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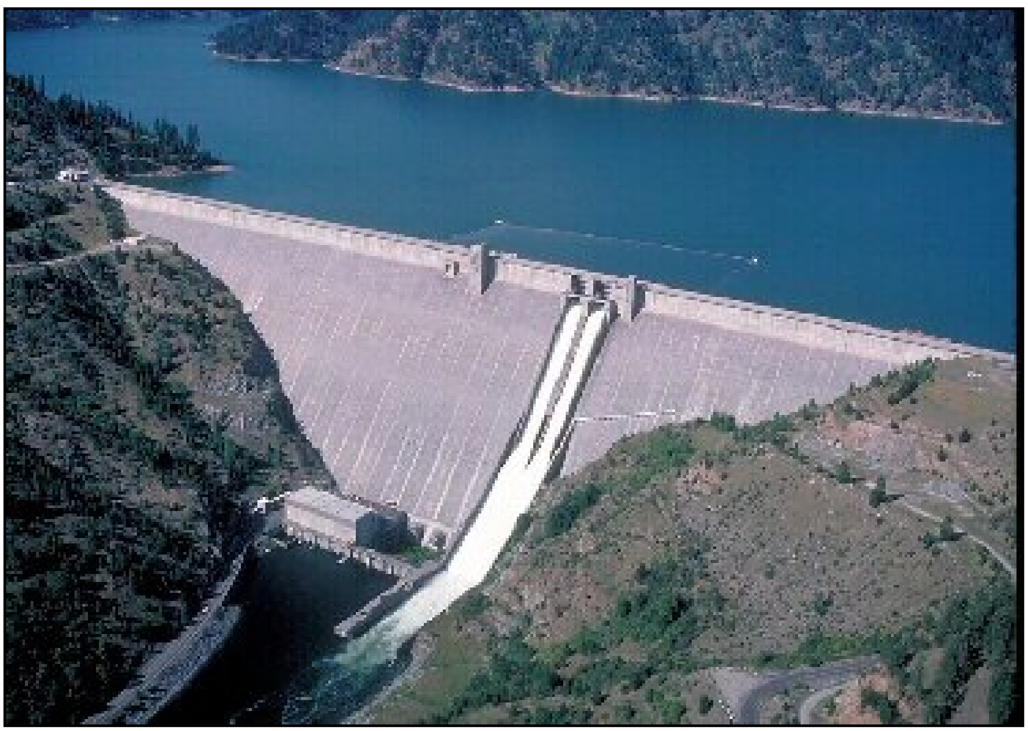
A PRELIMINARY ANALYSIS OF THE THERMAL REGIME OF DWORSHAK RESERVOIR



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EPA Region 10
September 2003

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ACKNOWLEDGEMENTS

This report relies heavily on a project completed by graduate students in Civil Engineering at the University of Washington. The project was a curriculum element in CEE577, Water Quality Management. The following students participated in the completion of the report:

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1.0 BACKGROUND

1.1 Introduction

EPA Region 10 is developing mathematical models of water temperature as decision support tools for watershed planning in the main Columbia and Snake rivers. This work has been primarily for the purpose of developing a Total Maximum Daily Load for thermal energy as required for water-quality limited river segments under Section 303 (d) of the Clean Water Act. Products of this effort include a one-dimensional, time-dependent model of thermal energy for the run-of-the river dams and free-flowing river segments (Yearsley et al, 2001); a two-dimensional model of Lake Roosevelt (Yearsley, 2002) and a two-dimensional model of Lower Granite reservoir (EPA 2002). Dworshak Dam and Reservoir on the North Fork of the Clearwater River in Idaho (Figure 1) is upstream of the four run-of-the-river Snake River dams (Lower Granite, Little Goose, Lower Monumental, Ice Harbor). Because Dworshak Dam can provide downstream temperature control, it plays an important role in watershed planning for the Clearwater, Snake and Columbia rivers. An effective mathematical model of water temperature may be useful for optimizing use of these temperature control features. This report represents a preliminary effort to assess the effectiveness of the two-dimensional mathematical model, CEQUAL-W2 for this purpose.

Dworshak Dam was completed in 1971. The reservoir reached full pool and began operating in 1973. The project is operated for flood reduction, hydroelectric power generation, recreation, water quality, and fish and wildlife uses. The US Army Corps of Engineers (USACE) is one of the Action Agencies[1] that operates or markets power from the Federal Columbia River Power System (FCRPS). Management of Dworshak Dam is the responsibility of the USACE as part of the coordinated regulation of the 10-dam FCRPS. This responsibility includes support of the Basinwide Recovery Strategy for endangered salmonids and is described in the 1995 Biological Opinion and the 2000 Biological Opinion. The Biological Opinions require that Dworshak Dam provide flow augmentation for the Snake River for the benefit of migrating juvenile salmon and steelhead from April through August. Since the project has temperature control structures that provide the capability for controlling the temperature of water releases, Dworshak Dams is also used to provide cold water during the summer for purposes of reducing water temperatures in the Snake River.

The multiple uses that Dworshak Dam provides are in conflict at times, particularly in the summer. High flows in July and August are desirable to downstream migrants, while high flows and low temperature are best for adult fall Chinook in September. Though cold water releases may be beneficial for migrating Snake River salmon and steelhead and for adult fall Chinook, they have a negative impact on growth rates of fish at the hatchery just downstream from the dam. Additional conflicts arise because recreation uses in the reservoir behind Dworshak Dam rely on pool elevations sufficient to launch pleasure boats.

1.2 Report Objectives

Finding an operational strategy for Dworshak Dam that addresses the needs of flood control, hydroelectric power generation, water quality and fish and wildlife uses in the Clearwater and

[1] The Bonneville Power Administration (BPA), the US Army Corps of Engineers (USACE) and the Bureau of Reclamation (BOR) comprise the Action Agencies; the agencies that operate or market power from the Federal Columbia River Power System.

Snake rivers is not, as one might expect, straightforward. A report developed in response to Reasonable and Prudent Alternative (RPA) 143 of the 2000 Biological Opinion outlines a program of data collection and mathematical model development to provide decision support pre-season planning of an operational strategy for the project **(**RPA Workgroup, 2003**).** One-dimensional mathematical models of water temperature have been used in this role with considerable success for river segments downstream from Dworshak Dam since 1999 (EPA, 2000). However, that given the water depth and long residence time of water in the reservoir behind the dam, a two-dimensional mathematical can provide valuable information regarding water quality conditions within the Dworshak pool and future options for flow augmentation.

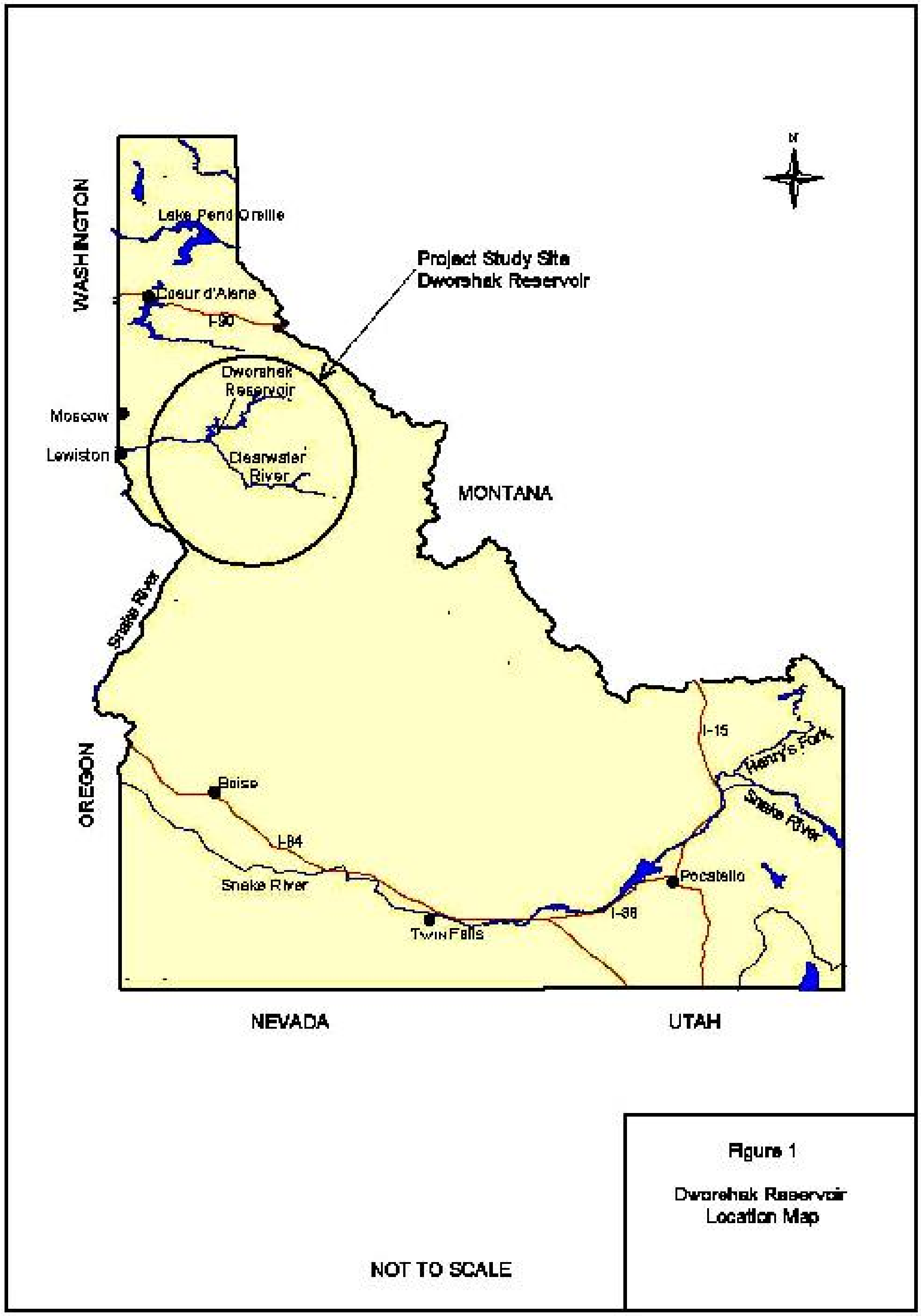

Figure 1. Location Map.

A two-dimensional water quality model that has been widely applied to projects like Dworshak Dam and Reservoir is CEQUAL-W2 (Cole and Buchak, 1995; Cole, 1997). Data input requirements for CEQUAL-W2 are considerable. Recent data collection programs initiated by the Action Agencies, in response to the requirements of RPA 143 of the 2000 Biological Opinion, as well as other data collected in earlier programs provide sufficient input data for the development of a preliminary model of water temperature in the reservoir. The objective of this report is to evaluate the model's utility as a decision support tool for this project and to provide an assessment of data needs for further modeling.

1.3 Project Characteristics[2]

Dworshak Dam is a multiple purpose concrete gravity structure completed in 1973 that controls water from a 2440-mile drainage area on the North Fork Clearwater River, Idaho.
The reservoir provides 3.5 million acre-feet of total storage and 2.0 million acre-feet of flood control storage (USACE 1986). Dworshak Dam has a maximum height of 717 feet and a crest length of 3,287 feet. The Dworshak Reservoir lies within a narrow, steep canyon and extends 53.6 miles upstream on the North Fork Clearwater River with a width range of 0.5 to 2 miles. Dworshak Dam is equipped with multilevel gates that are adjustable for selective withdrawal between full pool elevation of 1600 ft MSL (mean sea level) to the minimum pool elevation of 1445 ft MSL. Power facilities at the dam include two 90 megawatt generating units and one 220 megawatt generating unit, with room for future installations of three additional 220 megawatt generating units (USACE 1986).

The primary role of Dworshak Dam is to meet the overall flood regulation plan for the Columbia River, as described in the Columbia River Treaty Flood Control Plan by the Corps. The flood control plan involves three reservoir regulation periods: October through March (reservoir evacuation period), May through July (reservoir refill period), and July through August (summer recreation). Accordingly, rules for the evacuation of storage space at each reservoir have been developed.

The overall storage plan calls for the following:

- September – December: Draw the reservoir down to elevation 1558 feet, National Geodetic Vertical Datum (NGVD) by December 15 to provide 700,000 acre-feet (AF) of flood control storage. This is accomplished by using normal power load discharges.
- January – March: Maintain 700,000 AF of storage space, plus any additional that is required based on volume forecasts of available runoff.
- April – July: Refill at a rate that will provide safe flood control based on runoff volume forecasts, yet will allow a 95 percent probability of refill.
- July – August: Attempt to hold full pool or maximum elevation achieved during filing.

As noted previously, the July/August operations have been significantly modified in response to salmonid recovery efforts in the Lower Snake River. Rather than holding at full pool during this period, the reservoir is drawn down to provide higher flows and lower temperatures downstream.

