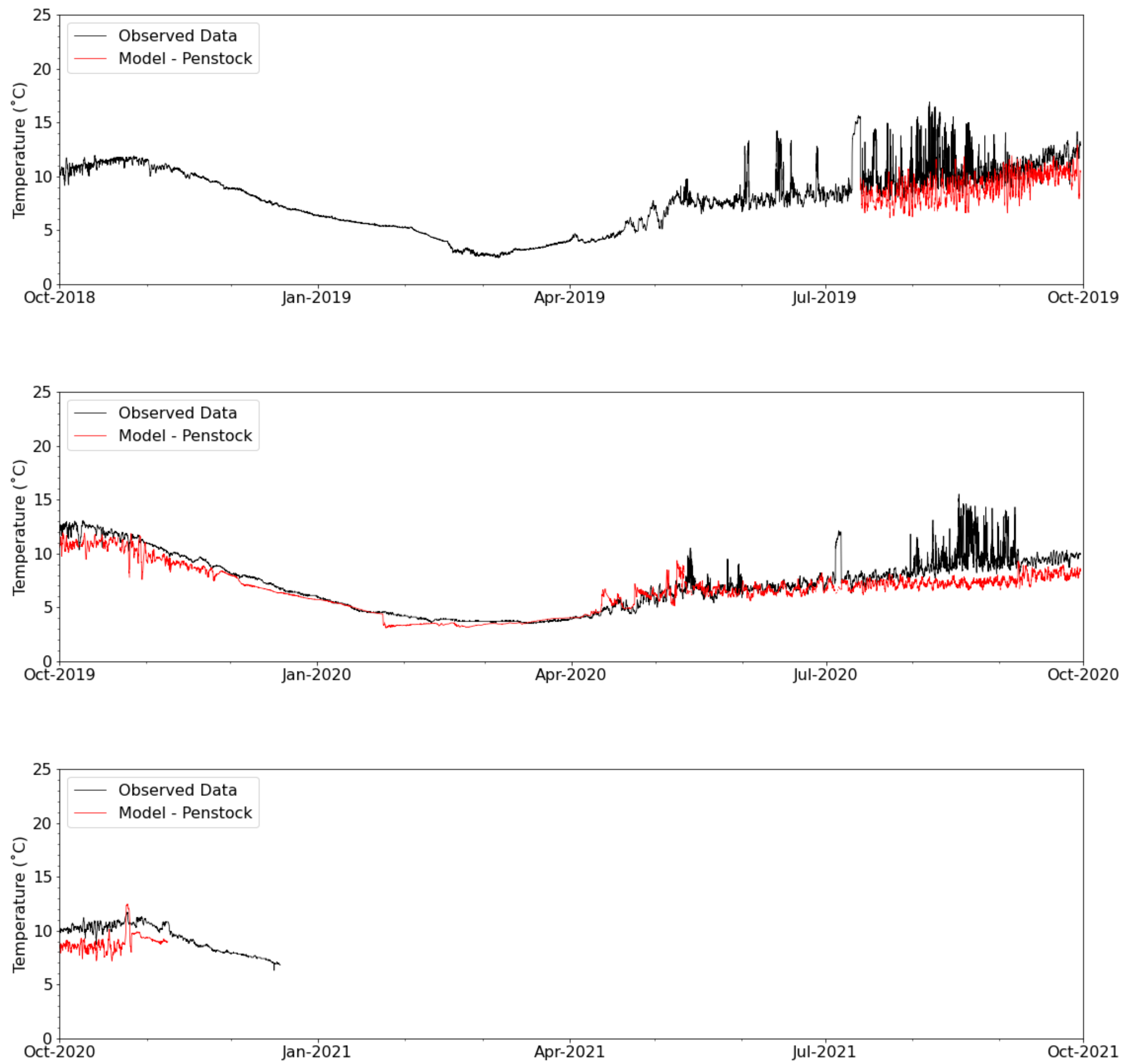


Figure 4.3-10. **Measured temperature in the Ross Powerhouse tailrace and modeled temperature in water released from Ross Dam.**

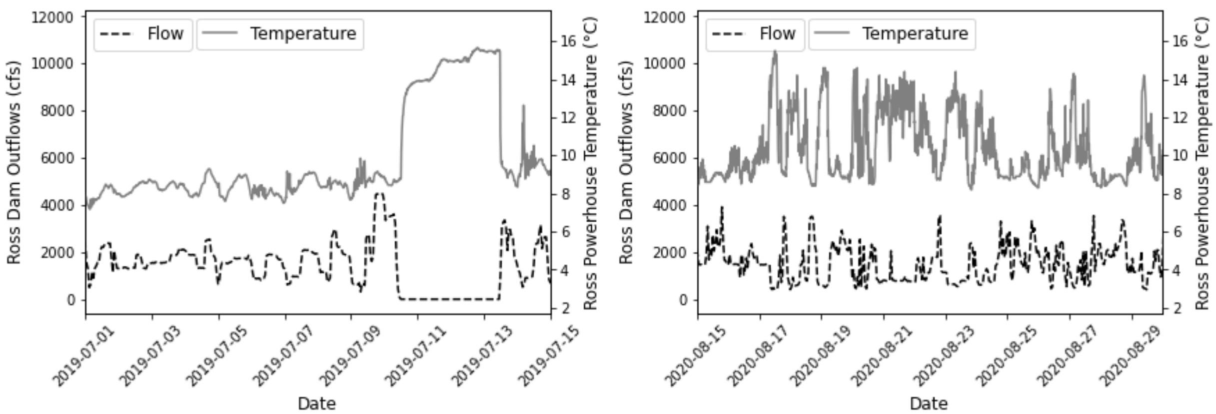


Figure 4.3-11. Ross Dam outflows and measured temperatures at the Ross Powerhouse tailrace in July 2019 (left panel) and August 2020 (right panel).

4.3.4.2 Diablo Lake

Initial water balance errors in the Diablo Lake model were resolved by deepening the lower Thunder Arm and the upstream portion of the Skagit Arm of Diablo Lake (fully described in Section 4.2.2.2). Following these changes, iterative adjustments to the volume of distributed tributary inflows achieved a water level calibration with an RMSE of 1.8 ft (0.05 m) that met the target for this statistic (Figure 4.3-12). Distributed inflows generally ranged from 0-177 cfs (0-5 m^3/s) with brief excursions that may be attributable to imprecision in the estimates for the flows out of Ross and Diablo dams. This magnitude of flow is reasonable for the Diablo Lake watershed, and the generally consistent, small range of flows suggests no bias in the inflows or outflows of the Diablo Lake model.

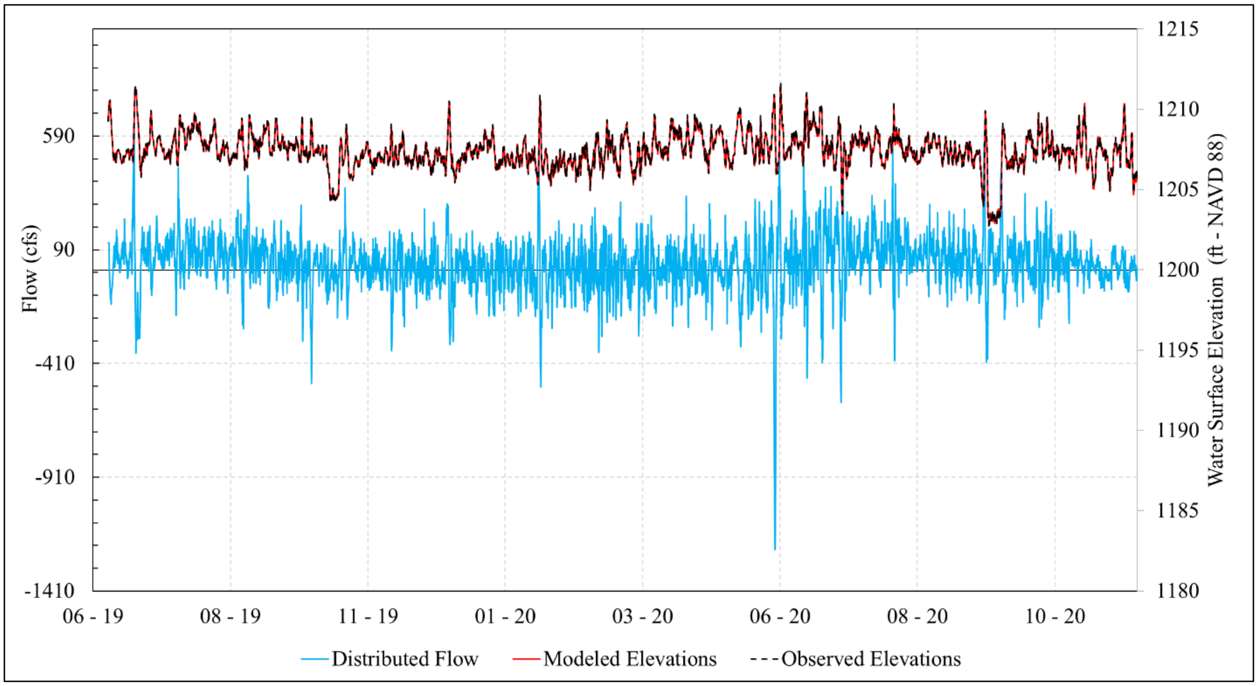


Figure 4.3-12. Diablo Lake distributed tributary inflow and water balance calibration shown by nearly identical observed water surface elevation and simulated water elevation (ft NAVD 88).

As in the Ross Lake model, calibration of the Diablo Lake model required magnifying the wind speed via the wind sheltering coefficient by factors of 2.5-4.0. In addition, the prevailing wind direction at Marblemount is generally north-south, whereas local experience by City Light field personnel indicates that wind in Diablo Lake tends to blow east-west. Accordingly, calibration improved when wind direction data from the Marblemount meteorology station was rotated by 90° clockwise in the Diablo Lake model.

A qualitative assessment of vertical profile figures comparing output from the Diablo Lake model against field data indicated an acceptable calibration in 2019 and 2020, with no major difference between the two profiling locations. However, in 2020, the shape of the observed thermocline was not well represented by the model simulation. This led to a minor disagreement between model and data in spring 2020 (Figure 4.3-13), a greater disagreement in summer 2020 (Figure 4.3-14), and a minor disagreement in autumn (Figure 4.3-15). Complete calibration results appear in Attachment B. Disagreement was less at the depth of dam withdrawals (consistently 118-125 ft deep at Diablo Dam), and this is reflected in the comparison of temperature between modeled dam releases and measured temperatures at the Diablo Powerhouse location (Figure 4.3-16). Comparison of dam releases and observed temperatures at the Diablo Powerhouse resulted in an RMSE of 0.66°C, MAE of 0.52°C, and NSE of 0.94. This MAE is slightly higher than the riverine target of 0.4°C due to disagreement with particularly warm observed temperatures at the Gorge Powerhouse location in July 2020.

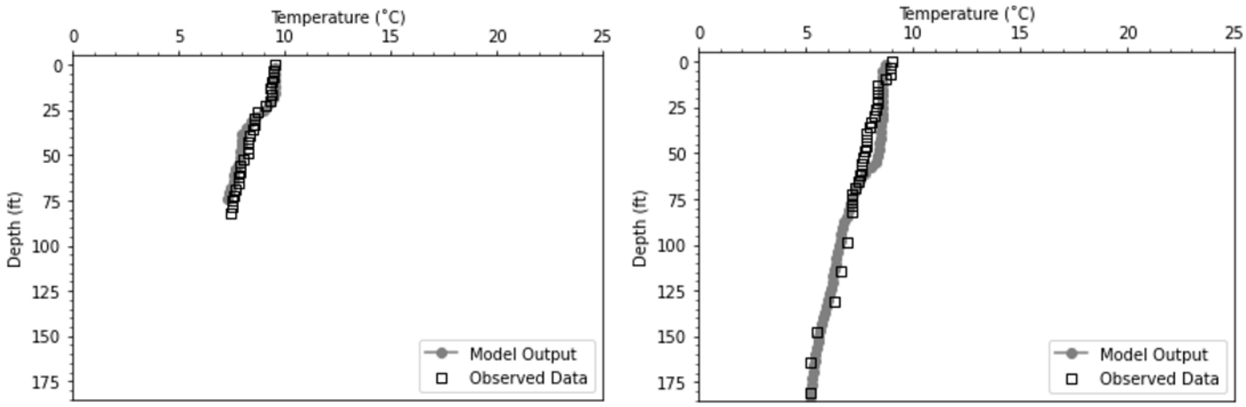


Figure 4.3-13. Model calibration at the Thunder Arm temperature buoy location (left panel) and the Diablo Dam location (right panel) on May 21, 2020.

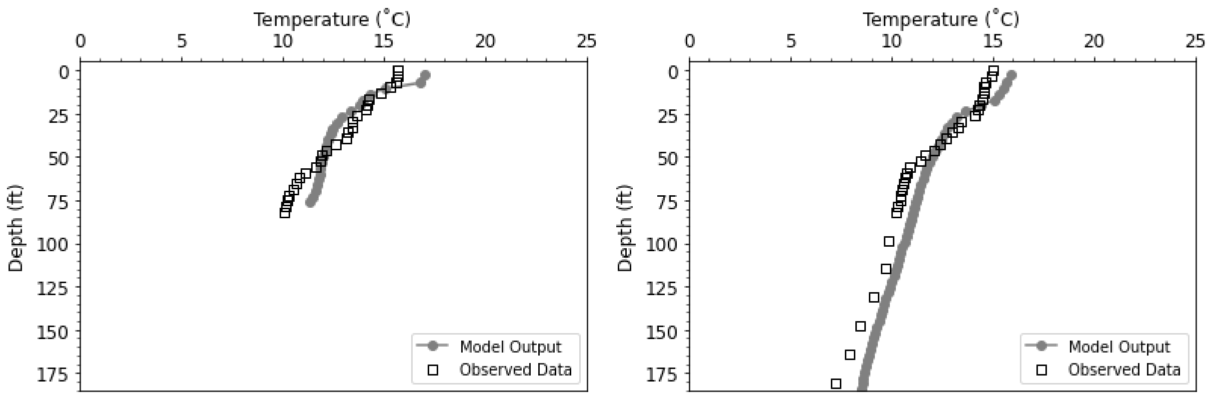


Figure 4.3-14. Model calibration at the Thunder Arm temperature buoy location (left panel) and the Diablo Dam location (right panel) on August 20, 2020.

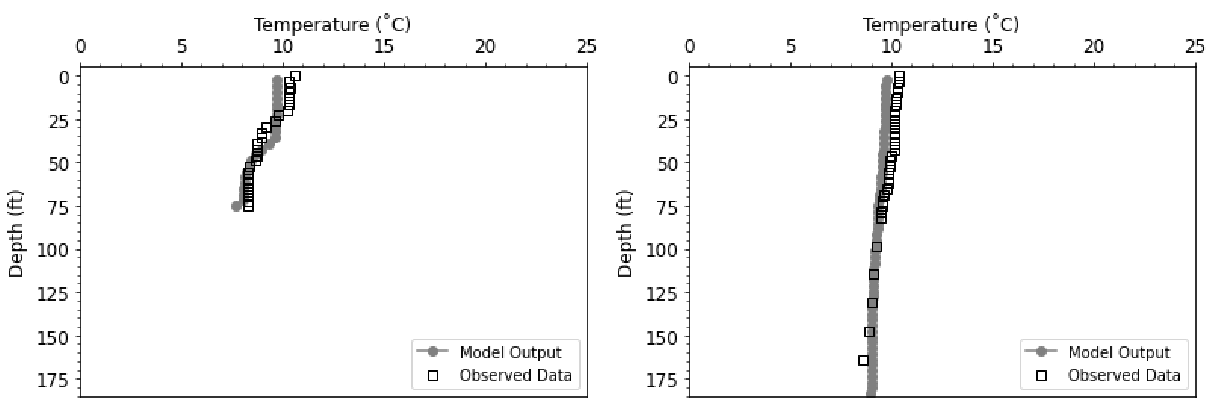


Figure 4.3-15. Model calibration at the Thunder Arm temperature buoy location (left panel) and the Diablo Dam location (right panel) on October 15, 2020.

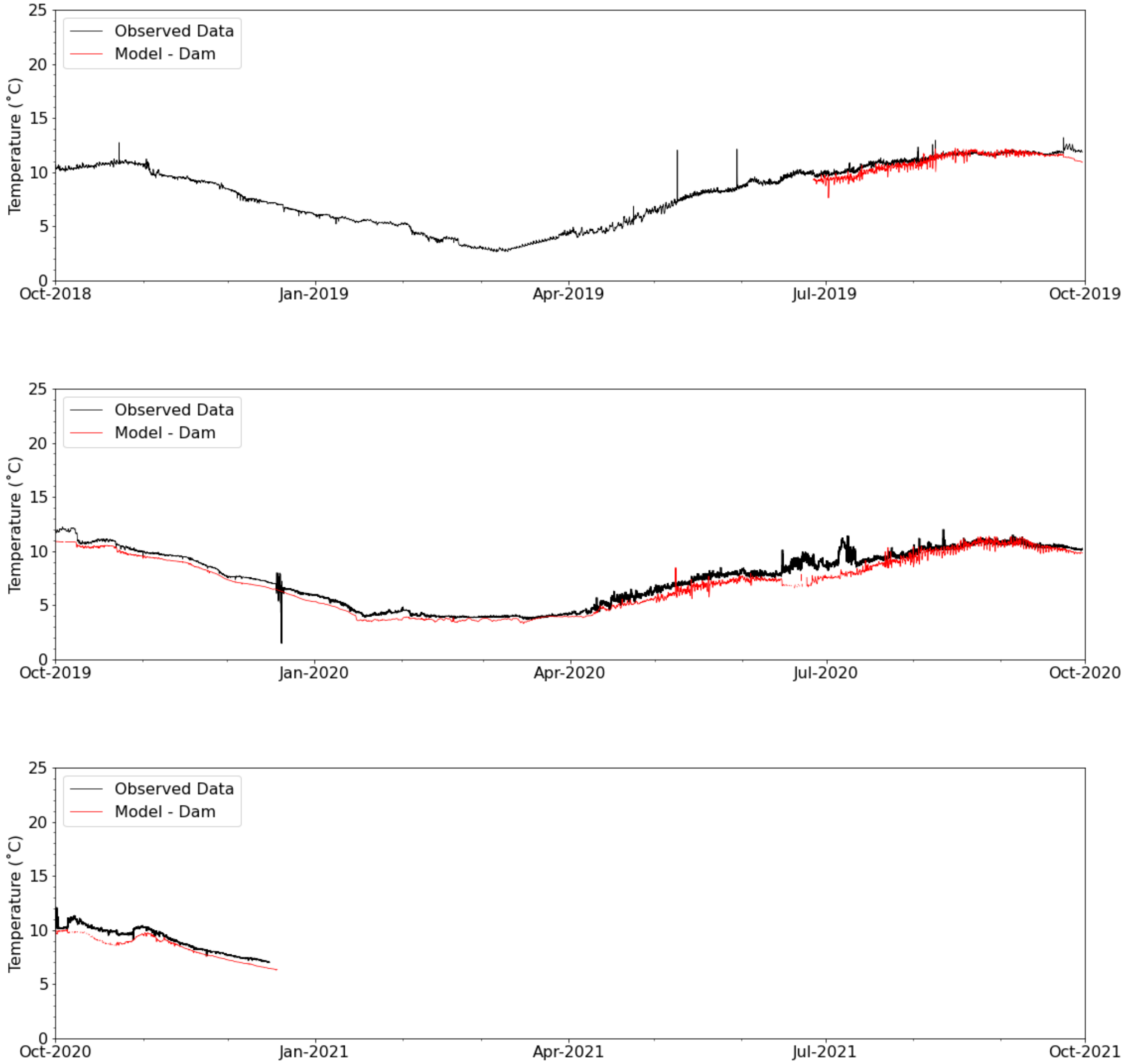


Figure 4.3-16. Observed temperature at the Diablo Powerhouse location downstream of Diablo Dam and modeled temperature in water released from Diablo Dam.

Error statistics (RMSE, MAE, and PBIAS) were calculated for the comparisons of modeled profiles with the calibration data described above (Section 4.3.3). Median values of RMSE and MAE across 28 calibration comparisons were at or below 0.5°C, and the median PBIAS was -0.7 percent (Table 4.3-6; full statistics appear in Attachment B). The 95th percentiles of the error statistics demonstrate that model output is nearly always within 1°C of observed data; a 95th percentile MAE value below 1°C indicates an acceptable calibration for the Diablo Lake model. Most profile comparisons have a bias of less than 2.5 percent. Mismatches between model output and calibration profiles can be explained by inaccurate model representations of the thermocline. This is likely attributable to the use of wind data as a calibration parameter and the subsequent, but necessary, coarse rotation and magnification of the wind direction and speed variables, respectively.

Table 4.3-6. Summary of temperature error statistics from Diablo Lake calibration comparisons.

Percentile	RMSE (°C)[1]	MAE (°C)[1]	PBIAS (%)[1]
95th	0.9	0.8	5.4
75th	0.6	0.5	2.4
Median	0.5	0.4	-0.7
25th	0.4	0.3	-2.1
5th	0.2	0.2	-3.8

1 RMSE: root mean squared error; MAE: mean absolute error, and PBIAS: percent bias.

4.3.4.3 Gorge Lake

The Gorge Lake model was calibrated for the period January 2019 to December 2020. A large drawdown event occurred in early April 2019 that lowered the lake level to 830 ft NAVD 88 (823.5 ft CoSD), which is about 48 ft (15 m) below lake levels under normal operations during the month of March (≈878 ft NAVD 88). The current version of the CE-QUAL-W2 model is unable to remain stable for such a hydraulic condition. For this study, hydraulic and meteorological information from March 28, 2019 were used to replace the conditions during the drawdown event between April 2 and April 7, 2019 (Figure 4.3-17).

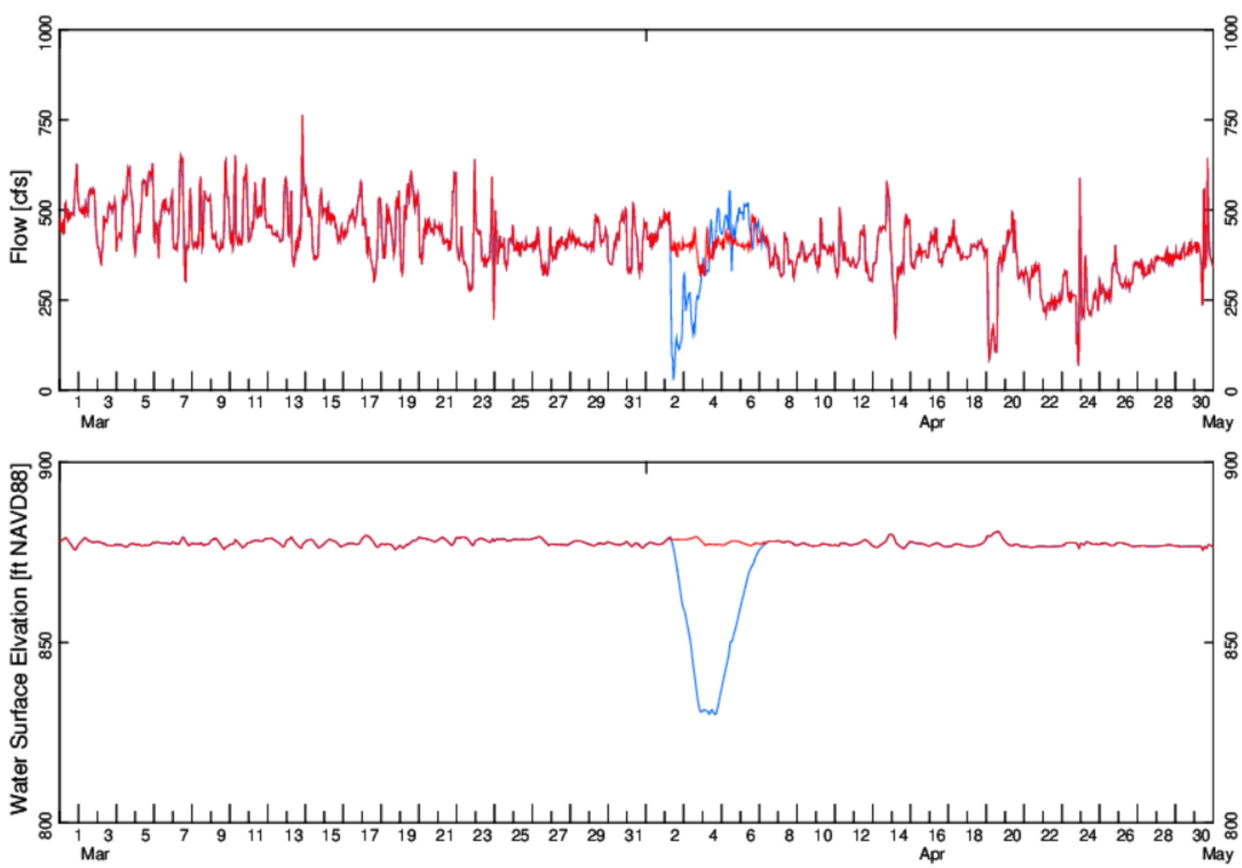


Figure 4.3-17. Modified hydraulic conditions (red line) and original hydraulic conditions (blue line).

Simulated water surface elevations were calibrated against observed water surface elevation data at USGS Gorge Lake near Newhalem gage (12177700) at Figure 4.3-18. The model simulates changes in water level well, including the drawdown event in October 2019. The difference between observed and modeled water surface elevation is mostly within 0.7 ft (0.2 m) between the model simulation and the measured data. The RMSE value is 0.16 ft (0.05 m), which met the target (< 0.2 m) for this statistic.

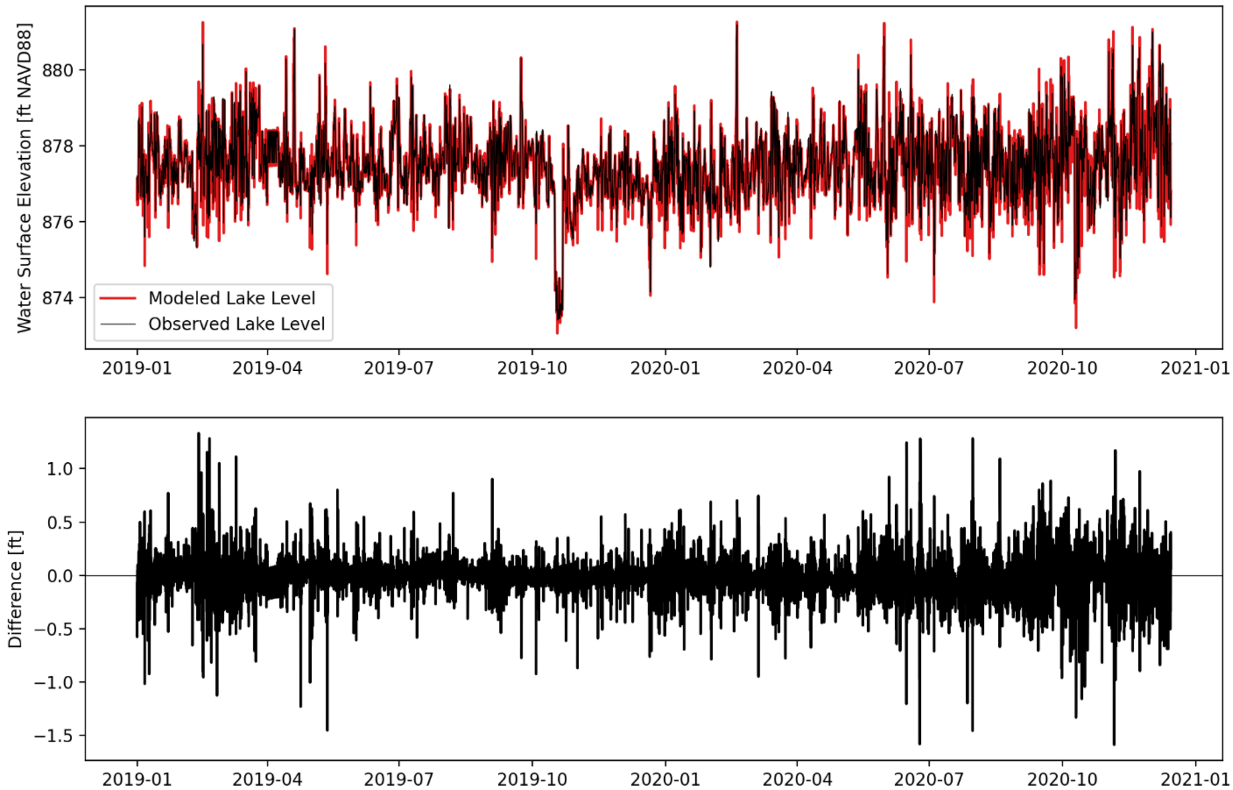


Figure 4.3-18. Comparison of observed and CE-QUAL-W2 model simulated water surface elevation at Gorge Lake (water-levels on top and calculated differences on bottom).

Daily averaged distributed inflows generally ranged from 0-177 cfs (0-5 m^3/s), with brief excursions that may be attributable to imprecision in the estimates for the flows out of Diablo and Gorge Dams (Figure 4.3-19). This magnitude of flow is reasonable for the Gorge Lake watershed, and the generally consistent, small range of flows suggests no bias in the inflows or outflows of the Gorge Lake model.

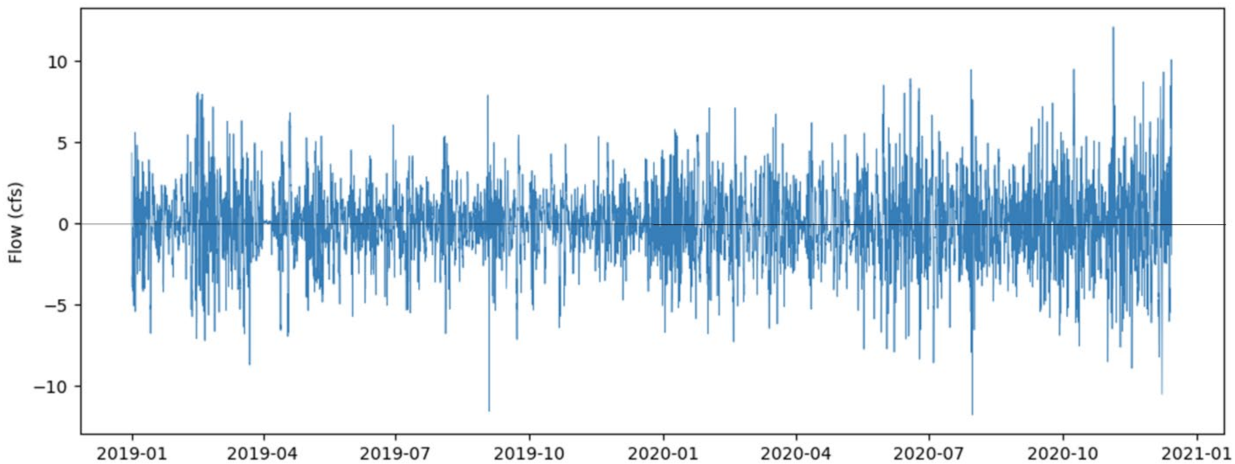


Figure 4.3-19. Gorge Lake model distributed tributary inflow.

As with the Ross Lake and Diablo Lake models, calibration of the Gorge Lake model required magnifying the wind speed via the wind sheltering coefficient. A constant factor of 3.0 was applied. In addition, the station at Marblemount is relatively sheltered and the prevailing wind direction there is generally north-south while the valley orientation of the Gorge Lake is northeast-southwest. Accordingly, calibration improved when wind direction data from the Marblemount meteorology station was rotated by 45° clockwise in the Gorge Lake model.

Comparison between modeled and observed temperatures at the Powerline, Midway, Log Boom (multiple depths at Log Boom), and Newhalem USGS gage locations are shown in Figures 4.3-20 to Figure 4.3-26. Although there are some differences, the model reproduces seasonal temperature patterns well. The model overpredicts temperature at Midway during summer. Based on preliminary investigation, this is likely due to limited available bathymetry data at this reach, which is relatively coarse. The model also tends to underpredict temperature at depth during the summer months at the Log Boom (furthest downstream calibration site on Gorge Lake). At perhaps the most important monitoring station, the USGS Skagit River at Newhalem station below the Gorge Powerhouse, the calibration matches closest of all of the Gorge Lake calibration locations.

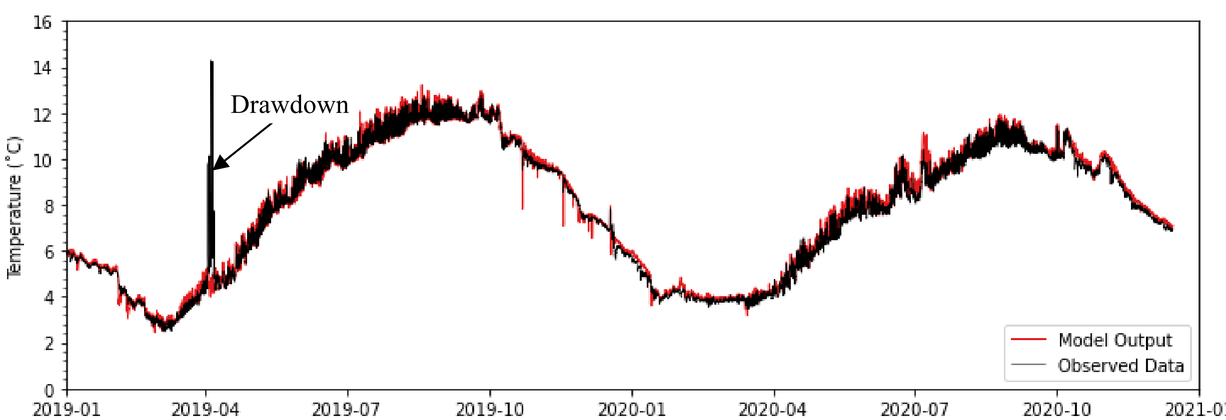


Figure 4.3-20. Model calibration at the Powerline temperature location.

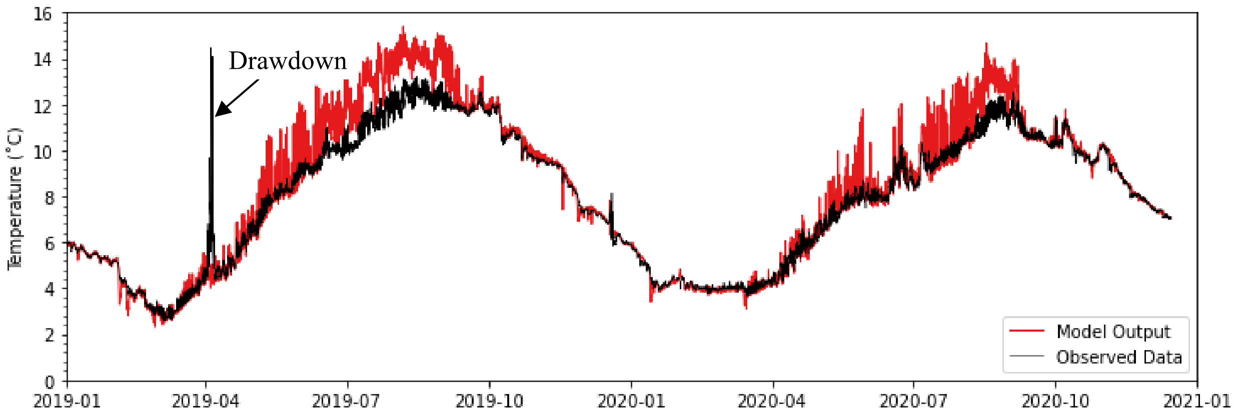


Figure 4.3-21. Model calibration at the Midway temperature location.

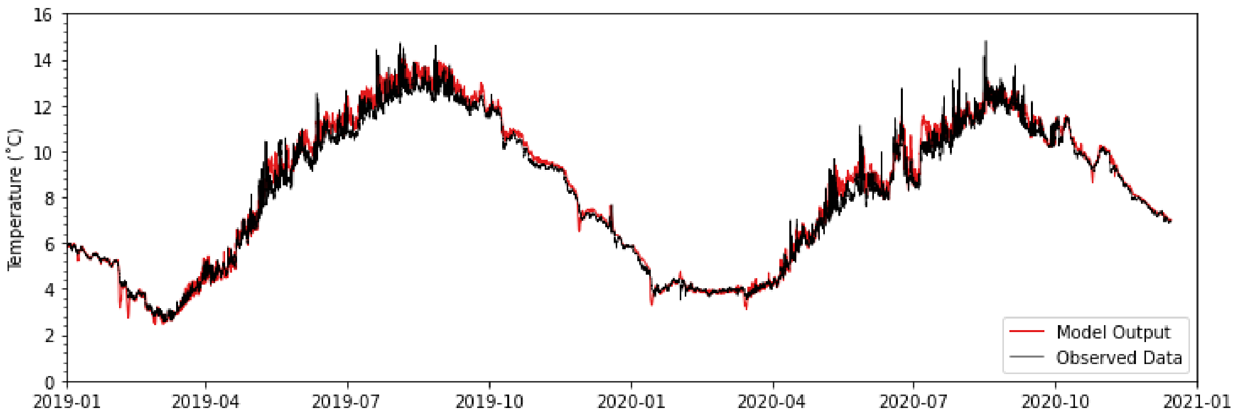


Figure 4.3-22. Model calibration at the Log Boom temperature location – depth 20 ft.

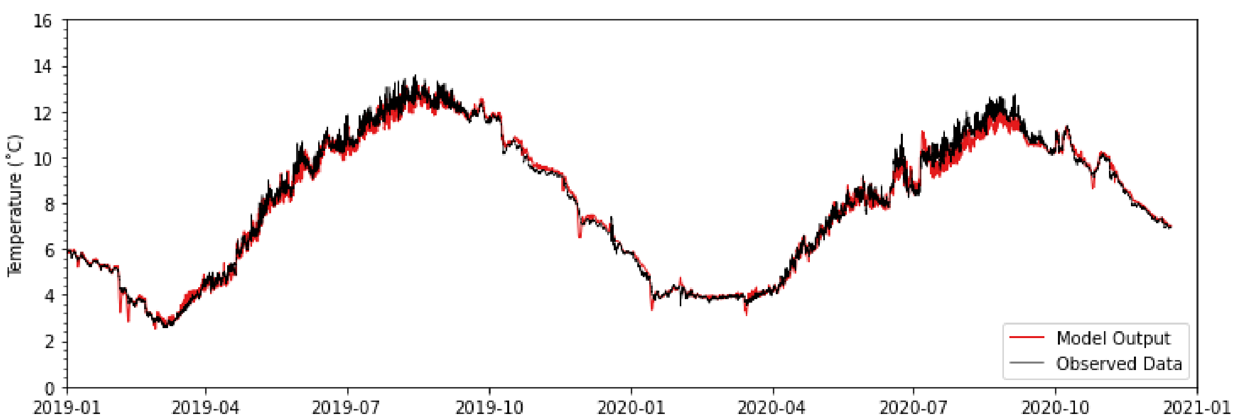


Figure 4.3-23. Model calibration at the Log Boom temperature location – depth 40 ft.

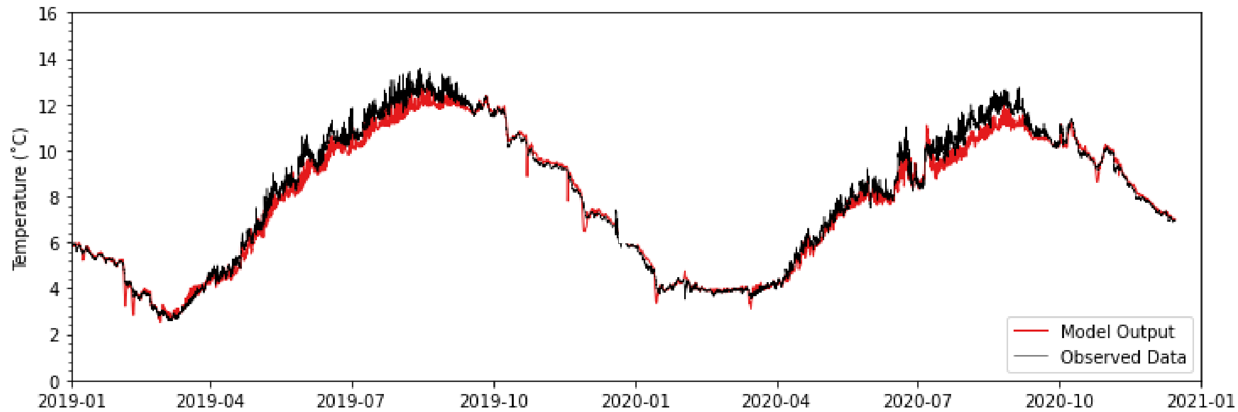


Figure 4.3-24. Model calibration at the Log Boom temperature location – depth 60 ft.

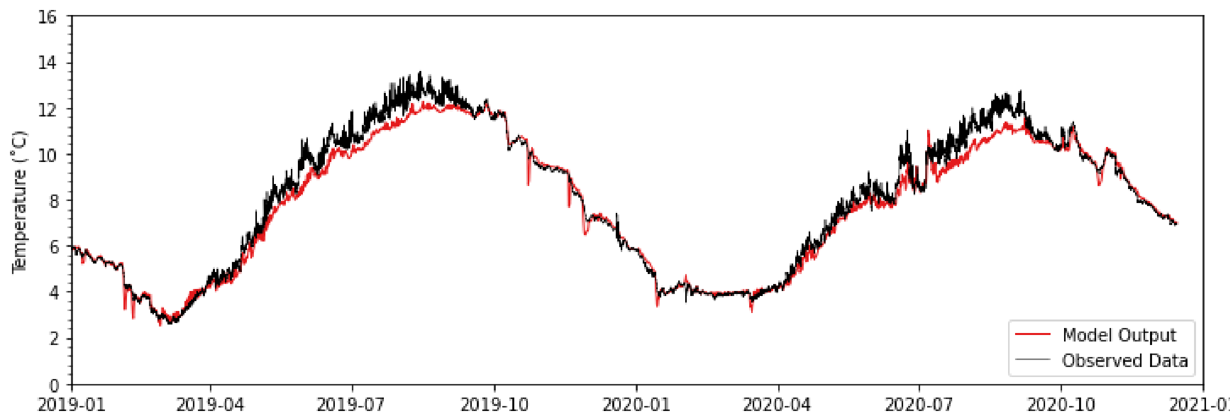


Figure 4.3-25. Model calibration at the Log Boom temperature location – depth 80 ft.

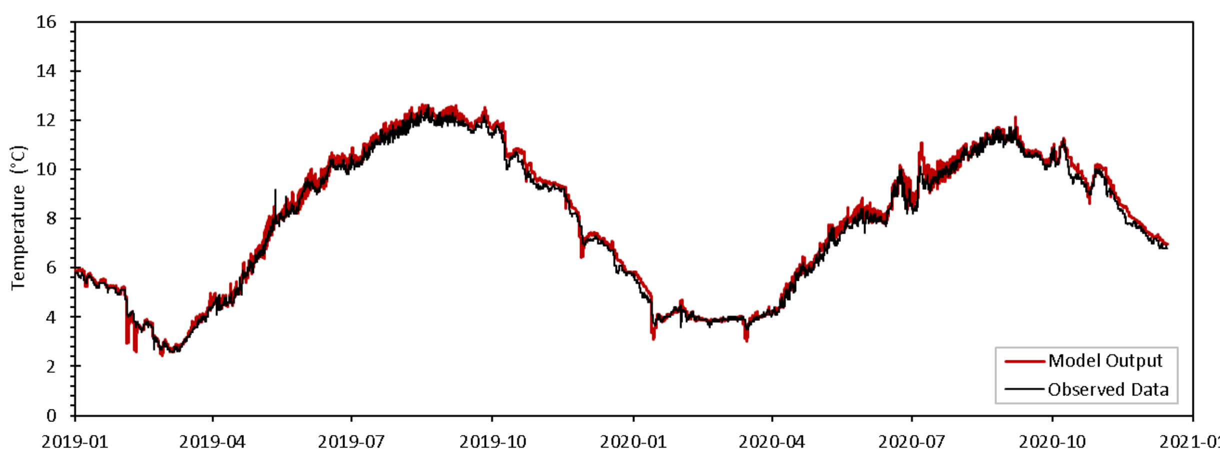


Figure 4.3-26. Model calibration at the USGS Skagit River at Newhalem gage (12178000).

Error statistics (RMSE, MAE, and PBIAS) were calculated for the comparisons of modeled time-series with the calibration data described above (Section 4.3.3). Except for the Midway station, RMSE and MAE values for all stations are less than 0.5ºC (Table 4.3-7), and all stations including Midway are within the 1.0ºC calibration target. The bias at 20 ft deep at the Log Boom location is +2.5 percent but decreases to -3.4 percent at 80 ft deep at this location.

Table 4.3-7. Summary of temperature error statistics from Gorge Lake calibration comparisons – Powerline.

Location	RMSE (°C)[1]	MAE (°C)[1]	PBIAS (%)[1]
Powerline	0.4	0.2	0.6
Midway	0.8	0.5	3.4
Log Boom – depth 20 ft	0.4	0.3	2.5
Log Boom – depth 40 ft	0.3	0.2	-0.4
Log Boom – depth 60 ft	0.5	0.3	-2.5
Log Boom – depth 80 ft	0.5	0.4	-3.4
USGS Skagit River at Newhalem gage (12178000)	0.3	0.2	1.9

1 RMSE: root mean squared error; MAE: mean absolute error, and PBIAS: percent bias.

Figure 4.3-27 shows a time-series of observed temperature profiles at the Gorge Dam forebay log boom compared to those produced by the model. The observed data show limited thermal stratification at this location: temperature is well mixed in spring (8ºC), summer (12ºC), and fall (10ºC). The model reproduced the general trend of temperature changes over the seasons at this location, with the largest errors occurring during the summer in the lower water column when the model simulates slightly cooler temperatures (approximately 1ºC lower) than those observed. The ability to further reduce this remaining error is limited by the availability of local meteorology data, and it was determined to be acceptable for the anticipated applications of the model, but the slightly higher error should be noted if querying simulated data from the hypolimnion during the summer months.

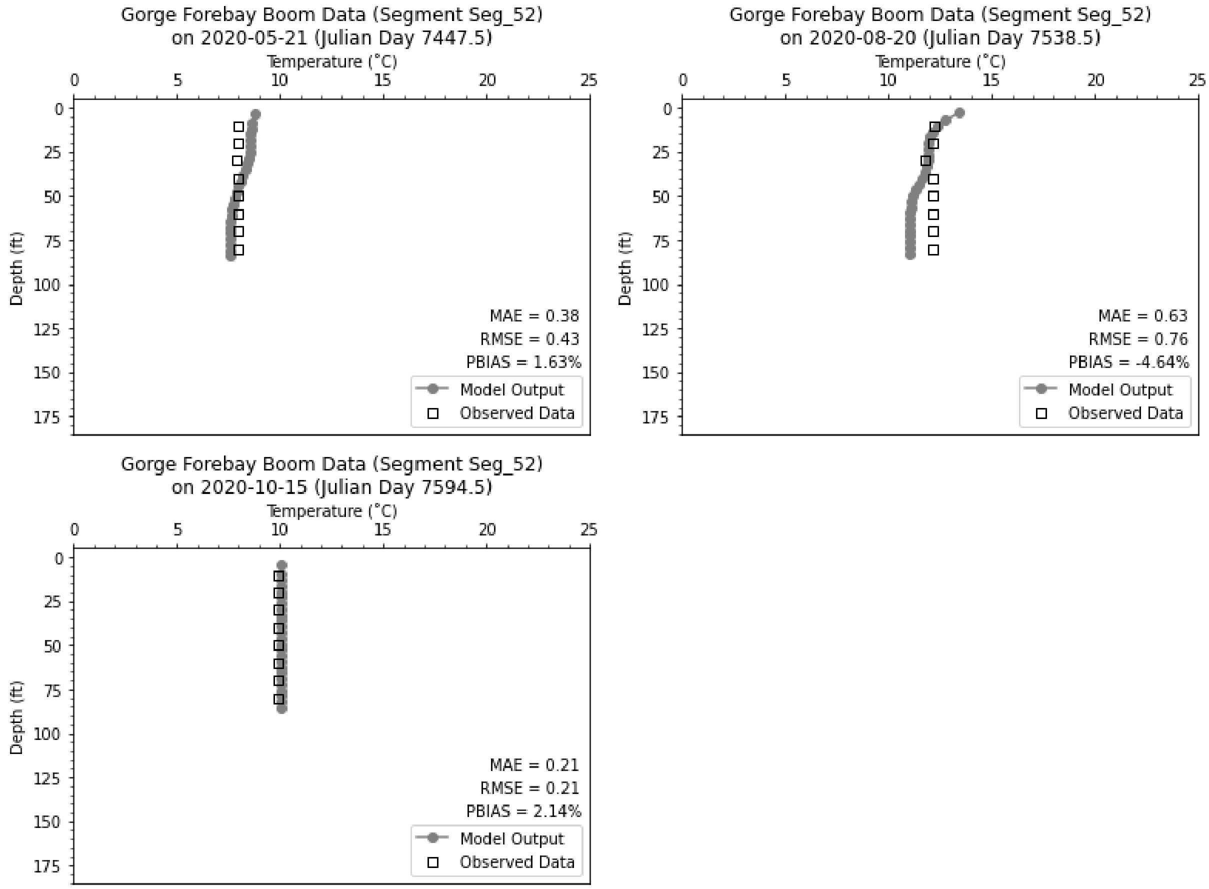


Figure 4.3-27. Model calibration at the Gorge Dam forebay logboom location (right panel) on May 21, 2020 (top left), August 20, 2020 (top right), and October 15, 2020 (lower left).

4.3.4.4 Skagit River

As discussed in Section 4.2.2.4, the Skagit River model is divided into three reaches: Gorge bypass reach, N2S, and S2C. The hydrodynamic and temperature calibration results of the three Skagit River model reaches are presented in the subsequent sections.

4.3.4.4.1 Gorge Bypass Reach

The dynamic nature of flows through the Gorge bypass reach made the available observed water-level data unsuitable for calibration of the CE-QUAL-W2 model. Instead, through discussions within model integration coordination meetings, it was noted that steady-state flow conditions simulated using the FA-05 Bypass Instream Flow Model Development Study HEC-RAS 2-D model (City Light 2023c) would be ideally suited as the target for calibration of the CE-QUAL-W2 model in this reach. Figure 4.3-28 shows the hydrodynamic calibration comparing CE-QUAL-W2 simulated longitudinal water levels with water levels from the calibrated FA-05 Bypass Instream Flow Model Development Study HEC-RAS 2-D model. The figure shows that the CE-QUAL-W2 model simulated water level is in adequate agreement with the HEC-RAS 2-D model simulated water level and thereby suitable for temperature and water quality modeling. The biggest deviation from the HEC-RAS 2-D water levels occurs at the Existing Feature 2 location, a feature for which the bed slope was reduced in the CE-QUAL-W2 model bathymetry file for stability purposes.

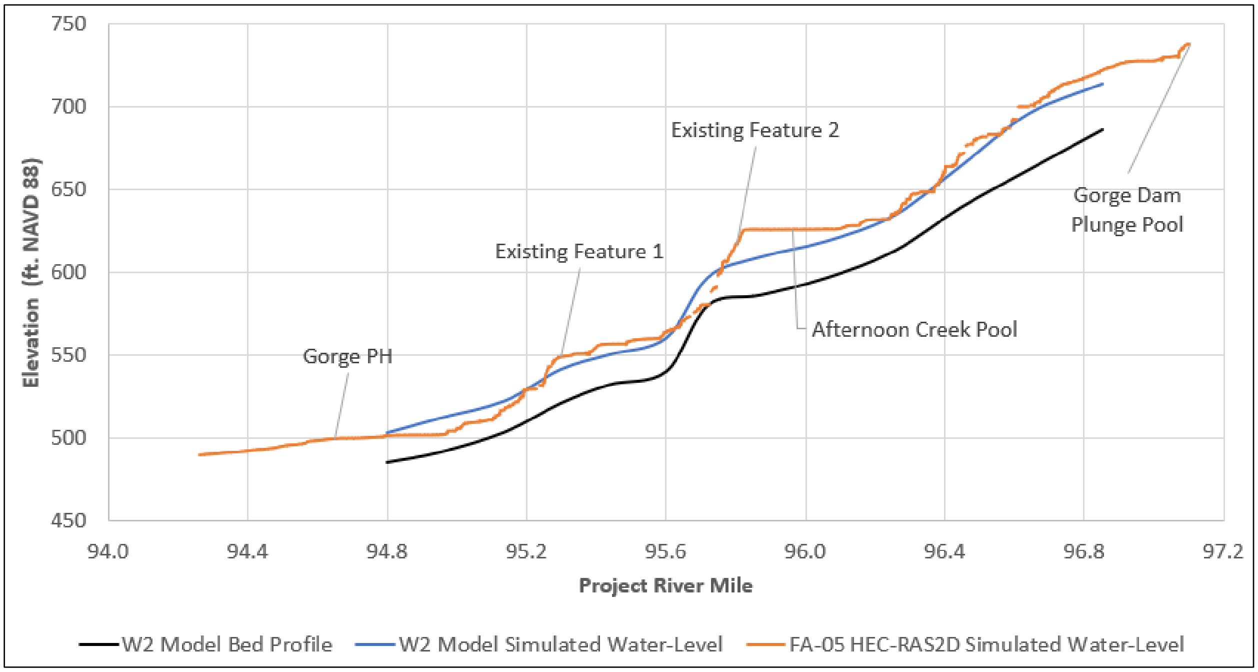


Figure 4.3-28. Water level comparison for the Gorge bypass reach simulated from the CE-QUAL-W2 model and FA-05 Bypass Instream Flow Model Development Study HEC-RAS 2-D model (City Light 2023c).

4.3.4.5 N2S Reach

Unlike the FA-02 Instream Flow Model Development Study (City Light 2023b), which applied three different sets of channel roughness coefficients to characterize this reach of river, the CE-QUAL-W2 model can only use a single set of roughness coefficients because the model must be run continuously over a wide range of flow conditions. Figure 4.3-29, Figure 4.3-30, and Figure 4.3-31 present comparisons of simulated and observed longitudinal water levels for low, moderate, and high flow conditions respectively. Each longitudinal water surface profile corresponds to a "steady-state" model simulation for which a single set of flow inputs is specified and held until simulated water levels in the model are constant. Because channel roughness varies as a function of flow depth, the calibration is prioritized for one flow condition and accepts a higher degree of error at other flows. The low-flow calibration profile was targeted for minimum error, and the moderate and high flows were applied as validation runs. Because of this, the model overpredicts water levels for moderate and high flows. The average water level errors were computed as 0.02 ft, 0.65 ft, and 0.91 ft for low, moderate, and high flow, respectively.

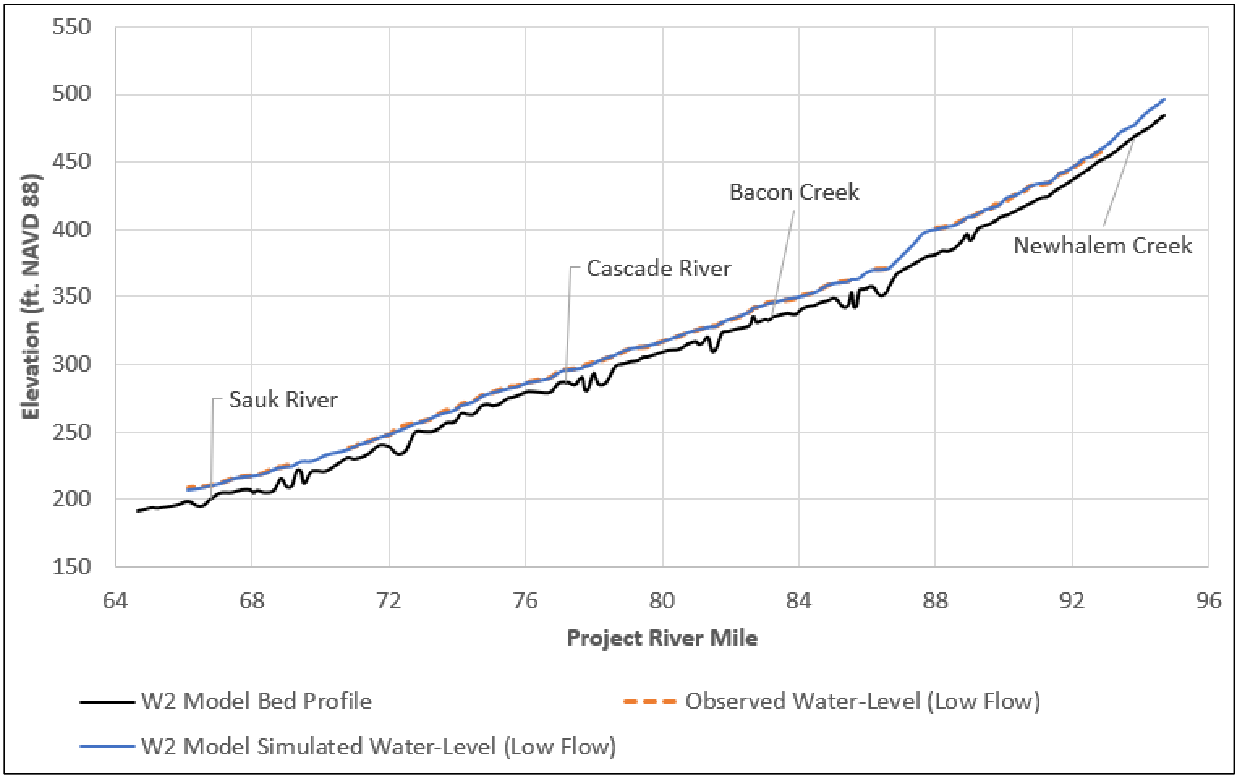


Figure 4.3-29. Observed and simulated longitudinal water levels in the N2S reach for low flow.

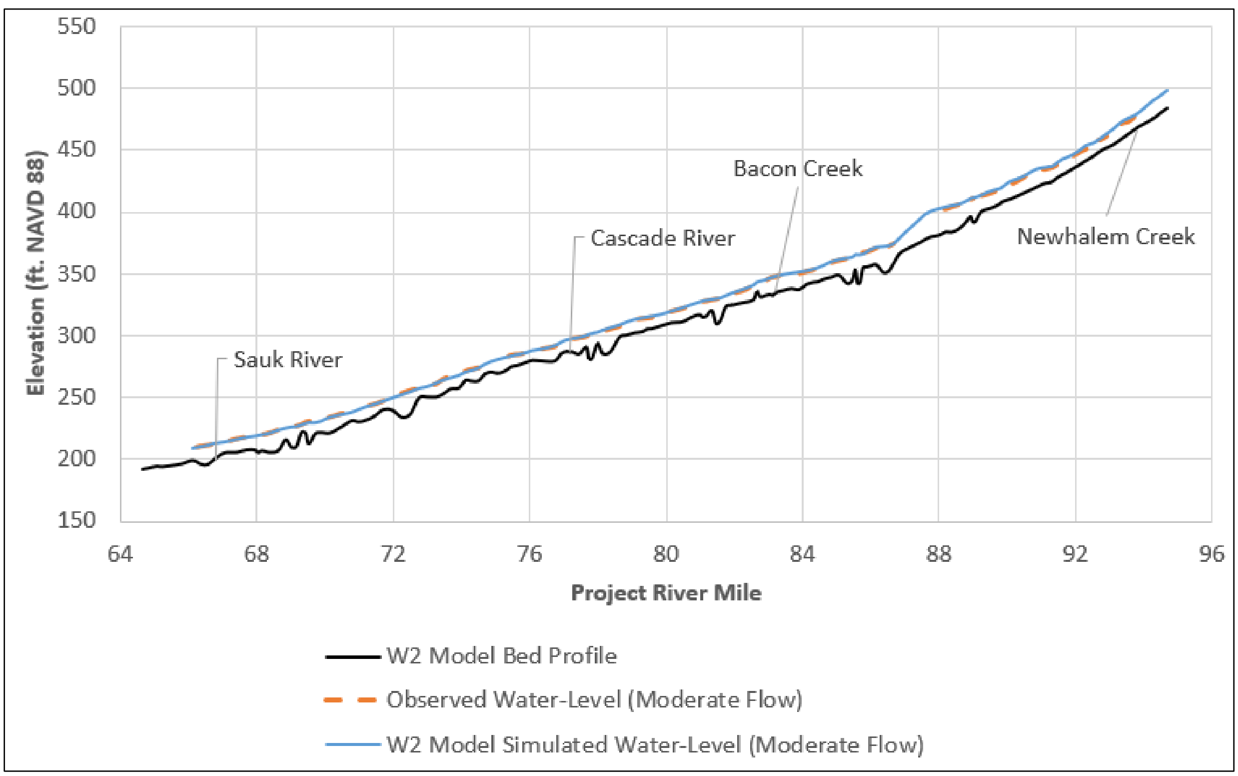


Figure 4.3-30. Observed and simulated longitudinal water levels in the N2S reach for moderate flow.

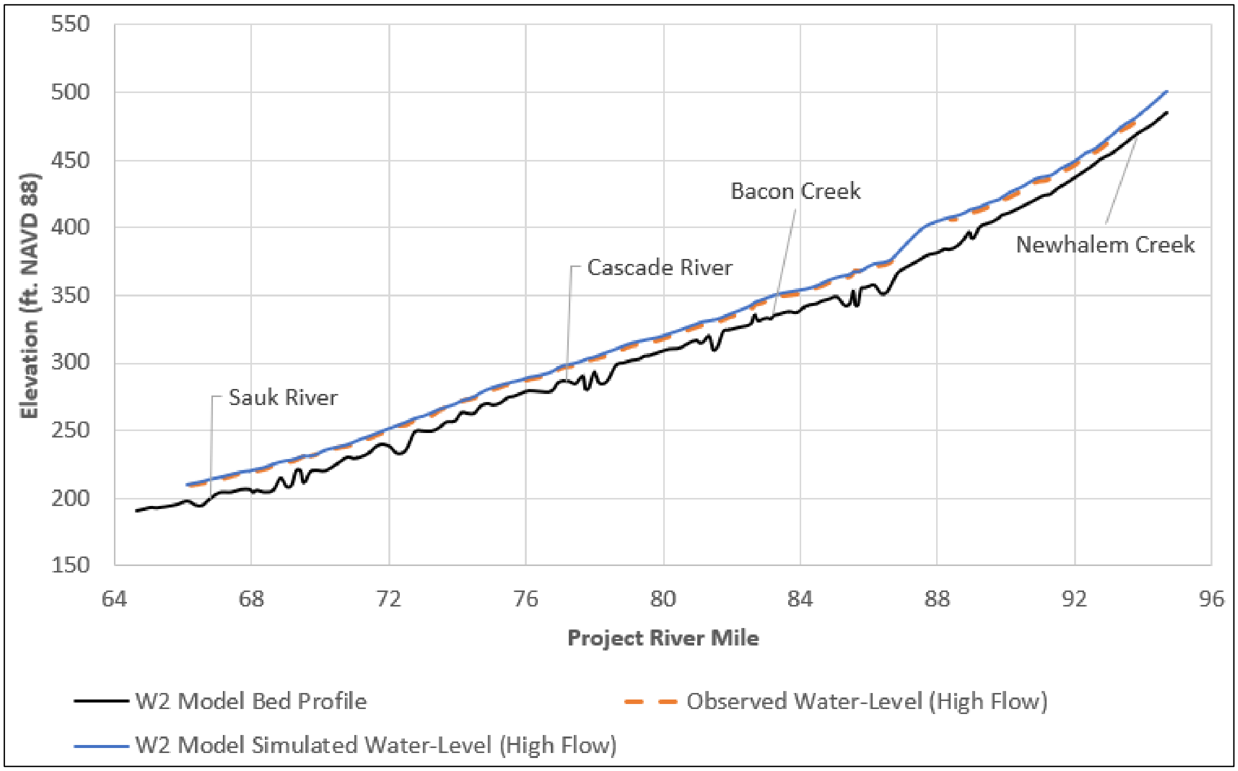


Figure 4.3-31. Observed and simulated longitudinal water levels in the N2S reach for high flow.

After establishing an acceptable water level calibration, the model's ability to simulate observed flows was evaluated. This step in the calibration process is performed to test the riverine model's representation of storage within the river channel and to check for errors in the input hydrology specified for the mainstem and tributaries along the simulated reach. Model computations agree with the magnitude and timing of flow hydrographs (Figures 4.3-32 and 4.3-33), and the MAE, RMSE, and PBIAS model calibration statistics listed below are all considered good. At PRM 86.0, which is near Alma Creek (USGS gage 12179000), the values of these statistics were 265 cfs (80 m^3/s), 390 cfs (119 m^3/s), and -2.1 percent, respectively. At PRM 79.0, which is at Marblemount (USGS gage 12181000), these statistics were 277 cfs (84 m^3/s), 462 cfs (141 m^3/s), and -2.2 percent, respectively.

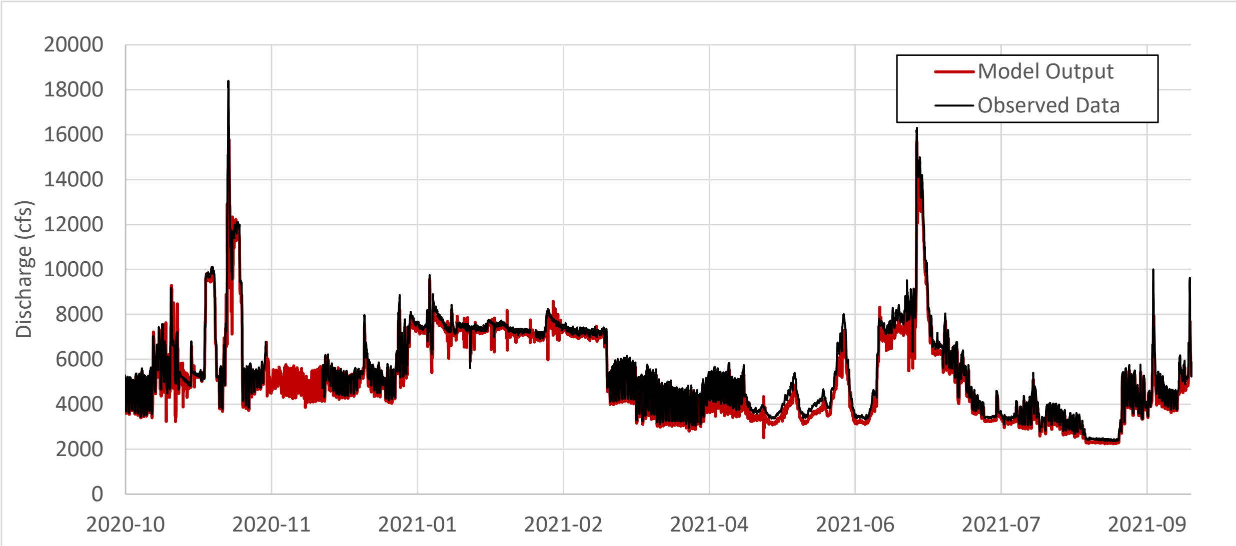


Figure 4.3-32. Observed and simulated flows at PRM 86.0, the USGS Skagit River above Alma Creek (12179000), October 2020 through September 2021.

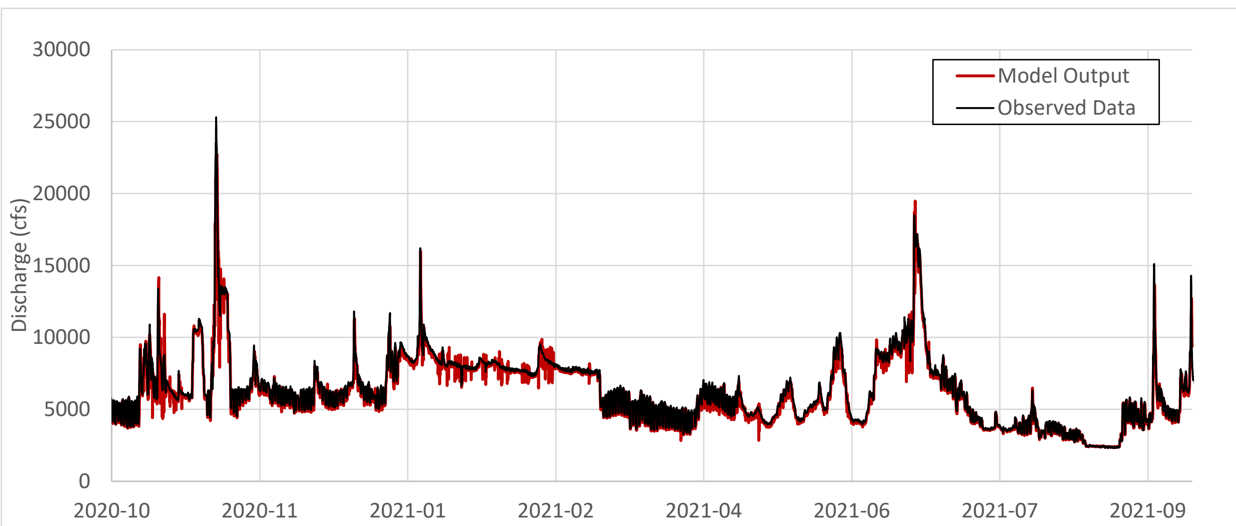


Figure 4.3-33. Observed and simulated flows at Skagit River PRM 79.0, USGS Skagit River Marblemount (12181000), October 2020 through September 2021.

The temperature calibration for the N2S reach was performed at five locations, with the calibration emphasizing a match to both seasonal and diurnal variations in observed stream temperatures. Figures 4.3-34 to 4.3-43 show the simulated temperature comparison with the observations at PRM 91.2 (both water year and monthly timescales), PRM 85.9 (only water year), PRM 79.0 (both water year and monthly timescales), PRM 75.6 (only water year), and PRM 69.3 (both water year and monthly timescales). Calibration statistics are reported along with those from the Sauk to Concrete reach in Section 4.3.4.7.

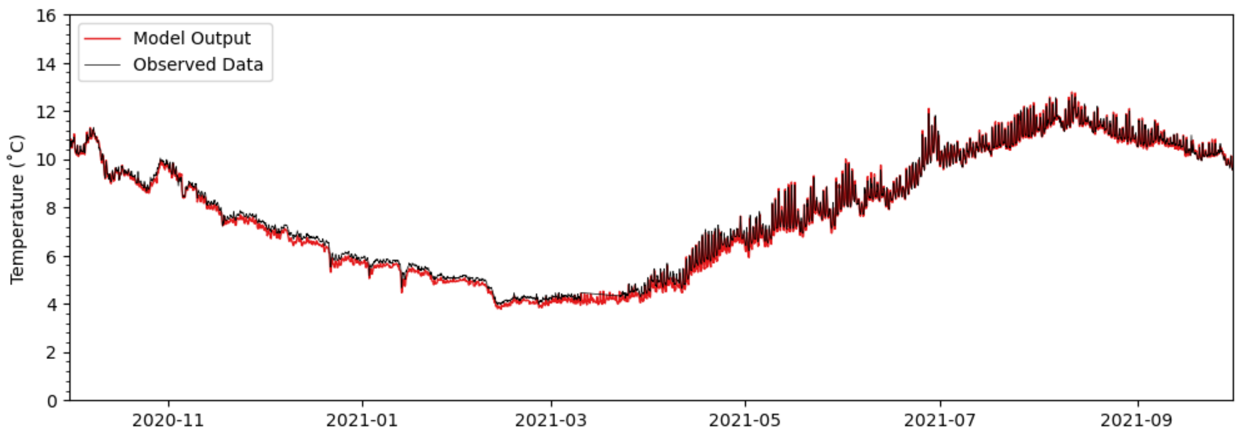


Figure 4.3-34. Observed and simulated temperatures at Skagit River PRM 91.6, City Light Station SKAGIT2, October 2020 through September 2021.

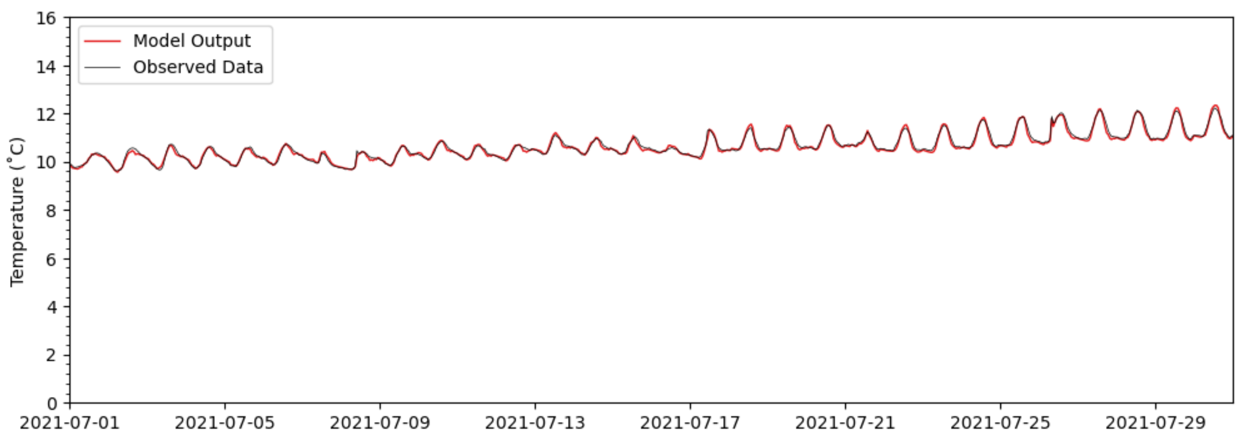


Figure 4.3-35. Observed and simulated temperatures at Skagit River PRM 91.6, City Light Station SKAGIT2, July 2021.

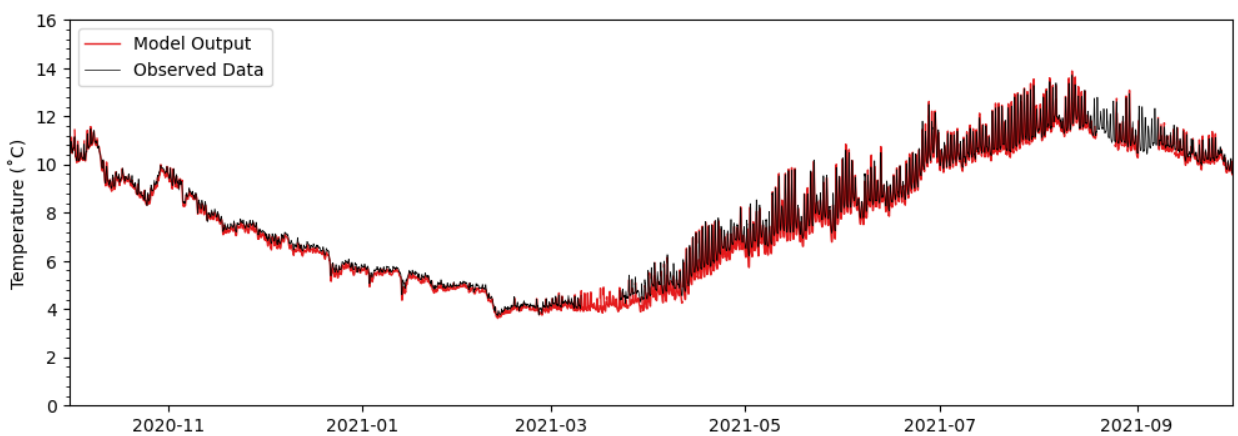


Figure 4.3-36. Observed and simulated temperatures at Skagit River PRM 85.9, City Light Station SKAGIT3, October 2020 through September 2021.

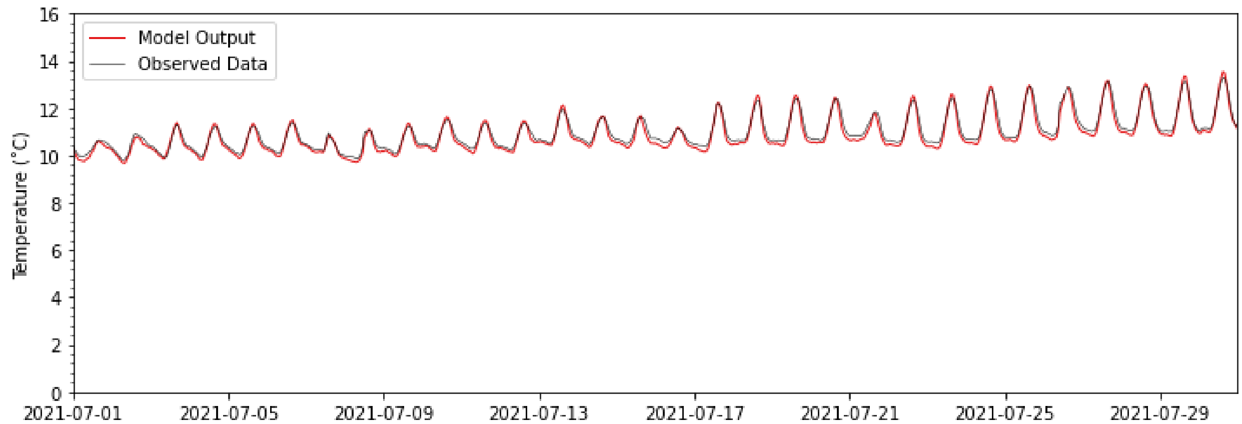


Figure 4.3-37. **Observed and simulated temperatures at Skagit River PRM 85.9, City Light Station SKAGIT3, July 2021.**

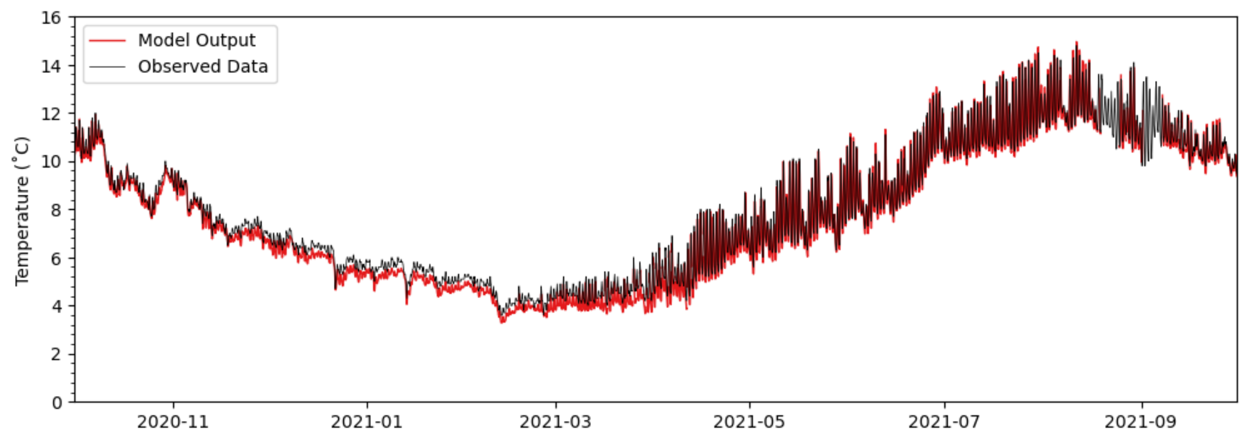


Figure 4.3-38. **Observed and simulated temperatures at Skagit River PRM 79.0, USGS Skagit River Marblemount gage (12181000), October 2020 through September 2021.**

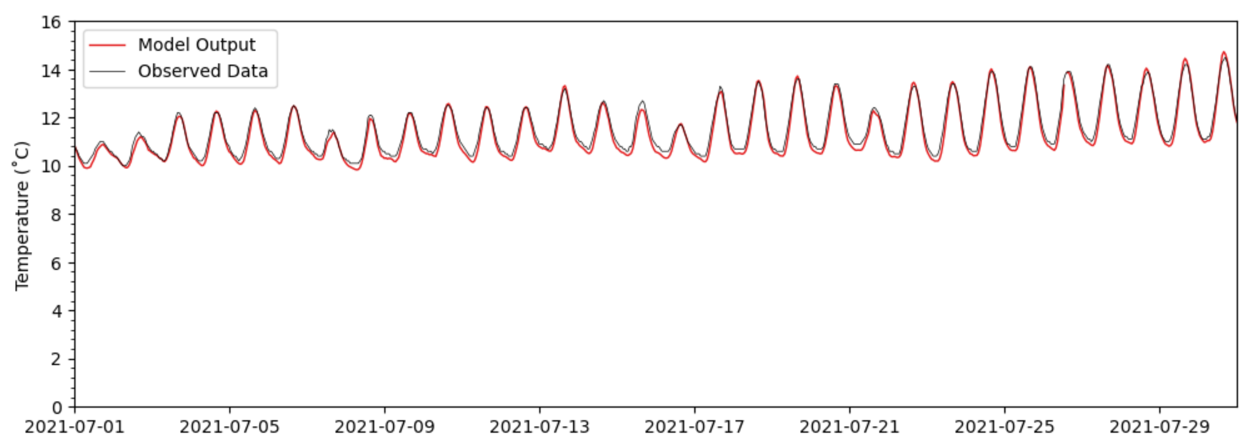


Figure 4.3-39. **Observed and simulated temperatures at Skagit River PRM 79.0, USGS Skagit River Marblemount gage (12181000), July 2021.**

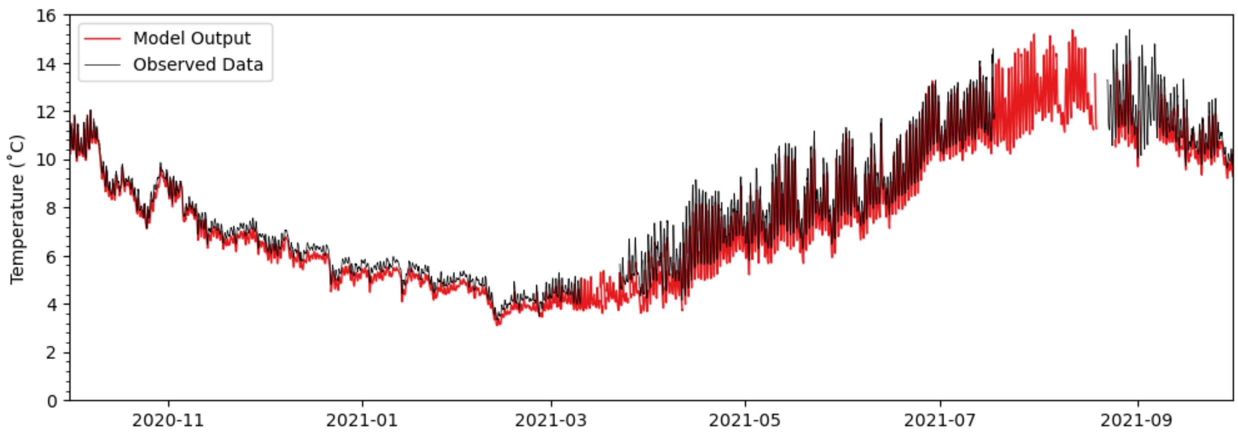


Figure 4.3-40. **Observed and simulated temperatures at Skagit River PRM 75.6, City Light Station SKAGIT4, October 2020 through September 2021.**

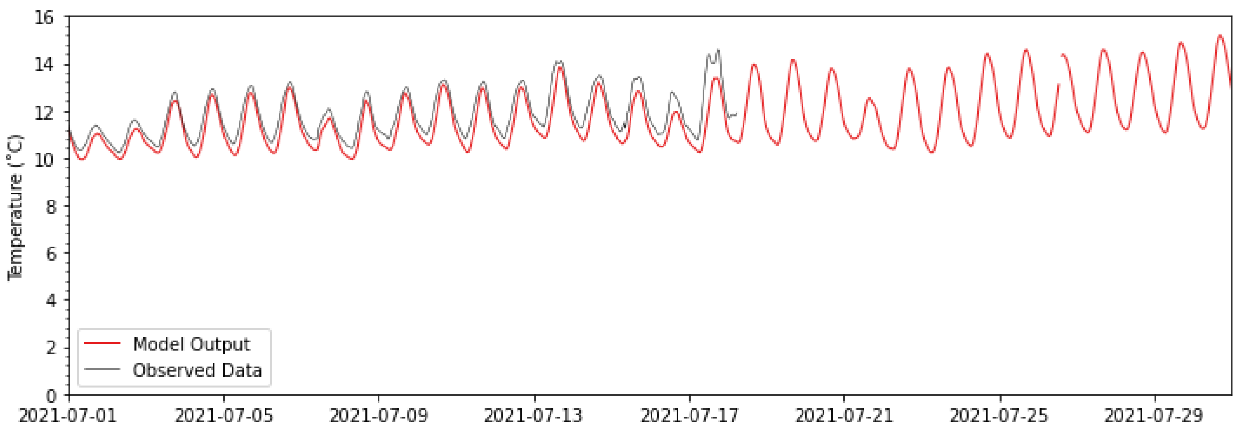


Figure 4.3-41. **Observed and simulated temperatures at Skagit River PRM 75.6, City Light Station SKAGIT4, July 2021.**

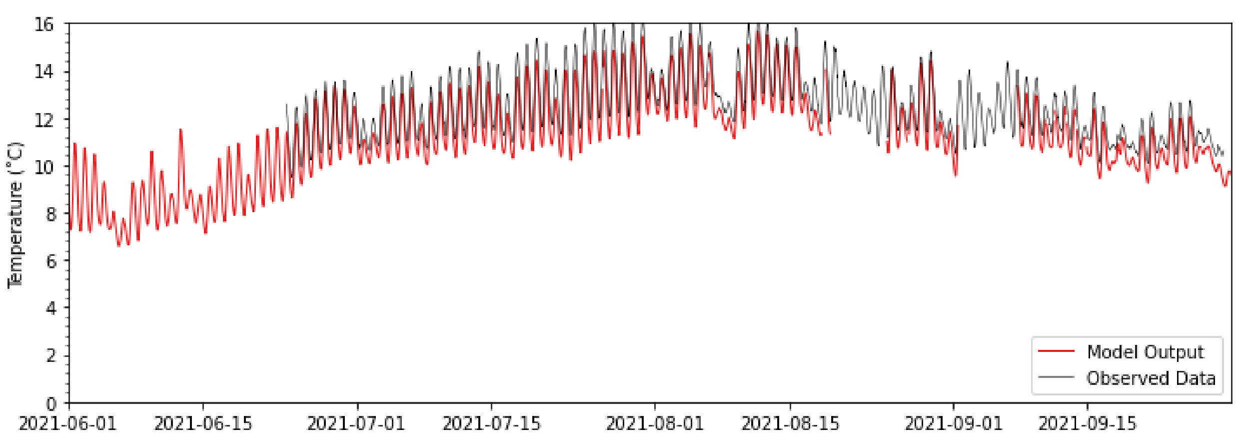


Figure 4.3-42. **Observed and simulated temperatures at Skagit River PRM 69.3, City Light Station SKAGIT5, June 2021 through September 2021.**

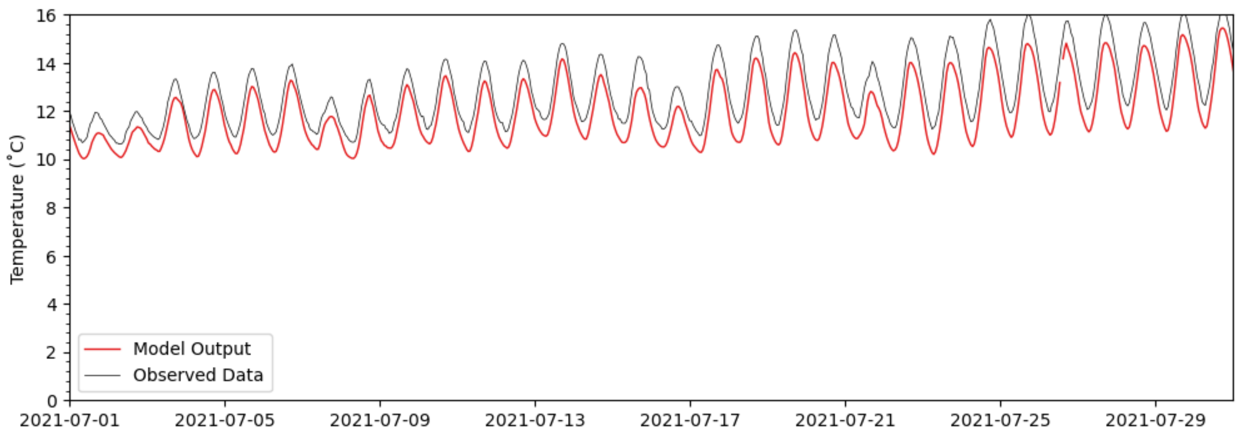


Figure 4.3-43. Observed and simulated temperatures at Skagit River PRM 69.3, City Light Station SKAGIT5, July 2021.

4.3.4.6 S2C Reach

The hydrodynamic calibration of the S2C reach was performed in a similar manner as the N2S reach, which began with calibration to water level elevation data collected on May 26, 2022 and August 19, 2022. Water level comparison with point water level observations acquired at PRM 62.13, PRM 60.04, and PRM 56.78 indicate good agreement with the observed water levels, with average water level errors of 0.99 ft and 0.32 ft for May 2022 and August 2022, respectively (Figure 4.3-44).

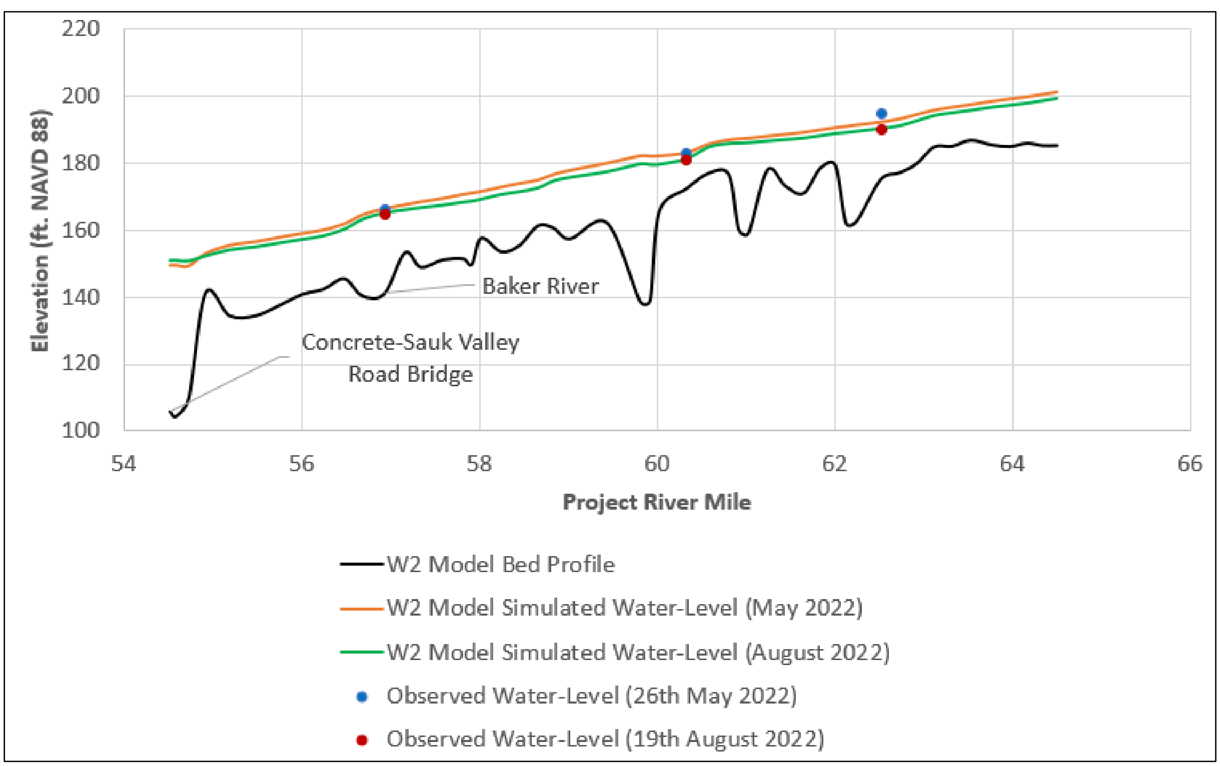


Figure 4.3-44. Point observations (dots) and simulated (solid line) longitudinal water levels in the S2C reach for May and August 2022.

Figure 4.3-45 shows the comparison of simulated flow at the Concrete-Sauk Valley Road Bridge location (PRM 54.6) with observed values from the USGS Skagit River at Concrete gage (12194000). Similar to the N2S reach, flow calibration results for the S2C reach model are also in good agreement with the timing of flow hydrographs, and the MAE, RMSE, and PBIAS model calibration statistics of 753 cfs (21.3 m^3/s), 1,355 cfs (38.4 m^3/s), and 2 percent are considered acceptable (stated target for flow was less 15 percent). Additionally, the largest errors occur during peak flow conditions, which are not critical for evaluating the Project's effects on temperature. If the error statistics were limited to low and moderate flows, they would further improve.

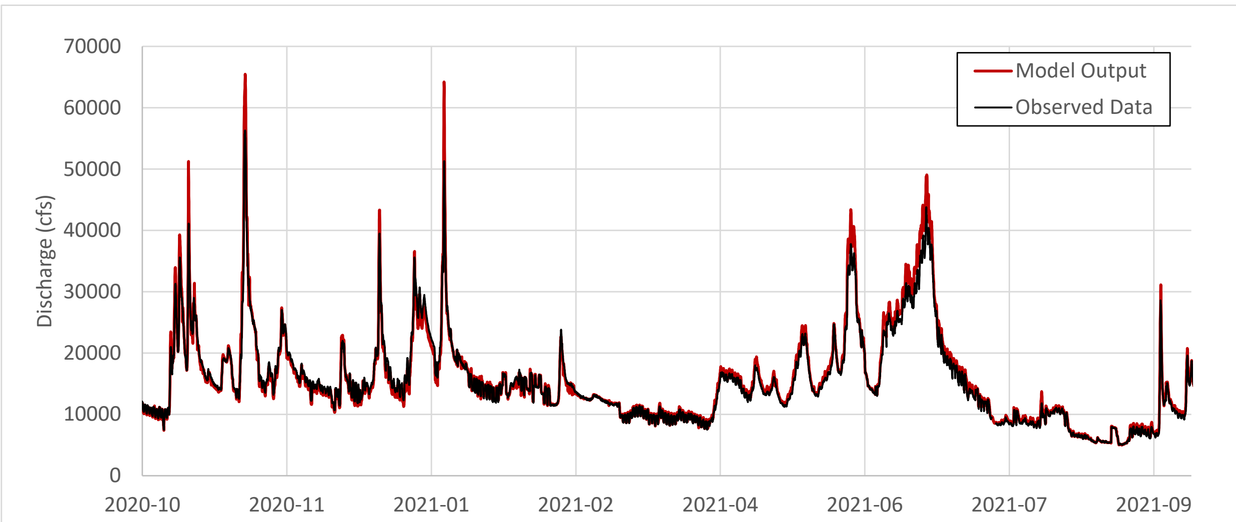


Figure 4.3-45. Observed and simulated flows at PRM 54.6, USGS Skagit River near Concrete gage (12194000).

The temperature calibration for the S2C reach was performed for PRM 60.8 and 54.5 (Figures 4.3-46, 4.3-47, 4.3-48, and 4.3-49). Calibration statistics are reported along with those from the N2S reach in Section 4.3.4.7.

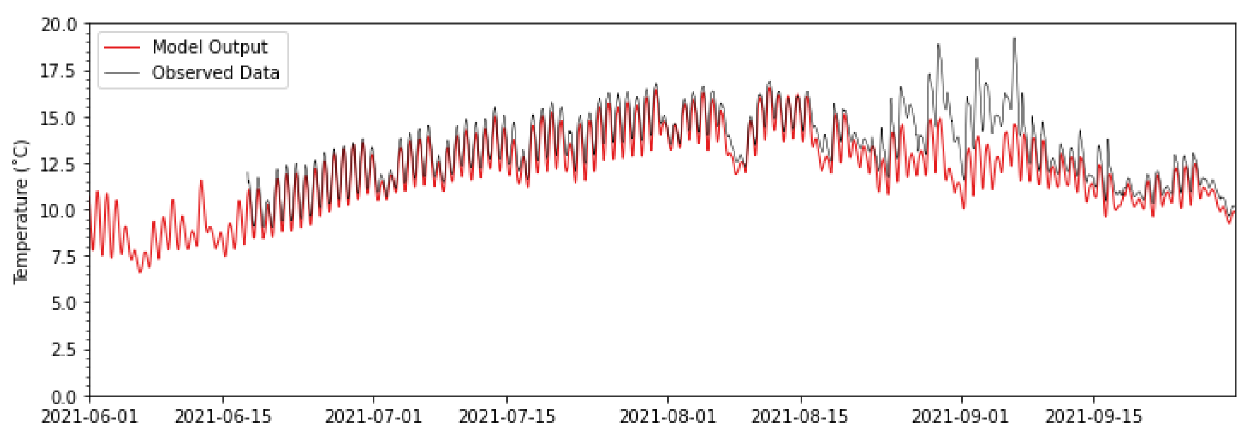


Figure 4.3-46. Observed and simulated temperatures at PRM 60.8, City Light Station SKAGIT6, in the S2C reach, October 2020 through September 2021.

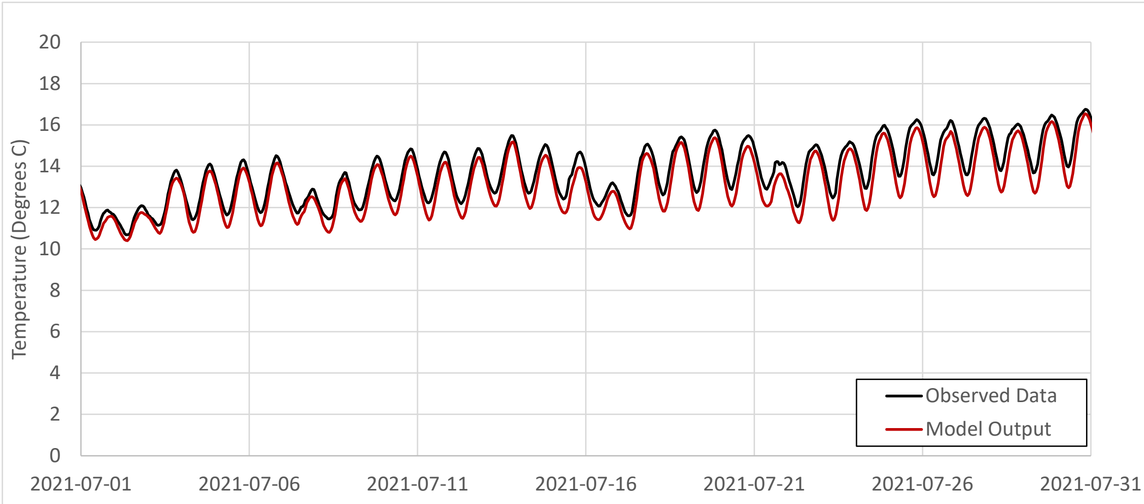


Figure 4.3-47. Observed and simulated temperatures at PRM 60.8, City Light Station SKAGIT6, in the S2C reach, July 2021.

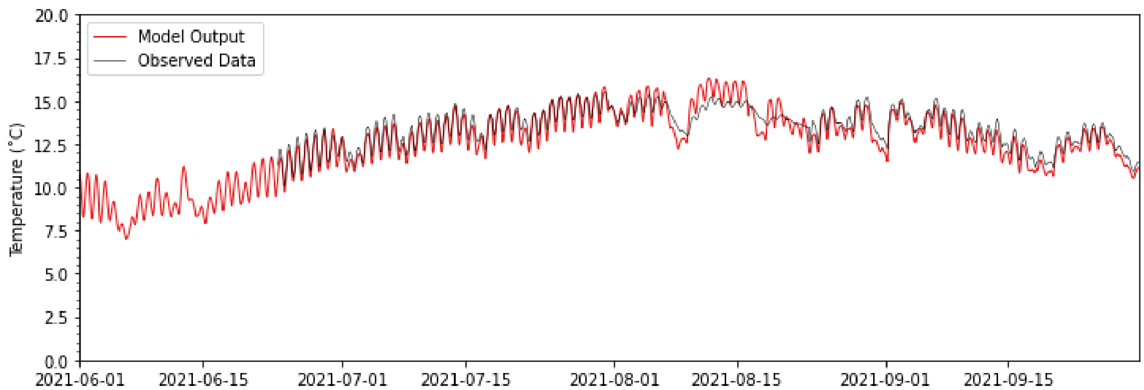


Figure 4.3-48. Observed and simulated temperatures at PRM 54.5, City Light Station SKAGIT7, October 2020 through September 2021.

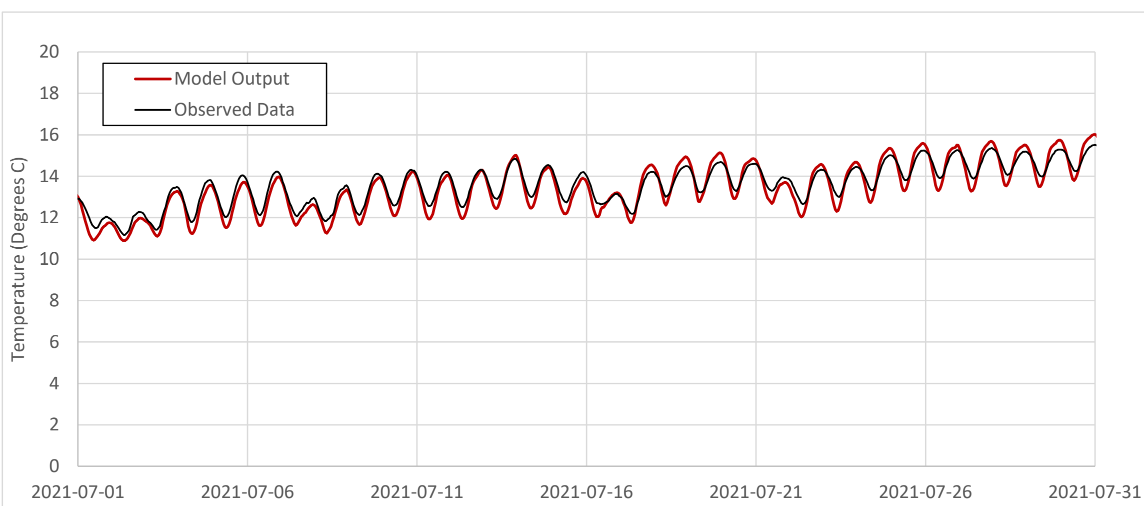


Figure 4.3-49. Observed and simulated flows at PRM 54.5, City Light Station SKAGIT7, July 2021.

4.3.4.7 Skagit River Calibration Statistics

Error statistics (RMSE, MAE, and PBIAS) were calculated for the comparisons of modeled temperature time series with the calibration data described above. No temperature calibration was performed for the Gorge bypass reach. RMSE, MAE, and bias statistics within the N2S reach are lowest at the upstream end near Newhalem and increase in the downstream direction, with maximum RMSE and MAE statistics of 0.8 and 0.1°C and a PBIAS of -5.1 percent at PRM 69.3 (Table 4-3.8). S2C reach error statistics and bias are lower than the N2S reach, with respective RMSE and MAE values of less than 0.1 and 0.2°C at both locations. Bias at the two S2C reach locations was less than 2 percent, with PRM 60.8 being slightly positive and PRM 54.6 being negative. Some of the error at the PRM 54.6 station can be attributed to error in the time series of Baker River outflow temperatures, which were based on estimated temperatures derived from observed temperatures at the USGS Skagit River at Newhalem gage.

Table 4.3-8. Temperature Calibration Statistics from Skagit River Calibration Comparisons.

PRM	Observed Station ID	RMSE (°C)[1]	MAE (°C)[1]	PBIAS (%)[1]
N2S Reach				
91.6	SKAGIT2	0.2	0.1	-1.4
85.9	SKAGIT3	0.2	0.1	-1.9
79.0	12181000	0.3	0.3	-2.9
75.6	SKAGIT4	0.7	0.3	-4.8
69.3	SKAGIT5	0.8	0.1	-5.1
S2C Reach				
60.8	SKAGIT6	< 0.1	0.1	< 0.1
54.6	SKAGIT7	< 0.1	0.2	-1.5

1 PRM: Project River-Mile; RMSE: root mean squared error; MAE: mean absolute error, and PBIAS: percent bias.

4.4 Consultation on Model Development and Calibration

A total of seven consultation workshops were held to apprise LPs of progress on the WQ Development Study and to solicit feedback and input. Of these, five workshops addressed model needs, data, and objectives, and two workshops addressed CE-QUAL-W2 model development and calibration.

The seven workshops were as follows:

- Workshop 1 (July 14, 2021) introduced the study team and identified past projects on which CE-QUAL-W2 has been used.
- Workshop 2 (October 1, 2021) described CE-QUAL-W2 data needs for both temperature and water quality modeling in the context of an introduction to the structure of a CE-QUAL-W2 model.
- Workshop 3 (November 23, 2021) presented the QAPP and compared data needed for model development with plans for data collection.

- Workshop 4 (December 20, 2021) presented potential model use cases, the data needs to create a model that could satisfy those use cases, and a discussion on the downstream extent of the Skagit River temperature model.
- Workshop 5 (January 25, 2022) presented a sampling framework to support the modeling of water quality variables, concluded the discussion of the downstream extent of the Skagit River temperature model, presented zooplankton data, and described the need for additional bathymetry data.
- Workshop 6 (April 26, 2022) presented the methodology used to develop the temperature models and introduced the approach for temperature calibration and a description of the installation of two new meteorological stations on Ross and Diablo lakes.
- Workshop 7 (June 28, 2022) presented the temperature calibration in the Project reservoirs and the river downstream and the Existing Conditions temperature simulation.

Dr. Scott Wells from Portland State University was retained as a subconsultant on April 7, 2022 to provide independent review consultation. Geosyntec and NHC provided model documentation and details on the modeling approach with Dr. Wells and met virtually with him on three occasions to receive feedback on the modeling approach and effort. These meetings are described below:

- Technical Advisory Meeting #1 (May 12, 2022): This meeting provided Dr. Wells with background information on the modeling efforts. Riverine side channels and available meteorology data were also discussed in detail.
- Technical Advisory Meeting #2 (July 8, 2022): During this meeting, the calibration of the Ross Lake and Diablo Lake models was discussed in detail. The calibration of the Gorge Lake and Skagit River models was discussed briefly, and the plan for sensitivity analyses (SA) was presented.
- Technical Advisory Meeting #3 (September 21, 2022): During this meeting the design of potential additional simulations with Dr. Wells, beyond those described in this report were discussed.

4.5 Without-Dams Simulation

4.5.1 Temporal and Geographical Extent

The calibrated models of Ross Lake, Diablo Lake, and Gorge Lake were modified to remove Ross Dam, Diablo Dam, and Gorge Dam and simulate the temperature in a free-flowing Skagit River. This simulation used the input files for the simulation period described in this report. As such, it is not a simulation of conditions prior to the construction of the Skagit River Hydroelectric Project because it does not include meteorology or river inflows in the early 20th century. Instead, it is an estimation of river temperatures between July 1, 2019 and December 1, 2020 had the dams not been present.

In this simulation, the portions of the Skagit River presently occupied by the Project reservoirs will be referred to as “the Ross Reach,” “the Diablo Reach,” and “the Gorge Reach.” Output from the model of the Gorge Reach was used as input to a newly developed model of the river channel between Gorge Dam and the USGS gage at Newhalem, Washington. This reach, which is generally dry under present conditions due to water being routed through the Gorge Dam penstocks, is referred to as "the Bypass Reach." Output from the model of the Bypass Reach was used as input to the Skagit River model described in this report, which was run without modification in the Without-Dams Simulation. The lack of modification to the Skagit River model implies a simplifying assumption that construction of the Project has not changed the river in ways that would affect temperature.

Although the calibrated models of Ross Lake and Diablo Lake simulate the Ruby and Thunder arms of these reservoirs, the Without-Dams Simulation does not include the reaches of Ruby and Thunder creeks presently submerged beneath Ross and Diablo lakes. For simplicity, these tributaries are modeled in the Without-Dams Simulation as entering directly into the Skagit River as though the presently submerged reaches of these creeks do not exist.

4.5.2 Bathymetry

The Without-Dams Simulation required development of a new representation of bathymetry in the Ross, Diablo, and Gorge reaches. The entirety of the Ross Lake and Diablo Lake bathymetries needed to be redeveloped. The Gorge Lake model, which already represented flowing reaches, required fewer modifications. No modification to the Skagit River model between the Gorge Powerhouse and RM 54 was necessary.

To create branches for the Ross and Diablo reaches, a 1915 USGS elevation survey of the river channel was used along with longitudinal profiles created from 1968 USGS contour maps, which depict 40-ft contours beneath the water surface in Ross and Diablo lakes. This allowed for the development of a longitudinal profile of the Ross and Diablo reaches. The Ross and Diablo reaches were divided into 12 branches. Branches were divided such that the slope of the river reach varied minimally within an individual branch.[8] These branches were simulated in four separate models to decrease runtime and simplify debugging. For the Gorge Reach, the Without-Dam grid covers a similar footprint to the Gorge Lake model grid; however, due to the increased hydraulic slope of the reach, the three mainstem Gorge Lake model branches were sub-divided into a total of six (Figure 4.5-1). Note: The term 'site' is used here to refer to the locations of each of the three Project dams, while the term 'outflow' is used to describe outflows through penstocks and spillways from each dam (e.g. Gorge Dam site vs. Gorge Dam outflow).

8 Branches 9.1 and 9.2, which are derived from a single "Branch 9" that existed in an early version of the Without-Dams model, are counted as 2 of the 12 branches.

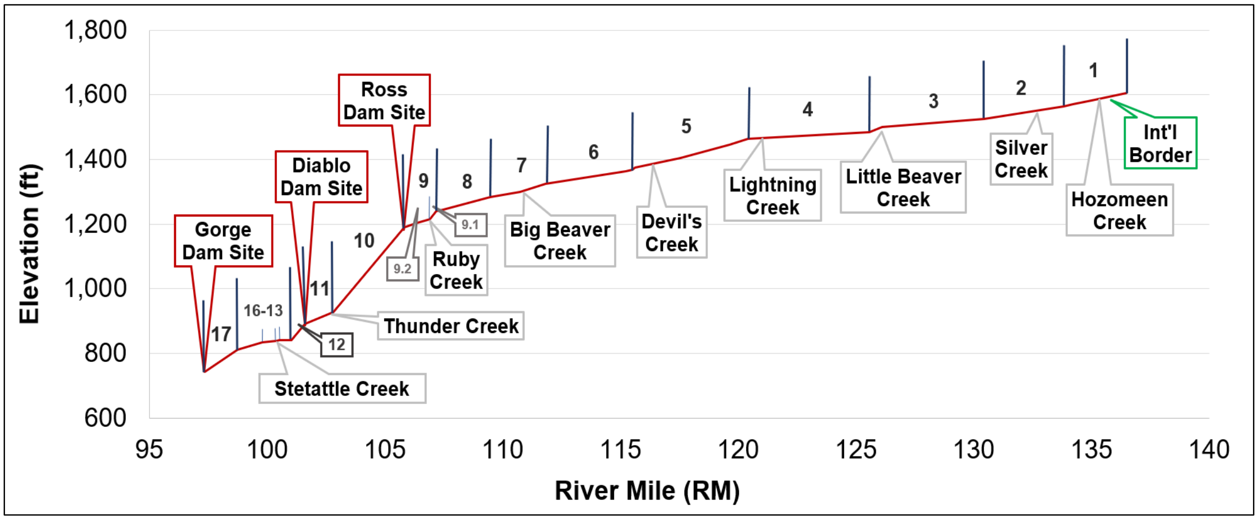


Figure 4.5-1 Without-Dams Simulation branch breaks of the Ross, Diablo, and Gorge reaches. River Miles are relative to RM 0 at Skagit Bay; Ross, Diablo, and Gorge reaches are sections between each respective dam site and the next dam upstream or, in the case of Ross Reach, the upstream extent of the model near RM 137.

For the Ross and Diablo Reaches, the river channel depicted in the 1968 contour maps was digitized, and model segments were created from the digitized riverbanks and channel centerline. Segment lengths were selected within a range of 450-650 ft to capture major curves within the channel without introducing more segments than necessary, which would require additional computing time (e.g., Figure 4.5-2). The number of segments in a branch ranged from 4 to 55, and every segment in a given branch was the same length (Table 4.5-1). The average channel width was calculated in each segment from measurements taken every 10 ft (longitudinally) from the digitized maps. For the Gorge Reach, the segmentation from the Gorge Lake model was used, the only exception being one additional segment was added to close the gap covering the area currently occupied by the Diablo Dam structure and tailrace.

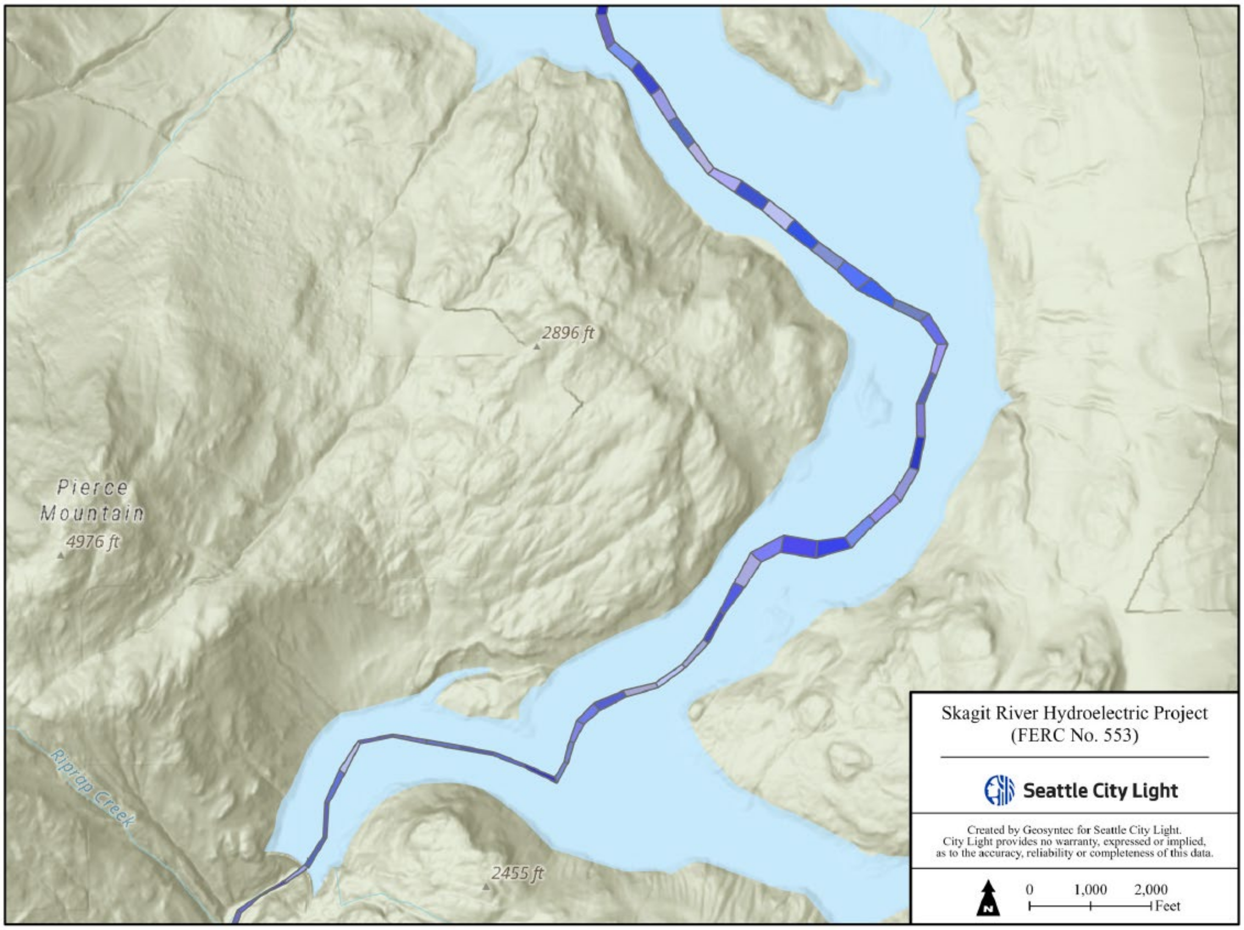


Figure 4.5-2. Example model segmentation of the Without-Dams Simulation Skagit River in present-day Ross Lake. Shading differentiates segments from one another visually and does not indicate differences between segments.

Table 4.5-1. Branches and segments in the Without-Dams Simulation.

Branch	Branch Length (ft)	Number of Segments	Length of Segments (ft)[1]	Landmark
1	11,418	25	457	Hozomeen Creek
2	19,099	40	477	Silver Creek.
3	26,515	55	482	Little Beaver Creek.
4	27,065	55	492	Lightning Creek.
5	26,211	55	477	Devil's Creek.
6	19,801	40	495	
7	13,326	25	533	Big Beaver Creek
8	10,863	20	543	
9.1	1,409	4	352	Ruby Creek.
9.2	5,684	10	568	Ross Dam Site
10	15,811	35	452	Thunder Creek.

Branch	Branch Length (ft)	Number of Segments	Length of Segments (ft)[1]	Landmark
11	6,508	10	651	Diablo Dam Site
12	3,065	4	766	Reflector Bar
13	2,627	11	239	Diablo PH
14	660	4	165	Stetattle Creek.
15	3,208	12	267	SR-20 Bridge
16	5,603	9	622	
17	7,299	11	663	Gorge Dam Site

1 Each segment in Branches 1-11 has the same length. The length reported for Branches 12-17 is the average of the segments in each branch.

Layer thicknesses of the channels of the Ross and Diablo Reaches were set at 0.25 m so that the model could represent differences in river flow rate and temperature at different depths. Subsequently, the remaining task in the development of a bathymetry file was to determine the width of each cell in each segment. This was done first for the river channel and then for the floodplain. These are described separately in the following paragraphs.

Defining the dimensions of the historical river channel required several assumptions due to the low resolution of the available bathymetric data for the Ross and Diablo reaches. It was first assumed that the channel bed width was 5 m for the entirety of each branch. Then, it was assumed that during the high flow season (i.e., early April to late July), the river channel flows full when conveying the average flow rate, yet this flow rate does not exceed the capacity of the river channel (i.e., the average flow rate during the high-flow season does not induce flow on the floodplain). The average flow rate of the high-flow season was calculated for the sum of all tributaries contributing flow to the downstream-most channel division of each model branch.

The assumptions described above provided the width of the bottom of the channel of the Skagit River and the volume of water flowing in that channel. These were combined with measurements of the channel width from the 1968 contour maps and an assumption that the channel is trapezoidal. With these four pieces of information, Manning's equation[9] was used to solve for the water depth at bankfull conditions in the downstream-most channel division of each branch, and then it was assumed that the bankfull water depth was the same in all channel divisions of a given branch. Manning's n coefficient values of 0.035 for wide valley reaches and 0.045-0.060 for canyon reaches[10] were used. With the bottom channel width, top channel width, and bankfull water depth, the width of the 0.25-m thick model cells were calculated that defined the vertical structure of the channel in each model segment.

9 Manning's equation calculates channel velocity from channel slope, width, depth, and roughness. In this calculation, slope was known, roughness was assumed, width was measured, the average flow was used, and we solved for water depth.

10 Values were taken from guidance provided in the CE-QUAL-W2 users' manual.

In the Gorge Reach, the slope of the terrain is relatively variable as it transitions from a narrow canyon coming out of the Diablo Dam site upstream of Reflector Bar, through the Stetattle Creek reach, and then dropping off gradually as it approaches Gorge Dam. Due to this variable slope, the model grid layers were increased to maintain model stability. In the narrow canyon coming out of the Diablo Dam site the layer heights are set to 2.0 m, and the remainder of the model layer heights are set to 1.0 m, which matches those used in the Gorge Lake model grid. The model grid layer widths representing the channel (and floodplain) were sampled directly from the available bathymetry data, which included the 1915 contour data, 2017 bathymetric survey, and topobathymetric LiDAR.

In the floodplain of the Ross and Diablo reaches, "floodplain divisions" were defined manually based on the presence or absence of river meanders (Figure 4.5-3). These generally encompassed between three and ten segments. The digital elevation models (DEMs) that were created from 1968 contours and 2016 and 2018 LiDAR data for the reservoir models (see Section 4.2.2.1) were used to determine the width of each floodplain division in 1-m layers. This is the same process used to create the bathymetry file for the reservoir models that represent present-day conditions.

The width of each 1-m layer in a floodplain division was used to calculate the volume of that layer for that floodplain division. This volume was divided among the segments in the floodplain division, and widths were assigned to the floodplain layers of these segments accordingly. Floodplain layers were then added to the representation of bathymetry on top of the channel layers (Figure 4.5-4). The preservation of volume in floodplain divisions implies that, in areas where the river channel meanders, the floodplain layers are not as wide as the river floodplain. This approximation provides a reasonable representation of volume in the model bathymetry file, which is critical for representing water depth and travel time in the simulated river.

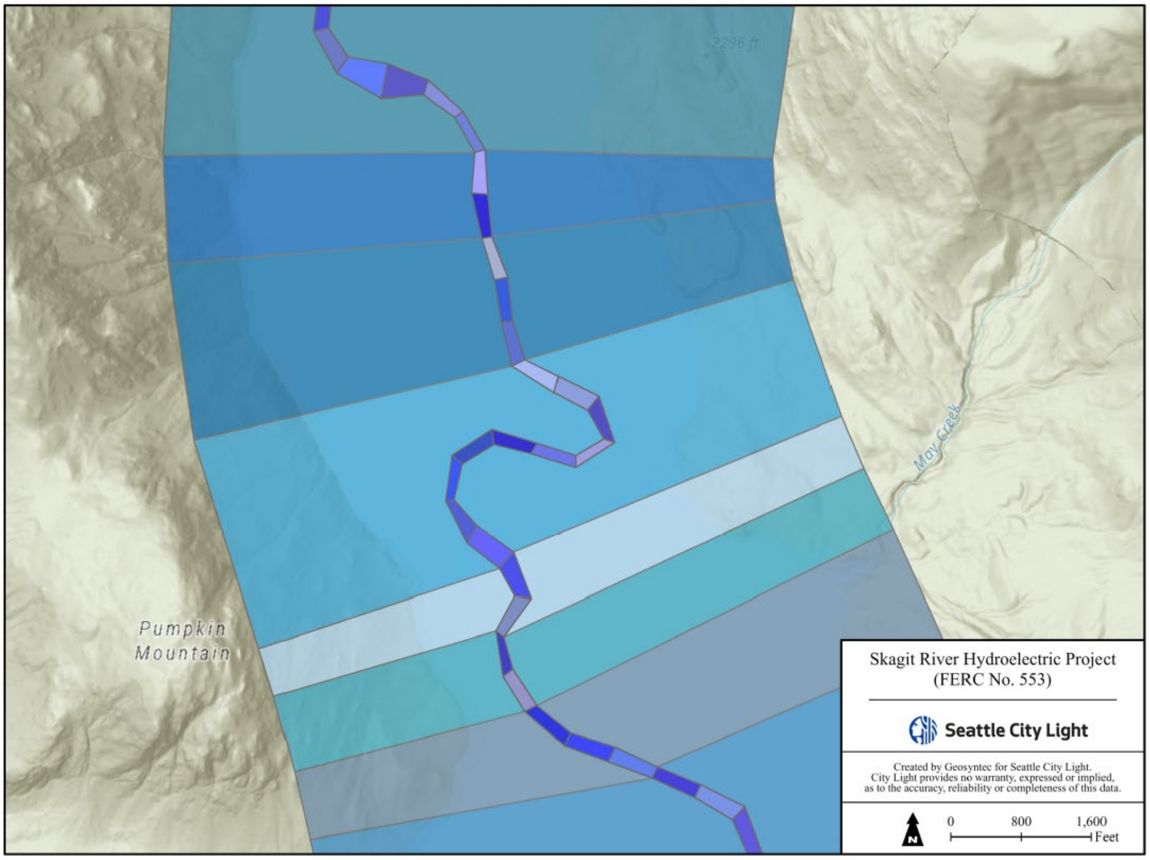


Figure 4.5-3. Example floodplain divisions grouping segments with and without river meanders in the Ross Reach. Shading differentiates segments from one another visually and does not indicate differences between segments.

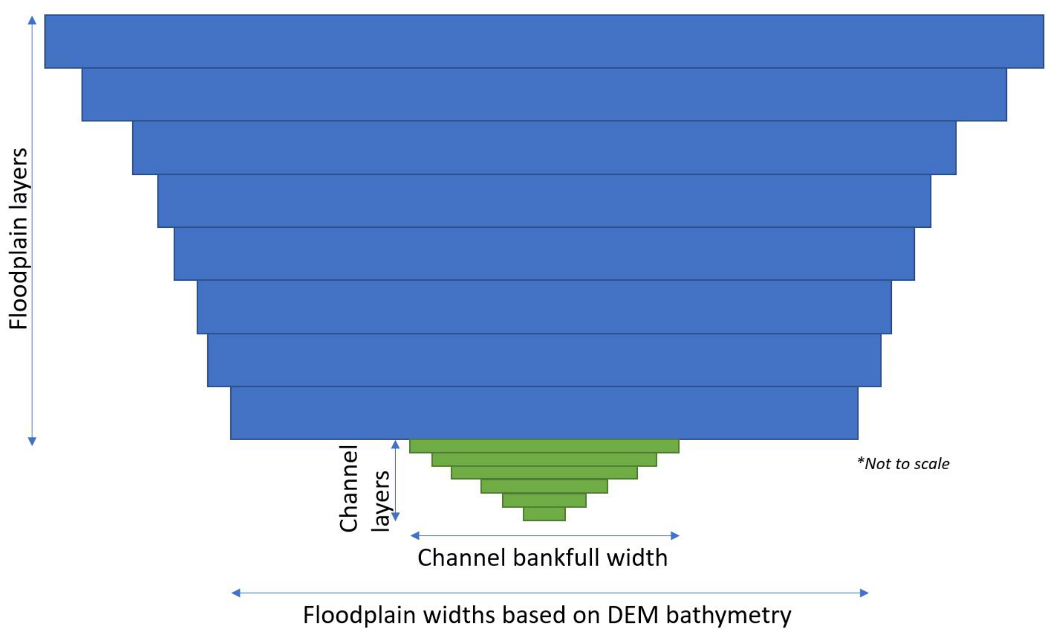


Figure 4.5-4. Cross-sectional profile of channel and floodplain layer geometry.

As noted previously, in the Gorge Reach, no special consideration defining the floodplain was necessary because this reach is entirely within a narrow canyon. The floodplain layer widths were sampled directly from the available bathymetry data as part of the same process used to define the channel bathymetry.

Finally, the orientations of the channel segments for the Ross and Diablo reaches were generated by comparing the vector defined by the segment centerline to true north. Segment lengths, orientations, and cell widths were written to a file readable by CE-QUAL-W2. For the Gorge Reach, the orientation from the Gorge Lake model was used.

4.5.3 Other Input Files

For the Ross Reach, Diablo Reach, and Gorge Reach, topographic shading files were created using the same algorithm as that used for the reservoir models (see Section 4.2.6) given the Without-Dams segmentation and a water surface elevation equal to the top of the channel. Vegetative shading was specified as 120 ft tall trees covering the floodplain up to the river channel.

Control files were created for each of the four models encompassing the Ross and Diablo reaches that specified the entrances of tributaries from the reservoir model into the Without-Dams river segments. The control file for the Gorge Model and Gorge Reach was left unchanged with the exception that all flows from the upstream Diablo model were routed through the Reflector Bar canyon rather than the Diablo Powerhouse. The distributed tributary inflow files from the reservoir models were divided among the branches of the Without-Dams Simulation.

The shade files, control files, and distributed tributary inflow files of the Skagit River model downstream of the Gorge Powerhouse were left unchanged because it is reasonable to assume that these inputs are similar for this reach under both the Without-Dams case and existing conditions.

4.5.4 Quality Control Analyses

Measurements of Without-Dams flow in the Skagit River are available at the USGS Skagit River at Newhalem gage (12178000) prior to the construction of the Project. However, a direct comparison between output from the Without-Dams simulation and historical measurements at this gage prior to the Project construction is not useful because pre-Project flows in the Skagit River at Newhalem were likely closely tied to concurrent inflows, and these data are not available to calibrate the Without-Dams model. Consequently, the modeled Without-Dams flows were compared to City Light's "Naturalized" time-series of daily discharges that is available for the Ross Dam site, the Diablo Dam site, the Gorge Dam site, Newhalem, and Marblemount (e.g., Figures 4.5-5 and 4.5-6 for the Diablo and Gorge Dam Sites, respectively). The time-series show exceptionally close matches in terms of the timing and magnitude of both wet and dry season flows. This implies that the Without-Dams simulation provides a reasonable representation of possible flow in the Ross, Diablo, and Gorge reaches in the absence of the Project.

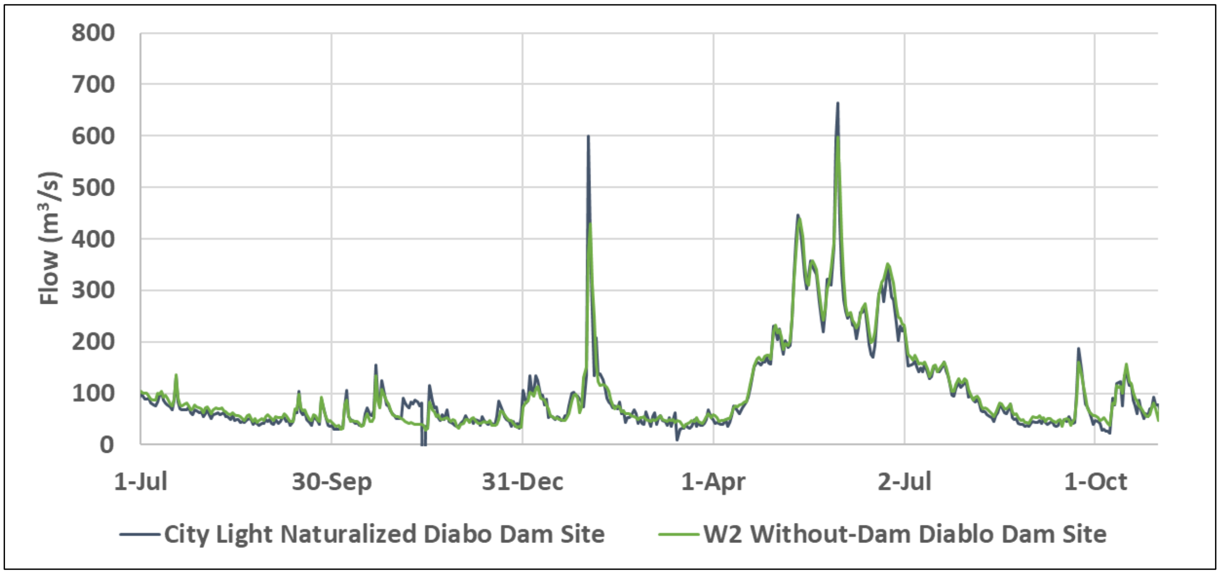


Figure 4.5-5. Without-Dam simulation flows and City Light "Naturalized" flows at the Diablo Dam site.

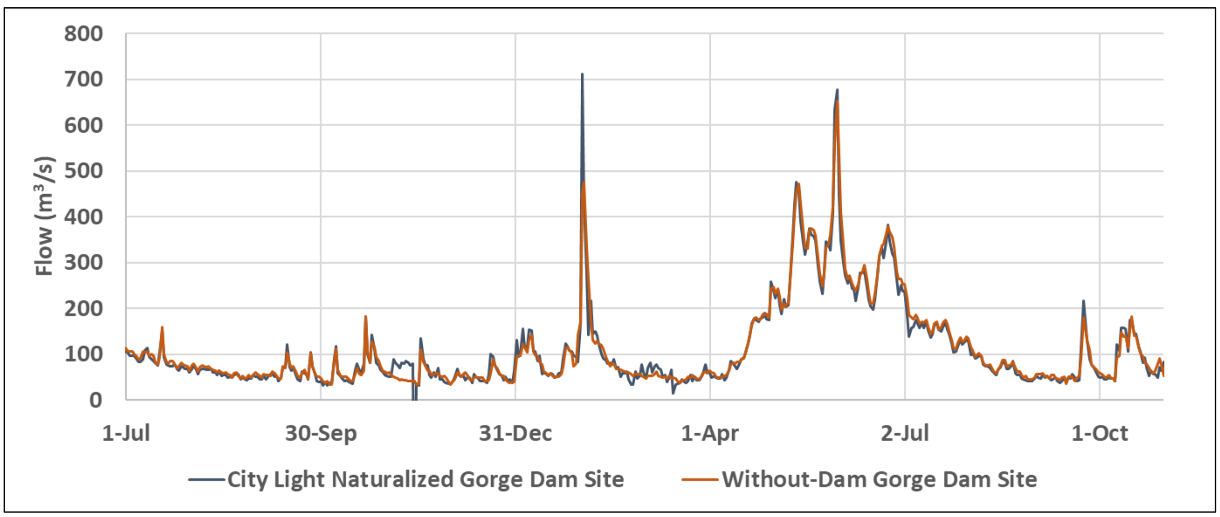


Figure 4.5-6. Without-Dam simulation flows and City Light "Naturalized" flows at the Gorge Dam site.

Temperature data in the Skagit River collected prior to the construction of the Project was not available. Thus, four analyses were completed to confirm that the results in the Ross and Diablo reaches are reasonable. First, flow and temperature in the Skagit River inflow were compared to simulated temperatures in the upper Ross Reach. Flow was greater relative to the Skagit River inflow at locations 6 and 11.3 miles downstream in the Ross Reach due to tributaries joining the Ross Reach (Figure 4.5-7). Winter temperatures in the inflowing Skagit River and Upper Ross Reach were nearly identical, and summer temperatures in the Upper Ross Reach were much warmer than in the Skagit River. This is consistent with the hypothesis that warming occurs over the open topography of the glacial valley flooded by Ross Lake as well as the observation from recent monitoring data that summer temperatures in the surface water of Ross Lake increase well beyond those of the inflowing Skagit River due to solar radiation (Seattle City Light 2022a).

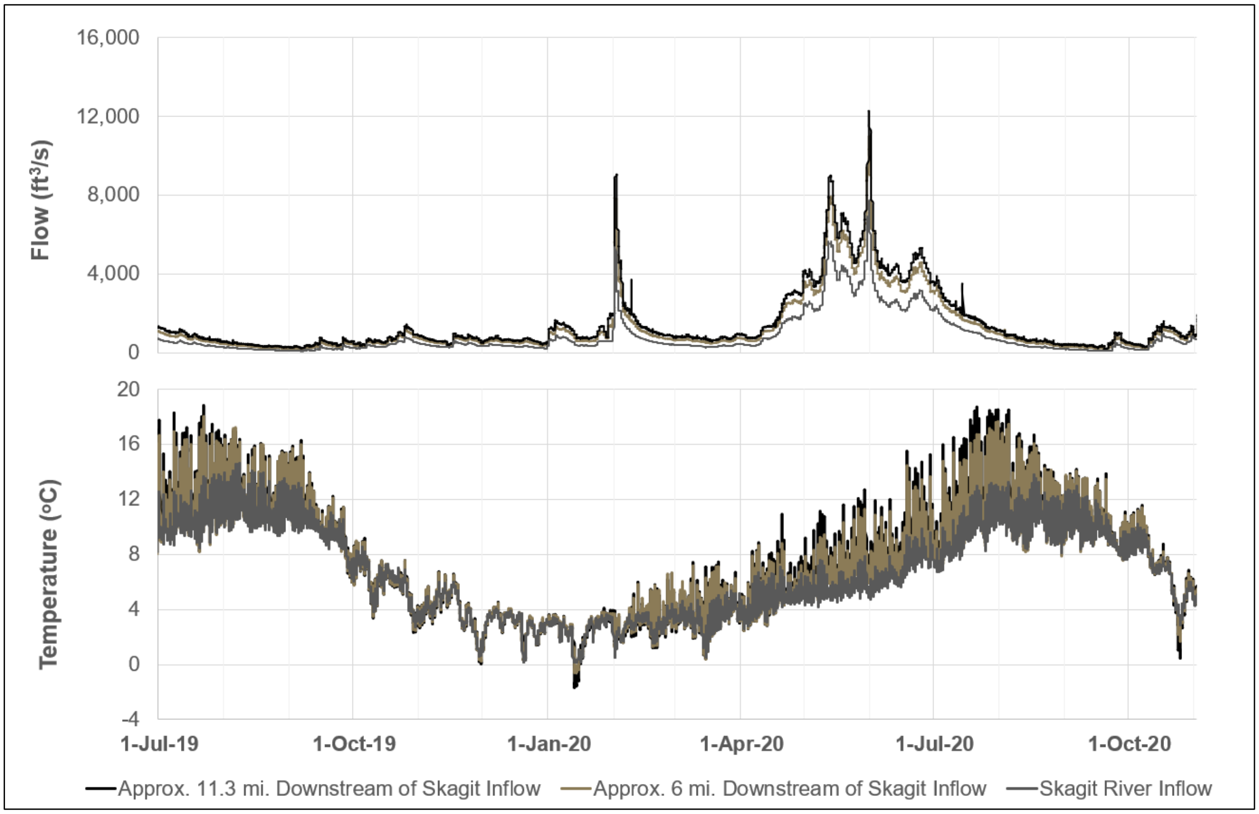


Figure 4.5-7. Flow (top panel) and temperature (bottom panel) at two locations in the simulated Ross Reach and the observed Skagit River inflow upstream.

Second, an observation that elevated water level during times of high flow can lead to shallow water on the simulated floodplain was investigated. This is an expected consequence of defining a channel depth that holds the average flow during the high-flow season; flows above this average will occupy bathymetric layers corresponding to the floodplain. The study team checked that observed temperature fluctuations during summer (i.e., when the water is on the floodplain) did not occur due to shallow water on a wide floodplain layer experiencing unreasonable solar heating. Surface and bottom water temperatures in a segment located in the upper portion of the Ross Reach were nearly identical, indicating that fluctuations observed in the simulated temperature of the Skagit River are due to meteorological forcing and variation of river inflow temperatures. Their variation in a plausible range implies that they are reasonable and not artefacts of model development.

Third, the range of summer temperatures in the Ross Reach were compared with those measured in the Sauk River. For this comparison, model output from a location upstream of Ruby Creek was selected so that both points of comparison would have some influence of glacier-fed tributaries, but neither would be dominated by glacial melt (Figure 4.5-8). Simulated temperatures in the Ross Reach occur in a range similar to those measured at the downstream end of the Sauk River were observed, suggesting that the warm summer temperatures simulated in the Ross Reach are reasonable. The difference in temperature in the late summer 2020 (beginning in late August and continuing into the following months) may be due to decreasing air temperatures in the headwaters of the Skagit River and the different reservoirs of groundwater that discharge into these two rivers.

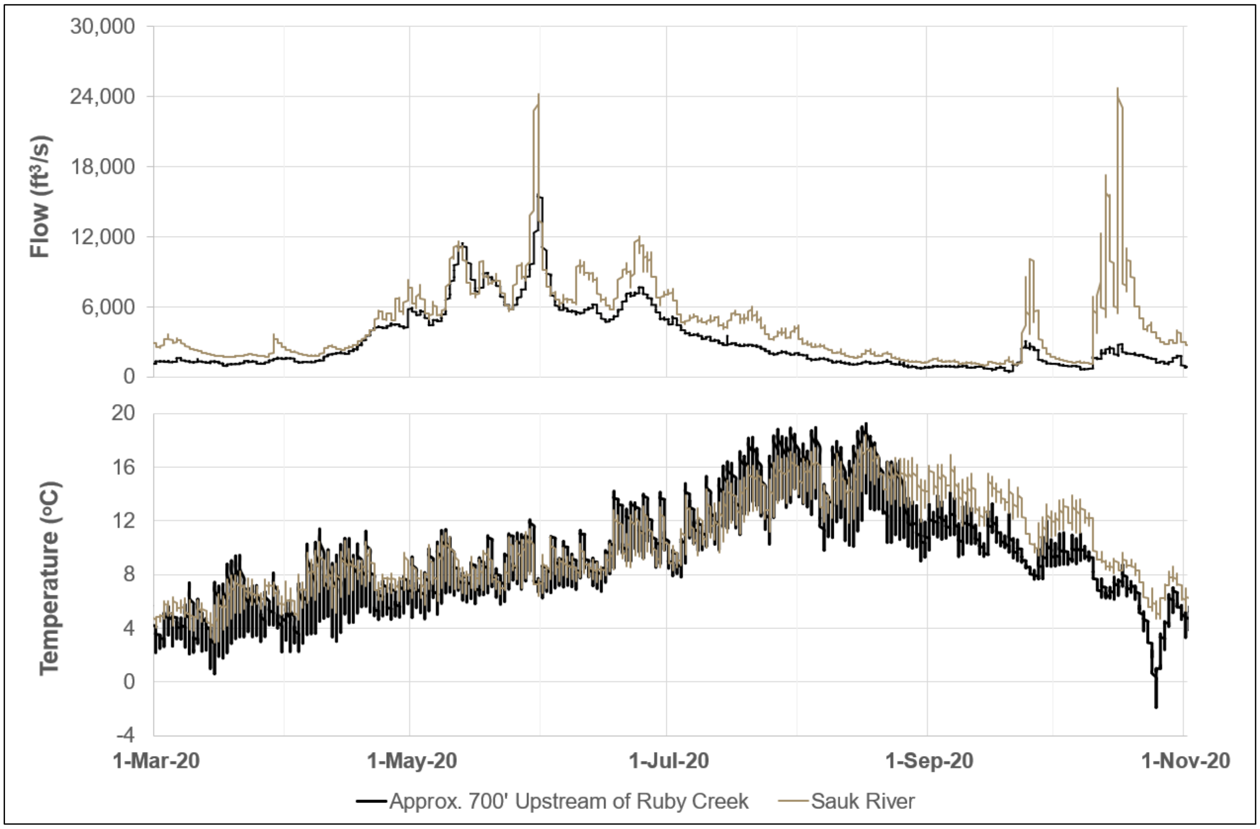


Figure 4.5-8. Flow (top panel) and temperature (bottom panel) measured in the Sauk River and simulated in the Ross Reach upstream of the confluence with Ruby Creek.

Fourth, during initial review of model results, it was observed that summertime temperatures at downstream locations in the Ross and Diablo reaches were notably lower than those further upstream. To verify that this was a realistic representation of Skagit River temperatures, river temperatures simulated in river segments above and below the Skagit River confluences with Ruby Creek and Thunder Creek were compared to temperatures of the inflowing Skagit River and Ruby and Thunder Creeks themselves. Simulated summertime temperatures in the Ross Reach were notably higher than observed temperatures in the upper Skagit River inflow (Figure 4.5-9), but that they decrease when flows are mixed with the inflow of colder Ruby Creek (i.e., in Figure 4.5-10, simulated temperatures downstream of the confluence are lower than upstream of the confluence because of the colder observed Ruby Creek inflow). A similar comparison was made for the Thunder Creek confluence; a cold Thunder Creek joins the Skagit River and cools the water relative to the warmer temperatures upstream of the confluence (Figure 4.5-11).

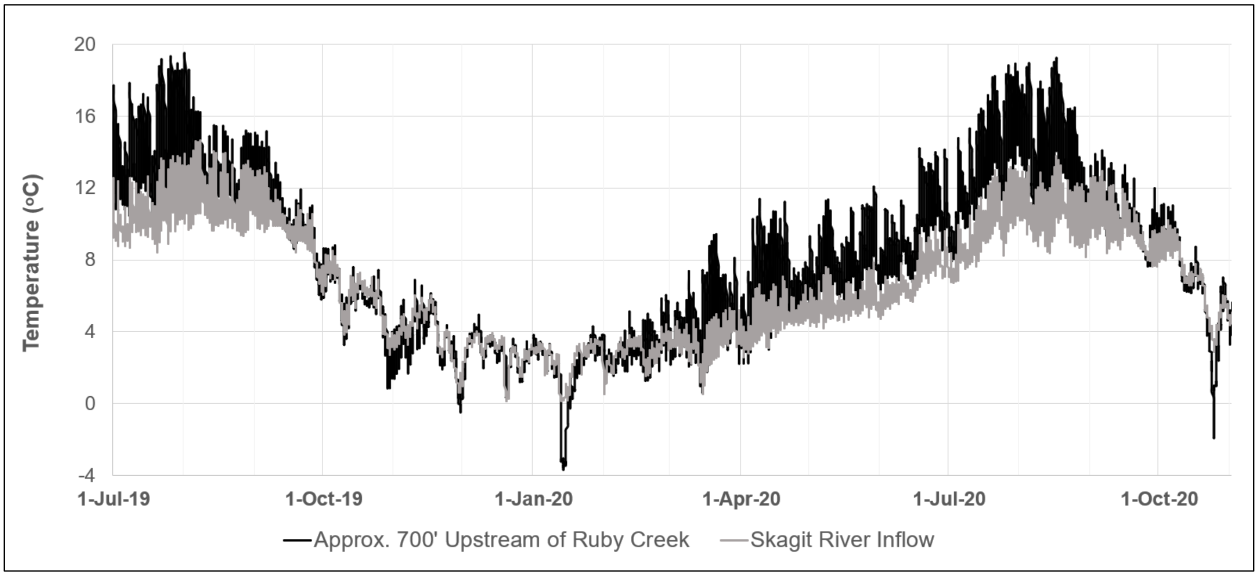


Figure 4.5-9. **Measured temperatures in the inflowing Skagit River (upstream of Ross Lake) and simulated temperatures in the Ross Reach approximately 700 ft upstream of the Skagit River confluence with Ruby Creek.**

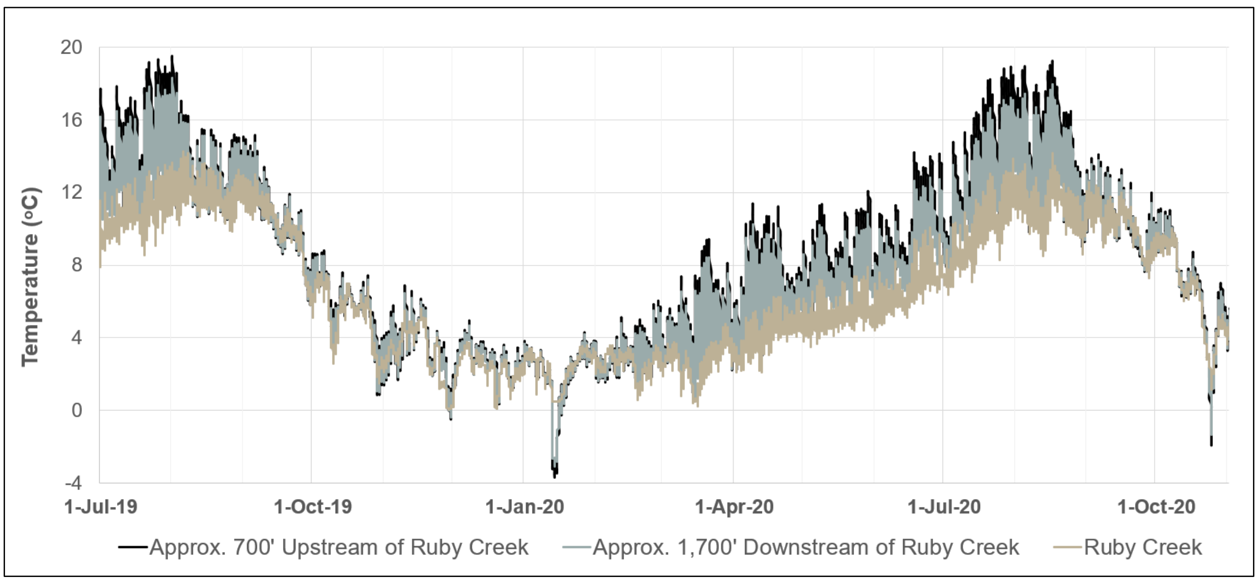


Figure 4.5-10. **Measured temperatures in Ruby Creek and simulated temperatures in the Ross Reach upstream and downstream of the Skagit River confluence with Ruby Creek.**

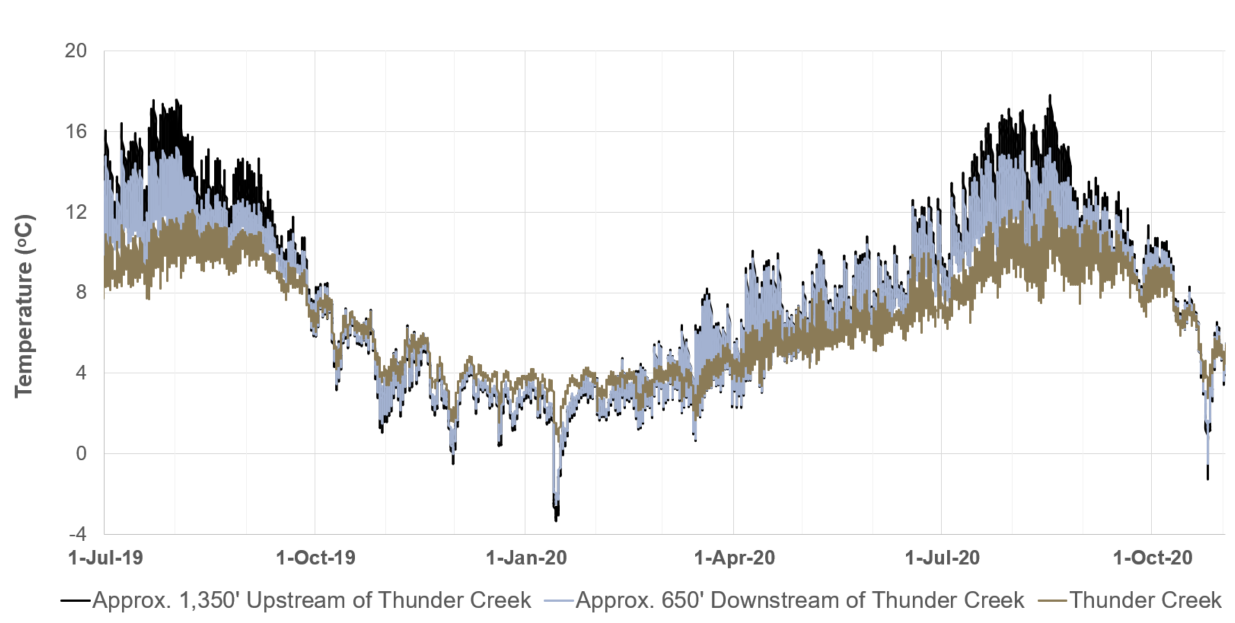


Figure 4.5-11. Measured temperatures in Thunder Creek and simulated temperatures in the Diablo Reach upstream and downstream of the Skagit River confluence with Thunder Creek.

These four comparisons indicate that the temperatures simulated in the Ross and Diablo reaches are reasonable representations of river temperatures that could have occurred Without-Dams on the Skagit River. Variations appear to be driven by meteorological and hydrological forces, not our methods of model development and execution.

5.0 RESULTS

5.1 Sensitivity Analyses

Sensitivity analysis helps identify various sources of uncertainty in a numerical model and their impact on the overall performance of the model. SA studies usually include identifying some key input datasets or model parameters and analyzing the model's response as these are varied in several model runs. The main goal of SA is to characterize the overall uncertainty of a model and identify the most important physical forcings of the system being modeled. Some of the general benefits of SA include:

- Identifying potential deficiencies in model development and underlying assumptions;
- Identifying the parameters or input variables with the strongest impact on the model output, hence the driving physical processes; and
- Understanding the discrepancies between model results and observed data.

It is critical for any SA to recognize the importance of the selected parameters regarding the model objective and the implication of different values for each parameter. In the development of the four hydrodynamic and temperature models, available information regarding each waterbody was used to replicate the study areas and their physical and hydrological characteristics. Some of the input variables were estimated using available data and adjusted based on logical assumptions. For example, the flow and temperature data for some tributaries were unavailable; ungaged tributary flow and temperatures were estimated using data from nearby gaged tributaries (see Section 4.2.4 above). Similar uncertainty also existed for meteorological datasets due to the lack of observed data on or adjacent to Ross, Diablo, or Gorge lakes. Lastly, several model parameters, such as friction coefficients and heat transfer coefficients, were left at the CE-QUAL-W2 default values for some waterbodies (e.g., some parameters varied for reservoirs were not varied for rivers and vice versa), because data did not exist to justify departing from default values. This SA process iteratively varied these parameters. SA simulations 1-8, as described in Table 5.1-1, were performed in series, i.e., outputs from Ross Lake were passed downstream to Diablo Lake, then Gorge Lake, and then the Skagit River. These include all simulations that vary boundary flow or temperature conditions. Other SA simulations were performed in isolation, i.e., upstream input files were external boundary conditions instead of outputs from an upstream model.

Table 5.1-1. SA simulation descriptions.

Simulation	Parameter	% Variation/Fixed Value/Change	Sensitivity Propagated Downstream?
1	Flow rate in input files (tributaries and main stem Skagit)	+20%	Y
2	Flow rate in input files (tributaries and main stem Skagit)	-20%	Y
3	Boundary water temperature	+20%	Y
4	Boundary water temperature	-20%	Y
5	Ratio of spillway to powerhouse flows from April through November	+100%	Y
6	Ratio of spillway to powerhouse flows from April through November	-50%	Y
7	Elevation range of flows at dam powerhouse	Subtract 5 layers from top	Y
8	Elevation range of withdrawal flows at dam powerhouse	Subtract 5 layers from bottom	Y
9	Skagit riverbed roughness coefficient	+20%	N
10	Skagit riverbed roughness coefficient	-20%	N
11	Wind sheltering coefficient	+100%	N
12	Wind sheltering coefficient	-50%	N
13	Wind direction	Rotate by 90 degrees relative to observed (clockwise for Ross and Skagit River, counterclockwise for Diablo and Gorge)	N
14	Sediment temperature	+25%	N
15	Sediment temperature	-25%	N
16	Vegetative shade	Eliminate	N
17	Sediment heat transfer coefficient	Set to 0	N
18	Sediment heat transfer coefficient	Set to 0.5	N
19	Sediment heat transfer coefficient (TSEDF)	Set to 1.0	N
20	Light extinction coefficients: vertical light extinction (EXH20) and shortwave radiation absorption (β)	EXH20 = 0.25, β = 0.63	N
21	Light extinction coefficients: vertical light extinction (EXH20) and shortwave radiation absorption (β)	EXH20 = 1.40, β = 0.50	N
22	Longitudinal eddy diffusivity	0.1 m^2/s	N
23	Longitudinal eddy diffusivity	10 m^2/s	N
24	Longitudinal eddy diffusivity	100 m^2/s [1]	N
25	Longitudinal eddy viscosity	0.1 m^2/s	N
26	Longitudinal eddy viscosity	10 m^2/s	N
27	Longitudinal eddy viscosity	30 m^2/s	N

1 To maintain model stability the longitudinal eddy diffusivity was limited to 40 m^2/s within the Diablo Lake.

Model sensitivity was assessed by calculating mean percentage differences in flow and temperature between SA model output and calibrated model time series. Models were generally considered sensitive to a given parameter if the ratio of the percent difference in flow or temperature relative to the percent variation in the parameter (see Table 5.1-1) exceeded 25 percent. For example, if a 50 percent increase in a specific parameter resulted in a temperature difference greater than 12.5 percent, the model would be considered sensitive to that parameter. Flow and temperature output were observed at each dam's withdrawal structures, and at two downstream Skagit River locations (Marblemount, and upstream of the Sauk River confluence). For temperature, percentage differences were calculated on hourly model output, as well as 7-day average of daily maxima (7DADMax) output, over two distinct time periods: WY 2020 (October 1, 2019 – October 1, 2020), and the peak flow period of 2020 defined as the months of April through November.

5.1.1 Ross Lake

All SA simulations, except those varying bed channel roughness (Simulations 9 and 10) and vegetative shade (Simulation 16), which were assumed to have negligible impact on the reservoir, were performed for Ross Lake. Modeled temperatures were found to be most sensitive to inflow temperatures (Simulations 3 and 4) and wind sheltering (Simulations 11 and 12). Because modeled flows in Ross Lake were determined by the input files described above, flows were unaffected by scenarios other than 1 and 2, those that adjusted input flow volumes.

In Simulations 3 and 4, the 7DADMax withdrawal temperatures at Ross Lake were about equally sensitive to an increase in inflow temperature and decrease in inflow temperature (Figure 5.1-1). A 20 percent increase in inflow temperature resulted in an increase in withdrawal temperatures by an average of 5.8 percent during WY 2020. A 20 percent decrease in inflow temperature resulted in a decrease in withdrawal temperatures by an average of 6.2 percent during WY 2020.

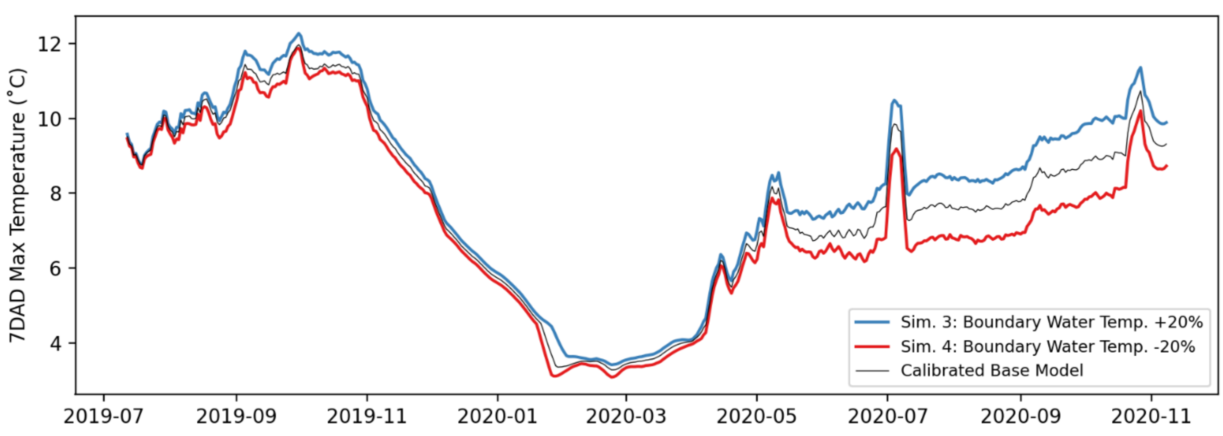


Figure 5.1-1. Impacts of boundary water temperature variation of +/-20 percent on withdrawal temperature at Ross Lake.

In Simulations 11 and 12, increasing the wind sheltering coefficient (i.e., increasing wind magnitude) resulted in greater mixing (Figure 5.1-2). This results in warmer 7DADMax withdrawal temperatures during summer and colder withdrawal temperatures during winter. Decreasing the wind sheltering coefficient resulted in less mixing and colder withdrawal temperature.

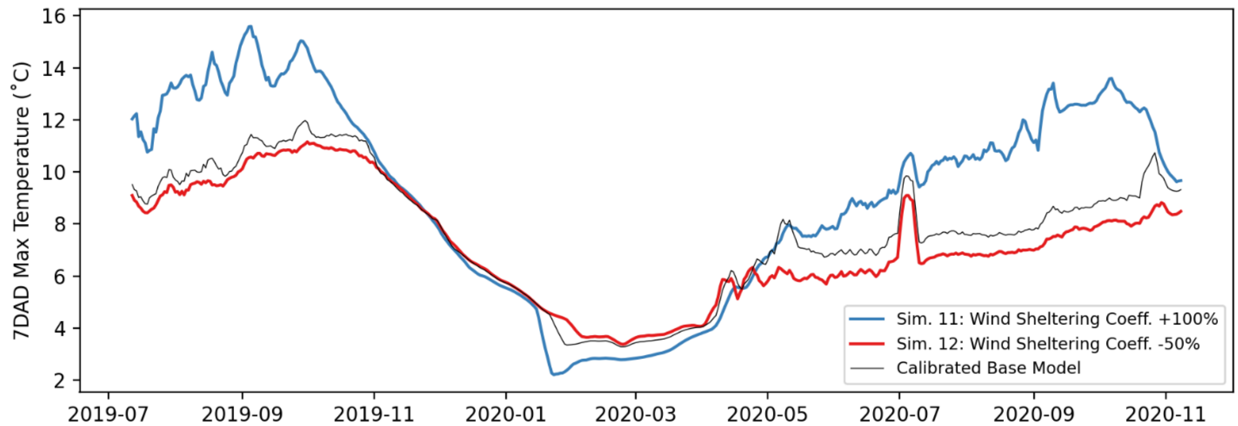


Figure 5.1-2. Impacts of wind sheltering coefficient variation of +100 percent/-50 percent on withdrawal temperatures at Ross Lake.

Ross Lake SA results can be found in Table 5.1-2 and a complete set of figures displaying the results from all the SA simulations can be found in Attachment C.1.

Table 5.1-2. Summary of SA results for Ross Lake (Model considered sensitive to simulations in bold text).

	Percent Difference Relative to Calibrated Base Model Simulation							
	Hourly Water Temperature		**Hourly Outflow**		**7DADMax Temperature**		**7-day Average Daily Mean Flow**	
Simulation	**WY 2020[1]**	**April-Nov 2020**	**WY 2020[1]**	**April-Nov 2020**	**WY 2020[1]**	**April-Nov 2020**	**WY 2020[1]**	**April-Nov 2020**
1	**-0.80**	**0.30**	**18.33**	**18.24**	**-0.52**	**0.49**	**18.18**	**18.18**
2	**-3.37**	**-7.37**	**-22.38**	**-22.33**	**-3.22**	**-7.05**	**-22.22**	**-22.22**
3	**5.79**	**8.27**	**0**	**0**	5.79	8.18	**0**	**0**
4	**-6.20**	**-9.32**	**0**	**0**	-5.95	-8.89	**0**	**0**
5	0	0.09	0	0	-0.02	0.08	0	0
6	**-0.11**	**-0.12**	**0**	**0**	**-0.20**	**-0.24**	**0**	**0**
7	-0.04	-0.06	0	0	-0.07	-0.09	0	0
8	0.04	-0.01	0	0	0.16	-0.03	0	0
9	SA not performed							
10	SA not performed							
11	**11.11**	**21.52**	**0**	**0**	**12.23**	**22.98**	**0**	**0**
12	**-5.20**	**-11.75**	**0**	**0**	**-5.52**	**-11.36**	**0**	**0**
13	**-2.58**	**-5.07**	**0**	**0**	**-1.70**	**-3.52**	**0**	**0**

Simulation	Percent Difference Relative to Calibrated Base Model Simulation							
	Hourly Water Temperature		Hourly Outflow		7DADMax Temperature		7-day Average Daily Mean Flow	
	WY 2020[1]	April-Nov 2020	WY 2020[1]	April-Nov 2020	WY 2020[1]	April-Nov 2020	WY 2020[1]	April-Nov 2020
14	0.45	0.40	0	0	0.45	0.41	0	0
15	-0.52	-0.54	0	0	-0.45	-0.49	0	0
16	SA not performed							
17	-0.52	-0.57	0	0	-0.57	-0.57	0	0
18	-0.24	-0.26	0	0	-0.27	-0.32	0	0
19	Identical inputs to Existing Conditions Simulation							
20	0.46	0.68	0	0	0.48	0.71	0	0
21	-0.49	-0.69	0	0	-0.42	-0.61	0	0
22	**-3.49**	**-5.59**	**0**	**0**	**-3.10**	**-4.83**	**0**	**0**
23	**3.53**	**4.63**	**0**	**0**	**2.72**	**3.35**	**0**	**0**
24	**6.45**	**8.51**	**0**	**0**	**4.89**	**6.13**	**0**	**0**
25	0.21	0.28	0	0	0.33	0.44	0	0
26	**-0.76**	**-1.36**	**0**	**0**	**-1.30**	**-1.92**	**0**	**0**
27	**-0.99**	**-1.99**	**0**	**0**	**-1.69**	**-2.74**	**0**	**0**

1 WY beginning on October 1 of 2019 and ending October 1 of 2020.

5.1.2 Diablo Lake

All SA simulations, except those varying bed channel roughness (Simulations 9 and 10) and vegetative shade (Simulation 16), which were assumed to have negligible impact on the reservoir, were performed for Diablo Lake. Similar to the findings from Ross Lake, model temperatures were found to be most sensitive to modifications of temperatures in input files and adjustments to the wind sheltering coefficients used during calibration, which had the effect of increasing observed wind speeds relative to those from the Marblemount RAWS station (see Section 4.2.8). Like Ross Lake, flows were not significantly affected by scenarios other than 1 and 2, those that varied input tributary flow rates (i.e., volumes).

Simulations 3 and 4 demonstrated that Diablo Lake system is slightly more sensitive to an increased inflow temperature than decreased in inflow temperature (Figure 5.1-3). A 20 percent increase in inflow temperature resulted in an increase in 7DADMax withdrawal temperatures by an average of 7.0 percent during WY 2020. A 20 percent decrease in inflow temperature, however, only resulted in a decrease in 7DADMax withdrawal temperatures by an average of 6.6 percent during WY 2020. Peaks in 7DADMax temperature are attributable to spills from Diablo Dam. Subsequent analyses have indicated that the effects of warmer and cooler water are caused by the elevation of the penstock openings at Diablo Dam, the operational elevation of Diablo Lake, and the thickness of the summertime thermocline in Diablo Lake. Adding warm water to the surface mixed layer can push the thermocline lower and have more of an effect on withdrawal temperatures than adding colder water because the penstock openings of Diablo Dam are located near the bottom of the thermocline in cooler water.

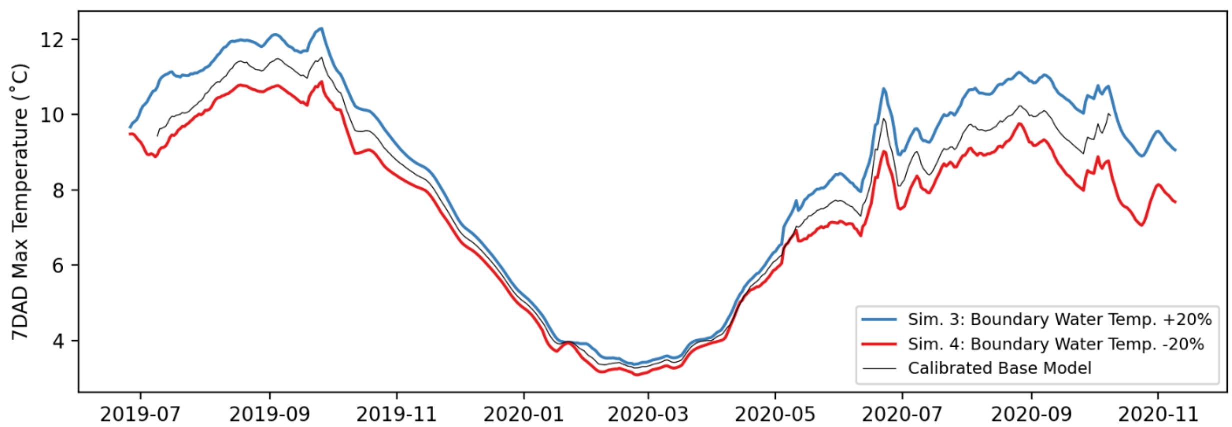


Figure 5.1-3. Impact of boundary temperature variation by +/- 20 percent on withdrawal temperature at Diablo Lake.

During calm periods in Simulations 11 and 12, adjustment to the wind sheltering coefficient had minimal effect on withdrawal temperature (Figure 5.1-4). During a high-wind event, increasing the wind sheltering coefficient results in greater mixing and warmer 7DADMax withdrawal temperature. Decreasing the wind sheltering coefficient results in less mixing and colder 7DADMax withdrawal temperature.

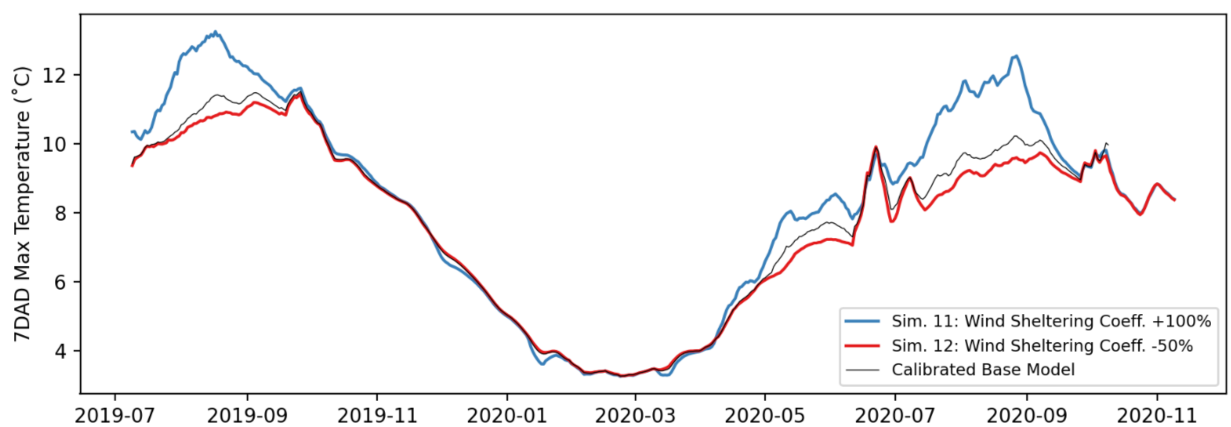


Figure 5.1-4. Impact of wind sheltering coefficient variation by +100 percent/-50 percent on withdrawal temperatures at Diablo Lake.

Diablo Lake SA results can be found in Table 5.1-3, and a complete set of figures displaying the results from all the SA simulations can be found in Attachment C.2.

Table 5.1-3. Summary of SA results for Diablo Lake (Model considered sensitive to simulations in bold text).

