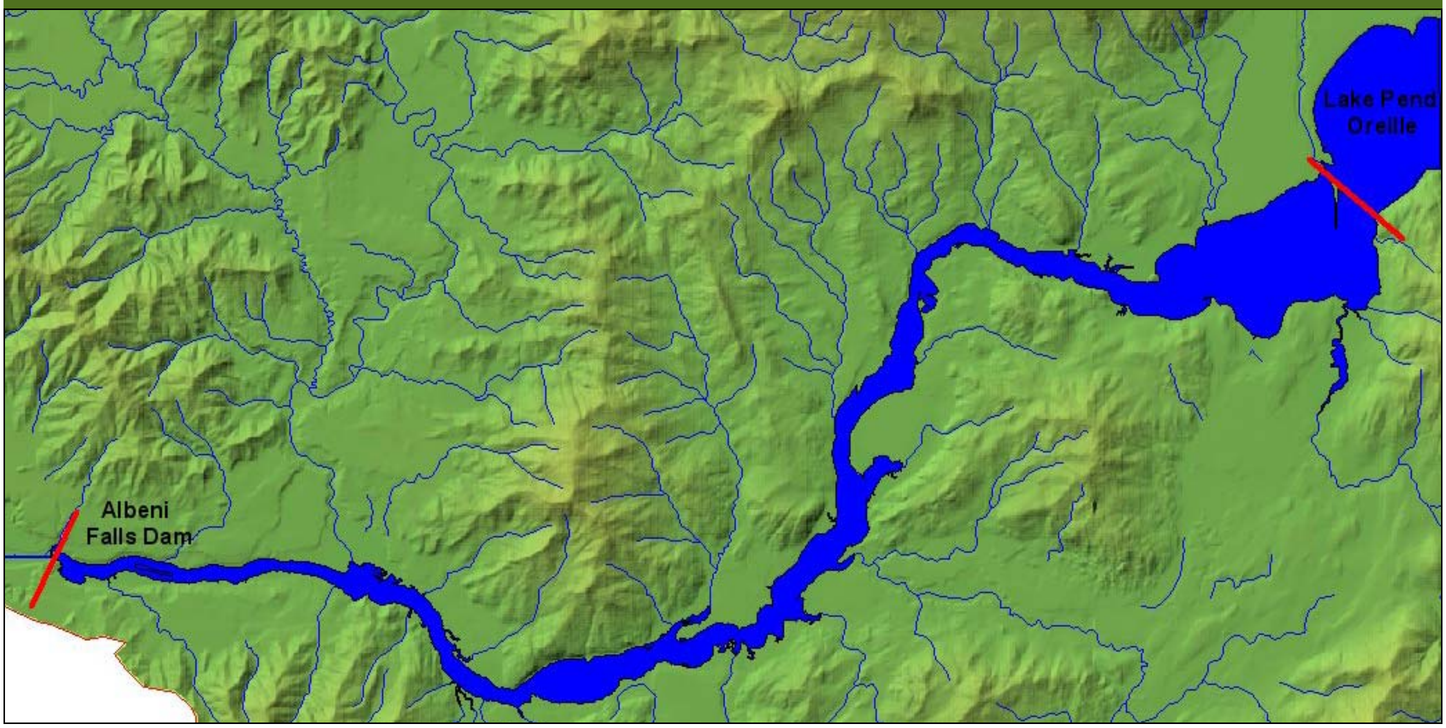
Idaho Pend Oreille River Model

Model Scenario Simulations



Water Quality Research Group
Department of Civil and Environmental Engineering
Maseeh College of Engineering and Computer Science

Technical Report EWR-01-07, March 2007

Portland State University

Pend Oreille River Model:
Model Scenario Simulations

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Technical Report EWR-01-07

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Introduction

The Idaho Department of Environmental Quality is interested in developing a temperature and water quality Total Maximum Daily Load (TMDL) allocation for the Pend Oreille River between the Long Bridge near the historical Lake Pend Oreille outlet and Albeni Falls Dam (U.S. Army Corps of Engineer's reservoir) as shown in Figure 1.

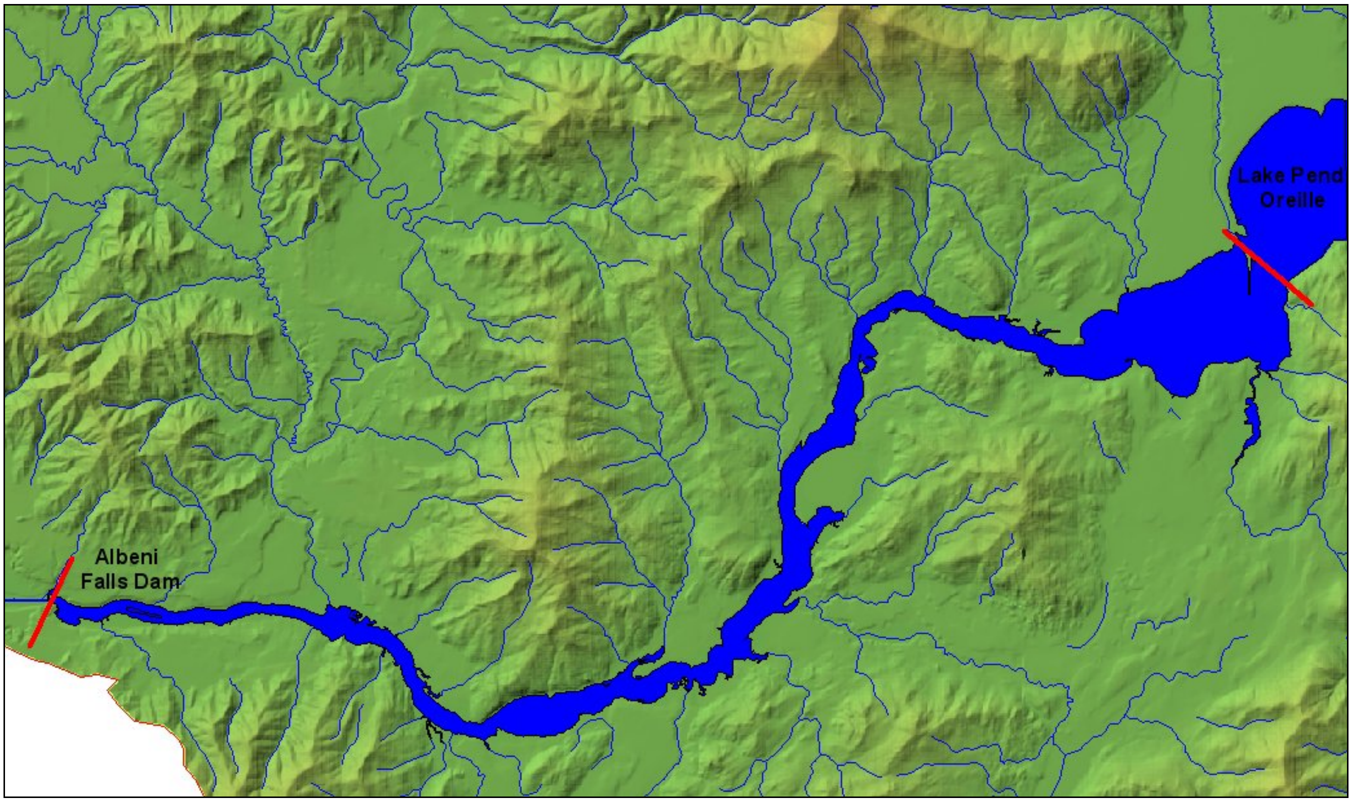

Figure 1: Pend Oreille River downstream of Lake Pend Oreille.

The objectives of this project were to

- Develop a hydrodynamic and temperature model of Pend Oreille River using CE-QUAL-W2 Version 3.2
- Calibrate the CE-QUAL-W2 model to field data collected during 2004 and 2005 using the following water quality variables:
  - flow, water surface elevation, and velocity
  - temperature
  - dissolved oxygen
  - nutrients (NO_3-N+NO_2-N, NH_4-N, PO_4-P)
  - algae – chlorophyll a
  - BOD_5 and dissolved organic matter and particulate organic matter compartments (both labile and refractory) for the organic matter cycling with algae
  - periphyton
- Run model scenarios to investigate the thermal loading impacts of various river system influences such as the Albeni Falls Dam, point sources, and non-point sources.

The model chosen for development was CE-QUAL-W2 Version 3.2 (Cole and Wells, 2004). This is a two-dimensional unsteady hydrodynamic and water quality model that includes typical eutrophication constituents (algae, nutrients, temperature, organic matter, dissolved oxygen, pH). Portland State University's Water Quality Research Group is a center for development of this modeling tool (see http://www.cee.pdx.edu/w2).

The model simulation was run from January 1st, 2004 to September 25th, 2005. The calibration period focused on the summers during each year when water quality data were obtained and is well documented in the companion report:

> Annear, R. L.; Berger, C. J.; and Wells, S. A. (2006) "Pend Oreille River Model: Model Development and Calibration," Technical Report EWR-02-06, Department of Civil and Environmental Engineering, Portland State University, Portland, OR.

Table 1 lists the model scenarios considered for the Pend Oreille River in Idaho. The second column in the table indicates which scenarios were completed and compared with the existing conditions. Not all of the scenarios were conducted because the initial set of scenarios completed provided sufficient information to the Idaho Department of Environmental Quality to evaluate the impact of thermal loadings

Table 1: Pend Oreille River, Idaho Model Scenarios

Scenario	Comp-leted	Albeni Falls Dam	NPDES (Point Sources)	Tributaries (Non Point Sources, NPS)	Shade conditions
1. Current Simulation	Yes	In	Current quantity and quality	Current quantity and quality	Shade limited to topographic features
2. Impounded with No NPDES	Yes	In	Out, no discharges	Current quantity and quality	Shade limited to topographic features
2.5 Impounded with No NPS	Yes	In	Current quantity and quality	Current quantity, estimated natural temperature and quality	Shade limited to topographic features
3. Impounded with No NPDES or NPS	No	In	Out, no discharges	Current quantity, estimated natural temperature and quality	Shade limited to topographic features
4. Un-impounded	Yes	Out	Current quantity and quality	Current quantity and quality	Shade limited to topographic features
5. Un-impounded with No NPDES	No	Out	Out, no discharges	Current quantity and quality	Shade limited to that provided by topographic features
6. Un-impounded with No NPDES or NPS	No	Out	Out, no discharges	Current quantity, estimated natural temperature and quality	Shade limited to topographic features
7. Potential Natural Vegetation with Current Condition	No	In	Current quantity and quality	Current quantity and quality	Shade includes Potential Natural Vegetation and topographic features.
8. Natural	Yes	Out	Out, no	Current quantity,	Shade includes

Scenario	Comp-leted	Albeni Falls Dam	NPDES (Point Sources)	Tributaries (Non Point Sources, NPS)	Shade conditions
Conditions Simulation			discharges	estimated natural temperature and quality	Potential Natural Vegetation and topographic features.

The model scenarios completed from Table 1 resulted in the following model comparisons:

1. Existing Conditions to Natural Conditions (Scenarios 1 and 8)
2. Point Source Contributions (Scenarios 1 and 2)
3. Non-point Source Contributions (Scenarios 1 and 2.5)
4. Albeni Falls Dam Contribution (Scenarios 1 and 4)
5. Vegetation Bank Shading (Scenario 8, varying SRF, Vegetation density)

Comparisons were made between model scenarios using the following model outputs:

1. Time Series Comparisons
    a. Locations
        - 10 km downstream (Model Segment 39)
        - 36 km downstream (Model Segment 136)
        - Albeni Falls Dam (Model Segment 183)
    b. Statistics
        - Daily average: bottom (1 m depth volume-weighted), surface (1 m depth volume-weighted) and volume weighted (over the full vertical column)
        - Daily maximum: surface (1 m depth volume-weighted)
2. Longitudinal Profile Comparisons
    a. Statistics, August 16th, 2004
        - Daily average: volume weighted
        - Daily maximum: surface (1 m depth volume-weighted)

In addition to the time series and longitudinal profile comparisons between model scenarios statistics were developed to evaluate how statistically significant are the similarities between the model scenario outputs compared. The null hypothesis, H_0, is case where there are differences between the mean values in the two model scenario results (μ_1 and μ_2). The corresponding alternative hypothesis, H_a is where the mean values in the two model scenario results are the same. The test of the null hypothesis is the P-value test, where the smaller the P-value is, the stronger the evidence against the null hypothesis, and hence the more similar are the model results.

Table 2 lists the P-value statistics used when comparing the model output between scenarios. The P-value statistics were calculated over a 2 year period from 01/01/2004 to 09/24/2005.

Table 2: P-value statistics used for comparing model results between scenarios.

P-value	Description	Interpretation
P < 0.1	statistically significant	Model results between scenarios are the same, i.e. no difference
0.1 < P < 0.2	probably statistically significant	Model results between scenarios are similar
0.2 < P < 0.3	possibly statistically significant	Model results between scenarios have some similarities
0.3 < P	not statistically significant	Model results between scenarios are not the same.

Evaluation of Existing Conditions to Natural Conditions

The cumulative thermal loading contributions to the Pend Oreille River from point sources, non-point sources, Albeni Falls Dam and the lack of vegetative shade were evaluated by comparing results from model scenario l, existing conditions, and scenario 8, natural conditions with no point sources, no non-point sources, no dam and including vegetative shade.

Time Series Plots

Daily Average Temperatures

Figure 2 shows the daily average surface temperature 10 km downstream from the Long Bridge for Model Scenario 8 (Natural Conditions, no dam, no NDPES, no NPS, and with vegetative shade) and Model Scenario 1 (Existing Conditions). The figure shows that there is an increase in the daily average temperatures from January 1st to March 1st for the natural conditions scenario compared to existing conditions. The increased temperatures are somewhat a result of the water depth at the upstream end of the river being 2 m deeper in the existing scenario than the no dam scenario. The shallower depth in Scenario 8 allows the river temperature to respond more quickly to air temperatures. Figure 3 shows the same river temperatures from Figure 2 and the air temperature used in the model. Also, the shallower river depth in Scenario 8 results in the river connection to the lake being restricted to the surface layers of the lake rather than deeper water in the lake which may be colder. The result is the lake is only passing downstream the warmer surface water to the river. In Scenario 1 there are 2 m of additional depth to pass colder from the lake to the river.

Figure 4 shows the daily average 1 m volume-weighted bottom temperature for Scenarios 1 and 8 at 10 km downstream from Long Bridge. Figure 5 is a time series plot of the daily average of the volume-weighted temperature (over the full depth) for the two models scenarios at 10 km downstream of Long Bridge.

The volume-weighted temperatures are calculated for each model segment using the volume of each segment layer (cell) multiplied by the temperature of each cell and then summed over the full depth of the model segment. This summation is then divided by the total volume of the layers in the segment. The calculation is represented by:

$$T_{vw} = \frac{\sum_{k=KT}^{KMP} T_k V_k}{\sum_{k=KT}^{KMP} V_k}$$

where T_{VW} is the volume-weighted temperature for a model segment, T_k is the temperature in layer k, and V_k is the volume of layer k. k ranges of the number of layers from KT, the surface, to KMP, the bottom of the model segment.

Figure 6 shows the daily average 1 m volume-weighted surface temperature for Scenarios 1 and 8 at 35 km downstream from the Long Bridge. Figure 7 shows the daily average 1 m volume-weighted bottom temperature 35 km downstream from the Long Bridge for the two scenarios. The figure indicates there are some temperature differences in July between the two models which results from the limited water circulation in the deep pool located at 35 km downstream. The temperature differences between the two model scenarios are limited to this deep pool. Figure 8 shows the daily average of the volume-weighted temperature (over the full depth) over time for the two models scenarios at 35 km downstream of Long Bridge in 2004.

The daily average temperature time series figures also include the Idaho Water Quality Standards' daily average numeric temperature criteria of 19.0 ºC.

Figure 9 shows a time series plot of the continuous (hourly) outflow temperature from Albeni Falls Dam from Scenario 1 and the outflow temperature from Scenario 8, the Natural Conditions for the same location. Figure 9 also includes the Idaho Water Quality Standards' daily maximum numeric temperature criteria of 22.0 ºC. Table 3 lists the statistical significance of how similar are the modeled temperatures between scenarios.

The P value statistics at 35 km downstream for the daily average bottom temperature suggests the two scenarios are the same or similar in. Table 3. This shows the limitation of strictly using P values to identify differences between scenarios. The scenarios tested equivalent because the average over the whole simulation of the daily average values of the two scenarios are not that different. Although one scenario may be warmer or cooler during part of the year, the differences over the whole simulation period even out. The P-value statistic can identify an average bias over the whole simulation, but not during specific time periods (or seasons).

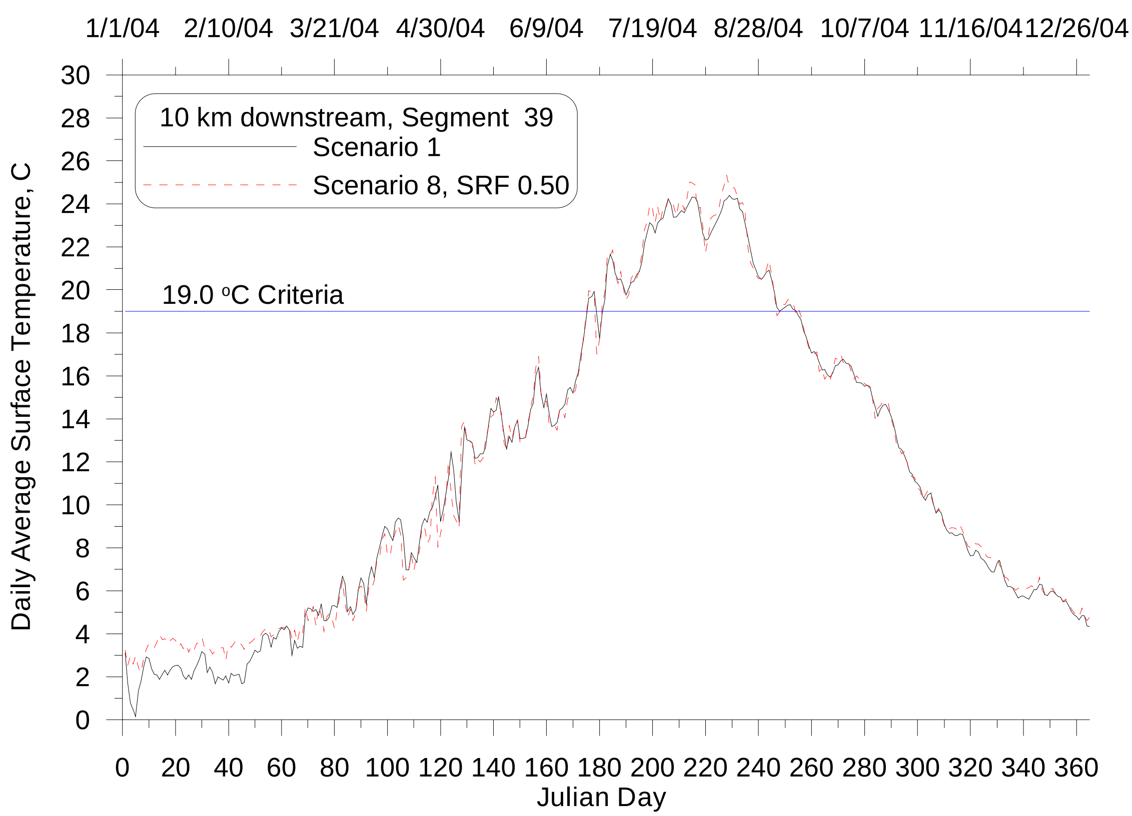

Figure 2: Daily average surface temperature time series at 10 km downstream from Lake Pend Oreille for the Natural Conditions (8) and Existing Conditions (1) Scenarios, 2004.

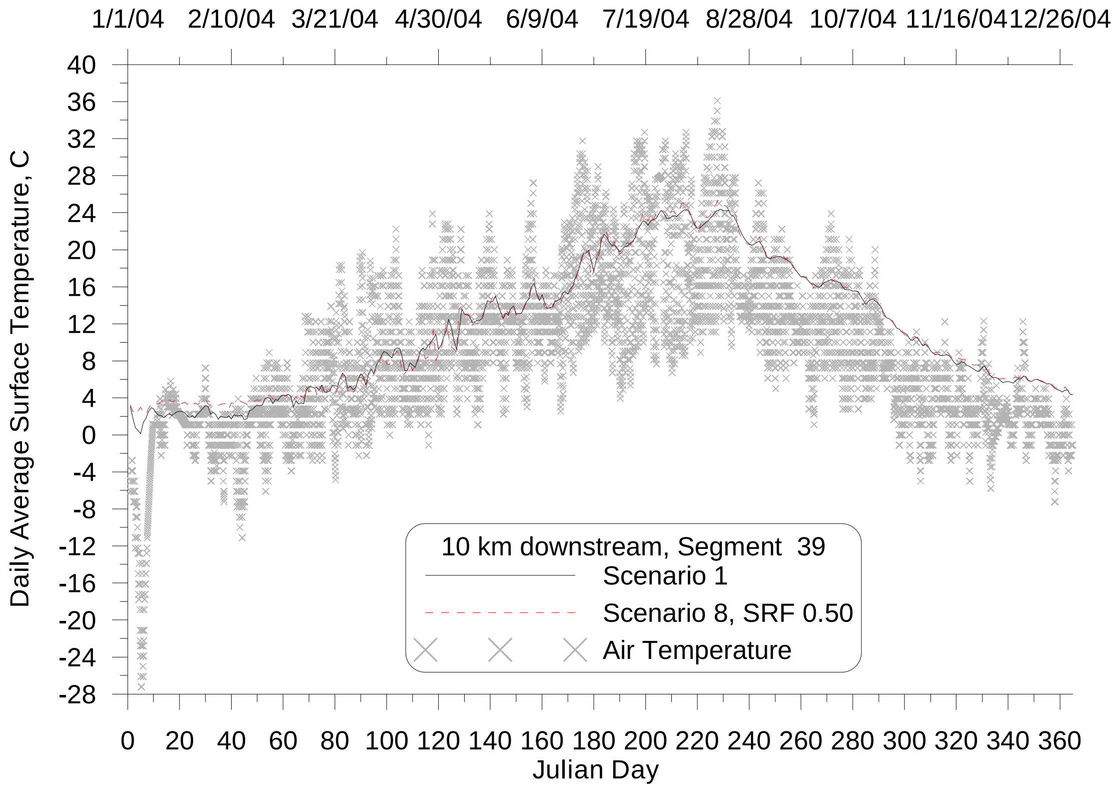

Figure 3: Daily average surface temperature time series at 10 km downstream from Lake Pend Oreille for the Natural Conditions (8) and Existing Conditions (1) Scenarios and Air Temperature, 2004.

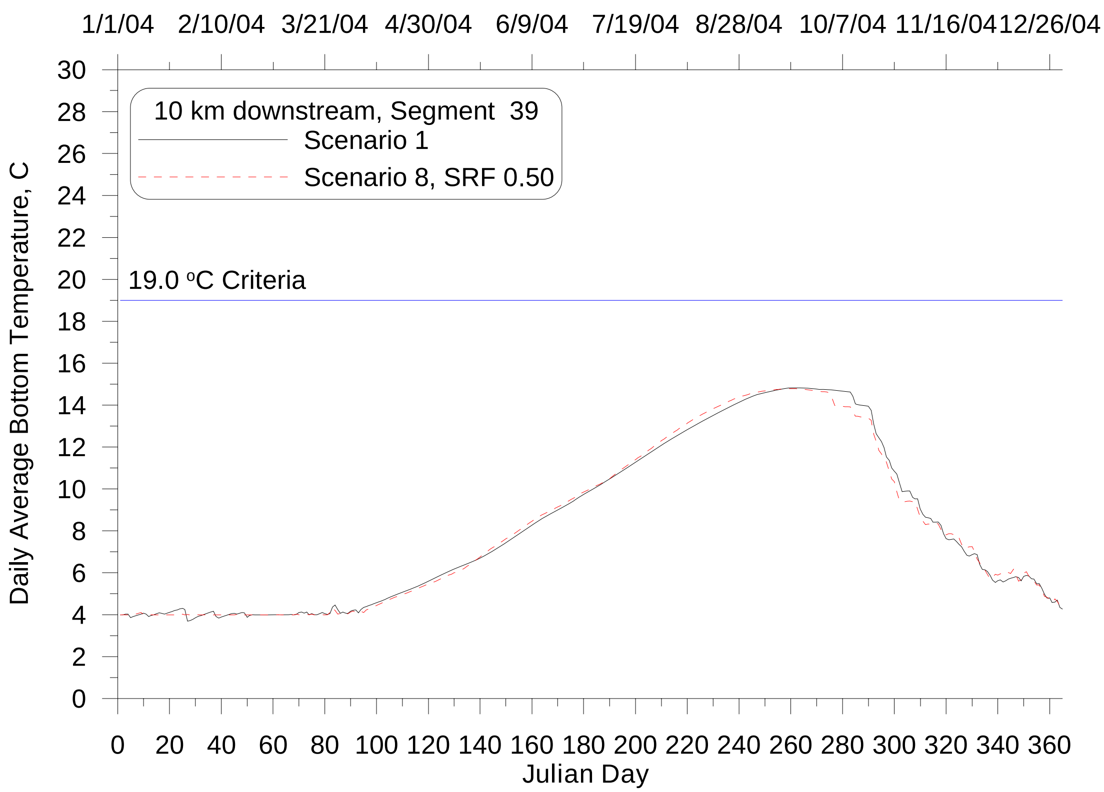

Figure 4: Daily average bottom temperature time series at 10 km downstream from Lake Pend Oreille for the Natural Conditions (8) and Existing Conditions (1) Scenarios, 2004.