[2] The text and figures associated with Section 1.3 of the report have been excerpted from a USACE memorandum entitled "Selective Withdrawal Technology at Dworshak Dam, Idaho" dated August 28, 2002

1.3.1 Water Temperature Control

Selective withdrawal technology was incorporated into the design of Dworshak Dam so the quality of the water released from the dam, especially water temperature, could be managed. Water temperature management of release flows from the dam is most effective during the summer. The National Marine Fisheries Service Forum Technical Management Team has used water from Dworshak Dam to augment and cool Snake River summer flows since the early 1990s. Since 1998, the Dworshak pool has been drafted to elevation 1520 feet, NGVD by August 31. Typically, target water release temperatures have varied from 48°F (8.9°C) to 51° F (10.6°C) during July and August. The target water temperatures are selected as a balance between fish production at the downstream Dworshak National Fish Hatchery and anadromous fishery needs in the lower Snake River. Cool summer releases from Dworshak Dam typically contribute from 25 to 45 percent of the Snake River flow.

1.3.2 Selective Withdrawal Structure

Water is released from the dam for water temperature control via three selector gate units and/or three regulating outlets during normal operating conditions. Each of the multiple level selector gate units is adjustable so water withdrawal can be made from full pool elevation (1600 feet, NGVD) to the minimum pool elevation (1445 feet, NGVD). Water passing through the selector gate units guide water to hydroelectric penstocks located at elevation 1395 feet, NGVD. One of the selector gate units services a 250-WM generator (hydraulic capacity of 5,800 cubic feet per second) while the other two selector gate units service two 100-MWgenerators (2,200 cfs each). The 250-MW selector gate unit is actually composed of one master gate that is operated simultaneously with two slave gates. The three gates are operated as one selector gate unit. The two 100-MW selector gate units are each composed of a master and slave gate. The two 100-MW selector gate units are operated as independent units. The hydraulic capacity of the 250-MW generator varies from 3515 cfs to 2740 cfs for gross heads of 457 and 630 feet respectively. The hydraulic capacity of the 100-MW generator varies from 2680 to 1880 cfs for gross heads between 480 to 630 feet
(Figure 2).

Selector gate units are designed to pass water over the top of the gate units, called an overshot mode, or under the bottom of the gate units, called an undershot mode. The reservoir elevation range for operation in the overshot mode is from 1600 to 1500 feet, NGVD. The minimum design submergence restriction to prevent cavitation is 30 feet, but for safety reasons, 35 feet is used as the criterion.

The undershot mode operation can be operated in the reservoir pool range between 1600 feet, NGVD and 1445 feet, NGVD. Between these elevations, there are at least 40-feet of head provided to flow under the gate to prevent cavitation. The minimum elevation for the undershot mode is elevation is 1435 feet, NGVD (Figure 3).

It is important to note that there is a zone in the reservoir that cannot be accessed via the selector gates. The zone that cannot be reached is between elevations 1465 feet (lowest elevation of a selector gates in the overshot position) and 1430 feet (lowest elevation of the selector gates in the undershot position) (Figure 4).

There are three regulating outlets at Dworshak Dam available for evacuation of reservoir storage below the spillway crest when release flows that exceed generation capacity are needed. Their invert elevation is 1350 feet, NGVD. Discharge capacity of the three outlets varies from 23,100 cfs at the minimum pool elevation of 14445 feet to 39,750 cfs at the full pool elevation of 1600 feet, NGVD. Water releases through the regulating outlets can be made while selector gate releases are

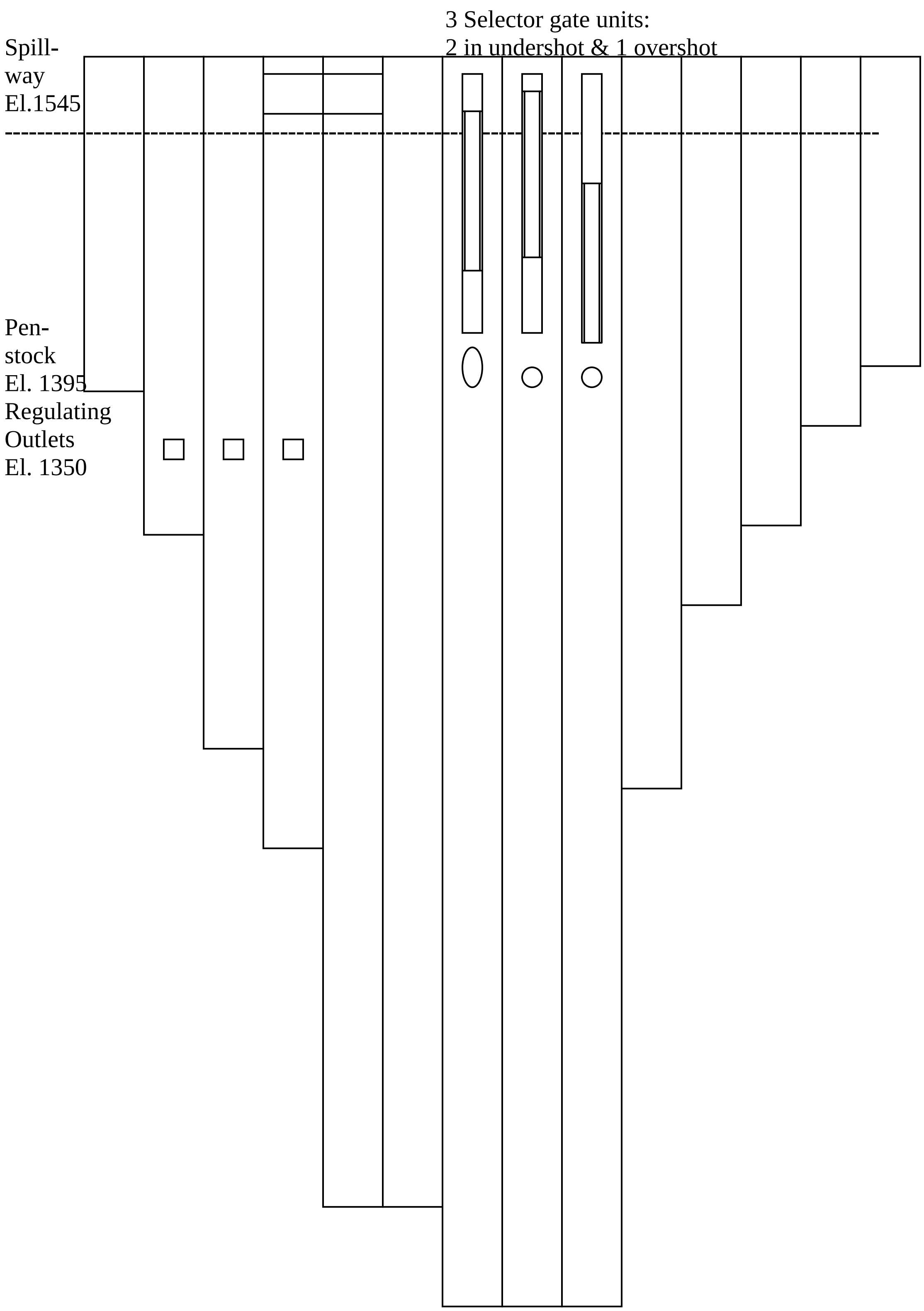

Figure 2. Dworshak Dam face, looking from upstream to downstream

Limits of Selector Gate Positioning.

Limit of Lowest Elevation Overshot Position

Limit of Lowest Elevation Undershot Position

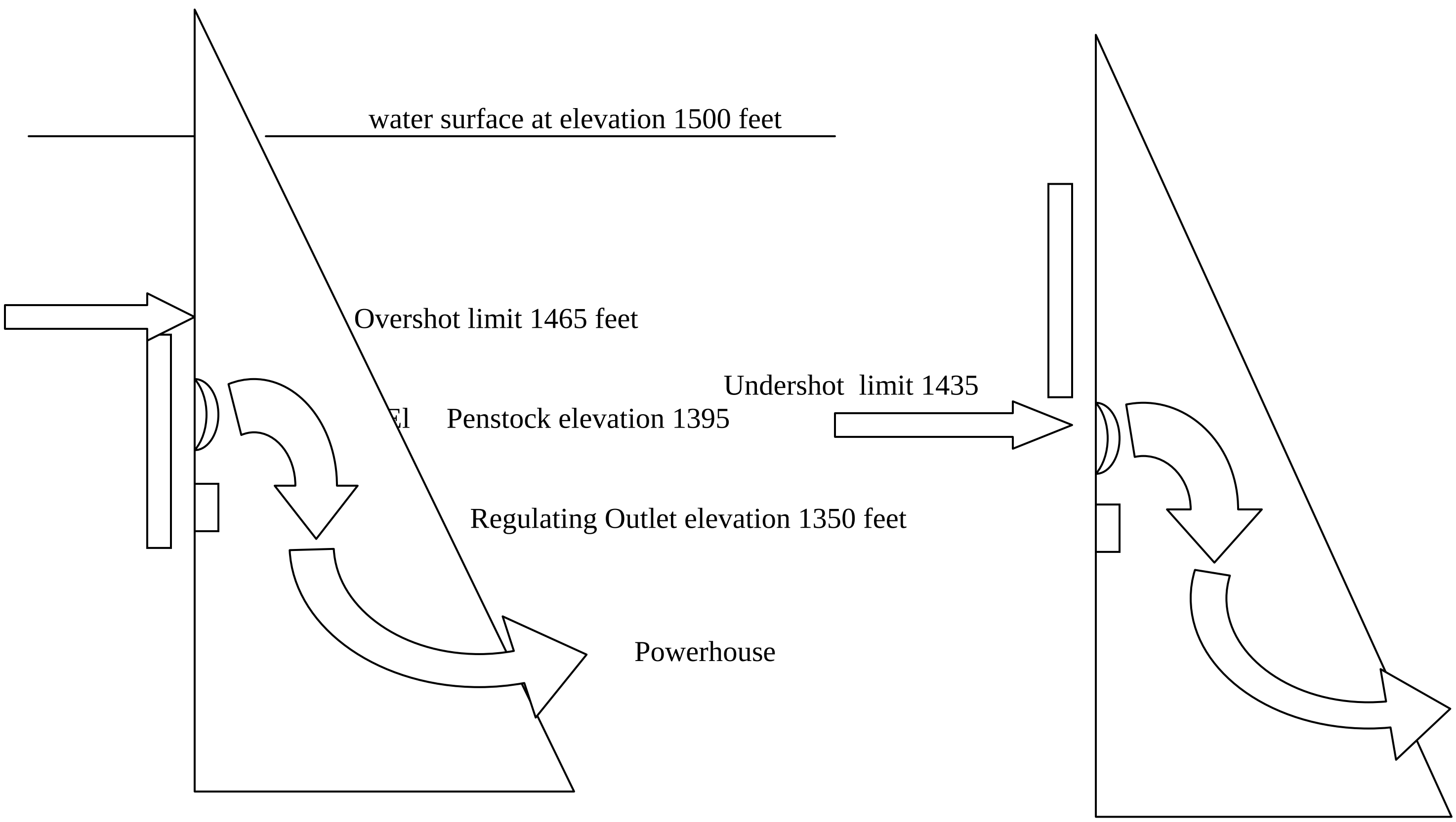

Figure 3. Dworshak Dam selective withdrawal structure schematic

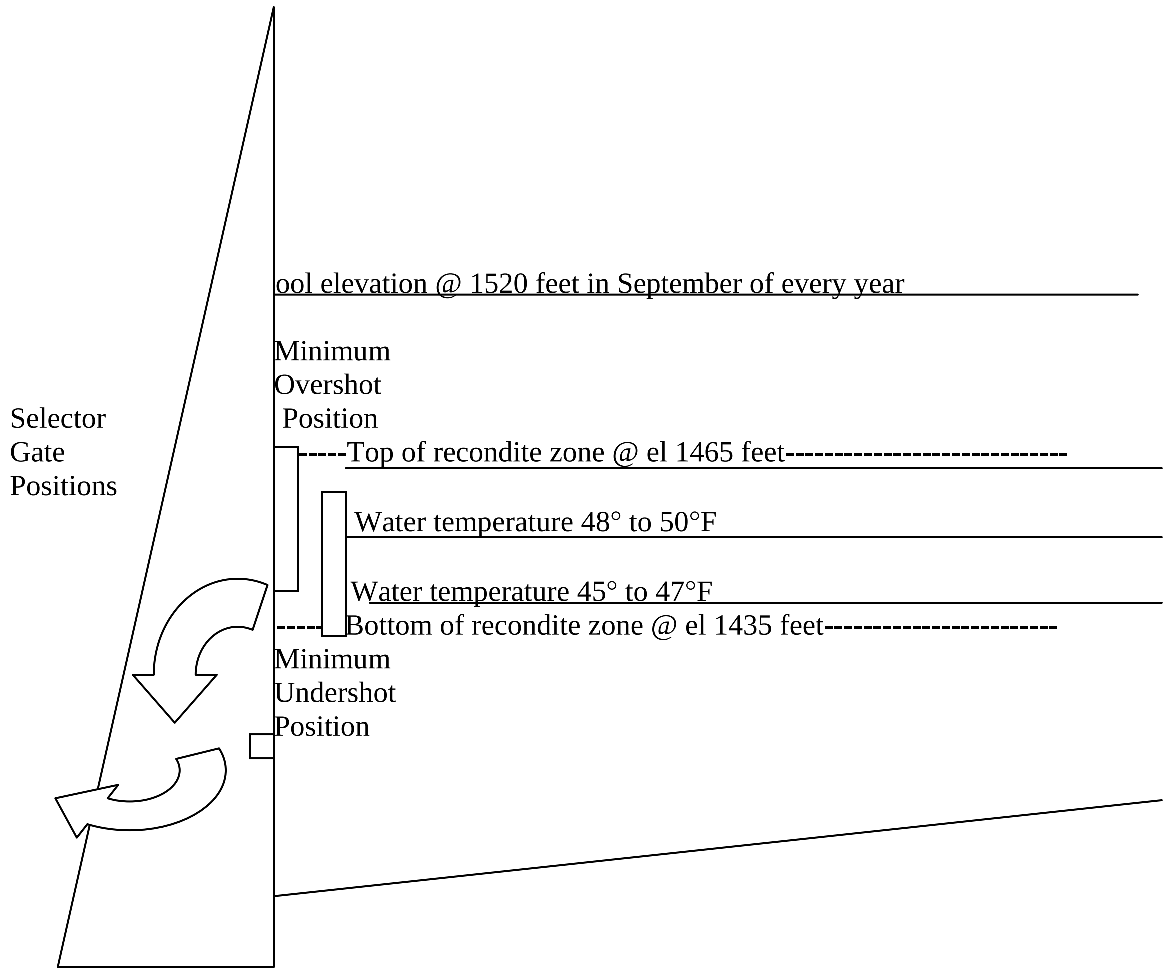

Figure 4. Dworshak Reservoir pool limitations in September

being made. The temperature of water released through the regulating outlet is typically between 42°F (5.6°C) and 43° F (6.1°C). (Figures 2 and 3).

