Updated Pend Oreille River Model
Development, Calibration, and Application

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November 2009

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Updated Pend Oreille River Model Development, Calibration, and Application Draft

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Final report
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Prepared for U.S. Army Corps of Engineers
Abstract: The operation of Albeni Falls dam has altered water surface elevations in the Pend Oreille River and adjoining Lake Pend Oreille during the summertime. The higher summertime water surface elevations have influenced both the thermal exchange between the river and lake and time of travel to the dam. A two-dimensional hydrodynamic and water quality model of the Pend Oreille River was developed by the Idaho Department of Environmental Quality to characterize the thermal budget of the Pend Oreille River and support the development of a Total Maximum Daily Load for water temperature on the Pend Oreille River. A number of deficiencies contributing to inaccuracies in the original IDEQ model are noted in this report. Revisions to the IDEQ model were made by the COE and updated model calibration results presented for 2004 and 2005. Model calibrations were improved allowing the revised model to more accurately portray the physical flow environment in the Pend Oreille River and the associated thermal characteristics. The major sources of model improvements were changing the upstream boundary condition, use of alternative weather data, updating model coefficients, and modifications to the model grid.

The revised model was used to investigate impacts of Albeni Falls Dam on water temperatures in the Pend Oreille River by simulating existing and natural conditions. The influence of Albeni Falls Dam on Pend Oreille River temperatures is dependent upon the time of year, river reach, and temperature metric. The following conclusions were derived from a statistical evaluation of the simulated water temperatures in the Pend Oreille River during the critical summertime period throughout the study period. The exchange of cooler subsurface water from Lake Pend Oreille to the Pend Oreille River has been promoted by the existence and operation of Albeni Falls Dam. The maximum daily average surface water temperatures for existing conditions are generally equal to or cooler than natural conditions over nearly all of the Pend Oreille River. Daily average water temperatures released from Albeni Falls Dam during the summertime are similar to pre-dam conditions while daily maximum temperature are slightly cooler. Water temperatures during natural conditions are more responsive to changes in hydrologic and meteorologic conditions compared to existing conditions causing natural river temperatures to be warmer during hot weather and slightly cooler during cool weather events when compared to existing conditions.
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Preface

The U.S. Army Engineer District Seattle (NWS) funded the work described in this report. The report was prepared by Mr. Mike Schneider, U.S. Army Engineer Research and Development Center (ERDC)-Coastal and Hydraulic Laboratory (CHL) and Mr. Kent Easthouse, U.S. Army Seattle District. Mr. Ed Zapel (NWS) and Stewart Rounds (USGS) provided the technical review of this work.
Unit Conversion Factors

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Introduction

Background

The Albeni Falls Dam (AFD) is located on the Pend Oreille River (POR) in northern Idaho State at river mile 90.1 about 2.5 miles upstream of the Washington and Idaho State borders (Figure 1). The Project is owned and operated by US Army Corps of Engineers, Seattle District. Construction of the Project was initiated in 1951 with the final generating unit placed in service in 1955. The authorized purposes for Albeni Falls Dam include flood control, water supply, hydropower, recreation, and navigation. The operation of Albeni Falls dam has altered water surface elevations in the Pend Oreille River and adjoining Lake Pend Oreille (LPO). Albeni Falls Dam varies the level of Lake Pend Oreille according to the season. The lake is maintained in its normal range of between 2,062.0 and 2062.5 ft during the summertime. In the fall, the lake is drafted to its winter level of 2051.0 ft. to provide room for flood storage. The lake is maintained in its low range until the spring snowmelt again refills the lake for the summer season.

Figure 1 Location Map of Albeni Falls Dam, Pend Oreille River, and Lake Pend Oreille.
Portland State University (PSU) developed and calibrated a hydrodynamic and water quality model of the Pend Oreille River (POR) from Lake Pend Oreille (LPO) to Albeni Falls Dam (AFD) using CE-QUAL-W2 for the Idaho Department of Environmental Quality (IDEQ) (PSU 2006). The purpose of the modeling effort was to support IDEQ in developing a temperature Total Maximum Daily Load (TMDL) for the Idaho portion of the Pend Oreille River. As part of the Watershed Advisory Group (WAG) the Seattle District Corps of Engineers (COE) reviewed this model and identified several deficiencies with the model which were presented to IDEQ, the Environmental Protection Agency (EPA) Region 10, the Washington Department of Ecology (WDOE) and others at WAG meetings in 2006 and 2007. During a November 18, 2008 meeting with IDEQ, EPA Region 10, and WDOE, the COE presented a revised version of the original IDEQ model which solved many of the deficiencies of the original model, and provided improved simulations of the hydraulic and water temperatures in the Pend Oreille River. At this November 18, 2008 meeting IDEQ and EPA Region 10 agreed that the COE updated model was an improvement and gave the COE the authority to finalize model updates. Once model updates were finalized, IDEQ and EPA Region 10 agreed that the updated model would be used to support IDEQ in the development of a Pend Oreille River temperature TMDL.

**Objectives**

The objectives of this project were to:

- Revise and update the existing IDEQ Pend Oreille River CE-QUAL-W2 model
- Calibrate the updated model to field data collected during 2004 and 2005 using the following variables:
  - Flow and water surface elevation
  - Water Temperature
- Compare the updated model calibration with the original model calibrations
- Generate updated model simulations based on IDEQ scenarios for existing and natural conditions in the Pend Oreille River

This report first presents an overview of the deficiencies of the original IDEQ model and the reasons they were deemed critical to accurately mod-
eling water temperatures in the Pend Oreille River. Second, the report de-
tails the revisions made by the COE to the original model and presents
model calibration data. Third, the report presents model simulation re-
sults for existing and natural conditions for 2004 and 2005 using IDEQ
scenarios and methods. Fourth, an alternative method to assess model re-
sults with different travel times by using frequency analysis is presented.
And lastly, the report discusses the use of the CE-QUAL-W2 model for
compliance determinations with temperature standards at a 0.3 °C toler-
ance.
Review of Existing Model

Overview

The Idaho Water Quality rules have identified the designated uses for the Pend Oreille River from Pend Oreille Lake to the Washington border are cold water aquatic life, primary contact recreation and domestic water supply. Idaho numeric temperature water quality standards require an instantaneous maximum water temperature of 22 °C or less with a maximum daily average water temperature of no greater than 19 °C for protection of the cold water aquatic life beneficial use. An important exception to the numerical temperature standards for the state of Idaho is the recognition that no impairment of beneficial uses or violation of water quality standards shall occur where natural background conditions exceed any applicable water quality criteria. The Idaho Department of Environmental Quality has set a 0.3 °C limit on human-caused increase in water temperature above natural background temperatures when the estimated natural background temperature is above the applicable numeric criteria. The Pend Oreille River has been identified as water quality impaired as cited in the 2008 Integrated Report (IDEQ, 2008) and temperature has been listed as the cause of impairment to the Cold Water Aquatic Life beneficial use of the river. Consequently, the river was included in the 303(d) list as impaired for temperature, and IDEQ is developing a total maximum daily load (TMDL) for the main stem of the Pend Oreille River from Lake Pend Oreille to the Idaho/Washington border. The TMDL for temperature is designed to identify the primary sources of heat causing the thermal impairments in the POR and allocate heat loads to these sources that will lead to compliance with Idaho state temperature standards.

A CE-QUAL-W2 water quality model was developed for the Pend Oreille River to support the development of a TMDL for water temperature. The CE-QUAL-W2 model is a two-dimensional, laterally averaged, hydrodynamic and water quality model. Contractors from PSU developed a CE-QUAL-W2 model for IDEQ which simulates “natural” and existing water temperatures in the Pend Oreille River in Idaho between Sandpoint and Albeni Falls Dam. A technical report summarizing the development of the POR model was prepared by PSU entitled “Idaho Pend Oreille River Model, Model Development and Calibration” (Annear and Wells, 2006). The application and analyses of the POR model to various existing and “natu-
r al” conditions simulations with and without the influence of Albeni Falls Dam was documented in the report entitled “Idaho Pend Oreille River Model, Model Scenario Simulations” (Annear et. al, 2007a).

As part of the WAG, the Corps of Engineers, Seattle District (COE) conducted a review of the POR model (COE, 2007a) and identified several deficiencies in the proposed POR model. Of particular importance was the model’s use of summertime POR flows almost twice the actual observed levels for the model simulations of existing conditions for 2004 and 2005. The use of incorrect flows prompted the revision of the model as described in “Idaho Pend Oreille River Model, Model Scenario Simulations (Annear et. al. 2007b). The COE subsequently conducted further review of this model and report as contained in (COE, 2007b). These observations were also presented to the WAG in 2007 and 2008.

Methods

A review by the COE of the IDEQ CE-QUAL-W2 model input, results, and analyses methodology for the Pend Oreille River temperatures has identified a number of issues regarding the accuracy, reliability, and applicability of model results used in the temperature TMDL. The nature of these modeling deficiencies has an important influence on characterization of the thermal budget of the POR and impacts of Albeni Falls Dam. This document discusses the sources of error in the current hydrodynamic and water quality model of the Pend Oreille River. An updated model is presented that more accurately portrays the physical environment in the Pend Oreille River and the associated thermal characteristics. The results from this revised model are presented and thermal properties of the Pend Oreille River with and without Albeni Falls Dam are presented.

Model Deficiencies

The adequacy or deficiency of a numerical model will be based in part upon how the results will be applied to the decision making process. Water Temperature Total Maximum Daily Load studies often utilize numerical models to simulate water temperatures in a water body based on current conditions or hypothesized alternative and ‘natural’ conditions. These simulated thermal characteristics are then used to determine compliance with numeric standards or when applicable the “natural conditions”. The IDEQ has stipulated that simulated temperature differences with toleranc-
es of 0.3 °C between existing and the applicable numeric standard will provide the basis for determining non-compliance with water quality standards. The temperature metrics used by IDEQ to assess compliance with water quality standards on the Pend Oreille River have involved simulated daily maximum and average water temperatures in individual computational cells with particular attention placed on surface and bottom cells. The use of simulated temperatures in a single cell at a specific point in time to determine water quality compliance places a premium on developing a model that provides accurate and unbiased estimates. It is recognized that uncertainty in model estimates can never be eliminated because of limitations to quantifying existing and hypothetical natural river conditions through direct observation or with numerical models. However, the uncertainty in model estimates and selection of temperature compliance metrics and methodology should be carefully considered when using model results to settle issues related to state water quality statutes.

Issues related to the accuracy and reliability of the IDEQ temperature model of the Pend Oreille River were raised by the COE on numerous occasions through the Watershed Advisory Group. The initial IDEQ model report was found to be based on an inaccurate hydrograph where assumed summer flows were nearly twice the observed conditions resulting in the first revision of the modeling study. The accuracy and reliability of the revised IDEQ calibrated model of the Pend Oreille River were reviewed through a comparison with observed water temperature data. The most comprehensive data set collected in the Pend Oreille River upstream of Albeni Falls Dam and used by PSU for the model was collected by the US Army Corps of Engineers during 2004-2006. The five COE sampling stations for water temperature profiles used to develop the Pend Oreille River CE-QUAL-W2 model are shown in Figure 2. Issues of IDEQ model inaccuracy remain with regards to the simulation of surface temperatures, the applied thermal flux between Lake Pend Oreille and the Pend Oreille River, the simulation of bottom temperatures, the simulation of natural Lake Pend Oreille elevations, the channel bathymetry, and the numerical mesh used to simulate surface exchange processes. The following section discusses each of these issues in greater detail.
Figure 2 Water temperature sampling stations in the Pend Oreille River and Lake Pend Oreille provided by the US Army Corps of Engineers and US Navy.

**Surface Temperatures**

The attention to surface water temperatures in Pend Oreille River has been heightened in this TMDL because IDEQ has defined compliance with the daily maximum water temperature standard in individual surface cells. The ability to accurately simulate the daily maximum temperature in a single surface cell is a much greater challenge than establishing the daily maximum temperature over the water column. Detailed hourly observations of surface and subsurface temperatures were collected at Riley Creek, Albeni Falls Dam, and the Long Bridge in the Pend Oreille River by the US Army Corps of Engineers, Seattle District from April to November for the years 2004 to 2006. This data set constitutes the most comprehensive record of surface and subsurface temperatures in the Pend Oreille River and was the focus of determining the predictive error of the IDEQ model of the Pend Oreille River. The results of this analysis were documented in USACE, 2007 Appendix B for the Riley Creek sampling station. The time
history of hourly observed and calculated water temperatures in the Pend Oreille River near Riley Creek at depths of 3, 20, and 40 ft are shown in Figure 3 for the period from June 21-September 21, 2004. The IDEQ model calculated surface temperature over-predicted the observed conditions consistently and to a significant degree throughout the critical summertime period in 2004. The mean error in daily maximum surface temperatures in the Pend Oreille River at Riley Creek during the critical summertime period in 2004 was 1 °C with a maximum error over 3 °C. The diurnal variation in calculated surface temperature was much larger than observed as was the vertical gradient in water temperature between the surface and 40 ft.

![Figure 3](image-url) **Figure 3** Time history of hourly calculated and observed water temperatures in the Pend Oreille River near Riley Creek, June 21-September 21, 2004 (Tmp-cal 3 ft = Calculated temperature at a depth of 3 ft, Tmp-obs 3 ft = Observed temperature at a depth of 3 ft)

The use of a model that over-predicts surface temperatures is a concern because the compliance methodology used by IDEQ features temperatures simulated in surface cells. An example of the application of numerical model results that over-predicts observed surface conditions in the determination of compliance with IDEQ temperature standards is illustrated in Figure 4. The calculated temperature profiles on July 25, 2004 for exist-
ing conditions (scenario 1) and natural conditions (scenario 8) of the Pend Oreille River near Riley Creek are shown in light blue and pink, respectively. The daily maximum standard in this case (red line) is determined to be 0.3 °C warmer than surface temperatures determined by the natural conditions simulation. A violation of the IDEQ standards is indicated by the simulated existing conditions exceeding the calculated standard in this case. However, the observed conditions (green circles) indicate a wide disparity between the observed and calculated maximum temperature conditions in this reach of the river. The observed maximum daily temperature was about 2.5 °C cooler than the calculated standard. Updating the thermal model of the POR (dark blue line) by eliminating many of the biased estimates in the temperature field will result in a more accurate description of thermal properties and related thermal impacts in the POR.

![Temperature Profiles in the Pend Oreille River near Riley Creek](image)

**Figure 4.** Observed and Calculated Temperature Profiles in the Pend Oreille River near Riley Creek, July 25, 2004 at 1800 hrs. (SC1-Existing Conditions, SC8-Natural Conditions)

**Thermal Flux between Lake Pend Oreille and Pend Oreille River**

A critical component of this study centers on the exchange of water and heat between Lake Pend Oreille and the Pend Oreille River. The IDEQ temperature model begins at the Railroad Bridge at Sandpoint and does
not include the much deeper Lake Pend Oreille. Lake Pend Oreille becomes strongly stratified during the summer months where surface temperatures routinely exceed the numeric temperature standards for rivers. The higher lake levels during the summer months with Albeni Falls Dam in place allow greater exchange of subsurface water between the lake and river when compared to the shallower conditions without Albeni Falls Dam. The current IDEQ model assumes the temperature profile observed at the Contest Point Sampling station in Lake Pend Oreille (ALFLPS in Figure 2) applies at the upstream boundary at the Railroad Bridge at Sand Point. Unfortunately, this temperature boundary conditions causes water temperatures that are consistently warmer than observed (average 0.7-1.5°C) just 0.75 miles downstream at The Long Bridge. The IDEQ model consistently overestimates the thermal flux of heat to the Pend Oreille River during the critical summertime period.

The observed and calculated water temperatures in the Pend Oreille River at The Long Bridge were reviewed for the critical summer period of June 21-September 21, 2004. The IDEQ POR thermal model consistently over predicted the observed water temperatures at The Long Bridge during this period despite the close proximity to the upstream boundary (The Long Bridge located segment 7 – Upstream boundary at segment 2). The mean error during this 93 day period ranged from 0.7°C at a 10 ft depth to 1.5°C near the channel bottom at a depth of 25 ft. The time history of hourly observed and calculated water temperatures in the Pend Oreille River at The Long Bridge during July and August of 2004 are shown in Figure 5 for depths of 3, 10, 15, and 25 ft. A statistical summary of error statistics is also provided for each sampling station. The surface temperatures calculations are highly correlated with the observed conditions but contain a warm bias. The standard error in the water temperature estimates increase with depth across the four sampling stations. The prediction of the transport of colder subsurface water into The Long Bridge reach of the POR was not captured by the model. The utility of the model to accurately reproduce the heat budget in the POR is significantly compromised by the consistently large errors observed near the upstream boundary.
Figure 5. Observed and Calculated Water Temperatures in the Pend Oreille River at The Long Bridge, July-August, 2004

A. Depth 15 feet; B. Depth 25 ft; C. Depth 3 feet; D. Depth 10 feet
Bottom Temperatures

The CE-QUAL-W2 assumes hydrostatic pressures throughout the water column and does not solve the vertical momentum equation. This simplified set of governing equations of fluid motion, in conjunction with coarse resolution of steeply sloped deep reaches of the Pend Oreille River, can result in erroneous estimates of bottom water temperatures. For the IDEQ model, in certain river segments, single mesh cells are isolated from neighboring river segments’ preventing the advection of constitutes to and from these cells. The only mechanism for heat exchange into these cells is through diffusive processes which are much slower than advectively driven exchange which dominates river environments. There were no observed temperatures in these deep water reaches of the Pend Oreille River at the time of model development. The use of modeled bottom water temperatures with the current mesh and in the absence of conclusive evidence of cold water stagnation in these deep regions are highly speculative, unreliable, and should be used with caution in any comparative analysis.