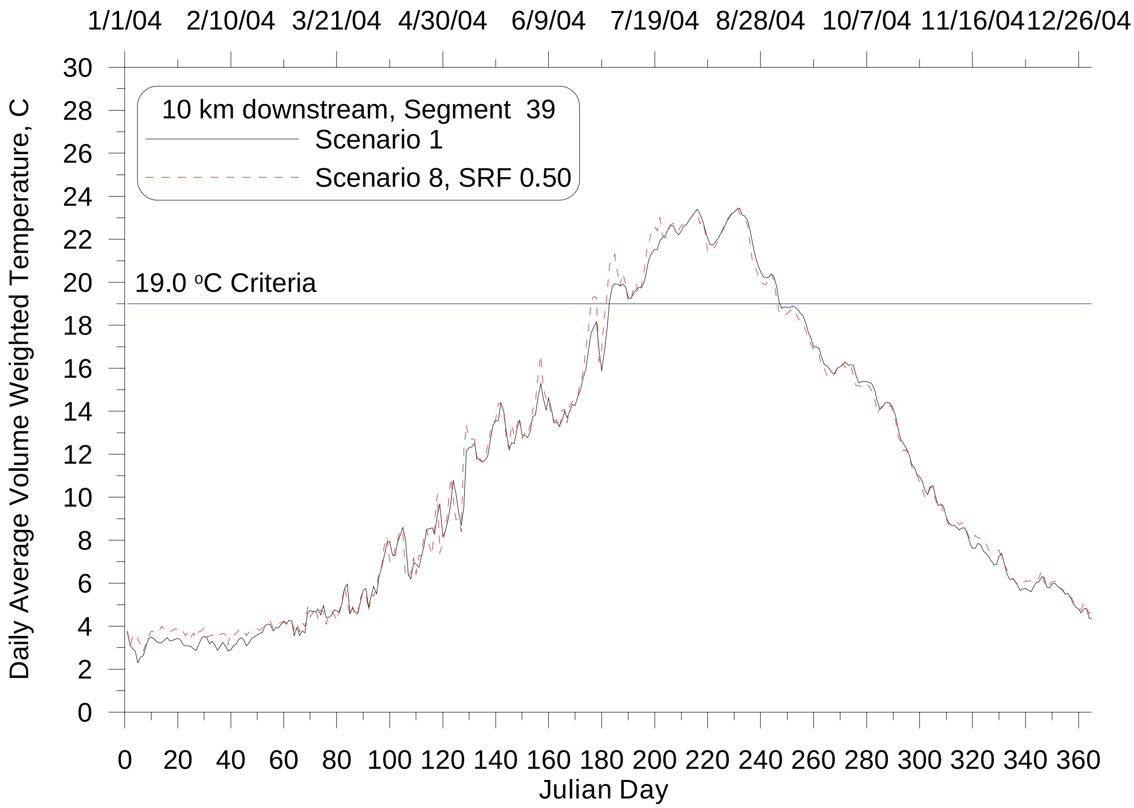

Figure 5: Daily average volume weighted temperature time series at 10 km downstream from Lake Pend Oreille for the Natural Conditions (8) and Existing Conditions (1) Scenarios, 2004.

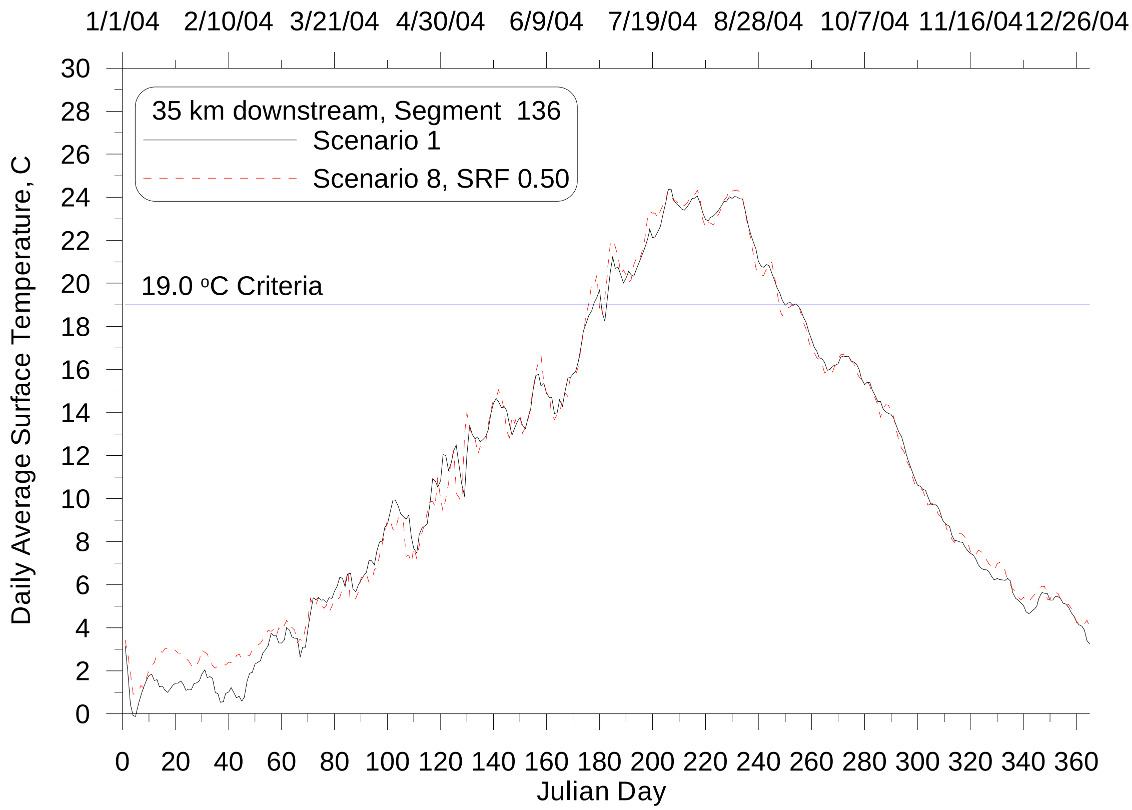

Figure 6: Daily average surface temperature time series at 35 km downstream from Lake Pend Oreille for the Natural Conditions (8) and Existing Conditions (1) Scenarios 2004.

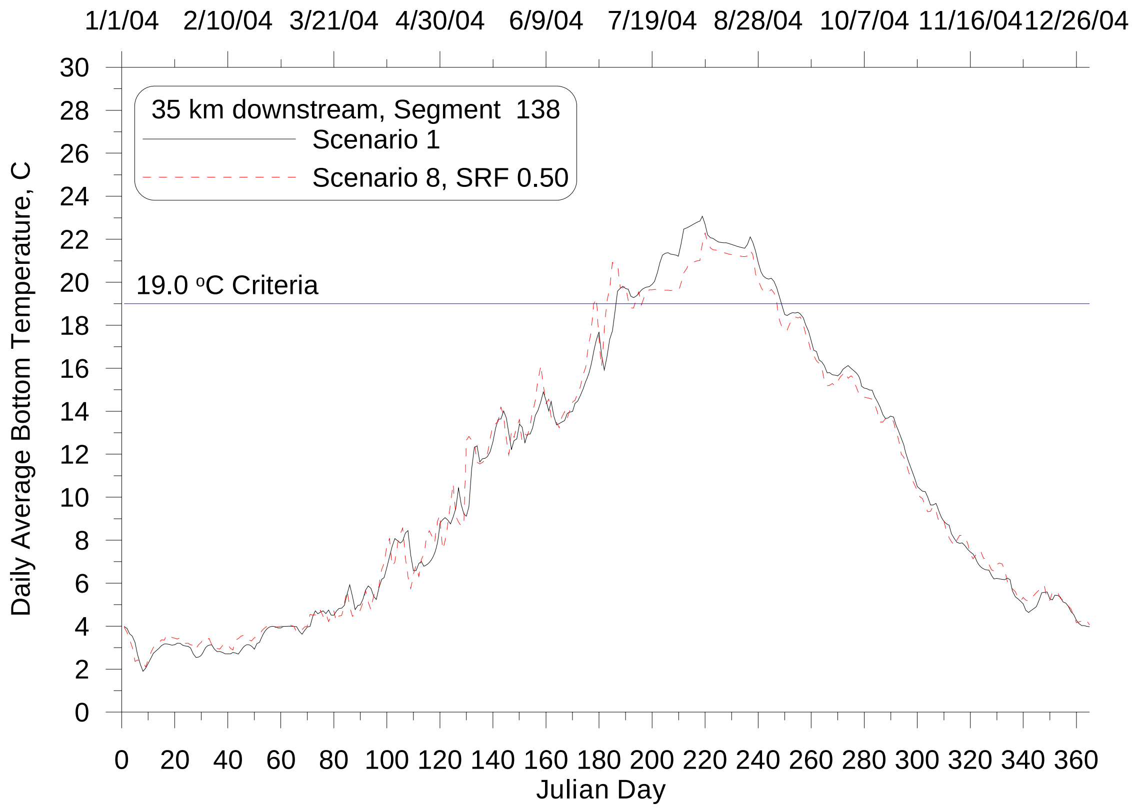

Figure 7: Daily average bottom temperature time series at 35 km downstream from Lake Pend Oreille for the Natural Conditions (8) and Existing Conditions (1) Scenarios, 2004.

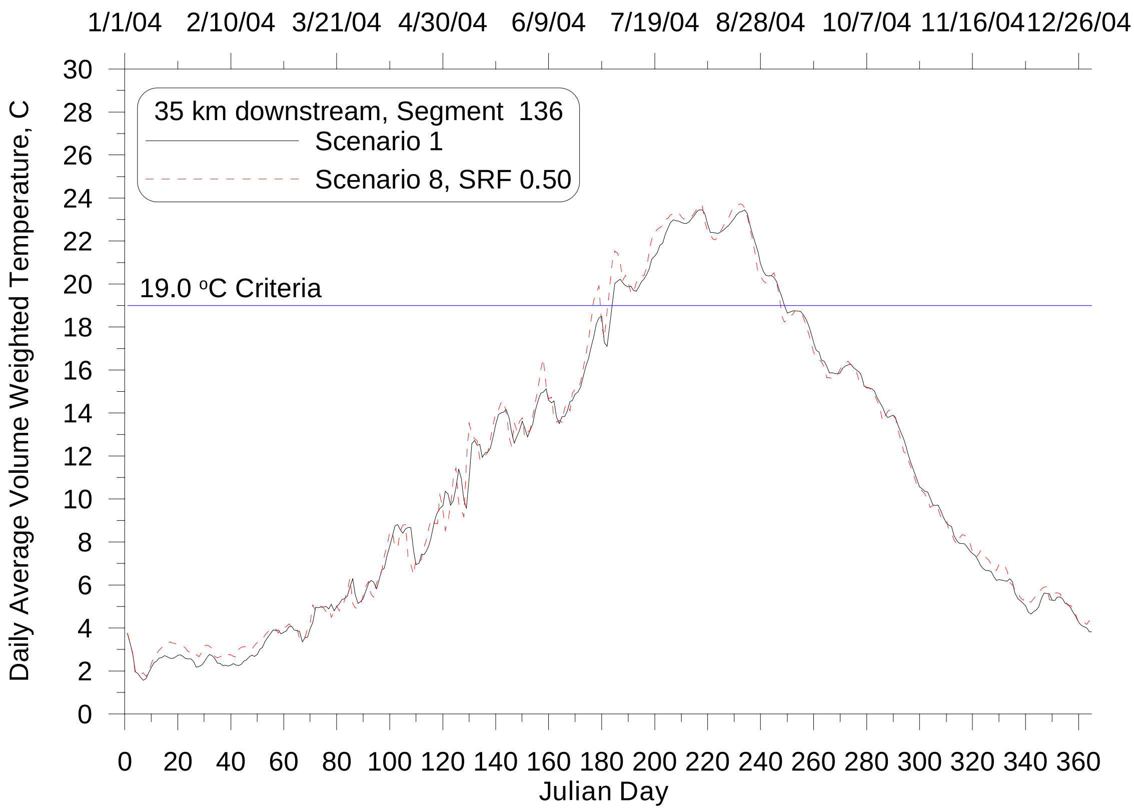

Figure 8: Daily average volume weighted temperature time series at 35 km downstream from Lake Pend Oreille for the Natural Conditions (8) and Existing Conditions (1) Scenarios, 2004.

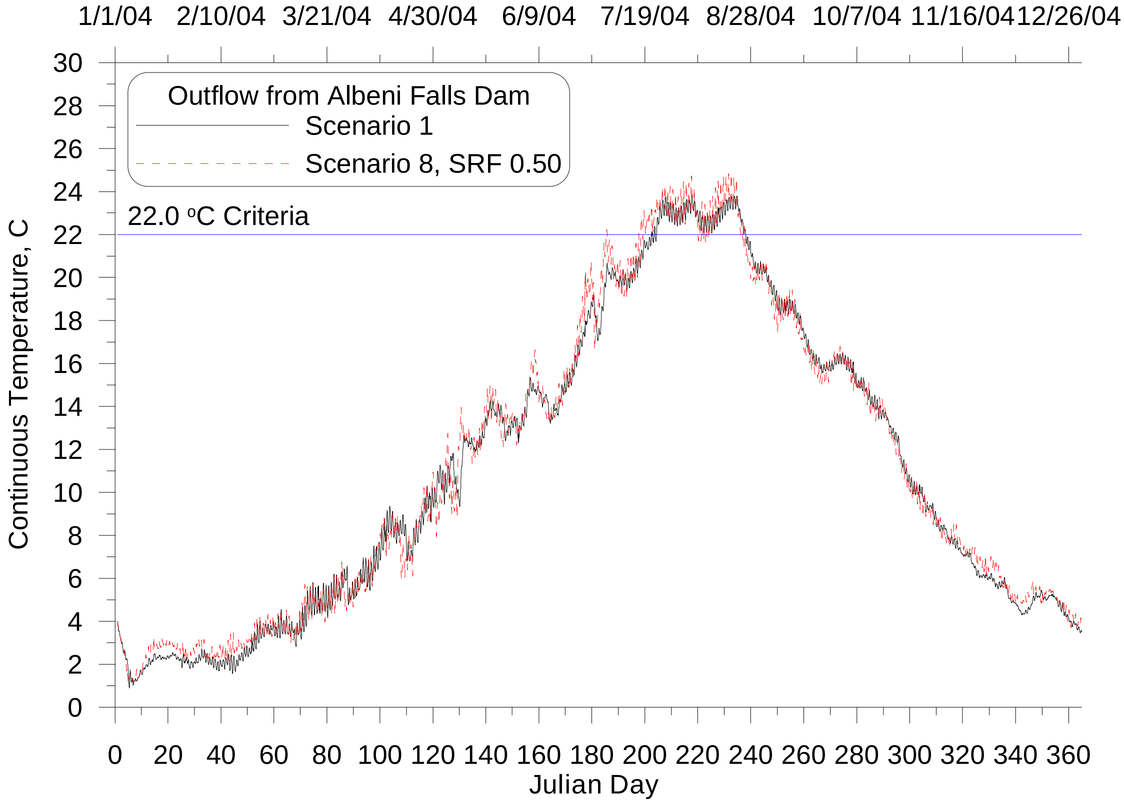

Figure 9: Continuous outflow temperature time series at Albeni Falls Dam for the Natural Conditions (8) and Existing Conditions (1) Scenarios, 2004.

Table 3: Statistical significance in time series results between the Natural Conditions (8) and Existing Conditions (1) Scenarios.

Scenario 1 and Scenario 8 Comparison	P-value	Result
Daily average surface temperature, 10 km	0.42	not statistically significant, results are not the same
Daily average bottom temperature, 10 km	0.12	probably statistically significant, results are similar
Daily average volume-weighted, 10 km	0.24	possibly statistically significant, results have some similarities
Daily average surface temperature, 35 km	0.33	not statistically significant, results are not the same
Daily average bottom temperature, 35 km	0.01	statistically significant, results are the same[1]
Daily average volume-weighted, 35 km	0.33	not statistically significant, results are not the same
Continuous volume-weighted, outflow temperature at Albeni Falls Dam	1.00	not statistically significant, results are not the same
[1] The P-value statistics reflects 2 years, if only one year was used (2004, shown in Figure 7) the P-Value would be 0.10, probably statistically significant, results are similar.		

Daily Maximum Temperatures

Figure 10 shows the daily maximum of the 1 m volume-weighted surface temperature for Scenarios 1 and 8 at 10 km downstream from the Long Bridge. Figure 11 shows the temperature difference over time between the daily maximum temperatures in Figure 10.

Figure 12 shows the daily maximum of the 1 m volume-weighted surface temperature for Scenarios 1 and 8 at 35 km downstream from the Long Bridge. Figure 11 shows the temperature difference over time between the daily maximum temperatures in Figure 12. The figures also include the Idaho Water Quality Standards' daily maximum numeric temperature criteria of 22.0 ºC. Table 4 lists the statistical significance of how similar are the daily maximum temperatures between the two scenarios.

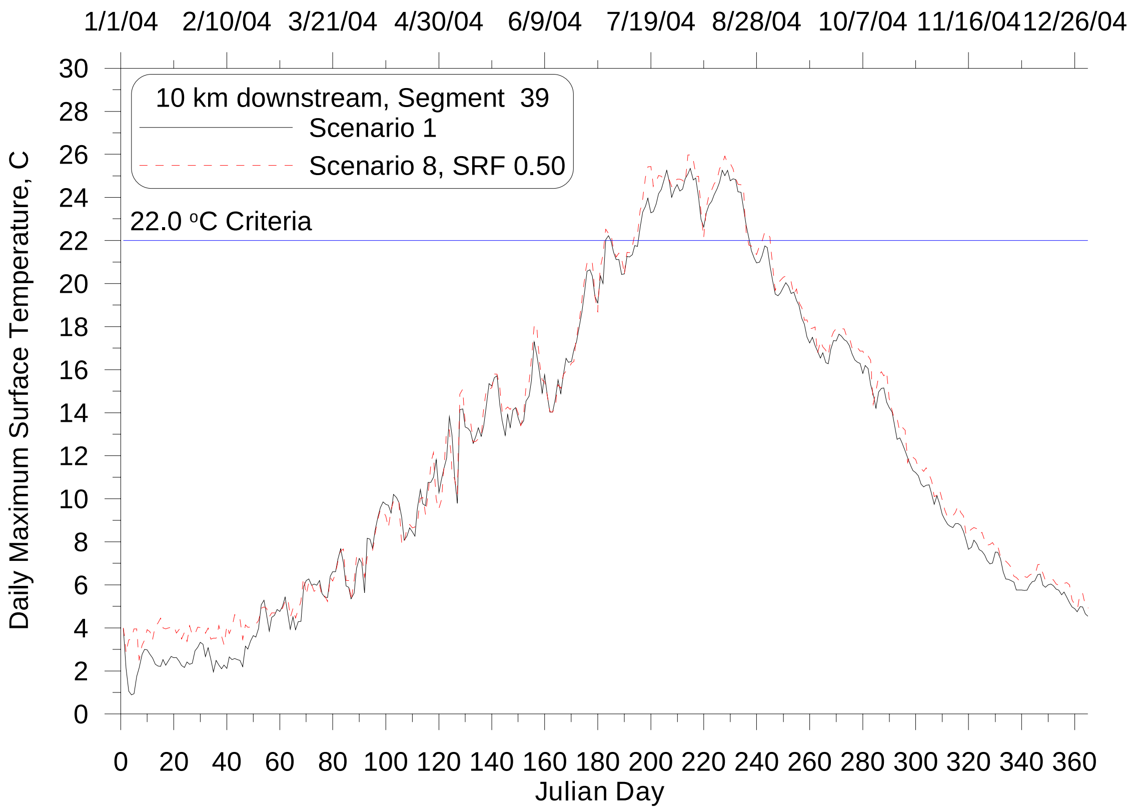

Figure 10: Daily maximum surface temperature time series at 10 km downstream from Lake Pend Oreille for the Natural Conditions (8) and Existing Conditions (1) Scenarios, 2004.

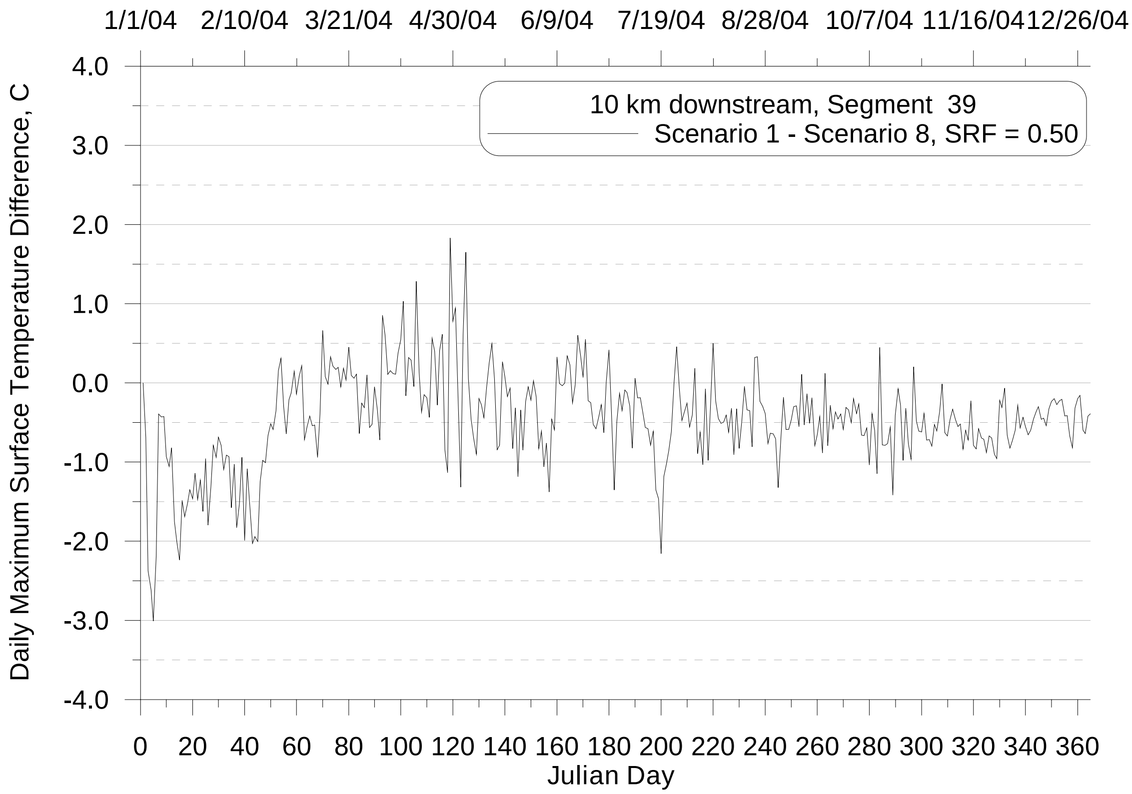

Figure 11: Daily maximum surface temperature difference time series at 10 km downstream from Lake Pend Oreille between the Natural Conditions (8) and Existing Conditions (1) Scenarios, 2004.

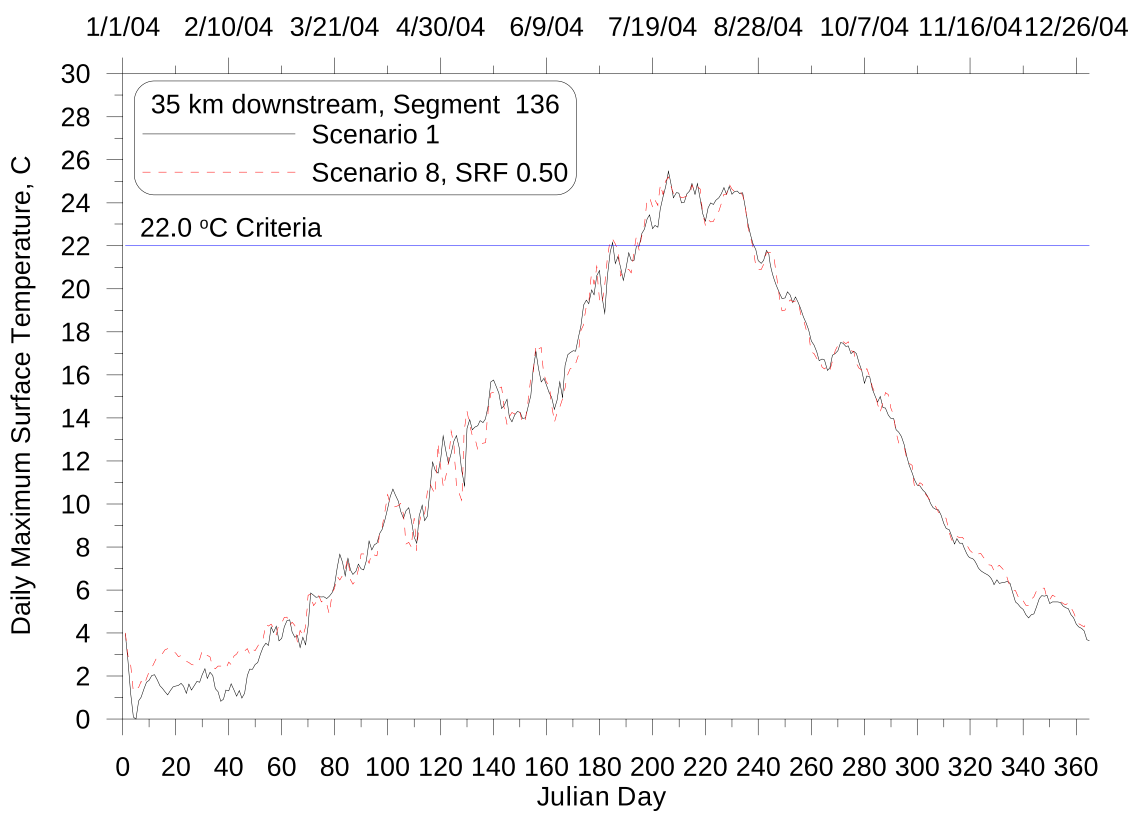

Figure 12: Daily maximum surface temperature time series at 35 km downstream from Lake Pend Oreille for the Natural Conditions (8) and Existing Conditions (1) Scenarios, 2004.

