Temperature Modeling of Lost Creek Lake Using CE-QUAL-W2

A Report on the Development, Calibration, Verification, and Application of the Model

Tammy L. Threadgill, Daniel F. Turner, Laurie A. Nicholas, Barry W. Bunch, Dorothy H. Tillman, and David L. Smith

April 2017

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A Report on the Development, Calibration, Verification, and Application of the Model

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Final report

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Portland, Oregon 97208

Under  Project 329825, “Temperature Modeling of Lost Creek Lake Using CE-QUAL-W2”
Abstract

The Engineer Research and Development Center (ERDC) Environmental Laboratory (EL) assisted the U.S. Army Corps of Engineers (USACE), Portland District (CENWP) in updating a CE-QUAL-W2 (W2) model of Lost Creek Lake based on a previous version of W2. The model was calibrated using data from calendar year (CY) 2001 validated with data from calendar years 2003 and 2010. One set of W2 parameters were successfully applied to all calendar year types (2001 is a dry year; 2003 is a normal year; and 2010 is a wet year). This model and the corresponding study results provided CENWP with more refined estimates of water temperatures so that more defendable water temperature targets can be discussed with the state of Oregon. This is extremely important because the Rogue and Applegate temperature Total Maximum Daily Loads and Rogue Spring Chinook Conservation Plan require USACE to review the Rogue Basin Project operations to determine whether improvements to downstream temperature can be achieved for the benefit of endangered fish. In addition to modeling the basic calibration for three years, a modified version of W2 was used to create a predictive model to determine the best blending of the intake ports to meet the temperature targets.
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Preface

This study was conducted for the U.S. Army Corps of Engineers (CENWP), Portland, Oregon, under Project Number 329825, “Temperature Modeling of Lost Creek Lake Using CE-QUAL-W2.”

The work was performed by the Water Quality and Contaminant Modeling Branch (WQCMB), Environmental Processes and Engineering Division (EP), U.S. Army Engineer Research and Development Center (ERDC), Environmental Laboratory (EL). At the time of publication, Dr. Dorothy Tillman was Chief, WQCMB; Warren P. Lorentz was Chief, EP, Dr. Al Cofrancesco, CEERD-EZT, was the Senior Science and Technology Manager. The Deputy Director of ERDC-EL was Dr. Jack E. Davis and the Director was Dr. Beth Fleming.

COL Bryan S. Green was Commander of ERDC; Dr. David W. Pittman was the ERDC Executive Director.
## Unit Conversion Factors

<table>
<thead>
<tr>
<th>Multiply</th>
<th>By</th>
<th>To Obtain</th>
</tr>
</thead>
<tbody>
<tr>
<td>acre-feet</td>
<td>1.2335</td>
<td>cubic meters</td>
</tr>
<tr>
<td>cubic feet</td>
<td>0.02831685</td>
<td>cubic meters</td>
</tr>
<tr>
<td>degrees Fahrenheit</td>
<td>(F-32)/1.8</td>
<td>degrees Celsius</td>
</tr>
<tr>
<td>feet</td>
<td>0.3048</td>
<td>meters</td>
</tr>
<tr>
<td>gallons (U.S. liquid)</td>
<td>3.785412 E-03</td>
<td>cubic meters</td>
</tr>
<tr>
<td>square miles</td>
<td>2.589998 E+06</td>
<td>square meters</td>
</tr>
<tr>
<td>Langley per day</td>
<td>0.48</td>
<td>watts per square meter</td>
</tr>
</tbody>
</table>
**Acronyms and Units**

14WS 14th Weather Squadron  
AM Applegate Lake Model  
BOD Biochemical Oxygen Demand  
CENWP U.S. Army Corps of Engineers, Portland District  
CY Calendar year (January 1 through December 31)  
DO Dissolved oxygen  
ELWS Water surface elevation  
ERDC Engineer Research and Development Center  
ISS Inorganic suspended solids  
LCL Lost Creek Lake  
LCLM Lost Creek Lake Model  
NH₄ Ammonium  
NO₃ Nitrate  
OM Organic matter  
RO Regulating Outlet  
STR₁ Represents the fixed invert intake with centerline elevation of 1852.5 ft  
STR₂ Represents the fixed invert intake with centerline elevation of 1797.5 ft  
STR₃ Represents the fixed invert intake with centerline elevation of 1737.5 ft  
STR₄ Represents the fixed invert intake with centerline elevation of 1647.5 ft  
STR₅ Represents the turbidity conduit intake with centerline elevation of 1602.5 ft
TDS  Total dissolved solids
TMDL  Total Maximum Daily Loads
USACE  U.S. Army Corps of Engineers
USGS  U.S. Geological Survey
W2  CE-QUAL-W2 model
1 Introduction

1.1 Objectives

The goal of this project is to develop and calibrate current W2 models for Lost Creek Lake and Applegate Lake so these models can be used to fully evaluate the effects of operational changes on release temperatures at William L. Jess Dam on the Rogue River.

1.2 Background

The Rogue and Applegate temperature Total Maximum Daily Loads (TMDL) and Rogue Spring Chinook Conservation Plan require the USACE to review Rogue Basin Project temperature operations to determine whether improvements to downstream temperature can be achieved for the benefit of fish (ODEQ 2008)(ODFW 2007)(USACE and ODEQ 2009). Oregon Department of Fish and Wildlife (ODFW) will probably also request that the USACE review project temperature operations in connection with the Rogue Fall Chinook Conservation Plan, which was adopted in January 2013 (ODFW 2013).

In the TMDL, the state of Oregon stated that the Corps could evaluate the prescribed temperature targets. This modeling effort refines the estimates of water temperatures at the site of USACE dams in the Rogue Basin and provides more defendable water temperature targets for discussion with the state of Oregon.

Lost Creek Lake is located twenty eight miles northeast of Medford, Oregon on the Rogue River in Jackson, County, Oregon approximately 157.2 miles upstream of its mouth. The William L. Jess Dam was constructed with earth and rock fill and is about 3,600 ft long and about 345 ft high. The primary authorized purposes of the dam are flood damage reduction, fisheries enhancement, irrigation, and municipal and industrial water supply; hydropower, water quality, and recreation are secondary authorized purposes. At maximum pool, Lost Creek Lake is 10 miles long, 3,430 acres, and stores approximately 465,000 acre-ft of water (USACE 1991). Figure 1 is a Google Earth screenshot of the project study area.
1.3 Approach

In order to determine whether the Corps can meet TMDL requirements through operational changes, it was necessary to develop water temperature models of each reservoir. To date, the Corps has in place CE-Qual-W2 (W2) temperature models for both Lost Creek and Applegate projects. Both projects also have selective withdrawal structures, which allow the projects to release water from fixed elevations in the reservoirs. Both models were run using previous versions of W2 and were calibrated to earlier datasets (90s and prior).
2 Model Selection and Development

W2 is the code selected to develop the Lost Creek Lake Model (LCLM). W2 is a 2D longitudinal-vertical hydrodynamics and water quality model. It is capable of modeling basic eutrophication processes and is best suited for long, narrow waterbodies that do not exhibit substantial lateral variation. W2 has been applied to hundreds of studies on various types of waterbodies (rivers, reservoirs, lakes, and estuaries) all over the world. For a list of the model applications, see the W2 website: [http://www.ce.pdx.edu/w2/](http://www.ce.pdx.edu/w2/).

2.1 CE-QUAL-W2 description

The numerical modeling code known as W2, version 3.7 (Cole and Wells 2011), was configured for application to Lost Creek Lake. W2 uses a finite difference solution of the laterally averaged equations of fluid motion (Cole and Wells 2013). It allows for application to very complex water systems because it accommodates multiple branches and multiple waterbody types. W2 allows the user to set up variable grid spacing (longitudinally and vertically), time variable boundary conditions, numerous inflows and outflows, and time variable concentrations for each water quality constituent of interest. W2 (V3.7) contains a user-defined port selection algorithm, which allows the user to specify a varying number of elevations for dam structures. Although this feature is not utilized in the calibration, future scenarios may benefit. In addition to water temperature, W2 is capable of modeling water surface elevation, flow, and twenty-eight water quality constituents such as total dissolved solids (TDS), inorganic suspended solids (ISS), ammonium (NH4), biochemical oxygen demand (BOD), nitrate (NO3), phytoplankton, dissolved oxygen (DO), and organic matter (OM). This study focuses only on temperature; consequently, the other constituents will not be discussed.

