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WATER QUANTITY AND WATER QUALITY ANALYSES FOR THE LAKE TAPPS WATER RIGHT APPLICATIONS

Prepared for: Washington State Department of Ecology

Project No. 020071A-001-03 • May 5, 2010

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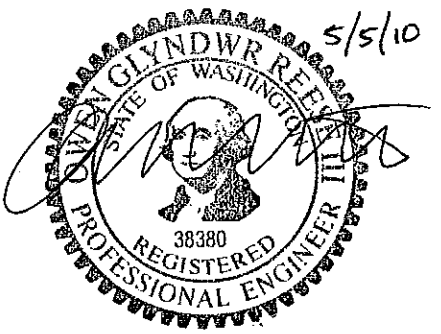

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1 Introduction

This report describes the water quantity and water quality analyses performed to evaluate the water right applications for the Lake Tapps Reservoir Water Rights and Water Supply Project. These analyses were performed for the Washington State Department of Ecology (Ecology) and Washington State Attorney General's Office by Aspect Consulting, LLC. (Aspect).

1.1 Context for Investigation

The water quantity and quality analyses were performed as a component for the Reports of Examination (ROEs) of four interrelated applications submitted for the same project. These include three municipal water rights applications for new appropriations (S2-29920, R2-29935, and S2-29934) filed in 2000 and a change/transfer application (CS2-160822CL) filed in 2005 for existing pre-code water right claim number 160822 (Puget Claim).

Following submission of an application for a new appropriation, Ecology is required to investigate and determine what water, if any, is available for appropriation, and to what beneficial use or uses the water can be applied. To approve the water right application Ecology must issue written findings of fact and determine that each of the following four requirements of RCW 90.03.290 has been satisfied:

1) Water is available for appropriation;
2) The proposed appropriation would be put to a beneficial use;
3) The proposed appropriation would not impair existing water rights; and,
4) The proposed appropriation would not be detrimental to the public interest.

The first element of the four part test is answered directly in the Instream Resource Protection Program for the Puyallup River Basin (WAC 173-510), which closed the White River and all tributaries "to further consumptive appropriations" [WAC 173-510-040(3)]. However, a stream closure may be overridden "in situations where it is clear that overriding considerations of the public interest will be served" [RCW 90.54.020(2)(a)]. Evaluation of the "overriding considerations of the public interest" (OCPI) involves weighing what important public interests would be served versus the public interests that may be harmed.

The evaluations in this report were performed to address criteria 1, 3 and 4 of the four part test, as well as quantify public benefits and harms related to water quantity and quality for the OCPI analysis. Specifically, the effect of the project on the following public interests was evaluated:

- Stream flows in the affected reaches of the White and Puyallup Rivers.
- Minimum Instream Flow in Puyallup River at Puyallup.
- Recreational water levels in Lake Tapps.

- Water quality in the affected reaches of the White and Puyallup Rivers for the key parameters related to flow (temperature and dissolved oxygen)
- Reliability of the proposed water supply.

These analyses form one component of Ecology's overall evaluation of the water rights. The complete evaluation will be detailed in the Reports of Examination issued for the water rights. The results in this report were also shared with Cascade Water Alliance (Cascade) prior to publication, and were used in the Environmental Impact Statement prepared for the project by Cascade (2010).

1.2 Summary of Water Supply Project

Cascade is seeking to develop a municipal water supply from Lake Tapps in Pierce County. The water supply would withdraw up to 54,300 acre feet of water per year (afy) from Lake Tapps. This is equivalent to an annual average flow of 75 cubic feet per second (cfs) or about 48 million gallons per day (mgd). The water would be treated in a treatment plant built near the lake, then transmitted to Cascade members. Cascade is an alliance of water purveyors currently consisting of 8 members generally located in east and south King County (City of Bellevue, City of Issaquah, City of Kirkland, City of Redmond, City of Tukwila, Covington Water District, Skyway Water and Sewer District and Sammamish Plateau Water and Sewer District).

Lake Tapps Reservoir and the accessory hydropower facilities were built by predecessors to Puget Sound Energy in 1911, and operated for hydropower generation until 2004. The land surrounding the lake was developed as lakefront residences, and Lake Tapps became heavily used for recreation. In later years, hydropower generation became less economical and PSE and a task force of interested parties sought financially viable alternatives to preserve the lake. In 2000, PSE submitted three water right applications for a municipal water supply. Cascade later purchased Lake Tapps, its accessory facilities, water rights, and applications from PSE.

A key component of the development of a water supply from Lake Tapps, and the focus of this report, is the evaluation of the water right applications submitted by PSE and Cascade for the project.

1.3 Water Right Applications

PSE and Cascade have submitted four interrelated water right applications to Ecology for the project:

1. Diversion from White River for Municipal Supply: S2-29920 proposes to divert up to 1,000 cfs[1] of water, not to exceed a withdrawal of 54,300 afy, from the White River to be used for municipal supply.

[1] PSE originally submitted applications to divert and store up to 2,000 cfs with an annual quantity of 72,400 afy (equal to 100 cfs annual average). Cascade has subsequently scaled back the applications to a 1,000 cfs instantaneous maximum and 54,300 afy annual quantity (equal to 75 cfs annual average) on the diversion application, and 135 cfs instantaneous maximum and 54,300 afy annual quantity on the withdrawal application.

2. Storage in Lake Tapps for Municipal Supply: R2-29935 seeks a reservoir permit to store in Lake Tapps up to 46,700 acre feet per year diverted from the river pursuant to application S2-29920.
3. Withdrawal from Lake Tapps for Municipal Supply: S2-29934 seeks a secondary permit to divert a daily peak rate of up to 135 cfs, not to exceed an annual withdrawal of 54,300 af/y, for consumptive use as a municipal, commercial, and industrial water supply.
4. Change to Hydropower Claim: CS2-160822CL seeks to add or otherwise confirm water use under the water right claim for reservoir level maintenance, protection and enhancement of fish and wildlife, and maintenance of water quality for recreational purposes in the reservoir.

The first three of these applications would authorize development of Lake Tapps for municipal supply. These are the key applications and are the main focus of this report. The change to the hydropower claim is also integral to the evaluation in this report, but in a different context. It forms the baseline from which the effects of the water supply project are measured. The following section provides additional detail about the hydropower water right claim, and the change to the claim.

1.4 Existing Hydropower Water Right Claim

The existing hydropower water right claim (Surface Water Claim 160822) allows for the continuous diversion of up to 2,000 cfs from the White River for generation of hydropower. The claim has a priority date of 1895, and the hydropower use pre-dates the State of Washington's 1917 water code. A Pierce County Superior Court decree[2] in 1910 confirmed the 2,000 cfs withdrawal and established a minimum flow of 30 cfs below the diversion dam. Use of the water right claim was limited by a 1986 settlement agreement with the Muckleshoot Indian Tribe that established a minimum flow of 130 cfs at the Reservation boundary and provided for a supplementary water budget dedicated to fish transportation flows. PSE is currently operating the Reservoir under an Interim Operating Agreement with the U.S. Army Corps of Engineers that established a higher minimum flow for the White River.

On November 22, 2005, PSE submitted an application to add or otherwise confirm water use under the water right claim for reservoir level maintenance, protection and enhancement of fish and wildlife, and maintenance of water quality for recreational purposes in the reservoir. Ecology is currently processing this change application and anticipates issuing a decision prior to or concurrently with the ROEs for the three new water rights.

[2] Pacific Coast Power Co. v. Quilquilion (Decree No 28120, dated April 13, 1910).

1.5 History of the Water Right Applications and their Evaluation

PSE originally filed the three municipal water right applications in 2000 and 2002, anticipating that the water supply project would operate concurrently with PSE's existing hydropower operations at Lake Tapps. In support of the water right applications, PSE's consultant, HDR Engineering, Inc., developed the Lake Tapps Systems Model to simulate how the new water rights would affect river flows and reservoir levels in the watershed. These analyses formed the basis for three ROEs issued by Ecology in 2003 approving the new water rights. The ROEs were appealed by multiple parties.

In 2004, PSE ceased generating hydropower. The Pollution Control Hearings Board (PCHB), acting on the appeal of the ROEs, remanded them to Ecology with the requirement that the project be evaluated without ongoing hydropower operations. A new, non-hydropower, baseline from which to measure the impacts of the proposed water supply was defined based on the assumed continued operation of Lake Tapps for water quality and recreational uses.

Ecology and its consultant team evaluated the water supply project (Proposed Action) relative to the non-hydropower baseline and issued a Draft ROE for public comment on September 25, 2006. Ecology received numerous comment letters from public agencies, Native American tribes, and other interested parties and individuals. On consideration of the comments, Ecology concluded additional water quantity analyses were warranted. Aspect, working as a consultant for Ecology, has been conducting the additional analyses.

This report documents those analyses, focusing on recent results and the modifications made to the model and related analyses since publication of the 2006 Draft ROE. Since 2006, the Cascade Water Alliance (Cascade)[3] has reached negotiated agreements with the Muckleshoot and Puyallup tribes, and the Lake Tapps Community Council. These agreements have been incorporated into the model scenarios. The model has also been revised to include a new approach to simulating local inflows and outflows from Lake Tapps, new water supply withdrawal scenarios, new minimum flows at the diversion dam, a revised priority of water use in Lake Tapps, and other changes. This latest version of the model is referred to as the "Remand ROE Model" in this report.

[3] Cascade purchased the water rights and Lake Tapps infrastructure from PSE.

2 Description of Puyallup – White River Basin

The project site is located within the Puyallup-White River Watershed, Water Resource Inventory Area (WRIA) 10. The project area, structures, and topography are shown in Figure 1.

The Puyallup River originates on the north and western slopes of Mt. Rainier and drains an area of about 970 square miles. The White River, with a drainage area of 494 square miles, is the main tributary to the Puyallup River. It joins the Puyallup River 10.2 miles above the mouth of the Puyallup River at Commencement Bay in Tacoma.

The White River Hydroelectric Project diverts water from the White River at a diversion dam located near the Town of Buckley. Diversion of water into Lake Tapps reduces flows in the roughly 21-mile reach of the White River between the diversion dam and the tailrace canal. This reach is referred to in this report as the Reservation Reach. The Reservation Reach passes through the Muckleshoot Indian Reservation, then travels by the cities of Auburn and Pacific before it is joined by outflow from Lake Tapps at the tailrace canal.

Water diverted from the White River is conveyed to Lake Tapps through an 8-mile series of flumes, canals, settling basins and pipelines. A fish screen facility is installed in the canal to prevent fish from being trapped in the lake. The fish screen diverts a flow of roughly 20 cfs from the canal to convey fish back to the White River. The remaining canal flow enters Lake Tapps and is stored pending release through the penstocks and turbines of the Dieringer Powerhouse. The powerhouse releases water to the tailrace canal, which rejoins the White River about 3.6 miles upstream of the confluence with the Puyallup River. The reach of the White River below the tailrace canal is referred to in this report as the Lower White River.

Due to the historical significance of the White River Hydroelectric Project and flood control issues on the White and Puyallup Rivers, the United States Geological Survey (USGS) has maintained numerous streamflow gages in the Puyallup Basin (Figure 2). Data from these gages has been used to develop the historical flow data that is input into the Lake Tapps Systems Model.

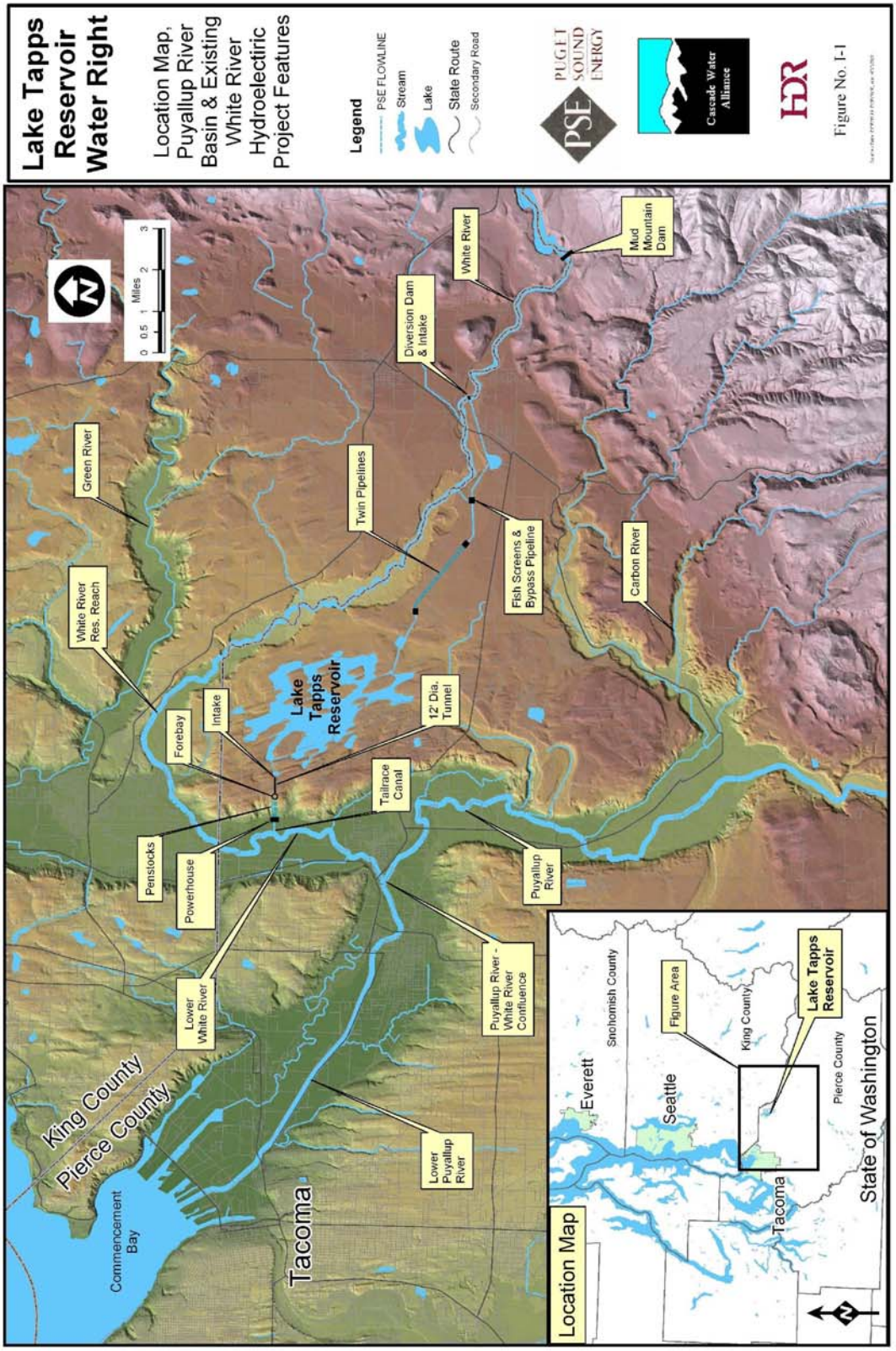


Figure 1 – Lake Tapps Project Area (modified from Figure 1-1 of TM 1 [HDR 2002])

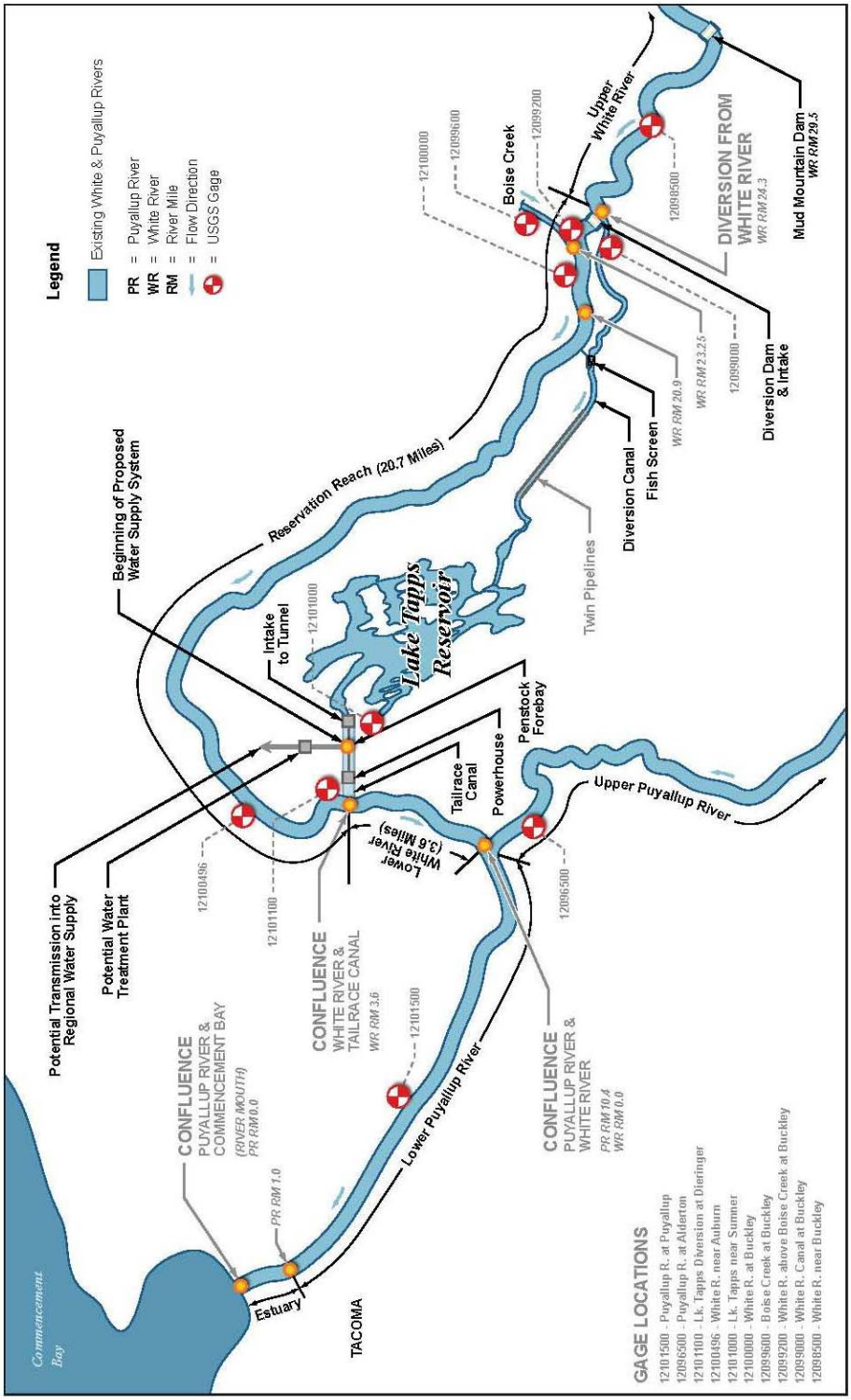


Figure 2 – Stream Reaches and Gages of the White and Puyallup Rivers (Figure 5-2 in Cascade 2009)

3 Lake Tapps Systems Model

3.1 History of Water Quantity Analyses

The water quantity analyses for the evaluation of the Lake Tapps water rights have been based on the Lake Tapps Systems Model, a computer model that simulates flows in the White and Puyallup River systems under different operating regimes. The Lake Tapps Systems Model has evolved through the water rights permitting and appeals process, with modifications at each step of the process. The following sections describe the evolution of the model.

3.1.1 Preliminary Permit Model

As a component of the technical analyses for the Preliminary Permit, HDR, PSE's consultant, developed the original version of the Lake Tapps Systems Model. The modeling approach and results are documented in three Technical Memoranda (TMs) that are part of the Lake Tapps Water Right Feasibility Report (HDR 2002). TMs 12 and 13 document the selection of STELLA® as the modeling platform and describe the work plan for developing the water quantity model in STELLA. TM 16 provided a detailed description of model development and presented results for Lake Tapps surface elevation and stream flows in the Lower White and Puyallup Rivers.

This version of the model was based on historical flow data from water years (WY) 1991 to 2001. Results were presented for a normal year (WY 1998), a dry year (WY 1993), and a drought year (WY 2001) selected from that period. The scenarios evaluated assumed continuation of hydropower operations.

3.1.2 ROE Model

The Preliminary Permit Model was reevaluated in 2004 in response to requirements of the original ROE, cessation of hydropower operations, and issues raised during the appeal of the original ROE. The model was modified by R2 Resource Consultants, working for PSE. The *Affidavit Mike Ramey and Clair Yoder In Support Of Motion For Partial Summary Judgment On Issues 33 And 61* on May 18, 2004, describes the changes to the model that were made between the feasibility study and the issue of the Remand Order. Key changes made to the model include revising the mitigation elements to reflect the conditions of the 2003 ROE and adding a scenario reflecting non-hydropower operations.

3.1.3 Draft Remand ROE Model

The model was again modified for the draft Remand ROE to extend the period of record to 2002, revise the diversions for maintaining lake water quality (i.e., flushing) in the baseline scenario, and add new mitigation elements, among other changes. The modifications were made by Aspect, under contract to Ecology through the Attorney General's Office, and model results were documented in a report titled Water Quantity Model Results Compendium for the Lake Tapps Water Right Applications (Aspect 2006).

3.1.4 Remand ROE Model

Aspect again modified the model to incorporate and address comments received on the draft Remand ROE, comments received through a series of modeling workshops with the Lake Tapps Community Council Modeling Workgroup and Cascade in December through March 2009, the agreements reached between Cascade and other interested parties, and the reduced withdrawal quantities requested by Cascade. The changes made to the model are documented in this report.

3.2 Water Quantity Model Description

The Lake Tapps System Model was developed in the STELLA software environment. The STELLA model is primarily a graphical and object-oriented environment that uses time-series data, user-input and logic functions to perform a mass balance of flows through the system. Models are constructed in STELLA in three modeling layers: the interface layer, the map/model layer, and the equations layer.

Users run the model from the model interface layer that contains all of the options to run the Remand ROE analyses, and access to the model output. Output from the model is summarized as time-series of flows, volume or stages for each element of the model in customized tables and pasted into Microsoft Excel spreadsheets for further manipulation.

The map/model layer is the primary layer for the construction of the model. In the Lake Tapps System Model, there are two main areas where the system components and their interrelationships are defined. The physical system layout module included the key hydraulic and infrastructure elements of the Lake Tapps System. Separate modules are used to calculate each of the primary elements in the physical system layout module.

The equations layer contains all of the underlying code to run the model. Typically, all of the code in the equations layer is written by the STELLA software based on the graphical relationships defined in the map/model layer.

3.2.1 Changes to the Remand ROE Model

3.2.1.1 Model Interface

The Remand ROE model interface (Figure 3) has been streamlined to remove obsolete mitigation approaches and operating schemes, and now focuses on the parameters used in the Remand ROE analysis. The model retains the ability to simulate calibration scenarios and different operational capacities (e.g. diversion caps and maximum tailrace releases), but these options have been moved to a separate interface section off the main screen. A separate interface has been added to the user to perform sensitivity analyses by varying key input parameters (such as flow in the White River). Additionally, the interface includes instructions on the settings used to simulate baseline vs. proposal scenarios and the diversion scenarios included in the Remand ROE analysis.

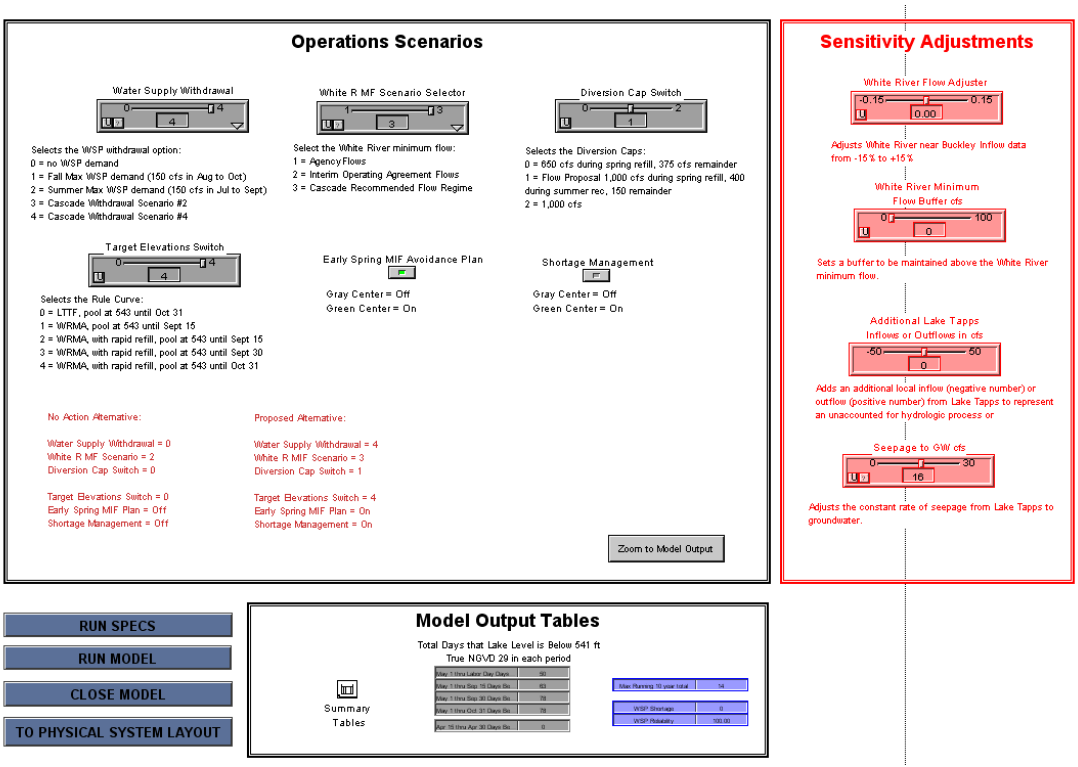


Figure 3 – User Interface Main Screen for the Remand ROE Model

3.2.1.2 Physical System Layout

The *Physical System Layout* module of the Remand ROE model is a schematic representation of key elements used to route water through the Lake Tapps system. The layout has been edited to include only those options used in the Remand ROE analysis. Major changes from the ROE model components and their interrelationships were typically made in the separate modules. The physical system layout view for the Remand ROE model is shown in Figure 4 below.

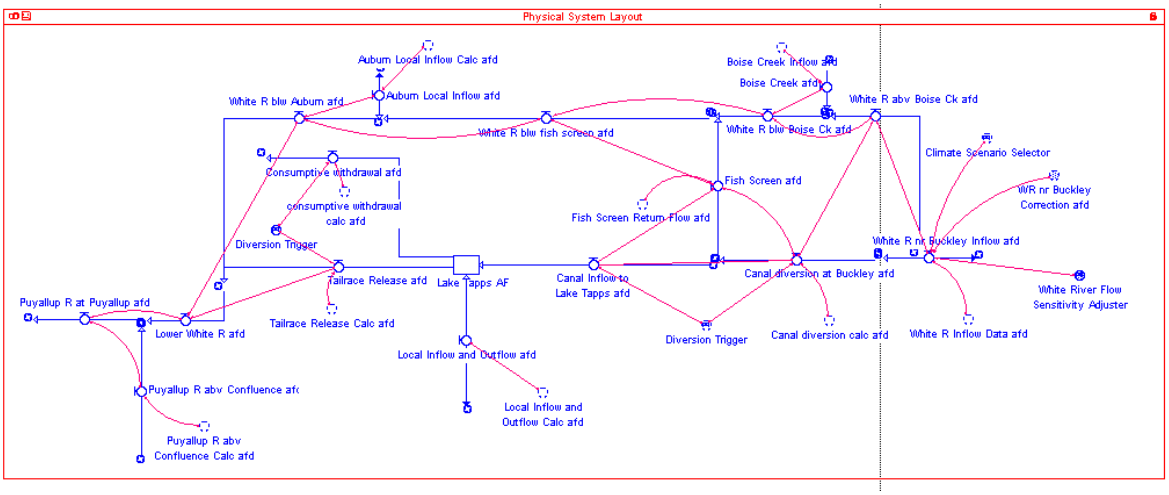


Figure 4 – The Physical System Layout of the Remand ROE Model

3.2.1.3 Canal Diversion

There are two primary canal diversion modules that are used to calculate the diversion canal flows in the model: the *Potential Diversion Calculations* module and the *Final Diversion Calculations* module. Previously these two modules provided three options for determining canal diversions based on historic records: USGS gage data, PSE's Accusonic gage data, or a water balance between upstream and downstream gages. A fourth option has been added that combines the gage data from the USGS and PSE by selecting on a day-by-day basis the data that appears most accurate for that day. This option was added concurrently with the White River near Buckley Correction series described in Section 3.2.1.5. The combined gage data (fourth option) was used in model validation runs, to see how accurately the model can match historic reservoir elevations and river flows. The other three data series remain in the model, but are not used for validation or predictive runs.

The model includes a final option for canal diversion that is used for predictive runs. The predictive run option calculates diversion from the White River according to rules selected by the user such as defining which minimum flow in the White River must be followed, how much flushing flow is needed to maintain water quality, caps on diversions from the White River, and which mitigation elements are included in the Proposed Action.

3.2.1.4 Local Losses and Gains in Lake Tapps

In prior versions of the model, local gains and losses occurring in Lake Tapps from processes such as evaporation, leakage, stormwater runoff, etc. were simulated by conducting a water balance based on calculated canal inflow and historical records of lake stage, and tailrace release. The resulting balance term fluctuated widely and did not always make physical sense (particularly on a day-to-day level). Multiple days had losses from the lake of more than 1,000 cfs. This variability impacted the accuracy of model results, particularly by under predicting diversion from the White River and over predicting tailrace releases.

In preparation of the Remand ROE, Ecology reevaluated the balance term and concluded that it would be appropriate to replace it with reasonable estimates of the gains and losses from the individual hydrologic processes occurring in the lake. A summary of the evaluation of the balance term and the development of the alternate approach are described below.

3.2.1.4.1 Evaluation of the balance term Used in Prior Analyses

The balance term was developed by R2 Resources, Inc. and is documented in their April 2004 memorandum. The original balance term was developed using an 11-year period of record. Ecology subsequently extended the period of record to 12-years and calculated the balance term for the additional year. The Lake Tapps balance term was calculated on a daily basis according to the following formula:

Balance Term = Δ Storage – Canal Inflow + Fish Return Flow – Tailrace Release

Storage and the tailrace release data are available from historic records. Records are also available for the canal diversion but the quality of the measurements during low flow periods are questionable. Instead, the canal inflow was calculated from the historical

records for the White River above and below the diversion dam according to the following formula:

Canal Inflow = White River near Buckley – White River at Buckley + Boise Creek.

The White River near Buckley gage is above the diversion dam and the White River at Buckley gage is below the diversion dam. Boise Creek enters the White River between the diversion dam and the White River at Buckley gage.

The calculation of canal inflow using the mass balance approach results in some flows that are unrealistic in that they are either negative or greater than the canal capacity. For the 12-year period, there are 357 days with unrealistic flows. These flows were corrected by substituting observed data from the PSE gage, if available. If data from the PSE gage were not available, then the USGS gage data were used.

The resulting balance term incorporates the effects of all hydrologic processes that are not separately included in the equation on page 11. Those processes include precipitation, evaporation, stormwater inflows, seepage to groundwater, groundwater inflows, irrigation or septic return flows, point source discharges, withdrawals, releases from Lake Tapps other than through the tailrace and fish return, etc. The balance term also includes error from the Lake Tapps stage gage, and the tailrace, White River, and Boise Creek flow gages. Finally, it also contains errors introduced from the stage-storage relationship for Lake Tapps.

The balance term varies seasonally and from day to day. Monthly averages are shown in Table 1 and range from -42 cfs in August to 138 cfs in December. The seasonal variation of the balance term is logical in that one would expect losses during summer from evaporation and seepage, and gains during winter from precipitation and stormwater. However, the variability through summer (some months are losses and others are gains) and the low November term are indicators of the influence of errors on the balance term.

Table 1 – Lake Tapps Balance Term by Month

	Lake Tapps balance term Statistics in cfs		
Month	Average	Minimum	Maximum
January	94	-3,075	1,955
February	112	-1,034	2,268
March	94	-954	1,356
April	23	-929	712
May	-14	-1,911	1,973
June	31	-609	772
July	-10	-775	535
August	-42	-625	609
September	2	-886	495
October	105	-1,126	1,381
November	27	-2,133	1,786
December	138	-1,484	1,785
Annual	46.4	-3,075	2,268

On a daily basis, the influence of gage error is more profound. The balance term ranges from -3,075 cfs up to 2,268 cfs. These values are not hydrologically realistic. The Lake Tapps stage gage is a likely source for the large day-to-day errors because a small change in stage represents a large inflow or outflow. The gage is also susceptible to erroneous measurements from wind effects or gage malfunction (i.e. the float becoming stuck). These conditions occasionally result in the appearance of a large inflow to lake followed the next day by a large outflow, or vice versa.

The concern with using the Lake Tapps balance term is that it treats the gage error as though it represents real water. This can lead to underestimating some impacts of the proposed water supply project and overestimating others. On average, the Lake Tapps balance term adds about 47 cfs as an inflow to the lake. That water is available in the model for satisfying the water supply withdrawal. To the extent that the 47 cfs represents gage error and not real water, use of it to satisfy the water supply withdrawal underestimates the impact of the project on lake levels and withdrawals from the Reservation Reach of the White River.

Use of the Lake Tapps balance term also results in overestimation of impacts to the reaches downstream of the tailrace. The model uses a rule curve to determine releases from the lake. If the balance term indicates a large inflow, and the lake elevation is at or above the target, then according to the rule curve the large local inflow would be released through the tailrace. The water supply project typically causes the reservoir to be below the rule curve during the late summer period. Under this scenario, large local inflows would be stored rather than released. When comparisons are made between the baseline and with project scenarios, storage of the large local inflow results in a decreased flow in the lower White and Puyallup Rivers. Previous model results using the Lake Tapps balance term indicated that the water supply project would cause impacts of up to 1,400 cfs in those reaches. That estimate is unrealistic, and is entirely a result of the Lake Tapps balance term.

It is important to note that the balance term approach was developed when the scenarios being evaluated, such as hydropower and full diversion, generally had more water routed through the lake. The balance term was more appropriate then, because the magnitude of the balance term was small relative to the canal inflows and tailrace releases. In addition, under those scenarios the Reservation Reach of the White River was not impacted by the Proposed Action.

3.2.1.4.2 Estimates of Individual Local Losses and Inflows to Lake Tapps

An alternative approach to the balance term is to estimate the physical processes that result in inflows to or outflows from the lake. The primary physical processes affecting lake storage are precipitation falling directly on the lake, stormwater runoff entering the lake or flow line, evaporation from the lake water surface, releases from the lake to maintain flow in Bowman creek, and seepage losses to groundwater. The five primary processes can be quantified using available climate records, basin characteristics, and hydrogeologic studies.

Leakage through the powerhouse valves and gates is included in the model, but was not included in the calculation of local inflows and losses, because leakage is directly measured by the tailrace gage. The tailrace gage records were used for model calibration

and validation, so including a separate term for valve leakage would double count its contribution. Valve leakage was estimated at 36 cfs on average (see Section 3.2.1.8) whenever water is not being intentionally released through the tailrace.

Several processes were not included in this approach because they are difficult to quantify or are thought to be insignificant quantities. Examples of processes excluded from the revised model are septic or irrigation return flows, shallow subsurface groundwater inflows to the Lake, non-stormwater point source discharges, and withdrawals from the lake for irrigation. Most of these processes (return flows, groundwater inflows, point source discharges) are inflows to the lake. All are thought to be relatively small and likely either somewhat cancel each other out, or result in a small net inflow whose exclusion from the model is conservative.

The Lake Tapps Systems Model simulates the period from 1988 to 2002 on a daily time step. Ideally, the individual processes would be quantified on a daily basis for the same period; however, data are not available from all sources for the full time period (i.e. evaporation data is only available until 1995, and the hydrologic model used to estimate stormwater inflows only simulates up to 1996). Daily data was used where available. Where data were missing, long-term monthly averages from the common period of record of the climate data sources (1961 to 1995) were used.

Details of the data sources and approach used for estimating each series are presented below.

3.2.1.4.2.1 PRECIPITATION

The amount of precipitation falling directly on the water surface of the lake was calculated by multiplying the historical daily precipitation values from a nearby weather station by the model's prediction of lake surface area. Lake surface area changes depending on the operations scenario, so the precipitation series will vary slightly between model runs.

The McMillin Reservoir precipitation gage (Coop # 455224) was chosen to represent site precipitation based on its proximity, period of record, and similar elevation. The McMillin Reservoir station is located at the City of Tacoma's drinking water storage reservoir about eight miles southwest of Lake Tapps. It is the closest long-term weather station to the Lake and is located at a similar elevation (579 feet for the weather station vs. ~540 feet for the Lake). The period of record for the McMillin Reservoir precipitation observations is 1948 to present.

Daily precipitation values from the historical record were used in the model. Missing records were replaced with zero if only one or two consecutive days were missing. Precipitation data for the entire month of August 1995 was missing, and was replaced with the long-term average precipitation for August.

3.2.1.4.2.2 STORMWATER INFLOWS

Stormwater inflows into Lake Tapps and the diversion canal were estimated using the Western Washington Hydrology Model 3 (WWHM), version 1.0, developed by Ecology. WWHM is a hydrologic model that simulates runoff based on historical climate data (precipitation and evaporation), basin area, land use, and soil properties. The stormwater

inflow series does not vary with lake operations, and therefore is constant between model runs.

The period of record for the WWHM simulation is 1948 to 1996. Because of the limited period of record, stormwater flows were estimated on a daily basis through 1996. After that, the long-term (1961-1995) monthly average was used.

According to a 2005 Watershed Characterization study published by the Washington State Department of Transportation (WSDOT), the subbasin area that drains to Lake Tapps, either directly or through the diversion canal, is 10,918 acres as shown in Figure 5.

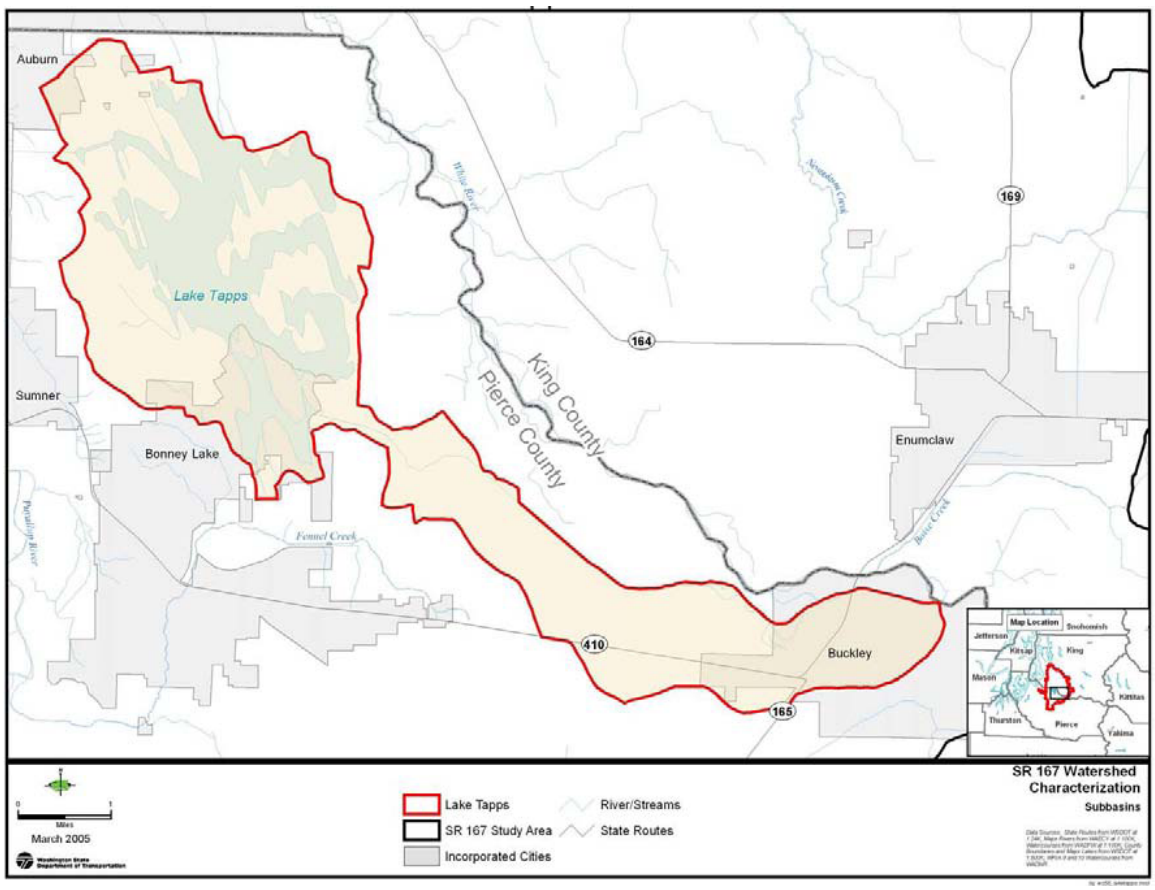


Figure 5 – The Lake Tapps Subbasin from WSDOT 2005

The WSDOT study also provided a breakdown of land use within the Lake Tapps basin (Table 2). As soils in the vicinity of Lake Tapps are typically tills or mudflow deposits (WSDOT 2005), all pervious land uses were simulated as occurring on till soils. The surface area of Lake Tapps was excluded from WWHM because it is already accounted for in the precipitation calculations described above. The standard WWHM soil property assumptions for pervious and impervious land types were used.

Table 2 – WWHM Model Input

Land Use	Percent of Basin	Area in Acres	WWHM Land Type
Water	19%	2,074	Excluded
Forest	21%	2,293	Till - Forest
Shrub/Grass urban	15%	1,638	Till - Grass
Shrub/Grass crop	18%	1,965	Till - Grass
Paved	9%	983	Impervious
Bare	1%	109	Till - Grass
Forest urban	17%	1,856	Till - Forest

3.2.1.4.2.3 EVAPORATION

Evaporation from the lake surface was estimated from historical observations of pan evaporation made at the Puyallup 2W Experimental Station (Coop# 456803), located in Puyallup approximately 8 miles west of Lake Tapps. The station is located at an elevation of 50 feet, about 490 feet lower than Lake Tapps, but is the closest pan evaporation station to the lake. As with precipitation, the quantity of water evaporating from the lake surface was calculated by multiplying the daily average evaporation by the lake surface area on that day and therefore varies slightly between scenarios.

Monthly averages of pan evaporation were calculated using total evaporation from all months with greater than 26 days of data. Pan evaporation was converted to evaporation from a free water surface by multiplying by a pan coefficient of 0.80. The pan coefficient was determined using Map 4 of NOAA Technical Report NWS 33 (1982). The monthly averages were converted to daily values by dividing by the number of days in the month.

The period of record for pan evaporation data is 1961 to 1995. During the later portion of the period of record, data were typically only collected for a few months in summer. Where data are available, actual monthly totals were used. Missing data were replaced with the long-term monthly average. Evaporation in January and December was assumed negligible.

3.2.1.4.2.4 SEEPAGE FROM LAKE TAPPS

Lake Tapps is an artificial water body located above the regional groundwater system. As such, water seeps from Lake Tapps to recharge groundwater. Pacific Groundwater Group used isotopic analysis of nearby wells to estimate seepage from the Lake (PGG 1999 as reported in TM 27, HDR & Golder Associates 2002). That analysis resulted in a range of seepage estimates from 3.7 to 22.4 cfs, with a mean of 13 cfs.

HDR and Golder Associates (TM 27, 2002) also estimated the variation in seepage rate throughout the year as a function of water surface elevation in the reservoir. They concluded that seasonal variations are about ±3 percent.

A value of 16 cfs, was used to represent losses from seepage in the Lake Tapps Systems Model. This value is slightly higher than the mean estimate with no seasonal variation. The sensitivity of the model to variations in seepage is evaluated in Section 7 of this report.

3.2.1.4.2.5 RELEASE TO BOWMAN CREEK

Approximately 1 cfs is released from Lake Tapps to supply water to Bowman Creek. The release is made through a pipeline located near the County Park. It generally occurs continuously throughout the year, except during periods of abnormally low reservoir elevation. For modeling purposes, the release was assumed continuous at 1 cfs.

3.2.1.4.2.6 DIKE SEEPAGE

The dikes forming Lake Tapps are designed to allow modest seepage. Although several dikes have v-notch weirs installed for measuring seepage, records of seepage measurements were not available from Cascade or PSE. Dike seepage of 0.25 cfs was included in the model based on an estimate from Cascade (Michael Gagliardo, pers. comm.). For simplicity, dike seepage was assumed to occur year-round, though it actually only occurs when the lake water surface is near full.

3.2.1.4.2.7 RESULTS OF THE LOCAL FLOWS APPROACH

The local flows approach results in a time series that varies from day-to-day and over the 15-year model period of record. The daily values in the series range from 37.5 cfs of water lost from the lake on hot and dry July and August days up to an inflow to the lake of 408 cfs during a large storm in November of 1995.

Monthly averages of the local flows time series are shown in Table 3and Figure 6. The net inflow/outflow series ranges from an average inflow of about 27 cfs in November to an average outflow of over 29 cfs in July and August. On average, the local flows approach results in an estimated 2cfs loss (outflow) from the lake.

Table 3 – Average Monthly Flows for the Local Flows Approach

	Monthly Average Flow in cfs						
Month	Precip.	Stormwater Inflows	Evap.	Seepage to GW	Release to Creek	Dike Seepage	Net Gain/Loss
Jan	12.9	19.3	0.0	-16	-1	-0.25	14.9
Feb	11.3	21.6	-1.5	-16	-1	-0.25	14.1
Mar	12.7	19.6	-3.4	-16	-1	-0.25	11.6
Apr	15.3	18.4	-7.2	-16	-1	-0.25	9.3
May	10.7	6.2	-12.2	-16	-1	-0.25	-12.5
Jun	8.8	5.5	-13.7	-16	-1	-0.25	-16.6
Jul	3.9	1.2	-16.9	-16	-1	-0.25	-29.0
Aug	2.9	1.1	-15.3	-16	-1	-0.25	-28.5
Sep	4.5	1.9	-9.9	-16	-1	-0.25	-20.7
Oct	13.1	3.3	-3.7	-16	-1	-0.25	-4.4
Nov	24.9	20.5	-1.7	-16	-1	-0.25	26.5
Dec	14.0	17.9	0.0	-16	-1	-0.25	14.7
Average	11.3	11.4	-7.1	-16	-1	-0.25	-1.7

Note: Negative numbers indicate outflows from the lake, positive number indicate inflow to the lake.

The local flows approach is not a static series like the balance term. The local inflows and outflows are calculated, in part, from the Lake Tapps surface area. The surface area changes between model runs depending on the scenario, so the series is not constant though the differences are minor. The results presented in this section are from the Baseline\No Action model run.

Comparison with balance term. A comparison of the monthly averages for the balance term and the local flows approach is shown in Figure 7. Both have similar seasonal patterns, but the balance term results in larger inflows through the wet season. Losses during summer are roughly similar, with the exception that the balance term is positive, on average, in June.

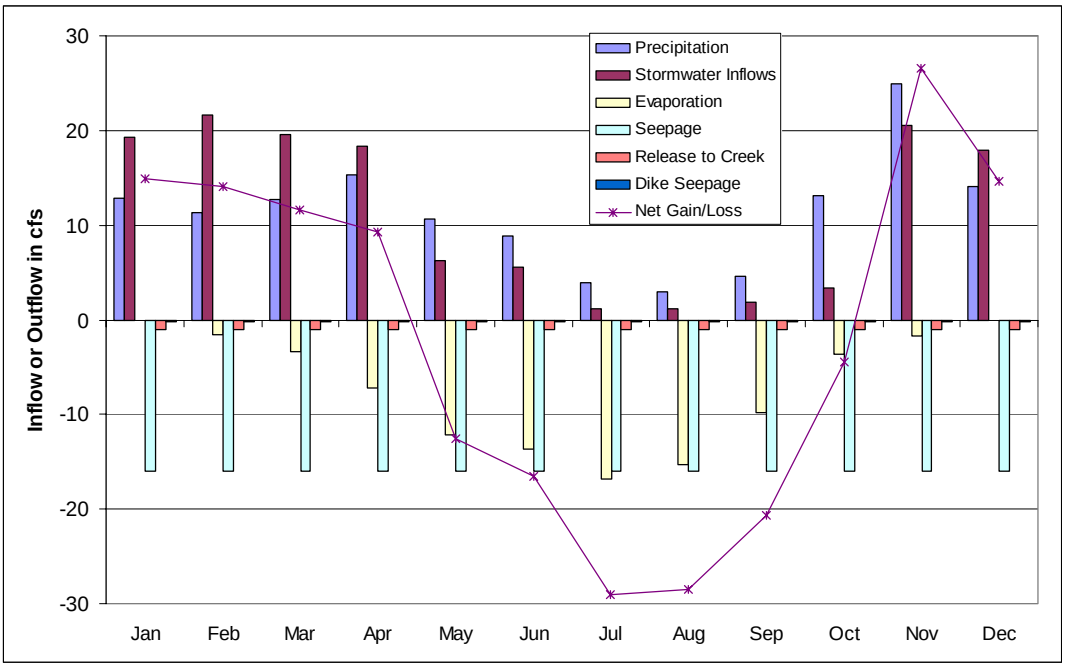


Figure 6 – Monthly Gains and Losses from Lake Tapps using the Local Flows Approach

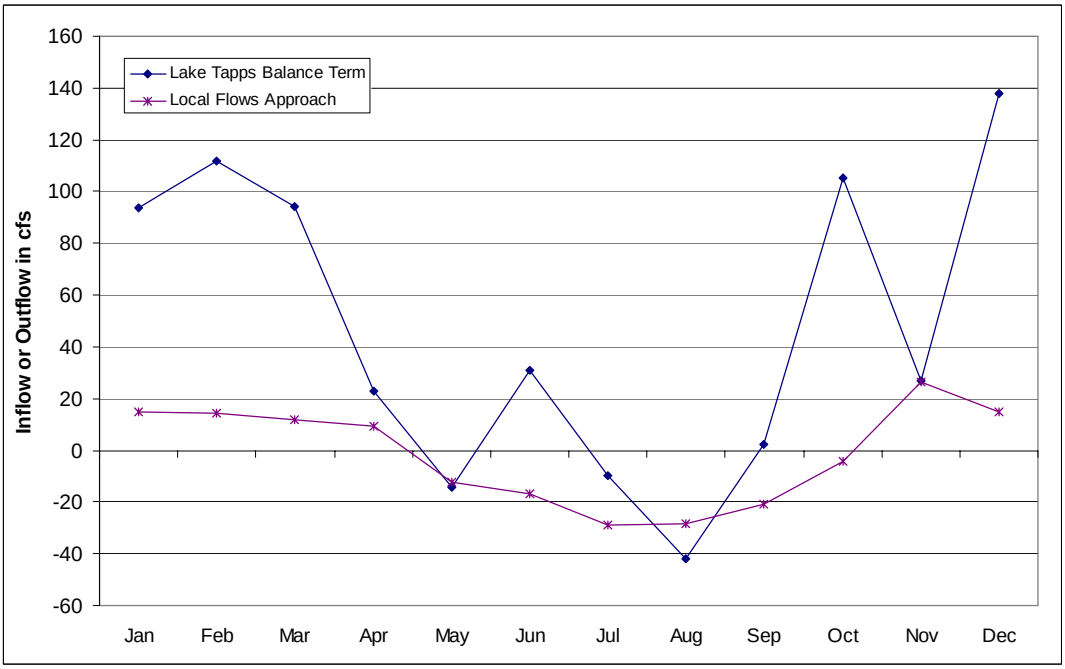


Figure 7 – Monthly Comparison of Balance Term and Local Flows Approach

Observed Losses During Periods of Low Diversion and Release

There have been several week- to month-long periods since 1988 when the lake has been operated with limited diversions and releases. These periods offer a chance to calculate directly the net gain\or loss from the lake with a minimum of gage error. A summary of lake balance calculations for 13 of these periods is shown in Table 4.

Table 4 – Lake Balance Calculations during Periods of Low Inflow and Outflow

Period	Length of Period in days	Canal Gage in cfs	Tailrace Gage in cfs	Change in Storage in cfs	Net Local Outflow in cfs
Jun 29 to Sep 25, 1988	88	0	6	-32	-25
Jul 8 to Aug 22, 1990	45	1.0	11	-33	-23
Aug 5 to 20, 1991	15	0.6	7	-30	-23
Aug 3 to 16, 1992	13	0	10	-39	-29
Sep 8 to 17, 1993	9	0	19	-56	-38
Sep 6 to 22, 1994	16	0	8	-33	-26
Aug 21 to 31, 1995	10	0	10	-43	-34
Aug 15 to 21, 1999	6	0	14	-32	-17
Sep 9 to 14, 2000	5	3.0	23	-37	-17
Aug 3 to 22, 2001	19	0.2	4	-44	-40
Aug 4 to 23, 2002	20	0	11	-37	-26
Jul 18 to Aug 14, 2003	27	0	27	-58	-31
Sept 8 to Oct 16, 2009	36	a	36	-44	-8

Notes:
a - assumed to be zero during this period of known outage (Michael Gagliardo, pers. comm). Some inflow may have occurred, but it was not measured as the USGS canal gage is no longer operational.

The average net local outflow for the July through August events (i.e., the first 12 rows in Table 4) is 27 cfs, which agrees closely with the 29 cfs average for July and August calculated using the Local Flows Approach. The close agreement lends confidence to the accuracy of the local flows approach for estimating losses from the lake in summer.

Similarly, the recent September and October period can be used to evaluate the accuracy of the local flows approach in early fall. This event had a net local outflow of 8 cfs, which is lower but generally consistent with the 12.5 cfs average for September and October from the local flows approach. This comparison suggests that model may be roughly accurate in estimating, and may slightly overestimate, lake losses in early fall.

3.2.1.5 White River near Buckley Correction Series

The upstream input time series for the model is the historical record from the White River near Buckley USGS gage. However, there are continuity problems when records from this gage are compared with records from gages located in the diversion canal, below the diversion dam, and from Boise Creek (the only significant inflow known to occur near the diversion dam). Ideally, the flow measured upstream would be equal to the flow in the diversion canal plus the flow in the river downstream of the diversion dam less the inflow from Boise Creek.

The gages involved in calculating a mass balance for the diversion dam are:

- Upstream: White River near Buckley (12098500), rated fair.

- Canal: White River Canal at Buckley (12099000), rated poor, and generally considered to have problems with low flows and backwater situations caused be high flows, or PSE's Accusonic gage which went online in January 1997 and measures velocity and stage so should not be as susceptible to backwater conditions.
- Downstream: White River at Buckley (12100000), rated fair, but generally thought to be more accurate because it relied on hydraulic control provided by the concrete structure protecting the Tacoma pipeline crossing.
- Boise Creek: Boise Creek at Buckley (12099600), rated fair except for flows above 200 cfs, which are poor.

According to USGS protocol (Rantz 1982), a rating of fair indicates that 95 percent of daily discharge measurements are considered to be within 15 percent of the actual flow. A poor rating indicates less than fair accuracy.

To improve the accuracy of the canal records, a time series was created that combined the USGS and PSE gage data by selecting on each day the measured flow that more closely agreed with measurements from the other gages. The combined series used the USGS gage records 60 percent of the time and the PSE gage 40 percent.

After creating the combined canal time series, a correction factor was calculated as the difference between the observed outflows and the sum of the inflows according to the following equation:

Correction Factor = White River at Buckley + Combined Canal – White River near Buckley – Boise Creek

The correction factor is applied to the White River near Buckley gage, and thus affects the total amount of water entering the system and available for diversion. Overall, the correction series ranges from -3,481 to 1,916 cfs with an average of 17.7 cfs. Eighty percent of values are between -160 and 160 cfs. There are only 77 days (1.5 percent of the period of record) where the magnitude of the correction factor exceeds 500 cfs (either positive or negative). These largest corrections typically occur during high flows. The average flow on days when the correction is greater than 500 cfs is 3,643 cfs. By comparison, the average river flow at the near Buckley gage is 1,445 cfs for the period of record. On average, the correction factor (17.7 cfs) represents an increase of 1.2 percent.

An example of the development of the White River near Buckley correction series is shown in Figure 8 for the spring and summer of 1994, a drought year. As shown in the figure, the White River near Buckley is typically higher than the calculated series in spring and early summer (particularly during periods of higher flow). Later in the summer, the observed record is generally lower than the calculated series. The resulting correction series is therefore negative in early spring and positive in the summer. For the period shown in Figure 8, the correction series ranges from -235 to 191 cfs with an average of 17.6 cfs. Approximately two thirds of the correction series values are between -100 and 100 cfs.

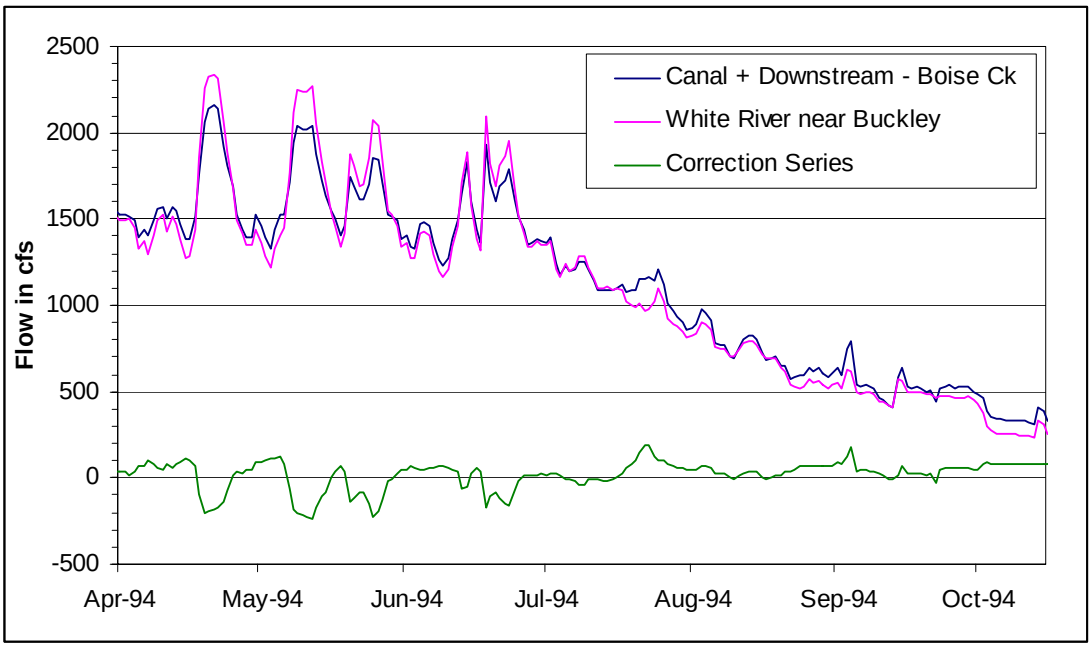


Figure 8 – White River near Buckley Correction Series in Summer 1994

3.2.1.6 Lake Level Elevation Datum

There has been confusion over the Lake Tapps water surface elevation data because there have historically been two different, but unfortunately similar, elevation datums. The USGS has reported elevations relative to both the direct stage gage readings, and what was thought to be the National Geodetic Vertical Datum of 1929 (NGVD 29). In 2009, Aero-metric re-surveyed the stage gage and identified that the elevations being reported by the USGS as NGVD 29 were over one foot higher than the actual NGVD 29. After performing a verification survey, the USGS concurred that the published water surface elevations were erroneous and corrected the historic water surface elevations (USGS 2009).

The Remand ROE model was revised to report results in the true NGVD 29 datum. Given the prior confusion over lake level datums, this report uses “feet true NGVD 29” to distinguish between the correct NGVD 29 datum and the data previously reported by the USGS as NGVD 29.

