Snake River Temperature TMDL Model Scenarios

(DRAFT)

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACRONYMS/ABBREVIATIONS

Acronyms/Abbreviations	Definition
7DADM	7-day Average Daily Maximum
7Q10	7-day Average Low Flow with a One-In-Ten-Year Recurrence Interval
BBNC	Biologically Based Numeric Criteria
DMR	Discharge Monitoring Report
HCC	Hells Canyon Complex
HUA	Human Use Allowances
IDEQ	Idaho Department of Environmental Quality
IMD	Internal Management Directive
IPC	Idaho Power Company
MGD	Million gallons per day
No PS	No Point Sources
NPDES	National Pollution Discharge Elimination System
ODEQ	Oregon Department of Environmental Quality
PNV	Potential Natural Vegetation
PSU	Portland State University
RM	River Mile
SRF	Shading Reduction Factor
STP	Sewage Treatment Plant
TMDL	Total Maximum Daily Load
Tt	Tetra Tech
TTools	Shade calculation software
W2	CE-QUAL-W2
WLA	Waste Load Allocation
WWTP	Wastewater Treatment Plant

1.0 INTRODUCTION

This document discusses the development and results of the various model scenarios used to support the Snake River Temperature TMDL and then presents the temperature change relative to baseline conditions for each scenario. The calibrated Snake River CE-QUAL-W2 (“W2”) model for temperature (Tetra Tech 2023) was used for scenario simulations. The extent of the model domain for the Snake River was from River Mile (RM) 398 at Adrian, OR to RM 176 at the Oregon, Idaho, and Washington triple border, covering a stretch of 222 miles (Figure 2-1). The calibrated model and scenario models span the period from January 2014 to December 2018. This period includes the critical summer (non-spawning) and spawning seasons (October 23 to April 15).

2.0 MODEL SCENARIO INTERPRETATION

This section discusses the calculation metrics that were used when evaluating the scenarios.

2.1 SIGNIFICANT DIGITS AND ROUNDING

The TMDL analysis, interpretation of the model results, and all scenarios account for significant digits and rounding. To evaluate human use allowance (HUA) attainment, Oregon Department of Environmental Quality (DEQ) tracks temperature values to the hundredths place. Because some of the HUAs assigned to source categories are expressed out to the hundredths, attainment must also be tracked in a similar manner. DEQ has a permit-related internal management directive (IMD) on rounding and significant digits (DEQ 2013). The TMDL analysis follows the rounding procedures outlined in this IMD. For significant figures the IMD states that for “calculated values” (which includes model results), if the digit being dropped is a “5,” it is rounded up. For example, DEQ is proposing a 0.30 °C HUA assignment. If the model predicts a temperature increase of 0.304 °C, it is rounded down to 0.30 °C, resulting in attainment. However, if the model shows a warming of 0.305°C, it is rounded up to 0.31 °C, leading to a non-attainment result.

2.2 CALCULATING THE 7-DAY AVERAGE MAXIMUM TEMPERATURE

For each scenario the 7-day average daily maximum (7DADM) temperature was calculated using the hourly model output for every day in the model period (2014–2018). The 7DADM was calculated using the procedure outlined in DEQ’s Temperature IMD (DEQ 2008). As outlined in the document, the 7DADM temperature is calculated by first calculating the daily maximum for each day, followed by calculating a rolling average of the daily maxima, the result for which is assigned to the 7th day. The 7-day rolling average of daily maximum temperatures resets at the start of a new temperature criterion period only for the river segment from Hells Canyon Dam to the Oregon/Washington/Idaho state line, due to different Biologically Based Numeric Criteria (BBNC) for spawning and critical summer seasons. For instance, from Hells Canyon Dam to the Oregon–Washington–Idaho border, no 7DADM values are reported (i.e., marked as not applicable [NA]) between April 16–21 and October 23–28 due to this reset.

2.3 BIOLOGICALLY BASED NUMERIC CRITERIA

The applicable Oregon temperature criteria for the Snake River and Hells Canyon Complex reservoirs are defined in DEQ Water Quality Standards, Chapter 340 (OAR 340-041-0121, Table 121B[1,2]) and are summarized below:

1. Oregon/Washington Border to Hells Canyon Dam (RM 176 to 247.5)
   - Salmon and Steelhead Migration Corridors: 20 °C
   - Salmon and Steelhead Spawning Through Fry Emergence: 13 °C from October 23 to April 15
2. Hells Canyon Dam to Adrian (RM 247.5 to RM 398)
   - Redband or Lahontan Cutthroat Trout: 20 °C

These criteria are referenced in rule as the biologically based numeric criteria (or BBNC). The BBNC vary spatially and temporally and are evaluated based on 7DADM temperature. Essentially, a 7DADM of 20°C applies year-round from Adrian to the Oregon/Washington border, but downstream of Hells Canyon dam, a spawning criterion of 13°C also applies from October 23 to April 15, as shown in Figure 2-1.

DEQ conducted a stringency analysis to compare Oregon's BBNC with those of Idaho and Washington. As documented in the TMDL and Technical Support Document, the analysis concluded that Oregon's criterion is protective of both Idaho's and Washington's criteria; therefore, the scenario comparisons in this memo focus on Oregon's temperature criteria.

[1] https://secure.sos.state.or.us/oard/viewSingleRule.action?ruleVrsnRsn=309372
[2] https://www.oregon.gov/deq/wq/Documents/wqsCurr340-041-0121t.pdf

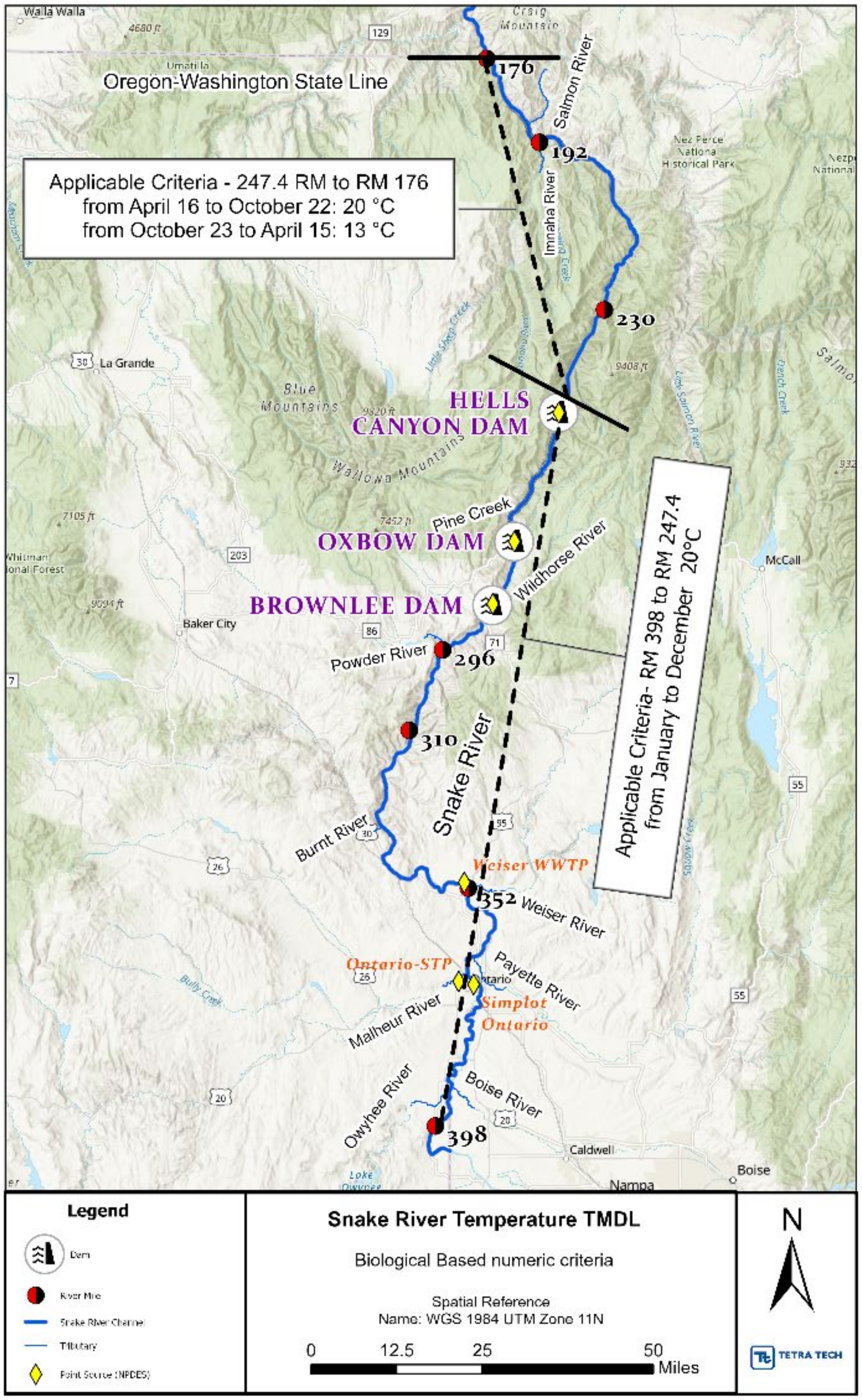

Figure 2-1. Snake River TMDL project area map showing the model extent including river miles, point sources, tributaries, and where seasonal spawning criteria apply. The 20 °C applies year-round; however, the 13 °C criterion functionally supersedes it during the seasonal spawning period. Unlike the 13 °C criterion, the 20 °C criterion does not have a defined seasonal timeframe, as indicated in the label.

3.0 MODEL SCENARIOS

This section describes the model conditions associated with each of the ten scenarios summarized in Table 3-1. The starting point, or baseline, for the no point source, no dams, and restored vegetation scenarios is the calibration model scenario. Details of the W2 model setup and calibration for the calibration scenario are provided in the model development reports (Wells et al., 2021b; Tetra Tech 2023). The calibration model incorporates major tributaries of the Snake River, operations of the Idaho Power Company (IPC) Hells Canyon Complex (HCC) dams, National Pollution Discharge Elimination System (NPDES) discharges, and shading effects from existing vegetation and topography. As described in Section 3.4, the background scenario (which removes dams and anthropogenic sources direct to the river) is used as a baseline instead of the calibration model for some scenarios and for some comparisons aimed at evaluating the effect of management changes to the 0.3°C HUA because thermal stratification in the Hells Canyon complex reservoirs simulated within the calibration scenario was confounding interpretation of scenarios and anthropogenic inputs.

Table 3-1. Snake River Temperature TMDL scenarios: Descriptive summary.

Scenario	Alias	Baseline	Equivalent to Baseline Except
No point source	No PS	Calibration	No NPDES-permitted point source discharges
No dams	-	Calibration	Represents Snake River stream morphology without HCC dams. Bathymetry: Reservoirs have estimated historic channel. Shade: Reservoirs have restored vegetation along historic channel and where there is dam infrastructure.
Restored vegetation	-	Calibration	Shade: Restored vegetation conditions on riverine channel.
Background	-	Calibration	No NPDES-permitted point source discharges Bathymetry: Reservoirs have estimated historic channel. Shade: Restored vegetation conditions on riverine and along the historic channel under the reservoirs and at dam infrastructure.
Tributary A	-	Background	Oregon tributaries’ temperature increased by 0.3 °C. Idaho tributaries increased by 0.14 °C with Payette River increased by 0.3 °C.
Tributary B	-	Background	Tributaries set to attain the applicable temperature criteria.
TMDL waste load allocations	WLA	Background	NPDES- permitted point source discharges set at waste load allocation (WLA) effluent discharge. WLA temperatures for Oxbow and HCC dams are calculated using flow rate in background model.
HUA Attainment	-	Background	Include all modifications from scenarios 5 and 6.
Surrogate	-	Background	Boundary condition temperatures at location of Hells Canyon Dam outlet are adjusted per the surrogate measure target*.
Reserve capacity 0.1 °C	-	Background	Equivalent to attainment scenario except Snake River mainstem temperature boundary condition at RM 398 increased by 0.1 °C
Reserve capacity 0.15 °C	-	Background	Equivalent to attainment scenario except Snake River mainstem temperature boundary condition at RM 398 increased by 0.15 °C

3.1 NO POINT SOURCES (NO PS)

This scenario is identical to the calibration scenario, except that all point source discharges in

Figure 2-1 were removed from the W2 model. Table 3-2 presents monthly mean 7DADM temperature at Hells Canyon Dam for the no PS scenario. Temperatures range between 1.9–3.8 °C during winter (January–February). In spring (March–May), temperatures rise gradually and average between 4.6–14.8 °C. Summer (June–August) marks the warmest period, with temperature peaking between 16.8–23.6 °C. Temperatures then gradually cool through the fall, with October ranging from 15.9–18.6 °C and November between 10.6–13.2 °C. By December, temperatures drop further, averaging about 6.2–7 °C.

Table 3-2. Mean 7DADM temperature by month and year for the no point source scenario at Hells Canyon Dam.

Month	Mean 7DADM Temperature (°C)				
	2014	2015	2016	2017	2018
January	3.0	3.7	3.1	2.6	3.0
February	1.9	3.6	3.0	2.2	3.8
March	4.6	6.7	6.4	5.6	5.1
April	9.0	9.8	10.6	10.0	9.9
May	12.1	12.9	14.3	13.5	14.8
June	16.9	17.1	17.5	16.8	18.4
July	20.4	20.5	20.4	20.9	21.3
August	22.9	22.5	22.1	23.3	23.6
September	22.2	21.2	21.2	22.3	21.6
October	18.6	18.4	17.1	15.9	16.3
November	12.8	13.2	12.3	10.6	11.3
December	6.9	6.6	7.0	6.5	6.2

3.2 NO DAMS

To evaluate the impact of the HCC dams on water flow and temperature in the Snake River, a no dams scenario was developed. This scenario involved two key modifications: (1) the HCC dams were removed from the model configuration, and (2) the river bathymetry was updated to represent the natural channel geometry prior to dam construction. These changes were implemented to simulate river conditions as they would exist without the influence of the dams.

Converting the HCC reservoirs into W2 river segments presented a significant challenge, as dam removal can introduce instability into the model due to steeper water surface slopes and increased velocities. To mitigate these effects, targeted modifications were made to HCC reservoir models to maintain numerical stability in both water surface elevation and temperature computations. This section describes the methodology used to remove the Brownlee, Oxbow, and Hells Canyon reservoirs from the W2 models while preserving stability under the no dams scenario.

Reservoir Modifications

Brownlee: The Brownlee reservoir is the largest among the HCC reservoirs, and its W2 model encompasses 5 waterbodies, 7 branches, and two tributaries. The model also includes 6 structures, consisting of 5 turbines and 1 gate, positioned in the last model segment. These structures direct water from the reservoir to the downstream reach that flows into the Oxbow reservoir. These structures were removed from the model and replaced by a spillway that approximates natural channel flow to convert the reservoir into a free-flowing river. Additionally, the bottom slope was increased to a minimum of 0.000001 to prevent the model from removing shallow segments during water surface calculations. These modifications are consistent with the temperature modeling methodology applied to free-flowing segments of the Snake River (Tetra Tech, 2023).

After these modifications, the W2 model was still unstable as some of the river segments dried up at the beginning or middle of the simulation due to the steep, non-zero slope of the water surface. Attempts to stabilize the model, such as reducing the maximum time step for model calculations or starting with an initial high water surface elevation as recommended by the W2 User Manual (Wells 2021a), were only partially successful. As a result, the Brownlee model was divided into two separate models. The upstream model includes waterbodies 1-4, while the downstream model contains waterbody 5. The Powder River previously simulated as a branch in the Brownlee Reservoir model was also simulated as a tributary in the downstream model, as its shallow depth caused model instability. Three small segments representing the turbine inlet channel in the reservoir model were removed and replaced with a segment that has the size of three segments and the same width as the upstream segment. With this setup, no changes were made to the size or meteorological input for the model segments. By using an initial high water surface elevation and adjusting the maximum time step, the model was stabilized, allowing for calculations of flow and water temperature throughout the modeling period.

Oxbow: Oxbow is the smallest reservoir among the HCC reservoirs, and its W2 model comprises one waterbody, one branch, and two tributaries. The Wildhorse River and the discharge from Brownlee Dam's turbines are tributaries in the reservoir model. The model has three gates that withdraw water from the reservoir to the Hells Canyon reservoir at different elevations. To convert the Oxbow model into a free-flowing river, the gate structures and the Brownlee turbines' discharge were removed from the W2 model, and the river bottom slope was increased to 0.000001. Subsequently, the model was linked to the upstream W2 model, and a spillway was used as the downstream boundary for the model. The initial water surface elevation in the model was set at a high level, and the maximum computational time was adjusted to address instabilities in river water surface calculations.

Hells Canyon: The Hells Canyon reservoir model consists of one waterbody, one branch, and two tributaries, with tributary 1 representing discharge from upstream gates. The model discharges water to the downstream reach via two gates and a withdrawal, which were removed to convert the W2 to a river model. Like upstream models, the river bottom slope was increased to 0.000001, a spillway was used for the downstream boundary, and the model was linked to the upstream W2 model using flow and temperature boundaries. Additionally, the model started with a high initial water surface elevation and the maximum computational time was adjusted to address model instabilities.

Channel Bathymetry

Pre-dam topographic elevation data for the Snake River at the locations of the HCC reservoirs were not available, posing challenges for accurately modifying river bathymetry. However, discharge simulations for the upstream and downstream reaches of the HCC reservoirs under existing conditions have demonstrated that the W2 model can effectively simulate river discharge and water surface elevations when provided with detailed bathymetric data (Tetra Tech, 2023). The existing bathymetry of the HCC reservoirs offers vertical and horizontal resolutions comparable to those of the upstream and downstream river segments, suggesting that the model should perform reasonably well in calculating water surface elevations and streamflow following dam removal. Additionally, any experimental modifications to the bathymetry may have introduced numerical instabilities, which would have required substantial time and effort to resolve given the model's size and the duration of the simulation. As a result, no modifications were made to the river channel bathymetry for simulating the no dams condition, except for enforcing a minimum non-zero slope for the river channel. It is important to note, however, that this approach does not account for historical alterations to the river channel profile caused by sedimentation or other geomorphological processes.

Table 3-3 presents monthly mean 7DADM temperature at Hells Canyon Dam for the no dams scenario. Temperatures range from 0.8–6.5 °C during January–February, increase to 7–18 °C in March–May, and peak at 18–25.7°C in June–August. From September through December, temperature gradually decline, ranging between 1.9–21.2 °C.

Table 3-3. Mean 7DADM temperature by month and year for the no dams scenario at Hells Canyon Dam.

Month	Mean 7DADM Temperature (°C)				
	2014	2015	2016	2017	2018
January	1.3	2.4	2.2	0.8	3.2
February	3.4	6.5	5.0	3.1	4.8
March	8.9	9.8	9.0	7.0	7.2
April	12.1	14.0	13.4	10.6	11.6
May	17.0	18.0	16.7	14.4	16.9
June	20.7	23.5	21.1	18.0	20.5
July	25.4	25.7	24.8	24.7	25.5
August	25.6	24.3	24.7	24.6	24.7
September	21.2	19.8	19.3	20.3	19.4
October	15.0	16.5	14.1	12.2	13.0
November	6.3	7.2	8.9	7.5	6.5
December	4.5	2.6	1.9	2.7	2.6

3.3 RESTORED VEGETATION

This scenario represents restored streamside vegetation and associated shade along the riverine segments upstream and downstream of the reservoirs. Potential Natural Vegetation (PNV) was estimated using the LANDFIRE Biophysical Settings dataset[3], which includes both ephemeral (e.g., riparian and grassland) and perennial vegetation types (e.g., hardwood, conifer, hardwood-conifer, and shrubland), as well as classifications for water, sparse vegetation, and bare land.

The W2 model requires vegetation elevation on both the left and right banks of each river segment, along with a Shading Reduction Factor (SRF[4]). For segments where shade-producing vegetation is present only along part of the bank, the SRF was calculated by multiplying vegetation density by its opaqueness[5]. In this study, a conservative opaqueness value of 85% was applied, consistent with EPA and DEQ recommendations. For example, a segment with 50% vegetation density and 85% opaqueness results in an SRF of 0.425.

Topographic shading may differ between the existing and no-dam scenarios because the Snake River has a lower water surface elevation under free-flowing conditions. Therefore, maximum topographic angle for each model segment was calculated from the river bathymetry and a 30-meter DEM combined dataset using Oregon DEQ's TTools, following the same approach described in the model calibration report (Tetra Tech, 2023).

While the LANDFIRE dataset provides historical vegetation species, it does not include vegetation height. Therefore, average tree heights for each vegetation species were obtained from published literature to support this analysis (Table 3-4). Using average heights helps account for natural disturbances such as flooding and wildfire, which influence vegetation structure over time. Vegetation height for each class was then derived by averaging the species heights for W2 input.

Table 3-5 presents monthly mean 7DADM temperature at Hells Canyon Dam for the restored vegetation scenario. Temperatures range from 1.9–3.7 °C during January–February, increase to 4.5–14.7 °C in March–May, and peak at 16.7–23.5°C in June–August. From September through December, temperature gradually declined, ranging between 6.2–22.3°C.

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[3] https://www.landfire.gov

[4] The shading reduction factor (SRF) adjusts for partial shading or low vegetation density by reducing the shading effect applied to a model segment.

[5] Opaqueness is the degree to which vegetation blocks sunlight, with 100% opaqueness fully blocking light and lower values allowing partial light transmission.

Table 3-4. Snake River Riparian historical vegetation types and their average heights.

Class	Species	Average Height (meter)	Source
Hardwood	Aspen	15.24	U.S. Forest Service (access Link)
Conifer	Western Larch	42.5	USDA (access Link)
	Western Juniper	5.5	USDA (access Link)
	Interior Douglas-Fir	33.5	USDA (access Link)
	Grand Fir	35	USDA (access Link)
	Interior Ponderosa Pine	33.5	USDA (access Link)
	Curlleaf Mountain-Mahogany	1	Oregon State University (access Link)
	Ponderosa Pine	33.5	USDA (access Link)
	Cottonwood	23.5	USDA (access Link)
Riparian	Bluegrass Scabland	0.61	USDA (access Link)
Shrubland	Wyoming Big Sagebrush	0.76	USDA (access Link)
	Salt Desert Shrub	1	USDA (access Link)
	Chokecherry-Serviceberry-Rose	9.14	USDA (access Link)
	Big Sagebrush-Bluebunch Wheatgrass	0.46	Utah Native Plant Society (access Link)
	Saltbush-Greasewood	1.35	USDA (access Link)
	Curlleaf Mountain-Mahogany	7	USDA (access Link)

Table 3-5. Mean 7DADM temperature by month and year for the restored vegetation scenario at Hells Canyon Dam.

Month	Mean 7DADM Temperature (°C)				
	2014	2015	2016	2017	2018
January	3.0	3.7	3.2	2.6	2.9
February	1.9	3.6	2.9	2.2	3.7
March	4.5	6.7	6.3	5.6	5.0
April	9.0	9.7	10.5	10.0	9.9
May	12.2	12.8	14.1	13.4	14.7
June	16.8	16.9	17.4	16.7	18.3
July	20.5	20.2	20.3	20.9	21.1
August	22.8	22.4	22.0	23.2	23.5
September	22.2	21.2	21.1	22.3	21.6
October	18.6	18.4	17.1	15.9	16.3
November	12.8	13.3	12.4	10.7	11.2
December	6.9	6.8	7.1	6.5	6.2

3.4 BACKGROUND SCENARIO

The background scenario has the same tributary inputs and boundary assumptions at RM 398 as the calibration scenario but has no point sources, restored vegetation, and no dams (combined with historic channel bathymetry). The background scenario is used as the baseline condition for the following scenarios described in this section (i.e., tributary, WLA, attainment, HCC surrogate target, and reserve capacity) and for some comparisons aimed at evaluating the effect of management changes to the 0.3°C HUA. This was done because turbulent flow conditions (i.e., plunge flow) simulated by the model at the head of Brownlee Reservoir resulted in unrealistic temperature changes during certain times of day that skewed the 7DADM and made it challenging to isolate the temperature change associated with some management scenarios. As described in Section 7.0, Plunge Flow Analysis, a significant effort was made to identify the sources of this artifact and minimize its impact on model calculations.
Table 3-6 presents monthly mean 7DADM temperature at Hells Canyon Dam for the background scenario. Temperatures range from 0.8–6.5 °C during January–February, increase to 7–18 °C in March–May, and peak at 18–25.7°C in June–August. From September through December, temperatures gradually decline, ranging between 1.9–21.2°C.

Table 3-6. Mean 7DADM temperature by month and year for the background scenario at Hells Canyon Dam.

Month	Mean 7DADM Temperature (°C)				
	2014	2015	2016	2017	2018
January	1.3	2.4	2.2	0.8	3.2
February	3.4	6.5	5.0	3.1	4.8
March	8.9	9.8	9.0	7.0	7.2
April	12.1	14.0	13.4	10.6	11.6
May	17.0	18.0	16.7	14.4	16.9
June	20.7	23.5	21.1	18.0	20.5
July	25.4	25.7	24.8	24.7	25.5
August	25.6	24.3	24.7	24.6	24.7
September	21.2	19.8	19.3	20.3	19.4
October	15.0	16.5	14.1	12.2	13.0
November	6.3	7.2	8.9	7.5	6.5
December	4.5	2.6	1.9	2.7	2.6

3.5 TRIBUTARY A AND B SCENARIOS

The tributary A scenario is the same as the background scenario except tributary temperatures were increased by the assigned TMDL HUA allocations. Tributary B scenario is used to evaluate the effects of the Snake River of tributary temperatures set to their respective TMDL HUA allocations. Tributary B scenario is used to evaluate the effects of tributary temperatures set to attain the applicable temperature criteria at their mouths. Major tributaries included in the W2 model are presented in Table 3-7. In general, Oregon tributaries were assigned a temperature increase of 0.3 °C, while Idaho tributaries were assigned 0.14 °C, except for the Payette River, which also received a 0.3 °C allocation. These allocations represent the allowable thermal contributions from tributaries, accounting for both natural and anthropogenic sources of warming. Tributary B scenario temperatures represent the tributaries attaining the applicable temperature criteria. The Malheur River and Owyhee River are designated for cool water species use which is a temperature narrative criterion. The temperature target that implements the cool water species narrative was not available on the Malheur or Owyhee so 22°C was used as an estimate. This temperature is cooler and thus more protective relative to temperatures targets developed for other rivers designated for cool water species use in Oregon, e.g. Long Tom River (24.0°C), Rickreall Creek (22.8°C), and Klamath River (28.0 °C). Maximum temperatures for Idaho tributaries were set at the cold water use 22 daily maximum criterion as an estimate. The actual temperature targets for these tributaries may be warmer due to Idaho's natural condition provisions. However, estimates of natural temperatures are not available.

A triangular scaling pattern was used to adjust tributary temperatures so they attain the target temperatures in Table 3-7. The first step in the approach is to identify the seasonal period (start and end dates) to adjust temperatures. Generally, this period is focused to when the temperatures exceed the criteria with some buffer to avoid compression of the seasonal warming and cooling pattern in the spring and fall. The second step is to determine the annual maximum temperature in the timeseries and the day it occurs. If more than one day has a maximum temperature value (ties), the earliest date in that year is used. This day becomes the peak of the triangular scaling pattern. Then the maximum temperature reduction (t_reduction) needed to attain the target is computed. A triangular scaling factor is computed that linearly scales values between 0 and 1 according to their position within the seasonal adjustment period. Specifically, values remain 0 before the start date in the same year, increase linearly from 0 at the start date to 1 on the date of the maximum temperature, then decrease linearly back to 0 at the end date and any date after that in the same year. If the maximum temperature occurs on the start or end date of the seasonal adjustment period, the scaling pattern is in the form of a right triangle. This occurs during the spawning period on the Imnaha River.

Finally, each temperature (t) in the timeseries is adjusted by reducing it according to the scaling factor and the maximum reduction. Temperatures are reduced using t - (t_reduction * scaling factor). If any temperature values within the seasonal adjustment period still exceed the target after adjustment, all the temperatures on that day are further reduced equally so the maximum temperature on that day attains the target. The calibration temperatures and the adjusted tributary B temperatures are shown in Figure 3-1 through Figure 3-12.

presents monthly mean 7DADM temperatures at Hells Canyon Dam for the tributary scenario. Temperatures range from 0.9–6.6 °C during January–February, increase to 7.1–18 °C in March–May, and peak at 18.2–25.7°C in June–August. From September through December, temperatures gradually decline, ranging between 1.9–21.2°C.

Table 3-7. Snake River tributaries model scenario temperature setup.

Tributaries	State	River Mile	Tributary A TMDL HUA Assignment Temperature (°C)	Oregon Tributary B Scenario Temperature (°C)	Oregon and Idaho Tributary B Scenario Temperature (°C)
Snake River Boundary Condition	OR/ID	398	0.00	Same as calibration	20
Owyhee River	OR	392	0.30	22	22
Boise River	ID	391	0.14	Same as calibration	22
Malheur River	OR	369	0.30	22	22
Payette River	ID	364.33	0.30	Same as calibration	22
Weiser River	ID	350.25	0.14	Same as calibration	22
Burnt River	OR	327.67	0.30	20	20
Powder River	OR	289	0.30	20	20
Wildhorse River	ID	283.5	0.14	Same as calibration	22
Pine Creek	OR	269.6	0.30	20	20
Imnaha River	OR	191.67	0.30	18 (summer) 13 (spawning)	18 (summer) 13 (spawning)
Salmon River	ID	188.33	0.14	Same as calibration	22

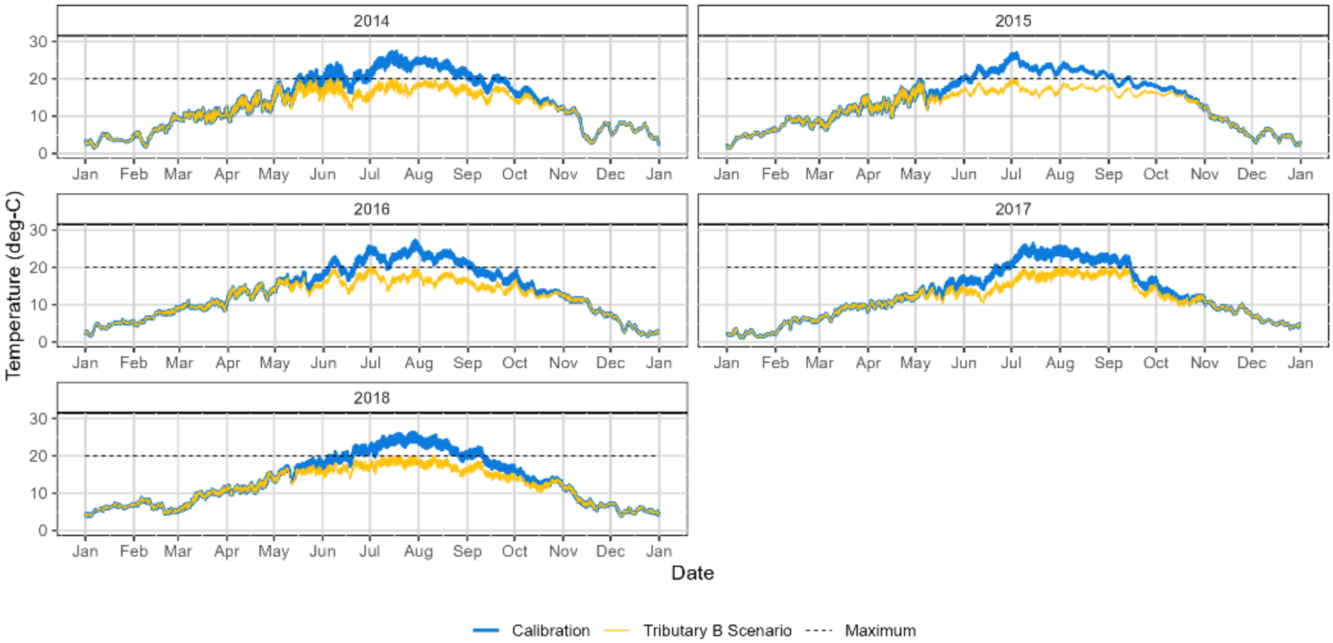


Figure 3-1. Snake River boundary condition Calibration vs Tributary B scenarios temperatures.

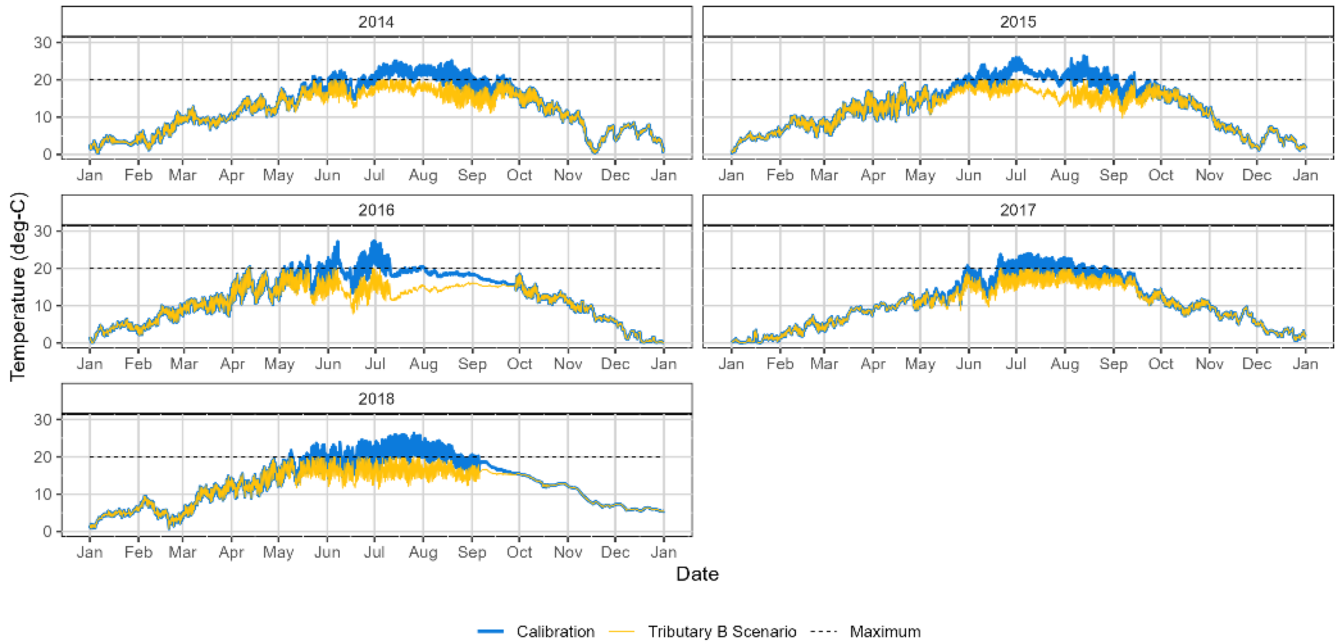


Figure 3-2. Owyhee River Calibration vs Tributary B scenarios temperatures.

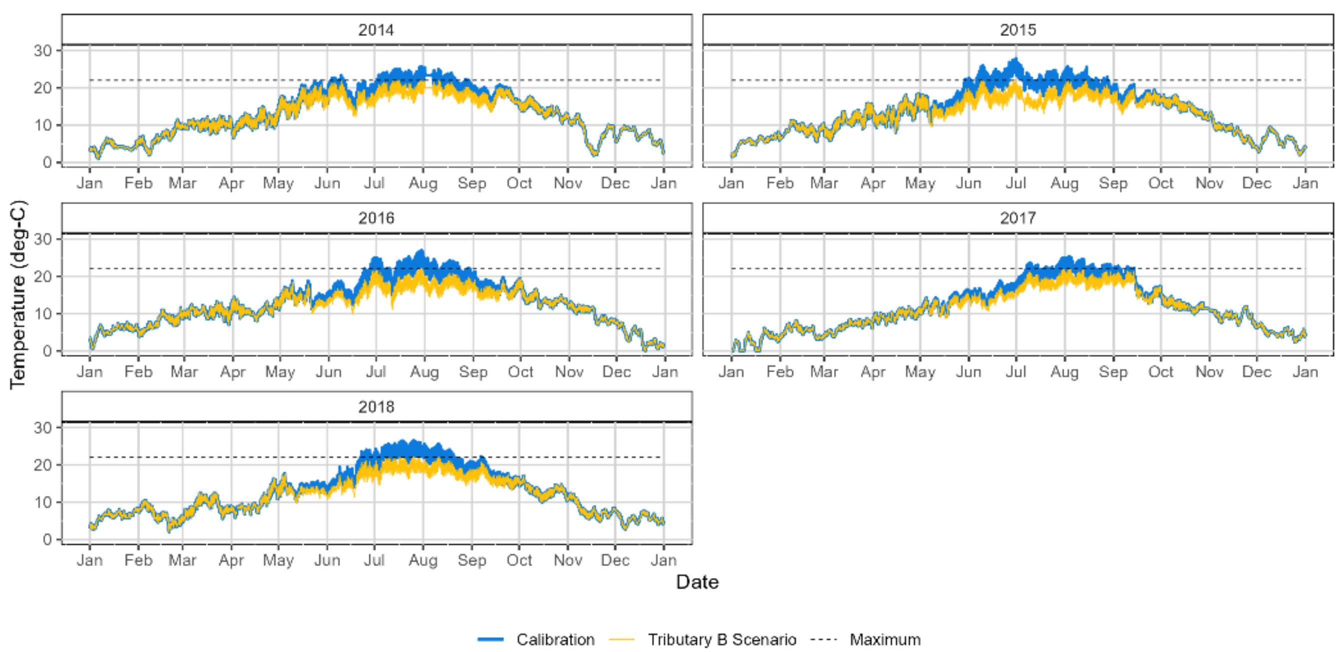


Figure 3-3. Boise River Calibration vs Tributary B scenarios temperatures

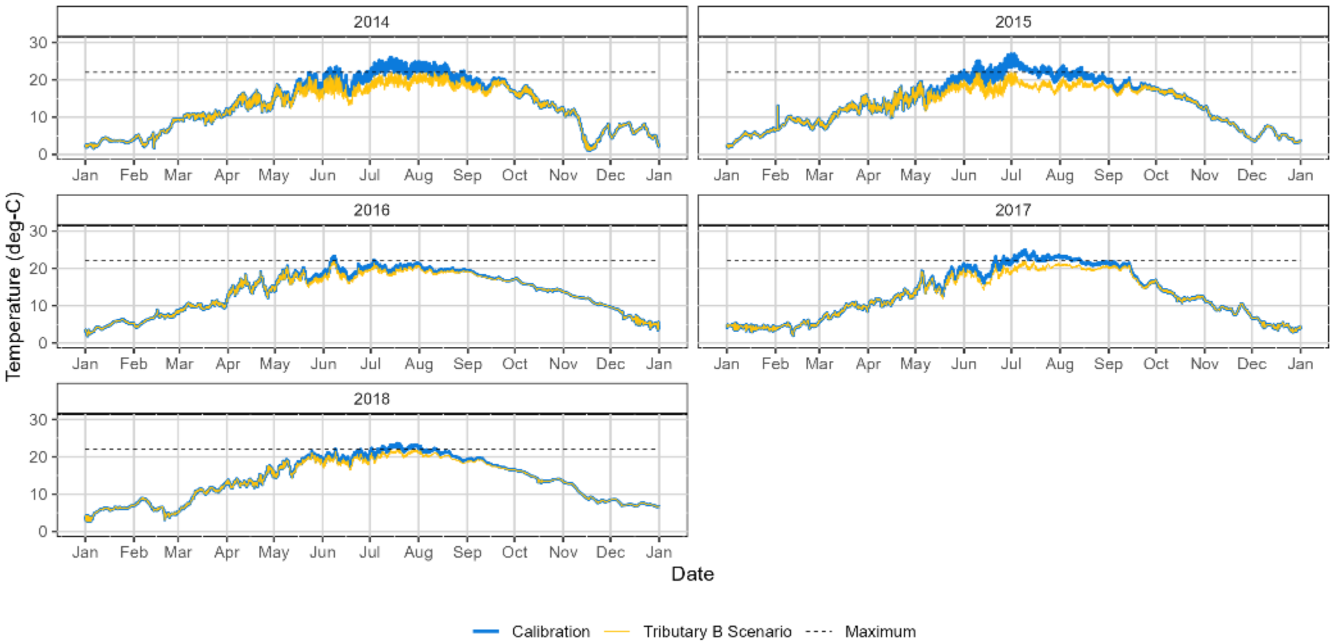


Figure 3-4. Malheur River Calibration vs Tributary B scenarios temperatures.

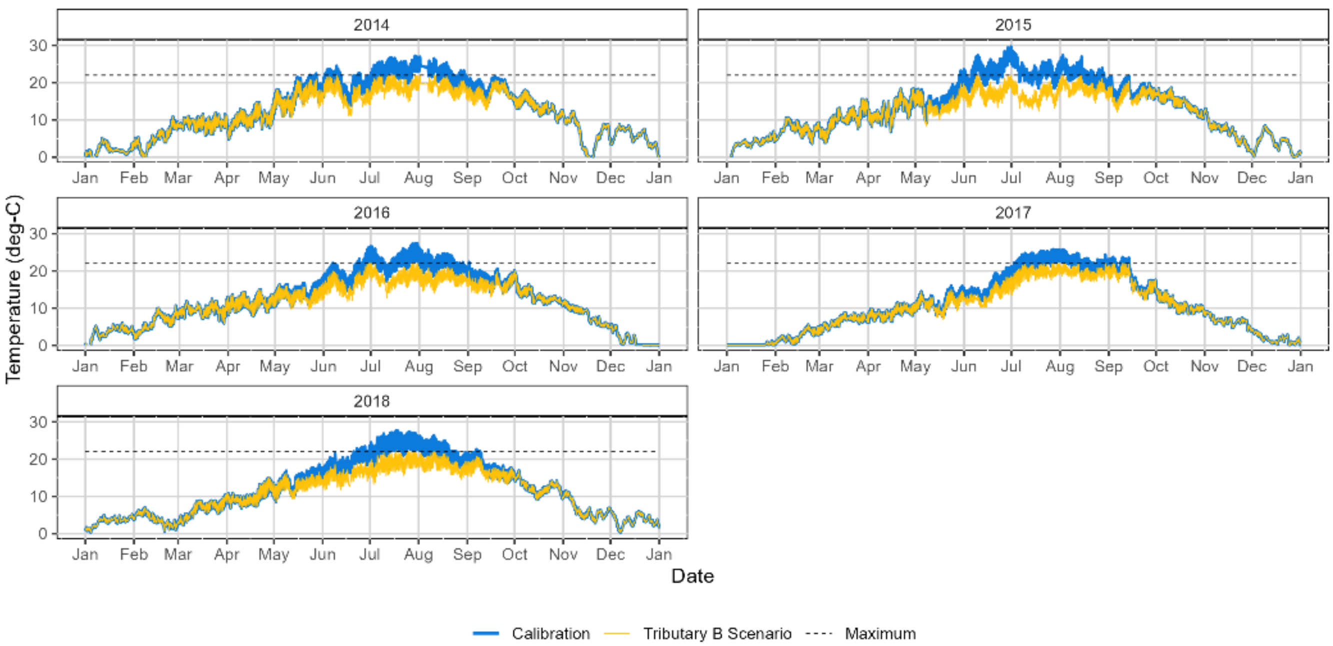


Figure 3-5. Payette River Calibration vs Tributary B scenarios temperatures

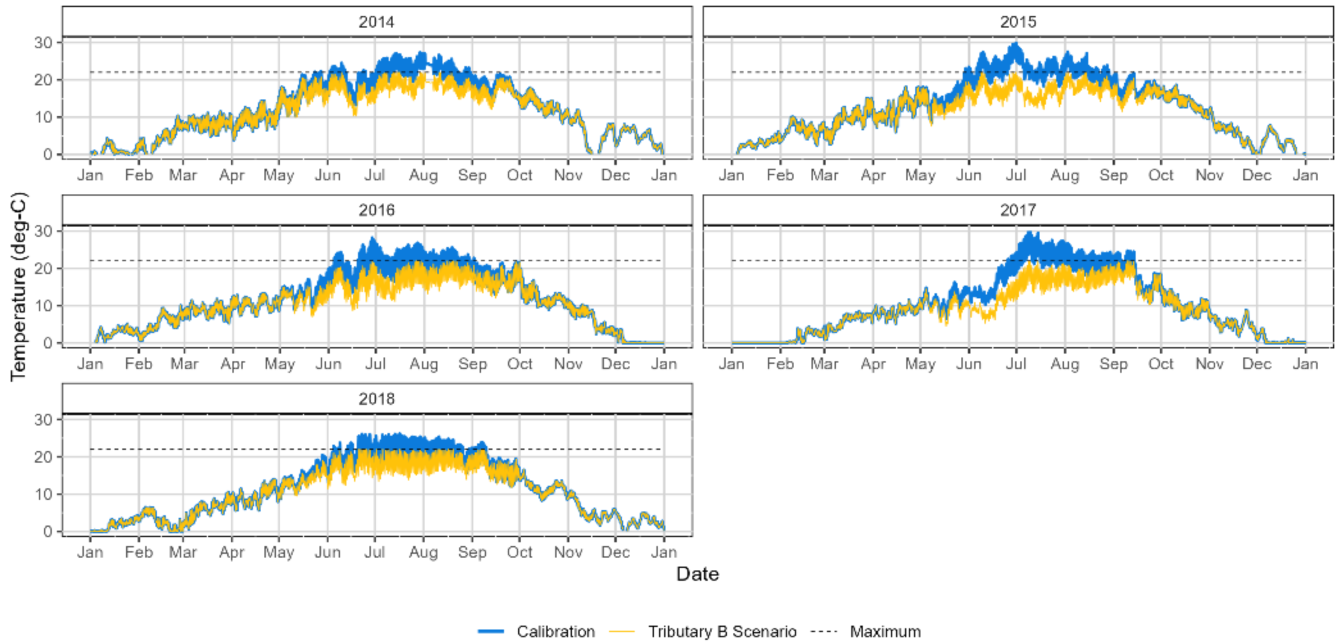


Figure 3-6. Weiser River Calibration vs Tributary B scenarios temperatures.

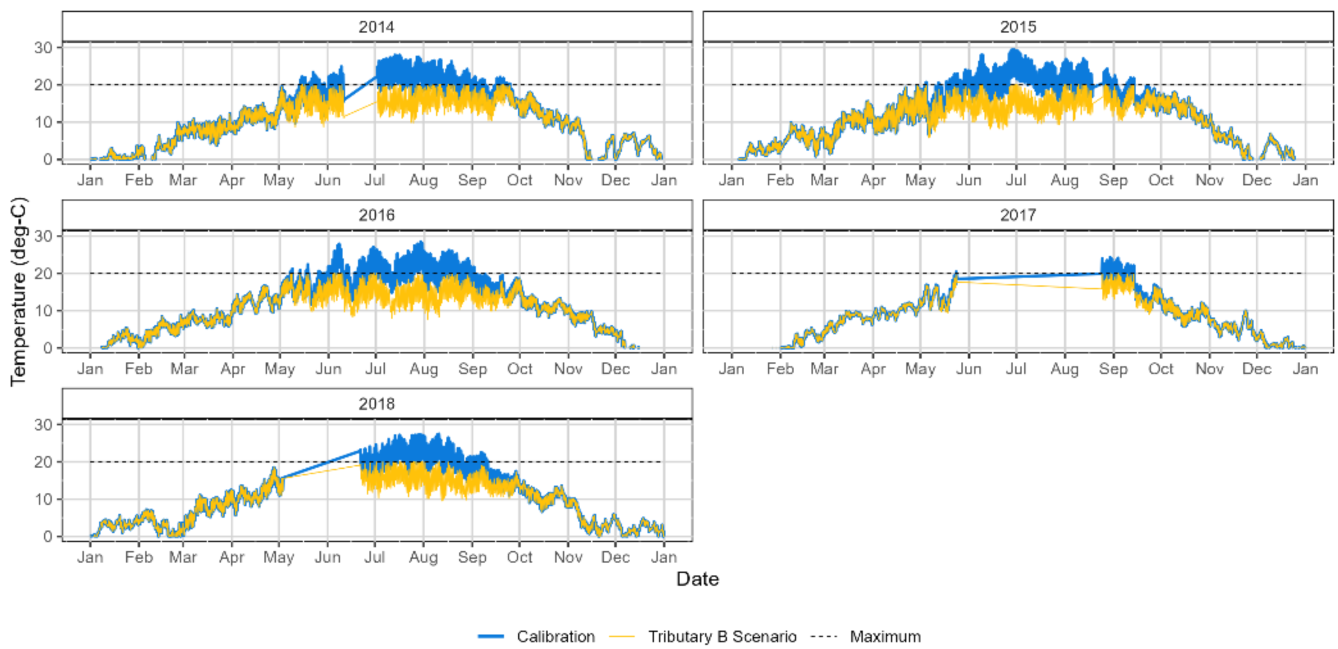


Figure 3-7. Burnt River Calibration vs Tributary B scenarios temperatures

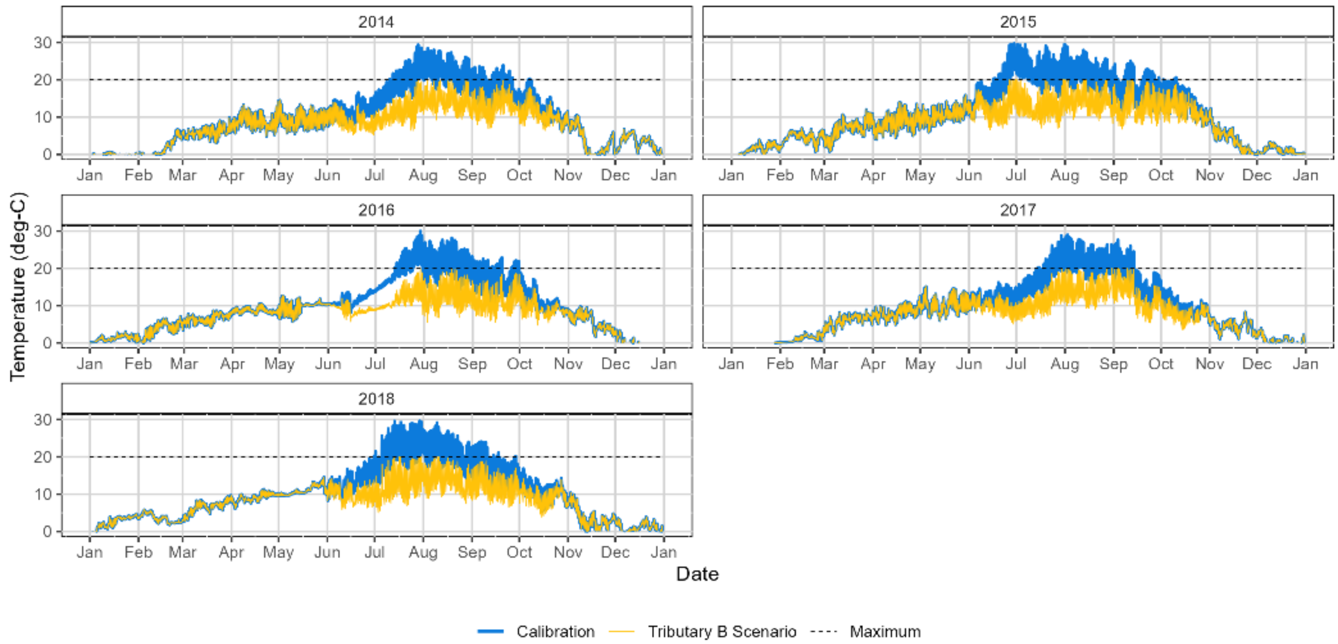


Figure 3-8. Powder River Calibration vs Tributary B scenarios temperatures.

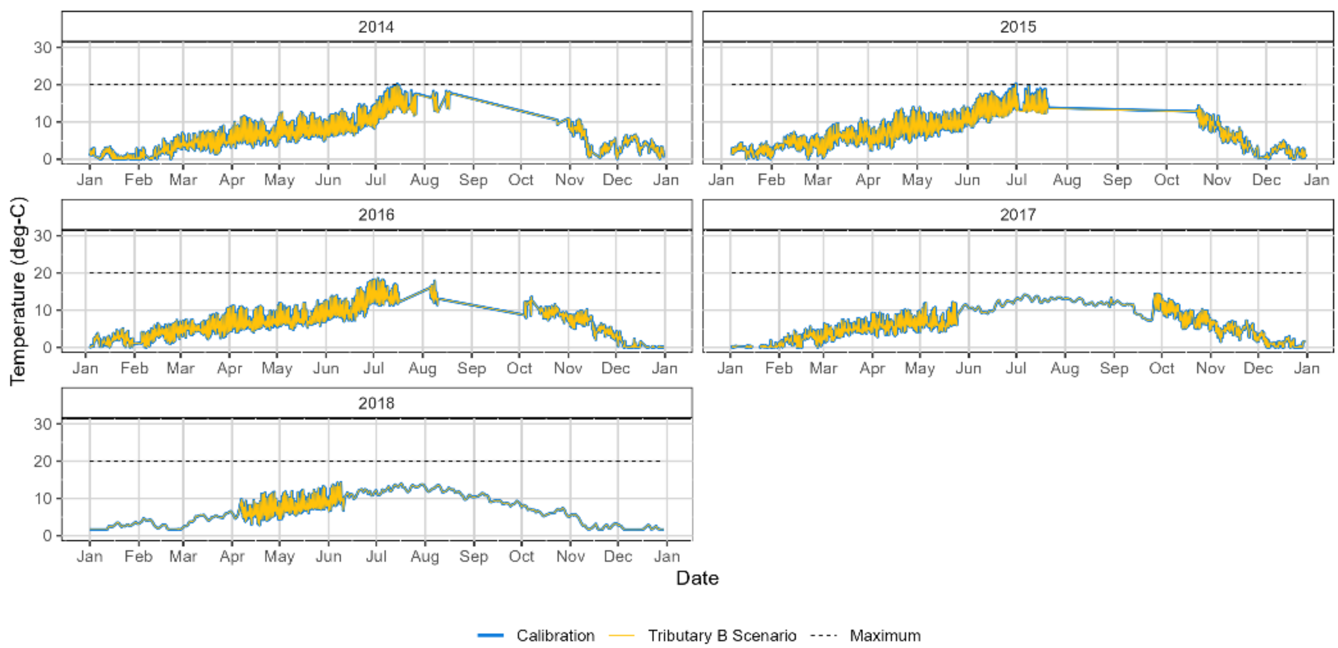


Figure 3-9. Pine Creek Calibration vs Tributary B scenarios temperatures (no adjustment)

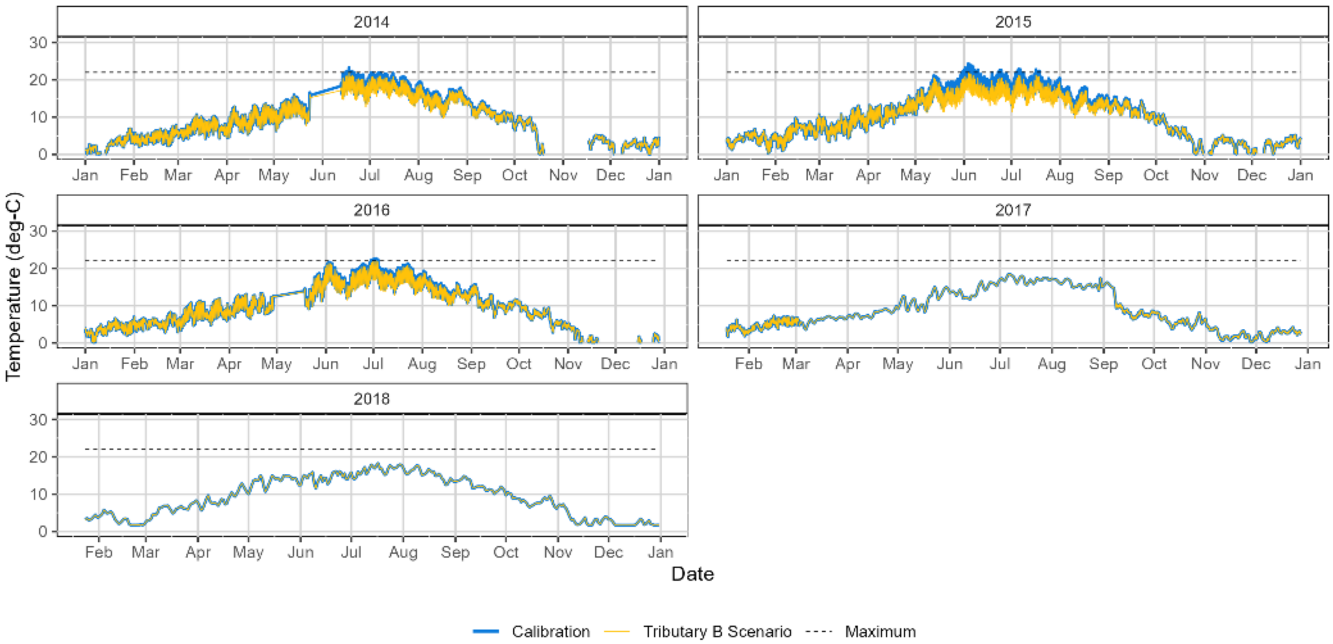


Figure 3-10. Wildhorse River Calibration vs Tributary B scenarios temperatures.

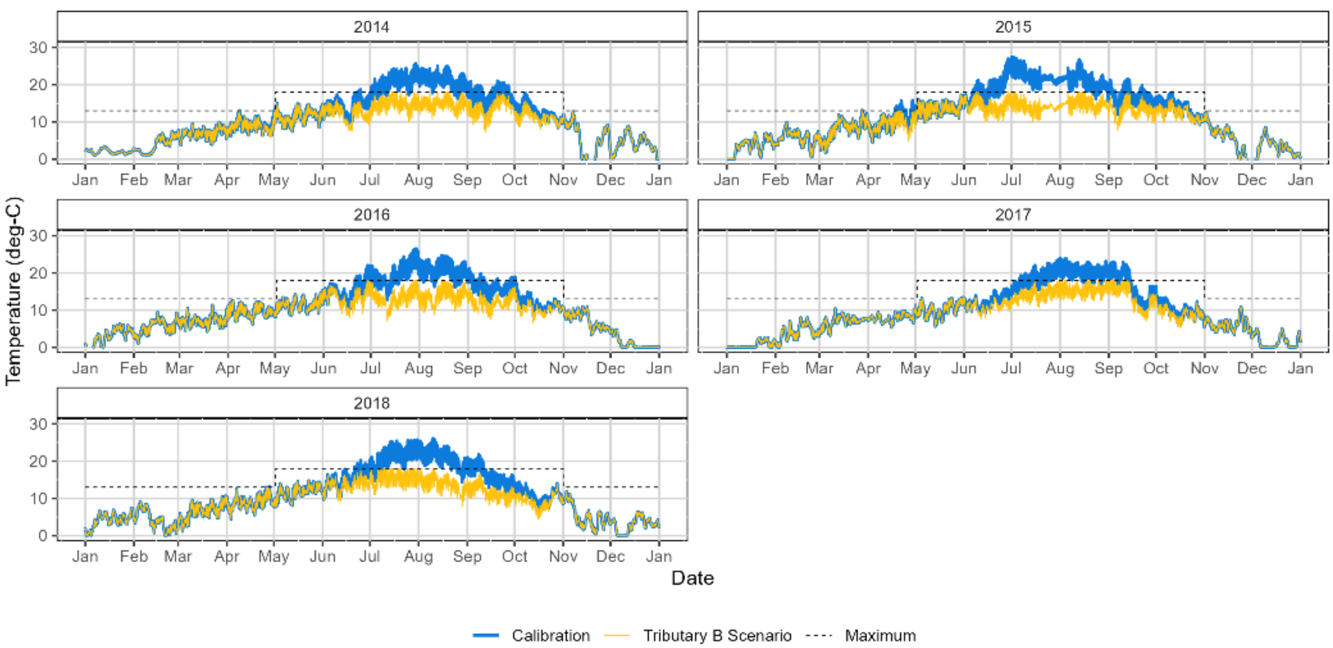


Figure 3-11. Imnaha River Calibration vs Tributary B scenarios temperatures (no adjustment)

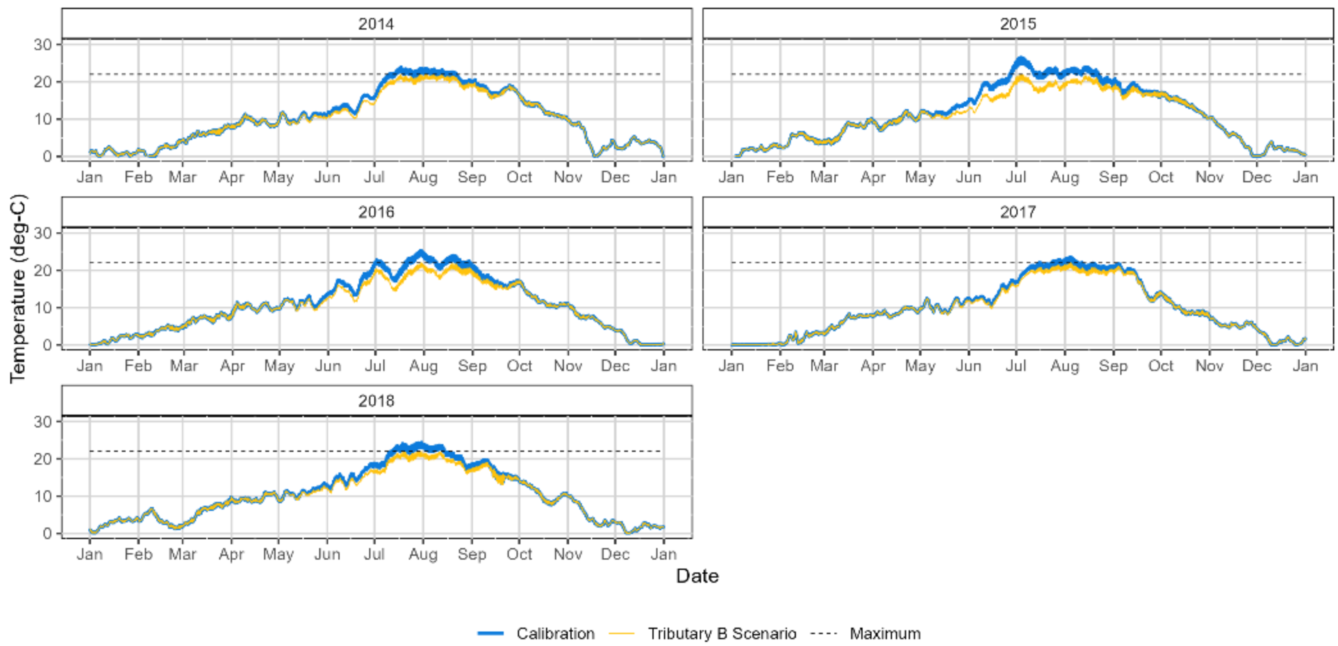


Figure 3-12. Salmon River Calibration vs Tributary B scenarios temperatures (no adjustment)

3.6 WASTE LOAD ALLOCATION SCENARIO

This scenario is identical to the background scenario; except that point source discharges are included in the model and reflect the TMDL waste load allocations. The WLA scenario evaluates the thermal impact of all point source dischargers set at the WLA discharge.

The NPDES-permitted facilities that discharge within the modeling domain and are included in the waste load allocation scenario are summarized in Table 3-8. The NPDES individual permit for Amalgamated Sugar (OR2002526) was terminated in May 2025 and therefore was excluded from the WLA scenario. The outfall from the City of Fruitland Wastewater Treatment Plant (WWTP) (ID0021199) was moved to the Payette River. The discharge from this facility is incorporated into the tributary model scenario.

Table 3-8. NPDES permittees discharging to the Snake River.

NPDES Permittee	EPA Number	Receiving Stream	River Mile
Amalgamated Sugar Company (terminated)	OR0002526	Snake River	385
IPC Brownlee Power Plant	ID0020907	Oxbow Reservoir	284.5
IPC Hells Canyon Power Plant	OR0027278	Snake River	247.34
IPC Oxbow Power Plant	OR0027286	Hells Canyon Reservoir	272
Ontario STP	OR002062	Snake River	369.25
Simplot-Ontario[6]	OR0002402	Snake River	370.33
Weiser WWTP	ID0020290	Snake River	350.75

The approach for point sources in Oregon was to use the maximum current thermal loads at critical 7Q10 low flow conditions as the starting point to calculate HUA assignments and waste load allocations. The model was then used to determine if this amount of warming would provide sufficient capacity for other source categories and reserve capacity. For all point sources, it was determined that thermal WLAs could be set equal to or slightly greater than current maximum thermal loads. Model results are discussed in Section 4.7. The HUA assigned to each facility is therefore based on the temperature increase above the applicable criteria using the maximum effluent discharge and 7Q10 river flows. **Equation 2-1** was used to calculate the change in temperature associated with the point source maximum effluent discharge.

Maximum effluent discharge was based on the maximum effluent temperature reported on discharge monitoring reports from 2014 to 2018. DMRs submitted by the Hells Canyon Power Plant and Oxbow Power Plant report temperature as a temperature change (ΔT) above ambient background temperature. Ambient background temperature was not available on the DMRs. Discharge temperature was calculated by adding the reported ΔT to the calibrated model simulated temperature outflow from

[6] Simplot-Ontario was previously known as Heinz Frozen Foods.

each dam. The resulting maximum temperature was used as the maximum effluent temperature. The specific temperature used is summarized in Table 3-9.

The effluent flow was based on the average dry weather design flow, maximum flow allowed by the NPDES permit, or a maximum effluent flow reported on DMRs. The specific discharge used is summarized in Table 3-9. Idaho point sources discharging to the Snake River were set at discharge levels consistent with the 2004 Snake River Hells Canyon TMDL or their Idaho NPDES permit. For the Weiser WWTP, the WLA discharge and temperature values were set to 2.4 MGD (0.11 m^3/s) and 22.2 °C, respectively. For the Brownlee Power Plant, the discharge was set to the NPDES permitted limit of 17.35 MGD (0.76 m^3/s), with a constant temperature value of 25.45 °C, representing the maximum flow-weighted average effluent temperature calculated for June through September to limit daily heat load at the outfall, as presented in the NPDES permit fact sheet (Idaho DEQ, 2023a and 2023b).

7Q10 is a low flow statistic defined as the 7-day average low flow with a one-in-ten-year recurrence interval (7Q10). The 7Q10 river flow is used as the critical low flow for temperature TMDLs. It is applied in the calculation of loading capacity and allocations. The 7Q10 was calculated for each point source using a 30-year (1989–2019) record of historical flow observations from the upstream USGS gaging station. The 7Q10 river discharge was calculated using a DEQ R package[7], which applies the methodology outlined in the DFLOW user manual (Rossman 1999). This approach determines design flow based on the lowest m-day average flow recorded for each year, where m is a user-defined averaging period. The m-day averages are computed using arithmetic means. A log-Pearson Type III probability distribution is then fitted to the annual minimum m-day flow series. The design flow is derived from this distribution as the flow value with a non-exceedance probability of 1/r, where r is the specified return period. The 7Q10 and gage station used for each point source is summarized in Table 3-9. The daily maximum effluent temperatures (°C) used in the WLA model scenario were calculated using **Equation 2-2**. The HUA assignment ΔT values, along with the maximum effluent flow, and applicable criteria presented in Table 3-9 were used in **Equation 2-3a**. Note: **Equation 2-3a** and **Equation 2-3b** are mathematically equivalent since WLA is calculated using ΔT in **Equation 2-2**. The daily average model simulated river flow from the upstream segments of each point source were used for Q_R in **Equation 2-2** and **Equation 2-3a**. Effluent temperatures were capped at a maximum of 32 °C for consistency with Oregon's thermal plume limitations in OAR 340-041-0053(2)(d)(B).

$$\Delta T_{ps} = \left(\frac{Q_E}{Q_E + Q_R}\right) \cdot (T_E - T_C)$$ **Equation 2-1**

where,

$\Delta T_{ps} =$ The river temperature increase (°C) above the applicable river temperature criterion using 100% of river flow.

$Q_E =$ The daily mean effluent flow (cfs).
When effluent flow is in million gallons per day (MGD) convert to cfs:

$$\frac{1 \text{ million } gallons}{1\ day} \cdot \frac{1.5472\ ft^3}{1 \text{ million gallons}} = 1.5472$$

$Q_R =$ The daily mean river flow rate, upstream (cfs). 7Q10 was used for Q_R.

$T_E =$ The daily maximum effluent temperature (˚C)

$T_C =$ The point of discharge applicable river temperature criterion (˚C)

[7] https://github.com/OR-Dept-Environmental-Quality/dflowR

$WLA = (\Delta T) \cdot (Q_E + Q_R) \cdot C_F$ **Equation 2-2**

where,

$WLA =$ Waste load allocation (kilocalories/day), expressed as a rolling seven-day average.

$\Delta T =$ The assigned portion of the human use allowance and the maximum temperature increase (°C) above the applicable river temperature criterion using 100% of river flow not to be exceeded by each individual source from all outfalls combined.

$Q_E =$ The daily mean effluent flow (cfs).
When effluent flow is in million gallons per day (MGD) covert to cfs:
$\frac{1{,}000{,}000\ gallons}{1\ day} \cdot \frac{0.13368 ft^3}{1\ gallon} \cdot \frac{1\ day}{86{,}400\ sec} = 1.5472\ ft^3/sec$

$Q_R =$ The daily mean river flow rate, upstream (cfs).
When river flow is <= 7Q10, Q_R = 7Q10. When river flow > 7Q10, Q_R is equal to the daily mean river flow, upstream.

$C_F =$ Conversion factor using flow in cubic feet per second (cfs): 2,446,665
$\left(\frac{1\ \text{m}}{3.2808\ \text{ft}}\right)^3 \cdot \frac{1000\ kg}{1\ m^3} \cdot \frac{86400\ sec}{1\ day} \cdot \frac{1\ kcal}{1\ kg\ \cdot 1℃} = 2{,}446{,}665$

$T_{E\_WLA} = \frac{(Q_E + Q_R) \cdot (T_C + \Delta T) - (Q_R \cdot T_C)}{Q_E}$ **Equation 2-3a** (using ∆T)

$T_{E\_WLA} = \frac{(WLA)}{Q_E \cdot C_F} + T_C$ **Equation 2-3b** (using WLA)

where,

$T_{E\_WLA} =$ Daily maximum effluent temperature (°C) allowed under the waste load allocation.
When T_{E_WLA} is > 32°C, T_{E_WLA} = 32°C as required by the thermal plume limitations in OAR 340-041-0053(2)(d)(B).

$WLA =$ Waste load allocation (kilocalories/day) from **Equation 2-2**

$\Delta T =$ The assigned portion of the HUA at the point of discharge. Represents the maximum temperature increase (°C) above the applicable river temperature criterion using 100% of river flow not to be exceeded by each individual source from all outfalls combined.

$Q_E =$ The daily mean effluent flow (cfs).
When effluent flow is in million gallons per day (MGD) convert to cfs:
$\frac{1\ \text{million}\ gallons}{1\ day} \cdot \frac{1.5472\ ft^3}{1\ \text{million gallons}} = 1.5472$

$Q_R =$ The daily mean river flow rate, upstream (cfs).
When river flow is <= 7Q10, Q_R = 7Q10. When river flow > 7Q10, Q_R is equal to the daily mean river flow, upstream.

$T_C =$ The point of discharge applicable river temperature criterion (°C)

$C_F =$ Conversion factor for flow in cfs: 2,446,665

$$\left(\frac{1\ m}{3.2808\ ft}\right)^3 \cdot \frac{1000\ kg}{1\ m^3} \cdot \frac{86400\ sec}{1\ day} \cdot \frac{1\ kcal}{1\ kg\ \cdot 1℃} = 2{,}446{,}665$$

Table 3-9

Table 3-9 shows WLA effluent temperatures for each Oregon NPDES facility. For all NPDES discharges, flow was withdrawn from the upstream segment to isolate and remove the influence of discharge on the point source evaluation.

Table 3-10 presents monthly mean 7DADM temperature at Hells Canyon Dam for the waste load allocation scenario. Temperatures range from 0.9–6.6 °C during January–February, increase to 7.1–18 °C in March–May, and peak at 18.1–25.7°C in June–August. From September through December, temperatures gradually decline, ranging between 2–21.2°C.

Table 3-9. Maximum effluent discharge and 7Q10 river flow used to calculate the HUA assignment and waste load allocations for each NPDES point source.

NPDES Permitted	Permit Number	7Q10 Gage ID	River 7Q10 Flow (CFS)	Maximum Effluent Flow		Maximum Effluent Temperature (°C)	Applicable Temperature Criteria (°C)	HUA Assignment ΔT (°-C)
				MGD	CFS			
Simplot-Ontario	OR0002402	USGS 13213100	4,755	4.3	6.71	32.0	20	0.017
Ontario STP	OR002062	USGS 13213100	4,755	3.06	4.59	20.4	20	0.001
Oxbow Power Plant	OR0027286	IPC 13290030	6,854	12.15	18.7	27.6	20	0.021
Hells Canyon Power Plant	OR0027278	IPC/USGS 13290450	6884	10.5	16.25	27.8	Spawning: 13 Year Round: 20	0.035 0.019

Table 3-10. Mean 7DADM temperature by month and year for the waste load allocation scenario at Hells Canyon Dam.

Month	Mean 7DADM Temperature (°C)				
	2014	2015	2016	2017	2018
January	1.4	2.5	2.2	0.9	3.3
February	3.5	6.6	5.1	3.2	4.9
March	9.0	9.9	9.1	7.1	7.2
April	12.2	14.1	13.5	10.6	11.6
May	17.0	18.0	16.8	14.4	16.9
June	20.7	23.6	21.2	18.1	20.5
July	25.4	25.7	24.8	24.7	25.5
August	25.6	24.3	24.7	24.6	24.7
September	21.2	19.8	19.3	20.4	19.5
October	15.1	16.5	14.2	12.3	13.1
November	6.5	7.4	9.0	7.6	6.6
December	4.7	2.7	2.0	2.8	2.7

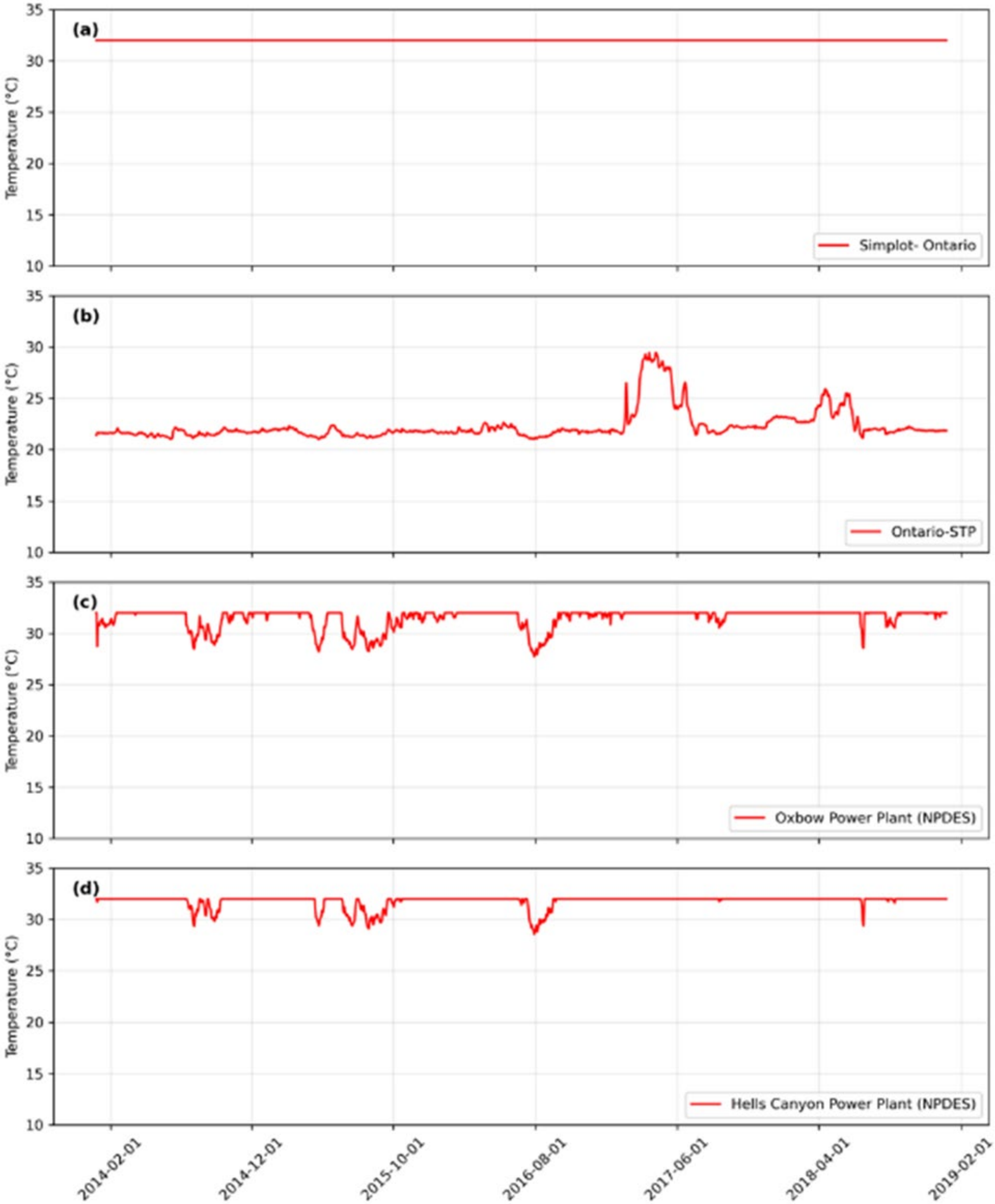


Figure 3-13. WLA effluent temperature calculated for (a) Simplot-Ontario b) Ontario-STP (c) Oxbow Power Plant (NPDES) (d) Hells Canyon Power Plant (NPDES).

3.7 HUA ATTAINMENT SCENARIO

The goal of this scenario is to evaluate the combined effects of point and nonpoint sources when set to their respective TMDL allocations. It builds upon the background scenario, with tributary temperatures and point source discharges and temperatures adjusted to reflect their assigned allocations, as described in Section 3.5 and Section 3.6. Note: Dam discharge allocation is addressed separately in Section 3.8 (surrogate scenario).

Table 3-11 presents monthly mean 7DADM temperature at Hells Canyon Dam for attainment scenario. Temperatures range from 0.9–6.7 °C during January–February, increase to 7.2–18.1 °C in March–May, and peak at 18.2–25.8°C in June–August. From September through December, temperatures gradually decline, ranging between 2.1–21.2°C.

Table 3-11. Mean 7DADM temperature by month and year for the waste load allocation scenario at Hells Canyon Dam.

Month	Mean 7DADM Temperature (°C)				
	2014	2015	2016	2017	2018
January	1.5	2.5	2.3	0.9	3.3
February	3.6	6.7	5.2	3.2	4.9
March	9.1	10.0	9.2	7.2	7.3
April	12.3	14.1	13.6	10.7	11.7
May	17.1	18.1	16.9	14.5	17.0
June	20.8	23.6	21.2	18.2	20.6
July	25.5	25.8	24.9	24.8	25.5
August	25.6	24.4	24.7	24.6	24.8
September	21.2	19.9	19.4	20.4	19.5
October	15.1	16.6	14.2	12.3	13.1
November	6.5	7.4	9.1	7.7	6.6
December	4.7	2.7	2.1	2.9	2.8

3.8 SURROGATE SCENARIO

The objective of this scenario is to evaluate the impact of Hells Canyon Dam releases when they are set to attain the TMDL surrogate temperature targets. This scenario is identical to the background scenario, except for modifications to the boundary condition temperatures at Hells Canyon Dam. Specifically, when the 7DADM temperature at Hells Canyon Dam exceeded 12.0 °C (October 21 – April 15), or 19.0 °C (April 16 – October 20) the hourly release temperatures were set to match the background temperatures at Hells Canyon Dam. On days when the background scenario 7DADM was less than or equal to these thresholds, the hourly release temperatures were set at constant values of 12.0 °C or 19.0 °C, respectively.

The trigger temperature for reverting to background conditions during the fall spawning period begins on October 21, two days before the spawning period starts. This approach prevents downstream warming due to travel time between Hells Canyon Dam and Stateline, which is approximately 1.5 days. If releases were warmer than the background temperature (e.g., maintained at 19.0 °C) through October 23, the resulting downstream daily maximums during the first two days of the spawning period would also be elevated and included in the 7-day average, causing a temperature increase.

The hourly surrogate temperature targets input into the model are illustrated in Figure 3-14. Table 3-12 presents monthly mean 7DADM temperature at Hells Canyon Dam for the surrogate scenario. Temperatures range from 12–25.7 °C across the modeling period.

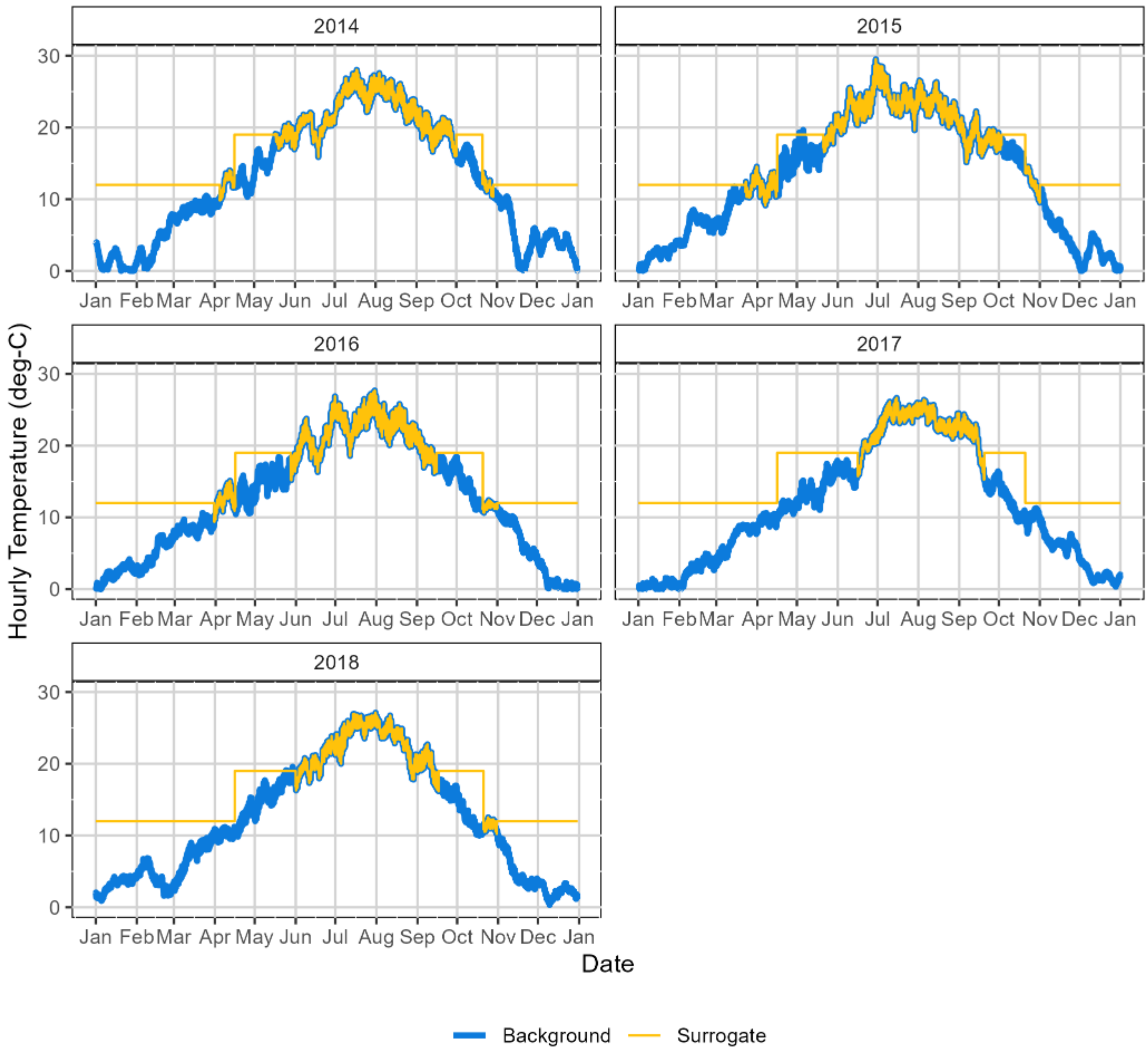


Figure 3-14. Snake River hourly water temperature boundary condition at Hells Canyon Dam for each year in the model period: Comparison of surrogate scenario (orange) and background scenario (blue). For temperatures above 12.0°C, and 19.0 °C, the orange line representing the surrogate model overlaps and obscures the blue line of the background model.

Table 3-12. Mean 7DADM temperature by month and year for the surrogate scenario at Hells Canyon Dam.

Month	Mean 7DADM Temperature (°C)				
	2014	2015	2016	2017	2018
January	12.00	12.00	12.00	12.00	12.00
February	12.00	12.00	12.00	12.00	12.00
March	12.00	12.02	11.99	12.00	12.00
April	15.09	15.28	15.52	14.80	14.80
May	19.21	19.16	18.98	19.00	19.00
June	20.67	23.53	21.17	19.34	20.55
July	25.42	25.71	24.80	24.75	25.50
August	25.55	24.33	24.69	24.56	24.72
September	21.16	19.80	19.85	21.40	20.11
October	17.21	17.57	17.19	17.19	17.21
November	11.98	11.96	11.99	12.00	11.98
December	12.00	12.00	12.00	12.00	12.00

3.9 RESERVE CAPACITY SCENARIOS: BOUNDARY + 0.10°C AND 0.15°C

These scenarios evaluate the combined effects of point and nonpoint sources set at their respective TMDL allocations, along with a reserve capacity allocation corresponding to a 0.1 °C and 0.15°C temperature increase at the upstream boundary of the Snake River model (RM 398), near the Oregon/Idaho border at Adrian. It is identical to the attainment scenario, except that the upstream water temperature boundary condition at Adrian is increased by 0.1 °C and 0.15°C. Two scenarios were run with different temperature increases to evaluate the effect of increased temperature inputs at the upstream extent of the model and TMDL project boundary.

Table 3-13

Table 3-13 and Table 3-14 present monthly mean 7DADM temperature at Hells Canyon Dam for reserve capacity 0.1 °C and 0.15 °C scenarios. Across the modeling period, temperatures range from 0.9–25.8 °C for reserve capacity 0.1 °C and 0.98–25.8 for reserve capacity 0.15 °C.

Table 3-13. Mean 7DADM temperature by month and year for the reserve capacity (boundary condition + 0.1 °C) scenario at Hells Canyon Dam.