During high runoff or flood conditions, a spill way (crest elevation 1545 feet) is also used to evacuate water from the reservoir. Theoretically, the spill way could be used for water temperature control. The spillway can be used anytime the pool is above elevation 1545 feet, NGVD. However, the spillway is not used for regular temperature control operations because of the high Total Dissolved Gas levels that it produces. Typically, the spillway is only used during high runoff and flood events.

1.3.3 Water Temperature Monitoring

Water temperature is monitored at several locations at Dworshak Dam. The major water temperature control point is at the Dworshak National Hatchery. Use of the selective withdrawal flexibility at the project is governed by the resulting water temperatures achieved at the hatchery. Power generation via the three turbines is accomplished using a combination of the releases via the selective withdrawal structures (in overshot and/or undershot modes). When needed release flows exceed the generation capacity of the three generators, the non-power producing regulating outlets are also used.

Water temperature data is available from resistance thermal devices (RTDs) embedded in the face of the dam during the time of construction. They are located at elevations 1574, 1549, 1524, 1499, 1474, 1449, 1394, 1349, 1324, 1299, 1249, 1199, 1149, 1099, and 1049 feet, NGVD. In addition, four floating sensors follow reservoir fluctuations at depths of 1, 5, and 10 and 20 feet. One sensor is located on the downstream side of the dam at the nose pier of powerhouse bay number 2.

1.3.4 Reservoir Thermal Structure

The thermal structure of the reservoir can be monitored throughout the summer season using the RTDs. The reservoir displays typical thermal stratification patterns seen in reservoirs with a warm epilimnion layer where the surface waters can exceed 68°F (20°C), a rapidly cooling middle zone metalimnion layer, and a deep, cold hypolimnion layer. The thermocline, the limnologically important depth in the metalimnion that exhibits the greatest water temperature change per depth, typically occurs about forty to fifty feet from the surface and is usually about 55°F.

The project operators set the selector gates using the water temperature data from the RTDs to obtain the desired target at the hatchery. Typically, the hatchery does not want water less than 48°F (8.9°C), and would prefer water that is about 50°F (10.0°C). Consequently, the selector gates are continually changed throughout the summer to withdraw water from near to but below the thermocline. By September, the zone of water below the thermocline that is between 45°(7.2°C) and 50°F falls into the zone that is unavailable for operational use. Consequently, release waters in September are either about 42°F(5.6°C) or about 55°F(12.8°C), depending on whether the selector gates are in the overshot or undershot position (Fig. 3 and 4).

1.4 Clearwater River Watershed Characteristics

The Clearwater River watershed has a total drainage area of approximately 9,570 square miles. It is located in north central Idaho and is a major tributary of the Snake River, which is a major branch of the Columbia River. Basin elevations range from 750 to 9,000 ft MSL.

The general course of the North Fork Clearwater is westerly from the Bitterroot Range in the eastern and northeastern areas of the basin. The North Fork joins the Clearwater River approximately 40 miles east of Lewiston and then drains a densely forested, sparsely populated, undeveloped area of 2,440 square miles above the Dworshak Dam. Topography and runoff characteristics naturally divide the Clearwater River basin into two major drainage areas, referred to as the Upper and Lower Clearwater River watersheds (USACE 1986). The lower watershed consists primarily of steep barren hills and plateaus. The plateaus are generally areas used for dry-farming methods and growing crops of wheat, peas, and lentils (USACE 1986).

1.4.1 Geography and Soils

The headwaters of the North Fork Clearwater River begin in a mountainous area underlain by metamorphic rocks of the Belt Series (MT) and igneous granite rocks of the Idaho Batholith. There are various rock types that underlay the Clearwater River drainage area. Valley walls in the lower river course are metamorphic rocks of the Orofino Series and lavas of the Columbia Plateau occur at various locations in the western reaches of the basin. The lava flows are thought to have changed the original drainage pattern of the Clearwater basin resulting in the current course of the North Fork Clearwater River which cuts across old valleys and ridges.

Soils in the basin are composed of the major rock types, including decomposed granite and sedimentary materials. The soil layer over the basin is considered to be thin and is underlain by an impervious rock. This impervious rock layer contributes to the basin's high runoff (USACE 1986).

1.4.2 Climate

Mild summers, cold winters, and abundant snowfall between the months of November through April characterize the climate of the Clearwater River watershed. Snow accumulation generally begins in late September or October and continues to increase until April or May. The accumulation of snow over the Clearwater River basin influences the manner in which Dworshak Reservoir is operated (USACE 1986). Temperatures within the watershed fluctuate month-to-month and year-to-year. The mean annual precipitation for the basin varies from 24 to 70 inches depending on elevation. On the average 60 to 70 percent of the total annual precipitation falls during the months of October to March, 20 to 30 percent during April through July and 5 to 15 percent during August and September.

1.4.3 Hydrology

A major part of the annual runoff for the Clearwater River basin originates in the upper watershed, as a combination of winter rain and spring snowmelt. Heavy precipitation, dense timber, sparse population, and very limited development characterize principal runoff areas within the upper watershed. The stream flow pattern in the upper watershed heavily influences the operation of Dworshak Reservoir. Stream flows are generally low from late July through February, with increasing flows in March, and high flows during April through June. The average annual runoff for the North Fork Clearwater above Dworshak Dam based on flow data for the period 1974-2002 reported on the Columbia River Data Access in Real Time (DART) Web site (http://www.cqs.washington.edu/dart) is 5540 cfs. The reservoir residence time, based on the average annual flow and reservoir volume at full pool, is 316 days.

The lower watershed consists of approximately 1,530 square miles or about 16 percent of the total basin. Natural March to July stream flow in the lower watershed represents about 5 percent or less of the total March to July runoff from the entire Clearwater River Basin. Peak discharges and runoff from the lower watershed are considered to have little or no impact on the operation of Dworshak Reservoir (USACE 1986).

1.5 Water Quality and Quantity Issues Associated with Dworshak Dam

Although water quality within the Clearwater River basin is generally high, water quality and quantity problems have occurred in the Snake River downstream from the dam as a result of activities within the Clearwater basin. Some of these issues are directly influenced by the operation of the Dworshak Dam and Reservoir. The Dworshak Dam has also affected resident and anadromous fish communities in the Clearwater River basin as well as the Snake and Columbia Rivers. Water quality, quantity and fisheries issues associated with the Dworshak Dam and Reservoir are discussed below.

1.5.1 Water Quality Issues

Post-dam conditions within the Dworshak Reservoir, the Clearwater River and in the Snake River differ greatly from the water quality conditions associated with the free-flowing river. Water temperature, dissolved oxygen concentrations, turbidity, and total dissolved gas concentrations in the Clearwater River, both above and below the dam, have been affected by the impoundment. Water temperatures in the Lower Clearwater River have been impacted by the thermal structure of the reservoir during periods of stratification. During the summer-fall reservoir stratification period, June-November, river temperatures in the Clearwater River below the dam vary from 7 to 16˚C. Water temperatures in the Clearwater River are cooler in June-September and warmer from October to November as a result of the discharges from Dworshak Dam (USACE 1986). Operations of the Dworshak Dam have also resulted in slower warming spring temperatures and slower cooling fall temperatures.

Dissolved oxygen concentrations during summer months are lower in the reservoir than pre-dam conditions. Dissolved oxygen levels during the summer months can fall to 35 to 45 percent of saturation at the deepest parts of the reservoir.

Dissolved gas concentrations have also increased due to the construction of the Dworshak Dam. During periods of spill from the dam, the total concentration of dissolved gas downstream of the dam has been measured at levels above the State of Idaho’s 110 percent standard. This standard was designed for waters designated for salmonid spawning. Total dissolved gas measurements have ranged from 97 percent to a maximum of 128 percent (USACE 1986). Typically, Dworshak is operated to avoid releasing water over the spillway in amounts that exceed the 110 percent standard.

1.5.2 Water Quantity Issues

The construction of the Dworshak Dam significantly altered the flow regime of the North Fork Clearwater River, Clearwater River and the Snake River. The reservoir stores large volumes of water that would have flowed freely to the Snake and Columbia Rivers. The Dworshak Reservoir has reduced flood events and peak flows on the Snake and Columbia Rivers. The Dworshak Dam operations now focus on flow augmentation to provide water for the Dworshak Steelhead Migration Hatchery located below the dam, and to augment summer flows to cool the Snake River for salmonids.

1.5.3 Fisheries Issues

Because the Dworshak Dam does not have a fish passage facility, the entire anadromous wild steelhead and chinook fishery was eliminated from the Clearwater River with the exception of the lower 1.9 miles of the river. Kokanee salmon, smallmouth bass, bull trout and west slope cutthroat are present within the system above the dam and are influenced by reservoir operations. While bull trout are listed as an endangered species and affected by dam operations, their subpopulations are stable and secure. Above the dam, reservoir fluctuations due to flood control and power peaking have interfered with riparian vegetation and reservoir limnology, causing variable primary productivity and loss of resident fish stocks within the reservoir (Idaho Department of Water Resources, 2000)

2.0 DESCRIPTION OF MATHEMATICAL MODEL

2.1 CEQUAL-W2 Version 3.1

The version 3.1 of the mathematical water quality model CE-QUAL-W2 (Cole and Buchak, 1995) was selected for this project to simulate water temperatures in the Dworshak Reservoir. CE-QUAL-W2 is a two-dimensional, longitudinal/vertical, hydrodynamic and water quality model (Figure 5). Because the model assumes lateral homogeneity, it is best suited for relatively long and narrow water bodies exhibiting longitudinal and vertical water quality gradients (Cole and Buchak 1995).

The water quality algorithms of CE-QUAL-W2 include modeling of 21 constituents in addition to temperature including nutrient, phytoplankton, and dissolved oxygen (DO) interactions during anoxic conditions (Cole 1997). Each of which is modeled based on laterally averaged equations of momentum, continuity, and transport. Complete details on model theory and structure, and an extensive bibliography for theoretical development and application are given in Cole and Buchak (1995).