The calculated temperature field for existing conditions was determined in each grid cell of the main-stem Pend Oreille River at August 14, 2004 at 1800 hours as shown in Figure 6 for the IDEQ model. One curious feature of this simulation is the consistent occurrence of cold water ponding in isolated bottom cells. The retention of cold water in selected isolated bottom cells of the POR model persists throughout the entire summer period. The simulation of temperatures in these cells is a consequence of the numerical representation of the channel bottom and is not reliable estimates of water temperature.
Natural Pend Oreille Lake Elevation

Historic elevations of Lake Pend Oreille prior to the construction of Albeni Falls Dam are available from 1929 to 1950. The IDEQ modeled lake levels for 2004 and 2005 without Albeni Falls Dam were found to be up to 3 feet lower than the historic minimum lake level on record. The calculated lake levels in segment 2 (upstream most segment of POR at Railroad bridge at Sandpoint) for scenario 4 (without Albeni Falls Dam) are shown in Figure 7 (dark blue line WSE-seg2-sc4) along with the minimum lake levels observed prior to the completion of Albeni Fall Dam (light blue WSE min 1930-1950). The calculated lake levels for most of August were up to several feet less than the observed minimum lake levels of Lake Pend Oreille. A revised estimate of LPO water surface elevations based on the pre-dam rating curve (flow-lake stage relationship) was developed based on the observed POR flows for 2004 and shown in Figure 7 as the curve labeled WSE rating curve (medium blue curve). The revised LPO stage using the pre-dam rating curve was generally 2-3 feet higher than the IDEQ model estimates throughout the entire year.
The lake level and associated river stage is a critical model input for estimating the thermal conditions in the Pend Oreille River especially in the shallow transitional reach at Sand Point. The average depth of flow in this reach is only several feet deep. Raising the lake level by an additional 3 ft will greatly increase the depth of flow in the transitional reach of the Pend Oreille River and increase the residence time in this area for the same flow conditions. The correct lake stage is also important for the determination of the exchange of cooler subsurface waters from LPO in the POR.

Figure 7 Lake elevation sensitivity analysis showing the Scenario 4 modeled “natural” lake elevation (WSE Seg2-sc4) the Scenario 4RC revised “natural” lake elevation using the Corps rating curve (WSE (rating curve)), the Scenario 1C “existing” conditions lake elevation (WSE seg2-sc1), and the minimum recorded lake elevation from 1930-1950 (WSEmin 1930-1950).
Channel Bathymetry

The channel bathymetry is a critical component in estimating the exchange of water from Lake Pend Oreille into the Pend Oreille River. The existing IDEQ model does not accurately reflect the low flow channel bathymetry or the narrow channel features at The Long Bridge or the Railroad Bridge. An aerial photograph of the LPO and POR at Sand Point is shown in Figure 8. A long peninsula extends from the north shore at Sandpoint causing a significant constriction of the channel leading from Lake Pend Oreille to the Pend Oreille River. The channel width in the IDEQ mesh on segment 2 (Railroad Bridge at Sand Point) has a width of 2581 meters at an elevation of 628 meter (2060 ft). This segment top width in the grid is consistent with a north shore to south shore distance but inconsistent with the actual historic conveyance channel at the Railroad Bridge. The minimum channel width near the railroad channel was estimated to be about 1125 m based on land features observed in the aerial photograph and from a 1927 map of Lake Pend Oreille (USGS 1927). The channel becomes even narrower (1000 m width) downstream of the Railroad bridge as defined by the end of the peninsula at the Long Bridge to a point on the south shore. The available conveyance channel becomes broad just downstream of the Long Bridge where the width of the channel approaches 3000 m.
Grid Surface Resolution

The IDEQ model simulated “natural” conditions without the influence of Albeni Falls Dam using a single water body mesh for the entire domain. The water surface slope in the Pend Oreille River changes sharply downstream of the confluence with the Priest River as it approaches the Albeni Falls area under these conditions as shown in Figure 9. The water surface slope over the 4.8 mile reach downstream of the Priest River confluence without Albeni Falls Dam is a function of river flow rate and is greater during low flow conditions.
The numerical model CE-QUAL-W2 allows for only a single reference surface cell to be identified per water body in the computation of the water surface elevation and as a consequence, the size of the surface cell is forced to expand vertically to properly capture the slope of the free flowing river. As a consequence, the depth of the surface cells in the IDEQ model throughout most of the grid of the “natural” condition simulation (i.e. Scenario 8 without Albeni Falls Dam) are 3 to 4 meters deep as shown in Figure 10. The surface cell sizes abruptly change dimensions as the flow rate changes and discrete changes to the reference surface cell are determined by the model. The surface cell depths assigned in the existing conditions simulations (i.e. Scenario 1C with Albeni Falls Dam) remained nearly constant at about 1.5 meters throughout the summer months since the water surface slope was nearly zero and LPO water surface elevations were maintained near full pool conditions. This coarser resolution of the surface heat exchange process in the “Natural conditions” simulation introduces a modeling bias when compared to the existing conditions simulations with Albeni Falls Dam in place which used a much smaller surface cells height.

Figure 9. Computed water surface elevation in the Pend Oreille River without Albeni Falls Dam in place as a function of segment number for a total discharge of 1274 cms and 624 cms using the IDEQ model.
The deeper surface cells will tend to moderate temperature changes or dampen the range in temperatures while also influencing the vertical exchange of heat between the surface cell and the underlying water body. One solution to this numerically induced grid bias is to reorganize the grid into two water bodies at the break in the water surface slope near the confluence of the Priest River.

**Figure 10.** Surface Cell Height at Segment 136 for with (Scenario 1c) and without (Scenario 8) Albeni Dam using the IDEQ model of the POR, June 21-September 5, 2004.
Model Development and Calibration

Introduction

The following description of model development and calibration relies heavily on previous work conducted by Portland State University under contract from Idaho State, Department of Environmental Quality. The bulk of the model input remains unchanged or slightly modified based on additional information or alternative formulations. The following sections will address the modeling features that have been changed from conditions reported in Pend Oreille River Model: Model Development and Calibration dated November 2006 (PSU, 2006) and the rational for these proposed updates.

Model Geometry

Bathymetry

The most recent bathymetry data for the Pend Oreille River was collected by the U.S. Geological Survey in 1996 (Fields et al., 1996). Additional detailed bathymetry has been collected in the forebay and tailwater of Albeni Falls Dam by the USACE Seattle District in 2007 (reference survey). A series of historical hydrographic surveys of Lake Pend Oreille and the Pend Oreille River were found in a review of the records. A river survey of the Pend Oreille River including Albeni Falls as early as 1898 was found in the maps archive of the Seattle District US Army Corps of Engineers. NOAA Chart 18554 contains depth sounding throughout Lake Pend Oreille from a series of hydrographic surveys compiled from 1940-1969 as shown in the Figure 11 near Sandpoint. The elevation datum for this chart is 2048.15 and all depths are listed in feet. The NOAA chart shows the abrupt change in depth from the west end of Lake Pend Oreille through the railroad bridge and The Long Bridge at Sand Point. The wide shallow channel downstream of Sand Point is shown to have a maximum depth of 6 ft or 2042.15 with the low flow channel running along the south shore. This map also shows the peninsula extending from Sandpoint for both bridges
that constricts the channel width to about 1000 m in places. These channel features are critical components shaping the velocities and vertical exchange of water between Lake Pend Oreille and the Pend Oreille River.

Figure 11. Pend Oreille River and Lake Pend Oreille Depth Sounding near Sandpoint ID: reproduced from NOAA chart 18544.
The hydrographic survey transects from the 1996 USGS survey through the transitional reach between the lake and the river was examined in greater detail because of the importance of this bathymetry in influencing the heat budget of the POR. The survey transects 57-64, elevation data (red symbols) and elevation contours are shown in Figure 12. The survey shows a deep area in Lake Pend Oreille with maximum depth of about 60 ft at full pool conditions. Both the railroad and Long bridge cause a significant constriction of the channel as the depth continues to become shallower. The channel both widens and becomes shallow downstream of the Long Bridge with the minimum elevation on Transect 60 of about 2042 ft. The low flow channel is shown near the south shore of this reach with the reappearance of a deeper well defined channel on transect 59. This broad shallow channel reach plays two important roles in shaping the heat budget of the POR. First, the shallow channel will define the vertical exchange of water with LPO with the channel invert acting as an obstruction in preventing deeper cold water from entering the main reach of the POR. Secondly, this broad shallow reach will act as an effective heat exchanger since the ratio of surface area to volume (effective depth) is small.
Downstream of Transect 57, the POR width remains much more uniform but contains several deep pockets of glacial origin. The transect number, survey data (red symbols), and elevation contours near the Riley Creek Campground are shown in Figure 13. The deepest pool in the reach between the LPO and Albeni Falls Dam is shown in this figure on transect 26 containing a minimum elevation of 1903 ft. The minimum elevation at the bounding survey transects of 25 and 27 are 2013 and 1990 ft respectively. A second deep hole in the channel is indicated just downstream on transect 23. These abrupt changes in bathymetry pose challenges for 2 dimensional laterally averaged modeling of both heat exchange and the transport of water because of the potential vertical momentum generated by this topography. These isolated deep holes may be capable of capturing cooler water during the summer months and provide a refuge to warmer surface water.
The POR channel becomes much more uniform downstream of the confluence with the Priest River. The channel width ranged from 1033 to 1583 over this reach while the average channel bottom elevation spans the range from 2037 to 2043 ft. The transect number, survey data (red symbols), and elevation contours from Albeni Falls Dam to the confluence with the Priest River are shown in Figure 14 The channel cross section is closely approximated by a trapezoid in this reach with the exception of the island and braided channel at transect 5.
Model Grid Development

The IDEQ model grid extended from the railroad bridge at Sandpoint to Albeni Falls Dam, a distance of about 28.3 miles. This reach was subdivided equally in 182 longitudinal segments with a constant segment length of 250.54 meters. In addition to the main-stem Pend Oreille River, 6 side channels were included in the representation of the water body. A plan-view representation of the mesh segmentation has been reproduced from model calibration report (PSU, 2007; Figure 7) as shown in Figure 15.

The vertical discretization of each segment consisted of 92 cells 1 meter high beginning at elevation 580 meters to elevation 672 meters. The maximum pool elevation reproduced in the subsequent simulation was 628.5 meters rendering about half of the grid unused. A plan view of the active portion of the grid illustrating the computational cells in the main-stem POR and the six side channels is shown in Figure 16. The location of the side channels is noted in this figure as are the grids for each of these separate branches. The Priest River is the only prominent tributary to the POR.
and is represented by a source at segment 151. The selected temperature compliance locations corresponding with a 10 kilometer distance from LPO, 35 kilometer distance from LPO, and Albeni Falls Dam are located at segments 39, 136, and 183.

Figure 15. Pend Oreille River Plan view Grid Segmentation; taken from (PSU, 2007a) Figure 7.

**Bottom Cells**

The focus on the temperature response in the bottom cell at the 10 Km and 35 Km compliance locations puts a premium on accurately replicating the exchange and transport of heat to these cells. Isolated cells without a neighboring segment cell can artificially trap cold water and introduce significant errors into water temperature simulations. A total of 13 isolated bottom cells are contained in the main-stem branch of the POR shown in Figure 16 including the compliance segment 39 (10 Km distance from LPO). The updated grid of the POR does not contain these isolated bottom cells. The methodology for eliminating these isolated bottom cells involved adding cells to an adjacent segment with a minimal width of 10 me-
ters. This modification to the grid allows the advective transport of heat into and out of bottom cells without adding a significant volume to the grid. The CE-QUAL-W2 model does not solve the vertical momentum equation and caution should be taken in simulations of water temperature in regions of the grid where abrupt changes in depth are present.

**Vertical Cell Heights**

Another limitation of the POR grid is the limited resolution of channel conveyance properties at low flows and lake levels simulated for natural conditions without Albeni Falls Dam in place. The minimum lake level for the without Albeni Falls Dam simulations of 624 ft resulted in only three active cells in shallow segments located in the transitional reach near LPO (segments 11-14). A wiser choice for vertical cell heights in this area would have been 0.5 meter heights for channel elevations ranging from 620 – 625 meters. This elevation range accounts for more than half of the channel storage for conditions without Albeni Falls Dam. This recommendation to improve the vertical resolution of the grid was not acted upon because of the time required to regenerate the grid and associated shading parameters.
Volumetric Properties

An important property of the grid for assessing the exposure time of flows traveling through the POR involves the volumetric or channel storage properties. The volumetric properties (cubic meters) of the POR grid were determined as a function of channel elevation as shown in Figure 17. The included table presents the same information in terms of elevation in feet and storage in thousand-acre-ft (kaf). The POR’s main channel total volume (blue line) is shown to be nearly identical to the combined main-channel and side channel storage (pink line). At a full pool elevation of 2062 ft., the total channel storage in the POR from Albeni Falls Dam to LPO assuming a flat water surface slope is 253 kaf. The theoretical travel time assuming bulk flow conditions of 10, 20, and 40 kcfs were determined assuming constant full pool conditions as 12.8, 6.4, and 3.2 days, respectively (Figure 17). This table provides reasonable estimates of the time of travel or exposure duration for flow entering the POR from LPO.

This data summary also indicates that half the river storage occurs in the upper 13-14 feet of the water column. The typical summertime lake stage
for conditions without Albeni Falls Dam in place is closer to 2050 ft with an associated storage volume of 140.8 kaf or about 56 percent of the full pool storage. The corresponding theoretical travel times through the POR without Albeni Falls Dam are nearly one-half the time of full pool conditions.

Cell Widths

The cell widths in the POR grid were determined by interpolating elevation data collected from the hydrographic survey. A contour map of the cell widths are shown in Figure 18. An inconsistency noted in these channel width estimates involved the role of the abutment constrictions of the Railroad and The Long Bridges located near Sandpoint ID. The critical minimum channel widths at these structures were estimated to be about 1000 meters using geo-referenced aerial photos of the channel and historic maps (USGS 1927). The widths used in the POR grid did not consider the
impacts of these channel obstructions and were nearly twice as large as the actual channel widths.

![Diagram of channel obstructions and temperatures](image)

**Figure 18. Pend Oreille River Channel Width Contours (50 meter contour interval)**

**Upstream Boundary**

The selection of the upstream boundary at the Railroad bridge creates a problem for designating temperature boundary conditions for model simulations. The approach taken by the IDEQ POR model was to apply observed temperature conditions from LPO near Contest Point to the upstream boundary. The problem with this approach was the large overestimation of temperatures observed at a sampling station near The Long Bridge. This study investigated moving the upstream boundary into Lake Pend Oreille at Contest Point. However, this expanded grid also contained significant phase errors in observed and calculated water temperatures the Long Bridge station. Thus, the modified grid proposed in this investigation involved deleting the 5 segments (segments 2-6) upstream of The Long Bridge and using the observed temperature profiles at The Long Bridge sampling station as the upstream temperature boundary condition. This approach shortens the POR reach length by about 4100 ft and eliminates the errors in the actual channel dimensions caused by the bridge.
abutments. The grid segmentation numbering will be altered by this update by subtracting 5 to each old segmentation reference. For example, the 35 Km compliance segment was 136 in the old grid and is now segment 131. The grid attributes remain unchanged except for the removal of the first five upstream segments and the added cells preventing the occurrence of isolated bottom cells. A number of cells with 10 m widths (5 cells added to segment 192) were added in the Morton Slough branch to maintain at least two active segments during low flow conditions without Albeni Falls Dam. Although this grid change was not required to maintain numerical stability for the existing conditions simulations, the grid change was made to maintain consistent grid geometry for both natural and existing conditions. The alternative POR grid used for simulation with Albeni Falls Dam in place is shown in Figure 19.

Figure 19. Alternative Pend Oreille River Numerical Grid for Existing Conditions with Albeni Falls Dam
Surface Layer

The application of the POR grid as presented in the modeling reports with and without Albeni Falls Dam creates significant differences in surface cell dimensions that contribute to differences in surface cell thermal conditions. CE-QUAL-W2 allows only one reference water surface layer for a water body. This computational limitation does not present a problem with the size of surface cells when the water surface slope is small. However, when simulating the POR without Albeni Falls Dam, the water surface slope is not small downstream of the confluence with the Priest River. With the single water body formulation, the depth of the surface cells will increase with the distance from the falls resulting in surface cell depths as large as 3 to 4 meters near the upstream boundary. The simulation of surface water temperatures is a prominent attribute being used to assess compliance with IDEQ water temperature standards. An alternative POR grid based on a two water body representation is proposed to control the size of surface cells throughout the Albeni Falls simulation reach.

The alternative POR grid for “natural” conditions resolved the POR in two reaches or water bodies. The main-stem is divided into two pieces consisting of Albeni Falls to just below the confluence with Priest River and from the Priest River confluence to the POR at The Long Bridge. The alternative POR grid and associated features are shown in Figure 20. The channel features are identical with those used in the “alternative existing” conditions grid (Figure 19). The segmentation numbering of important river features has changed with this reordering of the grid. For example, the 35 Km compliance location is located at segment 131. Albeni Falls represents the downstream limit of the POR and is located at segment 230.
Boundary Conditions

Upstream Boundary Conditions

Lake Pend Oreille Water Surface Elevation

The upstream boundary condition for both “Existing and Natural” conditions consisted of the time history of LPO water surface elevations. The existing conditions LPO water surface elevations were based on data collected near Hope, ID on Lake Pend Oreille (USGS 12392500). These boundary conditions remained unchanged from the original model formulation and allow the inflow magnitude and vertical distribution of flow to be calculated by the model. Figure 21 and Figure 22 show time series plots of the water surface elevation data for existing conditions in 2004 and 2005, respectively. The calculated inflow discharge ($Q_{in}\text{-Existing}$) from Lake Pend Oreille is also displayed in both of these figures for existing
condition. The operating conditions during the critical period of the summer time maintain constant lake levels by passing inflow. The specified outflow (Q_out-Existing) was highly correlated with the estimated inflow to the POR for existing conditions. The flow contribution from Priest River was less than 50 cms throughout the summer months in 2004 and 2005 except for a short period at the end of June in 2005.