2.2 Project approach

W2 is well-suited for application to Lost Creek Lake for the following reasons:

1. W2 is appropriate for modeling narrow waterbodies with spatially varying depths. Lost Creek Lake is estimated to be 1.5 miles wide at its widest part, but it varies greatly in depths along the length of the reservoir.
2. W2 is capable of modeling hydrodynamics of a reservoir quite well.
3. W2 has been applied to hundreds of systems and is well known, understood, and widely accepted.
4. W2 is capable of providing a wide variety of model output for comparison to observed data.
5. W2 can simulate various responses due to changes in loads and rates.

Three in-lake monitoring stations (LSCR3, LSCR9, and LSCR11) were used for evaluating model performance during calibration. Although temperature data was available from LSCR2, the model grid did not encompass that station (discussed later). Therefore, the LSCR2 data was not used in the calibration process. Temperature data at the dam and downstream from the dam were also used for calibration. The locations of the sites are shown in Figure 2.

![Figure 2. In-lake profile monitoring stations. Site locations provided by Kinsey Friesen (CENWP).](image)

### 2.3 Calibration strategy

Several factors were used to determine which calendar years (CY) were used to calibrate and validate the model. The largest limiting factor was the availability of observed data. Since more data was available for 2001, CY01 was used to develop a calibrated model. Once an acceptable set of calibration parameters were found, the same set of model parameters were used for CY03 and CY10. Each of the years represents various water year types: 2001 was a dry year, 2003 was an average year, and 2010 was a wet year.
3 Data Analysis and Model Preparation

This section reviews data availability and their use in defining the calibration input files. W2 has several data requirements to meet before simulations can begin:

1. Bathymetry of the waterbody(ies)
2. Flow and temperature characteristics for boundaries, major tributaries, and point sources
3. Dam operations and structure locations
4. Stage data
5. Meteorological conditions: air temperature, dew point temperature, wind speed, wind direction, cloud cover, and short wave solar radiation (if available)

3.1 Model geometry

3.1.1 Bathymetry data

The bathymetry file for the LCLM was originally developed by Mike Schneider (USACE) for the original W2 model of Lost Creek Lake. Due to lack of documentation, it is unknown where he obtained the bathymetry data (sediment range analysis, cross sections, etc.). The current model utilized the original bathymetry file and then refined the grid. Upon completion of this model update, CENWP completed a new survey of the reservoir. Due to time constraints and analysis of the data by CENWP, ERDC decided to not update the model with the new bathymetry.

3.1.2 Model grid development

Lost Creek Lake was split into two branches, with Branch 1 extending from the Rogue River just downstream from Prospect, OR, approximately 7 miles to the dam, and Branch 2 is a side channel that enters the mainstem of the reservoir about 1.5 miles upstream from the dam. The reservoir was modeled with 58 longitudinal segments, varying in length from 200.0 to 350.0 m, and 104 vertical layers of uniform 1 m (3.28 ft) height.

Table 1 provides a description of the branches in the reservoir; the segment numbers do not include the inactive (or “null”) segments that start and end each branch (required in W2). Figure 3 shows an image of
the longitudinal segments used in the model along with the branch configuration, and Figure 4 is a Google Earth image with the model grid overlay.

Table 1. Geometry characteristics.

<table>
<thead>
<tr>
<th>Description</th>
<th>Branch</th>
<th>Segment Start</th>
<th>Segment End</th>
<th># Segments</th>
<th>Slope</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mainstem – Prospect to Dam</td>
<td>1</td>
<td>2</td>
<td>47</td>
<td>46</td>
<td>0.000</td>
</tr>
<tr>
<td>Branch 2 – Ungauged leg of the lake</td>
<td>2</td>
<td>50</td>
<td>57</td>
<td>8</td>
<td>0.000</td>
</tr>
</tbody>
</table>

Figure 3. Longitudinal segments with branch configuration for the LCLM.

Figure 4. Google Earth image with model grid overlay (produced by W2Tools) for the LCLM.
The bathymetry of the LCLM that has been developed has been verified to replicate the observed storage-elevation curve (obtained from CENWP). Figure 5 shows the storage-elevation curve represented by the model compared to the observed storage-elevation curve (or volume-elevation curve). This provides ERDC with confidence that the bathymetry is good and sufficient for the LCLM. A complete copy of the bathymetry file is in Appendix A. All model input files were delivered to CENWP.

As stated previously, another in-lake profile station was available for CY01; however, due to the fact that the bathymetry did not extend the full length of the true reservoir, this station (LSCR2) was not considered for model evaluation purposes. In order to best represent the full reach of the reservoir and incorporate the bottom elevation changes, the model would need to be set up with two waterbodies: one river and one reservoir. Setting the current model up this way is outside the scope of this project due to the complexity of developing a riverine-reservoir model.

### Figure 5. Volume-elevation curve comparison for the LCLM.

![Volume-elevation Curve Comparison](image)

#### 3.1.3 Dam features and withdrawal locations

Table 2 presents an abbreviated list of segment numbers in the LCLM bathymetry with a brief description of what site is located at the segment.
For example, the in-lake monitoring site, LSCR11, is represented by segment 47, which is the dam, in the LCLM bathymetry.

<table>
<thead>
<tr>
<th>Segment</th>
<th>Length (m)</th>
<th>Distance Upstream from Dam (m)</th>
<th>Distance Upstream from Dam (miles)</th>
<th>Identification/Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>Boundary (Null Segment)</td>
</tr>
<tr>
<td>2</td>
<td>300.000</td>
<td>11150.000</td>
<td>6.928</td>
<td>Beginning of Branch 1</td>
</tr>
<tr>
<td>18</td>
<td>250.000</td>
<td>6900.000</td>
<td>4.287</td>
<td>In-lake Station: LSCR3</td>
</tr>
<tr>
<td>34</td>
<td>250.000</td>
<td>2900.000</td>
<td>1.802</td>
<td>In-lake Station: LSCR9</td>
</tr>
<tr>
<td>36</td>
<td>250.000</td>
<td>2400.000</td>
<td>1.491</td>
<td>Branch 2 Enters Here</td>
</tr>
<tr>
<td>47</td>
<td>200.000</td>
<td>0.000</td>
<td>0.000</td>
<td>Dam/In-lake Station: LSCR11</td>
</tr>
<tr>
<td>48</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>Boundary (Null Segment)</td>
</tr>
<tr>
<td>49</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>Boundary (Null Segment)</td>
</tr>
<tr>
<td>50</td>
<td>300.000</td>
<td>2550.000</td>
<td>1.584</td>
<td>Beginning of Branch 2</td>
</tr>
<tr>
<td>57</td>
<td>300.000</td>
<td>300.000</td>
<td>0.186</td>
<td>End of Branch 2</td>
</tr>
<tr>
<td>58</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>Boundary (Null Segment)</td>
</tr>
</tbody>
</table>

### 3.2 Flow and elevations

#### 3.2.1 Model inflow boundaries

##### 3.2.1.1 Upstream and downstream boundaries

Mean daily flow for the Rogue River below Prospect, OR (14330000) was available from the United States Geological Survey (USGS) for all years for both calibration and validation of the model. Flow from this site was used as the upstream boundary condition. However, the measured flow did not include flow from the South Fork Rogue River, the confluence of which is between the head of the reservoir and the Rogue River gage. All branches in W2 require input files for flow and temperature. However, since the second branch in this case does not have a major inflow, a dummy file of zero flows was used as input for the model. This branch was modeled to capture the geometry of the reservoir and to maintain the volume-elevation relationship. In essence, this will have no impact on the model. The model will fill solely using the upstream inflow. At the downstream boundary, located at the dam, total outflows were available for all calendar years from the Northwestern Division Corps Water Management System (CWMS) database. The elevation data available at the dam were used solely for model-to-data comparison.
The flow from the monitored station above (Rogue River below Prospect, OR) does not account for all flows into the reservoir. The South Fork Rogue River also accounts for a large amount of flow; however, recent data is limited for this river. There are two stations available on the South Fork Rogue River, but the active station is approximately 10 miles upstream from the confluence with the Rogue River. Due to the inaccuracy associated with flow estimation, a decision was made to account for any water balance issues by using the water balance utility (available with the W2 download).

Table 3 displays the data sources for flow and elevation for various locations: the upstream boundary (PRSO), the downstream boundary (William Jess Dam), and three in-lake locations in the lake. Figure 6- Figure 8 are plots of all flow data used as input for the model at the upstream and downstream boundary for all three calendar years.