Simulation	Percent Difference Relative to Calibrated Base Model Simulation							
	Hourly Water Temperature		Hourly Outflow		7DADMax Temperature		7-day Average Daily Mean Flow	
	WY 2020[1]	April-Nov 2020	WY 2020[1]	April-Nov 2020	WY 2020[1]	April-Nov 2020	WY 2020[1]	April-Nov 2020
1	**0.90**	**2.52**	**17.03**	**16.28**	**0.96**	**2.61**	**18.14**	**16.99**
2	**-0.84**	**-1.29**	**-22.36**	**-21.87**	**-0.06**	**0.01**	**-22.26**	**-21.74**
3	**6.95**	**8.67**	**-0.06**	**-0.22**	**6.62**	**8.36**	**-0.04**	**-0.10**
4	**-6.56**	**-8.27**	**-0.06**	**-0.22**	**-5.68**	**-6.87**	**-0.04**	**-0.10**
5	-0.06	-0.10	0	0	0.14	0.16	0	0.00
6	**-0.22**	**-0.51**	**0**	**0**	**-0.57**	**-1.16**	**0**	**0.00**
7	-0.01	-0.11	0	0	-0.08	-0.23	0	0.00
8	-0.04	-0.08	0	0	0.01	-0.05	0	0.00
9	SA not performed							
10	SA not performed							
11	**3.17**	**5.91**	**0**	**0**	**5.59**	**9.26**	**0**	**0.00**
12	**-1.33**	**-2.38**	**0**	**0**	**-1.99**	**-3.38**	**0**	**0.00**
13	**-0.55**	**-0.89**	**0**	**0**	**-1.00**	**-1.51**	**0**	**0.00**
14	0.05	0.04	0	0	0.10	0.05	0	0.00
15	-0.10	-0.10	0	0	-0.06	-0.10	0	0.00
16	SA not performed							
17	-0.17	-0.17	0	0	-0.12	-0.15	0	0.00
18	-0.11	-0.11	0	0	-0.08	-0.14	0	0.00
19	SA not performed, identical to Existing Conditions Simulation							
20	-0.07	-0.10	0	0	-0.02	-0.07	0	0.00
21	-0.05	-0.07	0	0	-0.06	-0.15	0	0.00
22	-0.08	-0.12	0	0	-0.06	-0.15	0	0.00
23	**1.24**	**1.80**	**0**	**0**	**0.42**	**0.41**	**0**	**0.00**
24	**1.99**	**2.99**	**0**	**0**	**0.59**	**0.63**	**0**	**0.00**
25	0.03	0.06	0	0	0.10	0.11	0	0.01
26	-0.41	-0.51	0	0	-0.43	-0.6	0	0.00
27	-0.44	-0.29	0	0	-0.17	0.03	0	0.00

1 WY beginning on October 1 of 2019 and ending October 1 of 2020.

5.1.3 Gorge Lake

All SA simulations, except those varying bed channel roughness (Simulations 9 and 10), which were assumed to have negligible impact on the reservoir, and setting the sediment heat exchange factor to 1 (Simulation 19), which had a parameter value already being used in the calibrated model, were performed for Gorge Lake. Modeled temperatures were found to be most sensitive to boundary flows and temperatures, with some minor sensitivity to wind sheltering. As modeled flows in Gorge Lake were determined by external boundary conditions, flows were unaffected by scenarios that did not vary boundary flow volumes.

Generally, Gorge Lake temperatures were most sensitive to the temperature of its tributaries and flow from Diablo Lake (Figure 5.1-5); increasing inflow by 20 percent increased Gorge Lake withdrawal temperatures by 31 percent during WY 2020, while decreasing boundary temperatures by 20 percent decreased withdrawal temperatures by 7.5 percent over the same time period. On a smaller timescale, temperatures were also sensitive to the ratio of spillway to powerhouse flows from Diablo Lake, with a greater ratio of spillway flows creating warmer water in the reservoir. Similarly, varying wind sheltering coefficients had the ability to impact temperatures during high wind events with velocities greater than 4 meters per second (Figure 5.1-6). The sensitivity of temperature to wind sheltering confirmed the usefulness of wind data as a calibration parameter. Gorge Lake SA results can be found in Table 5.1-4; a complete set of figures displaying these results can be found in Attachment C.3 (flow figures were excluded because they did not show significant variation from the calibrated model, apart from simulations that directly varied boundary flows).

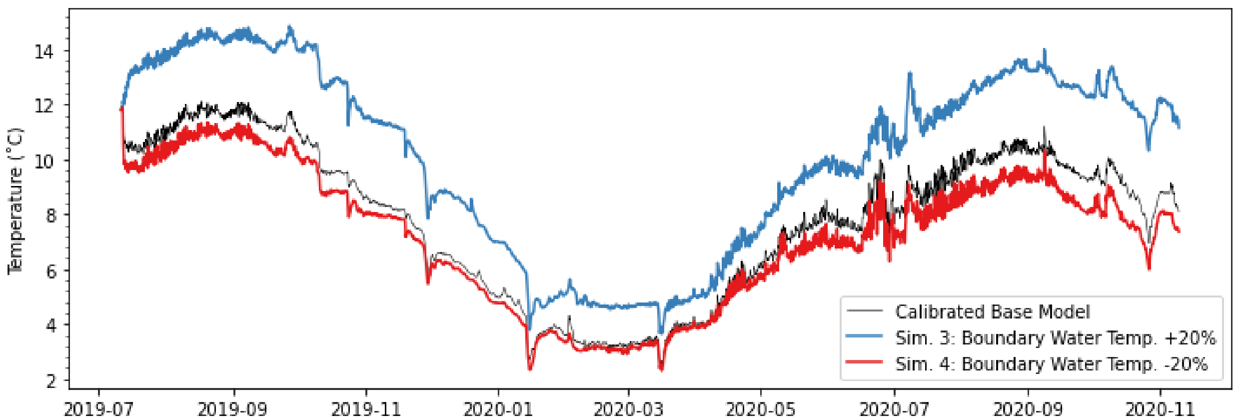


Figure 5.1-5. Impact of boundary temperature variation by +/- 20 percent on withdrawal temperatures at Gorge Lake.

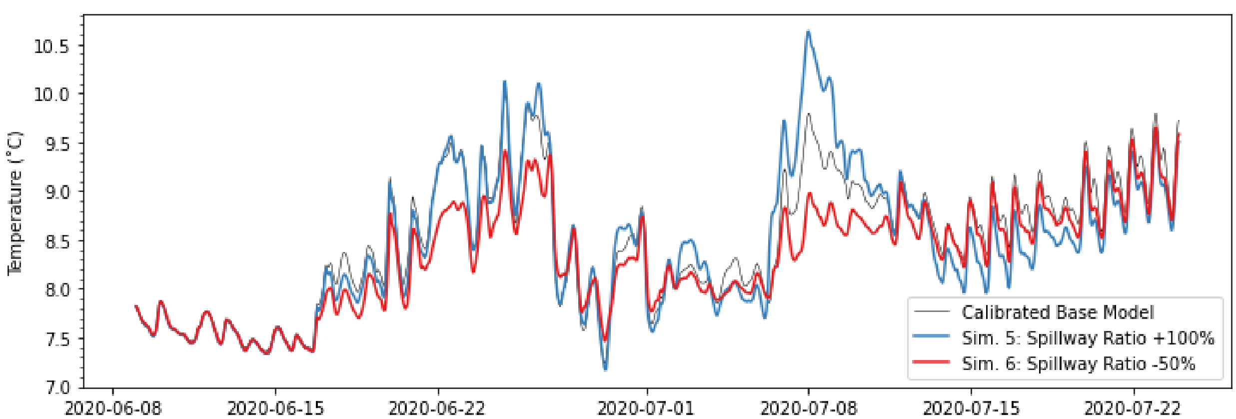


Figure 5.1-6. Impact of spillway-powerhouse flow ratio variation by +100 percent/-50 percent on withdrawal temperatures at Gorge Lake during summer 2020.

Table 5.1-4. Summary of temperature SA results from Gorge Lake (Model considered sensitive to simulations in bold text).

Simulation	Percent Difference Relative to Calibrated Base Model Simulation							
	Hourly Water Temperature		Hourly Outflow		7DADMax Temperature		7-day Average Daily Mean Flow	
	WY 2020[1]	April-Nov 2020	WY 2020[1]	April-Nov 2020	WY 2020[1]	April-Nov 2020	WY 2020[1]	April-Nov 2020
1	**-0.7**	**1.6**	**20**	**20**	**0.0**	**1.3**	**20**	**20**
2	**-0.4**	**-1.2**	**-20**	**-20**	**-0.2**	**-0.5**	**-20**	**-20**
3	**31.3**	**28.5**	**0**	**0**	**29.8**	**27.6**	**0**	**0**
4	**-7.5**	**-9.4**	**0**	**0**	**-7.4**	**-8.0**	**0**	**0**
5	-0.2	-0.5	0	0	-0.1	-0.4	0	0
6	-0.3	-0.9	0	0	-0.4	-0.7	0	0
7	-0.1	-0.7	0	0	-0.2	-0.6	0	0
8	-0.1	-0.6	0	0	-0.1	-0.3	0	0
9	SA not performed							
10	SA not performed							
11	**-0.6**	**0.9**	**0**	**0**	**1.1**	**2.1**	**0**	**0**
12	**0.2**	**-0.3**	**0**	**0**	**-0.5**	**-1.0**	**0**	**0**
13	0	0	0	0	-0.2	-0.3	0	0
14	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0
16	0.1	0.1	0	0	0.2	0.1	0	0
17	-0.2	-0.2	0	0	-0.2	-0.3	0	0
18	-0.1	-0.1	0	0	-0.1	-0.2	0	0
19	SA not performed							
20	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0
22	0	0	0	0	0.1	0.1	0	0
23	0.1	0.1	0	0	-0.4	-0.5	0	0
24	0.1	0.2	0	0	-0.5	-0.7	0	0
25	0	0	0	0	0	0	0	0
26	0	0	0	0	-0.2	-0.3	0	0
27	0	0	0	0	-0.4	-0.5	0	0

1 WY beginning on October 1 of 2019 and ending October 1 of 2020.

5.1.4 Skagit River between Newhalem and PRM 54.6

All 27 SA simulations were performed for the Skagit River model. Model temperatures were found to be most sensitive to boundary flows and temperatures, with some minor sensitivity to wind sheltering. Outside of the simulations that varied boundary flows, modeled flows in the Skagit River were not found to be significantly sensitive to variations in other model parameters. While SA results were calculated at model segments near Marblemount and upstream of the Sauk River confluence, results were not found to be significantly different at the two locations. For this reason, only results from the location upstream of the Sauk River are shown.

Generally, Skagit River temperatures were most sensitive to the temperatures of its tributaries and flow from Gorge Lake (Figure 5.1-7). On a smaller timescale, temperatures were also sensitive to the ratio of spillway to powerhouse flows from Gorge Lake, with a greater ratio of spillway flows creating warmer water in the river during summer, when the reservoir temperatures are slightly non-isothermal (Figure 5.1-8). Similarly, varying wind sheltering coefficients impacted temperatures, with higher coefficients causing lower temperatures during high wind events (Figure 5.1-9). These event-specific variations were not as large as those observed in the upstream lakes. Skagit River SA results can be found in Table 5.1-5; a complete set of figures displaying these results can be found in Attachment C.4 (flow figures were excluded because they did not show significant variation from the calibrated model, apart from simulations that directly varied boundary flows).

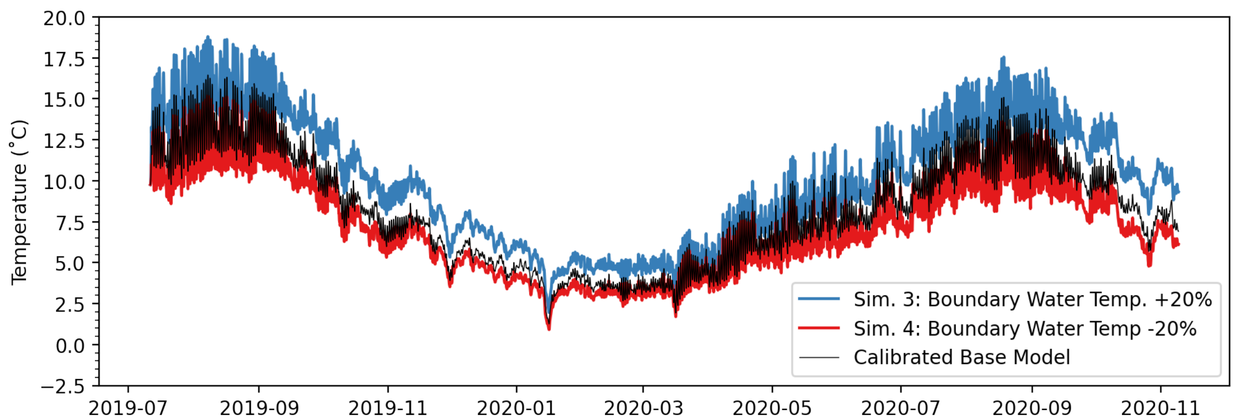


Figure 5.1-7. Impact of boundary temperature variation by +/- 20 percent on Skagit River temperatures upstream of the Sauk River confluence.

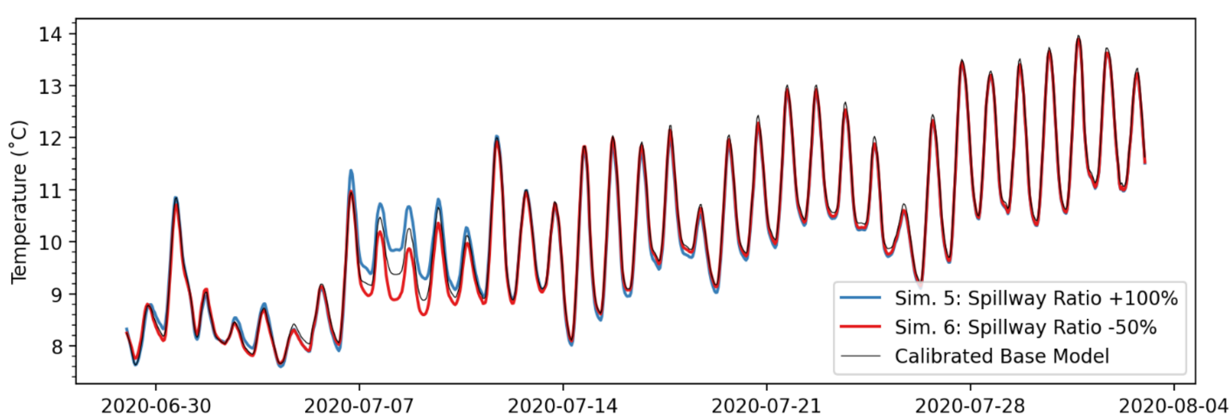


Figure 5.1-8. Impact of spillway-powerhouse flow ratio variation by +100 percent/-50 percent on Skagit River temperatures upstream of the Sauk River confluence.

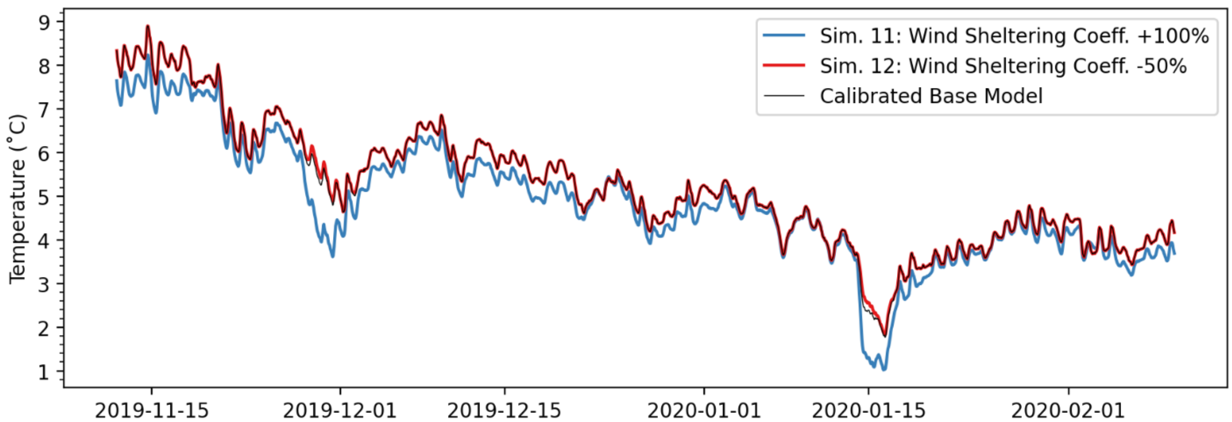


Figure 5.1-9. Impact of wind sheltering coefficient variation by +100 percent/-50 percent on Skagit River temperatures upstream of the Sauk River confluence.

Table 5.1-5. Summary of temperature SA results from the Skagit River upstream of the Sauk River confluence (Model considered sensitive to simulations in bold text).

Simulation	Percent Difference Relative to Calibrated Base Model Simulation							
	Hourly Water Temperature		Hourly Outflow		7DADMax Temperature		7-day Average Daily Mean Flow	
	WY 2020[1]	April-Nov 2020	WY 2020[1]	April-Nov 2020	WY 2020[1]	April-Nov 2020	WY 2020[1]	April-Nov 2020
1	**7.8**	**8.5**	**20**	**20**	**6.7**	**7.1**	**20**	**20**
2	**0**	**0.4**	**-20**	**-20**	**0.8**	**1.3**	**-20**	**-20**
3	**24.8**	**22.1**	**0**	**0**	**22.5**	**20**	**0**	**0**
4	**-12**	**-12.8**	**0**	**0**	**-11**	**-11.7**	**0**	**0**
5	-0.1	-0.2	0	0	0	-0.2	0	0
6	-0.1	-0.4	0	0	-0.1	-0.4	0	0
7	0	-0.4	0	0	0	-0.3	0	0
8	0	-0.3	0	0	0	-0.3	0	0
9	0	0	0	0	-0.9	-0.8	0	0
10	**-0.1**	**-0.3**	**0**	**0**	**1**	**1**	**0**	**0**
11	**-4.6**	**-3**	**-0.9**	**-1**	**-3.8**	**-2.4**	**-1**	**-1**
12	0.1	0	0	0	0	-0.1	0	0
13	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0
16	0.7	0.6	0	0	1.5	1.3	0	0
17	-0.9	-1.1	0	0	-1.9	-2.3	0	0
18	-0.3	-0.4	0	0	-0.7	-0.8	0	0
19	0.3	0.4	0	0	0.7	0.8	0	0
20	0	0	0	0	0	0.1	0	0

Simulation	Percent Difference Relative to Calibrated Base Model Simulation							
	Hourly Water Temperature		Hourly Outflow		7DADMax Temperature		7-day Average Daily Mean Flow	
	WY 2020[1]	April-Nov 2020	WY 2020[1]	April-Nov 2020	WY 2020[1]	April-Nov 2020	WY 2020[1]	April-Nov 2020
21	0.2	0.3	0	0	0.5	0.7	0	0
22	0	0	0	0	0	0	0	0
23	0	-0.1	0	0	0	-0.1	0	0
24	0.1	-0.7	0	0	-0.2	-1.1	0	0
25	0	0	0	0	0	0	0	0
26	0.1	0.3	2.3	1.9	-0.1	0.1	0.3	0.3
27	0.1	0.3	2.3	1.8	-0.1	0.1	0.3	0.3

1 WY beginning on October 1 of 2019 and ending October 1 of 2020.

5.2 Existing Conditions Characterization

The calibrated models were used to simulate existing conditions in the Project reservoirs and the Skagit River downstream. In this "Existing Conditions simulation," the time series representing the upstream flow and temperature input to the Diablo Lake model, Gorge Lake model, and Skagit River model downstream of Gorge Dam were created from the output of the model upstream. This differs from the models used to establish and evaluate calibration (described in Section 4.3), which used monitoring data as upstream inputs and were run in isolation from each other. The Existing Conditions simulations in Ross Lake will therefore be the same as the calibrated model, but all downstream models will differ because all upstream errors due to imperfect calibration will propagate downstream. The Existing Conditions simulation will be used as the basis for comparison for future model scenarios, where potential changes in inflow hydrology to Ross Lake or management of Ross Dam will lead to new model output that will be passed downstream to the Diablo Lake, Gorge Lake, and Skagit River models.

The subsections below show examples of the 7DADMax temperature in outflows from the dams and key locations of the river. These allow for an evaluation of the performance of scenarios relative to regulatory criteria or other objectives. Additionally, cross-sectional contour plots in the reservoirs provide a characterization of temperature across geographical locations and depths at a single time. These allow comparison of spatial changes that may occur in modeled management scenarios.

5.2.1 Applicable Numeric Water Quality Standards

Applicable numeric criteria for temperature from Ecology are shown in Table 5.2-1.

Table 5.2-1. Temperature criteria

Use or Location	Measurement	Timing	Numeric Criteria
Char Spawning and Rearing	7DADMax	All year	12°C (53.6°F)
Salmon and trout spawning	7DADMax	Sept. 1 to June 15	13°C (55.4°F)
Core summer salmonid habitat	7DADMax	June 16 to Aug. 31	16°C (60.8°F)
Gorge bypass reach	One-day maximum (1DMax)	All year	Human activities may not increase temperature above 21°C. When natural conditions exceed a 1DMax of 21°C, no temperature increase will be allowed that will raise the receiving water temperature by greater than 0.3°C, nor shall such temperature increases, at any time, exceed $t = 34/(T + 9)$.
Lakes and reservoirs[1]	7DADMax[2]	All year	No more than 0.3°C (0.54°F) above natural conditions.

1 This criterion applies only to Ross Lake. Diablo and Gorge lakes are regulated as rivers under these temperature criteria.
2 WAC 173-201A-200(1)(c)(vi) provides that temperature measurements should be taken to represent the “dominant aquatic habitat” of the monitoring site, which would not include the reservoir’s surface.

5.2.2 Ross Lake

The 7DADMax of modeled Ross Dam releases peaked in October (Figure 5.2-1). This is likely explained by a combination of warmer water remaining in the reservoir following summer heating and the deepening of the thermocline due to vertical mixing in autumn, which brings warmer surface water closer to the depth of the penstocks. Unsurprisingly, dam releases were coolest in mid-winter. A spill event in July 2020 increased the temperature of dam releases notably; other brief spills did not, either due to spillway flow volumes being negligible compared to powerhouse flow volumes (observed in June 2020), or due to the deepening of the thermocline in autumn (observed in October 2020).

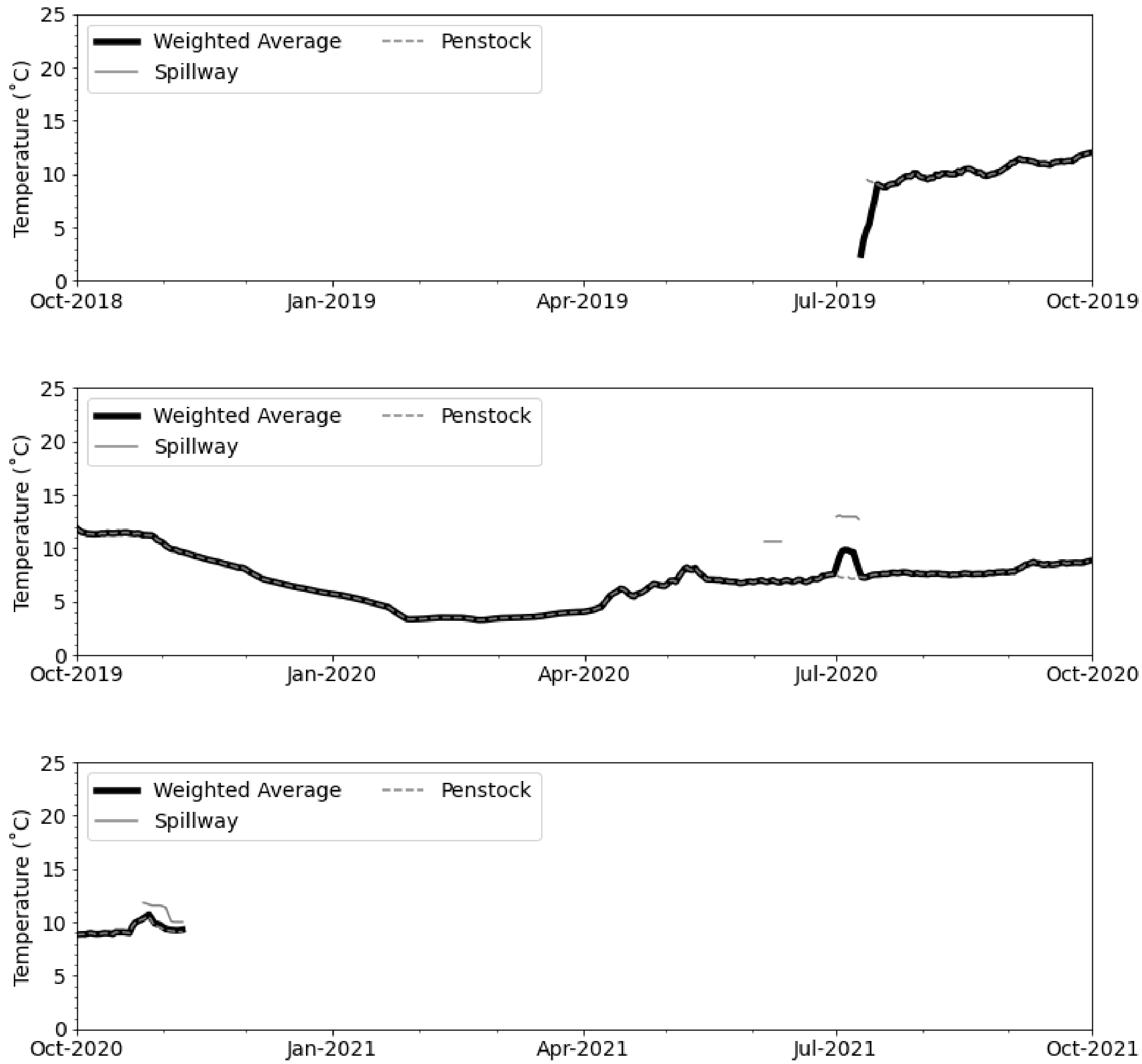
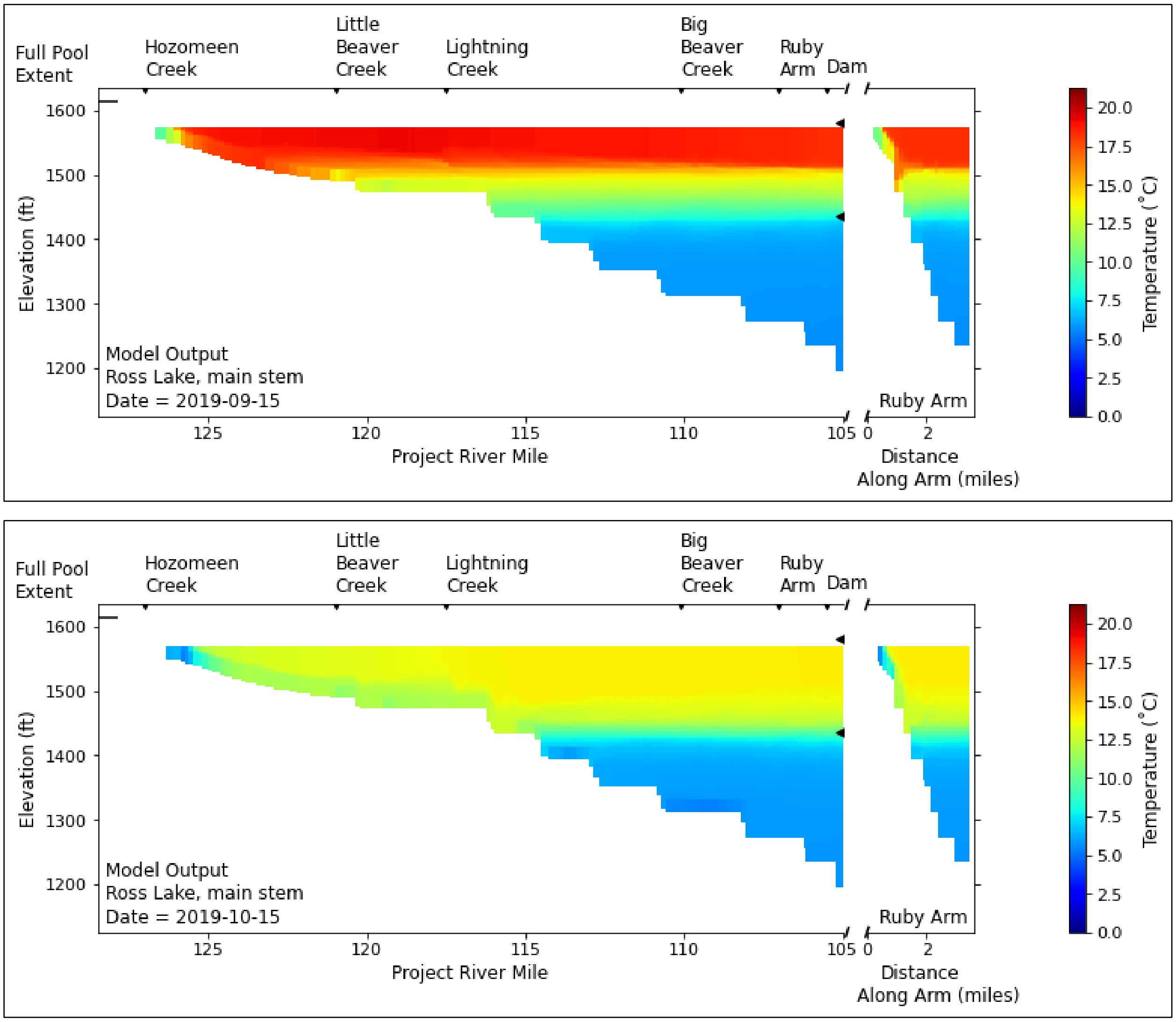


Figure 5.2-1. 7DADMax temperatures of simulated dam releases from Ross Dam.

Consistent with monitoring data, contour plots of simulated temperatures in Ross Lake show pronounced summer stratification and fall overturn in September and October, respectively (Figure 5.2-2). Contour plots of other simulated months depict isothermal winter conditions, the entry of warming river water as an overflow into the reservoir with lowered water level in spring, and surface heating due to solar radiation in early and mid-summer (Attachment D.1).



Note: The Skagit River inflow is at the upper left of each image, and Ross Dam is near River Mile 105. Farthest right is a depiction of Ruby Arm, in which Ruby Creek enters at Mile 0 and discharges at the right side of each panel where Ruby Arm connects to the mainstem of Ross Lake, near River Mile 107. Other notable tributaries are included at the top of each panel to aid geographic orientation. Black arrows indicate the depths of spillway and penstock withdrawals from the reservoir.

Figure 5.2-2. Modeled temperature in September (upper panel) and October (lower panel) 2019 in Ross Lake. Flow is from left to right.

5.2.3 Diablo Lake

The 7DADMax of temperatures of modeled Diablo Dam releases were generally similar to those of Ross Dam (Figure 5.2-3). These time series and similar ones at 25 ft depth in the dam forebay do not exceed 16°C in the summer. Although the spillway of Diablo Dam is used more frequently than that of Ross Dam, the temperature of surface water and mid-depth water are frequently similar in Diablo Lake, with a maximum difference occurring in September (e.g., Figure 5.2-4; other months appear in Attachment D). Consequently, spillway usage rarely causes the temperature of water released from Diablo Dam to deviate notably from the temperature of the water passing through the penstocks, especially when evaluated over a 7-day averaging period. As at Ross Dam, the spillway event in July 2020 moved enough warmer surface water to create a temporary increase in temperatures released from Diablo Dam.

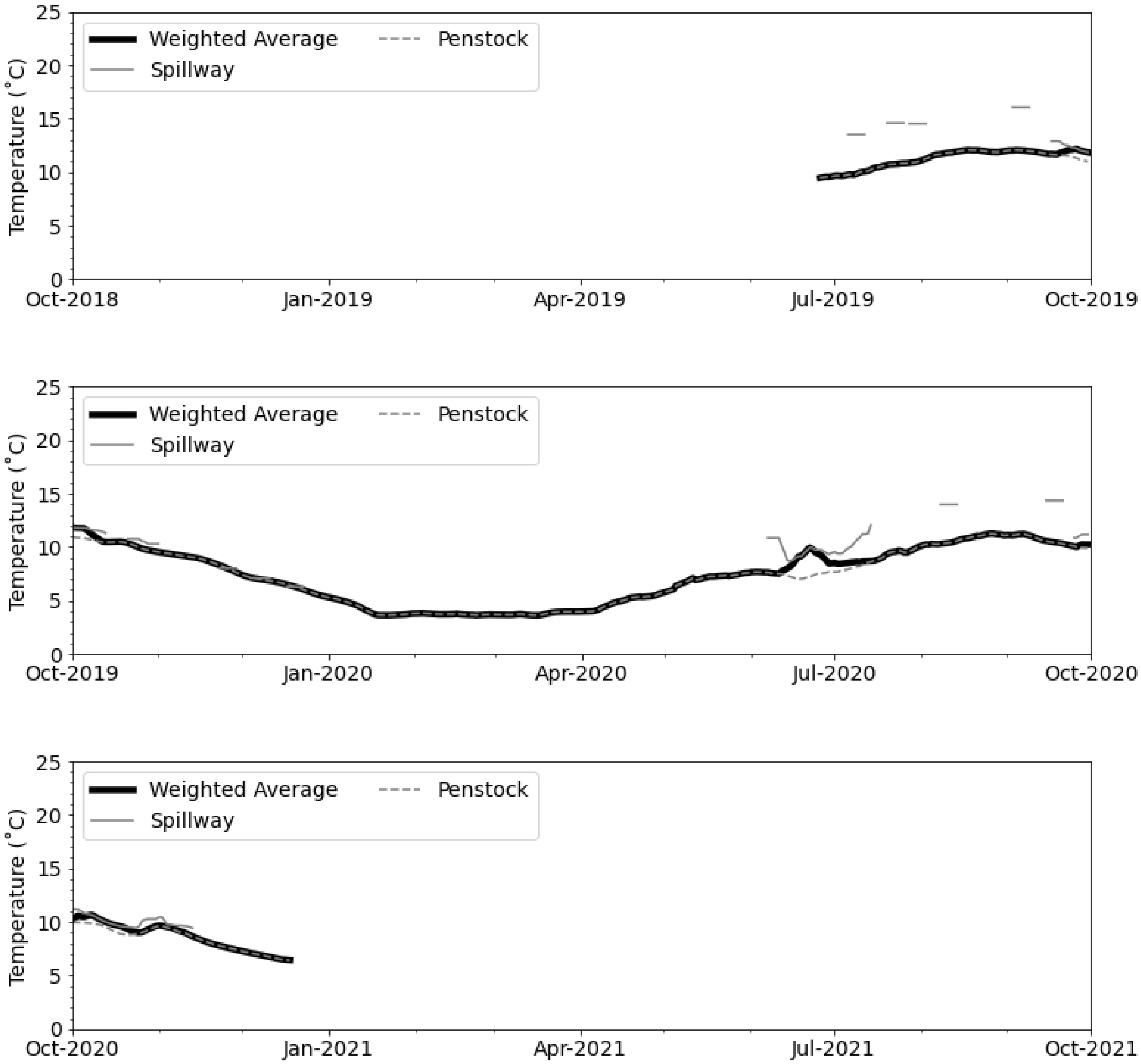
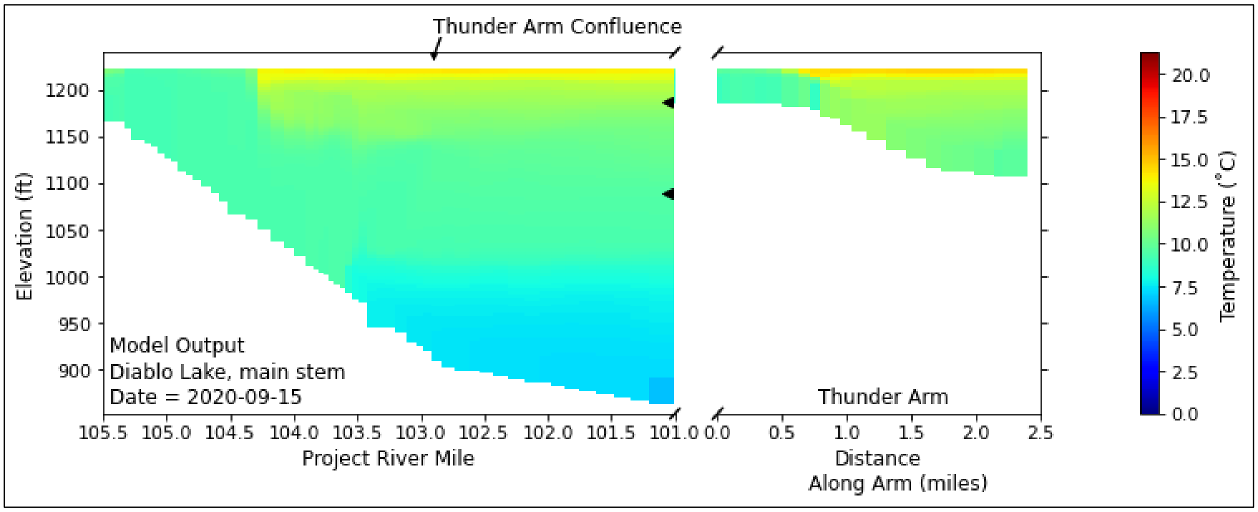


Figure 5.2-3. 7DADMax temperatures of simulated dam releases from Diablo Dam.



Note: Flow is from left to right. The Ross Dam releases enter Diablo Lake at the left of the image and Diablo Dam is near the center of the image near River Mile 101. To the right is a depiction of Thunder Arm, in which Thunder Creek enters at Mile 0 and discharges at the right side of the image where Thunder Arm connects to the mainstem of Diablo Lake, near River Mile 103. Black arrows indicate the depths of spillway and penstock withdrawals from the reservoir.

Figure 5.2-4. Modeled temperature in September 2020 in Diablo Lake.

5.2.4 Gorge Lake

The 7DADMax of Gorge Dam releases resemble Diablo Dam releases closely, and spill had a minimal influence on the average temperature (Figure 5.2-5). The maximum 7DADMax from Gorge Dam was 12.0°C, which is 4.0°C lower than the numeric temperature criteria threshold of 16.0°C meaning that Gorge Lake easily meets the applicable water quality criteria. This occurs because Gorge Lake is usually isothermal with only a minor thermal gradient in simulated reservoir temperatures in August, a month when surface water temperatures are expected to be highest (Figure 5.2-6). Nonetheless, the deep penstock intakes send cooler water downstream even when the surface water has warmed relative to deep water.

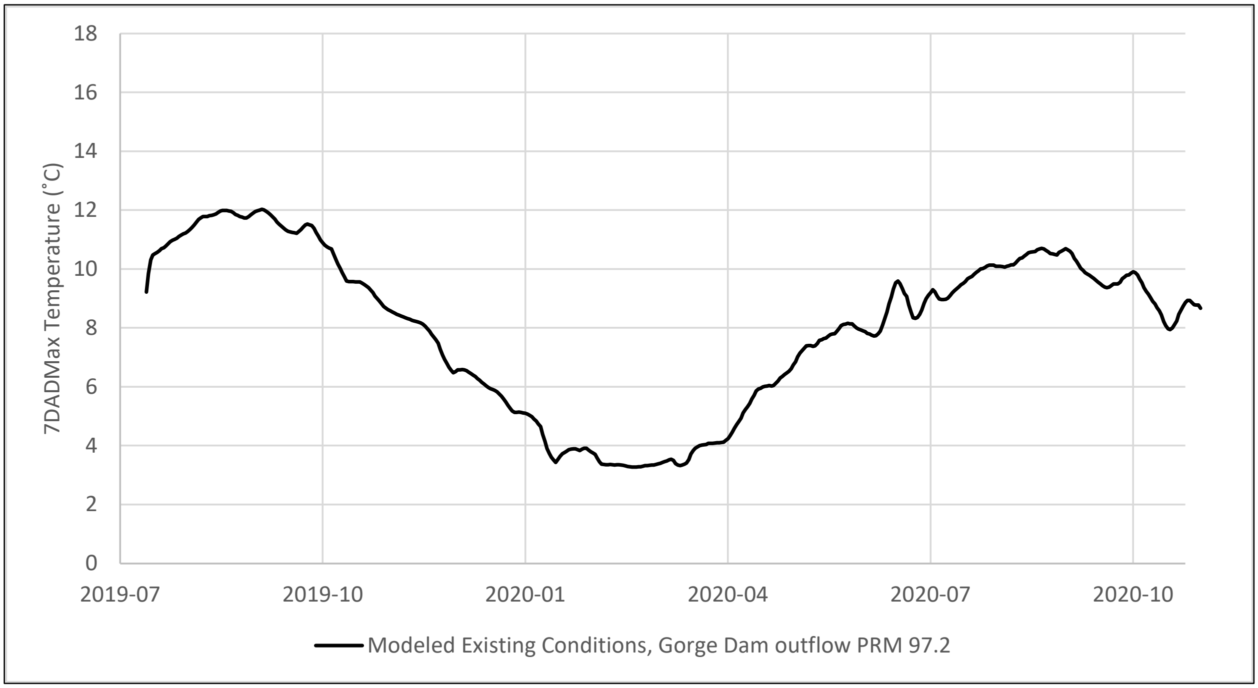
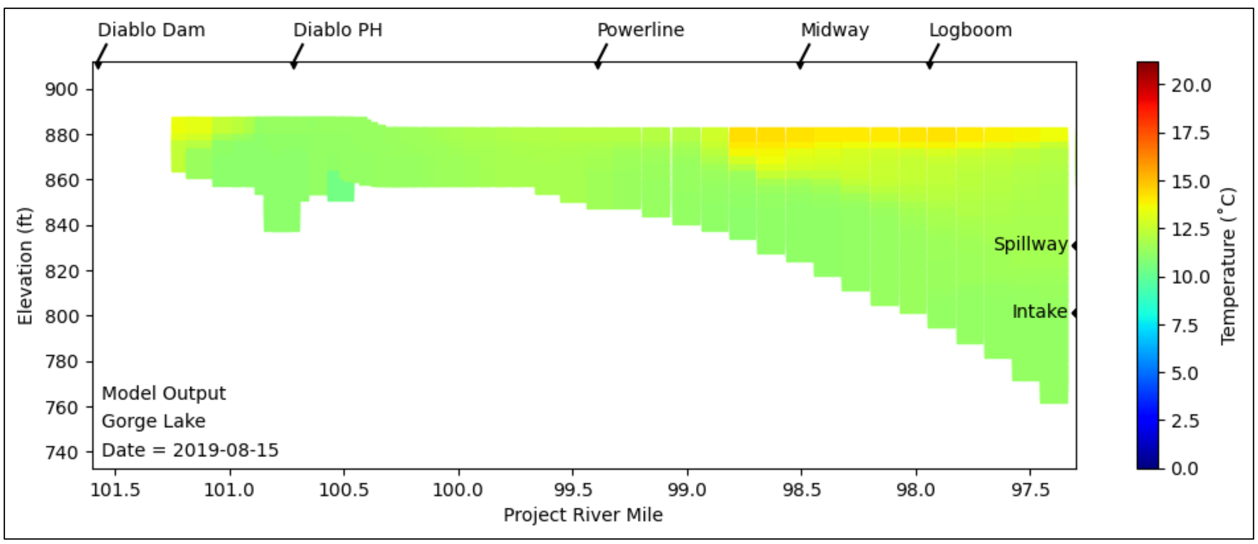


Figure 5.2-5. 7DADMax temperatures of simulated dam releases from Gorge Dam outflow PRM 97.2.



Note: Flow is from left to right. The Diablo Dam releases enter Gorge Lake at the left of the image and Gorge Dam is at right. Black lines indicate the depths of spillway and penstock intakes.

Figure 5.2-6. Modeled temperature on August 15, 2020 in Gorge Lake.

5.2.5 Gorge Bypass Reach

Except during spill events at Gorge Dam (typically fewer than 10 per year), flow in the Gorge bypass reach is limited to accretion, spill-gate seepage, tributary input (including Afternoon Creek), and precipitation runoff. Spills account for less than 5 percent of the annual hydrograph in the Gorge bypass reach.

Existing conditions in the Gorge bypass reach were evaluated based on the temperatures of specified spill releases simulated using the Gorge Lake model. There were five spills from Gorge Dam during the existing conditions simulation period of July 2019 through November 2020. The maximum temperatures simulated from each of the five spills are listed in Table 5.2-2; the highest temperature is 11.3°C, Spill temperature data from Gorge Dam were not available, so the spill temperatures should be considered non-calibrated.

Table 5.2-2. Maximum simulated temperatures of five Gorge Dam spill releases between July 2019 and November 2020.

Spill Event	Max Temperature of Spill Release (°C)
August 2019	11.3
February 2020	4.3
June 2020	10.0
October 2020	8.8
November 2020	9.3

5.2.6 Skagit River between Newhalem and PRM 54.6

Stream temperature dynamics in the Skagit River downstream of Newhalem are much different than those in the reservoirs. Figure 5.2-7 presents simulated 7DADMax temperatures for seven Skagit River model segments located between Gorge Powerhouse and Concrete, for the existing conditions simulation period beginning in July 2019 and extending through October 2020. The plot presents data from five model segments located between Gorge Dam at PRM 97.2 and a station on the upstream side of the Sauk River confluence at PRM 69.3, two Skagit River locations downstream of the Sauk River confluence at PRM 64.5 and at the Concrete-Sauk Valley Road Bridge below the Baker River. The figure shows a clear warming trend in the downstream direction below the Gorge Dam outflow during the summer months, and a mild cooling trend in the same direction through late fall into January. Included in Figure 5.2-7 is an orange line showing Ecology's 13°C salmon and trout spawning criterion and the core summer salmonid habitat criterion of 16°C (for their respective periods of applicability).

The same trends in the river temperatures that are evident in the simulated Existing Conditions simulation model output can also be seen using observed temperature data that are available within the model domain and also downstream beyond PRM 54.6. Figure 5.2-8 provides a similar comparison of Skagit River 7DADMax temperatures using temperature data collected by the USGS at Newhalem (PRM 94.2), Marblemount (PRM 79.0), and Mount Vernon (PRM 17). The PRM 94.2 and 79.0 show a similar timing of seasonal changes in stream temperature which is a confirmation of the model's performance. Also, the addition of data from Mount Vernon shows that the summer season warming trend exhibited through the study reach also continues downstream. Significantly more exceedances of both the 13 and 16°C Ecology criteria are evident at Mount Vernon in the plot.

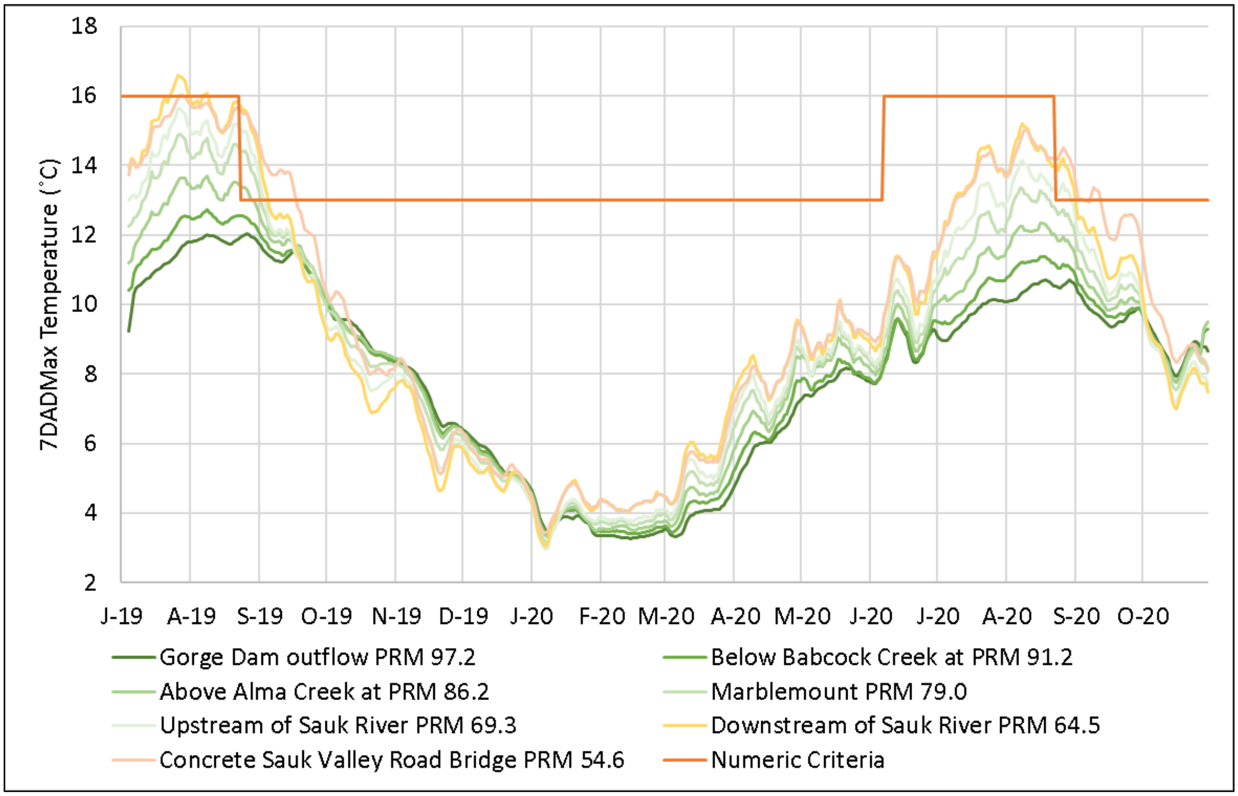


Figure 5.2-7. July 2019 through October 2020 simulated 7DADMax temperatures from five locations between upstream of the Sauk River confluence at PRM 69.3 (green lines), two Skagit River locations downstream of the Sauk River confluence (orange/yellow lines).

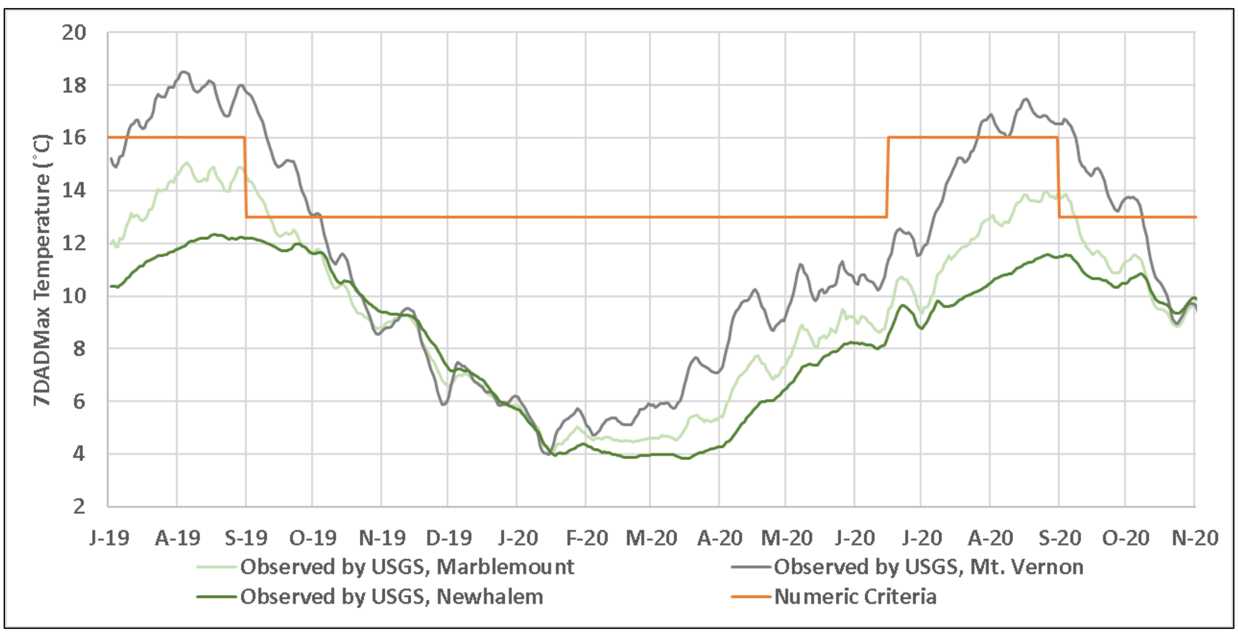


Figure 5.2-8. July 2019 through October 2020 observed 7DADMax temperatures from three USGS monitoring locations at Newhalem PRM 94.2 (dark green), Marblemount PRM 79.0 (light green), and Mount Vernon PRM 17.0 (grey).

Table 5.2-3, a summary of the simulated stream temperatures as they relate to the Ecology temperature criteria, includes the metrics average 7DADMax, maximum 7DADMax, and a count of the number of days the numeric temperature criteria are exceeded. The 16°C criterion was only exceeded in 2019 and only at two stations downstream of the Sauk River (PRM 64.5). The 13°C criterion was exceeded more frequently in the late summer months of both 2019 and 2020, but only downstream of PRM 86.2 near Alma Creek.

Table 5.2-3. Summary of simulated Skagit River 7DADMax temperatures at seven model segments between Gorge Dam and the Concrete-Sauk Valley Road Bridge at PRM 54.6, July 2019 to October 2020, with comparison to numeric water quality criteria.

Location	PRM	Reach Length (Miles)	Count of Days Numeric Criteria 7DADMax Limit Exceeded				Maximum 7DADMax Value				Average 7DADMax			
			16°C		13°C		16°C		13°C		16°C		13°C	
			June 16-Aug. 31		Sept. 1-June 15		June 16-Aug. 31		Sept.1-June 15		June 16-Aug. 31		Sept.1-June 15	
			2019[2]	2020	2019	2020[3]	2019[2]	2020	2019	2020[3]	2019[2]	2020	2019	2020[3]
Gorge Dam outflow	97.2	-	0	0	0	0	12.0	10.7	12.0	10.7	11.4	9.6	8.8	6.2
Below Babcock Creek	91.2	6	0	0	0	0	12.7	11.4	12.5	11.1	12.0	10.1	8.8	6.3
Above Alma Creek	86.2	5	0	0	5[1]	0	13.7	12.3	13.4	11.9	13.0	10.7	8.9	6.6
Marblemount	79	7.2	0	0	9[1]	0	14.9	13.3	14.4	12.7	14.0	11.5	8.8	6.8
Upstream of Sauk River	69.3	9.7	0	0	11[1]	7	15.6	14.1	15.0	13.5	14.6	12.0	8.6	7.0
Downstream of Sauk River	64.5	4.8	11	0	13	9	16.6	15.2	15.7	14.2	15.5	12.9	8.5	7.4
Concrete Sauk Valley Road Bridge[4]	54.6	9.9	2	0	25	16	16.0	15.0	15.6	14.5	15.2	12.9	9.2	7.6

1 Continuously recorded empirical temperature data collected in 2021-2022 showed no exceedances of the 13°C criterion at these locations (FA-01a WQ Monitoring Study, City Light 2023a).

2 The existing conditions simulation began on July 10, the period between June 16 and July 9, 2019 is not included in the calendar year 2019 totals.

3 The existing conditions simulation ended on November 11, 2020, the period between November 12 and August 31, 2020 is not included in the calendar year 2020 totals.

4 All temperature criteria exceedances simulated at PRM 54.6 under the Existing Conditions simulation occur at times when observed temperature data is available and used as the model input time-series to define Baker River stream temperatures. Observed Baker River temperature data is available June 15, 2019 – September 30, 2019, and June 18, 2020 – September 30, 2020.

The temperature dynamics within the reach begin exhibiting a more variable thermal signature that is driven by the heat budget processes dominating the riverine system rather than those of the upstream reservoirs. During the summer months, both the average and maximum seasonal 7DADMax values increase as water moves downriver (Figure 5.2-7). Simulated summer (June 16-August 31) 7DADMax values increase with distance downstream to the Concrete-Sauk Valley Road Bridge (PRM 54) (Table 5.2-3), and the rate of change is generally higher upstream of Marblemount (Table 5.2-4 and Figure 5.2-9). The only exception being the reach between PRM 91.2 and 86.2 where the longitudinal rate of 7DADMax increase (rate of 0.19°C per mile) is higher than it is in the upstream reach between PRM 97.2 and PRM 91.2 (rate of 0.12°C per mile). The higher rate within the reach between PRM 91.2 and PRM 86.2 may be due to the steeper slope relative to other reaches, which causes more turbulence, and which may increase heat exchange with the atmosphere. The outputs do not show a clear relationship between the rate of longitudinal increase in 7DADMax value and PRM during winter.

Table 5.2-4. Longitudinal rate of seasonal maximum 7DADMax value increase between Skagit River model segments.

Reach PRMs	Landmark	Reach Length (Miles)	7DADMax Increase between Segments (°C) [1]		Longitudinal Rate of 7DADMax Increase (°C per mile)	
			June 16 - Aug. 31	Sept. 1 – June 15	June 16 - Aug. 31	Sept. 1 – June 15
97.2 to 91.2	Below Newhalem	6	0.7	0.5	0.12	0.08
91.2 to 86.2	Below Babcock Creek	5	1.0	0.9	0.19	0.17
86.2 to 79.0	Below Alma Creek	7.2	1.2	1.0	0.08	0.14
79.0 to 69.3	Below Marblemount	9.7	0.7	0.6	0.05	0.06
69.3 to 64.5	Sauk River	4.8	1.0	0.6	0.06	0.13
64.5 to 54.6	Above Concrete	9.9	-0.6	-0.1	-0.04	0.01

1 Positive values indicate a 7DADMax increase in the downstream direction.

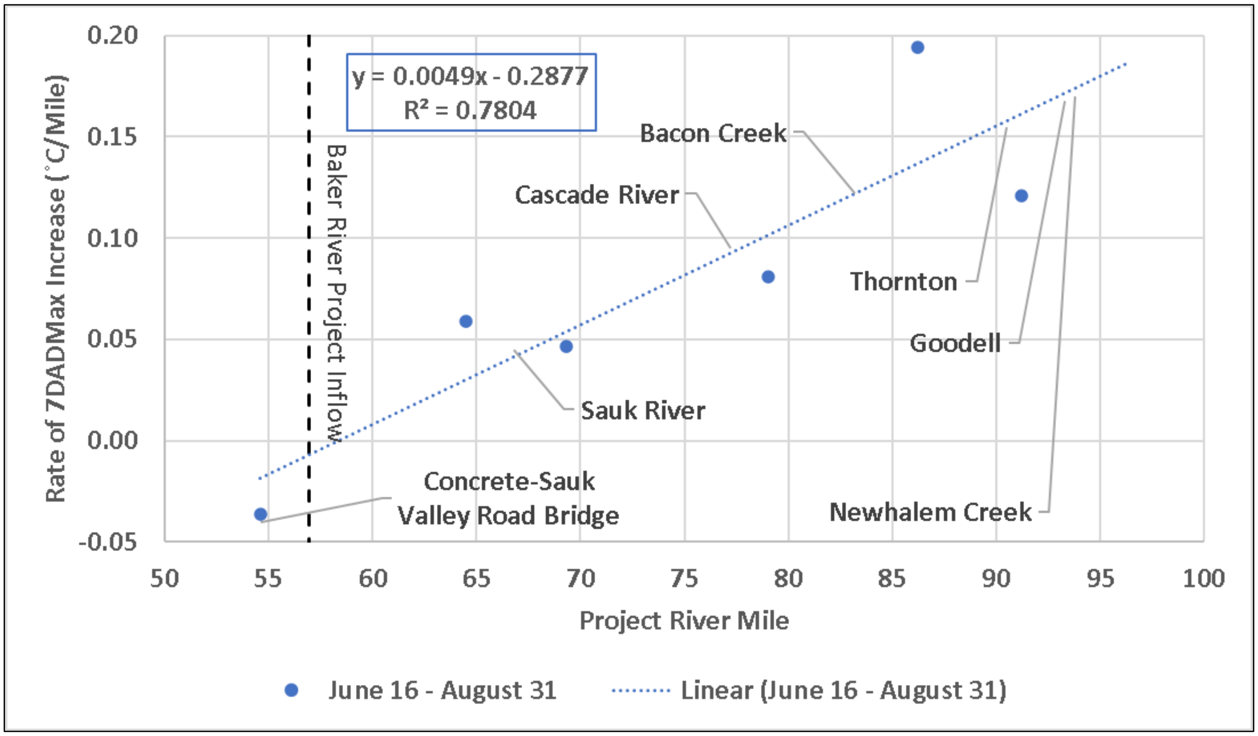


Figure 5.2-9. Longitudinal rate of temperature maximum 7DADMax value increase between Skagit River model segments for the period June 16 through August 31.

5.3 Without-Dams Simulation

5.3.1 Comparison of Temperatures at Dam Outflow Locations

Temperatures of water released from Ross Dam modeled under Existing Conditions were much cooler in the summer months than those associated with the Without-Dams simulation at the Ross Dam site. However, the seasonal decrease in temperature during the fall began much later under simulated existing conditions when compared with simulated Without-Dams temperatures (Figure 5.3-1). Overall, simulated temperatures of dam releases under existing conditions were less variable throughout the year than Ross Reach temperatures in the Without-Dams simulation, with smaller ranges between daily high and low temperatures and less seasonal fluctuation.

Without-Dams simulation temperatures peaked in August near 18°C and reached their lowest in January around -3°C, whereas simulated Existing Conditions dam releases ranged from an annual minimum around 4°C in the early spring to an annual maximum of 12-13°C at the beginning of October. Diurnal fluctuations in the Without-Dams simulation were as much as 4-7°C in spring and summer months, compared with daily variations of up to 1-4°C in dam releases under modeled existing conditions. Seven-day rolling averages of daily maximum temperatures in the Without-Dams simulation and releases from Ross Dam under modeled existing conditions are shown in Figure 5.3-2. These results are derived from those shown in Figure 5.3-1 and thus exhibit similar trends. They are consistent with the understood effect of deep-release dams on downstream temperatures, i.e., reservoirs moderate temperature fluctuations that would be observed in a free-flowing river and the deep withdrawal of the dam leads to a lower maximum temperature (and higher minimum temperature) released downstream than would occur in a river without the dam.

The simulated Without-Dams temperatures indicate that in the absence of the Project, riverine temperatures in the Skagit River at the current location of Ross Dam would not only often exceed the 12°C char spawning and rearing criterion set by the Ecology but also at times the core summer salmonid habitat criterion of 16°C. Temperatures without dams might exceed the salmon and trout spawning criterion (13°C between September 1 and June 15) in the early autumn of some years.

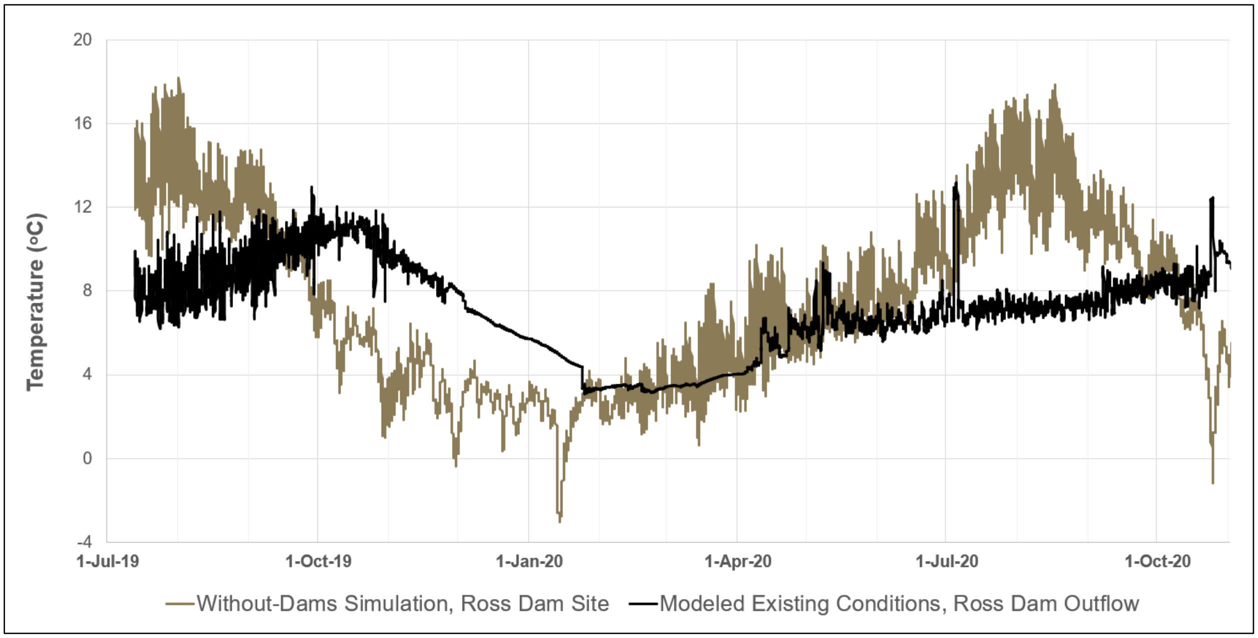


Figure 5.3-1. Simulated temperatures at the Ross Dam Site in the Without-Dams simulation and simulated releases from Ross Dam in the Existing Conditions simulation.

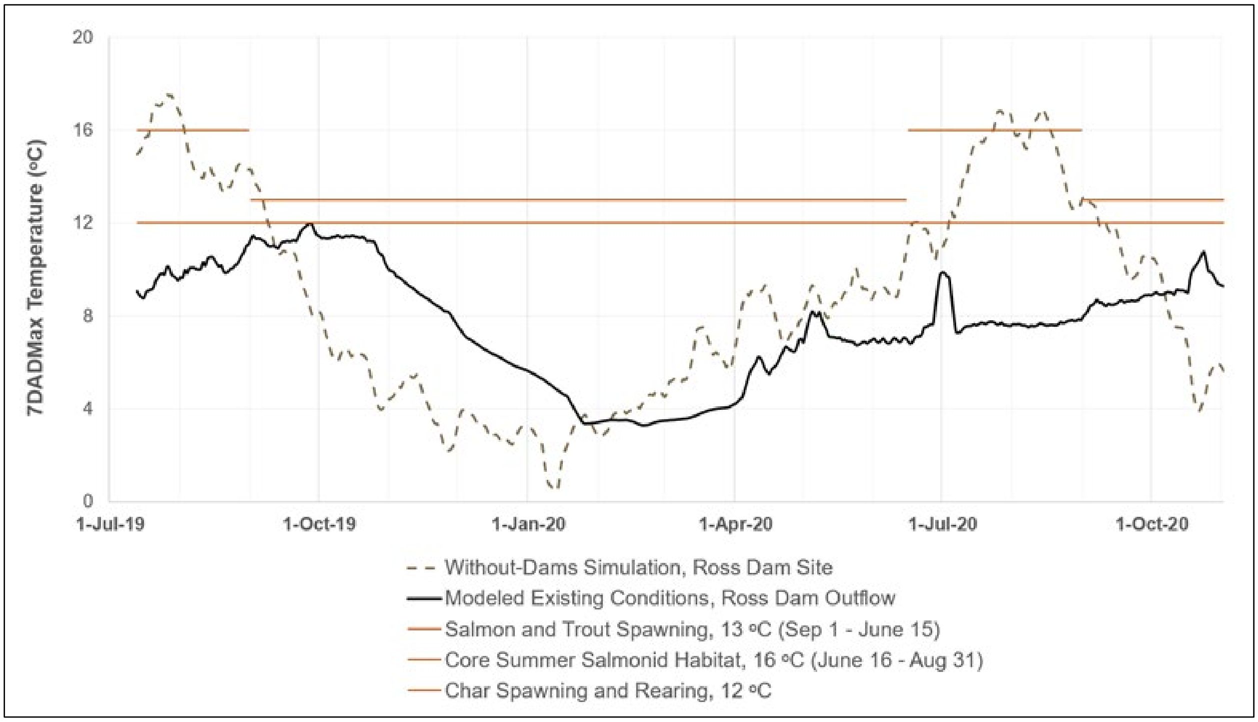


Figure 5.3-2. Simulated 7DADMax temperatures at the Ross Dam Site in the Without-Dams simulation and simulated releases from Ross Dam in the Existing Conditions simulation.

Temperatures modeled under existing conditions of water released from Diablo Dam were also cooler in summer and peaked later in the year when compared with simulated Without-Dams temperatures at the Diablo Dam Site (Figure 5.3-3). Temperatures in the existing conditions dam releases were less seasonally variable throughout the year and showed much less diurnal variation than in the Without-Dams simulation. Without-Dams simulation temperatures peaked in August around 15°C and were lowest in January at just below -2°C, whereas temperatures of dam releases modeled under existing conditions ranged from an annual minimum around -1°C in early spring to an annual maximum of 11-12°C in late September or early October. Diurnal temperature fluctuations in the Without-Dams simulation were as much as 4-6°C in spring and summer months, compared with daily high-low fluctuations in dam releases of at most 1-2°C under existing conditions.

Figure 5.3-4 compares 7DADMax temperatures in the Without-Dams simulation and water released from Diablo Dam in the Existing Conditions simulation. This analysis considers Diablo Dam releases from both the powerhouse penstocks and the spillway after the two flows have mixed downstream of the powerhouse. These results show, as expected, that Diablo Dam moderates the diurnal and yearly fluctuation of temperature in the river and cools the river in summer. These results suggest that, in the absence of the Project, 7DADMax temperatures in the Skagit River at the Diablo Dam site would not exceed the temperature criteria for core summer salmonid habitat or salmon and trout spawning, but they would exceed the criterion for char spawning and rearing during most of July and August.

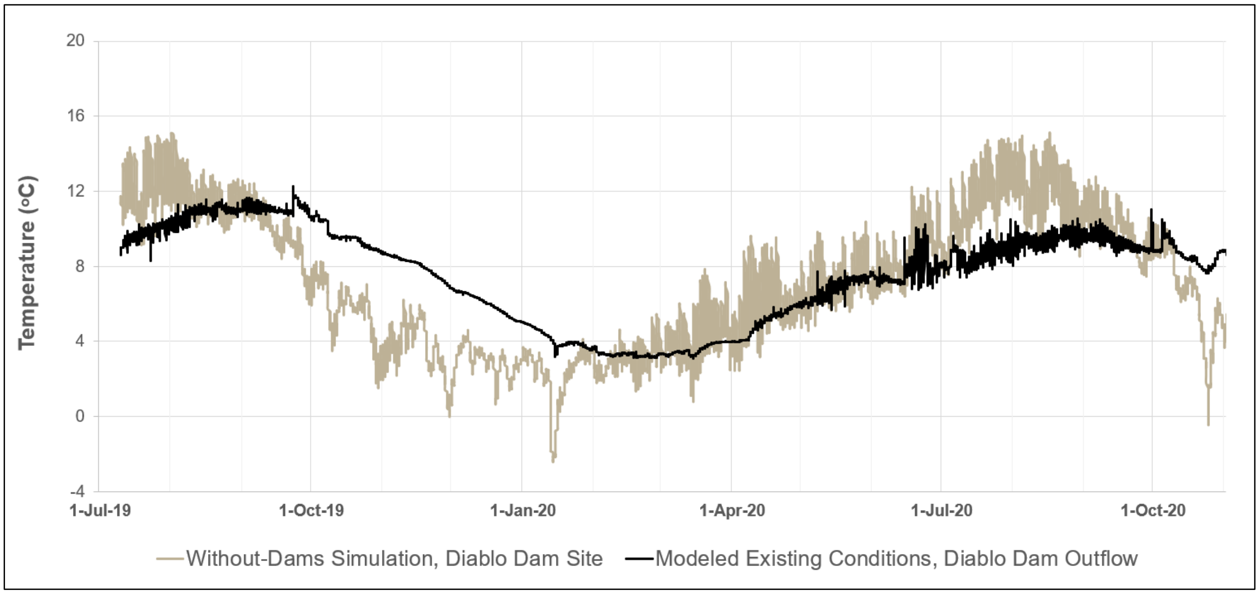


Figure 5.3-3. **Simulated temperatures at the Diablo Dam site in the Without-Dams simulation and simulated releases from Diablo Dam in the Existing Conditions simulation.**

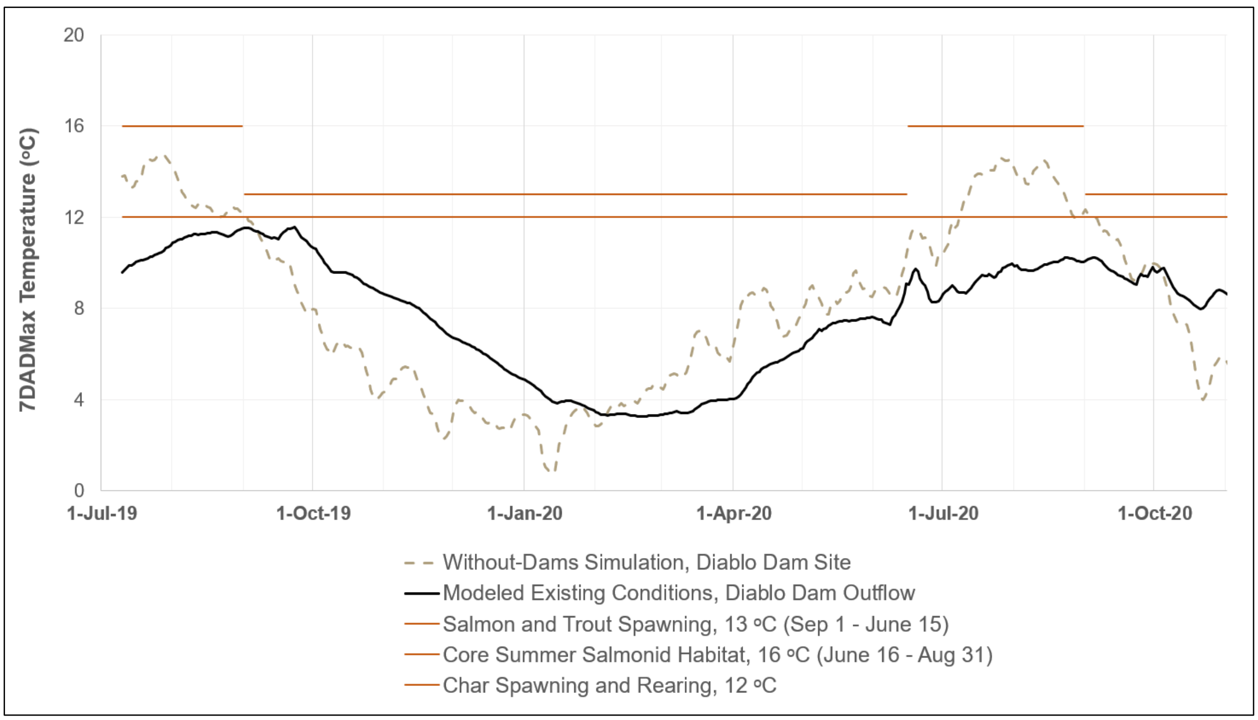


Figure 5.3-4. **Simulated 7DADMax temperatures at the Diablo Dam site in the Without-Dams simulation and simulated releases from Diablo Dam in the Existing Conditions simulation.**

Temperature patterns modeled under existing conditions at the Gorge Dam site outflow were similar to those at the Ross and Diablo dam site outflows, namely cooler in the summer months and warmer in the fall months when compared with simulated Without-Dams temperatures at the dam site (Figure 5.3-5). Also, like the upstream dam outflows, temperatures in the Existing Conditions dam releases showed much less diurnal variation than in the Without-Dams simulation. Figure 5.3-6 compares 7DADMax temperatures in the Without-Dams simulation and dam outflows under modeled existing conditions. This analysis considers releases from both the powerhouse penstocks to be fully mixed before passing through the Gorge bypass reach. However, the analysis was also performed with time-series of Without-Dam simulated temperatures after flows were routed through the Gorge bypass reach to Newhalem and the results varied by less than 0.1°C. These results suggest that, without the dams in place, 7DADMax temperatures in the Skagit River at the Gorge Dam site would not exceed the temperature criteria for core summer salmonid habitat, but they would exceed the criterion for char spawning and rearing during much of July and August. The criterion for salmon and trout spawning may be exceeded for a couple weeks after September 1 in some years.

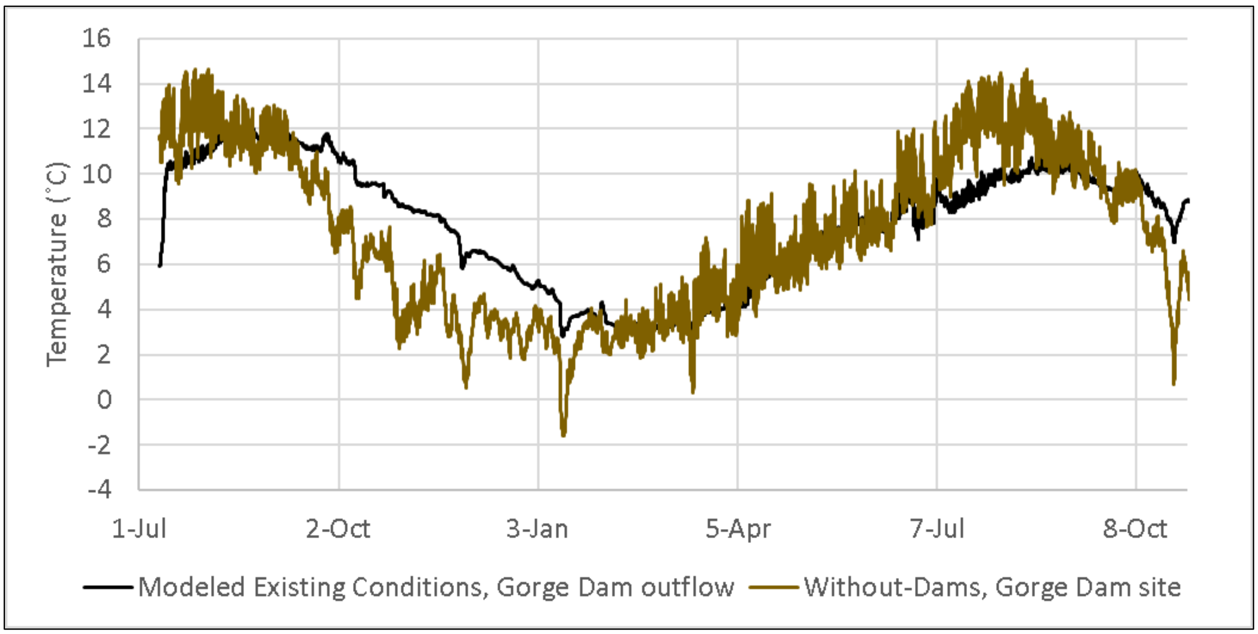


Figure 5.3-5. Simulated temperatures at Gorge Dam site in the Existing Conditions simulation and Without-Dams simulation.

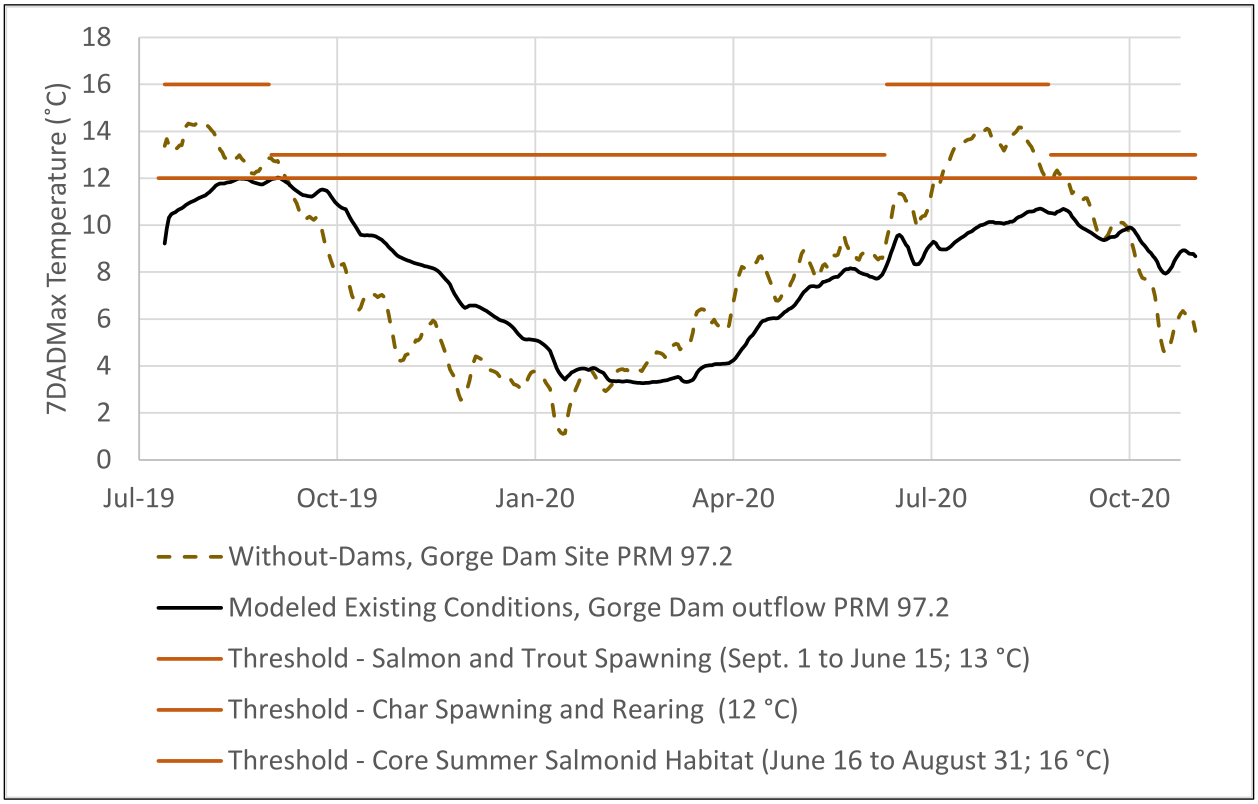


Figure 5.3-6. Simulated 7DADMax temperatures at Gorge Dam site in the Existing Conditions simulation and Without-Dams simulation.

5.3.2 Comparison of River Temperatures

River temperatures modeled in the Existing Conditions simulation and the Without-Dams simulation were evaluated at six Skagit River sites between Newhalem and Concrete, WA: Below Babcock Creek (PRM 91.2), Above Alma Creek (PRM 86.2), Marblemount (PRM 79.0), upstream of the Sauk River (PRM 69.3), downstream of the Sauk River (PRM 64.5), and downstream of the Baker River (i.e., below Puget Sound Energy's Baker River Hydroelectric Project outflow) at the Concrete-Sauk Valley Road Bridge (PRM 54.6). The simulated temperatures for both model simulations are shown in Figures 5.3-7, 5.3-9, 5.3-11, 5.3-13, 5.3-15, and 5.3-17.

In general, the difference in the simulated temperatures and magnitude of diurnal variation between the Existing Conditions and Without-Dams simulations diminishes with increasing distance downstream of Gorge Dam, particularly below the Sauk River confluence (as noted previously, at the Gorge Dam outflow the magnitude of diurnal variation is much smaller in the Existing Condition simulation than the Without-Dams simulation). Figures 5.3-8, 5.3-10, 5.3-12, 5.3-14, 5.3-16, and 5.3-18 show the simulated 7DADMax temperatures in the Existing Conditions and Without-Dams simulations at each of the six Skagit River sites.

These results similarly show that Gorge Dam outflows moderate the riverine 7DADMax temperatures throughout the year and that moderation decreases in the downstream direction, especially downstream of the Sauk River confluence. However, while not readily visible in the hourly temperature time-series, the 7DADMax temperature figures show that 7DADMax temperature reductions resulting from the Project during in the summer of 2019 were smaller than they were in the summer of 2020. For example, the maximum 7DADMax temperature at Marblemount during the summer of 2019 was 14.9°C under existing conditions and 15.2°C in the Without-Dams simulation (a 0.3°C difference), whereas during the summer of 2020 the 7DADMax temperatures were 13.3°C and 14.7°C, respectively (a 1.4°C difference). It is not clear what conditions may have created a lower 7DADMax temperature in 2020 in the Existing Conditions simulation, while the simulated 7DADMax temperatures in the Without-Dams simulation were very similar from year to year. However, any year-to-year variability in peak summer 7DADMax temperature difference between the simulations is nearly undetectable downstream of the confluence with the Sauk River.

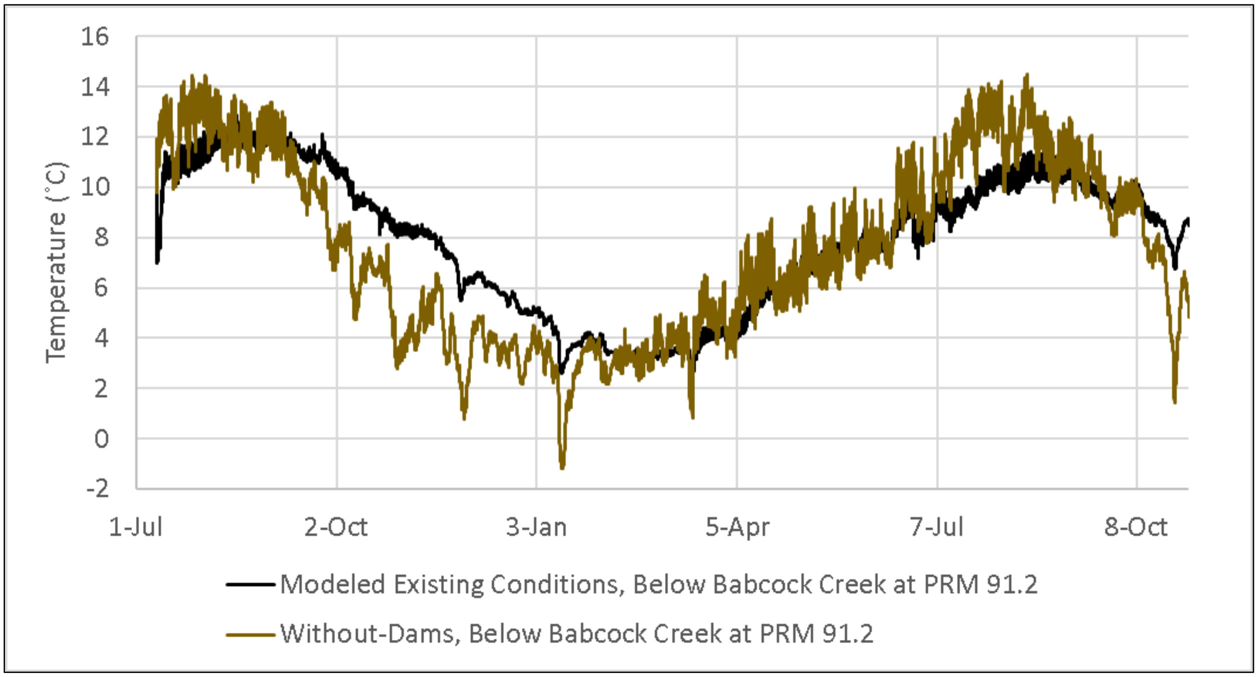


Figure 5.3-7. **Simulated temperatures below Babcock Creek (PRM 91.2) in the Existing Conditions and Without-Dams simulations.**

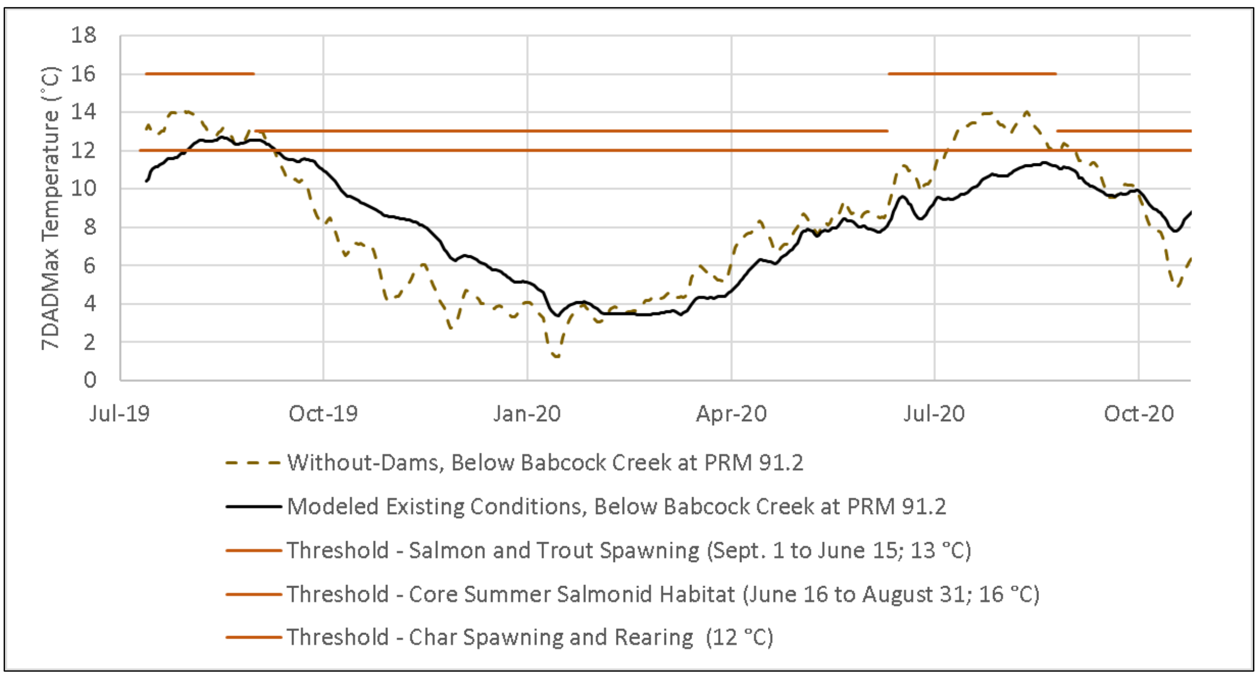


Figure 5.3-8. **Simulated 7DADMax temperatures below Babcock Creek (PRM 91.2) in the Existing Conditions and Without-Dams simulations.**

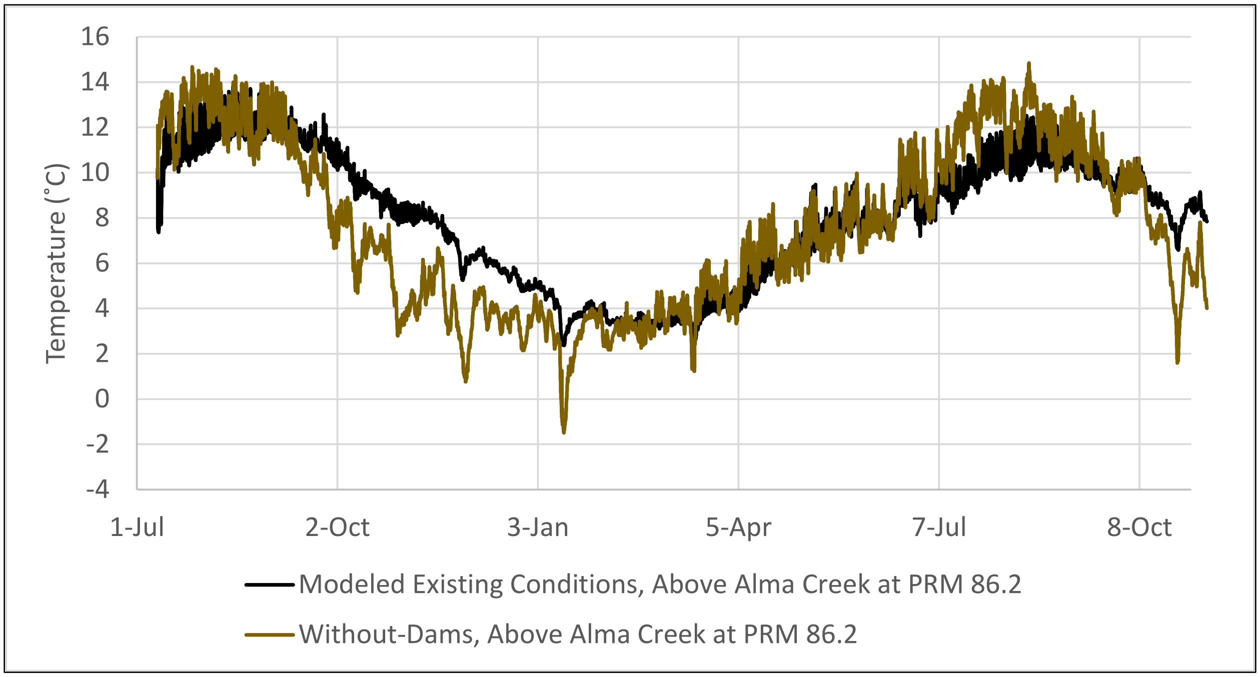


Figure 5.3-9. **Simulated temperatures above Alma Creek (PRM 86.2) in the Existing Conditions and Without-Dams simulations.**

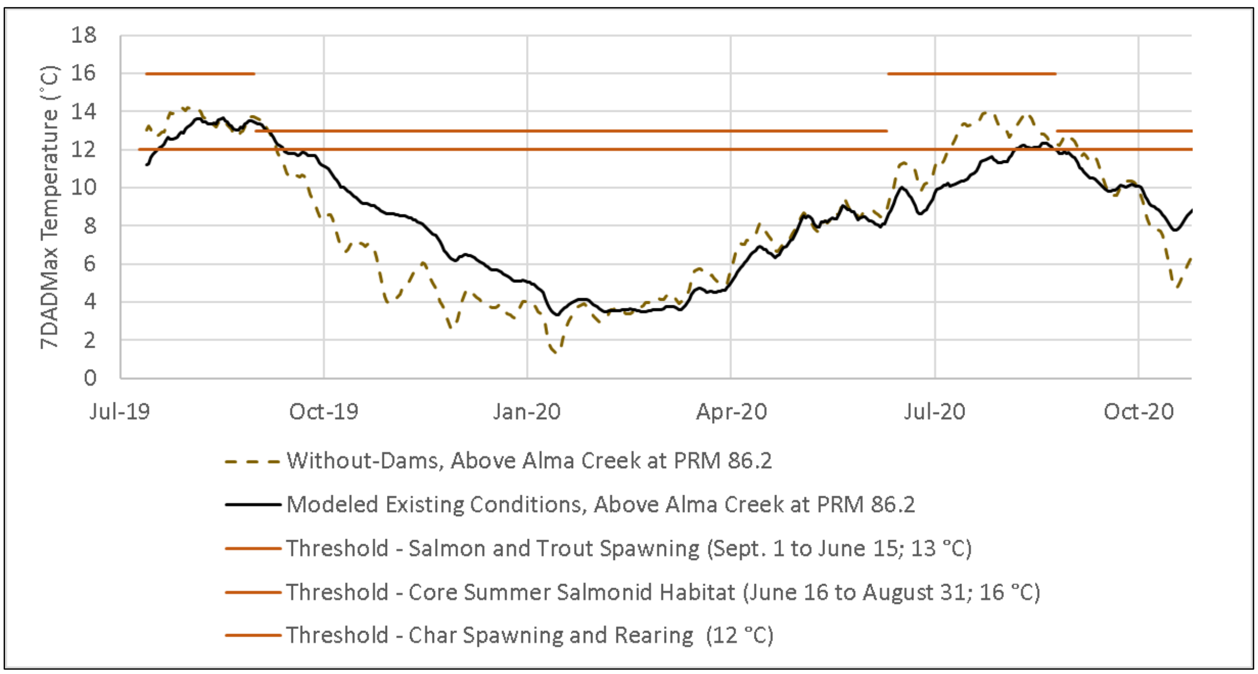


Figure 5.3-10. **Simulated 7DADMax temperatures above Alma Creek (PRM 86.2) in the Existing Conditions and Without-Dams simulations.**

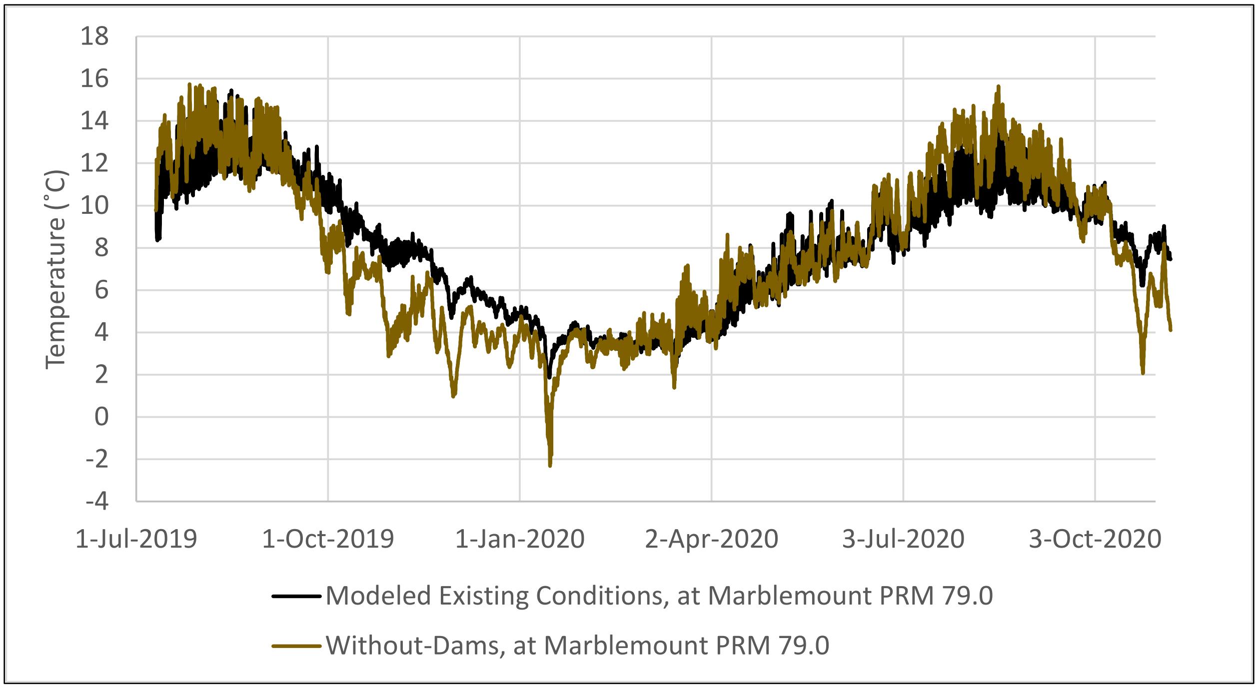


Figure 5.3-11. Simulated temperatures at Marblemount (PRM 79.0) in the Existing Conditions and Without-Dams simulations.

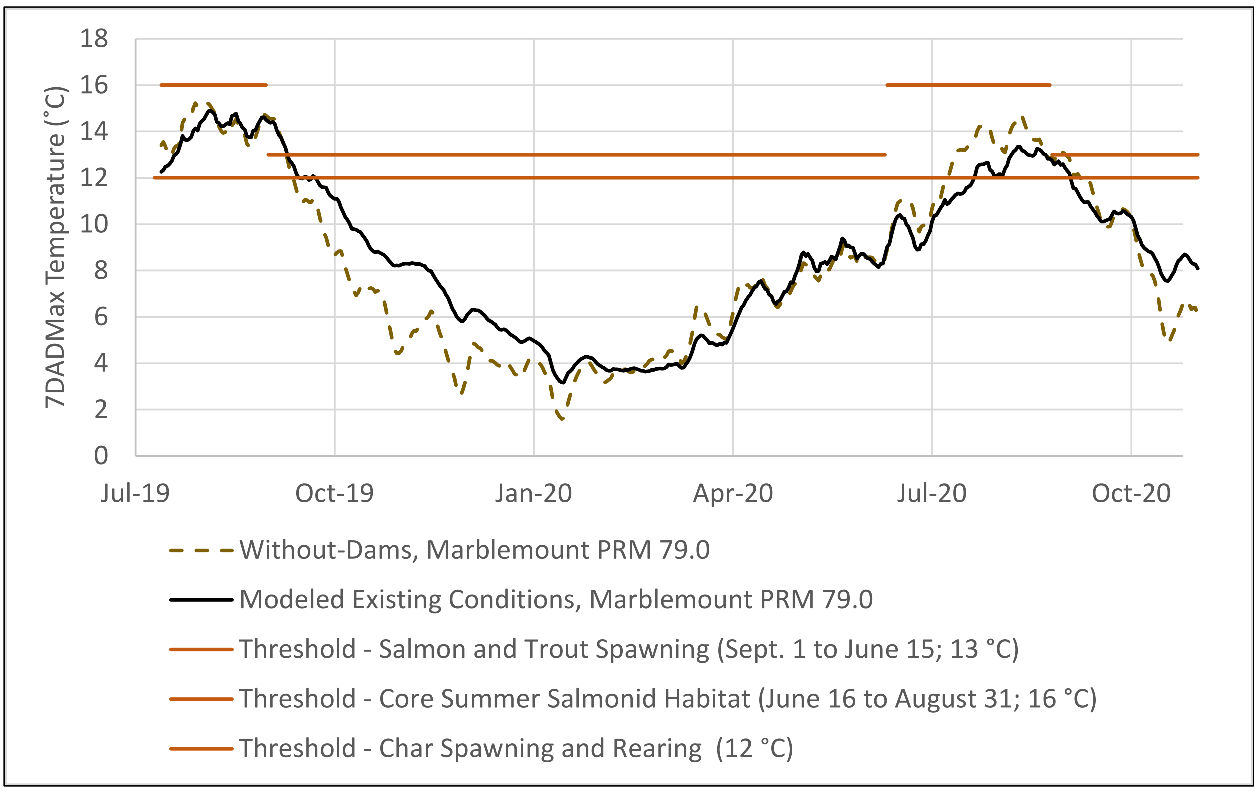


Figure 5.3-12. Simulated 7DADMax temperatures at Marblemount (PRM 79.0) in the Existing Conditions and Without-Dams simulations.

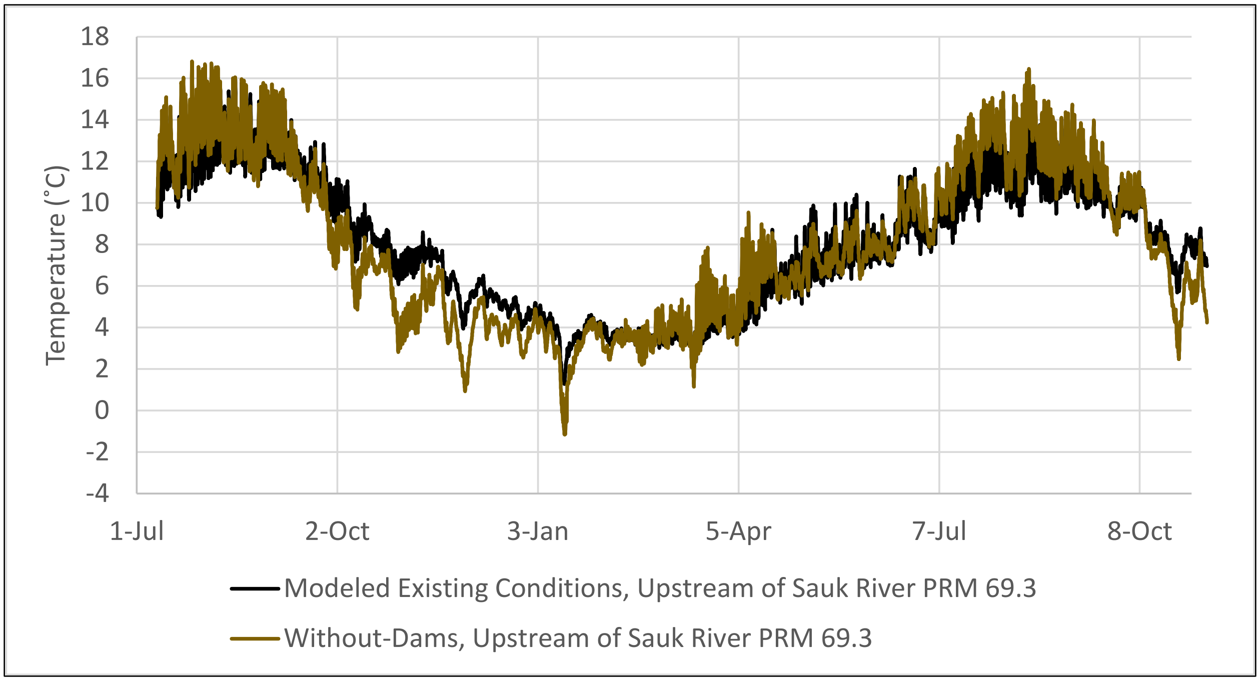


Figure 5.3-13. Simulated temperatures upstream of Sauk River confluence (PRM 69.3) in the Existing Conditions and Without-Dams simulations.

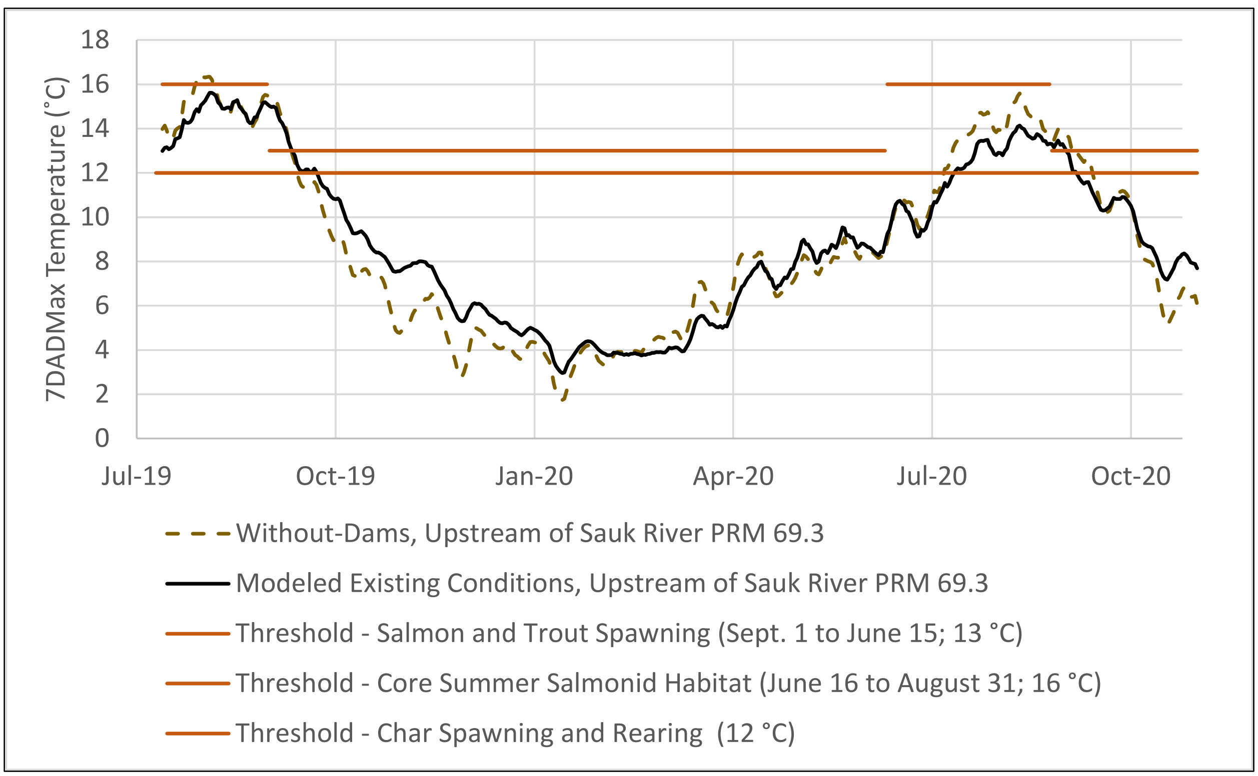


Figure 5.3-14. Simulated 7DADMax temperatures upstream of Sauk River confluence (PRM 69.3) in the Existing Conditions and Without-Dams simulations.

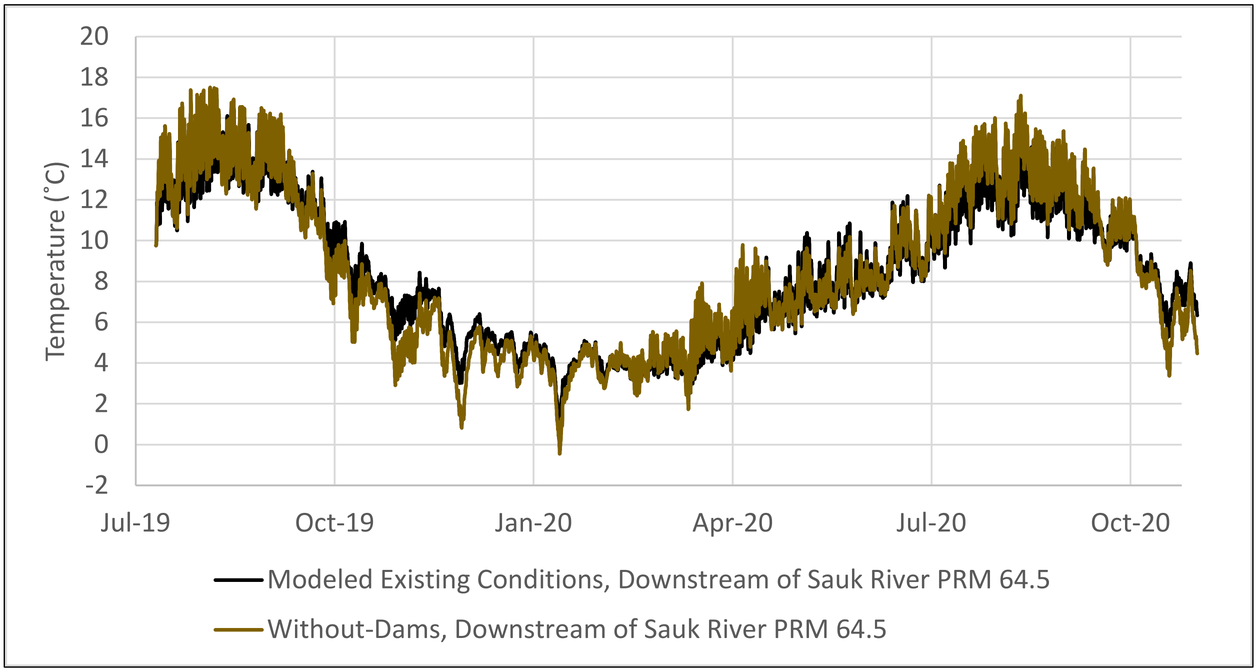


Figure 5.3-15. Simulated temperatures downstream of Sauk River confluence (PRM 64.5) in the Existing Conditions and Without-Dams simulations.

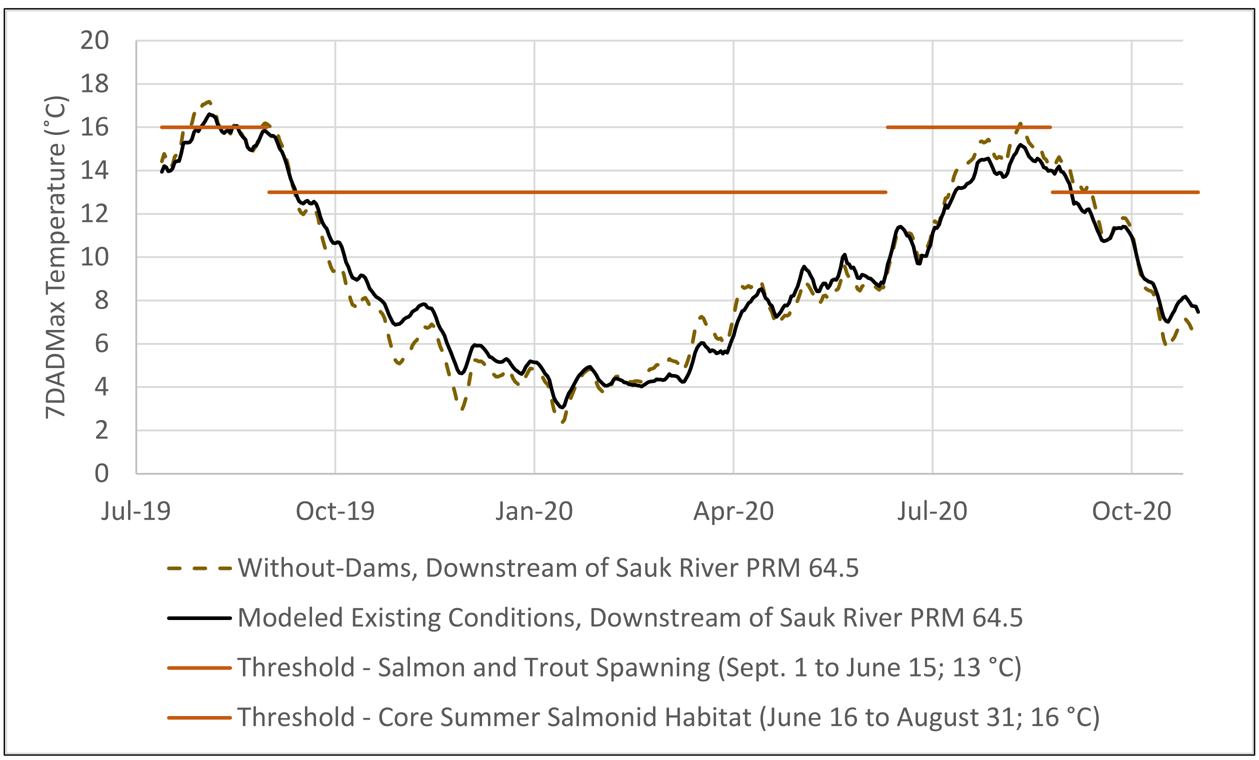


Figure 5.3-16. Simulated 7DADMax temperatures downstream of Sauk River confluence (PRM 64.5) in the Existing Conditions and Without-Dams simulations.

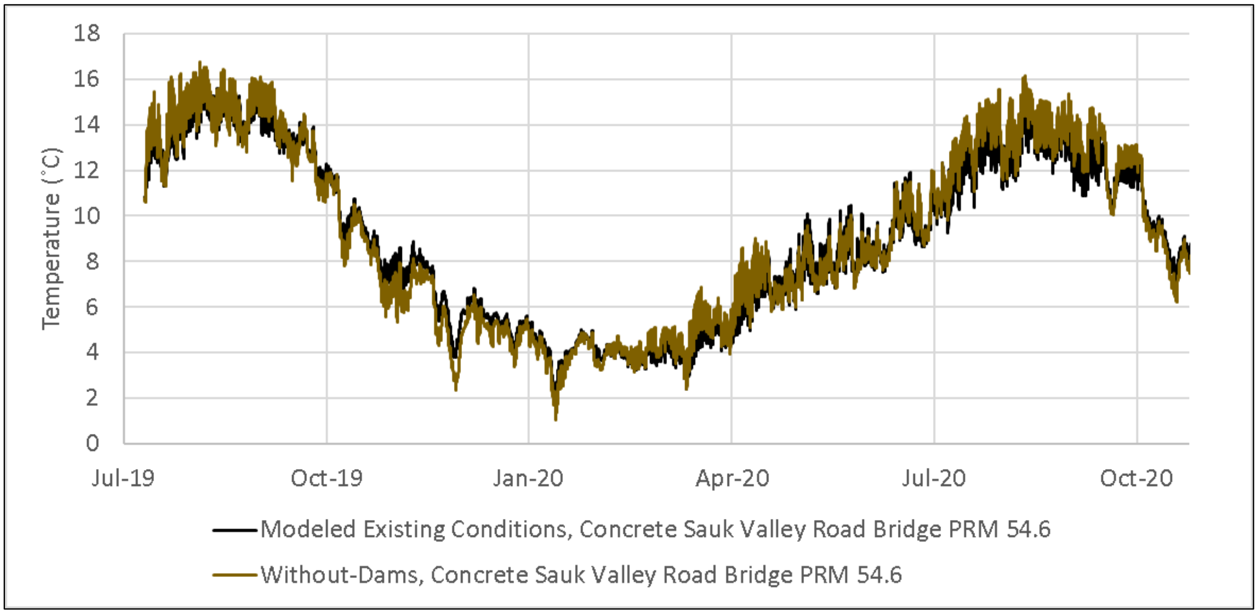


Figure 5.3-17. Simulated temperatures downstream of Baker River confluence at Concrete Sauk Valley Road (PRM 54.6) in the Existing Conditions and Without-Dams simulations.

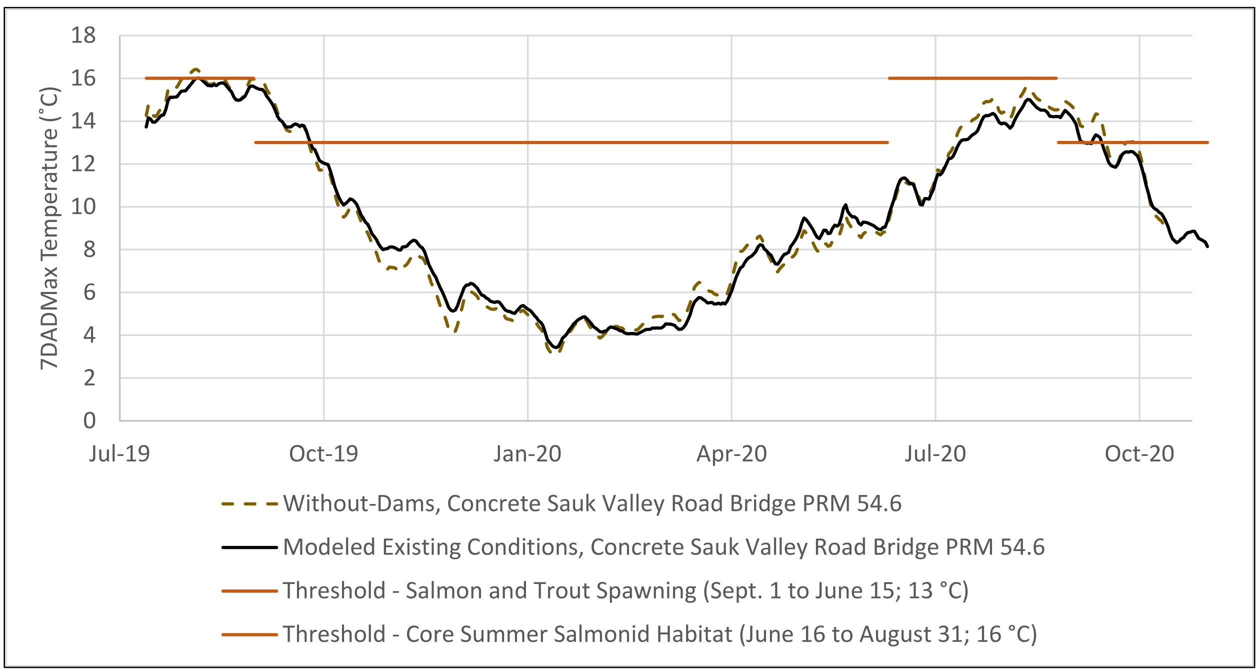


Figure 5.3-18. Simulated 7DADMax temperatures downstream of Baker River confluence at Concrete Sauk Valley Road (PRM 54.6) in the Existing Conditions and Without-Dams simulations.

5.3.3 Summary of Project Impacts on River Temperature

The effects of the dams on instream temperatures were evaluated using a metric referred to as the "temperature delta," which is frequently used to evaluate effects on stream temperatures and is calculated here as the difference between the rolling 7DADMax stream temperatures simulated with the Existing Conditions and Without-Dams models. A positive temperature delta indicates warmer stream temperatures under Existing Conditions compared to the Without-Dams simulation, and a negative temperature delta indicates colder water temperatures under Existing Conditions simulation compared to the Without-Dams simulation.

$$7DADMax\ Delta_{Day(i)} = Existing\ Conditions\ 7DADMax_{Day(i)} - Without\text{-}Dams\ 7DADMax_{Day((i)}$$

Figure 5.3-19 shows the time-series of the temperature delta between the 7DADMax temperatures calculated from the Existing Conditions and Without-Dams models at the Gorge Dam site outflow and six downstream Skagit River analysis locations for a model simulation spanning from July 2019 through October 2020. The black "Zero Delta" line indicates zero difference between the two time series. The further a time series deviates from the line, the greater the Project's effect. Table 5.3-1 provides seasonal averages of the delta time series at each site. The resulting temperature delta is greatest at the Gorge Dam site where the Existing Conditions 7DADMax temperature is more than 2°C warmer (positive delta) than the Without-Dams model in the winter months, on average, and more than 1.5°C colder (negative delta) in the summer months. The magnitude of the delta decreases systematically moving downstream of Gorge Dam, with the minimum occurring at the Concrete Sauk Valley Road Bridge PRM 54.6 site, which is influenced by Puget Sound Energy's Baker River Hydroelectric Project outflow, where there is a winter delta of 0.39°C warmer and a summer delta of 0.19°C colder. The magnitudes of the fall and winter deltas continue to decrease in the downstream direction, even downstream of the Baker River.

Across several locations of interest, temperatures of the river in the Without Dams simulation exceeded the salmon and trout spawning criterion (13°C) on 3 to 13 more days of Water Year 2020 than did temperatures of the river in the Existing Conditions simulation (Table 5.3-2). Additionally, while the Existing Conditions simulation showed that temperatures of the dam outflows did not exceed either the char spawning and rearing criterion (12°C) or the core summer salmonid habitat criterion (16°C), the former was exceeded in the Without Dams simulation for approximately two months at the Ross, Diablo, and Gorge Dam sites, and the latter was exceeded for 18 days at the Ross Dam Site. The core summer salmonid habitat criterion (16°C) was also exceeded for 3 days at one downstream location in the Without Dams simulation and 0 days at the six assessed river locations in the Existing Conditions simulation. This is consistent with the cooling effects that the deep-release dams have on river temperatures downstream.

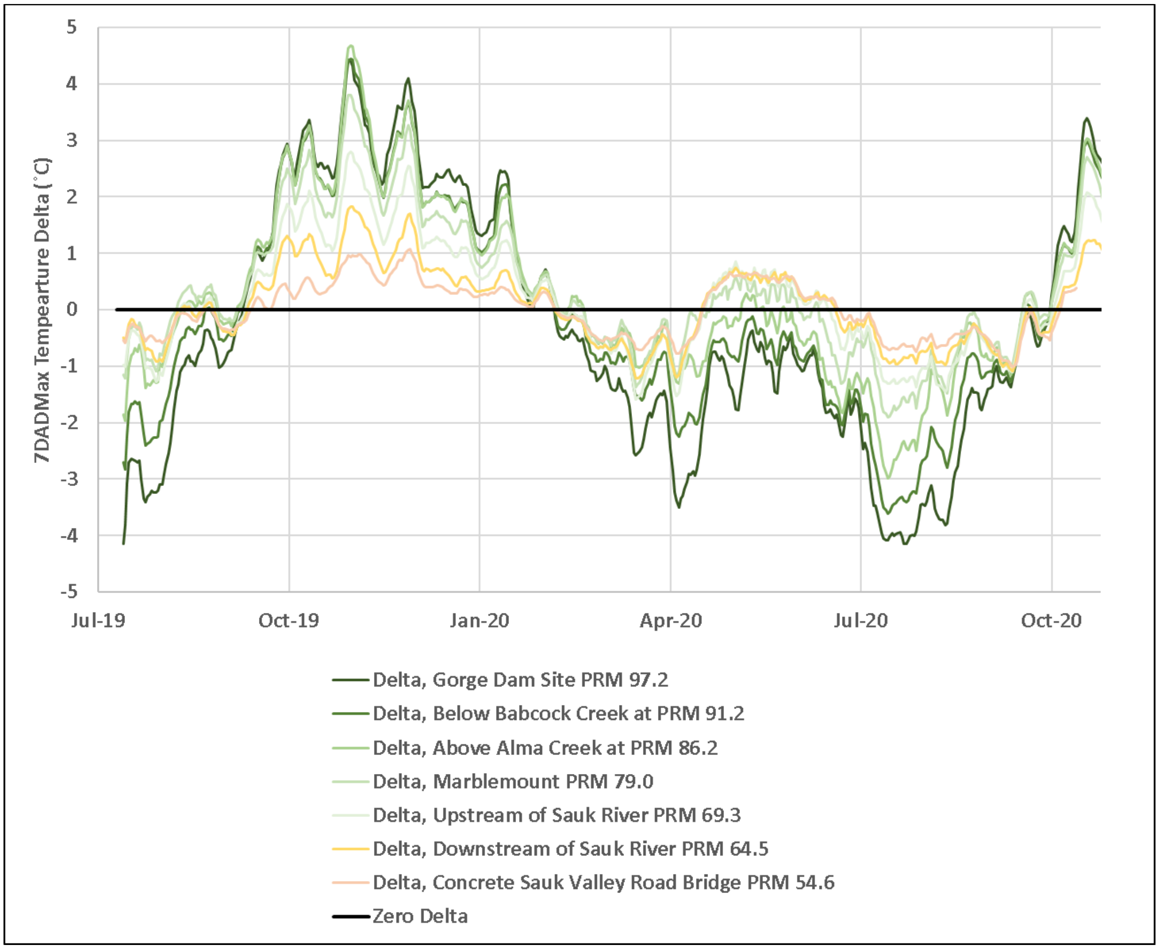


Figure 5.3-19. Time series of the difference or delta between the 7DADMax temperature calculated from the Without-Dams and Existing Conditions models for Gorge Dam and six downstream Skagit River locations.

Table 5.3-1. 7DADMax Temperature Delta (Existing Conditions minus Without-Dams simulation) Statistics for Gorge Dam and six downstream Skagit River locations.

Reference Location	PRM	Reach Length (Miles)	Average Temperature Delta (Existing Conditions minus Without-Dams Simulation), °C		
			Annual	Spring and Summer (Feb - Sep)	Fall and Winter (Oct - Jan)
Gorge Dam Site	97.2		-0.39	-1.54	+2.20
Below Babcock Creek	91.2	6.0	-0.11	-1.05	+2.00
Above Alma Creek	86.2	5.0	+0.23	-0.57	+2.03
Marblemount	79.0	7.2	+0.32	-0.29	+1.68
Upstream of Sauk River	69.3	9.7	+0.15	-0.32	+1.22
Downstream of Sauk River	64.5	4.8	+0.05	-0.25	+0.73
Concrete Sauk Valley Road Bridge	54.6	9.9	-0.01	-0.19	+0.39

Table 5.3-2. 7DADMax temperature exceedances under Existing Conditions and the Without-Dams simulation for the Ross Dam, Diablo Dam, and Gorge Dam sites and four locations in the Skagit River.[1]

		Number of Days Exceeding Ecology Criteria (calendar-year 2020 only)					
		Char Spawning and Rearing	12°C	Salmon and Trout Spawning	13°C (Sep 1-Jun 15)	Core Summer Salmonid Habitat	16°C (Jun 16-Aug 31)
Location	PRM	Existing	Without Dams	Existing[3]	Without Dams	Existing[3]	Without Dams
Ross Dam Site	105.7	0	70	0	1	0	18
Diablo Dam Site	101.6	0	59	0	0	0	0
Gorge Dam Site	97.2	0	55	0	0	0	0
Below Babcock Creek	91.2	0	55	0	0	0	0
Above Alma Creek	86.2	19	59	0	0	0	0
Marblemount	79.0	45	62	0	4	0	0
Upstream of Sauk River	69.3	57	70	7	10	0	0
Downstream of Sauk River	64.5	N/A	N/A	9	19	0	3
Concrete Sauk Valley Road Bridge	54.6	N/A	N/A	16	26[2]	0	0

1 Tabulated exceedances are limited to calendar-year 2020, January 1, 2020 through November 8, 2020 (end of existing condition simulation).

2 Four of 26 simulated exceedances at PRM 54.6 occur during the first week of October 2020, after lower Baker River temperature monitoring ended on September 30, 2021. These exceedance counts, all of which exceeded the Ecology threshold by less than 0.1 degrees C, are potentially affected by error in estimates of Baker River water temperatures used as inputs to the model. Observed Baker River temperature data is available June 15, 2019 – September 30, 2019, and June 18, 2020 – September 30, 2020.

3 Tabulated counts of existing conditions simulation exceedances of the Ecology Salmon and Trout Spawning (13°C) criteria and Core Summer Salmonid Habitat (16°C) criteria within the Skagit River downstream of Gorge Dam are provided for both calendar-year 2019 and 2020 within Table 5.2-3.

6.0 DISCUSSION AND FINDINGS

6.1 Implications of Results

This study has met the goals and objectives stated in Section 2.0 of this study report. Hydrodynamic and temperature models have been developed for Ross Lake, Diablo Lake, Gorge Lake, and the Skagit River downstream of the Project to PRM 54 in Concrete, Washington. The models have been calibrated to match field data, and inconsistencies between model output and field data have been understood in the context of available input data. This model development and calibration were conducted in consultation with Dr. Scott Wells of Portland State University, as well as a group of LPs. The models have been evaluated for sensitivity, and they have been used to simulate the Skagit River under existing conditions and without the dams in place. The Without-Dams simulation goes beyond the goals and objectives of the WQ Model Development Study, providing a new and useful understanding of the effect of the Project on temperatures in the Skagit River.

In addition to these modeling objectives, the following tasks are being completed outside of the work documented within this study report:

- Development of water quality (nutrients and productivity, in particular) models for the Project reservoirs and the Skagit River downstream of the Gorge Development.
- Application of the temperature and water quality models to evaluate potential flow management scenarios.

The calibration results presented above indicate that the four CE-QUAL-W2 models (Ross, Diablo, Gorge, and the Skagit River) can be used to predict the temperature of water leaving Project reservoirs and flowing downstream to PRM 54.6 in Concrete, Washington. This indicates that they can be used to evaluate the impacts of potential management scenarios on the temperature downstream from the Project.

The temperature calibration statistics from Gorge Lake and Diablo Lake indicate that the models of these reservoirs can predict water column temperatures in the locations where monitoring data are available. City Light deployed an on-reservoir meteorological station in May 2022 on Monkey Island in the center of Diablo Lake. The wind data from this meteorological station are expected to improve the representation of wind in the Diablo Lake model when this model is extended to simulate 2021 and 2022. Subsequently, the model should represent the Diablo Lake thermocline with greater accuracy, thus increasing confidence in the simulated transition from warm surface water temperatures to colder deep-water temperatures. The experience of City Light field personnel indicates that the wind speed and direction are similar between Diablo Lake and Gorge Lake; strong winds blow up or down the Skagit River canyon and affect the mainstem of both reservoirs similarly. Thus, data from the Diablo Lake meteorological station will be used to improve the Gorge Lake model for 2021-2022 in a similar manner to Diablo Lake.

On Ross Lake, qualitative and quantitative evaluation of temperature calibration indicates that the model can be used with confidence to understand broad seasonal and spatial trends of the physical limnology of this reservoir. Some vertical profiles are not characterized by the model within the calibration targets established in the modeling QAPP. These occur mostly in up-reservoir locations in early summer. City Light has invested in an on-reservoir meteorological station that was installed in May 2022 on a point of land[11] on the east shoreline of Ross Lake. Informing the 2021-2022 temperature model of Ross Lake with wind data from this station is expected to improve the model representation of surface water temperatures and thermocline shape and thus increase confidence in model representation of spatial and temporal temperature change at key depths and during key seasons.

The sensitivity analyses conducted indicate that the temperature models of Project reservoirs are most sensitive to the temperature of tributary inflows and wind speed and direction. The temperature of water released from dams is sensitive to the ratio of water passing through dam spillways and dam penstocks. The simulated temperatures at various locations in the Skagit River model are sensitive to the temperature of tributary inflows and spillway-powerhouse flow ratios at the upstream dams. These sensitivity analyses provide a useful indication of the variations in the system that may be explored in future management scenarios (e.g., as modified dam operations) as well as possible natural variations that could have the largest effects (e.g., increasing tributary temperatures due to climate change).

The simulation of existing conditions demonstrates that the reservoir models, and the output tools that have been developed to support them, provide a robust characterization of the physical limnology of Project reservoirs. Therefore, the Existing Conditions simulation provides a reliable baseline for comparison with simulations of potential alternative Project management scenarios. Downstream, the Existing Conditions simulation characterizes the Skagit River under baseline conditions, including the extent to which temperatures exceed Ecology's relevant criteria at multiple locations between the Gorge Lake outflow and the Concrete Sauk Valley Road bridge (which is located a short distance downstream of the regulated Baker River, below which the Project has less influence). The Existing Conditions simulation results shows that for the summers of 2019 and 2020, exceedances of the 13°C salmon and trout spawning criterion and the core summer salmonid habitat criterion of 16°C increase in frequency with distance downstream. There are no exceedances of the 16°C threshold upstream of the Sauk River in 2019 and no exceedances of the 13°C threshold upstream of PRM 86.2 (near Alma Creek). The rate at which summer stream temperatures increase is greatest immediately below Gorge Lake (approximately 0.17°C per mile), and the rate of change decreases relatively consistently to the confluence of the Sauk River at PRM 64.5 (less than 0.05°C per mile),[12] the largest tributary within the modeled river system. This warming trend is consistent with other models of river systems located downstream of cold-water release reservoirs.

The Without-Dams simulation demonstrates the utility of these models for analysis of the Project beyond a characterization of existing conditions. It also provides new information regarding the effects of the Project on Skagit River temperatures. Modeled temperatures from this simulation are lower in winter and higher in summer than the modeled temperatures of the Existing Conditions simulation. This indicates that the Project provides a moderating influence on the temperature of the river downstream, a finding that is consistent with what is expected for a deep-release reservoir in a temperate region and is consistent with what has been observed or simulated in these types of

[11] This point of land is known as Cat Island. It is an island at full pool water levels and a peninsula at lower water levels.

[12] This corresponds to a rate change of approximately 0.005°C per mile per mile (i.e., -0.12 degrees C per mile / 25 miles), the slope of the linear regression fit to the data below Gorge Dam shown in Figure 5.2-9.

systems worldwide. The warmer summer temperatures of the Without-Dams simulation lead to more frequent modeled exceedances of the char spawning and rearing and the salmonid spawning temperature criteria than under the Existing Conditions simulation. This indicates that the deep-release reservoirs of the Project provided cold water to the Skagit River that increased the number of days in water year 2020 during which the river met temperature criteria.

6.2 Status of June 9, 2021 Notice

The June 9, 2021 Notice identified items of discussion related to the implementation of this WQ Model Development Study. The status of these is summarized in Table 6.1-1.

Table 6.1-1. Status of WQ Model Development Study modifications identified in the June 9, 2021 Notice.

Study Modifications Identified in the June 9, 2021 Notice	Status
Seattle City Light ("SCL") will modify FA-01 to include development of a CE-QUAL-W2 model to evaluate temperature impacts from the Project on aquatic resources. SCL will seek and incorporate the input of Scott Wells and the Oregon and Washington USGS Water Science Centers in the development of the CE-QUAL-W2 model. The model will be developed and implemented within the two-year study timeframe. The CE-QUAL-W2 model will be used to evaluate, among other things, the impact of cold-water releases from Ross reservoir on fishery resources. Action item: SCL will schedule one or more workshops with the LPs, as needed, to collaborative develop this model.	The CE-QUAL-W2 model of hydrodynamics and temperature has been developed and calibrated within the two-year timeframe for the simulation period of July 2019 through December 2020. The model has been used to evaluate the impact of cold-water releases from Ross Lake on temperature in the reservoirs and river downstream. The models are available to simulate other scenarios of interest. Dr. Scott Wells has been retained as part of the City Light consultant team to act as an advisor for reservoir and river modeling. City Light discussed CE-QUAL-W2 model development and calibration with LPs in a series of collaborative Water Quality Resource Work Group meetings that occurred between July 2021 and June 2022.
SCL will provide a QAPP that meets Ecology's standards and judge existing data based on the QAPP. If the existing data cannot be confirmed, the data will be reviewed on a case-by-case basis in collaboration with the LPs. Action item: SCL to provide provisional data summary by the end of July 2021 to identify gaps and ensure those gaps are addressed through data collection in the study time frame, followed by a full summary in the Initial Study Report. Action item: The existing data will be reviewed to determine data gaps that need to be filled through the implementation of the study plan.	The Water Quality Monitoring Study QAPP, which is based on Ecology's Standard Operating Procedures, was included as an attachment to the Water Quality Monitoring Study RSP. City Light submitted the provisional data summary to LPs on September 3, 2021. The full water quality data summary and analysis is provided as Attachment D to the FA-01a Water Quality Monitoring Study Interim Study Report (City Light 2022a).
SCL will modify FA-01 to clarify that SCL will evaluate measures of biological productivity including primary producers and will collaborate with the LPs to develop a sampling study. In addition, SCL will execute an expanded benthic macroinvertebrate sampling program to include the Project reservoirs, Skagit River to the estuary (through reference reach sampling mutually agreed to by SCL and the LPs),	City Light has developed and implemented a sampling plan that provides the data needed to allow for the modeling of a range of water quality parameters, including nutrient dynamics, to address questions of productivity. City Light also substantially expanded the scope of its macroinvertebrate sampling (now including both Benthic macroinvertebrates and invertebrate drift), in the Project reservoirs, tributaries to the reservoirs in

Study Modifications Identified in the June 9, 2021 Notice	Status
varying seasons, varying habitat types, and invertebrate drift. The sampling program will be developed in collaboration with the LPs and informed by NPS Appendix A.[13]	the reservoirs' varial zones, and the Skagit River downstream of the Project, including a downstream expansion of sampling sites (downstream to the SR 9 Bridge). The sampling plan was informed by the content of NPS Appendix A and discussed with LPs extensively before adoption.
SCL will modify the study plan to conduct an initial assessment of nitrogen and phosphorous in the Project Reservoirs, representative major reservoir tributaries, and Skagit River to the estuary (through mutually agreed sampling program including reference reaches). An assessment for nutrient data collection will be developed in coordination with tributary habitat sampling, water quality modeling, and the food web study. The sampling design will be developed in collaboration with the LPs. SCL will also modify the study plan to initiate modelling of nutrient and productivity components after 1) the CE-QUAL-W2 model for temperature is developed, and 2) data sources and years available are evaluated against the objectives of the LPs. Concurrently SCL would continue to collect proposed water quality parameter data and develop the CE-QUAL-W2 framework and integration with Operations model and other modelling tools in order to perform a sensitivity analysis to determine the accuracy and sensitivity of the tool (and data needs) for illustrating nutrient dynamics under alternative operational scenarios. SCL anticipates that this effort will be initiated during the second year of study and completed prior to the filing of the Updated Study Report.	The modifications to the monitoring plan have occurred as described above. Development of the water quality model is underway. This study report documents hydrodynamic and temperature model development, calibration, and results. The following tasks are in the process of being completed: ▪ Development and calibration of water quality (nutrients and productivity, in particular) models for the Project reservoirs and the Skagit River downstream of the Gorge Development. ▪ Application of the temperature and water quality models to evaluate potential flow management scenarios. City Light will provide the results of these tasks in a subsequent addendum to this study report.
SCL will convene a workshop with concerned LPs to discuss parameters, frequency, monitoring locations, and temporal overlap with existing data. This workshop will occur in August 2021 after the data gaps in the QA/QC analysis are presented by SCL. The workshop will also identify the parameters to be modeled by CE-QUAL-W2, potential gaps in the model, and the approach to filling the gaps. Where the model will not adequately describe the effects of Project operation scenarios on water quality parameters, empirical data collection requirements will be developed by SCL in collaboration with the LPs and informed by NPS Appendix A.	City Light convened the workshop as described and reached concurrence with LPs regarding a sampling plan that allows for data collection to support the modeling of a range of water quality parameters, including nutrient dynamics to address questions of productivity. The plan addresses sampling frequency, monitoring locations, and temporal overlap with existing data. A plan describing the approach to collection of water quality data for use in the modeling was shared with LPs.

[13] Taylor-Goodrich, K.F. Re: North Cascades National Park Service Complex comments on Seattle City Light's Revised Study Plan for the relicensing of the Skagit Project (#553), Appendix A. Letter to K.D. Bose, Secretary, Federal Energy Regulatory Commission, May 5, 2021.

7.0 VARIANCES FROM FERC-APPROVED STUDY PLAN AND PROPOSED MODIFICATIONS

This FA-01b WQ Model Development Study is consistent with references to temperature modeling contained in the June 9, 2021 Notice and approved by FERC in its SPD dated July 16, 2021. The Without-Dams simulation represents a positive variance from the agreed-upon approach for the WQ Model Development Study because the Without-Dams simulation goes beyond the goals and objectives of the WQ Model Development Study and provides a new and useful understanding of the effect of the Skagit River Hydroelectric Project on temperatures in the Skagit River.

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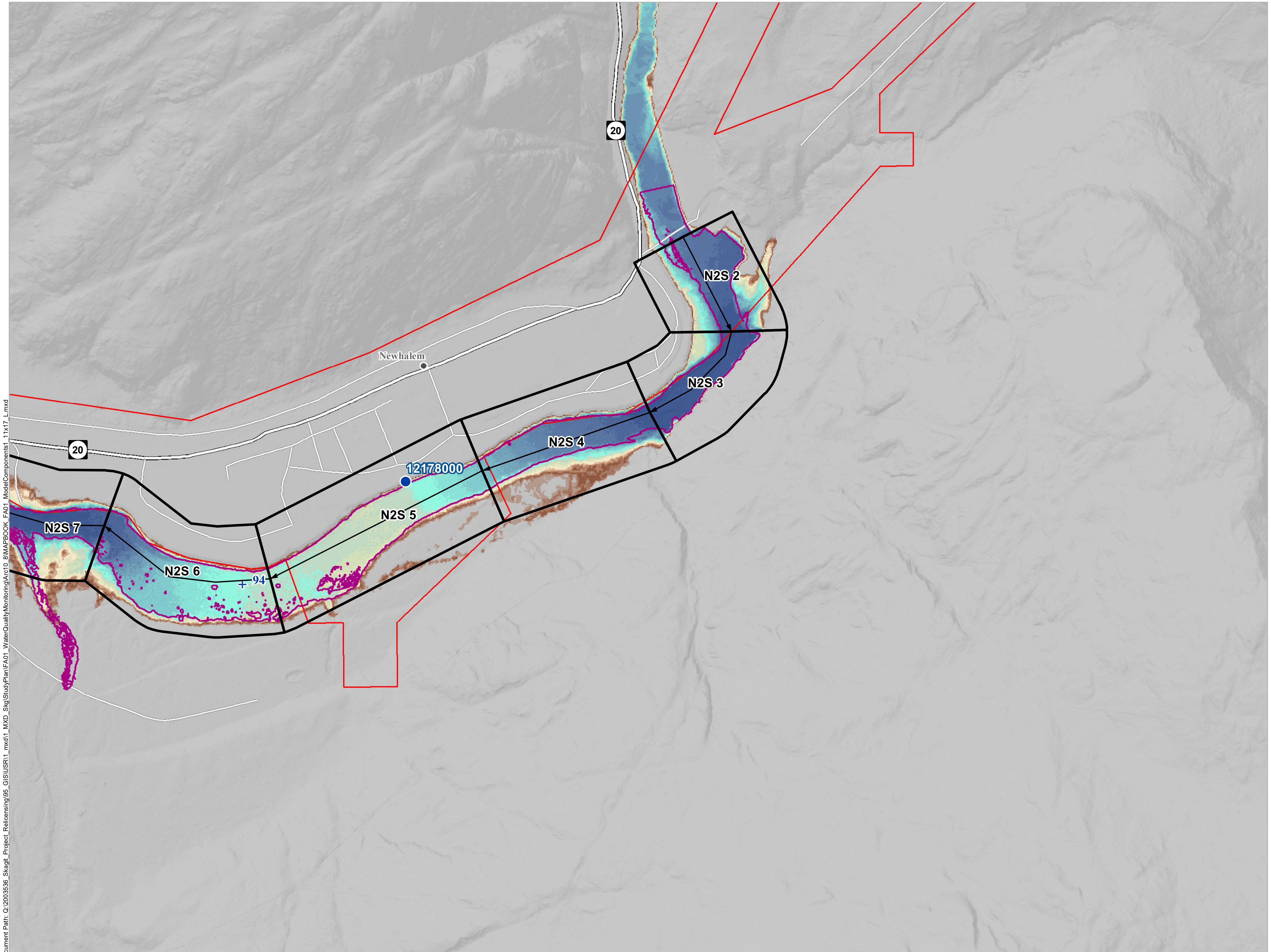
WATER QUALITY MODEL DEVELOPMENT STUDY

ATTACHMENT A

SKAGIT RIVER CE-QUAL-W2 MODEL SEGMENTS, RELATIVE FLOODPLAIN ELEVATIONS, AND SIDE-CHANNELS FROM NEWHALEM TO CONCRETE



SKAGIT RIVER CE-QUAL-W2 MODEL SEGMENTS, RELATIVE FLOODPLAIN ELEVATIONS AND SIDE CHANNELS FROM NEWHALEM TO CONCRETE

FERC Project Boundary
Mitigation Parcel
Project River Miles (PRM)
National Park / National Recreation Area Boundary
Stream Gage (USGS)
Level Logger
Side Channel Monitoring Site
Side Channel (GE-04 Study)
Sept. 2016 Wetted Channel
Simulated March 2021 Inundation (FA-02 Study)

CE-QUAL-W2 Model

Model Centerline
Model Segment

Calibration Monitoring Site

Temperature
Flow & Stage
Flow, Stage & Temperature

Relative Elevation Model (2021)

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-9 - -8	1 - 2
-8 - -7	2 - 3
-7 - -6	3 - 4
-6 - -5	4 - 5
-5 - -4	5 - 6
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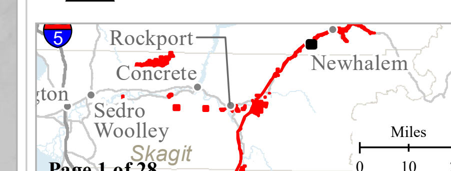

Seattle City Light

SKAGIT RIVER HYDROELECTRIC PROJECT (FERC NO. 553)

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Data Source: Northwest Hydraulic Consultants, NSD, Washington Department of Natural Resources.