Month	Mean 7DADM Temperature (°C)				
	2014	2015	2016	2017	2018
January	1.47	2.48	2.33	0.94	3.33
February	3.56	6.68	5.2	3.23	4.91
March	9.06	9.98	9.17	7.16	7.3
April	12.27	14.13	13.58	10.73	11.68
May	17.14	18.08	16.85	14.47	16.98
June	20.78	23.59	21.23	18.17	20.57
July	25.48	25.75	24.86	24.8	25.53
August	25.59	24.38	24.71	24.61	24.75
September	21.22	19.87	19.35	20.42	19.49
October	15.1	16.58	14.24	12.34	13.13
November	6.5	7.42	9.08	7.67	6.63
December	4.72	2.73	2.08	2.86	2.77

Table 3-14. Mean 7DADM temperature by month and year for the reserve capacity (boundary condition + 0.15 °C) scenario at Hells Canyon Dam.

Month	Mean 7DADM Temperature (°C)				
	2014	2015	2016	2017	2018
January	1.5	2.51	2.35	0.98	3.4
February	3.6	6.72	5.24	3.27	4.97
March	9.09	10.02	9.2	7.19	7.36
April	12.3	14.16	13.6	10.78	11.73
May	17.16	18.11	16.88	14.51	17.02
June	20.8	23.62	21.26	18.2	20.61
July	25.5	25.77	24.88	24.83	25.57
August	25.62	24.4	24.73	24.65	24.79
September	21.26	19.9	19.4	20.46	19.54
October	15.15	16.63	14.29	12.39	13.19
November	6.54	7.48	9.13	7.73	6.69
December	4.77	2.77	2.11	2.92	2.81

4.0 SCENARIO COMPARISONS

When comparing the hourly results from two model scenarios to determine the temperature changes, the following steps were taken:

1. Calculate 7DADM temperatures (as described in Section 1.2).
2. Calculate daily differences when 7DADM temperature equals or exceeds BBNC. Determine the difference in 7DADM temperatures between Scenario 1 (baseline) and Scenario 2 (scenario comparison) for each day, but only when the 7DADM in either scenario equals or exceeds the applicable BBNC. If both scenarios are below BBNC or if no 7DADM value is available, record the result as NA.
3. Calculate the 95th Percentile: For each model output location, calculate the 95th percentile of the valid 7DADM differences across the full model period and relevant seasonal windows. The 95th percentile of the 7DADM was used for scenario comparisons instead of the maximum 7DADM because turbulent flow conditions simulated by the model at the head of Brownlee Reservoir resulted in unrealistic temperature changes during certain times of day that skew the 7DADM for scenario comparisons (see Section 7.0). Using the 95th percentile also reduces the influence of potential modeling artifacts, such as numerical stability errors that may occur with changes in flow and temperature inputs. When the percentile falls between two data points, the value is determined through linear interpolation rather than rounding.
4. Apply rounding: Round the differences from the previous step to two decimal places (°C) for presentation in tables or plots, using the rounding procedure described in Section 2.1.

In total, 10 different comparisons were made using both the calibration and background scenarios. Each comparison scenario was designed to address a specific question. The questions or topics addressed by each comparison scenario are summarized in Table 4-1.

Table 4-1. Snake River Temperature TMDL scenarios: Explanation of comparisons.

Scenario Baseline	Scenario Comparison	Question/topic addressed
No point source	Calibration	Effect of NPDES-permitted point source discharges.
No dams	Calibration	Effect of existing dams and reservoir operations.
Restored vegetation	Calibration	Effect of fully restored vegetation along the Snake River mainstem.
Background	Calibration	Effect of anthropogenic sources that were quantified and represented in the model.
Background	Tributary A	Effect of Snake River tributary temperatures set at their respective TMDL HUA allocations.
Background	Tributary B	Effect of Snake River tributaries attaining the applicable temperature criteria.
Background	TMDL waste load allocations	Effect of point source discharge at WLAs levels.
Background	HUA Attainment	Effect of point and nonpoint sources set at their respective TMDL allocations. Evaluates attainment of the Human Use Allowance
Background	Surrogate	Effect of Hells Canyon Dam releases set at the TMDL surrogate measure temperature target.
Background	Reserve capacity 0.1 °C	Effect of point and nonpoint sources set at their respective TMDL allocations plus a hypothetical allocation of reserve capacity equal to 0.1°C increase at the upstream Snake River model boundary (RM 398) near the Oregon/Idaho border at Adrian.
Background	Reserve capacity 0.15 °C	Effect of point and nonpoint sources set at their respective TMDL allocations plus a hypothetical allocation of reserve capacity equal to 0.15 °C increase at the upstream Snake River model boundary (RM 398) near the Oregon/Idaho border at Adrian.

4.1 NO POINT SOURCES VS. CALIBRATION

The 95th percentile change in 7DADM temperature resulting from permitted NPDES point sources was determined by calculating the difference between the calibration and no point source scenarios. Figure 4-1 and Figure 4-2 illustrate the effects of point sources from Adrian to the head of Brownlee Dam (RM 398 to RM 345.75), and from below Hells Canyon Dam to the Washington state line (RM 247.34 to RM 176), respectively. The maximum observed impact was a 0.08 °C increase downstream of the Hells Canyon Dam Powerplant (NPDES) discharge on July 28, 2014. Upstream of Brownlee Reservoir, the maximum temperature change was 0.02 °C. During the spawning season (October 23 to April 15) downstream of Hells Canyon Dam, where the BBNC threshold differs due to salmon and steelhead migration corridors, the maximum 95th percentile 7DADM change was 0.06 °C (Figure 4-3), compared to 0.08 °C for the modeling period and the non-spawning season (Figure 4-2 and Figure 8-14). Note: Temperature change results within the HCC reservoirs are not provided due to the influence of the plunge point, as discussed in Section 7.0. Supplementary plots of model results are provided in Section 8.0 (Figure 8-1 through Figure 8-17).

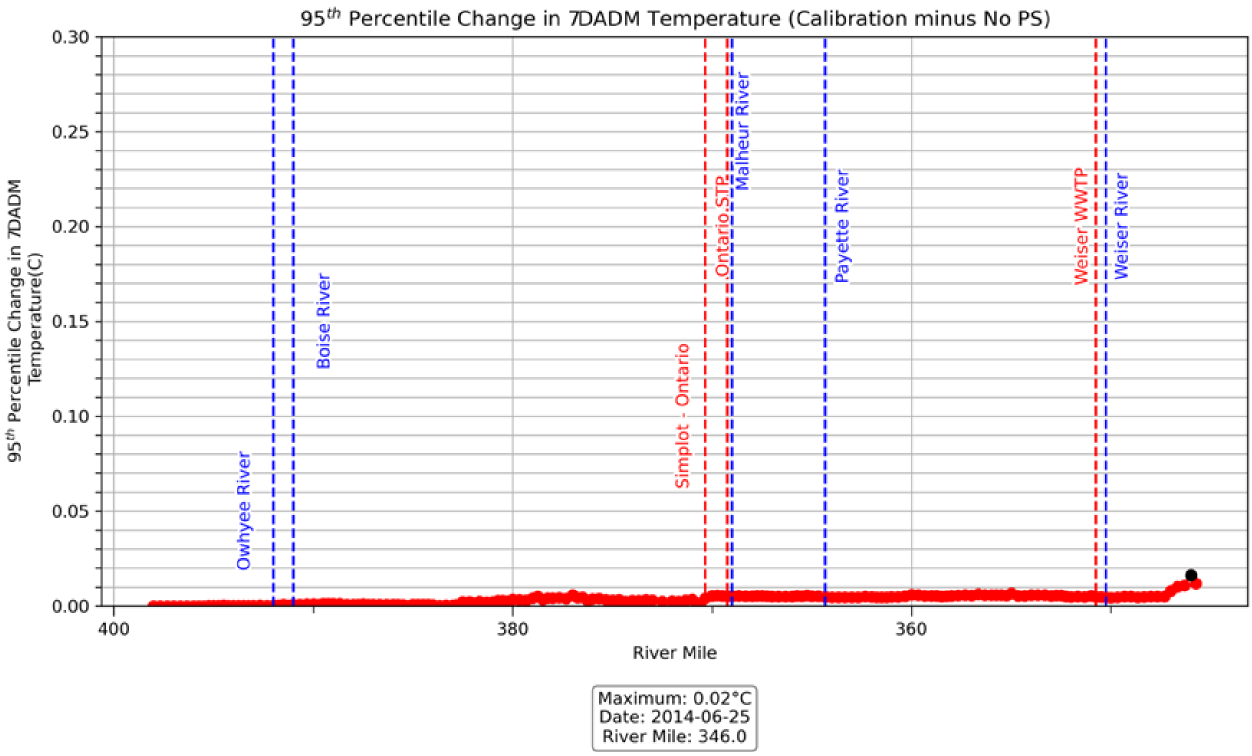


Figure 4-1. 95th percentile change in 7DADM temperature above applicable criteria due to the impacts of current point source discharges, from Adrian to head of Brownlee Reservoir, during the 2014–2018 modeling period.

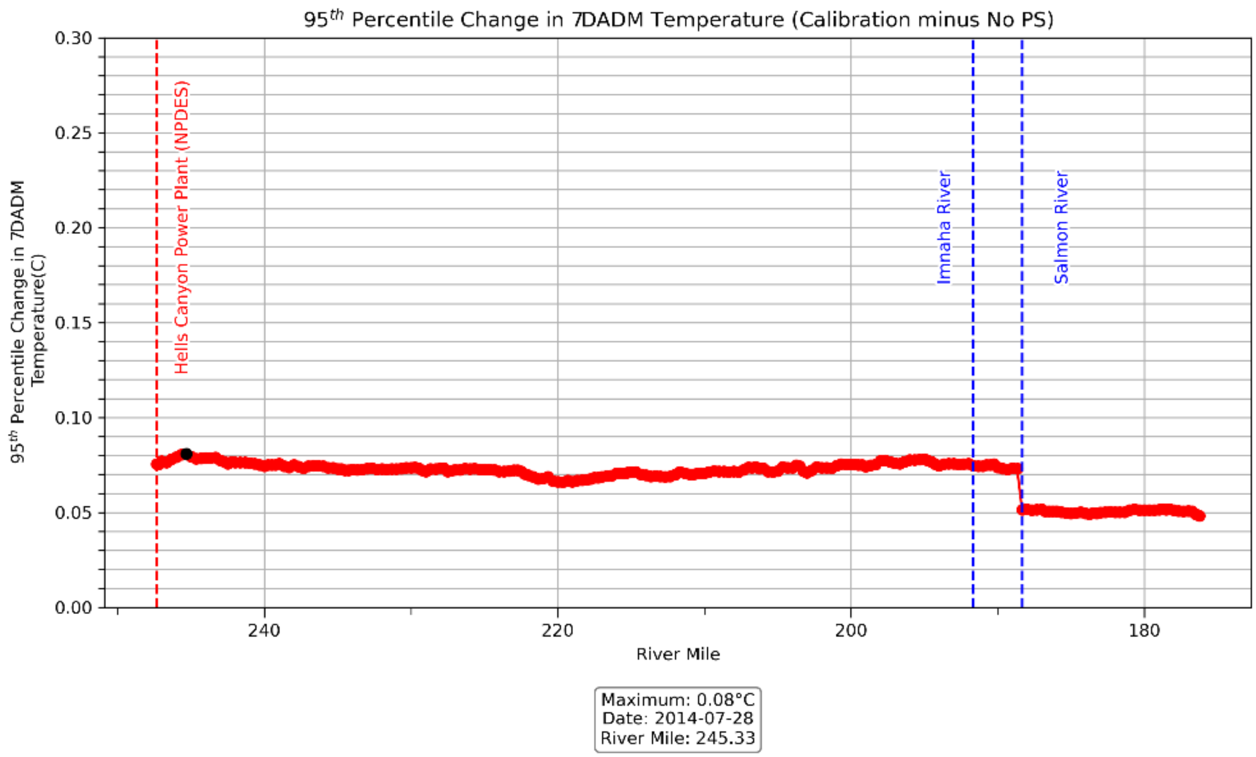


Figure 4-2. 95th percentile change in 7DADM temperature above applicable criteria due to the impacts of current point source discharges, from Hells Canyon Dam to Washington state line, during the 2014–2018 modeling period.

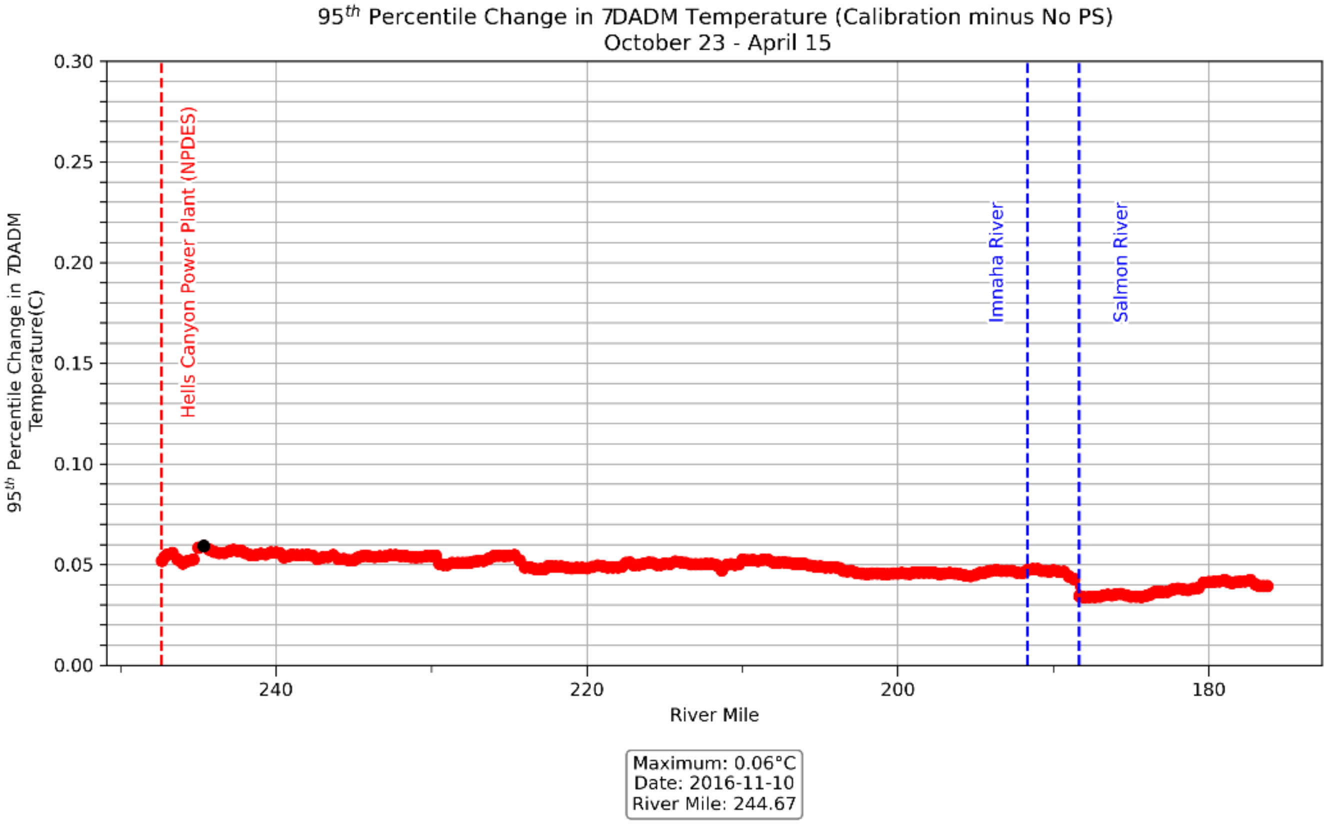


Figure 4-3. 95th percentile change in 7DADM temperature above applicable criteria during spawning season (October 23- April 15) due to the impacts of current point source discharges, from Hells Canyon Dam to Washington state line.

4.2 NO DAMS VS. CALIBRATION

The effects of HCC Dam operations on Snake River temperatures, from below Hells Canyon Dam to the Washington state line for the full modeling period and spawning season, are shown in Figure 4-4 and Figure 4-5. The 95th percentile impact of dam operation on 7DADM temperatures, based on BBNC criteria, is estimated at 4.6 °C for the overall modeling period and 6.36 °C during the spawning season. These impacts are observed in the river segment immediately downstream of Hells Canyon Dam. Supplementary plots of model results are provided in Section 8.0 (Figure 8-18 through Figure 8-26).

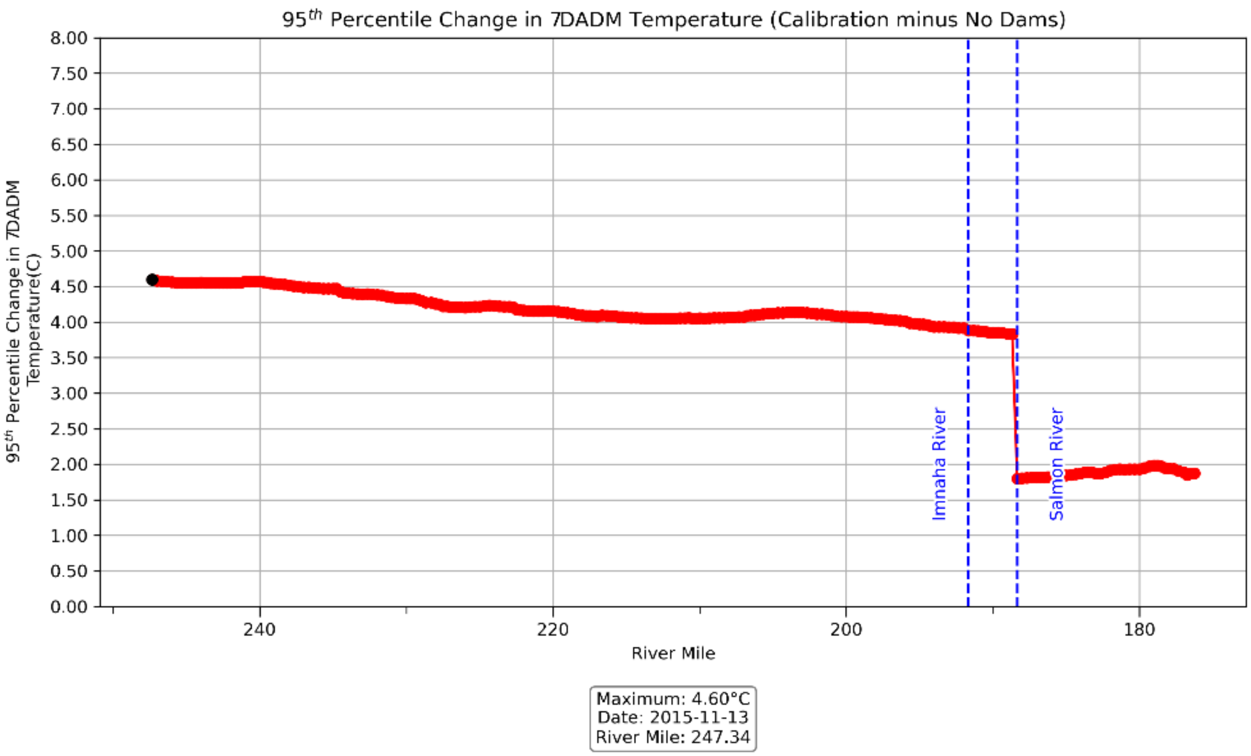


Figure 4-4. 95th percentile change in 7DADM temperature above applicable criteria due to discharge impacts of HCC Dams, from Hells Canyon Dam to Washington state line, during the 2014–2018 modeling period.

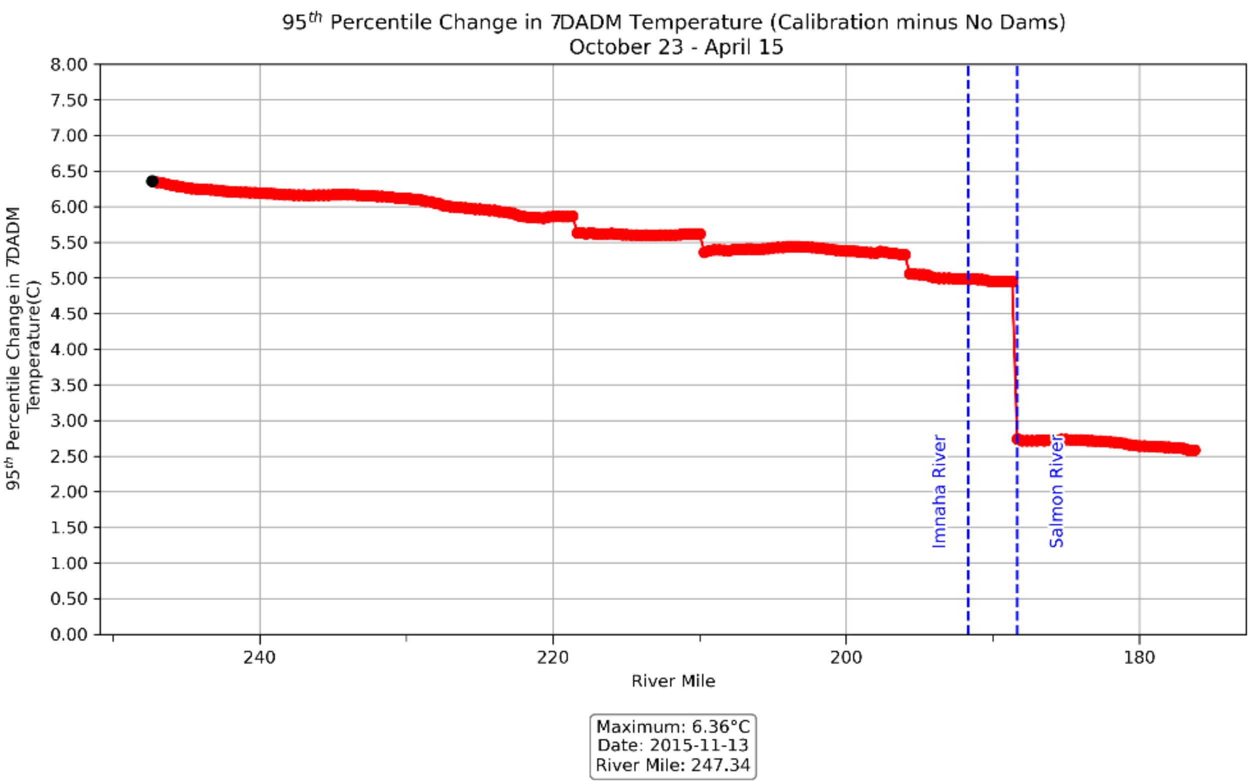


Figure 4-5. 95th percentile change in 7DADM temperature above applicable criteria during spawning season (October 23- April 15) due to discharge impacts of HCC Dams, from Hells Canyon Dam to Washington state line.

4.3 RESTORED VEGETATION VS. CALIBRATION

The effects of restored vegetation in riverine sections on Snake River temperatures, from Adrian to head of Brownlee Reservoir and below Hells Canyon Dam to the Washington state line for the full modeling period, are shown in

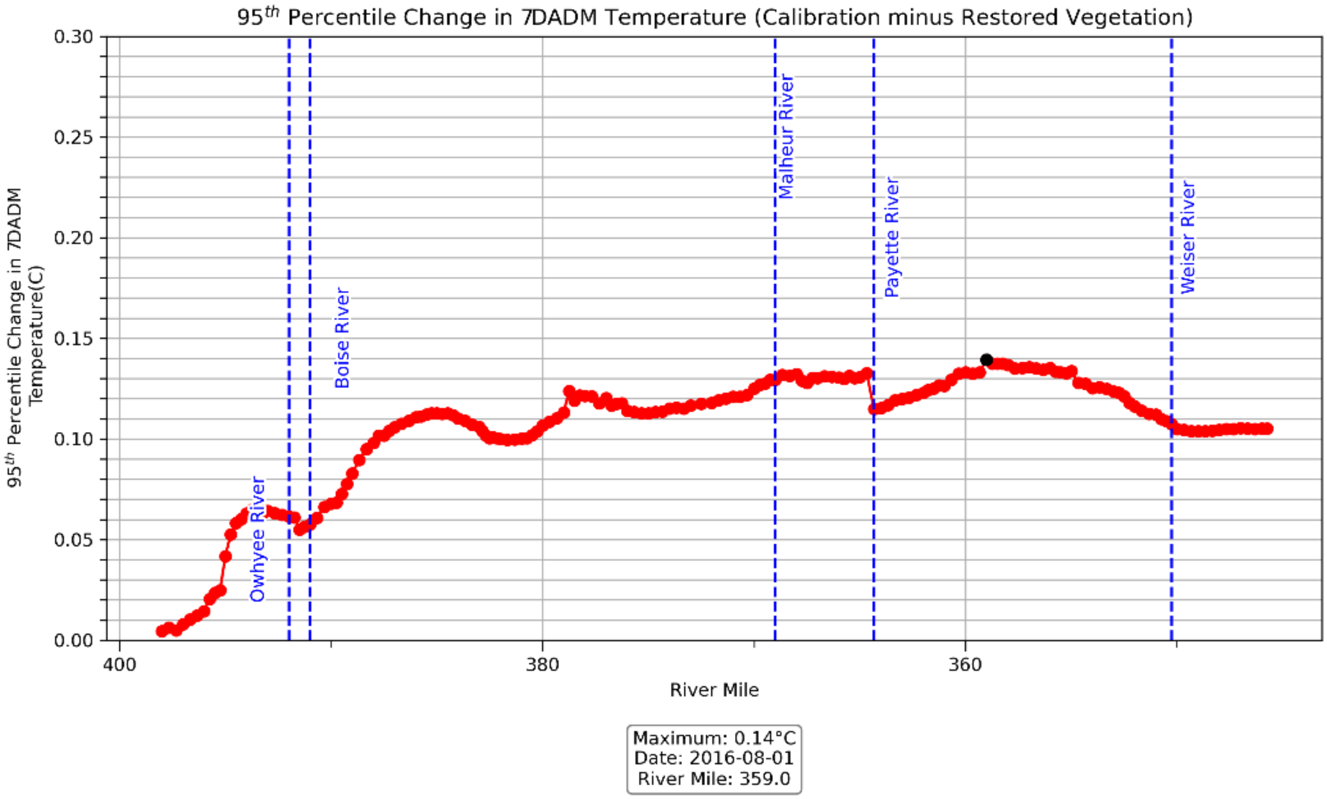


Figure 4-6 to Figure 4-8. The 95th percentile impact of riverine restored vegetation on 7DADM temperatures, based on BBNC criteria, is estimated at 0.14°C for the overall modeling period upstream of Brownlee Reservoir (

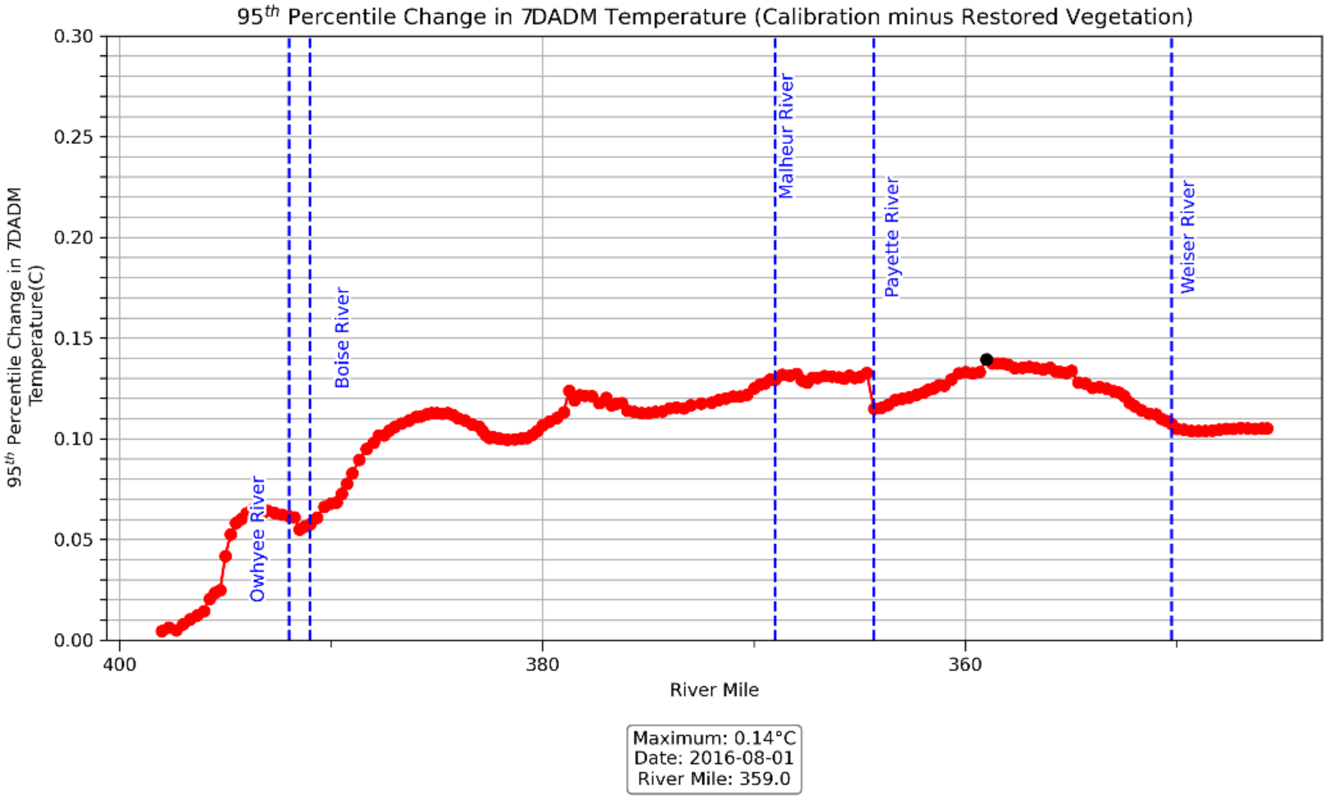


Figure 4-6). For the downstream of Hells Canyon Dam, the estimated impacts are 0.15 °C for the modeling period and 0.04 °C during spawning season (Figure 4-7 and Figure 4-8, respectively). These impacts are observed at RMs 224 and 210, respectively. A comparison by RM within the HCC reservoirs is not provided due to the influence of the plunge point, as discussed in Section 7.0.

The effects of restored vegetation on water temperature are small because of the width of the Snake River, which limits the effects of shading on the water column. Supplementary plots of model results are provided in Section 8.0 (Figure 8-27 through Figure 8-43).

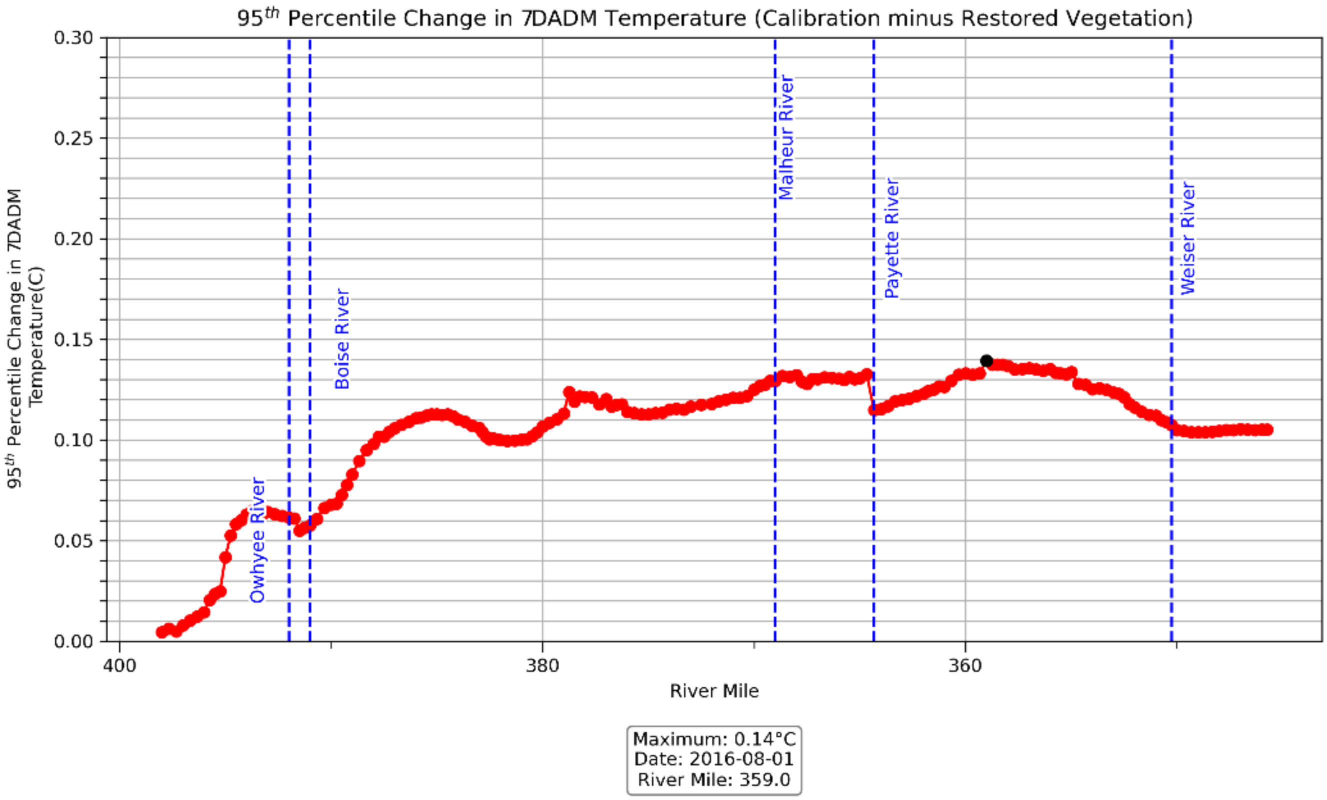


Figure 4-6. 95th percentile change in 7DADM temperature above applicable criteria due to the impacts of reduced vegetation, from Adrian to head of Brownlee Reservoir, during the 2014-2018 modeling period.

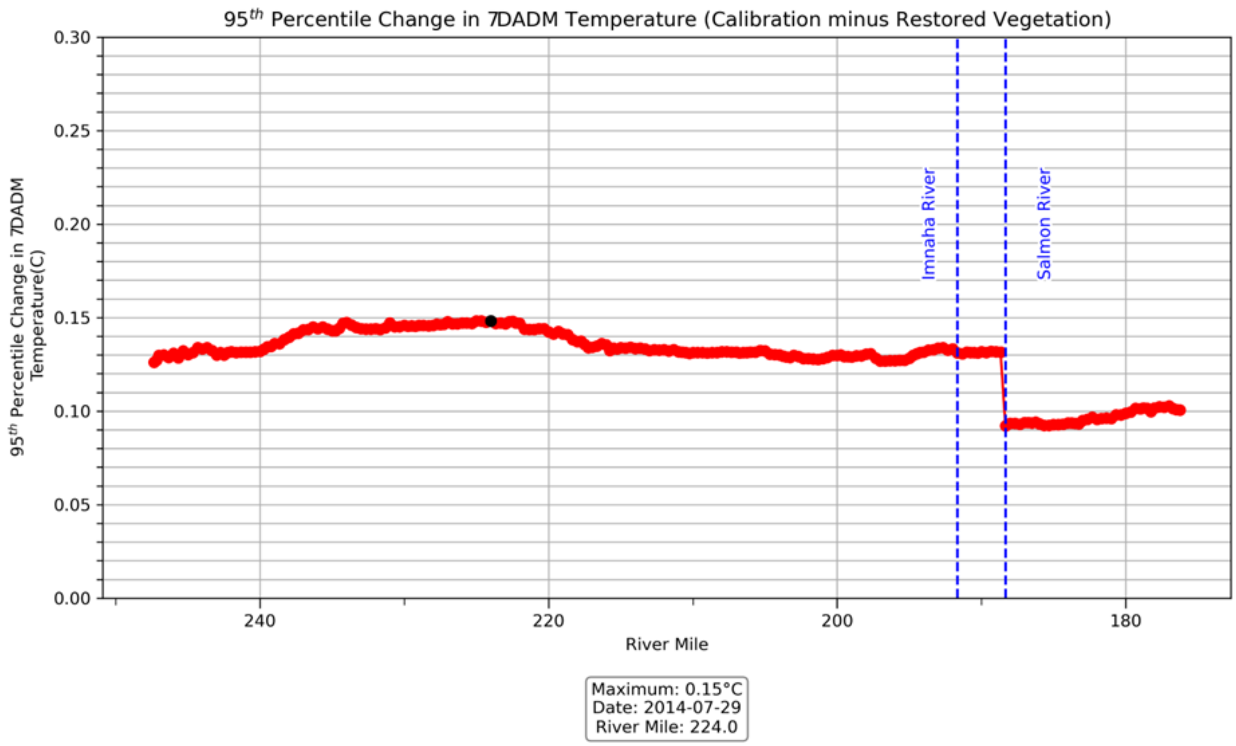


Figure 4-7. 95th percentile change in 7DADM temperature above applicable criteria due to the impacts of reduced vegetation, from Hells Canyon Dam to Washington state line, during the 2014-2018 modeling period.

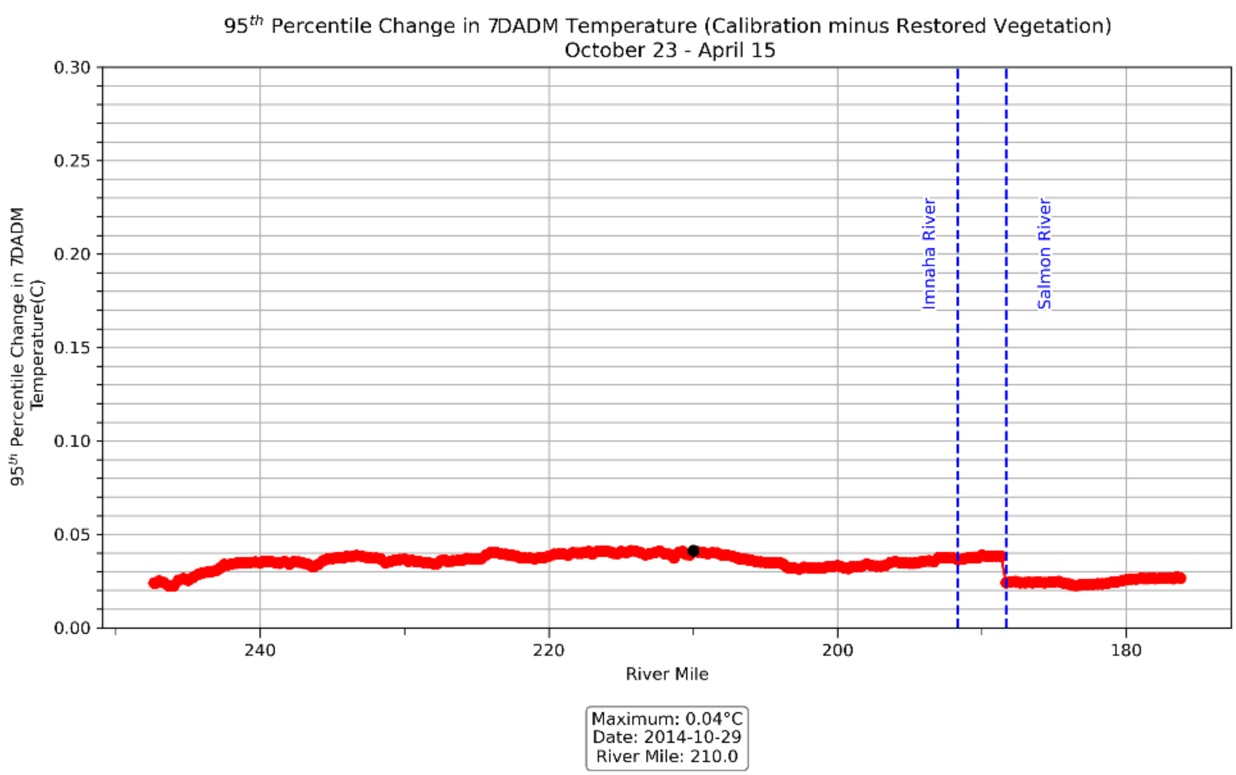


Figure 4-8. 95th percentile change in 7DADM temperature above applicable criteria during spawning season due to the impacts of reduced vegetation, Snake River, from Hells Canyon Dam to Washington state line.

4.4 BACKGROUND VS. CALIBRATION

This scenario evaluates the stream temperature response resulting solely from background thermal sources to the Snake River described in Section 3.4. The scenario is based on a combination of three prior configurations: no dams, no PS, and restored vegetation. Specifically, the river channel within the HCC reservoir areas is reconfigured to reflect the estimated historical channel geometry. All permitted point source discharges are set to zero, and riparian vegetation is restored throughout the river corridor and across the HCC reservoir footprints, consistent with the restoration assumptions described earlier in Sections 3.1 through 3.3.

The effects of anthropogenic sources on Snake River temperatures, from Adrian to the head of Brownlee Reservoir, and from below Hells Canyon Dam to the Washington state line, are illustrated in

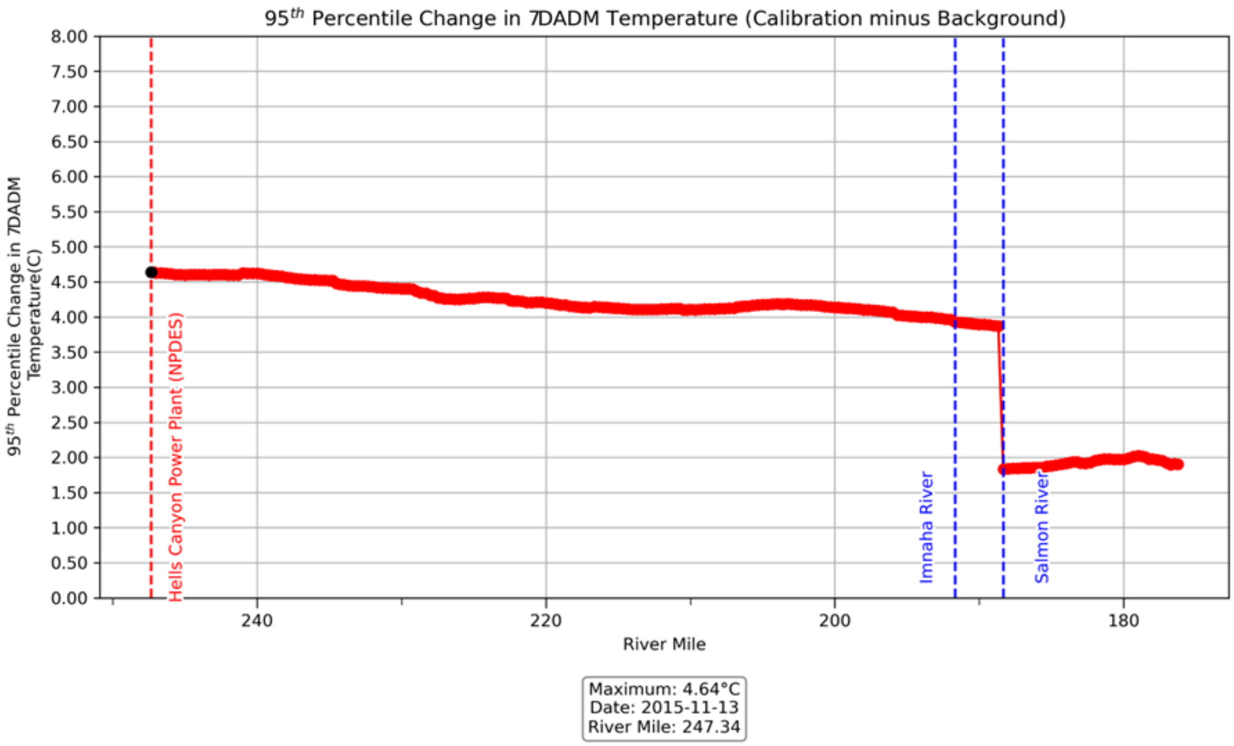


Figure 4-9 to Figure 4-11. Based on BBNC criteria, the 95th percentile impact of anthropogenic sources on 7DADM temperatures is estimated at 0.14 °C for the Adrian-to-Brownlee reach and 4.64 °C for the reach below Hells Canyon Dam over the full modeling period. The impact below Hells Canyon Dam increases to 6.42 °C during the spawning season (Figure 4-11), exceeding the impact observed during the modeling period (Figure 4-10).

Supplementary plots of model results are provided in Section 8.0 (Figure 8-44 through Figure 8-60).

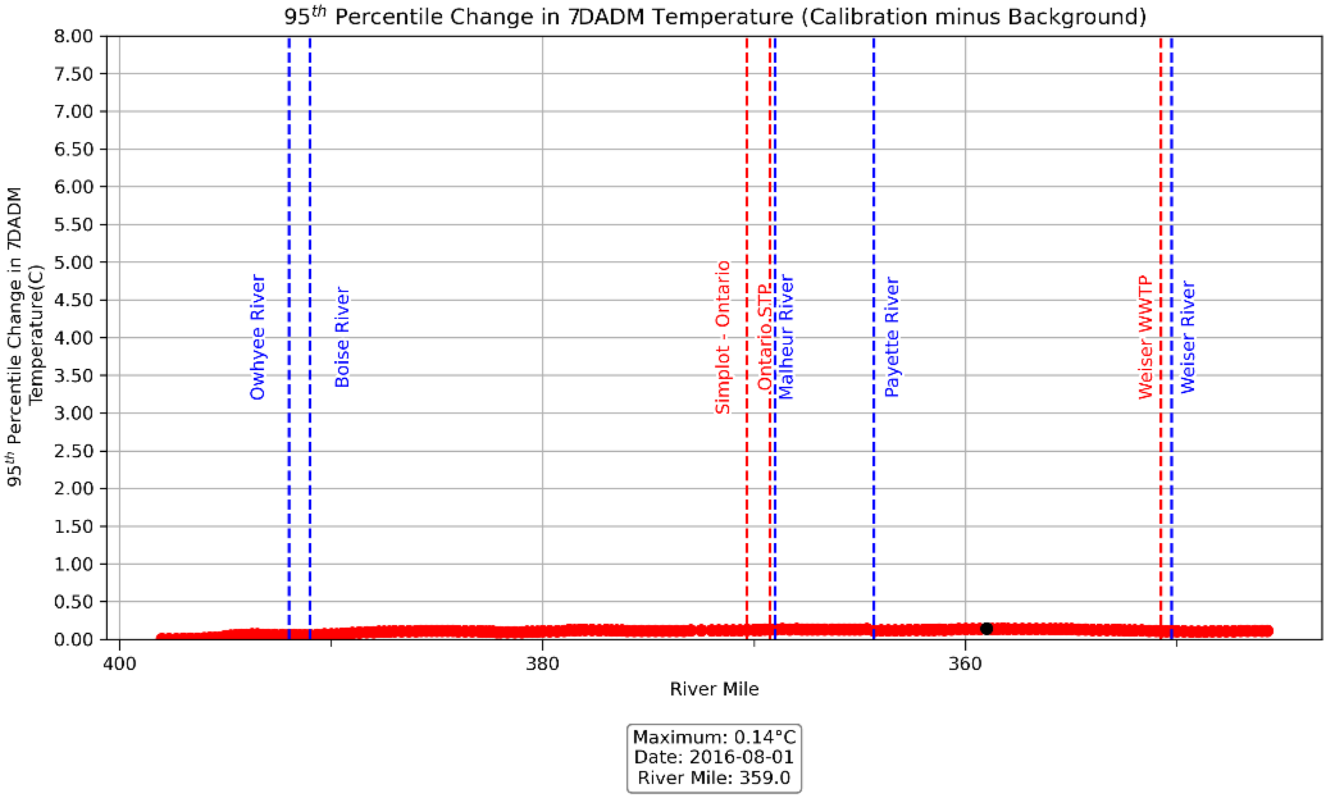


Figure 4-9. 95th percentile change in 7DADM temperature above applicable criteria due to the impacts of anthropogenic sources, from Adrian to head of Brownlee Reservoir, during the 2014 to 2018 modeling period.

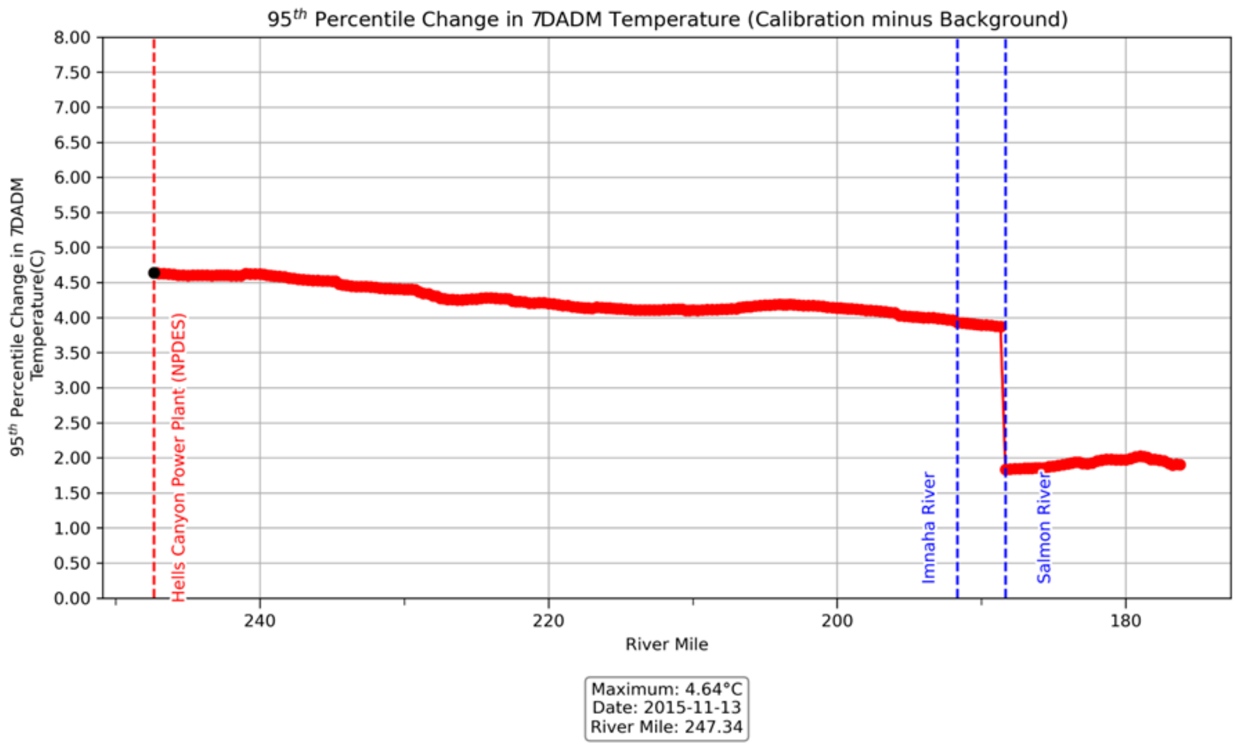


Figure 4-10. 95th percentile change in 7DADM temperature above applicable criteria due to impacts of anthropogenic sources, from Hells Canyon Dam to Washington state line, during the 2014-2018 modeling period.

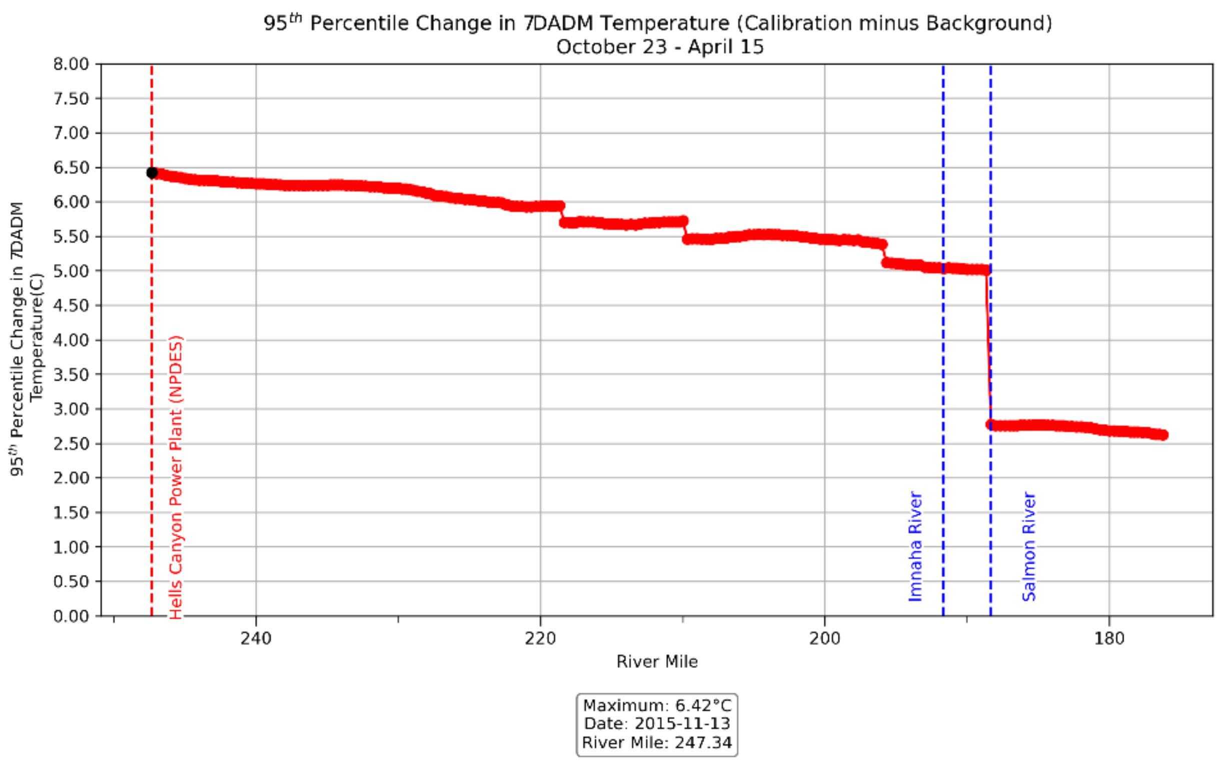


Figure 4-11. 95th percentile change in 7DADM temperature above applicable criteria during spawning season (October 23- April 15) due to the impacts of anthropogenic sources, from Hells Canyon Dam to Washington state line.

4.5 TRIBUTARY A VS. BACKGROUND

The effects of tributary temperature TMDL allocations on Snake River temperatures, from Adrian to the Washington State line, are presented in Figure 4-12 and

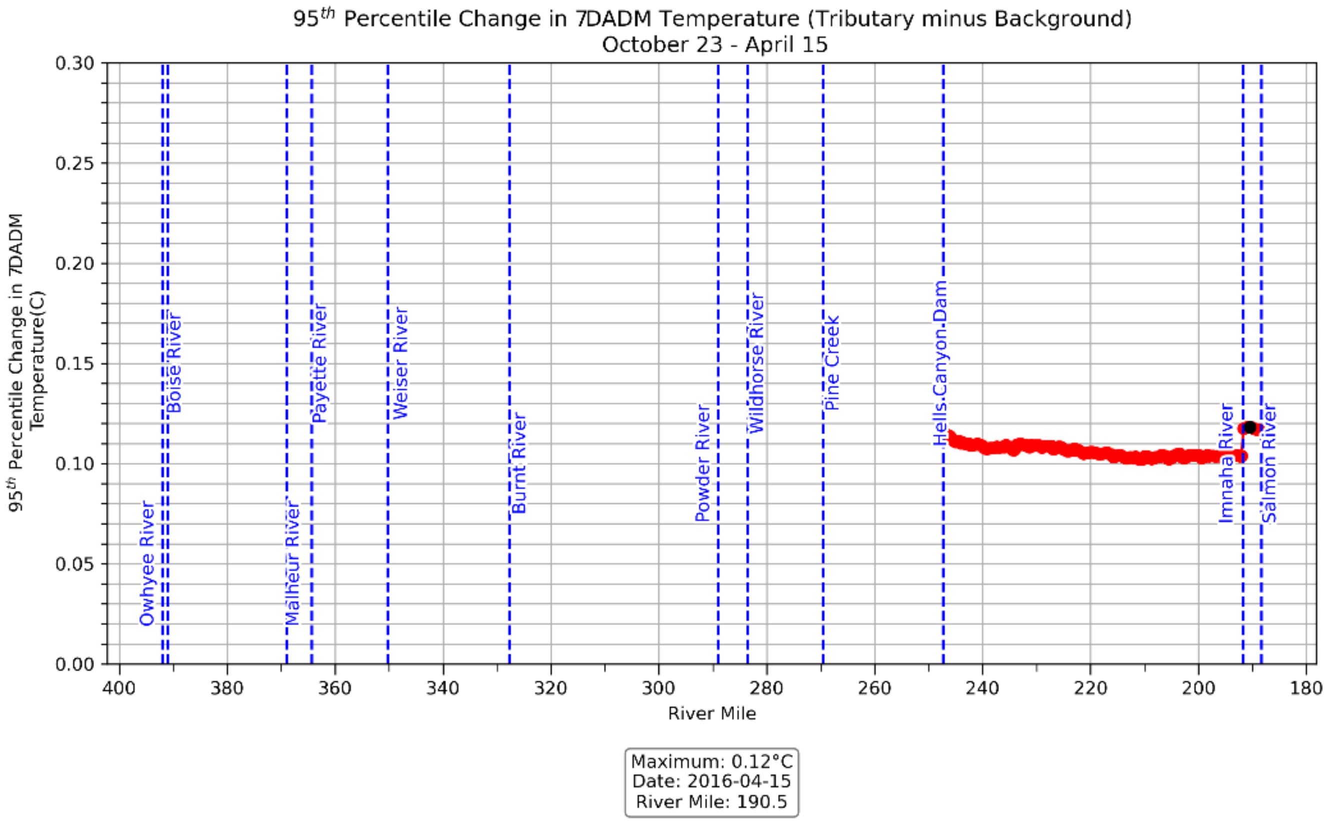


Figure 4-13 for both the overall modeling period and the spawning season. Based on BBNC criteria, the 95th percentile impact of tributary allocations on 7DADM temperatures is estimated at 0.15 °C for the full modeling period and 0.12 °C during the spawning season.

Supplementary plots of model results are provided in Section 8.0 (Figure 8-61 through Figure 8-69).

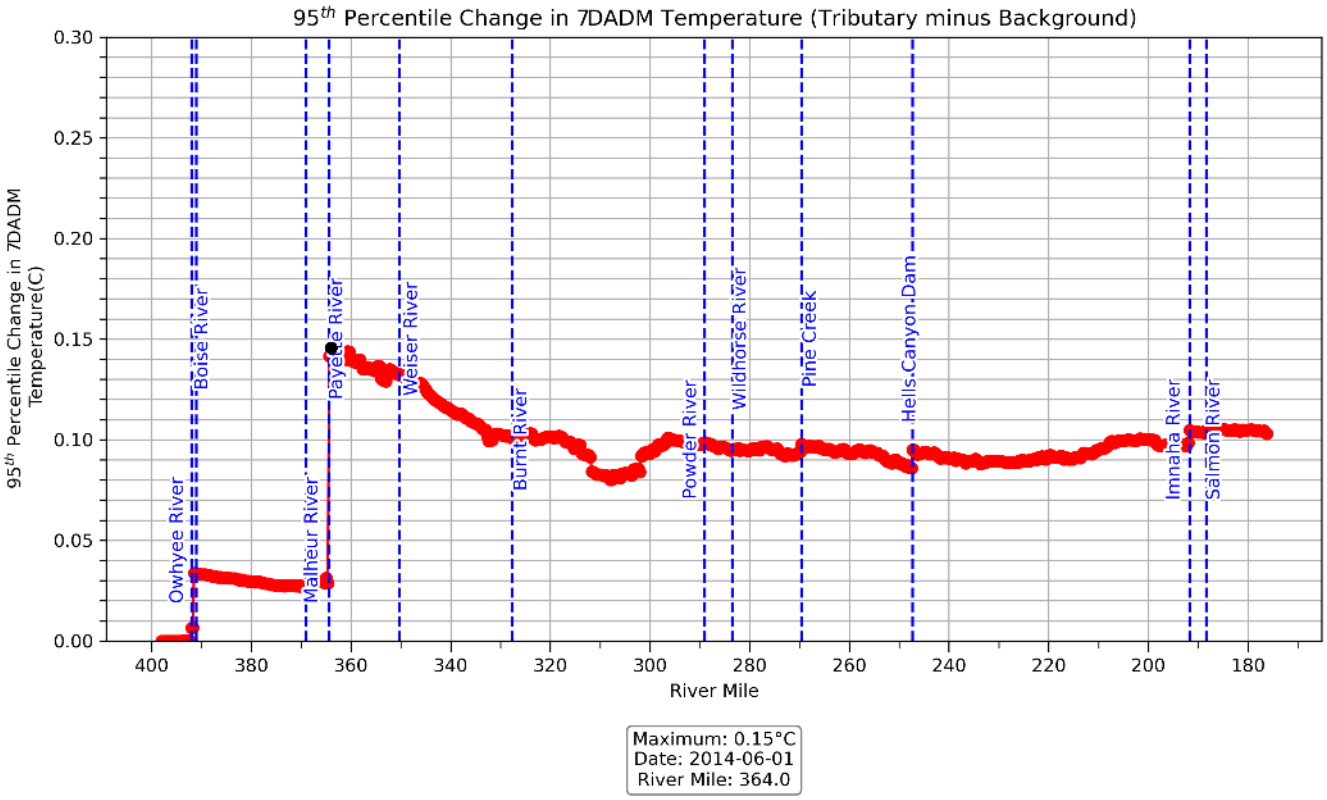


Figure 4-12. 95th percentile change in 7DADM temperature above applicable criteria due to tributary temperature TMDL allocation, from Adrian to Washington State line, during the 2014-2018 modeling period.

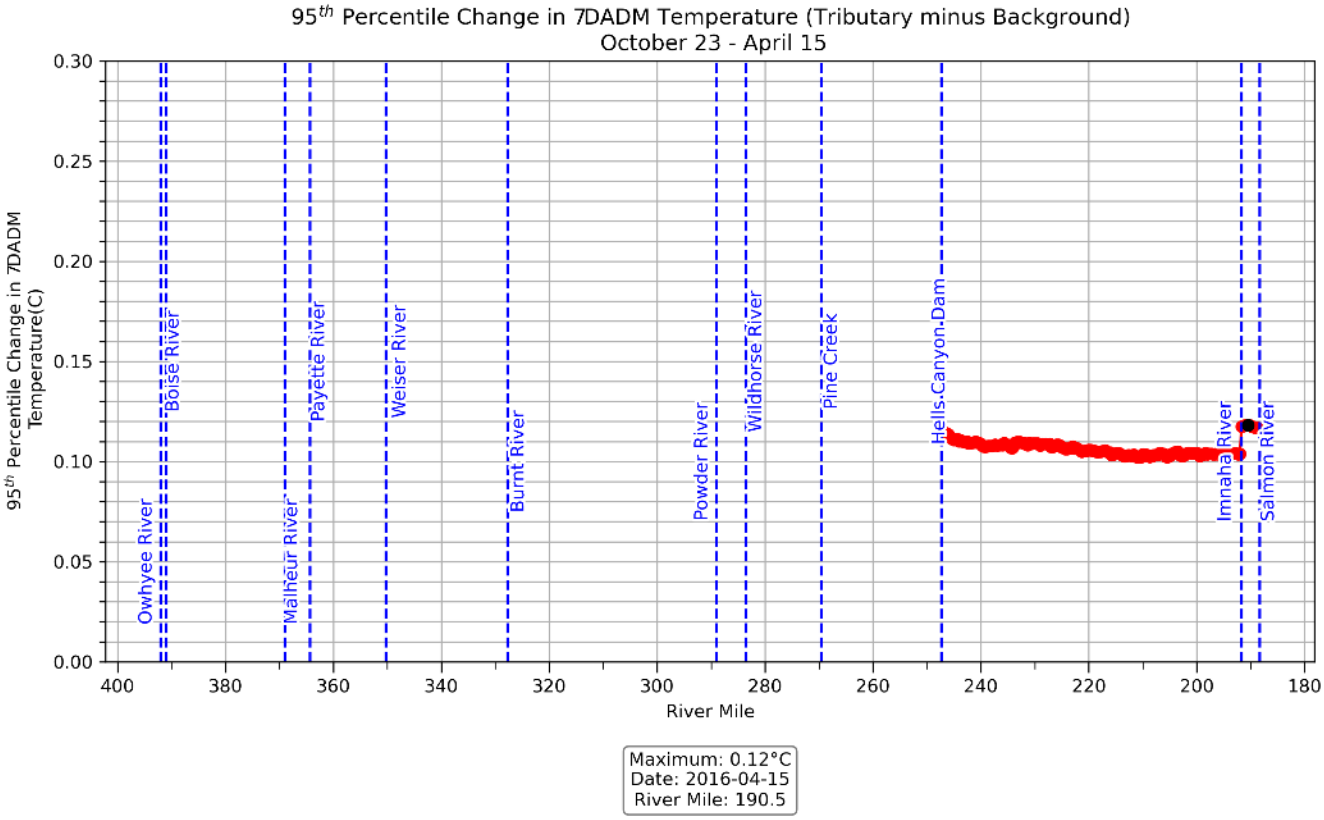


Figure 4-13. 95th percentile change in 7DADM temperature above applicable criteria during spawning season (October 23- April 15) due to tributary temperature TMDL allocation, from Adrian to Washington State line.

Note: Upstream of Hells Canyon Dam, the spawning use criterion does not apply; therefore, no change was calculated.

4.6 TRIBUTARY B VS. BACKGROUND

The effects of Oregon tributary temperature criteria exceedances on the Snake River temperatures, from Adrian to the Washington State line, are presented in Figure 4-18 and Figure 4-19 for both the overall modeling period and the spawning season. Based on BBNC criteria, the 95th percentile impact of Oregon tributary temperaure criteira exceedances on 7DADM temperatures is estimated at 0.37 °C for the full modeling period and 0.01 °C during the spawning season.

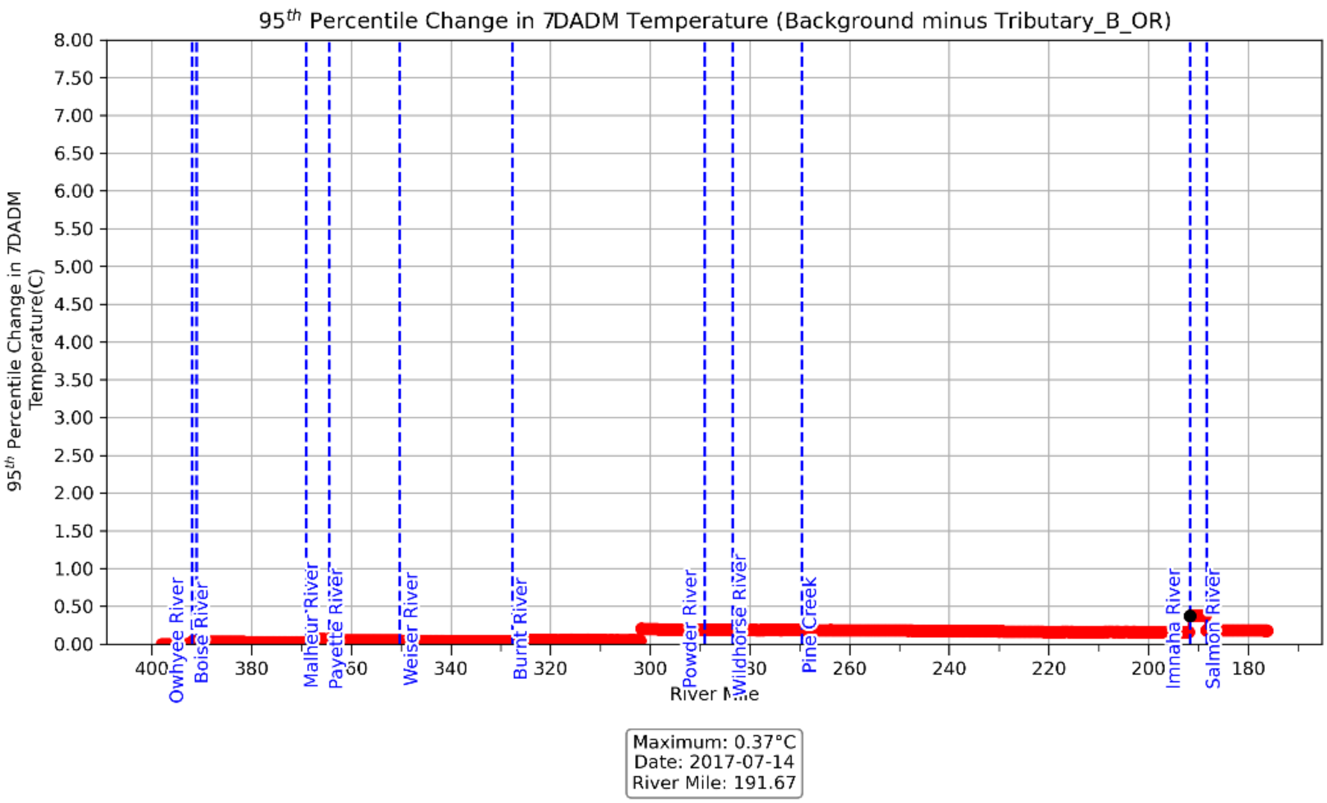


Figure 4-14. 95th percentile change in 7DADM temperature above applicable criteria due to temperature criteria exceedances on Oregon tributaries, from Adrian to Washington State line, during the 2014-2018 modeling period.

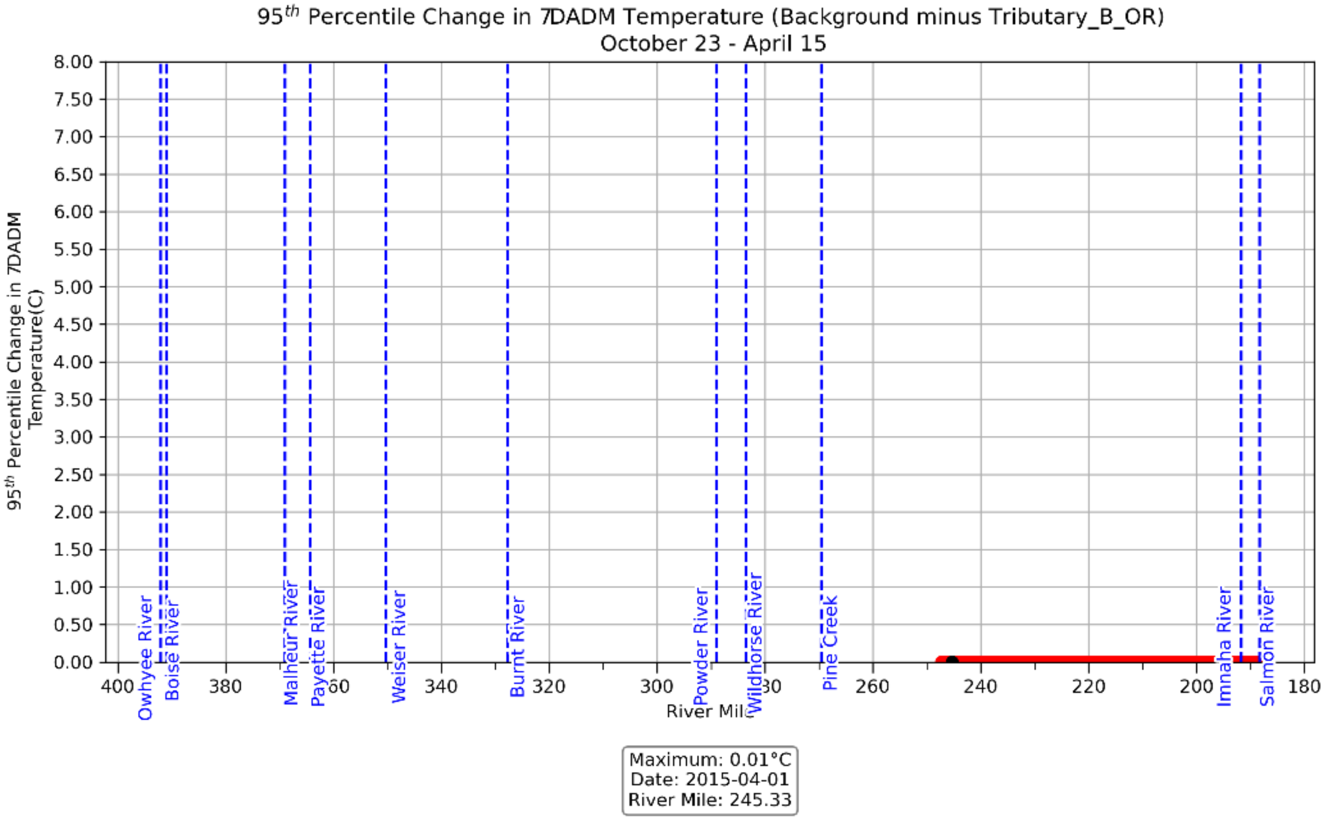


Figure 4-15. 95th percentile change in 7DADM temperature above applicable criteria during spawning season (October 23- April 15) due to temperature criteria exceedances on Oregon tributaries, from Adrian to Washington State line.

Note: Upstream of Hells Canyon Dam, the spawning use criterion does not apply; therefore, no change was calculated.

The effects of Oregon and Idaho tributary temperature criteria exceedances on the Snake River temperatures, from Adrian to the Washington State line, are presented in Figure 4-20 and Figure 4-21 for both the overall modeling period and the spawning season. Based on BBNC criteria, the 95th percentile impact of Oregon and Idaho tributary temperaure criteira exceedances on 7DADM temperatures is estimated at 6.90°C for the full modeling period and 0.10 °C during the spawning season.

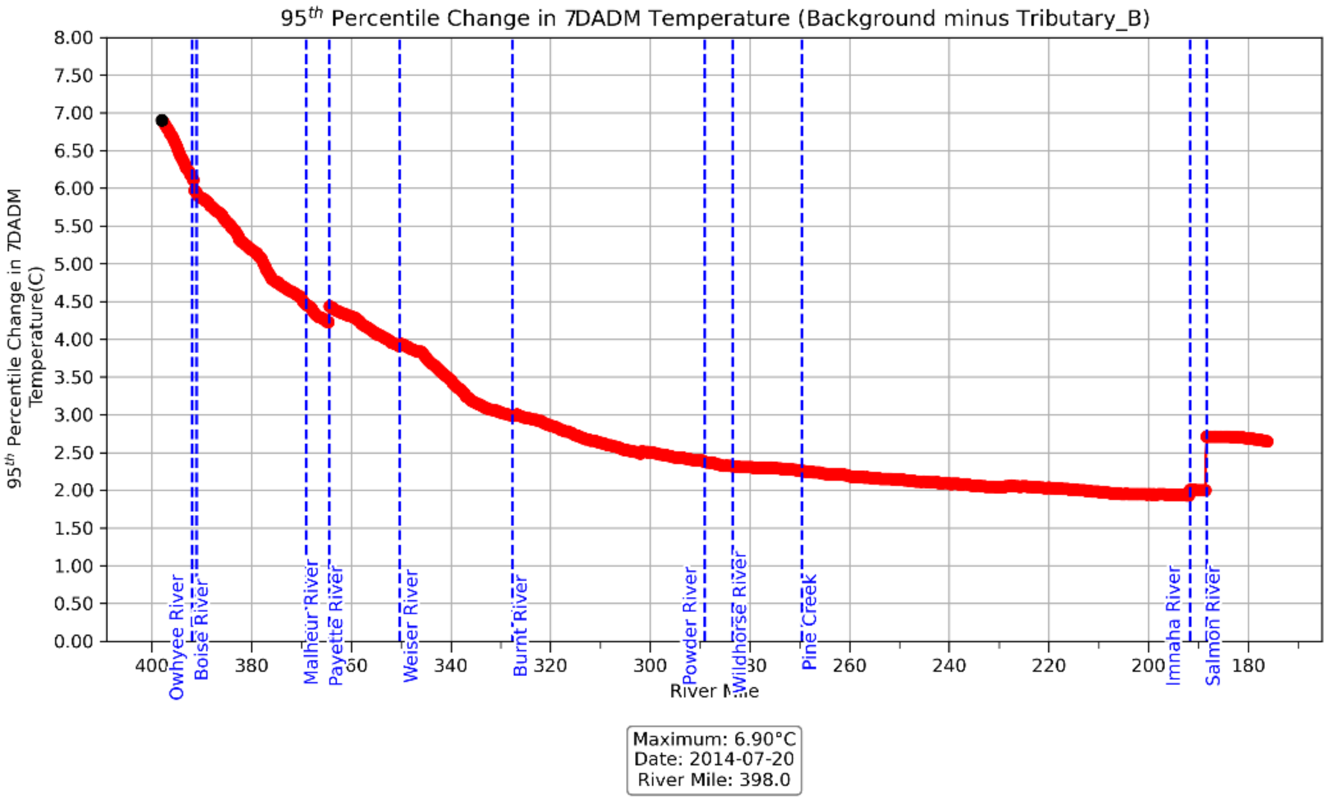


Figure 4-16. 95th percentile change in 7DADM temperature above applicable criteria due to temperature criteria exceedances on Oregon and Idaho tributaries, from Adrian to Washington State line, during the 2014-2018 modeling period.

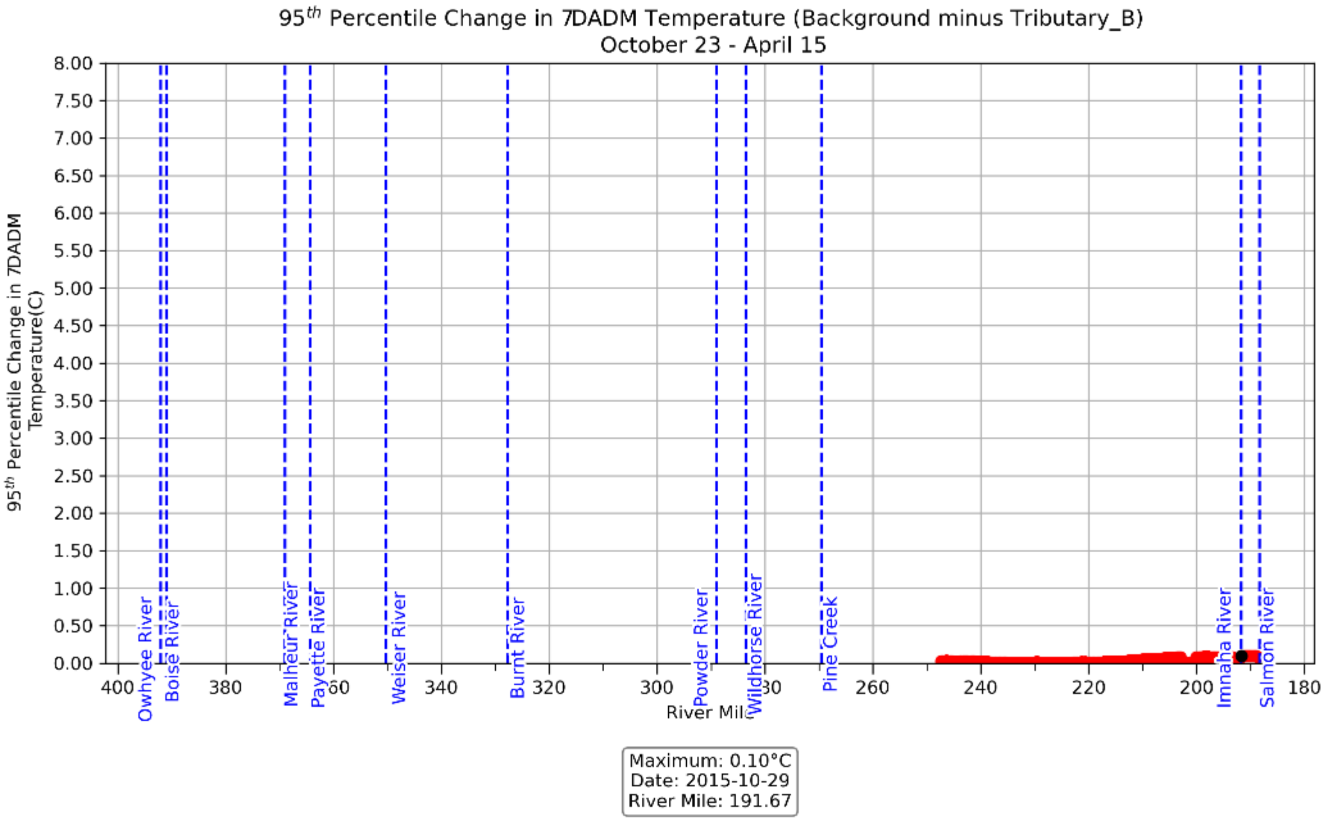


Figure 4-17. 95th percentile change in 7DADM temperature above applicable criteria during spawning season (October 23- April 15) due to temperature criteria exceedances on Oregon and Idaho tributaries, from Adrian to Washington State line.

4.7 WASTE LOAD ALLOCATION VS. BACKGROUND

The effects of point source discharges at WLA levels on Snake River temperatures, from Adrian to the Washington State line, are presented in Figure 4-18 and Figure 4-19 for both the overall modeling period and the seasonal spawning season. Based on BBNC criteria, the 95th percentile impact of WLA discharge on 7DADM temperatures is estimated at 0.06 °C for the full modeling period and 0.11 °C during the spawning season.

Supplementary plots of model results are provided in Section 8.0 (Figure 8-70 through Figure 8-78).

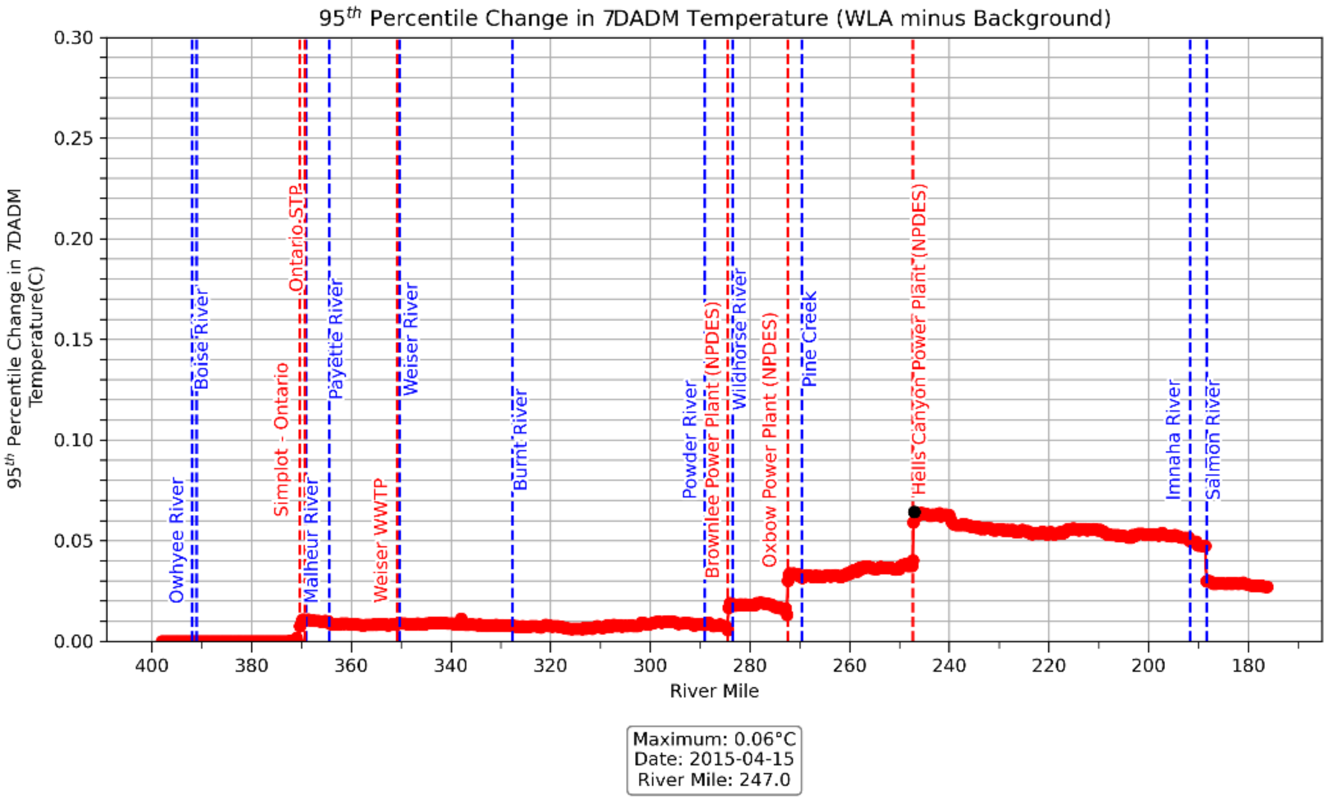


Figure 4-18. 95th percentile change in 7DADM temperature above applicable criteria due to effect of point source discharges at WLA levels, from Adrian to Washington State line, during the 2014-2018 modeling period.

