

# Willowmoor Floodplain Restoration Project

# Preliminary Dynamic Weir Analysis

## Technical Memorandum

September 2018

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*A service provider to the  
King County Flood Control District.*

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## EXECUTIVE SUMMARY

Since 1964, outflows from Lake Sammamish have been controlled by a weir at the lake outlet and conveyed by a constructed channel known as the Transition Zone (TZ) from the weir to the Sammamish River. The TZ and the weir were constructed by the U.S. Army Corps of Engineers as part of the Sammamish River Improvement Project. This project deepened the river channel by about 6 feet and resulted in the substantial lowering of winter maximum water surface elevations in Lake Sammamish. The primary objective of the 1964 project was to reduce flooding in the Sammamish River valley downstream of Lake Sammamish. As the local project sponsor, King County has maintenance responsibility for TZ operations and maintenance.

While the weir and TZ have performed adequately most of the time, changed conditions in both basin hydrology and vegetation management in the TZ have impacted the hydraulic performance of the TZ, resulting in increased Lake Sammamish water surface elevation between 1998 and 2010. Since 2011, King County has engaged in more aggressive vegetation maintenance practices to help balance the flood control function of the TZ on both lake levels and river flow with beneficial habitat function. These maintenance practices, while effective, have come with costly permitting and mitigation requirements.

The Willowmoor Floodplain Restoration project may modify the existing TZ weir to better optimize hydraulic performance while preserving and restoring fish habitat. A conceptual design process, concluded in 2015, identified the need to examine the costs and benefits of a dynamic weir configuration relative to the current static or “fixed” weir configuration to achieve these objectives. This preliminary analysis assessed the following weir configurations to provide a relative comparison of the performance of fixed and dynamic weir operations.

1. Fixed weir: A fixed weir is one with a fixed elevation at which water flows over the weir.
2. Manually operated dynamic weir: A weir in which the water overflow elevation can be adjusted manually, seasonally, twice per year.
3. Remotely operated dynamic weir: A weir in which the water overflow elevation can be adjusted in real time by remote control.

The results of this analysis indicate that modifying the weir element to either dynamic weir configuration (manually or remotely operated) is necessary to meet competing project criteria related to lake level control and regulatory requirements for wetland protection. In our analysis, the remotely operated dynamic weir shows the maximum estimated flood benefit among the alternatives, 0.42 feet Lake stage reduction, during an early winter storm event. As winter progresses however, the river stage rises and river conveyance capacity decreases, diminishing the magnitude of this flood benefit. For mid to late winter storms, the maximum lake stage reduction is 0.22 feet.

The ability to predict large storm events and total rainfall in advance is low and achieving the maximum level of flood benefit requires a three-day lake water release. Therefore the ability to respond to climate events and trigger operation of a remotely operated dynamic weir in a timely manner creates significant operational risk. The remotely operated weir also carries several large and intangible risks related to jurisdictional authority and stakeholder expectations. In two regional case studies with similar high flexibility in weir operation, a Lake Management District has been formed. Operating cost assumptions presented here for the remotely operated dynamic weir are high to reflect these risks.

A manually operated dynamic weir can meet the project objectives with lower capital costs, lower

operating costs, and significantly lower operational risk than a remotely operated dynamic weir. Weir screening criteria are summarized in Table ES-1 below. Based on the analysis presented here, the County and consultant project team recommends moving the alternatives analysis forward with a manually operated dynamic weir configuration in both variations of the split channel alternative.

Table ES-1. Dynamic Weir Screening Criteria

Dynamic Weir Screening Criteria	Fixed Weir	Manually Operated Dynamic Weir	Remotely Operated Dynamic Weir 1-Day Release	Remotely Operated Dynamic Weir 3-Day Release
<b>Meets All Required Project Criteria</b>	No	Yes	Yes	Yes
<b>Operational Risk<sup>1</sup></b>	Low	Low	Medium-High	High
<b>Maximum Flood Benefit<sup>2</sup> (feet) Representative Early Winter Event</b>	0.08	0.12	0.20	0.42
<b>Maximum Flood Benefit (feet) Representative Late Winter Event</b>	0.00	0.05	0.07	0.22
<b>Range of Capital Cost</b>	\$60,000 - \$90,000	\$70,000 - \$100,000		\$290,000 – \$390,000
<b>Amortized Annual Cost of O&amp;M</b>	\$2,900	\$7,700		\$62,800
<b>Net Present Value of O&amp;M</b>	\$78,000	\$208,000		\$1,700,000
<b>Range of Total Cost</b>	\$138,000-\$168,000	\$278,000-\$378,000		\$1,990,000 \$2,090,000

1 – Operational risk is a qualitative value rated low to high and based on four factors; a) Predictability of technology performance, i.e. how well known and commonly utilized is the technology in similar conditions, b) Predictability of appropriate timing and magnitude of required weir adjustments, c) Risk of vandalism or mechanical failure interfering with weir performance, and d) Uncertainty around jurisdictional implementation authority.

2 – Maximum flood benefit is defined as the maximum estimated reduction in Lake Sammamish stage relative to existing conditions found for each of the four weir management scenarios presented here.

## 1.0 INTRODUCTION

Since 1964, outflows from Lake Sammamish have been controlled by a weir at the lake outlet and conveyed by a constructed channel known as the Transition Zone (TZ) from the weir to the Sammamish River, a length of about 1,400 feet. The TZ and the weir were constructed by the U.S. Army Corps of Engineers as part of the Sammamish River Improvement Project. This project deepened the river channel by about 6 feet and resulted in the substantial lowering of winter maximum water surface elevations in Lake Sammamish. The primary objective of the 1964 project was to reduce flooding in the Sammamish River valley downstream of Lake Sammamish. Since then, King County has sought to balance the hydraulic impact of the weir and TZ on lake levels and river flows with beneficial habitat function in the TZ.

The two primary features of the 1964 project are the TZ and the Lake Sammamish outlet weir (referred to in this technical memorandum as the TZ weir). The TZ weir, located in the river channel at the lake outlet, was designed to maintain minimum Lake Sammamish water surface elevations. It acts as the primary control on lake elevation and discharge during low to moderate flows. In 1998, the Corps of Engineers replaced the original grouted riprap weir with a concrete weir. The new weir includes a notch that allows lake discharge into the TZ during low-flow periods, thus improving fish passage during these conditions.