Figure 21. Pend Oreille Lake Elevation and Pend Oreille River Flows with and without Albeni Falls Dam, June 21-September 21, 2004 (Existing=with Albeni Falls Dam, Natural=without Albeni Falls Dam).
The “Natural” conditions LPO hydraulic conditions consisted of estimates of LPO water surfaced elevation without Albeni Falls Dam in place. In the original PSU model, the natural upstream boundary condition consisted of the time history of inflow to the POR allowing the model to determine the LPO water surface elevations throughout the simulation period. Consequently, the estimated LPO water surface elevation was not consistent with historic observations prior to the completion of Albeni Falls Dam. In some cases, the simulated LPO water surface elevation was several feet below the minimum historically observed conditions for a specific date (Figure 7). These artificially low water surface conditions directly influenced the travel time and heat exchange properties throughout the POR for natural conditions which required a different formulation for this investigation.
In this new model revision, the basis for estimating the LPO lake levels without Albeni Falls Dam through the simulation period of 2004 and 2005 involved the generation of the lake stage rating curve based on observed data prior to the completion of Albeni Falls Dam. Daily observations of Lake Pend Oreille Stage near Hope ID, (USGS, 12392500) and the Pend Oreille River discharge at Newport, WA (USGS, 12395500) from 1929-1941 were used to generate a rating curve as shown in Figure 23. A third order polynomial curve was fit to these data and used with estimates of inflow discharge to the POR in 2004 and 2005 to estimate Lake Pend Oreille stage during this time period. The estimated natural POR flows and LPO stage for 2004 and 2005 are shown in Figure 21 and Figure 22. The inflows to the POR under natural conditions were similar to those observed during existing conditions. The calculated natural POR flows were slightly higher than the observed existing flow conditions because of the depletion of channel and lake storage during the study year.

![Figure 23 Lake Pend Oreille Water Surface Elevation as a function of Pend Oreille River Flow at Newport, WA, 1929-1941](Figure23)

\[ \text{wse} = 0.00000468q^3 - 0.00136q^2 + 0.268511q + 2045.4 \]

\[ R^2 = 0.9987 \quad q \text{ (cfs)} \]
Water Temperatures

The vertical and longitudinal properties of water temperatures in the Pend Oreille River and Lake Pend Oreille were monitored at several locations in 2004 and 2005 with the most complete data sets consisting of continuous (one hour frequency data) water temperature measurements gathered by U.S. Navy and the U.S. Army Corps of Engineers. The water temperature data from U.S. Navy buoy was available from a station located in the deep southern end of Lake Pend Oreille near the LPO deep moor weather station as shown in Figure 2. The U.S. Army Corps of Engineers maintained two temperature monitoring sites in the north end of LPO near Contest Point (ALFLPS) and near Anderson Point (ALFLPD). A sampling station in the POR at The Long Bridge (ALFPORLB) was maintained in shallow water about 0.8 miles downstream of the railroad bridge. The nature of the POR at this location is one of transitioning from the much deeper lake environment to a shallow river environment. The two sampling stations maintained in the POR well downstream from the entrance were near Riley Creek (ALFPORRC) and at Albeni Falls Dam (ALFFB). Water temperatures in the POR were collected by other groups and agencies but will not be addressed in this discussion because the limited amount of data and duplicate station locations makes the data of limited utility.

A review of the observed water temperature records collected by the Seattle District COE during the two study years provides important information regarding the thermal characterization of the POR and interaction with LPO. The water temperature contours as a function of station location, depth, and time of year are shown in Figure 24 for the three POR and two LPO sampling stations for June 21-September 21, 2005. The horizontal black lines in this figure indicate the location of the observed data with the sampling depths indicated in the Figure title for each station. For example, the water temperature contours displayed in Figure 24 were based on observed hourly data in Lake Pend Oreille near Anderson Point at depths of 2, 5, 10, 25, 50, 75, 100, 150, 200, 250, and 300 ft. The water temperature contours were based on a linear interpolation between the data points located in time and space. The stations are ordered from upstream to downstream vertically in this figure (Lake stations on top and river stations on the bottom).
The water temperatures in Lake Pend Oreille (ALFLPD and ALFLPS) are vertically stratified throughout the summer period in contrast to the nearly uniform vertical distribution of temperatures at the two downstream stations in the Pend Oreille River (ALFPORRC and ALFFB). The conditions at The Long Bridge (ALFPORLB) located in the transitional reach of the POR show a vertical variation in water temperatures limited by the shallow depth at this station. Colder water temperatures of 5 and less reside in LPO near Anderson Point throughout the summertime at depths greater than 200 ft. Surface water temperatures in LPO exceed 19 °C by the end of June and 22 °C by mid-July and reach maximum temperatures in excess of 24 °C. The variation of water temperatures in the thermocline region in LPO exhibit a cyclical pattern consistent with internal seiching activity where a wide range of temperatures are observed cycling between warmer and colder temperatures (note: variation in location of temperatures ranging from 8-10 °C indicated by the dark blue contours in Figure 24). A frequency analysis (fast fourier series transform) of temperatures observed at a depth of 75 ft in LPO near Anderson Point determined a fundamental period of oscillation of about 58 hours or about 2 ½ days. The surface temperatures in LPO begin cooling down in August with temperatures falling below 22 °C by the third week in August and below 19 °C by September 9, 2005.

The patterns of surface temperatures in the POR were similar to the patterns observed in LPO throughout the summertime of 2005. A prominent difference between thermal condition in the lake and river during the summertime is the occurrence of warmer water temperatures throughout the water column in the POR whereas the warmer water temperatures are limited to the upper portion of the water column in the lake. These temperature observations are consistent with the transport of surface oriented water from LPO into POR due to the shallow channel properties in the transitional reach of the POR at Sandpoint. A shallow low water channel with a minimum channel elevation of 622 meter acts as a barrier to the transport of much colder subsurface water from LPO into the POR. As a consequence, the availability of colder subsurface water was not observed downstream of The Long Bridge.
Figure 24. Water Temperature Contours in the Pend Oreille River and Lake Pend Oreille as a function of depth and sampling station, June 21-Sept 21, 2005 (ALFLPD-Lake Pend Oreille near Anderson Point: depths 2,5,10,25,50,75,100,200,250,300 ft, ALFLPS-Lake Pend Oreille near Contest Point: depths 2,5,10,30,40,50 ft, ALFPORLB-Pend Oreille River at The Long Bridge: depths 2,10,20,25 ft, ALFPORRC-Pend Oreille River at Riley Creek: depths 2,10,20,40 ft, ALFFB-Pend Oreille River at Albeni Falls Dam: depths 2,10,20,40 ft)
The similarities in surface water temperatures are illustrated by hourly temperatures by sampling station and time at a constant depth of 2 ft as shown in Figure 25 for the critical summertime period in 2005. The maximum daily water temperatures in the lake were generally greater than observed in the POR at Albeni Falls Dam during the first half of the critical summer time period. The maximum water temperatures were observed to exceed 25 °C at the LPO sampling stations or about 1 °C warmer than observed in the POR at Albeni Falls Dam. During the cooling period of the summer the temperatures at Albeni Falls Dam were generally slightly warmer than observed in LPO. The rapid reduction in surface temperatures at the lake stations can be attributed to vertical mixing of cooler subsurface waters with warm surface water during the exposure to cooler weather conditions.

Figure 25. Time history of hourly surface water temperatures in the Pend Oreille River and Lake Pend Oreille, June 21-Sept 21, 2005 (Depth 2 ft at ALFPOD-Lake Pend Oreille near Anderson Point, ALFLPS-Lake Pend Oreille near Contest Point, ALFPORLB-Pend Oreille River at The Long Bridge, ALFPORRC-Pend Oreille River at Riley Creek, ALFFB-Pend Oreille River at Albeni Falls Dam, Ta-l-hourly air temperatures at Hoodoo, ID)
The IDEQ model of the POR used the observed temperature profile in LPO near Contest Point as the upstream temperature boundary at the railroad bridge for existing conditions simulations. For the natural conditions without Albeni Falls Dam model, a uniform temperature equal to the observed surface temperature in LPO near Contest Point was used as the upstream temperature boundary condition. The predictive errors in the model temperature calibration as determined at The Long Bridge were noted earlier in the Section reviewing the existing model (Figure 5) and demonstrate the need to examine alternative temperature boundary conditions.

The updated POR model uses the observed temperature profile in the POR at The Long Bridge as the upstream boundary condition for both simulations with and without Albeni Falls Dam. These temperature boundary conditions are applied to a grid that begins at The Long Bridge and not at the railroad bridge as in the IDEQ formulation. This change in upstream boundary involves the removal of 5 segments and the shortening of the model domain by about ¾ of a mile. An input temperature boundary condition file was generated by extrapolating the cell centered temperatures from the observed temperature data at station ALFPORLB for depths of 2, 10, 20, and 25 ft for 2004 and 2005. Estimates of POL levels with and without Albeni Falls Dam were used to determine the appropriate cell temperatures in segment 2. The temperature time history in the POR at The Long Bridge during the critical summertime period for 2004 and 2005 are shown in Figure 26 and Figure 27. These data show the cycling of cold subsurface water in the POR at The Long Bridge during both years. The passage of weather systems as noted by the change in air temperatures at the Hoodoo weather station, are correlated with water temperature changes in the POR at The Long Bridge. The extent and duration of cold front passage over the basin during 2004 resulted in large changes in observed water temperature in the POR at The Long Bridge (Figure 26). The bottom water temperatures remained about 5 degree colder than surface temperatures during much of July and the first 10 days in August of 2005 (Figure 27). The vertical gradients in temperature during both years were small by the end of August and throughout the critical period in September.
Figure 26. Water temperatures in the Pend Oreille River at The Long Bridge by depth as a function of time, June 21-Sept 21, 2004 (ALFPORL10-10 ft deep, ALFPORL15-15 ft deep, ALFPORL25-25 feet deep, ALFPORL3-3 ft deep, Tair-hourly air temperatures at Hoodoo, ID)

Figure 27. Water temperatures in the Pend Oreille River at The Long Bridge by depth as a function of time, June 21-Sept 21, 2005 (ALFPORL10-10 ft deep, ALFPORL20-20 ft deep, ALFPORL25-25 feet deep, ALFPORL2-2 ft deep, Tair-hourly air temperatures at Hoodoo, ID)
Downstream Boundary Conditions

The downstream boundary conditions used in the revised POR model involved Albeni Falls Dam discharges for existing conditions and a discharge rating curve for Albeni Falls. The Albeni Falls Dam flows were not changed from those applied in the IDEQ model. The flow rates during the critical summer-time period in 2004 and 2005 in the POR at Albeni Falls Dam are shown in Figures 21 and 22 as Qout-existing. In both years, the operation of the spillway was required to pass river flows in excess of powerhouse capacity. Higher river flows were experienced in 2005 compared to 2004 resulting in shorter travel times in the POR. The type of structure applied at Albeni Falls Dam to withdraw water from the forebay was unchanged from the IDEQ model. This structure consisted of a line sink with a width of 30 meters at an effective elevation of 622 m. Distinguishing between powerhouse and spillway releases was not identified as a critical element in describing these boundary conditions because of the small amount of spill, shallow flow conditions, and the lack of a vertical thermal gradient in the river at the dam during the time period of interest in the simulation.

The downstream boundary condition representing the influence of Albeni Falls was based on a rating curve expressing the river discharge as a function of the water surface elevation at the falls. The “weir” formulation used by the IDEQ model of the POR is shown in Figure 28 as the blue curve. In 1945 the Corps of Engineers developed a rating curve for the Pend Oreille River based on the river stage about 430 feet upstream of the falls. This data was digitized from the original figure (COE, 1945) as shown by the green symbols in Figure 28. An equation was fit to this set of data points defining the discharge as a power function of the head differential at the falls with crest elevation of 619.6 m as shown in the red curve. The estimated POR flows during the summer time ranged from 250-1250 cms during the years 2004 and 2005. The difference in river stage calculated by these alternative downstream rating curves for Albeni Falls assuming similar flow condition ranged from 0.8 to 1.1 meters. To put this in a different context the segment at Albeni Falls during a low flow of 250 cms has only three active cells with a maximum depth of 2.2 meters using the alternative COE rating curve versus about 3.2 meters for the IDEQ formulation. The different depths of flow during low flow conditions using alternative Albeni Falls rating curves can result in significant impacts on POR temperature exchange and transport.
Meteorological Conditions

The meteorologic conditions in the original IDEQ model of the POR consisted of hourly air temperature, dew point temperature, wind speed, wind direction, cloud cover, and solar radiation derived from three different stations. The primary weather station for air and dew point temperatures, wind speed and direction was located at the Sandpoint Airport (National Weather Service station KSZT) with missing data calculated from data observed from the weather station at Priest Lake (RAWS station PLKI1). The cloud cover and solar radiation were derived from data collected at the Kettle Falls weather station (RAWS station KTLW1). The location of these weather stations relative to the POR is shown in Figure 29. This hourly assemblage of weather data was applied to the entire POR for the years 2004 and 2005.
The short coming of this weather data set includes both the large number of records missing from the Sandpoint weather station and synthesized from remote stations and the potential for localized weather conditions or “lake effects” impacting the observations at the Sandpoint weather station. The Sandpoint weather station is located less than 1 mile from the shoreline of the western embayment of Lake Pend Oreille at an elevation of 2126 ft. It is plausible that this large body of water being colder than the overlying air during much of the summer time can influence the weather conditions as monitored at Sandpoint. These localized conditions may not be representative of weather conditions experienced on the Pend Oreille River well removed from Lake Pend Oreille. An onshore breeze during the
hot summertime conditions would tend to transport cooler air into the Sandpoint area.

The Priest Lake weather station is located almost 27 miles away from the Sandpoint station and 28.2 miles from Albeni Falls Dam at elevation 2600 ft. The weather station near Kettle Falls Washington is at elevation 1310 ft and is 60.8 miles from Albeni Falls Dam and about 75 miles from the Sandpoint weather station. These remote locations at different elevations can result in weather conditions that can be significantly different than experienced at Sandpoint or on the POR introducing a degree of error into the applied weather conditions throughout the study area.

A review of weather stations in the vicinity of the POR was conducted and several additional data sources were identified. Two weather stations were located close to the Pend Oreille River at the Priest River (APRSWXNET/CWOP station C4582) and Morton North (MNET UPR station UP455) but were not active during the study years of 2004 or 2005. The Navy maintains the Deep Moor Weather Station (LPO) located on a platform positioned on the lake, north-east of Cape Horn Peak in the south end of Lake Pend Oreille. This station was installed on August 18 2006 and could not be used for model simulations. A fourth weather station at Hoodoo (RAWS station HAYI1) was active during both study years, located close to the Pend Oreille River, and contained all the weather parameters needed by the CEQUAL-W2 model but cloud cover on an hourly frequency since June 27, 2001. The weather station at Hoodoo is located at elevation 2270 ft and is about 6.3 miles south of the POR and 11.7 miles from Albeni Falls Dam as shown in Figure 29.

Systematic differences in hourly air temperatures were observed between the Sandpoint and Hoodoo weather stations for 2004 and 2005 during the critical summertime period. Both air and dew point temperatures were consistently warmer at the Hoodoo weather station during the summer months. The instantaneous air and dew point temperatures are shown in Figure 30 for June 30 – July 30, 2004. The daily maximum air temperatures were consistently warmer at the Hoodoo station when compared with the Sandpoint data during this period.
The daily average air temperatures were calculated at the Sandpoint and Hoodoo weather stations from June 21-September 21, for 2004 and 2005 as shown in Figure 31. The Hoodoo daily average air temperatures were almost always warmer than the corresponding temperatures at Sandpoint and the degree of difference between these two stations increased for warmer conditions. For example, when the mean daily air temperature at Hoodoo was 15 °C the corresponding air temperature at Sandpoint was 14 °C based on the linear regression equation fitted to these data shown in Figure 31. Similarly, when the mean daily average air temperature at Hoodoo was 25 °C it was generally about 3 degrees warmer than observed at Sandpoint.
Similar types of comparisons of other meteorologic parameters could be conducted between these weather stations to further define differences in weather conditions. The relevant effects of using alternative input weather data sets can be investigated by conducting simulations of the overall heat budget of the POR. The original IDEQ POR thermal model includes an upstream heat flux that significantly overestimates temperatures entering the Idaho reach of the POR based on calculated and observed temperatures at The Long Bridge. The predictive errors in water temperatures at Albeni Falls Dam by the IDEQ POR model don’t contain this consistent predictive bias. The heat exchange calculated during the passage of water from LPO to AFD is driven primarily by the applied weather conditions that may be underestimated when using the IDEQ weather data formulation. The overestimation of the upstream thermal flux coupled with the underestimation of heat transfer during passage using the IDEQ Sandpoint weather data leads to more accurate estimates of POR water temperatures at Albeni Falls Dam.

**Figure 31.** Daily average air temperature at Sandpoint (KSZT) and Hoodoo (HAY11) weather stations during June 21-September 21, 2004.
Air and Dew Point Temperatures

The weather data from the Hoodoo weather station was used in the updated simulation of thermal conditions in the POR. Air and dew point temperatures were generally recorded on an hourly frequency at the Hoodoo station. Instances where hourly data was missing were estimated from a linear interpolation of temperatures contained in the record provided that the duration of missing data was limited to several hours or less. The hourly record of air and dew point temperatures for the critical summer time period in 2004 and 2005 are shown in Figure 32 and Figure 33. The passage of both hot and cold fronts is notable in these records with daily maximum air temperatures changing from over 36 °C on July 21, 2005 to only 22 °C on the following day, July 22, 2005. The severity of cold front passage during the summer of 2004 is also noteworthy during August 3-8 and August 22-28. The daily maximum air temperature on August 24-25 were less the 15 °C and substantially colder than water temperatures in the POR.

![Graph showing air and dew point temperatures](image-url)

**Figure 32**, Observed hourly air and dew point temperature near the Pend Oreille River at the Hoodoo weather station, June 21-September 21, 2004.
Idaho Water Quality Standards allow for exceedances of the water temperature criteria when the air temperature of a given day is extremely high (temperature must exceed the ninetieth percentile of a yearly series of the maximum weekly maximum air temperature data calculated over the historic record measured at the nearest weather reporting station; IDAPA 58.01.02.080.03). From the 30 year record, IDEQ calculated the 90th percentile of the annual series of maximum weekly maximum water temperatures at Sandpoint, ID as 97.0 °F (33.9 °C). The dates in 2004 when this air temperature exemption is in effect based on the observations from the Hoodoo station were June 23, July 14, 15, 16, 17, 24, 25, and August 1, 2, 12,13,15, 16. The dates in 2005 when this air temperature exemption is in effect based on the records from the Hoodoo station were June 21, July 21, and August 5, 6, 7, 8, 9, and 22.
Wind Speed and Direction

The wind field plays a prominent role in both the heat exchange process and vertical mixing of thermal energy throughout the water column. The wind speed and direction observed at the Hoodoo weather station are shown in Figure 34 and Figure 35 for the years 2004 and 2005. The wind speed generally builds up during the day reaching peak values during the late afternoon and evening hours. The daily maximum wind speeds were consistently higher during the summer of 2004 when compared to 2005.