**Table 3. Data sources for flow and elevation at the model boundaries.**

<table>
<thead>
<tr>
<th>River/Location Name</th>
<th>Mile</th>
<th>Location and ID</th>
<th>Source</th>
<th>Variable</th>
<th>Calendar Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rogue River below Prospect</td>
<td>169.4</td>
<td>PRSO; USGS #14330000</td>
<td>USGS</td>
<td>Flow, Mean Daily</td>
<td>2001, 2003, 2010</td>
</tr>
</tbody>
</table>

**Figure 6. Flow input data for upstream and downstream boundaries for CY01.**
Figure 7. Flow input data for upstream and downstream boundaries for CY03.

Figure 8. Flow input data for upstream and downstream boundaries for CY10.
3.2.1.2 Tributaries

No gauged streams discharge into Lost Creek Lake. For this reason, no tributaries were defined in the model. However, when ERDC obtained the original model files from CENWP, only one inflow was specified: USGS flow at Prospect, OR (USGS 14330000). There appeared to be a correction applied to that version of the model as well as in subsequent simulations. The assumption is that the correction is accounting for the additional inflow from the South Fork Rogue River (see Figure 9). The model from CENWP was initially calibrated and run for 1990, 1991, and 1999. In more recent years, however, the flow at the closest gauged station (USGS 14334700) to the reservoir is inactive (monitoring ceased in 1992); the next closest active station on the South Fork Rogue River is approximately 10 miles upstream. The flow here (USGS 14332000) underestimates the actual total flows into the lake (see Figure 10); for this reason alone, ERDC decided that instead of making two corrections (adding flows at Prospect and having a distributed tributary) to account for the flow, the model would be better simply by having one correction factor to the flows: the distributed tributary.

Due to the variation observed water surface elevations in early 2003, the model for 2003 had to be run two times in order for the model to best fit the observed water surface elevations. Again, the distributed tributary is used typically when there are ungauged flows entering the system. In this case, the flows are mostly from the South Fork McKenzie River. Figure 11 is the total flow that was added to the system to account for the water balance problems.

Figure 9. USGS Map of all surface-water sites near upstream boundary.
Figure 10. Historical flows (through 1992) for the upstream stations.

Figure 11. Distributed tributary inflow input data.
3.2.2 Model outflow boundaries

The amount of flow withdrawn through each intake port is not measured; however, gate settings are recorded. Gate settings information was obtained from CENWP as an Excel spreadsheet. These values were then used to develop the necessary file for W2 (QWO file).

Figure 12-Figure 14 is a plot of the outflow specified at each intake structure. ERDC applied conditions to the total outflow based on elevations and operations procedures as detailed in the *Master Water Control Manual* (USACE 1991) to apportion the total outflow to each intake port.

*Figure 12. Outflow input data at specified structure for CY01.*
Figure 13. Outflow input data at specified structure for CY03.

Figure 14. Outflow input data at specified structure for CY10.
3.3 Temperature

3.3.1 Model boundaries

For all calendar years, temperature at the upstream boundary was defined with mean daily temperature from the Rogue River at Prospect (USGS 14330000). Temperature at the upstream boundary was also used as input for the second branch. However, since flows for the second branch are input as zero, the temperature will have no impact on the model.

Temperature data at the dam were used as calibration data for the model. Table 4 presents the locations and sources for temperature data, and Figure 15 provides a time-series plot of temperature at the upstream boundary as defined in the model for all calendar years.

Table 4. Data sources for temperature at the model boundaries.

<table>
<thead>
<tr>
<th>River/Location Name</th>
<th>Mile</th>
<th>Location and ID</th>
<th>Source</th>
<th>Variable</th>
<th>Calendar Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rogue River below Prospect (Upstream Boundary)</td>
<td>169.4</td>
<td>PRSO; USGS #14330000</td>
<td>USGS</td>
<td>Temperature, Mean Daily</td>
<td>2001, 2003, 2010</td>
</tr>
</tbody>
</table>

Figure 15. Temperature input data for the upstream boundary for 2001, 2003, and 2010.
3.3.2 Tributaries

Since tributaries were not monitored, there are none being modeled. However, because a distributed tributary must be used to improve the water balance, the upstream temperature input file was duplicated and used as input temperature for the distributed tributary. There was no temperature data available at any other gages (South Fork McKenzie) for the time period modeled; for that reason alone, the upstream boundary temperature was used as input for the distributed tributary.

3.4 Meteorological data

Hourly meteorological data were requested from the 14th Weather Squadron (14WS) at Medford, OR (28 miles southwest of Lost Creek Lake). Figure 16-Figure 21 provide a mean daily time-series plots for various meteorological conditions at the upstream boundary as defined in the model for CY01.

Figure 16. Air and dewpoint temperature input data for 2001.
Figure 17. Air and dewpoint temperature input data for 2003.

Figure 18. Air and dewpoint temperature input data for 2010.
Figure 19. Cloud cover input data for 2001.

Figure 20. Cloud cover input data for 2003.
3.5 CE-QUAL-W2 control file

The control file for the model calibration (CY01) can be found in Appendix B along with a table detailing any differences for all other model simulations. In order to keep this section concise, only parameters related to temperature are discussed.

3.5.1 Calculations, transport scheme, and heat exchange

Since evaporation is always considered in the surface heat exchange calculations in W2, it is important to turn the evaporation calculation (EVC) on if needed. According to the manual, if calculated inflows are used in setting up a model, then EVC is set to OFF; however, in the case of the LCLM, EVC is set to ON since we are using direct USGS inflows and evaporation is not included in USGS flows.

The transport solution scheme used in the LCLM is the ULTIMATE scheme, which is a higher order solution scheme that reduces numerical diffusion and eliminates the over- and undershoots that the QUICKEST scheme generates near regions of shear concentration gradients (Cole and Wells 2013).
In the W2 control file, the user must specify heat exchange parameters. The first parameter specified is the approach used for computing surface heat exchange (SLHTC). For the LCLM, ERDC chose to use a term-by-term (TERM) heat exchange because it is more theoretically sound according to Cole and Wells (2013) and because it produced better model results than the equilibrium temperature method (ET). Shortwave solar radiation was available, but ERDC chose to let the model calculate it internally because this produced better results (SROC = OFF). Although ERDC was provided with hourly meteorological data, W2 was still allowed to interpolate the input data to correspond to the model time-step by setting the METIC parameter to ON. The wind speed measurement height was set to 10 m in the LCLM as indicated by the 14WS. All other heat exchange parameters were set to the suggested manual values.

### 3.5.2 Extinction coefficients

The extinction coefficient card contains two important coefficients for temperature calibration. The extinction coefficient for pure water (EXH20) is set to 0.55 m⁻¹, which is greater than the default value for a temperature-only model (0.45 m⁻¹). However, the value is within the range of values for EXH2O for oligotrophic to eutrophic lakes, 0.2-1.66 m⁻¹; the higher value accounts for the turbidity of the lake. The BETA parameter determines the fraction of incident solar radiation absorbed at the water surface and is also set to the value of 0.55 in the LCLM model. The W2 manual suggests that typical values for BETA are approximately 0.2-0.7 (Cole and Wells 2013).

### 3.5.3 Selective withdrawal

W2 is capable of modeling a temperature control tower with selective withdrawal features. The latest version also has the added capability of dynamic port selection; however, since this was not used for the current model, it will not be discussed here.

