Priest River Model

Model Development, Calibration and Scenarios Report

July 2014

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Department of Civil and Environmental Engineering
Maseeh College of Engineering and Computer Science

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Priest River Model:
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by

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Table of Contents

List of Figures

List of Tables

Introduction

The objective of this project is to develop a CE-QUAL-W2 temperature model of the Priest River between Priest Lake and the Pend Oreille River and to investigate the potential impact of cooler flows released from Priest Lake. The model was developed and calibrated to simulate between July 1 and September 24, 2013. Scenarios were modeled using 25%, 50%, and 75% hypolimnetic water for Priest Lake outflows. Total outflows from Priest Lake were unchanged relative to measured flow rates, and only the percentage of hypolimnetic water used for lake outflows was varied. Priest Lake water levels remained unaltered.

This report documents phase 2 of the project, which involved modeling the Priest River using detailed bathymetry to determine the impact of management scenarios on Priest River temperatures. Phase 1, which applied a simplified model to evaluate the feasibility of reducing Priest River temperatures if cooler water is released from Priest Lake, has been completed (Berger et al., 2013).

This report was organized into the following sections:

1. Background on the model chosen for the analysis – CE-QUAL-W2
2. Data requirements for the model development
3. Grid development
4. Meteorological data
5. Hydrology for all model inflows
6. Temperatures for all model inflows
7. Model Calibration
8. Evaluation of temperature prediction results from different model scenarios
9. Summary of model results

CE-QUAL-W2

The model used for the project was the public domain model, CE-QUAL-W2 (Cole and Wells, 2013). This model is a 2-dimensional (longitudinal-vertical) hydrodynamic and water quality model capable of predicting water surface, velocity, temperature, nutrients, multiple algae, zooplankton, periphyton, and macrophyte species, dissolved oxygen, pH, alkalinity, multiple CBOD groups, multiple suspended solids groups, multiple generic constituents (such as tracer, bacteria, toxics), and multiple organic matter groups, both dissolved and particulate. The model is set up to predict these state variables at longitudinal segments and vertical layers

Typical model longitudinal resolution is between 100-1000 m; vertical resolution is usually between 0.5 m and 2 m. The model can also be used in quasi-3-D mode, where embayments are treated as separate model branches off the main stem of the reservoir. The user manual and documentation can be found at the PSU website for the model: http://www.cee.pdx.edu/w2.

Dr. Wells and his group have been the primary developers of this model for the ERDC (Engineer Research and Development Center), Environmental Laboratory, Waterways Experiments Station Corps of Engineers for the last 15 years. Since 2000, this model has been used extensively throughout the world in 116 different countries in lakes, reservoirs, estuaries, and river systems (see Table 1).

Table 1: CE-QUAL-W2 applications between 2000-2006.

Water body	Known Number of Applications
Reservoirs	319+
Lakes	287+
Rivers	436+
Estuaries	82+
Pit Lakes	10+

Overview of Modeling Data Requirements

In order to set up this model specific data were required. These data included meteorological, bathymetric, flow and temperature data (Table 2).

Table 2: Data needs for modeling the Priest River.

#	Data Type	Why necessary?
1	Bathymetric x-y-z data of the river	Construct model segments and layers
2	Flow rates (Q) and temperatures (T)	These are the model boundary conditions and calibration data; continuous data are preferable, otherwise the model can use any temporal resolution available
3	Flow rates and locations of outflows from the system, including irrigation and other water withdrawals	These are model boundary conditions.
4	Meteorological data such as air temperature, dew point temperature (or relative humidity), wind speed and direction, solar radiation and cloud cover at an hourly frequency	These are model boundary conditions.

Model Bathymetry

Model bathymetry was developed using 46 cross sections measured by Kalispel Tribe. For each cross section, latitude and longitude were measured at a reference point. The following sections describe the bathymetry development process.

The first step was to determine the surface and bottom elevation of each cross section. A DEM (digital elevation model) was downloaded from http://ned.usgs.gov. The resolution of the DEM was one third arc-second (approximately 10 meters). Specific points were found using the longitude and latitude provided by the field measurement, and elevations were extracted from the DEM. Using the elevations of the reference points, elevations at all other measured points in a cross section were calculated based on the measured height difference.

The river was divided into 7 branches and 225 active segments. Segment length in the Priest River model was 313.3 meters.

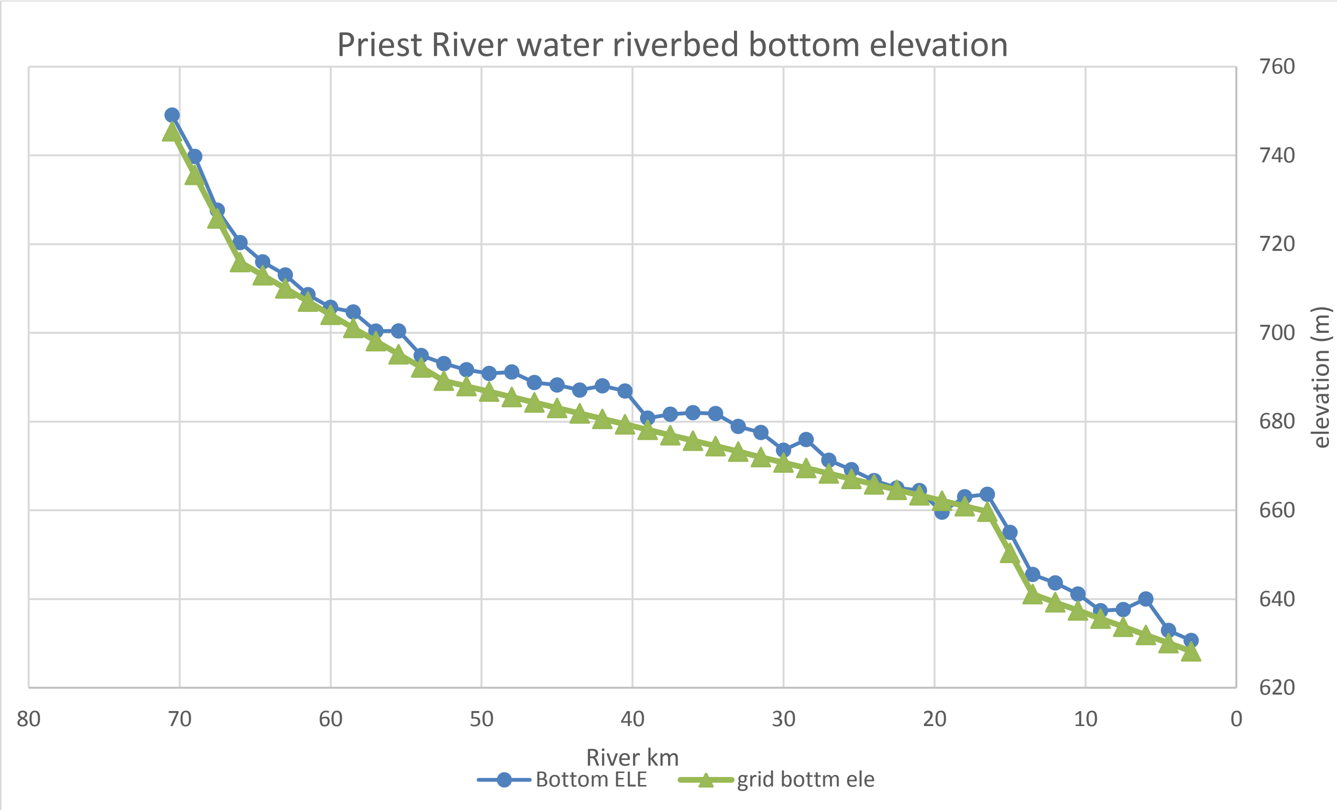

Figure 1: Branches of Priest River Model along with bottom elevations of 46 cross-sections.

Once the bottom elevation at each cross section was determined, the width of each layer was calculated by dividing the cross sectional area of each layer with the thickness of the layer. Layer thicknesses were selected as 1 feet (0.3048 m). Figure 2 illustrates the width calculation. Figure 3 shows the approach for calculating width at layers that are above the measured cross section. For model segments located between measured cross sections, cell widths were determined using linear interpolation.

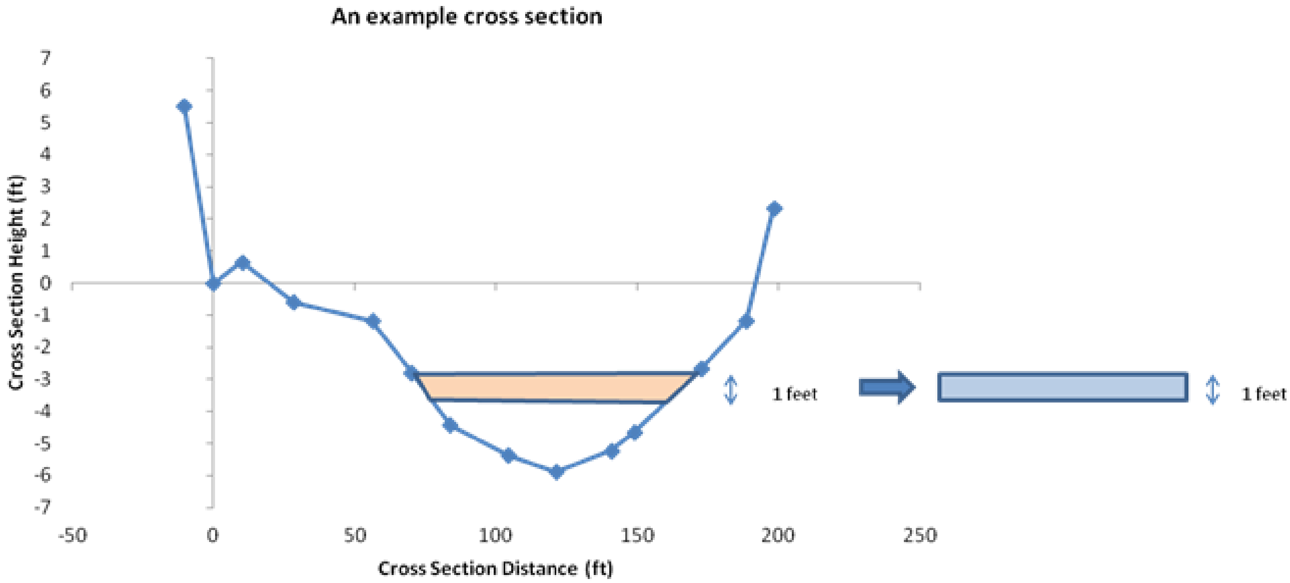

Figure 2: Sketch of width calculation (1) The orange shape represents the cross section area at the target layer. The blue rectangle represents the resulted model grid.

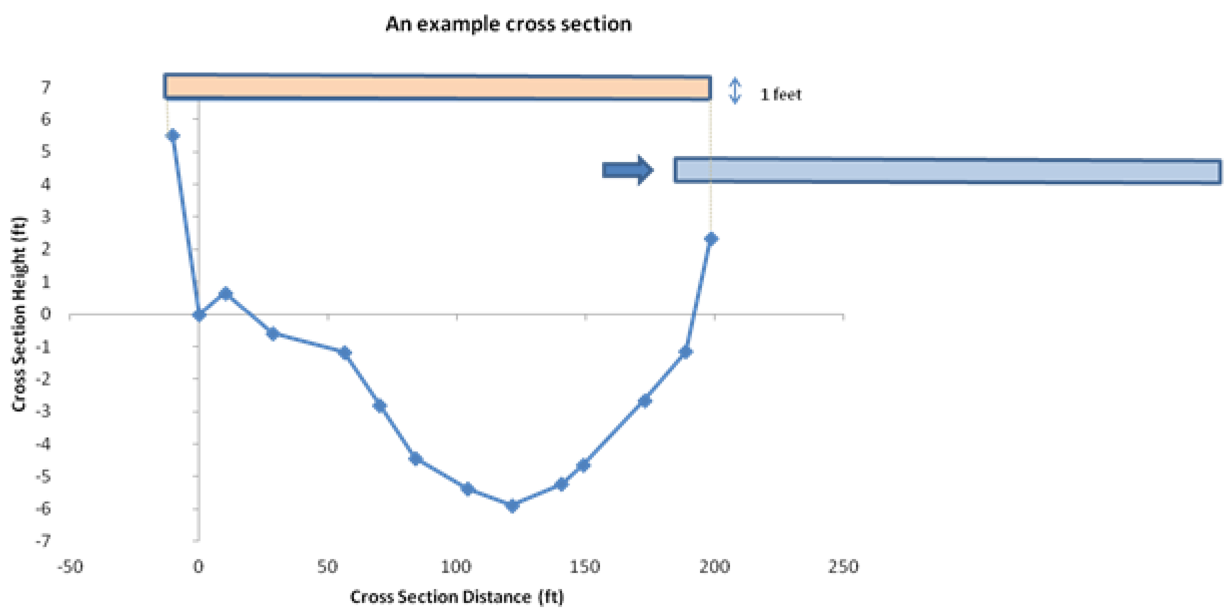

Figure 3: Sketch of width calculation theory (2 The farthest bank measurements at both sides are used as boundary of the cross sections. The orange shape represents the cross section area at the specific layer.

Segment Orientation

Segment orientation was determined using satellite images from Google Earth. As is shown in Figure 4, two points on the opposite side of the river were selected, and segment orientation was calculated from the angle between these two points. This process was performed for all the 46 measured cross sections.

Figure 4: Snapshot of determining segment orientation with Google Earth.

For segments between measured cross sections, segment orientations were linearly interpolated. The resulted grid has a smooth transaction between segments. Figure 5 shows that the model grid captures the general trend of river orientation.

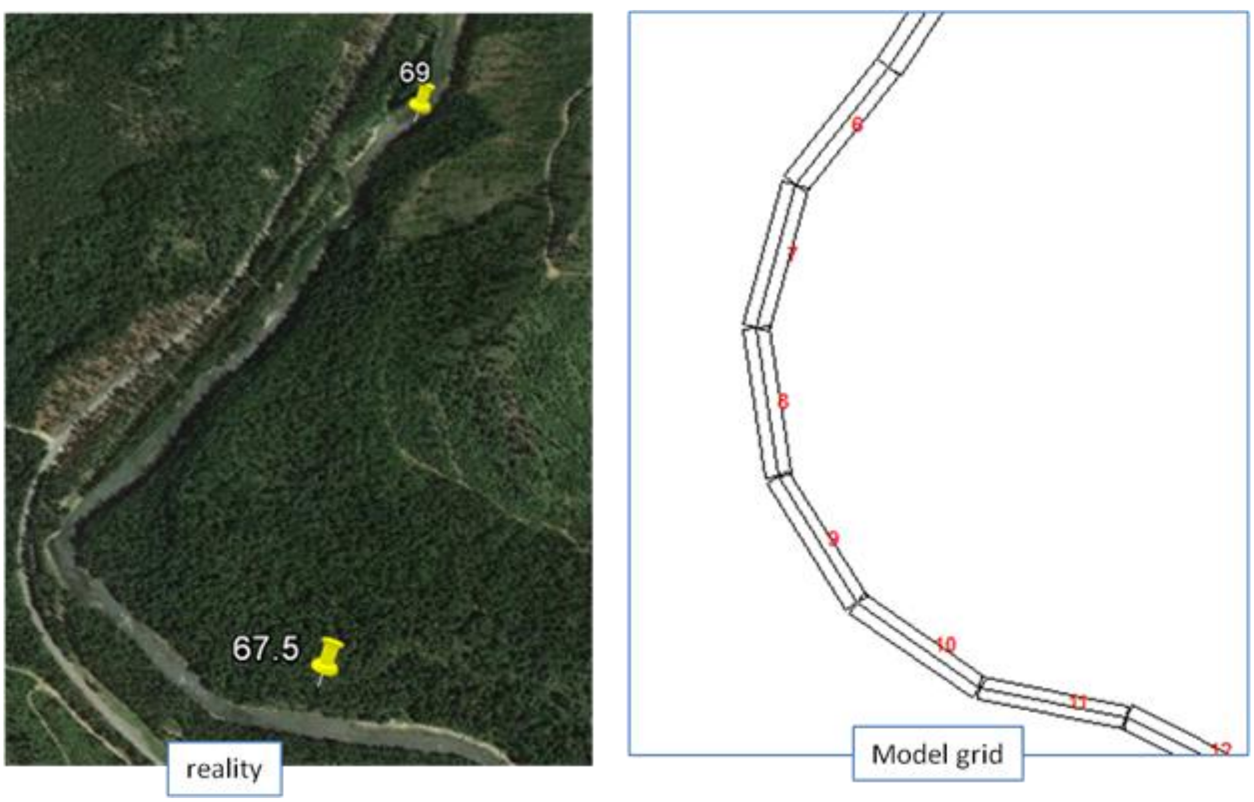

Figure 5: Comparison of segment orientation in reality and model.

A summary of the lengths, the number of active segments, and spacing for each branch in the reservoir is shown in Table 3. Model grid plan view is shown in Figure 6. A summary of model grid statistics is displayed in Table 4.