Figure 34. Observed hourly wind speed and direction near the Pend Oreille River at the Hoodoo weather station, June 21-September 21, 2004.
Solar Radiation and Cloud Cover

The short wave radiation observed at the Hoodoo weather station was available throughout the summer time period of 2004 and 2005 as shown in Figure 36 and Figure 37. The period associated with cold air temperatures in August of 2004 correspond closely with days of heavy cloud cover and greatly diminished incident short wave radiation. The cloud cover data was based on observation at the Sandpoint weather station for both study years. Short periods of missing data were estimated through interpolation between observed data.
Figure 36. Observed hourly short wave radiation data from Hoodoo weather station and cloud cover data from the Sandpoint Airport weather station for June 21-September 21, 2004.

Figure 37. Observed hourly short wave radiation data from Hoodoo weather station and cloud cover data from the Sandpoint Airport weather station for June 21-September 21, 2005.
Model Calibration

The revised calibration of the Pend Oreille River model involved model simulations from January 1, 2004 to September 21, 2005. The evaluation of model performance was limited to the critical summertime period of June 21-September 21 for each year. This period for evaluation was selected because it corresponds with the period where water temperatures exceed Idaho State water quality standards of 19 and 22 °C. The summary of model error statistics over the entire simulation period were found to misrepresent the ability of the model to reproduce temperature metrics used to determine compliance with IDEQ water temperature standards.

Model calibration was conducted by comparing model predictions with measured data from the study domain. The revised POR model extends from the Long Bridge to Albeni Falls Dam a distance of 27.5 miles. The numerical grid was modified to correspond with this shorter river reach. The without Albeni Falls Dam grid was further reordered to resolve the POR reach into two water bodies to control the size of the surface layer cell throughout most of the study area. Another major change in the model calibration was to use weather data taken from the Hoodoo weather station. The upstream temperature boundary condition was composed of observed or estimated Lake Pend Oreille stage and the observed temperature profile in the POR at the Long Bridge (ALFPORLB). The natural condition scenario estimated the LPO stage by applying a pre-dam rating curve with estimates of the inflow hydrograph to the POR for each study year. A revised rating curve based on an observed pre-dam relationship was used to formulate a new downstream discharge boundary condition at Albeni Falls.

Several of CE-QUAL-W2 model parameters were revised to provide better agreement with observed conditions. The discussion of the updated model development will focus on the response of calculated hydrodynamic and temperature properties. The determination of secondary water quality constitutes was not altered from the previous IDEQ model formulation. In general, there was a very weak coupling between these secondary water quality constitutes and the overall heat budget of the POR.
Model Parameters

The updated model parameters used in the revised model formulation are summarized in this section. The parameter values listed in Table 1 reflect input levels contained in the model input files for the IDEQ version of the POR and were not always consistent with the values reported in the modeling reports. The revised parameter values used in this study are reported in the column with the COE label. The value of other model parameters can be found in the original modeling report in Table 11 (PSU, 2006).

A uniform wind sheltering coefficient of 0.90 was used in this formulation of the POR. The wind magnitude and direction was taken from a different weather station (Hoodoo) in this investigation and may account for the increase in this coefficient from the original study. The application of the larger wind sheltering coefficient will result in larger wind speeds applied to estimate the effects of mixing and evaporative heat exchange.

The coefficients influencing the absorption of solar radiation were revised for this updated version of the POR model. The COE, Seattle District has been measuring the transparency of water in LPO and the POR with secchi disk measurements since 2005. The secchi disk depths during the summer months in the forebay of Albeni Falls Dam ranged from 8 to 20 ft during 2005 and 2006. The transparency of water in LPO near Contest Point was found to range from 13 to 33 ft during this same time period. The clarity of water was observed to generally improve during the summer at both stations. A series of equations relating water transparency as determined by a secchi depth measure and the extinction coefficient for water (EXH2O) and the fraction of incident solar radiation absorbed in the surface layer (BETA) are given in the CE-QUAL-W2 users manual (Cole and Wells, 2006). The range in the extinction coefficient was determined from the range in Secchi disk observations at the two sampling stations noted above as 0.20 to 0.58. The range in the value of BETA was estimated as 0.18 to 0.46. The final constant values of BETA and EXH2O used in this study were 0.40 and 0.20, respectively. These coefficients will have the effect of transmitting more incident solar radiation to greater depths in the water column when compared to the previously applied coefficients.

The final change in model parameters used in this version of the POR was to apply a different formulation for vertical eddy viscosity. The formulation for vertical eddy viscosity used in the original IDEQ model “W2” dif-
fers only in the estimation of the mixing length from the “W2N” formulation. A simulation using the W2N formulation of vertical eddy viscosity was found to create slightly more vertical exchange of temperatures when compared to the W2 formulation.

### Table 1. Summary of Model Parameters used with IDEQ and updated COE Pend Oreille River Model

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
<th>Units</th>
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<td>WSC</td>
<td>Wind sheltering coefficient</td>
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The channel roughness coefficient as reflected by Manning’s n, was held constant at 0.036 for all grid segments. This coefficient was identical to the value cited in the calibration report (Annear and Wells, 2006) but slightly less than the 0.040 value contained in the original model input files obtained from PSU. The river discharge determined in the model without Albeni Falls Dam in place is sensitive to the channel roughness coefficient. The simulations with a rougher channel resistance were investigated and found to result in slightly lower discharges during the summer months than observed, based on the applied boundary conditions.

Hydrodynamics

The only hydrodynamic parameter available for calibration was water surface elevation data measured at Albeni Falls Dam. The Lake Pend Oreille stage was used as an upstream boundary condition in both the model of the Pend Oreille River with and without Albeni Falls Dam. The observed and calculated water surface level data at the model’s upstream and downstream boundary are shown in Figure 38 and Figure 39 throughout the critical summertime period. The slope in the water surface of the Pend Oreille River is small throughout the summer months and decreases as the river flow falls. The calculated water surface elevation was generally within 0.2 meters of the observed conditions at Albeni Falls Dam during the summer months.
Figure 38  Observed and Calculated Water Surface Elevation in the Pend Oreille River at Albeni Falls Dam, June 21-September 21, 2004

Figure 39  Observed and Calculated Water Surface Elevation in the Pend Oreille River at Albeni Falls Dam, June 21-September 21, 2005
The model of the Pend Oreille River without Albeni Falls Dam imposed both an upstream and downstream rating curve. Observed water surface profiles of the POR prior to Albeni Falls Dam were found in the COE archives for a range of flow conditions 20.2 to 168.6 kcfs (USCOE, 2000). The POR model was setup to simulate two of these observed flow conditions for 20.2 and 87.3 kcfs using the established rating curve boundary conditions. The LPO stage was estimated from the results shown in Figure 17 and the downstream stage was determined by the model from the relationship in Figure 28. The resulting calculated and observed water surface profiles for 20.2 kcfs and 87.3 kcfs steady flow conditions are shown in Figure 40. The model closely reproduced both the river stage pattern and associated discharge. The calculated river discharge of 19.7 kcfs was only 0.5 kcfs less than the estimated observed river flow while the higher discharge was reproduced to within 0.1 kcfs. These data support the observation that gradient in the water surface elevation of the POR changed abruptly near the confluence with the Priest River typically falling about 10 feet over the course of about 5 miles to the falls.

![Figure 40 Observed and Calculated Water Surface Elevations in the POR without Albeni Falls Dam for river flows of 20.2 and 87.3 kcfs.](image-url)
Water Temperature

The observed and calculated water temperatures in the POR were compared at the Long Bridge, Riley Creek, and Albeni Falls Dam temperature monitoring stations (see Figure 2) during the summer months of 2004 and 2005. The calculated water temperatures generated from the IDEQ and COE POR models were compared with hourly observations at each of these sampling locations to provide a performance measure of the alternative models. These error statistics also provide a means of determining the reliability of model results in characterizing the thermal characteristics of the POR. A detailed comparison of calculated and observed water temperatures at other locations were not pursued in this evaluation because of the limited information contained in grab sample data and issues of data reliability with some of the continuously sampled data.

A statistical summary of the predictive error of the IDEQ POR model and the updated POR model are listed in Table 2. The predictive error was estimated by subtracting the hourly observed water temperature from the calculated value during the summertime from June 21-September 21, 2004 and 2005. The model bias was estimated from the mean predictive error value with positive values indicating an overestimation of observed conditions. With the updated POR model the size of the predictive error in water temperatures was reduced at every sampling station for both years during the summertime. The overestimation of surface temperatures was greatly reduced at Long’s Bridge and near Riley Creek. The magnitude of the predictive error and range of the 90 percent confidence interval were reduced significantly (more than 50% in many cases).

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<th>n</th>
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<th>Standard Error (°C)</th>
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<td>Standard Error (°C)</td>
<td>Absolute Error (°C)</td>
<td>Percentile 5(^{th}) (°C)</td>
<td>Percentile 95(^{th}) (°C)</td>
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\(^*\) Sampling Stations ALFPORLBxx POR at The Long Bridge, ALFPORRCxx POR near Riley Creek, ALFFBxx POR at Albeni Falls Dam, ALFIRB POR at Albeni Falls Dam with xx as the depth of sample in feet.

\(^@\) Model version IDEQ-proposed formulation (PSU, 2007a), COE updated formulation presented in this report.

\(^&\) Predictive error = Calculated – Observed water temperature.
The Long Bridge

The conditions at the Long Bridge closely reflect the thermal heat exchange from LPO to the POR. The surface temperatures calculated at the Long Bridge (ALFPORLB3) by the original IDEQ POR model during the summertime of 2004 overestimated observed conditions by 0.69 °C and exhibited a 90 percent confidence interval ranging from +0.04 to +1.59 °C meaning that 5 percent of the predictive errors were larger than 1.59 °C. In contrast, the COE POR model closely reproduced the observed conditions with the mean value of the predictive error of -0.03 °C and a 90 percent confidence interval ranging from -0.34 to 0.21 °C. The standard error was reduced by over 50% from 0.47 to 0.17 °C. The time history of observed and calculated surface temperatures and the corresponding predictive errors at the Long Bridge during the summer months of 2004 are shown in Figure 41. The sizes of the predictive errors for the IDEQ model were larger during the periods of increasing temperatures and smaller during periods of decreasing water temperature.

![Figure 41. Observed and Calculated Water Temperatures in the Pend Oreille River at depth of 3 feet at The Long Bridge, June 21-September 21, 2004 (Predictive Error = Calculated-Observed, Model version IDEQ and COE)](image)

The sizes of the predictive errors in subsurface temperatures at The Long Bridge were larger than those observed at the surface for both model formulations. The IDEQ model estimates near the channel bottom at The
Long Bridge (ALFPORLB25) during 2004 were on average 1.08 °C warmer than observed during the summer months using the IDEQ POR model with a 90 percent confidence interval ranging from -1.10 to 4.08 °C. The larger errors in subsurface temperatures are related to the periodic seiching of subsurface water at The Long Bridge. The mean error in bottom temperature at The Long Bridge in the updated POR model was just 0.20 °C with 90 percent confidence interval ranging from -.61 to 0.99 °C. The time history of observed and calculated bottom temperatures (ALFPORLB25) and the corresponding predictive errors at The Long Bridge during the summer months of 2004 are shown in Figure 42. The sizes of the predictive errors for the IDEQ model were larger during the periods of increasing temperatures and smaller during periods of decreasing water temperature. The timing of the arrival of both colder and warmer water near the bottom of the channel at The Long Bridge was over-estimated in the IDEQ model during summer of 2004 and was caused by the use of observed temperature profiles from Lake Pend Oreille at Contest Point (ALFLPS Figure 2) at the upstream boundary. The high frequency temperature fluctuations closely reproduced in the COE version of the POR model. However, the influence of seiching activity causing subsurface fluctuations in water temperature during the last 30 days of the summer were greatly reduced as were the size of the predictive errors in the IDEQ model.

![Figure 42 Observed and Calculated Water Temperatures in the Pend Oreille River at a depth of 25 feet at The Long Bridge, June 21-September 21, 2004 (Predictive Error = Calculated-Observed, Model version IDEQ and COE)]
The close proximity of the upstream boundary to The Long Bridge will limit the size of the predictive errors presented in this evaluation for the COE version of the POR. This evaluation does highlight the limitations of using water temperature profiles observed in LPO near Contest Point as upstream boundary conditions for the POR model as applied in the IDEQ POR model. The reliability of temperature estimates throughout the POR is significantly influenced by inflowing temperatures assumed or calculated in the original IDEQ model formulation being considerably warmer than observed conditions. The treatment of the upstream boundary condition in the COE POR model has removed this source of error in the thermal budget of the POR.

A complete set of observed and predicted water temperatures during both 2004 and 2005 are shown in Appendix A for all the sampling stations. In general, the predictive error during the 2004 season at The Long Bridge were larger than observed during the 2005 season because of the decreased seiching activity in 2005.

**POR near Riley Creek**

The simulation of temperatures in the POR near Riley Creek is critical to the characterization of temperature patterns well downstream from the influence from LPO. This station was located upstream of the confluence of the POR with Riley Creek and close to the deepest channel feature identified in survey transects (Figure 2, ALFPORRC). The observed data at this station shows temperatures to be weakly stratified (Figure 4) with depth during the entire summertime period.

The surface water temperatures in the POR near Riley Creek (ALFPORRC2) were over-estimated by the IDEQ model of the POR during the critical summertime period. The surface temperatures calculated near Riley Creek by the IDEQ POR model during the summertime of 2004 overestimated observed conditions by an average of 0.46 °C and exhibited a 90 percent confidence interval ranging from -0.22 to +1.68 °C (5 percent of the predictive errors were larger than 1.68 °C). The COE POR model generated much more reliable estimates of surface temperatures with a mean value of the predictive error of -0.15 °C and a 90 percent confidence interval ranging from -0.65 to 0.53 °C. The standard error of the updated POR model of existing conditions was reduced by about 38% from 0.58 to
0.36 °C. The time history of observed and calculated surface temperatures and the corresponding predictive errors in the POR near Riley Creek during summer months of 2004 are shown in Figure 43. The updated COE model of the POR experienced periods of both over and under-estimation of surface temperatures compared to the IDEQ model of the POR which produced estimates which were consistently warmer than observed. The overestimation of surface temperature on the POR near Riley Creek by the IDEQ model centered on July 24 corresponds with a period when subsurface temperatures were overestimated at The Long Bridge as shown in Figure 42 indicating the influence of errors introduced from the boundary.

![Figure 43 Observed and Calculated Water Temperatures in the Pend Oreille River at a depth of 3 feet near Riley Creek, June 21-September 21, 2004 (Predictive Error = Observed-Calculated, Model version IDEQ and COE)](image)

The sizes of the predictive errors in subsurface temperatures in the POR near Riley Creek were also more closely reproduced with the updated model of the POR. The IDEQ model water temperature estimates at a depth of 40 ft (ALFPORRC40) during 2004 were on average -0.05 °C cooler than observed during the summer months reflecting little seasonal bias in these predictions. However, the standard error in water temperatures
using the IDEQ model was 0.44 °C with a 90 percent confidence interval ranging from -0.98 to 0.60 °C. The mean error in temperature in POR near Riley Creek at 40 ft of depth in the updated POR model was just -0.21 °C with 90 percent confidence interval ranging from -.64 to 0.21 °C. The standard error of estimate using the updated POR model in the POR near Riley Creek at a depth of 40 ft was 0.26 °C or about 59 percent of the standard error exhibited by the IDEQ POR model. The time history of observed and calculated bottom temperatures (ALFPORRC40) and the corresponding predictive errors at Riley Creek during the summer months of 2004 are shown in Figure 44. A daily temperature variation is not evident at 40 ft of depth. The updated model does a superior job of predicting the smaller weekly variations in water temperature at this location. There is a tendency for the COE model to under predict temperatures during the passage of cold weather at this location.

Figure 44 Observed and Calculated Water Temperatures in the Pend Oreille River at a depth of 40 feet near Riley Creek, June 21-September 21, 2004 (Predictive Error = Calculated-Observed, Model version IDEQ and COE)
**POR at Albeni Falls Dam**

The thermal characteristics in the POR at Albeni Falls Dam reflect the cumulative changes in water temperatures caused by the exposure to meteorologic conditions and tributary contributions. Albeni Falls Dam is also located just 2.2 miles upstream of the Washington and Idaho border with a short travel time associated with this reach. The observed water temperatures at AFD have been sampled both above and below the dam during both study years. A temperature string recorded the vertical variation in temperatures in the forebay of AFD at depths of 2, 10 20 and 40 ft was conducted during the 2005 season only. These data indicate little variation in water temperatures as a function of depth was evident in the forebay of AFD. There have been data collected in the forebay of AFD that identifies lateral gradients in water temperatures. This lateral gradient is likely associated with the mixing zone of the Priest River and Pend Oreille Rivers during high tributary runoff when temperature differentials are present between the two rivers (Schneider, 2003).

The water temperatures in the POR at Albeni Falls Dam at station ALFIRFB during the summertime of 2004 exceeded 19 °C from the last week and June through the first week in September. The sampling depth at station ALFIRFB varied as a function of the forebay elevation but was generally greater than 15 ft. The vertical temperature profile data collected at Albeni Falls Dam during the summer time of 2005 showed an average temperature difference between depths of 2 ft and 40 ft of less than 0.1 °C.

The IDEQ POR model exhibited a slight bias in the estimation of POR temperatures at AFD during the summertime of 2004 with the calculated temperatures overestimating observed conditions by an average of 0.21 °C. The COE POR model reproduced more reliable estimates of POR temperatures at AFD with the mean value of the predictive error of -0.13 °C and a 90 percent confidence interval ranging from -0.55 to 0.37 °C. The standard error of the updated POR model of existing conditions was reduced by about 36% from 0.44 to 0.28 °C when compared to the IDEQ formulation.