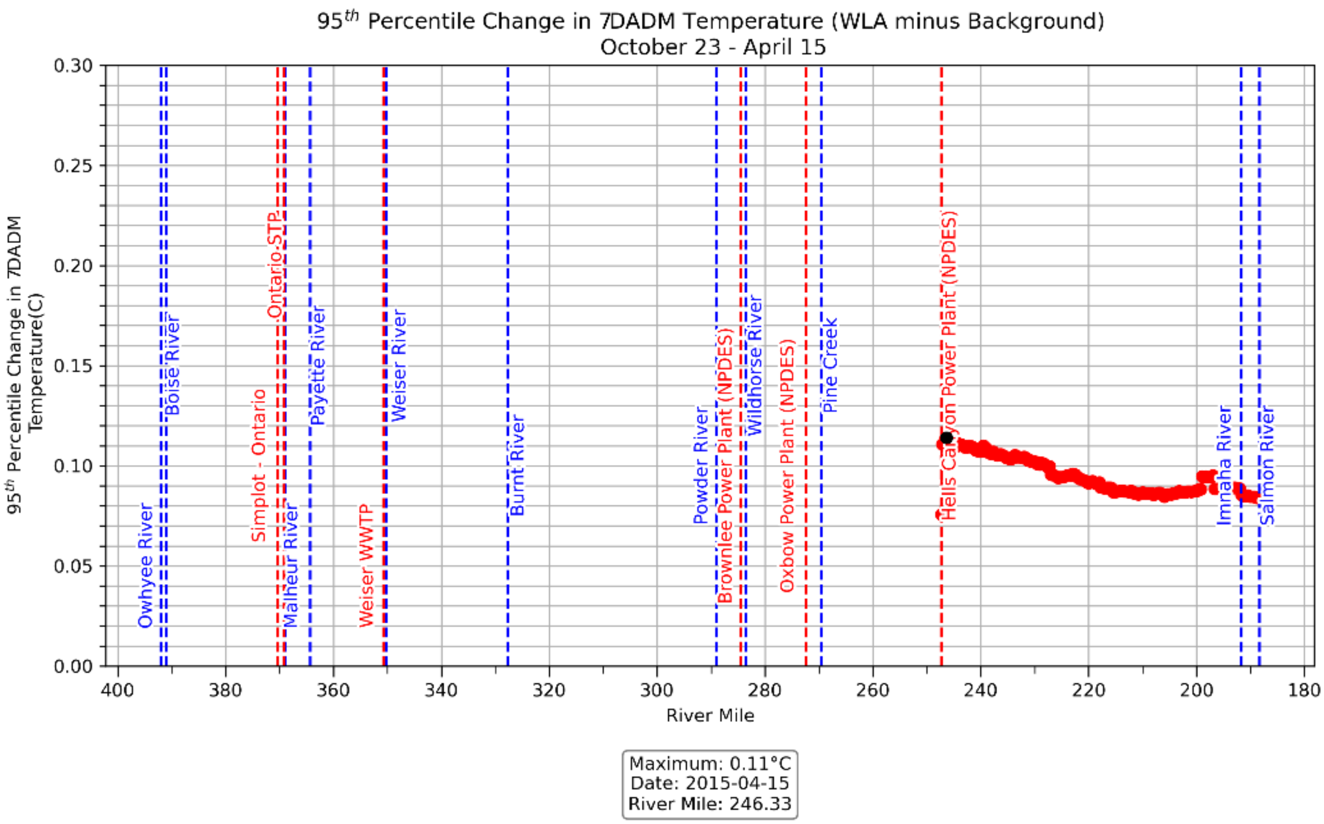
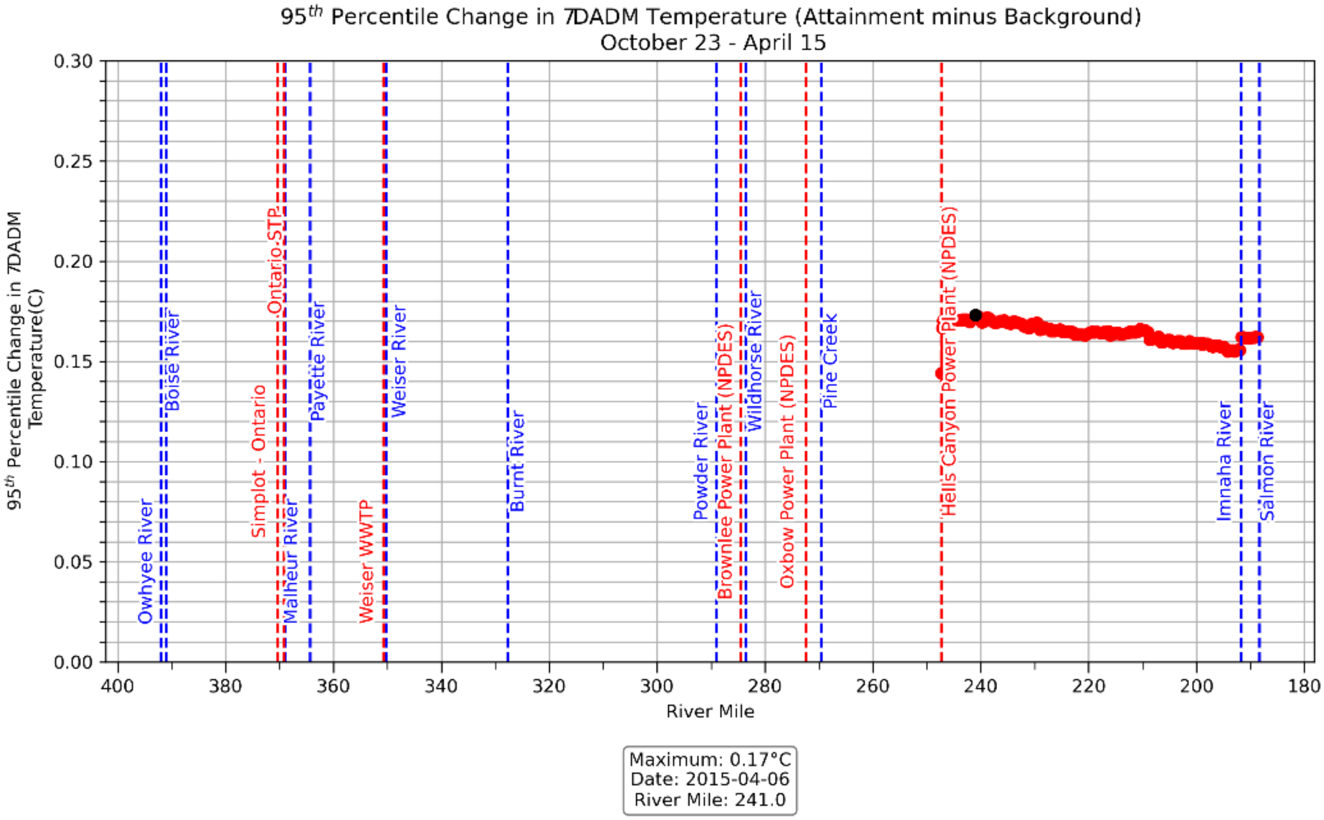


Figure 4-19. 95th percentile change in 7DADM temperature above applicable criteria during spawning season (October 23- April 15) due to effect of point source discharge at WLA levels, from Adrian to Washington State line.

Note: Upstream of Hells Canyon Dam, the spawning use criterion does not apply; therefore, no change was calculated.

4.8 HUA ATTAINMENT VS. BACKGROUND

Figure 4-20



and Figure 4-21 illustrate the influence of point source and nonpoint source discharges set at their allocation levels on Snake River temperatures, spanning from Adrian to the Washington State line. The results are shown for both the full simulation period and the spawning season, respectively. Relative to BBNC criteria, the 95th percentile increase in 7DADM temperatures due to combined effects of point source and nonpoint source discharges is estimated at 0.15 °C for the entire modeling period and 0.17 °C during the spawning season.

Supplementary plots of model results are provided in Section 8.0 (Figure 8-79 through Figure 8-87).

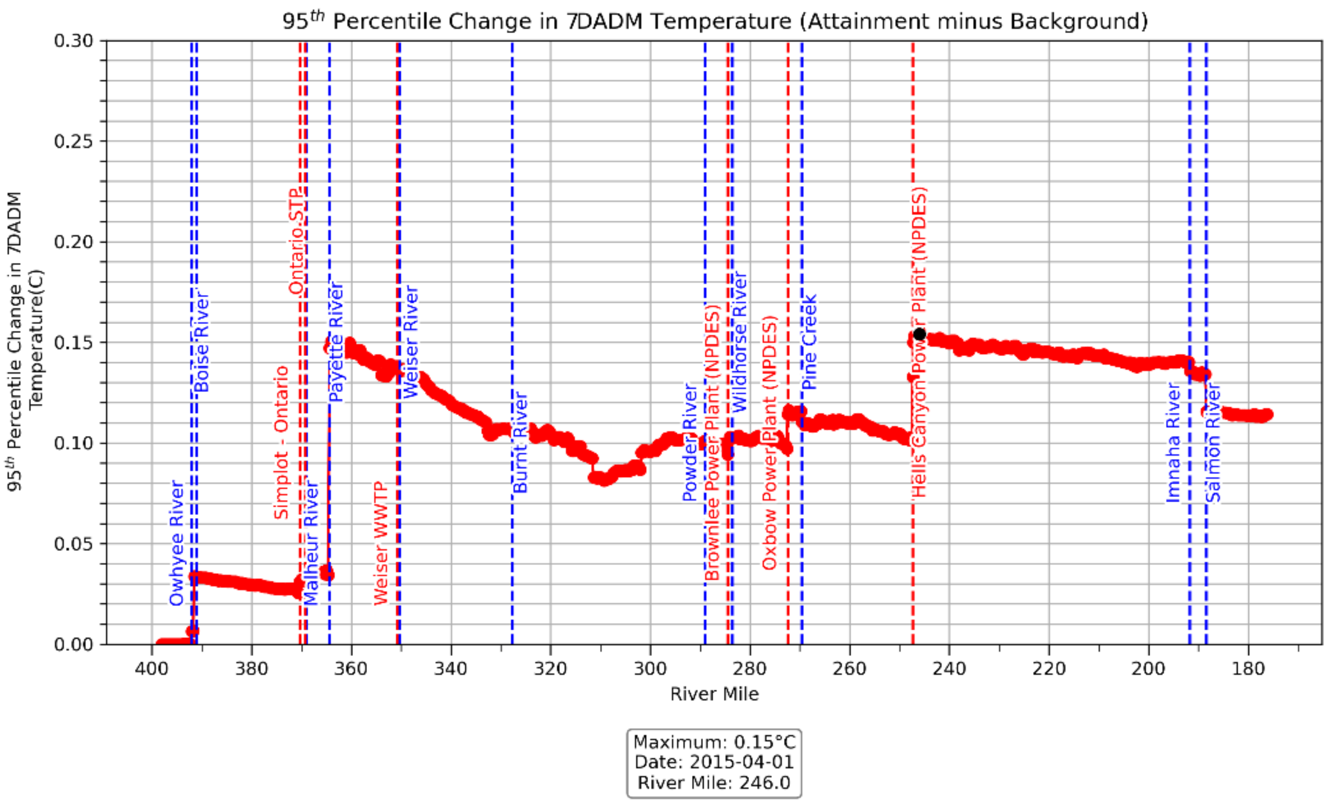


Figure 4-20. 95th percentile change in 7DADM temperature above applicable criteria due to combined effects of point source and nonpoint source discharges, from Adrian to Washington State line, during the 2014-2018 modeling period.

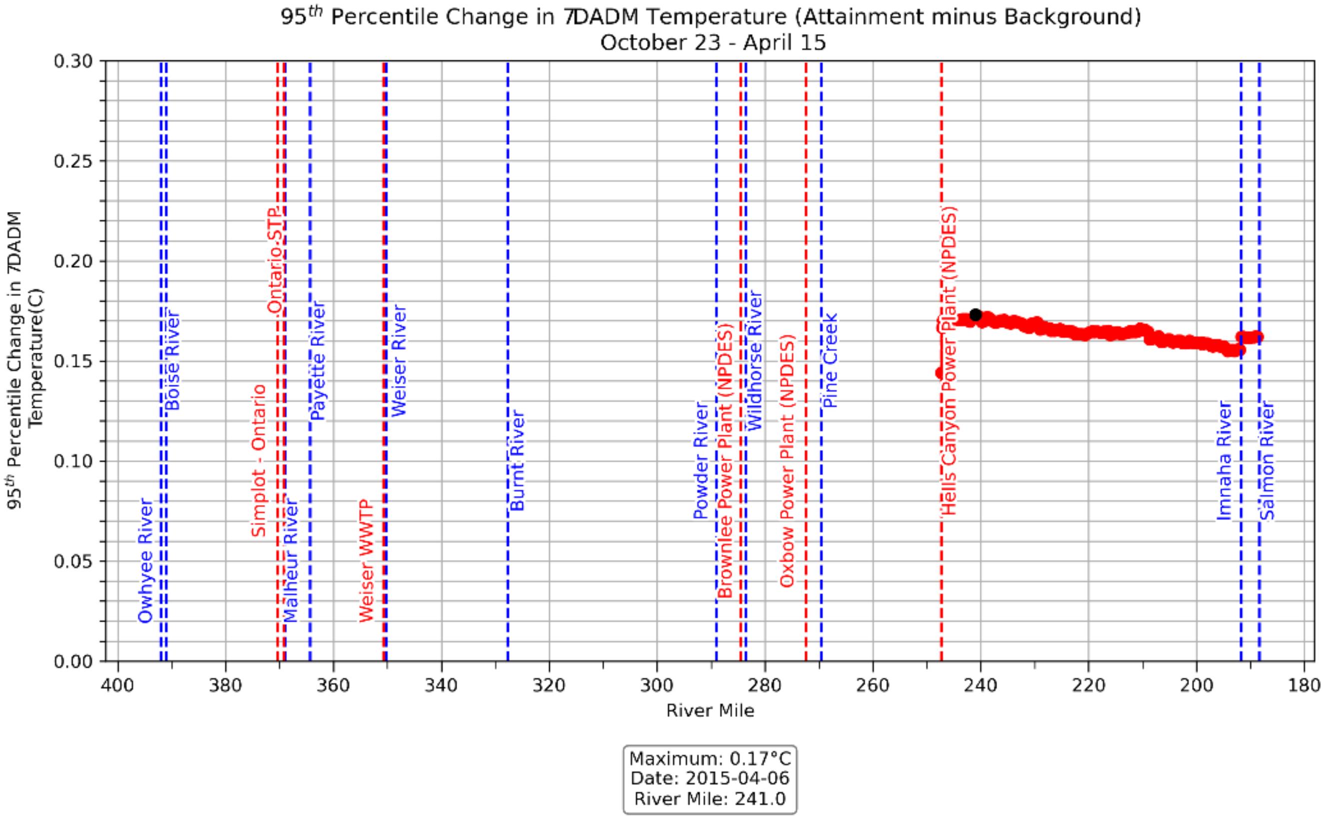


Figure 4-21. 95th percentile change in 7DADM temperature above applicable criteria during spawning season (October 23- April 15) due to combined effects of point source and nonpoint source discharges, from Adrian to Washington State line.

Note: Upstream of Hells Canyon Dam, the spawning use criterion does not apply; therefore, no change was calculated.

4.9 HCC SURROGATE TARGET VS. BACKGROUND

Analysis of the 95th percentile change in 7DADM temperature showed no difference between the background and surrogate model scenarios (

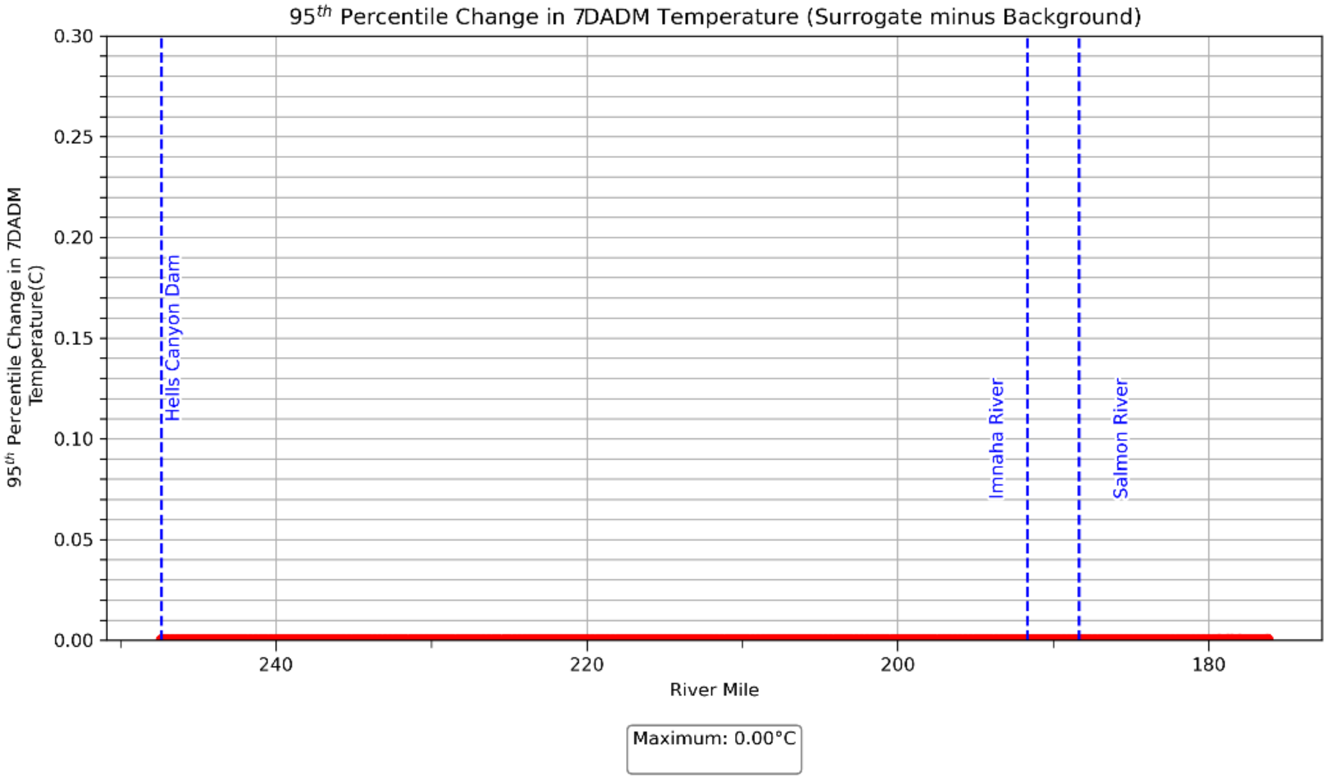


Figure 4-22).

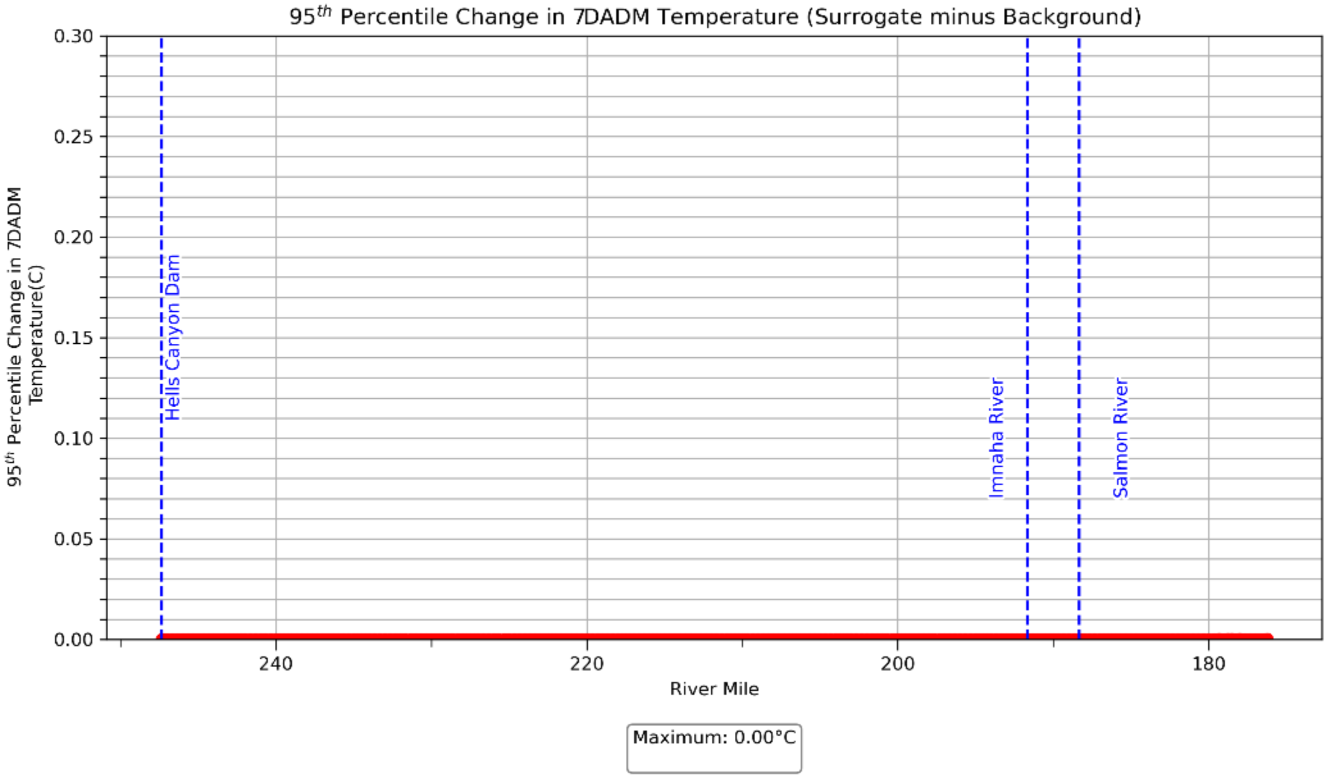


Figure 4-22. 95th percentile change in 7DADM temperature above applicable criteria due to effect of Hells Canyon Dam releases set at target temperatures, from Hells Canyon Dam to Washington State line, during the 2014-2018 modeling period.

4.10 RESERVE CAPACITY: BOUNDARY CONDITION + 0.10°C VS. BACKGROUND

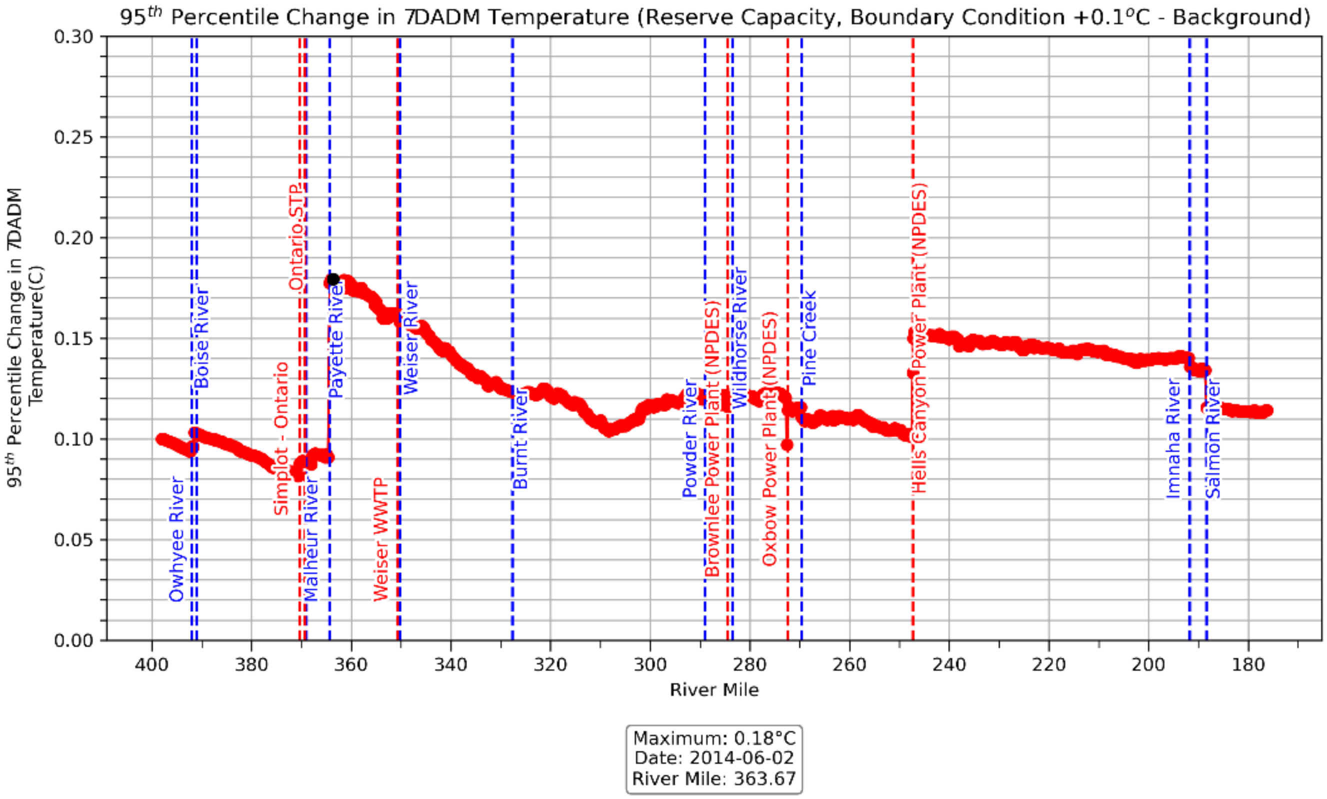


Figure 4-23 presents the 95th percentile change in 7DADM temperature under the 0.1 °C reserve capacity scenario, compared to the background scenario. During the full modeling period, the maximum impact is estimated at 0.18 °C, occurring near the confluence with the Payette River at RM 363.67. For the spawning season, the greatest change in 95th percentile temperatures is 0.17 °C, observed downstream of Hells Canyon Dam at RM 241 (Figure 4-24).

Supplementary plots of model results are provided in Section 8.0 (Figure 7-88 through Figure 7-96).

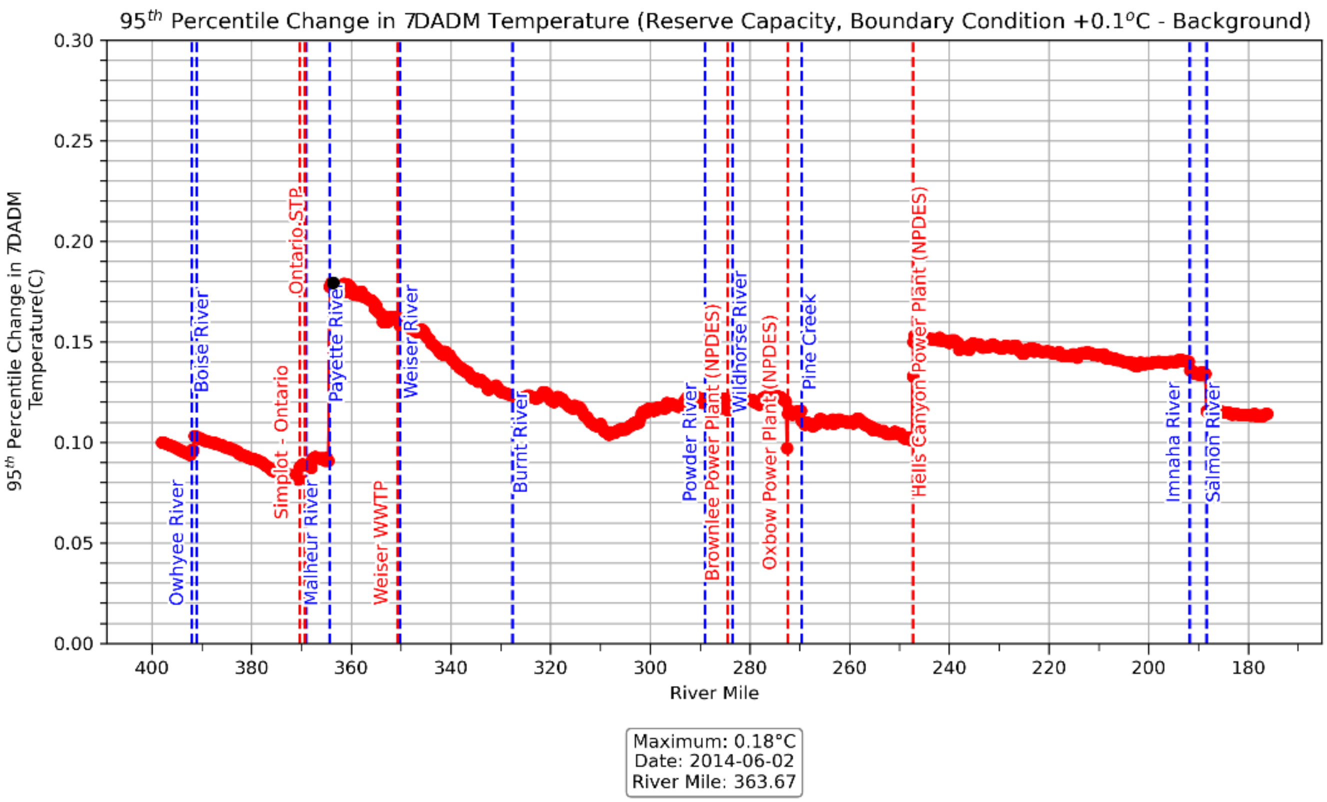


Figure 4-23. 95th percentile change in 7DADM temperature above applicable criteria due to the combined effects of point and nonpoint sources set at their respective TMDL allocations, along with a hypothetical reserve capacity allocation corresponding to a 0.1 °C temperature increase at Adrian, during the 2014-2018 modeling period.

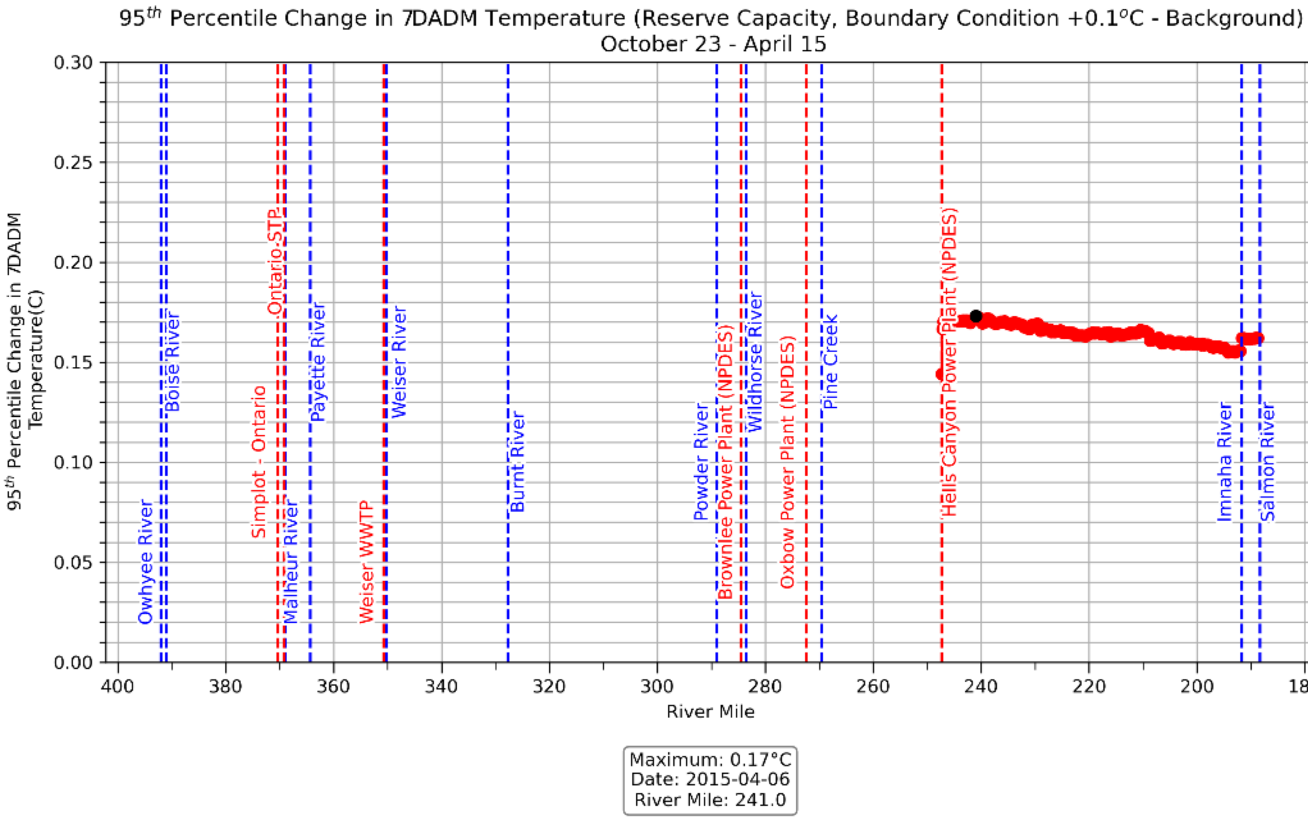


Figure 4-24. 95th percentile change in 7DADM temperature above applicable criteria during spawning season (October 23- April 15) due to the combined effects of point and nonpoint sources set at their respective TMDL allocations, along with a hypothetical reserve capacity allocation corresponding to a 0.1 °C temperature increase at Adrian.

Note: Upstream of Hells Canyon Dam, the spawning use criterion does not apply; therefore, no change was calculated.

4.11 RESERVE CAPACITY: BOUNDARY CONDITION + 0.15°C VS. BACKGROUND

The maximum change in 95th percentile 7DADM temperatures during the full modeling period is 0.19 °C, occurring near the confluence with the Payette River at RM 363.33 (Figure 4-25). During the spawning season, the maximum change below Hells Canyon Dam is 0.21 °C, observed near the dam outlet at RM 246.67 (Figure 4-26).

Supplementary plots of model results are provided in Section 8.0 (Figure 8-97 through Figure 8-105).

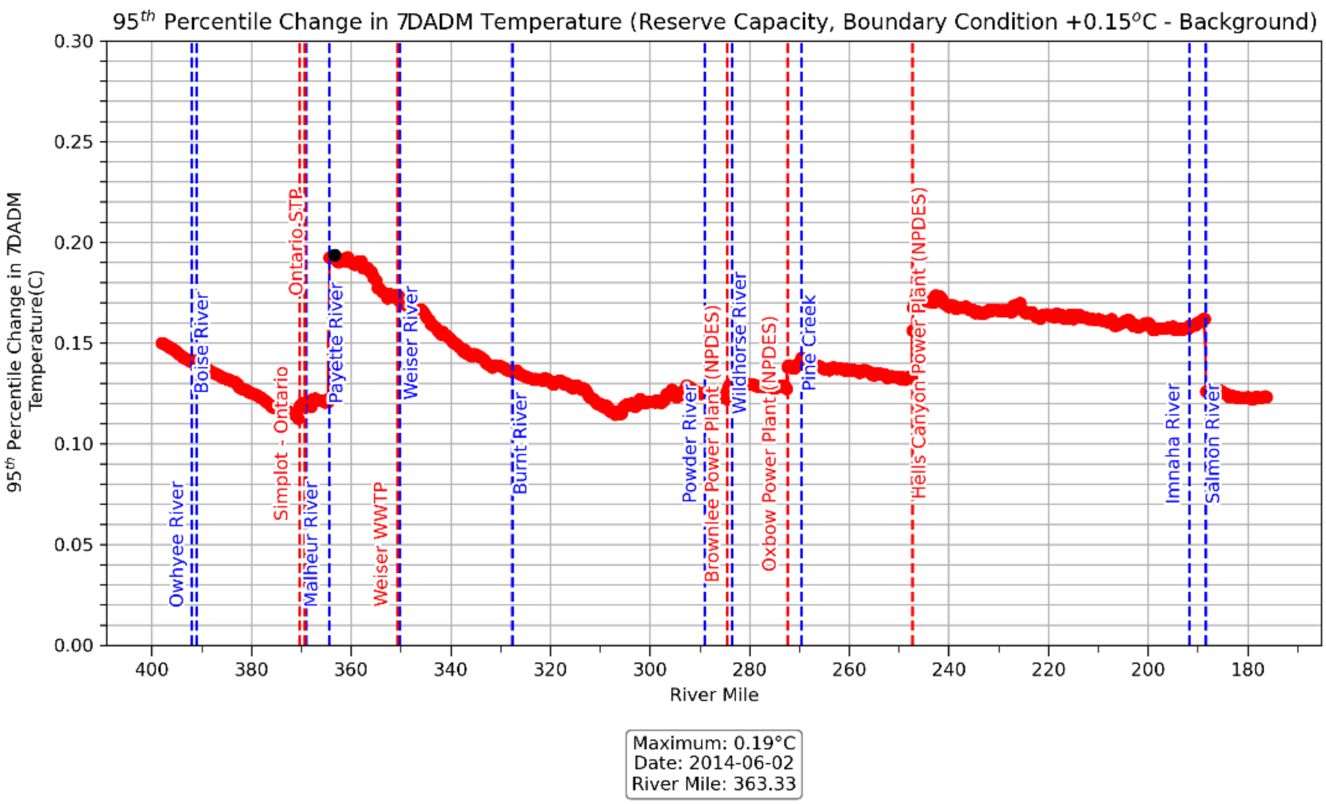


Figure 4-25. 95th percentile change in 7DADM temperature above applicable criteria due to the combined effects of point and nonpoint sources set at their respective TMDL allocations, along with a hypothetical reserve capacity allocation corresponding to a 0.15 °C temperature increase at Adrian, during the 2014-2018 modeling period.

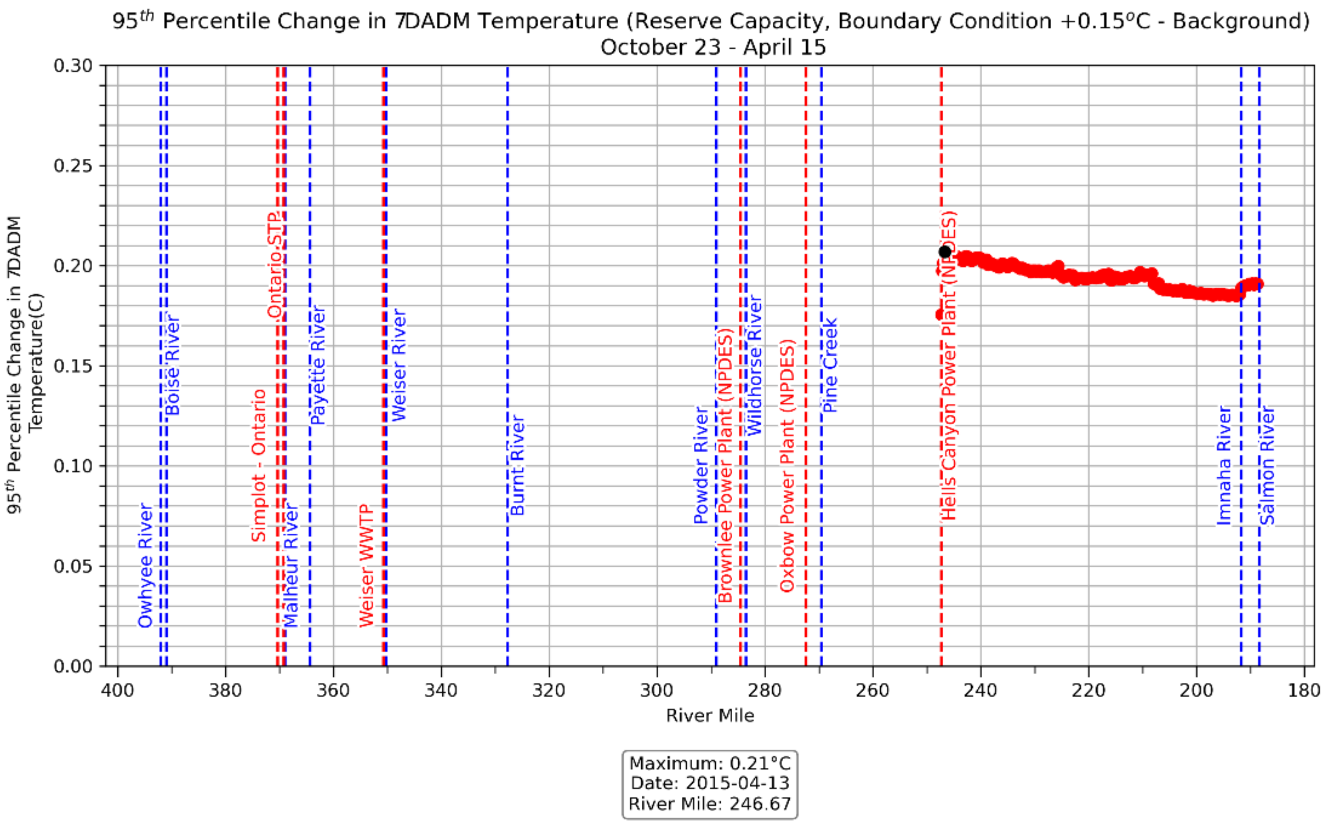


Figure 4-26. 95th percentile change in 7DADM temperature above applicable criteria during spawning season (October 23- April 15) due to the combined effects of point and nonpoint sources set at their respective TMDL allocations, along with a hypothetical reserve capacity allocation corresponding to a 0.15 °C temperature increase at Adrian.

Note: Upstream of Hells Canyon Dam, the spawning use criterion does not apply; therefore, no change was calculated.

5.0 EFFECTS OF HYDROLOGIC MODIFICATION ON FLOWS AND TEMPERATURE PATTERNS

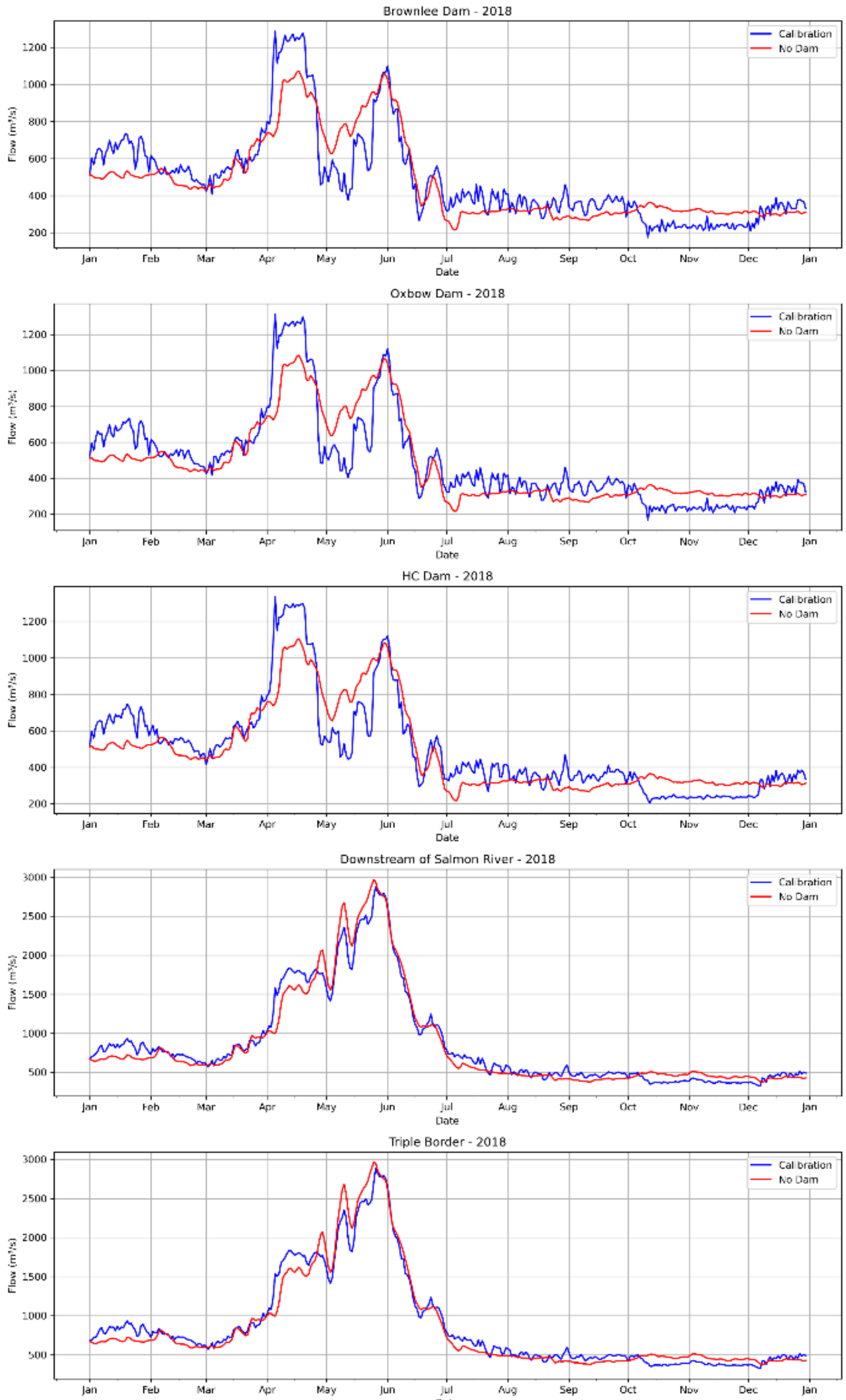


Figure 5-1 through Figure 5-4 present example comparisons of daily average flow, 7DADM temperature, daily average temperature, and daily maximum temperature between the calibration and no dams scenarios at five locations, Brownlee Dam, Oxbow Dam, Hells Canyon Dam, downstream of Salmon River, and the triple border, for the year 2018. Table 5-1 and Table 5-2

Table 5-2 summarize the monthly average statistics for daily average flow and 7DADM temperature at the Hells Canyon Dam for 2014–2018. Comparable figures and tables for 2014–2017 and selected locations are provided in Figure 8-106 through Figure 8-121 and Table 8-1 through Table 8-8 in Section 8.2.

In general, the comparison between the calibration and no dams scenarios (2014–2018) at Hells Canyon Dam reveals a distinct seasonal pattern due to hydropower operation and water storage. During winter (January–February) and early spring (March–April), calibration flows are consistently higher, averaging 37–78 m^3/s above flows in the no dams scenario. In May and June, the pattern reverses, with the no dams flows exceeding calibration flows by roughly 151 m^3/s and 30 m^3/s, respectively, as the reservoirs reduce the peak snowmelt runoff. From July through September, differences are relatively small, with calibration maintaining slightly higher flows, typically 20–70 m^3/s above the no dams scenario. In October and November, the no dams flows are generally higher (50–86 m^3/s), while by December the two scenarios converge with little (3–8 m^3/s) difference. Overall, the calibration scenario produces a more regulated hydrograph, characterized by higher winter and summer flows but reduced spring peaks and fall discharges, whereas the no dams scenario preserves more natural variability with sharper snowmelt peaks.

Both daily and monthly averages across all temperature statistics are higher in the calibration scenario compared to the no dams scenario during September through January. The monthly mean 7DADM temperature differences for the 2014–2018 modeling period show a clear seasonal pattern. In January, the no dams scenario is generally cooler than calibration by about 0.8–1.1 °C across all sites, except for 2018. From February through August, the differences become positive, with the no dams scenario showing higher temperatures, peaking in July with an increase of up to 4.7 °C at Brownlee Dam. Beginning in September, the trend reverses, with calibration producing higher temperatures than the no dams scenario. The strongest effect occurs in October–December, with increases of ~1.7–3.0 °C in October, ~2.5–4.7 °C in November, and ~2.4–3.8 °C in December across all locations for the calibration scenario vs. the no-dams scenario due to thermal storage in the reservoirs.

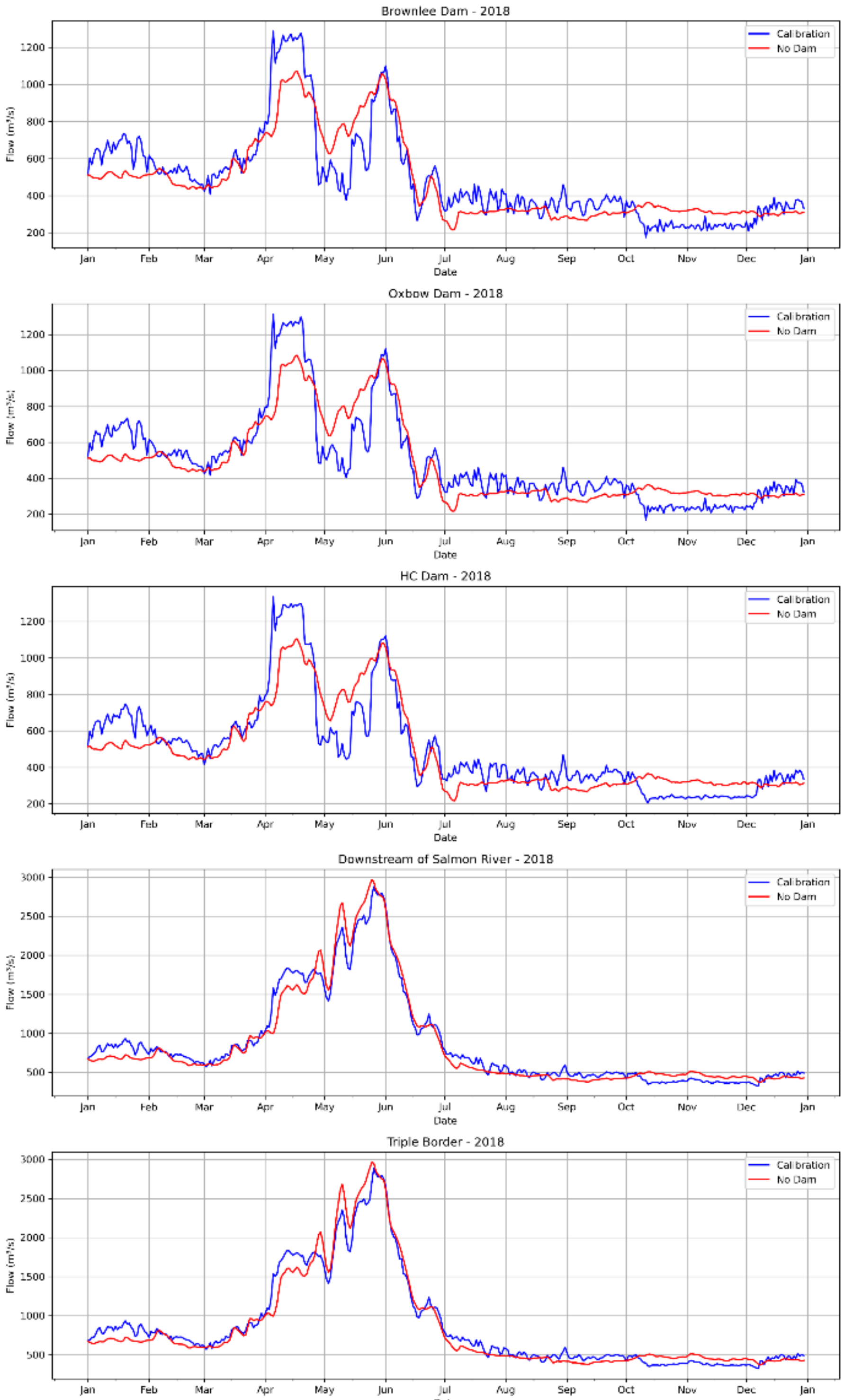


Figure 5-1. Modeled daily average flow in 2018 for Snake River segment at Brownlee Dam, Oxbow Dam, Hells Canyon Dam, downstream of Salmon River, and triple border, comparing calibration and no dams scenarios.

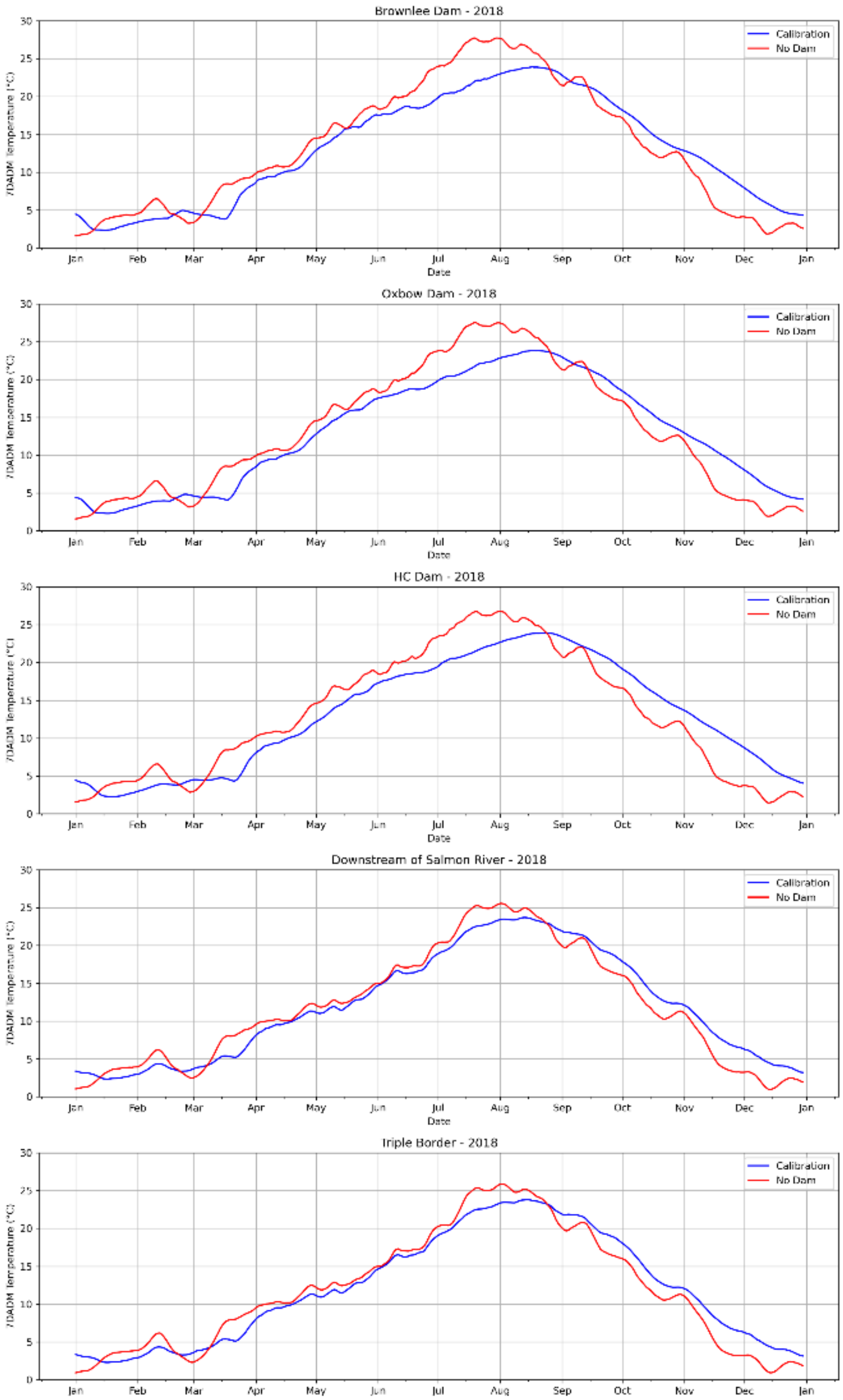


Figure 5-2. Modeled 7DADM average temperature in 2018 for Snake River segment at Brownlee Dam, Oxbow Dam, Hells Canyon Dam, downstream of Salmon River, and triple border, comparing calibration and no dams scenarios.

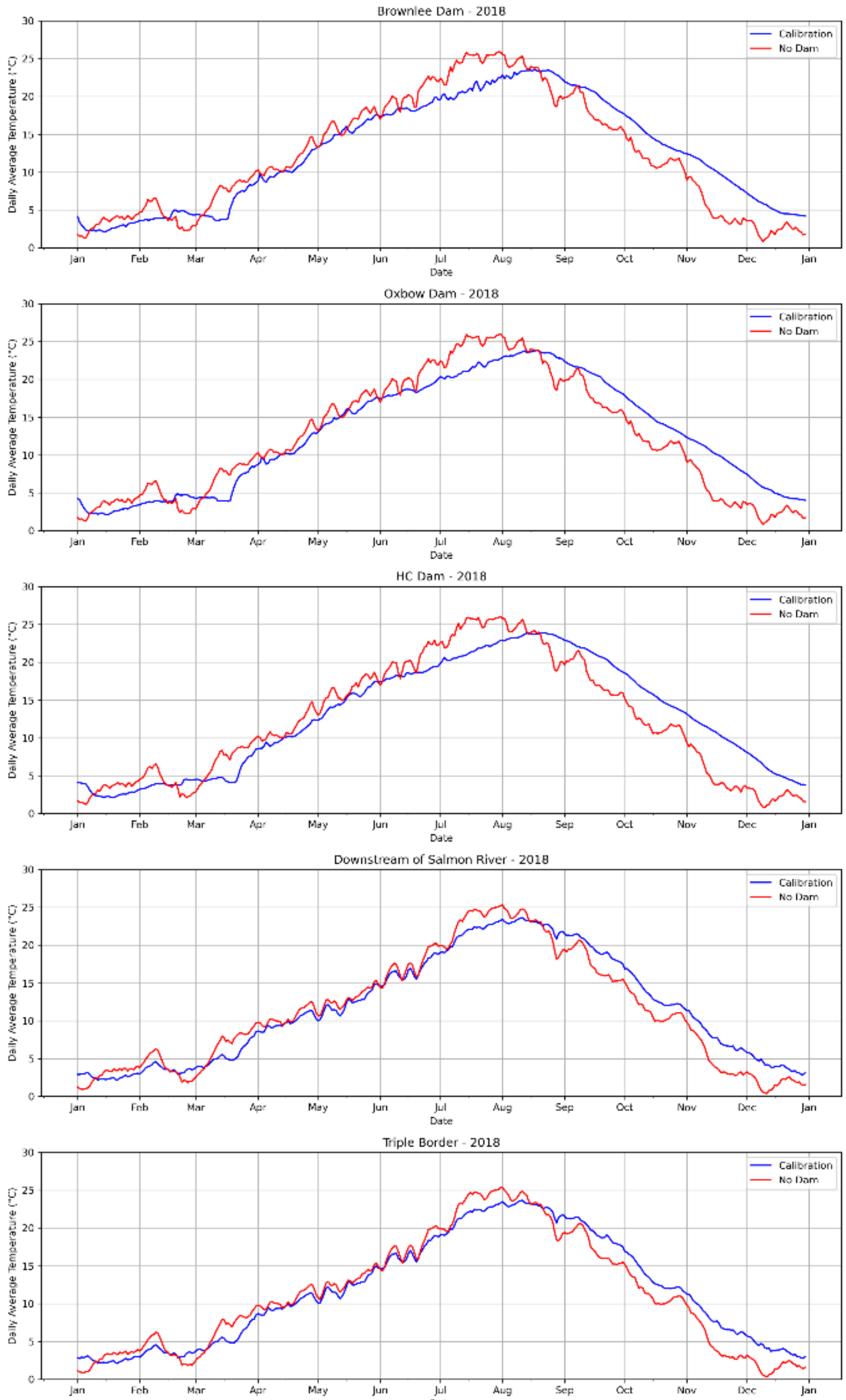


Figure 5-3. Modeled daily average temperature in 2018 for Snake River segment at Brownlee Dam, Oxbow Dam, Hells Canyon Dam, downstream of Salmon River, and triple border, comparing calibration and no dams scenarios.

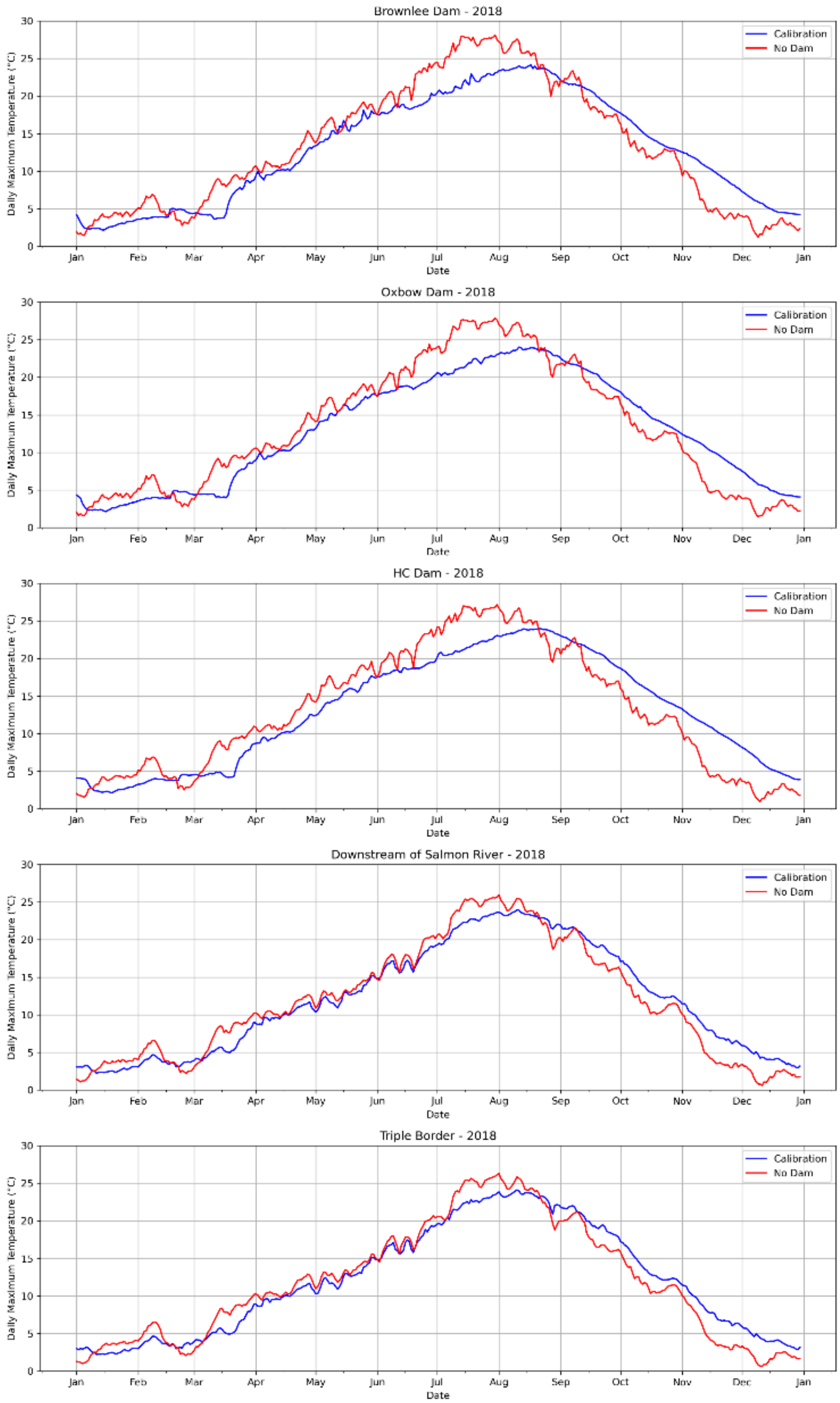


Figure 5-4. Modeled daily maximum temperature in 2018 for Snake River segment at Brownlee Dam, Oxbow Dam, Hells Canyon Dam, downstream of Salmon River, and triple border, comparing calibration and no dams scenarios.

Table 5-1. Mean daily average flow statistics by month and year for the calibration and no dams scenarios at Hells Canyon Dam.

Month	Mean Daily Average Flow (m^3 s^{-1})									
	2014		2015		2016		2017		2018	
	Calibration	No Dams	Calibration	No Dams	Calibration	No Dams	Calibration	No Dams	Calibration	No Dams
January	260.37	279.22	421.82	339.99	431.76	314.68	382.56	318.06	653.92	515.68
February	314.63	348.40	533.41	484.43	420.39	392.09	805.02	703.03	537.75	491.74
March	534.54	461.14	316.96	354.74	548.76	516.35	1707.29	1528.60	589.05	570.80
April	441.51	399.37	266.96	263.30	570.65	573.50	1883.68	1800.95	1081.88	941.71
May	344.93	456.16	248.14	363.28	479.79	589.66	1232.84	1473.10	685.43	859.73
June	395.25	409.28	262.41	290.27	390.73	409.99	1049.89	1114.94	587.98	607.89
July	362.07	291.51	289.89	251.59	300.92	244.58	500.68	399.82	382.25	296.18
August	266.27	259.80	245.93	229.26	242.09	226.90	340.75	305.63	353.86	313.49
September	252.11	250.94	264.89	260.10	280.49	284.98	404.13	320.90	355.97	292.29
October	246.36	311.70	250.19	286.77	289.54	318.47	296.78	361.16	261.15	333.12
November	245.27	304.40	239.24	302.96	232.04	311.51	244.91	393.13	237.20	314.33
December	352.97	352.58	304.96	337.27	273.16	308.01	458.91	433.07	323.41	307.89

Table 5-2. Mean 7DADM temperature by month and year for the calibration and no dams scenarios at Hells Canyon Dam.

Month	Mean 7DADM Temperature (°C)									
	2014		2015		2016		2017		2018	
	Calibration	No Dams	Calibration	No Dams	Calibration	No Dams	Calibration	No Dams	Calibration	No Dams
January	3.00	1.33	3.71	2.37	3.07	2.22	2.64	0.87	2.98	3.22
February	1.85	3.38	3.60	6.53	2.96	5.05	2.15	3.11	3.77	4.80
March	4.55	8.90	6.75	9.87	6.35	9.04	5.63	7.03	5.06	7.21
April	9.01	12.12	9.76	14.01	10.64	13.46	9.98	10.63	9.89	11.60
May	12.18	17.00	12.79	17.98	14.30	16.74	13.44	14.37	14.77	16.89
June	16.88	20.67	16.95	23.54	17.48	21.16	16.76	18.05	18.35	20.51
July	20.49	25.43	20.28	25.71	20.32	24.82	20.89	24.76	21.17	25.53
August	22.83	25.56	22.42	24.33	22.10	24.70	23.29	24.60	23.53	24.75
September	22.21	21.18	21.18	19.82	21.17	19.32	22.35	20.39	21.56	19.47
October	18.58	15.02	18.41	16.53	17.08	14.18	15.90	12.28	16.28	13.08
November	12.79	6.37	13.22	7.31	12.35	8.95	10.66	7.56	11.26	6.50
December	6.96	4.56	6.66	2.61	7.04	1.92	6.51	2.71	6.09	2.59

6.0 SUMMARY

This report evaluates the effects of various heat sources on Snake River water temperature from Adrian (RM 398) to the Washington State line (RM 176), including point source discharges, dam releases, restored vegetation, tributary warming, waste load allocations, and upstream temperature increases. Table 6-1 summarizes the maximum 95th percentile increase in Snake River 7DADM temperature above the BBNC criteria resulting from various heat sources across 10 comparison scenarios. The greatest increases in river temperature occurred under the no dam and background conditions, with temperature rises of 4.0°C and 4.64°C during the modeling period (2014-2018) and 6.36°C and 6.42°C during the spawning season of those years, respectively.

Tributary adjustment and waste load allocation led to temperature increases of 0.15°C and 0.06°C, respectively, during the modeling period. The attainment and reserved capacity scenarios showed slightly higher increases up to 0.19 °C due to the cumulative thermal contributions from TMDL allocations for both tributaries and point sources.

Table 6-1. Maximum 95th percentile increase in Snake River 7DADM temperature above applicable criteria resulting from the various heat sources.

Scenario #	Scenario	Baseline	Modeling Period		Spawning Season	
			Change (°C)	River Mile	Change (°C)	River Mile
1	No point sources	Calibration	0.08	245.33	0.06	244.67
2	No dams	Calibration	4.60	247.34	6.36	247.34
3	Restored vegetation	Calibration	0.15	224.0	0.04	210
4	Background	Calibration	4.64	247.34	6.42	247.34
5	Tributary	Background	0.15	364	0.12	190.5
6	TMDL waste load allocations	Background	0.06	247	0.11	246.33
7	Attainment	Background	0.15	246	0.17	241
8	Surrogate	Background	0	NA	0	NA
9	Reserve capacity 0.1 °C	Background	0.18	363.67	0.17	241
10	Reserve capacity 0.15 °C	Background	0.19	363.33	0.21	246.67

7.0 PLUNGE FLOW ANALYSIS

Within the impounded sections of the Snake River (HCC reservoirs) the water column exhibits thermal stratification. At the head of Brownlee Reservoir, the cooler inflow from the Snake River sinks beneath the warmer surface layers of the reservoir due to density differences. As it moves through subsurface layers, this denser, cooler water gradually warms by mixing and then either blends into the water column or travels onward as a subsurface current, a phenomenon known as plunge flow (Figure 7-1) (Akiyama and Stefan 1984).

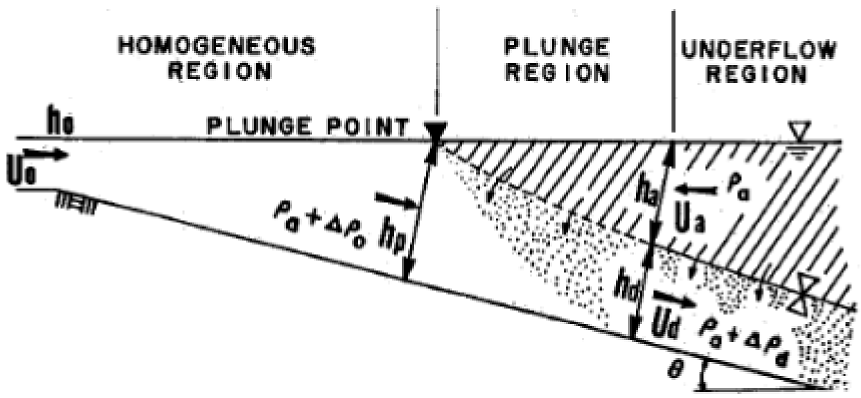


Figure 7-1. Conceptual illustration of plunge flow regions, including the homogeneous zone, plunge region, and underflow region (from Akiyama and Stefan 1984).

When comparing the 95th percentile change in 7DADM temperatures between the point sources (PS) and no PS scenarios, the maximum estimated impact of point source discharges on the Snake River 7DADM temperature was 0.36°C at RM 317 within Brownlee Reservoir. This change is significantly greater than the 0.02°C difference observed at the head of Brownlee Reservoir, upstream of RM 330. This discrepancy was unexpected, given that no point source discharges are included in the model downstream of the Weiser River or within the Brownlee Reservoir itself. Additionally, tributary water temperatures remain unchanged between the two scenarios, and both simulations were conducted using the same maximum computational time steps, with no evidence of significant numerical instability.

Variations in the inflow's rate or temperature can shift the location of the plunge point and influence the reservoir's overall thermal structure. While the changes applied in this scenario may have a minimal effect on the reservoir's average temperature, direct one-to-one comparisons of hourly segment temperatures, as used in BBNC calculations, were found to exaggerate these localized thermal variations due to the location of the plunge point. For example, Figure 7-2 shows hourly temperature outputs for the PS and no PS scenarios at RM 320 (segment 90), RM 317 (segment 100), and RM 314 (segment 110), respectively, in Brownlee model over the period from September 1 to September 10, 2018. This period corresponds to the time window during which the maximum 7DADM temperature difference was observed in Brownlee Reservoir. At RM 320, water temperature appears to be influenced by flow turbulence and thermal mixing, disrupting the typical diurnal pattern where daily peaks occur around midday. In contrast, RM 317 and RM 314 exhibit a more consistent diurnal cycle. The variability at RM 320 leads to both positive and negative temperature differences between the PS and no PS scenarios within the same day. By RM 317, the water column becomes more thermally stable. However, a likely shift in flow direction, either in the PS or No PS scenario, on September 5 results in higher temperatures in the no PS scenario compared to the PS scenario during the period from September 6 to 10. At RM 314, the hourly temperature pattern further stabilizes, and the differences between the PS and no PS scenarios reduces and becomes more reasonable.

According to a personal communication with W2 model developer Scott Wells on December 14, 2023, these observations suggest that the large temperature difference between the PS and no PS scenarios on September 5, 2018, is primarily due to transitional flow conditions within the reservoir. Positive temperature differences between the PS and no PS scenarios appear initially within the plunge region (e.g., segment 90), followed either by same-day negative changes or by delayed changes in downstream segments (Figure 7-2). This delay is likely related to the magnitude of flow turbulence. The turbulence near the plunge point appears to cause a temporary misalignment in the thermal structure of the reservoir at the plunge flow region rather than reflecting a true gain in heat content. These simulated effects may be exaggerated in the model compared to actual conditions.

To minimize the impact of such model artifacts, two approaches were investigated. First, reservoir segments were spatially aggregated into a single segment during post-processing to eliminate the influence of plunge flow on the 7DADM temperature calculation. Second, the attainment scenarios were developed using a background condition in which the reservoirs were removed from the W2 models, and the Snake River was represented as a continuous, free-flowing river (i.e., without dams). Following consultation with EPA and DEQ, the attainment scenarios were developed based on this background condition in order to maintain spatial resolution within the HCC reservoir locations and to support more realistic, artifact-free temperature assessments.

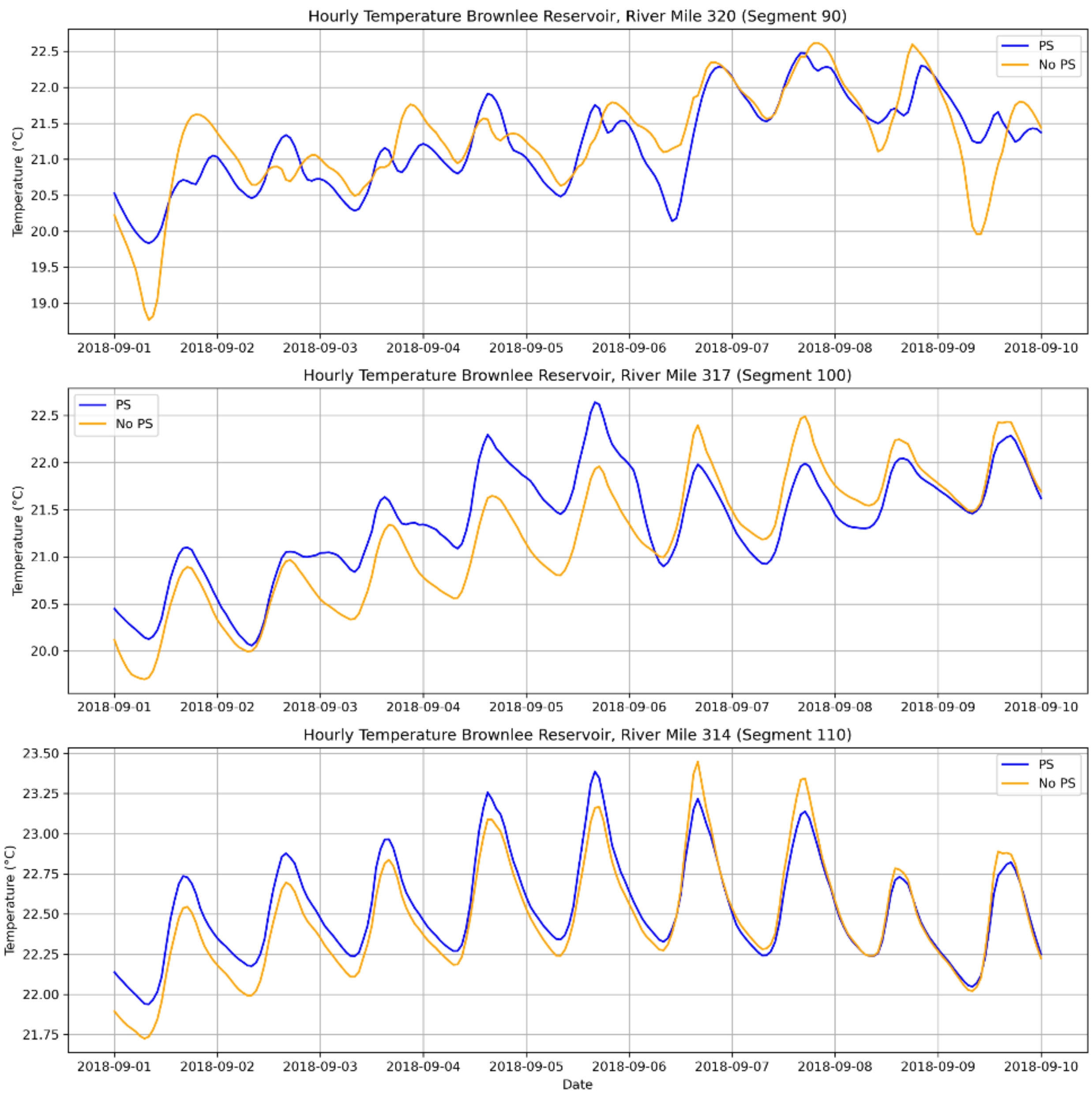


Figure 7-2. Simulated hourly water temperature for point sources and no point sources scenarios at RMs 320, 317, and 314 in Brownlee Reservoir.

8.0 SUPPLEMENTARY TABLES AND PLOTS

8.1 SUPPORTING MATERIALS FOR SECTION 4.0 (SCENARIO COMPARISON)

This section includes supplementary graphical information on the 7DADM temperature, the 95th percentile change in daily maximum, average, and minimum temperatures, as well as the 95th percentile change in 7DADM temperature during the critical summer (non-spawning season).

8.1.1 No Point Sources vs. Calibration

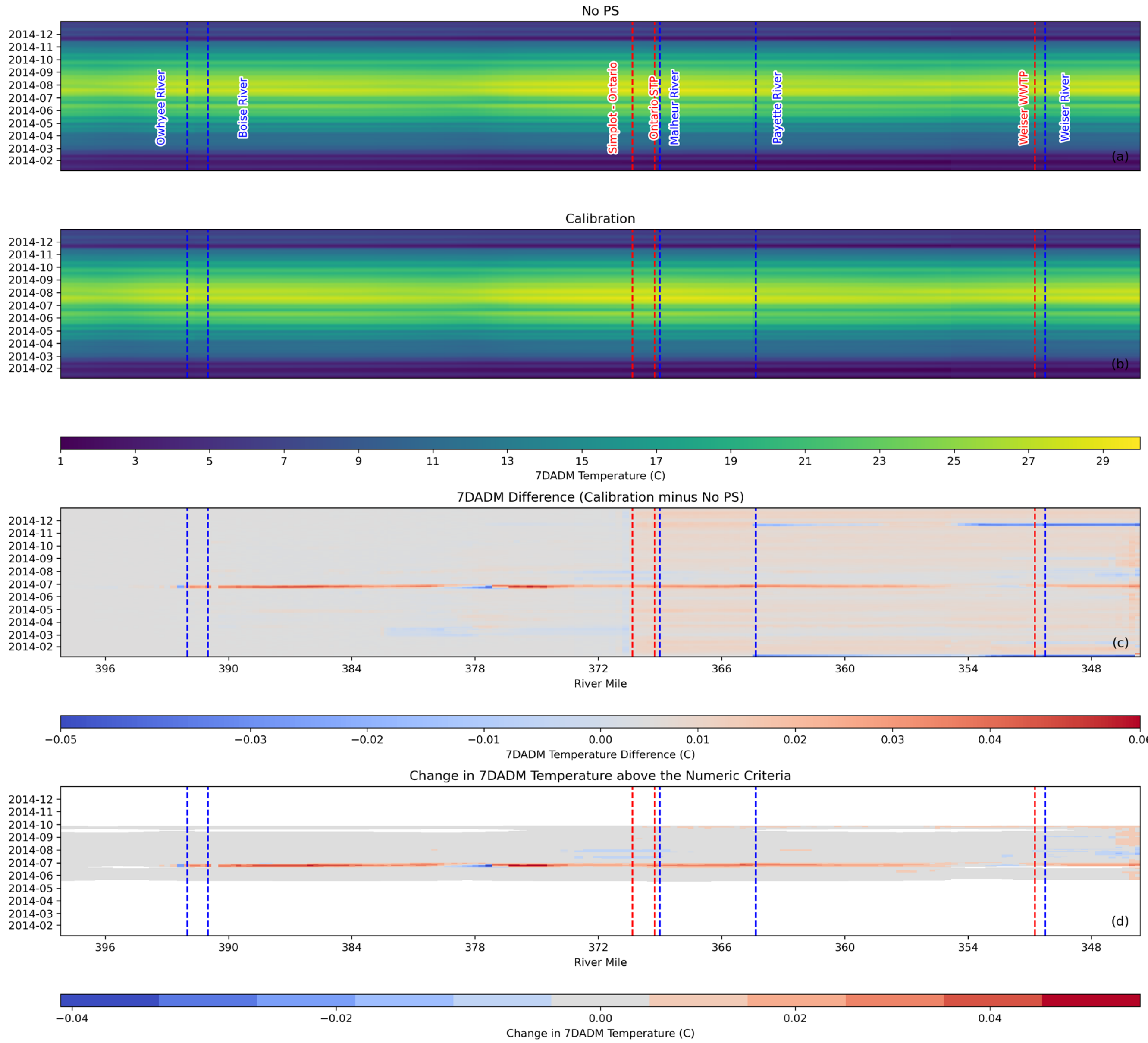


Figure 8-1. (a, b) 7DADM temperature for no PS and calibration scenarios, (c) temperature difference (calibration-no PS), and (d) change in 7DADM temperature above the numeric criteria where temperature from either scenario meets or exceeds the criterion, from Adrian to head of Brownlee Reservoir, 2014.

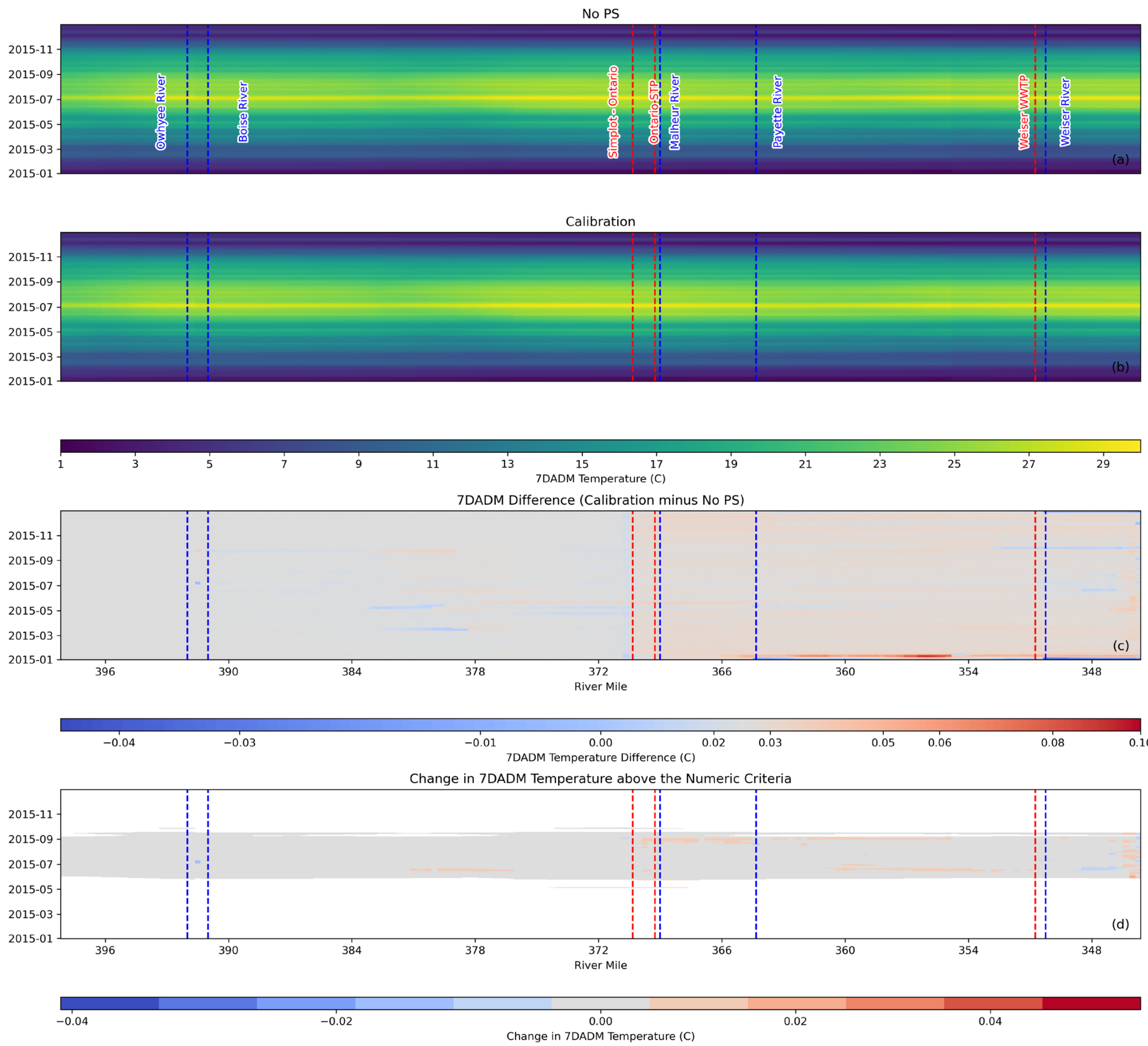


Figure 8-2 (a, b) 7DADM temperature for no PS and calibration scenarios, (c) temperature difference (calibration-no PS), and (d) change in 7DADM temperature above the numeric criteria where temperature from either scenario meets or exceeds the criterion, from Adrian to head of Brownlee Reservoir, 2015.

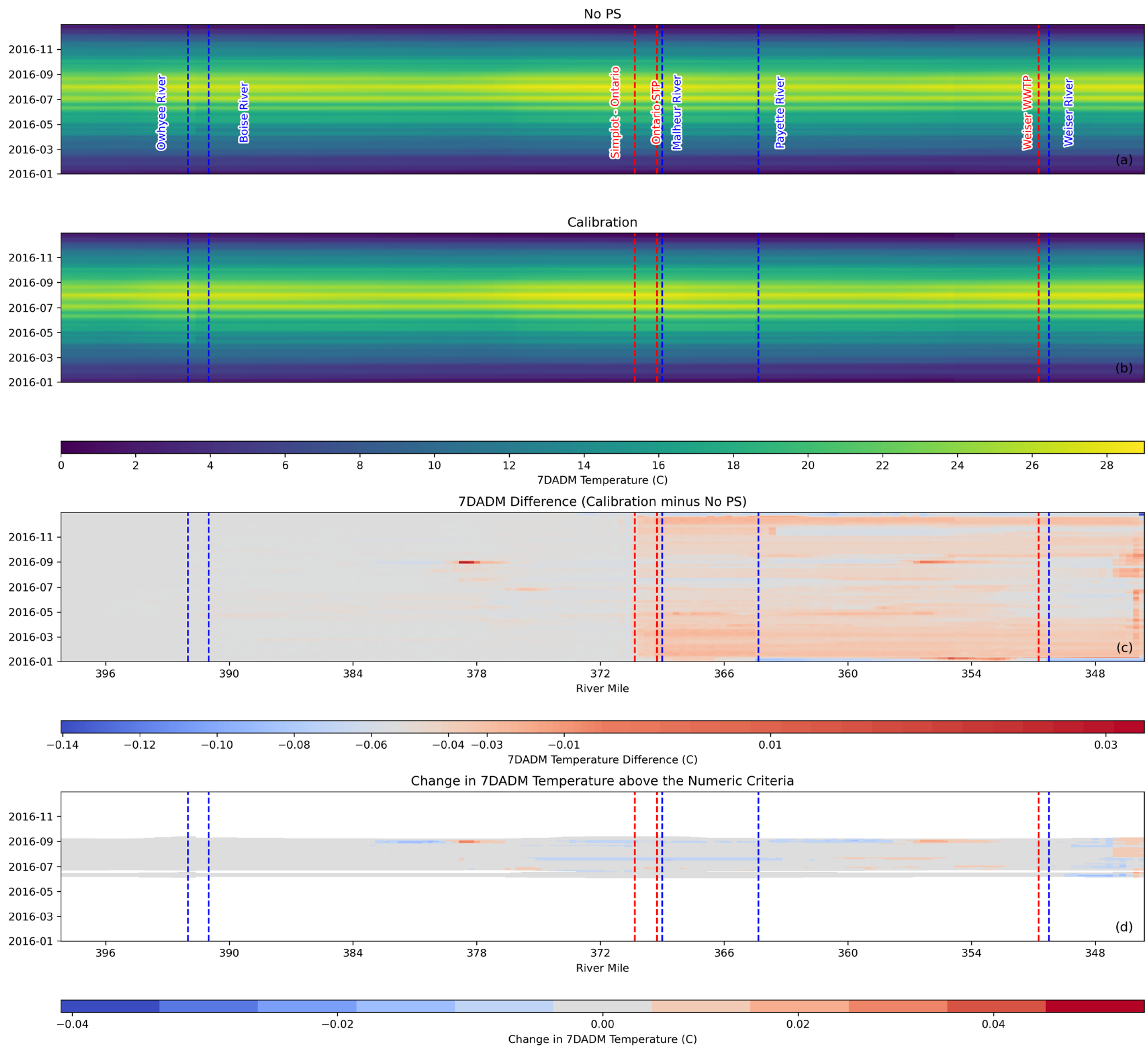


Figure 8-3. (a, b) 7DADM temperature for no PS and calibration scenarios, (c) temperature difference (calibration-no PS), and (d) change in 7DADM temperature above the numeric criteria where temperature from either scenario meets or exceeds the criterion, from Adrian to head of Brownlee Reservoir, 2016.