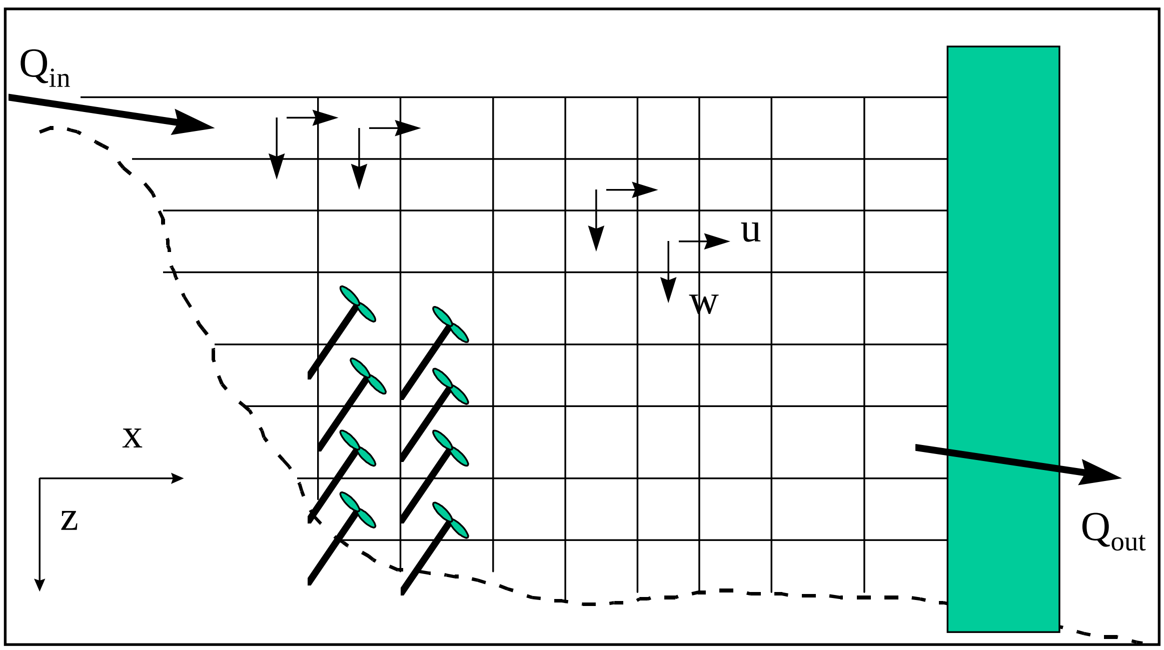

Figure 5. Two-dimensional (x-z) hydrodynamics model schematic. Source: Scott A. Wells Department of Civil Engineering Portland State University Portland, Oregon USA. http://cv-nt.technion.ac.il/courses/19225/Lecture1_intro_files/frame.htm

The time-varying solution technique of the model is based on an implicit, finite difference scheme that results from the simultaneous solution of the horizontal momentum equation and the free-water surface equation of vertically integrated continuity (Bales and Giorgino 1998). The computational time step is variable throughout the simulation to ensure numerical stability.

Application of CEQUAL-W2 to the prototype requires the following input data:

Bathymetery
Meteorology
Tributary Inflows and Temperatures
Outlet Flows

The most complete set of data for purposes of this assessment are from Calendar Year 2002. The data used to implement CEQUAL-W2 for Dworshak Dam and Reservoir are described below.

2.2 Bathymetry

Bathymetry data for the project was obtained from the limnological study of Dworshak Reservoir funded by the USACE (Falter et al, 1975). Table 4 in Falter et al (1975) describes the reservoir volume as a function of surface elevation and various figures in the document provide an estimate of the bottom slope. Reservoir widths at full pool were estimated from topographical maps at intervals of approximately one kilometer. Reservoir widths estimated in this way as a function of distance are shown in Figure 6. Accuracy and computational efficiency is much higher in applications of CEQUAL-W2 when the geometry varies smoothly. In light of this, a fourth-order curve was fit to the measured widths as shown in Figure 6. This curve, modified slightly as described below, was used to estimate reservoir widths at full pool for input to CEQUAL-W2.

The finite difference grid characterizing the reservoir comprised 26 longitudinal segments, each of which was 3200 meters long for a total modeled reservoir length of 83.2 kilometers. Each segment was further subdivided into vertical layers 3.0 meters in thickness. The deepest segment, the segment adjacent to the dam, had a total of 66 active vertical segments.

Since actual reservoir soundings were not available for this study, reservoir widths as a function of depth were estimated based on the assumption that the glacially-carved valley of the North Fork has the shape of an exponential curve. It was assumed that the exponential curve had the same shape along the entire length of the modeled portion of the reservoir. In addition, a multiplier was incorporated into the width estimate to account for the embayments associated with Elk Creek and the Little North Fork. For input to CEQUAL-W2, top widths (labeled “Smoothed” in Figure 6) were estimated at 3200 meter intervals using the polynomial fit. The multiplier and power to which the exponent was raised were adjusted so as to provide a good fit to the observed reservoir volume as reported in the limnologic study by Falter et al (1975). A typical cross section based on the exponential assumption is shown in Figure 7.

Figure 8 compares the observed and modeled volumes between full pool (1600 feet/487.69 meters NGVD) and the elevation to which the reservoir has been drafted for fish passage since 1998 (1520 feet/463.30 meters NGVD).

2.3 Meteorology

Hourly observations of air temperature, dew point, and wind speed and direction are available at the Dent Acres site adjacent to the reservoir (Figure 9). The Dent Acres site is part of the US Bureau of Reclamation’s (USBR) AgriMet system. Observations are available at this site beginning in

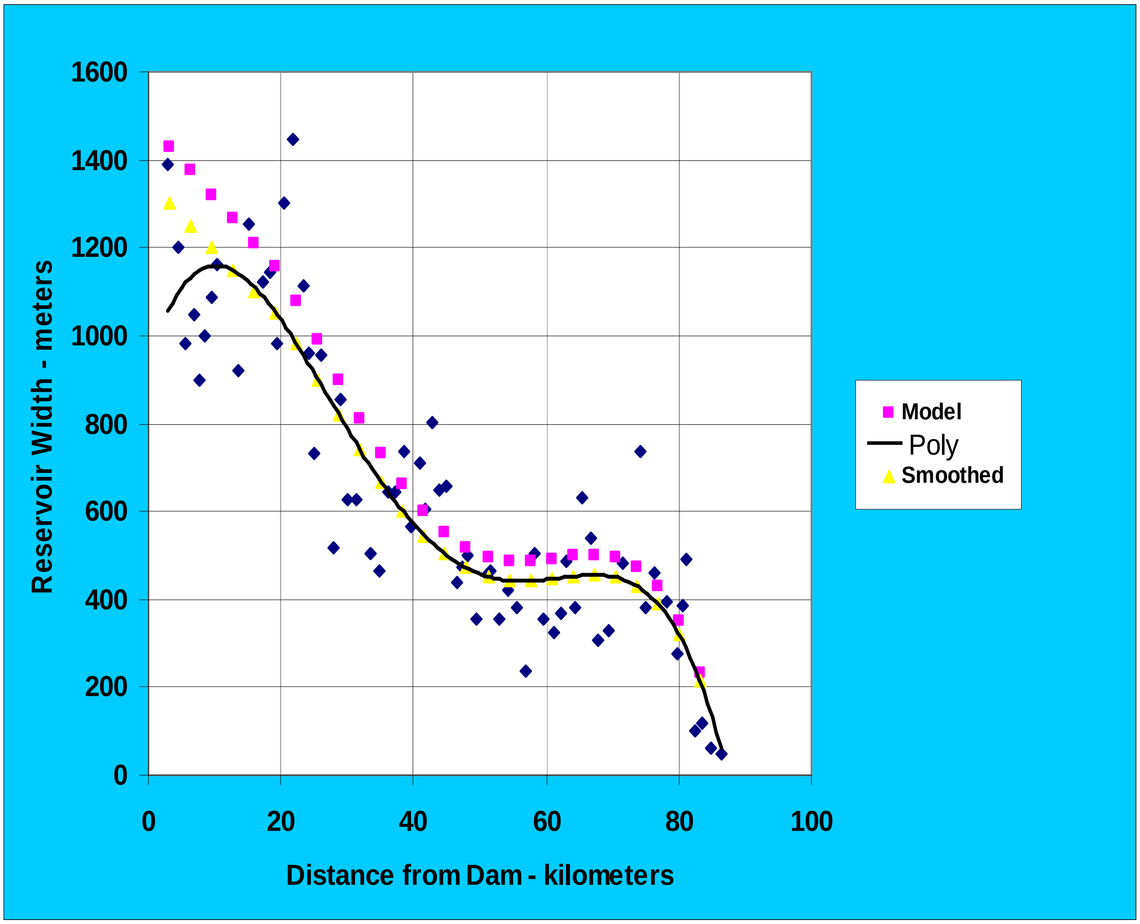

Figure 6. Measured and modeled reservoir widths of Dworshak Reservoir

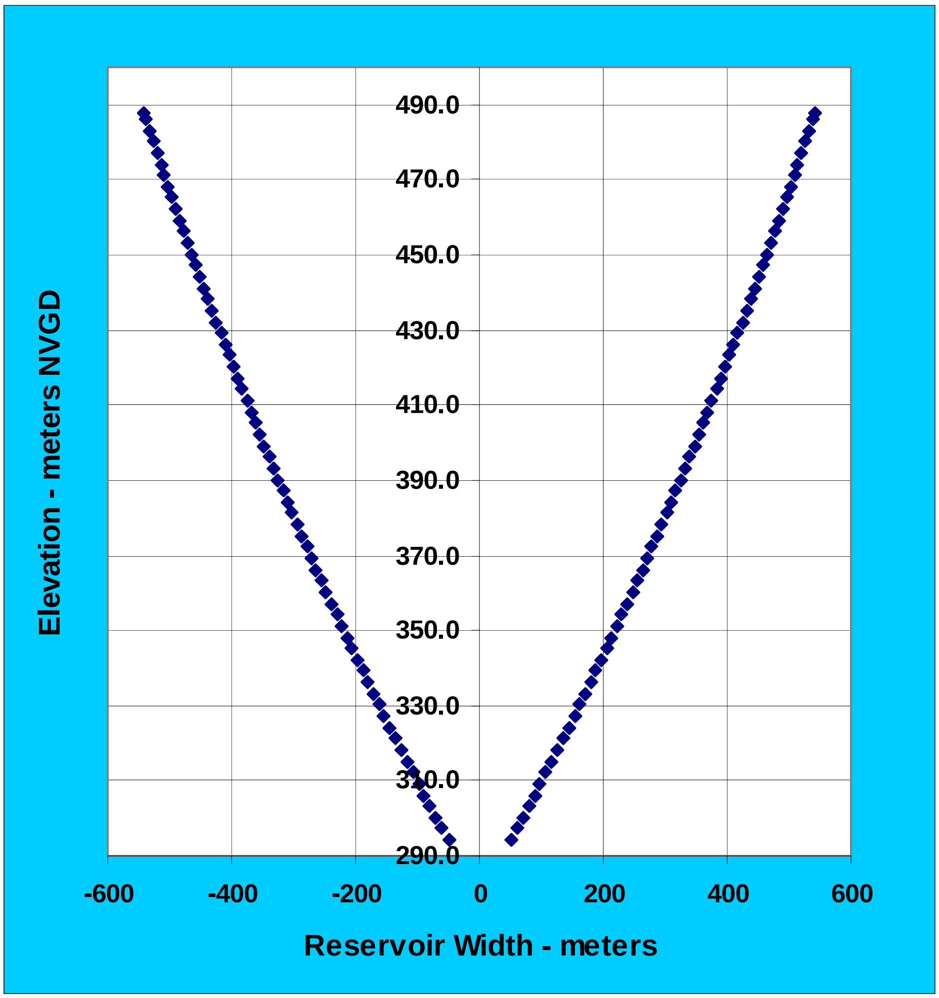

Figure 7. Typical reservoir cross-section based on an exponential shape

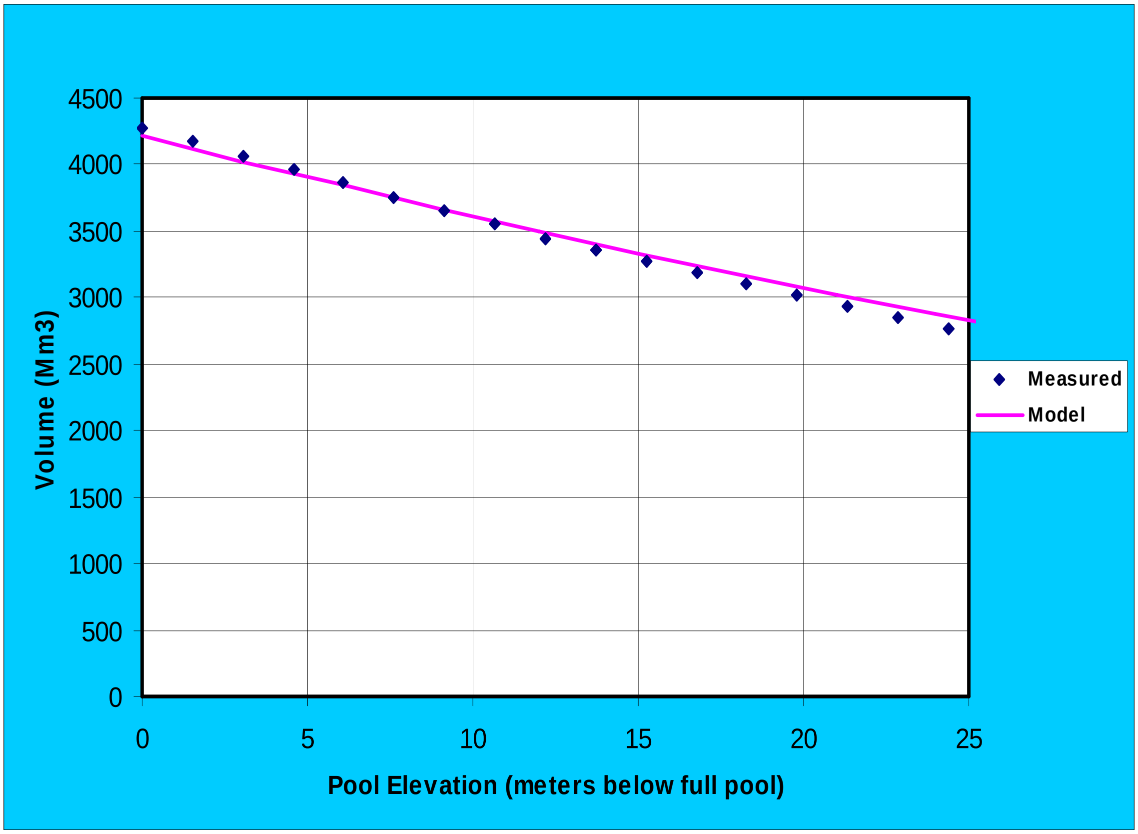

Figure 8. Modeled and observed reservoir volumes for Dworshak Reservoir

April 2002 and data are available at the AgriMet Web site (http://mac1.pn.usbr.gov/agrimet). Cloud cover is not observed at this site and it was, therefore, necessary to assume that the average hourly cloud cover for each day of the year based on the 54-year period of record at Lewiston, Idaho was adequate.