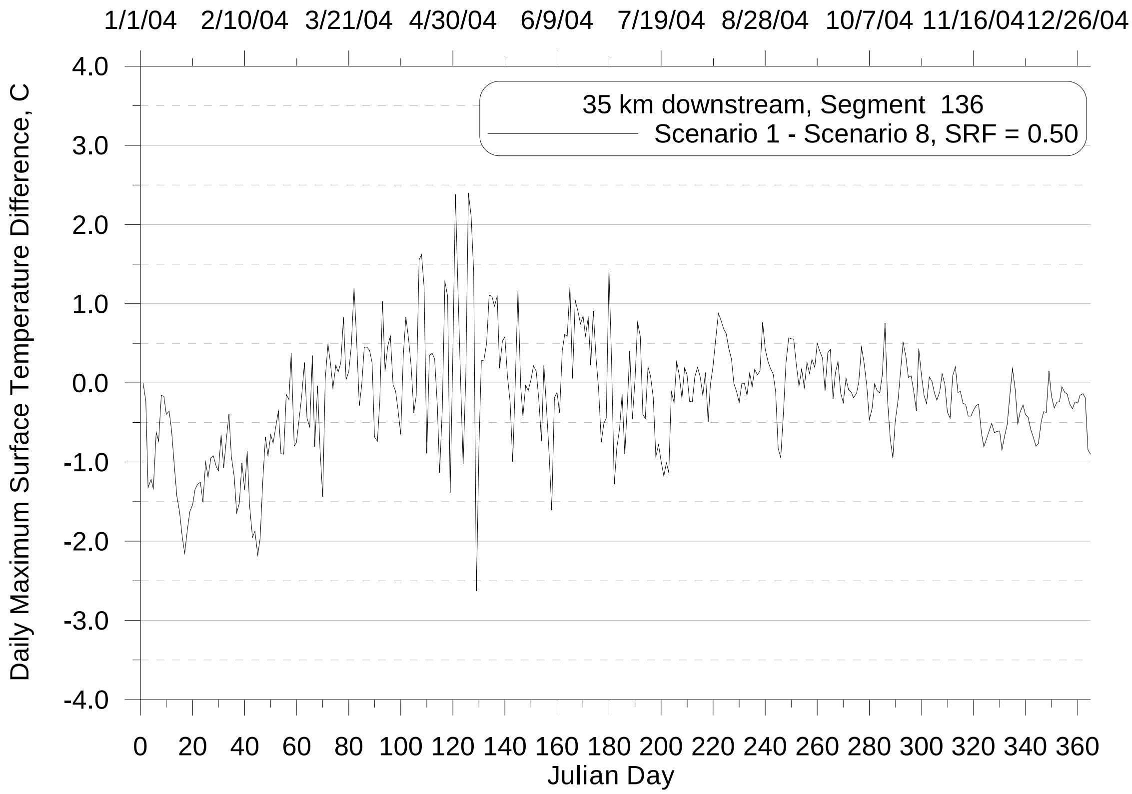

Figure 13: Daily maximum surface temperature difference time series at 35 km downstream from Lake Pend Oreille between the Natural Conditions (8) and Existing Conditions (1) Scenarios, 2004.

Table 4: Statistical significance in daily maximum time series results between the Natural Conditions (8) and Existing Conditions (1) Scenarios.

Scenario 1 and Scenario 8 Comparison	P-value	Result
Daily maximum surface temperature, 10km	0.78	not statistically significant, results are not the same
Daily maximum surface temperature, 35km	0.33	not statistically significant, results are not the same

Longitudinal Profiles

Figure 14 shows a longitudinal profile of the daily maximum 1 m volume-weighted surface temperature along the Pend Oreille River for August 14th, 2004 for Model Scenarios 1 and 8. The figure also includes the Idaho Water Quality Standards' daily maximum numeric temperature criteria of 22.0 ºC. Figure 15 shows a longitudinal profile of the daily average volume-weighted water temperature along the Pend Oreille River for August 14th, 2004. The figure also includes the Idaho Water Quality Standards' daily average numeric temperature criteria of 19.0 ºC. The figure indicates there is a temperature decrease for model segments 102 to 107 (RM 102.8 to 102.0) and corresponds to a deep pool in the river where temperatures are cooler for both model scenarios. Table 5 the statistical significance of how similar are the longitudinal profiles between the two scenarios.

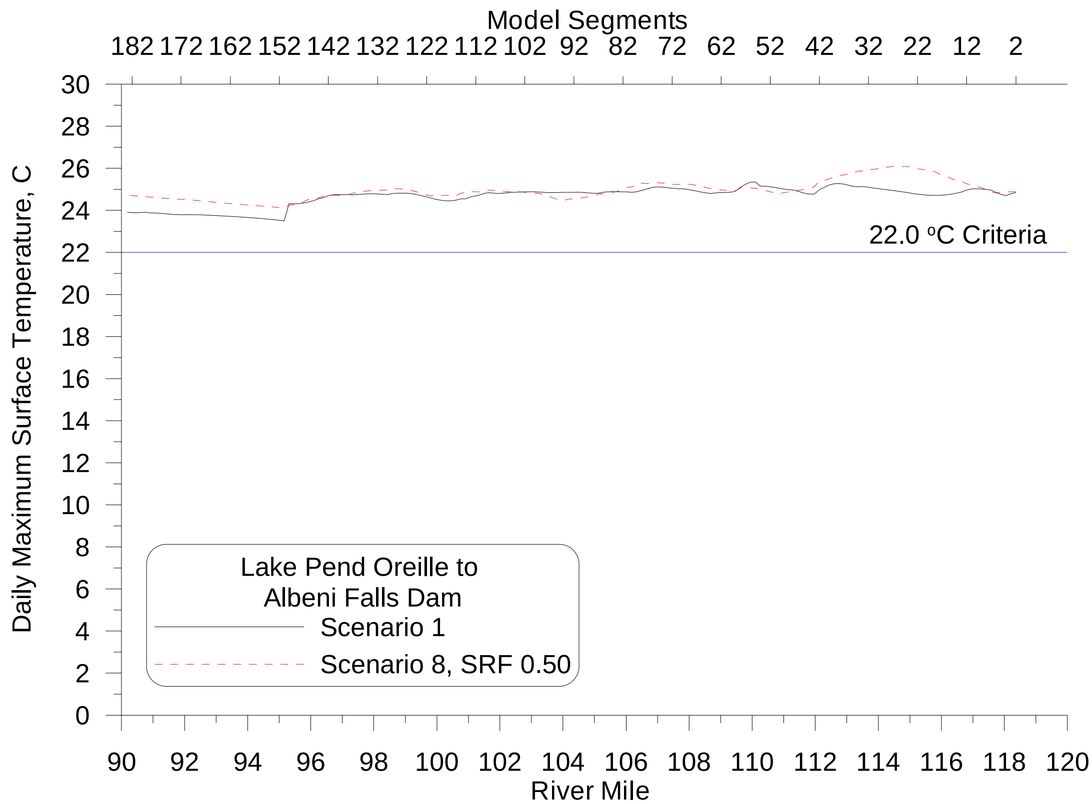

Figure 14: Daily maximum surface temperature longitudinal profile on August 16th, 2004 for the Natural Conditions (8) and Existing Conditions (1) Scenarios.

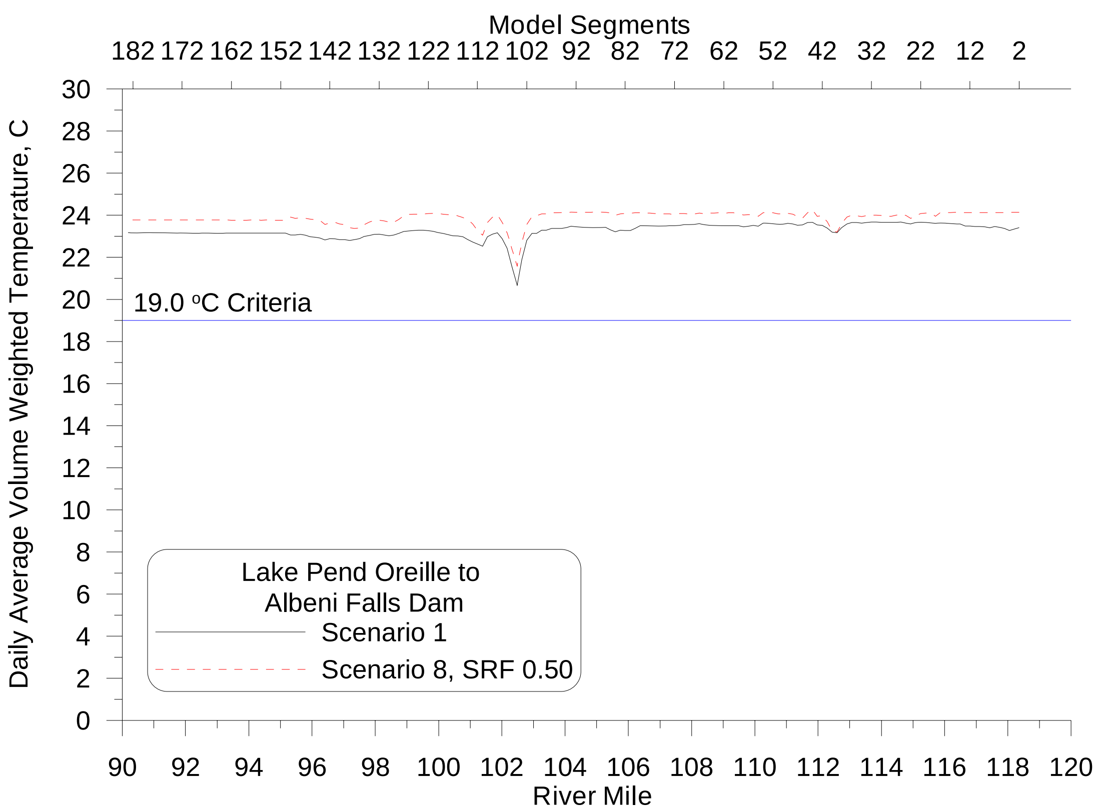

Figure 15: Daily average volume-weighted temperature longitudinal profile on August 16th, 2004 for the Natural Conditions (8) and Existing Conditions (1) Scenarios.

Table 5: Statistical significance in the longitudinal profile on August 16th, 2004 between the Natural Conditions (8) and Existing Conditions (1) Scenarios.

Scenario 1 and Scenario 8 Comparison	P-value	Result
Daily maximum surface temperature	1.00	not statistically significant, results are not the same
Daily average volume-weighted temperature	1.00	not statistically significant, results are not the same

Longitudinal Profile Snapshots

Figure 16 shows a longitudinal temperature profile snapshot on August 16th, 2004 for Model Scenario 1 (Existing Conditions) and Figure 17 shows a longitudinal temperature profile snapshot for Model Scenario 8 (Natural Conditions). Figure 18 shows a longitudinal temperature difference profile snapshot for the same time, showing the temperature difference between Model Scenarios 1 and 8.

Figure 19 shows a longitudinal temperature profile snapshot on August 8th, 2004 for Model Scenario 1 (Existing Conditions) and Figure 20 shows a longitudinal temperature profile snapshot for Model Scenario 8 (Natural Conditions). Figure 21 shows a longitudinal temperature difference profile snapshot for the same time, showing the temperature difference between Model Scenarios 1 and 8.

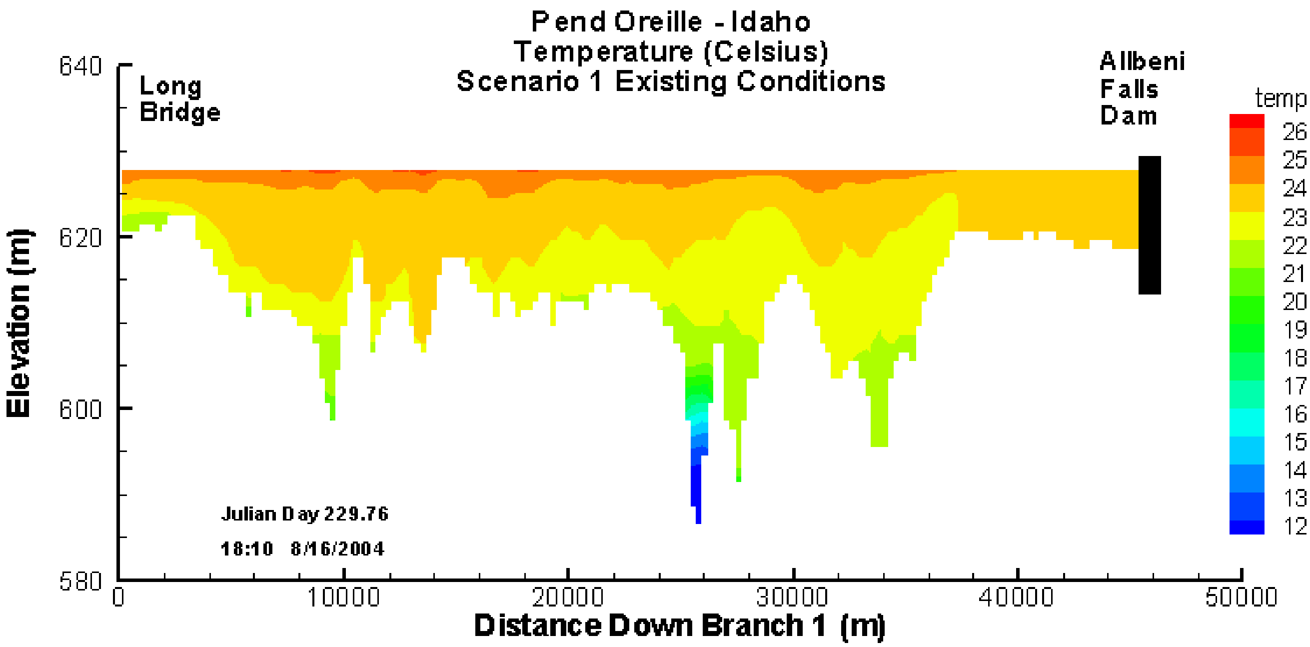

Figure 16: Longitudinal temperature profile for Model Scenario 1, Existing Conditions on August 16th, 2004.

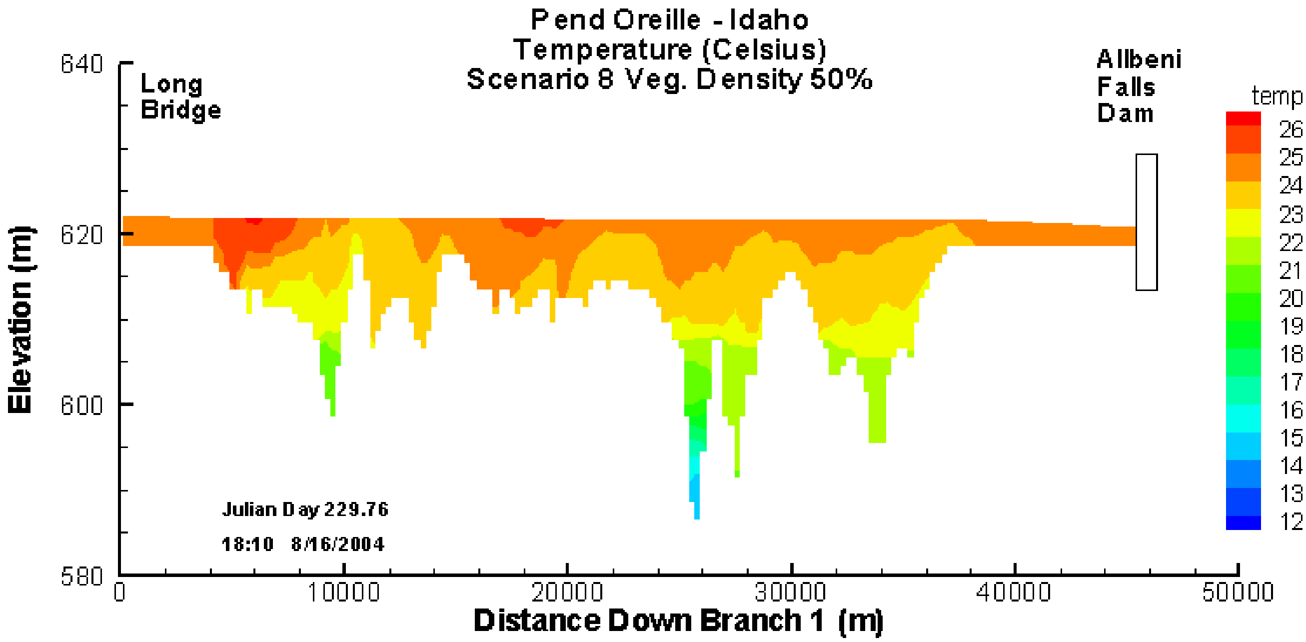

Figure 17: Longitudinal temperature profile for Model Scenario 8, Natural Conditions on August 16th, 2004.

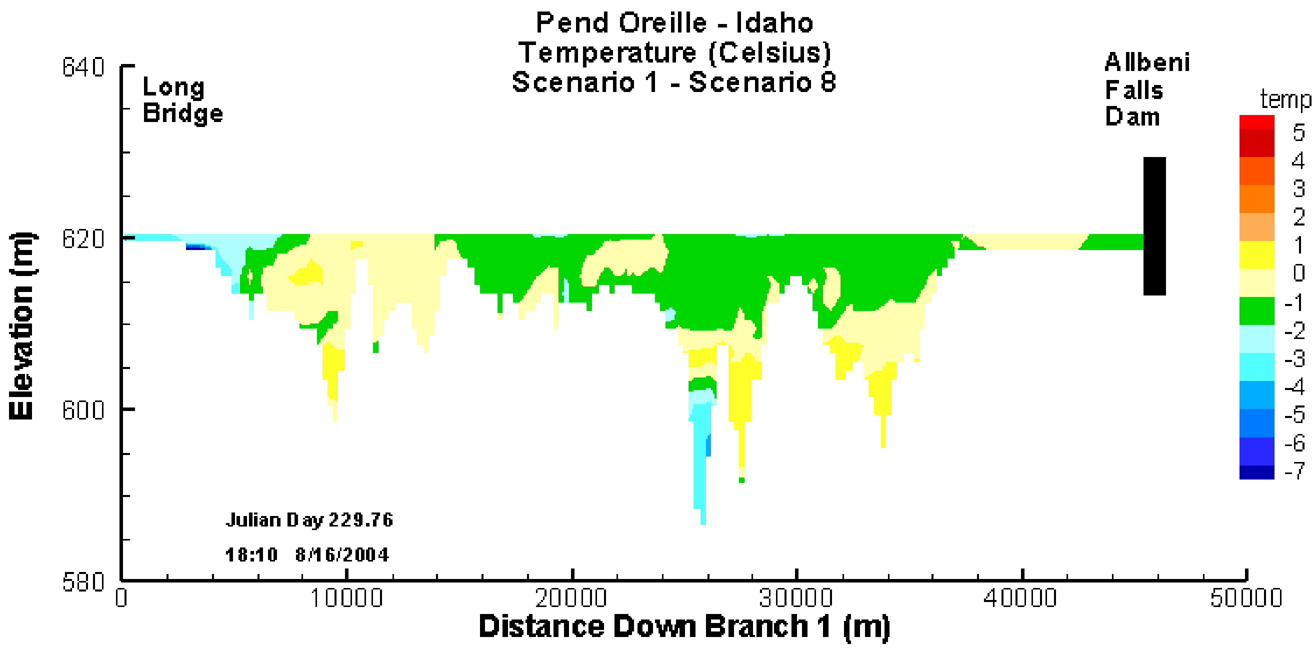

Figure 18: Longitudinal temperature profile difference, Existing Conditions (1) - Natural Conditions (8) Scenarios on August 16th, 2004.

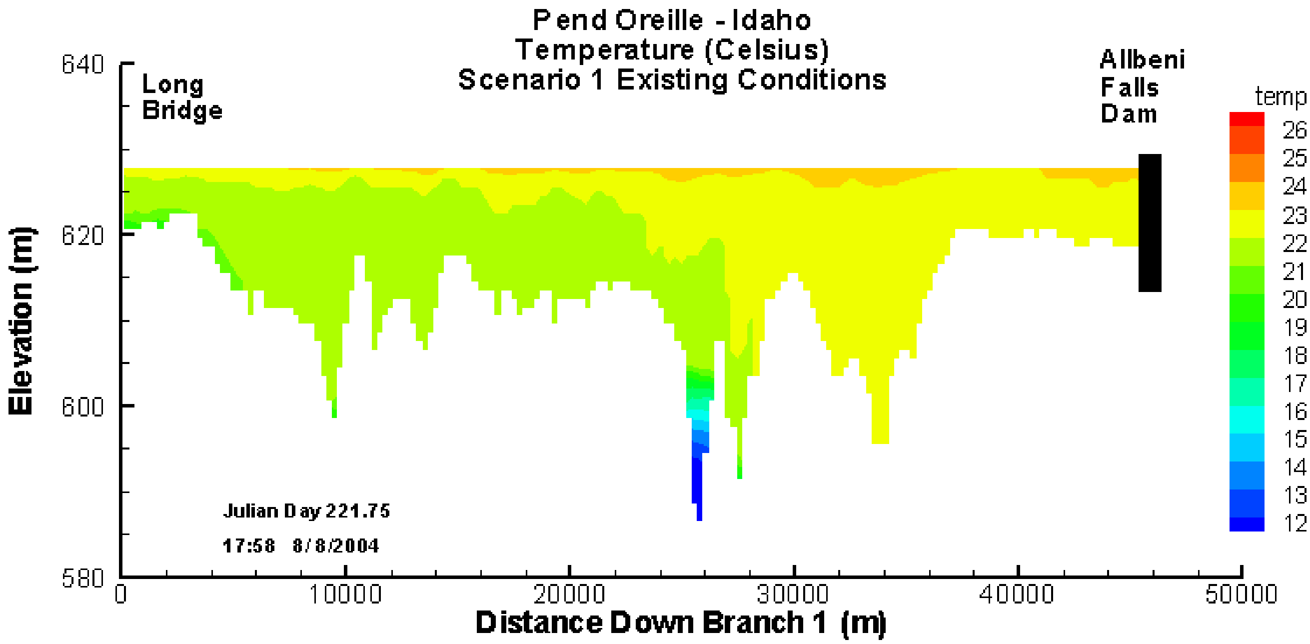

Figure 19: Longitudinal temperature profile for Model Scenario 1, Existing Conditions on August 8th, 2004.

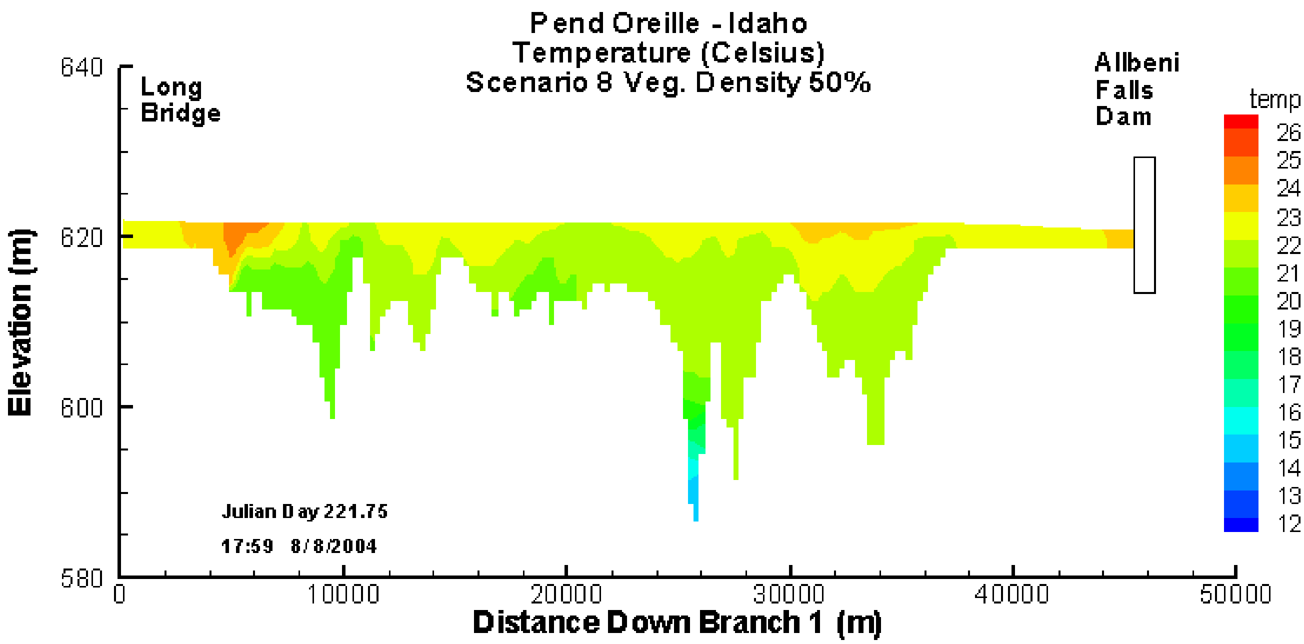

Figure 20: Longitudinal temperature profile for Model Scenario 8, Natural Conditions on August 8th, 2004.