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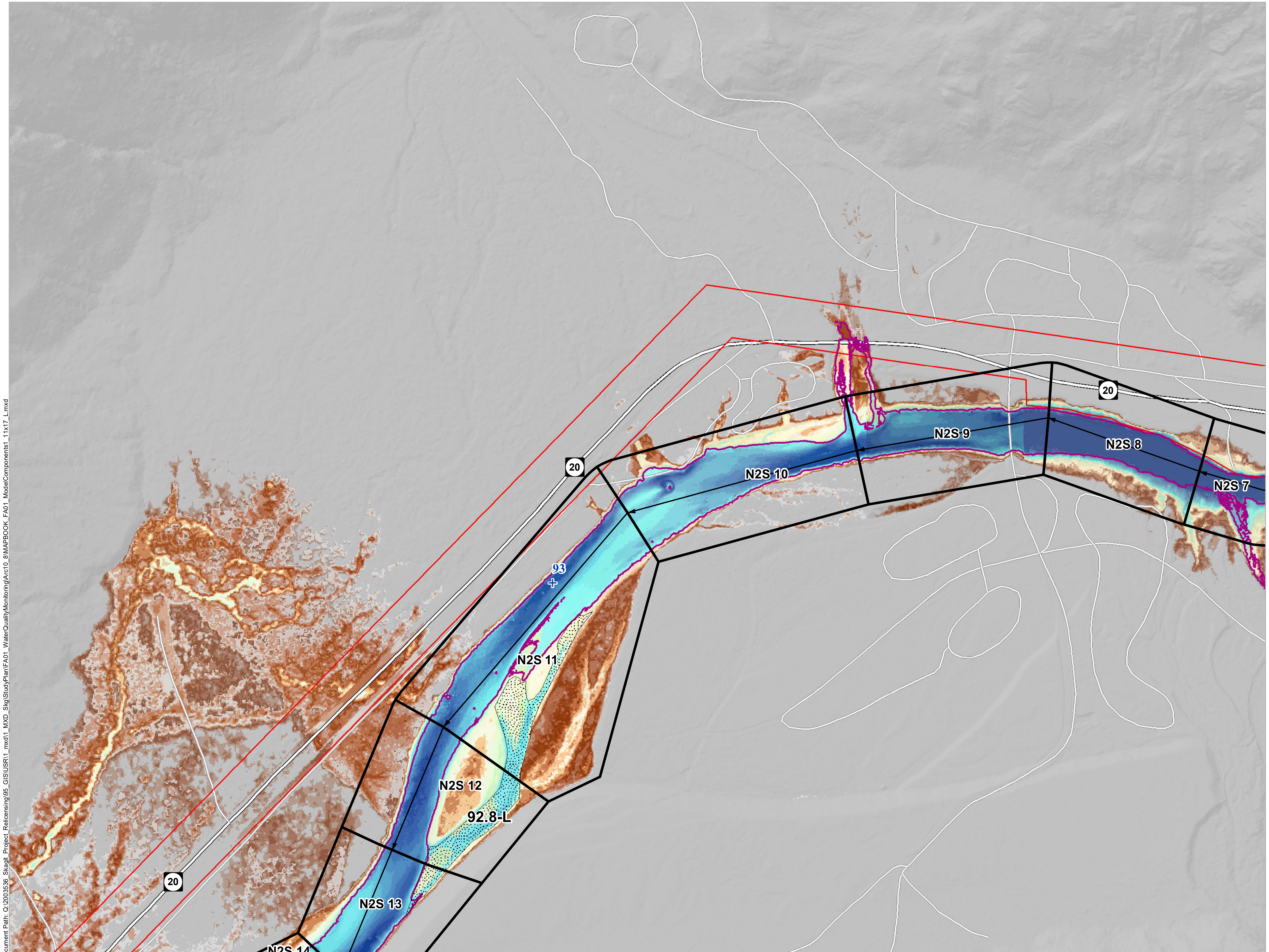

SKAGIT RIVER CE-QUAL-W2 MODEL SEGMENTS, RELATIVE FLOODPLAIN ELEVATIONS AND SIDE CHANNELS FROM NEWHALEM TO CONCRETE

- FERC Project Boundary
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- Stream Gage (USGS)
- Level Logger
- Side Channel Monitoring Site
- Side Channel (GE-04 Study)
- Sept. 2016 Wetted Channel
- Simulated March 2021 Inundation (FA-02 Study)

CE-QUAL-W2 Model

- Model Centerline
- Model Segment

Calibration Monitoring Site

- Temperature
- Flow & Stage
- Flow, Stage & Temperature

Relative Elevation Model (2021)

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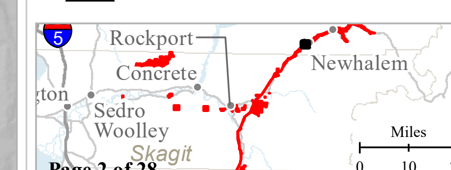

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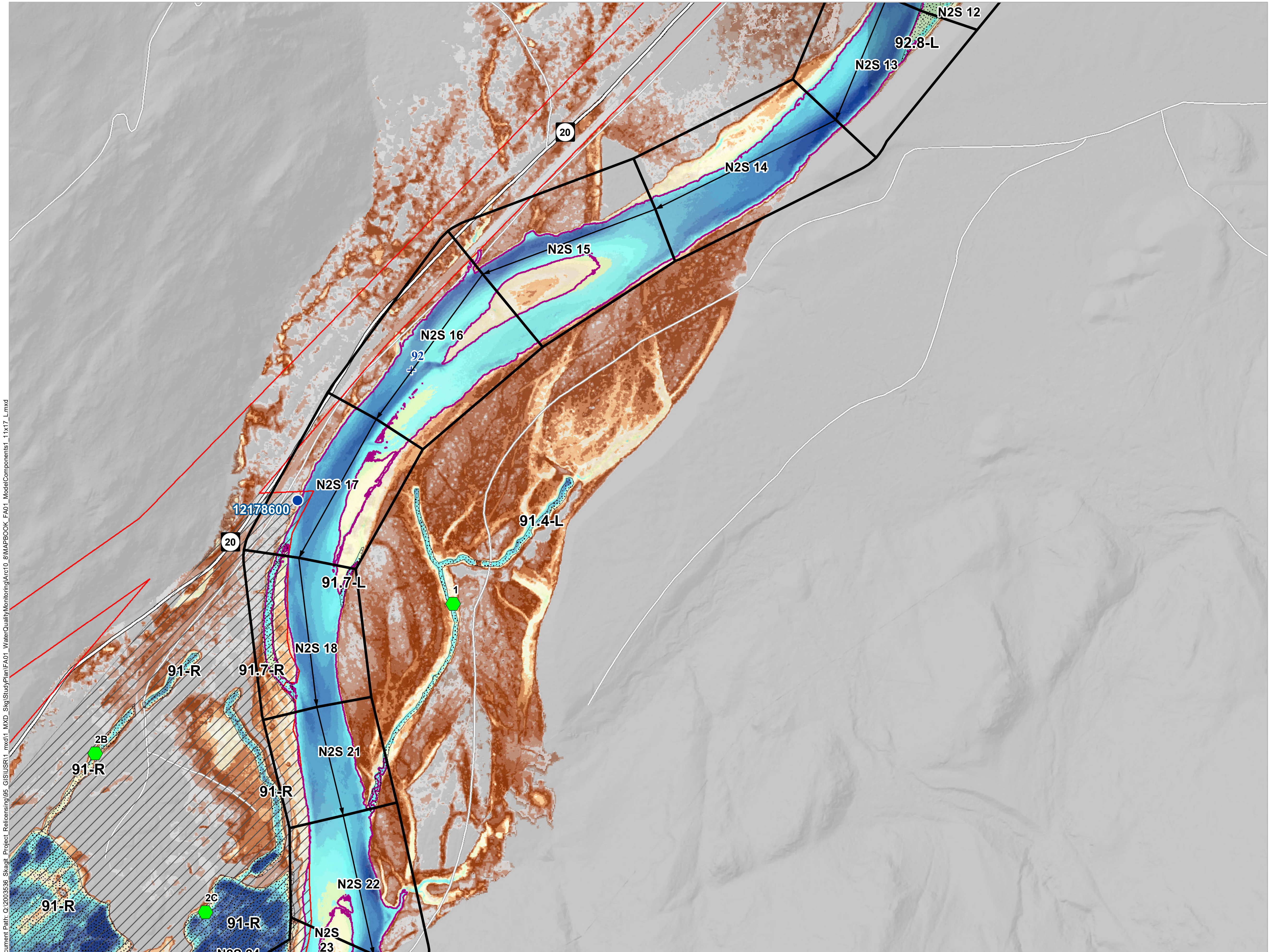

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- Sept. 2016 Wetted Channel
- Simulated March 2021 Inundation (FA-02 Study)

CE-QUAL-W2 Model

- Model Centerline
- Model Segment

Calibration Monitoring Site

- Temperature
- Flow & Stage
- Flow, Stage & Temperature

Relative Elevation Model (2021)

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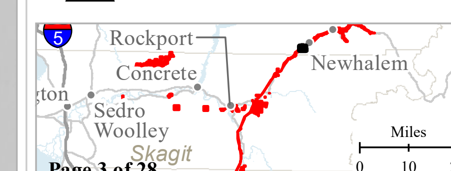

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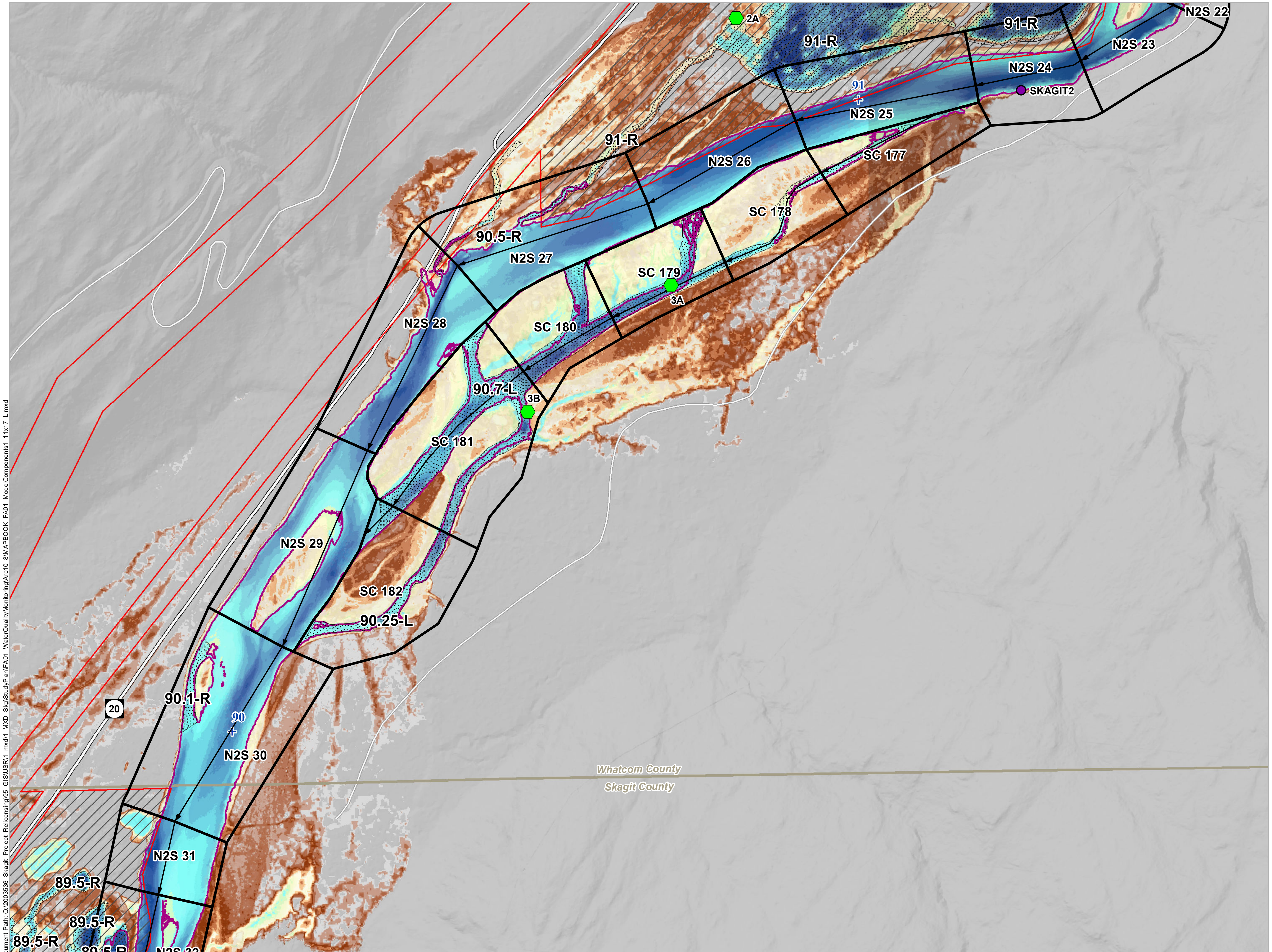

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CE-QUAL-W2 Model

- Model Centerline
- Model Segment

Calibration Monitoring Site

- Temperature
- Flow & Stage
- Flow, Stage & Temperature

Relative Elevation Model (2021)

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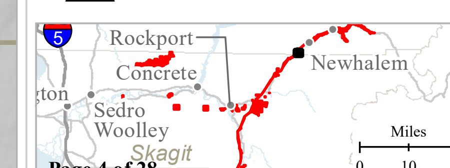

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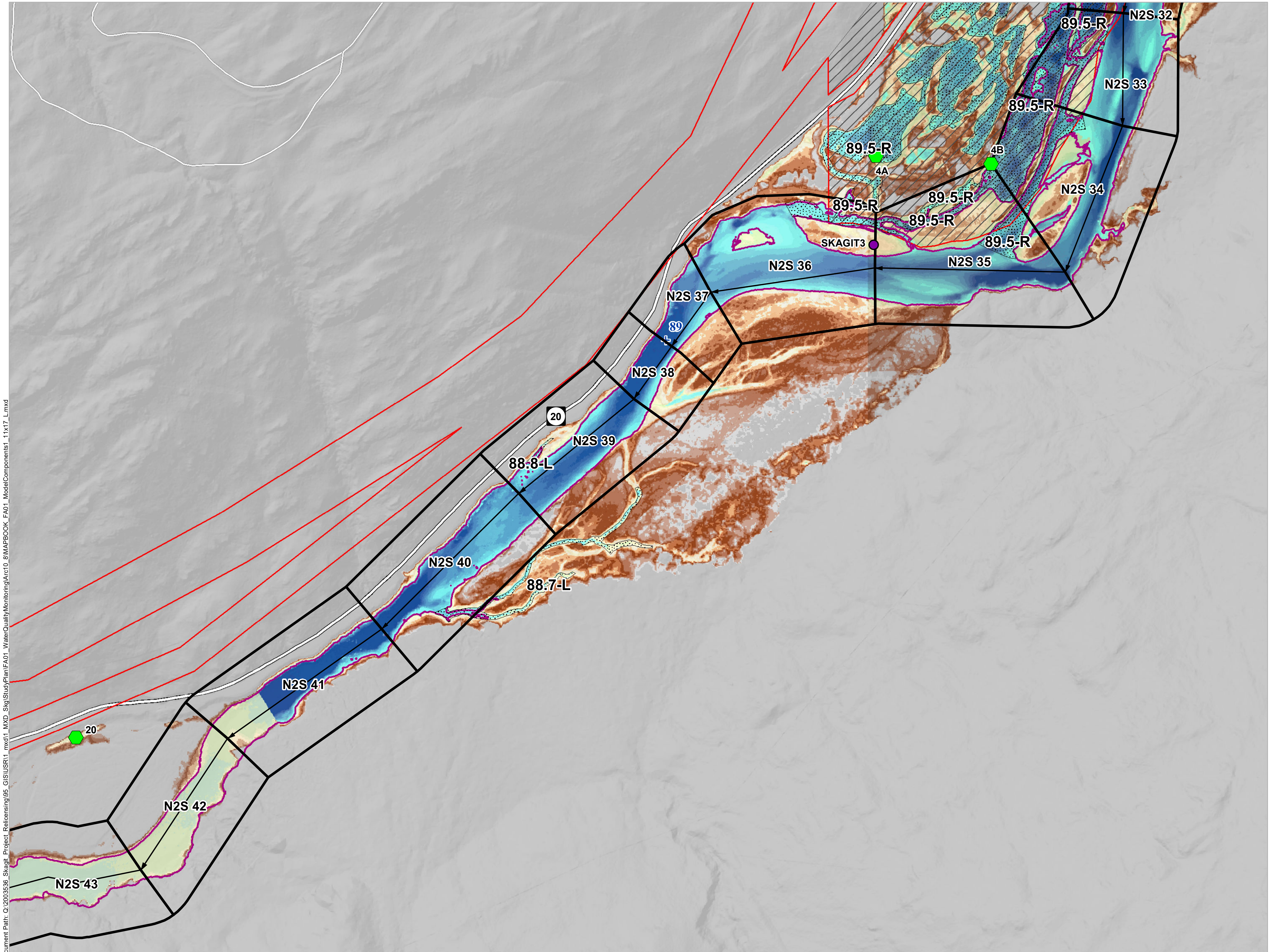

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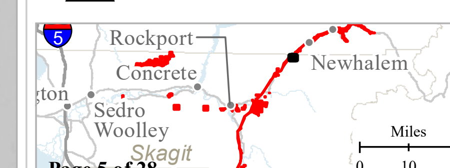

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SKAGIT RIVER HYDROELECTRIC PROJECT (FERC NO. 553)

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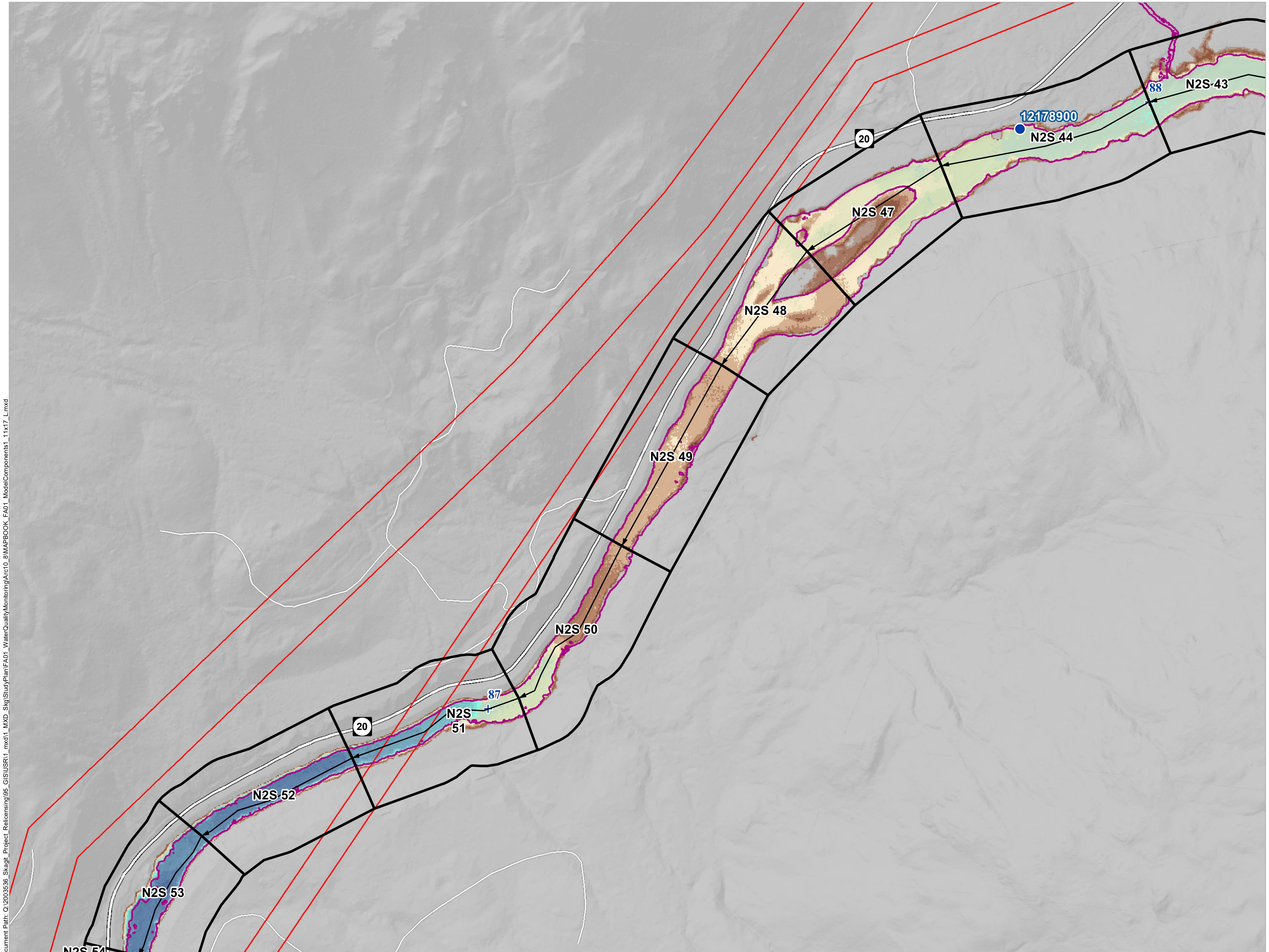

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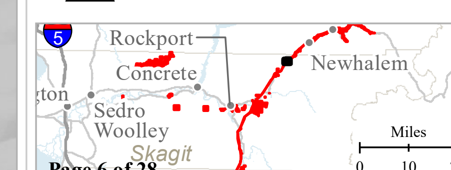
Relative Elevation Model (2021)

< -9	0 - 1
-9 - -8	1 - 2
-8 - -7	2 - 3
-7 - -6	3 - 4
-6 - -5	4 - 5
-5 - -4	5 - 6
-4 - -3	6 - 7
-3 - -2	7 - 8
-2 - -1	8 - 9
-1 - 0	> 9

N

0 300 600 Feet



Seattle City Light

SKAGIT RIVER HYDROELECTRIC PROJECT (FERC NO. 553)

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SKAGIT RIVER CE-QUAL-W2 MODEL SEGMENTS, RELATIVE FLOODPLAIN ELEVATIONS AND SIDE CHANNELS FROM NEWHALEM TO CONCRETE

FERC Project Boundary
Mitigation Parcel
Project River Miles (PRM)
National Park / National Recreation Area Boundary
Stream Gage (USGS)
Level Logger
Side Channel Monitoring Site
Side Channel (GE-04 Study)
Sept. 2016 Wetted Channel
Simulated March 2021 Inundation (FA-02 Study)

CE-QUAL-W2 Model

Model Centerline
Model Segment

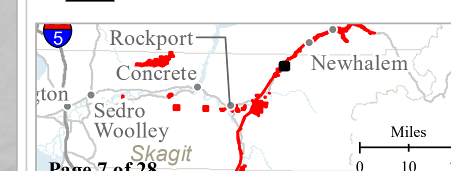
Calibration Monitoring Site

Temperature
Flow & Stage
Flow, Stage & Temperature

Relative Elevation Model (2021)

< -9	0 - 1
-9 - -8	1 - 2
-8 - -7	2 - 3
-7 - -6	3 - 4
-6 - -5	4 - 5
-5 - -4	5 - 6
-4 - -3	6 - 7
-3 - -2	7 - 8
-2 - -1	8 - 9
-1 - 0	> 9

N
0 300 600 Feet



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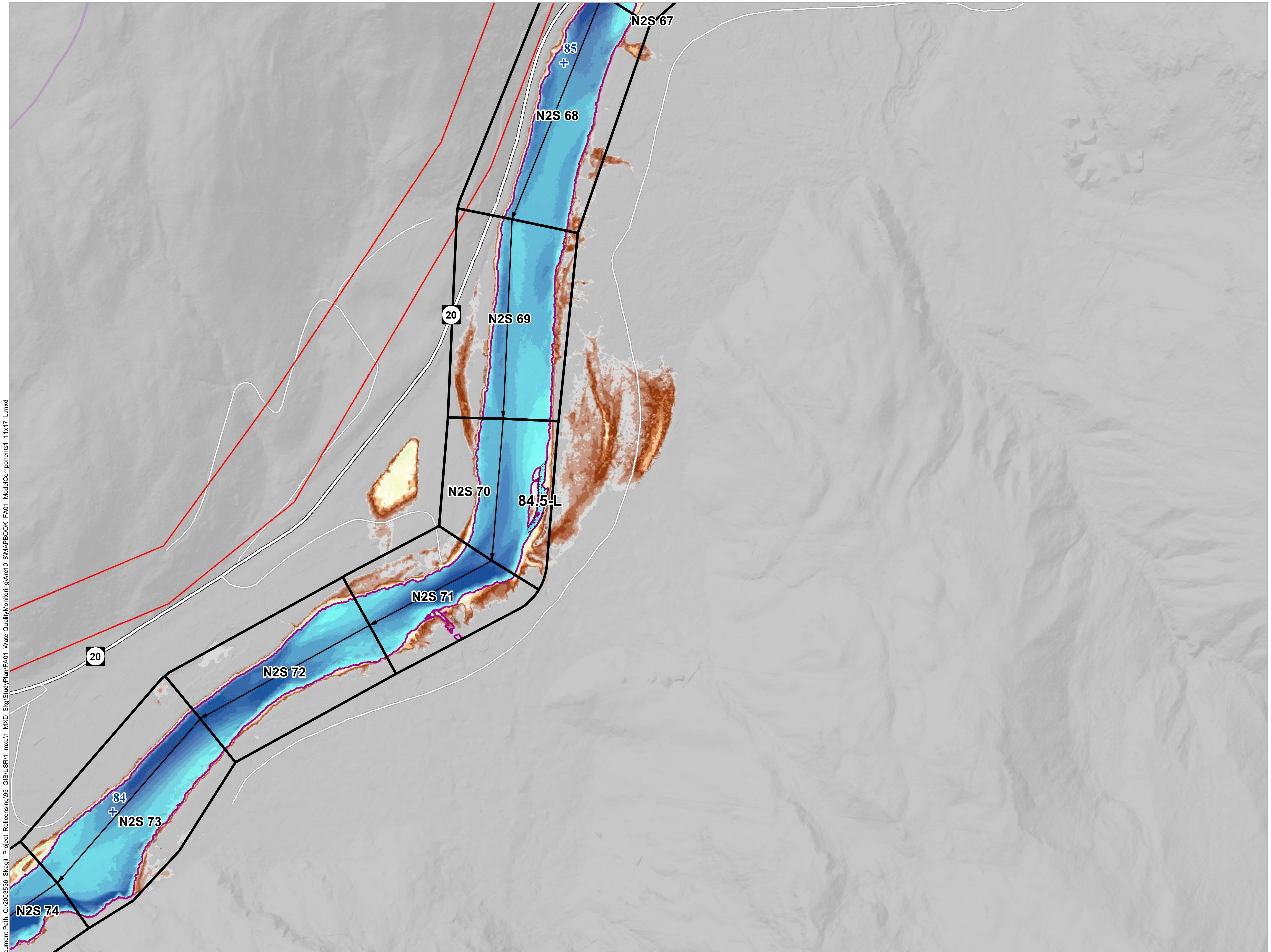

SKAGIT RIVER CE-QUAL-W2 MODEL SEGMENTS, RELATIVE FLOODPLAIN ELEVATIONS AND SIDE CHANNELS FROM NEWHALEM TO CONCRETE

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Model Segment

Calibration Monitoring Site

Temperature
Flow & Stage
Flow, Stage & Temperature

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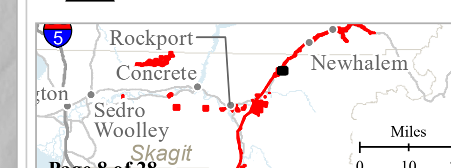
< -9	0 - 1
-9 - -8	1 - 2
-8 - -7	2 - 3
-7 - -6	3 - 4
-6 - -5	4 - 5
-5 - -4	5 - 6
-4 - -3	6 - 7
-3 - -2	7 - 8
-2 - -1	8 - 9
-1 - 0	> 9

N

0 300 600 Feet



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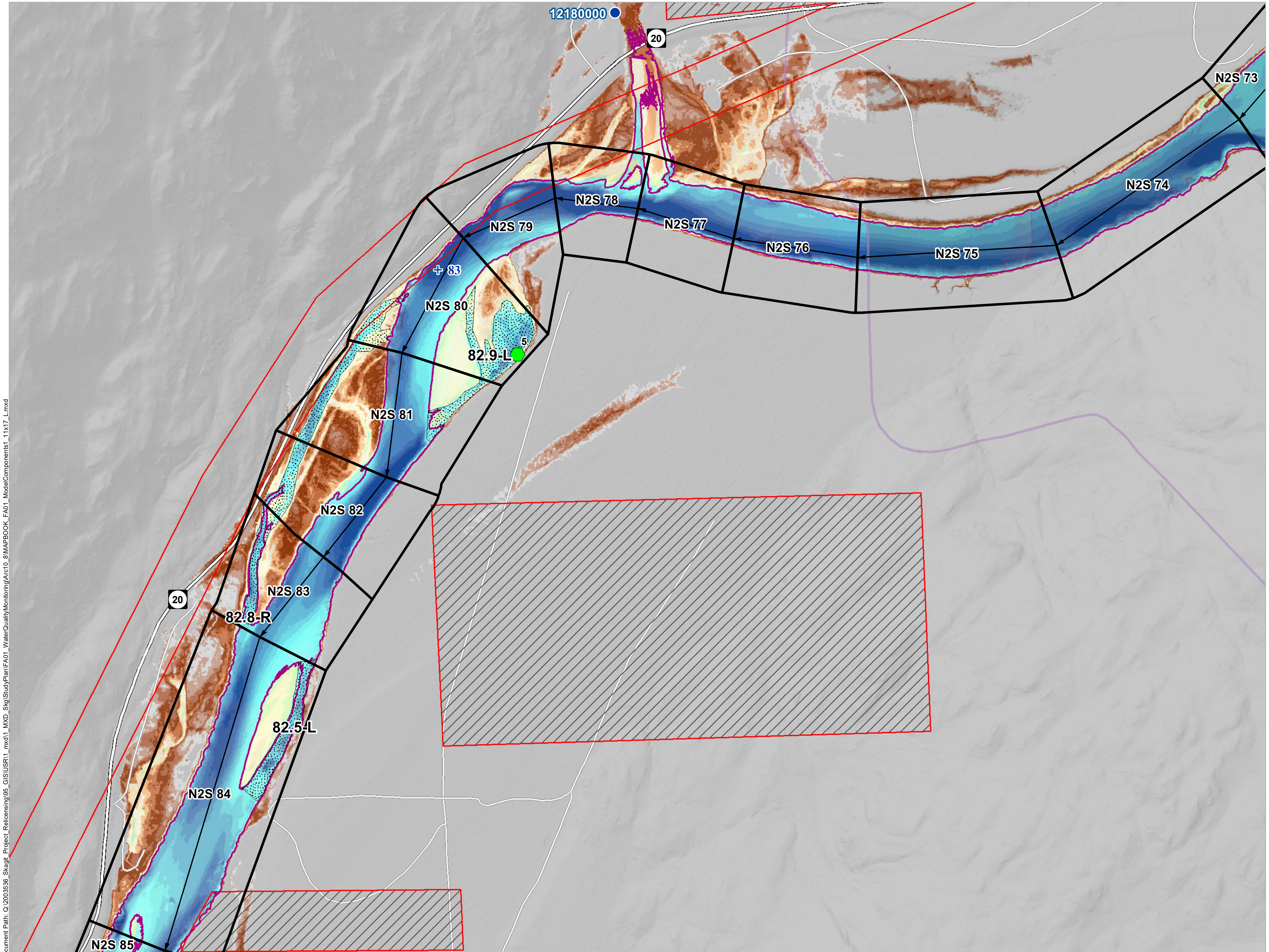

SKAGIT RIVER CE-QUAL-W2 MODEL SEGMENTS, RELATIVE FLOODPLAIN ELEVATIONS AND SIDE CHANNELS FROM NEWHALEM TO CONCRETE

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CE-QUAL-W2 Model

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Calibration Monitoring Site

- Temperature
- Flow & Stage
- Flow, Stage & Temperature

Relative Elevation Model (2021)

< -9	0 - 1
-9 - -8	1 - 2
-8 - -7	2 - 3
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-6 - -5	4 - 5
-5 - -4	5 - 6
-4 - -3	6 - 7
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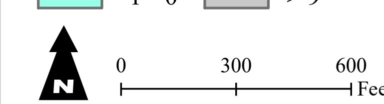
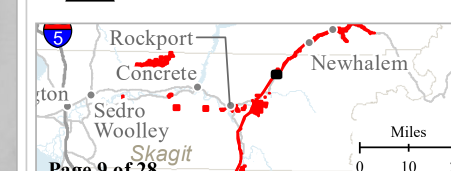
-2 - -1	8 - 9
-1 - 0	> 9





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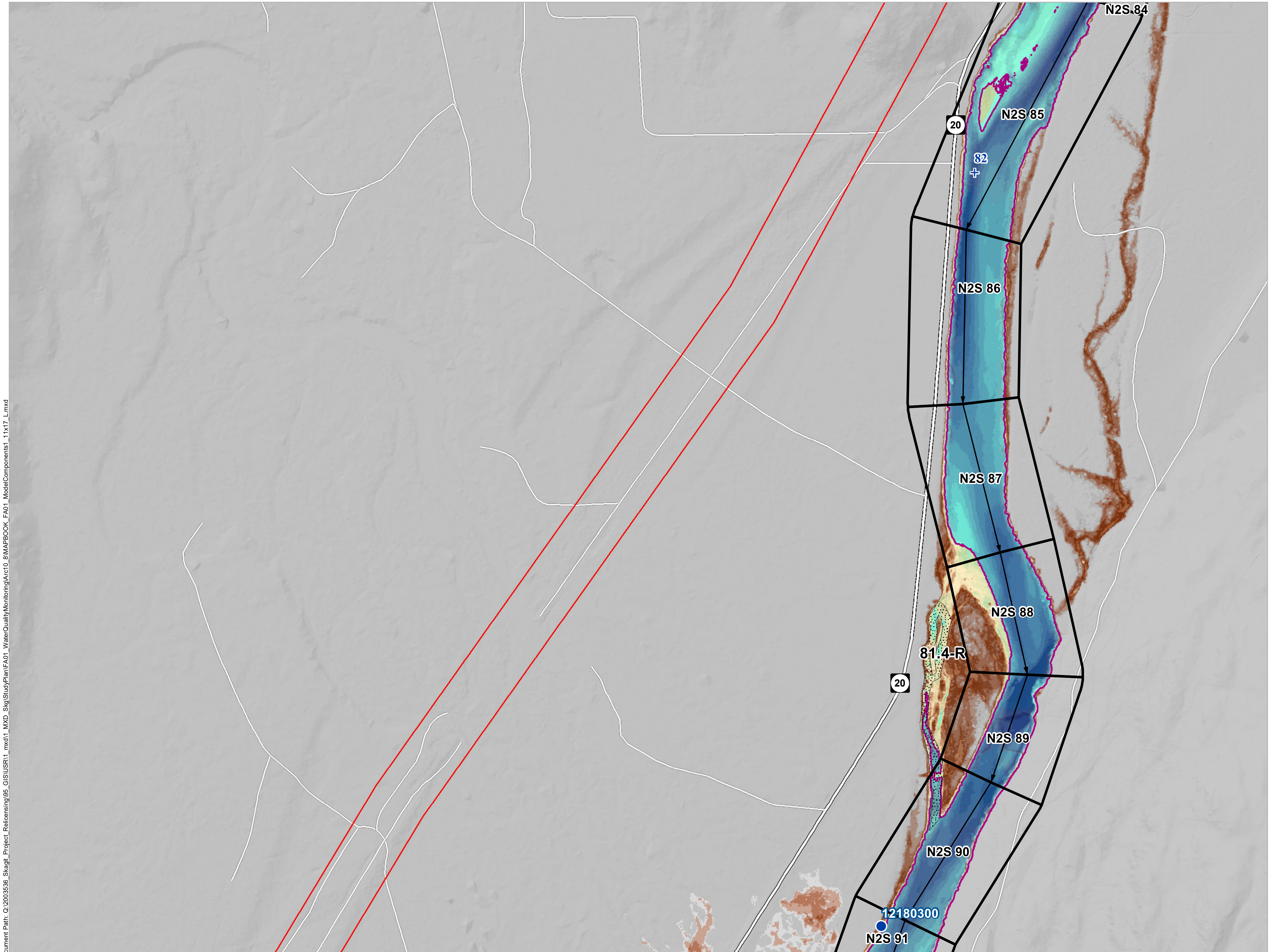

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< -9	0 - 1
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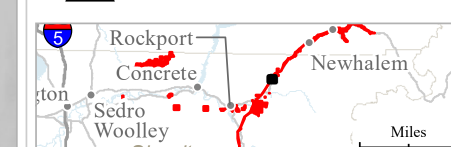
-5 - -4	5 - 6
-4 - -3	6 - 7
-3 - -2	7 - 8
-2 - -1	8 - 9
-1 - 0	> 9

N

0 300 600 Feet



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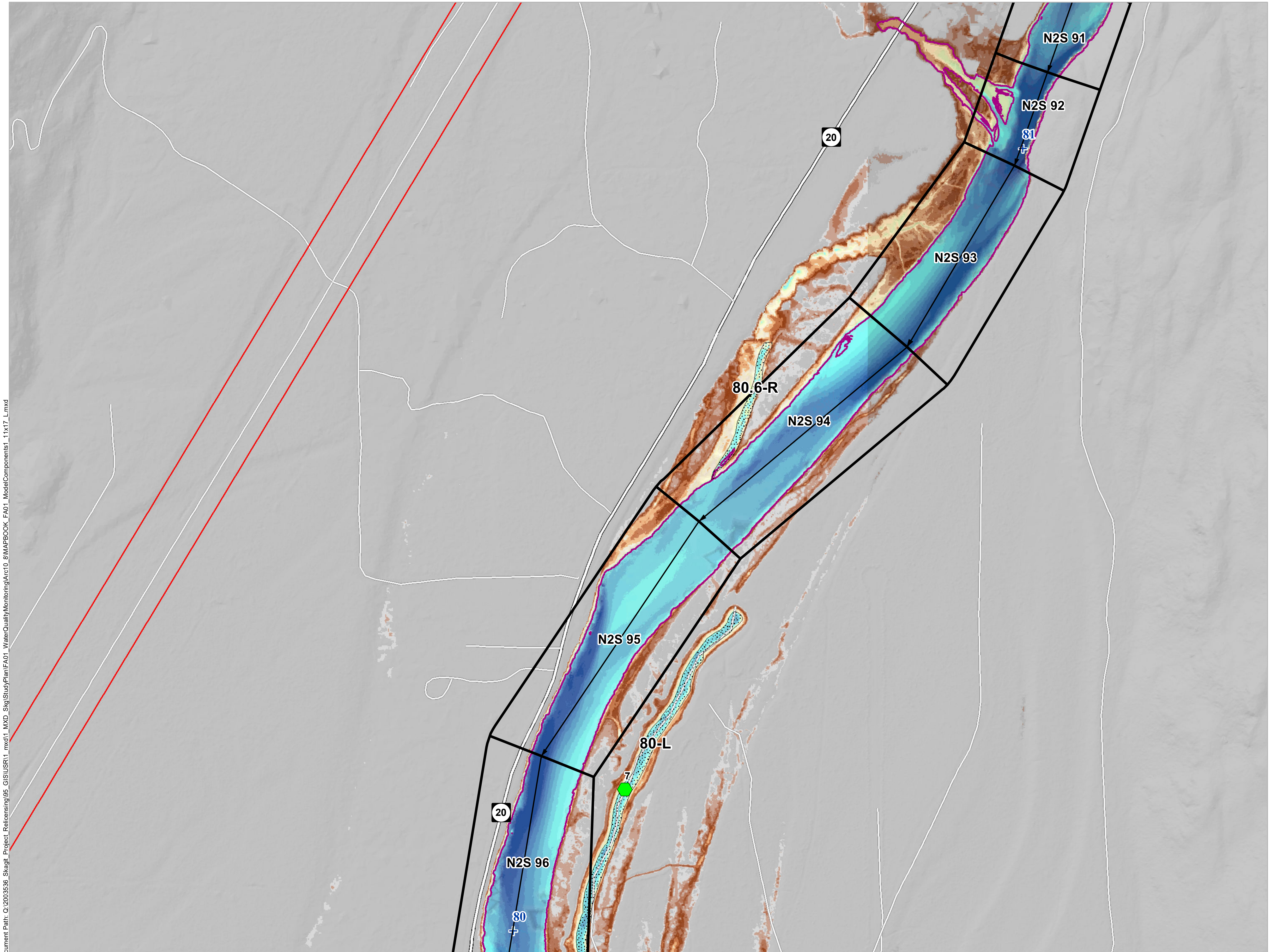

SKAGIT RIVER CE-QUAL-W2 MODEL SEGMENTS, RELATIVE FLOODPLAIN ELEVATIONS AND SIDE CHANNELS FROM NEWHALEM TO CONCRETE

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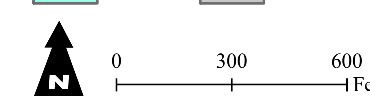
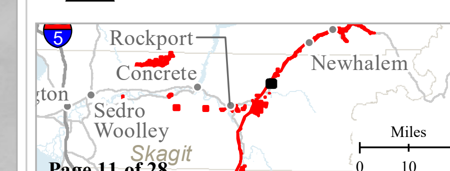
< -9	0 - 1
-9 - -8	1 - 2
-8 - -7	2 - 3
-7 - -6	3 - 4
-6 - -5	4 - 5
-5 - -4	5 - 6
-4 - -3	6 - 7
-3 - -2	7 - 8
-2 - -1	8 - 9
-1 - 0	> 9





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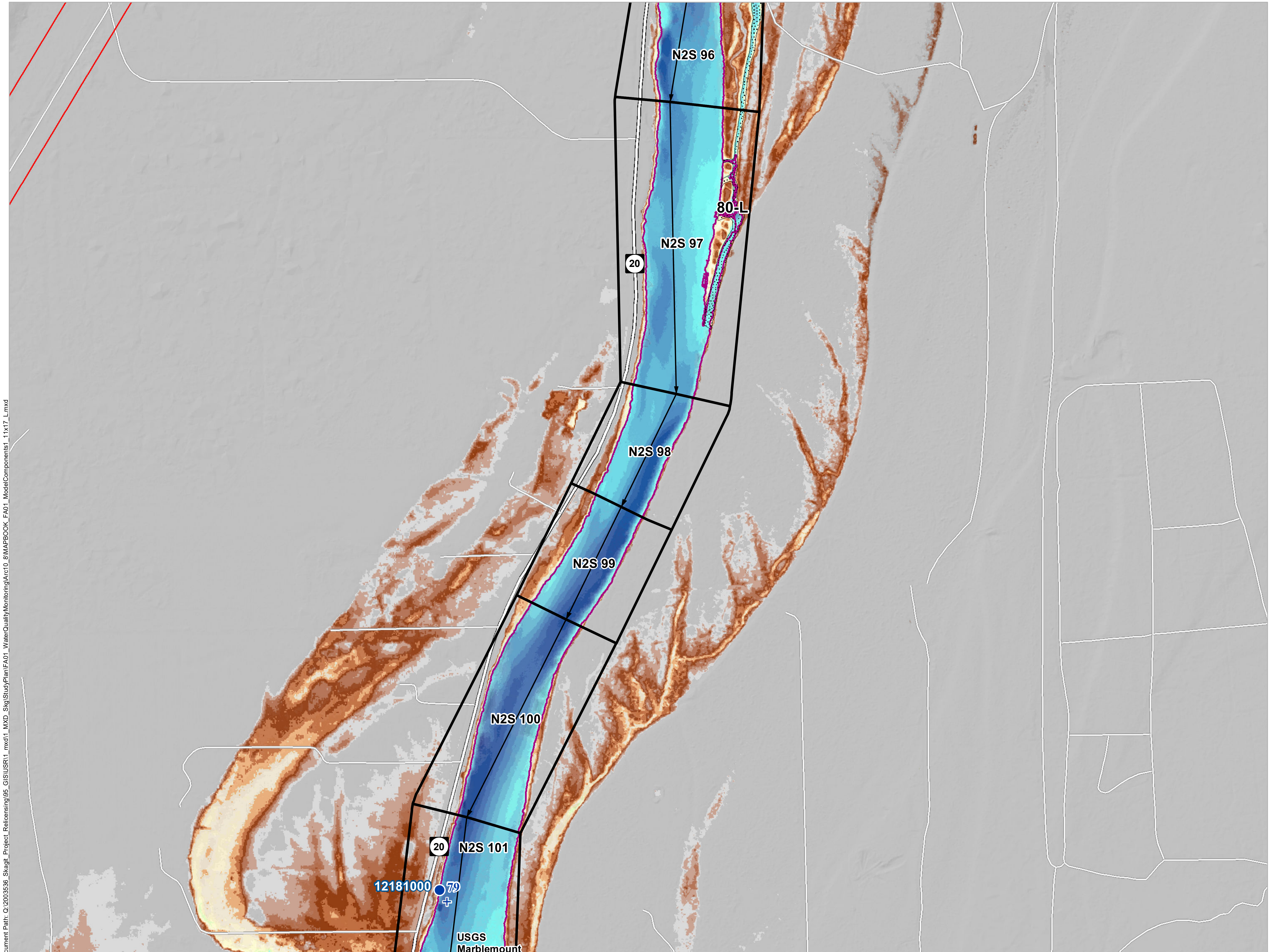

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CE-QUAL-W2 Model

- Model Centerline
- Model Segment

Calibration Monitoring Site

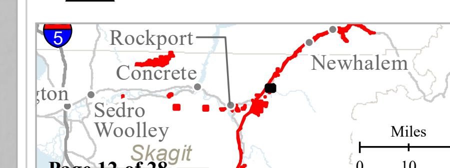
- Temperature
- Flow & Stage
- Flow, Stage & Temperature

Relative Elevation Model (2021)

< -9	0 - 1
-9 - -8	1 - 2
-8 - -7	2 - 3
-7 - -6	3 - 4
-6 - -5	4 - 5
-5 - -4	5 - 6
-4 - -3	6 - 7
-3 - -2	7 - 8
-2 - -1	8 - 9
-1 - 0	> 9

N

0 300 600 Feet



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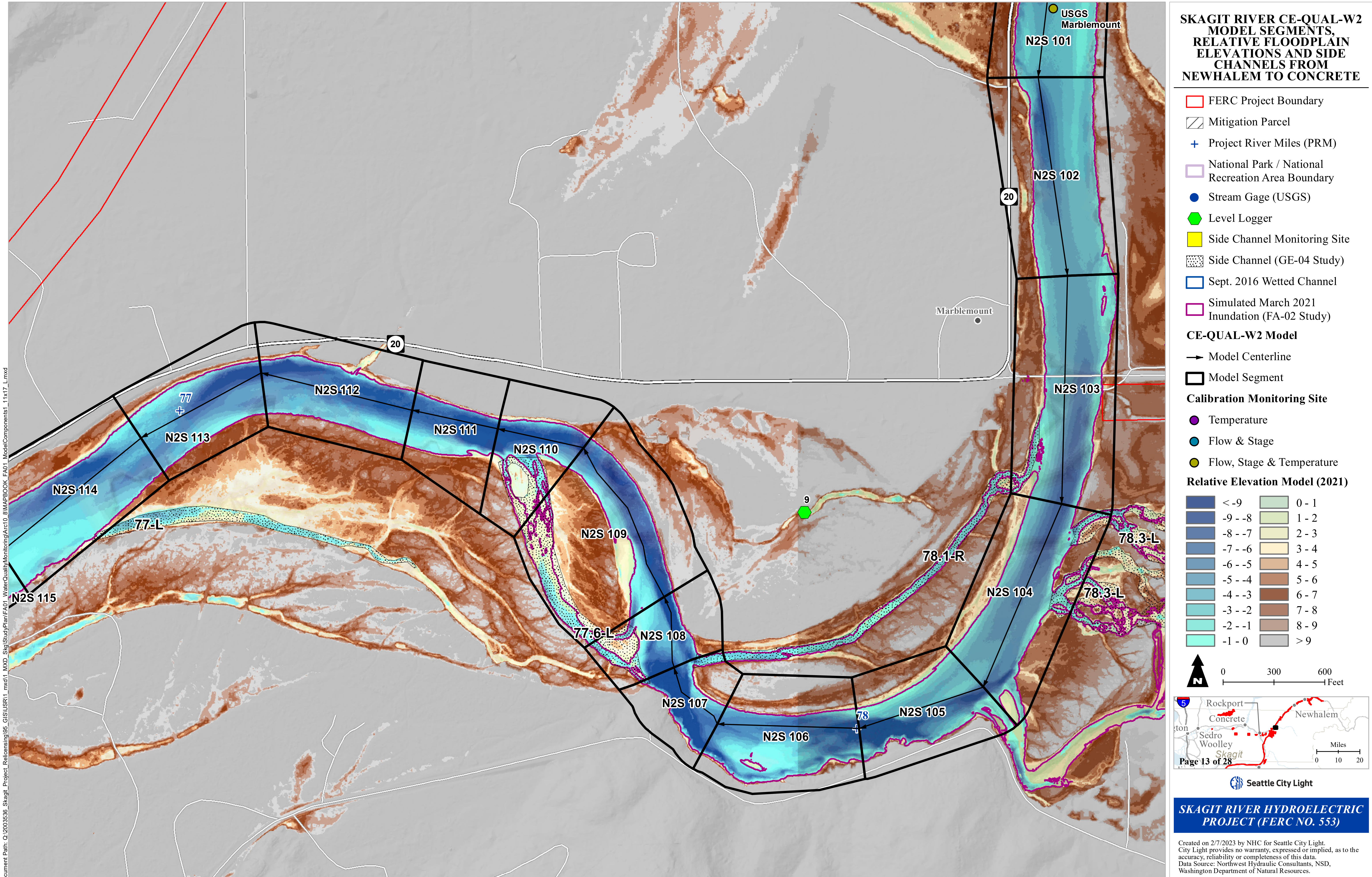
SKAGIT RIVER CE-QUAL-W2 MODEL SEGMENTS, RELATIVE FLOODPLAIN ELEVATIONS AND SIDE CHANNELS FROM NEWHALEM TO CONCRETE
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Relative Elevation Model (2021)
< -9
-9 - -8
-8 - -7
-7 - -6
-6 - -5
-5 - -4
-4 - -3
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-2 - -1
-1 - 0
0 - 1
1 - 2
2 - 3
3 - 4
4 - 5
5 - 6
6 - 7
7 - 8
8 - 9
> 9
0
300
600
Feet
Rockport
Concrete
Newhalem
Sedro Woolley
Skagit
Miles
0
10
20
Page 13 of 28
Seattle City Light
SKAGIT RIVER HYDROELECTRIC PROJECT (FERC NO. 553)
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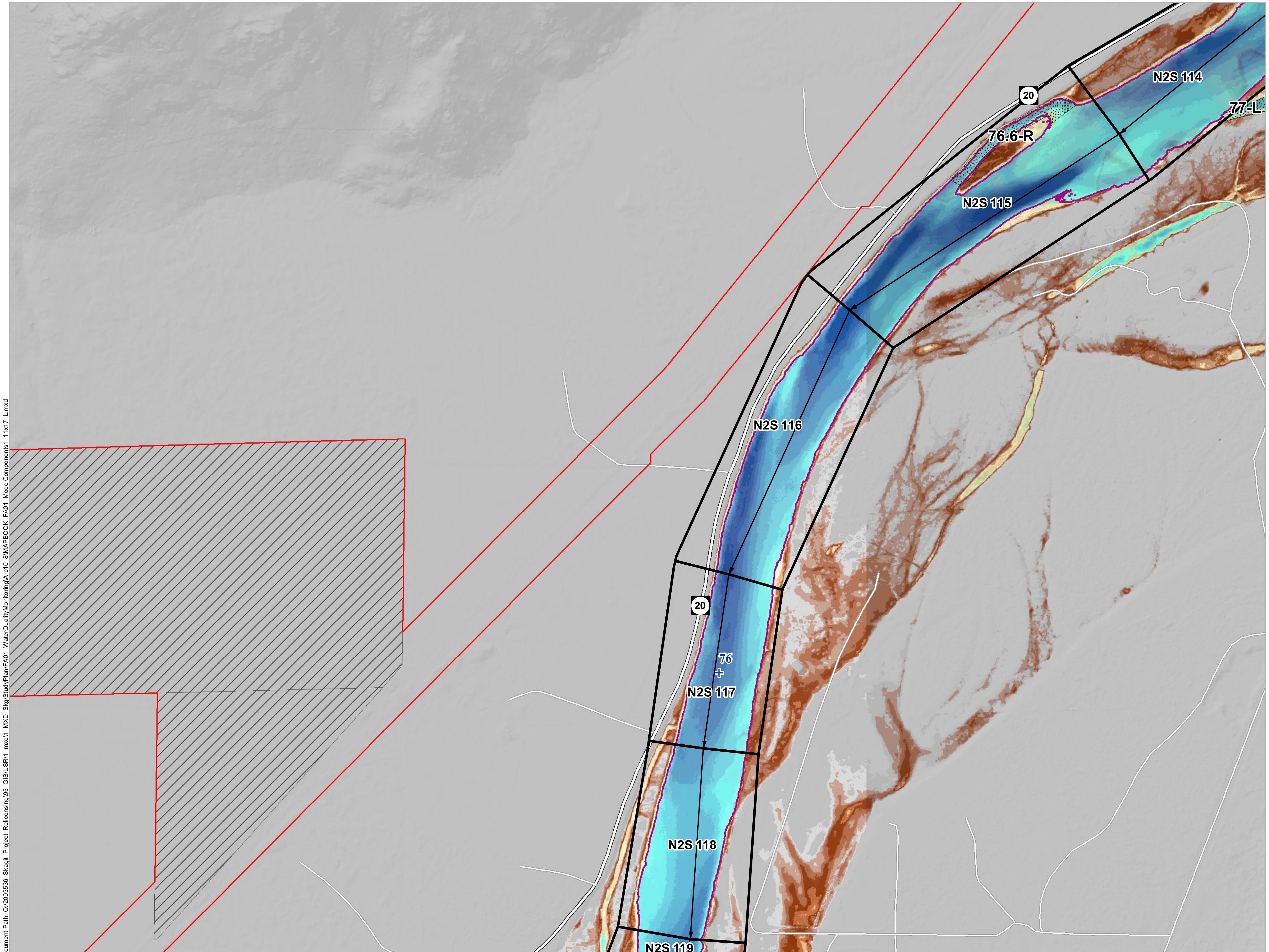
USGS Marblemount
Marblemount
N2S 101
N2S 102
N2S 103
N2S 104
N2S 105
N2S 106
N2S 107
N2S 108
N2S 109
N2S 110
N2S 111
N2S 112
N2S 113
N2S 114
N2S 115
20
77
78
9
77-L
77.6-L
78.1-R
78.3-L



SKAGIT RIVER CE-QUAL-W2 MODEL SEGMENTS, RELATIVE FLOODPLAIN ELEVATIONS AND SIDE CHANNELS FROM NEWHALEM TO CONCRETE

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< -9	0 - 1
-9 - -8	1 - 2
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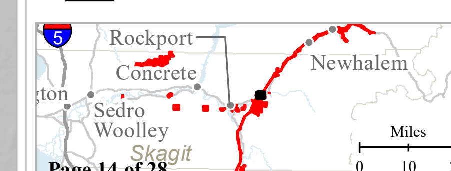
-6 - -5	4 - 5
-5 - -4	5 - 6
-4 - -3	6 - 7
-3 - -2	7 - 8
-2 - -1	8 - 9
-1 - 0	> 9

N

0 300 600 Feet



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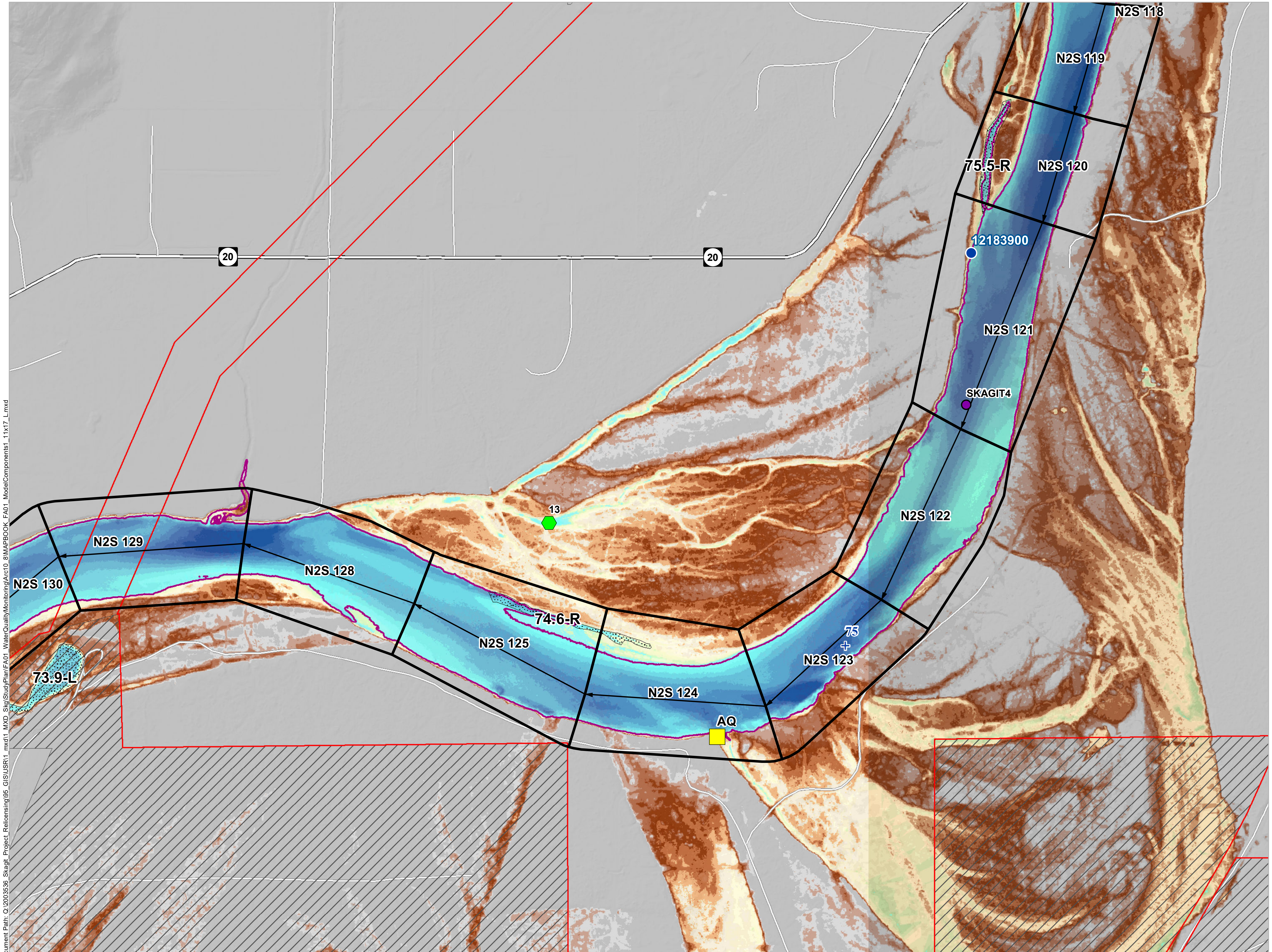

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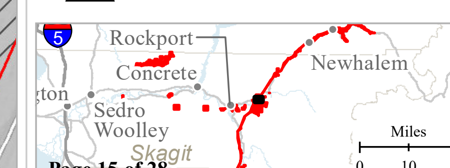
-4 - -3	6 - 7
-3 - -2	7 - 8
-2 - -1	8 - 9
-1 - 0	> 9

N

0 300 600 Feet



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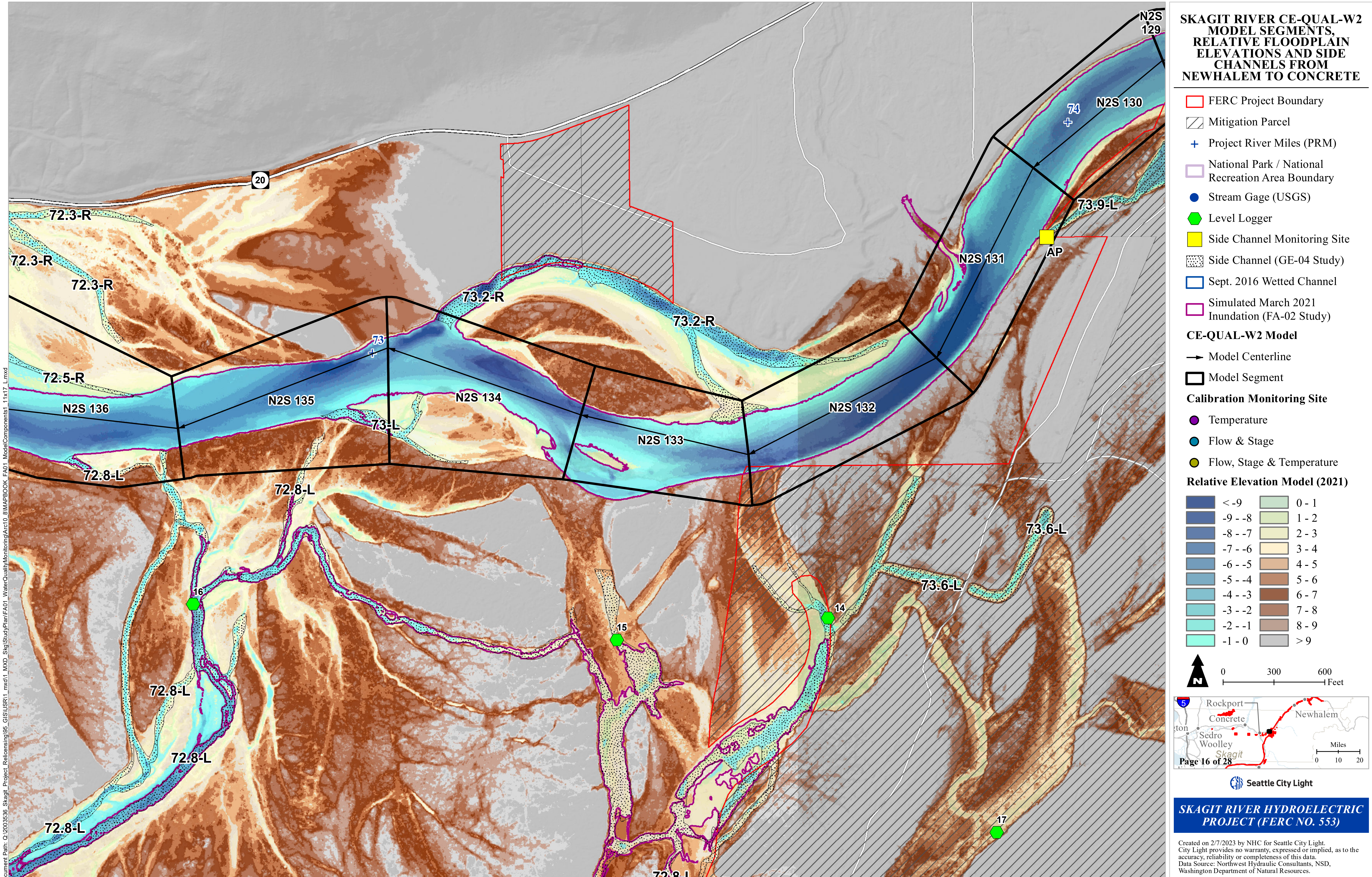

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< -9
-9 - -8
-8 - -7
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-4 - -3
-3 - -2
-2 - -1
-1 - 0
0 - 1
1 - 2
2 - 3
3 - 4
4 - 5
5 - 6
6 - 7
7 - 8
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N
0
300
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Feet
Rockport
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Newhalem
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0
10
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Page 16 of 28
Seattle City Light
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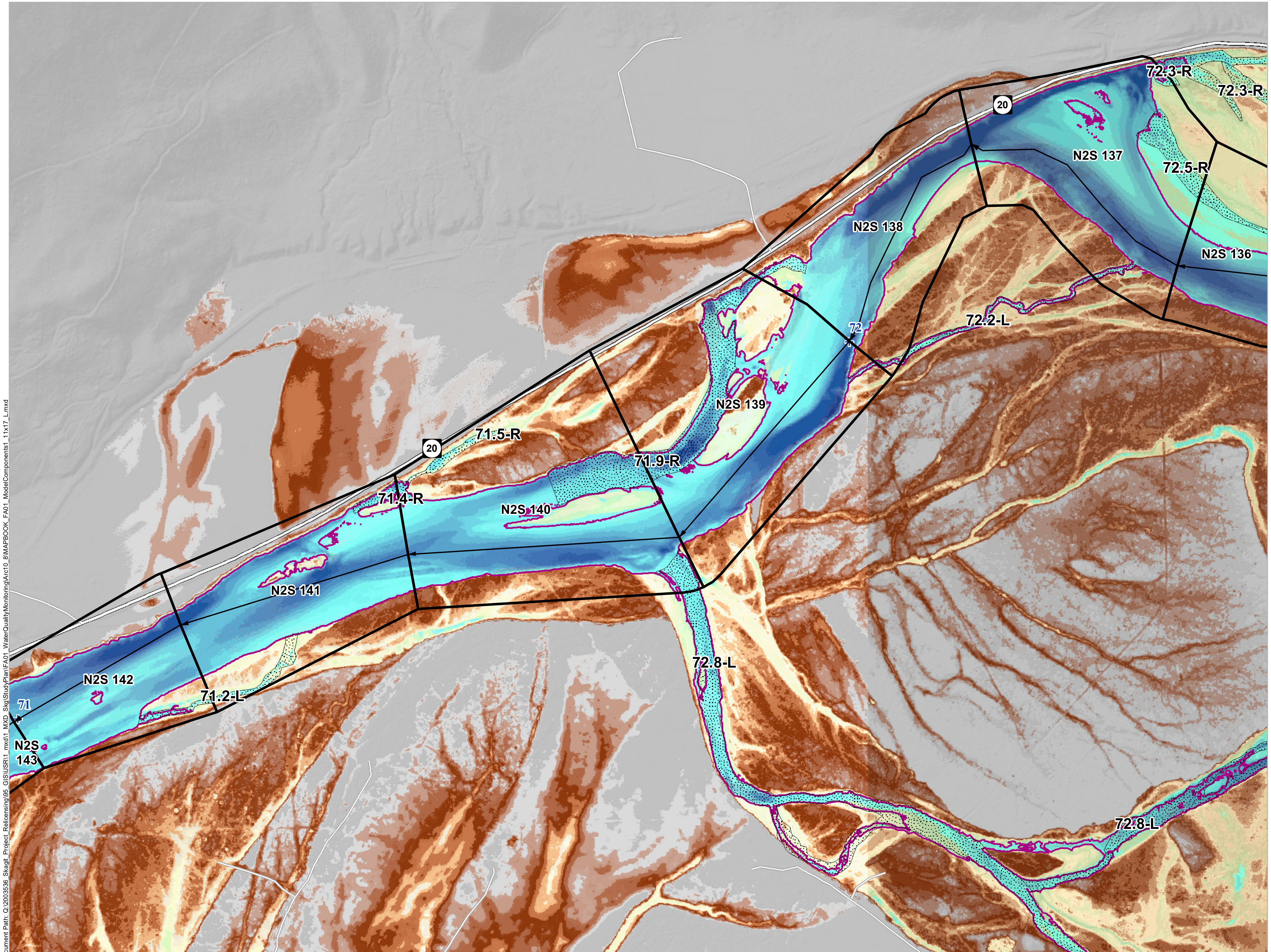
20
N2S 129
N2S 130
N2S 131
N2S 132
N2S 133
N2S 134
N2S 135
N2S 136
73
74
AP
72.3-R
72.5-R
73.2-R
73-L
72.8-L
73.6-L
73.9-L
14
15
16
17



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-2 - -1	8 - 9
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N

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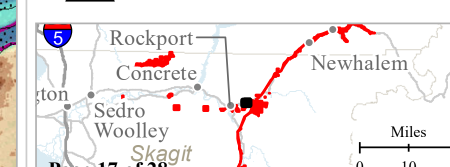

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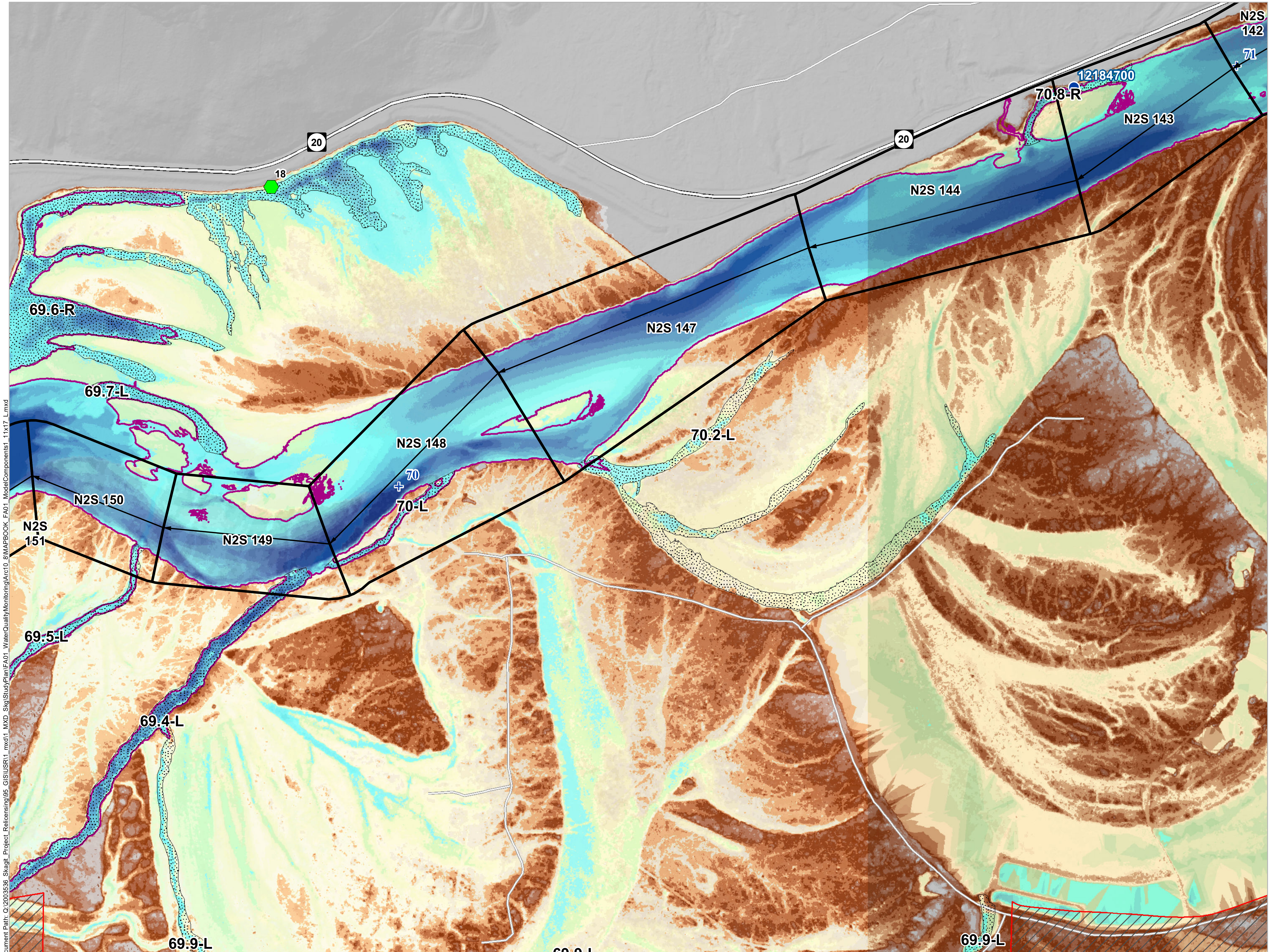

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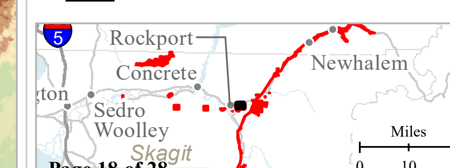
N
0 300 600 Feet



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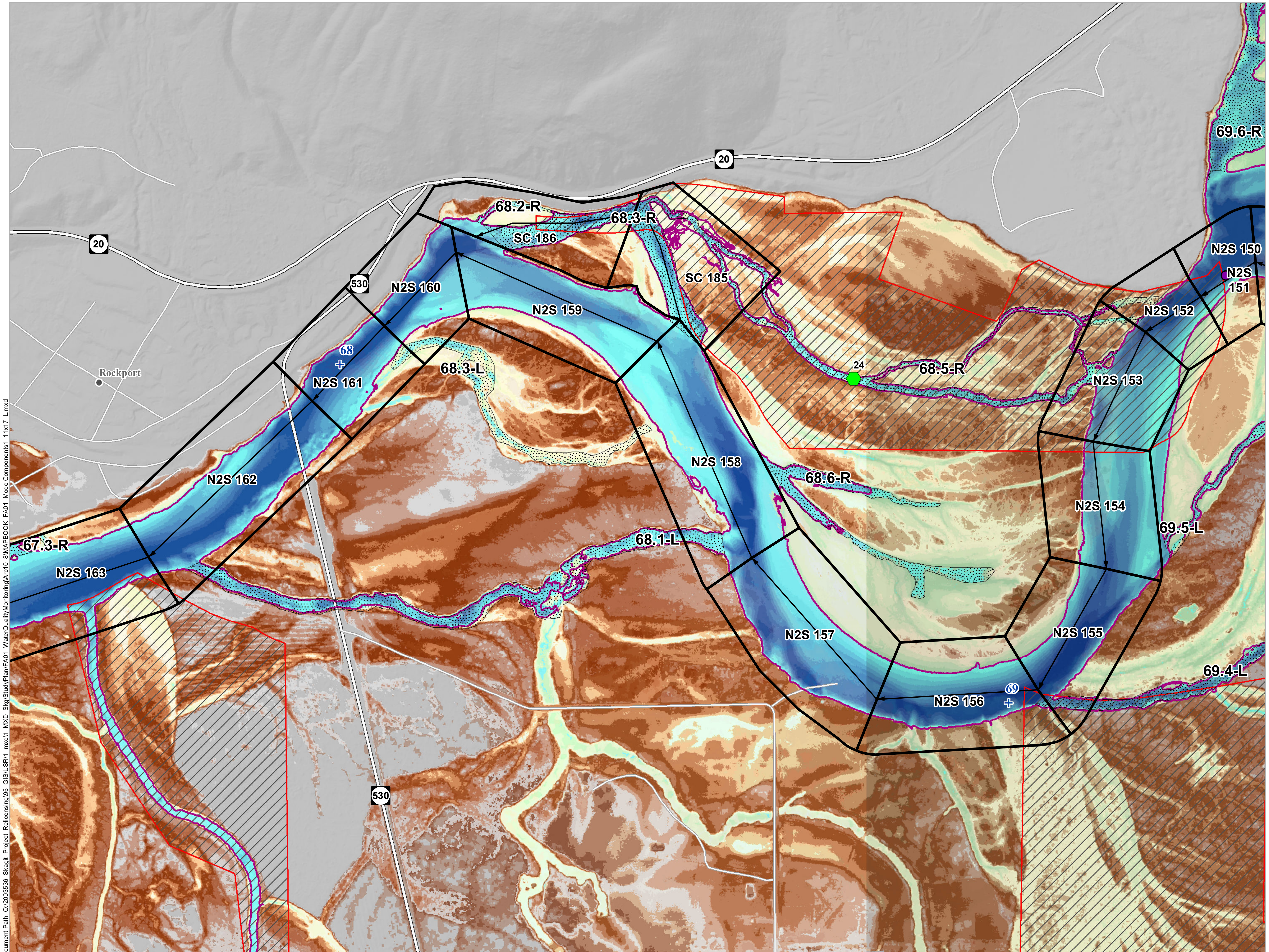
SKAGIT RIVER CE-QUAL-W2 MODEL SEGMENTS, RELATIVE FLOODPLAIN ELEVATIONS AND SIDE CHANNELS FROM NEWHALEM TO CONCRETE



FERC Project Boundary
Mitigation Parcel
Project River Miles (PRM)
National Park / National Recreation Area Boundary
Stream Gage (USGS)
Level Logger
Side Channel Monitoring Site
Side Channel (GE-04 Study)
Sept. 2016 Wetted Channel
Simulated March 2021 Inundation (FA-02 Study)

CE-QUAL-W2 Model

Model Centerline
Model Segment

Calibration Monitoring Site

Temperature
Flow & Stage
Flow, Stage & Temperature

Relative Elevation Model (2021)

< -9	0 - 1
-9 - -8	1 - 2
-8 - -7	2 - 3
-7 - -6	3 - 4
-6 - -5	4 - 5
-5 - -4	5 - 6
-4 - -3	6 - 7
-3 - -2	7 - 8
-2 - -1	8 - 9
-1 - 0	> 9

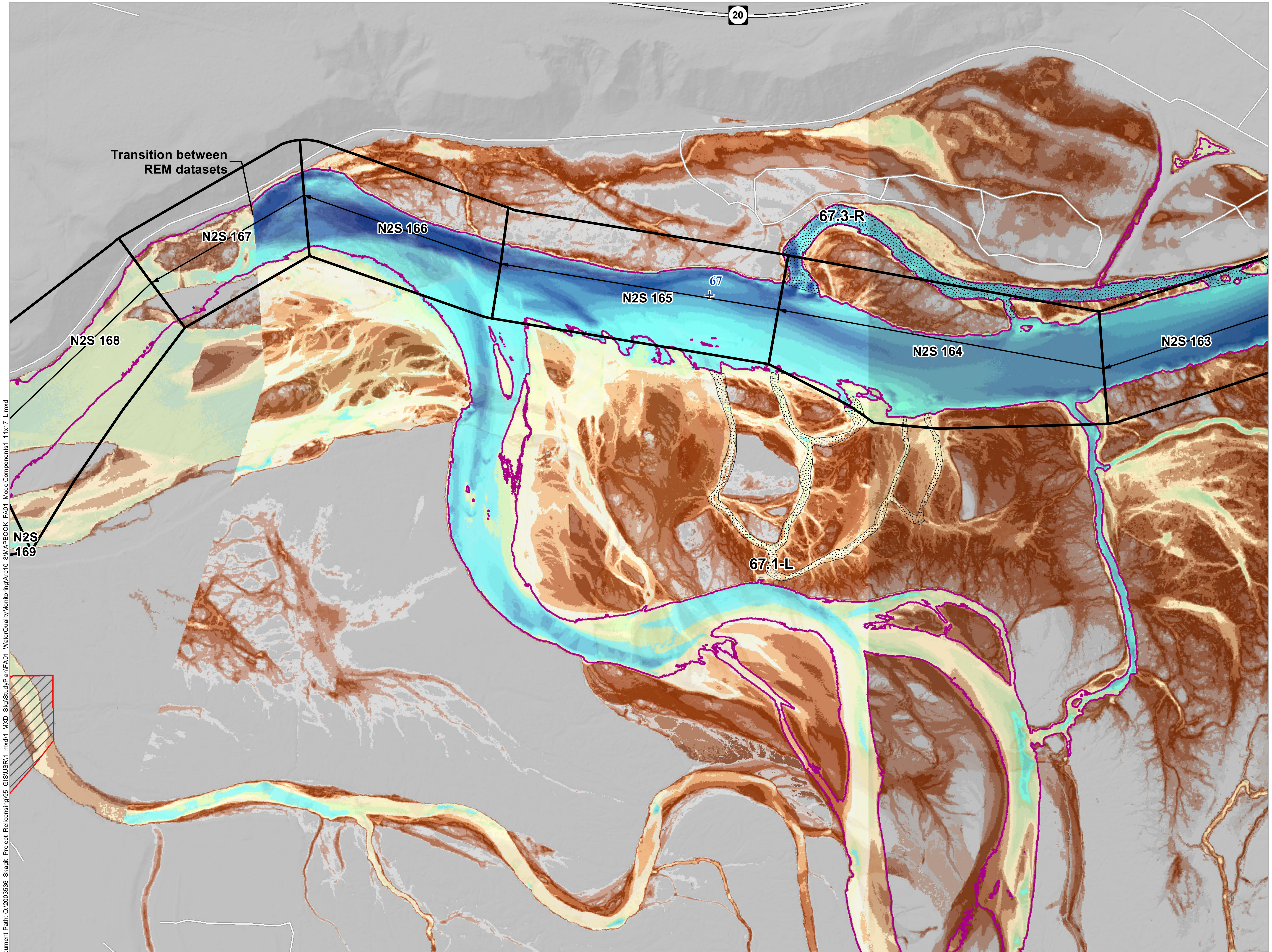
N
0 300 600 Feet

Rockport
Concrete
Newhalem
Sedro Woolley
Skagit
Miles
0 10 20

Seattle City Light

SKAGIT RIVER HYDROELECTRIC PROJECT (FERC NO. 553)

SKAGIT RIVER CE-QUAL-W2 MODEL SEGMENTS, RELATIVE FLOODPLAIN ELEVATIONS AND SIDE CHANNELS FROM NEWHALEM TO CONCRETE



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CE-QUAL-W2 Model

- Model Centerline
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Calibration Monitoring Site

- Temperature
- Flow & Stage
- Flow, Stage & Temperature

Relative Elevation Model (2021)

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-3 - -2	7 - 8
-2 - -1	8 - 9
-1 - 0	> 9

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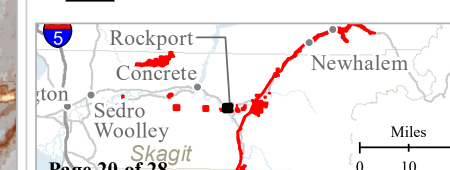

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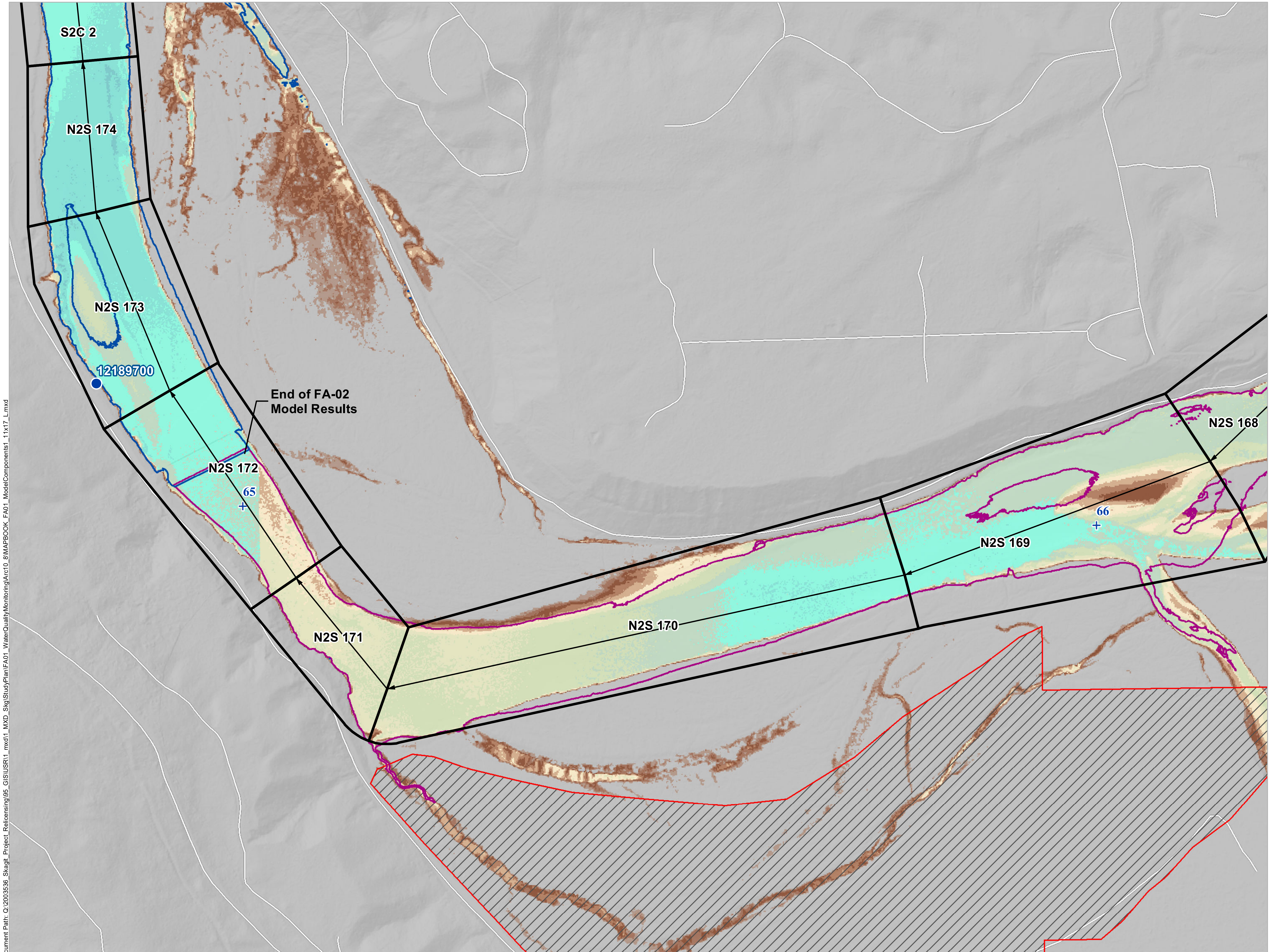

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CE-QUAL-W2 Model

- Model Centerline
- Model Segment

Calibration Monitoring Site

- Temperature
- Flow & Stage
- Flow, Stage & Temperature

Relative Elevation Model (2021)

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-4 - -3	6 - 7
-3 - -2	7 - 8
-2 - -1	8 - 9
-1 - 0	> 9

N
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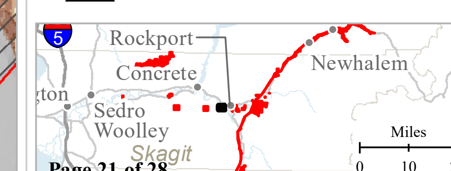

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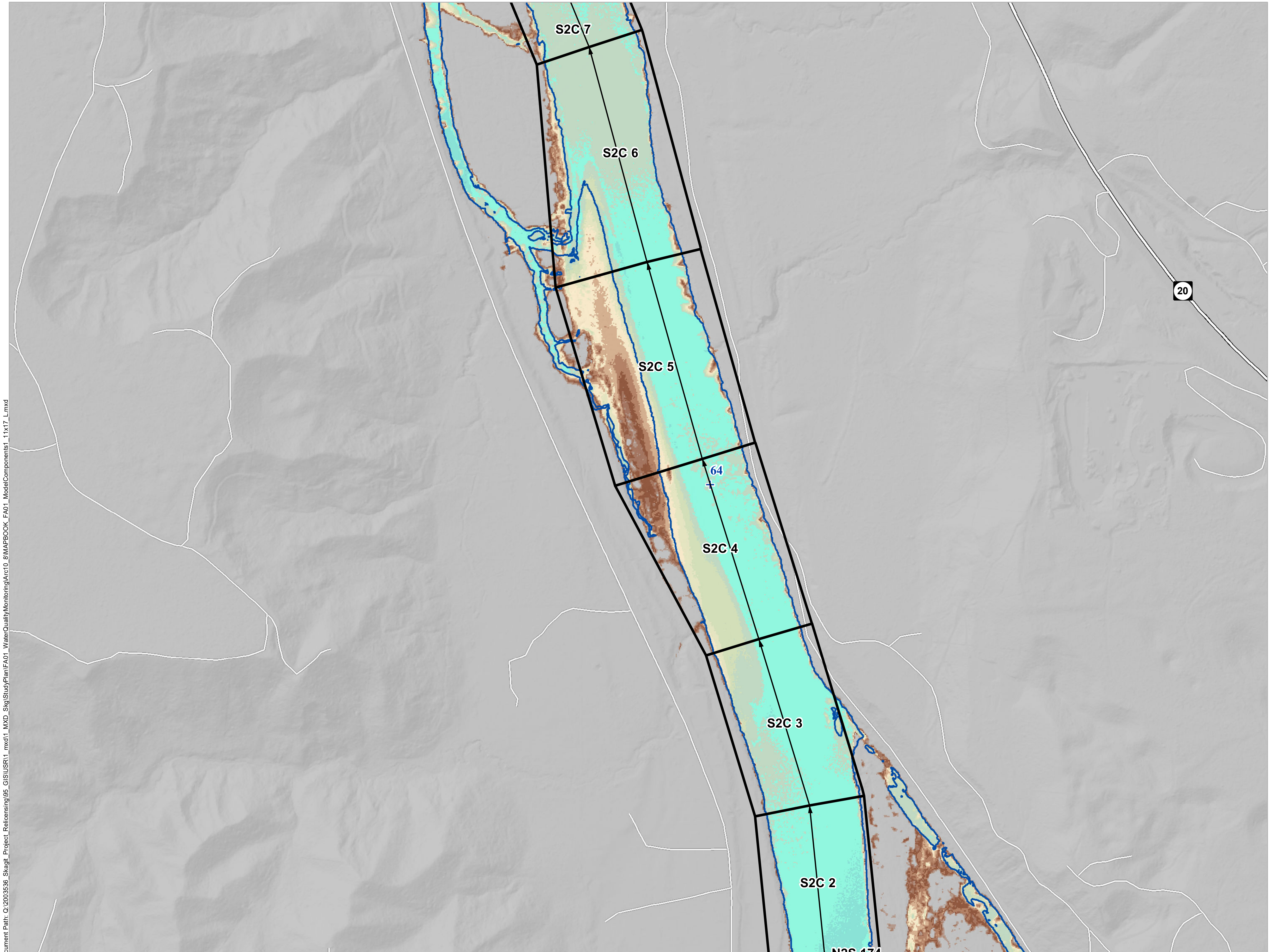

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CE-QUAL-W2 Model

- Model Centerline
- Model Segment

Calibration Monitoring Site

- Temperature
- Flow & Stage
- Flow, Stage & Temperature

Relative Elevation Model (2021)

< -9	0 - 1
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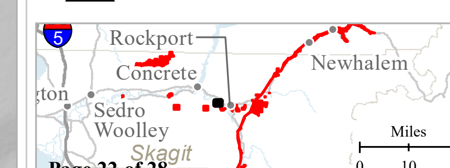
-5 - -4	5 - 6
-4 - -3	6 - 7
-3 - -2	7 - 8
-2 - -1	8 - 9
-1 - 0	> 9

N

0 300 600 Feet



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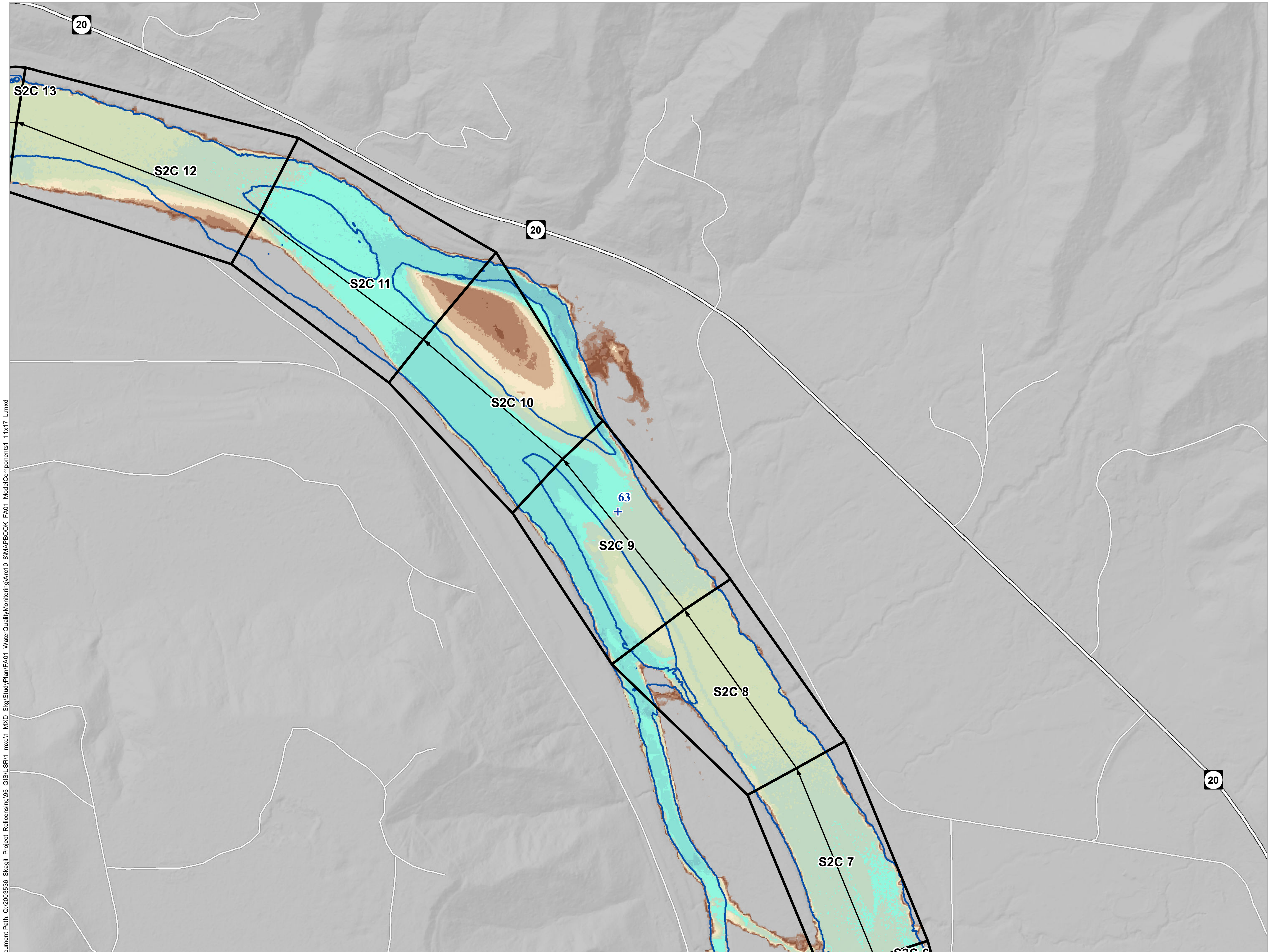

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CE-QUAL-W2 Model

- Model Centerline
- Model Segment

Calibration Monitoring Site

- Temperature
- Flow & Stage
- Flow, Stage & Temperature

Relative Elevation Model (2021)

< -9	0 - 1
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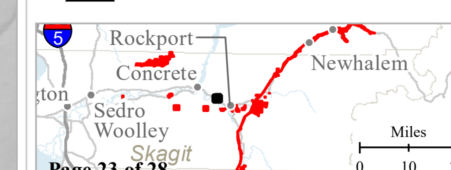
-3 - -2	7 - 8
-2 - -1	8 - 9
-1 - 0	> 9

N

0 300 600 Feet



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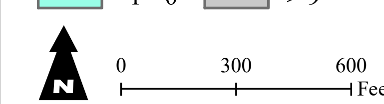

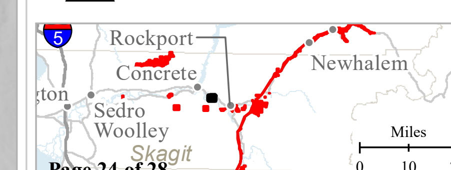

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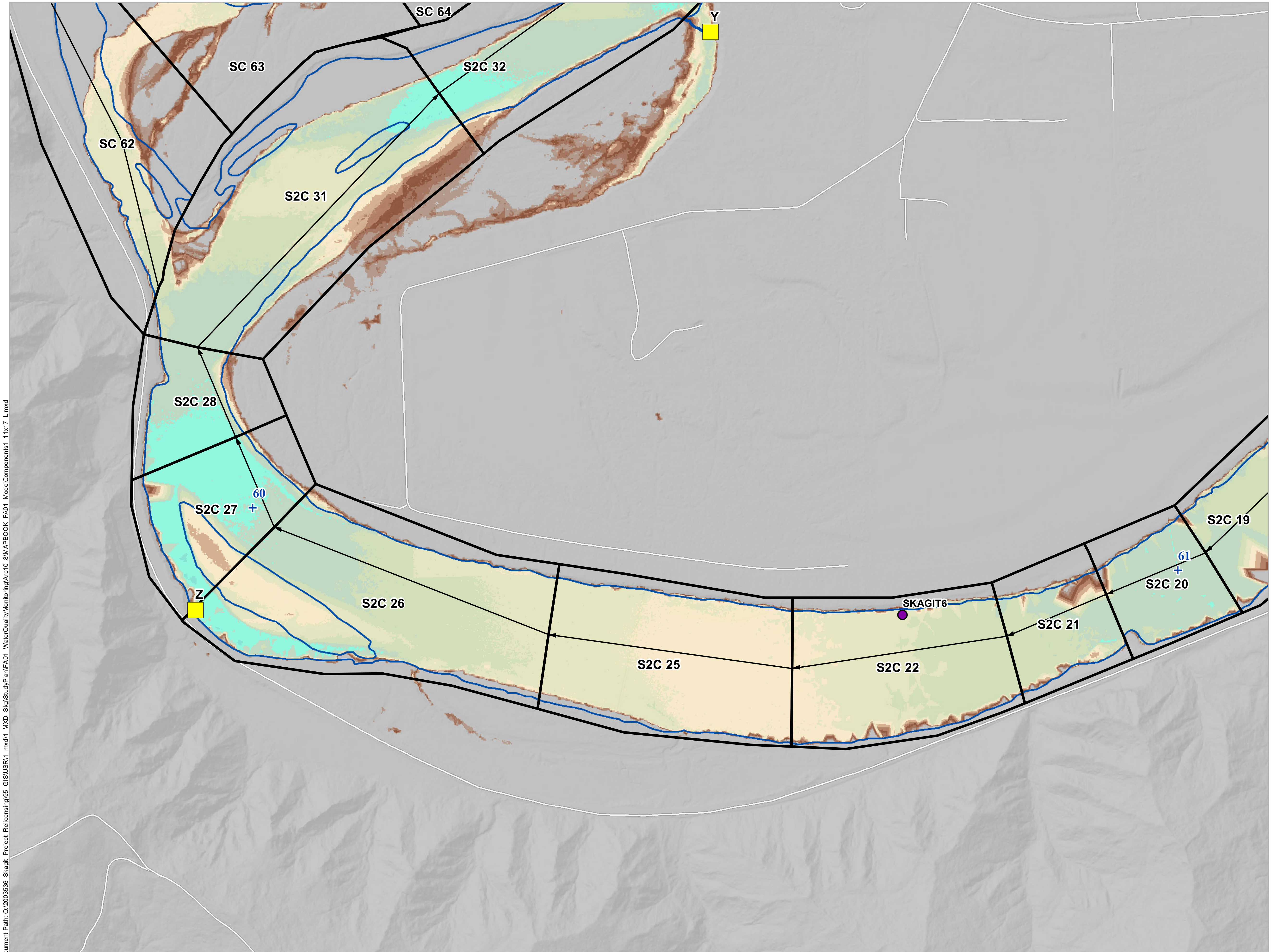

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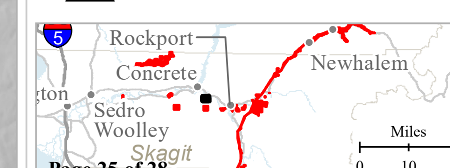

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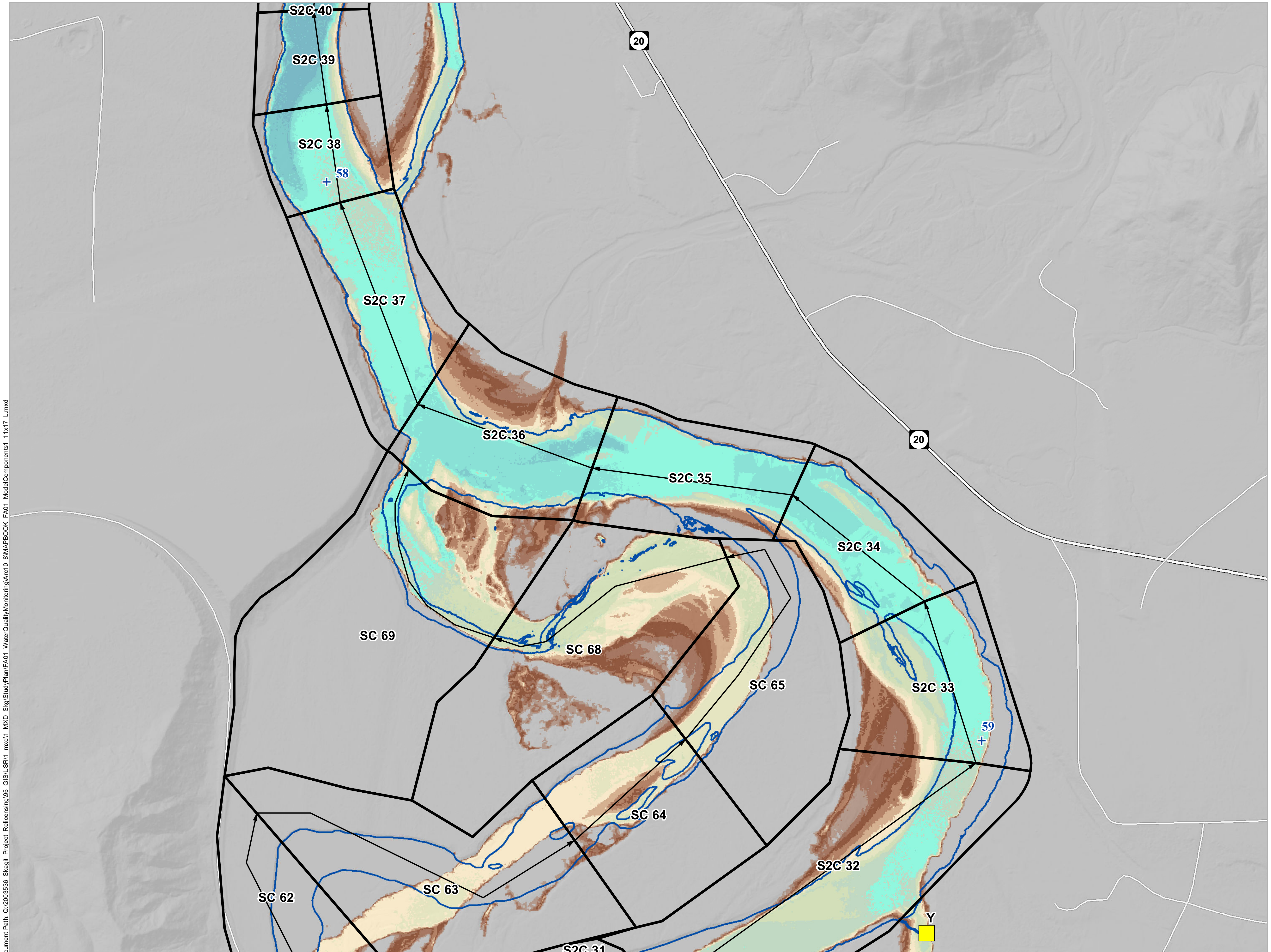

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CE-QUAL-W2 Model

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Flow & Stage
Flow, Stage & Temperature

Relative Elevation Model (2021)

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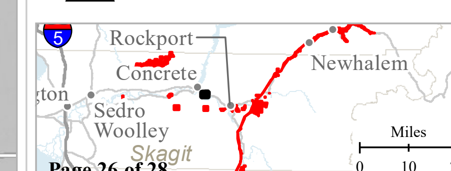
0 300 600 Feet



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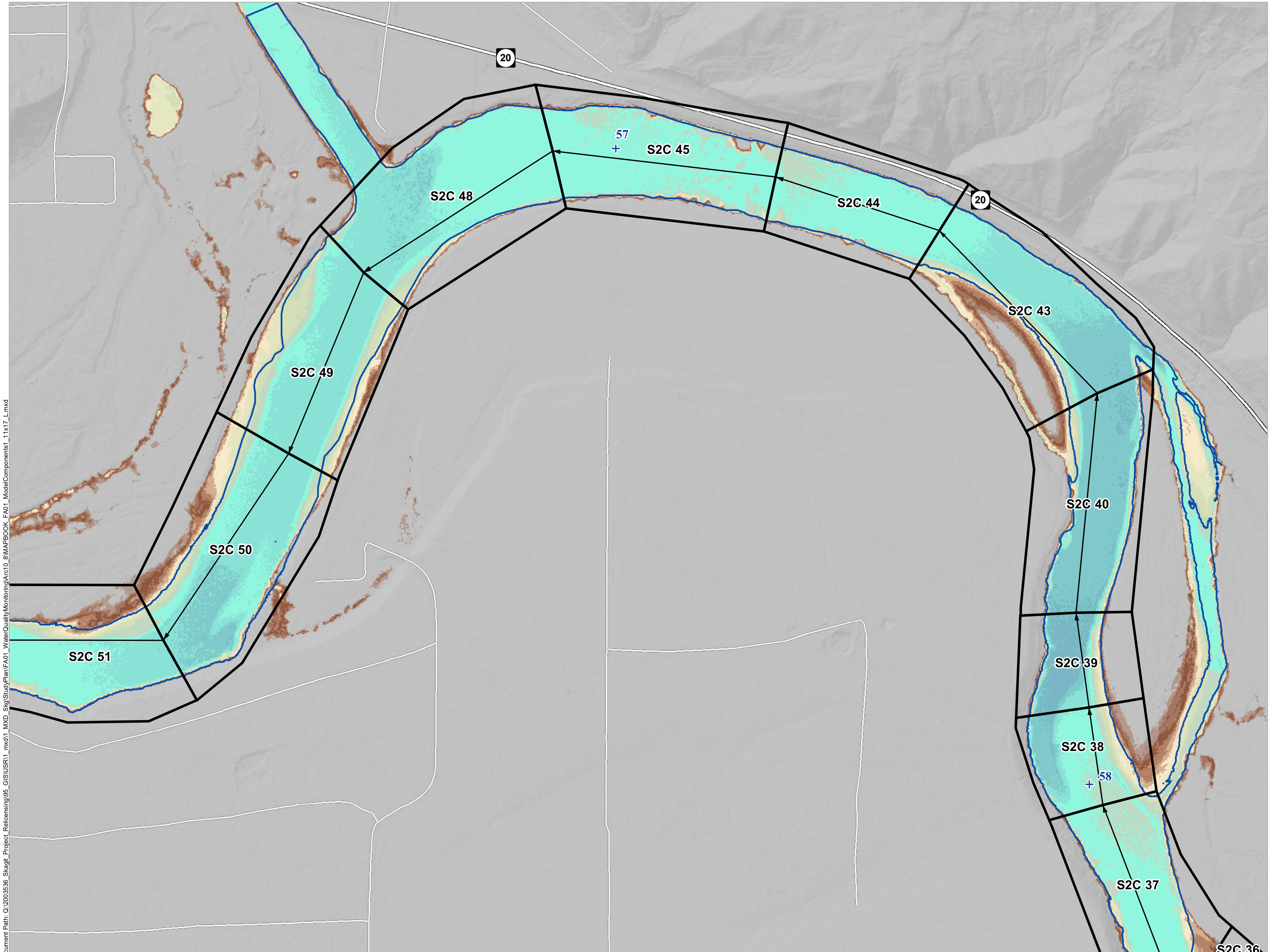

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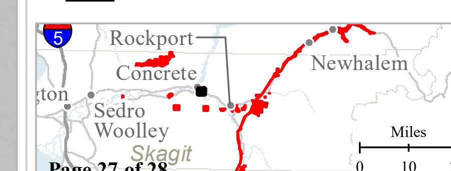

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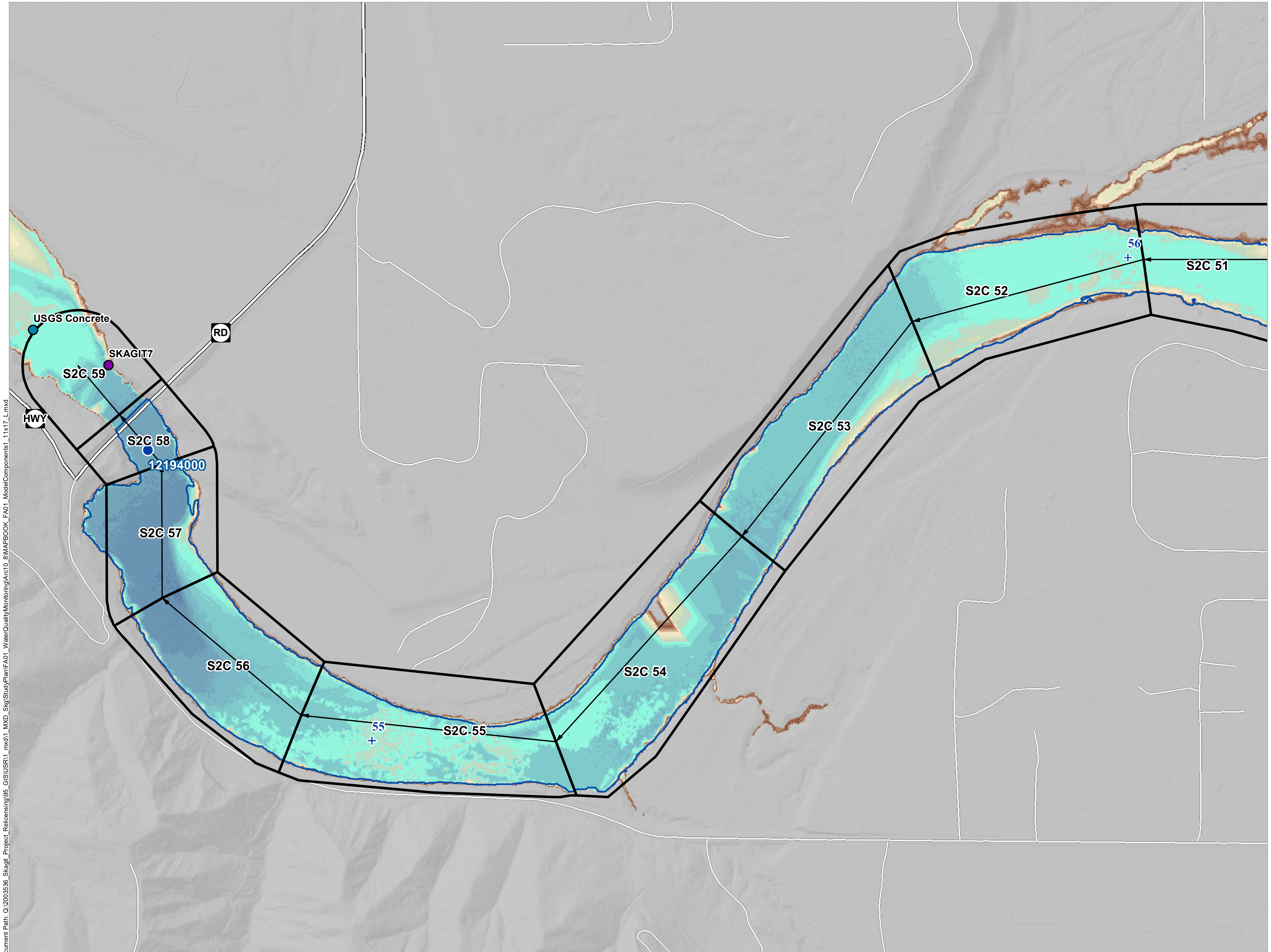

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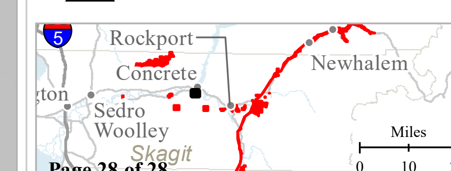

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WATER QUALITY MODEL DEVELOPMENT STUDY

ATTACHMENT B

MODEL CALIBRATION STATISTICS AND FIGURES

B.1 Calibration Statistics

Tables B-1 and B-2 show the statistics for Ross Lake and Diablo Lake calibration comparisons that underlie Tables 4.3-1 and 4.3-2 in the study report, respectively.

Table B-1. Calibration Statistics from Ross Lake Calibration Comparisons.

Date	RMSE (°C)	MAE (°C)	PBIAS (%)
Little Beaver			
7/11/2019	1.3	1.0	-5.4
8/19/2019	1.0	0.7	3.6
9/11/2019	0.7	0.6	3.0
10/10/2019	0.4	0.4	3.2
11/19/2019	1.2	1.2	-13.1
6/16/2020	1.8	1.7	-14.2
7/7/2020	1.0	0.8	-4.6
8/13/2020	2.5	2.1	-10.5
9/21/2020	1.8	1.5	-8.7
10/14/2020	0.9	0.9	-5.9
Skymo			
7/11/2019	0.6	0.4	1.2
8/19/2019	1.1	0.9	-0.9
9/11/2019	0.8	0.5	0.3
10/10/2019	0.7	0.7	4.9
11/19/2019	1.0	1.0	-10.4
6/16/2020	0.9	0.7	-5.9
7/7/2020	1.4	1.2	-7.3
8/13/2020	2.1	1.9	-6.3
9/21/2020	1.0	0.8	-5.1
10/14/2020	0.8	0.7	-4.8
Pumpkin Mountain			
7/11/2019	0.6	0.5	4.1
8/19/2019	0.3	0.3	-1.4
9/11/2019	0.5	0.4	0.2
10/10/2019	0.5	0.4	2.8
11/19/2019	0.6	0.6	-5.5
5/18/2020	0.8	0.7	-5.3
6/16/2020	0.6	0.5	2.4
7/7/2020	0.6	0.5	-1.4
8/13/2020	1.4	1.3	-2.3
9/21/2020	1.1	0.9	-5.9
10/14/2020	1.0	0.7	-4.0

Date	RMSE (°C)	MAE (°C)	PBIAS (%)
Log Boom			
7/11/2019	0.8	0.6	3.2
7/18/2019	1.3	1.0	6.6
8/3/2019	1.1	1.1	3.2
8/18/2019	1.1	0.9	3.5
9/3/2019	0.4	0.4	1.3
9/18/2019	0.8	0.7	0.4
10/3/2019	0.6	0.6	2.5
10/18/2019	0.4	0.3	1.9
Dam Face			
9/3/2019	1.2	0.9	5.5
9/18/2019	0.9	0.7	3.6
10/3/2019	0.8	0.7	5.1
10/18/2019	0.7	0.6	5.1
11/3/2019	0.5	0.4	2.1
11/18/2019	0.5	0.4	-4.0
12/3/2019	0.5	0.3	1.0
Spillway Boom			
12/18/2019	0.4	0.4	-5.0
1/3/2020	0.2	0.2	-2.3
1/18/2020	0.1	0.1	1.8
2/3/2020	0.9	0.9	-21.7
2/18/2020	0.7	0.5	-11.5
3/3/2020	0.5	0.4	-10.1
3/18/2020	0.1	0.1	2.1
4/3/2020	0.1	0.1	0.0
4/18/2020	0.5	0.4	7.6
5/3/2020	1.2	1.1	19.7
5/18/2020	1.2	1.1	2.3
6/3/2020	0.4	0.3	1.3
6/18/2020	0.5	0.4	-1.2
7/3/2020	1.8	1.6	6.3
7/18/2020	1.3	1.2	1.5
8/3/2020	2.3	1.9	2.8
8/18/2020	1.6	1.5	-1.5
9/3/2020	2.0	2.0	-3.2
9/18/2020	0.6	0.5	-2.3
10/3/2020	0.8	0.7	-4.4
10/18/2020	0.4	0.4	0.0
11/3/2020	1.1	1.1	-9.3

Table B-2. Calibration Statistics from Diablo Lake Calibration Comparisons.

Date	RMSE (°C)	MAE (°C)	PBIAS (%)
Temperature Monitoring Buoy			
8/15/2019	0.6	0.4	2.6
10/17/2019	0.3	0.3	-1.8
5/21/2020	0.2	0.2	-1.3
7/23/2020	0.5	0.4	0.8
8/20/2020	0.8	0.7	1.2
9/24/2020	0.5	0.4	-3.3
10/15/2020	0.4	0.4	-1.3
11/10/2020	0.6	0.5	3.0
Log Boom			
7/1/2019	0.5	0.3	-1.9
7/16/2019	0.5	0.4	-0.7
8/1/2019	0.5	0.4	3.2
8/16/2019	0.9	0.9	7.1
9/1/2019	0.7	0.6	3.6
9/16/2019	0.2	0.2	1.4
10/1/2019	0.4	0.3	-2.0
10/16/2019	0.5	0.4	-2.3
11/1/2019	0.5	0.5	-2.9
11/16/2019	0.5	0.5	-4.1
12/1/2019	0.2	0.2	-3.1
12/16/2019	0.5	0.4	-6.1
Dam Face			
8/15/2019	1.0	0.9	5.9
10/17/2019	0.6	0.4	-0.6
5/21/2020	0.4	0.3	2.3
7/22/2020	0.3	0.2	-0.4
8/20/2020	0.7	0.7	4.4
9/24/2020	0.5	0.3	-0.8
10/15/2020	0.4	0.4	-3.3
11/10/2020	0.5	0.4	-0.3

B.2 Ross Lake Calibration Figures

Calibration figures comparing output from the Ross Lake model with observed data from Ross Lake between July 2019 and October 2020 appear in Figures B.2-1 through B.2-12. Each figure displays the data at different locations for a given month. In Figures B.2-1 through B.2-5 and B.2-7 through B.2-12, the dates of the dam forebay locations (Log Boom, Dam Face, or Spillway Boom) do not always match the date of the uplake locations because dam forebay data were sampled from continuous thermistor chain data every two weeks. In Figure B.2-6, only dam forebay data are shown because no monitoring in uplake locations occurred during winter.

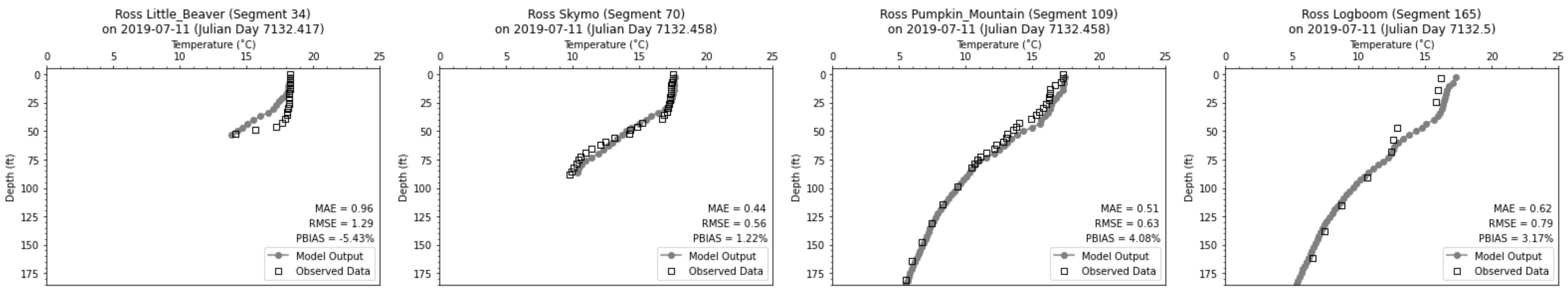


Figure B.2-1. Ross Lake model calibration, July 2019, from uplake locations (left) to the dam forebay (right).

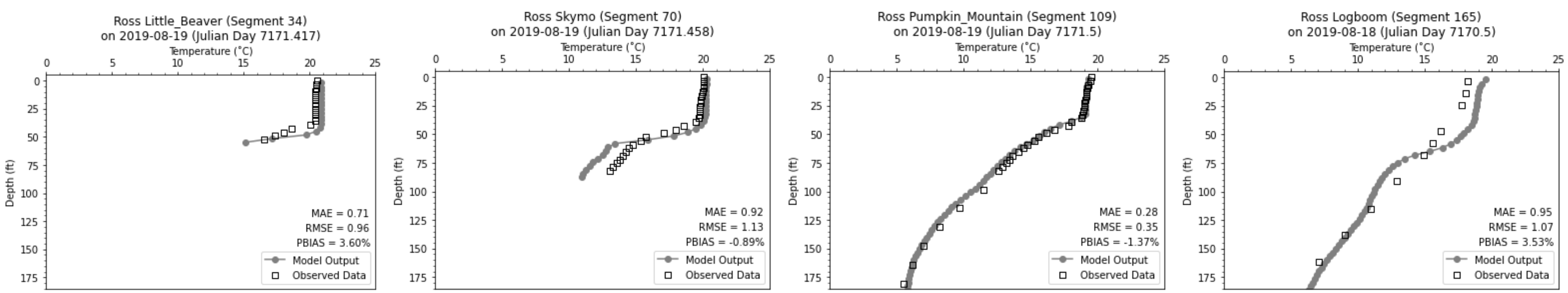


Figure B.2-2. Ross Lake model calibration, August 2019, from uplake locations (left) to the dam forebay (right).

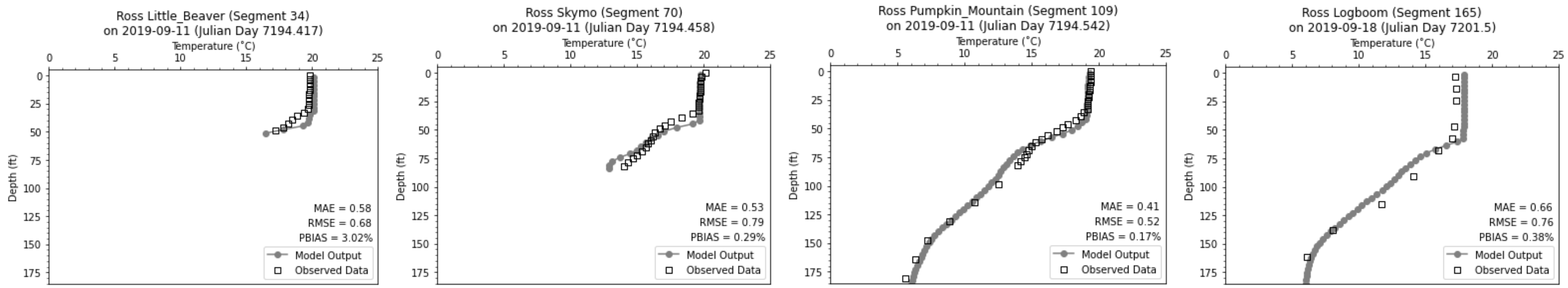


Figure B.2-3. **Ross Lake model calibration, September 2019, from uplake locations (left) to the dam forebay (right).**

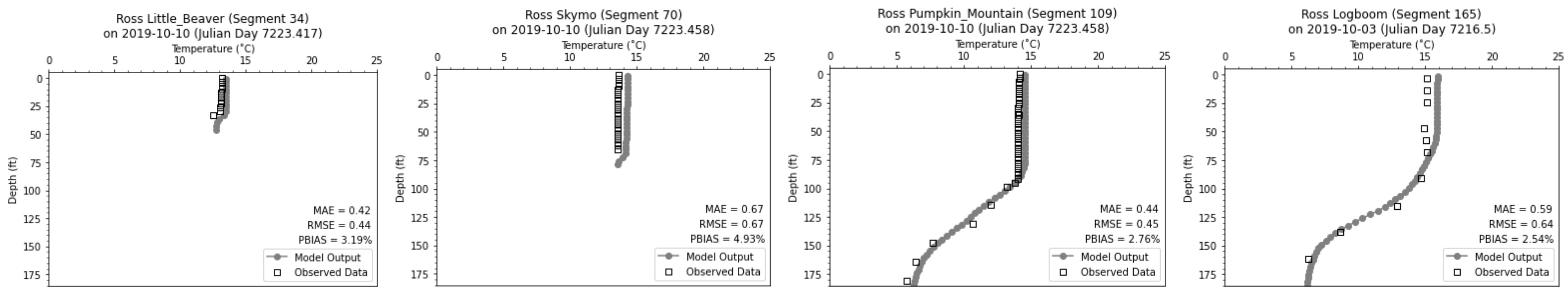


Figure B.2-4. **Ross Lake model calibration, October 2019, from uplake locations (left) to the dam forebay (right).**

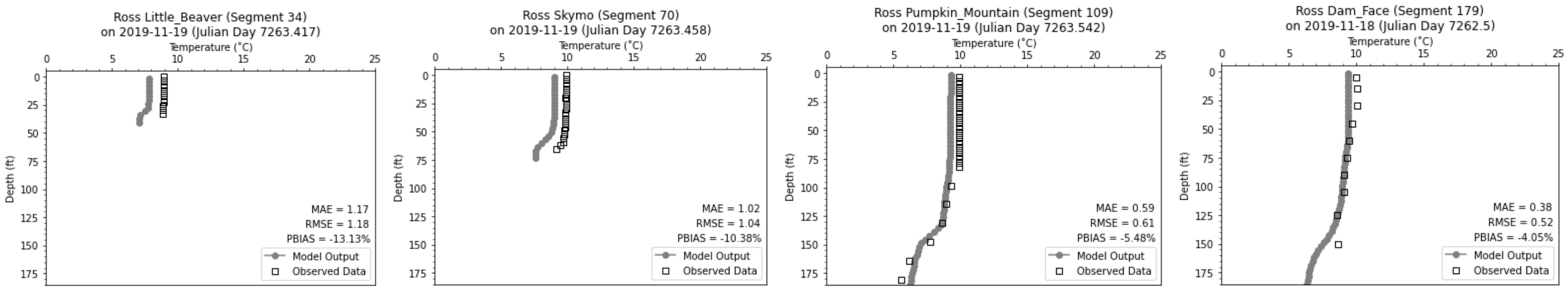


Figure B.2-5. Ross Lake model calibration, November 2019, from uplake locations (left) to the dam forebay (right).

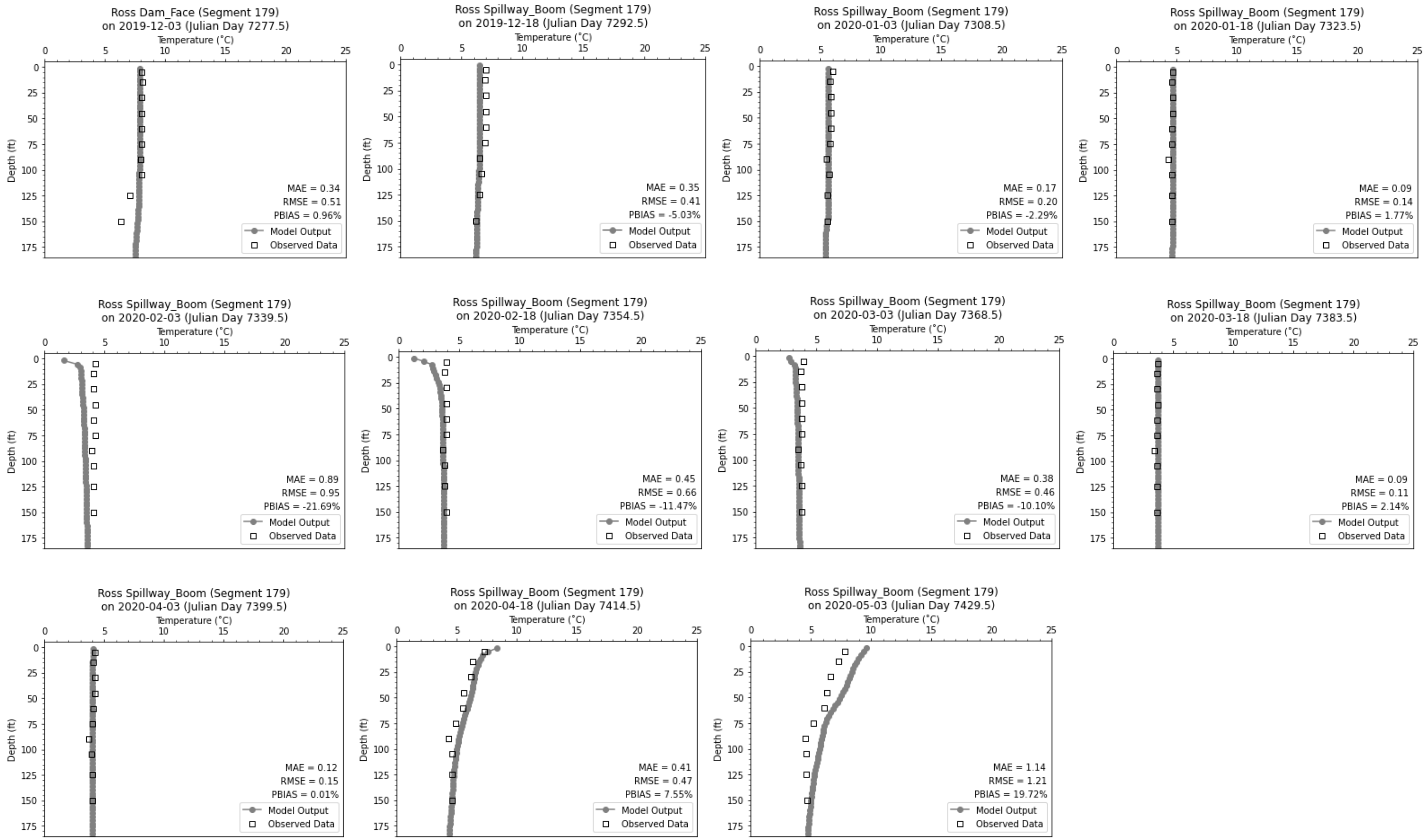


Figure B.2-6. Ross Lake model calibration from December 2019 through May 2020 in the Ross Dam forebay.

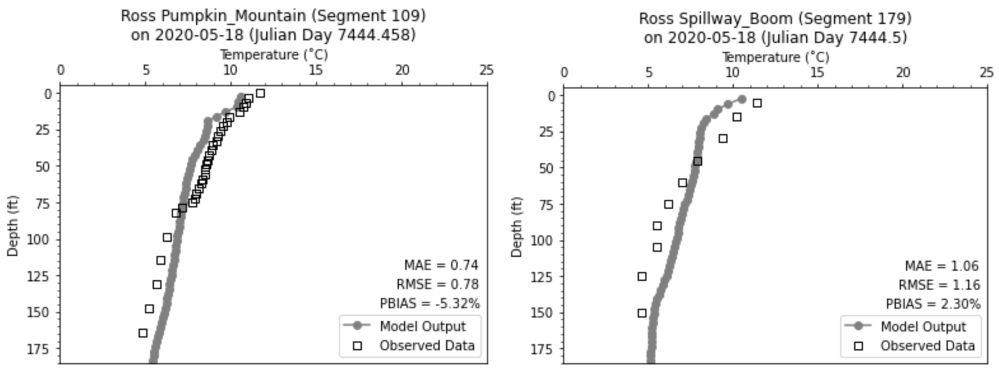


Figure B.2-7. Ross Lake model calibration, May 2020, at the Pumpkin Mountain location (left) and the dam forebay (right). The left side of the figure is blank to maintain consistent spacing with other figures in this attachment.

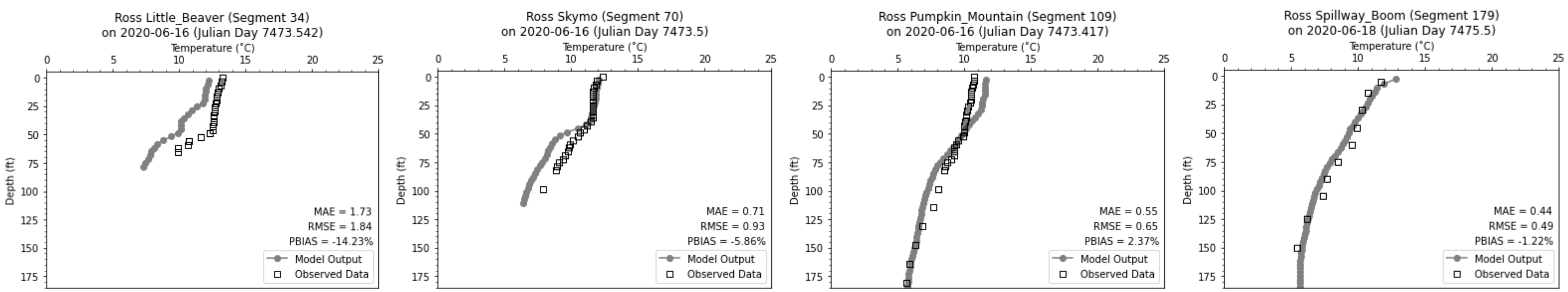


Figure B.2-8. Ross Lake model calibration, June 2020, from uplake locations (left) to the dam forebay (right).

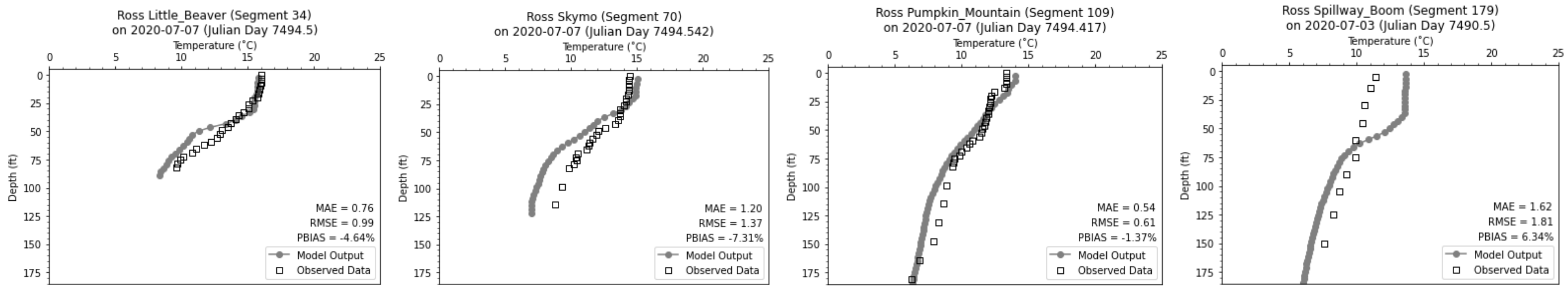


Figure B.2-9. Ross Lake model calibration, July 2020, from uplake locations (left) to the dam forebay (right).

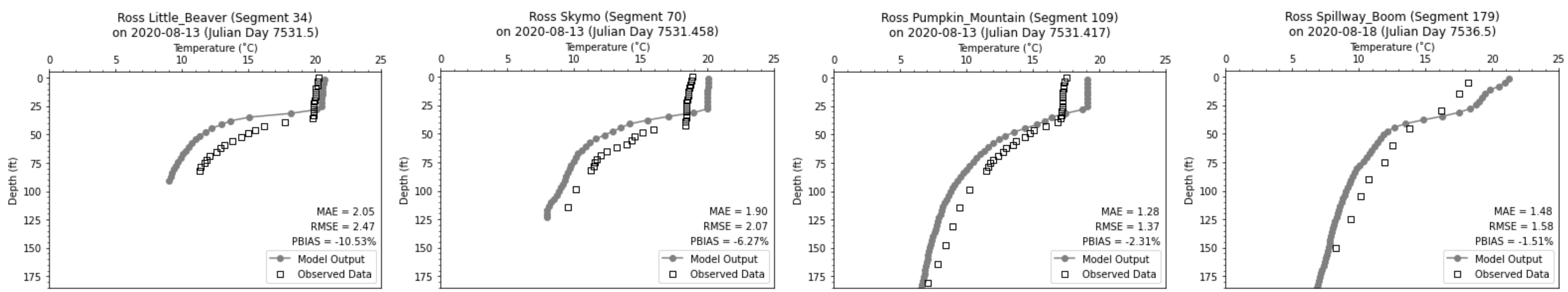


Figure B.2-10. Ross Lake model calibration, August 2020, from uplake locations (left) to the dam forebay (right).

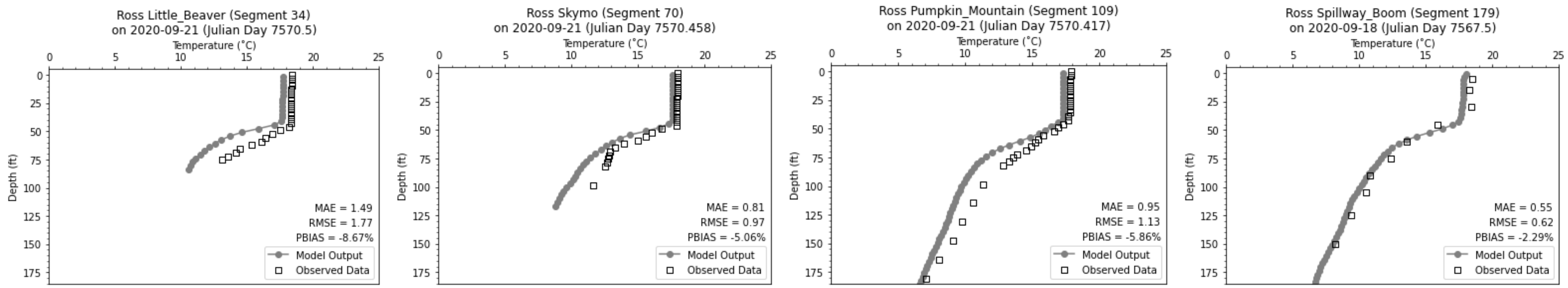


Figure B.2-11. Ross Lake model calibration, September 2020, from uplake locations (left) to the dam forebay (right).

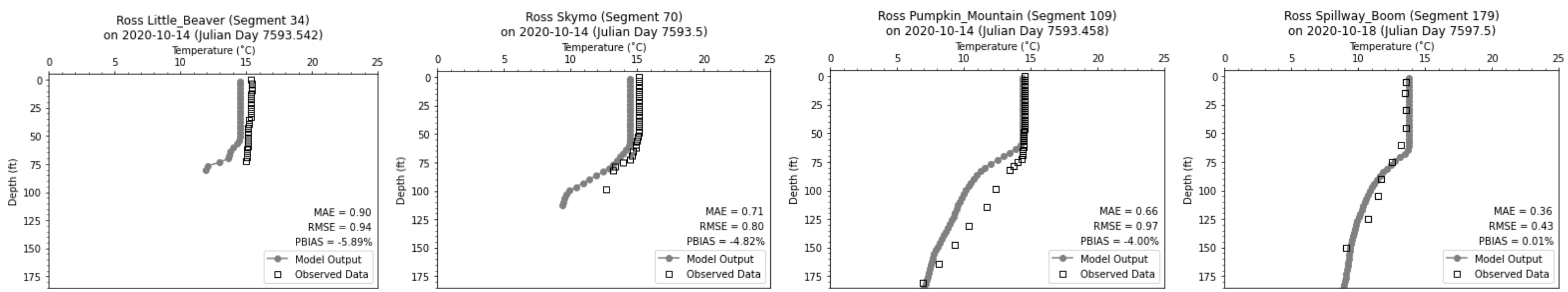


Figure B.2-12. Ross Lake model calibration, October 2020, from uplake locations (left) to the dam forebay (right).

B.3 Diablo Lake Calibration Figures

Calibration comparisons of output from the Diablo Lake model with observed data from Diablo Lake between July 2019 and November 2020 appear in Figure B.3-1 through Figure B.3-10. Data from a thermistor chain in the dam forebay called "Diablo Boom" were collected continuously in 2019 and sampled every two weeks for comparison with model output. Data from monitoring excursions to the Thunder Arm location called "Diablo Buoy" and a forebay location called "Diablo Dam" were collected every two months in 2019 and monthly in 2020 except for June.

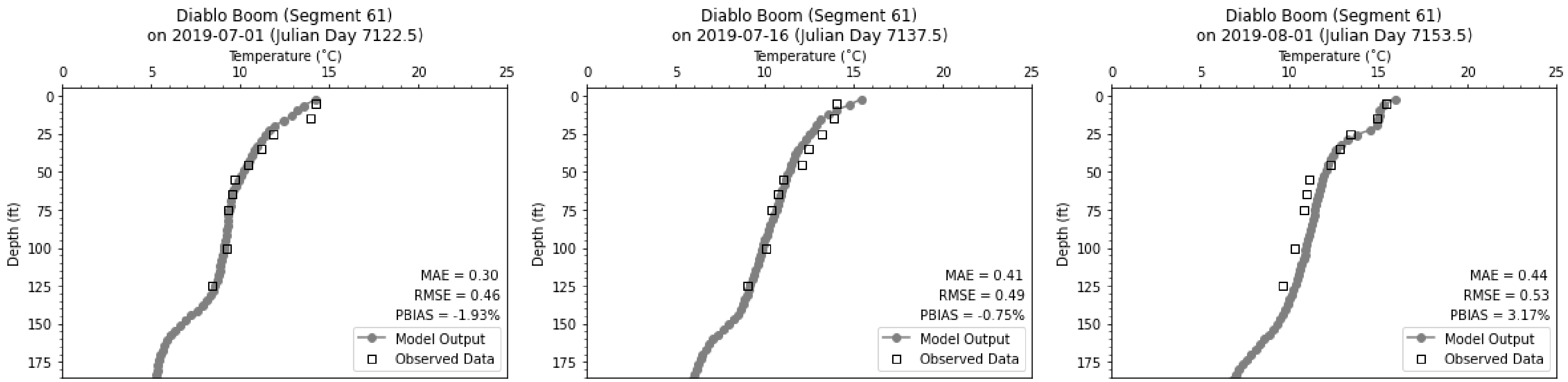


Figure B.3-1. Diablo Lake model calibration, 1 July 2019 (left), 16 July 2019 (center), and 1 August 2019 (right) in the dam forebay.

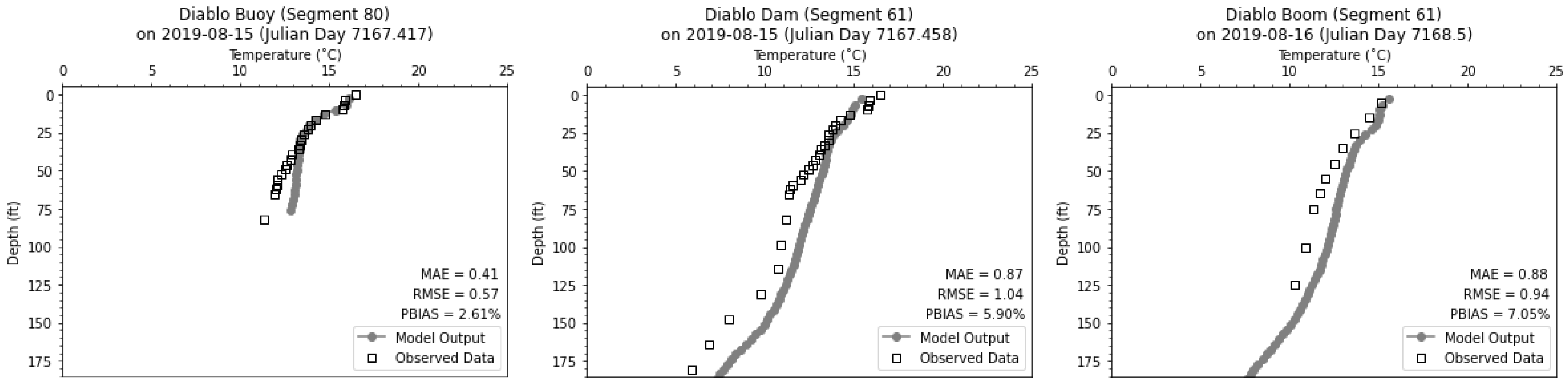


Figure B.3-2. Diablo Lake model calibration, August 2019, in the Thunder Arm location (left) and the dam forebay (center and right).

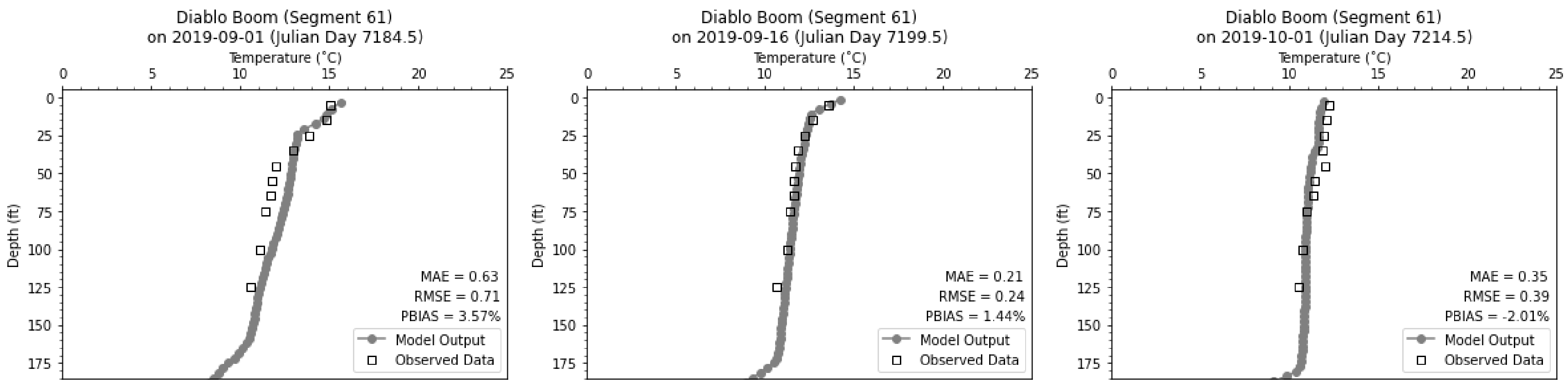


Figure B.3-3. Diablo Lake model calibration, 1 September 2019 (left), 16 September 2019 (center), and 1 October 2019 (right) in the dam forebay.

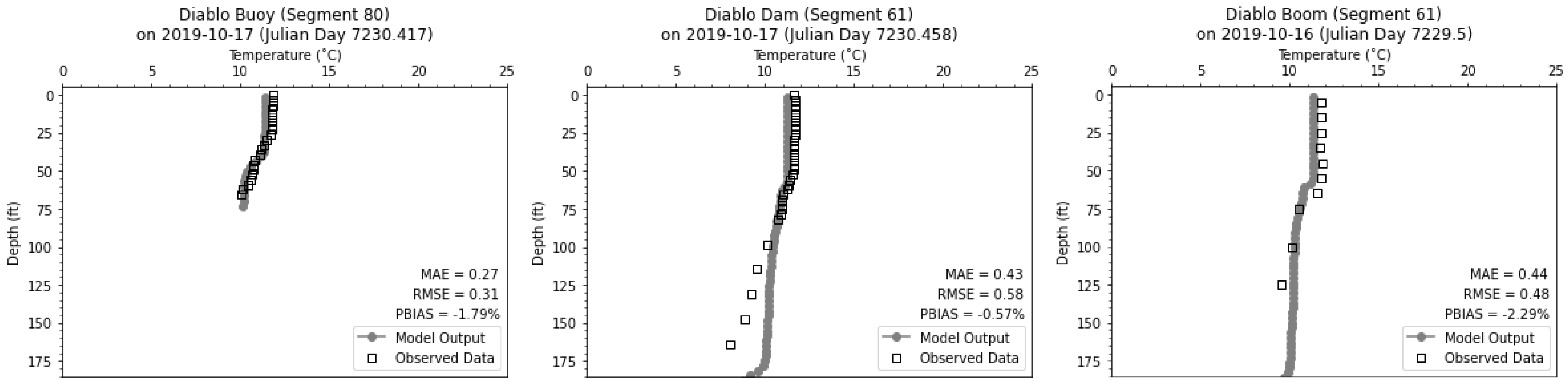


Figure B.3-4. Diablo Lake model calibration, October 2019, in the Thunder Arm location (left) and the dam forebay (center and right).

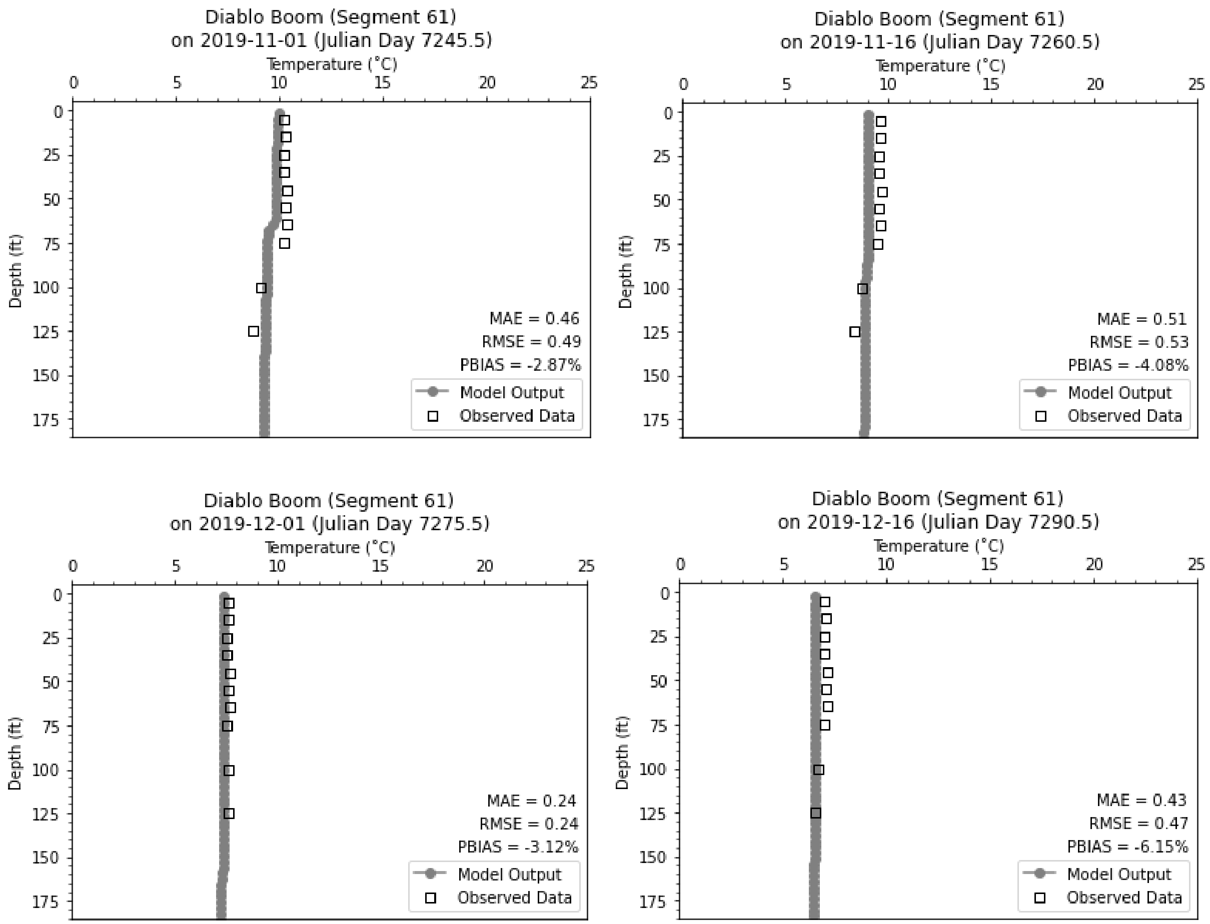


Figure B.3-5. Diablo Lake model calibration, November 1, 2019 (upper left), November 16, 2019 (upper right), 1 December 1, 2019 (lower left), and December 16, 2019 (lower right) in the dam forebay.

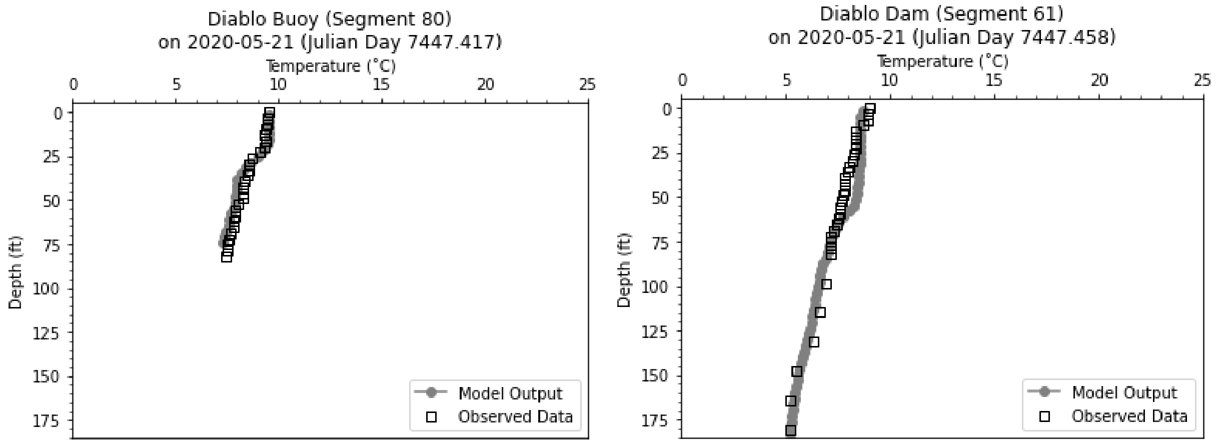


Figure B.3-6. Diablo Lake model calibration, May 2020, in the Thunder Arm location (left) and the dam forebay (right).

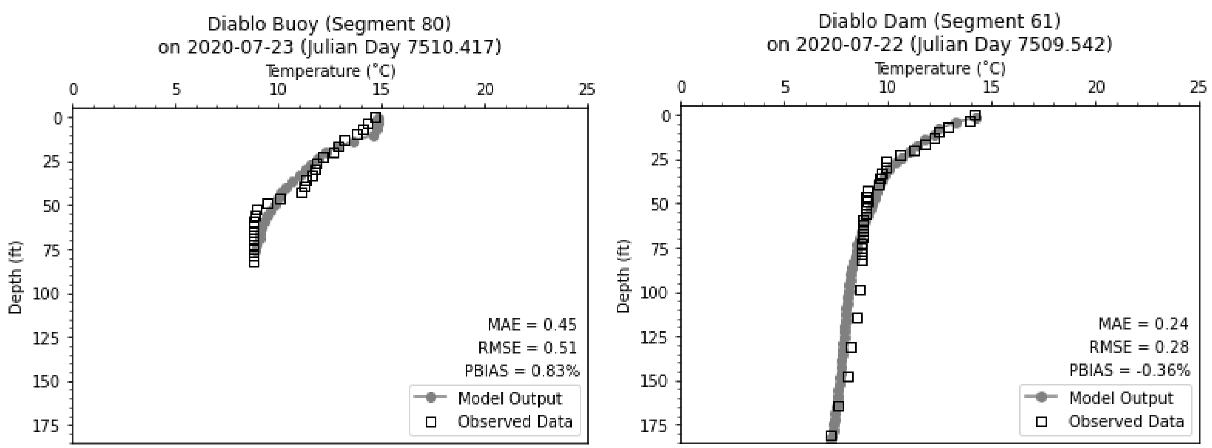


Figure B.3-7. Diablo Lake model calibration, July 2020, in the Thunder Arm location (left) and the dam forebay (right).

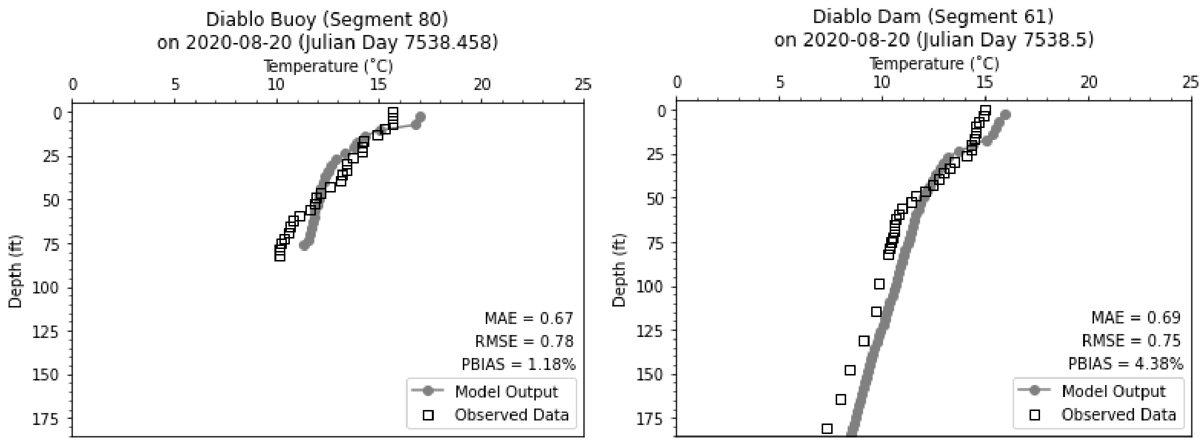


Figure B.3-8. Diablo Lake model calibration, August 2020, in the Thunder Arm location (left) and the dam forebay (right).

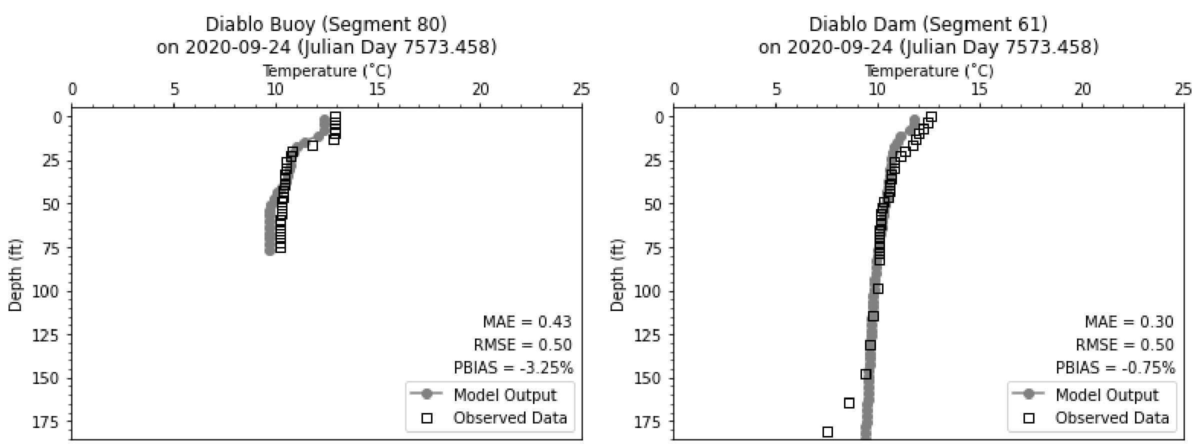


Figure B.3-9. Diablo Lake model calibration, September 2020, in the Thunder Arm location (left) and the dam forebay (right).

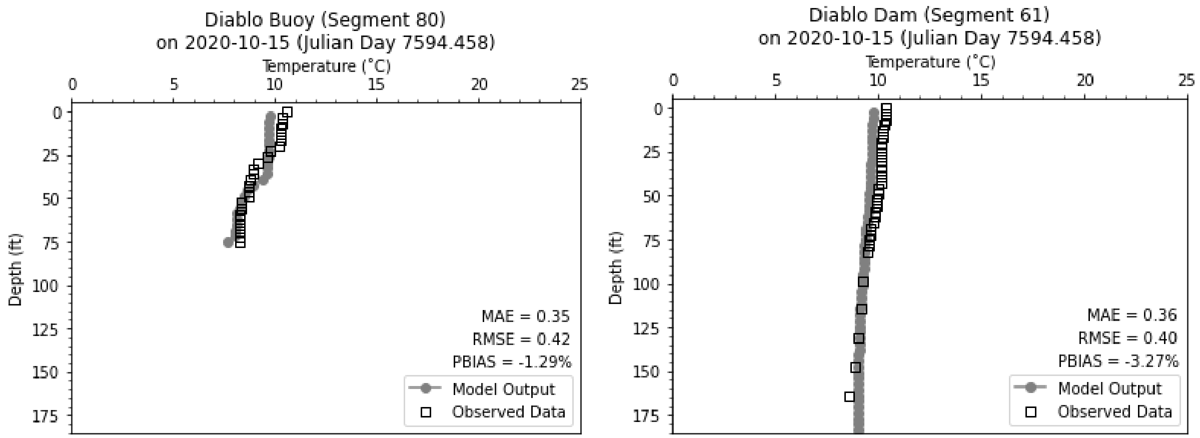


Figure B.3-10. Diablo Lake model calibration, October 2020, in the Thunder Arm location (left) and the dam forebay (right).

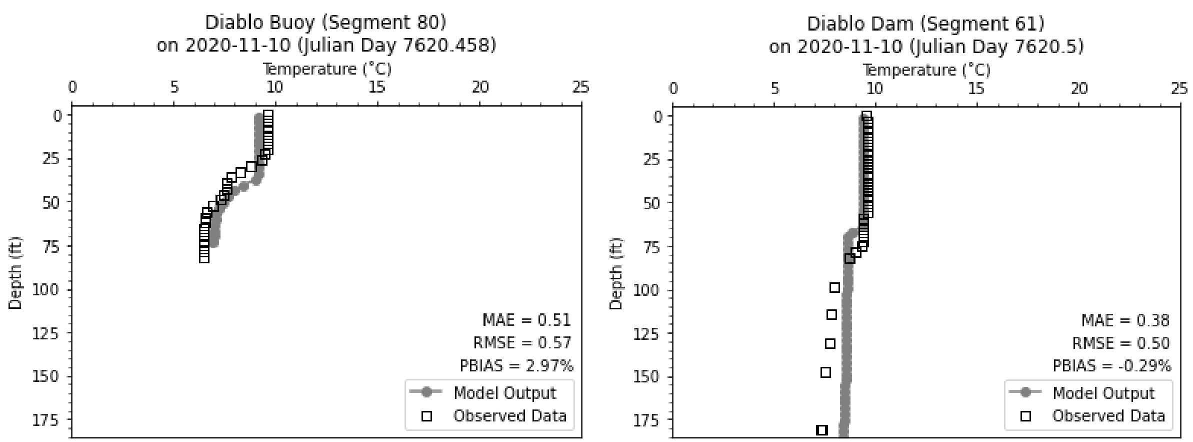


Figure B.3-11. Diablo Lake model calibration, November 2020, in the Thunder Arm location (left) and the dam forebay (right).

WATER QUALITY MODEL DEVELOPMENT STUDY

ATTACHMENT C

SENSITIVITY ANALYSIS FIGURES

C.1 Ross Lake Sensitivity Analysis Figures

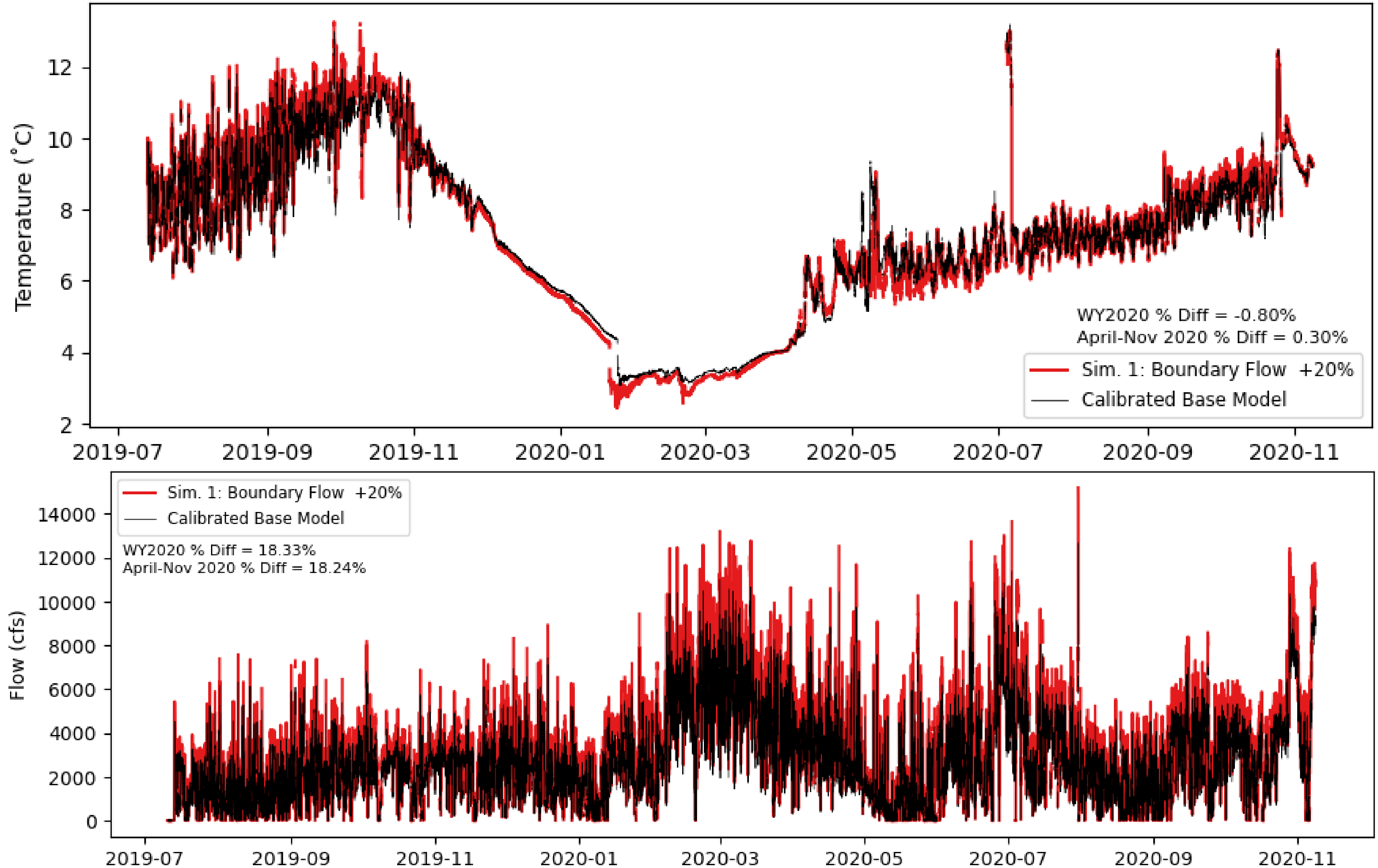


Figure C.1-1. Ross Lake outflow continuous hourly flow and temperature variation for Simulation 1 (Increase Boundary Flows by 20 percent).

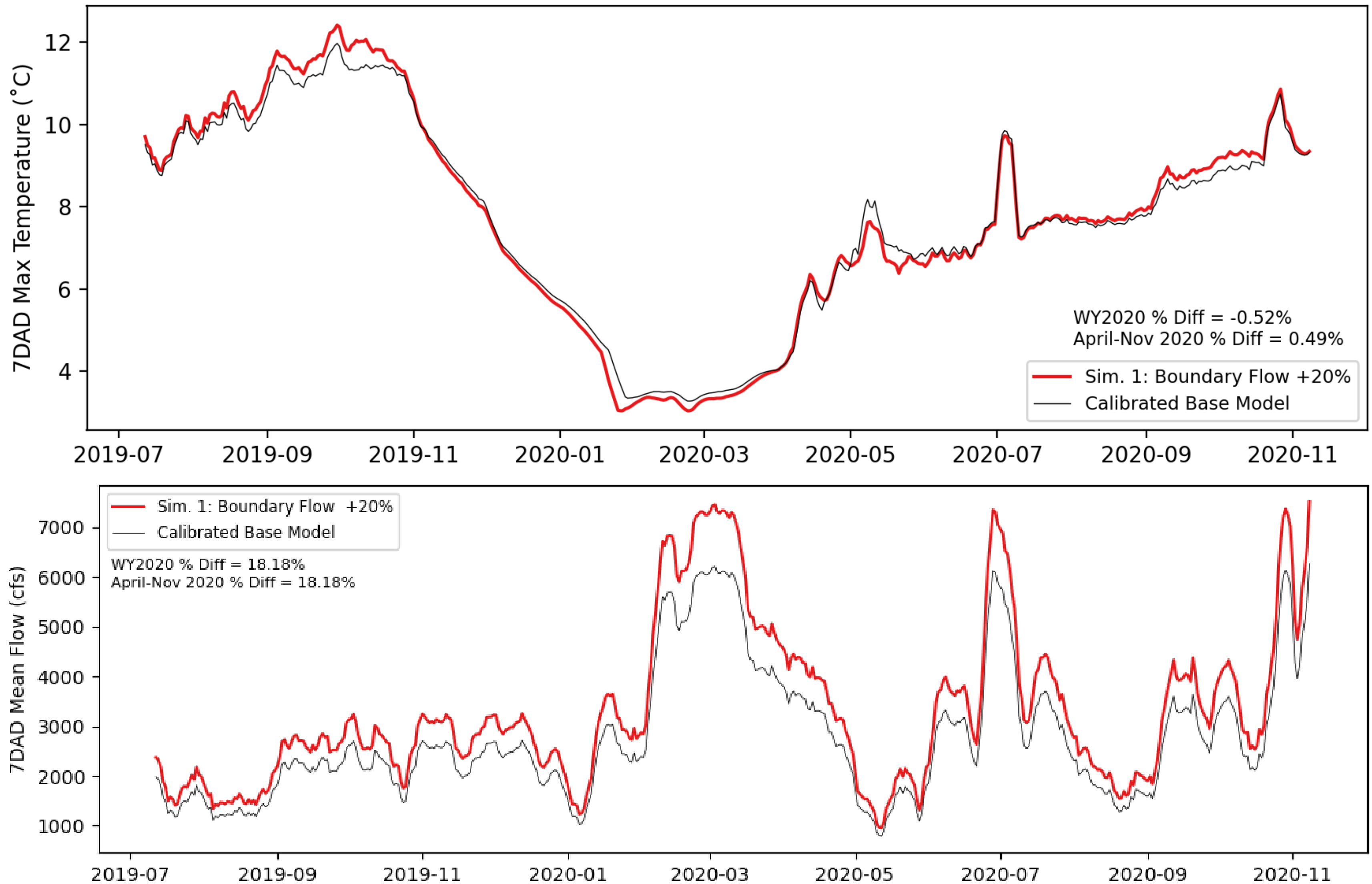


Figure C.1-2. Ross Lake outflow 7DAD-mean flow and max temperature variation for Simulation 1 (increase boundary flows by 20 percent).

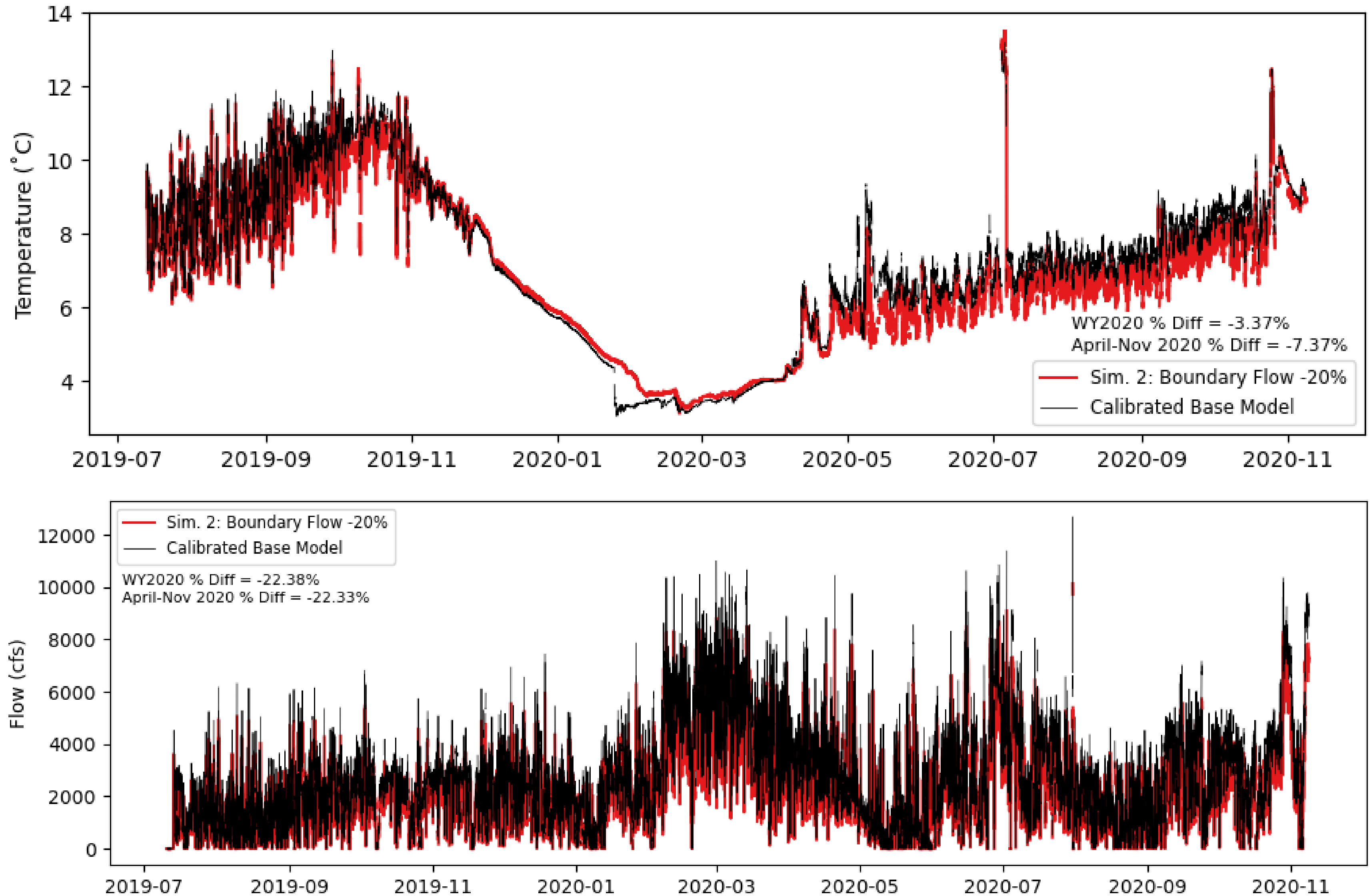


Figure C.1-3. Ross Lake outflow continuous hourly flow and temperature variation for Simulation 2 (decrease boundary flows by 20 percent).

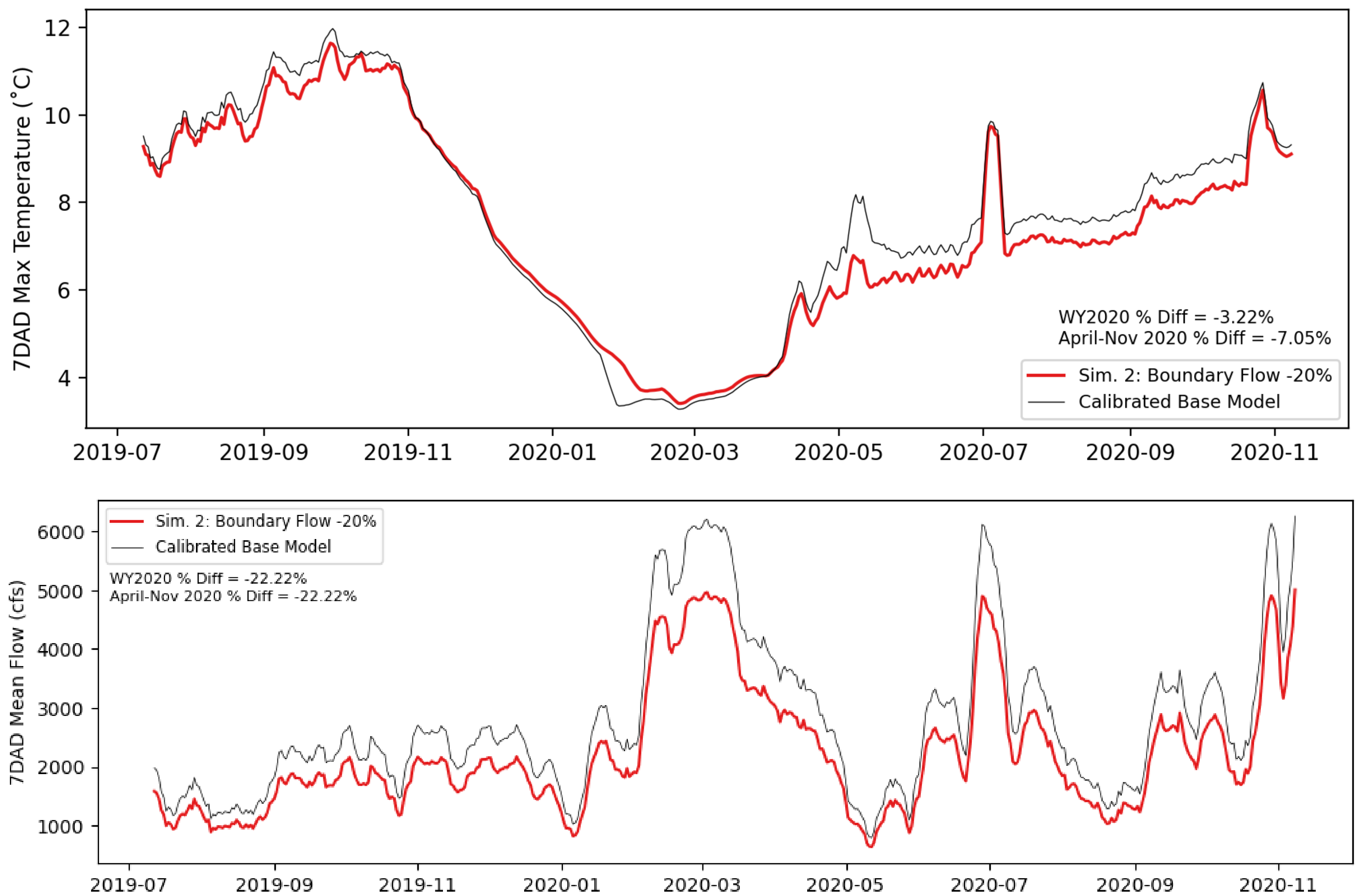


Figure C.1-4. Ross Lake outflow 7DAD-mean flow and max temperature variation for Simulation 2 (decrease boundary flows by 20 percent).

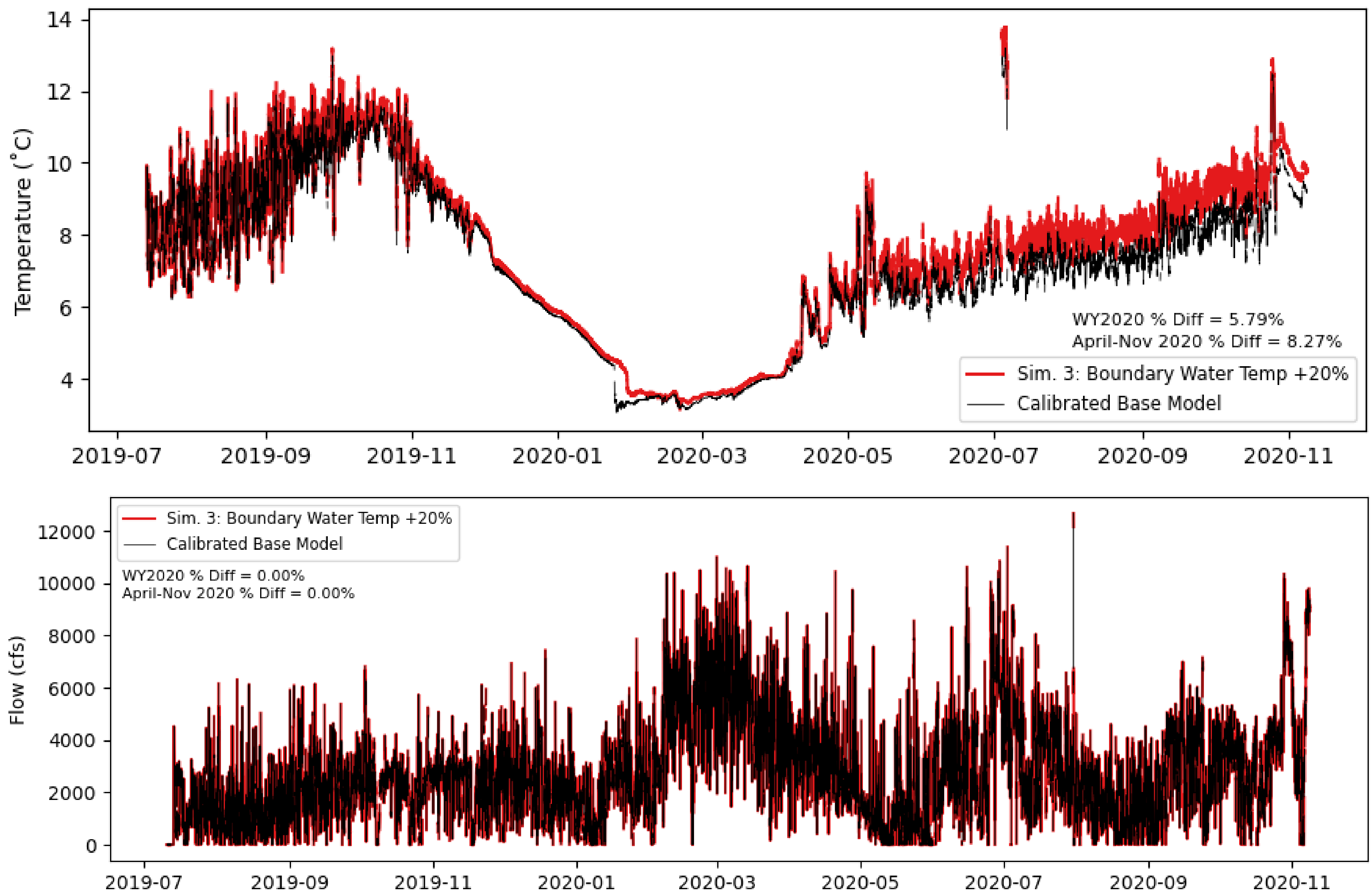


Figure C.1-5. Ross Lake outflow continuous hourly flow and temperature variation for Simulation 3 (increase boundary temperatures by 20 percent).

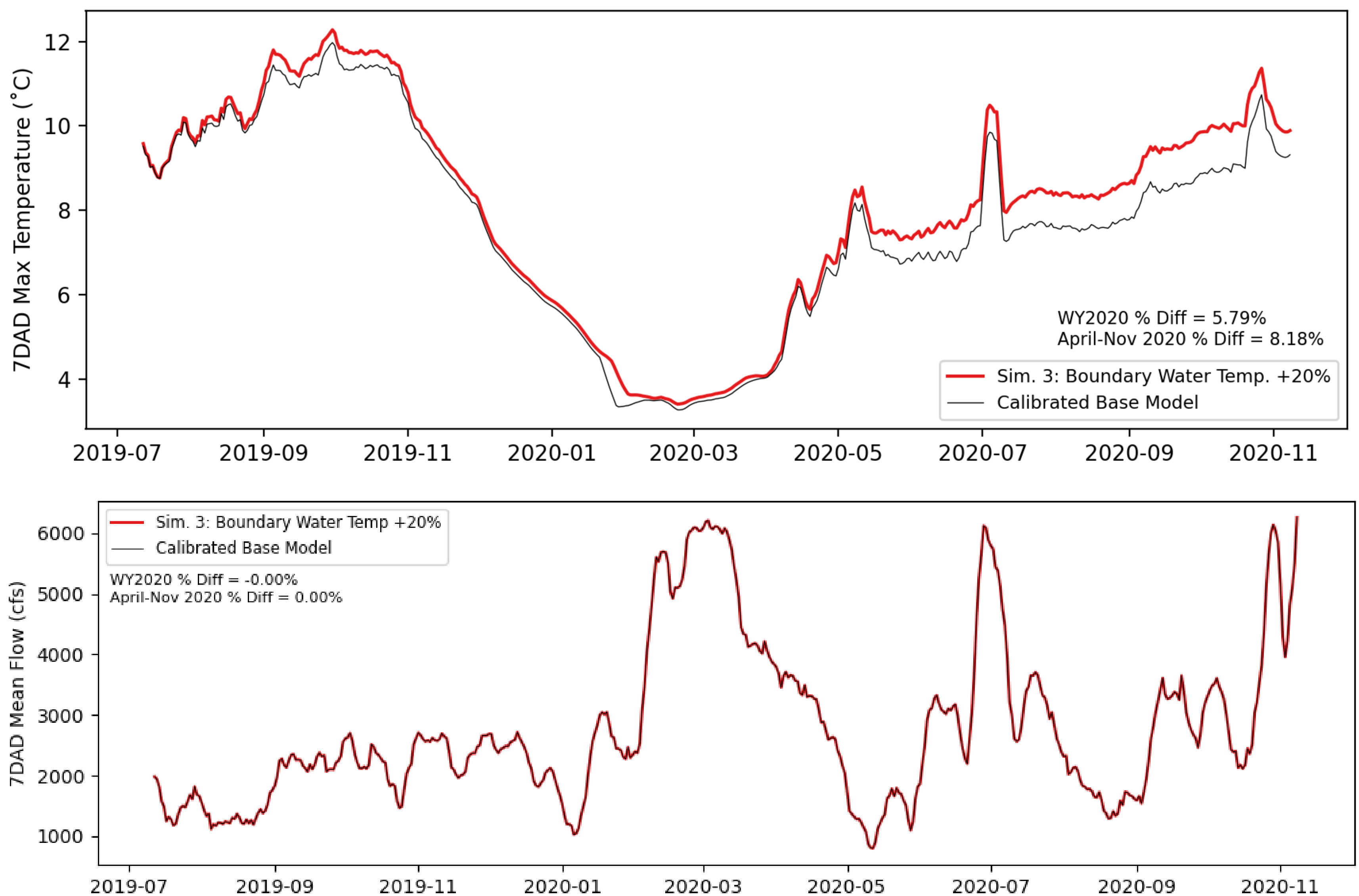


Figure C.1-6. Ross Lake outflow 7DAD-Mean flow and max temperature variation for Simulation 3 (increase boundary temperatures by 20 percent).

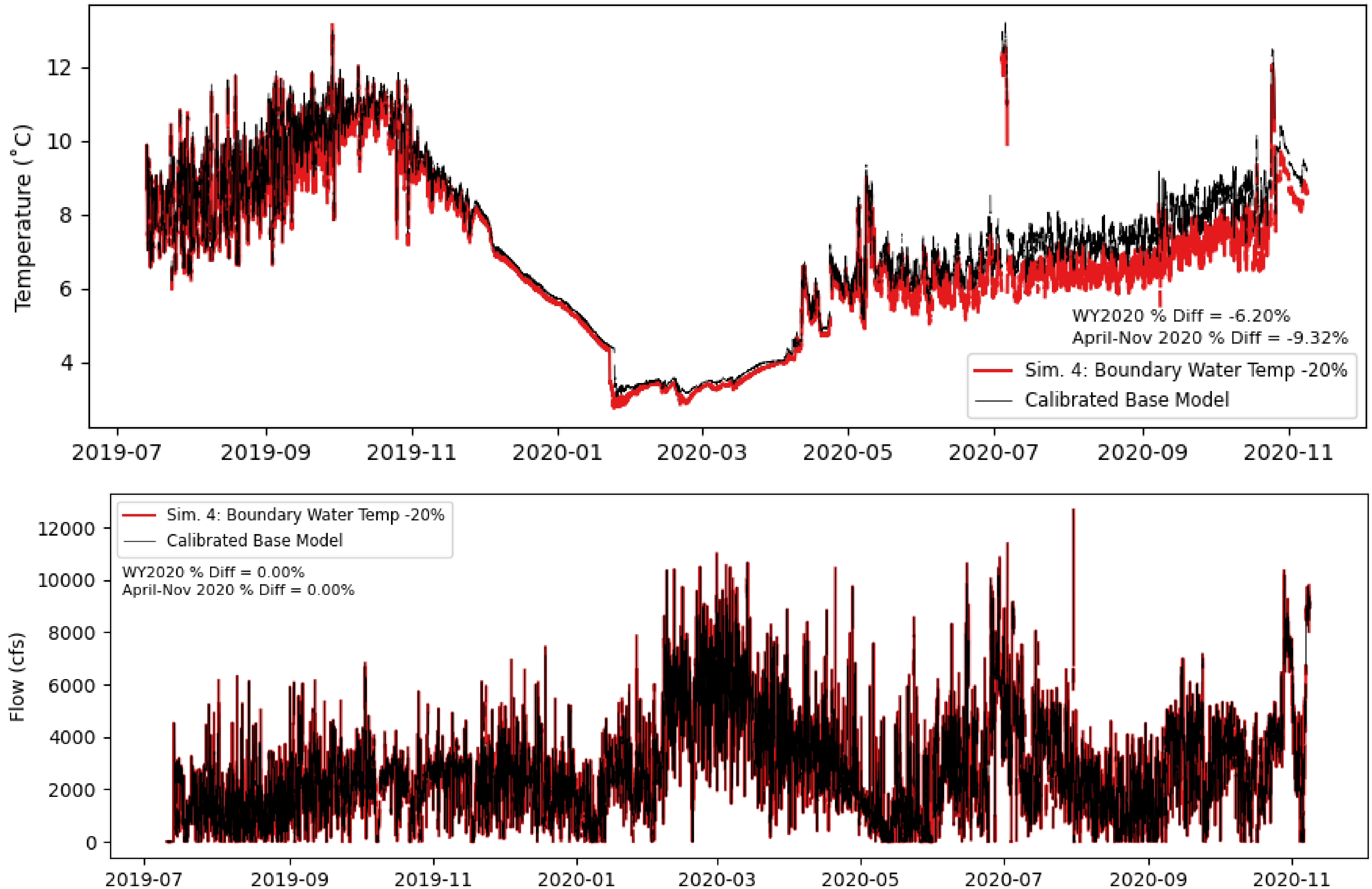


Figure C.1-7. Ross Lake outflow continuous hourly flow and temperature variation for Simulation 4 (decrease boundary temperatures by 20 percent).

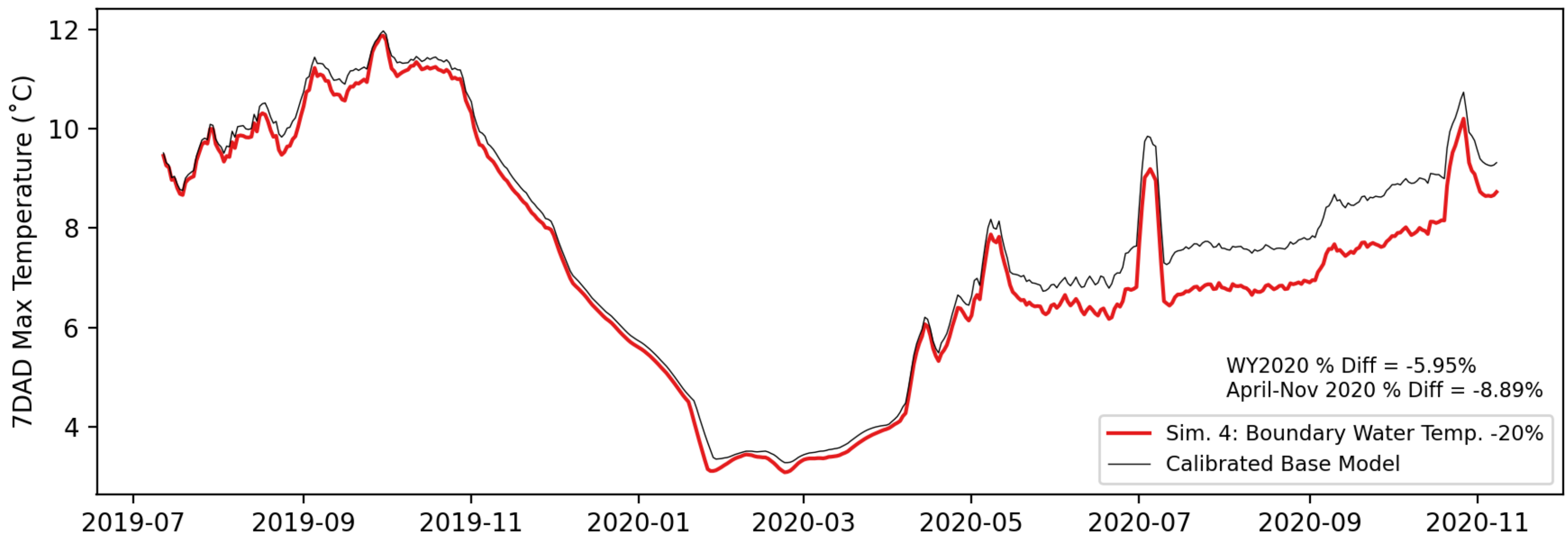


Figure C.1-8. **Ross Lake outflow 7DAD-Mean flow and max temperature variation for Simulation 4 (decrease boundary temperatures by 20 percent).**

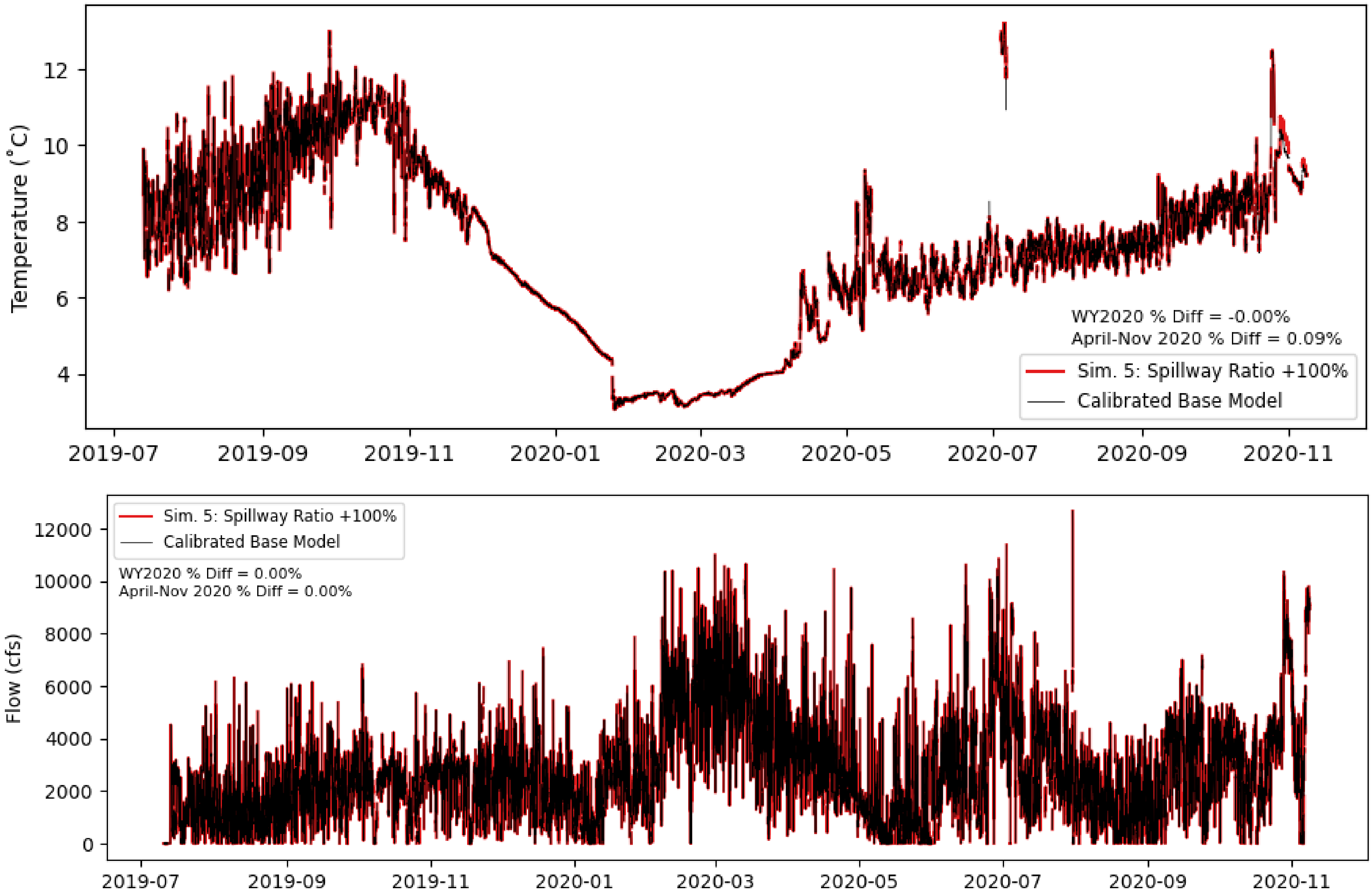


Figure C.1-9. Ross Lake outflow continuous hourly flow and temperature variation for Simulation 5 (double spillway-powerhouse flow ratio).