The relationships between the three datums are depicted on Figure 9, prepared by Aero-metric (2009), and are given by the following formulas:

True NGVD 29 = Stage Gage – 0.50 feet

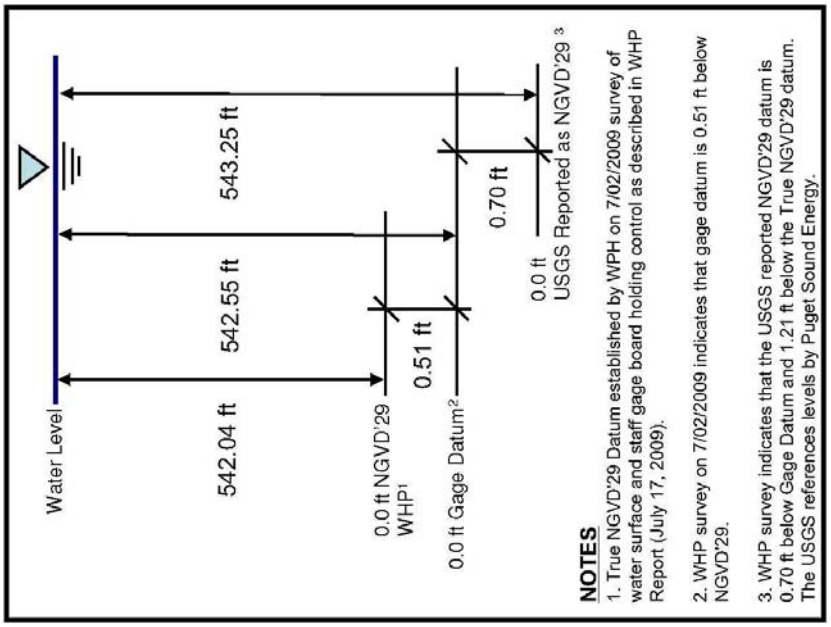
True NGVD 29 = former USGS NGVD 29 – 1.20 feet

Former USGS NGVD 29 = Stage Gage + 0.7 feet

Lake Tapps Reservoir

Comparison of Equivalent Water Levels*			
Normal Range of Full Pool	Aerometric[1] (True NGVD'29) (ft)	Gage Datum[2] (ft)	USGS Reported[3] (ft)
High	542.5	543.0	543.7
Low	541.0	541.5	542.2

*Refer to notes in Datum Sketch.



NOTES

1. True NGVD'29 Datum established by WPH on 7/02/2009 survey of water surface and staff gage board holding control as described in WHP Report (July 17, 2009).

2. WHP survey on 7/02/2009 indicates that gage datum is 0.51 ft below NGVD'29.

3. WHP survey indicates that the USGS reported NGVD'29 datum is 0.70 ft below Gage Datum and 1.21 ft below the True NGVD'29 datum. The USGS references levels by Puget Sound Energy.

DATUM SKETCH

Figure 9 – Comparison of Datums for Lake Tapps Water Surface Elevation (Aero-metric 2009).

3.2.1.7 Lake Tapps Storage-Elevation Relationship

The storage-elevation relationship plays an important role in the reservoir routing procedure used to calculate the Lake Tapps local inflow term, and in the simulation of Lake Tapps water levels. The Lake Tapps stage-storage relationship used in the previous versions of the model was provided by PSE and was based on lake bathymetry data from 1956.

In early 2009, Cascade and HDR conducted an aerial topographic survey of the lake to improve the storage-elevation relationship (HDR, 2009b). The survey was conducted during the winter, when the lake was drawn down to elevation 536.35 ft true NGVD 29. Information from the survey was used to update the Storage-Elevation relationship used in the model for elevations above 537 ft true NGVD 29 (the next contour above the water surface). Below that elevation, the original 1956 bathymetry data was used.

A comparison of the storage-elevation relationships from 1956 and 2009 is shown in Figure 10. The 2009 survey work indicated that there is slightly more storage capacity at higher reservoir elevations than shown in the 1956 bathymetry. At the elevation 542.5 ft true NGVD 29 (the upper end of normal full pool), active storage is 48,065 acre feet according to the 2009 relationship. This is 1,400 acre feet more than the active storage of 46,655 acre feet indicated by the 1956 relationship, a 3 percent increase.

The 2009 storage-elevation relationship was used in the Remand ROE model.

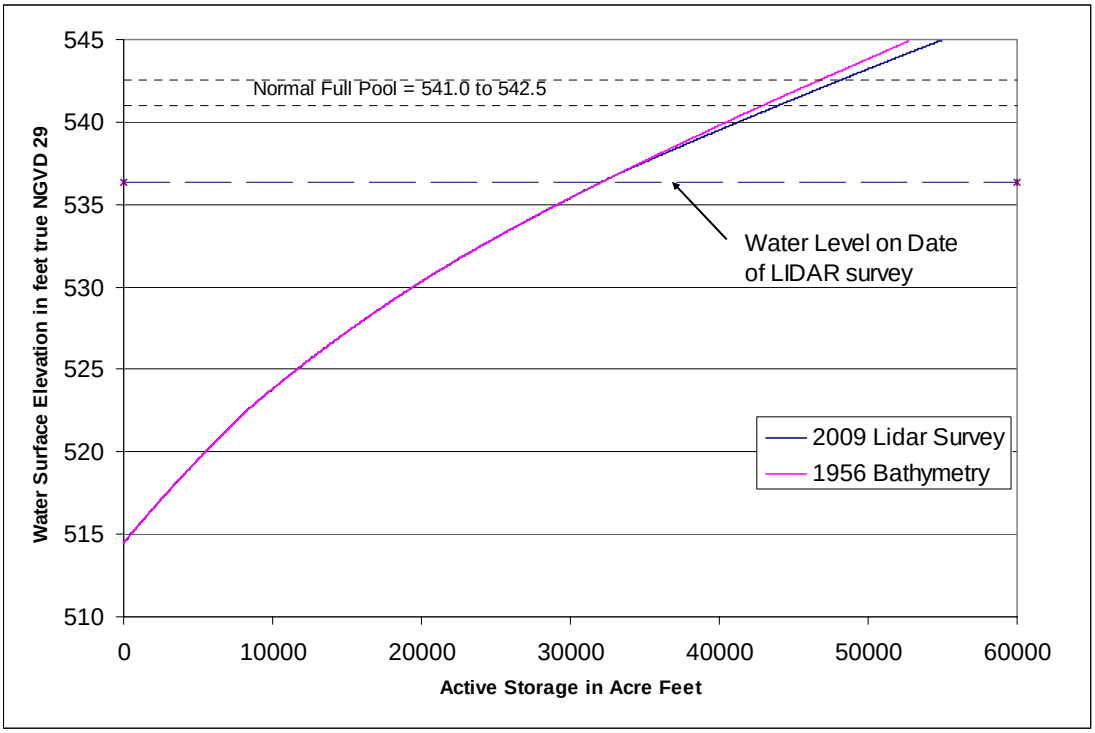


Figure 10 – Comparison of Storage Elevation Curves from 1956 Bathymetry and 2009 Lidar Survey.

3.2.1.8 Powerhouse Valve Leakage

The valves and gates in the powerhouse do not close tightly and leak some water into the tailrace whenever water is not being intentionally released. An average leakage of 36 cfs was included in the model for the baseline condition, based on analyses by HDR (2009). Valve leakage was assumed 0 cfs for the water supply scenarios, based on required improvements to the withdrawal structure and penstocks.

HDR (2009) used historical records from the tailrace gage to evaluate the magnitude of valve leakage using two approaches: 1) calculate the average flow from the complete record on days when flow was less than a threshold and there was no precipitation, and 2) calculate the average tailrace flow in August and September from 2005 to 2008. The first approach yielded an estimated leakage of 33 to 39 cfs (depending on the threshold). The second approach yielded an average leakage of 36 cfs.

3.2.1.9 Period of Record

The period of record for the Remand ROE model was extended to include water years 1988 through 2002. Previously the period of record of the model was 1991 through 2002 and was limited by the period of record of the Lake Tapps stage gage, which was a key component of the balance term. Elimination of the balance term allowed for extending the period of record back to 1988, when White River at Auburn flow records began. The White River at Auburn gage is used in the model to calculate the local inflow to the White River.

The 1988 to 2002 period of record is drier than average, particularly in summer and early fall. August is a critical month for operation of the system as water supply and recreation needs peak, snowmelt typically has ended and river flows are low. A comparison of average August flows in the White River is shown in Figure 11.

The hydroclimate categories developed by HDR (2002; TM 15) are also shown in Figure 11. The hydroclimate categories are:

Wet: greater than 75 percent exceedance (1.5 year recurrence)
Normal: between 75 and 25 percent exceedance (1.5 to 4-year recurrence)
Dry: between 25 and 10 percent exceedance (4 to 10 year recurrence)
Drought: less than 10 percent exceedance (less than 1 in 10 year recurrence)

These definitions were applied to August average flows to identify normal, dry and drought years. Based on August average flows, there are two dry years (1995 and 1996) and four drought years (1989, 1992, 1994, and 2001) in the period of record of the model. On average, a fifteen year period would have 2.25 dry years, and 1.5 drought years – or about 4 out of 15 years drier than normal. Our period has six drier than average years, and twice the expected number of drought years. In comparison, in the forty-nine years preceding the record used in the model (i.e. 1939 to 1987) there were 3 drought years and 7 dry years.

The model is conservative because it is based on a drier than normal period. Model results likely overstate the frequency that impacts would be expected to occur. If it were possible to use the full record of the upstream gage in the model, it is probable that the results would show less frequent impacts to water supply availability and October recreational levels.

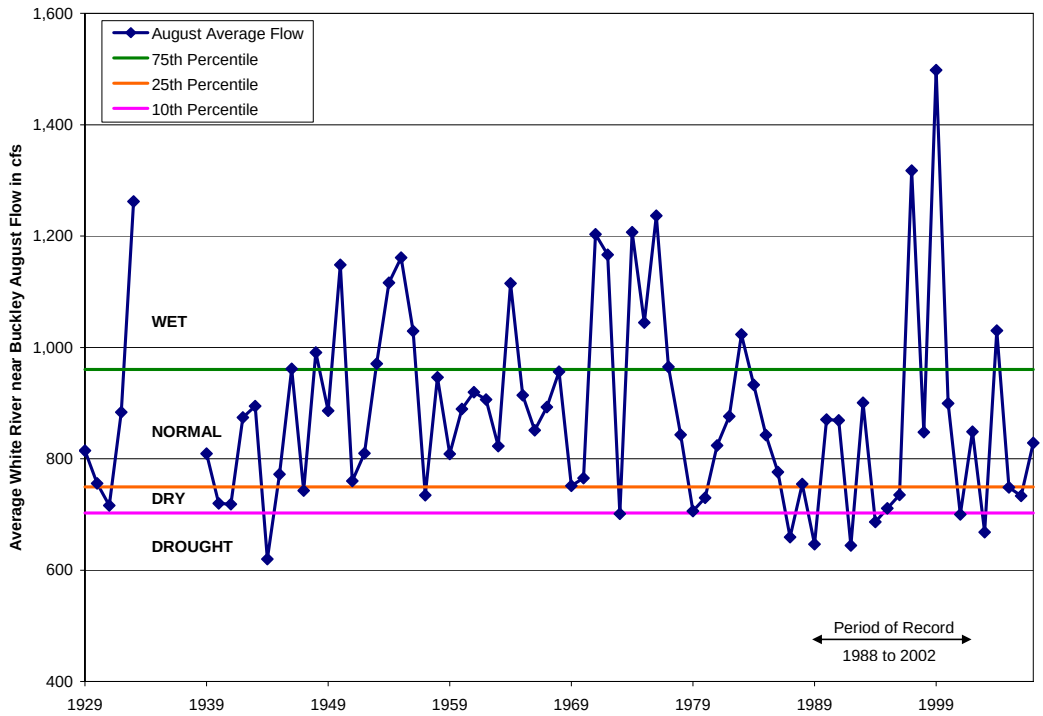


Figure 11 - Average Flow for August in the White River near Buckley

3.3 Water Quantity Model Validation

Model validation was performed to confirm that the Model was accurately simulating the water balance in Lake Tapps. The Model was validated by attempting to reproduce the historical record for Lake Tapps stage, by running the model with historical diversions from the White River and historical tailrace releases. If the Model accurately simulates the minor inflows and outflows, then the validation runs should reproduce the historical storage volume in the lake, or its surrogate, water surface elevation. If the model does not reproduce the historical storage volume, it could indicate issues with simulation of the minor inflows and outflows, or it could be caused by gage error in the historical data from the canal or tailrace gages. Since the model does not include a methodology for accounting for error in the Lake Tapps stage gage or tailrace gage, some divergence from the historical record is expected.

When a validation run under predicts the historic reservoir elevation it indicates that according to the historical record, more water entered the lake or less was lost from the lake then is predicted by the model. This could happen because one or more hydrologic processes are incorrectly represented (e.g., stormwater inflows are actually greater than predicted by WWHM) or it could happen because there are significant measurement errors in the historical record.

To test the accuracy during critical summer conditions, model validation runs were conducted starting on July 1 of each year. Results for each year are shown in Appendix A. Of the 15 years (WY 1988 to 2002) simulated, the model under predicted historic

storage in the critical summer period in 7 years, over predicted storage in 5 years, and more or less matched historic reservoir storage in 3 years. Examples of under, over, and accurate prediction of reservoir storage are shown in Figure 12.

Under prediction of historic reservoir storage, such as in 1991, could be caused by one or more of the following three reasons: 1) more water entered the lake then was predicted by the model, 2) losses from the lake were less than anticipated by the model, or 3) the gage error was biased toward under predicting inflows or over predicting outflows. Under prediction of storage is acceptable, because it indicates that the model is conservative. Under prediction means that the model is making less water available to the lake then indicated by historic records.

Over prediction of storage, like that shown for 1994, occurs for the opposite of the reasons listed above: 1) more water left the lake then was predicted by the model, 2) losses from the lake were greater than anticipated by the model, or 3) gage error was biased toward over-predicting inflows or under-predicting outflows. Over prediction of lake storage is more of a concern because it indicates that for those periods the model is making more water available to the lake then is indicated by historic records. However, it is uncertain if the error is in the historical records, or in the model assumptions.

When the model accurately predicts local inflows and outflows, and there is little error in the historic gage records, there is close agreement between the observed record and the model predicts (as occurs in 1988 and other years). The summer of 1988 was an important period because the canal was closed for several months in a row and tailrace releases were minimized. With little inflow from the canal and outflow from the tailrace, changes in lake level are caused by local inflows and outflows. During summer, the lake loses more water to evaporation, and seepage to groundwater and other minor losses then it gains from precipitation and stormwater inflows. The processes causing the losses do not change rapidly, so without inflow from the canal, the lake level decreases at a relatively constant rate. This can be seen in Figure 12 between July 1 and the last week of September. The model very accurately reproduces the decline in water levels during this period (the validation run plots almost exactly on top of the historical data in Figure 12), which adds confidence that it is appropriately simulating the lake inflows and outflows.

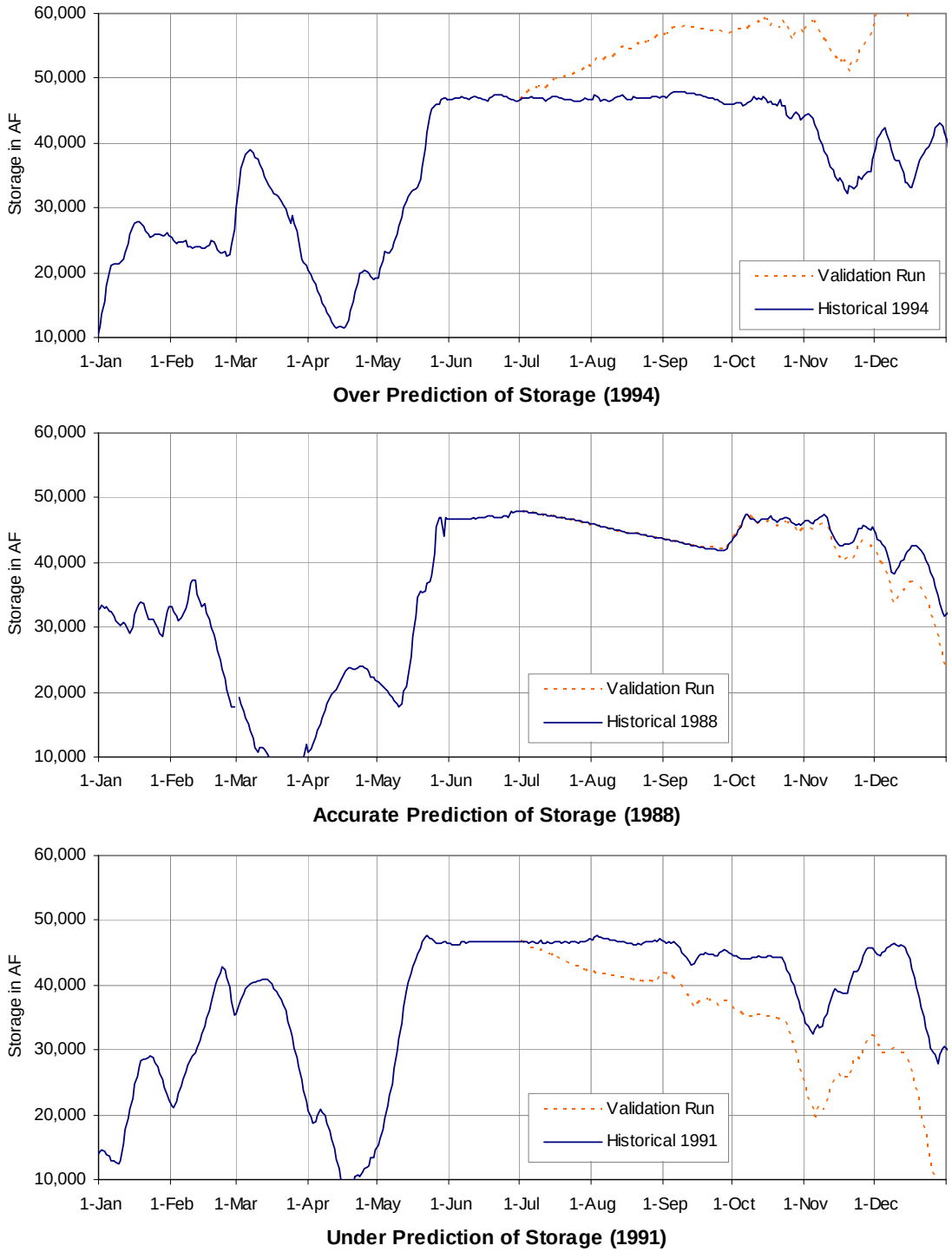


Figure 12 – Model Validation Results from 1988, 1991, and 1994.

Next, we examined validation results for each year to look for patterns with climate conditions. We found that there appears to be no real pattern between model validation results and the hydrology in a particular year (Table 5). In our analysis, the first step was to assign each water year a hydroclimate category (wet, normal, dry or drought – see Section 3.2.1.9) indicating the

amount of flow in the White River near Buckley using information presented in TM 15 (HDR 2002). For model validation, we looked at annual flow, spring 7-day low flow, and fall 7-day low flow for defining normal, dry and drought conditions.

Table 5 – Model Validation Results by Water Year

Water Year	Annual Water Yield	7-Day Spring Low Flow	7-Day Fall Low Flow	Model Validation Results for Summer
1988	Dry	Normal	Normal	Accurate
1989	Normal	Normal	Dry	Under Prediction
1990	Normal	Wet	Normal	Under Prediction
1991	Wet	Normal	Dry	Under Prediction
1992	Dry	Normal	Dry	Under Prediction
1993	Dry	Dry	Normal	Over Prediction
1994	Drought	Wet	Drought	Over Prediction
1995	Normal	Normal	Normal	Over Prediction
1996	Wet	Normal	Normal	Accurate
1997	Wet	Dry	Wet	Over Prediction
1998	Normal	Normal	Dry	Accurate
1999	Wet	Wet	Normal	Slight Over Prediction
2000	Normal	Normal	Wet	Accurate
2001	Drought	Drought	Drought	Slight Under Prediction
2002	Normal	Normal	Wet	Under Prediction

The model under predicted reservoir storage in summer in wet, normal, dry and drought water years. It over predicted reservoir storage in wet, normal, dry and drought years. Consequently, there is no correlation between model validation results and climate condition. The most accurate predictions occurred in dry, normal, and wet years. Since local inflows and outflows to the lake should be similar between years with similar climate conditions (e.g., evaporation from the lake in summer should be roughly the same from one drought year to another), the lack of correlation between validation result and climate scenario eases the concern that hydrologic phenomena are not being simulated correctly and suggests that gage error may be largely responsible.

In the majority of years (10 of 15 water years) the model validation runs either accurately predicted, or under predicted storage in the lake. Both of these results indicate that the model is acceptable for use, since under prediction is a conservative result (less water available). The years where validation runs over-predict historical storage are of greater concern because they indicate that the model under simulating losses or overestimating inflows. Or, of course, the error could be in the historical gage records used to drive diversions or releases in the validation run.

Of the four years where the model more than slightly over-predicts storage, two (1995 and 1997) were normal or wet years, and over-prediction is less of a concern. The two remaining years of over-prediction (1993 and 1994) were dry or drought years and the over-prediction warrants further investigation. Figure A-6 in Appendix A shows the validation results for WY 1993. The model diverges from observed storage in early July, stabilizes for a bit, then continues to diverge dramatically in August. An additional outflow from the Lake of between 100 and 150 cfs (shown by the green balance term line in the lower graph) would have been required in order to match reservoir levels throughout August, then the outflow would need

to cease suddenly in early September. Similarly, Figure A-7 shows the validation results for WY 1994. The model diverges from observed storage on July 1, and continues diverging steadily through the first week of September when it stabilizes. An additional outflow of over 100 cfs would have been necessary to match the historical storage. Additional outflows of this magnitude that start and stop suddenly are not hydrologically realistic, and more likely represent the magnitude of gage error occurring at that time.

The concern that the model is misrepresenting physical processes is allayed by the lack of relationship with climate conditions that explains the years where it was not conservative. It would be a concern if the model over predicted storage only in drought years, or in years with low flows in fall, but that is not the case. The lack of relationship in model validation results with climate conditions, coupled with the close agreement between and observed losses during periods of low inflow and outflow (see Section 3.2.1.4.2.7), strongly suggest that gage error is the largest driver behind poor model validation in some years.

Overall, the validation results support that the model is acceptable for use (and likely conservatively over estimates losses from the lake in summer); however, some caution should be applied in interpreting results from years where validation runs over predicted historic storage.

4 Framework for Water Quantity and Water Quality Analyses

Evaluation of environmental effects of a project requires establishing a point of reference, or baseline condition, from which to measure the proposed changes. The baseline condition should represent what would most likely occur if the proposed project did not go forward. For many projects, the baseline condition is easily established as either the existing conditions of the project site, or its historical operations. The baseline condition is not as easily defined for the Lake Tapps Water Supply Project (Proposed Action) as the historical operations of Lake Tapps for hydropower have recently ceased, and the project is currently operating under interim and temporary agreements.

For evaluation of the Proposed Action, the baseline condition was selected as the continued maintenance of Lake Tapps for water quality and recreational uses under the anticipated conditions of the change to the hydropower water right (see Section 1.4). The detailed assumptions and operating rules that comprise the baseline condition are outlined in Section 4.1.

The basic framework for the water quantity and quality analyses is a direct comparison of pairs of model runs that represent 1) the baseline condition and 2) a with water supply scenario. The set of assumptions and operating rules used to simulate the proposed action are detailed in Section 4.2.

The water quantity and quality analyses presented in this report will be used in the Reports of Examination for the four water right applications (see Section 1.3) prepared by Ecology, and in the Environmental Impact Statement (EIS) for the project prepared by Cascade Water Alliance. In the EIS, the baseline condition will be referred to as the No Action alternative.

There are varying levels of uncertainty in the set of assumptions and operating rules that define the baseline condition and proposed action. Some are well-defined, such as the minimum flows, target reservoir levels, and diversion limits proposed by the applicant. Others elements are either variable, or uncertain, such the design and performance of the U.S. Army Corps of Engineers' (USACE) planned replacement of the diversion dam, or the amount of stormwater inflows entering Lake Tapps, or seepage leaving the lake to recharge groundwater, or the future effects of climate change. The potential effect of these uncertainties was incorporated in a sensitivity analysis (Section 7) that examined three components of uncertainty:

1) uncertainties with the proposed operations such as the timing of water supply withdrawals,
2) uncertainties with hydrologic processes or infrastructure performance, and
3) the potential effects of climate change.

4.1 Baseline Condition

As described above, the baseline condition is intended to represent the continued maintenance of Lake Tapps for water quality and recreational uses under the conditions of the change to the hydropower water right. This condition is thought to represent what is most likely to occur if the Proposed Action does not happen.

The specific assumptions and operating rules used to simulate the baseline condition are described below, with the source of some elements identified in parentheses:

Diversion:

- Diversions from the White River are allowed for water quality, reservoir maintenance, and recreational uses.
- Diversions are capped at 650 cfs during the refill period and 375 cfs for the remainder of the year.
- Diversion of up to 20 cfs is allowed to operate the fish screen, regardless of the flow in the White River.
- All other diversions from the White River must comply with the minimum flows established under an Interim Operating Agreement with USACE (see Section 4.1.1). These flows vary throughout the year from 350 to 500 cfs.
- Water is diverted for recreational use to meet or maintain the target reservoir elevation.
- Water is not normally diverted to maintain lake water quality. Under the conditions of the change to the Puget Claim, a water quality study would be performed to determine if diversions are necessary to maintain lake water quality. In lieu of the results of that study, it is assumed that diversions for water quality (i.e., flushing flows) are not necessary.
- The White River diversion dam will be replaced with a more efficient structure.

Lake Tapps Water Levels:

- The lake is operated to maintain Normal Full Pool at 542.5 feet true NGVD 29 from April 15 to October 31.
- Fall drawdown occurs from November 1 to December 15.
- Winter low pool of 529.5 ft true NGVD 29 is maintained from December 16 to the end of February.
- Refill starts on March 1 and continues until the lake reaches Normal Full Pool, or June 15, whichever is earlier.

Tailrace Releases:

- Tailrace releases occur primarily in fall to draw the lake down to prevent aquatic plant growth in Lake Tapps, and for maintenance, but may also occur anytime throughout the year to maintain lake levels in the target range.

- Leakage through the tailrace continues to occur at a rate of 36 cfs (see Section 3.2.1.8).

Additional details about two key elements of the baseline condition (White River Minimum Flow, and Lake Tapps Water Levels) are provided below.

4.1.1 White River Minimum Flow

PSE and USACE have established an Interim Operating Agreement identifying minimum flows for the White River below the diversion dam as shown in Table 6. These flows apply at the White River above Boise Creek at Buckley gage (USGS 12099200).

Table 6 – Interim Operating Agreement Minimum Flow

Month	Flow (cfs)	Month	Flow (cfs)
January	350	July	500
February	350	August	500
March	350	September	500
April	400	October	500
May	400	November	350
June	400	December	350

4.1.2 Lake Tapps Reservoir Operations

The Baseline Condition assumes that the lake would continue to follow the annual pattern of being full in summer for recreation, drawdown down in fall and kept at a lower level through winter for maintenance and milfoil control, and refilled in spring. The model uses a fixed minimum and maximum elevation targets for each day of the year (termed a "rule curve") to simulate this seasonal pattern of water levels. If water levels are above the maximum elevation target, the model releases water and/or curtails diversions until the target elevation is met. If water levels are below the minimum, the model increases diversions and/or curtails releases until the reservoir is at the target elevation.

Slightly different rule curves are assumed for the Baseline Condition and Proposed Action as shown in Figure 13. The Baseline Condition assumes that the lake would be operated in accordance with the March 31, 2004 agreement between PSE and the Lake Tapps Community. That agreement establishes a normal full pool elevation of 541.0 to 542.5[4] feet true NGVD 29 from April 15 through October 31 to allow recreation.

[4] The normal full pool elevations in 2004 Lake Tapps Homeowner's Agreement were based on direct reading of the stage gage rather than NGVD 29. The target elevation range of 541.0 to 542.5 feet true NGVD 29 used in the model corresponds to 541.5 to 543 feet range in stage

The 2004 agreement does not specify lake levels outside of setting the normal full pool level and duration. For modeling purposes, we developed a rule curve for fall, winter, and spring based on the historical pattern of operations. Starting in November, the reservoir was assumed to be drawn down to an elevation of 529.5 feet, where it would remain through winter. The winter low pool allows for control of aquatic plants and maintenance of levees. Spring refill begins in March to reach normal full pool by April 15.

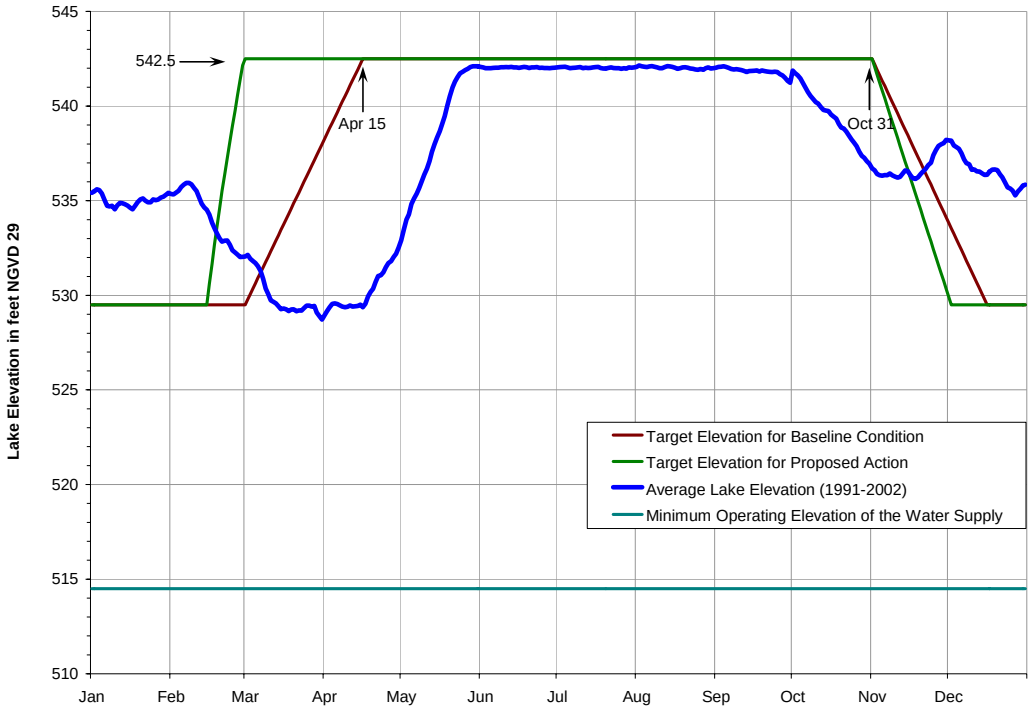


Figure 13 – Lake Target Elevations for Baseline Condition and Proposed Action

4.2 Proposed Action

The water right applications, if approved, would allow the Proposed Action to withdraw water from Lake Tapps at a maximum instantaneous rate of up to 135 cfs not to exceed an annual withdrawal of 54,300 acre feet (or 75 cfs). The water would be treated, conveyed in a regional transmission system and put to consumptive use as a municipal, commercial, and industrial water supply.

This section describes how the water supply withdrawal was simulated in the Remand ROE Model.

in the 2004 agreement. See Section 3.2.1.6 on page 21 for more information about relationship between datums used for the Lake Tapps water surface elevation.

4.2.1 White River Minimum Flow

The Proposed Action includes a minimum flow regime for the White River at the diversion dam (termed the Cascade Recommended Flows) to protect instream resources in the White River Reservation Reach. The Cascade Recommended Flows are based on the White River Management Agreement between Cascade and the Puyallup and Muckleshoot Tribes.

The Cascade Recommended Flows are equal to or higher than any of the previous minimum flows enacted or proposed for operation of the White River diversion dam. The Cascade Recommended Flows range from 500 cfs for August 7 through October 31 (and also late February) to 875 cfs in May as shown in Table 7. These flows are compared with the Interim Operating Agreement flows assumed for the Baseline Condition in Figure 14.

Table 7 - Cascade Recommended Flows

Time Period	Minimum Flow in cfs	Time Period	Minimum Flow in cfs
January 1-14	650	July 1-23	800
January 15-31	525	July 23 - Aug 6	650
February 1-14	550	August 7-14	500
February 15-29	500	August 15-31	500
March 1-14	550	September 1-14	500
March 15-31	725	September 15-30	500
April 1-14	775	October 1-14	500
April 15-30	825	October 15-31	500
May 1-14	875	November 1-14	500
May 15-31	875	November 15-30	550
June 1-14	800	December 1-14	550
June 15-30	800	December 15-31	600

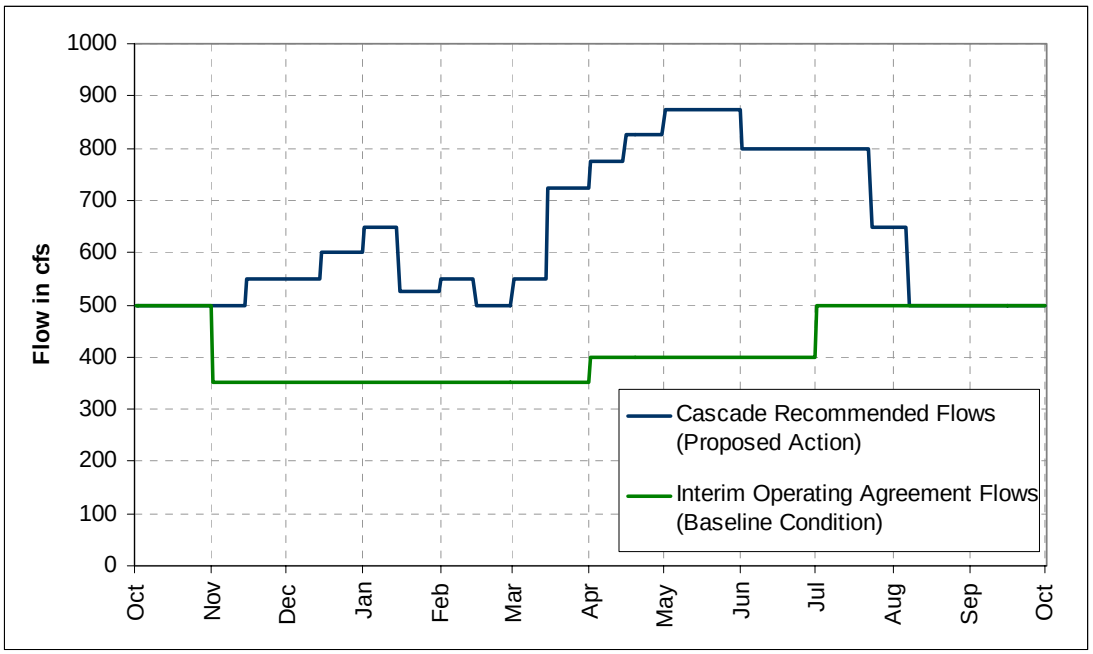


Figure 14 – Minimum Flows for the White River Reservation Reach

4.2.2 Diversion Caps

The following caps on diversions from the White River were incorporated into the model for the Proposed Action:

- 1,000 cfs from February 15 until the reservoir reaches normal full pool or July 1, whichever is earlier.
- 400 cfs from the end of spring refill through October 31 or the start of fall drawdown, whichever is earlier.
- 150 cfs for the remainder of the year.

These diversion caps were established in the White River Management Agreement between Cascade and the Puyallup and Muckleshoot Tribes.

4.2.3 Water Supply Withdrawal

The model includes three main scenarios for the seasonal pattern of water supply withdrawals: a realistic seasonal pattern of withdrawals based on recent water use data, and two peak scenarios that represent worst-case for recreation and aquatic resources. The three scenarios are compared in Figure 15. Most of the modeling work presented in this report, including the evaluation of the Proposed Action in Sections 5 and 6, used the realistic withdrawal pattern. The peak withdrawal scenarios are used in the sensitivity analyses in Section 7.1.1.

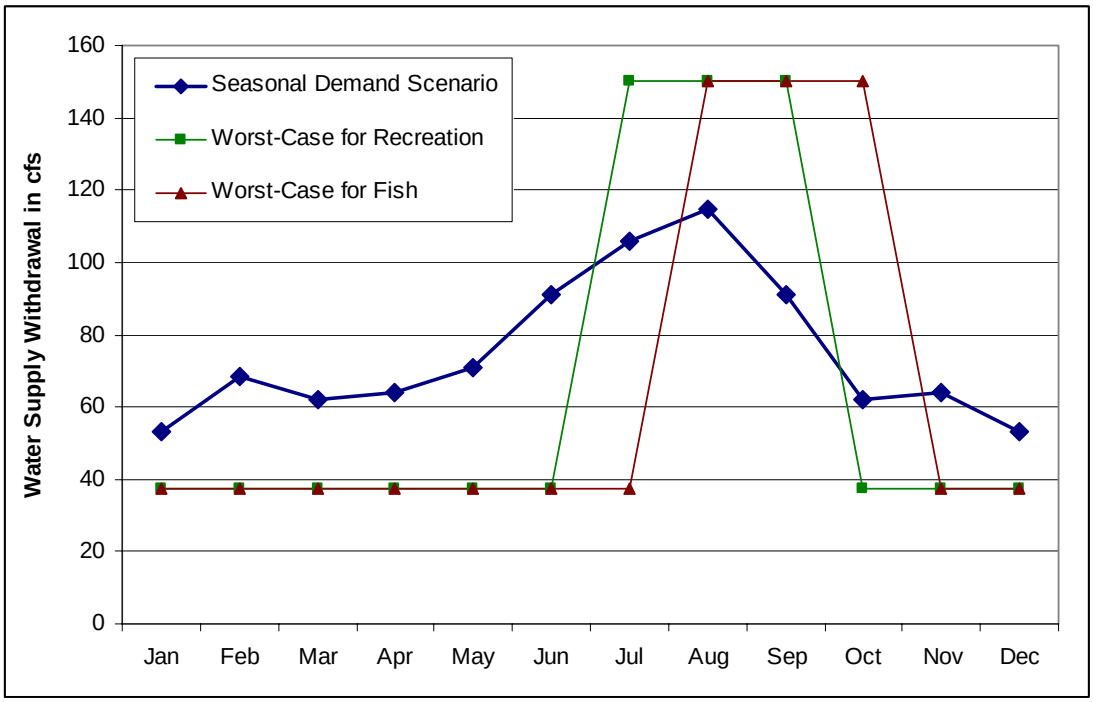


Figure 15 – Water Supply Withdrawal Scenarios

The seasonal demand scenario was developed by Aspect, based on information provided by Cascade on the actual percent of annual water consumption by Cascade members occurring in each month (Gagliardo 2009). Those monthly percentages were applied to the 75 cfs average annual withdrawal of the water right applications to calculate monthly average withdrawals. The resulting series ranges from 53 cfs in January and December up to 115 cfs in August.

The worst-case scenarios have been a component of the modeling analyses since the Preliminary Permit model. They each include three consecutive months of withdrawal at 150 cfs, the original maximum rate in the application for the withdrawal water right[5]. The worst-case for recreation assumes maximum withdrawals in July through September, the key summer recreation period. The worst-case for fish assumes maximum withdrawals in August through October, when river flows are lowest and Pink, Coho and fall Chinook salmon are migrating upstream and spawning. Withdrawals during the remainder of the year in both scenarios are constant at 37.2 cfs, which was calculated to yield an annual average of 75 cfs.

4.2.3.1 Shortage Management

The Proposed Action also includes a shortage management plan to reduce water demand during periods of shortage. The shortage management plan would include different stages

[5] Cascade has subsequently scaled back the maximum instantaneous withdrawal rate to 135 cfs. This change was made after analysis of the 150 cfs scenarios was completed. This change adds additional conservatism to these scenarios.

of response, depending on the severity of the water shortage. Stage 1 and Stage 2 shortage management were included in the model based on information provided by Cascade on the probable percent reductions in demand in each month (Gagliardo 2009). The pattern of monthly water supply withdrawals under normal conditions, and Stage 1 and Stage 2 shortage management is shown in Figure 16. This information was developed by Cascade based on reductions in demand achieved by regional water suppliers when shortage management plans were used in recent droughts (e.g., 1989 and 2001).

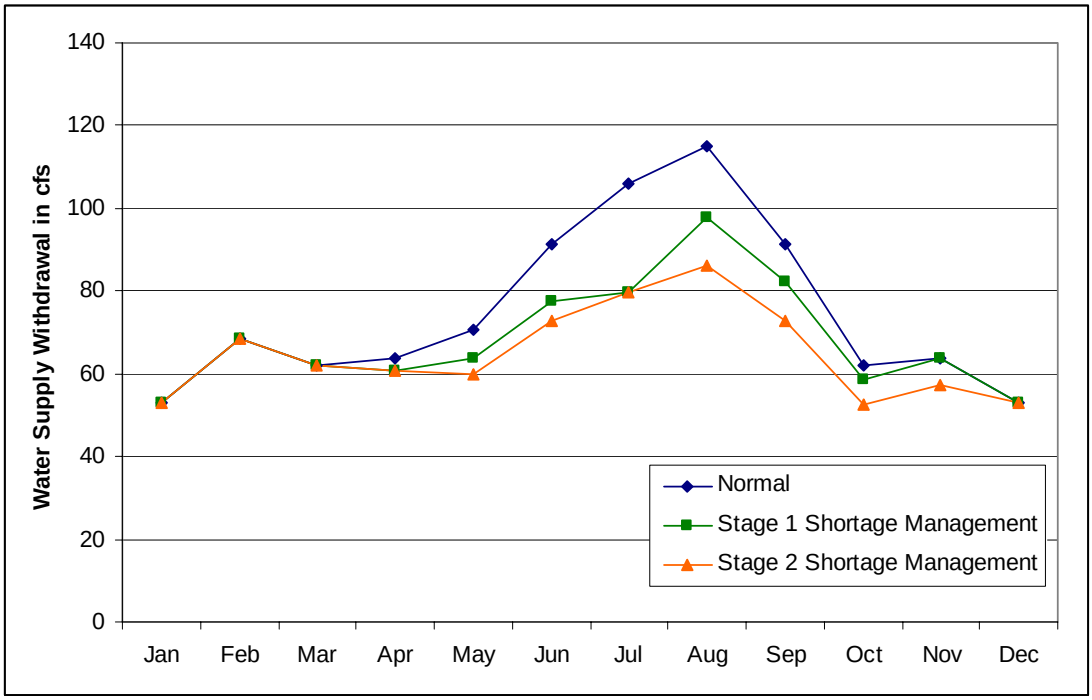


Figure 16 – Water Supply Withdrawals during Shortage Management

Stage 1 shortage management was applied in dry years, which were defined as years when the average flow in August and September was below the 75th percentile and above the 90th percentile. The model period of record had two dry years – 1995 and 1996 and Stage 1 shortage management was applied in both years. It affects water supply demand in April through October, with a maximum reduction of 25 percent in July.

Stage 2 shortage management was applied in drought years, which were defined as years when the average flow in August and September was below the 90th percentile. Stage 2 shortage management was applied in the model in the fours years (1989, 1992, 1994, and 2001) that met this definition. Stage 2 affects water supply demand in April through November, with a maximum reduction of 25 percent in July and August.

4.2.4 Lake Tapps Reservoir Operations

Simulation of the Proposed Action assumes an annual pattern of reservoir water surface elevations based on the agreements with the Lake Tapps Community Council and the Puyallup and Muckleshoot Tribes. The effects of those agreements on Lake Tapps operations were simulated as the following target elevations:

Recreation Season: Attempt to maintain 542.5 feet from April 15 to October 31.

Fall Drawdown: Steady reservoir drawdown starting November 1 and ending at elevation 529.5 feet true NGVD 29 on December 1.

Spring Refill: Rapid refill of the reservoir starting February 15 at the maximum rate allowed by the diversion cap of 1,000 cfs. If sufficient water is available, the reservoir could be full by early March, however this seldom occurs.

Winter Lowpool: Maintain a reservoir elevation of 529.5 ft true NGVD 29 from December 1 to February 15.

The "rule curve" or seasonal pattern of target reservoir elevations for the Proposed Action is shown in Figure 13.

The model assumes that the operator attempts to maintain reservoir elevation at the upper end of full pool, 542.5 feet true NGVD 29. Feedback from Lake Tapps homeowners indicated that a slightly lower elevation (around 542 feet) is currently preferred for recreation. To maximize the use of storage in the normal full pool range, the operator would need to bring the reservoir to the upper end of full pool prior to the critical dry period. Realistically, they may elect to maintain the slightly lower elevation in spring and early summer and bring the reservoir to full just at the end of snowmelt and the start of the dry season. In some normal or wet years, the operator may elect to maintain the lower elevation all year round. Rather than attempt to capture this complexity in the model, we assumed that the reservoir was kept full. This is a slightly non-conservative assumption, but not unreasonable as a skilled operator could likely predict flows during the snowmelt period sufficiently in advance to be able to reliably refill the last half foot of the reservoir in July.

4.2.4.1 Withdrawal Priority

The Proposed Action was simulated with the following priorities for water use in the system when insufficient flow is available to meet all needs:

1. Diversion Canal Fish Screen
2. White River Minimum Flow
3. Recreational Lake Levels (from April 15 to September 30)
4. Water Supply Withdrawals
5. Maintain Lake Levels (from October 1 to April 14)

The relative priority of maintaining lake levels and the water supply withdrawal changes throughout the year and was determined based on Cascade's agreement with the Lake Tapps Community Council. From April 15 to September 15, maintenance of recreation lake levels at normal full pool has priority over withdrawals for water supply. No water may be withdrawn for water supply if the reservoir is not above 541.0 feet true NGVD 29.

From September 16 to September 30, maintenance of lake levels is still a priority over water supply withdrawals, however the agreement allows for the lake to be below

recreational levels on 10 percent of days in that period. Cascade's agreement with the Lake Tapps Community Council specifies that compliance will be measured by the 10-year running total of days below 541.0 feet true NGVD 29. While this total is less than 15 days[6], water may be withdrawn for water supply regardless of the lake elevation. Once this total reaches 15, water may only be withdrawn if the lake level is above 541.0 feet true NGVD 29.

From October 1 to April 14, water supply withdrawals are a higher priority than maintenance of lake levels.

4.2.5 Puyallup River Minimum Instream Flow Mitigation

The proposed water rights for the Proposed Action would be junior to the Puyallup River Minimum Instream Flow (WAC 173-510-030). To avoid impairing low flows in the Puyallup River during the period when the project has the highest potential to affect flow, the Proposed Action includes a mitigation component called the Early Spring MIF Avoidance Plan. Under this plan, diversions from the White River would be reduced from February 15 to March 31 on days when flow is below the Puyallup MIF. Diversions would be reduced by the lesser of the amount of the water supply withdrawal that day or the amount necessary to meet the MIF.

[6] There are 15 days from September 16 and September 30, inclusive. In 10 years, there are 150 days in that period. Ten percent of 150 gives 15 days when the lake may be below the recreational level.

5 Water Quantity Evaluations

The water quantity evaluations were focused on model runs simulating 1) the Baseline\No Action scenario and 2) the Proposed Action scenario. The model predicted flows in the Reservation Reach, Lower White River and Puyallup River, Lake Tapps water levels, and the amount of water available for water supply withdrawals under the two scenarios. Key results are presented below and are generally organized by location in the basin and priority of water use. Detailed results for the Baseline\No Action and Proposed Action scenarios are included in Appendix B.

Additional water quantity model runs were also performed to examine the sensitivity of the model to various uncertainties. The sensitivity analyses and results are discussed in Section 7.

5.1 White and Puyallup Rivers

5.1.1 Annual Average Flows

A comparison of annual average flows provides a clear indication of which reaches would be affected by the Proposed Action, and the overall magnitude of that impact. Annual average flows at various points in the watershed calculated for the Baseline and Proposed Action scenarios are shown in Table 8. The Proposed Action would reduce the flow in the White River below the tailrace and the Puyallup River below the confluence by the amount of the water supply withdrawal. However, the Reservation Reach is affected differently than the reaches downstream of the tailrace.

Table 8 – Average flows

Scenario	Annual Average Flow in cfs (WY 1988-2002)				
	White River Reservation Reach	Canal Diversion	Tailrace Release	Lower White River	Lower Puyallup River
Baseline	1,366	97	75	1,594	3,229
Proposed Action	1,330	132	40	1,523	3,158
Difference	-35	+35	-35	-71	-71
Percent change	-2.6%	+36%	-47%	-4.5%	-2.2%

Note: Numbers may not add exactly due to rounding.

Roughly half of the water supply withdrawal would be obtained by increasing diversions from the White River, and the other half would come from reducing tailrace releases. The average flow in the Reservation Reach would be reduced by 35 cfs (or 2.6%). Downstream of the tailrace, the average flow in both the lower White River and the Lower Puyallup River would be reduced by 71 cfs, a 4.5% and 2.2% reduction, respectively. Note that the total change shown in Table 8 is less than the full 75 cfs amount of the water right applications because of reduced water supply withdrawals during shortage management.

5.1.2 Monthly Average Flows

Monthly average flows for the affected reaches were calculated to look at the seasonal timing of the changes in flow. The change in monthly average flows is shown in Figure 17. Positive values represent an increase in flows with the Proposed Action. The change in the Lower White River from Figure 17 is equal to the sum of the changes in the tailrace release and White River below the diversion dam. The change in the Lower Puyallup River is not shown in the figure, but would be equal to the change in the Lower White River.

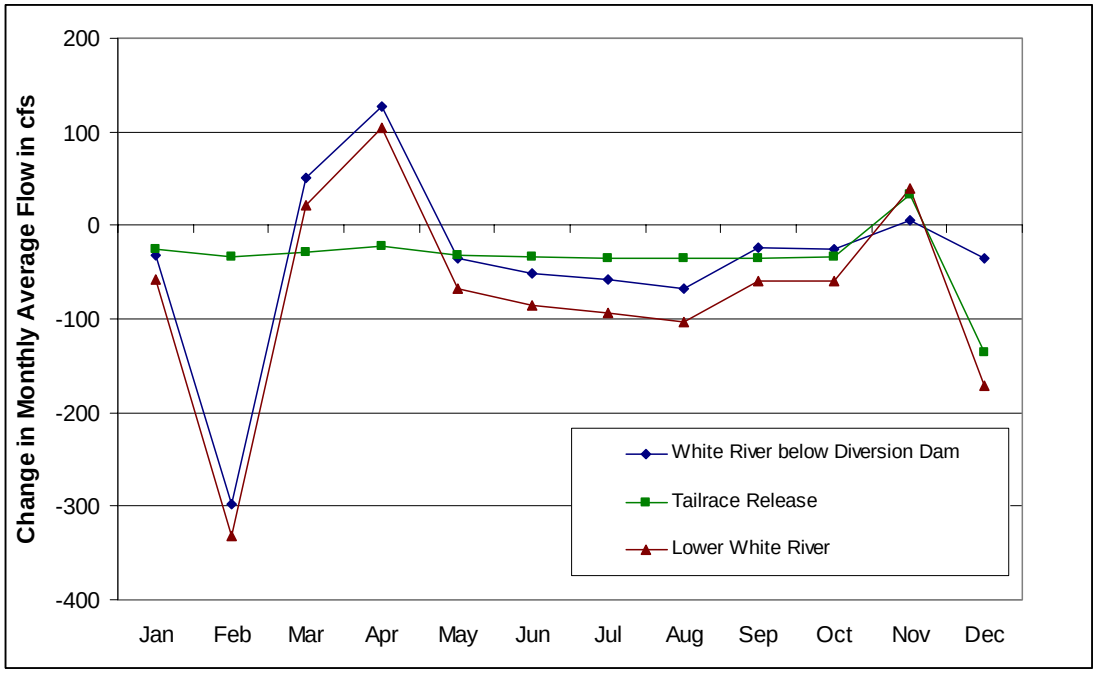


Figure 17 - Change in Monthly Average Flows

The Proposed Action would increase average flows in March, April, and November, and would decrease flows in the remaining months. The largest change in monthly average flows in the White River would occur in February, when the Proposed Action would cause a roughly 300 cfs decrease in river flows. This happens because the Proposed Action (See Section 4.2.4) allows refill starting on February 15. Refill starts on March 1 under the Baseline assumptions, so for the last weeks of February water is being diverted to refill the reservoir under the Proposed Action and not under the Baseline. Refill is also allowed at a higher rate (1,000 cfs) under the Proposed Action, than in the Baseline (650 cfs). The earlier start and higher refill rate combine to be beneficial to flows in March and April because refill is completed earlier.

Through the recreation season, the Proposed Action would divert more water from the White River to meet water supply needs. The amount of additional diversions would grow through summer as the water supply withdrawal increases. The increase in diversions (and corresponding decrease in Reservation Reach flow) peaks at 68 cfs in August. Combined with the decrease in tailrace releases, the lower White and Puyallup

Rivers would experience an average decrease of just over 100 cfs in August. The impact on flows would be lower in September and October as water demand subsides.

The Proposed Action would cause a slight increase in river flows in November, particularly downstream of the tailrace. This occurs because the period for fall drawdown is shorter under the Proposed Action (November 1 to December 1) than in the Baseline (November 1 to December 15), causing the Proposed Action to release water through the tailrace at higher flow. Other than November, the tailrace release under the Proposed Action would be consistently lower than the Baseline, primarily because the Proposed Action includes measures to reduce leakage from the powerhouse valves (described in more detail in Section 7.1.2).

5.1.3 Daily Flows

The various operating priorities and mitigation elements included in the Proposed Action would have the potential to affect flows on a day-to-day basis in a manner not characterized by the evaluations of annual or monthly average change in flows. For example, when the Early Spring Avoidance Plan is triggered the Proposed Action would increase flows in the Reservation Reach and lower White and Puyallup Rivers. Or diversions under the Proposed Action may increase in the summer immediately following a step down in the Cascade Recommended Flows.

A summary of the predicted daily changes in flow for the Reservation Reach and Lower White River are shown in Table 9. Over the entire modeled period the Proposed Action would increase flows in the Reservation Reach 12 percent of the time, leave flows unchanged 21 percent of the time, and cause a decrease in flows 68 percent of the time. The increases in flows typically occur because of the higher minimum flow of the Proposed Action. These increases typically would occur when the flow in the White River upstream of the diversion dam is higher than the minimum flows of the Baseline scenario, but close to or lower than the minimum flows of the Proposed Action. There would be no change in the Reservation Reach when upstream flows are at their lowest (i.e. lower than both sets of minimum flows) or during fall drawdown. The remainder of the time, the Proposed Action would decrease flows in the White River by diverting water for the water supply.

In the Lower White River, flows are either increased or decreased, but seldom remain unchanged. This occurs because of project repairs to reduce leakage through the powerhouse valves. The increases in flows in the Lower White River are caused by the changes at the diversion discussed in the previous paragraph, and by difference in the timing of refill and drawdown.

Table 9 – Summary of Change in Flows in White River

White River Reach	Frequency of Change in Flows			Maximum Increase in cfs	Maximum Decrease in cfs
	Increase	No Change	Decrease		
Reservation Reach	12%	21%	68%	568	-980
Lower White River	17%	1%	82%	532	-1,294

The maximum increases and decreases in daily flow are also shown in Table 9. The magnitude of the change in daily flow ranges from large increases (532 to 568 cfs) on a

few days to large decreases (980 to 1,294 cfs) on others. The largest increases occur in March, when Refill has been completed under the Proposed Action, but continues under the Baseline. The largest impacts occur during large rainstorms in February. During these events, Refill has started with the Proposed Action so diversions of up to 1,000 cfs are allowed from the White River. The additional stormwater inflow from the large rainstorm is also stored to refill the reservoir, whereas under the Baseline operating rules it was released to the Lower White River. These large changes are rare and more typically the change (in either direction) is much smaller.

Histograms of the magnitude of changes in daily flow are shown in Figure 18 for the Reservation Reach. These figures count the number of days in the 15-year modeled period where the change in flows falls in each category. The categories are listed by the upper end of their range. For example, the -50 category shown in Figure 18 represents a change in flow of between -100 and -50 cfs. Generally, the figures show that most of the changes resulting from the Proposed Action would be in the range of a decrease of 100 cfs to an increase of 50 cfs.

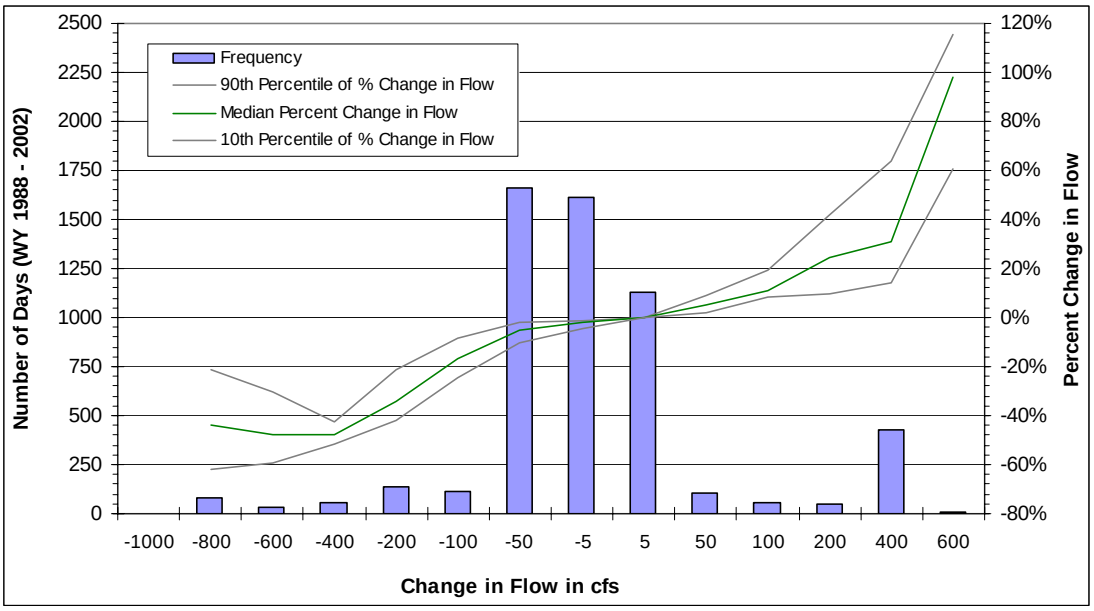


Figure 18 – Changes in Flow in the White River Reservation Reach over the Entire Modeled Period

Figure 18 also includes information about how large the changes in flow are relative to the flow in the river. A large change may not be very important if flows are high, and a small change may be very important if flows are low.

Reading Figure 18 may be a little confusing. The secondary vertical axis shows the percent change in flow, and the three lines [representing the median percent change in flow (green line), 10th percentile (gray line on bottom) and 90th percentiles (gray line on top)] are read on this axis. For example, decreases in flow of 50 to 100 cfs occur on roughly 1,650 days out of the 15-year model period of record (reading the leftmost of the three highest bars on the vertical axis to the left). On average, these decreases represent a 5 percent reduction in river flow (indicated by reading where the green line crosses the

-50 bar on the vertical axis to the right), and most of the time the change in flow represents a decrease of 2 to 10 percent of the flow in the river (indicated by reading where the 10th and 90th percentile lines cross the -50 bar on the vertical axis to the right).

The most common changes in flow are small relative to the flow in the river. Roughly 80 percent of the time the change in flow in the White River would be between a 100 cfs decrease and a 50 cfs increase, and would represent less than 5 percent change in river flow. However, the largest changes can be significant (representing a 20 to 60 percent decrease, or a 60 to 115 percent increase), but occur very infrequently as indicated in Figure 18.

5.1.4 Puyallup River MIF

Model runs for each scenario were evaluated to tally the number of days that flow would be below the MIF in the Puyallup River at Puyallup, and the volume of MIF shortfall. These results were calculated for each month, season, and water year. A summary of these results by season for each baseline and Proposed Action scenario is presented in Table 10.