Table 3. Model Grid Branch Summary

Branch Number	Number of active segments	Upstream active segment	Downstream active segment	Centerline Length of Branch, m	Segment Length, m
1	15	2	16	4500	313.3
2	7	19	25	2100	313.3
3	38	28	65	11400	313.3
4	120	68	187	36000	313.3
5	10	190	199	3000	313.3
6	18	202	219	5400	313.3
7	17	222	238	4800	313.3

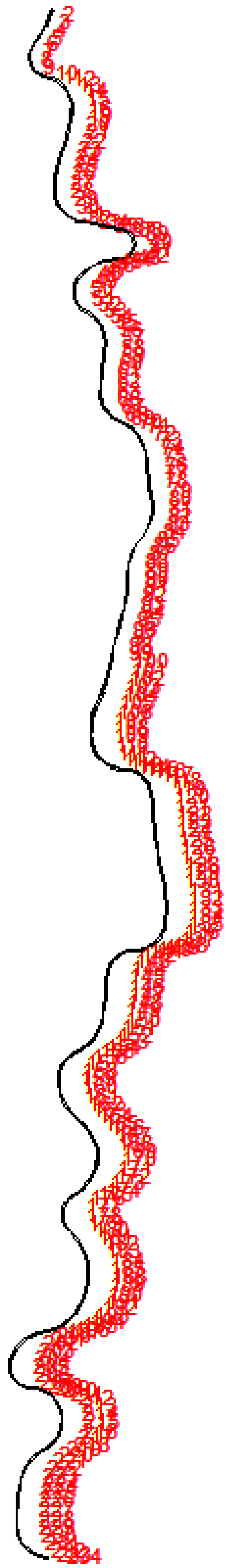

Figure 6: Priest River Model Grid, plan view.

Table 4: Summary of reservoir model grid details.

Number of water bodies	5
Number of branches	7
Number of segments	239
Minimum grid elevation	630.32 m
Maximum grid elevation	752.47 m
Number of layers	38
Layer thickness	0.3048 m
Latitude	48.462°
Longitude	-116.9°

Meteorological Data

Meteorological data for 2013 were gathered from a remote automated weather station (RAWS) located near Priest Lake, Idaho. The Priest Lake RAWS station is shown in Figure 7. Table 5 shows the station's location, station ID, elevation, coordinates and the weather constituents measured. Figure 8 shows the proximity of the Priest Lake RAWS station to the Priest River. The Priest Lake RAWS site is 6.5 miles from the Priest Lake outlet dam and 27 miles from the City of Priest River, Idaho and the Pend Oreille River. The meteorological data were measured at hourly intervals.

Figure 7: Photograph of the Priest Lake RAWS weather station (Western Regional Climate Center).

Table 5: Priest Lake RAWS station summary.

Station ID	Elevation (ft-m)	Latitude	Longitude	Meteorological Parameters
PLKI1	2915 ft - 797m	48.575°	-116.964°	Air Temperature, Wind Speed, Wind Direction, Solar Radiation, Relative Humidity

Figure 8: Priest Lake RAWS meteorological station and the Priest River.

Figure 9 shows hourly air temperature data measured at the Priest Lake RAWS station for 2013. Dew point temperature T_{dew} was estimated (Figure 10) with relative humidity and air temperature T_{air} data using:

$$T_{dew} = \left[0.655 + 0.36\left(\frac{\%\ \text{Relative Humidity}}{100}\right)\right] T_{air}$$

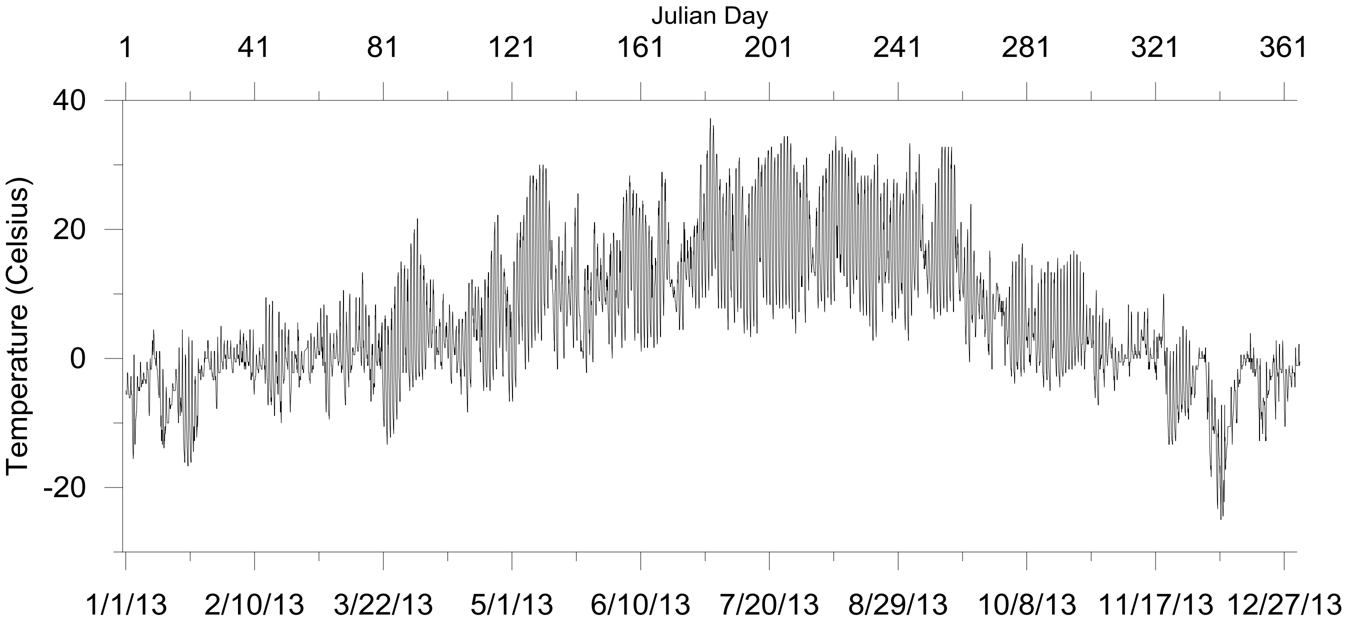

Figure 9: Priest Lake air temperature (°C) 2013.

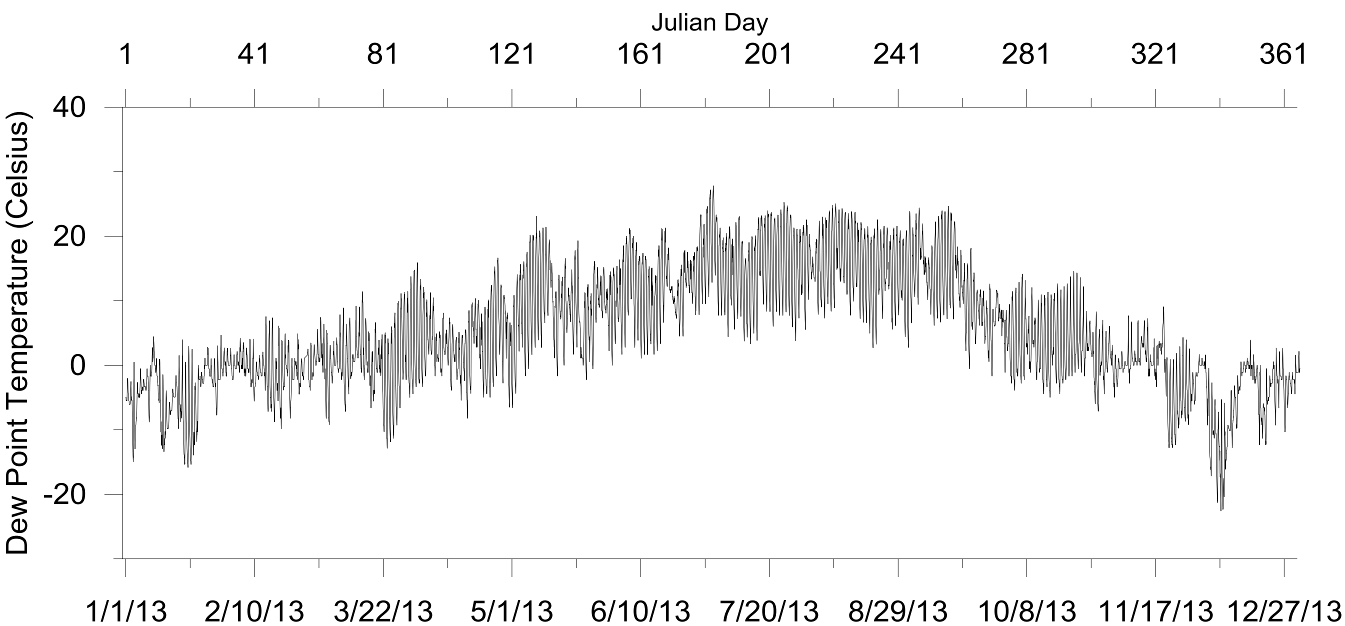

Figure 10: Priest Lake dew point temperature (°C) 2013 calculated from relative humidity data.

Figure 11 shows hourly short wave solar radiation data collected from the Priest Lake station. CE-QUAL-W2 uses cloud cover data and air temperature data to calculate long wave radiation. In the absence of measured cloud cover data, cloud cover data was back calculated (Cole and Wells, 2014). Theoretical clear sky solar radiation was calculated based on the geographic location of the Priest Lake RAWS station. The ratio between the measured value and the theoretical clear sky radiation was used to calculate cloud over a value ranging from 0 (no clouds) to 10 (complete cloud cover):

$$C = \sqrt{\frac{1}{0.0065}\left(1 - \frac{\varphi_{measured}}{\varphi_{theoretical clearsky}}\right)}$$

where C: cloud cover in tenths

$\varphi_{measured}$: measured short-wave solar radiation

$\varphi_{theoretical\ clear\ sky}$: computed from theoretical formulae with no cloud cover

Cloud cover data was calculated at hourly intervals (Figure 12).

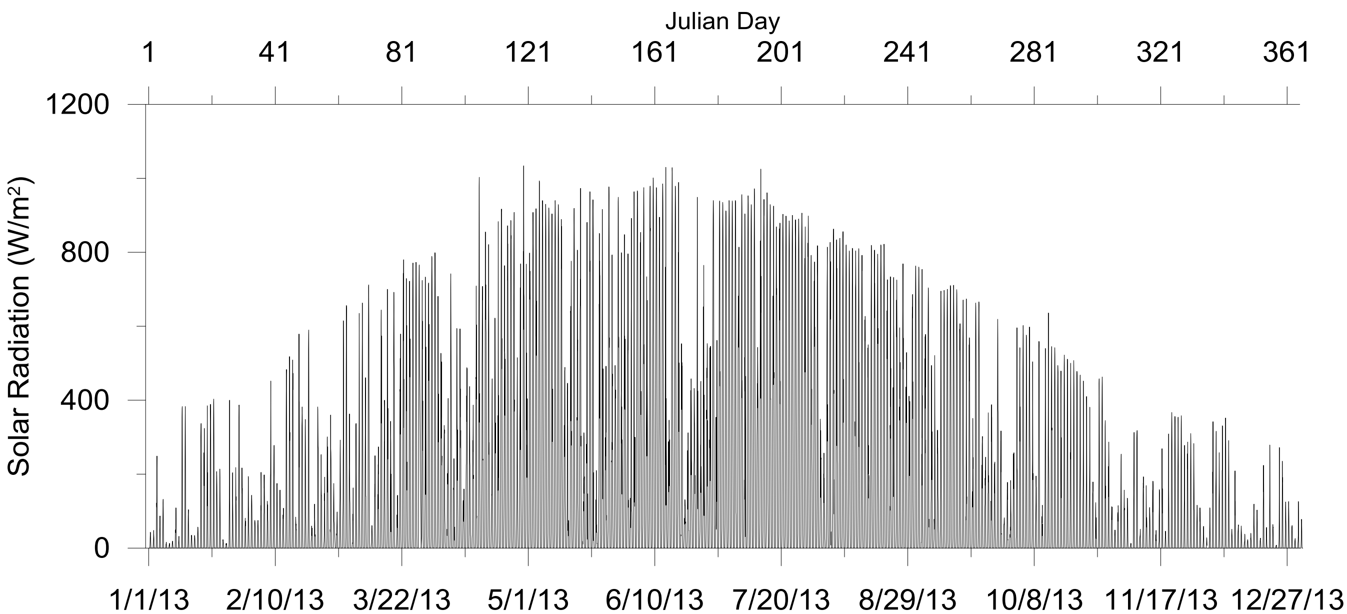

Figure 11: Priest Lake RAWS short wave solar radiation (W/m²) 2013.

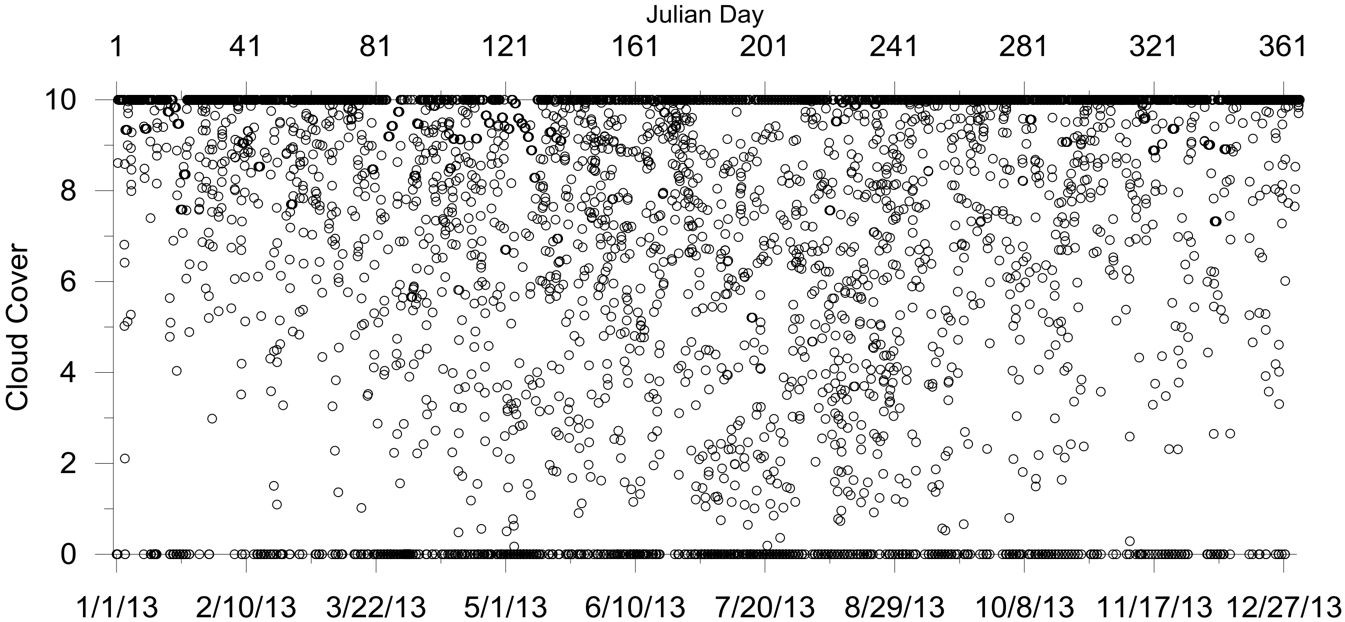

Figure 12: Priest Lake RAWS calculated hourly averaged cloud cover 2013.

Wind direction data were measured instantaneously every hour. Figure 13 shows the annual rose plot of wind direction. Figure 14 shows the plot of wind speed data.

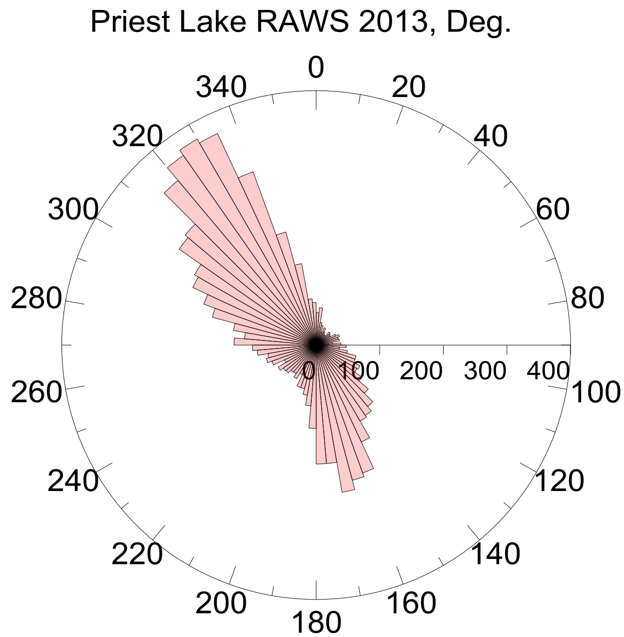

Figure 13: Priest Lake RAWS wind direction rose plot 2013.