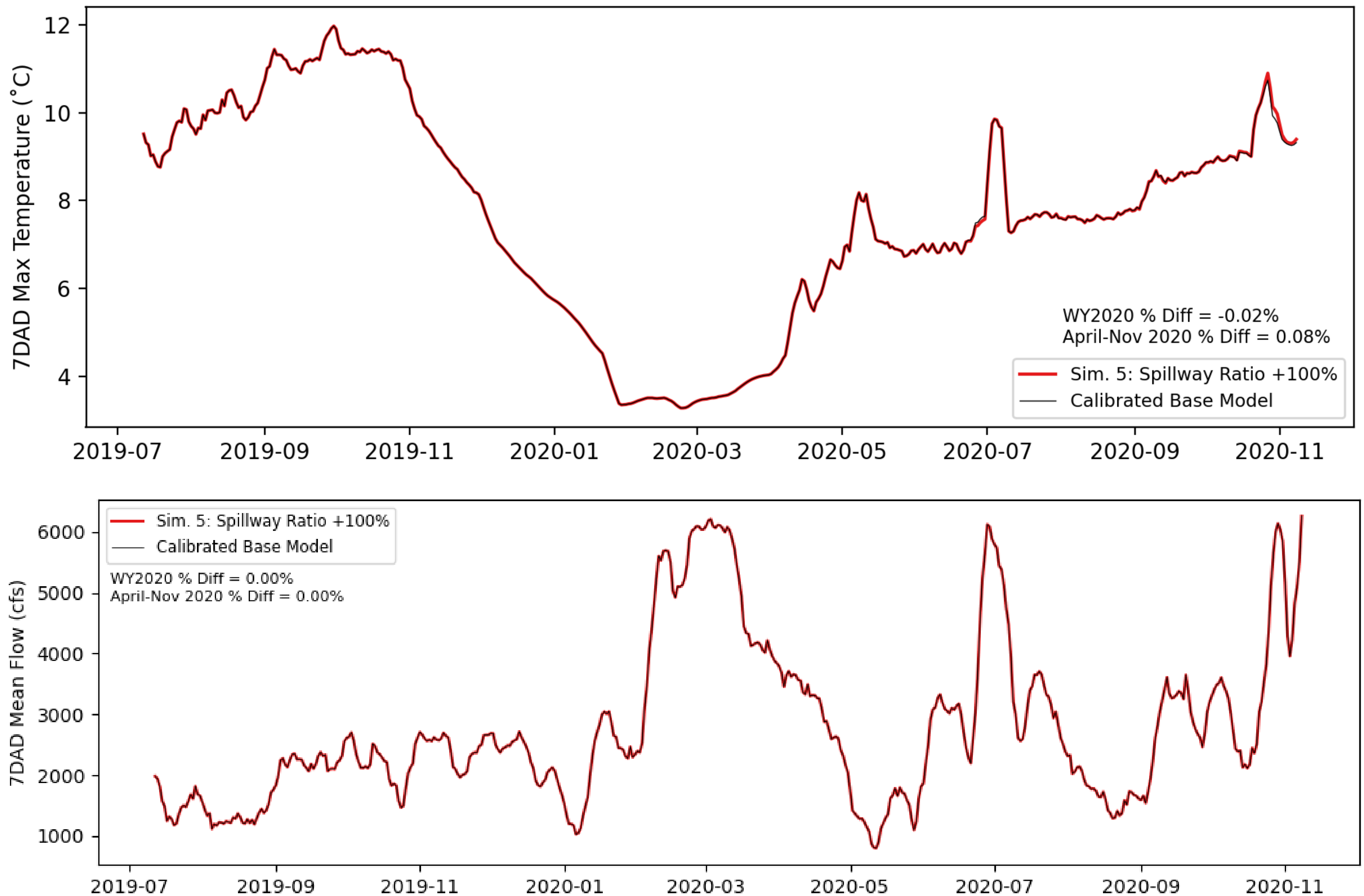


Figure C.1-10. Ross Lake outflow 7DAD-Mean flow and max temperature variation for Simulation 5 (double spillway-powerhouse flow ratio).

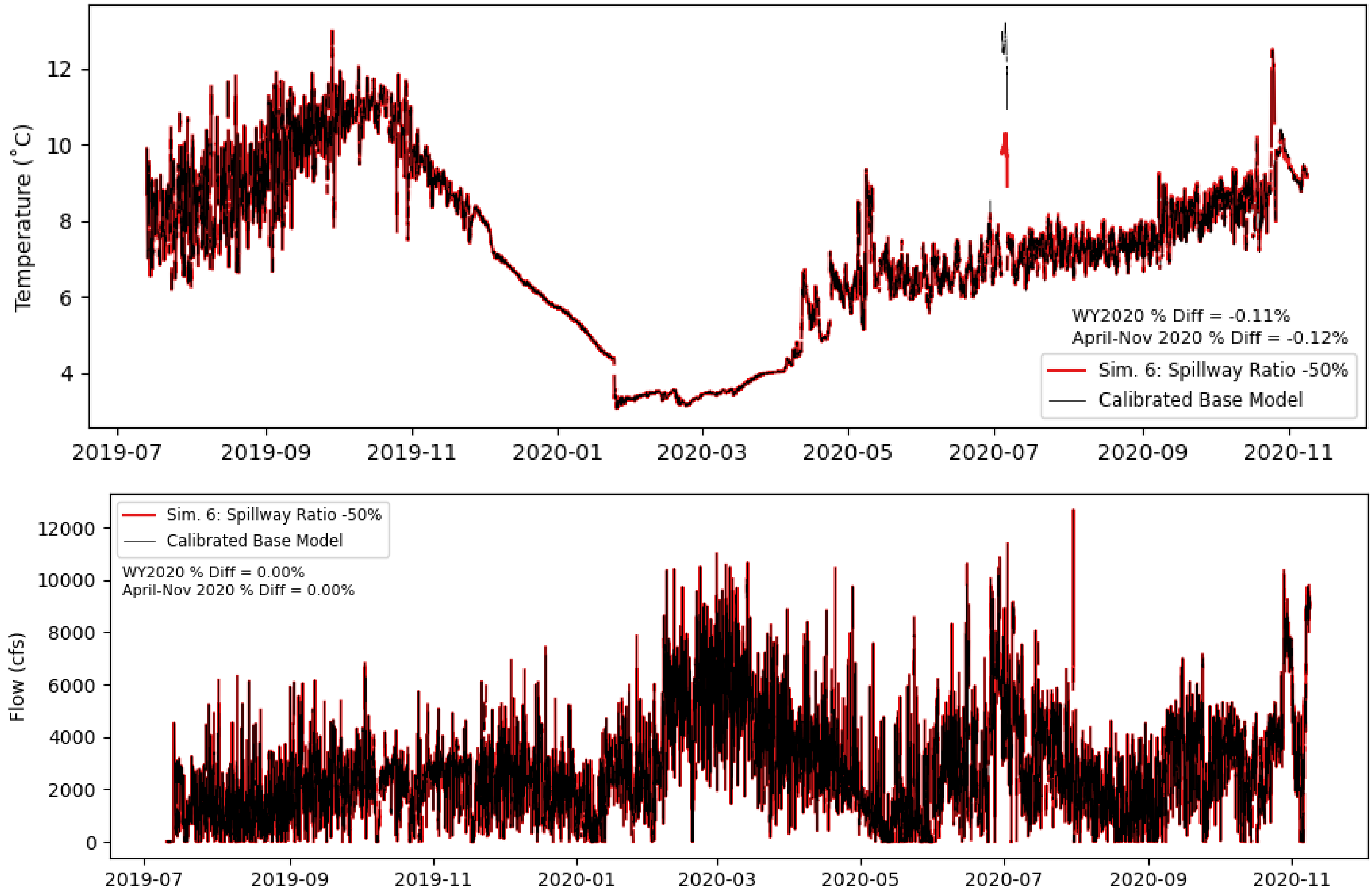


Figure C.1-11. Ross Lake outflow continuous hourly flow and temperature variation for Simulation 6 (halved spillway-powerhouse flow ratio).

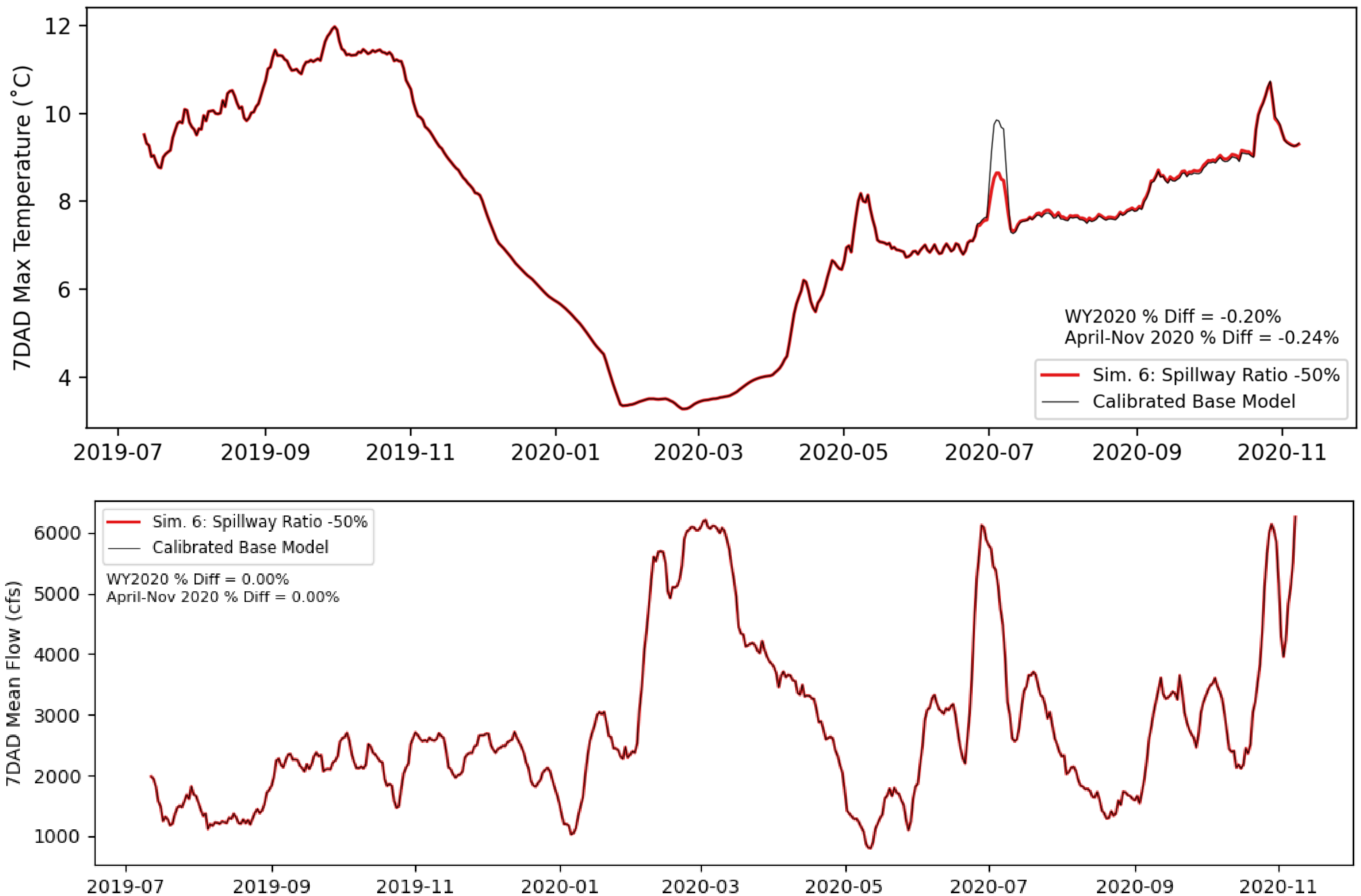


Figure C.1-12. Ross Lake outflow 7DAD-Mean flow and max temperature variation for Simulation 6 (halve spillway-powerhouse flow ratio).

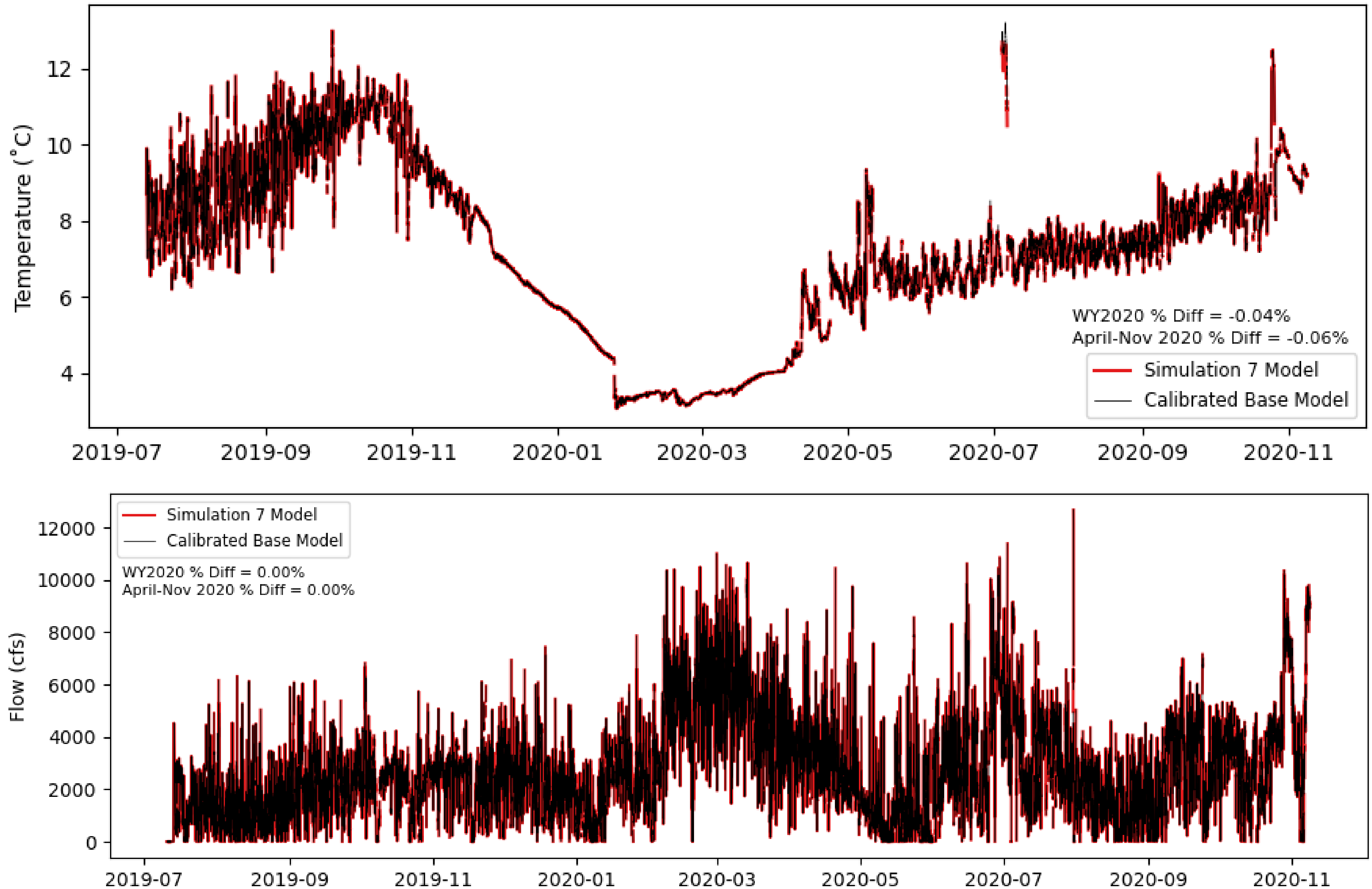


Figure C.1-13. Ross Lake outflow continuous hourly flow and temperature variation for Simulation 7 (remove top 5 withdrawal layers).

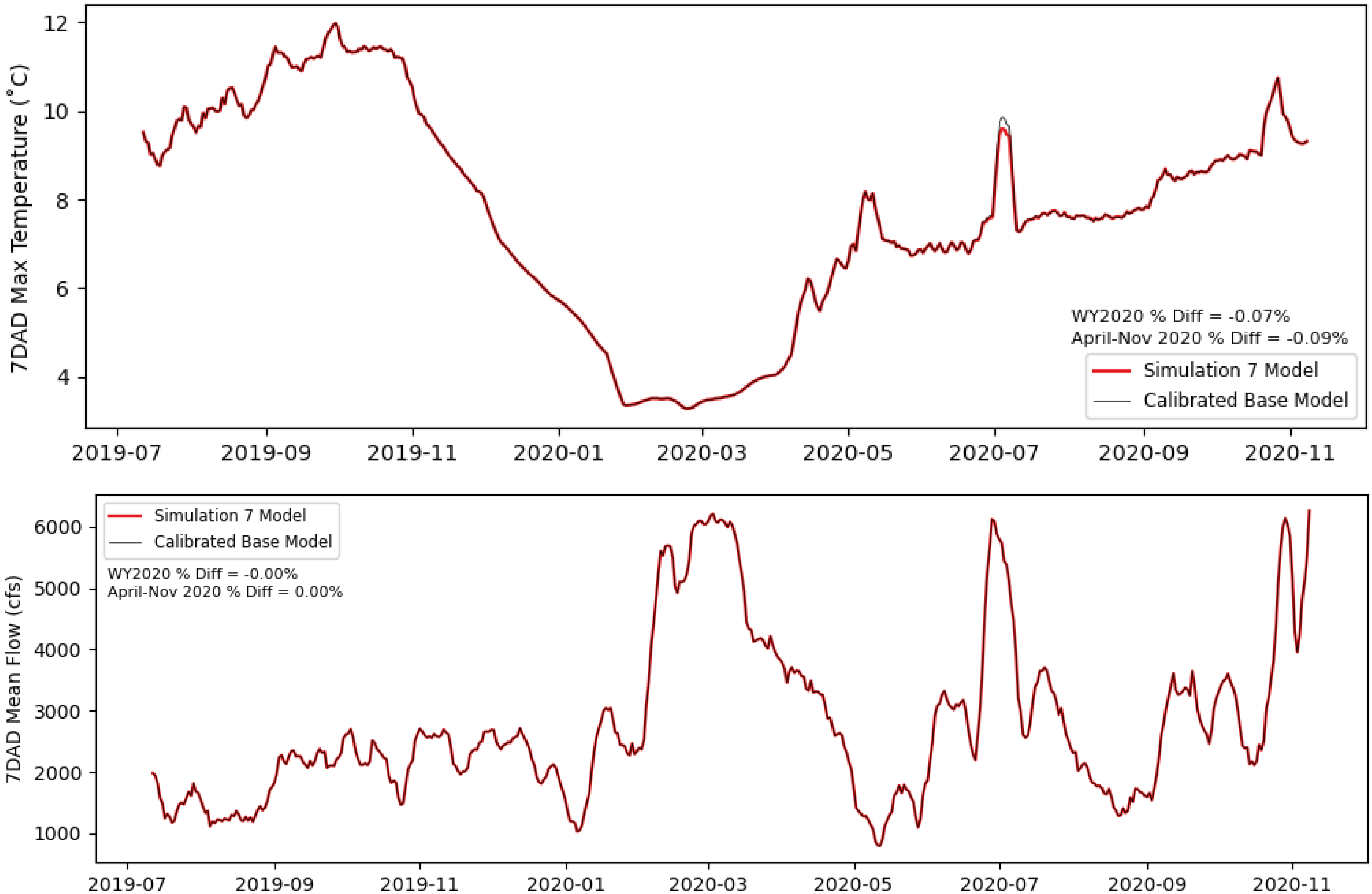


Figure C.1-14. Ross Lake outflow 7DAD-mean flow and max temperature variation for Simulation 7 (remove top 5 withdrawal layers).

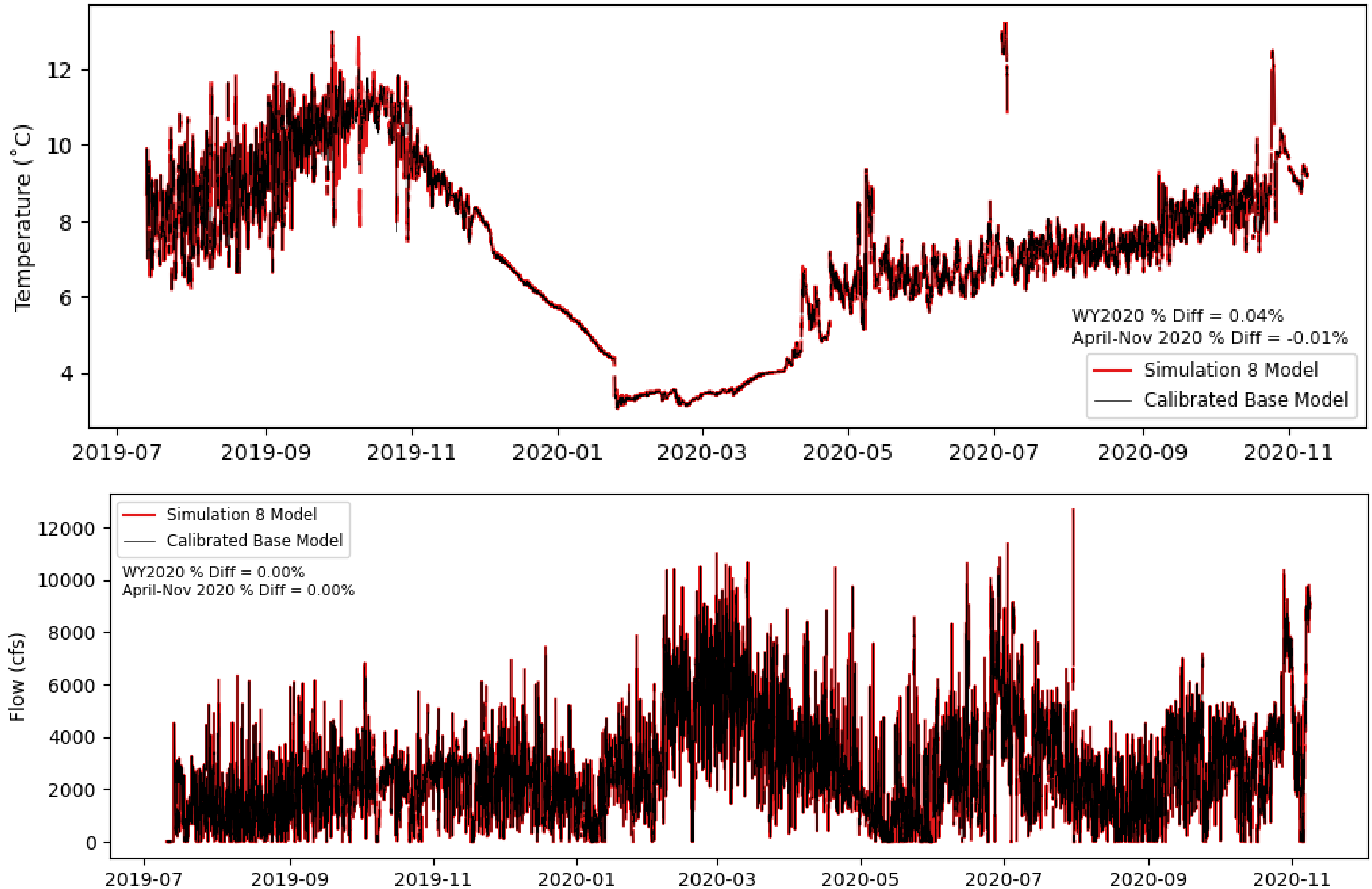


Figure C.1-15. Ross Lake outflow continuous hourly flow and temperature variation for Simulation 8 (remove bottom 5 withdrawal layers).

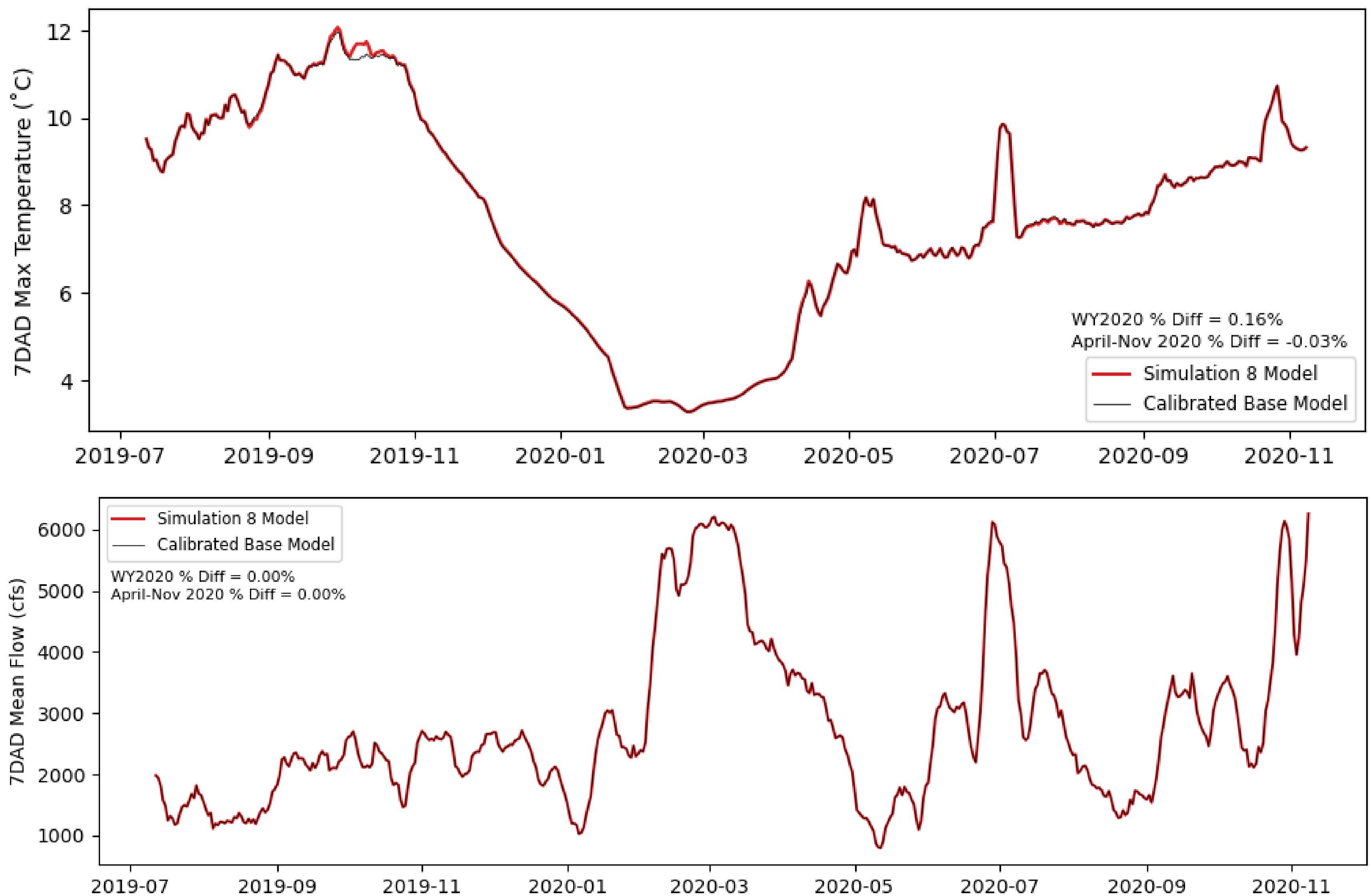


Figure C.1-16. Ross Lake outflow 7DAD-mean flow and max temperature variation for Simulation 8 (remove bottom 5 withdrawal layers).

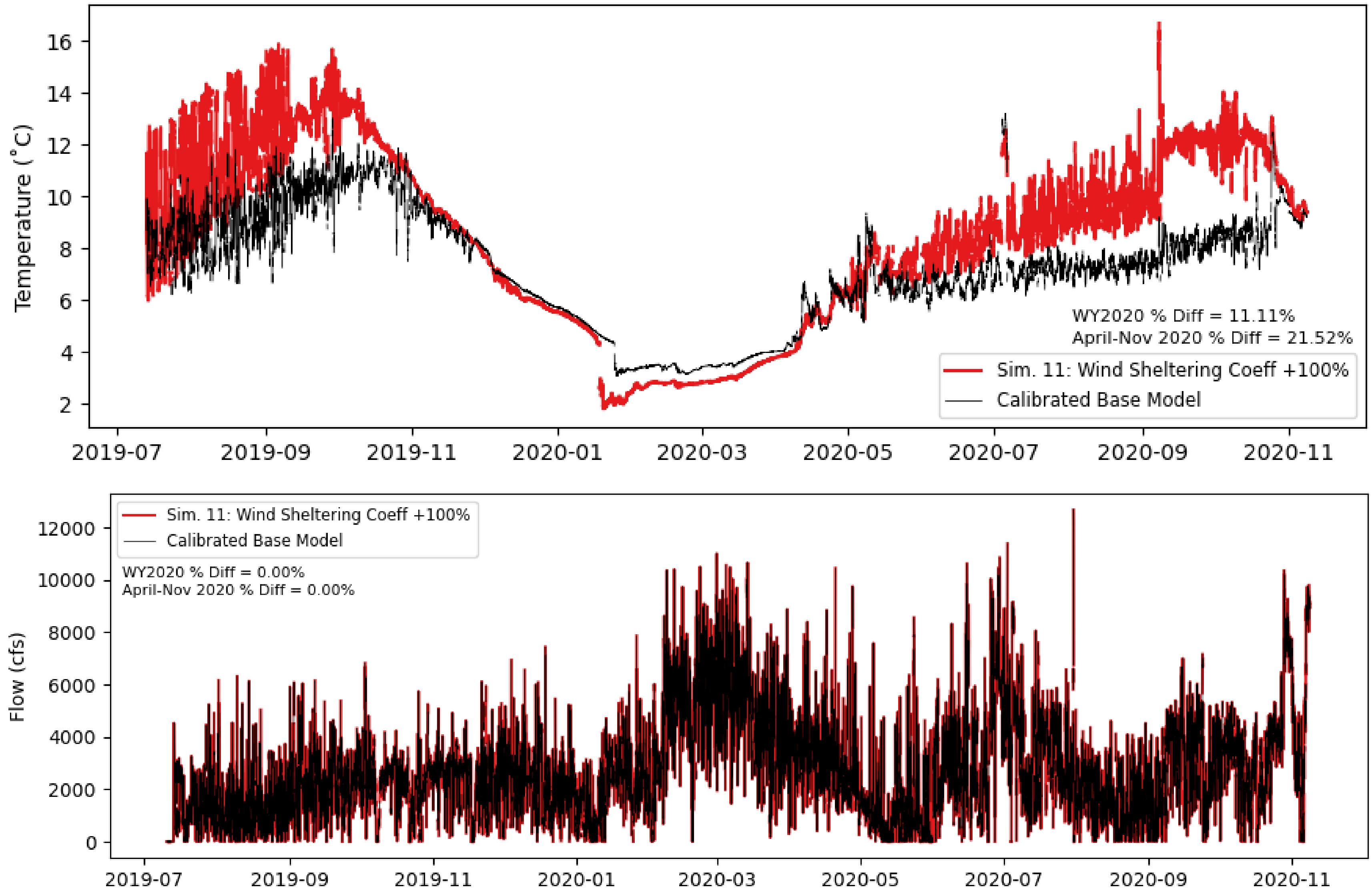


Figure C.1-17. Ross Lake outflow continuous hourly flow and temperature variation for Simulation 11 (double wind sheltering coefficient).

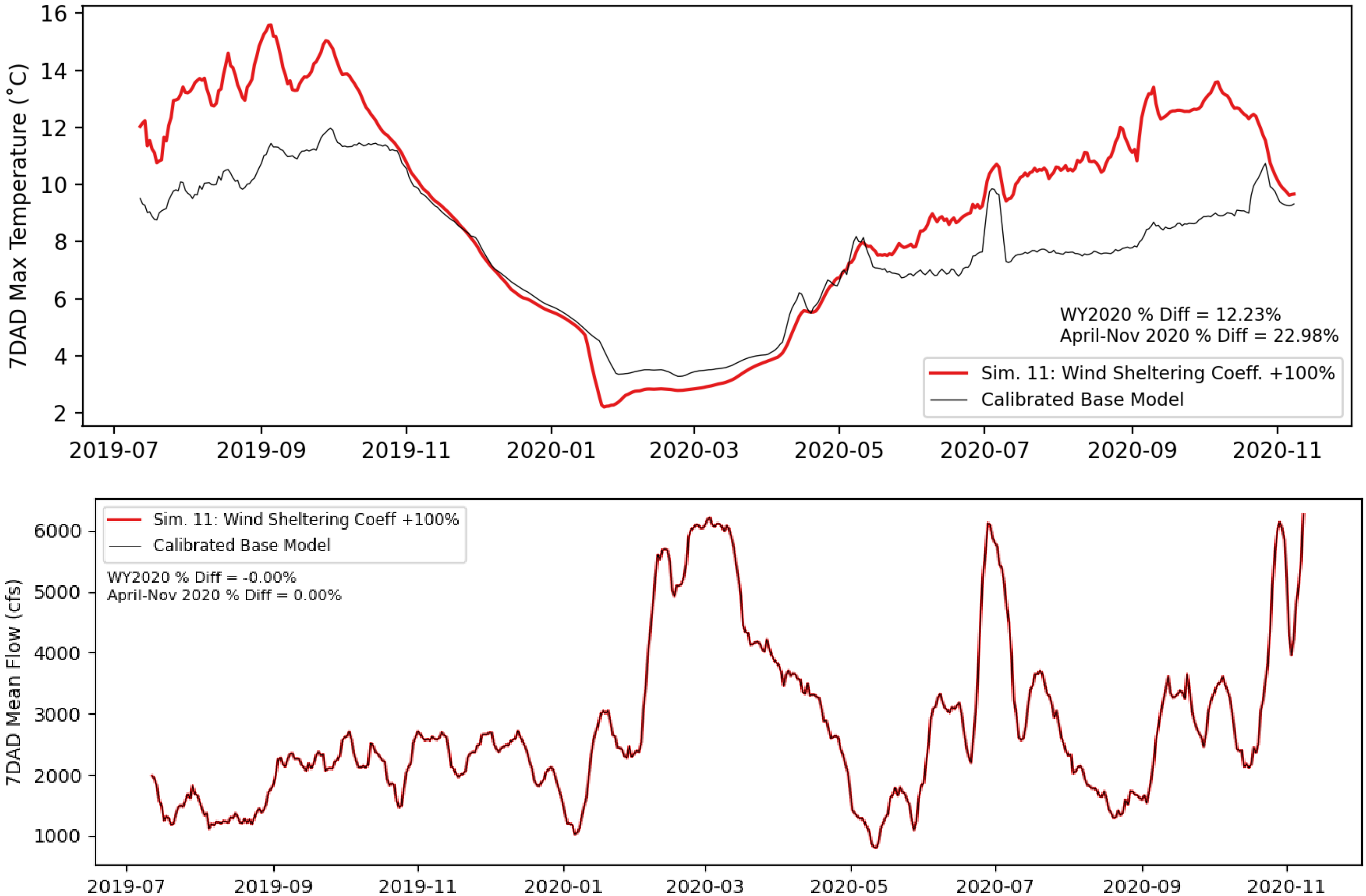


Figure C.1-18. **Ross Lake outflow 7DAD-Mean flow and max temperature variation for SA Simulation 11 (double wind sheltering coefficient).**

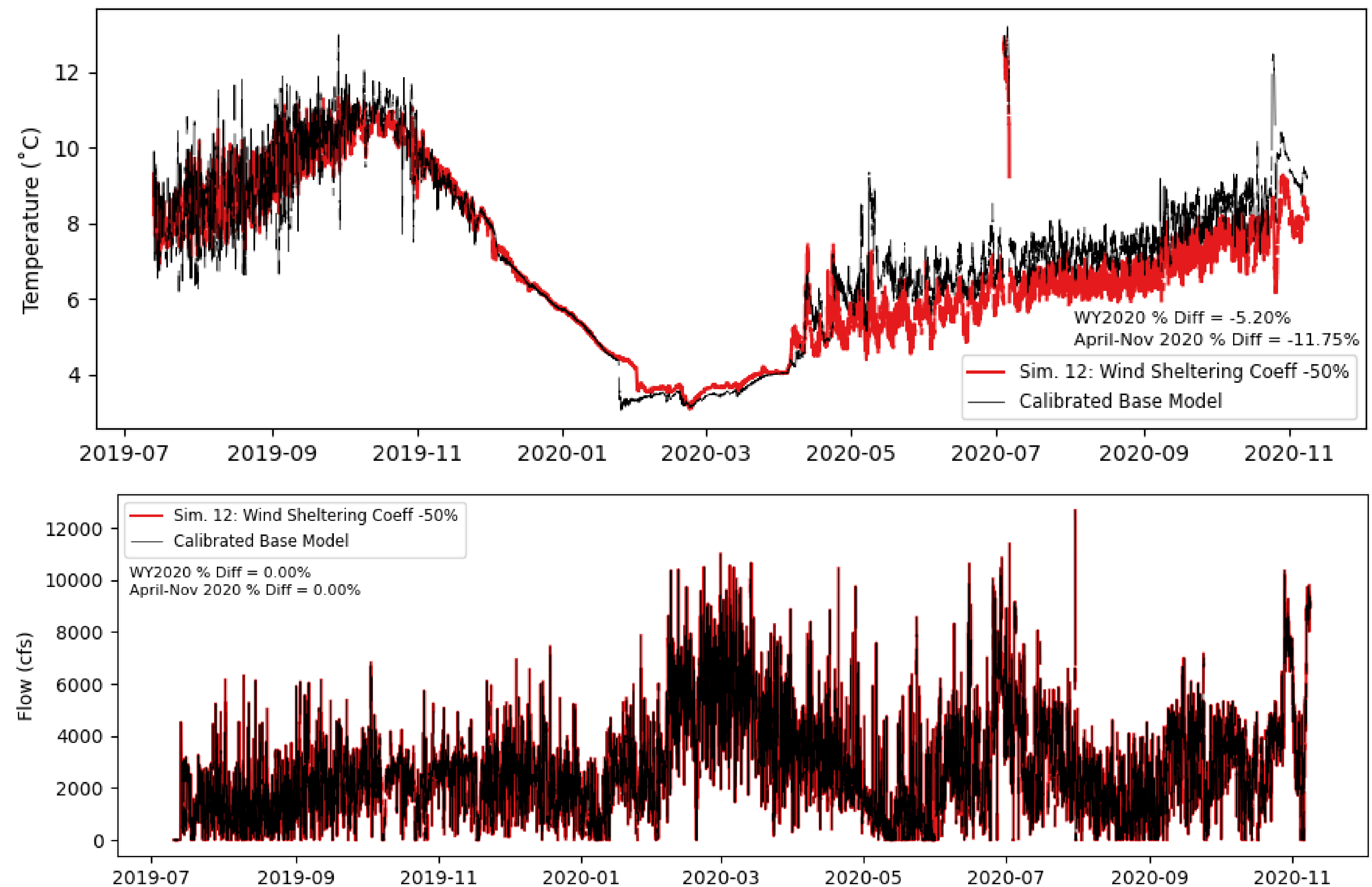


Figure C.1.19. Ross Lake outflow continuous hourly flow and temperature variation for Simulation 12 (halved wind sheltering coefficient).

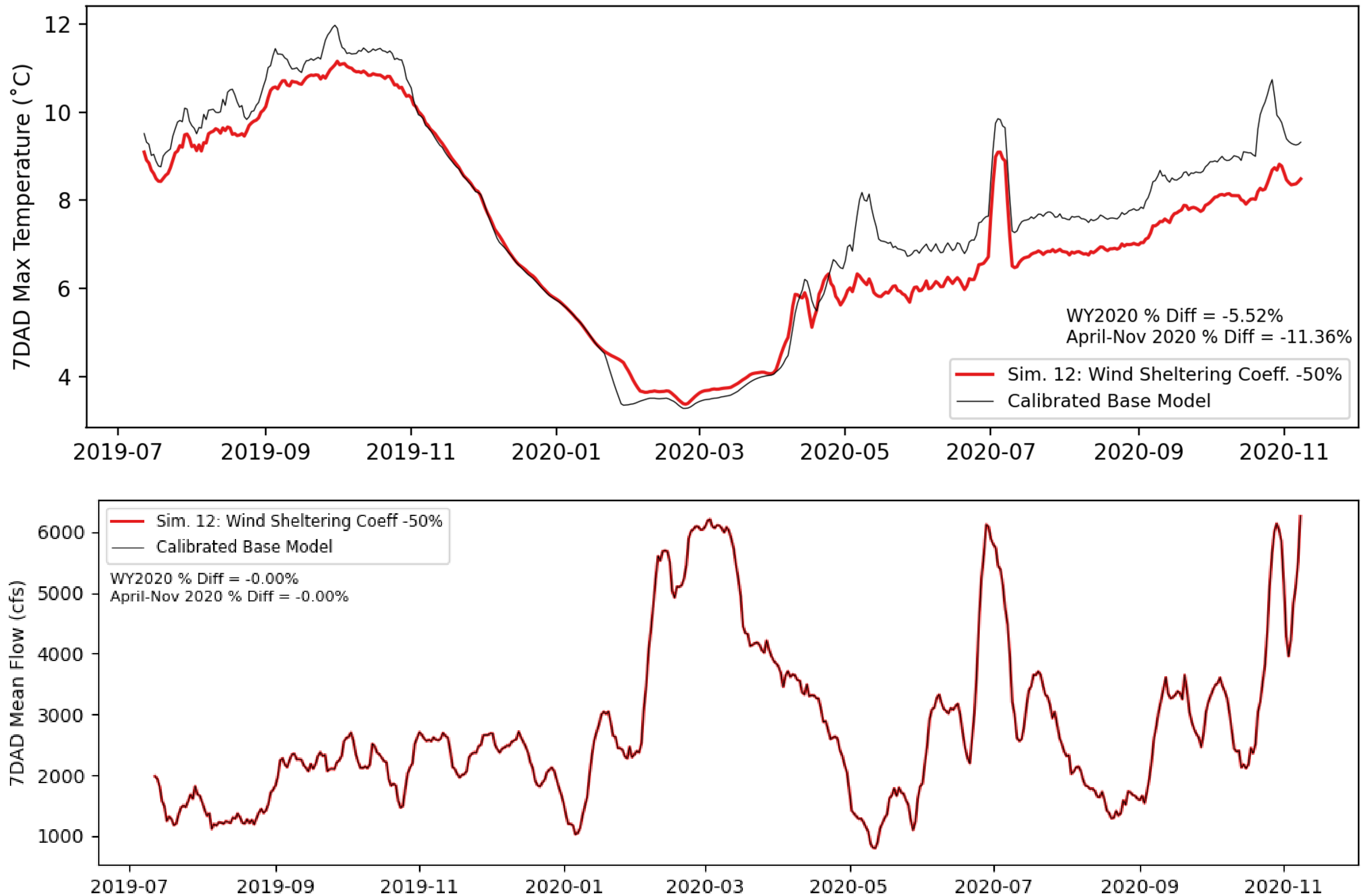


Figure C.1-20. **Ross Lake outflow 7DAD-Mean flow and max temperature variation for Simulation 12 (halve wind sheltering coefficient).**

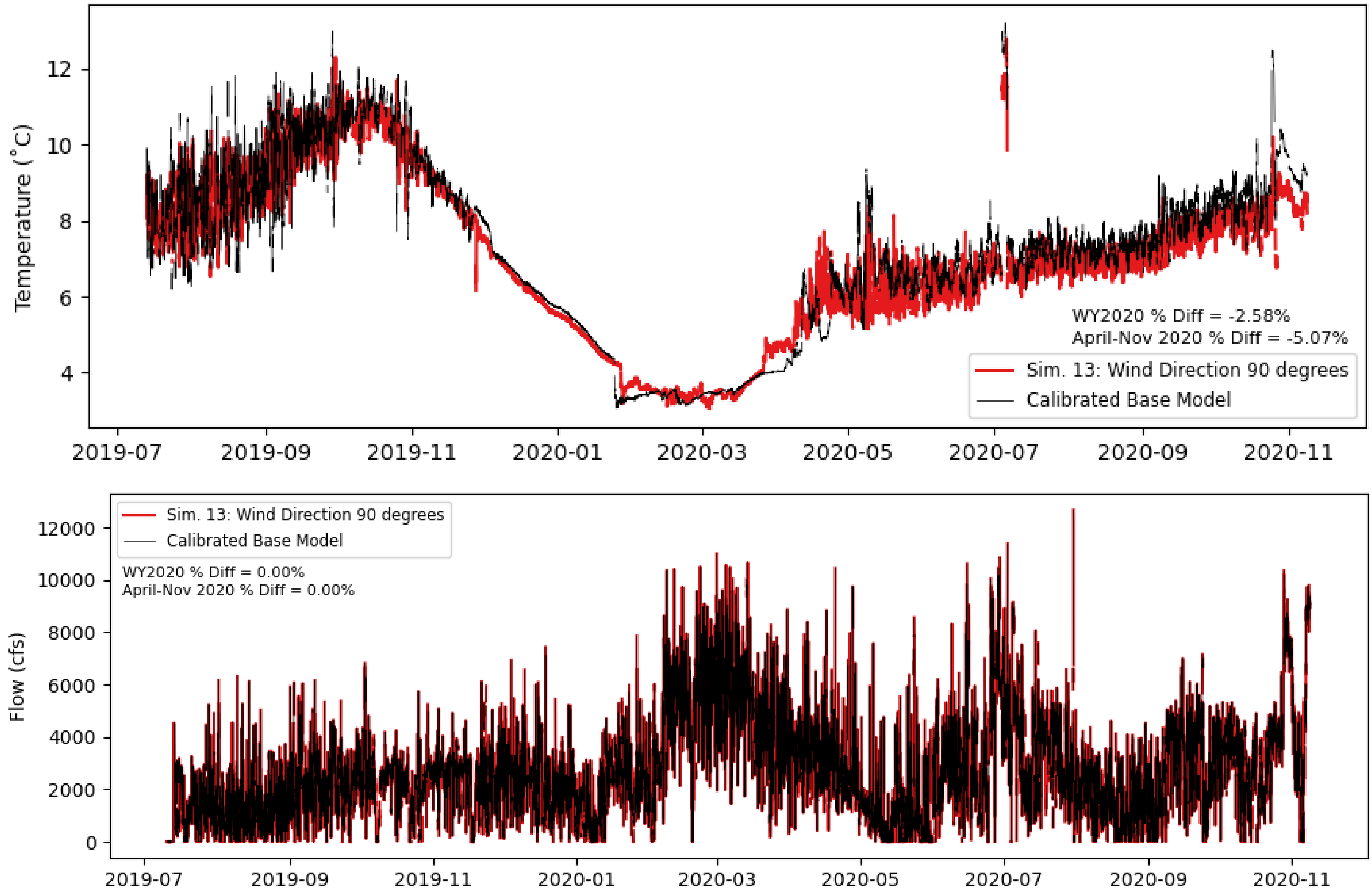


Figure C.1-21. Ross Lake outflow continuous hourly flow and temperature variation for Simulation 13 (rotate wind direction 90 degrees clockwise).

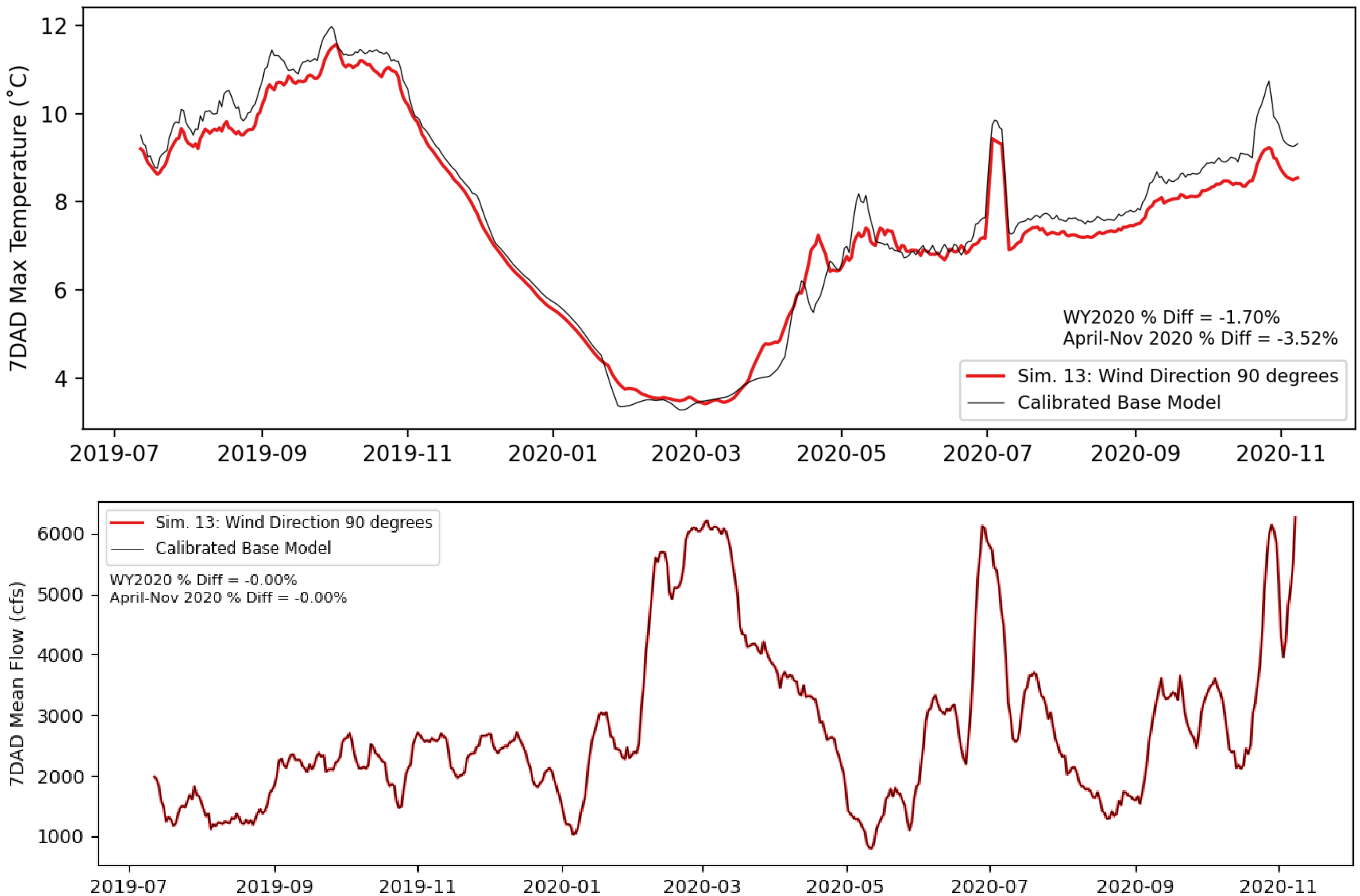


Figure C.1-22. Ross Lake outflow 7DAD-Mean Flow and max temperature variation for Simulation 13 (rotate wind direction 90 degrees counter-clockwise).

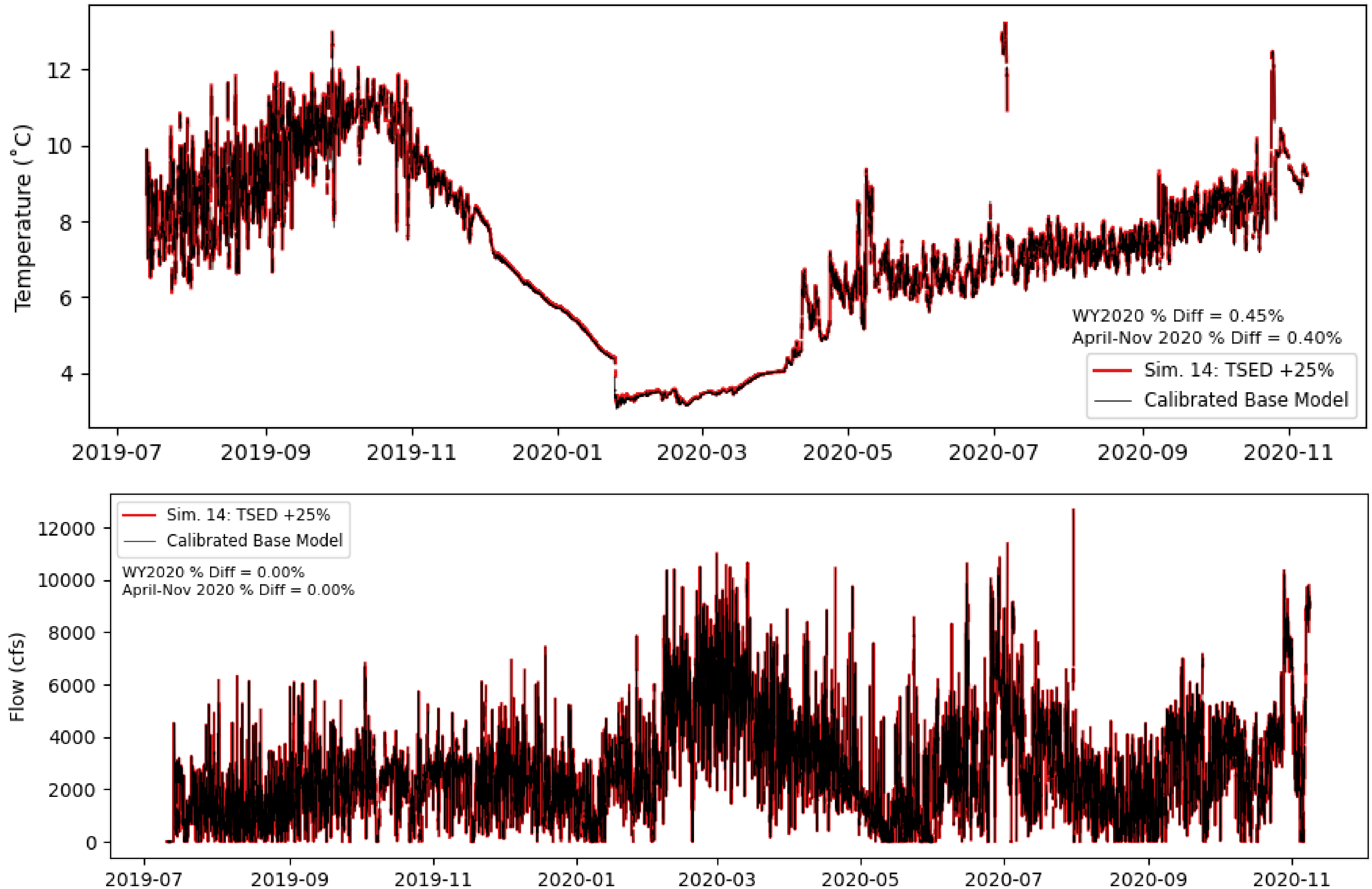


Figure C.1-23. Ross Lake outflow continuous hourly flow and temperature variation for Simulation 14 (increase sediment temperature by 25 percent).

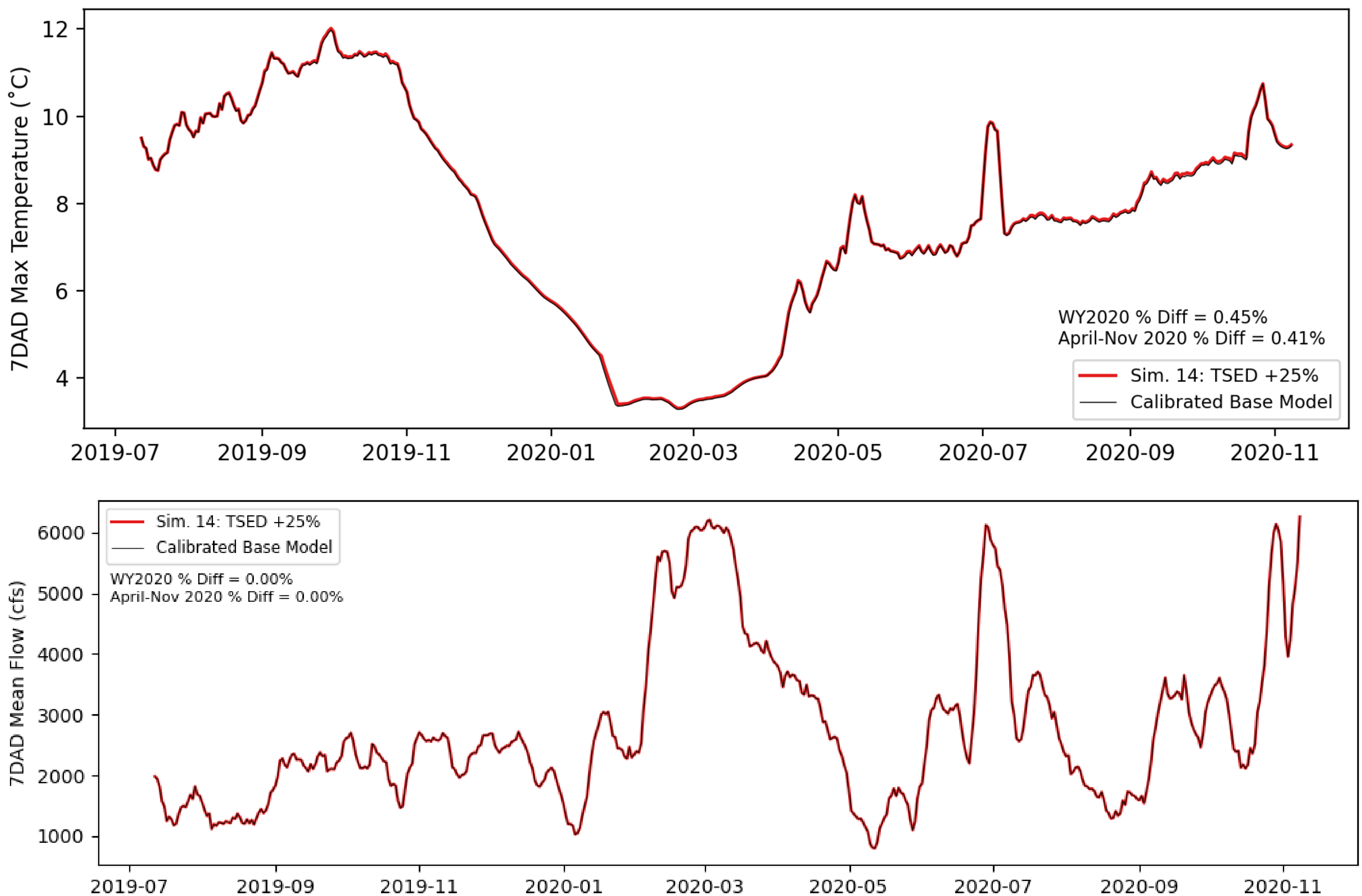


Figure C.1-24. Ross Lake outflow 7DAD-Mean flow and max temperature variation for Simulation 14 (increase sediment temperature by 25 percent).

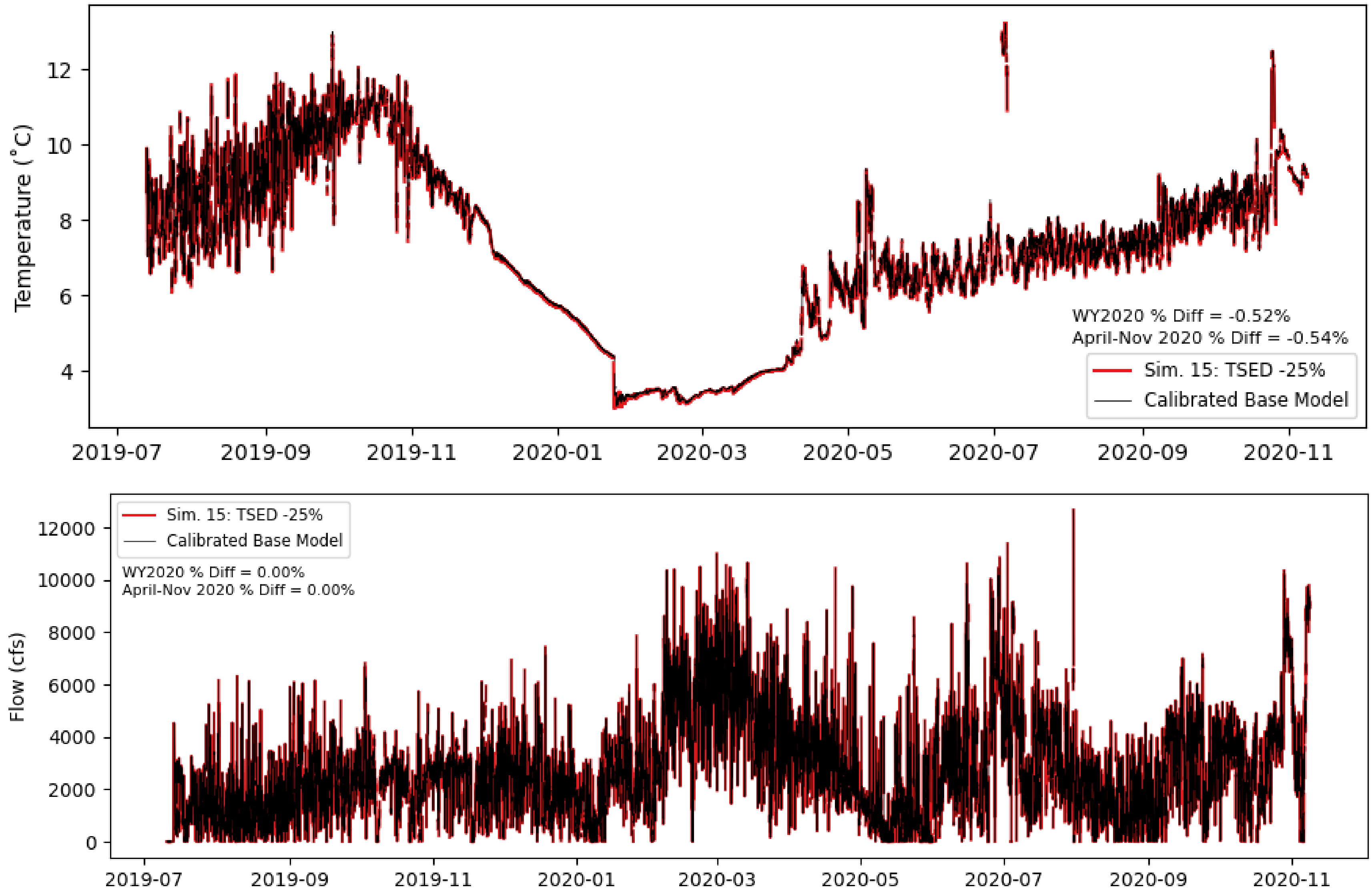


Figure C.1-25. Ross Lake outflow continuous hourly flow and temperature variation for Simulation 15 (decrease sediment temperature by 25 percent).

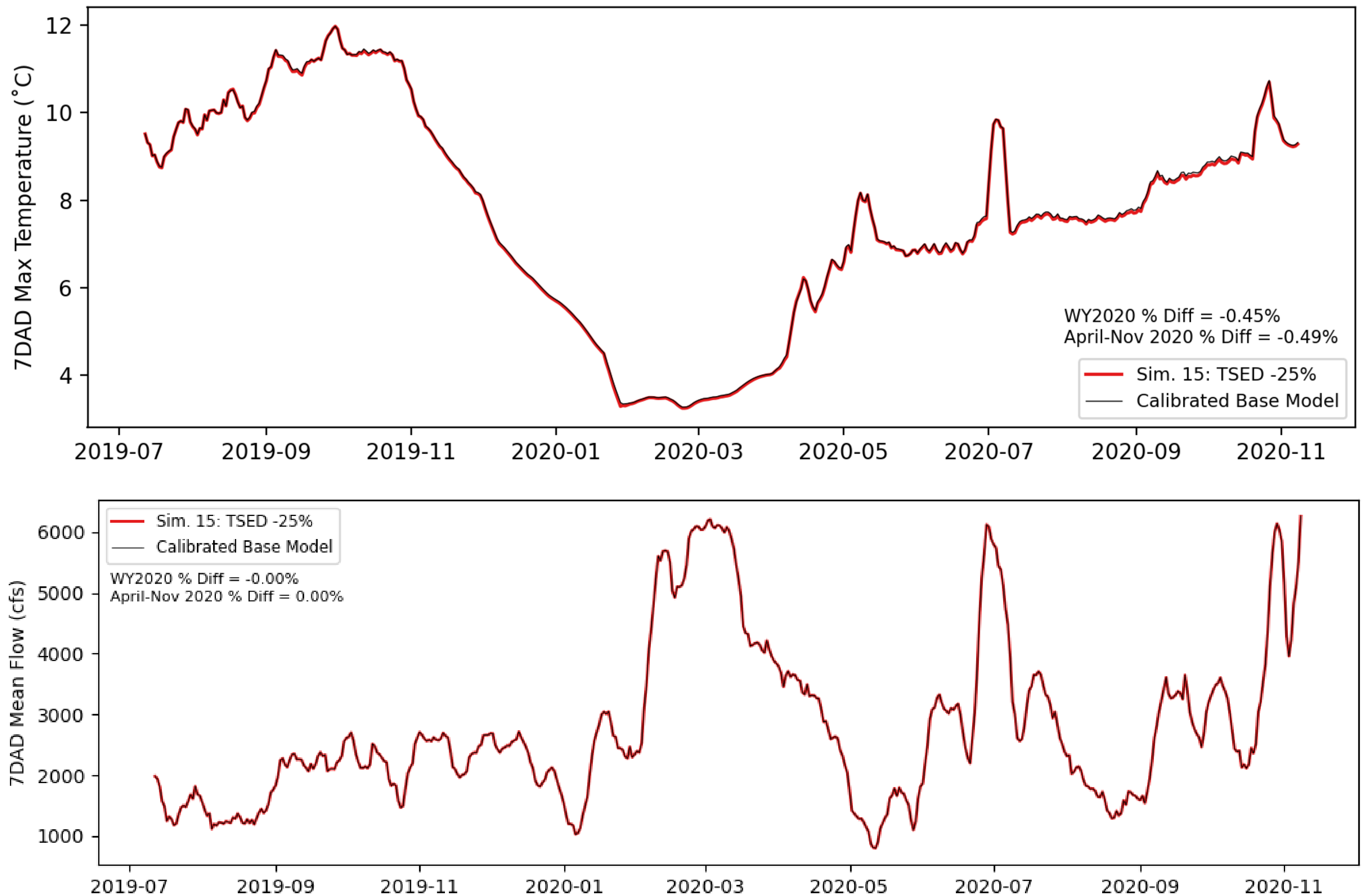


Figure C.1-26. Ross Lake Outflow 7DAD-Mean Flow and Max Temperature Variation for Simulation 15 (decrease sediment temperature by 25 percent).

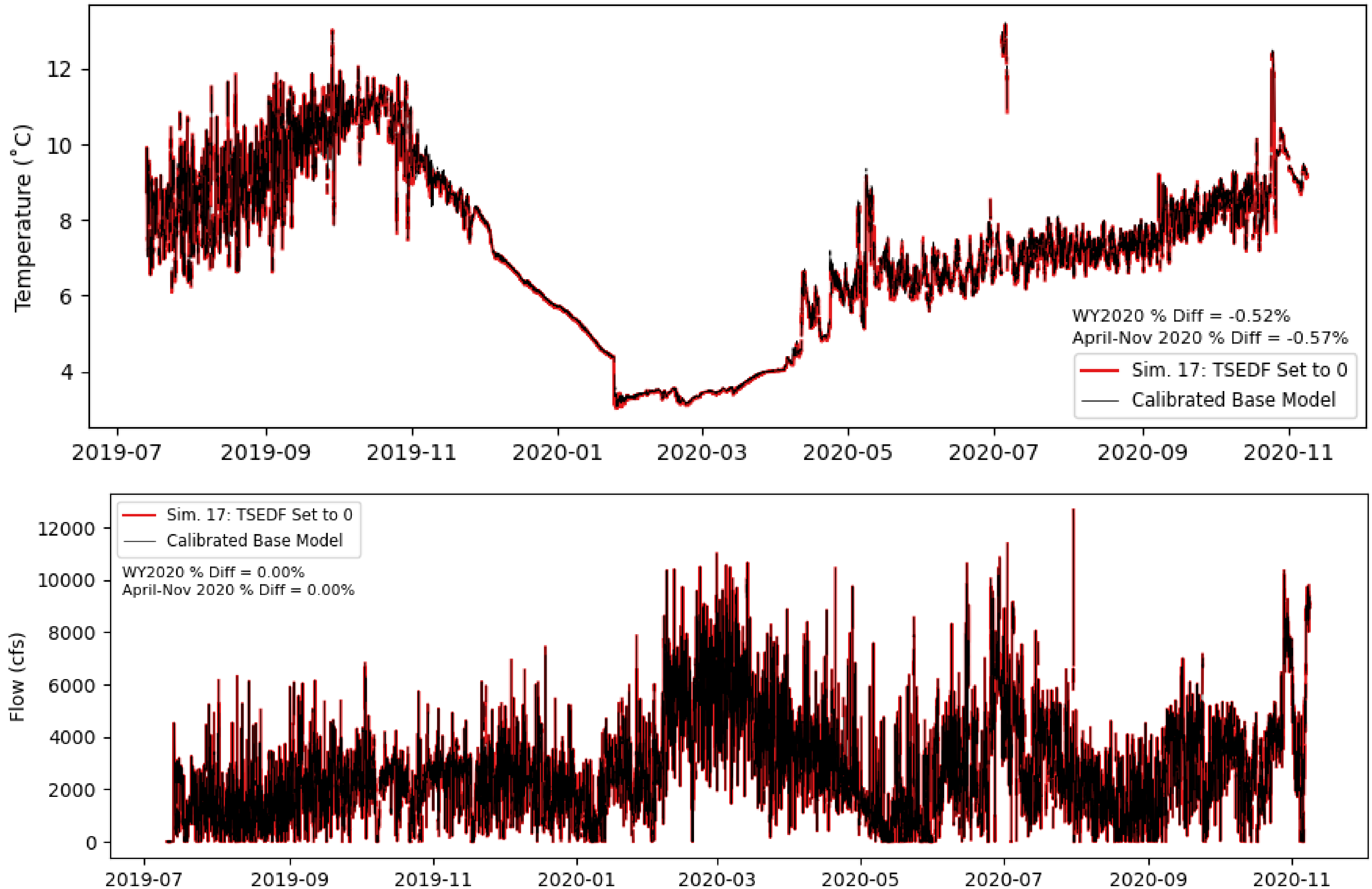


Figure C.1-27. Ross Lake outflow continuous hourly flow and temperature variation for Simulation 17 (set sediment heat exchange coefficient to 0).

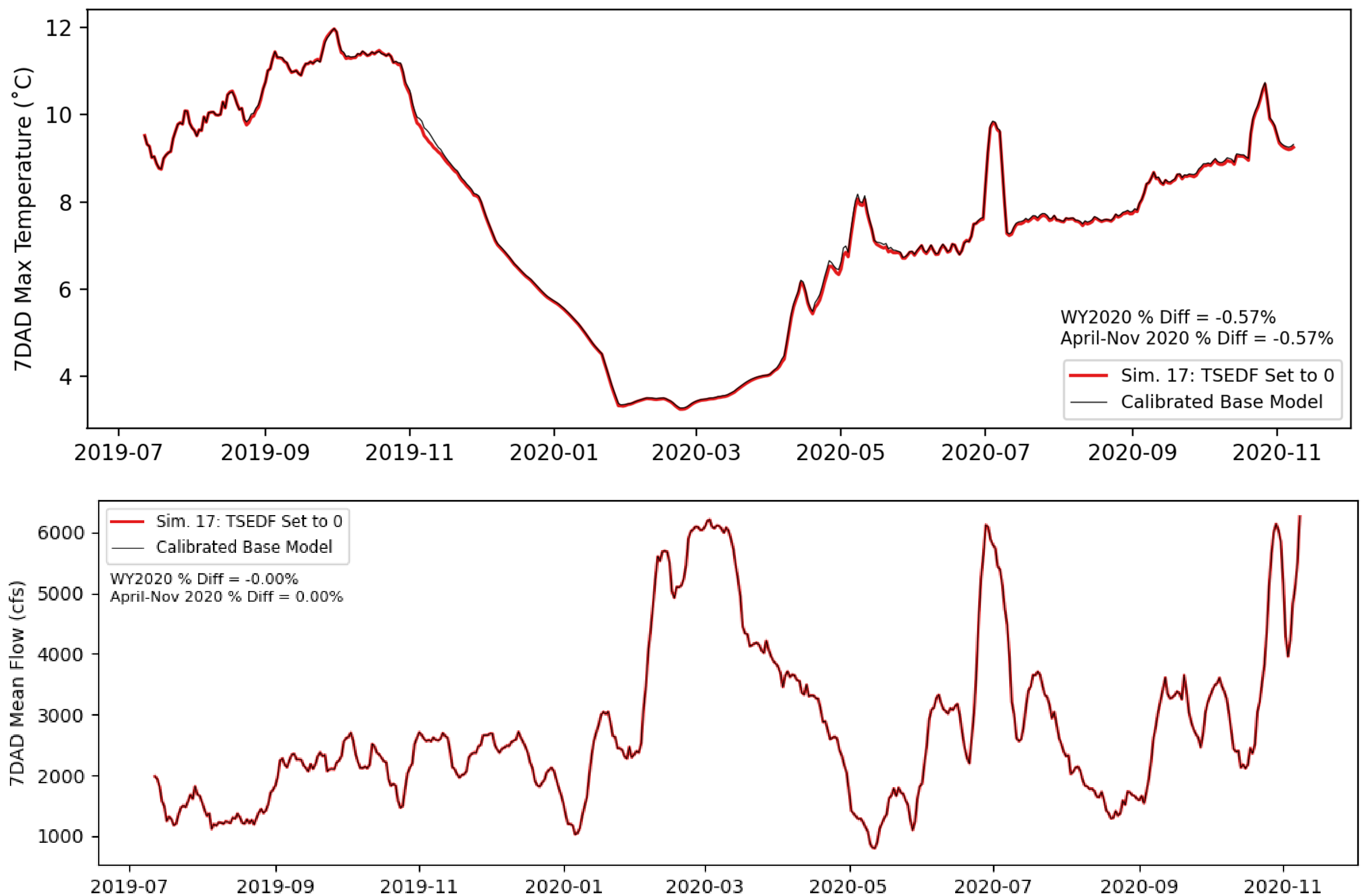


Figure C.1-28. Ross Lake outflow 7DAD-Mean flow and max temperature variation for Simulation 17 (set sediment heat exchange coefficient to 0).

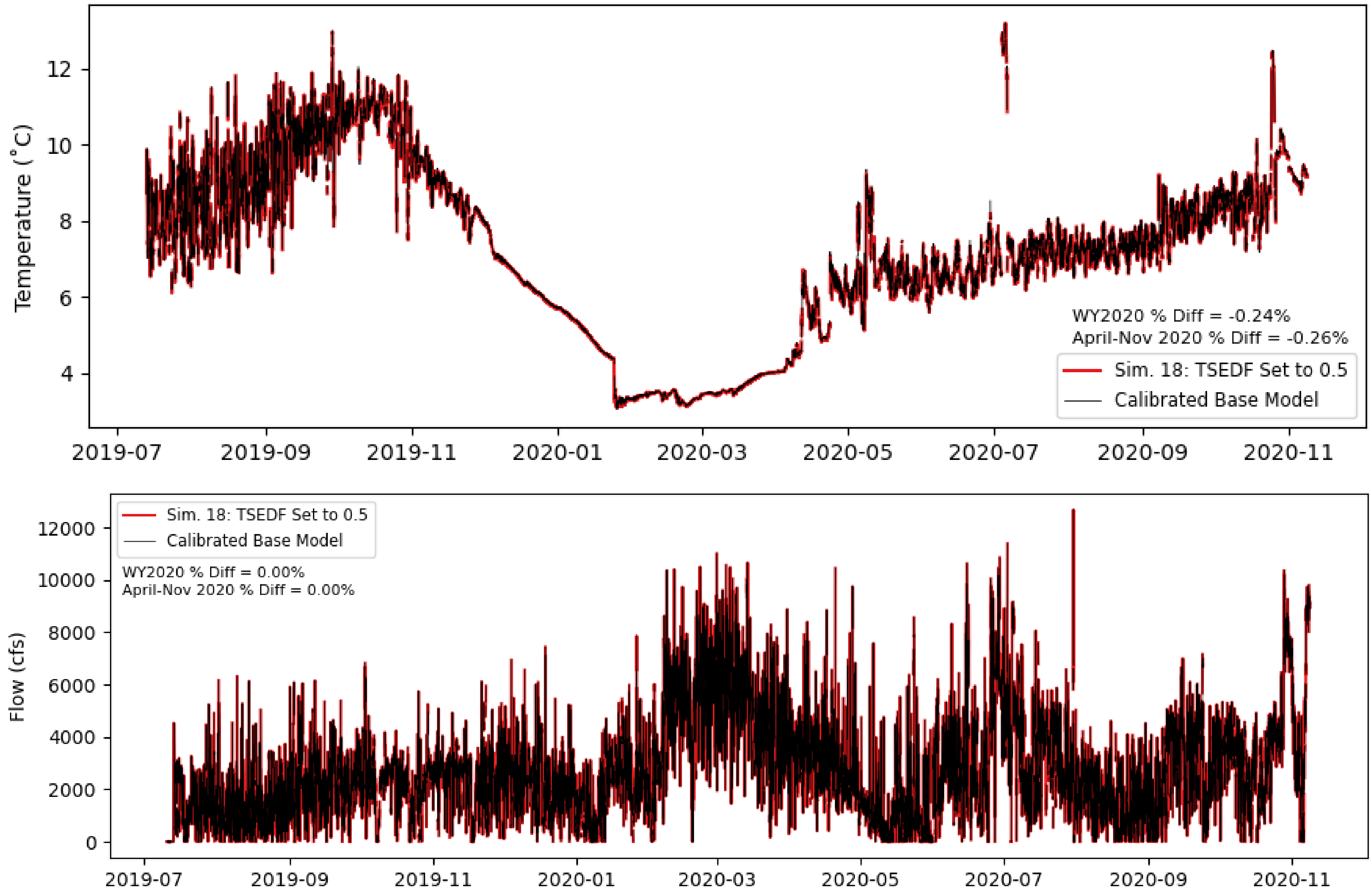


Figure C.1-29. Ross Lake outflow continuous hourly flow and temperature variation for Simulation 18 (set sediment heat exchange coefficient to 0.5).

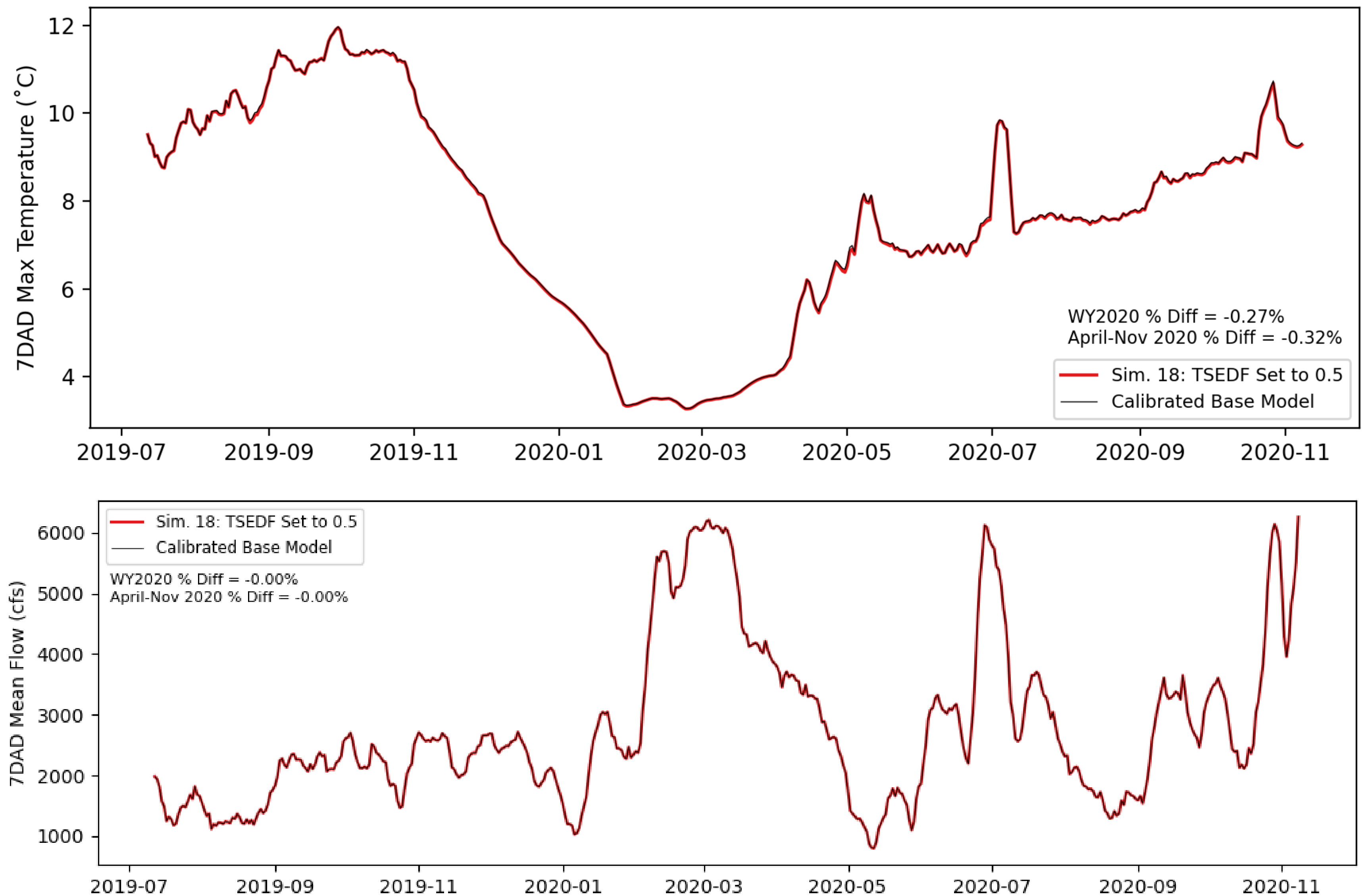


Figure C.1-30. Ross Lake outflow 7DAD-Mean flow and max temperature variation for Simulation 18 (set sediment heat exchange coefficient to 0.5).

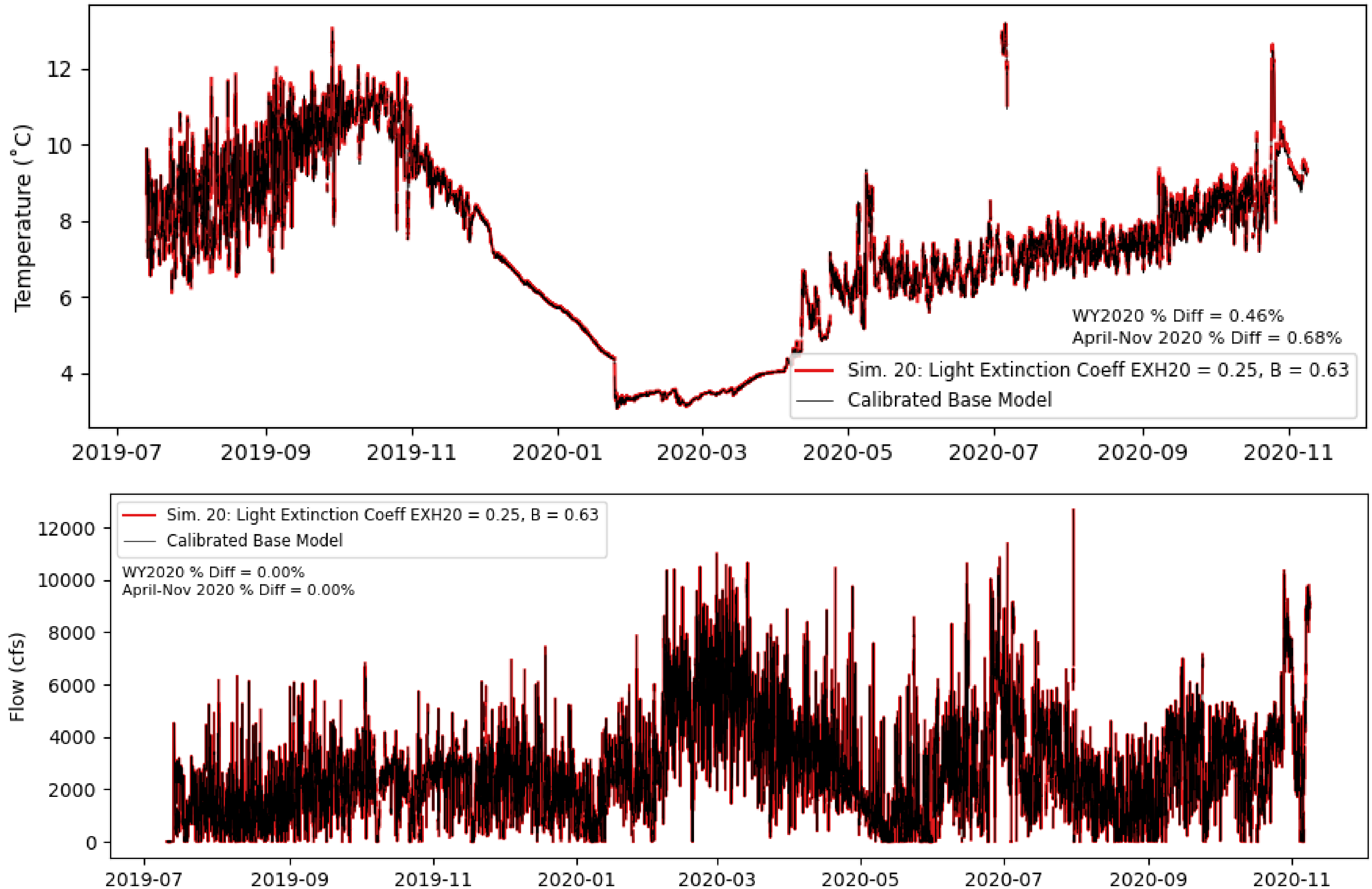


Figure C.1-31. Ross Lake outflow continuous hourly flow and temperature variation for Simulation 20 (increase light absorption coefficient, reduce vertical light extinction).

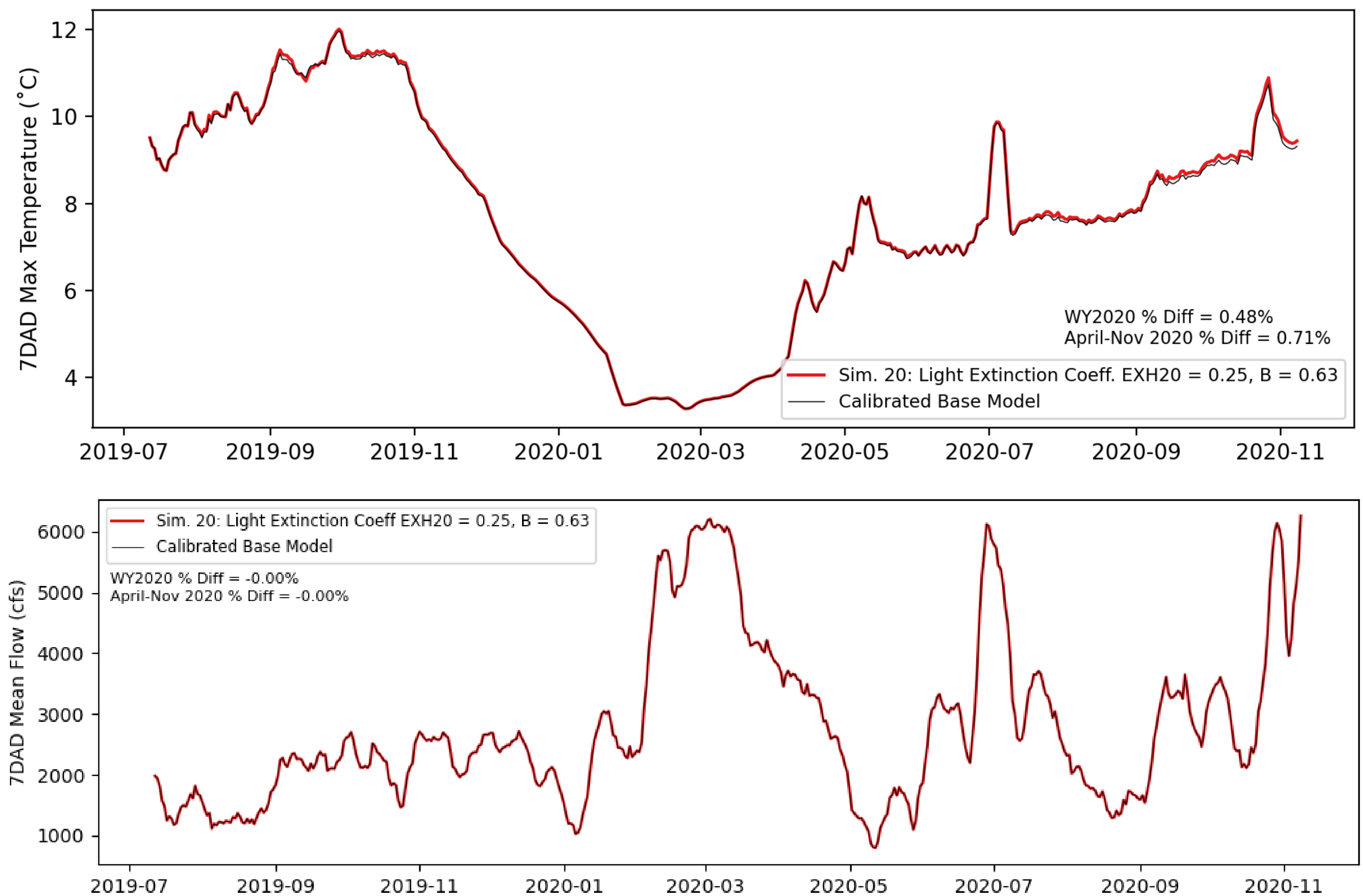


Figure C.1-32. Ross Lake outflow 7DAD-Mean flow and max temperature variation for Simulation 20 (increase light absorption coefficient, reduce vertical light extinction).

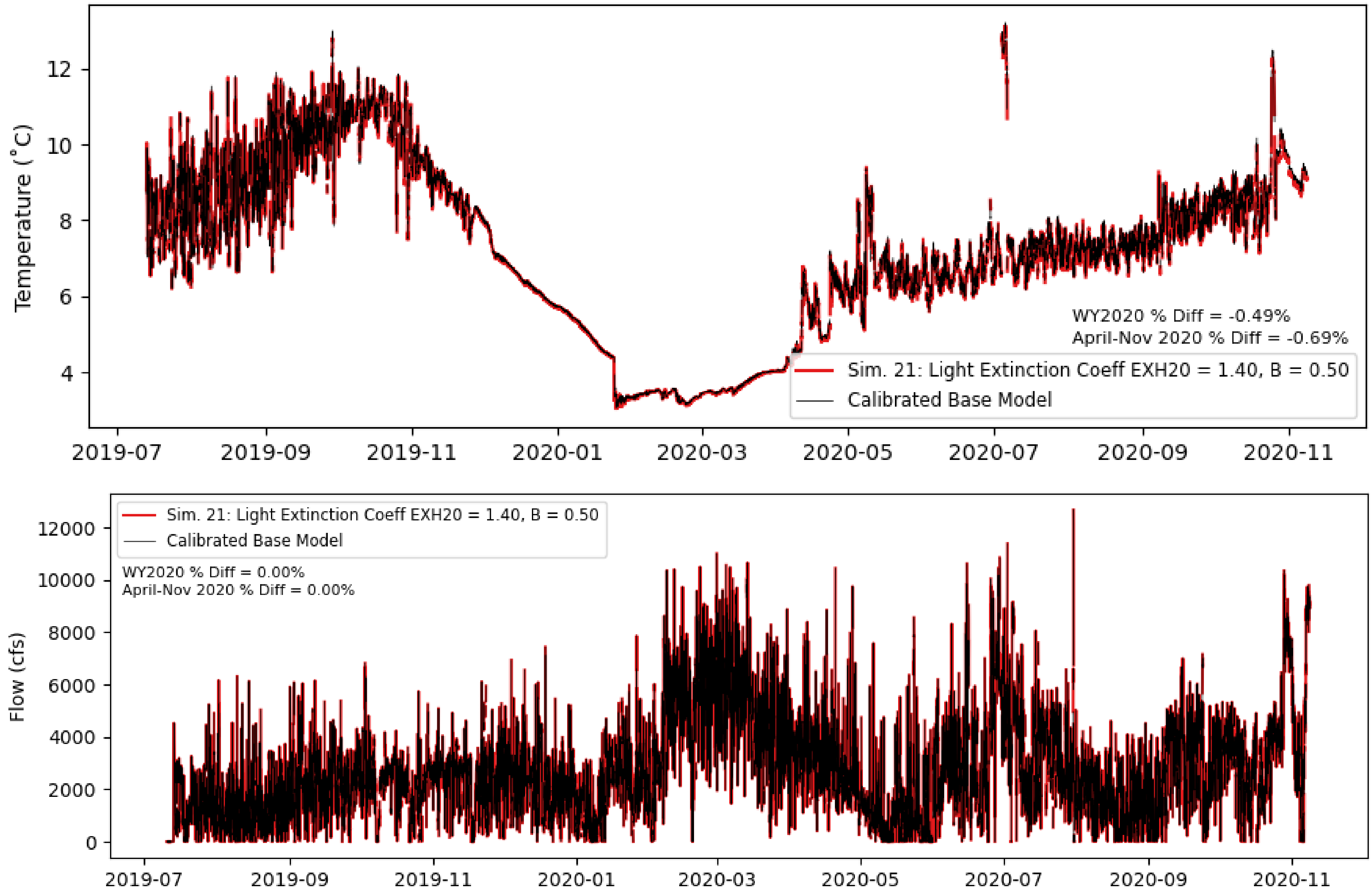


Figure C.1-33. Ross Lake outflow continuous hourly flow and temperature variation for Simulation 21 (decrease light absorption coefficient, increase vertical light extinction).

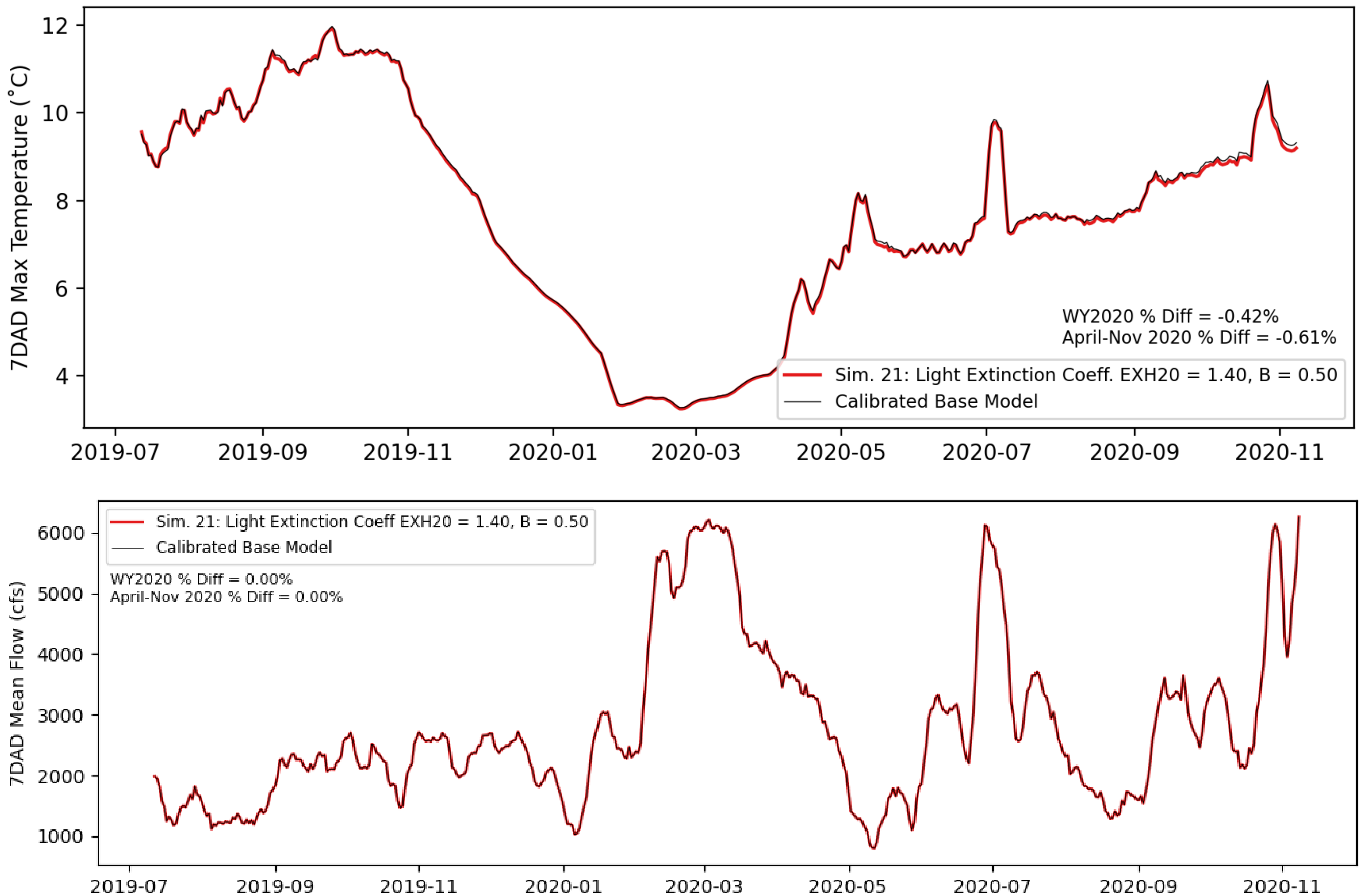


Figure C.1-34. Ross Lake outflow 7DAD-Mean flow and max temperature variation for Simulation 21 (decrease light absorption coefficient, increase vertical light extinction).

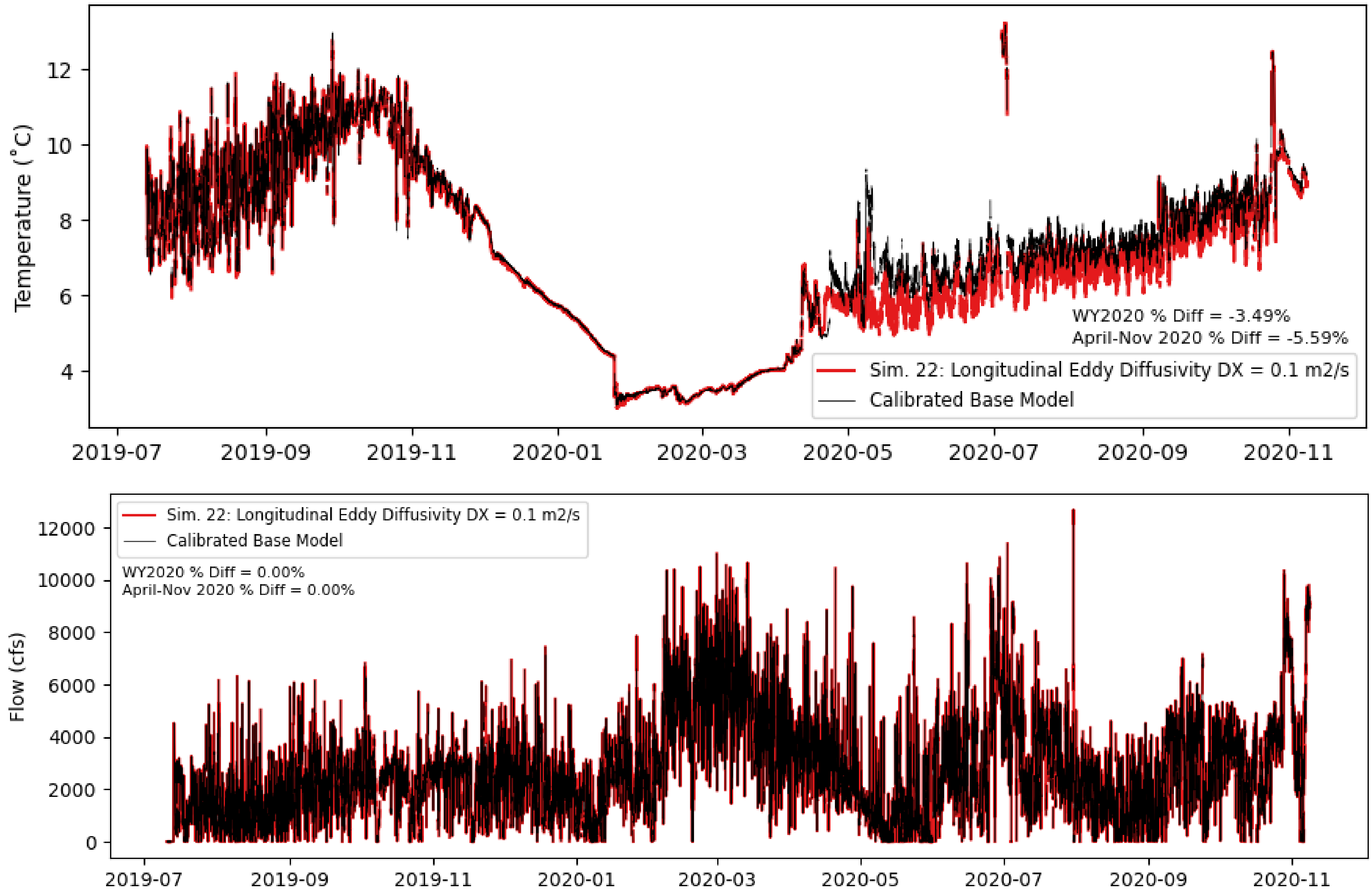
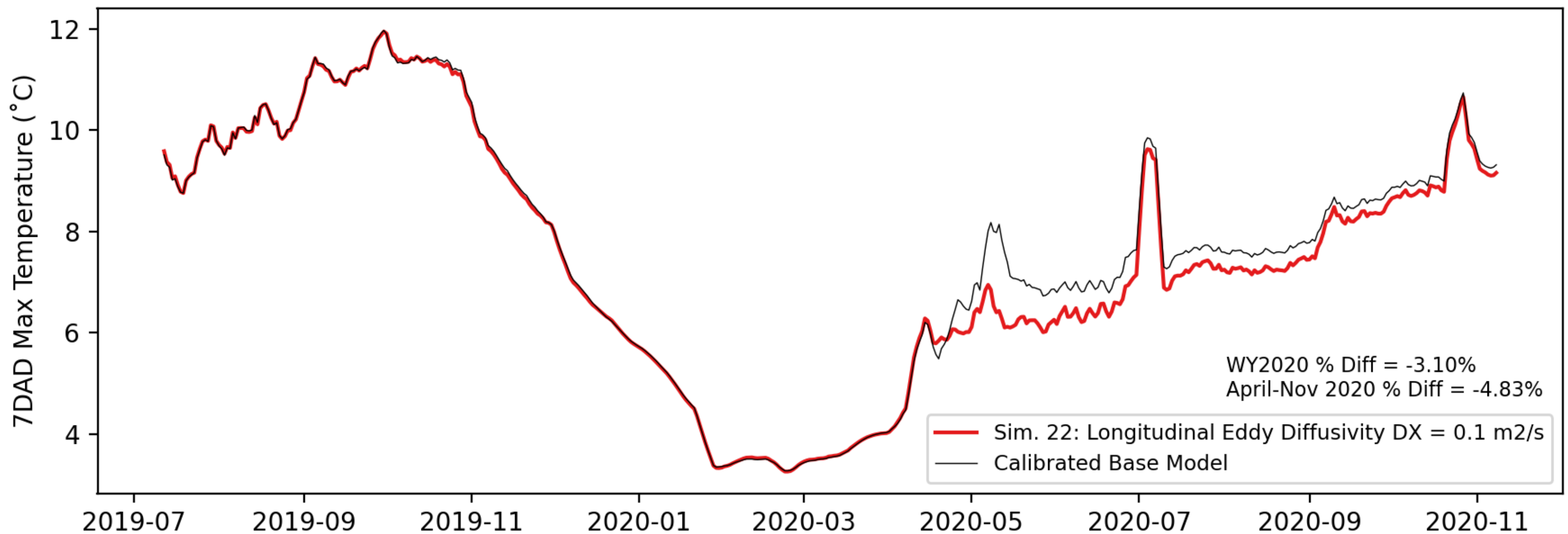


Figure C.1-35. Ross Lake outflow continuous hourly flow and temperature variation for Simulation 22 (set longitudinal eddy diffusivity to 0.1 m2/s).



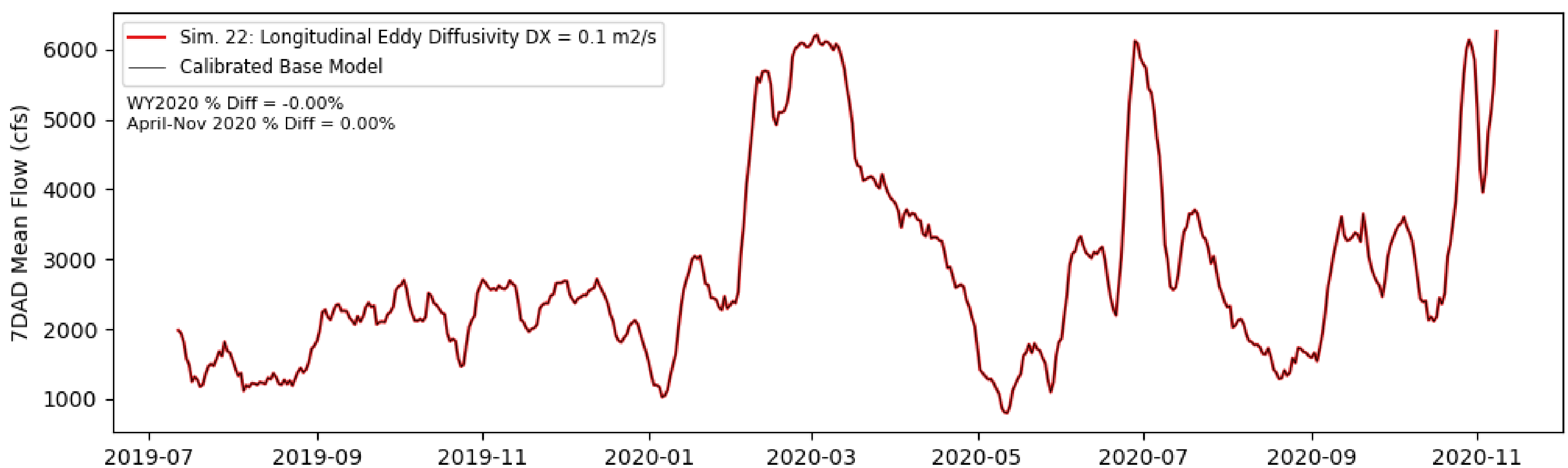


Figure C.1-36. Ross Lake outflow 7DAD-Mean flow and max temperature variation for Simulation 22 (set longitudinal eddy diffusivity to 0.1 m2/s).

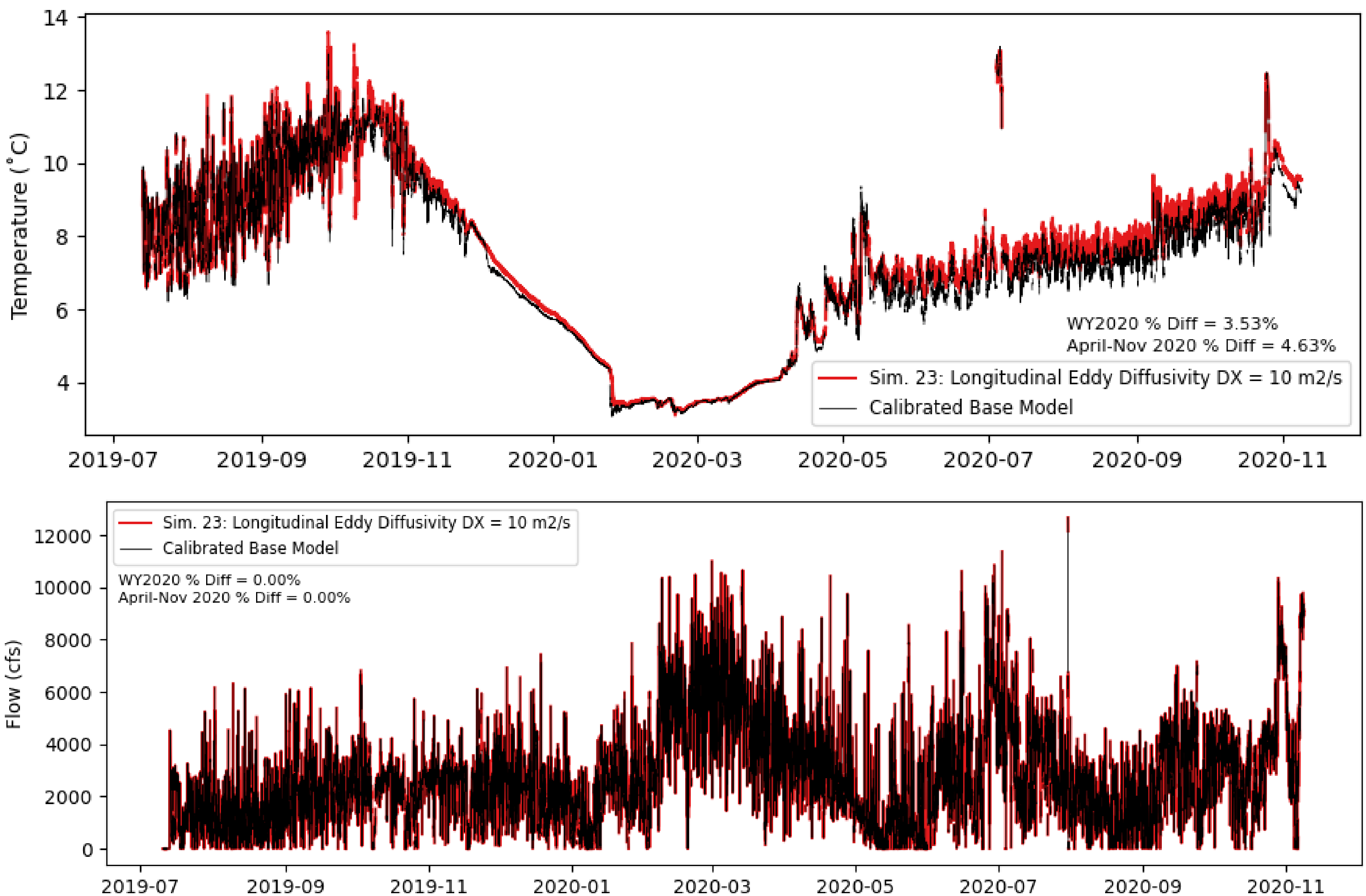


Figure C.1-37. Ross Lake outflow continuous hourly flow and temperature variation for Simulation 23 (set longitudinal eddy diffusivity to 10 m2/s).

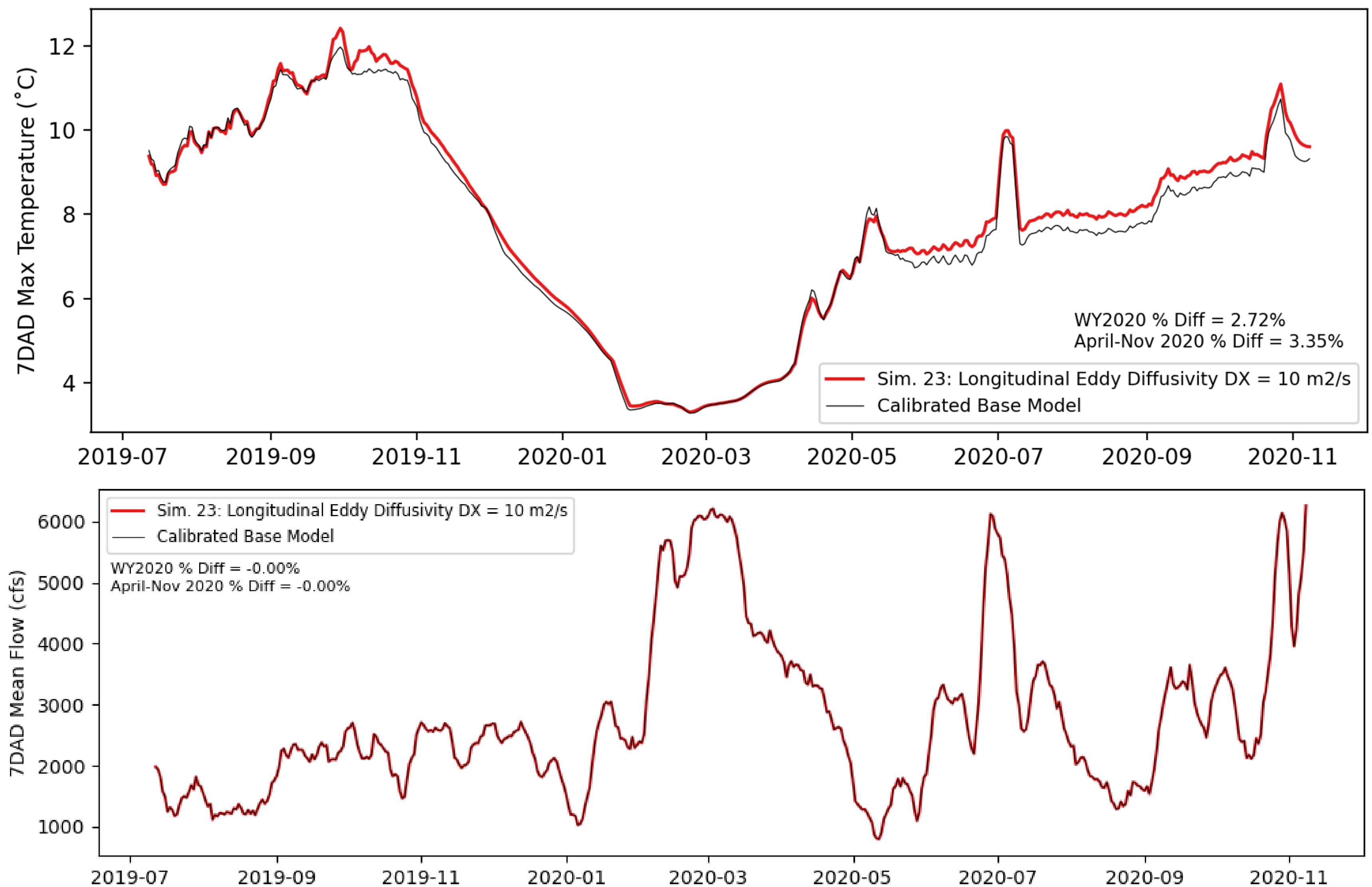


Figure C.1-38. Ross Lake outflow 7DAD-Mean flow and max temperature variation for Simulation 23 (set longitudinal eddy diffusivity to 10 m2/s).

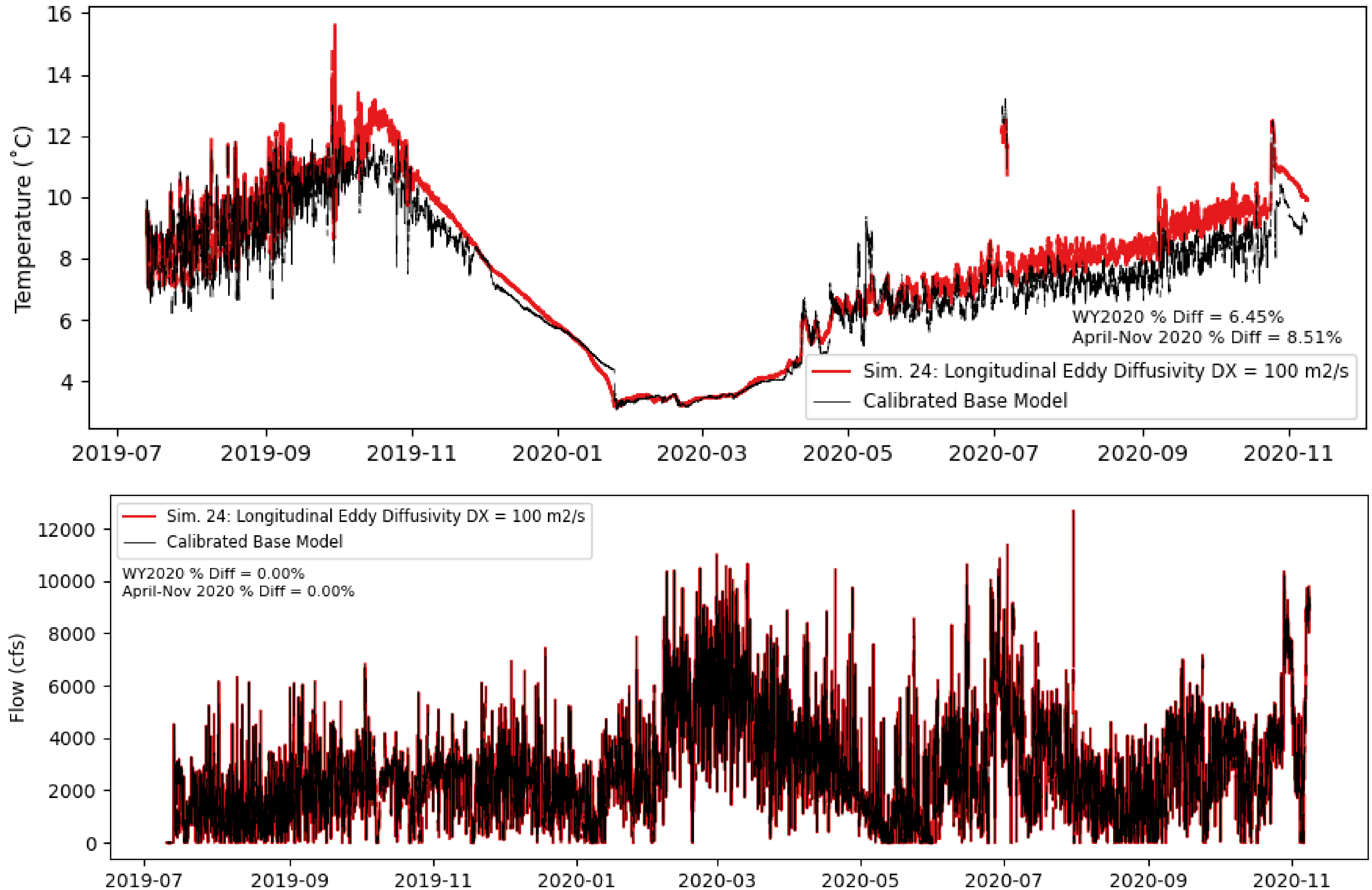


Figure C.1-39. Ross Lake outflow continuous hourly flow and temperature variation for Simulation 24 (set longitudinal eddy diffusivity to 100 m2/s).

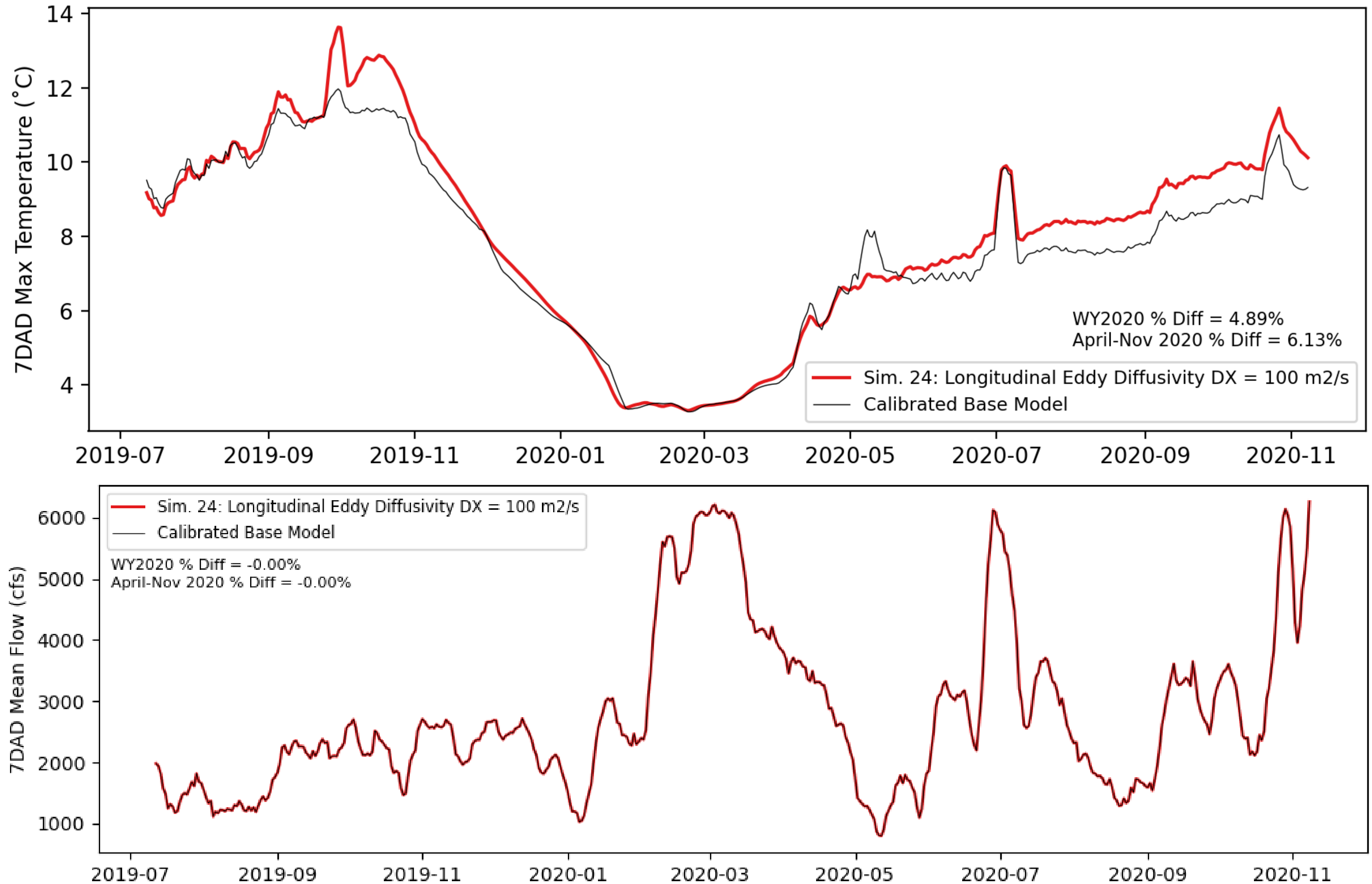


Figure C.1-40. Ross Lake outflow 7DAD-Mean flow and max temperature variation for Simulation 24 (set longitudinal eddy diffusivity to 100 m2/s).

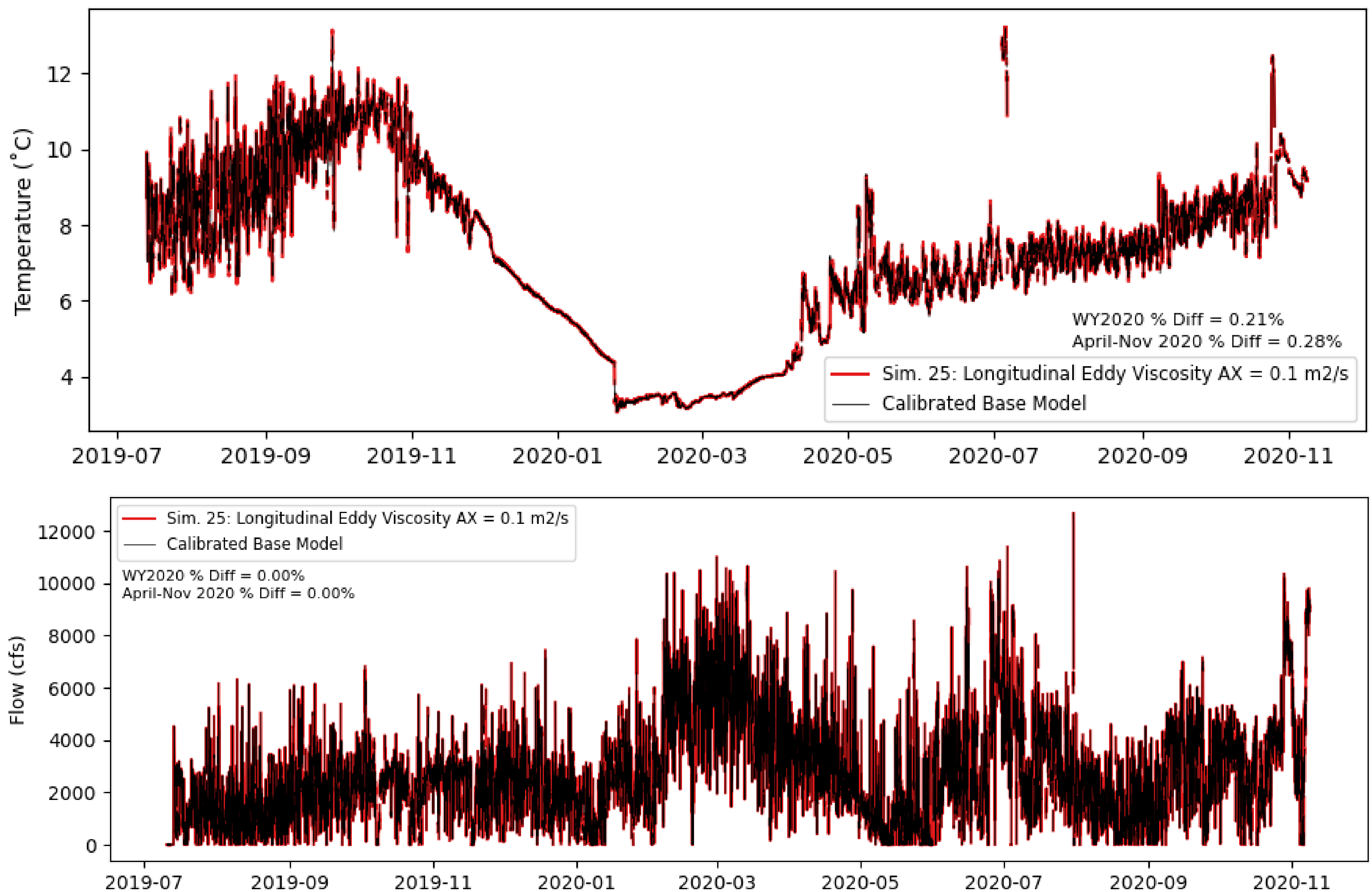


Figure C.1-41. Ross Lake outflow continuous hourly flow and temperature variation for Simulation 25 (set longitudinal eddy viscosity to 0.1 m2/s).

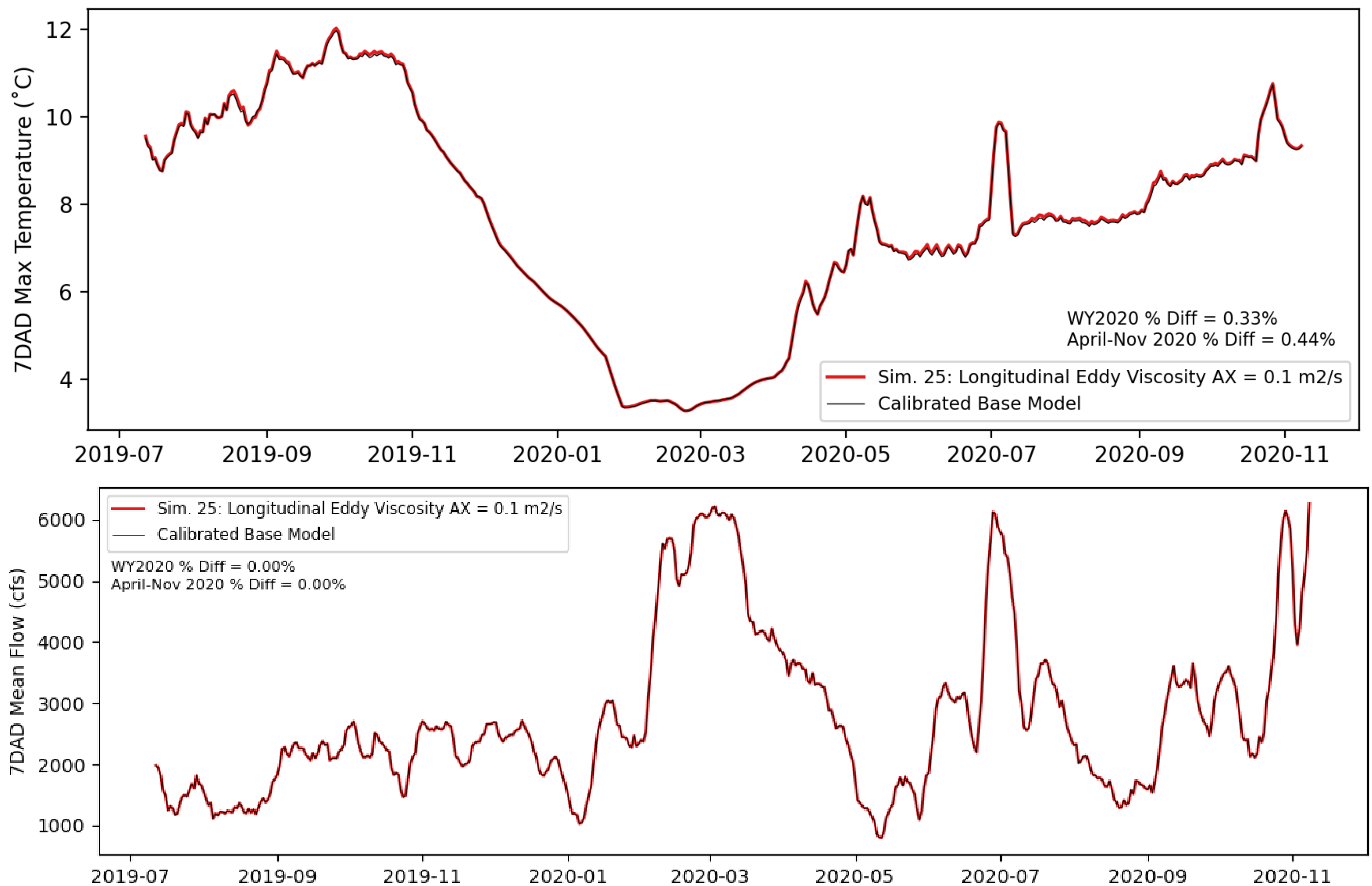


Figure C.1-42. Ross Lake outflow 7DAD-Mean flow and max temperature variation for Simulation 25 (set longitudinal eddy viscosity to 0.1 m2/s).

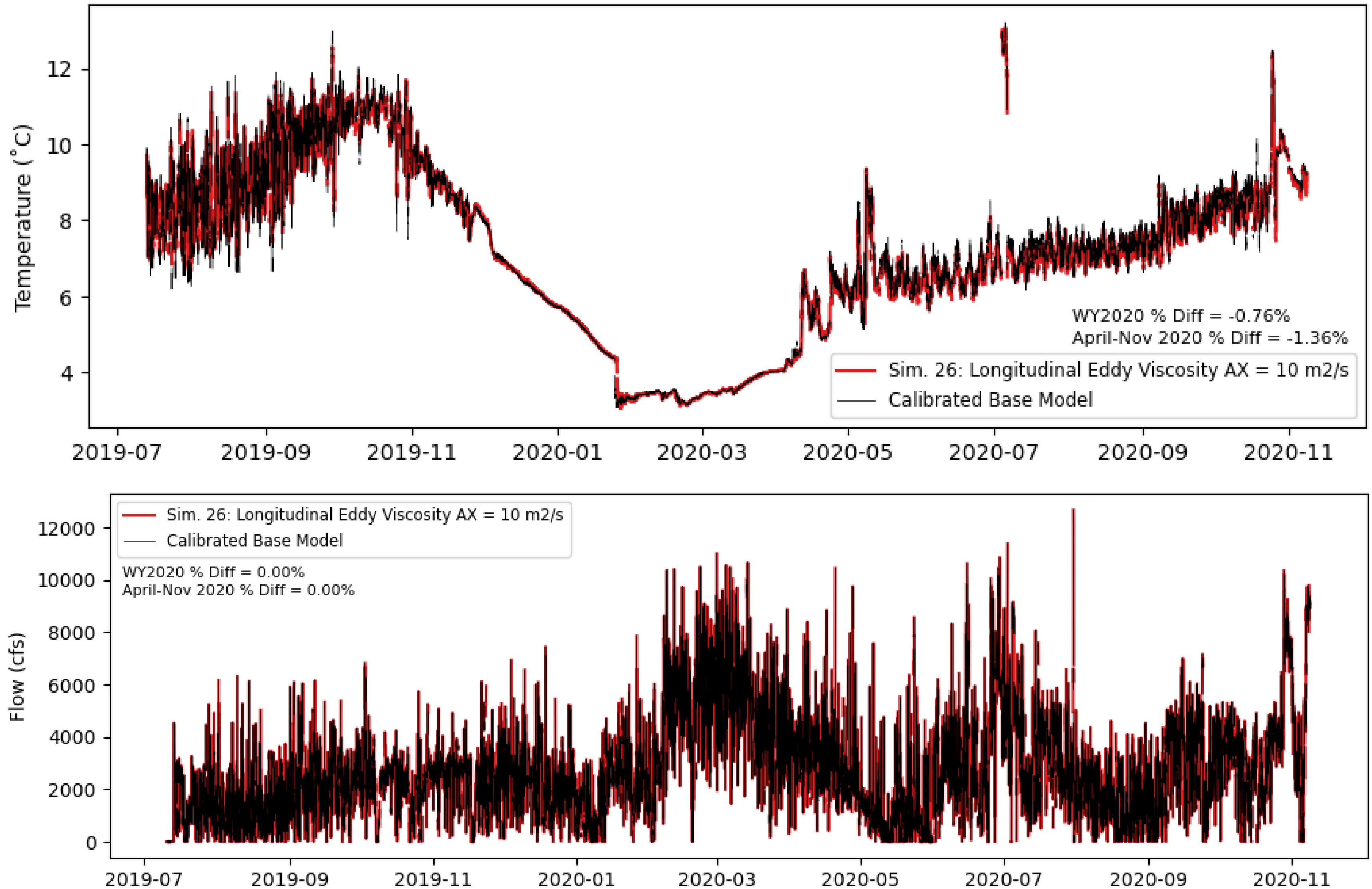


Figure C.1-43. Ross Lake outflow continuous hourly flow and temperature variation for Simulation 26 (set longitudinal eddy viscosity to 10 m2/s).

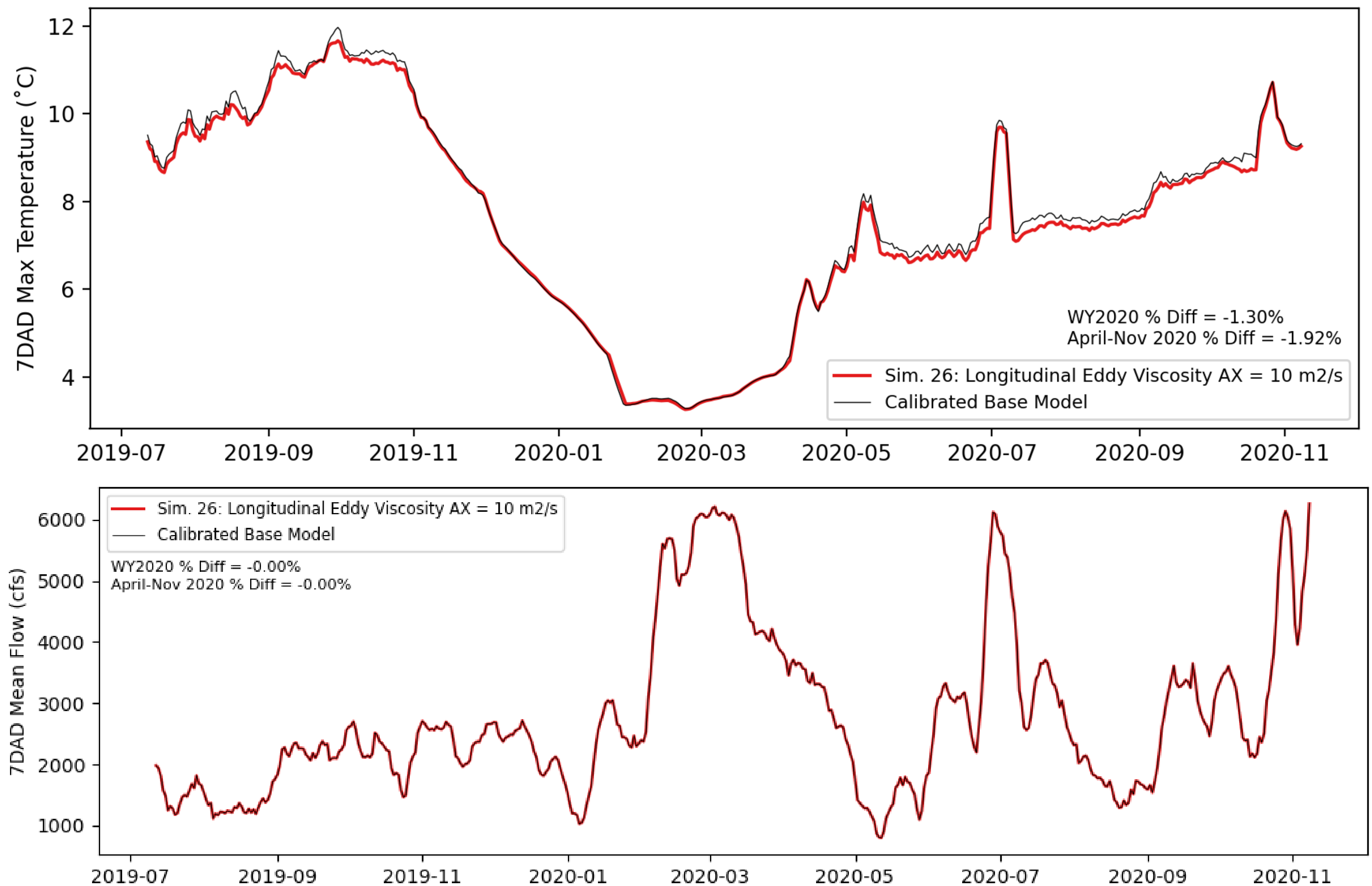


Figure C.1-44. Ross Lake outflow 7DAD-Mean flow and max temperature variation for Simulation 26 (set longitudinal eddy viscosity to 10 m2/s).

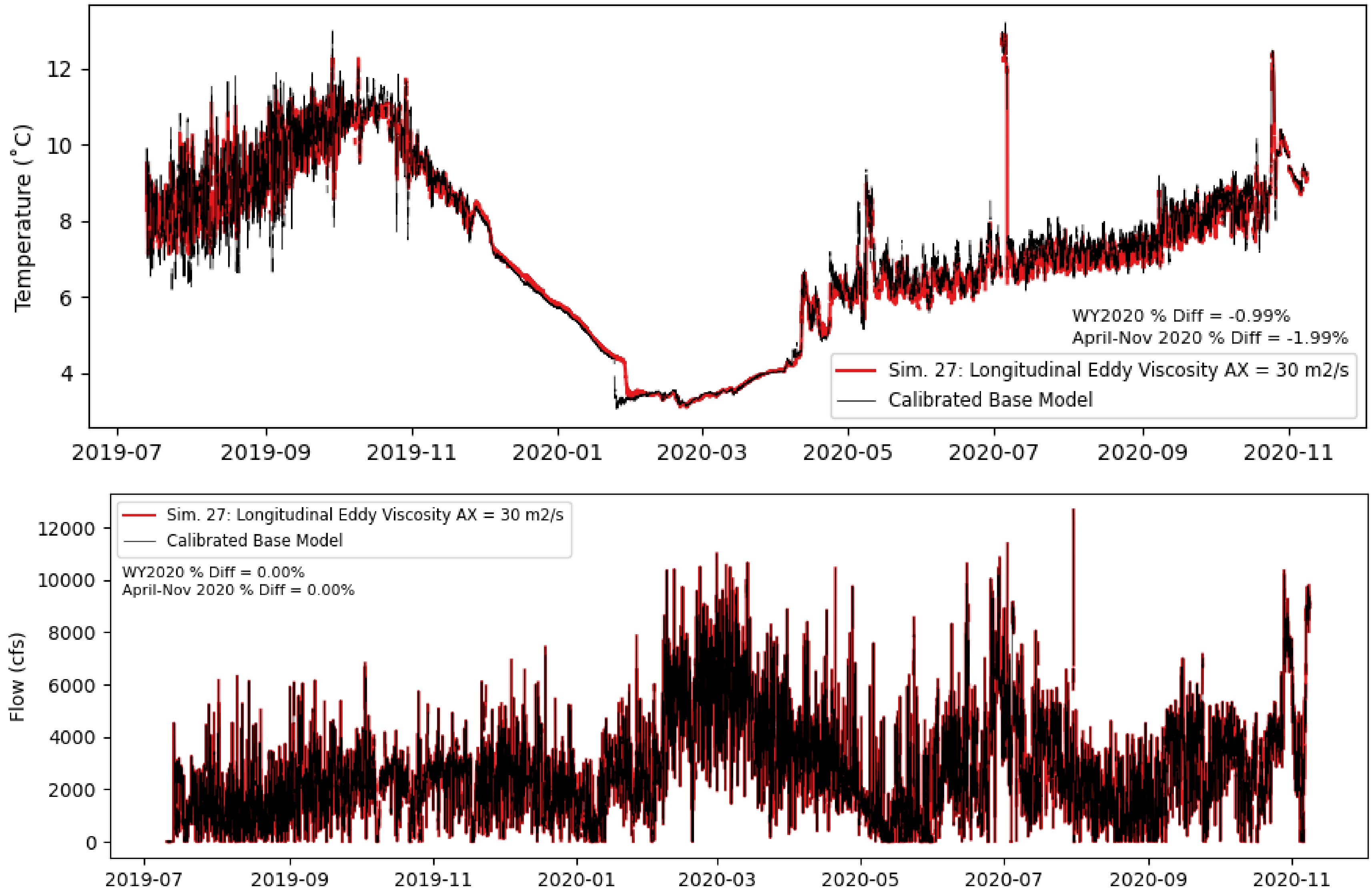


Figure C.1-45. Ross Lake outflow continuous hourly flow and temperature variation for Simulation 27 (set longitudinal eddy viscosity to 30 m2/s).

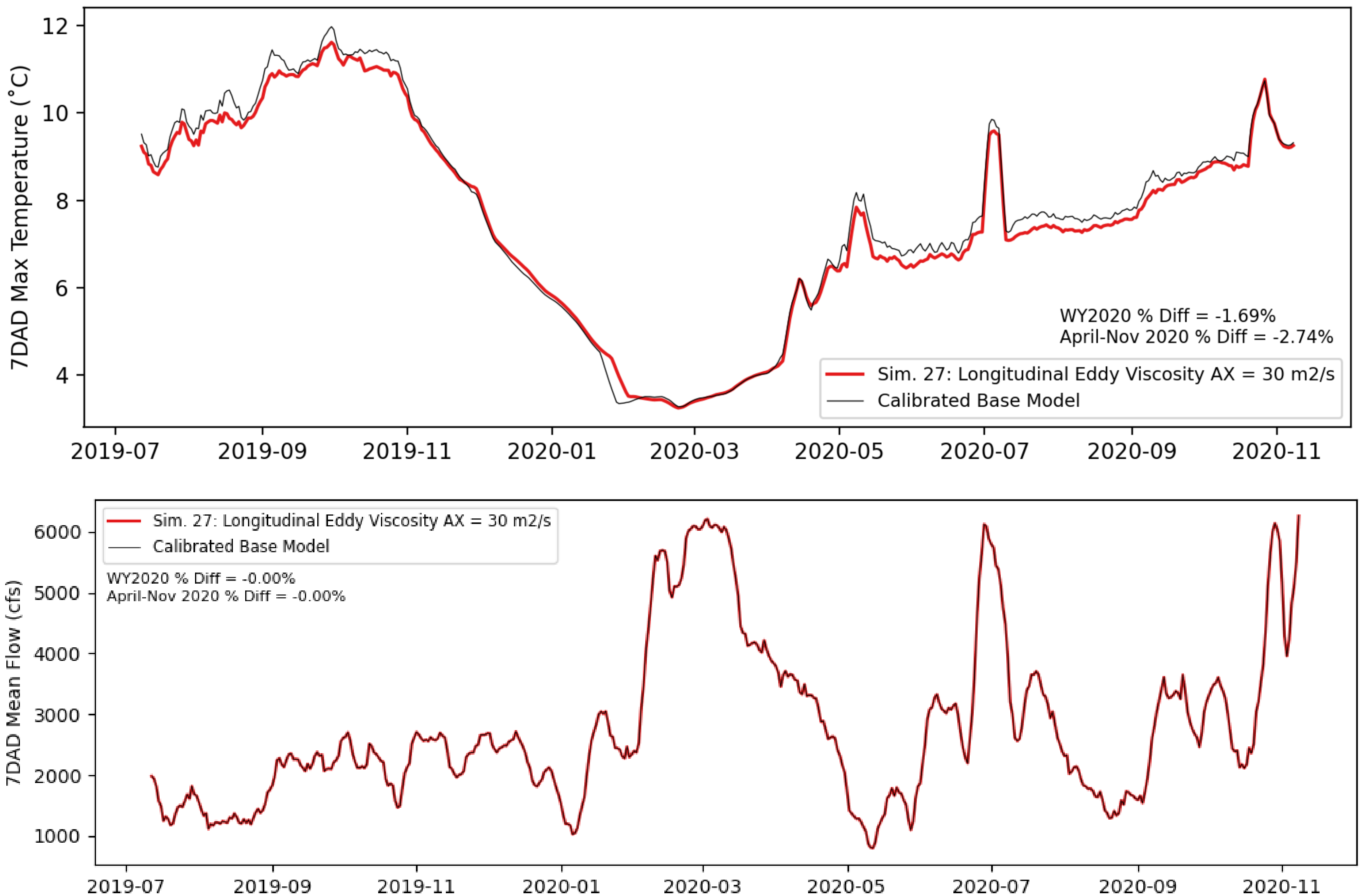


Figure C.1-46. Ross Lake outflow 7DAD-Mean flow and max temperature variation for Simulation 27 (set longitudinal eddy viscosity to 30 m2/s).

C.2 Diablo Lake Sensitivity Analysis Figures

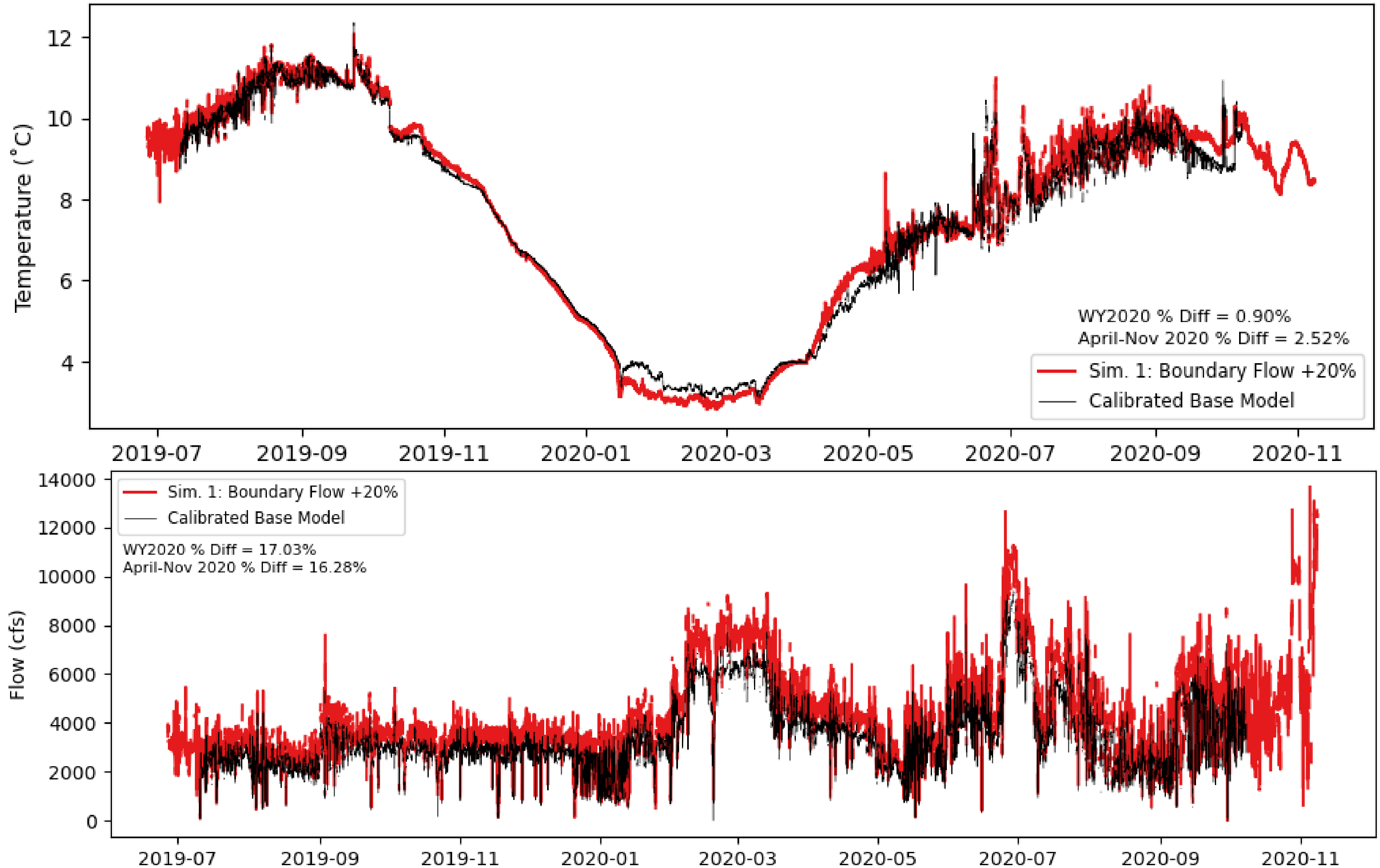
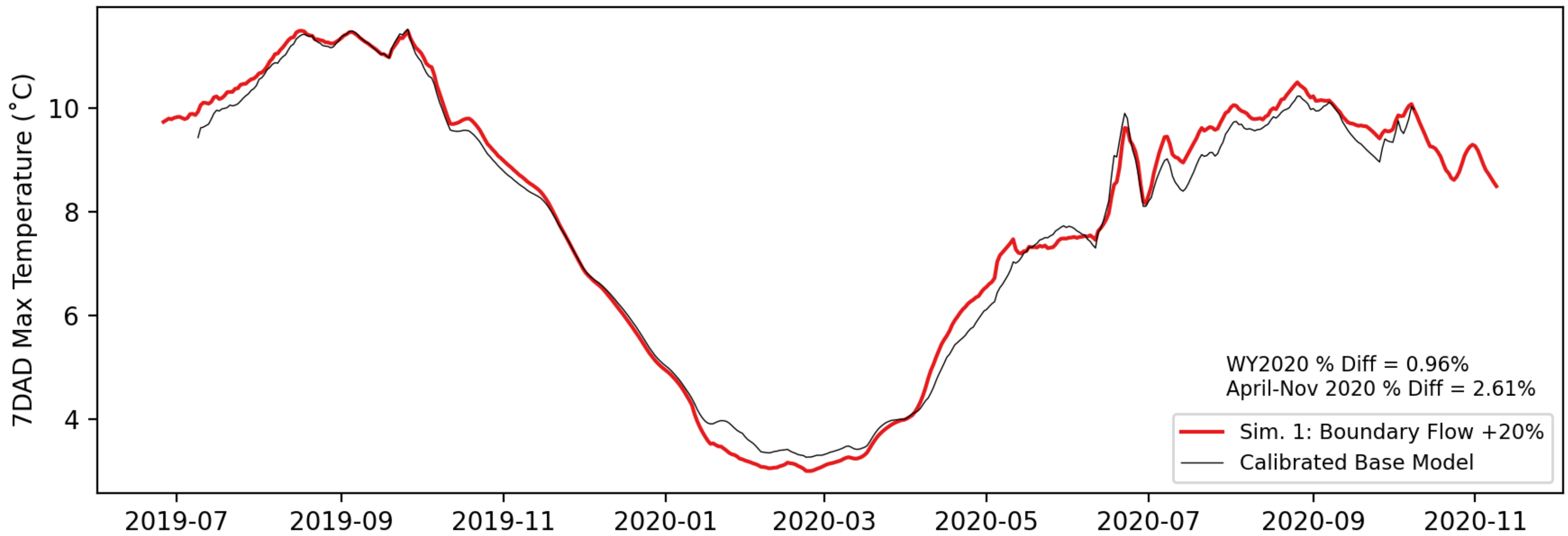


Figure C.2-1. Diablo Lake outflow continuous hourly flow and temperature variation for SA Simulation 1 (increase boundary flows by 20 percent).



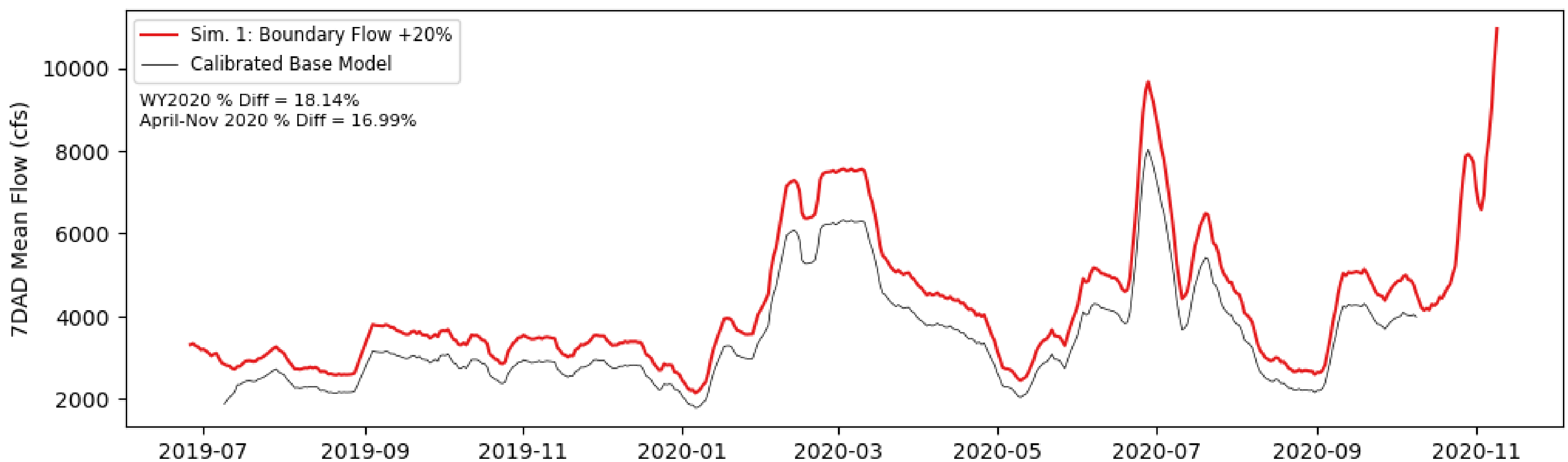


Figure C.2-2. Diablo Lake outflow 7DAD-Mean flow and max temperature variation for SA Simulation 1 (increase boundary flows by 20 percent).

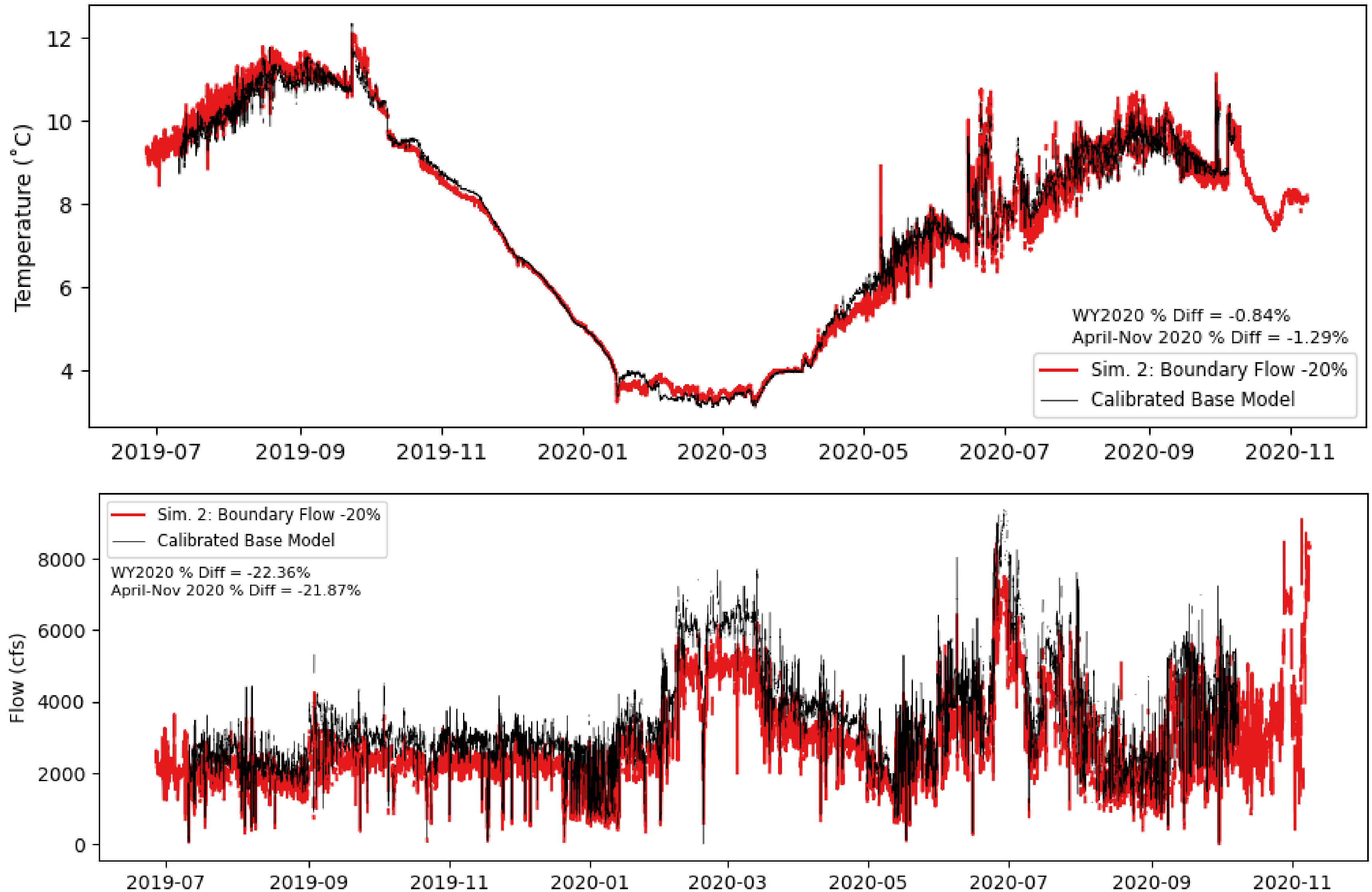


Figure C.2-3. Diablo Lake outflow continuous hourly flow and temperature variation for SA Simulation 2 (decrease boundary flows by 20 percent).

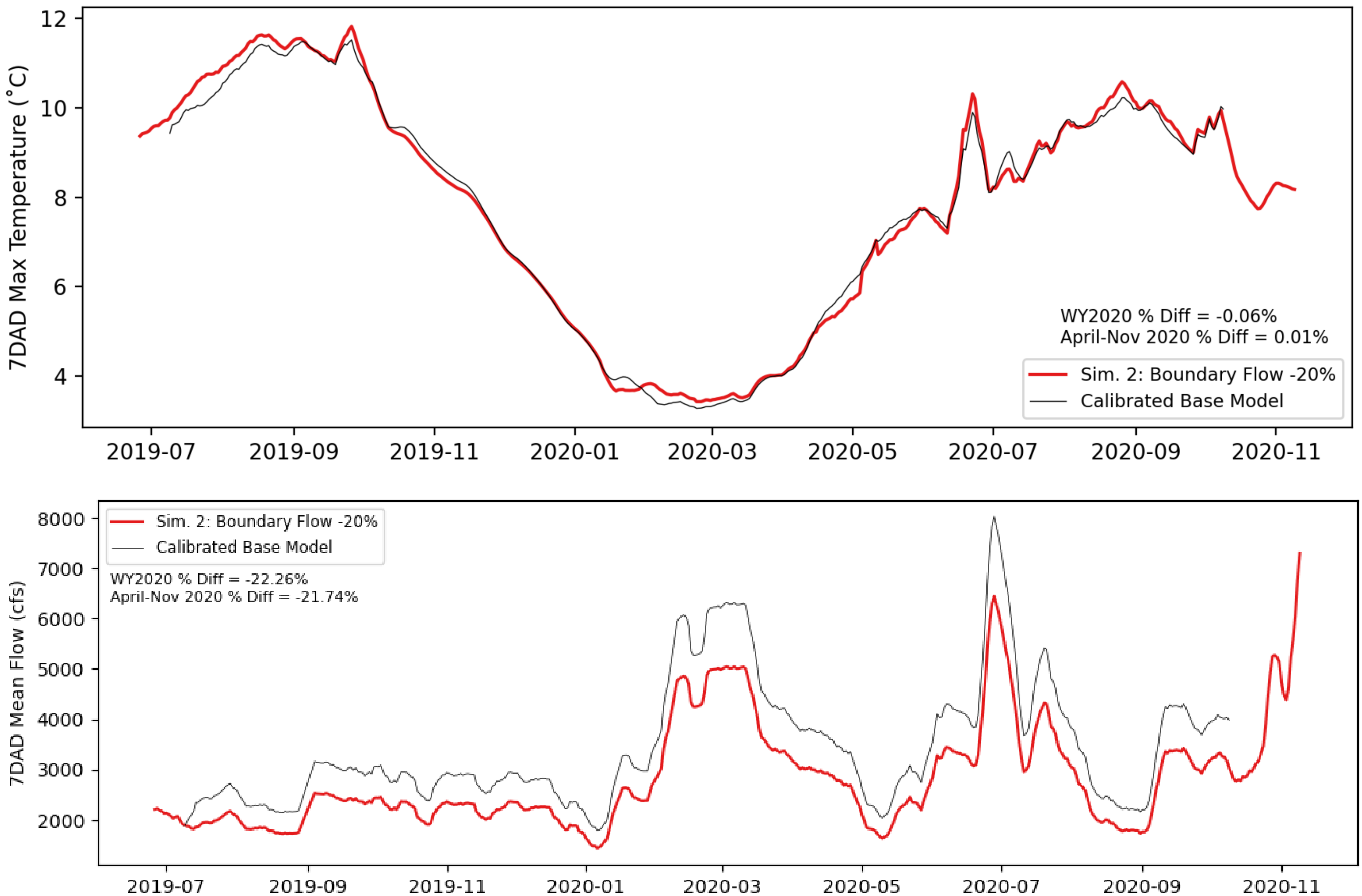


Figure C.2-4. Diablo Lake outflow 7DAD-Mean flow and max temperature variation for SA Simulation 2 (decrease boundary flows by 20 percent).

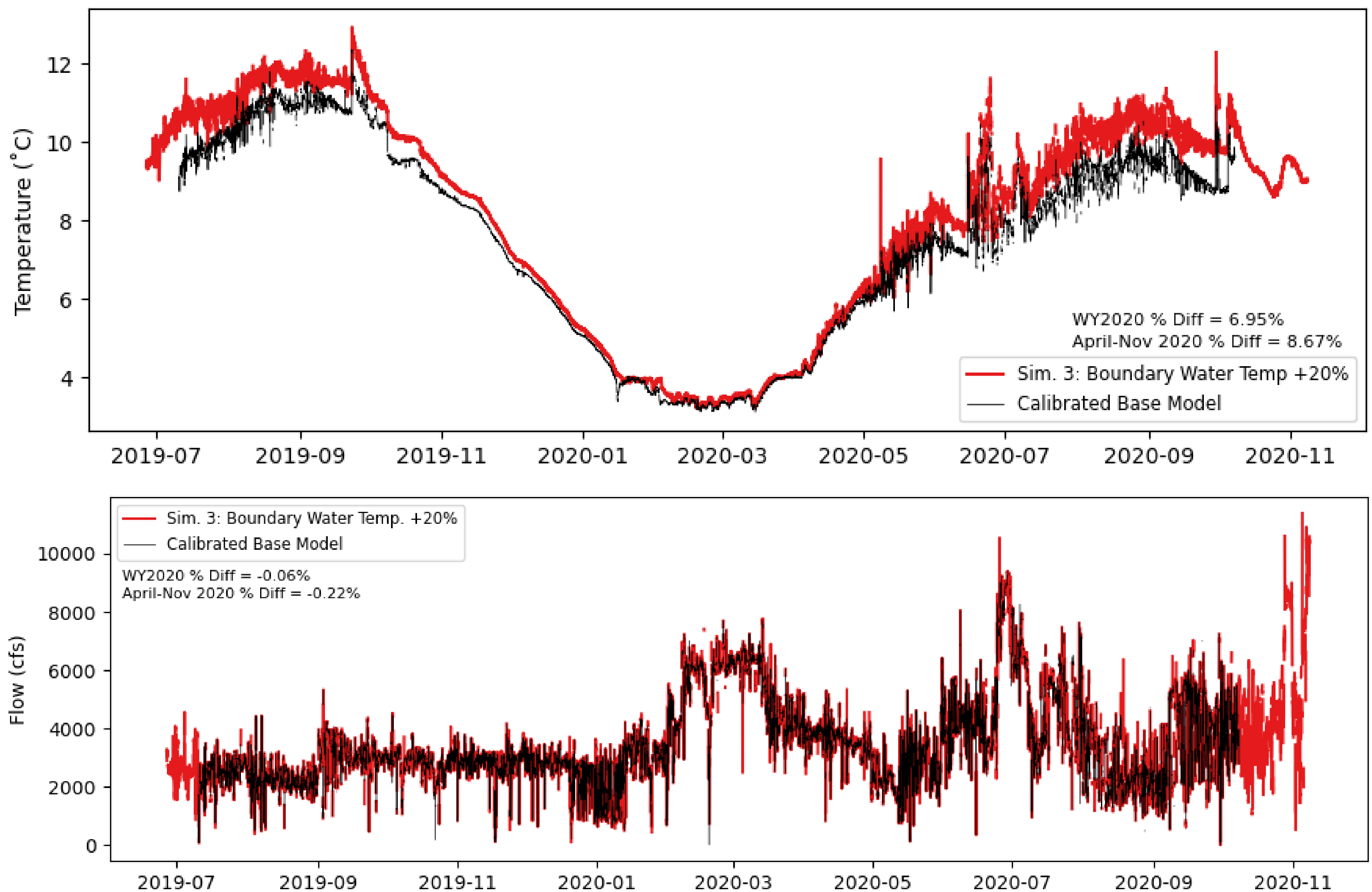


Figure C.2-5. **Diablo Lake outflow continuous hourly flow and temperature Variation for SA Simulation 3 (increase boundary temperatures by 20 percent).**

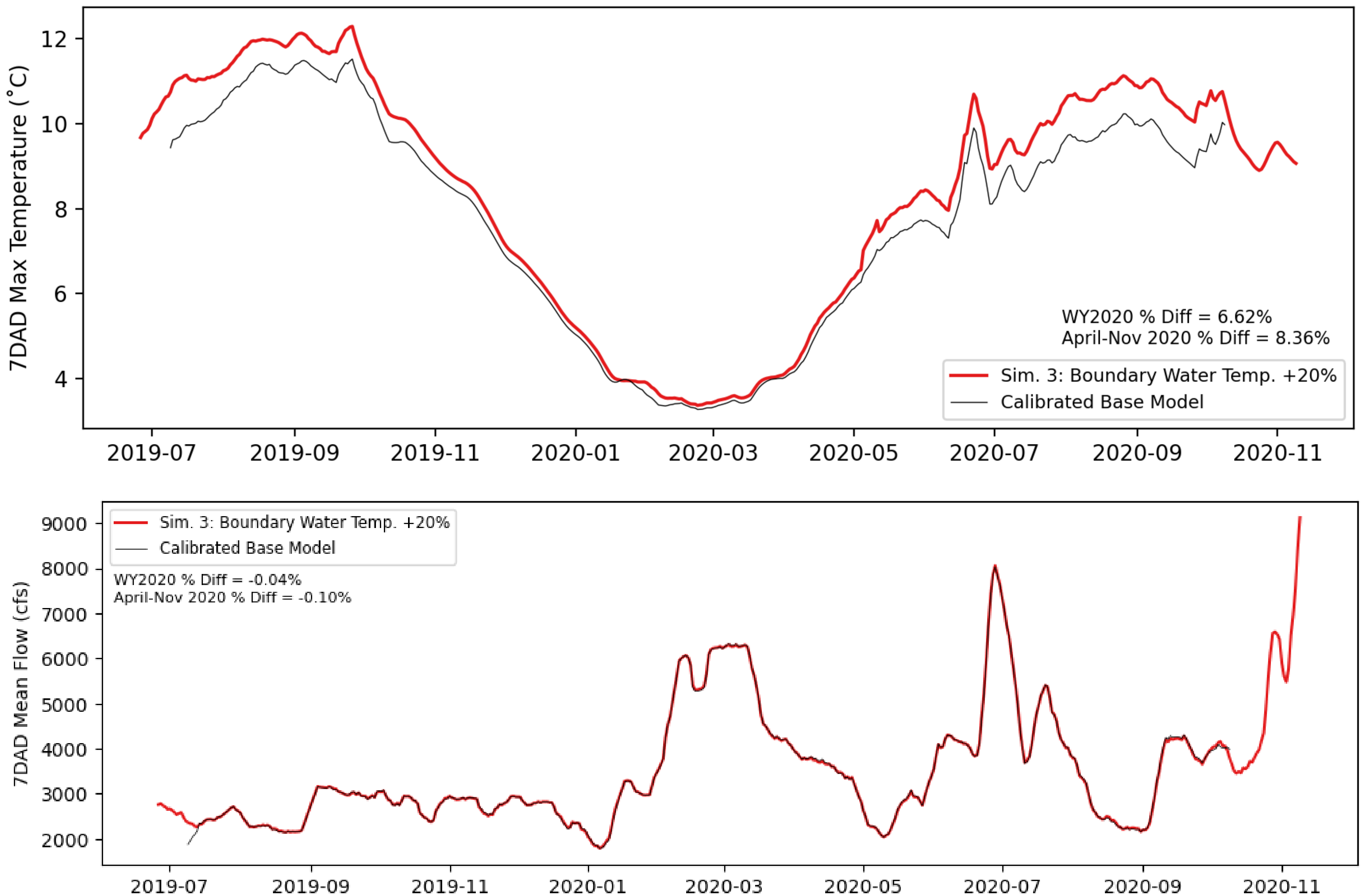


Figure C.2-6. Ross Lake outflow 7DAD-Mean flow and max temperature variation for SA Simulation 3 (increase boundary temperatures by 20 percent).

