Valsetz Water Storage Concept Analysis

Appendix B

Water Quality, Water Quantity, Hydrology, and Sediment Transport

Prepared for:
Polk County
Dallas, Oregon

Prepared by:
ENVIRON International Corporation
Seattle, Washington

Date:
June 2011

Project Number:
30-23897

Contents

Final Report

Valsetz Water Storage Concept Analysis

Appendix B

Water Quality, Water Quantity, Hydrology, and Sediment Transport

1 Introduction

This Valsetz Water Storage Concept Analysis is funded by a Senate Bill 1069 [2008] Water Conservation, Reuse, and Storage Grant Program grant awarded by the Oregon Water Resources Commission on November 20, 2008. The grant provides funding for developing information needed to evaluate development of a water conservation, reuse, or storage project in the South Fork Siletz Basin. The funded planning study includes collection of streamflow and environmental information, completion of hydrologic, streamflow, and water demand analyses, development of baseline environmental impacts assessments and completion of a storage concept and alternative analysis.

The purpose of this study is to conduct an appraisal level assessment of potential environmental effects and potential benefits of the Valsetz water storage project. The assessment focuses on three storage concept alternatives determined by dam height and reservoir storage. This analysis serves as a preliminary, concept-level review of the resources that may be affected if a project were developed. This initial investigation relies on existing information, an extremely limited amount of field data and some preliminary modeling and analysis. This is a first step in understanding potential effects in the area that would be inundated by a project and the Siletz and Luckiamute Rivers. Further investigation and technical studies will be required to definitively evaluate the magnitude and type of impacts and feasibility of project development.

This appendix summarizes the data collection efforts completed in 2010 related to hydrology, water quality, and meteorology in the South Fork Siletz River and basin. The appendix also summarizes the results of modeling that was conducted to provide initial estimates of reservoir capacity, sediment transport, reservoir water quality, water temperature expected downstream of the three alternatives dam configurations examined for the South Fork Siletz River. The Luckiamute River was examined in less detail. The assessment focuses on three storage concept alternatives:

1. Low Dam Option (Storage: 14,000 Acre-feet; Water level at 1,120 ft)
2. Medium Dam Option (Storage: 70,000 Acre-feet; Water level at 1,160 ft)
3. High Dam Option (Storage: 162,000 Acre-feet; Water level at 1,200 ft)

2 Methods

2.1 Existing Flood Flows and Long Term Hydrographs for Siletz and Luckiamute Rivers

Streamflow data used in the analysis were drawn from limited field data collection, existing public data and estimates generated through analysis. The United States Geological Survey (USGS) publication Estimation of Peak Discharges for Rural Unregulated Streams in Western Oregon (USGS, 2005) was used to estimate flood peaks at the USGS gage (14305500) on Siletz River near Siletz, and at the USGS gages (14189500 and 14190000) on Luckiamute River. The USGS gage near Siletz is located on Siletz River 50 km downstream of the proposed Valsetz reservoir. The USGS gage near Hoskins (14189500) is located on the upstream Luckiamute River only 15 km southeast of the Valsetz reservoir. Flood peak discharges at all three locations were based on the stream records summarized in Table 1.

Flood peak discharges for the South Fork of Siletz River at the proposed reservoir site and the North Fork of Siletz River at the confluence were estimated using the USGS regression equation for ungaged watersheds in Oregon Region 1 (Coastal Watersheds, Table 10 of the USGS publication). The calculated flood peaks are also summarized in Table 1.

The USGS gage on Siletz River has continuous flow records since 1924. The flow hydrograph for that station is depicted in Figure 1. The flows at the North Fork Siletz River (at the confluence) were obtained by correlating the USGS gage flows on Siletz with the flow measurements on the North Fork during 2009 and 2010. The estimated flows are depicted in Figure 2. The flows at the South Fork Siletz at Valsetz were also obtained by correlating the USGS gage flows on Siletz with the flow measurements on the South Fork at Siletz during 2009-2010. These flows are depicted in Figure 3.

The correlations employed in the above regressions were based on only 4 to 5 flow measurements on the South Fork and North Fork of Siletz River. The coefficient of determination (R^2) between measured flows at the USGS gage and ENVIRON's streamflow measurements are between 0.88 and 0.97. These coefficients are considered statistically good correlations; however, the coefficients are for one year's data only. The 2009-2010 water year was a relatively average water year, so we expect the estimates of average flows attained through this analysis are quite reliable. The correlation between the USGS gage and the measurements taken in 2009-2010 were assumed to be constant. Given the lack of data, this assumption cannot be tested; therefore, substantial deviation from the estimates, particularly in extreme wet or dry years, is highly possible. The potential magnitude of error cannot be estimated. Collection of additional flow data in the South Fork Siletz River is highly recommended. .

Table 1. Estimated Flood Peaks on Siletz and Luckiamute Rivers

River	Gage	Area (sq. miles)	Flood Peak Discharges (cubic feet per second) for Selected Return Periods (years)						
			2	5	10	25	50	100	500
Siletz River	USGS gage - Siletz (14305500)	203	19,900	26,200	30,300	35,400	39,200	43,000	51,800
	South Fork Siletz at Valsetz(1)	17	2,167	3,065	3,498	4,182	4,693	5,206	6,388
	North Fork Siletz at confluence(1)	43	5,067	7,101	8,061	9,580	10,709	11,839	14,428
Luckiamute River	USGS gage - Hoskins (14189500)	34	2,990	3,980	4,630	5,440	6,040	6,640	8,040
	USGS gage - Pedee (14190000)	116	6,390	8,710	10,300	12,500	14,200	16,000	20,400

(1) Values calculated using regression equation

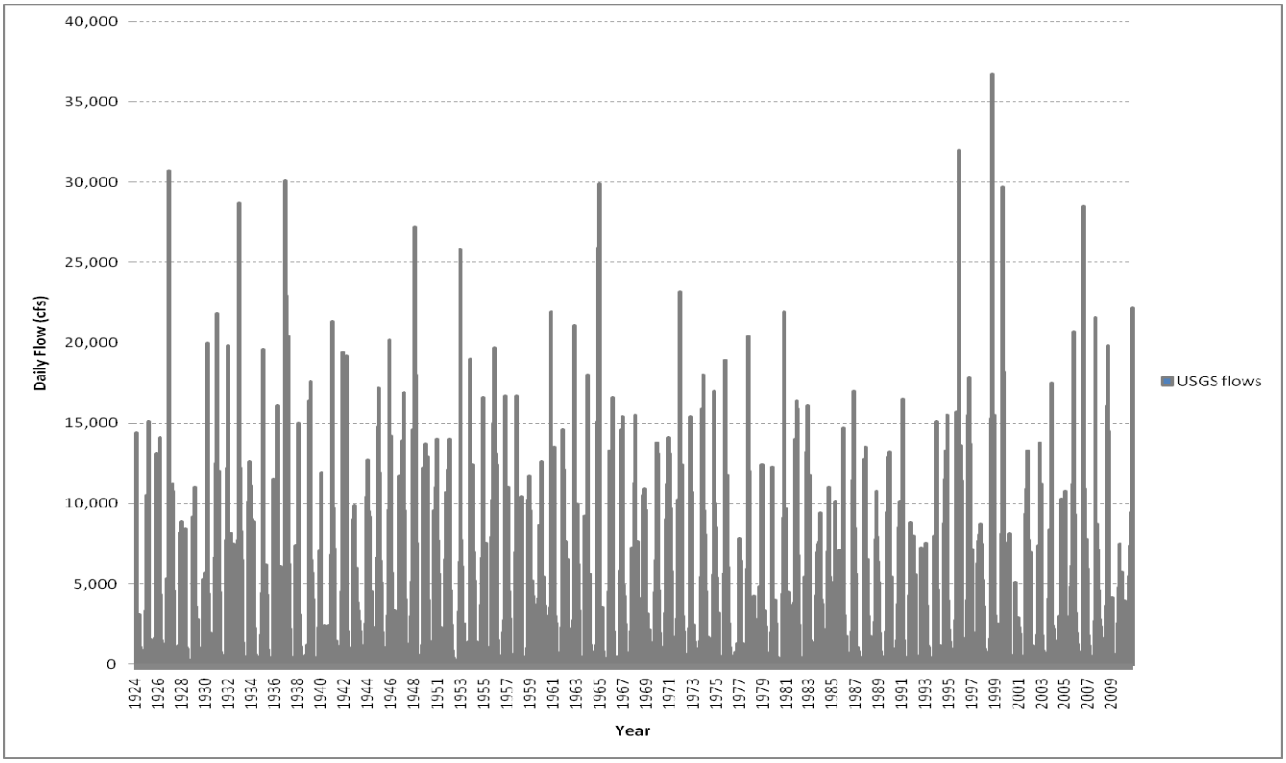

Figure 1. Average Daily Flows – USGS Gage –Siletz River

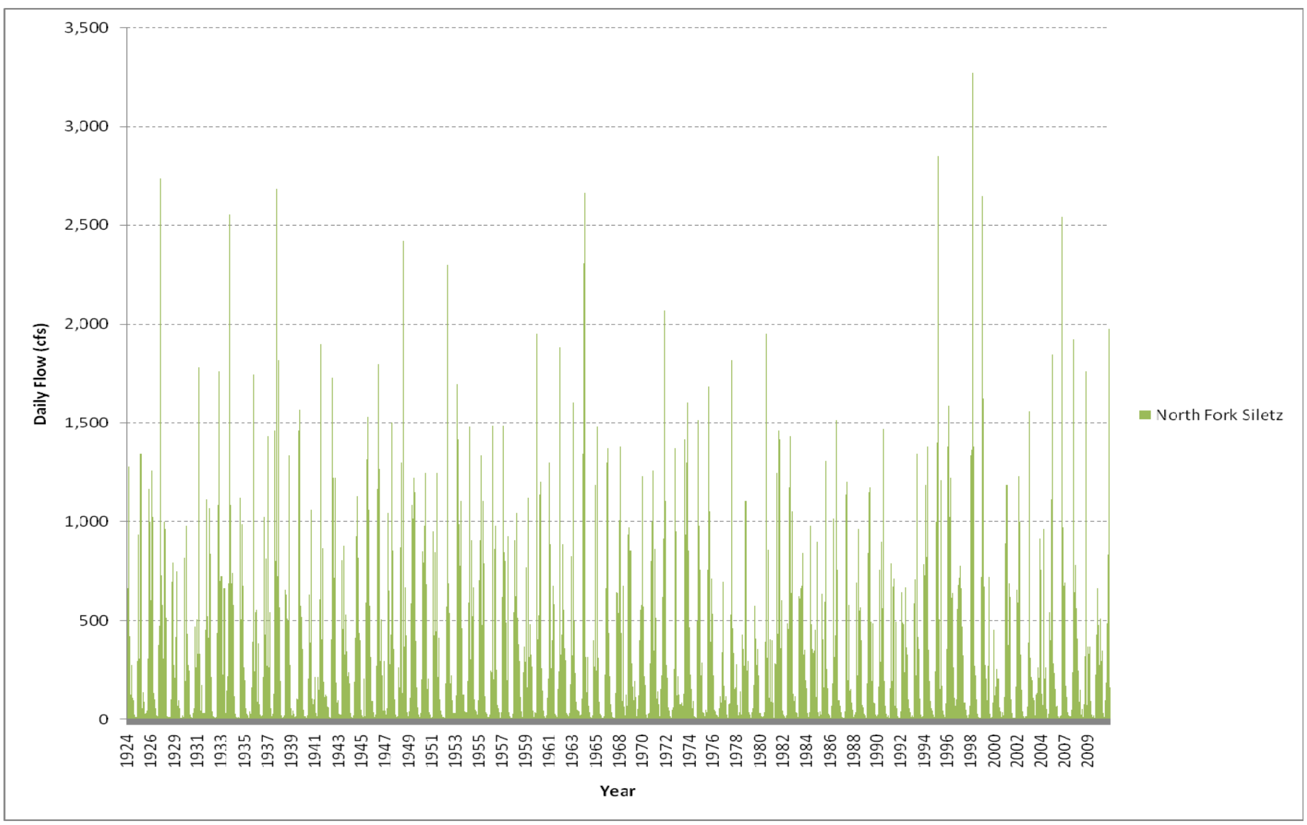

Figure 2. Average Daily Flows (Estimated) – North Fork of Siletz River at the Confluence