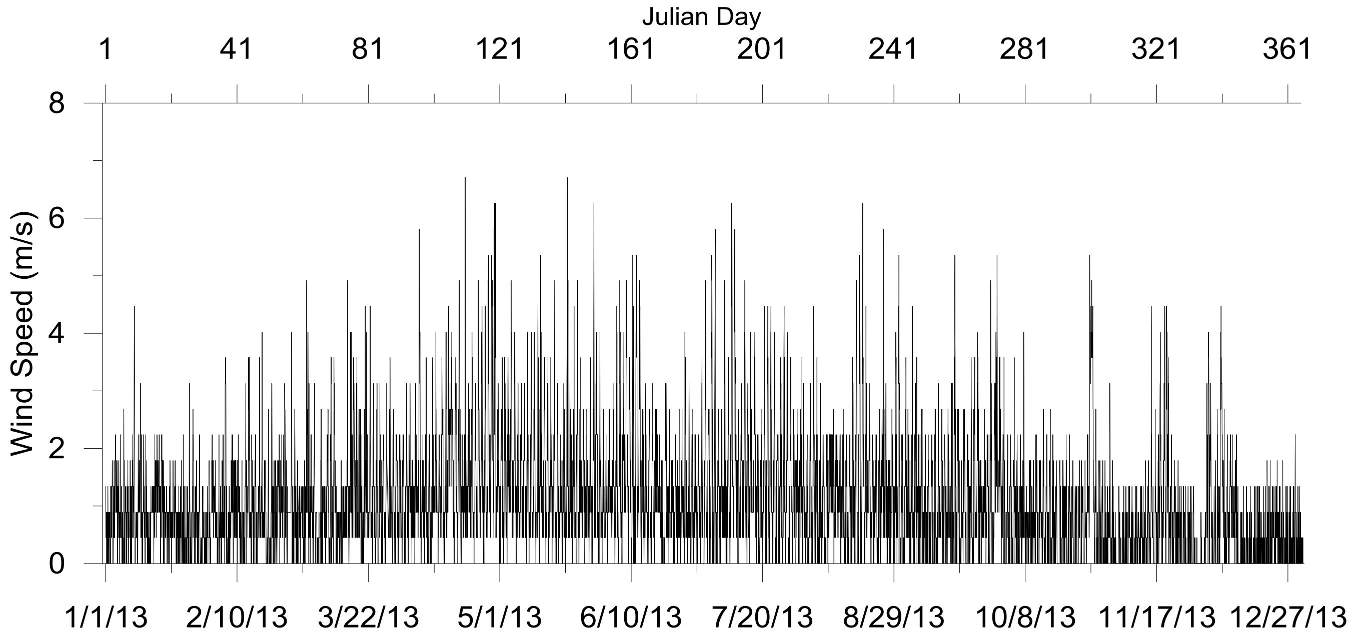

Figure 14: Priest Lake RAWS wind speed (m/s) 2013.

River Inflows

Upstream Boundary

Because flow data were not available at the lake outlet to the Priest River (Figure 15), flow rates were estimated by subtracting flow rates at Binarch Creek from flow rate data or estimated flow rates for Priest River near Coolin, Idaho Site (Kalispel Tribe site DICK1). Continuous data measured at DICK1 were available for parts of August and September, 2013. Data for other times during 2013 were estimated using a correlation (Figure 16) developed between the Priest River near Priest River Gage (USGS 12395000) and the Priest River near Coolin gaging station (USGS 12394000). The Coolin gaging station had been discontinued until Kalispel Tribe began gathering data again in the summer of 2013. These data were daily average flow rates measured between 1948 and 1986. Figure 17 shows the estimated flow rates for the upstream boundary (Figure 17).

Figure 15: Priest River near the Priest Lake Outlet (OUT1). Flow rates at the upstream boundary at OUT1 were estimated by subtracting Binarch Creek flow rates (BIN1) from flow rate data or estimated flows measured at the Priest River near Cooling station (DICK1).

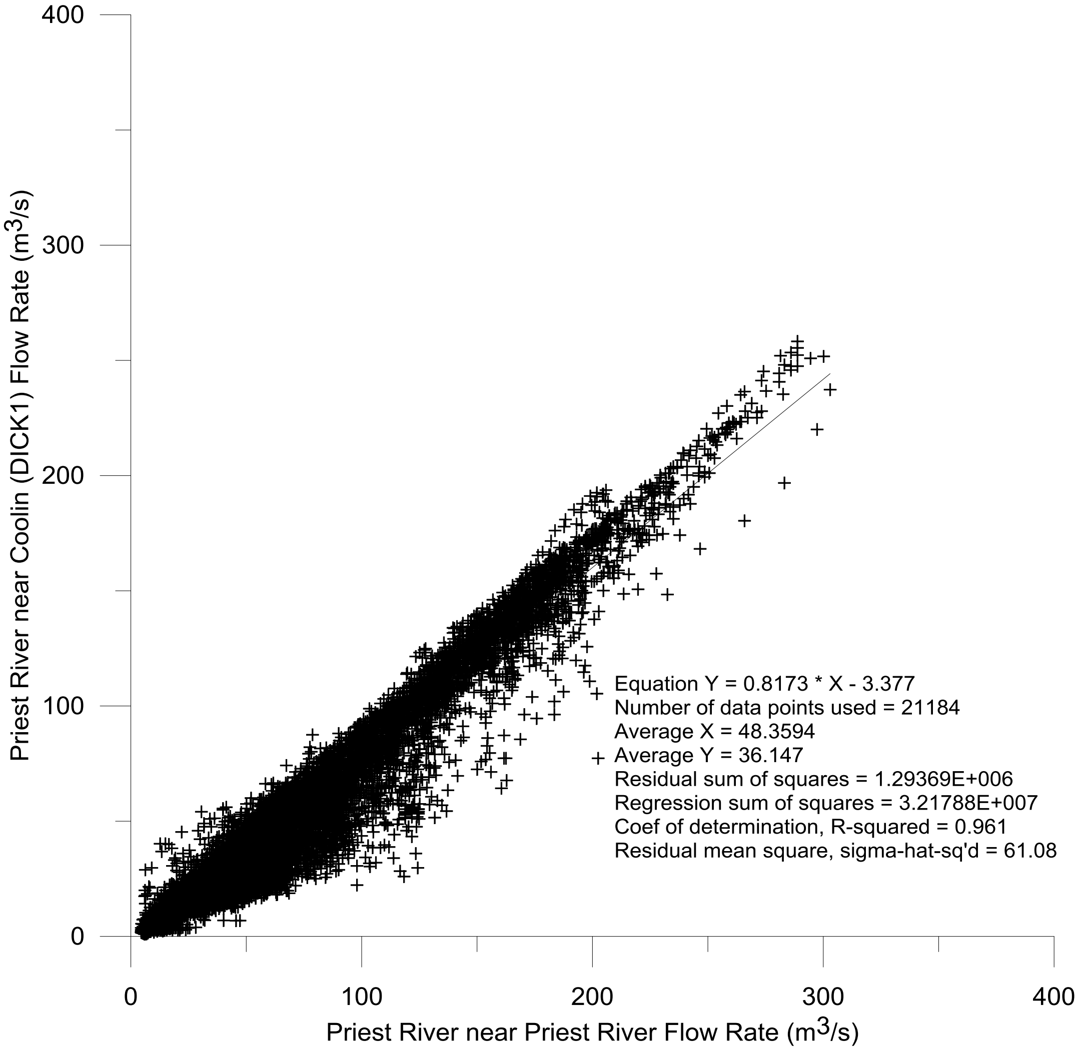

Figure 16: Flow rate correlation between Priest River near Coolin (USGS 12394000 or Kalispel Site DICK1) and Priest River near Priest River (USGS 12395000). Flow rate data were daily averages measured between 1948 and 2006.

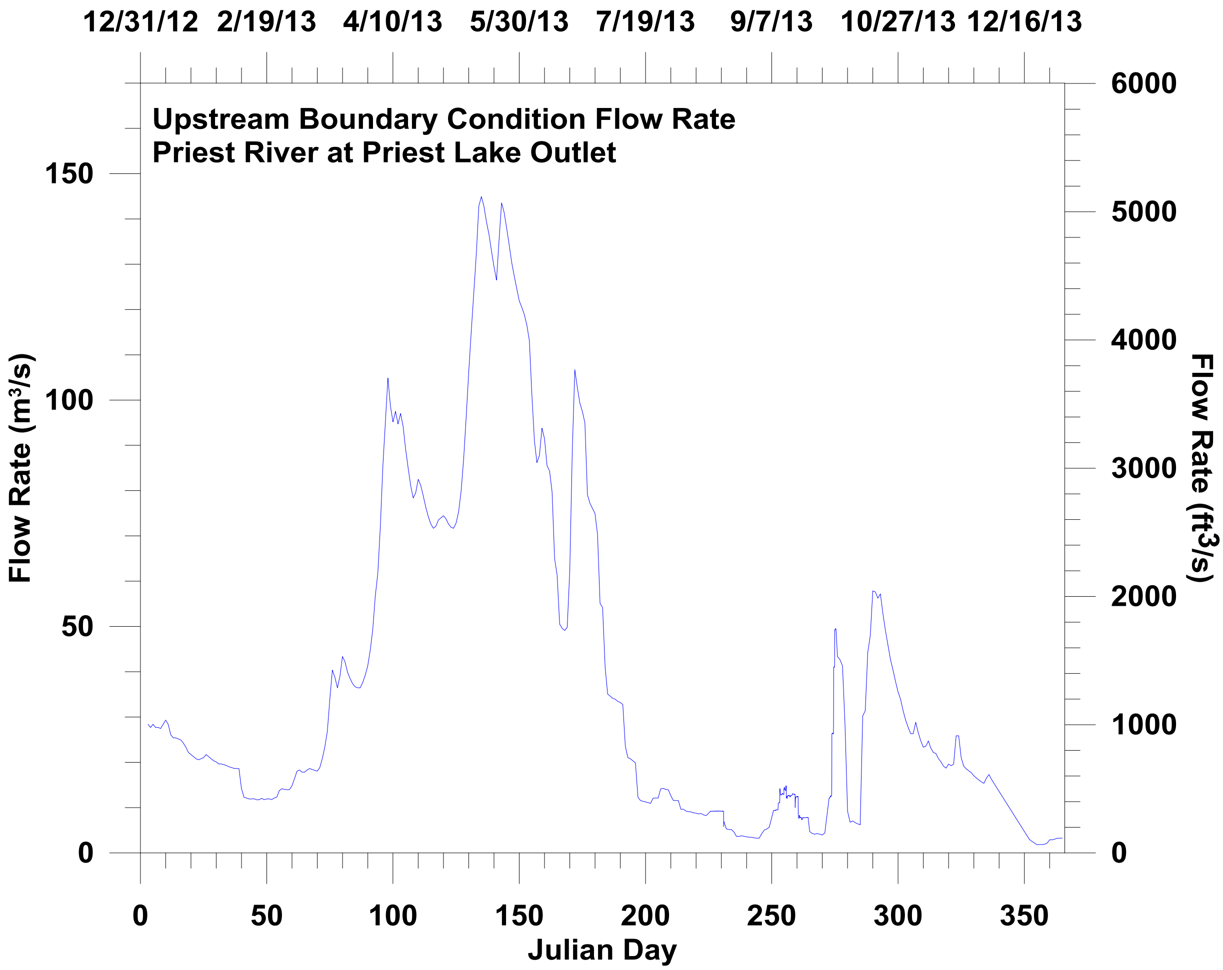

Figure 17: Flow rate of Priest River model upstream boundary. 2013

Tributary Flow Rates

Tributary flows from Binarch Creek, East River, Lower West Branch Priest River, Upper West Branch Priest River, Quartz Creek, Saddler Creek, Sanborn Creek and Big Creek were estimated by Kalispel Tribe by applying the effective discharge method (Appendix A). Figure 18 and Figure 19 show estimated flow rates for these tributaries.

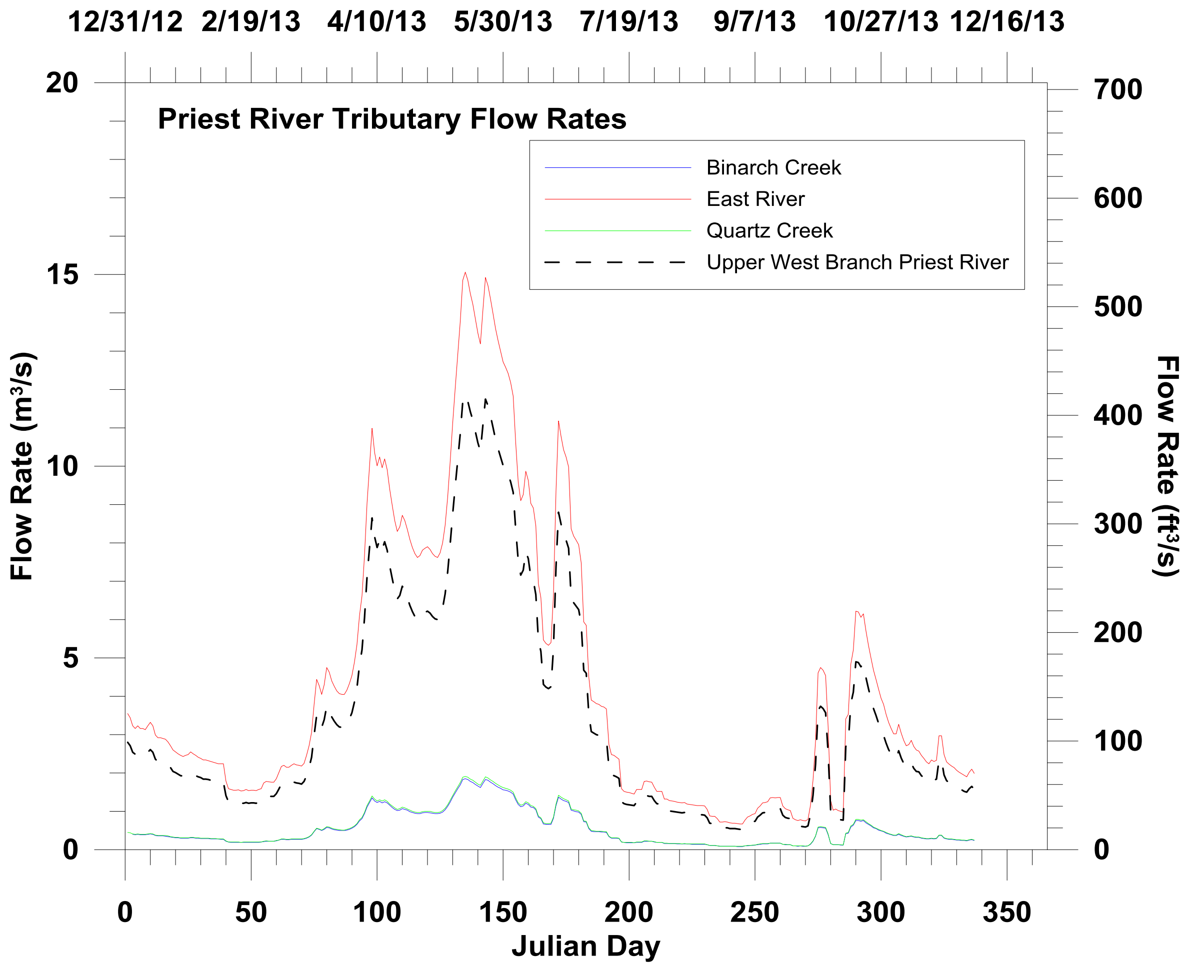

Figure 18: Estimated flow rates for Binarch Creek, East River, Quartz Creek and the Upper West Branch Priest River.

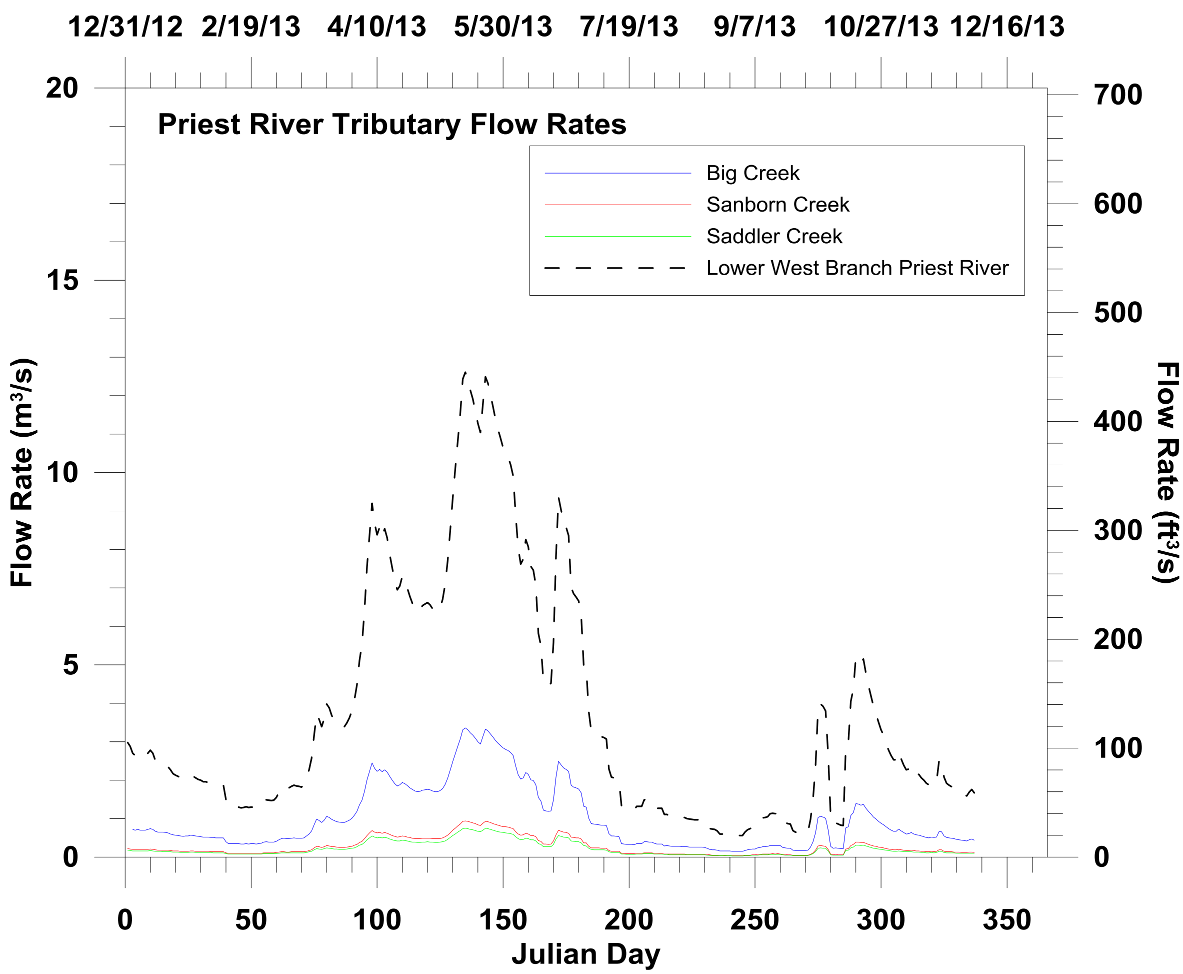

Figure 19: Estimated flow rates for Big Creek, Sanborn Creek, Saddler Creek and the Lower West Branch Priest River.