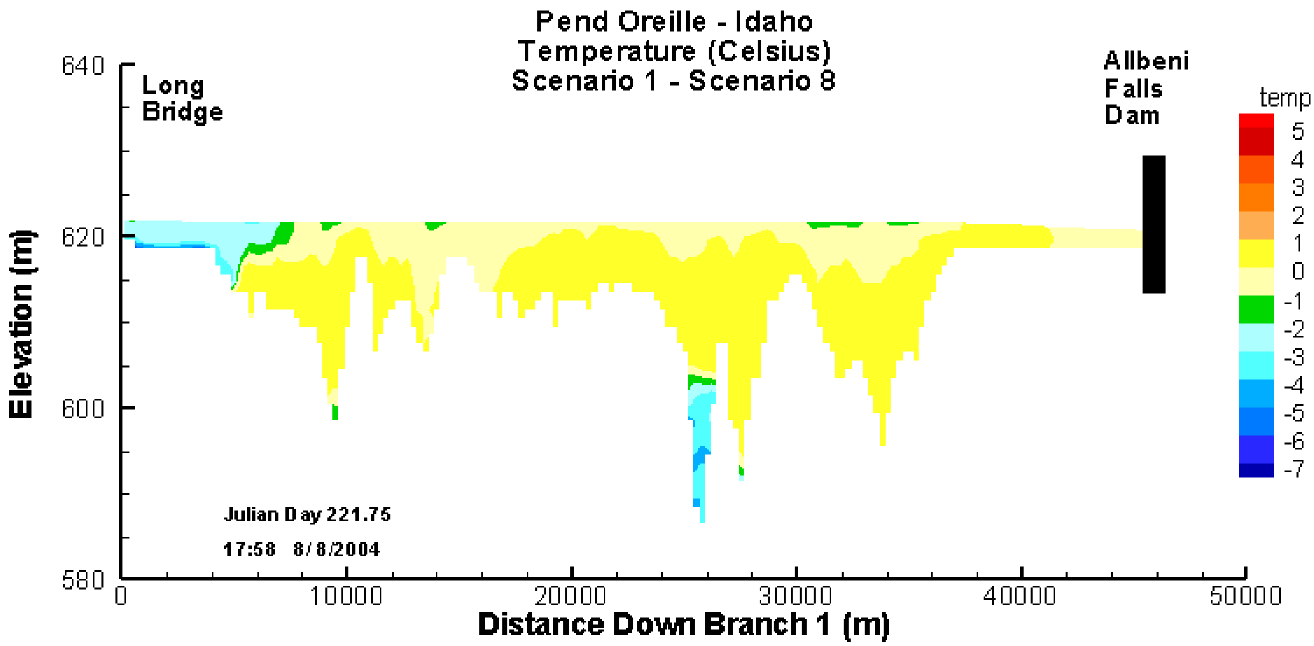

Figure 21: Longitudinal temperature profile difference, Existing Conditions (1) - Natural Conditions (8) Scenarios on August 8th, 2004.

Evaluation of WLA/point source contributions

The point source thermal loading contributions to the Pend Oreille River were evaluated by comparing results from Model Scenario l (Existing Conditions) and Scenario 2 (Existing Conditions with no point sources, NPDES).

Time Series Plots

Daily Average Temperatures

Figure 22 shows the daily average surface temperature10 km downstream from the Long Bridge for Model Scenario 2 (no NPDES) and Model Scenario 1 (Existing Conditions) over time in 2004.

Figure 23 shows the daily average 1 m volume-weighted bottom temperature for Scenarios 1 and 2 at 10 km downstream from Long Bridge. Figure 24 is a time series plot of the daily average of the volume-weighted temperature (over the full depth) for the two models scenarios at 10 km downstream of Long Bridge.

Figure 25 shows the daily average 1 m volume-weighted surface temperature for Scenarios 1 and 2 at 35 km downstream from the Long Bridge. Figure 26 shows the daily average 1 m volume-weighted bottom temperature 35 km downstream from the Long Bridge for Model Scenarios 1 and 2. Figure 27 shows the daily average of the volume-weighted temperature (over the full depth) over time for the two models scenarios at 35 km downstream of Long Bridge in 2004.

Figure 28 shows a time series plot of the continuous (hourly) outflow temperature from Albeni Falls Dam for Model Scenarios 1 and 2. Table 6 lists the statistical significance of how similar are the modeled temperatures between scenarios.

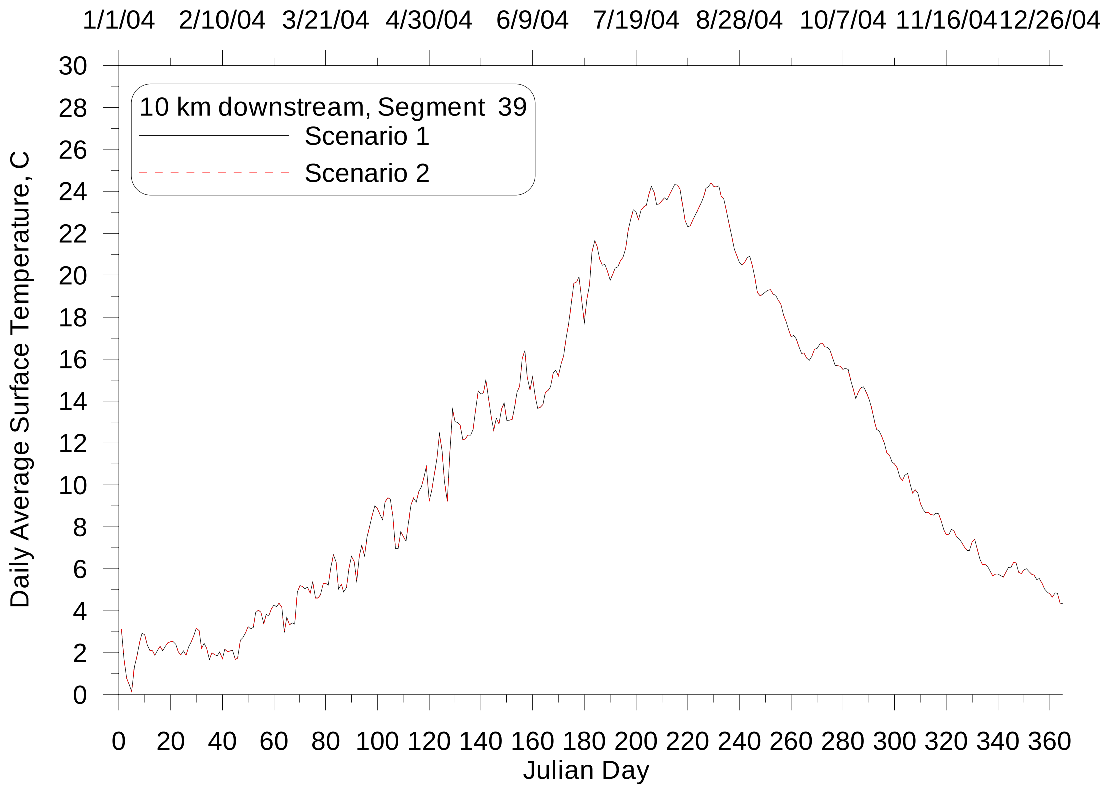

Figure 22: Daily average surface temperature time series at 10 km downstream from Lake Pend Oreille for the Impounded with no NPDES (2) and Existing Conditions (1) Scenarios, 2004.

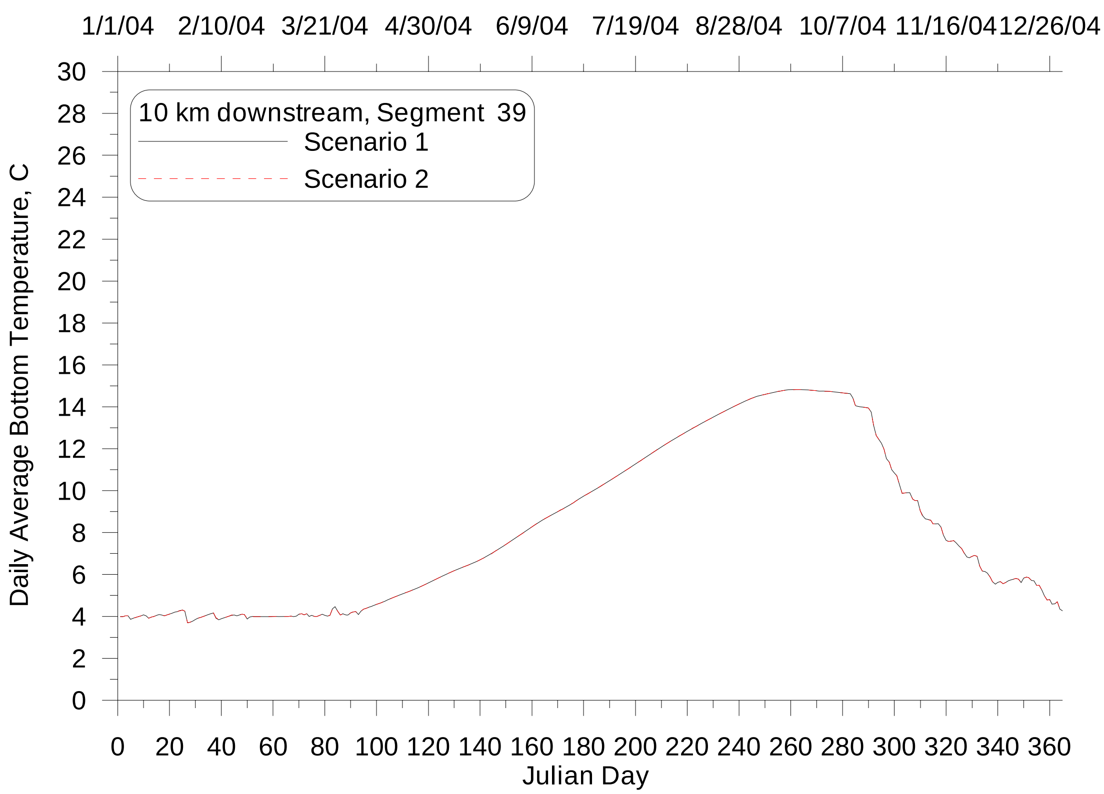

Figure 23: Daily average bottom temperature time series at 10 km downstream from Lake Pend Oreille for the Impounded with no NPDES (2) and Existing Conditions (1) Scenarios, 2004.

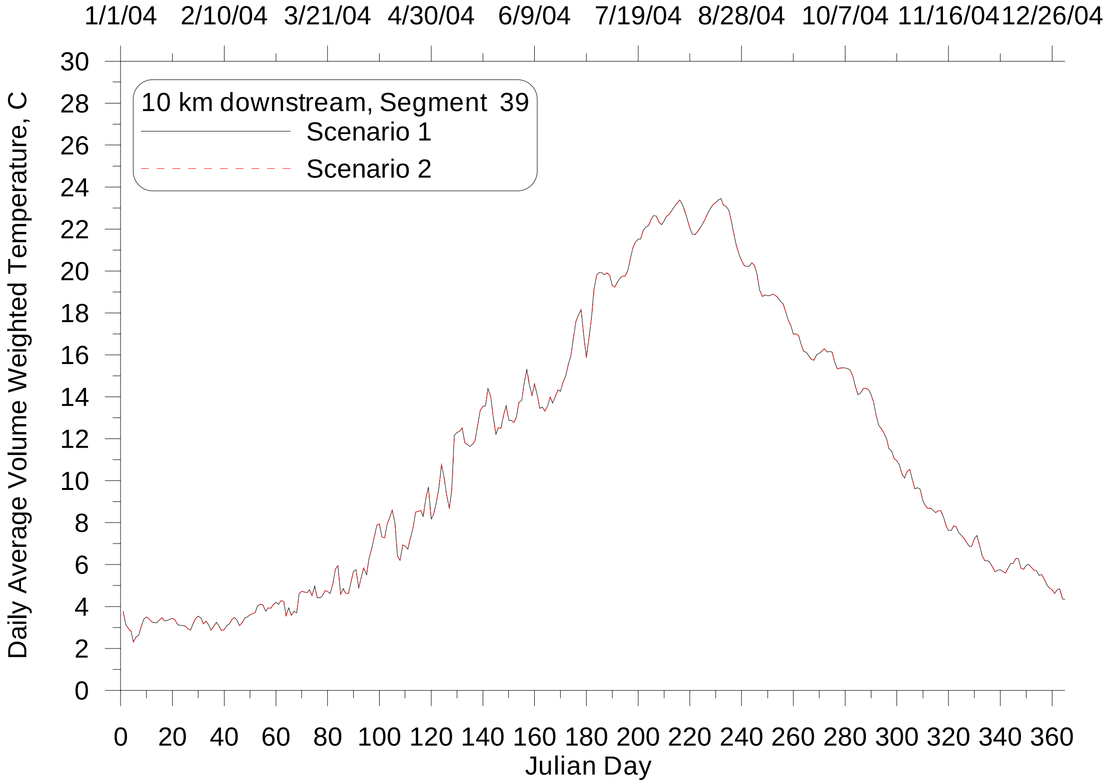

Figure 24: Daily average volume weighted temperature time series at 10 km downstream from Lake Pend Oreille for the Impounded with no NPDES (2) and Existing Conditions (1) Scenarios, 2004.

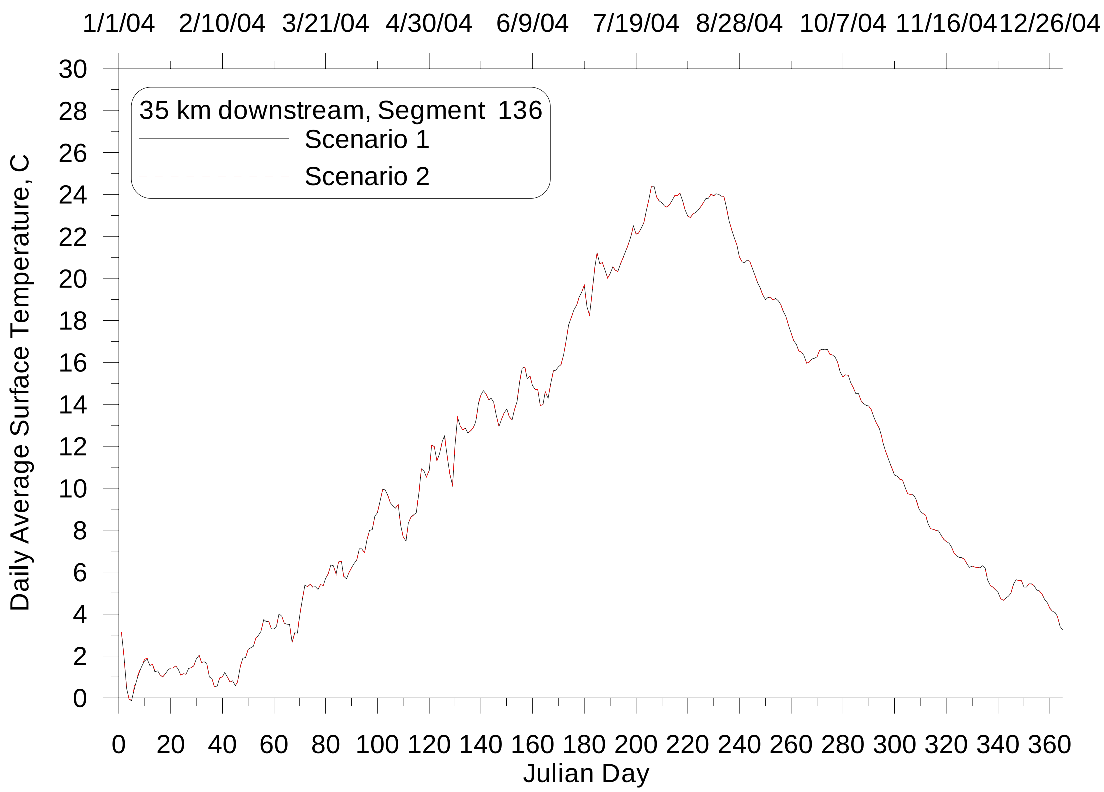

Figure 25: Daily average surface temperature time series at 35 km downstream from Lake Pend Oreille for the Impounded with no NPDES (2) and Existing Conditions (1) Scenarios, 2004.

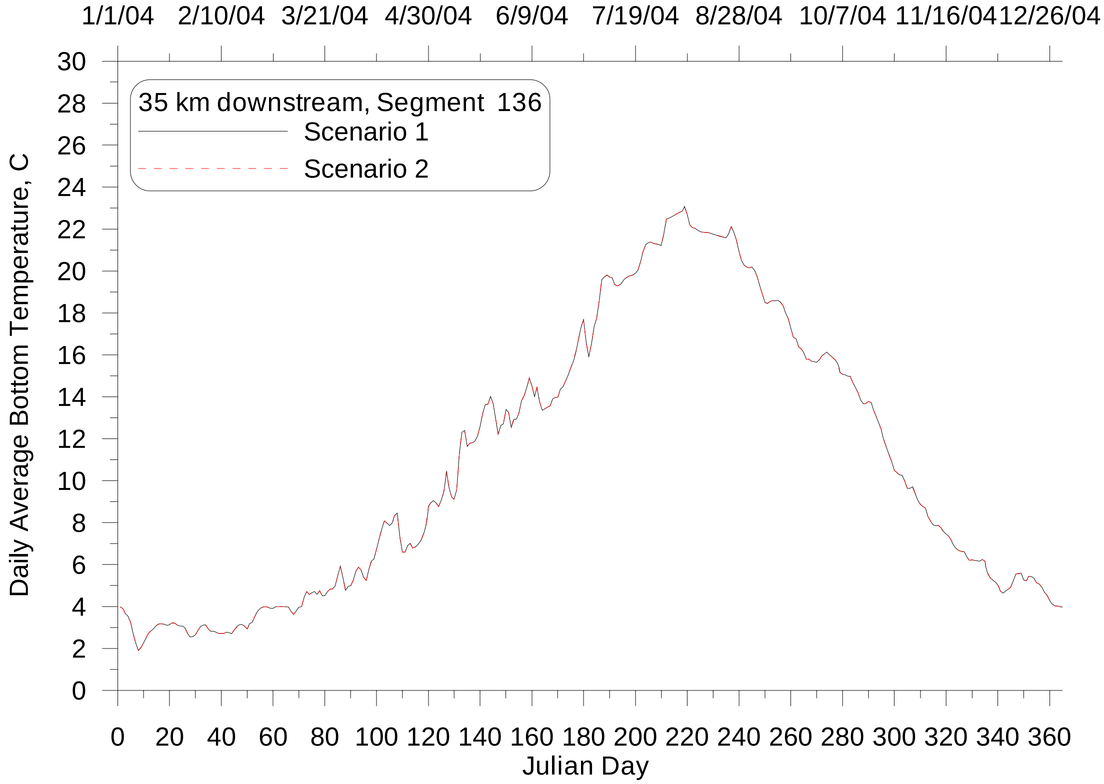

Figure 26: Daily average bottom temperature time series at 35 km downstream from Lake Pend Oreille for the Impounded with no NPDES (2) and Existing Conditions (1) Scenarios, 2004.

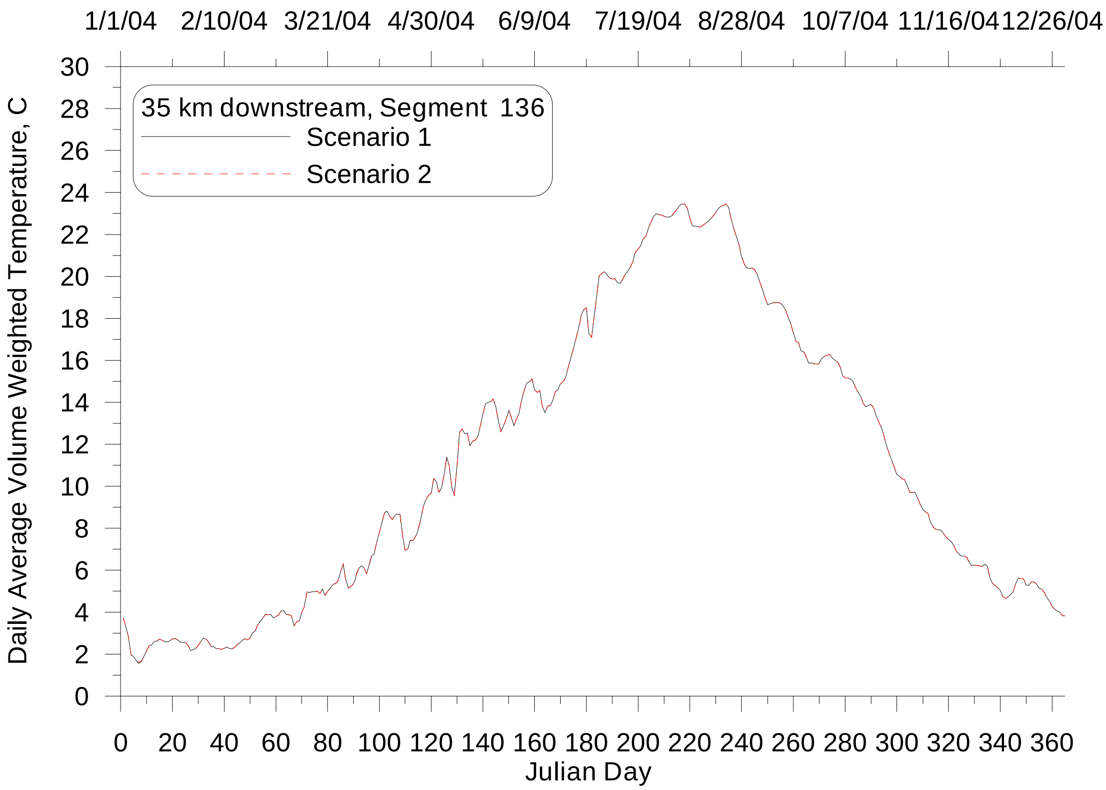

Figure 27: Daily average volume weighted temperature time series at 35 km downstream from Lake Pend Oreille for the Impounded with no NPDES (2) and Existing Conditions (1) Scenarios, 2004.

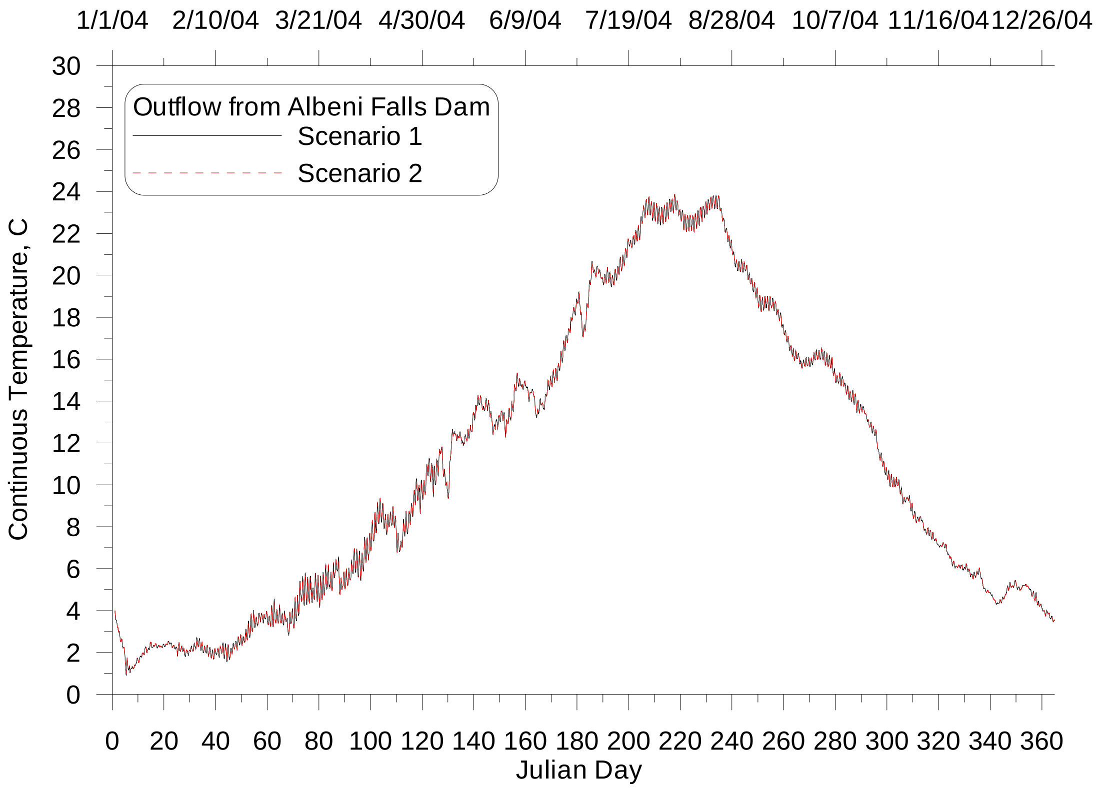

Figure 28: Continuous outflow temperature time series at Albeni Falls Dam for the Impounded with no NPDES (2) and Existing Conditions (1) Scenarios, 2004.

Table 6: Statistical significance in time series results between the Impounded with no NPDES (2) and Existing Conditions (1) Scenarios.

Scenario 1 and Scenario 2 Comparison	P-value	Result
Daily average surface temperature, 10 km	0.00	statistically significant, results are the same
Daily average bottom temperature, 10 km	0.00	statistically significant, results are the same
Daily average volume-weighted, 10 km	0.00	statistically significant, results are the same
Daily average surface temperature, 35 km	0.00	statistically significant, results are the same
Daily average bottom temperature, 35 km	0.00	statistically significant, results are the same
Daily average volume-weighted, 35 km	0.00	statistically significant, results are the same
Continuous volume-weighted, outflow temperature at Albeni Falls Dam	0.00	statistically significant, results are the same

Daily Maximum Temperatures

Figure 29 shows the daily maximum of the 1 m volume-weighted surface temperature for Scenarios 1 and 2 at 10 km downstream from the Long Bridge. Figure 12 shows the daily maximum of the 1 m volume-weighted surface temperature for Scenarios 1 and 2 at 35 km downstream from the Long Bridge. Table 7 lists the statistical significance of how similar are the daily maximum temperatures between the two scenarios.