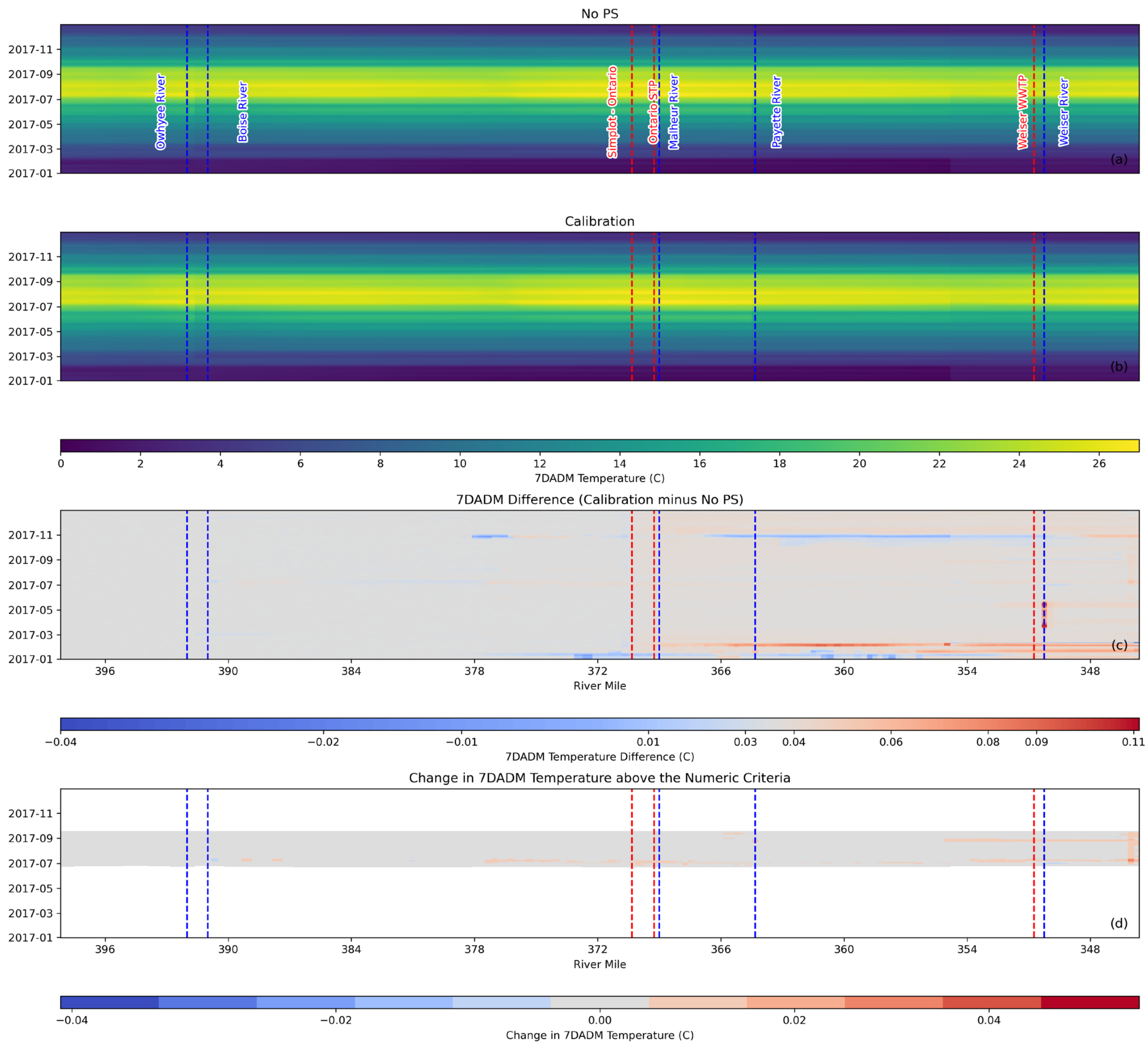


Figure 8-4. (a, b) 7DADM temperature for no PS and calibration scenarios, (c) temperature difference (calibration-no PS), and (d) change in 7DADM temperature above the numeric criteria where temperature from either scenario meets or exceeds the criterion, from Adrian to head of Brownlee Reservoir, 2017.

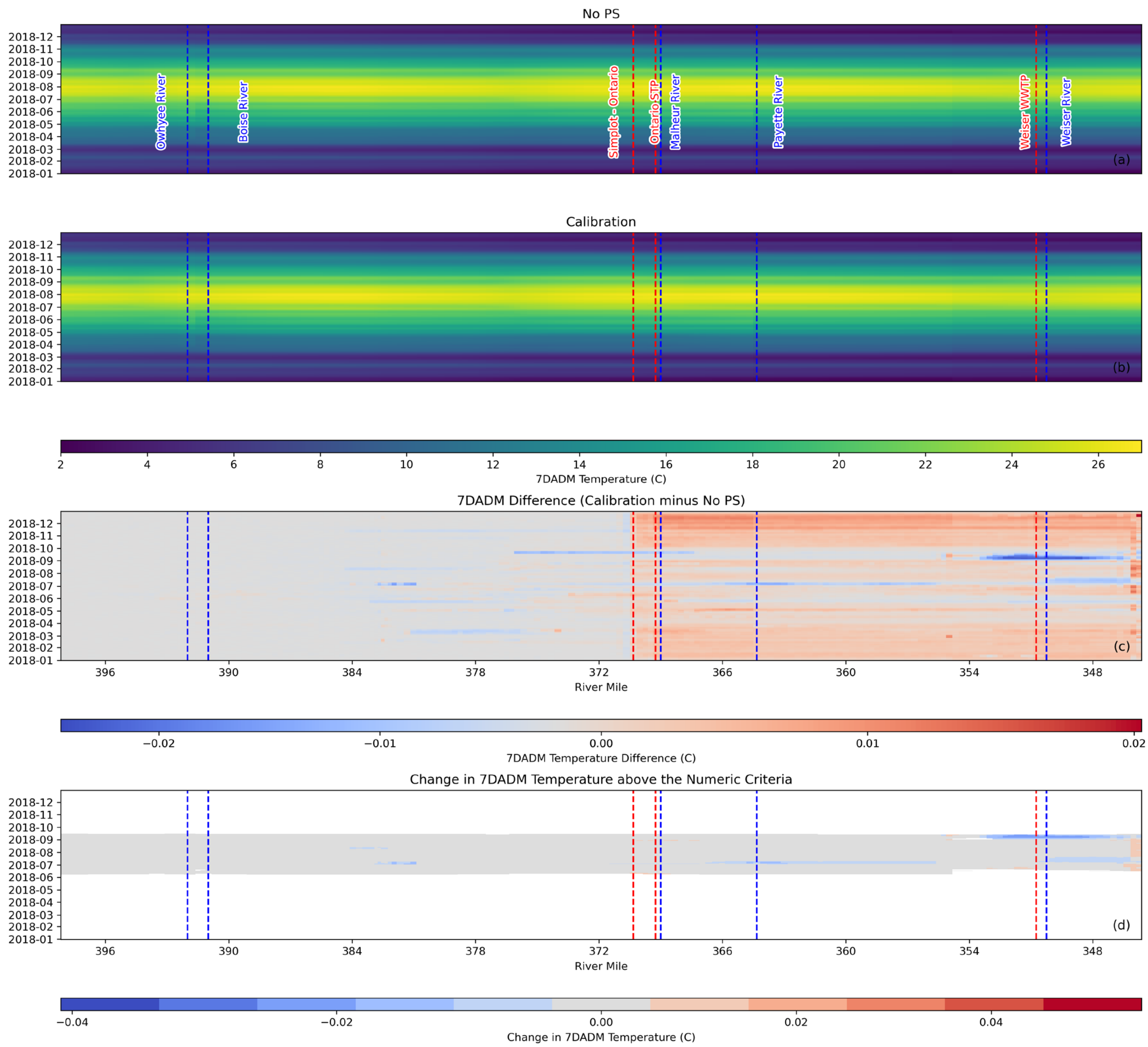


Figure 8-5. (a, b) 7DADM temperature for no PS and calibration scenarios, (c) temperature difference (calibration-no PS), and (d) change in 7DADM temperature above the numeric criteria where temperature from either scenario meets or exceeds the criterion, from Adrian to head of Brownlee Reservoir, 2018.

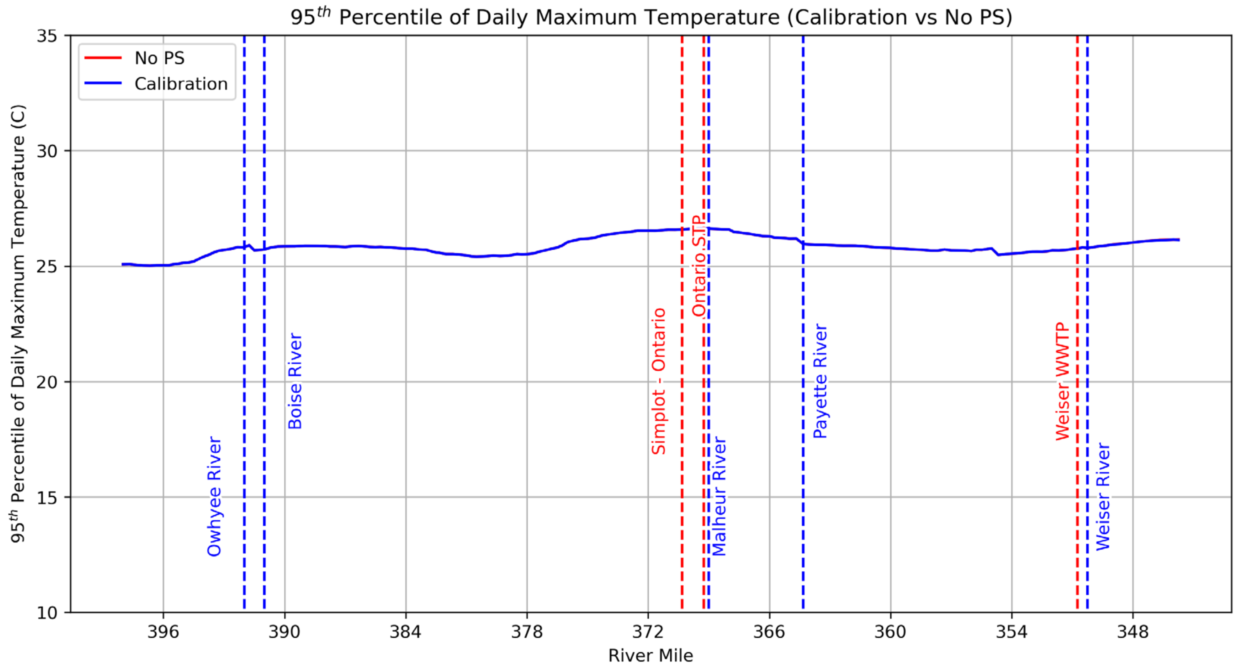


Figure 8-6. 95th percentile of daily maximum temperature for calibration and no PS scenarios, from Adrian to head of Brownlee Reservoir, 2014-2018.

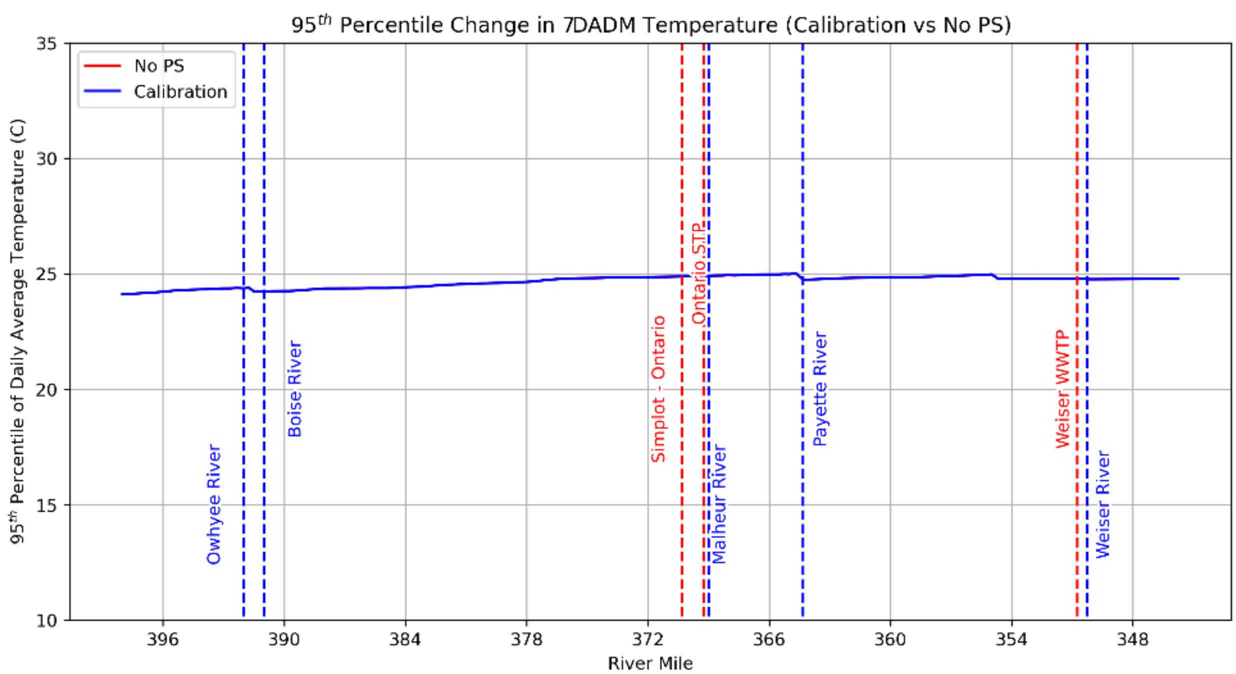


Figure 8-7. 95th percentile of daily average temperature for calibration and no PS scenarios, from Adrian to head of Brownlee Reservoir, 2014-2018.

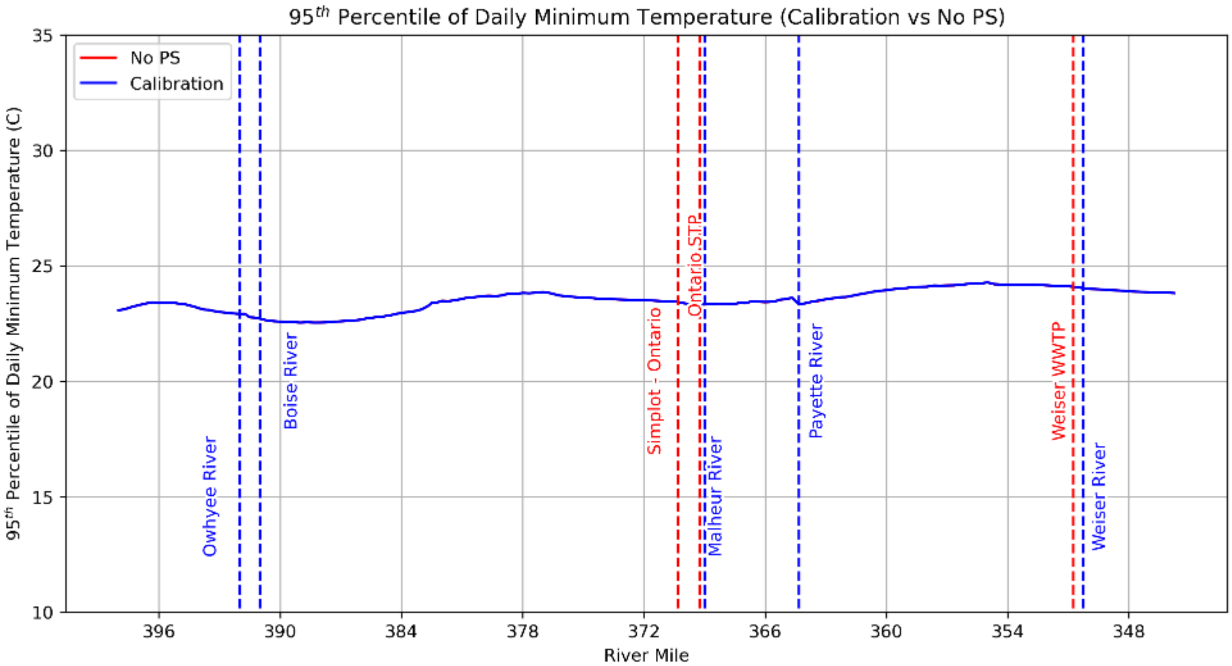


Figure 8-8. 95th percentile of daily minimum temperature for calibration and no PS scenarios, from Adrian to head of Brownlee Reservoir, 2014-2018.

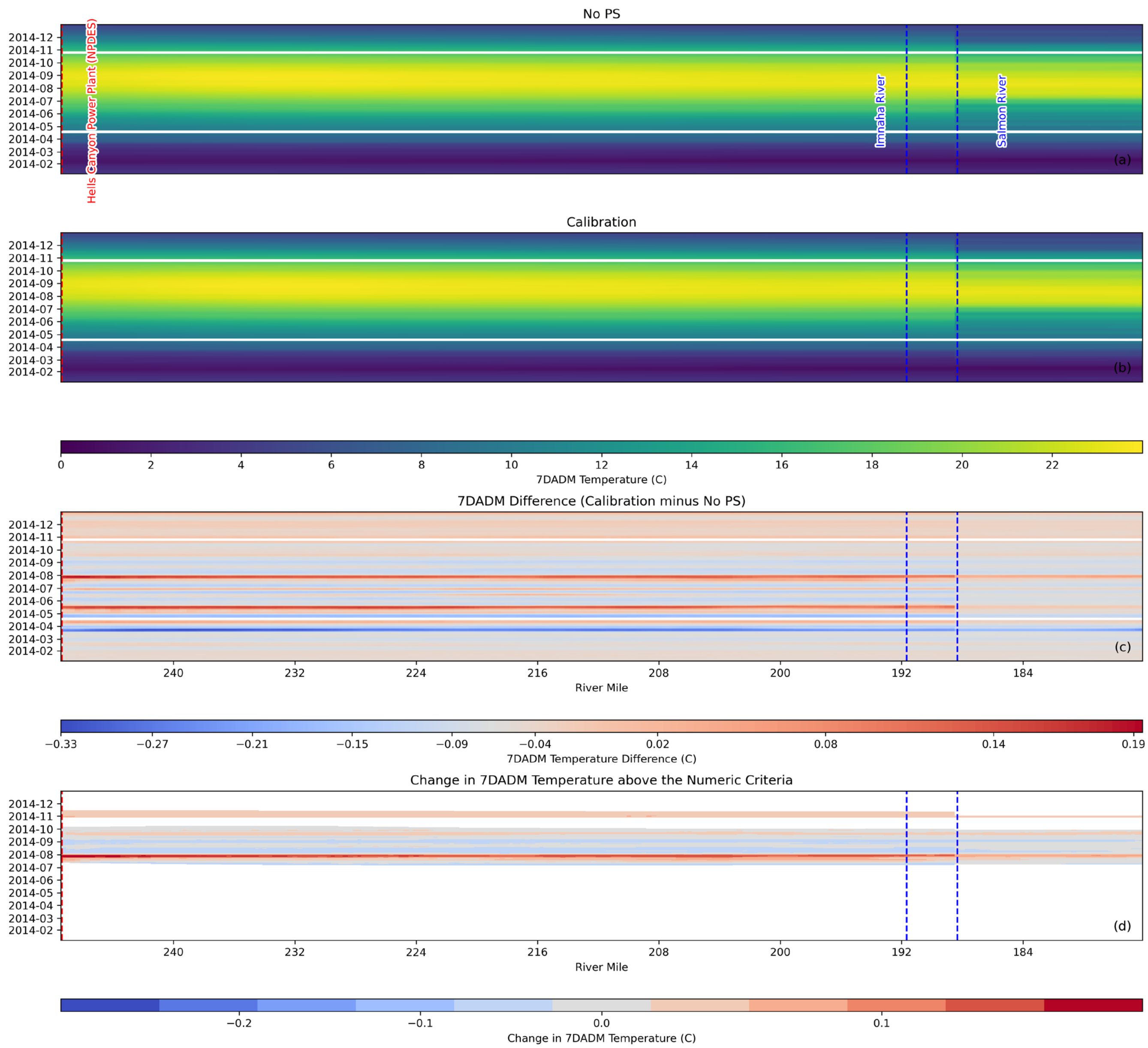


Figure 8-9. (a, b) 7DADM temperature for no PS and calibration scenarios, (c) temperature difference (calibration-no PS), and (d) change in 7DADM temperature above the numeric criteria where temperature from either scenario meets or exceeds the criterion, from HC Dam to Washington state line, 2014.

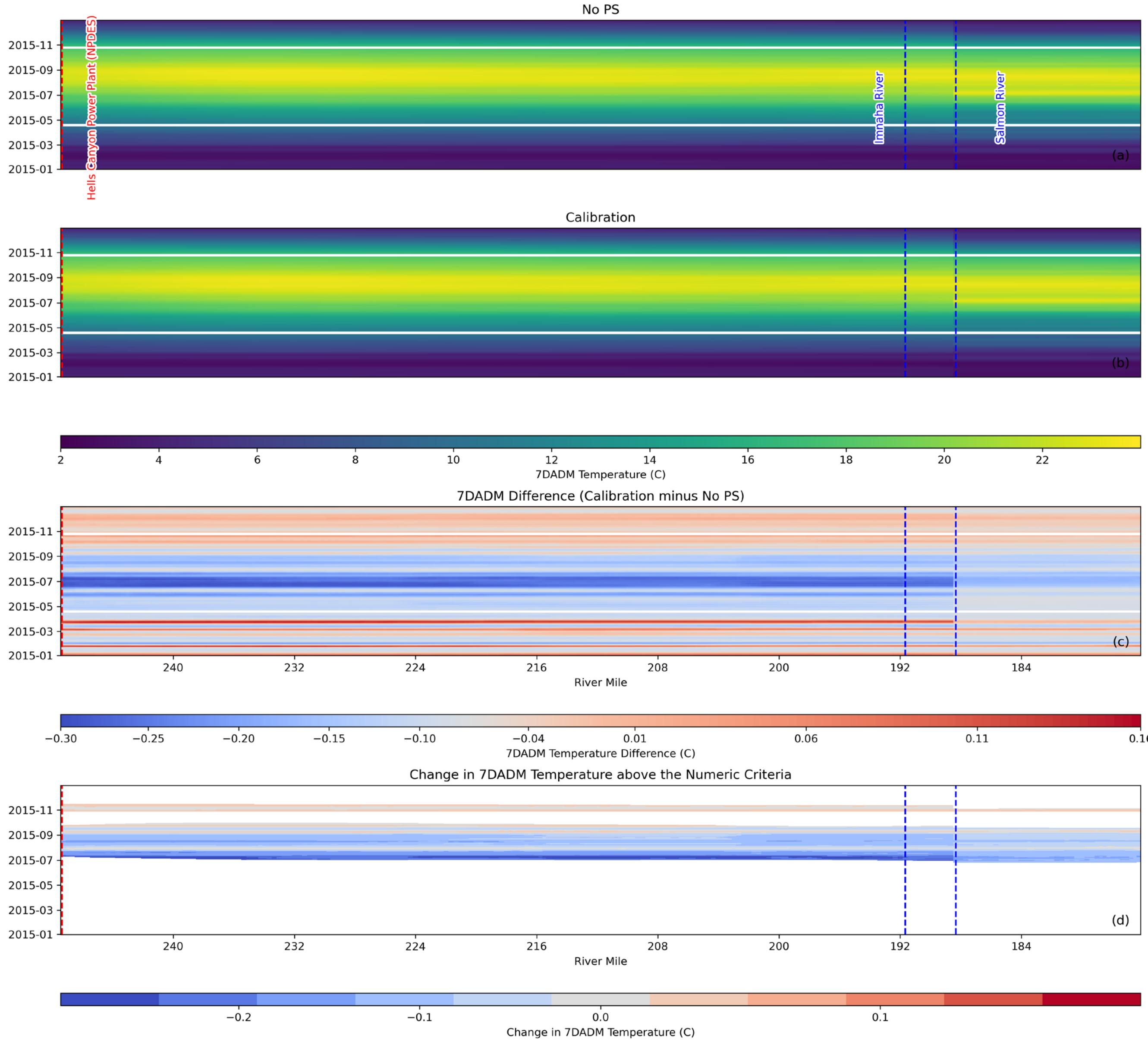


Figure 8-10. (a, b) 7DADM temperature for no PS and calibration scenarios, (c) temperature difference (calibration-no PS), and (d) change in 7DADM temperature above the numeric criteria where temperature from either scenario meets or exceeds the criterion, from HC Dam to Washington state line, 2015.

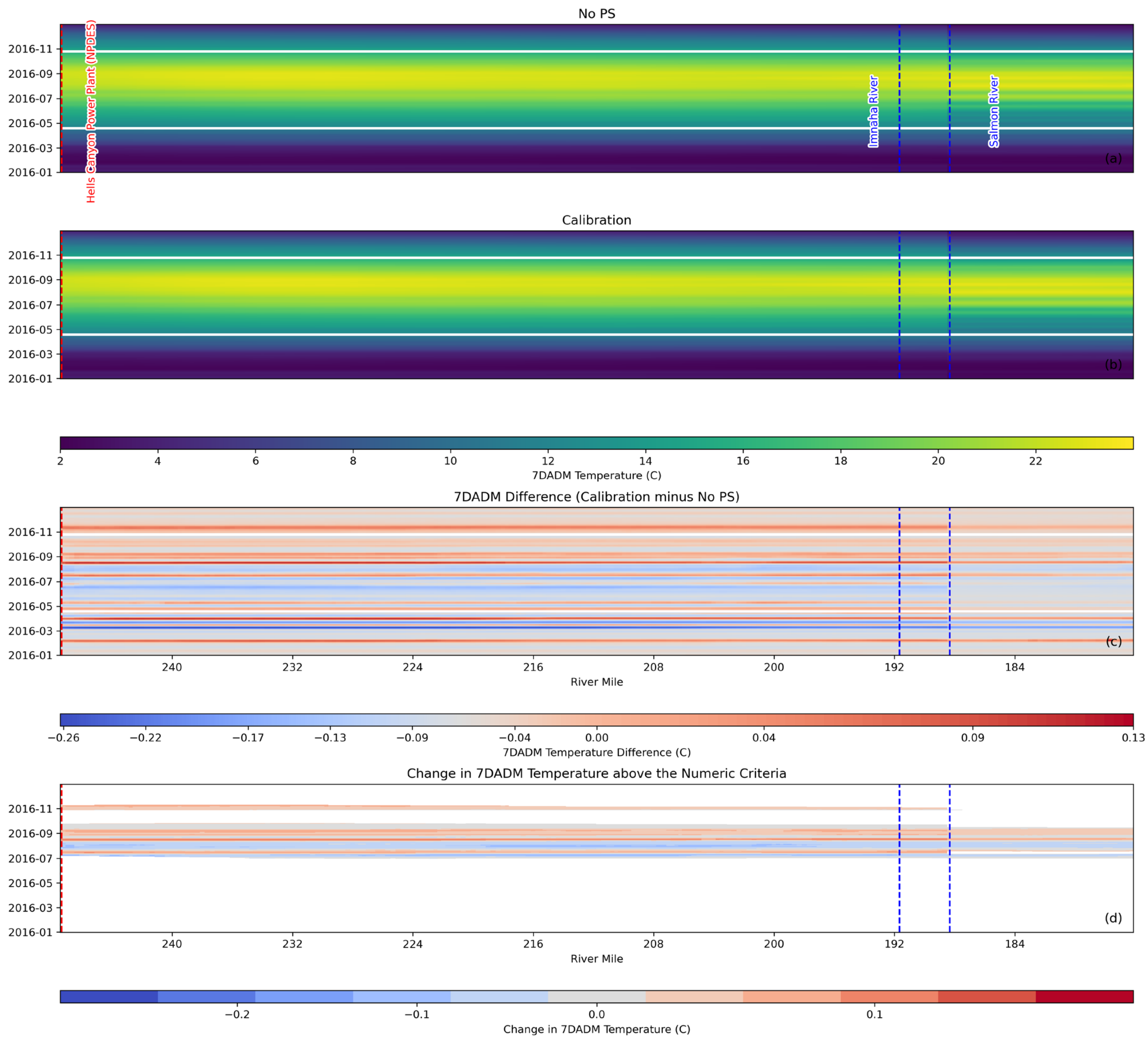


Figure 8-11. (a, b) 7DADM temperature for no PS and calibration scenarios, (c) temperature difference (calibration-no PS), and (d) change in 7DADM temperature above the numeric criteria where temperature from either scenario meets or exceeds the criterion, from HC Dam to Washington state line, 2016.

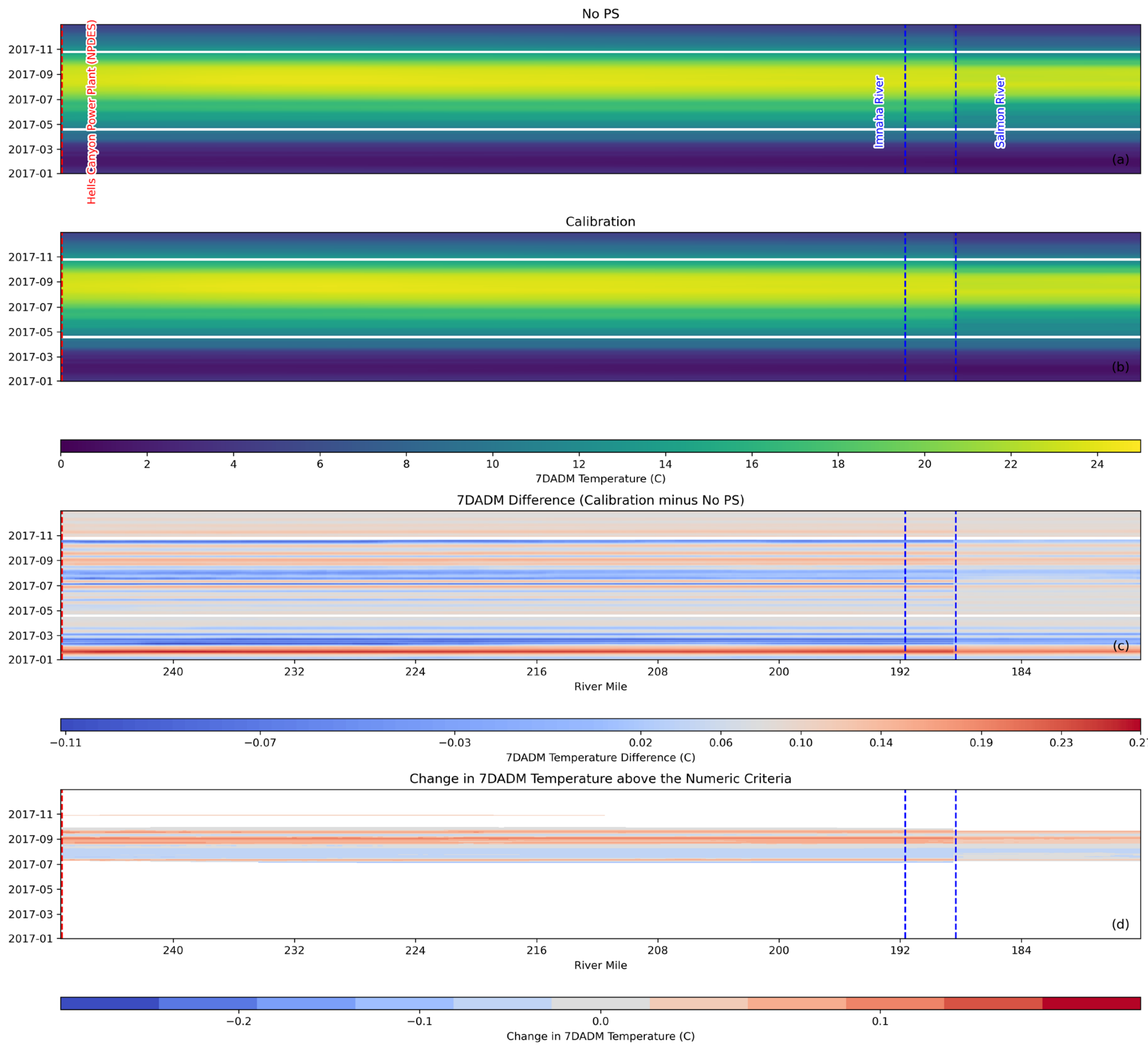


Figure 8-12. (a, b) 7DADM temperature for no PS and calibration scenarios, (c) temperature difference (calibration-no PS), and (d) change in 7DADM temperature above the numeric criteria where temperature from either scenario meets or exceeds the criterion, from HC Dam to Washington state line, 2017.

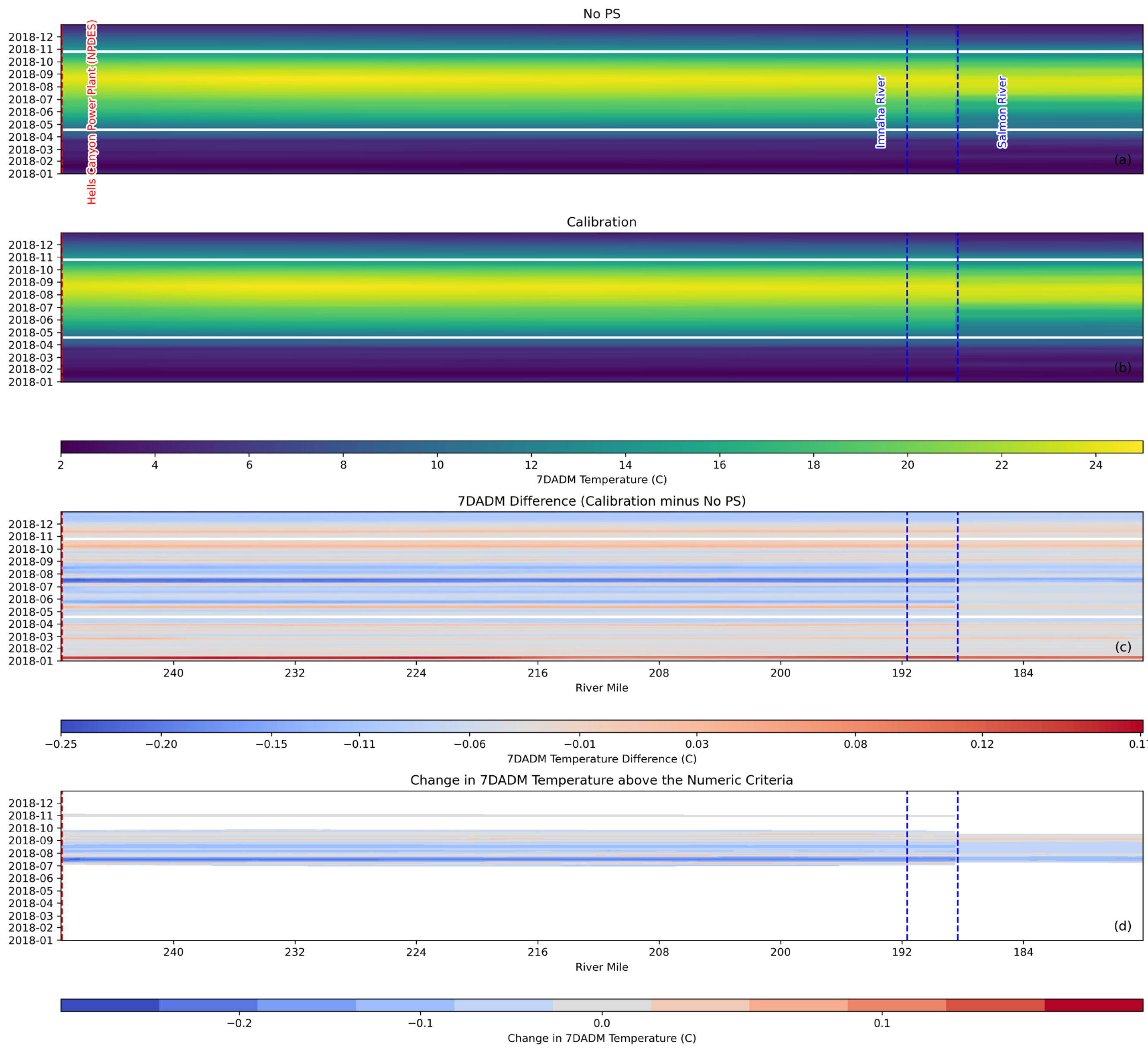


Figure 8-13. (a, b) 7DADM temperature for no PS and calibration scenarios, (c) temperature difference (calibration-no PS), and (d) change in 7DADM temperature above the numeric criteria where temperature from either scenario meets or exceeds the criterion, from HC Dam to Washington state line, 2018.

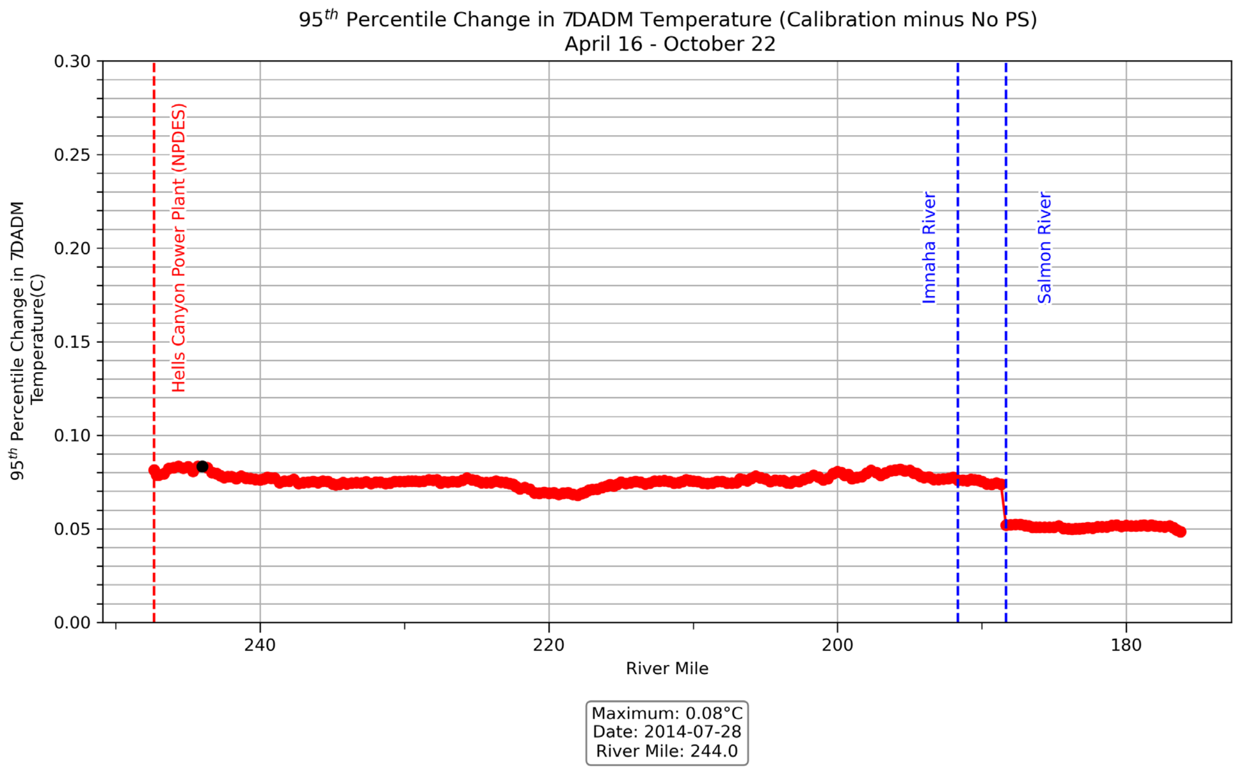


Figure 8-14. 95th percentile change in 7DADM temperature above applicable criteria during critical summer period.

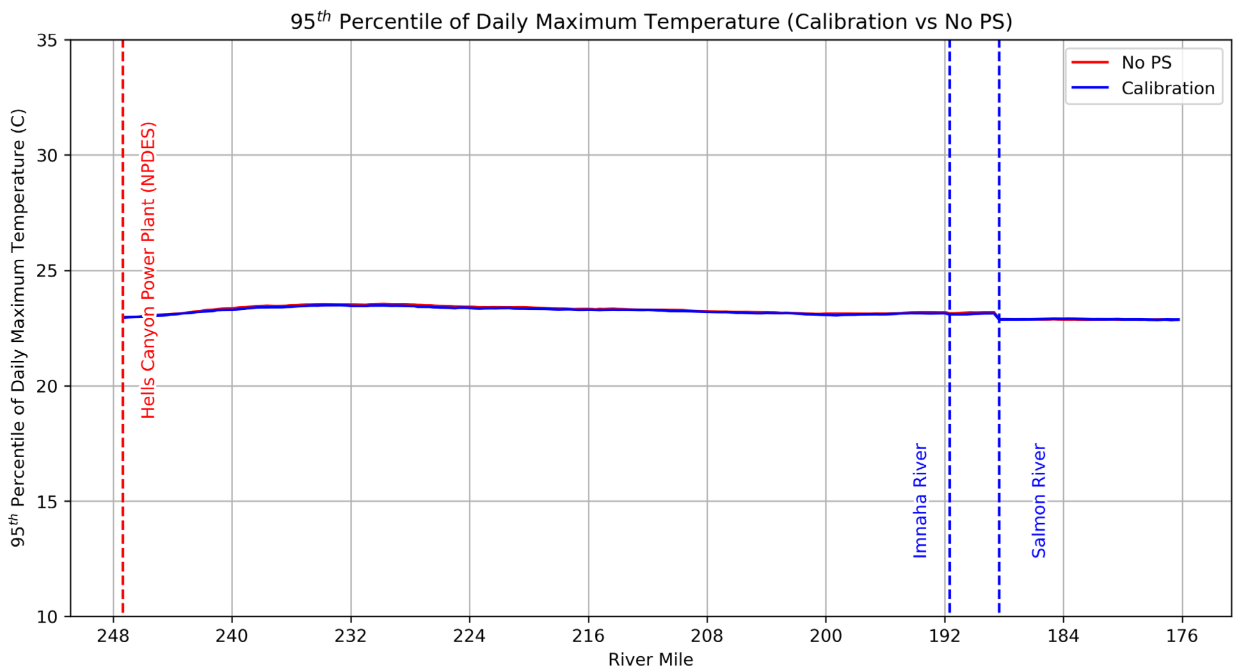


Figure 8-15. 95th percentile of daily maximum temperature for calibration and no PS scenarios, from HC Dam to Washington state line, 2014-2018.

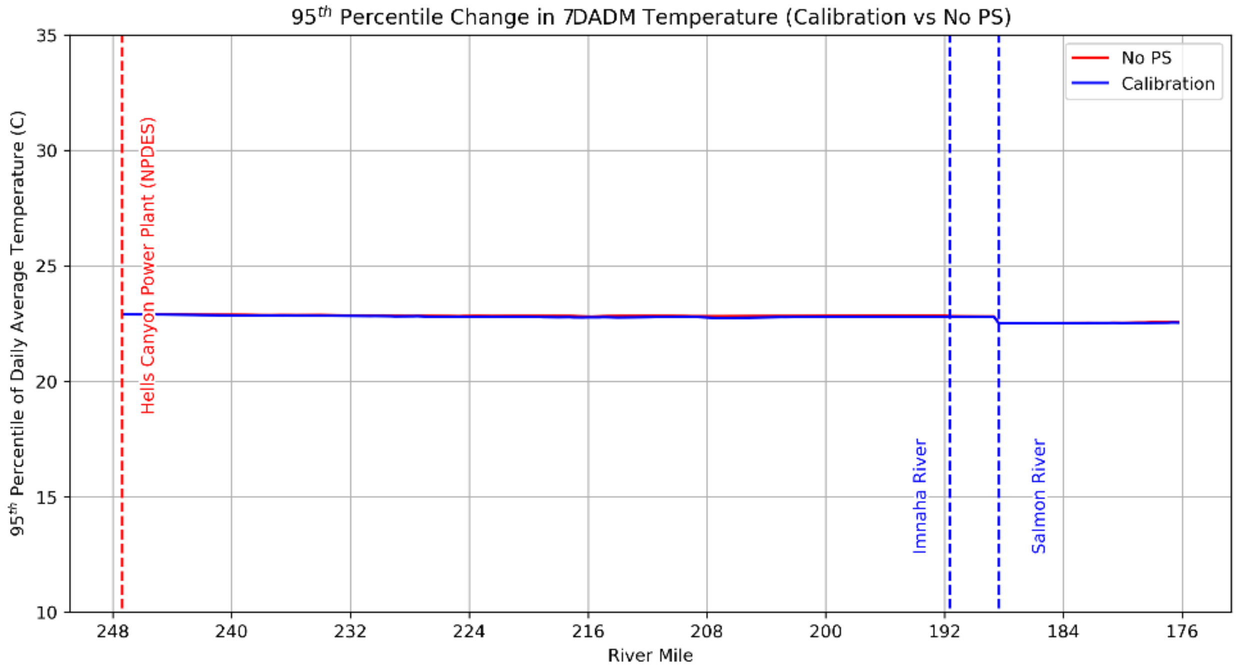


Figure 8-16. 95th percentile of daily average temperature for calibration and no PS scenarios, from HC Dam to Washington state line, 2014-2018.

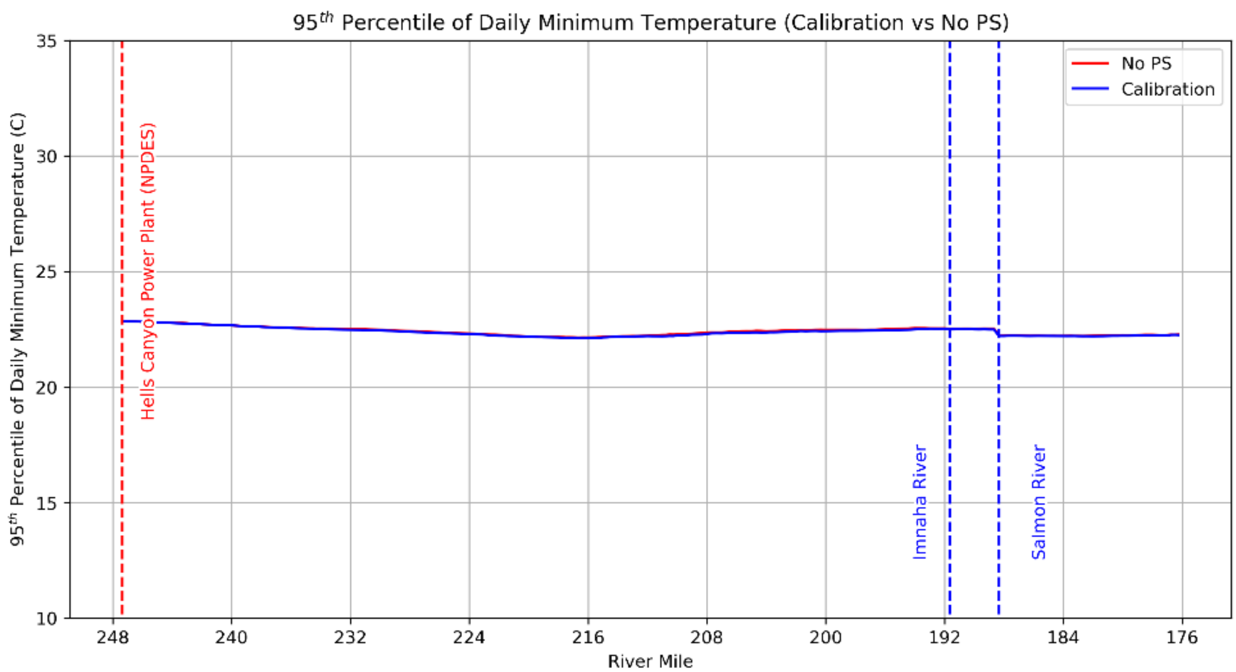


Figure 8-17. 95th percentile of daily minimum temperature for calibration and no PS scenarios, from HC Dam to Washington state line, 2014-2018.

8.1.2 No Dams vs. Calibration

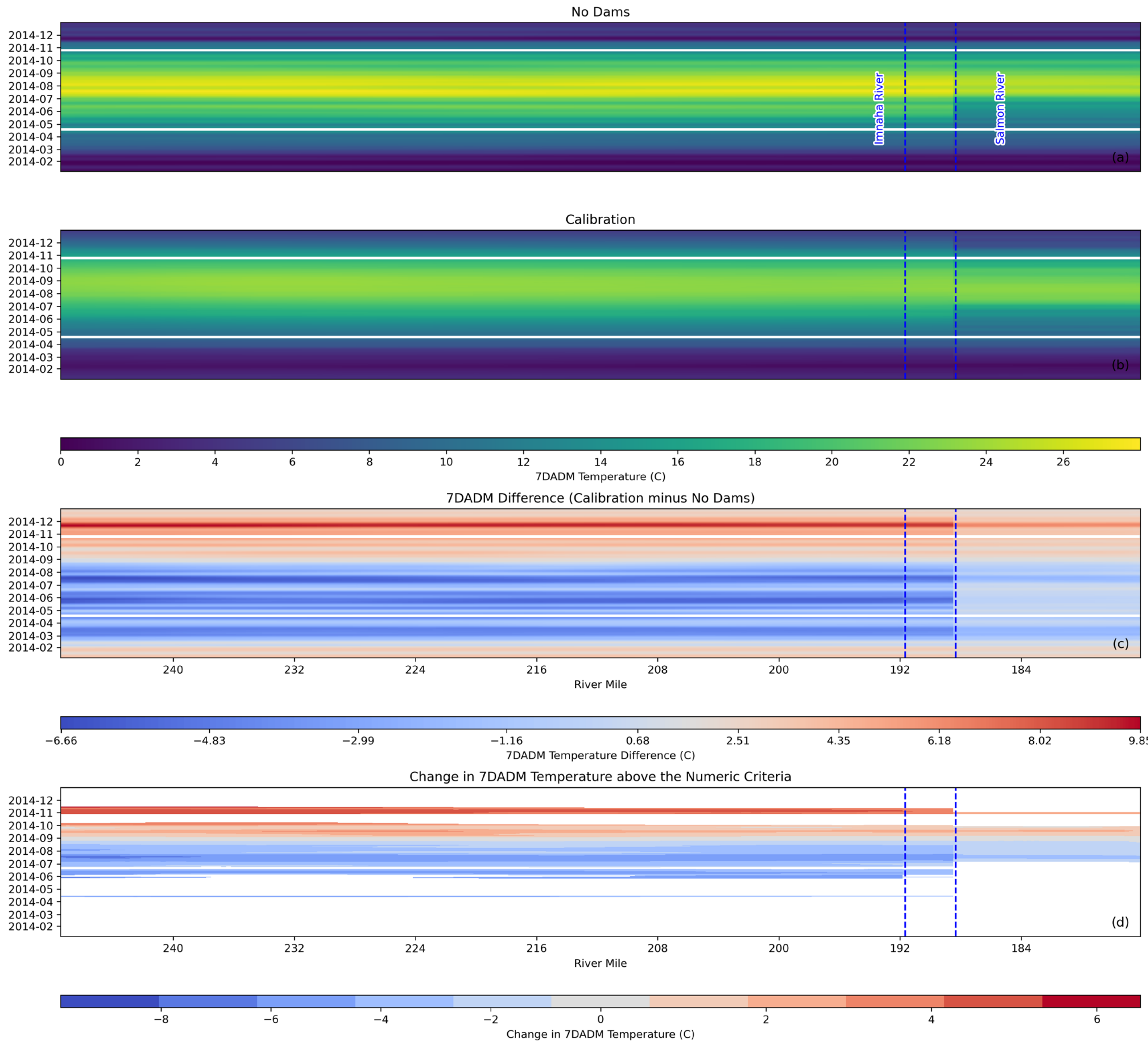


Figure 8-18. (a, b) 7DADM temperature for no dams and calibration scenarios, (c) temperature difference (calibration-no dams), and (d) change in 7DADM temperature above the numeric criteria where temperature from either scenario meets or exceeds the criterion, from HC Dam to Washington state line, 2014.

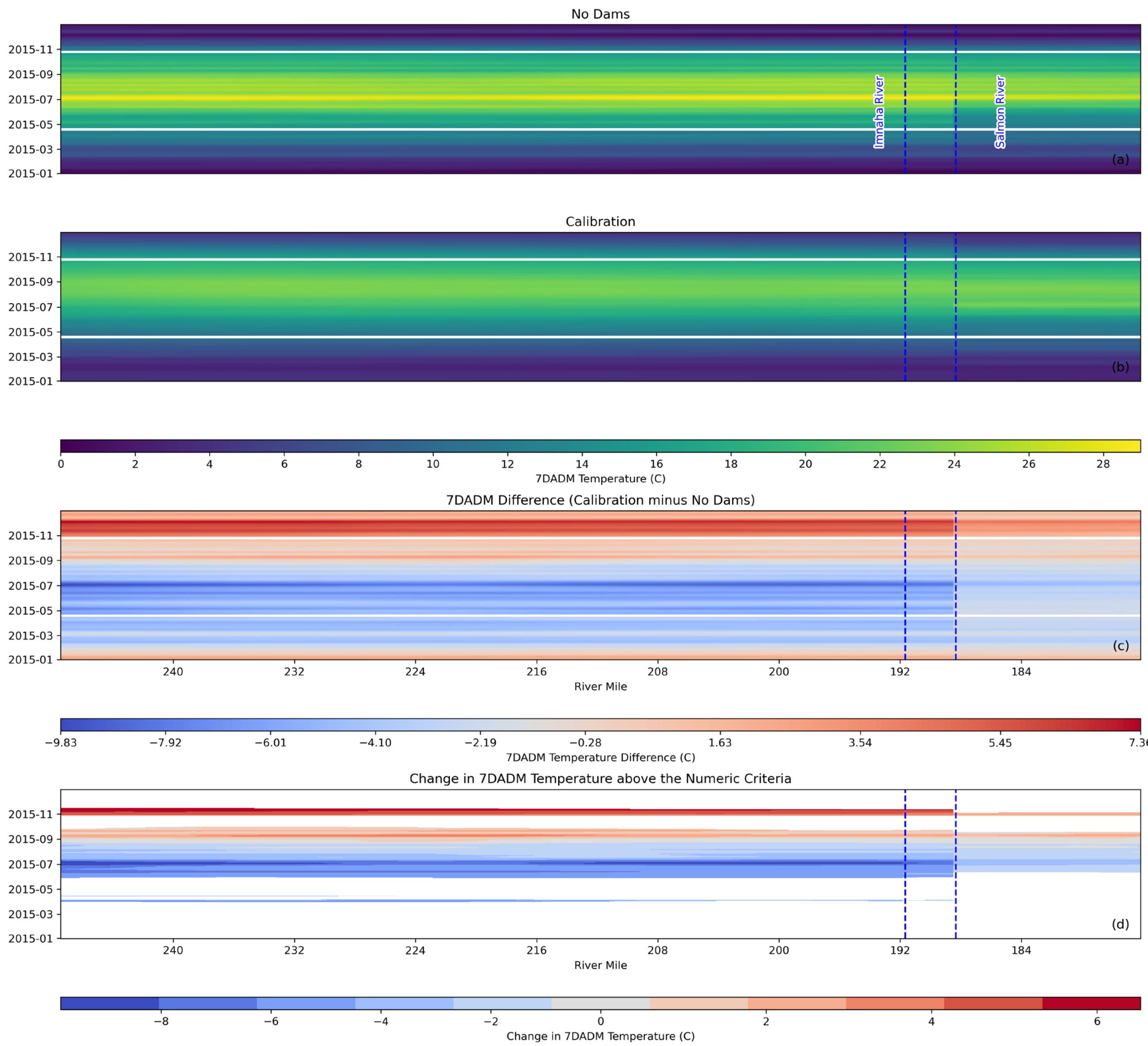


Figure 8-19. (a, b) 7DADM temperature for no dams and calibration scenarios, (c) temperature difference (calibration-no dams), and (d) change in 7DADM temperature above the numeric criteria where temperature from either scenario meets or exceeds the criterion, from HC Dam to Washington state line, 2015.

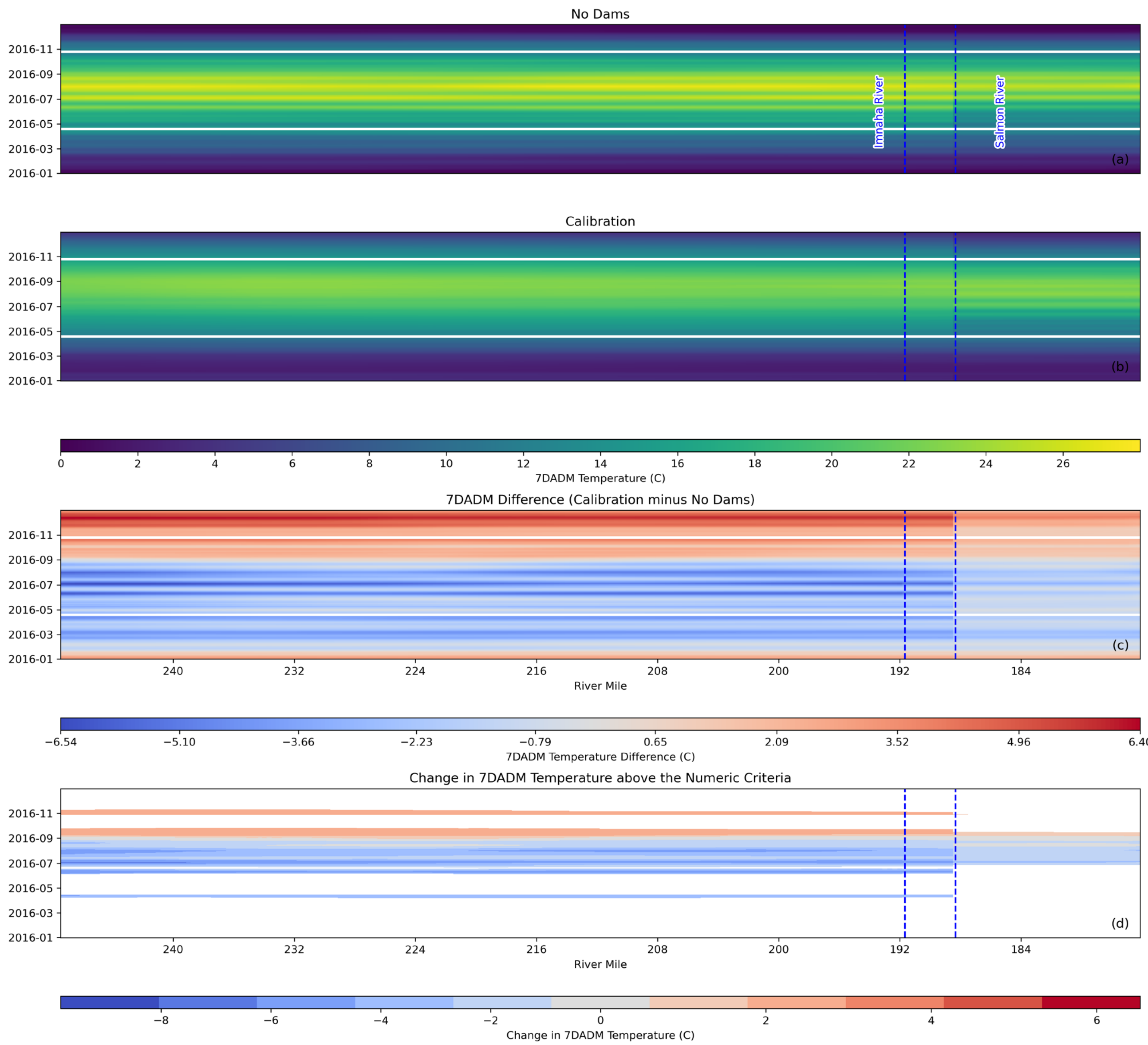


Figure 8-20. (a, b) 7DADM temperature for no dams and calibration scenarios, (c) temperature difference (calibration-no dams), and (d) change in 7DADM temperature above the numeric criteria where temperature from either scenario meets or exceeds the criterion, from HC Dam to Washington state line, 2016.

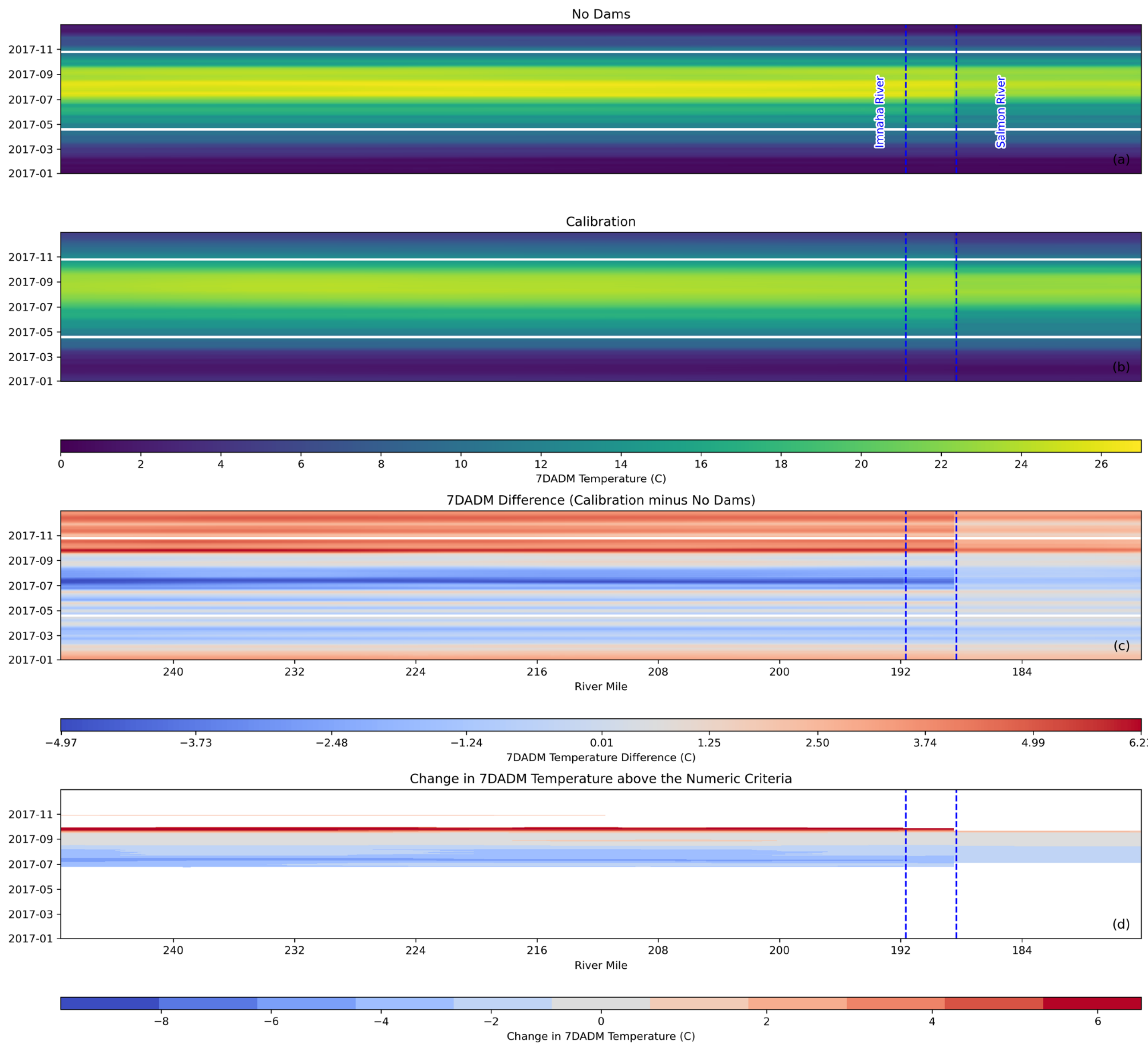


Figure 8-21. (a, b) 7DADM temperature for no dams and calibration scenarios, (c) temperature difference (calibration-no dams), and (d) change in 7DADM temperature above the numeric criteria where temperature from either scenario meets or exceeds the criterion, from HC Dam to Washington state line, 2017.

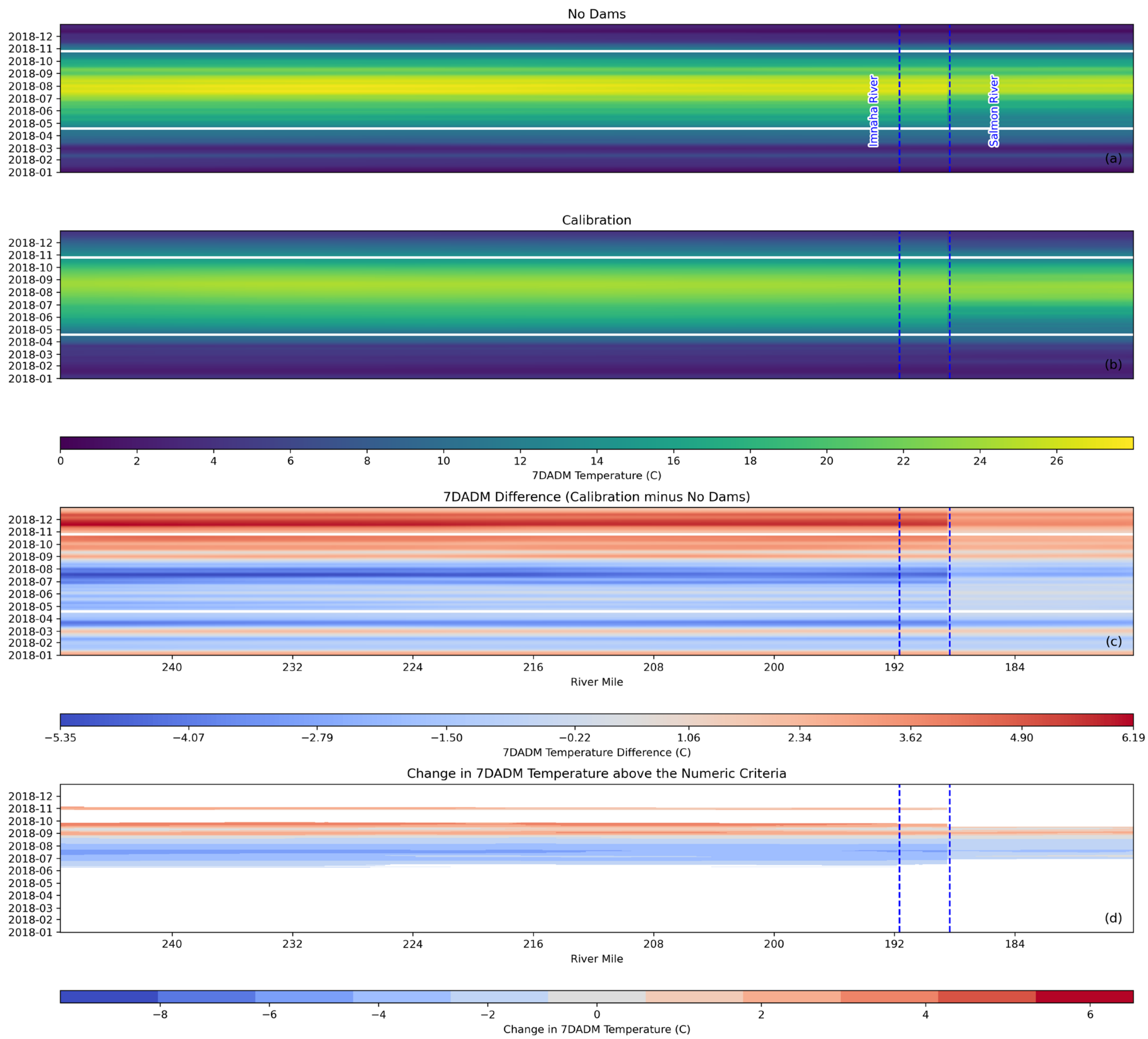


Figure 8-22. (a, b) 7DADM temperature for no dams and calibration scenarios, (c) temperature difference (calibration-no dams), and (d) change in 7DADM temperature above the numeric criteria where temperature from either scenario meets or exceeds the criterion, from HC Dam to Washington state line, 2018.

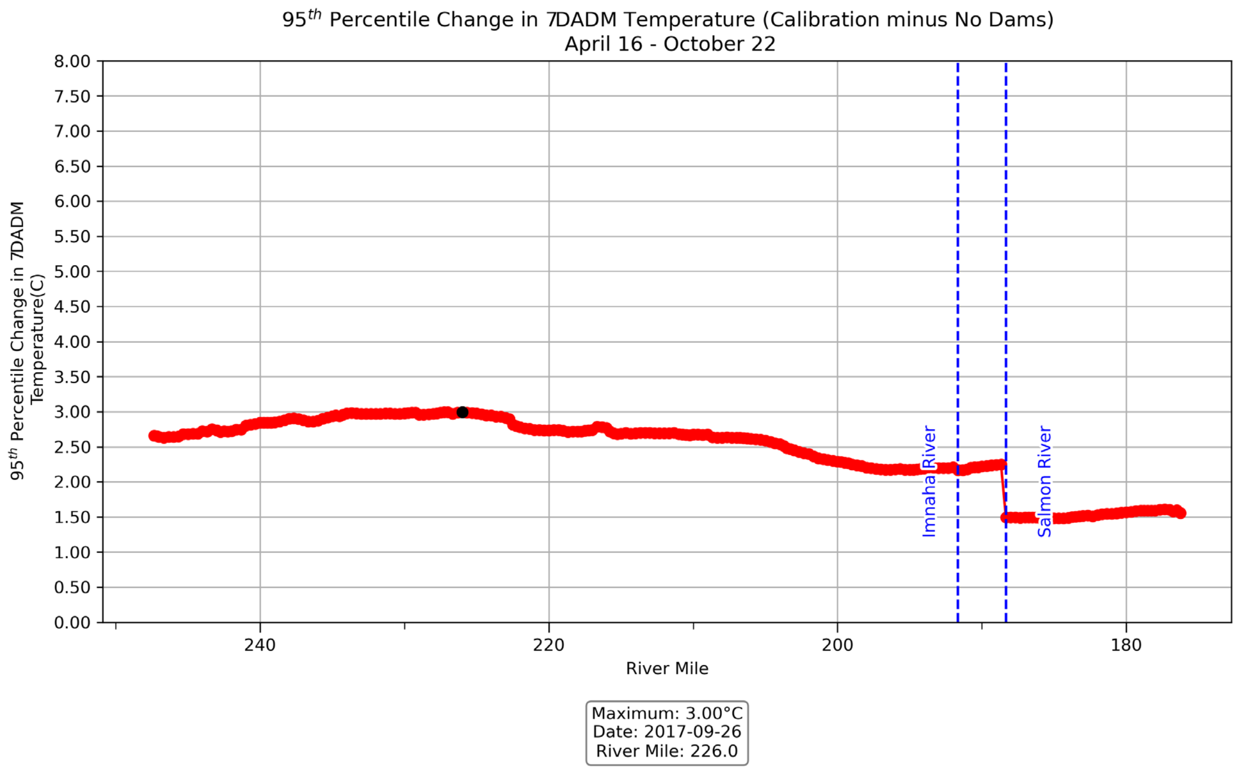


Figure 8-23. 95th percentile change in 7DADM temperature above applicable criteria during critical summer period.

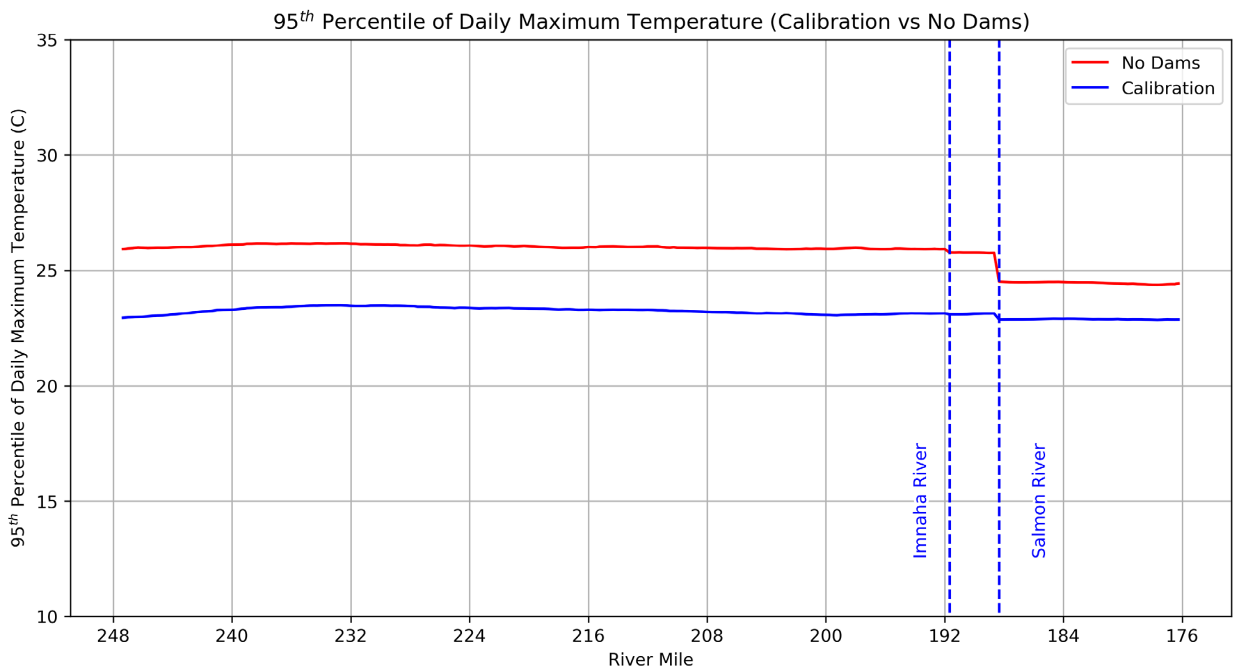


Figure 8-24. 95th percentile of daily maximum temperature for calibration and no dams scenarios, from HC Dam to Washington state line, 2014-2018.

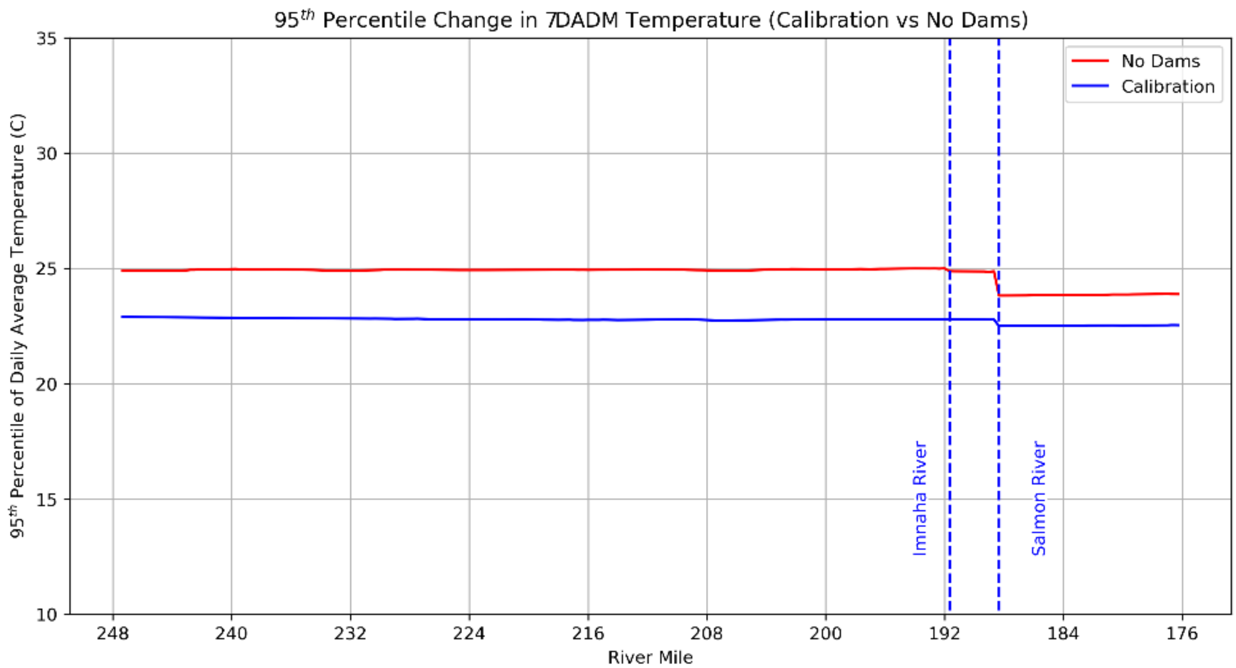


Figure 8-25. 95th percentile of daily average temperature for calibration and no dams scenarios, from HC Dam to Washington state line, 2014-2018.

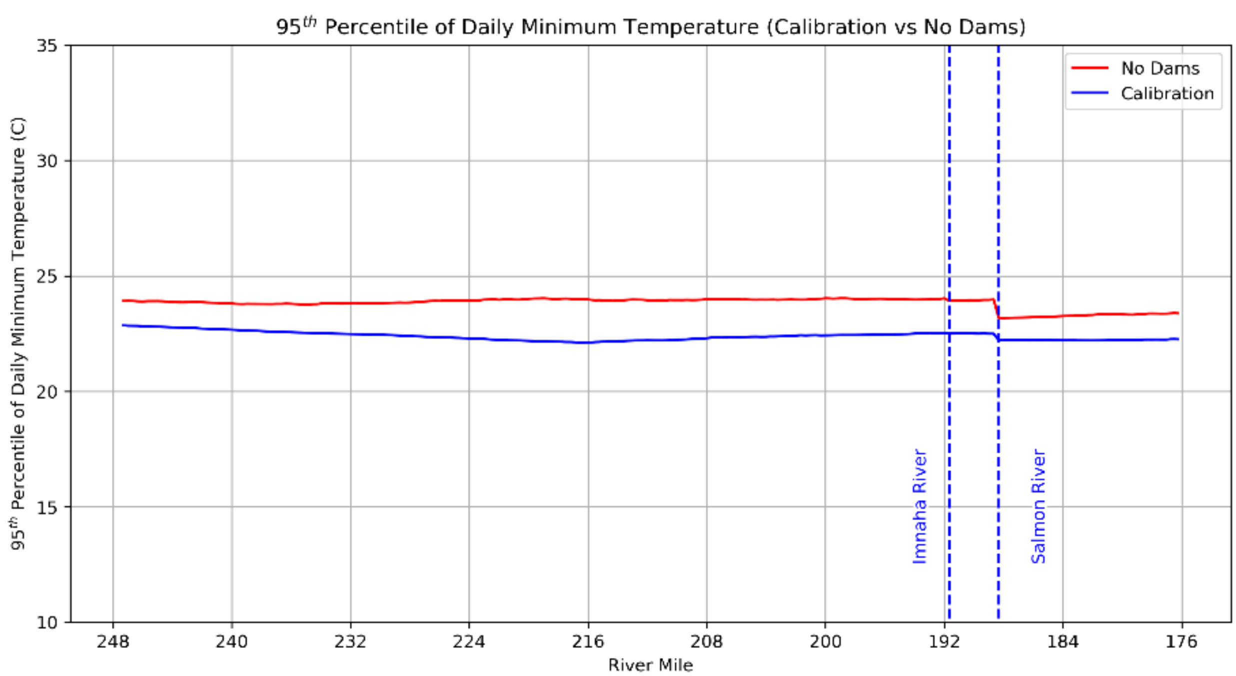


Figure 8-26. 95th percentile of daily minimum temperature for calibration and no dams scenarios, from HC Dam to Washington state line, 2014-2018.

8.1.3 Restored Vegetation vs. Calibration

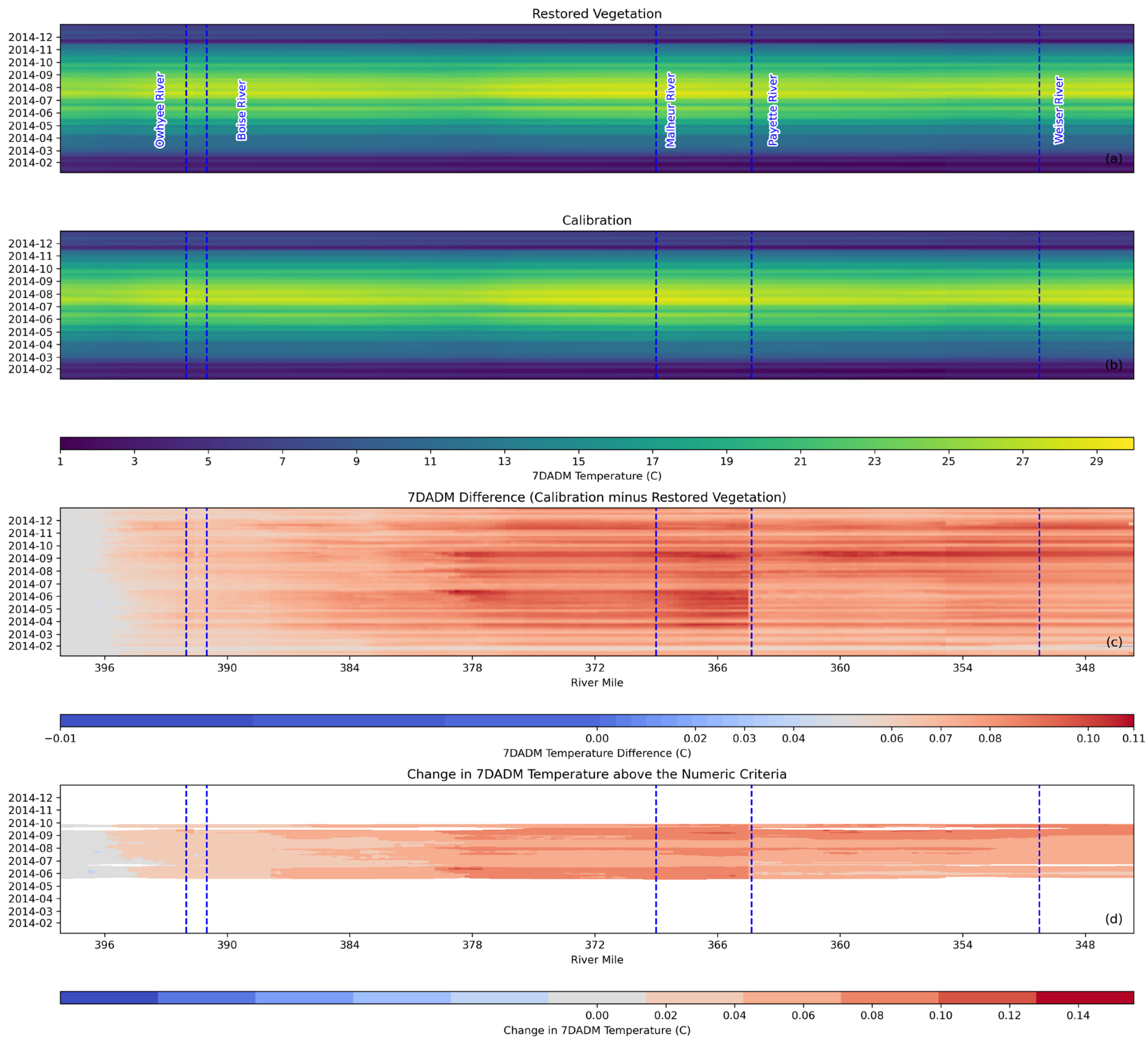


Figure 8-27. (a, b) 7DADM temperature for restored vegetation and calibration scenarios, (c) temperature difference (calibration-restored vegetation), and (d) change in 7DADM temperature above the numeric criteria where temperature from either scenario meets or exceeds the criterion, from Adrian to head of Brownlee Reservoir, 2014.

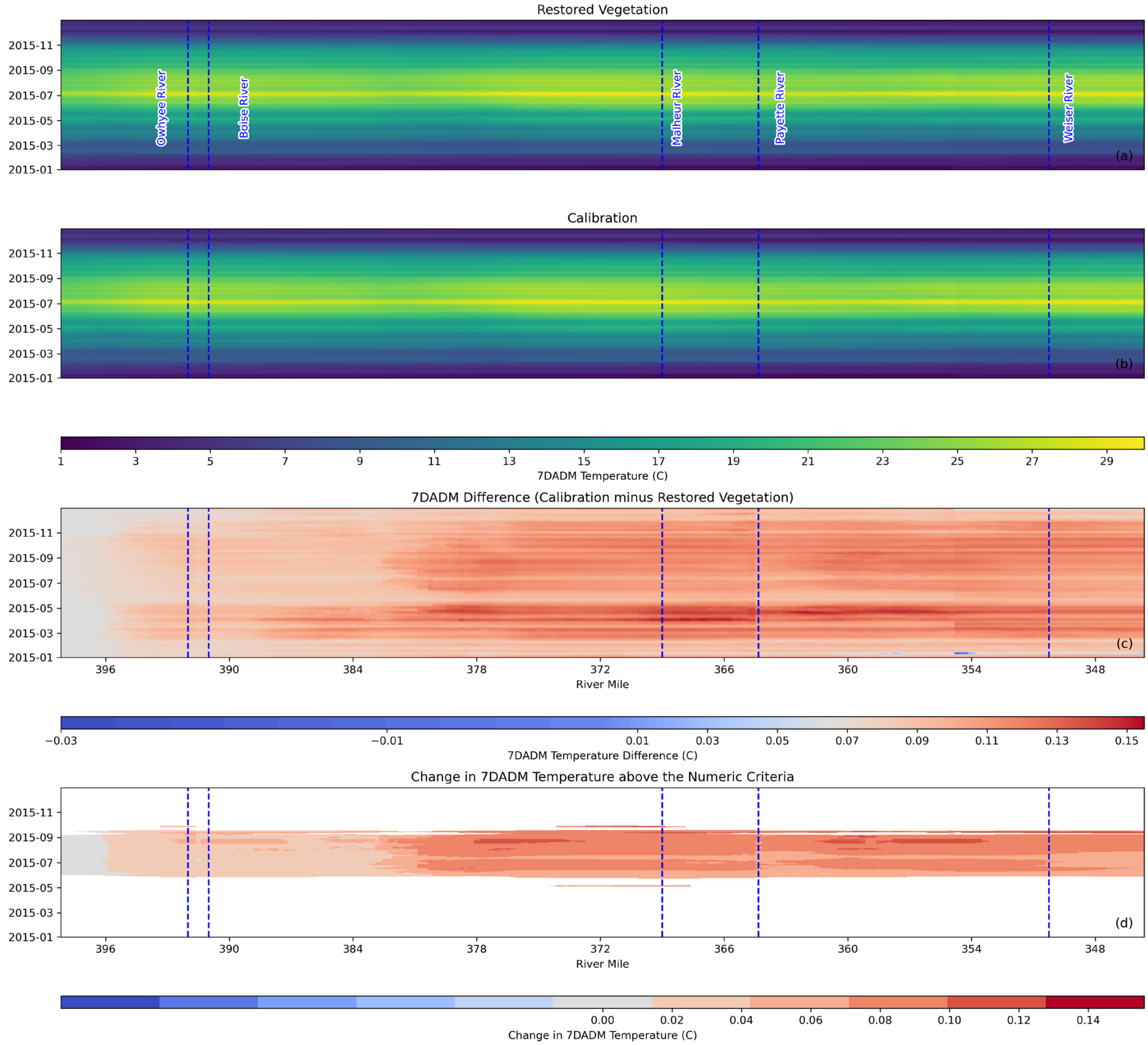


Figure 8-28. (a, b) 7DADM temperature for restored vegetation and calibration scenarios, (c) temperature difference (calibration-restored vegetation), and (d) change in 7DADM temperature above the numeric criteria where temperature from either scenario meets or exceeds the criterion, from Adrian to head of Brownlee Reservoir, 2015.