Table 10 – Number of Days and Volume of Puyallup River MIF Excursions

Month	Total Number of Excursions in Days in 15 years			Volume of MIF Shortfall in acre feet		
	No Action	Proposed Action	Difference	No Action	Proposed Action	Difference
January	43	48	5	29,474	31,783	2,309
February	38	49	11	15,521	19,811	4,290
March	55	41	-14	29,685	12,507	-17,178
April	46	18	-28	27,514	7,810	-19,704
May	5	7	2	1,734	2,465	732
June	18	21	3	10,143	12,438	2,295
July	18	24	6	4,045	5,078	1,032
August	39	69	30	8,638	15,355	6,717
September	52	84	32	8,665	14,067	5,403
October	137	153	16	43,201	53,535	10,334
November	27	21	-6	6,387	6,152	-235
December	20	23	3	7,254	7,496	241
Total	498	558	60	192,260	188,497	-3,763

The total number of MIF excursions over the model period of record would increase by 60 with the Proposed Action, or 4 additional days of MIF excursion per year on average. The MIF excursions would be caused by increased diversions from the White River on days when the White River was above its minimum flow, but flows in the upper Puyallup

River were low. They would also be caused by the reduction in tailrace discharges from fixing leakage through the powerhouse valves.

The total volume of MIF shortfall would decrease by 3,763 acre feet (about 2 percent), primarily because of the Early Spring Avoidance Plan and faster refill under the Proposed Action. In simple terms, the refill strategy under the Proposed Action can be described as quickly filling when flows are high and reducing diversions when flows are below the Puyallup MIF. This significantly reduces both the number and magnitude of MIF excursions in March and April as shown in Table 10.

5.1.5 Exceedance Hydrographs

An exceedance flow is a statistical calculation of the daily flow that would be exceeded with a given frequency. For example, the 10-percent exceedance flow has a 10 percent chance of being exceeded in any given year. In other words, higher flows would only be expected to occur on that day in 1 in 10 years. Therefore, the 10-percent exceedance flows are peak flows, the 50-percent exceedance flows are median flows, and the 90-percent exceedance flows represent low flows. Calculations were performed for the 10-, 50-, and 90-percent exceedance flows on each day of the year.

The exceedance hydrograph for the Reservation Reach is shown in Figure 19. Similar exceedance hydrographs for the lower White River and lower Puyallup River are included in Appendix B.

Most of the time the Proposed Action would decrease flows in the Reservation Reach, as shown by the dotted lines (with Proposed Action) being below the solid lines (without Proposed Action) at all three exceedance probabilities. The differences are most notable during spring refill and from July to September.

During spring refill, the Proposed Action would decrease flows from February 15 to March 1 (except when flows are below the minimum flow). After March 1, the lowest flows, shown by the 10 percent exceedance curve, would be increased; but average and higher flows would decrease until about March 22 (when the reservoir is typically full under the Proposed Action). From March 22 to April 15, flows in the Reservation Reach generally would be higher with the Proposed Action.

Through summer, the exceedance flows for Reservation Reach are uniformly lower under the Proposed Action, except when flows are at or below the minimum. The magnitude of the decrease in flows grows throughout summer as water supply demand increases. In September and October, the lowest flows are protected but higher flows would decrease to maintain reservoir levels and meet water supply needs.

During fall draw down in November and December, there would be little impact to the Reservation Reach, because diversions are minimal in order to help draw down the lake.

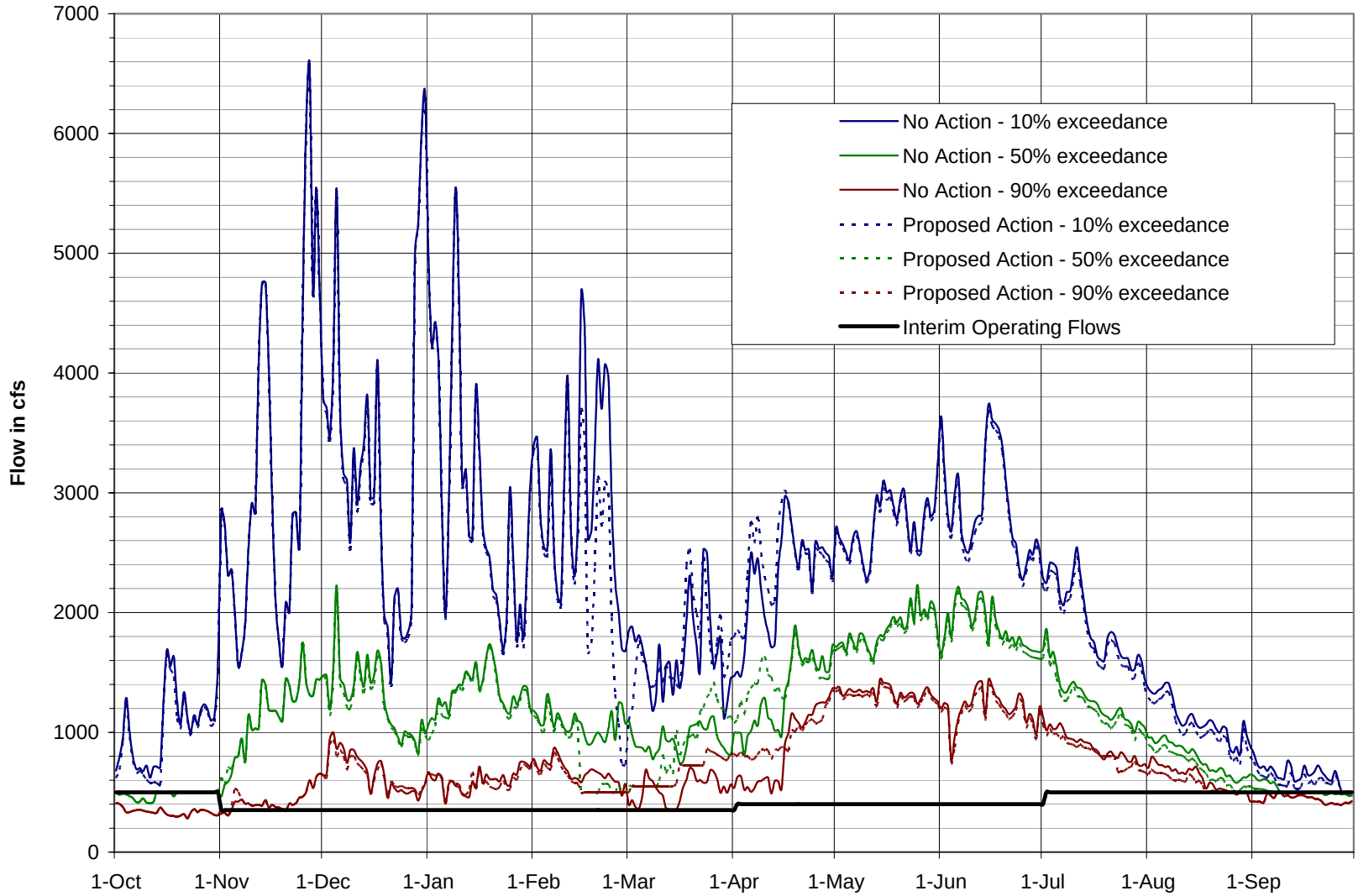


Figure 19 – Exceedance flows for the White River Reservation Reach

5.1.6 7Q10 and 7Q20 Low Flows

The 7Q10 is the 7-day average low flow that occurs with a frequency of once in 10 years. Similarly, the 7Q20 is 7-day average low flow that occurs with a frequency of once in 20 years. These flows are important in water quality management of rivers because many NPDES permits and Total Maximum Daily Load (TMDL) processes use them for calculating allowable pollutant loads and mixing zone sizes.

In the Amendment to the Puyallup River TMDL (Pelletier 1994), Ecology calculated the 7Q10 and 7Q20 for the White River at 199 cfs and 162 cfs, respectively. These calculations used the Log-Pearson Type III distribution with data from climatic years (April 1 to March 31) 1914 to 1991. The Puyallup River TMDL also reports the 7Q10 and 7Q20 for the Puyallup River at Puyallup as 757 cfs and 681 cfs, respectively, using the same approach. In the 2001 Cascade Pole NPDES permit, Ecology revised its calculation of the Puyallup River 7Q10 to 741 cfs using Chow's method for log-normally distributed data and flow records for water years 1928 to 1998.

The impact of the water supply project on 7Q10 and 7Q20 low flows was calculated from the fifteen years of model results using the Log Pearson Type III statistical approach. The limitations of using this technique are 1) the results do not compare directly to the previous estimates of 7Q10 because of the different periods of record and 2) the results are statistically weak because only 15 years of data were used to predict low flows with recurrence intervals of 10 and 20 years. Given these limitations, the estimates of 7Q10 and 7Q20 should be viewed as an indicator of the potential impact rather than a quantitative prediction of the impact. The results are shown in Table 11.

Table 11 – 7Q10 and 7Q20 Flows in cfs

Proposed Action Scenario	Lower White River		Puyallup River at Puyallup	
	7Q10	7Q20	7Q10	7Q20
Puyallup River TMDL	199	162	757	681
Baseline	377	359	742	695
Proposed Action	346	327	714	669
Difference	-31	-32	-28	-26

The 7Q10 and 7Q20 low flows for the Lower White River would be about 32 cfs lower under the Proposed Action. This is caused by the reduction in leakage from the powerhouse valves. These results are significantly higher than the historical values included in the Puyallup River TMDL because of the cessation of hydropower generation and the adoption of higher minimum flows for the diversion dam. Therefore, the Proposed Action would not impact the waste load allocation for the White River.

In the Puyallup River, the Proposed Action would cause slightly less of a reduction in 7Q10 and 7Q20 relative to the Baseline. The 7Q10 and 7Q20 flows with the Proposed Action would also be lower than those used in the Puyallup River TMDL. Such a reduction theoretically would reduce the allowable discharges from NPDES permit holders, but given its small magnitude is unlikely to have an actual effect. As the reduction is caused by repairing leakage from the powerhouse valves, it should not be considered a detrimental effect of the Proposed Action.

5.1.7 Wetted Area

Total wetted area was calculated for six reaches of the White and Puyallup Rivers using relationships between flow and wetted area that had been established by prior studies (Herrera Environmental Consultants 2006 and 2007, R2 Resource Consultants 2004). These relationships are summarized in Table 12.

Table 12– Wetted Area vs. Flow Relationships for the White and Puyallup Rivers

Reach	Relationship of Flow in cfs to Wetted Area in acres	Source	Limitations
Upper Reservation Reach (RM 24.3 to 20.9 - diversion dam to fish screen)	Area = 0.0182 * Flow + 44.84	Figure 7 in Herrera 2006	Developed for flows less than 4,000 cfs
Middle Reservation Reach (RM 20.9 to 9.1 - fish screen to levees)	Area = 0.1116 * Flow + 101.93	Figure 7 in Herrera 2006	Developed for flows less than 4,000 cfs
Lower Reservation Reach (RM 9.2 to 3.6 - levees to tailrace)	Area = 0.0397 * Flow + 93.94	Figure 7 in Herrera 2006	Developed for flows less than 4,000 cfs
Reservation Reach Focused Study Area (RM 12.9 to 14.4)	Side Channel Wetted Area = 0.0309 * Flow + 1.2	Figure 10 in Herrera 2007	Only includes wetted area of side channels; developed for flows less than 1,200 cfs.
Lower White River (RM 3.6 to 0.0 - tailrace to confluence)	Non-linear lookup table	Table 2 in R2 2004	Developed for flows less than 3,000 cfs
Lower Puyallup River (RM 10.4 to 5.9 - confluence to USGS gage)	Non-linear lookup table	Table 3 in R2 2004	Developed for flows less than 28,100 cfs

Daily average flow results from the model of each of the five reaches were used to calculate the wetted area in that reach on each day of each model run. Statistics were then calculated on the difference in wetted area between the Proposed Action and Baseline for each reach, and are shown in Table 13.

On average, the Proposed Action would decrease wetted area by about 10 acres, with most of the change (80 percent) occurring in the Middle Reservation Reach. There would be much smaller change in the Upper Reservation Reach, and Lower White and Puyallup Rivers.

Table 13 – Change in Wetted Area by Reach

Statistic	Change in Wetted Area in Acres						Total
	White River Reservation Reach				Lower White	Lower Puyallup	
	Upper	Middle	Lower	Focused Study Area			
	RM 20.9 to 24.3	RM 9.1 to 20.9	RM 3.6 to 9.1	RM 12.9 to 14.4	RM 0.0 to 3.5	RM 5.9 to 10.4	
Average	-0.6	-3.5	-1.2	-0.8	-0.3	-0.2	-5.8
Minimum	-17.8	-109.4	-38.9	-18.9	-4.2	-4.2	-174.5
Maximum	10.3	63.4	22.6	14.3	2.2	2.0	100.5

Notes:
1) White River RM 24.3 is the diversions dam, RM 20.9 is the fish return, RM 9.1 is the approximate upstream end of the levees, RM 3.6 is the tailrace and RM 0 is the confluence with the Puyallup River.
2) Puyallup RM 10.4 is the confluence with the White River and RM 5.9 is Melroy Bridge, the approximate upstream end of tidal influence.
3) The Focused Study Area Reach overlaps with the Middle Reservation Reach and therefore was not included in the total wetted area calculations for the Reservation Reach.

The minimum and maximum rows of Table 13 represent largest one-day changes in wetted area that would occur with the Proposed Action. The largest decrease in wetted area, a loss of 174.5 acres, occurs in February during spring refill. The largest increase in wetted area would occur in mid-March when the reservoir has completely refilled under the Proposed Action but would still be refilling under the Baseline scenario.

It is important to view the magnitude of the changes relative to total amount of wetted area available in each reach. A summary of the average percent change in wetted area is shown in Table 14. Typically the reduction in wetted area is less than 1 percent, except in the Middle Reservation Reach (and the Focused Study Area which is a sub-reach of the Middle Reservation Reach). The Middle Reservation Reach passes through a broader valley with more side channels, and thus is more susceptible to changes in flow. Note that in all cases the average percent reduction in wetted area is less than the average percent reduction in flow.

Table 14 - Percent Change in Wetted Area in Acres by Reach

Statistic	Scenario	White River Reservation Reach				Lower White	Lower Puyallup	Total
		Upper	Middle	Lower	Focused Study Area			
		RM 20.9 to 24.3	RM 9.1 to 20.9	RM 3.6 to 9.1	RM 12.9 to 14.4	RM 0.0 to 3.5	RM 5.9 to 10.4	
Average Wetted Area in Acres	Baseline	66.5	236.8	143.5	24.1	46.5	112.8	606.1
	Proposed Action	65.9	233.3	142.3	23.3	46.2	112.6	600.3
	Difference	-0.6	-3.5	-1.2	-0.8	-0.3	-0.2	-5.8
Percent Change	Percent Change	-0.9%	-1.4%	-0.8%	-3.3%	-0.6%	-0.2%	-1.0%

5.1.8 River Stage

River stage was calculated for the Puyallup River at Puyallup gage location using the stage-discharge relationship (shown in Figure 20) developed by the USGS (Gage #12101500, Rating Table 13). River stage is calculated in the water quantity model for each day based on the predicted flow in the Lower Puyallup River.

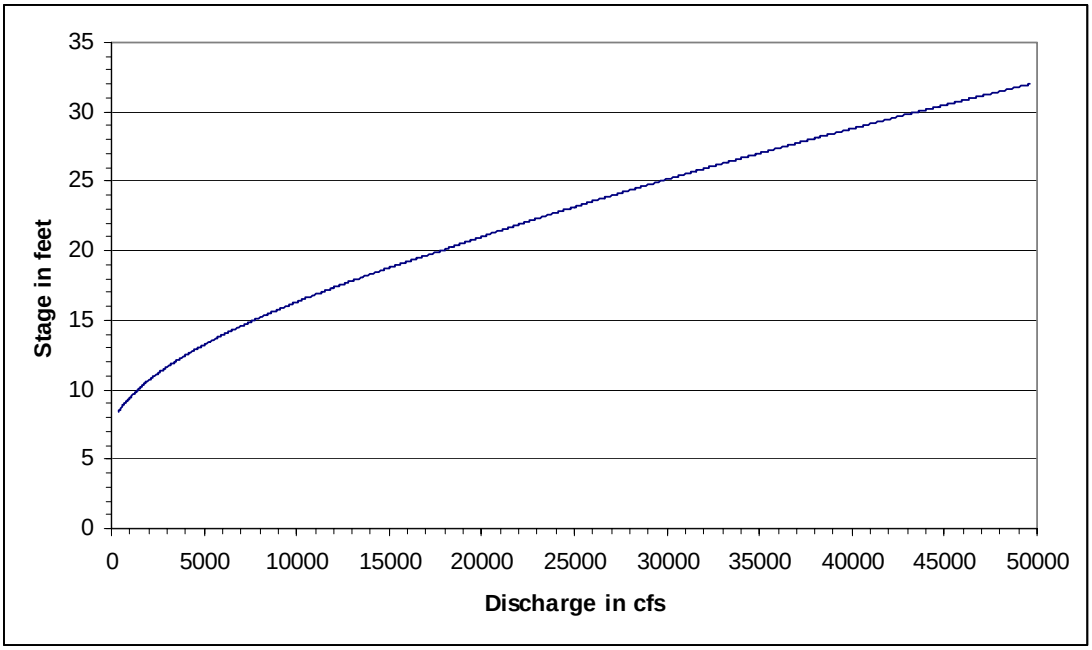


Figure 20 – Stage vs. Discharge Relationship for the Puyallup River at Puyallup

A summary of the change in Puyallup River stage with the Proposed Action is shown in Table 15. The Proposed Action would reduce stage by 0.06 feet (less than 1 inch) on average, with a range from a half foot increase to 1 foot decrease.

Table 15 – Change in Puyallup River Stage

	Change in Stage in Feet		
	Maximum	Average	Minimum
Proposed Action	0.49	-0.06	-0.99

5.2 Recreational Lake Levels

The ability to maintain lake levels under both the Baseline and Proposed Action scenarios was evaluated by tallying the number of days during various periods of the April 15 to October 31 recreation season when the lake would be drawn below normal full pool (541.0 feet true NGVD 29). These results are summarized in Table 16.

Table 16 – Days of Recreation Impact

Calendar Year	Baseline		Proposed Action			
	Apr 15 to Sep 30	Oct 1 to Oct 31	Apr 15 to Apr 30	May 1 to Sep 15	Sep 16 to Sep 30	Oct 1 to Oct 31
1987	--	0	--	--	--	6
1988	0	0	0	0	0	5
1989	0	28	0	0	11	31
1990	0	0	0	0	0	0
1991	0	5	0	0	0	27
1992	0	0	0	0	0	3
1993	0	0	0	0	0	27
1994	0	5	0	0	0	25
1995	0	0	0	0	0	0
1996	0	0	0	0	0	0
1997	0	0	0	0	0	0
1998	0	0	0	0	0	13
1999	0	0	0	0	0	0
2000	0	0	0	0	0	0
2001	0	0	13	0	0	8
2002	0	--	0	0	1	--
Total Days	0	38	13	0	12	145
Total % of Days	0%	8%	5%	0%	5%	31%

Under the Baseline scenario, there would be sufficient water to maintain recreational levels from April 15 to September 30 in all years and through the end of October in most years. There would be some years (3 out of 15) when the lake would dip below recreational levels prior to the end of October. The worst of these years is 1989, which is shown in Figure 21.

In 1989, involuntary drawdown of the reservoir would start in early September under both the Baseline and Proposed Action, though the rate of drawdown would be greater under the Proposed Action. With the Proposed Action, the lake level would meet Normal Full Pool from April 15 through September 15; however, it would drop below that level shortly thereafter. The remaining days in September would count toward the 10% of time that impacts to recreation are allowed under the 2009 Community Agreement. If subsequent years had similar drawdown, Cascade would need to reduce water supply withdrawals to meet recreation commitments. Under the Baseline scenario, the lake would be maintained within the Normal Full Pool range until October 1. In both scenarios, recreation would be impacted throughout October.

As shown in Table 16 and Figure 21, the addition of the water supply withdrawal makes it more difficult to maintain lake levels, particularly in late September and October. The model results show that Cascade would be able to keep their commitments to maintain recreational levels through September 15 all the time, and maintain them through

September 30 ninety percent of the time. But, some curtailment of water supply withdrawals would be necessary to do so (see Section 5.3).

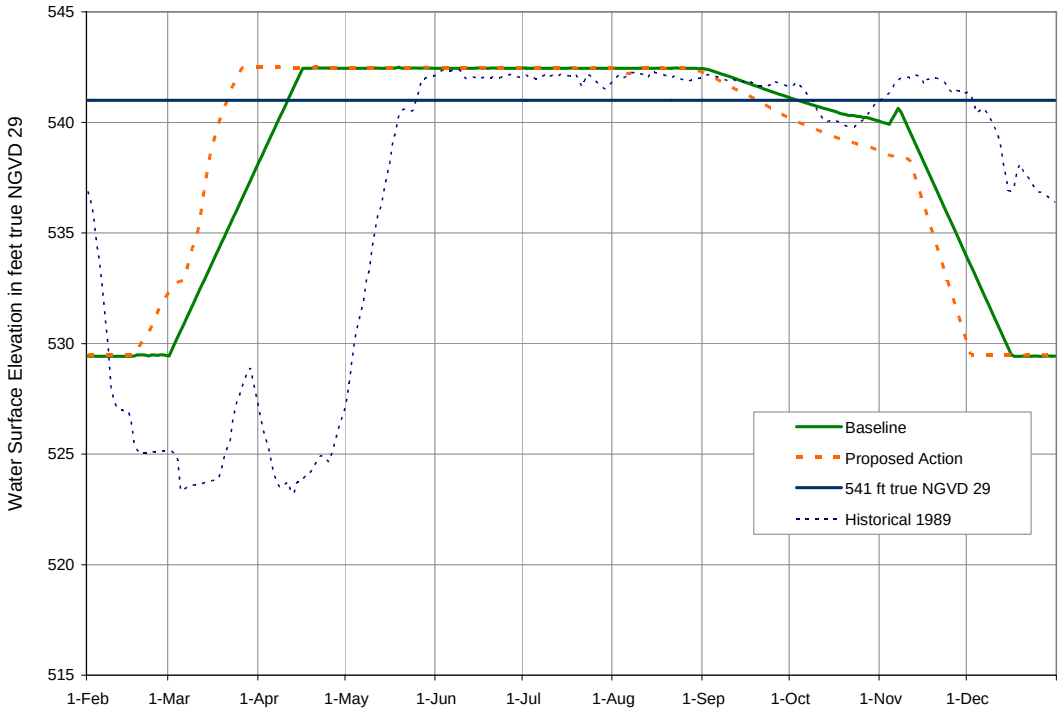


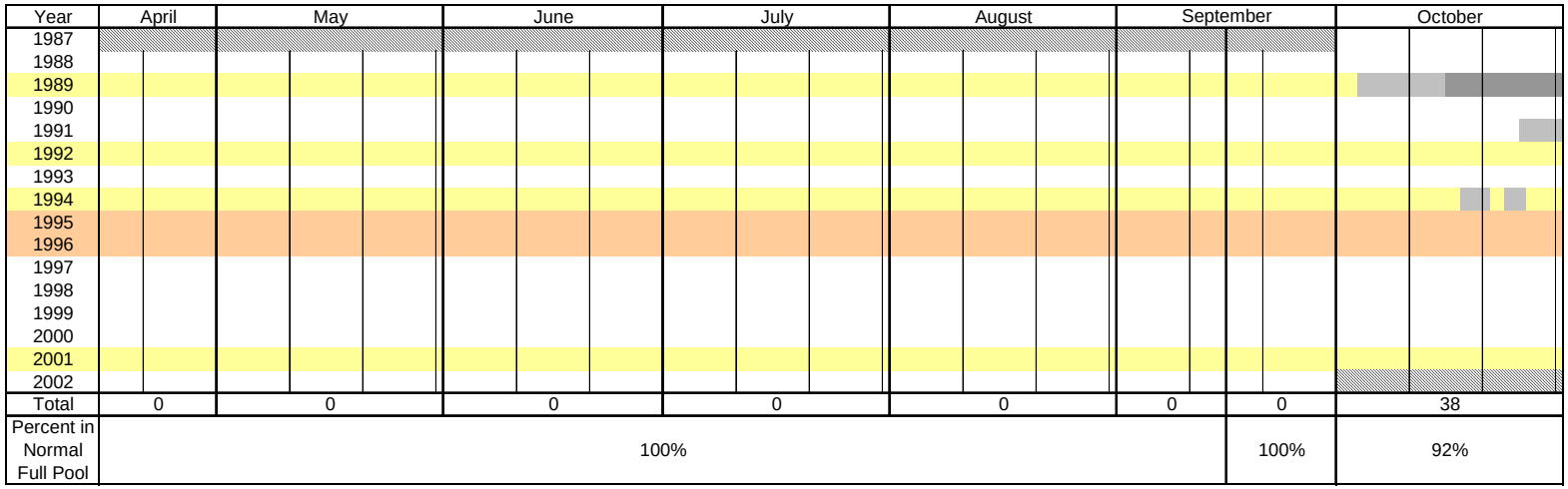
Figure 21 – Modeled Reservoir Elevations in 1989.

A graphical representation of the days the lake would be below normal full pool during the recreation season is shown in Figure 22. In Figure 22, days when the lake would be below Normal Full Pool (541.0 feet NGVD 29) by less than 0.5 foot are shaded light gray, by 0.5 to 1.0 foot are gray, and by more than 1 foot are black. Dry years are indicated in orange, and drought years are yellow. A diagonal hatch indicates days in 1987 and 2002 that are outside the model period of record.

Figure 22 indicates that with the Proposed Action the lake would be within the normal full pool range from May to mid-September, the most desirable period for lake recreation. There would be one year (2001) when refill would be delayed into late April, but in all cases the lake could fill by May 1. The lake would be below normal full pool 5 percent of the time from September 16 to 30, and 31 percent of the time in October.

The majority of impact to late season recreation would occur in drought years, like 1989, 1992, 1994, and 2001. These years are indicated by the yellow shading in Figure 22. Dry years have exceedance probability of 10 to 25 percent; drought years have an exceedance probability of less than 10 percent. It is worth noting that the model period of record has more drought years than would be expected. This could result in overstatement of the potential impacts of the Proposed Action on recreation, river flows, and other parameters.

Baseline Scenario



Proposed Action

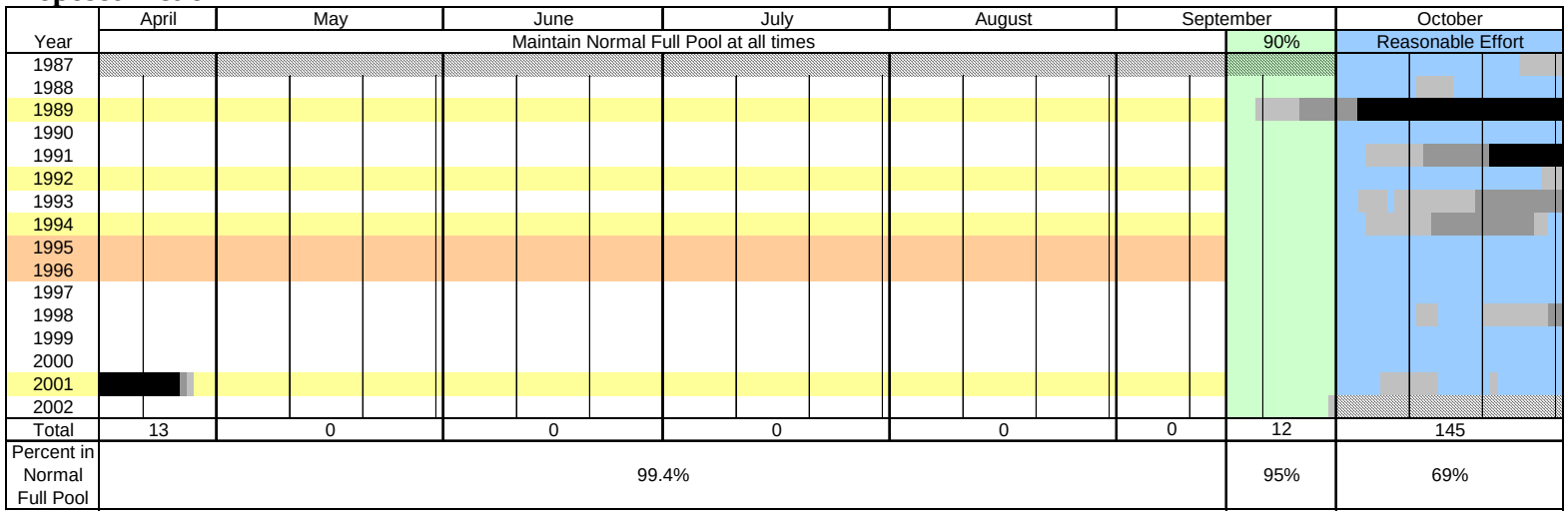


Figure 22 – Days of Recreational Impact Under Baseline and Proposed Action

Days when the lake would be below normal full pool (541.0 feet true NGVD 29) by less than 0.5 foot are shaded light gray, by 0.5 to 1.0 foot are gray, and by more than 1 foot are black. Dry years are indicated in orange, and drought years are yellow.

The average lake elevation would increase slightly with the Proposed Action as result of the earlier refill. The average lake elevation under the Baseline scenario is 538.1 feet true NGVD 29 and would increase to 538.5 feet with the Proposed Action. This small change in average lake elevation indicates that there is unlikely to be a noticeable difference in seepage from the lake to groundwater, and if the change does occur it would likely be positive (more aquifer recharge).

5.3 Water Supply Withdrawal

The previous section identified the challenge in meeting both recreational and water supply needs during dry and drought summers. During most of the recreation season, withdrawals for water supply would be a lower priority then maintaining lake levels. The exception is October, when water supply takes priority.

When water supply is not a higher priority, there is the potential that not enough water would be available from the White River or from storage in Lake Tapps to allow for water supply withdrawals. The modeling results indicate that there would be no shortage for water supply in most years (10 of 15), as shown in Table 17. The shortages that would occur are generally short (ranging from 1 to 9 days).

Table 17 – Water Supply Reliability

Water Year	Days of Water Supply Shortage	Jul -Sept Average Water Supply Withdrawal in cfs		
		Modeled	Target	Difference
1988	0	104.0	104.0	0
1989	1	78.7	79.5	-0.8
1990	0	104.0	104.0	0
1991	3	101.0	104.0	-3.0
1992	9	72.2	79.5	-7.3
1993	5	98.9	104.0	-5.1
1994	5	75.5	79.5	-4.1
1995	0	86.4	86.4	0
1996	0	86.4	86.4	0
1997	0	104.0	104.0	0
1998	0	104.0	104.0	0
1999	0	104.0	104.0	0
2000	0	104.0	104.0	0
2001	0	79.5	79.5	0
2002	0	104.0	104.0	0
Average	1.5 per year	93.8	95.1	-1.4
Total Days of Water Supply Shortfall	23			
Daily Reliability	99.58%			

Notes:
1) Orange rows indicate dry years, when Stage 1 shortage management was applied, and yellow rows indicate drought years and Stage 2 shortage management.
2) Target water supply withdrawal incorporates Stage 1 and Stage 2 reductions in demand.

The priority structure was built into the model such that Cascade would completely cease withdrawals on any day when the lake level fell below a trigger point set near the lower end of normal full pool. Realistically, Cascade would not suddenly stop withdrawing water from Lake Tapps. Instead, they would likely be able to forecast the potential for shortage ahead of time and implement more stringent shortage management measures, or use alternate supplies. As such, the days of shortage described above may not be the best metric. Instead, it may be more appropriate to average those few days of shortage over a longer period to look at what reduction in demand would be necessary to conserve the same volume of water.

The three columns on the right of Table 17 compare the average July through September water supply withdrawal achieved in the model versus the target. The difference indicates the additional reduction in demand that would be necessary to avoid the water supply shortages. The reductions range from 0.8 to 7.3 cfs or an additional 1 to 11 percent lowering of demand or additional water from an alternative supply.

Finally, given that the model simulates an unusually dry period, and that a simplistic trigger was used to indicate when to reduce water supply to protect recreational levels, the actual reliability of the Proposed Action probably would be higher than indicated by the model results.

6 Water Quality Evaluations

This section documents the water quality analyses performed in evaluating the Lake Tapps Water Rights. The analyses evaluated temperature and dissolved oxygen in the Reservation Reach of the White River, temperature in the Lower White River and flushing in Lake Tapps.

6.1 White River Reservation Reach Temperature

Water temperature was calculated at RM 4.9 and 15.5 using regression equations developed by Keta Waters (2006) and flow predictions from the water quantity model.

The equations developed by Keta Waters relate daily maximum water temperature to air temperature as measured at SeaTac and flow measured at the Buckley and Auburn gages as follows:

RM 15.5:

$$Tw = \mathbf{5.8} - \mathbf{0.36}Ta^{mean} + \mathbf{0.29}Ta^{min} + \mathbf{0.34}Ta^{max} - \mathbf{3.0}\log(Q_{Buckley}) + \mathbf{0.14}\log(Q_{Auburn}),$$

RM 4.9:

$$Tw = \mathbf{5.1} - \mathbf{0.28}Ta^{mean} + \mathbf{0.33}Ta^{min} + \mathbf{0.33}Ta^{max} + \mathbf{1.2}\log(Q_{Buckley}) - \mathbf{5.4}\log(Q_{Auburn}),$$

Where Tw is the estimated daily maximum water temperature (°C),
Ta^{mean} is the daily mean air temperature at SeaTac(°F),
Ta^{min} is the daily minimum temperature at SeaTac (°F),
Ta^{max} is the maximum air temperature at SeaTac (°F),
$Q_{Buckley}$ is the flow at the Buckley gage (cfs), and
Q_{Auburn} is the flow at the Auburn gage (cfs).

The regression equations were used to predict water temperature on each day from July 1 to October 31 of each year simulated. Keta Waters originally developed the relationship using data from July 1 to September 30. Extension of the relationship beyond its original limits may result in increased error in temperature predictions, particularly at lower air temperatures and higher flows.

The seven-day average of daily maximum (7-DADMax) temperatures was calculated for each day by averaging that day's daily maximum temperature with the daily maximum temperatures of the three days prior and the three days after that date.

Average 7-DADMax temperatures for the Baseline and Proposed Action are shown in Table 18. The results are grouped into two date ranges because a lower temperature standard applies after September 14. Generally, water temperature is one to two degrees higher at the downstream location (RM 4.9) than RM 15.5.

The Proposed Action would increase average 7-DADMax temperatures in the White River, as shown in Table 18. However, the magnitude of the increase is generally small, ranging from 0.03 to 0.11 °C on average.

Table 18 – 7-DADMax Temperatures

Scenario	Average 7-DADMax Temperature in °C		Percent of Time above Standard	
	RM 4.9	RM 15.5	RM 4.9	RM 15.5
July 1 to September 14 (Temperature Standard = 16 °C)				
Baseline	17.16	15.32	84%	29%
Proposed Action	17.27	15.40	85%	32%
Difference	0.11	0.08	1%	3%
September 15 to October 31 (Temperature Standard = 13 °C)				
Baseline	14.58	13.41	76%	62%
Proposed Action	14.62	13.44	77%	62%
Difference	0.04	0.03	1%	0%

Table 18 also indicates the frequency with which water temperature would be above the State Water Quality standard (WAC 173-201A). The White River from latitude 47.2438 longitude -122.2422 (just above the tailrace) to Mud Mountain dam (including tributaries) is designated as having Core Summer Salmonid Habitat, which has a corresponding Aquatic Life Temperature Criterion of 16 °C. Ecology (2006b) establishes a lower temperature criterion of 13 °C from September 15 to July 1 for the White River between the tailrace and diversion dam (excluding the portions within the Muckleshoot Indian Reservation) to provide additional protection for salmonid spawning and incubation.

Under the Baseline scenario, the 7-DADMax would exceed the 16 °C temperature criterion 29 percent of the time at RM 15.5 and 84 percent of the time at RM 4.9. In comparing the Proposed Action to the Baseline, the percent of time temperatures exceed the criterion would increase by 1 to 3 percent. The 13 °C criterion would be exceeded 62 to 76 percent of the time under the Baseline scenario, but there would be little change with the Proposed Action.

In July and early August, there are periods when the Proposed Action would improve water temperatures because of the higher minimum flows. A histogram of the change in temperature for this period is shown in Figure 23. About 2 percent of the time the Proposed Action would improve water temperatures and 7 percent of the time there would be no change. But most frequently, the Proposed Action would increase temperature – typically by 0.01 to 0.1 °C at RM 15.5 and 0.1 to 0.3 °C at RM 4.9.

From September 15 to October 31, the Proposed Action would either leave temperatures unchanged (35% frequency) or cause an increase in temperature as shown in Figure 24. Most of the time the increase would be less than 0.3 °C, but on a few occasions (less than 1%) the temperature could increase by as much as 0.6 °C. The Proposed Action would only increase temperature during this period because the minimum flow (500 cfs) would be the same as the Baseline.

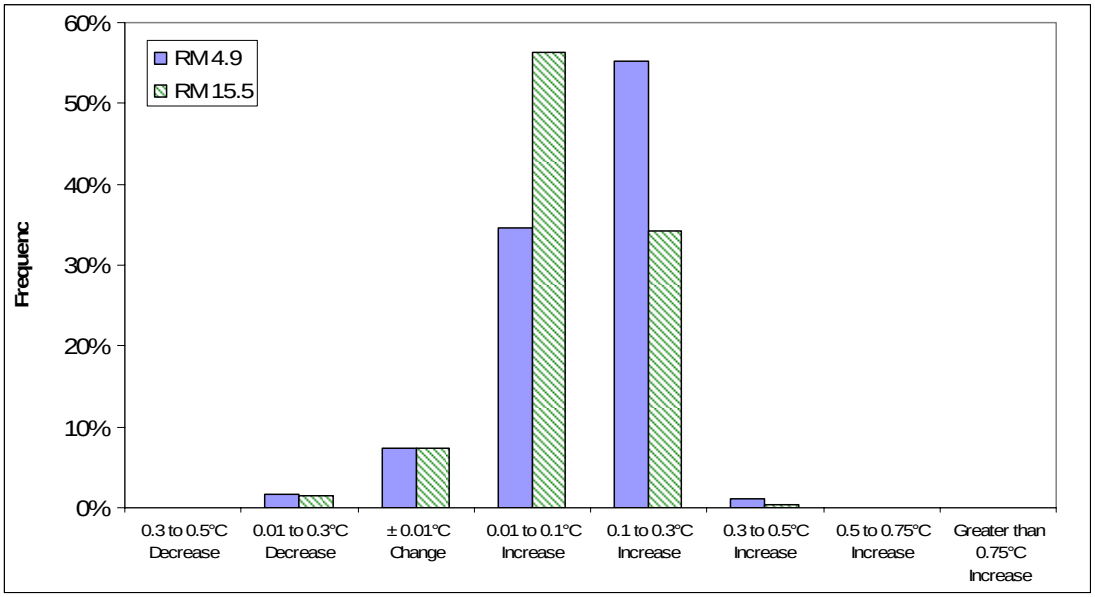


Figure 23 – Change in 7-DADMax Temperature - White River Reservation Reach, July 1 - September 14

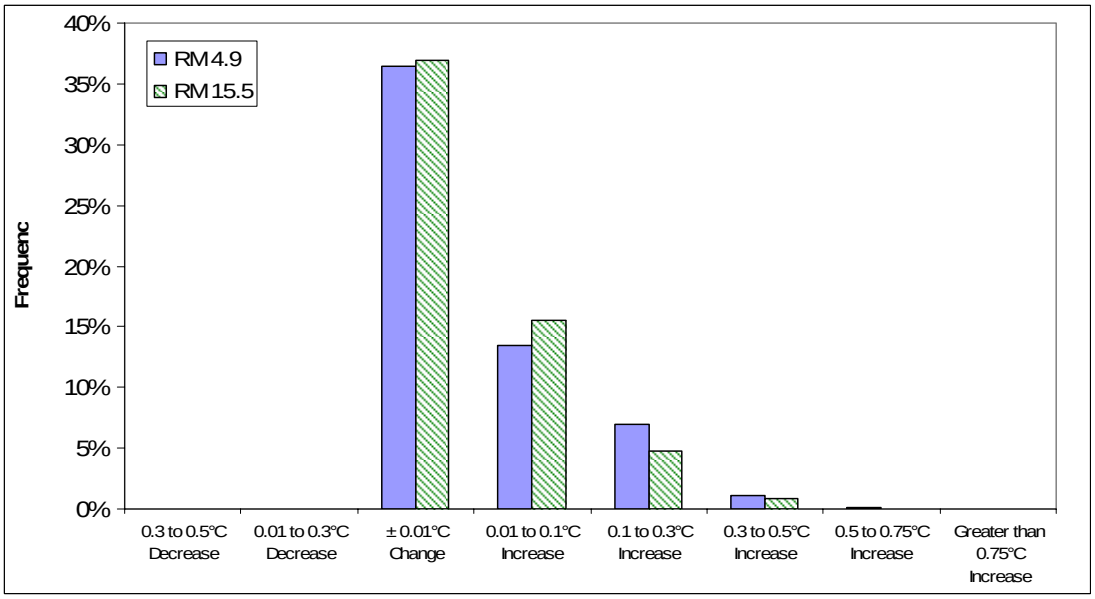


Figure 24 – Change in 7-DADMax Temperature - White River Reservation Reach, September 15 to October 31

These predicted temperatures for the Baseline and Proposed Action scenarios were used to evaluate if the Proposed Action would potentially cause a violation of the State Water Quality standard. For this evaluation, a violation of the temperature standard was considered to occur when the 7-DADMax temperature without the Proposed Action is within 0.3˚C of the temperature criterion (i.e. 15.7 or 12.7°C) and the Proposed Action would cause an increase of more than 0.3 ˚C. The results are shown in Table 19.

Table 19 – Exceedances of Temperature Standard in Reservation Reach

Total Number of Days of Exceedances of the White River Temperature Standard (WY 1988 - 2002) July 1 to September 14		Total Number of Days of Exceedances of the White River Temperature Standard (WY 1988 - 2002) September 15 to October 31	
RM 4.9	RM 15.5	RM 4.9	RM 15.5
13	3	2	0

Note: A day of exceedance is considered to occur when the 7-DADMax temperature for that day without the Proposed Action is >15.7˚ C from July 1 to September 14 or >12.7˚ C from September 15 to October 31 and the Proposed Action would cause an increase of more than 0.3˚ C.

Based on the modeling results for flow and the regression equation for relating water temperature to flow, the Project would have the potential to cause a limited number of exceedances of the temperature standard. The exceedances generally occur farther downstream from the point of diversion. These exceedances would occur less than less 1% of the time.

6.2 White River Reservation Reach Dissolved Oxygen

Limited dissolved oxygen data collected under non-hydropower operating conditions is available for the White and Puyallup Rivers. Thus, it was not possible to develop a correlation between flow and dissolved oxygen as was done by Keta Waters for temperature. But, the ability for water to hold dissolved oxygen is dependent on temperature.

To investigate the potential effects of the Proposed Action on dissolved oxygen concentrations in the Reservation Reach, we used the temperature results at RM 4.9 and RM 15.5 to calculate the saturated dissolved oxygen concentration according to an equation developed by the Committee on Sanitary Engineering Research (1960):

$$DO_{sat} = 14.652-.041022*T_w+0.007991*T_w^2-7.7774x10^{-5}*T_w^3$$

Where DO_{sat} is the saturated dissolved oxygen concentration in mg/L, and T_w is water temperature in degrees Celsius.

DO saturation values are the expected equilibrium concentration of DO for a given water temperature and salinity. Colder water can hold higher concentrations of DO compared to warm water, and fresh water holds higher amounts relative to marine waters. This approach does not calculate the actual DO concentration in the Reservation Reach, as upstream oxygen demands (such as wastewater treatment plant discharges) and other dissolved constituents in the water could reduce the concentration below saturation. If DO is below the saturation point because of upstream oxygen demands, then there would be no immediate change in DO concentrations if water temperature increases. However, DO concentrations that might otherwise recover by natural re-aeration at a lower temperature would have less opportunity to do so. Similarly, if the DO concentration is saturated or near saturation, temperature changes would not cause an immediate impact to DO, but DO would eventually drop to equilibrate to the new temperature.

The Proposed Action would slightly reduce the capacity of the river to carry dissolved oxygen by raising average temperatures in the Reservation Reach (Table 20). The average reduction in DO saturation at RM 15.5 would be 0.01 mg/L, increasing to a reduction of 0.1 mg/L downstream at RM 4.9. Generally, the DO saturation concentration would be above the state standard of 9.5 mg/L at both locations. However, the Proposed Action would cause a 0 to 1 percent increase in the frequency saturation was below the standard.

The range of predicted impacts on DO saturation is shown in Table 21. The Proposed Action could cause a decrease of up to 0.22 mg/L on some days, but more typically would leave DO unchanged. And on a few days, DO may be slightly higher. The Proposed Action is unlikely to cause a violation of the State Standard for DO (0.2 mg/L decrease when DO is below 9.5 mg/L) because DO saturation was well above 9.5 mg/L on the two days when the decrease exceeded 0.2 mg/L.

Table 20 – Dissolved Oxygen Saturation in White River Reservation Reach

Scenario	Average Daily Minimum DO Saturation in mg/L		Percent of Time below 9.5 mg/L	
	RM 4.9	RM 15.5	RM 4.9	RM 15.5
Baseline	9.81	10.14	31%	5%
Proposed Action	9.71	10.13	32%	5%

Table 21 – Magnitude of Changes in Dissolved Oxygen Saturation in White River Reservation Reach

Change in Dissolved Oxygen Saturation in mg/L					
RM 4.9			RM 15.5		
Minimum	Average	Maximum	Minimum	Average	Maximum
-0.22	-0.02	0.04	-0.17	-0.01	0.03

6.3 Lower White River Temperature

Water temperature in the Lower White River potentially would be affected by changes in flow and water temperature in the Reservation Reach and changes in flow and water temperature in the tailrace release from Lake Tapps. The daily maximum water temperature in the White River just downstream of tailrace was calculated using the following mixing equation:

$$T_{LowerWhite} = \frac{\left(Q_{Reservation\,Reach} \times T_{Reservation\,Reach} + Q_{Tailrace} \times T_{Tailrace}\right)}{\left(Q_{Reservation\,Reach} + Q_{Tailrace}\right)}$$

Where T = daily maximum water temperature in °C, and Q = daily average flow in cfs.

Daily model results were used for the Reservation Reach and tailrace flows. Between July 1 and October 31, Reservation Reach temperatures were predicted using the regression based on flow and air temperature developed by Keta Waters (2006). Outside this period, monthly average temperatures were used for both the Reservation Reach and tailrace release as shown in Table 22.

Table 22 – Water temperature assumptions used to predict temperature in the Lower White River.

Month	Daily Maximum Water Temperature in ˚C	
	Reservation Reach	Tailrace
January	4.8	5.2
February	5.7	6
March	6.7	7.5
April	9.0	8.7
May	10.5	10.9
June	13.1	13.3
July	Regression equation	14.1
August		15.1
September		16.7
October		14.2
November	6.5	11.2
December	5.0	8.3

These temperature assumptions were developed from limited available data. The Reservation Reach temperatures are from periodic spot measurements from various studies at RM 4.9 between 1998 and 2006 that provide 8 to 9 data points per month. Tailrace temperatures are based on continuous monitoring in the summers of 2004, 2005, 2007, and 2009 by the Puyallup Tribe of Indians[7] and single measurements in each month in 2004 (Ecology 2006).

These data do not form a solid, consistent data set. Given the limited availability of data, it was necessary to mix daily average and daily maximum temperatures, continuous monitoring results and spot temperature measurements, and data from different time periods and hydropower operating regimes. These inconsistencies strongly suggest that the predicted temperature results for the Lower White River should be used only for examining concepts and trends and not viewed as accurate predictions of future conditions, particularly in terms of comparisons to the Washington State Surface Water Quality Standards.

The results indicate that the Proposed Action cause both increases and decreases in temperature in the Lower White River (Figure 25) depending on the time of year. Over the full 15-year period of record, the Proposed Action would lower temperatures 29 percent of the time, leave them unchanged 36 percent of the time, and raise them 35 percent of the time. It would lower temperatures by more than 1 ˚C on a few occasions, and raise temperature by up to 1 ˚C on a few others.

[7] This analysis was updated in late January 2010 to incorporate the data collected by PTI, which generally indicated cooler tailrace temperatures in summer than previously thought. The results of this analysis are slightly different from those published in the Draft EIS. The data collected by PTI are provided in Appendix C.

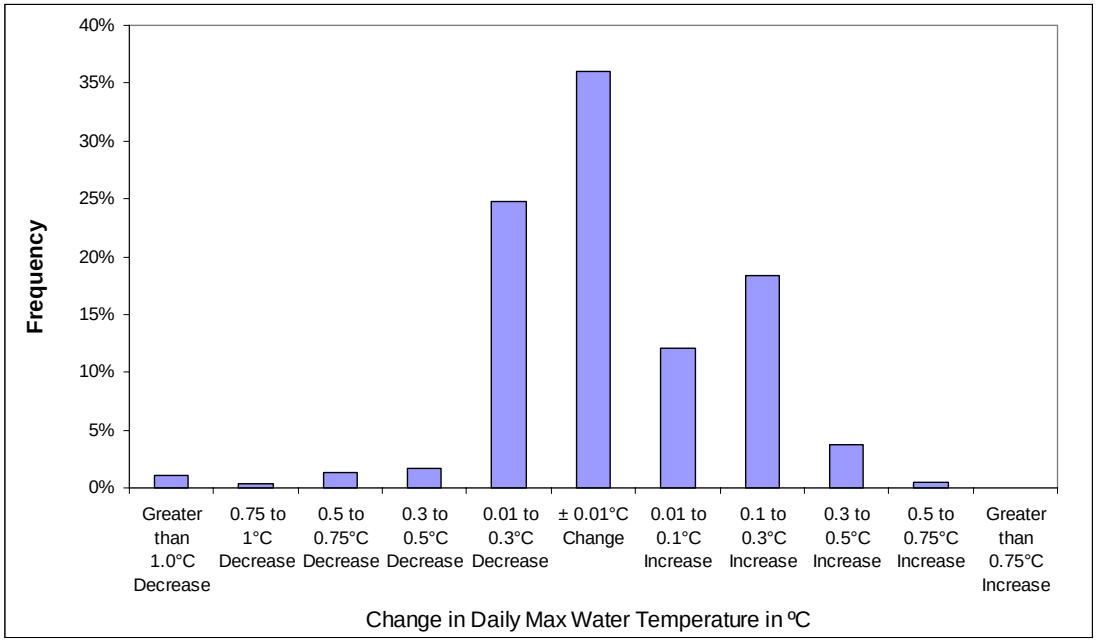


Figure 25 – Change in Daily Max Temperature in the Lower White River

The average change in Lower White River temperature is shown by month in Figure 26. On average, the Proposed Action would raise temperatures most notably in July and August, but also in April, September, and November, and lower temperatures the remainder of the year. The increases in temperatures are primarily caused by two factors: (1) higher temperatures in the Reservation Reach caused by increased diversions from the White River, and (2) a reduction in releases of cooler water from Lake Tapps during summer caused by stopping leakage. The largest decreases would occur in December, when drawdown would be completed under the Proposed Action, but still be occurring under the Baseline scenario. The tailrace discharge is warmer than the river in December, so reducing tailrace releases would reduce river temperature.

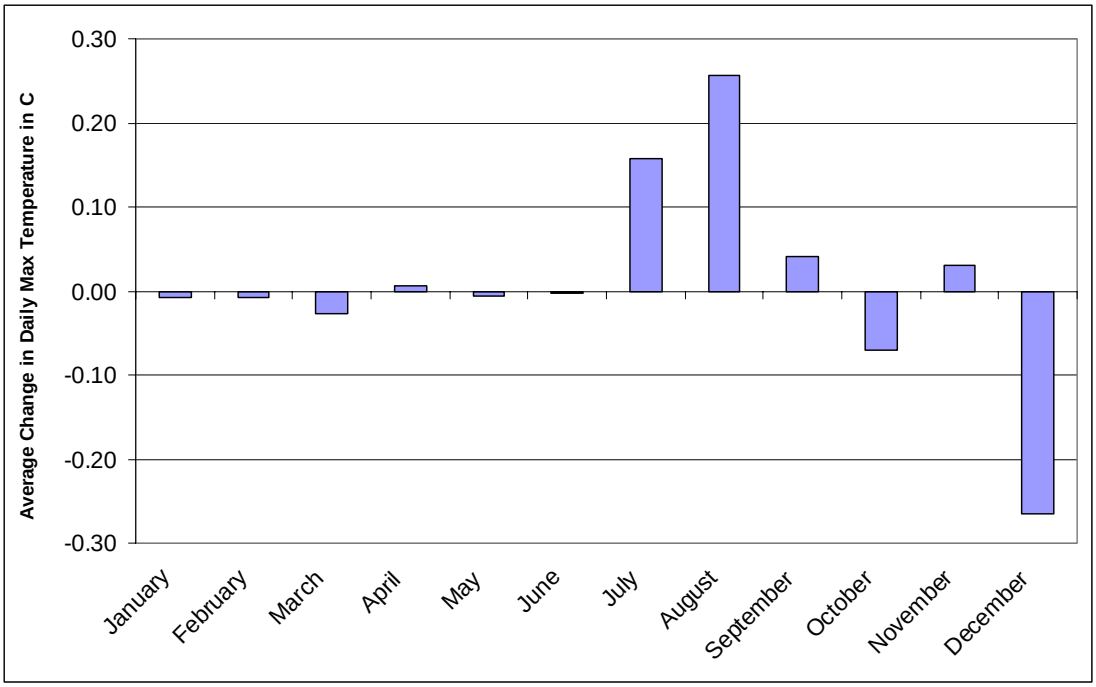


Figure 26 – Monthly Average Change in Lower White River Temperature

6.4 Lake Tapps Water Quality

Water quality in Lake Tapps will be evaluated, primarily qualitatively, in the Reports of Examination. This section provides results of an analysis of lake flushing rates for both scenarios. Lake flushing is just one component that affects lake water quality.

Flushing rates were calculated from the model results by dividing the average lake volume by the average volume of water leaving the lake (tailrace release plus the water supply withdrawal). This calculation provides an estimate of the theoretical flushing rate, or the upper bound on flushing. The results are shown in Table 23.

Table 23 – Lake Tapps Flushing Rate and Residence Time

Scenario	Lake Flushing Rate	
	in 1/year	in %/day
Baseline	1.4	0.4%
Proposed Action	2.1	0.6%

The Proposed Action would increase flushing by 50%, but not to a level sufficient to control algal growth by itself. Under the Baseline, the lake would have a flushing rate of about 1.4 per year (or 0.4% per day), meaning that the average volume of Lake Tapps would turn over a little more than once in a year. The Proposed Action would increase lake flushing to around 2.1 per year (or 0.6% per day) For both scenarios, the flushing rate is not sufficient to control algal growth by itself. Where the phosphorus concentrations in flushing water are similar to those in the lake, flushing controls algal

growth by physically removing algae from the lake fast enough that population levels do not have time to increase to a nuisance level. This typically requires flushing rates of 10 to 15% per day (Cooke et al. 1993).

7 Sensitivity Analyses

The water quantity and quality analyses presented in the previous sections of this report are based on a set of assumptions about the proposed project, the hydrologic conditions in the watershed, and the future hydrologic conditions. The best effort was made to assemble those assumptions from reliable data sources, scientifically sound approaches, and reasonable approximations where direct information is not available. However, uncertainties remain about how some elements of the project would operate, how accurately hydrologic processes have been represented, and what future climate conditions would be.

This section examines the sensitivity of the water quantity and quality analyses to these uncertainties. Each area of uncertainty is examined in a series of model runs focused on changing a single variable. Results are presented for a few key metrics related to river flow, lake recreation, and water supply reliability.

7.1 Sensitivity to Uncertainty in Proposed Operations

This series of sensitivity analyses examines uncertainties in how the proposed project may operate, such as the timing of water supply withdrawals, or whether flushing is necessary to maintain water quality in Lake Tapps. Results for all sensitivity runs related to uncertainty or flexibility in the proposed operations are shown in Table 24.

7.1.1 Pattern of Water Supply Withdrawals

The water rights would constrain the annual quantity and instantaneous rate at which water could be withdrawn from Lake Tapps, but there is considerable flexibility within those constraints. The primary model runs presented above used a seasonal pattern of water supply withdrawals based on actual consumption data from Cascade members. These sensitivity runs examine worst-case scenarios of three consecutive months of continuous pumping at the maximum instantaneous rate of 150 cfs[8]. The July to September Max run represents a worst-case for lake recreation, and the August to October Max run represents a worst-case for river flows and fish habitat.

The sensitivity runs indicate the primary impacts of these withdrawal patterns would be water supply reliability and late season recreation. Flow in the White River would still be protected by the minimum flow regime, so the lowest flows would not change. It also would not affect the frequency that flows in the Reservation Reach are decreased.

There would be no impact on peak summer recreation, but Cascade would have to curtail water supply withdrawals more frequently to protect lake levels as shown by a dip in frequency that demand is met from 99.6 to 99.2 percent. Although not shown in Table 24, Cascade would be able to meet its commitments to maintain lake levels from September

[8] Cascade has subsequently scaled back the maximum instantaneous withdrawal rate to 135 cfs. This change was made after analysis of the 150 cfs scenarios was completed. This change adds additional conservatism to these scenarios.

15 to September 30 ninety percent of the time. However, recreation in October would be impacted. The totals days of recreational impact would increase from 170 days to 224 or 281 depending on the scenario and the worst-case for recreation turns out to be the August to October maximum withdrawal scenario.

7.1.2 Ability to Control Valve Leakage from Lake Tapps

The valves and gates in the Dieringer powerhouse are known to leak, and tailrace flow measurements during periods when the valves are closed indicate an average leakage of 36 cfs. Cascade, through its agreement with the Puyallup and Muckleshoot Tribes, has committed to reducing valve leakage and would do so through planned modification to both the intake structure and powerhouse valves. It is likely that these changes can eliminate the leakage, and leakage of 0 cfs was assumed for the primary model run for the Proposed Action. However, it is possible that leakage cannot be eliminated, for example, if some of the leakage is coming from another source. Two sensitivity runs were performed to examine the effects of some leakage occurring with the Proposed Action. These runs used a powerhouse leakage of 9 cfs (75% reduction) and 18 cfs (50%) reduction under the Proposed Action.

The results indicate that there would be greater impact to average flows in the Reservation Reach, causing an additional reduction in the average flow of 5.6 to 11.4 cfs. However, the lowest flows were not affected, nor was the frequency of decreases in flows.

Recreation during the peak summer season would not be impacted under either leakage scenario. Cascade would be able to meet its recreation commitments from September 15 to 30 with 9 cfs of leakage, but would have trouble with 18 cfs, exceeding the 90 percent rule by 1 day. The 9 cfs leakage scenario had a moderate impact on October recreation and water supply reliability. The 18 cfs leakage scenario had a much greater impact on both metrics.

7.1.3 Flow Necessary to Maintain Lake Tapps Water Quality

In earlier analyses for this project there was uncertainty in whether a flushing flow would be needed to maintain water quality in Lake Tapps once hydropower generation ceased. Water quality monitoring results since 2004 indicate that lake water quality has actually improved with less flow from the White River (Citation). Based on these results, a flushing flow was not included the in Baseline or Proposed Action assumptions. However, it is expected that the applicant would be required to conduct a water quality study to determine the diversions necessary to maintain lake water quality. It is possible that study could recommend a flushing flow, so flushing was included in the sensitivity analysis. The two flushing flows evaluated (Seasonal Flushing, and Upper Bound Flushing) were developed for the 2006 Draft Reports of Examination.

The Seasonal Flushing sensitivity run uses a seasonally variable flushing rate, under the concept that the benefits of flushing flows depend on the time of year and other operating conditions for the reservoir. It assumes a flushing flow of 70 cfs for spring refill, 175 cfs during the recreation season, 0 cfs in fall drawdown, and 50 cfs in winter.