Distributed Tributary Flow Rates

Gains and losses due to groundwater flows and smaller tributaries were modeled as distributed tributaries for model branches 2 through 6. Flow rates were estimated using measured data, estimated tributary flow rates, and assuming the conservation of water volume. Un-gaged flows were divided between the five branches by using the fractional lineal distance along the river. This approach has been successfully applied in other modeling studies (Wells et al., 2003; Annear et al., 2003; Roberts et al., 2012). Branches 2 through 6 are located between the Priest River near Priest River, ID gaging station (USGS 12395000) and the Priest River near Coolin, ID station (USGS 12394000 or Kalispel Tribe site DICK1). The Priest River near Priest River, ID gage is located 3.4 miles upstream of the Pend Oreille River and the Priest River near Coolin, ID station is located approximately 4.3 miles below the outlet dam at Priest Lake. Flow rates of the distributed tributaries were estimated using the following equation:

$$Q_{dist} = \frac{L_{Br}}{L_{Tot}}\left(Q_{Pr} - Q_{DICK1} - Q_{EAR1} - Q_{LWB1} - Q_{QUA1} - Q_{BIG1} - Q_{SAD1} - Q_{SAB1} - Q_{UWB1}\right)$$

where,

Q_{dist} = Flow rate of distributed tributary, m^3/s

Q_{Pr} = Priest River near Priest River (USGS 12395000) flow rate, m^3/s

Q_{DICK1} = Priest River near Coolin (USGS 12394000 or Kalispel Tribe site DICK1) flow rate, m^3/s

Q_{EAR1} = East River flow rate, m^3/s

Q_{LWB1} = Lower West Branch Priest River flow rate, m^3/s
Q_{QUA1} = Quartz Creek flow rate, m^3/s
Q_{BIG1} = Big Creek flow rate, m^3/s
Q_{SAD1} = Saddler Creek flow rate, m^3/s
Q_{SAB1} = Sanborn Creek flow rate, m^3/s
Q_{UWB1} = Upper West Branch Priest River flow rate, m^3/s
L_{Br} = Branch length, m
L_{Tot} = Total reach length of model branches 2 thru 6, m

Continuous data were available from the Priest River near Priest River, ID gage for all of 2013. Continuous data from the Kalispel Tribe DICK1 station were available for parts of August-September, 2013 and flow rates for the rest of the year were estimated using a regression equation (Figure 16). Figure 20 shows the estimated distributed tributary flow rates. Negative flow rates, which occurred for a small fraction of the simulation period, represent a net loss to groundwater. Distributed tributary inflows/outflows were a small percentage of total river inflows, and contributed less than 10% of the flow rate measured at the Priest River near Priest River gage.

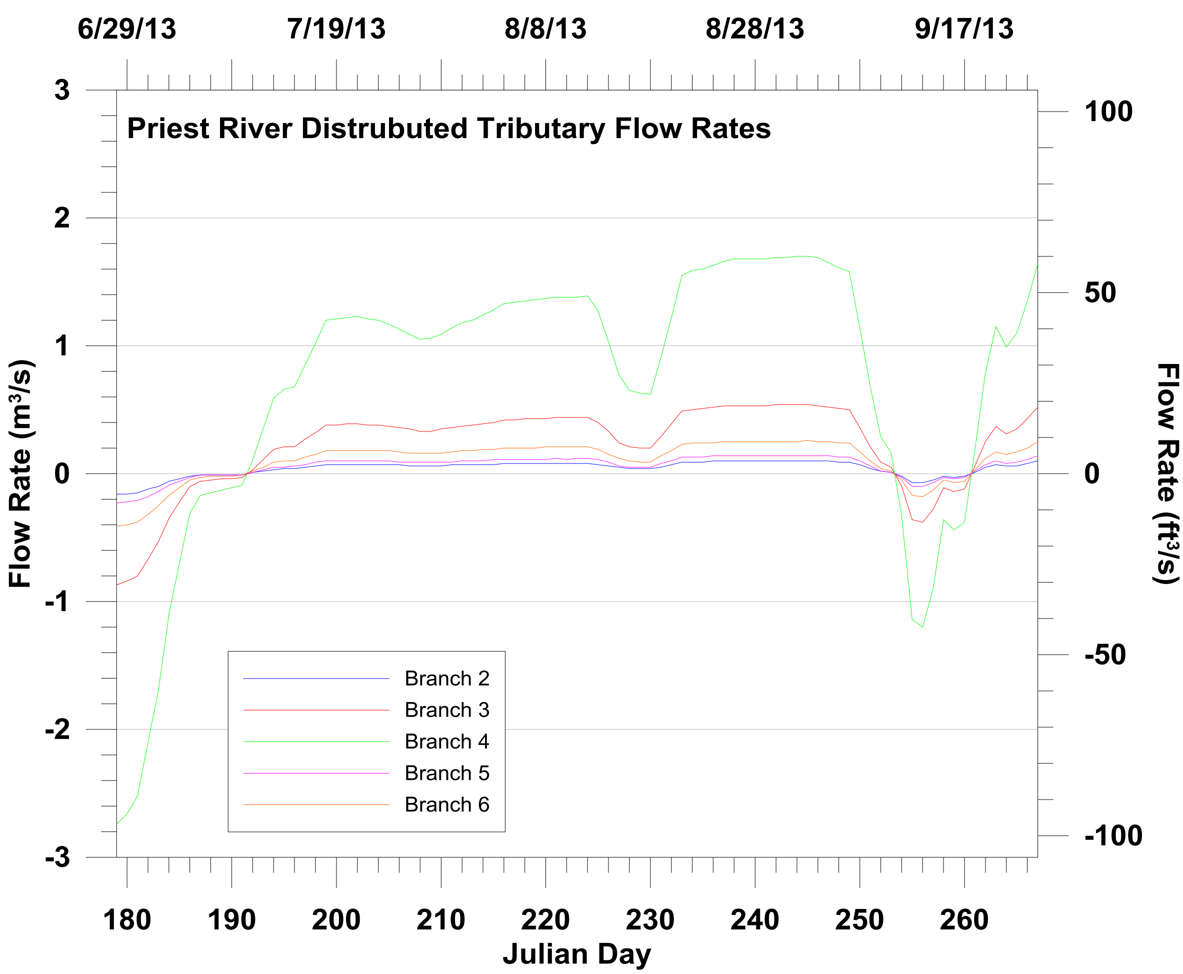

Figure 20: Estimated distributed tributary flow rates.

Inflow Temperatures

Continuous temperature data measured at Kalispel Site OUT1 were used for the upstream boundary condition. Site OUT1 is located immediately downstream of the Priest Lake Outlet dam. Temperature data were also available for Binarch Creek, East River, and the West Branch Priest River (Figure 21). Distributed tributary inflow temperatures were also developed from data measured at a nearby stream.

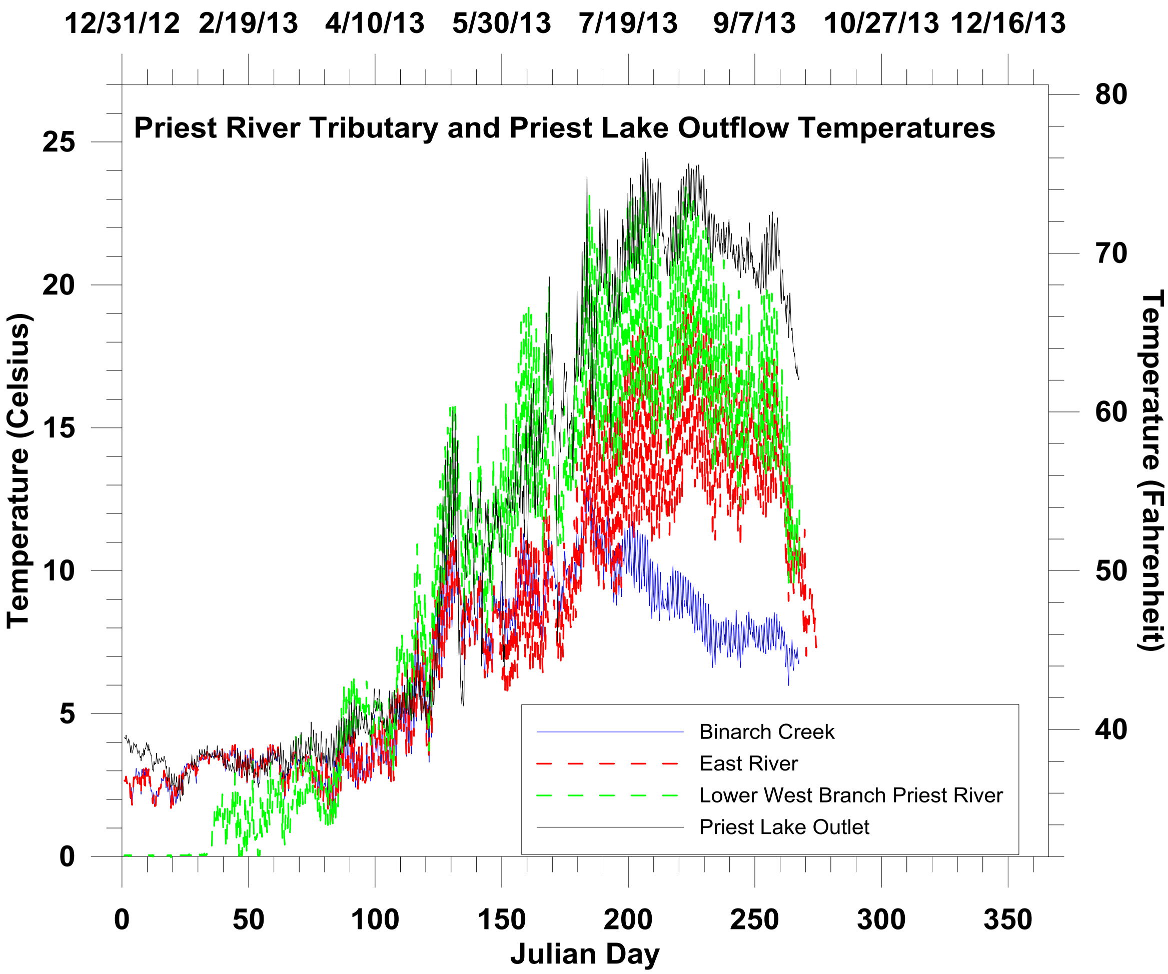

Figure 21: Inflow temperatures of the upstream boundary condition (Priest Lake Outlet), Binarch Creek, East River and the Lower West Branch Priest River.

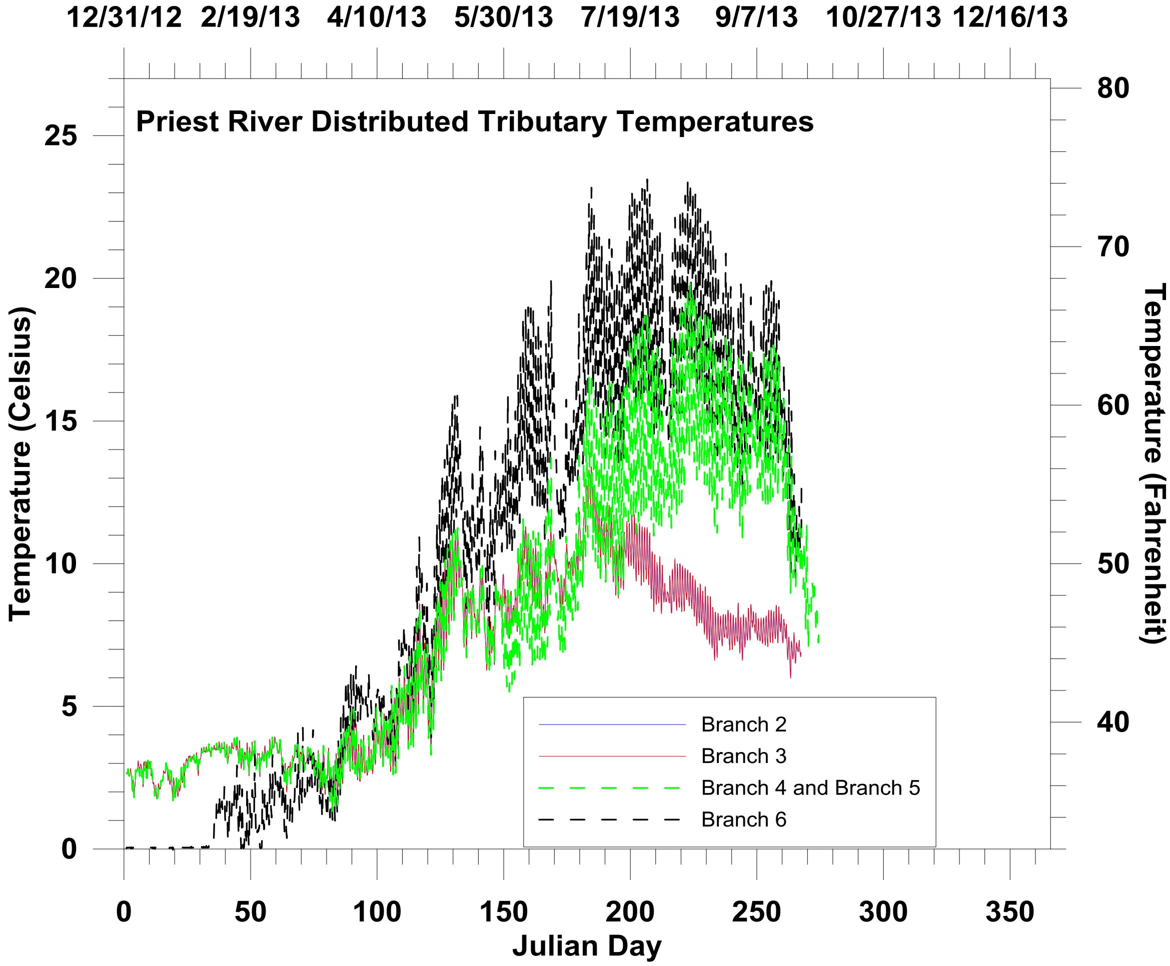

Figure 22: Priest River distributed tributary temperatures.

Calibration

The calibration period was from July 1, 2013 to September 24, 2013. The calibration consisted of evaluating model hydrodynamics (flow rate) first and then evaluating temperature. The data for calibrating the model consisted of continuous flow rate and temperature data. Figure 23 and Figure 24 show the location of the flow and temperature monitoring sites where data were used in the model calibration. Calibrated model parameters are shown in Table 6.

Figure 23: Priest River Calibration Sites (1).

Figure 24: Priest River Calibration Sites (2).

Table 6. W2 Model Water Quality Parameters.

Variable	Description	Units	Typical values*	Values
AX	Longitudinal eddy viscosity (for momentum dispersion)	m^2/sec	1	1
DX	Longitudinal eddy diffusivity (for dispersion of heat and constituents)	m^2/sec	1	1
CBHE	Coefficient of bottom heat exchange	Wm^2/sec	0.30	0.30
TSED	Sediment (ground) temperature	^oC		6.2
WSC	Wind sheltering coefficient		0.6-2.0	1.0-1.8
BETA	Fraction of incident solar radiation absorbed at the water surface		0.40	0.40
EXH20	Light Extinction	m^{-1}	0.2 - 4	0.25
* Cole and Wells (2013)				

Hydrodynamics

Table 7 lists the hydrodynamic monitoring sites, site descriptions, and the types of data monitored.

Table 7: Pend Oreille River, Box Canyon Reach water level and flow measurement sites.

Site ID	Site Name	Agency	Model Seg	RM	Data Types
USGS 12394000 or Kalispel Tribe DICK1	Priest River near Coolin, Idaho	USGS and Kalispel Tribe	25	39.6	Flow
USGS 12395500	Priest River near Priest River, Idaho	USGS	219	3.2	Flow

Data measured at the flow gaging stations USGS 12394000 (Kalispel Site DICK1) and USGS 12395500 were used for flow rate calibration. The model predicted flow rate errors are shown in Table 8. Comparisons between model predictions and data were shown in Figure 25 and Figure 26 for the 2 sites.

Table 8: Model error statistics for water levels measured at Cusick.