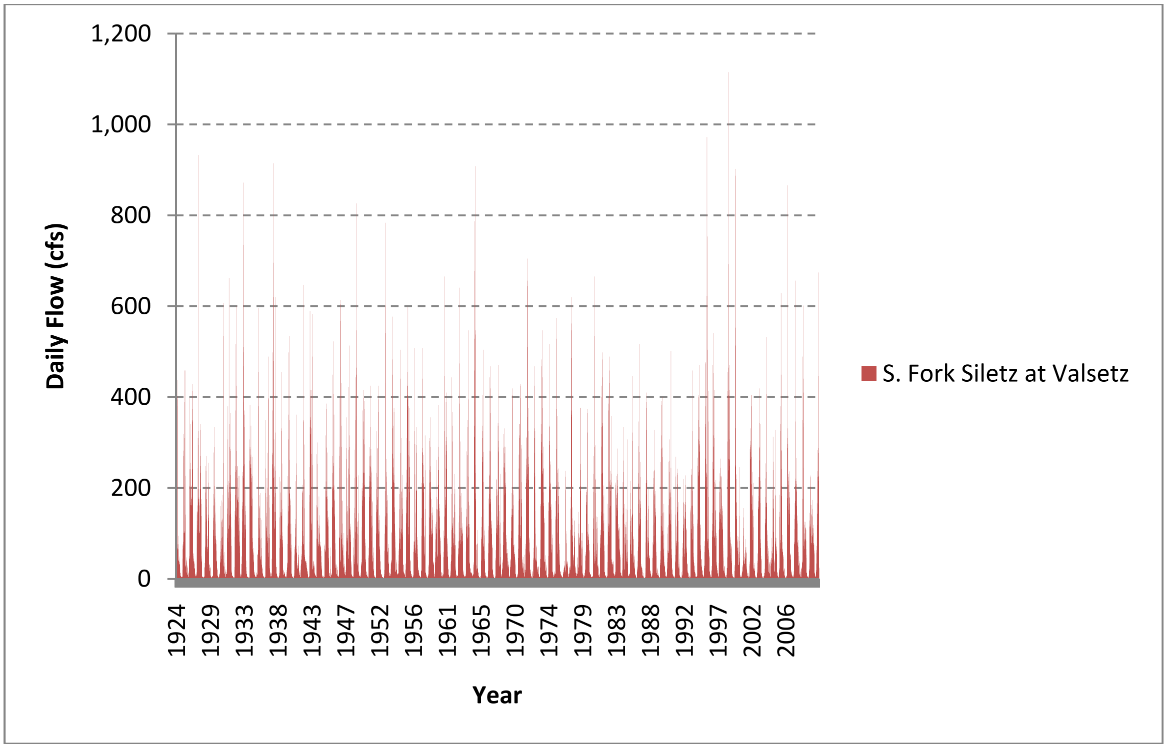

Figure 3. Average Daily Flows (Estimated) – South Fork of Siletz River at Valsetz

2.2 Estimate of Reservoir Withdrawals and Reservoir Filling Time

2.2.1 Reservoir Withdrawals

For modeling purposes, two withdrawals from the reservoir are assumed for reservoir conditions including (a) withdrawal for in-stream water needs of South Fork Siletz River downstream of the reservoir to ensure instream flow equal to natural flows or instream water right flows (whichever is less), and (b) withdrawal for water supply/water demand. The estimated water withdrawal for the project is estimated from the monthly municipal demand forecasted for 2050, less the estimated water supply obtained from water sources other than future reservoirs (see Appendix A for details). As is discussed in Appendix A, there is considerable uncertainty regarding future water demand; therefore three likely scenarios for water use were developed in an attempt to bracket the likely water withdrawals from the reservoir. These withdrawal scnearios are summarized in Table 2 below. Note that the estimated water withdrawals to satisfy regional water demand are those presented in Table 9 in Appendix A, but are converted from mgd to cfs.

The instream flow right (second column in the table) in the Siletz River ranges from 60 cfs during late fall, winter, and early spring, and reduce to 30 cubic feet per second (cfs) in late spring, and to 10 cfs in summer. The minimum instream flow requirements are generally equivalent to the instream flow rights except when natural flows are less than minimum instream flow estimates. When natural flows are less than the instream flow rights, the minimum instream flow is equal to the natural flows. The instream rights specifically indicate that the rights do not have priority over the right to use water for human consumption or the use of waters legally released from storage.

Table 2. Valsetz Reservoir Water Withdrawals

Month	Instream Flow Water Rights (cfs)[1]	Withdrawals to Satisfy Regional Water Demand		
		Average Need (cfs)	Min. Need (cfs)	Max. Need (cfs)
Jan	60	0	0	0
Feb	60	0	0	0
Mar	60	0	0	0
Apr	60	0	0	4
May	60	0	0	4
Jun 1-15	30	0	0	12
Jun 16-30	30	20	0	12
Jul 1-15	10	41	30	51
Jul 16-31	10	41	30	51
Aug	10	41	30	51
Sep 1-15	10	20	0	12
Sep 16-30	10	0	0	12
Oct 1-15	30	0	0	12
Oct16-31	40	0	0	12
Nov	60	0	0	4
Dec	60	0	0	4

Note: [1] The estimated water released downstream from the reservoir for minimum instream flows are listed in the table, except when natural flows are less than minimum instream flow estimates and then downstream releases from the reservoir are equal to the natural flows.

For modeling purposes we have assumed that the instream flow right or the natural flow, whichever is less, will be met. For example, if flow into the reservoir is 8 cfs in August, 8 cfs was assumed to be released from the reservoir instead of the 10 cfs listed in Table 2.

Reservoir withdrawals for water supply needs of Polk and Lincoln County (not anticipated from the other sources), are presented using three estimates. These withdrawals are associated with current water demand analysis projected for 2050 (Appendix A, Water Supply Demand and Water Rights Analysis). The estimated average withdrawal from the reservoir to meet the water supply needs is provided in column 3 of Table 2. The minimum projected water supply needs is provided in column 4 of Table 2 and the maximum water supply needs are provided in column 5 of Table 2. The assumptions associated with these withdrawals are provided in Appendix A (Water Supply Demand and Water Rights).

2.2.2 Reservoir Filling Time

Frequency analysis of streamflow data in Section 3.1 indicates that average daily flows on the South Fork of Siletz River, measured just downstream of the Valsetz dam site (Figure 3), are just slightly higher than the anticipated long-term average daily flows. For the reservoir filling period, we assumed the following:

- The recorded flows downstream of Valsetz dam are representative average inflows to the reservoirs,
- Water from the reservoirs is withdrawn to satisfy instream flow needs (Column 2, Table 2); and
- Water is withdrawn to satisfy average water supply needs (Column 3, Table 2).

2.3 River and Reservoir Modeling

Two hydraulic models were used to simulate hydraulics and temperature for Valsetz reservoirs and for Siletz River from Valsetz to the existing USGS gage. The hydrodynamics and temperature of the Siletz reservoir and the existing Siletz River above the reservoir are simulated using the CEQUAL-W2 model, Version 3.6 (Cole and Wells 2008, Wells 2010). This model is a two-dimensional, (distributed in elevation, but laterally homogenous) hydrodynamic and water quality model. It is well suited for long and narrow water bodies such as lakes, rivers, and estuaries. The model was developed by the US Army Corps of Engineers Waterways Experiment Station, and Portland State University.

The hydrodynamics and temperature in the Siletz River (50-km reach) downstream of the reservoir are simulated using the USEPA QUAL-2K model (Chapra et al. 2008). The QUAL-2K is a one-dimensional (vertically and laterally mixed) stream water quality model that simulates steady-state flows while the heat budget and temperature are simulated as a function of meteorological data. The one-dimensional channel model for Siletz River is appropriate, because the river is, on average, a shallow stream. The outlet for the reservoir was assumed to withdraw water from the lower portion of the reservoir.

The CEQUAL-W2/QUAL-2K model simulations are conducted for the following conditions:

- Existing Conditions on Siletz River (no reservoir),
- Small reservoir (Storage: 14,000 Acre-feet; Water level at 1,120 ft),
- Medium reservoir (Storage: 70,000 Acre-feet; Water level at 1,160 ft), and
- Large reservoir (Storage: 162,000 Acre-feet; Water level at 1,200 ft).

2.3.1 CEQUAL-W2 Model Development

The following provides an overview of the input parameters for the model.

Model Grid: 16 vertical layers and six horizontal segments.

Simulation Period: February 2010 - November 2010

Boundary Conditions- Stream flow in the South Fork Siletz River near the confluence with the North Fork is developed using a regression between simultaneous measurements at the ENVIRON gage on the near the former Valsetz Dam and the instantaneous ENVIRON measurements collected in the South Fork Siletz River near the confluence with the North Fork.

Continuous water temperature data were available from three locations: 1) near the form Valsetz Dam, 2) in the South Fork Siletz River near the confluence with the North Fork Siletz River, and 3) in the North Fork Siletz River, near the confluence with the South Fork. The temperature recorders at the former dam location and in the North Fork either malfunctioned or were lost, so data for those two site ended in July 2010. The missing data were estimated by correlating the data from the downstream South Fork Siletz River location with the partial data sets collected at the other two sites. The resulting regression equation was used to extrapolate the missing data. The same temperature time series is used in all simulations.

Inflow Conditions: The CEQUAL-W2 simulations were conducted for:

(a) *Average flow conditions* - Statistical analysis of USGS gage flows on Siletz River and their correlation with the South Fork Siletz flows at Valsetz indicates that the 2010 flow conditions are slightly greater than the average flow conditions. The average estimated flows are summarized in Table 3 below.

(b) *Drought flow conditions* - Low flow frequency analysis of the USGS gage flow records is conducted to determine flow during a 100-year drought and other extreme droughts. A historical year of drought flow from the USGS gage record was chosen; then the flow time series at the ENVIRON gage site near the former Valsetz dam was developed using the Valsetz flow – USGS gage flow regression. The estimated daily average flows for different months at different drought conditions are summarized in Table 4.

Meteorological Data –Air temperature, dew temperature, wind and wind direction monitored by ENVIRON at the former town of Valsetz between February and November 2010 are used as inputs to the model (at 2 hour intervals). The meteorological station malfunctioned for two months between March 19, 2010 and May 26, 2010. The two month gap in the data was filled in by interpolating data between the last known values on March 19 and May 26 in the meteorological time series. The same meteorological time series was used in all simulations. The meteorological data, averaged for each month, are summarized in Table 5.

Table 3. Estimated Average Daily Flows at Valsetz

Month	Average Daily Flows South Fork Siletz River at Valsetz (cfs)
January	113
February	94
March	66
April	46
May	36
June	24
July	10
August	4
September	7
October	25
November	104
December	102

Table 4. Estimated Drought Flows at Valsetz for Selected Months

Drought	Estimated Daily Low Flows at Valsetz (cfs)				
	July	Aug	Sep	Oct	Nov
100-year	1.7	1.5	1.2	1.4	1.7
50-year	1.7	1.5	1.4	1.5	1.8
25-year	2.2	1.6	1.6	1.5	2.0
10-year	2.8	1.9	1.8	1.8	2.9
5-year	3.2	2.2	1.9	2.1	5.6
2-year	3.9	2.6	2.4	2.8	13.3

Table 5. Meteorological Data recorded at Valsetz (February – November, 2010)

Month	Air Temperature (deg. Celsius)	Dew Temperature (deg. Celsius)	Wind direction (degrees-clockwise from north)	Wind Speed (m/sec)
Feb	6.2	2.5	3.6	0.5
Mar	5.5	3.6	2.4	0.3
Apr	7.6(1)	6.5(1)	0.0	0.0
May	9.6(1)	8.4(1)	1.0	0.0
Jun	12.1	9.3	5.9	0.0
Jul	19.3	13.0	5.9	0.0
Aug	15.4	10.7	4.6	0.5
Sep	13.8	11.7	4.9	0.2
Oct	9.2	7.2	4.0	0.3
Nov	8.7	8.0	3.7	0.2

Note: (1) Data extrapolated

Withdrawal outflows – The withdrawals from the reservoir were assumed consistent with Table 2 (Section 3.1). Water is assumed to be withdrawn from the reservoir at low-water level outlet (from the deepest part of the reservoir). Most reservoirs stratify in the summer with warm and oxygen rich water near the top of the water column and colder oxygen poor water near the bottom. Multilevel outlets are used in several Northwest reservoirs to regulate and adjust temperature and oxygen mixtures at different times of the year to optimized water quality for aquatic resources. Reservoir operations can also affect temperature but were not calculated as this was beyond the scope of this project. Once the range of a potential projects is selected, the effects of multi-level outlets should be evaluated to optimize water quality downstream of the reservoir.