Table 24 – Sensitivity Results for Uncertainty in Proposed Operations

Sensitivity Run		White River Flows			Recreation		Water Supply Reliability
		Average Change in Flow in cfs	Frequency of Decrease in Flow	Frequency flows are below Cascade Recommended Flow in Aug-Oct	Number of Days Below 541.0 ft		Frequency Demand is Met
					May 1 to Sep 15	Apr 15 to Oct 31	
Primary Model Runs	No Action	--	--	29.5%	0	38	--
	Proposed Action	-35.4	67.6%	29.1%	0	170	99.6%
Pattern of Water Supply Withdrawals							
Jul-Sep Max	Proposed Action	-34.8	67.6%	29.1%	0	224	99.2%
Aug-Oct Max	Proposed Action	-32.3	67.6%	29.1%	0	281	99.2%
Ability to Control Valve Leakage from Lake Tapps							
Leakage = 9 cfs	Proposed Action	-41.0	67.8%	29.1%	0	224	99.3%
Leakage = 18 cfs	Proposed Action	-46.8	67.7%	29.1%	0	268	99.1%
Flow Necessary to Maintain Lake Tapps Water Quality							
Seasonal Flushing	No Action	--	--	30.4%	0	35	--
	Proposed Action	-3.8	19.6%	29.1%	0	168	99.6%
Upper Bound Flushing	No Action	--	--	32.2%	0	35	--
	Proposed Action	120.9	19.6%	29.1%	0	168	99.6%
Operation of Diversion Dam with Buffer on Minimum Flow							
Buffer = 10 cfs	No Action	--	--	29.5%	0	50	--
	Proposed Action	-35.2	67.0%	29.1%	0	200	99.5%
Buffer = 25 cfs	No Action	--	--	29.5%	0	59	--
	Proposed Action	-34.8	66.3%	29.1%	0	230	99.2%

The Upper Bound Flushing sensitivity run assumes that the maximum amount of flushing possible is necessary to maintain water quality in Lake Tapps. In this run, all water available above minimum flows was diverted up to the diversion cap in order to flush Lake Tapps.

Flushing affects both the Baseline and Proposed Action, so both scenarios were modeled with the higher flushing flows.

Either flushing flow would reduce the impacts of the Proposed Action on the White River relative to the Baseline, though average flows in the river would be lower for both. Addition of a flushing essentially makes the Baseline look worse, and the Proposed Action comparatively better.

Flushing flows would do little to improve late season recreation or water supply reliability, because in critical conditions all water available is already being diverted to meet those needs.

7.1.4 Operation of Diversion Dam with Buffer on Minimum Flow

Members of the Modeling Technical Committee of the Lake Tapps Community Council raised the issue of whether Cascade would operate the diversion dam with an additional, informal buffer in order to be sure that flows below the dam were at or above the minimum flow. Such a buffer was not included in the primary modeling runs under the assumption that the replacement for the diversion dam would be engineered to provide more accurate measurement and control of downstream releases then is possible with the current structure. Sensitivity runs were performed with a buffer of 10 cfs and 25 cfs above the minimum flow to represent conditions should Cascade determine that using a buffer is necessary. The buffer was applied to both the Baseline and Proposed Action scenarios.

A 10 cfs buffer had little effect on flows in the White River. The average reduction in flows would be very slightly lower, and flows would be reduced slightly less frequently. The lowest flows, of course, would not be affected. October recreation would be impacted more frequently for both the Baseline and Proposed Action, and water supply reliability would dip slightly.

The 25 cfs buffer had a more dramatic effect on late season recreation and water supply reliability. However, with either buffer, Cascade would be able to meet its commitments to always maintain recreational levels through September 15, and maintain lakes levels ninety percent of the time from September 15 to September 30.

7.2 Sensitivity to Uncertainty in Hydrologic Processes

In general, the hydrologic processes and measurements are less certain than how the project would operate. Stream gages typically have an accuracy of ±5 to 15%, and some processes, such as evaporation, seepage to groundwater, are difficult to observe or measure. This collection of runs examines the sensitivity of the evaluations to uncertainty in hydrologic parameters. This analysis generally focuses on runs that would make less water available. The opposite case (that more water is available) is equally likely, but is less interesting from a decision-making perspective and was not evaluated as thoroughly. Results for this batch of sensitivity runs are shown in Tables 25 and 26.

Table 25 – Sensitivity Results for Uncertainty in Hydrologic Processes (1 of 2)

Sensitivity Run		White River Flows			Recreation		Water Supply Reliability
		Average Change in Flow in cfs	Frequency of Decrease in Flow	Frequency flows are below Cascade Recommended Flow in Aug-Oct	Number of Days Below 541.0 ft		Frequency Demand is Met
					May 1 to Sep 15	Apr 15 to Oct 31	
Primary Model Runs	No Action	--	--	29.5%	0	38	--
	Proposed Action	-35.4	67.6%	29.1%	0	170	99.6%
Accuracy of White River above Buckley Gage							
Gage -10%	No Action	--	--	39.9%	0	91	--
	Proposed Action	-32.9	63.5%	39.3%	4	301	97.6%
Gage -5%	No Action	--	--	34.8%	0	61	--
	Proposed Action	-34.4	66.0%	34.6%	0	253	99.0%
Gage + 10%	No Action	--	--	20.3%	0	20	--
	Proposed Action	-36.9	70.7%	20.3%	0	96	100.0%
Seepage to Groundwater from Lake Tapps							
10 cfs	No Action	--	--	29.4%	0	24	--
	Proposed Action	-36.5	68.0%	29.1%	0	149	99.8%
20 cfs	No Action	--	--	29.5%	0	53	--
	Proposed Action	-34.8	67.5%	29.1%	0	196	99.5%
32 cfs	No Action	--	--	29.6%	0	98	--
	Proposed Action	-33.1	66.7%	29.1%	0	257	99.1%

Table 26 – Sensitivity Results for Uncertainty in Hydrologic Processes (2 of 2)

Sensitivity Run		White River Flows			Recreation		Water Supply Reliability
		Average Change in Flow in cfs	Frequency of Decrease in Flow	Frequency flows are below Cascade Recommended Flow in Aug-Oct	Number of Days Below 541.0 ft		Frequency Demand is Met
					May 1 to Sep 15	Apr 15 to Oct 31	
Primary Model Runs	No Action	--	--	29.5%	0	38	--
	Proposed Action	-35.4	67.6%	29.1%	0	170	99.6%
Local Inflows and Outflows to/from Lake Tapps							
+10 cfs inflow	No Action	--	--	29.4%	0	20	--
	Proposed Action	-37.3	68.3%	29.1%	0	146	100.0%
-10 cfs outflow	No Action	--	--	29.5%	0	76	--
	Proposed Action	-33.9	67.1%	29.1%	0	232	99.3%
-20 cfs outflow	No Action	--	--	29.6%	0	112	--
	Proposed Action	-32.7	66.6%	29.1%	0	278	99.0%
-50 cfs outflow	No Action	--	--	29.6%	0	267	--
	Proposed Action	-30.1	64.5%	29.1%	11	397	97.0%
Available Storage in Lake Tapps							
Use 1956 Bathymetry	No Action	--	--	29.4%	0	54	--
	Proposed Action	-35.4	67.4%	29.1%	0	200	99.5%

7.2.1 Accuracy of White River near Buckley Gage

This set of sensitivity runs examines what would happen if the actual amount of water in the river upstream of the diversion dam were higher or lower than indicated by the gage readings. These runs assume that the Buckley gage is uniformly biased either high or low. Although the accuracy of a single stream gage reading is ±5 to 15 percent, it is unlikely that the gage would be uniformly be biased by that much either positively or negatively. The continuity analyses performed in calculating the White River near Buckley correction factor (see Section 3.2.1.5) indicate that the gage may be very slightly biased low on average (i.e. there is slightly more water in the river than reported at the gage).

Sensitivity runs were performed with the following adjustments to the gage record: 10 percent less flow, 5 percent less flow, and 10 percent more flow. These changes to the gage record were applied to both the Baseline and Proposed Action since inaccuracy of the gage would affect both. Note that it is not realistic that the gage is uniformly biased across all flows. High flows are likely the least accurate, and low or mid-range flows are likely more accurate. The magnitude of gage error would change over time as the channel shifts. These simplified scenarios were included in the sensitivity analysis not because the gage is believed to be inaccurate to this level, but more to represent what would happen if the flow in the river changed over time.

With 10 percent less flow in the river, Cascade would not be able to meet its commitments to maintain lake levels during the peak recreation season and water supply reliability would be severely impacted. In this scenario, the project does not seem viable as currently defined.

With 5 percent less flow in the river, the project probably would still be viable, but October recreation and water supply reliability would be impacted. Cascade would be able to meet its commitments to maintain lake levels through the end of September. However, the impact to water supply reliability is significant.

With more flow in the river, there is less impact on recreation and the water supply has no issues with reliability. The impact of the project on the Reservation Reach is actually greater under this run, since more water can be diverted in September and October to meet recreation and water supply needs.

7.2.2 Seepage to Groundwater from Lake Tapps

The amount of water that seeps through the bottom sediments of Lake Tapps to recharge groundwater has been estimated at 3.7 to 22.4 cfs (PGG 1999). A constant seepage of 16 cfs was used in the primary model runs. Sensitivity runs were performed with seepage set at 10 cfs, 20 cfs, and 32 cfs in both the Baseline and Proposed Action.

The 20 cfs seepage run resulted in a slight reduction in the relative impact of the Proposed Action on the river, and minor changes to late season recreation and water supply reliability. Summer recreation would not be impacted, and Cascade would be able to meet its commitments through the end of September.

With seepage of 32 cfs, late season recreation and water supply reliability would be significantly impacted. Cascade would still be able to meet its lake level commitments through September 30, but would have to reduce water supply withdrawals to do so.

If seepage is less than 16 cfs, recreation and water supply reliability benefit. Flows would be slightly higher in the White River, but the relative impact of the Proposed Action would be greater decreasing average flows by an additional 1 cfs. This happens because less water would need to be diverted under the Baseline scenario to maintain lake levels.

7.2.3 Local Inflows and Outflows to/from Lake Tapps

These sensitivity runs represent the overall uncertainty in the approach used to estimate the local inflows and outflows to Lake Tapps. These runs could represent an unknown hydrologic process, or bias in the estimates of the known processes. Local inflows to and outflows from Lake Tapps are most critical in summer and early fall months. The estimates used in the primary model runs for these outflows agreed closely with independent calculations of the lake water balance during periods in summer when diversions and tailrace releases were low, such as maintenance outages (see Section 3.2.1.4.2.7). In fact, the average net flow calculated by water balance (27 cfs) was 2 cfs lower than the net outflow calculated by the model. This close agreement suggests that the error in the net local inflows and outflows is small, and slightly conservative, during the critical summer months. Nevertheless, sensitivity runs were performed with constant additional outflows of 10 cfs, 20 cfs and 50 cfs, and an additional inflow of 10 cfs. These additional outflows and inflows were applied to the Baseline and Proposed Action.

An additional outflow of 10 cfs would cause moderate additional impacts to water supply reliability and October recreation. There would be no impact to recreational levels through September 30. The relative impact of the Proposed Action on the White River would decrease slightly.

At an additional outflow of 20 cfs, Cascade would begin to have trouble meeting its commitments to recreational levels from September 15 to 30. The ninety percent commitment would be exceeded by 4 days. Water supply reliability would be significantly impacted, and October recreation would be impacted over 50 percent of the time.

With an additional outflow of 50 cfs, the project is not able to maintain recreational levels in summer even with severe impacts to water supply reliability. The project is not viable as currently defined with this level of additional outflow; however, there is nothing to indicate that this level of additional outflow is occurring.

The additional inflow of 10 cfs improved water supply reliability to 100 percent and slightly reduced recreational impacts. The relative impact of the Proposed Action on flow in the Reservation Reach would be slightly greater because less water needs to be diverted to maintain the lake under the Baseline scenario.

7.2.4 Available Storage in Lake Tapps

In 2009, Cascade commissioned a Lidar survey of Lake Tapps. That survey indicated that the upper portion of the Lake had more storage than indicated by the earlier storage-elevation relationship developed from 1956 Bathymetry (HDR, 2009b). The more recent survey is thought to be superior to the earlier work because it would reflect and changes to lake topography since 1956, and used Lidar technology which measures topography at many more locations than would have been surveyed using earlier techniques. However, a sensitivity run was performed using the older storage-elevation curve to look at the

sensitivity of the results to changes in storage in the upper portion of the reservoir. The older curve was used in both the Baseline and Proposed Action.

Using the old relationship, the impact of the Proposed Action on the White River was essentially unchanged. There would be slightly more days of recreation impact in October, and slightly lower water supply reliability. There would be no impact to recreation through September 30.

According to the older relationship, the lake has 1,400 acre feet less storage when full (see Section 3.2.1.7). Storage of 1,400 acre feet is enough to provide 100 cfs of water supply for 7 days.

7.3 Climate Change

Climate change is the change in the state of the climate over time from both natural causes and human activities. The earth's climate always has been changing and will continue to change, but recently there has been significant concern about the increasing role of human activities in altering the climate, particularly through the emission of greenhouse gases. Climate change has the potential to affect air temperatures and precipitation patterns in the Pacific Northwest in ways that could exacerbate current stresses on water resources (Vano et al. 2009). According to the Intergovernmental Panel on Climate Change (IPCC), the leading international group evaluating climate change, "warming in western mountains [of North America] is projected to cause decreased snowpack, more winter flooding and reduced summer flows, exacerbating competition for over-allocated water resources" (IPCC 2007a).

It is relevant to consider the potential effects of climate change in evaluating the availability of water for a new major regional water supply such as the Proposed Action. Our evaluation of the potential for climate change to impact water resources in the White River and Lake Tapps includes the following components:

- A summary of international consensus on climate change, focusing on conclusions relevant to the Pacific Northwest.
- A summary local consensus on climate change in the Pacific Northwest and its potential effects on water supplies.
- An examination of the results and limitations of two previous studies predicting the potential impacts of climate change on the White River basin.
- A description of why climate-impacted flow results from one of those studies could not be used with the Lake Tapps Systems Model to draw quantitative predictions of the effect of climate change on the Proposed Action.
- Qualitative predictions and recommendations for the Proposed Action based on the above analyses.

At the international level, the IPCC is the leading international group evaluating climate change. Established by the World Meteorological Organization and by the United Nations Environment Programme, the IPCC aims to "provide the world with a clear scientific view on the current state of climate change and its potential environmental and socio-economic consequences" (IPCC n.d.). The IPCC has developed a suite of emissions

scenarios that are used in General Circulation Models ("GCMs") by climate scientists to simulate a range of potential future climate conditions.

The IPCC provides Assessment Reports at regular intervals and their Fourth Assessment Report, published in 2007, is the most recent. The IPCC's Fourth Assessment Report consists of four documents: a synthesis report, and working group reports on 1) the physical science, 2) impacts, adaptation, and vulnerability, and 3) mitigation of climate change. The Fourth Assessment Report is a consensus document that was produced and reviewed by hundreds of scientists. The Synthesis Report (IPCC 2007b) included the following conclusions relevant to this project:

- Warming of the climate system is unequivocal.
- Most of the global average warming over the past 50 years is very likely due to anthropogenic (i.e., those derived from human activities) greenhouse gas increases.
- With current climate change mitigation policies and related sustainable development practices, global greenhouse gas emissions will continue to grow over the next few decades.
- Anthropogenic warming and sea level rise will continue for centuries even if greenhouse gas emissions were to be reduced sufficiently for greenhouse gas concentrations to stabilize.
- Warming in western mountains of North America is projected to cause decreased snowpack, more winter flooding, and reduced summer flows, exacerbating competition for over-allocated water resources.

The IPCC has developed a suite of scenarios (IPCC 2000) for greenhouse gas emissions in the 21st century in the absence of additional climate policies. These scenarios are based on a range of assumptions about population growth, economic development and technological advancement in the various regions of the world. The scenarios are grouped into four families (A1, A2, B1, and B2) that represent different development pathways:

- The A1 scenarios are characterized by rapid economic development, a mid-century world population peak, and fast technological growth. The A1 scenarios are subdivided based on the primary energy source fueling growth (F for fossil fuel intensive, T for renewable fuels, and B for balanced).
- A2 assumes separate regional economies, with high population growth and disparate economic development and technological advancement.
- B1 is described as a convergent world assumption, with a high level of social and environmental consciousness, equitable income distribution, a rapid shift to a service and information economy and a mid-century population peak as with A1.
- The B2 world has moderate population and economic growth, but with higher environmental and social consciousness working to develop sustainability issues at local and regional levels.

These scenarios form the emissions scenarios form the backbone for scientific investigations into the potential effects of climate change. These emissions scenarios are

used with global climate models to predict future world-wide climate conditions. Global climate models produce results at a large scale, with a resolution of 1 to 5 degrees latitude or longitude. These results require additional analysis to be applied a local scale.

In the Puget Sound region, the University of Washington's Climate Impacts Group (CIG) has been leading the effort to evaluate the potential effects of climate change locally using down-scaled results from global climate models. One component of that effort has been a assisting the Climate Change Technical Committee (CCTC) of the Regional Water Supply Planning Process, a regional planning process involving state agencies, public utilities, water purveyors (including Cascade), tribes, and non-profit organizations. The goal of the planning process is "to develop substantive technical information regarding current and emerging water resource management issues in and around King County" (Regional Water Supply Planning Process n.d.). The CCTC in a document titled Climate Change Building Blocks (CCTC 2006) reached consensus on the following conclusions relevant to this study:

- The global average temperature has increased during the twentieth century and is forecasted to increase in the twenty-first century.
- Warming in the Puget Sound Region has increased at a faster rate than the global average and increases in temperature are forecasted to continue.
- Forecasted increases in temperatures associated with climate change will further reduce snowpack and glaciers in the Pacific Northwest mountains.
- Global precipitation is projected to increase, although there is less certainty in predicting changes in precipitation than in temperature.
- Climate change is projected to increase winter flows and decrease summer flows in snowmelt influenced river systems of the Pacific Northwest.
- Climate change is projected to increase the frequency of drought events in the Pacific Northwest.
- Climate change is forecasted to increase temperatures of rivers, streams, lakes, and river mouth estuaries in the Puget Sound Region.

From this foundation of understanding, CIG has proceeded to quantify the impact of climate change on water resources using this general approach (Palmer 2007):

1) Use climate model results for future climate conditions on a global scale,
2) Re-scale global climate data down to a river basin scale,
3) Downscale climate model data to simulate streamflows under altered climate conditions using hydrologic modeling
4) Assess the effects of altered streamflows on water resource systems using systems simulation models.

This approach has been used in two studies specific to the White River and a Lake Tapps water supply in particular (Ball 2004, and Palmer and Polebitski 2009). These studies are not directly applicable because the assumptions about how the water supply would operate are significantly different from the current proposal (such as older White River

minimum flows, outdated project mitigation elements, an earlier version of the reservoir operations rule curve, older water supply demand projections, etc.).

Ball (2004) used results from four climate models from the IPCC's 3rd Assessment Report (2001) to create an ensemble average: ECHAM4, GFDL_R30, HadCM3, and DOEPCM. Ball notes that he chose the four specific GCMs because they were "among the most respected and widely used." He used results from these models for the A2 emissions scenario – the scenario with the highest greenhouse gas emissions by the end of the 21st century. These results were downscaled to the local level, then run through a hydrologic model to project streamflows in the White River. The predicted streamflows were then used in a systems simulation model to predict the effect on reservoir operations.

Ball's report suggests that climate change will alter the hydrology of the White River Basin by producing higher winter streamflows, earlier spring run off and lower summer streamflows. He found that decreased streamflow will reduce the frequency that flows in the White River would be above the minimum flow. This would reduce the potential safe yield of Lake Tapps, decreasing it at a rate of about 2.8 cfs (1.8 MGD) per decade. However, with the operating rule assumed by Ball, the safe yield would be above a 75 cfs water right through the end of his study in 2060. He also concluded that summer recreational lake level targets would likely be met with reduced reliability as water is released for mitigation and withdrawn for municipal uses (note that mitigation releases are no longer included in the Proposed Action).

Palmer and Polebitski's 2009 study paralleled Ball's earlier work (Ball was a graduate student working with Dr. Palmer) but incorporate updates to the climate models, methodology, and assumptions about operations. Palmer and Polebitski used results from three climate models (ECHAM5, GISS_ER and IPSL_CM4) from the IPCC's 4th Assessment Report (2007). Each model was coupled with one emission scenario – ECHAM with A2, GISS with B1, and IPSL with A2. These couples were selected in earlier work by Polebitski et al (2007) based on the recommendation of the Washington State Climatologist, Dr. Phil Mote, and because the three models provide a range of values for both precipitation and temperature as shown in Figure 27. The results shown in Figure 27 are for the 2040s.

All three model-emission scenario couples indicate an increase in temperature, with IPSL-A2 having the largest increase (4 °F), followed by ECHAM-A2 (2.5 °F) and GISS-B1 (2 °F). The results for precipitation vary more widely from a roughly 3 percent decrease to a 9 percent increase. The two models using the A2 scenario predicted an increase in precipitation, and model using B1 predicting a slight decrease.

Temperature and precipitation results from these climate models and emission scenarios were down-scaled to the White River basin and applied to a hydrologic model, again built in DHSVM. Climate-impacted flows were predicted for three future time periods (2025, 2050, and 2075) for each of the three climate model-emission scenario couples. These climate-impacted flows were then used in a systems model to evaluate the impact to minimum flows in the White River, Lake Tapps recreation, and the water supply withdrawal. As previously discussed, the assumptions used in the system model about how the water supply would operate do not reflect the current Proposed Action, and thus

are not quantitatively presented here. However, they generally found that with climate change impacts, sufficient water may not be able available to meet all needs. Specifically they concluded:
"Climate change coupled with recreational constraints restricted the ability of Lake Tapps to provide water reliably to Cascade's customers in all simulations, even under the most optimistic warming scenarios."

"Without climate change, thoughtful operation of this system could meet both the recreational needs and those of the water utility. Under scenarios with climate change, Lake Tapps has the capacity to meet one need reliably, not both."

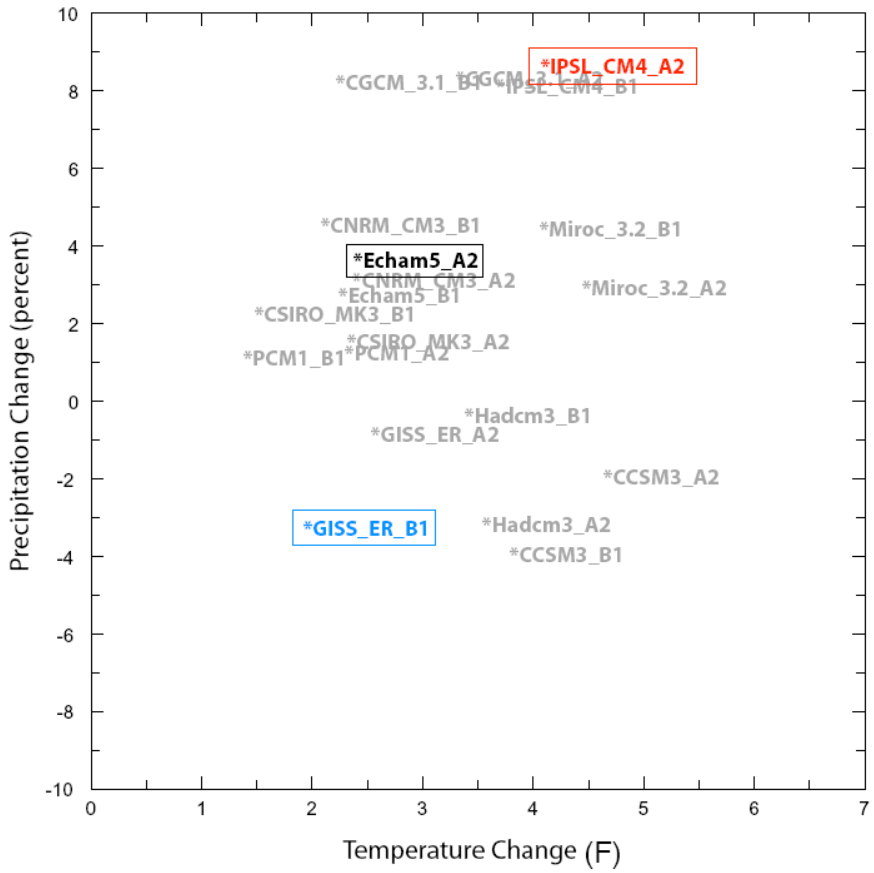


Figure 27 – Change in Annual Average Temperature and Precipitation in the 2040s for Various Combinations of Climate Models and Emissions Scenarios. (Mote et al. 2005*)*

Palmer and Polebitski's predictions of climate-impacted streamflows in the White River near Buckley are upstream of the diversion dam and thus are not subject to the limitations about differing assumptions in project operations. Their results for predicted effect of climate change on monthly average flows in the White River are shown in Figure 28 for each of the three time periods. The ensemble averages presented in Figure 28 are the average of the three climate model – emission scenario couples selected to represent the range of potential future climate conditions. We have added the Cascade Recommended Flows to Figure 28 to allow direct comparison.

The predicted results for climate-impacted flows indicate an increasing shift in the timing of peak streamflows. Currently, average streamflows peak in June as a result of snow

melt. As temperatures increase, less snow will accumulate and snow melt will occur more rapidly, shifting the peak streamflows to January. The start of the shift away from a snowmelt peak is evident in the 2025 results, and by 2075 there would no longer be a snowmelt peak. Late summer streamflows are predicted to decrease as well, and by 2075 the average streamflow is predicted to be just above the Cascade Recommended Minimum flow.

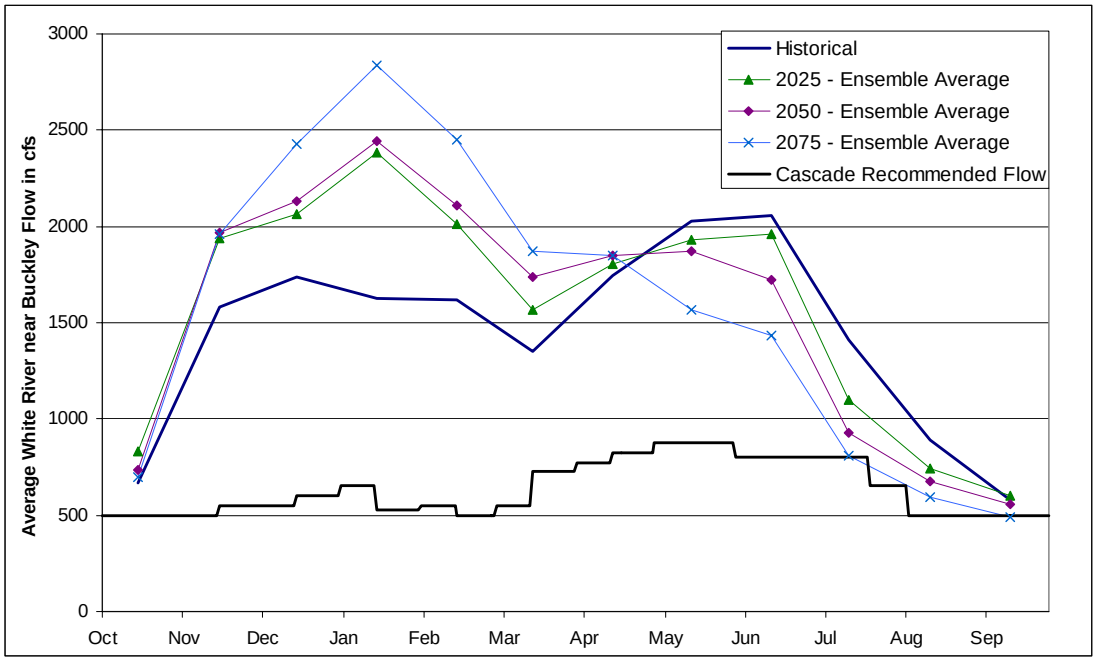


Figure 28 – Predicted Monthly Flows in the White River near Buckley in 2025, 2050, and 2075

On average, these model results predict a roughly 8 percent increase in flow in the White River as shown in Table 27. However, most of that increase would come in late fall and winter. Summer flows are predicted to decline over time, decreasing by 17.8 percent by 2025 up to 38 percent by 2075. Spring flows are predicted to increase slightly.

Table 27 – Potential Effects of Climate Change on Seasonal Streamflows at the White River near Buckley

Scenario	Spring (MAM)	Summer (JJA)	Fall (SON)	Winter (DJF)	Annual
2025 Ensemble Average	2.8%	-17.8%	19.7%	31.3%	8.0%
2050 Ensemble Average	6.1%	-28.1%	16.3%	36.3%	7.0%
2075 Ensemble Average	3.7%	-38.0%	11.7%	57.1%	8.8%

Aspect attempted to use the climate-impacted flows developed by Palmer and Polebitski for the White River above Buckley in the current version of the Lake Tapps Systems Model. However, on careful evaluation of the flow data, a large drop in flows was identified on July 1 of most years. The decrease is shown in Figure 29, circled in red.

This decrease occurs in all three model-emission scenario couples. A sudden decrease in average flows of several hundred cfs is not hydrologically realistic. Similar steps down in flow also occur at the start of August and September, but are not as pronounced.

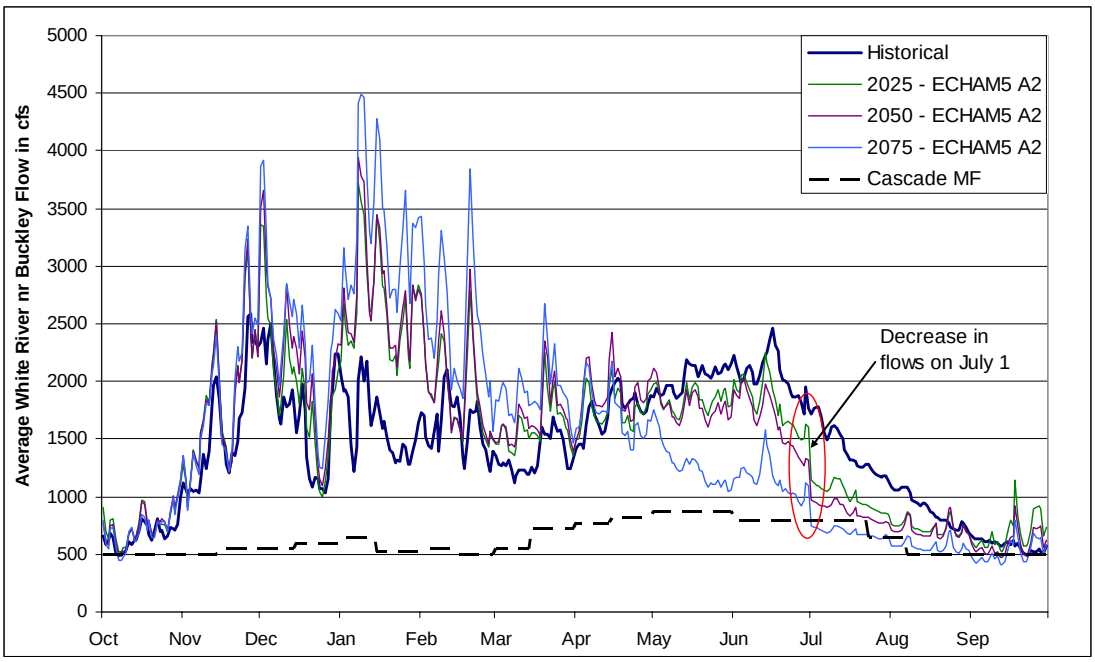


Figure 29 - Decrease in flows on July 1 in Climate-Impacted Streamflow Scenarios

Further investigation with the study's authors indicated that the sudden decrease in streamflows was caused by a bias-correction routine used to correct an over-prediction of flows resulting, in part because of an error in the flow network in the hydrologic model. The streamflow network (which had been generated automatically from topography) incorrectly routed South Prairie Creek into the White River instead of the Carbon River. The authors attempted to correct this error by subtracting most of the flow in S. Prairie Creek from the White River series, then using a bias-correction routine (described in Polebitski et al. 2007). The bias-correction routine used different factors each month, which explains why the discontinuities occur at the start of the month.

When used in the Lake Tapps Systems model, these climate-impacted flows erroneously create a water shortage on July 1 resulting in water supply and recreational impacts that affect the remainder of the summer. The magnitude of the error introduced is such that the climate-impacted flows, unfortunately, cannot be used in the systems model and thus we cannot make quantitative predictions about the impact of climate change on the water supply project.

The sensitivity analyses presented in Section 7.2, particularly the sensitivity runs that examined 5 and 10 percent decreases in flow in the White River at Buckley, can be used as an imperfect surrogate for actual climate change model runs. A year-round reduction of 10 percent was sufficient to cause the project to be unable to meet both its recreation and water supply goals. The potential reductions in late summer streamflows with climate change are predicted to be greater than 10 percent. However, the climate change results

predict an overall increase in the average annual flow, particularly during winter. And, the model runs used in the sensitivity analyses were based on a particularly dry period of the historical record so the sensitivity may be overstated.

The future is uncertain and future predictions of climate-change impact are, at best, imperfect and should be used only as indicators of what might happen, not an exact description of what will happen. Climate models are being used to make predictions decades into the future, then these large scale results are being down-scaled to the watershed level, then run through a hydrologic model, then used in a systems model. Each of the steps has its limitations and uncertainties and the process as a whole has been described as a "cascade of uncertainties" (IPCC 2001). Further, the work by IPCC and CIG presented in this discussion is based on emissions scenarios that do not include the effects of world initiatives to reduce climate change. However, this uncertainty should not be used as an excuse to set aside uncomfortable results.

The weight of scientific evidence, including that developed internationally and locally through consensus processes, suggests that climate change has the potential to place a severe strain on water resources in western Washington. It would be wise for Cascade to incorporate adaptive management measures (such as additional shortage management, supplemental water sources, or use of MMD for summer flow augmentation) into the Project to allow for adaptation to the potential impacts of climate change. Otherwise, it is possible that the Project may not always be able to meet all its recreation and water supply goals. As the lowest priority water use during the critical summer months, water supply would be the first to be impacted.

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APPENDIX A

Model Validation

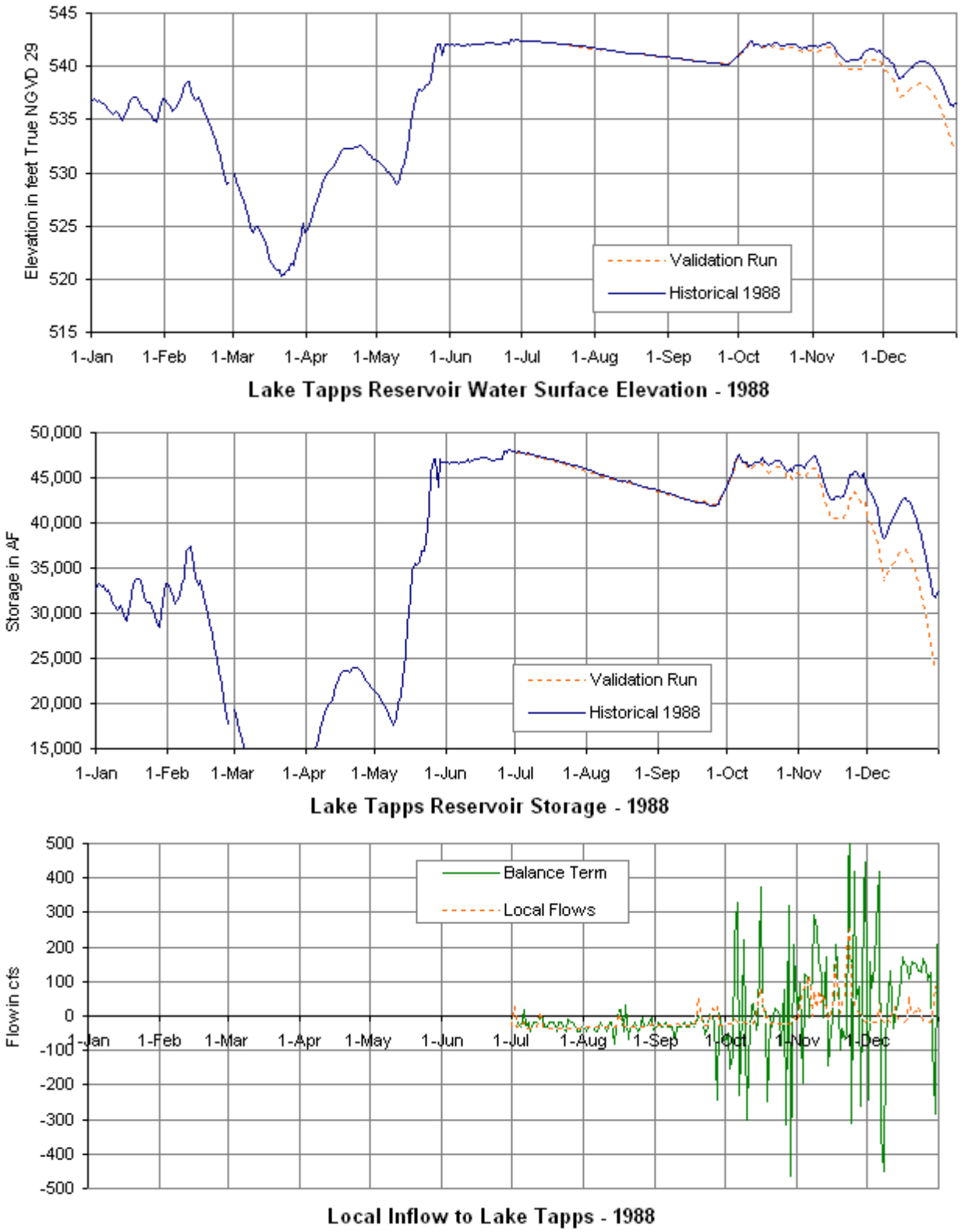


Figure A-1 Model Validation for WY 1988

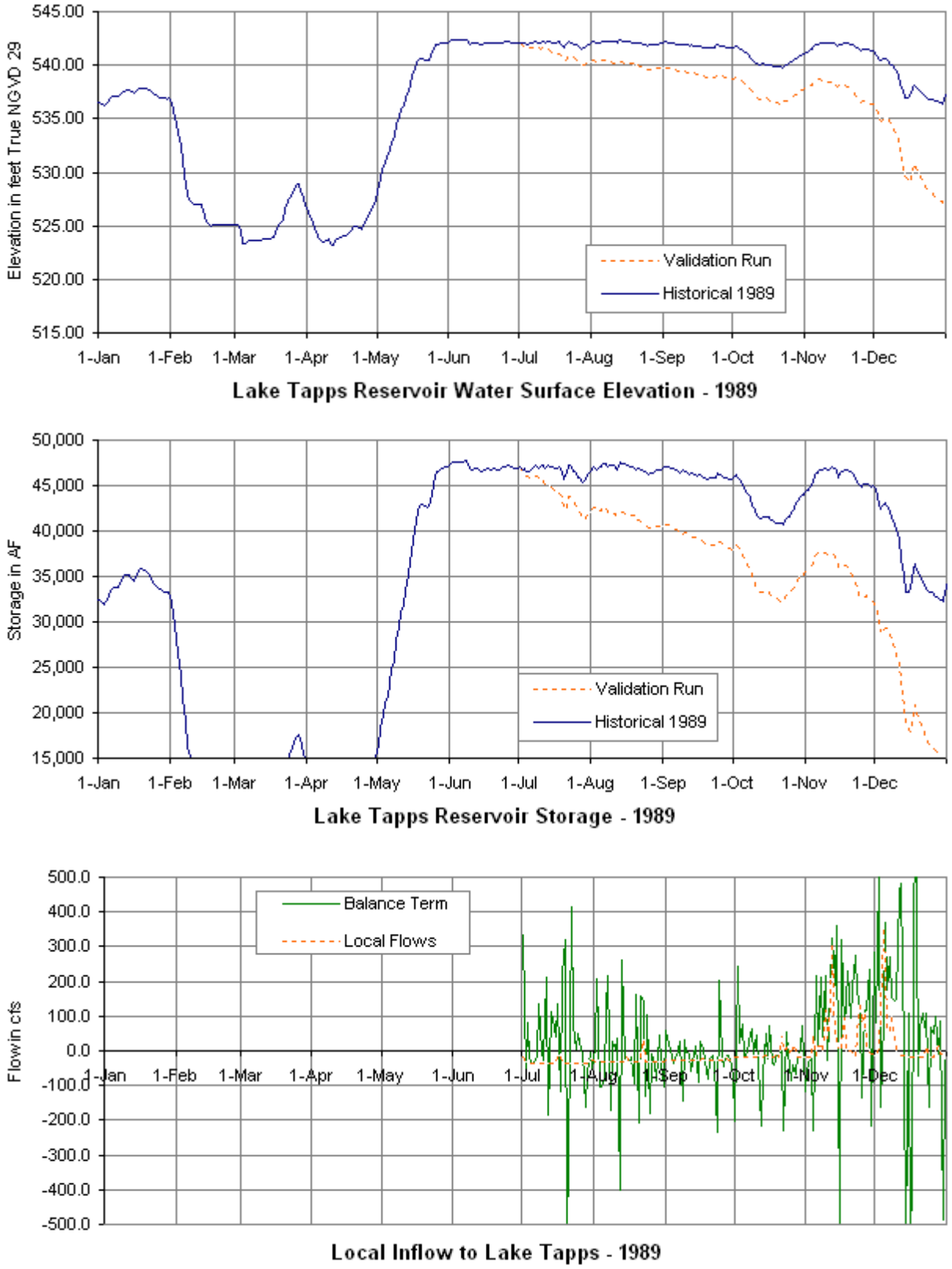
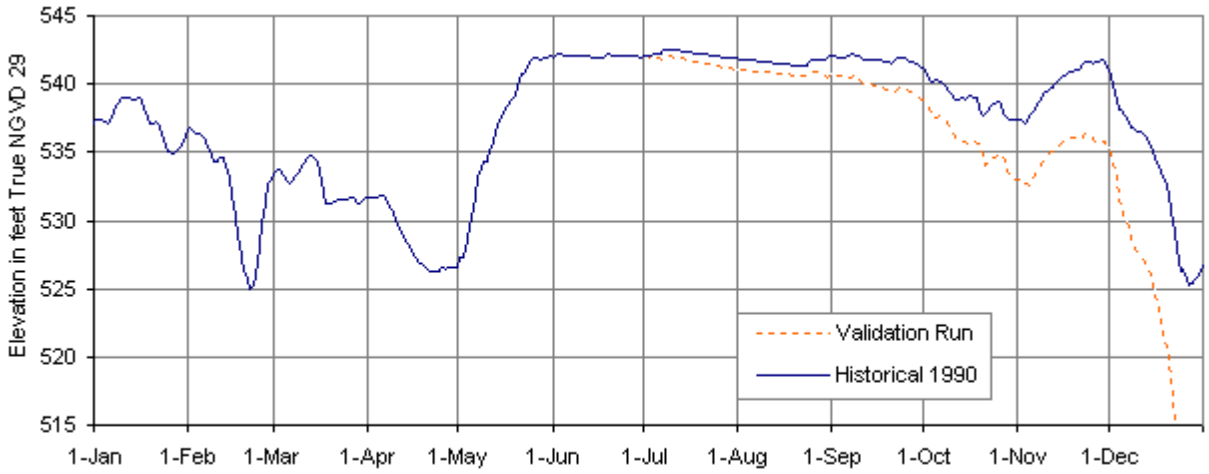
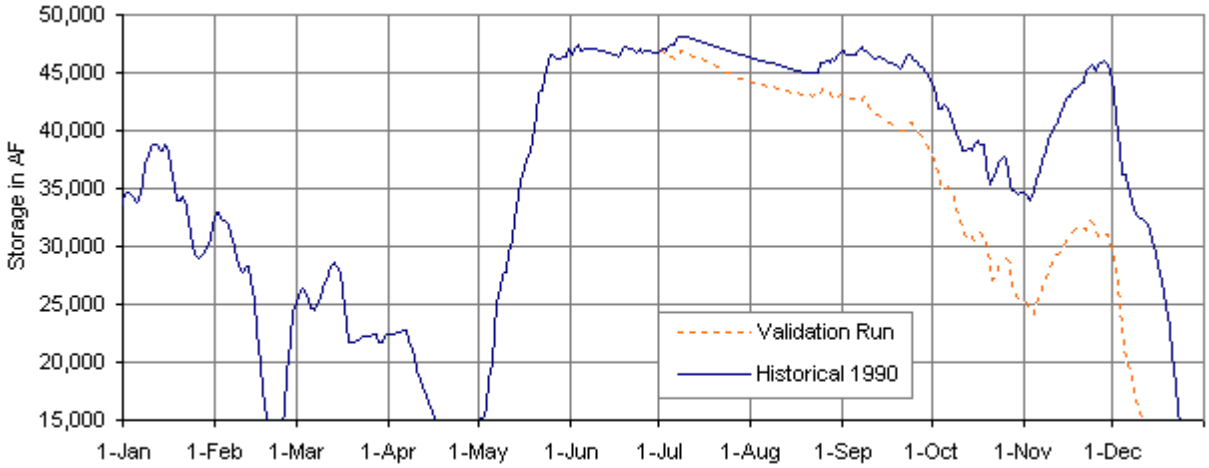
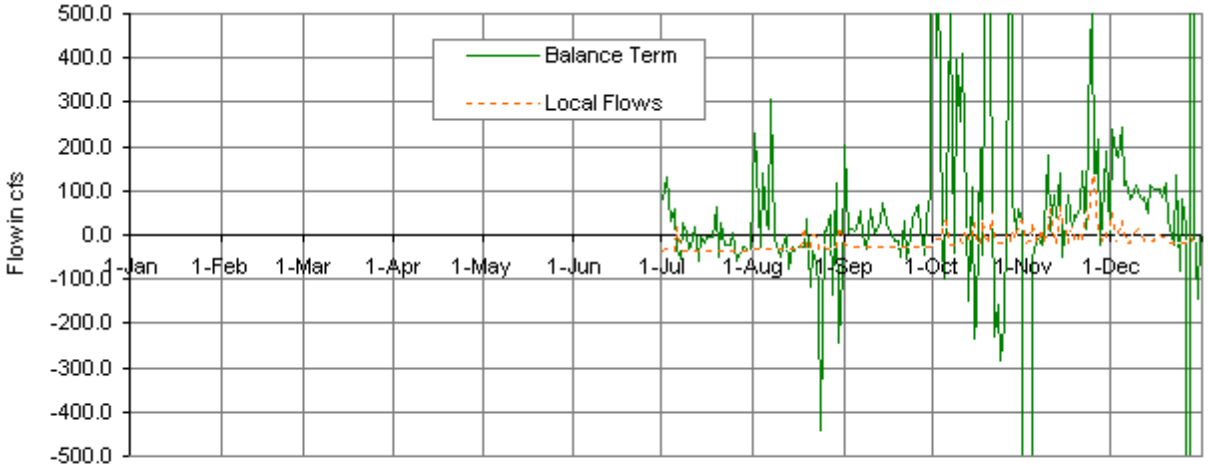


Figure A-2 Model Validation for WY 1989



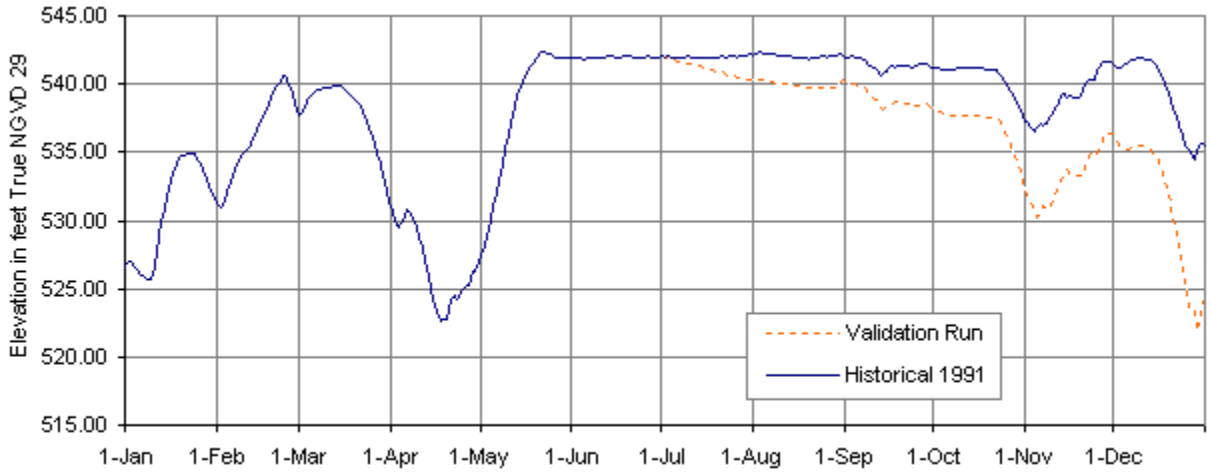
Lake Tapps Reservoir Water Surface Elevation - 1990



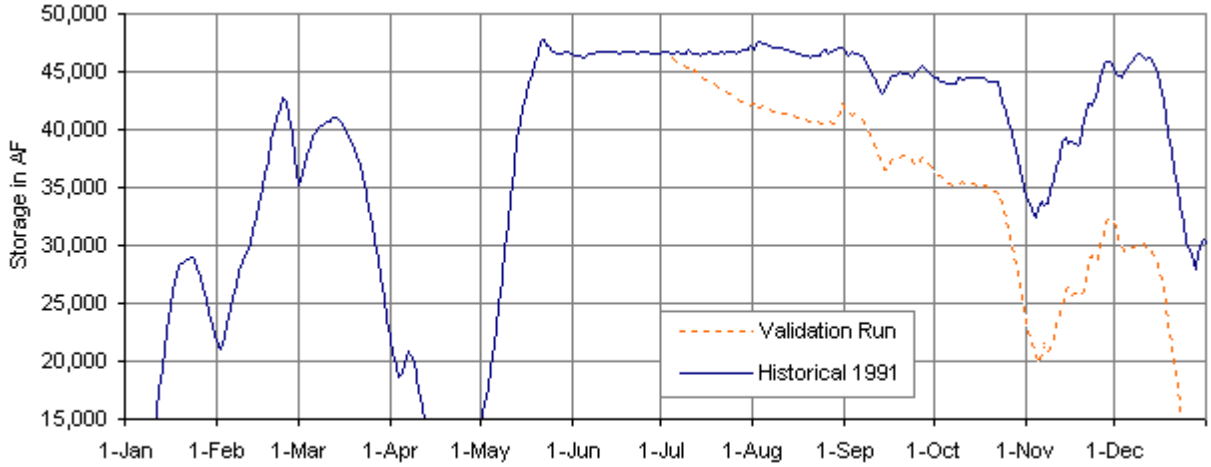


Local Inflow to Lake Tapps - 1990

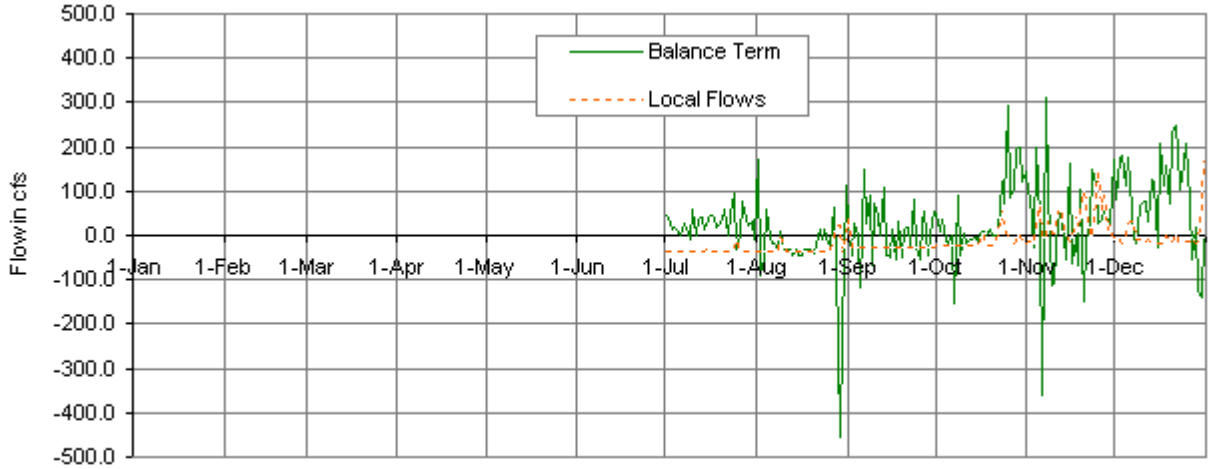
Figure A-3 Model Validation for WY 1990



Lake Tapps Reservoir Water Surface Elevation - 1991



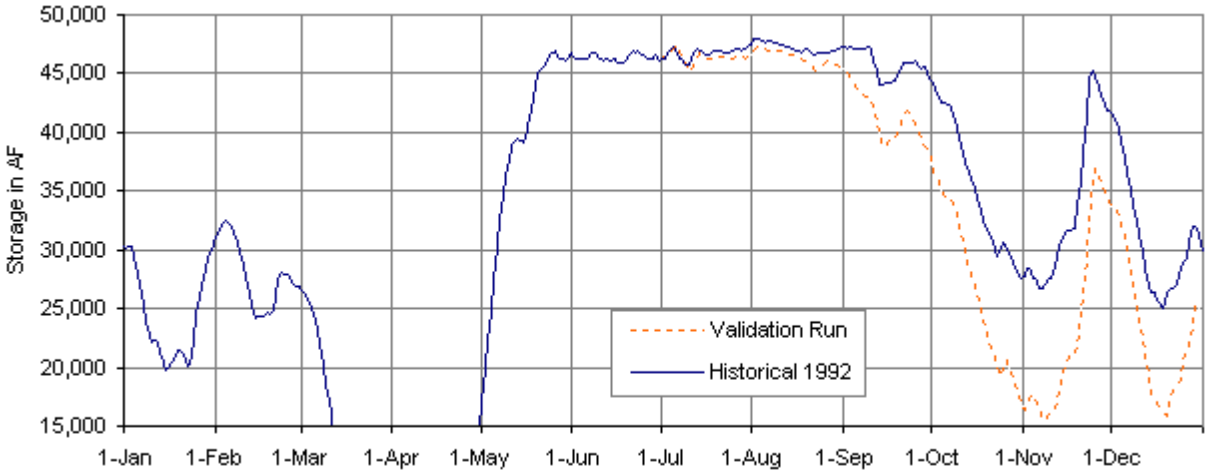
Lake Tapps Reservoir Storage - 1991



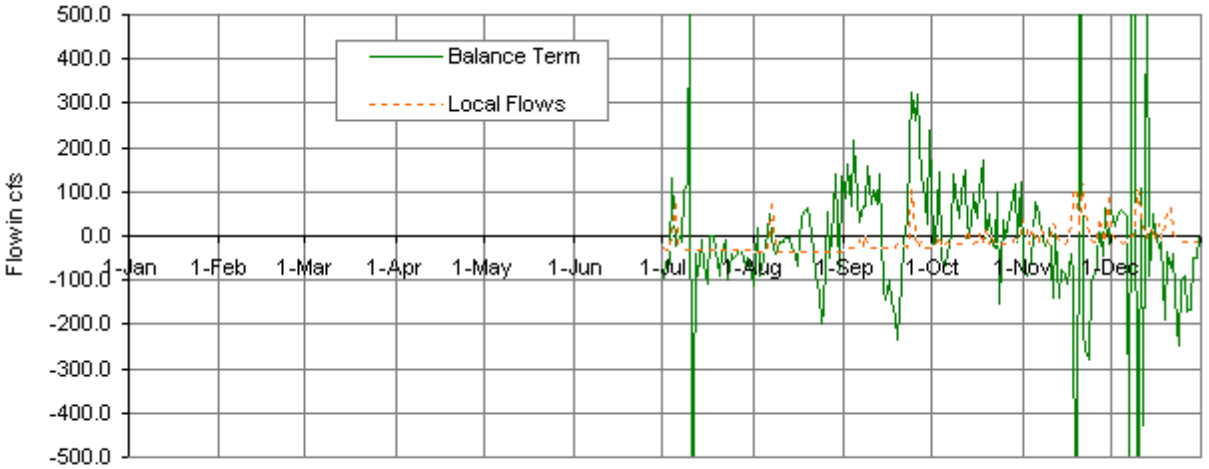
Local Inflow to Lake Tapps - 1991

Figure A-4 Model Validation for WY 1991

Lake Tapps Reservoir Water Surface Elevation - 1992



Lake Tapps Reservoir Storage - 1992



Local Inflow to Lake Tapps - 1992

Figure A-5 Model Validation for WY 1992

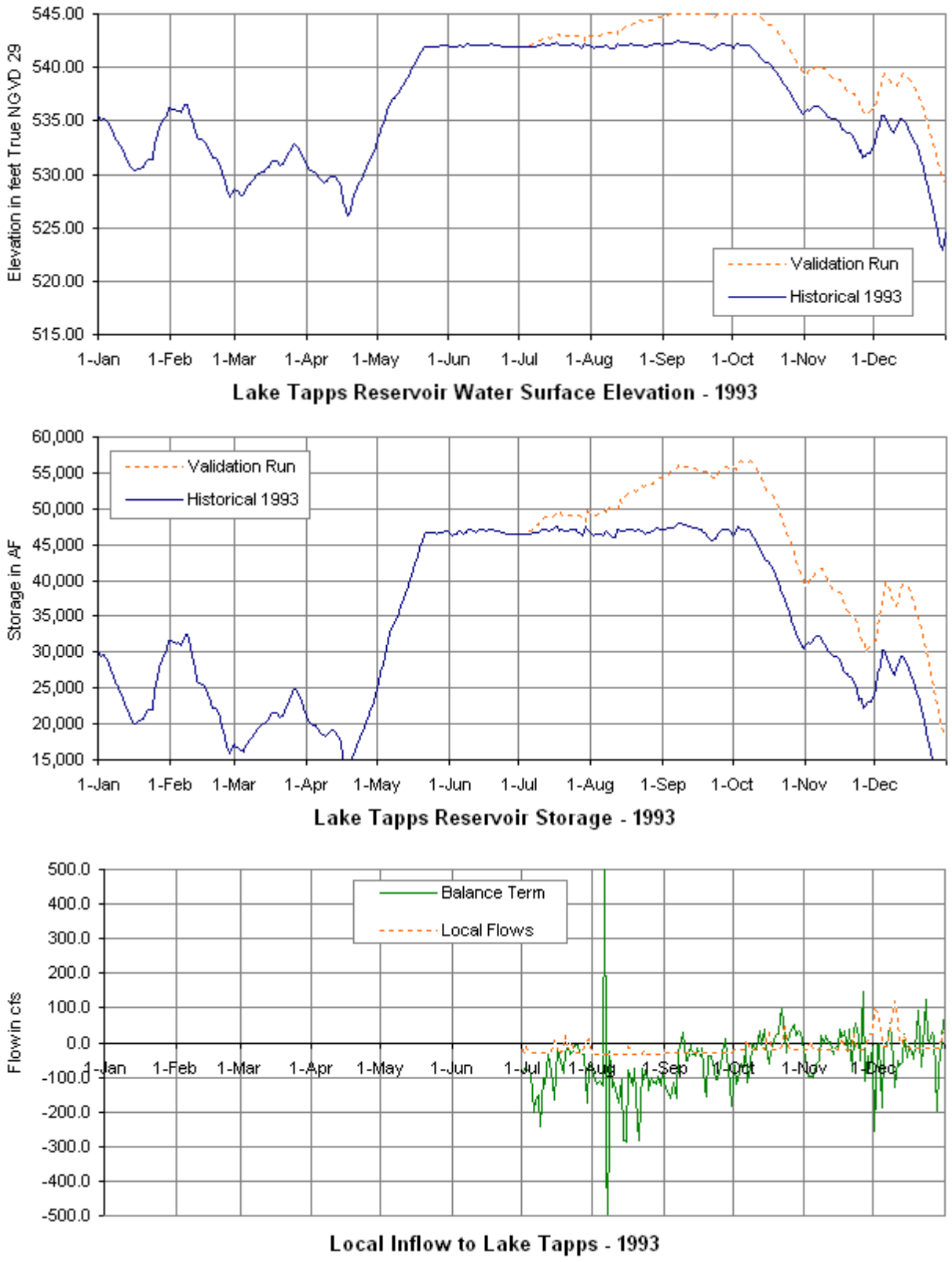


Figure A-6 Model Validation for WY 1993

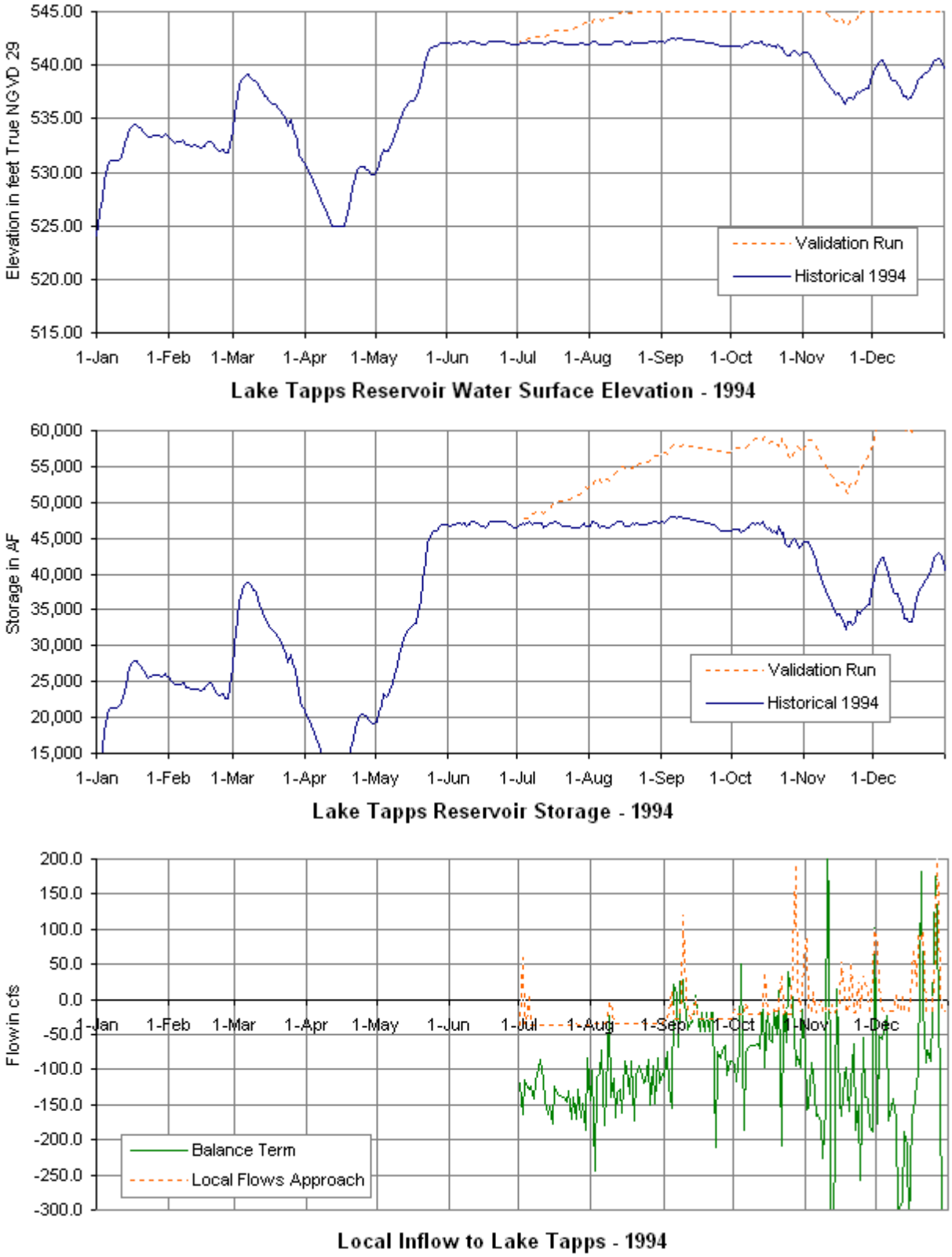
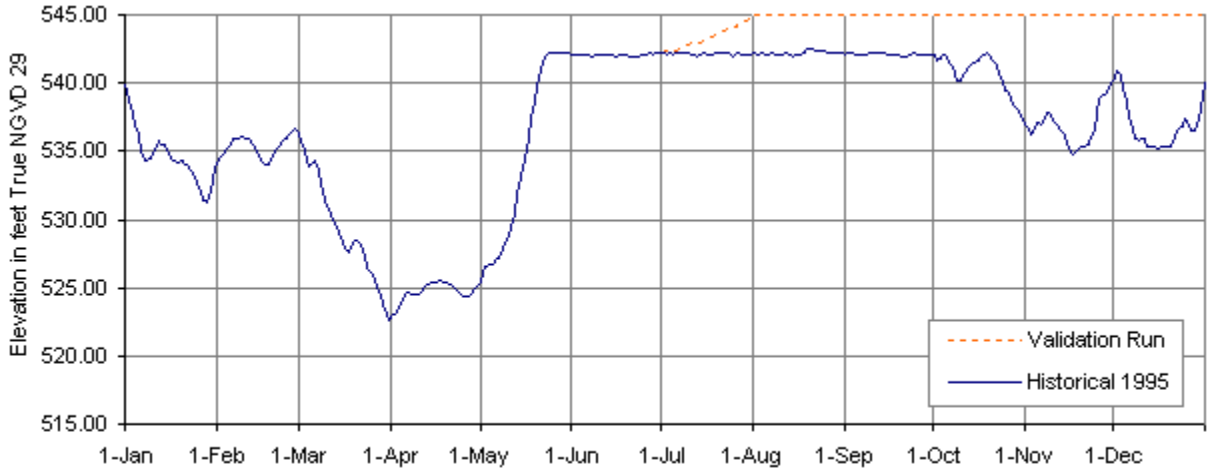
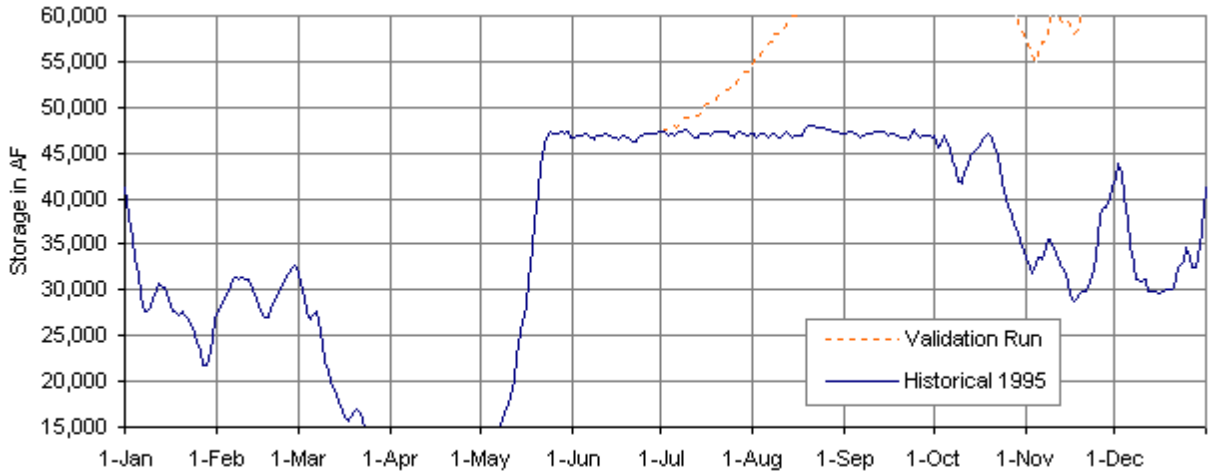