The time history of observed and calculated surface temperatures and the corresponding predictive errors in the POR at Albeni Falls Dam during summer months of 2004 are shown in Figure 45. The standard prediction error of the updated COE model at AFD was similar to the standard pre-
diction error at The Long Bridge located near the upstream boundary with LPO. During the period when POR temperatures were warming, the updated POR model performed as good as or better than the IDEQ POR model. Both model formulation performed equally well during the period when POR temperatures were cooling down.

![Figure 45 Observed and Calculated Water Temperatures in the Pend Oreille River at Albeni Falls Dam, June 21-September 21, 2004 (Predictive Error = Calculated-Observed, Model version IDEQ and COE)](image)

**Discussion**

A review of the POR model performance based on the predictive errors for water temperature near the upstream boundary with LPO, at a deep water station located at Riley Creek, and at Albeni Falls Dam during the summer time period for 2004 and 2005 has demonstrated a significant improvement with the updated model formulation. The persistent over prediction bias of surface temperatures demonstrated in the IDEQ model has been reduced significantly at The Long Bridge and at Riley Creek sampling stations. The variance in the predictive error has been significantly reduced at the primary sampling stations in the POR as shown in Figure 46. This figure graphically demonstrates both the large predictive error biases (mean error) and variances (standard error) at The Long Bridge sampling.
stations for the IDEQ model formulation compared to the COE formulation. The primary source of the model improvement was the use of observed temperatures at The Long Bridge at the upstream boundary. The variance and bias of model predictions were also improved on the POR near Riley Creek with significant improvements in the simulation of surface temperatures for both years. The primary source of this improved model was the use of the alternative weather data at Hoodoo and the influence of model coefficients on the vertical distribution of heat. The variation in the standard error of the POR model was significantly smaller at Albeni Falls Dam. The improvements in the model at reproducing temperatures at AFD are largely attributed to the updated temperature boundary condition, representative weather data, and updated model coefficients.

The consistent overestimation of the thermal flux at the upstream boundary in the IDEQ model taken with the small prediction bias in water temperatures in the POR at Albeni Falls Dam suggests that the heat exchange governed by the imposed meteorologic data (Sand Point-primary station) was underestimated. The small bias and standard errors generated by the updated POR modal at Albeni Falls Dam could only be generated with the use of weather data from the Hoodoo station in combination with the application of the observed temperature profiles at The Long Bridge at the upstream boundary.

**Model Uncertainty**

It should be noted that in spite of the significant improvements in model performance, the uncertainty in model predictions relative to a temperature tolerance of 0.3 °C is still quite large. The role of model uncertainty in determining compliance with state water quality statutes with a suitable degree of confidence is an important consideration when interpreting model results. The reliability of model estimates will improve at larger temporal and spatial scales. For instance, estimates of daily maximum temperature in a surface cell will be less reliable than estimates of the volume integrated daily maximum temperature over a river reach (multiple segments). In addition, the observations of water temperatures at the channel bottom in the deepest reaches of the POR were not available to estimate the reliability of the model at these locations. Considerable care
should be taken when interpreting model estimates in these regions given the known limitations of the model discussed previously.

The importance of considering model uncertainty in interpreting model results can be demonstrated by the following example where model simulations errors are compared to the small detection tolerance used for determining water temperature compliance in the current TMDL for temperature. This example will compare the updated model prediction errors of surface water temperatures near Riley Creek with the temperature tolerance of 0.3 C used to assess compliance with IDEQ water quality standards. During the summer from June 21-September 21 2004, the calculated surface water temperatures in the POR near Riley Creek exceeded the observed temperatures by 0.3 C or more than 10 percent of the time. The exceedance of this small temperature tolerance is a numerical artifact associated with modeling errors and uncertainty and does not constitute a physically meaningful event worthy of determining compliance with water quality standards. If decisions regarding model estimates exceeding of a small temperature tolerance were to include a factor of safety scaled with the reliability of the model estimate (twice the standard error of estimate 0.72 C), the frequency of falsely interpreting model estimates would become much smaller and the reliability of decisions addressing compliance with water quality standards enhanced. In this case, the calculated surface water temperatures in the POR near Riley Creek exceeded the observed temperatures by 0.3+0.72=1.02 C or more only 1.0 percent of the time.
Figure 46: Summary of Prediction Error of Pend Oreille River Water Temperatures by Model Formulation, Sampling Station, and year for June 21-September 21, 2004 and 2005 (Mean Error; Pink Range = Mean Error +/- Standard Error, Black Circles= 5 and 95 percentile, Yellow Highlight IDEQ Model)
Model Results and Discussion

The existing hydrodynamic and water quality conditions in the Pend Oreille River with Albeni Falls Dam in place were modeled for the entire 2004 season and through September 25 of 2005 using the updated model as described in this report. The natural conditions were modeled with the aforementioned updates without Albeni Falls Dam, no NPDES point sources, tributary flows unchanged from exiting conditions with estimated natural temperatures, and shading with Potential Natural Vegetation. These conditions reflect scenario 8 properties presented in previous modeling application reports (PSU, 2007a) and will be referred to as either natural conditions or without Albeni Falls Dam in this report. Results will be presented using (1) the Time Series methodology and (2) an alternative frequency analysis methodology.

Results (Time Series Methodology)

The following presentation of model results follows the methodology adopted by IDEQ for interpreting Idaho water quality standards for temperature in the Pend Oreille River TMDL (IDEQ, 2008). The assessment of compliance with IDEQ water temperature standards has been based on the simulated daily average and maximum temperatures in a surface and bottom cell at a distance of 10 and 35 kilometers from the railroad bridge near Sandpoint Idaho, at Albeni Falls Dam, and throughout the entire POR on August 8 and 16, 2004. The presentation of model results will focus on the critical summer period during 2004 and 2005 that fully encompasses the period when water temperatures are 19°C and warmer.

The IDEQ interpretation of these model results are based on pairing results of daily average, maximum or volume weighted temperatures with and without Albeni Falls Dam for a river segment or cell for a time series. The determination of non-compliance with state water quality standards has been determined by comparing existing temperature metrics with either the numeric criteria or natural conditions (the larger of the two). An exceedance of the water temperature standard in the state of Idaho occurs when the simulated existing condition are warmer than the simulated natural condition or applicable criteria by a measurable amount defined to be
0.3 °C. It should be noted that this methodology does not account for differences in travel time between model scenarios with and without Albeni Falls Dam nor does this Time Series analysis quantify the systemic impacts of AFD to the thermal loading of the POR. The presentation of model results in this report using the Time Series methodology does not imply that the Seattle District Corps of Engineers agrees with or accepts this data analysis approach as the basis for evaluation the impacts of Albeni Falls Dam.

The thirteen evaluation metrics adopted by IDEQ for the Pend Oreille River temperature model include:

- 10 km Surface Cell Daily Average
- 10 km Bottom Cell Daily Average
- 10 km Volume Weighted Daily Average
- 35 km Surface Cell Daily Average
- 35 km Bottom Cell Daily Average
- 35 km Volume Weighted Daily Average
- 10 km Surface Cell Daily Maximum
- 35 km Surface Cell Daily Maximum
- Albeni Falls Outflow Daily Maximum
- August 16 Longitudinal Profile Surface Daily Maximum
- August 16 Longitudinal Profile Volume Weighted Daily Average
- August 16 Longitudinal Profile Entire Water Column Daily Maximum
- August 8 Longitudinal Profile Entire Water Column Daily Maximum

**Daily Average Temperatures – 10 Km Surface Cell**

The daily average surface temperatures located 10 km downstream from Lake Pend Oreille for natural conditions were warmer than existing conditions most of the time throughout the summer period in 2004 and 2005. The daily average temperatures in the surface cell located 10 km (Figure 15) downstream from LPO were determined during the summer period for 2004 and 2005 with and without Albeni Falls Dam in place as shown in Figure 47 and Figure 48. The temperature differences based on subtracting the calculated daily average existing condition from the applicable numeric criterion (warmer of natural conditions and 19 C) in the surface cell in segment 34, are shown in these figures when the simulated existing temperatures were equal to or larger than 19 C. This temperature difference is positive when natural conditions are warmer than existing condi-
tions and negative when existing conditions are warmer than natural conditions.

The influence of travel time differences (i.e. lag time) between existing and natural conditions on surface temperatures can be seen in the lagged response in surface temperatures between these conditions. This thermal phenomenon is most evident in June and early July of 2004 when periods of cooler surface temperatures caused by fluctuating conditions in LPO arrive slightly later in the existing conditions simulation when compared to natural conditions.

The existing daily average surface conditions 10 Km downstream of LPO were on average about 0.3 C cooler than natural conditions during the critical summertime periods in 2004 and 2005 when existing conditions were 19 C or warmer. The daily average surface temperatures 10 Km downstream from LPO were equal to or cooler than the applicable temperature criteria 87 percent of the time (161 out of the 186 days). The maximum daily average surface temperatures at the 10 km surface cell for natural conditions was about 25.4 °C compared to 24.2 °C for existing conditions. Natural conditions were colder than existing conditions on several days and these events were associated with differential transport of water following the passage of cold weather. The water temperatures at the 10 Km location are strongly influenced by the heat exchange between the POR and LPO. However, the shallow and wide channel near Sandpoint ID acts as an effective heat exchanger with the shallower conditions associated with natural conditions being more responsive to atmospheric thermal inputs. Thus, the shallower natural conditions simulation heats up faster from mid June through mid August during peak summer temperatures, and then cools down faster from mid August through September during cooler late summer/fall temperatures.
Figure 47  Time History of Simulated Daily Average Surface Temperatures in the Pend Oreille River Located 10 Kilometers Downstream from Lake Pend Oreille with and without Albeni Falls Dam, June 21-September 21, 2004

Figure 48  Time History of Simulated Daily Average Surface Temperatures in the Pend Oreille River Located 10 Kilometers Downstream from Lake Pend Oreille with and without Albeni Falls Dam, June 21-September 21, 2005
Daily Average Temperatures – 10 Km Bottom Cell

The simulated water temperatures near the bottom of the POR for existing conditions 10km downstream of LPO never exceeded 19 °C during the summertime of 2004 and 2005. The daily average temperatures in the bottom cell 10 Km downstream for LPO during the critical summertime period in 2004 and 2005 were on average 1.7 C cooler for existing conditions compared to natural conditions (18.5 C natural conditions, 16.8 C for existing conditions). The daily average temperatures in a bottom cell located 10 km downstream from LPO were determined during the summer period for 2004 and 2005 with and without Albeni Falls Dam in place as shown in Figure 49 and Figure 50. The natural conditions temperatures were considerably warmer than existing conditions at the bottom of the POR 10 km downstream of LPO. The natural conditions daily average temperatures exceeded 19 °C for over 30 days during each simulation period and reached a maximum temperature of 21.7 °C.

The flat temperature response for existing conditions during much of the summer indicates the isolation of cooler water in this deep water pocket. The retention of cold water for long periods of time in the POR has not been documented. The limitations of the model in accurately simulating water exchange and mixing in coarsely resolved topography with abrupt changes in water depth should be noted and caution applied when interpreting model results in this area.
**Figure 49** Time History of Simulated Daily Average Bottom Temperatures In the Pend Oreille River Located 10 Kilometers Downstream from Lake Pend Oreille with and without Albeni Falls Dam, June 21-September 21, 2004

**Figure 50** Time History of Simulated Daily Average Bottom Temperatures In the Pend Oreille River Located 10 Kilometers Downstream from Lake Pend Oreille with and without Albeni Falls Dam, June 21-September 21, 2005
Daily Average Temperatures – 10 Km Volume Weighted

The simulated daily average volume weighted water temperatures in the POR 10 Km downstream of LPO for existing conditions were generally cooler than natural conditions during periods of hot weather and warmer during periods of colder weather during the summertime of 2004 and 2005. The volume weighted temperature provides a representative measure of heat contained in a given river segment for each day of the critical summertime period. The volume weighted average will be influenced by the retention of cooler water at depth but will also reflect the greater volume of water in the near surface cells experiencing active exchange from solar radiation and advective exchange from upstream river segment.

The daily average volume weighted temperatures throughout the water column located 10km downstream from LPO were determined during the summer period for 2004 and 2005 with and without Albeni Falls Dam as shown in Figure 51 and Figure 52. The simulation without Albeni Falls Dam approached a maximum of 23.5 °C in both 2004 and 2005. The simulation with Albeni Falls Dam in place reached maximum temperatures of 21.8 and 22.4 °C, respectively for 2004 and 2005. The volume weighted daily average temperatures 10 Km downstream from LPO for existing conditions were about 0.5 C cooler than natural conditions when averaged over the critical summertime periods in 2004 and 2005 (19.8 C natural conditions and 19.3 C existing conditions). The daily average volume weighted temperatures at this location consistently exceeded 19 °C during the second week in July and remained above this level through early September. As previously noted, the water temperatures at this location are strongly influenced by the heat exchange between the POR and LPO, and by the heat exchange in the shallow wide channel near Sandpoint, ID.

Daily Average Temperatures – 35 Km Surface Cell

The daily average surface temperatures for natural conditions at the 35k distance downstream from LPO were both warmer and colder than existing conditions throughout the summer period in 2004 and 2005. The daily average temperatures in a surface cell located 35km (Figure 15) downstream from LPO were determined during the summer period for 2004
Figure 51 Time History of Simulated Daily Volume Weighted Temperatures In the Pend Oreille River Located 10 Kilometers Downstream from Lake Pend Oreille with and without Albeni Falls Dam, June 21-September 21, 2004

Figure 52 Time History of Simulated Daily Volume Weighted Temperatures In the Pend Oreille River Located 10 Kilometers Downstream from Lake Pend Oreille with and without Albeni Falls Dam, June 21-September 21, 2005
and 2005 with and without Albeni Falls Dam in place as shown in Figure 53 and Figure 54. The maximum daily surface temperature at the 35km surface cell for natural conditions was about 24.2 °C compared to 23.4 °C for existing conditions. The temperature difference between these simulations (without AFD minus with AFD) were also calculated when the existing condition temperature estimates exceeded 19 °C. During the warmest weather conditions, the daily average surface temperatures for existing conditions were consistently cooler than natural conditions. The opposite condition was present during the end of August and through September when cool weather patterns were present. The average surface temperature during the critical summertime period 35 Km downstream from LPO was 20.7 for existing conditions and 20.6 for natural conditions.

The influence of travel time differences (i.e. lag time) between existing and natural conditions strongly influences simulated temperatures at the 35 Km location. For example, the arrival of colder surface water at a distance 35k downstream of LPO at the end of August 2004 for natural conditions occurred about 3 to 5 days before the arrival of this same cold water front for existing conditions. It is this differential transport of colder water during the end of summer time period that is a major source for daily average surface temperatures for existing conditions to exceed natural conditions. The timing of the occurrence of daily average surface temperatures of 19 °C or warmer at this location was within several days between existing and natural conditions.

**Daily Average Temperatures – 35 Km Bottom Cell**

The daily average temperature in the bottom cell 35 Km downstream from LPO reached 19 °C for only two days in 2005 for existing conditions but exceeded 19 °C from July 14 to September 5, in 2004. In general, the bottom daily average temperatures for existing conditions were cooler than estimated for natural conditions. The average of summertime daily average bottom temperatures were about 1 °C cooler for existing conditions compared to natural conditions for the two years of study (19.7 °C natural versus 18.6 °C existing). The daily average temperatures in a bottom cell
**Figure 53** Time History of Simulated Daily Average Surface Temperatures in the Pend Oreille River Located 35 Kilometers Downstream from Lake Pend Oreille with and without Albeni Falls Dam, June 21-September 21, 2004

**Figure 54** Time History of Simulated Daily Average Surface Temperatures in the Pend Oreille River Located 35 Kilometers Downstream from Lake Pend Oreille with and without Albeni Falls Dam, June 21-September 21, 2005
located 35km downstream from LPO were determined during the summer period for 2004 and 2005 with and without Albeni Falls Dam in place as shown in Figure 55 and Figure 56. The flat temperature response during much of the summer indicates the isolation of cooler water in this deep water pocket which was more prominent for the deeper existing condition compared to the shallower natural conditions. The bottom water temperatures were warmer on average for natural conditions when compared to existing conditions at this point in the POR. Again, caution should be used when applying these simulations of bottom temperatures since no confirmation of model accuracy in simulating these processes was available.

![Graph of temperature changes](image.png)

Figure 55 Time History of Simulated Daily Average Bottom Temperatures in the Pend Oreille River Located 35 Kilometers Downstream from Lake Pend Oreille with and without Albeni Falls Dam, June 21-September 21, 2004

**Daily Average Temperatures – 35 Km Volume Weighted**

The daily average volume weighted POR temperatures located 35 Km downstream from LPO for existing conditions were generally cooler than natural conditions during the first half of the summer and slightly warmer
during the second half of the summer. The daily average volume weighted temperatures throughout the water column located 35km downstream from LPO were determined during the summer period for 2004 and 2005 with and without Albeni Falls Dam as shown in Figure 57 and Figure 58. The daily average volume weighted POR temperatures when averaged over the critical summertime period for 2004 and 2005 were 20.2°C for both natural and existing conditions. The water temperature simulations without Albeni Falls Dam approached a maximum of 24.2°C in 2005 with existing conditions reaching a maximum temperature of 23.4°C. The timing and duration of 19°C degree temperatures at the 35km location was similar to those simulated at the 10k location.

