 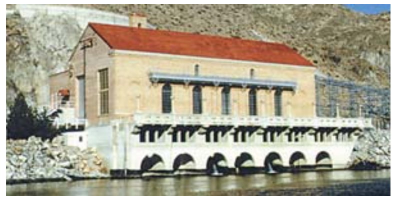 

PUBLIC UTILITY DISTRICT NO. 1 *of* CHELAN COUNTY
P.O. Box 1231, Wenatchee, WA 98807-1231 • 327 N. Wenatchee Ave., Wenatchee, WA 98801
(509) 663-8121 • Toll free 1-888-663-8121 • www.chelanpud.org

April 11, 2014

VIA ELECTRONIC FILING

Honorable Kimberly D. Bose, Secretary, and
Nathaniel J. Davis, Sr., Deputy Secretary
FEDERAL ENERGY REGULATORY COMMISSION
888 First Street, NE
Washington, DC 20426

Ms. Patricia S. Irle, Hydropower Projects Manager
Washington Department of Ecology
Central Regional Office
15 West Yakima Avenue, Suite 200
Yakima, WA 98902-3452

Re: **Lake Chelan Hydroelectric Project No. 637**
License Article 401 and Water Quality Certification Condition V.B
Chelan River Water Temperature Modeling Quality Assurance Project Plan

Dear Secretary Bose, Deputy Davis, and Ms. Irle:

On November 30, 2007, the Federal Energy Regulatory Commission's (Commission) issued its "*Order Modifying and Approving Quality Assurance Project Plan, Article 401 and WQC Condition V.B,*"[1] requiring the Public Utility District No. 1 of Chelan County, Washington (Chelan PUD) to file a revised quality assurance project plan (QAPP) by April 30, 2012, to provide the results of a study to determine the geomorphic influences on water temperatures in the Chelan River in order to address temperature, velocity, depth, and substrate to determine the best methods to achieve the biological objectives for cutthroat trout.

On September 2, 2010, and October 15, 2013, the Commission issued orders[2,3] granting Chelan PUD to file the QAPP for the Chelan River Temperature Modeling Study by the first extended deadline of September 1, 2013, then by the second extended deadline of April 15, 2014.

Chelan PUD hereby respectfully files the QAPP for Commission approval and submits the QAPP to the Washington Department of Ecology (WDOE). Prior to this filing, Chelan PUD obtained the WDOE's final comments. This QAPP was developed collaboratively with WDOE, with additional input from the U.S. Environmental Protection Agency (EPA). It has undergone several revisions and refinement of

[1] 121 FERC ¶ 62,154 (2007)
[2] 132 FERC ¶ 62,147 (2010)
[3] The October 15, 2013, order has no FERC Cite number.

scope. A final draft was submitted to WDOE on January 15, 2014, and WDOE responded with additional comments on February 21, 2014. A conference call with WDOE, EPA, Chelan PUD and its consultant (WEST Consultants) was held on March 7. WDOE provided comments as text edits within the document and as numbered side-bar comments and questions. Text edits were incorporated into the final QAPP. All side-bar comments and/or recommendations from WDOE along with Chelan PUD's responses are included in the attached document "Response to Ecology (WDOE) Comments Dated February 21, 2014 Regarding Draft Quality Assurance Project Plan Chelan River Temperature Model Issued January 15, 2014."

Please contact me or Steven Hays at (509)661-4181 if you would like to discuss this work or if additional information would be helpful.

Sincerely,

Michelle Smith
License and Compliance Manager
(509)661-4180

Attachments:

Quality Assurance Project Plan for the Chelan River Temperature Model
Response to Ecology (WDOE) Comments Dated February 21, 2014 Regarding Draft Quality Assurance Project Plan Chelan River Temperature Model Issued January 15, 2014

Quality Assurance Project Plan

Chelan River Temperature Model

by

WEST Consultants, 12509 Bel-Red Road, Suite 100, Bellevue, WA 98005-2535, and
Public Utility District Number 1 of Chelan County, 327 North Wenatchee Avenue,
Wenatchee, WA 98801

April 15, 2014

Publication No. <to be added>

This plan is available on the Department of Ecology home page on the World Wide Web at
<to be added>

Quality Assurance Project Plan

Chelan River Temperature Model

April 15, 2014

Approvals

Raymond Walton, WEST Consultants	Date
Steve Hays, Chelan PUD	Date
Paul Pickett, EAP, SCS	Date
Tom Mackie, EAP, CRO/ERO	Date
Pat Irle, WQ, CRO	Date
Charlie McKinney, WQ, CRO	Date
Ben Cope, EPA Region X	Date

Table of Contents

1. Abstract

The Lake Chelan Hydroelectric Project (FERC Project No. 637), or "Project", is operated by the Public Utility District No. 1 of Chelan County (District). Pursuant to their Federal Energy Regulatory Commission (FERC) license, the District is required to monitor and evaluate conditions in the Chelan River, which stretches about four miles from the outlet of Lake Chelan to the Columbia River. This includes measuring water temperatures, monitoring achievement of biological objectives (cutthroat trout population in the Chelan River above the falls, steelhead and Chinook below the falls), recommending and implementing measures (to the extent practicable) to meet biological objectives, and assessing the water quality data collected. The District must also study the geomorphic influences on water temperatures in the Chelan River in order to address temperature, velocity, depth, and substrate to determine the best methods to achieve the biological objectives for cutthroat trout. This Quality Assurance Project Plan (QAPP) will define the proposed scope, data sources, data quality, and reliability of the proposed temperature model to achieve the study objectives.

2. Project Description

2.1 CWA 401 Certification and FERC License

On June 1, 2004, the Washington State Department of Ecology (Ecology) amended and reissued a 401 water quality certification (Order 1233) to the Public Utility District No. 1 of Chelan County (District) for the Lake Chelan Hydroelectric Project (Project). This water quality certification followed a decision from the Washington State Pollution Control Hearing Board upholding the water quality certification, with the inclusion of nine additional specific clarifications and requirements. On November 6, 2006, the Federal Energy Regulatory Commission (FERC) issued a license to the District to operate the project for 50 years. Additionally, in 2008, under the provisions of 33 USC 1341 (FWPCA § 401), the District submitted an application to Ecology to amend the 401 water quality certification as part of a license amendment to modernize generating units at the Project. In November 2008, Ecology issued a water quality certification (Ecology Order 6215) for the amendment application under Section 401 of the federal Clean Water Act. On May 31, 2012, the District requested an amendment to the 401 water quality certification to modify the hydraulic capacity of the Project. Subsequently, on August 28, 2012, Ecology issued a modified and amended 401 water quality certification, Ecology Order No. 9389.

Under current conditions, which include a minimum flow of 80 cfs, it is not known what level of support for fish, and water temperature for such use, can reasonably be achieved in the Chelan River. To make that determination, the 401 water quality certification for the Project license contains conditions for a ten-year adaptive management plan, which will allow time to determine what level of fish support and water temperature is reasonable and feasible to achieve. The current completion date for determining whether the biological objectives can be met is April 30, 2019. By or before the end of the ten-year adaptive management schedule, the District is to provide Ecology with the information necessary to make a determination on whether the biological objectives in the 401 water quality certification (and CRBEIP) and the state water quality standards have been achieved. Ecology has agreed to review the degree of attainment of the biological objectives and water quality standards and the application of all known, reasonable and feasible measures, and based on the results of the review, initiate a process to modify the applicable standards through rulemaking or such alternative process as may otherwise be authorized under applicable state and federal law (Ecology, 2008).

Under the 401 permit, The District is required to monitor and evaluate conditions in the Chelan River below Lake Chelan. This includes measuring water temperatures, monitoring achievement of biological objectives, recommending and implementing measures to meet biological objectives, and assessing the water quality data collected. There is also a requirement to study the geomorphic influences on water temperatures in the Chelan River in order to address temperature, velocity, depth, and substrate to determine the best methods to achieve the biological objectives for cutthroat trout.

To prepare for these evaluations, as well as for the eventual setting of water quality standards for the Chelan River, the District needs to collect sufficient data to evaluate potential measures that may be suggested for attainment of biological objectives. These could include increased flow releases, riparian vegetation propagation, gravel seeding of streambed, and possible streambed modification to attempt development of thermal refugia areas for cutthroat.

Ultimately, the District intends to develop a numerical temperature model to evaluate the potential effects of different flows, shade, and channel modification on water temperatures in the Chelan River. Several conditions of the 401 water quality certification relate to water temperature. These include requirements that the District:

- Develop a Quality Assurance Project Plan for water quality monitoring and temperature modeling (Order 1233, 5.B);
- Conduct a study to determine the geomorphic influences on water temperatures in the Chelan River in order to address temperature, velocity, depth, and substrate to determine the best methods to achieve the biological objectives for cutthroat trout (Order 1233, 5.B.iv);
- Conduct a riparian feasibility study to better characterize the opportunities for the establishment of riparian vegetation on the banks of the Chelan River (Order 1233, 10.E);
- Collect data on temperatures in the Chelan River and, if appropriate, evaluate its ability to comply with the temperature standards (Order 1233, C).

FERC issued a license to the District for the Project as described below.

2.2 Description of Study Area and Project

Study Area

Lake Chelan is the largest and deepest natural lake in Washington State. It is divided into two distinct basins on either side of a prominent sill. The sill is a glacial moraine rising to within 135 feet of the lake's surface. The larger Lucerne Basin contains over 92 percent of the total lake volume and has a maximum depth of 1,486 feet. The Lucerne Basin is fed by tributaries that originate in the forested and glacial areas of the Cascade Mountains. The largest inflow comes from the Stehekin River at the head of the lake. Water flowing into the Lucerne Basin will reside there for approximately 10 years on average. A longitudinal profile of Lake Chelan is shown in Figure 1.

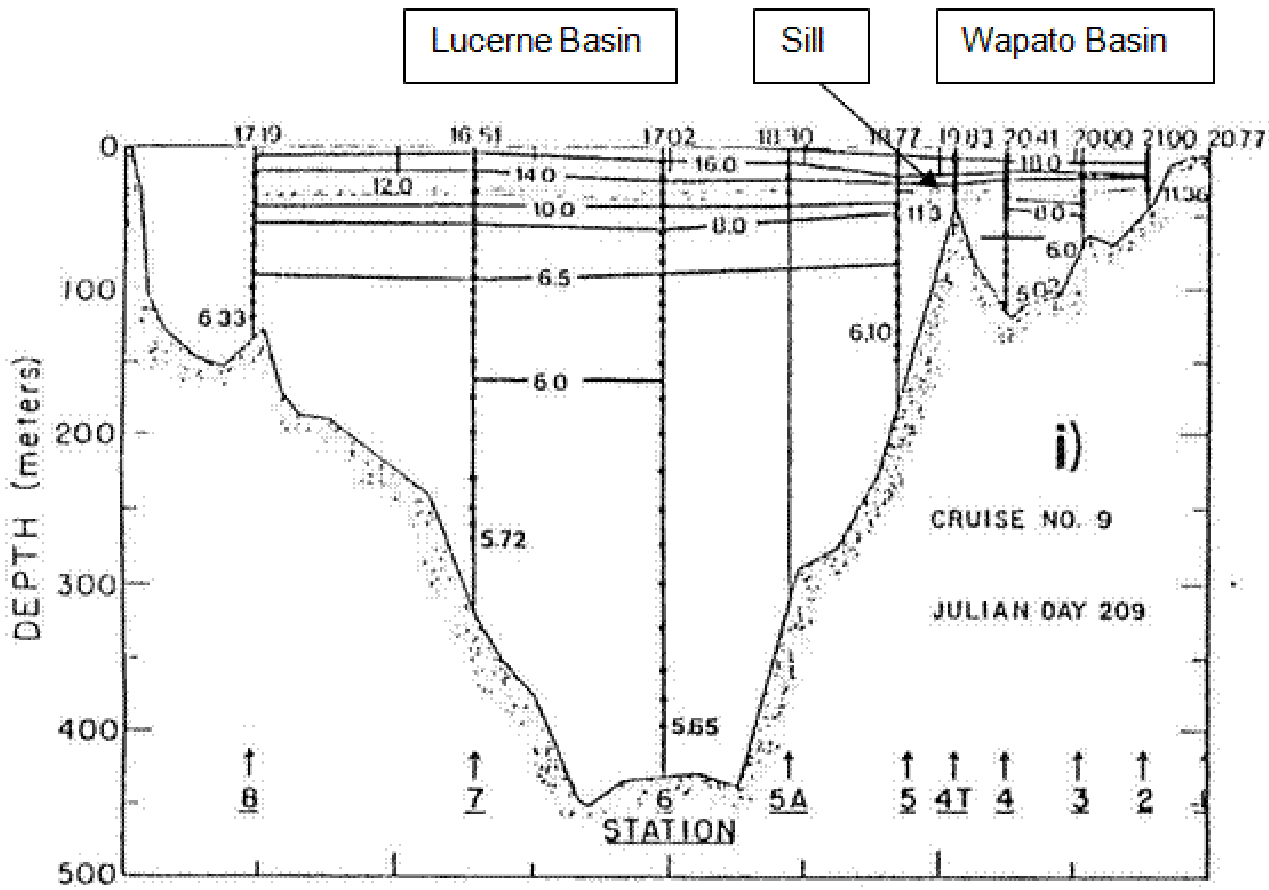

Figure 1. Longitudinal Profile of Lake Chelan (from Ecology, 1989)

To the southwest, the smaller Wapato Basin is at its deepest 400 ft and receives most of its water input from the upper lake. Because of its smaller volume, water in the Wapato Basin resides there only about 0.8 years on average. This estimation excludes the effects of inter-basin mixing. Although the Wapato Basin represents only a small portion of the lake, most of the developed areas within the lake's watershed occur in this region.