Site ID	Number of Comparisons	Mean Error, m^3/s	Mean Absolute Error, m^3/s	Root Mean Square Error, m^3/s
USGS 12394000 or Kalispel Tribe DICK1	458	-0.05	0.25	0.58
USGS 12395500	8161	0.07	1.18	1.89

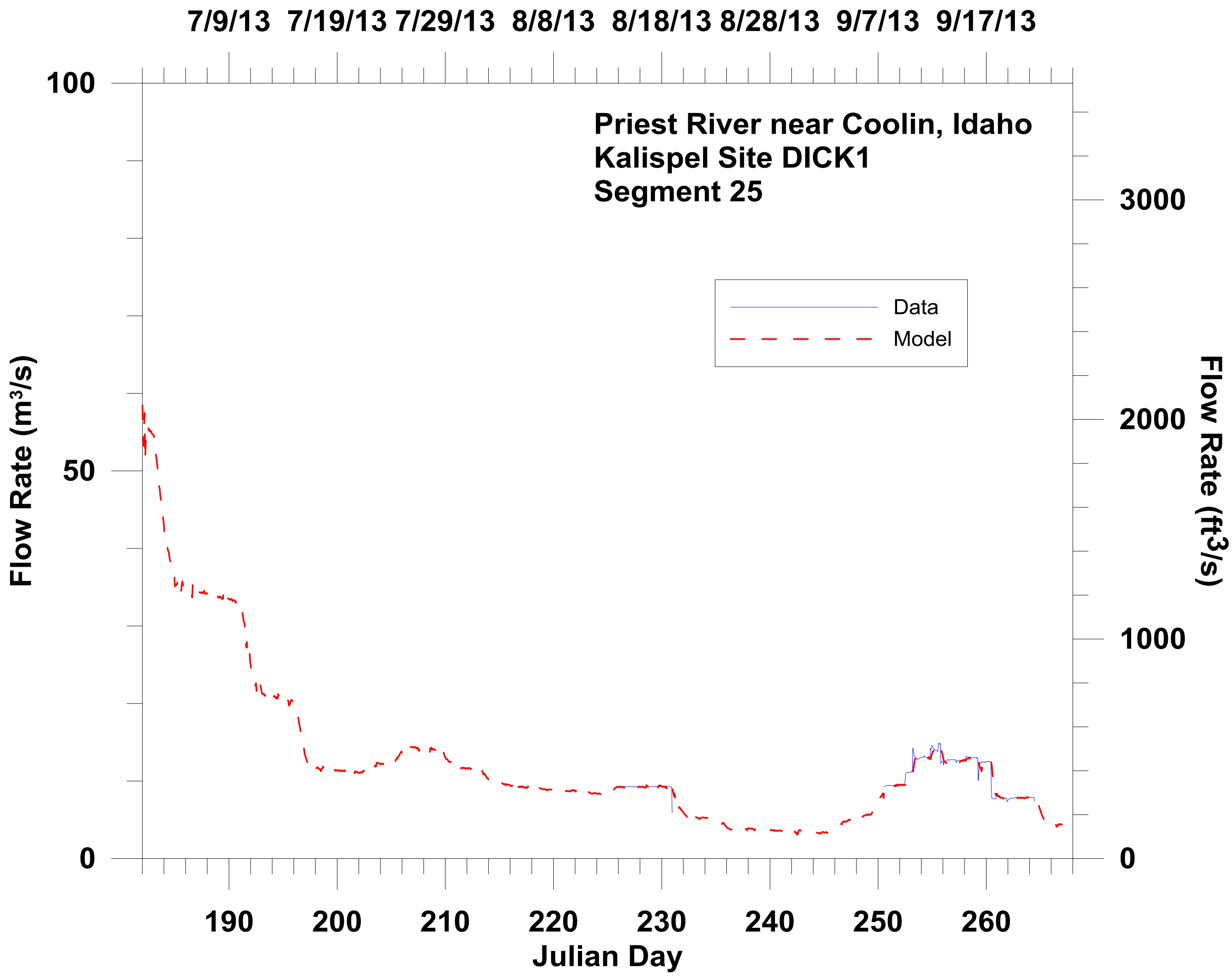

Figure 25: Flow data and predicted flow rates for the Priest River near Coolin, ID (DICK1) gaging station.

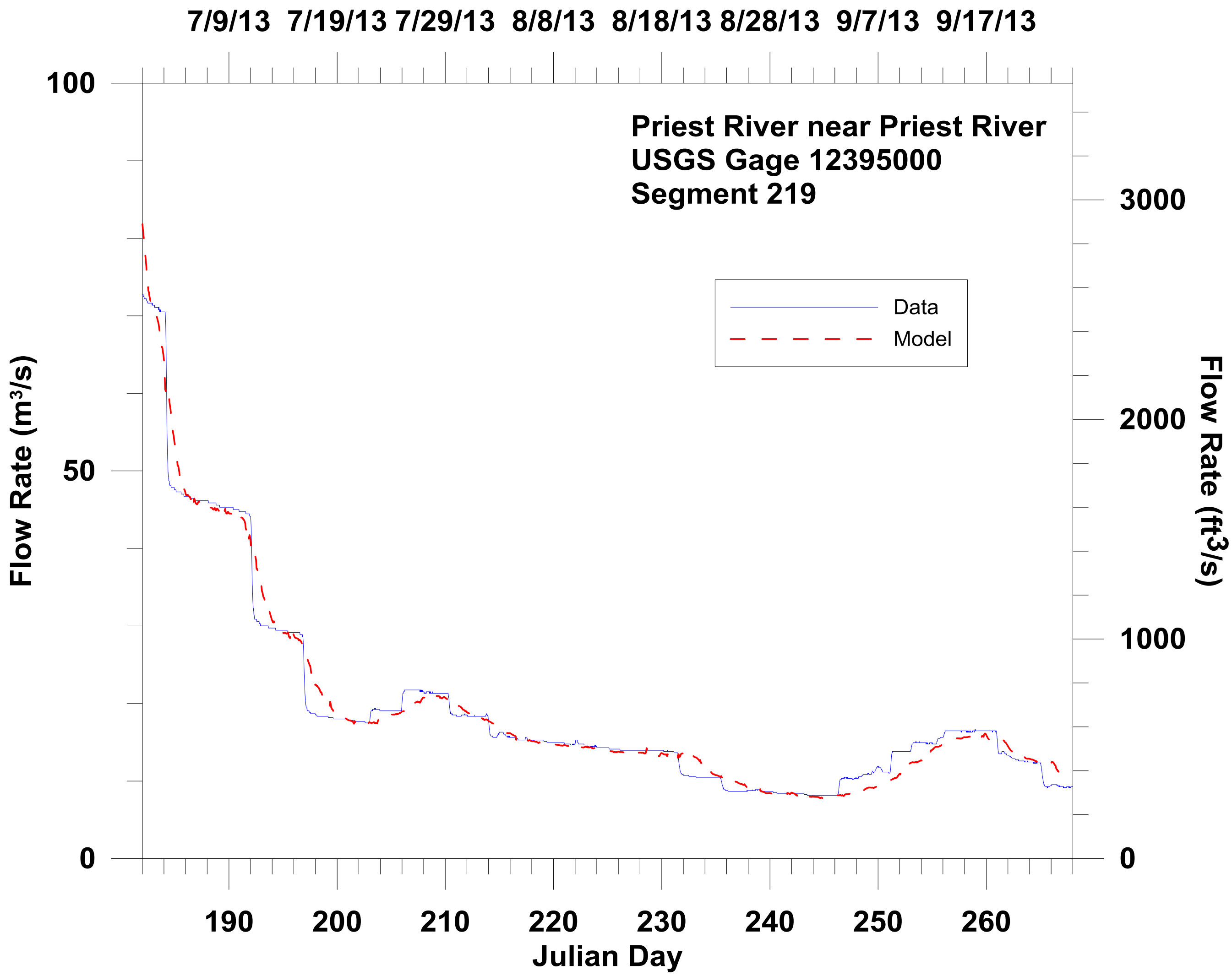

Figure 26: Flow data and predicted flow rates for the Priest River near Priest River, ID (USGS 12395500) gaging station.

Temperature

Table 9 lists the temperature monitoring sites used for temperature calibration.

Table 9: Priest River temperature calibration sites.

Site ID	Agency	Model Segment	RM
N21	Kalispel Tribe	3	43.5
N18	Kalispel Tribe	49	35.3
N23	Kalispel Tribe	52	34.9
N20	Kalispel Tribe	121	21.6
N3	Kalispel Tribe	123	21.3
N22	Kalispel Tribe	191	8.6
N19	Kalispel Tribe	216	4.1

Error statistics for continuous recorded data are shown in Table 10. The average mean absolute error of the continuous data was 0.70 °C. Average mean error for was 0.02 °C. Plots of model temperature predictions and data are shown in Figure 35 through Figure 41 in the Appendix B.

Table 10: Model error temperature statistics.

Site ID	Model Segment	Number of Comparisons	Mean Error, °C	Mean Absolute Error, °C	Root Mean Square Error, °C
N21	3	2032	0.07	0.14	0.19
N18	49	2040	0.05	0.76	0.97
N23	52	2040	0.12	0.98	1.21
N20	121	2040	0.30	0.78	0.96
N3	123	1536	0.10	0.56	0.74
N22	191	1456	-0.66	0.92	1.12
N19	216	2040	0.16	0.76	0.96
Average			0.02	0.70	0.88

Scenarios

Two sets of scenarios were simulated, one set assuming 8° C hypolimnetic temperatures in Priest Lake and another set assuming 10° C temperatures. Upstream inflows (Priest Lake outflows) were assumed to consist of 25%, 50%, and 75% of hypolimnetic water. Scenarios were compared with an existing conditions simulation. Hypolimnetic water was used in Priest Lake outflows between July 1 and September 24.

The assumption of 8° C and 10° C hypolimnetic temperatures seems reasonable given lake temperature data gathered in 1994 and 1995 (Rothrock and Mosier, 1997). The isotherms show that the thermocline is at a depth between 10 and 20 m and water temperatures in the hypolimnion are mostly below 8° C.

Average August and September temperatures during 2013 for the scenarios using 8° C hypolimnetic temperatures are shown in Figure 28 and Figure 29, respectively. Figure 30 and Figure 31 show temperatures for August and September, 2013 with 10° C hypolimnetic temperatures. As shown in the figures, there is natural cooling during this time period of the warm epilimnetic water leaving Priest Lake. River temperatures are cooled several degrees Celsius by including hypolimnetic water in the Priest Lake outflows. The temperature benefits extend all the way down to the river's mouth at the Pend Oreille River.

The total amount of hypolimnetic water used by the scenarios is shown in Figure 32. Also shown is the volume of the hypolimnion assuming a thermocline depth in Priest Lake of 15 m, which is equivalent to a thermocline elevation of 728 m. The Priest Lake volume-elevation curve is shown in Figure 33. The amount of cold water from the hypolimnion that was diverted during a single year was a fraction of the total hypolimnetic water in Priest Lake. Figure 34 shows the flow rate from the hypolimnion.

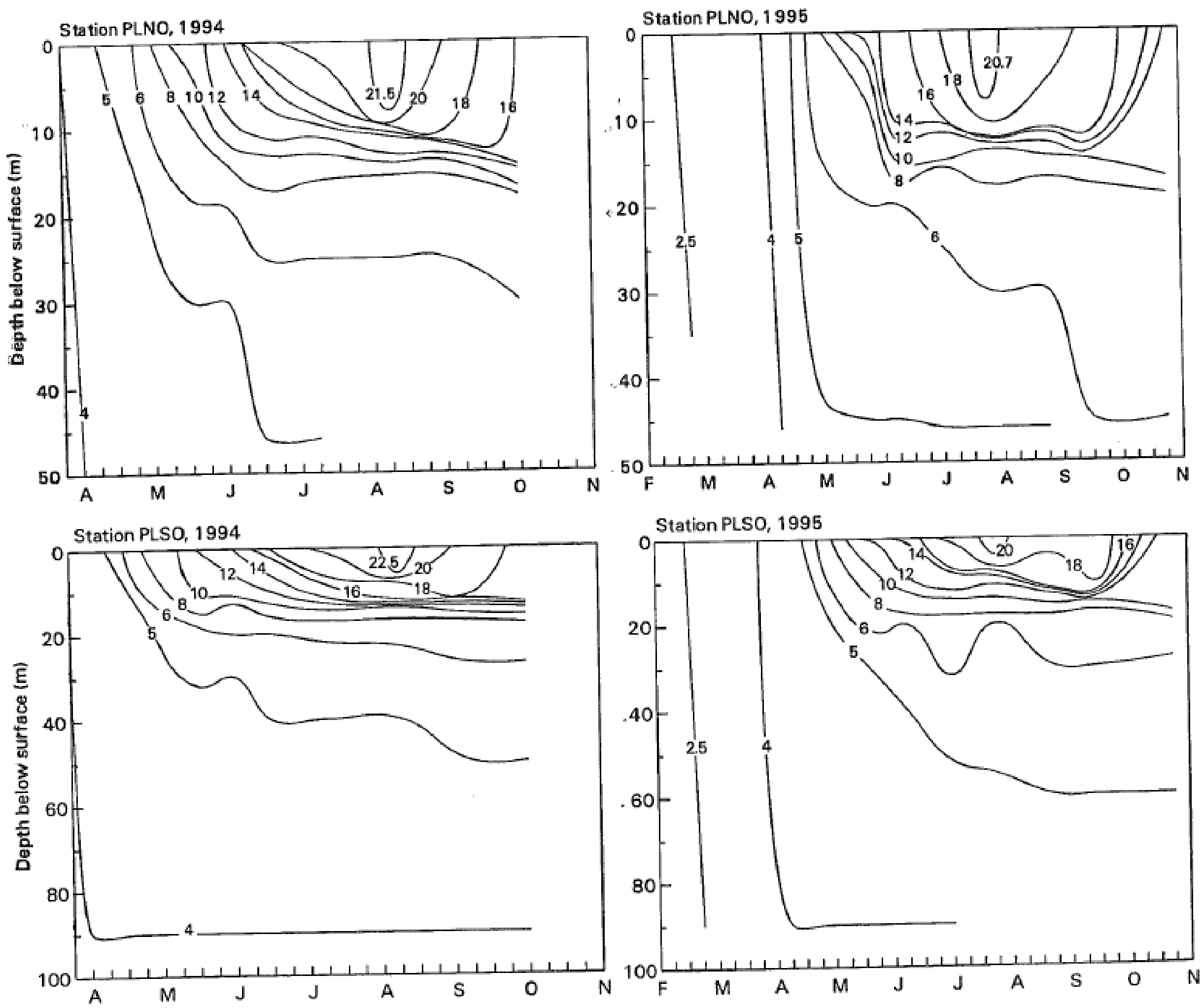

Figure 27. Priest Lake depth-time isotherms measured between October, 1994 and 1995 (Rothrock and Mosier, 1997). Station PLNO is in northern Priest Lake and and station PLSO is located in southern Priest Lake.

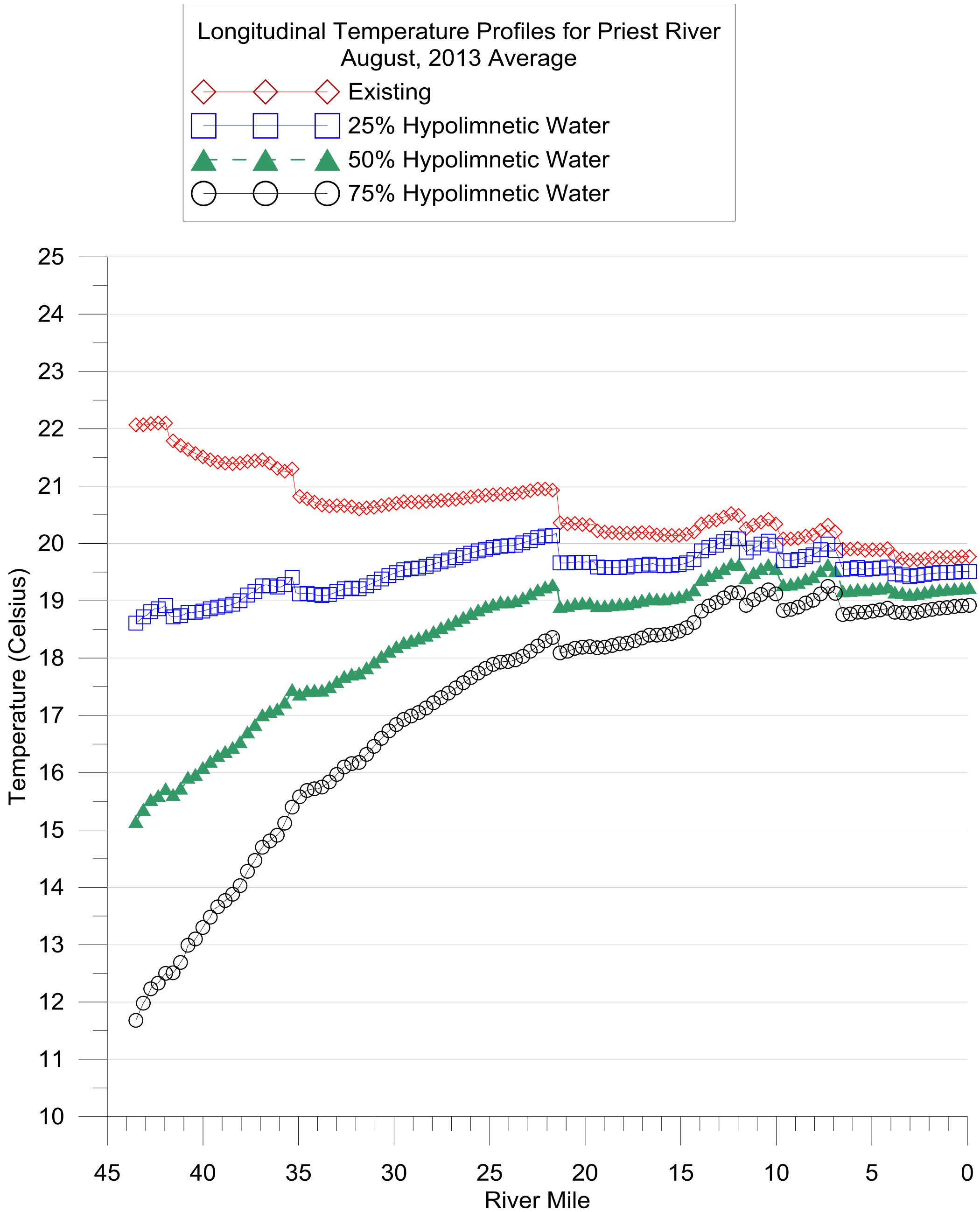

Figure 28. Longitudinal profiles of August, 2013 average temperatures for Priest River using 8° Celsius hypolimnetic temperatures.