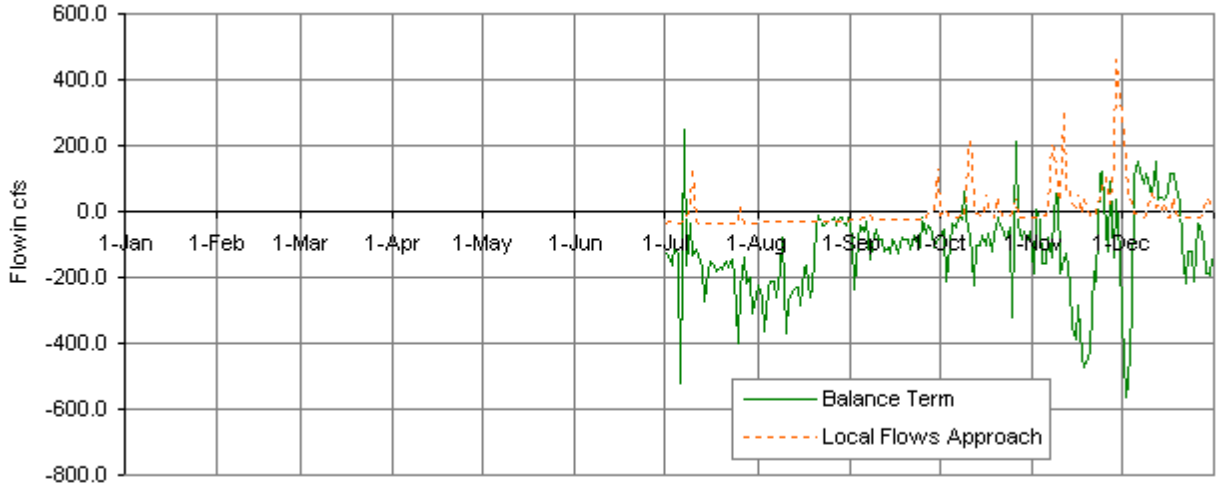
Figure A-7 Model Validation for WY 1994



Lake Tapps Reservoir Water Surface Elevation - 1995



Lake Tapps Reservoir Storage - 1995



Local Inflow to Lake Tapps - 1995

Figure A-8 Model Validation for WY 1995

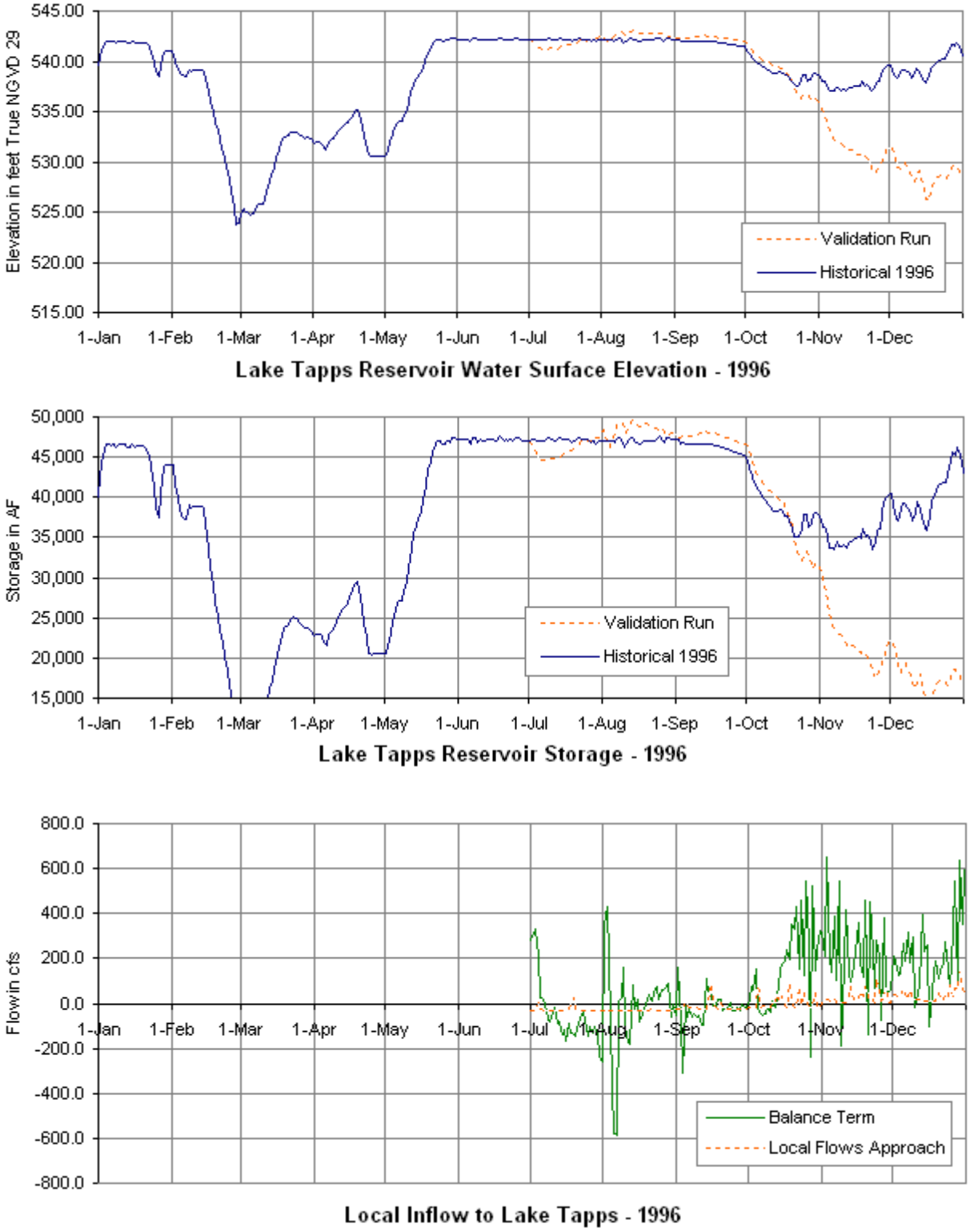
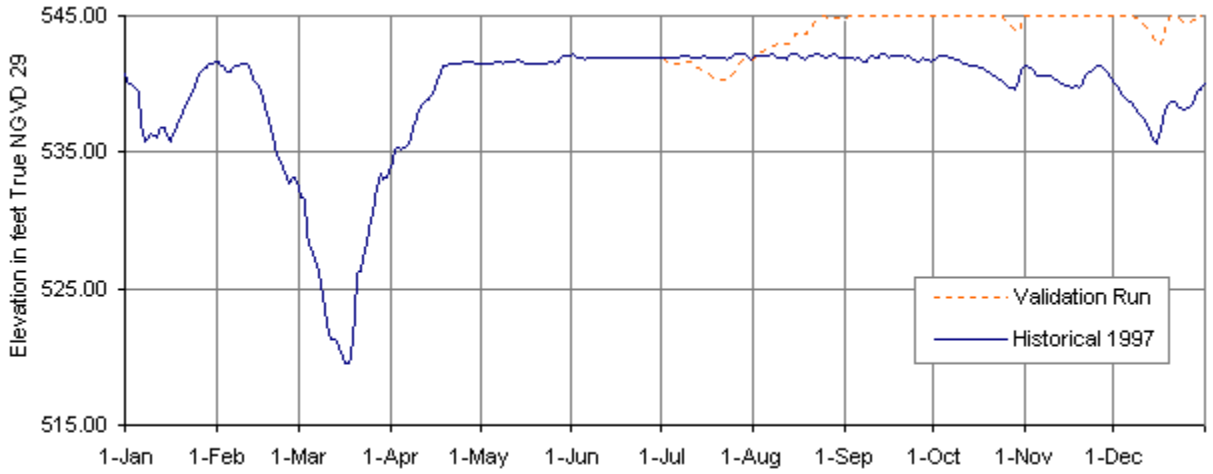
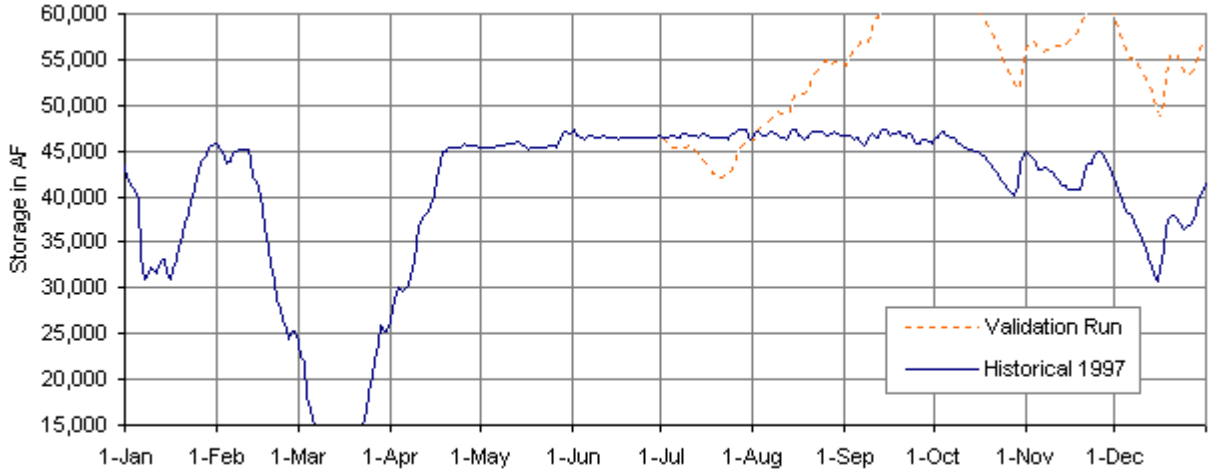


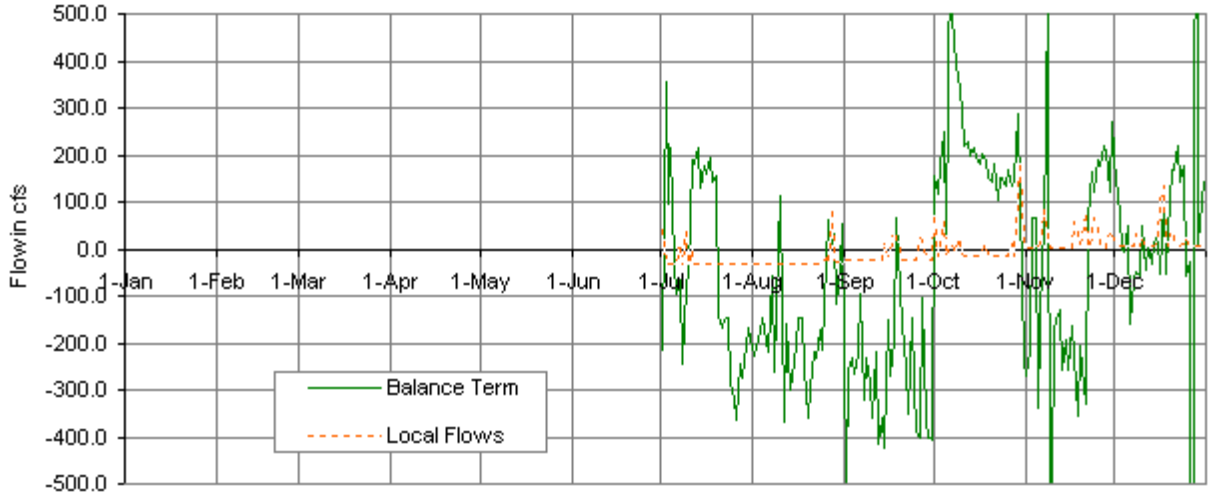
Figure A-9 Model Validation for WY 1996



Lake Tapps Reservoir Water Surface Elevation - 1997



Lake Tapps Reservoir Storage - 1997



Local Inflow to Lake Tapps - 1997

Figure A-10 Model Validation for WY 1997

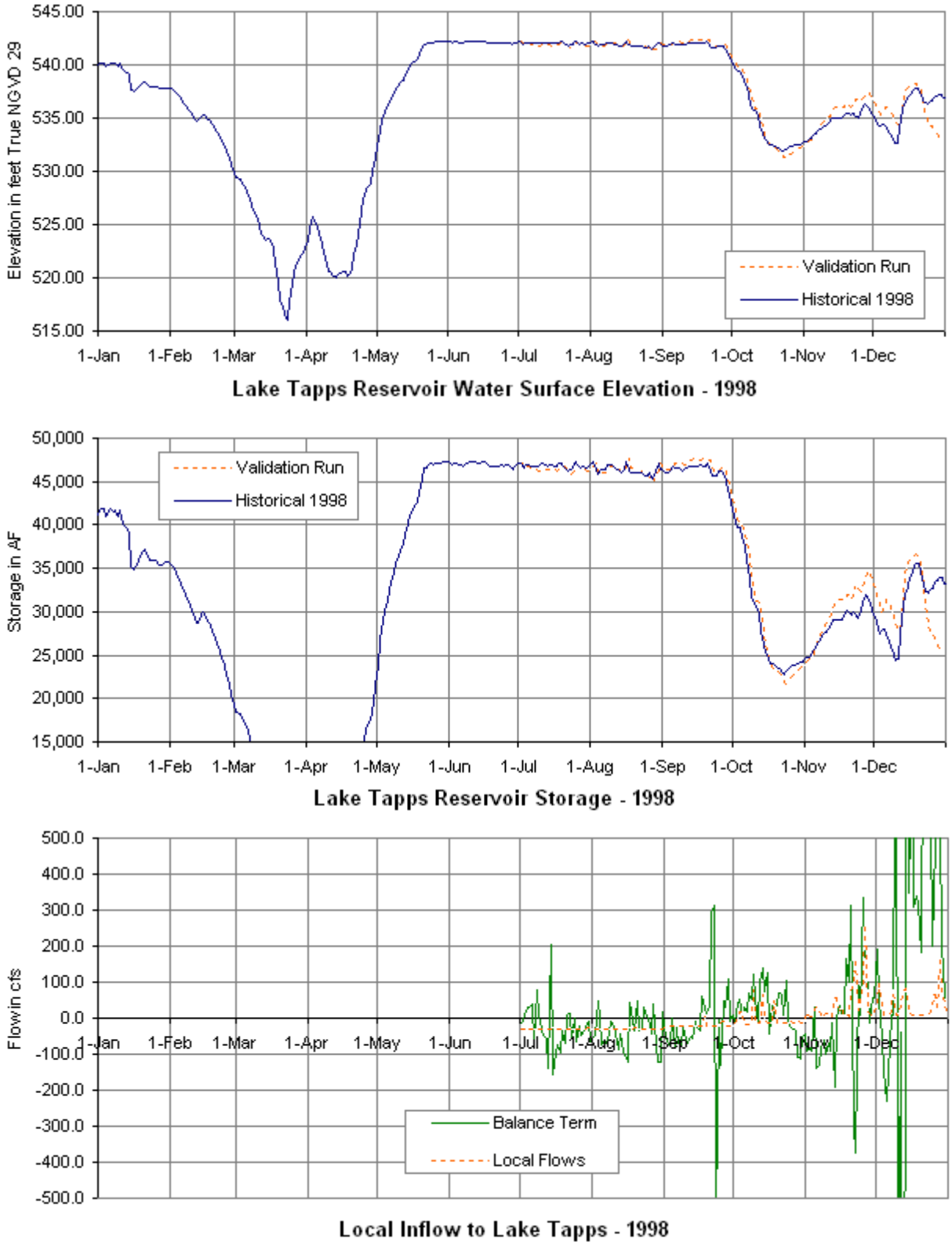
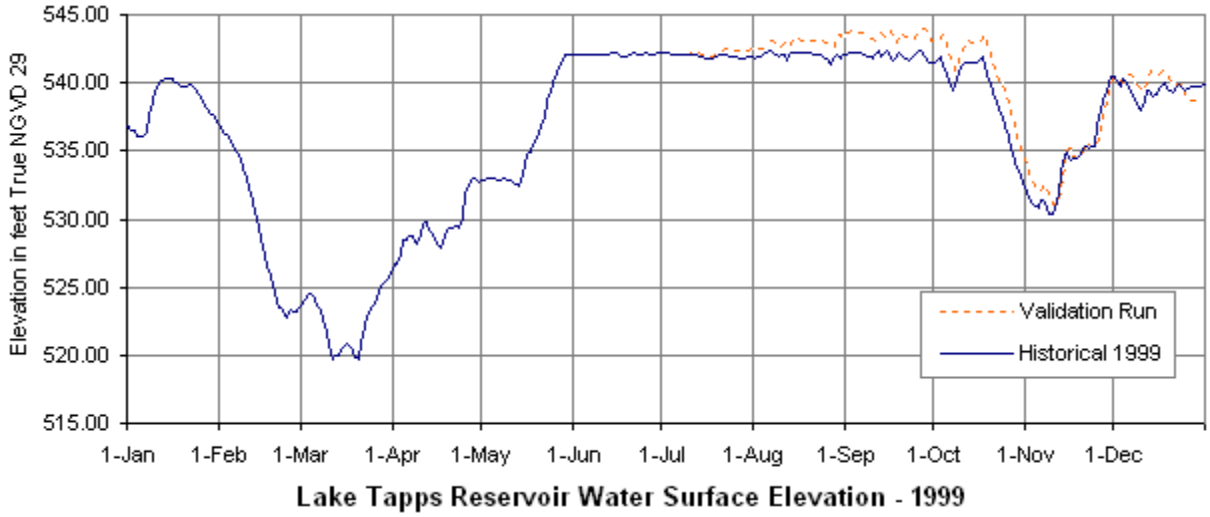
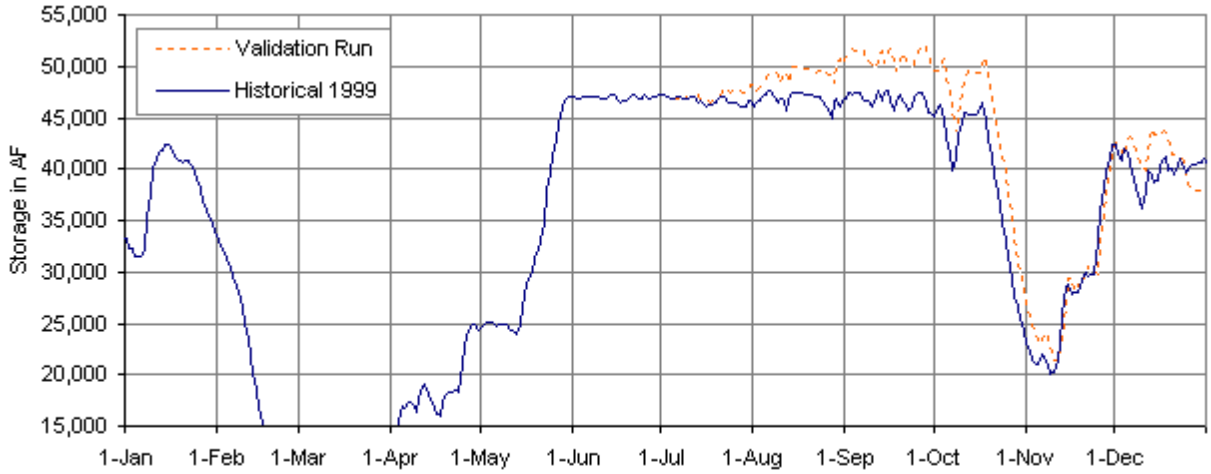


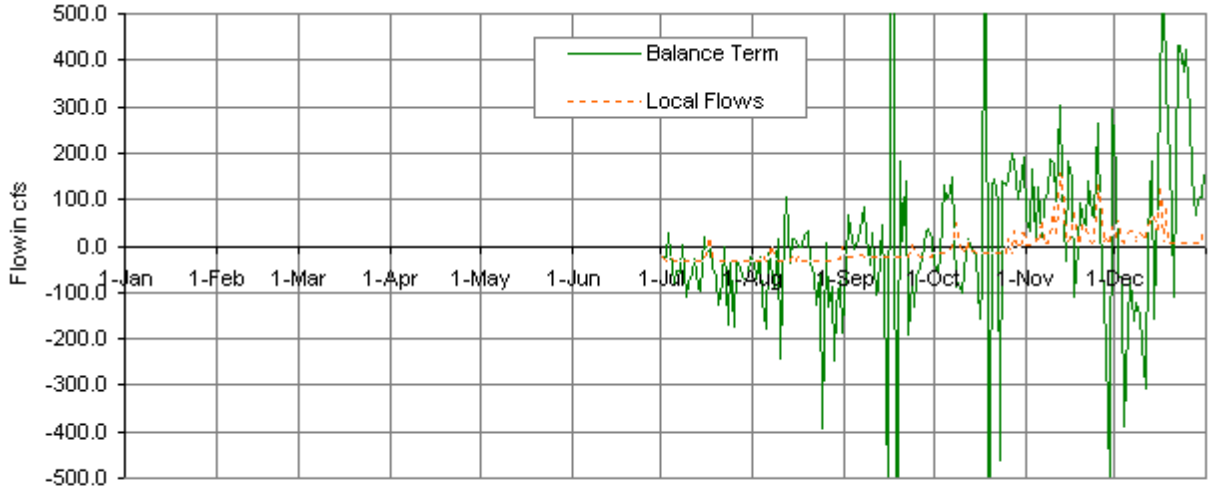
Figure A-11 Model Validation for WY 1998



Lake Tapps Reservoir Water Surface Elevation - 1999



Lake Tapps Reservoir Storage - 1999



Local Inflow to Lake Tapps - 1999

Figure A-12 Model Validation for WY 1999

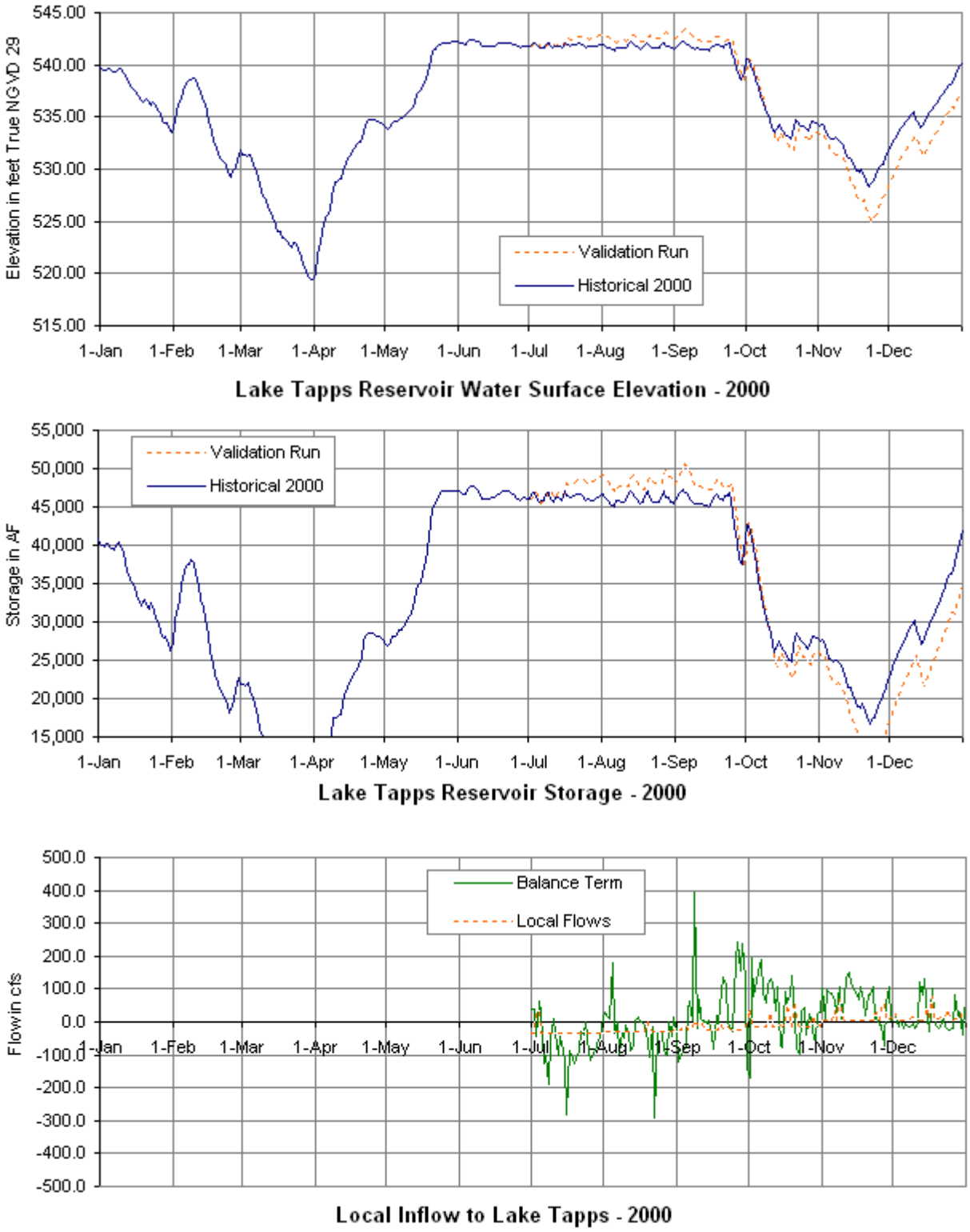
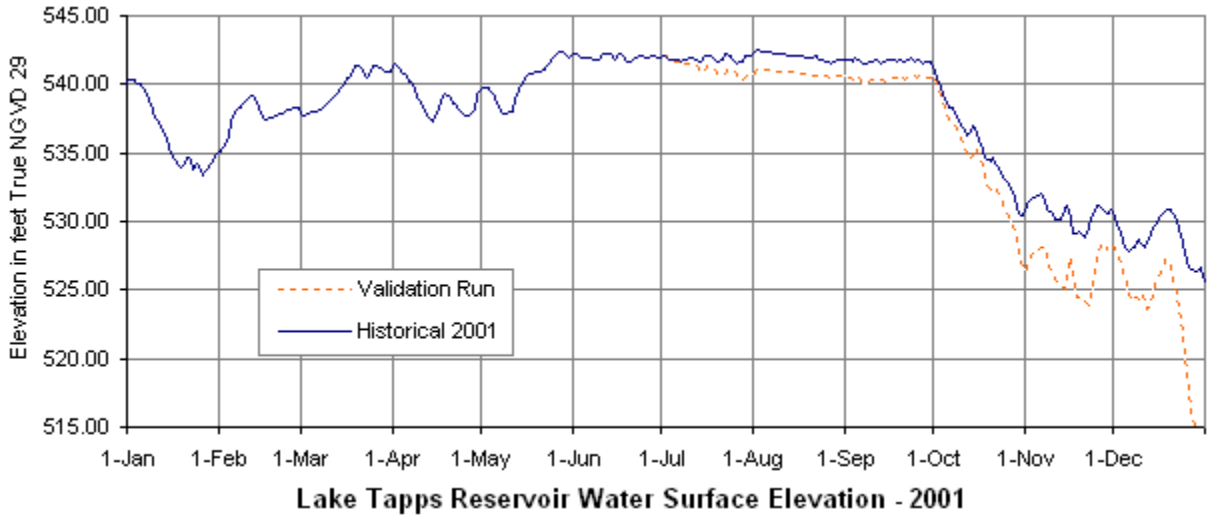
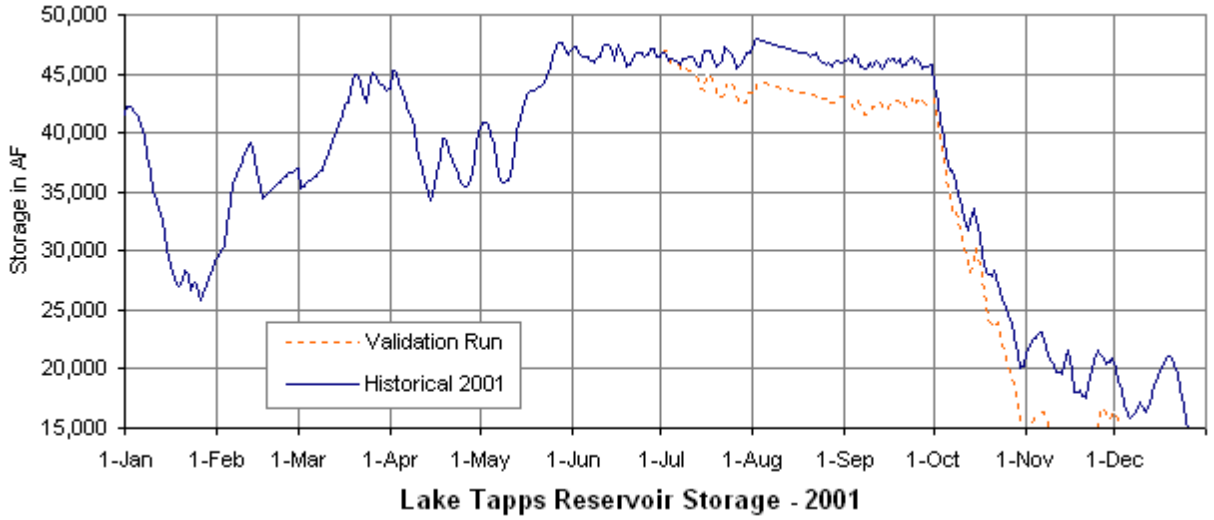


Figure A-13 Model Validation for WY 2000





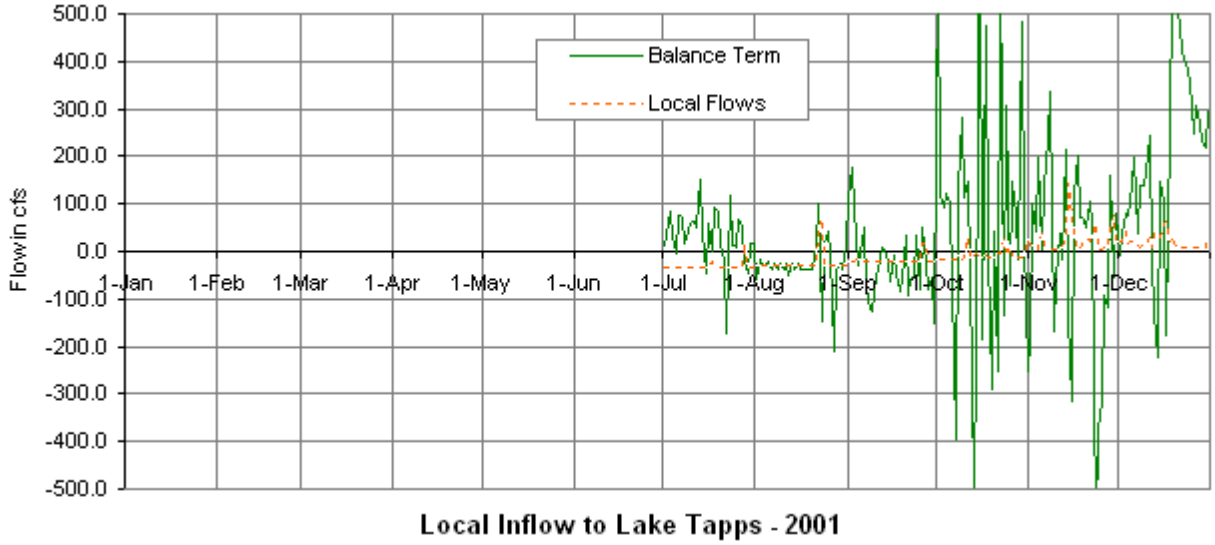


Figure A-14 Model Validation for WY 2001

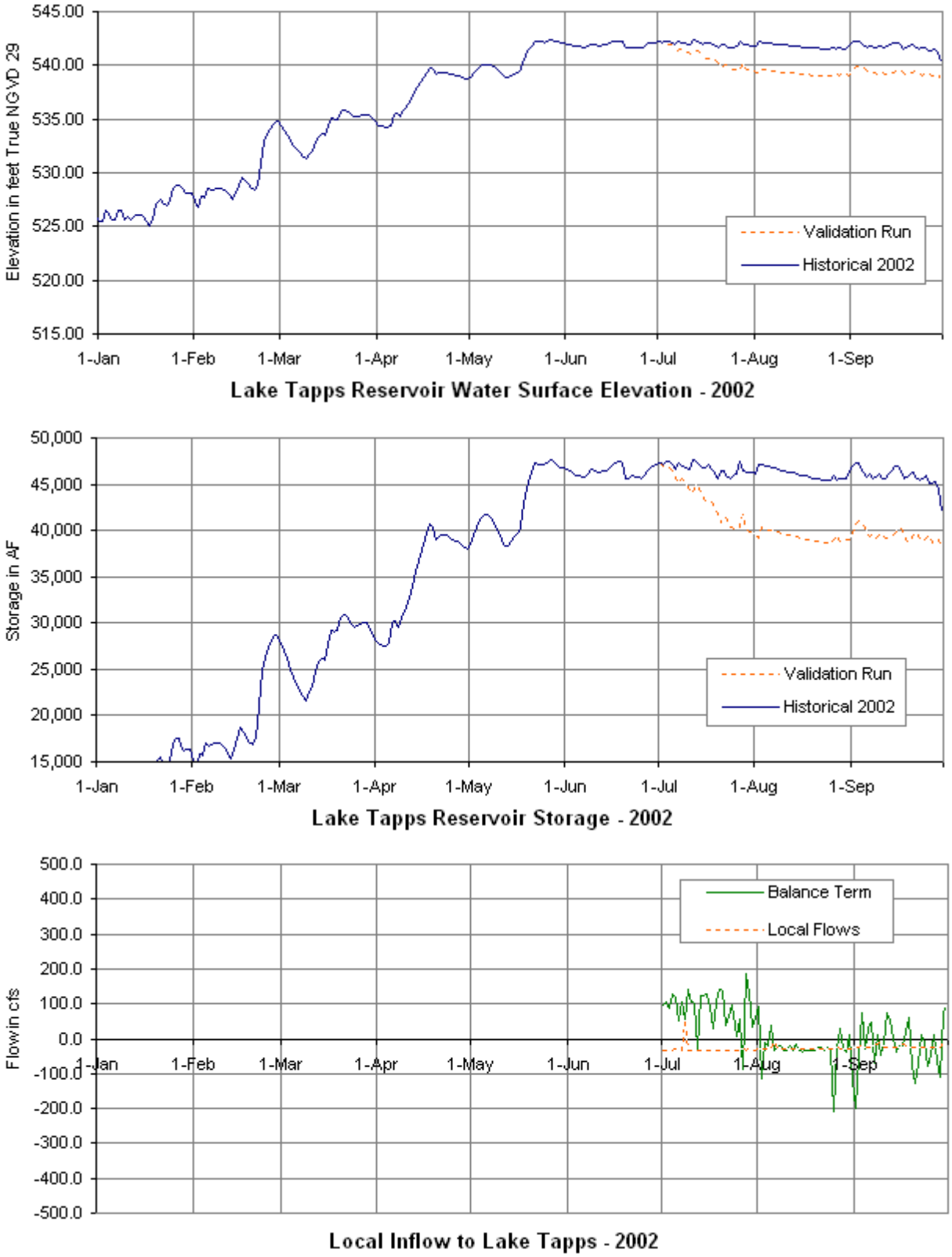


Figure A-15 Model Validation for WY 2002

APPENDIX B

Model Results for Baseline\No Action and Proposed Action Scenarios

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B.1 Average Flows

Table B1 – Annual Average Flows in the Affected Reaches of the White and Puyallup Rivers

Scenario	Average Flows in cfs (WY 1988-2002)				
	White River Reservation Reach	Canal Diversion	Tailrace Release	Lower White River	Lower Puyallup River
Baseline	1366	97	75	1594	3229
Proposed Action	1330	132	40	1523	3159
Difference	-35	35	-35	-71	-71

Table B2 – Monthly Average inputs and outputs from the Lake Tapps System Model for No Action (all values in cfs unless otherwise noted).

Component	Varies	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg.
Inputs														
White River nr Buckley:														
White R nr Buckley Gage Data	Daily	1636	1624	1348	1762	2054	2078	1419	872	575	665	1596	1731	1445
White R nr Buckley Correction	Daily	42	28	29	-11	-14	-19	14	36	31	27	3	45	18
Total White R nr Buckley Flow	Daily	1678	1652	1376	1751	2040	2059	1433	908	606	692	1599	1776	1462
Boise Creek	Daily	54	55	46	43	31	26	16	9	8	14	48	50	33
Diversion Canal:														
Diversion Cap	Varies	375	1000 cfs until full or July 1					375	375	375	375	375	375	
Fish Return	Constant	20	20	20	20	20	20	20	20	20	20	20	20	20
Stormwater Inflows	see below	included in stormwater inflows to Lake Tapps												
Lake Tapps:														
Precipitation on Lake	Daily	12.9	11.3	12.7	15.3	10.7	8.8	3.9	2.9	4.5	13.1	24.9	14.0	11.2
Evaporation	Monthly	0.0	-1.5	-3.4	-7.2	-12.2	-13.7	-16.9	-15.3	-9.9	-3.7	-1.7	0.0	-7.1
Stormwater Inflows	Daily	19.3	21.6	19.6	18.4	6.2	5.5	1.2	1.1	1.9	3.3	20.5	17.9	11.3
Seepage to Groundwater	Constant	-16.0	-16.0	-16.0	-16.0	-16.0	-16.0	-16.0	-16.0	-16.0	-16.0	-16.0	-16.0	-16.0
Release to Bowman Creek	Constant	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0
Dike Seepage	Constant	-0.25	-0.25	-0.25	-0.25	-0.25	-0.25	-0.25	-0.25	-0.25	-0.25	-0.25	-0.25	-0.25
Total Local Gains\Losses	Daily	14.9	14.1	11.6	9.3	-12.5	-16.6	-29.0	-28.5	-20.7	-4.4	26.5	14.7	-1.9
Powerhouse Valve Leakage	Constant	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Water Supply Project Operations:														
White River MF	Two weeks	350	350	350	400	400	400	500	500	500	500	350	350	413
Water Supply Withdrawal	Monthly	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Res. Target Elev. (ft NGVD 29)	Varies	529.49	529.49	534.01	541.50	542.49	542.49	542.49	542.49	542.49	542.49	538.01	530.47	538.19
Auburn Local Inflow	Daily	141	208	106	130	81	70	41	41	32	38	160	166	100
Upper Puyallup River	Daily	2114	2010	1668	1743	1743	1817	1437	1048	771	974	2111	2214	1635
Puyallup River MIF	Two weeks	1400	1450	1655	1853	2000	2000	1863	1390	1070	1000	1053	1255	1500
Outputs														
White River:														
White R abv BC at Buckley	Daily	1632	1604	1036	1512	1970	1986	1348	824	549	637	1574	1742	1366
White R at Auburn	Daily	1847	1886	1208	1705	2103	2101	1425	895	608	709	1801	1978	1519
Lower White River	Daily	1887	1928	1245	1744	2140	2138	1461	931	644	746	2165	2141	1594
Lake Tapps:														
Canal Diversion	Daily	45	48	340	239	70	73	85	84	57	55	26	35	97
Early Spring MIF Avoidance	Daily	0	0	0	0	0	0	0	0	0	0	0	0	0
Canal Inflow to Lake Tapps	Daily	25	28	320	219	50	53	65	64	37	35	6	15	77
Res. Elev. (ft NGVD 29)	Daily	529.43	529.44	533.64	541.32	542.45	542.45	542.44	542.44	542.26	541.92	538.24	530.58	538.08
Tailrace Release	Daily	40	42	36	39	37	37	36	36	36	37	364	163	75
Puyallup River:														
Lower Puyallup River	Daily	4001	3938	2913	3487	3883	3955	2897	1979	1415	1720	4276	4355	3229

Table B3 – Monthly Average inputs and outputs from the Lake Tapps System Model for Proposed Action (all values in cfs unless otherwise noted).

Component	Varies	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg.
Inputs														
White River nr Buckley:														
White R nr Buckley Gage Data	Daily	1636	1624	1348	1762	2054	2078	1419	872	575	665	1596	1731	1445
White R nr Buckley Correction	Daily	42	28	29	-11	-14	-19	14	36	31	27	3	45	18
Total White R nr Buckley Flow	Daily	1678	1652	1376	1751	2040	2059	1433	908	606	692	1599	1776	1462
Boise Creek	Daily	54	55	46	43	31	26	16	9	8	14	48	50	33
Diversion Canal:														
Diversion Cap	Varies	150	1000 cfs until full or July 1					400	400	400	400	170	150	
Fish Return	Constant	20	20	20	20	20	20	20	20	20	20	20	20	20
Stormwater Inflows	see below	included in stormwater inflows to Lake Tapps												
Lake Tapps:														
Precipitation on Lake	Daily	12.8	12.2	16.2	15.5	10.7	8.8	3.9	2.9	4.5	13.1	23.0	13.1	11.4
Evaporation	Monthly	0.0	-1.7	-4.3	-7.3	-12.2	-13.7	-16.9	-15.3	-9.8	-3.6	-1.5	0.0	-7.2
Stormwater Inflows	Daily	19.3	21.6	19.6	18.4	6.2	5.5	1.2	1.1	1.9	3.3	20.5	17.9	11.3
Seepage to Groundwater	Constant	-16.0	-16.0	-16.0	-16.0	-16.0	-16.0	-16.0	-16.0	-16.0	-16.0	-16.0	-16.0	-16.0
Release to Bowman Creek	Constant	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0
Dike Seepage	Constant	-0.25	-0.25	-0.25	-0.25	-0.25	-0.25	-0.25	-0.25	-0.25	-0.25	-0.25	-0.25	-0.25
Total Local Gains\Losses	Daily	14.9	14.9	14.3	9.4	-12.5	-16.6	-29.0	-28.5	-20.7	-4.5	24.7	13.7	-1.8
Powerhouse Valve Leakage	Constant	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Water Supply Project Operations:														
White River MF	Two weeks	581	525	646	802	875	800	756	529	500	500	527	577	635
Water Supply Withdrawal	Monthly	53.0	67.8	61.8	62.6	66.9	84.6	95.4	104.9	81.1	58.9	62.2	53.0	71.0
Res. Target Elev. (ft NGVD 29)	Varies	529.49	536.05	542.49	542.49	542.49	542.49	542.49	542.49	542.49	542.49	535.99	529.49	539.25
Auburn Local Inflow	Daily	141	208	106	130	81	70	41	41	32	38	160	166	100
Upper Puyallup River	Daily	2114	2010	1668	1743	1743	1817	1437	1048	771	974	2111	2214	1635
Puyallup River MIF	Two weeks	1400	1450	1655	1853	2000	2000	1863	1390	1070	1000	1053	1255	1500

Outputs														
White River:														
White R abv BC at Buckley	Daily	1601	1307	1086	1639	1935	1934	1290	756	526	612	1579	1707	1330
White R at Auburn	Daily	1815	1589	1259	1832	2067	2050	1367	827	585	684	1807	1943	1484
Lower White River	Daily	1830	1597	1266	1848	2072	2054	1368	828	586	687	2204	1970	1523
Lake Tapps:														
Canal Diversion	Daily	77	345	290	112	106	125	142	152	80	80	20	70	132
Early Spring MIF Avoidance	Daily	0	4	4	0	0	0	0	0	0	0	0	0	1
Canal Inflow to Lake Tapps	Daily	57	325	270	92	86	105	122	132	60	60	0	50	112
Res. Elev. (ft NGVD 29)	Daily	529.36	531.18	539.99	542.18	542.47	542.47	542.43	542.43	542.03	541.40	536.27	529.44	538.50
Tailrace Release	Daily	15	8	7	16	5	4	1	0	0	3	397	27	40
Puyallup River:														
Lower Puyallup River	Daily	3944	3607	2934	3591	3815	3871	2804	1876	1356	1661	4315	4184	3159

B.2 Hydrographs by Water Year

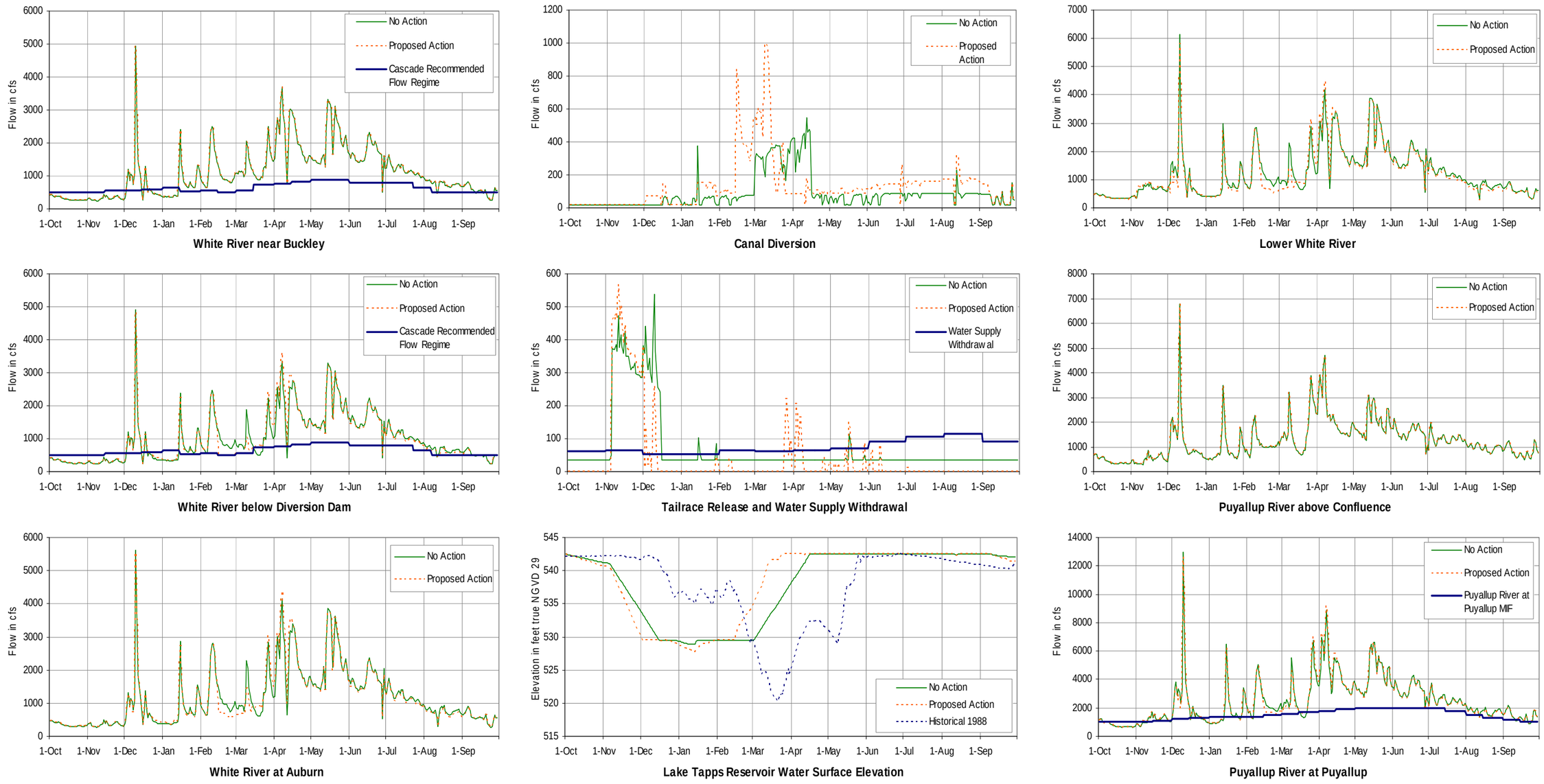


Figure B-1 – Lake Tapps System Hydrographs, Water year 1988

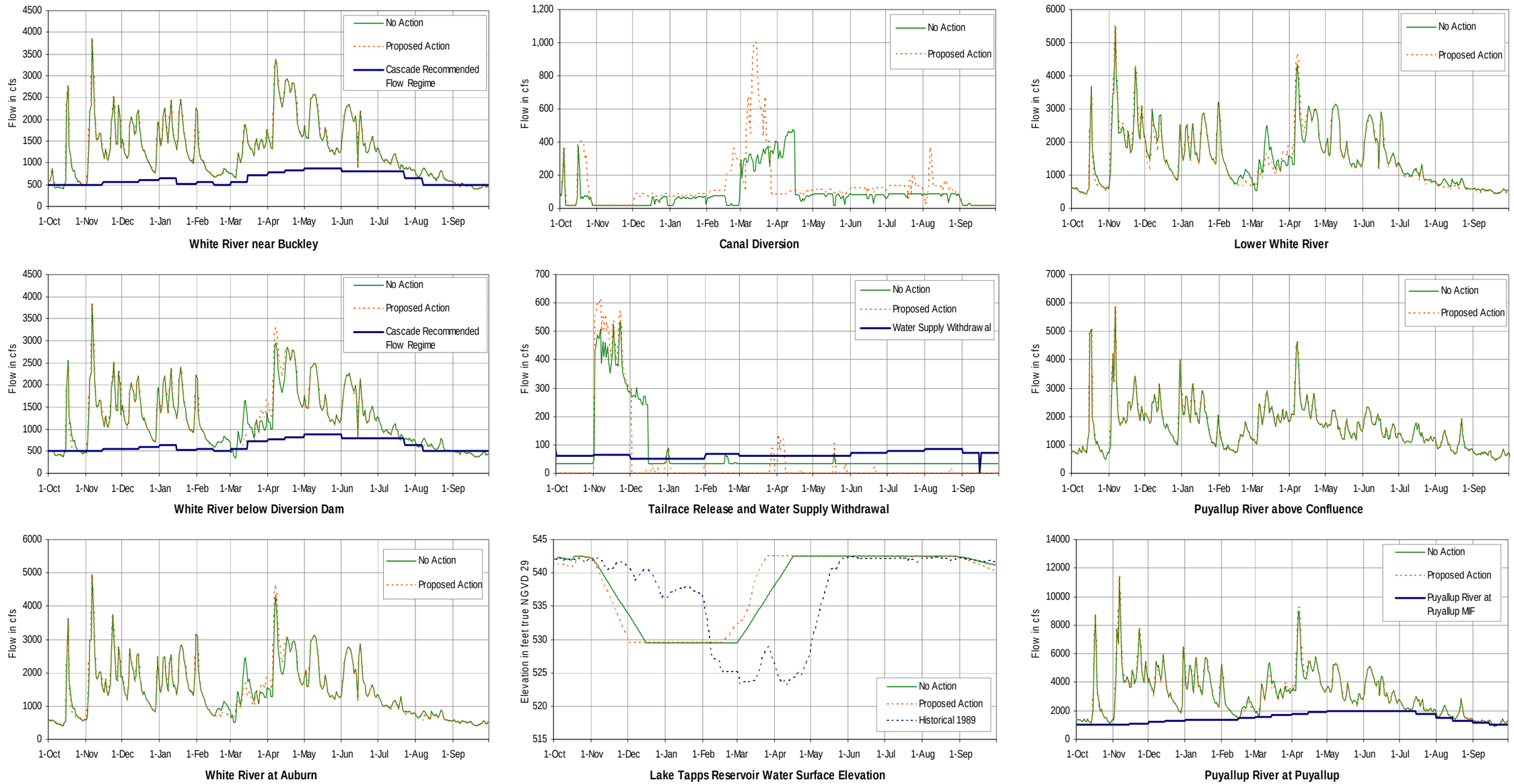


Figure B-2 – Lake Tapps System Hydrographs, Water year 1989

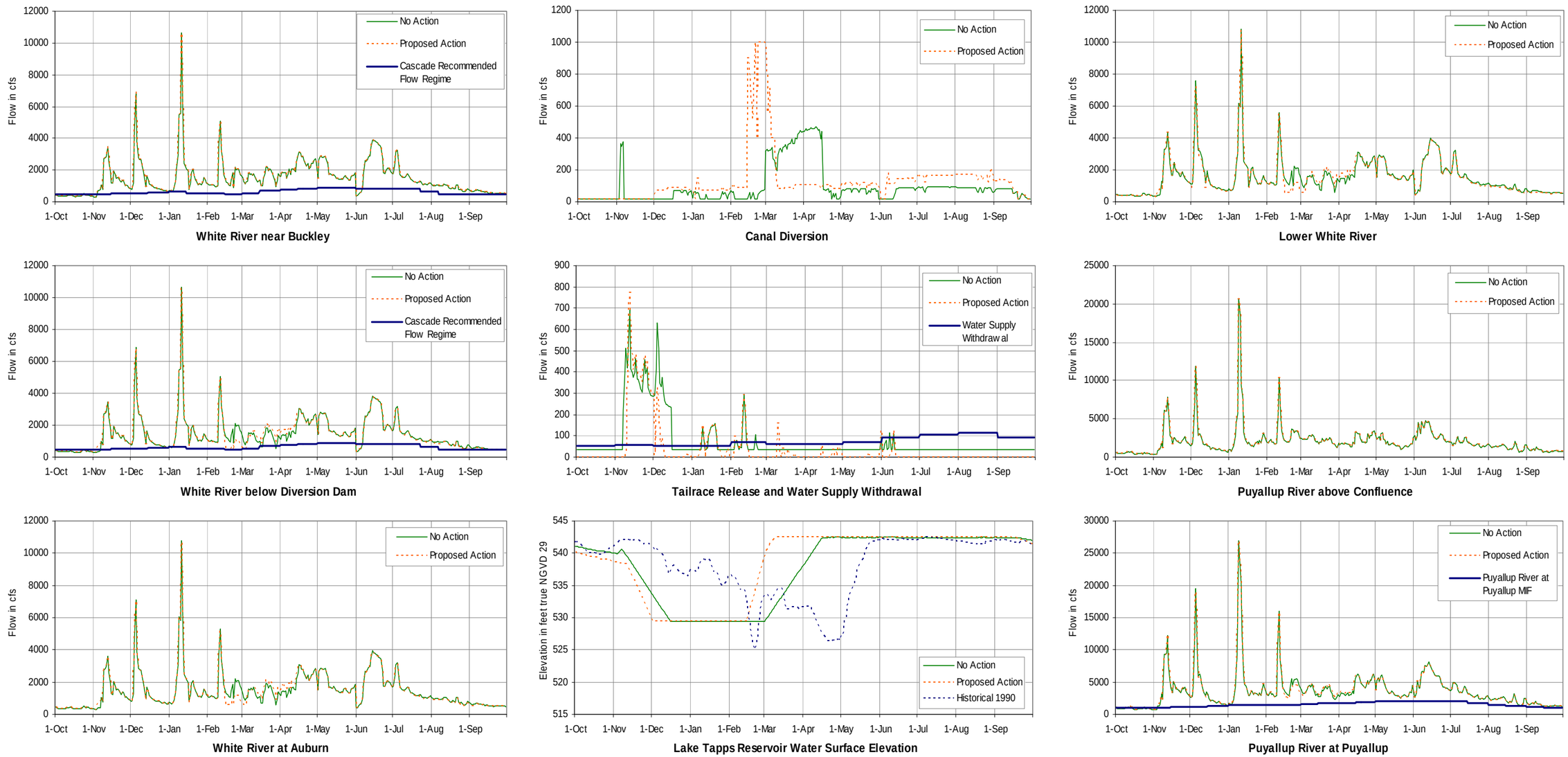
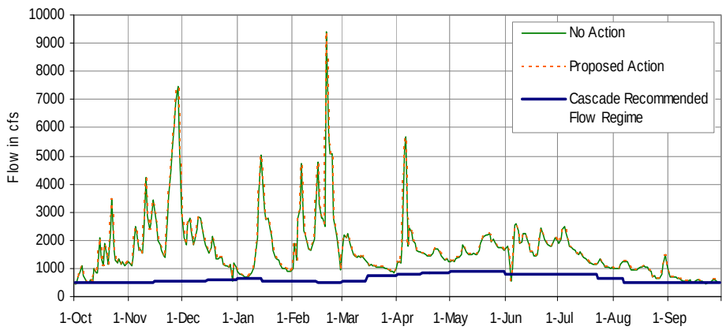
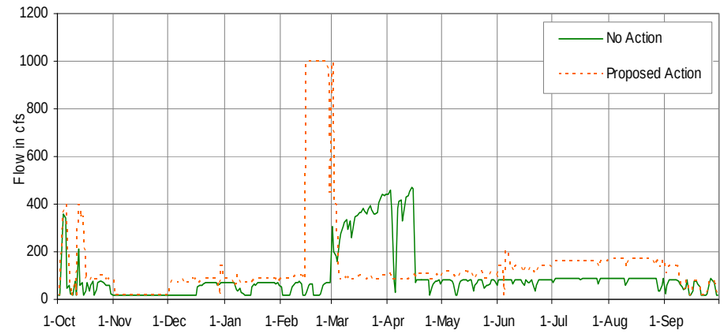