The climate of the Chelan area is characterized by warm dry summers, and cool winters. The average maximum temperature in the summer is in the mid-80^{o}F (near 30^{o}C) and in the winter is close to freezing (http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?wa1350). The climate is semi-arid with an average annual total of about 11 inches of precipitation. More than half of this precipitation occurs during the winter months of November-February. Along Lake Chelan, the monthly distribution and range of temperatures is similar, but Stehekin is considerably wetter with an average annual precipitation close to 36 inches. Inflows to Lake Chelan are mainly due to snowmelt with peaks inflows during April-July.

During the spring and summer months, seasonal warming causes the waters of both basins of the lake to develop a pronounced vertical stratification where colder, deeper waters are isolated by an upper warm layer. This is because the warmer surface water is less dense than the colder water below. Wind generated waves cause these surface waters to mix to depths of 100 to 130 ft -- the thermocline depth.

During the winter, when surface and subsurface waters approach the same temperature, thorough mixing occurs. Full circulation is likely to occur every few years. Surface temperatures during the summer are considerably warmer in the Wapato Basin than in the Lucerne Basin (Ecology, 1989). Table 1 lists Lake Chelan characteristics.

Table 1. Lake Chelan Characteristics (Ecology, 1989)

Parameter	Wapato Basin	Lucerne Basin	Lake Chelan
Maximum Length (mi)	12	38.4	50.4
Maximum Width (mi)	1.8	1.4	1.8
Mean Width (mi)	1.1	1.0	1.0
Maximum Depth (ft)	400	1486	1486
Mean Depth (ft)	141.1	590.6	472.4
Surface Area (sq mi)	13.5	38.6	52.1
Percent of Lake Surface Area	26.0	74.0	100.0
Volume (acre-ft)	1,207,963	14,592,837	15,800,800
Percent of Lake Volume	7.6	92.4	100.0
Watershed Area (sq mi)			923.9
Water Residence (yr)			10.6
Lake Surface Elevation (ft)			1099.1

The Stehekin River is the main inflow to Lake Chelan and the Chelan River is the only outflow. Inflows from the Stehekin River are measured at USGS streamflow gage 12451000 Stehekin River at Stehekin, WA, and outflows in the Chelan River (powerhouse plus spill) at USGS streamflow gauge USGS 12452500 Chelan River at Chelan, WA. Table 2 summarizes these flows by month.

The Project

The Lake Chelan Hydroelectric Project (FERC No. 637) is located on the Chelan River near the City of Chelan in Chelan County, Washington. The Project generates 48 megawatts of hydropower. The Project includes a diversion dam in the upper Chelan River, which is located at the southeast end of Lake Chelan. The dam controls the elevation of Lake Chelan and the flow into the Chelan River. Water flowing through the powerhouse empties into a tailrace about 1,700 feet from the Columbia River (Ecology, 2008).

Table 2. Summary of Inflows and Outflows to Lake Chelan

	Stehekin River Inflows (cfs)			Lake Chelan Outflows (cfs)		
	Minimum	Mean	Maximum	Minimum	Mean	Maximum
January	86	424	1856	31	1660	3651
February	115	402	1209	64	1580	4308
March	194	538	1757	43	1460	2390
April	549	1440	4644	16	1430	4416
May	1475	3550	5810	16	2380	7435
June	1412	4150	7738	104	4110	9566
July	1034	2630	5479	967	3530	7479
August	612	1240	2716	429	1780	3525
September	392	687	1399	601	1520	2407
October	218	617	2072	388	1740	2850
November	148	718	3192	347	1720	3287
December	125	522	1896	320	1720	2962
Annual	864	1411	2008	1133	2048	3139

Notes: 1 USGS 12451000 Stehekin River at Stehekin, WA (December 1910 – September, 2013)
2 USGS 12452500 Chelan River at Chelan, WA (November 1903 – September, 2013)

The Lake Chelan Dam is a steel-reinforced concrete gravity structure. It is approximately 40 feet high and 490 feet long, and contains eight spillway bays and a separate conduit (low level outlet) to release water collected from the bottom of the forebay. The low level outlet is used to provide required flows to the Chelan River channel and to release excess water up to about 500 cubic feet per second (cfs). When the spillway gates are open to manage lake levels during periods when inflow to Lake Chelan exceeds the capacity of the powerhouse, as needed from May – August and during fall or winter floods, the excess water is discharged down the Chelan River channel. Lake levels and spillway discharges are managed, to the extent feasible, to limit discharge to the Chelan River channel to no greater than 6,000 cfs during normal operations for control of lake levels. Seiches and extreme inflow conditions may result in spillway flows above 6,000 cfs for lake level control and plant safety.

An underground penstock connecting the dam to the powerhouse delivers water to power the turbine generators (Figure 2). It delivers water from the dam at the southeasterly end of Lake Chelan to the powerhouse at Chelan Falls, a vertical drop of nearly 350 feet. This steel and concrete tunnel is approximately 2.2 miles long. The only visible portion of the tunnel is a 125-foot-high surge tank constructed on the hill above the plant to absorb hydraulic momentum of the water in case of load rejection. The penstock must undergo a federally required inspection every five years. The water is discharged into the tailrace located on the east side of the powerhouse where it flows into the Columbia River.

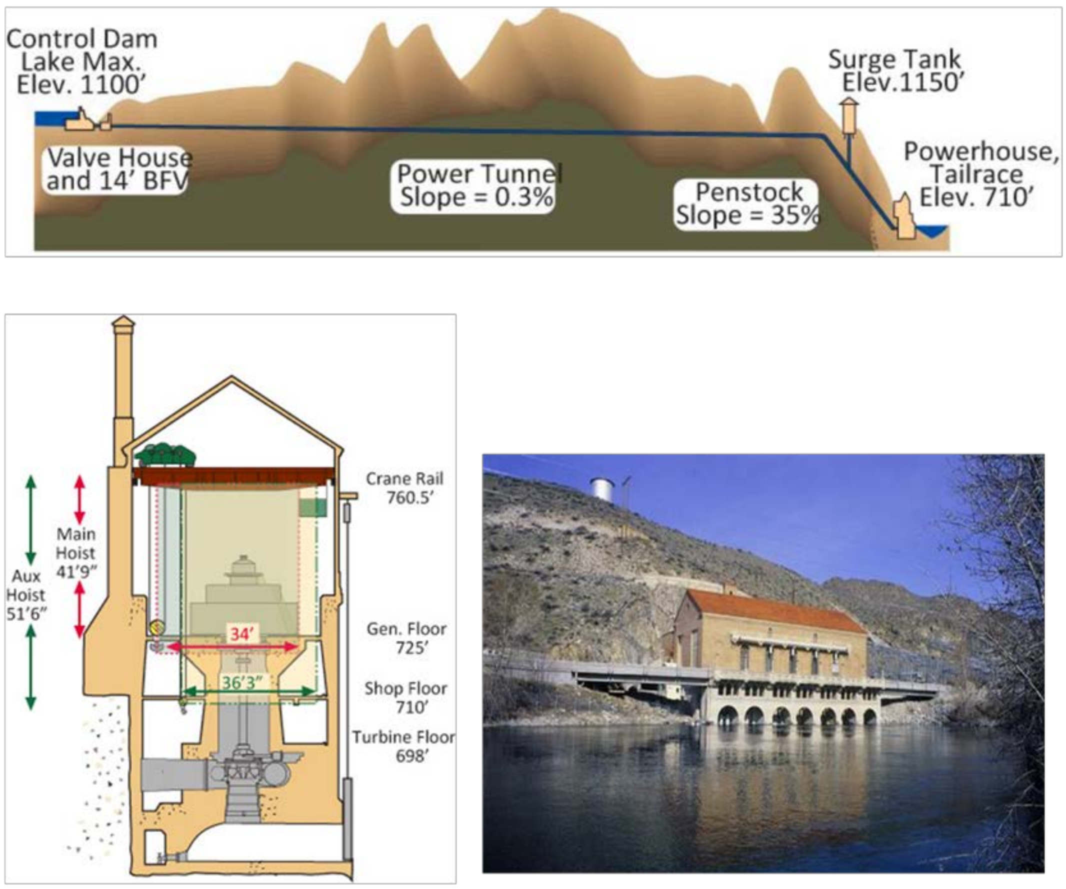

Figure 2. Lake Chelan Hydroelectric Project general views.

The Chelan River is 4.1 miles long from the Lake Chelan Dam to where it discharges to the Columbia River. It can be conceptually divided into four reaches (shown in Figure 3).

1. Reach 1 – Extending 2.29 miles downstream from the Lake Chelan Dam. This reach has a gradient of about one percent. Total length = 2.3 miles.
2. Reach 2 – Between 2.29 and 3.04 miles downstream from the dam, with a lower gradient than Reach 1. Total length = 0.75 miles.
3. Reach 3 – Between 3.04 and 3.53 miles downstream from the dam. This reach is very steep (5-10 percent) and is lined with steep bedrock walls, and is commonly referred to as "The Falls". Total length = 0.4 miles.
4. Reach 4 – From 3.53 downstream from the dam, to its confluence with the tailrace near the Columbia River. This reach has a gradient of less than two percent. Total length = 0.5 miles (Figure 4).

Figure 3. Chelan River showing study reaches

Figure 4. Chelan River Reach 4 showing habitat channel and structures.

2.3 State Water Quality Standards

The goal of the State of Washington is to "maintain the highest possible standards to ensure the purity of all water of the state consistent with public health and public enjoyment thereof, the propagation and protection of wild life, birds, game, fish, and other aquatic life, and the industrial development of the state, and to that end require the use of all known available and reasonable methods by industries and others to prevent and control the pollution of the waters of the state of Washington" (RCW 90.48.010). Under the State's current water quality standards, approved by the U.S. Environmental Protection Agency in February 2008, the designated uses for the Chelan River include salmonid spawning, rearing, and migration (WAC 173-201A-600(1).)

Numerical Criteria for Temperature

The numerical criterion for temperature for the river and tailrace is a 7-DADMax of 17.5ºC, where the 7-DADMax is the average of the daily maximum temperatures of seven consecutive days (WAC 173-201A-200(1)(c)). When the temperature of the waterbody is warmer than this criterion due to natural causes, then human actions should not cause the 7-DADMax to increase by more than 0.3ºC. When the natural water conditions are less than the criterion, then human actions should not cause the 7-DADMax to increase by more than 28/(T+7)ºC.

The state standards also include specific options for modifying water quality standards by developing site-specific criteria or performing a Use Attainability Analysis (WAC 173-201A-430 and 440.) (Ecology, 2008) within a 10-year compliance schedule (WAC 173-201A-510(5)).

Designated Uses: Fisheries

The current water quality standards for the Chelan River were not attained prior to establishment of minimum flows under the new FERC License for the Lake Chelan Hydroelectric Project. Prior to 2009, in most years the bypassed section of the Chelan River was nearly dry as a result of project operations and lake level management under the previous FERC license. Only during wet years or during project maintenance did the river channel receive substantial flow. When flow was not being released into the river below the dam, fish habitat was restricted to a few isolated pools in the gorge section of the bypassed reach and a short section of river below the powerhouse tailrace. Summer and fall Chinook salmon had been observed using the tailrace and lower river for spawning under the right conditions, while smallmouth bass and suckers used the available habitat for rearing (PUD No. 1 of Chelan County, 2002).