Surface Boundary Conditions – Streamflow and meteorological data collected at the site are used in developing the CEQUAL model coefficients. The default values for hydraulic coefficients (horizontal eddy viscosity, horizontal eddy diffusivity, etc), ice and heat exchange coefficients were used where no other information was available.

Computational Time Step –An auto-stepping algorithm is used to calculate the time step. The algorithm decreases the time step during high flows, and increases it during low flows. A minimum time step of 1 second is used.

Vertical eddy viscosity is computed utilizing the W2 computational algorithm, usually used for lakes and reservoirs, where wind shear is dominant.

The Chezy coefficient of 70 is used to specify friction along the bottom of the reservoir. A value of 70 is considered typical for streams and reservoirs, although it can vary significantly.

Evaporation - The reservoir was assumed to be exposed to the wind (with minimum wind sheltering) and the sun (no significant shading effect was assumed). Evaporation from the lake was calculated using the Ryan-Harleman method utilizing available air temperature and relative humidity data collected in summer of 2010. This method provides good evaporation estimates from larger size lakes (Cole and Wells, 2008, Table A-5) and is recommended by several researchers (i.e. Adams et al., 1981) for use as the evaporation method for natural lakes.

Other Considerations – No modeling of any water quality constituents other than water temperature was conducted. Precipitation to the reservoir water surface is not modeled. Water losses due to infiltration were not included in the model. Since none of the reservoirs have been constructed, the reservoir model could not be calibrated to real data.

2.3.2 QUAL-2K Model Development

The QUAL-2K model was used to route the outflows from the CEQUAL model through Siletz River downstream to the USGS gage. The QUAL-2K model simulations were conducted in 24-hour time cycles for every two weeks between February and November (i.e. March 1st, March 15th, et cetera, through November 1st). The following provides an overview of the input parameters for the model.

Model Schematics – The 50-km reach of the Siletz River was modeled in five reaches with each reach characterized with a representative longitudinal slope.

Model Hydraulics – ENVIRON intermittent channel surveys at several locations were used as representative Siletz River channel sections. The Manning formula was used to simulate flow in the model. A Manning roughness coefficient is developed for each reach based on the photographic documentation of field visits to the river. Coefficients are assumed 0.03 to 0.04 in the main channel and 0.10 to 0.15 in the overbank floodplain.

Input Series – The inflow (flow and temperature time series) from the South Fork Siletz River at the former town of Valsetz was used for the inflow sat the upstream end of the proposed reservoir. The North Fork Siletz River discharges into the Siletz River 7.0 km downstream of the proposed dam. The temperature and flow of this discharge was treated as a point source. Inflows from all other tributaries downstream of the reservoir were assumed to be lateral inflows to the Siletz River. No information was available for any of the lateral inflows so they are calculated by subtracting the South Fork Siletz River flows at Valsetz and North Fork Siletz River flows from the flows at the USGS gage on Siletz River. The difference in flow was assumed to be reflective of tributary inflows. These flows were distributed evenly along the river.

Other Parameters – Meteorological data measured at the historical Valsetz town site (air temperature, dew point temperature, wind speed) were assumed representative for all modeling reaches. The cloud cover was assumed to be 20 percent and the creek was assumed to be exposed to the sun.

2.3.3 Assumptions and Caveats

Calibration of either CEQUAL-W2 or QUAL-2K is not possible. The CEQUAL model was used to evaluate a reservoir that has not yet been constructed. The model can be finalized and calibrated after a reservoir is constructed. The calibration of the QUAL-2K model would require more information on the channel geometry, and lateral inflows along it 50-km reach so that it can be calibrated to the observed water surface elevations. Both models were used only for comparative evaluation of reservoir alternatives. The models cannot be used to estimate water surface elevations in Siletz River downstream of the proposed dam site. Once more detail bathymetry of Siletz River becomes available, the existing CEQUAL model can be extended further downstream to include a two-dimensional channel model of the Siletz River.

The modeling accuracy could be improved with additional data. For example, additional surveyed cross-sections downstream of the proposed dam would improve the QUAL-2K modeled hydraulics, and the estimates of flows and water surface elevations. Additional information on flow and water temperature of smaller tributaries to Siletz River would also improve the model. Sensitivity analysis could be conducted to evaluate the effects of shading and cloud coverage on temperature in the river. This additional data collection was beyond the scope of this study.

No simulations were conducted in the November through February period because no measurements were available. This information is necessary to complete full-year simulation of the annual water budget.

2.4 Sediment Transport at Potential Discharge Points in the Luckiamute River

The United States Geological Survey (USGS) publication Estimation of Peak Discharges for Rural Unregulated Streams in Western Oregon (USGS, 2005) was used to estimate flood peaks at six diversion locations on Luckiamute River watershed.

Estimates of channel erosion and erosion potential at the proposed diversion sites were developed using one-dimensional hydraulic and sediment transport model HEC-RAS (Version 4.0) developed by the US Army Corps of Engineers (Corps) Hydraulic Engineering Center (HEC)(2008a, 2008b, 2008c).

3 Results

3.1 Comparative Evaluation of Reservoir Alternatives

3.1.1 Water Storage Capacity

The reservoir simulation analysis indicates that the small-size reservoir, medium-size reservoir and the large-size reservoirs have sufficient water volume capacities to satisfy both the instream flow needs and the range of water supply-water demand needs specified in Table 2. The reservoirs seem to have sufficient water storage with average flow conditions and typical drought conditions in the Siletz River. Table 6 summarizes the simulated water surface elevations between February and November under the modeling scenarios using average and drought flow conditions. Each scenario is simulated using the range of average, minimum, and maximum potential withdrawals. The depletion of water volume in each reservoir is expected to be replaced in the November through February period and in the years with higher than-average inflows from the Siletz River.

3.1.2 Reservoir Filling

Estimates for reservoir filling are preliminary dependent on the amount of water available in the basin for any given year, which is extremely variable. Filling time was calculated using a range of meteorological conditions, intended to bracket the possible stream flows that could occur after construction of the reservoir. The range includes average flow, mild drought flows, extreme drought flows, and wetter than normal conditions.

The inflow to the reservoir under each of these conditions was developed using the following assumptions:

1. <u>Average Conditions</u>: The reservoir was assumed to receive the average estimated inflows presented in Table 3 (using regression analysis between the Valsetz River USGS gage and the ENVIRON gage on South Fork Siletz River). Inflow into the reservoir was assumed constant until the reservoir is full.
2. <u>Mild Drought</u>: The reservoir was assumed to receive inflows similar to mild drought conditions, as recorded by the USGS gage in year 1957. The assumed reservoir inflows are estimated using the flows developed by regressing the 1957 flows against the measured flows in the south Fork Siletz River. The filling time estimate assumes mild drought conditions would continue year after year during the reservoir is filled.
3. <u>Extreme Drought</u>: The reservoir was assumed to receive inflows similar to the extreme drought recorded at the USGS gage in 1989. During that year the annual flow volume in Siletz River was over 20 percent lower than normal. The filling time estimate assumes extreme drought conditions would continue year after year during the reservoir is filled.
4. <u>Wetter Conditions</u>: The reservoir was assumed to receive inflows similar to average wet conditions. The year 1933 was assumed to be representative of wetter than average years. A 10-year flood occurring during the winter 1933, as recorded by the USGS gage. These wet conditions subsequently continue during reservoir filling time.

All four modeled scenarios include an average water withdrawal for water supply to the counties and instream flows to protect aquatic resources in the Siletz River as specified in Table 2. The above conditions are different than the conditions used in simulations for Table 6 and are used only to provide range of estimates of anticipated reservoir filling time. The calculations are provided in Table 7 and do not include evaporation losses. Although these losses affect the reservoir filling time, their influence is significantly smaller than the range of uncertainties associated with wet/dry simulation scenarios.

Table 6. Simulation Withdrawal Results

Reservoir Size	Normal Water Surface Elevation (ft) - February	Simulated Water Surface Elevation (ft) - November								
		Average Flow Conditions			2-year Drought - Siletz River			100-year Drought - Siletz River		
		Average Withdrawals	Minimum Withdrawals	Maximum Withdrawals	Average Withdrawals	Minimum Withdrawals	Maximum Withdrawals	Average Withdrawals	Minimum Withdrawals	Maximum Withdrawals
Small	1120.1	1122.9	1124.4	1120.2	1119.0	1121.7	1115.6	1113.7	1116.8	1109.9
Medium	1160.0	1158.8	1159.8	1157.7	1157.0	1157.9	1155.8	1155.2	1156.3	1154.1
Large	1200.0	1197.9	1198.5	1197.2	1196.7	1197.3	1196.0	1195.6	1196.3	1194.9

Table 7 - Reservoir Filling Time Estimated At Different Flow Conditions				
Reservoir	Scenario 1 - Average Conditions	Scenario 2 - Mild Drought Conditions (Year 1957)	Scenario 2 - 10-year Wet Conditions (year 1933)	Scenario 3 (Extreme Drought - 1989)
	Filling Time - Average Anticipated Flows (years)	Filling Time - Average Anticipated Flows (years)	Filling Time - Anticipated Flows (years)	Filling Time - Anticipated Flows (years)
Small	3	6	1	Will not fill
Medium	16	28	4	
Large	38	66	10	

The expected filling time for the small reservoir is between 1 to 6 years. The medium reservoir could fill as fast as 4 years or as long as 28 years. The large reservoir could fill as fast as 10 years, or as slow as 66 years. During the periods of extreme drought, similar to that which occurred in 1989, the reservoir would not fill. The reservoir filling time could be accelerated if withdrawal for water supply is reduced during the filling time.

3.1.3 Temperature Stratification – Average Years versus Drought Years

The water at the surface of the reservoir is warmer than the temperature of the river at the same location with no reservoir in place under all three reservoir size alternatives (Figure 4). There is no substantial difference in the surface temperature for any reservoir size except during summer. In general, the surface water of the medium and the large reservoirs stays warmer than the smaller reservoir, especially in the summer.

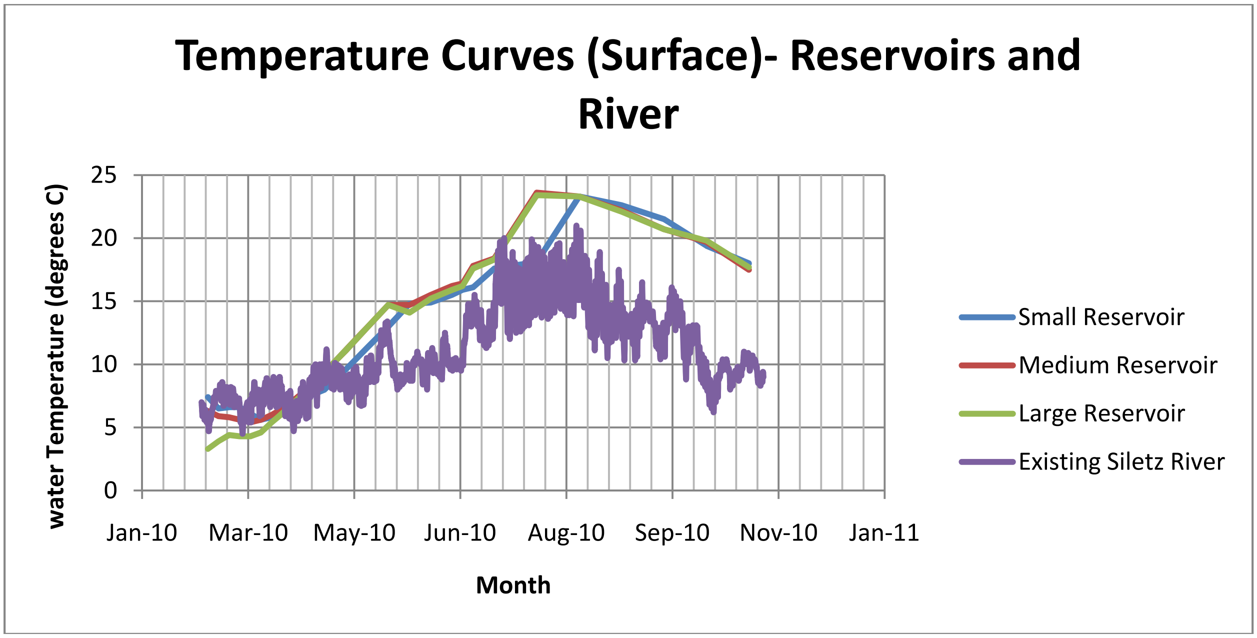

Figure 4. Reservoir Alternatives Surface Temperature Curves and Existing Siletz River Temperature

There is strong vertical temperature stratification within the reservoir under all three alternative reservoir sizes. This stratification is expected to be similar between small and medium reservoirs (Figures 6 and 7). The greatest difference in temperature between the surface and the bottom waters occurs during the summer season. The large reservoir is the deepest (over 100 feet deep), so the stratification is significantly different than the other two reservoirs (Figure 7). The temperature at the bottom of the large reservoir stays significantly colder throughout the year (Figure 5) and its stratification is only interrupted briefly during winter when the temperature of the surface water cools and approaches the temperature of the bottom of the reservoir.