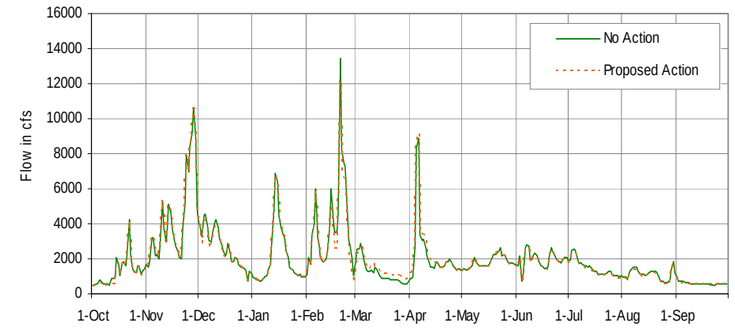
Figure B-3 – Lake Tapps System Hydrographs, Water year 1990



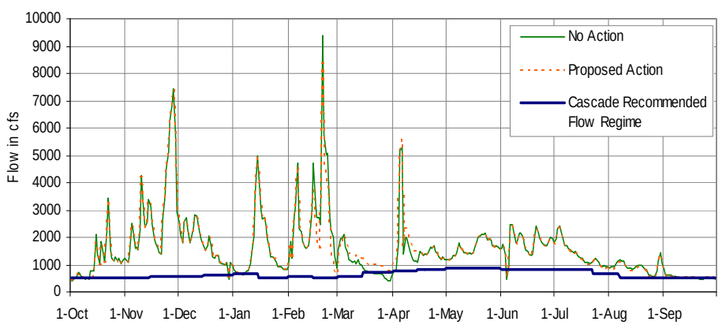
White River near Buckley



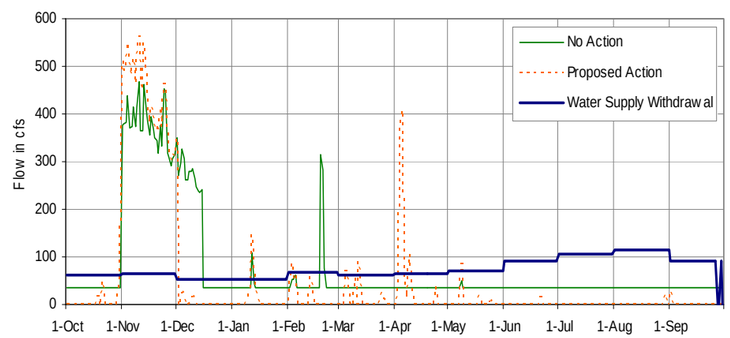
Canal Inflow



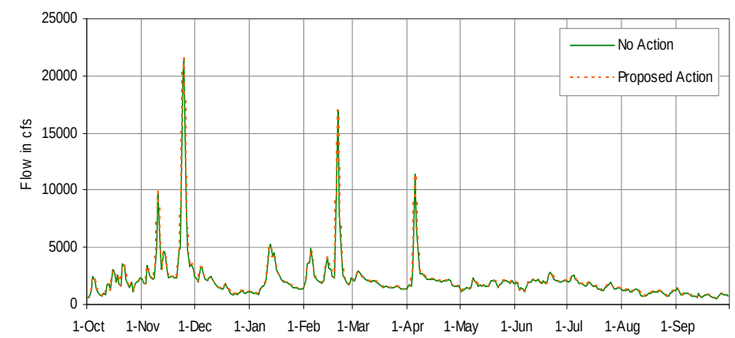
Lower White River



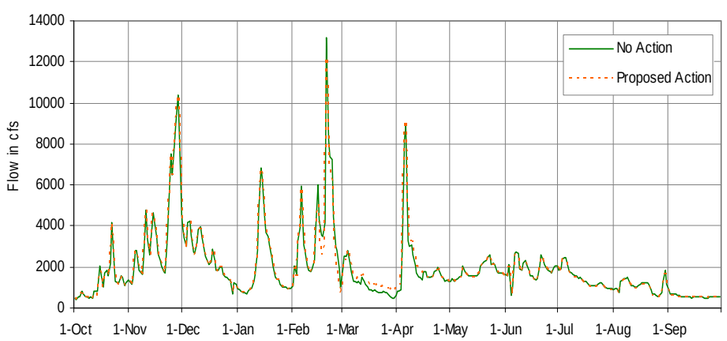
White River below Diversion Dam



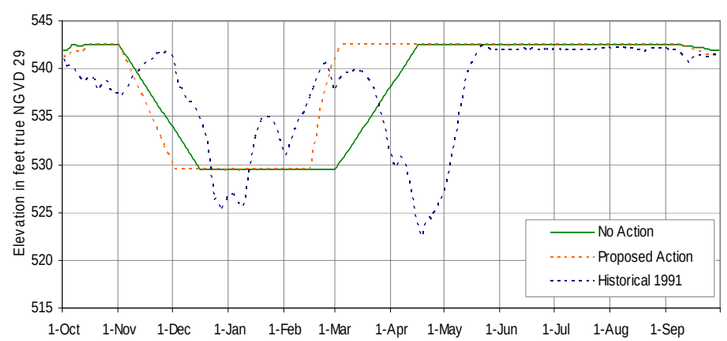
Tailrace Release and Water Supply Withdrawal



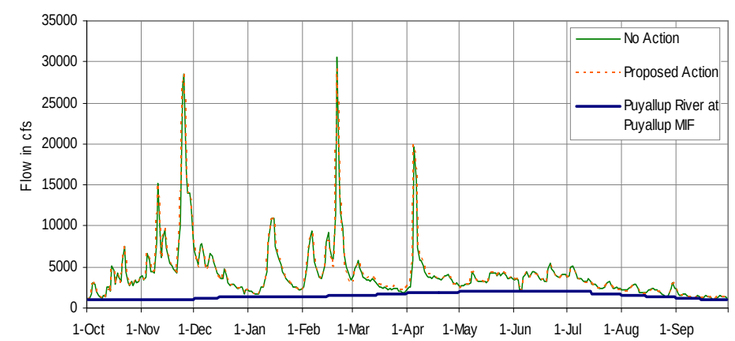
Puyallup River above Confluence



White River at Auburn



Lake Tapps Reservoir Water Surface Elevation



Puyallup River at Puyallup

Figure B-4 – Lake Tapps System Hydrographs, Water year 1991

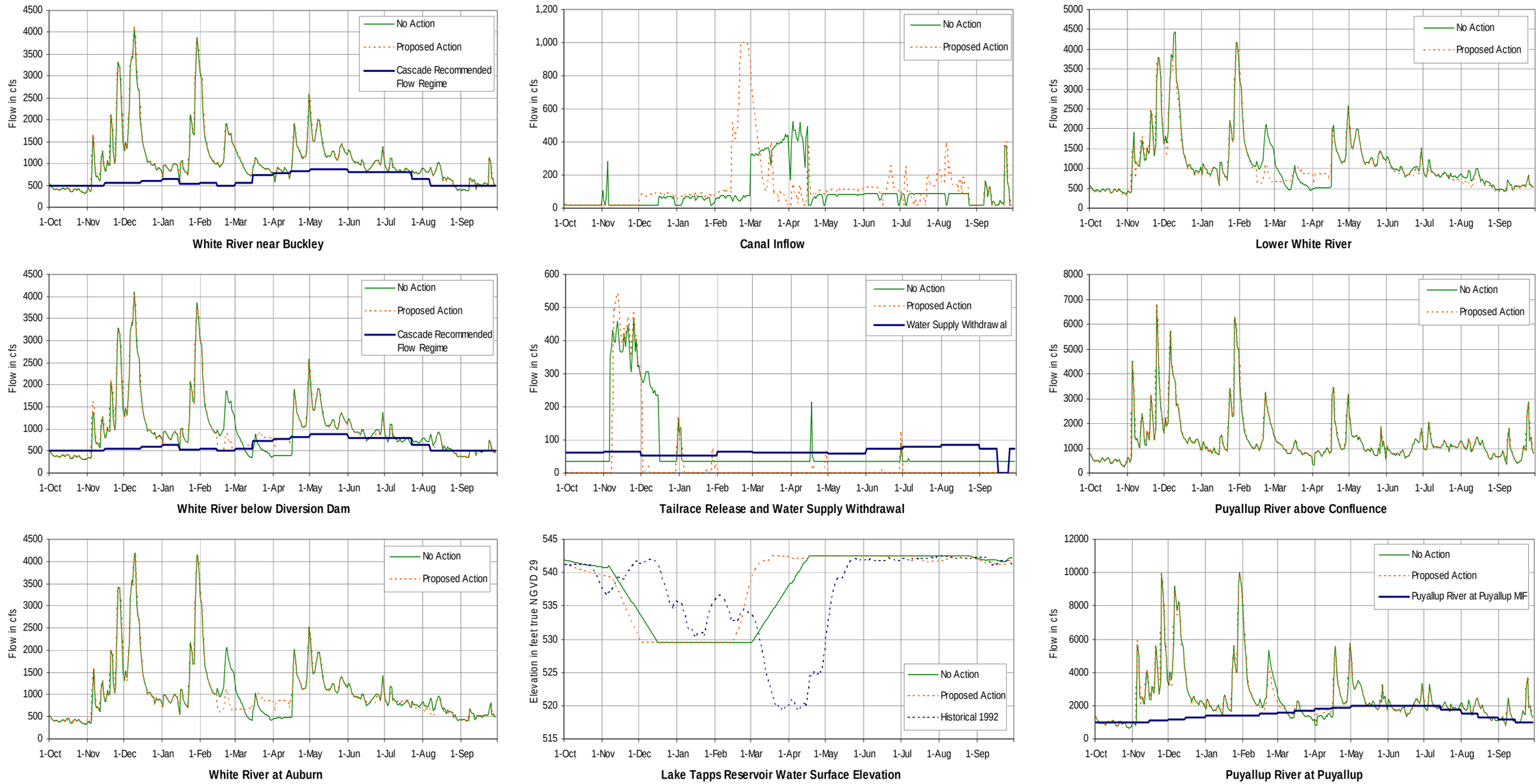


Figure B-5 – Lake Tapps System Hydrographs, Water year 1992

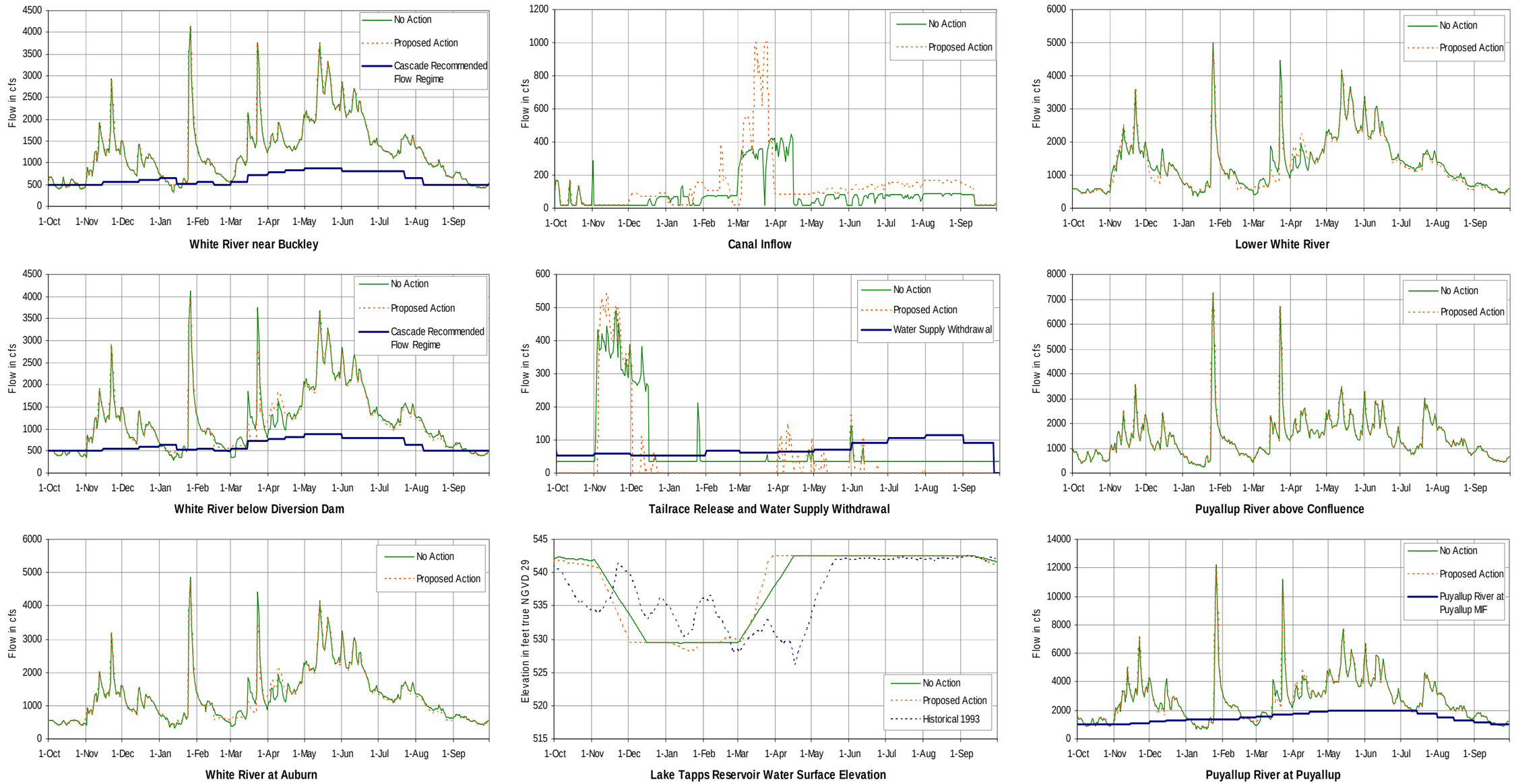


Figure B-6 – Lake Tapps System Hydrographs, Water year 1993

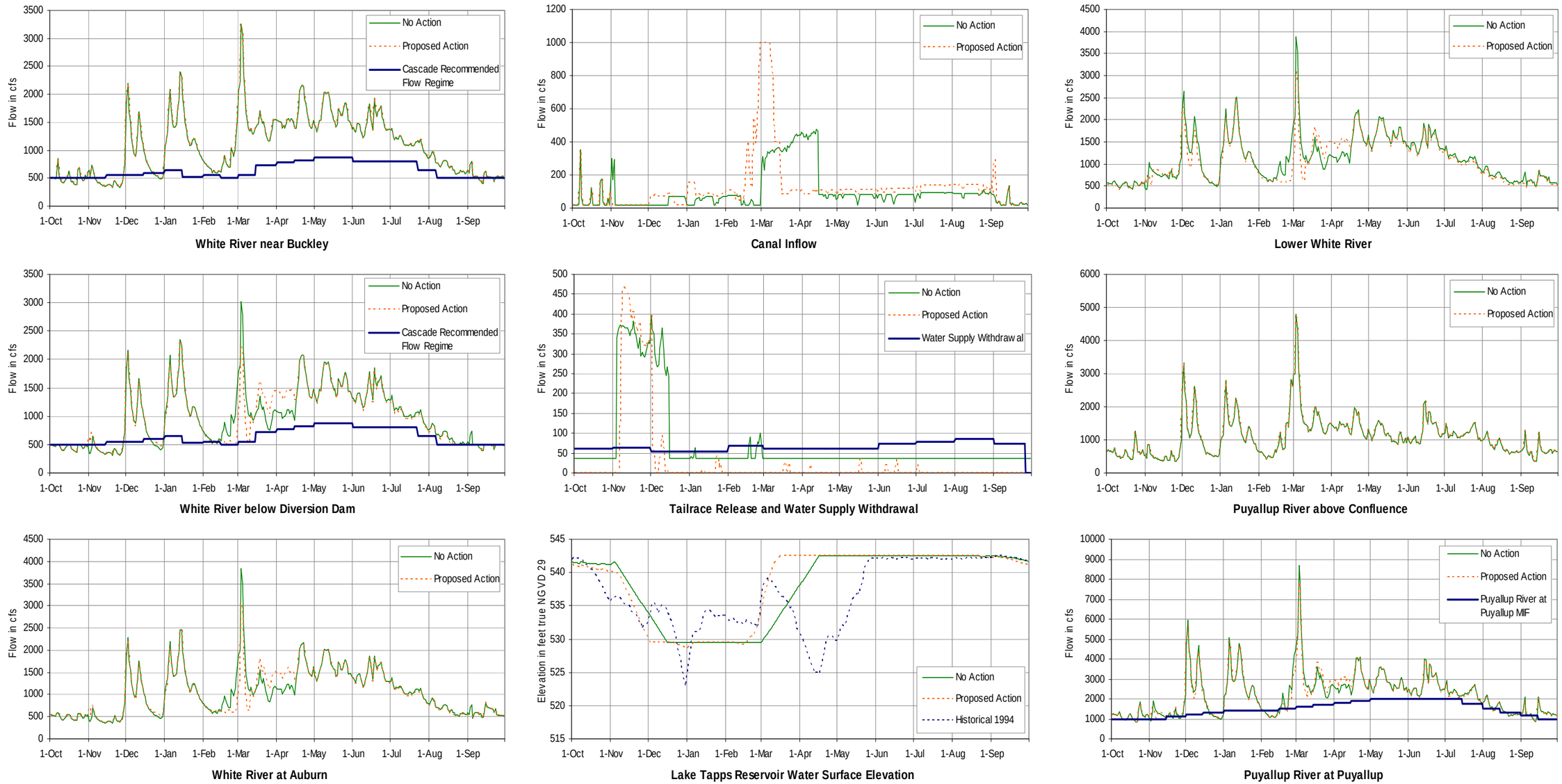


Figure B-7 – Lake Tapps System Hydrographs, Water year 1994

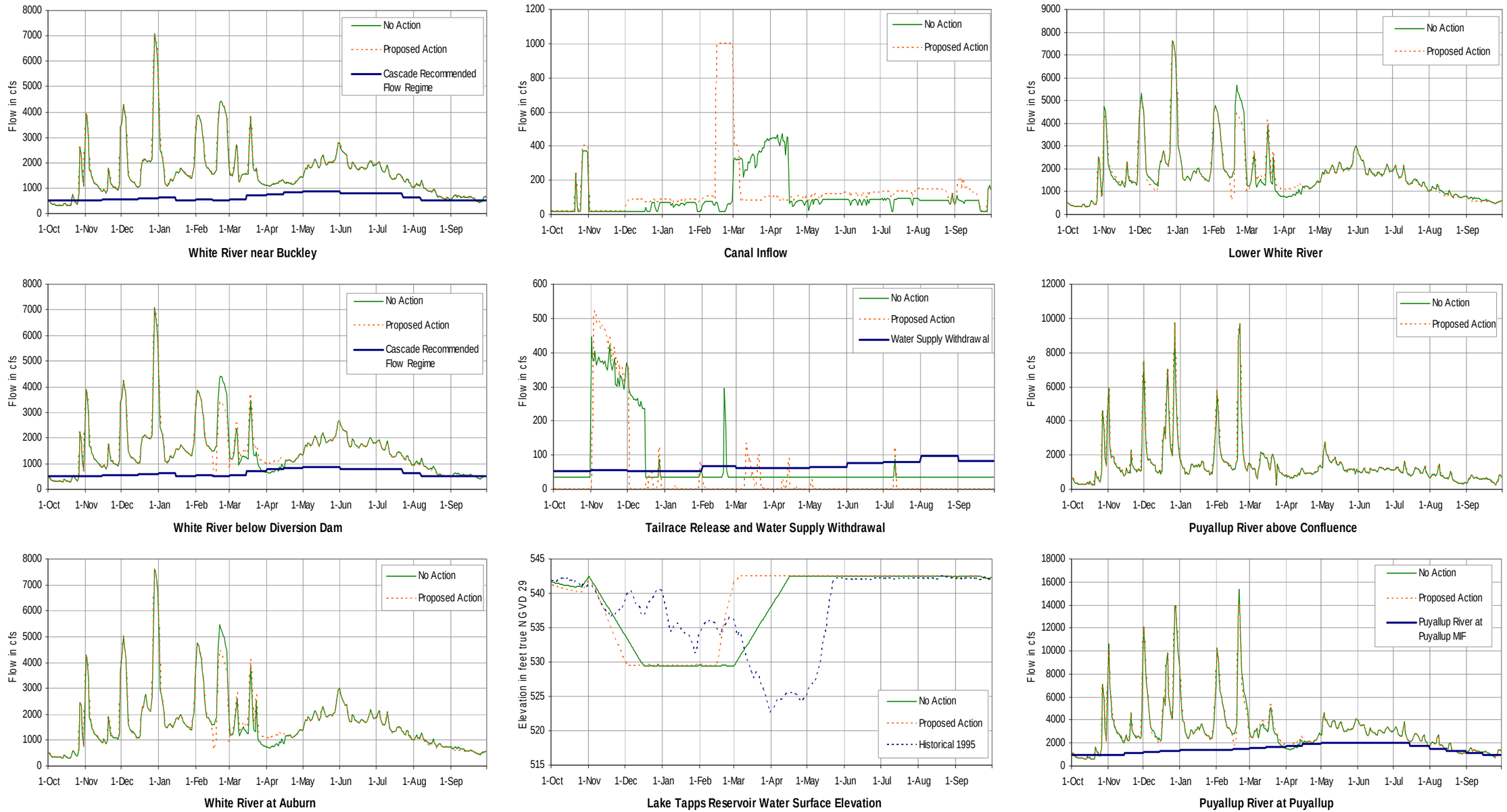


Figure B-8 – Lake Tapps System Hydrographs, Water year 1995

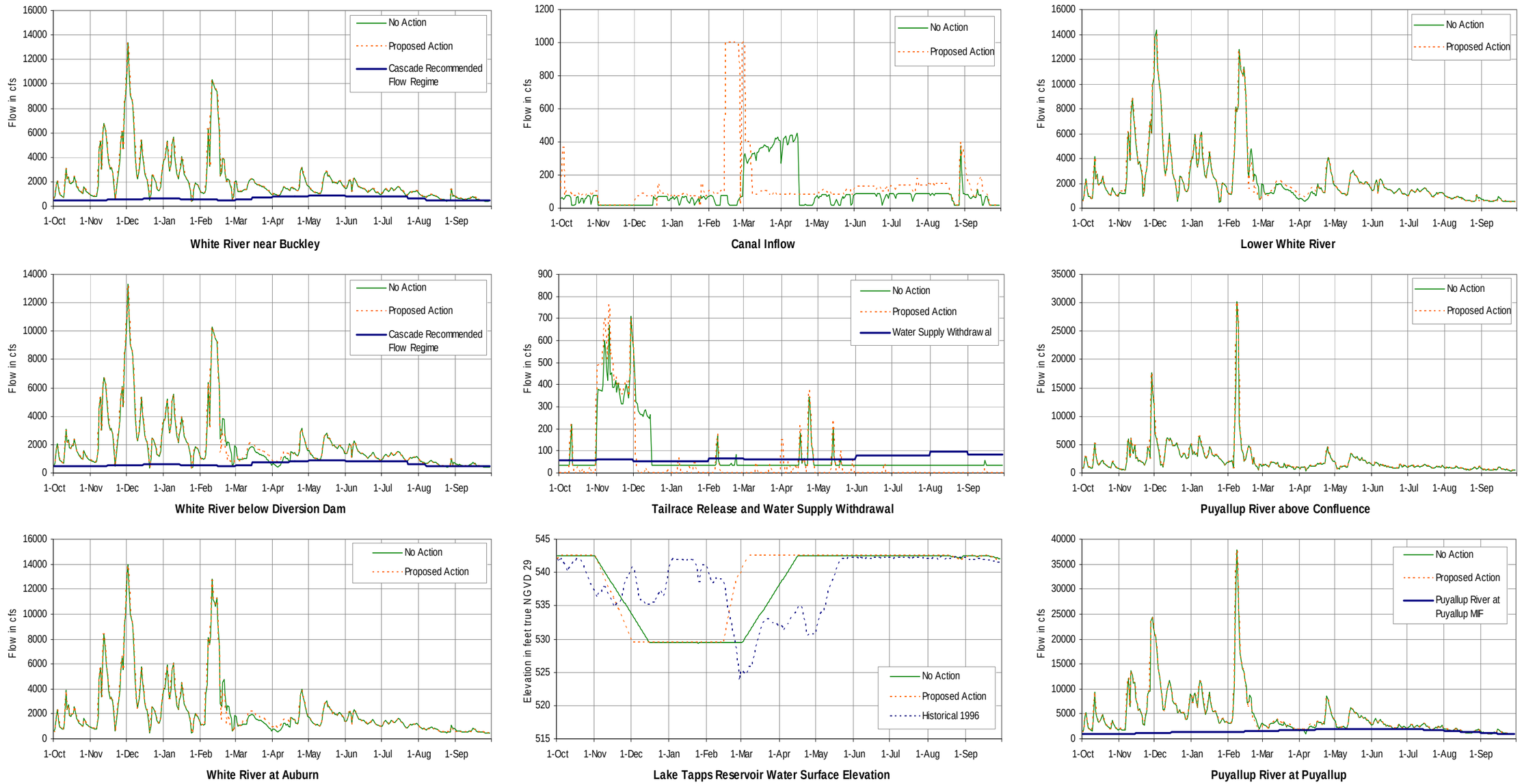
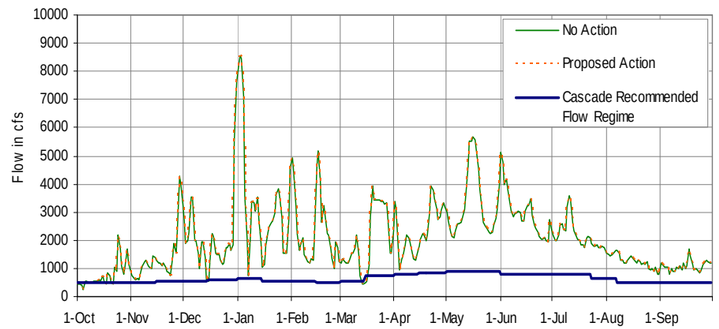
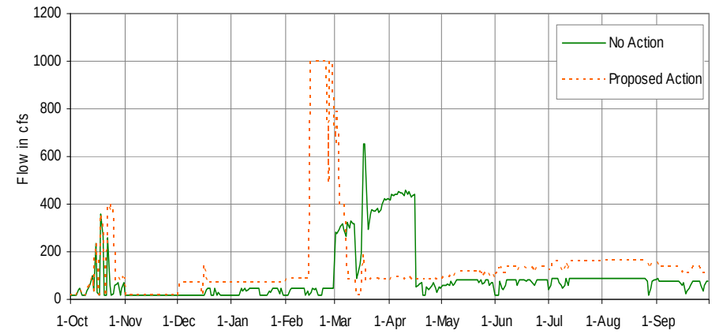


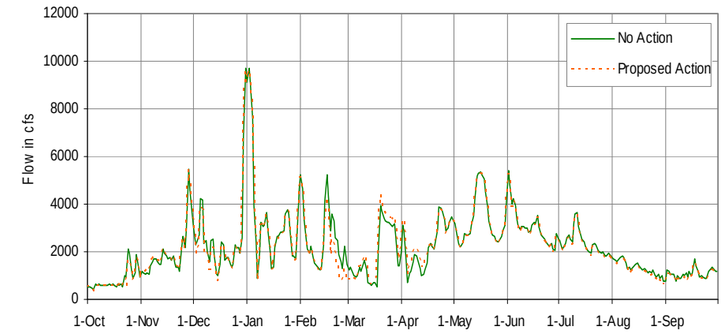
Figure B-9 – Lake Tapps System Hydrographs, Water year 1996



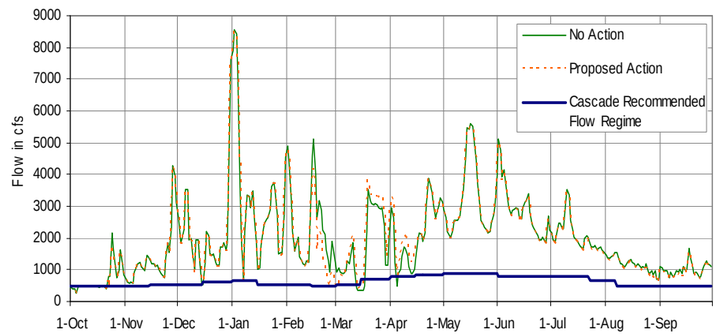
White River near Buckley



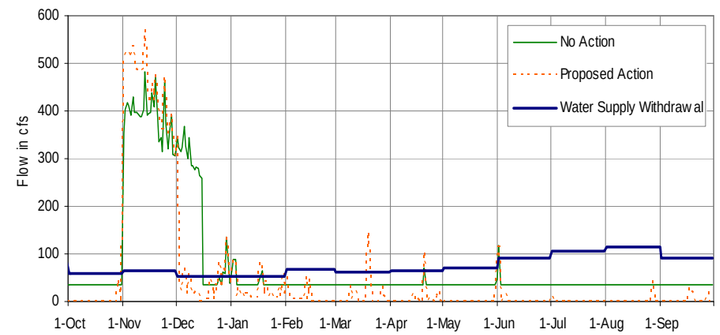
Canal Inflow



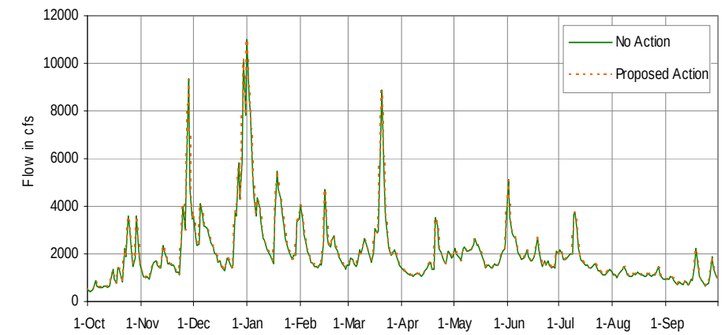
Lower White River



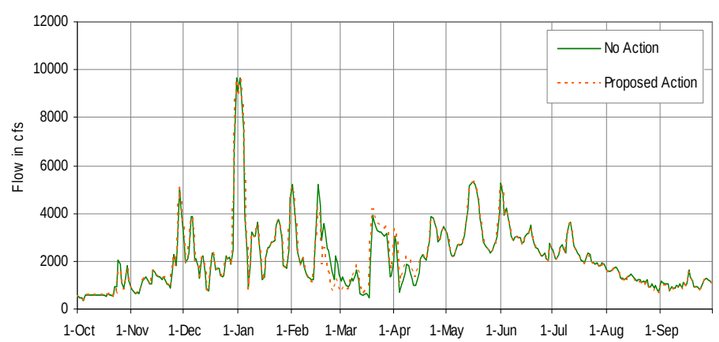
White River below Diversion Dam



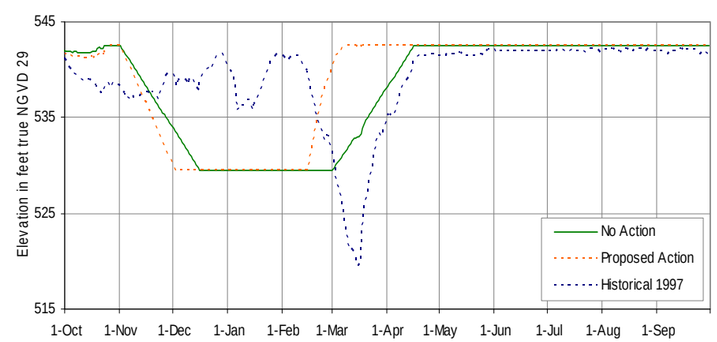
Tailrace Release and Water Supply Withdrawal



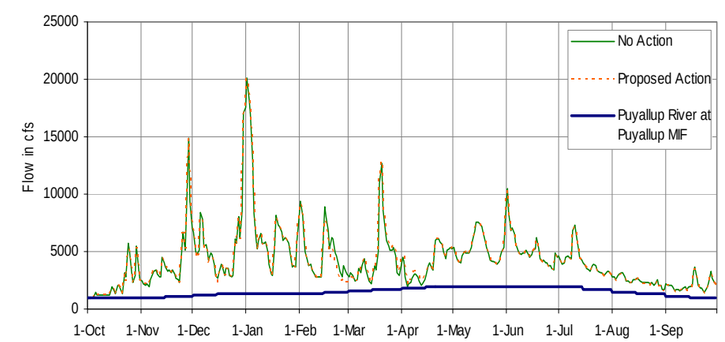
Puyallup River above Confluence



White River at Auburn



Lake Tapps Reservoir Water Surface Elevation



Puyallup River at Puyallup

Figure B-10 – Lake Tapps System Hydrographs, Water year 1997

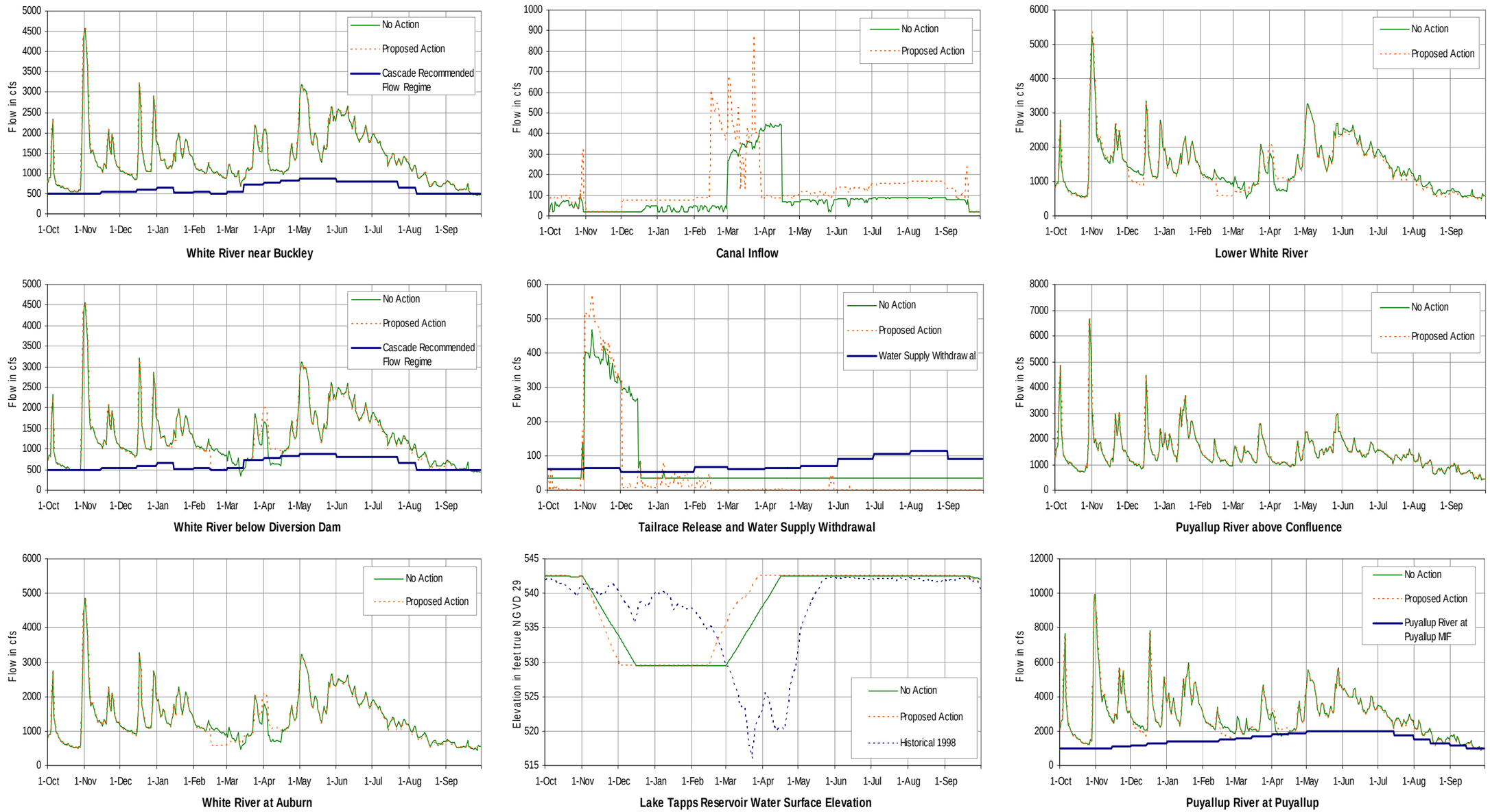


Figure B-11 – Lake Tapps System Hydrographs, Water year 1998

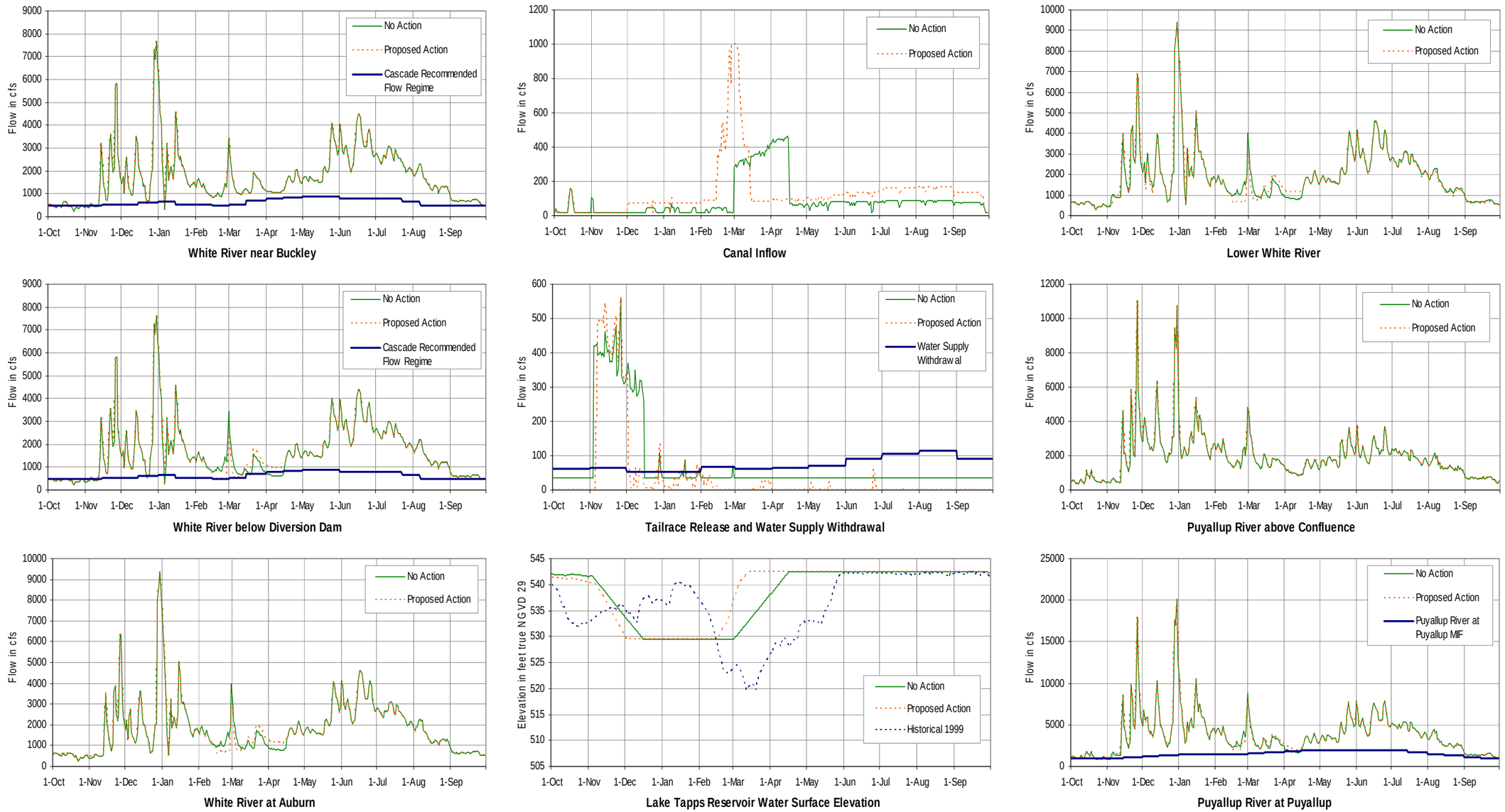


Figure B-12 – Lake Tapps System Hydrographs, Water year 1999

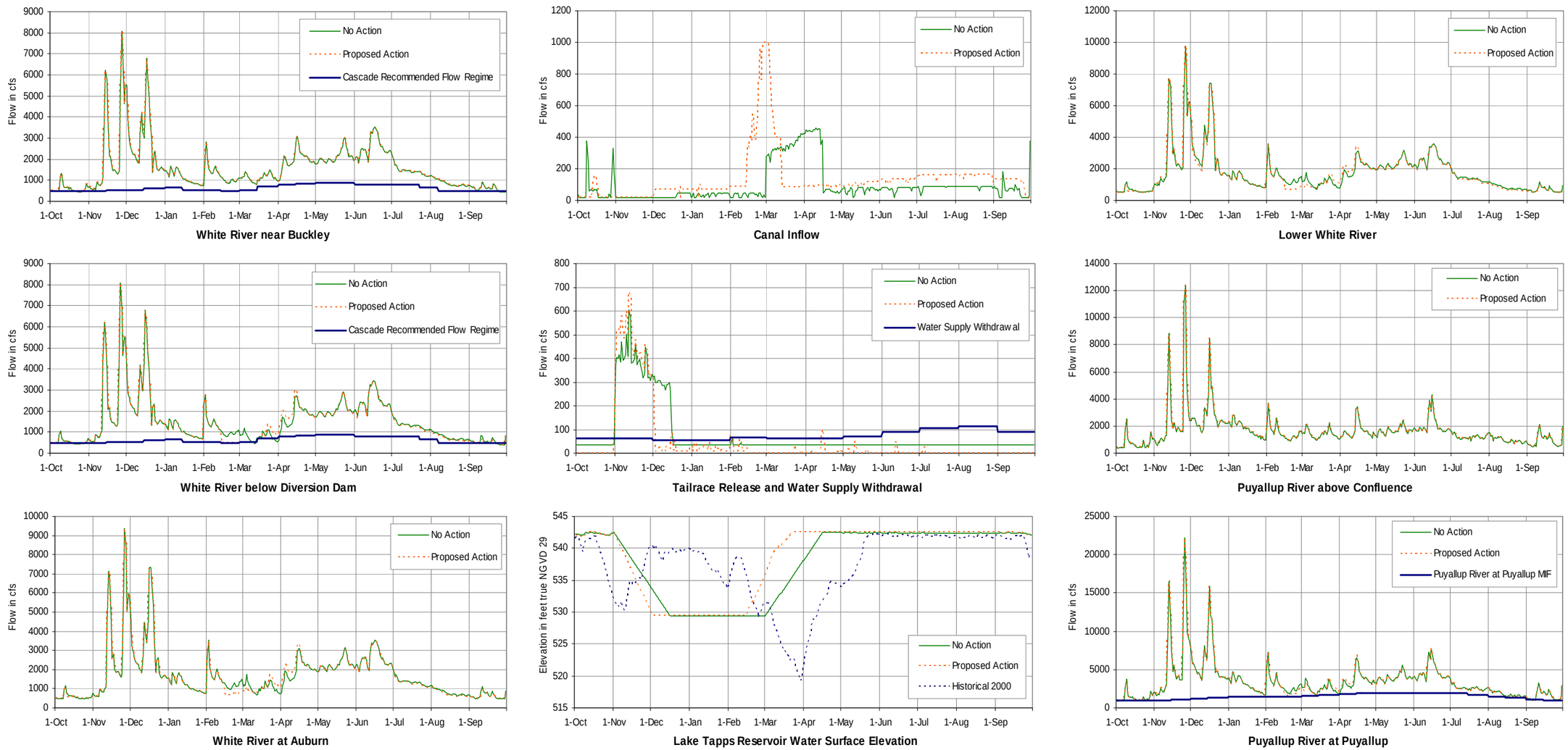


Figure B-13 – Lake Tapps System Hydrographs, Water year 2000

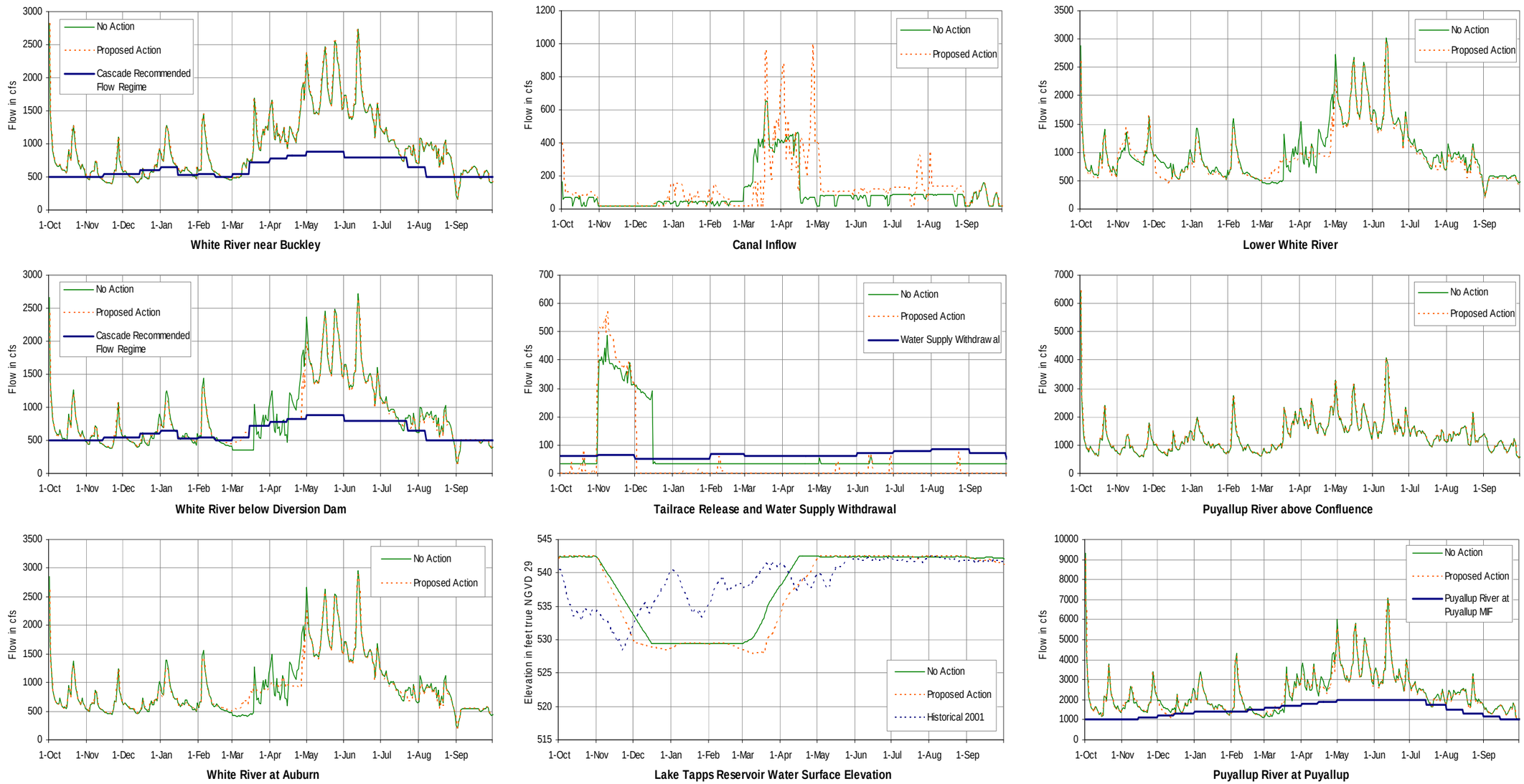


Figure B-14 – Lake Tapps System Hydrographs, Water year 2001

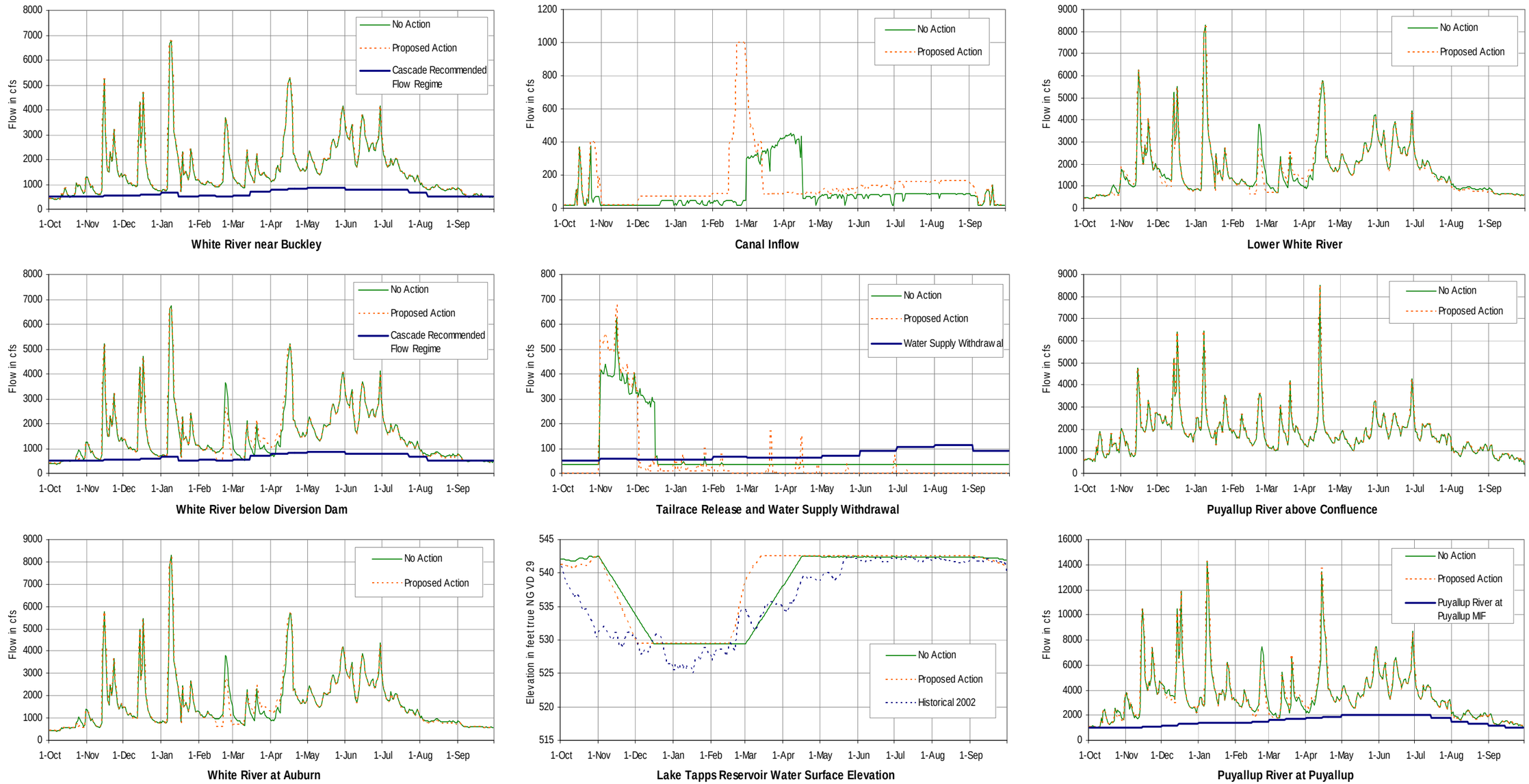
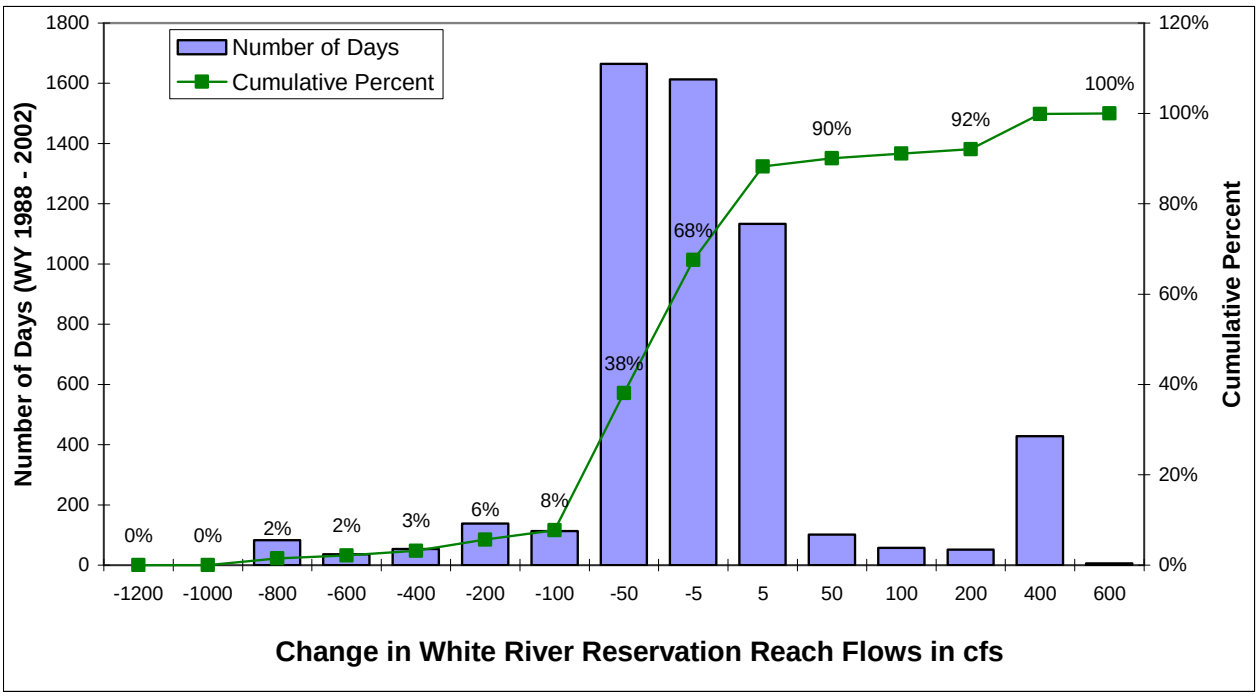


Figure B-15 – Lake Tapps System Hydrographs, Water year 2002

B.3 White River Reservation Reach Results

Table B4 – Histogram of Change in Flow in the White River Reservation Reach

Change in Flows in cfs	Number of Days (WY 1988 - 2002)	Cumulative Number of Days	Cumulative %
-1500	0	0	0%
-1200	0	0	0%
-1000	0	0	0%
-800	83	83	2%
-600	36	119	2%
-400	54	173	3%
-200	138	311	6%
-100	113	424	8%
-50	1665	2089	38%
-5	1613	3702	68%
5	1133	4835	88%
50	101	4936	90%
100	57	4993	91%
200	52	5045	92%
400	428	5473	100%
600	6	5479	100%
800	0	5479	100%
1000	0	5479	100%
1200	0	5479	100%
1500	0	5479	100%
2000	0	5479	100%

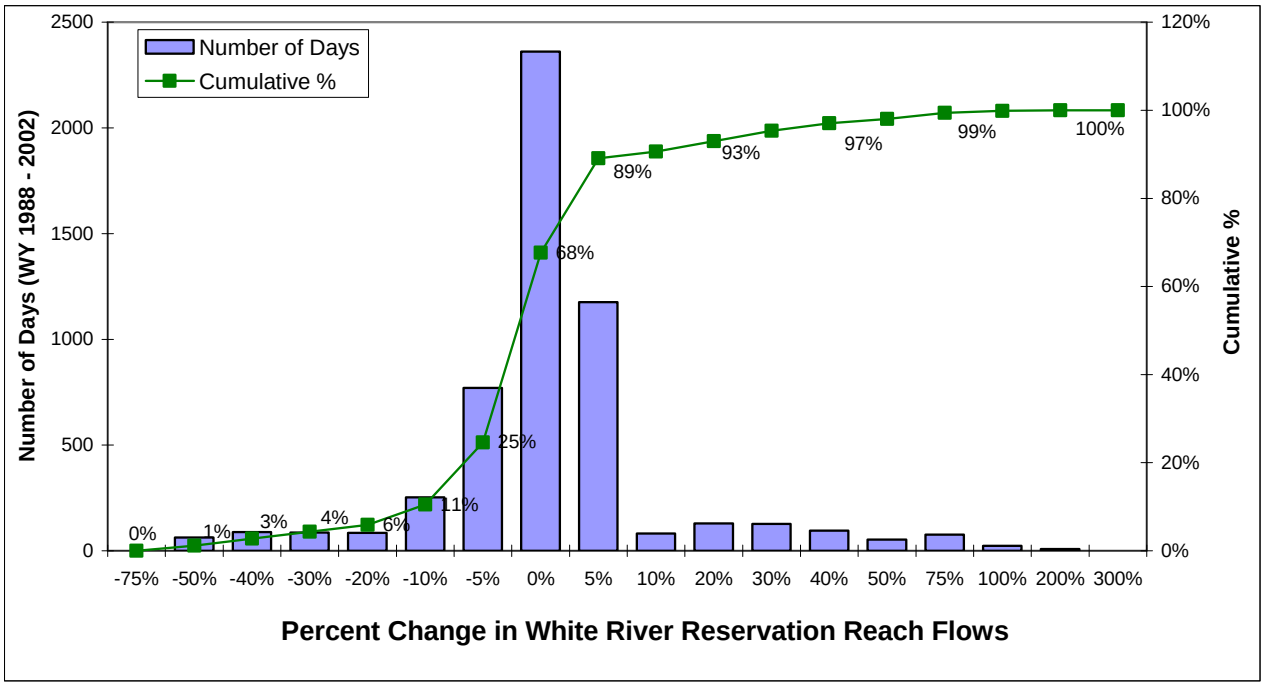


Note:

1) Histogram categories are labeled for the upper end of the category range. For example the -50 category represents changes in flows of -100 to -50 cfs.