The Willowmoor Floodplain Restoration project (the Project, see Figure 1) will modify the existing TZ weir to optimize hydraulic performance and excavate a side channel in the left bank floodplain of the TZ to further optimize hydraulic performance and enhance aquatic habitat. This combination of improvements was identified in the *Concept Summary Design Report* (King County, 2015) and selected as the preferred restoration alternative by the King County Flood Control District Executive Committee (District). A preliminary analysis evaluated the expected performance of various project alternatives against management targets (see Section 3.0) that indicate how well a given alternative achieves established project objectives:

- Manage for flood control in Lake Sammamish and downstream communities.
- Maintain summer low flow in the Sammamish River for fish passage.
- Maintain the hydrology (surface water and groundwater characteristics) of wetlands along the shore of Lake Sammamish.

The preliminary analysis assessed multiple configurations for a side channel and a fixed TZ weir (a “fixed” weir is one with a fixed elevation at which water flows over it). It also assessed the seasonal control of outflows through a dynamic weir system (a weir in which the water overflow elevation can be varied) to improve project performance. Two adjustable weir configurations were evaluated: a manually operated dynamic weir (using control gates, for example) and a remotely operated dynamic weir (using real-time control systems, for example).

This Preliminary Weir Analysis technical memorandum is part of a body of work that will inform the Willowmoor Floodplain Restoration Preliminary Design; it will serve as an appendix to the Preliminary Basis of Design Report (Figure 2). The District will use the findings presented in this technical memorandum to select a weir/side channel configuration for detailed evaluation during the Project alternatives analysis.