A sensitivity analysis was conducted to evaluate the effect of drought conditions on a typical annual temperature curve in the reservoir. These simulations are considered approximate as no meteorological data was available for historical periods of drought on Siletz River. In general departures from the projected temperature curve due to even extreme drought conditions were negligible for the large reservoir (in order of 0.1 – 0.2 degrees Celsius), small for the medium reservoir (around 1 degree Celsius), and high for the small reservoir (up to 4 to 5 degrees Celsius) (Figure 7). Thus, reduction in volume of water in the small reservoir significantly promotes vertical mixing of water within the reservoir and reduces temperature stratification. This sensitivity analysis on reservoir inflows also indicates the sensitivity of the temperature modeling to different assumptions regarding reservoir withdrawals.

A sensitivity analysis was conducted to evaluate the effect of drought conditions on a typical annual temperature curve in the reservoir. These simulations are considered approximate as no meteorological data was available for historical periods of drought on Siletz River. In general departures from a temperature curve due to even extreme drought conditions were negligible for the large reservoir (in order of 0.1 – 0.2 degrees Celsius), small for the medium reservoir (around one degree Celsius), and high for the small reservoir (up to 4 to 5 degrees Celsius)

(Figure 7). Thus, reduction in volume of water in the small reservoir significantly promotes vertical mixing of water within the reservoir and reduces temperature stratification.

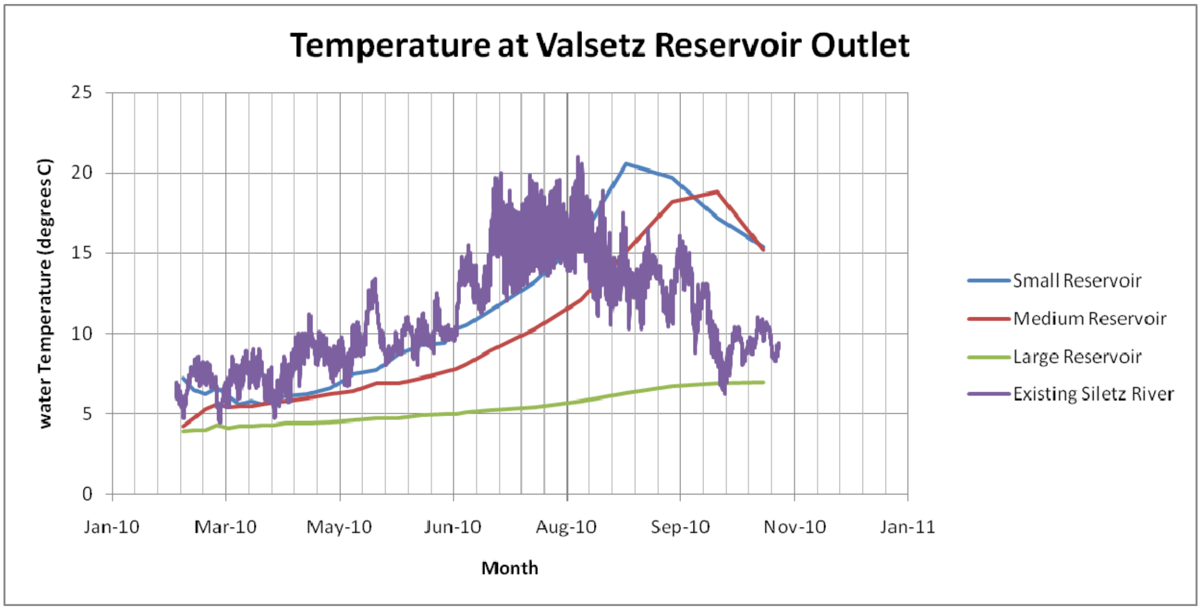

Figure 5. Reservoir Alternatives Bottom Temperature Curves and Existing Siletz River Temperature

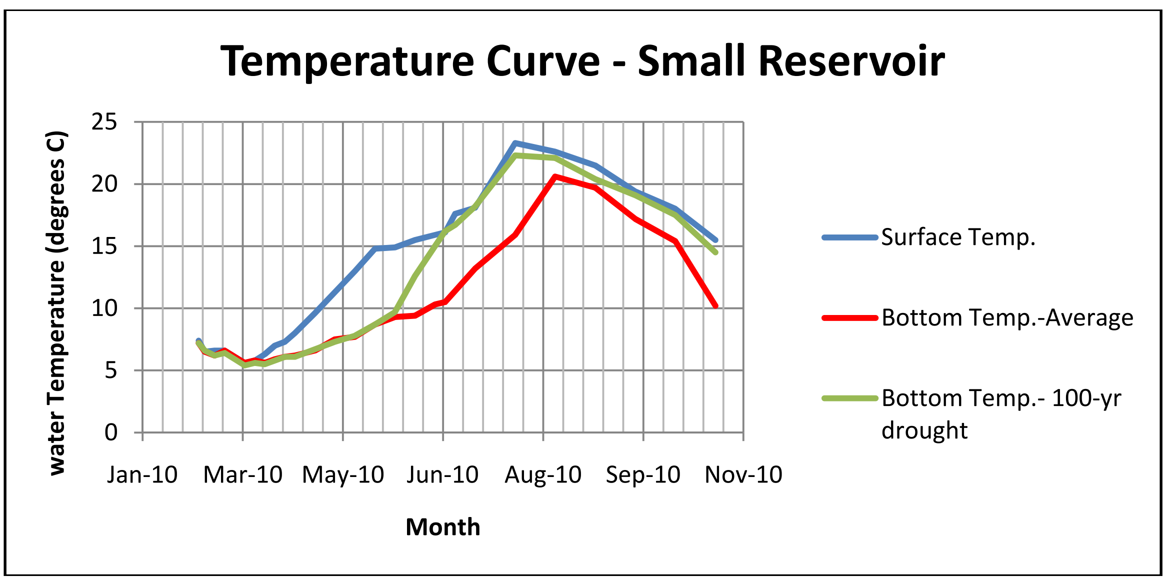

Figure 6. Annual Temperature Curves – Small Reservoir

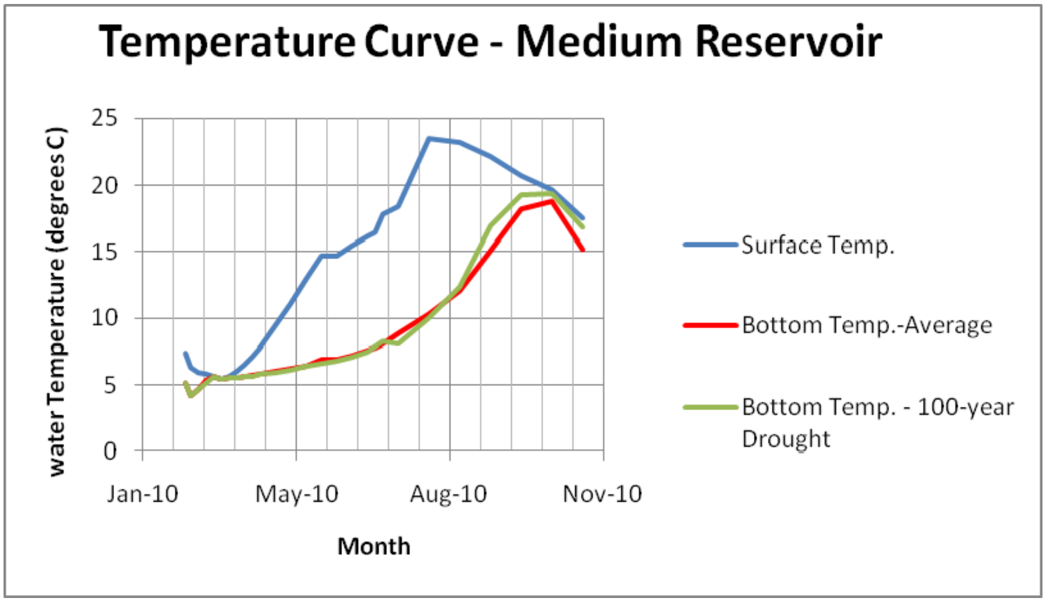

Figure 7. Annual Temperature Curves – Medium Reservoir.

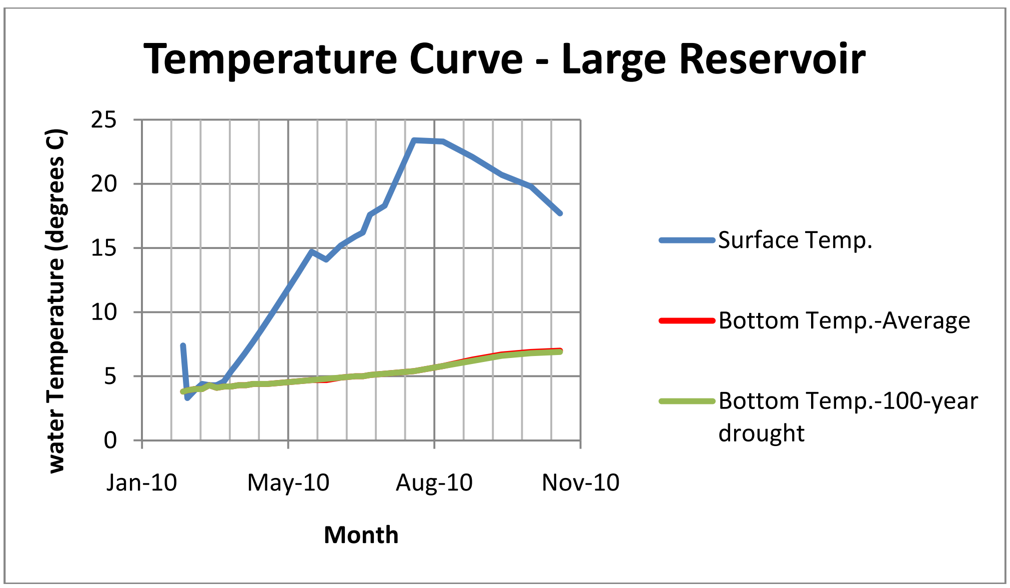

Figure8. Annual Temperature Curves – Large Reservoir

3.1.4 Impact on Siletz River Temperature Downstream of the Reservoir

The preliminary modeling indicates that the impact on temperature in Siletz River downstream from the reservoir varies throughout the year, and is significantly different for each alternative. The selected modeling simulations from the QUAL-2K model at different months in the year are depicted in Figures 9 through 18. All simulations assume water would be released from near the bottom of the reservoir and that withdrawals are equal to those presented in Table 2. A multiple-level outlet would likely have different water temperature impacts. The modeling suggests the three conclusions described in the bullets following Figures 9 through 18.