The Chelan River Biological Evaluation and Implementation Plan (Lake Chelan Comprehensive Settlement Agreement, Attachment B, Chapter 7, CRBEIP, October 8, 2003) includes biological objectives to be achieved in the Chelan River. The conditions of the 401 water quality certification require the District to implement minimum instream flows for fish identified in the 401 water quality certification (see 401 water quality certification dated November 19, 2008, Ecology Order No. 6215, paragraph E) and CRBEIP as follows:

Reach	Dates	Dry year (cfs)	Average year (cfs)	Wet year (cfs)
1,2,and 3[1]	Jul 16 – May 14	80 all months	80	80
	May 14		Ramp up to 200	Ramp up to 320
	May 15 – Jul 15		200	320
	Jul 16		Ramp down to 80	Ramp down to 80
4[2] Spawning flow	Mar 15 to May 15 and Oct 15 to Nov 30	80 + 240 pumped (320)	320 by combination of spill and pumping Incubation flow, as needed	320 by combination of spill and pumping Incubation flow, as needed

[1] Flows measured at the dam by calibrated gate opening
[2] Flows measured at the dam or through calibrated pump discharge curves

i) The minimum instream flow requirements set forth in the 401 water quality certification are considered minimum values.

ii) Higher flows may be determined to be needed by the Chelan River Fish Forum (CRFF) or by Ecology, as a result of studies performed as part of the CRBEIP.

iii) Ecology retains the right to amend the instream flow requirements specified in this certification to provide adequate habitat and to meet the biological objectives for cutthroat in Reaches 1, 2, and 3 of the Chelan River, or for fall Chinook or steelhead in Reach 4 of the Chelan River, or any species included in the future on a state or federal listing of endangered or threatened species.

iv) With respect to instream flows for spawning in Reach 4, incubation flows are added as needed in all years, including dry years, per Washington State Pollution Control Hearings Board (PCHB) Order dated April 21, 2004 (Confederated Tribes v. Ecology, PCHB No. 03-075.)

2.4 Sources and Analysis of Existing Data

Sources of Data

In the vicinity of the Project, the District currently measures:

- Flows through the Project, including flows from the penstock through the powerhouse, spillway discharges (the 8 spillway bays are 20 feet wide, with 14 foot high tainter gates and spillway crest at El. 1087; total spill capacity 31,200 cfs), and releases to the Chelan River through the low-level outlet (capacity 500 cfs).

- Lake Chelan elevations measured at a USGS gage No.2452000 near Lakeside, Washington, which represent water levels at the Project's forebay.
- Temperature probes at eight locations along the Chelan River since October 2009. These include the low-level outlet, the top of Reach 1, the end of Reach 1, the end of Reach 3, the top of Reach 4, the end of Reach 4, and two devices at the tailrace pump intake (Table 3 and Figure 5).
- Seven vertically deployed temperature probes in the Project's forebay at the Low Level Outlet intake, since September 2009, recording water temperature at five-feet intervals from the river bed at the base of the intake structure, at about El. 1070 (NGVD 1912), up to just below maximum water level, at about El. 1099.2 (Table 3, Figure 6 and Figure 7).

There are five meteorology stations in the vicinity of the Chelan River (Figure 8). We propose to use data from AgWeatherNet "Chelan South" station for model studies. This gauge measures a number of parameters including air temperature, relative humidity, dew point temperature, wind speed and direction, and solar radiation. Details of the gauge can be found on the AgWeatherNet website at http://weather.wsu.edu/awn.php?page=station_details&UNIT_ID=330035.

Finally, the USGS has measured inflows to the upper end of Lake Chelan in the Stehekin River at gauge No. 12451000 since 1911 and outflows to the Chelan River at USGS gauge No. 12452500 since 1904.

Table 3. Temperature thermistor locations in Chelan River.

Temperature Thermistor Location and Type	Lattitude	Longitude	Depth/Structure
Forebay Thermistor String (Hobos)	47.834582	-120.013306	El. 1070, 1075, 1080, 1085, 1090, 1095, 1099.2 (Depth dependent on lake level)
Low Level Outlet Pipe (RTD)	47.834196	-120.012707	Probe in 84" Steel Pipe
Top of Reach 1 (Hobo)	47.833736	-120.010691	3" off river bed
End of Reach 1 (Hobo)	47.820842	-119.989457	3" off river bed
End of Reach 3 (Hobo)	47.811092	-119.985002	3" off river bed
Top of Reach 4 (Hobo)	47.810009	-119.984736	3" off river bed
End of Reach 4 (Hobo)	47.806075	-119.985777	3" off river bed
Tailrace Auto Pump Intake (RTD)	47.807915	-119.986297	Mounted on Intake Screen (Depth dependent on tailwater level)
Tailrace Shoreline at Pump Intake Hobo)	47.807733	-119.986291	3" off river bed

Figure 5. Location of temperature probes in the Chelan River

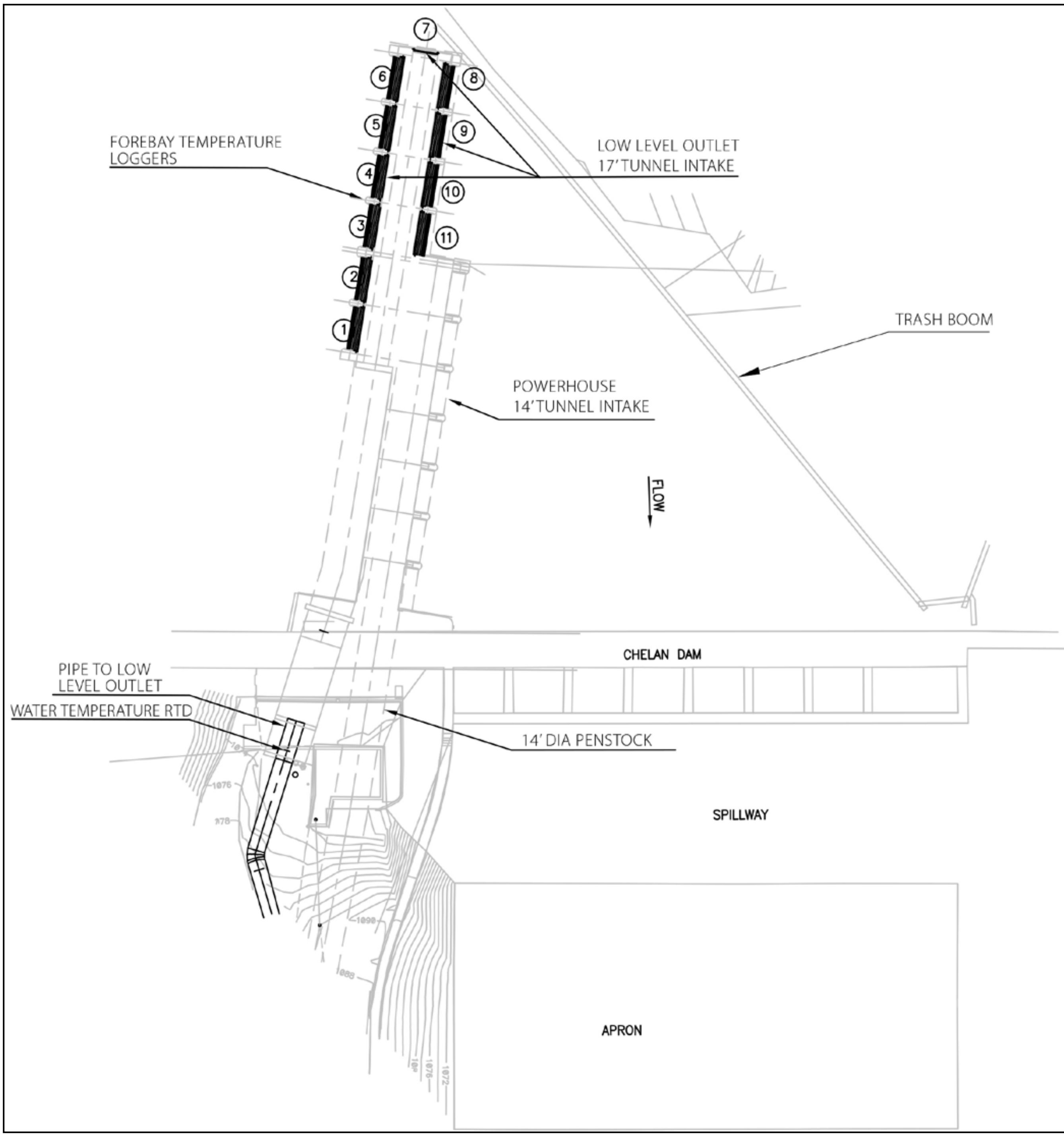

Figure 6. Low Level Outlet intake structure and temperature probe locations.

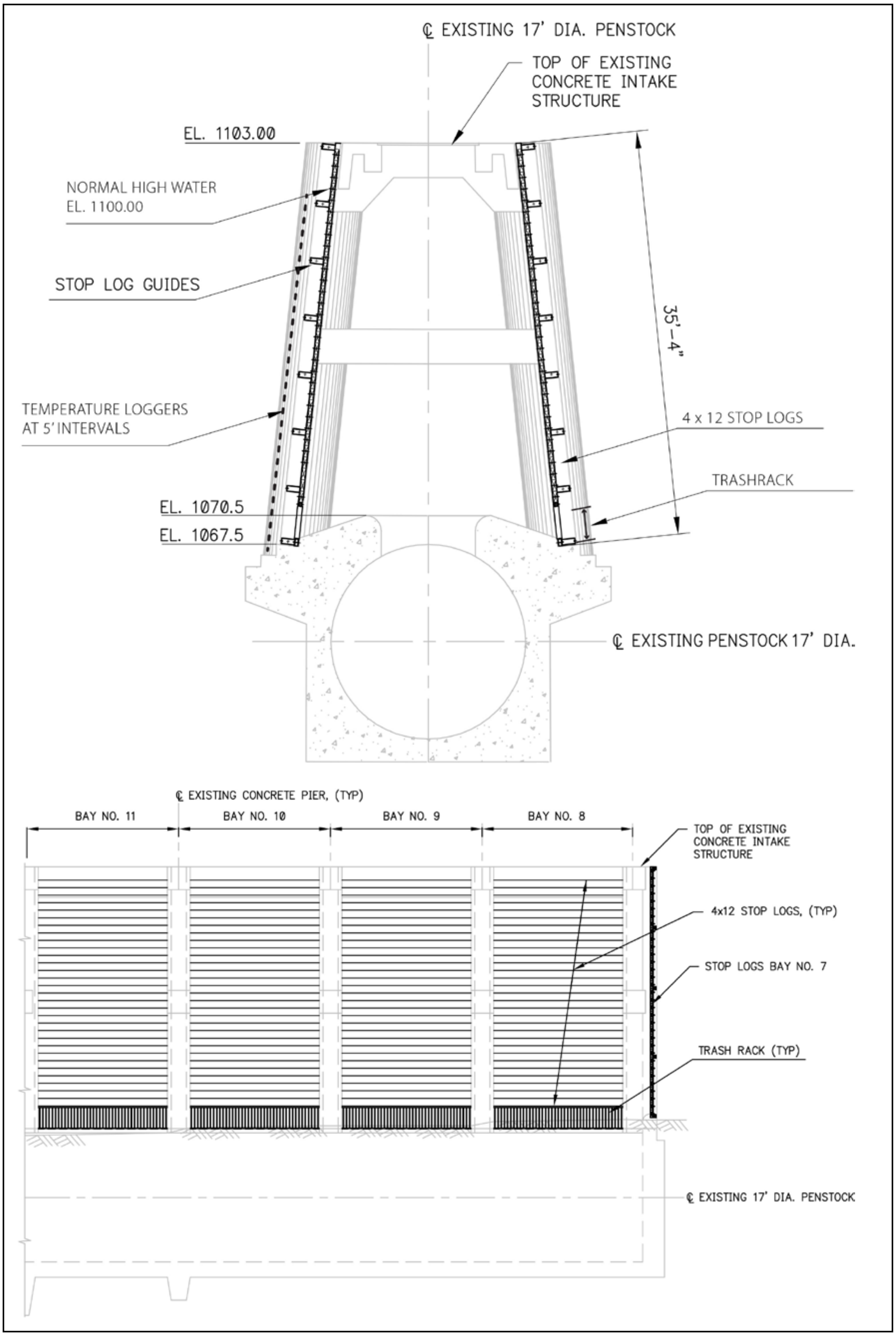

Figure 7. Low Level Outlet intake details and forebay thermistor string vertical position.