2.4 Tributary Inflow and Temperature

Upstream boundary conditions included measured daily stream flow and water temperature from the USGS gauging station 13340600, located at the inflow to Dworshak Reservoir on the North Fork of the Clearwater River (see Figure 9). The watershed represented by this gage has an area of 1440 square miles, approximately 60% of the total watershed above Dworshak Dam. The remaining 40% is not gauged. It was therefore assumed that the ungauged flow could be estimated by performing a water balance of the reservoir. Outflow at the dam and reservoir elevation are available on the DART site. The daily-average flows from the ungauged portions, $Q_{ungaged}$, of the watershed were estimated from:

$$Q_{ungaged} = \Delta V/\Delta t - Q_{out} - Q_{13340600} \qquad (1)$$

Where,

$\Delta V/\Delta t$ = the daily change in reservoir volume in time, Δt,

Q_{out} = the total daily outflow from the reservoir,

$Q_{13340600}$= the gauged daily flow at USGS gage 13340600.

Application of Eq. (1) resulted in negative flows on a few days. The estimated flow on days for which this occurred was calculated as the average of the preceding day and the following day. The observed reservoir elevation and the elevation simulated by the water budget are shown in Figure 10.

Input temperatures for the ungauged portion of the watershed were assumed to be the same as those observed at USGS gage 13340600. Tributary inflow and temperature for the calendar year 2002 are shown in Figures 11 and 12.

2.5 Outlet Flows

Hourly observations of spill and total outflow from Dworshak Dam are available from the DART Web site. These data are not specific as to the configuration and withdrawal schedule associated with the temperature control structure. These data are apparently recorded by the USACE (C. Knaak, personal communication), but were not available at the time of model development. Since this study is being treated as a preliminary analysis of the thermal structure of Dworshak Reservoir, the outlet flow data were reverse engineered to provide a reasonable comparison with observed outlet temperatures. The withdrawal schedule for outflows as a function of time and location is shown in Figure 13. It was assumed that there were only three outflow elevations (spillway elevation and two selector gate elevations). Elevations of selector outlets were chosen such that they were within the range of the selective withdrawal structure or penstocks as described above in Section 1.3. Outflows from each selector outlet were calculated such that the total flow-weighted average temperature (from all three outflow locations) was approximately equal to the observed downstream temperature.

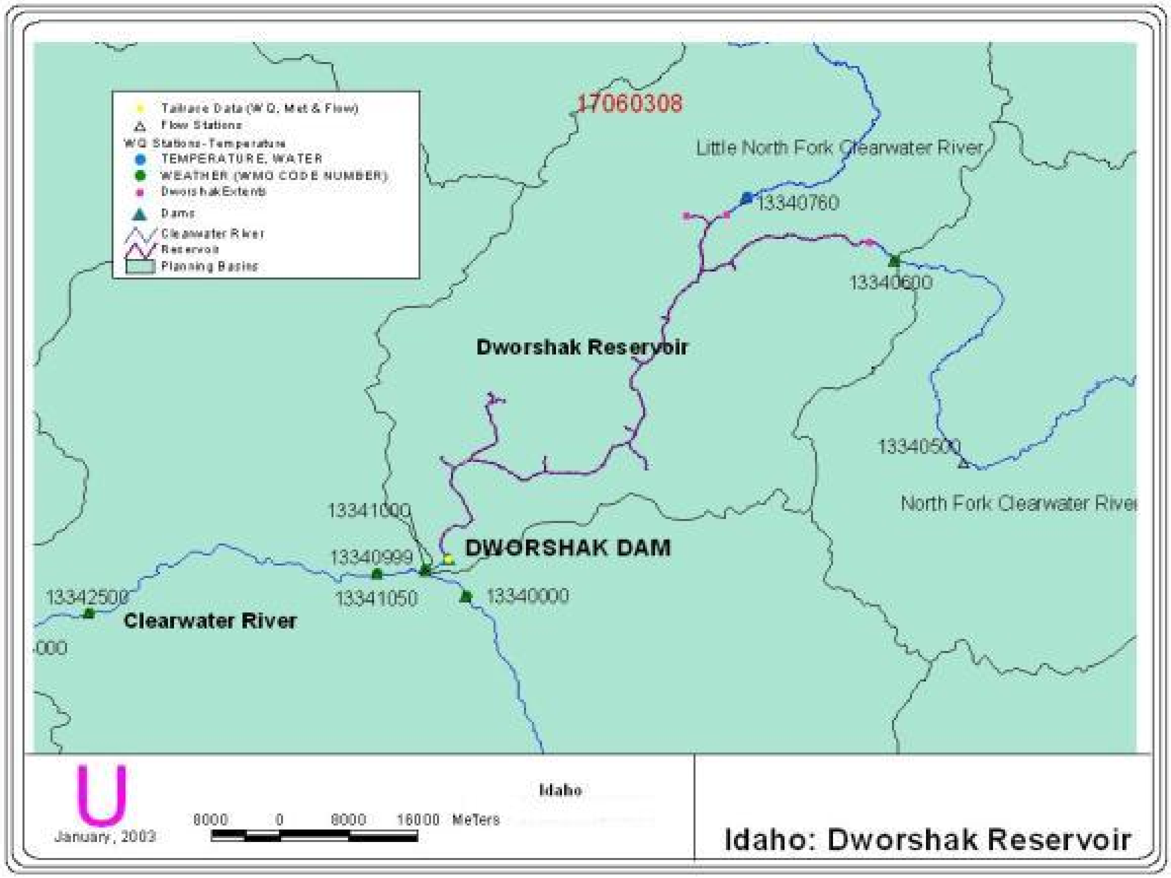

Figure 9. Water temperature and stream flow stations in the Clearwater River basin

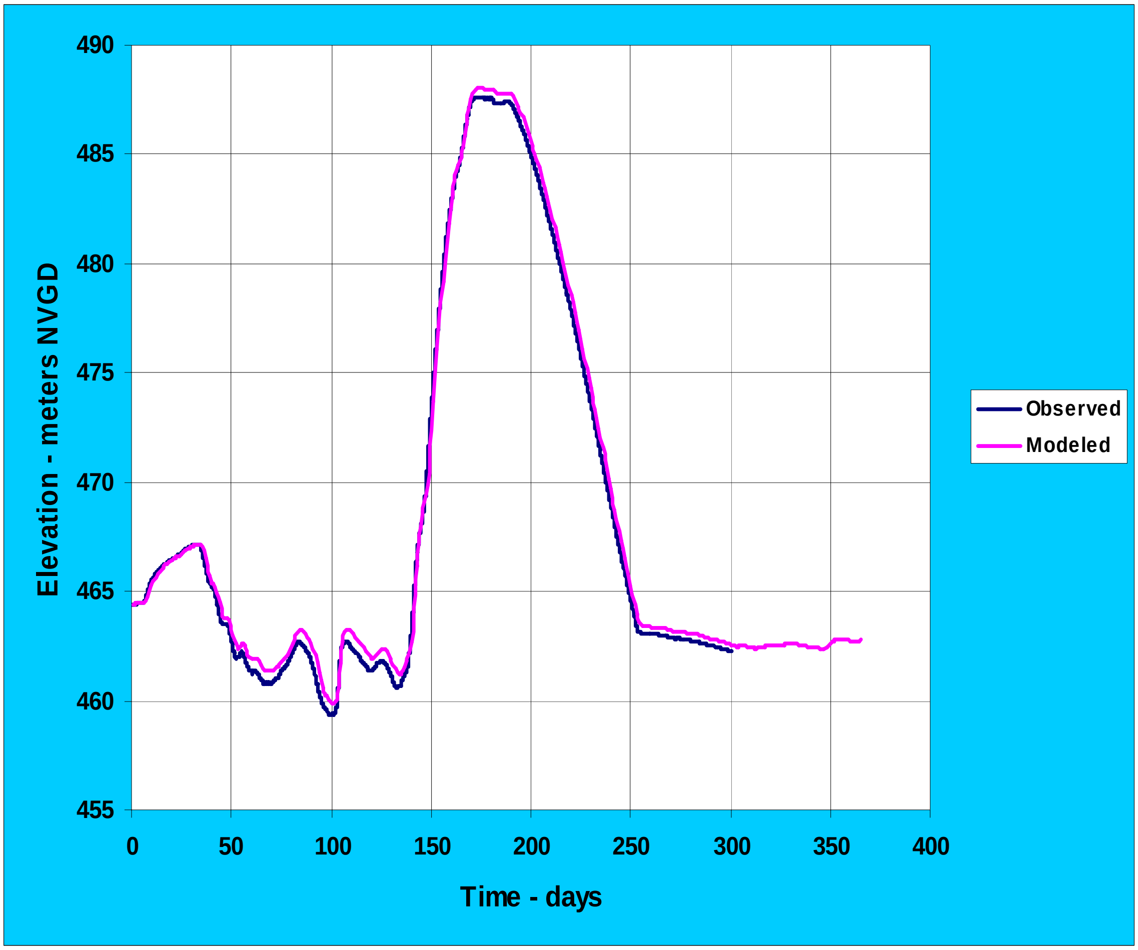

Figure 10. Measured and modeled pool elevation in Dworshak Reservoirs in 2002.

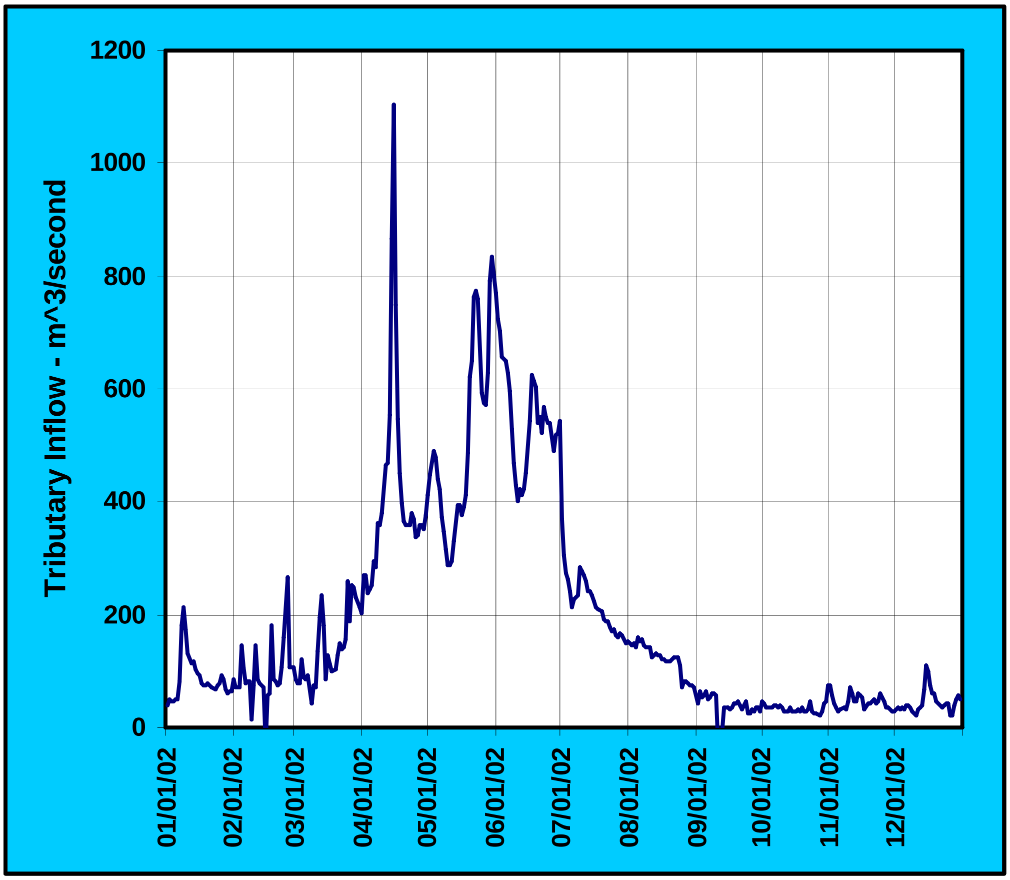

Figure 11. Tributary inflows to Dworshak Reservoir during the calendar year 2002 based on data from USGS gage station 13340600.