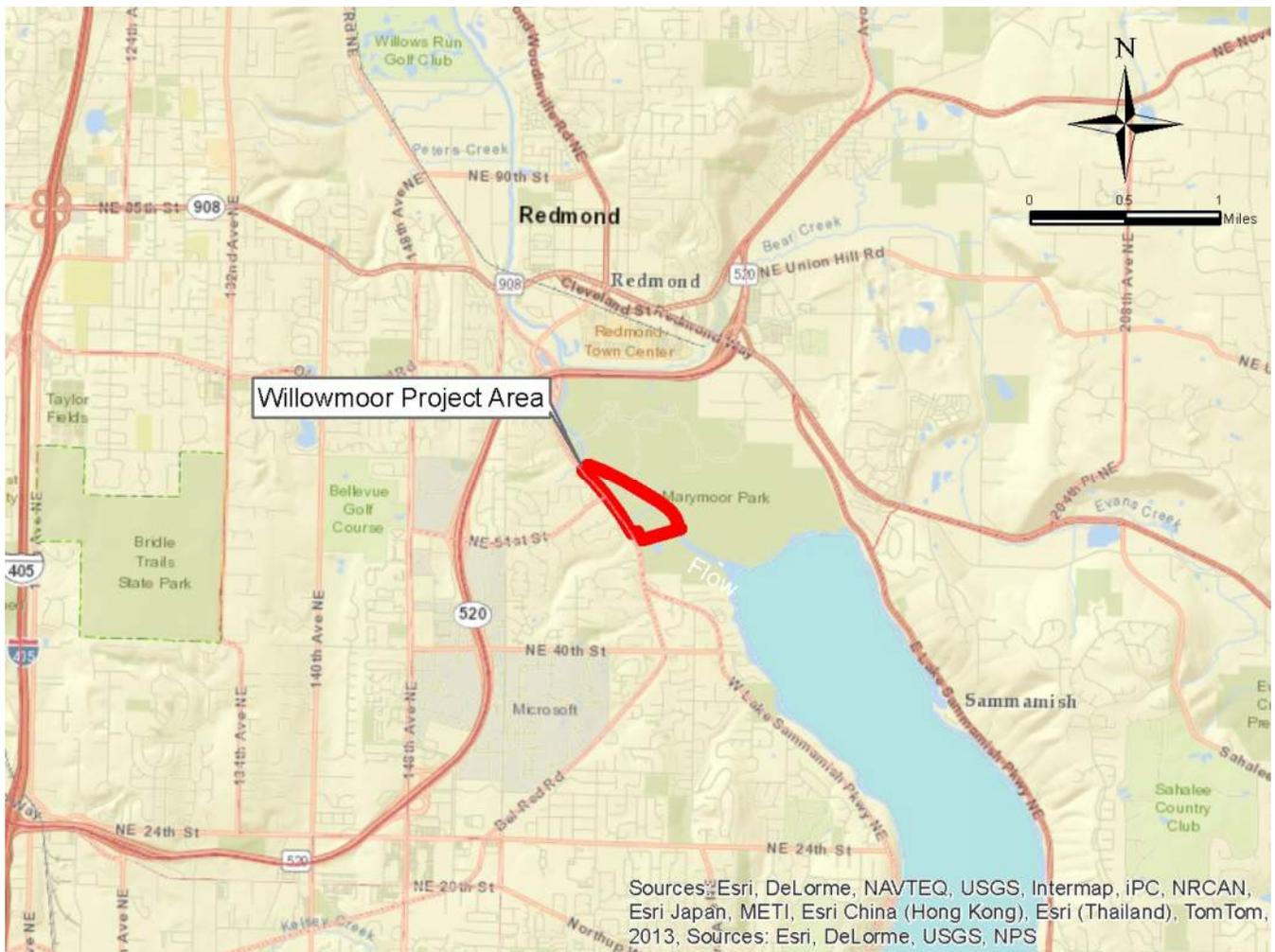


Figure 1. Willowmoor Project Vicinity Map

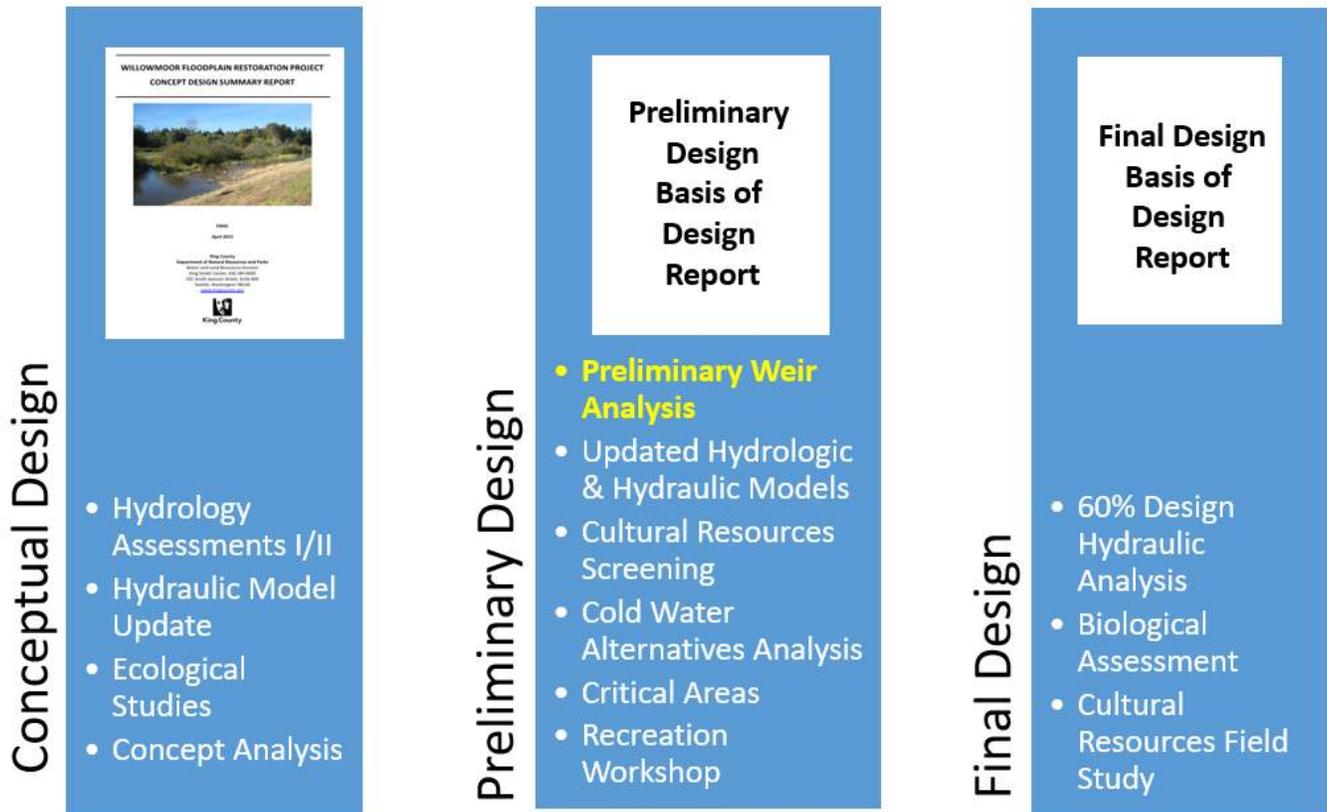


Figure 2. The Preliminary Weir Analysis as a Component of the Preliminary Design

## 2.0 ANALYTICAL APPROACH

The evaluation of alternative weir/side channel configurations was performed using a spreadsheet-based routing model. A routing model is a way to calculate how water moves over time through a lake, river, reservoir or similar water feature or system. The spreadsheet-based reservoir routing method selected for this study uses lake volume, weir discharge, and long-term flow and lake stage data to evaluate the routing of flow.

Input data for a routing model is in the form of a time-series—a set of data collected at discrete time intervals over a long period. The time-series used for this analysis was developed from lake elevation and outflow data collected from 2001 through May 2018. The behavior of the TZ weir has changed considerably over time due to vegetation and sediment management activities in the TZ. To compensate for this change, modified existing-conditions lake stage and stream flow time-series were developed using a variation on the standard reservoir routing model.

The spreadsheet-based model was selected for this preliminary study because it allows a relatively quick evaluation of the performance of alternative weir/side channel configurations. It provides the appropriate level of detail needed to define preliminary weir/side channel concepts. Findings from this modeling effort will be used to inform the selection of weir/side channel alternatives to be evaluated during the alternatives analysis. Use of this model also allows the design process to proceed in parallel with the development of detailed flow and stage data sets. For the alternatives analysis to be performed

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later in this Project, a longer-term inflow record will be used from a calibrated Hydrologic Simulation Model – FORTRAN (HSPF) computer model and an unsteady Hydrologic Engineering Center – River Analysis System (HEC-RAS) model currently in development to provide more robust routing. Derivation of the inflow time-series and application of the routing model are described in Appendix A.

### 3.0 LAKE STAGE AND FLOW TARGETS FOR PERFORMANCE EVALUATION

The performance of weir/side channel configuration alternatives was evaluated using lake level targets for Lake Sammamish and stream flow targets for the Sammamish River. These targets need to be attained in order to maintain or reduce flood levels, avoid potential habitat impacts, and meet operational requirements established during the original design of the TZ channel and control weir. They are also based on goals established during the concept design phase of this Project and documented in *Concept Design Summary Report* (King County, 2015). Table 1 summarizes the targets relevant to this preliminary weir analysis. Numerical values are based on the modified existing conditions flow and lake level lake time-series. During the alternatives analysis for this Project, additional criteria will be developed, such as flow, lake level, aquatic habitat and project implementation.

The modified existing-conditions lake level time-series was developed assuming a common maintenance condition. It did not include any lake surface elevations above 29.0 feet (measured in the National Geodetic Vertical Datum of 1929 (NGVD29); this is equivalent to 32.57 feet measured in the North American Vertical Datum of 1988 (NAVD88)). The ability of the weir/side channel configurations to meet reduction targets for lake levels at or above 29.0 feet NGVD29 is unknown. The long-term time-series that is being developed for the refined HSPF model is expected to contain inflow events large enough to generate lake levels at this elevation.

The long-term flow record did not include flow rate in the Sammamish River at the 100-year peak flow, so the performance of the weir/side channel configurations during very large peak flow events is unknown. The refined HSPF model is expected to contain flow events to generate more extreme flow events in the Sammamish River.

Table 1. Lake Sammamish Level and Sammamish River Flow Targets

No. <sup>a</sup>	Description	Criteria
<b>GOAL #1: Ensure the Transition Zone’s capability to provide necessary lake level control, flow conveyance, and downstream flood control.</b>		
3	Minimize impacts on tributary drainage systems along downstream river corridor	Maintain or reduce frequency and duration of increases in river level relative to existing <sup>b</sup> (pre-project) levels up to the 10-year return interval (1,500 cfs). Reported as the amount of time flow exceeds discrete flow rates.
6	Reduce average winter base lake level.	From November 1 through March 1, reduce the long-term average lake elevation from current level, estimated to be 26.83 feet National Geodetic Vertical Datum (NGVD29).
7	Reduce frequency and duration of high winter and spring lake levels relative to current conditions.	Reduce average number of days per year lake level exceeds elevation 27.0, 28.0 and 29.0 feet NGVD29.
8	Keep lake levels at or below 29.0 feet NGVD29 (1964 U.S. Army Corps of Engineers lake level criteria) up to the 40- year spring/10-year annual peak flow as identified in the Corps’ 1962 General Design Memo (GDM).	Maintain lake level below elevation 29 feet NGVD29 for flows less than 1,500 cfs in Sammamish River below Bear Creek. <b>Meeting this criterion is a requirement.</b>
9	Maintain minimum lake levels through summer as identified in the Corps’ 1962 GDM.	Maintain minimum lake level above 25.4 feet NGVD29 per 1962 Corps GDM. <b>Meeting this criterion is a requirement.</b>
<b>Goal #2: Enhance habitat conditions in the river channel, floodplain, buffers, associated tributaries, lacustrine wetlands and adjacent wetlands for kokanee, ESA-listed Chinook and steelhead, and other fish and wildlife species.</b>		
4	Maintain discharge at or above minimum existing summer flows for fish use.	From July 15 to September 15, maintain TZ weir outflows at or above 26 cfs, the computed current conditions average minimum flow from 2001 – 2018.
	Maintain inundation of lakeshore fringe wetlands.	<p>Maintain frequency and duration of lake level that sustain lake fringe wetlands and affect plant communities.</p> <ul style="list-style-type: none"> <li>• Minimum stage for analysis: Lake level maintained regularly for long duration throughout the growing season (greater than 48 days continuously on average). Estimated to be 26.63 feet NGVD29.</li> <li>• Mid stage for analysis: Lake level maintained regularly during the growing season (greater than 7 days continuously on average; greater than 14 days total during the growing season). Estimated to be 27.03 feet NGVD29.</li> <li>• Maximum stage for analysis: Lake level sustained for 14 days continuously once during evaluation period; upper limit affecting plant communities that are regularly maintained by saturation above lake level. Estimated to be 27.43 feet NGVD29.</li> </ul>