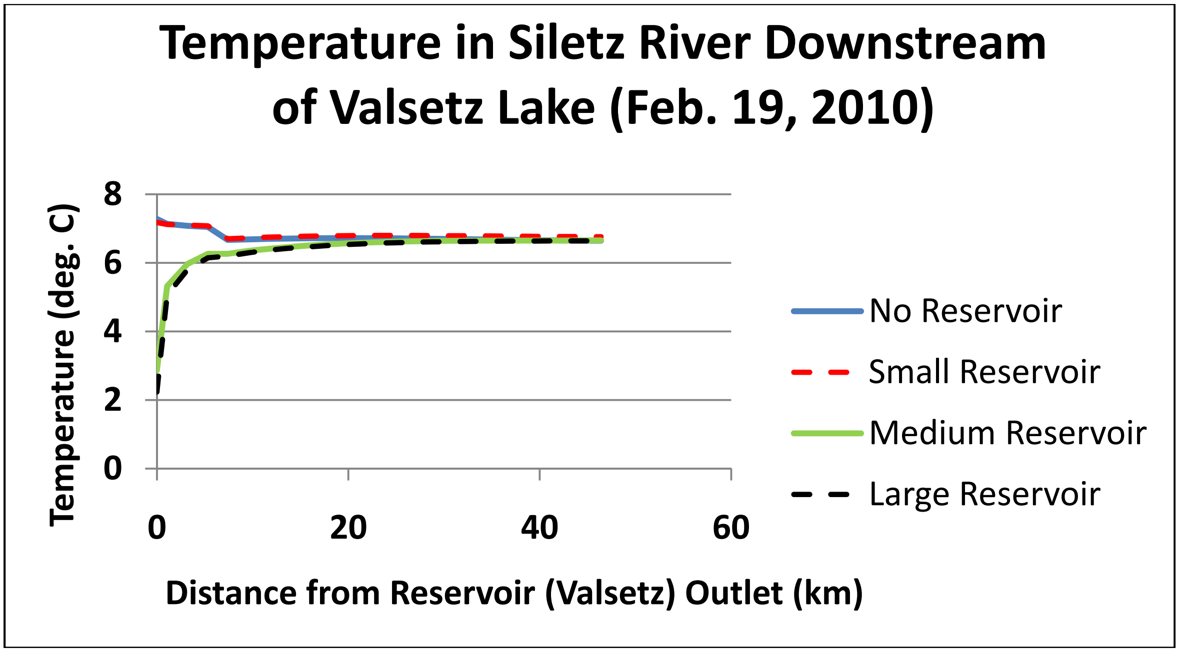

Figure 9. Temperature Curves on February 19, 2010 Downstream of Valsetz

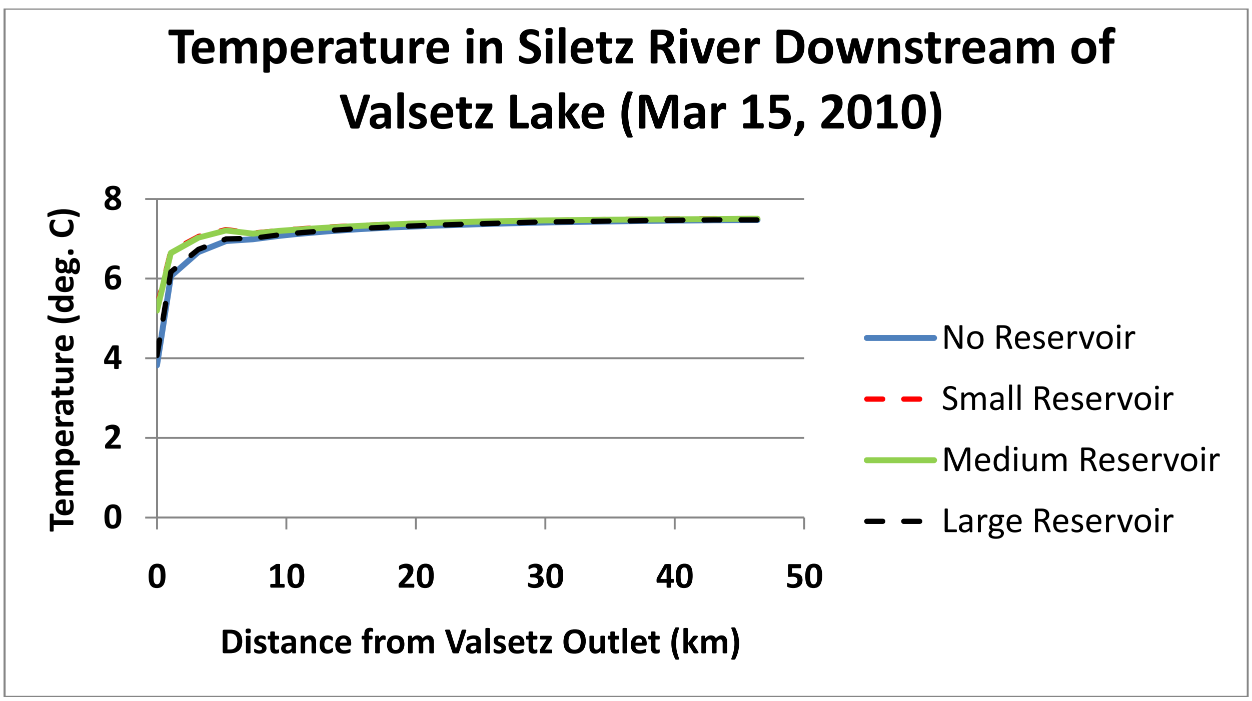

Figure 10. Temperature Curves on March 15, 2010 Downstream of Valsetz

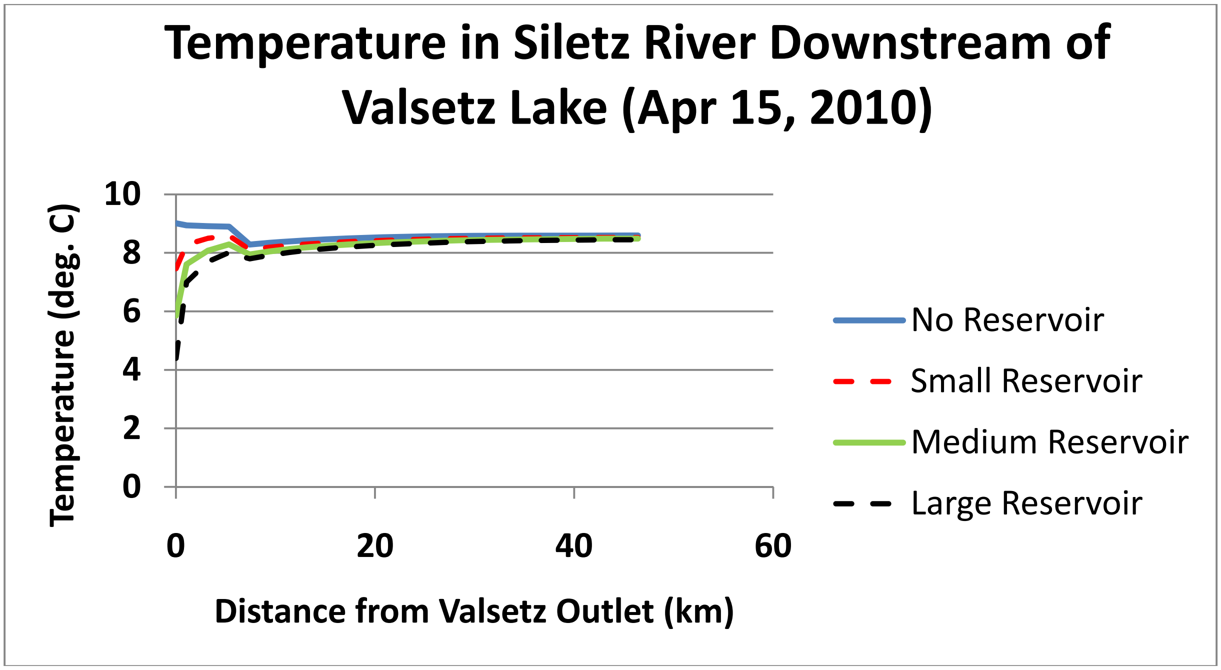

Figure 11. Temperature Curves on April 15, 2010 Downstream of Valsetz

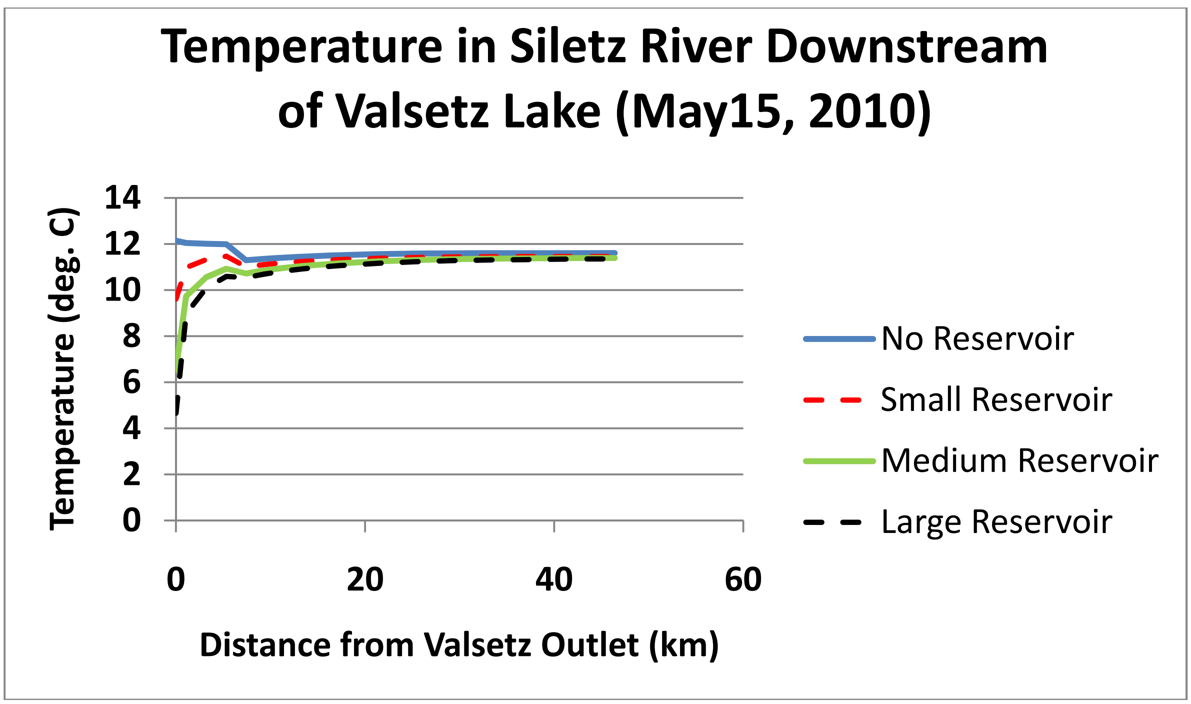

Figure12. Temperature Curves on May 15, 2010 Downstream of Valsetz

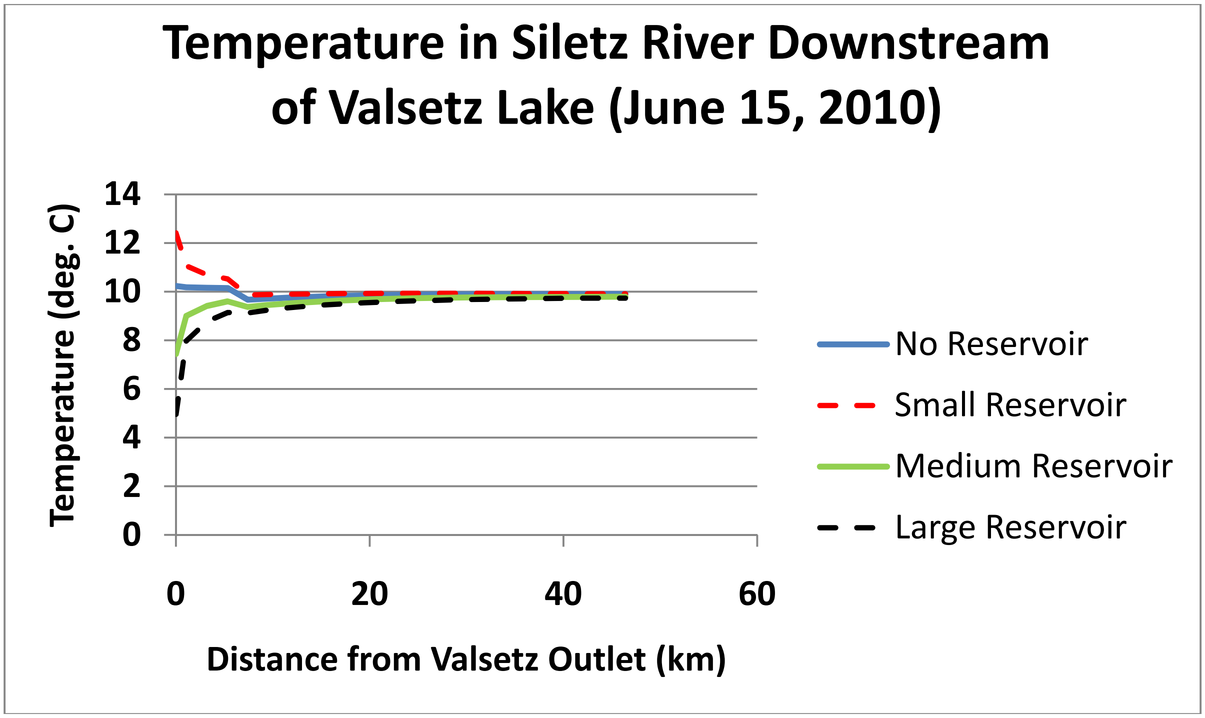

Figure13. Temperature Curves on June 15, 2010 Downstream of Valsetz

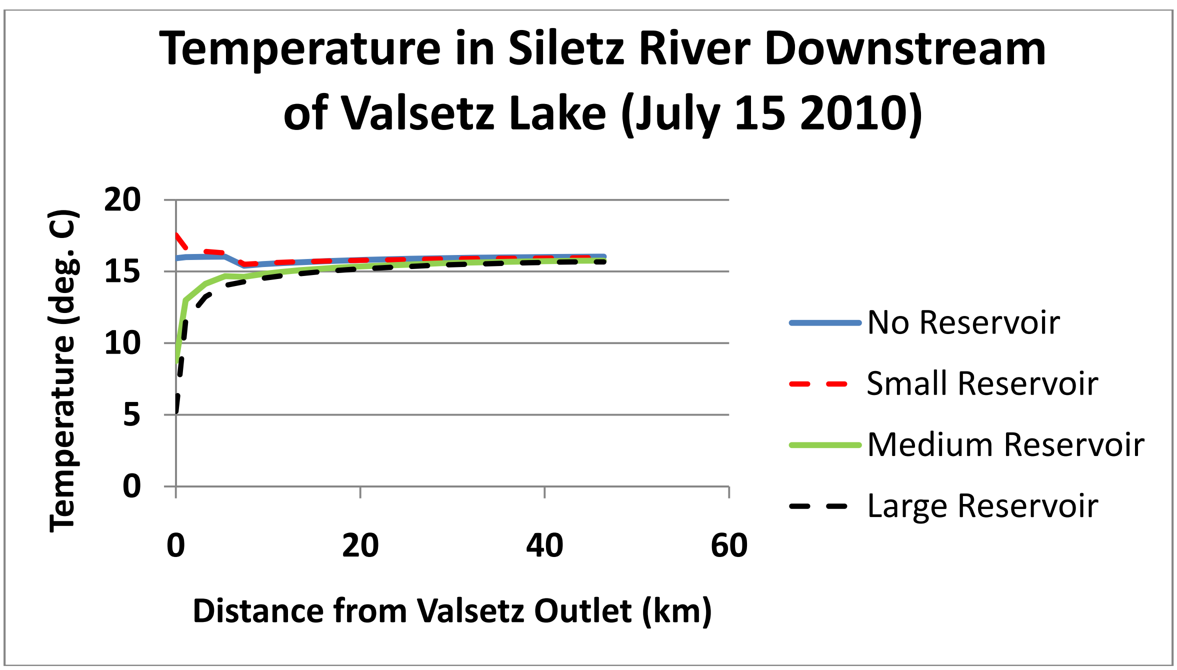

Figure 14. Temperature Curves on July 15, 2010 Downstream of Valsetz

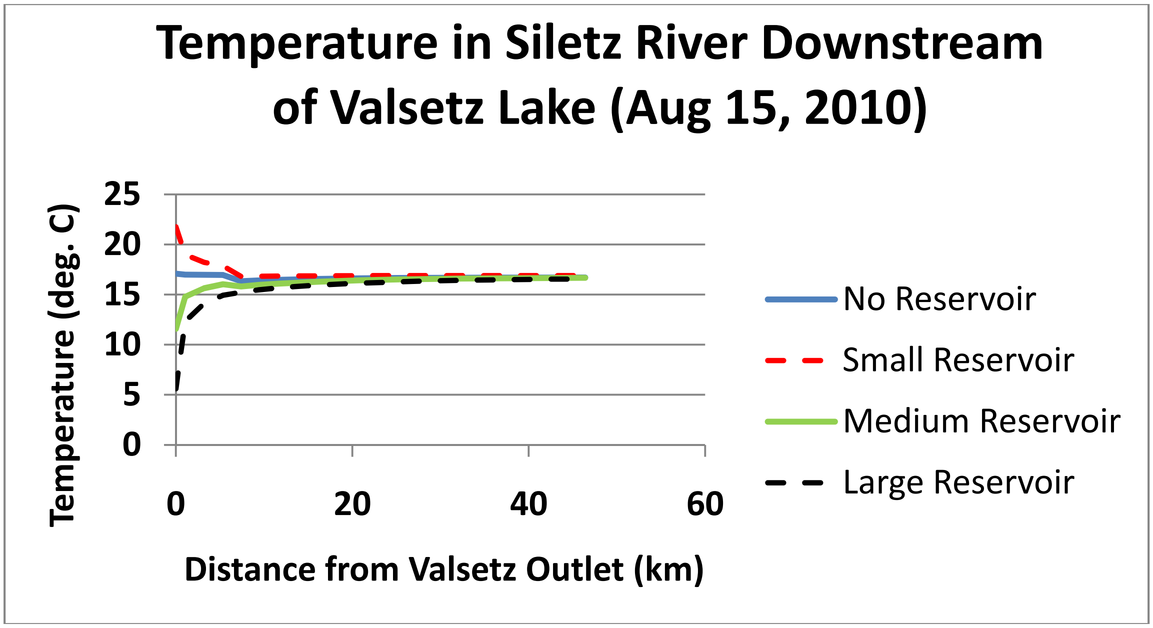

Figure 15. Temperature Curves on August 15, 2010 Downstream of Valsetz

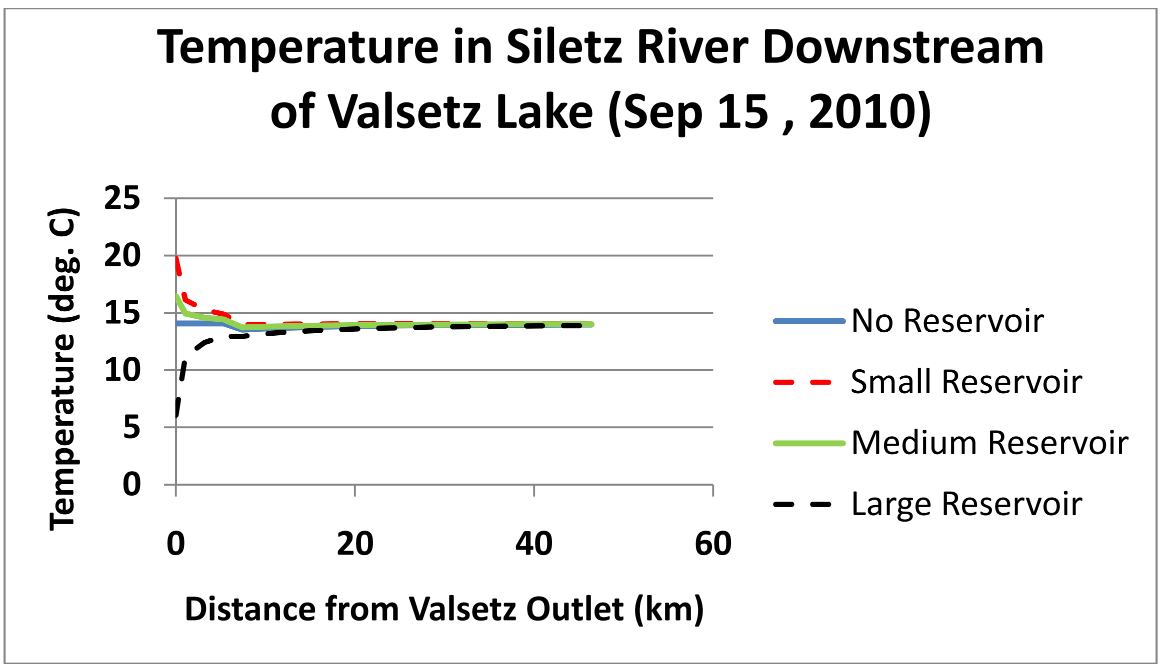

Figure 16. Temperature Curves on September 15, 2010 Downstream of Valsetz

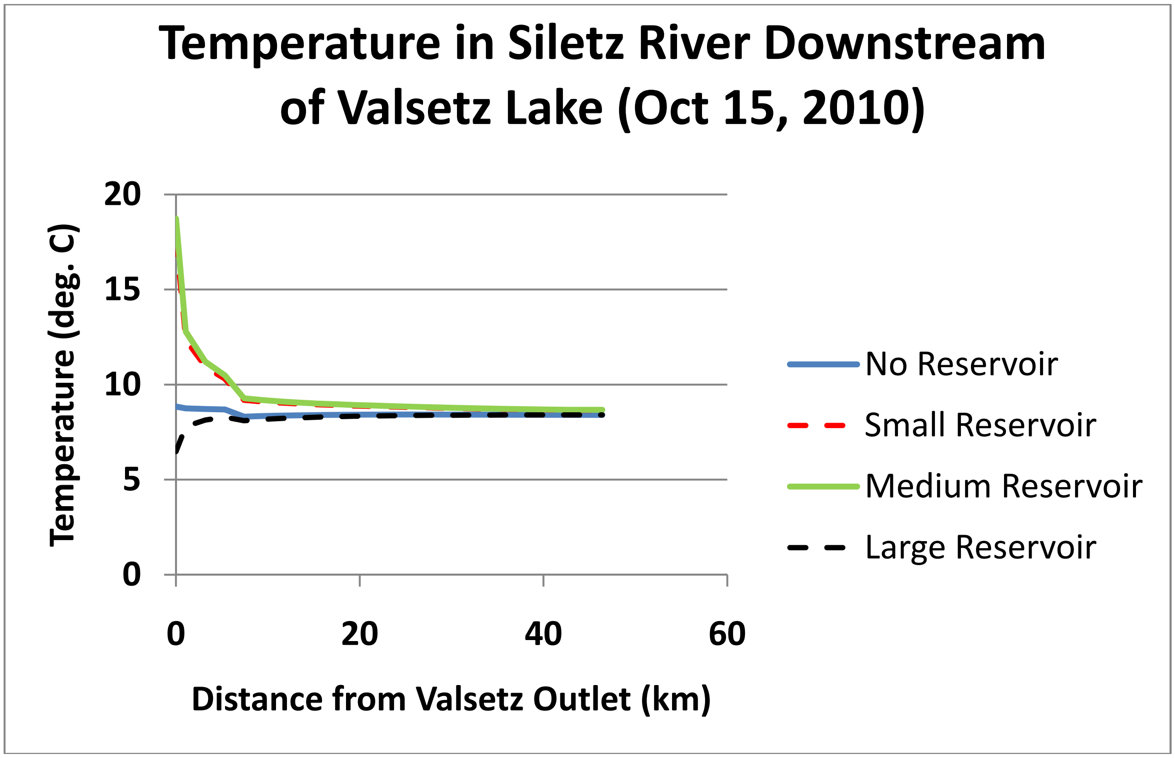

Figure 17. Temperature Curves on October 15, 2010 Downstream of Valsetz

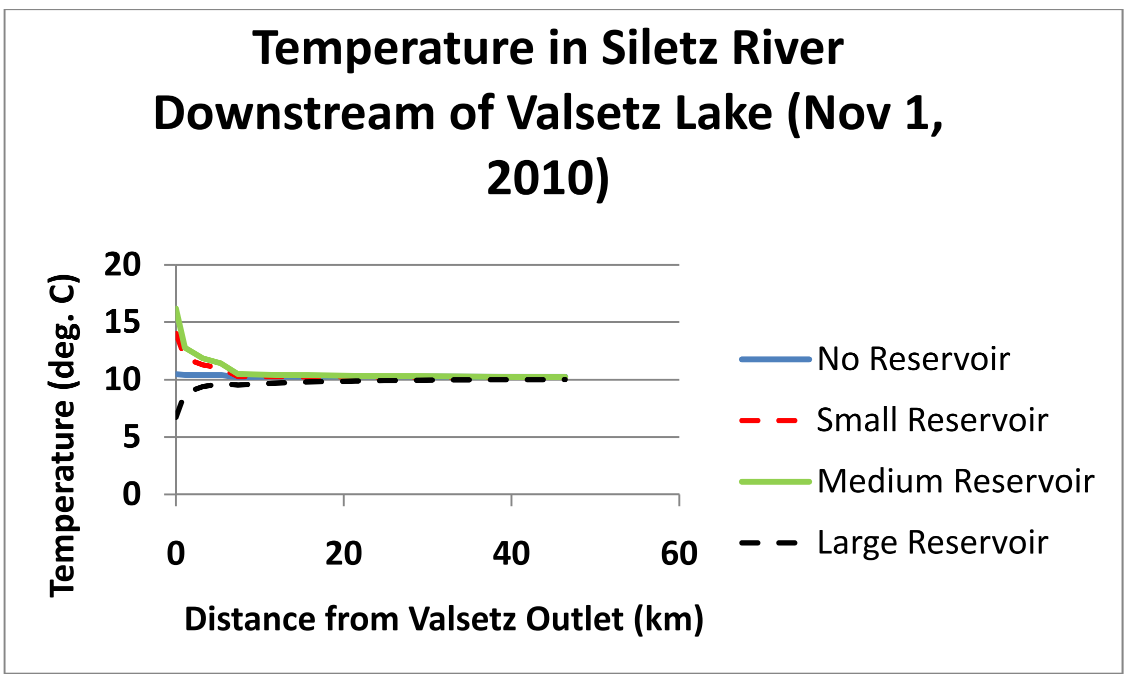

Figure 18. Temperature Curves on November 1, 2010 Downstream of Valsetz

- Temperature differences in the river between different reservoir alternatives are the largest in the reach immediately downstream of the reservoir. The differences progressively decrease in the downstream direction. A rapid drop in river temperature occurs downstream of the reservoir where the South Fork Siletz River reaches the confluence of the North Fork and those waters mix. This can be seen in most of the Figures.
- The model indicates that the minimum temperature difference between all alternatives is in March when all temperatures are very similar (Figure 10); the largest differences are in fall (Figures 17 and 18) when the releases from the medium and low reservoirs are expected to be warmer than the existing condition, while releases from the large reservoir remain cool.
- The small reservoir is projected to release water into the river that is warmer than the existing river water from June through November. In winter and spring, the small reservoir is projected to releases water that is either slightly cooler or at the same temperature as the existing river water. The medium reservoir releases water that is cooler than the current temperature condition in all months except the period from September through November. The model results indicate that the large reservoir would tend to release water that is cooler than current conditions throughout the year.

It is important to recognize that the modeling results are used for a simple comparison of temperature differences in the reservoirs throughout the year. Temperature and oxygen levels of water that are released downstream can be optimized using a multiple level inlet structure in the reservoir, which can mitigate water quality issues. A structure can be constructed in the reservoir that has inlets at different depths in the reservoir that can be opened and closed depending on the water temperature that is optimal for release downstream. This is most evident when looking at the large reservoir temperature differences between the top layer of water and the bottom layer of water. If cooler water is needed, it can be extracted from the bottom and if it is desirable to warm the water released downstream it could be taken from the top. Mixes of water at depth can be used to adjust the water temperature released downstream. This would make it possible to potentially warm the water in the winter and cool the water released downstream, depending on the reservoir size and ability to store cooler water.

Another important consideration is water temperatures that are released downstream during the filling of the reservoirs. A large dam will pass through the stages depicted in the report similar to the predictions for a small and medium dam. For the years it takes to get to the moderate size (roughly), water temperatures that are warmer than existing conditions are projected downstream of the dam. Potential mitigation for the warm water temperatures during the filling period could include a temporary pipe that will divert cooler tributary water directly into the river without warming in the reservoir. The pipe would probably have to be buried to keep water from getting warm or run along the bottom of a reservoir if cool water is present.

3.1.5 Uncertainty Due to Study Assumptions

The main limitations in this study were that the project-specific study data (stream-gage monitoring, temperature monitoring, meteorological data) cover a limited area and represent a period of less than one year. This data was labeled as “representative” of the Siletz River, realizing there is considerable uncertainty in its representativeness. This limitation was known prior to beginning the study but was appropriate for the concept-level analysis. Study conclusions should be interpreted with caution.