Figure 12. Temperature of tributary inflows during the calendar year 2002 to Dworshak Reservoir based on data from USGS gage station 13340600.

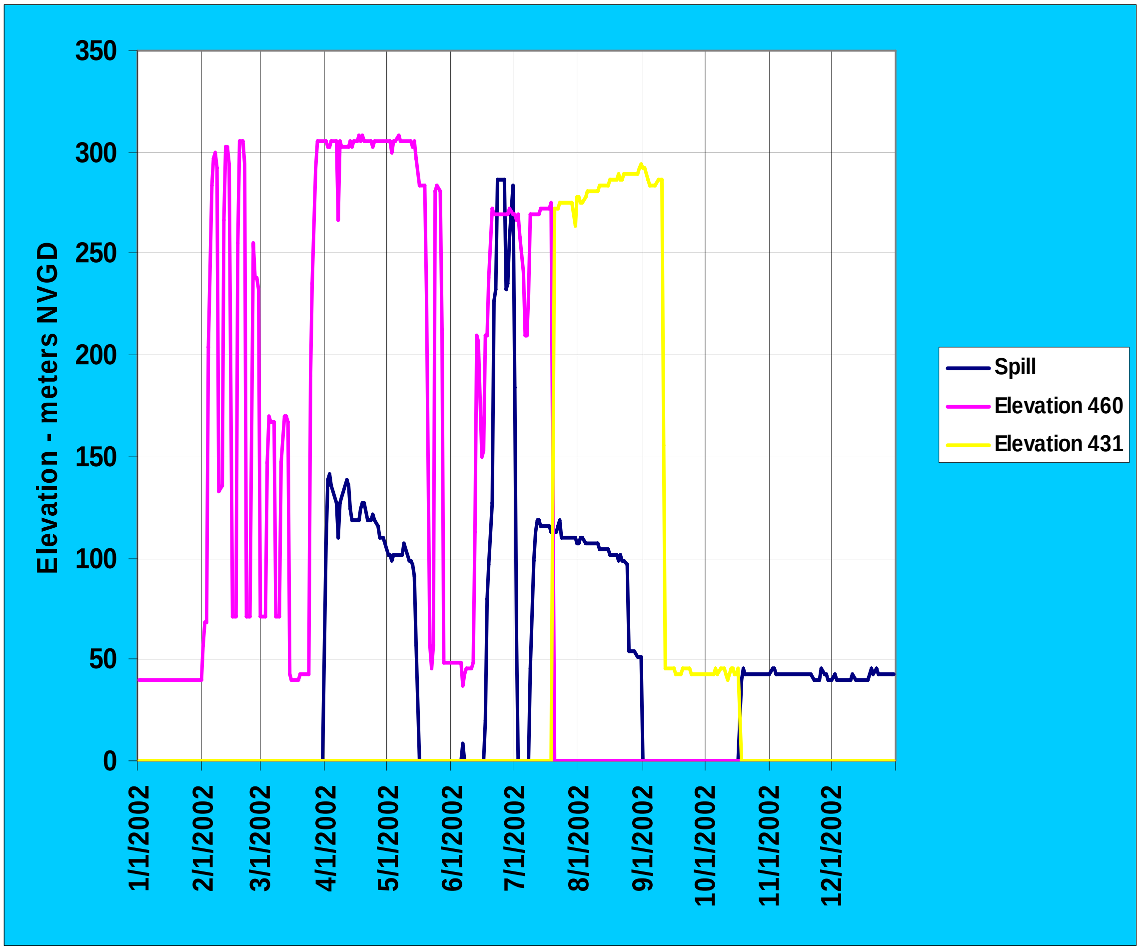

Figure 13. Inferred outflow schedule at Dworshak Dam during 2002

3.0 MODEL RESULTS

3.1 Outlet Temperatures

Observed and simulated outflow temperatures are shown in Figure 14. The simulation results demonstrate that it is possible to configure the modeled outflow in a simplified manner so as to match the observed fairly well as demonstrated in Figure 14. However, this is quite different from saying that the model correctly simulates outlet temperatures, since the outflow configuration was reverse-engineered to do so. A better assessment of model performance can be made at such time as operations data are available.

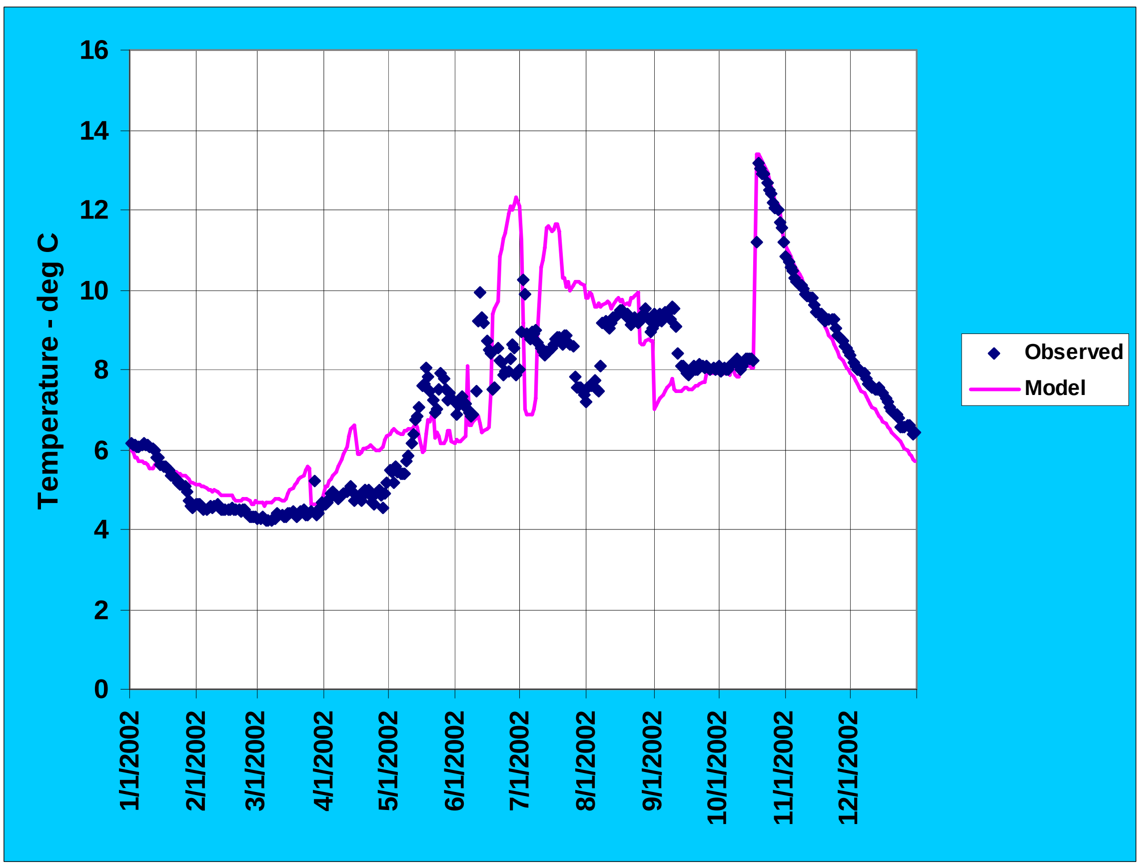

Figure 14. Simulated and observed outlet temperatures at Dworshak Dam during 2002.

3.2 Vertical Temperature Profiles

On June 9, 2002, the USACE began observing water temperature profiles near Dworshak Dam as part of RPA 143. These observations have been used to evaluate temperature simulations obtained with CEQUAL-W2. Simulated and observed temperature profiles for June 30, 2002; July 20, 2002; August 8, 2002; and August 28, 2002 are shown in Figures 15-18. In general, the simulated and observed are similar. Again, more detailed information regarding operations will be needed to assess model performance.

3.3 Longitudinal Temperature Profiles

Isopleths of width-averaged simulated water temperature on June 30, 2002; July 20, 2002; August 8, 2002; and August 28, 2002 are shown in Figures 19-22, respectively. There are no observational data, other than at the single site near the dam, to compare with the simulated longitudinal profiles. Based on the simulated results, one would conclude that dominant mechanism for distribution of thermal energy during the summer low flow period is vertical mixing rather than longitudinal advection. This is consistent with observations of reservoir temperature by Falter et al (1975) in 1972-1974 and also with the reservoir residence time of 316 days.

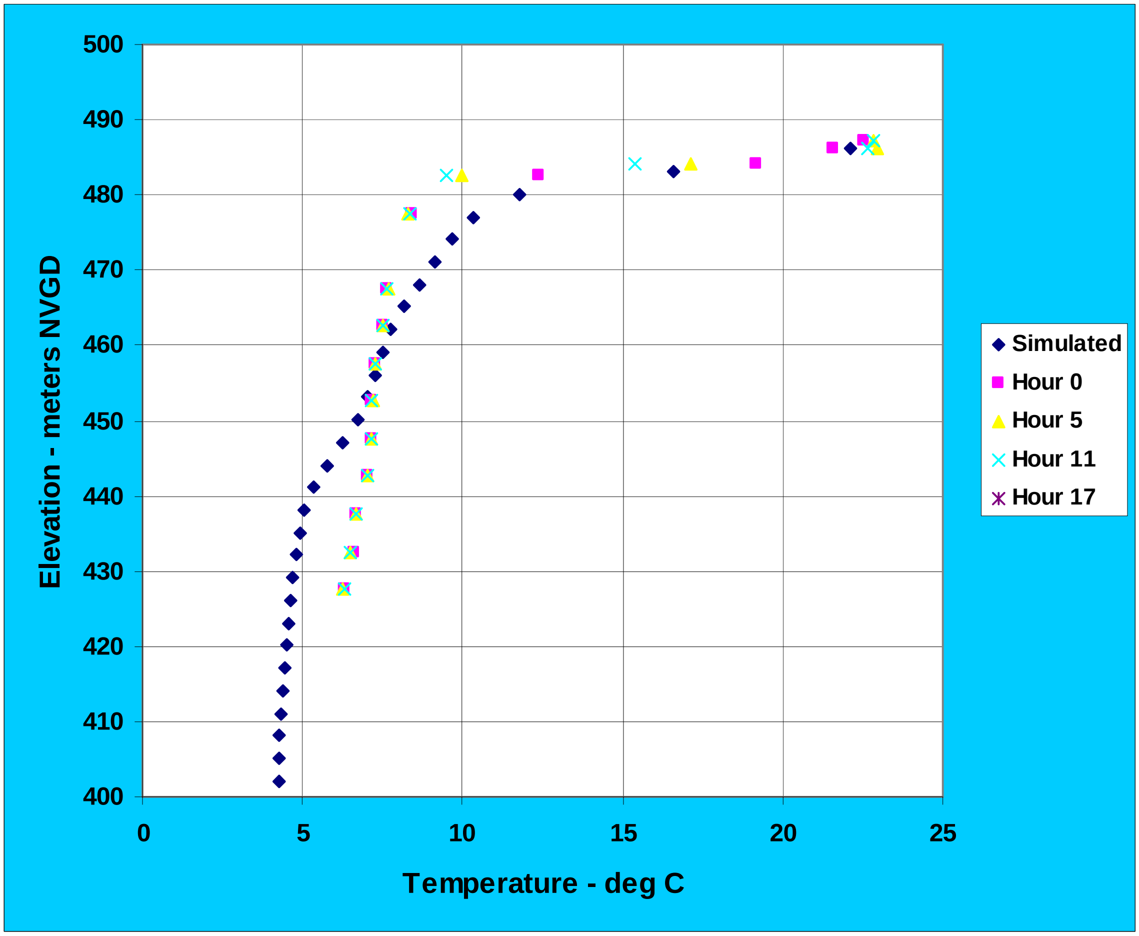

Figure 15. Simulated and observed water temperatures in Dworshak Reservoir at Dworshak Dam on June 30, 2002