a. Goals and target numbers are taken from the *Concept Design Summary Report* (King County, 2015)

b. Target values are based on the modified existing conditions time-series described in this technical memorandum.

## 4.0 SEASONS

Many of the targets described in Table 1 vary seasonally in recognition of the variation in the hydrologic conditions over the course of a year. The standard nomenclature for seasons (winter, spring, etc.) is retained for this analysis, but the transition dates are altered to better align with annual climatological periods. Seasons are defined as described below and shown in Figure 3 and Figure 4:

- Winter starts November 1 and ends March 1 to include the wettest months of the year. The average daily flow in the Sammamish River and average daily lake level in Lake Sammamish reach the highest levels during this period.
- Spring extends from March 1 to July 1. Generally, flow and lake level are still elevated during this period but not the extent that occurs in winter.
- Summer starts July 1 and ends on September 15 to correspond with the low flow period critical to fish passage.
- Fall extends from September 15 to November 1 and represents the relatively quick transition from dry to wet conditions.

The early growing season used for this analysis extends from February 1 through May 31 to focus on the early portion of the growing season (winter and spring) when lake levels are higher and have a greater impact on wetland vegetation growth. The growing season extends to November, but the lower lake levels that occur in the summer and fall are not relevant to the analysis.

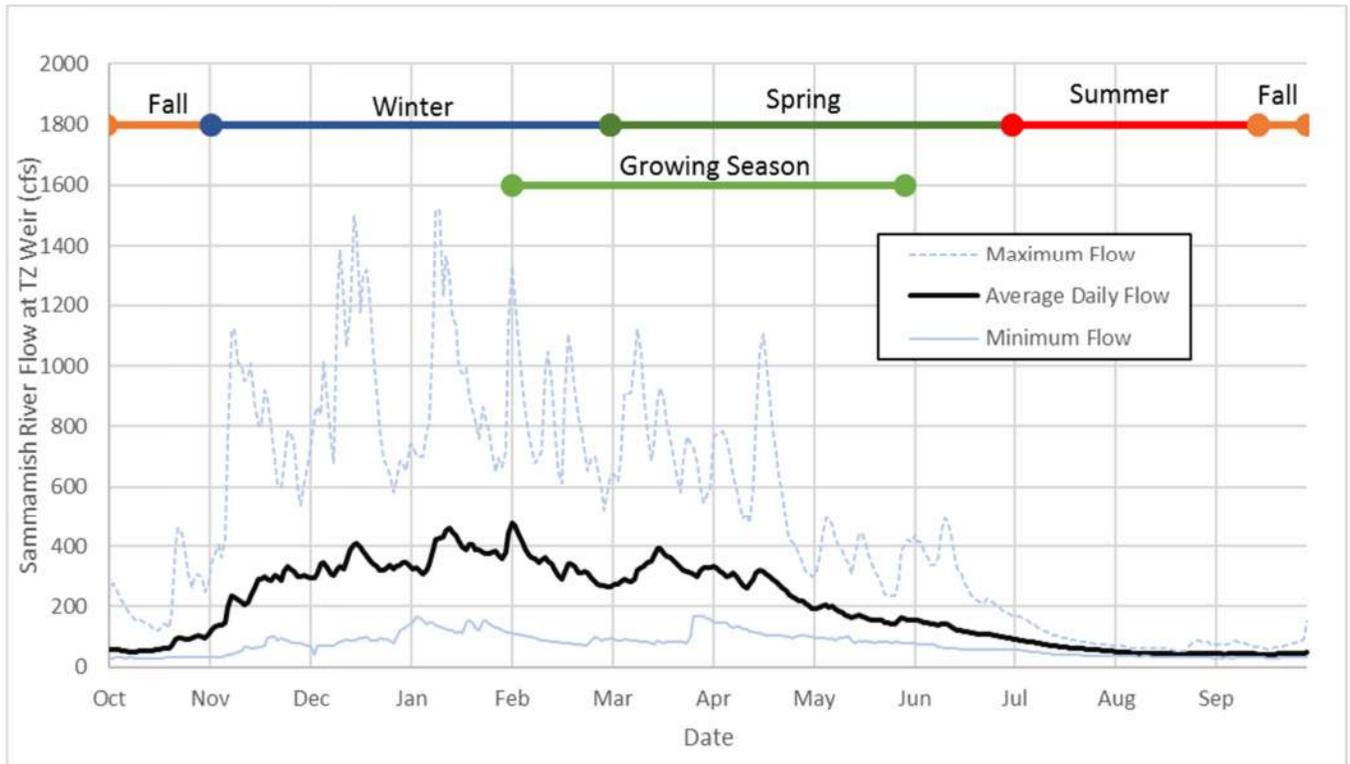


Figure 3. Average Daily Sammamish River Flow at TZ Weir (King County Gage 51M, 2001 – 2018).