As noted above for the 35 Km location, the influence of travel time differences (i.e. lag time) between existing and natural conditions strongly influences simulated temperatures at this location. The longer time of travel from LPO is evident in the lagged thermal response of existing conditions compared to natural conditions. The presence of cooler weather during August and September resulted in higher rates of declining temperatures without AFD compared to with AFD during both years of study.
Figure 57 Time History of Simulated Daily Average Volume Weighted Temperatures In the Pend Oreille River Located 35 Kilometers Downstream from Lake Pend Oreille with and without Albeni Falls Dam, June 21-September 21, 2004

Figure 58 Time History of Simulated Daily Average Volume Weighted Temperatures In the Pend Oreille River Located 35 Kilometers Downstream from Lake Pend Oreille with and without Albeni Falls Dam, June 21-September 21, 2005
Daily Maximum Temperatures – 10 Km Surface Cell

The daily maximum temperature in the surface cell was generally significantly warmer in the POR 10 kilometers downstream from LPO for natural conditions compared to existing conditions during the summer time of 2004 and 2005. The average daily maximum surface temperature 10 Km downstream of LPO was 21.0 °C during the critical summertime period for existing conditions and 21.4 °C for natural conditions. The daily maximum water temperatures in the surface cell as determined by the model have a short duration (seconds) and contain a high degree of variability from day to day and year to year. The size of a surface cell will vary in response to changing pool conditions, flow rates, and grid selection. The daily maximum surface temperatures located 10km downstream from LPO were determined during the summer period for 2004 and 2005 with and without Albeni Falls Dam as shown in Figure 59 and Figure 60. The peak daily maximum temperature at the surface approached 25.8 °C in both years for natural conditions compared to only 25.0 °C for existing conditions. The estimated daily maximum temperatures for existing conditions exceeded the applicable numeric criteria on only 9 out of 186 days during the critical summertime period during the two years of study. Moreover, these days were during the late August and September time period when the river was cooling down and not during periods of peak maximum temperatures simulated in July and early August.
**Figure 59** Time History of Simulated Daily Maximum Surface Temperatures in the Pend Oreille River Located 10 Kilometers Downstream from Lake Pend Oreille with and without Alben Falls Dam, June 21-September 21, 2004

**Figure 60** Time History of Simulated Daily Maximum Surface Temperatures in the Pend Oreille River Located 10 Kilometers Downstream from Lake Pend Oreille with and without Alben Falls Dam, June 21-September 21, 2005
Daily Maximum Temperatures – 35 Km Surface Cell

The daily maximum surface temperatures located 35km downstream from LPO were determined during the summer period for 2004 and 2005 with and without Albeni Falls Dam as shown in Figure 61 and Figure 62. The peak daily maximum temperature at the surface exceeded 25.8 °C on August 2, 2004 for natural conditions compared to only 24.6 °C for existing conditions. The shallower flow conditions for natural conditions contributes to a larger diurnal variation in water temperatures and consistently higher daily maximum temperatures at the water surface in the POR during hot weather conditions in July and early August. However, there were several days during cooler weather conditions in mid August and September during the summer of 2004 and 2005 when natural conditions were cooler than existing conditions and existing conditions exceeded the temperature criteria of 22 °C. The arrival of surface temperatures greater than 22 °C was one week earlier for natural conditions compared to existing conditions during 2005.

The water temperatures at 35 Km are strongly influenced by both the heat exchange between the POR and LPO, and the transport rate of this water downstream. As previously noted, the influence of differential transport rates between existing and natural conditions on surface temperatures is largely responsible for the 3 to 5 day lag in the arrival of colder surface water for existing conditions during cold weather events in August, and the cooling down phase of the river at the end of August and in September of 2004 and 2005. The longer time of travel from Sandpoint ID is evident in the lagged thermal response of existing conditions compared to natural conditions. The presence of cooler weather during August and September resulted in higher rates of declining temperatures without AFD compared to with AFD during both years of study.
Figure 61 Time History of Simulated Daily Maximum Surface Temperatures in the Pend Oreille River Located 35 Kilometers Downstream from Lake Pend Oreille with and without Albeni Falls Dam, June 21-September 21, 2004

Figure 62 Time History of Simulated Daily Maximum Surface Temperatures in the Pend Oreille River Located 35 Kilometers Downstream from Lake Pend Oreille with and without Albeni Falls Dam, June 21-September 21, 2005
Daily Maximum Temperatures – Albeni Falls Dam Outflow

The daily maximum temperature in the outflow from Albeni Falls Dam (or at the base of Albeni Falls for natural conditions) represents an integrated sample of the water column. The vertical gradients in water temperatures in the POR downstream of the confluence with the Priest River are small. However, the shallower flow conditions in the POR do experience a diurnal variation in bulk temperatures causing the daily maximum temperature to be higher than the daily average water temperatures at this location. This is a critical location in the assessment of thermal impacts caused by AFD because it marks the downstream limit of the POR model for water temperature at a little over 44 kilometers from Lake Pend Oreille. The water passing this location will experience the longest exposure to atmospheric heating and cooling processes. This location also contains the largest differential in travel time between natural and existing conditions and therefore the largest spatial separation for a parcel of water entering the POR at a common time.

The daily maximum outflow temperatures at the dam for existing conditions and at Albeni Falls for natural conditions were determined during the summer period for 2004 and 2005 as shown in Figure 63 Figure 64. The peak daily maximum temperature at Albeni Falls for natural conditions approached 25.0°C. The peak daily maximum temperature at Albeni Falls Dam over the two year study period was 23.9°C or about 1.1°C less than simulated for natural conditions. The maximum daily temperatures for existing conditions were consistently cooler than natural conditions during the warmest summer weather events. However, the influence of colder weather systems and the natural cooling down of LPO during the late summer caused daily maximum temperatures to decline more rapidly for natural conditions. The shallower flow conditions in the approach to ADF compared to conditions at the 10km and 35km river locations caused daily maximum temperatures to be smaller in comparison. The lagged response of thermal events at AFD for existing conditions compared to unimpounded conditions is evident in the time history of daily maximum temperatures. The onset of daily maximum temperatures in excess of 22°C occurred several days later in July for existing conditions compared to natural conditions and was extended for several days at the end of summer in August.
Figure 63 Time History of Simulated Daily Maximum Temperatures in the Pend Oreille River at Alben Falls Dam and at Alben Falls, June 21-September 21, 2004

Figure 64 Time History of Simulated Daily Maximum Temperatures in the Pend Oreille River at Alben Falls Dam and at Alben Falls, June 21-September 21, 2005
Daily Maximum Surface Temperatures – Entire POR August 16 2004

The final four water temperature compliance metrics involved system wide temperature properties along the entire reach of the POR for specific days in 2004. The date of August 16, 2004 was identified for compliance evaluation because it was one of the warmest days during the summer and followed six consecutive days where daily maximum air temperatures exceeded 33 °C as shown in Figure 65. The daily maximum air temperatures exception of 33.9 °C was exceeded at both the Sandpoint and Hoodoo weather stations on August 16 and therefore excludes this date for determining compliance with IDEQ standards.

![Graph showing air temperature and water temperature](image_url)

**Figure 65** Observed air temperature at the HooDoo weather station and calculated volume-weighted water temperatures in the Pend Oreille River with and without Albeni Falls Dam, July 22-August 19, 2004

The maximum daily surface temperatures were compared throughout the main-stem Pend Oreille River with and without Albeni Falls Dam on August 16 to provide additional information on impacts of ADF on system wide thermal properties. The daily maximum surface temperatures (dashed lines) without AFD were generally equal to or warmer than conditions with AFD in place as shown in

Figure 66. The numerical grid of the POR is shown in this figure with daily water temperature metrics to illuminate the location of deep and shallow
reaches of the river. The daily maximum surface temperature without AFD approached 25.8 °C within 10 Km of The Long Bridge compared to 24 °C with AFD. The temperature differences between these two conditions went from 0 to about 2 °C within a couple miles of Lake Pend Oreille. From this point downstream, the differences between the daily maximum water temperatures with and without ADF diminished with distance downstream from Lake Pend Oreille. The simulated maximum daily temperatures at Riley Creek without AFD were about 0.4 °C warmer than with AFD. The differences in daily maximum temperatures were generally small downstream of the confluence with the Priest River in this shallow water reach of the POR.

Figure 66 Calculated Daily Maximum (dashed lines) and Daily Volume Weighted Water Temperatures (solid lines) in the Pend Oreille River with (blue) and without (pink) Albeni Falls Dam, August 16, 2004.
Daily Average Volume Weighted Temperatures – Entire POR August 16 2004

The water temperatures were averaged over each model segment using a volume weighted approach during each day. The daily volume weighted temperatures are shown in Figure 66 with the solid lines with and without AFD. The volume weighted summary results in a much closer comparison of POR temperatures with and without AFD. The conditions without AFD were consistently warmer than with ADF upstream of the confluence with the Priest River. The two cases were nearly identical downstream of the Priest River. The retention of colder water in the deepest reaches of the POR with AFD in place results in a larger difference in volume weighted temperatures when compared to the unimpounded river. There is very little difference in daily volume weighted water temperatures in the POR between the entrance and exit of the study area indicating a degree of equilibrium has been reached with atmospheric heat exchange processes for both scenarios.

Daily Maximum Temperatures over Water Column – Entire POR August 16 2004

The third compliance metric proposed for use in the temperature TMDL for the POR involves the daily maximum temperature over the water column for August 16, 2004. This metric requires some addition explanation since the maximum daily water temperature is consistently found at the water surface and those results have already been presented. This temperature metric was presented in earlier reports as the temperature difference with and without AFD in each active grid cell for these simulations over the entire POR on August 16. Only active grid cells in the natural condition simulation were compared to the corresponding cell in the existing river simulation. This is the most complex definition for compliance determination because it requires the simulated maximum daily temperature in selected cells of the exiting conditions simulation to remain within 0.3 °C of the applicable temperature criteria based on the natural conditions simulation.
The thermal conditions throughout the POR on August 16, 2004 for natural conditions were similar to or warmer than water temperatures simulated for existing conditions. The daily maximum surface temperatures and daily average surface, volume weighted, and bottom temperature in each river segment of the POR with and without AFD for August 16, 2004 are shown in Figure 67. The solid lines represent daily average water temperatures with the bold line indicating the volume weighted water temperature over the water column. The daily average surface and bottom temperature in each segment are indicated by a narrow solid line above and below the bold volume weighted average temperature, respectively. In the shallow reach of the POR downstream of the Priest River, the surface, volume weighted, and bottom daily average temperatures are similar and appear as a single line for both natural and existing scenarios. The bottom temperatures remained cooler in the existing conditions than natural conditions with the exception of a short reached located near segment 80 where they were nearly equal. The daily average surface conditions in the existing conditions simulation were consistently cooler than calculated in the natural conditions scenario for the entire POR from LPO to the confluence with the Priest River. With very few exceptions, the thermal conditions over the entire water column were cooler for existing conditions when compared to natural conditions.

Figure 67  Calculated Daily Average Surface, Volume Weighted, and Bottom Temperature and Daily Maximum Surface Temperature by Pend Oreille River Segment with and without Albeni Falls Dam, August 16 2004 (Blue lines with AFD, Pink Lines without AFD, Solid Bold Line–Daily Average Volume Weighted, Dashed Line–Surface Daily Maximum, Solid Narrow – Daily Average Surface and Bottom Temperature)
The final compliance metric involved the daily maximum temperature over the water column in the entire POR on August 8, 2004. The reasoning used by IDEQ for selecting August 8 was the combination of a hot day with maximum entrainment of cooler water from the hypolimnion of Lake Pend Oreille (IDEQ, 2008). However, a review of the weather conditions and water temperatures on August 8, 2004 suggest conditions were atypically cold for mid summer conditions. The thermal conditions in the POR on August 8, 2004 were generated as a result of five days of cold weather conditions over the basin. During the previous two days on August 6-7, air temperatures remained below the average daily water temperature and these colder conditions were accompanied by heavy cloud cover and rain showers. The thermal conditions on the POR on August 8 reflect the effects of a sustained cold front occurring when POR temperatures were near their hottest conditions of the year. The daily average volume weighted temperatures dropped over 2°C during this time period in the POR at AFD and daily maximum temperatures decreased as much as 4°C some reaches of the river. The minimum air temperatures on August 8 at the Hoodoo weather station was 7.2°C a level that was previously observed over a month earlier on July 9 and would not be seen again until September 3.

The bulk thermal conditions throughout the POR on August 8, 2004 for natural conditions were similar to or colder than water temperatures simulated for existing conditions with the exception of temperatures located in the deepest segments of the POR and conditions near LPO. The daily maximum surface temperatures and daily average surface, volume weighted, and bottom temperature in each river segment of the POR with and without AFD for August 8, 2004 are shown in Figure 68. In the shallow reach of the POR downstream of the Priest River, the surface, volume weighted, and bottom daily average temperatures were similar and appear as a single line for both natural and existing scenarios. The bottom temperatures for existing conditions were both warmer and cooler than natural conditions depending upon the overall depth of the river. The maximum daily surface temperatures generally in-
creased with distance from LPO for both conditions. The maximum daily surface temperatures ranged from 21.5 °C near the entrance from LPO to nearly 22.9 °C near Riley Creek for both existing and natural conditions. The difference in thermal conditions in the POR on August 8 2004 for existing and natural conditions are a consequence of a prolonged cold front resulting in the shallower natural conditions to cool off more quickly than the existing condition. This analysis of water temperatures on August 8 strongly suggests that the daily maximum temperature in much of the POR for existing conditions were warmer than the applicable numerical criteria by a measurable amount.

**Figure 68** Calculated Daily Average Surface, Volume Weighted, and Bottom Temperature and Daily Maximum Surface Temperature by Pend Oreille River Segment with and without Albeni Falls Dam, August 8 2004 (Blue lines with AFD, Pink lines without AFD, Solid Bold Line-Daily Average Volume Weighted, Dashed Line- Surface Daily Maximum, Solid Narrow – Daily Average Surface and Bottom Temperature)

**Results (Frequency Analyses)**

The review of daily time histories of thermal conditions presented in the previous section using the IDEQ methodology does not account for the difference in travel time (i.e. lag time) with and without Albeni Falls Dam
nor does this method address the systemic impacts of AFD on the thermal loading of the Pend Oreille River. To rely solely on temperature differences between model scenarios of existing and natural conditions at a specific point in time and place is an unreliable indicator of project impacts on the thermal loading of the POR, and does not account for travel time differences between modeled scenarios. A more meaningful approach to characterizing thermal impacts to a river system where time of travel differences exists between model scenarios is through a frequency analysis of water temperatures. Frequency analysis was used to characterize impacts to thermal loadings in the Willamette River Basin for an EPA approved temperature TMDL.

A frequency analysis of daily water temperatures metrics in the POR with and without AFD was developed to provide for a more comprehensive summary of project impacts on the thermal regime of the POR. This analysis methodology lumps temperature data over the critical summertime period and ranks the frequency of occurrence for each event. This approach will reflect systemic impacts on the thermal regime of the POR through the comparison of the entire population of simulated temperature for the two cases under consideration. The persistent occurrence of warmer temperatures exceeding critical temperature criterion will be evident in the comparison of the frequency response at higher percentiles.

**Time of Travel**

An important property in understanding the differences in the thermal regime of the POR with and without AFD is the change in the time for travel over the study area. The modeled river discharges for natural and existing conditions were similar during the summer time period (Figure 21). However, the difference in lake and river stage result in differences in cross sectional area, depth of flow, and average velocity. Therefore, the time of travel of a modeled parcel of water entering the POR from Lake Pend Oreille until exiting at Albeni Falls Dam will be different between the with and without AFD scenarios.

The travel time was computed by the model for both study years with and without Albeni Falls Dam as shown in Figure 69 and Figure 70. At the beginning of summer, the time of travel is generally about 2-3 days for natural conditions and about one day longer for existing conditions. During high flow conditions, the transport of an
extreme thermal event introduced from LPO would take just 2 days to move through the entire reach for natural conditions and 3 days for existing condition. This causes a dislocation of this thermal event in the POR between these scenarios and highlights the limited value of characterizing the thermal budget of the POR based on a comparison of temperatures at a fixed location and time. A more meaningful characterization of the thermal budget of the POR will involve analyses of the thermal response over the entire critical summer time period.

The river flows continue to decrease during the summer time, however the lake and river stage remains stable for the with AFD scenario while the lake and river stages decrease for the without AFD scenario. This stage difference, results in longer travel times and a larger difference in time of travel between the impounded and unimpounded conditions from late July through mid September. On August 25, the travel time for 2004 was about 5 days for natural conditions and about twice as long (11 days) for existing conditions. A natural cooling down of Lake Pend Oreille and the Pend Oreille River system begins in late August as air temperatures and lake temperatures decrease. The longer travel time for the with AFD scenario versus the without AFD scenario results in a lag time of about 5 days in the movement of the cooler water downstream. The overall thermal response pattern is similar between the with and without AFD scenarios however, the with AFD scenario thermal response is shifted by about 5 days.

The river flows continue to decrease during the summer time causing longer travel times and a larger difference in time of travel between the impounded and unimpounded conditions. During the first week in August, the travel time for both years was about 3.5-4 days for natural conditions and about twice as long (8-9 days) for exiting conditions. The longer travel time causes differences in the exposure of a parcel of water to weather conditions. If the weather pattern consists of 4 hot days followed by 4 cold days during first week in August, the net heat content of a parcel of water entering the POR on August 1 is likely to be higher when passing Albeni Falls four days later compared to that same parcel of water passing Albeni Falls Dam 8 days later. Reversing the sequence of weather conditions will also reverse the outcome of water temperatures leaving the study area.
Figure 69: Calculated Time of Travel from Lake Pend Oreille to Albeni Falls Dam/Falls with and without Albeni Falls Dam, June 21 to September 21, 2004
Frequency Analyses

The frequency analysis focused on the temperature metrics involving daily average and maximum temperatures at the surface, daily maximum temperature at the channel bottom, and volume weighted daily average temperatures throughout the water column for each river segment. These simulated temperature properties were summarized over the critical summertime period from June 21-September 21, for 2004 and 2005. The frequency responses of each temperature metric were developed for five critical locations in the POR: Upstream boundary with LPO (The Long Bridge), 10 Km downstream from LPO, POR near Riley Creek about 26 Km downstream from LPO, 35 Km downstream from LPO, and POR at Albeni Falls Dam about 44 Km downstream from LPO. A tabular summary of daily maximum and average surface temperatures exceeding temperatures ranging from 19 to 25 °C during the critical summertime period of 2004 and 2005 at each of the five evaluation stations can be found in Tables 3-6. Additionally, the frequency response of the daily maximum surface water temperatures and daily average volume weighted water column temperatures were summarized by river segment for a longitudinal analysis of the POR.
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<tr>
<th>Location and Scenario</th>
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<tr>
<td>Natural Conditions Without AFD</td>
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<tr>
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<td><strong>Segment 131 (35 km downstream)</strong></td>
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<tr>
<td>Natural Conditions Without AFD</td>
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1 Idaho 22 °C daily maximum temperature criterion
### Table 4: Pend Oreille River modeled surface daily maximum temperature statistics for the time period June 21 to September 21, 2005.