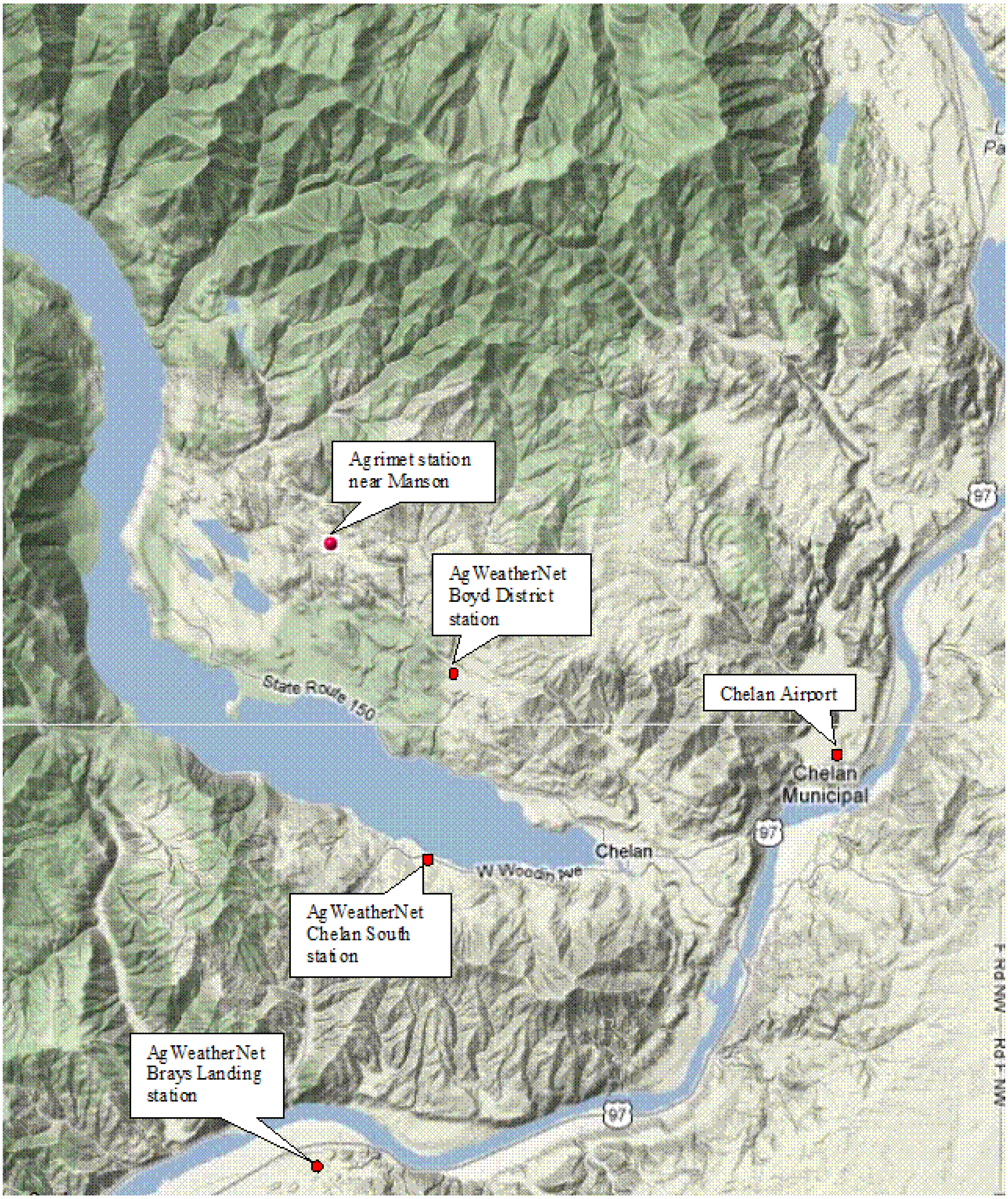

Figure 8. Meteorological stations near Chelan

Analysis of Existing Data

While thermal stratification of more than 2°C can occur in Lake Chelan during the summer months, significant stratification is not always seen in the Project's forebay. Figure 9 shows the difference in vertical forebay temperatures from September 2009 to January 2011 (nearest-surface values minus values at elevation 1070 feet). The figure shows that most of the time, there is little stratification (less than 0.5-1°C) in the forebay over its 25-30 feet of depth. However, there are periods when the stratification increases to 4°C or more as the near-bottom water becomes cooler. Figure 10 looks at the summer of 2010, and includes a 24-hour running average of air temperatures measured at the nearby "Chelan South" AgWeatherNet station. And Figure 11 includes the difference in temperatures between the top and bottom temperature sensors. From these figures, it is clear that the surface water temperatures generally follow the trend of the air temperatures, but that the deeper temperature excursions do not. We believe that the cooler temperatures seen at depth in the forebay are the result of seiching in the Wapato Basin of Lake Chelan forcing cooler water to rise towards the surface and enter the Chelan River channel, approximately 0.6 miles upstream of the Project's forebay.

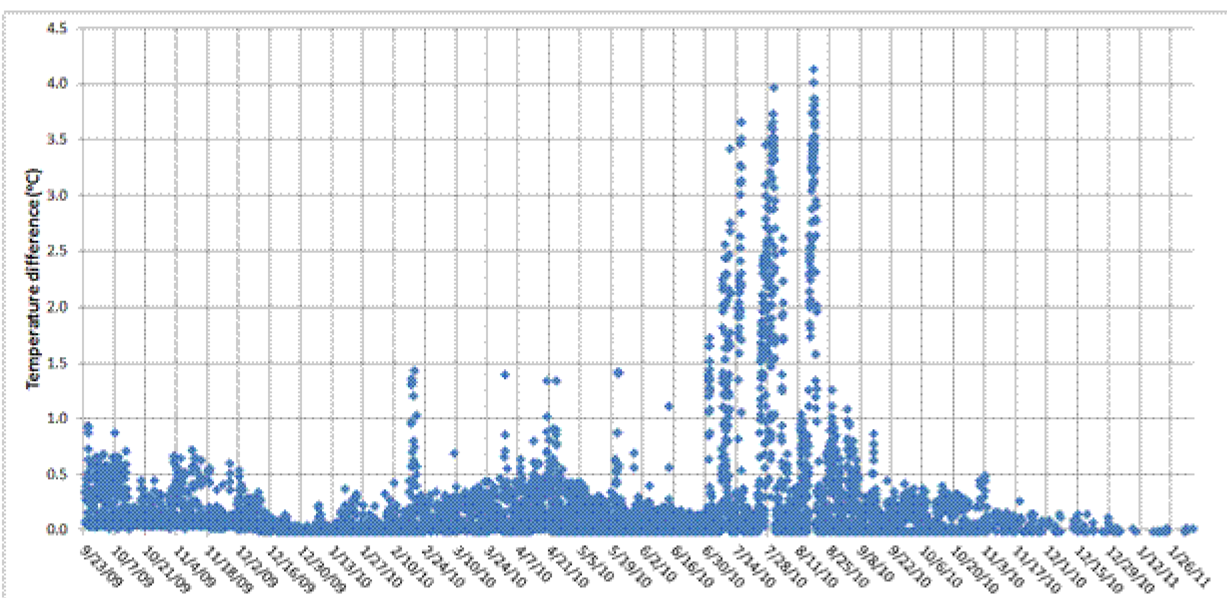

Figure 9. Vertical temperature difference in Lake Chelan forebay

If we compare temperatures measured at the Project's low-level outlet with those measured at the bottom of the forebay thermistor chain, at each time interval, we see that they are highly correlated (Figure 12). This shows that the low-level outlet is drawing water mainly from the bottom of the forebay, as confirmed during stratified conditions, thus accomplishing the requirement that the low level outlet design met the requirement to "maximize the potential for cold water withdrawal at the base of the dam" (Ecology Order 1233, X. D).

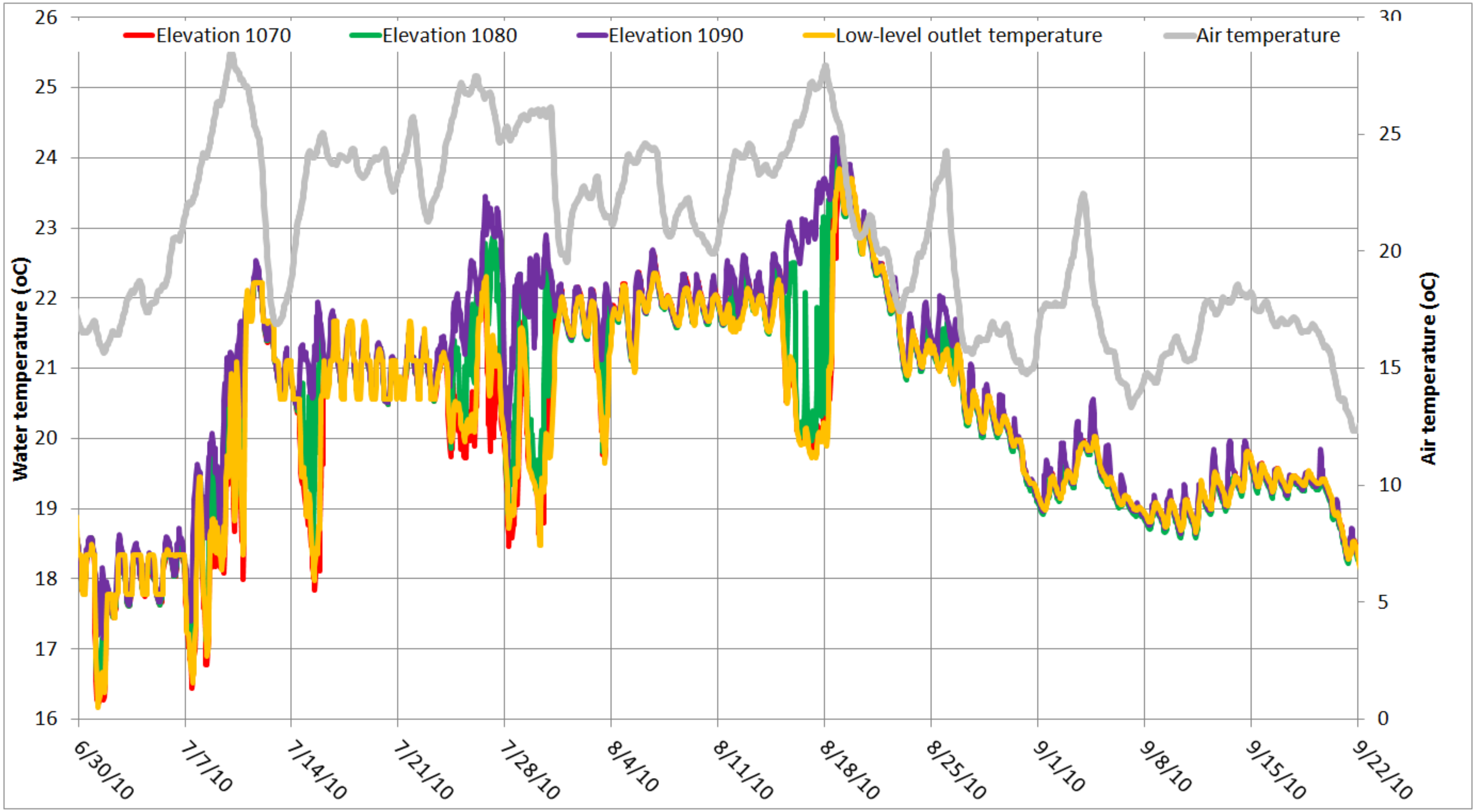

Figure 10. Time series of water temperatures in Lake Chelan forebay during summer of 2010.