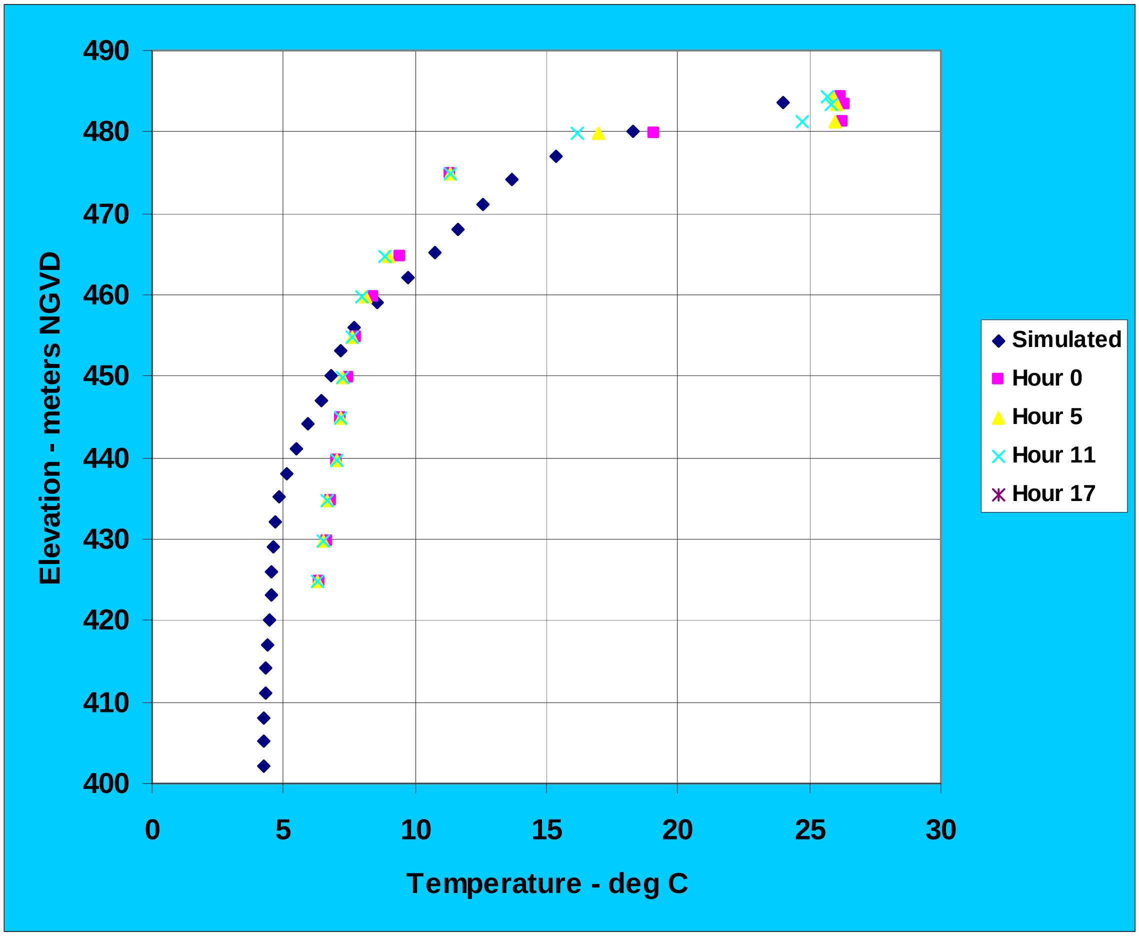

Figure 16. Simulated and observed water temperatures in Dworshak Reservoir at Dworshak Dam on July 20, 2002

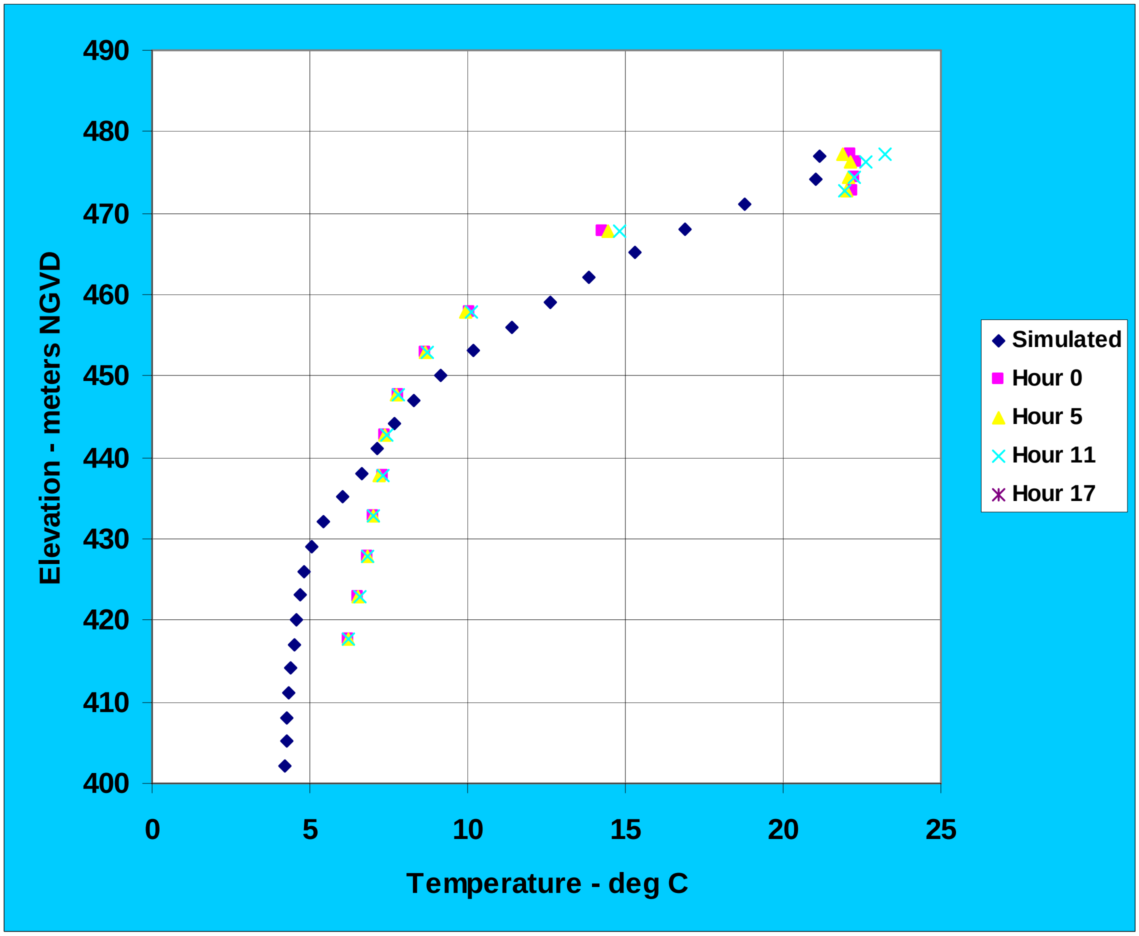

Figure 17. Simulated and observed water temperatures in Dworshak Reservoir at Dworshak Dam on August 8, 2002.

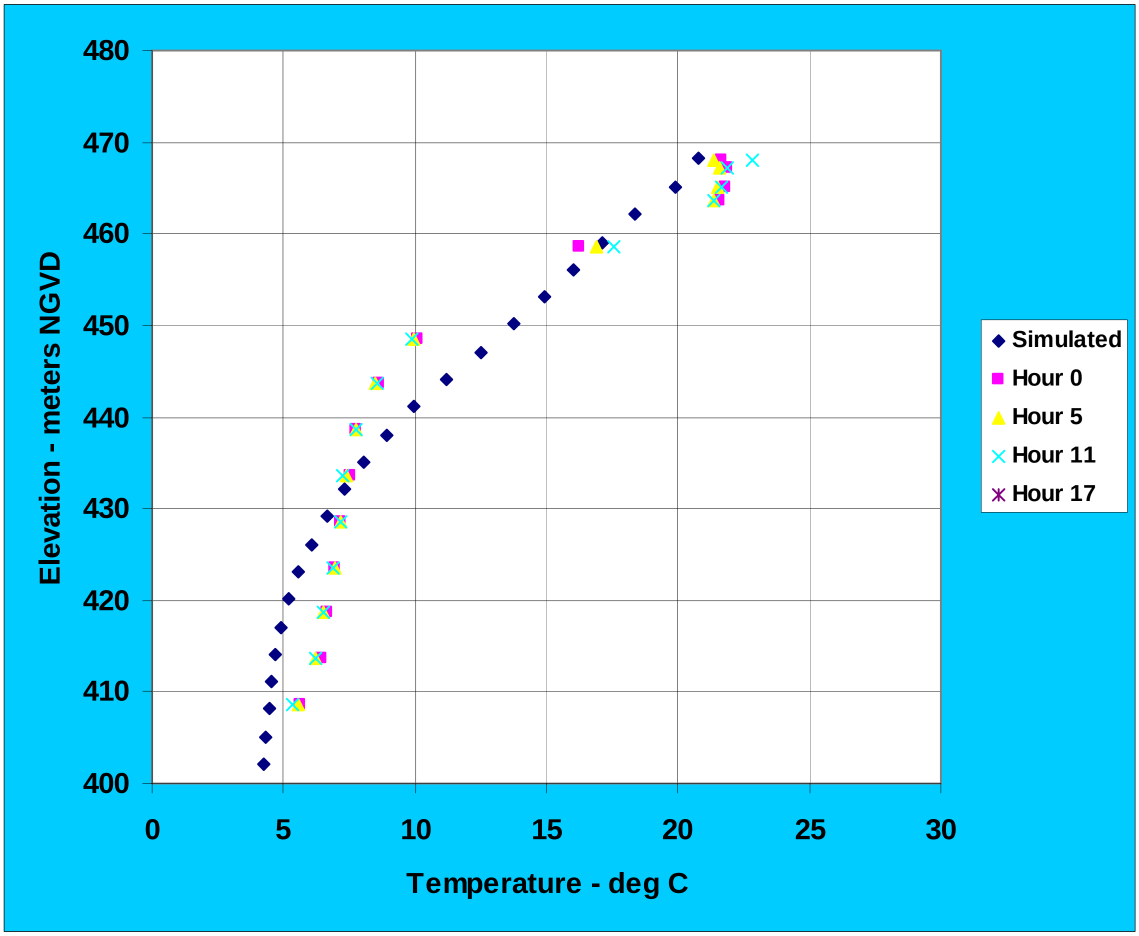

Figure 18. Simulated and observed water temperatures in Dworshak Reservoir at Dworshak Dam on August 28, 2003

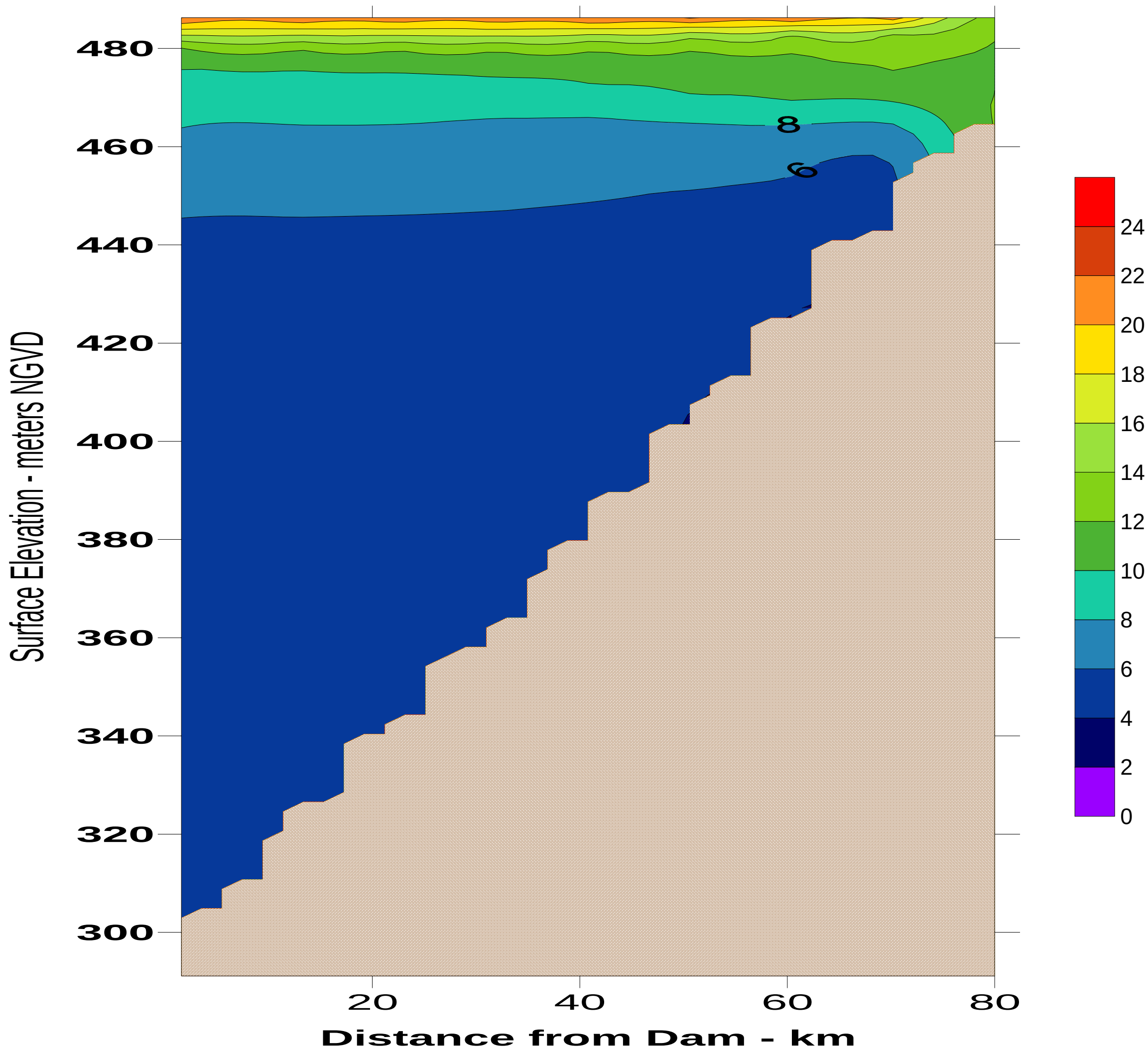

Figure 19. Simulated longitudinal temperature profiles in Dworshak Reservoir on June 30, 2002.