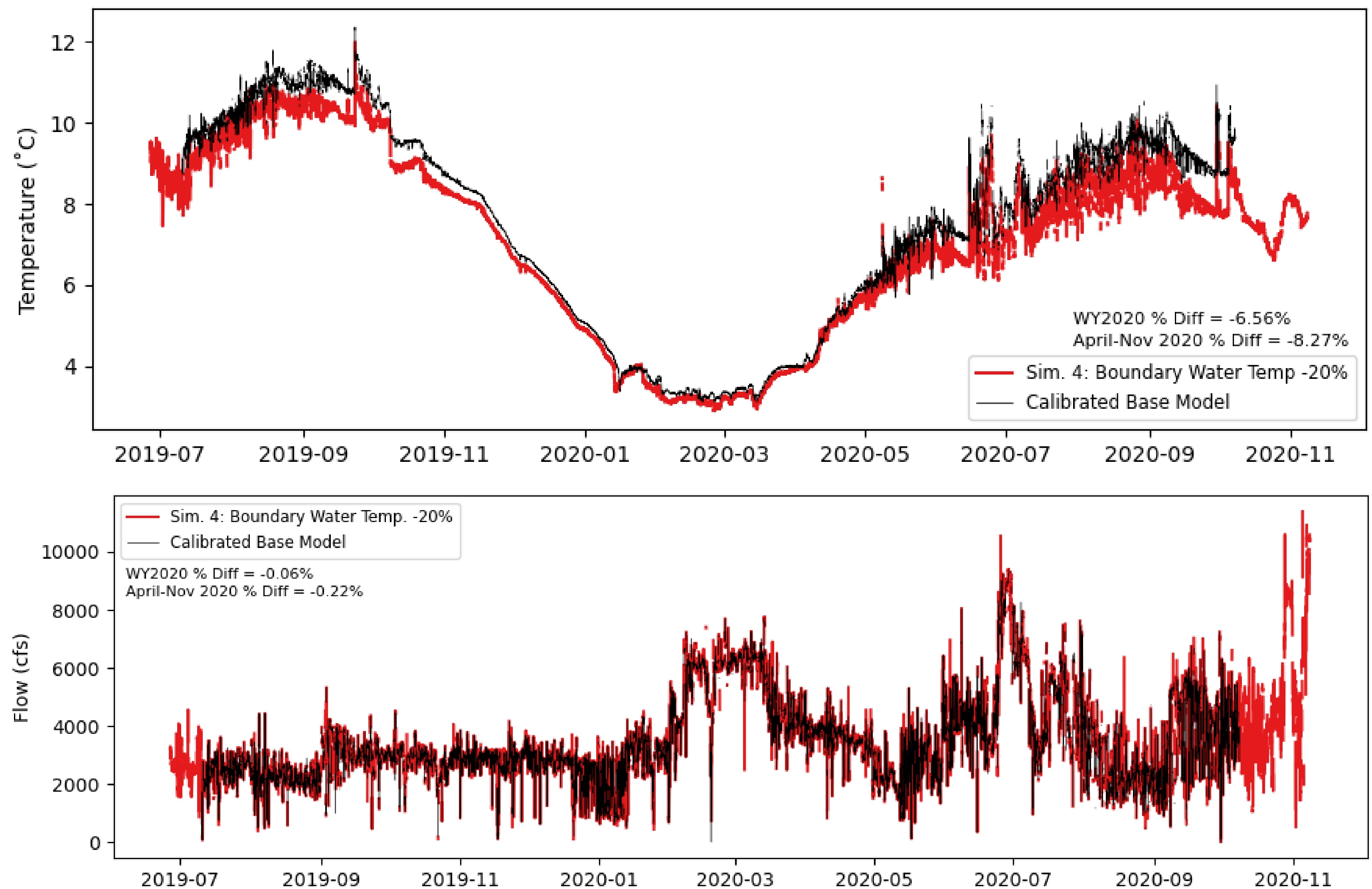


Figure C.2-7. Diablo Lake outflow continuous hourly flow and temperature variation for SA Simulation 4 (decrease boundary temperatures by 20 percent).

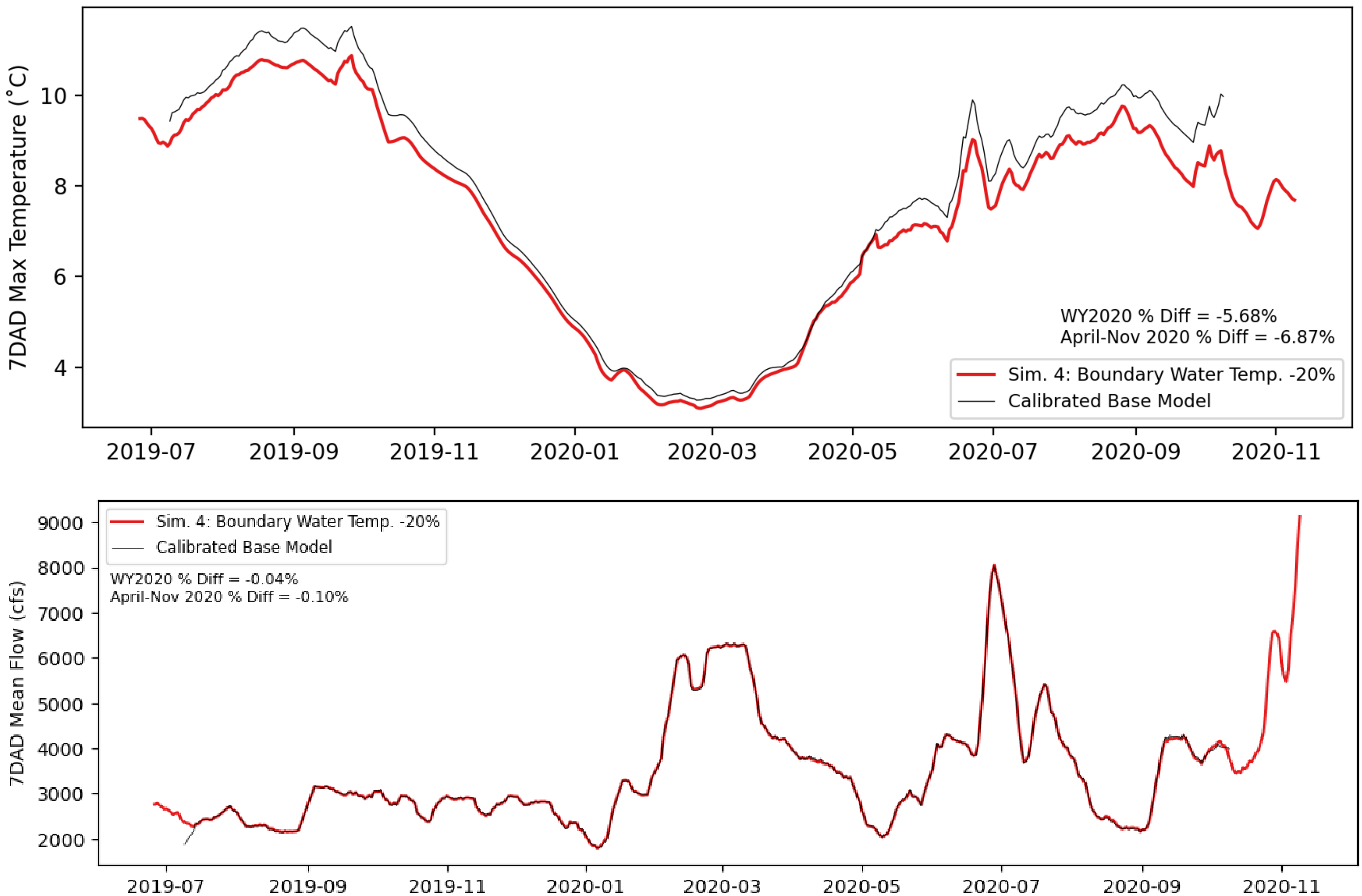


Figure C.2-8. Diablo Lake outflow 7DAD-Mean flow and max temperature variation for SA Simulation 4 (decrease boundary temperatures by 20 percent).

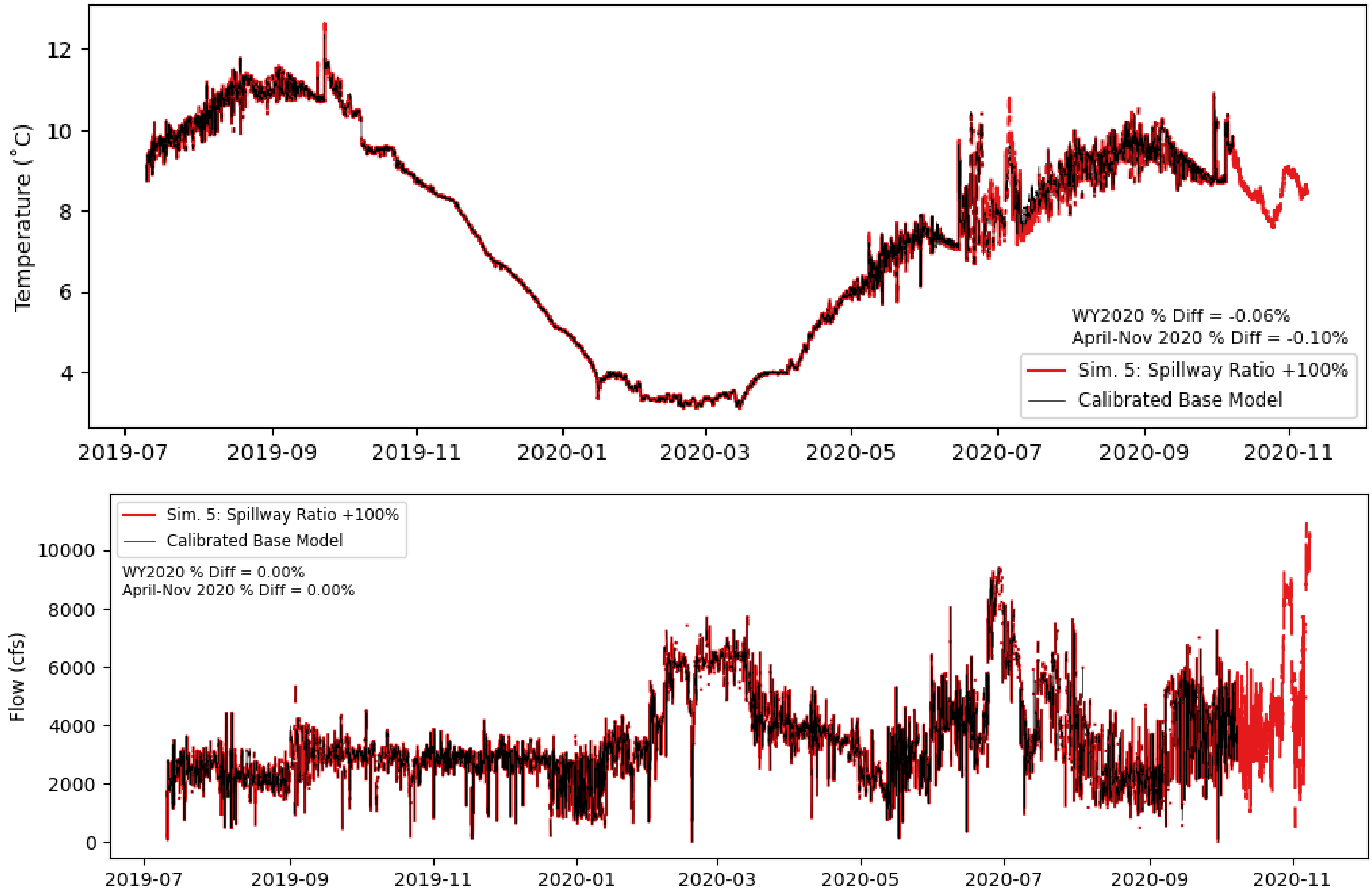
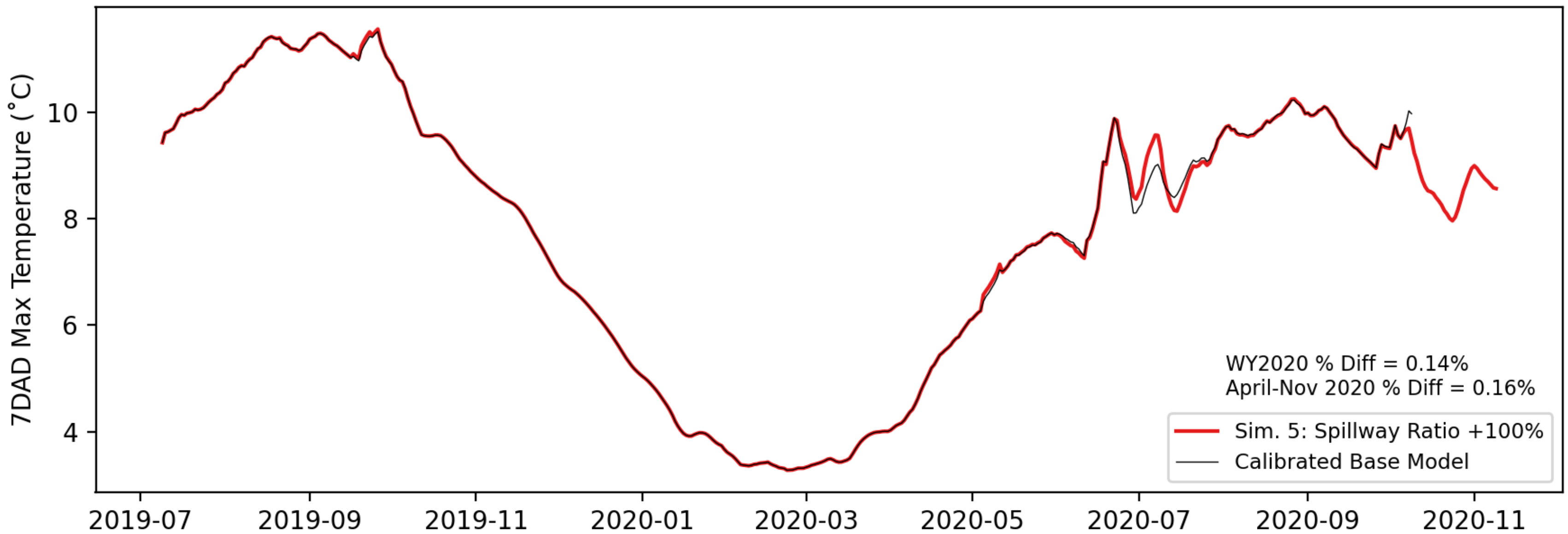


Figure C.2-9. Diablo Lake outflow continuous hourly flow and temperature variation for SA Simulation 5 (double spillway-powerhouse flow ratio).



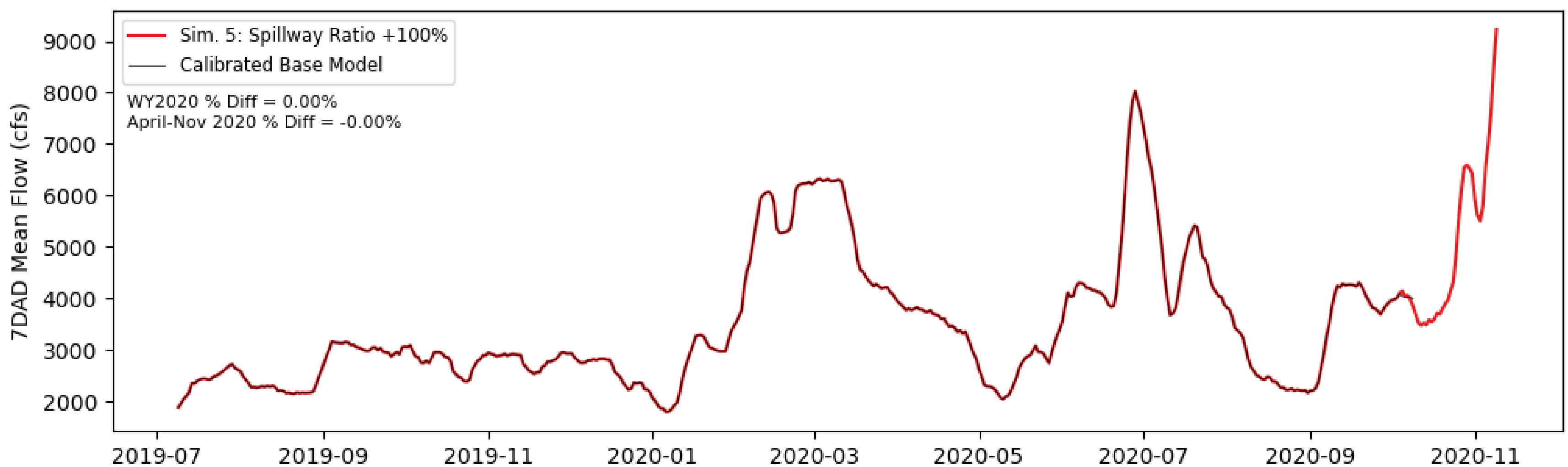


Figure C.2-10. Diablo Lake outflow 7DAD-Mean flow and max temperature variation for SA Simulation 5 (double spillway-powerhouse flow ratio).

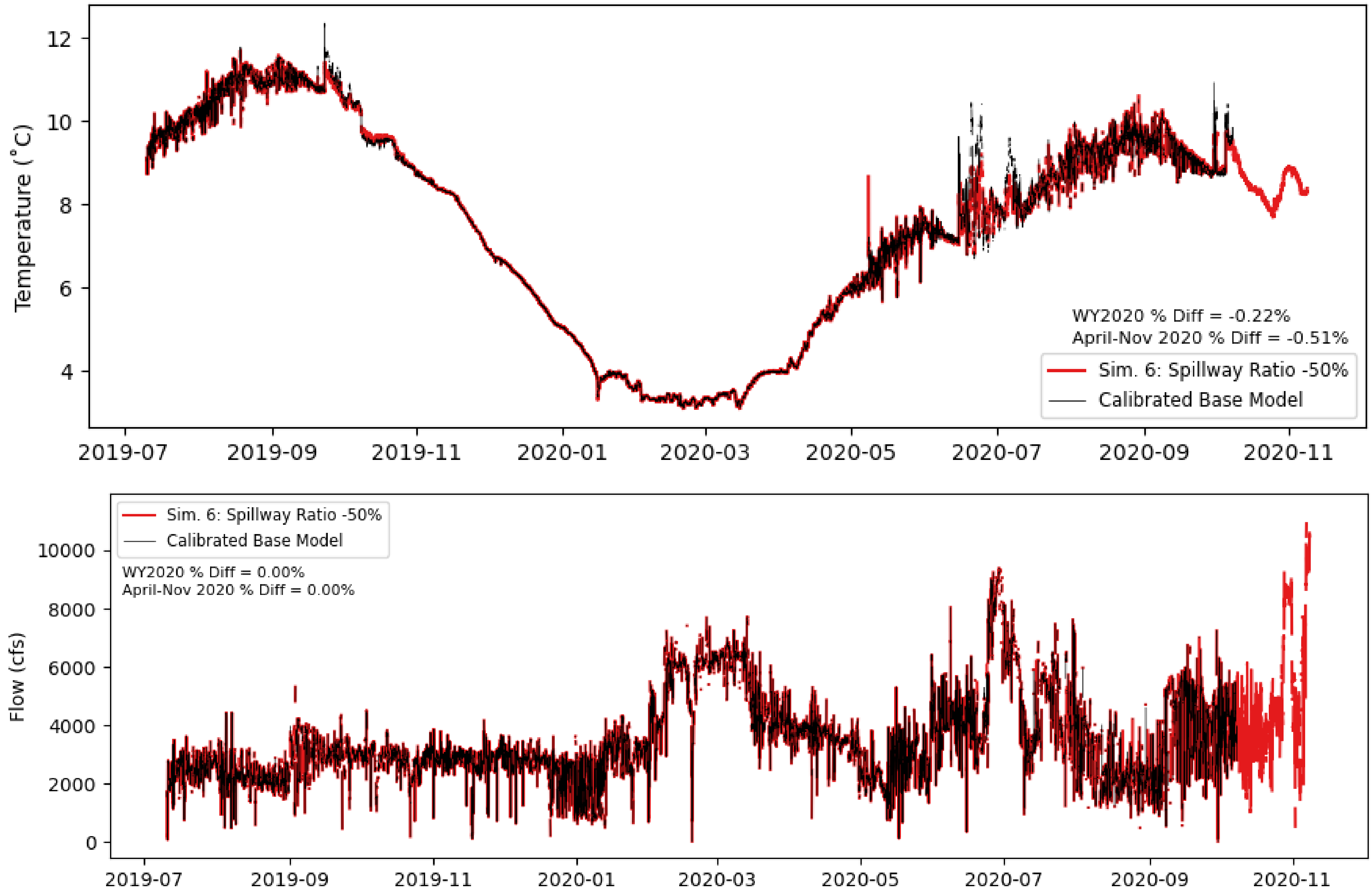


Figure C.2-11. Diablo Lake outflow continuous hourly flow and temperature variation for SA Simulation 6 (halve spillway-powerhouse flow ratio).

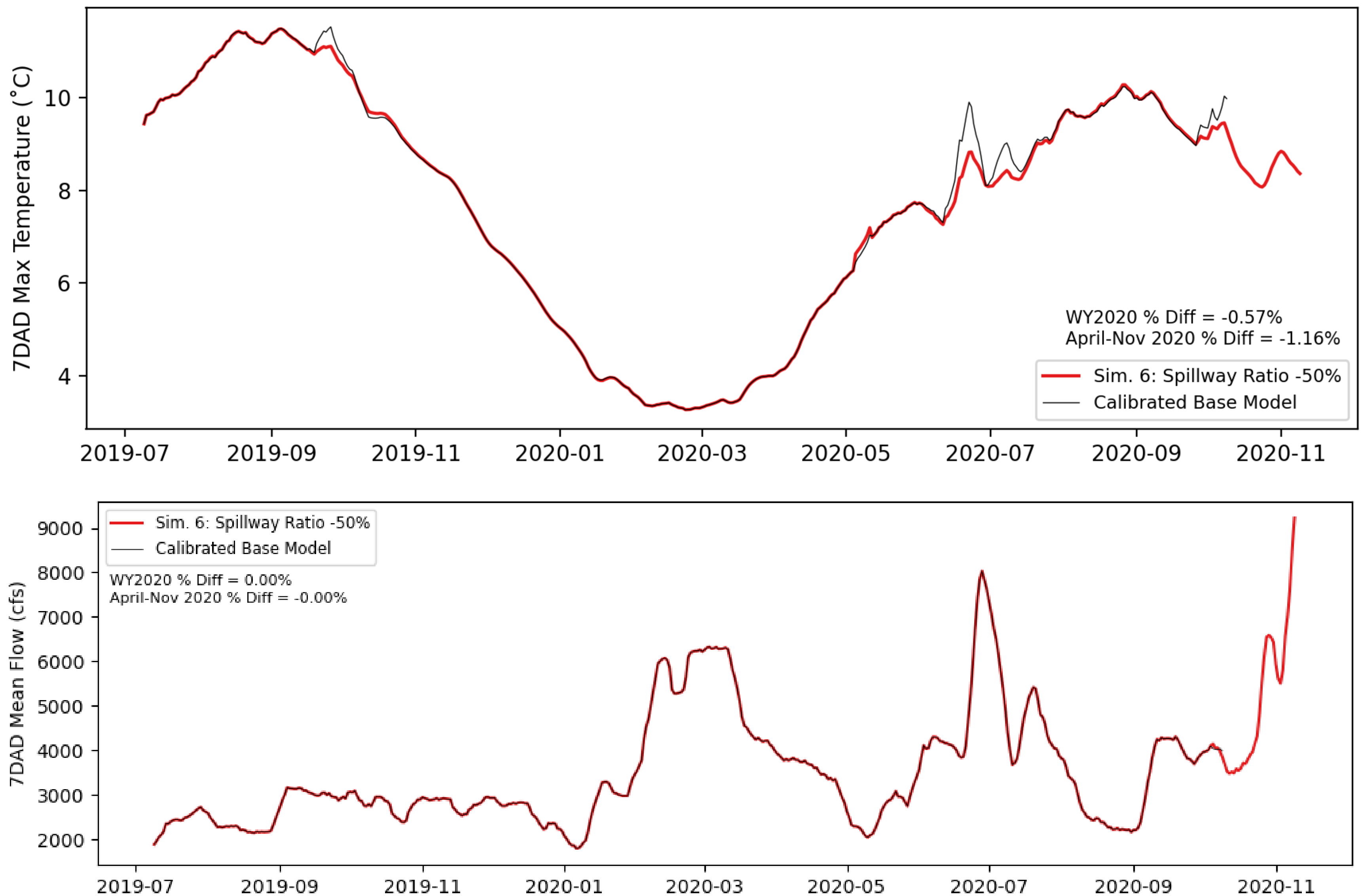


Figure C.2-12. Diablo Lake outflow 7DAD-Mean flow and max temperature variation for SA Simulation 6 (halve spillway-powerhouse flow ratio).

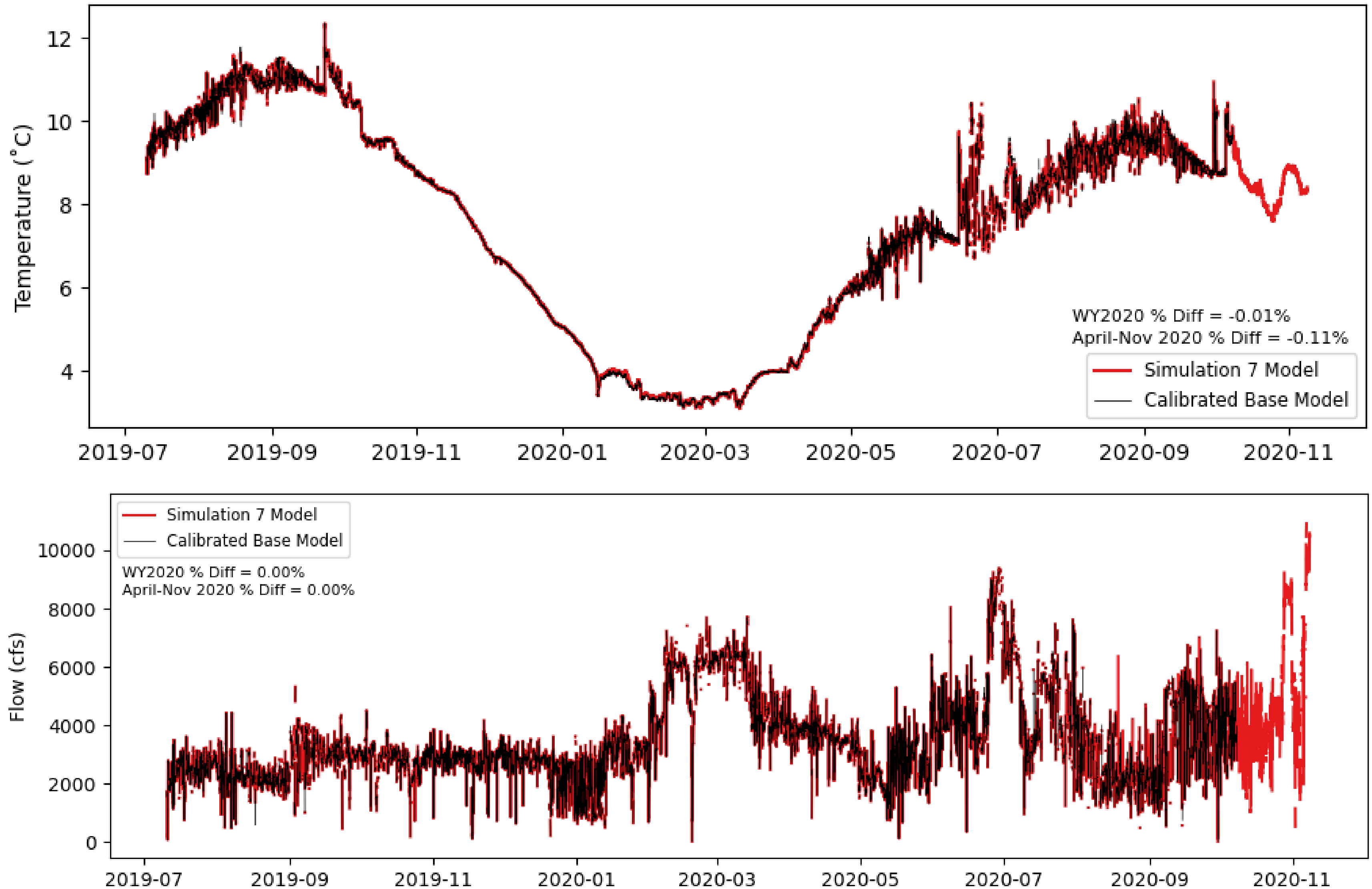


Figure C.2-13. Diablo Lake outflow continuous hourly flow and temperature variation for SA Simulation 7 (remove top 5 withdrawal layers).

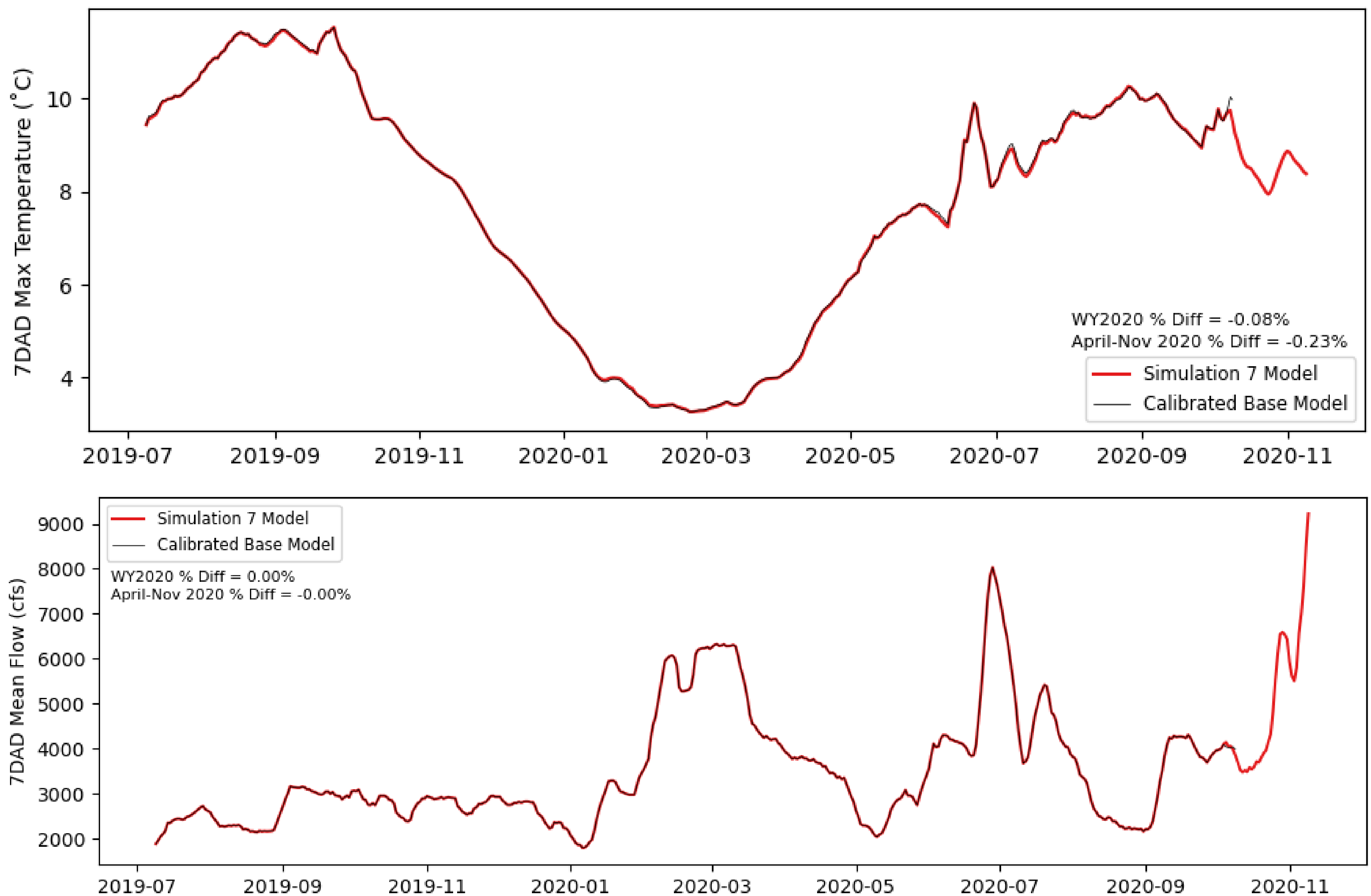


Figure C.2-14. Diablo Lake outflow 7DAD-Mean flow and max temperature variation for SA Simulation 7 (remove top 5 withdrawal layers).

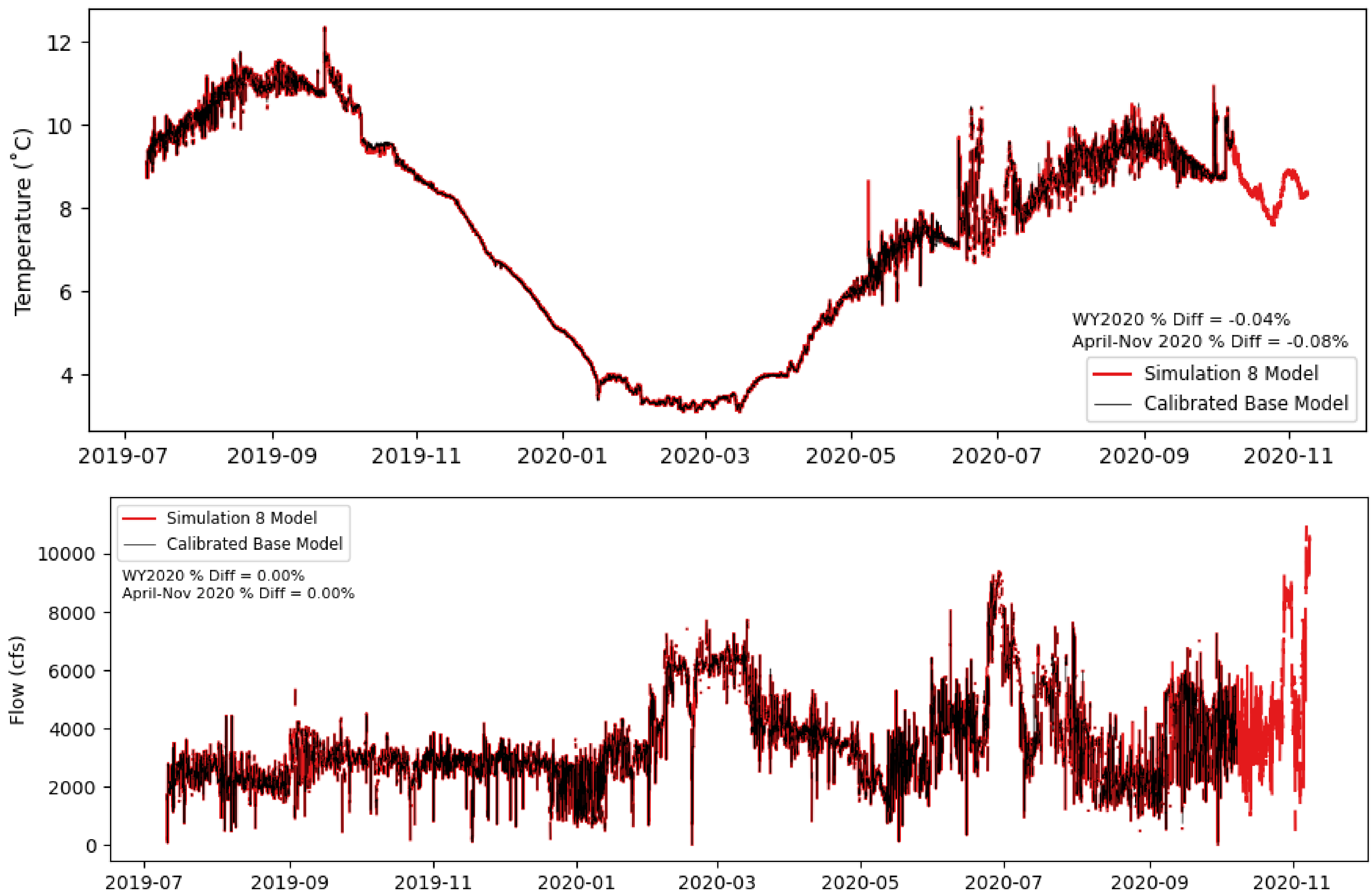


Figure C.2-15. Diablo Lake outflow continuous hourly flow and temperature variation for SA Simulation 8 (remove bottom 5 withdrawal layers).

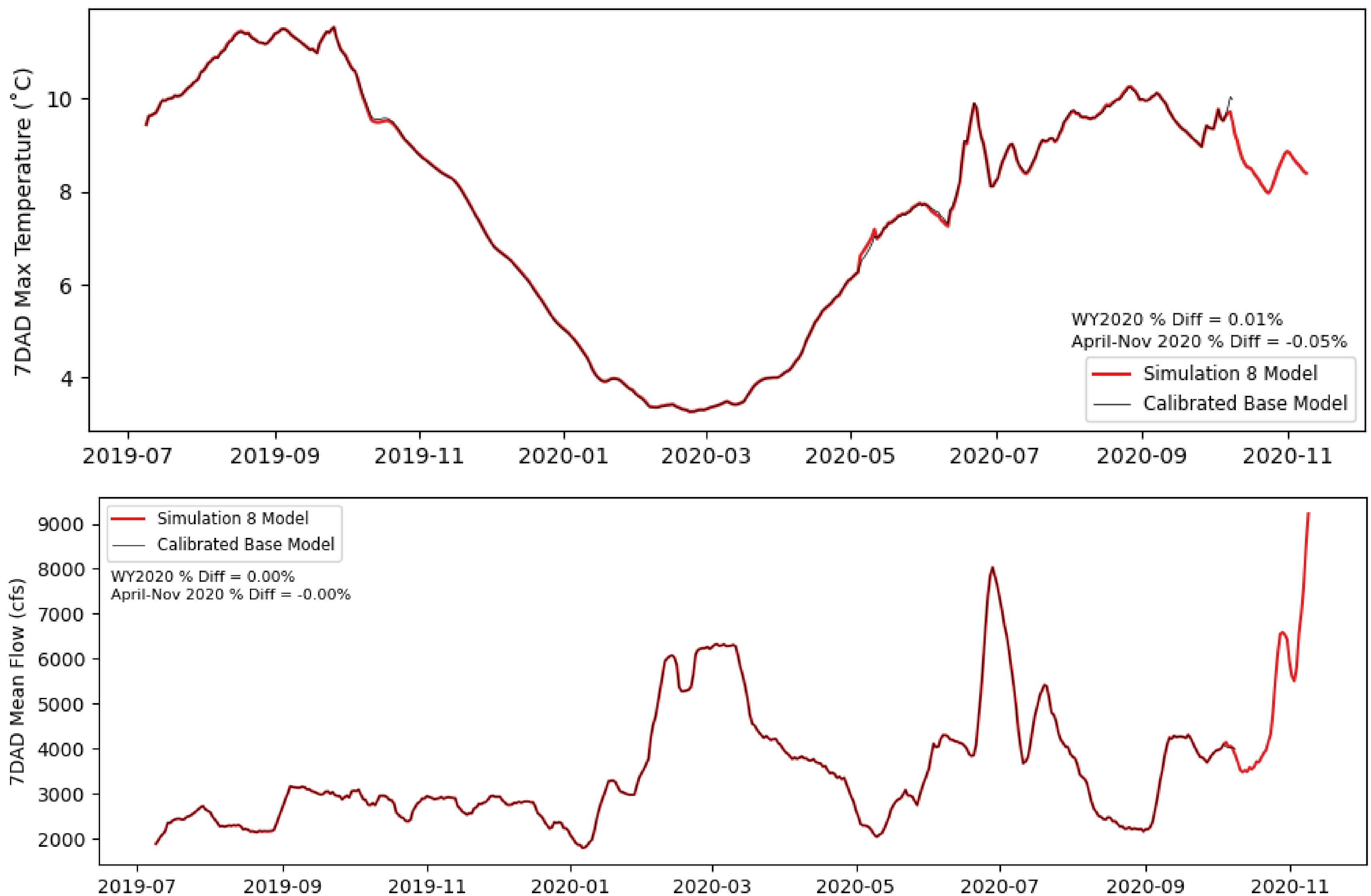


Figure C.2-16. Diablo Lake outflow 7DAD-Mean flow and max temperature variation for SA Simulation 8 (remove bottom 5 withdrawal layers).

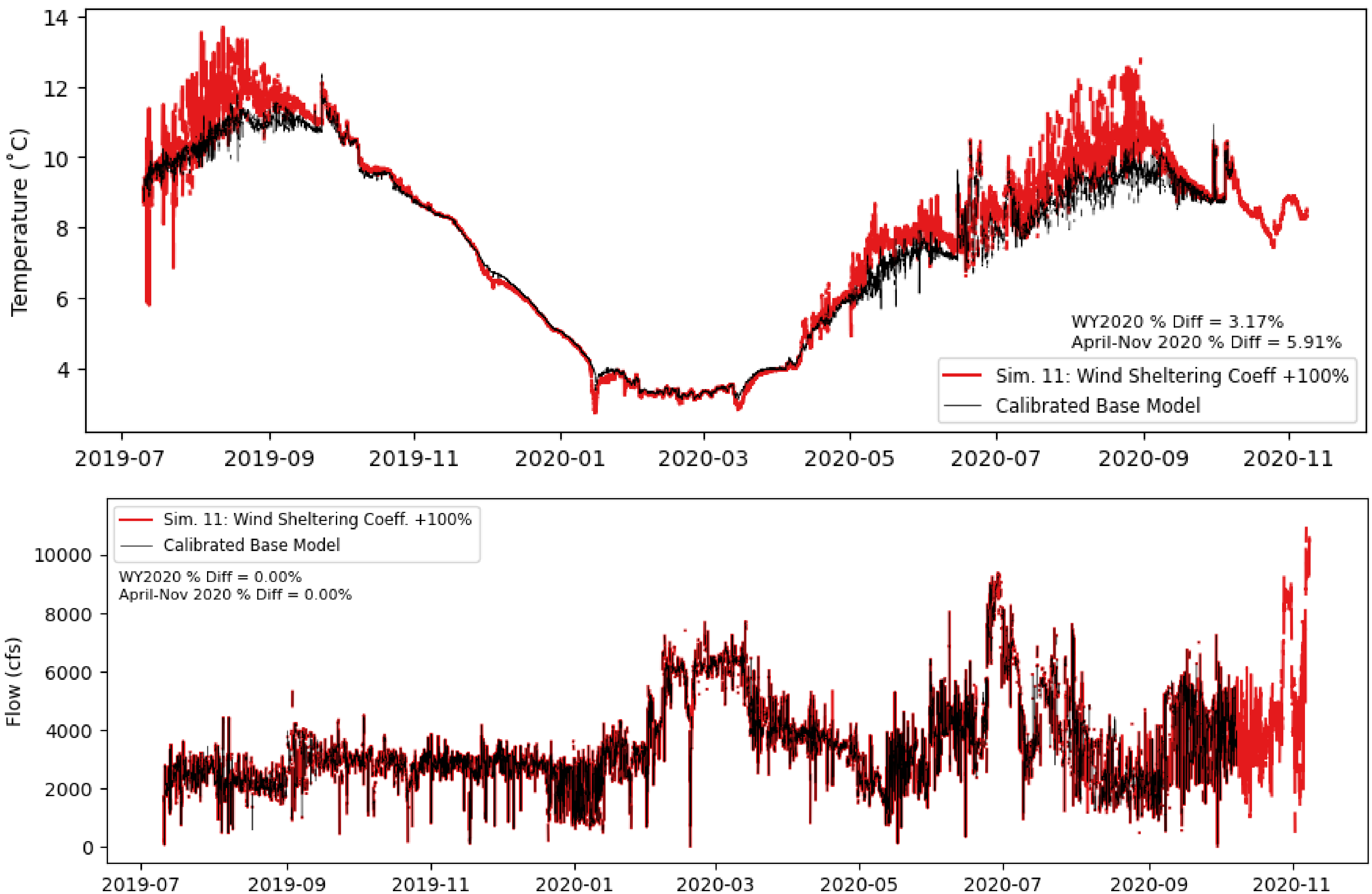


Figure C.2-17. Diablo Lake outflow continuous hourly flow and temperature variation for SA Simulation 11 (double wind sheltering coefficient).

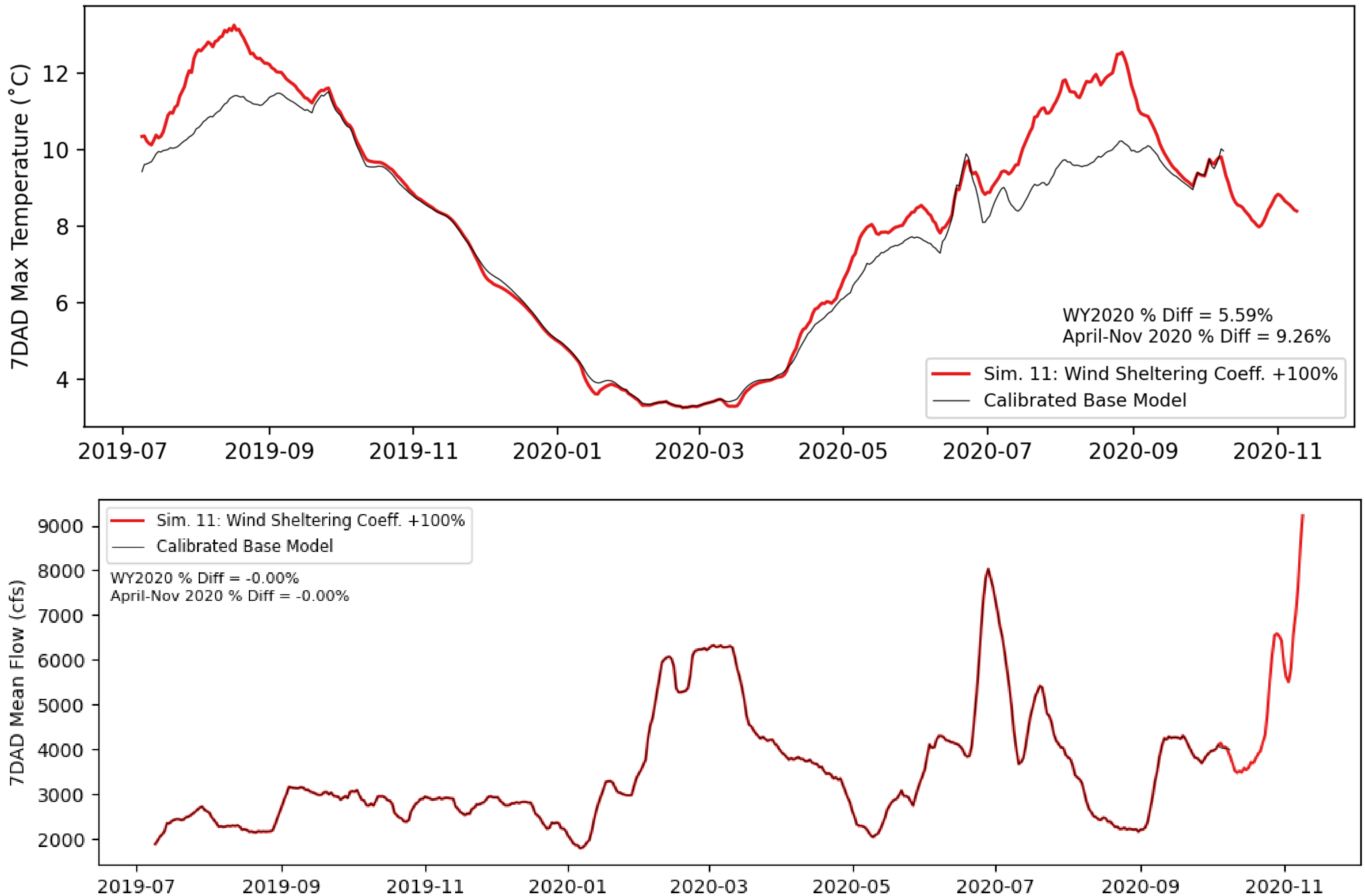


Figure C.2-18. Diablo Lake outflow 7DAD-Mean flow and max temperature variation for SA Simulation 11 (double wind sheltering coefficient).

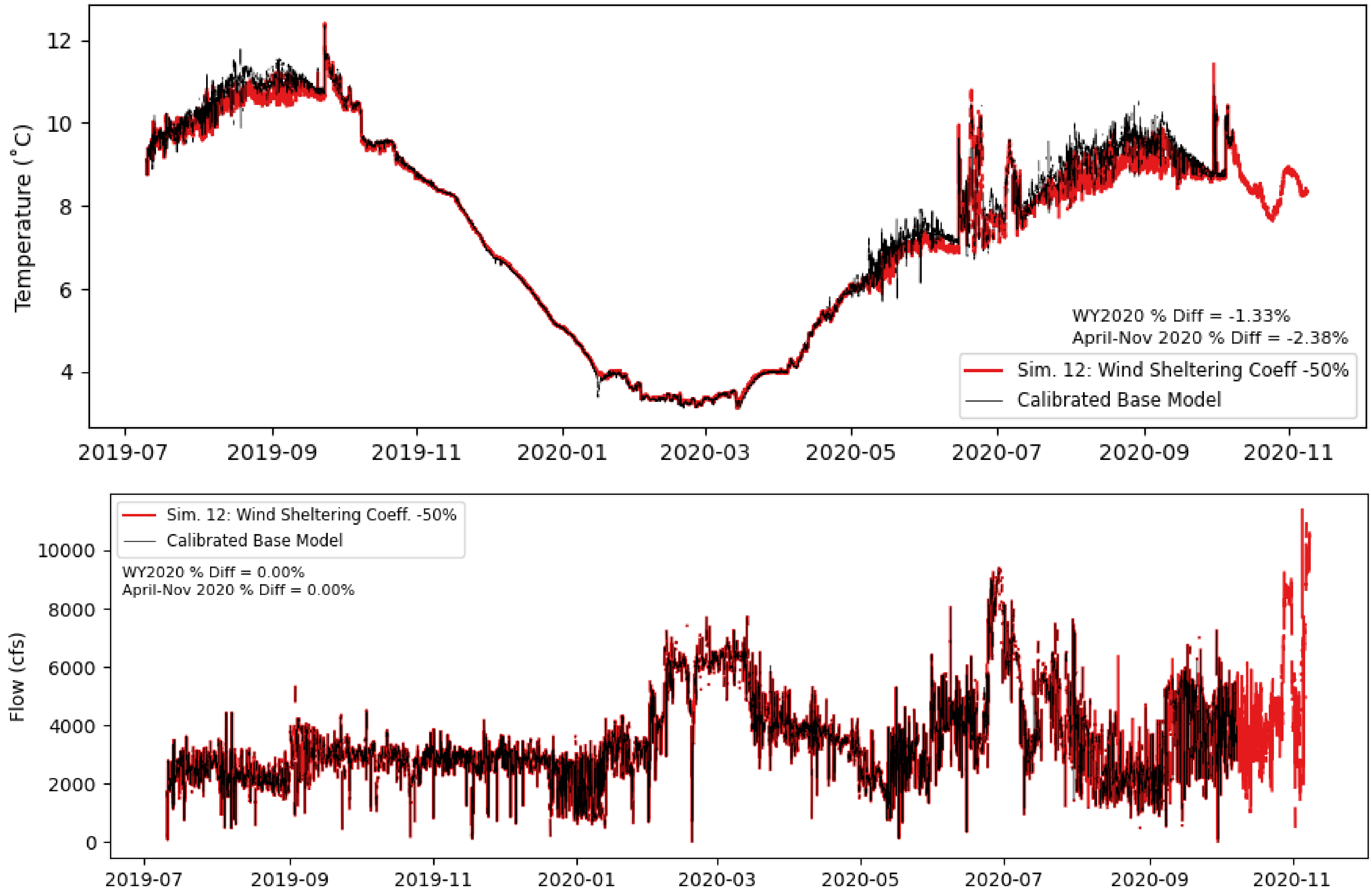


Figure C.2-19. Diablo Lake outflow continuous hourly flow and temperature variation for sa simulation 12 (halve wind sheltering coefficient).

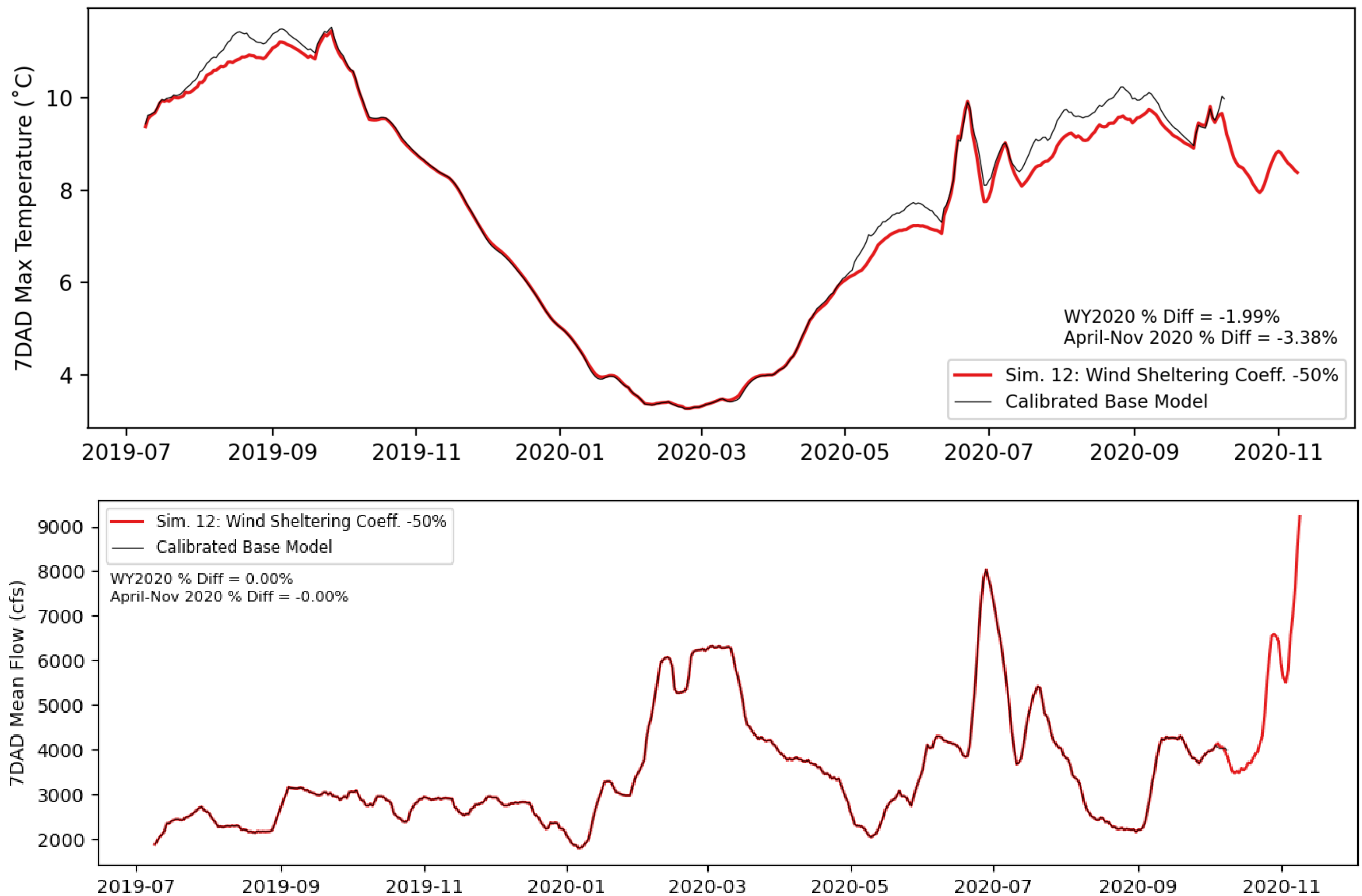


Figure C.2-20. Diablo Lake outflow 7DAD-Mean flow and max temperature variation for SA Simulation 12 (halve wind sheltering coefficient).

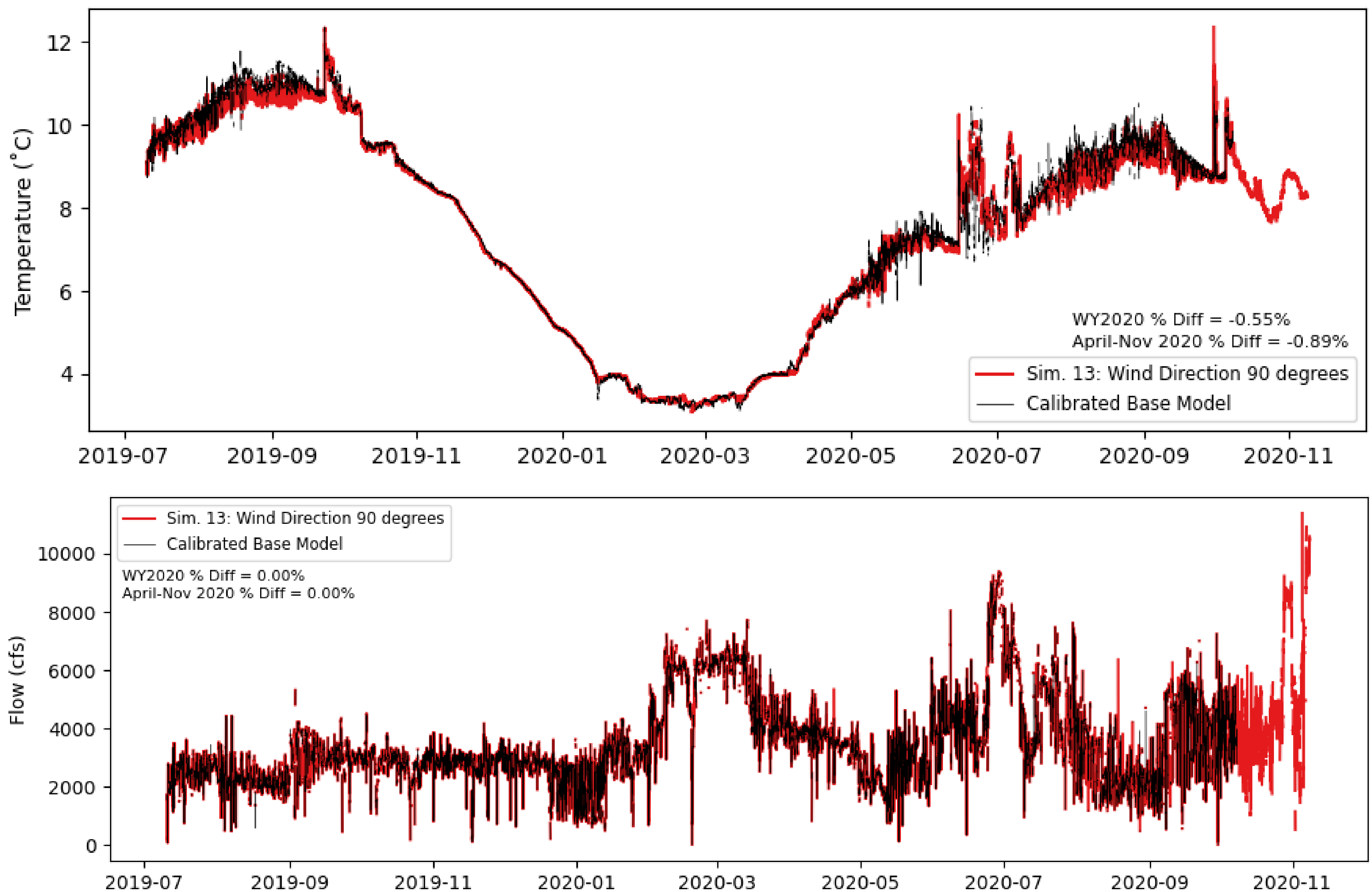


Figure C.2-21. **Diablo Lake Outflow Continuous Hourly Flow and Temperature Variation for SA Simulation 13 (rotate wind direction 90 degrees counter-clockwise).**

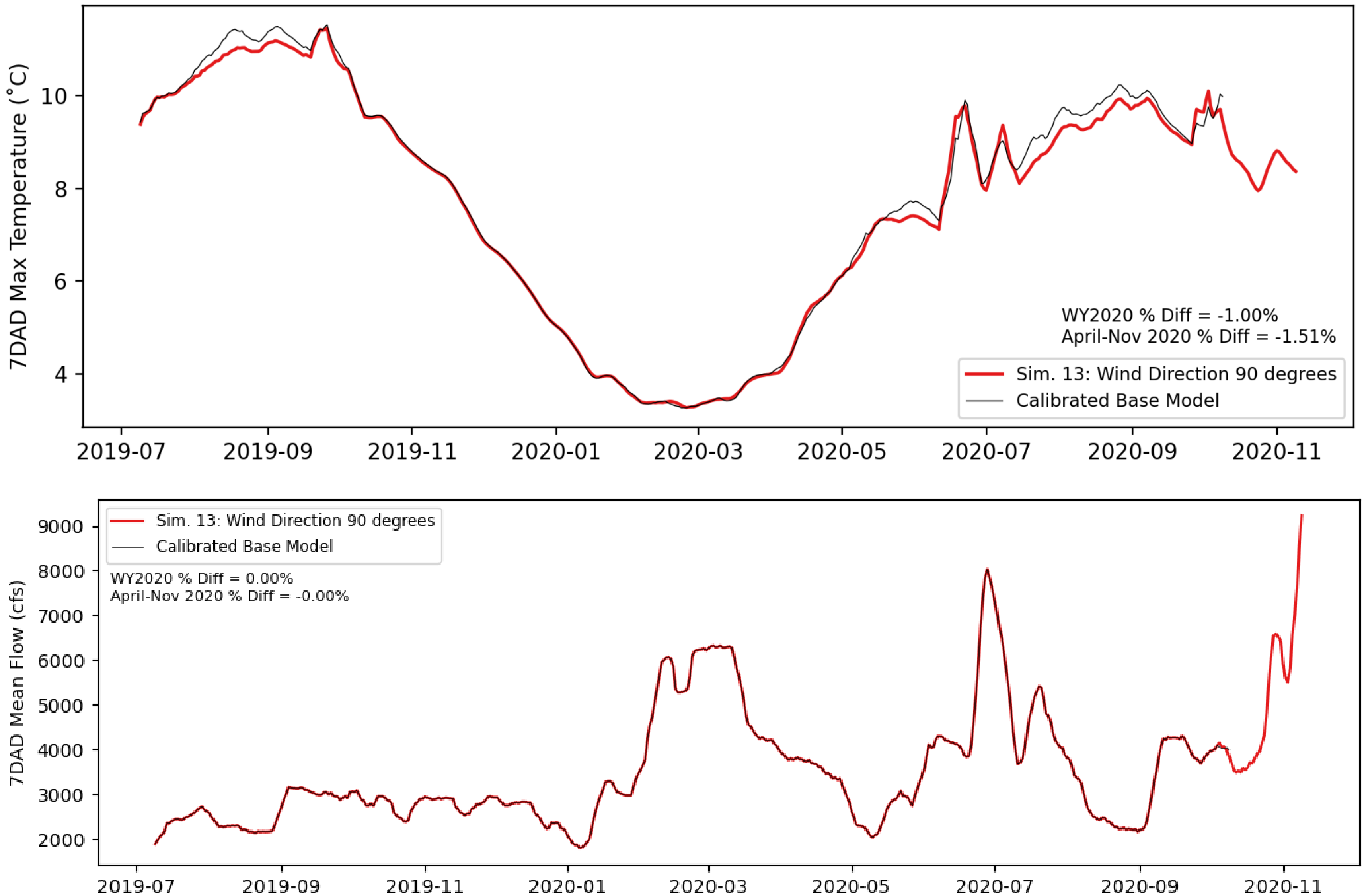


Figure C.2-22. Diablo Lake outflow 7DAD-Mean flow and max temperature variation for SA Simulation 13 (rotate wind direction 90 degrees counter-clockwise).

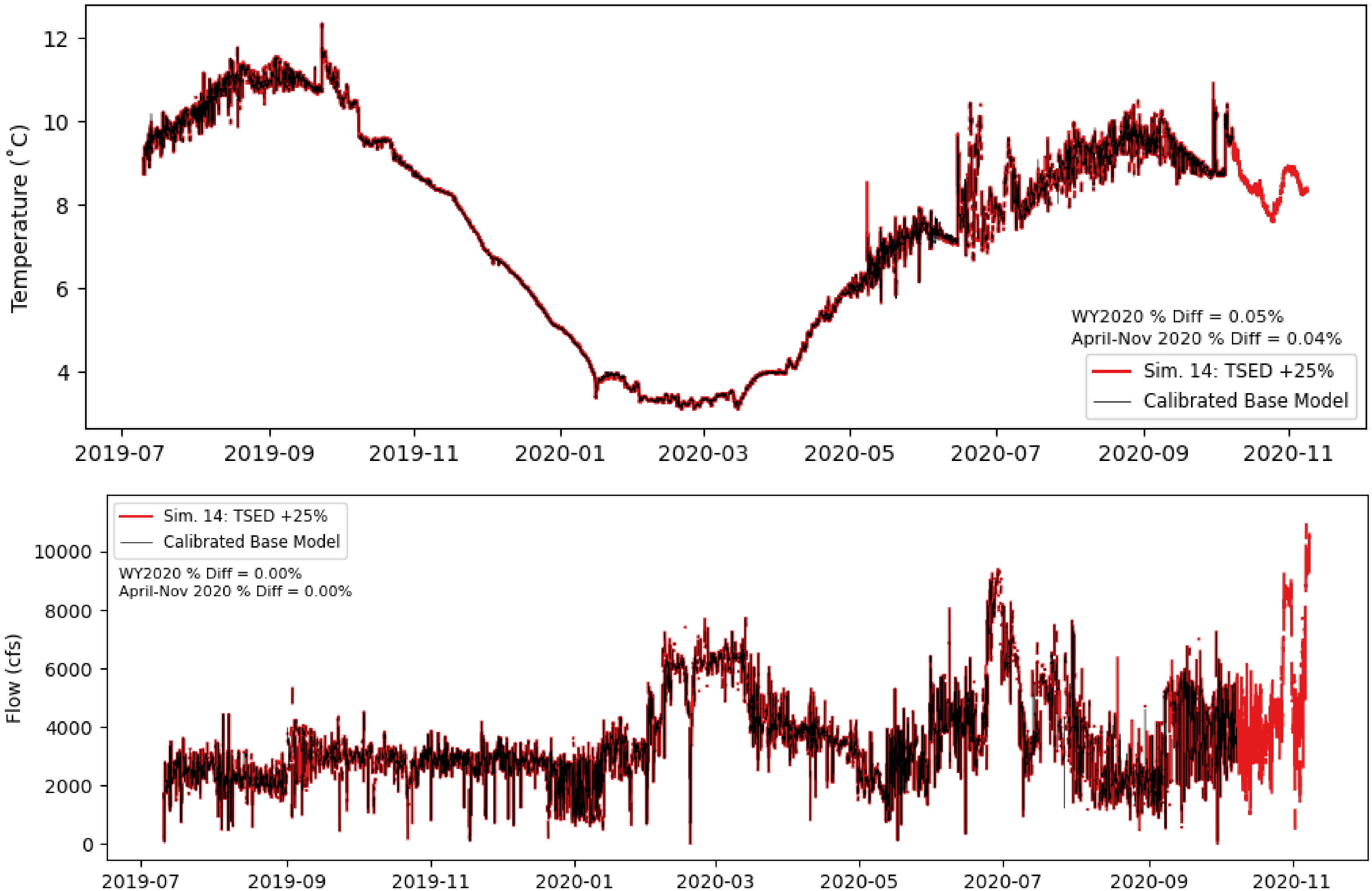


Figure C.2-23. Diablo Lake outflow continuous hourly flow and temperature variation for SA Simulation 14 (increase sediment temperature by 25 percent).

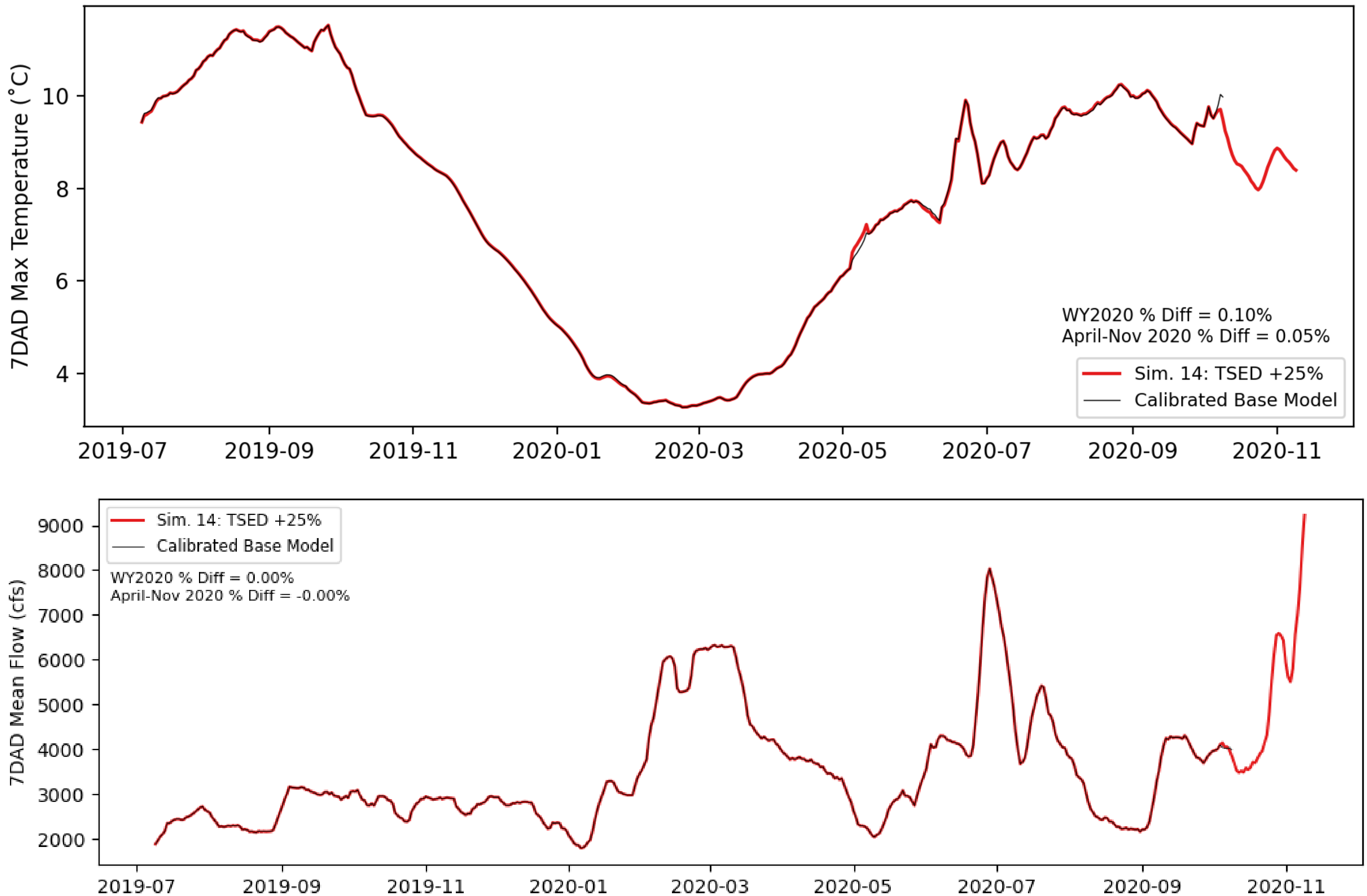


Figure C.2-24. Diablo Lake outflow 7DAD-Mean Flow and Max Temperature Variation for SA Simulation 14 (increase sediment temperature by 25 percent).

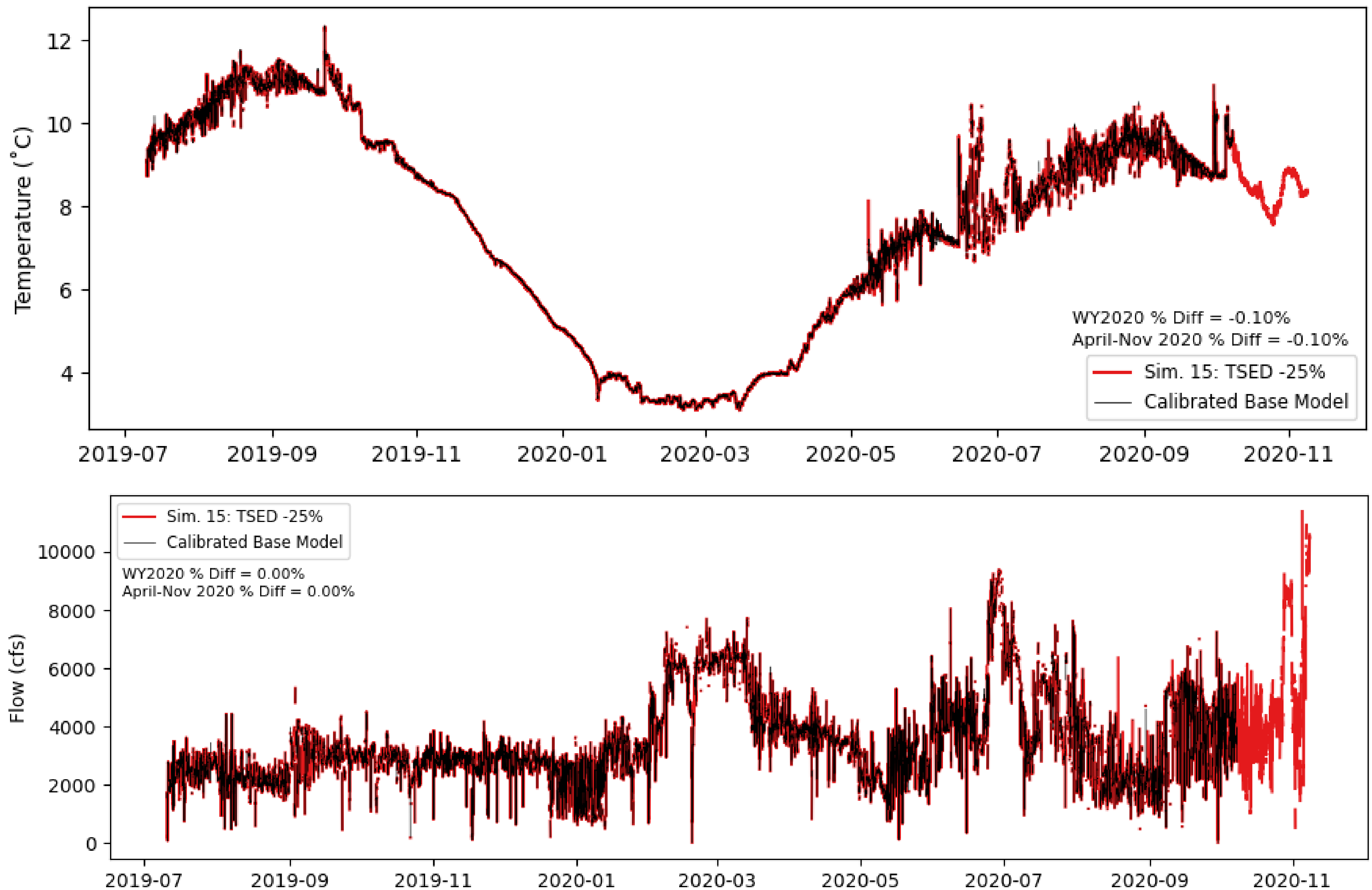


Figure C.2-25. Diablo Lake outflow continuous hourly flow and temperature variation for SA Simulation 15 (decrease sediment temperature by 25 percent.

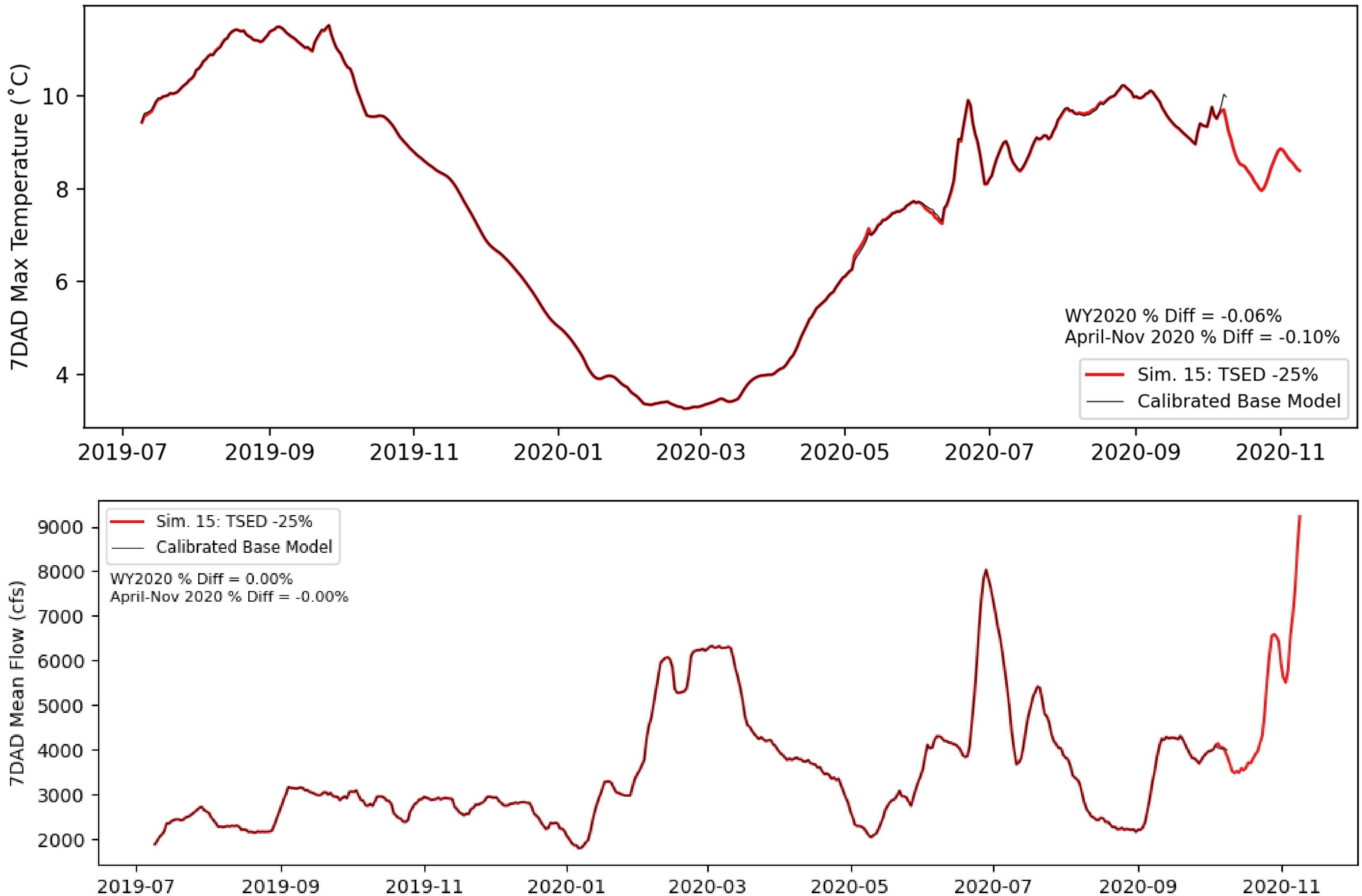


Figure C.2-26. Diablo Lake outflow 7DAD-Mean flow and max temperature variation for SA Simulation 15 (decrease sediment temperature by 25 percent).

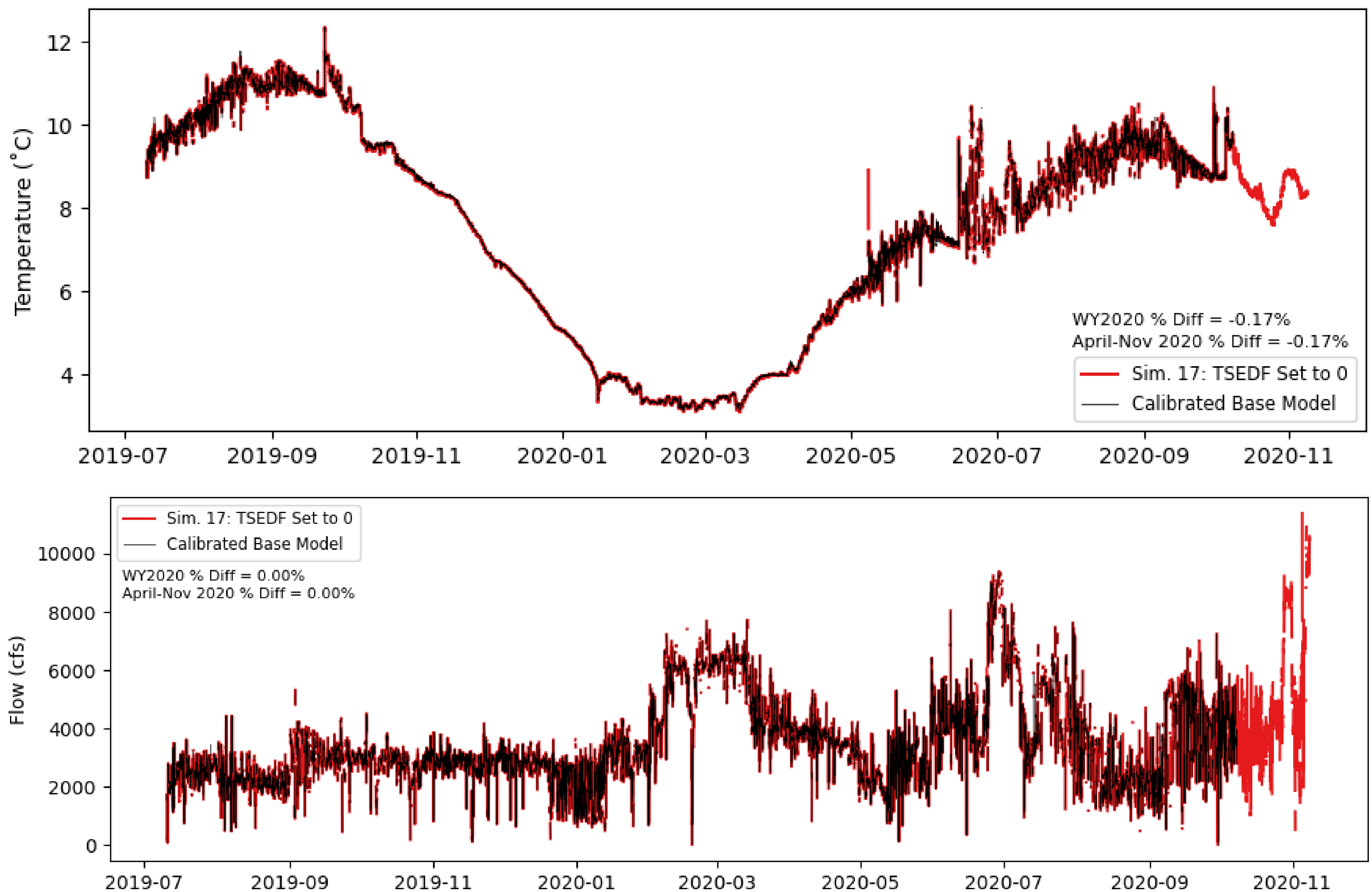
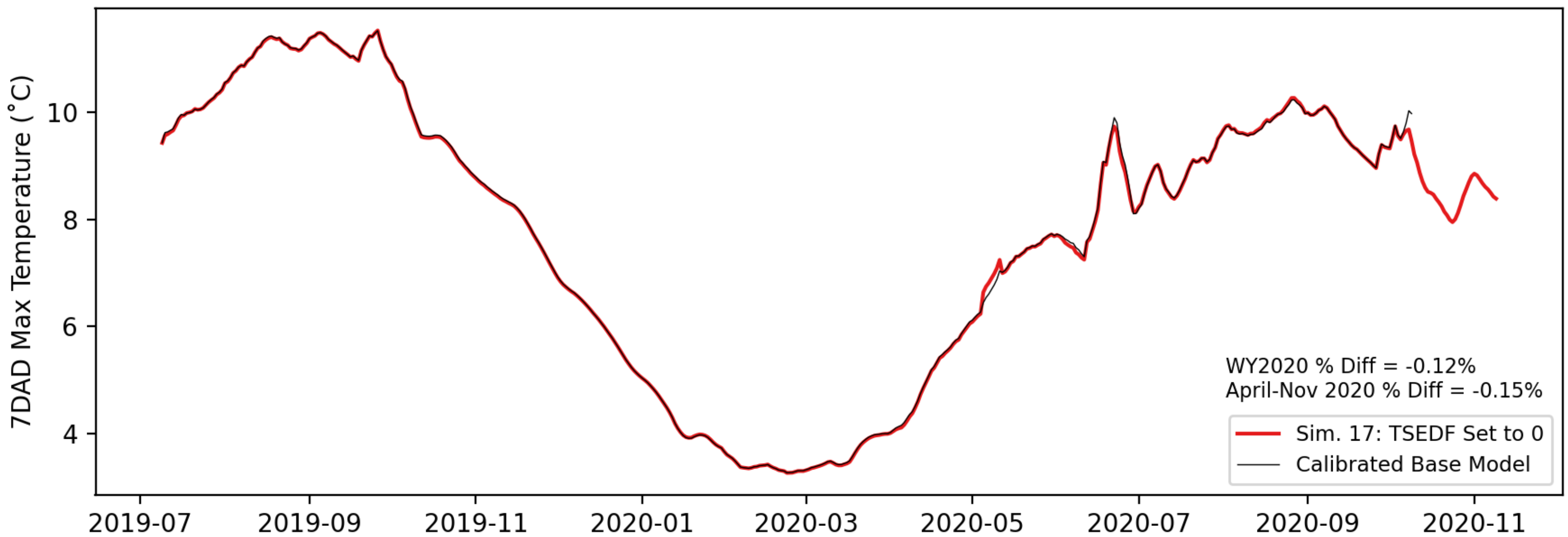


Figure C.2-27. Diablo Lake outflow continuous hourly flow and temperature variation for SA Simulation 17 (set sediment heat exchange coefficient to 0).



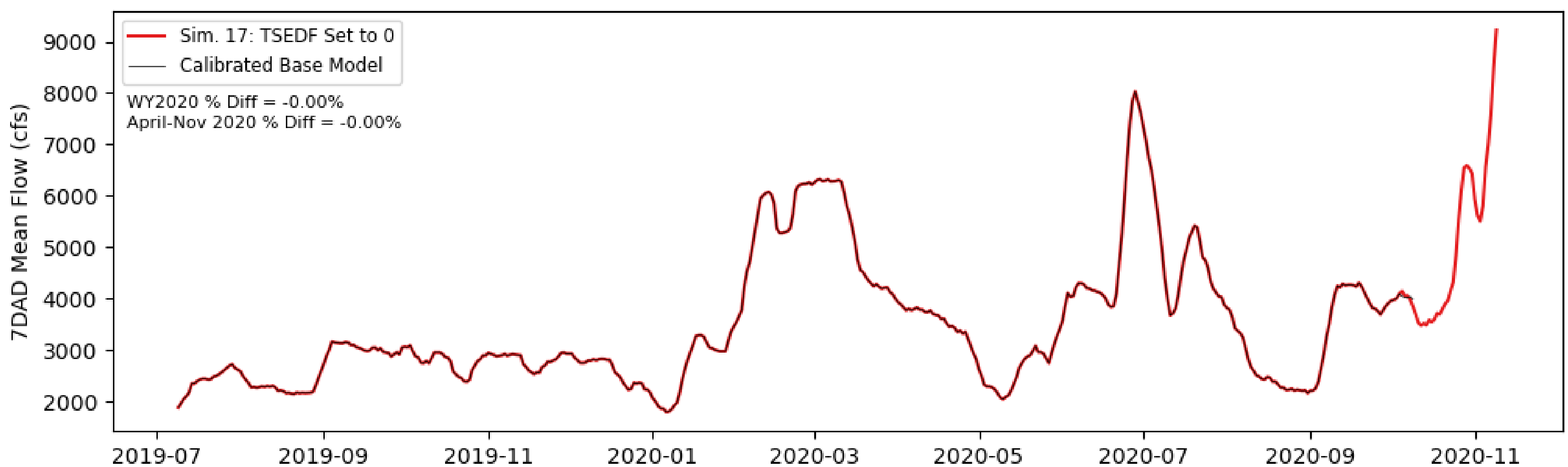


Figure C.2-28. Diablo Lake outflow 7DAD-Mean flow and max temperature variation for SA Simulation 17 (set sediment heat exchange coefficient to 0).

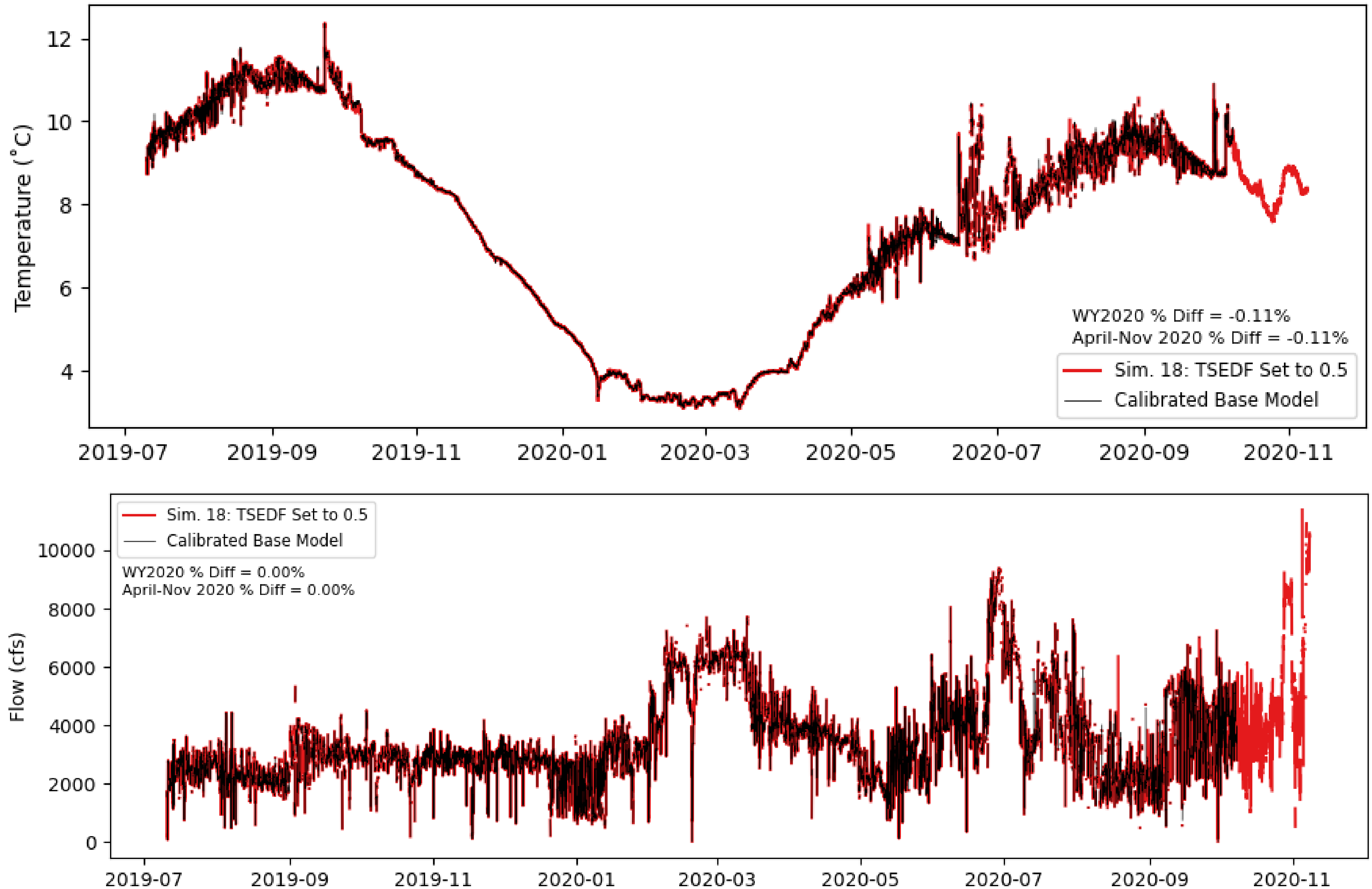


Figure C.2-29. Diablo Lake outflow continuous hourly flow and temperature variation for SA Simulation 18 (set sediment heat exchange coefficient to 0.5).

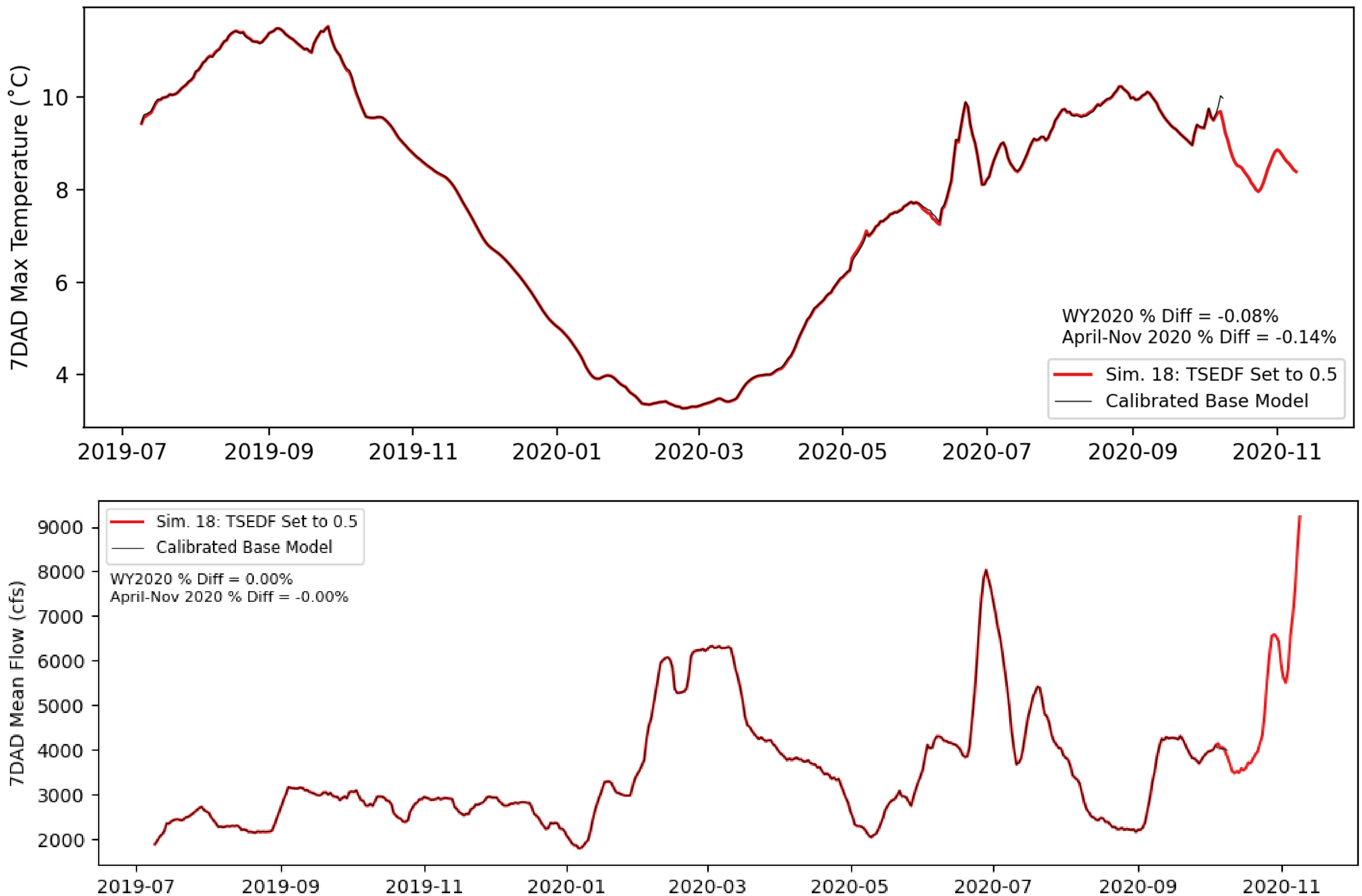


Figure C.2-30. Diablo Lake Outflow 7DAD-Mean Flow and Max Temperature Variation for SA Simulation 18 (set sediment heat exchange coefficient to 0.5).

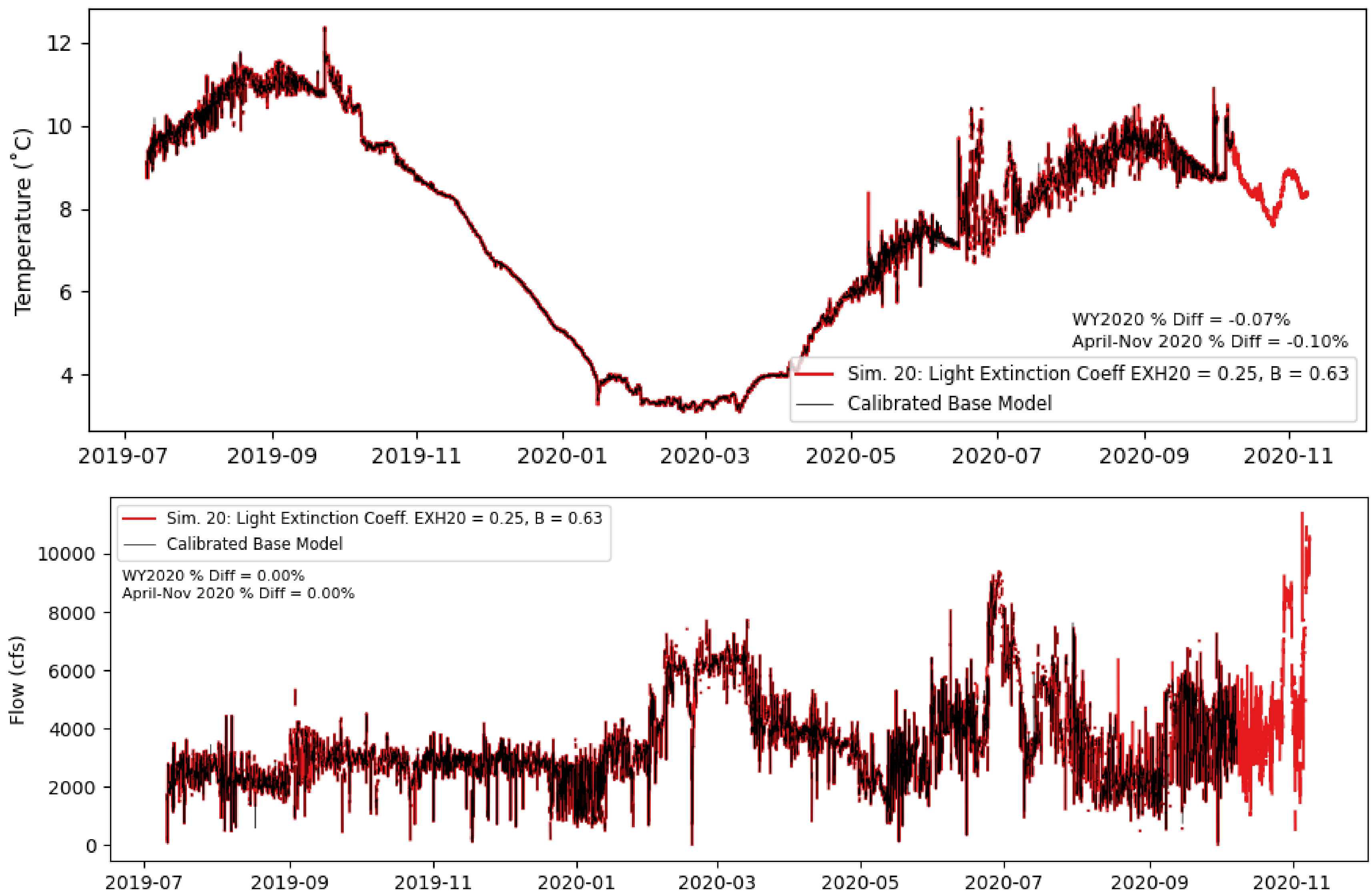


Figure C.2-31. Diablo Lake outflow continuous hourly flow and temperature variation for SA Simulation 20 (increase light absorption coefficient, reduce vertical light extinction).

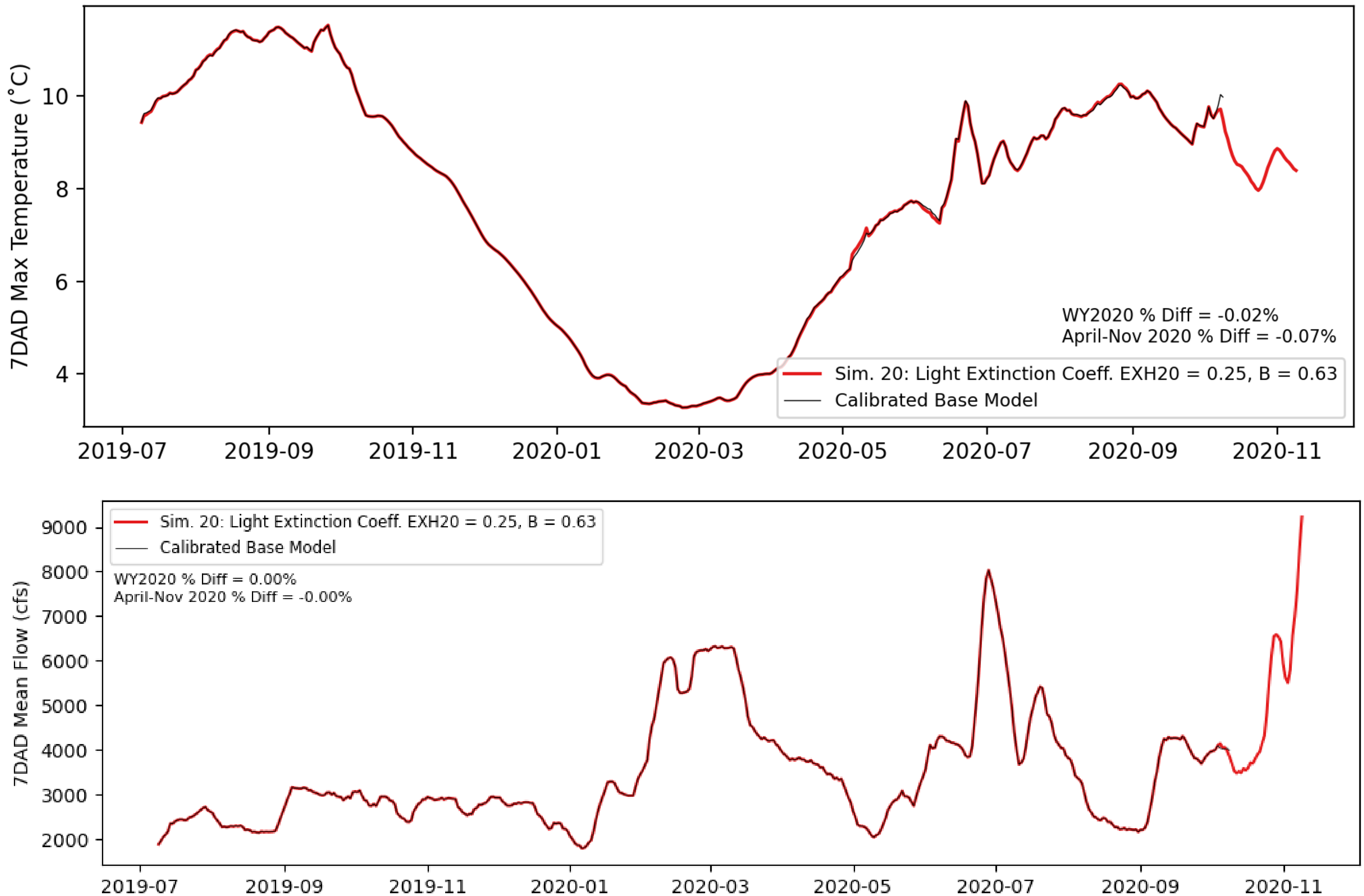


Figure C.2-32. Diablo Lake outflow 7DAD-Mean flow and max temperature variation for SA Simulation 20 (increase light absorption coefficient, reduce vertical light extinction).

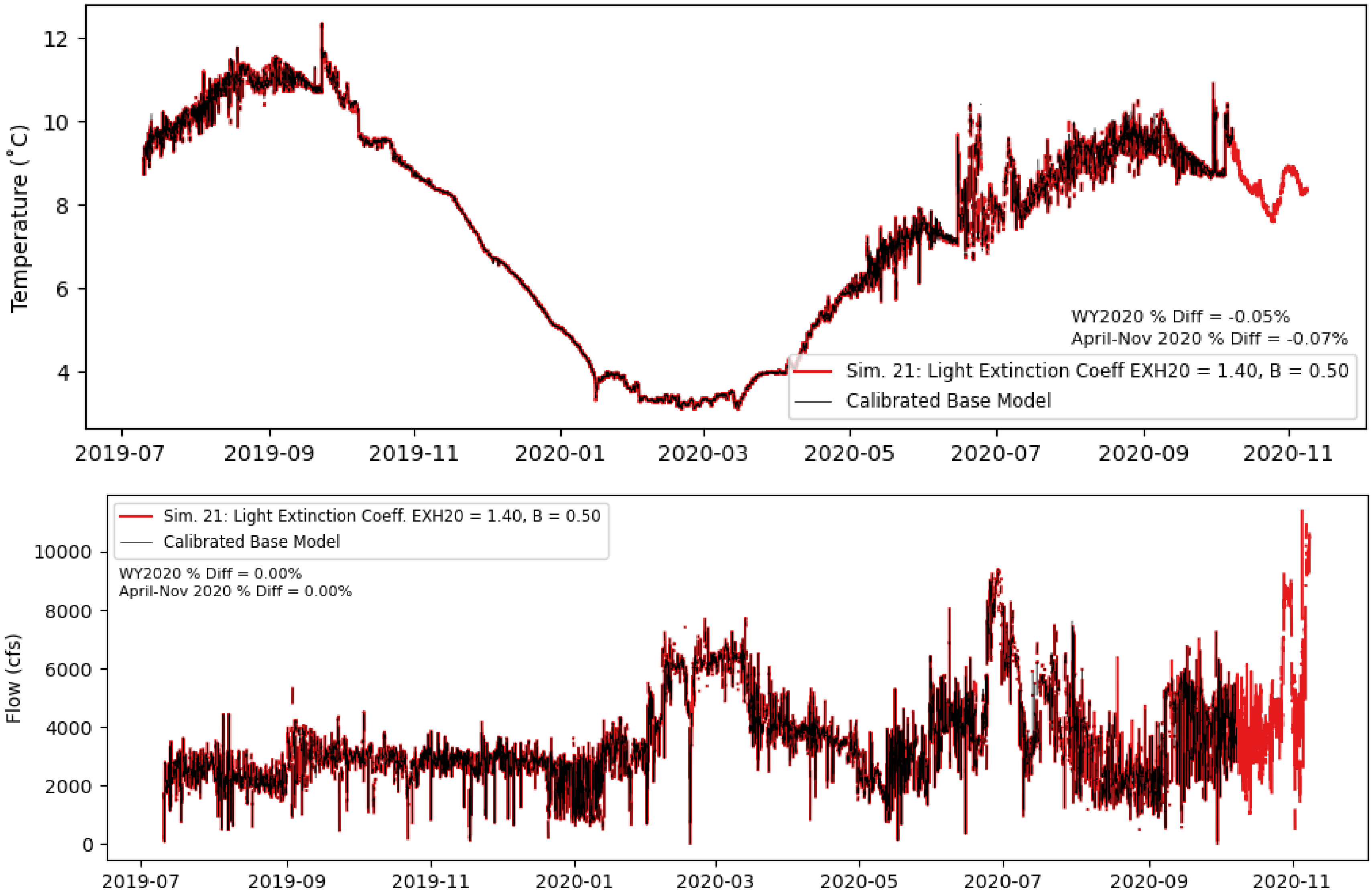


Figure C.2-33. **Diablo Lake outflow continuous hourly flow and temperature variation for SA Simulation 21 (decrease light absorption coefficient, increase vertical light extinction).**

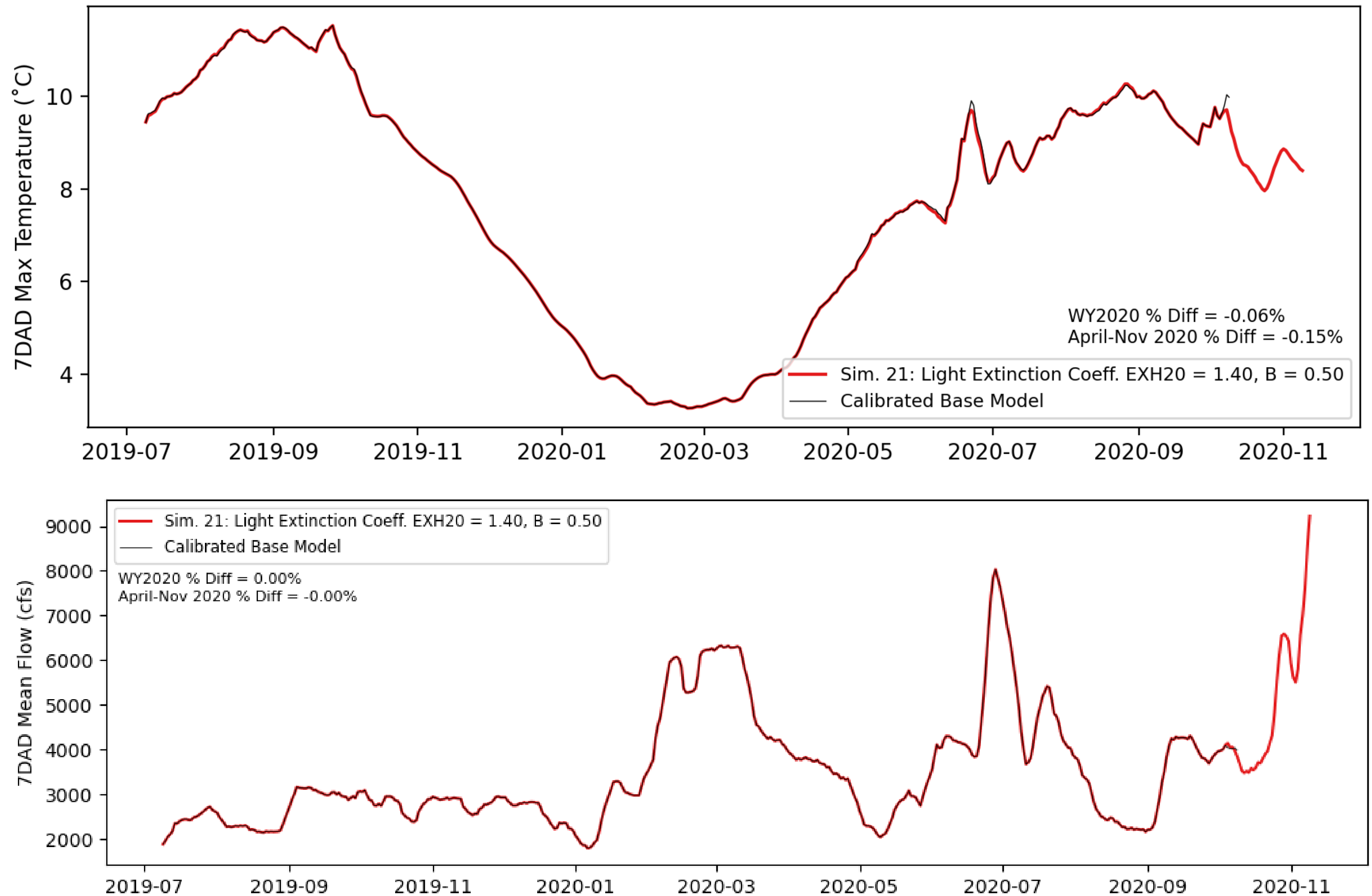


Figure C.2-34. Diablo Lake outflow 7DAD-Mean flow and max temperature variation for SA Simulation 21 (decrease light absorption coefficient, increase vertical light extinction).

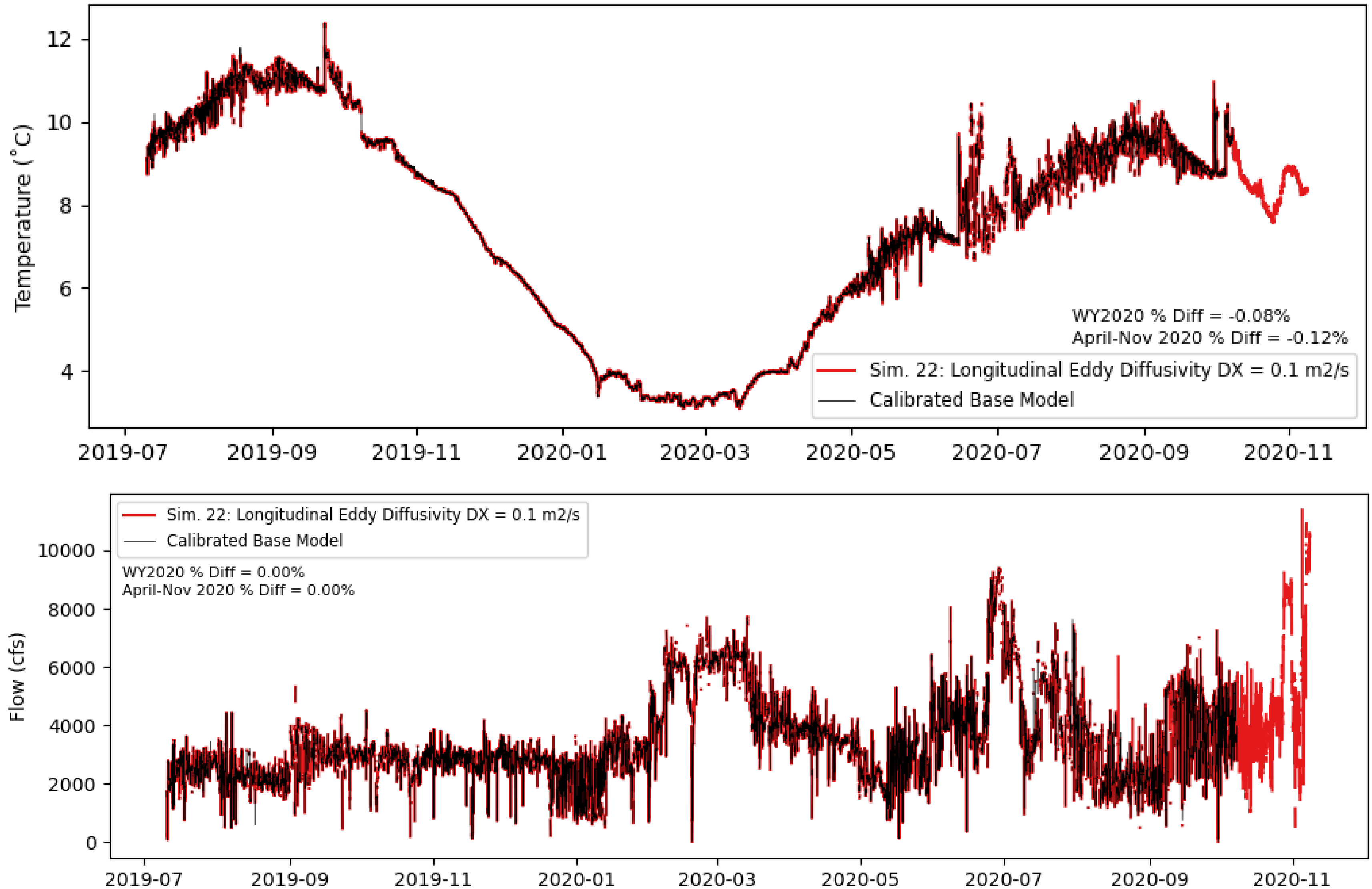


Figure C.2-35. Diablo Lake Outflow Continuous Hourly Flow and Temperature Variation for SA Simulation 22 (set longitudinal eddy diffusivity to 0.1 m2/s).

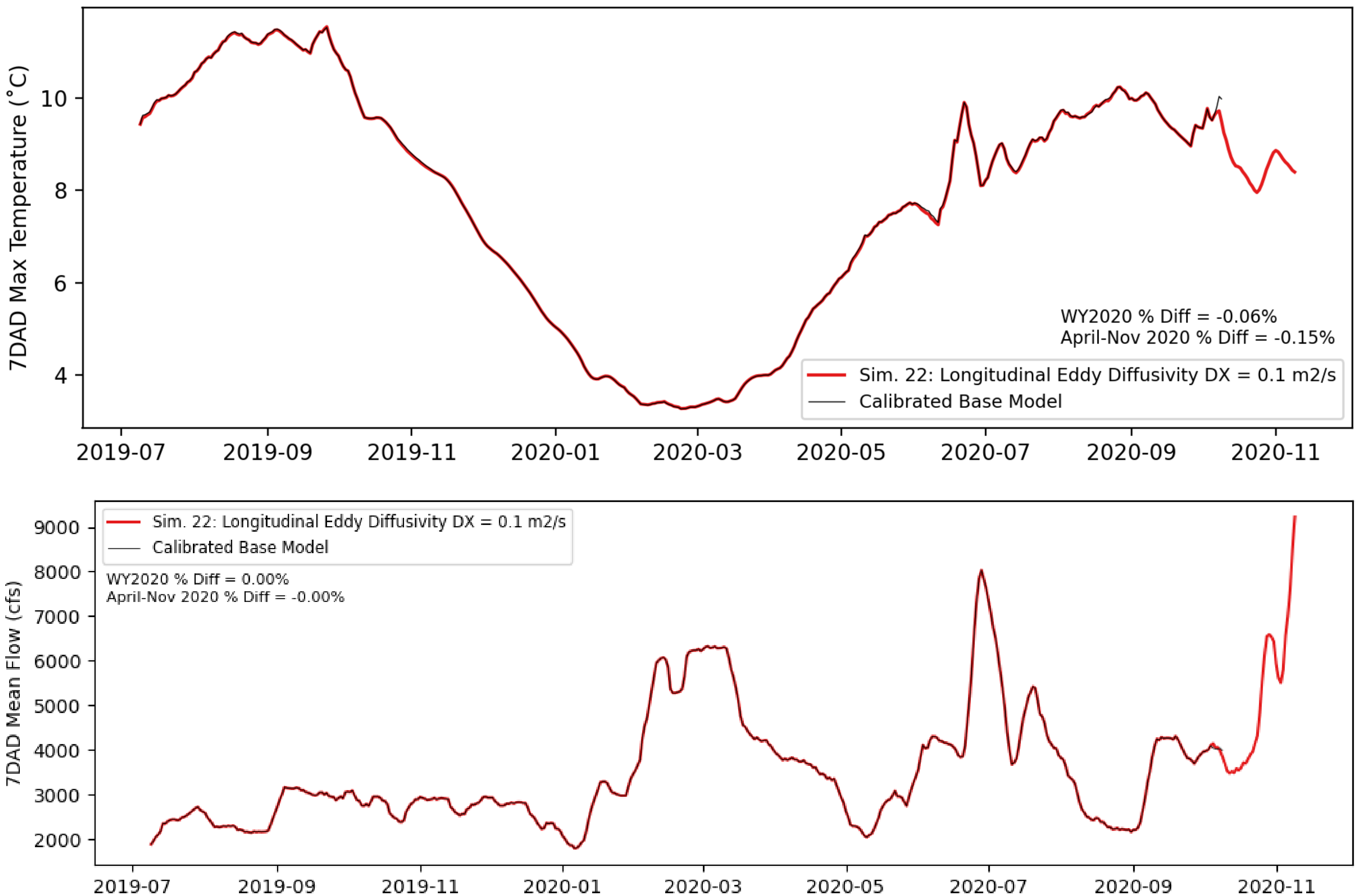


Figure C.2-36. Diablo Lake outflow 7DAD-Mean flow and max temperature variation for SA Simulation 22 (set longitudinal eddy diffusivity to 0.1 m2/s).

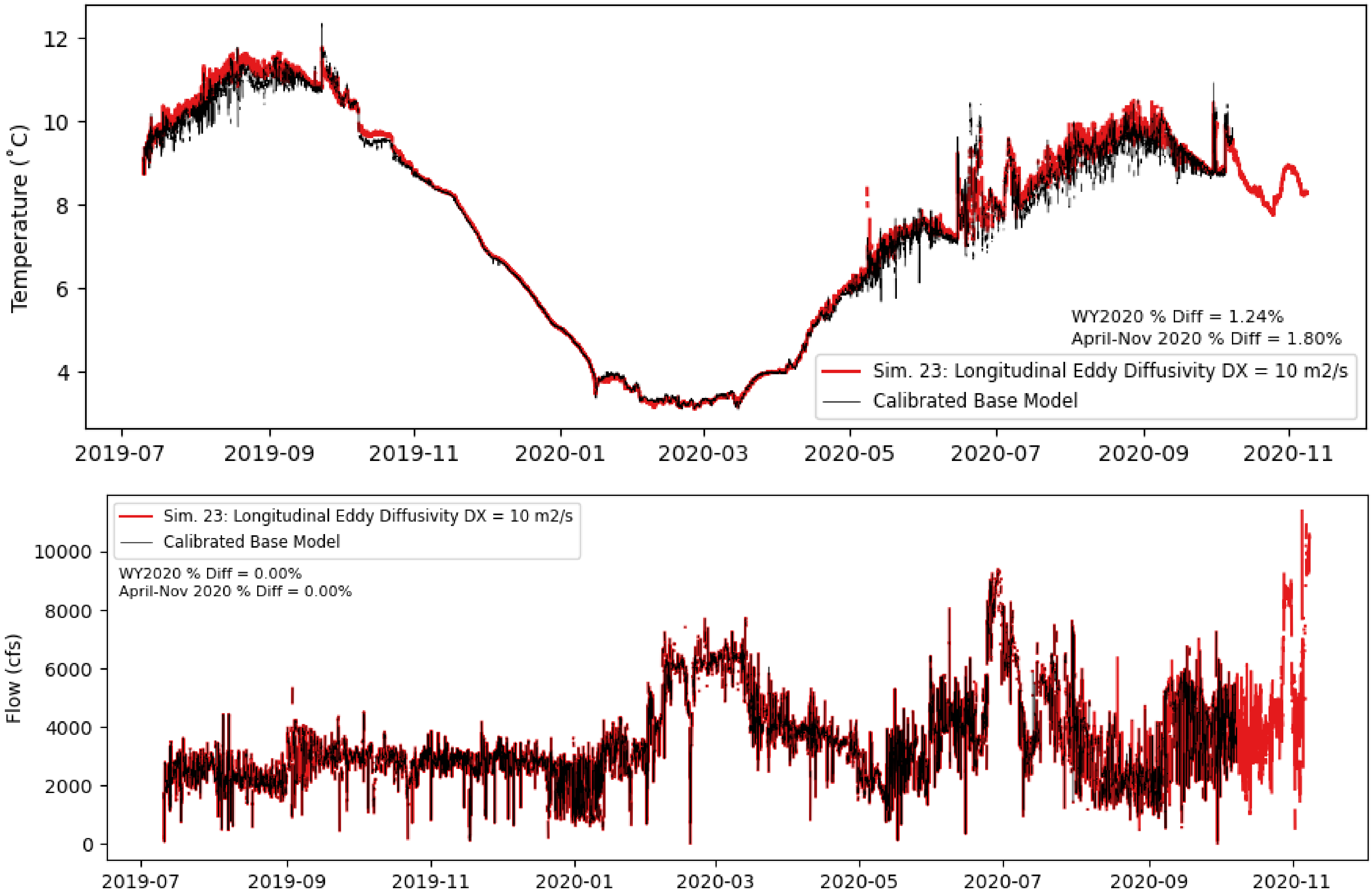


Figure C.2-37. Diablo Lake outflow continuous hourly flow and temperature variation for SA Simulation 23 (set longitudinal eddy diffusivity to 10 m2/s).

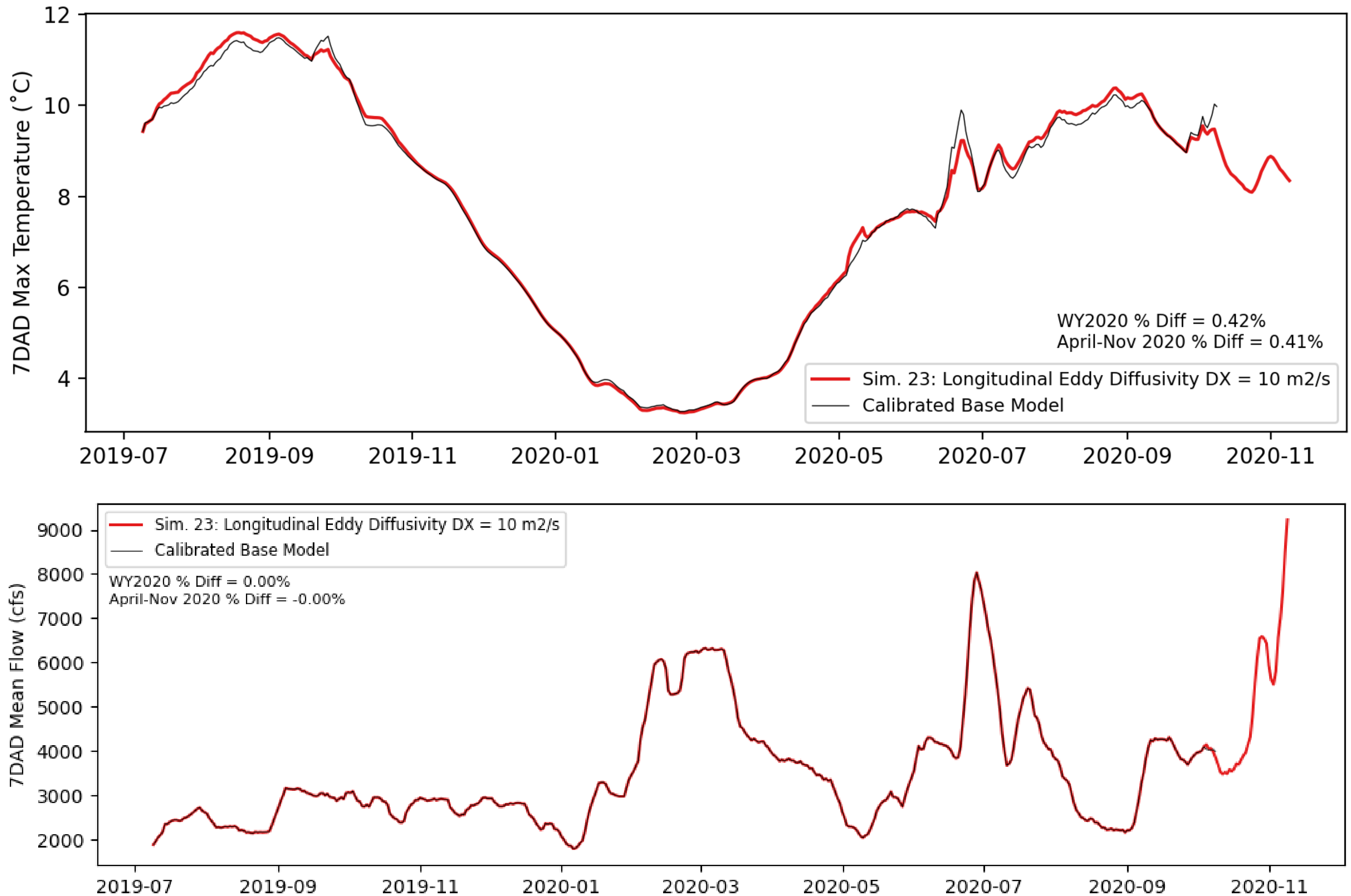


Figure C.2-38. **Diablo Lake outflow 7DAD-mean flow and max temperature variation for SA Simulation 23 (set longitudinal eddy diffusivity to 10 m2/s).**

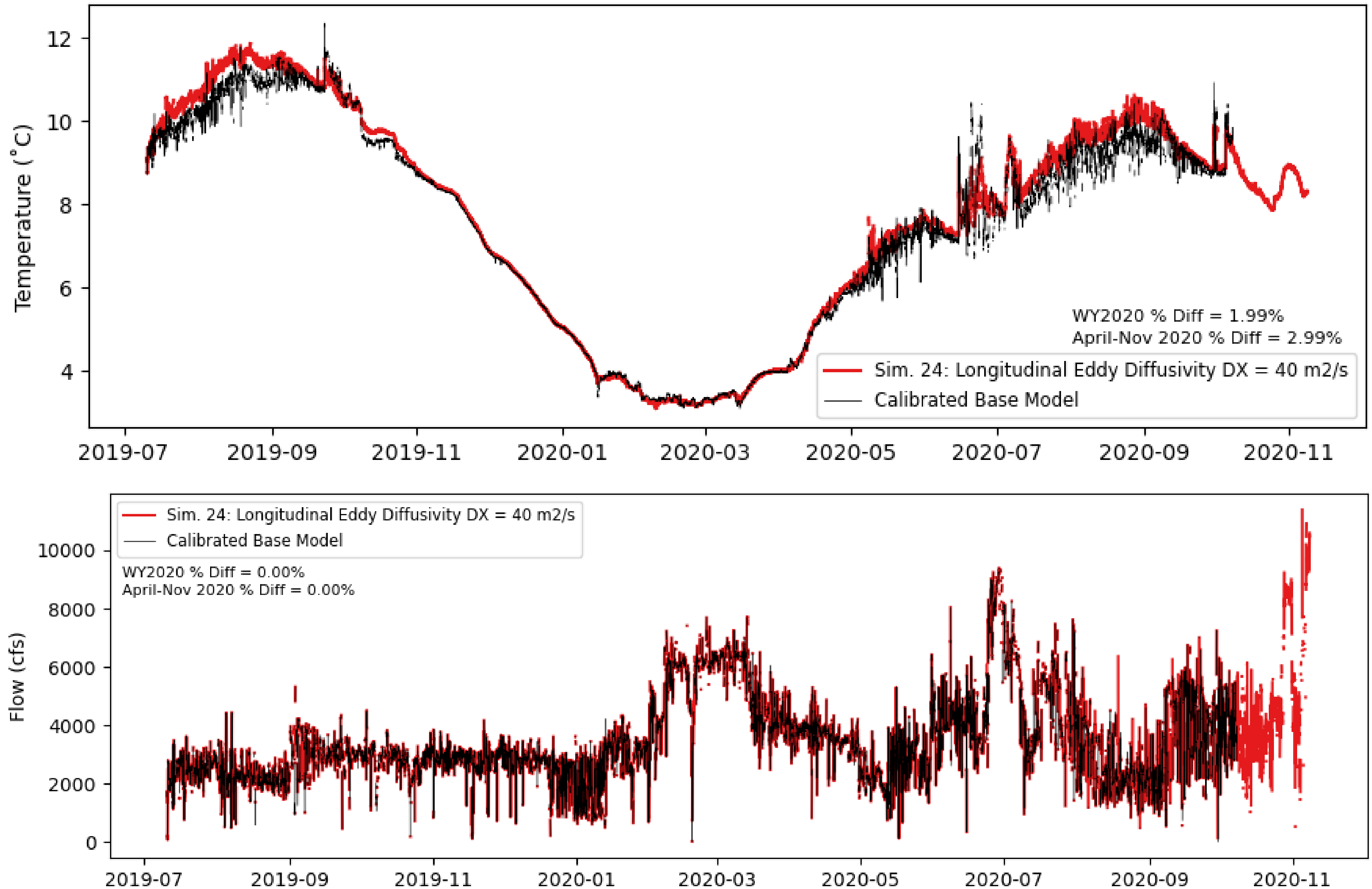


Figure C.2-39. Diablo Lake outflow continuous hourly flow and temperature variation for SA Simulation 24 (set longitudinal eddy diffusivity to 40 m2/s).

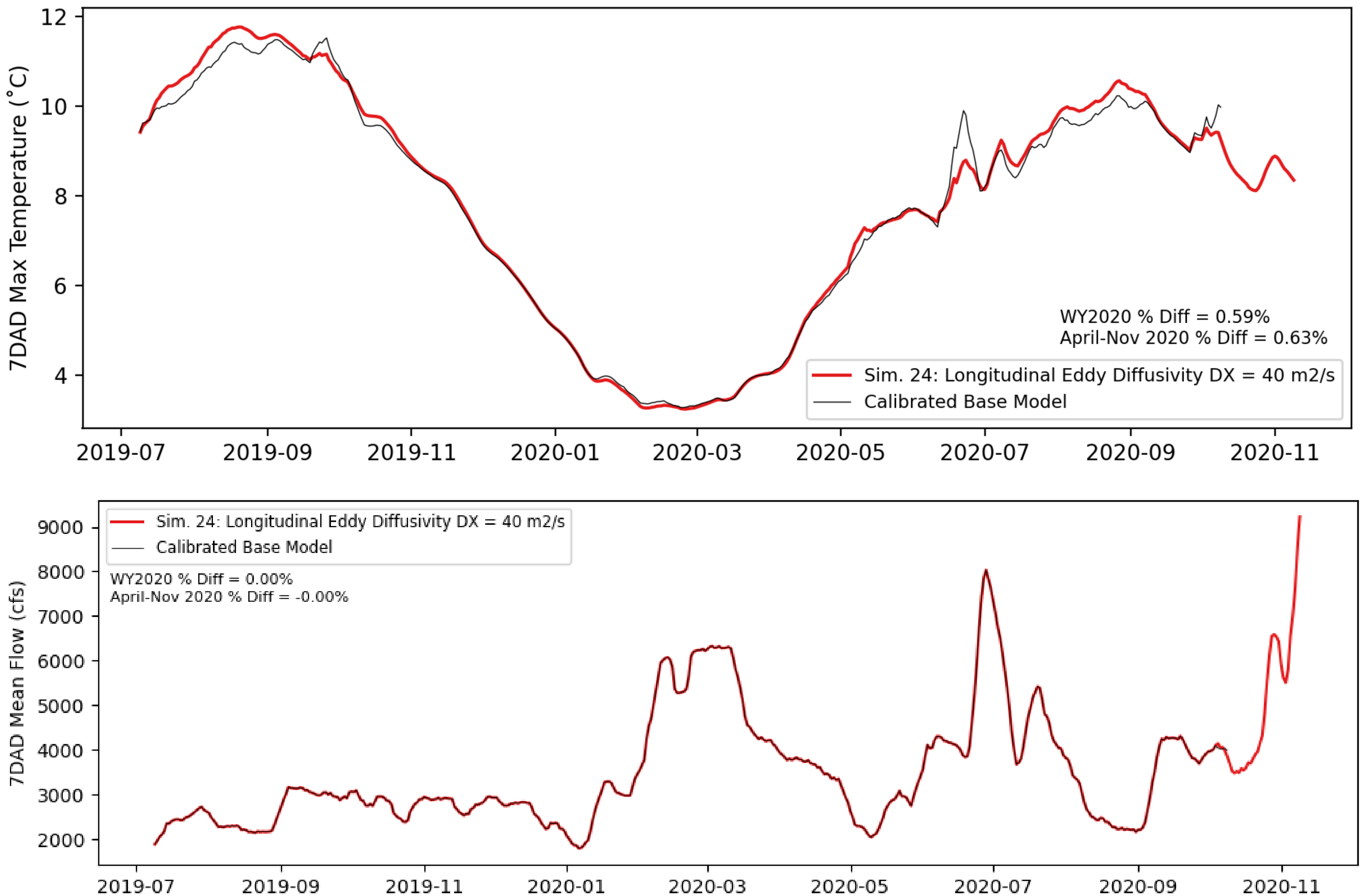


Figure C.2-40. Diablo Lake outflow 7DAD-Mean flow and max temperature variation for SA Simulation 24 (set longitudinal eddy diffusivity to 40 m2/s).

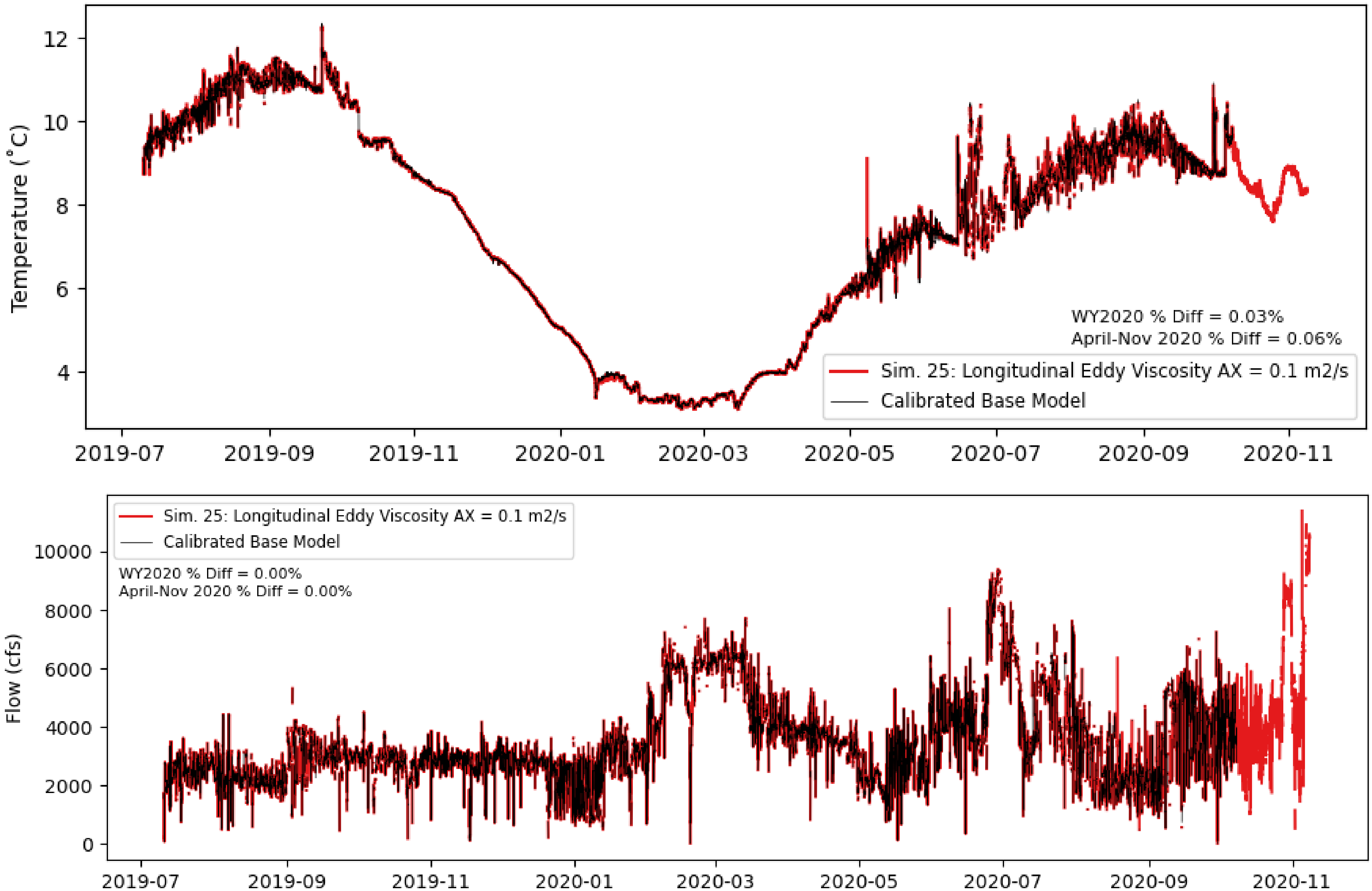


Figure C.2-41. Diablo Lake outflow continuous hourly flow and temperature variation for SA Simulation 25 (set longitudinal eddy viscosity to 0.1 m2/s).

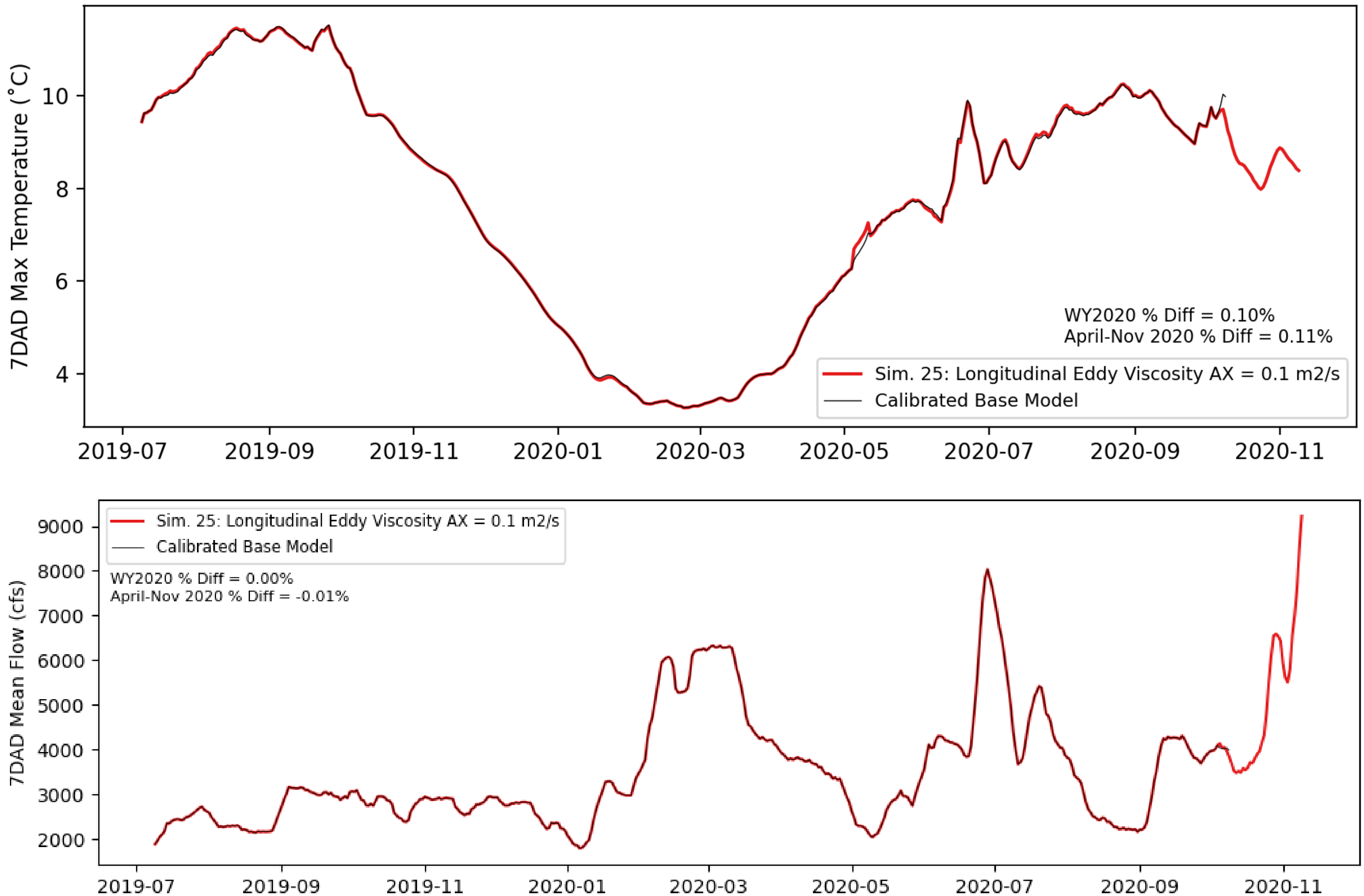


Figure C.2-42. Diablo Lake outflow 7DAD-Mean flow and max temperature variation for SA Simulation 25 (set longitudinal eddy viscosity to 0.1 m2/s).

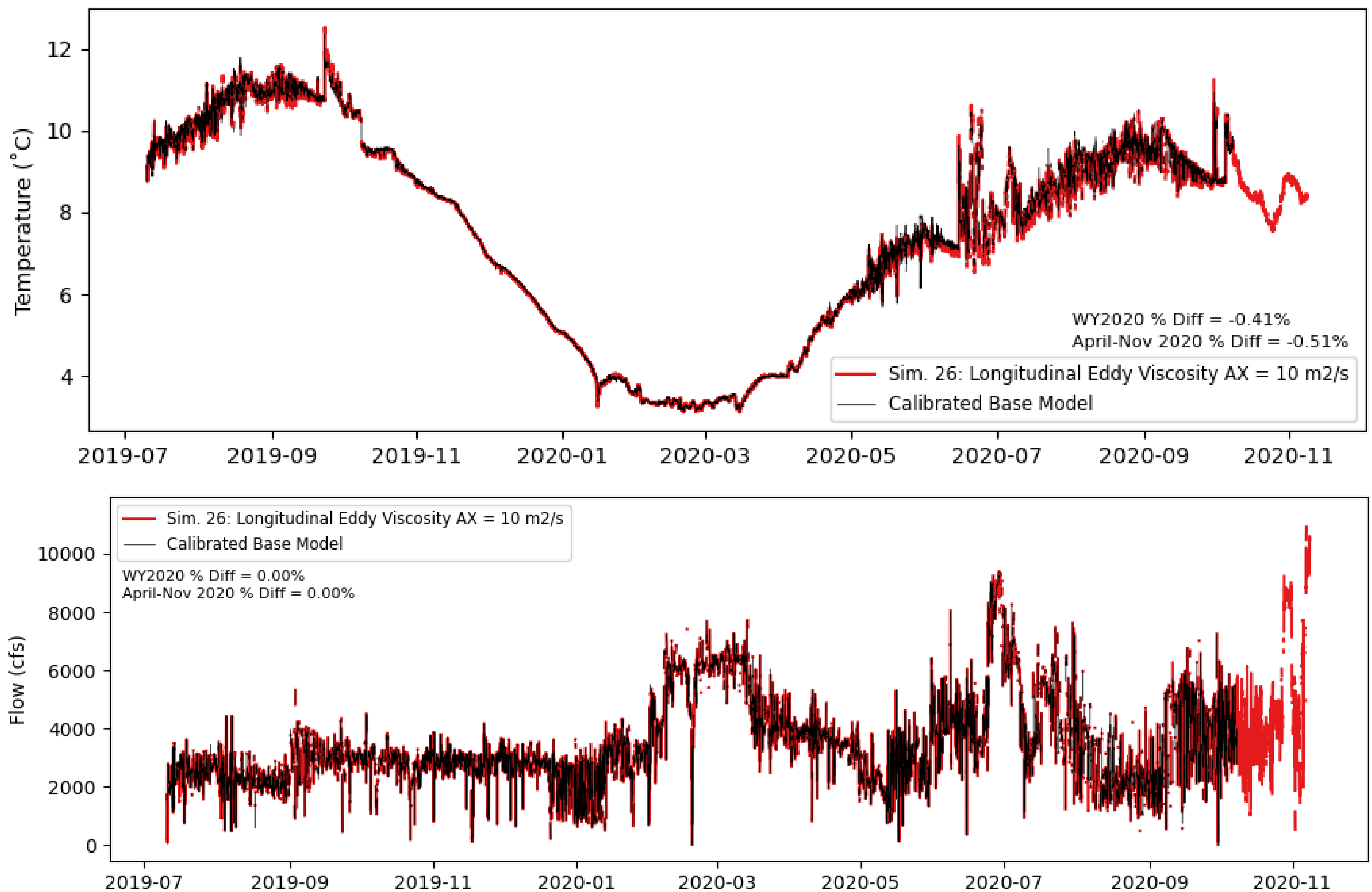


Figure C.2-43. Diablo Lake outflow continuous hourly flow and temperature variation for SA Simulation 26 (set longitudinal eddy viscosity to 10 m2/s).

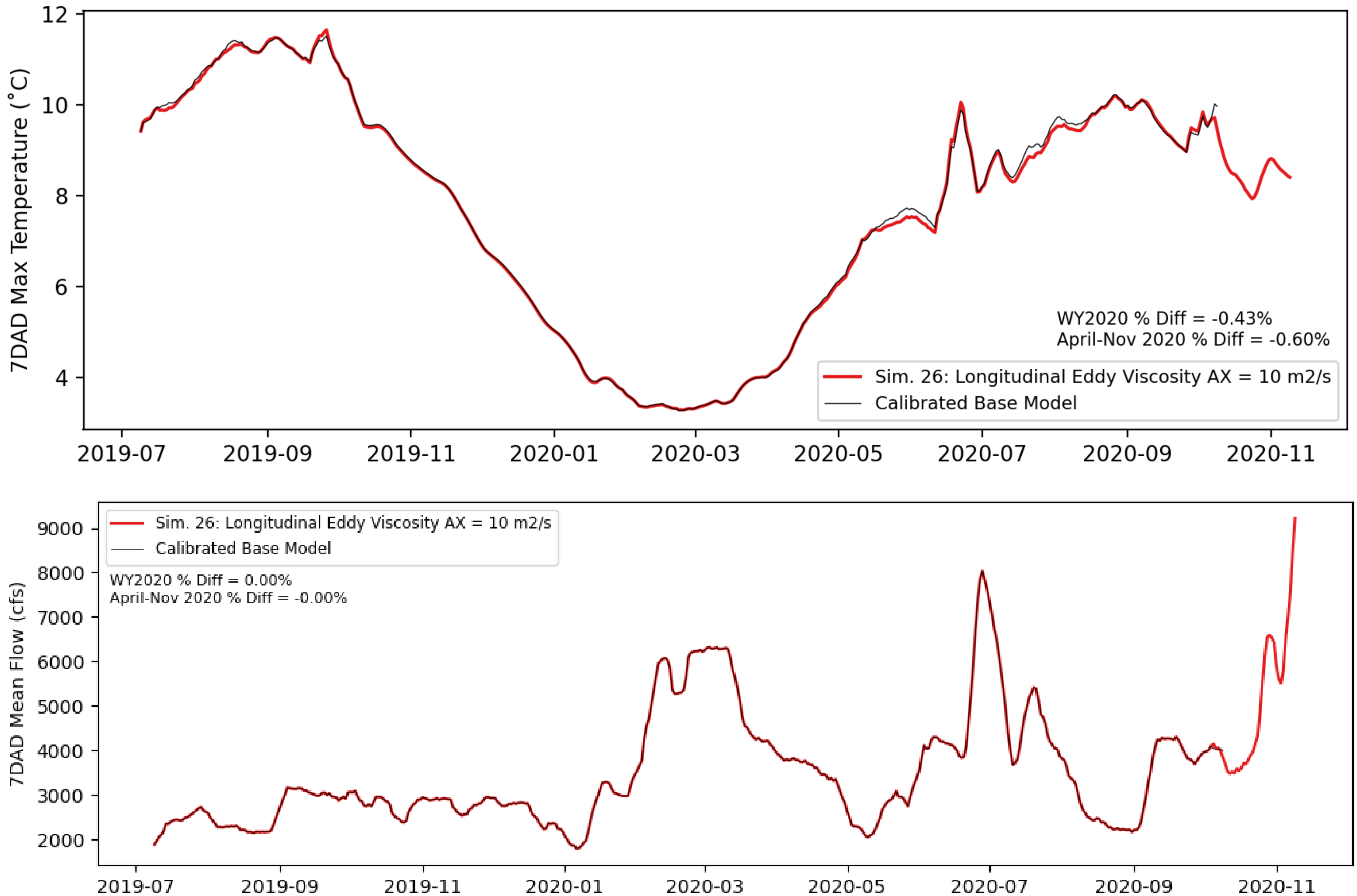


Figure C.2-44. Diablo Lake outflow 7DAD-Mean flow and max temperature variation for SA Simulation 26 (set longitudinal eddy viscosity to 10 m2/s).

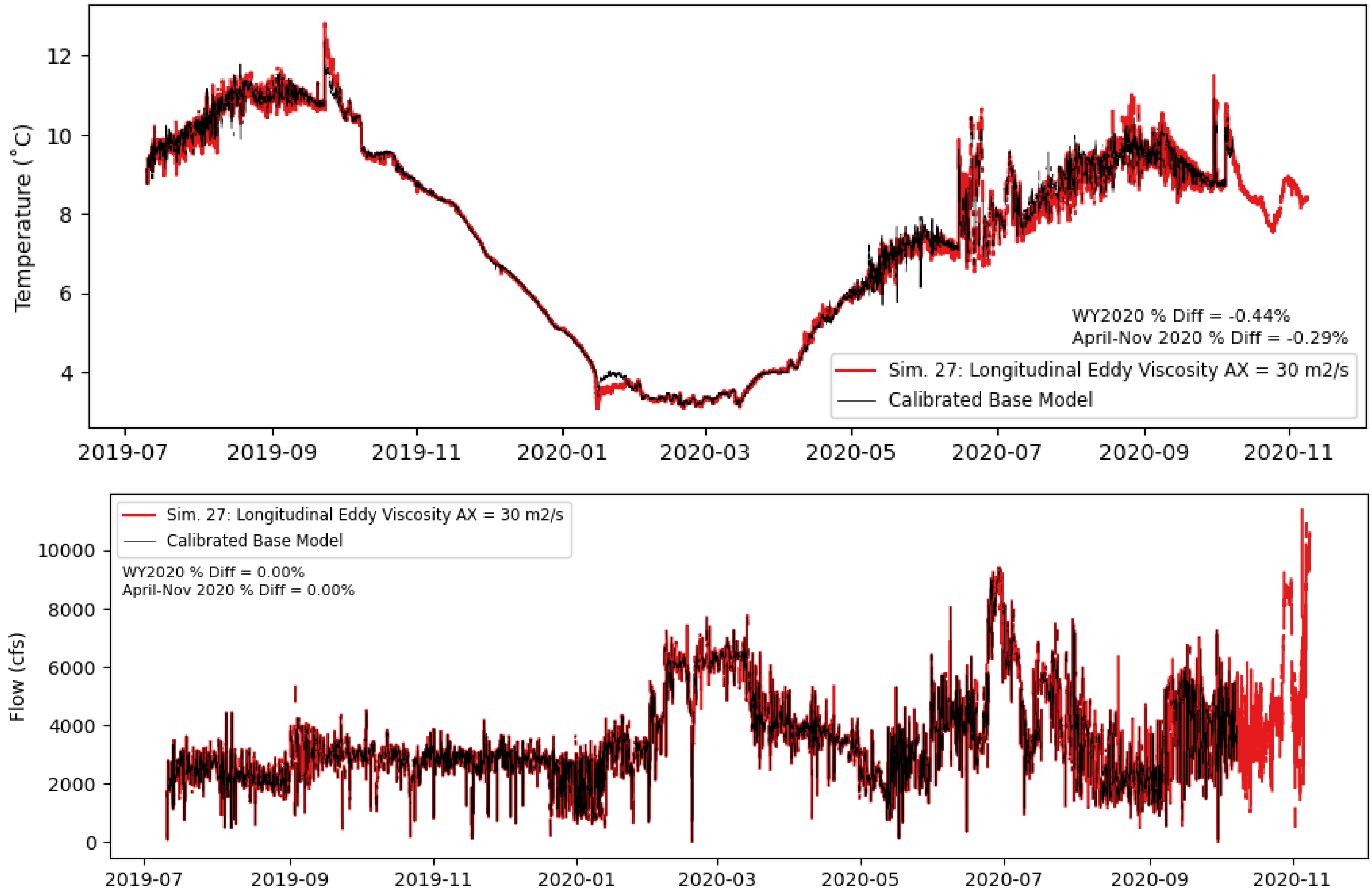


Figure C.2-45. Diablo Lake outflow continuous hourly flow and temperature variation for SA Simulation 27 (set longitudinal eddy viscosity to 30 m2/s).

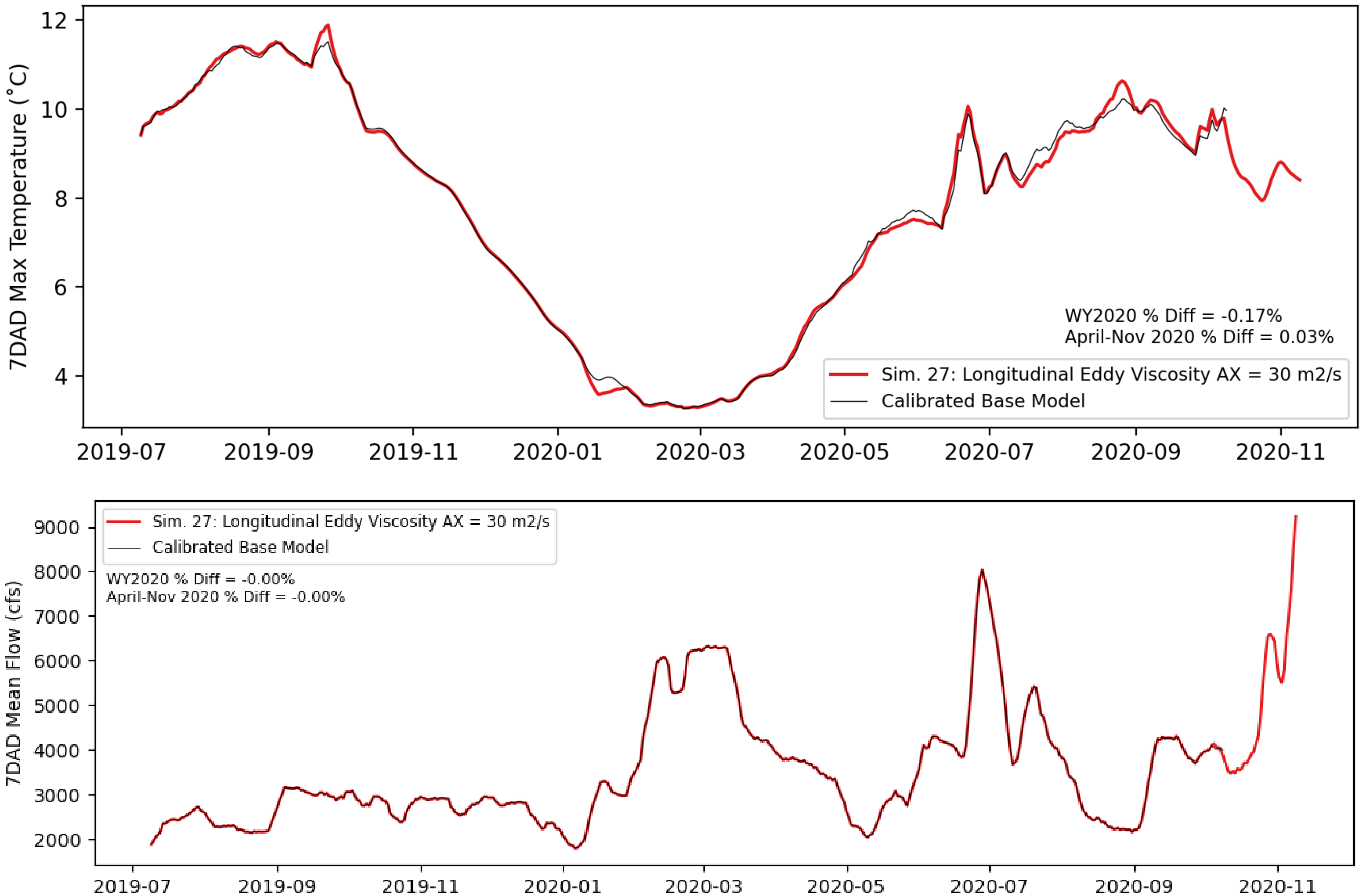


Figure C.2-46. Diablo Lake outflow 7DAD-Mean flow and max temperature variation for SA Simulation 27 (set longitudinal eddy viscosity to 30 m2/s).

C.3 Gorge Lake Sensitivity Analysis Figures

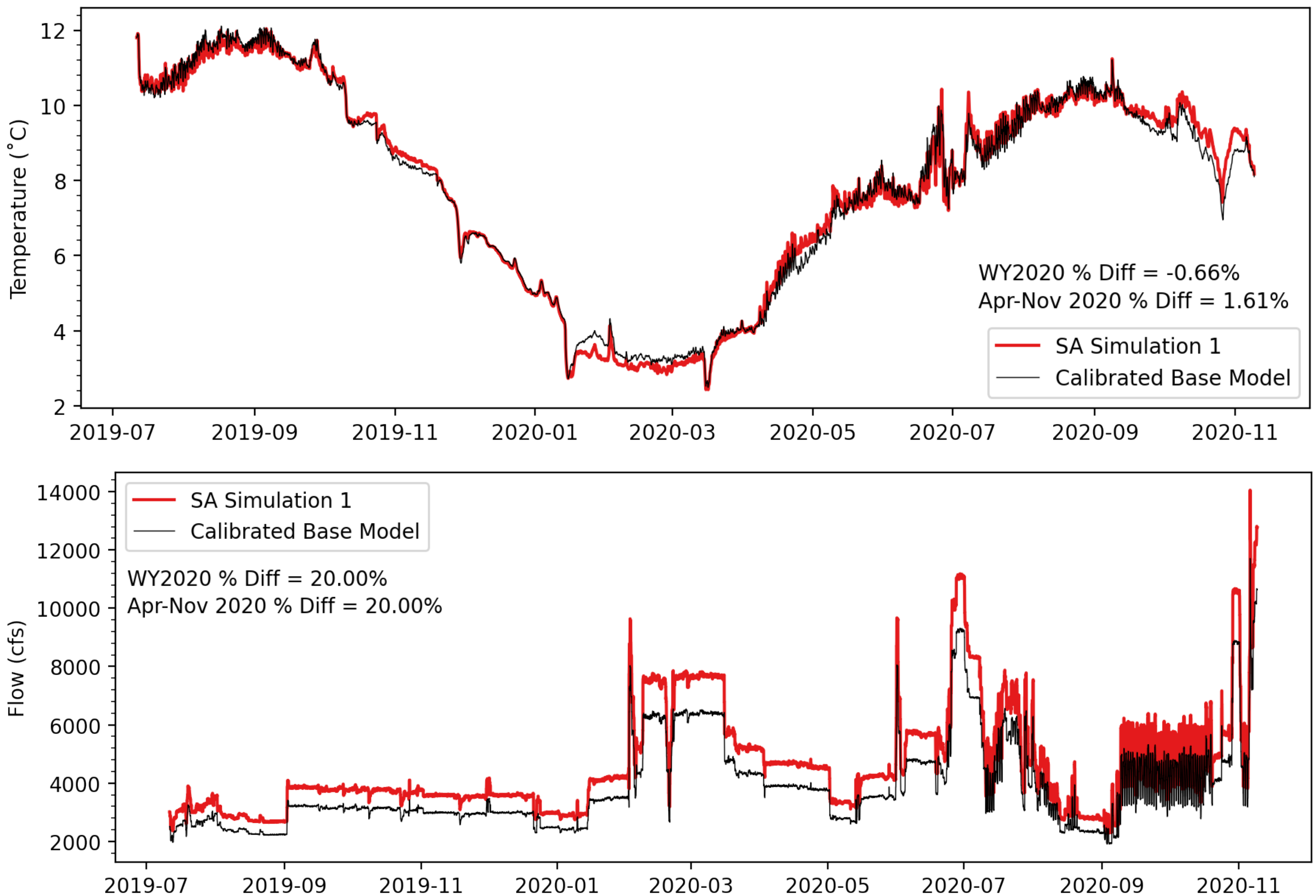


Figure C.3-1. Gorge Lake outflow continuous hourly flow and temperature variation for SA Simulation 1 (increase boundary flows by 20 percent).

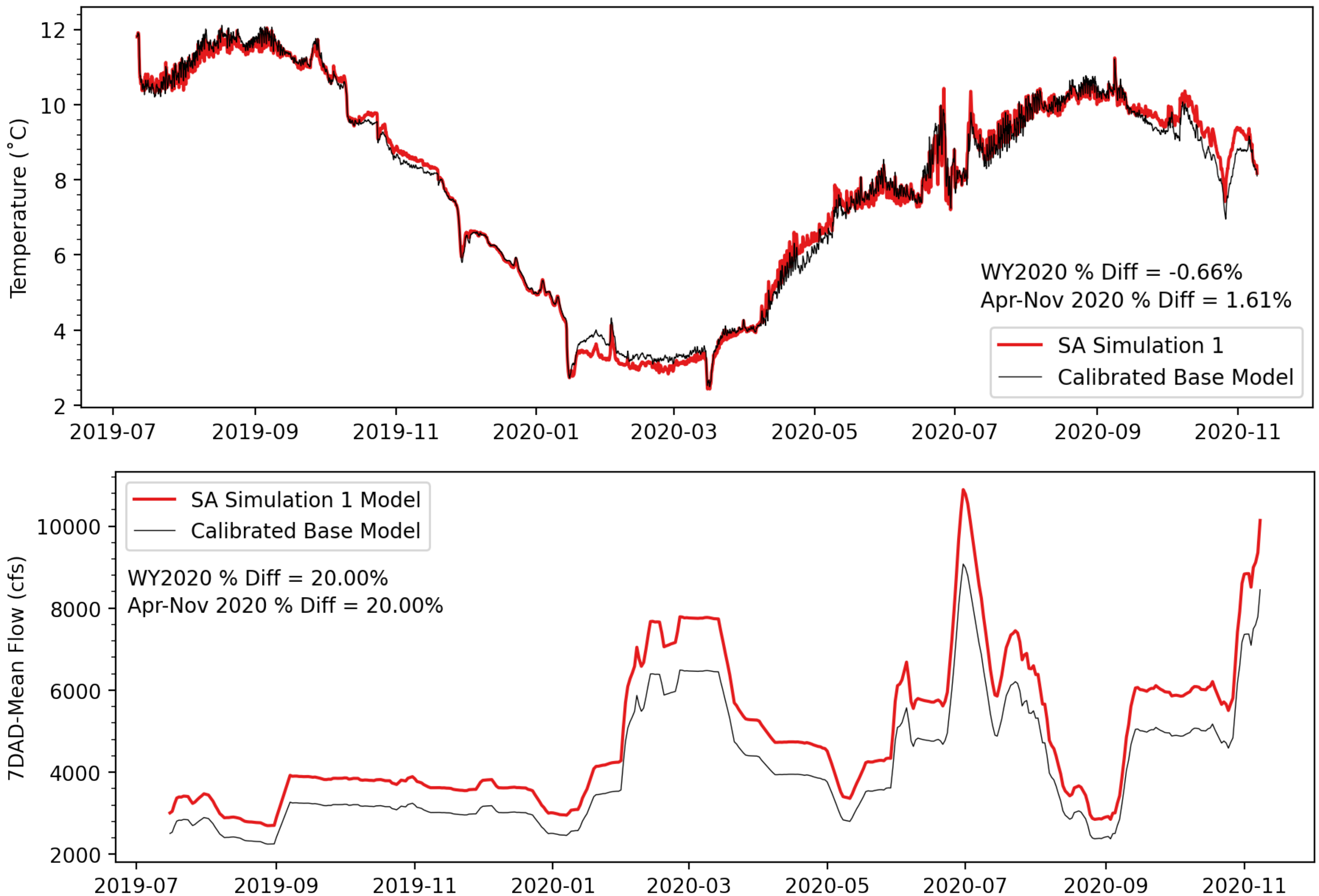


Figure C.3-2. Gorge Lake outflow 7DAD-Mean flow and max temperature variation for SA Simulation 1 (increase boundary flows by 20 percent).

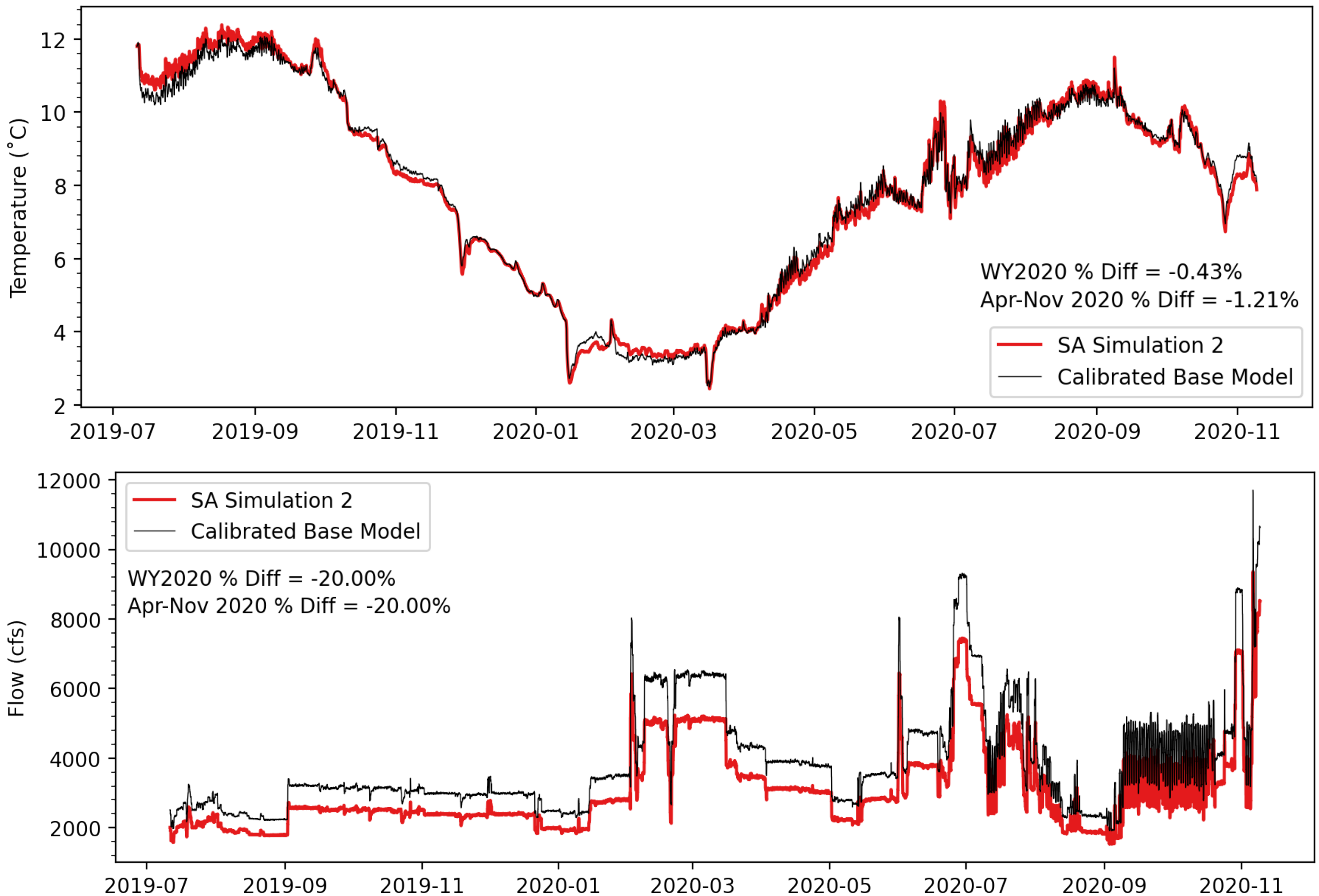


Figure C.3-3. Gorge Lake outflow continuous hourly flow and temperature variation for SA Simulation 2 (decrease boundary flows by 20 percent).