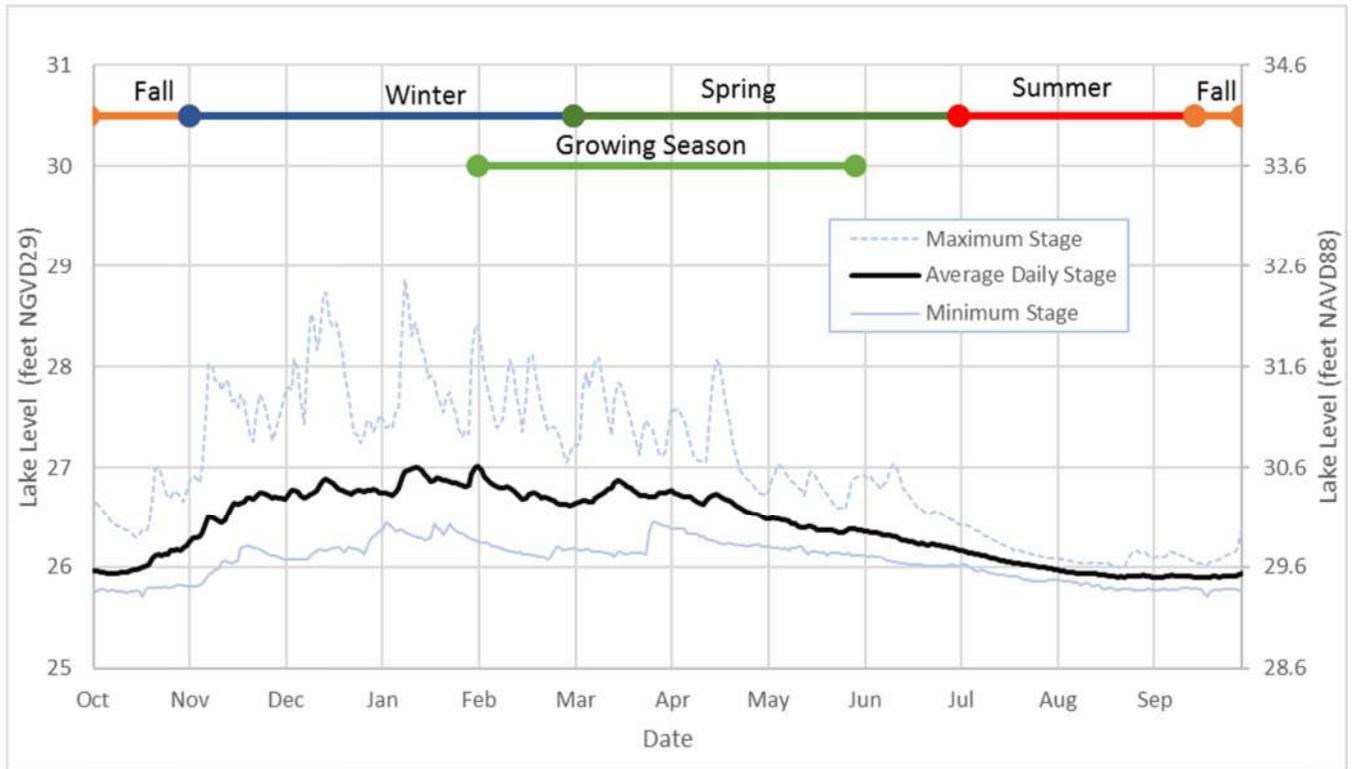


Figure 4. Average Daily Lake Sammamish Level (King County Gage 51M, 2001 – 2018)

## 5.0 WEIR/SIDE CHANNEL ALTERNATIVES

The weir/side channel alternatives consist of three main components: modifications to the TZ weir, the addition of a side channel, and seasonal adjustments to the TZ weir. The TZ weir and side channel configurations are shown in Figure 5 and Figure 6. Each component was iteratively adjusted to meet the flow and lake level targets listed in Table 2. Performance of the alternatives was evaluated using the spreadsheet routing model used to develop the modified existing conditions time-series (2001-2018) described in Appendix A.

### 5.1 ALTERNATIVE DEVELOPMENT

Three TZ weir alternatives were evaluated. Alternatives 1 and 2 were developed using a fixed weir structure that remains at one elevation year-round. The TZ weir would be retrofitted as a multi-chamber flash-board structure with concrete, aluminum, or wooden stop logs between slotted piers. The piers would be attached to the upstream face of the existing TZ weir on an approximate 10-foot spacing.

Alternative 3 was developed as a variation on the fixed weir that incorporates a seasonal adjustment to more precisely control lake levels during late winter and spring. This manually operated weir alternative would be nearly identical to the fixed weir alternatives. Stop logs would need to be inserted and removed once a year.