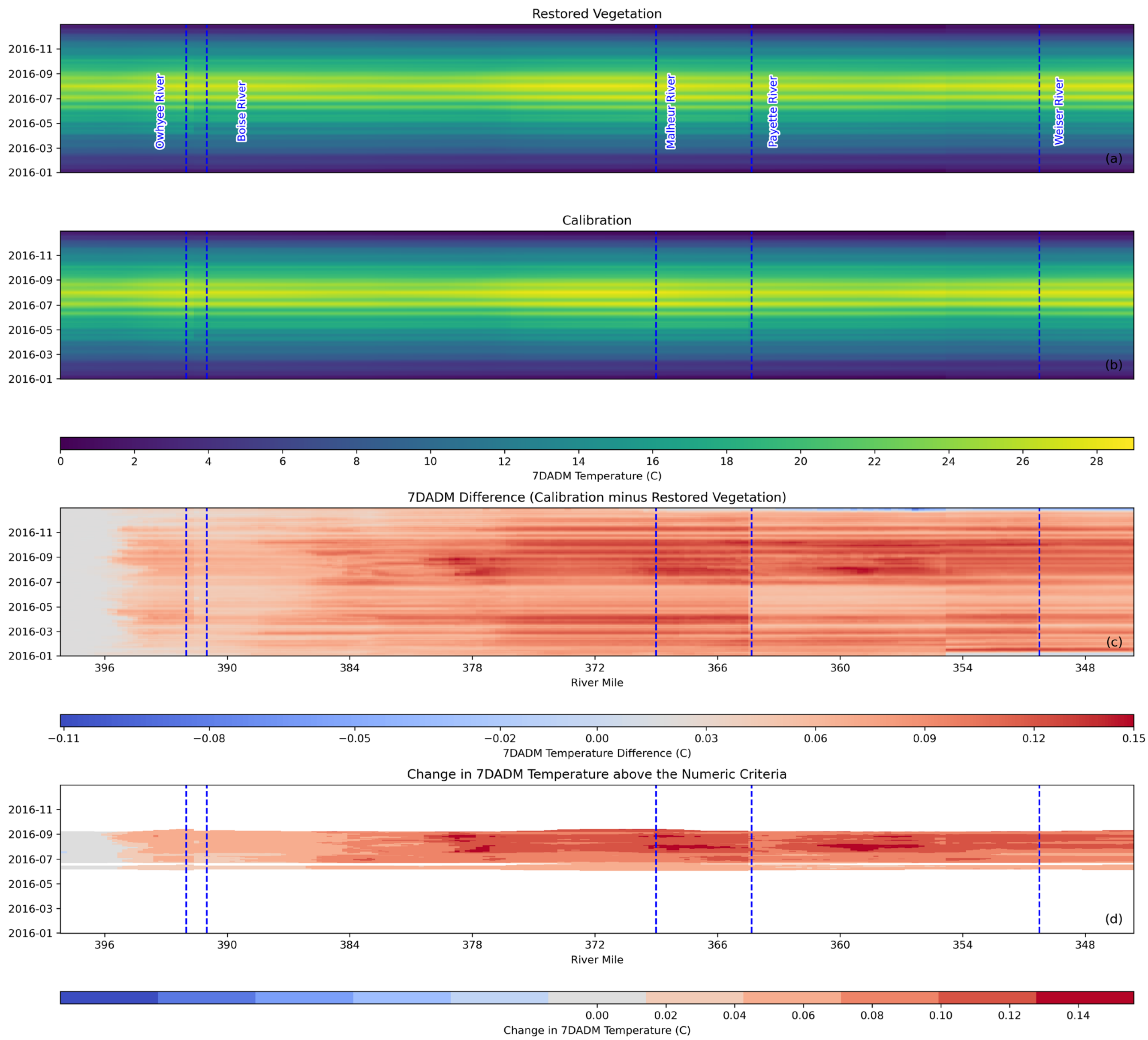


Figure 8-29. (a, b) 7DADM temperature for restored vegetation and calibration scenarios, (c) temperature difference (calibration-restored vegetation), and (d) change in 7DADM temperature above the numeric criteria where temperature from either scenario meets or exceeds the criterion, from Adrian to head of Brownlee Reservoir, 2016.

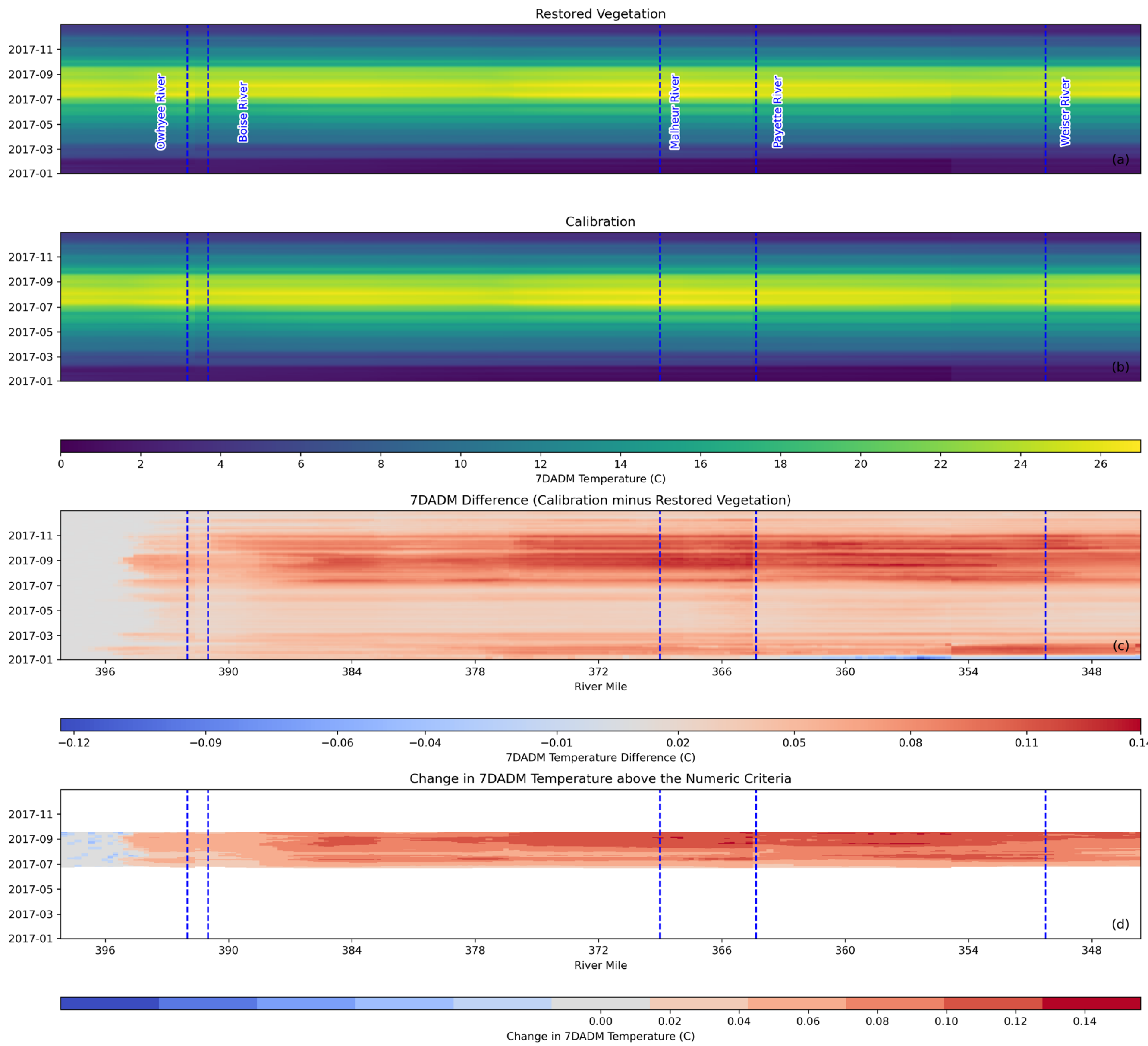


Figure 8-30. (a, b) 7DADM temperature for restored vegetation and calibration scenarios, (c) temperature difference (calibration-restored vegetation), and (d) change in 7DADM temperature above the numeric criteria where temperature from either scenario meets or exceeds the criterion, from Adrian to head of Brownlee Reservoir, 2017.

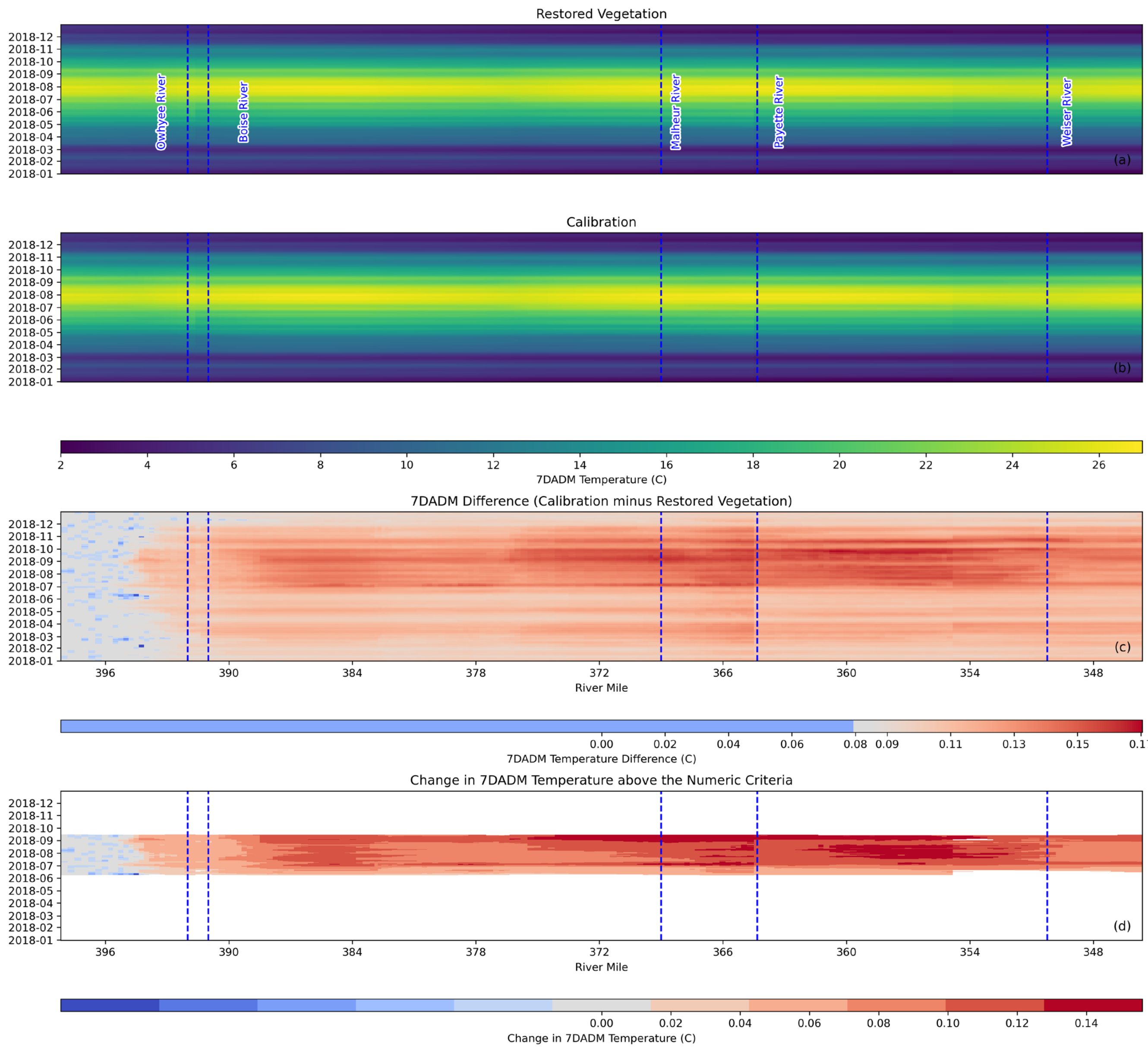


Figure 8-31. (a, b) 7DADM temperature for restored vegetation and calibration scenarios, (c) temperature difference (calibration-restored vegetation), and (d) change in 7DADM temperature above the numeric criteria where temperature from either scenario meets or exceeds the criterion, from Adrian to head of Brownlee Reservoir, 2018.

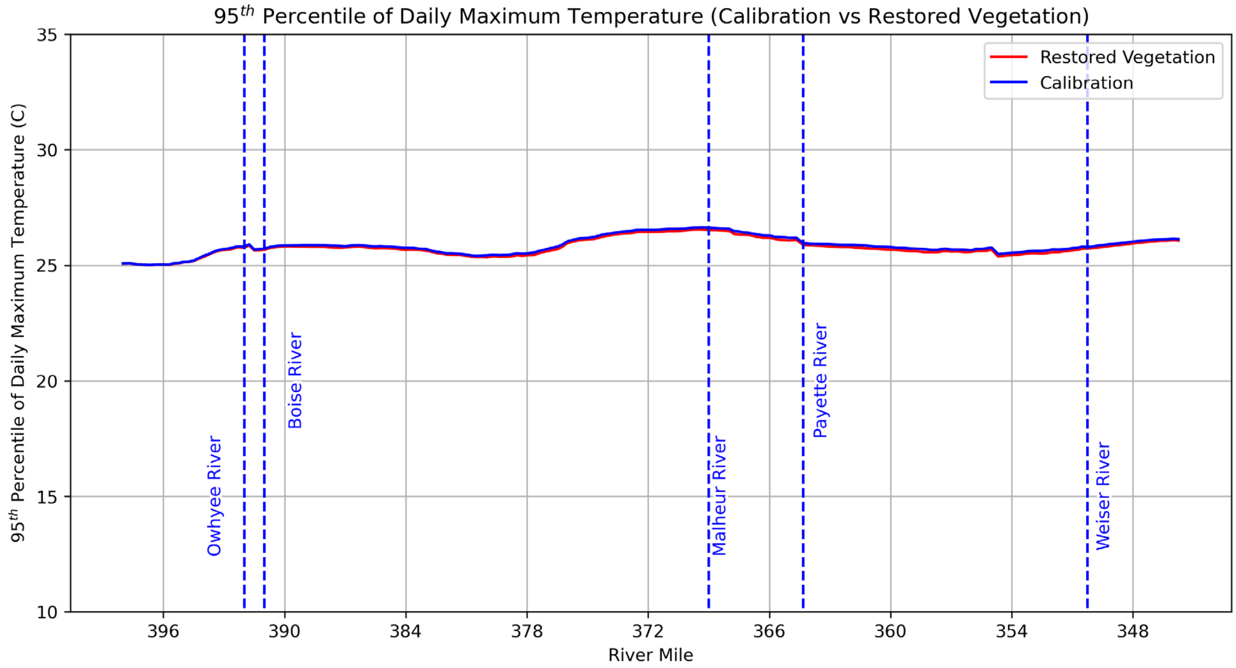


Figure 8-32. 95th percentile of daily maximum temperature for calibration and restored vegetation scenarios, from Adrian to head of Brownlee Reservoir, 2014-2018.

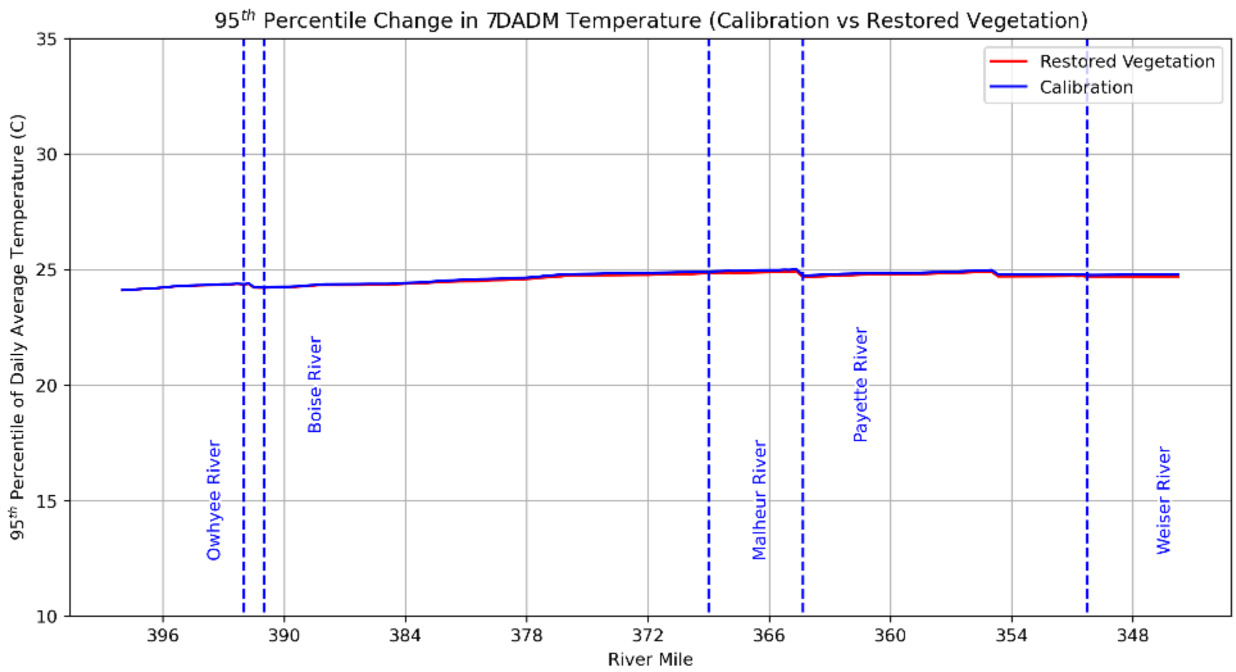


Figure 8-33. 95th percentile of daily average temperature for calibration and restored vegetation scenarios, from Adrian to head of Brownlee Reservoir, 2014-2018.

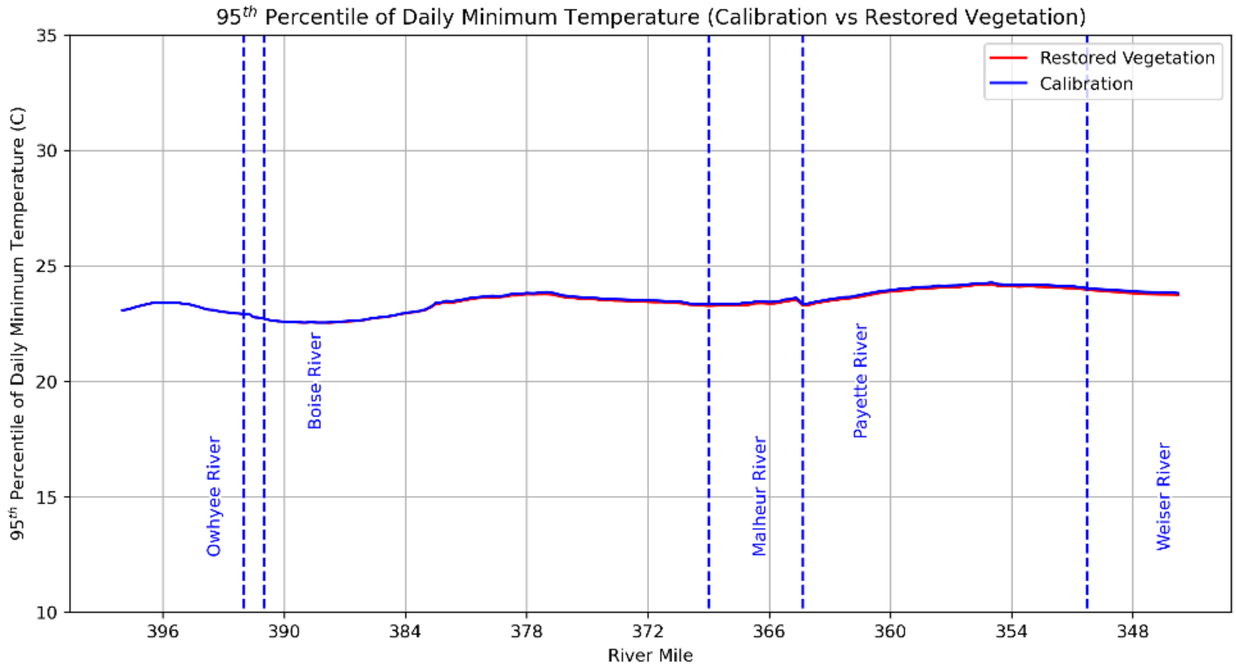


Figure 8-34. 95th percentile of daily minimum temperature for calibration and restored vegetation scenarios, from Adrian to head of Brownlee Reservoir, 2014-2018.

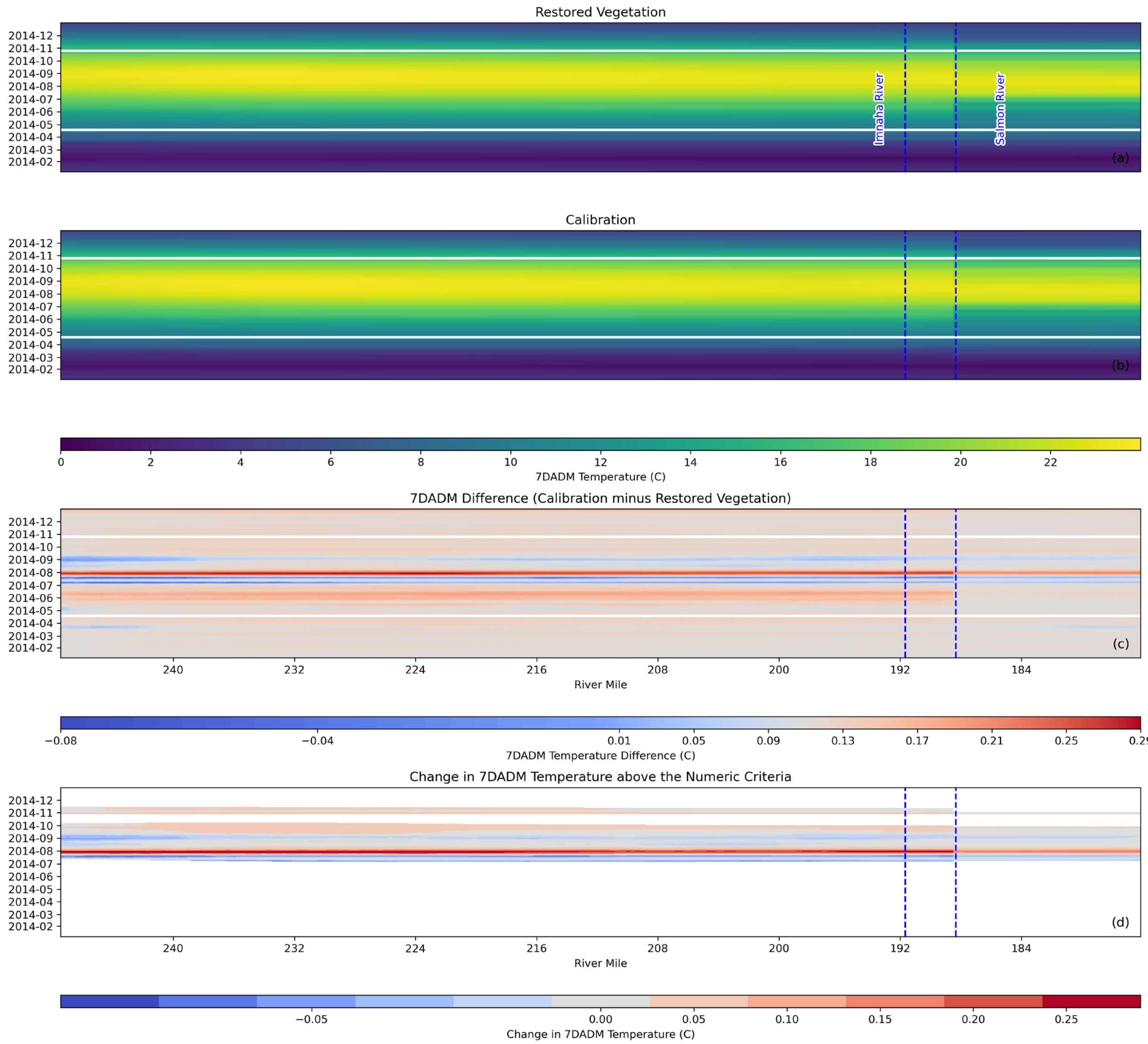


Figure 8-35. (a, b) 7DADM temperature for restored vegetation and calibration scenarios, (c) temperature difference (calibration-restored vegetation), and (d) change in 7DADM temperature above the numeric criteria where temperature from either scenario meets or exceeds the criterion, from HC Dam to Washington state line, 2014.

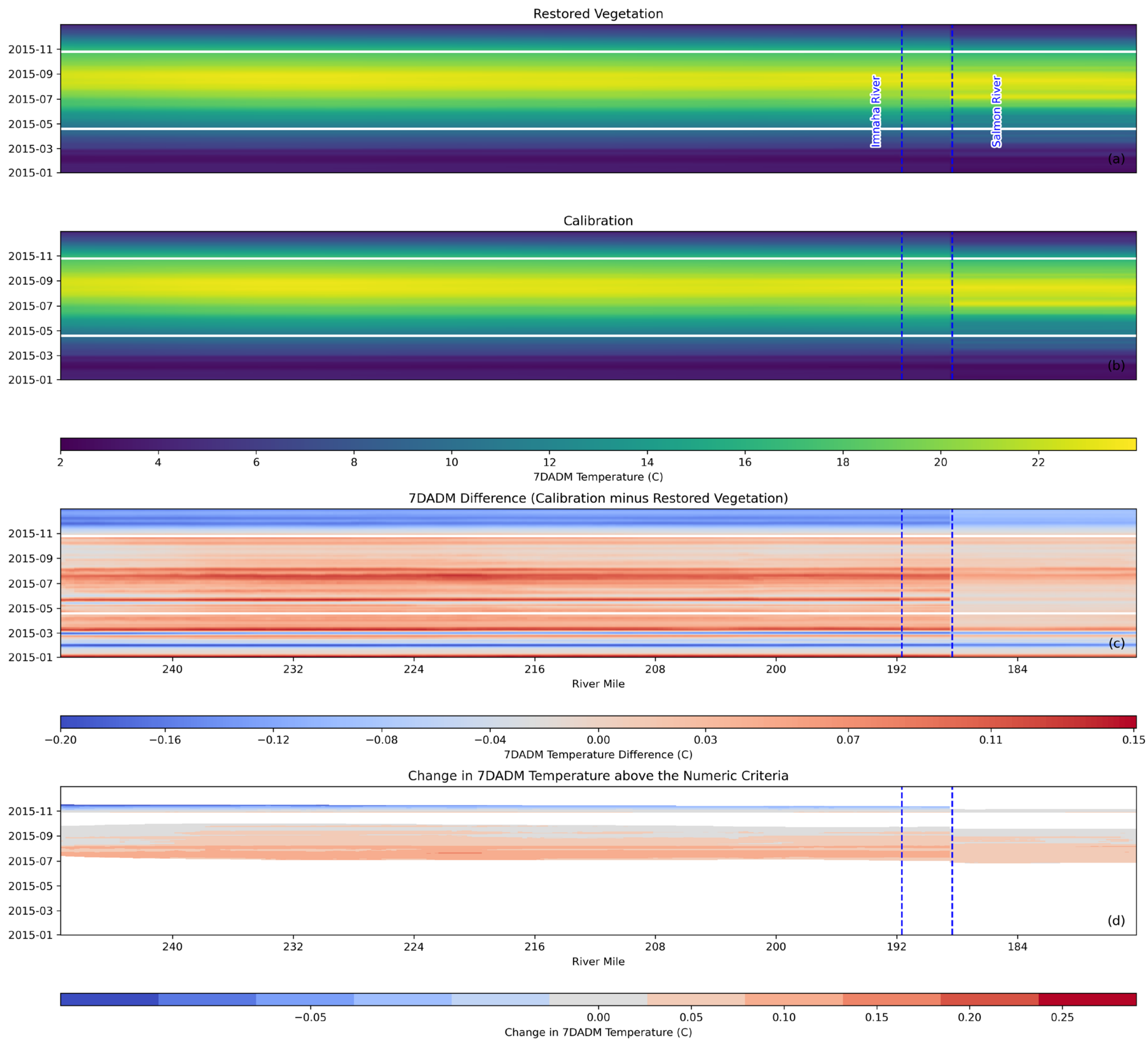


Figure 8-36. (a, b) 7DADM temperature for restored vegetation and calibration scenarios, (c) temperature difference (calibration-restored vegetation), and (d) change in 7DADM temperature above the numeric criteria where temperature from either scenario meets or exceeds the criterion, from HC Dam to Washington state line, 2015.

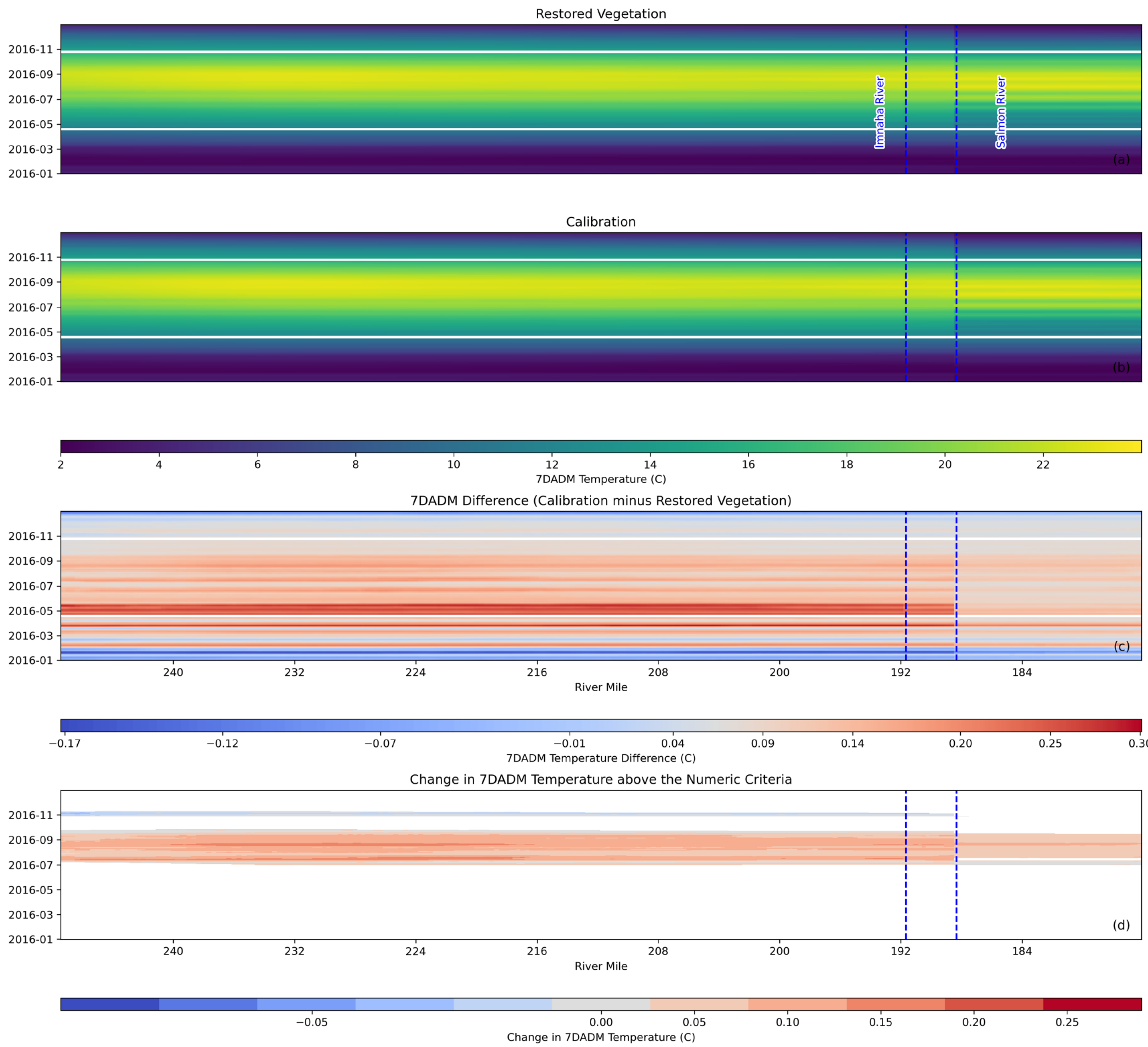


Figure 8-37. (a, b) 7DADM temperature for restored vegetation and calibration scenarios, (c) temperature difference (calibration-restored vegetation), and (d) change in 7DADM temperature above the numeric criteria where temperature from either scenario meets or exceeds the criterion, from HC Dam to Washington state line, 2016.

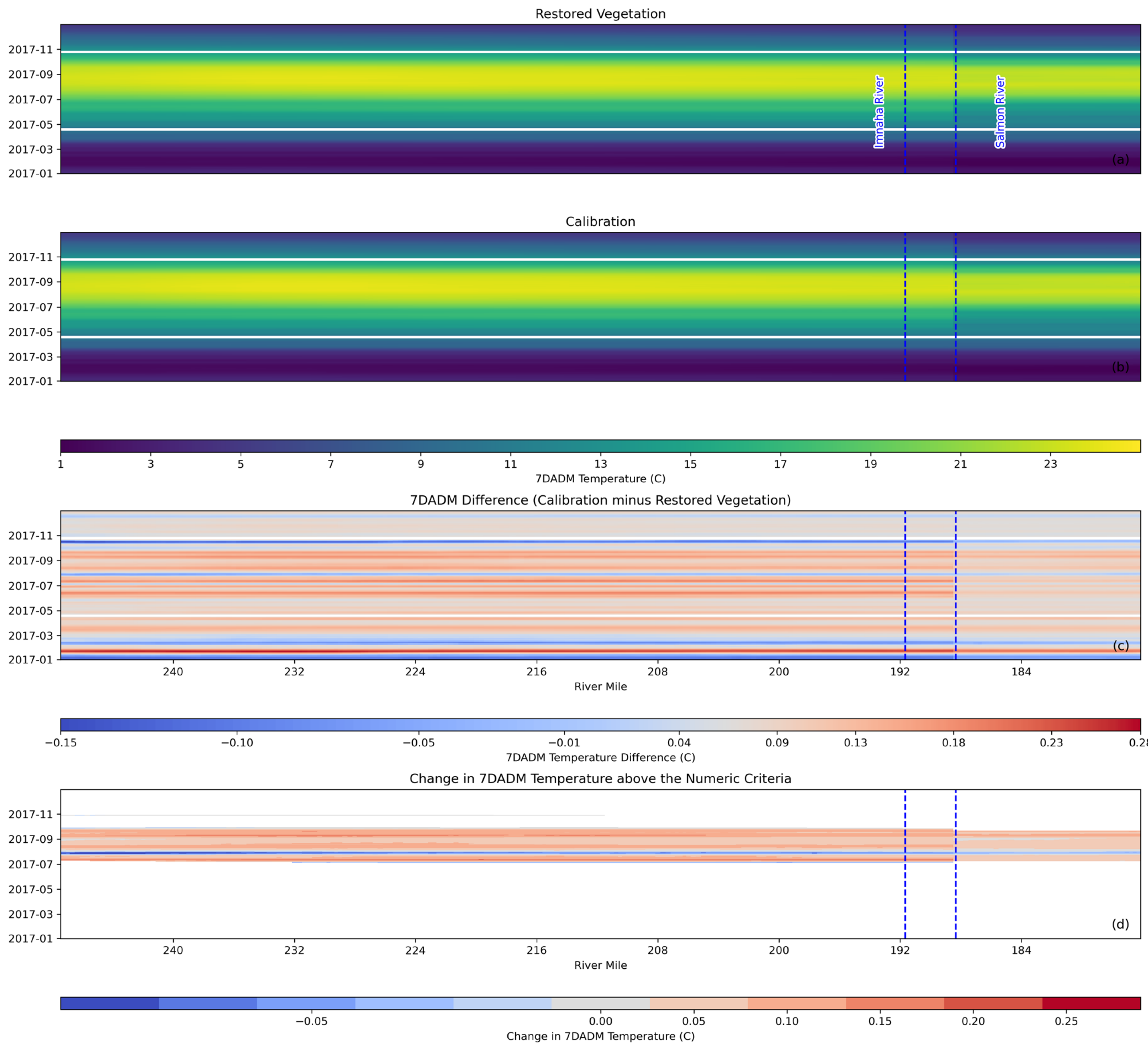


Figure 8-38. (a, b) 7DADM temperature for restored vegetation and calibration scenarios, (c) temperature difference (calibration-restored vegetation), and (d) change in 7DADM temperature above the numeric criteria where temperature from either scenario meets or exceeds the criterion, from HC Dam to Washington state line, 2017.

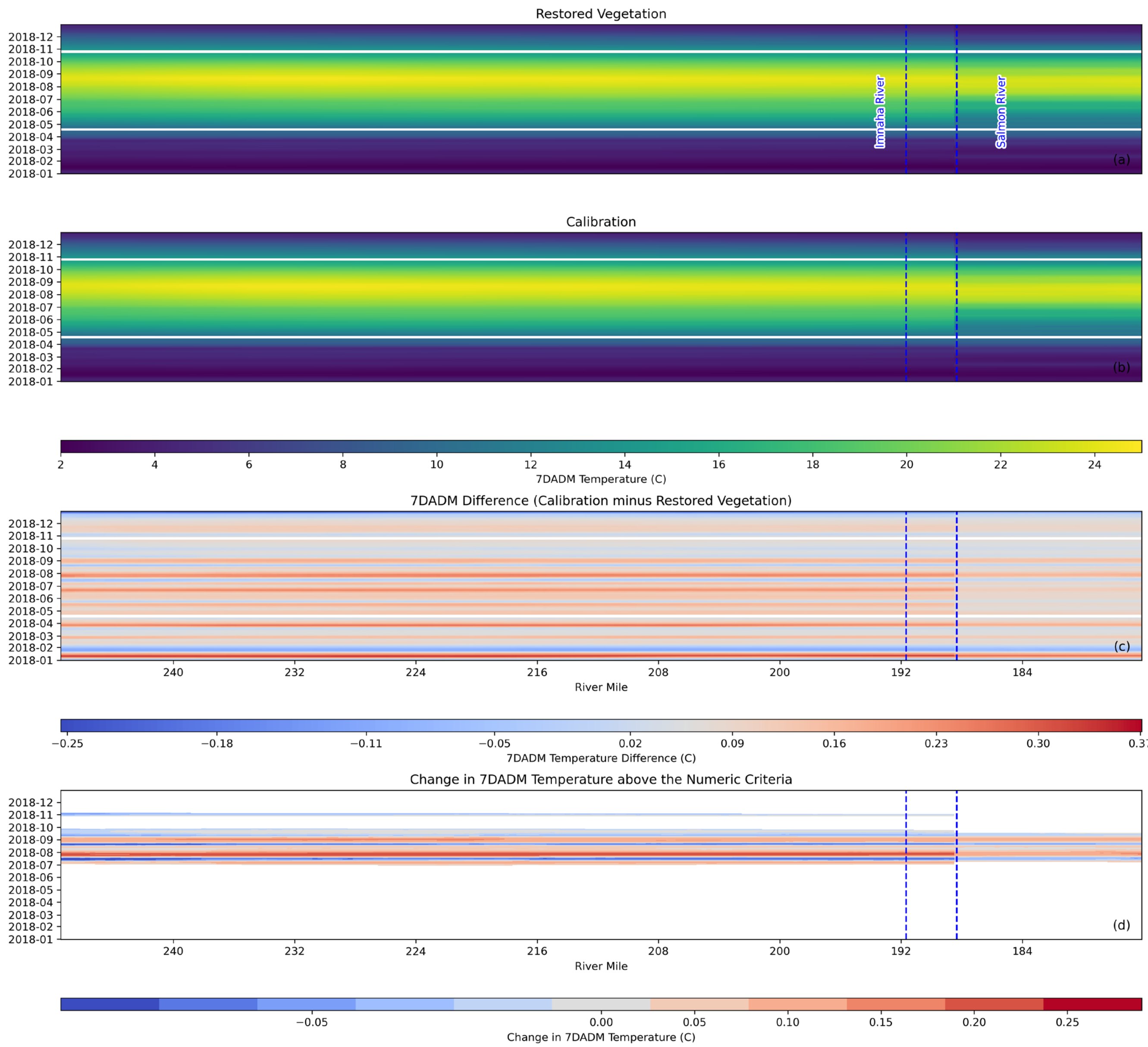


Figure 8-39. (a, b) 7DADM temperature for restored vegetation and calibration scenarios, (c) temperature difference (calibration-restored vegetation), and (d) change in 7DADM temperature above the numeric criteria where temperature from either scenario meets or exceeds the criterion, from HC Dam to Washington state line, 2018.

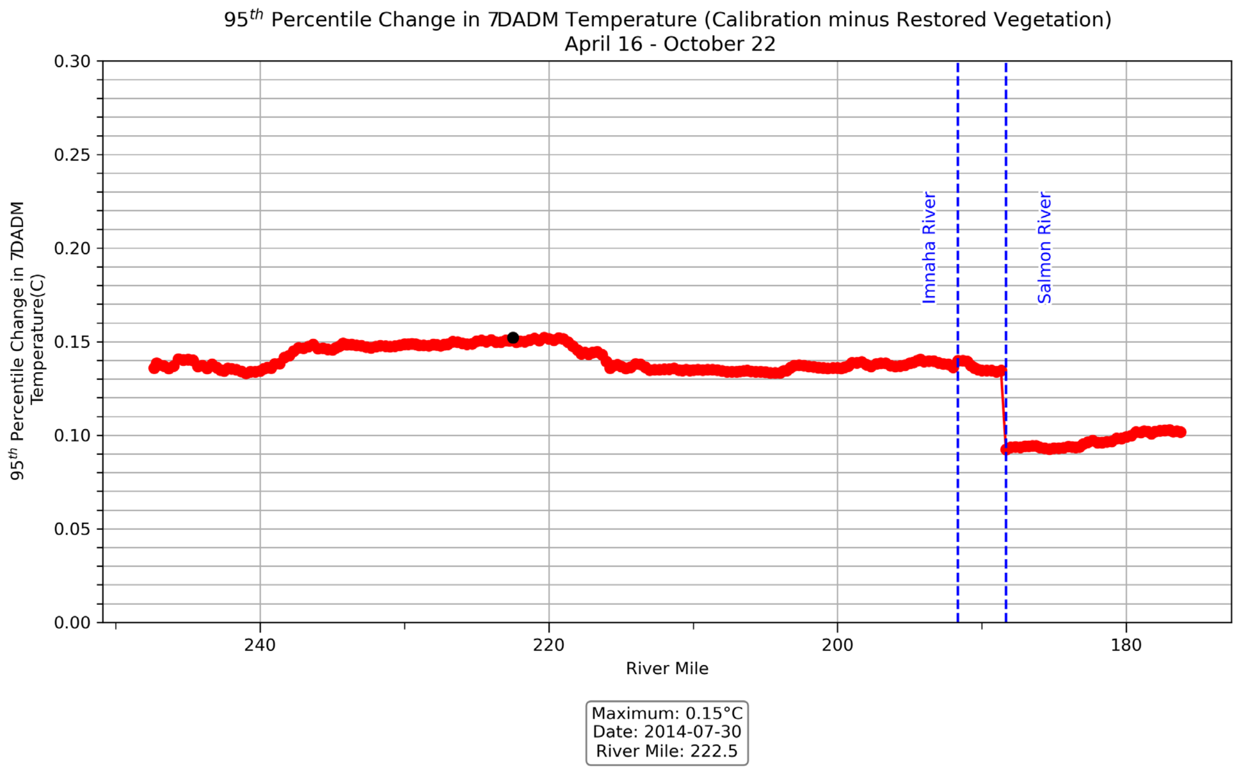


Figure 8-40. 95th percentile change in 7DADM temperature above applicable criteria during critical summer period.

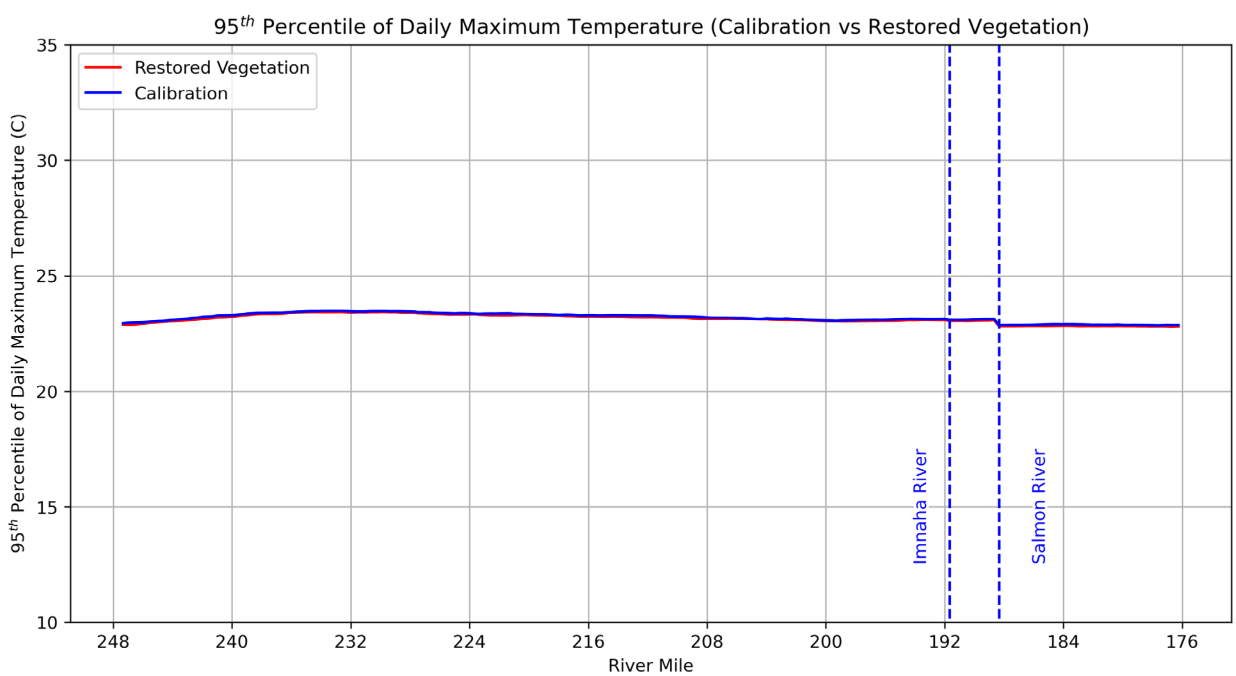


Figure 8-41. 95th percentile of daily maximum temperature for calibration and restored vegetation scenarios, from HC Dam to Washington state line, 2014-2018.

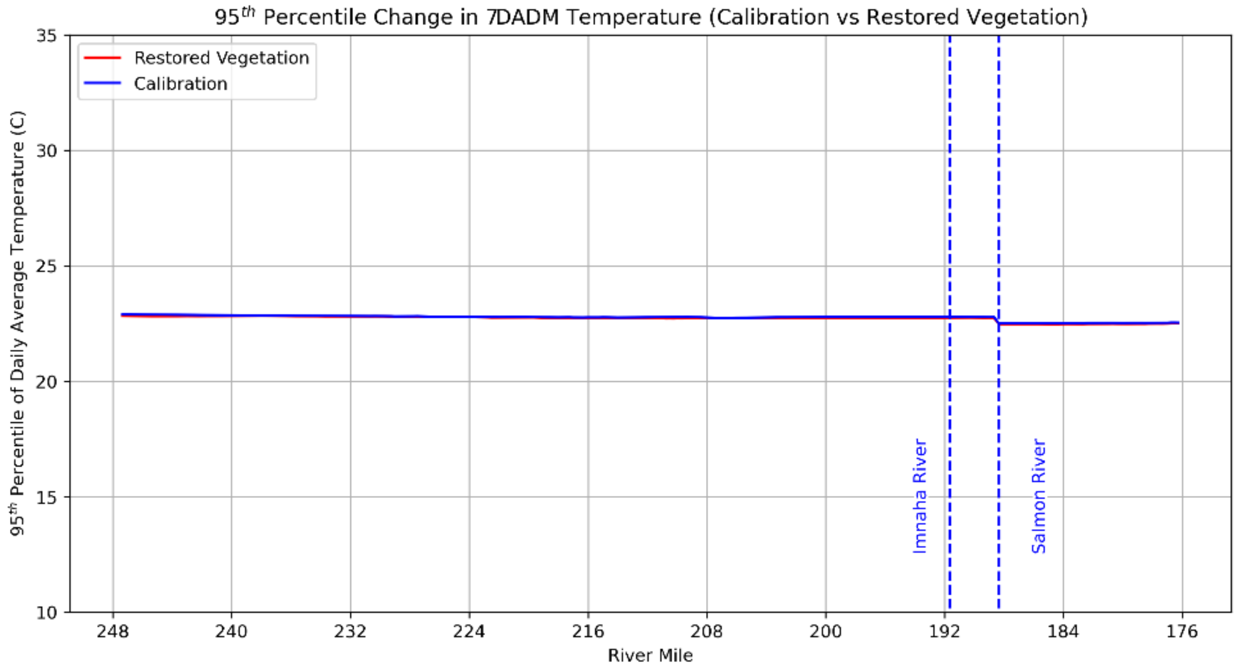


Figure 8-42. 95th percentile of daily average temperature for calibration and restored vegetation scenarios, from HC Dam to Washington state line, 2014-2018.

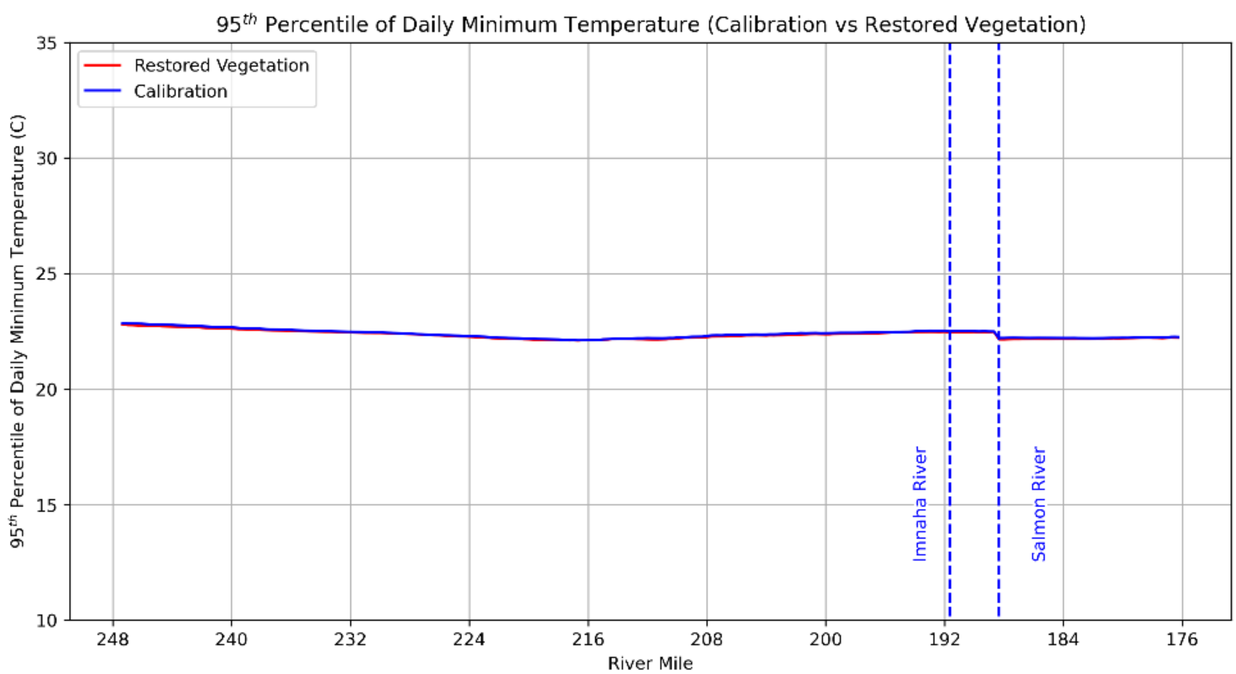


Figure 8-43. 95th percentile of daily minimum temperature for calibration and restored vegetation scenarios, from HC Dam to Washington state line, 2014-2018.

8.1.4 Background vs. Calibration

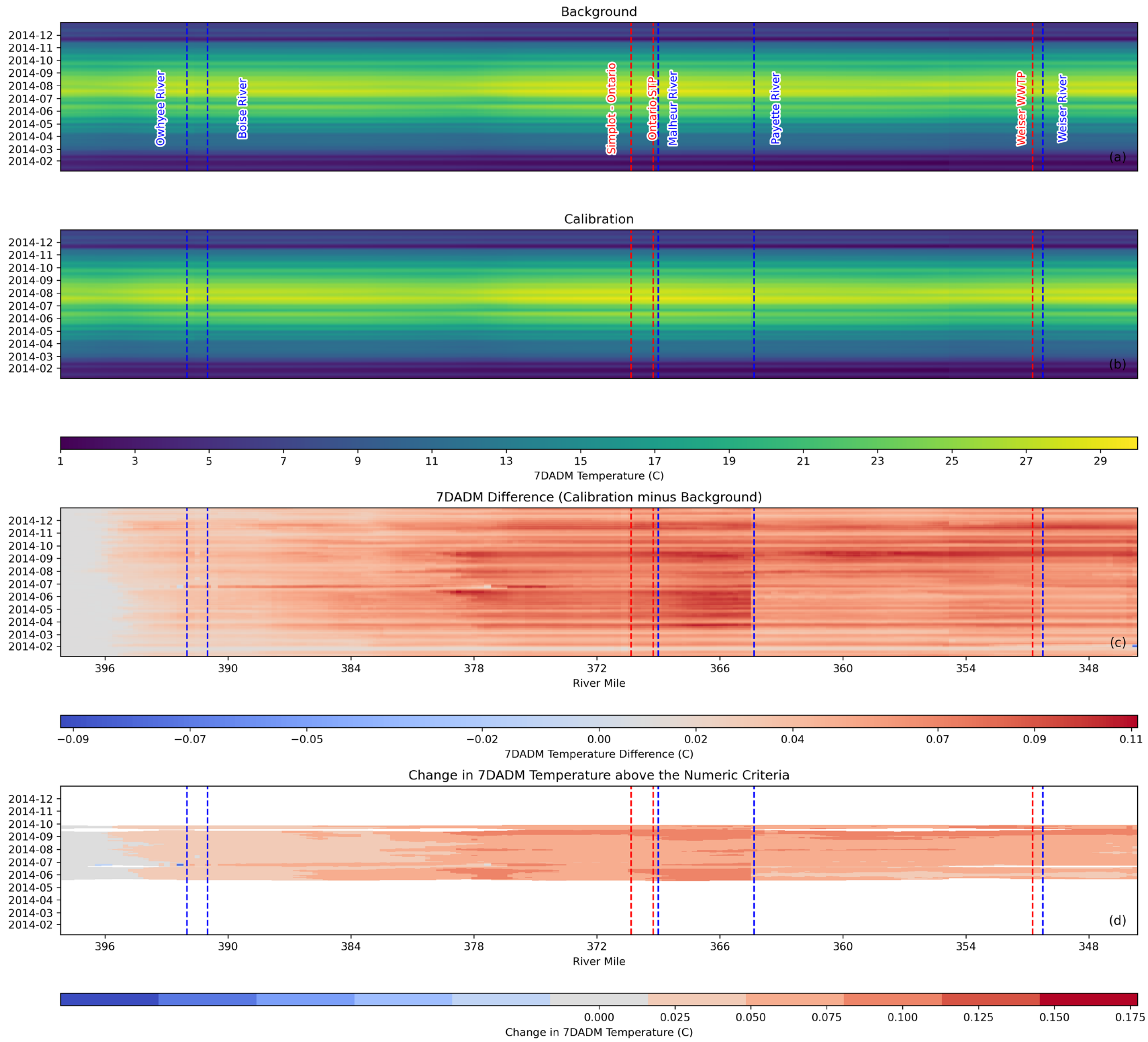


Figure 8-44. (a, b) 7DADM temperature for background and calibration scenarios, (c) temperature difference (calibration-background), and (d) change in 7DADM temperature above the numeric criteria where temperature from either scenario meets or exceeds the criterion, from Adrian to head of Brownlee Reservoir, 2014.

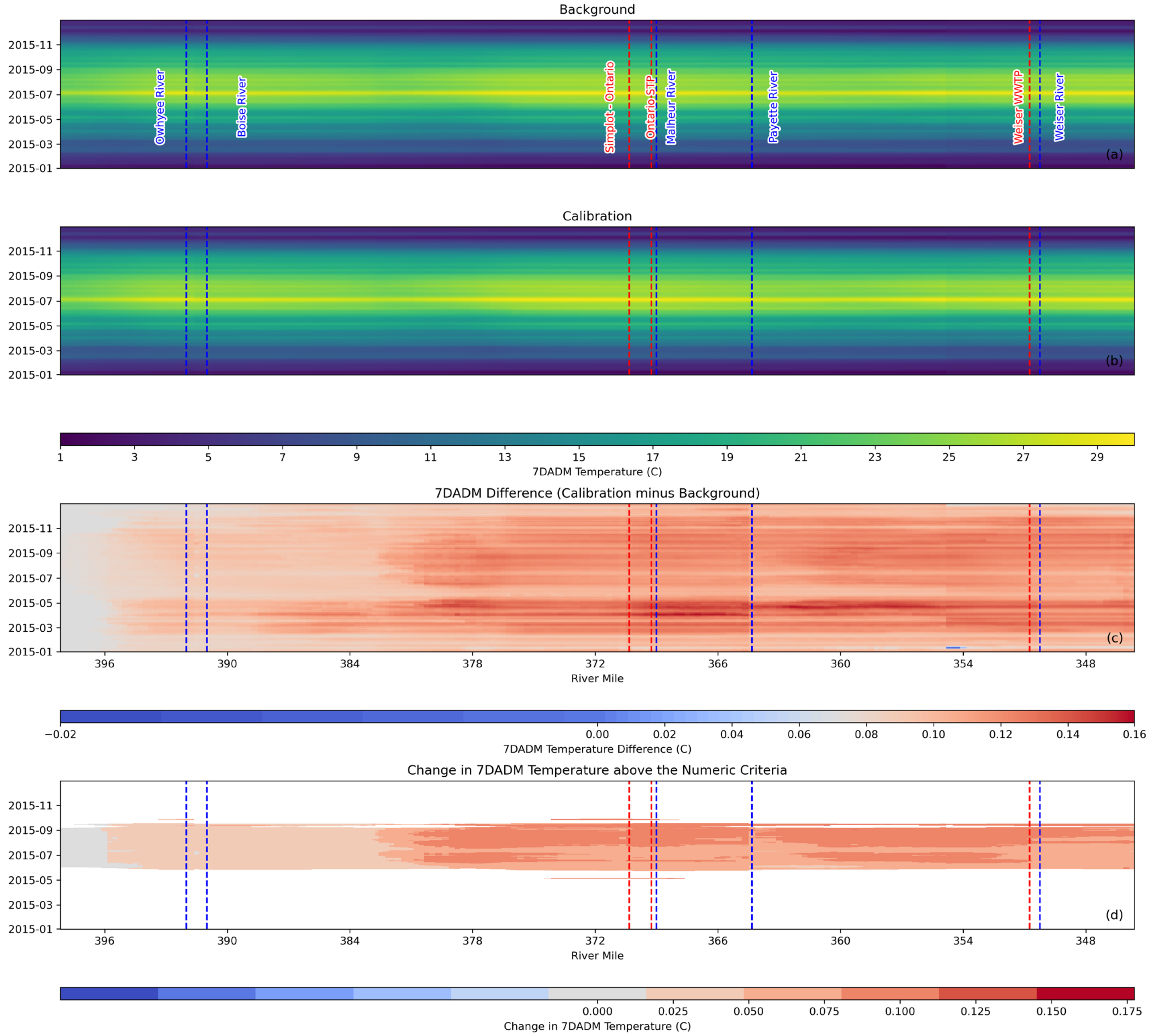


Figure 8-45. (a, b) 7DADM temperature for background and calibration scenarios, (c) temperature difference (calibration-background), and (d) change in 7DADM temperature above the numeric criteria where temperature from either scenario meets or exceeds the criterion, from Adrian to head of Brownlee Reservoir, 2015.

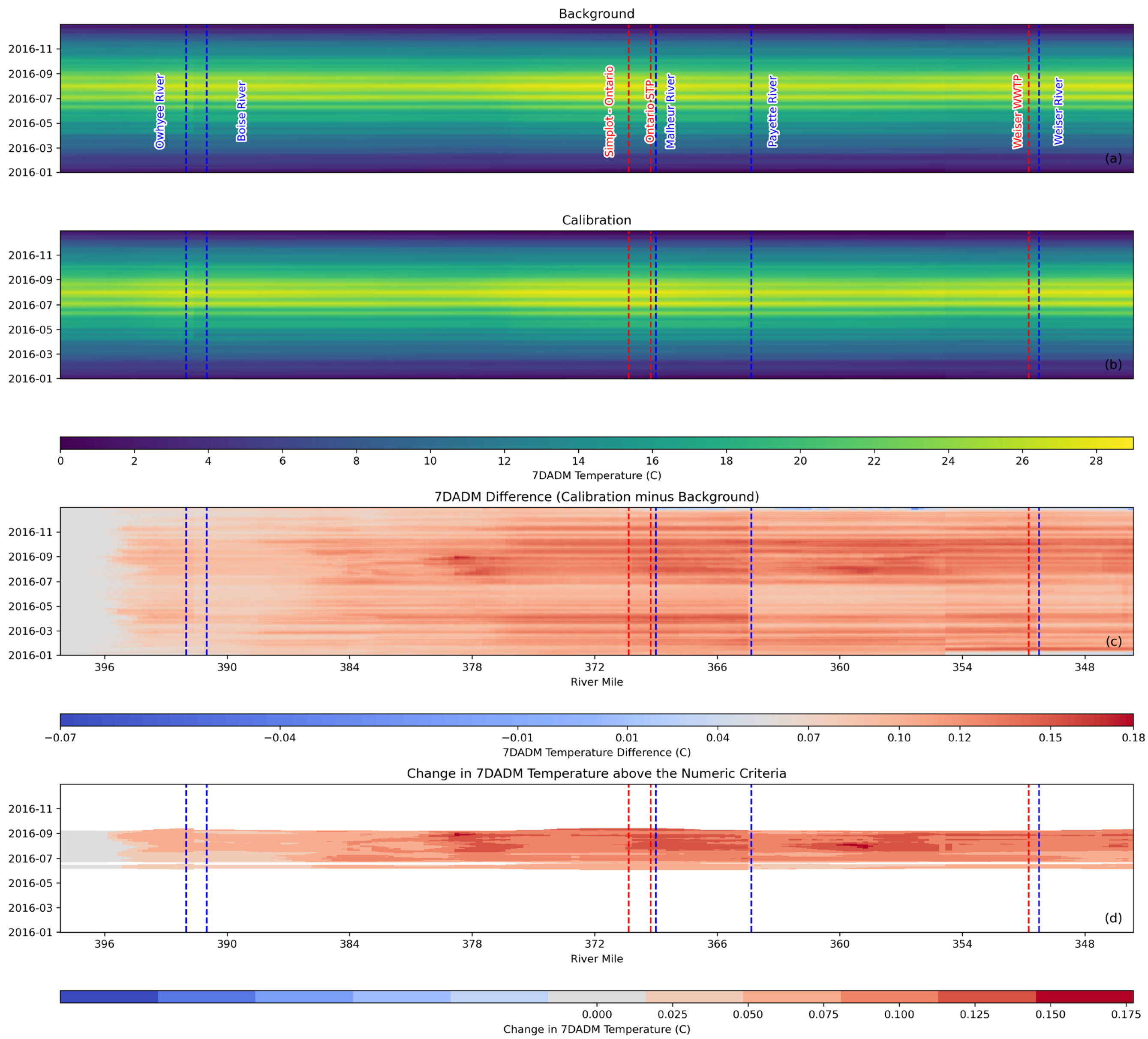


Figure 8-46. (a, b) 7DADM temperature for background and calibration scenarios, (c) temperature difference (calibration-background), and (d) change in 7DADM temperature above the numeric criteria where temperature from either scenario meets or exceeds the criterion, from Adrian to head of Brownlee Reservoir, 2016.

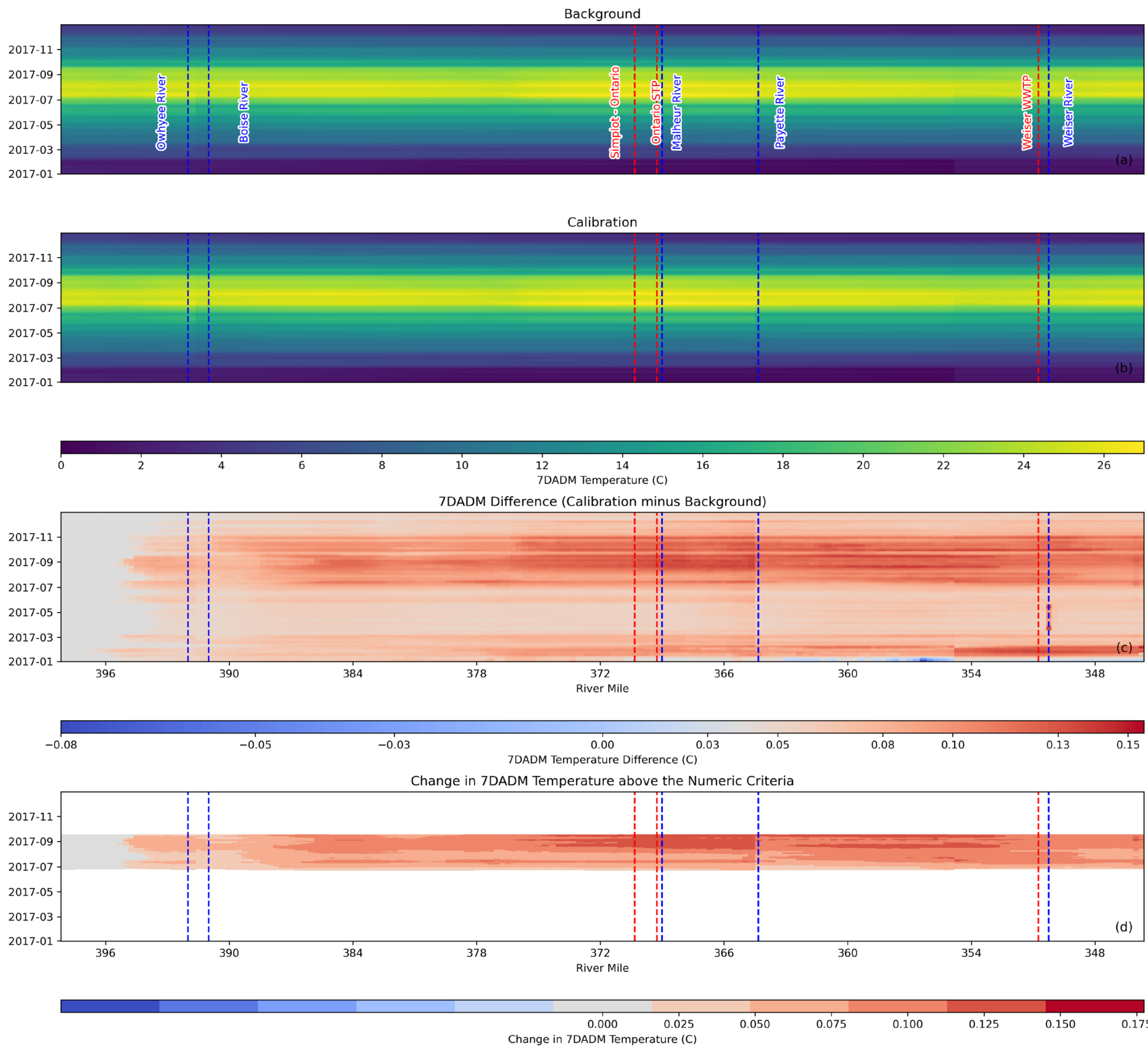


Figure 8-47. (a, b) 7DADM temperature for background and calibration scenarios, (c) temperature difference (calibration-background), and (d) change in 7DADM temperature above the numeric criteria where temperature from either scenario meets or exceeds the criterion, from Adrian to head of Brownlee Reservoir, 2017.

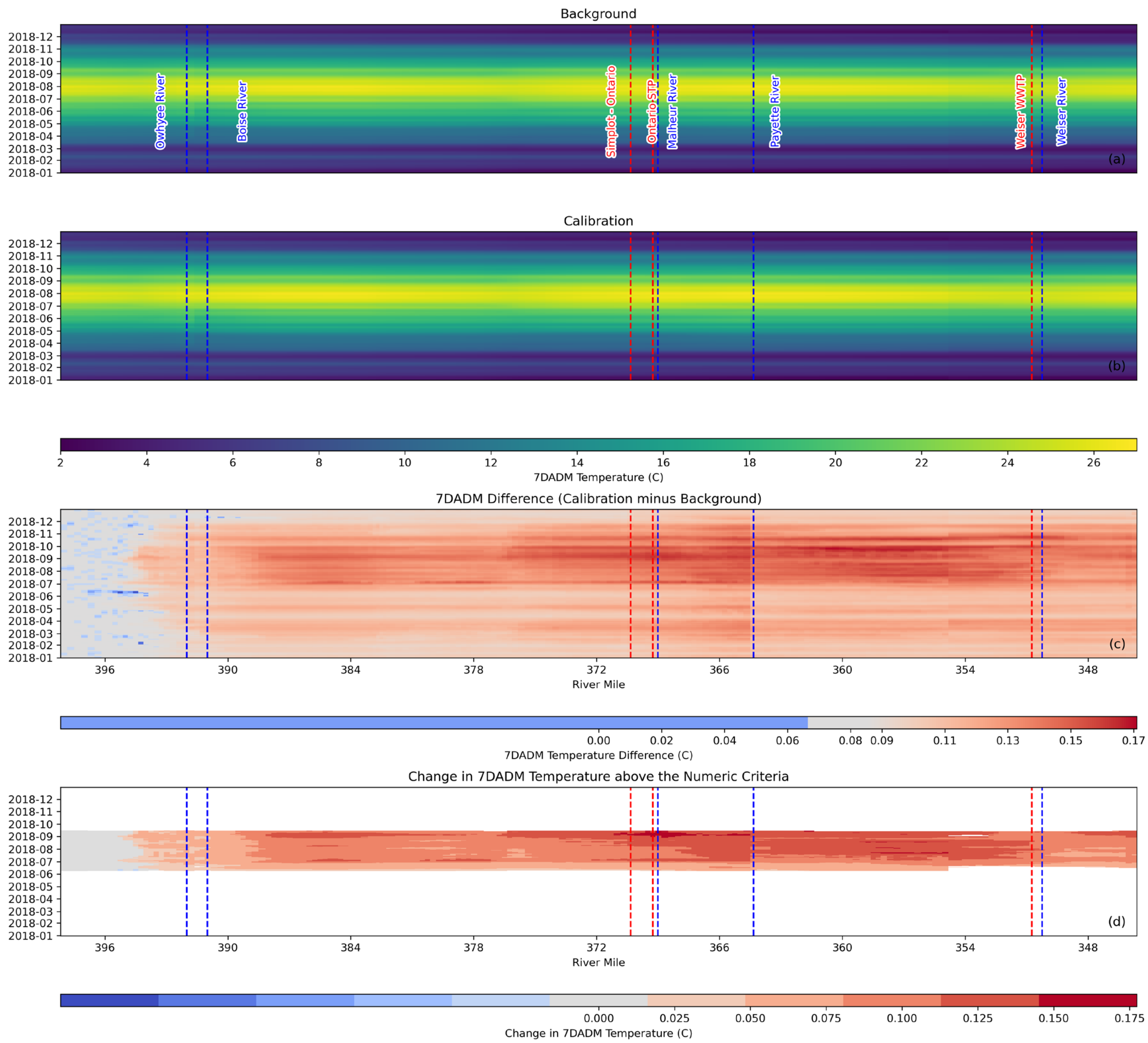


Figure 8-48. (a, b) 7DADM temperature for background and calibration scenarios, (c) temperature difference (calibration-background), and (d) change in 7DADM temperature above the numeric criteria where temperature from either scenario meets or exceeds the criterion, from Adrian to head of Brownlee Reservoir, 2018.

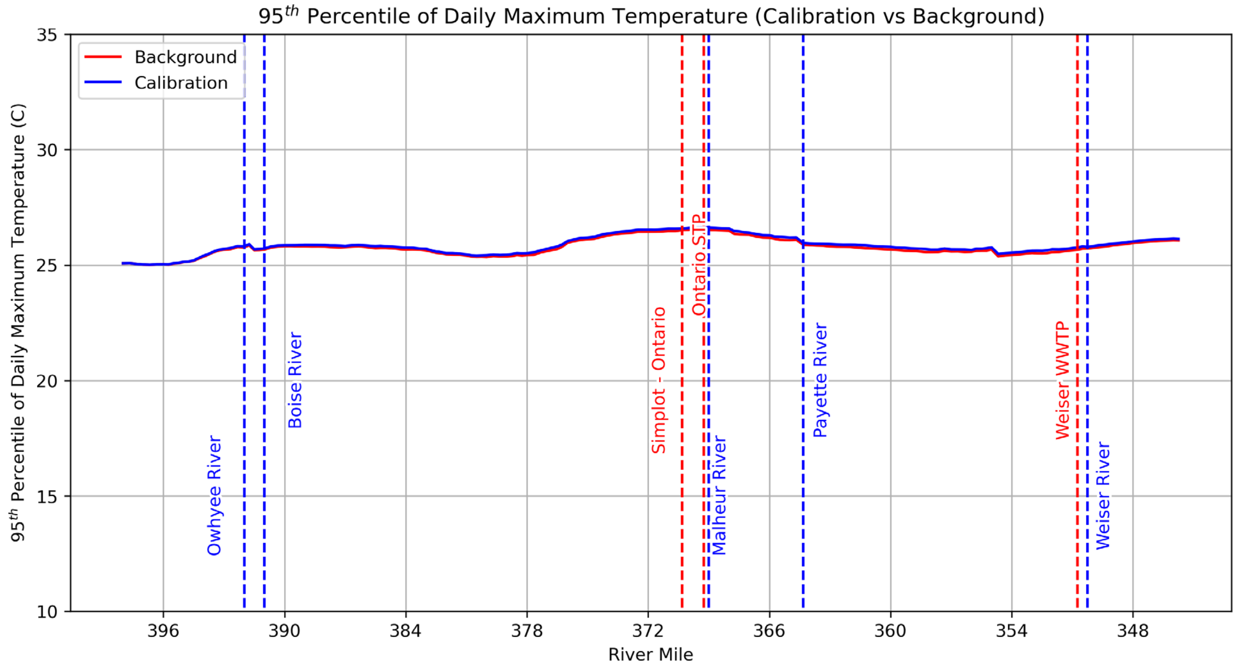


Figure 8-49. 95th percentile of daily maximum temperature for calibration and background scenarios, from Adrian to head of Brownlee Reservoir, 2014-2018.

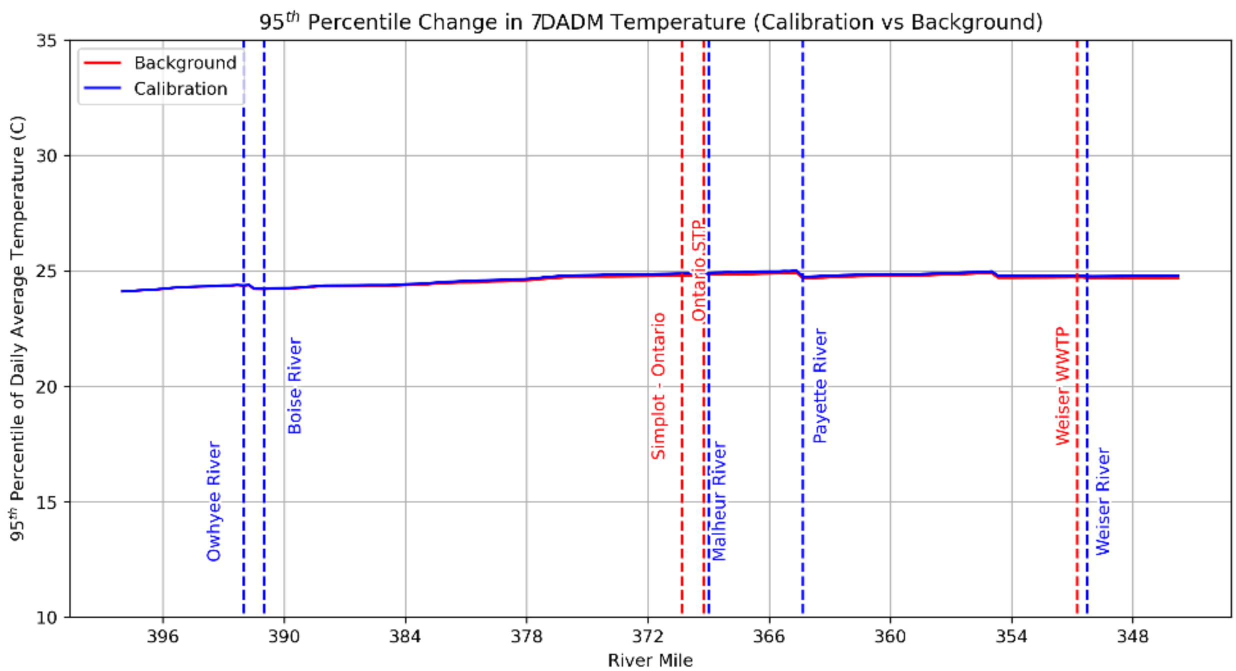


Figure 8-50. 95th percentile of daily average temperature for calibration and background scenarios, from Adrian to head of Brownlee Reservoir, 2014-2018.

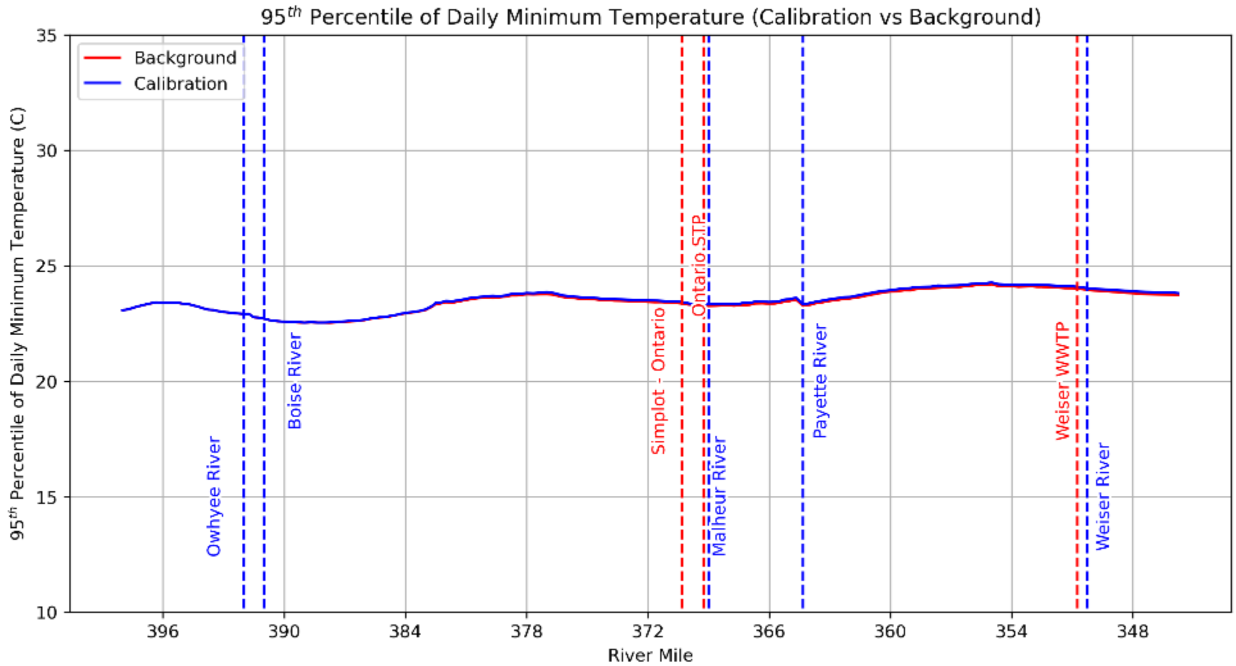


Figure 8-51. 95th percentile of daily minimum temperature for calibration and background scenarios, from Adrian to head of Brownlee Reservoir, 2014-2018.

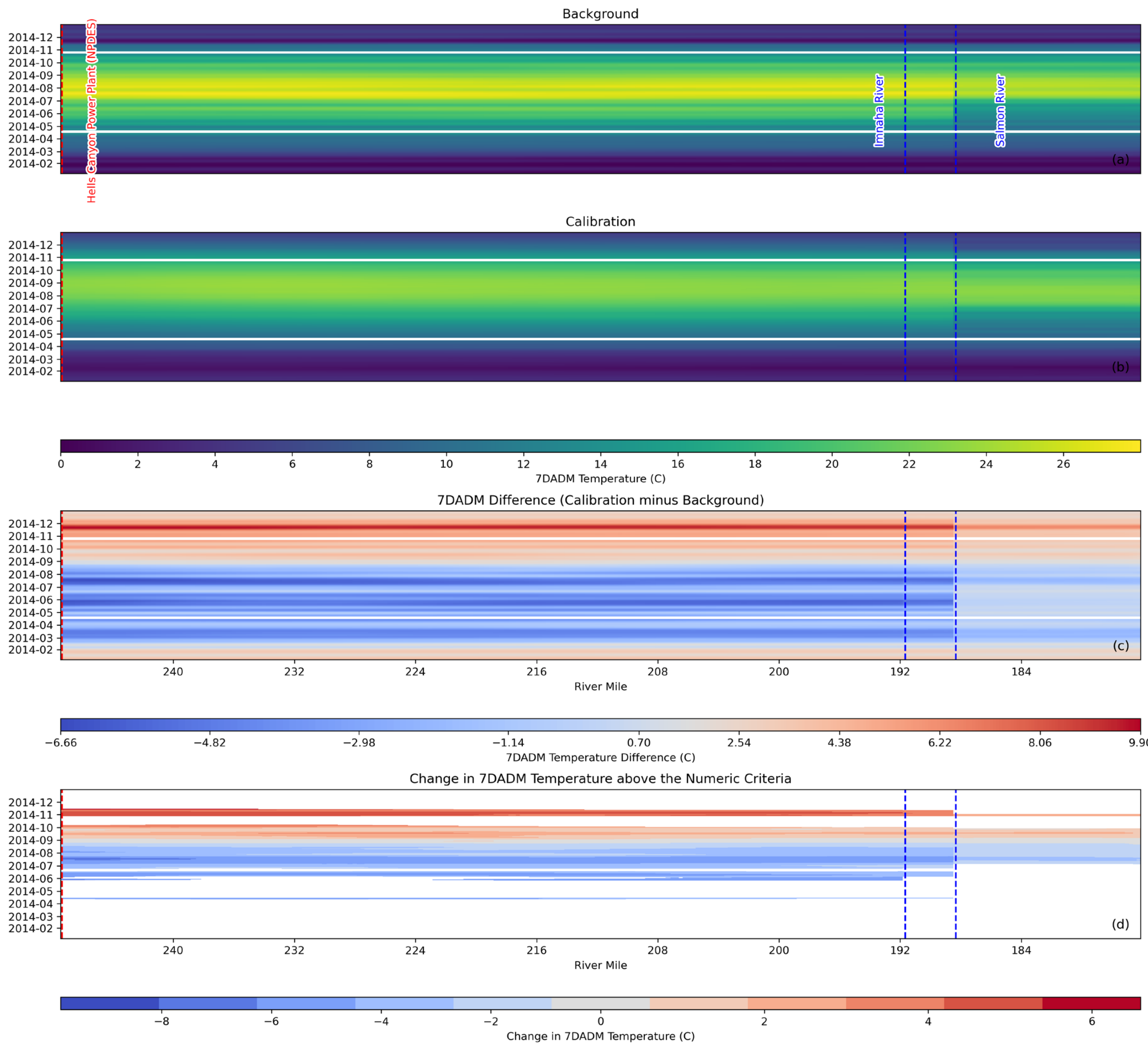


Figure 8-52. (a, b) 7DADM temperature for background and calibration scenarios, (c) temperature difference (calibration-background), and (d) change in 7DADM temperature above the numeric criteria where temperature from either scenario meets or exceeds the criterion, from HC Dam to Washington state line, 2014.