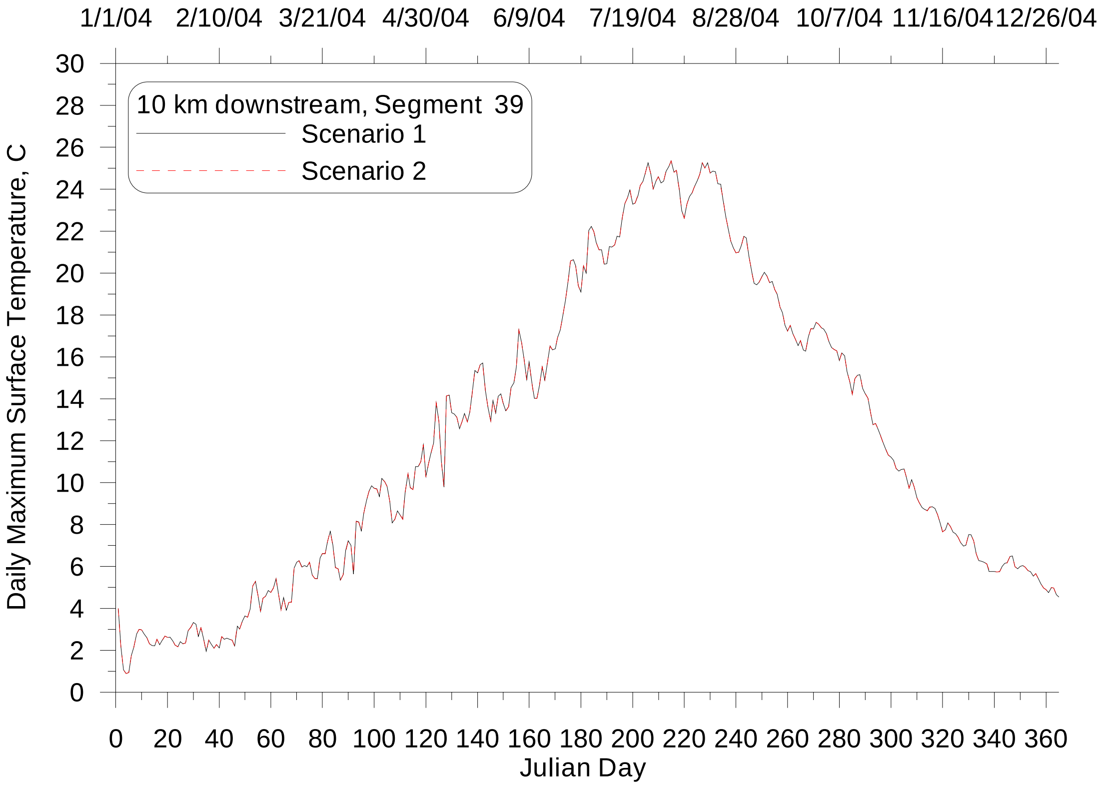

Figure 29: Daily maximum surface temperature time series at 10 km downstream from Lake Pend Oreille for the Impounded with no NPDES (2) and Existing Conditions (1) Scenarios, 2004.

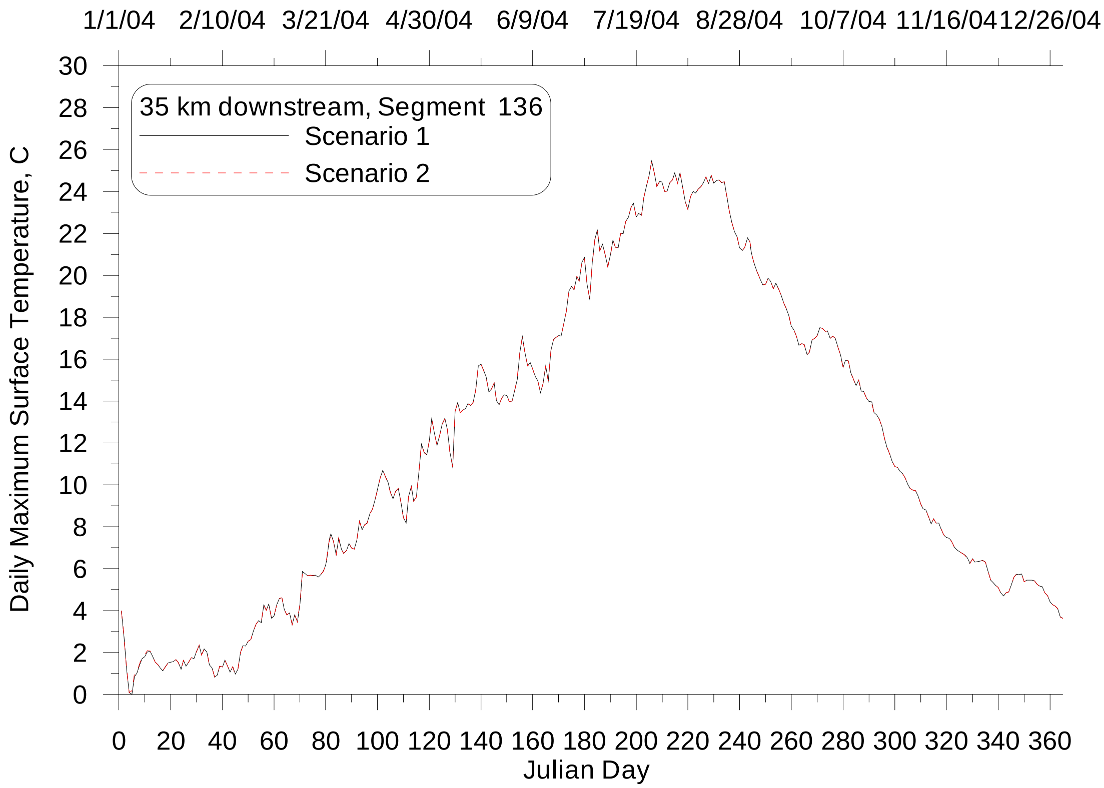

Figure 30: Daily maximum surface temperature time series at 35 km downstream from Lake Pend Oreille for the Impounded with no NPDES (2) and Existing Conditions (1) Scenarios, 2004.

Table 7: Statistical significance in daily maximum time series results between the Impounded with no NPDES (2) and Existing Conditions (1) Scenarios.

Scenario 1 and Scenario 2 Comparison	P-value	Result
Daily maximum surface temperature, 10km	0.00	statistically significant, results are the same
Daily maximum surface temperature, 35km	0.00	statistically significant, results are the same

Longitudinal Profiles

Figure 31 shows a longitudinal profile of the daily maximum 1 m volume-weighted surface temperature along the Pend Oreille River for August 14th, 2004 for Scenarios 1 and 2. Figure 32 shows a longitudinal profile of the daily average volume-weighted water temperature along the Pend Oreille River for August 14th, 2004. Table 8 the statistical significance of how similar are the longitudinal profiles between the two scenarios.

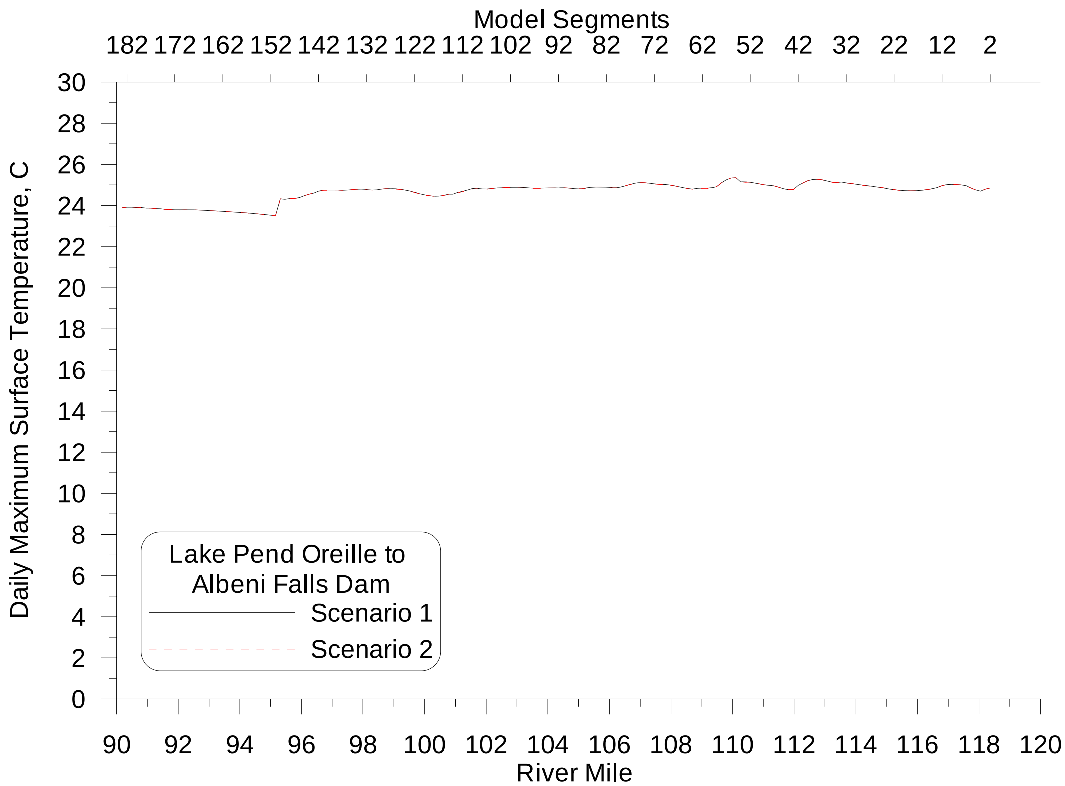

Figure 31: Daily maximum surface temperature longitudinal profile on August 16th, 2004 for the Impounded with no NPDES (2) and Existing Conditions (1) Scenarios.

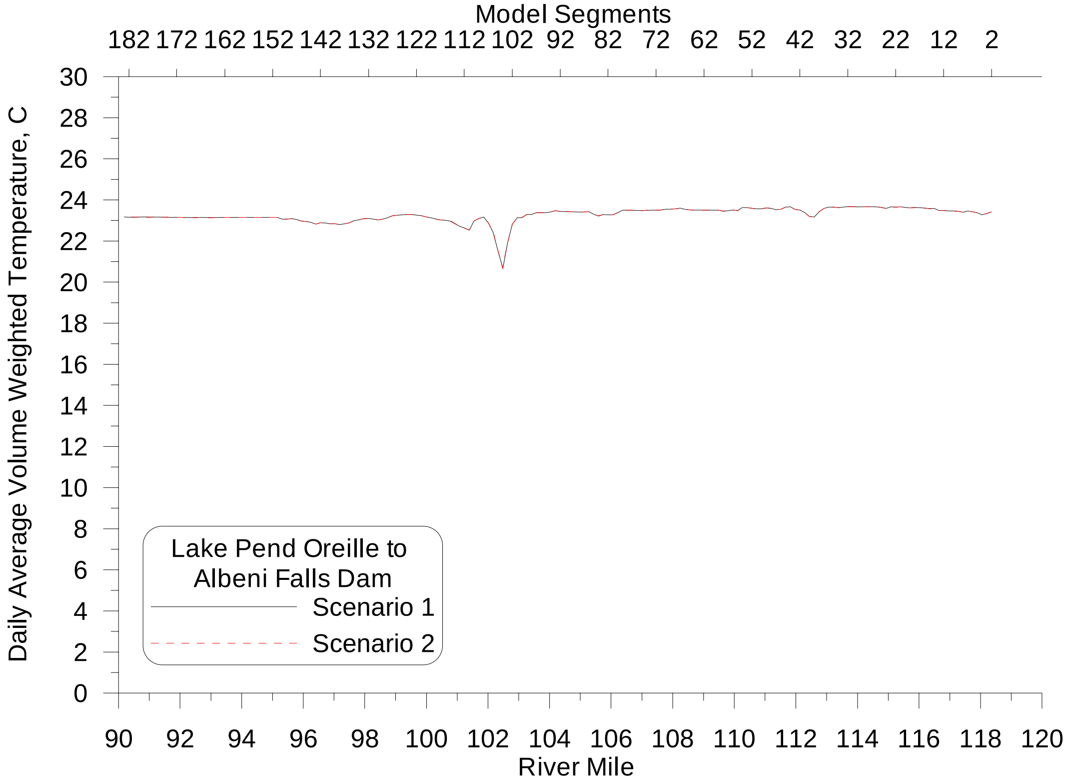

Figure 32: Daily average volume weighted temperature longitudinal profile on August 16th, 2004 for the Impounded with no NPDES (2) and Existing Conditions (1) Scenarios.

Table 8: Statistical significance in the longitudinal profile on August 16th, 2004 between the Impounded with no NPDES (2) and Existing Conditions (1) Scenarios.

Scenario 1 and Scenario 2 Comparison	P-value	Result
Daily maximum surface temperature	0.00	statistically significant, results are the same
Daily average volume-weighted temperature	0.00	statistically significant, results are the same

Evaluation of non-point source contributions

The non-point source thermal loading contributions to the Pend Oreille River were evaluated by comparing results from Model Scenario l (Existing Conditions) and Scenario 2.5 (Existing Conditions with No Non-Point Sources, LA/NPS).

Time Series Plots

Daily Average Temperatures

Figure 33 shows the daily average surface temperature 10 km downstream from the Long Bridge for Model Scenario 2.5 (no non-point source, NPS) and Model Scenario 1 (Existing Conditions) over time in 2004.

Figure 34 shows the daily average 1 m volume-weighted bottom temperature for Scenarios 1 and 2.5 at 10 km downstream from Long Bridge. Figure 35 is a time series plot of the daily average of the volume-weighted temperature (over the full depth) for the two models scenarios at 10 km downstream of Long Bridge.

Figure 36 shows the daily average 1 m volume-weighted surface temperature for Scenarios 1 and 2.5 at 35 km downstream from the Long Bridge. Figure 37 shows the daily average 1 m volume-weighted bottom temperature 35 km downstream from the Long Bridge for Model Scenarios 1 and 2.5. Figure 38 shows the daily average of the volume-weighted temperature (over the full depth) over time for the two models scenarios at 35 km downstream of Long Bridge.

Figure 39 shows a time series plot of the continuous (hourly) outflow temperature from Albeni Falls Dam for Model Scenarios 1 and 2.5. Table 9 lists the statistical significance of how similar are the modeled temperatures between scenarios.

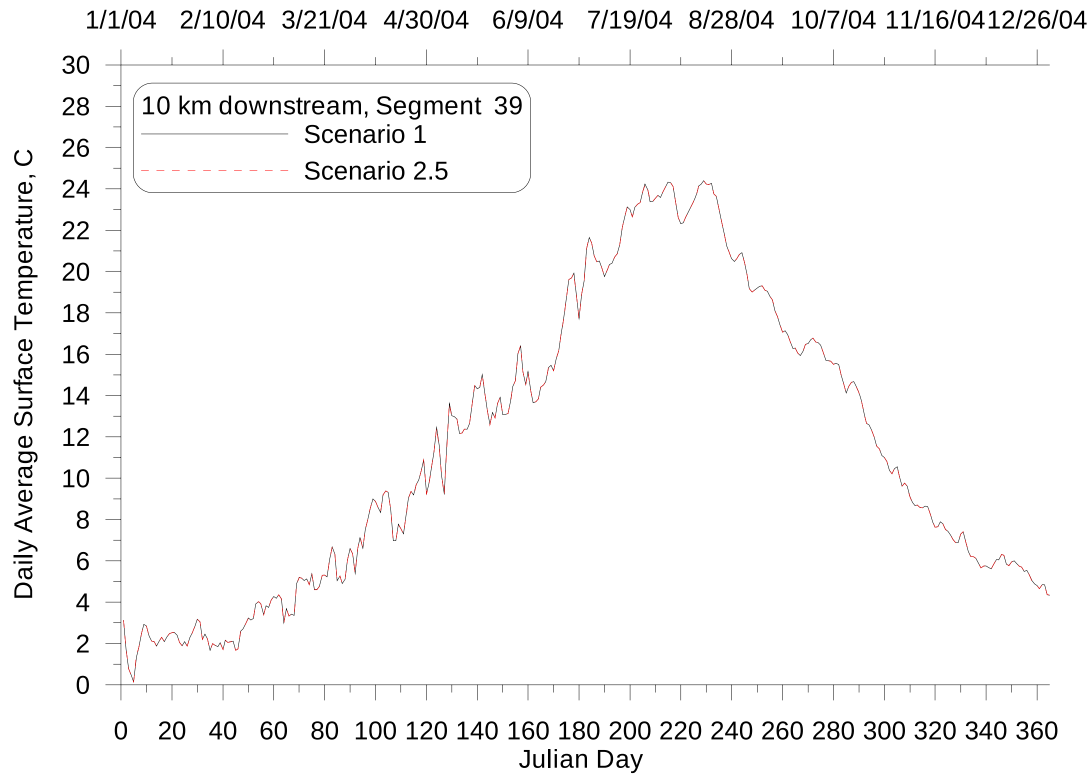

Figure 33: Daily average surface temperature time series at 10 km downstream from Lake Pend Oreille for the Impounded with no NPS (2.5) and Existing Conditions (1) Scenarios, 2004.

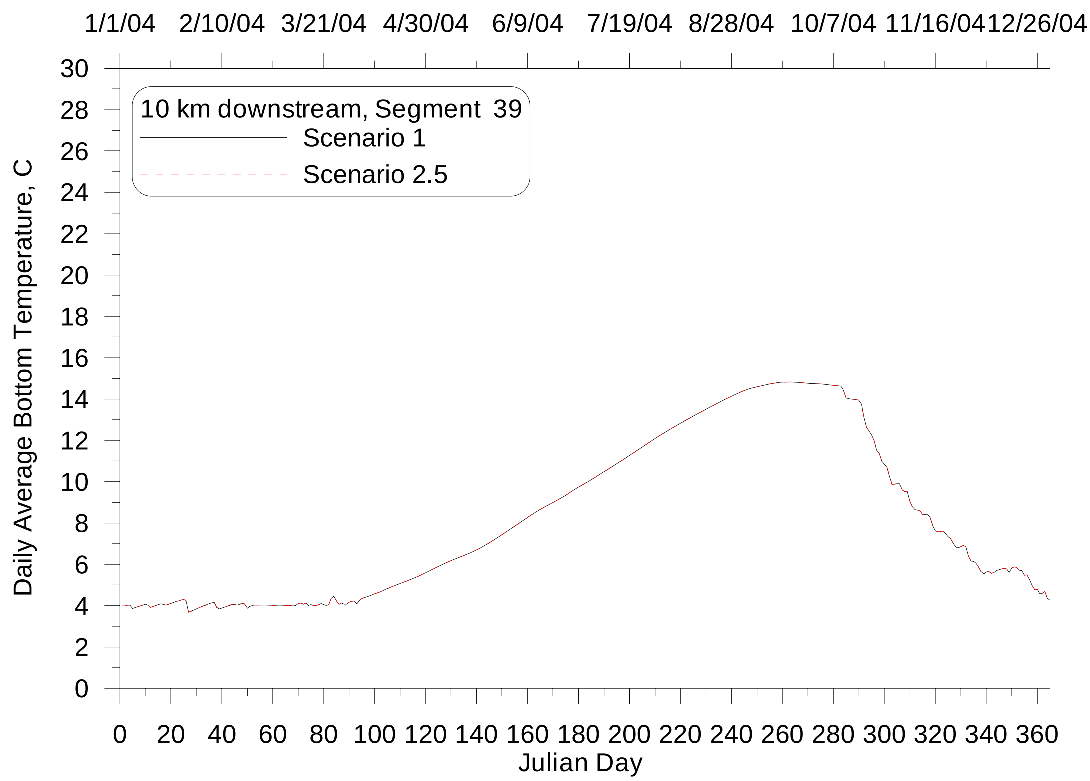

Figure 34: Daily average bottom temperature time series at 10 km downstream from Lake Pend Oreille for the Impounded with no NPS (2.5) and Existing Conditions (1) Scenarios, 2004.

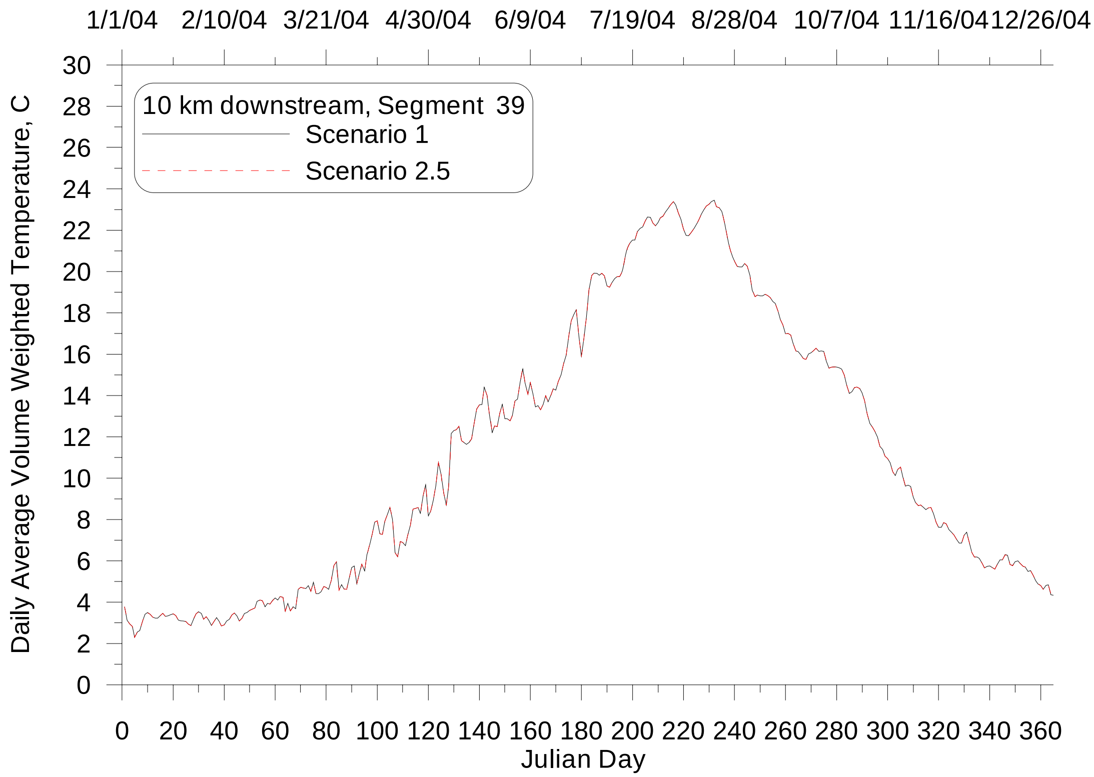

Figure 35: Daily average volume weighted temperature time series at 10 km downstream from Lake Pend Oreille for the Impounded with no NPS (2.5) and Existing Conditions (1) Scenarios, 2004.

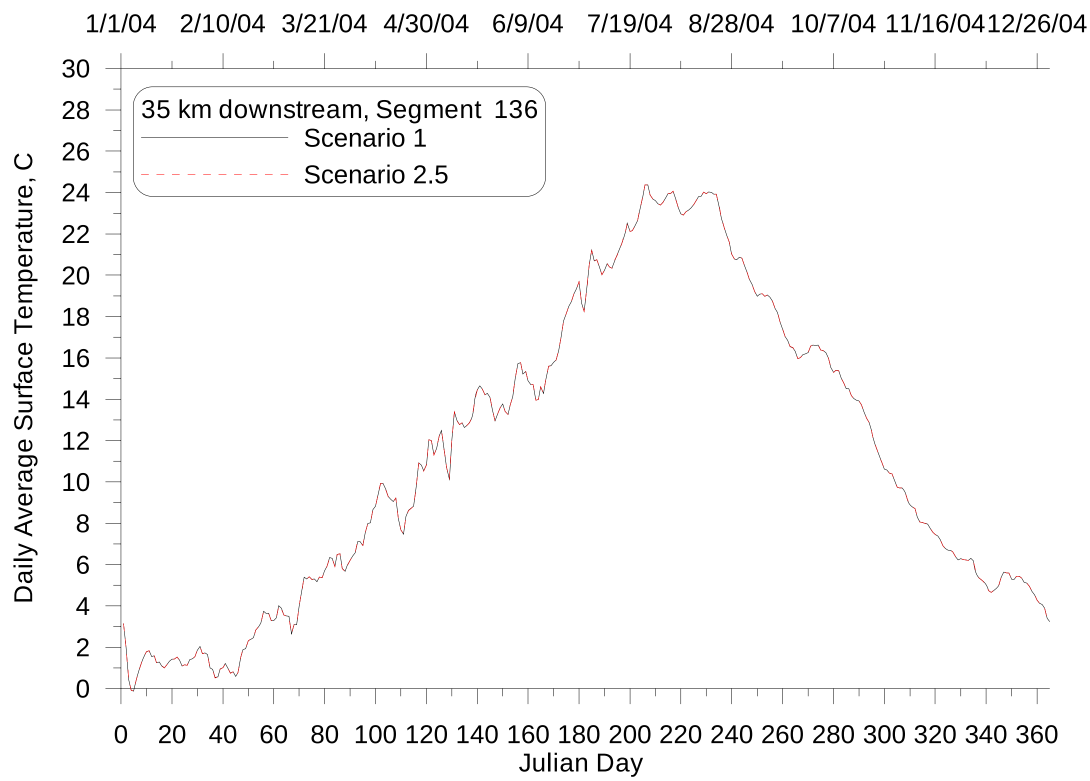

Figure 36: Daily average surface temperature time series at 35 km downstream from Lake Pend Oreille for the Impounded with no NPS (2.5) and Existing Conditions (1) Scenarios, 2004.