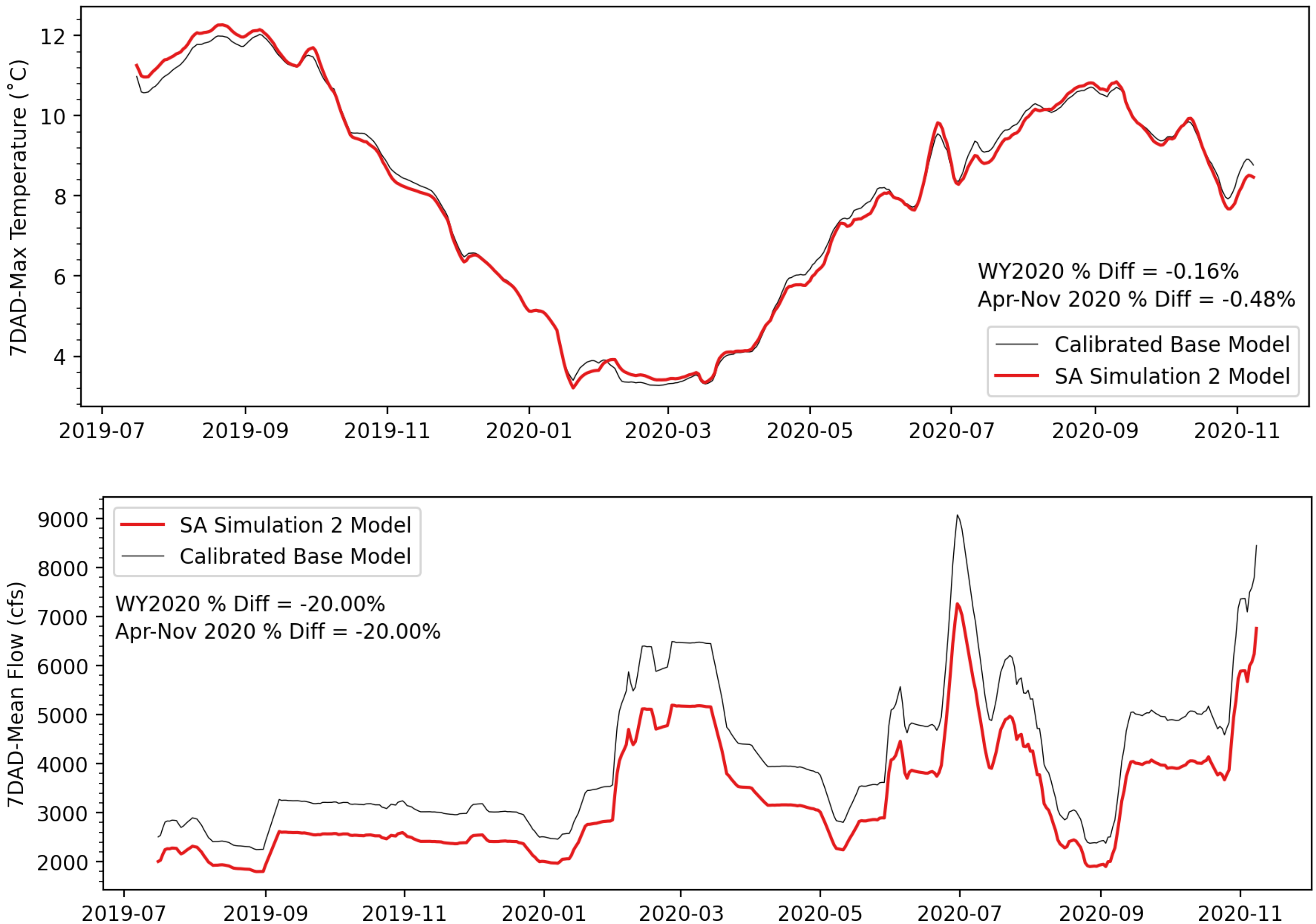


Figure C.3-4. **Gorge Lake outflow 7DAD-Mean flow and max temperature variation for SA Simulation 2 (decrease boundary flows by 20 percent).**

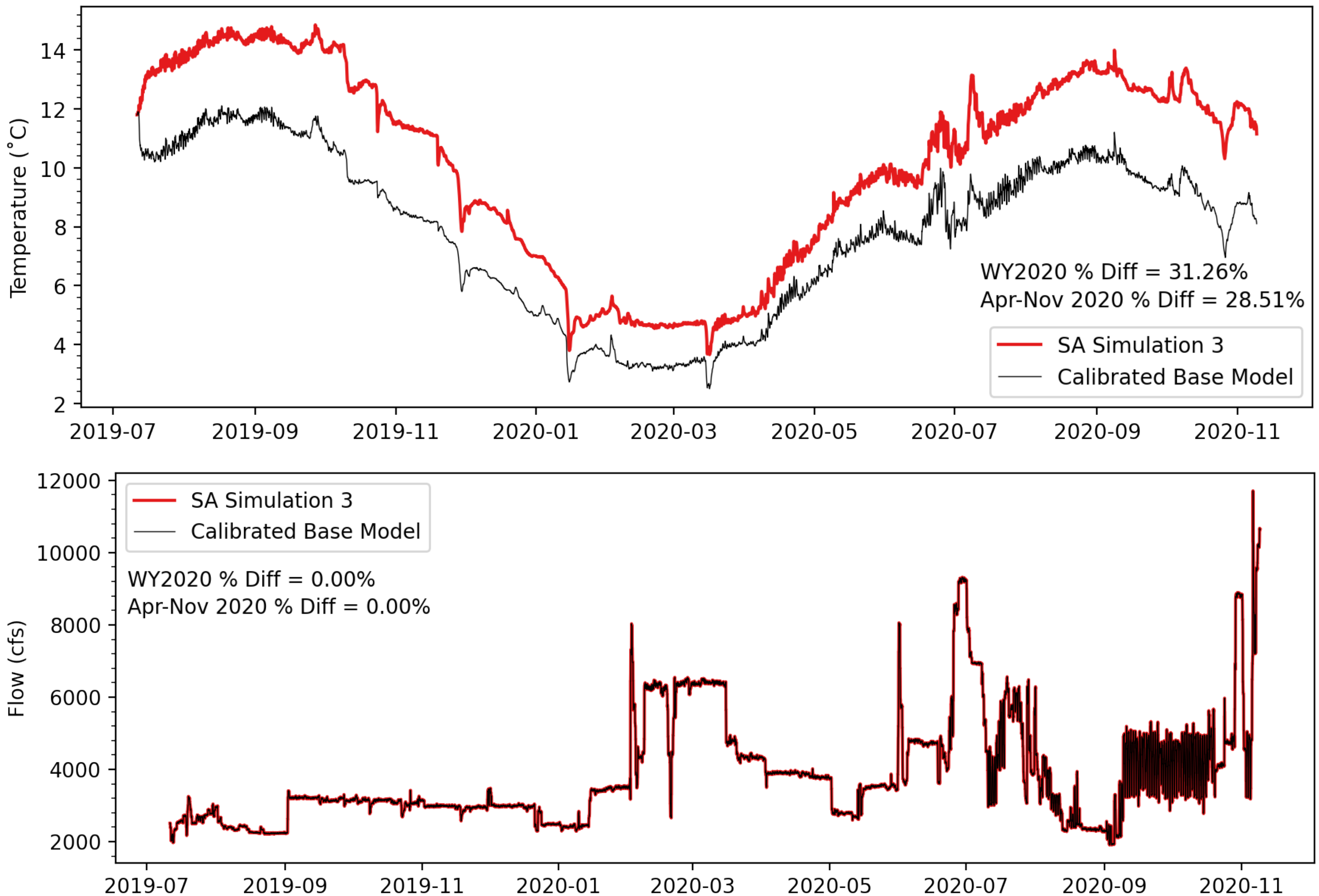


Figure C.3-5. Gorge Lake outflow continuous hourly flow and temperature variation for SA Simulation 3 (increase boundary temperatures by 20 percent).

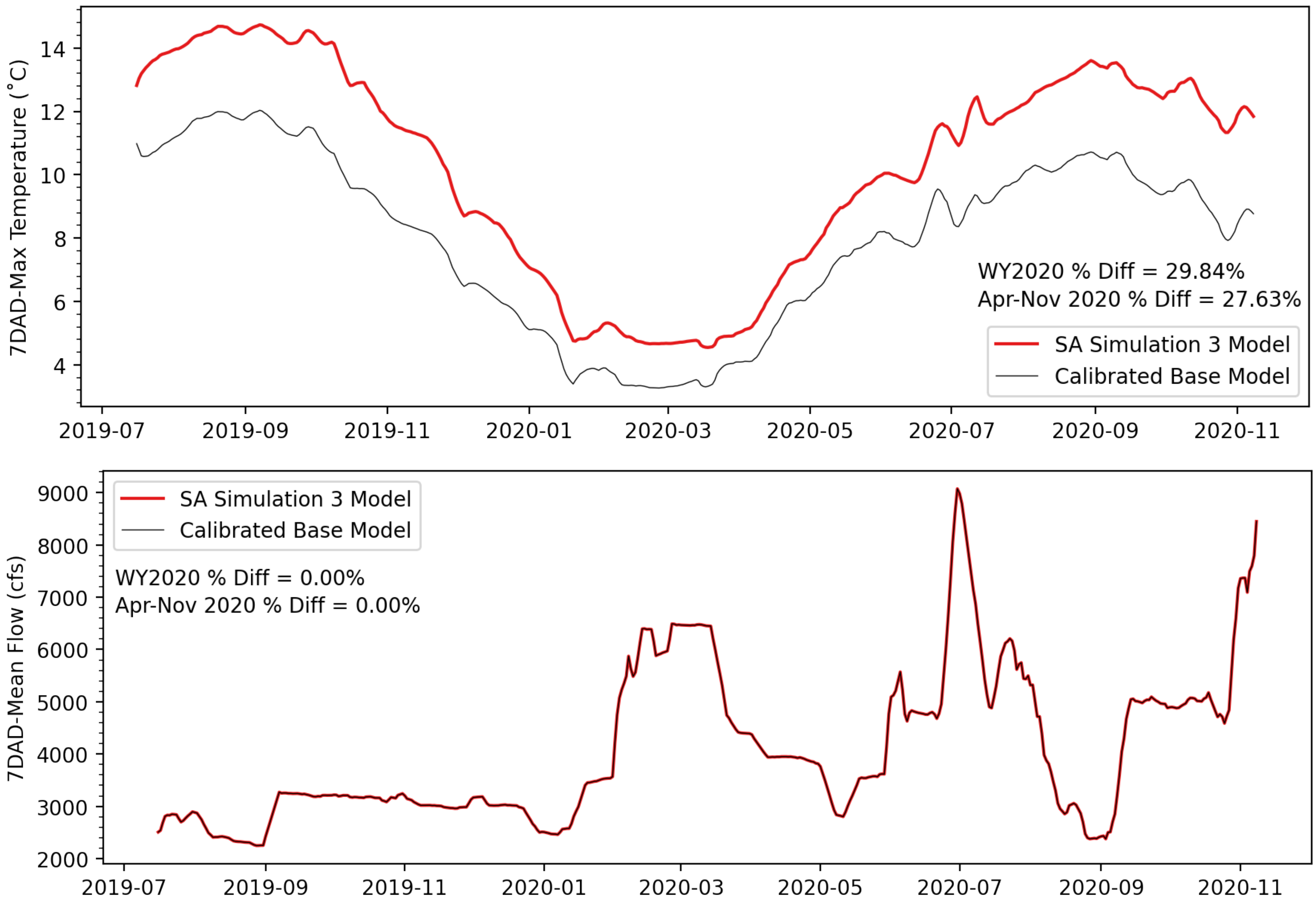


Figure C.3-6. Gorge Lake outflow 7DAD-Mean flow and max temperature variation for SA Simulation 3 (increase boundary temperatures by 20 percent).

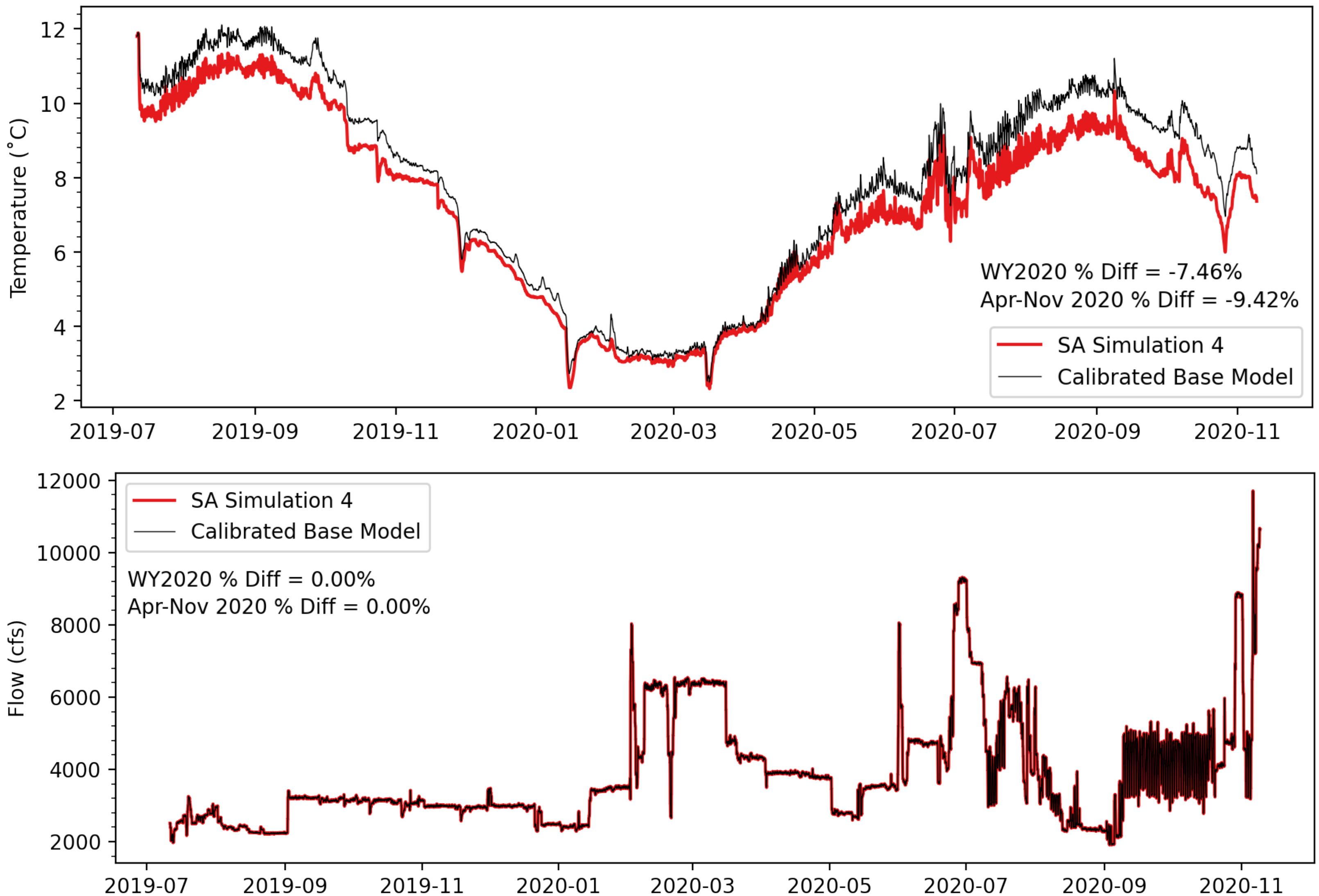


Figure C.3-7. Gorge Lake outflow continuous hourly flow and temperature variation for SA Simulation 4 (decrease boundary temperatures by 20 percent).

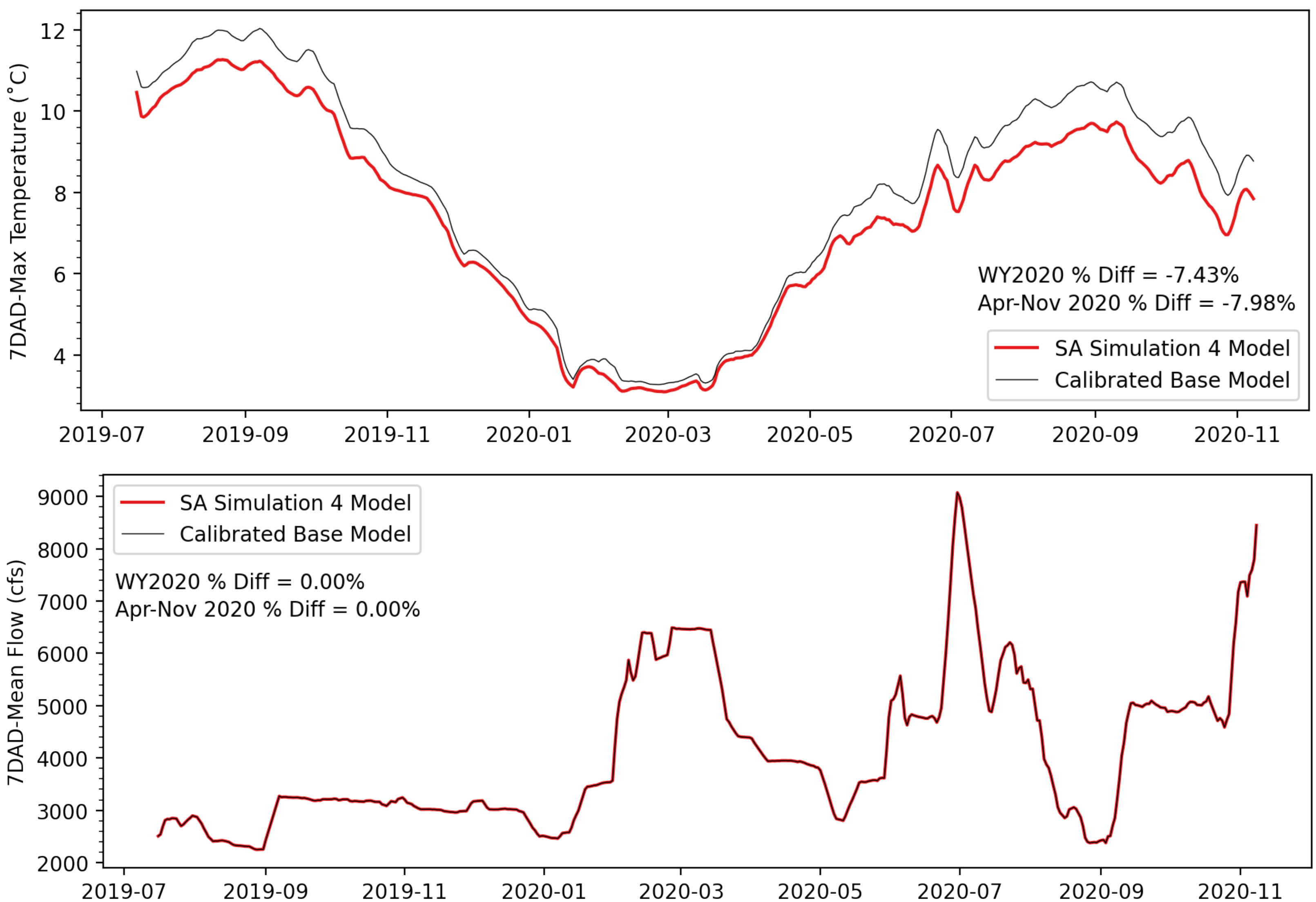


Figure C.3-8. **Gorge Lake outflow 7DAD-Mean flow and max temperature variation for SA Simulation 4 (decrease boundary temperatures by 20 percent).**

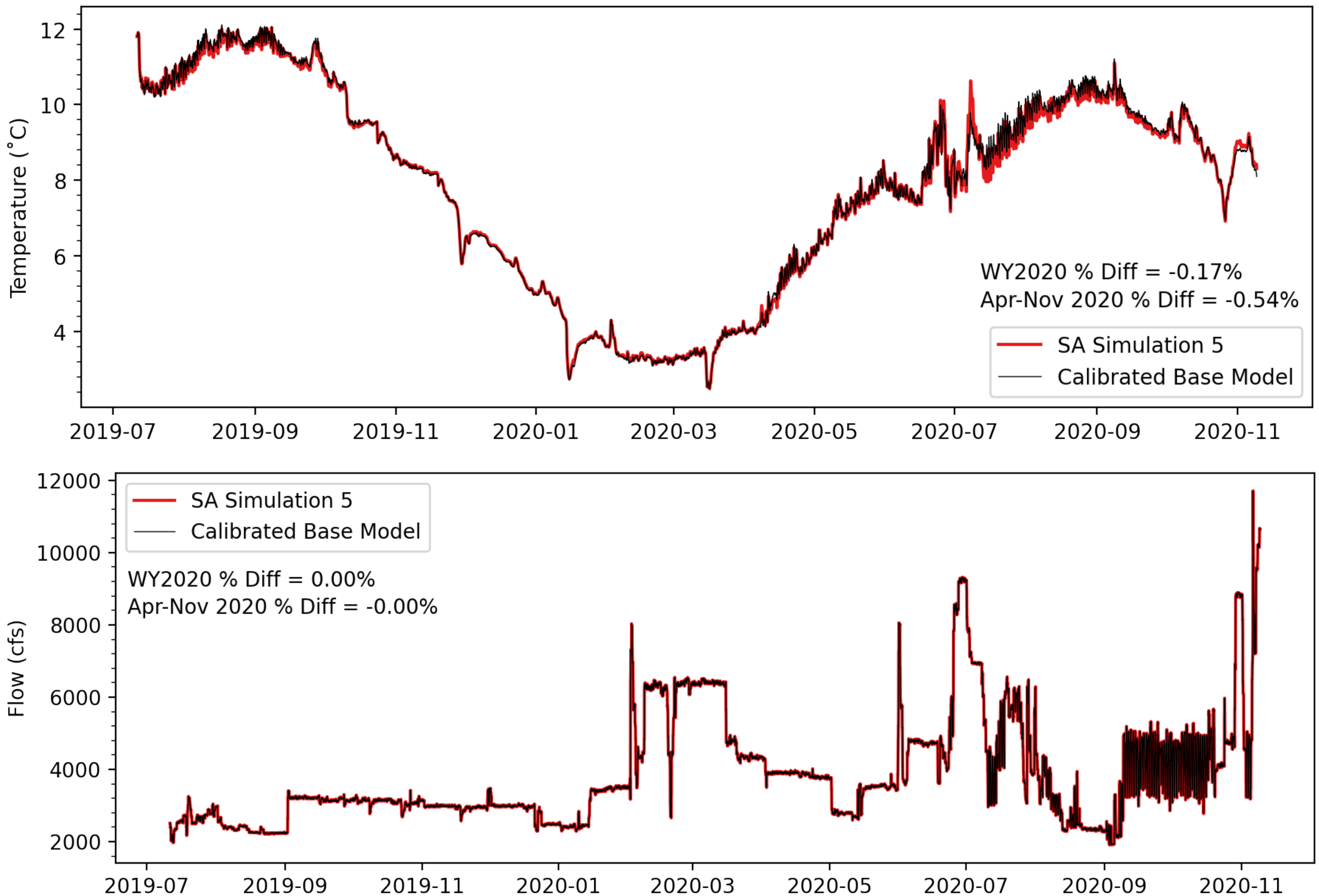


Figure C.3-9. Gorge Lake outflow continuous hourly flow and temperature variation for SA Simulation 5 (double spillway-powerhouse flow ratio).

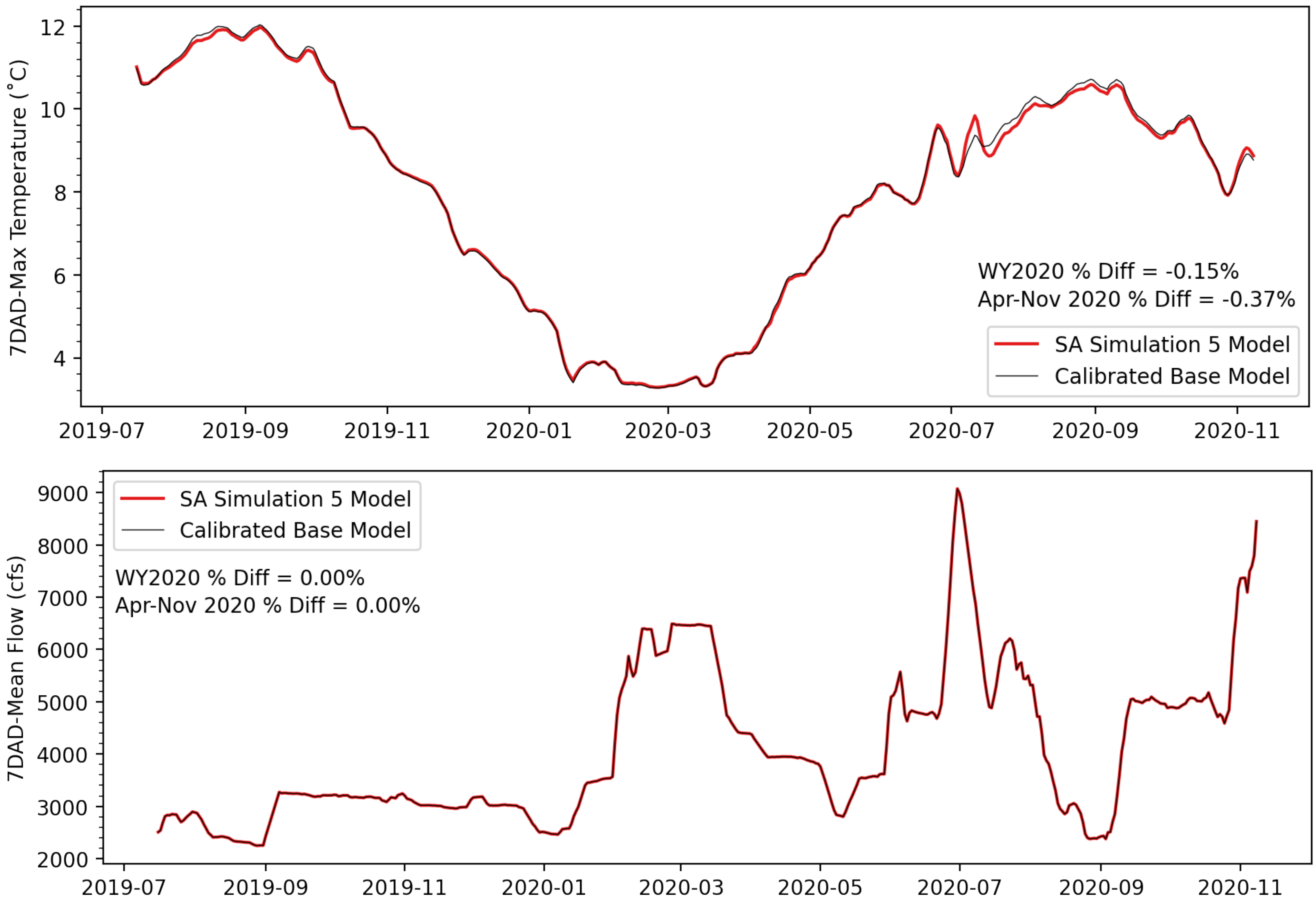


Figure C.3-10. Gorge Lake outflow 7DAD-Mean flow and max temperature variation for SA Simulation 5 (double spillway-powerhouse flow ratio).

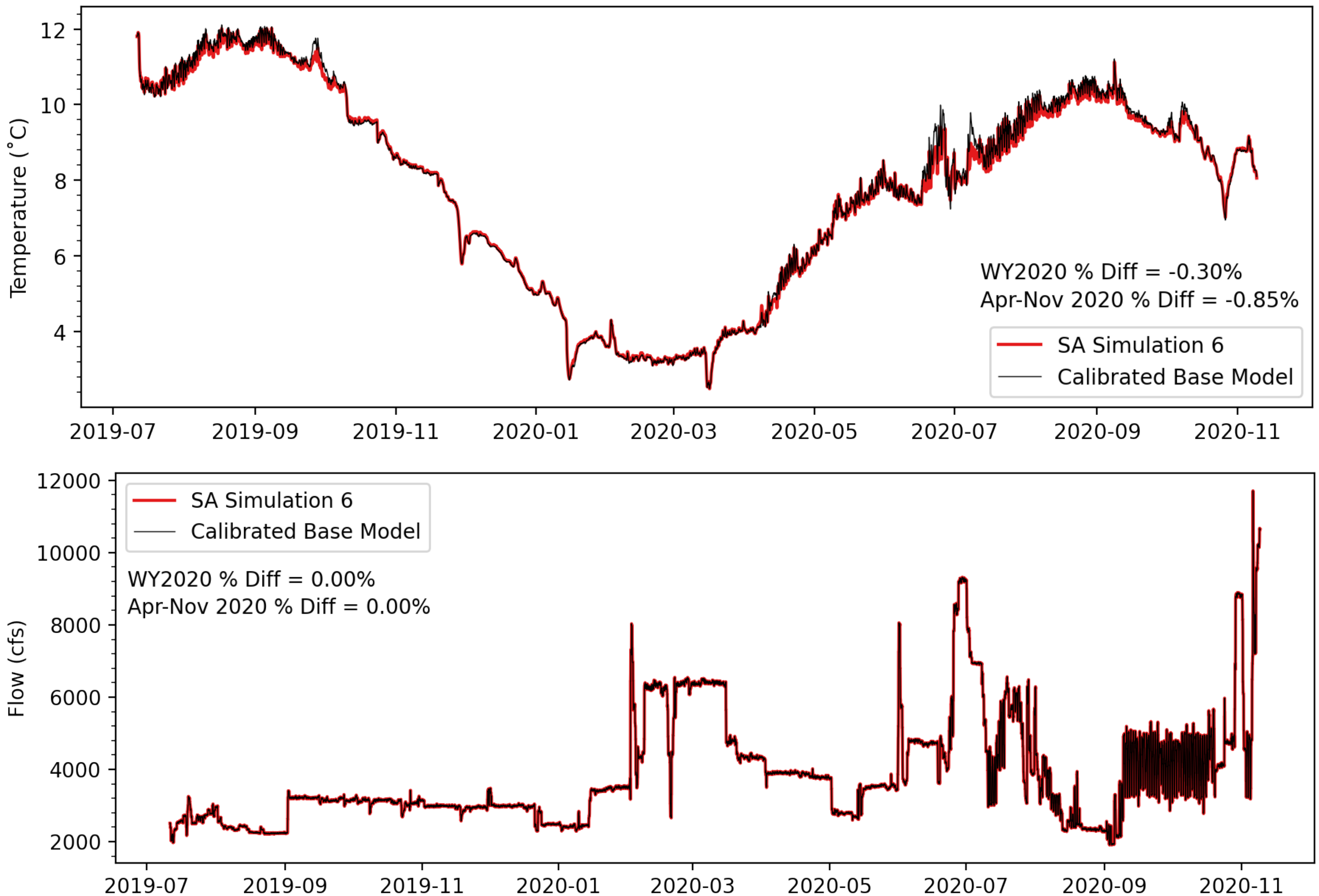
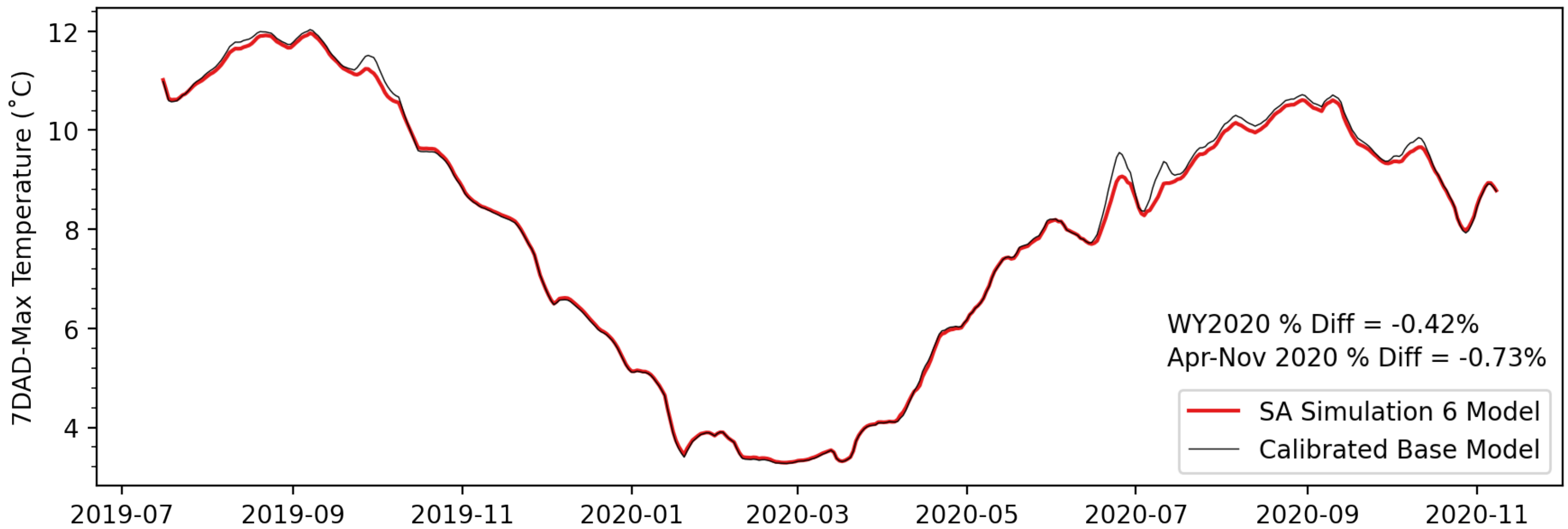


Figure C.3-11. Gorge Lake outflow continuous hourly flow and temperature variation for SA Simulation 6 (halve spillway-powerhouse flow ratio).



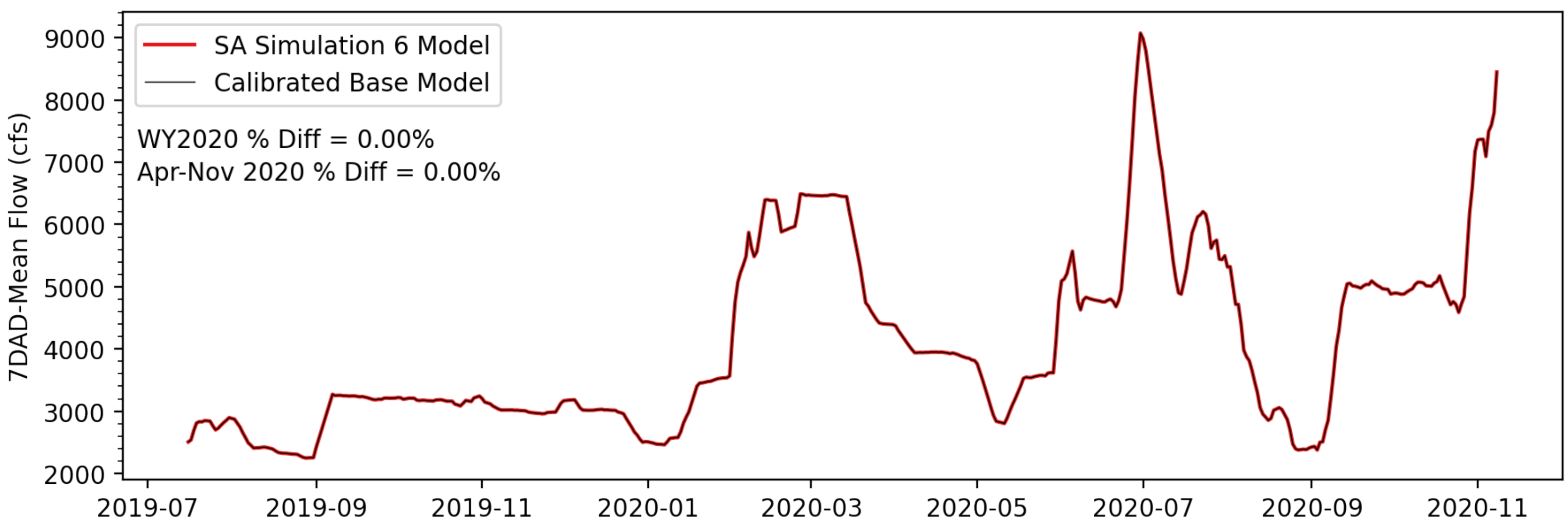


Figure C.3-12. Gorge Lake outflow 7DAD-Mean flow and max temperature variation for SA Simulation 6 (halve spillway-powerhouse flow ratio).

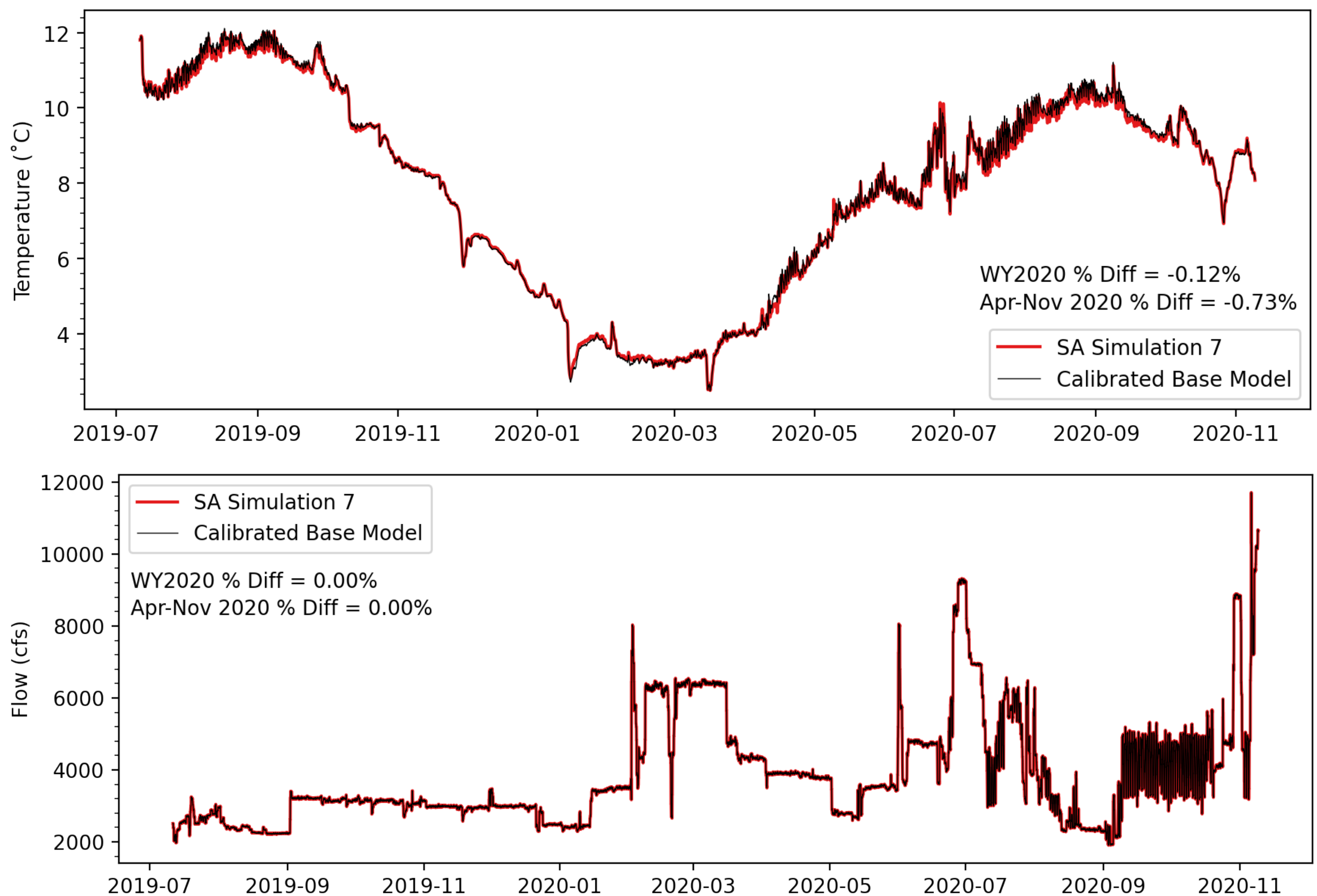


Figure C.3-13. Gorge Lake outflow continuous hourly flow and temperature variation for SA Simulation 7 (remove top 5 withdrawal layers).

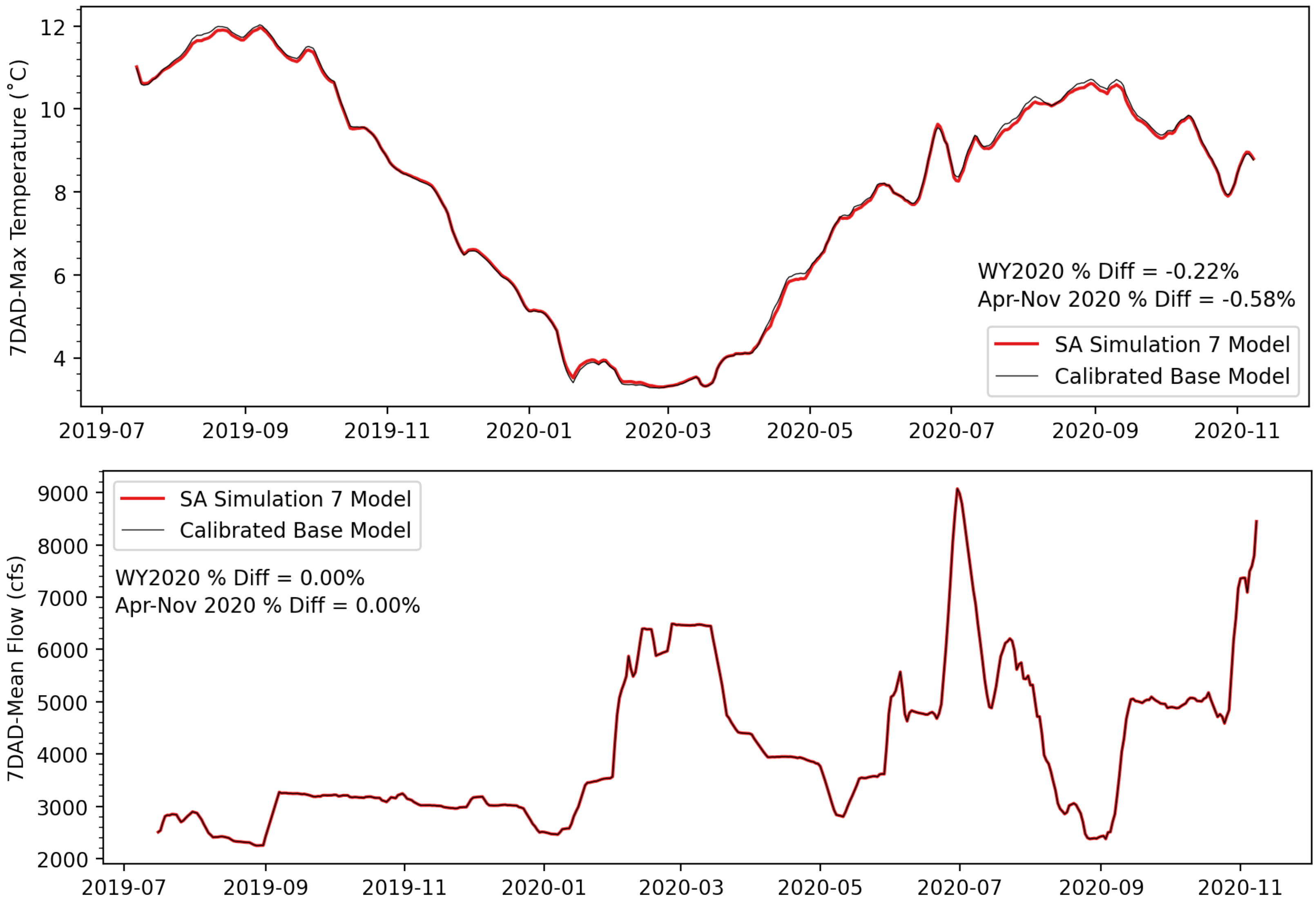


Figure C.3-14. Gorge Lake outflow 7DAD-Mean flow and max temperature variation for SA Simulation 7 (remove top 5 withdrawal layers).

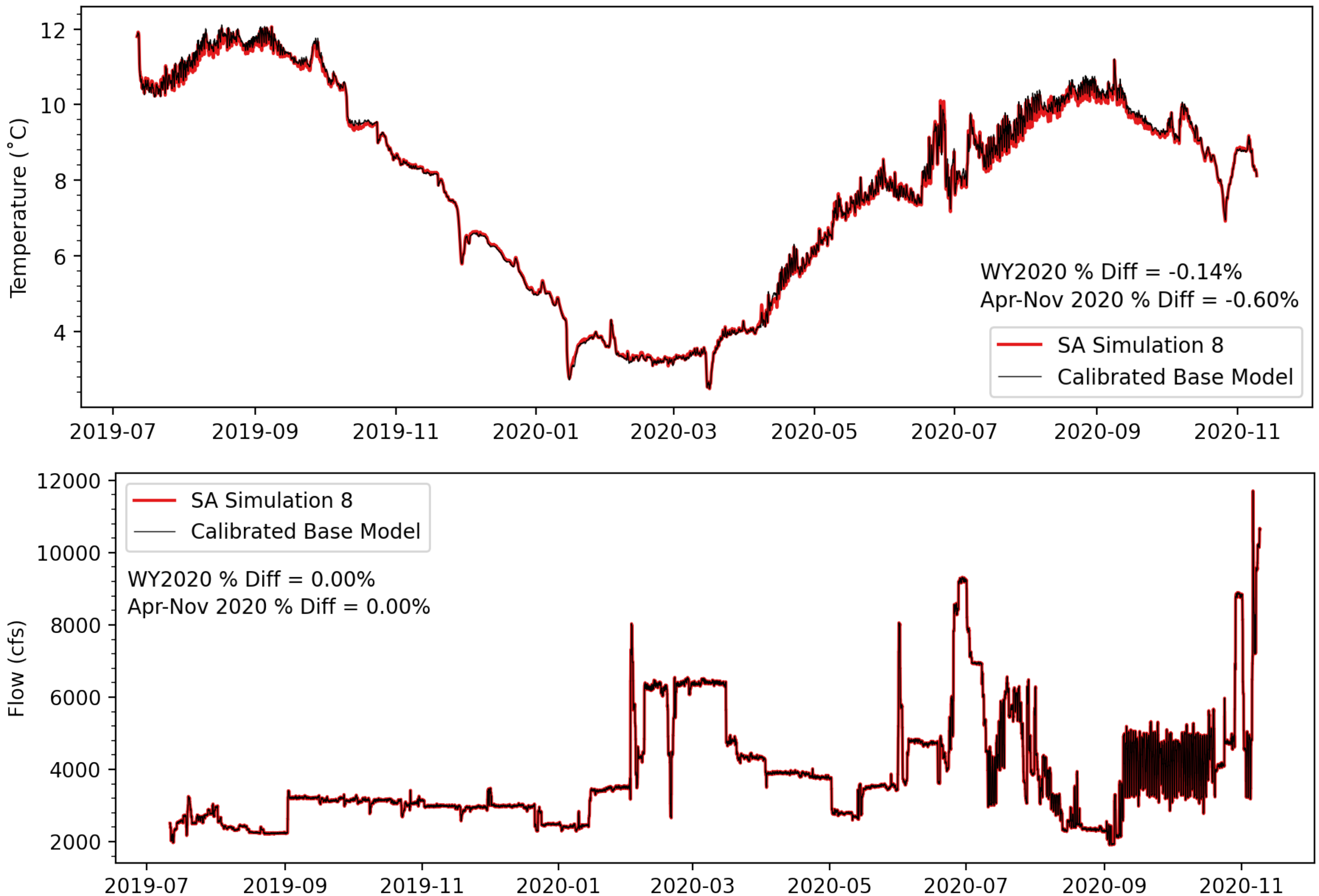


Figure C.3-15. Gorge Lake outflow continuous hourly flow and temperature variation for SA Simulation 8 (remove bottom 5 withdrawal layers).

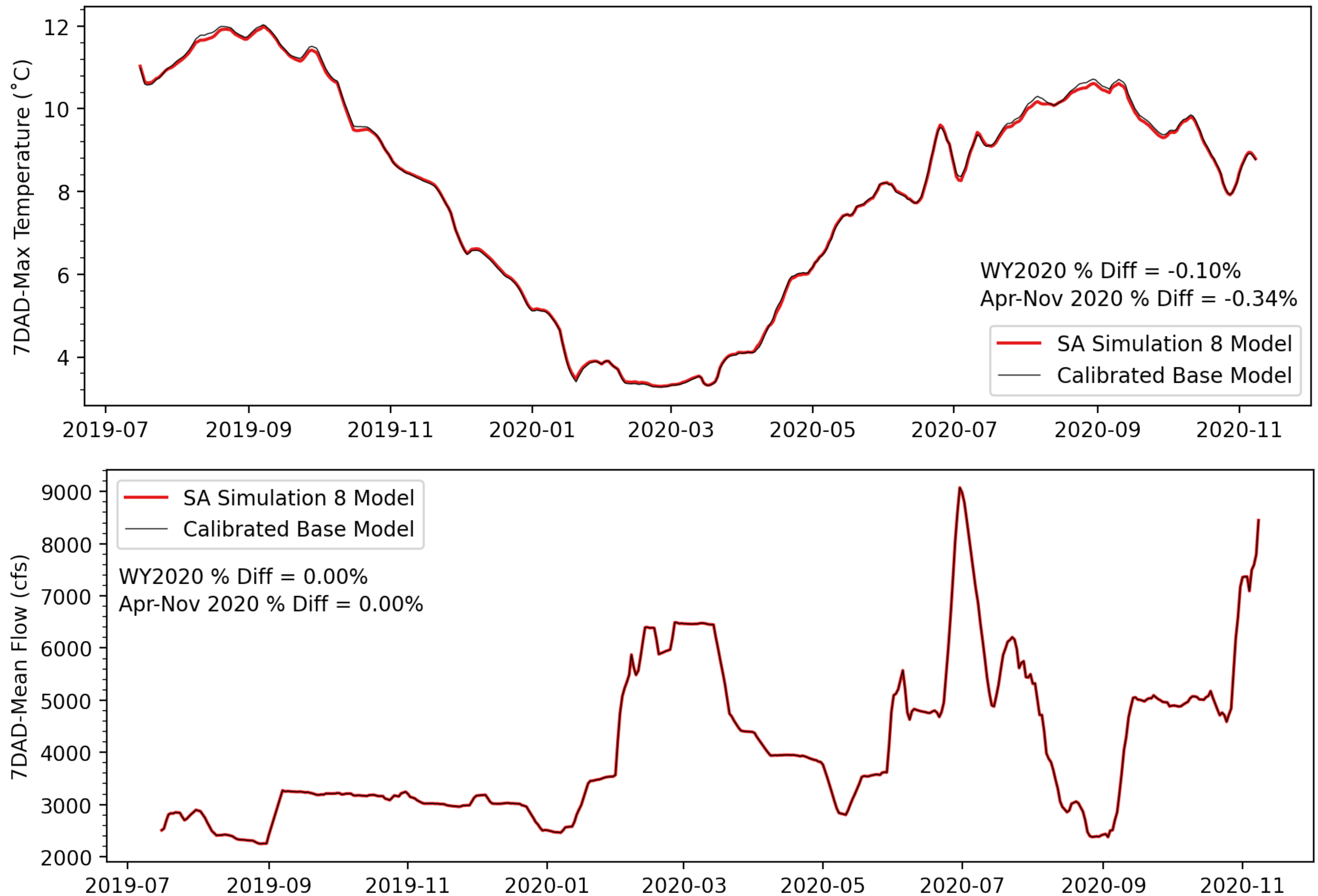


Figure C.3-16. Gorge Lake outflow 7DAD-Mean flow and max temperature variation for SA Simulation 8 (remove bottom 5 withdrawal layers).

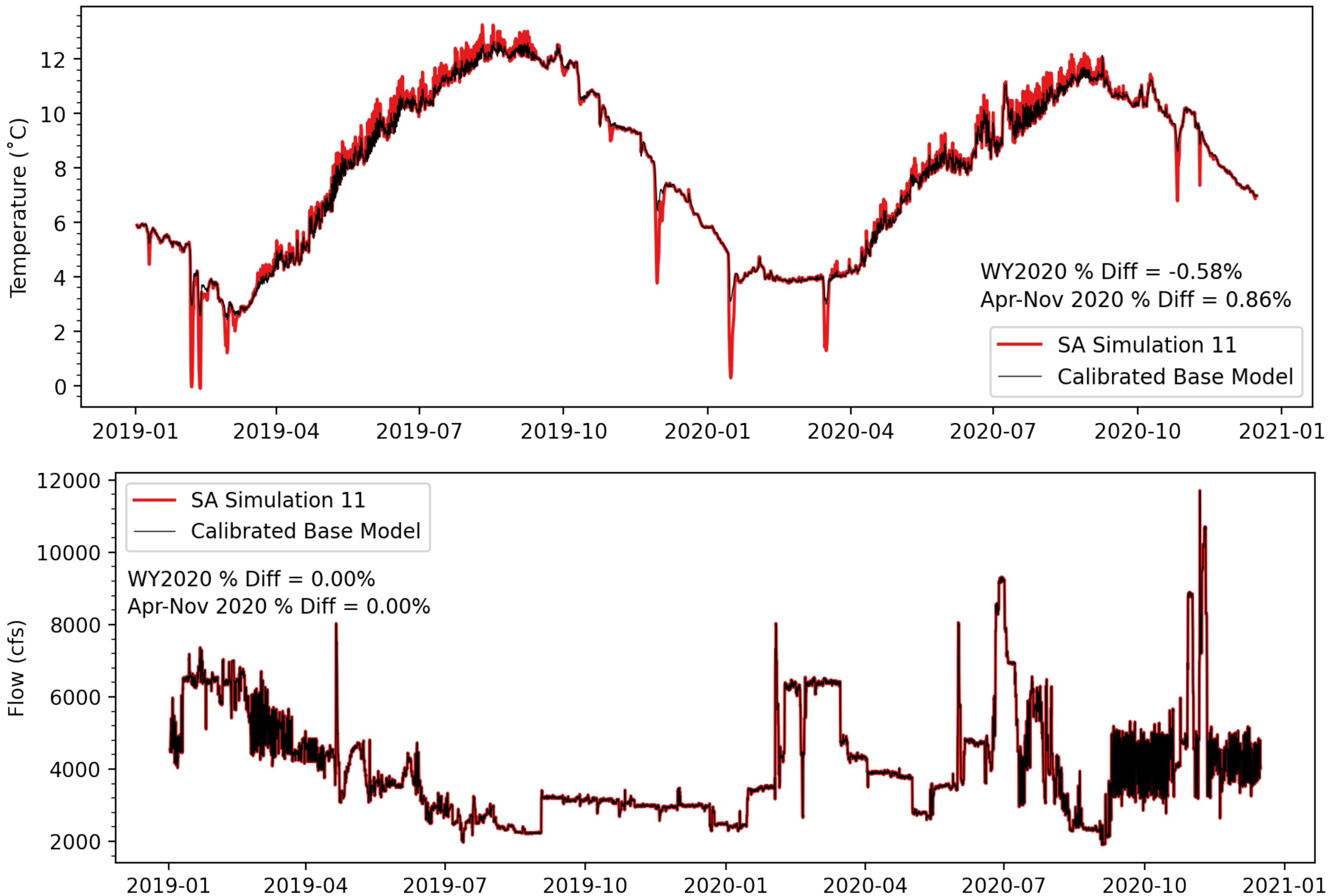


Figure C.3-17. Gorge Lake outflow continuous hourly flow and temperature variation for SA Simulation 11 (double wind sheltering coefficient).

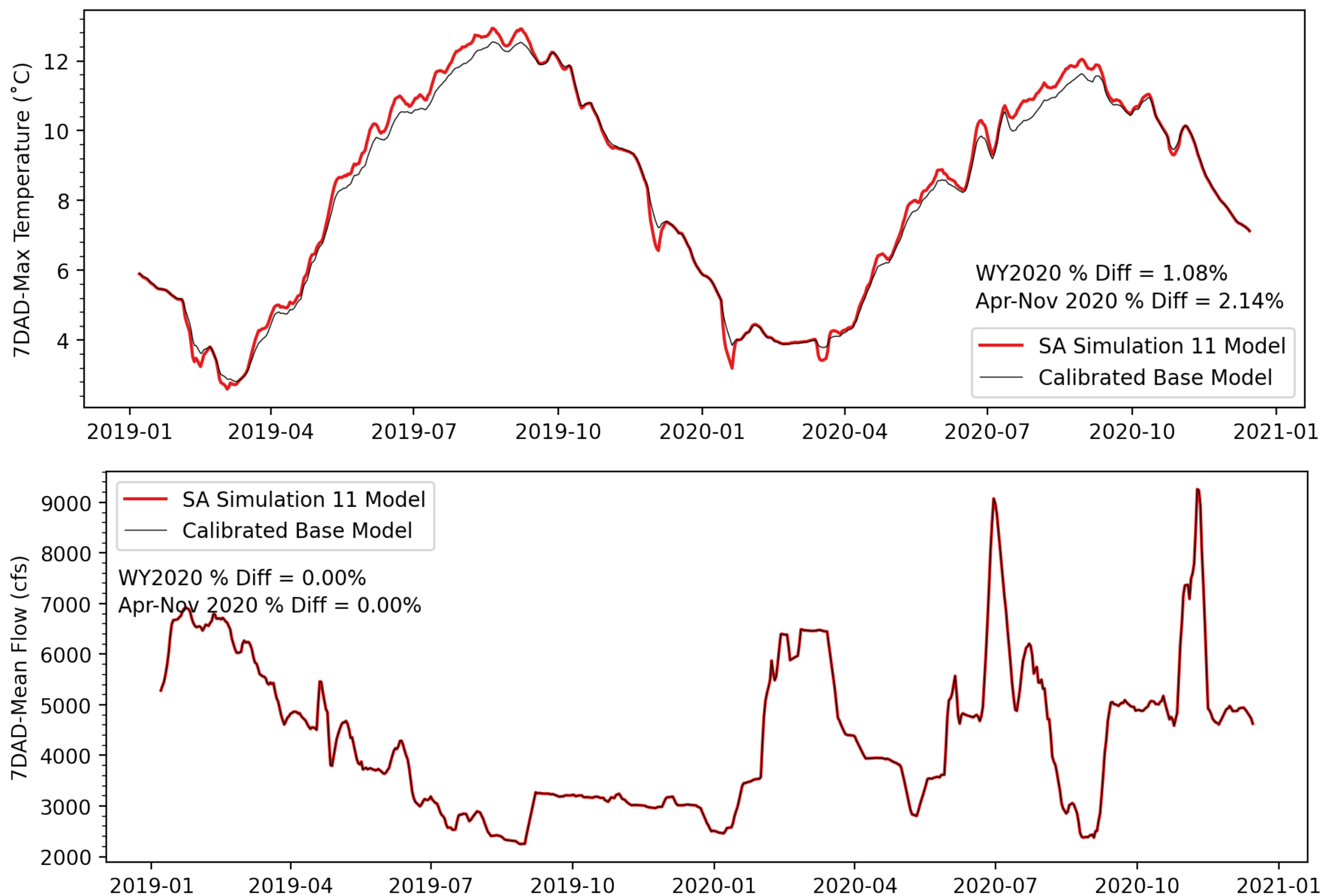


Figure C.3-18. Gorge Lake outflow 7DAD-Mean flow and max temperature variation for SA Simulation 11 (double wind sheltering coefficient).

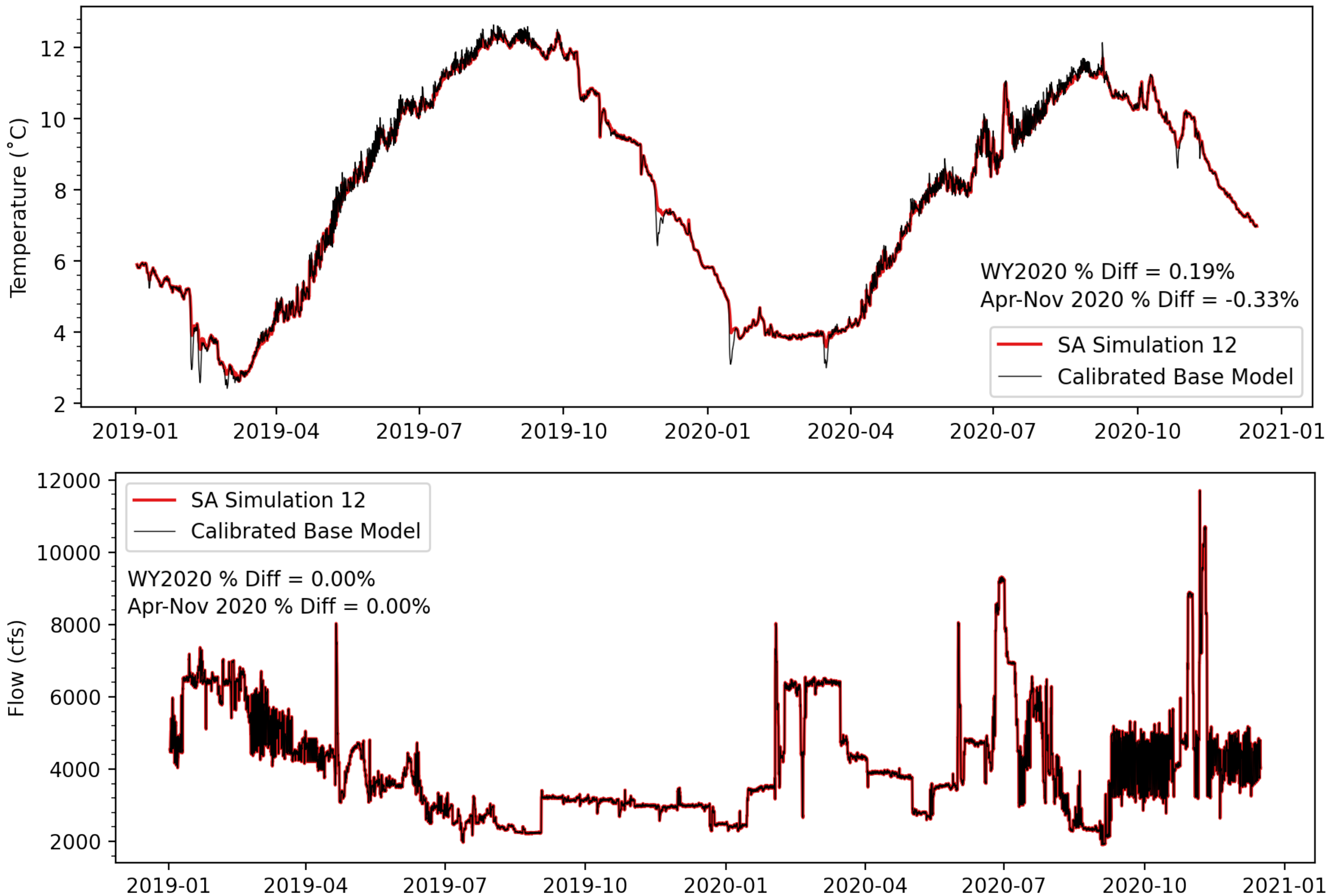


Figure C.3-19. Gorge Lake outflow continuous hourly flow and temperature variation for SA Simulation 12 (halve wind sheltering coefficient).

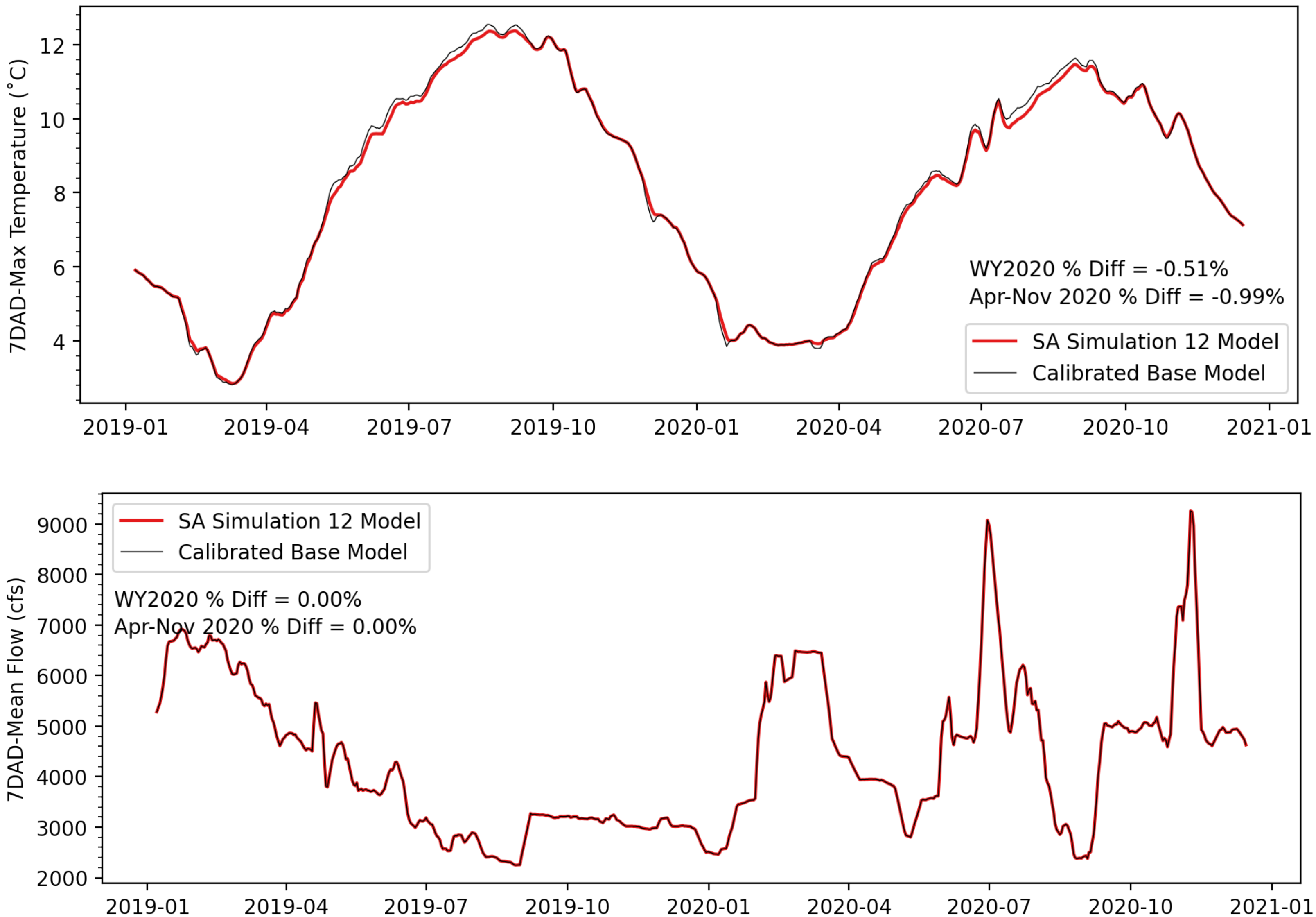


Figure C.3-20. Gorge Lake outflow 7DAD-Mean flow and max temperature variation for SA Simulation 12 (halve wind sheltering coefficient).

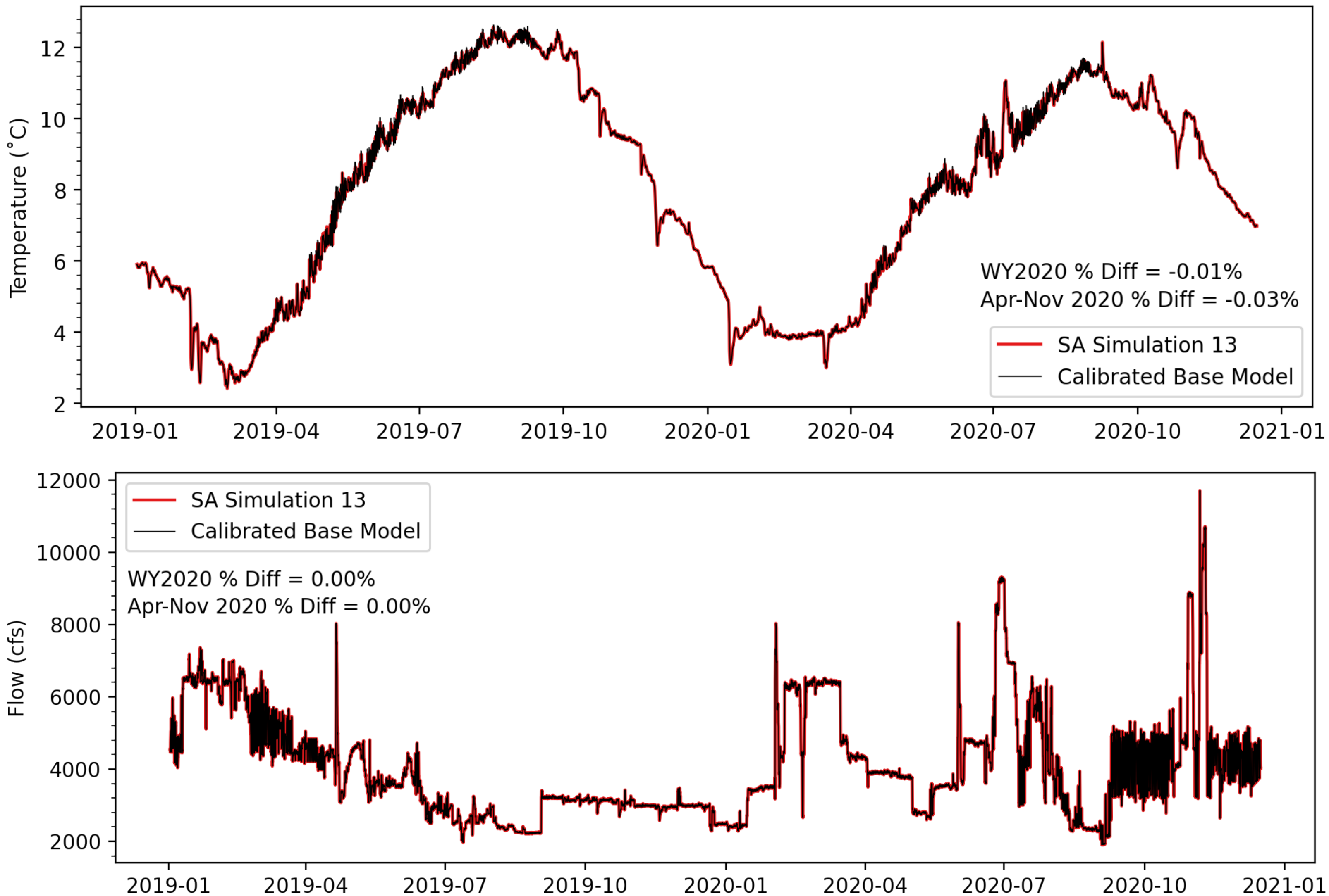


Figure C.3-21. Gorge Lake outflow continuous hourly flow and temperature variation for SA Simulation 13 (rotate wind direction 90 degrees counter-clockwise).

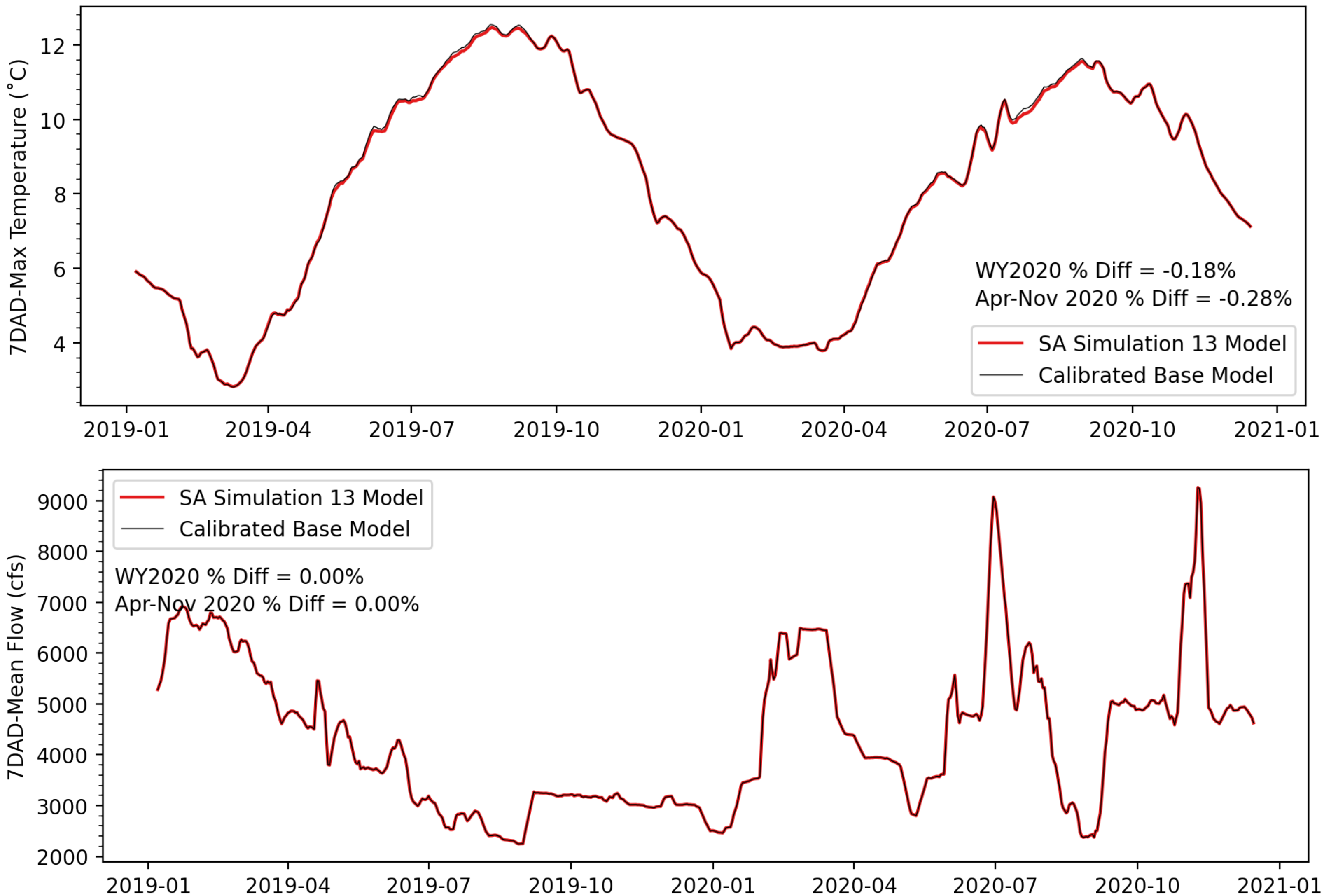


Figure C.3-22. Gorge Lake outflow 7DAD-Mean flow and max temperature variation for SA Simulation 13 (rotate wind direction 90 degrees counter-clockwise).

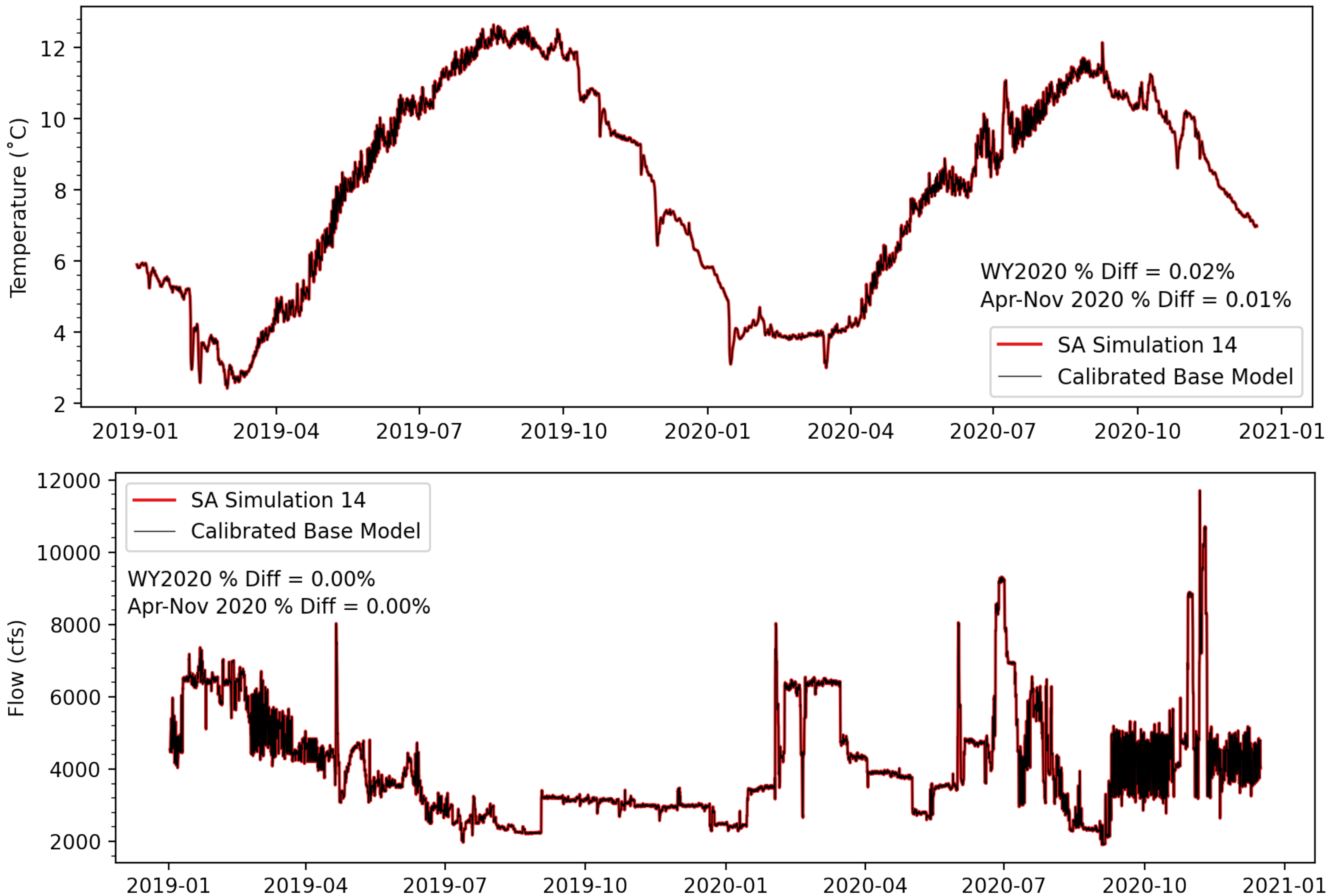


Figure C.3-23. Gorge Lake outflow continuous hourly flow and temperature variation for SA Simulation 14 (increase sediment temperature by 25 percent).

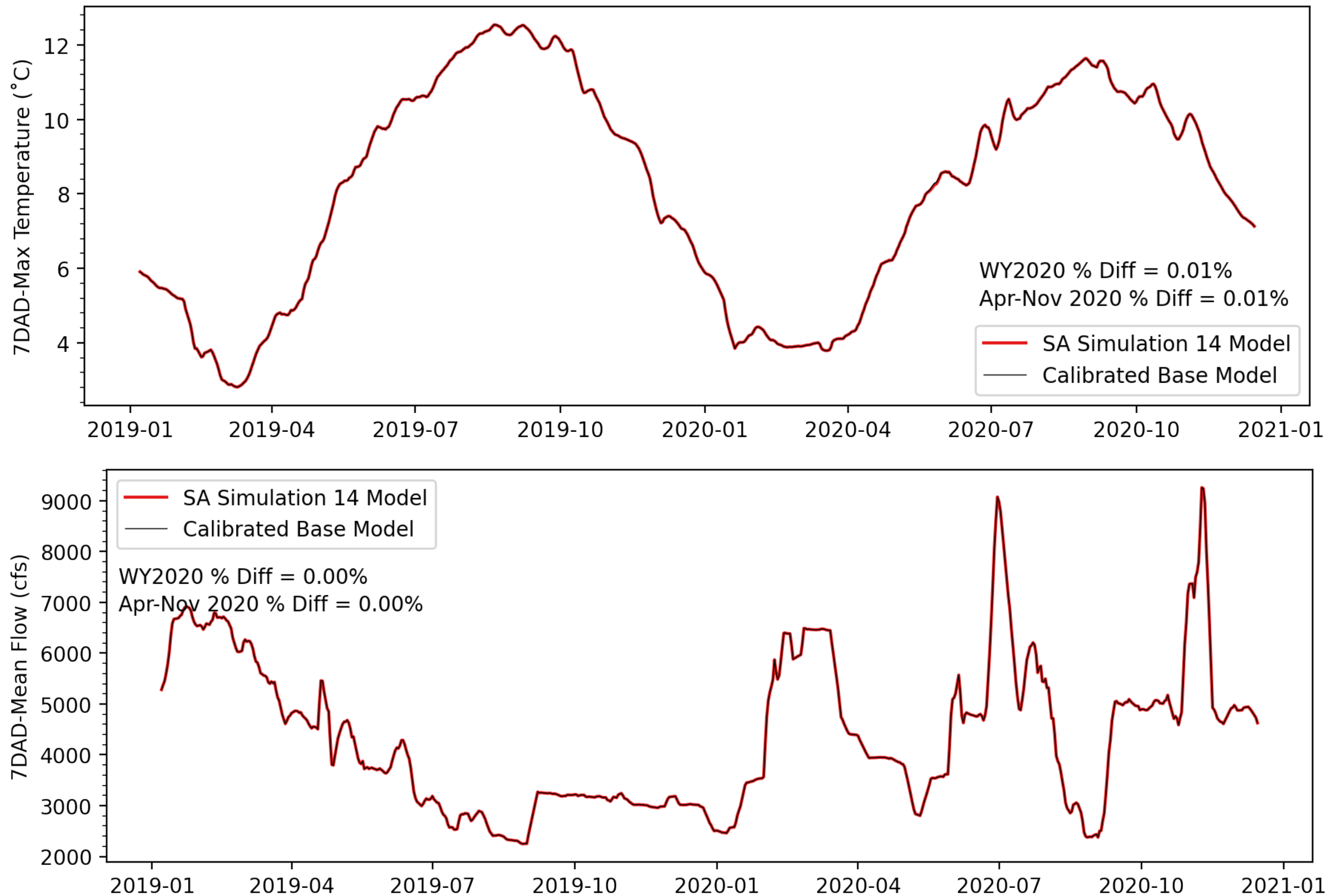


Figure C.3-24. Gorge Lake outflow 7DAD-Mean flow and max temperature variation for SA Simulation 14 (increase sediment temperature by 25 percent).

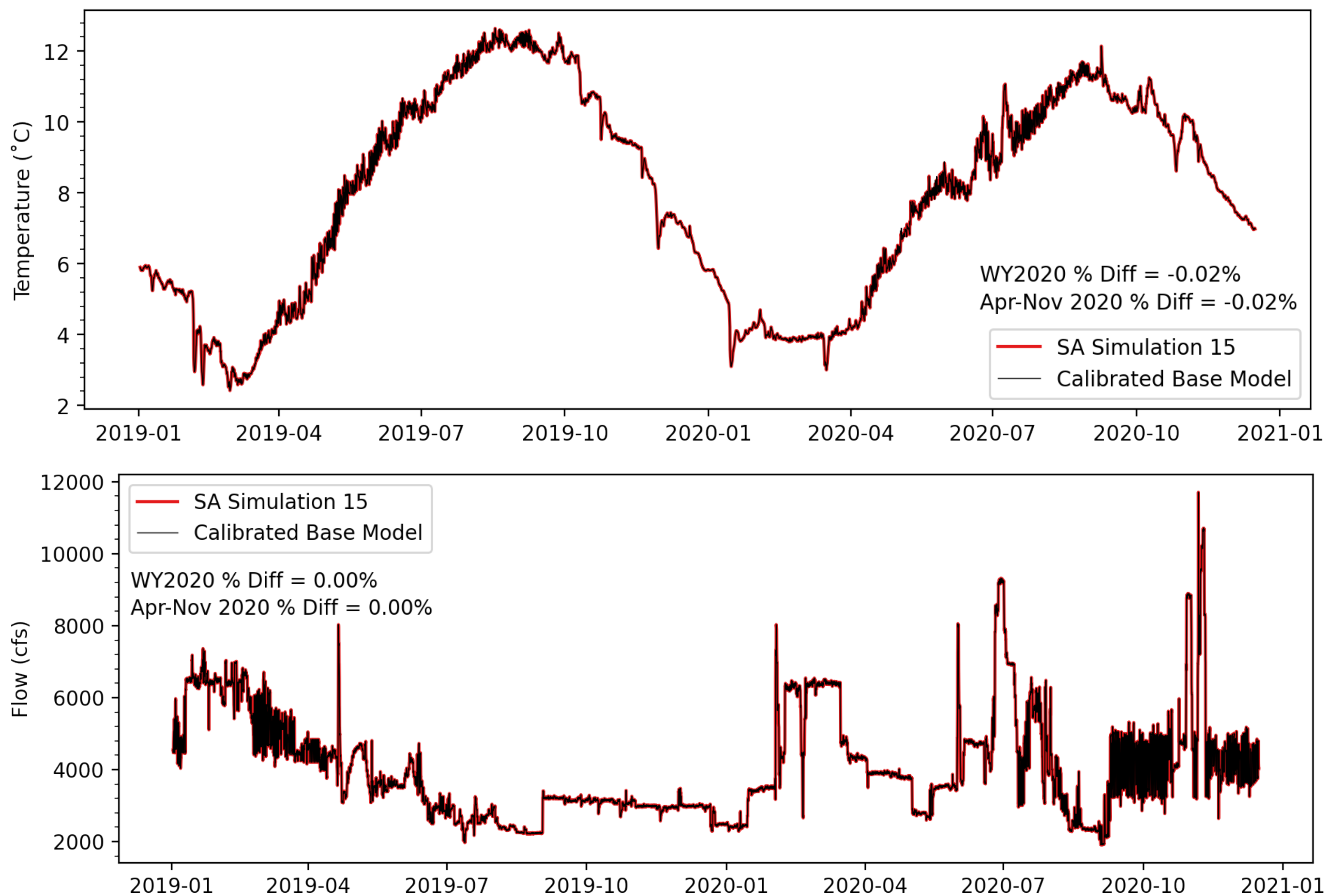


Figure C.3-25. Gorge Lake outflow continuous hourly flow and temperature variation for SA Simulation 15 (decrease sediment temperature by 25 percent.

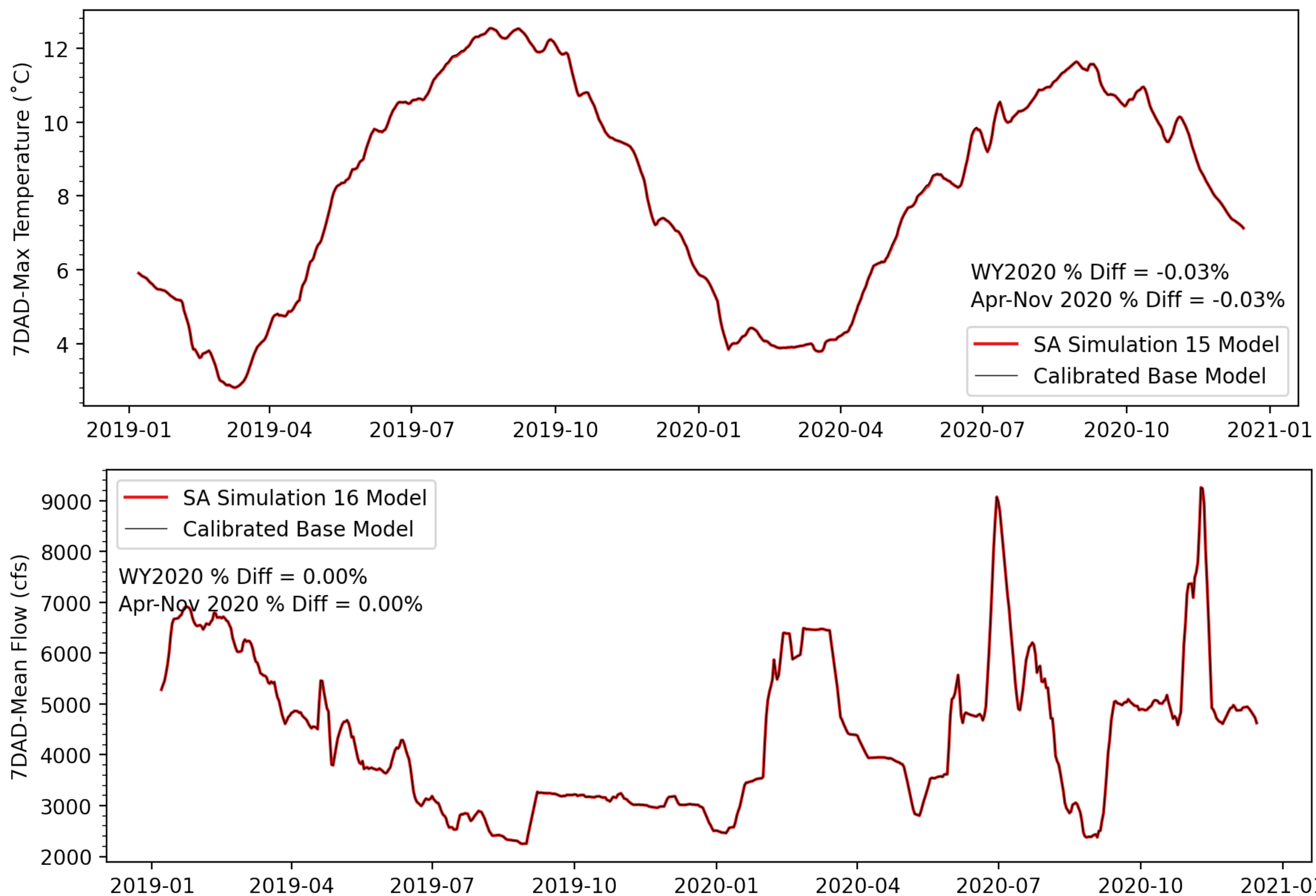


Figure C.3-26. Gorge Lake outflow 7DAD-Mean flow and max temperature variation for SA Simulation 15 (decrease sediment temperature by 25 percent).

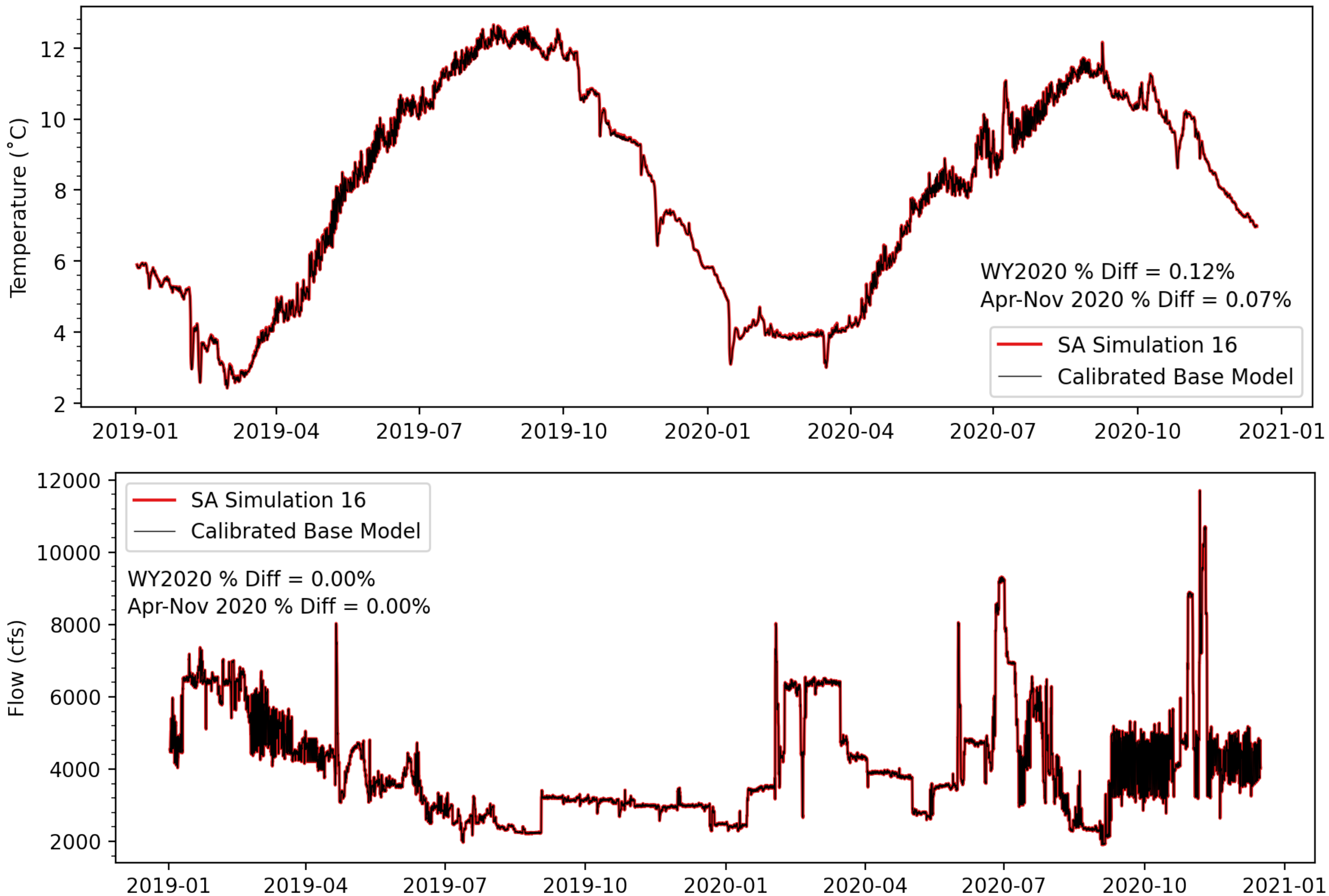
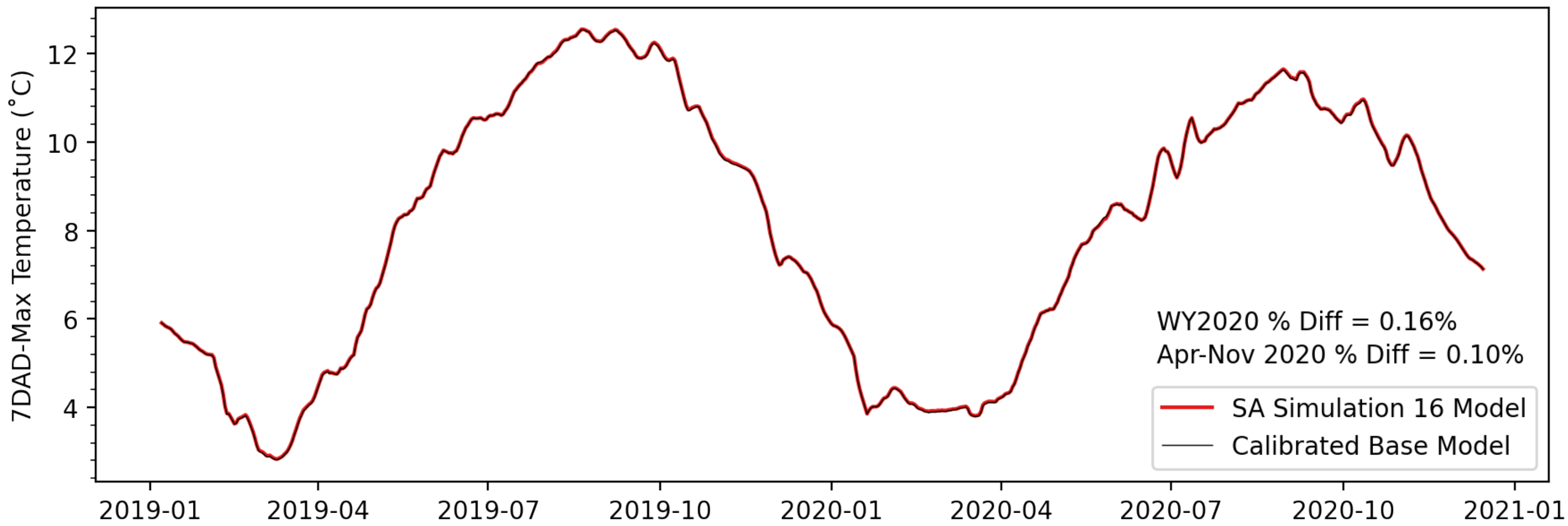


Figure C.3-27. Gorge Lake outflow continuous hourly flow and temperature variation for SA Simulation 16 (eliminate vegetative shade).



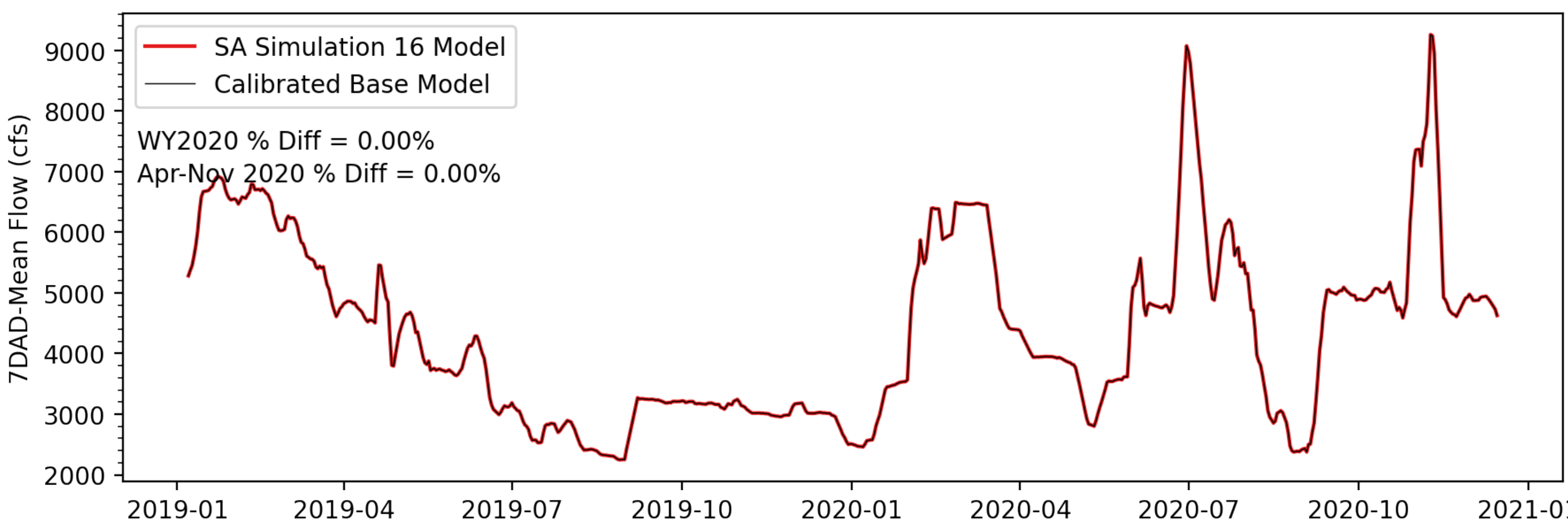


Figure C.3-28. Gorge Lake outflow 7DAD-Mean flow and max temperature variation for SA Simulation 16 (eliminate vegetative shade).

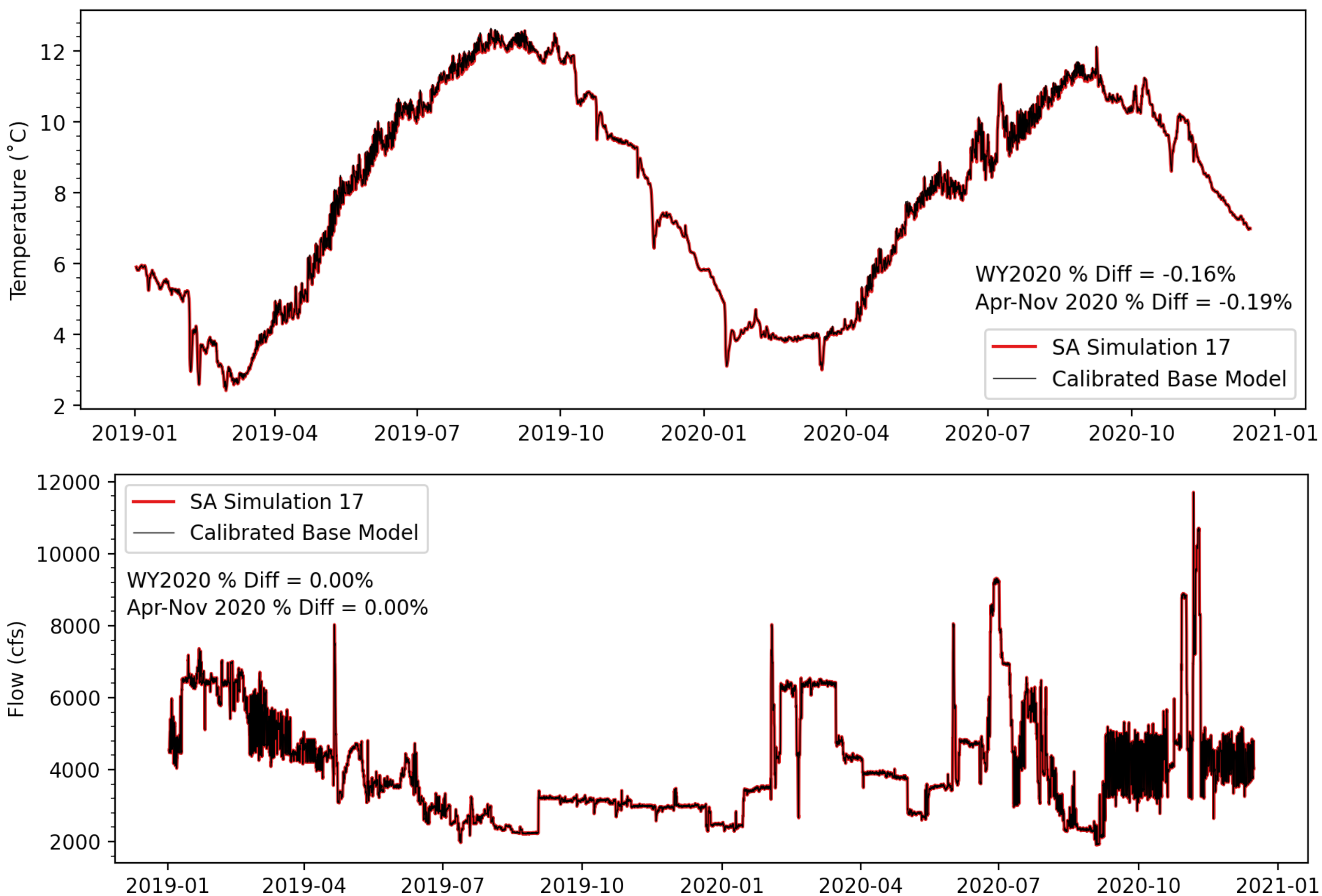


Figure C.3-29. Gorge Lake outflow continuous hourly flow and temperature variation for SA Simulation 17 (set sediment heat exchange coefficient to 0).

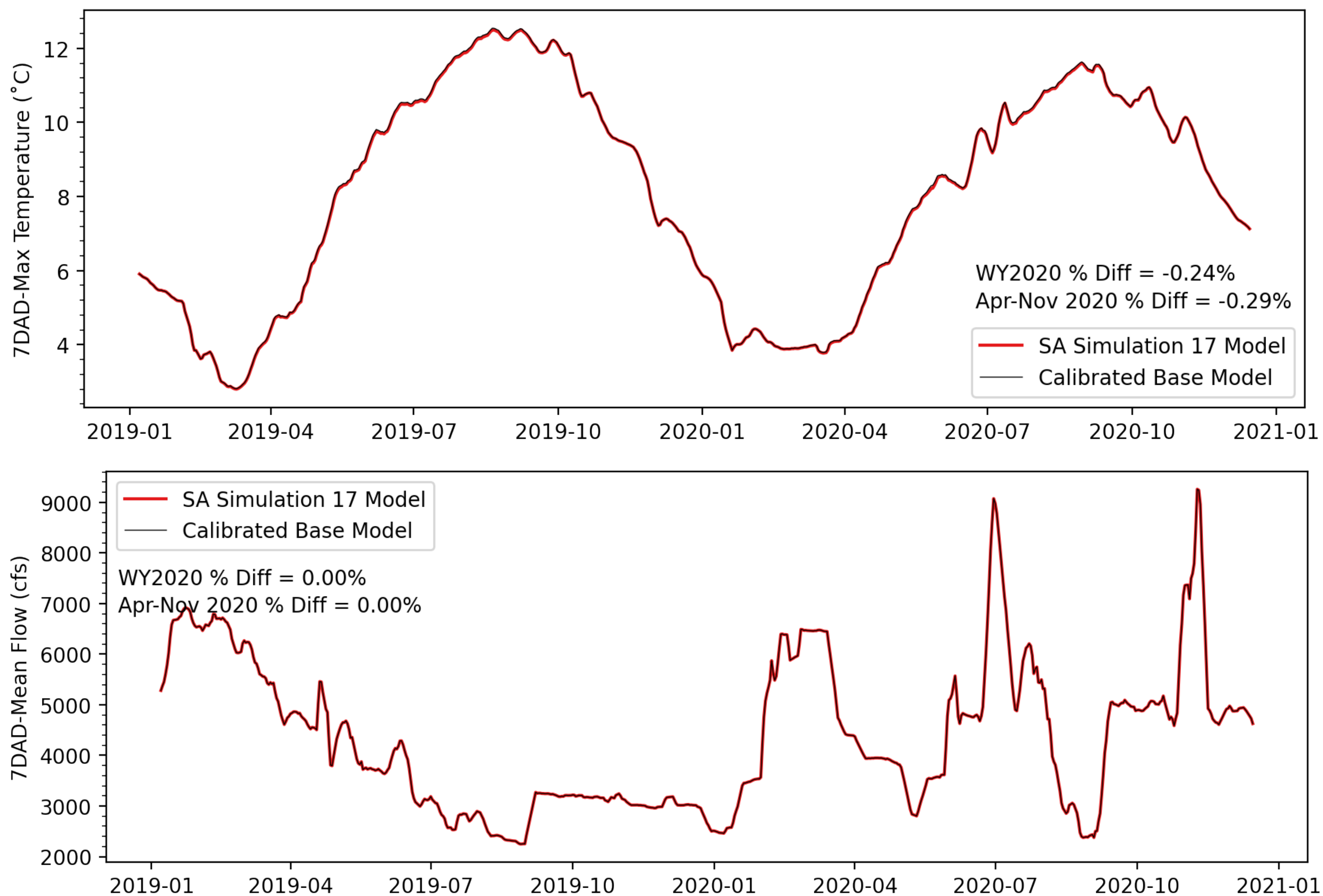


Figure C.3-30. Gorge Lake outflow 7DAD-Mean flow and max temperature variation for SA Simulation 17 (set sediment heat exchange coefficient to 0).

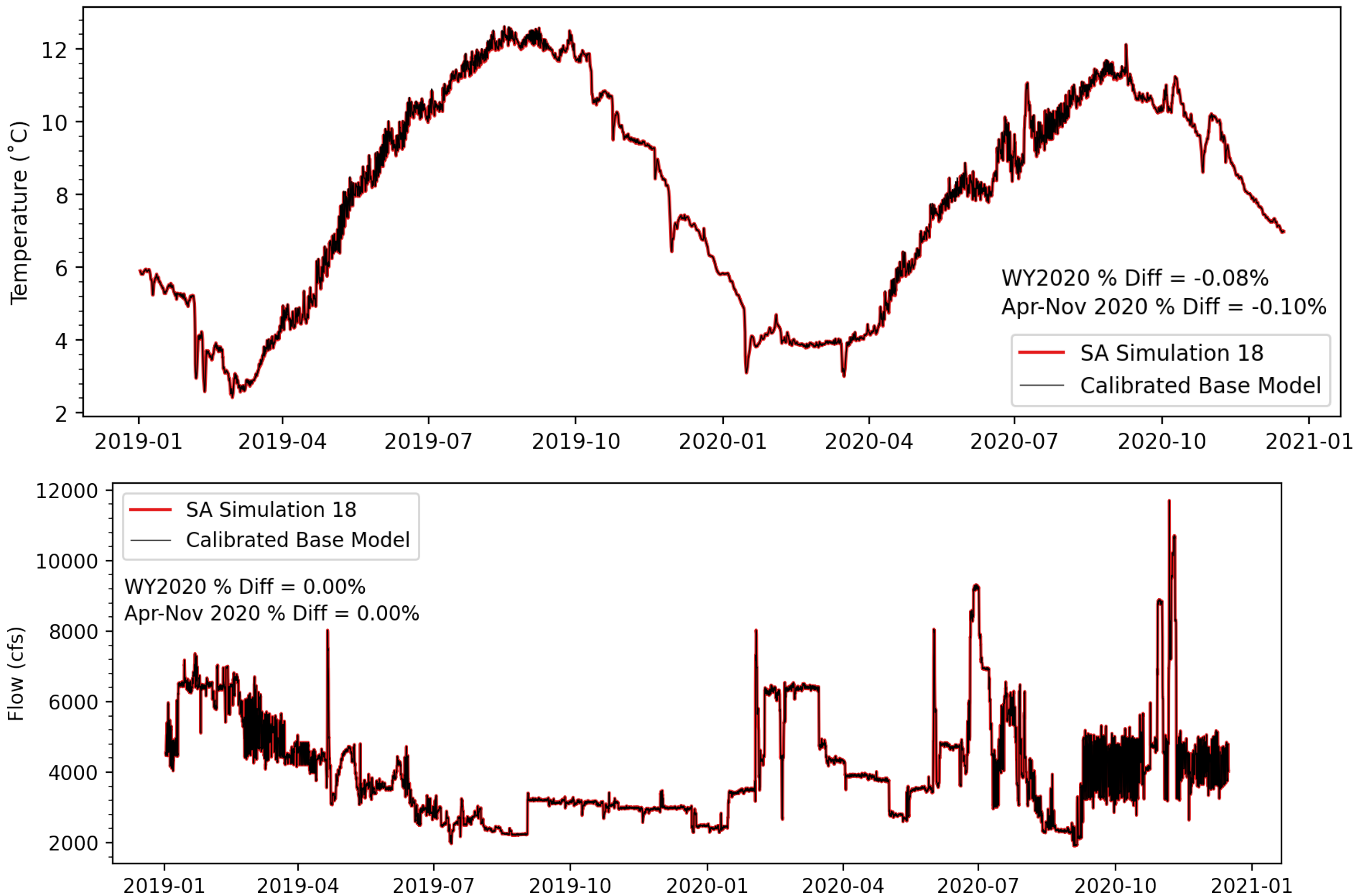


Figure C.3-31. Gorge Lake outflow continuous hourly flow and temperature variation for SA Simulation 18 (set sediment heat exchange coefficient to 0.5).

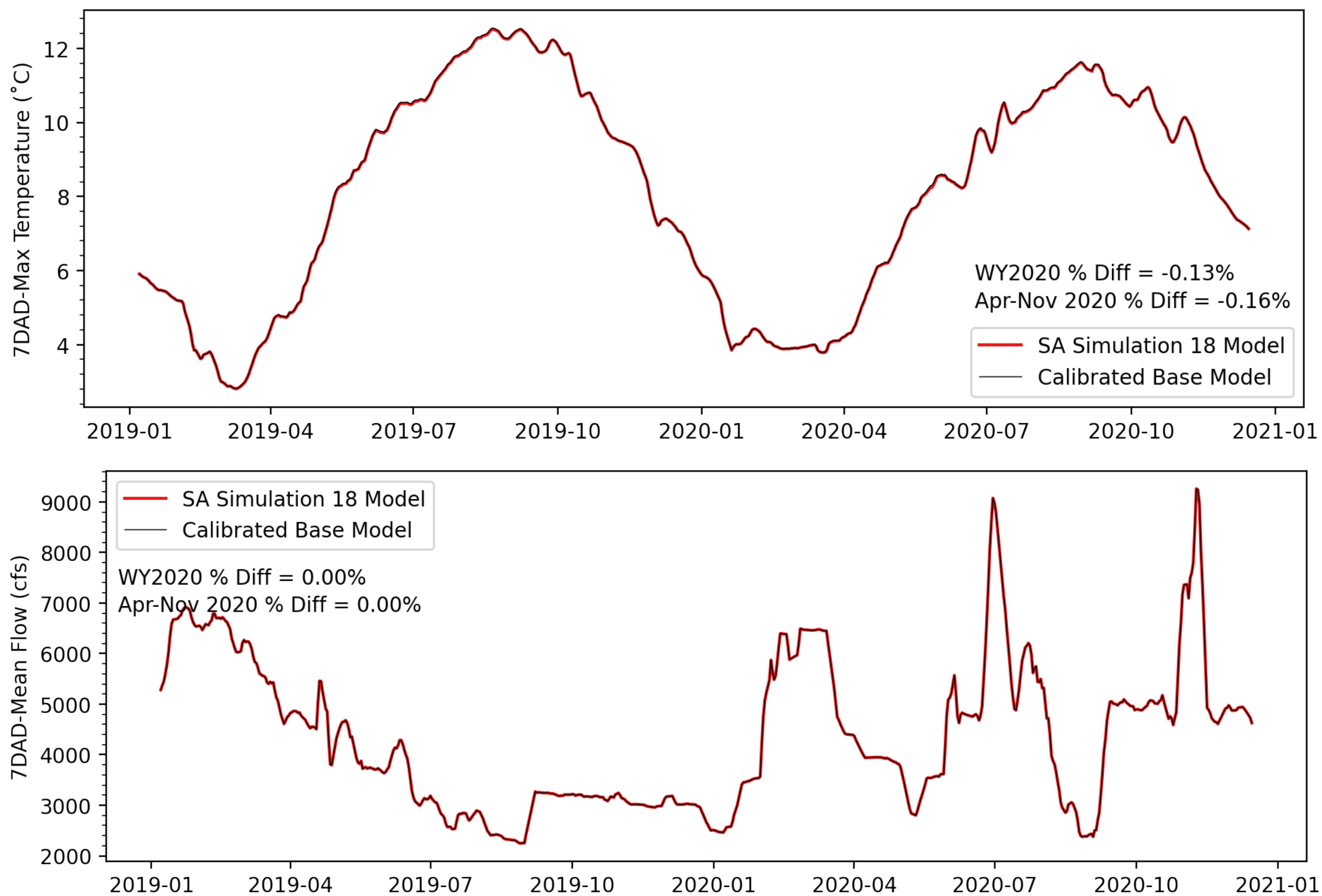


Figure C.3-32. Gorge Lake outflow 7DAD-Mean flow and max temperature variation for SA Simulation 18 (set sediment heat exchange coefficient to 0.5).

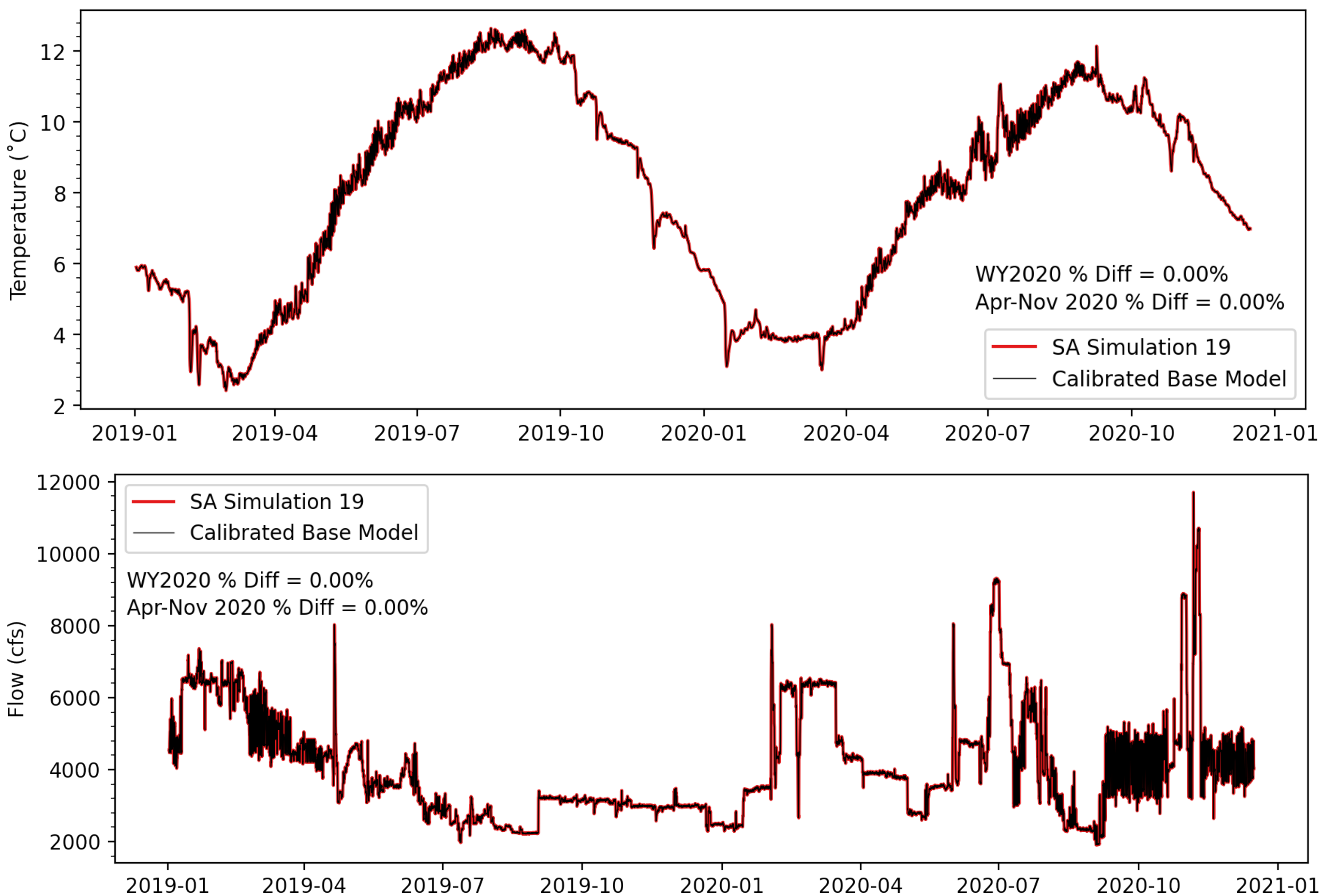


Figure C.3-33. **Gorge Lake outflow continuous hourly flow and temperature variation for SA Simulation 19 (set sediment heat exchange coefficient to 1.0).**

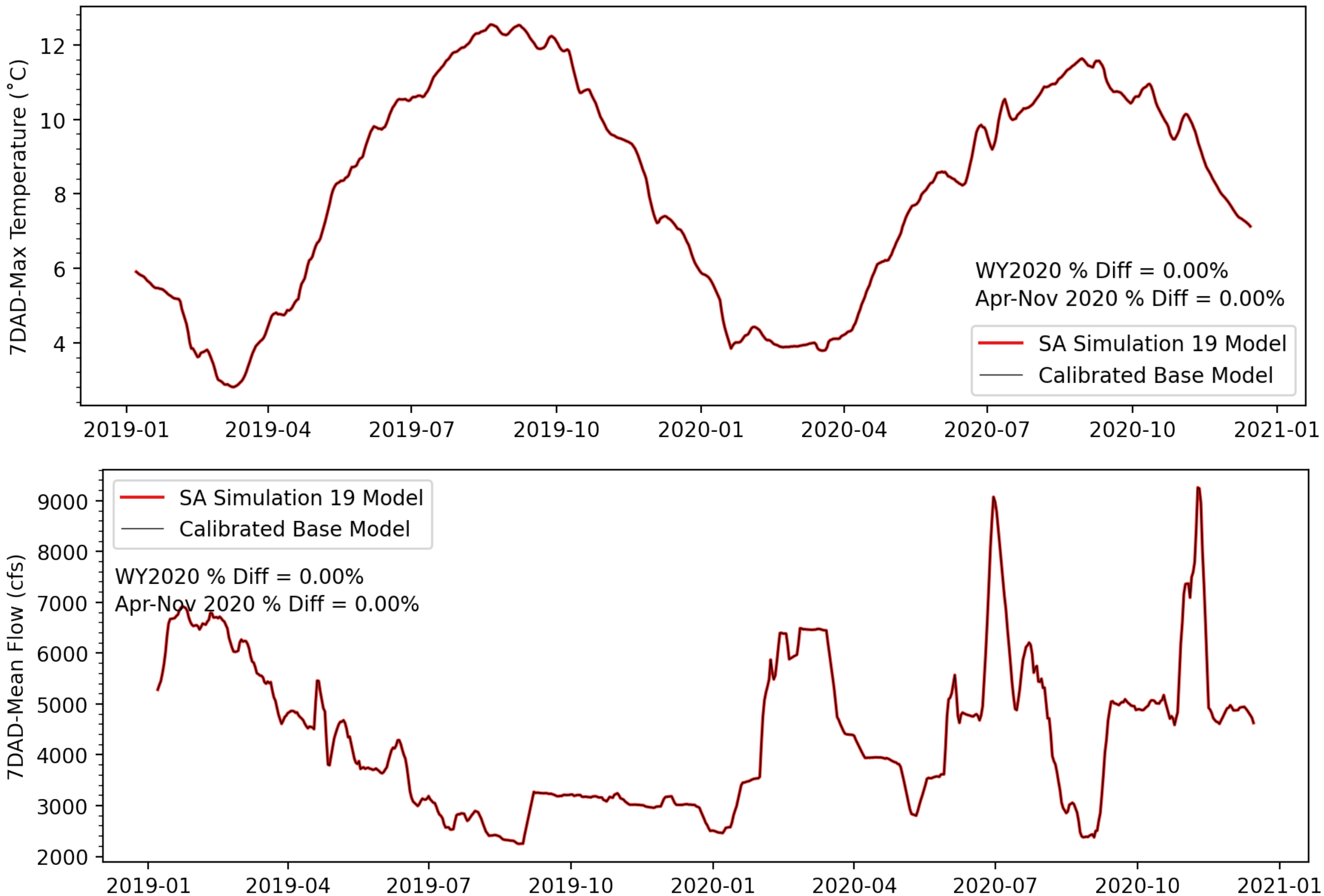


Figure C.3-34. Gorge Lake outflow 7DAD-Mean flow and max temperature variation for SA Simulation 19 (set sediment heat exchange coefficient to 1.0).

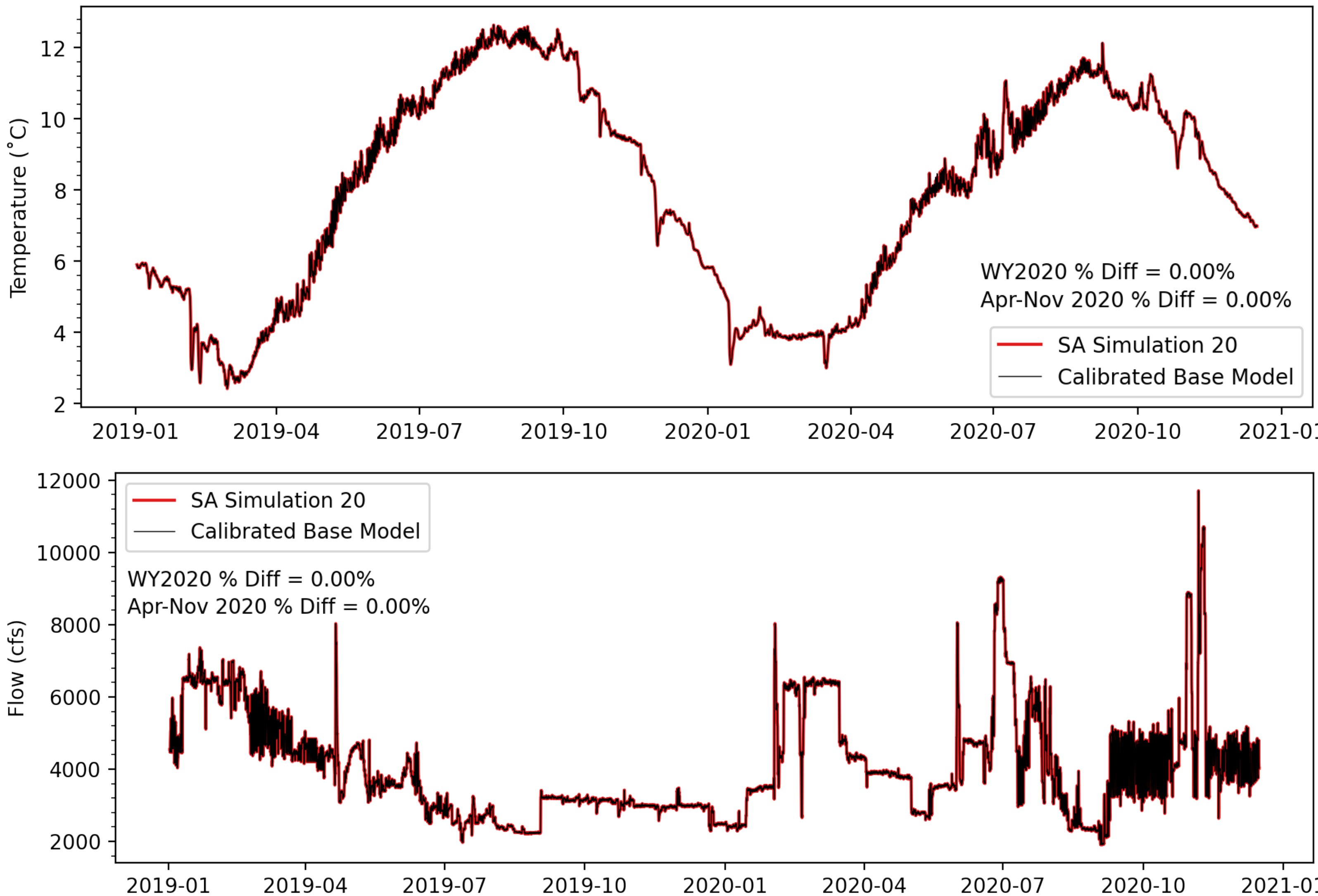


Figure C.3-35. Gorge Lake Outflow Continuous Hourly Flow and Temperature Variation for SA Simulation 20 (increase light absorption coefficient, reduce vertical light extinction).

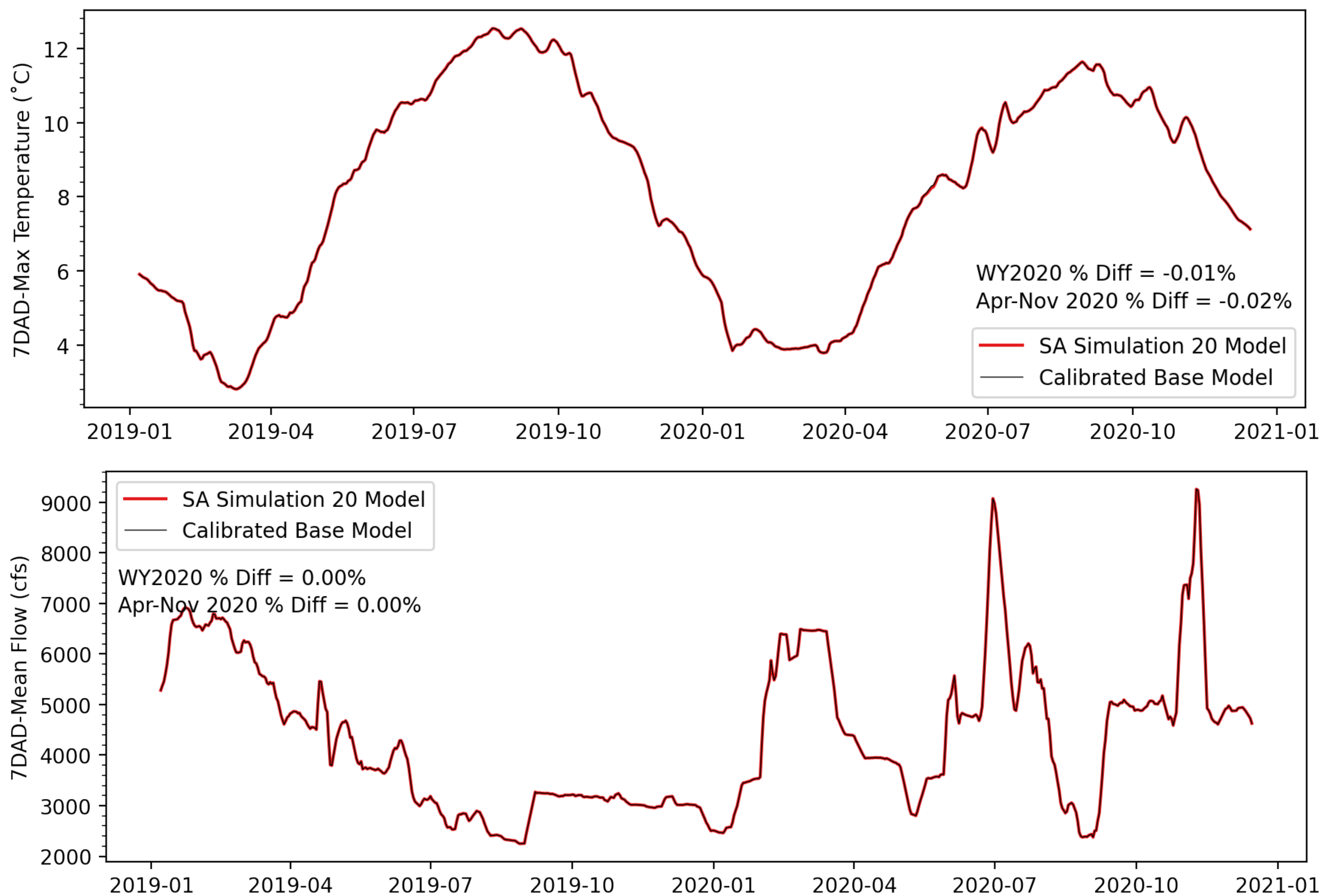


Figure C.3-36. **Gorge Lake outflow 7DAD-Mean Flow and Max Temperature Variation for SA Simulation 20 (increase light absorption coefficient, reduce vertical light extinction).**

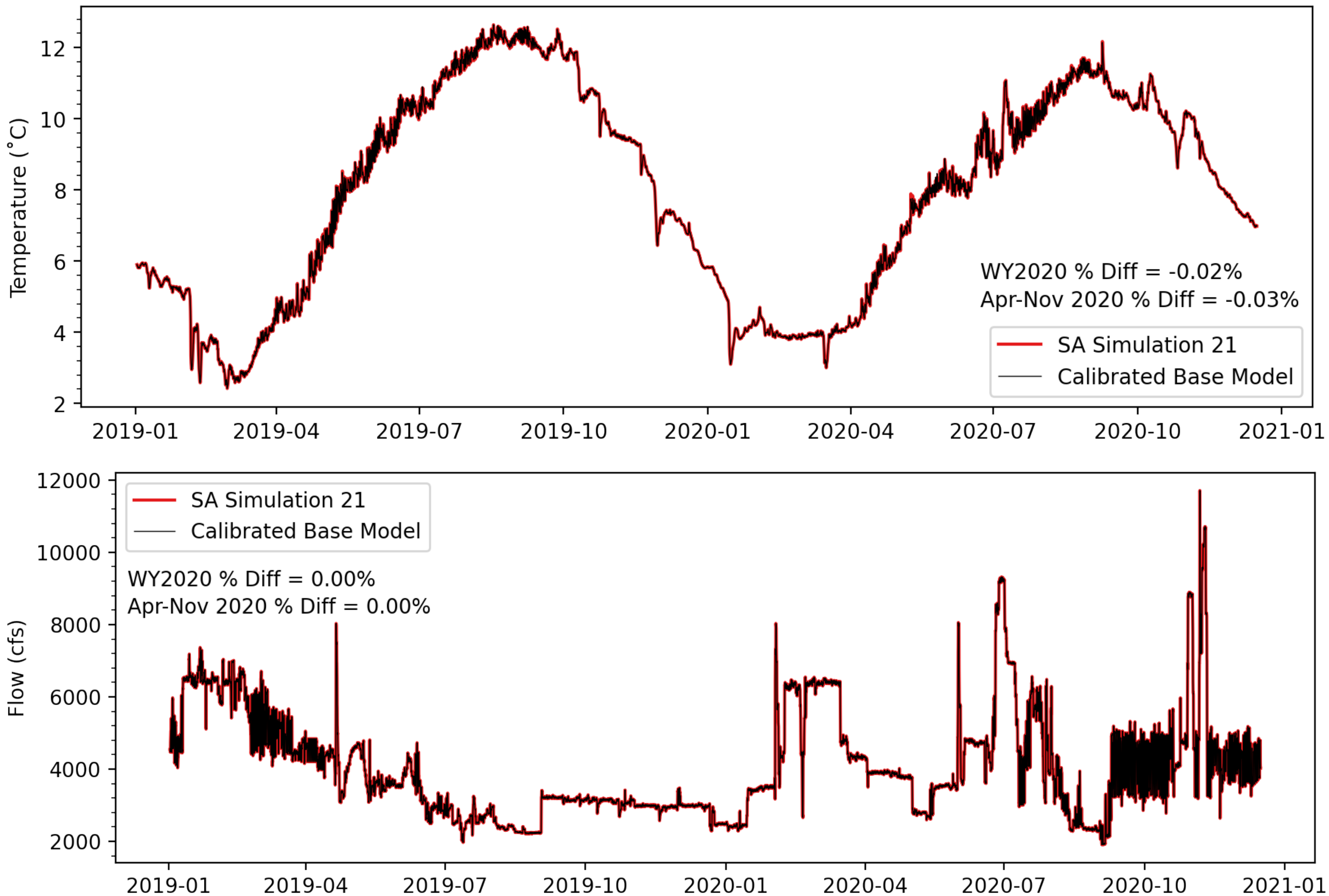


Figure C.3-37. Gorge Lake outflow continuous hourly flow and temperature variation for SA Simulation 21 (decrease light absorption coefficient, increase vertical light extinction).

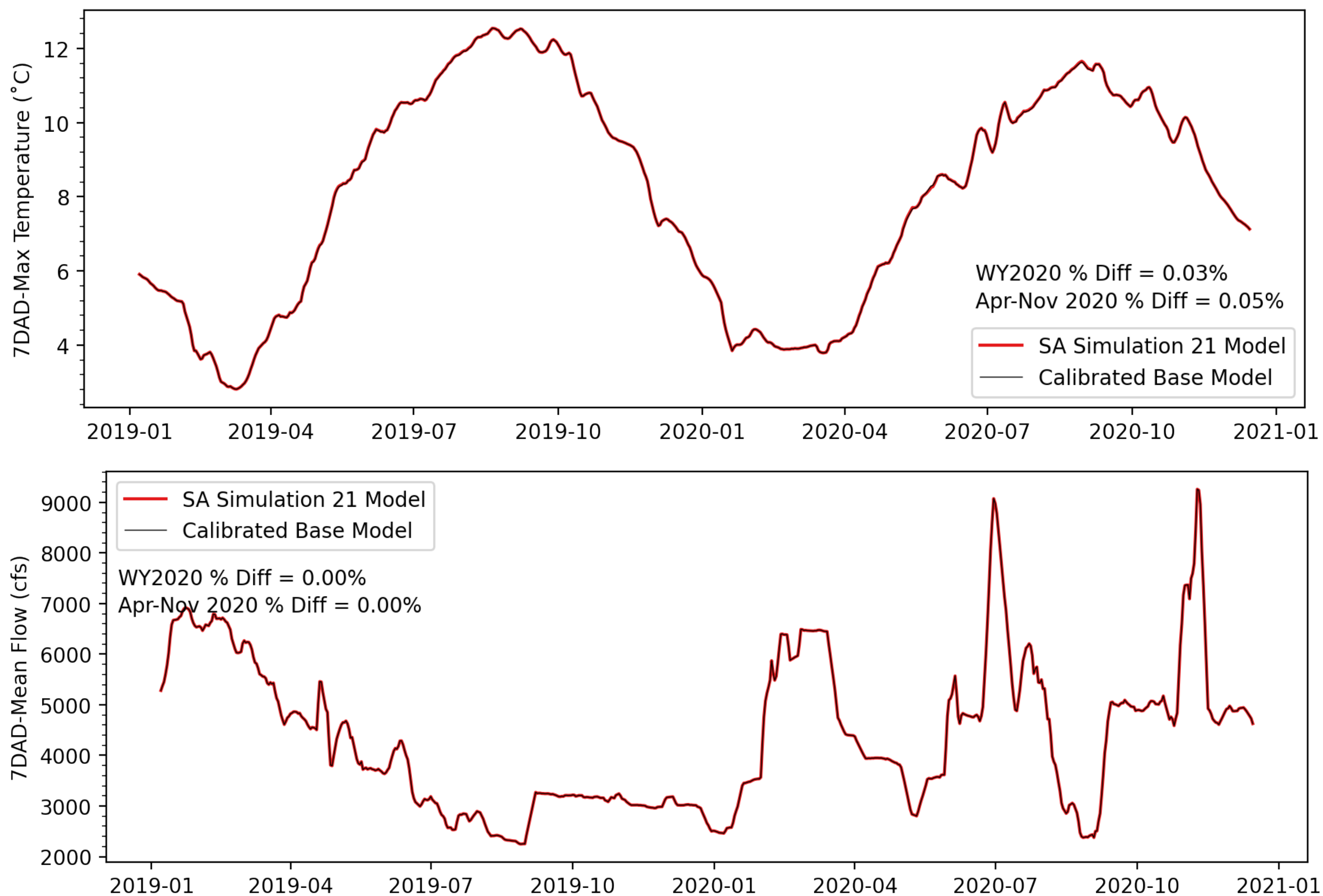


Figure C.3-38. **Gorge Lake outflow 7DAD-Mean flow and max temperature variation for SA Simulation 21 (decrease light absorption coefficient, increase vertical light extinction).**

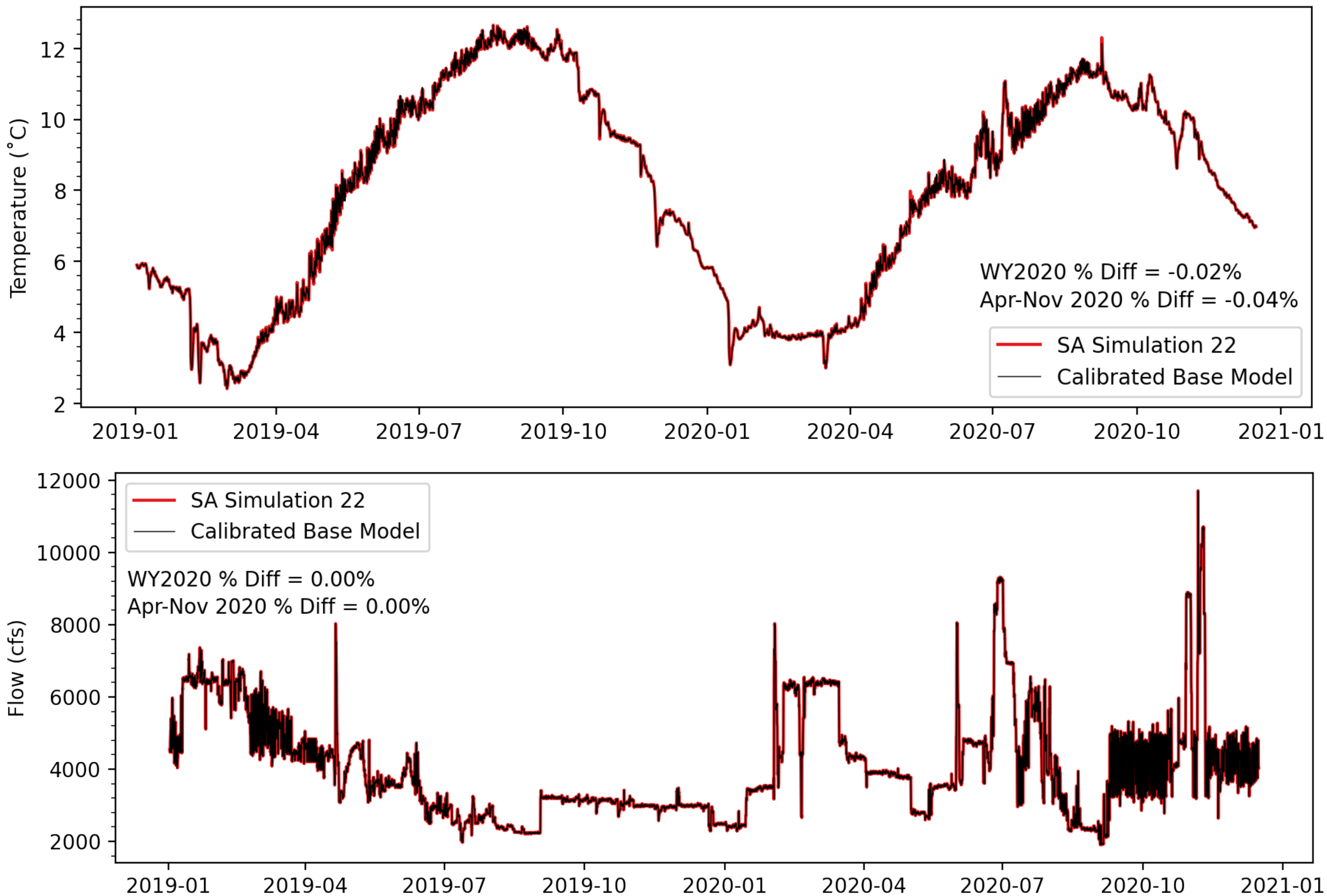


Figure C.3-39. Gorge Lake outflow continuous hourly flow and temperature variation for SA Simulation 22 (set longitudinal eddy diffusivity to 0.1 m2/s).

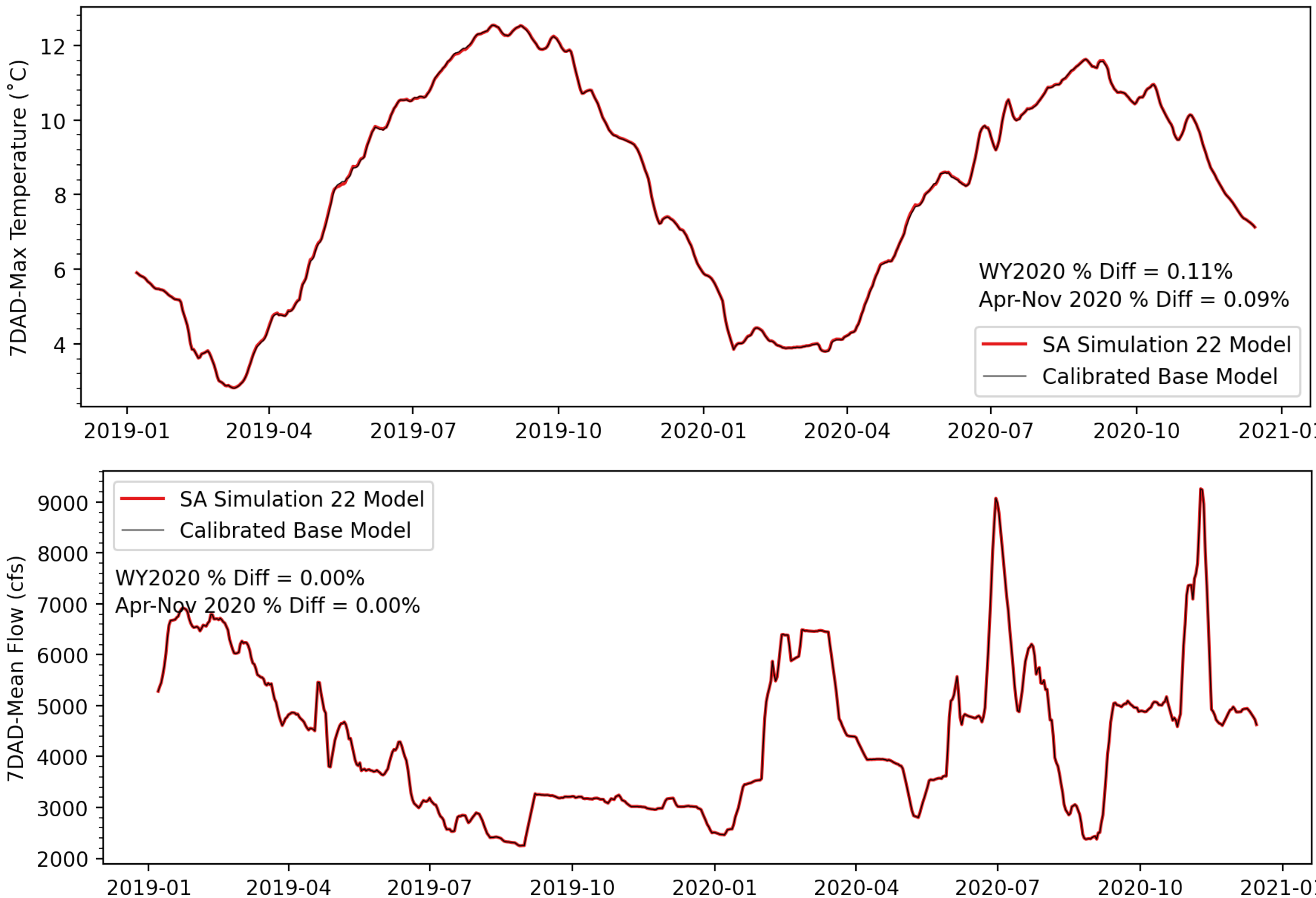


Figure C.3-40. Gorge Lake outflow 7DAD-Mean flow and max temperature variation for SA Simulation 22 (set longitudinal eddy diffusivity to 0.1 m2/s).

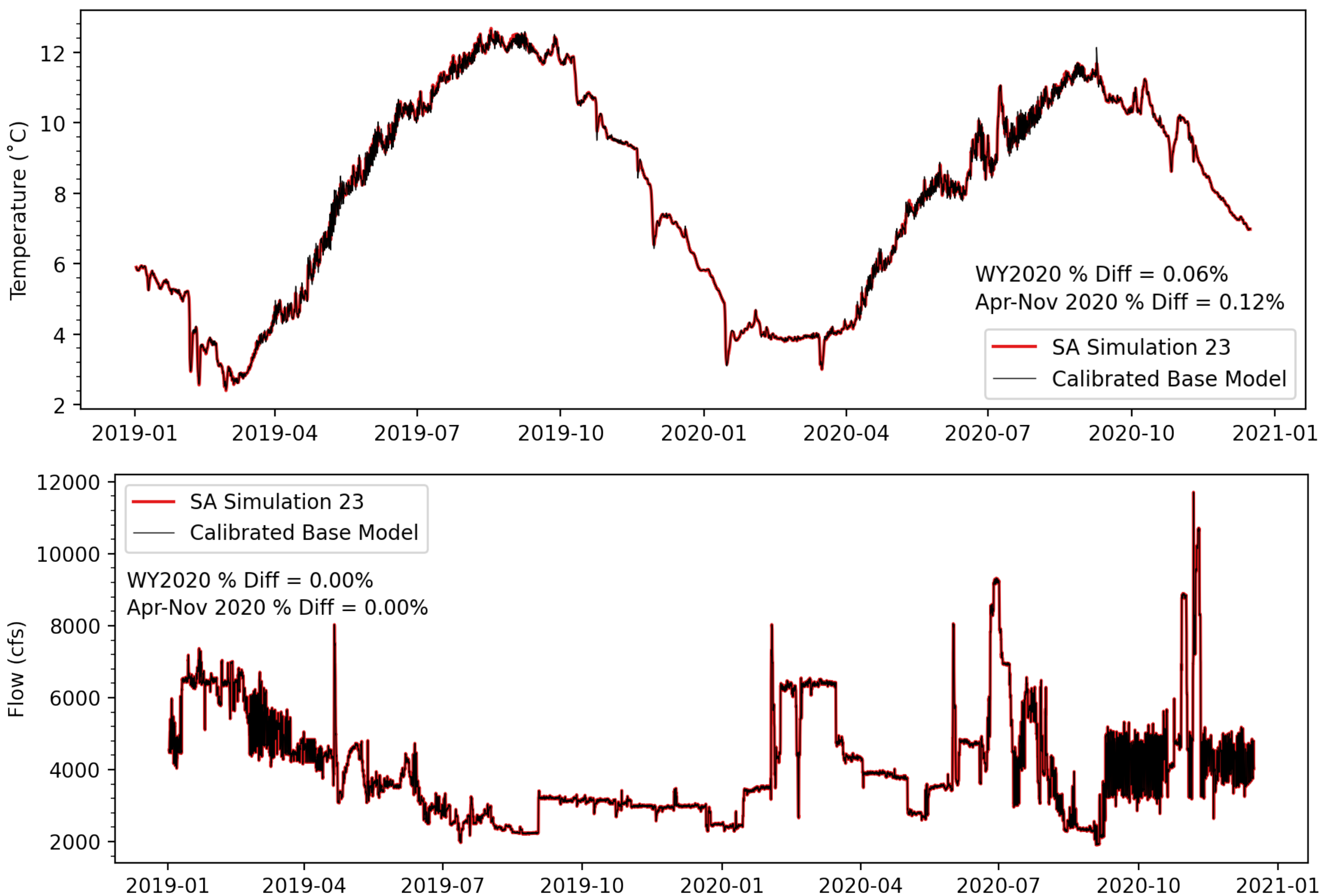


Figure C.3-41. Gorge Lake outflow continuous hourly flow and temperature variation for SA Simulation 23 (set longitudinal eddy diffusivity to 10 m2/s).

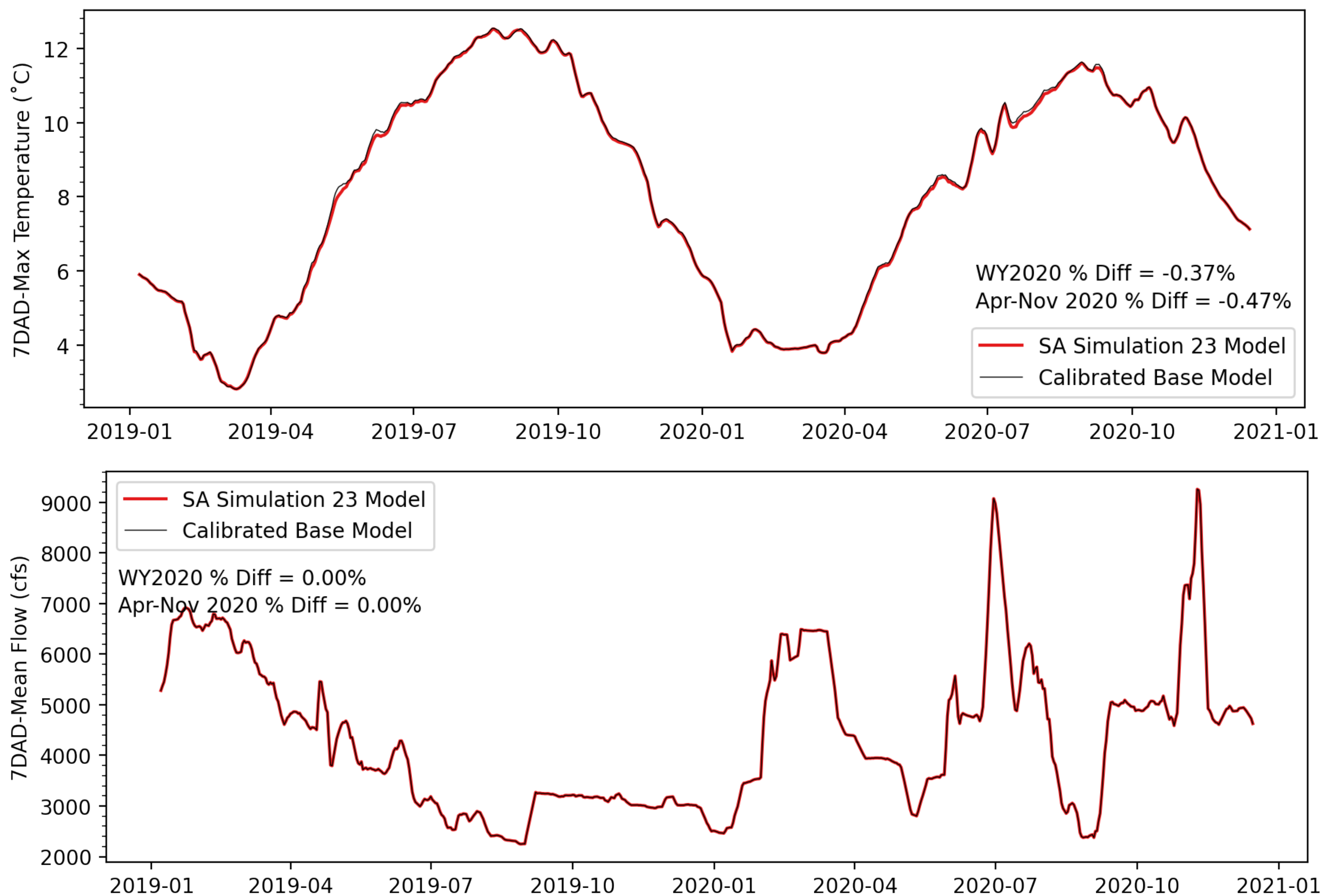


Figure C.3-42. Gorge Lake outflow 7DAD-Mean flow and max temperature variation for SA Simulation 23 (set longitudinal eddy diffusivity to 10 m2/s).

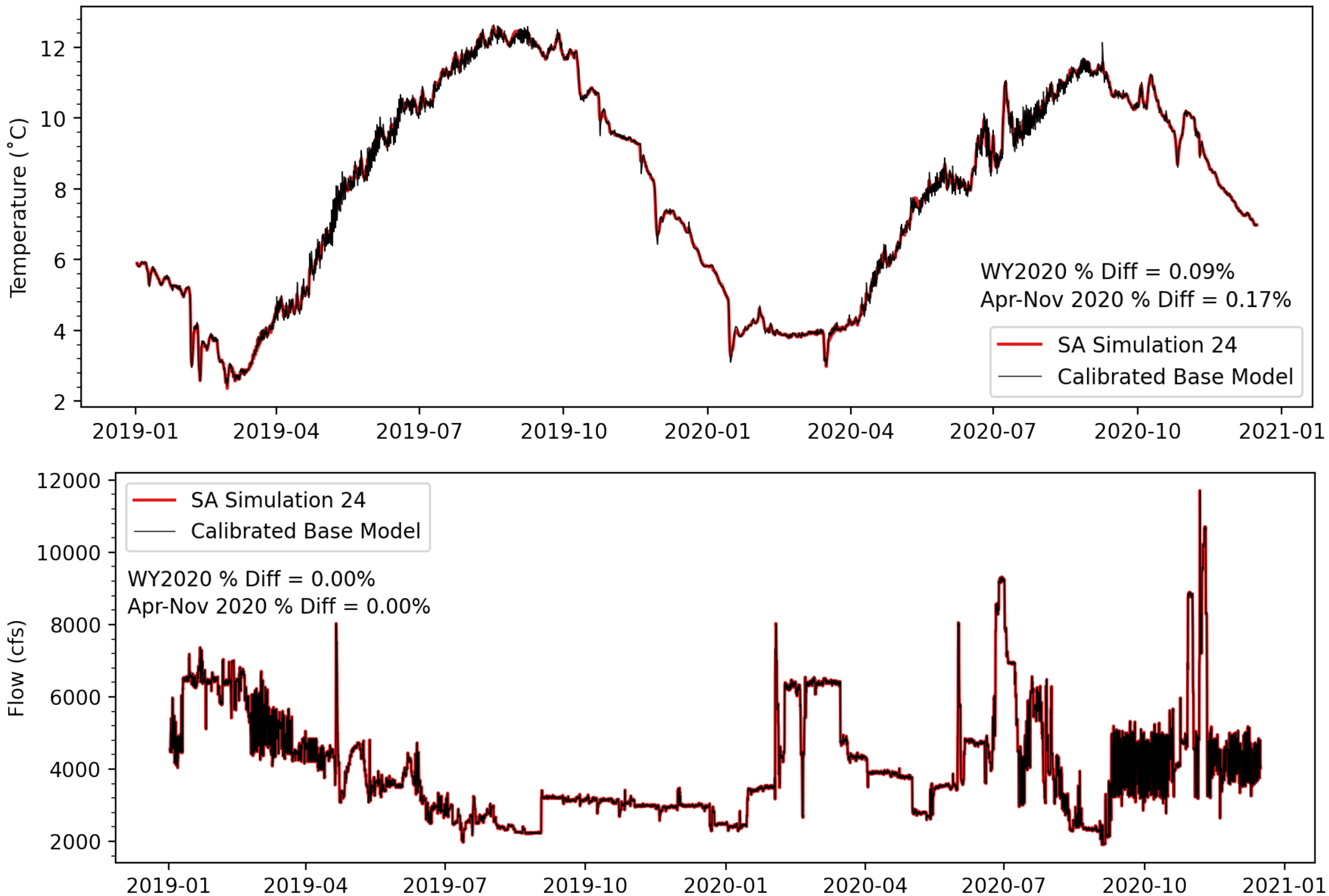


Figure C.3-43. Gorge Lake outflow continuous hourly flow and temperature variation for SA Simulation 24 (set longitudinal eddy diffusivity to 100 m2/s).

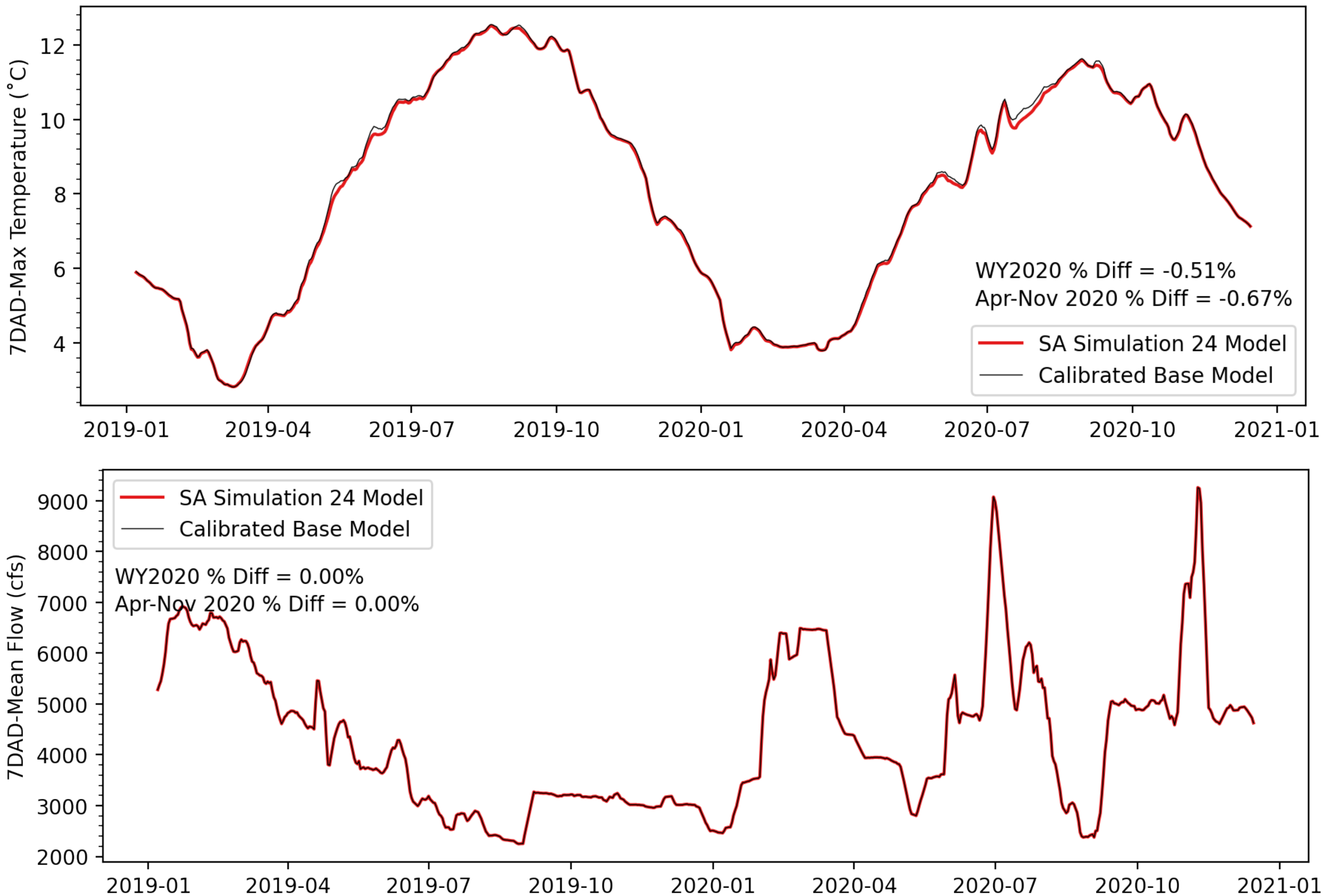


Figure C.3-44. Gorge Lake outflow 7DAD-Mean flow and max temperature variation for SA Simulation 24 (set longitudinal eddy diffusivity to 100 m2/s).

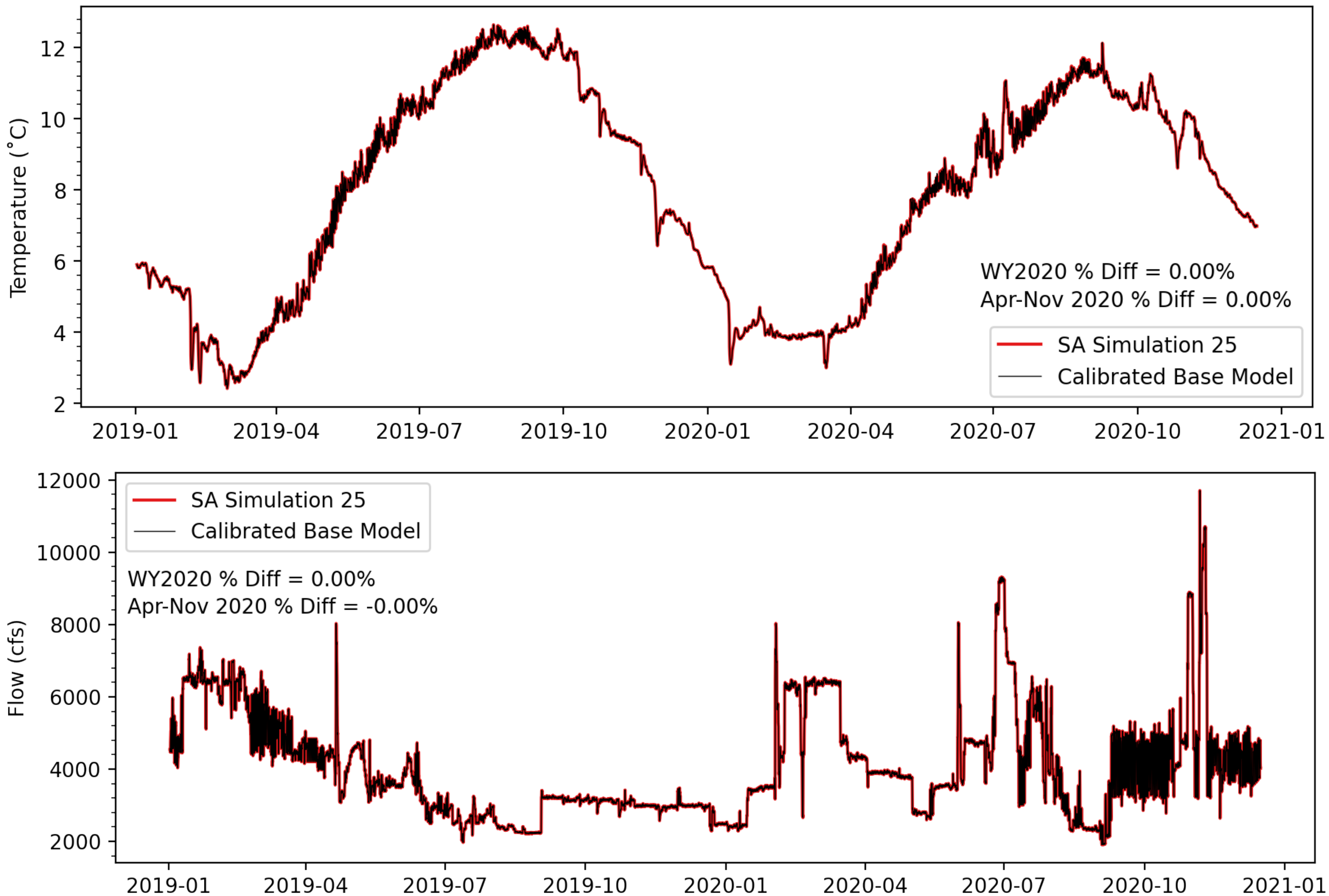


Figure C.3-45. Gorge Lake outflow continuous hourly flow and temperature variation for SA Simulation 25 (set longitudinal eddy viscosity to 0.1 m2/s).

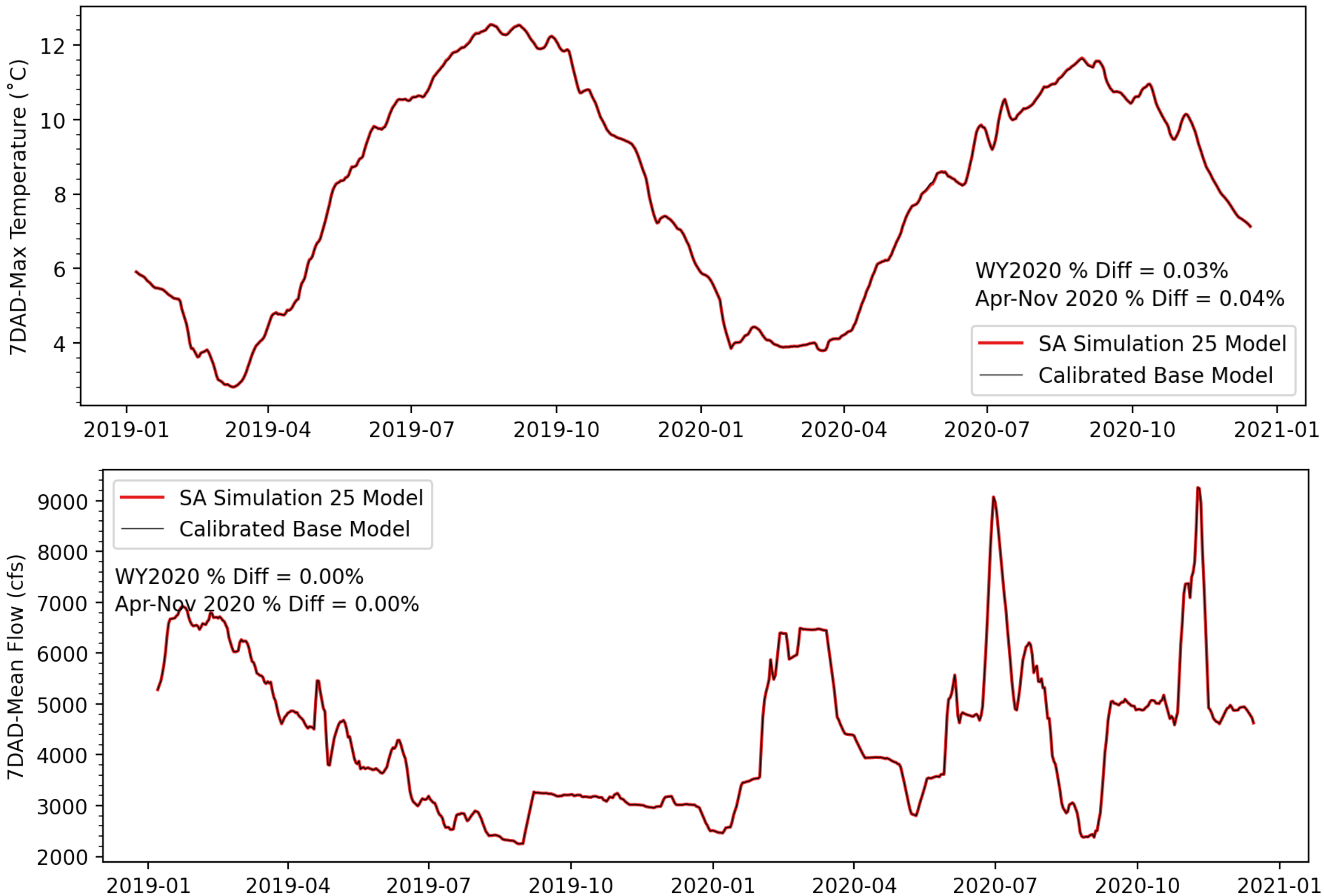


Figure C.3-46. Gorge Lake outflow 7DAD-Mean flow and max temperature variation for SA Simulation 25 (set longitudinal eddy viscosity to 0.1 m2/s).