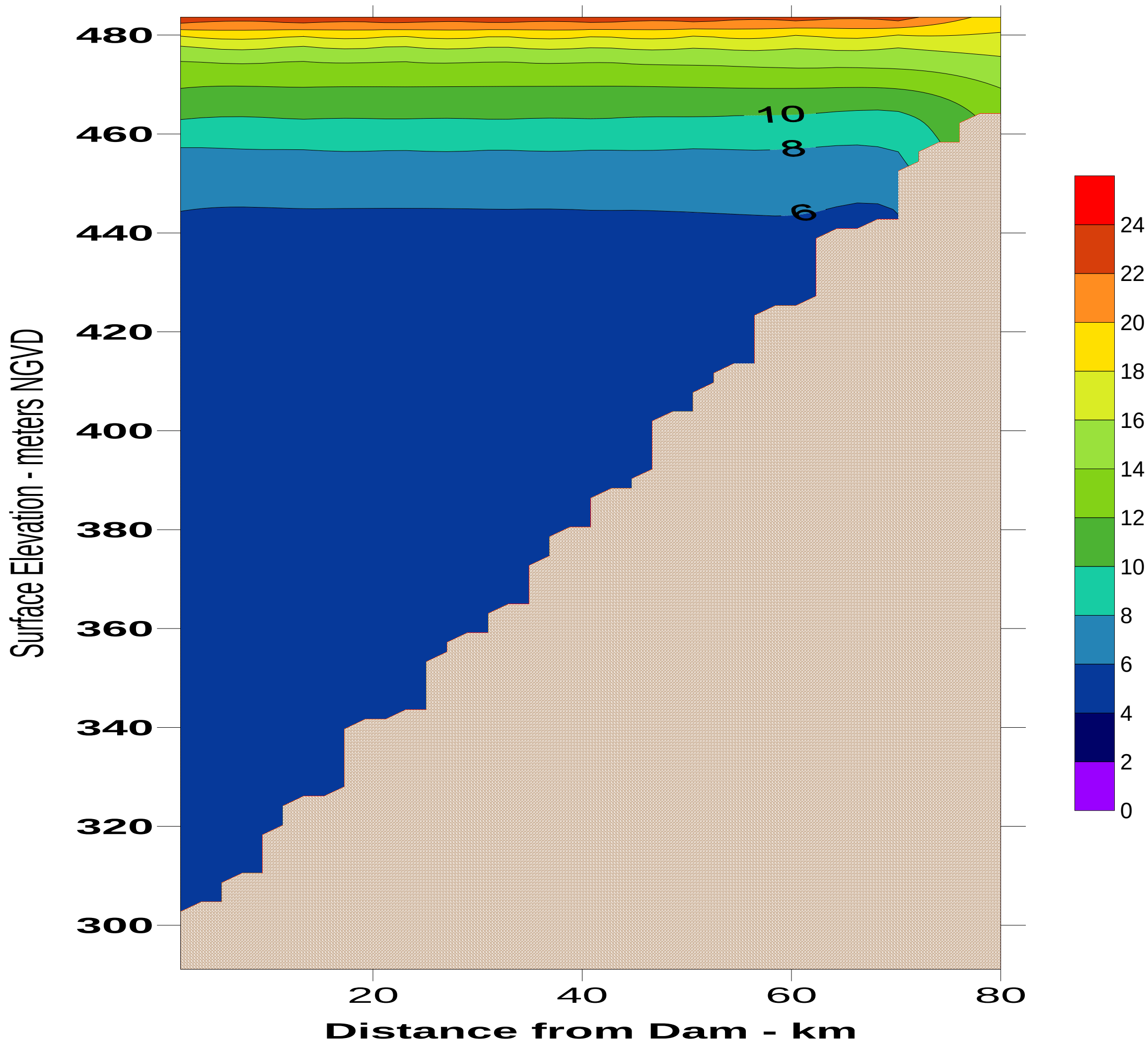

Figure 20. Simulated longitudinal temperature profiles in Dworshak Reservoir on July 20, 2002.

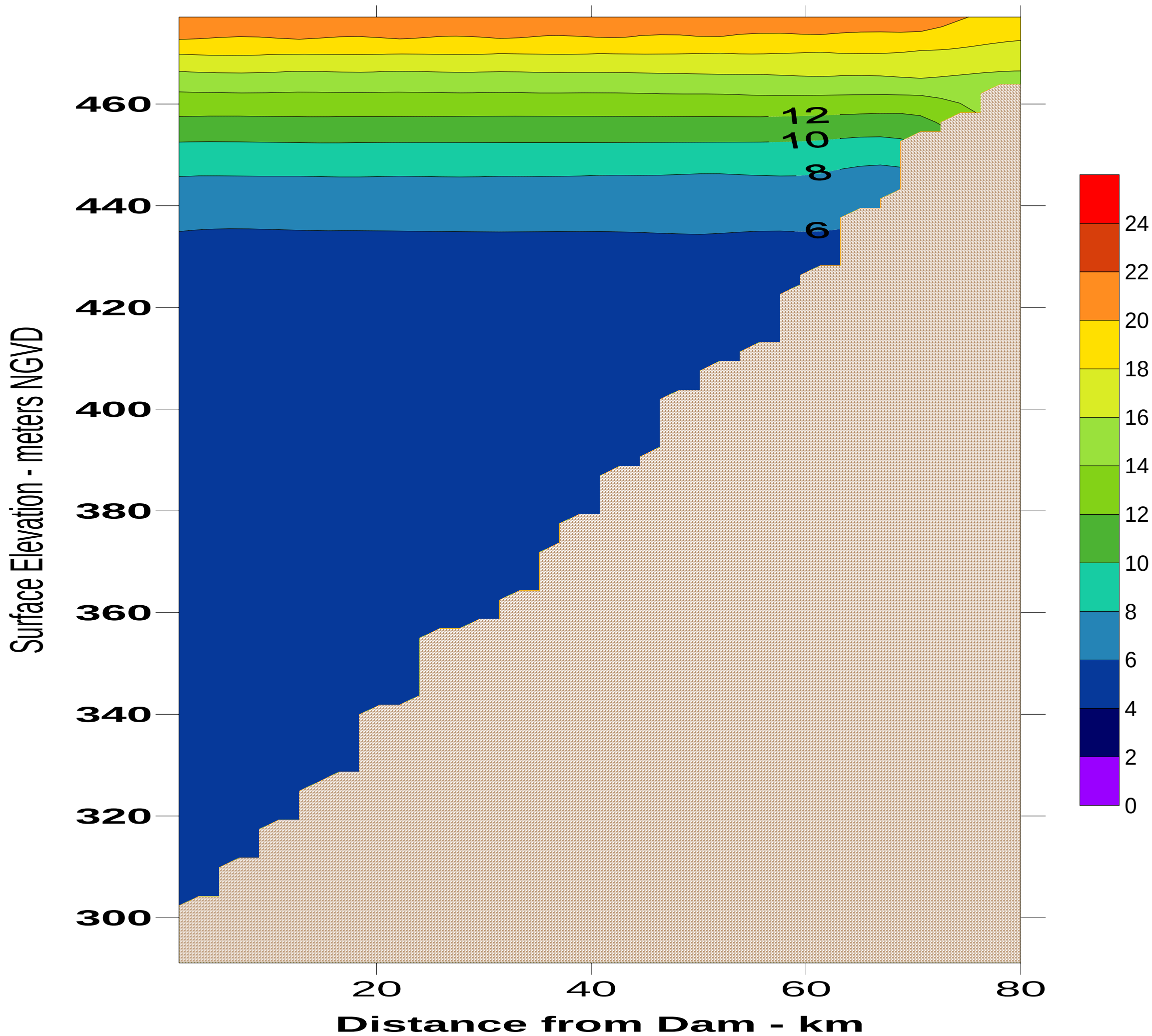

Figure 21. Simulated longitudinal temperature profiles in Dworshak Reservoir on August 8, 2002.

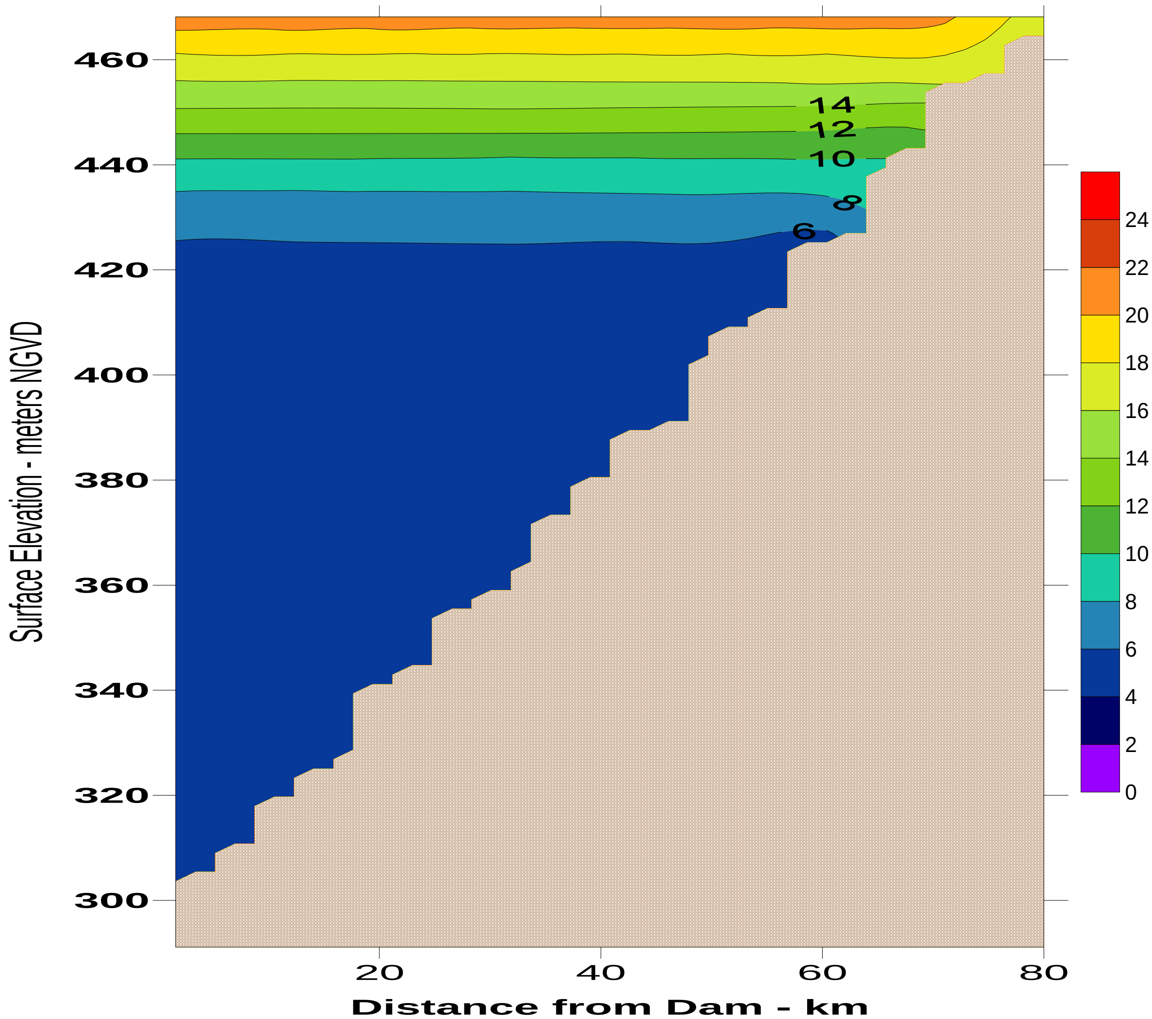

Figure 22. Simulated longitudinal temperature profiles in Dworshak Reservoir on August 28, 2002.

4.0 CONCLUSION and RECOMMENDATIONS

4.1 Conclusion

Based on these preliminary results, CEQUAL-W2 appears to be well-suited for simulating water temperatures in Dworshak Reservoir. Further testing with more detailed operations data will be required to confirm this, however.

4.2 Recommendations

Although these results are promising, additional work is necessary before accepting of CEQUAL-W2 as a decision support tool for managing water temperature releases from Dworshak Dam and Reservoir. Most of the this work is associated with expanding the monitoring program and includes:

- Recording and reporting water releases from the penstocks, regulating tubes and spillway and the daily configuration of the temperature control structures
- Observing cloud cover at the Dent Acres AgriMet weather station
- Improved monitoring of flow and temperature in the ungauged portion of the North Fork of the Clearwater River

In addition, some modifications to the CEQUAL-W2 software may be of value. For example, it does not appear to be the case that CEQUAL-W2 version 3.1 has the capability to simulate the operation of Dworshak Dam's temperature control structures. Although this study suggests that approximating the temperature control structures with three to five fixed outlets can lead to reasonable result, it may be worthwhile to consider adding algorithms that accommodate the movable shutters of the temperature control structure.

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