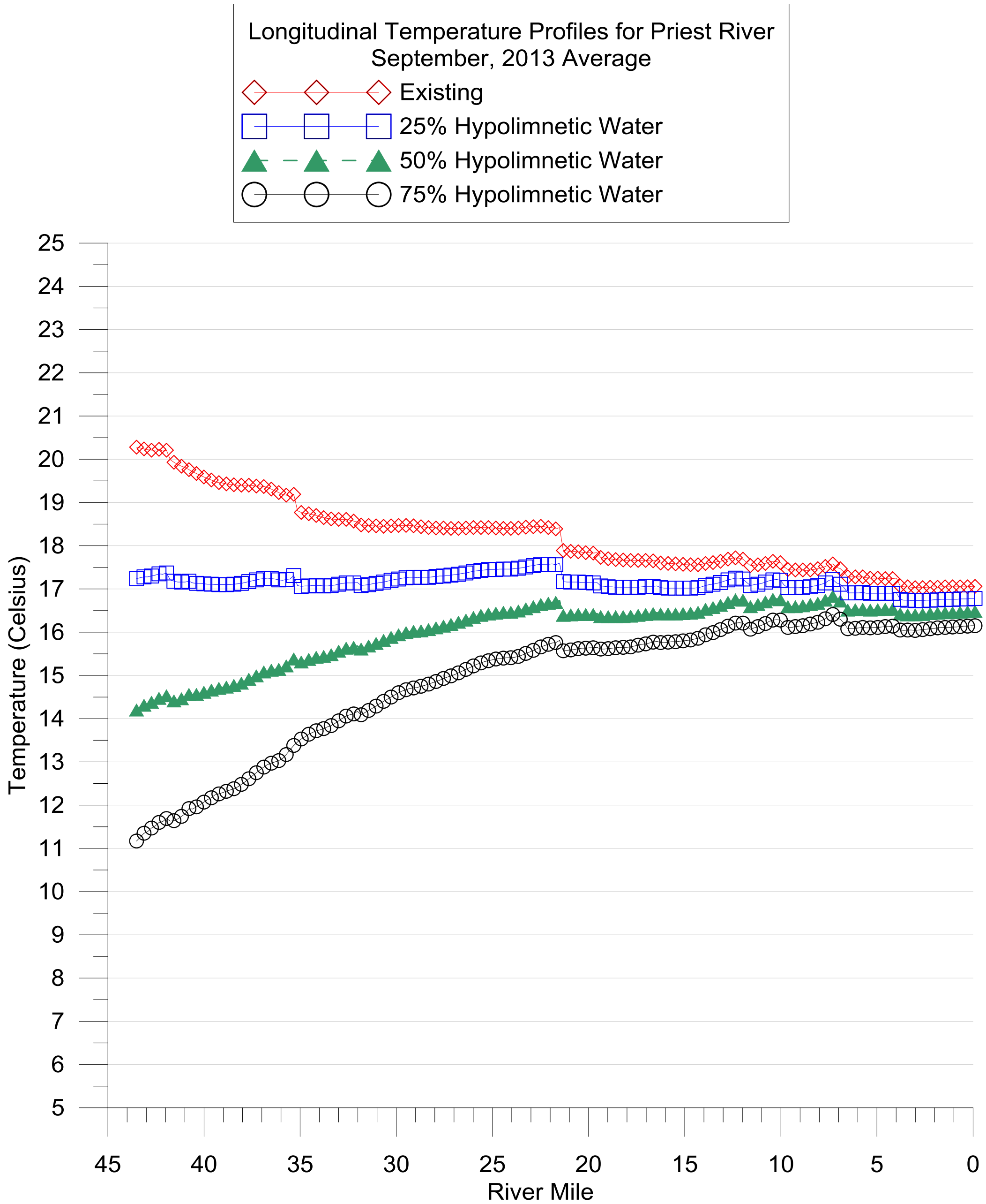

Figure 29. Longitudinal profiles of September, 2013 average temperatures for Priest River using 8° Celsius hypolimnetic temperatures.

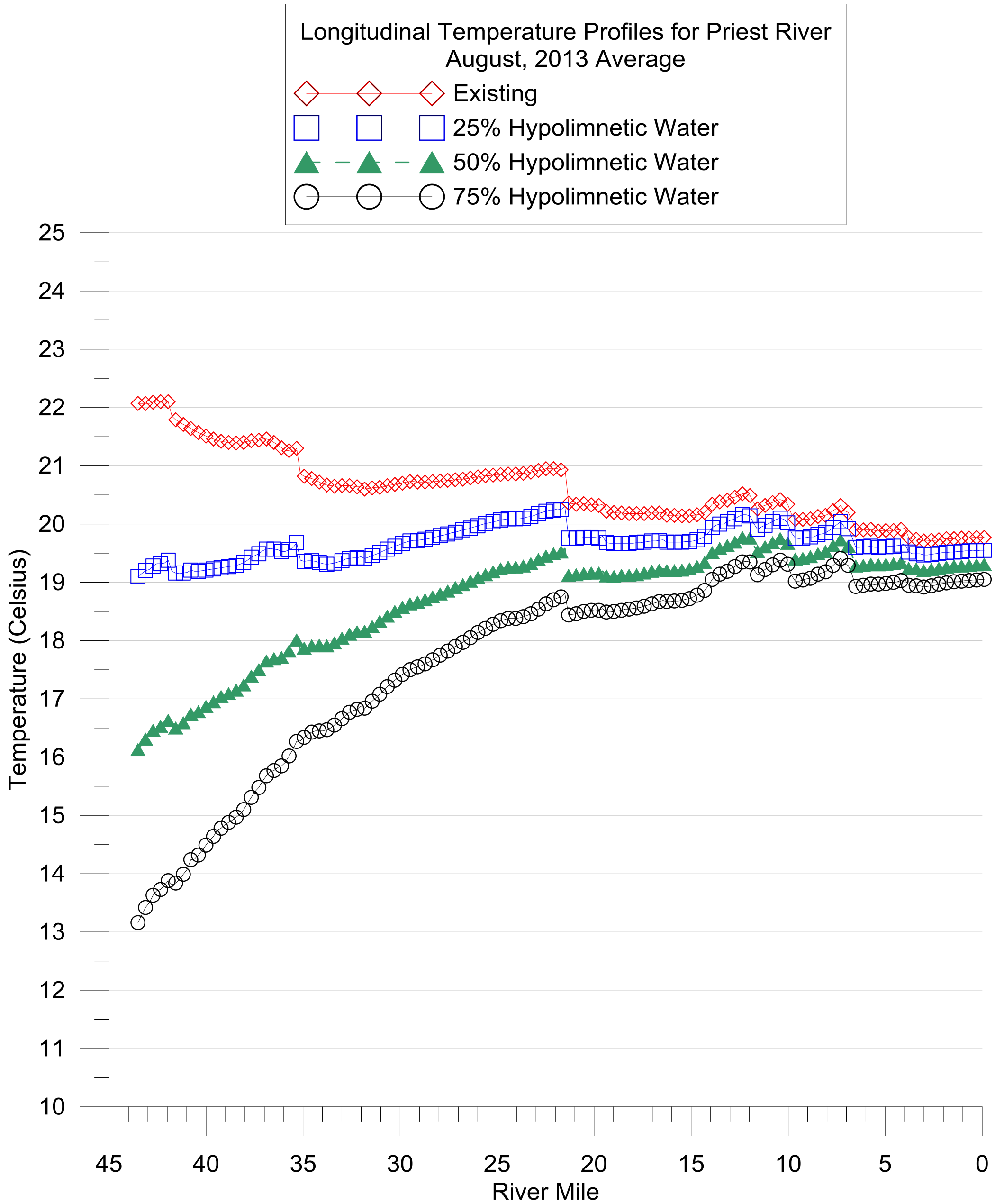

Figure 30. Longitudinal profiles of August, 2013 average temperatures for Priest River using 10° Celsius hypolimnetic temperatures.

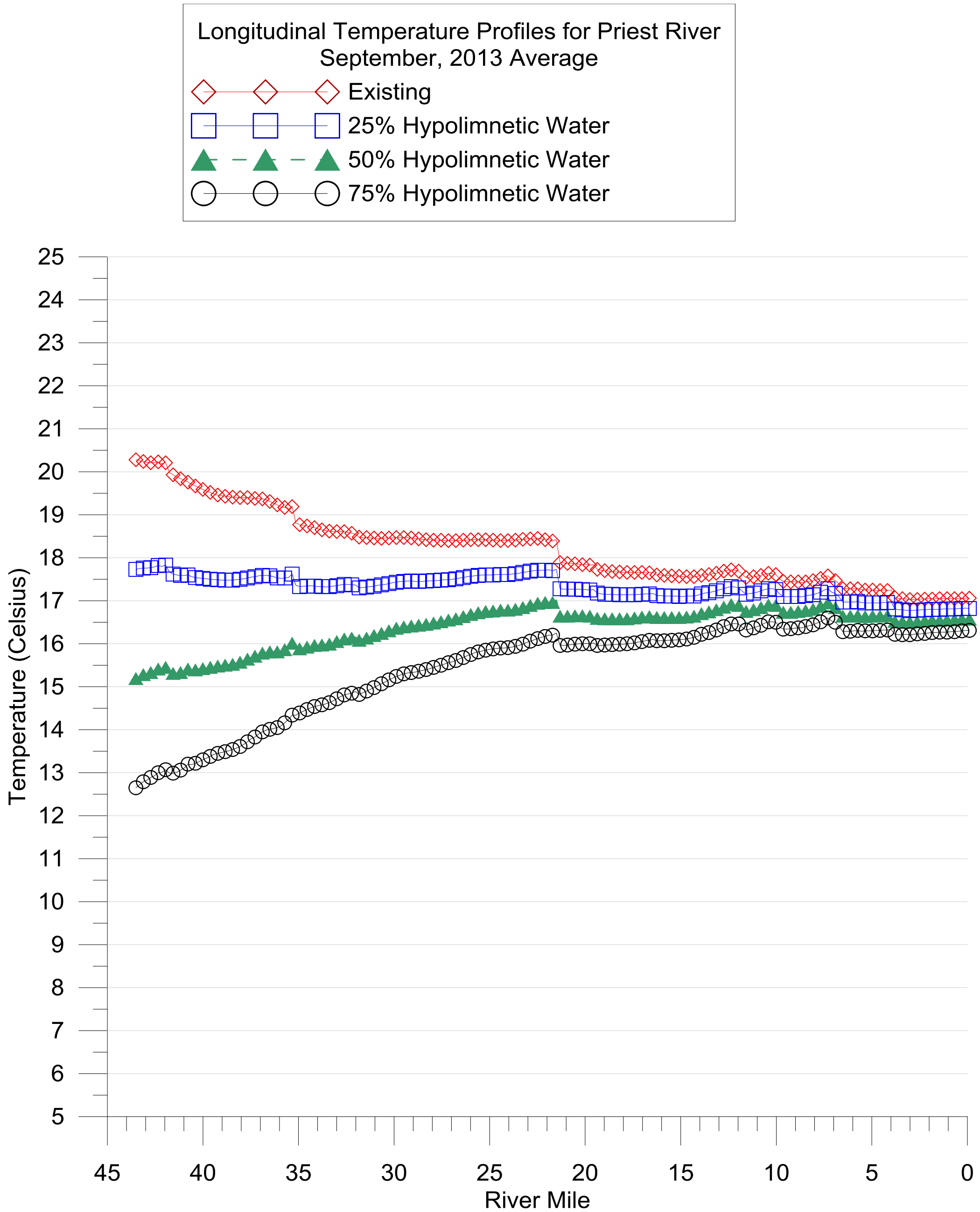

Figure 31. Longitudinal profiles of September, 2013 average temperatures for Priest River using 10° Celsius hypolimnetic temperatures.

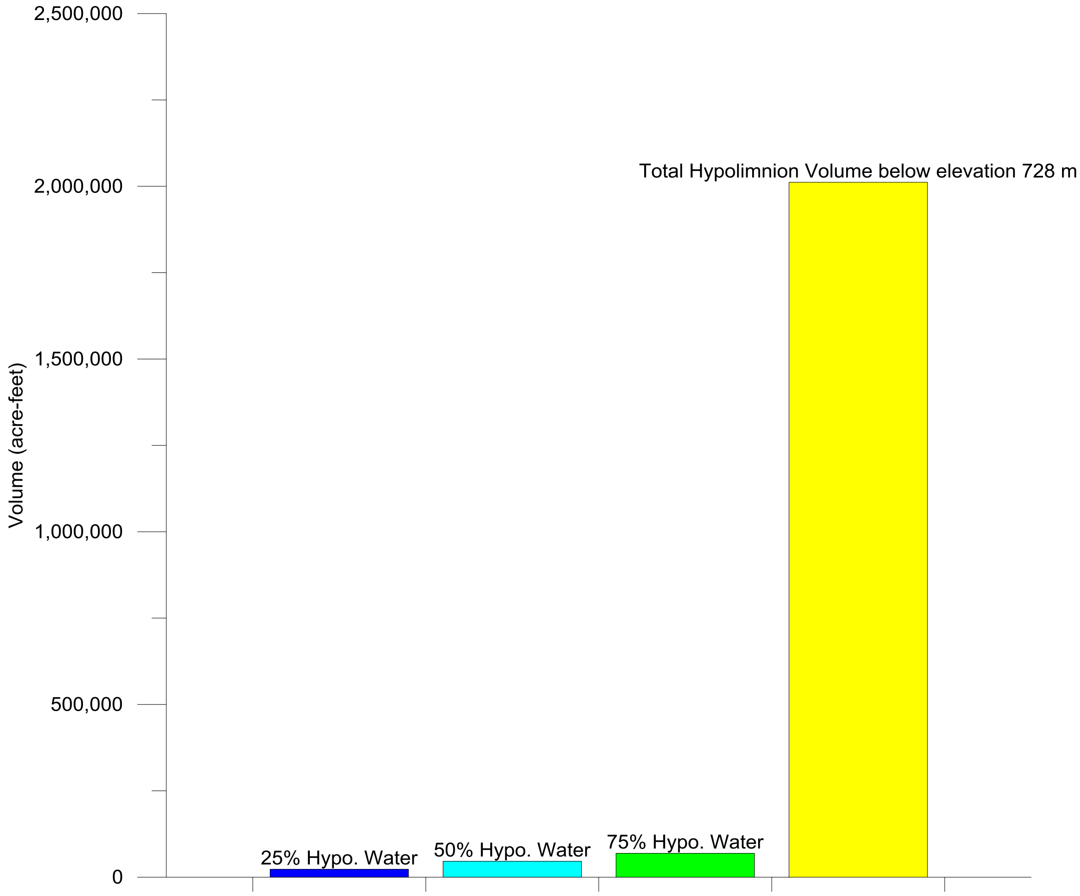

Figure 32. The total volume of hypolimnetic water used for the scenarios compared with the amount of hypolimnetic water in Priest Lake below elevation 728 m. Hypolimnetic water was only used in Priest Lake outflows between July 1 and September 24. Although the amount of hypolimnetic water in Priest Lake outflows varied, the total flow into the river remained the same as existing conditions. Priest Lake water levels remain unchanged.

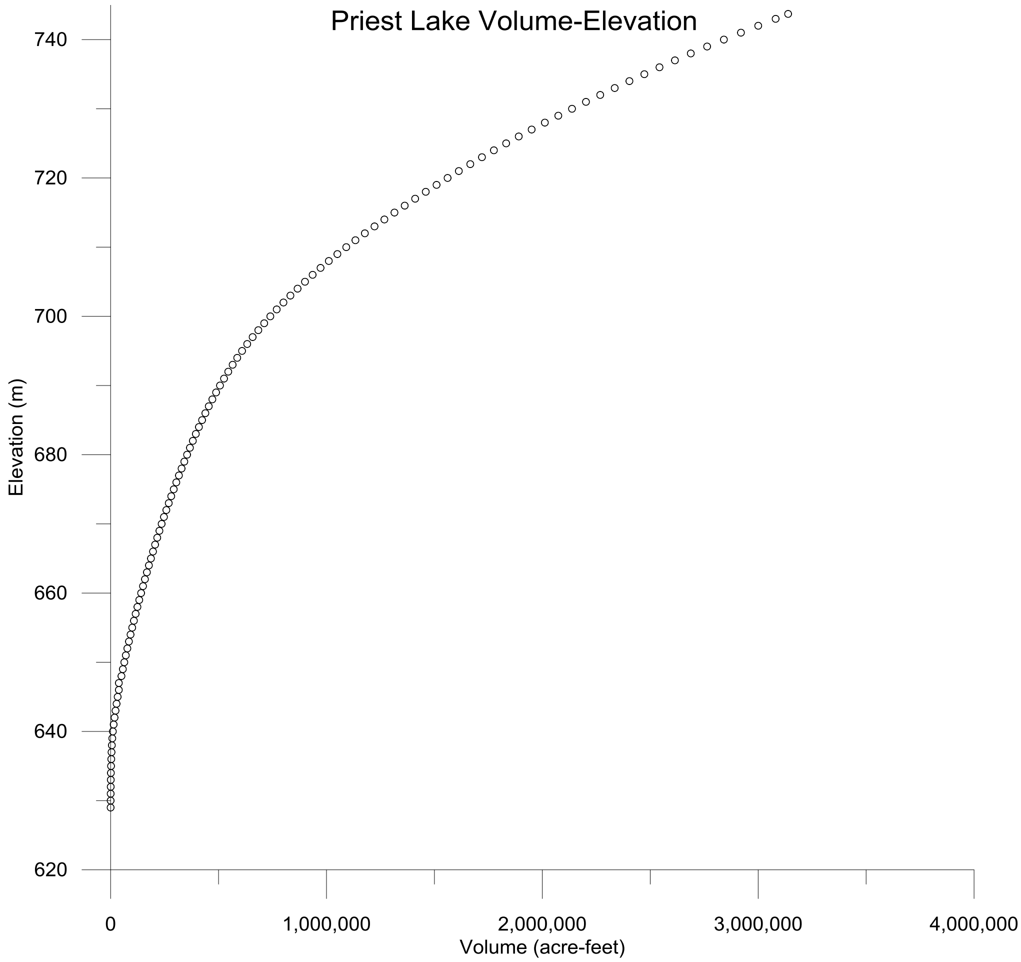

Figure 33. Priest Lake volume-elevation curve.