The Lost Creek Lake Water Temperature Control tower (WTC) has five intake structures into a common wet well: four water temperature control ports and one turbidity conduit. The turbidity conduit is used throughout the year to act as a water temperature control port or to flush the lower levels of the reservoir. The conduit is connected to the middle of the lowest fixed port at elevation 1,640 ft and is often responsible for 81% of the flow entering the tower through that lowest port (USACE 1991). Figure 22 is an
image of where each intake port is identified in the model control file. Two additional intakes are located on the WTC but neither use the tower wet well: a tower bypass intake and fish hatchery warm water supply intake. These two intakes are not explicitly represented in the model because their flow rates are negligible.
Figure 22. Schematic representation of the water temperature control port elevations. (This includes minimum head requirements).
4 Model Calibration – CY01

Final calibration results are presented in this section. In all of the time series plots shown, a black solid line represents model output, a solid red circle or solid or dashed red line represents measured data. Three statistics are also presented in the charts: mean error (ME), absolute mean error (AME), and root mean square error (RMSE). These statistics are calculated as shown in Equations 1-3. The model was output every day as a daily average; when making time series comparisons to the observed data, a tolerance of 0.5 days was used for the model output so that model output and measured data were compared spatially and temporally with minimal averaging. A tolerance of seven days was used for the model output when making profile plot comparisons. In both of the cases, the statistical comparison is a one-to-one comparison. We use the closest date and the closest depth for comparing values. The tolerances used also allowed enough spacing to avoid observed data averaging.

\[
ME = \frac{\sum_{1}^{n} (\text{model} - \text{data})}{n}
\]  

(1)

\[
AME = \frac{\sum_{1}^{n} \text{abs}(\text{model} - \text{data})}{n}
\]  

(2)

\[
RMSE = \sqrt{\frac{\sum_{1}^{n} (\text{model} - \text{data})^2}{n}}
\]  

(3)

Cumulative distribution plots are also presented in this section. For these plots, the solid black line represents model output and the dashed red line represents observed data. These plots are used to indicate how the model is behaving overall when compared to the observed values. For example, at high temperatures, the model over-/underpredicts temperature by XX deg-C, where XX represents the AME value. Scatter plots are also presented to give a statistical representation of how the model is behaving.
A general rule of thumb for water quality calibration is that the absolute mean error should be within 10% of the range of monitored data\(^1\), temperature AME should be within 1 deg-C (~1.8 deg-F), and elevations should be within 0.5 m (1.64 ft). Equation 4 is the equation used to calculate the target values for AME. These target values were calculated for each calendar year and will be presented in tabular form in the following sections. Units for these targets are consistent with the minimum and maximum values for each constituent. For example, for flow, the minimum, maximum, the AME, and 10% target are presented in cubic feet per second.

\[
\text{Target} = 0.10 \times ((\text{maximum observed value}) - (\text{minimum observed value}))
\]  

(4)

4.1 Flow

Since the model upstream boundary condition segment often changes based on the reservoir volume, ERDC cannot produce flow plots to verify that the upstream boundary condition for flow is satisfied. Model output along with observed data for CY01 at the dam is shown in Figure 23. Note that this is really just a representation that the data is being read correctly from the input outflow file. The AME for all data pairs for 2001 at the dam is 0.10 cfs, which is well less than 0.5% of the measured range of flows the calendar year. Table 5 presents several basic stats for flow. Based on Figure 23, the slope of the trendline fitted through the data pairs is 1.00 and the R-squared value is 1.00. Overall, the model only underpredicts outflow at the dam by 0.05 cfs.

<table>
<thead>
<tr>
<th>SITE</th>
<th>Observed Minimum</th>
<th>Observed Maximum</th>
<th>AME</th>
<th>ME</th>
<th>Slope</th>
<th>R-Squared</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dam</td>
<td>690.00</td>
<td>3210.00</td>
<td>0.10</td>
<td>-0.05</td>
<td>1.00</td>
<td>1.00</td>
</tr>
</tbody>
</table>

\(^1\) Wells, Scott. 2008. Personal communication with Tammy Threadgill. June 15. CE-QUAL-W2 Workshop, Portland, OR.
4.2 Temperature

The best hope in correctly predicting the outflow temperature is to correctly predict the in-lake temperature profiles at various locations in the reservoir. If the temperature profiles are not satisfactory, the chance of correctly predicting total outflow temperature is highly unlikely. Profile plots and statistical plots for all in-lake monitoring sites are presented in Figure 24-Figure 29. (Figure 2 shows the location of each of these sites.) A time series plot and statistical plots are presented for the dam in Figure 30. The average AME for each of the in-lake sites are within the acceptable target. Table 6 presents the calculated AME and the temperature target that ERDC attempted to reach for the in-lake sites and for the outflow temperature at the dam. Based on Figure 27-Figure 29, the average slope of the trendlines is 1.12, and the R-squared value is 0.91 for the in-lake sites. Based on the figures below, the model underpredicts the temperature by an average of 0.56 deg-C at the downstream in-lake sites and overpredicts temperature by approximately 0.50 deg-C at the furthest upstream in-lake site (LSCR3). At the dam, the AME is 0.56 deg-C, with a slope of 1.08 and an R-squared value of 0.98 (see Figure 30).
Table 6. Basic statistics for temperature (deg-C) for CY01 calibration.

<table>
<thead>
<tr>
<th>SITE</th>
<th>Observed Minimum</th>
<th>Observed Maximum</th>
<th>Target</th>
<th>AME</th>
<th>ME</th>
<th>Slope</th>
<th>R-Squared</th>
</tr>
</thead>
<tbody>
<tr>
<td>LSCR11 (CY AVG)</td>
<td>5.06</td>
<td>20.61</td>
<td>1.00</td>
<td>0.68</td>
<td>-0.17</td>
<td>1.08</td>
<td>0.96</td>
</tr>
<tr>
<td>LSCR9 (CY AVG)</td>
<td>5.03</td>
<td>21.15</td>
<td>1.00</td>
<td>0.90</td>
<td>-0.22</td>
<td>1.13</td>
<td>0.94</td>
</tr>
<tr>
<td>LSCR3 (CY AVG)</td>
<td>8.65</td>
<td>16.60</td>
<td>1.00</td>
<td>0.89</td>
<td>0.82</td>
<td>1.04</td>
<td>0.94</td>
</tr>
<tr>
<td>Dam (Outflow)</td>
<td>4.50</td>
<td>14.78</td>
<td>1.00</td>
<td>0.52</td>
<td>-0.12</td>
<td>1.13</td>
<td>0.98</td>
</tr>
</tbody>
</table>

Figure 24. Temperature profiles at LSCR11 in CY01 calibration.

Figure 25. Temperature profiles at LSCR9 in CY01 calibration.
Figure 26. Temperature profiles at LSCR3 in CY01 calibration.

Figure 27. Flow linear and cumulative distribution plots at LSCR11 for CY01 calibration.

Figure 28. Flow linear and cumulative distribution plots at LSCR9 for CY01 calibration.
Figure 29. Flow linear and cumulative distribution plots at LSCR3 for CY01 calibration.

Figure 30. Withdrawal temperature at the dam for CY01 calibration.
4.3 Water surface elevation

Model output along with observed data for water surface elevations (ELWS) in CY01 at the dam is shown in Figure 31. The AME for all data pairs for 2001 at the dam is 0.33 ft (~0.08 m). Table 7 presents the calculated AME and the 1.64 ft (0.5 m) target that ERDC attempted to reach. The slope of the trendline fitted through the data pairs is 1.01 and the R-squared value is 1.0. Overall, the model only underpredicts ELWS at the dam by 0.33 ft.

Table 7. Basic statistics for water surface elevations (ft) for CY01 calibration.

<table>
<thead>
<tr>
<th>SITE</th>
<th>Observed Minimum</th>
<th>Observed Maximum</th>
<th>Target</th>
<th>AME</th>
<th>ME</th>
<th>Slope</th>
<th>R-Squared</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dam</td>
<td>1775.63</td>
<td>1856.29</td>
<td>1.64</td>
<td>0.33</td>
<td>-0.33</td>
<td>1.01</td>
<td>1.00</td>
</tr>
</tbody>
</table>

Figure 31. Water surface elevations at the dam for CY01 calibration.
5 Calibration Discussion

Model calibration results and all model assumptions are discussed in this section. As stated previously, not only does this report detail graphical comparison, but the authors also present several statistical comparisons: AME, RMSE, and ME. Both the flow results and the temperature results will be discussed below. An inventory of files needed for the calibration runs can be found in Appendix B (Table B2).

5.1 Water surface elevation

As stated previously, due to the water balance instabilities in the model, a distributed tributary was added to the calibration run. This drastically improved the initial results. Figure 32 shows the impact of not using distributed tributary. Notice how the model severely underestimates the water surface elevation for ten months out of the year. By the end of the year, the model has almost 100 ft of elevation worth of unaccounted for water. Once the distributed tributary was added, and before any other parameters were modified, the improvement to the results was astounding (see Figure 33).
Figure 32. Time series and statistical plots of ELWS without the distributed tributary.
5.2 Temperature

Initially, before the water balance issues were corrected, the model was drastically miscalculating the temperature. However, once the distributed tributary was added, the model was still overpredicting the temperature (CY01-Run02). Upon observing the in-lake profile plots, the surface temperature was too warm. ERDC performed three more simulations with the following changes:

1. Set SROC = OFF in the control file. Due to the fact that the meteorological station is not located at the dam, ERDC has found in previous studies that the model performs better when the W2 is allowed to calculate SRO (short wave solar radiation) internally. Making this change had the most significant effect on the surface temperature. (CY01-Run03 – not plotted below)
2. Changed EXH20 from 0.45 to 0.55 in order to increase the amount of heat retained at the surface instead of letting the heat descend into the water column. After setting SROC = OFF above, although the surface water cooled down significantly, the water was still too warm from 10-50 feet below the surface. Next, the team changed BETA from 0.45 to 0.55. BETA is similar to EXH20 in that it also helps to retain more heat surface. These changes (independent of each other) had a very small positive impact on model temperature predictions. (CY01-Run05 shows these modifications together even though they were run in consecutive runs.)