Table B5 – Histogram of Percent Change in the White River Reservation Reach

Change in Flows in cfs	Number of Days (WY 1988 - 2002)	Cumulative Number of Days	Cumulative %
-75%	0	0	0%
-50%	63	63	1%
-40%	89	152	3%
-30%	86	238	4%
-20%	85	323	6%
-10%	253	576	11%
-5%	771	1347	25%
0%	2361	3708	68%
5%	1176	4884	89%
10%	82	4966	91%
20%	130	5096	93%
30%	127	5223	95%
40%	95	5318	97%
50%	53	5371	98%
75%	77	5448	99%
100%	23	5471	100%
200%	8	5479	100%
300%	0	5479	100%



Note:

1) Histogram categories are labeled for the upper end of the category range. For example the -5% category represents changes in flows of -10% to -5%.

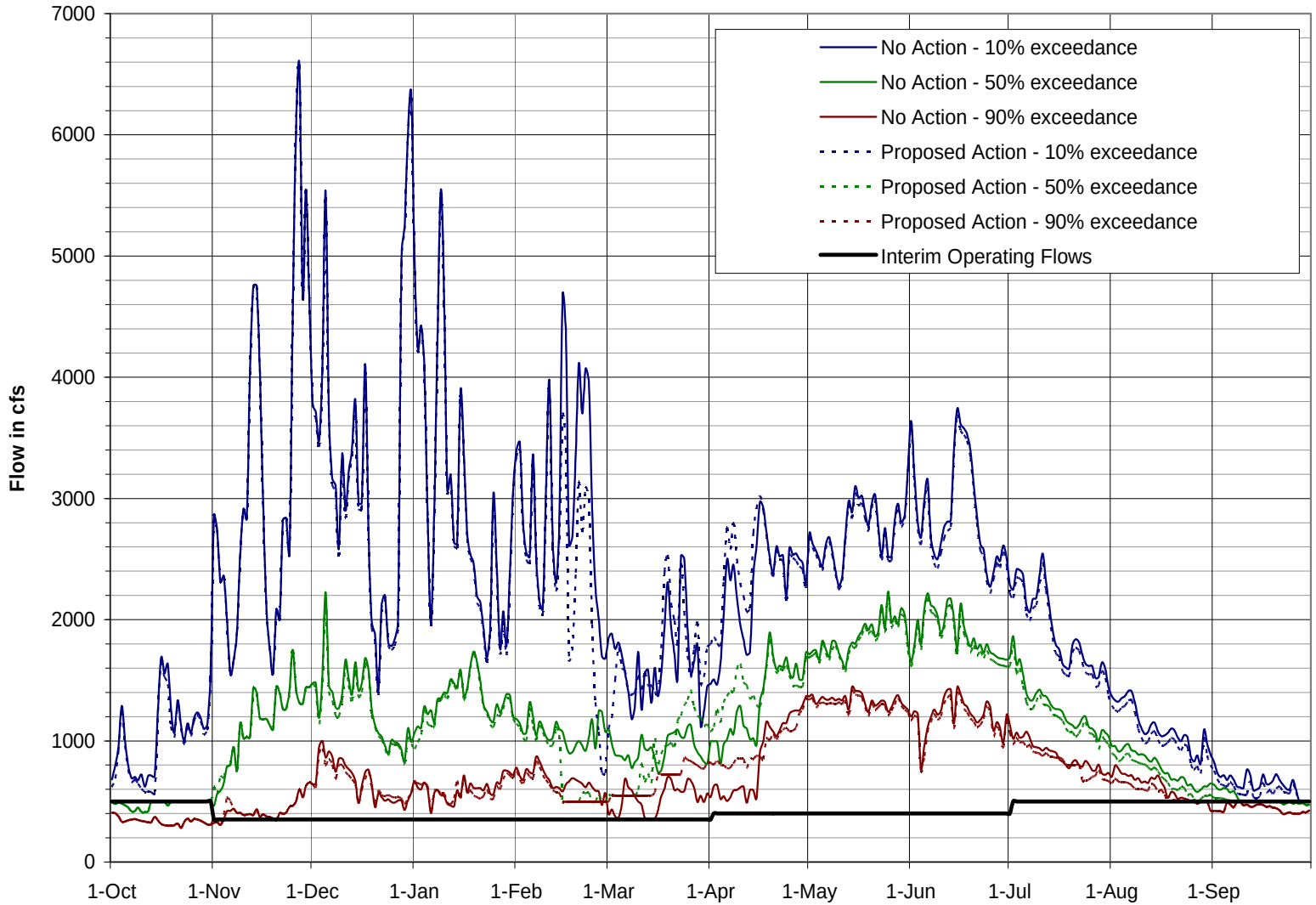


Figure B-16 Percent Exceedance Hydrograph for the White River Reservation Reach

B.3.1 Water Quality in the White River Reservation Reach Water Quality – Temperature

Table B-6 – Number of White river Reservation Reach Water Temperature Exceedances

Water Year	Number of Temp Exceedance July 1 to Sept 14		Sept 15 to Oct 31		Total	
	River Mile 4.9	River Mile 15.5	River Mile 4.9	River Mile 15.5	River Mile 4.9	River Mile 15.5
1988	0	0	2	0	2	0
1989	0	0	0	0	0	0
1990	0	0	0	0	0	0
1991	0	0	0	0	0	0
1992	8	3	0	0	8	3
1993	0	0	0	0	0	0
1994	0	0	0	0	0	0
1995	0	0	0	0	0	0
1996	5	0	0	0	5	0
1997	0	0	0	0	0	0
1998	0	0	0	0	0	0
1999	0	0	0	0	0	0
2000	0	0	0	0	0	0
2001	0	0	0	0	0	0
2002	0	0	0	0	0	0
Total	**13**	**3**	**2**	**0**	**15**	**3**

Note:

1) A temperature exceedance is considered to occur when the 7-DADMax temperature without the WSP is >15.7˚ C and the WSP would cause an increase of more than 0.3˚ C.

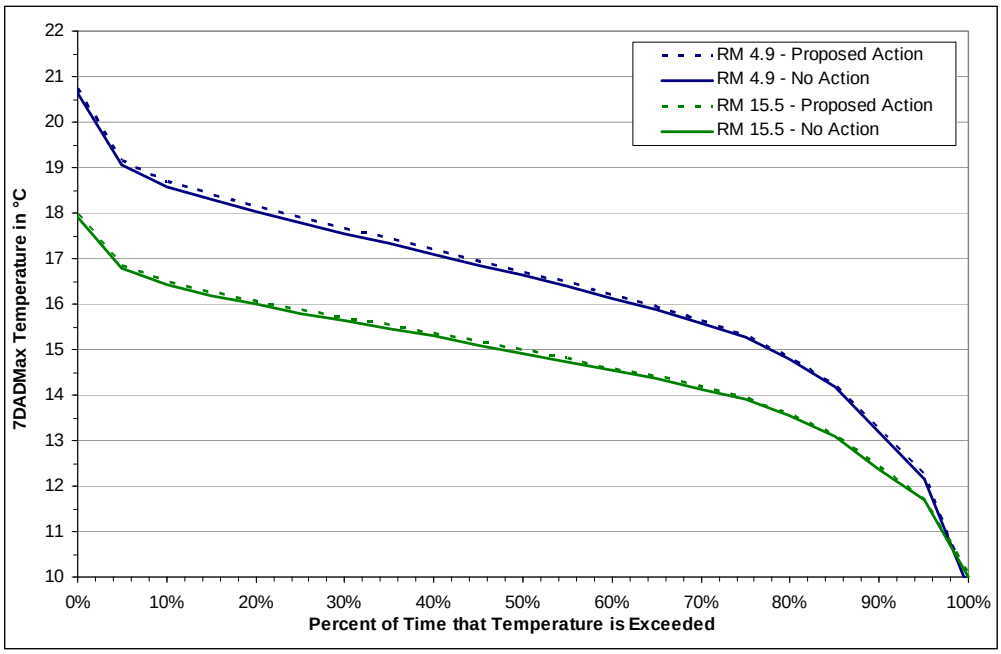


Figure B-17 – Duration Curves of 7DADMax Temperature in the White River Reservation Reach

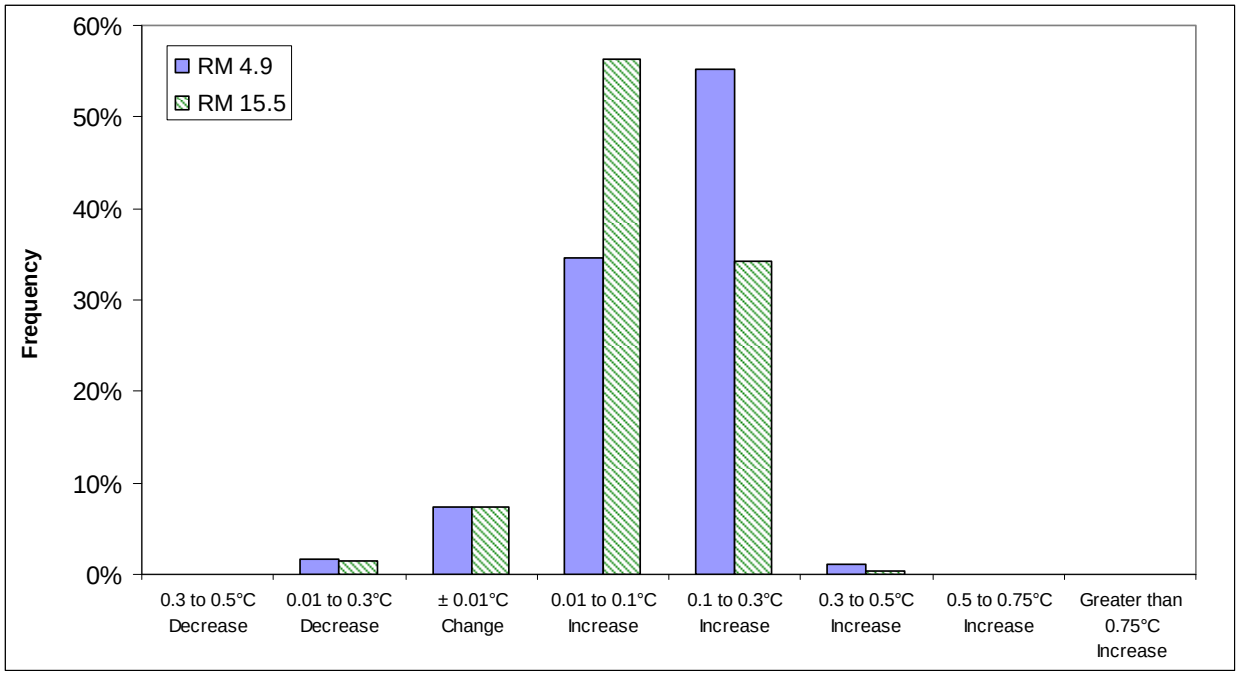


Figure B-18 – Frequency of Change in 7-DADMax Temperature in the White River Reservation Reach from July 1 to September 14

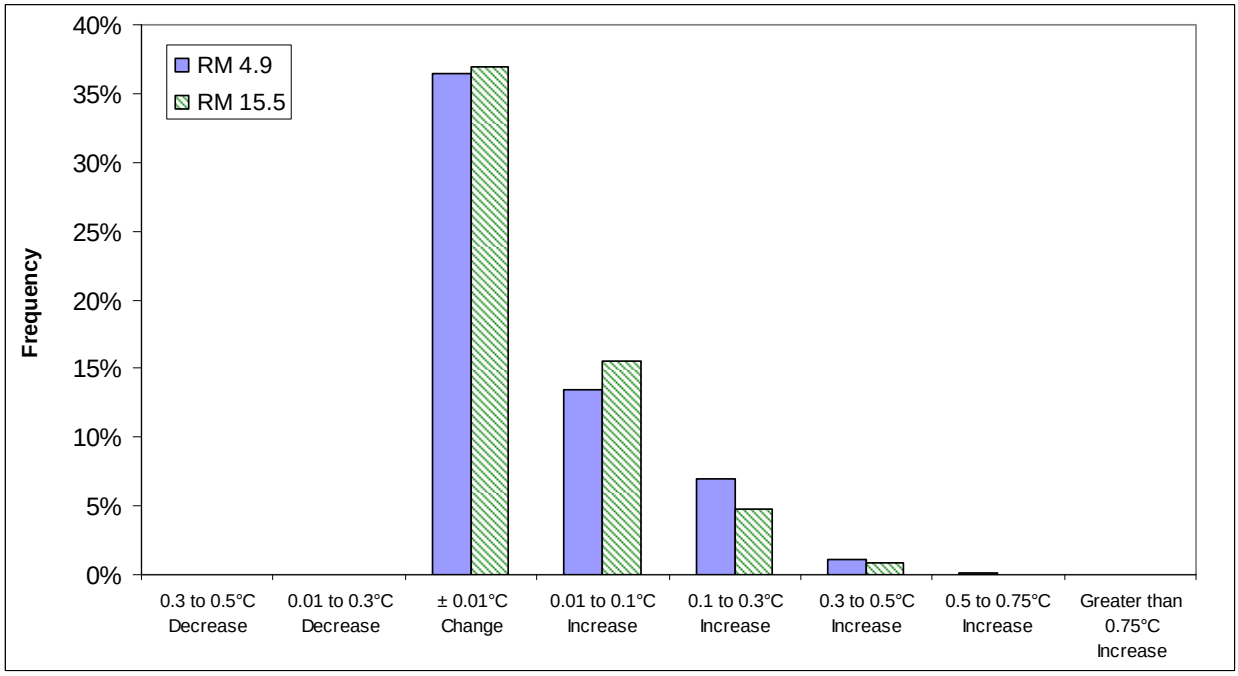


Figure B-19 – Frequency of Change in 7-DADMax Temperature in the White River Reservation Reach from September 15 to October 31

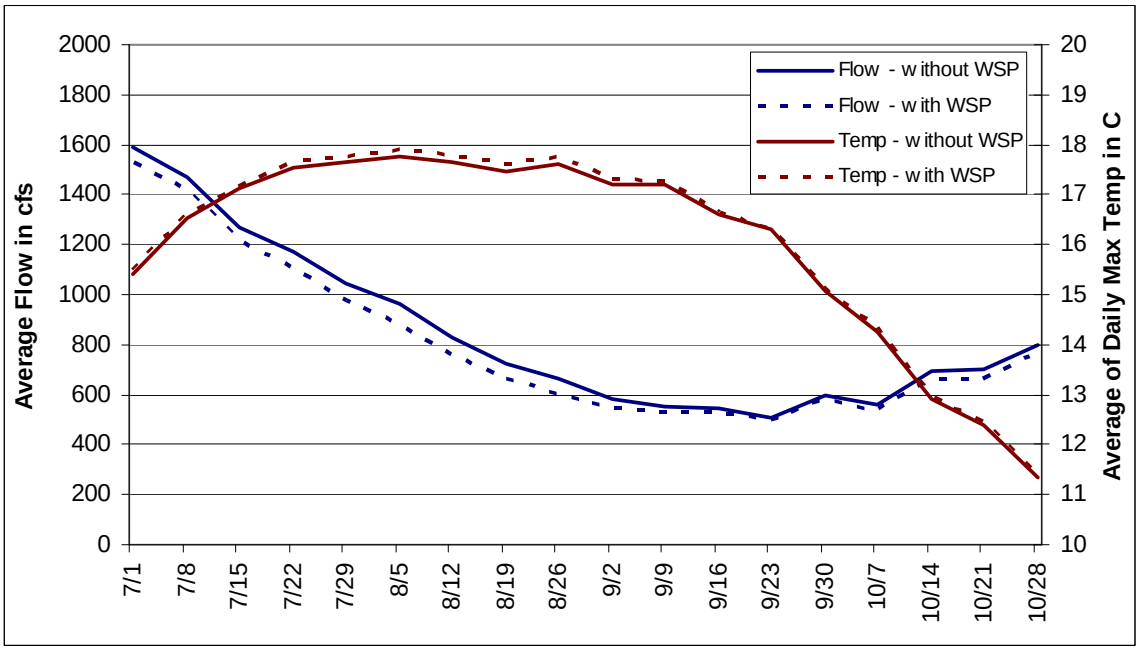


Figure B-20 – Comparison of Average Temperature and Flow by Week

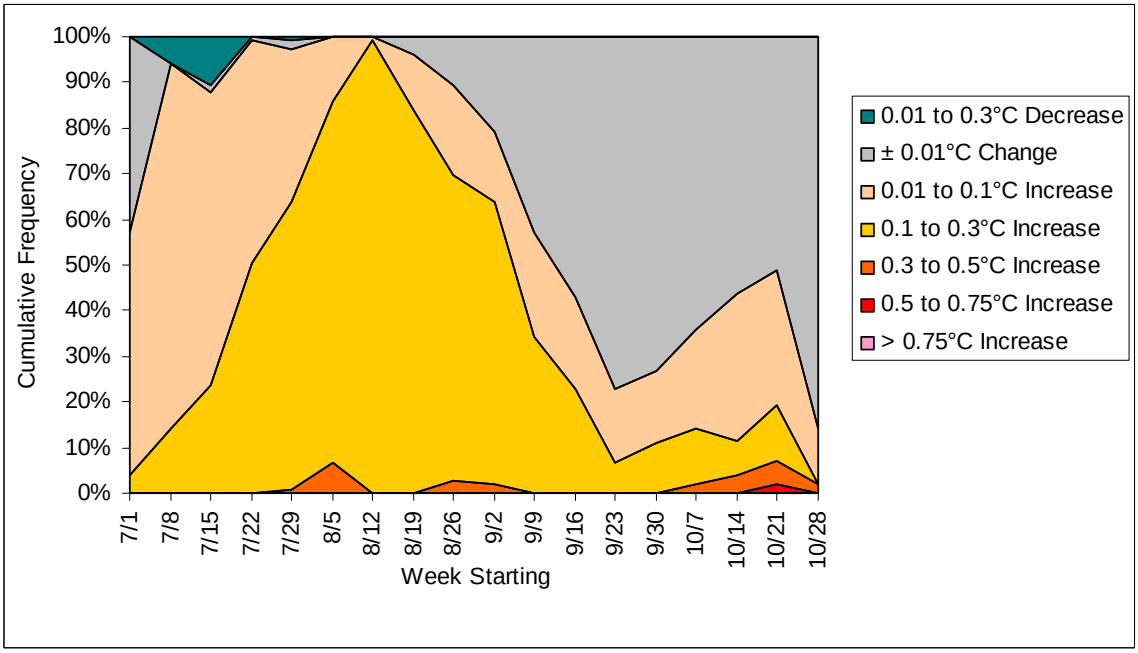


Figure B-21 – Frequency of Changes in 7-DADMax Temperature by Week.

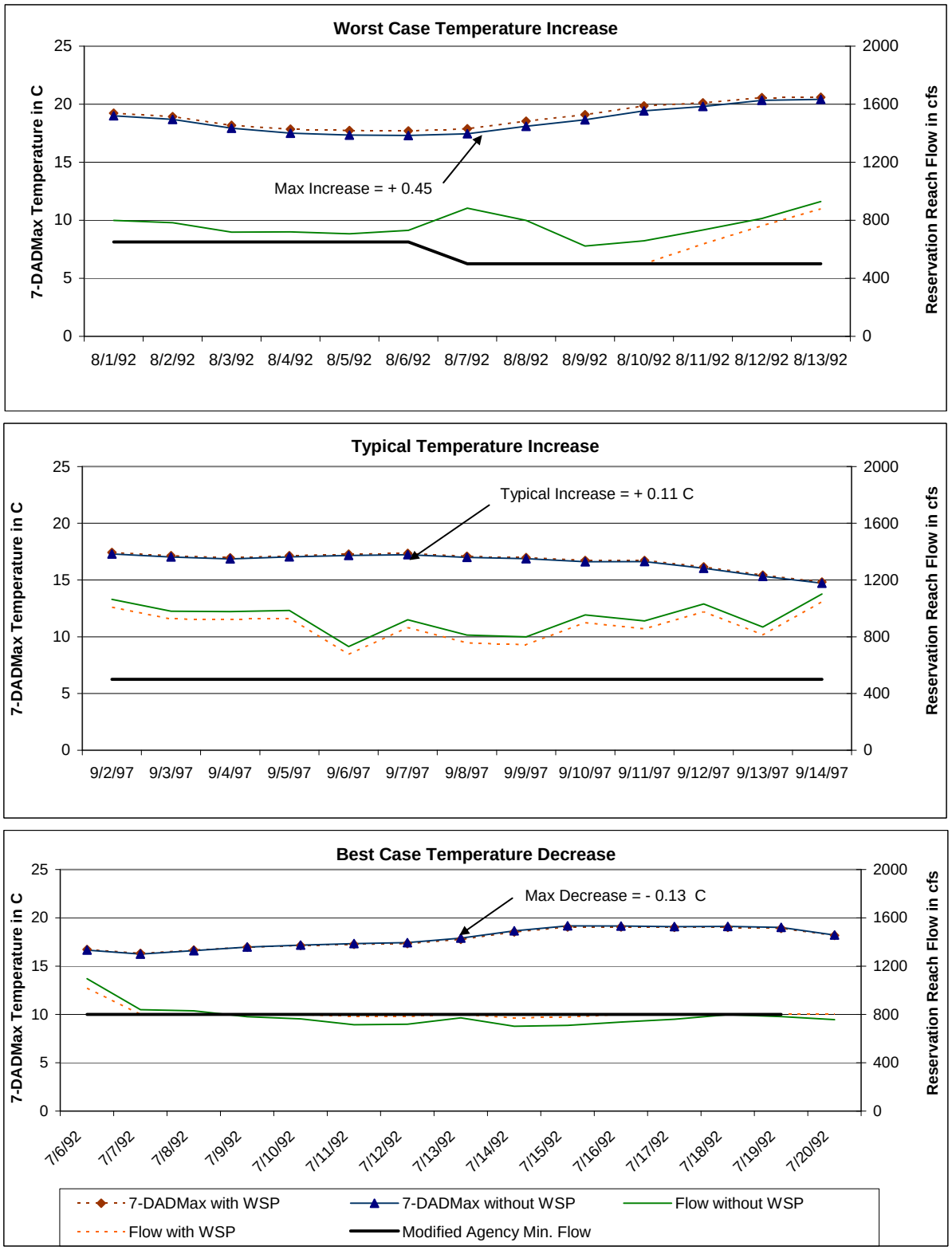


Figure B-22 – Maximum Increase, Decrease and Average Change in the White River Temperature at RM 4.9 from July 1 to September 14

B.3.2 Water Quality in the White River Reservation Reach Water Quality – Dissolved Oxygen

Table B-7 – Change in White River Dissolved Oxygen Saturation Concentrations in mg/L

River Mile 4.9			River Mile 15.5		
Maximum Decrease	Average Change	Maximum Increase	Maximum Decrease	Average Change	Maximum Increase
-0.22	-0.02	0.04	-0.17	-0.01	0.03

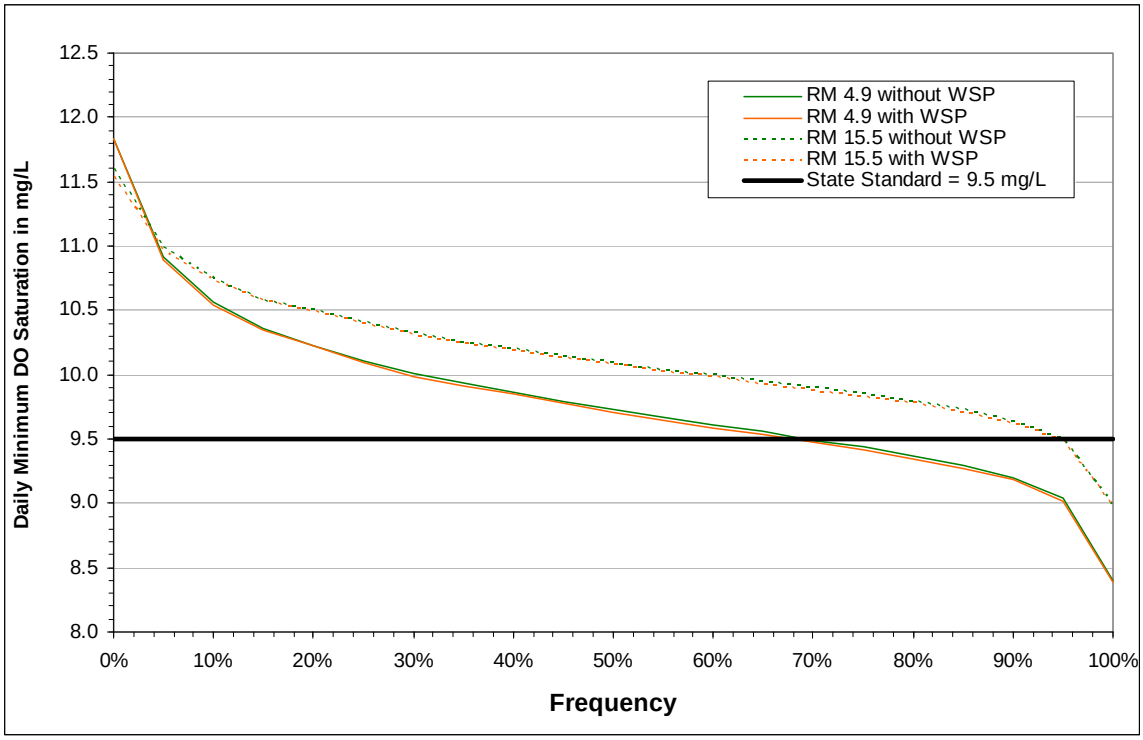


Figure B-23 – Duration Curves of Dissolved Oxygen Saturation Concentration in the White River Reservation Reach

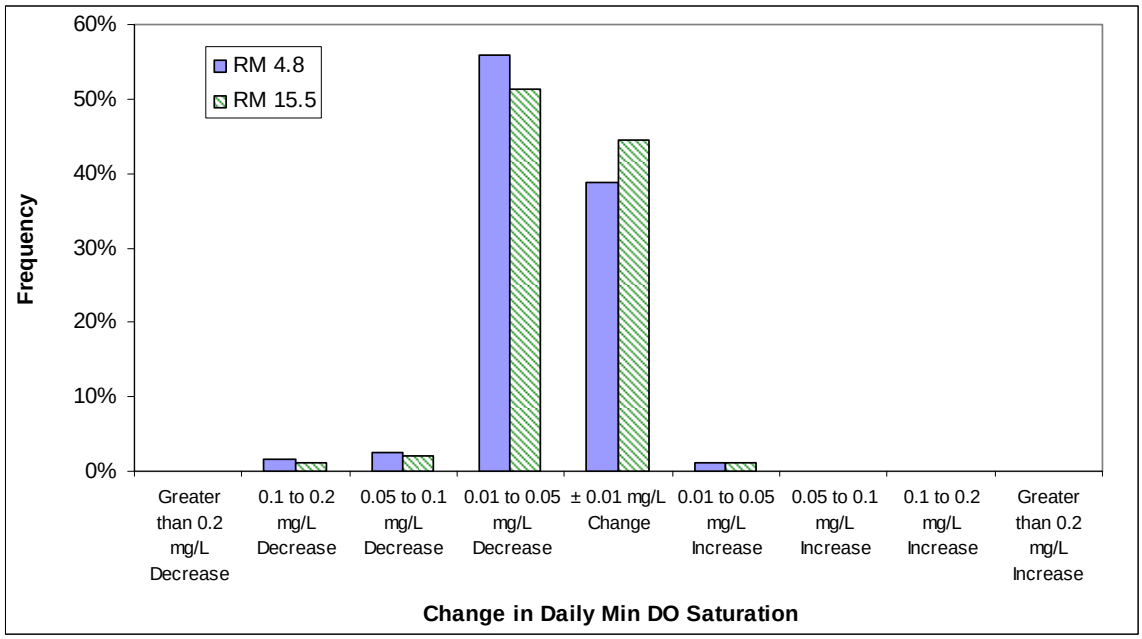


Figure B-24 – Frequency of Change in Daily Minimum Dissolved Oxygen Saturation in the White River Reservation Reach from July 1 to September 14

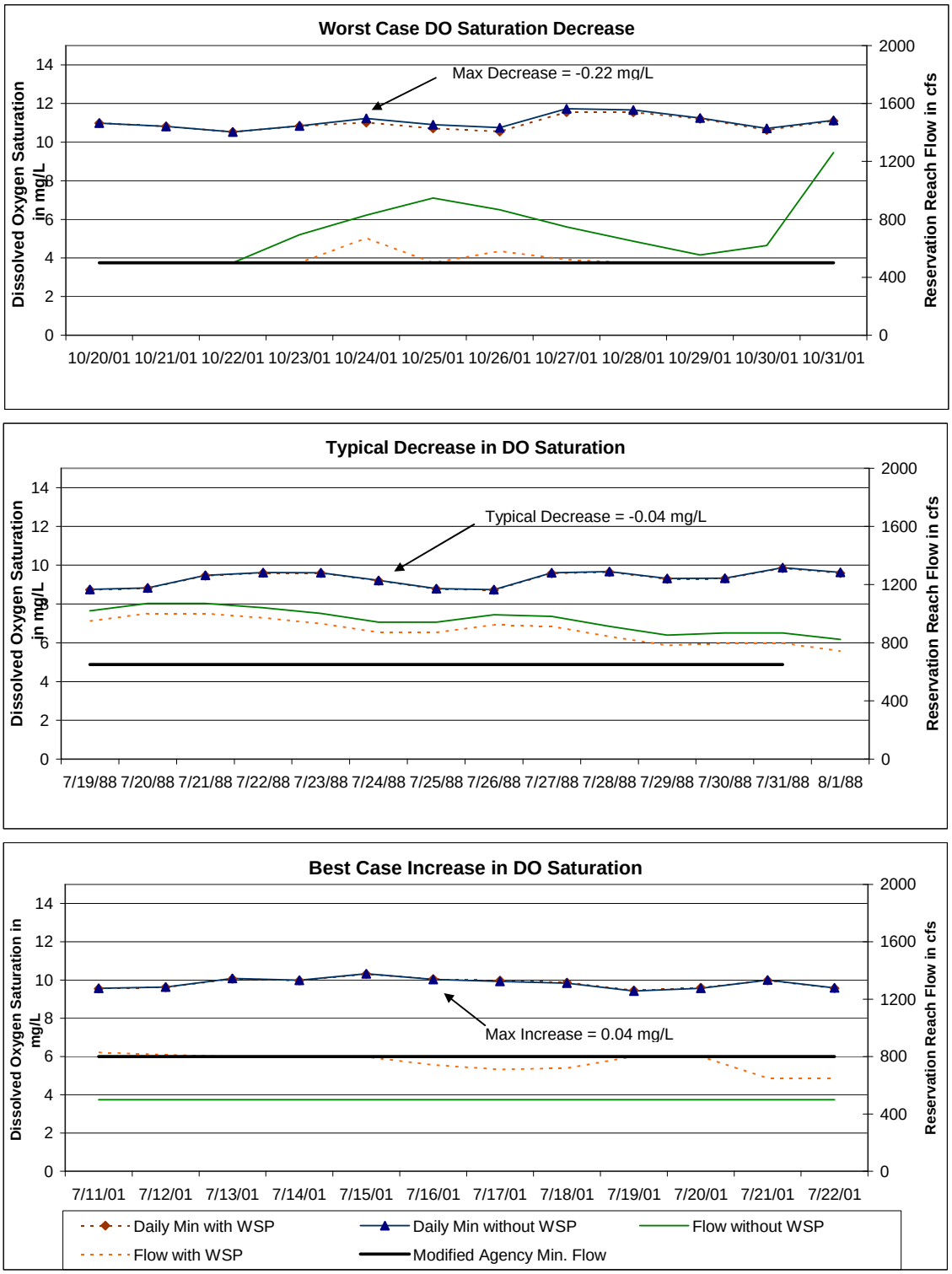
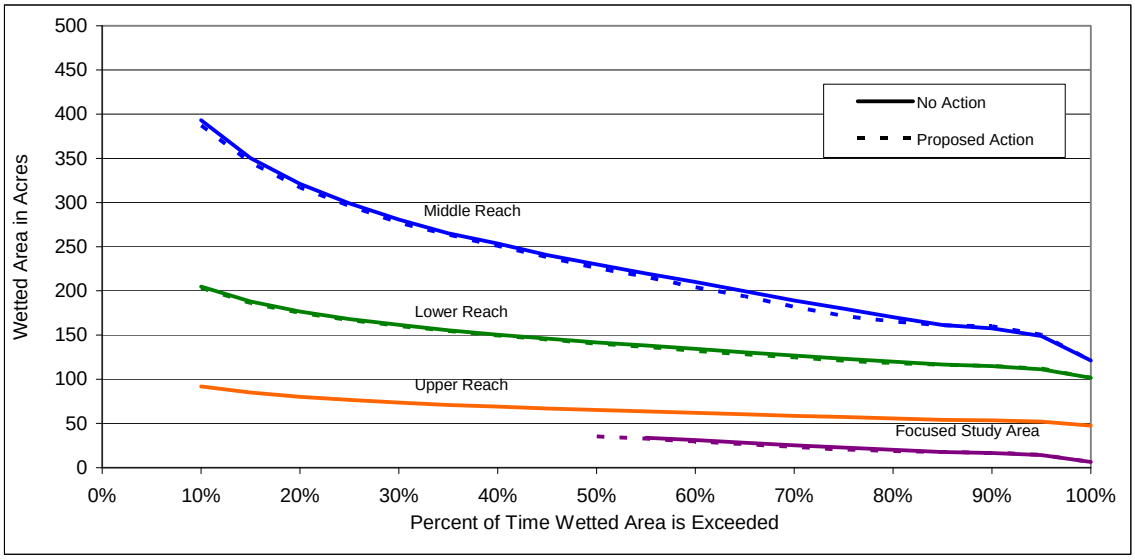


Figure B-25 – Maximum Increase, Decrease and Average Change in White River Dissolved Oxygen Saturation in the Reservation Reach

B.3.3 Habitat in the White River Reservation Reach

	Change in Wetted Area in Acres				Wetted Area: No Action			
	Upper Reach	Middle Reach	Lower Reach	Focused Reac	Upper Reach	Middle Reach	Lower Reach	Focused
Min	-17.8	-109.4	-38.9	-18.9				
Average	-0.6	-3.5	-1.2	-0.8	66.5	236.8	143.5	24.1
Max	10.3	63.4	22.6	14.3				

Percentile	Wetted Area in Acres							
	No Action				Proposed Action			
	Upper Reach	Middle Reach	Lower Reach	Focused Reach	Upper Reach	Middle Reach	Lower Reach	Focused Reach
0%	999999	999999	999999	999999	999999	999999	999999	999999
5%	999999	999999	999999	999999	999999	999999	999999	999999
10%	92	393	205	999999	91	387	203	999999
15%	85	350	188	999999	84	345	186	999999
20%	80	321	177	999999	80	317	175	999999
25%	77	299	168	999999	76	296	167	999999
30%	74	281	162	999999	73	277	160	999999
35%	71	265	155	999999	71	264	155	999999
40%	69	254	150	999999	69	251	150	999999
45%	67	241	146	999999	67	238	145	999999
50%	65	230	142	37	65	226	140	36
55%	64	220	138	34	63	216	137	33
60%	62	210	134	31	61	204	132	29
65%	60	199	130	28	59	194	128	27
70%	59	189	127	25	58	182	125	23
75%	57	180	123	23	56	172	121	21
80%	56	170	120	20	55	165	118	19
85%	54.2	161	117	18	54.1	161	116	18
90%	53.6	158	115	16.6	53.9	160	115	17
95%	52.2	149	111	14.2	52.4	150	112	15
100%	47.7	121	102	7	47.7	121	102	7



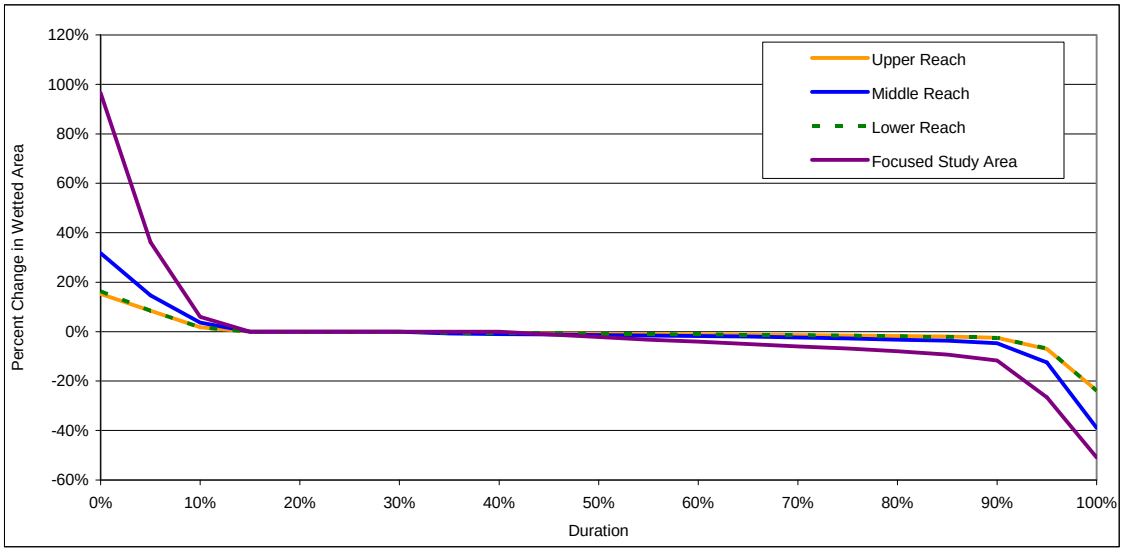
Notes:

1) Upper Reach: RM 20.9 to RM 24.3
2) Middle Reach: RM 9.1 and RM 20.9
3) Lower Reach: RM 3.6 to RM 9.1
4) Focused Study Area: RM 12.9 to 14.4
5) 999999 indicates the flow is out of the range of relationships for calculating wetted area

Figure B-26 – Duration Curves for Change in Wetted Area in the White River Reservation Reach

	Change in Wetted Area in Acres			
	Upper Reach	Middle Reach	Lower Reach	Focused Reach
Min	-24%	-39%	-24%	-51%
Average	-1%	-1%	-1%	-2%
Max	15%	32%	16%	97%

Percentile	Percent Change in Wetted Area			
	Upper Reach	Middle Reach	Lower Reach	Focused Reach
0%	15.2%	31.8%	16.3%	96.5%
5%	8.4%	14.6%	8.4%	36.1%
10%	1.8%	3.6%	1.7%	6.0%
15%	0.0%	0.0%	0.0%	0.0%
20%	0.0%	0.0%	0.0%	0.0%
25%	0.0%	0.0%	0.0%	0.0%
30%	0.0%	0.0%	0.0%	0.0%
35%	-0.4%	-0.7%	-0.4%	0.0%
40%	-0.6%	-1.0%	-0.6%	0.0%
45%	-0.7%	-1.1%	-0.7%	-1.1%
50%	-0.8%	-1.4%	-0.8%	-2.2%
55%	-1.0%	-1.6%	-1.0%	-3.3%
60%	-1.1%	-1.8%	-1.1%	-4.0%
65%	-1.2%	-2.0%	-1.2%	-5.0%
70%	-1.4%	-2.3%	-1.4%	-6.0%
75%	-1.6%	-2.7%	-1.6%	-6.9%
80%	-1.8%	-3.2%	-1.8%	-7.9%
85%	-2.0%	-3.6%	-2.0%	-9.2%
90%	-2.5%	-4.7%	-2.5%	-11.7%
95%	-7.1%	-12.5%	-6.8%	-26.6%
100%	-23.8%	-38.9%	-24.0%	-50.8%



Notes:

1) Upper Reach: RM 20.9 to RM 24.3
2) Middle Reach: RM 9.1 and RM 20.9
3) Lower Reach: RM 3.6 to RM 9.1
4) Focused Study Area: RM 12.9 to 14.4
5) 999999 indicates the flow is out of the range of relationships for calculating wetted area

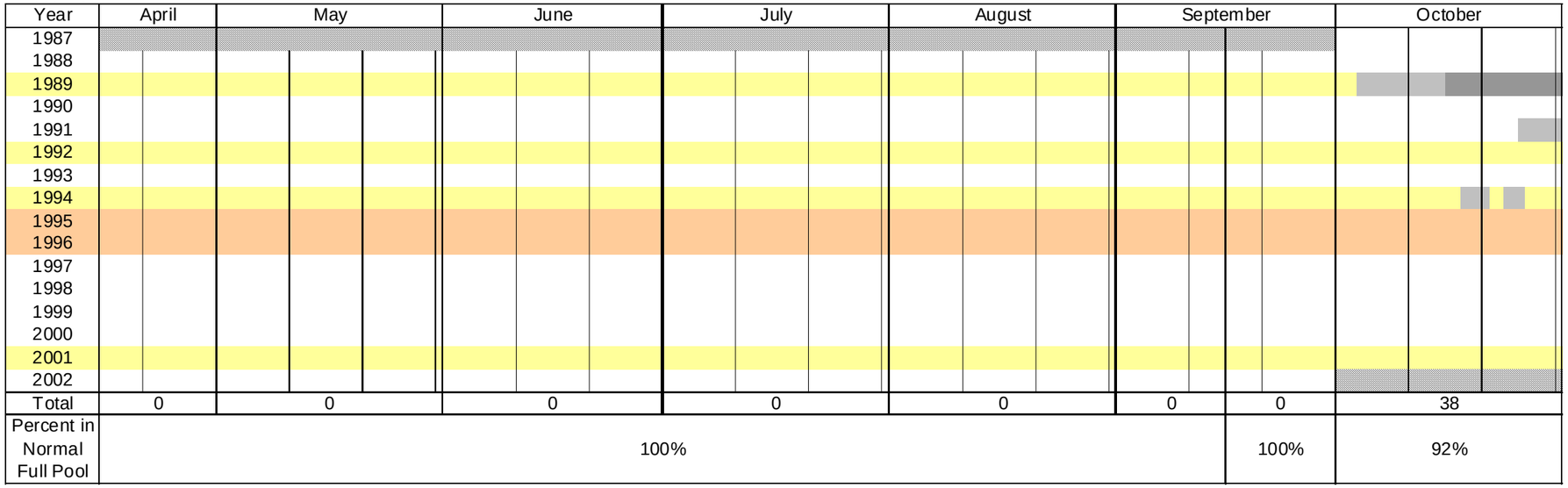
Figure B-27 – Duration Curves for Percent Change in Wetted Area in the White River Reservation Reach

B.4 Lake Tapps Results

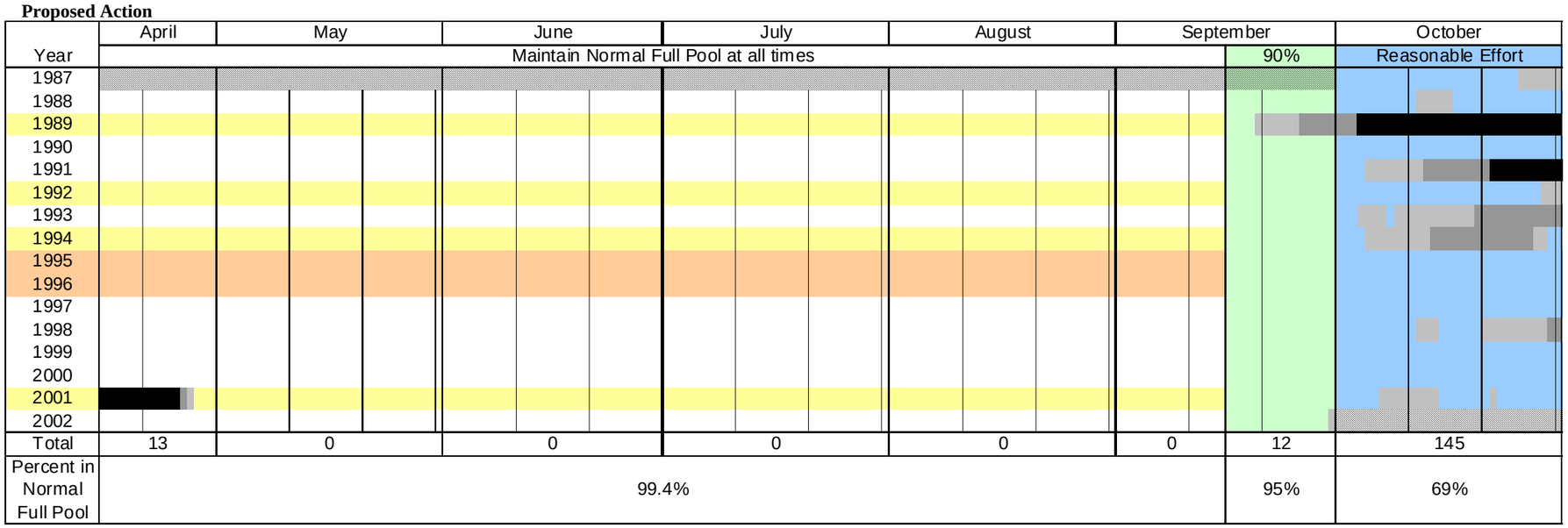
Table B-8 – Number of Days when the Lake Tapps Water Surface Elevation is below Minimum Recreation Levels by Water Year.

Calendar Year	Baseline		Proposed Action			
	Apr 15 to Sep 30	Oct 1 to Oct 31	Apr 15 to Apr 30	May 1 to Sep 15	Sep 16 to Sep 30	Oct 1 to Oct 31
1987		0				6
1988	0	0	0	0	0	5
1989	0	28	0	0	11	31
1990	0	0	0	0	0	0
1991	0	5	0	0	0	27
1992	0	0	0	0	0	3
1993	0	0	0	0	0	27
1994	0	5	0	0	0	25
1995	0	0	0	0	0	0
1996	0	0	0	0	0	0
1997	0	0	0	0	0	0
1998	0	0	0	0	0	13
1999	0	0	0	0	0	0
2000	0	0	0	0	0	0
2001	0	0	13	0	0	8
2002	0	0	0	0	1	
Total Days	0	38	13	0	12	145
Total % of Days	0%	8%	5%	0%	5%	31%

Baseline



Proposed Action



Notes:

- Indicates lake level less than 0.5 feet below Normal Full Pool
- Indicates lake level 0.5 to 1 feet below Normal Full Pool
- Indicates lake level more than 1 foot below Normal Full Pool
- Indicates a Drought Year, when Stage 2 Shortage Management was applied
- Indicates a Dry Year, when Stage 1 Shortage Management was applied
- Outside model period of record

B-28 – Periods when lake is below normal full pool (541.0 ft true NGVD 29) for Baseline and Proposed Action scenarios.

Table B-9 – Monthly Lake Tapps Residence Time, in days

Monthly Lake Residence Time in Days
No Action

MONTH	WATER YEAR															Average	Average
	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	Days	Years
10	649	664	599	668	628	656	630	627	551	657	614	649	665	665	659	639	1.75
11	63	47	57	50	56	53	60	52	44	48	50	52	47	50	48	52	0.14
12	57	70	58	68	68	66	62	70	63	60	66	61	64	66	63	64	0.18
1	228	247	149	241	220	207	251	251	259	224	255	233	259	259	249	235	0.64
2	259	240	150	160	259	259	199	181	214	259	259	250	251	259	258	230	0.63
3	374	374	374	374	373	367	374	374	374	371	374	374	374	357	374	372	1.02
4	629	629	629	629	528	580	629	629	334	610	629	629	629	629	629	598	1.64
5	595	651	639	662	671	612	671	671	553	664	671	671	671	660	671	649	1.78
6	665	671	554	671	639	594	671	671	671	625	671	671	671	654	669	651	1.78
7	671	671	671	671	665	671	671	641	671	671	671	671	671	671	671	669	1.83
8	671	671	671	671	670	671	671	671	669	671	671	671	671	669	671	671	1.84
9	665	647	667	664	651	662	661	669	657	671	669	671	669	664	664	663	1.82
Average	462	467	437	463	454	451	464	461	423	462	468	468	472	468	470	**459**	**1.26**

Monthly Lake Residence Time in Days
Proposed Action

MONTH	WATER YEAR															Average	Average
	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	Days	Years
10	372	372	381	354	345	432	351	413	326	383	331	358	384	354	429	372	1.02
11	42	32	45	33	42	38	44	37	30	33	33	39	32	33	32	36	0.10
12	102	133	102	140	130	124	118	125	118	96	121	102	114	140	110	118	0.32
1	155	158	92	149	139	166	162	161	156	117	118	116	131	169	124	141	0.39
2	157	144	109	155	172	140	144	180	163	160	140	135	138	127	144	147	0.40
3	254	267	331	331	375	253	343	280	366	325	323	337	340	150	335	307	0.84
4	269	295	333	239	372	215	393	368	199	342	373	377	341	305	323	316	0.87
5	278	375	322	325	403	287	395	375	296	330	327	333	326	386	337	340	0.93
6	247	328	246	263	311	235	322	312	306	252	264	259	260	303	257	278	0.76
7	227	304	228	228	296	227	302	290	303	227	228	228	226	303	227	256	0.70
8	211	278	211	209	277	211	280	247	246	208	211	211	211	271	211	233	0.64
9	258	319	261	283	447	310	384	291	289	258	261	265	263	319	256	298	0.81
Average	215	251	223	227	276	221	271	257	234	228	228	231	231	239	233	**238**	**0.65**

Table B-10 – Monthly Lake Tapps Flushing Rate, in number of times per year

No Action

MONTH	WATER YEAR															Average	Range	
	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002		Max	Min
10	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.06	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.06	0.05
11	0.48	0.64	0.52	0.60	0.53	0.57	0.50	0.57	0.68	0.62	0.60	0.58	0.64	0.60	0.63	0.58	0.68	0.48
12	0.54	0.44	0.53	0.46	0.46	0.47	0.50	0.44	0.50	0.52	0.47	0.51	0.49	0.47	0.50	0.49	0.54	0.44
1	0.14	0.13	0.21	0.13	0.14	0.15	0.12	0.12	0.12	0.14	0.12	0.13	0.12	0.12	0.12	0.13	0.21	0.12
2	0.11	0.12	0.19	0.17	0.11	0.11	0.14	0.15	0.14	0.11	0.11	0.11	0.12	0.11	0.11	0.13	0.19	0.11
3	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.09	0.08	0.08	0.09	0.08
4	0.05	0.05	0.05	0.05	0.06	0.05	0.05	0.05	0.09	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.09	0.05
5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.06	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.06	0.05
6	0.05	0.04	0.05	0.04	0.05	0.05	0.04	0.04	0.04	0.05	0.04	0.04	0.04	0.05	0.04	0.05	0.05	0.04
7	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
8	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
9	0.05	0.05	0.04	0.05	0.05	0.05	0.05	0.04	0.05	0.04	0.04	0.04	0.04	0.05	0.05	0.05	0.05	0.04
Annual	1.36	1.46	1.48	1.45	1.38	1.42	1.36	1.41	1.60	1.48	1.43	1.43	1.47	1.42	1.47	**1.44**	1.60	1.36

Proposed Action

MONTH	WATER YEAR															Average	Range	
	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002		Max	Min
10	0.08	0.08	0.08	0.09	0.09	0.07	0.09	0.08	0.10	0.08	0.09	0.09	0.08	0.09	0.07	0.08	0.10	0.07
11	0.72	0.93	0.66	0.90	0.71	0.78	0.68	0.81	0.99	0.92	0.90	0.78	0.93	0.90	0.93	0.84	0.99	0.66
12	0.31	0.23	0.31	0.22	0.24	0.25	0.26	0.25	0.26	0.32	0.26	0.30	0.27	0.22	0.28	0.27	0.32	0.22
1	0.20	0.20	0.34	0.21	0.22	0.19	0.19	0.19	0.20	0.26	0.26	0.27	0.24	0.18	0.25	0.23	0.34	0.18
2	0.18	0.19	0.26	0.18	0.17	0.20	0.19	0.16	0.18	0.18	0.20	0.21	0.21	0.22	0.19	0.19	0.26	0.16
3	0.12	0.12	0.09	0.09	0.08	0.12	0.09	0.11	0.08	0.10	0.10	0.09	0.09	0.21	0.09	0.11	0.21	0.08
4	0.11	0.10	0.09	0.13	0.08	0.14	0.08	0.08	0.15	0.09	0.08	0.08	0.09	0.10	0.09	0.10	0.15	0.08
5	0.11	0.08	0.10	0.10	0.08	0.11	0.08	0.08	0.10	0.09	0.09	0.09	0.10	0.08	0.09	0.09	0.11	0.08
6	0.12	0.09	0.12	0.11	0.10	0.13	0.09	0.10	0.10	0.12	0.11	0.12	0.12	0.10	0.12	0.11	0.13	0.09
7	0.14	0.10	0.14	0.14	0.10	0.14	0.10	0.11	0.10	0.14	0.14	0.14	0.14	0.10	0.14	0.12	0.14	0.10
8	0.15	0.11	0.15	0.15	0.11	0.15	0.11	0.13	0.13	0.15	0.15	0.15	0.15	0.11	0.15	0.14	0.15	0.11
9	0.12	0.09	0.11	0.11	0.07	0.10	0.08	0.10	0.10	0.12	0.11	0.11	0.11	0.09	0.12	0.10	0.12	0.07
Annual	2.09	2.05	2.06	2.14	1.76	2.14	1.75	1.92	2.18	2.01	2.18	2.07	2.19	2.12	2.19	**2.07**	2.19	1.75

Table B-11 – Monthly Average Water Supply Withdrawal and Reliability

Water Year	Days of WSP Shortage	Modeled WSP Withdrawal in cfs													July to September WSP Withdrawal in cfs		
		Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual Average	Modeled Withdrawal	Target Withdrawal	Difference
1988	0	61.8	63.9	53.0	53.0	66.1	61.8	63.9	70.7	91.3	106.0	114.8	91.3	74.8	104.0	104.0	0.0
1989	1	61.8	63.9	53.0	53.0	68.4	61.8	60.7	60.1	73.0	79.5	86.1	70.6	66.0	78.7	79.5	-0.8
1990	0	52.5	57.5	53.0	53.0	68.4	61.8	63.9	70.7	91.3	106.0	114.8	91.3	73.7	104.0	104.0	0.0
1991	3	61.8	63.9	53.0	53.0	68.4	61.8	63.9	70.7	91.3	106.0	114.8	82.1	74.3	101.0	104.0	-3.0
1992	9	61.8	63.9	53.0	53.0	66.1	61.8	60.7	60.1	73.0	79.5	86.1	51.1	64.2	72.2	79.5	-7.3
1993	5	52.5	57.5	53.0	53.0	68.4	61.8	63.9	70.7	91.3	106.0	114.8	76.0	72.4	98.9	104.0	-5.1
1994	5	61.8	63.9	53.0	53.0	68.4	61.8	60.7	60.1	73.0	79.5	86.1	60.8	65.2	75.5	79.5	-4.1
1995	0	52.5	57.5	53.0	53.0	68.4	61.8	60.7	63.6	77.6	79.5	97.6	82.1	67.2	86.4	86.4	0.0
1996	0	58.7	63.9	53.0	53.0	66.1	61.8	60.7	63.6	77.6	79.5	97.6	82.1	68.1	86.4	86.4	0.0
1997	0	58.7	63.9	53.0	53.0	68.4	61.8	63.9	70.7	91.3	106.0	114.8	91.3	74.7	104.0	104.0	0.0
1998	0	61.8	63.9	53.0	53.0	68.4	61.8	63.9	70.7	91.3	106.0	114.8	91.3	75.0	104.0	104.0	0.0
1999	0	61.8	63.9	53.0	53.0	68.4	61.8	63.9	70.7	91.3	106.0	114.8	91.3	75.0	104.0	104.0	0.0
2000	0	61.8	63.9	53.0	53.0	66.1	61.8	63.9	70.7	91.3	106.0	114.8	91.3	74.8	104.0	104.0	0.0
2001	0	61.8	63.9	53.0	53.0	68.4	61.8	60.7	60.1	73.0	79.5	86.1	73.0	66.2	79.5	79.5	0.0
2002	0	52.5	57.5	53.0	53.0	68.4	61.8	63.9	70.7	91.3	106.0	114.8	91.3	73.7	104.0	104.0	0.0
Average	1.5	58.9	62.2	53.0	53.0	67.8	61.8	62.6	66.9	84.6	95.4	104.9	81.1	71.0	93.8	95.1	-1.4

Total Days of Shortfall	23
Reliability	99.58%

Notes:

1) Orange rows indicate dry years, when Stage 1 shortage management was applied, and yellow rows indicate drought years and Stage 2 shortage management.

2) Target water supply withdrawal incorporates Stage 1 and Stage 2 reductions in demand.