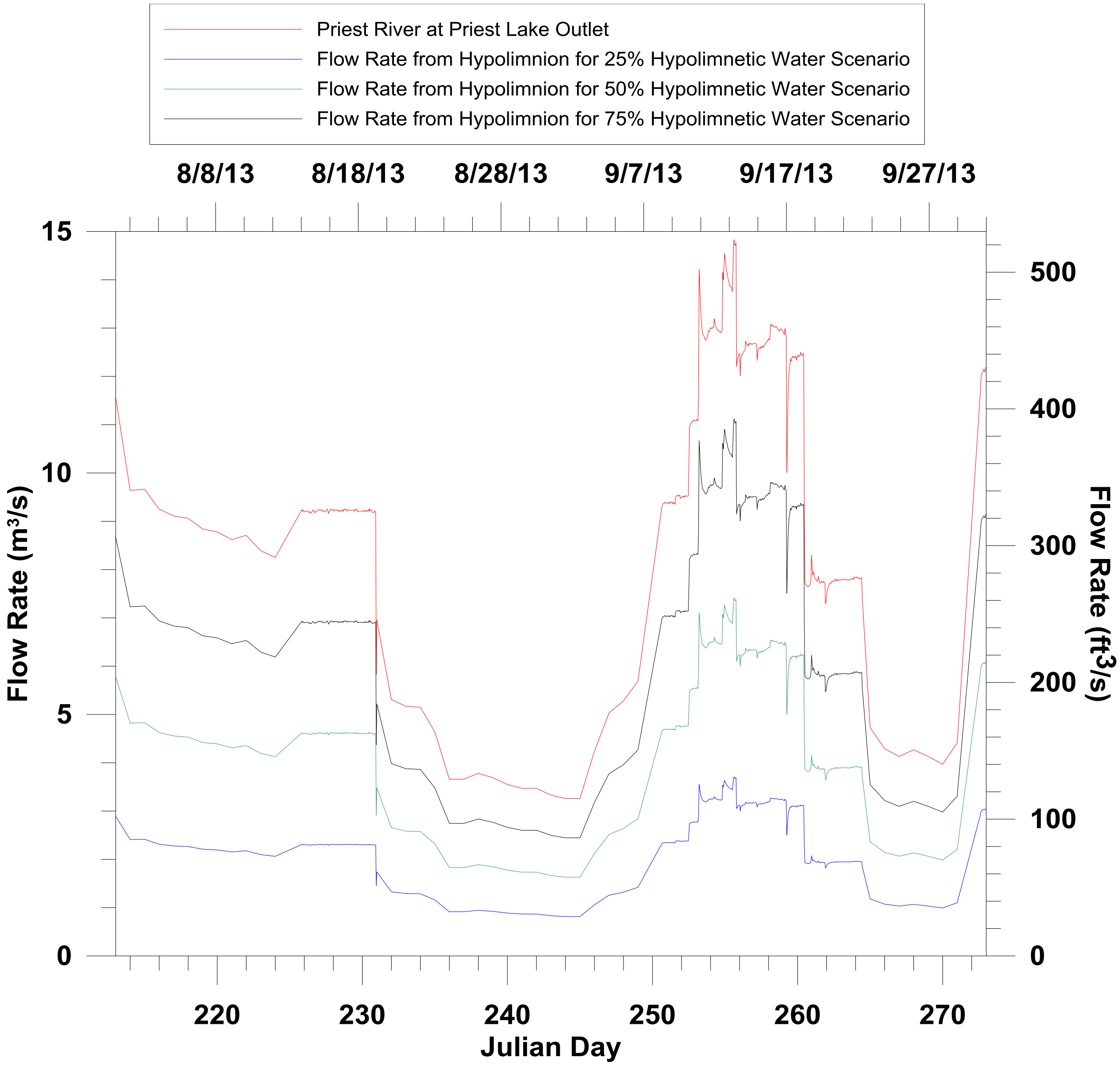

Figure 34. Flow rate from the hypolimnion for the scenaroios. The flow rate of the Priest River at the Priest Lake Outlet is also shown for comparison.

Summary

A water quality and hydrodynamic model, CE-QUAL-W2 Version 3.71 (Cole and Wells, 2013; http://www.cee.pdx.edu/w2), was applied to the Priest River, Idaho. This report summarized model development, calibration and scenario simulation.

The following tasks were completed:

- Creating flow, temperature, meteorological and bathymetric input files
- Calibrated the model for flow and temperature
- Created and ran scenarios where hypolimnetic water from Priest Lake were included in upstream inflows

The model calibration was calibrated to the period between July 1 and September 24, 2013, using flow and temperature field data. The mean absolute error of the continuous temperature data was 0.70 °C. The mean error was 0.02 °C.

Scenarios were run assuming the diversion of 8 °C or 10 °C hypolimnetic water from Priest Lake. Simulations with 25%, 50%, and 75% hypolimnetic water in Priest Lake outflows were modeled. Total outflows from Priest Lake were unchanged relative to measured flow rates, and only the percentage of hypolimnetic water used for lake outflows was varied. Priest Lake water levels would remain unaltered. The amount of cold water from the hypolimnion that was diverted was a small fraction of the total hypolimnetic water available in Priest Lake.

Scenarios predicted decreased water temperatures of several degrees Celsius immediately downstream of the Priest Lake outlet. As expected the temperature benefit of using hypolimnetic water decreased moving downstream, but was still up to a degree Celsius near the mouth at the Pend Oreille River.

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Appendix A

Tributary flow rates were estimated by Kalispel Tribe (Berntsen, 2014) using the methodology described below:

To generate daily discharge estimates for major ungaged Priest River tributaries, a regionalized duration curve method based on bankfull discharge and daily discharge data from USGS Gage 12395000 (Priest River near Priest River, Idaho) was used. Leopold (1994) suggested using the ratio of discharge to bankfull discharge (Q/Q_b) as a dimensionless discharge index to transfer a flow-duration relationship to an ungaged site from a nearby gaged site. For ungaged sites, the bankfull discharge may be estimated from regionalized discharge frequency relationships. In north Idaho, bankfull discharge can be approximated by the 1.5 year frequency discharge (Castro 1997).

To transfer the flow-duration relationship from Priest River to the ungaged tributaries, the following steps were used:

The 2013 daily discharge data from USGS Gage 12395000 were divided by the bankfull discharge (5,813 cfs). This created a dimensionless flow duration curve.

The 1.5 year frequency discharge ($Q_{1.5}$) was computed for each ungaged site using the following regression equation from Hortness and Berenbrock (2004):

$$Q_{1.5} = 0.748\ DA^{0.802}\ (E/1{,}000)^{3.28}\ (F + 1)^{-0.283}$$

Where DA = Drainage area (square miles)
E = Mean basin elevation (feet)
F = Percentage of forest cover in the basin

DA, E, and F were all derived using a geographic information system (GIS).

Daily discharge estimates for each ungaged tributary were calculated by multiplying the dimensionless flow duration curve from Step 1 by the associated ungaged $Q_{1.5}$.

There were limited instantaneous flow data available in 2013 for Binarch Creek, Lower West Branch Priest River, East River and Upper West Branch Priest River. Error statistics for the tributary flow estimates are listed in Table 11.

Table 11. Error statistics for tributary flow measurements.

	Binarch Creek	LWB Priest River	East River	UWB Priest River
# of Measurements	5	4	4	3
Mean Error (cms)	0.45	3.55	2.14	0.60
Mean Absolute Error (cms)	0.45	3.55	2.14	1.03
RMS Error (cms)	0.67	5.10	3.03	1.29

References:

Berntsen, Eric. 2014. Kalispel Tribe. Personal communication and write-up.

Castro, J.M. 1997. Stream classification in the Pacific Northwest: methodologies, regional analyses, and applications. PhD. dissertation, Oregon State University. 115 pp.

Hortness, J.E., and C. Berenbrock. 2004. Estimating the magnitude of bankfull flows for streams in Idaho: U.S. Geological Survey Water-Resources Investigations Report 03–4261. 37 pp.

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Appendix B

Model-data comparisons of temperature predictions are shown in Figure 35 through Figure 41.

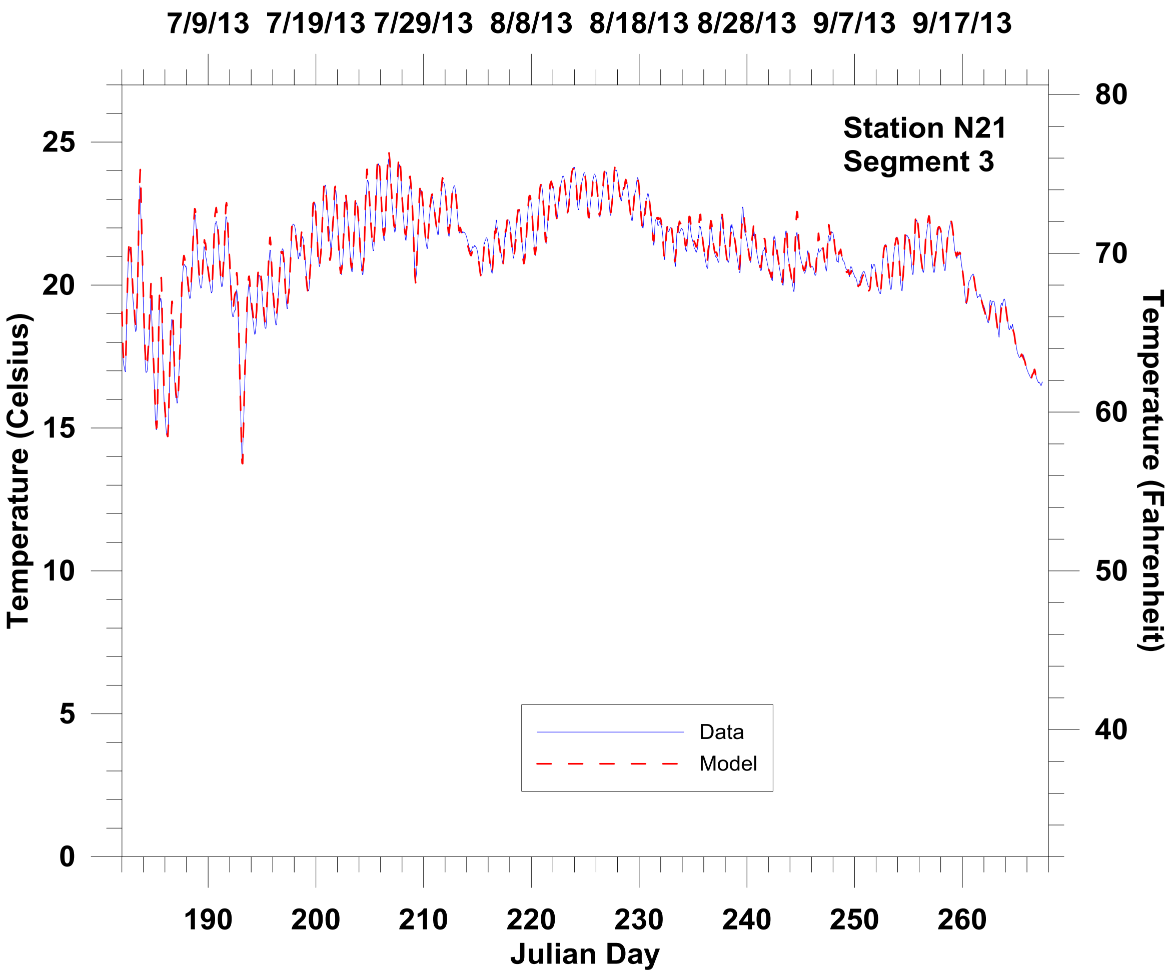

Figure 35: Model-data comparison of temperature predictions at Kalispel site N21.

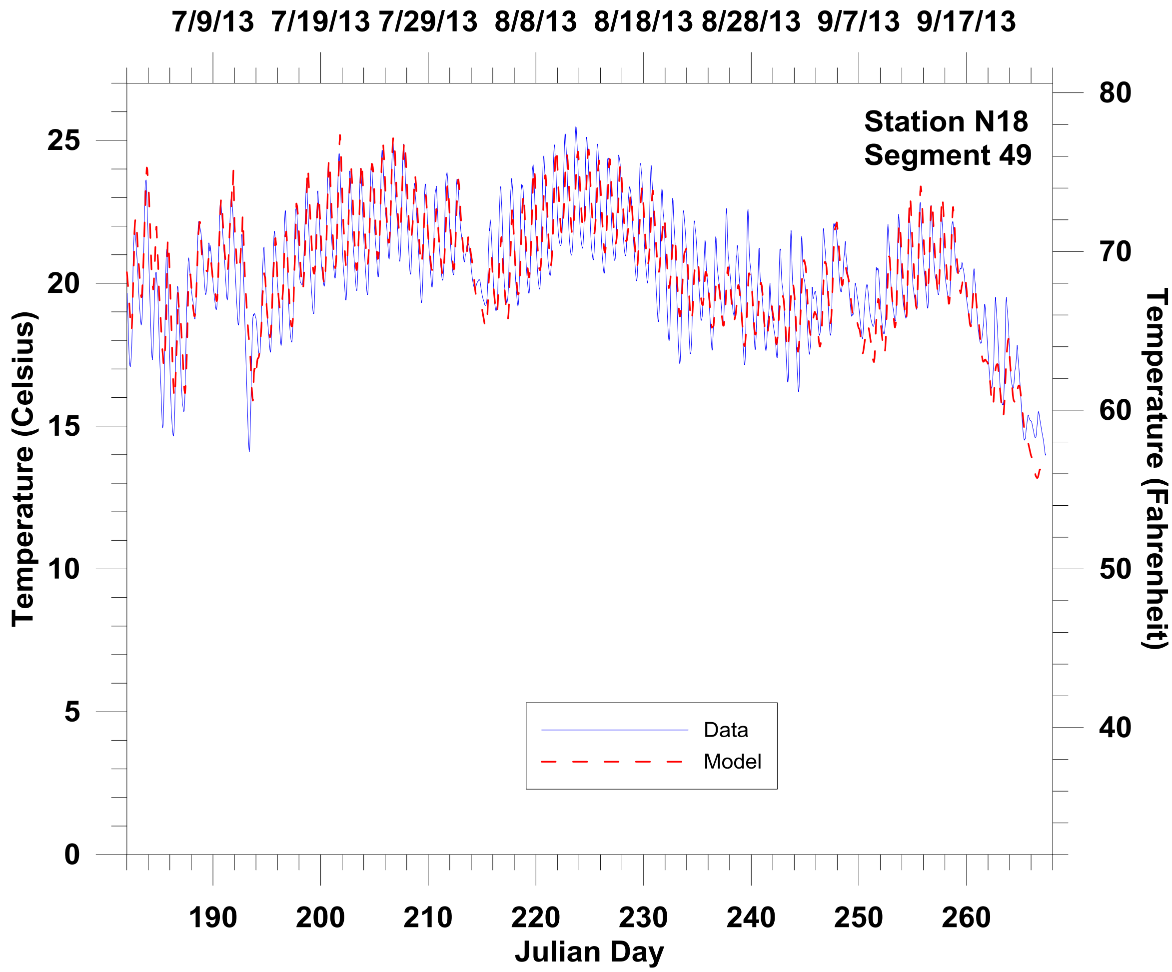

Figure 36: Model-data comparison of temperature predictions at Kalispel site N18.