3. During calibration, the team realized that the outflow for day 267 (September 24\textsuperscript{th}) was incorrect. The values for this day were replaced with the values from the previous day (note the spike in CY01-Run05). Sediment temperature was corrected to average air temperature for the year. Originally, it was 11.5 deg-C. Although this was a very close approximation, the value was corrected to 11.984. (CY01-Run09)

4. The final attempt to improve the in-lake profile temperature predictions was to modify the wind-sheltering coefficient during fall and winter periods when there are no leaves on the trees. This made a significant improvement to model predictions. (CY01-Run13)

Temperature comparisons at the in-lake stations and the dam between each of the runs discussed above are seen in Figure 34-Figure 37. In all of the plots below, the red dots are observed data. The time series comparison is more indicative of the gains in temperature improvement with the above modifications than are the profile comparisons.
Figure 34. Profile comparison at LSCR3.

Figure 35. Profile comparison at LSCR9.

Figure 36. Profile comparison at LSCR11.
Figure 37. Time series comparison at the dam for CY01.
6 Model Verification – CY03 and CY10

Model verification results are presented in this section. CY03 and 2010 were used because they had the same types of monitored data and similar available in-lake profile data. All of the plots and statistics presented in this section were developed in an identical manner to those in the previous section. Just as for the calibration runs, an inventory of data files can be found in Appendix B (Table B2).

6.1 Flow

Model output along with observed data for CY03 and 2010 at the dam is shown in Figure 38 and Figure 39. Again, this is really just a representation that the data is read correctly from the input outflow file. The AME for all data pairs for 2005 at the dam is 0.08 cfs, which is well less than 0.5% of the measured range of flows for the calendar year. Table 8 presents the 1% AME target that ERDC attempted to reach. The slope of the trendline fitted through the data pairs is 1.00, and the R-squared value is 1.0. Overall, the model only underpredicts outflow at the dam by less than 0.01 cfs.

<table>
<thead>
<tr>
<th>SITE</th>
<th>Observed Minimum</th>
<th>Observed Maximum</th>
<th>Target AME</th>
<th>AME</th>
<th>ME</th>
<th>Slope</th>
<th>R-Squared</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dam - 2003</td>
<td>800.00</td>
<td>5590.00</td>
<td>47.90</td>
<td>0.19</td>
<td>-0.03</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Dam - 2010</td>
<td>710.00</td>
<td>5820.00</td>
<td>51.10</td>
<td>0.90</td>
<td>0.68</td>
<td>1.00</td>
<td>1.00</td>
</tr>
</tbody>
</table>

Table 8. 1% Target for flow (cfs) for CY03 verification.
Figure 38. Withdrawal flow at the dam for CY03 verification.
6.2 Temperature

The data available for the verification years was a little different than in CY01. For CY03, only one sample data at one station was available (August 23 at LSCR11). For CY10, no true in-lake stations were monitored. In order to provide feedback on in-lake temperatures, ERDC chose to use temperatures from selected dates available from the temperature string located at the dam (in place since 2006). It is important to note that the temperature string data was only available through May. The 15th day of Jan-May was chosen as representative for each month in CY10. The segments used for data comparison can be found in Table 2.

Profile plots and statistical plots for all in-lake monitoring sites are presented in Figure 40-Figure 43. Time series plots and statistical plots are presented for the dam in Figure 44 (CY03) and Figure 45 (CY10). Table 9 presents the calculated AME and the temperature target that ERDC attempted to reach for the in-lake sites and for the outflow temperature at the dam. The average AME for each of the in-lake sites are
within the acceptable target of 1 deg-C. Based on Figure 41 and Figure 43, the average slope of the trendlines is 0.75 and the R-squared value is 0.90 for the in-lake profile site LSCR11 (dam temperature string) for both years. Overall, the model only underpredicts temperature at this site by approximately 0.51 deg-C in CY03 and 0.39 deg-C in CY10. At the dam (temperature string), the AME is 0.47 deg-C and 0.63 deg-C for CY03 and CY10, respectively (see Figure 44 and Figure 45). The model underpredicts temperature by an average of approximately 0.15 deg-C at the dam.

Table 9. Temperature stats (deg-C) for verification years.

<table>
<thead>
<tr>
<th>SITE</th>
<th>Observed Minimum</th>
<th>Observed Maximum</th>
<th>Target</th>
<th>AME</th>
<th>ME</th>
<th>SLOPE</th>
<th>R-squared</th>
</tr>
</thead>
<tbody>
<tr>
<td>LSCR11 (CY03 – one day only)</td>
<td>5.25</td>
<td>23.93</td>
<td>1.00</td>
<td>0.33</td>
<td>-0.25</td>
<td>0.98</td>
<td>0.99</td>
</tr>
<tr>
<td>Dam Temp. String (CY10 AVG)</td>
<td>4.51</td>
<td>14.72</td>
<td>1.00</td>
<td>0.53</td>
<td>-0.20</td>
<td>0.51</td>
<td>0.80</td>
</tr>
<tr>
<td>Dam (CY03)</td>
<td>4.72</td>
<td>13.50</td>
<td>1.00</td>
<td>0.48</td>
<td>0.06</td>
<td>1.12</td>
<td>0.97</td>
</tr>
<tr>
<td>Dam (CY10)</td>
<td>4.89</td>
<td>13.89</td>
<td>1.00</td>
<td>0.64</td>
<td>0.09</td>
<td>1.18</td>
<td>0.96</td>
</tr>
</tbody>
</table>

Figure 40. Temperature profile at LSCR11 in CY03 verification.
Figure 41. Flow linear and cumulative distribution plots at LSCR11 for CY03 verification.

![Flow linear and cumulative distribution plots at LSCR11 for CY03 verification.](image)

Figure 42. Temperature profiles at the dam temperature string in CY10 verification.

![Temperature profiles at the dam temperature string in CY10 verification.](image)
Figure 43. Flow linear and cumulative distribution plots at the dam temperature string for CY10 verification.

Figure 44. Withdrawal temperature at the dam for CY03 verification.
6.3 **Water surface elevation**

Model output along with observed data for ELWS CY03 at the dam is shown in Figure 46 and in Figure 47 for CY10. Table 10 presents several stats and lists the target AME for each verification year.

**Table 10. Basic statistics water surface elevations (ft) for CY03 verification.**

<table>
<thead>
<tr>
<th>SITE</th>
<th>Observed Minimum</th>
<th>Observed Maximum</th>
<th>Target AME</th>
<th>AME</th>
<th>ME</th>
<th>Slope</th>
<th>R-Squared</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dam (CY03)</td>
<td>1808.78</td>
<td>1872.01</td>
<td>1.64</td>
<td>0.61</td>
<td>-0.48</td>
<td>0.99</td>
<td>1.00</td>
</tr>
<tr>
<td>Dam (CY10)</td>
<td>1807.43</td>
<td>1872.60</td>
<td>1.64</td>
<td>0.43</td>
<td>-0.43</td>
<td>1.01</td>
<td>1.00</td>
</tr>
</tbody>
</table>
Figure 46. Water surface elevations at the dam for CY03 verification.

DAM - CY03

Water Surface Elevation

- RMSE = 1.29
- AME = 0.61
- ME = -0.48

y-intercept = 21.45
Slope = 0.98
R-Square = 1.00

Observed Water Surface Elevation, ft

Percent Less Than (%)

Measured Water Surface Elevation, ft
Figure 47. Water surface elevations at the dam for CY10 verification.