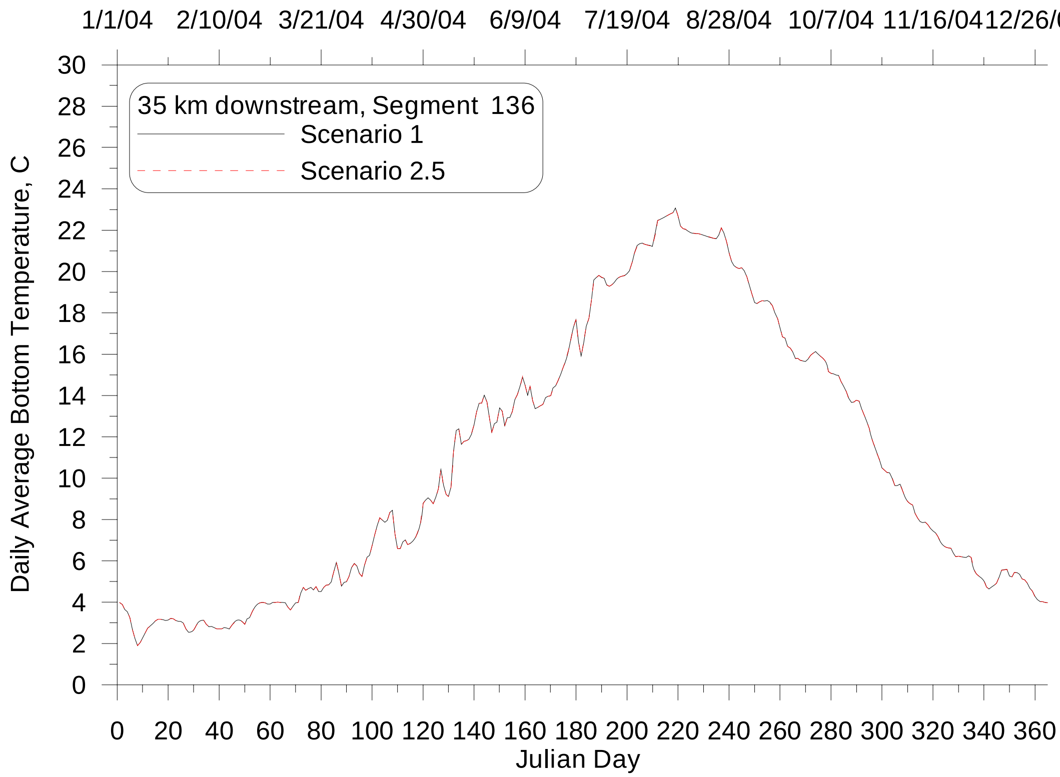

Figure 37: Daily average bottom temperature time series at 35 km downstream from Lake Pend Oreille for the Impounded with no NPS (2.5) and Existing Conditions (1) Scenarios, 2004.

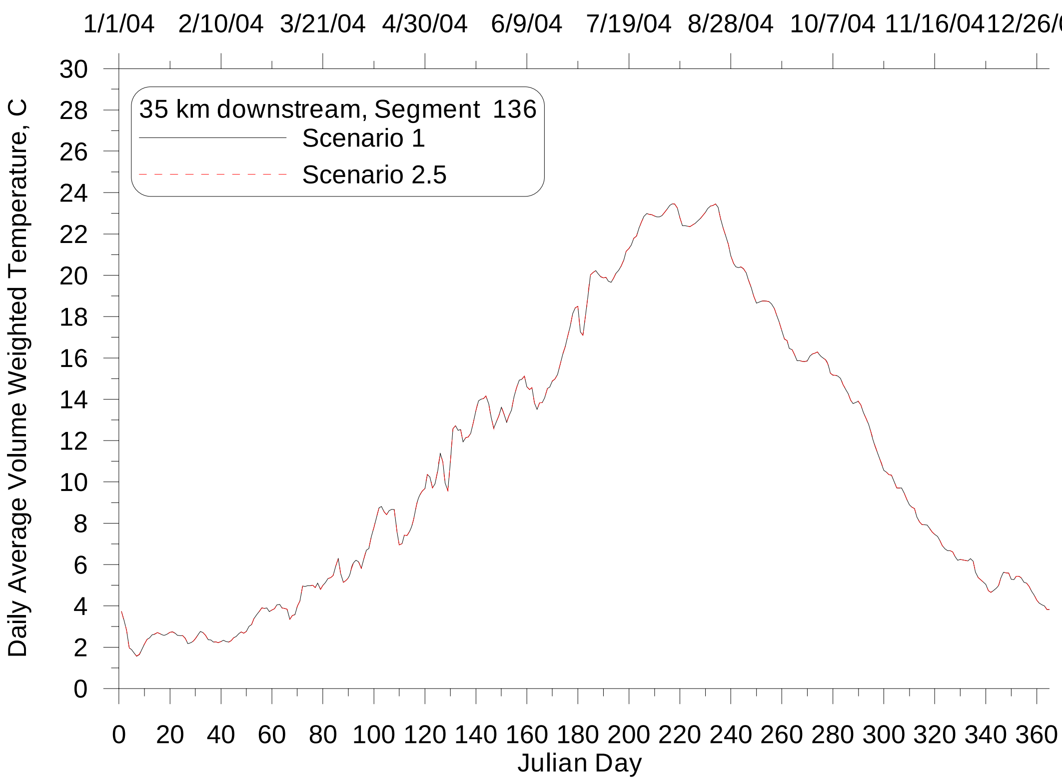

Figure 38: Daily average volume weighted temperature time series at 35 km downstream from Lake Pend Oreille for the Impounded with no NPS (2.5) and Existing Conditions (1) Scenarios, 2004.

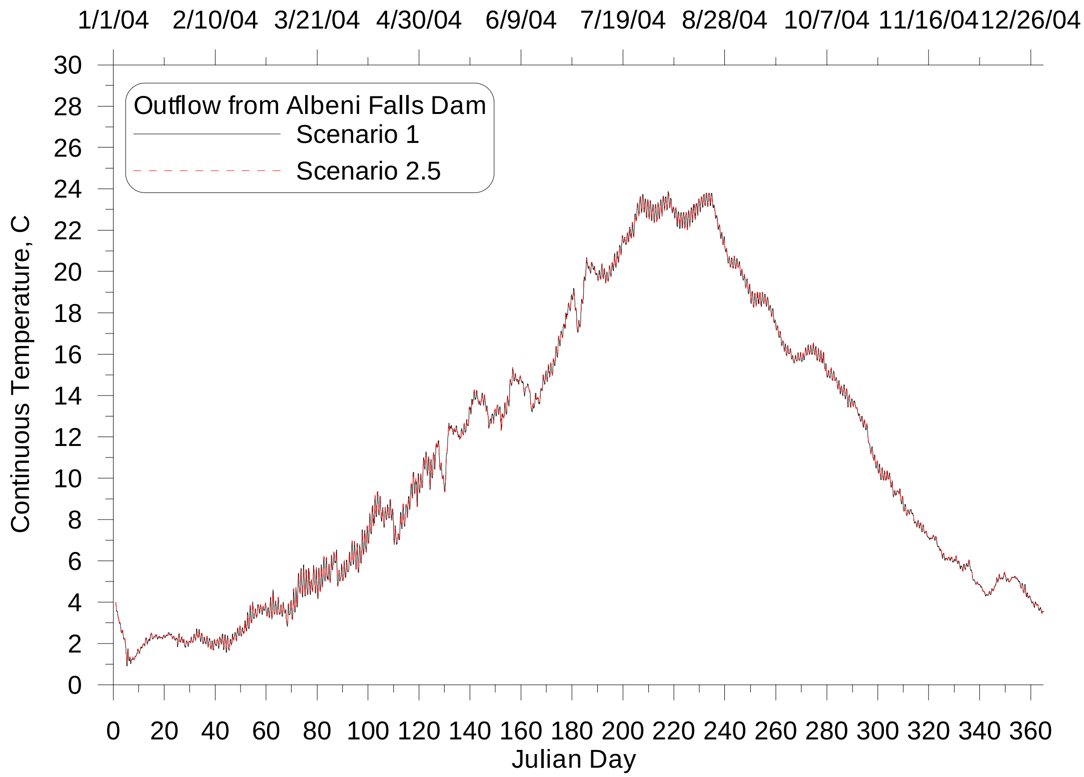

Figure 39: Continuous outflow temperature time series at Albeni Falls Dam for the Impounded with no NPS (2.5) and Existing Conditions (1) Scenarios, 2004.

Table 9: Statistical significance in time series results between the Impounded with no NPS (2.5) and Existing Conditions (1) Scenarios.

Scenario 1 and Scenario 2.5 Comparison	P-value	Result
Daily average surface temperature, 10 km	0.03	statistically significant, results are the same
Daily average bottom temperature, 10 km	0.18	probably statistically significant, results are similar
Daily average volume-weighted, 10 km	0.00	statistically significant, results are the same
Daily average surface temperature, 35 km	0.05	statistically significant, results are the same
Daily average bottom temperature, 35 km	0.01	statistically significant, results are the same
Daily average volume-weighted, 35 km	0.02	statistically significant, results are the same
Continuous volume-weighted, outflow temperature at Albeni Falls Dam	0.25	possibly statistically significant, results have some similarities

Daily Maximum Temperatures

Figure 40 shows the daily maximum of the 1 m volume-weighted surface temperature for Scenarios 1 and 2.5 at 10 km downstream from the Long Bridge. Figure 41 shows the daily maximum of the 1 m volume-weighted surface temperature for Scenarios 1 and 2.5 at 35 km downstream from the Long Bridge. Table 10 lists the statistical significance of how similar are the daily maximum temperatures between the two scenarios.

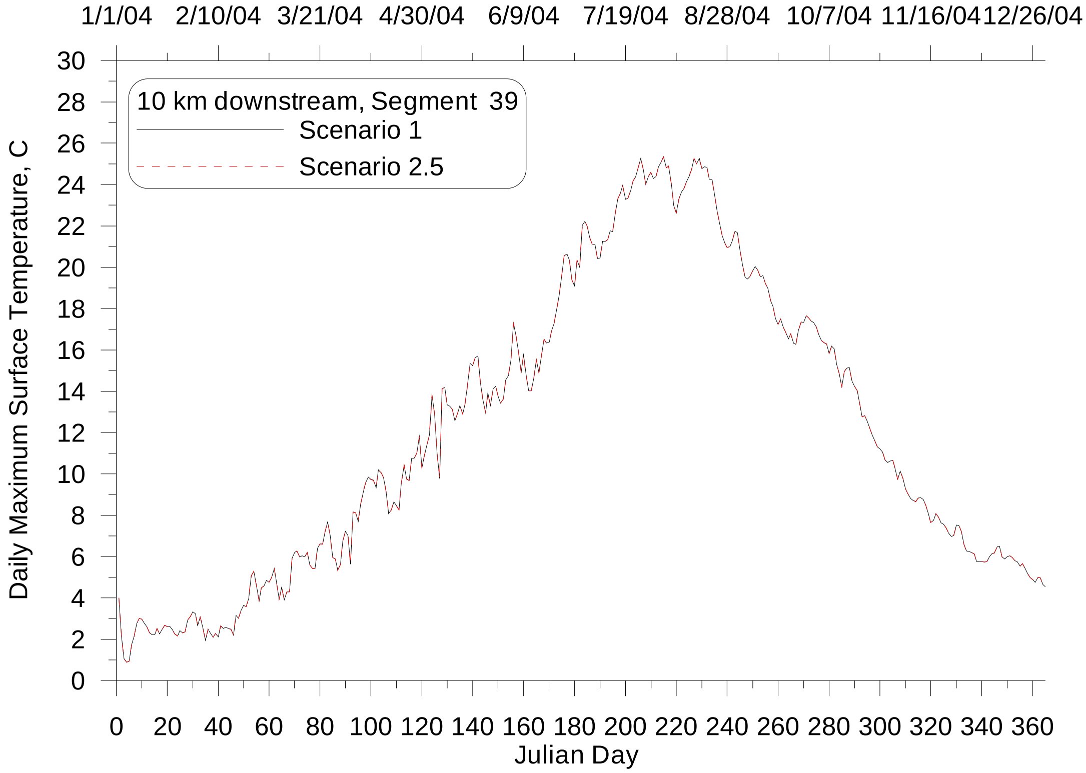

Figure 40: Daily maximum surface temperature time series at 10 km downstream from Lake Pend Oreille for the Impounded with no NPS (2.5) and Existing Conditions (1) Scenarios, 2004.

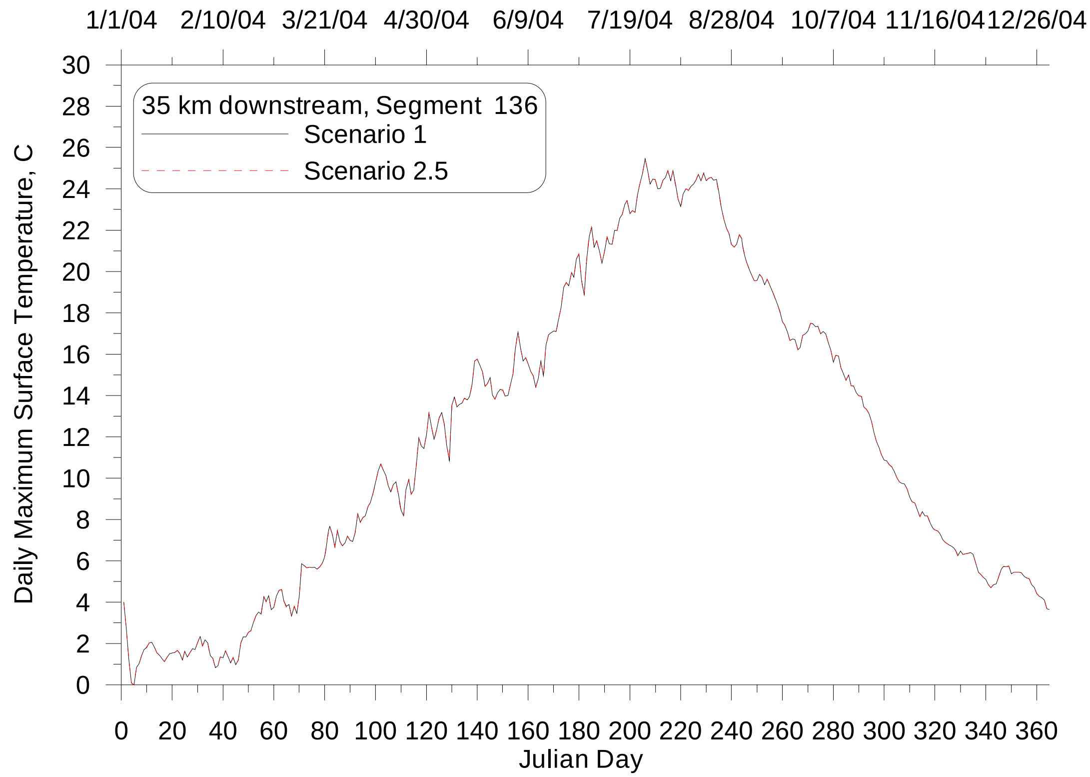

Figure 41: Daily maximum surface temperature time series at 35 km downstream from Lake Pend Oreille for the Impounded with no NPS (2.5) and Existing Conditions (1) Scenarios, 2004.

Table 10: Statistical significance in daily maximum time series results between the Impounded with no NPS (2.5) and Existing Conditions (1) Scenarios.

Scenario 1 and Scenario 2.5 Comparison	P-value	Result
Daily maximum surface temperature, 10km	0.05	statistically significant, results are the same
Daily maximum surface temperature, 35km	0.10	probably statistically significant, results are similar

Longitudinal Profiles

Figure 42 shows a longitudinal profile of the daily maximum 1 m volume-weighted surface temperature along the Pend Oreille River for August 14th, 2004 for Scenarios 1 and 2.5. Figure 43 shows a longitudinal profile of the daily average volume-weighted water temperature along the Pend Oreille River for August 14th, 2004. Table 11 the statistical significance of how similar are the longitudinal profiles between the two scenarios.

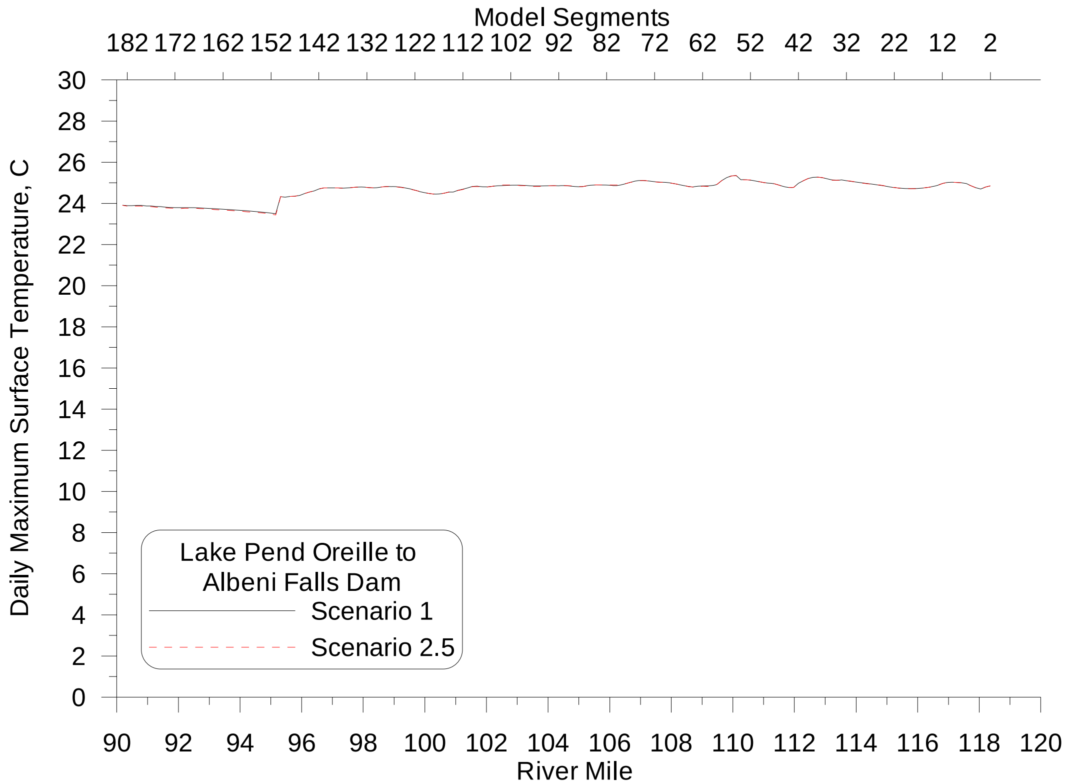

Figure 42: Daily maximum surface temperature longitudinal profile on August 16th, 2004 for the Impounded with no NPS (2.5) and Existing Conditions (1) Scenarios.

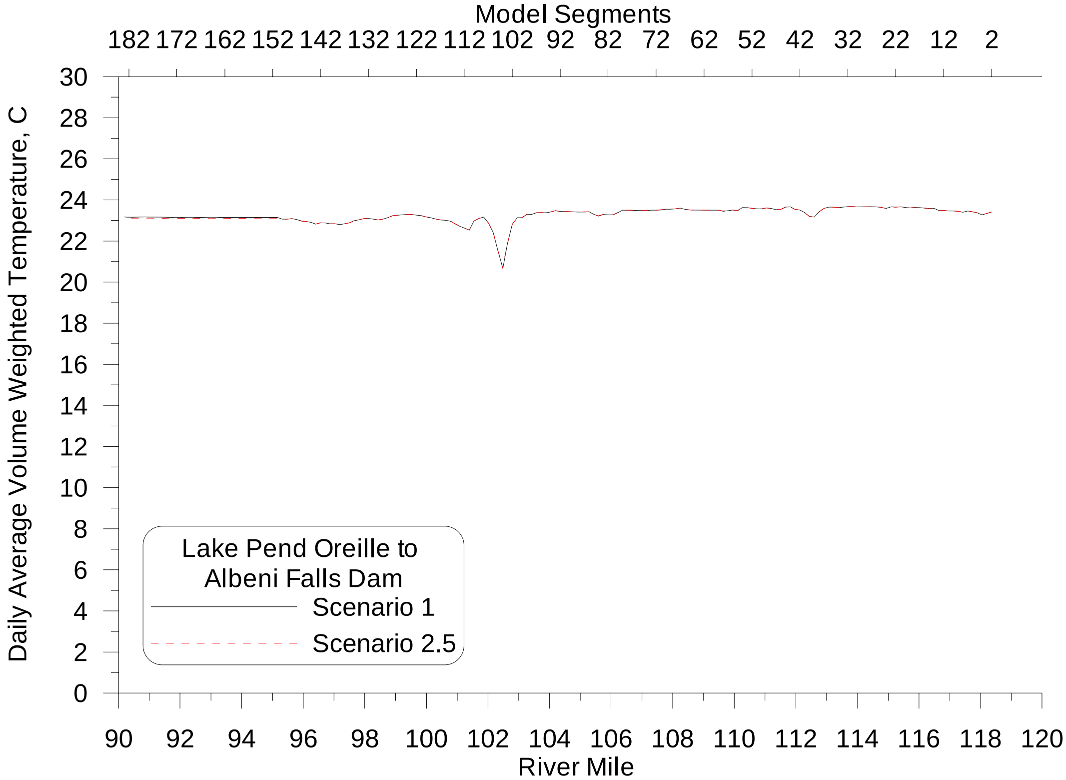

Figure 43: Daily average volume weighted temperature longitudinal profile on August 16th, 2004 for the Impounded with no NPS (2.5) and Existing Conditions (1) Scenarios.

Table 11: Statistical significance in the longitudinal profile on August 16th, 2004 between the Impounded with no NPS (2.5) and Existing Conditions (1) Scenarios.

Scenario 1 and Scenario 2.5 Comparison	P-value	Result
Daily maximum surface temperature	0.06	statistically significant, results are the same
Daily average volume-weighted temperature	0.16	probably statistically significant, results are similar

Evaluation of Albeni Falls Dam on Temperature

The thermal loading contribution from Albeni Falls Dam to the Pend Oreille River was evaluated by comparing results from Model Scenario l (Existing Conditions), and Scenario 4 (Existing Conditions with no Albeni Falls Dam in place).

Time Series Plots

Daily Average Temperatures

Figure 44 shows the daily average surface temperature 10 km downstream from the Long Bridge for Model Scenario 4 (No Dam) and Model Scenario 1 (Existing Conditions) over time in 2004.

Figure 45 shows the daily average 1 m volume-weighted bottom temperature for Scenarios 1 and 4 at 10 km downstream from Long Bridge. Figure 46 is a time series plot of the daily average of the volume-weighted temperature (over the full depth) for the two models scenarios at 10 km downstream of Long Bridge.

Figure 47 shows the daily average 1 m volume-weighted surface temperature for Scenarios 1 and 4 at 35 km downstream from the Long Bridge. Figure 48 shows the daily average 1 m volume-weighted bottom temperature 35 km downstream from the Long Bridge for Model Scenarios 1 and 4. Figure 49 shows the daily average of the volume-weighted temperature (over the full depth) over time for the two models scenarios at 35 km downstream of Long Bridge.

Figure 50 shows a time series plot of the continuous (hourly) outflow temperature from Albeni Falls Dam for Model Scenarios 1 and 4. Table 12 lists the statistical significance of how similar are the modeled temperatures between scenarios.

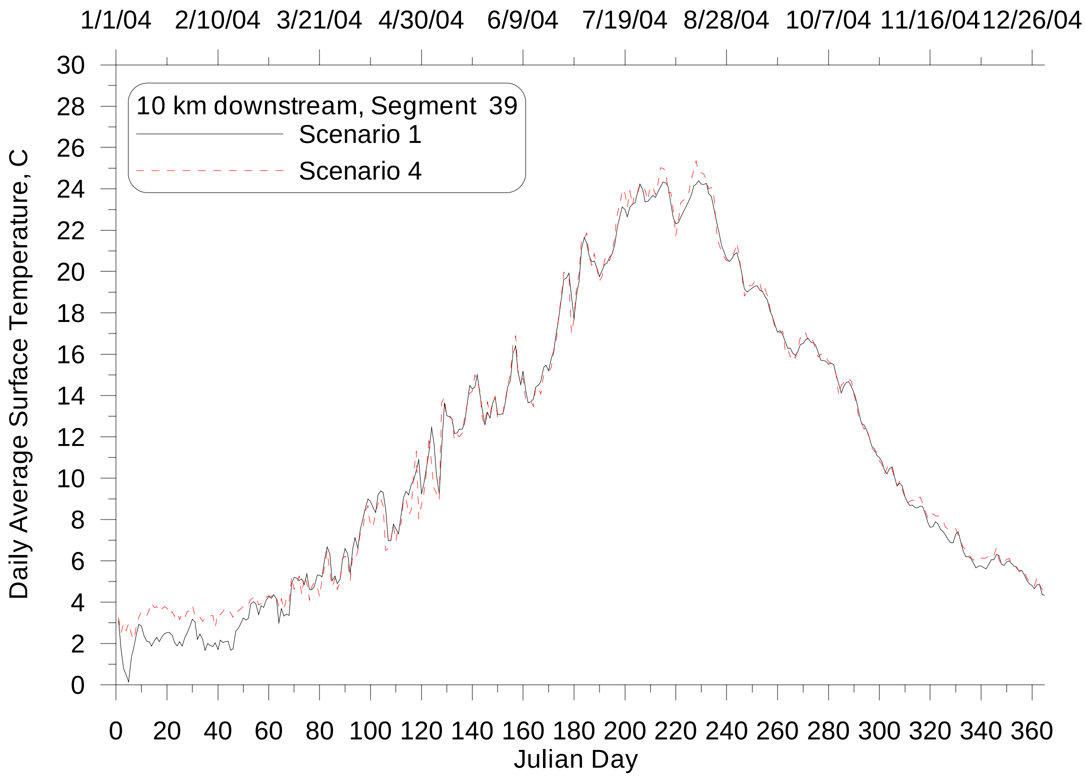

Figure 44: Daily average surface temperature time series at 10 km downstream from Lake Pend Oreille for the Unimpounded (4) and Existing Conditions (1) Scenarios, 2004.