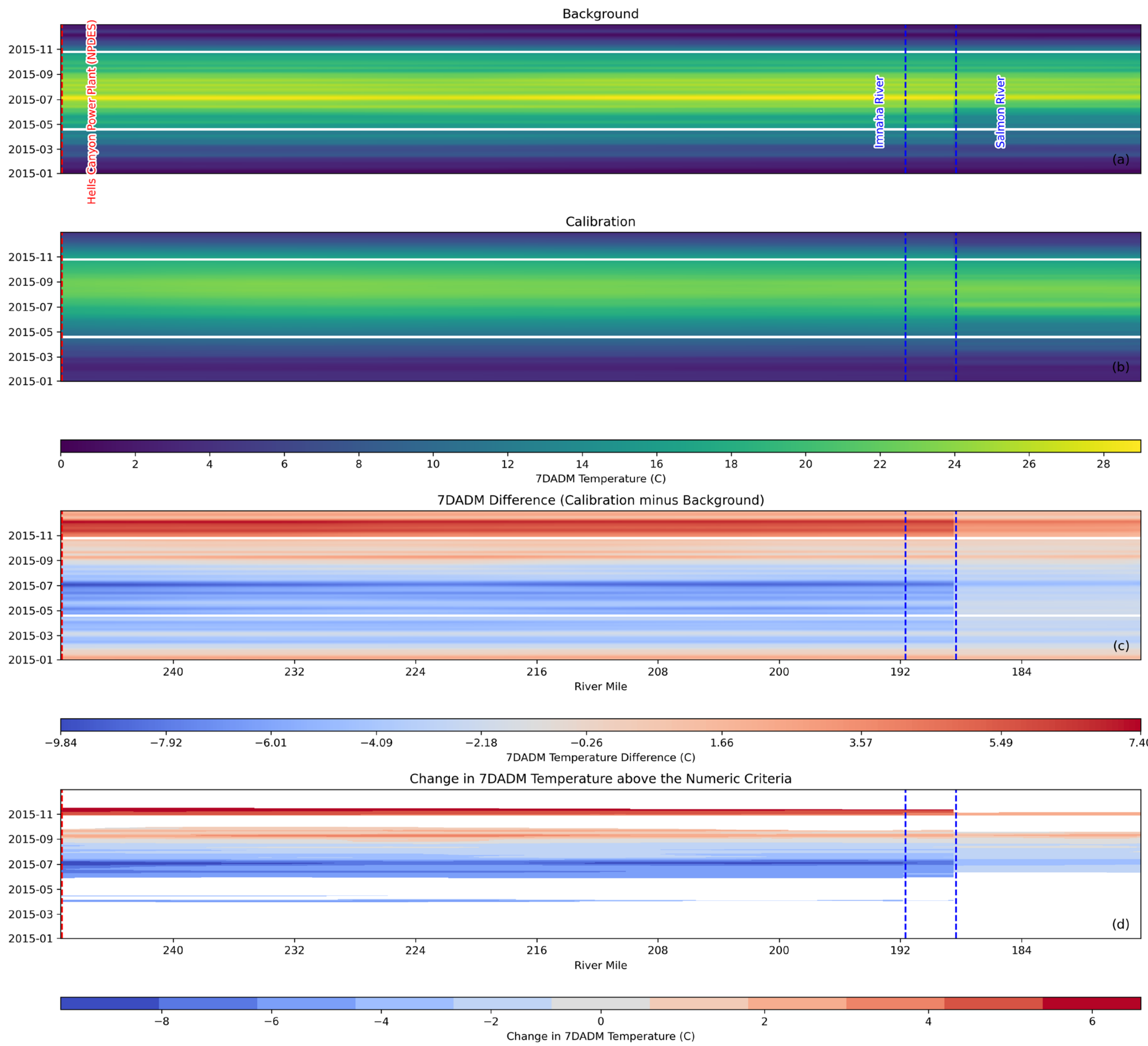


Figure 8-53. (a, b) 7DADM temperature for background and calibration scenarios, (c) temperature difference (calibration-background), and (d) change in 7DADM temperature above the numeric criteria where temperature from either scenario meets or exceeds the criterion, from HC Dam to Washington state line, 2015.

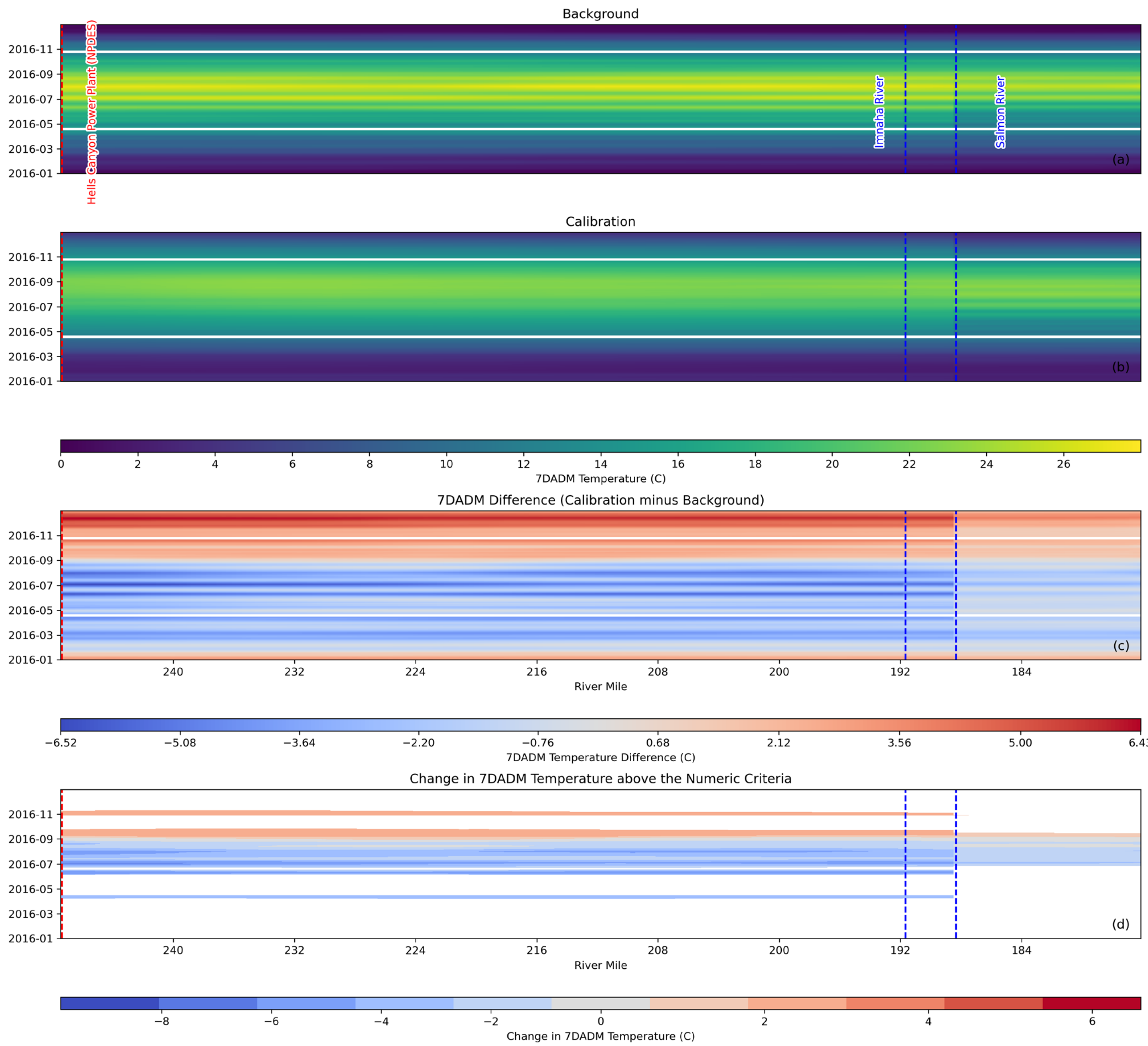


Figure 8-54. (a, b) 7DADM temperature for background and calibration scenarios, (c) temperature difference (calibration-background), and (d) change in 7DADM temperature above the numeric criteria where temperature from either scenario meets or exceeds the criterion, from HC Dam to Washington state line, 2016.

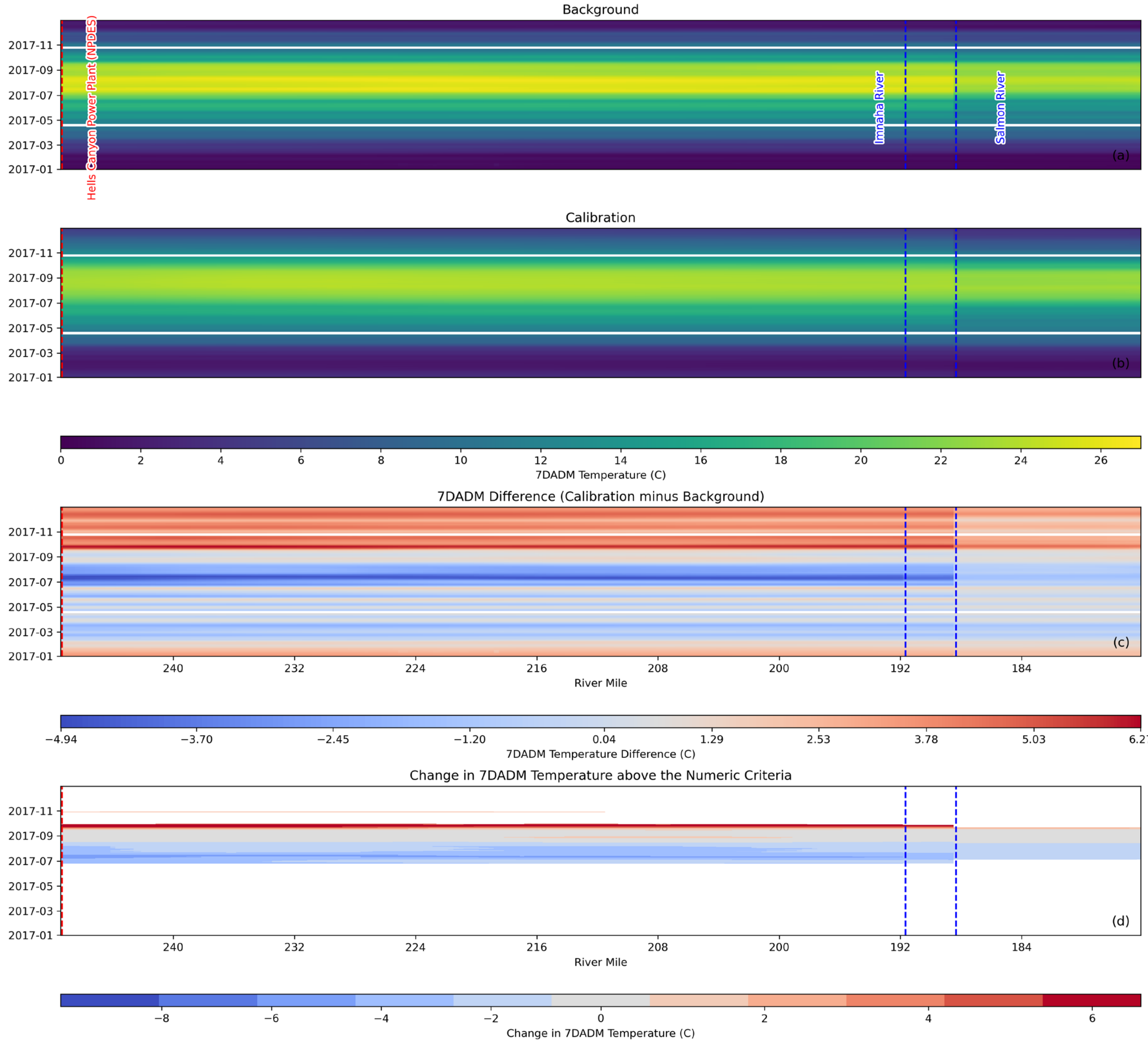


Figure 8-55. (a, b) 7DADM temperature for background and calibration scenarios, (c) temperature difference (calibration-background), and (d) change in 7DADM temperature above the numeric criteria where temperature from either scenario meets or exceeds the criterion, from HC Dam to Washington state line, 2017.

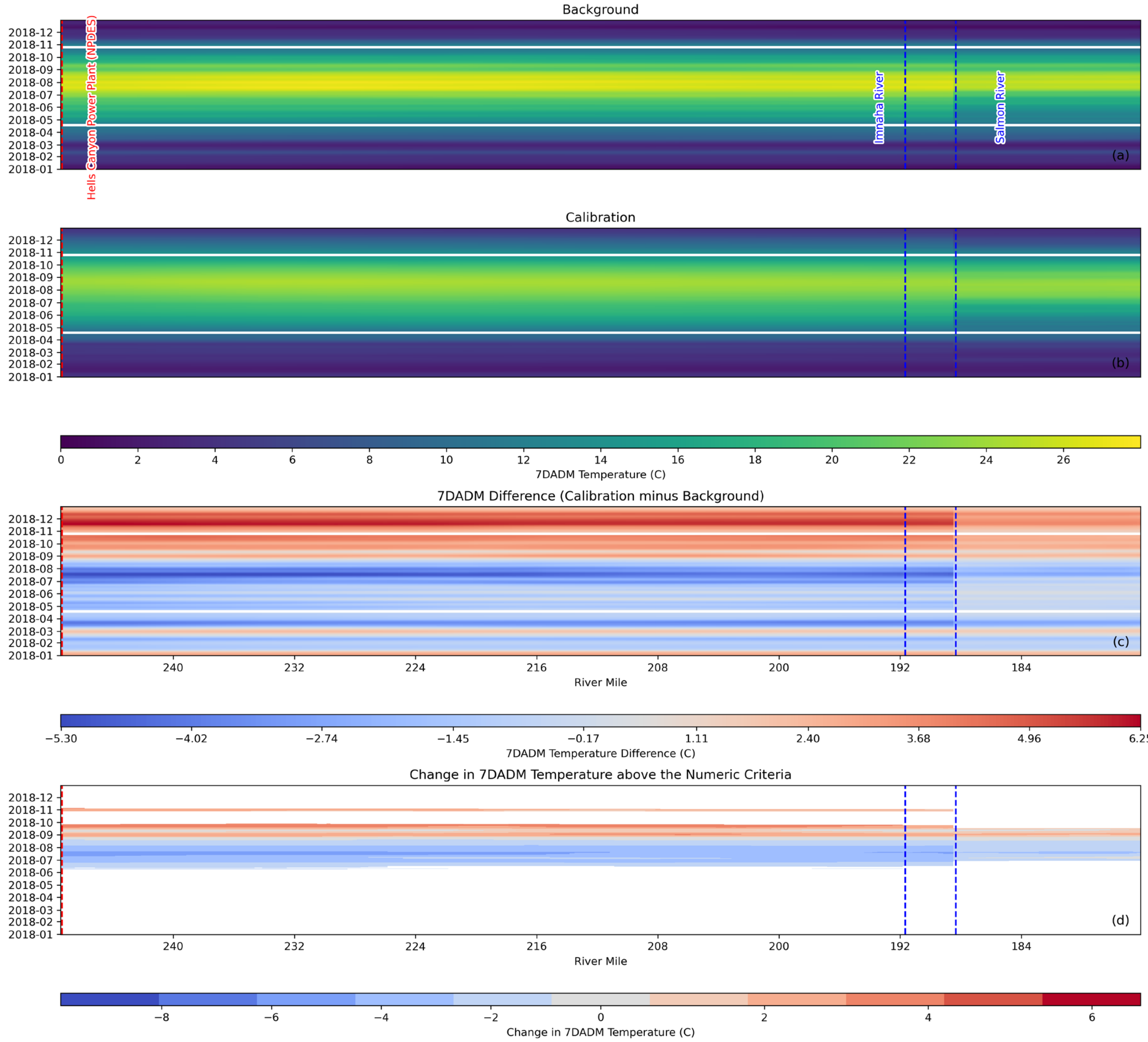


Figure 8-56. (a, b) 7DADM temperature for background and calibration scenarios, (c) temperature difference (calibration-background), and (d) change in 7DADM temperature above the numeric criteria where temperature from either scenario meets or exceeds the criterion, from HC Dam to Washington state line, 2018.

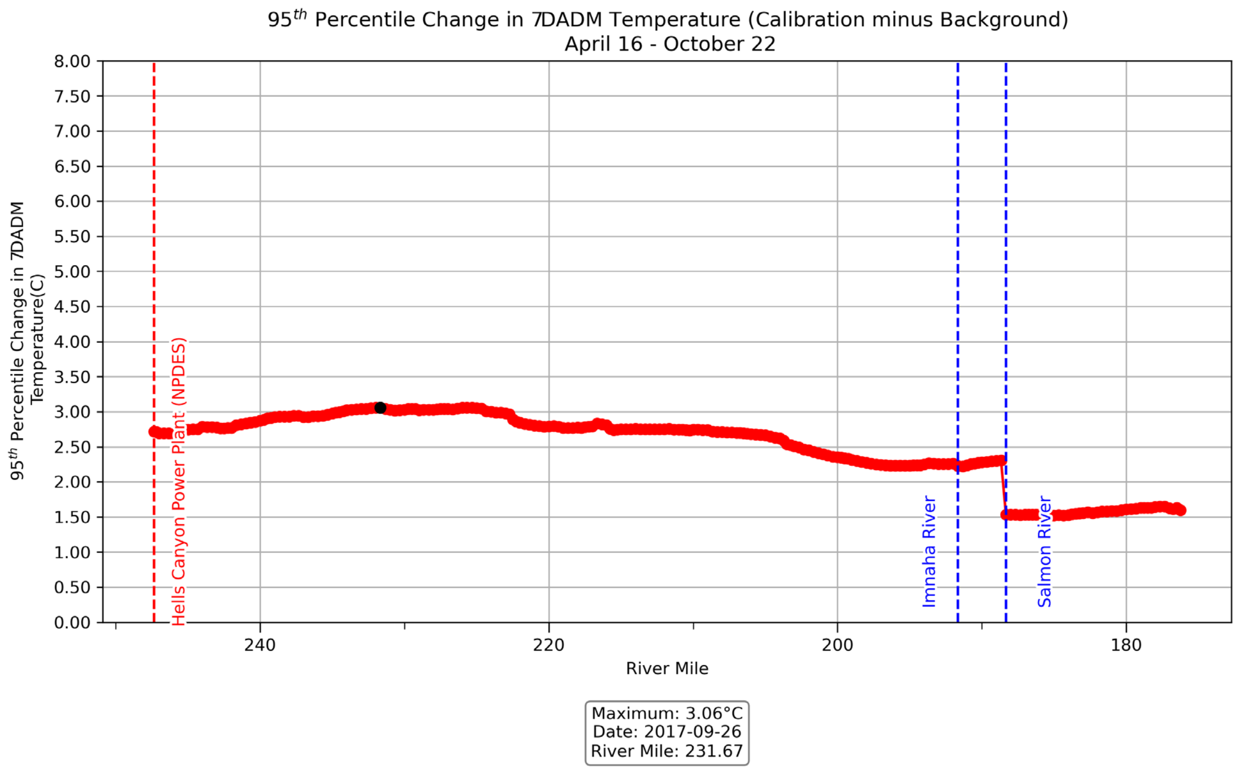


Figure 8-57. 95th percentile change in 7DADM temperature above applicable criteria during critical summer period.

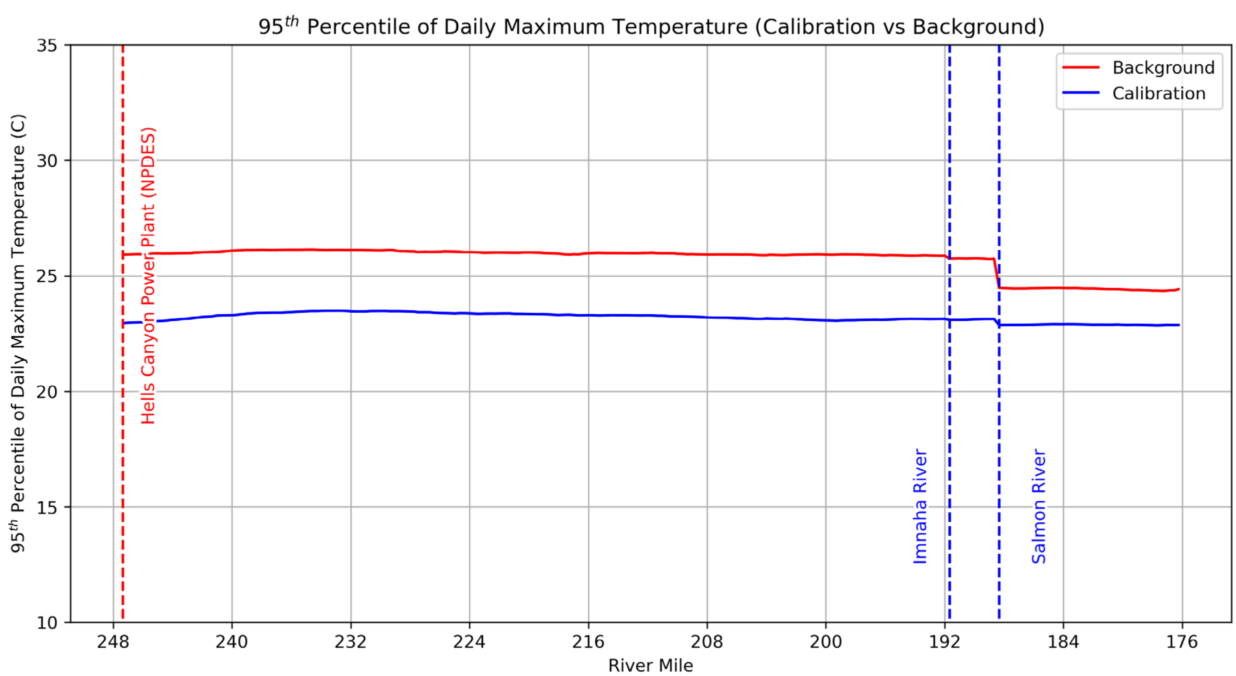


Figure 8-58. 95th percentile of daily maximum temperature for calibration and background scenarios, from HC Dam to Washington state line, 2014-2018.

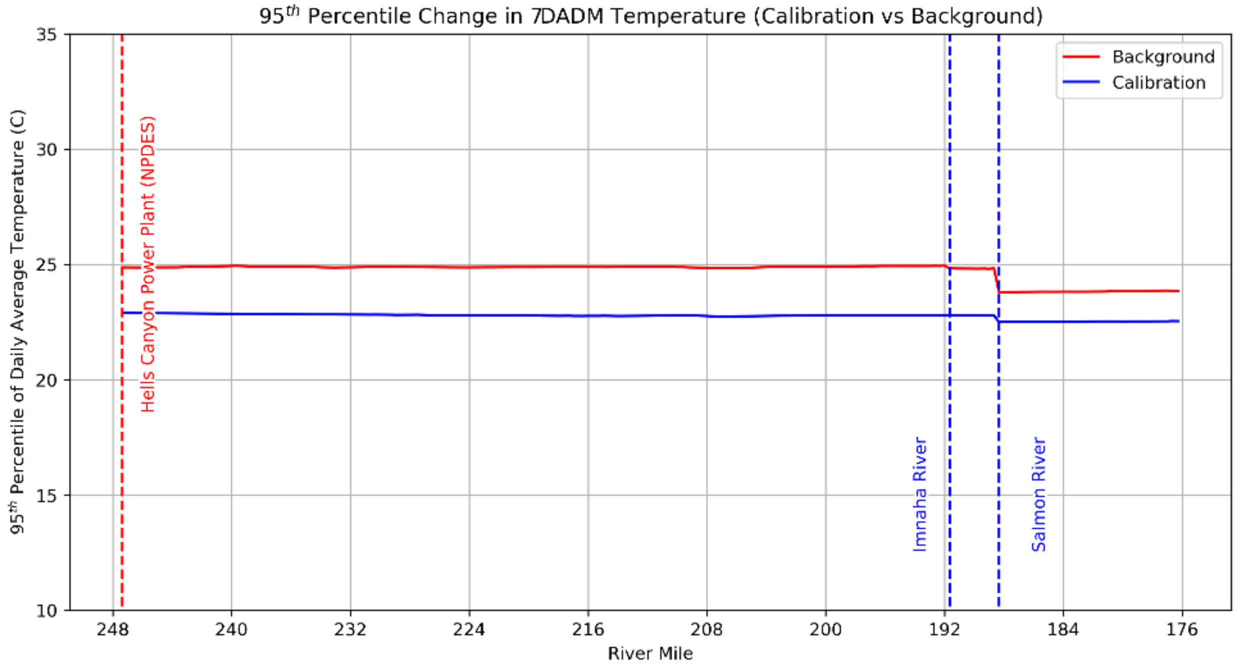


Figure 8-59. 95th percentile of daily average temperature for calibration and background scenarios, from HC Dam to Washington state line, 2014-2018.

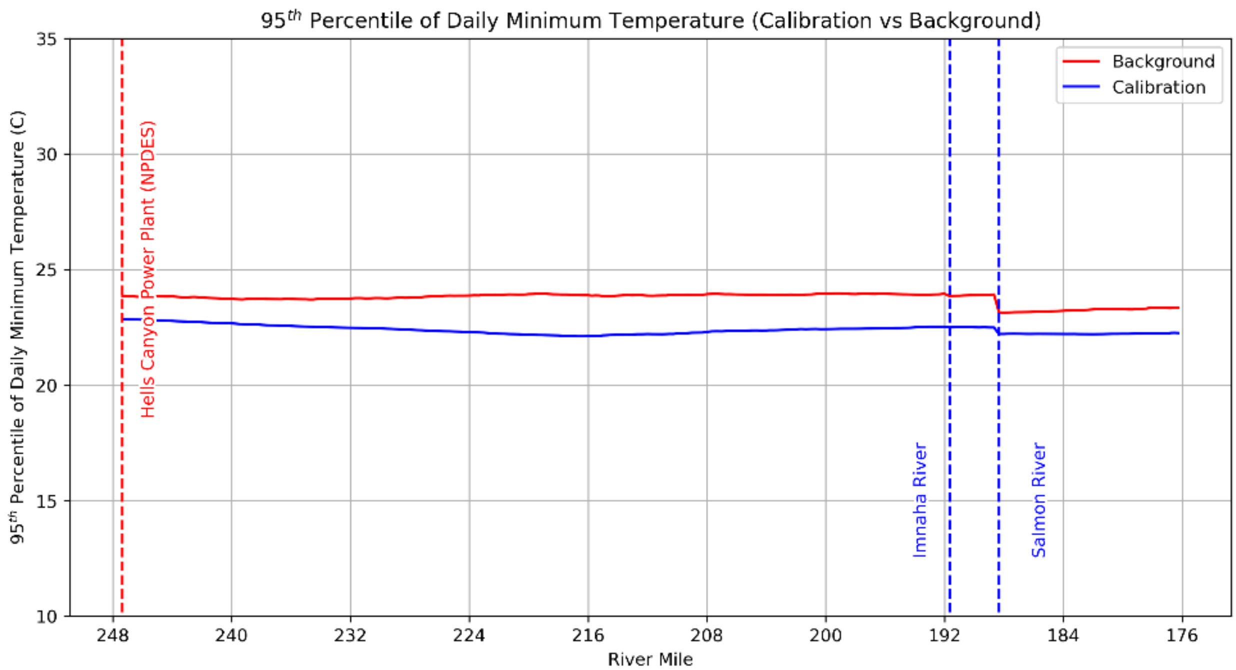


Figure 8-60. 95th percentile of daily minimum temperature for calibration and background scenarios, from HC Dam to Washington state line, 2014-2018.

8.1.5 Tributary A vs. Background

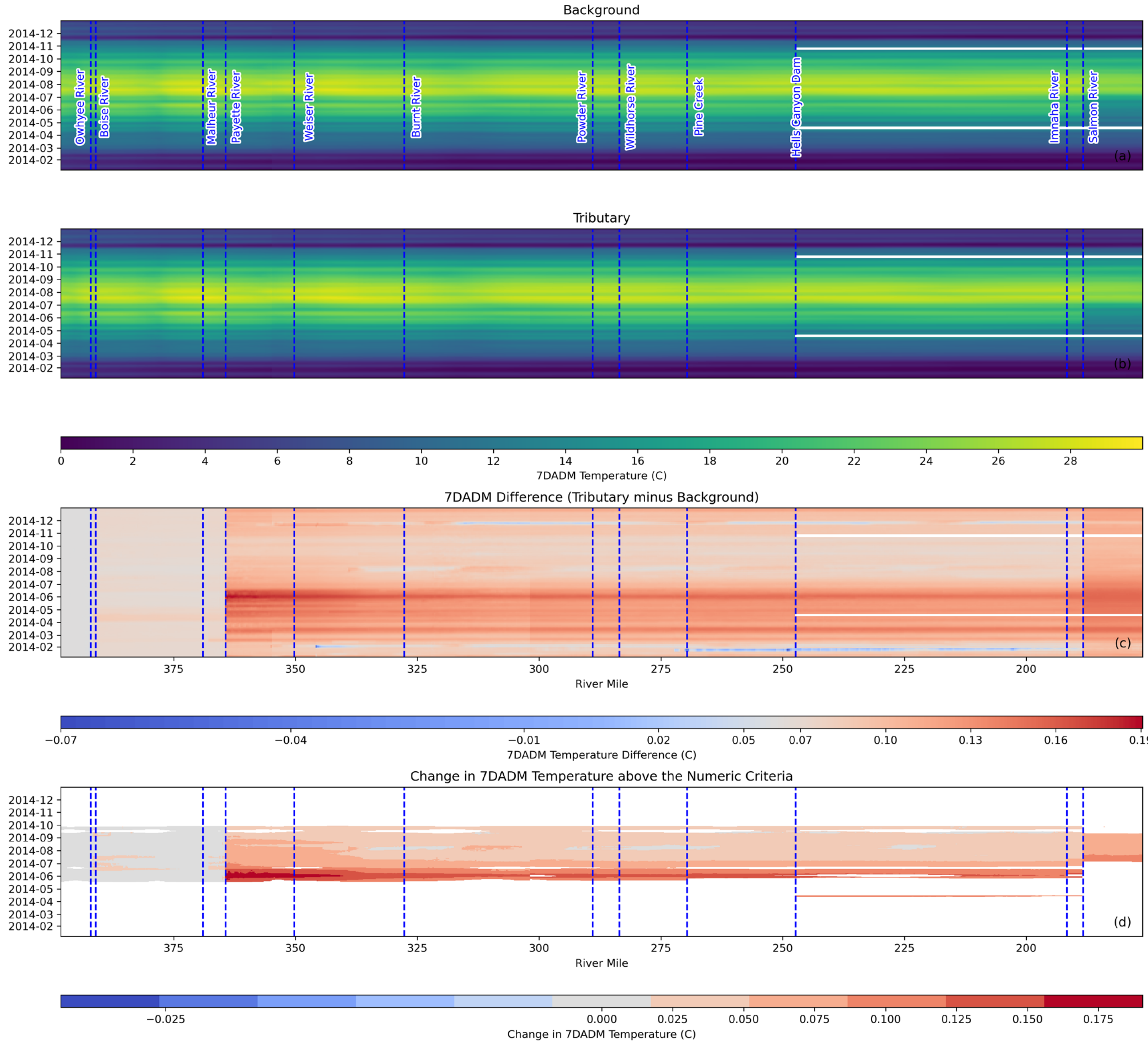


Figure 8-61. (a, b) 7DADM temperature for background and tributary scenarios, (c) temperature difference (tributary-background), and (d) change in 7DADM temperature above the numeric criteria where temperature from either scenario meets or exceeds the criterion, from Adrian to Washington state line, 2014.

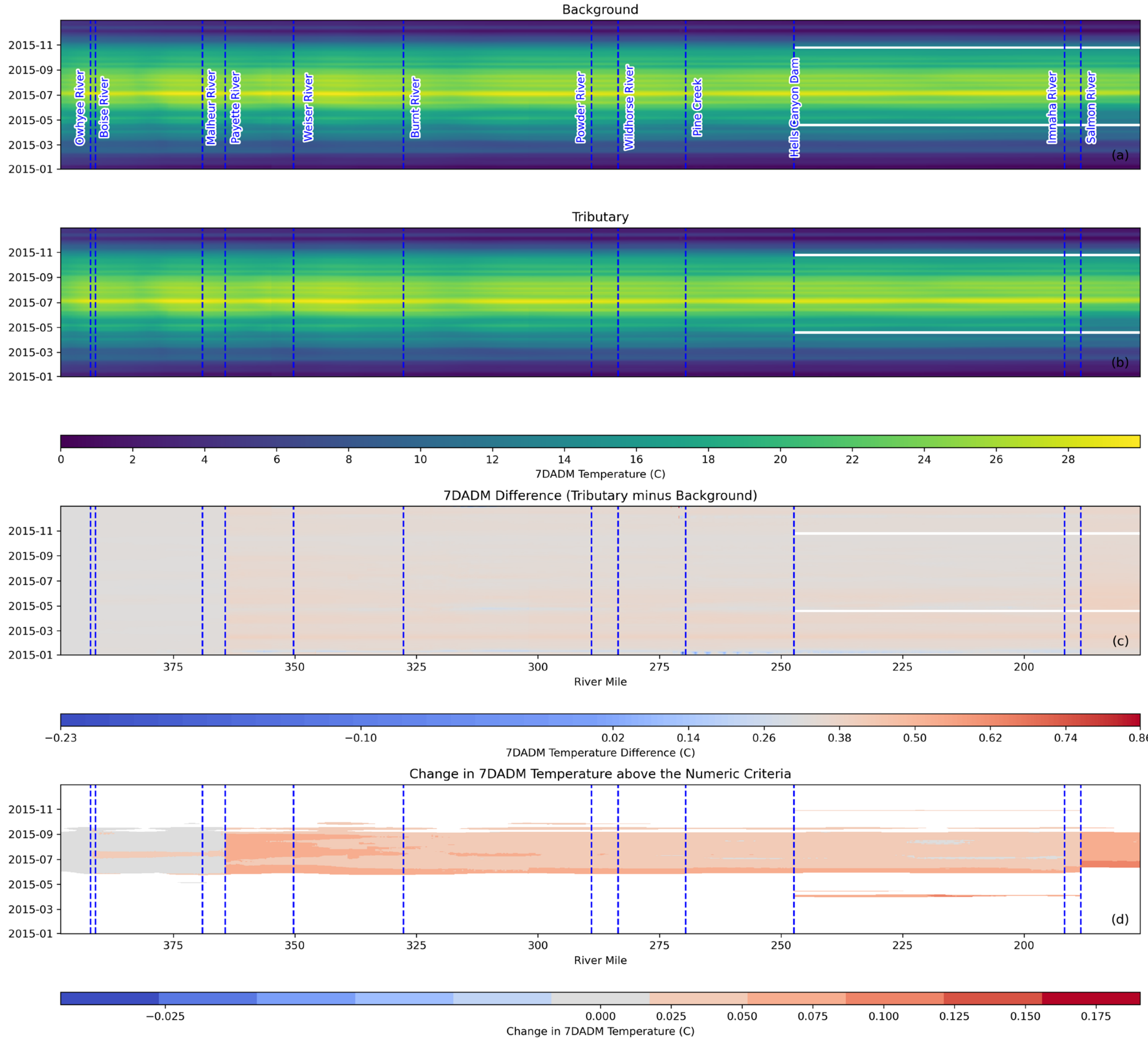


Figure 8-62. (a, b) 7DADM temperature for background and tributary scenarios, (c) temperature difference (tributary-background), and (d) change in 7DADM temperature above the numeric criteria where temperature from either scenario meets or exceeds the criterion, from Adrian to Washington state line, 2015.

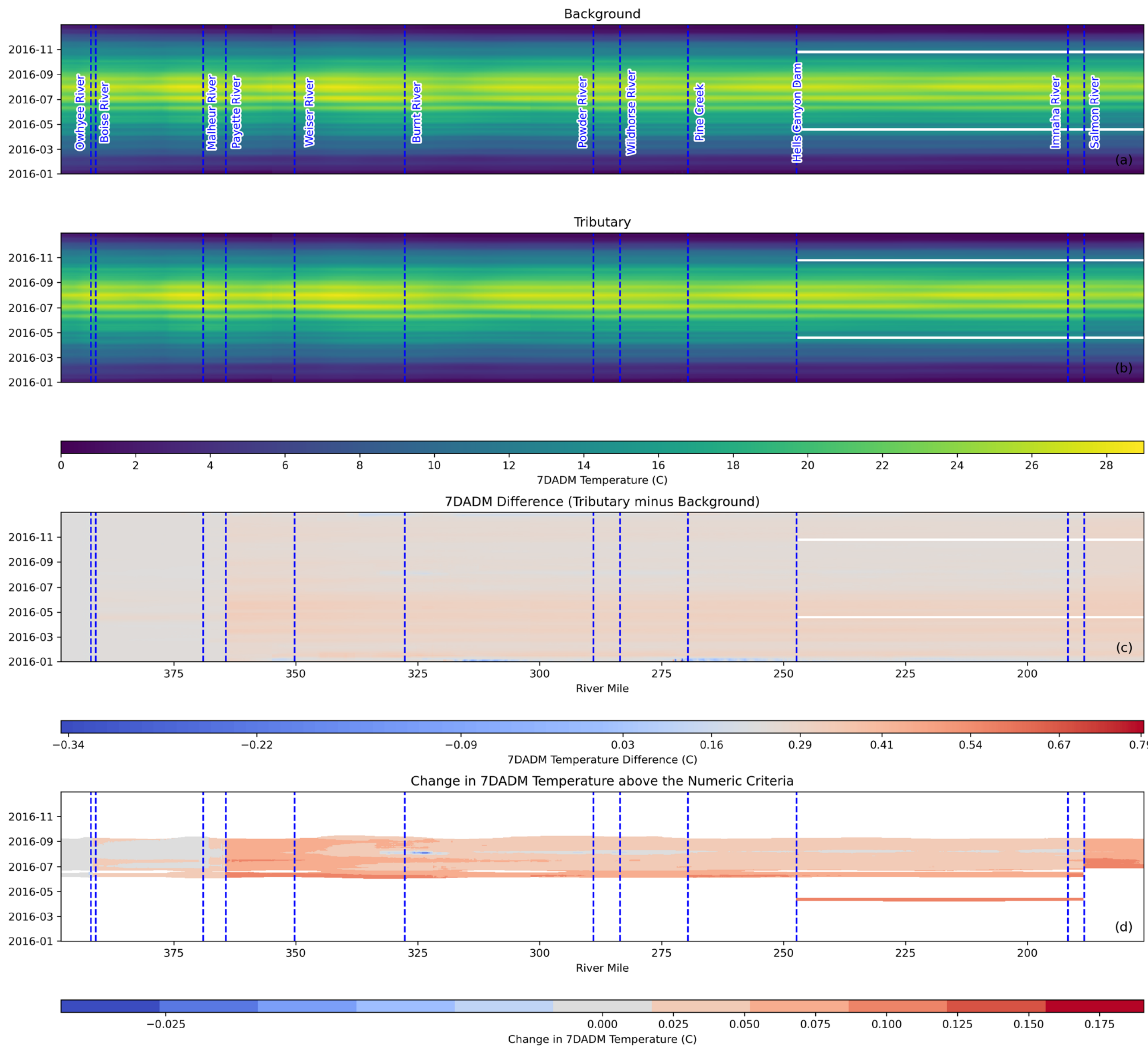


Figure 8-63. (a, b) 7DADM temperature for background and tributary scenarios, (c) temperature difference (tributary-background), and (d) change in 7DADM temperature above the numeric criteria where temperature from either scenario meets or exceeds the criterion, from Adrian to Washington state line, 2016.

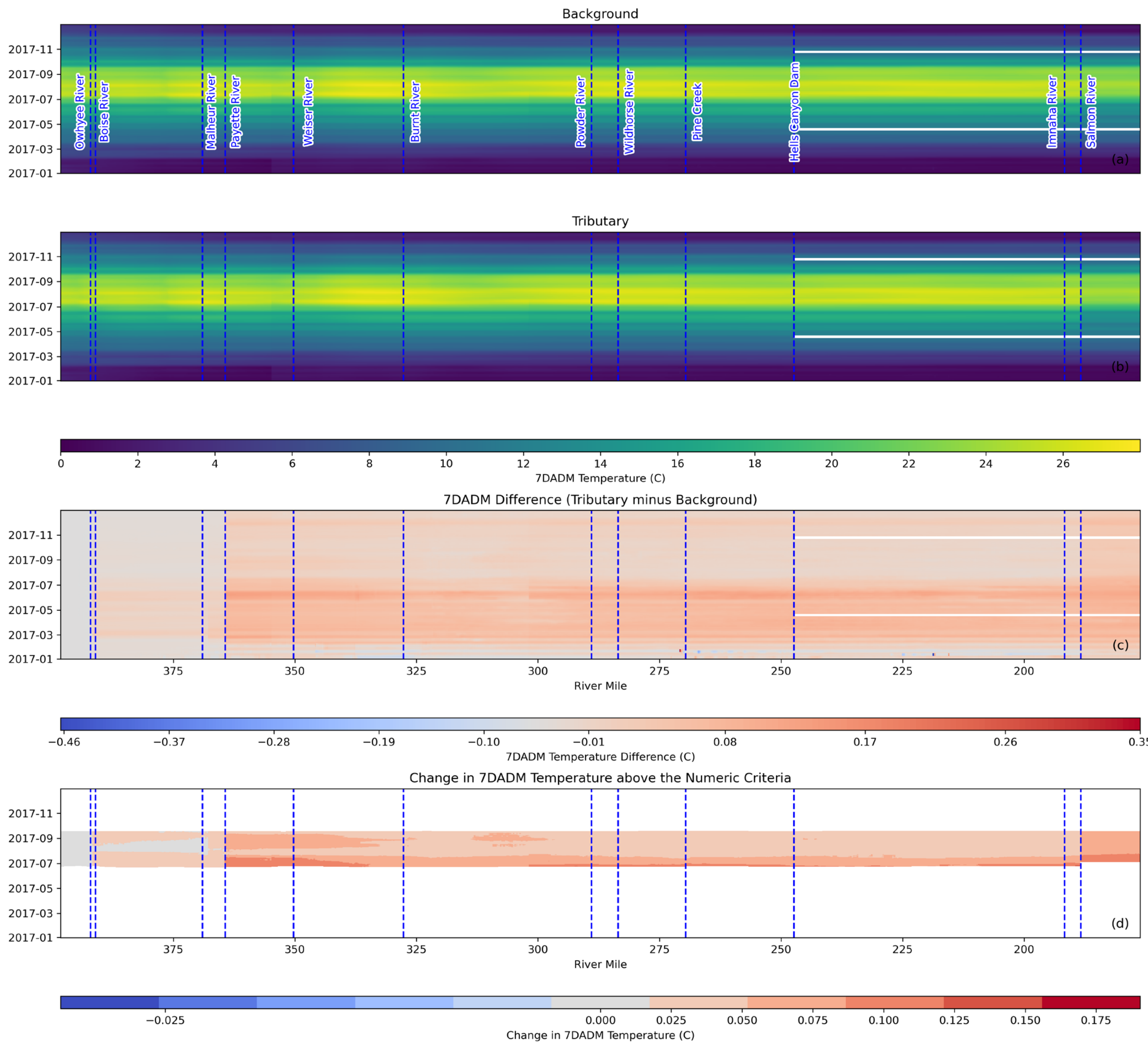


Figure 8-64. (a, b) 7DADM temperature for background and tributary scenarios, (c) temperature difference (tributary-background), and (d) change in 7DADM temperature above the numeric criteria where temperature from either scenario meets or exceeds the criterion, from Adrian to Washington state line, 2017.

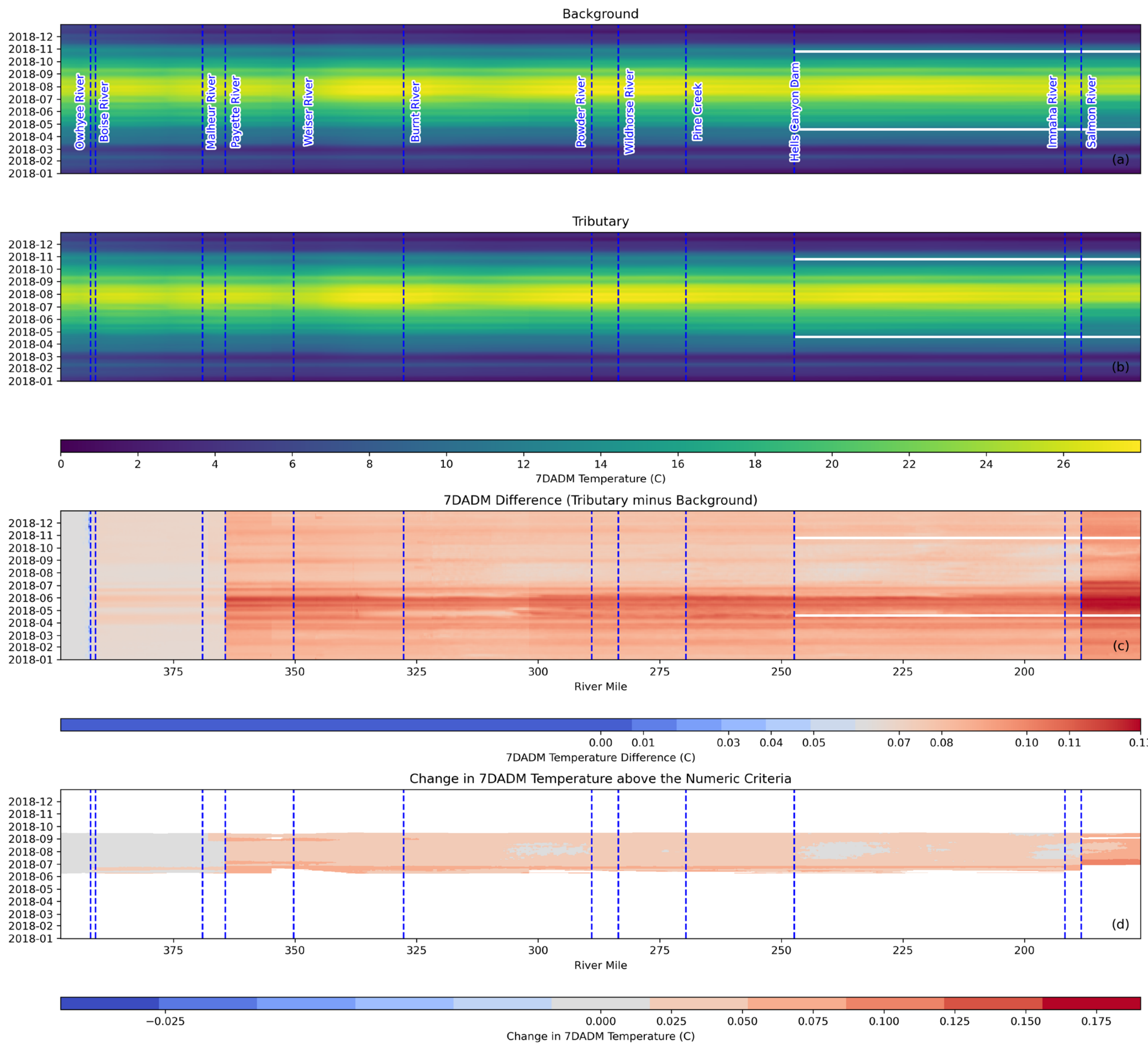


Figure 8-65. (a, b) 7DADM temperature for background and tributary scenarios, (c) temperature difference (tributary-background), and (d) change in 7DADM temperature above the numeric criteria where temperature from either scenario meets or exceeds the criterion, from Adrian to Washington state line, 2018.

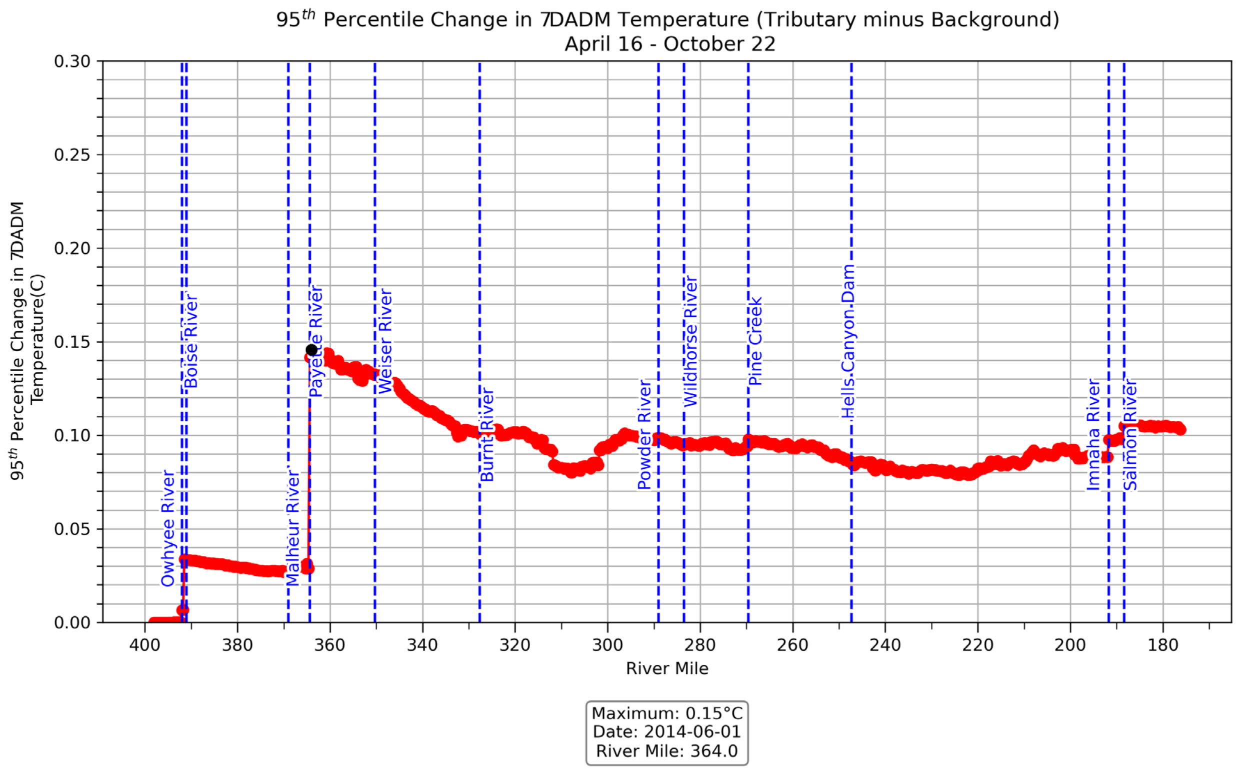


Figure 8-66. 95th percentile change in 7DADM temperature above applicable criteria during critical summer period.

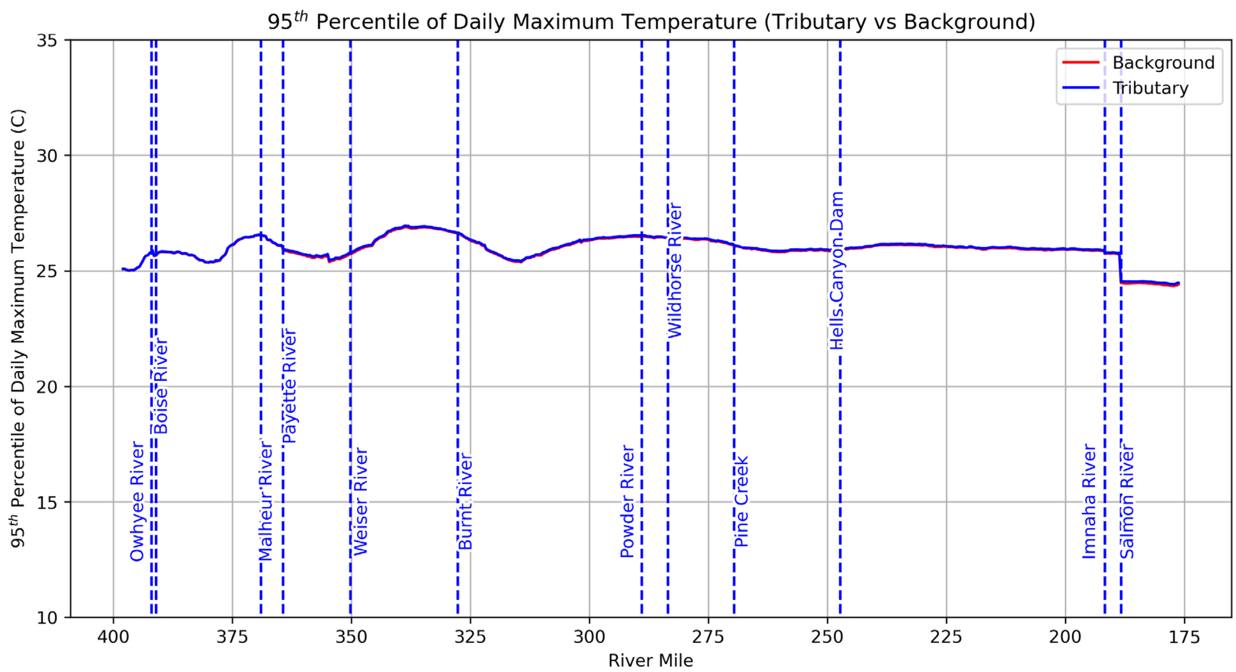


Figure 8-67. 95th percentile of daily maximum temperature for tributary and background scenarios, from Adrian to Washington state line, 2014-2018.

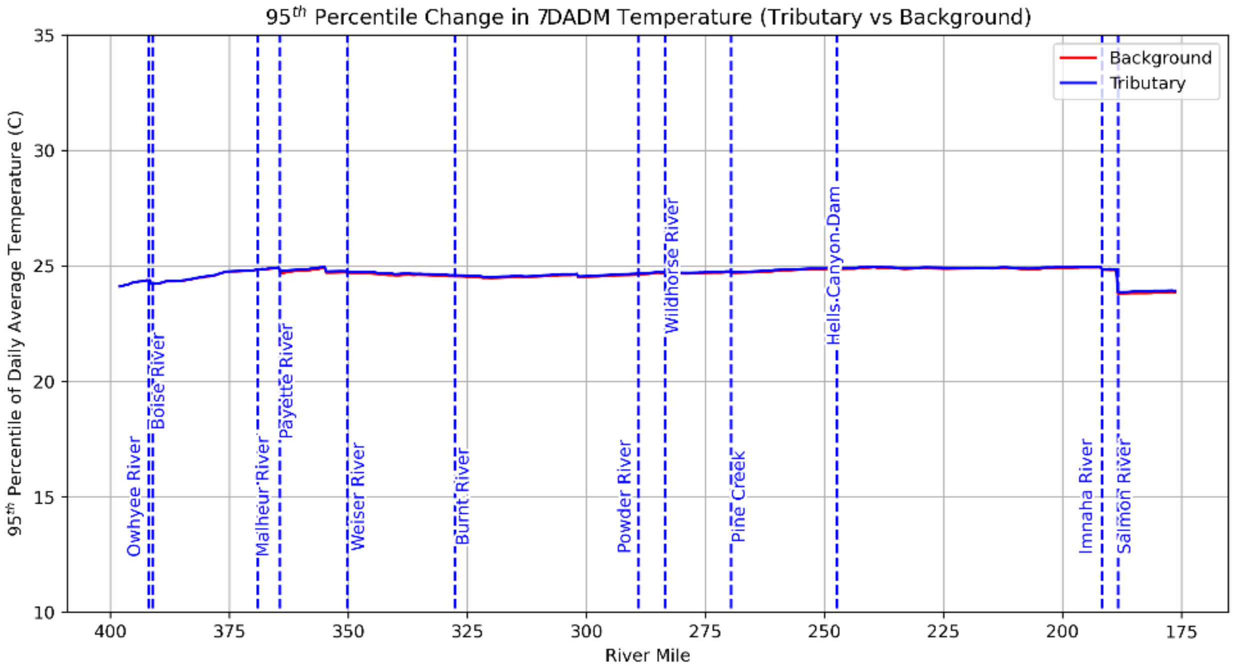


Figure 8-68. 95th percentile of daily average temperature for tributary and background scenarios, from Adrian to Washington state line, 2014-2018.

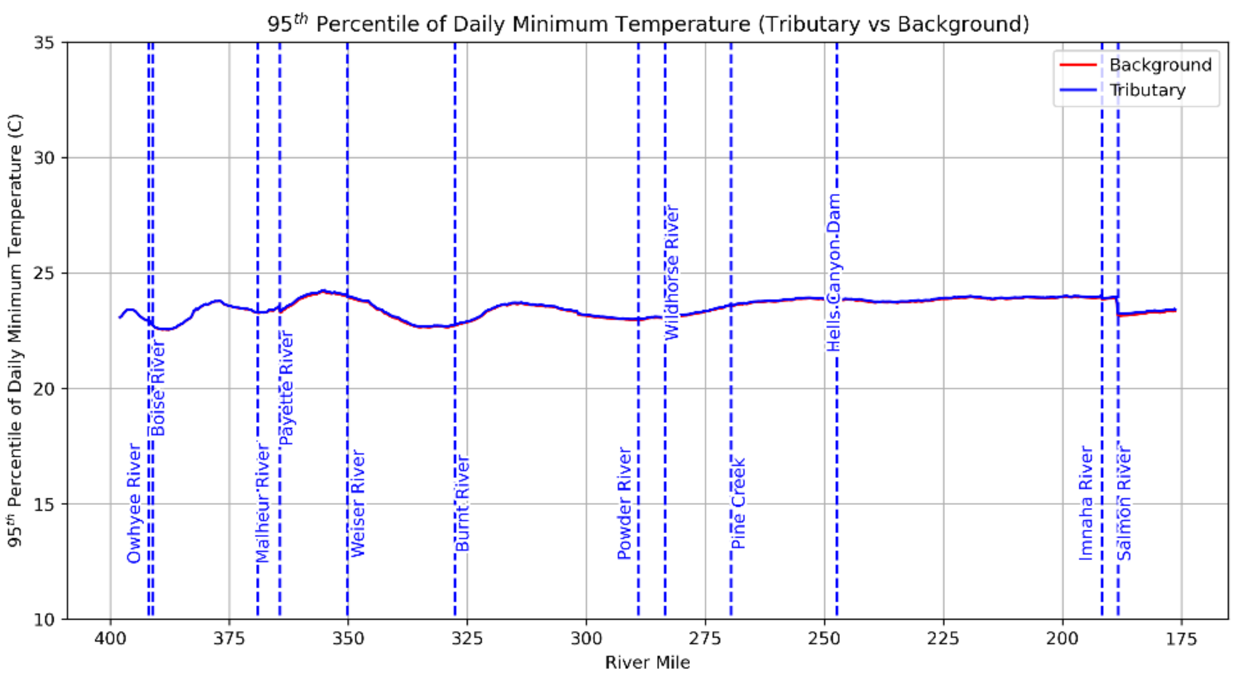


Figure 8-69. 95th percentile of daily minimum temperature for tributary and background scenarios, from Adrian to Washington state line, 2014-2018.

8.1.6 Waste Load Allocation vs. Background

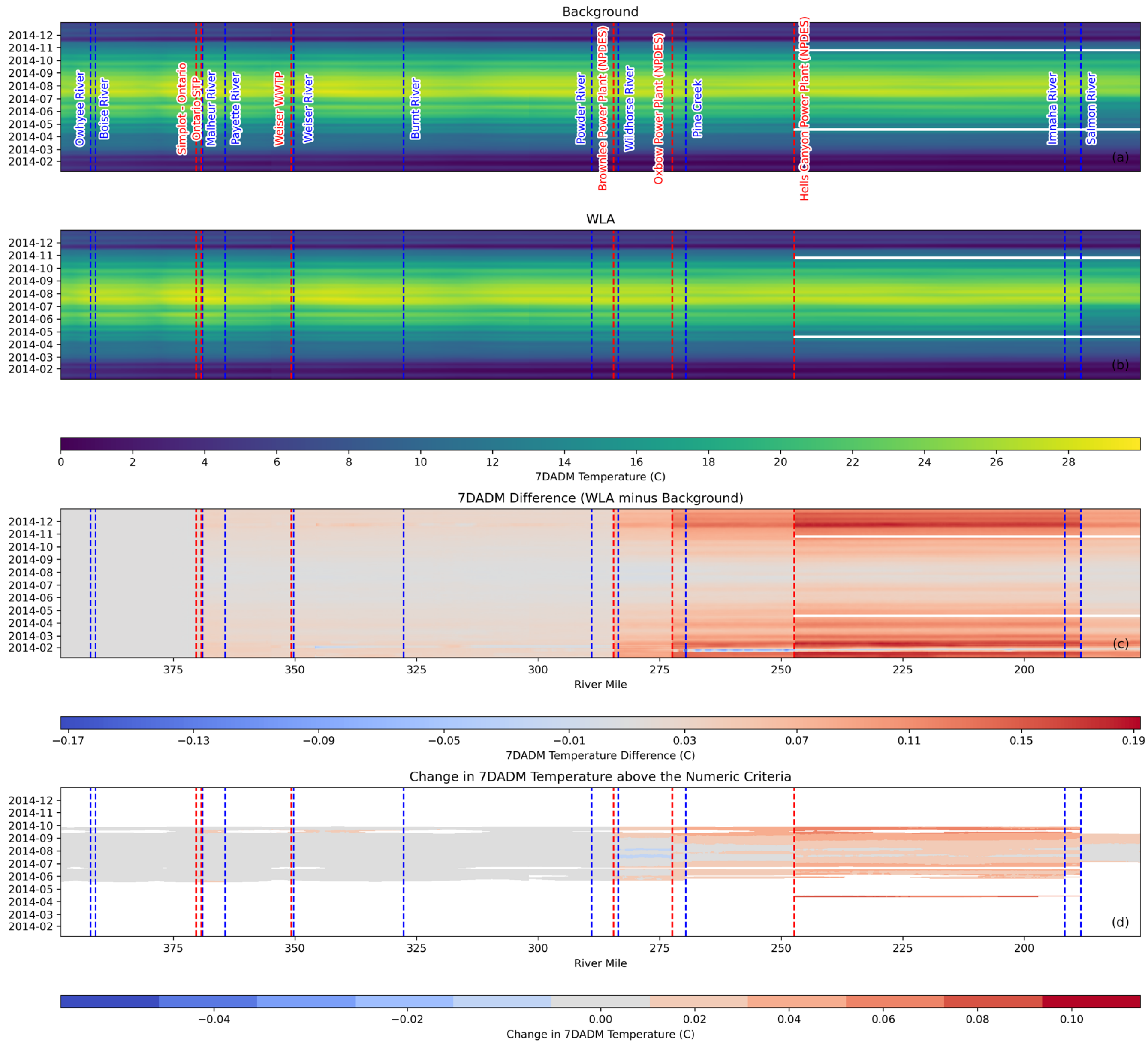


Figure 8-70. (a, b) 7DADM temperature for background and WLA scenarios, (c) temperature difference (WLA-background), and (d) change in 7DADM temperature above the numeric criteria where temperature from either scenario meets or exceeds the criterion, from Adrian to Washington state line, 2014.

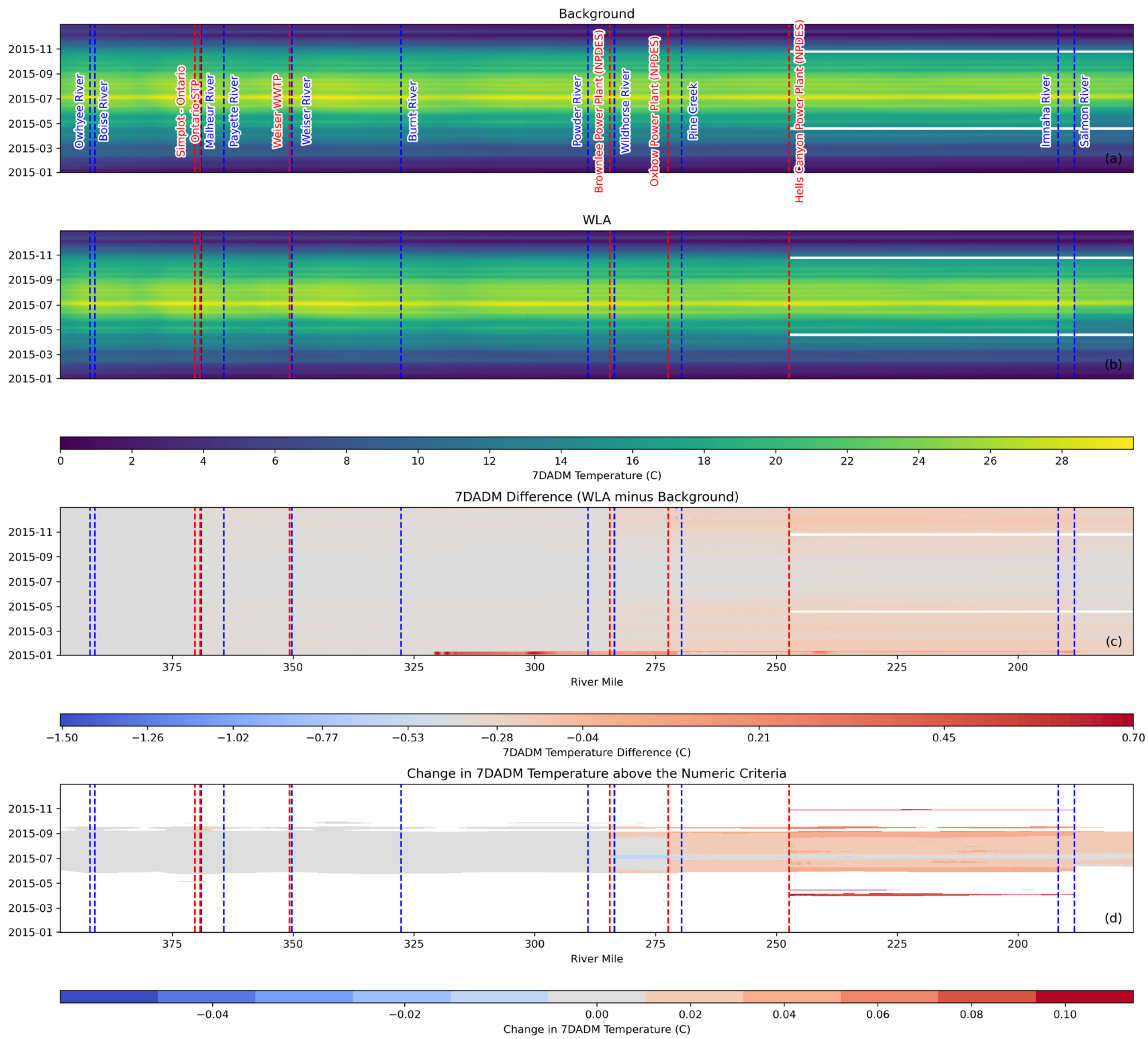


Figure 8-71. (a, b) 7DADM temperature for background and WLA scenarios, (c) temperature difference (WLA-background), and (d) change in 7DADM temperature above the numeric criteria where temperature from either scenario meets or exceeds the criterion, from Adrian to Washington state line, 2015.

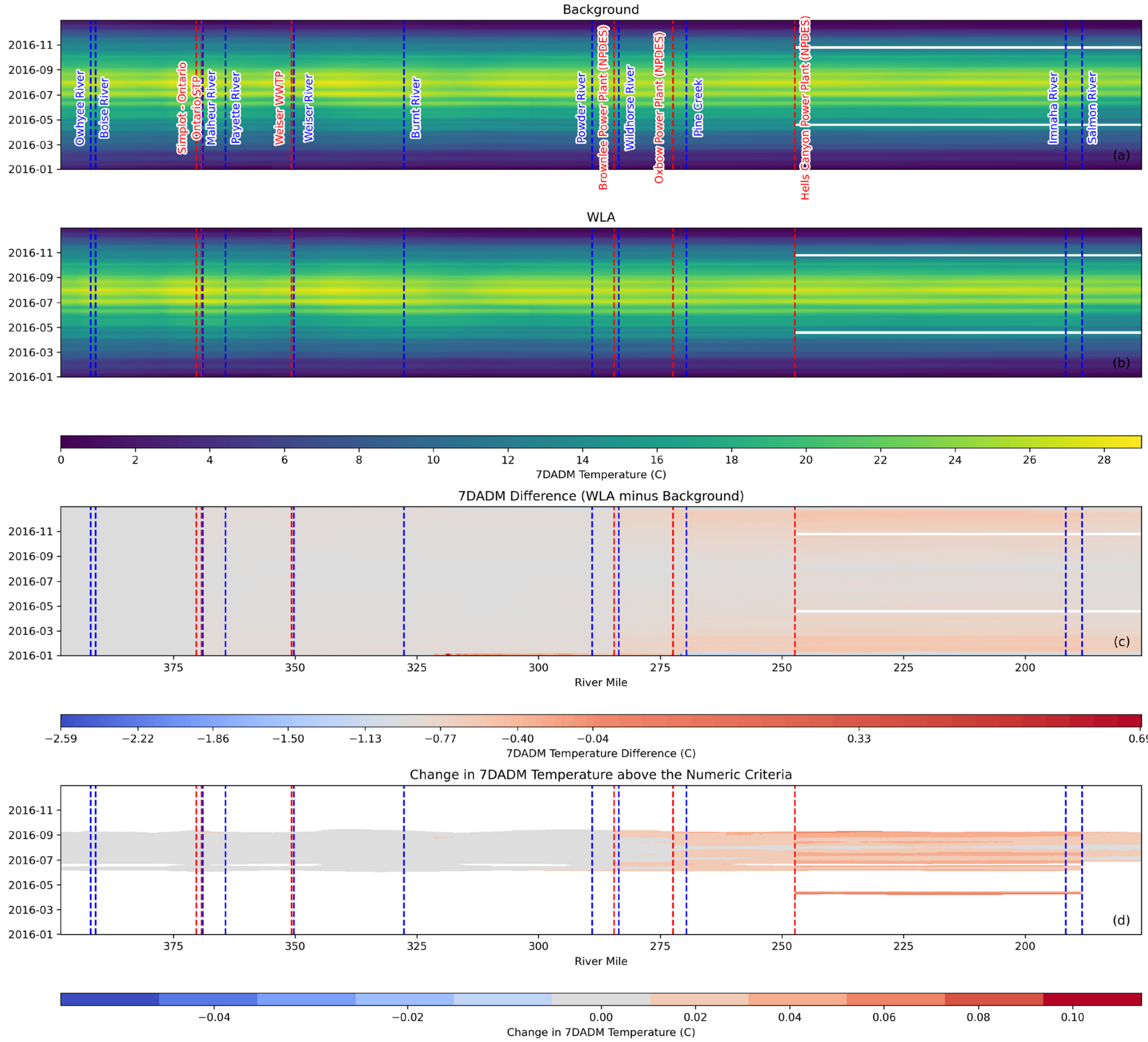


Figure 8-72. (a, b) 7DADM temperature for background and WLA scenarios, (c) temperature difference (WLA-background), and (d) change in 7DADM temperature above the numeric criteria where temperature from either scenario meets or exceeds the criterion, from Adrian to Washington state line, 2016.

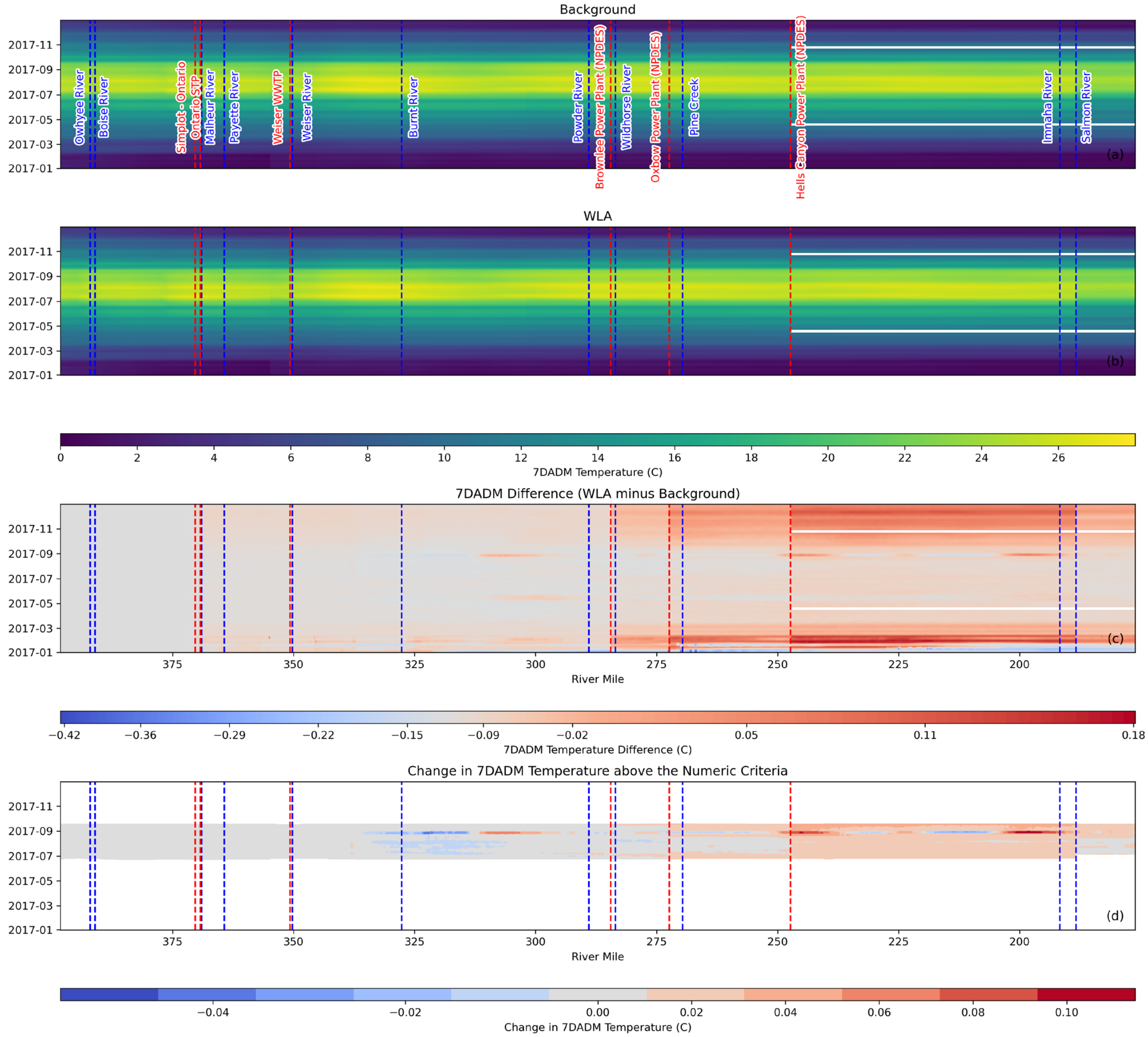


Figure 8-73. **(a, b) 7DADM temperature for background and WLA scenarios, (c) temperature difference (WLA-background), and (d) change in 7DADM temperature above the numeric criteria where temperature from either scenario meets or exceeds the criterion, from Adrian to Washington state line, 2017.**

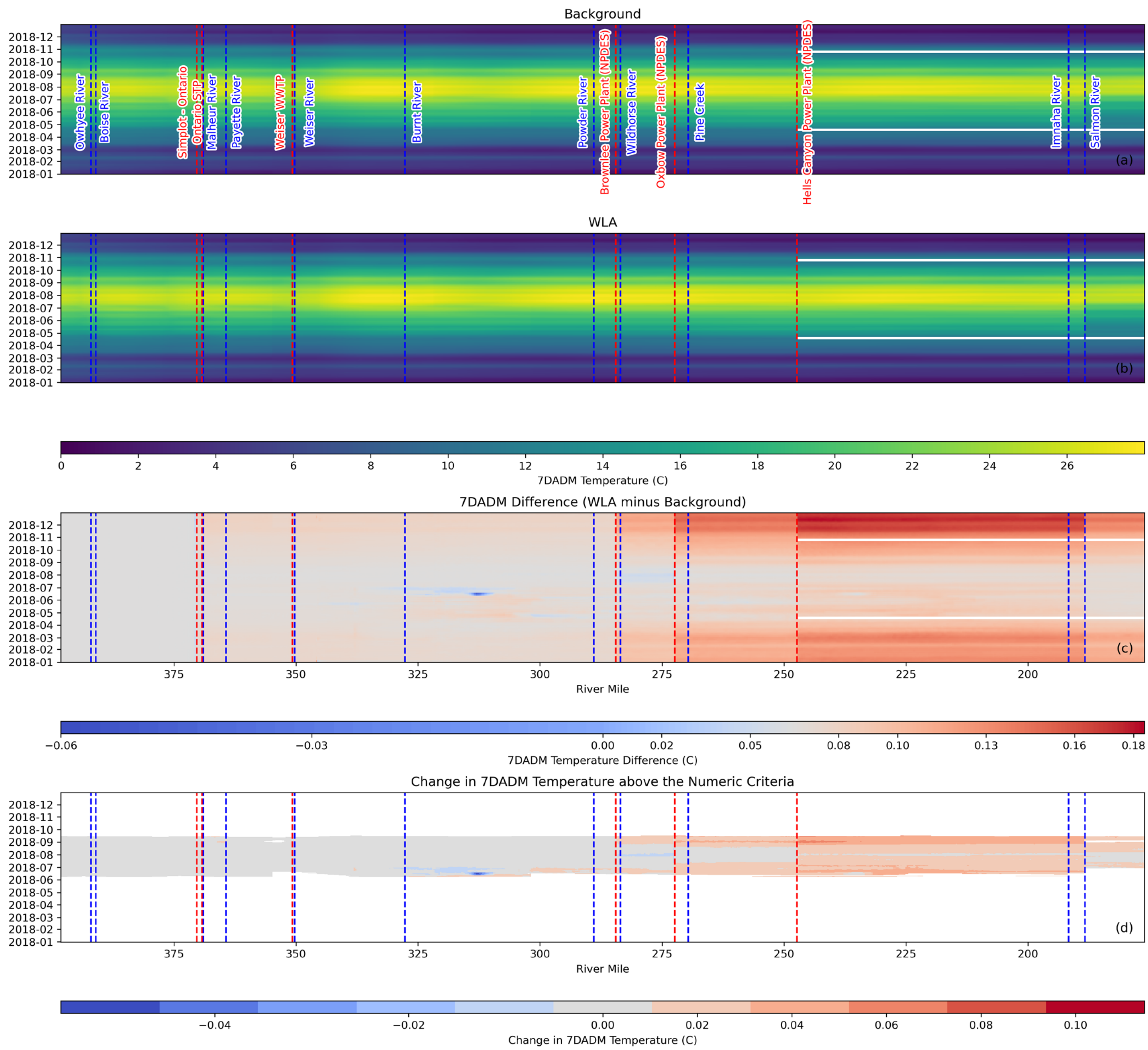


Figure 8-74. (a, b) 7DADM temperature for background and WLA scenarios, (c) temperature difference (WLA-background), and (d) change in 7DADM temperature above the numeric criteria where temperature from either scenario meets or exceeds the criterion, from Adrian to Washington state line, 2018.

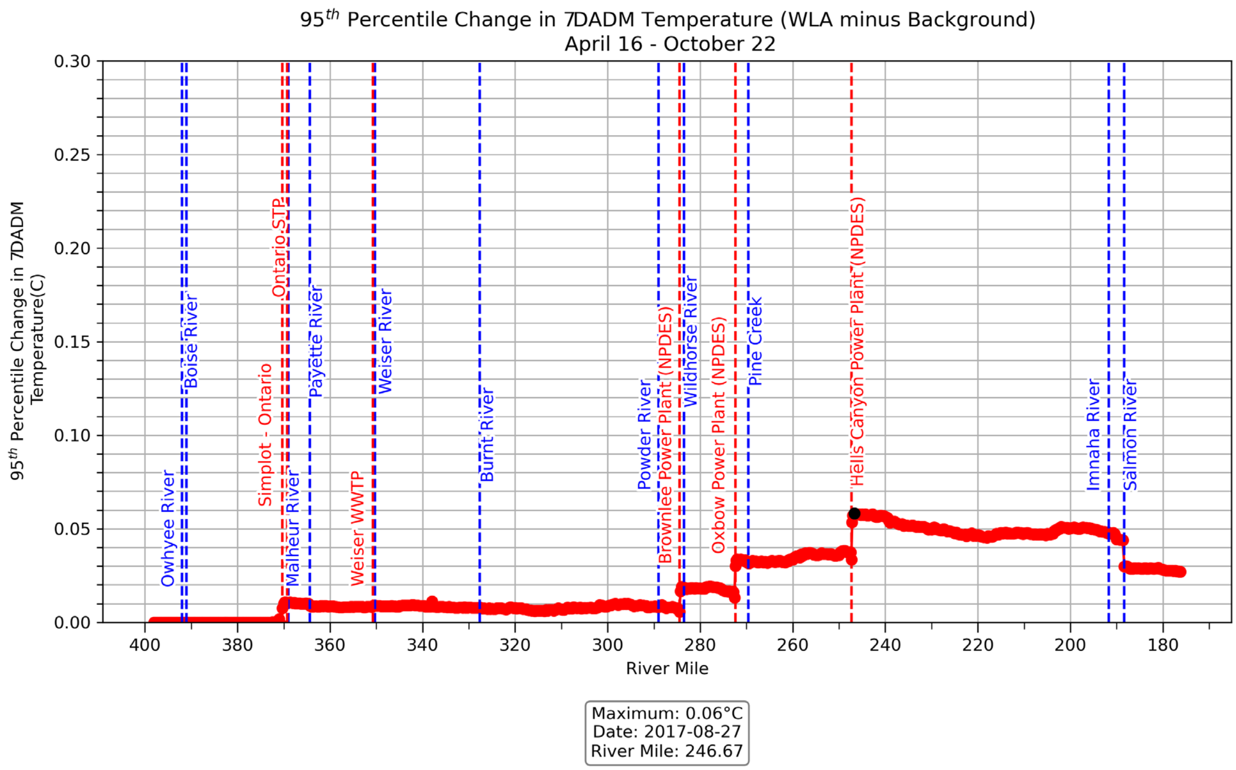


Figure 8-75. 95th percentile change in 7DADM temperature above applicable criteria during critical summer period.

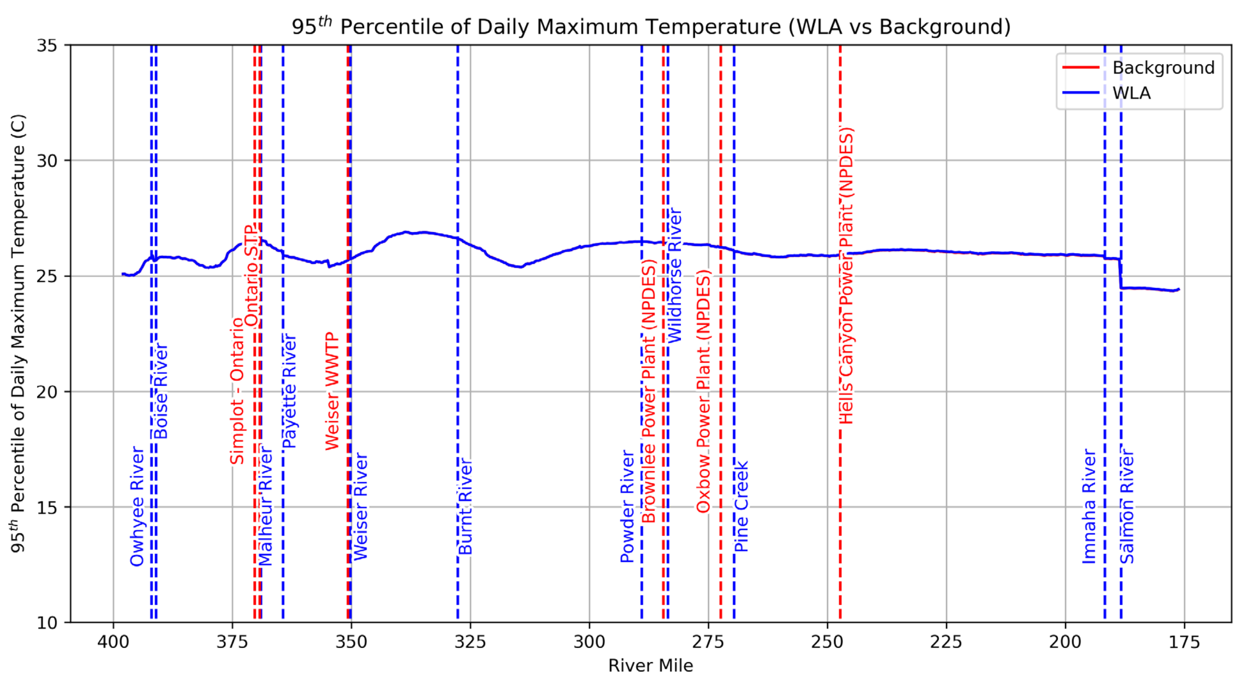


Figure 8-76. 95th percentile of daily maximum temperature for WLA and background scenarios, from Adrian to Washington state line, 2014-2018.

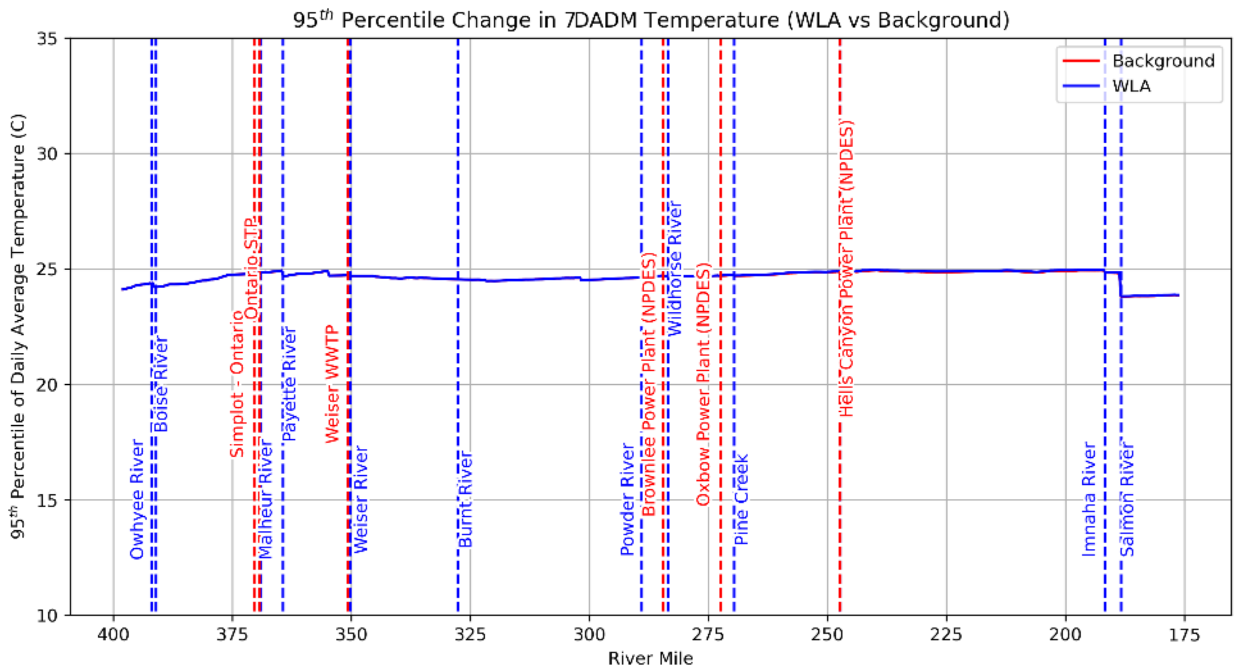


Figure 8-77. 95th percentile of daily average temperature for WLA and background scenarios, from Adrian to Washington state line, 2014-2018.