DAM - 2010
Water Surface Elevation

RMSE = 0.58
AME = 0.43
ME = -0.43

y-intercept = -14.84
Slope = 1.01
R-Square = 1.00

Observed Water Surface Elevation, ft

Percent Less Than (%)
7 Verification Discussion

This section serves to discuss the results and the impacts that changes have made on the model runs. Due to the similarity in available input data for each of the verification years compared to the calibration year, no changes were made to the control file. Just as for CY01, a distributed tributary was needed for both calendar years. The water balance utility used to calculate the distributed tributary flow had to be run two times for CY03 due to a sudden increase in the water surface elevations between February and April (see Figure 46). A distributed tributary is utilized in W2 when there is an inconsistent trend with the water balance and when the user can account for missing or too much flow (i.e., ungauged flows). It can be used to add or remove water from the system. In the case of the LCLM, a distributed tributary was used to add water to the system.

To develop a distributed tributary input file, initial model output and observed elevations must be input into the Water Balance Utility developed by Portland State University for use with W2. In the case of the LCLM for CY03, the utility had to be run two times on consecutive runs in order to obtain an acceptable water balance. Additionally, in the event the Water Balance Utility calculated negative flows, these flows were adjusted so that only positive flows were introduced in the model. More information on developing a distributed tributary file can be found in the “Release Notes” that accompany the full W2 download along with the Users’ Manual.
8 Predictive Port Selection Model Application

In order to provide CENWP with the best model to use for operation modifications, the calibrated model was used as a base run to set up a fully predictive model. The model will guide dam operations based on desired temperature targets. The temperature target presented is the bi-weekly target developed by Oregon Department of Fish and Wildlife for 2014 operations. The current version of W2 (v3.71 – 07/15/14) has an algorithm in it to do just this; however, it is limited to only blending temperatures with only two ports at a time. Oftentimes, even the calibration, as previously reported, has three to four ports operating at a time. Upon recommendation from CENWP, ERDC-EL reached out to Stewart Rounds (USGS) to see whether he would be willing to share his version of a less restrictive blending algorithm that is fully integrated with a previous version of W2 (v3.7 from 2012). Mr. Rounds provided ERDC-EL with his code and executables; the results from the USGS version of W2 will be presented in this section. Briefly, the PSU version of W2 results will be discussed as well. An inventory of all files used for each model simulation can be found in Appendix B (Table B3).

8.1 PSU – W2 predictive port selection

PSU’s current version of W2 has not fully integrated the algorithm developed by Mr. Rounds at USGS. According to personal correspondence with Dr. Scott Wells (2014), however, it is definitely on the list of model improvements for a future release. W2 is limited to blending temperatures between only two ports. In order to optimize the temperature release, the user must run the model multiple times with minor adjustments (date and temperature adjustments in the w2_selective.npt file). Below are the steps required to run the PSU-Predictive model:

1. Begin with base calibration run for desired year.
2. Place all outflows in topmost port.
3. Run the model with the automatic selection of outlet port control (DYNSTR1 CONTROL) turned ON. This will result in a qwo file that contains information regarding elevation of the withdrawal to get the closest desired temperature.
4. Based on the results from (3) above, create a new QOT input file. Ex: If in the QWO file from (3), flow was specified at the 4th intake port for days 300-365, then in the new QOT file for days 300-365, move the original flow into the column for intake 4.

5. Now turn OFF the DYNSTR1 CONTROL card turned on in (3). Turn ON the SPLIT1 CNTR card. Based on the results from (3), take a best guess on when blending should occur between which ports and update the SPLIT2 cards. Use the desired temperature targets in the TTARGET column.

6. Rerun and plot results. Based on results, modify the SPLIT2 cards as needed and rerun. Repeat this step as necessary.

As one can see, this method is quite cumbersome for the end user. At any point, the user wants to blend between more than 2 ports, more steps have to be repeated. It is a long and tedious task.

Model simulations were run for all years using the PSU version of the code; the results will be presented with the USGS results in the next section.

8.2 USGS – W2 predictive port selection

Detailed information on the development and modifications to the original W2 code can be found in “Improved Algorithms in the CE–QUAL–W2 Water-Quality Model for Blending Dam Releases to Meet Downstream Water-Temperature Targets” (Rounds and Buccola 2015). Specifics relating to setup of the Lost Creek Lake Predictive Model (LCLPM) will be discussed here. The USGS code uses an iterative process to determine the optimal flows that will produce the desired target temperatures. Of course, this means that the run time will also increase. In the case of the LCLPM, using this code tripled the run time (from about 3-5 minutes to 10-12 minutes).

There were no changes to the main control file from the calibration model (aside from output filename changes). All changes that were made were made in the w2_selective.npt file, which is required when the SELECTC card in the control file is turned ON. Although the structure of the w2_selective.npt file is very similar to the PSU version, there are several new options. The new cards are:
1. **TSSSHARE**: when blending occurs between two ports, having this option ON allows the flows to be best distributed based on desired temperature instead of an even 50-50 split between multiple outlets. (NOTE: For the LCLPM, this was set to ON.)

2. **DEPTH**: when a non-zero value is input, this allows the model to treat the outlet as a floating outlet. (NOTE: For the LCLPM, DEPTH was set to 0 since Lost Creek Dam consists of fixed ports.)

3. **MINFRAC**: this specifies the minimum flow rate (when a negative value is entered) or fraction (when a value 0-1 is entered) for a port when that port is active. (NOTE: For the LCLPM, according to the WCM ((USACE 1990), 19% of the flow from the lowest intake is associated with flows at that level. The rest of the flow is assumed to come from the turbidity conduit.)

4. **PRIORITY**: this specifies the priority for port operations. (NOTE: During various times of the year, CENWP operates to use more surface water sometimes and at other times, the cold lower waters are used. So for the fall and winter months, the priority was shifted to the bottom two ports. Outside of that the priority was to use the topmost port.)

5. **MINHEAD**: This is the minimum depth in meters for the outlet to be used. (NOTE: Technically, this should be set to 5 m, but since the centerline in the calibration run accounts for the intake roof and minimum head, the ERCD-EL chose not to modify the ESTR card in the W2_control.npt file. With that said, the LCLPM MINHEAD conditions are all set to 0.)

6. **MAXHEAD**: This is the maximum depth in meters for the outlet to be used. (NOTE: LCLPM MAXHEAD values are set to 0, as well.)

7. **MAXFLOW**: This is the maximum flow capacity of the port. A zero value indicates no maximum flow criterion. (NOTE: LCLPM values are all set to 0.)

As mentioned above, the minimum head values are accounted for in the specification of the ESTR in the main control file. Since this file was not modified, a MINHEAD was not specified. In the LCLPM w2_selective.npt file, the user will find that three split times were identified. The reason these dates were identified is due to operational constraints with seasonal withdrawal depths. Specifying it this way allowed ERDC-EL to set the PRIORITY based on which ports were desired.

The only other caveat that should be mentioned here is that, although only 19% of the flow from the lowest intake is taken at the level, there was no
easy way to have the model ONLY use 19% of the flow from here. As the model is set up now with TSSHARE ON and with Intake 4 and the turbidity conduit having the same priority, when flows are taken from either of those ports, a MINIMUM of 19% of the flow will be taken from the total flow. The remaining flow will be split between the two to optimize temperature targets; this results in the fact that more than 19% of the flow is actually taken at the elevation of Intake 4 instead of a hard 19-81% split between the intake and the turbidity conduit.

The user should note that in all of the following plots, the red lines represent a temperature target range. The ODFW targets are used for determining the target values; however, what is represented on the following plots is a target range, which is the ODFW temperature target +/- 1 deg-C, which is a standard measuring error for temperature.

Figure 48 is the w2_selective file used for all of the LCLPM model runs. Figure 49-Figure 59 are plots from CY01 (dry year) that compare the results from the calibration, the results from the PSU-W2 blending algorithm, and the results from the USGS-W2 blending algorithm. Figure 60-Figure 70 represent the same plots for CY03 (normal year), and Figure 71-Figure 81 represent CY10 (wet year). As one can see, the outflow temperatures are fairly consistent between the two blending algorithms; however, the flows and the releases are drastically different at times. Figure 82 shows the average percentage of model-predicted temperatures that fall within the desired target range. As one can see, the USGS algorithm produces better results more often than the calibration run and more often than the multi-step PSU version. To save the user multiple runs for the predictive mode model, ERDC-EL suggests that the USGS algorithm be used.
Figure 48. W2_Selective.NPT file used for the LCLPM.