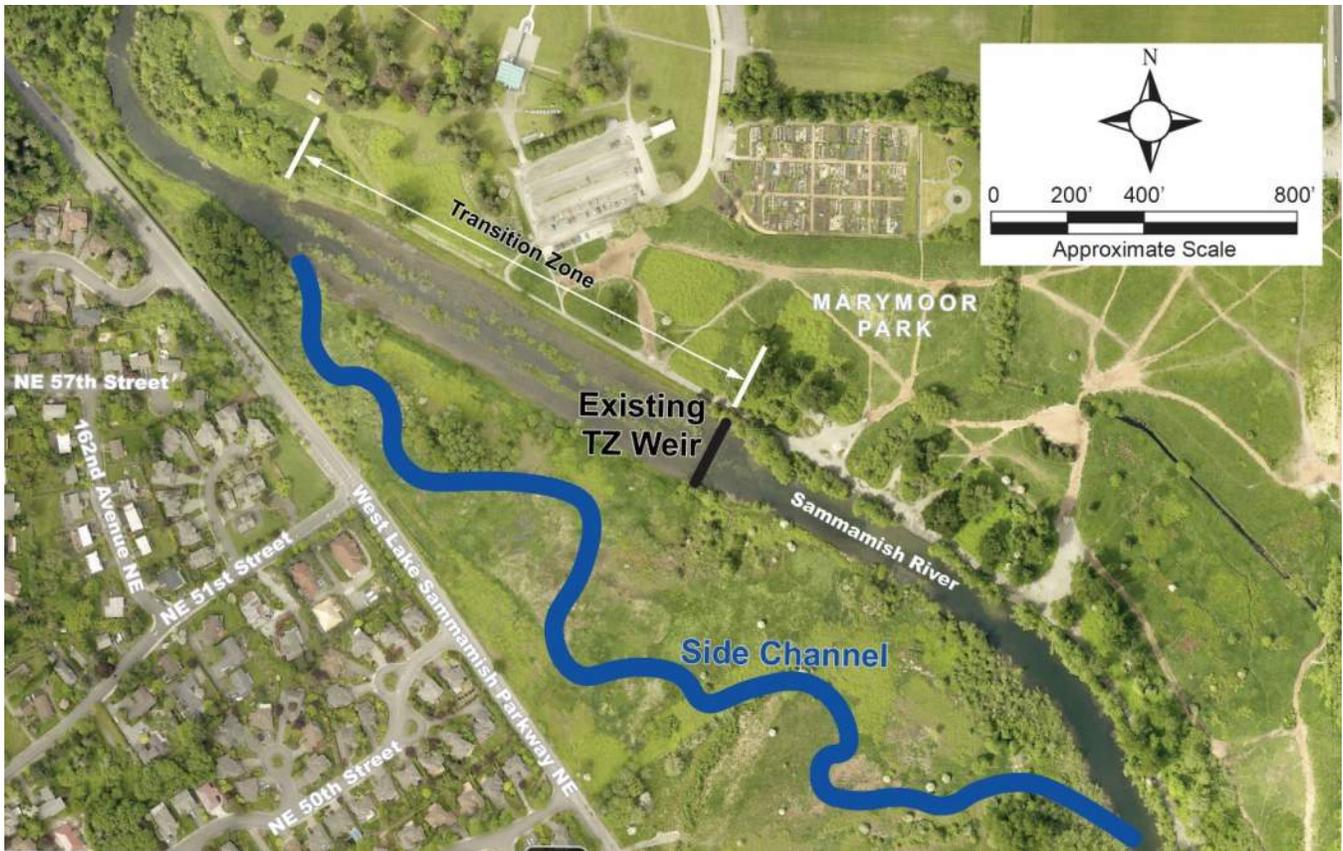


Figure 5. Plan View of TZ Weir and Side Channel Configuration

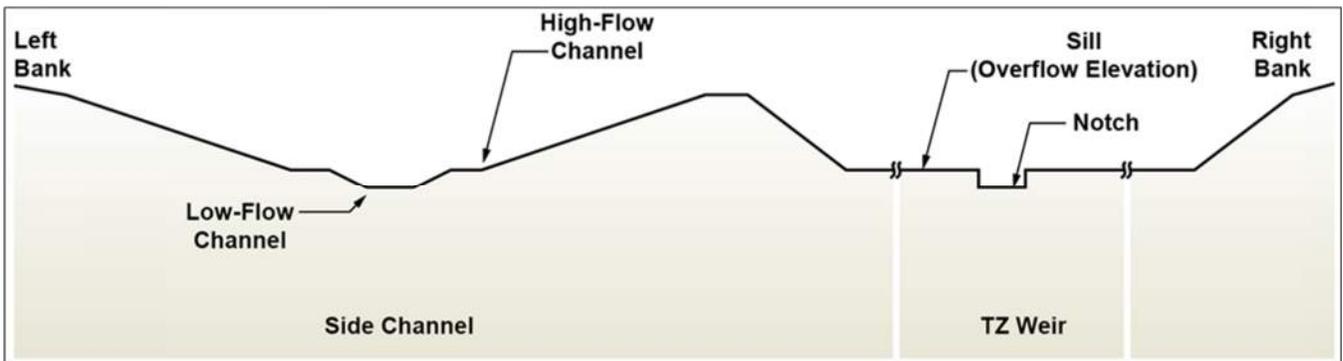


Figure 6. TZ Weir and Side Channel Configuration

Alternatives were developed consecutively, with the performance of earlier alternatives informing the configuration of later-developed alternatives. All alternatives incorporate a TZ weir with a 4-foot-wide notch and a side channel with a uniform low-flow channel bottom width of 5 feet. For the TZ weir, adjustments between alternatives were made to the notch invert (bottom) elevation and sill overflow elevation. Adjustments to the side channel included channel bottom elevation, channel depth, and width of the high-flow bench.

The sill overflow and notch invert elevations of the TZ weir were iteratively adjusted to maximize

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performance to meet the greatest number of evaluation criteria listed in Table 1. Differences between the alternatives are as follows:

- Alternative 1 – Fixed Weir, Flood Control Tuning (Fixed Weir-Flood):
  - The notch was set 0.7 feet above the existing notch invert.
  - The weir sill overflow was set 1.57 feet above the notch invert and slightly higher than the existing sill.
  - The side channel invert was set 0.57 feet above the notch invert and 1.0 feet below the sill overflow.
  - The side channel low-flow channel depth was set to 2 feet, with a high-flow channel width of 19 feet.
- Alternative 2 – Fixed Weir, Habitat Adjustment (Fixed Weir-Habitat):
  - Modifications for this alternative were made to meet the wetland evaluation criteria not met by Alternative 1 while still maximizing performance.
  - The notch was set 0.6 feet above the existing notch invert.
  - The weir sill overflow elevation was set 1.78 feet above the notch invert and 0.18 feet higher than the existing sill overflow.
  - The side channel invert was set 0.85 feet above the notch invert elevation and 0.93 feet below the sill overflow.
  - The side channel depth and high flow width were unchanged from Alternative 1.
- Alternative 3 – Manually Operated, Seasonally Adjusted Weir (Manually Operated Weir):
  - Modifications for this alternative were made to meet the evaluation criteria not met by Alternatives 1 and 2. To meet all criteria, seasonal adjustment of the weir using stoplogs was required.
  - Normal TZ Weir settings were defined as follows for July 1 through February 14:
    - The notch was set 0.76 feet above the existing notch invert.
    - The weir sill overflow elevation was set 1.45 feet above the notch invert, at about the existing sill elevation.
    - The side channel low-flow channel depth was set to 1.5 feet and the high-flow channel width was reduced by 2.0 feet.
  - Seasonal TZ Weir settings were defined as follows for February 15 through June 30:
    - The notch was set 1.28 feet above the existing notch invert and 0.52 feet above the normal weir setting.
    - The weir sill overflow elevation was set 1.08 feet above the notch invert, about 0.15 feet above the sill elevation for normal operation and the existing sill overflow.
    - The side channel invert would not change from the normal condition, but it would be slightly lower (0.06 feet) than the seasonal notch invert.

Table 2 summarizes all the components for each alternative. Figure 7 shows the notch and weir sill elevations for each alternative.