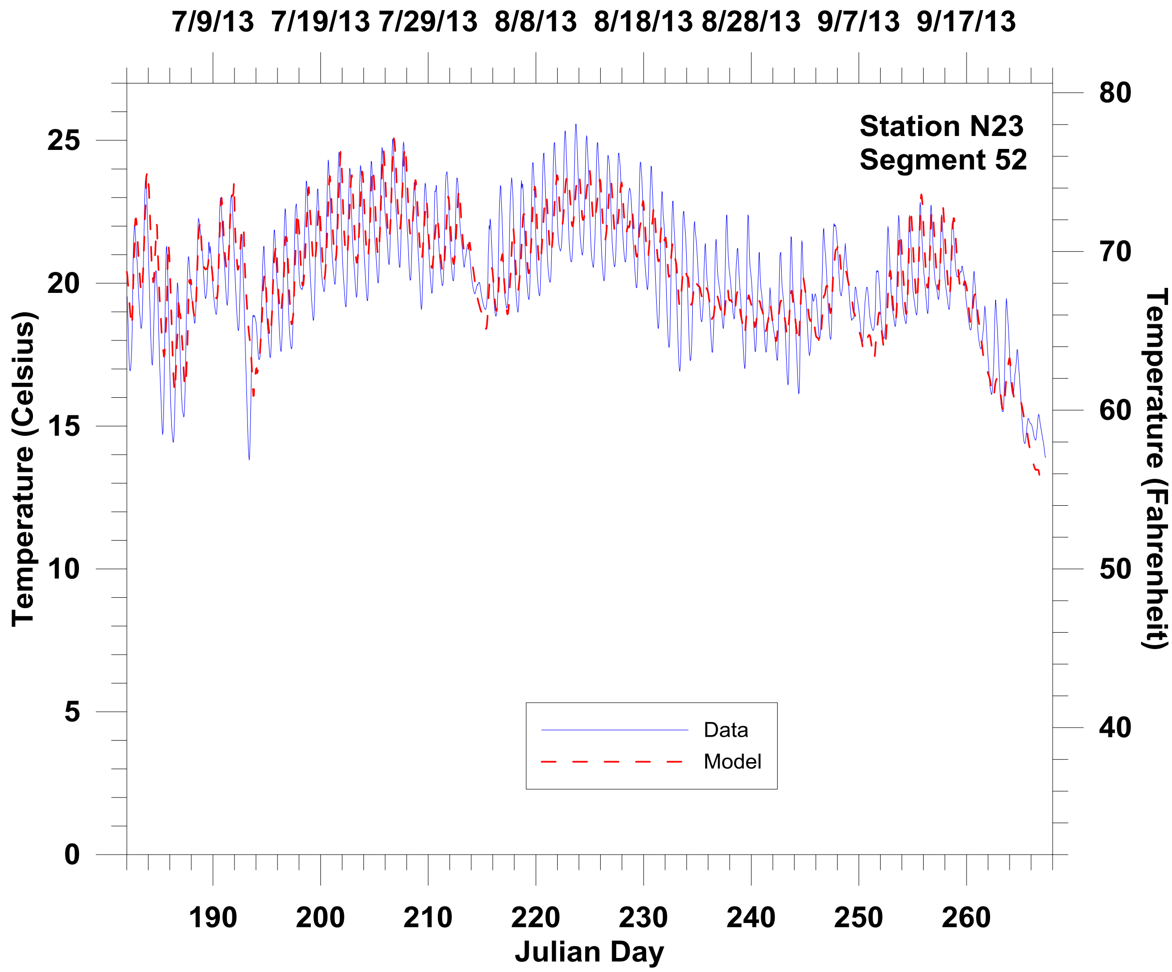

Figure 37: Model-data comparison of temperature predictions at Kalispel site N23.

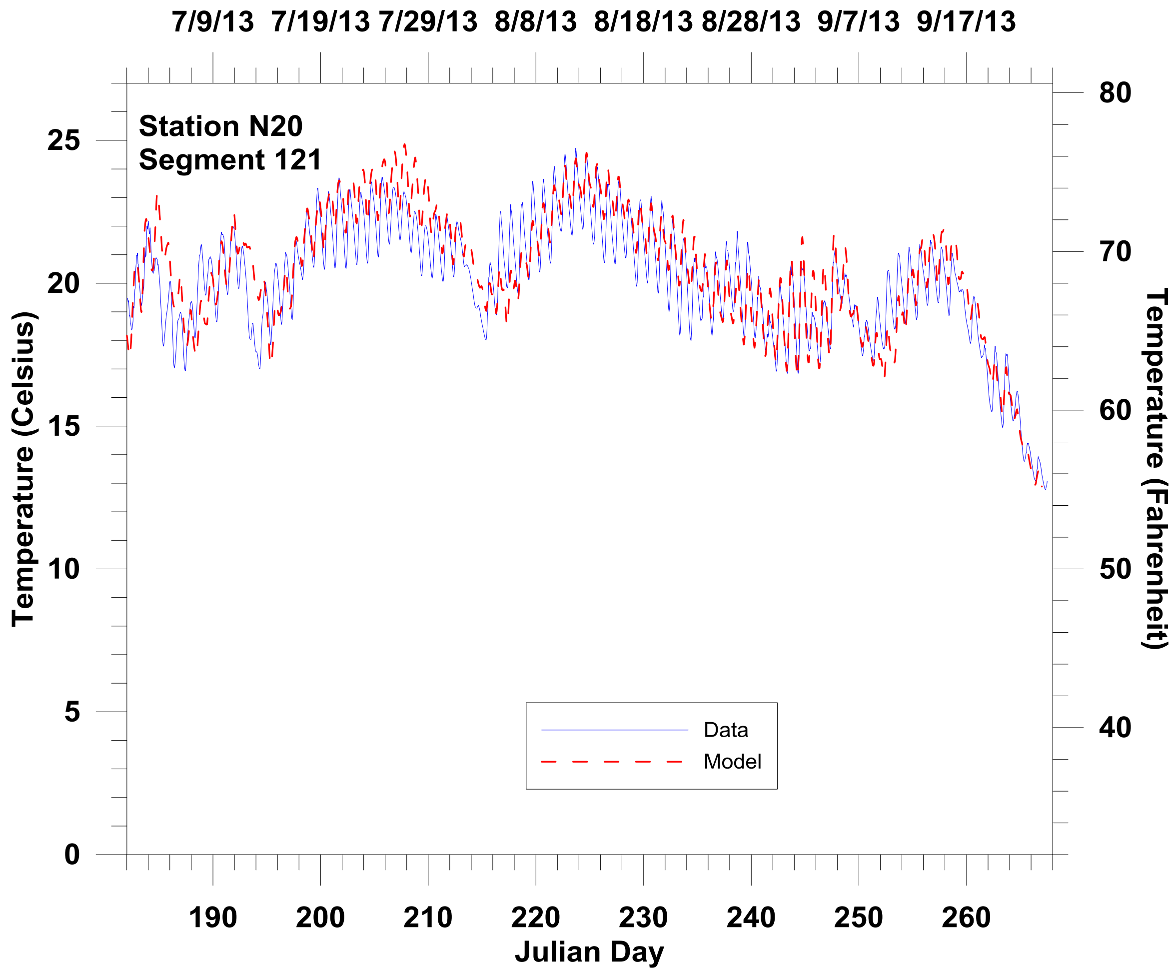

Figure 38: Model-data comparison of temperature predictions at Kalispel site N20.

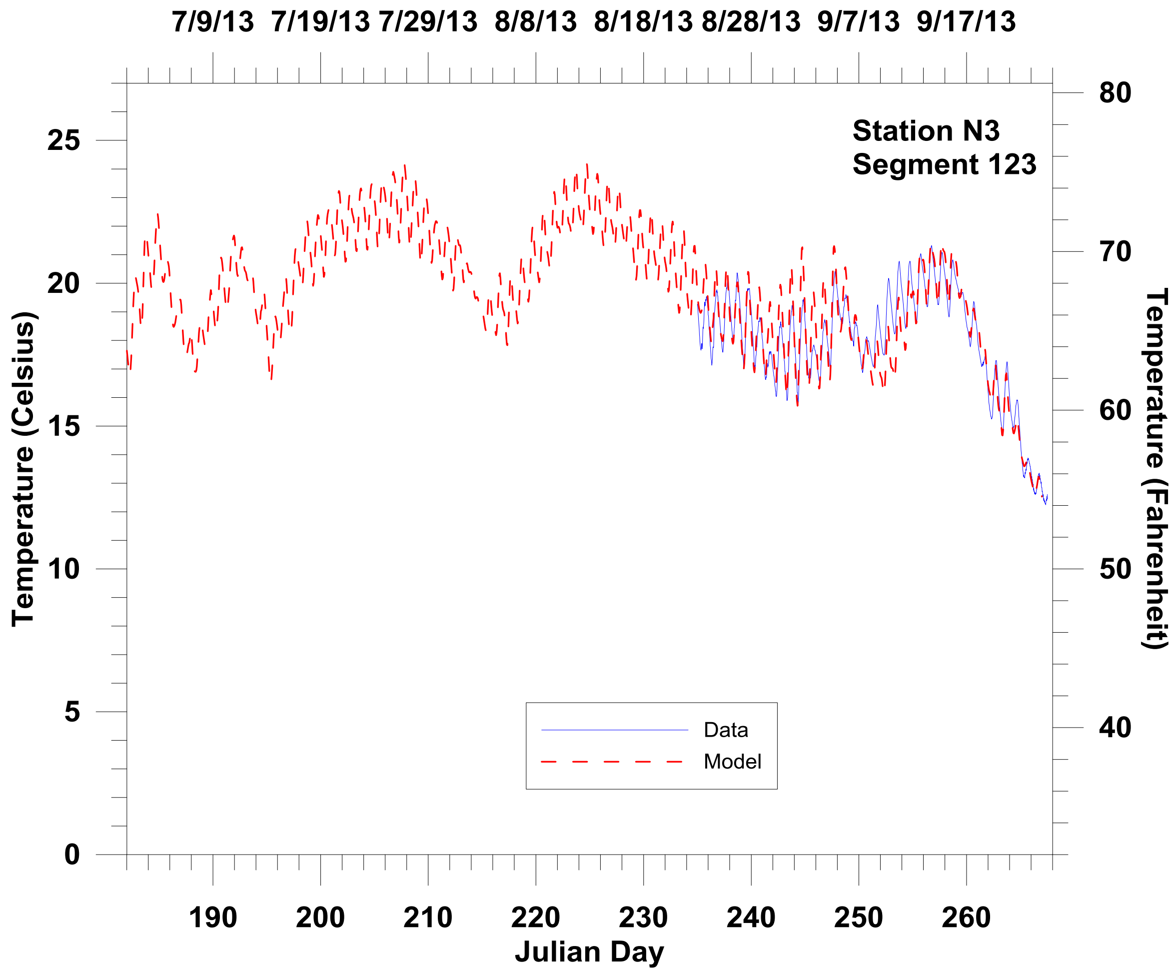

Figure 39: Model-data comparison of temperature predictions at Kalispel site N3.

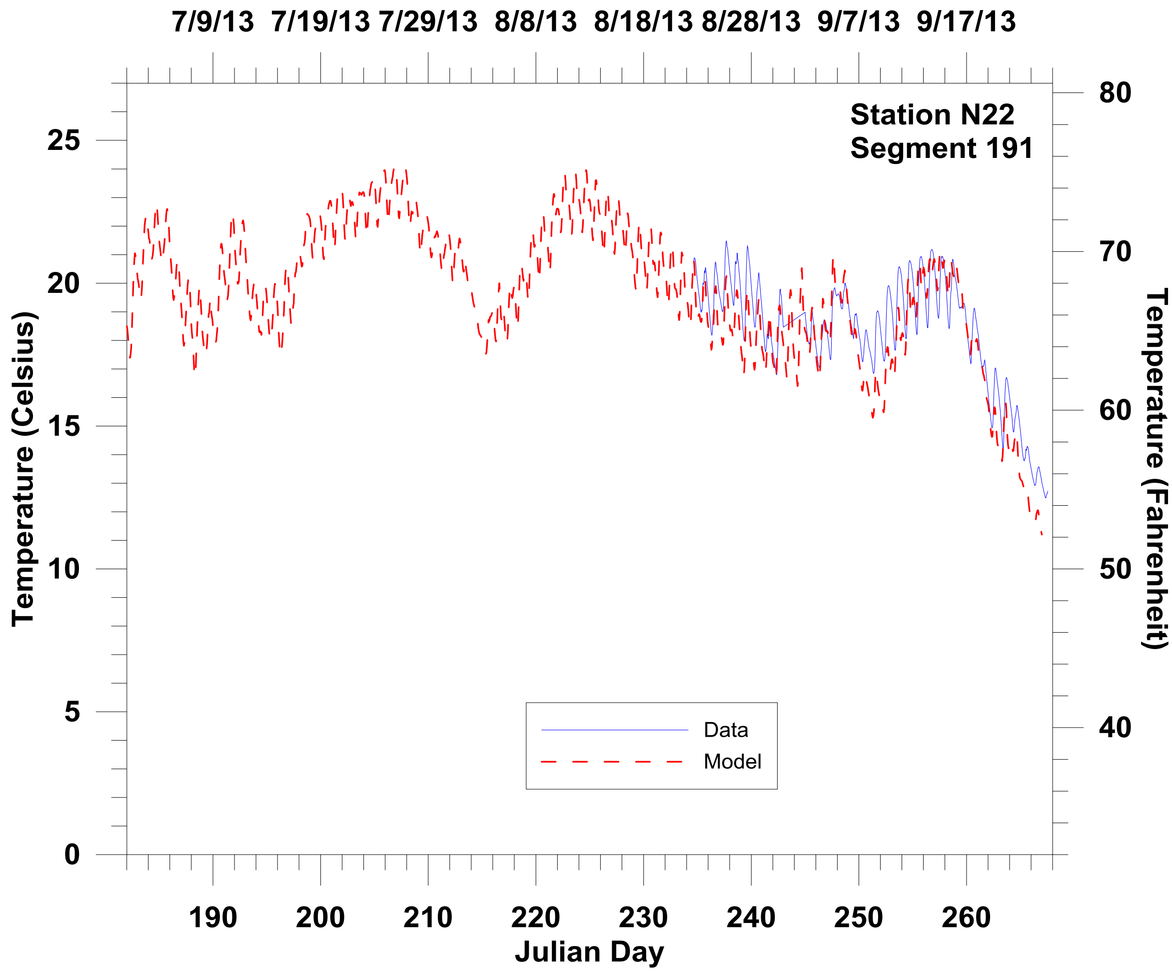

Figure 40: Model-data comparison of temperature predictions at Kalispel site N22.

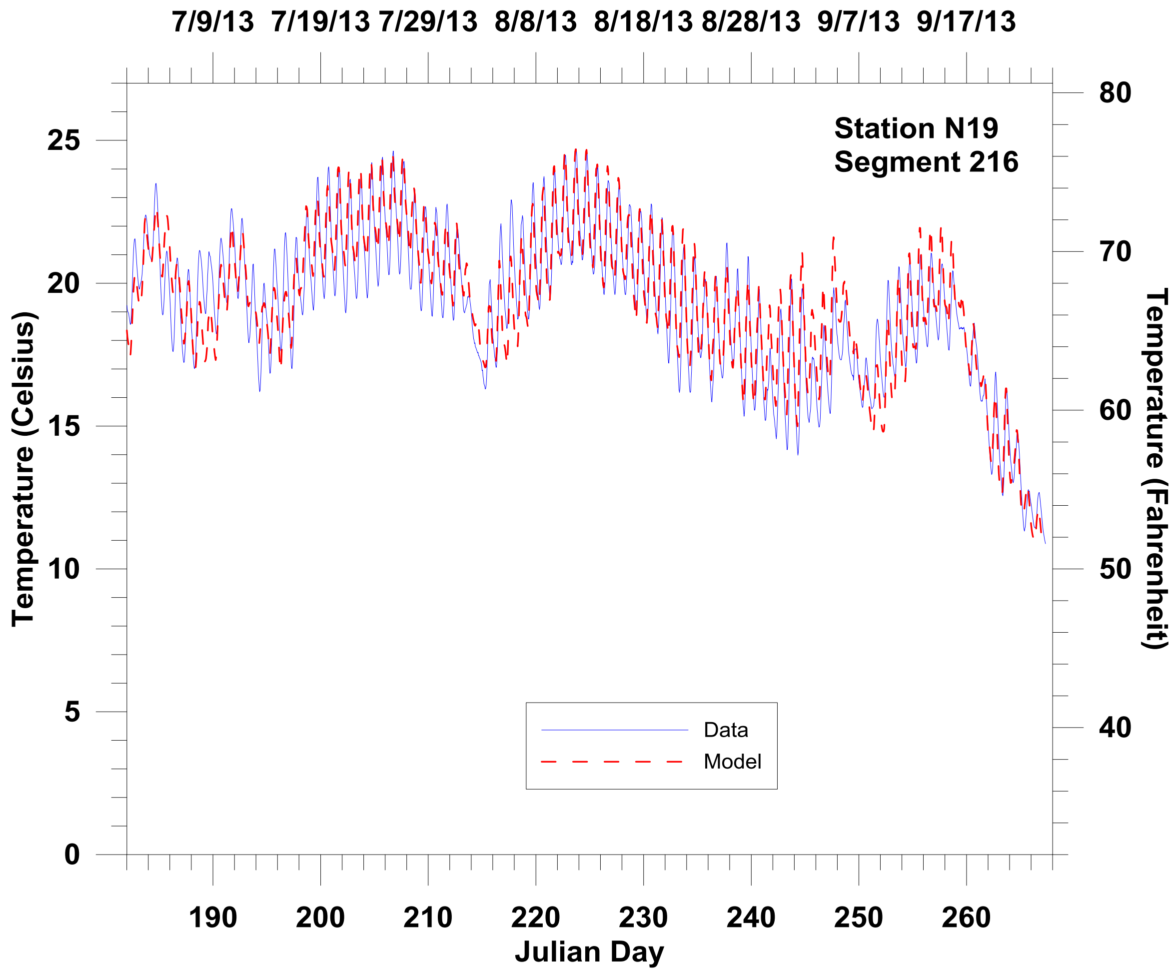

Figure 41: Model-data comparison of temperature predictions at Kalispel site N19.