The uncertainty associated with water quantity and water quality is less than or on the same level of uncertainty associated with other elements affecting results. For example, uncertainty in the time it takes to fill the reservoir related to periodical increase or decrease of Siletz River flows into the reservoir associated with either dry or wet years introduce approximately the same level of uncertainty as other elements such as use of the reservoir for water supply while filling or downstream in-stream fish flow needs that impact time of filling. A future study can address long-term (i.e. 50-year) reservoir operation using 50 years of the Siletz River simulated inflows (these flows would include both dry and wet periods) and would address operational reservoir behavior associated with these changes. A 50-year metrological time series of air temperature, dew temperature, and precipitation would have to be developed to assess this long-term behavior.

Another source of uncertainty is associated with the level of reservoir withdrawals. We have assumed that withdrawals for instream flow will be equal to instream flow water rights in the Siletz River downstream and that withdrawals for water supply will be equal to regional water deficit projections for the mid-21st century. It is possible that demand for reservoir withdrawals may change in future; however the range of withdrawal scenarios was modeled based on the 2011 best available science.

The reservoir operation scenarios only addressed each reservoir operating at either a normal water level or during drought years. The operation during a major flood was not addressed. Under these conditions, water from the reservoir would be spilled downstream to the river and possibly provide channel maintenance flows in addition to regular diversions for in-stream water needs and for water supply. Of course, all these scenarios will affect water temperature differently in Siletz River downstream, which can be addressed in future studies.

As explained before, the reservoir operation scenarios associated with multiple level discharge outlets were beyond the scope of this study. It is true that these scenarios could and will impact distribution of temperature in the Siletz River downstream. However, these simulations will be more appropriate when reservoir design details become readily available.

There is an uncertainty associated with changes of temperature in the Siletz River downstream of the reservoir. There are numerous Siletz River tributaries, and only the North Fork Siletz River and the main South Fork Siletz River recordings were available. They were assumed representative of all the other tributaries. The simulations in this study showed that the temperature downstream of the reservoir smoothly increased or decreased (with exception of a hard jump at the North Fork confluence), while, in the real world, there are numerous point increases or decreases (coincidental with the locations of tributaries). The impact of the individual tributaries may have to be addressed in future studies.

Not much information was available on the Siletz Creek downstream of the Siletz River confluence, so interpolation of the data was used between the USGS gage data and the monitored data available upstream of the confluence. In real world, many changes to temperature are possible and could occur in this reach.

3.2 Estimated Sediment Transport at Potential Discharge Points in the Luckiamute River

The purpose of this evaluation was to estimate potential for increased erosion or mobilization of the bed at the diversion locations given the increased flow in the tributaries that would occur when water was diverted into the Luckiamute River. We did not evaluate sediment transport in Luckiamute River, since no data on sediment load associated different flows was available. The analysis focused primary on the potential for significant bed-destabilizing erosion. Design engineers (i.e. Corps of Engineers and others) usually relate this “erosive velocity” in the river to the flow velocity that will mobilize a particle size with a median diameter (D50).

3.2.1 Peak Discharges at Discharge Points

The peak discharges on Luckiamute River were estimated using the USGS regression equation for ungaged watersheds in Oregon Region 1 (Coastal Watersheds) (Table 10 of the USGS publication). The calculated peak flows are shown in Table 8 below.

Table 8. Estimated Flood Peak Discharges at Discharge Points

Discharge Point/ Return Period (years)	Flood Peak Discharges (cfs)						
	2	5	10	25	50	100	500
DP1	2.38	3.27	3.75	4.52	5.11	5.71	7.10
DP2	1.81	2.50	2.86	3.47	3.92	4.39	5.46
DP3	2.94	4.04	4.61	5.56	6.28	7.01	8.70
DP4	2.94	4.04	4.61	5.56	6.28	7.01	8.70
DP5	1.23	1.71	1.96	2.38	2.70	3.02	3.78
DP6	9.48	12.08	13.30	15.42	16.97	18.50	21.87

3.2.2 Estimates of Channel Velocities and Erosion Potential at Proposed Diversion Sites

The hydraulic mode of the model HEC-RAS (Version 4.0) was used to estimate existing flow velocities, hydraulic depth, top flow width, and bottom shear stress, based on the channel geometry (obtained though surveying of Luckiamute River at diversion locations DP4, DP5, and DP6), channel flows (as estimated in Table 8), and channel and floodplain roughness. Discharge points 1, 2, and 3 were located on gated lands. Access was not available and no data was collected for those sites.