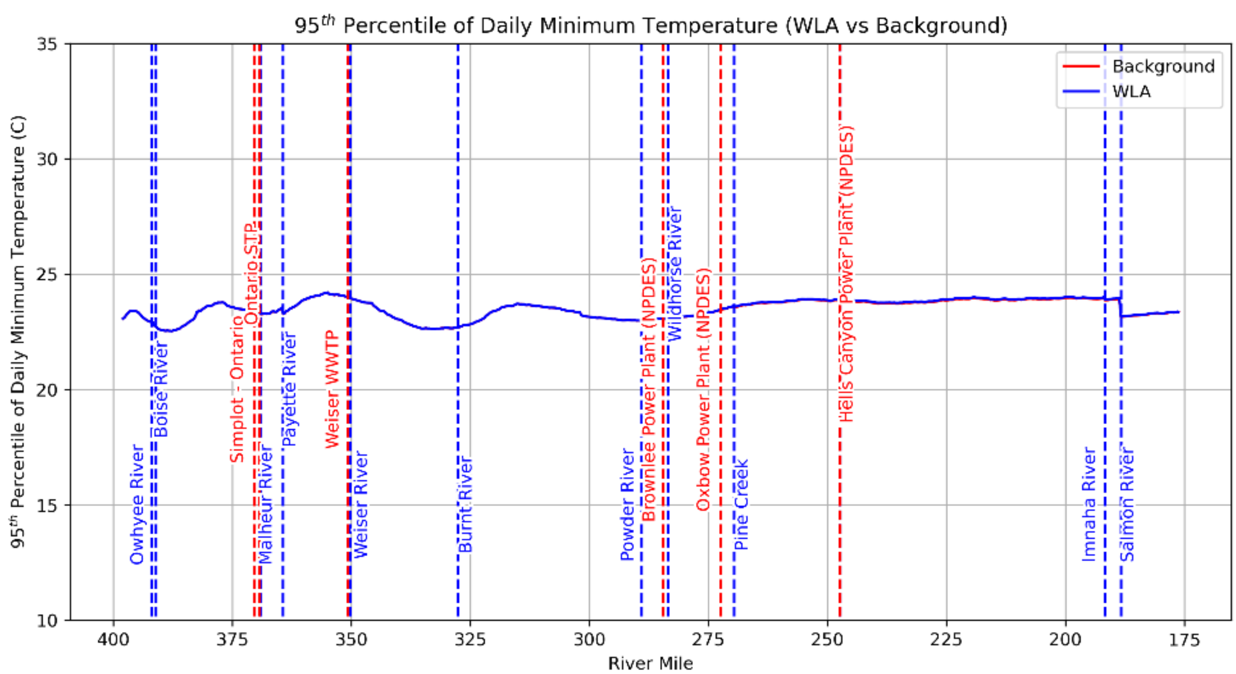


Figure 8-78. 95th percentile of daily minimum temperature for WLA and background scenarios, from Adrian to Washington state line, 2014-2018.

8.1.7 HUA Attainment vs. Background

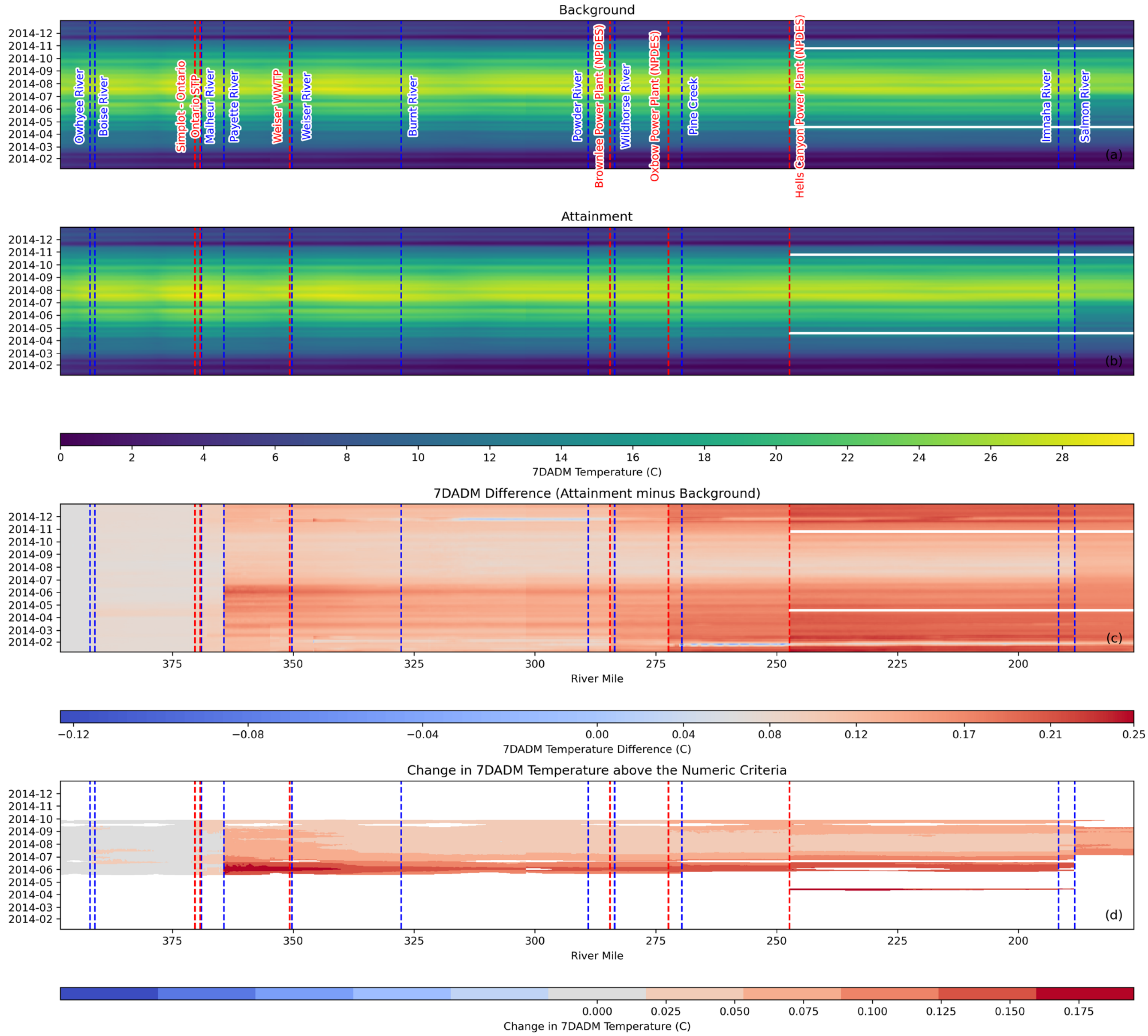


Figure 8-79. (a, b) 7DADM temperature for background and attainment scenarios, (c) temperature difference (attainment-background), and (d) change in 7DADM temperature above the numeric criteria where temperature from either scenario meets or exceeds the criterion, from Adrian to Washington state line, 2014.

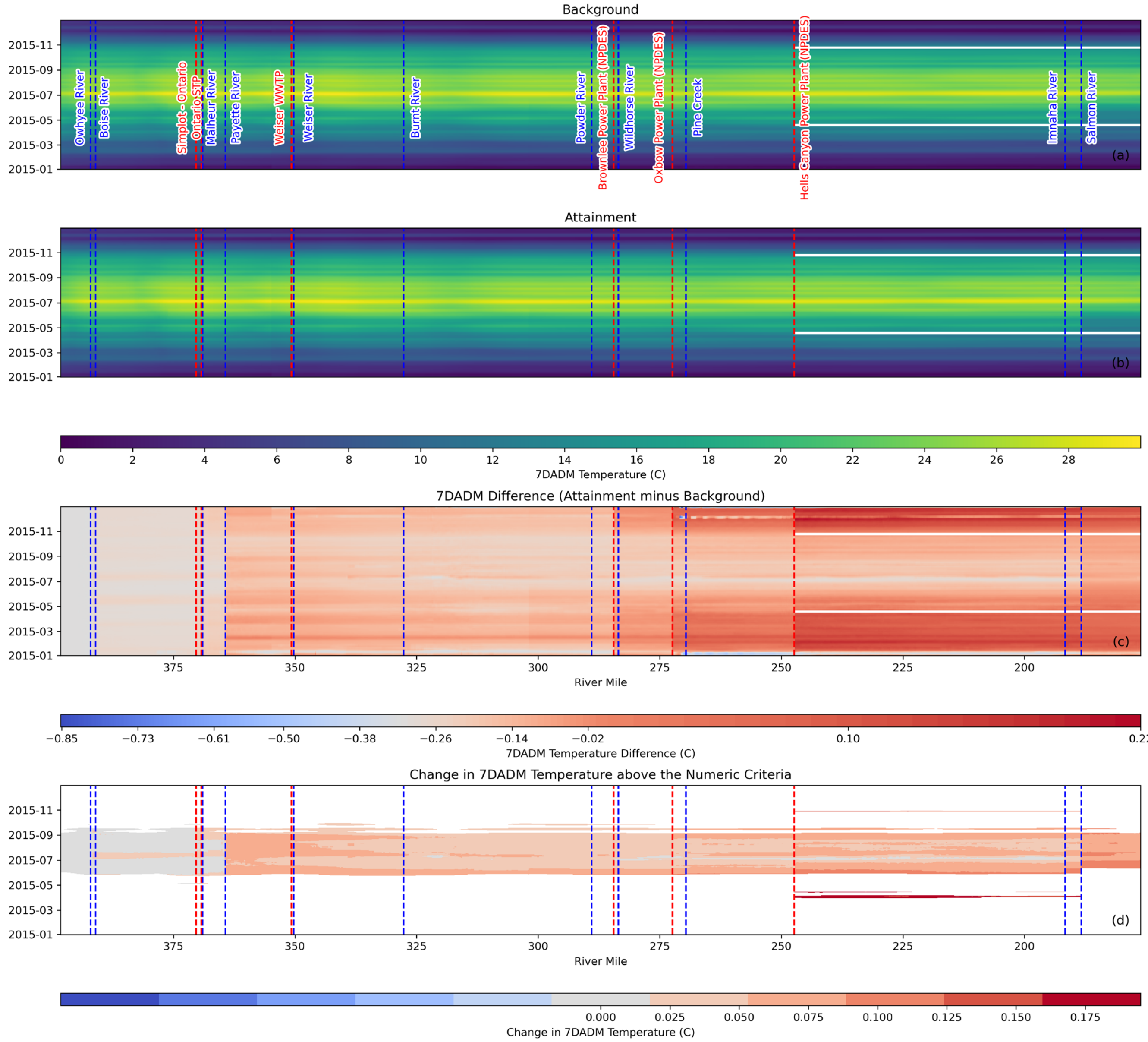


Figure 8-80. (a, b) 7DADM temperature for background and attainment scenarios, (c) temperature difference (attainment-background), and (d) change in 7DADM temperature above the numeric criteria where temperature from either scenario meets or exceeds the criterion, from Adrian to Washington state line, 2015.

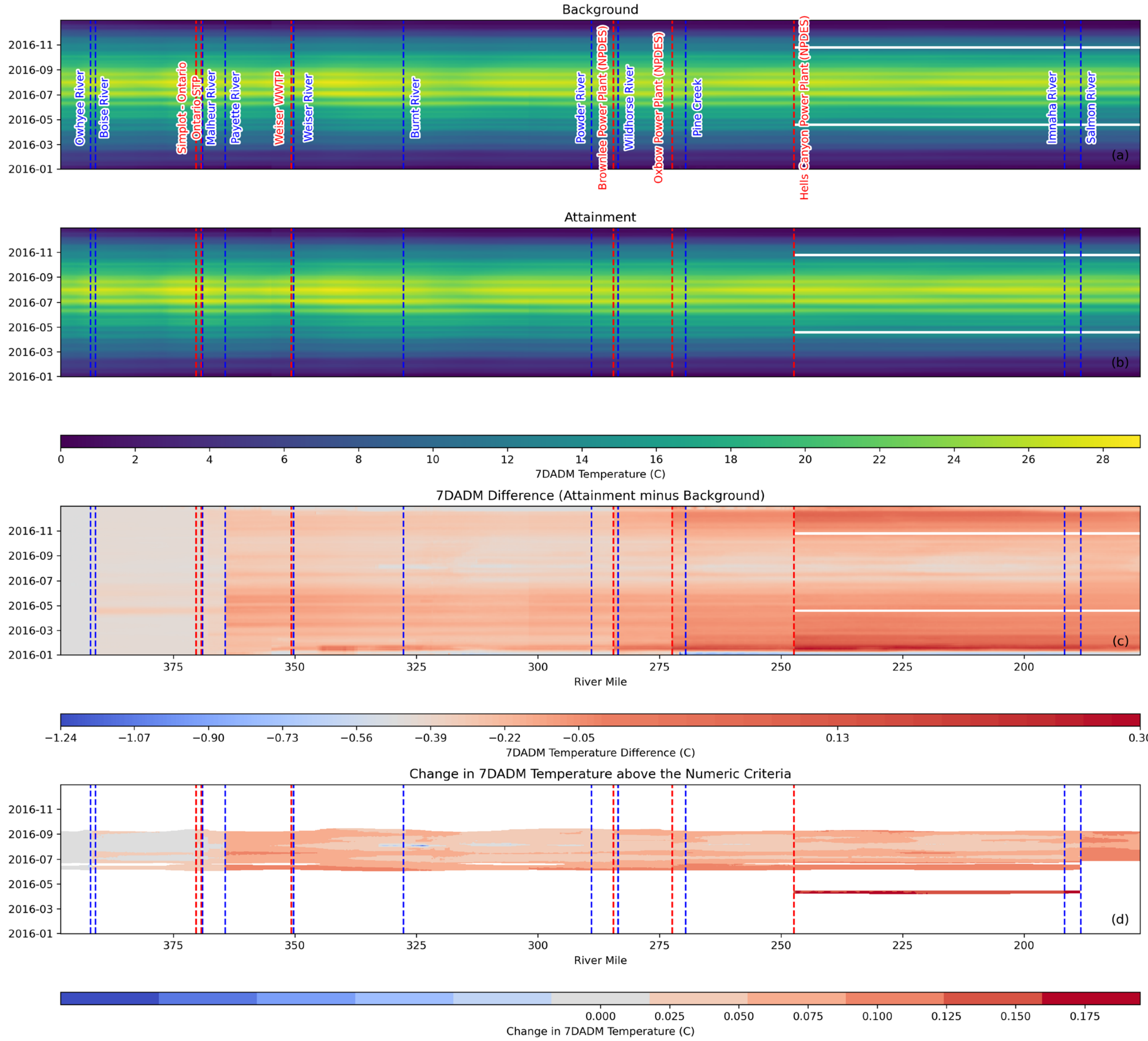


Figure 8-81. (a, b) 7DADM temperature for background and attainment scenarios, (c) temperature difference (attainment-background), and (d) change in 7DADM temperature above the numeric criteria where temperature from either scenario meets or exceeds the criterion, from Adrian to Washington state line, 2016.

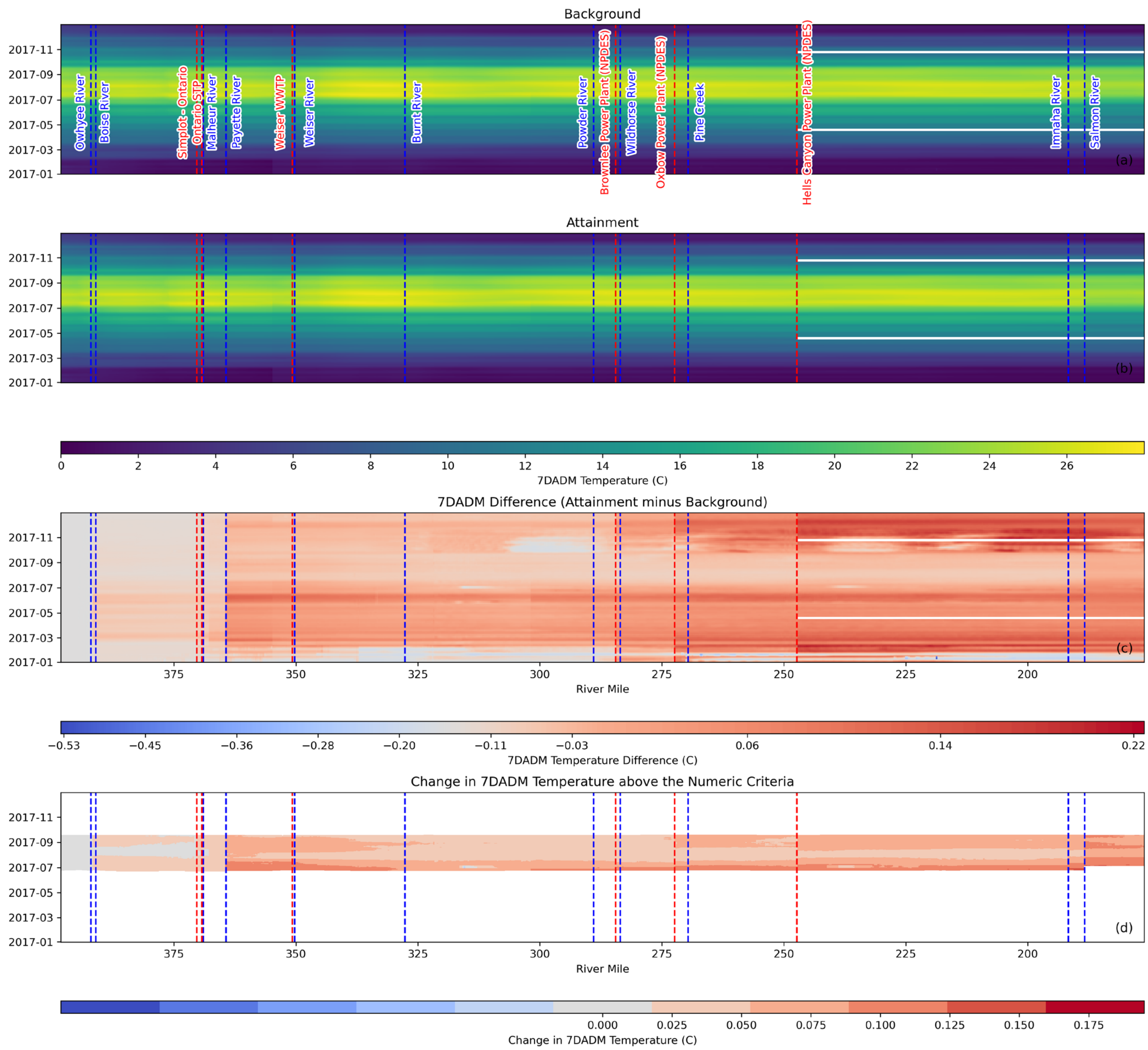


Figure 8-82. (a, b) 7DADM temperature for background and attainment scenarios, (c) temperature difference (attainment-background), and (d) change in 7DADM temperature above the numeric criteria where temperature from either scenario meets or exceeds the criterion, from Adrian to Washington state line, 2017.

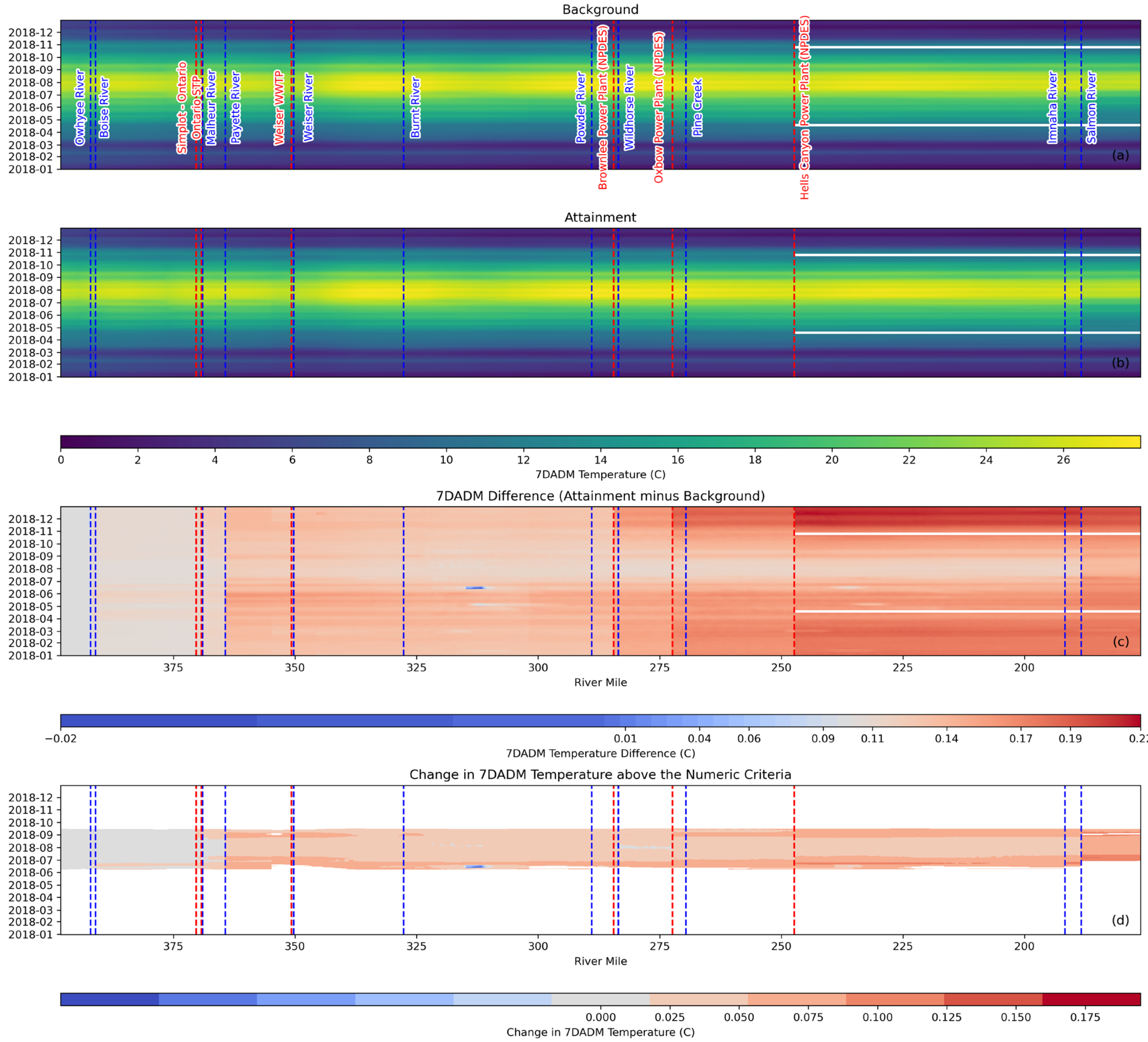


Figure 8-83. (a, b) 7DADM temperature for background and attainment scenarios, (c) temperature difference (attainment-background), and (d) change in 7DADM temperature above the numeric criteria where temperature from either scenario meets or exceeds the criterion, from Adrian to Washington state line, 2018.

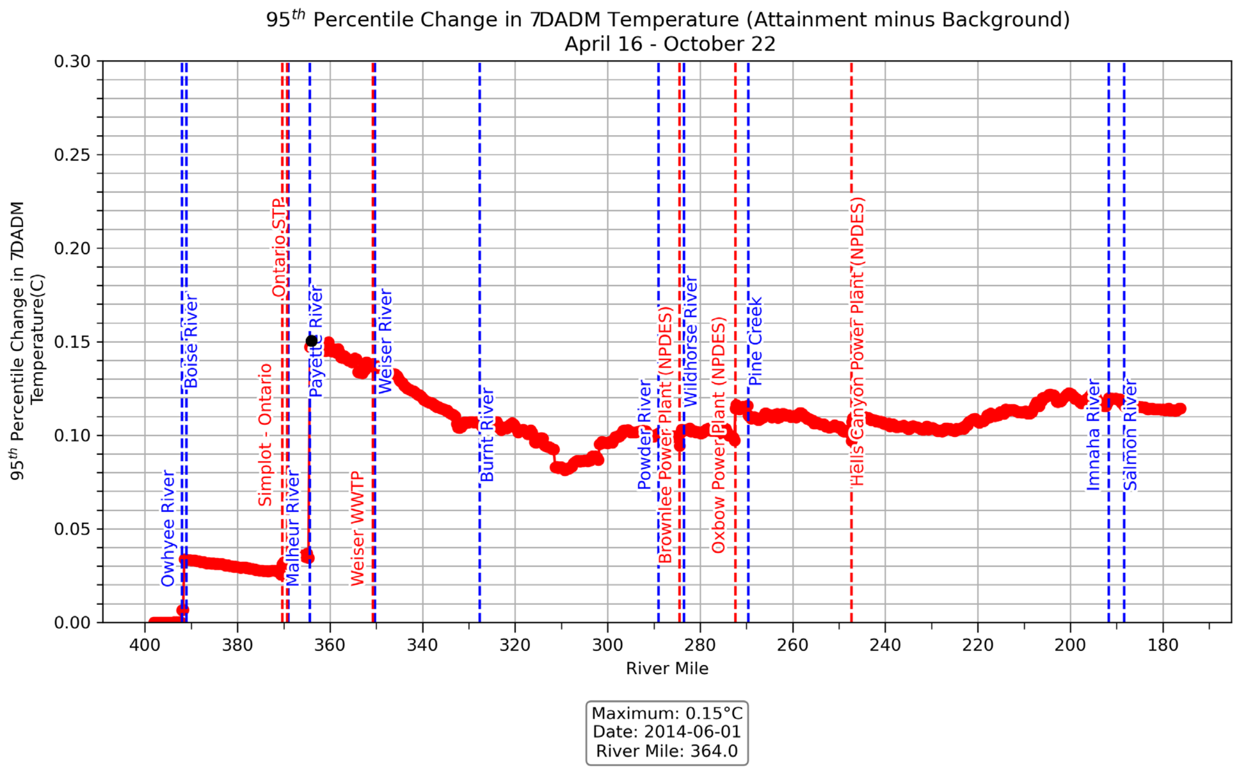


Figure 8-84. 95th percentile change in 7DADM temperature above applicable criteria during critical summer period.

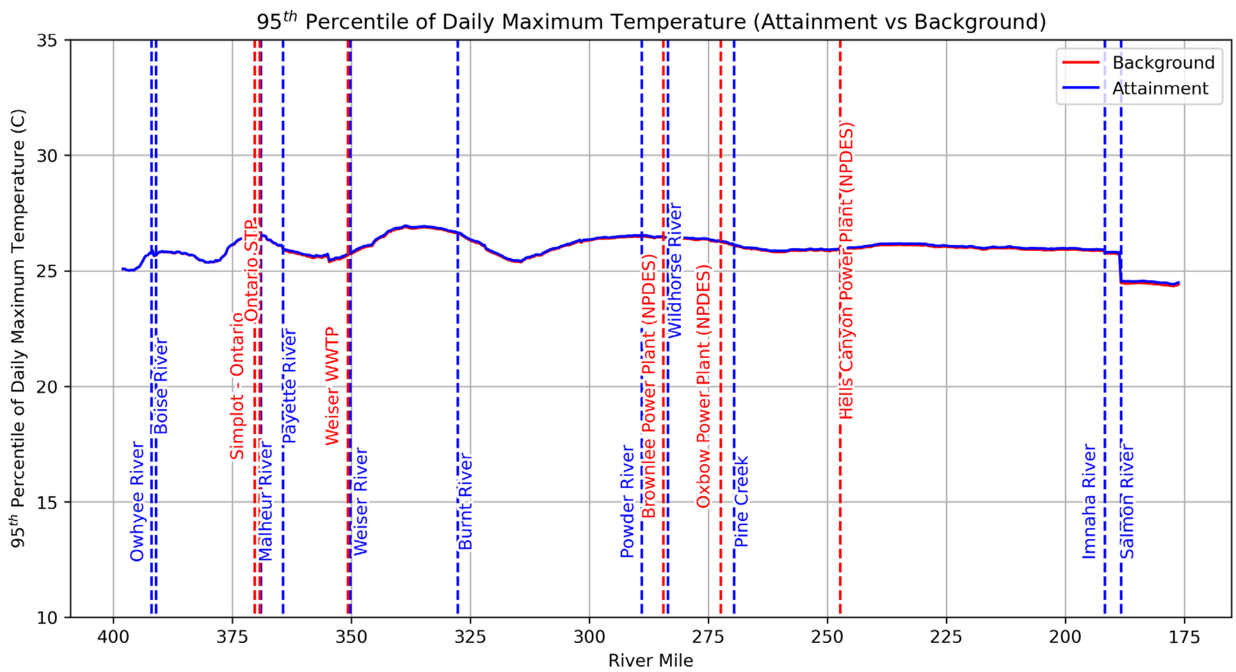


Figure 8-85. 95th percentile of daily maximum temperature for attainment and background scenarios, from Adrian to Washington state line, 2014-2018.

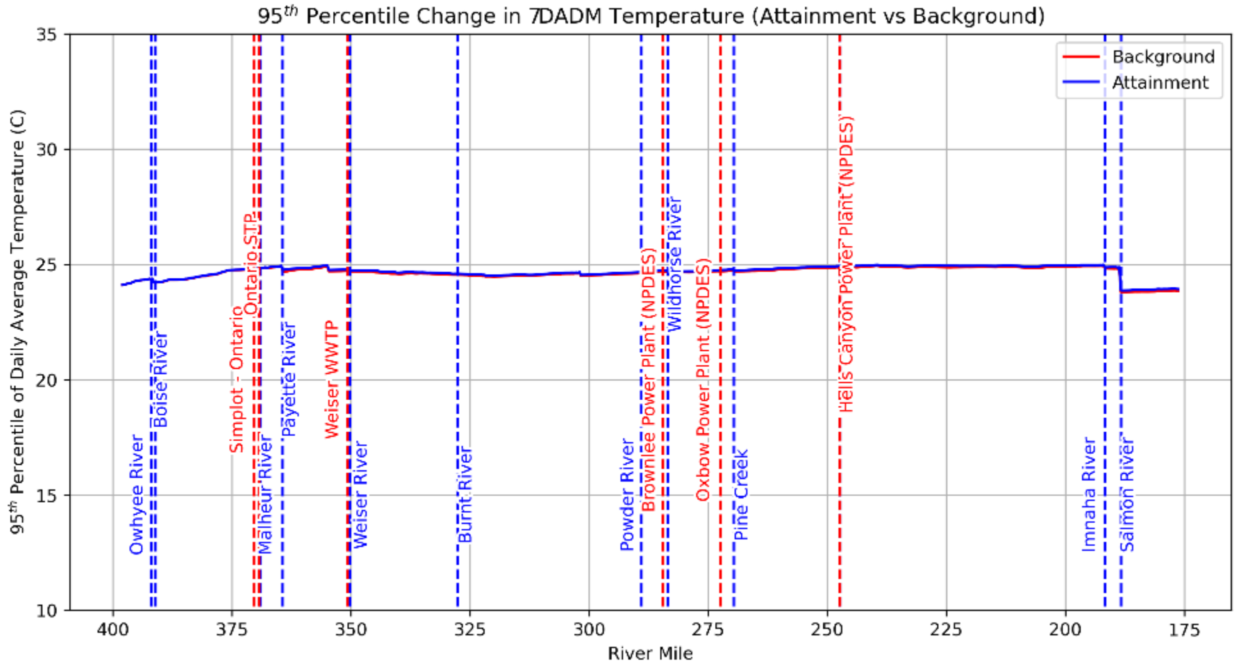


Figure 8-86. 95th percentile of daily average temperature for attainment and background scenarios, from Adrian to Washington state line, 2014-2018.

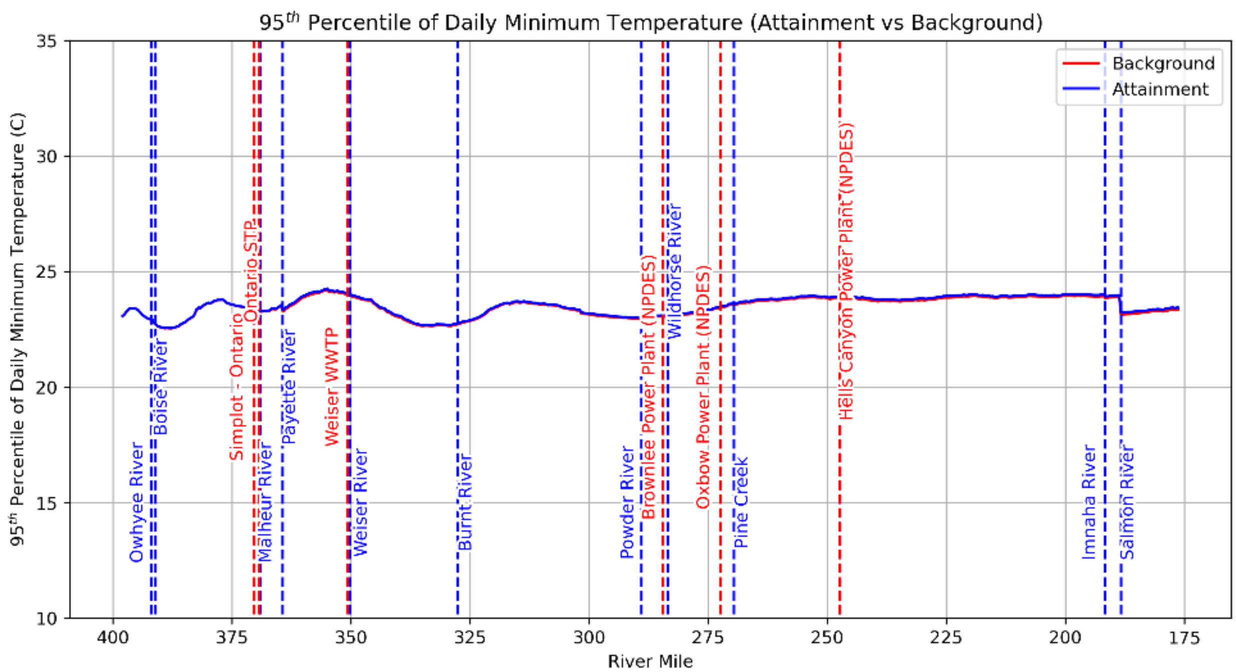


Figure 8-87. 95th percentile of daily minimum temperature for attainment and background scenarios, from Adrian to Washington state line, 2014-2018.

8.1.8 Reserve Capacity: Boundary Condition + 0.1°C vs. Background

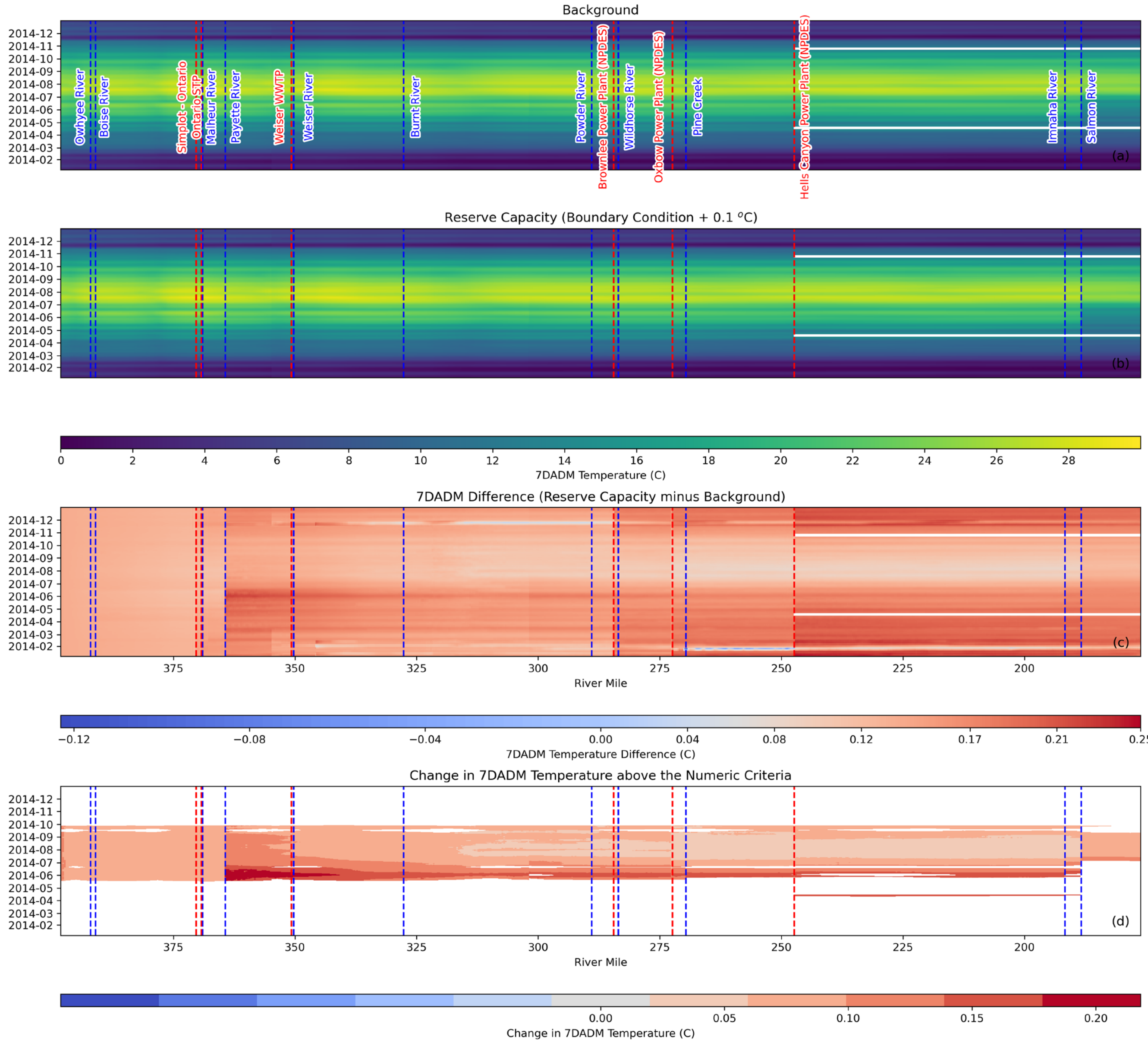


Figure 8-88. (a, b) 7DADM temperature for BC+0.1 and reserve capacity scenarios, (c) temperature difference (reserve capacity-BC+0.1-background), and (d) change in 7DADM temperature above the numeric criteria where temperature from either scenario meets or exceeds the criterion, from Adrian to Washington state line, 2014.

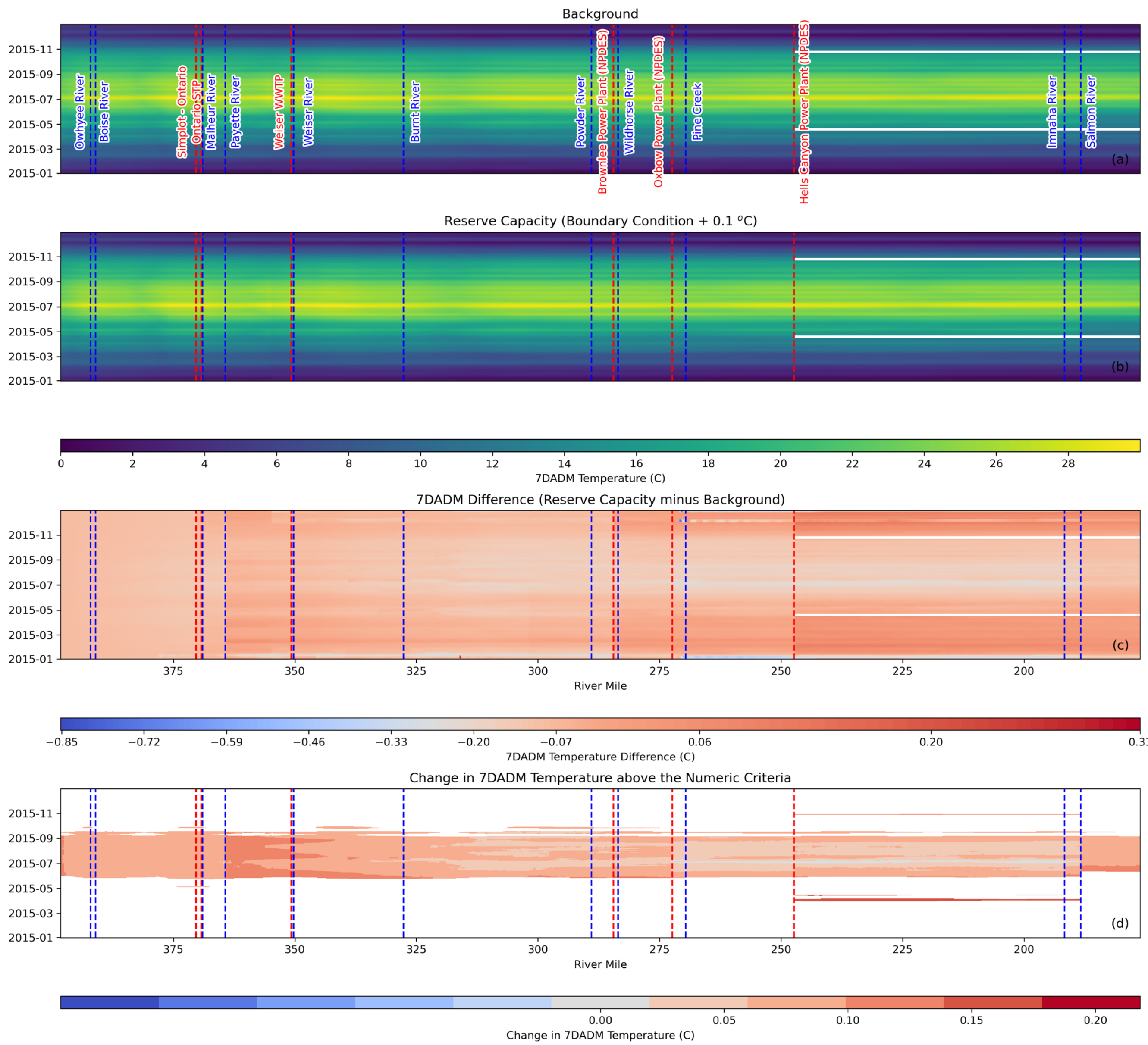


Figure 8-89. (a, b) 7DADM temperature for BC+0.1 and reserve capacity scenarios, (c) temperature difference (reserve capacity-BC+0.1-background), and (d) change in 7DADM temperature above the numeric criteria where temperature from either scenario meets or exceeds the criterion, from Adrian to Washington state line, 2015.

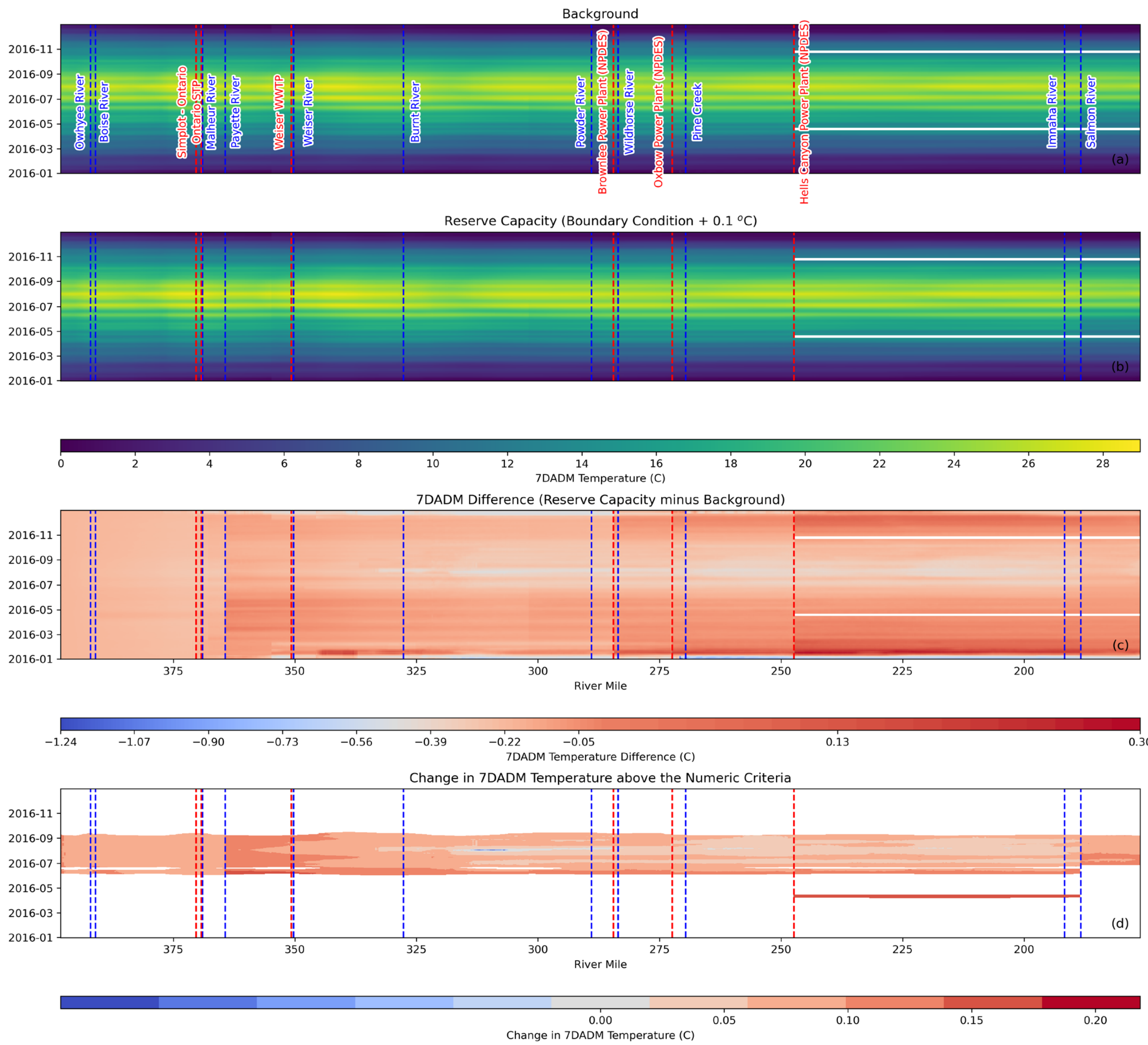


Figure 8-90. (a, b) 7DADM temperature for BC+0.1 and reserve capacity scenarios, (c) temperature difference (reserve capacity-BC+0.1-background), and (d) change in 7DADM temperature above the numeric criteria where temperature from either scenario meets or exceeds the criterion, from Adrian to Washington state line, 2016.

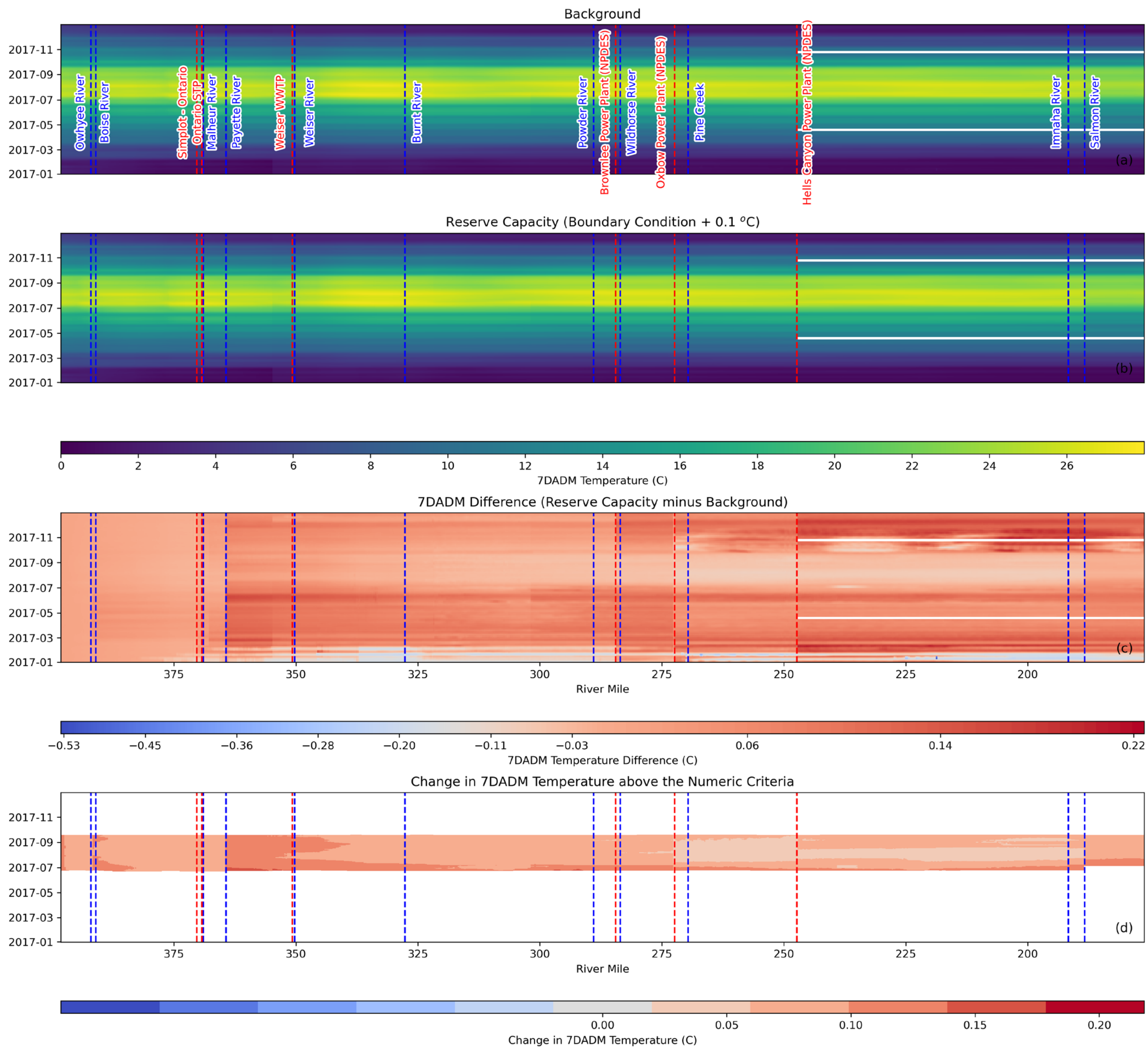


Figure 8-91. (a, b) 7DADM temperature for BC+0.1 and reserve capacity scenarios, (c) temperature difference (reserve capacity-BC+0.1-background), and (d) change in 7DADM temperature above the numeric criteria where temperature from either scenario meets or exceeds the criterion, from Adrian to Washington state line, 2017.

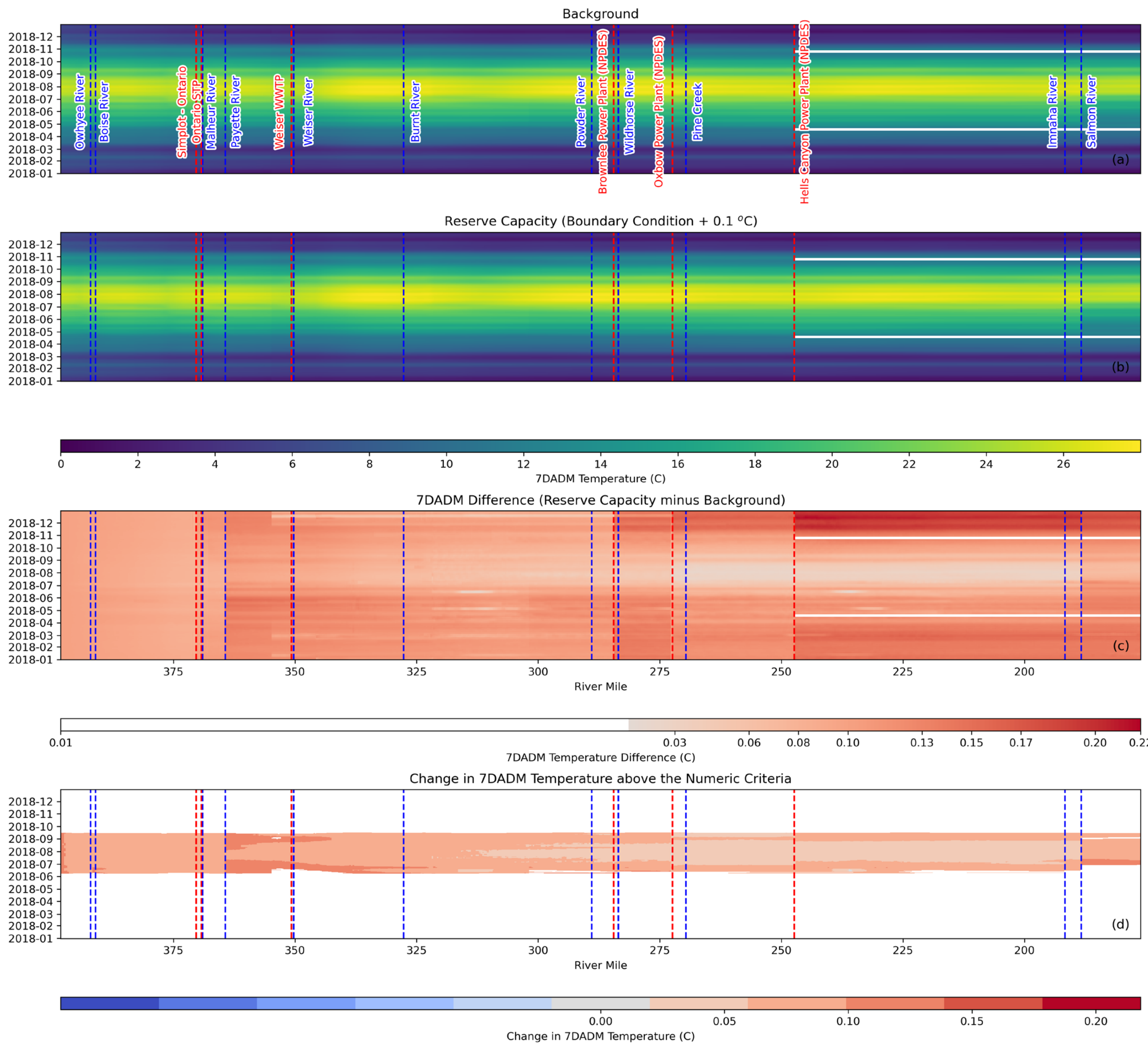


Figure 8-92. (a, b) 7DADM temperature for BC+0.1 and reserve capacity scenarios, (c) temperature difference (reserve capacity-BC+0.1-background), and (d) change in 7DADM temperature above the numeric criteria where temperature from either scenario meets or exceeds the criterion, from Adrian to Washington state line, 2018.

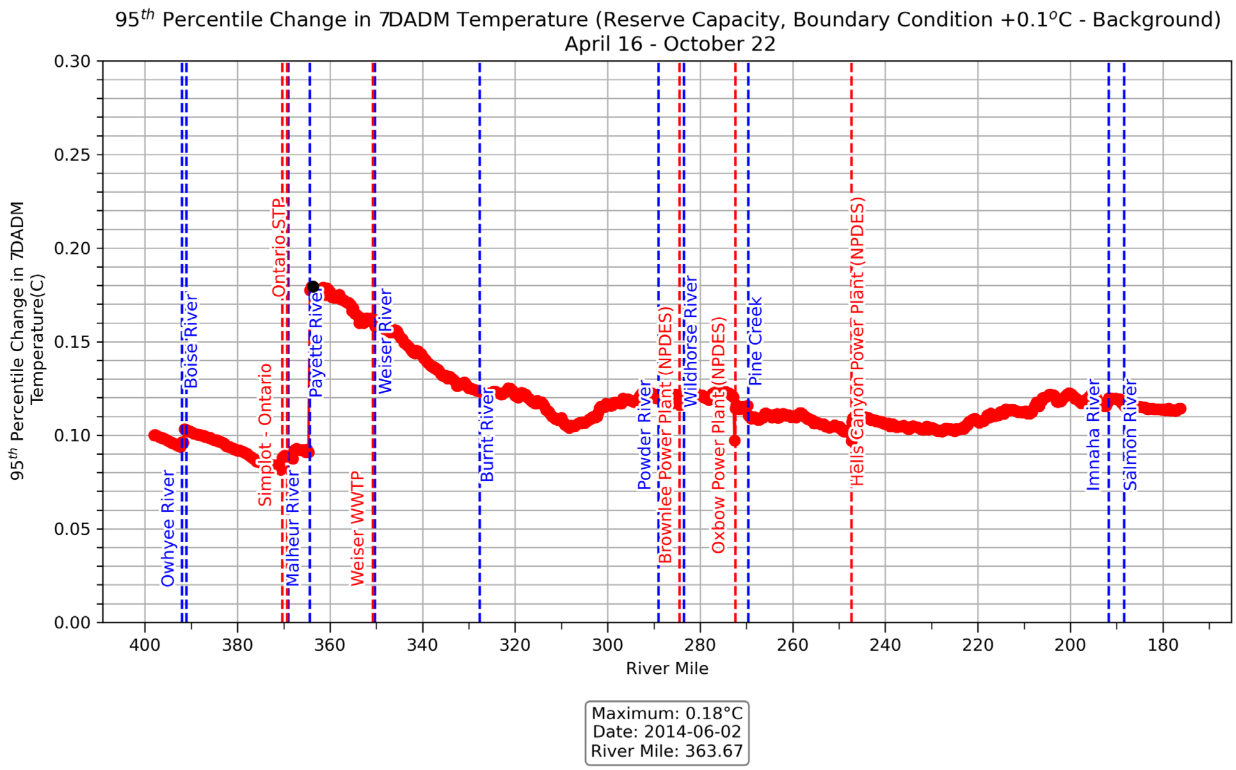


Figure 8-93. 95th percentile change in 7DADM temperature above applicable criteria during critical summer period.

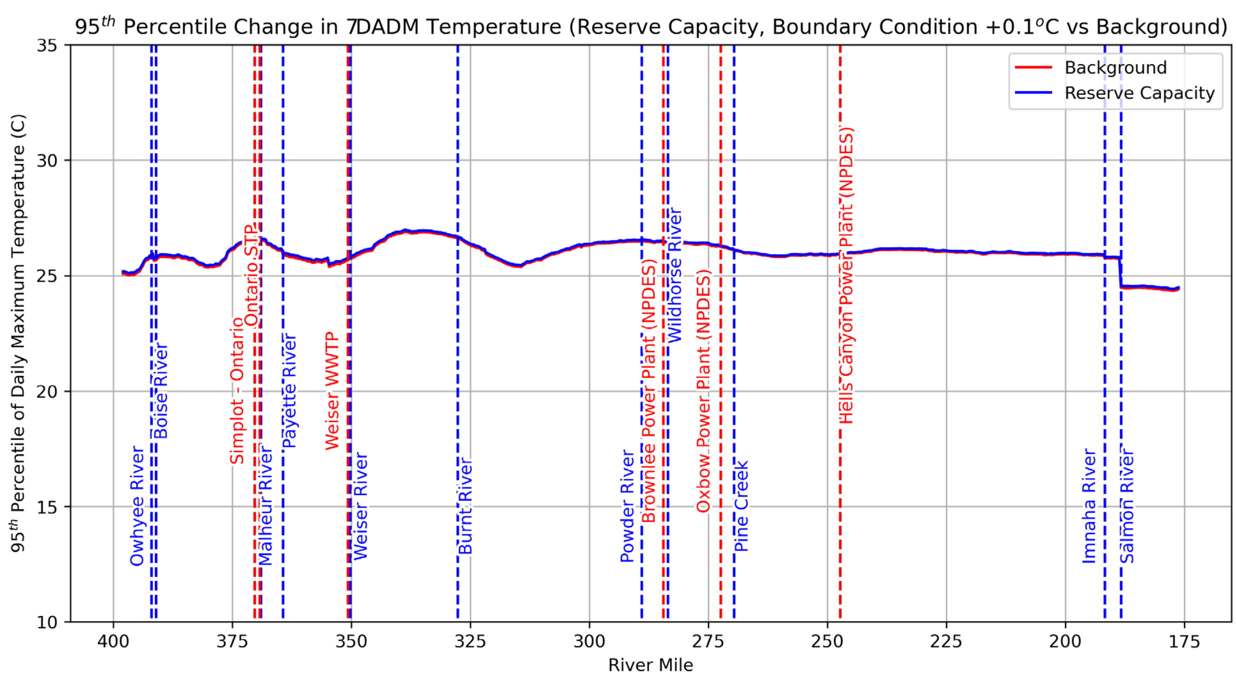


Figure 8-94. 95th percentile of daily maximum temperature for reserve capacity and background scenarios, from Adrian to Washington state line, 2014-2018.

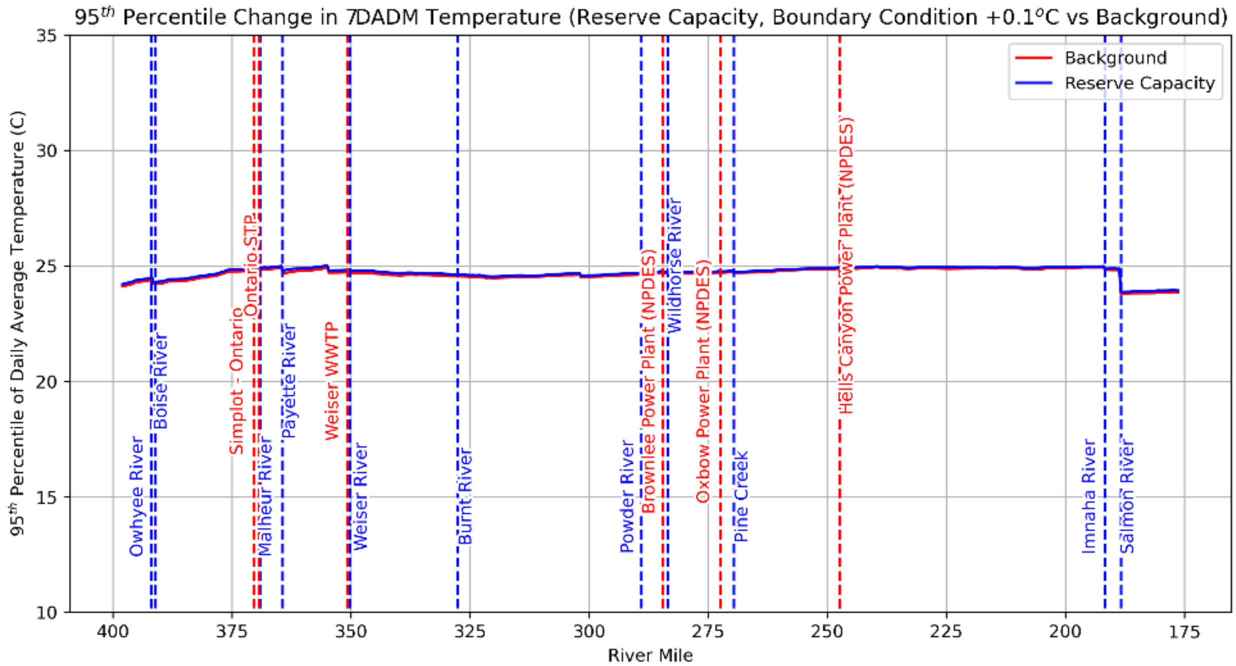


Figure 8-95. 95th percentile of daily average temperature for reserve capacity and background scenarios, from Adrian to Washington state line, 2014-2018.

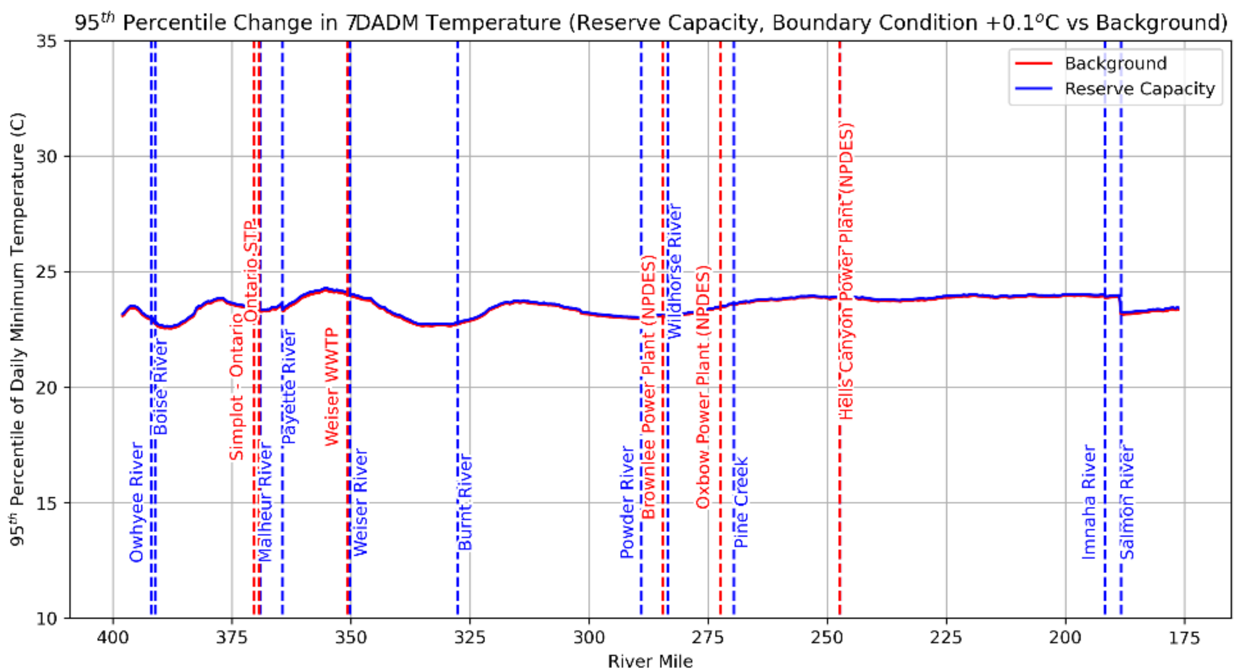


Figure 8-96. 95th percentile of daily minimum temperature for reserve capacity and background scenarios, from Adrian to Washington state line, 2014-2018.

8.1.9 Reserve Capacity: Boundary Condition + 0.1°C vs. Background

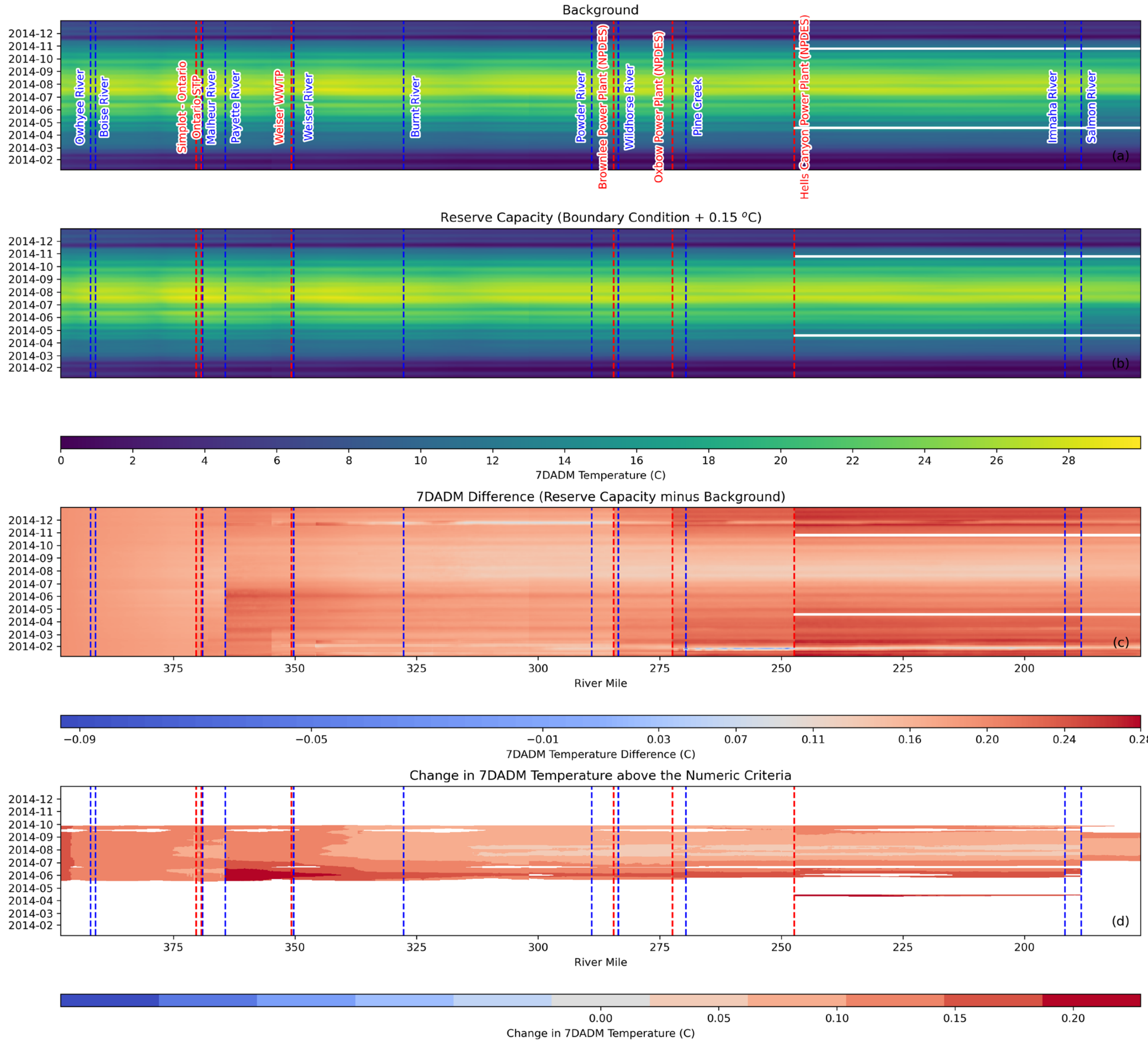


Figure 8-97. (a, b) 7DADM temperature for BC+0.15 and reserve capacity scenarios, (c) temperature difference (reserve capacity-BC+0.15-background), and (d) change in 7DADM temperature above the numeric criteria where temperature from either scenario meets or exceeds the criterion, from Adrian to Washington state line, 2014.

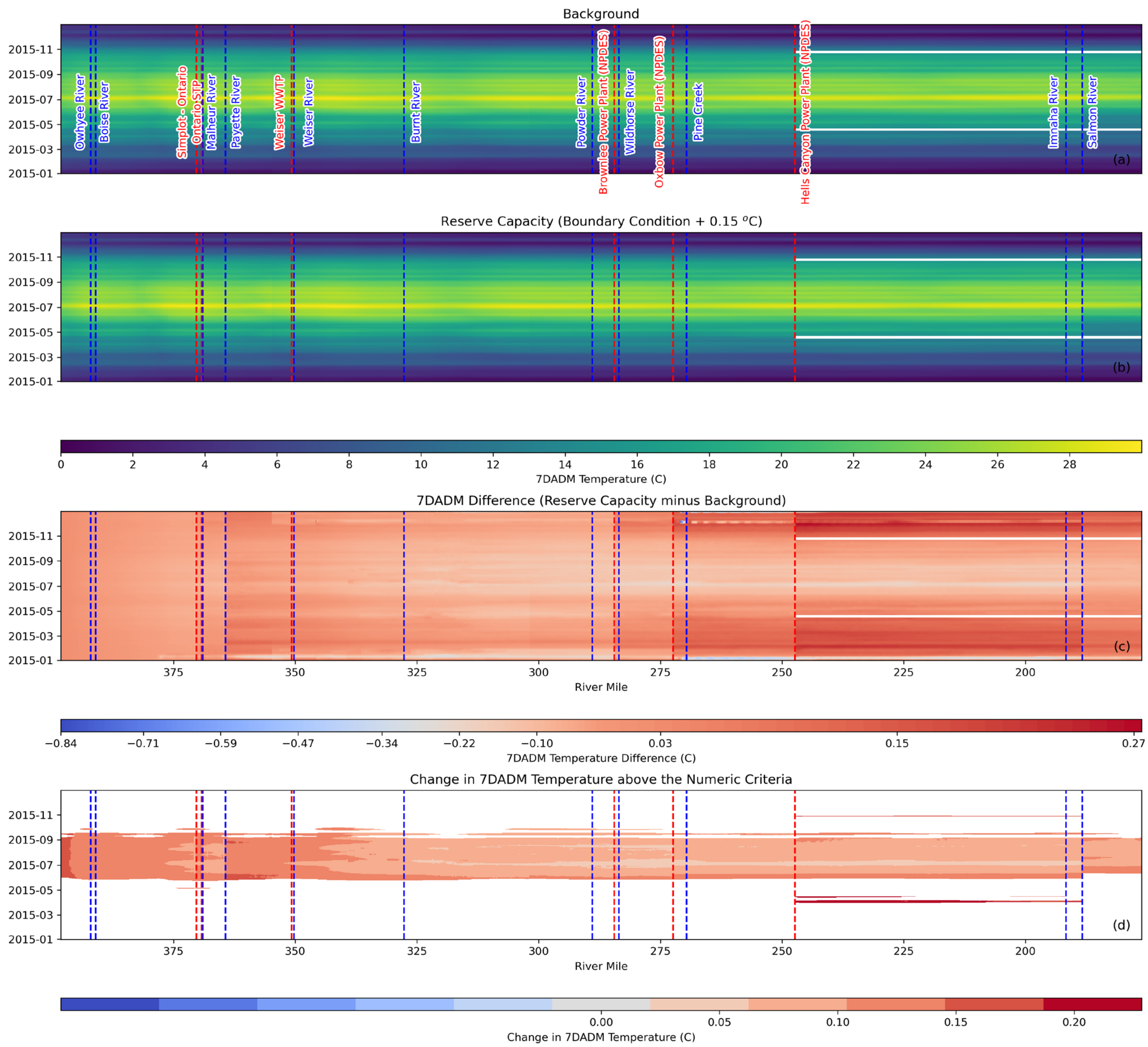


Figure 8-98. (a, b) 7DADM temperature for BC+0.15 and reserve capacity scenarios, (c) temperature difference (reserve capacity-BC+0.15-background), and (d) change in 7DADM temperature above the numeric criteria where temperature from either scenario meets or exceeds the criterion, from Adrian to Washington state line, 2015.

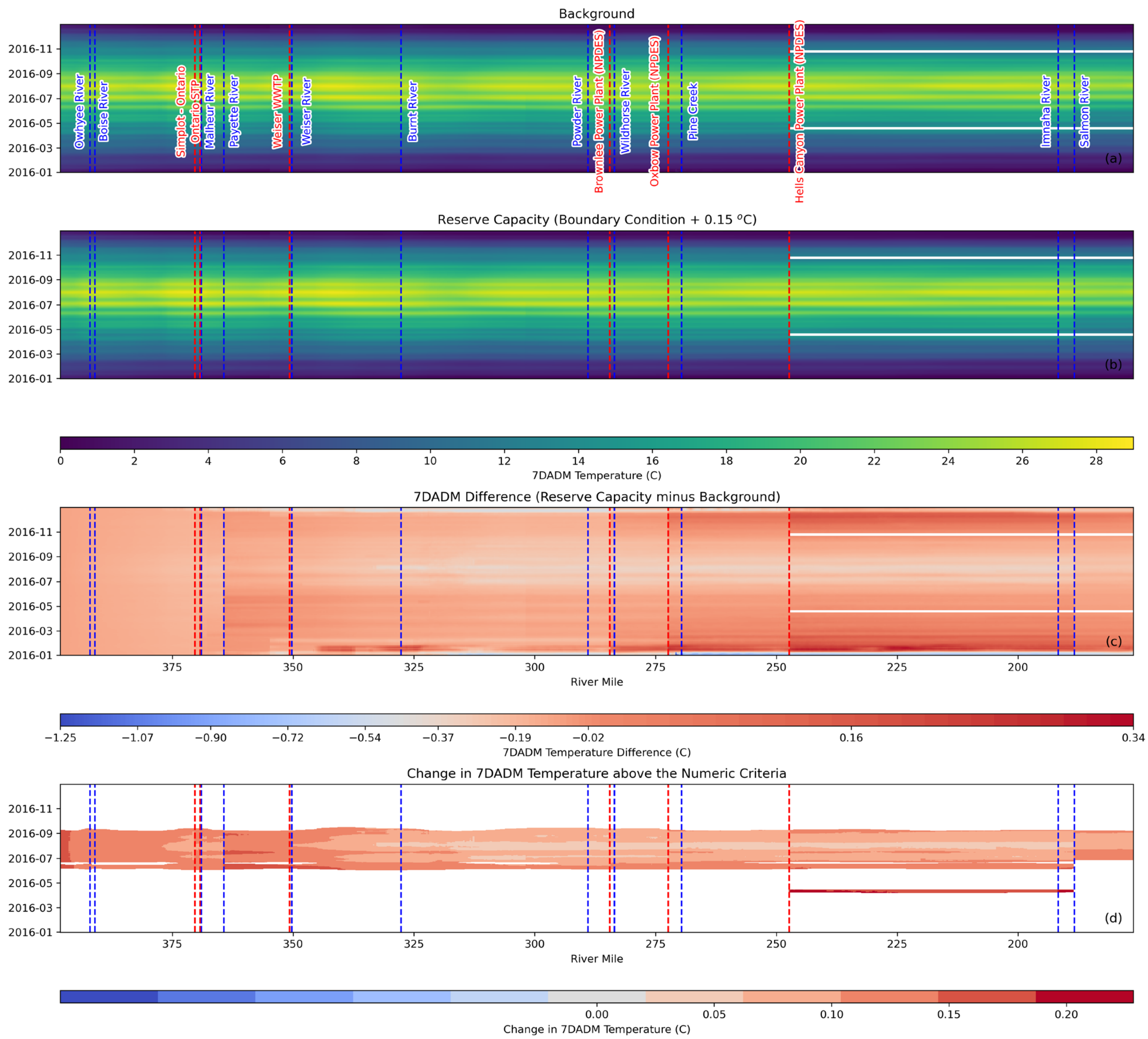


Figure 8-99. (a, b) 7DADM temperature for BC+0.15 and reserve capacity scenarios, (c) temperature difference (reserve capacity-BC+0.15-background), and (d) change in 7DADM temperature above the numeric criteria where temperature from either scenario meets or exceeds the criterion, from Adrian to Washington state line, 2016.

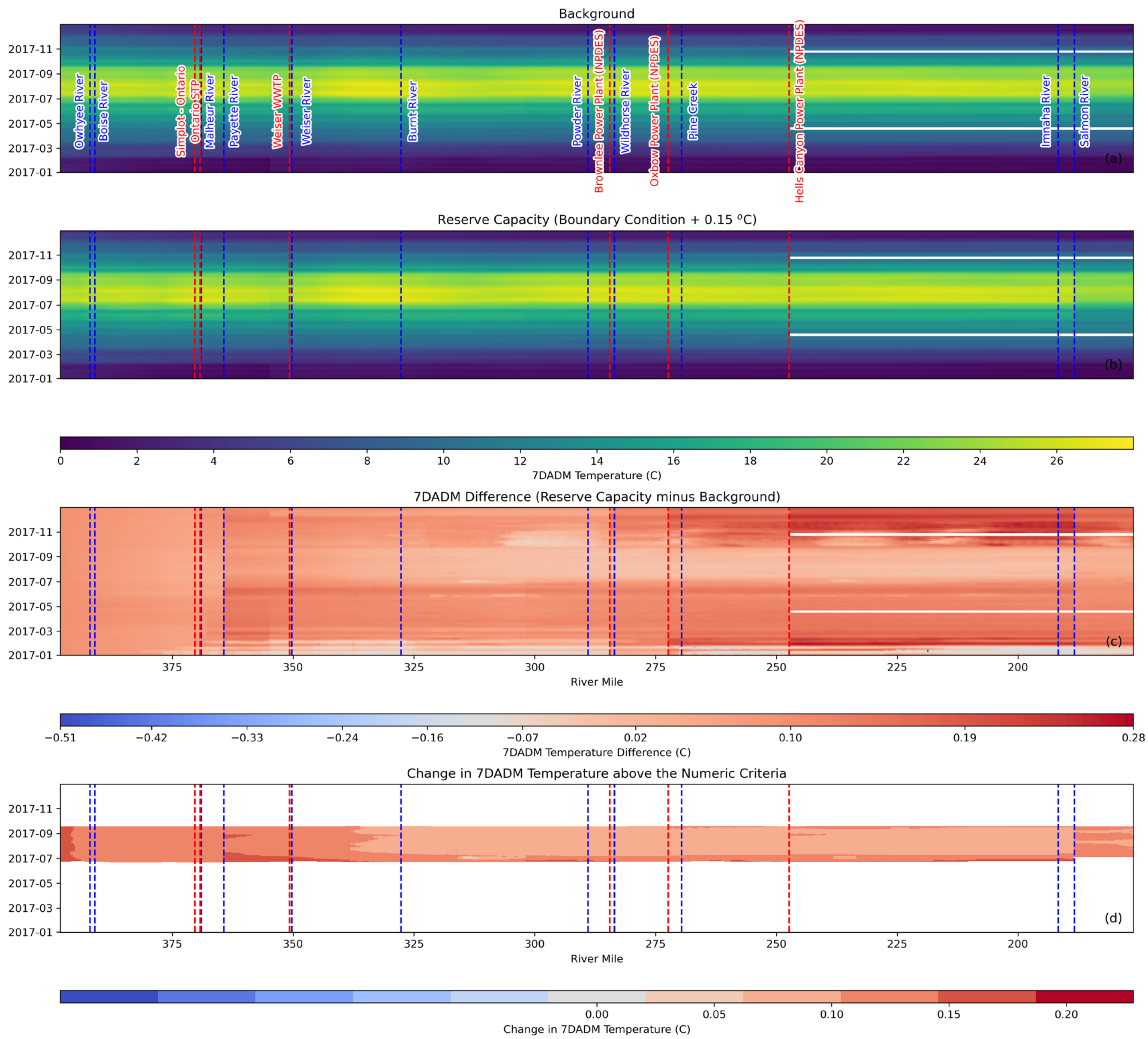


Figure 8-100. (a, b) 7DADM temperature for BC+0.15 and reserve capacity scenarios, (c) temperature difference (reserve capacity-BC+0.15-background), and (d) change in 7DADM temperature above the numeric criteria where temperature from either scenario meets or exceeds the criterion, from Adrian to Washington state line, 2017.

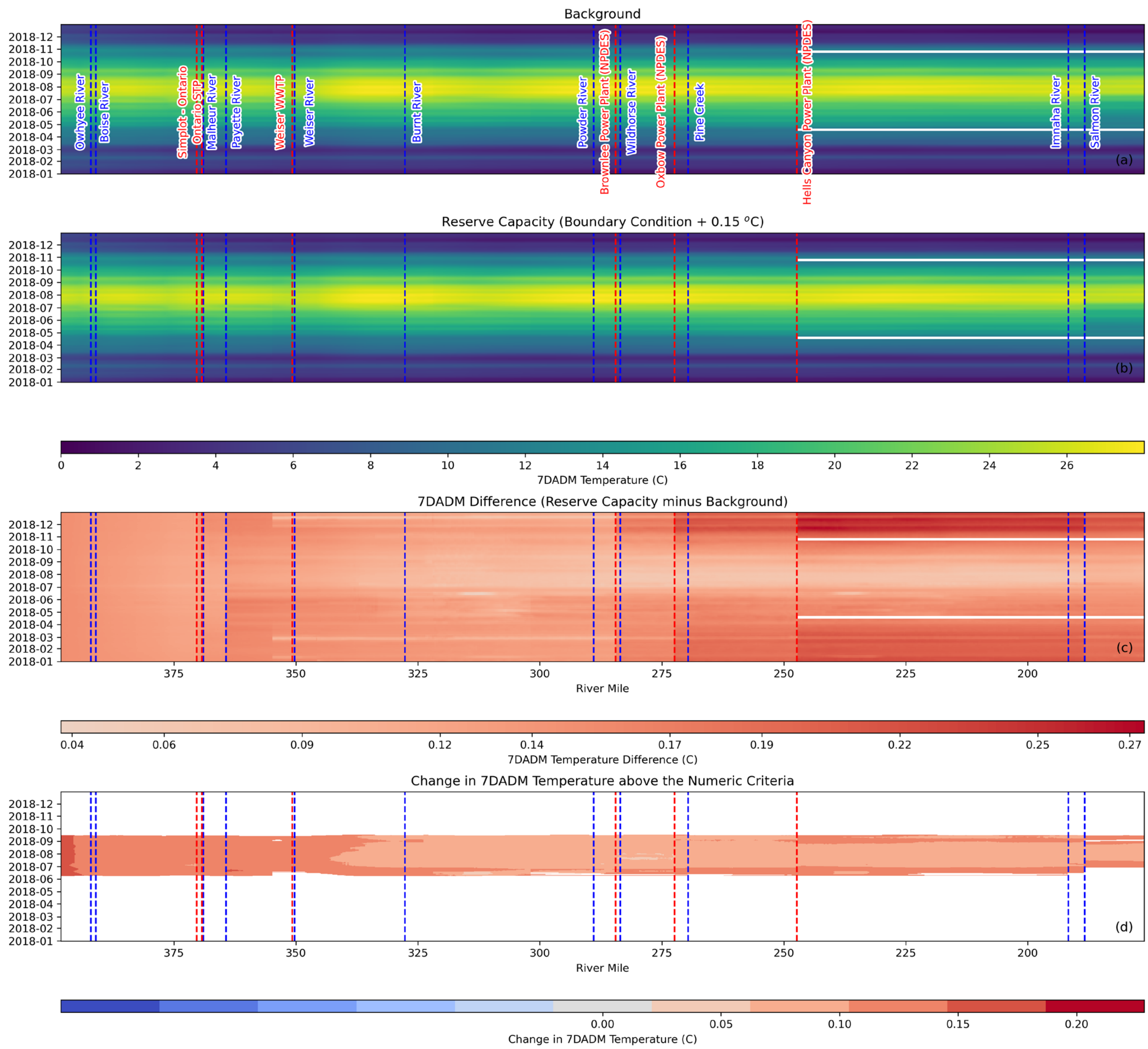


Figure 8-101. (a, b) 7DADM temperature for BC+0.15 and reserve capacity scenarios, (c) temperature difference (reserve capacity-BC+0.15-background), and (d) change in 7DADM temperature above the numeric criteria where temperature from either scenario meets or exceeds the criterion, from Adrian to Washington state line, 2018.