<table>
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<tr>
<th>Location and Scenario</th>
<th>Days Exceeding Temperature</th>
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</tr>
<tr>
<td>Existing Conditions With AFD</td>
<td>67</td>
</tr>
<tr>
<td>Natural Conditions Without AFD</td>
<td>71</td>
</tr>
</tbody>
</table>

1 Idaho 22 °C daily maximum temperature criterion
Table 5 Pend Oreille River modeled surface daily average temperature statistics for the time period June 21 to September 21, 2004.

<table>
<thead>
<tr>
<th>Location and Scenario</th>
<th>Days Exceeding Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>19 °C</td>
</tr>
<tr>
<td><strong>Segment 2 (The Long Bridge)</strong></td>
<td></td>
</tr>
<tr>
<td>Existing Conditions With AFD</td>
<td>54</td>
</tr>
<tr>
<td>Natural Conditions Without AFD</td>
<td>52</td>
</tr>
<tr>
<td><strong>Segment 34 (10 km downstream)</strong></td>
<td></td>
</tr>
<tr>
<td>Existing Conditions With AFD</td>
<td>62</td>
</tr>
<tr>
<td>Natural Conditions Without AFD</td>
<td>65</td>
</tr>
<tr>
<td><strong>Segment 102 (Riley Creek)</strong></td>
<td></td>
</tr>
<tr>
<td>Existing Conditions With AFD</td>
<td>62</td>
</tr>
<tr>
<td>Natural Conditions Without AFD</td>
<td>66</td>
</tr>
<tr>
<td><strong>Segment 131 (35 km downstream)</strong></td>
<td></td>
</tr>
<tr>
<td>Existing Conditions With AFD</td>
<td>67</td>
</tr>
<tr>
<td>Natural Conditions Without AFD</td>
<td>66</td>
</tr>
<tr>
<td><strong>Albeni Falls Dam Release</strong></td>
<td></td>
</tr>
<tr>
<td>Existing Conditions With AFD</td>
<td>63</td>
</tr>
<tr>
<td>Natural Conditions Without AFD</td>
<td>64</td>
</tr>
</tbody>
</table>

1 Idaho 19 °C daily average temperature criterion
Table 6 Pend Oreille River modeled surface daily average temperature statistics for the time period June 21 to September 21, 2005.

<table>
<thead>
<tr>
<th>Location and Scenario</th>
<th>Days Exceeding Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>19 °C</td>
</tr>
<tr>
<td>Segment 2 (The Long Bridge)</td>
<td></td>
</tr>
<tr>
<td>Existing Conditions With AFD</td>
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</tr>
<tr>
<td>Natural Conditions Without AFD</td>
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<tr>
<td>Segment 34 (10 km downstream)</td>
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</tr>
<tr>
<td>Existing Conditions With AFD</td>
<td>65</td>
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<tr>
<td>Natural Conditions Without AFD</td>
<td>65</td>
</tr>
<tr>
<td>Segment 102 (Riley Creek)</td>
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</tr>
<tr>
<td>Existing Conditions With AFD</td>
<td>66</td>
</tr>
<tr>
<td>Natural Conditions Without AFD</td>
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<tr>
<td>Segment 131 (35 km downstream)</td>
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<td>Existing Conditions With AFD</td>
<td>67</td>
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<tr>
<td>Natural Conditions Without AFD</td>
<td>68</td>
</tr>
<tr>
<td>Albeni Falls Dam Release</td>
<td></td>
</tr>
<tr>
<td>Existing Conditions With AFD</td>
<td>66</td>
</tr>
<tr>
<td>Natural Conditions Without AFD</td>
<td>65</td>
</tr>
</tbody>
</table>

1 Idaho 19 °C daily average temperature criterion

POR at Boundary with Lake Pend Oreille

The water exchange between LPO and the POR at the Long Bridge will determine the thermal loading introduced into the POR. The shallow channel reach downstream of the Long Bridge will act as an additional barrier for the transport of cold subsurface water into the POR. The frequency of calculated daily maximum and average surface, daily average bottom, and daily average volume weighted water temperature with and without Albeni Falls Dam were summarized for the upstream most river segment as shown in Figure 71. The temperature difference between these conditions at each percentile is also displayed for each metric with positive differences indicating the natural conditions are warmer than existing conditions.
The daily maximum surface temperatures calculated in the POR at the Long Bridge (segment 2) were similar for conditions simulated with AFD and without AFD. The similarity in surface temperatures is caused by the application of the same depth-temperature profile for both conditions. The small difference between these two scenarios develops as a result of the exchange and transport of heat between the upstream and downstream face of this boundary river segment. The number of days where the maximum daily surface temperatures exceeded 22 °C was greater for natural conditions compared to existing conditions by 3 and 1 days respectively for 2004 and 2005 (Tables 3 and 4).

The daily average surface temperatures in the POR at the Long Bridge were nearly the same for natural and existing conditions during the critical summertime period. In 2004, a total of 52 days out of 93 days had daily average surface temperatures warmer than 19 °C for natural conditions compared with 54 out of 93 days for existing conditions (Table 5). A total of 60 out of 93 days (64.5 %) exceeded 19 °C during the summertime in 2005 for both existing and natural conditions (Table 6).

The volume weighted daily average water temperatures in the POR at the Long Bridge for existing conditions were consistently cooler than for natural conditions. The volume weighted daily average water temperature most closely reflects differences in the thermal loading to the POR from LPO. The water temperature entering the POR for natural conditions ranged from 0.2 to 0.6 °C warmer than existing conditions. On average, the water temperatures entering the POR under existing conditions were 0.4 °C cooler than estimated for natural conditions. The cooler entrance water temperatures for existing conditions is directly related to the higher lake stage and exchange of cooler subsurface water between LPO and the POR.

The daily average bottom temperatures for existing conditions were consistently cooler than estimated for natural conditions in the POR at the Long Bridge. The daily average bottom temperatures were about 2 degree cooler at the 90 percentile for existing conditions compared to natural conditions as shown in Figure 71.
Figure 7.1 Cumulative Probability for Daily Maximum Surface and Daily Average Surface, Volume Integrated, Bottom Water Temperatures in the Pend Oreille River at the Long Bridge with and without Albeni Falls Dam during June 21-September 21, 2004 and 2005 (note: Temp Difference was computed as Without AFD minus With AFD for each Cumulative Probability)
10 Km Downstream from LPO

The POR reach located 10 km downstream of LPO represents conditions downstream of the shallow embayment by Sand Point and is associated with a deep channel segment. The frequency of calculated daily maximum and average surface, daily average bottom, and daily average volume weighted water temperature with and without Albeni Falls Dam were summarized for a river segment 34 located 10 km downstream of LPO as shown in Figure 72.

The daily maximum surface temperatures calculated in the POR 10 km downstream of LPO were cooler with AFD in place than without AFD at the 90th percentile by about 0.8 C. The peak daily maximum temperature for existing condition was 25.1 °C compared to 25.9 °C for natural conditions. The number of days with maximum daily surface temperatures greater than 22 °C was nearly the same in 2004 for natural (40 days) and existing (38 days) conditions (Table 3). However, the number of days with maximum daily surface temperatures greater than 22 °C totaled 44 days for natural conditions in 2005 compared to only 37 days for existing conditions (Table 4). Interestingly, the number of days where maximum daily surface temperatures exceeded 24 °C in 2004 and 2005 totaled 21 and 18 days respectively for natural conditions compared to only 10 and 12 days respectively for existing conditions.

The daily average surface temperatures in the POR 10 km downstream form LPO were warmer for natural conditions when compared to existing conditions during the critical summertime period. The degree of warming associated with the natural conditions compared to existing conditions became increasingly larger for warmer water temperatures. The corresponding 90th percentile temperatures were 24.1 °C for natural conditions compared to 23.5 °C for existing temperatures. The frequency of temperatures warmer than 19 °C was about the same for existing and natural conditions. However, about 10 percent of the summertime daily average surface temperatures exceeded 24 °C for natural conditions compared to only 1 percent for existing conditions. The peak daily average surface temperatures reaching 25.4 °C without AFD compared to 24.1 °C with AFD.

The volume weighted daily average water temperatures in the POR 10 km downstream of LPO were cooler for existing conditions when compared to natural conditions for base temperatures warmer than 20.6 °C. The natu-
nal conditions volume weighted daily average temperature at the 80th percentile was 22.0 °C compared to 21.0 °C for existing conditions.

The daily average bottom temperatures for existing conditions were consistently cooler than estimated for natural conditions in the POR 10 km downstream from LPO. The bottom temperatures were estimated to exceed 19 °C about 43 percent of the time for natural conditions compared to only 0 percent of the time for existing conditions.

**POR near Riley Creek**

The POR near Riley Creek located about 26 km downstream of LPO represents conditions near the deepest channel reach in the study area and corresponds with a sampling station for temperature supported throughout the two years of study. The frequency of calculated daily maximum and average surface, daily average bottom, and daily average volume weighted water temperature with and without Albeni Falls Dam were summarized for a river segment located near Riley Creek as shown in Figure 73.

The daily maximum surface temperatures calculated at in the POR near Riley Creek were cooler with AFD in place than without AFD at the 90th percentile by about 0.3 °C. The existing conditions experienced 5 fewer days of 22 °C and warmer compared to natural conditions (Tables 3-4) during the study year. The deeper flow conditions associated with existing conditions resulted in fewer occurrences of very warm daily maximum surface temperatures. The peak daily maximum temperature for existing condition was 24.8 °C compared to 25.7 °C for natural conditions.
Figure 72. Cumulative Probability for Daily Maximum Surface and Daily Average Surface, Volume Integrated, Bottom Water Temperatures in the Pend Oreille River at 10 Km downstream from Lake Pend Oreille with and without Albeni Falls Dam during June 21-September 21, 2004 and 2005 (note: Temp Difference was computed as Without AFD minus With AFD for each Cumulative Probability)
The daily average surface temperatures in the POR near Riley Creek were slightly warmer for natural conditions when compared to existing conditions during the critical summertime period. The major differences in daily average surface temperatures in the POR at Riley Creek between natural and existing conditions occur in the frequency of water temperatures warmer than 23.5 °C. The maximum daily average surface temperature reached 24.6 °C without AFD compared to 24.0 °C with AFD. The duration of daily average temperatures of 24 °C and warmer was 9 days for natural conditions compared to 0 days for existing conditions.

The volume weighted daily average water temperatures in the POR with and without AFD located near Riley Creek were similar and within the detection tolerance of the model up to the 90th percentile. The volume weighted daily average water temperatures were warmer for natural conditions compared to existing conditions for temperatures greater than 22.5 °C.

The daily average bottom temperatures for existing conditions were consistently cooler than estimated for natural conditions in the POR near Riley Creek. The bottom temperatures were estimated to exceed 21 °C about 33 percent of the time for natural conditions compared to only 0 percent of the time for existing conditions. The peak daily average temperatures for natural conditions were estimated to reach as high as 23.4 degrees compared with only 20.3 degrees for existing conditions.
Figure 73  Cumulative Probability for Daily Maximum Surface and Daily Average Surface, Volume Integrated, Bottom Water Temperatures In the Pend Oreille River near Riley Creek with and without Albeni Falls Dam during June 21-September 21, 2004 and 2005 (note: Temp Difference was computed as Without AFD minus With AFD for each Cumulative Probability)
35 Km Downstream from LPO

The POR 35 Km downstream from LPO reflects conditions in a deeper channel reach well removed from the conditions in LPO. The frequency of calculated daily maximum and average surface, daily average bottom, and daily average volume weighted water temperature with and without Albeni Falls Dam were summarized for a river segment located 35 km downstream from LPO as shown in Figure 74.

The daily maximum surface temperatures calculated at the 35 Km distance were cooler with AFD in place than without AFD at the 90% percentile by about 0.2 °C. The peak daily maximum temperature for existing condition was 24.8 °C compared to 25.7 °C for natural conditions. The daily maximum surface temperatures exceeded 25 °C on 6 days for natural conditions compared to zero days for existing conditions.

The daily average surface temperatures 35 km below LPO were similar for natural conditions when compared to existing conditions. The natural conditions temperatures were generally within plus or minus 0.4 °C of existing conditions over then entire temperature range. The number of days with daily average surface temperatures greater than 19°C totaled 66 days for natural conditions compared to 67 days for existing conditions in 2004 (Table 3), and 68 days for natural conditions compared to 67 days for existing conditions in 2005 (Table 4).

The volume weighted daily average water temperatures with and without AFD located 35 km below LPO were similar up to the 84th percentile. The estimated maximum volume weighted daily average temperature for the natural conditions was 24.2 °C compared with 23.4 °C for the existing condition.

The daily average bottom temperatures for existing conditions were consistently cooler than estimated for natural conditions at the 35 km section of the POR. The bottom temperatures were estimated to exceed 19 °C about 60 percent of the time for natural conditions compared to only 30 percent of the time for existing conditions. The peak daily average temperatures for natural conditions were estimated to reach as high as 23.9 degrees compared with only 21.1 degrees for existing conditions.
Figure 74 Cumulative Probability for Daily Maximum Surface and Daily Average Surface, Volume Integrated, Bottom Water Temperatures in the Pend Oreille River 35 kilometers downstream of Lake Pend Oreille with and without Albeni Falls Dam during June 21-September 21, 2004 and 2005 (note; Temp Difference was computed as Without AFD minus With AFD for each Cumulative Probability)
PORE at Albeni Falls Dam

Albeni Falls Dam represents the downstream extent of the POR study domain for this study and closely corresponds with the thermal properties entering the state of Washington. The frequency of calculated daily maximum and average surface, daily average bottom, and daily average volume weighted water temperature with and without Albeni Falls Dam were summarized for the river segment adjacent to Albeni Falls Dam as shown in Figure 75.

The daily maximum temperatures calculated in the forebay of AFD were cooler with AFD in place than without AFD at the 90th percentile by about 0.6°C. The peak daily maximum temperature for existing condition was 24.3°C compared to 24.9°C for natural conditions. The number of days with maximum daily surface temperatures greater than 22°C totaled 38 days for natural conditions compared to 35 days for existing conditions in 2004 (Table 3), and 34 days for natural conditions compared to 298 days for existing conditions in 2005 (Table 4). The number of days where maximum daily surface temperatures exceeded 24°C in 2004 and 2005 totaled 13 days per year for natural conditions compared to only 0 days for existing conditions.

The daily average surface temperatures at AFD were similar for the existing and natural conditions. The frequency responses of daily average surface temperatures for existing and natural temperatures were within 0.2°C for temperatures greater than 19°C. The number of days with daily average surface temperatures greater than 19°C totaled 64 days for natural conditions compared to 63 days for existing conditions in 2004 (Table 3), and 65 days for natural conditions compared to 66 days for existing conditions in 2005 (Table 4).

The volume weighted daily average water temperatures at AFD were similar with and without AFD. The observed and calculated vertical variation in water temperatures in the forebay of AFD were small for existing conditions and estimated to be even less for natural conditions.

The daily average bottom temperatures for existing conditions at AFD were similar to conditions simulated for natural conditions. The lack of vertical variations in water temperatures at AFD is demonstrated by the similarity between the temperatures curves for the daily average surface, bottom, and volume weighted metrics.
Figure 75 Cumulative Probability for Daily Maximum Surface and Daily Average Surface, Volume Integrated, Bottom Water Temperatures in the Pend Oreille River at Albeni Falls Dam 44 kilometers downstream of Lake Pend Oreille with and without Albeni Falls Dam during June 21-September 21, 2004 and 2005 (note: Temp Difference was computed as Without AFD minus With AFD for each Cumulative Probability)
Pend Oreille River – Longitudinal Summary

The daily average volume weighted water column temperatures and daily maximum surface water temperatures were summarized by river segment over the critical summer period from June 21-September 21 during the two study years 2004 and 2005 with and without Albeni Falls Dam. The water temperature corresponding to the 25, 50, 75, 90, and 99th percentile were calculated for each scenario for daily maximum surface temperature and volume weighted water column temperatures as shown in Figure 76 and Figure 77, respectively. The 99th percentile indicates the temperature magnitude exceeded 1 percent of the time or two days during the critical summertime period.

The daily maximum surface water temperatures were consistently warmer for natural conditions compared to existing conditions throughout the study reach as shown in Figure 76. The daily maximum temperatures were nearly identical at the upstream most river segment located near The Long Bridge. The daily maximum surface temperatures quickly increased for the natural conditions without Albeni Falls Dam in the shallow and wide river reach near Sandpoint ID. The maximum daily surface temperatures exceeded 26 °C in this reach and were typically several degrees warmer than existing conditions for percentiles of 50 percent and higher. The likelihood of the daily maximum surface temperature exceeding 24 °C at river segment 15 (3.75 km downstream of The Long Bridge) was 34 percent compared to only 7.0 percent for existing conditions.

The maximum daily surface temperatures remained relatively steady throughout the study area for the existing conditions simulation reaching maximum levels near the 35 Km river segment. The shallower flow conditions without Albeni Falls Dam resulted in the attainment of higher daily maximum temperatures throughout the most of the Pend Oreille River. The maximum daily surface temperatures decline near the confluence with the Priest River for both natural and existing conditions due to the presence of higher velocities and greater vertical exchange.
The evaluation of volume weighted water temperatures by river segment provides an opportunity to estimate the aggregate increase in water temperature from Lake Pend Oreille to Albeni Falls Dam or Albeni Falls. The volume weighted water temperatures by river segment at specific percentiles with and without Albeni Falls Dam are shown in Figure 77 for the critical summertime period from June 21-September 21, 2004-2005. The volume weighted water temperatures indicates only a small increase in water temperature were present in the Pend Oreille River during the summertime. The average temperature difference from the upstream most river segment to the downstream most river segment ranged from 19.5 to 20.3 °C for existing conditions a net increase of 0.80 °C. The average volume weighted temperature for natural conditions ranged from 19.9 to 20.2 °C for a net increase of 0.35 °C. The cooler temperatures entering
the POR during with AFD offsets the added heat gained during the longer passage through the river reach during the summer months. The average water temperatures entering the POR were 0.4 cooler for existing condition compared to natural conditions. The influence of cooler water retained in the deeper sections of the POR can be seen in the column averages for existing conditions at the 10 Km section and near Riley Creek. The temperatures associated with the warmest conditions indicated by the 90th and 99th percentile were consistently higher for natural condition when compared to existing conditions. The difference between median longitudinal temperature profile for natural and existing conditions using a volume weighted temperature estimate was less then +0.1 °C.