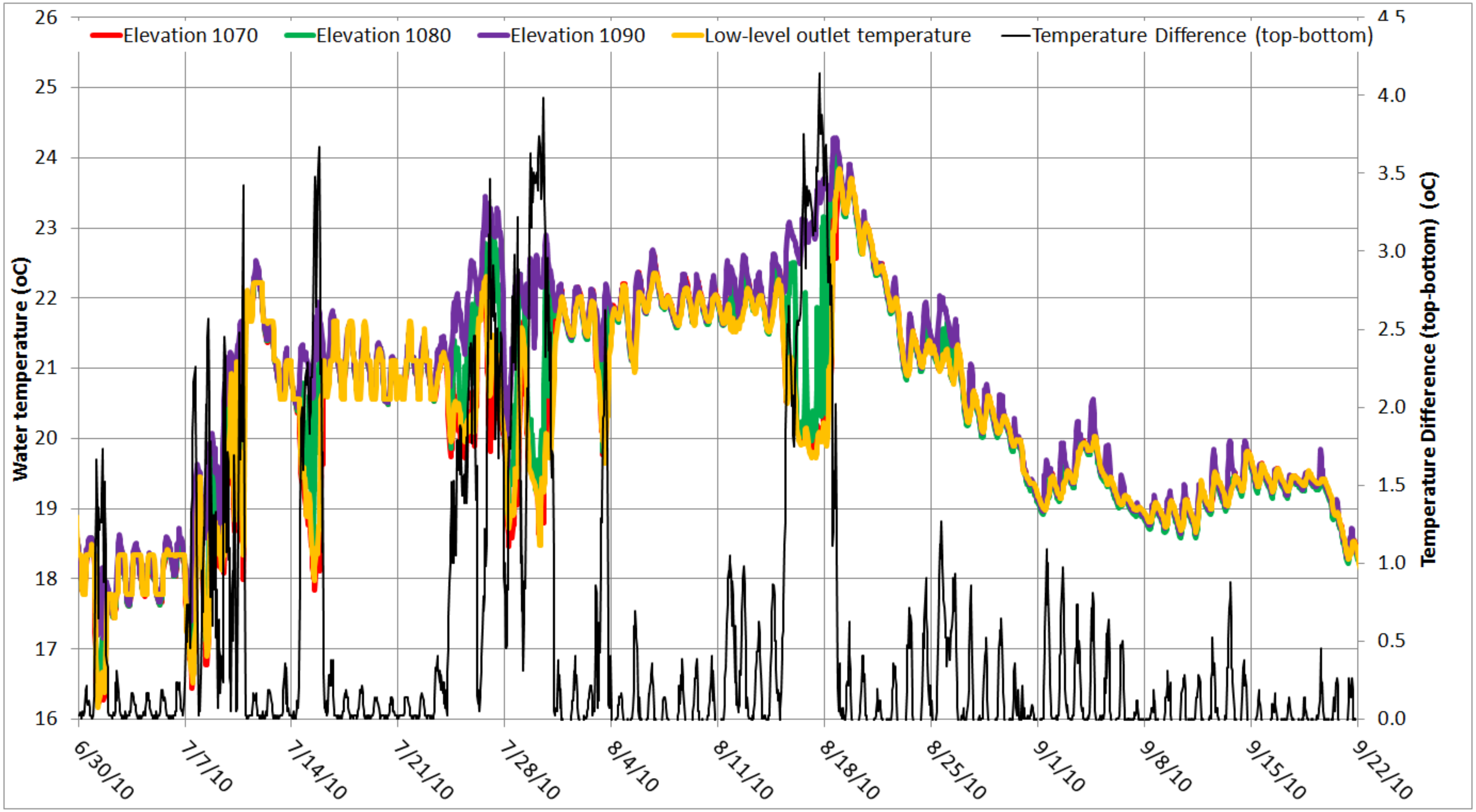

Figure 11. Time series of water temperatures and thermal stratification in Lake Chelan forebay during summer of 2010.

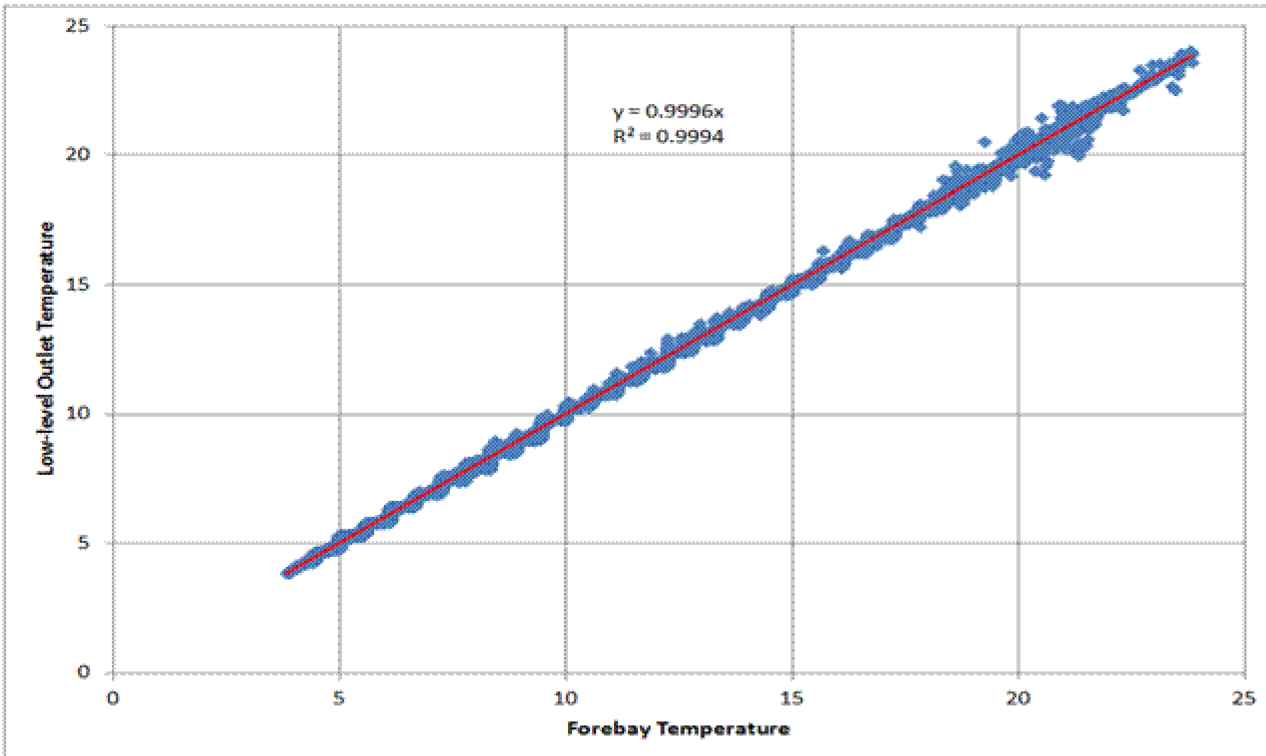

Figure 12. Correlation between near-bottom forebay temperatures and low-level release temperatures.

Finally, the difference in water temperatures measured along the Chelan River (between the thermistor at the upstream end of Reach 1 and the thermistor at the downstream end of Reach 3) show both seasonal increases and decreases as Lake Chelan water released through the Project either heats up or cools down in response either meteorological and/or groundwater conditions (Figure 13). The data also show that the change in temperature along the Chelan River is highly correlated with releases to the river from the Project (Figure 14). For releases in excess of about 800 cfs, there is relatively little change in river temperatures as the transit time along the 4.1-mile reach decreases.

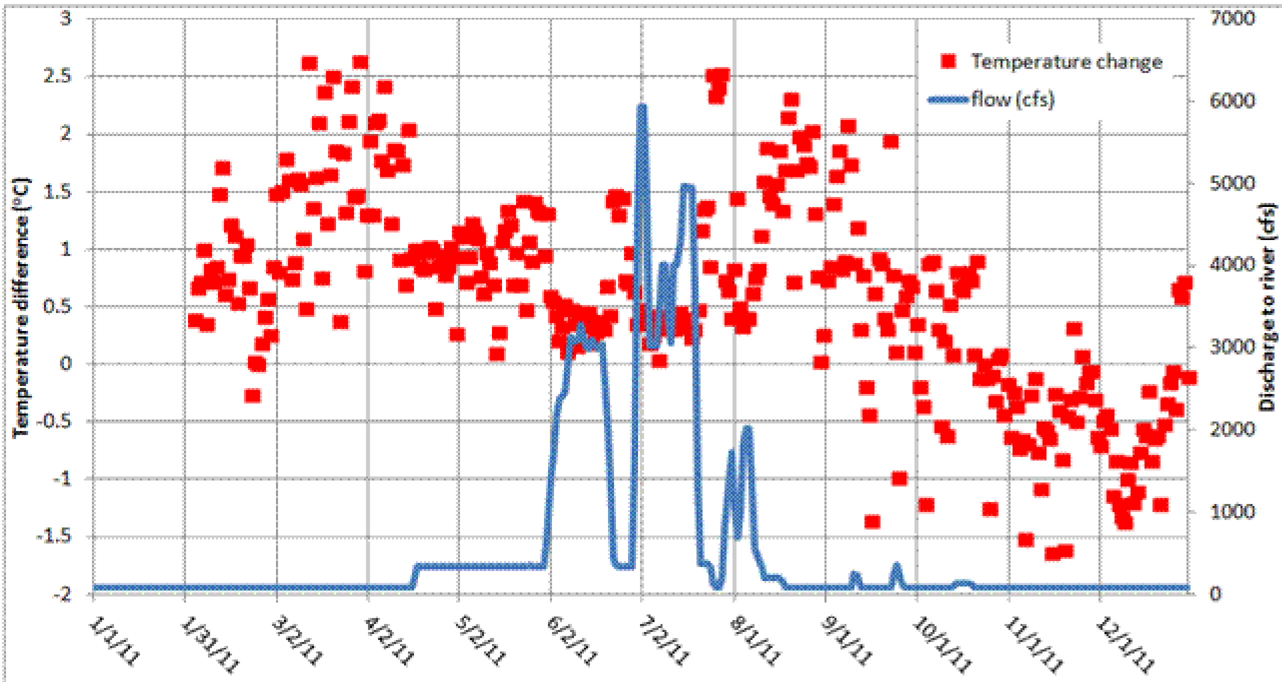

Figure 13. Comparison of flow and temperature change in bypassed reach (1-3).

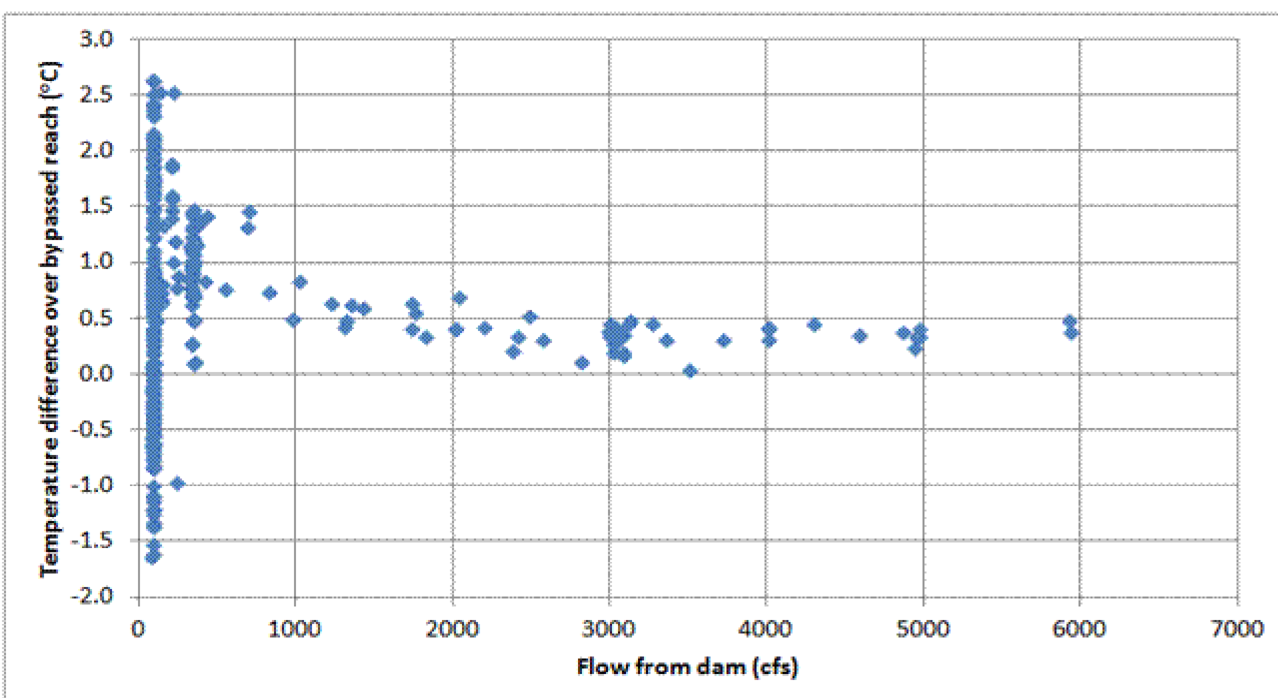

Figure 14. Comparison of flow and temperature change in bypassed reach (1-3) during 2011.