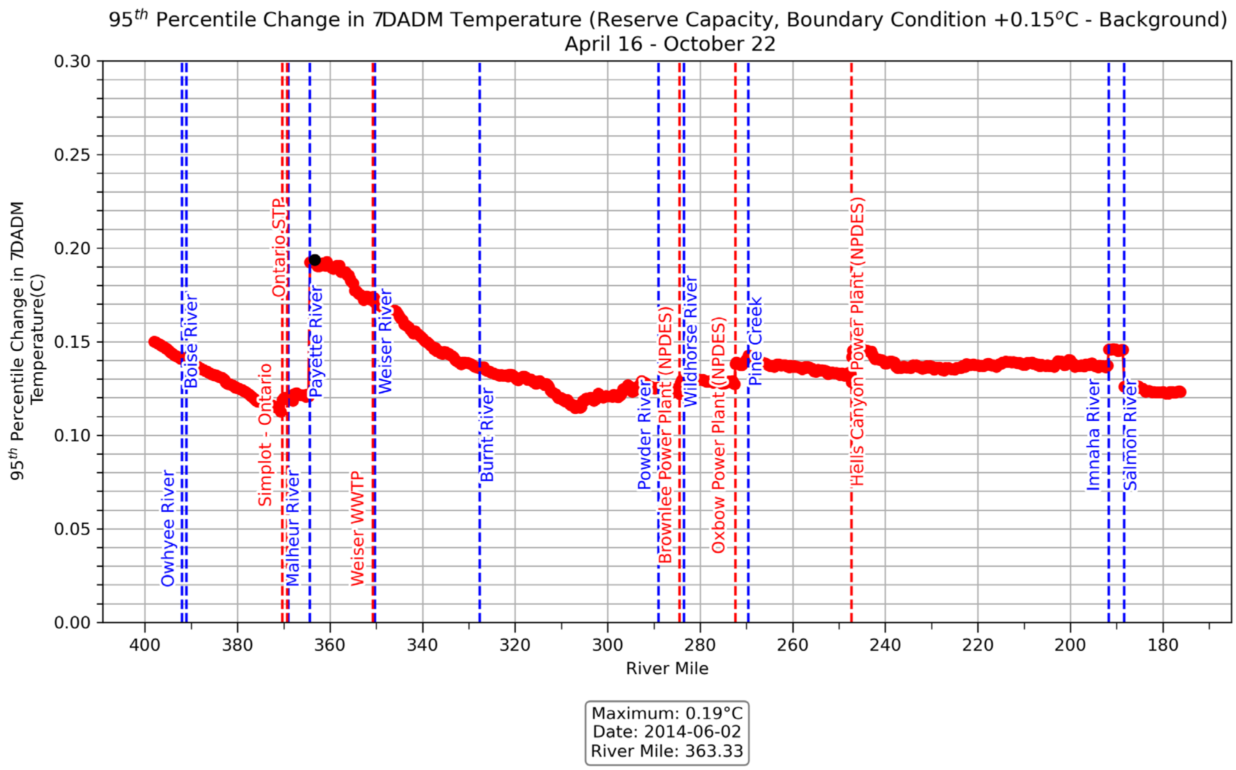


Figure 8-102. 95th percentile change in 7DADM temperature above applicable criteria during critical summer period.

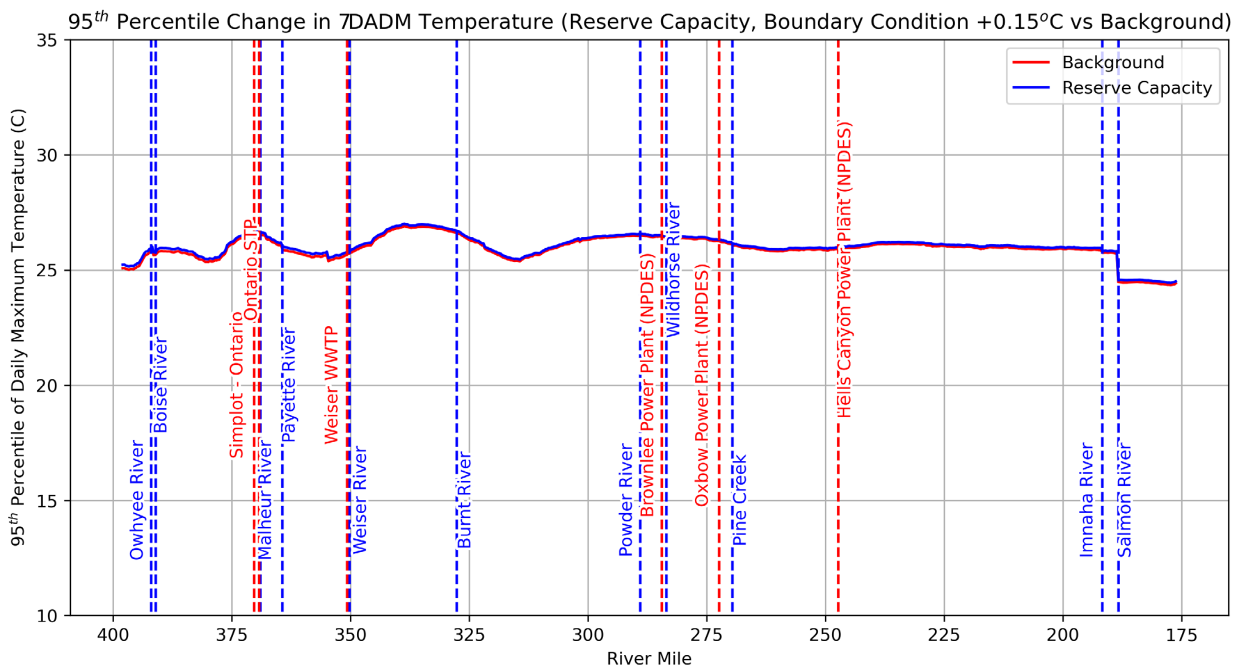


Figure 8-103. 95th percentile of daily maximum temperature for reserve capacity and background scenarios, from Adrian to Washington state line, 2014-2018.

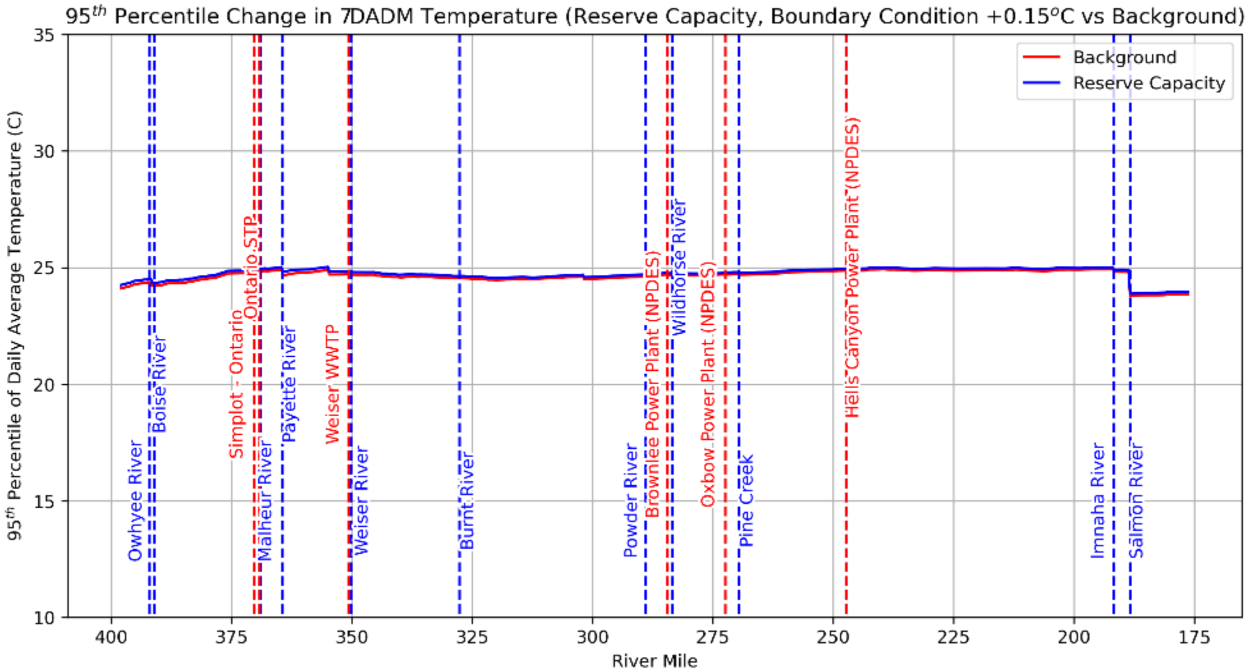


Figure 8-104. 95th percentile of daily average temperature for reserve capacity and background scenarios, from Adrian to Washington state line, 2014-2018.

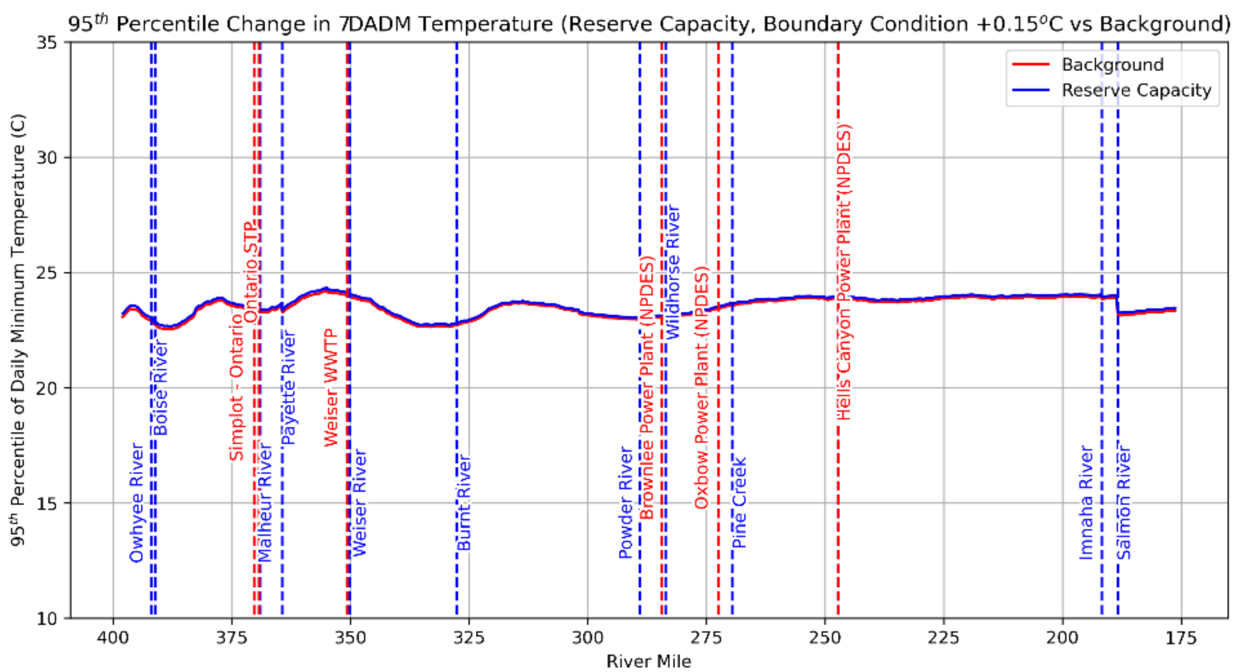


Figure 8-105. 95th percentile of daily minimum temperature for reserve capacity and background scenarios, from Adrian to Washington state line, 2014-2018.

8.2 Supporting Materials For Section 5.0 (Effects Of Hydrologic Modification On Flows And Temperature Patterns)

This section presents supplementary figures and tables showing the effects of Hells Canyon Dams on Snake River discharge and temperature at Brownlee Dam, Oxbow Dam, HellsCanyonDam, donstream of Salmon River confluence, and the triple border for 2014 through 2017.

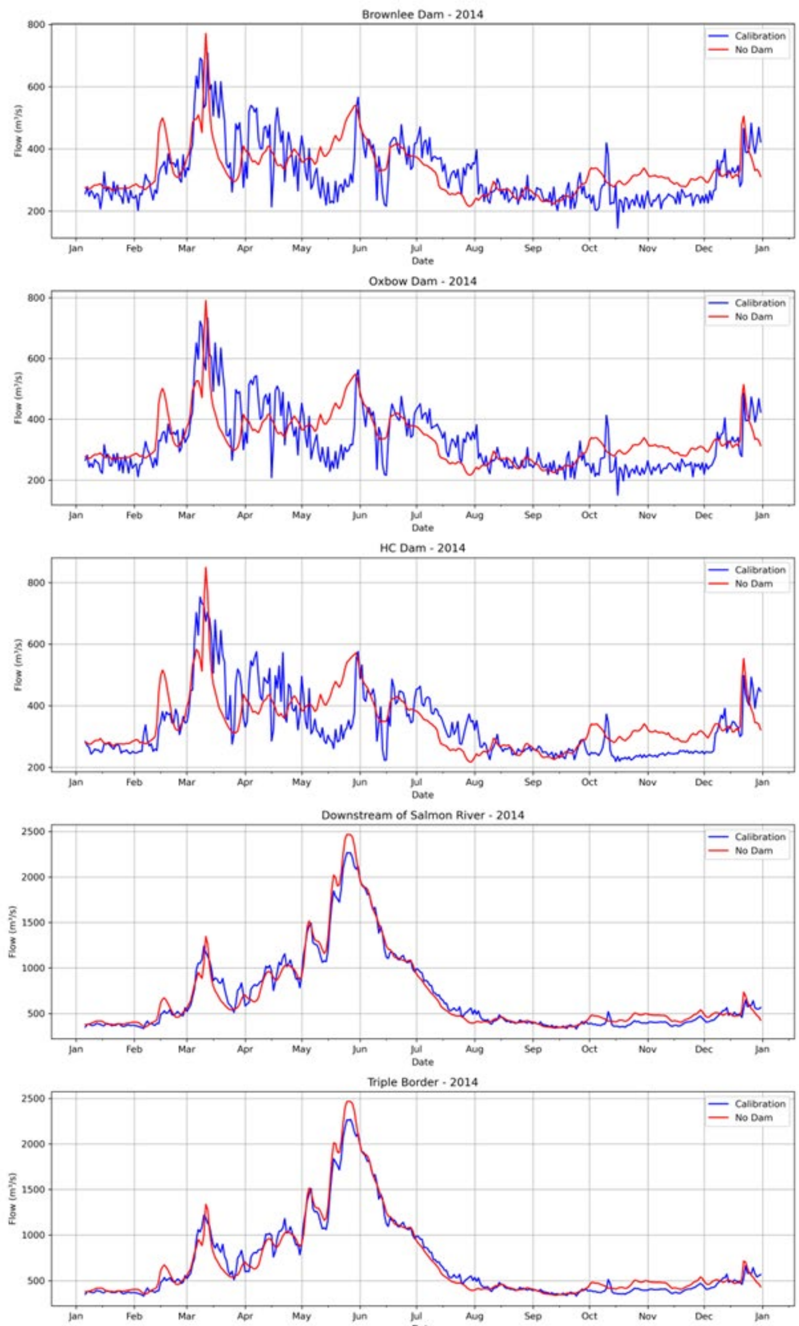


Figure 8-106. Modeled daily average flow in 2014 for Snake River segment at Brownlee Dam, Oxbow Dam, Hells Canyon Dam, downstream of Salmon River, and triple border, Hells Canyon Dam, comparing calibration and no dams scenarios.

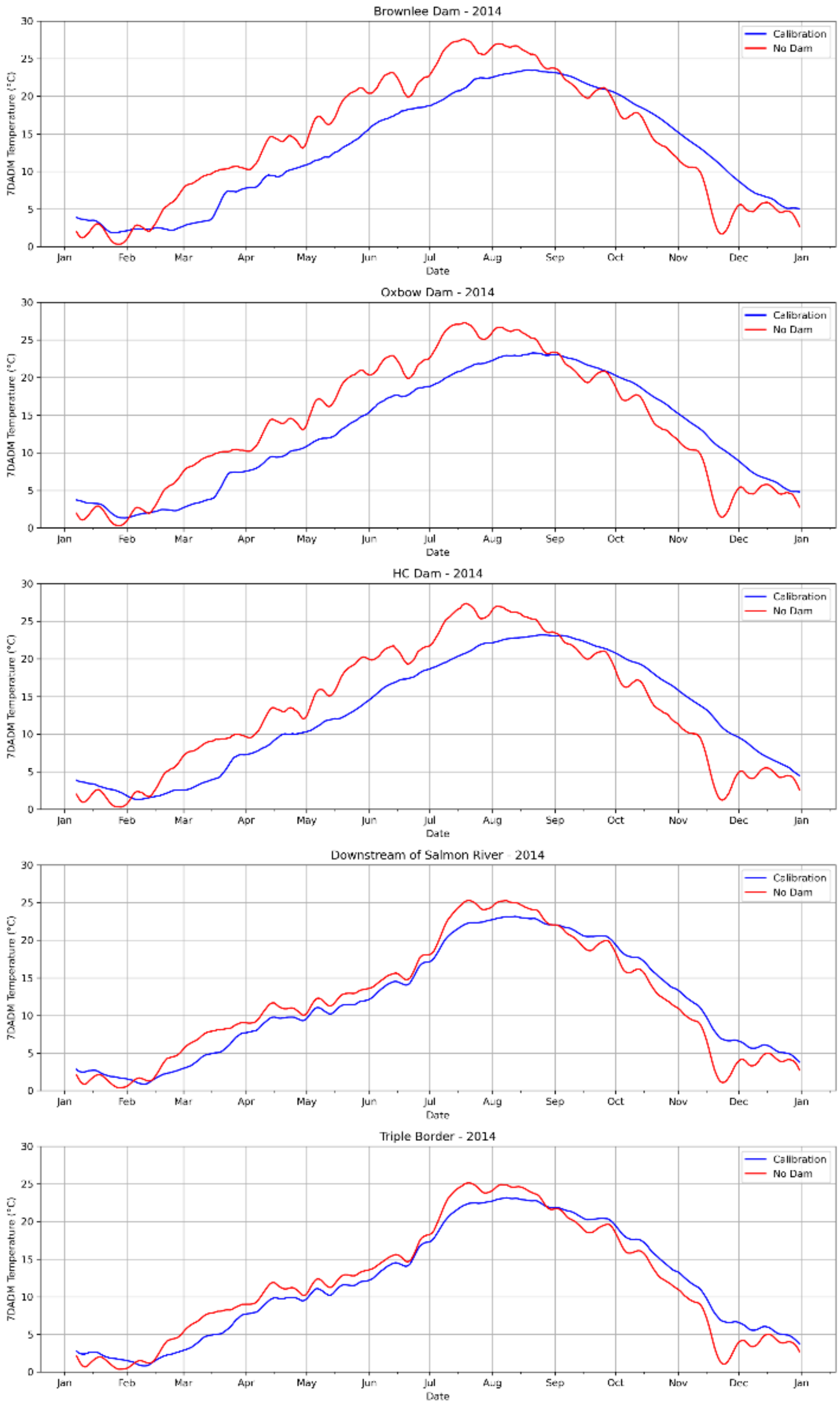


Figure 8-107. Modeled 7DADM average temperature in 2014 for Snake River segment at Brownlee Dam, Oxbow Dam, Hells Canyon Dam, downstream of Salmon River, and triple border, comparing calibration and no dams scenarios.

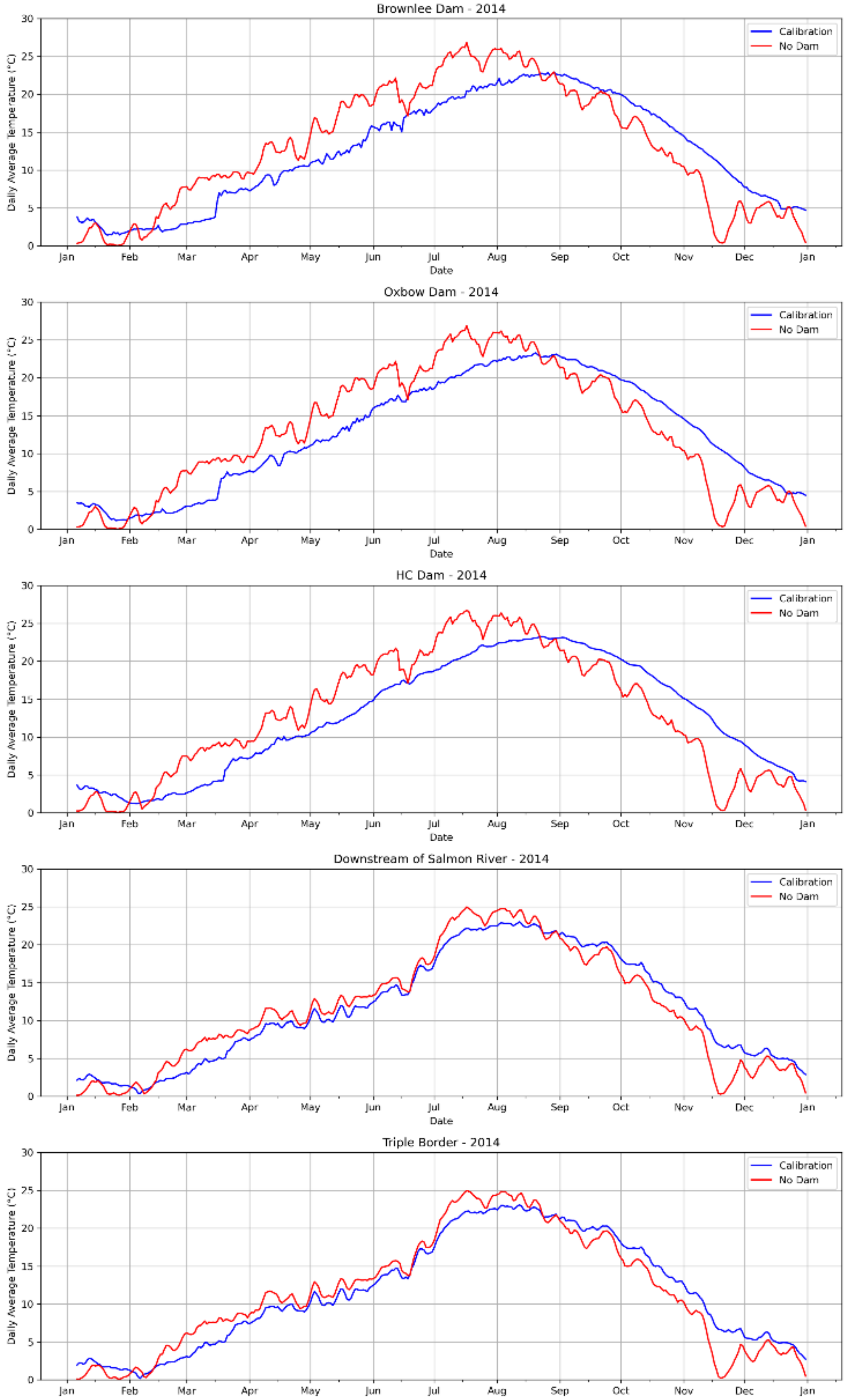


Figure 8-108. Modeled daily average temperature in 2014 for Snake River segment at Brownlee Dam, Oxbow Dam, Hells Canyon Dam, downstream of Salmon River, and triple border, comparing calibration and no dams scenarios.

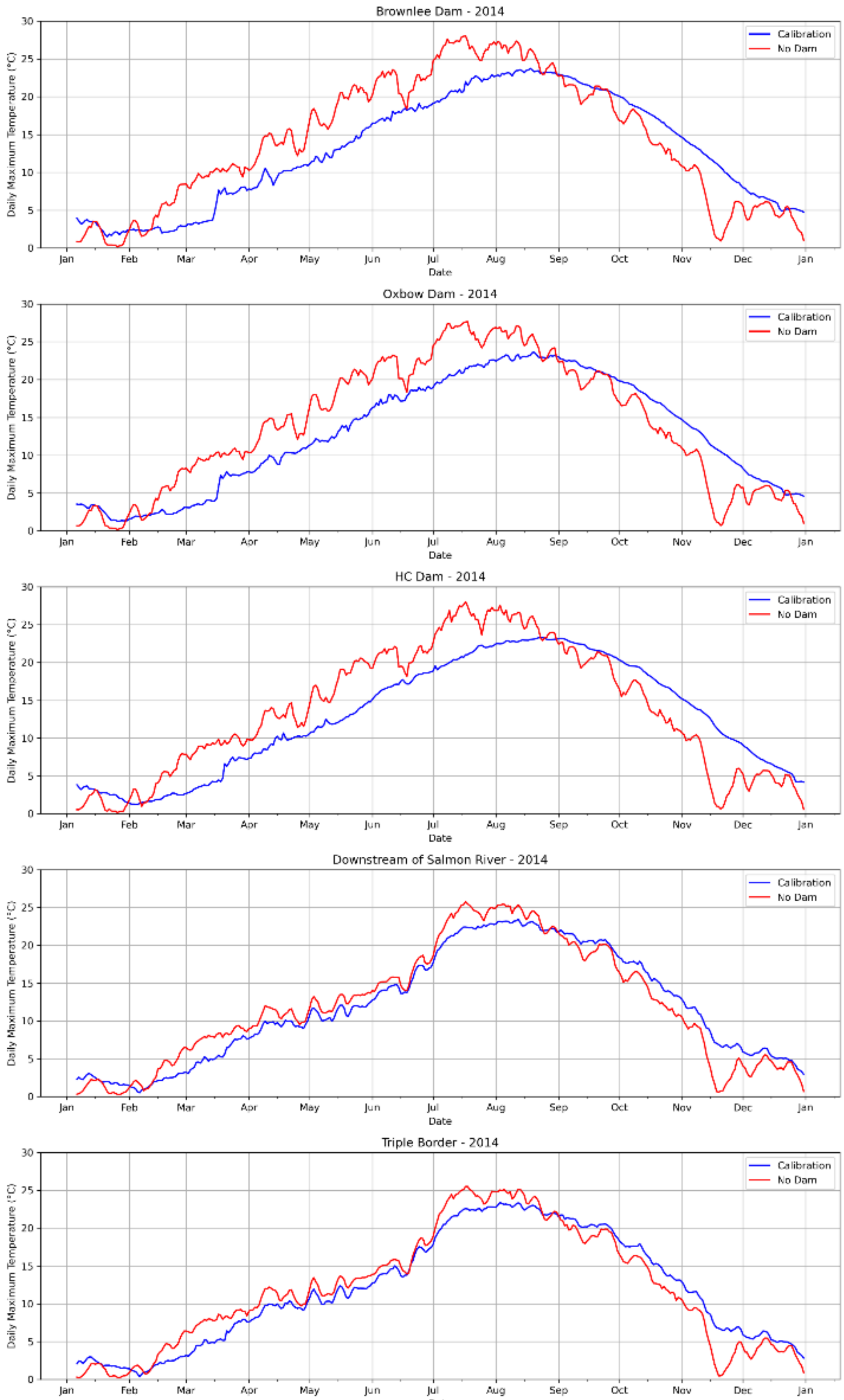


Figure 8-109. Modeled daily maximum temperature in 2014 for Snake River segment at Brownlee Dam, Oxbow Dam, Hells Canyon Dam, downstream of Salmon River, and triple border, comparing calibration and no dams scenarios.

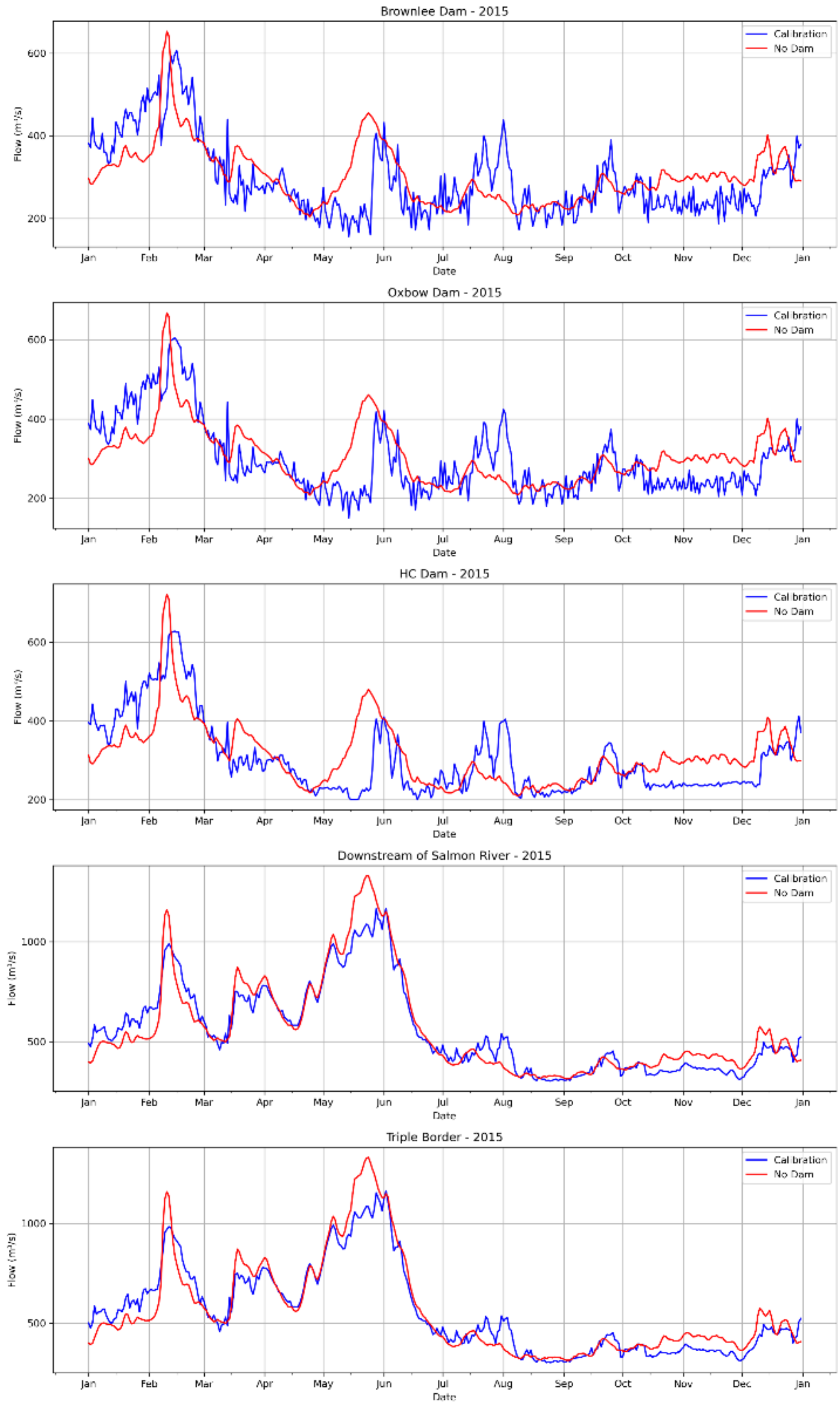


Figure 8-110. Modeled daily average flow in 2015 for Snake River segment at Brownlee Dam, Oxbow Dam, Hells Canyon Dam, downstream of Salmon River, and triple border, Hells Canyon Dam, comparing calibration and no dams scenarios.

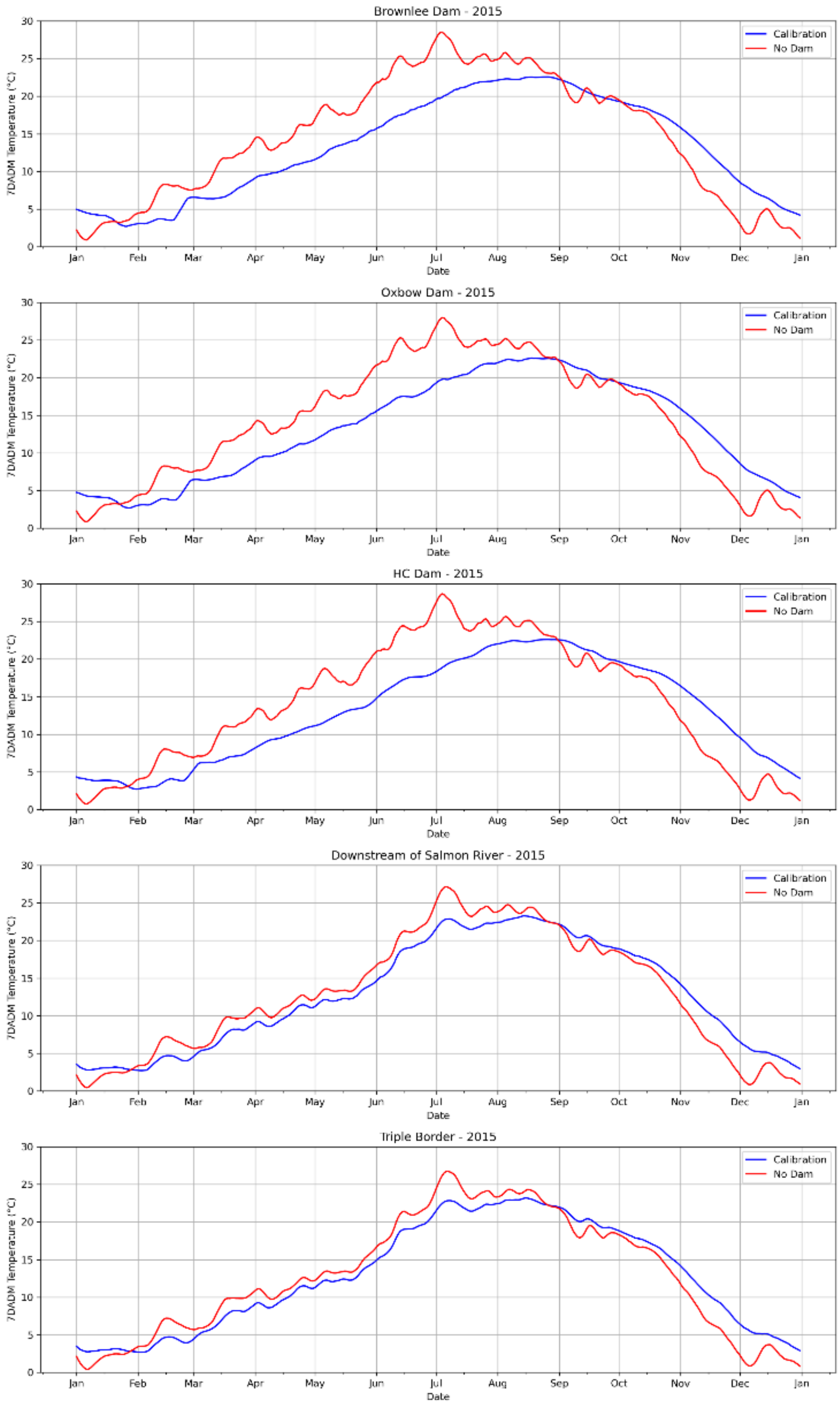


Figure 8-111. Modeled 7DADM average temperature in 2015 for Snake River segment at Brownlee Dam, Oxbow Dam, Hells Canyon Dam, downstream of Salmon River, and triple border, comparing calibration and no dams scenarios.

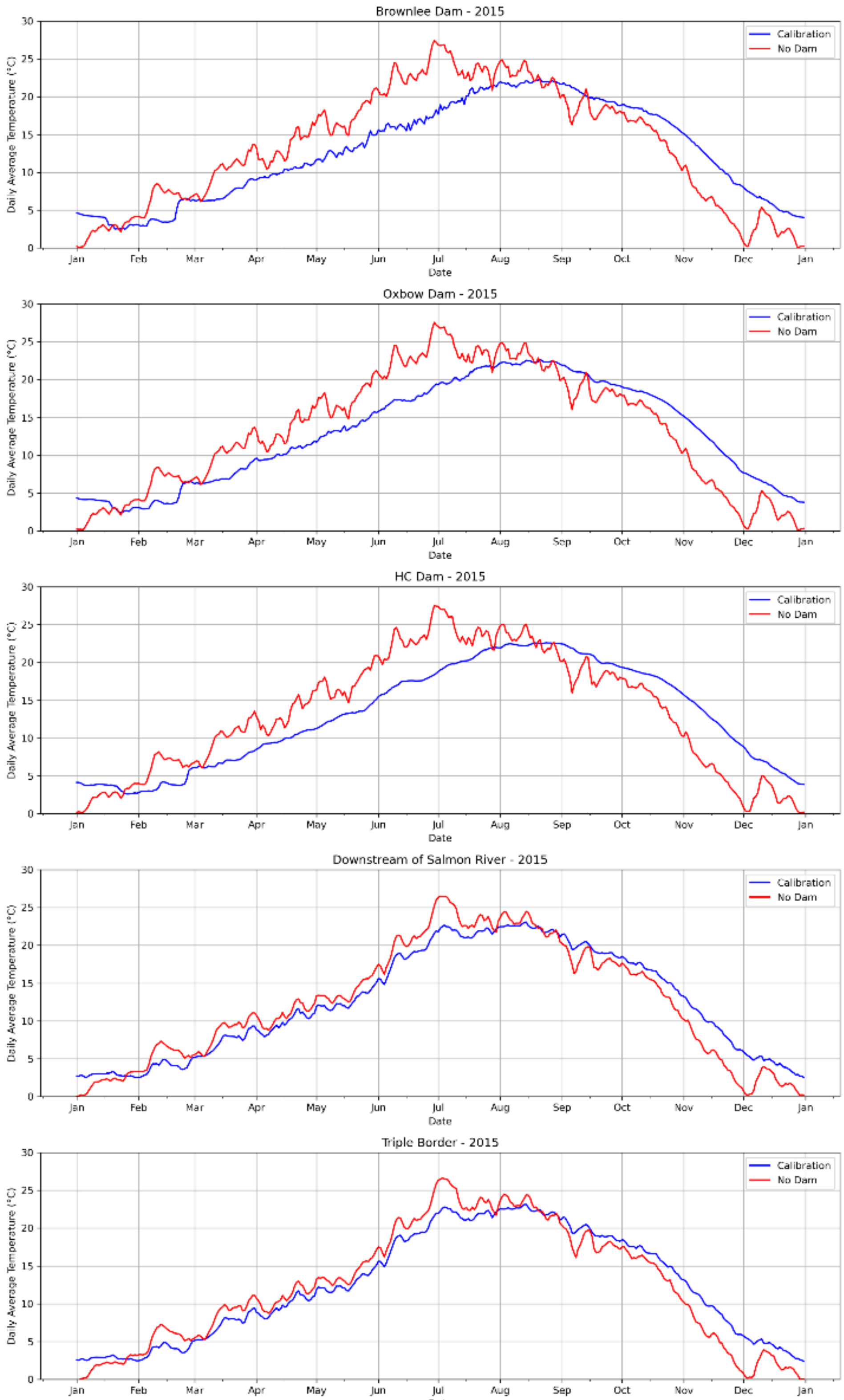


Figure 8-112. Modeled daily average temperature in 2015 for Snake River segment at Brownlee Dam, Oxbow Dam, Hells Canyon Dam, downstream of Salmon River, and triple border, comparing calibration and no dams scenarios.

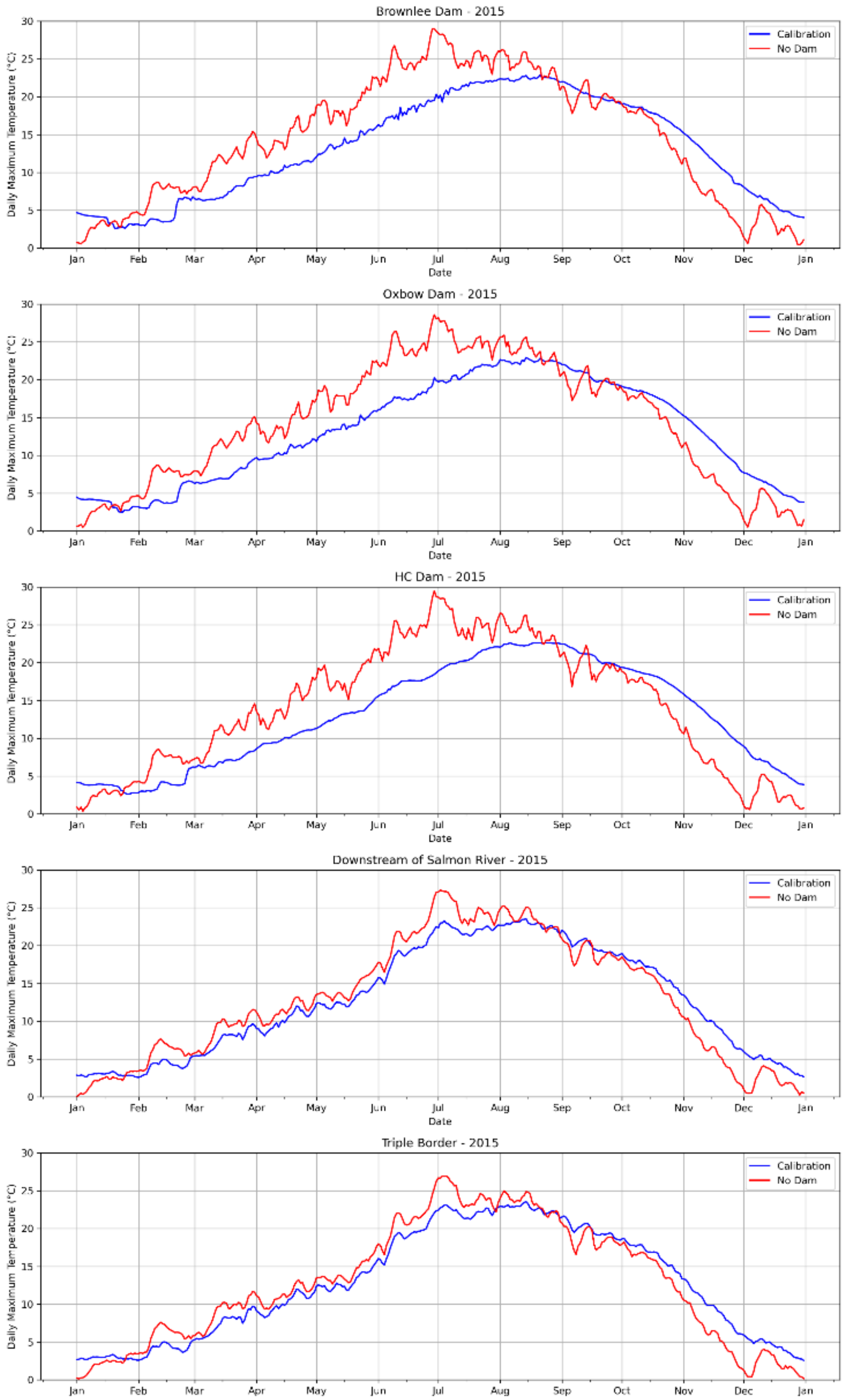


Figure 8-113. Modeled daily maximum temperature in 2015 for Snake River segment at Brownlee Dam, Oxbow Dam, Hells Canyon Dam, downstream of Salmon River, and triple border, comparing calibration and no dams scenarios.

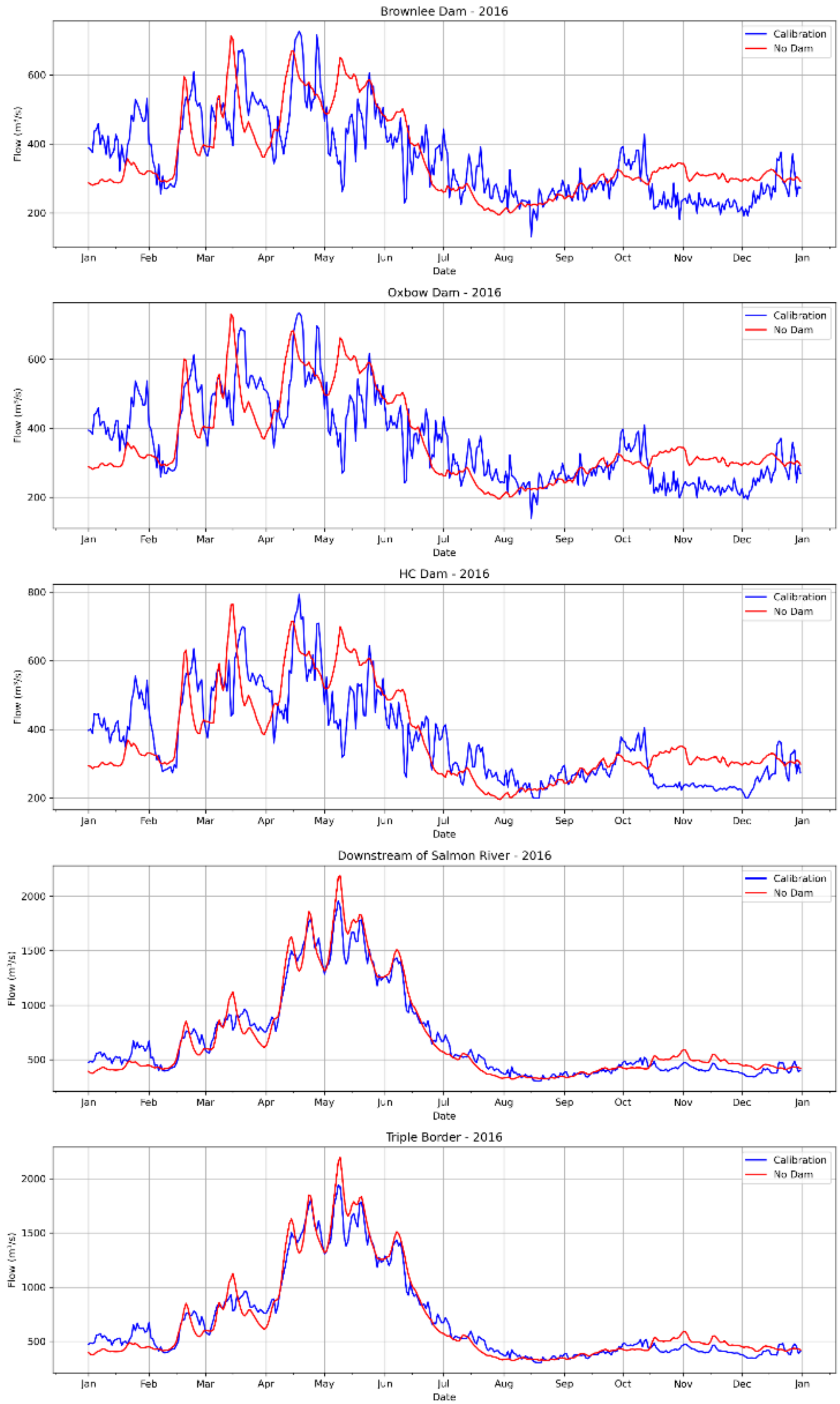


Figure 8-114. Modeled daily average flow in 2016 for Snake River segment at Brownlee Dam, Oxbow Dam, Hells Canyon Dam, downstream of Salmon River, and triple border, Hells Canyon Dam, comparing calibration and no dams scenarios.

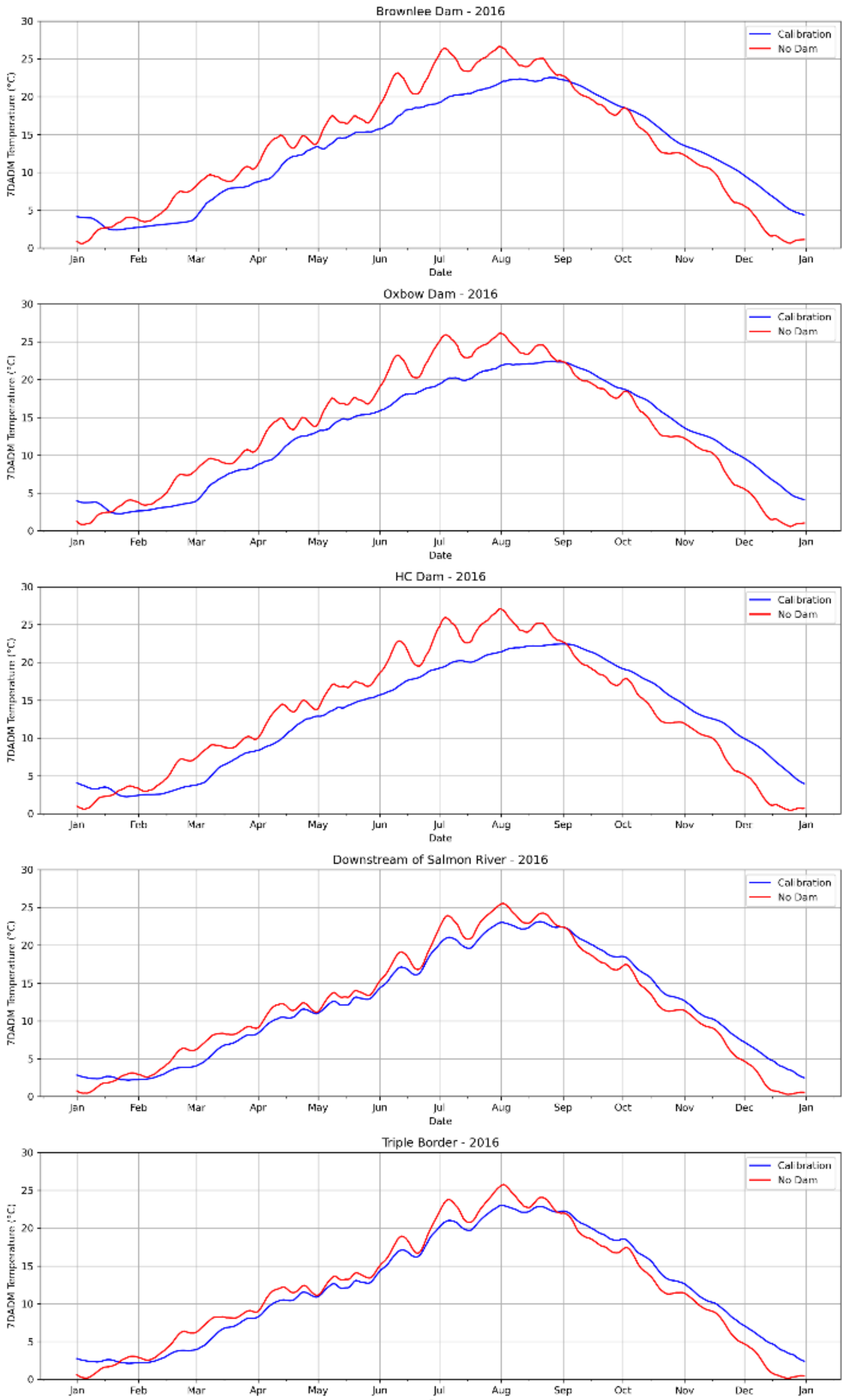


Figure 8-115. Modeled 7DADM average temperature in 2016 for Snake River segment at Brownlee Dam, Oxbow Dam, Hells Canyon Dam, downstream of Salmon River, and triple border, comparing calibration and no dams scenarios.

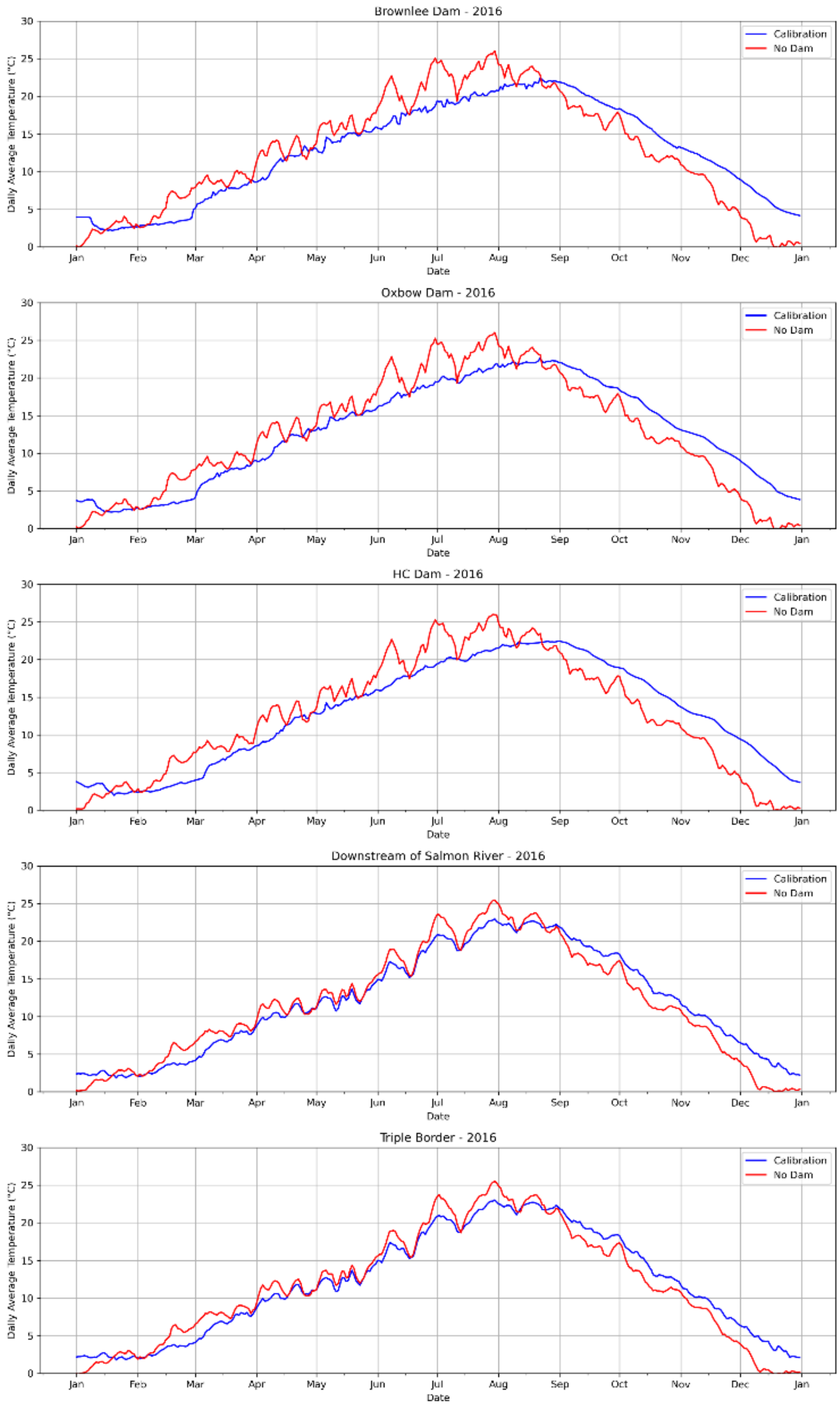


Figure 8-116. Modeled daily average temperature in 2016 for Snake River segment at Brownlee Dam, Oxbow Dam, Hells Canyon Dam, downstream of Salmon River, and triple border, comparing calibration and no dams scenarios.

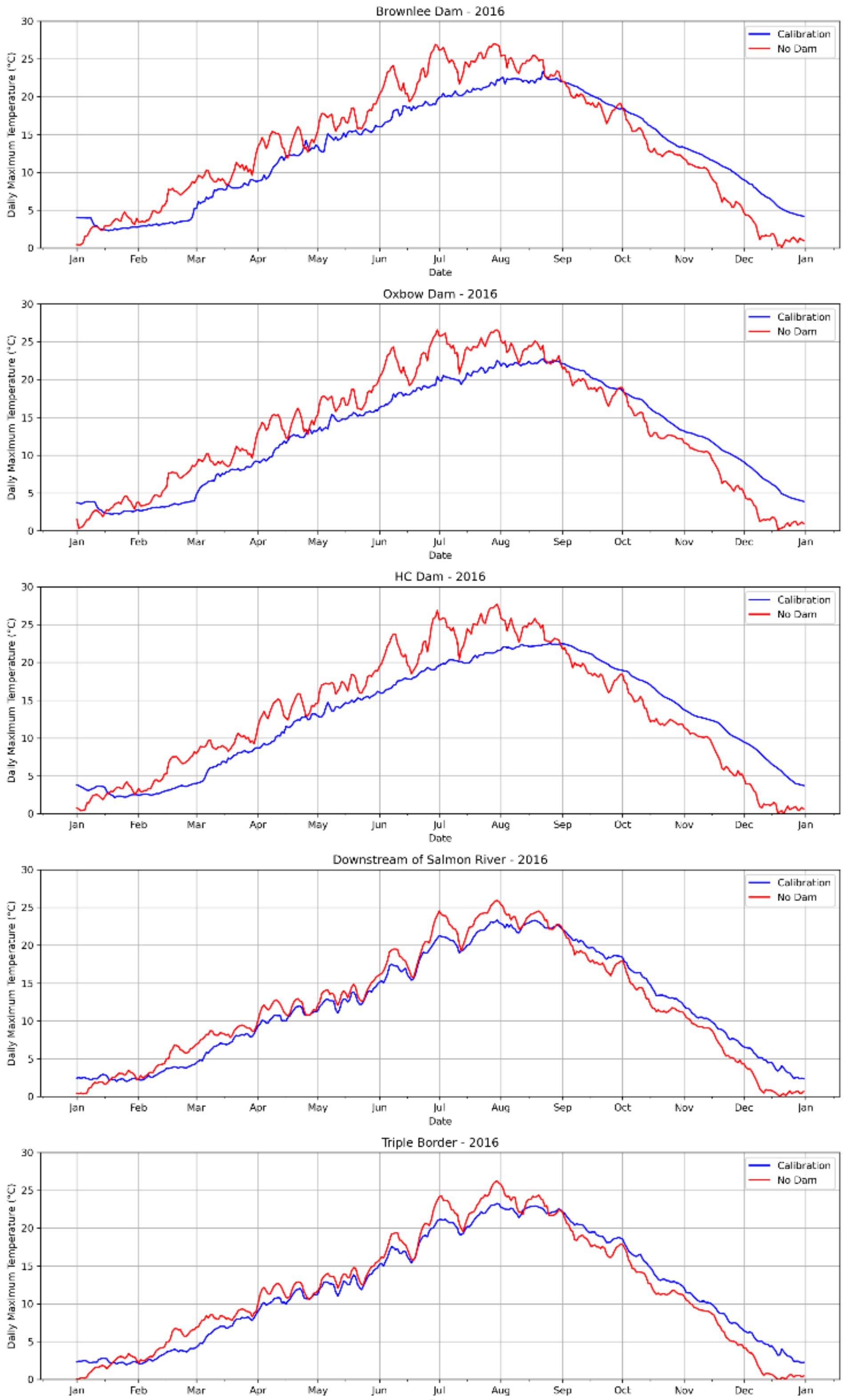


Figure 8-117. Modeled daily maximum temperature in 2016 for Snake River segment at Brownlee Dam, Oxbow Dam, Hells Canyon Dam, downstream of Salmon River, and triple border, comparing calibration and no dams scenarios.

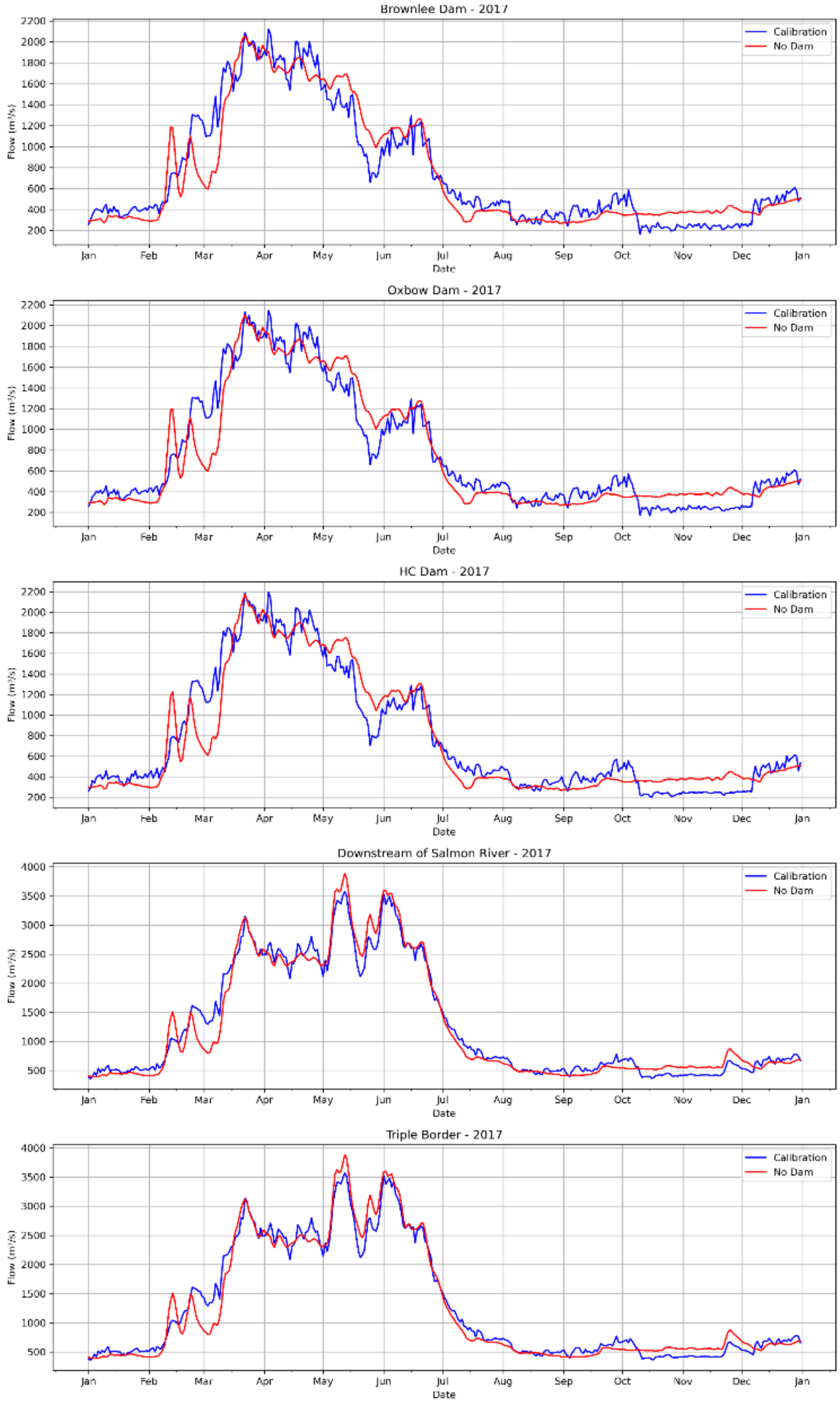


Figure 8-118. Modeled daily average flow in 2017 for Snake River segment at Brownlee Dam, Oxbow Dam, Hells Canyon Dam, downstream of Salmon River, and triple border, Hells Canyon Dam, comparing calibration and no dams scenarios.

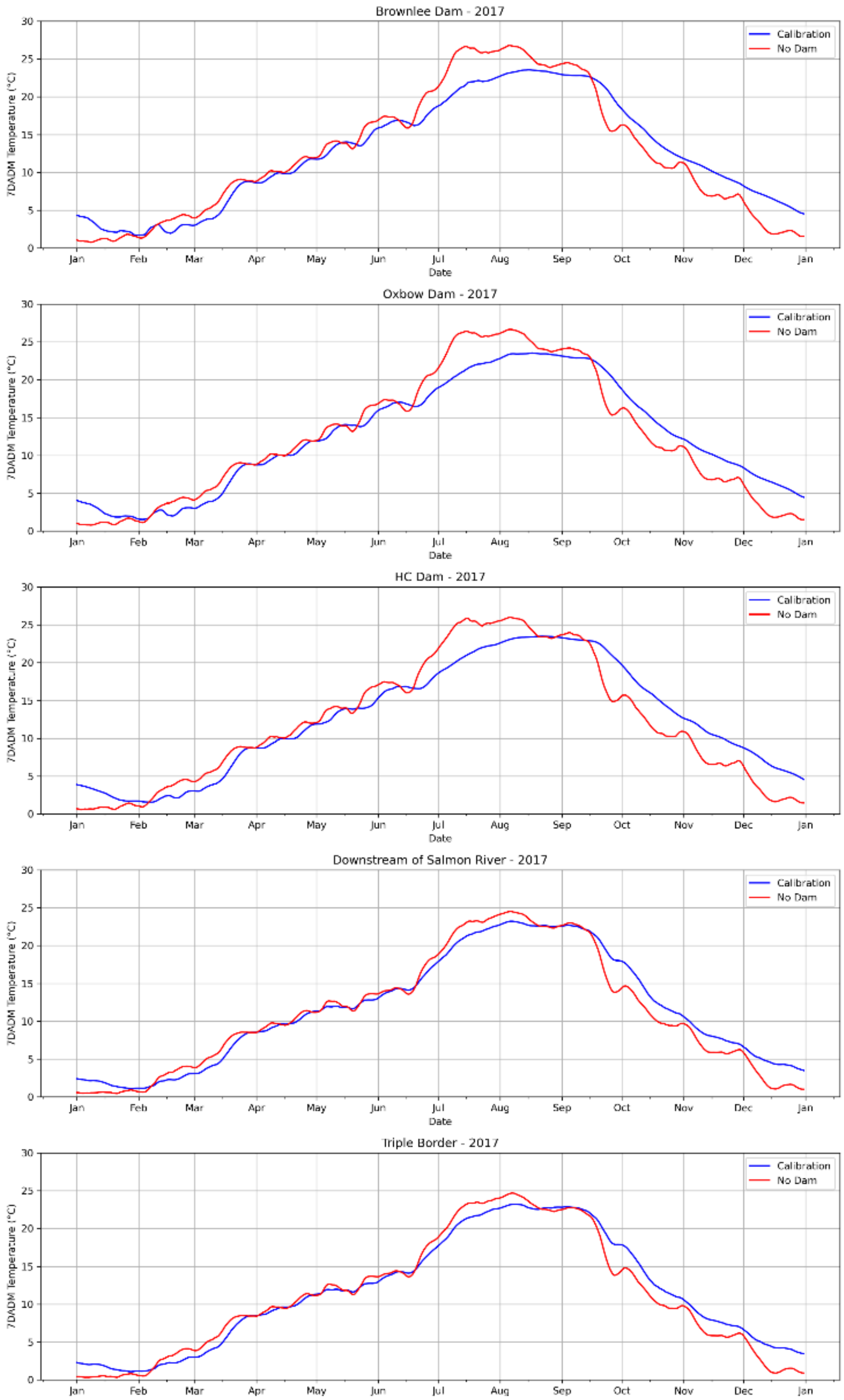


Figure 8-119. Modeled 7DADM average temperature in 2017 for Snake River segment at Brownlee Dam, Oxbow Dam, Hells Canyon Dam, downstream of Salmon River, and triple border, comparing calibration and no dams scenarios.

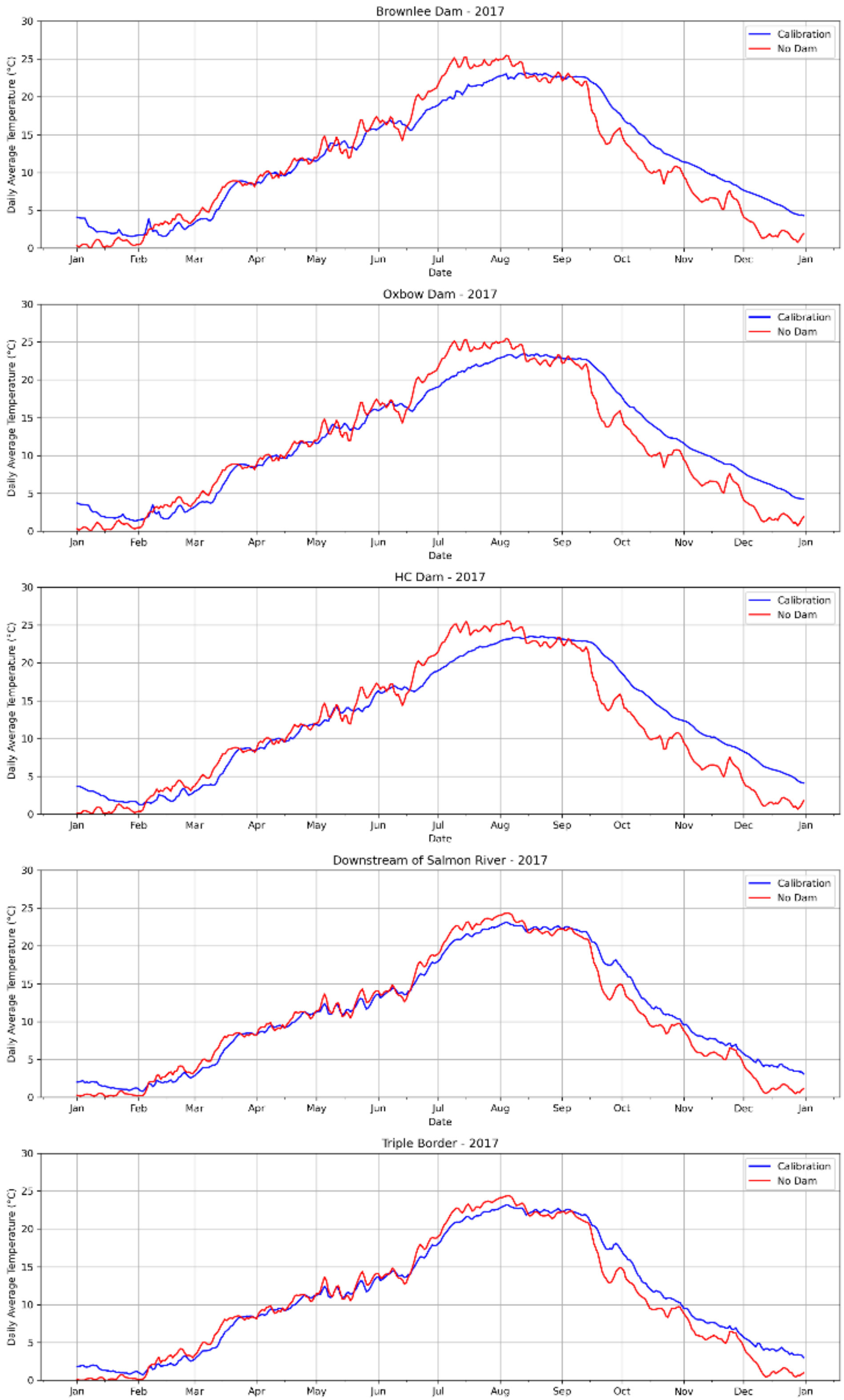


Figure 8-120. Modeled daily average temperature in 2017 for Snake River segment at Brownlee Dam, Oxbow Dam, Hells Canyon Dam, downstream of Salmon River, and triple border, comparing calibration and no dams scenarios.

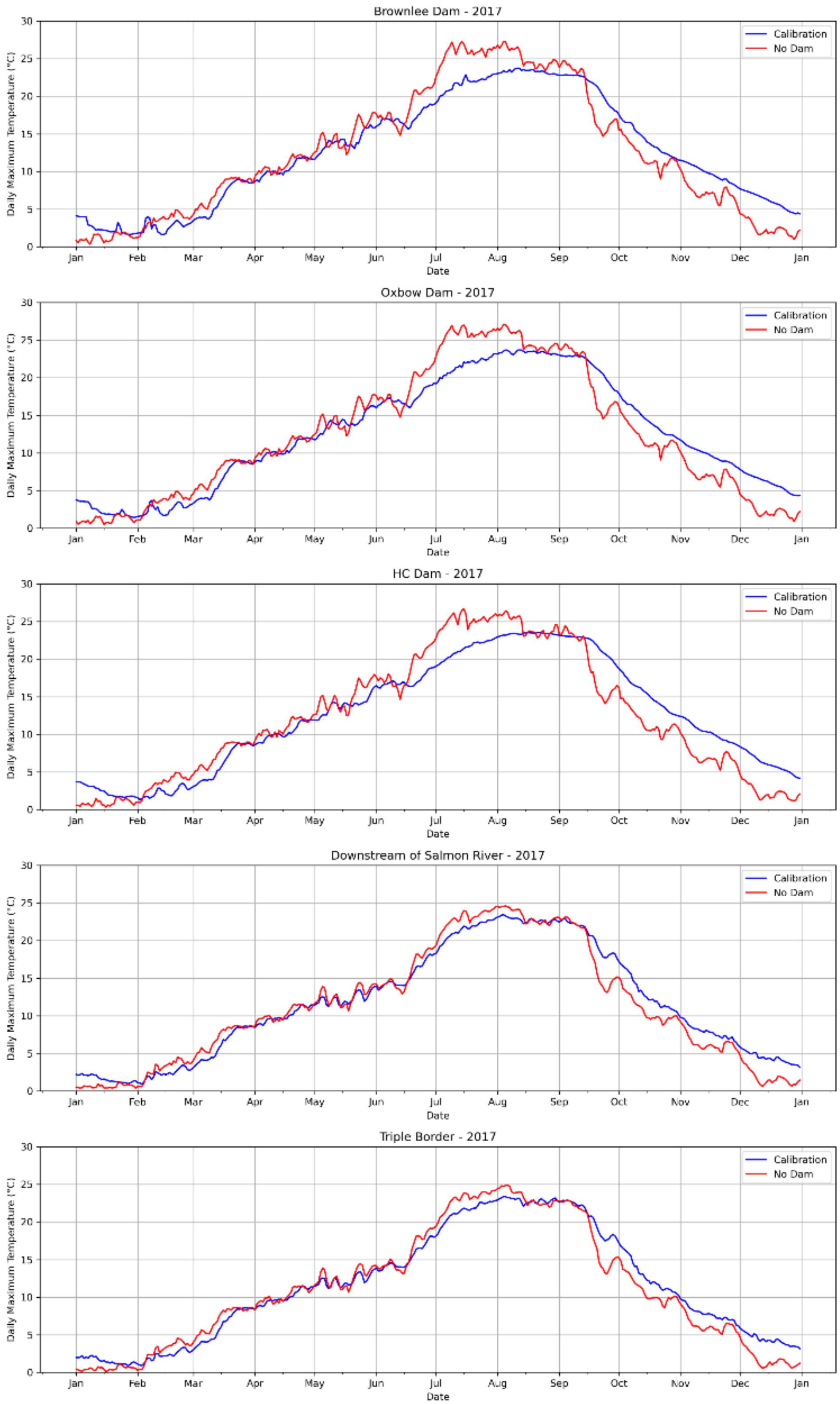


Figure 8-121. Modeled daily maximum temperature in 2017 for Snake River segment at Brownlee Dam, Oxbow Dam, Hells Canyon Dam, downstream of Salmon River, and triple border, comparing calibration and no dams scenarios.

Table 8-1. Mean daily average flow statistics by month and year for the calibration and no dams scenarios at Brownlee Dam.

Month	Mean Daily Average Flow ($m^3 s^{-1}$)									
	2014		2015		2016		2017		2018	
	Calibration	No Dams	Calibration	No Dams	Calibration	No Dams	Calibration	No Dams	Calibration	No Dams
January	257.39	275.76	413.11	331.51	423.53	306.17	380.13	312.58	645.07	507.62
February	305.00	339.53	500.20	454.07	400.40	374.55	778.27	677.87	526.26	479.33
March	489.55	420.36	299.75	337.44	512.74	478.80	1645.51	1478.76	571.76	555.54
April	418.60	373.24	251.91	250.15	532.09	536.26	1837.41	1753.10	1048.65	909.72
May	311.51	423.65	234.68	348.34	447.47	558.26	1183.43	1420.36	651.86	826.93
June	377.91	391.07	254.78	283.22	379.24	396.74	1007.89	1071.35	574.28	590.61
July	355.91	286.83	290.05	250.06	297.72	241.74	494.52	392.02	380.67	295.12
August	265.68	258.83	243.06	227.95	240.36	226.29	337.34	303.25	353.94	312.44
September	249.87	250.12	264.05	259.12	279.17	284.58	405.32	319.95	354.41	291.48
October	242.44	309.31	248.89	285.18	285.98	315.50	291.15	357.84	257.68	331.25
November	241.91	300.32	237.75	300.12	226.54	306.49	239.30	387.58	234.41	312.00
December	343.50	341.16	296.90	327.83	268.89	303.06	456.18	429.41	321.71	304.80

Table 8-2. Mean 7DADM temperature by month and year for the calibration and no dams scenarios at Brownlee Dam.

Month	Mean 7DADM Temperature (°C)									
	2014		2015		2016		2017		2018	
	Calibration	No Dams	Calibration	No Dams	Calibration	No Dams	Calibration	No Dams	Calibration	No Dams
January	2.82	1.55	3.81	2.74	3.10	2.54	2.78	1.20	2.94	3.28
February	2.35	3.84	4.10	6.95	3.17	5.56	2.52	3.24	4.12	4.87
March	5.02	9.65	7.13	10.79	7.15	9.55	5.92	7.04	5.31	7.31
April	9.35	13.20	10.33	14.55	11.16	13.82	10.09	10.60	10.19	11.43
May	12.85	18.31	13.66	18.57	14.61	16.76	13.59	14.29	15.34	16.59
June	17.57	21.66	17.70	24.20	17.83	21.83	16.83	18.02	18.39	20.70
July	20.84	26.11	21.15	25.91	20.55	25.08	21.23	25.34	21.43	26.35
August	23.17	25.75	22.40	24.36	22.26	24.53	23.29	25.34	23.56	25.47
September	21.86	21.15	20.67	20.17	20.58	19.72	21.84	20.82	20.80	20.07
October	18.09	15.53	18.02	16.84	16.37	14.65	14.78	12.66	15.28	13.47
November	12.20	6.83	12.38	7.63	11.84	9.25	10.13	7.71	10.67	6.71
December	6.46	4.92	6.21	2.91	6.72	2.26	6.38	2.81	5.65	2.95

Table 8-3. Mean daily average flow statistics by month and year for the calibration and no dams scenarios at Oxbow Dam.

Month	Mean Daily Average Flow ($m^3 s^{-1}$)									
	2014		2015		2016		2017		2018	
	Calibration	No Dams	Calibration	No Dams	Calibration	No Dams	Calibration	No Dams	Calibration	No Dams
January	258.49	276.52	415.99	333.17	426.41	307.47	380.08	313.70	646.77	509.01
February	306.95	341.10	509.84	462.02	405.38	378.56	785.52	683.94	528.56	482.12
March	502.61	430.79	304.38	342.05	525.43	491.96	1670.33	1495.40	577.65	559.92
April	425.51	380.91	256.40	254.03	544.06	547.51	1851.06	1768.36	1061.61	920.87
May	321.96	432.85	238.11	352.04	456.51	566.21	1196.38	1434.74	662.08	837.94
June	381.99	395.33	257.21	285.14	381.44	399.75	1019.86	1081.61	581.58	597.67
July	357.94	288.25	290.04	250.57	299.66	242.76	495.99	394.14	381.64	295.72
August	265.94	259.17	244.10	228.41	241.92	226.56	338.70	304.10	353.69	312.90
September	250.76	250.37	264.42	259.46	279.21	284.71	405.03	320.18	355.61	291.79
October	243.05	310.02	248.77	285.62	286.09	316.16	293.35	358.68	258.07	331.77
November	243.80	301.11	237.92	300.77	228.33	307.43	239.82	388.65	235.44	312.69
December	344.66	343.08	297.99	329.07	270.76	304.03	457.27	430.09	322.42	305.62

Table 8-4. Mean 7DADM temperature by month and year for the calibration and no dams scenarios at Oxbow Dam.

Month	Mean 7DADM Temperature (°C)									
	2014		2015		2016		2017		2018	
	Calibration	No Dams	Calibration	No Dams	Calibration	No Dams	Calibration	No Dams	Calibration	No Dams
January	2.69	1.49	3.77	2.66	3.04	2.44	2.61	1.12	2.94	3.29
February	2.09	3.72	3.99	6.88	3.17	5.44	2.35	3.18	4.08	4.87
March	4.95	9.48	7.12	10.62	6.95	9.50	5.89	7.07	5.29	7.38
April	9.25	13.05	10.30	14.06	11.07	13.86	10.14	10.56	10.19	11.41
May	12.88	18.15	13.59	18.29	14.65	16.91	13.64	14.29	15.31	16.71
June	17.48	21.53	17.34	23.86	17.81	21.77	16.96	17.97	18.48	20.68
July	20.73	25.83	20.70	25.52	20.51	24.61	21.19	25.29	21.33	26.08
August	22.95	25.41	22.42	23.93	22.16	24.04	23.35	25.18	23.47	25.38
September	21.85	20.84	20.77	19.76	20.70	19.54	21.99	20.81	21.00	20.00
October	18.08	15.42	18.05	16.66	16.51	14.64	15.04	12.60	15.58	13.51
November	12.18	6.71	12.48	7.63	11.86	9.29	10.14	7.65	10.68	6.85
December	6.46	4.85	6.17	2.92	6.63	2.23	6.34	2.79	5.66	2.97

Table 8-5. Mean daily average flow statistics by month and year for the calibration and no dams scenarios downstream of Salmon River.

Month	Mean Daily Average Flow ($m^3 s^{-1}$)									
	2014		2015		2016		2017		2018	
	Calibration	No Dams	Calibration	No Dams	Calibration	No Dams	Calibration	No Dams	Calibration	No Dams
January	373.65	392.39	570.40	489.32	541.66	427.90	493.36	431.54	817.07	679.64
February	439.50	473.66	785.49	734.42	575.31	542.01	1019.03	923.31	717.62	670.73
March	822.74	746.83	627.38	662.80	809.24	780.03	2216.49	2031.07	778.01	760.25
April	900.62	860.89	686.47	683.52	1308.97	1309.13	2500.23	2417.16	1654.43	1511.18
May	1612.57	1723.82	994.30	1110.34	1524.52	1634.92	2802.32	3044.14	2254.23	2431.42
June	1359.48	1374.05	689.91	718.13	1003.54	1023.80	2635.52	2702.09	1423.10	1443.86
July	671.53	603.04	447.25	410.44	515.53	457.51	944.74	845.67	640.42	555.32
August	428.66	418.10	352.63	332.46	350.68	335.87	525.71	490.96	491.62	451.54
September	370.20	368.02	365.61	360.49	384.02	388.90	560.73	476.81	472.77	406.17
October	387.81	452.44	357.08	393.04	449.15	473.78	482.91	541.92	401.39	471.86
November	402.23	462.32	358.12	422.26	418.31	499.02	474.76	623.26	380.55	458.05
December	508.25	511.25	433.97	469.01	396.73	432.96	646.34	623.61	438.10	424.83

Table 8-6. Mean 7DADM temperature by month and year for the calibration and no dams scenarios downstream of Salmon River.

Month	Mean 7DADM Temperature (°C)									
	2014		2015		2016		2017		2018	
	Calibration	No Dams	Calibration	No Dams	Calibration	No Dams	Calibration	No Dams	Calibration	No Dams
January	2.24	1.24	3.01	1.98	2.43	1.77	1.73	0.62	2.77	2.76
February	1.75	2.63	3.91	5.62	3.14	4.43	2.07	2.65	3.70	4.40
March	5.13	7.68	6.96	8.30	6.54	8.18	5.72	6.71	5.22	6.61
April	9.13	10.45	9.94	11.25	10.39	11.48	9.74	10.04	9.83	10.60
May	11.03	12.30	12.56	13.90	12.53	13.34	12.08	12.39	12.30	12.99
June	14.50	15.53	18.18	20.34	16.80	18.08	14.86	15.22	16.52	17.24
July	20.98	23.08	22.17	24.94	20.97	23.00	20.88	22.34	21.47	23.38
August	22.79	24.19	22.79	23.67	22.64	23.78	22.79	23.42	23.20	23.80
September	20.95	20.01	20.29	19.42	20.14	18.96	21.00	19.62	20.30	18.73
October	16.47	14.47	17.10	15.92	15.34	13.60	13.75	11.38	14.37	12.35
November	9.53	5.95	10.41	6.94	9.99	8.34	8.25	6.77	8.79	6.14
December	5.47	4.02	4.78	2.10	4.70	1.63	4.69	2.25	4.55	2.14

Table 8-7. Mean daily average flow statistics by month and year for the calibration and no dams scenarios at triple border.

Month	Mean Daily Average Flow (m3 s-1)									
	2014		2015		2016		2017		2018	
	Calibration	No Dams	Calibration	No Dams	Calibration	No Dams	Calibration	No Dams	Calibration	No Dams
January	373.53	392.25	569.96	488.81	540.89	427.64	492.70	431.53	817.16	679.58
February	438.67	472.89	785.60	734.06	575.44	541.22	1014.40	921.00	717.99	671.15
March	822.27	745.94	626.63	661.71	808.57	779.95	2212.99	2024.01	776.15	758.54
April	900.23	860.11	686.19	683.52	1306.27	1305.96	2500.35	2418.39	1651.57	1507.46
May	1606.96	1718.96	993.28	1108.96	1524.80	1635.22	2797.47	3039.00	2249.90	2427.96
June	1364.46	1378.59	692.46	721.14	1006.41	1026.70	2643.74	2710.54	1431.33	1452.10
July	673.26	605.44	446.93	410.58	516.57	458.60	948.44	849.27	641.75	556.36
August	428.87	417.96	353.34	332.68	350.74	335.70	526.32	491.91	491.11	451.76
September	370.12	367.81	365.42	360.21	383.42	388.46	559.99	476.10	473.34	406.04
October	387.75	452.10	356.74	392.62	449.03	472.98	483.81	541.82	401.64	471.60
November	401.97	462.25	358.48	422.60	418.65	499.59	474.13	622.59	380.59	458.13
December	507.83	511.71	433.23	468.78	396.84	433.16	645.41	623.64	437.54	424.93

Table 8-8. Mean 7DADM temperature by month and year for the calibration and no dams scenarios at triple border.

Month	Mean 7DADM Temperature (°C)									
	2014		2015		2016		2017		2018	
	Calibration	No Dams	Calibration	No Dams	Calibration	No Dams	Calibration	No Dams	Calibration	No Dams
January	2.20	1.16	2.96	1.93	2.38	1.60	1.66	0.50	2.70	2.64
February	1.68	2.48	3.88	5.58	3.07	4.35	2.03	2.59	3.63	4.31
March	5.04	7.61	6.94	8.39	6.46	8.10	5.67	6.66	5.15	6.36
April	9.18	10.60	9.97	11.15	10.36	11.47	9.71	9.95	9.79	10.66
May	11.11	12.30	12.67	13.84	12.48	13.29	12.03	12.34	12.24	13.03
June	14.52	15.45	18.26	20.23	16.82	17.94	14.77	15.21	16.52	17.16
July	21.08	23.12	22.16	24.62	20.98	22.85	20.87	22.40	21.50	23.38
August	22.74	23.88	22.69	23.44	22.50	23.68	22.86	23.45	23.32	24.14
September	20.79	19.79	20.16	19.05	20.06	18.77	21.07	19.64	20.42	18.68
October	16.44	14.58	17.00	15.84	15.33	13.65	13.66	11.50	14.32	12.42
November	9.48	6.08	10.36	7.05	9.96	8.38	8.19	6.72	8.75	6.12
December	5.42	4.03	4.71	2.06	4.60	1.62	4.63	2.16	4.50	2.10

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