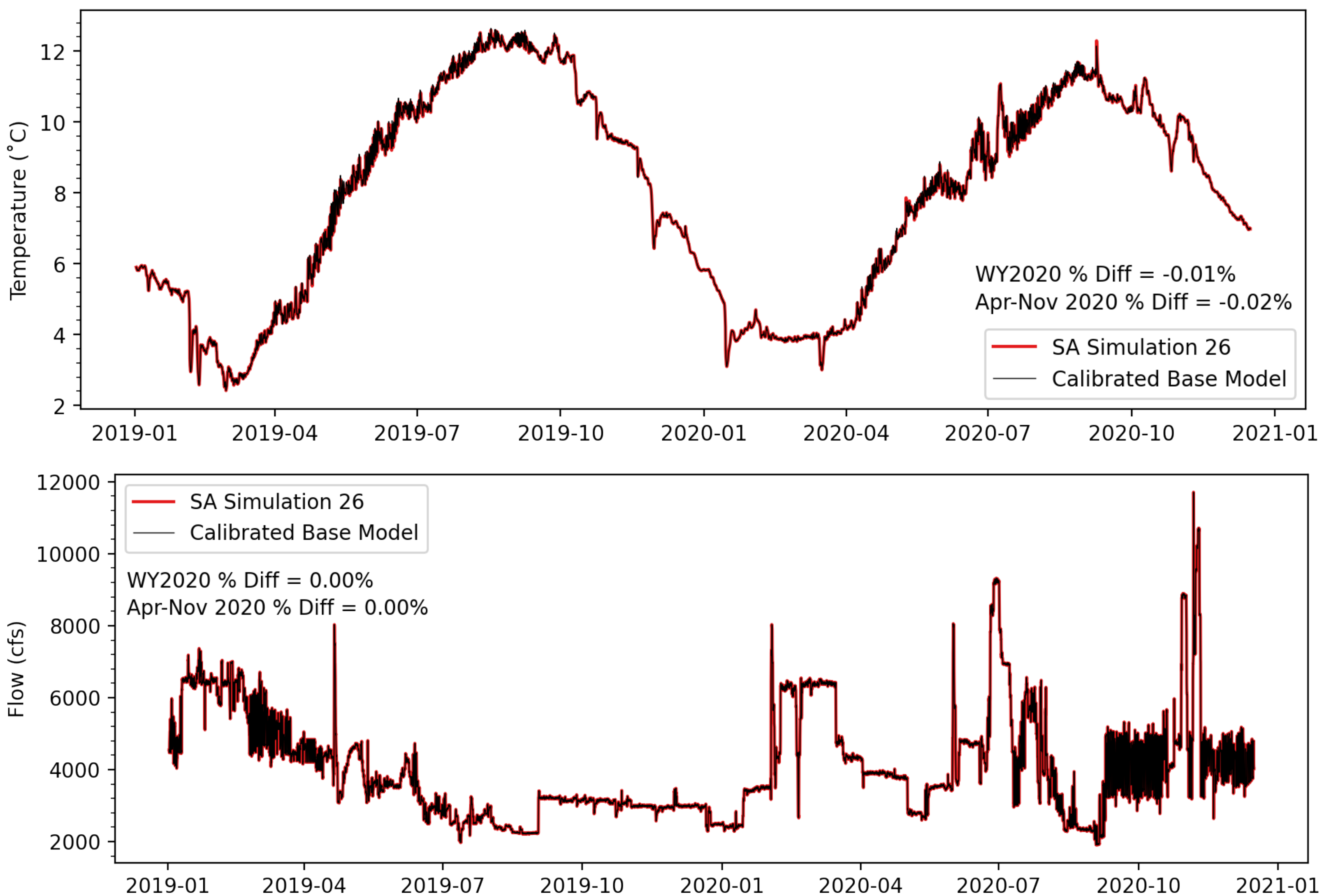


Figure C.3-47. Gorge Lake outflow continuous hourly flow and temperature variation for SA Simulation 26 (set longitudinal eddy viscosity to 10 m2/s).

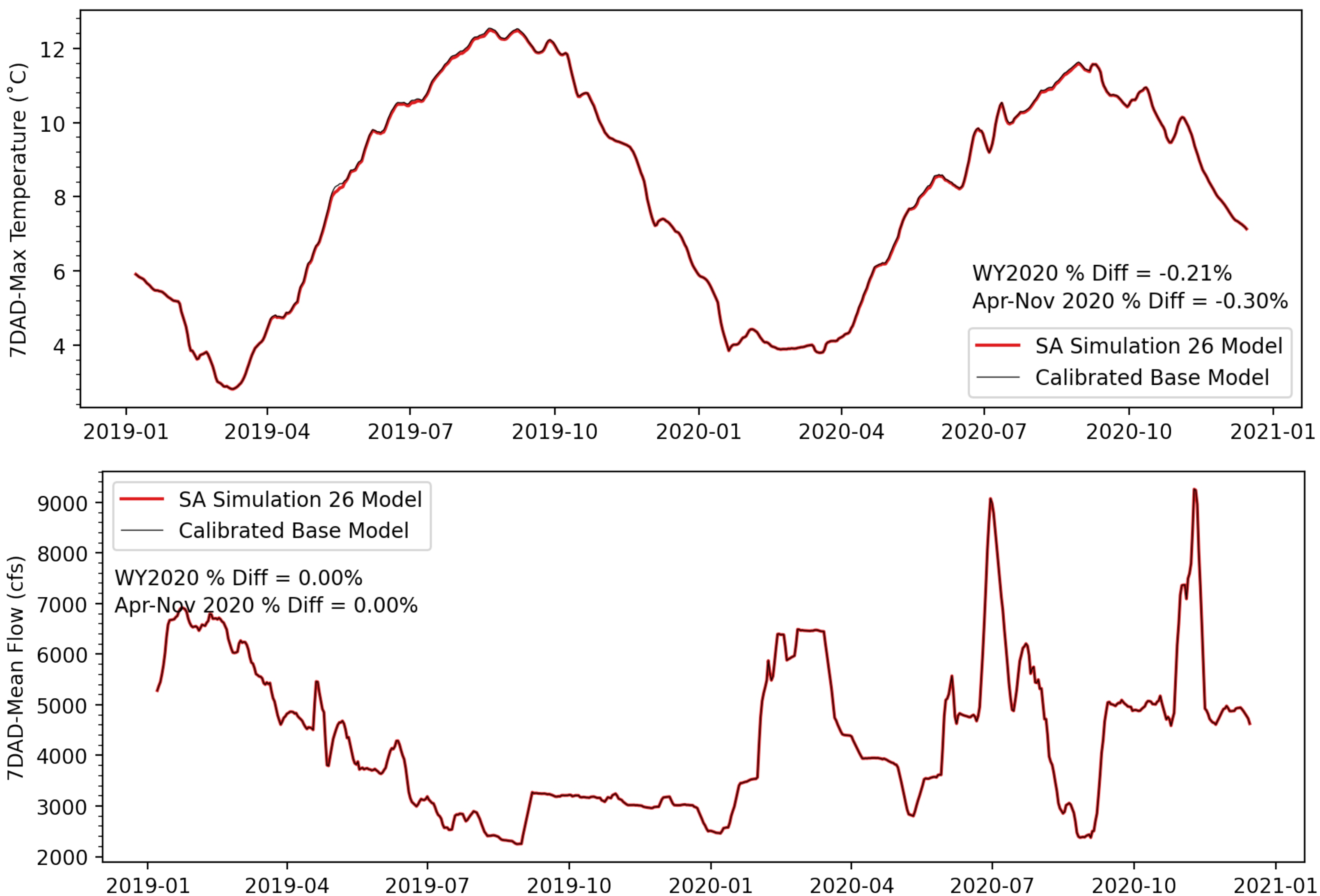


Figure C.3-48. Gorge Lake outflow 7DAD-Mean flow and max temperature variation for SA Simulation 26 (set longitudinal eddy viscosity to 10 m2/s).

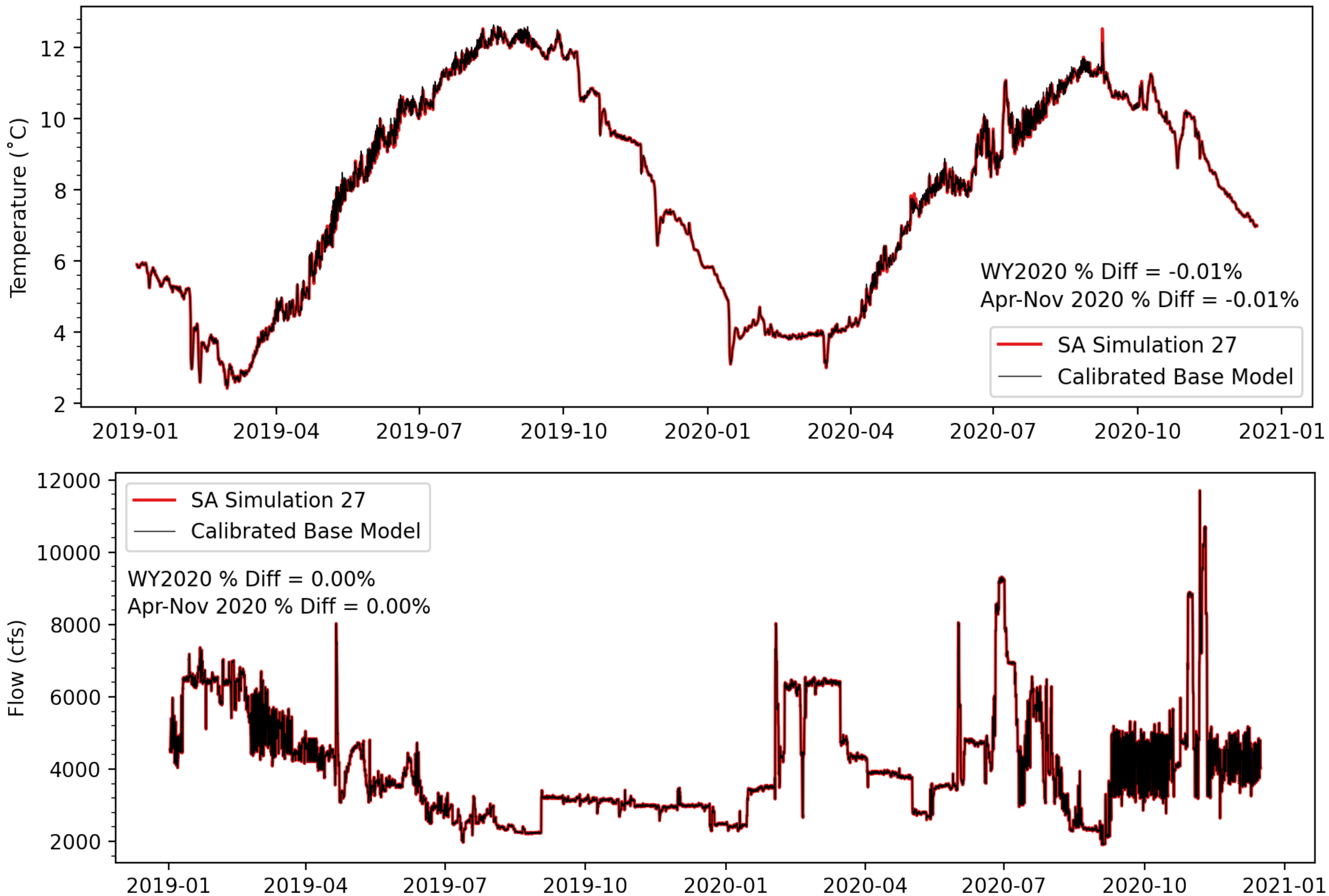


Figure C.3-49. Gorge Lake outflow continuous hourly flow and temperature variation for SA Simulation 27 (set longitudinal eddy viscosity to 30 m2/s).

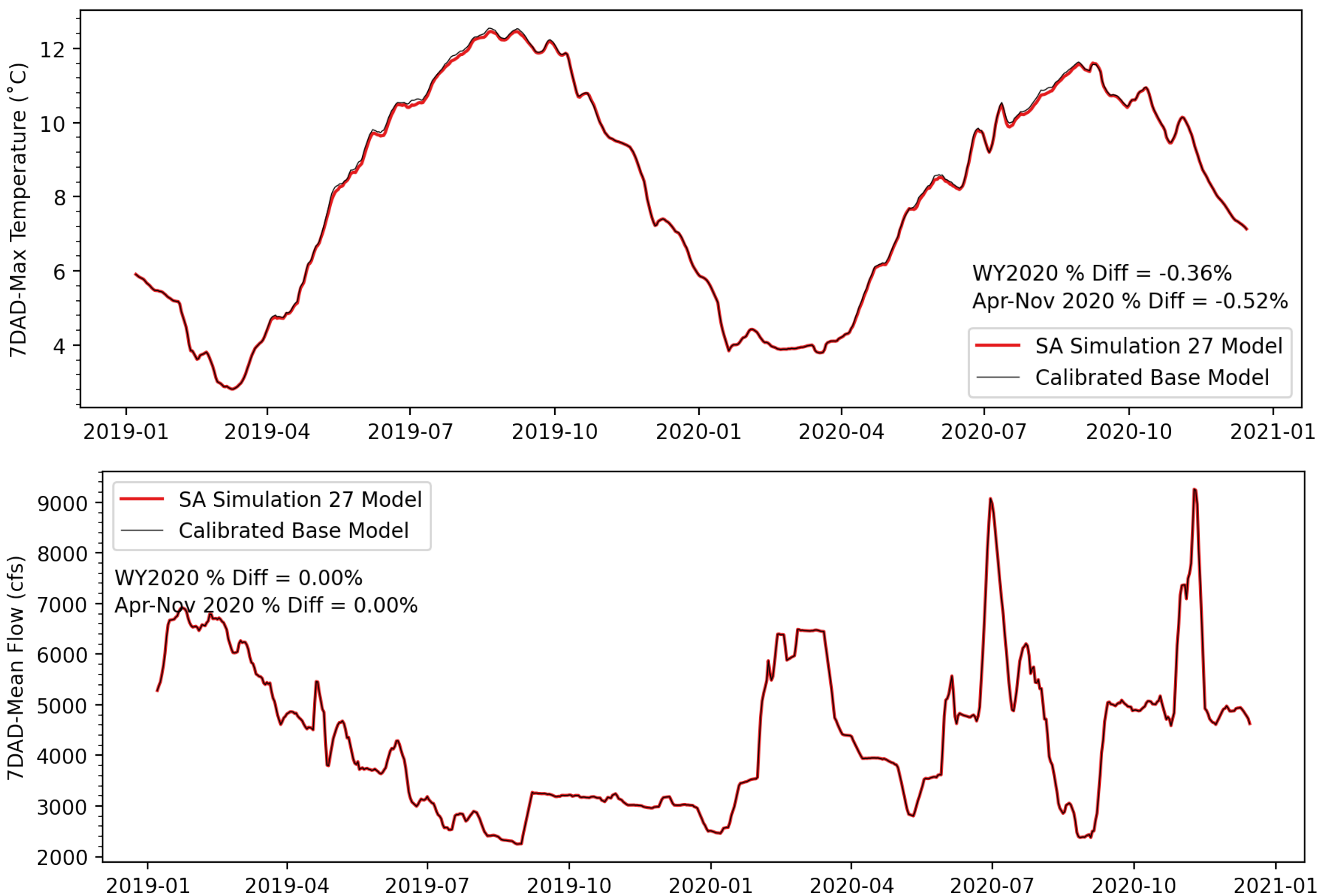


Figure C.3-50. Gorge Lake outflow 7DAD-Mean flow and max temperature variation for SA Simulation 27 (set longitudinal eddy viscosity to 30 m2/s).

C.4 Skagit River Sensitivity Analysis Figures

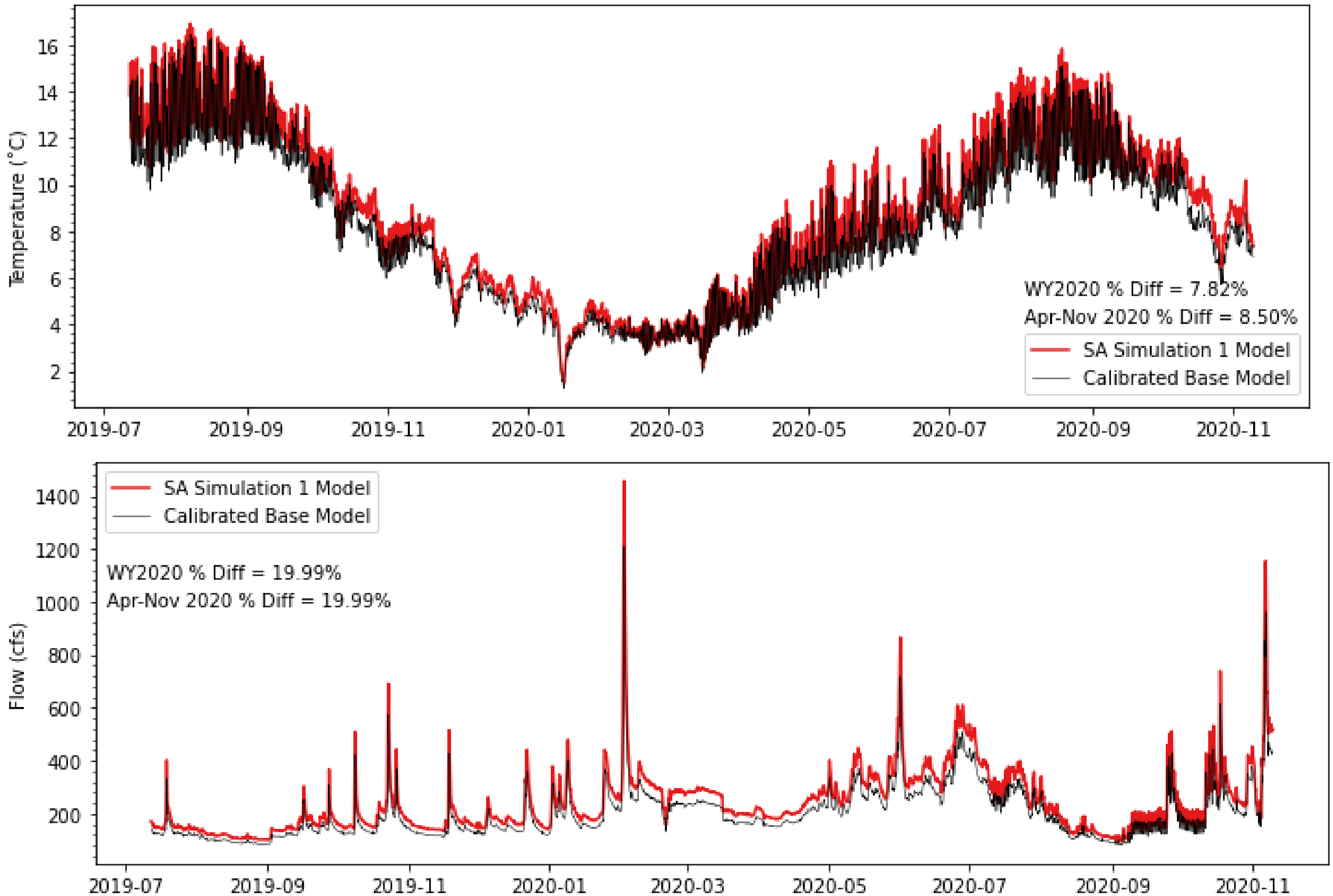


Figure C.4-1. Skagit River at Sauk River confluence continuous hourly flow and temperature variation for SA Simulation 1 (increase boundary flows by 20 percent).

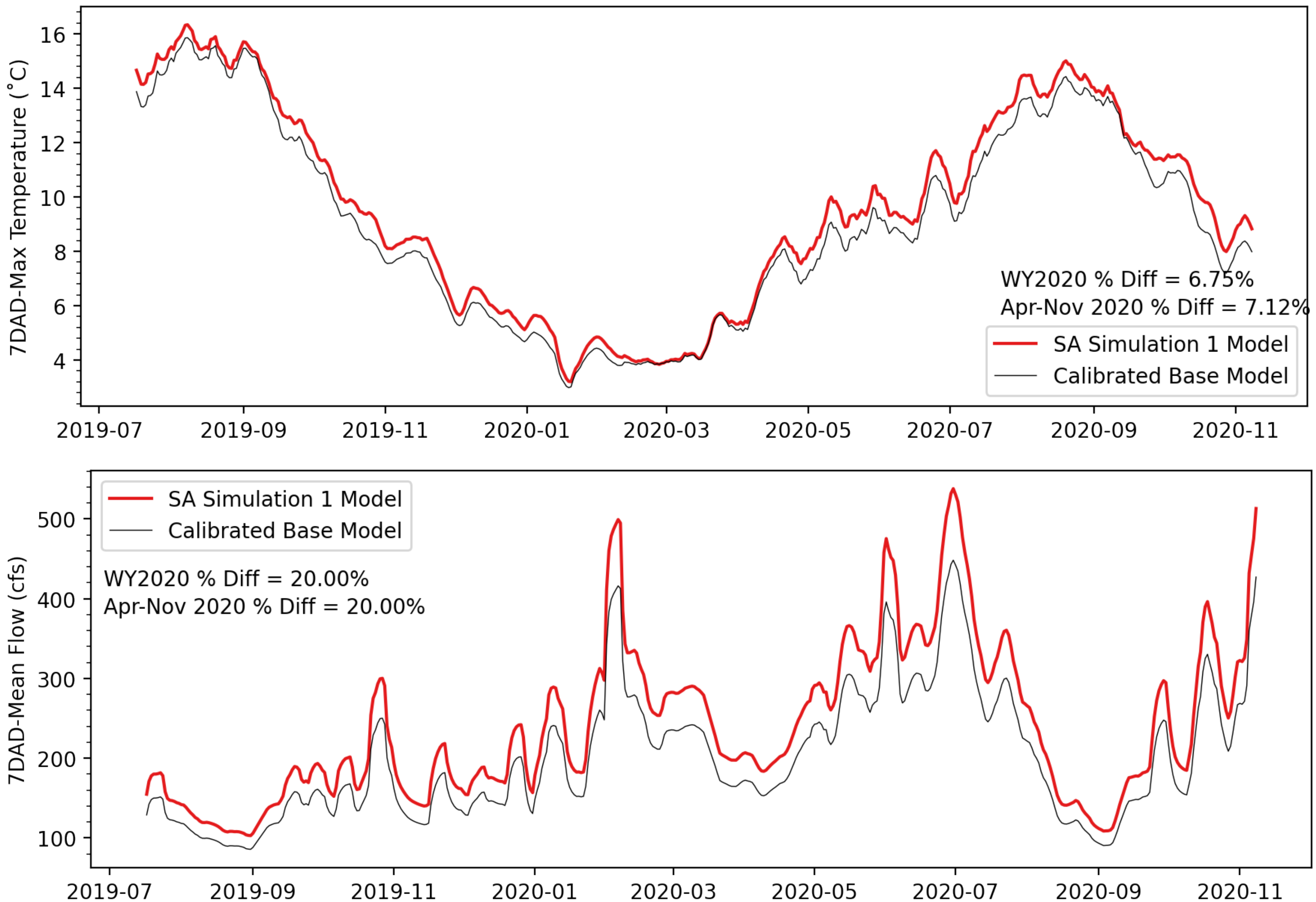


Figure C.4-2. Skagit River at Sauk River confluence 7DAD-Mean flow and max temperature variation for SA Simulation 1 (increase boundary flows by 20 percent).

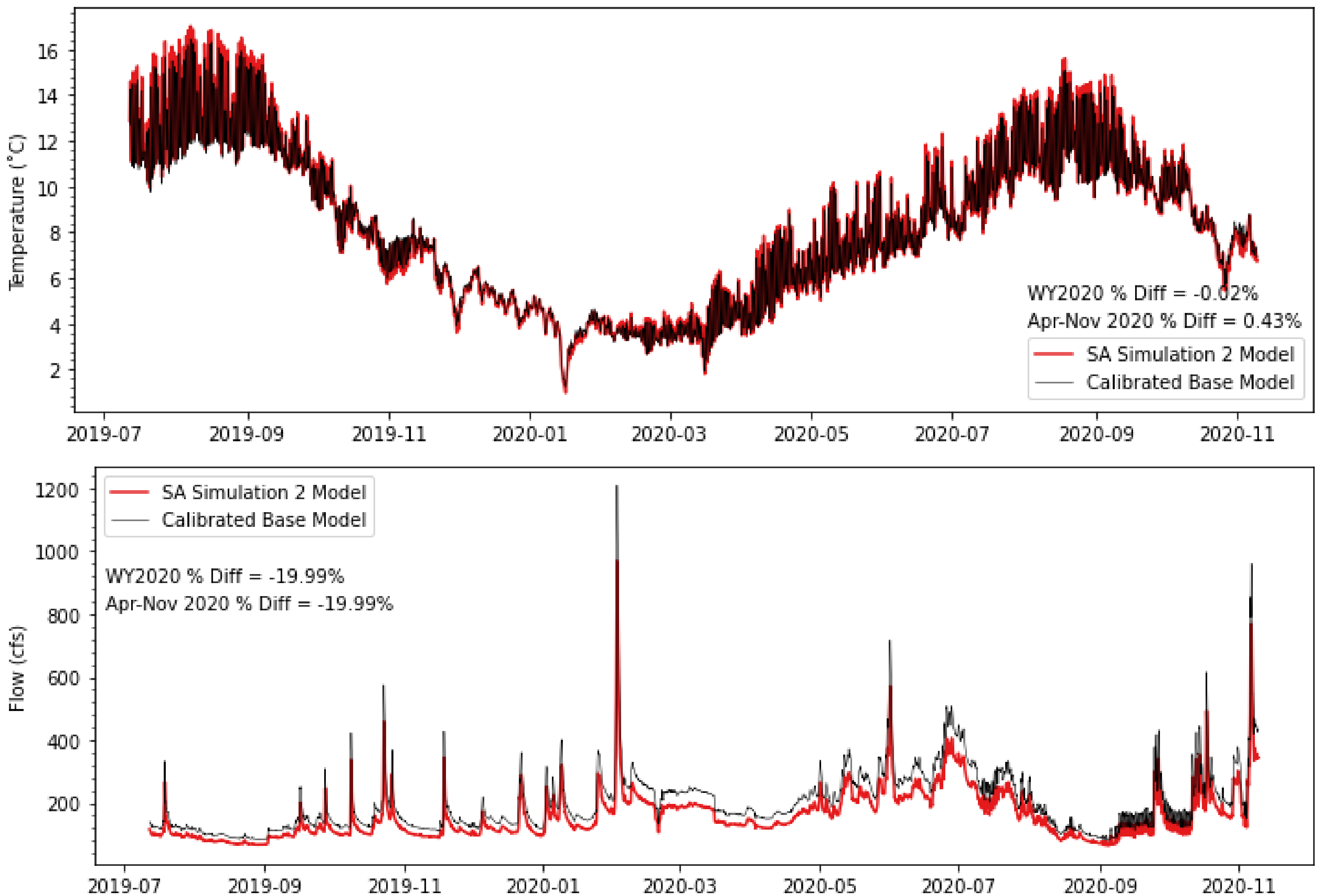


Figure C.4-3. Skagit River at Sauk River confluence continuous hourly flow and temperature variation for SA Simulation 2 (decrease boundary flows by 20 percent).

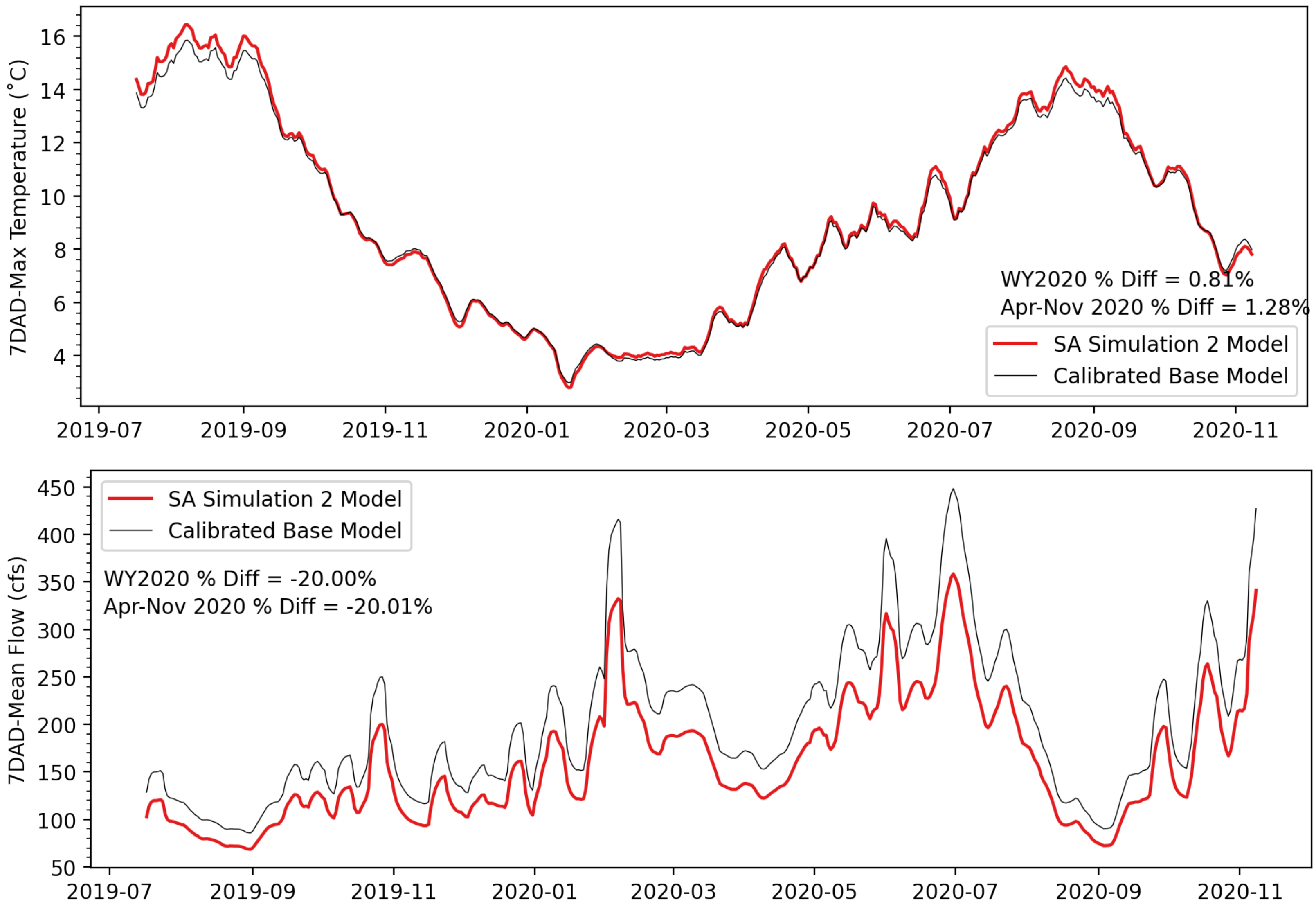


Figure C.4-4. Skagit River at Sauk River confluence 7DAD-Mean flow and max temperature variation for SA Simulation 2 (decrease boundary flows by 20 percent).

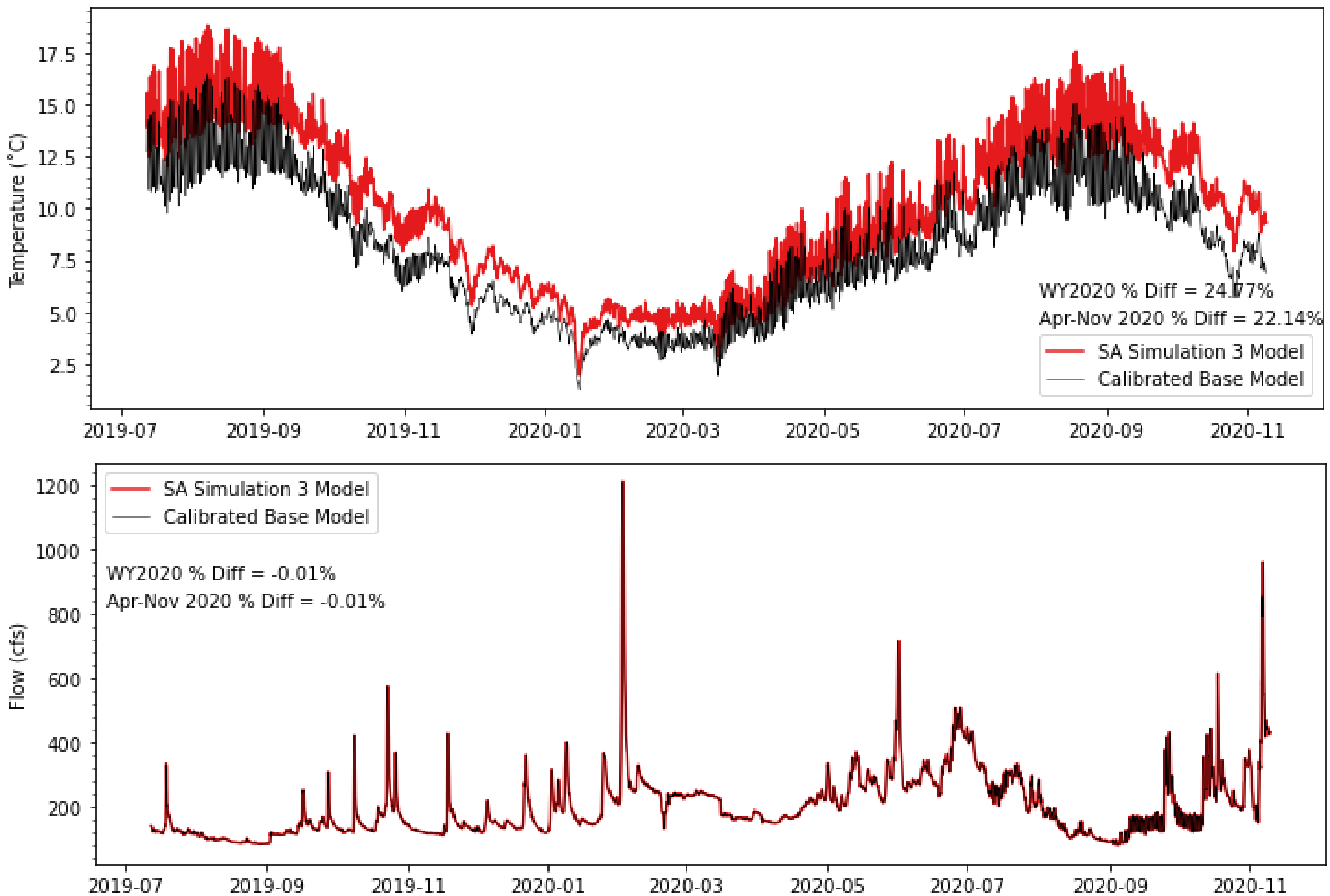


Figure C.4-5. Skagit River at Sauk River confluence continuous hourly flow and temperature variation for SA Simulation 3 (increase boundary temperatures by 20 percent).

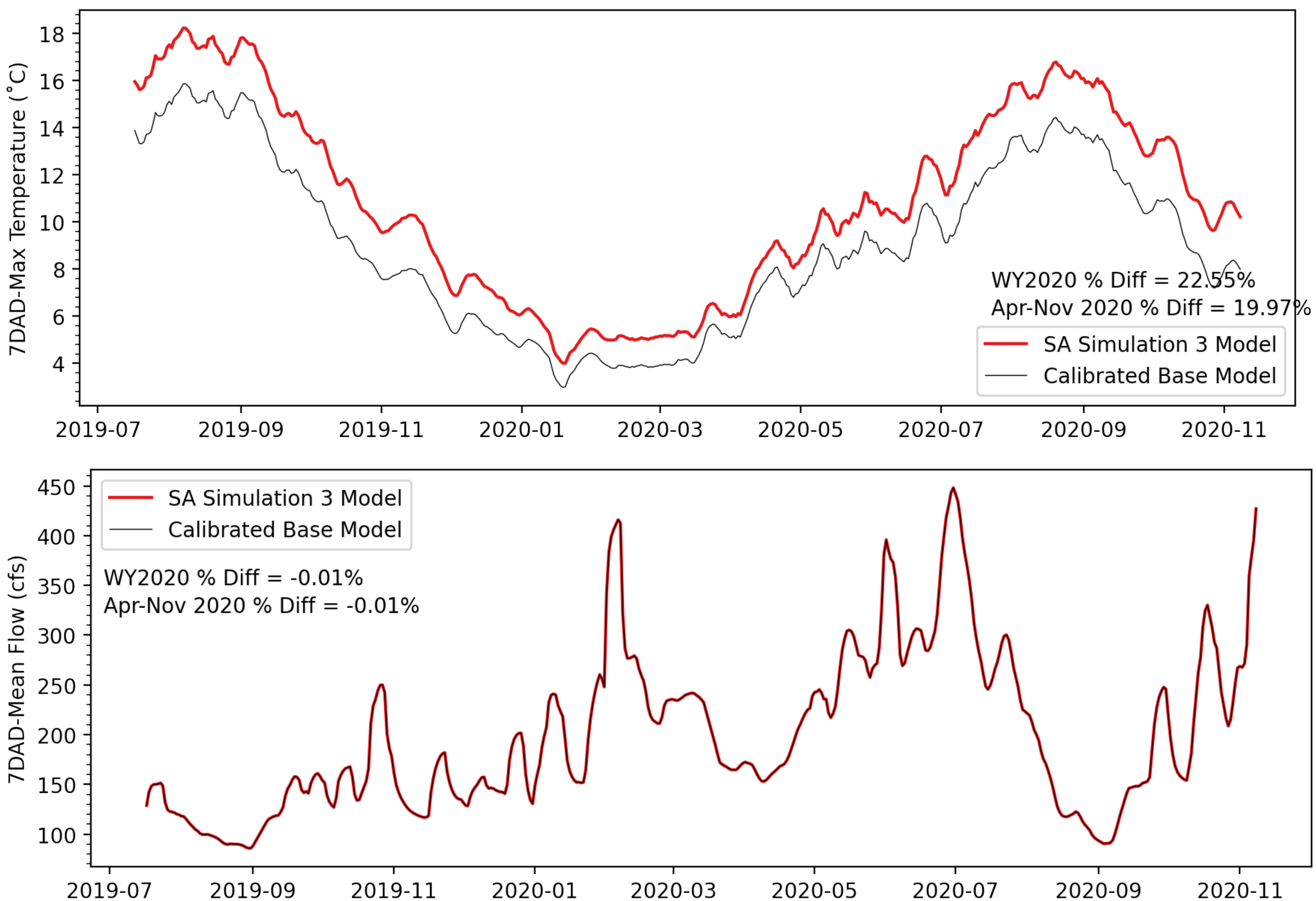


Figure C.4-6. Skagit River at Sauk River confluence 7DAD-Mean flow and max temperature variation for SA Simulation 3 (increase boundary temperatures by 20 percent).

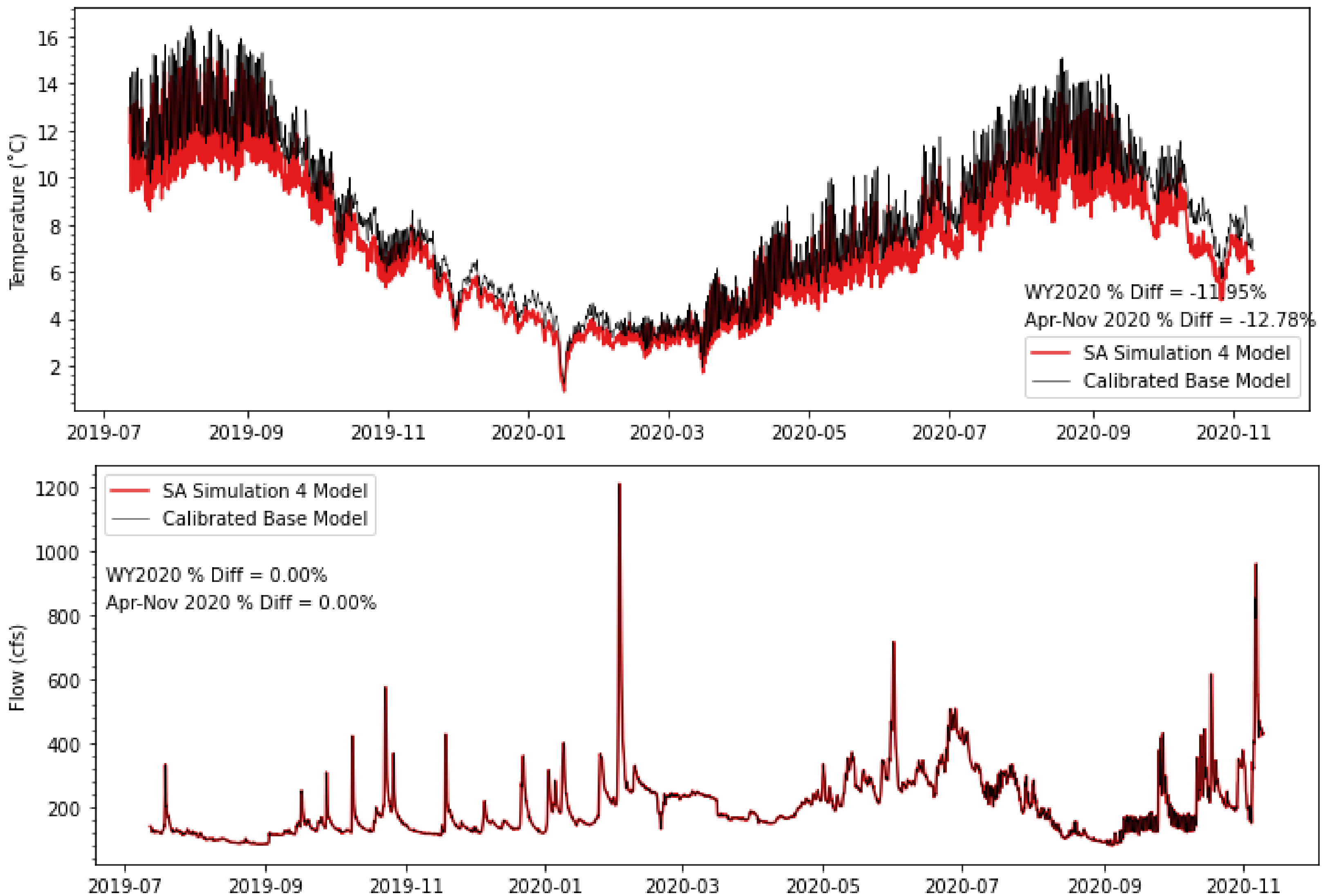


Figure C.4-7. Skagit River at Sauk River confluence continuous hourly flow and temperature variation for SA Simulation 4 (decrease boundary temperatures by 20 percent).

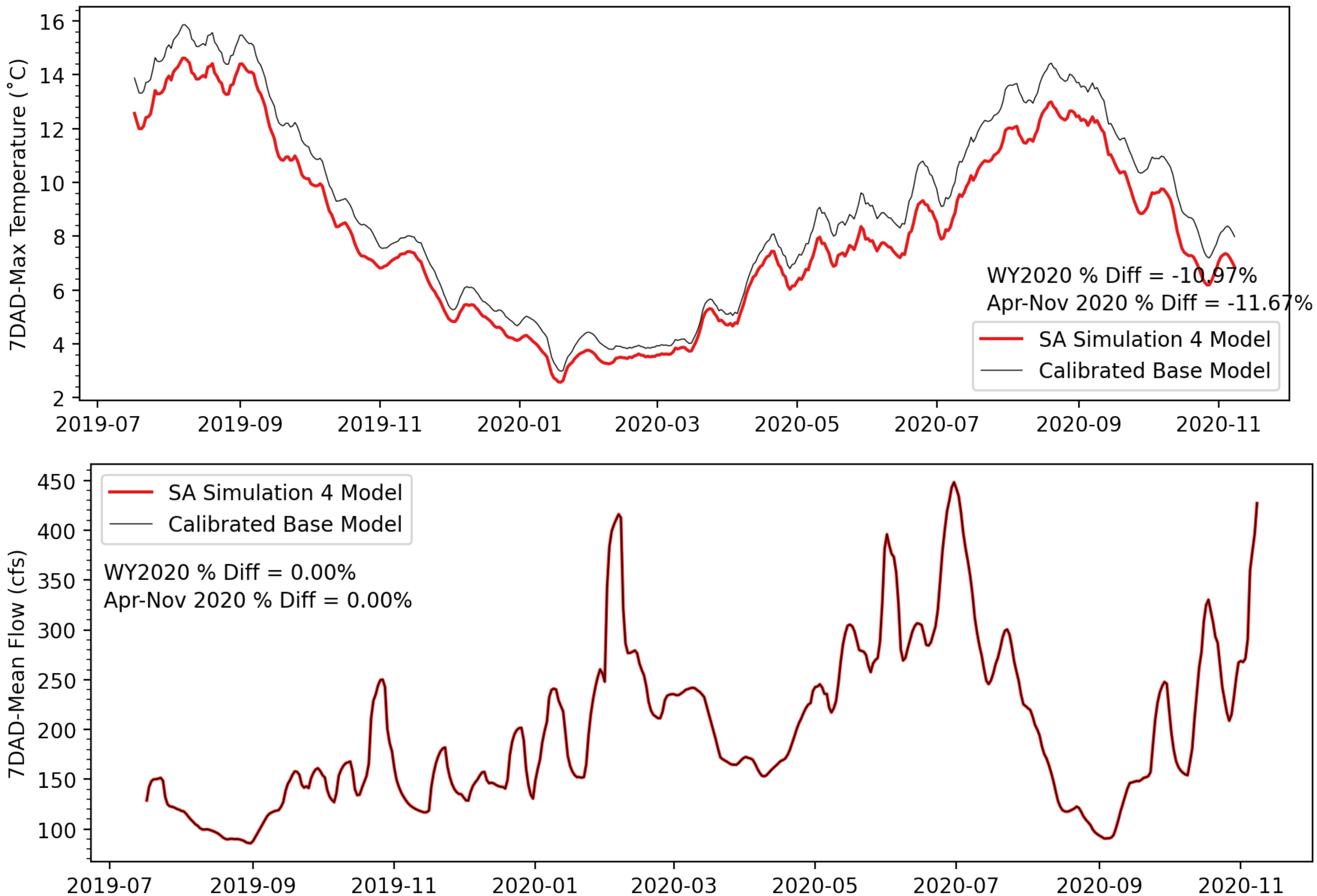


Figure C.4-8. Skagit River at Sauk River confluence 7DAD-Mean flow and max temperature variation for SA Simulation 4 (decrease boundary temperatures by 20 percent).

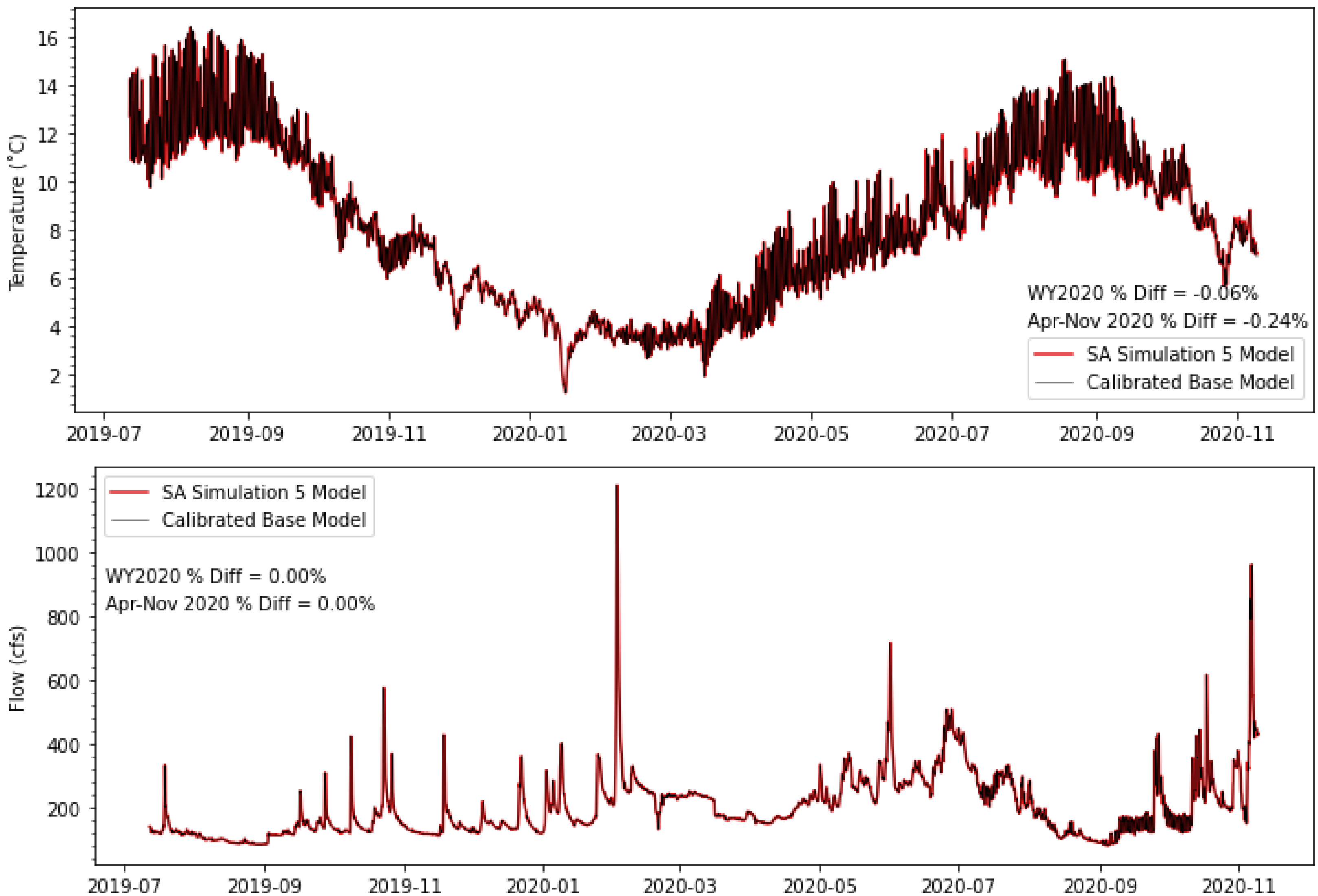


Figure C.4-9. Skagit River at Sauk River confluence continuous hourly flow and temperature variation for SA Simulation 5 (double spillway-powerhouse flow ratio).

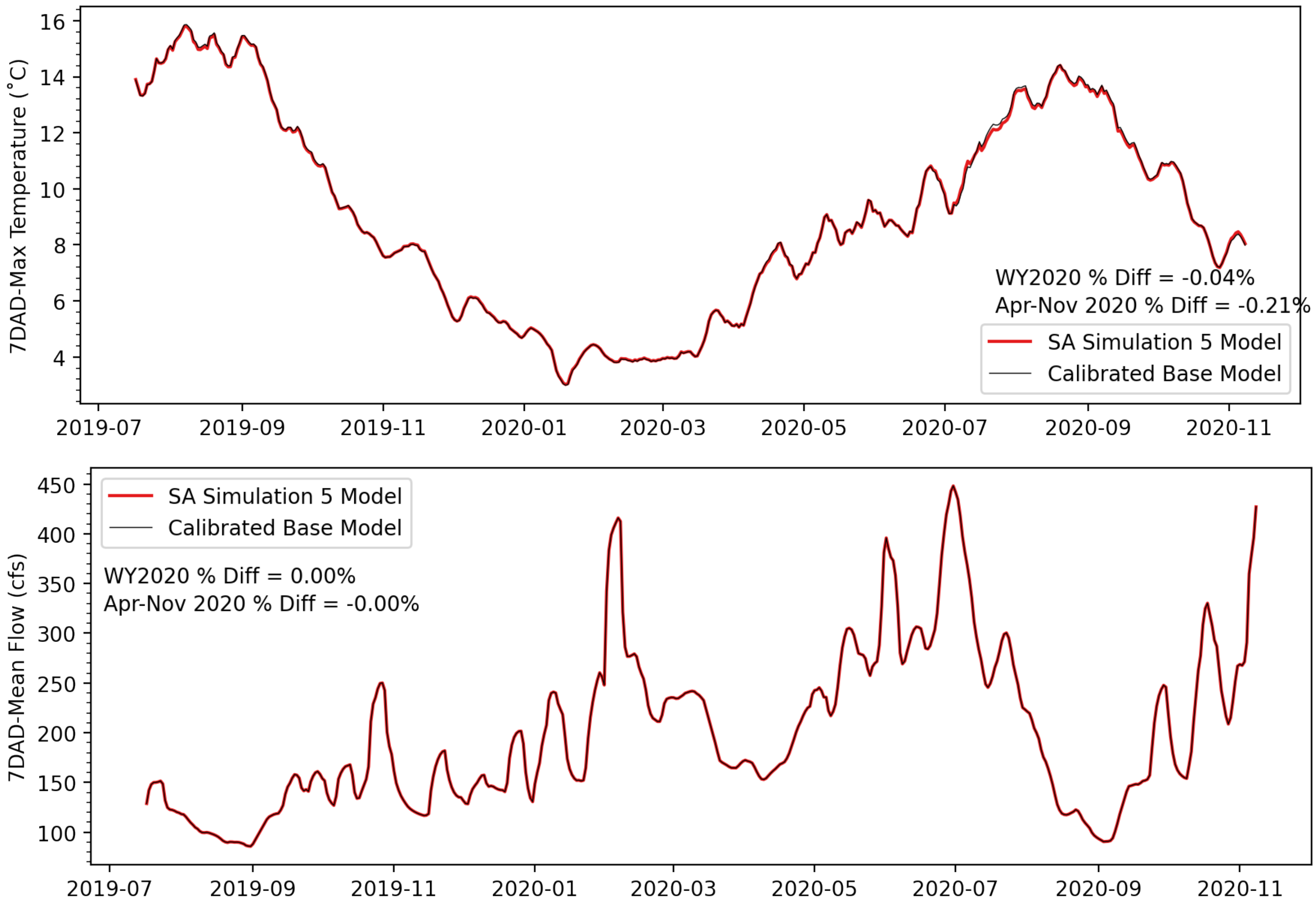


Figure C.4-10. Skagit River at Sauk River confluence 7DAD-Mean flow and max temperature variation for SA Simulation 5 (double spillway-powerhouse flow ratio).

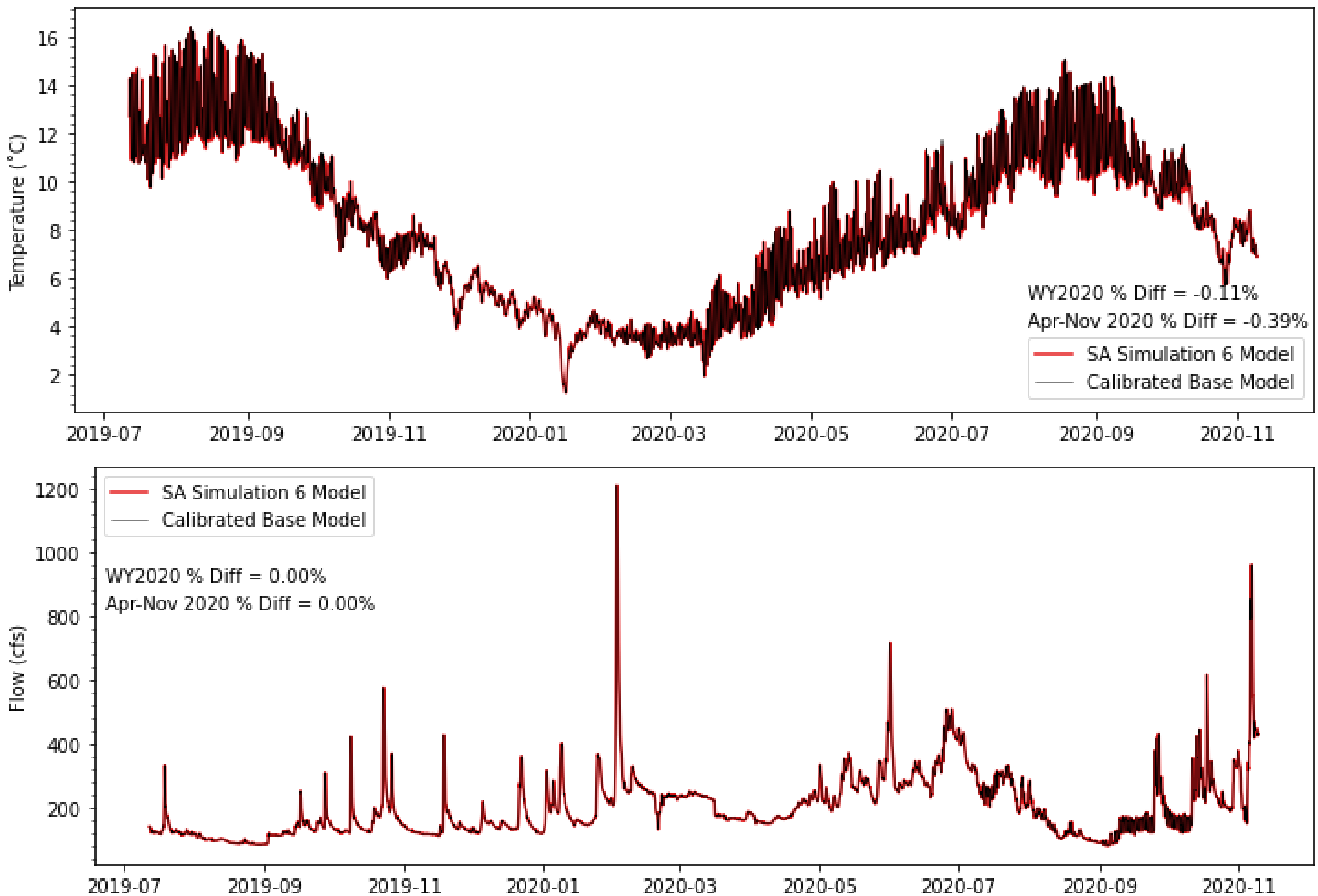


Figure C.4-11. Skagit River at Sauk River confluence continuous hourly flow and temperature variation for SA Simulation 6 (halve spillway-powerhouse flow ratio).

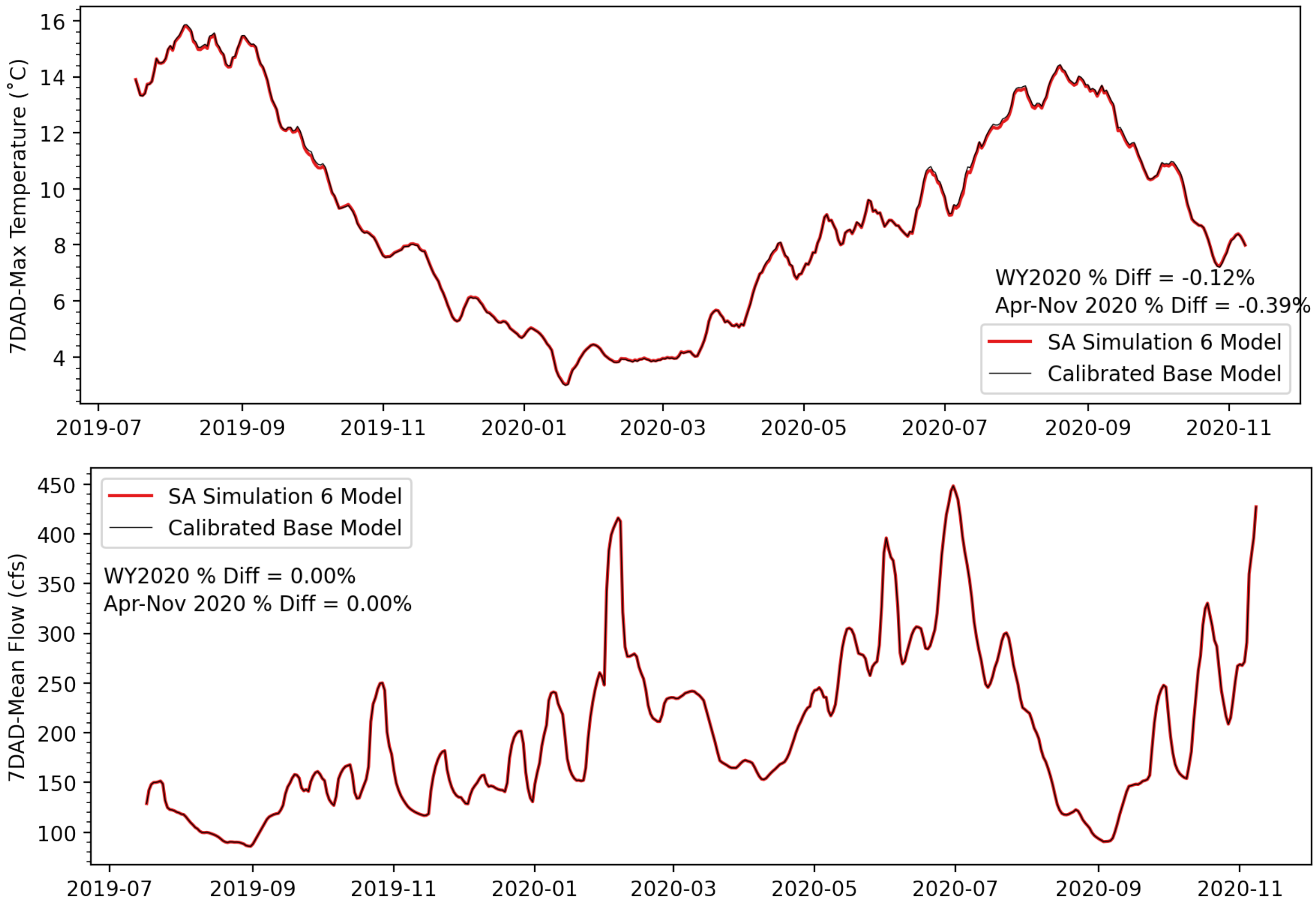


Figure C.4-12. Skagit River at Sauk River confluence 7DAD-Mean flow and max temperature variation for SA Simulation 6 (halve spillway-powerhouse flow ratio).

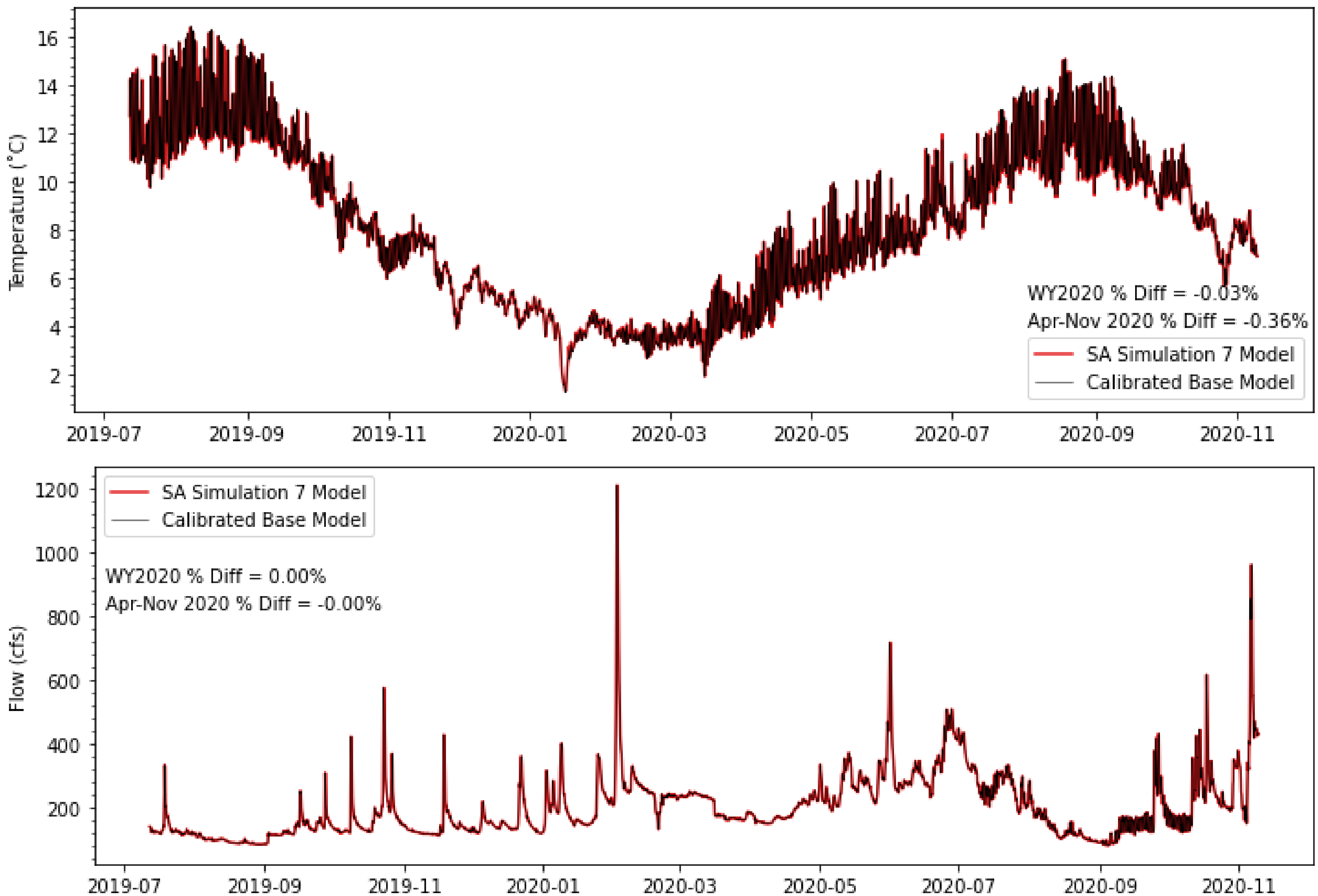


Figure C.4-13. Skagit River at Sauk River confluence continuous hourly flow and temperature variation for SA Simulation 7 (remove top 5 withdrawal layers).

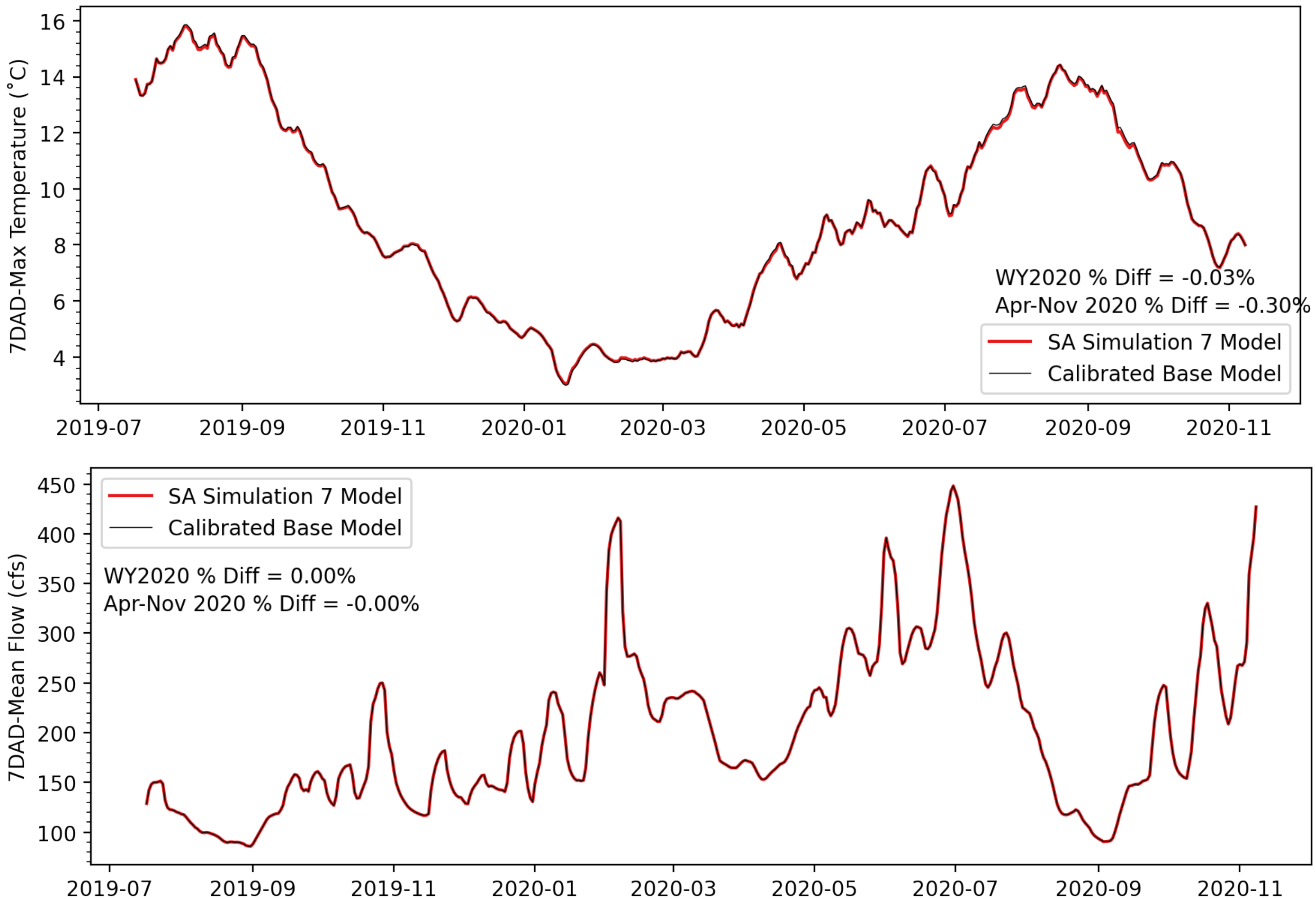


Figure C.4-14. Skagit River at Sauk River confluence 7DAD-Mean flow and max temperature variation for SA Simulation 7 (remove top 5 withdrawal layers).

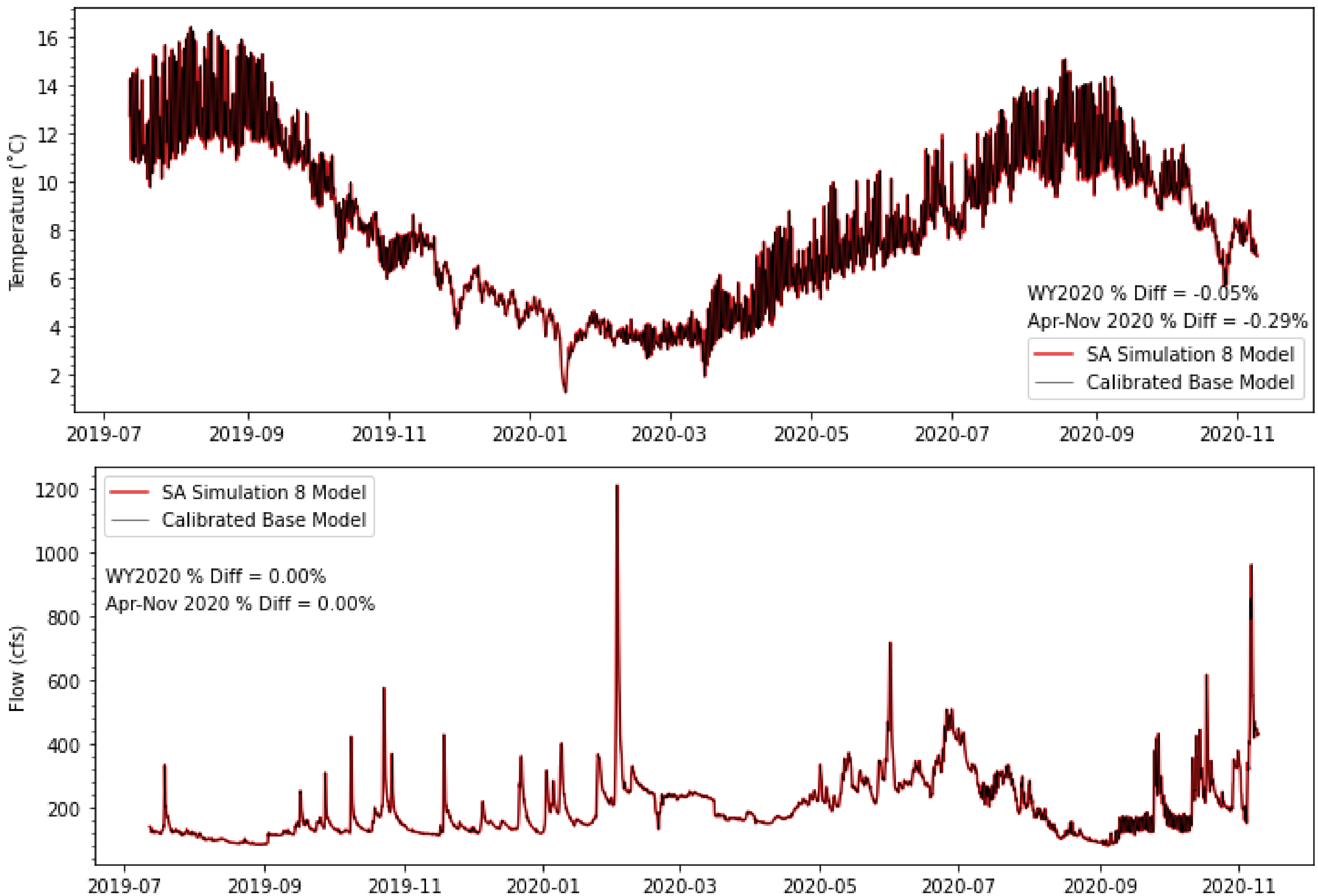


Figure C.4-15. Skagit River at Sauk River confluence continuous hourly flow and temperature variation for SA Simulation 8 (remove bottom 5 withdrawal layers).

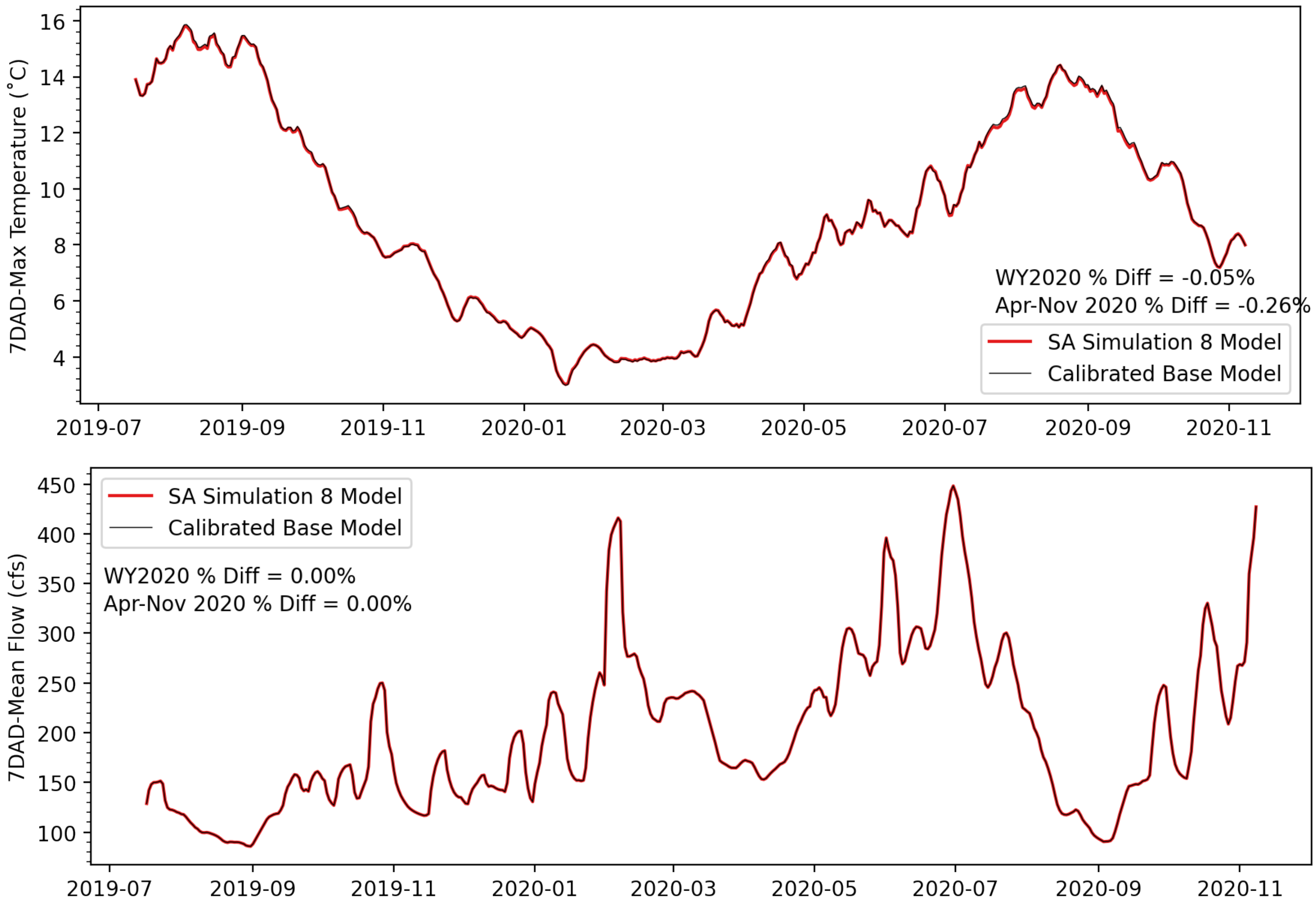


Figure C.4-16. Skagit River at Sauk River confluence 7DAD-Mean flow and max temperature variation for SA Simulation 8 (remove bottom 5 withdrawal layers).

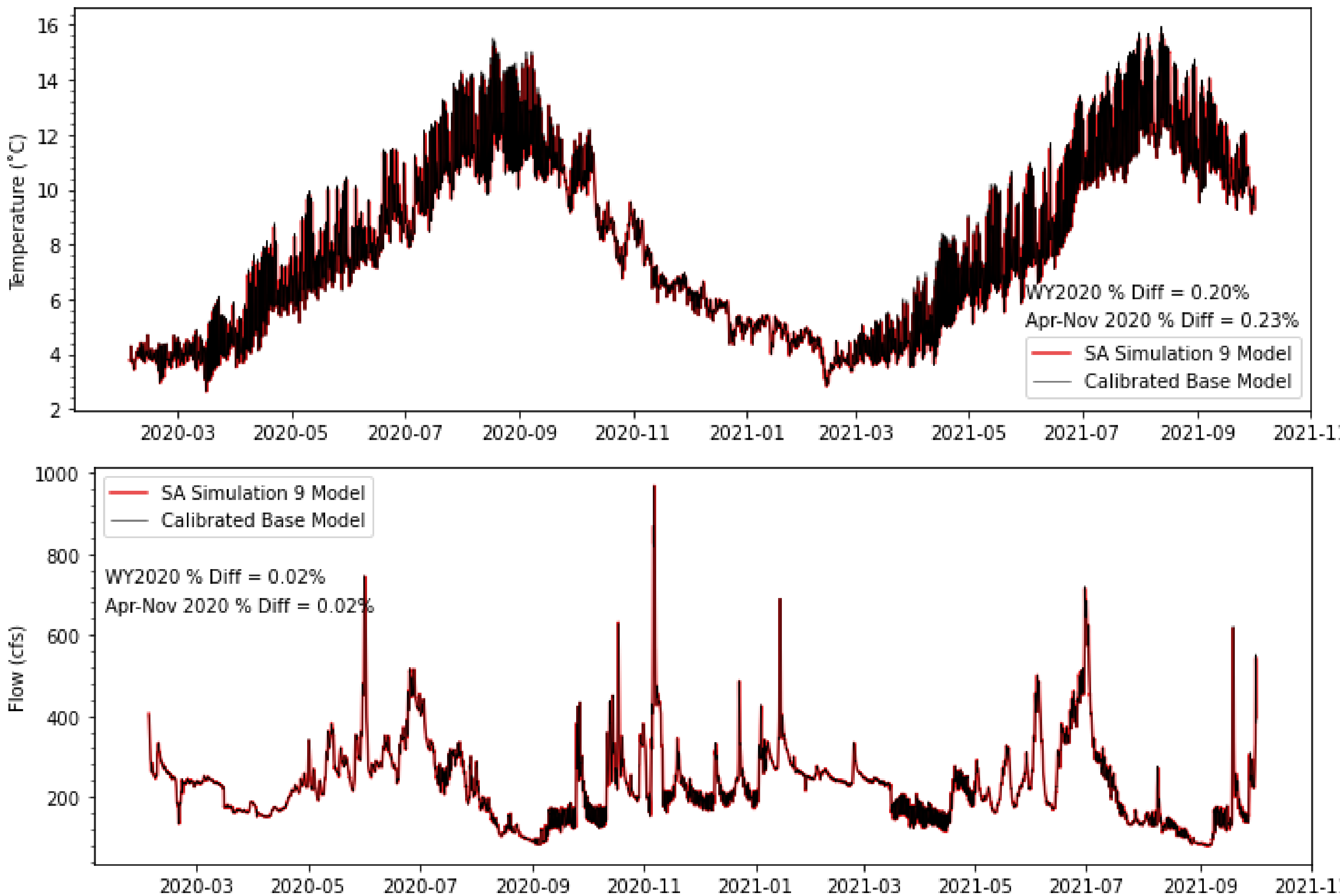


Figure C.4-17. Skagit River at Sauk River confluence continuous hourly flow and temperature variation for SA Simulation 9 (double river bed roughness coefficient).

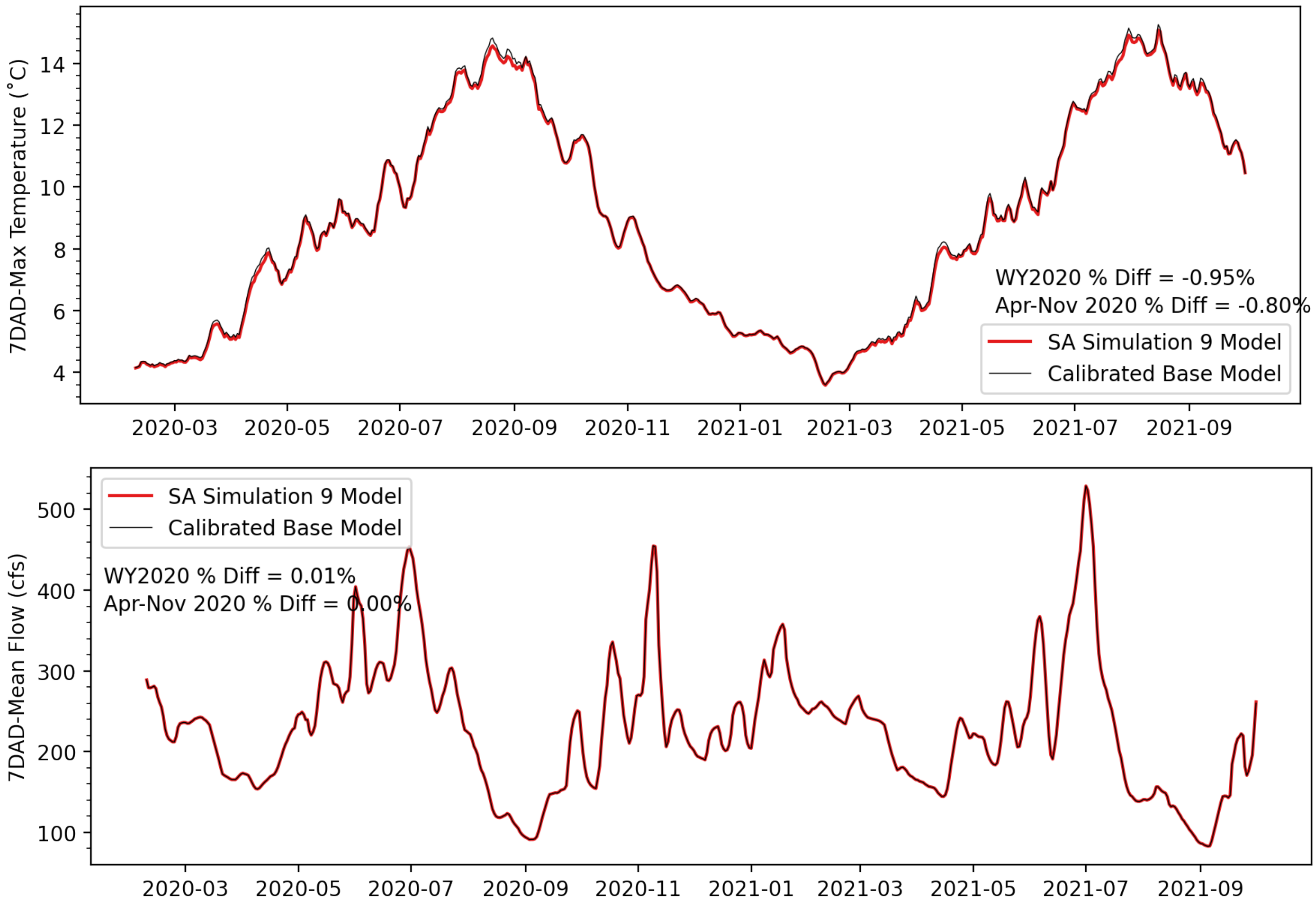


Figure C.4-18. **Skagit River at Sauk River Confluence 7DAD-Mean flow and max temperature variation for SA Simulation 9 (double river bed channel roughness coefficient).**

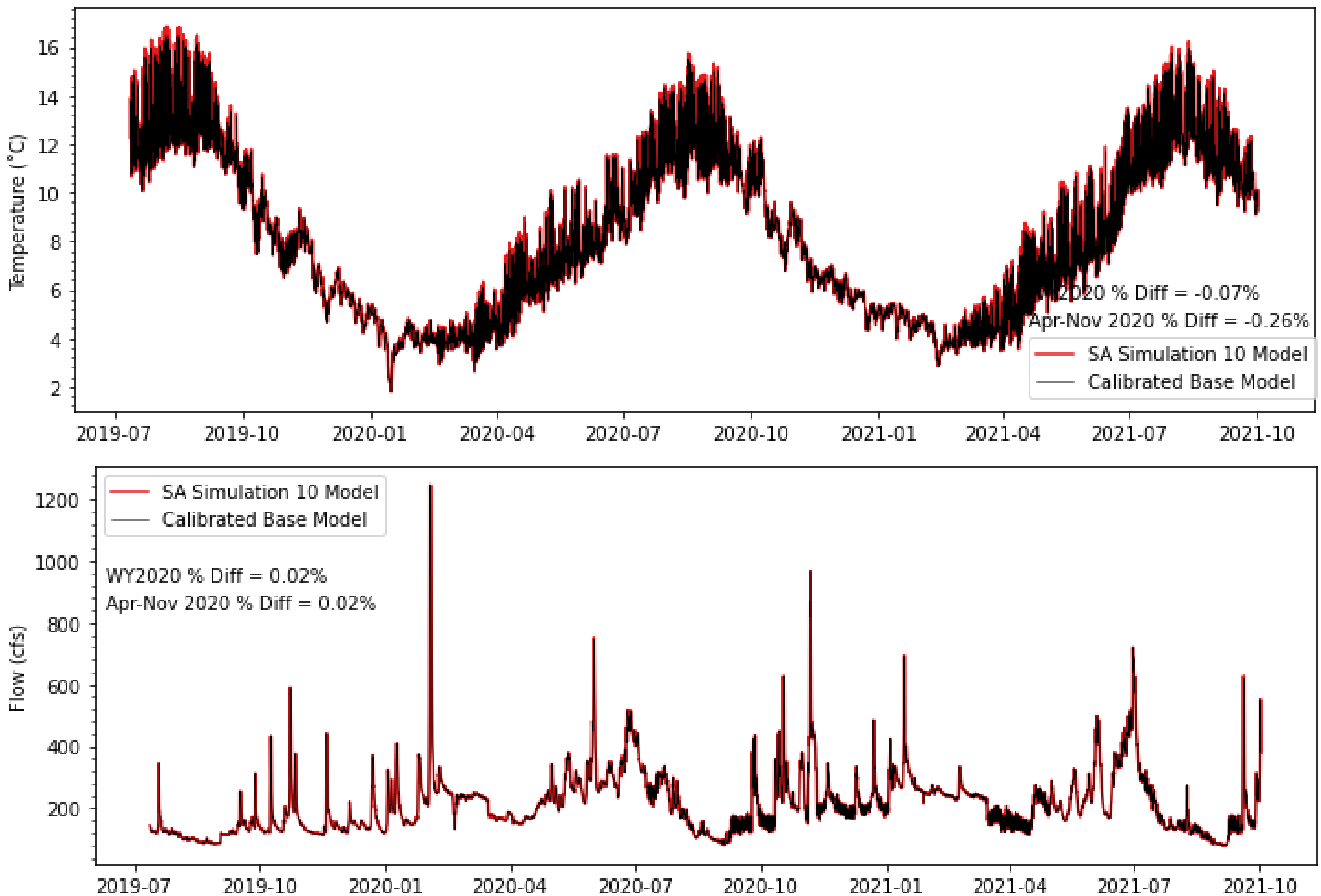


Figure C.4-19. Skagit River at Sauk River confluence continuous hourly flow and temperature variation for SA Simulation 10 (halve river bed roughness coefficient).

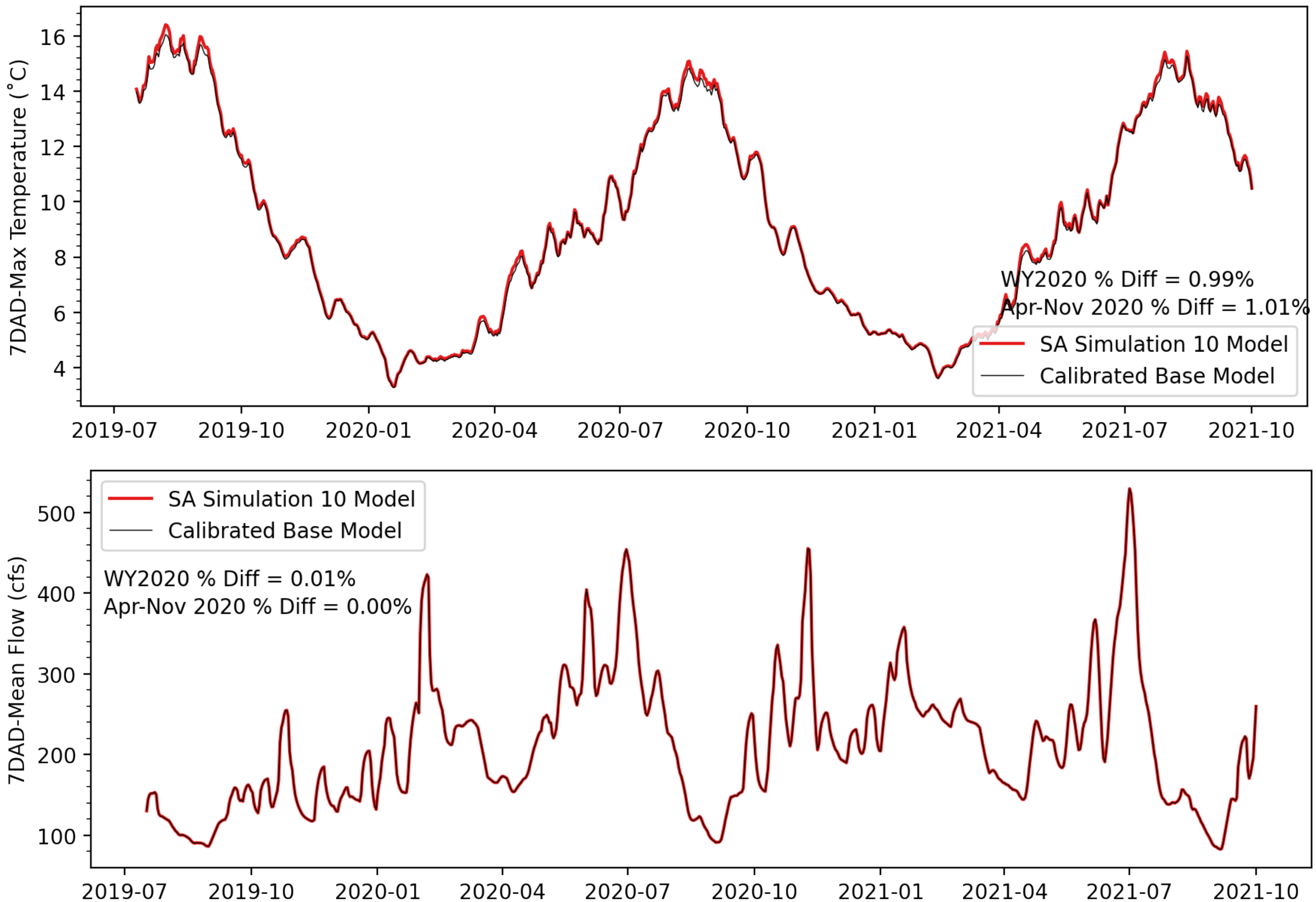


Figure C.4-20. Skagit River at Sauk River confluence 7DAD-Mean flow and max temperature variation for SA Simulation 10 (halve river bed channel roughness coefficient).

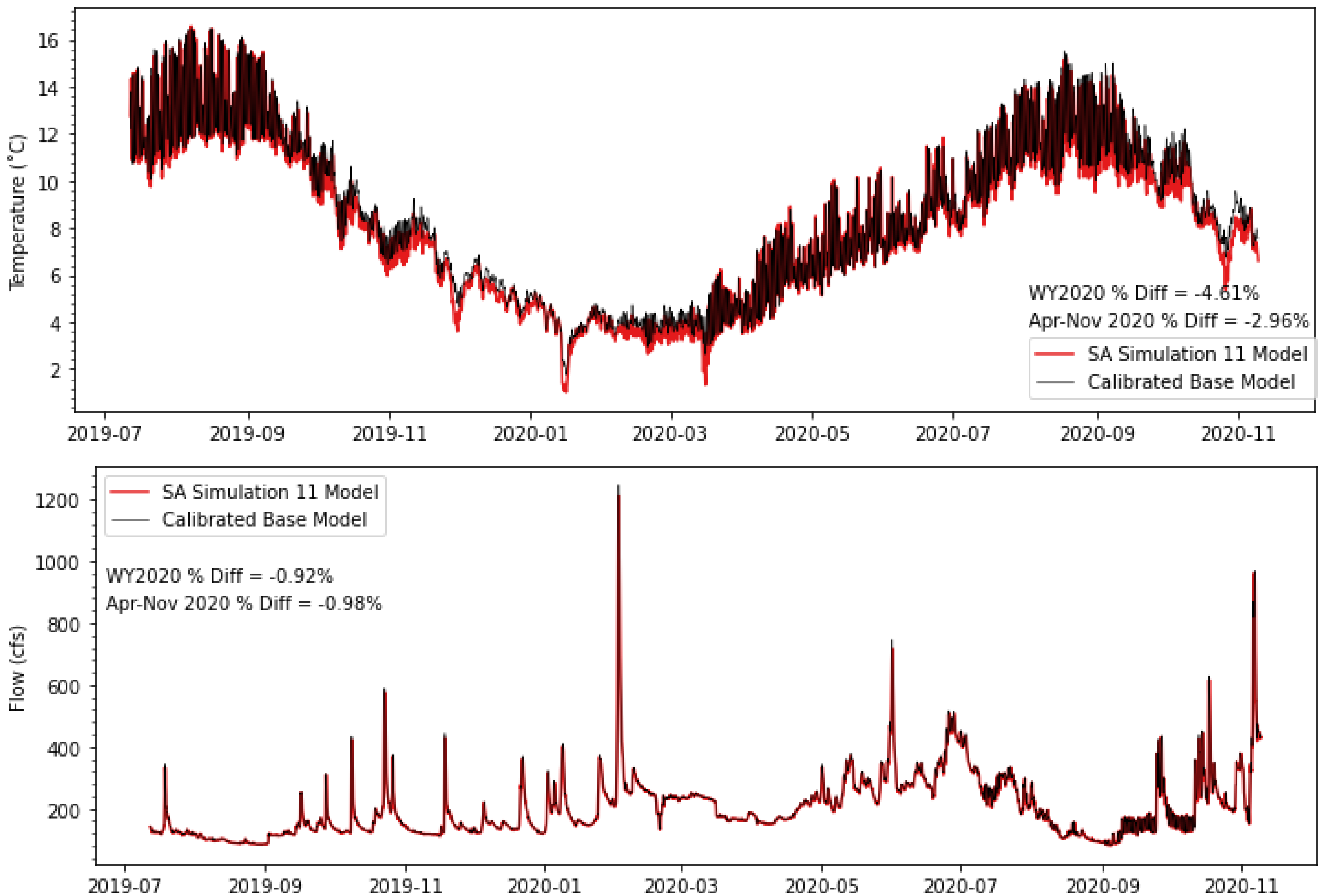


Figure C.4-21. Skagit River at Sauk River confluence continuous hourly flow and temperature variation for SA Simulation 11 (double wind sheltering coefficient).

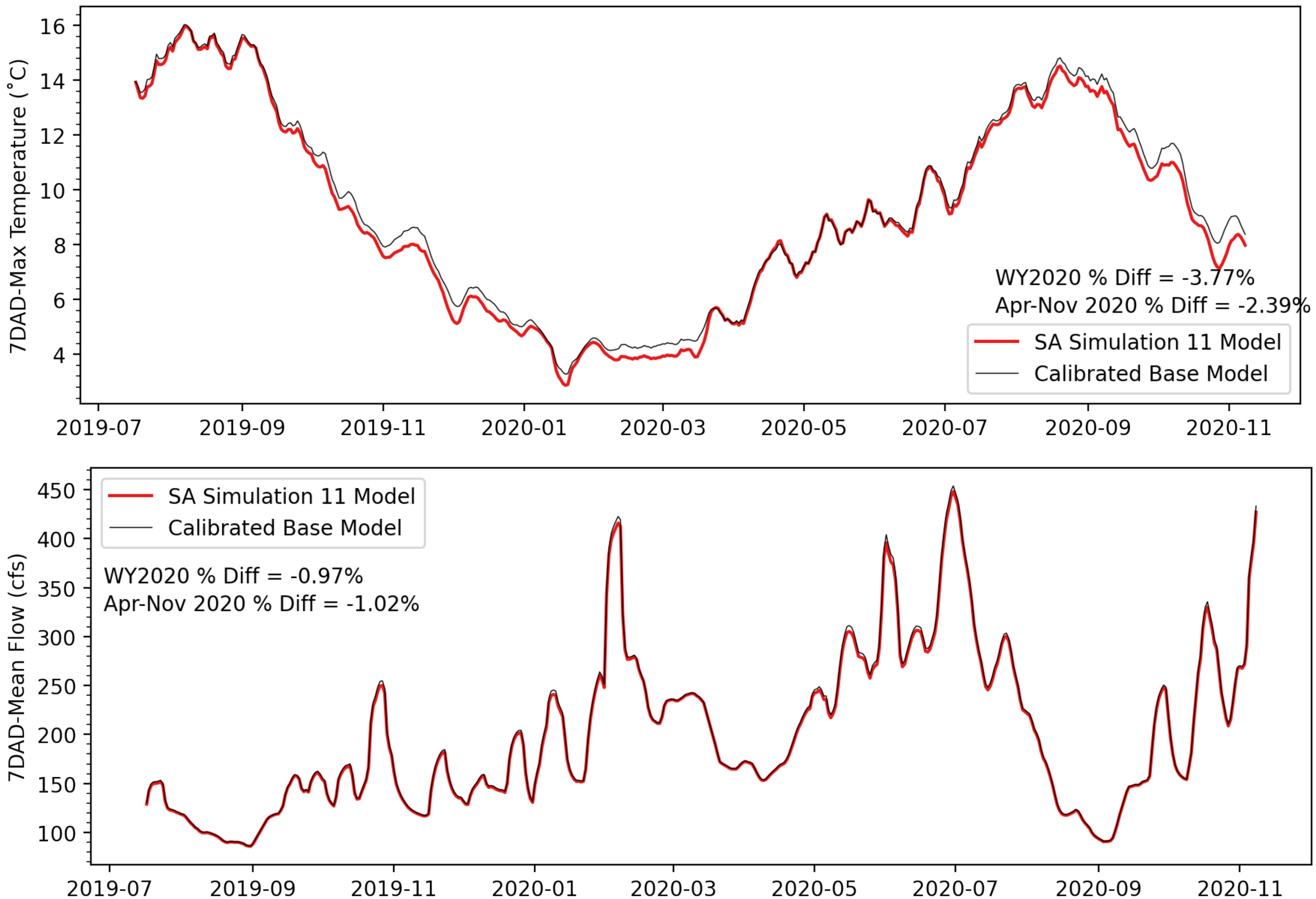


Figure C.4-22. Skagit River at Sauk River confluence 7DAD-Mean flow and max temperature variation for SA Simulation 11 (double wind sheltering coefficient).

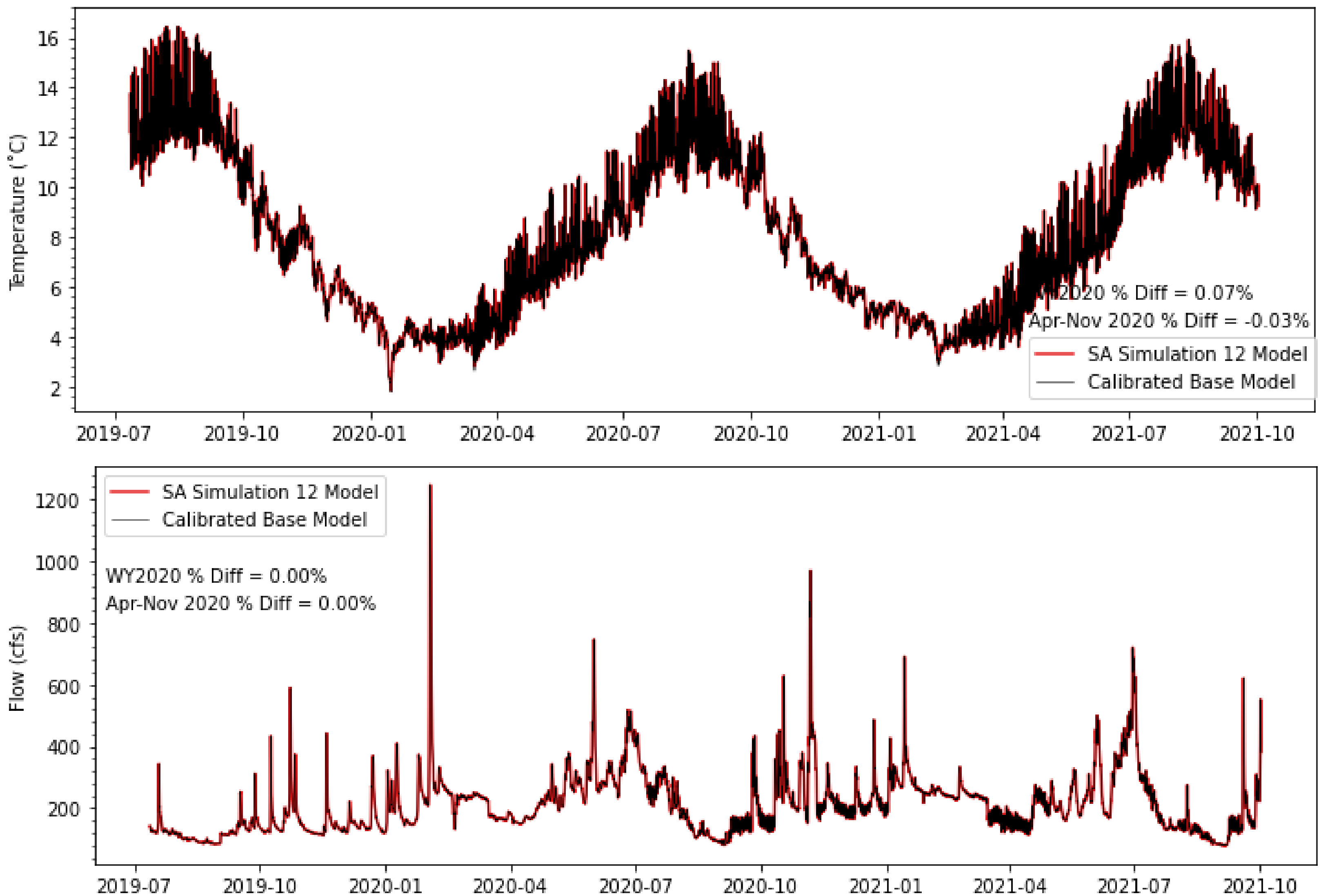


Figure C.4-23. Skagit River at Sauk River confluence continuous hourly flow and temperature variation for SA Simulation 12 (halve wind sheltering coefficient).

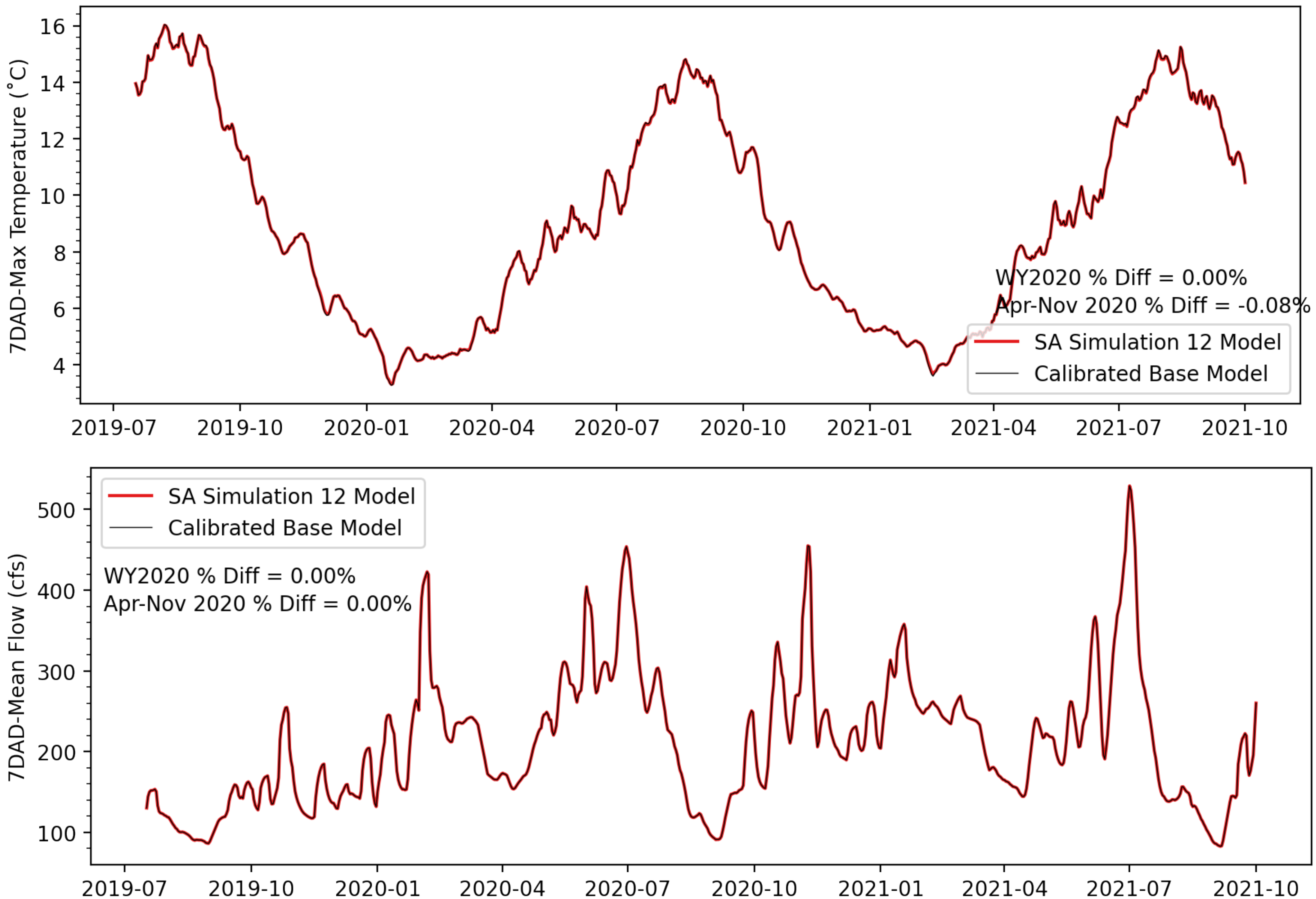


Figure C.4-24. Skagit River at Sauk River confluence 7DAD-Mean flow and max temperature variation for SA Simulation 12 (halve wind sheltering coefficient).

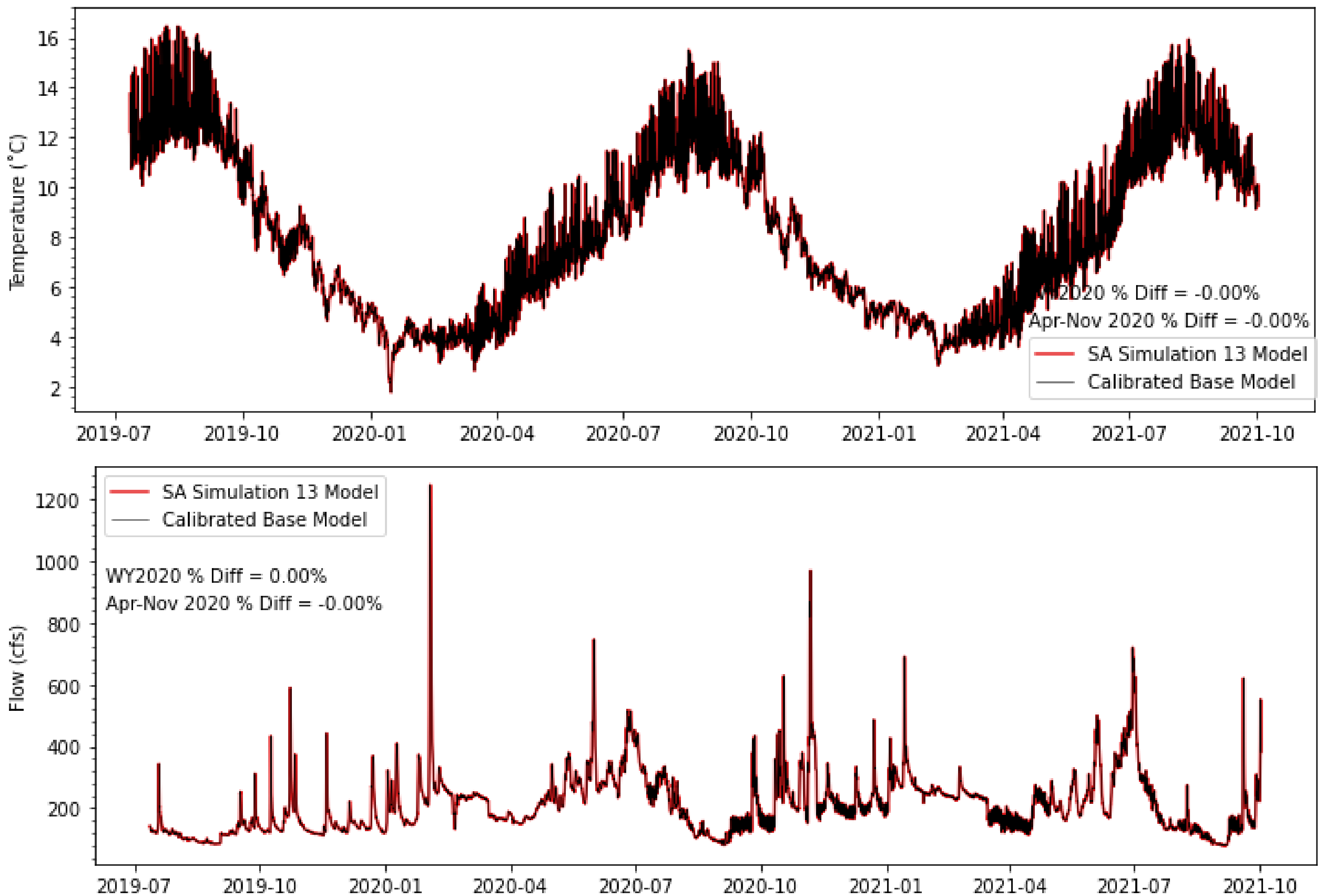


Figure C.4-25. Skagit River at Sauk River confluence continuous hourly flow and temperature variation for SA Simulation 13 (rotate wind direction by 90 degrees clockwise).

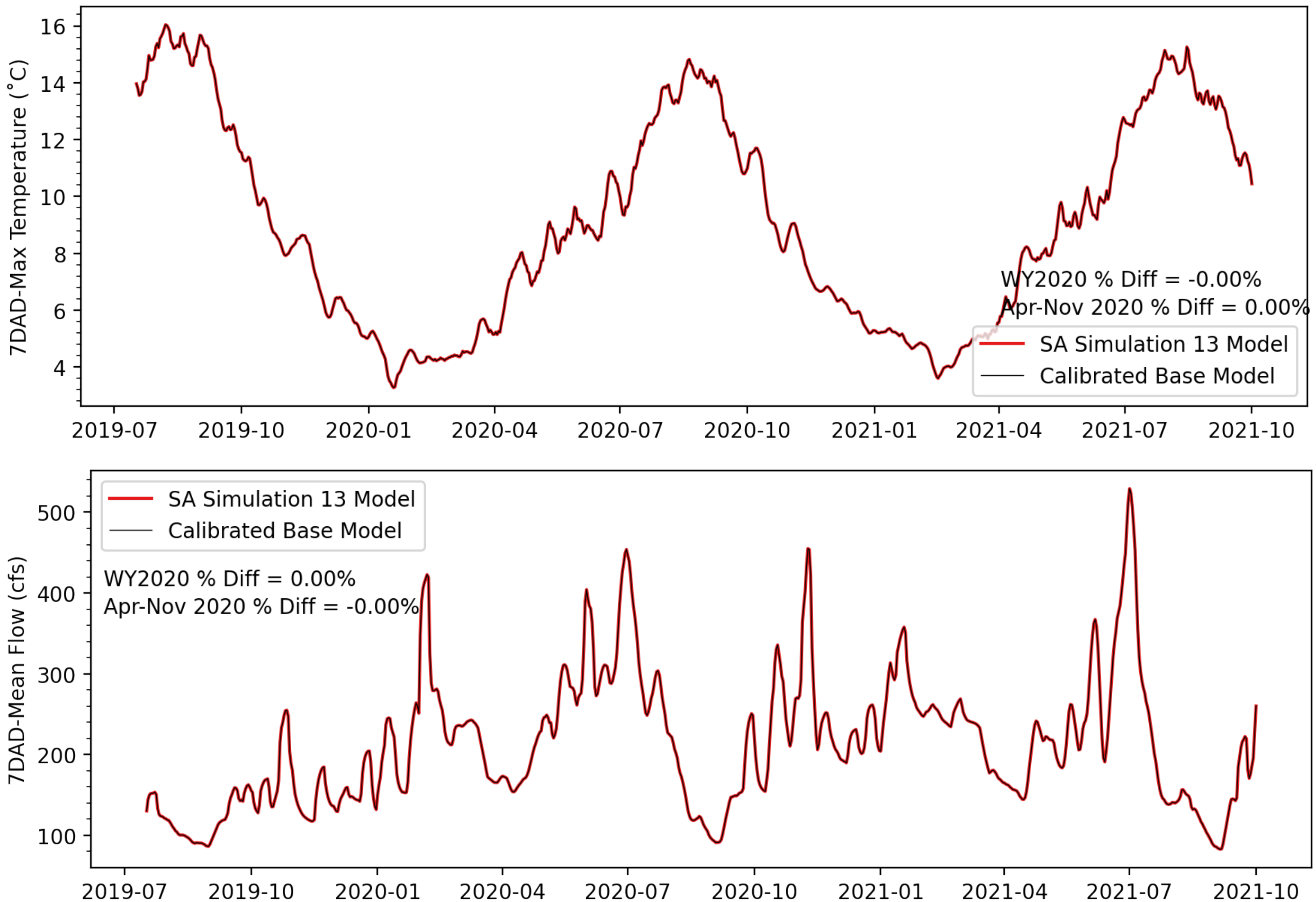


Figure C.4-26. Skagit River at Sauk River confluence 7DAD-Mean flow and max temperature variation for SA Simulation 13 (rotate wind direction 90 degrees clockwise).

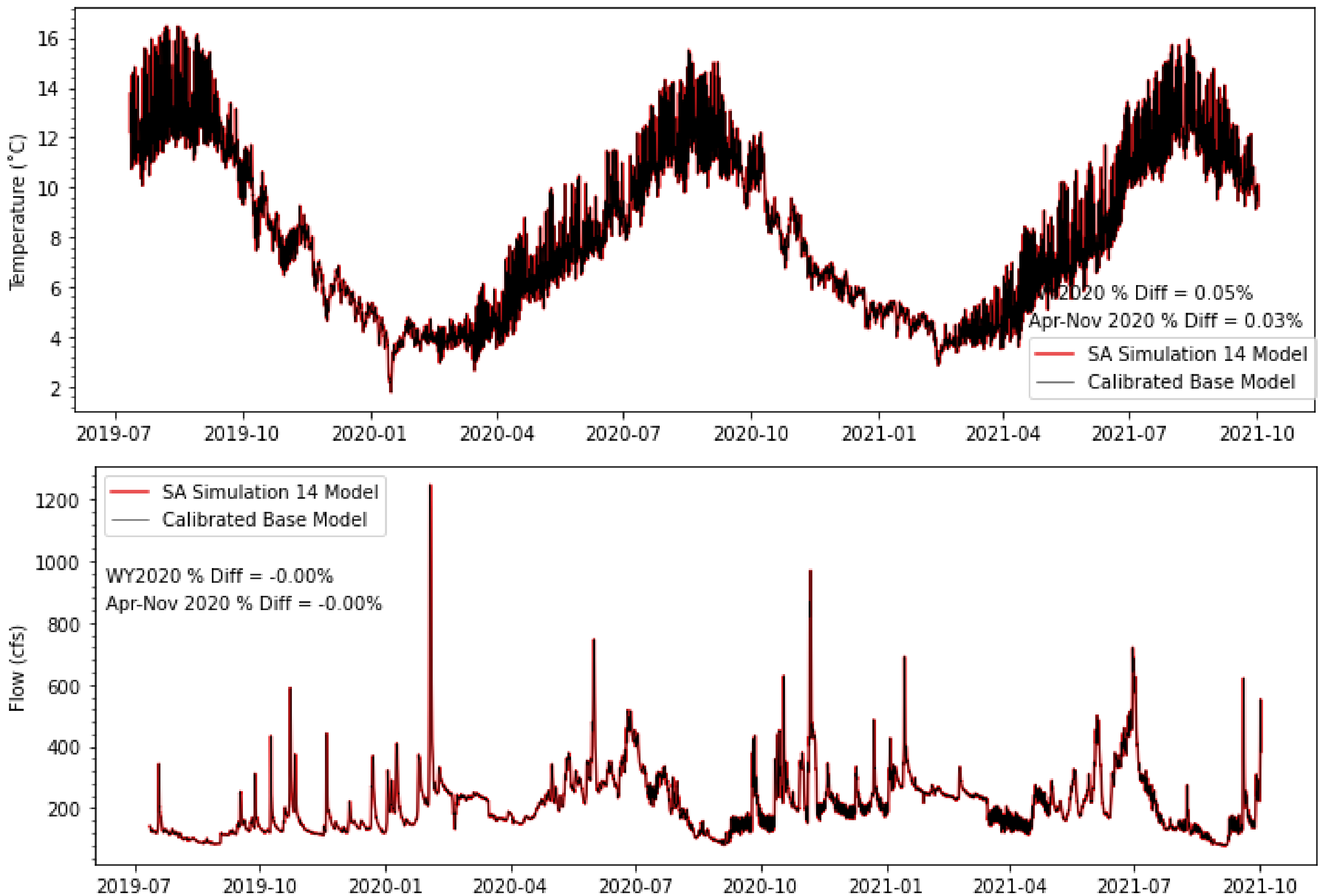


Figure C.4-27. Skagit River at Sauk River confluence continuous hourly flow and temperature variation for SA Simulation 14 (increase sediment temperature by 25 percent).

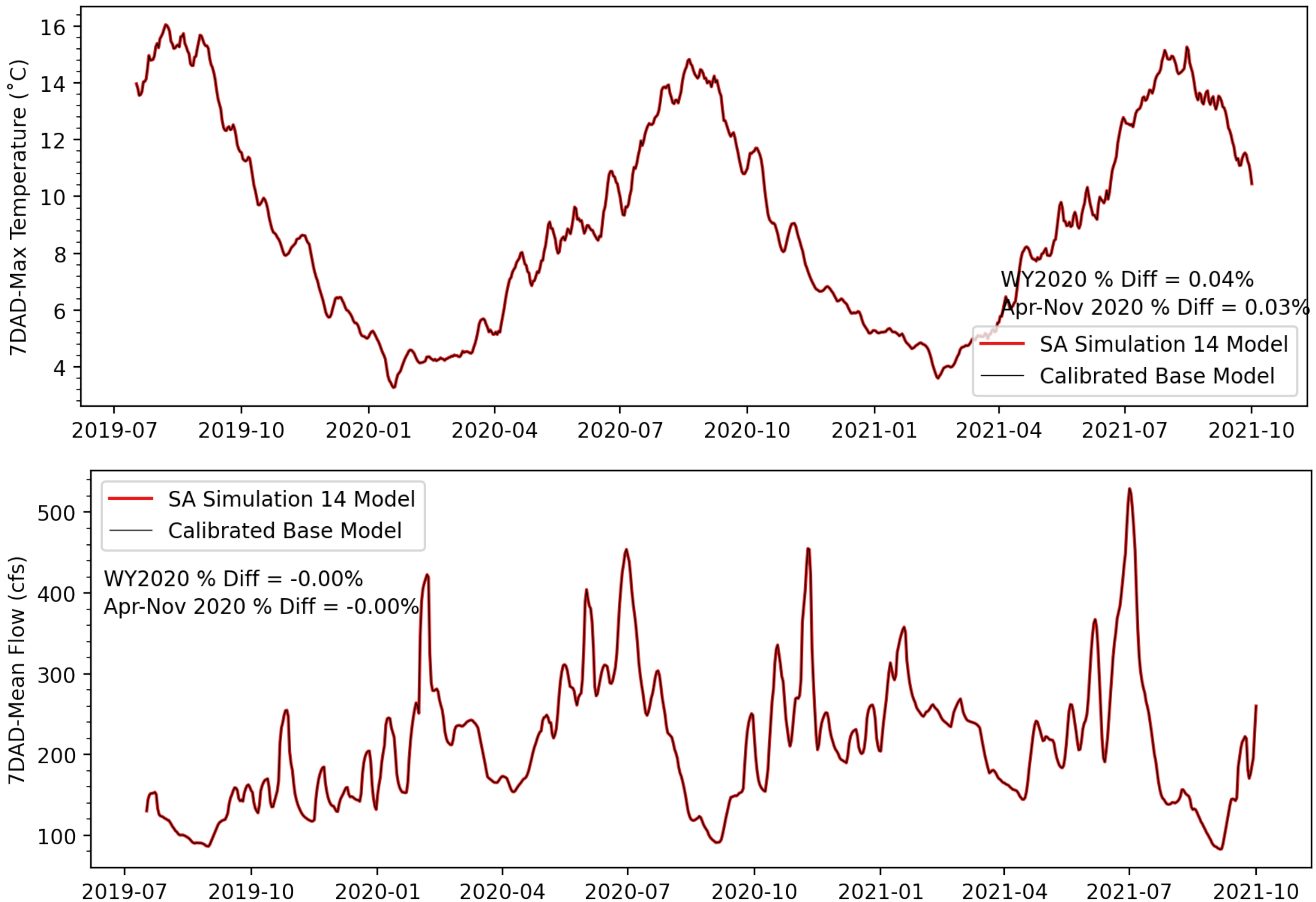


Figure C.4-28. Skagit River at Sauk River confluence 7DAD-mean flow and max temperature variation for SA Simulation 14 (increase sediment temperature by 25 percent).

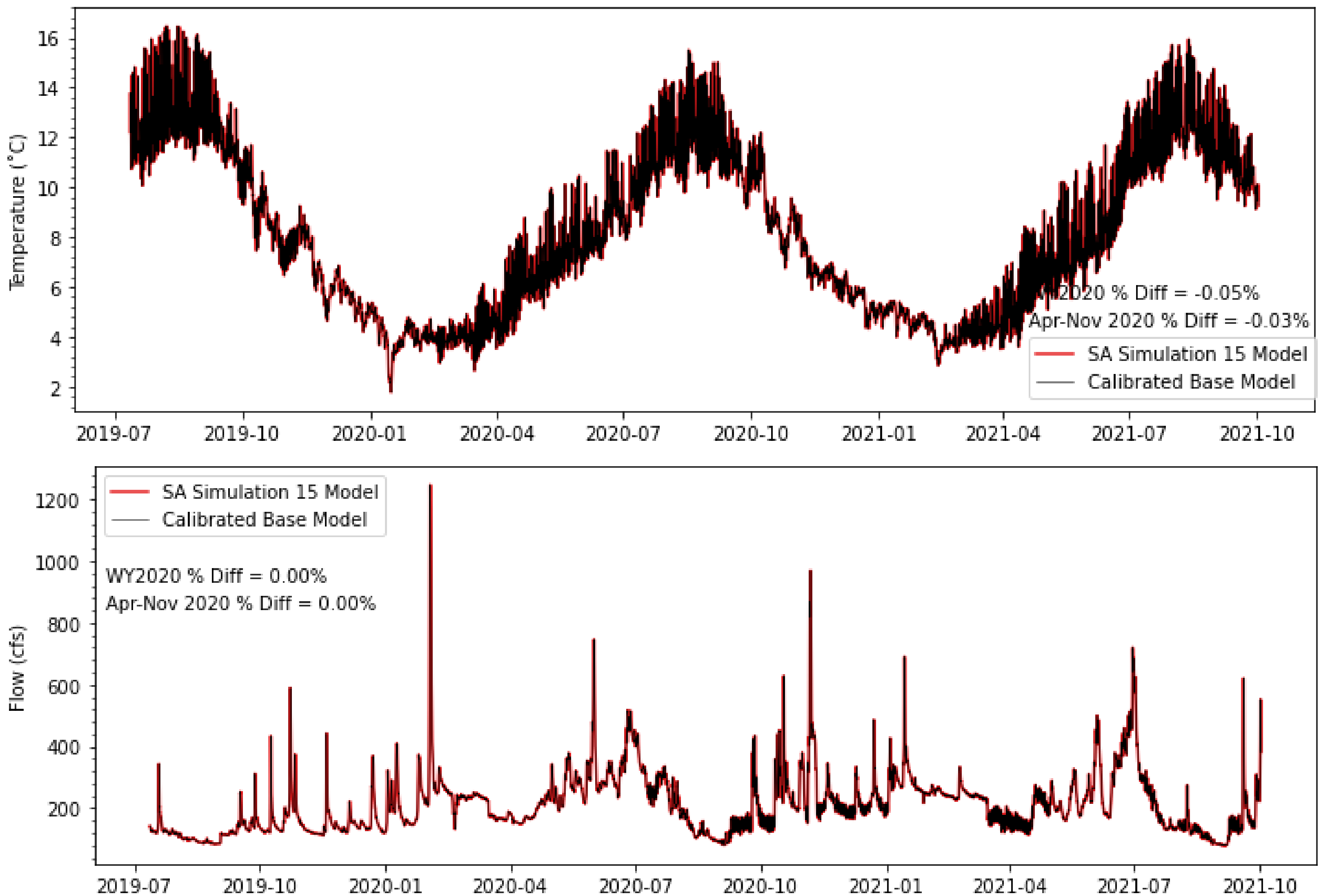


Figure C.4-29. Skagit River at Sauk River confluence continuous hourly flow and temperature variation for SA Simulation 15 (decrease sediment temperature by 25 percent).

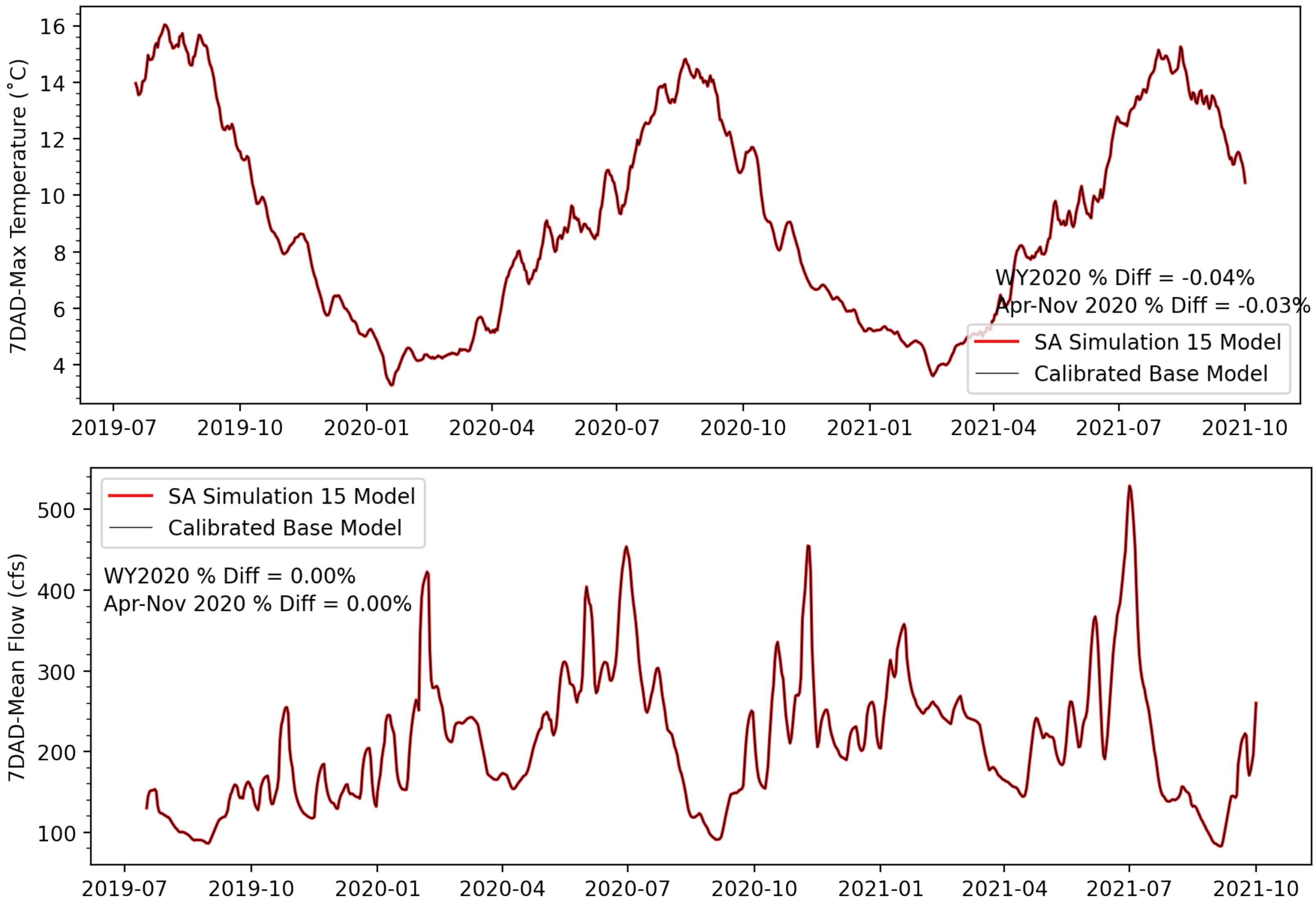


Figure C.4-30. Skagit River at Sauk River confluence 7DAD-Mean flow and max temperature variation for SA Simulation 15 (decrease sediment temperature by 25 percent).

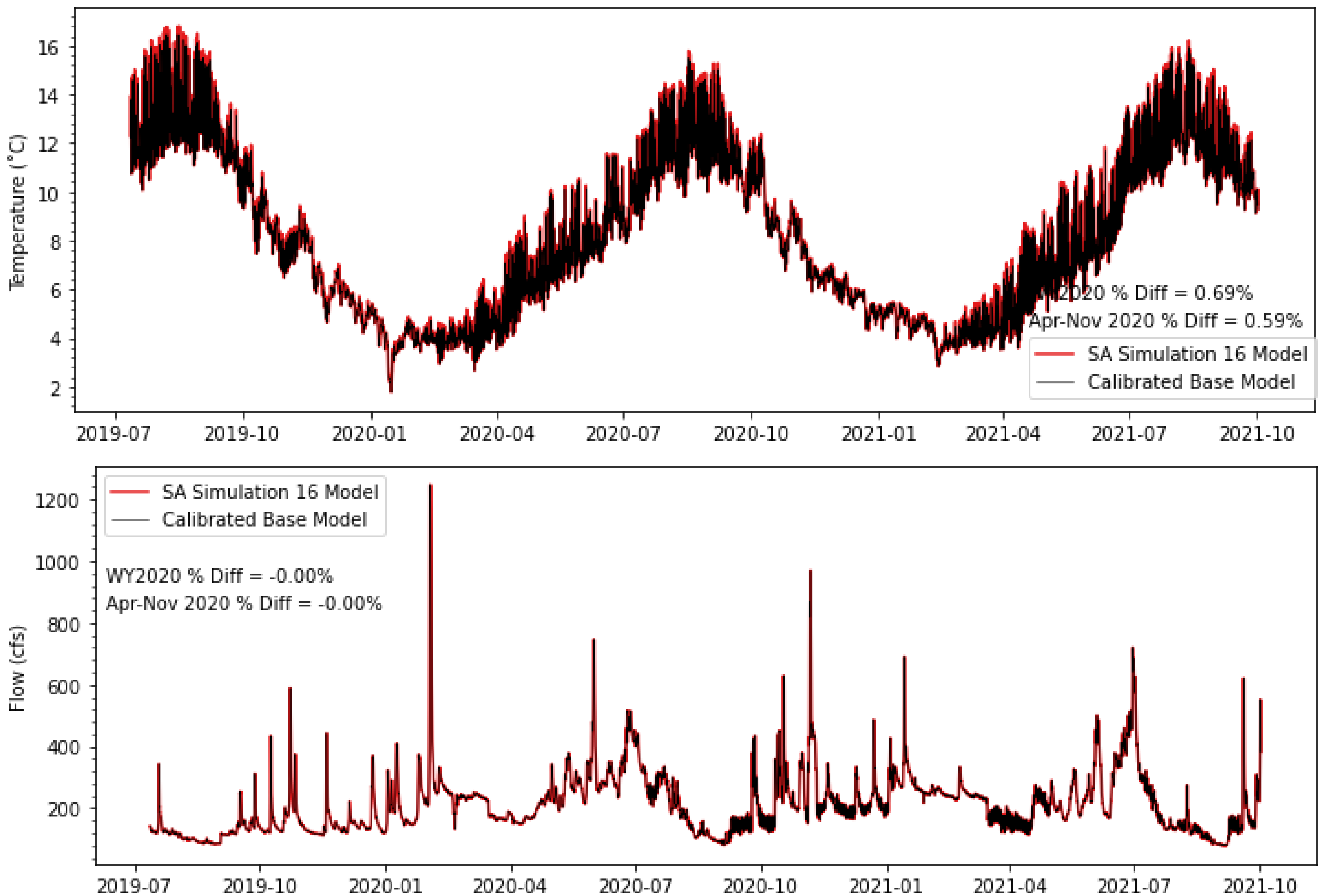


Figure C.4-31. Skagit River at Sauk River confluence continuous hourly flow and temperature variation for SA Simulation 16 (eliminate vegetative shade).

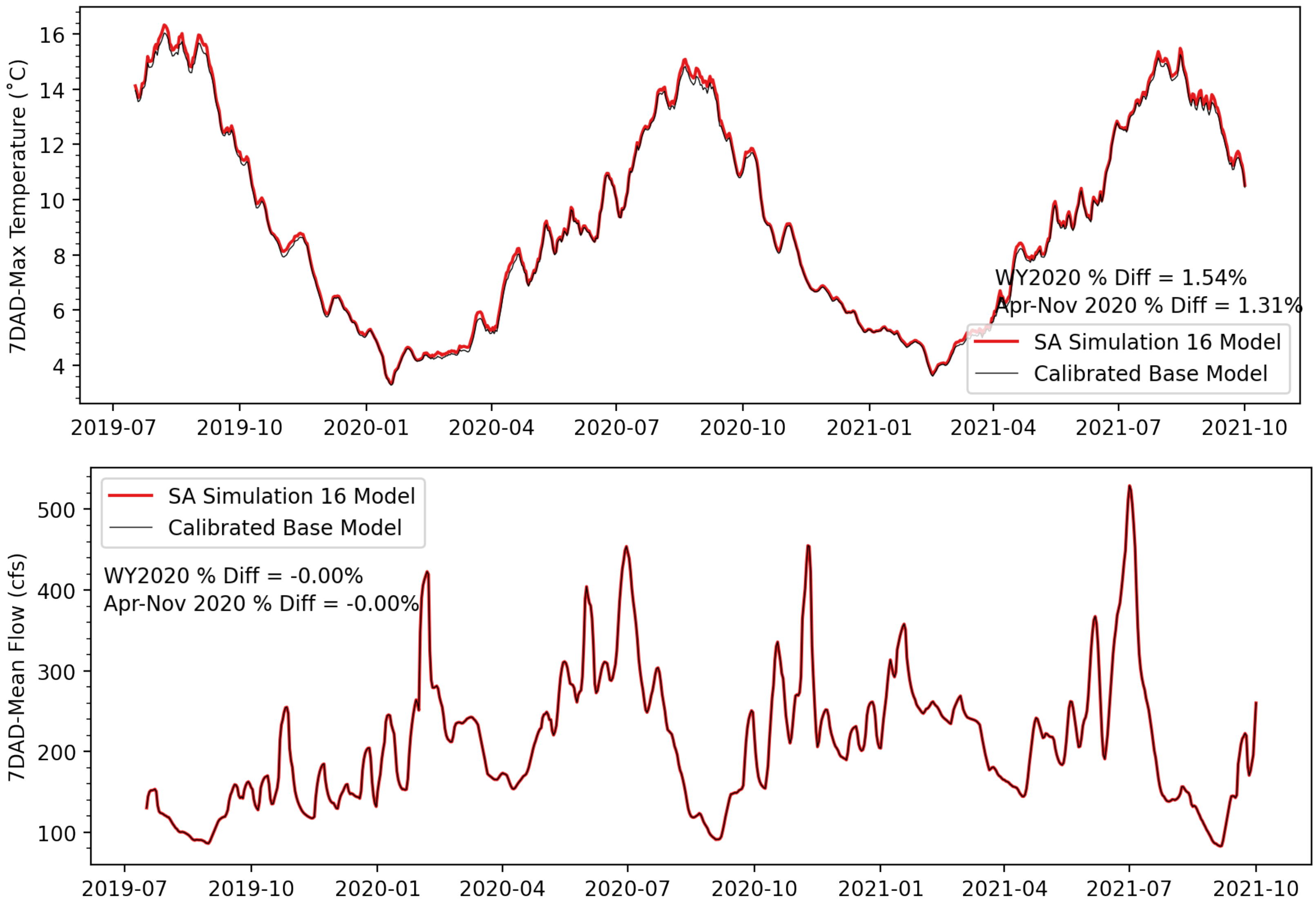


Figure C.4-32. Skagit River at Sauk River confluence 7DAD-Mean flow and max temperature variation for SA Simulation 16 (eliminate vegetative shade).

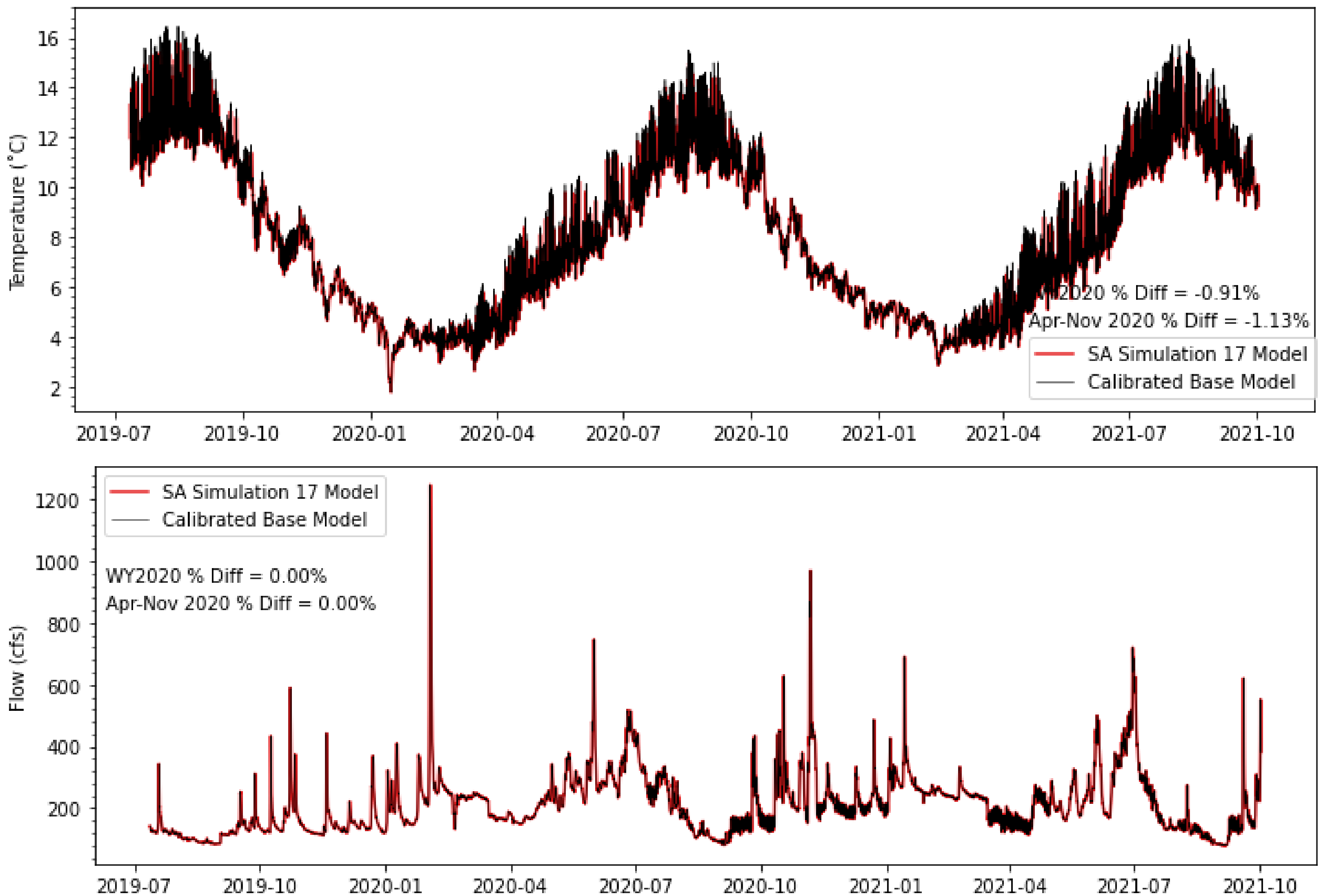


Figure C.4-33. Skagit River at Sauk River confluence continuous hourly flow and temperature variation for SA Simulation 17 (set sediment heat transfer coefficient to 0).

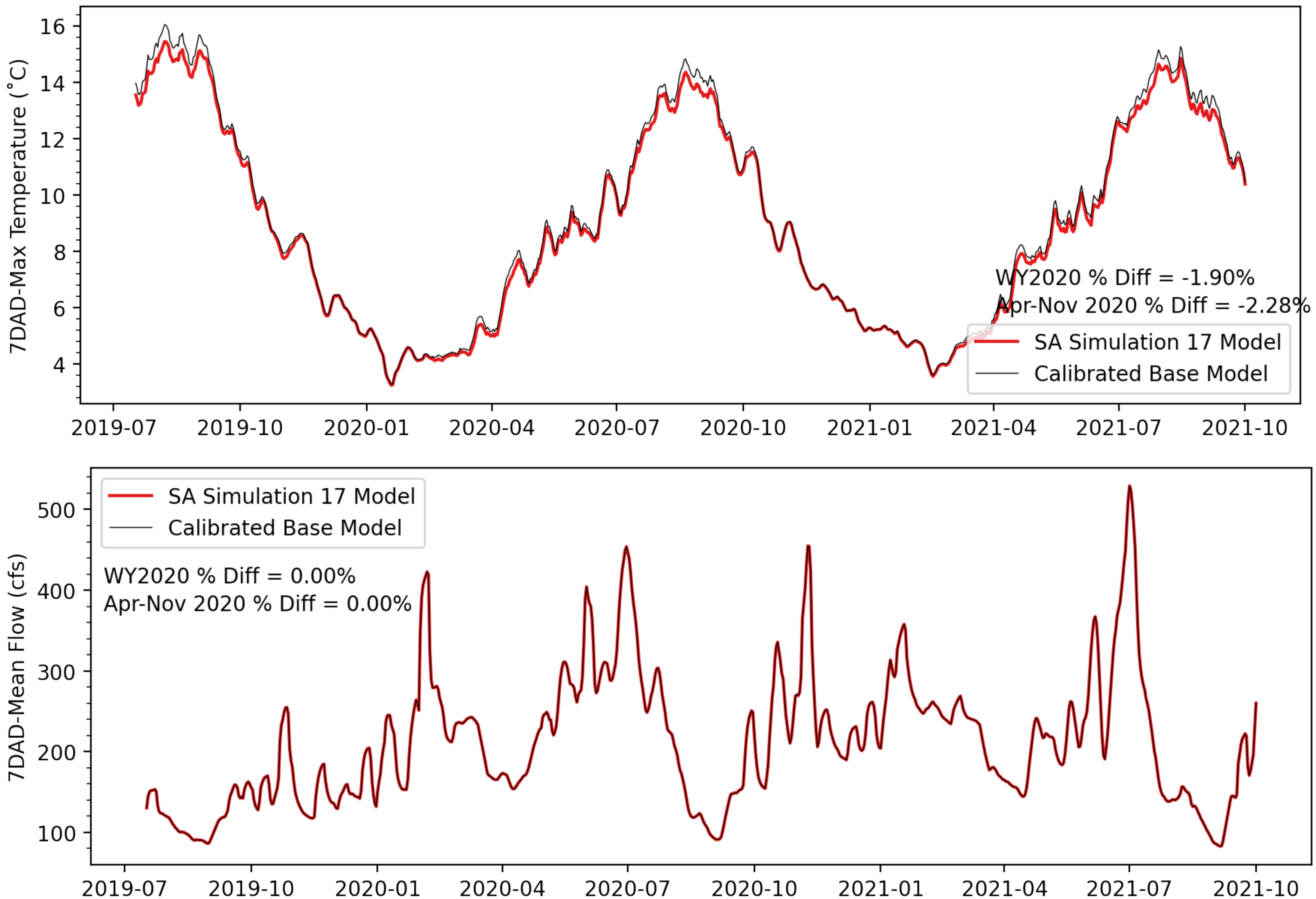


Figure C.4-34. Skagit River at Sauk River confluence 7DAD-Mean flow and max temperature variation for SA Simulation 17 (set sediment heat transfer coefficient to 0).

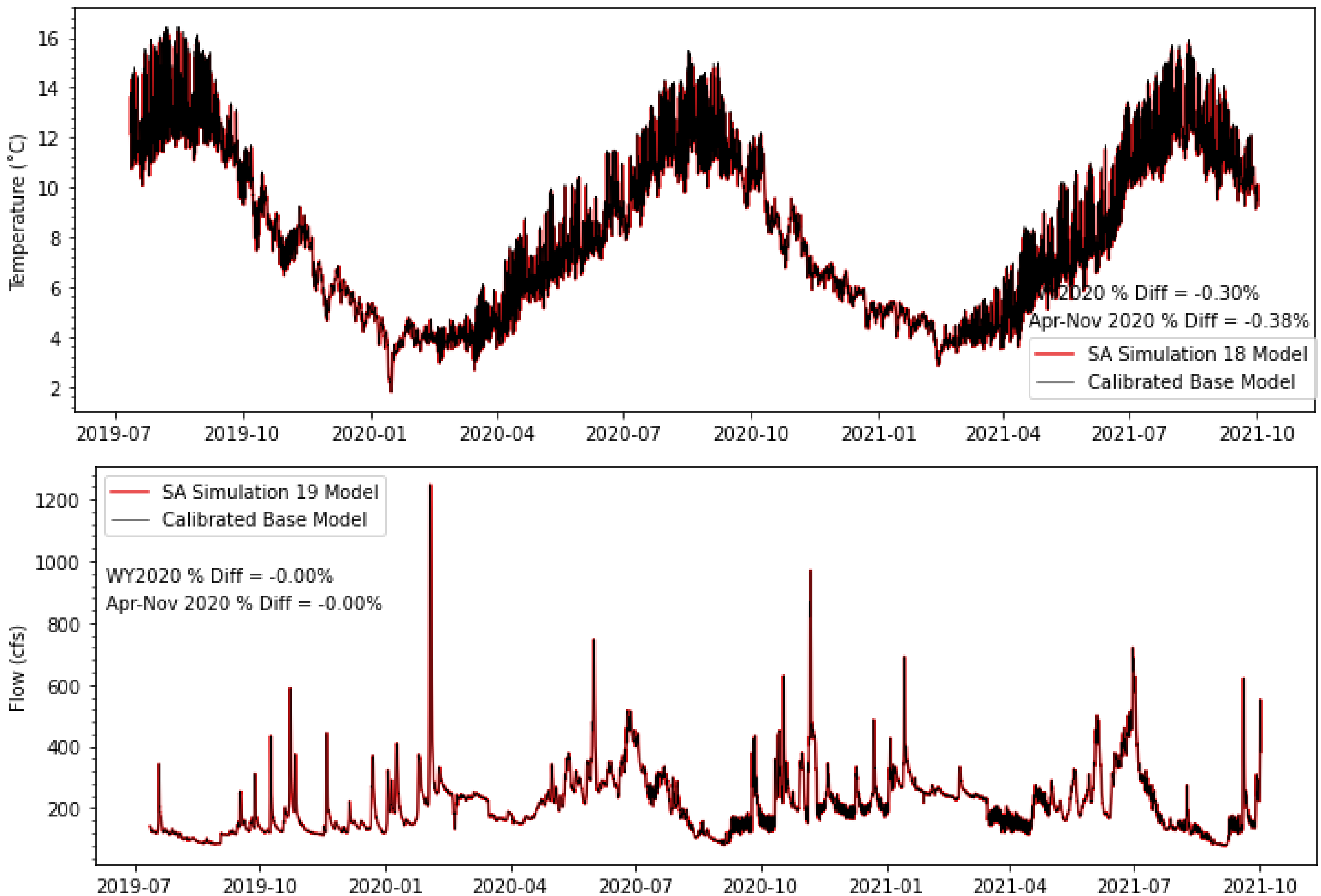


Figure C.4-35. Skagit River at Sauk River confluence continuous hourly flow and temperature variation for SA Simulation 18 (set sediment heat transfer coefficient to 0.5).

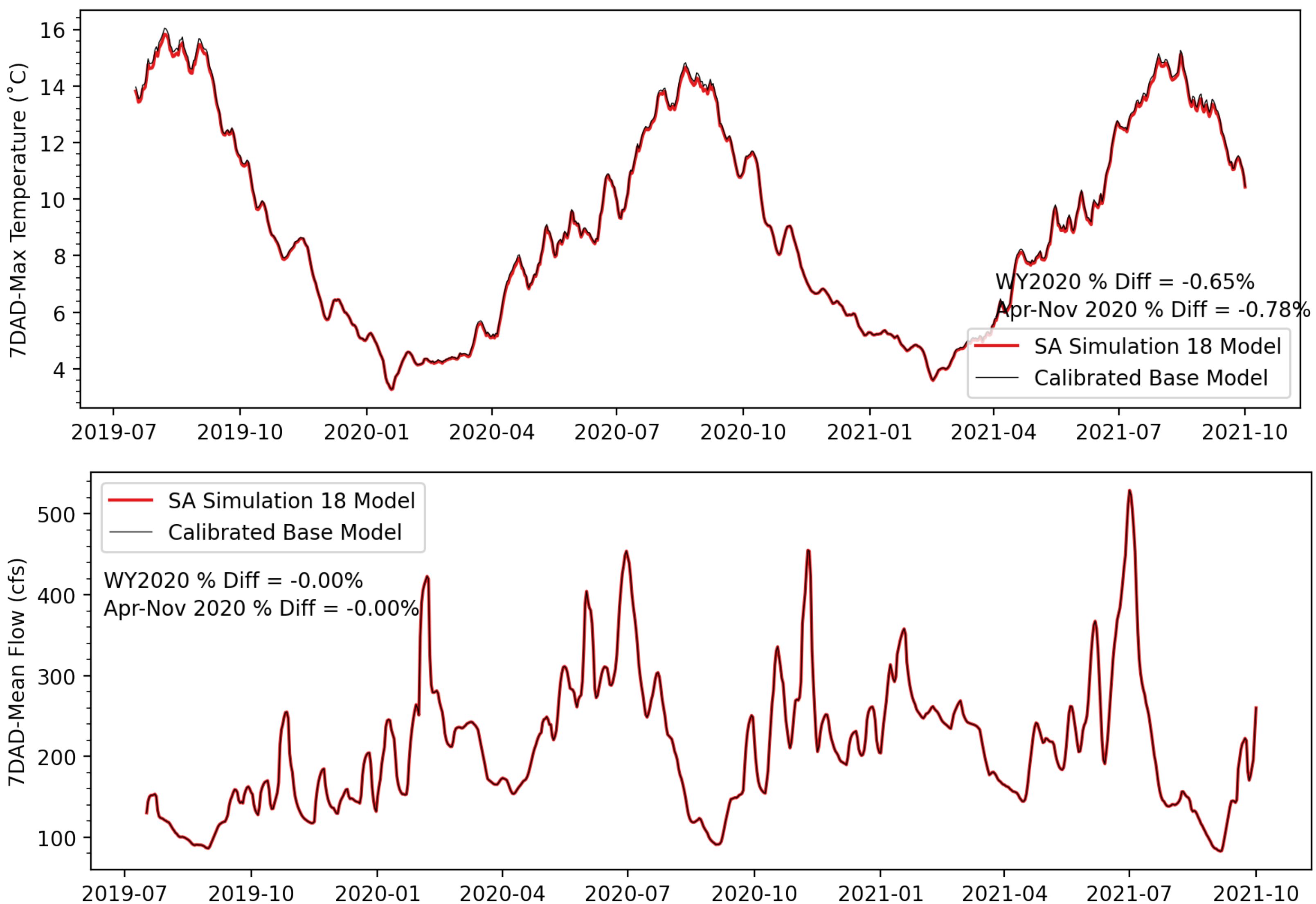


Figure C.4-36. **Skagit River at Sauk River confluence 7DAD-Mean flow and max temperature variation for SA Simulation 18 (Set sediment heat transfer coefficient to 0.5).**

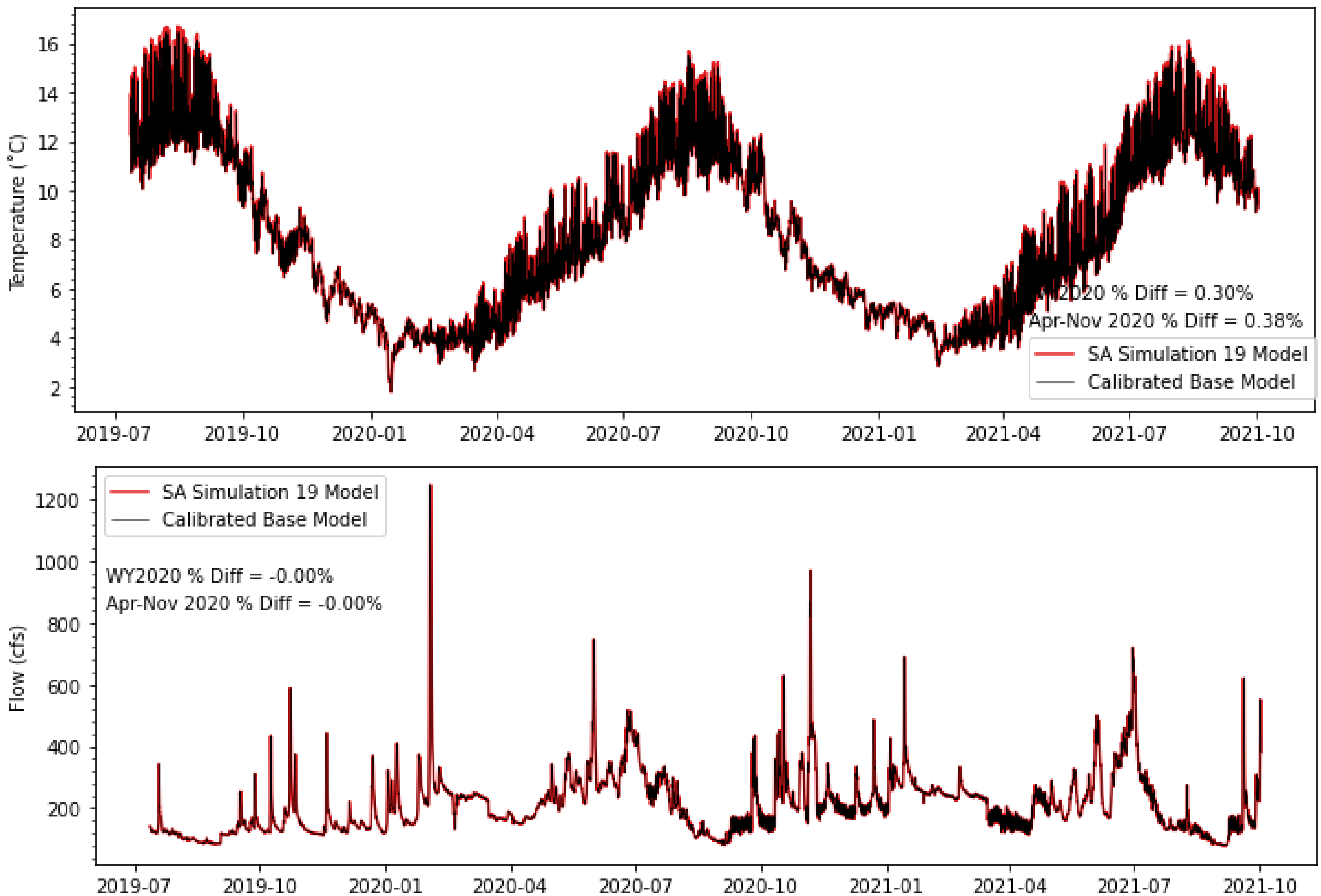


Figure C.4-37. Skagit River at Sauk River confluence continuous hourly flow and temperature variation for SA Simulation 19 (set sediment heat transfer coefficient to 1.0).

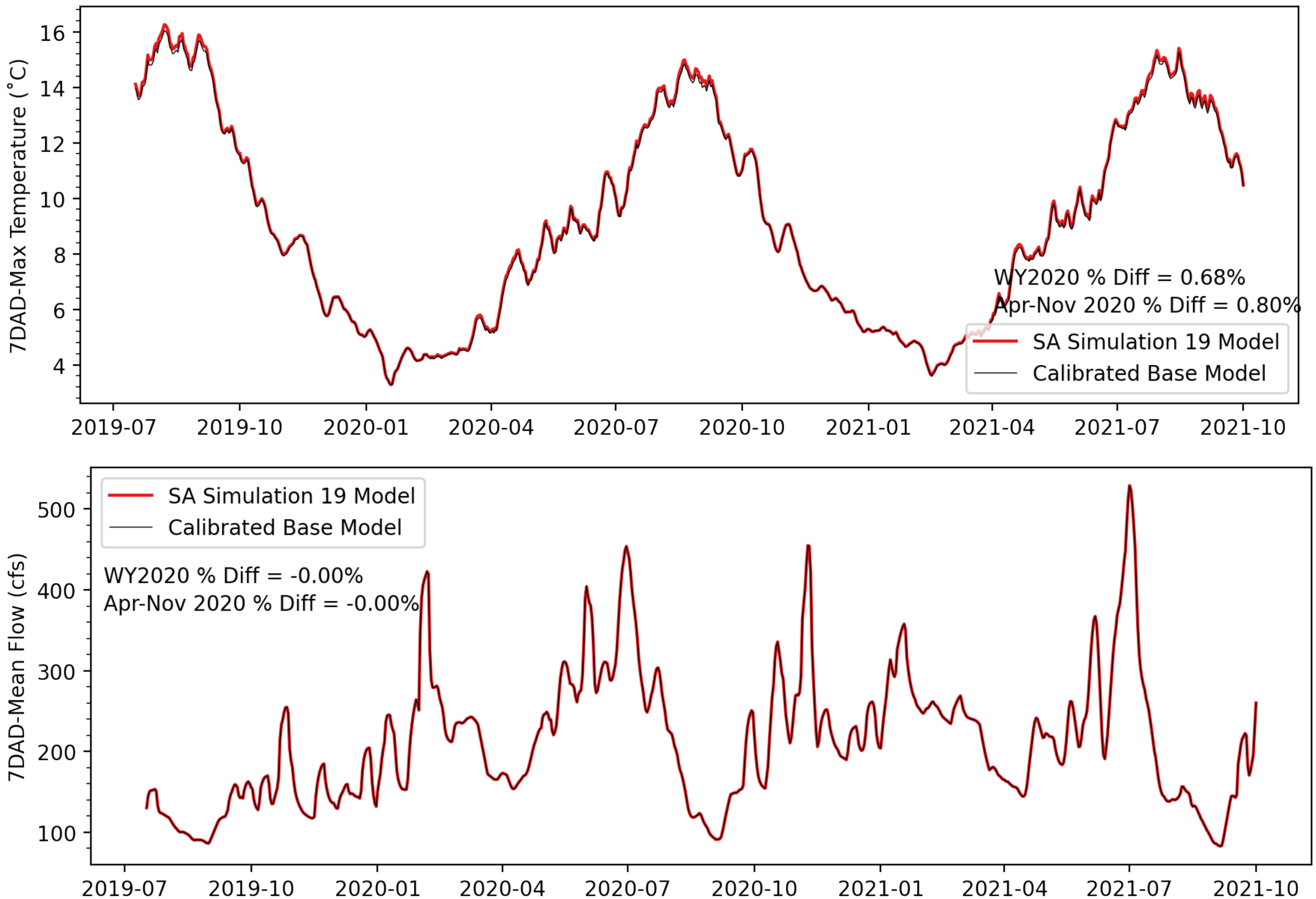


Figure C.4-38. Skagit River at Sauk River confluence 7DAD-Mean flow and max temperature variation for SA Simulation 19 (set sediment heat transfer coefficient to 1.0).

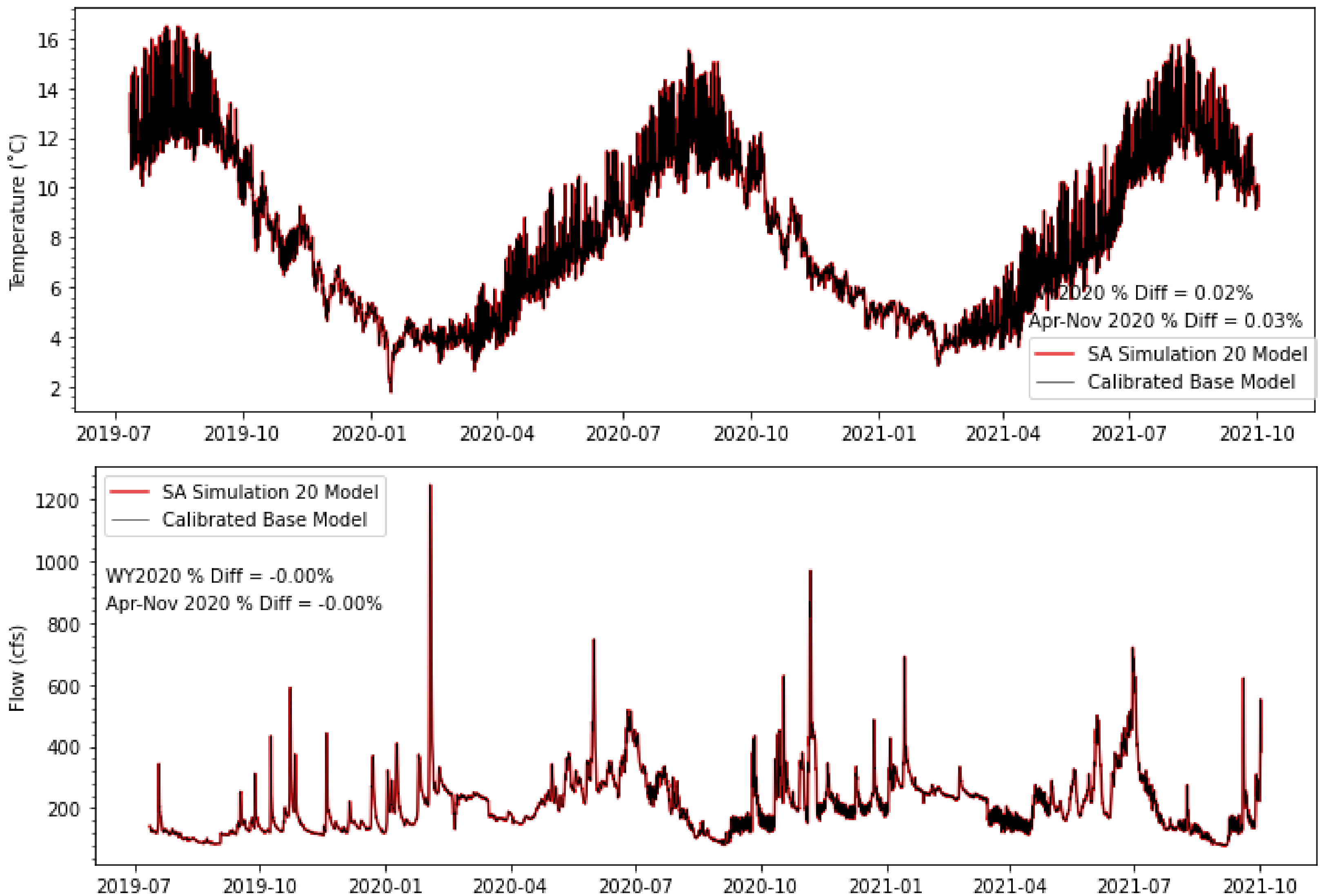


Figure C.4-39. Skagit River at Sauk River confluence continuous hourly flow and temperature variation for SA Simulation 20 (decrease vertical light extinction and increase light absorption).

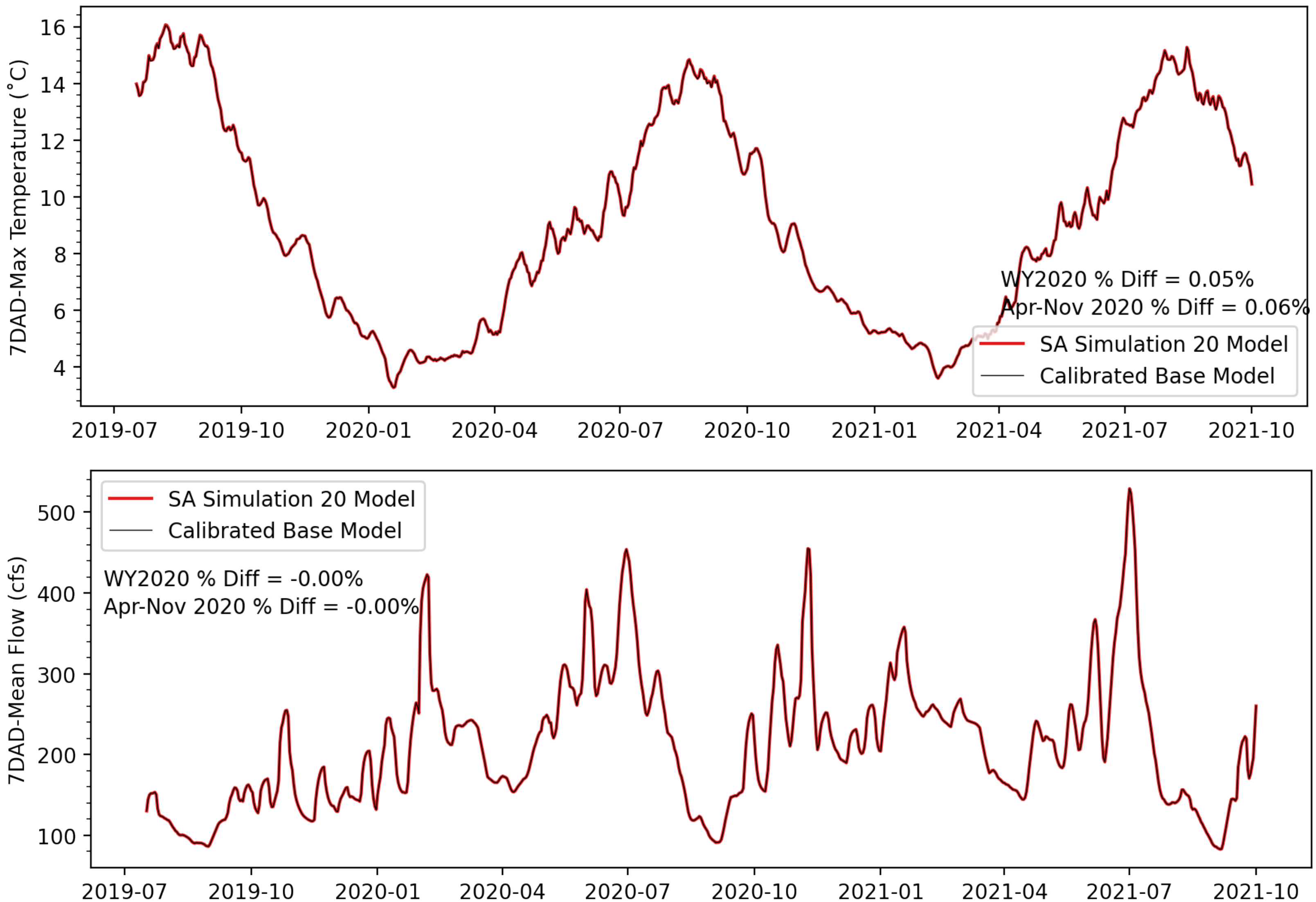


Figure C.4-40. Skagit River at Sauk River confluence 7DAD-Mean flow and max temperature variation for SA Simulation 20 (decrease vertical light extinction and increase light absorption).