Table 2. Summary of Configuration Alternatives

Component	Existing Condition	Alternative 1 Fixed Weir Flood	Alternative 2 Fixed Weir - Habitat	Alternative 3 Manually Operated Weir	
				Normal Condition	Seasonal Adjustment
<b>TZ Weir</b>					
Notch Invert Elevation NGVD29 (NAVD88)	23.48 (27.05)	24.18 (27.75)	24.08 (27.65)	24.24 (27.81)	24.76 (28.33)
Notch Width (feet)	4.0	4.0	4.0	4.0	4.0
Notch Depth (feet)	2.2	1.57	1.78	1.45	1.08
Weir Sill Overflow Elevation NGVD29 (NAVD88)	25.68 (29.25)	25.75 (29.32)	25.86 (29.43)	25.69 (29.26)	25.84 (29.41)
<b>Side Channel</b>					
Low Flow Channel Invert Elevation NGVD29(NAVD88)		24.75 (28.32)	24.93 (28.50)	24.70 (28.27)	
Low-Flow Channel Bottom Width (feet)	—	5.0	5.0	5.0	
Low-Flow Channel Depth (feet)	—	2.0	2.0	0.98	
High-Flow Channel Width (feet)	—	19.0	19.0	17.0	
Seasonal Adjustment Period	None	None	None	February 15 – June 30	

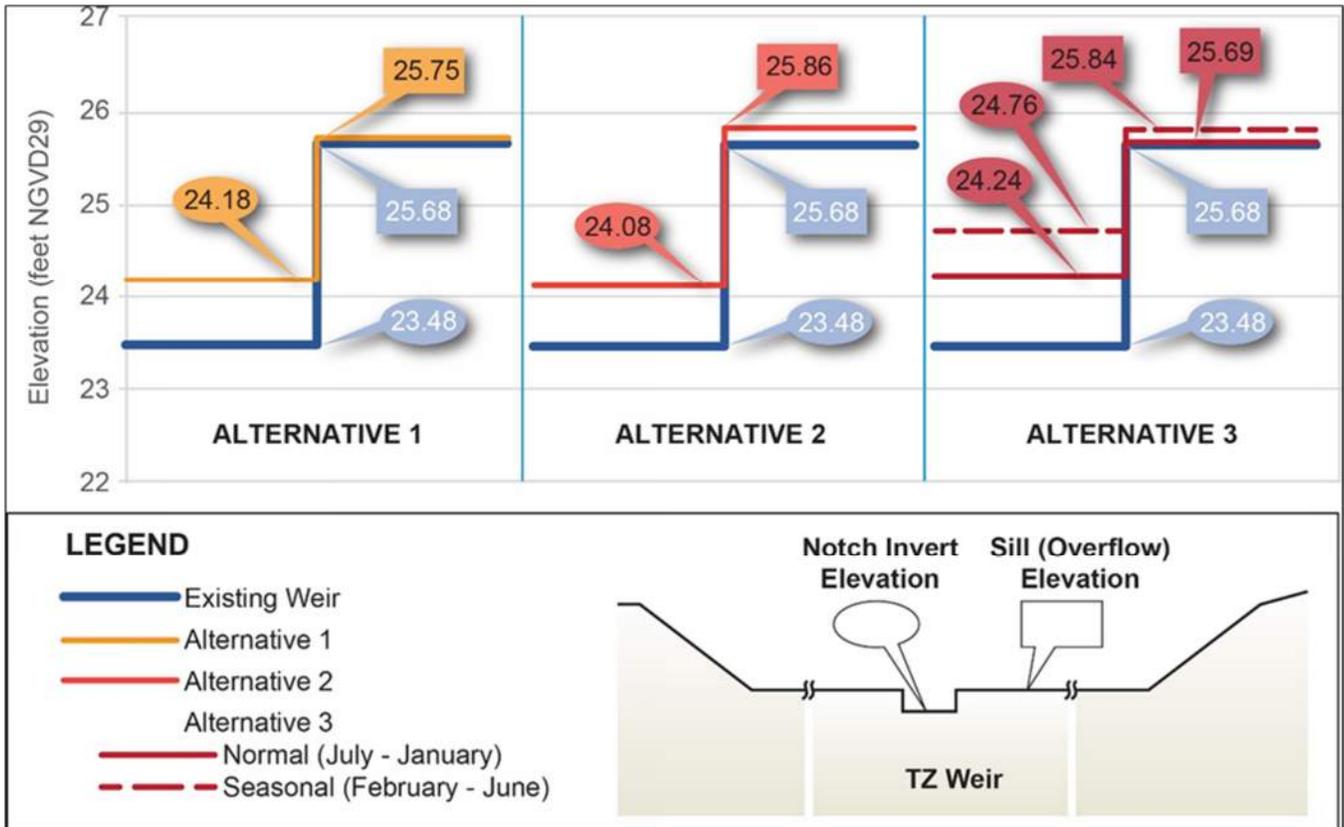


Figure 7. Notch and Sill Overflow Elevations for Weir Alternatives

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## 5.2 ROUTING MODEL FOR TZ WEIR/SIDE CHANNEL ALTERNATIVE EVALUATION

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The spreadsheet routing model was modified so that outflow included the side channel conveyance in addition to the TZ weir. Variable parameters (described below) for the TZ weir and the side channel were adjusted as needed to meet lake level and flow targets.

Conveyance in the side channel was computed assuming normal depth using Manning's equation. The shape of the channel was assumed to have a compound trapezoidal section with a smaller, inset channel to convey low flows and a wider floodplain channel to convey high flows. A 2:1 side-slope was assumed for the low-flow channel and 3:1 side-slope assumed for the high-flow channel. Longitudinal channel slope was assumed to be 0.5% based on site characteristics. The roughness coefficient was assumed to be 0.045 for the low-flow channel, which is representative of natural channel conditions, and 0.1 for the high-flow channel, which is typical of vegetated floodplain conditions. These channel characterizations are imprecise because the design channel configuration has not been established. Channel invert (bottom) elevation, bottom width and depth were varied as input parameters. The coefficients used in this analysis to account for channel roughness (essentially, the friction that flowing water encounters based on the texture of the surface it is flowing over) are based on typical stream conditions. These coefficients may not be representative of the actual condition in a constructed mature channel. Roughness coefficients will be adjusted as warranted during the preliminary design phase.

The TZ weir was modeled as a fixed structure using the standard weir formula—a compound structure with a river-spanning sill (the top of the sill represents the elevation at which lake water overflows the weir) and low-flow notch (the bottom of the notch is the elevation at which low flow normally discharges from the lake to the TZ). Weir coefficients were back-calculated from the rating curve currently used for the existing structure. The coefficient was estimated to be 2.1 for the notch and 2.3 for the sill spanning the river. Notch invert elevation, width, and depth were varied as input parameters. The weir coefficients used to calculate flow over the TZ weir are based on the existing TZ weir structure. These coefficients may not be representative of the alternative weir configurations evaluated in this technical memorandum. TZ weir operation will be refined during the preliminary design phase. Any adjustable features included in the replacement structure would allow operational changes to be made to adapt to changing hydrologic conditions.

The TZ weir was also analyzed as an adjustable weir with structure characteristics that would vary on a seasonal basis. Input parameters were identical to the fixed TZ case except that start and end dates were defined for the period that the weir elevation would be adjusted.

## 5.3 ALTERNATIVE EVALUATION

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Alternatives were evaluated relative to modified existing conditions and each other. Tables in the sections below highlight where criteria were not met. Criteria related to the 1% annual exceedance flood event (100-year flood) were not evaluated, as there were no flows approaching the 100-year flood in the time period used for this evaluation. However, it is expected that impacts of any of the weir alternatives would be negligible on the 100-year flood elevation because of the high flow capacity of the weir at the high lake stage.