W2_SELECTIVE.NPT
Selective input control file - LCL-CY01 S098 PortRun13
Temperature outlet control - frequency of output for temperature
OVT FREE TS2CFT
Structure outlet control based on time and temperature and branch
DYNSTR1 CONTROL NUM FREQ
OFF 1 0.63
DYNSTR1 ST/WD JB J0/W YEARLY TSTR TEND TEMP MSLEV ELEV1 ELEV2 ELEV3 ELEV4 ELEV5
1 4 4 1 1 1 1.0 46.0 3.3 5 564.442 547.078 528.590 302.185 458.442
MOUNT LOC IDRES ELEV DUNKEL
1 0 -1.0 OFF
AUTO ELEV CONTROL
1 ON
SPLIT1 CNTR NUM TSTOP TCONF
ON 3 0.250 0.015
SPLIT2 ST/WD JB YEARLY TSTR TEND T.getTarget DUNKEL ELEV1 ELEV2 ELEV3 ELEV4 ELEV5
1 4 4 1 1 1.0 46.0 3.3 5 564.442 547.078 528.590 302.185 458.442
3 4 4 1 1.0 46.0 3.3 5 564.442 547.078 528.590 302.185 458.442
3 1 2 3 4 5
MNFRC1 MNFRC2 MNFRC3 MNFRC4 MNFRC5 MNFRC6 MNFRC7 MNFRC8 MNFRM6 MNFRM8
1 2 3 4 5 6 7 8 9 10
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3 0 0 0 0 0 0 0 0 0
MNFPRP PR1001 PR1002 PR1003 PR1004 PR1005 PR1006 PR1007 PR1008 PR1009
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3 0 0 0 0 0 0 0 0 0
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2 11.50
3 11.00
4 10.50
5 10.00
6 9.50
7 9.00
8 8.50
9 8.00
10 7.50
11 7.00
12 6.50

(**NOTE: ELEV6-10 are cut off for better image clarity. These values are blank since there are only 5 ports.)
Figure 49. CY01 - LCLPM temperature comparison with target temperatures.

![Graph showing temperature comparison]

Figure 50. CY01 - Intake 1 - temperature into tower.

![Graph showing intake temperature into tower]

Figure 51. CY01 - Intake 2 - temperature into tower.

![Graph showing intake temperature into tower]
Figure 52. CY01 - Intake 3 - temperature into tower.

Figure 53. CY01 - Intake 4 - temperature into tower.

Figure 54. CY01 - Turbidity conduit - temperature into tower.
Figure 55. CY01 - Intake 1 - flow into tower.

Figure 56. CY01 - Intake 2 - flow into tower.

Figure 57. CY01 - Intake 3 - flow into tower.
Figure 58. CY01 - Intake 4 - flow into tower.

Figure 59. CY01 - Turbidity conduit - flow into tower.

Figure 60. CY03 - LCLPM temperature comparison with target temperatures.
Figure 61. CY03 - Intake 1 - temperature into tower.

![Graph showing temperature into tower for CY03 Intake 1.]

Figure 62. CY03 - Intake 2 - temperature into tower.

![Graph showing temperature into tower for CY03 Intake 2.]

Figure 63. CY03 - Intake 3 - temperature into tower.

![Graph showing temperature into tower for CY03 Intake 3.]

Figure 64. CY03 - Intake 4 - temperature into tower.

Figure 65. CY03 - Turbidity conduit - temperature into tower.

Figure 66. CY03 - Intake 1 - flow into tower.
Figure 67. CY03 - Intake 2 - flow into tower.

Figure 68. CY03 - Intake 3 - flow into tower.

Figure 69. CY03 - Intake 4 - flow into tower.
Figure 70. CY03 - Turbidity conduit - flow into tower.

Figure 71. CY10 - LCLPM temperature comparison with target temperatures.

Figure 72. CY10 - Intake 1 - temperature into tower.
Figure 73. CY10 - Intake 2 - temperature into tower.

Figure 74. CY10 - Intake 3 - temperature into tower.

Figure 75. CY10 - Intake 4 - temperature into tower.
Figure 76. CY10 - Turbidity conduit - temperature into tower.

Figure 77. CY10 - Intake 1 - flow into tower.

Figure 78. CY10 - Intake 2 - flow into tower.
Figure 79. CY10 - Intake 3 - flow into tower.

Figure 80. CY10 - Intake 4 - flow into tower.

Figure 81. CY10 - Turbidity conduit - flow into tower.
Figure 82. Average % of model temperature within the target range.
9 Summary and Conclusions

The USACE-ERDC-EL assisted CENWP in updating a W2 model of Lost Creek Lake based on inputs from an existing model of the reservoir. The model was calibrated using data from calendar year (CY) 2001 (dry), 2003 (normal), and 2010 (wet). Across all calendar years, the model captured the quantitative and qualitative trends for temperature and flow. Quantitatively, the model predicted temperatures within 1.0 deg-C for most of the calibration sites (in-lake sites and at the dam), which is far better than many other temperature studies (Arhonditsis and Brett 2004). Qualitatively, trends were consistent with measured data. Model performance statistics were paired temporally and spatially closely with the measured data.

In addition to a fully updated calibrated model, ERDC-EL also developed an application of the model using modified W2 code from the USGS that allows for a better functioning blending algorithm between multiple ports. Using this algorithm has multiple advantages over the current version of W2:

1. One run produces the results needed to obtain the target temperature. With a few minutes spent in updating the w2_selective file, the user can generate the results with far few runs.
2. Multiple outlets can be blended to reach desired temperature. The current version of W2 (PSU) limits the user to at most two ports being blended.

The major downfall of the USGS code is that the base W2 code is not the latest version of the code. The base for the USGS code was the first release of W2v3.7. According to personal correspondence with Dr. Scott Wells (PSU) and Mr. Stewart Rounds, the PSU version of W2 will be updated in a future release to include all of the USGS updates. A secondary downfall of this code is that due to its iterative nature, the run time is also increased (almost tripled in the case of LCLPM).

This model and the corresponding results from the study provide CENWP with a fully capable model in determining how operational changes will impact downstream water temperature. This is extremely important
because the Rogue and Applegate temperature Total Maximum Daily Loads (TMDL), Rogue Spring Chinook Conservation Plan, and possibly the Rogue Fall Chinook Conservation Plan require the Corps to review the operations to determine whether improvements to downstream temperature for the benefit of endangered fish can be achieved.

Additional work to consider would be the impacts of these temperatures on fish with respect to egg emergence data. This model, coupled with an in-depth fish analysis, would provide CENWP with invaluable information regarding dam operations and the impacts to fish.
References


Appendix A: Bathymetry File

This section contains an image of the bathymetry file used for the LCLM. The only difference between calendar years was the initial water surface elevation used in creating the bathymetry file. W2 V3.7 now has the capability to use a csv file developed in Excel. The images below (Figure A1-Figure A8) are pages from the Excel file used to develop the csv file; to read them correctly, it is important to know that page two contains the widths for the remaining depths of the reservoir for the first thirteen segments; page four gives the same information for segments 14-28, and so on. Table A1 is the initial water surface (ELWS) used in the development of the bathymetry files for each of the model simulations.

Table A1. Initial ELWS used in bathymetry files for all simulations.

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Figure A1. Page 1 from bathymetry development Excel file.

Figure A2. Page 2 from bathymetry development Excel file.
Figure A3. Page 3 from bathymetry development Excel file.

Figure A4. Page 4 from bathymetry development Excel file.
Figure A7. Page 7 from bathymetry development Excel file.

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Figure A8. Page 8 from bathymetry development Excel file.

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Appendix B: W2 Control File with Detailed Modifications

This appendix serves to present the control file (w2_con.npt) used for the calibration of the model (see Figure B1-Figure B11) along with a table of changes for every model run simulated (see Table B1). All other model simulations will be compared to the Calibration w2_selective.npt file. Discussions of all modifications are made in the main report text.
Figure B1. Page 1 from CY01 w2_con.npt file.

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**ICEM CON**

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<th>EMC</th>
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Figure B2. Page 2 from CY01 w2_con.npt file.
Figure B3. Page 3 from CY01 w2_con.npt file.
Figure B4. Page 4 from CY01 w2_con.npt file.
Figure B5. Page 5 from CY01 w2_con.npt file.
**Figure B6. Page 6 from CY01 w2_con.npt file.**

<table>
<thead>
<tr>
<th>ERDC/EL TR-17-4</th>
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</table>

![Image](image-url)
Figure B7. Page 7 from CY01 w2_con.npt file.
Figure B8. Page 8 from CY01 w2_con.npt file.
Figure B9. Page 9 from CY01 w2_con.npt file.