Hydraulic evaluation at these locations is considered very preliminary because only 1 to 3 cross-sections were available at each diversion location. The preliminary hydraulic evaluation is only used as an indicator of potential effects of diversion at each location, and not to quantitatively estimate potential erosion and deposition at each diversion location. The channel roughness (Manning coefficient) varies from 0.03 to 0.07 and the floodplain roughness varies from 0.07 to

0.10. These hydraulic modes were used to estimate the size sediments that move at certain velocities and bottom shear stress.

The flow velocity required to mobilize and transport sediment particles in a stream is a function of the particle sizes in the stream and stream gradient. The substrate at diversion point 4 is dominated by materials the size of small pebbles and smaller. The substrate at diversion point 5 is small cobble and gravel with a high component of fine materials. The substrate at diversion point 6 is dominated by small gravel and pebbles, also with a high component of finer material. The median size of particles (D50) in the bed at the diversion points is 4.3mm, 193.0mm, and 61.7mm for discharge points 4, 5, and 6 respectively. Gradient of the channels below the discharge points was <1%, 9%, and 3% for discharge points 4, 5, and 6, respectively. According to the widely accepted Shields theory of incipient motion (Vanoni, 2006), the sediment particles with a diameter smaller than the D50 diameter would be mobilized at flow velocities of 3.75 f/s, 5, f/s, and 6.5 ft/s for discharge points 4, 5, and 6, respectively while sediment particles larger than the D50 would tend to stay in place in those flow velocities. The flow that mobilizes the D50 is often referred to as the “erosive velocity”.

The *sediment* capacity mode of the model HEC-RAS (Version 4.0) was used to estimate the sediment capacity at targeted reaches of the Luckiamute River. The capacity method is used in the SAM Hydraulic Design Package for Channels developed by the Corps Waterways Experiment Station and is consistent with the US Army Corps guidelines of EM 1110-2-1601 (Corps 1994). This method is usually used in practice to analyze a stable channel and to estimate channel potential to transport sediment. This is only a theoretical estimate, as no information on sediment load is available. The SAM method predicts theoretical capacity of a creek to transport non-cohesive sediments at selected creek sections based on the existing hydraulic parameters and known sediment properties. Simulation results are presented as sediment discharge curves (relating creek sediment capacity and creek flows) for different sediment categories. Gradation of the bed sediment at different sections of the creek (at locations DP4, DP5, and DP6), is obtained by conducting Wolman pebble count (i.e. Rosgen, 1998) across targeted reaches of the creek. The transport capacity is calculated using the Engelund-Hansen sediment transport function (Vanoni, 2006).

The HEC-RAS model was run for the existing conditions (flows as specified in Table 1) and for the reservoir conditions assuming diversion of the 20 cfs flows from Valsetz reservoir to Luckiamute River at locations DP4, DP5, and DP6. The simulated velocities in the river at the three locations were compared with the literature-based maximum non-erodible velocities or the velocities at which the D50 particle size is mobilized (Bureau of Reclamation Erosion and Sedimentation Manual, 2010, Table 3-1). Although flows and velocities at each locations increase, as shown in Figures 19 and 20, resulting channel velocities at all locations were still less than the velocities required to mobilize the D50 particle size at each location (“erosive velocities”). Particles smaller than the D50 would, however, be mobilized, resulting in a coarser bed downstream of the discharge points.

At diversion location DP4, the increased discharge and subsequently increased channel velocities of 2.7 to 3 ft/sec were less than the maximum non-erosive velocity of 3.75 ft/sec. At DP5, the increased channel velocities of 3.8 to 4.0 ft/sec were less than the maximum non-erosive velocity of 6.5 ft/sec. The transport of the medium-sized particles may change substrate composition from sand and pebbles to medium gravel at DP4; and may result in a greater abundance of cobble at DP5. At diversion location DP6, the projected increased channel velocities of 4.2 to 4.7 ft/sec are less than, but very close to the velocity of 5.0 ft/sec which would mobilize the D50 particle size.   There is substantial uncertainty regarding the estimated velocity and substrate composition. Since the model results suggest increased flows would approach the velocity at which the median particle size is mobilized, the bed would be expected to get coarser downstream of this discharge point 6. A full analysis of sediment transport at these locations would require additional data collection, including sediment load information as a function of stream flow.