Sources of Temperature Response

Heat energy processes that control energy transfer to and from a given volume of water include:

- Shortwave solar radiation.
- Longwave radiation exchange between the stream and the adjacent vegetation, nearby cliffs, and the sky.
- Evaporative exchange between the stream and the air.
- Convective exchange between the stream and the air.
- Conduction transfer between the stream and the streambed.
- Groundwater exchange with the stream.

If the heat energy entering the water from these sources is greater than the heat energy leaving the water, then stream water temperature will rise. Water temperature change, which is an expression of heat energy exchange per unit volume, is most strongly influenced by solar radiation input and air temperature. It is also important to note that the time-of-travel along a river must also be considered when evaluating the "impacts" of a project, as travel-time differences caused by Project operations can change the reference volume of water that is being evaluated for thermal changes. However, we note that travel times in the Chelan River are generally short, perhaps up to a few hours, as the river is only 4.1 miles long.

Water temperatures in the Chelan River may be influenced by a variety of factors including:

- Magnitude of solar radiation.
- Shading (stream bank vegetation or surrounding hills).
- Meteorological conditions (cloud cover, haze, air temperature, humidity, wind).
- Water depth, volume, flow, slope and turbulence intensity.
- Heat exchange with the river bed, air, and atmosphere.
- Upstream temperatures.
- Temperature and volume of water inflows from groundwater.

A previous study (PUD No. 1 of Chelan County, 2002) used data from May through September from the years 2000, 2001, and 2002, in addition to an extreme hot-weather pattern from July 24 to August 6, 1998. Weather data originated from the U.S. Forest Service Chelan Ranger Station, located in the City of Chelan near the outlet of Lake Chelan, and flows and water temperatures were taken from the forebay, penstock, and powerhouse data sensors. The following observations were made:

- Lower flow releases are more responsive to weather than higher flows, and maximum daily water temperatures are generally higher with lower flows.
- Upstream water temperatures within the calibration data file showed that the mean daily input water temperatures in the forebay of Lake Chelan are already approaching equilibrium with the air temperature, even prior to entering the Chelan River channel. This is likely due to the top surface of Lake Chelan (and hence the

channel input water) acclimating to the weather regime.

- Generally, on warmer days, larger discharges of cooler water kept the stream from warming as much as smaller volumes.
- On some cooler days and at higher flows, the downstream water was actually warmer than at lower flows because the thermal mass of the larger volume of water was less capable of cooling as quickly.
- Smaller flows had a much larger diurnal range of temperatures than larger flows.
- Average 24-hour temperatures rarely exceeded 75.2ºF, but maximum 24-hour temperatures often exceeded this amount in low flow scenarios.

2.5 Goals and Objectives

Following a meeting with Ecology and the District on September 27, 2013, the group concluded that the temperature study of the Chelan River focus on a Use Attainability Analysis (UAA) rather than an analysis of temperatures changes caused by the Project. Therefore, the goals of a temperature model of the Chelan River are to:

1. Evaluate various means to decrease warm summer temperatures, such as the impacts of vegetation for shading, and
2. Provide a scientific tool to support the determination of what designated aquatic life uses are attainable.

WEST (2013) considered a number of models to simulate temperature conditions in the Chelan River. In addition, the report also considered whether a model of Lake Chelan should be included in the study to provide suitable boundary conditions for inflows to the Chelan River. The study concluded that (1) HEC-RAS (HEC, 2010) was the appropriate model to simulate hydraulics in the Chelan River, (2) that QUAL2kw (Pelletier et al., 2006) would be the appropriate model to simulate temperatures, and 3) the study did not require a temperature model of Lake Chelan at this time. These were initial recommendations subject to reconsideration during the course of the Chelan River temperature modeling.

The goals of the study are:

- The collect sufficient data to develop, calibrate and validate a numerical model of the Chelan River,
- To develop, calibrate, and validate numerical models of Chelan River hydraulics and water temperatures,
- To work with Ecology, the PUD and the study consultant to develop a range of alternatives that could lead to modified water temperatures in the Chelan River,
- To simulate these alternatives with the hydraulic and temperature models, and
- To provide this information to the resource agencies and habitat specialists to determine and recommend an appropriate cause of action to maximize use attainment in the Chelan River.

3. Study Design

3.1 Monitoring Parameters and Locations

WEST (2013) recommended that the existing data collection program (consisting of measurements of flows and water temperatures taken from the forebay, penstock, and powerhouse) be continued for two additional years, and that one additional temperature sensor be deployed in the lower part of Reach 1 (to be determined and not shown in Figure 5) to improve the spatial resolution of the observed water temperatures. The sensor will be similar in type and performance characteristics to those currently deployed.

The model study will use meteorological data (including air temperature, dew point temperature, wind speed, and solar radiation from the AgWeatherNet “Chelan South” station, and cloud cover from Chelan and Omak airports. Solar shading (from vegetation and surrounding topography) will be estimated from LiDAR data and direct observations, and used to modify the incident short-wave solar radiation input to the temperature model. As groundwater and hyporheic flows are difficult to measure, we propose to estimate their magnitudes and influence on temperatures in the Chelan River during model calibration.

3.2 Modeling Methods

Model Setup

WEST (2013) considered three temperature models that could be applied to model water temperatures in the Chelan River, CE-QUAL-W2 (Cole and Wells, 2011), HEC-RAS (HEC, 2010), and QUAL2Kw (Pelletier et al., 2006). The report recommended using HEC-RAS to model hydraulic and QUAL2Kw (to model temperature for the following reasons:

- HEC-RAS is in the public domain and agency (Corps of Engineers) supported.
- It can model the complex shapes of cross sections in the Chelan River without having to approximate the channel geometry.
- QUAL2Kw is in the public domain and agency (Ecology) supported, and is extensively used by Ecology and others to dynamically model streamflow temperatures.
- As the critical water temperature conditions occur in the Chelan River during relatively low flows, depth-averaged models are adequate, as the water will be well mixed due to turbulence in the small, complex channels.
- QUAL2Kw is a continuous-simulation model, and therefore can model the maximum water temperature each day.

Table 4 lists the various data sources to develop and calibrate a temperature model of the Chelan River. The geometry for HEC-RAS model will be developed from LiDAR data flown in 2009 and supplemented with existing channel sections where available. Cross sections will be developed nominally at 200-300 feet intervals. Inflows to the Chelan River and flows through the powerhouse to the lower river are measured by the District. The downstream boundary stage will be determined using the HEC-RAS model of the Rocky Reach Reservoir developed for the Corps of Engineers' Columbia River Treaty Study (CRT). This model uses inflows from Wells Dam and Rocky Reach Dam forebay elevations. Inflow temperatures to the Chelan River will be defined using existing measurements in the Project's forebay and low level outlet or most upstream temperature probe. Meteorology will be developed using data at the AgWeatherNet "Chelan South" station on the south shore of Lake Chelan. These data include air temperatures, dew point temperatures, wind speed, and incident short wave solar radiation.

Table 4. Summary of data to develop temperature models.

Data Type	Source
Geometry	2009 LiDAR coverage (0.68 points/sq ft and a vertical accuracy of 0.12 ft). If necessary, selected transects will be ground surveyed for confirmation of LiDAR data
Inflows	Project flows known
Downstream	HEC-RAS model of Rocky Reach reservoir
Inflow temperatures	Measured in forebay
Meteorology	Up to five stations available
Water temperature calibration data	7 stations from dam to Columbia River
Shade	LiDAR coverage and estimation of vegetation heights

HEC-RAS will first be run to simulate hydrodynamics in the Chelan River, and will compute velocities and water surface elevations at each cross section. Once the hydrodynamic model is running properly, QUAL2Kw will then be used to simulate the time histories of temperature at each cross section. The results will be exported to excel, and daily maximums and 7-DADMax values computed at each cross section.

Calibration and Validation

HEC-RAS will be calibrated to flows and QUAL2Kw calibrated to water temperatures measured during one water year of observations. The influence and possible magnitudes of groundwater exchange and hyporheic flow will be accessed during model calibration. The model will then be validated using a second water year of observations. To evaluate model performance, sensitivity analyses and error analysis can be used. The model study will include sensitivity to various sources of model uncertainty including roughness values

(Mannings *n*), groundwater discharges and hyporheic flows. The range of results will be used to characterize model uncertainty.

Model calibration will include visual comparison of time series, and various statistics such as mean error (ME), mean absolute error (MAE), root mean square error (RMSE), and Nash-Sutcliffe (NS) statistics. In general, the ME should be close to zero, the MAE and RMSE should be less than 1^{o}C, and the NS statistic should be close to 1.0. In addition, we will use scatter plots and other measures to assess the model's agreement with observations.

Simulation of Alternatives

To meet the study objectives, scenarios will be modeled to evaluate the potential benefits from adaptive management strategies designed to mitigate warm temperatures. These strategies may include manipulating the river channel, future development of a canopy of riparian vegetation, and increased flow for achieving the biological objectives. The scenarios to the modeled will be developed during consultations between Chelan County PUD, Ecology, and the study consultant.

Evaluate Means to Decrease Summer Temperatures: The model geometry will be modified to include physical modifications to the system such as (1) vegetative shading, (2) channel alterations, (3) changes in low-flow release strategies, etc., and each case simulated for the period of observations using the hydro-temperature model. The 7-DADMax will be computed for each scenario and the results compared between scenarios and existing conditions to assess the effectiveness of each proposed strategy.

Scientific Tools to Determine Designed Aquatic Life Uses: At this stage, beyond the development of the hydro-temperature model, no action is proposed to address this purpose. We anticipate that this determination will be addressed if it is found that means to decrease summer temperatures by physical modifications to the system or Project operations do not achieve the desired objectives.

4. Quality Objectives and Decision Criteria

4.1 Monitoring Objectives

Measurement Quality Objectives (MQOs) and methods for the field measurements in this study are summarized in Table 5.

Table 5. Field Measurement Quality Objectives and Methods (Chelan PUD 2007).

Parameter	Smallest Reference Level for Decision Making	Range of Instrument	Precision (Duplicate Samples)	Bias/ Accuracy	Sensitivity/ Resolution
Temperature	0.3°C	-5 to 50°C	20% RPD or ±0.05 units, whichever is least	± 0.1°C	0.01°C
Flow	10 cfs	0-500 cfs (LLO Flow)	N/A	5% of flow 5-25 cfs	1% of flow 1-5 cfs

4.2 Modeling Objectives

Model quality objectives are not being specified for existing data or for modeling results. However, the following acceptance criteria will be applied:

- *Data Reasonableness*. The quality of existing data will be evaluated where available. Sources within well-established programs will be acceptable based on the data quality standards of the source (such as National Weather Service or USGS data). Data will be reviewed for whether the amount of variability is appropriate, based on statistical measures, expected values, and comparison between data sets. Data with too much or too little variability will not be used.

- *Data Completeness*. Data sets will be used that are reasonably complete during the period of interest. Incomplete data sets will be used if they are considered representative of conditions during the period of interest.

- *Data Representativeness*. Data will be used that are representative of the location or time period under consideration. For example, attention will be paid to the variations in meteorological conditions throughout the study area, and to differences in seasonal conditions.

- *Model Calibration and Validation*. The primary measure of calibration and verification success will be by comparing observed versus modeled temperatures. Bias will be measured by the average residual of paired values (observed-modeled), and precision by the root mean square error of paired values. The goal of this study will be a bias of less than 0.2^{o}C and precision of less than 1.0^{o}C. A greater precision and bias will be acceptable if the model successfully predicts the average days per year that the river exceeds the water quality criterion, higher values are produced by a few outliers, visual inspection of the time series shows good matching of temperature patterns, or if sensitivity analysis shows that the bias and precision of results between paired runs (e.g. natural and current conditions) will be adequate to meet project objectives.