<table>
<thead>
<tr>
<th>NSF</th>
<th>Data</th>
<th>Value 1</th>
<th>Value 2</th>
<th>Value 3</th>
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</tr>
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<td>0.00000</td>
<td>0.00000</td>
<td>0.10000</td>
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<td>0.00000</td>
<td>0.00000</td>
<td>0.00000</td>
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</tr>
</tbody>
</table>

ERDC/EL TR-17-4 80
Figure B10. Page 10 from CY01 w2_con.npt file.

<table>
<thead>
<tr>
<th>File Type</th>
<th>Description</th>
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<td>Figure B10. Page 10 from CY01 w2_con.npt file.</td>
</tr>
<tr>
<td>ERDC/EL TR-17-4</td>
<td>Figure B10. Page 10 from CY01 w2_con.npt file.</td>
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</table>
Table B1. Changes to calibration w2_con.npt file for other runs.

<table>
<thead>
<tr>
<th>RUN</th>
<th>YEAR</th>
<th>TEMPI</th>
<th>TSED</th>
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</thead>
<tbody>
<tr>
<td>Calibration-2001</td>
<td>2001</td>
<td>5.444</td>
<td>11.984</td>
</tr>
<tr>
<td>Verification-2003</td>
<td>2003</td>
<td>5.667</td>
<td>12.513</td>
</tr>
<tr>
<td>Verification-2010</td>
<td>2010</td>
<td>5.167</td>
<td>11.743</td>
</tr>
</tbody>
</table>

Table B2. Inventory of files needed to run the LCLM.

<table>
<thead>
<tr>
<th>Run Name</th>
<th>CY01_Run13</th>
<th>CY03-Run03</th>
<th>CY10-Run02</th>
</tr>
</thead>
<tbody>
<tr>
<td>File Type</td>
<td>Calibration – 2001</td>
<td>Verification – 2003</td>
<td>Verification – 2010</td>
</tr>
<tr>
<td>WSC File</td>
<td>LCL-WSC-012314-ADJ.NPT</td>
<td>LCL-WSC-012314-ADJ.NPT</td>
<td>LCL-WSC-012314-ADJ.NPT</td>
</tr>
<tr>
<td>SHD File</td>
<td>LCL-SHD.NPT</td>
<td>10/17/13 1:49 pm</td>
<td>LCL-SHD.NPT</td>
</tr>
<tr>
<td>QOT File</td>
<td>LCL-QOUT-2001-5STR-012214.NPT</td>
<td>12/17/12 4:18 pm</td>
<td>LCL-QOUT-2003-5STR.NPT</td>
</tr>
</tbody>
</table>
Table B3. Inventory of files needed to run the LCLPM (predictive model).

<table>
<thead>
<tr>
<th>Run Name</th>
<th>CY01-USGS-PortRun13</th>
<th>CY03-USGS-PortRun01</th>
<th>CY10-USGS-PortRun01</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>File Type</td>
<td>Date Stamp</td>
<td>Date Stamp</td>
</tr>
<tr>
<td>SHD File</td>
<td>LCL-SHD.NPT</td>
<td>10/17/13 1:49 pm</td>
<td>LCL-SHD.NPT</td>
</tr>
<tr>
<td></td>
<td>LCL-BR2-QIN.NPT</td>
<td>12/17/12 4:18 pm</td>
<td>LCL-BR2-QIN.NPT</td>
</tr>
<tr>
<td></td>
<td>LCL-BR2-TIN.NPT</td>
<td>12/17/12 4:19 pm</td>
<td>LCL-BR2-TIN.NPT</td>
</tr>
</tbody>
</table>

**Note: The same w2_selective.npt file is used for all 3 cases!**
Appendix C: LCLM and LCLPM Files

This appendix serves to provide a description of each file needed to run the model. The files are grouped by year. As an aside, ERDC typically has the following file organization system (see Table C1).

Table C1. Typical File Organization

<table>
<thead>
<tr>
<th>CY01</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main folder for year identification for the particular model. Most models will be designed to run with multiple years.</td>
<td></td>
</tr>
<tr>
<td>Upon running the model, the results are moved out of the executables folder and into their own folder; typically, these folders are named something like CYXX_RunXX. NOTE: Always copy the control file (and any needed selective withdrawal files) used for the run into the results folder so that you can duplicate the run in the future if necessary.</td>
<td></td>
</tr>
<tr>
<td>Executables</td>
<td></td>
</tr>
<tr>
<td>This is where all of the necessary files needed to run the model are located: W2 executables, Inflows, Outflows, Temperature/Concentration files, Met files, Bathymetry, etc.</td>
<td></td>
</tr>
</tbody>
</table>

Table C2. Files needed to run LCL model for each year.

<table>
<thead>
<tr>
<th>File Description</th>
<th>CY01</th>
<th>CY03</th>
<th>CY10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Graph File</td>
<td>graph.npt</td>
<td>graph.npt</td>
<td>graph.npt</td>
</tr>
<tr>
<td>Control File</td>
<td>w2_con.npt</td>
<td>w2_con.npt</td>
<td>w2_con.npt</td>
</tr>
<tr>
<td>Bathymetry File</td>
<td>LCL-BATH-2001-FINAL.NPT</td>
<td>LCL-BATH-2003-FINAL.NPT</td>
<td>LCL-BATH-2010-FINAL.NPT</td>
</tr>
<tr>
<td>Wind Sheltering Coefficient File</td>
<td>LCL-WSC-012314-ADJ.NPT</td>
<td>LCL-WSC-012314-ADJ.NPT</td>
<td>LCL-WSC-012314-ADJ.NPT</td>
</tr>
<tr>
<td>Shade File</td>
<td>LCL-SHD.NPT</td>
<td>LCL-SHD.NPT</td>
<td>LCL-SHD.NPT</td>
</tr>
<tr>
<td>Branch 2 Inflow File (zero)</td>
<td>LCL-BR2-QIN.NPT</td>
<td>LCL-BR2-QIN.NPT</td>
<td>LCL-BR2-QIN.NPT</td>
</tr>
<tr>
<td>Branch 2 Temperature File (placeholder)</td>
<td>LCL-BR2-TIN.NPT</td>
<td>LCL-BR2-TIN.NPT</td>
<td>LCL-BR2-TIN.NPT</td>
</tr>
<tr>
<td>Dam Outflow File</td>
<td>LCL-QOUT-2001.5STR.NPT</td>
<td>LCL-QOUT-2003.5STR.NPT</td>
<td>LCL-QOUT-2010.5STR.NPT</td>
</tr>
</tbody>
</table>
Table C3. Files needed to run LCLPM model for each year.

<table>
<thead>
<tr>
<th>File Description</th>
<th>CY01</th>
<th>CY03</th>
<th>CY10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Graph File</td>
<td>graph.npt</td>
<td>graph.npt</td>
<td>graph.npt</td>
</tr>
<tr>
<td>Control File</td>
<td>w2_con.npt</td>
<td>w2_con.npt</td>
<td>w2_con.npt</td>
</tr>
<tr>
<td>Selective Withdrawal Control File</td>
<td>w2_selective.npt</td>
<td>w2_selective.npt</td>
<td>w2_selective.npt</td>
</tr>
<tr>
<td>Target Temperature File</td>
<td>dynsplit_selectiveX.npt</td>
<td>dynsplit_selectiveX.npt</td>
<td>dynsplit_selectiveX.npt</td>
</tr>
</tbody>
</table>

**NOTE: All other files are the same as found in Table C2**

Tammy L. Threadgill, Daniel F. Turner, Laurie A. Nicholas, Barry W. Bunch, Dorothy H. Tillman, and David L. Smith

The U.S. Army Corps of Engineers Engineer Research and Development Center (USACE-ERDC) Environmental Lab (EL) assisted USACE, Portland District (CENWP) in updating a CE-QUAL-W2 (W2) model of Lost Creek Lake based on a previous version of W2. The model was calibrated using data from calendar year (CY) 2001 validated with data from calendar years 2003 and 2010. One set of W2 parameters were successfully applied to all calendar year types (2001 is a dry year; 2003 is a normal year; and 2010 is a wet year). This model and the corresponding results from the study provided CENWP with more refined estimates of water temperatures so that more defensible water temperature targets can be discussed with the state of Oregon. This is extremely important because the Rogue and Applegate temperature Total Maximum Daily Loads and Rogue Spring Chinook Conservation Plan require the Corps to review the Rogue Basin Project operations to determine whether improvements can be achieved to downstream temperature for the benefit of endangered fish. In addition to modeling the basic calibration for three years, a modified version of W2 was used to create a predictive model to determine the best blending of the intake ports to meet the temperature targets.