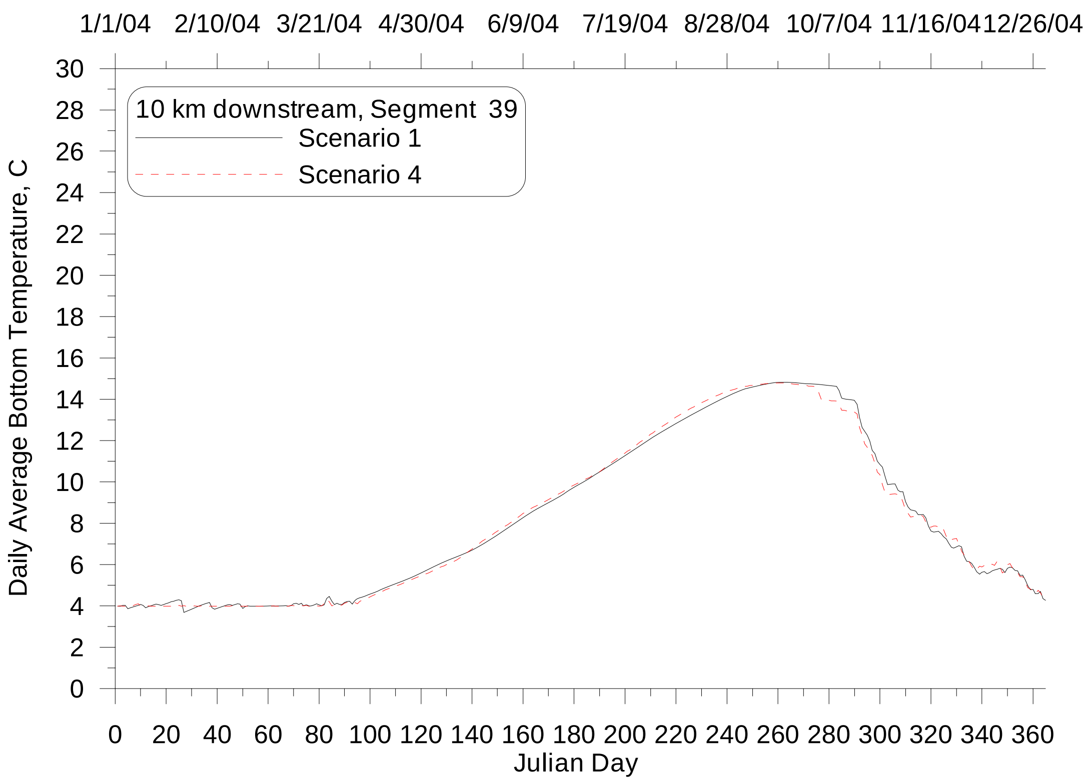

Figure 45: Daily average bottom temperature time series at 10 km downstream from Lake Pend Oreille for the Unimpounded (4) and Existing Conditions (1) Scenarios, 2004.

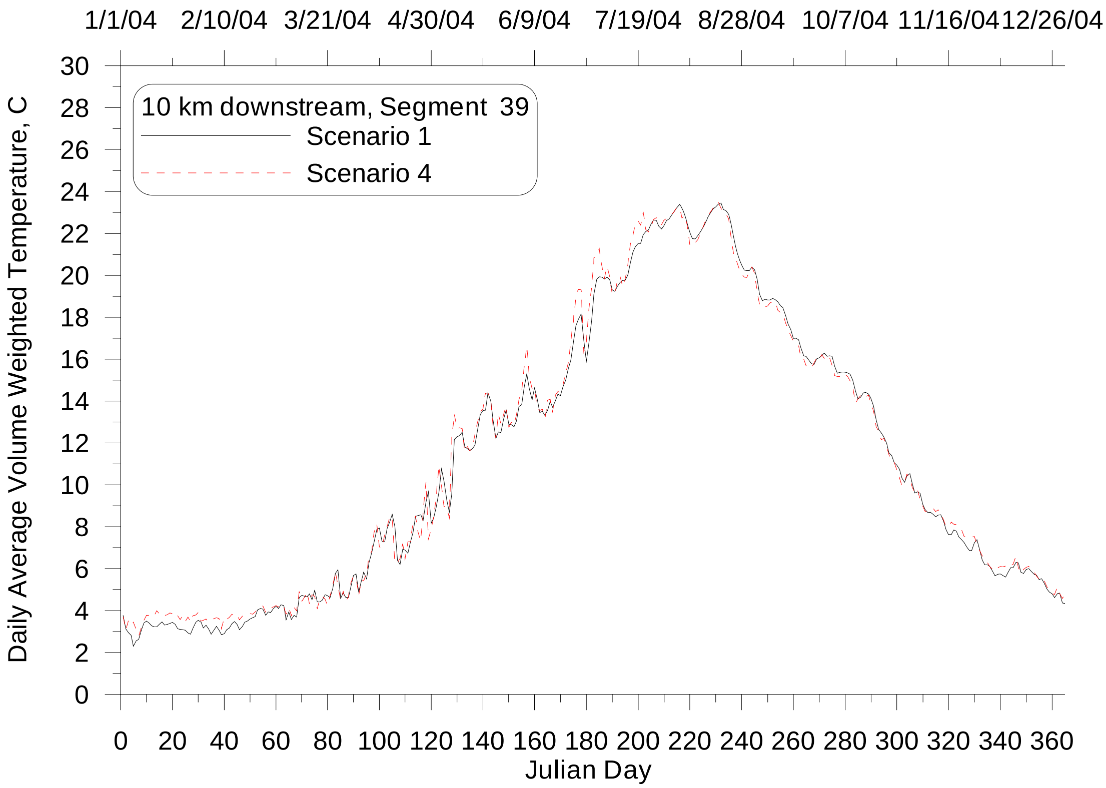

Figure 46: Daily average volume weighted temperature time series at 10 km downstream from Lake Pend Oreille for the Unimpounded (4) and Existing Conditions (1) Scenarios, 2004.

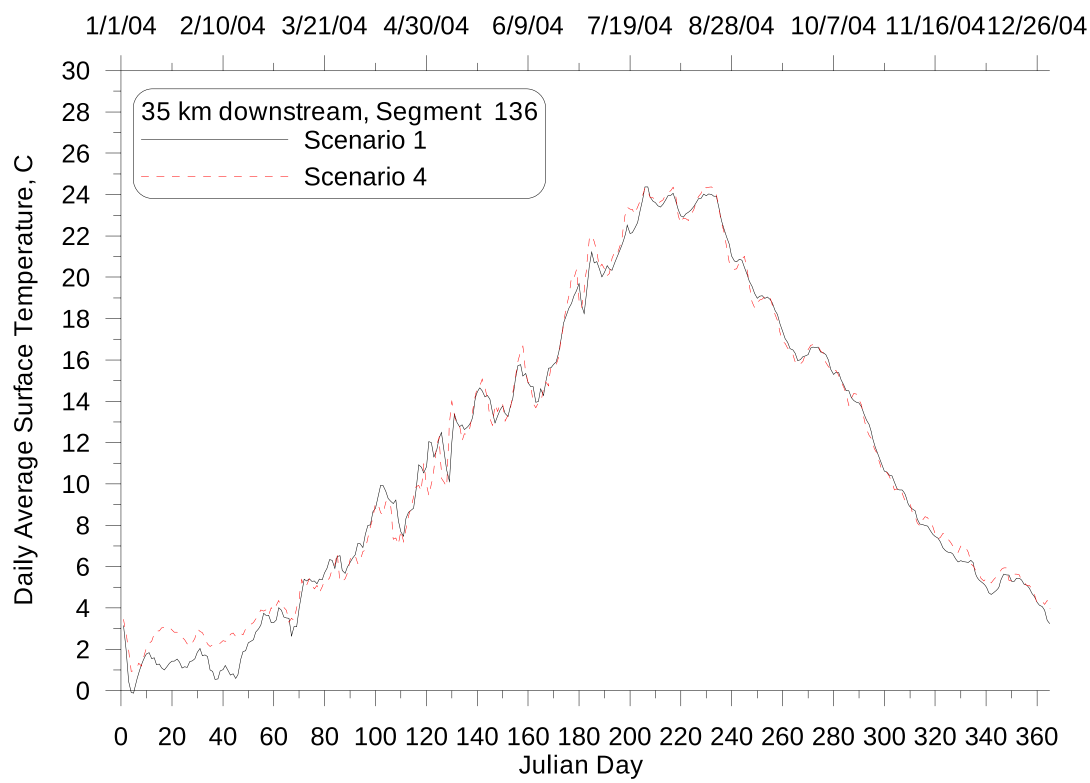

Figure 47: Daily average surface temperature time series at 35 km downstream from Lake Pend Oreille for the Unimpounded (4) and Existing Conditions (1) Scenarios, 2004.

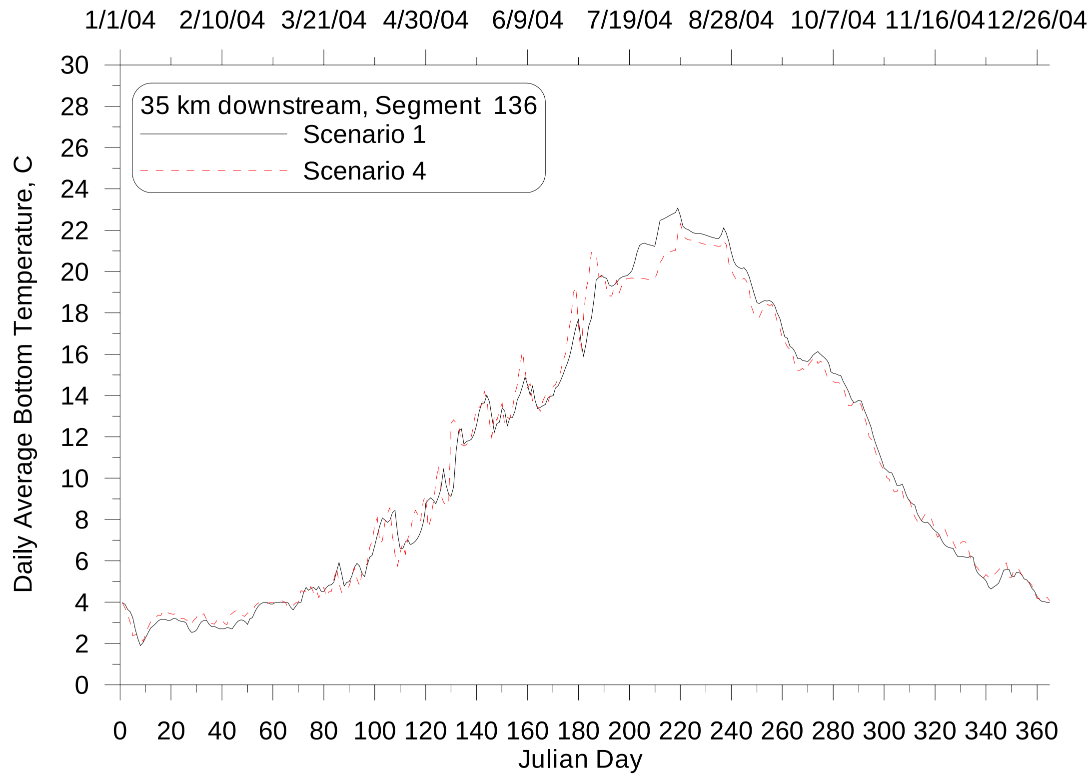

Figure 48: Daily average bottom temperature time series at 35 km downstream from Lake Pend Oreille for the Unimpounded (4) and Existing Conditions (1) Scenarios, 2004.

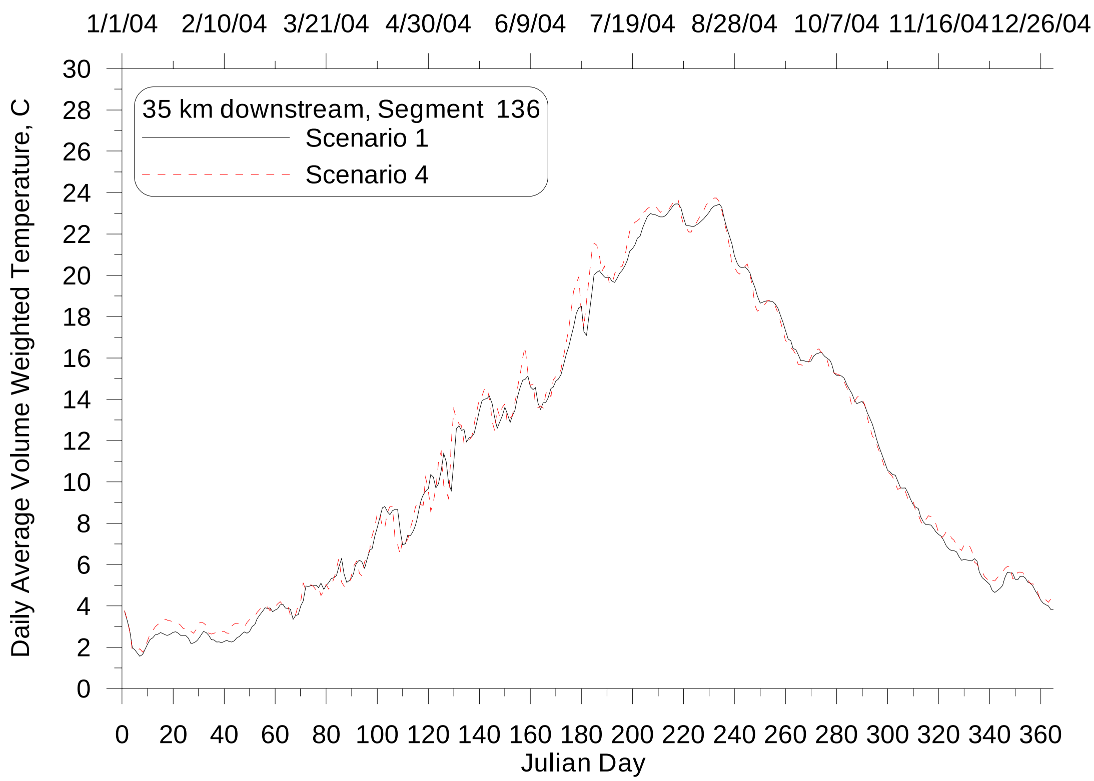

Figure 49: Daily average volume weighted temperature time series at 35 km downstream from Lake Pend Oreille for the Unimpounded (4) and Existing Conditions (1) Scenarios, 2004.

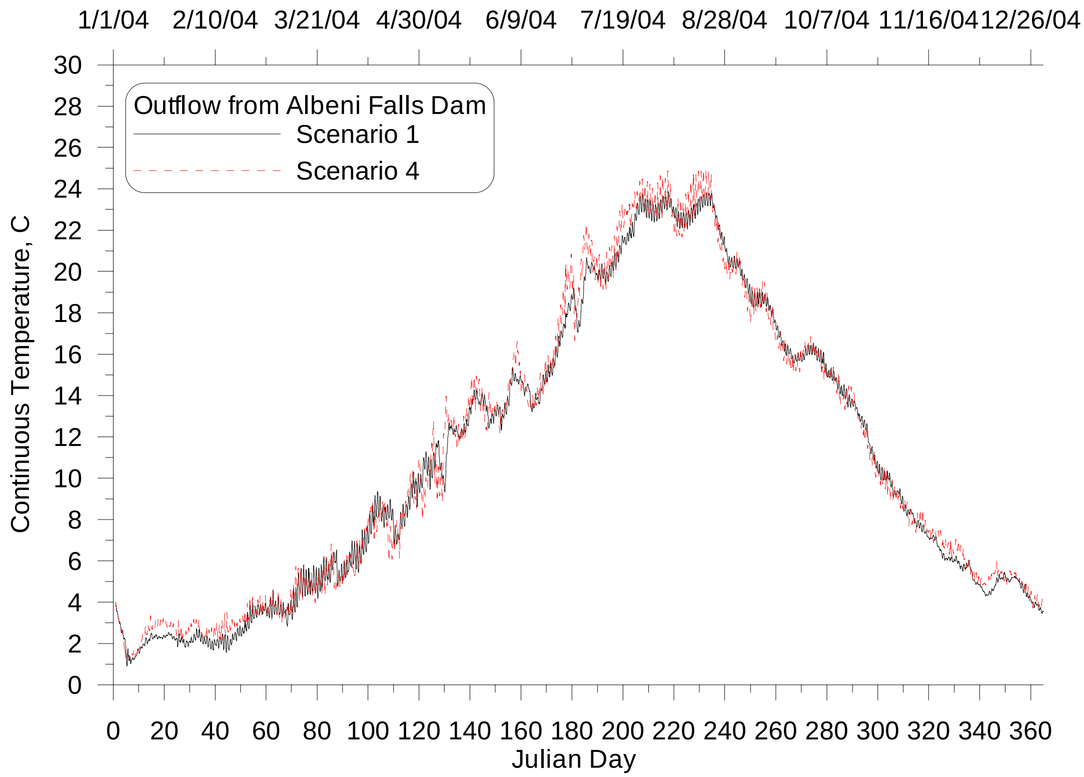

Figure 50: Continuous outflow temperature time series at Albeni Falls Dam for the Unimpounded (4) and Existing Conditions (1) Scenarios, 2004.

Table 12: Statistical significance in time series results between the Unimpounded (4) and Existing Conditions (1) Scenarios.

Scenario 1 and Scenario 4 Comparison	P-value	Result
Daily average surface temperature, 10 km	0.43	not statistically significant, results are not the same
Daily average bottom temperature, 10 km	0.15	probably statistically significant, results are similar
Daily average volume-weighted, 10 km	0.25	possibly statistically significant, results have some similarities
Daily average surface temperature, 35 km	0.37	not statistically significant, results are not the same
Daily average bottom temperature, 35 km	0.04	statistically significant, results are the same
Daily average volume-weighted, 35 km	0.36	not statistically significant, results are not the same
Continuous volume-weighted, outflow temperature at Albeni Falls Dam	1.00	not statistically significant, results are not the same

Daily Maximum Temperatures

Figure 51 shows the daily maximum of the 1 m volume-weighted surface temperature for Scenarios 1 and 4 at 10 km downstream from the Long Bridge. Figure 52 shows the daily maximum of the 1 m volume-weighted surface temperature for Scenarios 1 and 4 at 35 km downstream from the Long Bridge. Figure 53 shows the daily maximum of the 1 m volume-weighted surface temperature for Scenarios 1 and 4 at 23.4 km downstream from the Long Bridge, where the largest increase in temperature occurred between Model Scenarios 1 and 8. Table 13 lists the statistical significance of how similar are the daily maximum temperatures between the two scenarios.

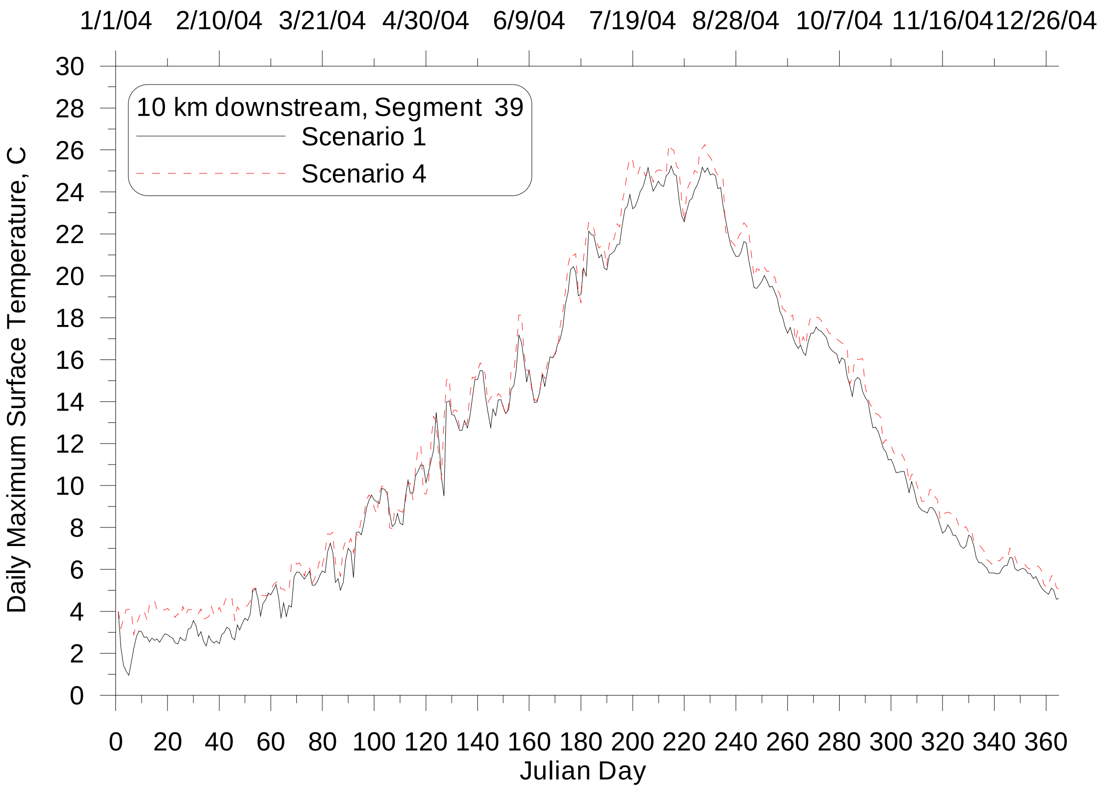

Figure 51: Daily maximum surface temperature time series at 10 km downstream from Lake Pend Oreille for the Unimpounded (4) and Existing Conditions (1) Scenarios, 2004.

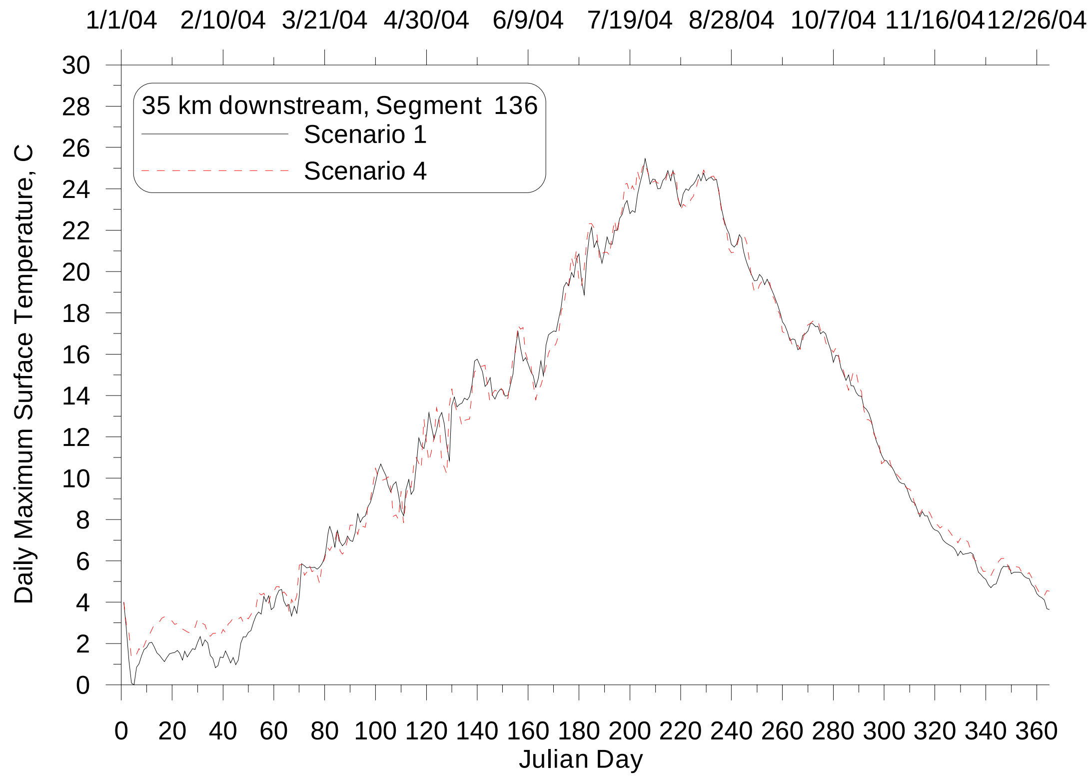

Figure 52: Daily maximum surface temperature time series at 35 km downstream from Lake Pend Oreille for the Unimpounded (4) and Existing Conditions (1) Scenarios, 2004.

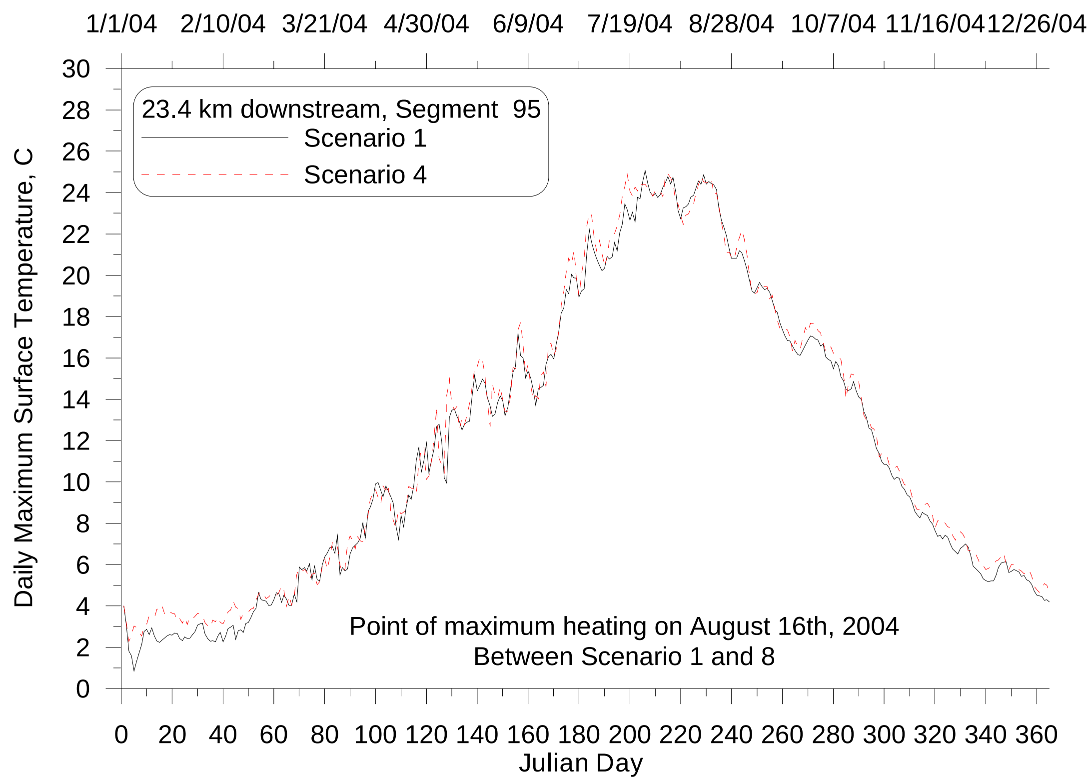

Figure 53: Daily maximum surface temperature time series at 23.4 km downstream from Long Bridge for the Unimpounded (4) and Existing Conditions (1) Scenarios, 2004. Based on the point of maximum heating on August 16th, 2004 between the Existing Conditions (1) and Natural Conditions (8) Scenarios.