5. Quality Control Procedures

5.1 Monitoring Data

Water temperatures are monitored at six locations in the Chelan River channel and tailrace with temperature recording data loggers (Onset HOBO Water Temp Pro v2) that are set to record the water temperature at hourly intervals. Continuous monitoring, reported as hourly averages, are also measured in the conduit that conveys water from the forebay at the base of the dam to the low level outlet and in the tailrace, representing forebay water from mixed depths after passing through the turbines. The HOBO temperature loggers are factory calibrated, but they are tested prior to each deployment in the field and after deployment. They are set to record at five minute intervals and placed in a water bath, which is initially packed with ice and raised in temperature by 2-3^{o}C at 10 minute intervals until the water temperature reached 30^{o}C or greater. The temperature of the water bath is measured with a NIST Traceable calibrated thermometer at the time of each five minute logging period for the HOBOs. The water bath is stirred periodically during each five minute period to assure that the water bath is well mixed. The HOBO temperature loggers are downloaded and the temperatures plotted against the temperatures recorded from the NIST Traceable calibrated thermometer. Any HOBO temperature logger that fails to consistently match the others and the NIST thermometer is rejected for deployment.

At the two locations with continuous monitoring, recorded several times a minute by the Project's computer system, the temperature sensors are calibrated with a 3-point test, using a thermal block calibrator at time of installation or repair. Because there are several sources for error or drift, including the sensor and the electronics linking with the computer system, these locations have been backed up with HOBO loggers located in the vicinity.

5.2 Model Study

At each project milestone, the lead internal reviewer will evaluate study details to that point. The lead reviewer will develop a series of "Comments" in a WORD document. Next, the Project Manager will review and respond to these comments making changes to the model study as necessary. In the same WORD document, the Project Manager prepares "Responses" to each comment. Once all responses have been prepared, the lead reviewer than evaluates the responses and prepares a series of "Backchecks". Each backcheck may either accept the response or require that additional work by performed. The process is repeated until the lead reviewer closes each comment, satisfied that they have been dealt with appropriately.

Project milestones include:

- Model development and calibration

- Simulation of alternatives
- Preparation of draft final report.

6. Data Review, Quality Assessment, and Validation

There is significant data collection that will be used to develop a temperature model of the Chelan River. Since the deployment of the Agrimet station at Manson in 1972, AgWeatherNet stations were deployed by Washington State University at Brays Landing in 2006, and at Chelan South and Boyd District in 2008. Together with temperature sensors deployed in the projects forebay and along the Chelan River since 2009, continuous flow measurements, a LiDAR survey, and some channel cross sections, there are plenty of data to develop a hydro-temperature model of the Chelan River.

Table 6 lists the various data types, the equipment used, and its reported precision.

Table 6. Field Measurement Quality Objectives for non-PUD Data.

Parameter	Location	Equipment	Agency	Precision	Source
Flows	Stehekin River Gauge No. 12451000		USGS	Fair (+/- 8%) with some Good (+/- 5%)	http://waterdata.usgs.gov/WA/nwis/current/?type=flow
Air temperature	Chelan S.	Model 107 Temperature Probe	AgWeatherNet	±0.2°C tolerance over the 0° to 50°C	http://weather.prosser.wsu.edu/awn.php?page=standardequipment
Relative humidity	Chelan S.	PC72V Relative Humidity and Temperature Transmitter Digital	AgWeatherNet	±2% RH at 23°C	http://weather.prosser.wsu.edu/awn.php?page=standardequipment
Wind speed	Chelan S.	Model 014A Met One Wind Speed Sensor	AgWeatherNet	0.11 m/s	http://weather.prosser.wsu.edu/awn.php?page=standardequipment
Wind direction	Chelan S.	Model 024A Met One Wind Direction Sensor	AgWeatherNet	5 degrees	http://weather.prosser.wsu.edu/awn.php?page=standardequipment
Solar Radiation	Chelan S.	CS300 Pyranometer	AgWeatherNet	±5% for daily total radiation	http://weather.prosser.wsu.edu/awn.php?page=standardequipment
LiDAR	Wenatchee area	Leica ALS50 Phase II laser system	Puget Sound regional Council	Vertical accuracy 0.12 ft (3.6 cm)	Watershed Science (2009)

LiDAR Data

A LiDAR survey was flown in 2009. These data have reviewed processed and reviewed by the Puget Sound Regional Council, and are accepted for use (USGS 2009). We will develop the initial model geometry using these data. The data have a horizontal resolution of 0.68 points/sq. ft. and a vertical accuracy of 0.12 feet. From the survey, a 3-ft by 3-ft DEM was developed.

Surveyed Channel Sections

Some channel sections have been surveyed by the District. We will review these data where they overlap with LiDAR data, and demonstrate that they meet survey data quality standards. These sections will be used to define the in-water portions of cross sections originally cut from the LiDAR data. Where channel surveys are not available, the District will conduct ground surveys of transects as needed to supplement LiDAR data. During 2014, District staff will access the current shade potential by estimating the heights of existing trees and their distances from the river.

River Inflows

The District monitors flows into the Chelan River (1) through the low-level outlet, (2) over the spillway, and (3) through the penstock to the powerhouse where it is discharged to the lower river. Flows in the low-level outlet are measured with an ultrasonic flow meter. Spillway flows are calculated from lake level readings and gate settings, for which rating tables exist. The rating tables have been conformed to accuracy standards in cooperation with the United States Geological Survey (USGS) through river stage and flow measurements in the river channel at an existing USGS stream hydrology station located a short distance downstream from the spillway apron. This gauging site is known as USGS 12452500 Chelan River and Chelan, which combines powerhouse discharge flows reported by the District with the spillway and low-level outlet flows, as corroborated with the stream gauging site (PUD No. 1 of Chelan County, 2007). Data for this site is reported at http://waterdata.usgs.gov/usa/nwis/nwisman/?site_no=12452500&agency_cd=USGS. The period of record given for this gauge spans from 1903 to present.

The District also has the ability to estimate flows to the Chelan River for "without Project" conditions using Lake Chelan levels and inflows to Lake Chelan measured from 1911 to present at USGS streamgauge No. 12451000 (Stehekin River at Stehekin), http://nwis.waterdata.usgs.gov/nwis/peak/?site_no=12451000&agency_cd=USGS&

Water Temperatures

Water temperatures have been measured hourly since fall 2009 (1) in the Project's forebay (thermistor string at 5-feet intervals from elevation 1070 to 1100 feet NAVD 29[1]), (2) in the low-level outlet, and (3) along the Chelan River (Figure 3). The temperature loggers (Onset HOBO Water Temp Pro v2) at each location are exchanged several times during the year

[1] The USGS website indicates the Lake Chelan headwater elevation is based on the NGVD of 1912 datum and to convert to NGVD 1929 subtract 1.73 feet. The Lake Chelan tailrace is based on the NGVD of 1912 datum and to convert to NGVD 1929 subtract 1.62 feet.

to retrieve the data. These data are reviewed for anomalies, such as being exposed to air as water levels decrease at the Project's forebay during annual drawdown or due to low tailwater levels, instrument malfunction producing obvious outliers, and unreasonable trending over time, which may indicate hyporheic flow.

Meteorological Data

We will use meteorological data from the "Chelan South" AgWeatherNet station (Figure 8). These data include air temperature, dew point temperature, wind speed, and incident short-wave solar radiation. These data have been reviewed by AgWeatherNet staff at Washington State University and are available for use.

Cloud cover is not measured at AgWeatherNet stations. The nearest weather stations that measure cloud cover are the Wenatchee Pangborn Field Airport and Omak Airport. These data have been reviewed and are available for use. Data from both sites will be considered when developing values for the Chelan River.

Downstream Stages

The Chelan River terminates at its confluence with the Columbia River. The backwater influence from the Columbia River is limited due to the steep gradients found in the Chelan River. The largest discharge found in the USGS records (Columbia River at Rock Reach Dam, 12453700) from 1961 to present occurred in June 1961. The flow was 535,000 cfs with a corresponding stage 635.5 feet.

There is an HEC-RAS model of Rocky Reach Reservoir developed for the Corps of Engineers' Columbia River Treaty (CRT) study. This model uses inflows at Wells Dam upstream and forebay elevations at Rocky Reach Dam. The District measures the forebay stage continuously and reports values each hour.

Model Quality Review

The hydro-temperature model study will be managed by a senior and experienced modeler. We will also assign another senior engineer, not directly involved in the model development, calibration, and application, to lead an internal review of the model study. The review process will follow the methodology of the Corps of Engineers' DrChecks process. The review process will be somewhat continuous during the modeling project, but focused at milestone events, such as model set-up, model calibration, model validation, and model reporting.

7. Project Responsibilities and Schedule

- *Steve Hays (The District).* Program manager, responsible for supervision and completion of field sampling, analysis of quality of project data, and responsible for review of draft and final reports.
- *Raymond Walton (WEST Consultants, Inc.).* Project manager and lead modeler, responsible for overall project management, preparation of QA Project Plan, supervision and completion of numerical modeling, and overall preparation of technical content of draft and final reports.
- *John Howard (WEST Consultants, Inc.).* Project engineer, responsible for internal review of model development and application.
- *Pat Irle and Paul Pickett (Ecology).* Responsible for review of draft QA Project Plan and final report, focusing on issues related to State of Washington water quality and permit compliance.

8. Project Schedule

The timing of technical works phases related to the temperature model study of the Chelan River depends, in part, on the collection and review of additional data. However, in general, sufficient data exist to develop and calibrate the model, and to begin model simulations of mitigation alternatives. Table 7 shows the schedule for the temperature model study and technical report.

Table 7. Project Milestones.

Report Milestone	Due Date
Draft Internal review	December 31, 2014
Draft External Stakeholder Review	February 28, 2015
Final Report Published	June 30, 2015

9. References

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USGS, "LiDAR Remote Sensing Data Collection: Wenatchee – USGS AOI, WA", prepared by Watershed Science, Corvallis, OR, for USGS, Seattle, WA, Spetember 24, 2009.

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WEST Consultants, Inc., "Technical Report on the Development of a CE-QUAL-W2 Model for the Rocky reach Hydroelectric Project", prepared for Public Utility District No.1 of Chelan County, Draft, July 2005.

WEST Consultants, Inc., "Chelan River Temperature Assessment", prepared for Public Utility District No.1 of Chelan County, Draft, November 2013.

Response to Ecology (WDOE) Comments Dated February 21, 2014

Regarding Draft Quality Assurance Project Plan

Chelan River Temperature Model

Issued January 15, 2014

COMMENT 1: Why is this included in this QAPP? If you want to include, perhaps you would also like to include the results in the description of the area and project.

RESPONSE 1: First bullet was removed as this study was completed prior to Low Level Outlet construction.

COMMENT 2: More information on hydrology would be helpful. Table of average "natural" inflows to the lake by month would be illustrative. High and low flow statistics would also be helpful (e.g. 7Q10 peak and low flow). Same for outflows from the Lake into the River.

RESPONSE 2: Summary of Stehekin River and Chelan River gauges included. Low flows into Lake Chelan are not very enlightening as the residence time is so long (tens of years). Low flows from the Project are not very enlightening because they are defined by Ecology Orders 1233 and 6215.

COMMENT 3: A graphic of the dam, penstocks, and powerhouse would be helpful.

RESPONSE 3: Included as Figure 2.

COMMENT 4: Because of the complexity of this reach, provide a zoomed-in map or diagram.

RESPONSE 4: Included as Figure 4.

COMMENT 5: Provide the definition of "natural"

RESPONSE 5: Added definition from WAC 173-201A-260.

COMMENT 6: Cite the "Compliance schedules for dams" in WAC 173-201A-510 (5).

RESPONSE 6: Added to text.

COMMENT 7: Move to end of this section.

RESPONSE 7: Moved to Section 2.1 – Project Description.

COMMENT 8: A table with all of the thermistor locations (description and lat/longs) and depths would be helpful.

RESPONSE 8: Table 3 was added with this information.

COMMENT 9: Describe dimensions, flows and when the flows occur.

RESPONSE 9: Dimensions added to this section and flow timing added to Section 2.2, Project

COMMENT 10: Provide a zoomed-in map of the forebay with location of thermistor strings, low level outlet thermistor, outlet inlet, etc.