Figure 77 Statistical Summary of Daily Average Volume Weighted Water Column Temperature by River Segment Number for June 21-September 21, 2004 and 2005 (Pink-without Albeni Falls Dam, Blue-with Albeni Falls Dam)
Volumetric Summary

The flow weighted average temperature was computed at Albeni Falls and Albeni Falls Dam for the critical summertime period during 2004 and 2005. Calculated flow and temperature data on an hourly frequency were integrated at Albeni Falls and Dam over the June 21 – September 21 period during 2004 and 2005 as listed in Table 7. The aggregate temperature at Albeni Falls and Albeni Falls Dam were nearly identical for the two years simulated. The natural temperatures were slightly warmer than existing conditions by 0.1 °C for both years. The first half of the summer generally was slightly warmer for natural conditions when compared to existing conditions with just the reverse condition during the second half of the summer when cooler weather prevailed. This approach favors higher flow conditions during the early summer period.

<table>
<thead>
<tr>
<th>Case</th>
<th>Parameter</th>
<th>2004</th>
<th>2005</th>
<th>Combined</th>
</tr>
</thead>
<tbody>
<tr>
<td>Albeni Falls</td>
<td>Temperature (°C)</td>
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<td>19.7</td>
<td>19.8</td>
</tr>
<tr>
<td>Albeni Falls</td>
<td>Temperature (°C)</td>
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<td>19.6</td>
<td>19.7</td>
</tr>
<tr>
<td>Albeni Falls</td>
<td>Flow (cms)</td>
<td>629.2</td>
<td>595.5</td>
<td>612.4</td>
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<tr>
<td>Albeni Falls</td>
<td>Flow (cms)</td>
<td>527.9</td>
<td>480.2</td>
<td>504.1</td>
</tr>
</tbody>
</table>

Discussion

Thermal Impacts of Albeni Falls Dam on the Pend Oreille River

The average water temperatures entering the Pend Oreille River from Lake Pend Oreille are slightly cooling for existing conditions compared to natu-
ral conditions. The greater exchange of cooler subsurface water is the reason for the cooler temperatures entering the river reach under existing conditions compared to natural conditions. The existence of thermal stratification in Lake Pend Oreille is a necessary component for cooler waters to enter the river. As the surface mixed layer in Lake Pend Oreille deepens during the late summer, the difference between water temperatures entering the POR with and without AFD becomes small. This cooler aggregate temperature entering the POR under existing conditions will have an influence on temperatures throughout the water column and the study domain. The transient nature of the subsurface thermal conditions in Lake Pend Oreille will generate distinct thermal events that enter into the POR with different temperatures and propagate through POR at different rates.

The bulk daily average temperatures exiting the study domain at Albeni Falls were nearly identical with and without AFD. The longer time of travel with the dam in place will cause slightly greater gains in water temperature compared to natural conditions on average. However, since the water entering the Pend Oreille River was slightly cooler for existing conditions compared to natural conditions, the higher uptake of heat is offset by the cooler initial temperature. The fate of individual parcels of water may experience different heating/cooling outcomes depending upon the initial temperatures entering the POR, flow conditions, and meteorologic conditions. However, the estimated water temperatures summarized over two years from June 21 to September 21 resulted in water temperatures at Albeni Falls Dam that were similar falling within the detection threshold of the model as demonstrated by the frequency analyses.

A seasonal component in water temperatures at Albeni Falls Dam was evident with and without AFD. During the first half of the summer when water temperatures were generally on the rise as a result of hot summer temperatures, the water temperatures in the POR were generally cooler with AFD in place compared to the unimpounded simulation. The opposite effect was noted during the second half of the summer period when a net cooling of the POR was evident for both scenarios as a result of cooler late summer early fall temperatures. The shallow flow conditions for natural conditions resulted in the efficient cooling of the smaller water body. During long and severe cold fronts following hot weather (as can be seen in August), the natural system cooled down at a faster rate than the existing
system and generated conditions where the existing temperatures were both warmer than the numeric criteria and natural conditions.

The daily maximum surface temperatures were generally warmer for natural conditions when compared to existing conditions. The warmer surface temperatures were generated for natural conditions in spite of the shorter exposure time to surface heat exchange processes. The shallower river conditions associated with Albeni Falls resulted in daily extremes in water temperature which were significantly warmer than existing conditions with Albeni Falls Dam. This observation was evident in 4 of the 5 river reaches studied with detailed frequency analyses. The only location where surface temperatures were not consistently warmer for natural conditions was at the upstream boundary where the surface temperatures were assumed to be similar. The difference in daily maximum temperatures was prominent throughout most of the study area with natural daily maximum surface temperatures exceeding 25°C in many locations.

The reliability of simulating bottom temperatures in the deepest reaches of the POR was not demonstrated in this study because observed water temperatures were not available. However, the presence of much colder water entering the POR during existing conditions and the formation of weak vertical thermal structure in the water column supports the conclusion that colder water will be retained near the channel bottom with Albeni Falls Dam when compared to the unimpounded condition. The statistical summary of bottom temperatures resulted in the conclusion that existing conditions are likely to yield cooler bottom water temperatures than natural conditions.

**Model Uncertainty**

The temperature simulations for the updated POR temperature model are substantially improved over the original IDEQ model. This improvement in the reliability of the model will further support the decisions based on these estimates. However, the uncertainty in model predictions relative to a temperature standard tolerance of 0.3°C is still large. It is important to recognize the measured model uncertainty and error when comparing model simulations between two scenarios and to choose an analysis methodology that can account for the different times of travel between alternative scenarios. The role of model uncertainty in determining compliance with state water quality statutes with a suitable degree of confidence is an important consideration in applying model results.
Frequency Analysis

It is clear from a review of thermal simulations of the Pend Oreille River with and without Albeni Falls Dam, that existing conditions can be different during the summer by a small measure both warmer and colder than pre-dam conditions when comparing temperatures on a specific date in a specific river reach cell. However, this comparison methodology does not accurately identify the source of the cited temperature differences nor does this metric consider the influence of differential transport rates (i.e. lag time) between existing and natural conditions on temperatures in a reach at a specific date and time. A frequency analysis of water temperatures in the POR with and without AFD was developed to provide for a more comprehensive summary of project impacts on the thermal regime, and to minimize the effects of model scenario travel time differences when comparing with and without AFD simulations. The frequency analyses of POR water temperatures presented in this report concludes that the existing thermal temperatures in the POR are similar to or colder than conditions estimated without Albeni Falls Dam. The source for the cooler conditions is the greater exchange of subsurface water with Lake Pend Oreille during the deeper summer time conditions and lower rates of heat gain that will be characteristic of a larger body of water subject to a fixed surface heat flux.
Conclusions and Recommendations

Conclusions

The updated CE-QUAL-W2 temperature model developed by the COE more accurately portrayed the physical flow environment in the Pend Oreille River and the associated thermal characteristics between Lake Pend Oreille and Albeni Falls Dam. Deficiencies in the original IDEQ temperature model were corrected by the COE resulting in an updated model. A review of the updated model performance based on the predictive errors for water temperature during the summer time period for 2004 and 2005 demonstrated a significant improvement with the updated model versus the IDEQ model. The over prediction bias of surface temperatures demonstrated in the IDEQ model was reduced and the variance in the predictive error was reduced at the primary sampling stations in the POR. The primary source of the model improvement was the use of observed temperatures at The Long Bridge at the upstream boundary, the use of the alternative weather data at Hoodoo station, the influence of model coefficients on the vertical distribution of heat, and revisions to the model grid.

Major Findings

The existence and operation of Albeni Falls Dam has established higher water surface elevations in Lake Pend Oreille and throughout the Pend Oreille River during the summer time. These higher water surface elevations effectively double the volume of water in the POR over natural conditions and increase the residence time of water moving through this reach during low flow conditions. These higher stage conditions also influence the exchange of water between LPO and the POR and the vertical distribution of heat in the POR. The lower velocities in the POR caused by deeper flow conditions influence the vertical exchange of energy and the establishment of density stratified flow conditions. These changes to the physical environment of the POR have resulted in the following impacts to the thermal regime of the river based on an evaluation of observed and modeled conditions for 2004 and 2005.
The larger depth of flow in the transitional reach between LPO and the POR for existing conditions results in the transport of larger volumes of cooler subsurface water into the POR. The availability of cooler subsurface water from LPO is highly transient during the first half of the summer and diminishes as the depth of the mixed surface layer deepens in Lake Pend Oreille with the arrival of cooler weather conditions. The average water temperatures entering the Pend Oreille River from Lake Pend Oreille for existing conditions was cooler by an average of 0.4 °C during the summer time of 2004-2005 when compared with natural conditions.

The observed release water temperatures at Albeni Falls Dam were very similar to observed surface water temperatures in Lake Pend Oreille during the summertime of 2004 and 2005. These observations support the assertion that seasonal temperatures in the POR are in general equilibrium with the local meteorologic conditions that are responsible for establishing the surface temperature regime in Lake Pend Oreille.

The deeper flow conditions in the POR with AFD in place result in a longer travel time from LPO to the dam. The difference in travel time between existing and natural conditions causes the spatial displacement of distinct thermal events emanating from LPO. The different propagation rates of these thermal events can result in daily temperature differences at a fixed location of comparison that is caused in part by travel time and does not reflect net heat exchange. The longer travel time with AFD in place will also change the exposure time history of water during transit. The net effect of the longer travel time for existing conditions on the heat budget of the POR is a complex process dependent upon the initial heat content of water entering the river, the time history of weather conditions during transit, and the river hydrograph.

The smaller volume of water present during natural conditions results in a water body that is more responsive to the metrological and hydrologic inputs to the system. The natural river will attain warmer water temperatures during prolonged periods of hot weather. Similarly, the rate of cooling of the POR under natural conditions will be greater than experienced by the POR under the deeper flow conditions with AFD in place when cold weather is present. The daily occurrence of natural river temperatures cooler than existing river temperatures in a river reach was often directly attributed to the influence of cooler weather events.
The timing and duration of water temperatures in excess of state numeric standards has not changed appreciatively at the downstream boundary of the study area with the presence of Albeni Falls Dam. The arrival of daily average temperatures of 19 °C or warmer occurs slightly later (several days) in the summer under existing conditions and lingers slighter longer (several days) as the river cools down. The appearance of daily maximum temperatures of 22 °C or warmer may occur up to a week later in the spring for existing conditions. The characterization of the timing of water temperatures exceeding a specific threshold can be highly variable and dependent upon spatial location, local weather conditions, and the development of thermal stratification in LPO.

The existing surface water temperatures in the POR with AFD in place are on average cooler than simulated for natural conditions during the summer time. In terms of the daily maximum temperatures, the existing conditions were consistently cooler than natural condition when evaluating the temperature field topology of 22 °C and warmer. The differences were more pronounced near deeper river reaches where small vertical gradients in water temperature can develop.

The temperature field simulated for existing conditions does not mimic the temperature field simulated for natural conditions when viewed through the response in individual grid cells at an instance in time and with a 0.3 °C temperature tolerance. Most of the temperature metrics presented in this study of the POR indicate a measurable enhancement to the thermal regime when summarized over the entire river reach and critical summertime period. Daily maximum and average surface water temperatures are warmer for natural conditions during the hottest period of the summer. The differential transport rates of cooler water temperatures entering the POR or generated in shallow river sections during cold weather events can be a primary source for temperature differences identified in the Time Series methodology.

The water temperatures near the channel bottom were found to be significantly cooler for existing conditions when compared to natural conditions at the critical evaluation stations with the exception of the POR near Albeni Falls Dam. The additional water depth and development of vertical temperature gradients for existing conditions provides a reasonable explanation for this observation. However, the reliability of estimated bottom temperatures in deep sections of the POR was not demonstrated in this
study and caution should be exercised in applying these model results. Furthermore, the CE-QUAL-W2 model assumes hydrostatic pressures throughout the water column and does not solve the vertical momentum equation which may limit the ability to simulate temperatures in bottom cells where steep gradients in the channel bottom are present.

The frequency analysis of simulated POR water temperatures with and without AFD provided the most thorough and comprehensive summary of the impacts of Albeni Falls Dam. Assessing the overall systemic temperature change instead of the instantaneous daily temperature change accounted for the variability in water temperatures represented by modeled scenarios where travel time differences and lag times between scenarios influence the timing and location of daily maximum and minimum temperatures. Frequency analysis is a useful tool in understanding the thermal regime of the Pend Oreille River and the cause and effect of temperature differences between the natural and existing model simulations.

**Recommendations**

**Data**

A considerable amount of focus on compliance with IDEQ water quality standards has been placed on water temperatures in the deepest reaches of the POR (channel bottom). However, no data has been collected regarding the retention of cooler water in these areas or the importance of this habitat to critical beneficial uses of the POR. Collection of water temperature data in these deep pockets of the POR would help identify the existence of cold water refugia in the POR and support further development and interpretation of the POR model.

A critical region for characterizing the thermal properties in the POR is the exchange of water with LPO. The POR channel bathymetry plays a critical role in the amount and timing of cooler subsurface water entering POR. The location of the critical point of flow control or sill elevation of the low flow channel in this transitional reach could be more accurately determined through the collection of addition bathymetric information.

Because the exchange of water between LPO and the POR is critical for modeling temperatures in the POR, it is recommended that the upstream
boundary condition be moved into Lake Pend Oreille. The assumption that with and without AFD conditions are similar at the Long Bridge may not be valid and differences between the amount and timing of the movement of cool subsurface water from LPO into the POR would be more accurately modeled with the upstream boundary in the lake.

Model Application for Washington Department of Ecology

The updated thermal model of the POR has resulted in significant changes to water temperatures at Albeni Falls and at Albeni Falls Dam. In general, water temperatures during the warming period of the summer were cooler than simulated by the original IDEQ version of the model. During second half of the study period the updated model results were similar to earlier estimates. These changes to model results should be incorporated into the evaluation of the model of the POR throughout Washington State.
References


Appendix A: Observed and Calculated Pend Oreille River Water Temperatures during June 21-September 21, 2004 and 2005
Figure 78 Observed and Calculated Water Temperatures in the Pend Oreille River at a depth of 10 feet at The Long Bridge, June 21-September 21, 2004 (Predictive Error = Observed - Calculated, Model version IDEQ and COE)

Figure 79 Observed and Calculated Water Temperatures in the Pend Oreille River at a depth of 15 feet at The Long Bridge, June 21-September 21, 2004 (Predictive Error = Observed - Calculated, Model version IDEQ and COE)
Figure 80 Observed and Calculated Water Temperatures in the Pend Oreille River at a depth of 20 feet near Riley Creek, June 21-September 21, 2004 (Predictive Error = Observed – Calculated, Model version IDEQ and COE)

Figure 81 Observed and Calculated Water Temperatures in the Pend Oreille River at a depth of 2 feet at The Long Bridge, June 21-September 21, 2005 (Predictive Error = Observed – Calculated, Model version IDEQ and COE)
**Figure 82** Observed and Calculated Water Temperatures in the Pend Oreille River at a depth of 10 feet at The Long Bridge, June 21-September 21, 2005 (Predictive Error = Observed - Calculated, Model version IDEQ and COE)

**Figure 83** Observed and Calculated Water Temperatures in the Pend Oreille River at a depth of 20 feet at The Long Bridge, June 21-September 21, 2005 (Predictive Error = Observed - Calculated, Model version IDEQ and COE)
Figure 84  Observed and Calculated Water Temperatures in the Pend Oreille River at a depth of 25 feet at The Long Bridge, June 21-September 21, 2005 (Predictive Error = Observed – Calculated, Model version IDEQ and COE)

Figure 85  Observed and Calculated Water Temperatures in the Pend Oreille River at a depth of 2 feet near Rilley Creek, June 21-September 21, 2005 (Predictive Error = Observed – Calculated, Model version IDEQ and COE)
Figure A9  Observed and Calculated Water Temperatures in the Pend Oreille River at a depth of 10 feet near Riley Creek, June 21-September 21, 2005 (Predictive Error = Observed – Calculated, Model version IDEQ and COE)

Figure 86  Observed and Calculated Water Temperatures in the Pend Oreille River at a depth of 20 feet near Riley Creek, June 21-September 21, 2005 (Predictive Error = Observed – Calculated, Model version IDEQ and COE)
Figure 87 Observed and Calculated Water Temperatures in the Pend Oreille River at a depth of 40 feet near Riley Creek, June 21-September 21, 2005 (Predictive Error = Observed – Calculated, Model version IDEQ and COE)

Figure A12 Observed and Calculated Water Temperatures in the Pend Oreille River at a depth of 2 feet at Alben Falls Dam, June 21-September 21, 2005 (Predictive Error = Observed – Calculated, Model version IDEQ and COE)
Figure A13: Observed and Calculated Water Temperatures in the Pend Oreille River at a depth of 10 feet at Albeni Falls Dam, June 21-September 21, 2005 (Predictive Error = Observed - Calculated, Model version IDEQ and COE)

Figure A14: Observed and Calculated Water Temperatures in the Pend Oreille River at a depth of 20 feet at Albeni Falls Dam, June 21-September 21, 2005 (Predictive Error = Observed - Calculated, Model version IDEQ and COE)
Figure 88  Observed and Calculated Water Temperatures in the Pend Oreille River at a depth of 40 feet at Albeni Falls Dam, June 21-September 21, 2005 (Predictive Error = Observed – Calculated, Model version DEQ and COE)