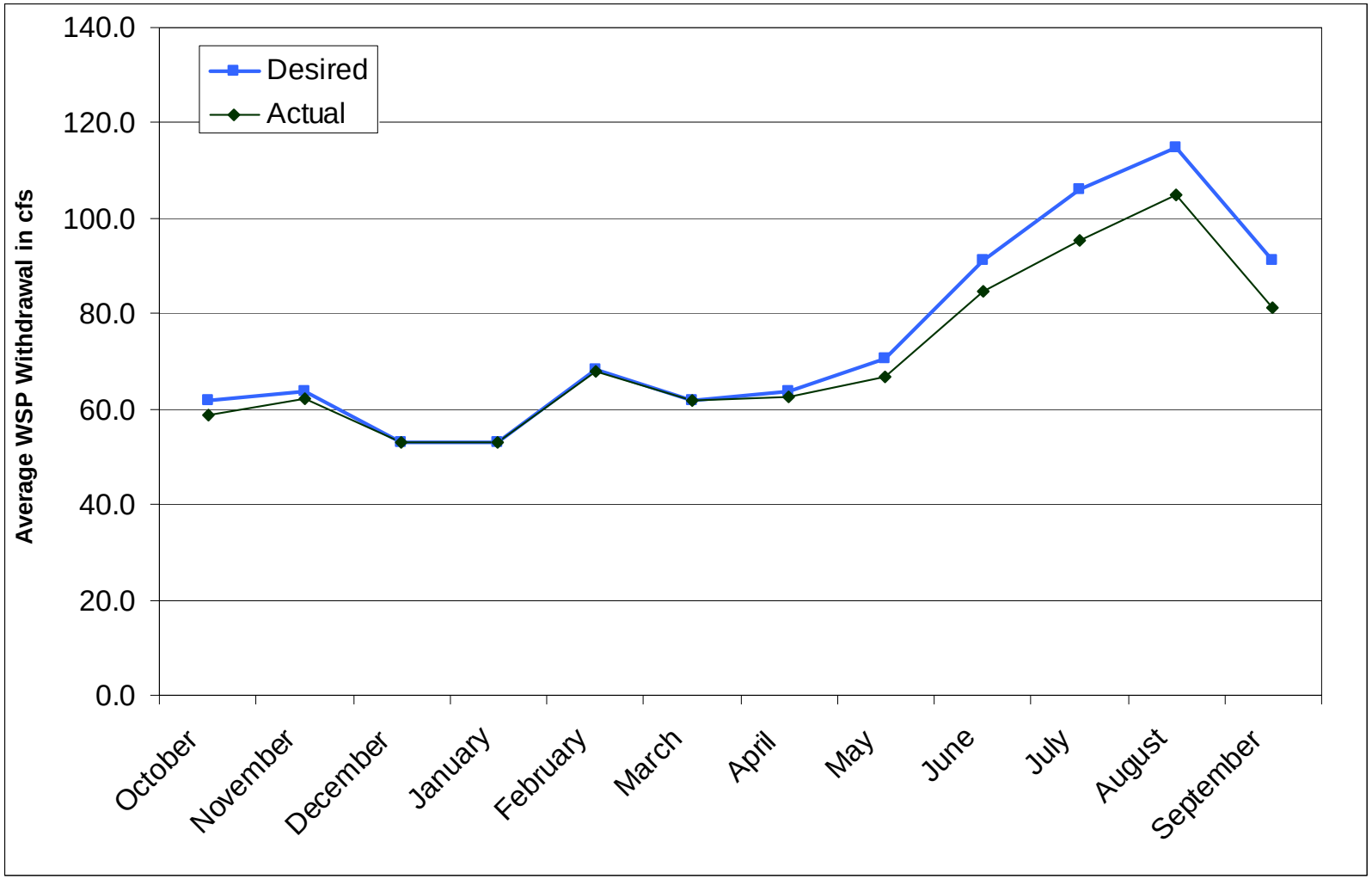
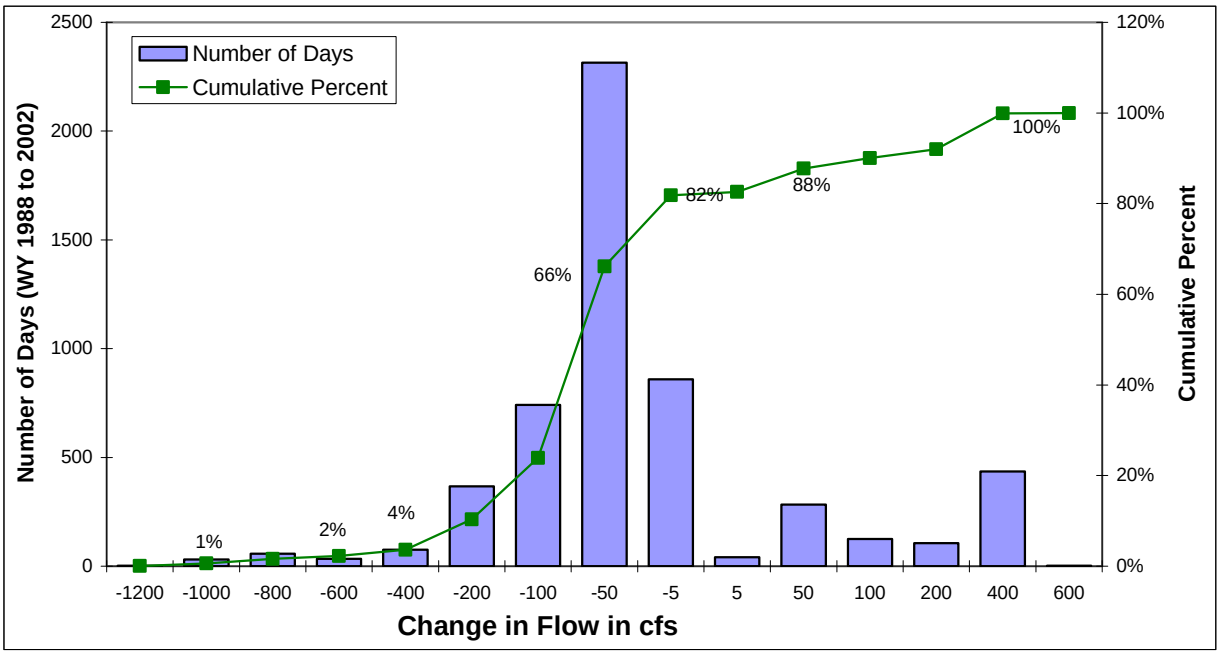


Figure B-29 – Monthly Average Water Supply Withdrawal

B.5 Lower White River Results

Table B12 – Histogram of Change in Flow in the Lower White River

Change in Flows in cfs	Number of Days (WY 1988 - 2002)	Cumulative Number of Days	Cumulative %
-1500	0	0	0%
-1200	3	3	0%
-1000	31	34	1%
-800	57	91	2%
-600	34	125	2%
-400	76	201	4%
-200	367	568	10%
-100	742	1310	24%
-50	2314	3624	66%
-5	859	4483	82%
5	42	4525	83%
50	284	4809	88%
100	126	4935	90%
200	106	5041	92%
400	435	5476	100%
600	3	5479	100%
800	0	5479	100%
1000	0	5479	100%
1200	0	5479	100%
1500	0	5479	100%
2000	0	5479	100%



Note:

1) Histogram categories are labeled for the upper end of the category range. For example the -100 category represents changes in flows of -150 to -100 cfs.

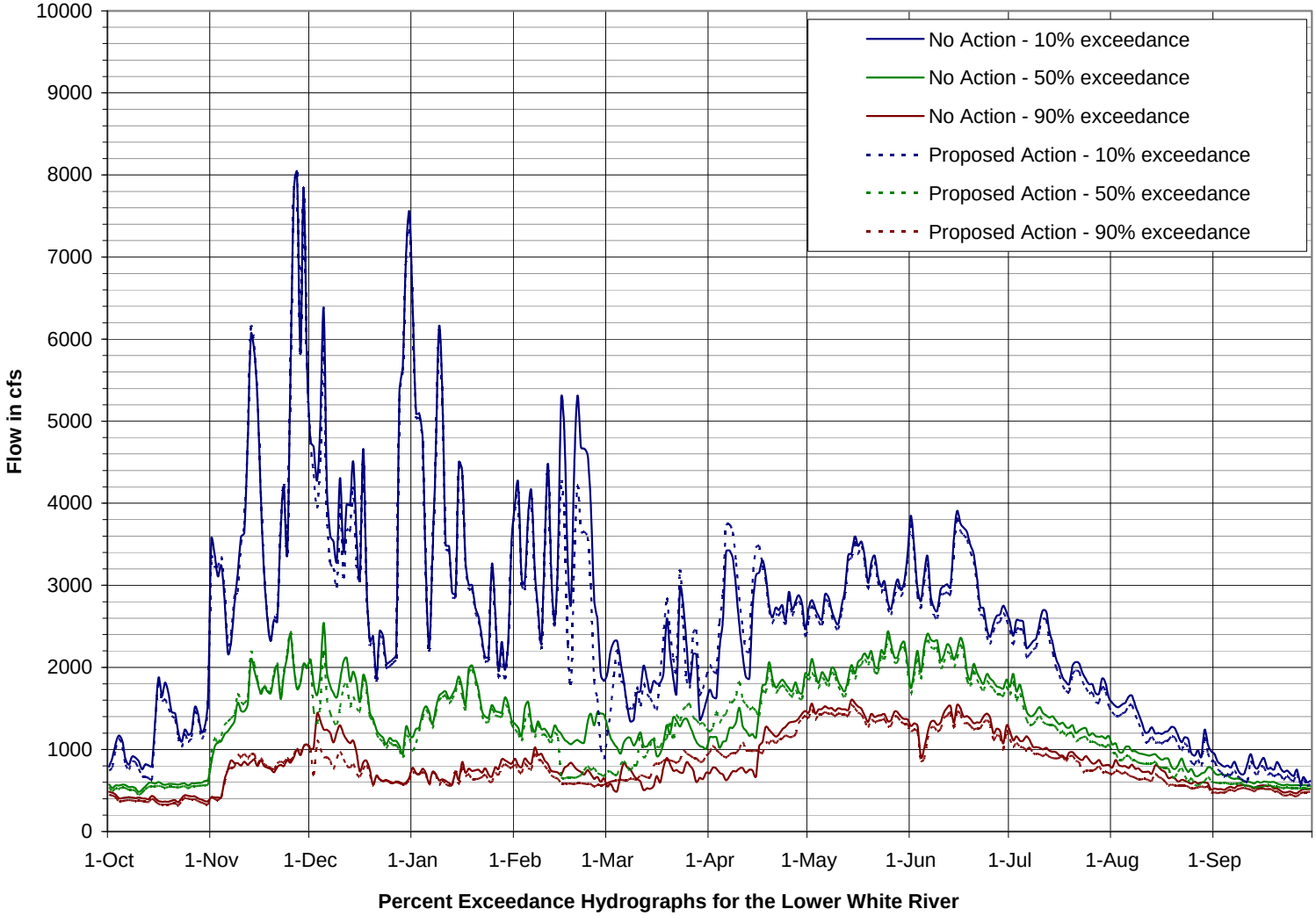


Figure B-30 – Daily Flow Exceedance Hydrograph for the Lower White

B.5.1 Lower White Water Quality

Table B-13 – Changes in Lower White River Temperature by Month

	Change in Lower White River Temperature in ºC		
Month	Average	Maximum Decrease	Maximum Increase
January	-0.01	-0.04	0.01
February	-0.01	-0.03	0.01
March	-0.03	-0.07	0.05
April	0.01	-0.03	0.03
May	-0.01	-0.01	0.01
June	0.00	-0.02	0.00
July	0.16	-0.10	0.65
August	0.26	-0.02	1.01
September	0.04	-1.03	0.69
October	-0.07	-1.57	0.73
November	0.03	-2.32	0.39
December	-0.27	-1.28	0.11

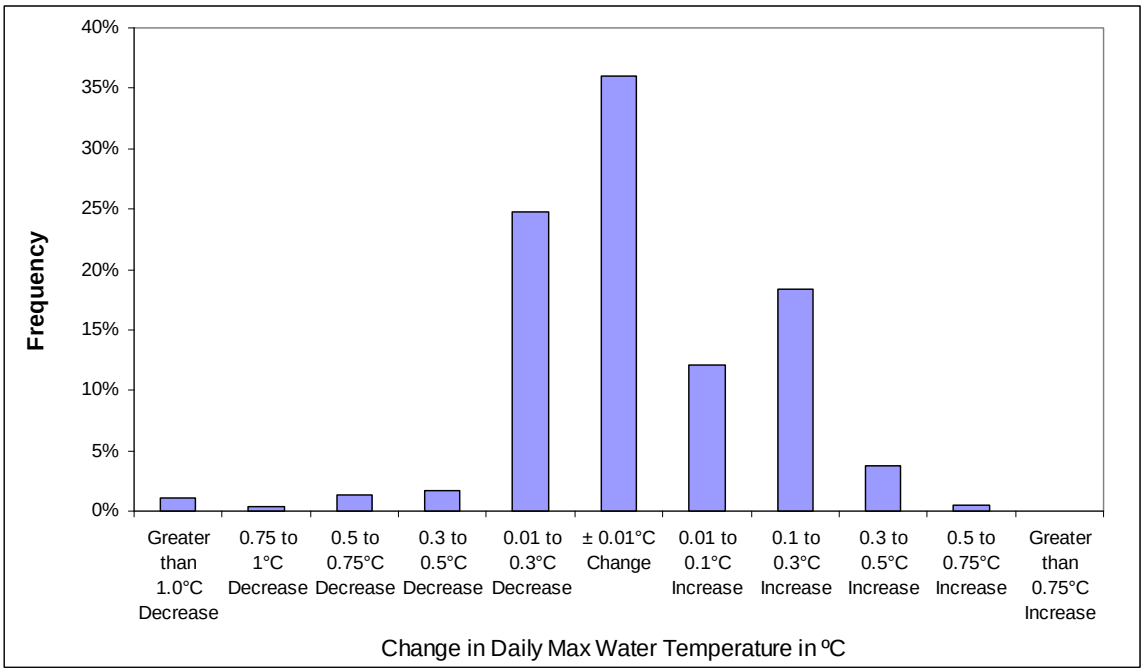


Figure B-31 – Change in Temperature Histogram for the Lower White River

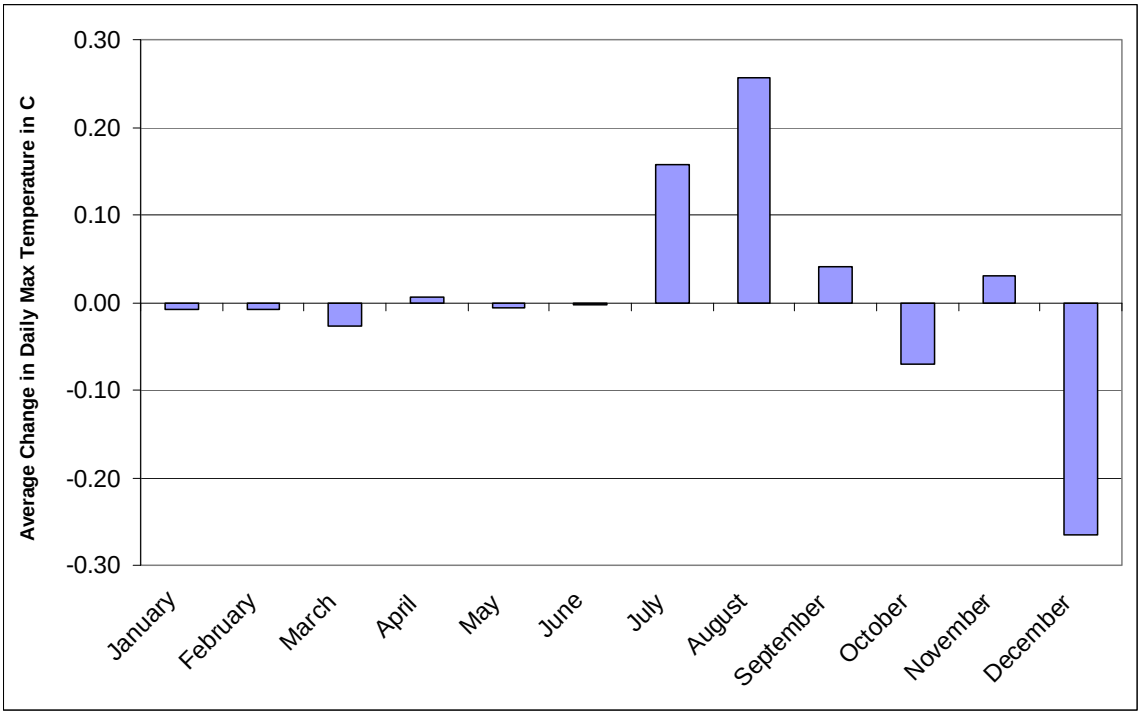


Figure B-32– Timing of Maximum Change in Lower White River Temperature by Month

Table B-14 – 7Q10 and 7Q20 Flows for the Lower White River

Calculation of 7Q10 and 7Q20 Flows for the Lower White River
No Action

	Return Period	P	Adjusted P	Variate	Interpolating K Value for Skew			7-Day Low Flow in cfs
					K_{low}	K_{high}	K	
					-0.1	**0.00**	**-0.038**	
	1.01	0.99	0.990	-2.33	-2.39961	-2.32635	-2.35	635
	1.25	0.8	0.800	-0.84	-0.83639	-0.84162	-0.84	511
	2	0.5	0.500	0.00	0.01662	0	0.01	453
	5	0.2	0.200	0.84	0.84611	0.84162	0.84	402
7Q10	10	0.1	0.100	1.28	1.27037	1.28155	1.28	**377**
7Q20	20	0.05	0.050	1.64	1.61594	1.64485	1.63	**359**
	50	0.02	0.020	2.05	1.99973	2.05375	2.03	339
	100	0.01	0.010	2.33	2.25258	2.32635	2.30	326

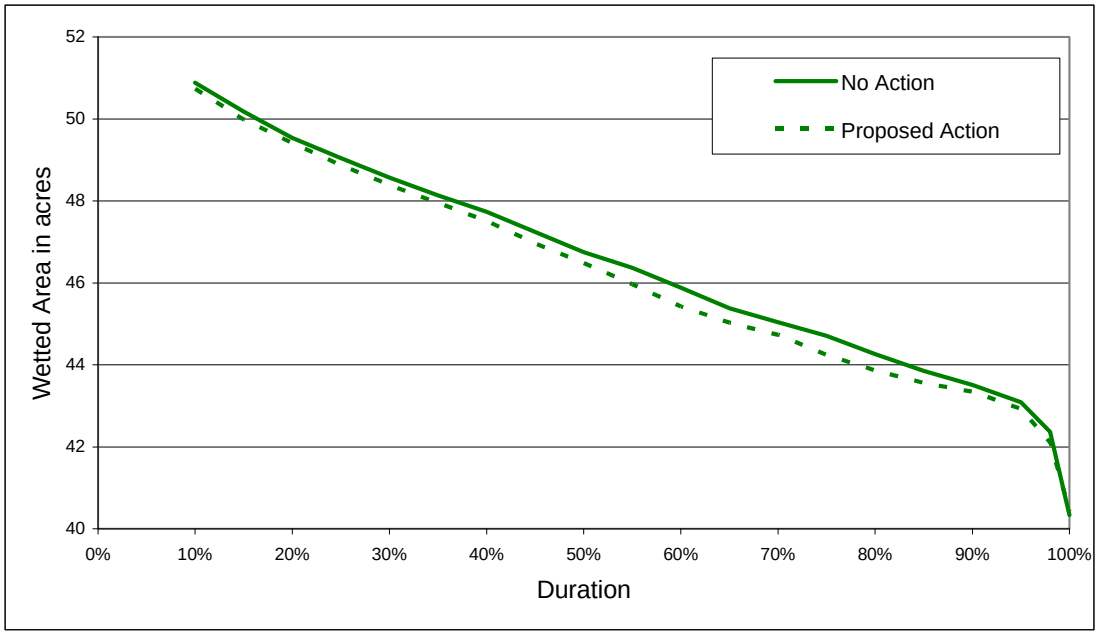
Calculation of 7Q10 and 7Q20 Flows for the Lower White River
Proposed Action

	Return Period	P	Adjusted P	Variate	Interpolating K Value for Skew			7-Day Low Flow in cfs
					K_{low}	K_{high}	K	
					-0.1	**0.00**	**1.282**	
	1.01	0.99	0.990	-2.33	-2.39961	-2.32635	-2.35	614
	1.25	0.8	0.800	-0.84	-0.83639	-0.84162	-0.84	483
	2	0.5	0.500	0.00	0.01662	0	0.01	423
	5	0.2	0.200	0.84	0.84611	0.84162	0.84	370
7Q10	10	0.1	0.100	1.28	1.27037	1.28155	1.28	**346**
7Q20	20	0.05	0.050	1.64	1.61594	1.64485	1.63	**327**
	50	0.02	0.020	2.05	1.99973	2.05375	2.03	307
	100	0.01	0.010	2.33	2.25258	2.32635	2.30	294

B.5.2 Lower White River Habitat

	Change in Wetted Area in Acres
Min	-4.22
Average	-0.26
Max	2.22

Percentile	Wetted Area in Acres	
	No Action	Proposed Action
0%	999999	999999
2%	999999	999999
8%	999999	999999.0
10%	50.9	50.7
15%	50.2	50.0
20%	49.5	49.4
25%	49.0	48.9
30%	48.6	48.4
35%	48.1	48.0
40%	47.7	47.5
45%	47.2	47.0
50%	46.7	46.5
55%	46.4	46.0
60%	45.9	45.4
65%	45.4	45.0
70%	45.0	44.7
75%	44.7	44.2
80%	44.3	43.9
85%	43.9	43.6
90%	43.5	43.3
95%	43.1	42.9
98%	42.4	42.1
100%	40.3	40.4



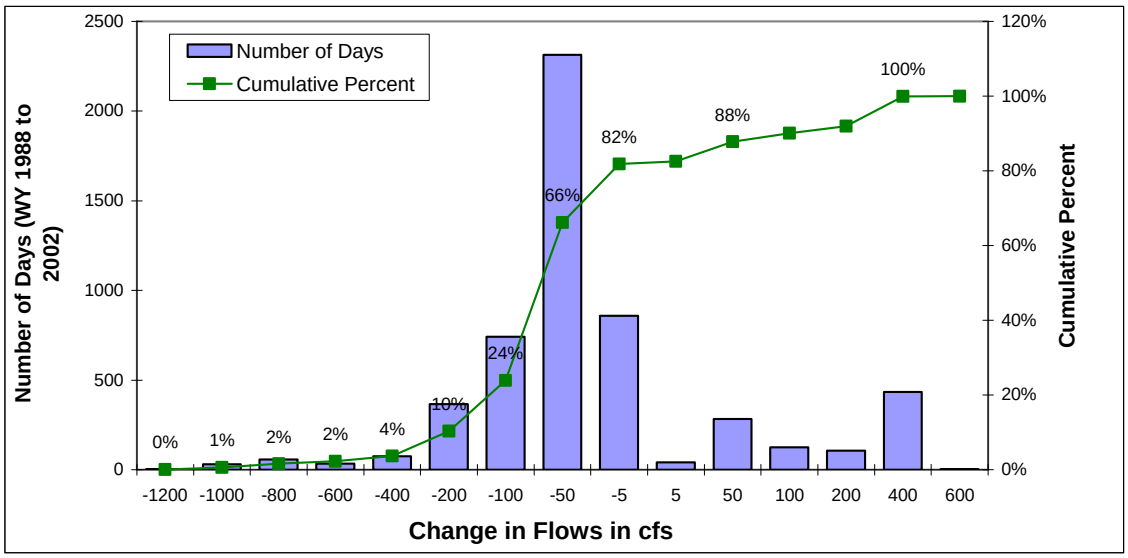
Note:
1) 999999 indicates the flow is out of the range of relationships for calculating wetted area

Figure B-33 – Duration Curve of Change in Wetted Area in the Lower White River

B.6 Puyallup River Results

Table B-15 – Histogram of Change in Flow in the Lower Puyallup River

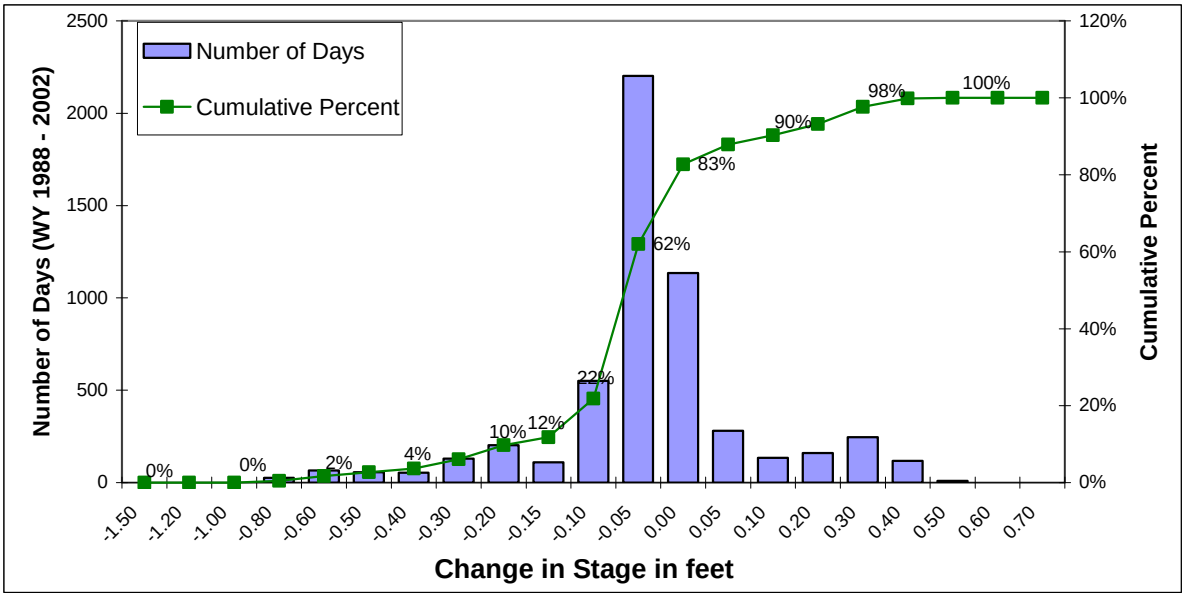
Change in Flows in cfs	Number of Days (WY 1988 - 2002)	Cumulative Number of Days	Cumulative %
-1500	0	0	0%
-1200	3	3	0%
-1000	31	34	1%
-800	57	91	2%
-600	34	125	2%
-400	76	201	4%
-200	367	568	10%
-100	742	1310	24%
-50	2314	3624	66%
-5	859	4483	82%
5	42	4525	83%
50	284	4809	88%
100	126	4935	90%
200	106	5041	92%
400	435	5476	100%
600	3	5479	100%
800	0	5479	100%
1000	0	5479	100%
1200	0	5479	100%
1500	0	5479	100%
2000	0	5479	100%



Note:
1) Histogram categories are labeled for the upper end of the category range. For example the -50 category represents changes in flows of -100 to -50 cfs.

Table B-16 – Histogram of Change in Stage in the Lower Puyallup River

Change in Stages in ft	Number of Days (WY 1988 - 2002)	Cumulative Number of Days	Cumulative %
-1.5	0	0	0%
-1.2	0	0	0%
-1	0	0	0%
-0.8	26	26	0%
-0.6	65	91	2%
-0.5	57	148	3%
-0.4	54	202	4%
-0.3	130	332	6%
-0.2	203	535	10%
-0.15	110	645	12%
-0.1	550	1195	22%
-0.05	2203	3398	62%
0	1135	4533	83%
0.05	280	4813	88%
0.1	134	4947	90%
0.2	160	5107	93%
0.3	246	5353	98%
0.4	117	5470	100%
0.5	9	5479	100%
0.6	0	5479	100%
0.7	0	5479	100%



Note:

1) Histogram categories are labeled for the upper end of the category range. For example the -5% category represents changes in stages of -0.10 to -0.05 feet.

Table B-17 – Minimum Instream Flow Excursions in Puyallup River at Puyallup

WY	No Action			Proposed Action		
	Number of Excursions in Days	Total Volume in acre feet	Average Shortfall in cfs	Number of Excursions in Days	Total Volume in acre feet	Average Shortfall in cfs
1988	77	34,750	228	76	36,672	243
1989	7	613	44	11	1,257	58
1990	27	8,344	156	30	10,354	174
1991	0	-	0	3	50	8
1992	109	52,835	244	116	41,243	179
1993	55	28,783	264	72	31,419	220
1994	56	15,361	138	69	19,865	145
1995	49	20,729	213	48	18,848	198
1996	25	6,602	133	30	6,016	101
1997	4	307	39	4	593	75
1998	11	1,093	50	15	1,992	67
1999	26	4,333	84	21	4,174	100
2000	16	1,970	62	25	3,621	73
2001	35	16,516	238	34	12,251	182
2002	1	23	12	4	143	18
Total	**498**	**192,260**	**195**	**558**	**188,497**	**170**

Table B-18 – Seasonality of Minimum Instream Flow Excursions in the Puyallup River at Puyallup

Month	Number of Excursions in Days			Volume of MIF Shortfall in acre feet		
	No Action	Proposed Action	Difference	No Action	Proposed Action	Difference
1	43	48	5	29,474	31,783	2,309
2	38	49	11	15,521	19,811	4,290
3	55	41	-14	29,685	12,507	(17,178)
4	46	18	-28	27,514	7,810	(19,704)
5	5	7	2	1,734	2,465	732
6	18	21	3	10,143	12,438	2,295
7	18	24	6	4,045	5,078	1,032
8	39	69	30	8,638	15,355	6,717
9	52	84	32	8,665	14,067	5,403
10	137	153	16	43,201	53,535	10,334
11	27	21	-6	6,387	6,152	(235)
12	20	23	3	7,254	7,496	241
Total	498	558	60	192,260	188,497	(3,763)

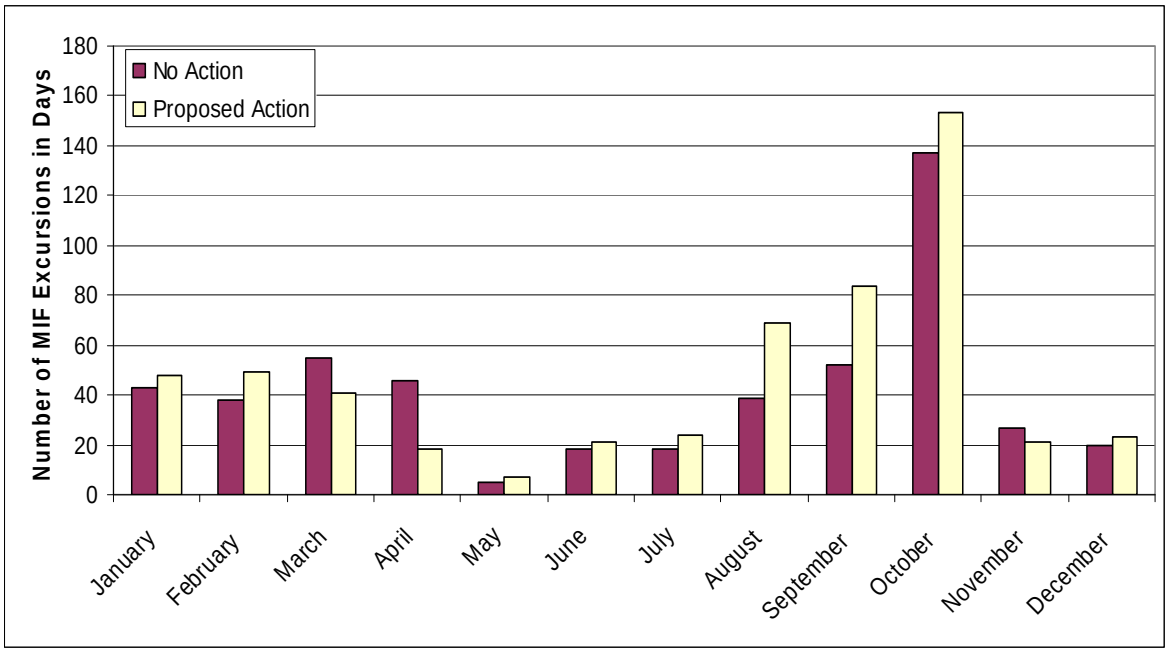


Figure B-34 – Seasonality of Minimum Instream Flow Excursions in the Puyallup River at Puyallup

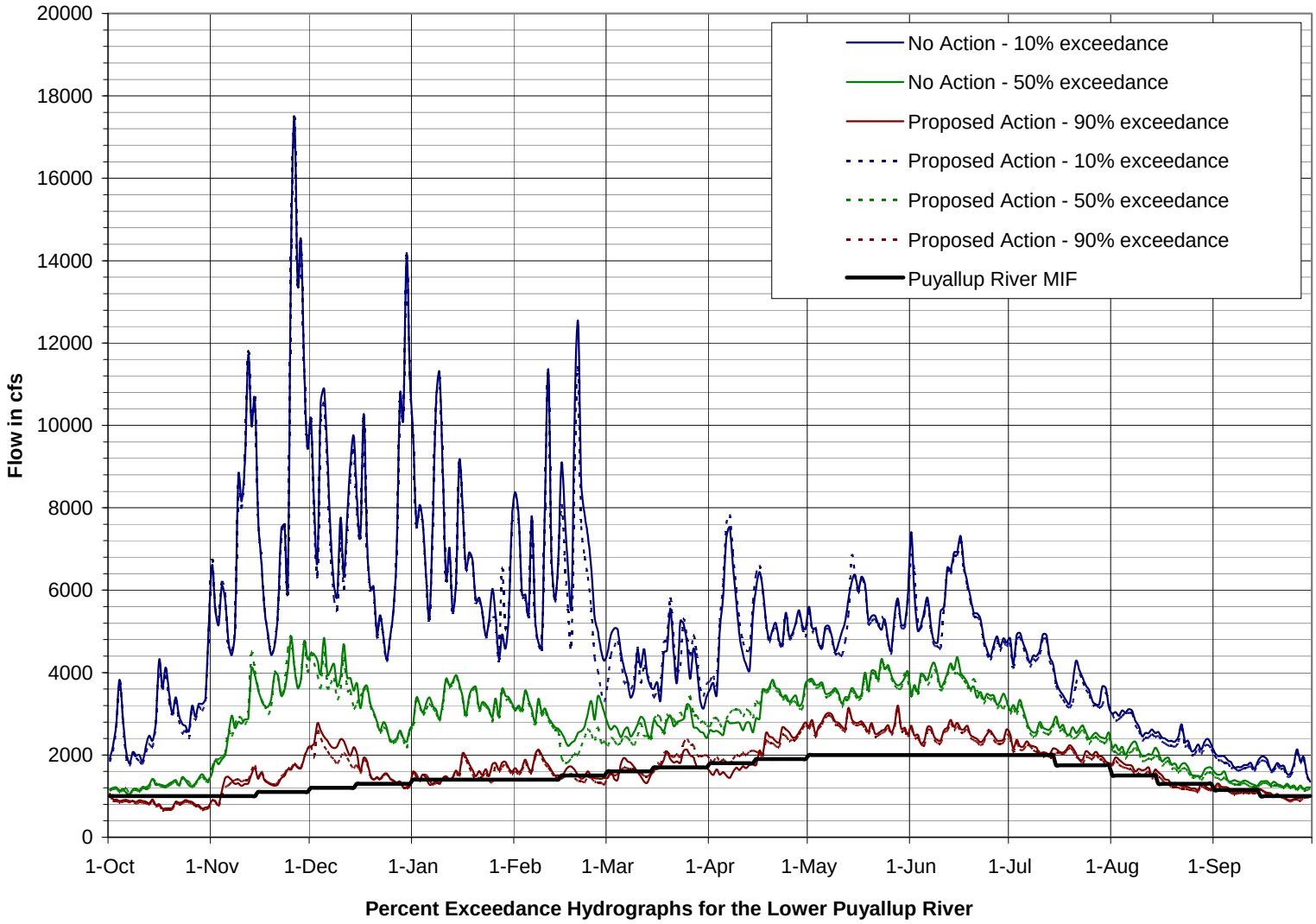


Figure B-35 – Daily Flow Exceedance Hydrograph for the Lower Puyallup River

B.6.1 Lower Puyallup River Water Quality

Table B-19 – 7Q10 and 7Q20 Flows for the Lower Puyallup River

Calculation of 7Q10 and 7Q20 Flows for the Lower Puyallup River
No Action

	Return Period	P	Adjusted P	Variate	Interpolating K Value for Skew			7-Day Low Flow in cfs
					K_{low}	K_{high}	K	
					-0.2	**-0.10**	**-0.166**	
	1.01	0.99	0.990	-2.33	-2.47226	-2.39961	-2.45	1521
	1.25	0.8	0.800	-0.84	-0.83044	-0.83639	-0.83	1112
	2	0.5	0.500	0.00	0.03325	0.01662	0.03	942
	5	0.2	0.200	0.84	0.84986	0.84611	0.85	803
7Q10	10	0.1	0.100	1.28	1.25824	1.27037	1.26	**742**
7Q20	20	0.05	0.050	1.64	1.58607	1.61594	1.60	**695**
	50	0.02	0.020	2.05	1.94499	1.99973	1.96	647
	100	0.01	0.010	2.33	2.1784	2.25258	2.20	618

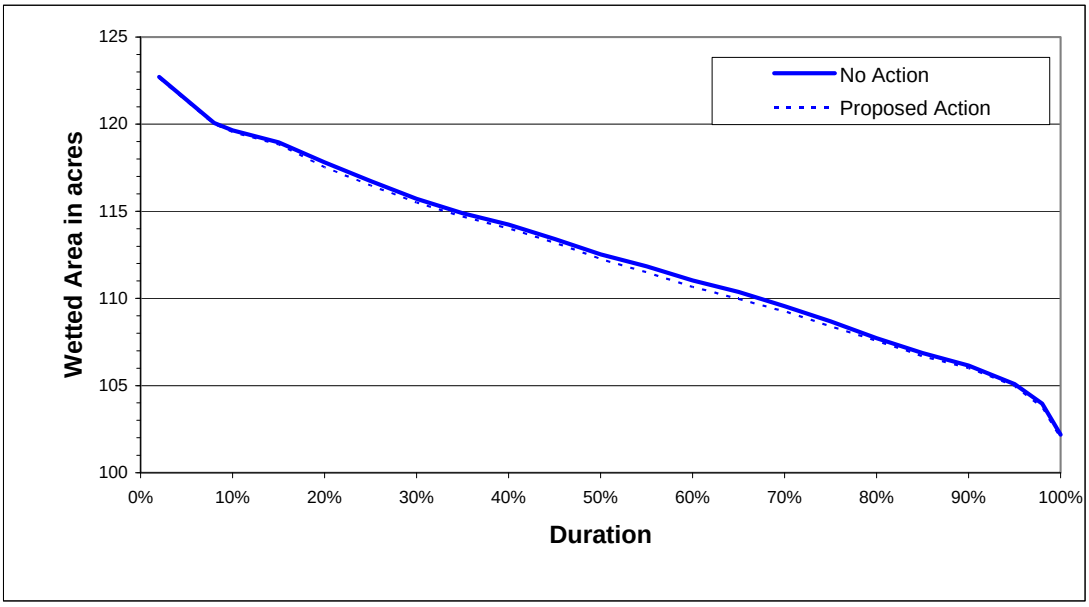
Calculation of 7Q10 and 7Q20 Flows for the Lower Puyallup River
Proposed Action

	Return Period	P	Adjusted P	Variate	Interpolating K Value for Skew			7-Day Low Flow in cfs
					K_{low}	K_{high}	K	
					-0.2	**-0.10**	**1.270**	
	1.01	0.99	0.990	-2.33	-2.47226	-2.39961	-2.45	1480
	1.25	0.8	0.800	-0.84	-0.83044	-0.83639	-0.83	1078
	2	0.5	0.500	0.00	0.03325	0.01662	0.03	910
	5	0.2	0.200	0.84	0.84986	0.84611	0.85	775
7Q10	10	0.1	0.100	1.28	1.25824	1.27037	1.26	**714**
7Q20	20	0.05	0.050	1.64	1.58607	1.61594	1.60	**669**
	50	0.02	0.020	2.05	1.94499	1.99973	1.96	622
	100	0.01	0.010	2.33	2.1784	2.25258	2.20	594

B.6.2 Lower Puyallup River Habitat

	Change in Wetted Area in Acres
Min	-4.2
Average	-0.2
Max	2.0

Percentile	Wetted Area in Acres	
	No Action	Proposed Action
0%	999999	999999
2%	122.7	122.6
8%	120.1	120.0
10%	119.6	119.5
15%	119.0	118.8
20%	117.8	117.5
25%	116.7	116.5
30%	115.7	115.5
35%	114.9	114.7
40%	114.2	114.0
45%	113.4	113.2
50%	112.5	112.3
55%	111.8	111.5
60%	111.0	110.7
65%	110.4	110.0
70%	109.6	109.3
75%	108.7	108.4
80%	107.7	107.6
85%	106.9	106.7
90%	106.1	106.0
95%	105.1	105.0
98%	104.0	103.7
100%	102.2	102.0



Note:
1) 999999 indicates the flow is out of the range of relationships for calculating wetted area

Figure B-36 – Duration Curve of Change in Wetted Area in the Lower Puyallup River

APPENDIX C

PTI Tailrace Temperature Monitoring Data

The temperature monitoring data in this appendix was provided courtesy of the Puyallup Tribe of Indians. The data was collected in the summers of 2004, 2005, 2007, and 2009 at a monitoring location in the tailrace under the East Valley Highway bridge. Data was collected using a StowAway TidbiT temperature logger installed at the bridge, approximately 5 feet from the left bank and about 4 inches above the bottom of the channel. Data was collected every 30 minutes. The daily minimum, average, and maximum temperatures, and 7-DADMax temperatures presented in this appendix were calculated by Aspect Consulting.

Table C-1. Temperature Monitoring Data from June to September 2004

Date	Temperature in °C			7-DADMax[1]	Flag[2]
	Minimum	Average	Maximum		
6/30/2004	15.58	15.88	16.21		
7/1/2004	15.58	15.92	16.21		
7/2/2004	15.58	15.95	16.37		
7/3/2004	15.74	16.05	16.21	16.37	
7/4/2004	15.89	16.18	16.37	16.50	
7/5/2004	16.06	16.13	16.53	16.46	
7/6/2004	15.89	16.27	16.68	16.41	
7/7/2004	14.79	16.10	17.16	16.39	
7/8/2004	15.26	15.71	15.89	16.37	
7/9/2004	15.74	15.95	16.06	16.32	
7/10/2004	15.74	15.95	16.06	16.26	
7/11/2004	15.58	15.94	16.21	16.14	
7/12/2004	15.58	15.97	16.21	16.19	
7/13/2004	15.74	15.97	16.21	16.23	
7/14/2004	15.74	16.08	16.37	16.32	
7/15/2004	15.89	16.13	16.21	16.37	
7/16/2004	15.89	16.17	16.37	16.44	
7/17/2004	16.21	16.33	16.68	16.50	
7/18/2004	16.21	16.30	16.53	16.55	
7/19/2004	16.06	16.40	16.68	16.66	
7/20/2004	16.06	16.41	16.68	16.73	
7/21/2004	16.37	16.54	16.68	16.80	
7/22/2004	16.21	16.55	17.00	16.86	
7/23/2004	16.37	16.62	16.84	16.93	
7/24/2004	16.06	16.63	17.16	17.02	
7/25/2004	16.37	16.72	17.00	17.11	
7/26/2004	16.53	16.80	17.16	17.16	
7/27/2004	16.68	16.87	17.32	17.23	
7/28/2004	16.68	16.95	17.32	17.25	
7/29/2004	16.84	17.03	17.32	17.32	
7/30/2004	16.84	17.09	17.32	17.37	
7/31/2004	17.00	17.12	17.32	17.41	
8/1/2004	17.00	17.21	17.48	17.46	
8/2/2004	17.00	17.26	17.48	17.50	
8/3/2004	16.84	17.23	17.64	17.55	
8/4/2004	17.16	17.39	17.64	17.69	
8/5/2004	17.00	17.38	17.64	17.73	
8/6/2004	17.16	17.42	17.64	17.80	
8/7/2004	17.00	17.48	18.28	17.87	
8/8/2004	17.48	17.56	17.80	17.89	
8/9/2004	17.00	17.55	17.96	17.94	
8/10/2004	17.32	17.68	18.12	17.98	b
8/11/2004	17.32	17.45	17.80	17.94	a

Table C-1. Temperature Monitoring Data from June to September 2004 (Cont.)

Date	Temperature in °C			7-DADMax[1]	Flag[2]
	Minimum	Average	Maximum		
8/12/2004	17.48	17.66	17.96	17.96	
8/13/2004	17.48	17.70	17.96	17.96	
8/14/2004	17.48	17.77	17.96	17.96	
8/15/2004	17.64	17.80	17.96	18.01	
8/16/2004	17.80	17.90	17.96	18.05	
8/17/2004	17.48	17.83	18.12	18.14	
8/18/2004	17.64	17.86	18.12	18.28	
8/19/2004	17.64	17.90	18.28	18.44	
8/20/2004	17.64	18.12	18.61	18.65	
8/21/2004	18.44	18.55	18.93	18.82	
8/22/2004	17.96	18.58	19.09	19.02	
8/23/2004	17.96	18.61	19.42	19.16	
8/24/2004	18.61	18.92	19.26	19.23	
8/25/2004	18.93	19.26	19.58	19.26	
8/26/2004	18.77	19.04	19.26	19.23	
8/27/2004	18.77	18.98	19.09	19.16	
8/28/2004	18.77	18.98	19.09	19.09	
8/29/2004	18.61	18.78	18.93	19.05	
8/30/2004	18.61	18.80	18.93	19.02	
8/31/2004	18.61	18.68	18.77	19.00	
9/1/2004	18.12	18.74	19.26	18.98	
9/2/2004	18.28	18.81	19.09	18.95	
9/3/2004	18.61	18.81	18.93	18.91	
9/4/2004	18.61	18.78	18.93	18.77	
9/5/2004	18.28	18.61	18.77	18.52	
9/6/2004	17.96	18.49	18.61	18.29	
9/7/2004	17.00	17.38	17.80	18.10	
9/8/2004	17.00	17.23	17.48	18.06	
9/9/2004	16.84	17.29	17.48	18.01	
9/10/2004	16.84	17.24	17.64	18.01	
9/11/2004	17.16	17.95	18.61	18.12	
9/12/2004	17.96	18.27	18.44	18.24	
9/13/2004	18.28	18.43	18.61	18.35	
9/14/2004	18.12	18.31	18.61		
9/15/2004	17.96	18.16	18.28		
9/16/2004	18.12	18.17	18.28		d

Notes:
1) 7-DADMax is the 7-day average of daily maximum temperatures, calculated by averaging that days's
2) Flags indicate periods of missing data as follows:
a - missing less than 6 hours of data
b - missing 6 to 12 hours of data
c - missing 12 to 18 hours of data
d - missing 18 to 24 hours of data

Table C-2. Temperature Monitoring Data from July to September 2005

Date	Temperature in °C			7-DADMax[1]	Flag[2]
	Minimum	Average	Maximum		
7/12/2005	14.68	15.35	15.79		
7/13/2005	14.68	15.28	15.79		
7/14/2005	14.84	15.26	15.63		
7/15/2005	15.00	15.39	16.11	15.88	
7/16/2005	14.84	15.47	15.95	15.93	
7/17/2005	14.84	15.50	16.11	15.97	
7/18/2005	15.32	15.57	15.79	16.00	
7/19/2005	15.00	15.61	16.11	16.02	
7/20/2005	15.32	15.71	16.11	16.06	
7/21/2005	15.63	15.74	15.79	16.11	
7/22/2005	15.63	15.91	16.27	16.20	
7/23/2005	15.48	15.89	16.27	16.27	
7/24/2005	15.48	15.88	16.42	16.13	
7/25/2005	15.48	16.03	16.42	16.29	
7/26/2005	14.84	15.64	16.58	16.29	
7/27/2005	13.75	14.58	15.16	16.24	
7/28/2005	13.75	14.73	16.90	16.20	
7/29/2005	12.98	14.37	16.27	16.04	
7/30/2005	12.83	14.15	15.95	15.57	
7/31/2005	12.83	14.43	16.11	15.26	
8/1/2005	12.67	13.70	15.32	14.74	
8/2/2005	12.67	12.97	13.29	14.32	
8/3/2005	12.52	12.83	12.98	13.96	
8/4/2005	12.83	13.05	13.29	13.60	
8/5/2005	12.98	13.07	13.29	13.38	
8/6/2005	13.29	13.39	13.44	13.44	
8/7/2005	13.29	13.48	13.60	13.58	
8/8/2005	13.44	13.56	13.75	13.66	
8/9/2005	13.44	13.56	13.75	13.73	
8/10/2005	13.44	13.66	13.91	13.80	
8/11/2005	13.29	13.65	13.91	13.86	
8/12/2005	13.44	13.59	13.75	13.89	
8/13/2005	13.60	13.69	13.91	13.93	
8/14/2005	13.60	13.84	14.06	13.97	
8/15/2005	13.75	13.82	13.91	14.00	
8/16/2005	13.75	13.85	14.06	14.06	
8/17/2005	13.60	13.89	14.22	14.08	
8/18/2005	13.75	13.94	14.06	14.11	
8/19/2005	13.60	13.91	14.22	14.17	
8/20/2005	13.60	13.95	14.06	14.20	
8/21/2005	13.91	14.07	14.22	14.26	
8/22/2005	13.91	14.12	14.37	14.28	
8/23/2005	13.75	14.07	14.22	14.28	
8/24/2005	13.75	14.11	14.68	14.35	
8/25/2005	13.60	13.99	14.22	14.40	
8/26/2005	13.75	14.04	14.22	14.42	
8/27/2005	14.06	14.22	14.53	14.46	
8/28/2005	13.91	14.30	14.53	14.44	
8/29/2005	13.91	14.30	14.53	14.51	
8/30/2005	13.91	14.17	14.53	14.57	
8/31/2005	14.06	14.31	14.53	14.59	

Table C-2. Temperature Monitoring Data from July to September 2005 (Cont.)

Date	Temperature in °C			7-DADMax[1]	Flag[2]
	Minimum	Average	Maximum		
9/1/2005	13.91	14.42	14.68	14.62	
9/2/2005	13.91	14.29	14.68	14.64	
9/3/2005	14.06	14.48	14.68	14.70	
9/4/2005	14.06	14.45	14.68	14.75	
9/5/2005	14.22	14.38	14.68	14.79	
9/6/2005	14.37	14.81	15.00	14.89	
9/7/2005	14.37	14.60	14.84	14.95	
9/8/2005	14.22	14.72	15.00	15.05	
9/9/2005	14.37	14.73	15.32	15.14	
9/10/2005	14.06	14.55	15.16	15.23	
9/11/2005	14.37	14.91	15.32	15.32	
9/12/2005	15.00	15.21	15.32	15.45	
9/13/2005	15.00	15.30	15.63	15.52	
9/14/2005	15.16	15.31	15.48	15.63	
9/15/2005	15.48	15.62	15.95	15.70	
9/16/2005	15.48	15.56	15.79	15.79	
9/17/2005	15.63	15.78	15.95	15.79	
9/18/2005	15.32	15.64	15.79		
9/19/2005	15.32	15.68	15.95		
9/20/2005	15.48	15.54	15.63		c

Notes:
1) 7-DADMax is the 7-day average of daily maximum temperatures, calculated by averaging that days's
2) Flags indicate periods of missing data as follows:
a - missing less than 6 hours of data
b - missing 6 to 12 hours of data
c - missing 12 to 18 hours of data
d - missing 18 to 24 hours of data

Table C-3. Temperature Monitoring Data from June to August 2007

Date	Temperature in °C			7-DADMax[1]	Flag[2]
	Minimum	Average	Maximum		
6/28/2007	12.22	12.42	12.69		
6/29/2007	12.53	12.67	13.16		
6/30/2007	12.38	12.49	12.69		
7/1/2007	12.69	12.80	13.00	12.91	
7/2/2007	12.53	12.69	12.84	12.96	
7/3/2007	12.53	12.77	13.00	12.93	
7/4/2007	12.84	12.88	13.00	12.98	
7/5/2007	12.84	12.85	13.00	12.95	
7/6/2007	12.84	12.88	13.00	12.98	
7/7/2007	12.69	12.87	13.00	13.00	
7/8/2007	12.69	12.81	12.84	13.00	
7/9/2007	12.69	12.92	13.00	13.00	
7/10/2007	12.84	13.01	13.16	13.00	
7/11/2007	12.69	12.84	13.00	13.00	
7/12/2007	12.84	12.88	13.00	13.02	
7/13/2007	12.69	12.90	13.00	13.05	
7/14/2007	12.84	12.92	13.00	13.02	
7/15/2007	12.84	12.97	13.00	13.05	
7/16/2007	13.00	13.01	13.16	13.07	
7/17/2007	12.84	12.96	13.00	13.11	
7/18/2007	12.84	12.95	13.16	13.14	
7/19/2007	12.84	12.97	13.16	13.16	
7/20/2007	12.84	13.05	13.31	13.16	
7/21/2007	12.84	13.01	13.16	13.18	
7/22/2007	13.00	13.03	13.16	13.18	
7/23/2007	13.00	13.04	13.16	13.16	
7/24/2007	12.84	13.01	13.16	13.14	
7/25/2007	13.00	13.07	13.16	13.14	
7/26/2007	12.69	12.84	13.00	13.14	
7/27/2007	12.84	12.95	13.16	13.14	
7/28/2007	12.84	13.02	13.16	13.14	
7/29/2007	12.84	13.00	13.16	13.11	
7/30/2007	12.84	13.00	13.16		
7/31/2007	12.84	12.98	13.16		
8/1/2007	12.84	12.93	13.00		b

Notes:
1) 7-DADMax is the 7-day average of daily maximum temperatures, calculated by averaging that days's
2) Flags indicate periods of missing data as follows:
a - missing less than 6 hours of data
b - missing 6 to 12 hours of data
c - missing 12 to 18 hours of data
d - missing 18 to 24 hours of data

Table C-4. Temperature Monitoring Data from July to August 2009

Date	Temperature in °C			7-DADMax[1]	Flag[2]
	Minimum	Average	Maximum		
7/1/2009	10.02	10.37	10.64		
7/2/2009	10.02	10.36	10.48		
7/3/2009	10.02	10.28	10.48		
7/4/2009	10.17	10.39	10.48	10.66	
7/5/2009	10.33	10.57	10.80	10.69	
7/6/2009	10.33	10.57	10.80	10.75	
7/7/2009	10.33	10.58	10.96	10.82	
7/8/2009	10.33	10.53	10.80	10.87	
7/9/2009	10.33	10.63	10.96	10.89	
7/10/2009	10.48	10.78	10.96	10.91	
7/11/2009	10.33	10.65	10.80	10.94	
7/12/2009	10.33	10.73	10.96	10.98	
7/13/2009	10.48	10.74	10.96	11.00	
7/14/2009	10.64	10.82	11.11	11.05	
7/15/2009	10.80	10.95	11.11	11.09	
7/16/2009	10.64	10.88	11.11	11.13	
7/17/2009	10.64	11.03	11.27	11.20	
7/18/2009	10.80	10.98	11.11	11.22	
7/19/2009	10.64	11.08	11.27	11.27	
7/20/2009	10.64	11.21	11.42	11.29	
7/21/2009	10.96	11.09	11.27	11.33	
7/22/2009	10.96	11.24	11.42	11.40	
7/23/2009	10.96	11.19	11.27	11.45	
7/24/2009	11.11	11.34	11.58	11.49	
7/25/2009	11.11	11.39	11.58	11.56	
7/26/2009	11.11	11.39	11.58	11.62	
7/27/2009	11.42	11.57	11.73	11.71	
7/28/2009	11.42	11.59	11.73	11.73	
7/29/2009	11.58	11.73	11.89	11.82	
7/30/2009	11.42	11.69	11.89	11.89	
7/31/2009	11.42	11.65	11.73	11.96	
8/1/2009	11.73	12.02	12.21	12.00	
8/2/2009	11.73	11.83	12.05	12.05	
8/3/2009	11.89	12.04	12.21	12.12	
8/4/2009	11.89	12.04	12.05	12.19	
8/5/2009	11.89	12.10	12.21	12.23	
8/6/2009	11.89	12.13	12.36	12.30	
8/7/2009	11.89	12.11	12.21	12.34	
8/8/2009	12.05	12.22	12.52	12.43	
8/9/2009	12.21	12.28	12.52	12.50	
8/10/2009	12.05	12.34	12.52	12.63	
8/11/2009	12.05	12.40	12.67	12.72	
8/12/2009	12.21	12.46	12.67	12.74	
8/13/2009	12.36	12.57	13.29	12.80	
8/14/2009	12.36	12.60	12.83	12.87	
8/15/2009	12.36	12.57	12.67	12.94	
8/16/2009	12.52	12.77	12.98	13.03	
8/17/2009	12.52	12.84	12.98	13.00	
8/18/2009	12.52	12.85	13.14	13.09	
8/19/2009	12.67	12.98	13.29	13.20	
8/20/2009	12.83	13.02	13.14	13.27	

Table C-4. Temperature Monitoring Data from July to August 2009 (Cont.)

Date	Temperature in °C			7-DADMax[1]	Flag[2]
	Minimum	Average	Maximum		
8/21/2009	12.67	13.14	13.45	13.36	
8/22/2009	12.83	13.20	13.45	13.43	
8/23/2009	13.14	13.30	13.45	13.45	
8/24/2009	12.98	13.38	13.61		
8/25/2009	12.98	13.39	13.61		
8/26/2009	13.14	13.35	13.45		c

Notes:
1) 7-DADMax is the 7-day average of daily maximum temperatures, calculated by averaging that days's
2) Flags indicate periods of missing data as follows:
a - missing less than 6 hours of data
b - missing 6 to 12 hours of data
c - missing 12 to 18 hours of data
d - missing 18 to 24 hours of data

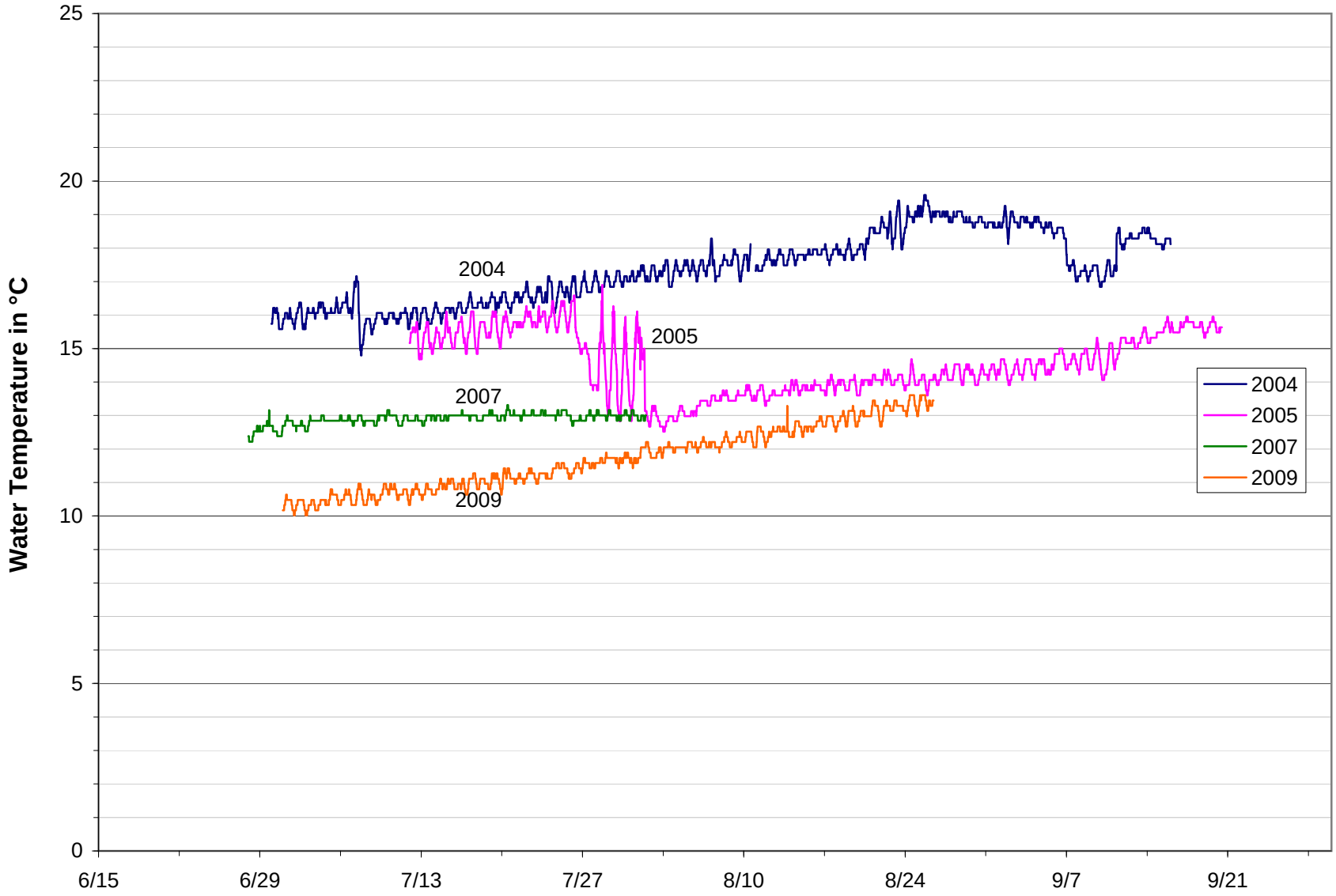


Figure C-1

PTI Tailrace Temperature Monitoring Data

Lake Tapps, Pierce County, WA

Aspect Consulting
February 5, 2010
S:\Lake Tapps Water Right Support 020071\Remand ROE\Modeling\Deliverables\2009 Model Report\Final\Model Report Appendix C.xls