RESPONSE 10: Figures 6 and 7 added.

COMMENT 11: Seven thermistors, if I counted correctly? Say this explicitly. Also, are they anchored at these depths (suggesting that the surface one varies in depth), or are they floating (moving vertically but constant depth)? If the former, do you have a way to track the depth of the string?

RESPONSE 11: Text modified to clarify.

COMMENT 12: I only count 6.

RESPONSE 12: Text modified to clarify there are eight temperature probes.

COMMENT 13: However, only one has been used? What about the USGS met data you discuss later? What would you do with data from the other stations? How relevant would that data be?

RESPONSE 13: The text has been modified to note that while five nearby meteorological stations were noted, only the closest one (AgWeatherNet Chelan South Station) will be used. There is no discussion of "USGS met data" in the report.

COMMENT 14: **P**rovide a table of these stations with their official designation, sponsoring organization, parameters monitored (needed for model) and link to data.

RESPONSE 14: See Response 13. The information for AgWeatherNet Chelan South Station is included in the text.

COMMENT 15: What constitutes "significant"?

RESPONSE 15: Text changes to say greater than 2°C.

COMMENT 16: **S**ee comment above – does the shallowest string vary in depth, and what is the range it can vary by?

RESPONSE 16: The response to Comment 11 notes that the thermistors have fixed elevations. Therefore, the vertical difference is the temperature of the shallowest in-water thermistor minus the temperature at the near-bottom thermistor. The word "nearest" is added to the text to clarify this.

COMMENT 17: Could you be more specific? E.g., show % of time that delta is less than 0.3°C for each of the months of June, July and August?

RESPONSE 17: The analysis based on 0.3˚C would not be very relevant as the discussion is about vertical stratification not temperature gain over a reach. Also, the temperature loggers have sufficient measurement error to make a perceived difference of 0.3°c only marginally significant. In addition, the focus of the study is towards conditions in the Chelan River below the dam, where water temperatures quickly equilibrate to ambient thermal loading, as evidenced by empirical measurements since 2009. Also, a UAA rather than temperature compliance will be the likely end product of this model study. The discussion in the report was simply to note that vertical stratification was periodically observed in the temperature data in the forebay.

COMMENT 18: Can you demonstrate this with data? This should be something that can be analyzed and shown. The "Lake Chelan Water Quality Assessment" (Ecology 1989) provides a detailed analysis that could be helpful. It appears that steady winds along the basin push water up into the Wapato basin and can push cold hypolimnetic water over the sill. Wapato appears to have minimal seiching of its own, but perhaps enough to push cold water up towards the outlet. It could be helpful to explore if conditions can be identified (wind speed and direction for example) that correlate with the cooler, deeper water.

RESPONSE 18: This would be very difficult to do without the data collected during 1989 and supporting meteorological data (some of which does not exist). In addition, it would take a considerable effort to analyze, and the result would not really change the proposed modeling approach proposed for the Chelan River.

COMMENT 19: Could you show me that this is sizeable, relative to solar radiation, by doing a quick calculation for me? E.e., mid day July 1 for solar vs. 100oF for convection.

RESPONSE 19: Text change to "either heats up or cools down in response either meteorological and/or groundwater conditions". The reponse to either solar radiation or convection is better evaluated later using the temperature model.

COMMENT 20: Blow this graph up, improve its quality (higher dpi) and put on a single landscape page.

RESPONSE 20: Done.

COMMENT 21: Also, could you add graph, plot delta temperature of top minus bottom over time?

RESPONSE 21: Done.

COMMENT 22: Could you explain in more detail how you calculated this? E.g., By adding all the lowest forebay thermistors and averaging them?

RESPONSE 22: Text is modified to clarify.

COMMENT 23: Another question: How representative of "natural" conditions is the bottom temperature? Are you proposing to use the LLO as representative of "natural" inflow to the river?

RESPONSE 23: The purpose of this analysis and text is to report observations, not to comment on whether they represent "natural" conditions. This is because it is difficult to determine what are "natural" conditions in a system where the lake's surface could be different (generally higher) than conditions before the dam was built.

COMMENT 24: Thanks for the plot!

RESPONSE 24: You're welcome.

COMMENT 25: Explain exactly how "temperature difference" is calculated, including which monitoring location(s) are used. (Figure 9, too)

RESPONSE 25: Text modified to clarify.

COMMENT 26: Thanks for the plot!

RESPONSE 26: You're welcome.

COMMENT 27: Perhaps nearby cliffs, as well?

RESPONSE 27: “Cliffs” added.

COMMENT 28: To bridge from this discussion to the specific case, discuss processes in a moving stream – advective transport, turbulence and mixing, kinetic energy dissipation – which can affect temperatures as well.

RESPONSE 28: Two sentences are added relating to the effects of flow rate versus travel time and volume of water as they relate to heat exchange processes.

COMMENT 29: What is meant by this?

RESPONSE 29: “Intensity” changed to “magnitude”

COMMENT 30: And slope and turbulence perhaps

RESPONSE 30: Text modified to include.

COMMENT 31: Citation? Add some discussion of previous model used, its limitations, and some of the concerns about model use expressed at the time.

RESPONSE 31: Citation added. Also, a “discussion of previous model used, its limitations, and some of the concerns about model use expressed at the time” is the subject of the companion “Chelan River Temperature Assessment” report. Since we are not proposing to use the SNTEMP model, we believe it better to keep the focus of this QAPP on what we plan to do moving forward.

COMMENT 32: How do you know?

RESPONSE 32: This was noted in the 2002 report (not as a conclusion of this analysis).

COMMENT 33: Are we using the top surface as the input temperature of water to the Chelan River? Vs. the LLO?

RESPONSE 33: Not necessarily. We can use top or bottom to evaluate potential thermal changes during passage along the Chelan River. However, at minimum flows the LLO is the sole source of water. When the spillgates are in use, the water coming from the spillway bays is a mixture of water from elevation 1087 to the surface. The temperature logger at the top of Reach 1 is positioned to measure the input temperature consisting of the mixture of spill bay water and LLO water.

COMMENT 34: Provide Celsius temperature, since that’s what the standards use/

RESPONSE 34: Done.

COMMENT 35: This section should be used to describe the goals and objectives of the study. Needs overall statement of goal

RESPONSE 35: Text modified, and paragraphs switched.

COMMENT 36: This summary is not exactly accurate.

RESPONSE 36: Text modified, and paragraphs switched.

COMMENT 37: Based on the comments from EPA, the first purpose should be considered optional.

RESPONSE 37: Based on our discussions, the item is removed from the text at this time.

COMMENT 38: These looks like objectives, but should be stated more clearly and definitively

RESPONSE 38: Text modified, and paragraphs switched.

COMMENT 39: I think it would be very helpful if all information about data collection be combined in one location and on one table, perhaps following the discussion of the selection of the models.

RESPONSE 39: We had separated them because Table 4 represents ongoing data collection by Chelan PUD, whereas Table 5 represents ongoing data collection by outside agencies, over whom we have no control of their data methods and quality.

COMMENT 40: Show on the zoomed-in diagram I suggested.

RESPONSE 40: Text changed to "To Be Determined". The proposed new monitoring location is for an intermediate location between the beginning and end of Reach 1, primarily to determine if water temperatures in this section reach equilibrium in the upper end of this section. This information could be useful for evaluating the potential for shade or channel narrowing in this section of the Chelan River. The "zoomed in" diagram was recommended for a different section of the Chelan River (Reach 4).

COMMENT 41: A discussion is needed here of the meteorological parameters needed for modeling and and where the data will be obtained. This section also needs to address methodology for shade, channel morphology, and ground water.

RESPONSE 41: Text added to address these considerations.

COMMENT 42: Discuss the short-comings of HEC-RAS and the potential advantages and shortcomings of QUAL2kw as a "Phase 2" model. Show that data collection would serve either one

RESPONSE 42: Text was revised to "recommend" that HEC-RAS be used to model hydraulics and that QUAL2Kw be used to model temperature.

COMMENT 43: Why not just measure the stage? Otherwise you have another model that needs data collection, runing, etc.

RESPONSE 43: We would still need to develop stages for historic conditions. The HEC-RAS model already exists and is simple to use. Also, except when backwatered by high flows in the Columbia River, the hydraulic control for the Reach 4 habitat channel is at the last riffle, where the final temperature probe is located, and at the base of this riffle the habitat channel water mixes with tailrace water. In addition, we could explore how sensitive this boundary is.

COMMENT 44: Which one?

RESPONSE 44: Text modified to clarify that we propose to use the AgWeatherNet "Chelan South" station for meteorological data.

COMMENT 45: Need to include shade and ground water exchange

RESPONSE 45: This table discusses sources of data. Groundwater exchange, I think, will be a model calibration variable. It would be extremely difficult to measures, especially at low flows (80 cfs) over the 3.5 mile length of Reaches 1-3. Shade was added to the table.

COMMENT 46: Need to include horizontal resolution.

RESPONSE 46: Added to table. Also added ground surveys as necessary to confirm LiDAR data.

COMMENT 47: Explain how. Seepage runs?

RESPONSE 47: "Groundwater inflows" removed from table. Text added to "Calibration and validation"

COMMENT 48: Combine this with Tables 3 and 4.

RESPONSE 48: Disagree. This table (now Table 4) summarizes the general data types for modeling needs. The other two tables (now Tables 5 and 6) specific present station data and collection methods, and fall in different report sections. This format is similar to the September 2004 Ecology QAPP for the Pend Oreille River.

COMMENT 49: We should discuss this. It might be better to calibrate to two years.

RESPONSE 49: Disagree. In my view, a model is better justified if there are separate calibration and validation steps. However, having said that, it is not uncommon for some further model adjustments after "validation", so the point might be moot. The following sentence was added: "The influence and possible magnitudes of groundwater exchange and hyporheic flow will be accessed during model calibration."

COMMENT 50: Provide specific information on how the model quality will be evaluated. What metrics will be used for precision and bias, how will data be pooled, etc?…

RESPONSE 50: Text added to explain. As a further note, empirical data for 2010 – 2013 already exists and the calibrated model can be used to "backcast" temperatures for comparison with this empirical data to further evaluate the model.

COMMENT 51: As noted above, goals and objectives should be stated clearly. Then you can just say "to meet the study objectives…"

RESPONSE 51: Text modified.

COMMENT 52: Describe the process for choosing scenarios. Will there be consultations between PUD, Ecology, and WEST on this point?

RESPONSE 52: Text modified to note consultation.

COMMENT 53: I suggest this all be moved under the 401 certification requirements.

RESPONSE 53: Text moved, and blended with similar text.

COMMENT 54: This seems out of place and perhaps unnecessary.

RESPONSE 54: Text moved (see Response 53).

COMMENT 55: You should consider doing a spot measurement with a spirit thermometer when visiting the HOBO.

RESPONSE 55: The Hobos are run through an accuracy test from 0.2°C – 30°C, using a water bath and NIST Calibrated traceable lab thermometer, both before and after each deployment. Chelan PUD will add field measurements with a spirit pocket thermometer to the deployment protocol. The Hobo is not readable in the field, so the pre-deployment test in the office is necessary to assure proper function.

COMMENT 56: This might go better under "Quality Assessment" in a subsection on model quality review. Provide details on when this review will occur.

RESPONSE 56: Moved as suggested.

COMMENT 57: Citation?

RESPONSE 57: Added.

COMMENT 58: Consider additional cross-section this summer. This could be combined with a seepage survey and shade assessment.

RESPONSE 58: The following was added: "Where channel surveys are not available, the District will conduct ground surveys of transects as needed to supplement LiDAR data". Also, added this to table as noted in response to comment 46.

COMMENT 59: Would it be possible to work with AgriMet to upgrade a weather station to include cloud cover? The Wenatchee Airport is a fair distance away and up on a plateau farther from the foothills. Alternatively, you may want to use Omak as well (a similar distance in the opposite direction) and take an average.

RESPONSE 59: We don't believe this is feasible for a number of reasons. First, cloud cover has a minor influence on solar radiation if incident short-wave solar radiation is measured (which the AgWeatherNet stations do). Second, the AgWeatherNet stations have a uniform set of equipment. They are not likely to want to add more instrumentation and maintain it. Third, we would still need to use existing cloud cover data to process historic data. We did modify the text to mention to Omak cloud cover data.