Table 13: Statistical significance in daily maximum time series results between the Unimpounded (4) and Existing Conditions (1) Scenarios.

Scenario 1 and Scenario 4 Comparison	P-value	Result
Daily maximum surface temperature, 10km	0.78	not statistically significant, results are not the same
Daily maximum surface temperature, 35km	0.37	not statistically significant, results are not the same

Longitudinal Profiles

Figure 54 shows a longitudinal profile of the daily maximum 1 m volume-weighted surface temperature along the Pend Oreille River for August 14th, 2004 for Scenarios 1 and 4. Figure 55 shows a longitudinal profile of the daily average volume-weighted water temperature along the Pend Oreille River for August 14th, 2004. Table 14 the statistical significance of how similar are the longitudinal profiles between the two scenarios.

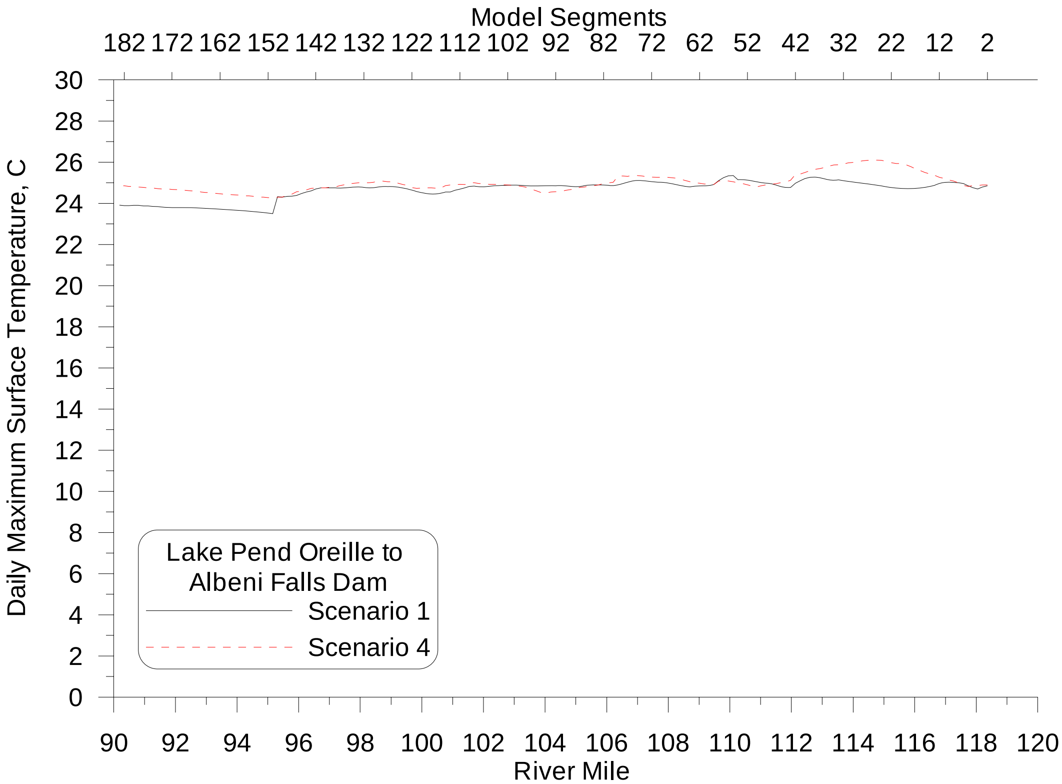

Figure 54: Daily maximum surface temperature longitudinal profile on August 16th, 2004 for the Unimpounded (4) and Existing Conditions (1) Scenarios.

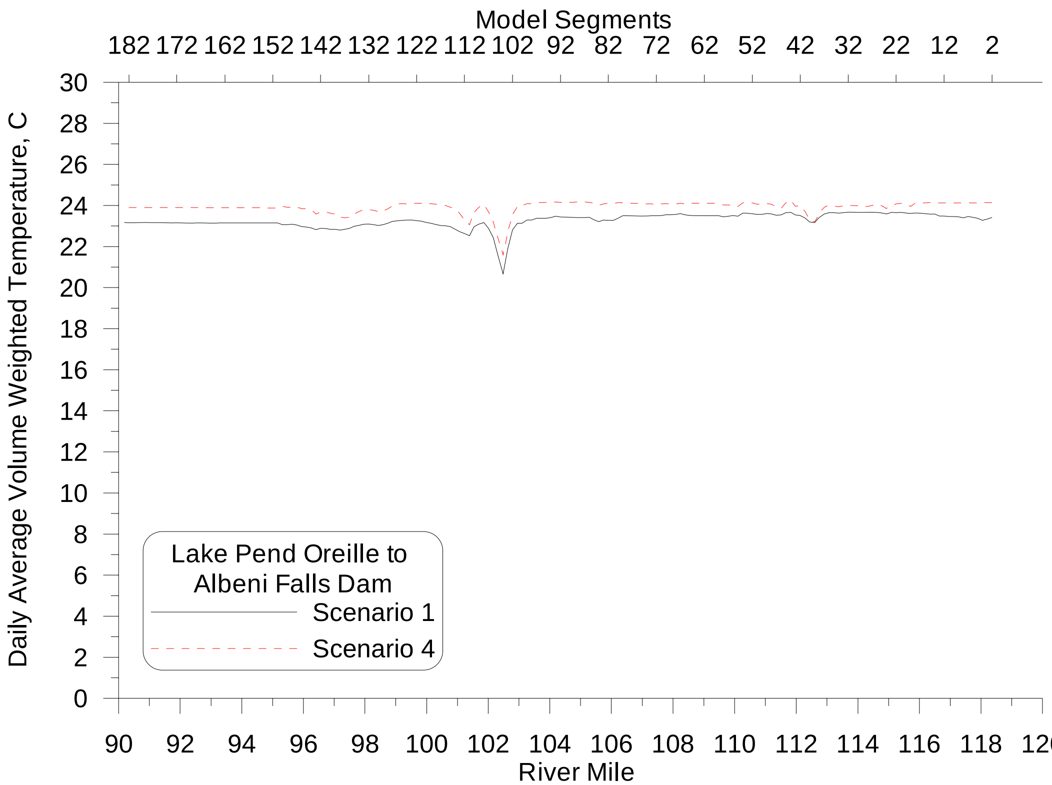

Figure 55: Daily average volume weighted temperature longitudinal profile on August 16th, 2004 for the Unimpounded (4) and Existing Conditions (1) Scenarios.

Table 14: Statistical significance in the longitudinal profile on August 16th, 2004 between the Unimpounded (4) and Existing Conditions (1) Scenarios.

Scenario 1 and Scenario 2.5 Comparison	**P-value**	**Result**
Daily maximum surface temperature	1.00	not statistically significant, results are not the same
Daily average volume-weighted temperature	1.00	not statistically significant, results are not the same

Evaluation of Pend Oreille River Bank Shading

The influence of vegetation density on shading and hence on water temperature to the Pend Oreille River was evaluated by comparing results from Model Scenario 8 using several different vegetation densities.

Time Series Plots

Daily Maximum Surface Temperatures

Figure 56 shows a time series plot of the daily average 1 m volume-weighted surface temperature for 4 different vegetation densities used with Model Scenario 8. Table 15 lists the statistical significance of how similar are the modeled temperatures between scenarios.

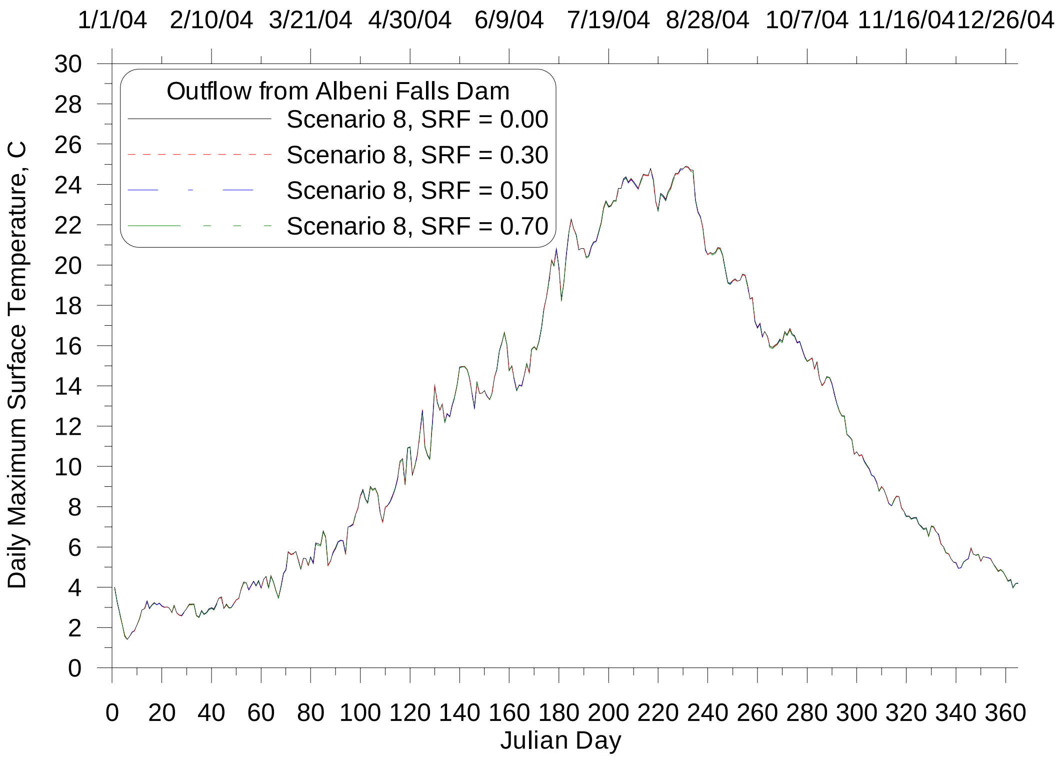

Figure 56: Daily maximum surface temperature time series at the Albeni Falls Dam location for Natural Conditions (8) Scenarios with various vegetation densities 2004.

Table 15: Statistical significance in time series results between Natural Conditions Scenarios (8) with various vegetation densities.

Scenario 8 Comparisons	P-value	Result
Daily maximum surface temperature, SRF 0.0 vs. 0.30	0.04	statistically significant, results are the same
Daily maximum surface temperature, SRF 0.0 vs. 0.50	0.06	statistically significant, results are the same
Daily maximum surface temperature, SRF 0.0 vs. 0.70	0.08	statistically significant, results are the same

Summary

Scenarios for the temperature TMDL were simulated using CE-QUAL-W2 Version 3.2 for the Pend Oreille River in Idaho. The model scenarios were shown in Table 1. For each set of scenarios model results were compared to existing and natural (no dam) conditions. These results included analysis of daily averages and daily maximums at fixed locations and longitudinal plots at fixed times. The results of these individual comparisons are shown in each section of this report:

- Existing Conditions to Natural Conditions
- WLA/point source contributions
- Non-point source contributions
- Albeni Falls Dam on Temperature
- Pend Oreille River Bank Shading

Statistics and graphical comparisons were made to assess impacts of the Albeni Falls Dam, bank shading, WLA and point sources, and non-point contributions to temperature in the Pend Oreille River, Idaho.

Appendix A: Additional Longitudinal Profile Snapshots

Figure 57 shows a longitudinal temperature difference profile snapshot on August 16th, 2004 showing the temperature difference between Model Scenario 1 (Existing Conditions) and Model Scenario 8 (Natural Conditions). The figure includes a refined temperature difference scale to discern smaller increases in temperature. Figure 58 shows a longitudinal profile of the locations where the river temperature exceeds 22 °C and the increase in temperature above the Natural Conditions exceeds 0.3 °C (shown as a 1 value and red in color).

Figure 59 shows a longitudinal temperature difference profile snapshot on August 8th, 2004 showing the temperature difference between Model Scenario 1 (Existing Conditions) and Model Scenario 8 (Natural Conditions). Figure 60 shows a longitudinal profile of the locations where the river temperature exceeds 22 °C and the increase in temperature above the Natural Conditions exceeds 0.3 °C (shown as a 1 value and red in color).

The travel time in the Pend Oreille River from the Long Bridge to the Albeni Falls Dam were reviewed. In the Existing Conditions Scenario (1) the average velocity over nine sample locations on August 8th and Aug 16th, were 0.20 m/s and 0.21 m/s, respectively. In the Natural Conditions Scenario (8) the average velocity over nine sample locations on August 8th and Aug 16th, were 0.41 m/s and 0.45 m/s, respectively. When comparing these average velocities over the whole Pend Oreille River reach of 45.5 km there is a time lag of 31.2 hours between the two scenarios for both dates. This indicates it takes an additional 31.2 hours for water travel through from Long Bridge to Albeni Falls Dam in Scenario 1 than in Scenario 8. The difference in travel times between the scenarios will influence the location of daily peak temperatures in each scenario.

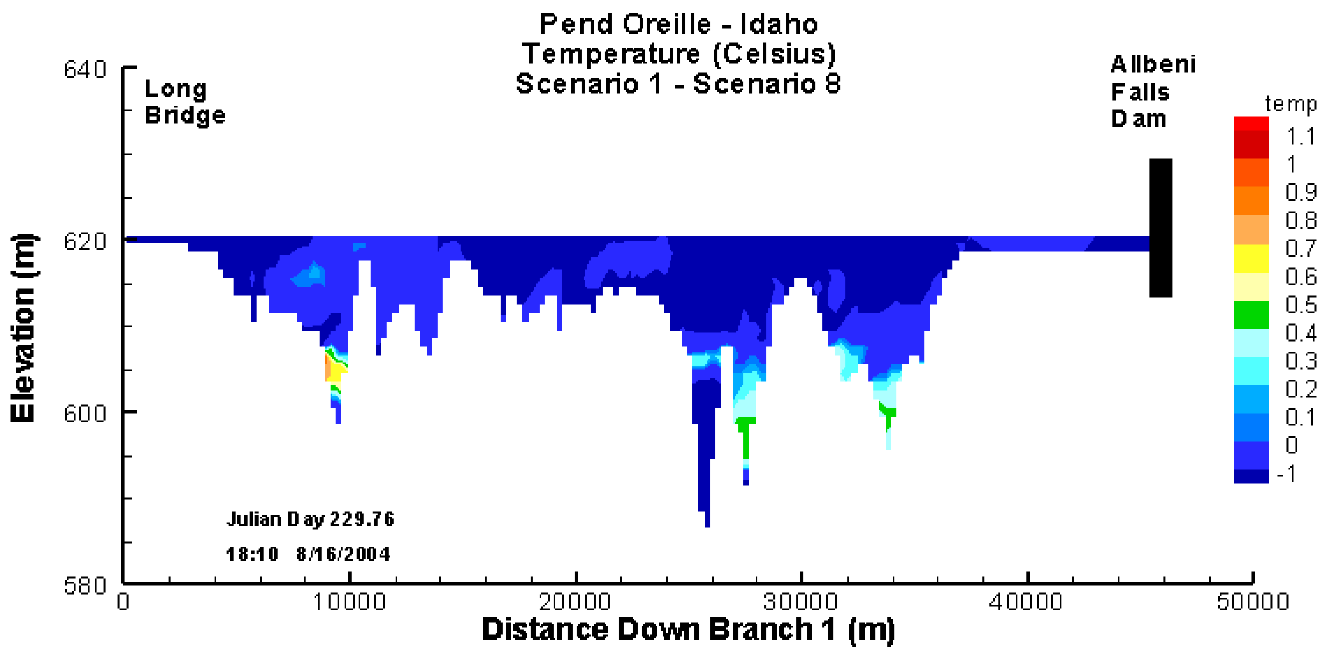

Figure 57: Longitudinal temperature profile difference, Existing Conditions (1) - Natural Conditions (8) Scenarios on August 16th, 2004 with a refined temperature difference scale

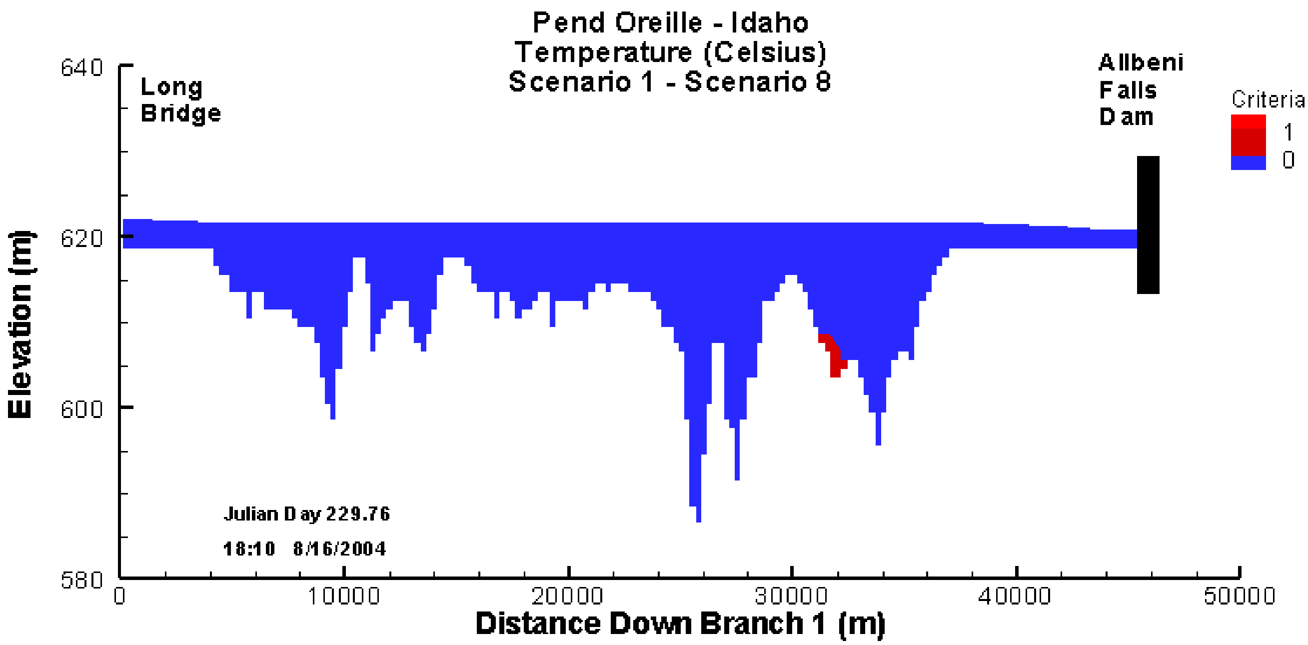

Figure 58: Longitudinal temperature profile difference, Existing Conditions (1) - Natural Conditions (8) Scenarios on August 16th, 2004 red indicates temperature difference was above 0.3 °C and river temperature was above 22 °C.

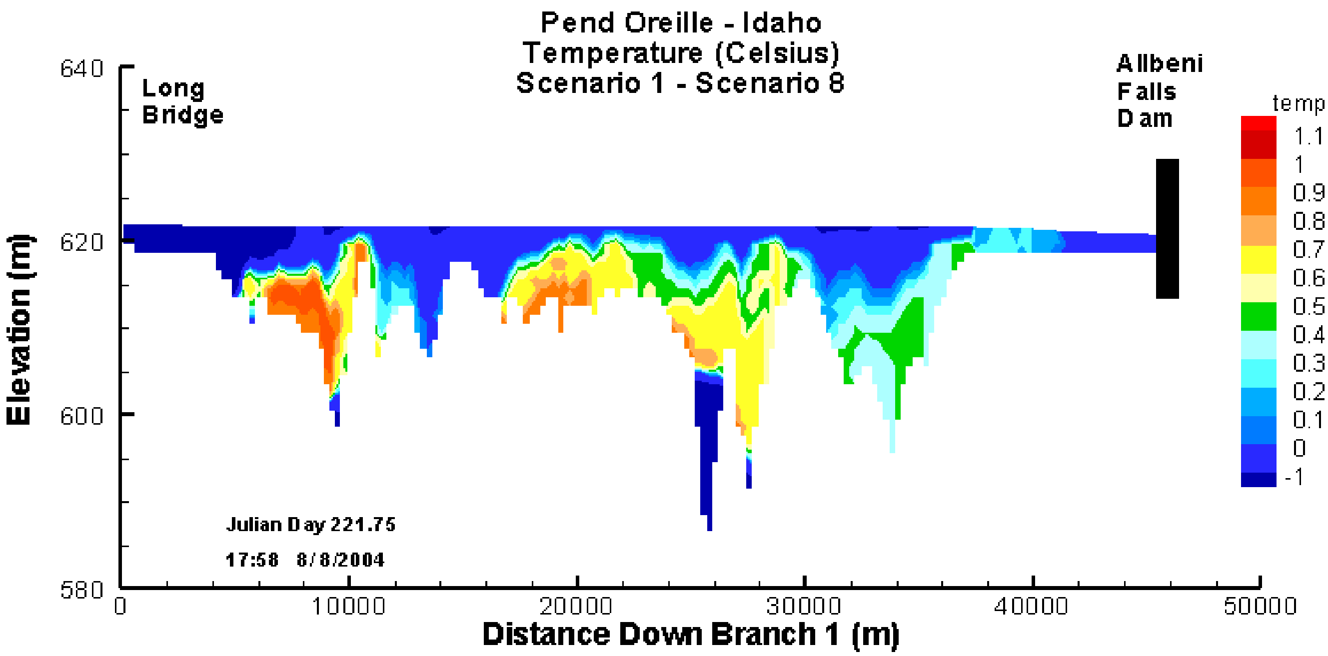

Figure 59: Longitudinal temperature profile difference, Existing Conditions (1) - Natural Conditions (8) Scenarios on August 8th, 2004 with a refined temperature difference scale.

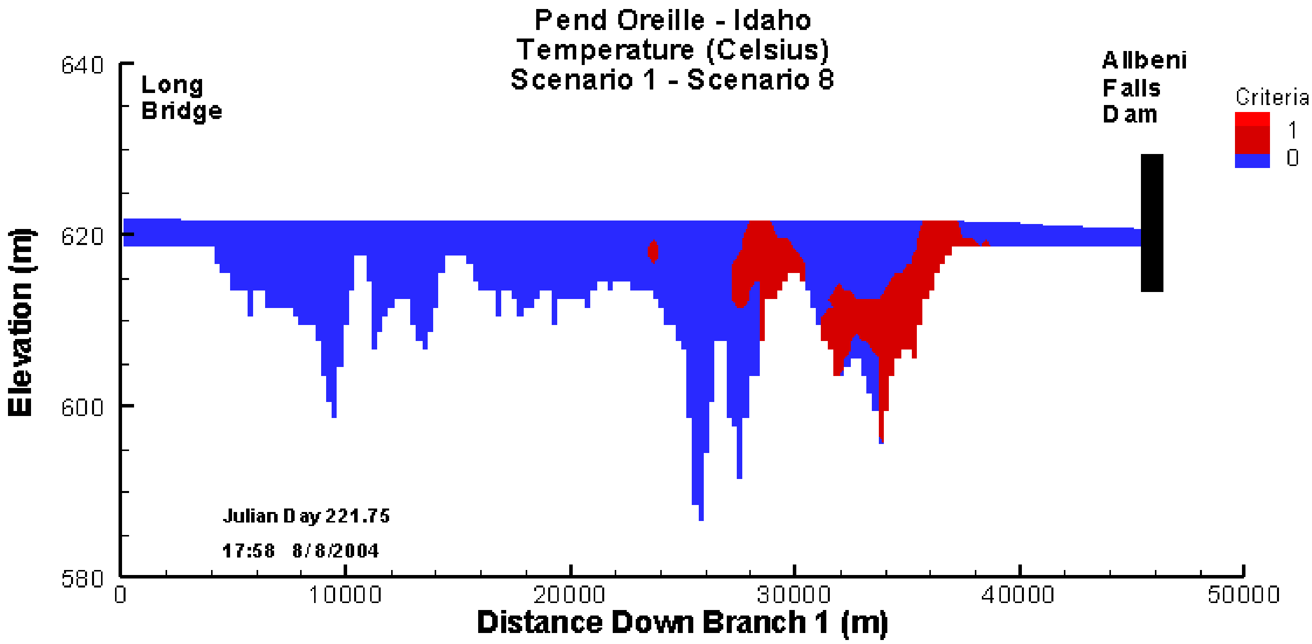

Figure 60: Longitudinal temperature profile difference, Existing Conditions (1) - Natural Conditions (8) Scenarios on August 8th, 2004 red indicates temperature difference was above 0.3 °C and river temperature was above 22 °C

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