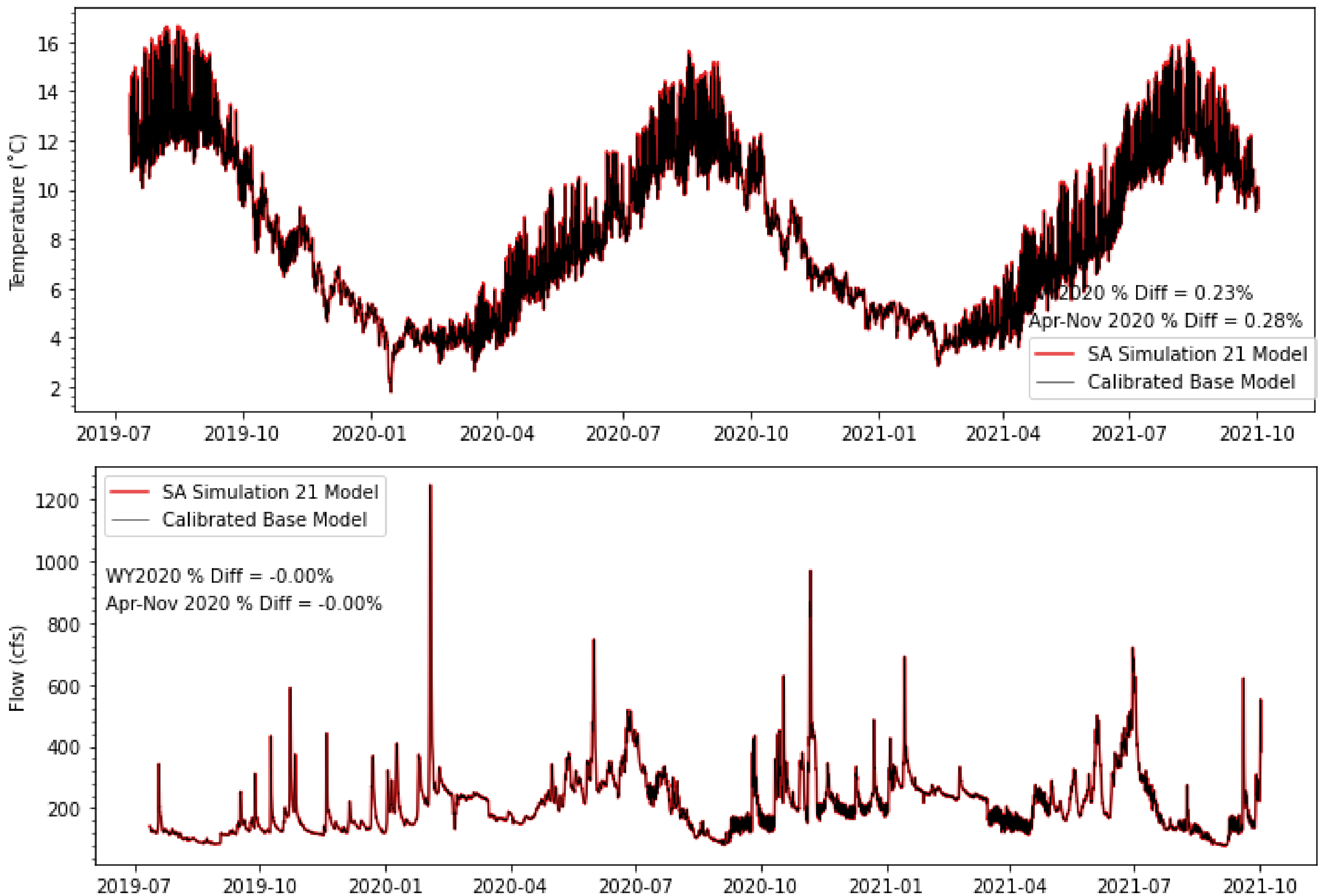


Figure C.4-41. Skagit River at Sauk River confluence continuous hourly flow and temperature variation for SA Simulation 21 (increase vertical light extinction and decrease light absorption).

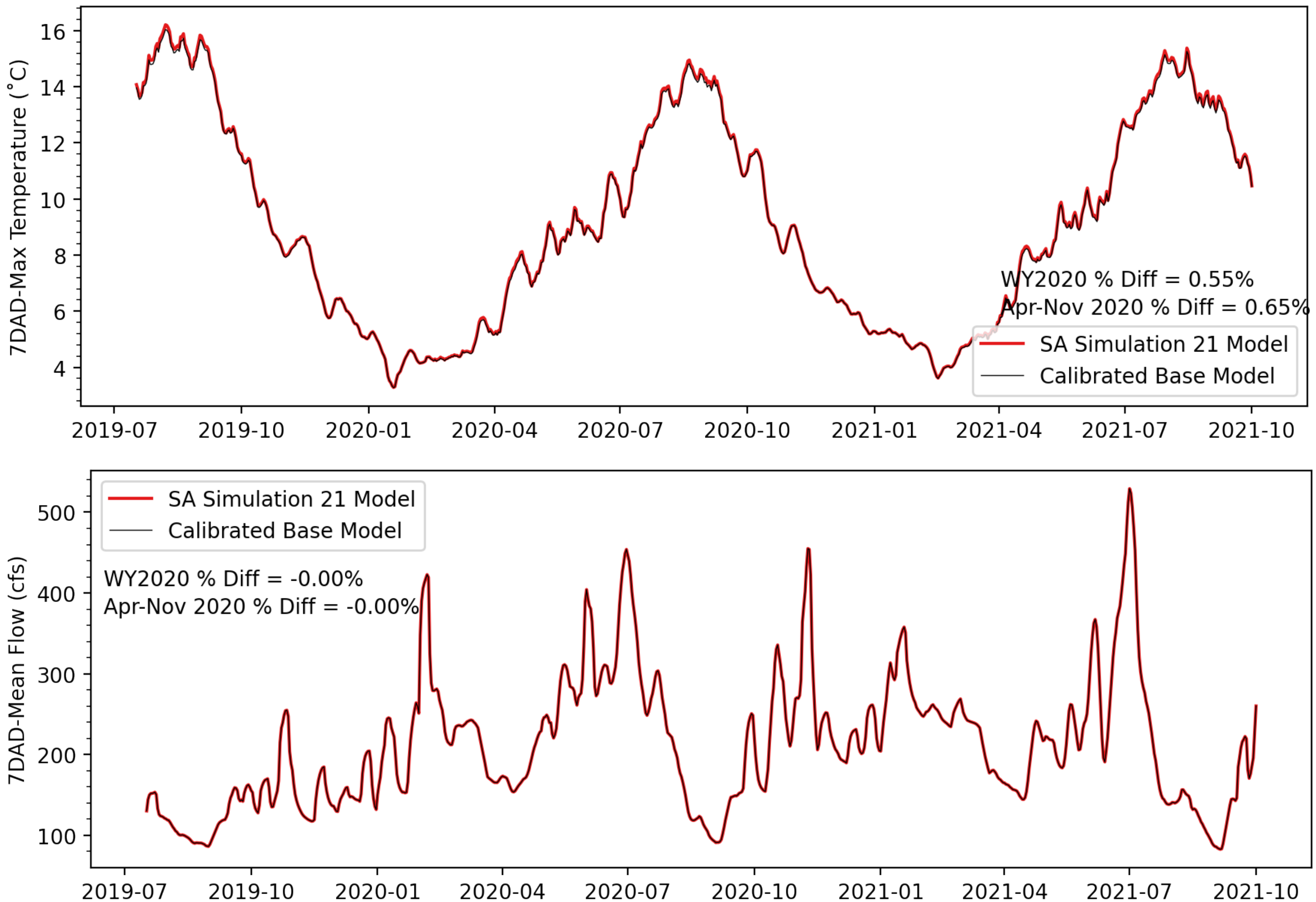


Figure C.4-42. Skagit River at Sauk River confluence 7DAD-Mean flow and max temperature variation for SA Simulation 21 (increase vertical light extinction and decrease light absorption).

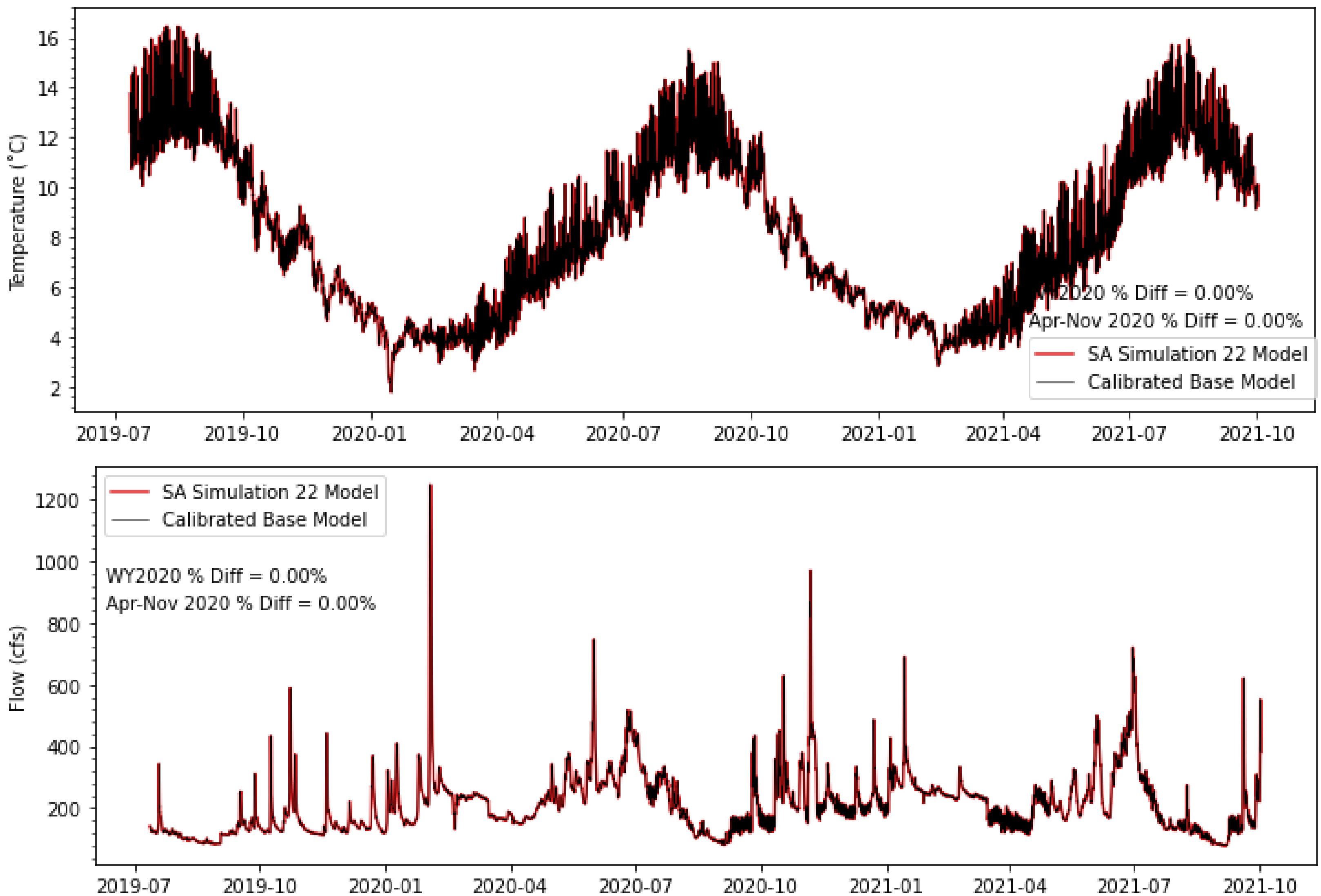


Figure C.4-43. Skagit River at Sauk River confluence continuous hourly flow and temperature variation for SA Simulation 22 (set longitudinal eddy diffusivity to 0.1 m2/s).

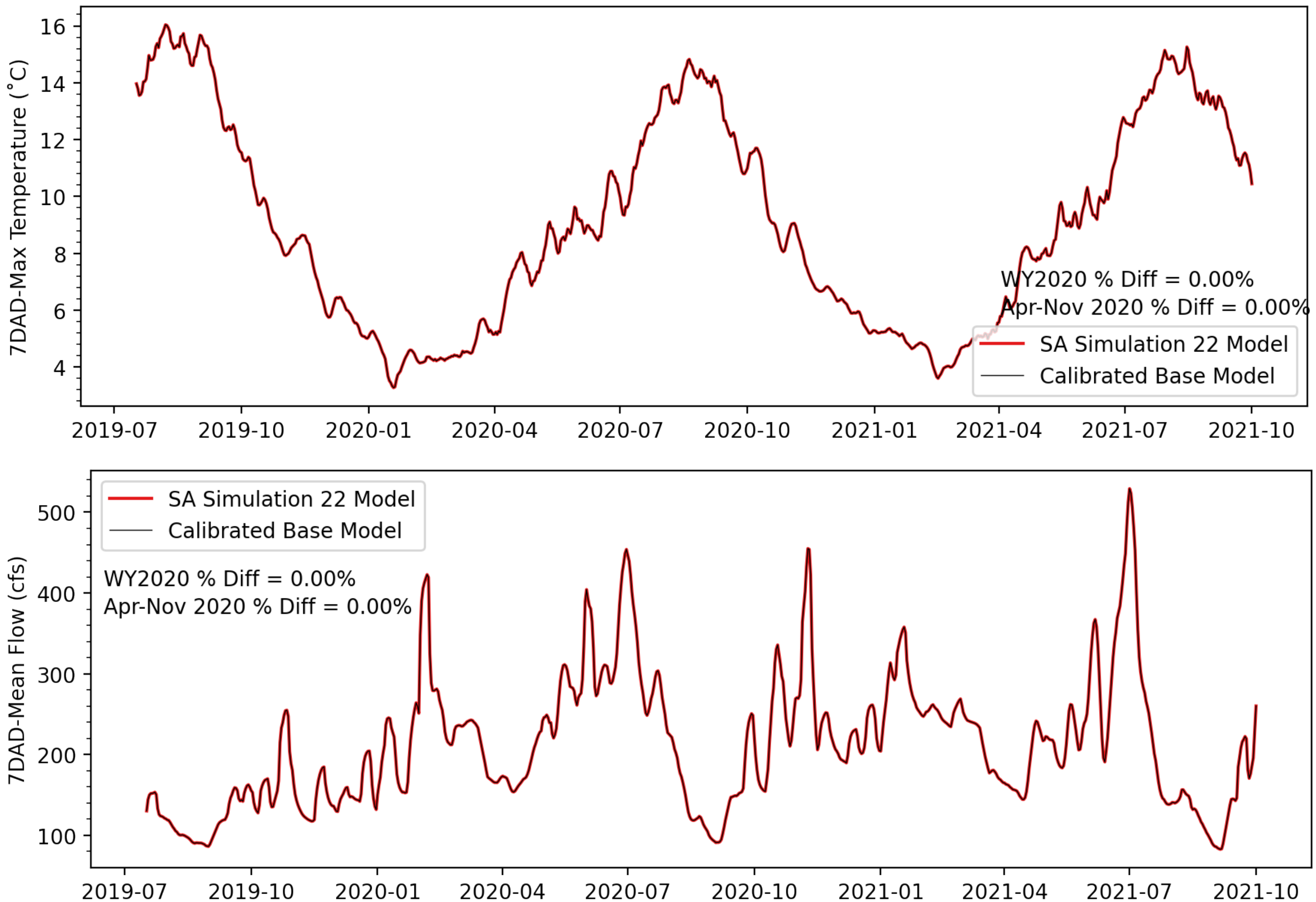


Figure C.4-44. Skagit River at Sauk River confluence 7DAD-Mean flow and max temperature variation for SA Simulation 22 (set longitudinal eddy diffusivity to 0.1 m2/s).

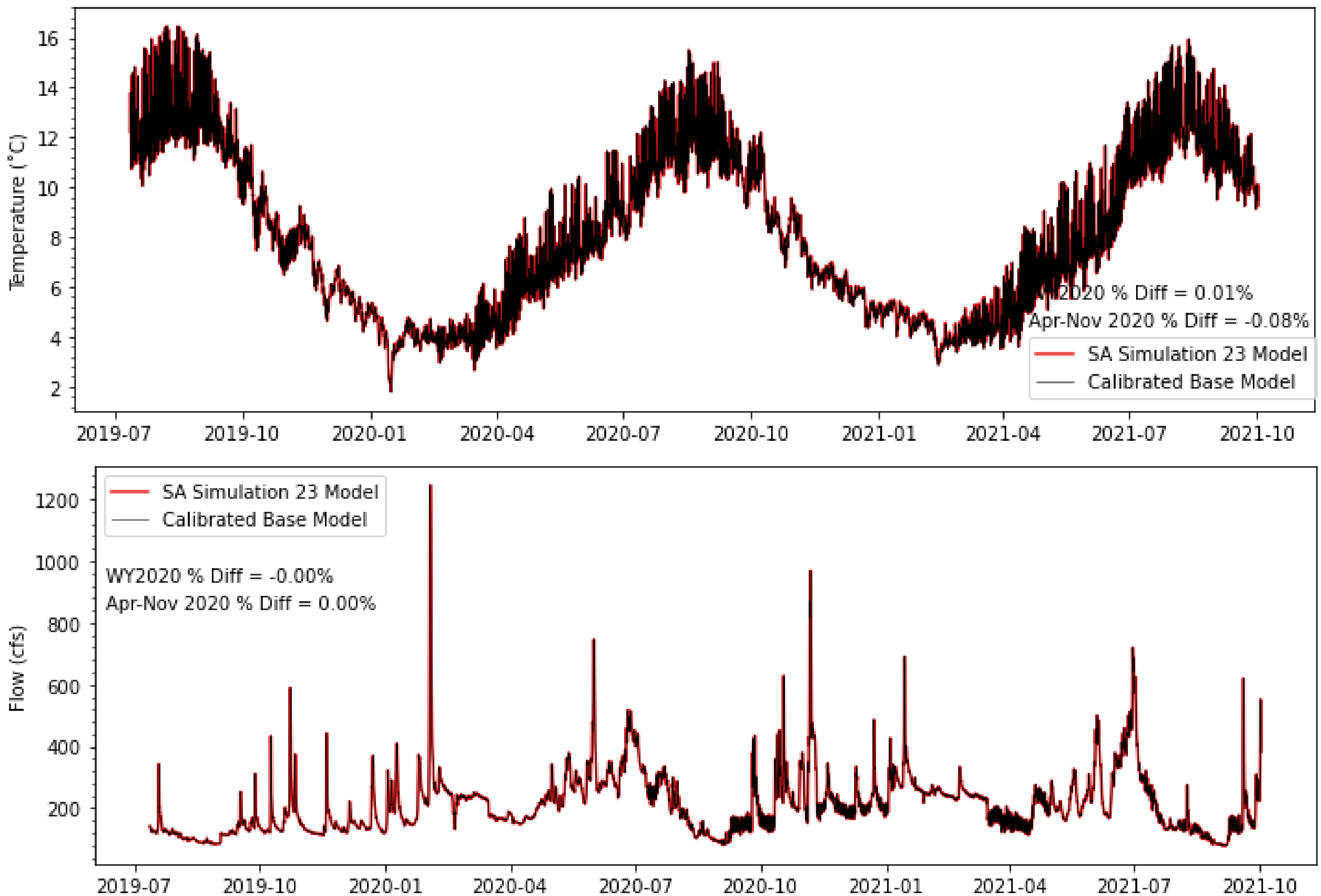


Figure C.4-45. **Skagit River at Sauk River confluence continuous hourly flow and temperature variation for SA Simulation 23 (set longitudinal eddy diffusivity to 10 m2/s).**

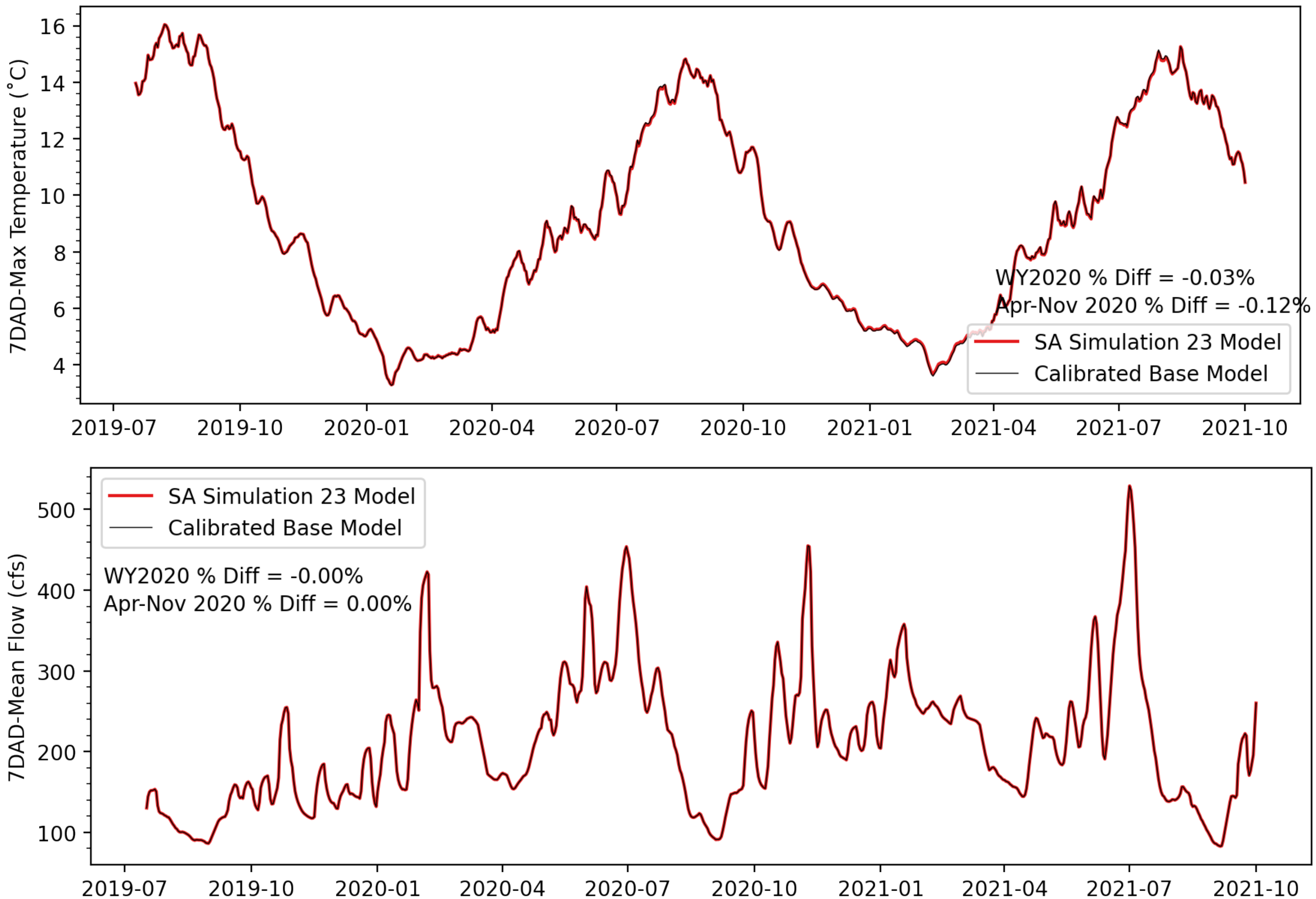


Figure C.4-46. **Skagit River at Sauk River confluence 7DAD-Mean flow and max temperature variation for SA Simulation 23 (set longitudinal eddy diffusivity to 10 m2/s).**

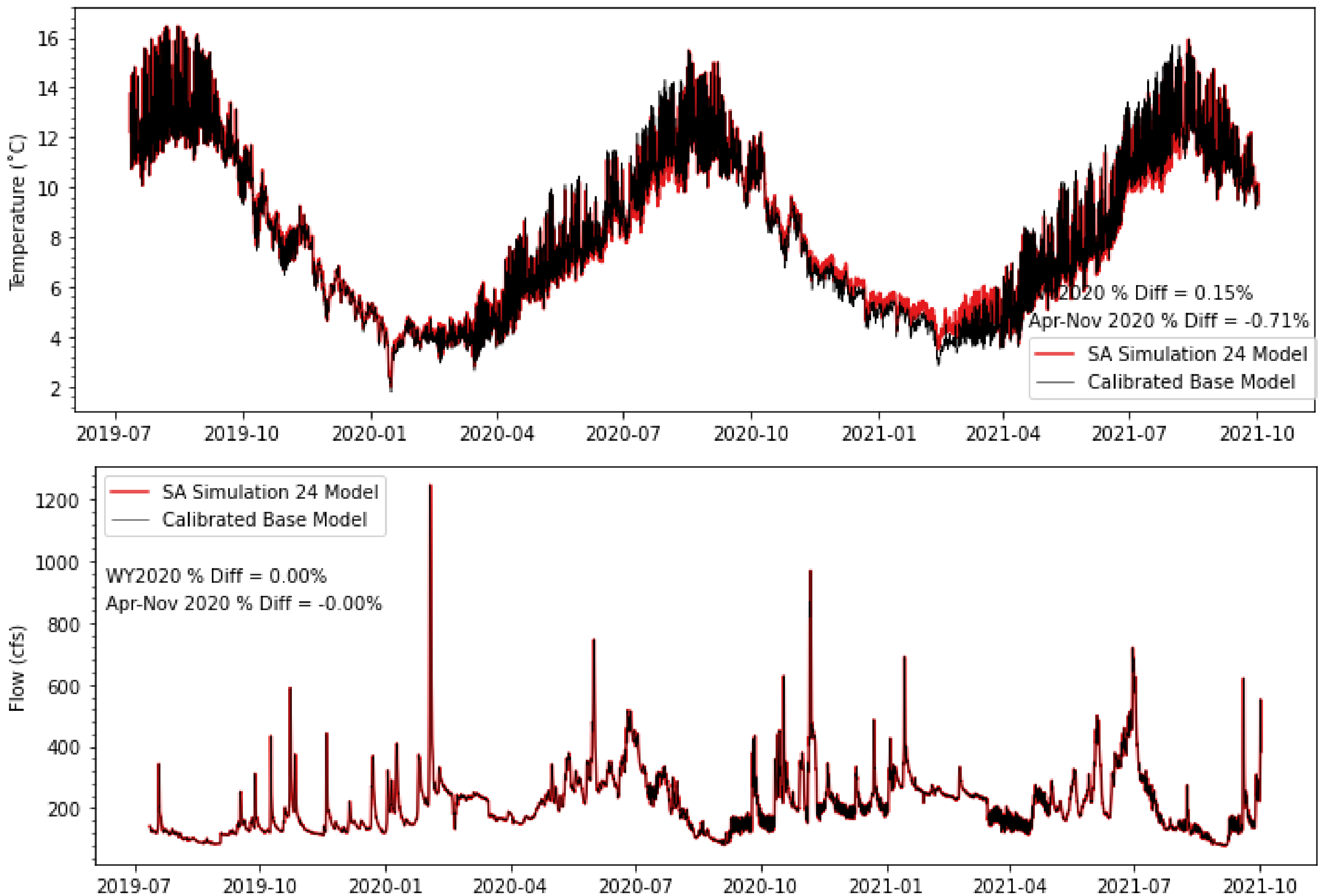


Figure C.4-47. Skagit River at Sauk River confluence continuous hourly flow and temperature variation for SA Simulation 24 (set longitudinal eddy diffusivity to 100 m2/s).

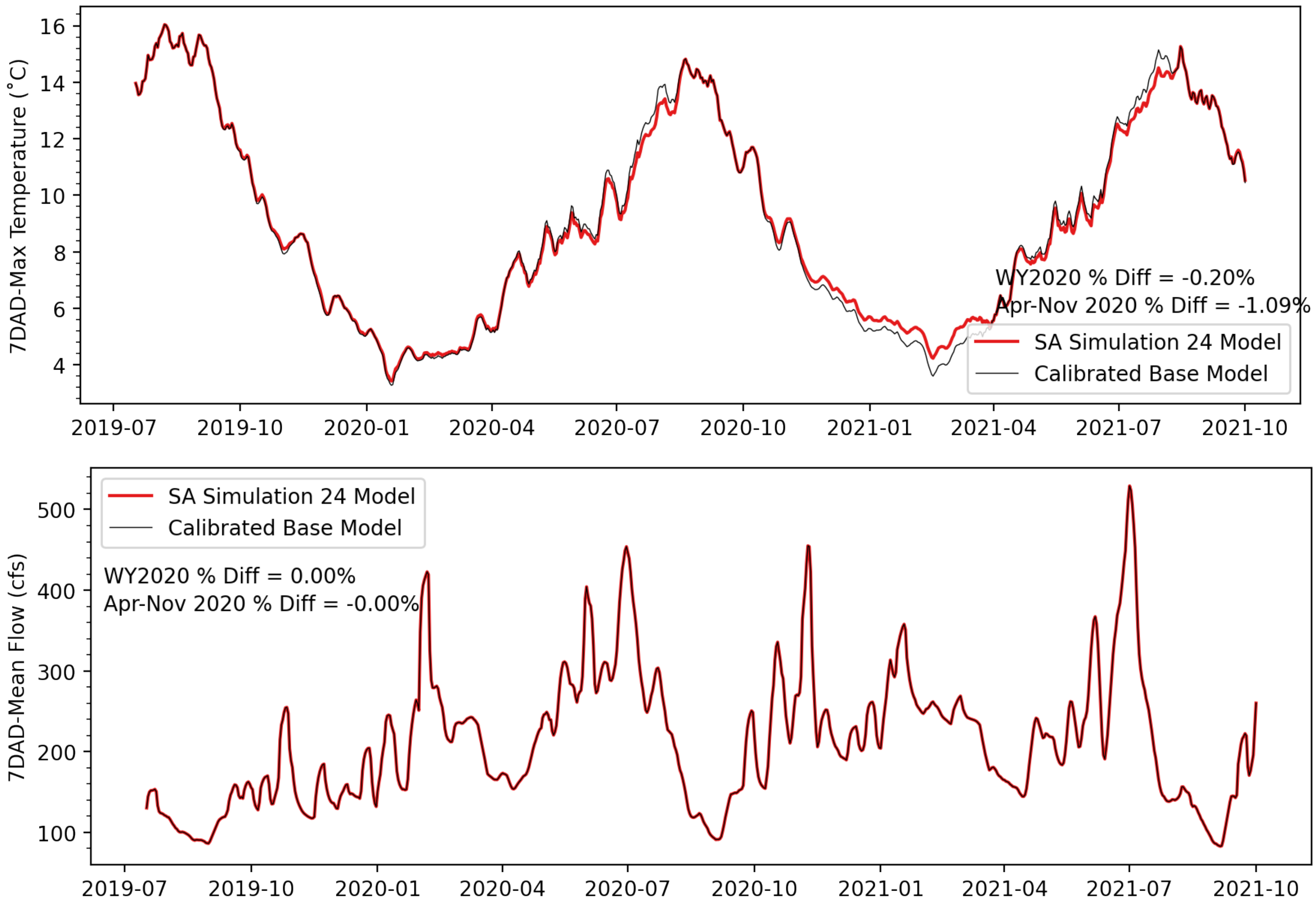


Figure C.4-48. Skagit River at Sauk River confluence 7DAD-Mean flow and max temperature variation for SA Simulation 24 (set longitudinal eddy diffusivity to 100 m2/s).

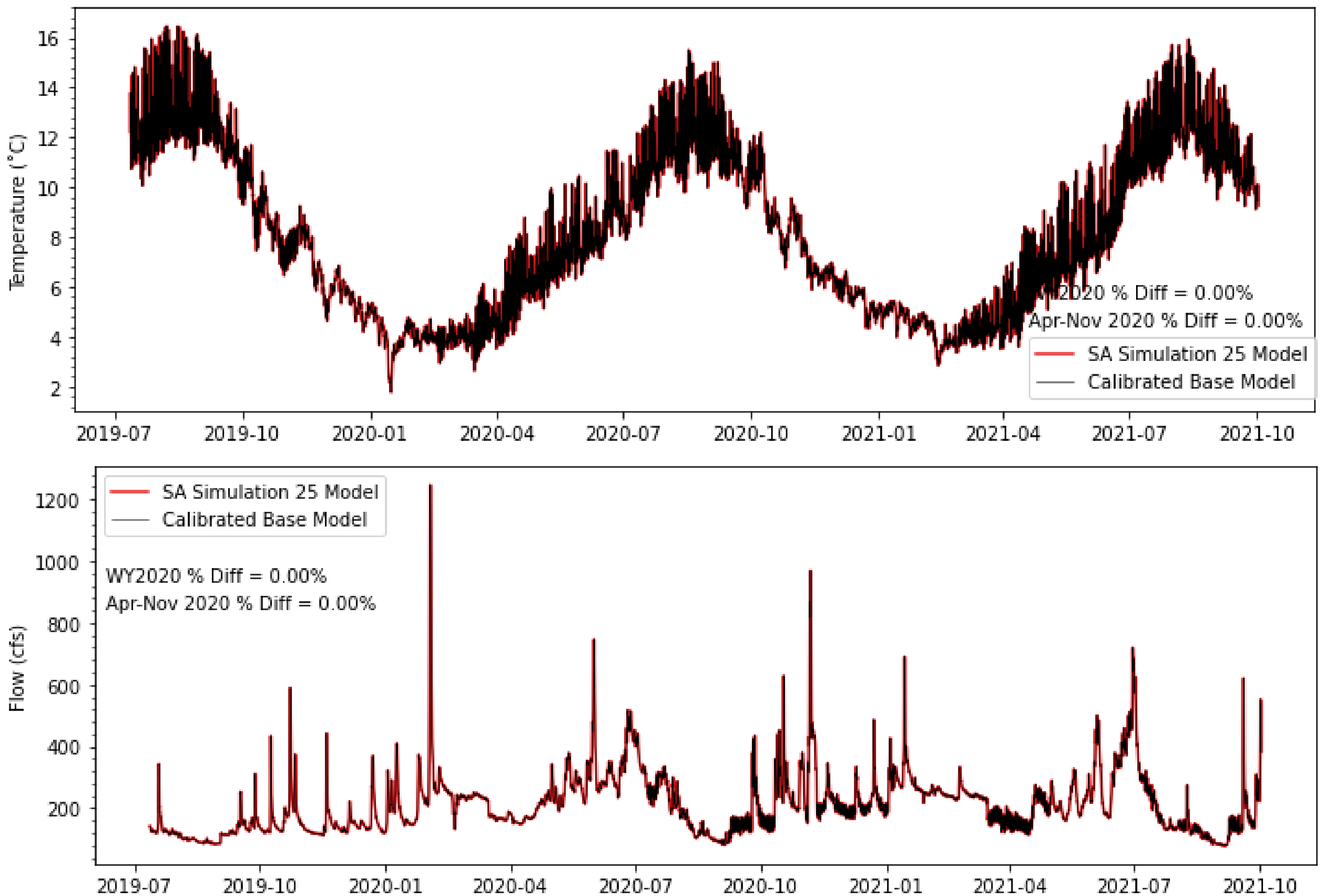


Figure C.4-49. Skagit River at Sauk River confluence continuous hourly flow and temperature variation for SA Simulation 25 (set longitudinal eddy viscosity to 0.1 m2/s).

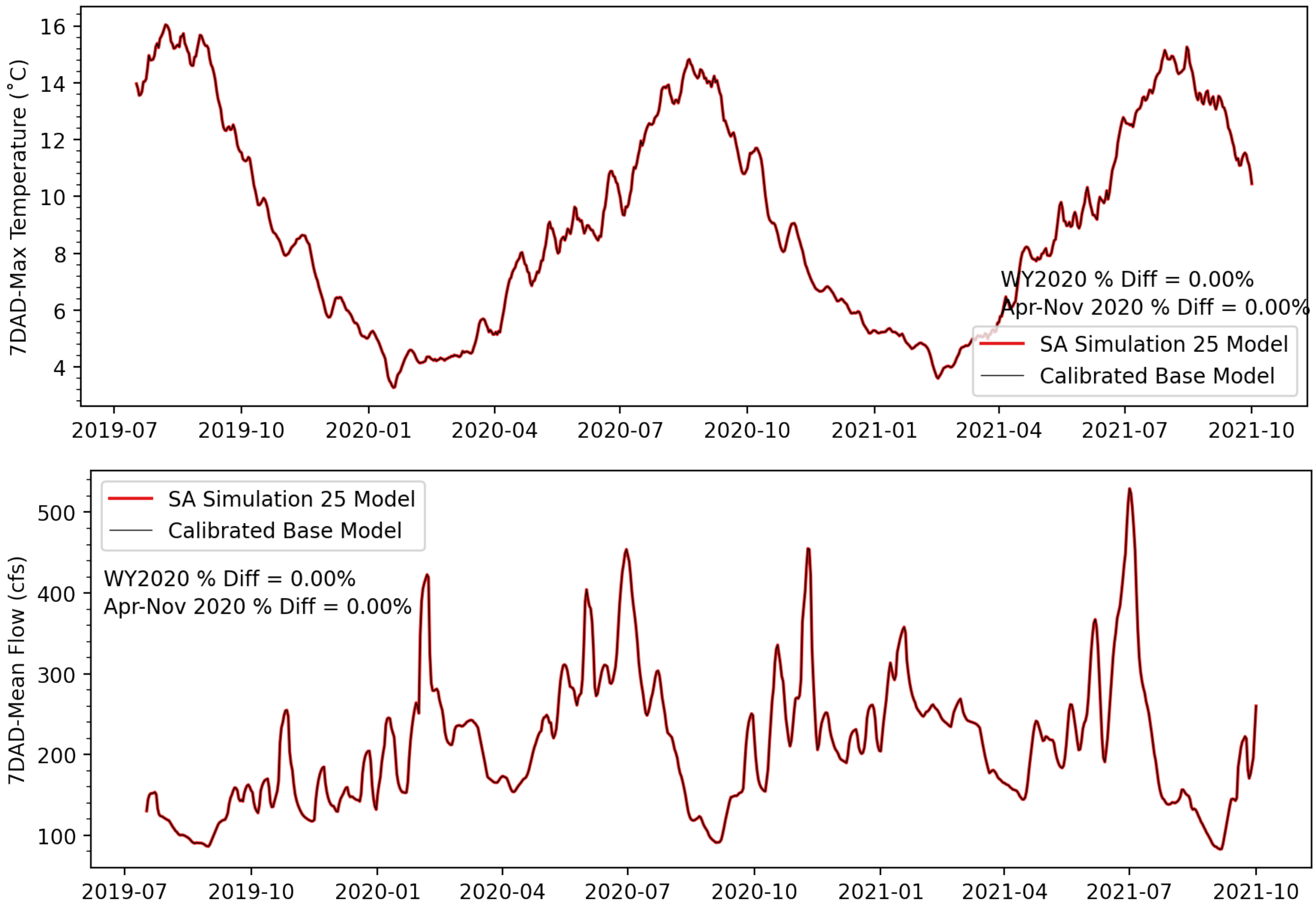


Figure C.4-50. **Skagit River at Sauk River confluence 7DAD-Mean flow and max temperature variation for SA Simulation 25 (set longitudinal eddy viscosity to 0.1 m2/s).**

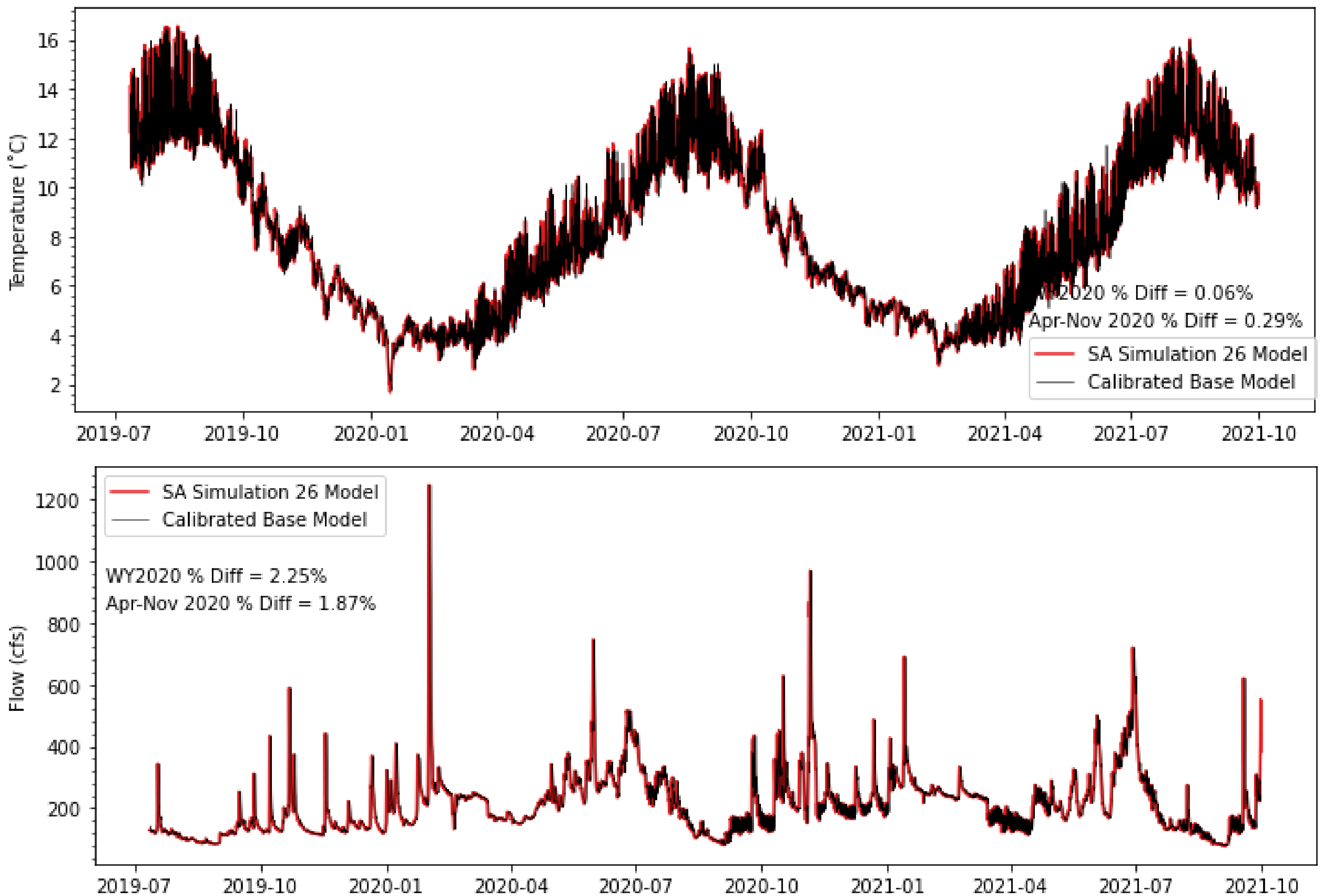


Figure C.4-51. Skagit River at Sauk River confluence continuous hourly flow and temperature variation for SA Simulation 26 (set longitudinal eddy viscosity to 10 m2/s).

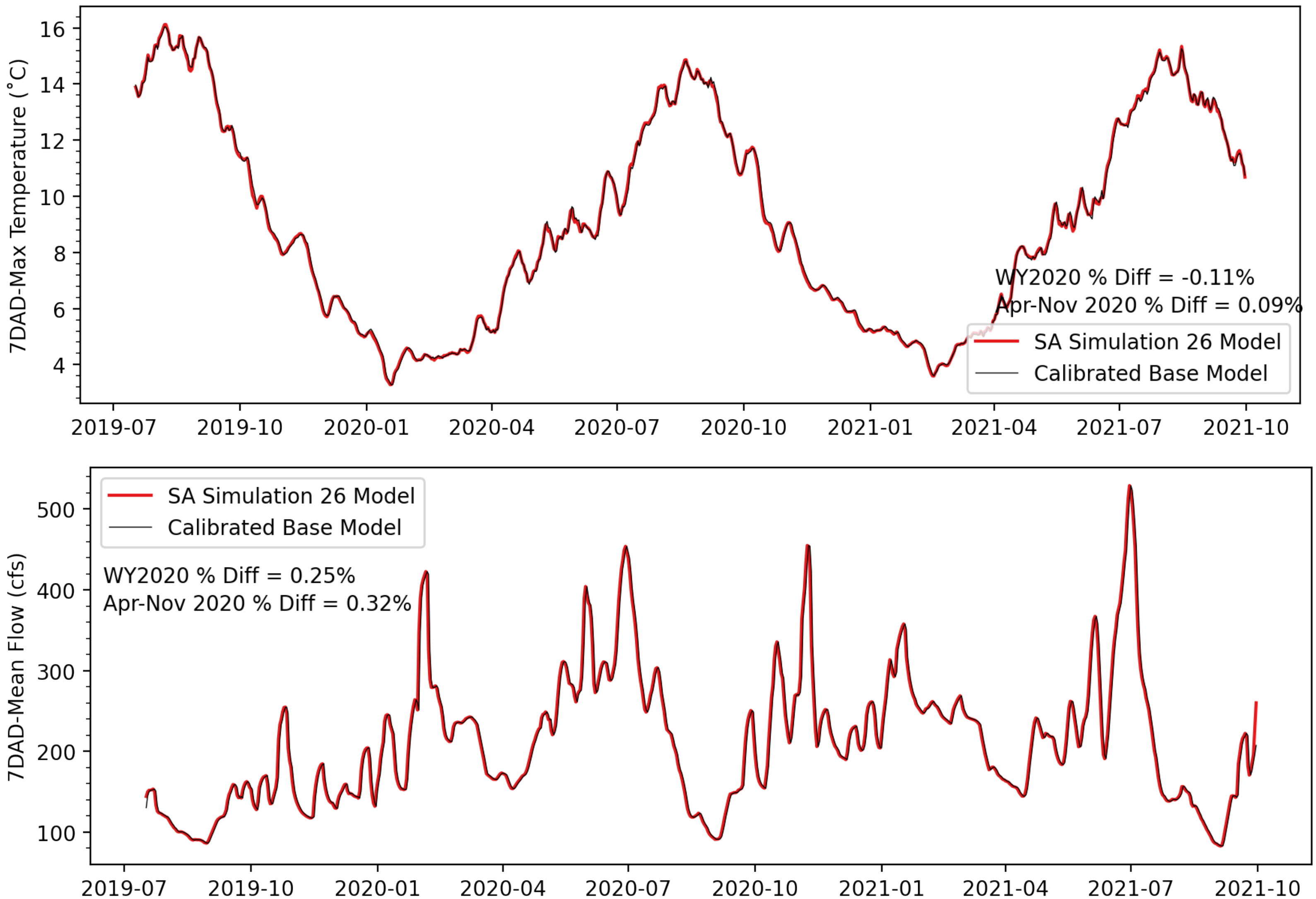


Figure C.4-52. Skagit River at Sauk River confluence 7DAD-Mean flow and max temperature variation for SA Simulation 26 (set longitudinal eddy viscosity to 10 m2/s).

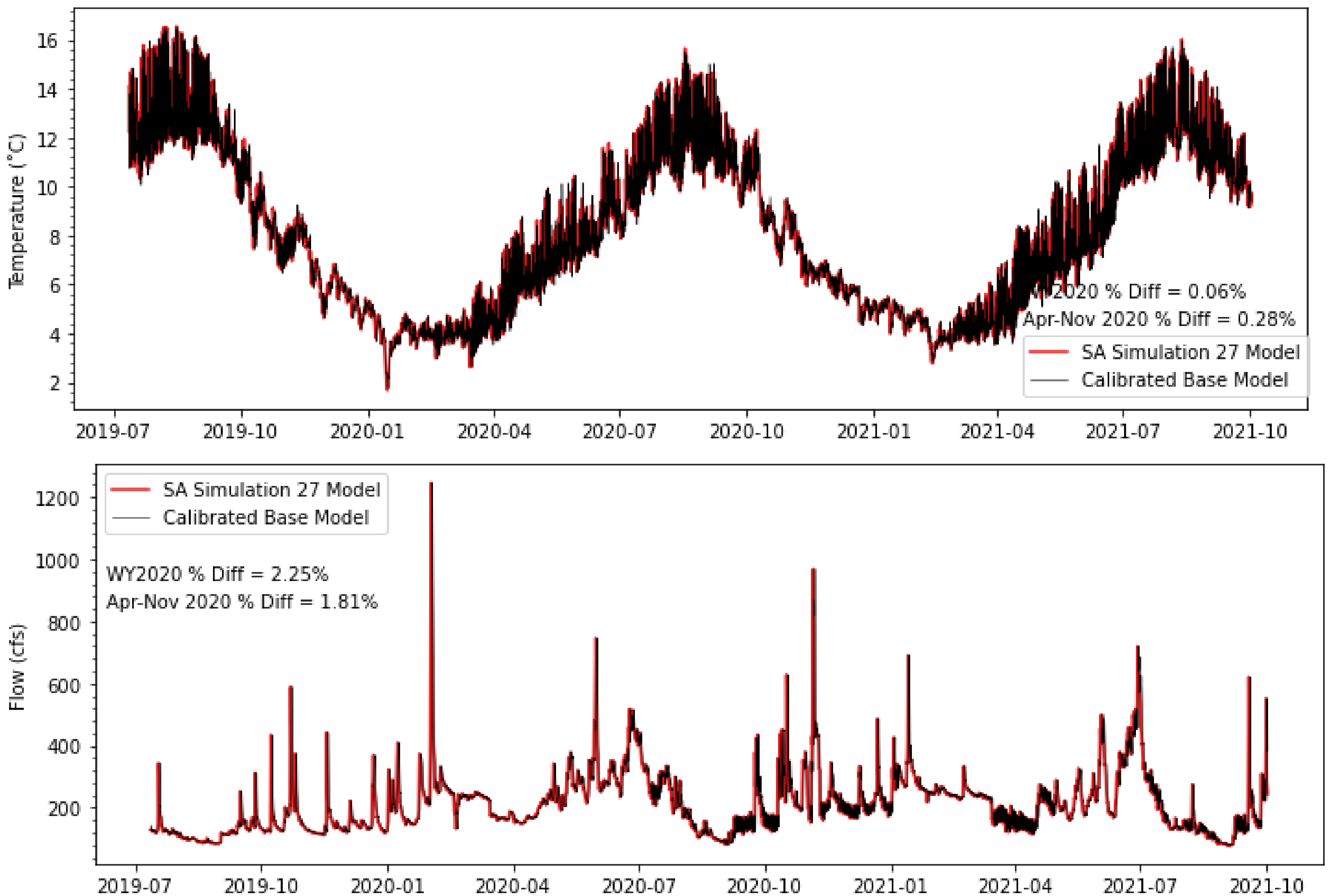


Figure C.4-53. **Skagit River at Sauk River confluence continuous hourly flow and temperature variation for SA Simulation 27 (set longitudinal eddy viscosity to 30 m2/s).**

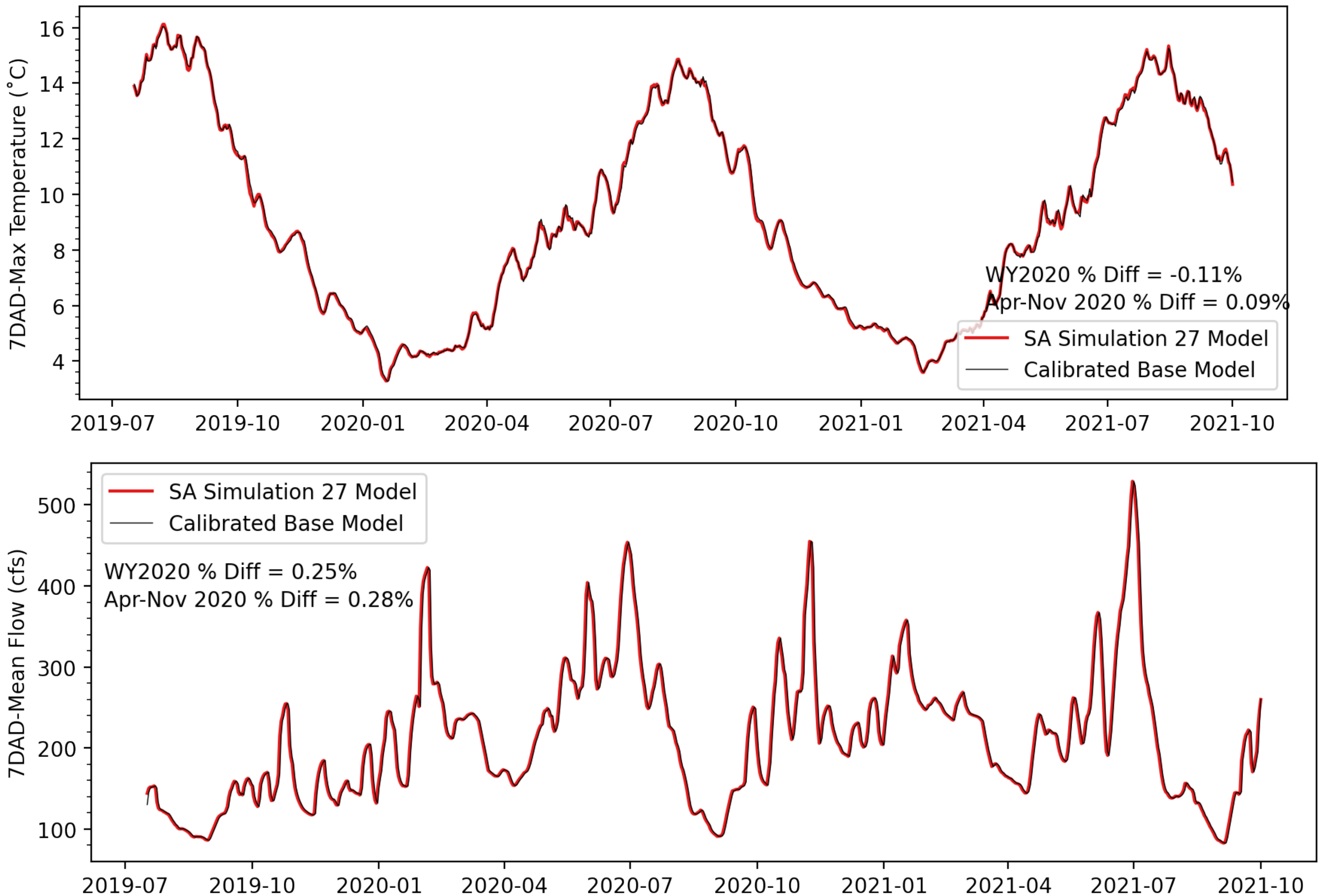


Figure C.4-54. **Skagit River at Sauk River confluence 7DAD-Mean flow and max temperature variation for SA Simulation 27 (set longitudinal eddy viscosity to 30 m2/s).**

WATER QUALITY MODEL DEVELOPMENT STUDY

ATTACHMENT D

EXISTING CONDITIONS SIMULATION FIGURES

D.1 Ross Lake Temperature Contour Plots

Contour plots were generated to visualize the cross-sectional temperatures in Ross Lake. These plots appear in Figures D.1-1 through D.1-17. Temperatures are generated as model output from July 2019 through November 2020. Plots were generated to depict the 15th day of each month, with the exception of November 2020. This plot was generated on November 8th due to the model duration. Flow is from left to right on each plot. The Skagit River inflow is at the upper left of each image, and the Ross Dam is near the right at River Mile 105. Furthest right is a depiction of Ruby Arm, in which Ruby Creek enters at Mile 0 and discharges at the right side of each image where Ruby Arm connects to the mainstem of Ross Lake, near River Mile 107. Other notable tributaries are included at the top of each image to aid geographic orientation. Black arrows indicate the depths of spillway and penstock withdrawals from the reservoir.

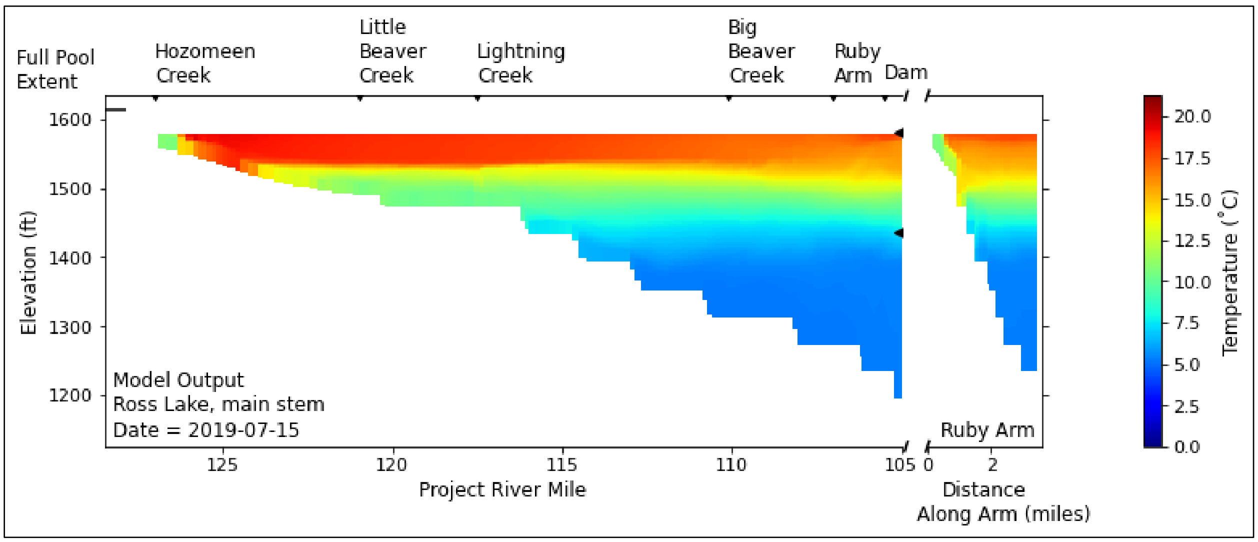


Figure D.1-1. Ross Lake cross-sectional temperature contour plot on July 15, 2019.

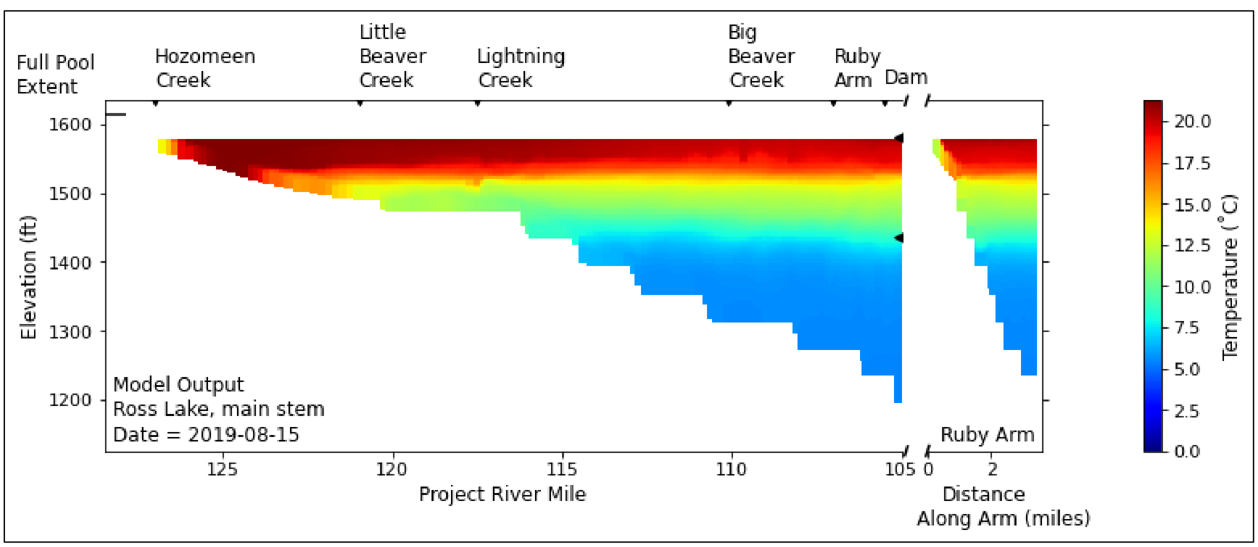


Figure D.1-2. Ross Lake cross-sectional temperature contour plot on August 15, 2019.

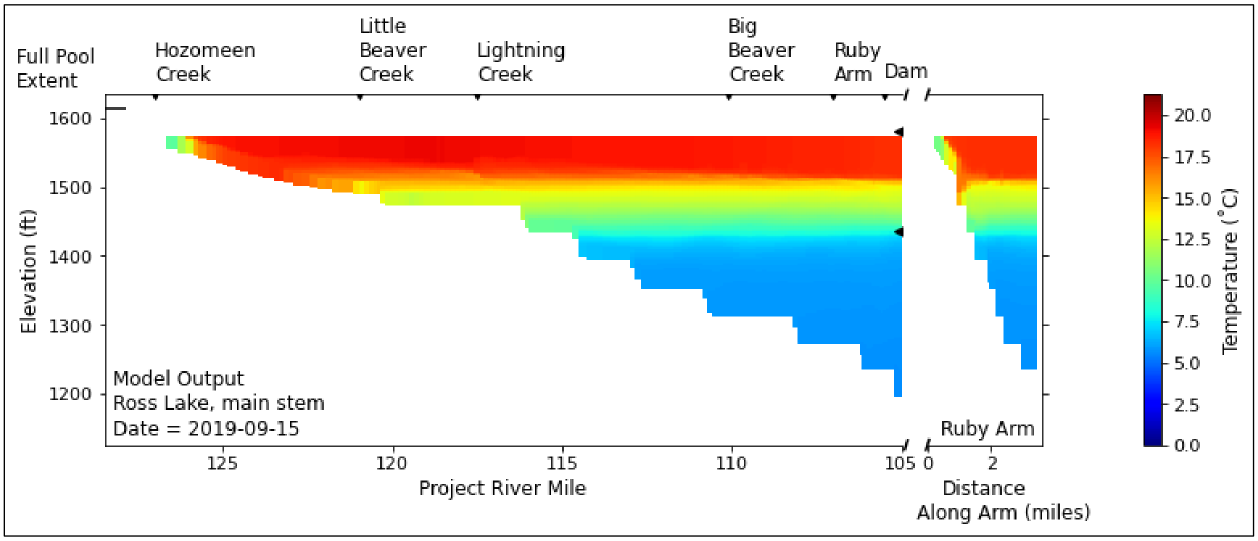


Figure D.1-3. **Ross Lake cross-sectional temperature contour plot on September 15, 2019.**

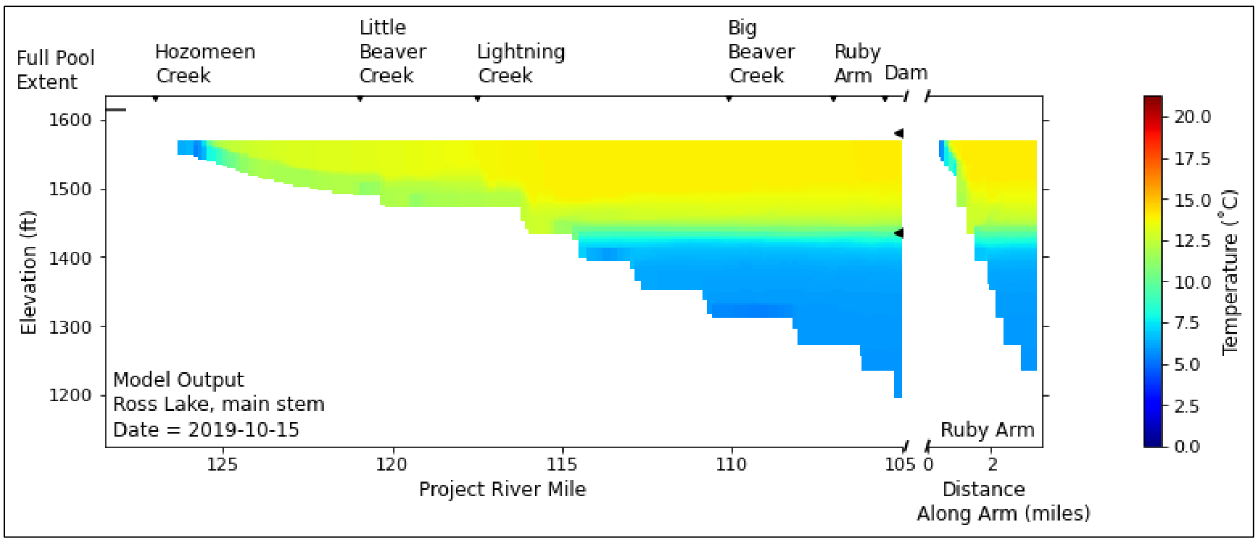


Figure D.1-4. **Ross Lake cross-sectional temperature contour plot on October 15, 2019.**

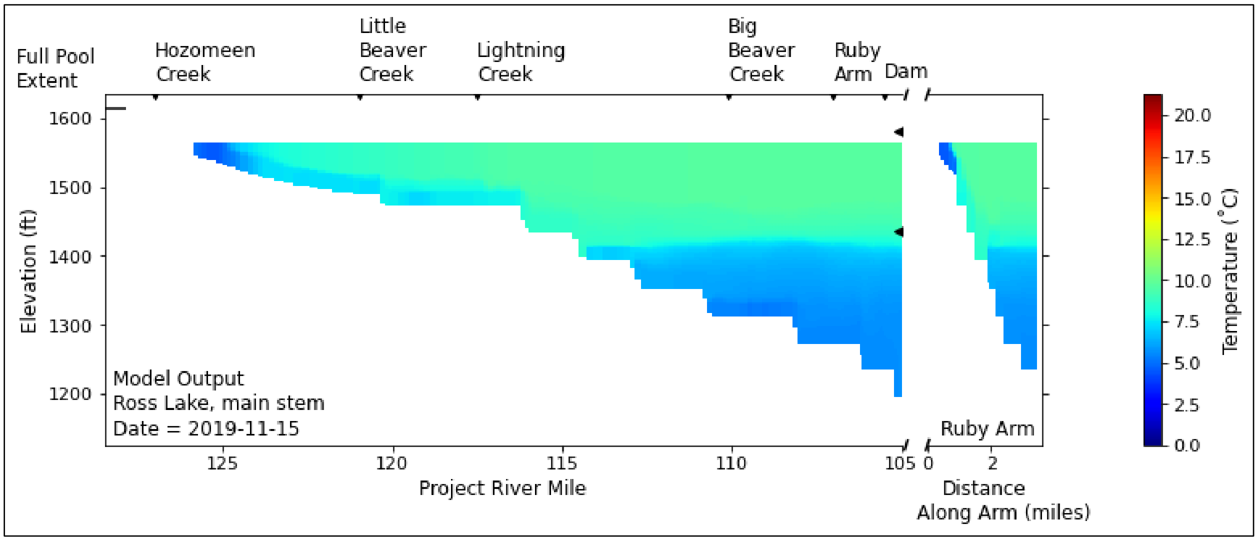


Figure D.1-5. Ross Lake cross-sectional temperature contour plot on November 15, 2019.

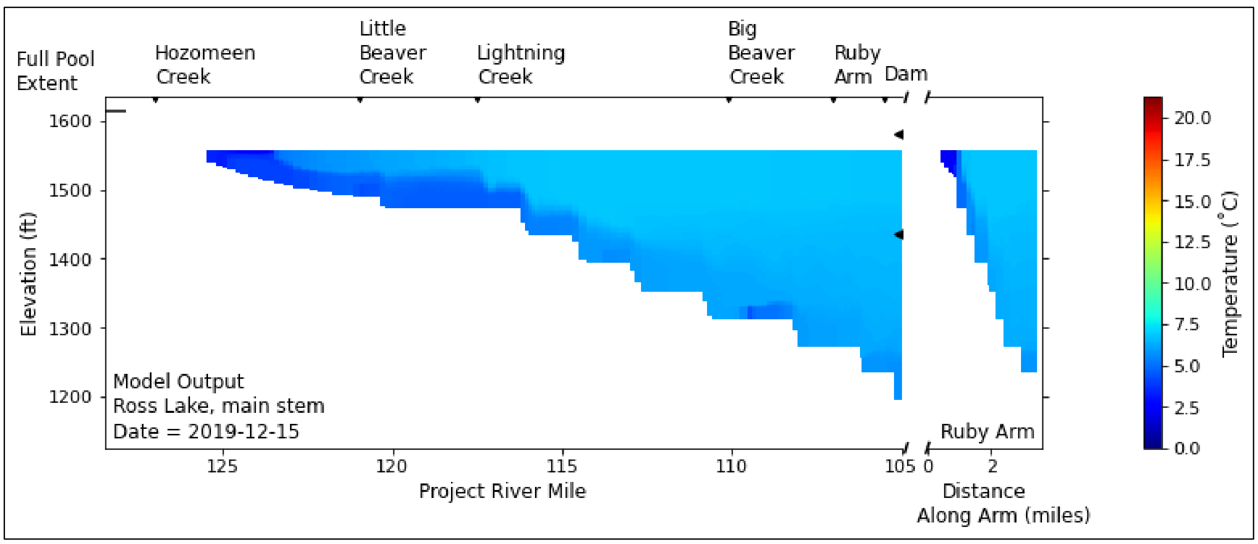


Figure D.1-6. Ross Lake cross-sectional temperature contour plot on December 15, 2019.

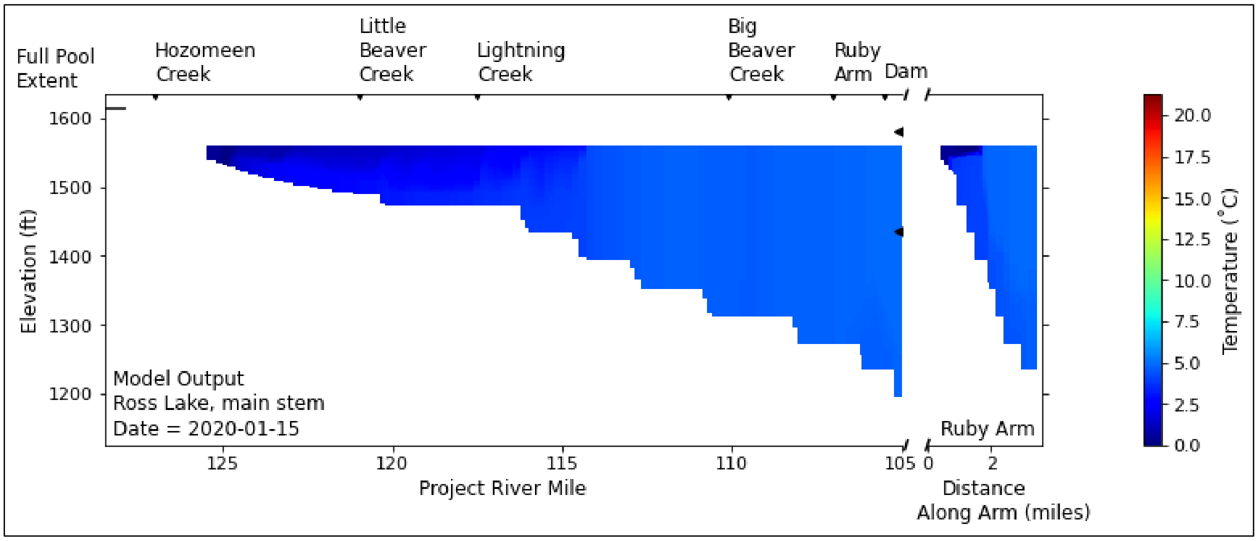


Figure D.1-7. **Ross Lake cross-sectional temperature contour plot on January 15, 2020.**

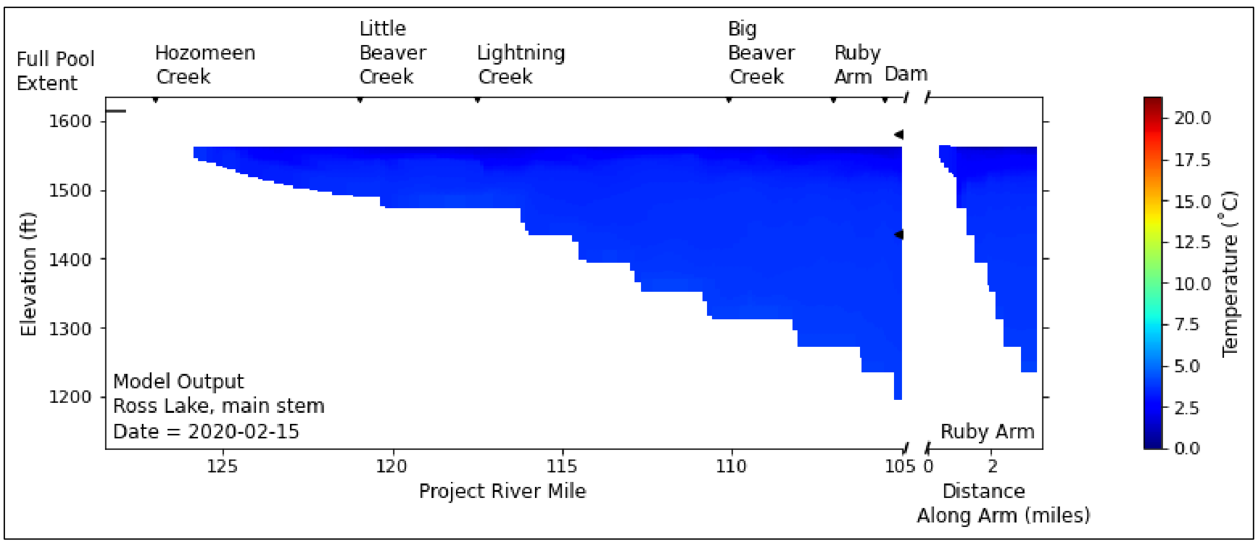


Figure D.1-8. **Ross Lake cross-sectional temperature contour plot on February 15, 2020.**

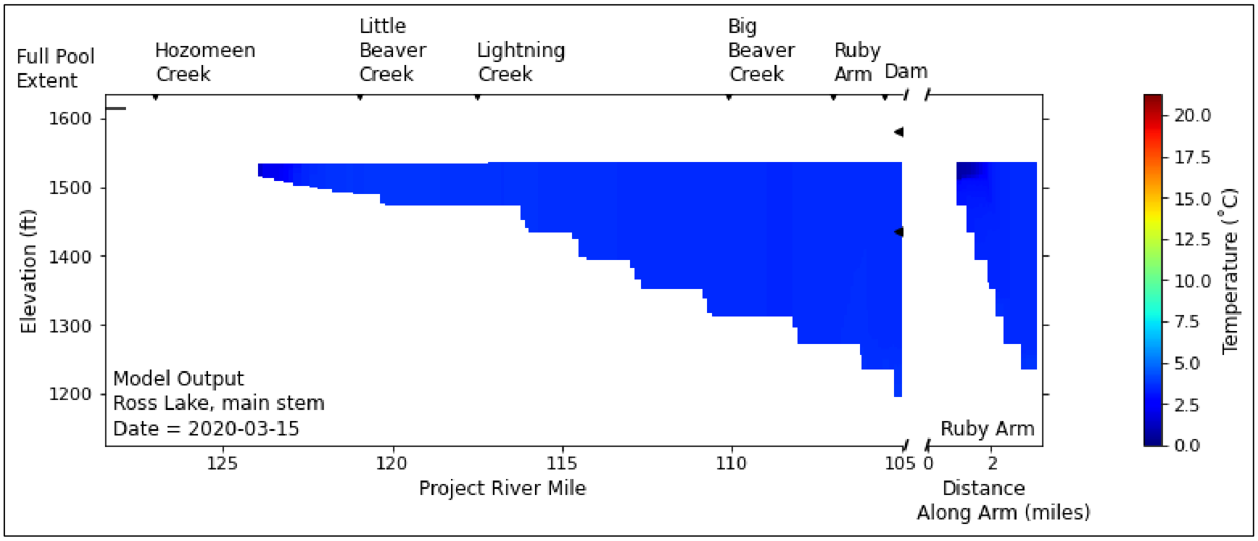


Figure D.1-9. **Ross Lake cross-sectional temperature contour plot on March 15, 2020.**

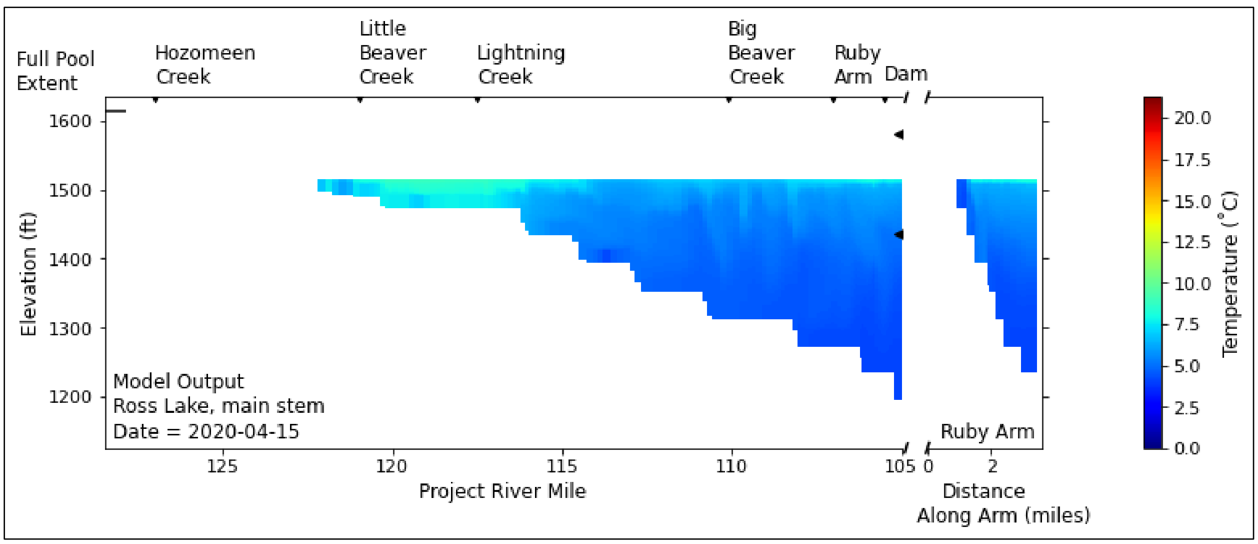


Figure D.1-10. **Ross Lake cross-sectional temperature contour plot on April 15, 2020.**

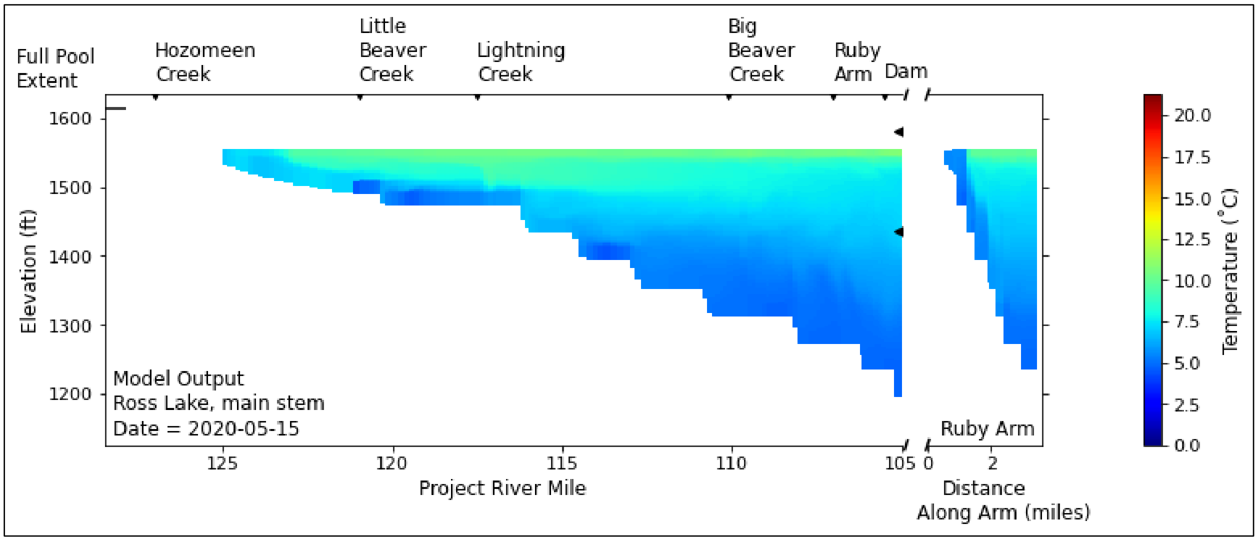


Figure D.1-11. Ross Lake cross-sectional temperature contour plot on May 15, 2020.

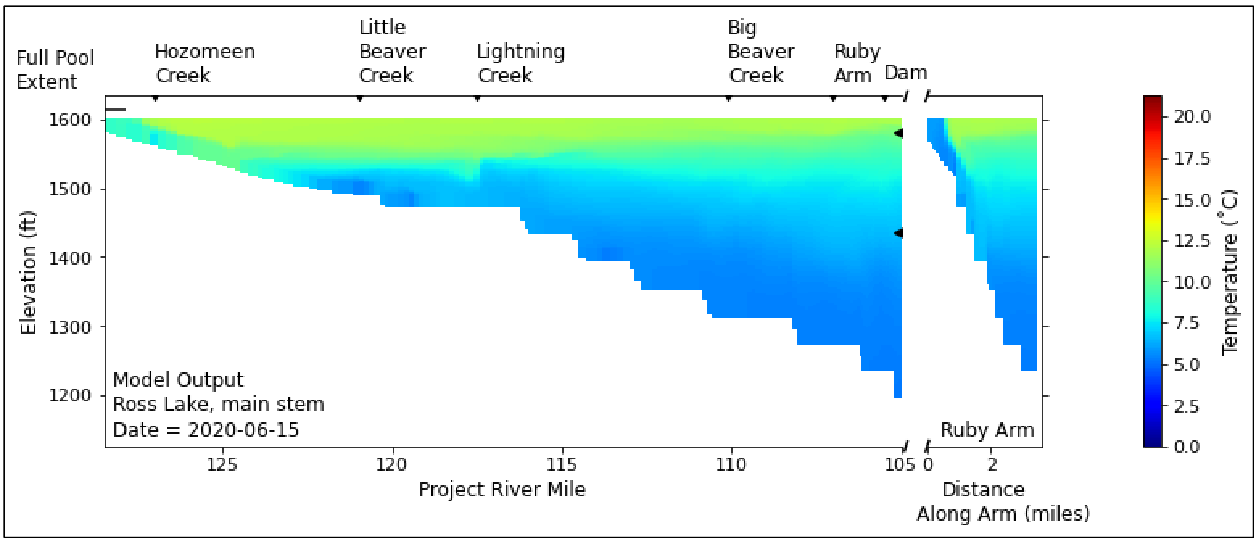


Figure D.1-12. Ross Lake cross-sectional temperature contour plot on June 15, 2020.

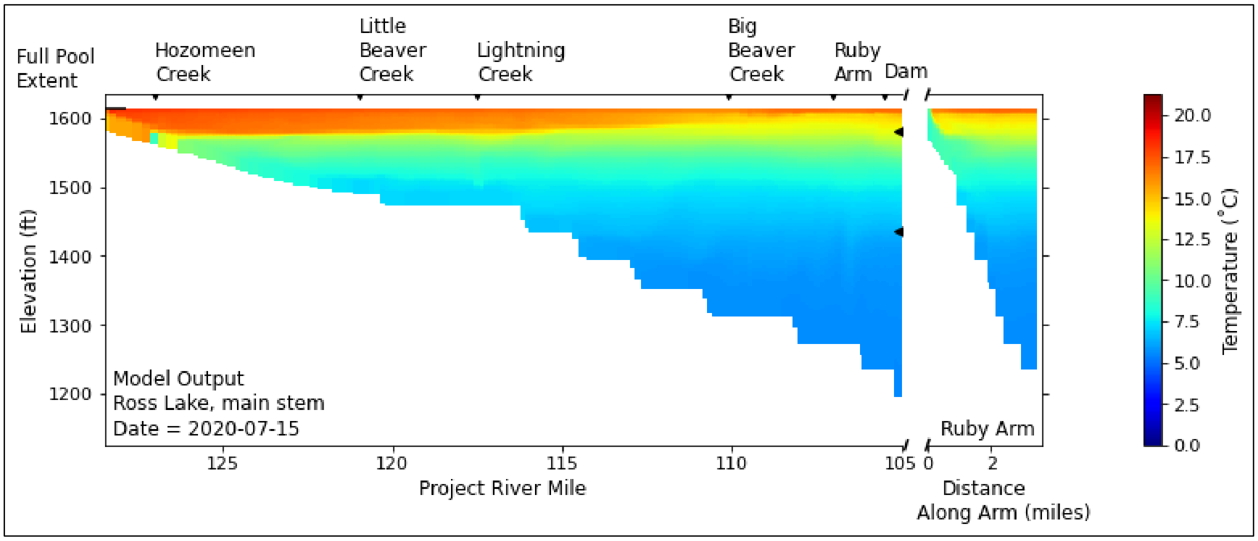


Figure D.1-13. **Ross Lake cross-sectional temperature contour plot on July 15, 2020.**

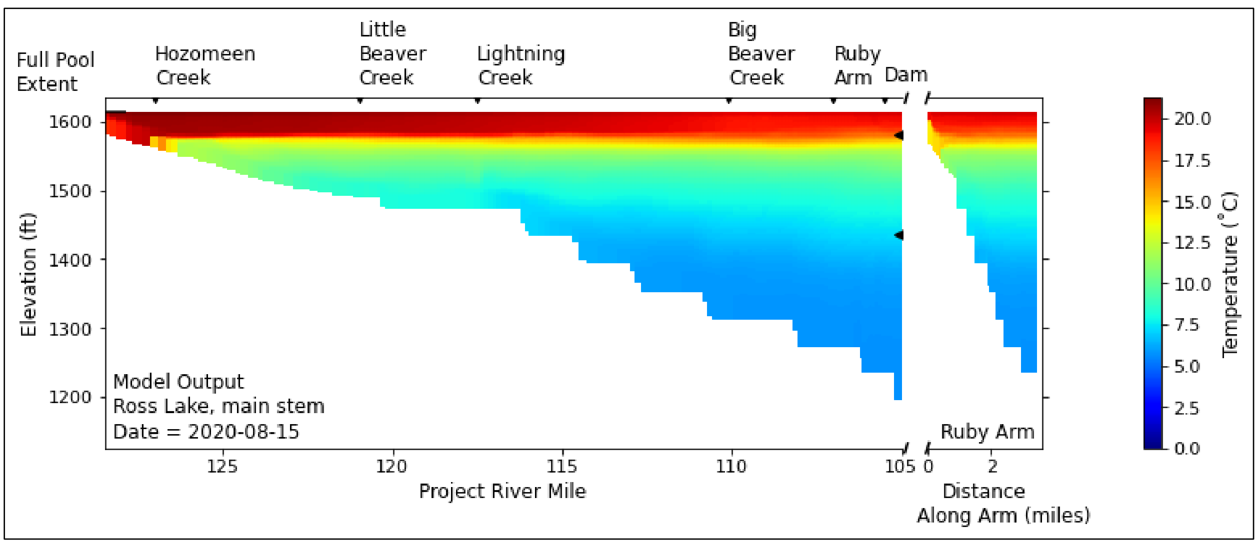


Figure D.1-14. **Ross Lake cross-sectional temperature contour plot on August 15, 2020.**

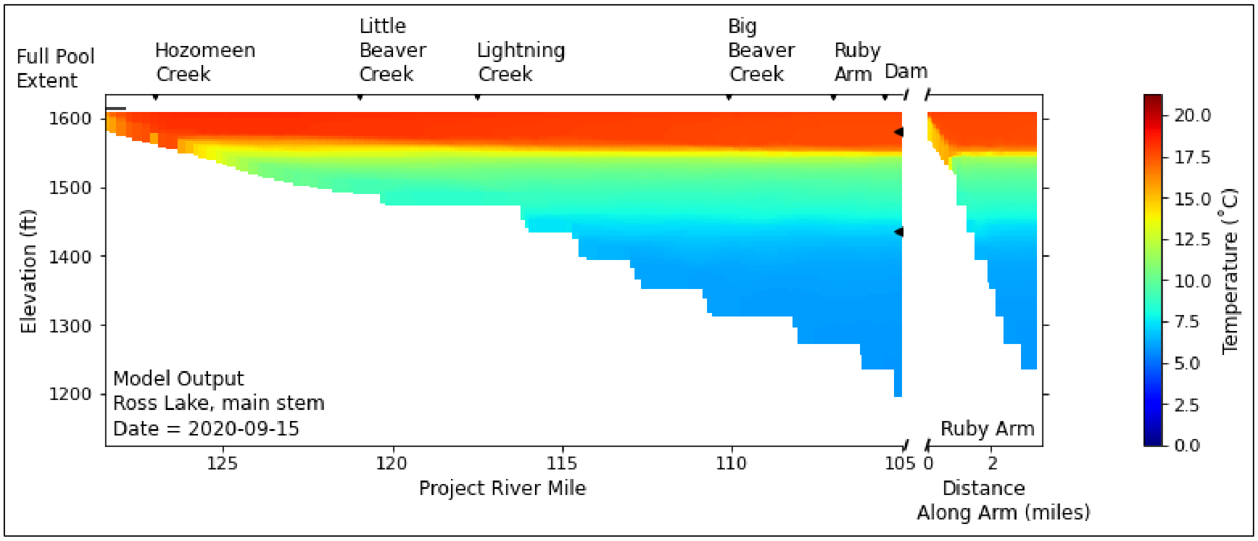


Figure D.1-15. Ross Lake cross-sectional temperature contour plot on September 15, 2020.

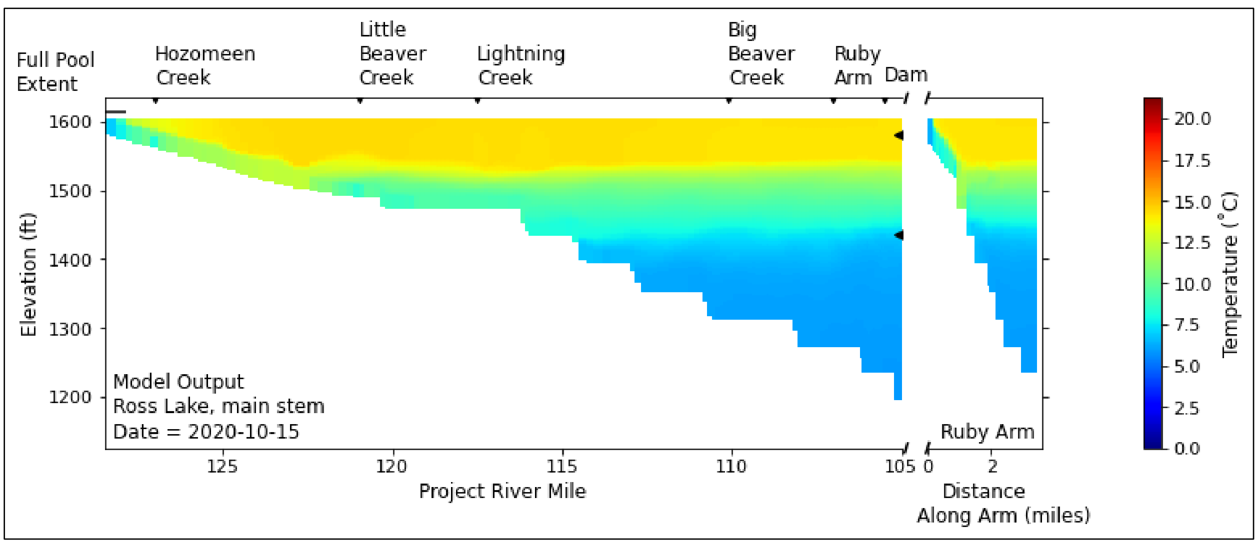


Figure D.1-16. Ross Lake cross-sectional temperature contour plot on October 15, 2020.

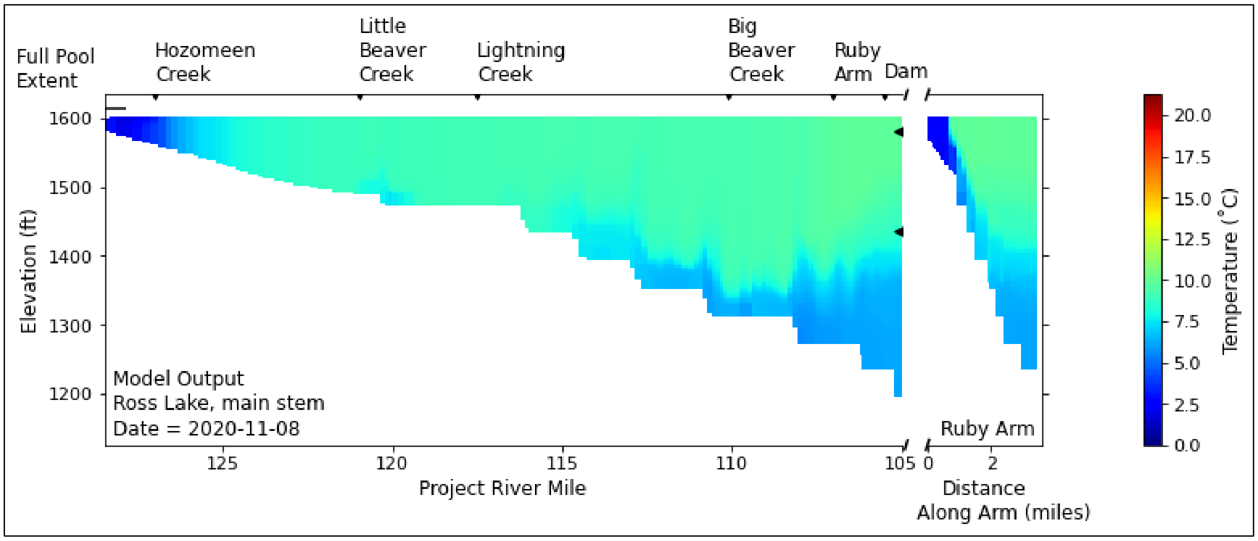


Figure D.1-17. Ross Lake cross-sectional temperature contour plot on November 8, 2020.

D.2 Diablo Lake Temperature Contour Plots

Contour plots were generated to visualize the cross-sectional temperatures in Diablo Lake. These plots appear in Figures D.2-1 through D.2-18. Temperatures are generated as model output from July 2019 through December 2020. Plots were generated to depict the 15th day of each month. Flow is from left to right on each plot. The Ross Dam releases enter Diablo Lake at the left of the image and Diablo Dam is near the center of the image at River Mile 101. To the right is a depiction of Thunder Arm, in which Thunder Creek enters at Mile 0 and discharges at the right side of the image where Thunder Arm connects to the mainstem of Diablo Lake, near River Mile 103. **Black arrows indicate the depths of spillway and penstock withdrawals from the reservoir.**

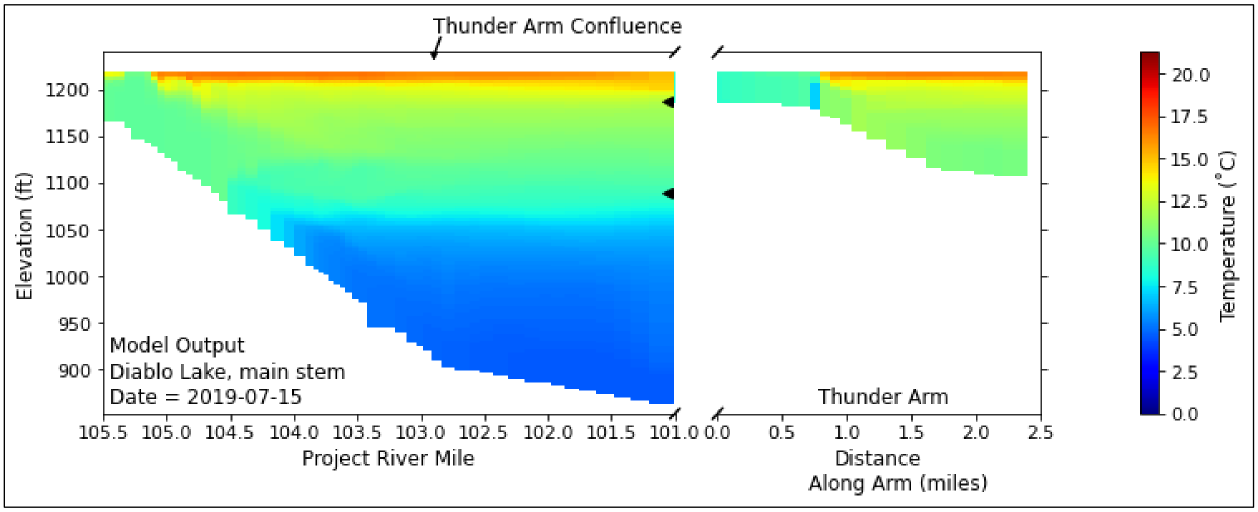


Figure D.2-1. Diablo Lake cross-sectional temperature contour plot on July 15, 2019.

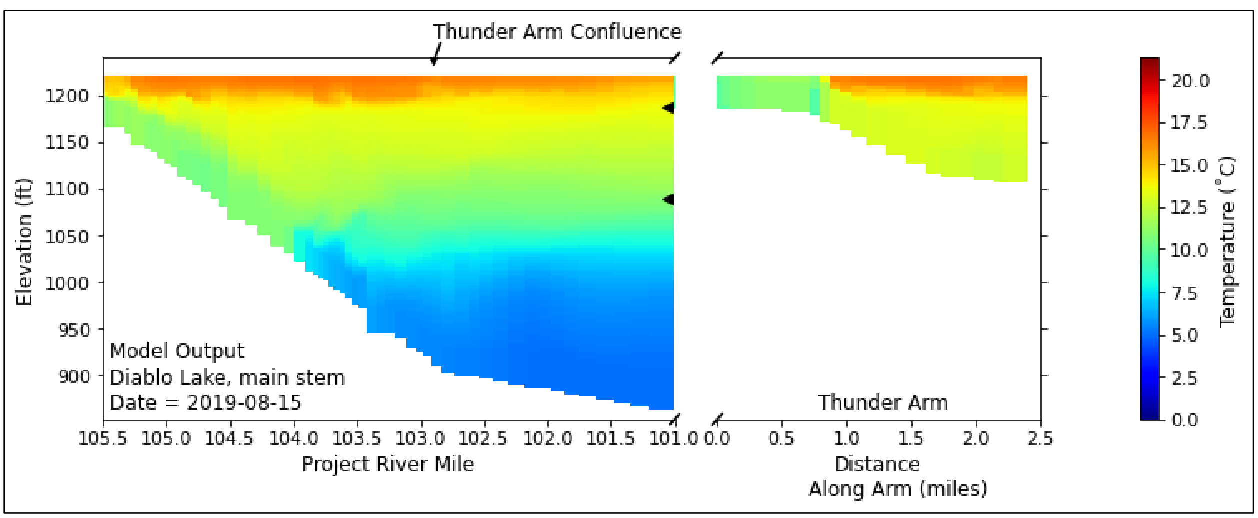


Figure D.2-2. Diablo Lake cross-sectional temperature contour plot on August 15, 2019.

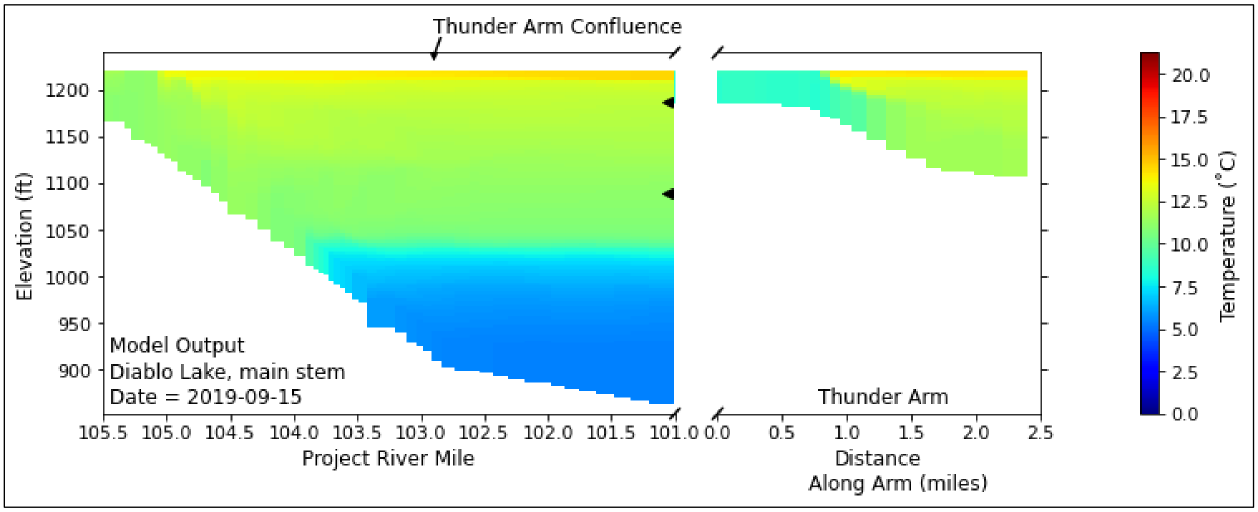


Figure D.2-3. Diablo Lake cross-sectional temperature contour plot on September 15, 2019.

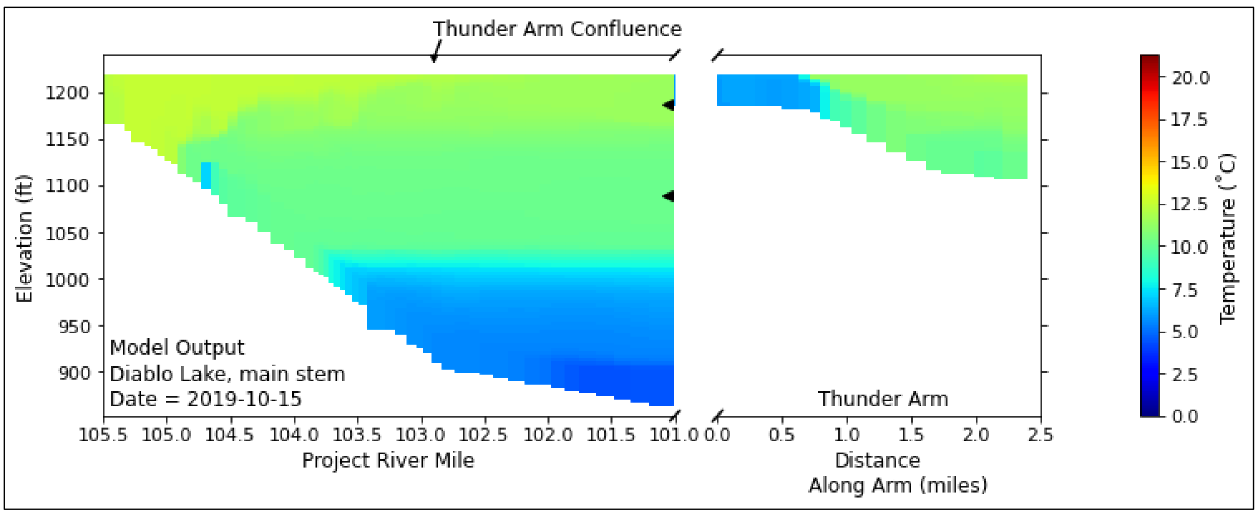


Figure D.2-4. Diablo Lake cross-sectional temperature contour plot on October 15, 2019.

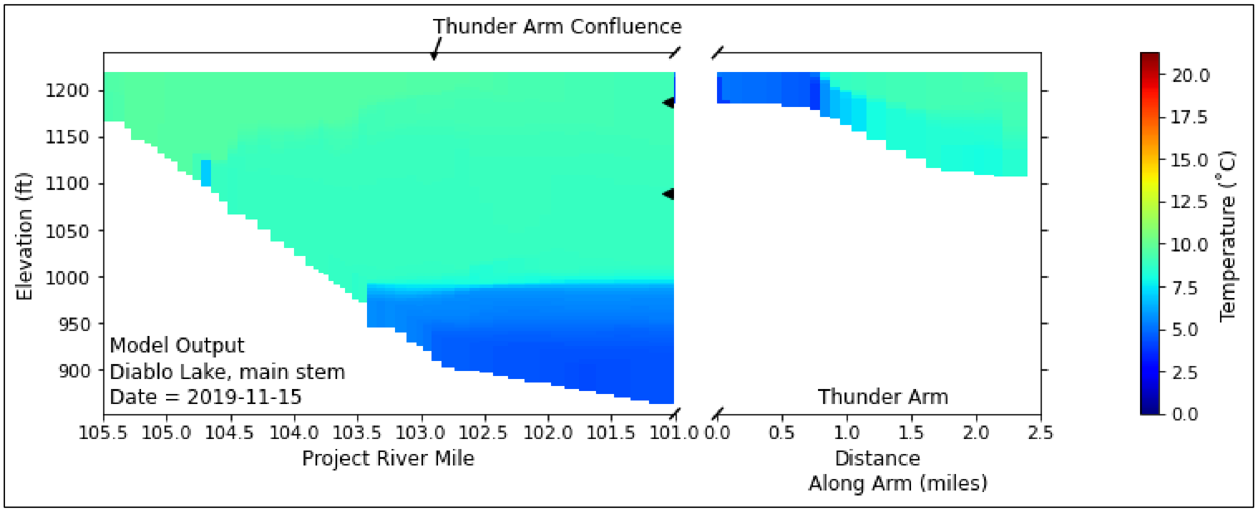


Figure D.2-5. **Diablo Lake cross-sectional temperature contour plot on November 15, 2019.**

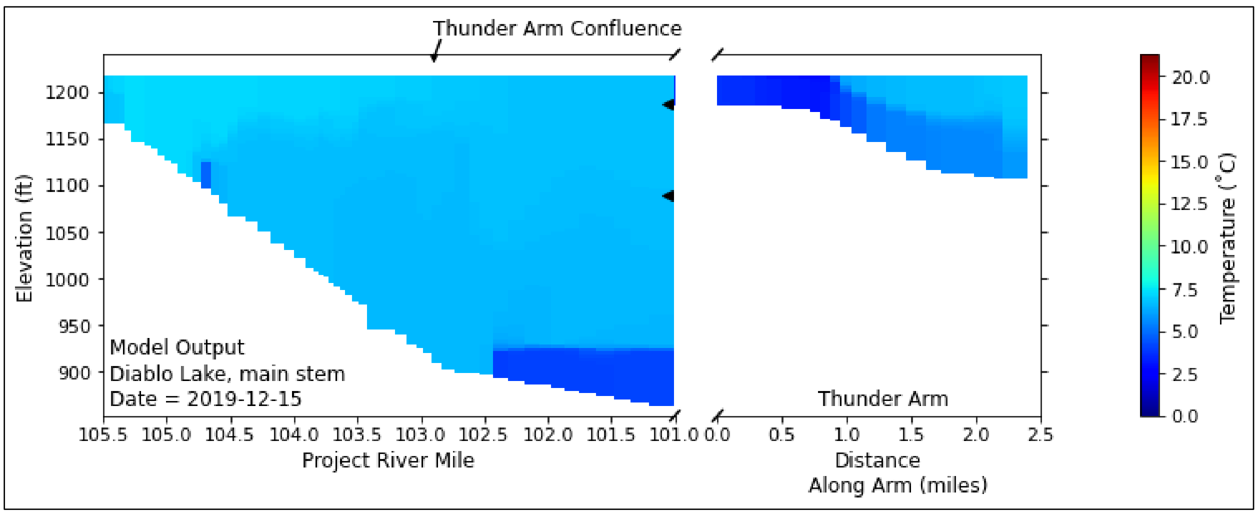


Figure D.2-6. **Diablo Lake cross-sectional temperature contour plot on December 15, 2019.**

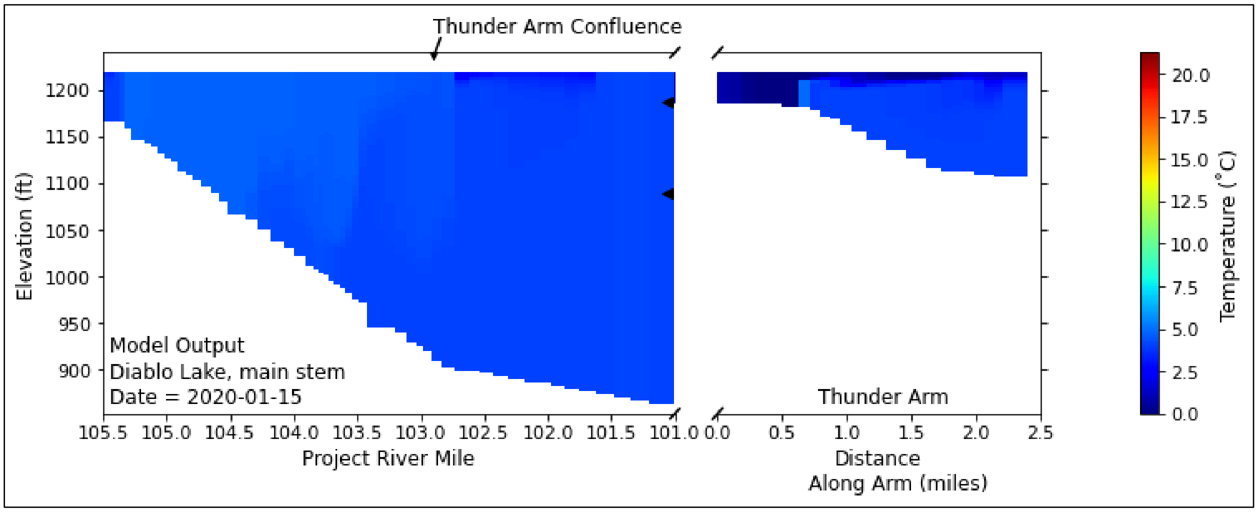


Figure D.2-7. Diablo Lake cross-sectional temperature contour plot on January 15, 2020.

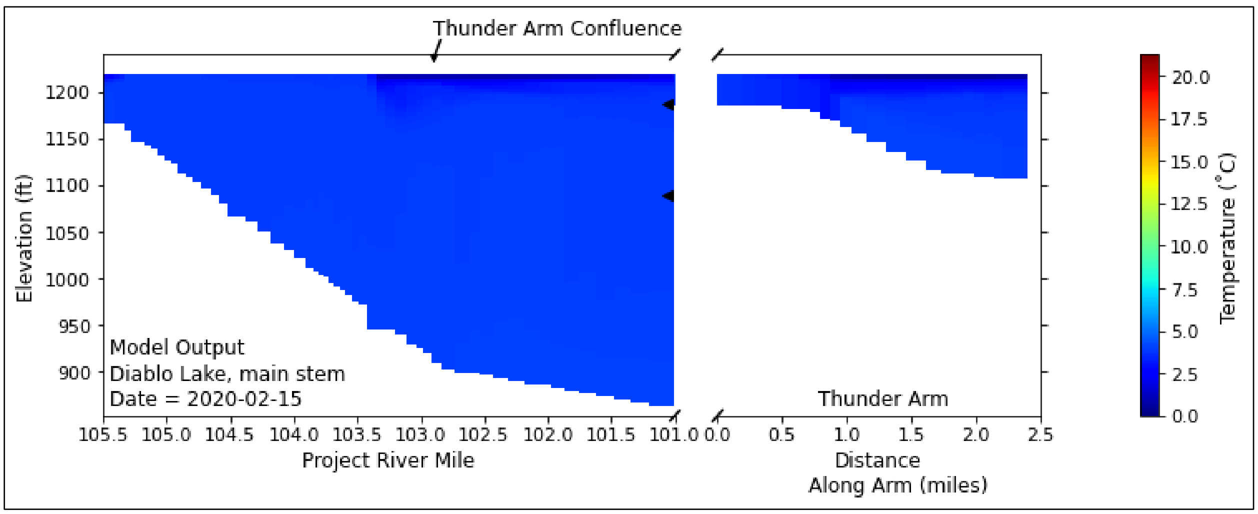


Figure D.2-8. Diablo Lake cross-sectional temperature contour plot on February 15, 2020.

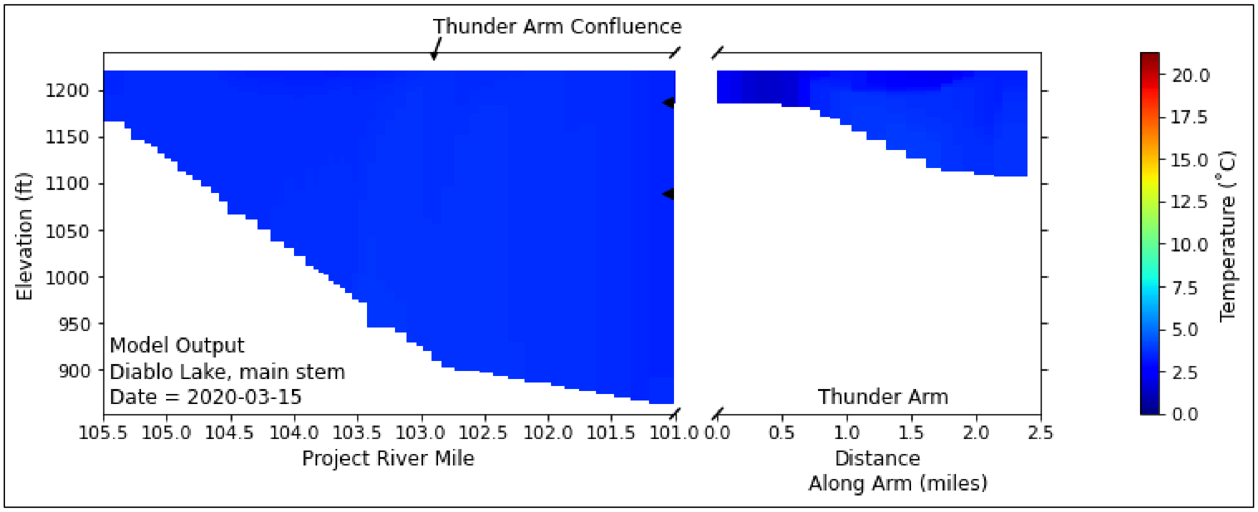


Figure D.2-9. Diablo Lake cross-sectional temperature contour plot on March 15, 2020.

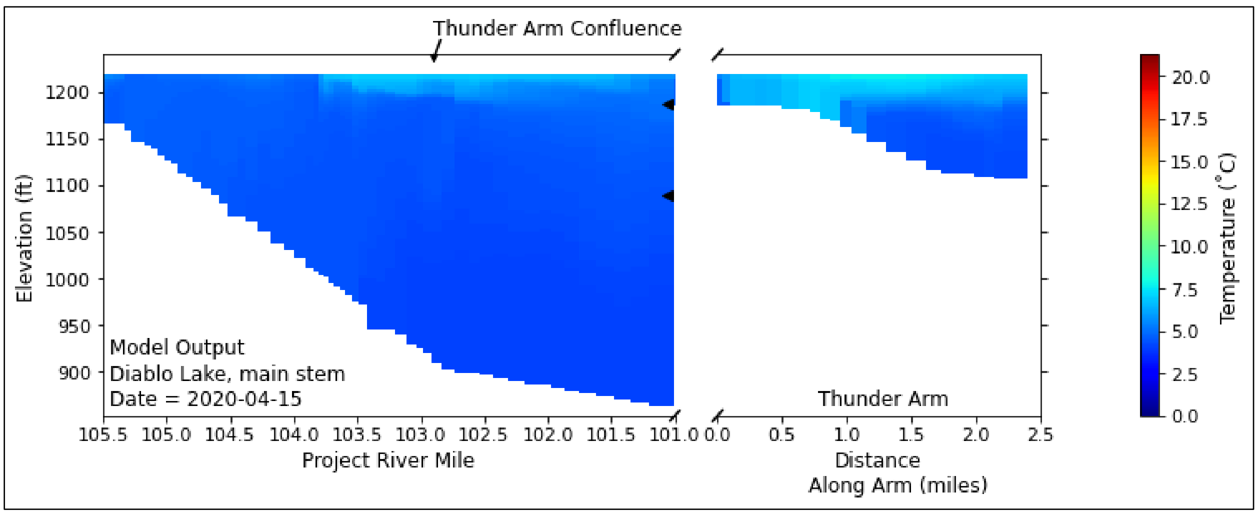


Figure D.2-10. Diablo Lake cross-sectional temperature contour plot on April 15, 2020.

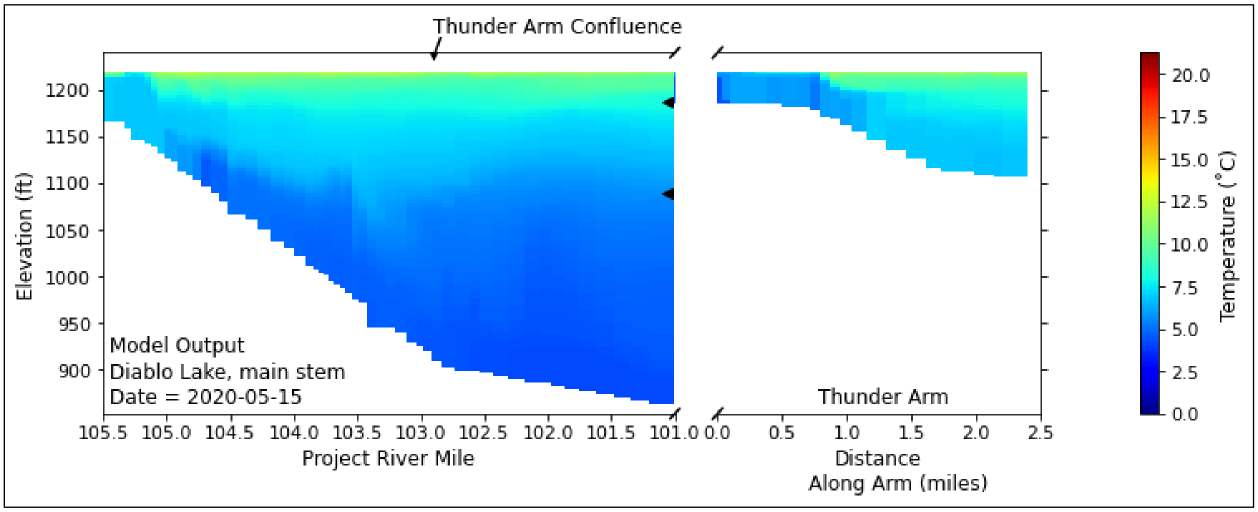


Figure D.2-11. Diablo Lake cross-sectional temperature contour plot on May 15, 2020.

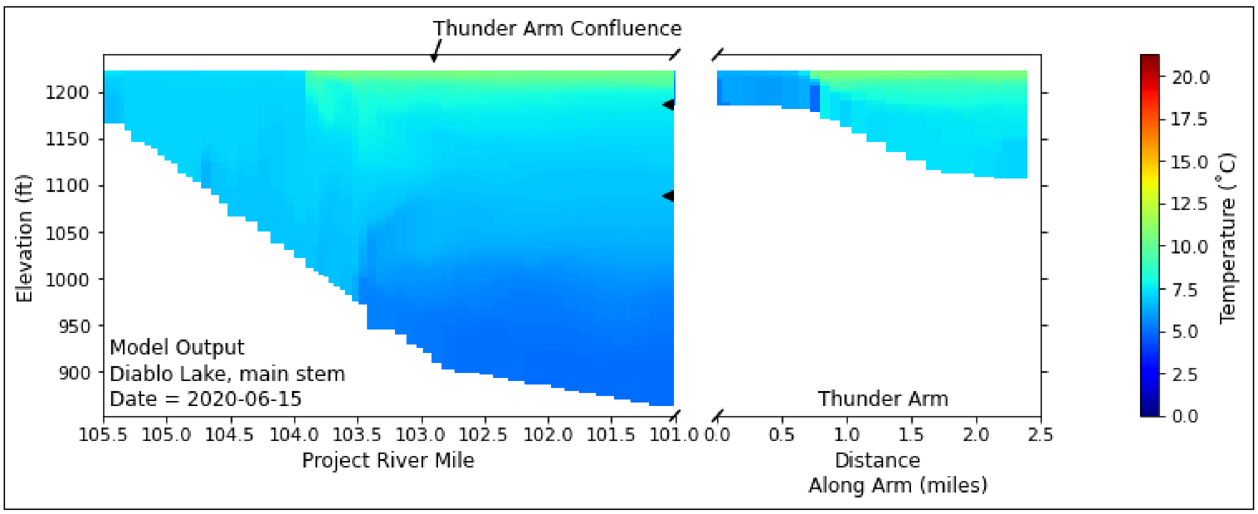


Figure D.2-12. Diablo Lake cross-sectional temperature contour plot on June 15, 2020.

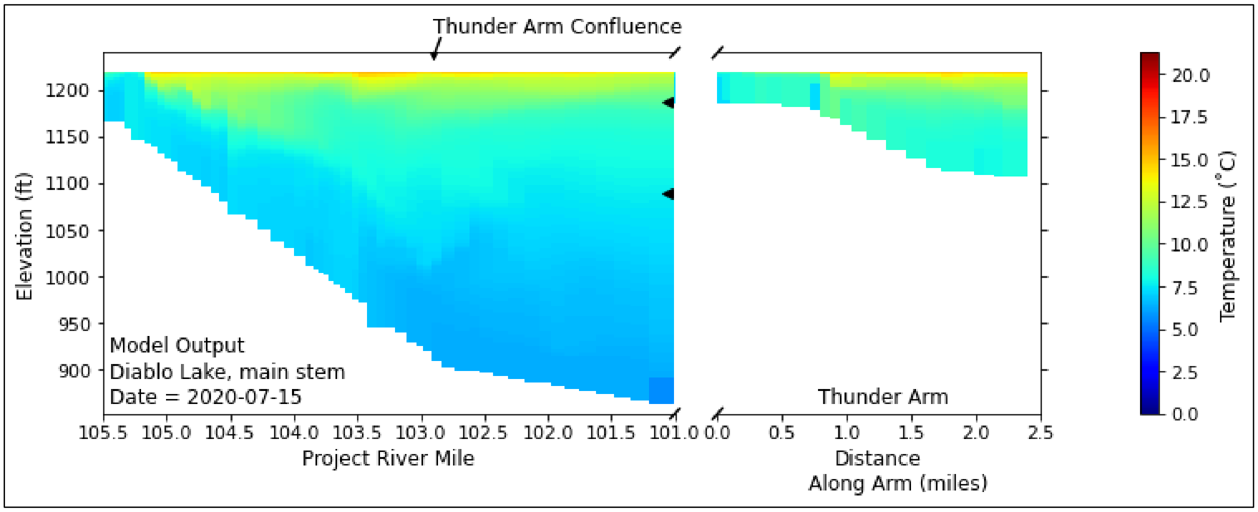


Figure D.2-13 Diablo Lake cross-sectional temperature contour plot on July 15, 2020.

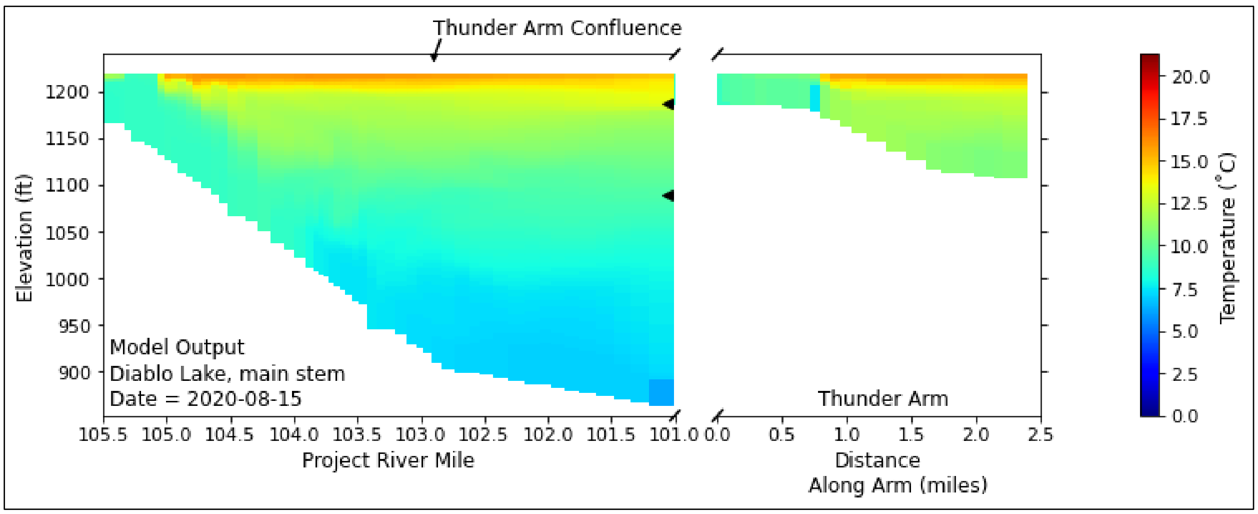


Figure D.2-14. Diablo Lake cross-sectional temperature contour plot on August 15, 2020.

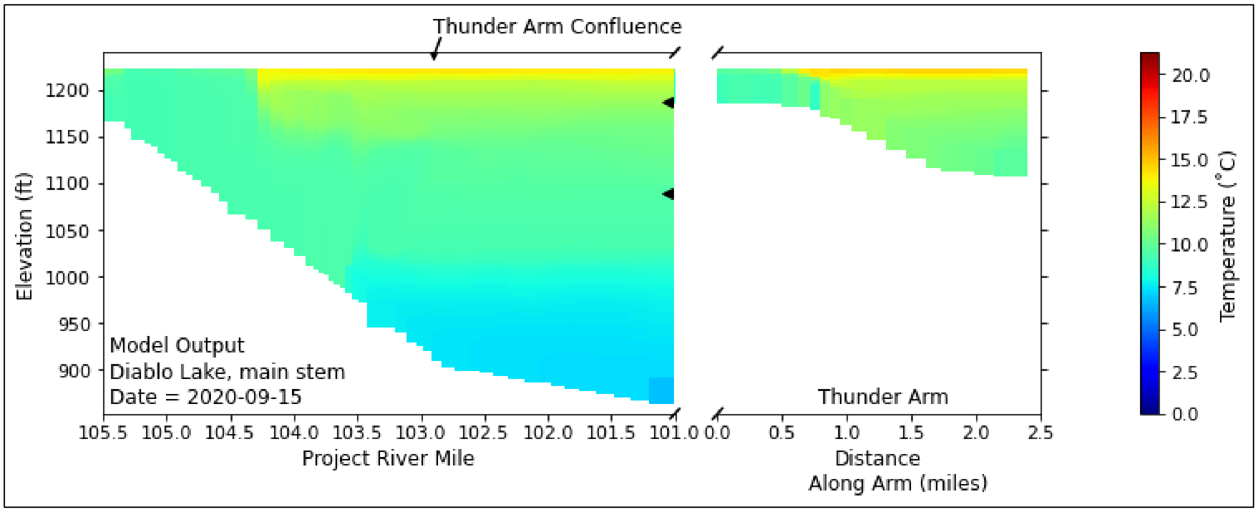


Figure D.2-15. Diablo Lake cross-sectional temperature contour plot on September 15, 2020.

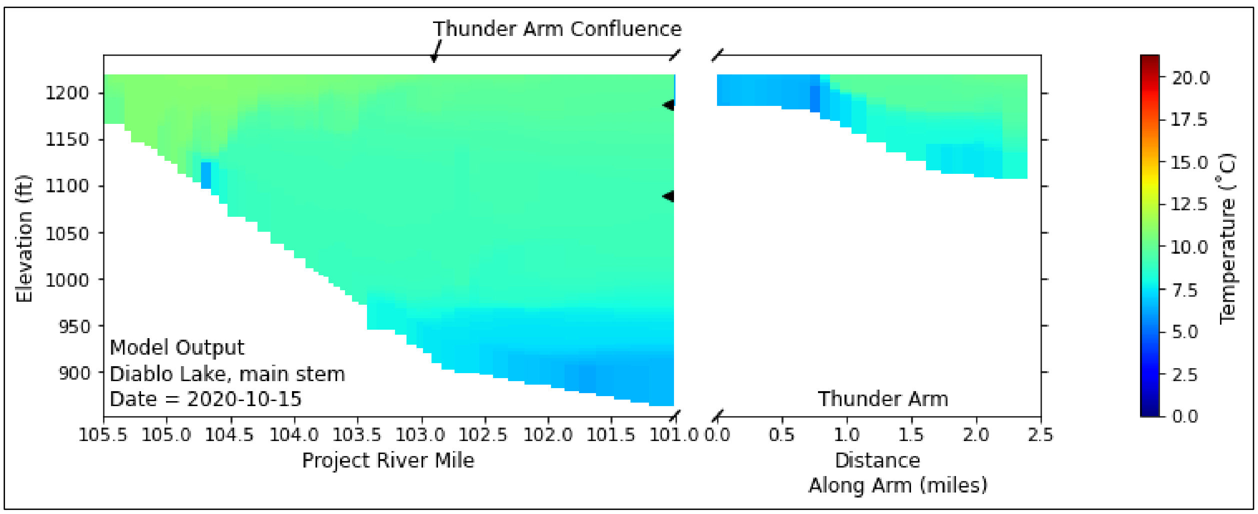


Figure D.2-16. Diablo Lake cross-sectional temperature contour plot on October 15, 2020.

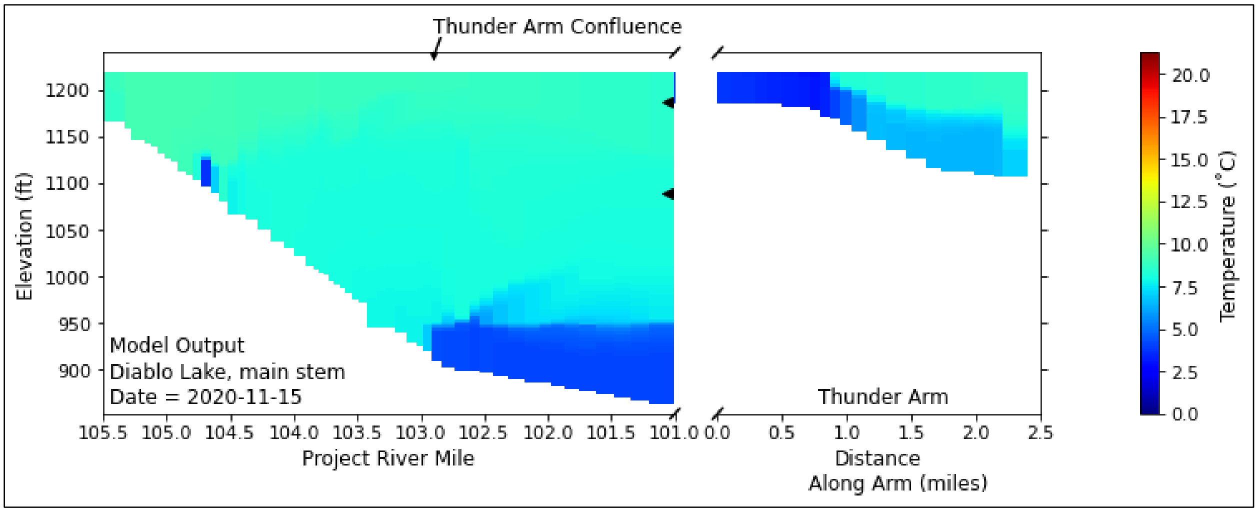


Figure D.2-17. Diablo Lake cross-sectional temperature contour plot on November 15, 2020.

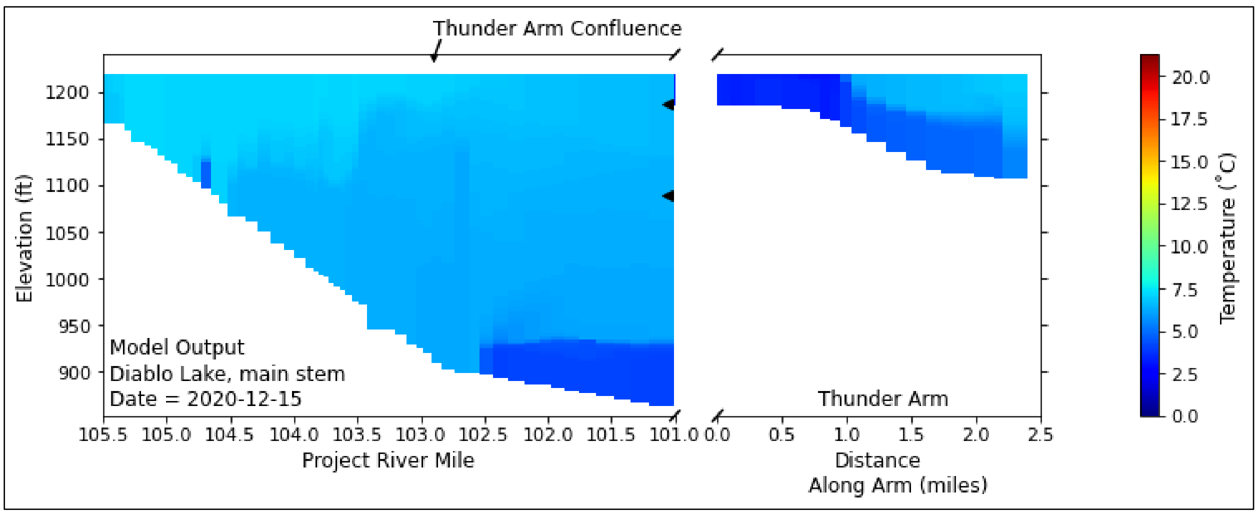


Figure D.2-18. Diablo Lake cross-sectional temperature contour plot on December 15, 2020.

D.3 Gorge Lake Temperature Contour Plots

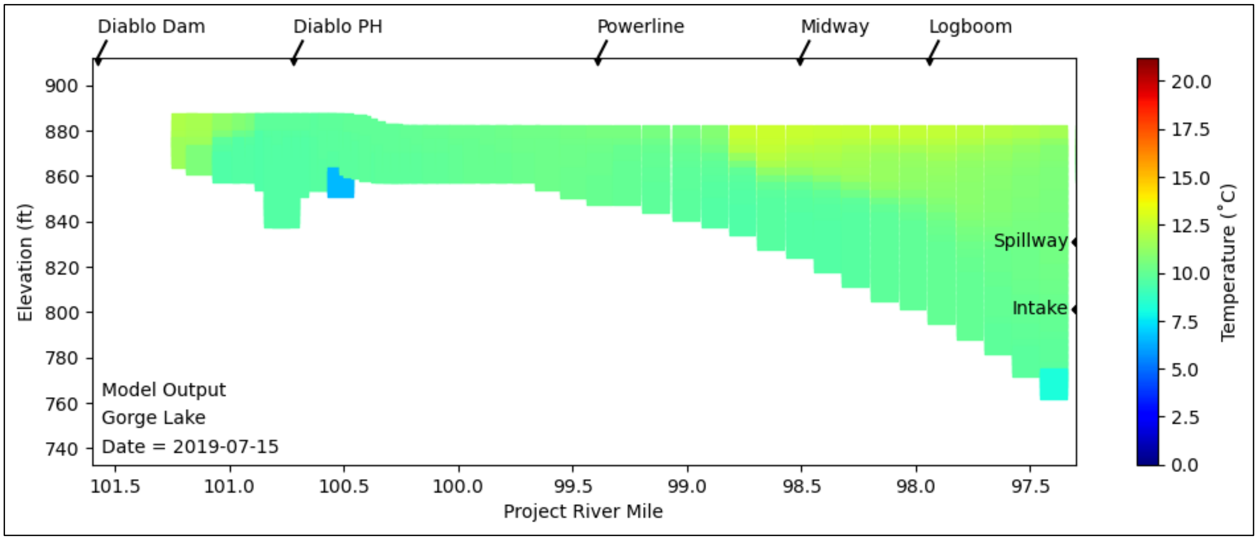


Figure D.3-1. Gorge Lake cross-sectional temperature contour plot on July 15, 2019. Black arrows indicate the depths of spillway and penstock withdrawals from the reservoir.

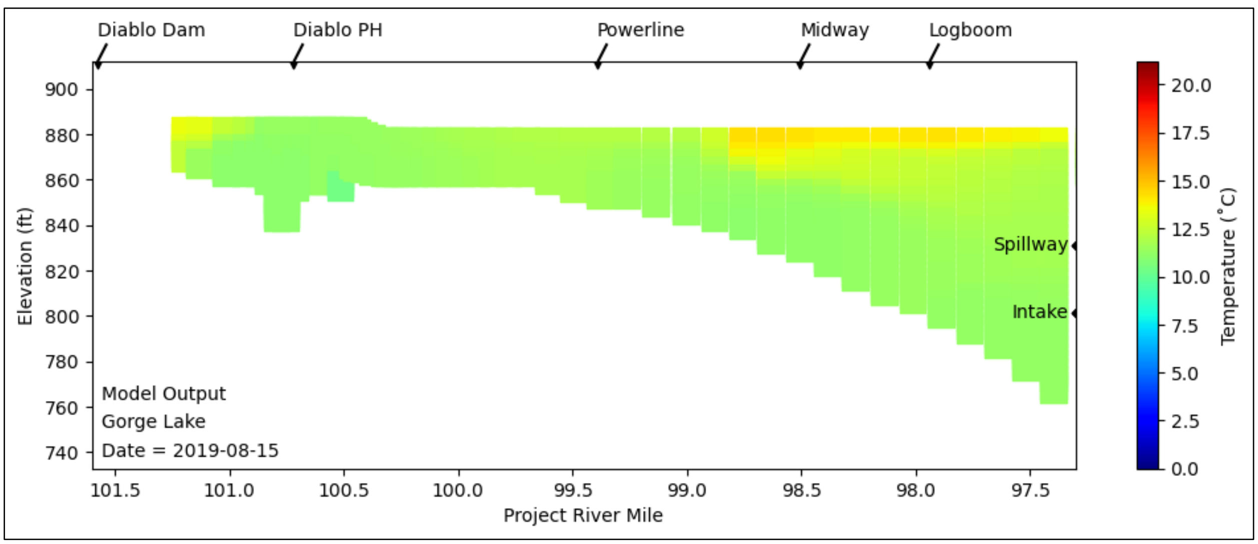


Figure D.3-2. Gorge Lake cross-sectional temperature contour plot on August 15, 2019. Black arrows indicate the depths of spillway and penstock withdrawals from the reservoir.

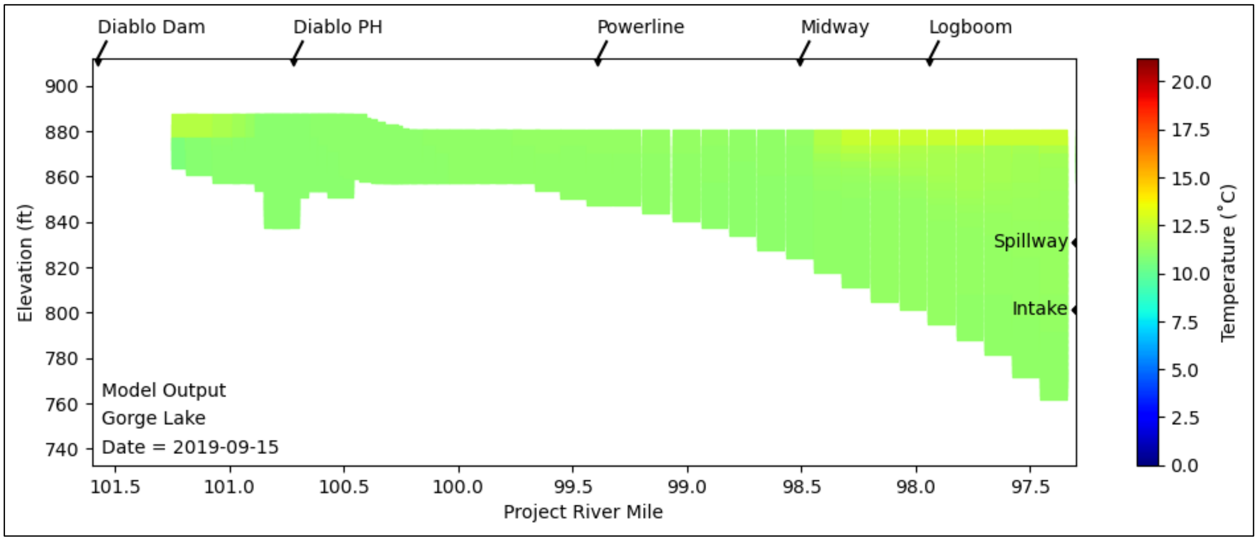


Figure D.3-3. **Gorge Lake cross-sectional temperature contour plot on September 15, 2019. Black arrows indicate the depths of spillway and penstock withdrawals from the reservoir.**

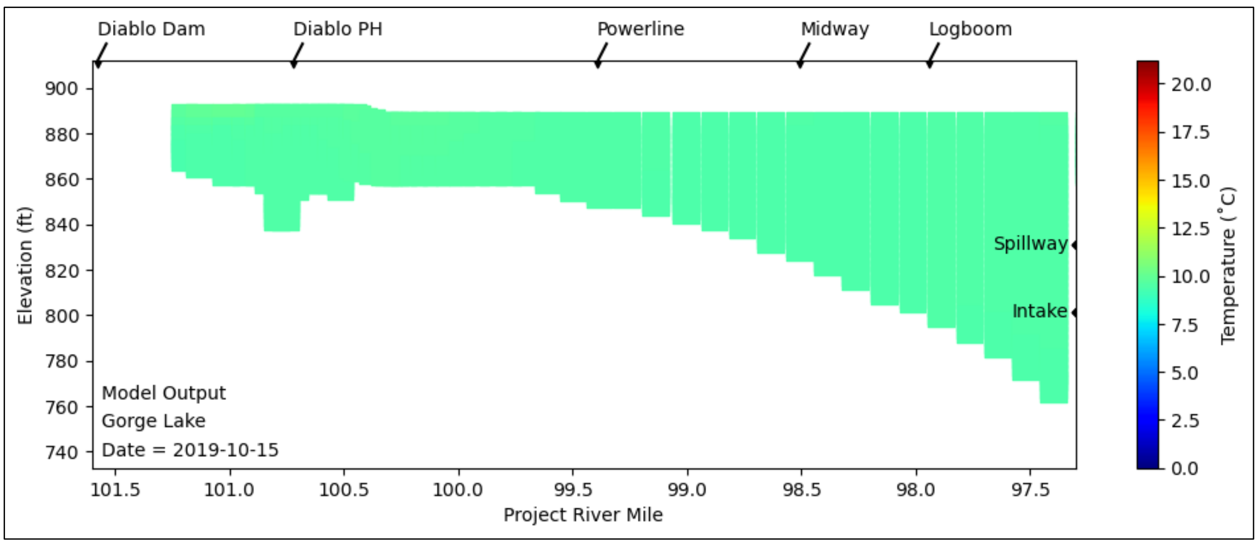


Figure D.3-4. **Gorge Lake cross-sectional temperature contour plot on October 15, 2019. Black arrows indicate the depths of spillway and penstock withdrawals from the reservoir.**

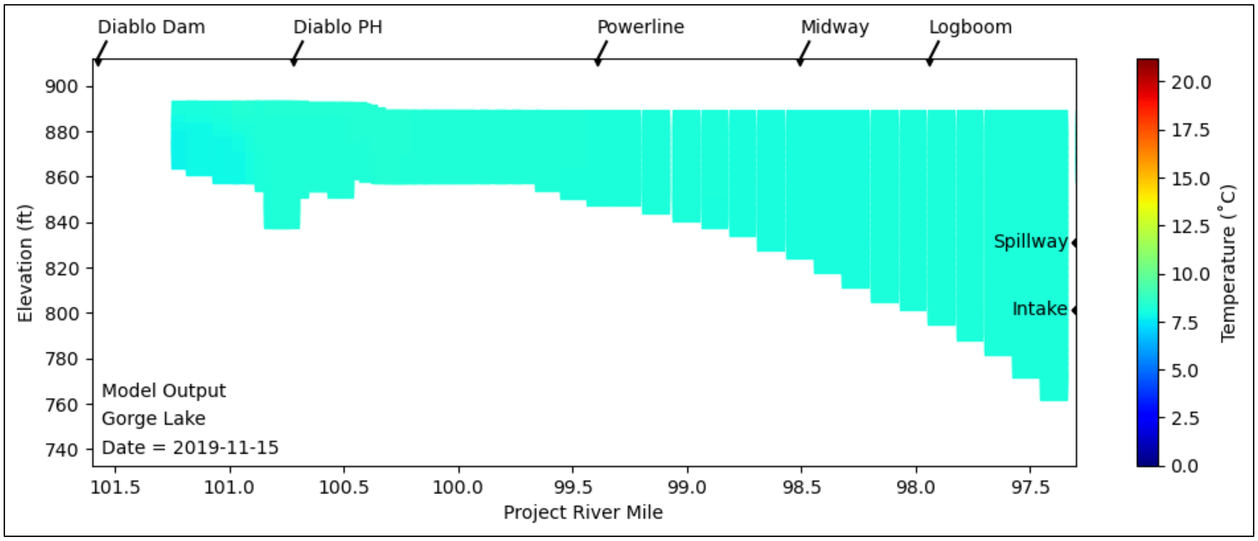


Figure D.3-5. **Gorge Lake cross-sectional temperature contour plot on November 15, 2019. Black arrows indicate the depths of spillway and penstock withdrawals from the reservoir.**

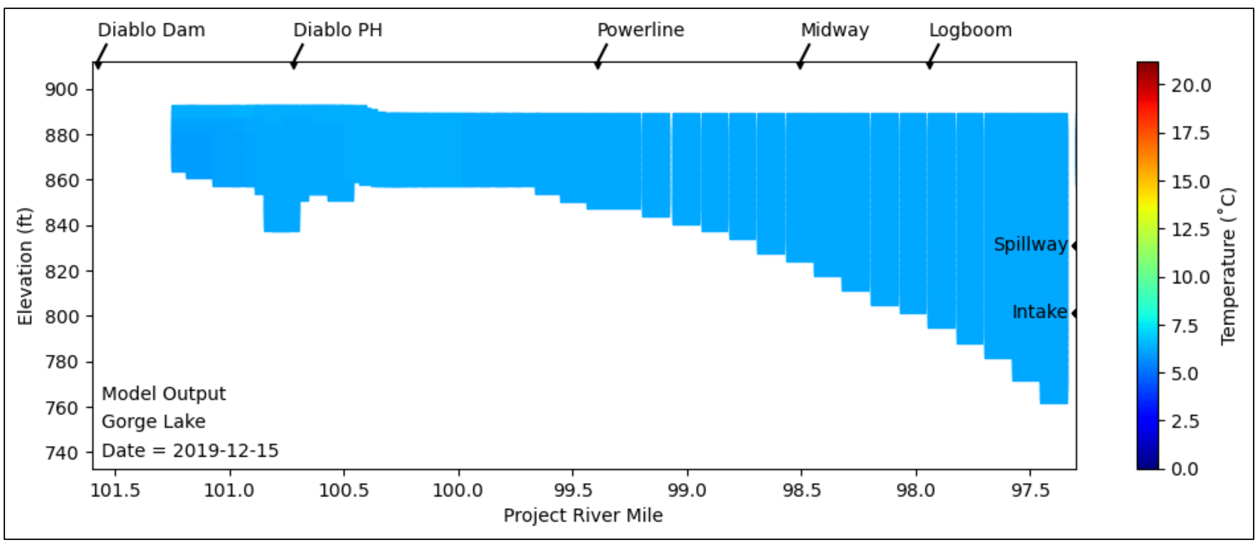


Figure D.3-6. **Gorge Lake cross-sectional temperature contour plot on December 15, 2019. Black arrows indicate the depths of spillway and penstock withdrawals from the reservoir.**

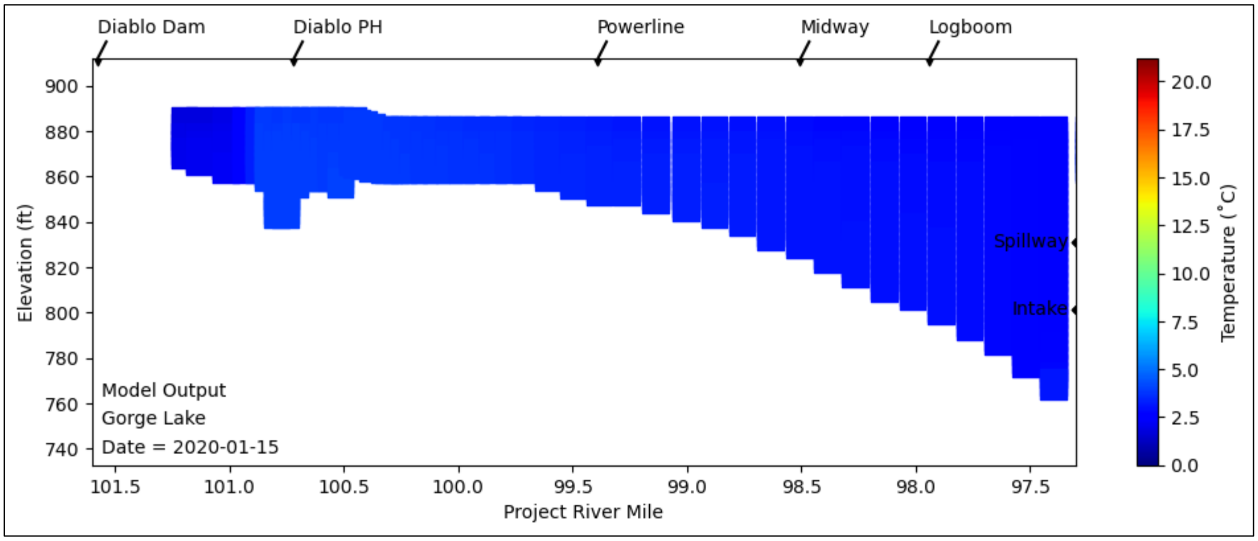


Figure D.3-7. Gorge Lake cross-sectional temperature contour plot on January 15, 2020. Black arrows indicate the depths of spillway and penstock withdrawals from the reservoir.

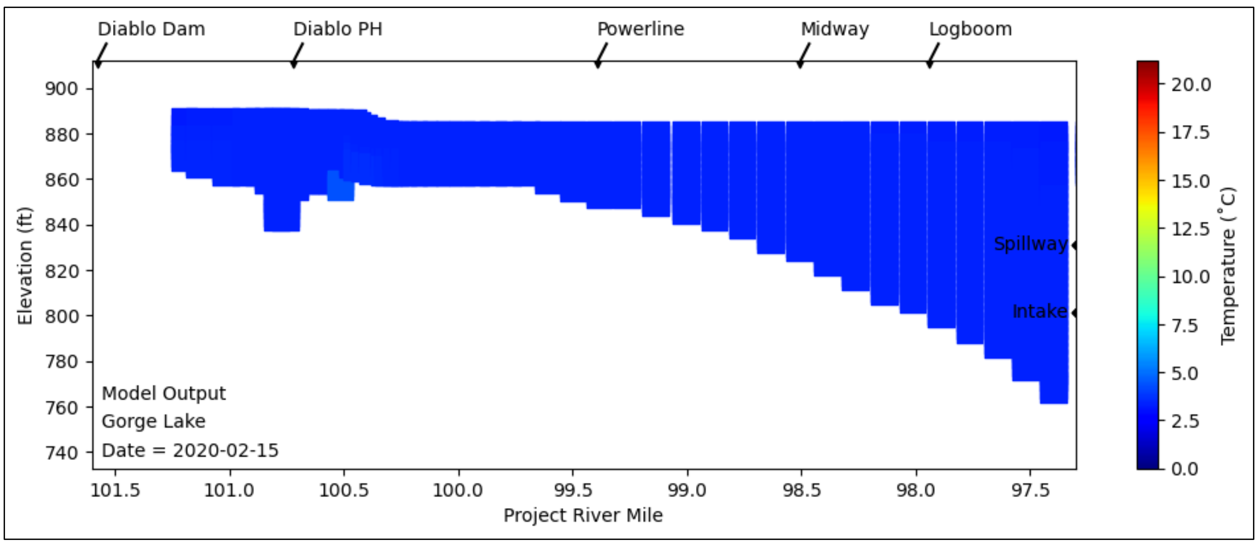


Figure D.3-8. Gorge Lake cross-sectional temperature contour plot on February 15, 2020. Black arrows indicate the depths of spillway and penstock withdrawals from the reservoir.

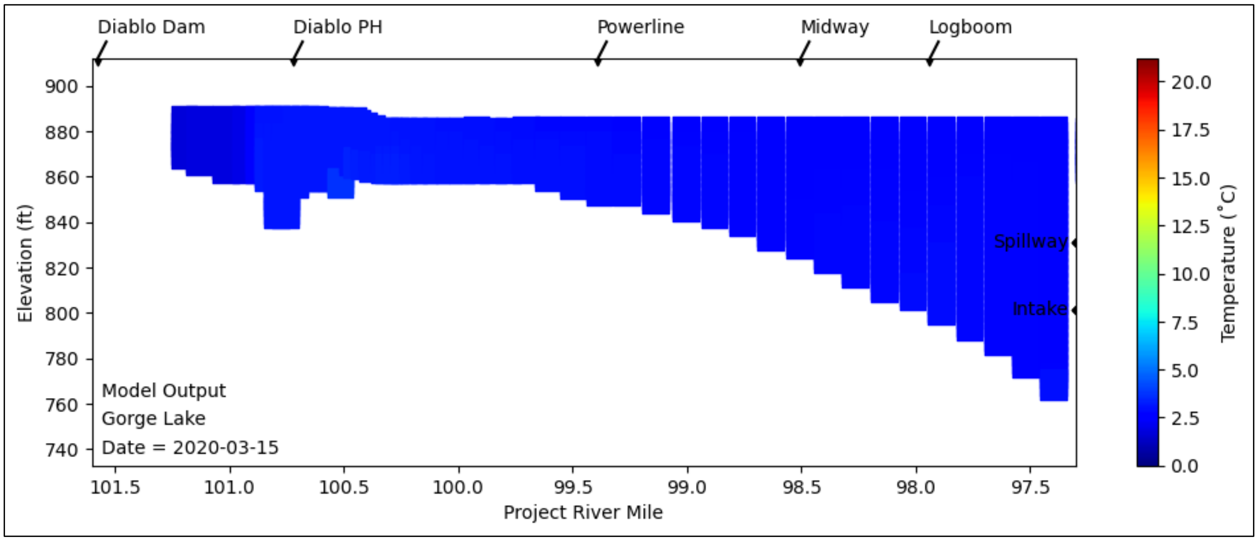


Figure D.3-9. **Gorge Lake cross-sectional temperature contour plot on March 15, 2020. Black arrows indicate the depths of spillway and penstock withdrawals from the reservoir.**

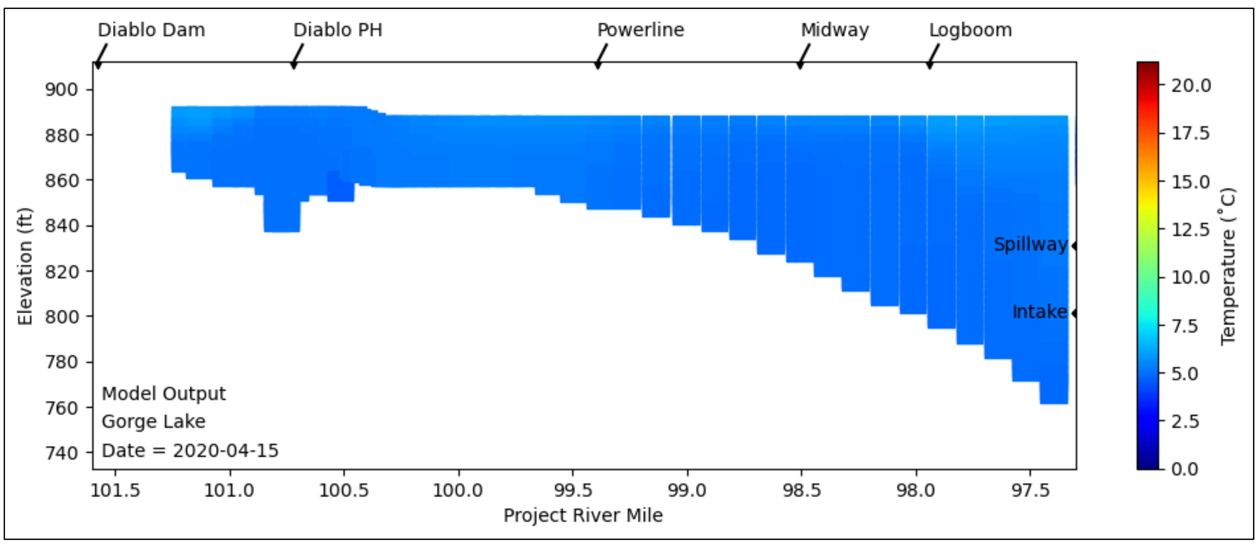


Figure D.3-10. **Gorge Lake cross-sectional temperature contour plot on April 15, 2020. Black arrows indicate the depths of spillway and penstock withdrawals from the reservoir.**

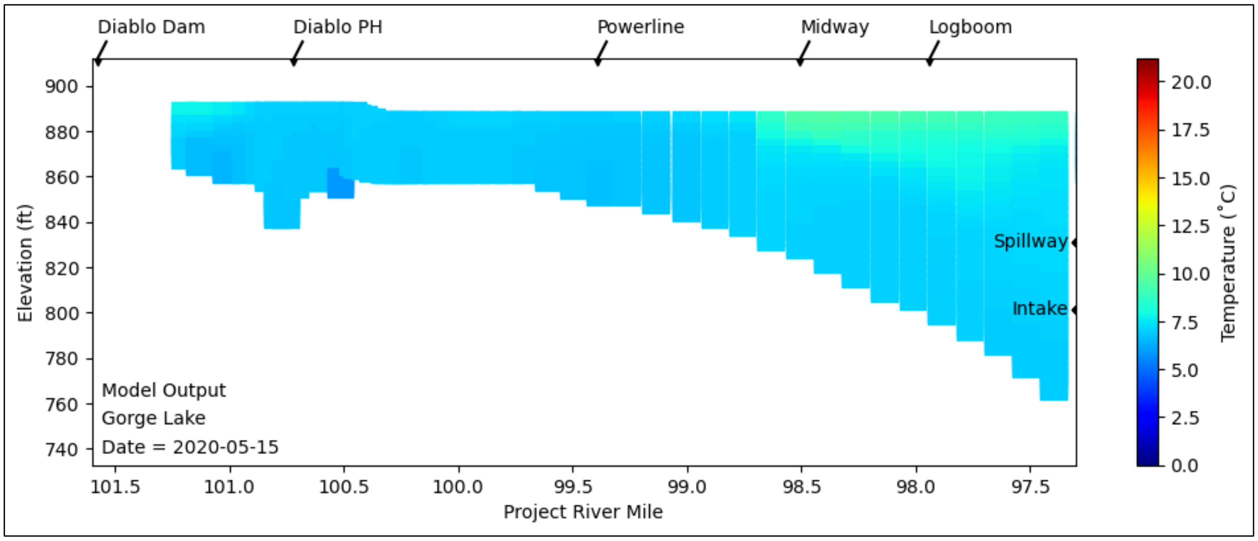


Figure D.3-11. Gorge Lake cross-sectional temperature contour plot on May 15, 2020. Black arrows indicate the depths of spillway and penstock withdrawals from the reservoir.

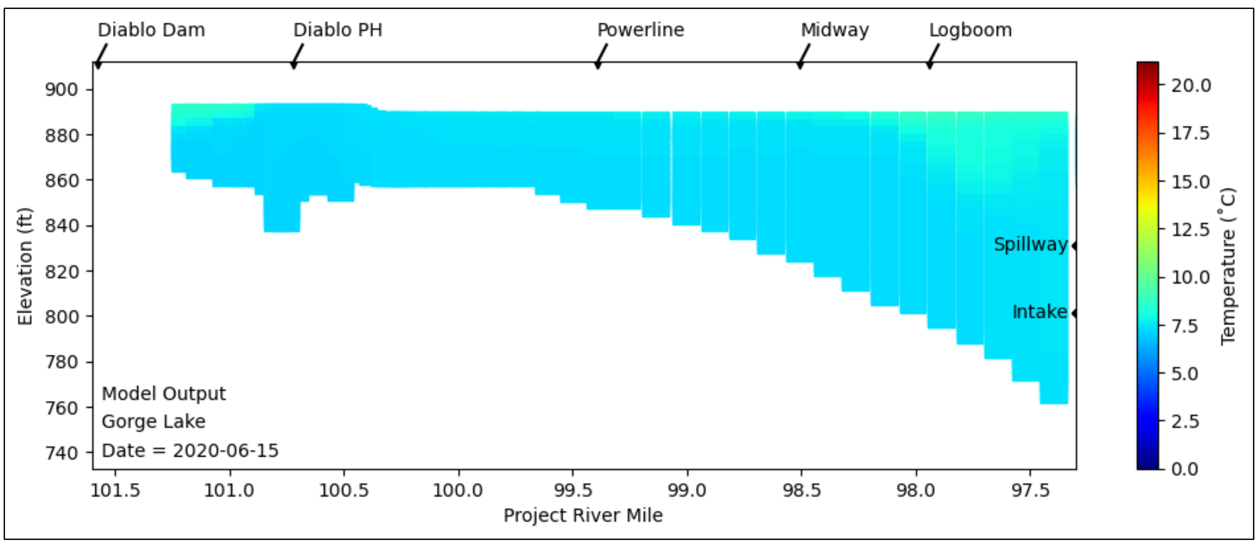


Figure D.3-12. Gorge Lake cross-sectional temperature contour plot on June 15, 2020. Black arrows indicate the depths of spillway and penstock withdrawals from the reservoir.

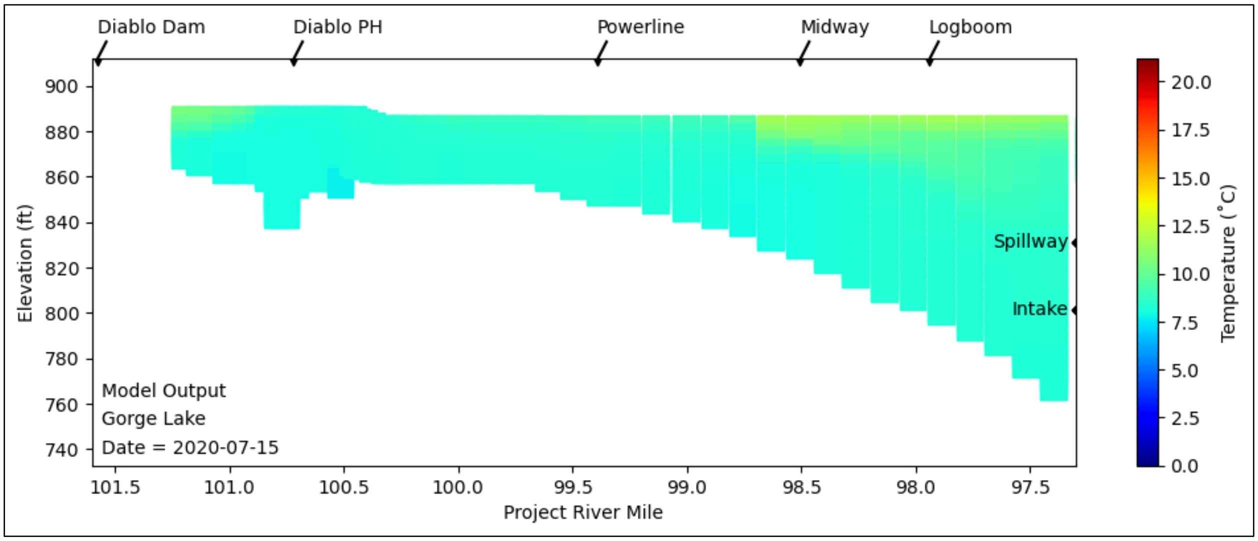


Figure D.3-13 Gorge Lake cross-sectional temperature contour plot on July 15, 2020. Black arrows indicate the depths of spillway and penstock withdrawals from the reservoir.

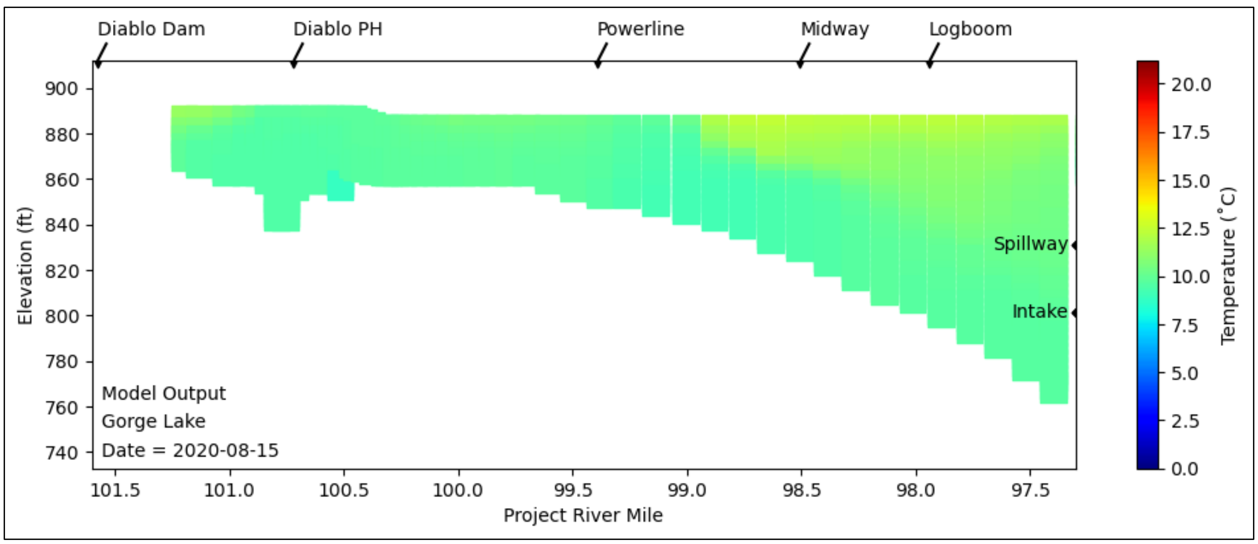


Figure D.3-14. Gorge Lake cross-sectional temperature contour plot on August 15, 2020. Black arrows indicate the depths of spillway and penstock withdrawals from the reservoir.

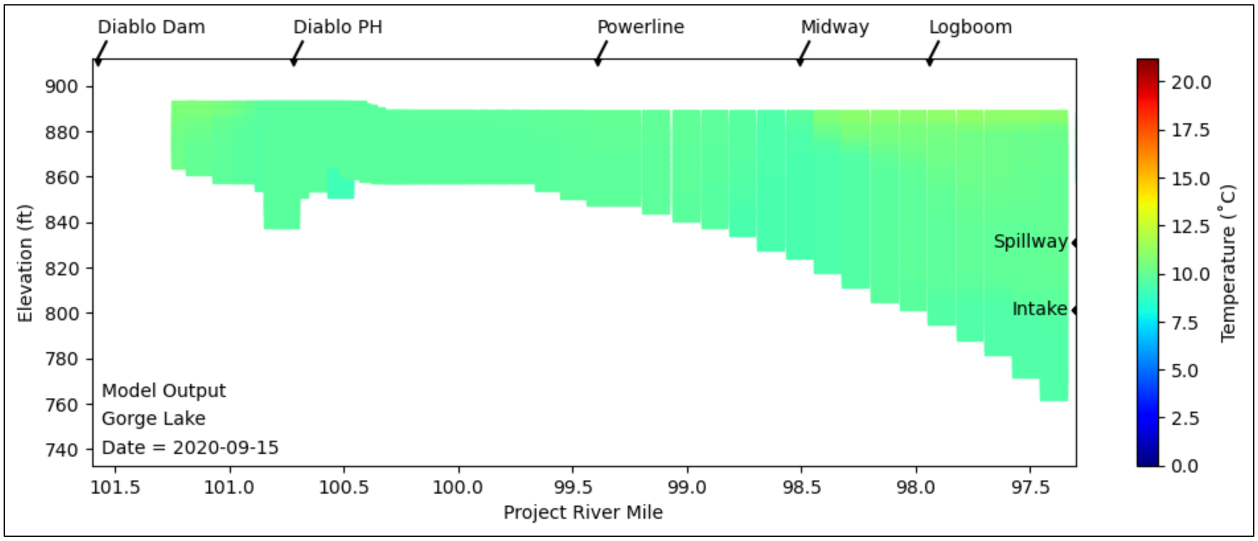


Figure D.3-15. Gorge Lake cross-sectional temperature contour plot on September 15, 2020. Black arrows indicate the depths of spillway and penstock withdrawals from the reservoir.

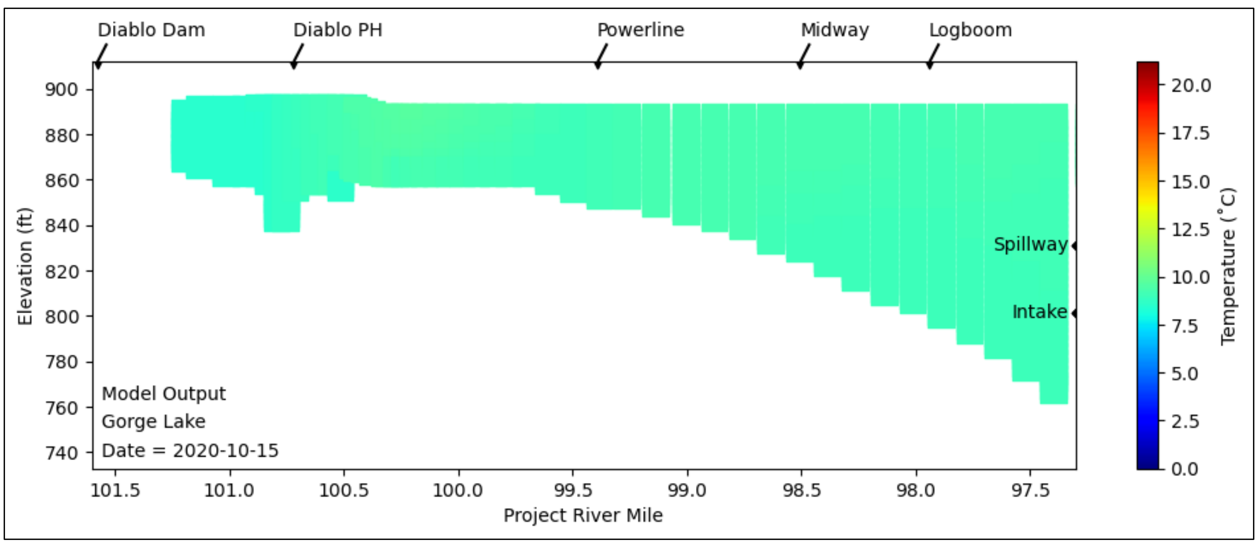


Figure D.3-16. Gorge Lake cross-sectional temperature contour plot on October 15, 2020. Black arrows indicate the depths of spillway and penstock withdrawals from the reservoir.