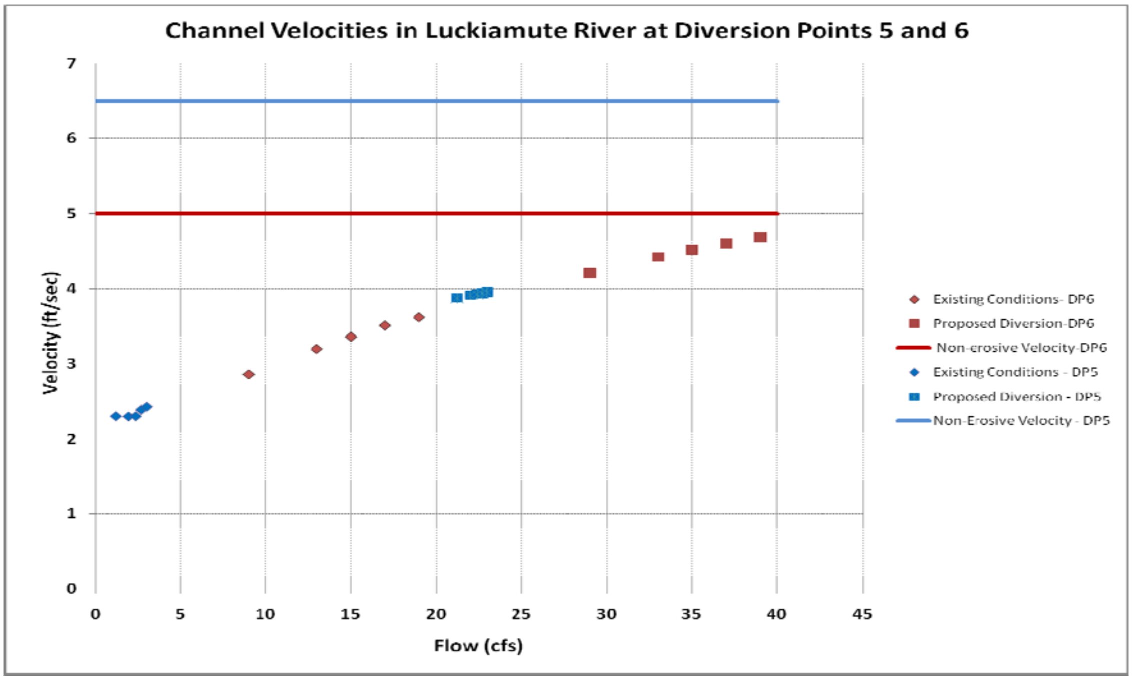

Figure 19 – Channel Velocities in Luckiamute River at Diversion Points 5 and 6. "Non-erosive velocity" is the velocity at which the median particle size (D50) is mobilized.

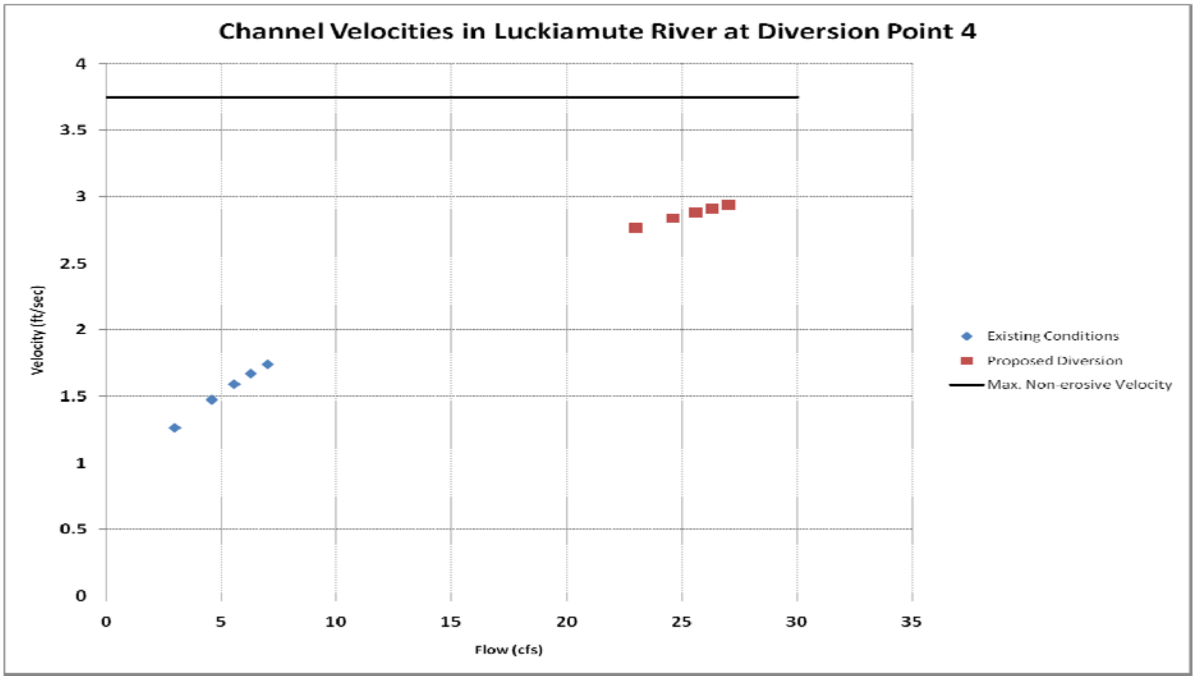

Figure 20– Channel Velocities in Luckiamute River at Diversion Point 4. "Non-erosive velocity" is the velocity at which the median particle size (D50) is mobilized.

Comparative evaluation of categories of sediment transport and predicted sediment channel capacity at the three diversion locations is presented in Figure 21. The transport capacity at locations DP5 and DP6 is significantly higher than the sediment transport capacity at DP4.

The selected discharge points were very preliminary. Future design and citing of the discharge points should incorporate an extensive evaluation of the potential effects on substrate. Several mitigation options could potentially be implemented to reduce or avoid the effects of diverting water on the channel morphology. For example, potential effects would be reduced if the location of discharge were located farther downstream where the channel would be able to accommodate flows greater than 20 cfs. Additionally, the discharge structure can be designed to minimize localized erosion and erosion control structures can be used in the channel near the discharge point to minimize the potential for down cutting.

4 Conclusions

The following summarizes the conclusions of this study.

4.1 Capacity to Meet Demand

The reservoir simulation analysis indicates that all three reservoirs options have sufficient capacity to satisfy both the instream flow needs and the water supply-water demand needs specified in Table 5. The reservoirs are sufficient under the average and drought flow conditions in the Siletz River.

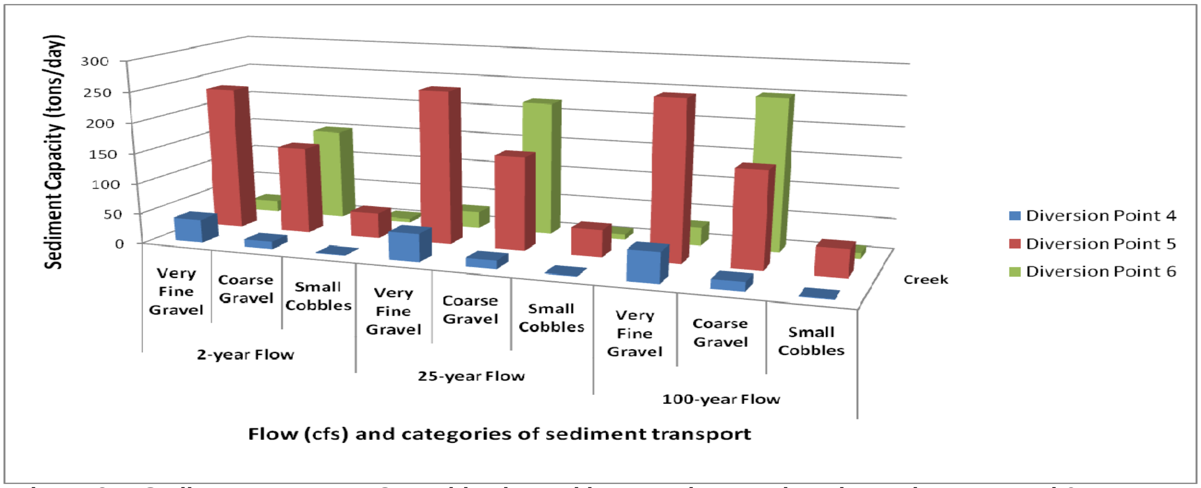

Figure 21– Sediment Transport Capacities in Luckiamute River at Diversion Points 4, 5, and 6

4.2 Downstream Temperature Effects

All three reservoirs are expected to vertically stratify. Surface water temperatures reach approximately 23°C under all the alternatives and will generally be warmer on the surface than the natural river temperature throughout the year except in winter and early spring (Figure 4).

The water near the bottom of the reservoirs would be substantially cooler than the temperature of the river during much of the year for the three reservoir alternatives (Figure 5). The small and medium reservoirs would become warmer than the river beginning about mid-August through the fall. The large reservoir is basically cooler than the river water during the entire year providing potential to provide cooler water downstream in the summer.
Temperature differences in the river between the three reservoir alternatives are the largest in the reach immediately downstream of the reservoir. The differences progressively decrease in the downstream direction.

Based on modeling assumptions discussed above, the minimum temperature difference between all alternatives is expected to be in March when all temperatures are modeled to be very similar; the largest temperature differences likely would occur in fall when the releases from the medium reservoir or low reservoir are expected to be warm, while the high reservoir remains cool.

The small reservoir, as modeled, generally releases water into the river that is warmer than current conditions throughout the year, except during the winter season. The medium reservoir is projected to release water that is cooler than the current temperature condition in all months except the period from August through November. The large reservoir releases water that is expected to be cooler than current conditions throughout the year.

A reservoir that is approximately the size of the large reservoir and perhaps as small as the medium reservoir appears to have the potential to provide water to the river during the summer that is cooler than existing conditions. A multiple level intake would provide flexibility to adjust temperature and oxygen levels in water released from a larger reservoir.

4.3 Sediment Transport and Erosion at the Alternative Discharge Points

Assuming no more than 20 cfs will be discharged at any point, modeling indicates that the bedload transport would be expected to increase at discharge points 4 and 5, but significant erosion of the bed is not expected. Bed erosion is possible at discharge point 6. Additional investigation downstream of all the potential discharge points is recommended to ensure significant changes to channel morphology will not be triggered by the discharges. Bed erosion could potentially be minimized or avoided with mitigation measures.

5 References

Bureau of Reclamation. 2010. Erosion and Sedimentation Manual. [online]. Available from: http://www.usbr.gov/pmts/sediment/kb/ErosionAndSedimentation/index.html.

Chapra, S. 2008. QUAL2K: A Modeling Framework for Simulating River and Stream Water Quality. Documentation, Version 2.11. Environmental Protection Agency Ecosystem Research Division. [online]. Available from: http://www.epa.gov/athens/wwqtsc/html/qual2k.html.

Cole, T. and Wells, S. 2008 CEQUAL-W2: A Two-Dimensional Laterally Averaged, Hydrodynamic and Water Quality Model. User Manual, Version 3.6. US Army Corps of Engineers, Waterways Experiment Station and Department of Civil Engineering, Portland State University. Prepared for US Army Corps of Engineers, Washington, D.C.

United States Army Corps of Engineers. 1994. Hydraulic Design of Flood Control Channels. Engineering Manual EM 1110-2-1601., Washington DC.

United States Army Corps of Engineers. 2008a. HEC-RAS River Analysis System, User's Manual. Version 4.0, March 2008. Hydrologic Engineering Center, Davis, California.

United States Army Corps of Engineers. 2008b. HEC-RAS River Analysis System, Hydraulic Reference Manual. Version 4.0, March 2008. Hydrologic Engineering Center, Davis, California.

United States Army Corps of Engineers. 2008c. HEC-RAS River Analysis System, Applications Guide. Version 4.0, March 2008. Hydrologic Engineering Center, Davis, California.

United States Geological Survey. 2005. Estimation of Peak Discharges for Rural, Unregulated Streams in Western Oregon. Scientific Investigation Report, 2005-5116. US Department of Interior, USGS, Reston, Virginia.

Vanoni, V.A. 2006. Sedimentation Engineering, Manuals and Reports on Engineering Practice. No. 54. American Society of Civil Engineers.

Wells, S. 2010. W2 Version 3.6 Release Notes. November 10, 2010. Portland State University, Portland, Oregon.