### 5.3.1 Alternative 1: Fixed Weir - Flood

Alternative 1 meets all evaluation criteria except for maintaining wetland inundation. Alternative 1 performance is shown in Table 3 through Table 6.

Overall, this alternative resulted in the largest reduction in lake level of all alternatives analyzed. The average daily lake level was lowered by a small amount in the winter/spring and over 0.1 feet in the summer. Long-term average daily lake level is shown in Figure 8 and average daily Sammamish River flow in Figure 9.

Alternative 1 provided the greatest reduction in the number of days lake level was above threshold elevations, with 2 fewer days per year on average when lake level was above elevation 27.0 feet NGVD29.

This alternative meets the Corps requirement for minimum summer lake level and the lake level/flow criteria. Figure 10 shows a plot of the daily paired lake level/river flow.

For all other evaluation criteria, this alternative either matched targets or showed only an incremental improvement in stage or flow.

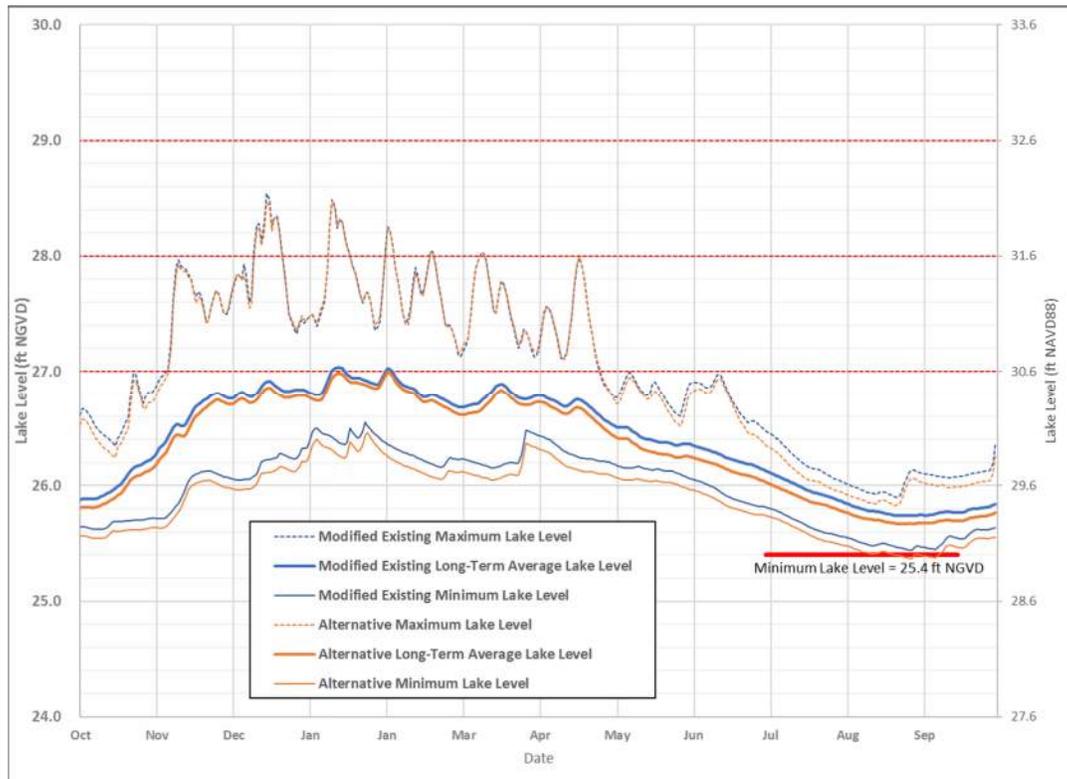


Figure 8. Alternative 1 Average Daily Sammamish Lake Level

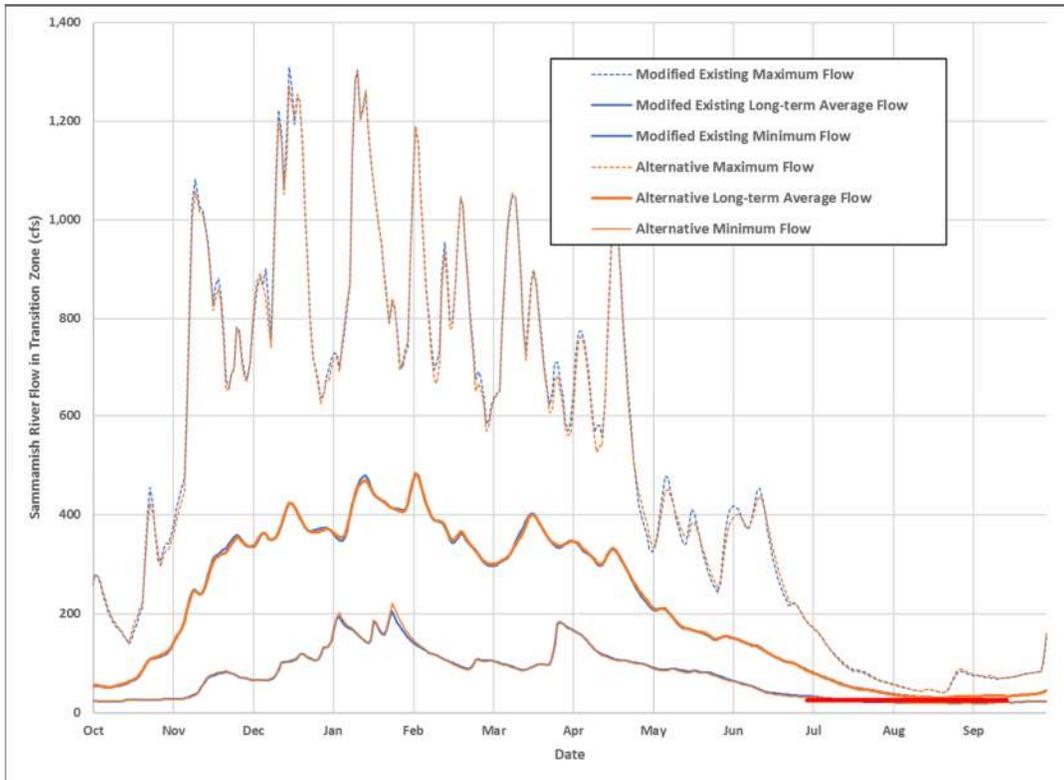


Figure 9. Alternative 1 Average Daily Sammamish River Flow in Transition Zone

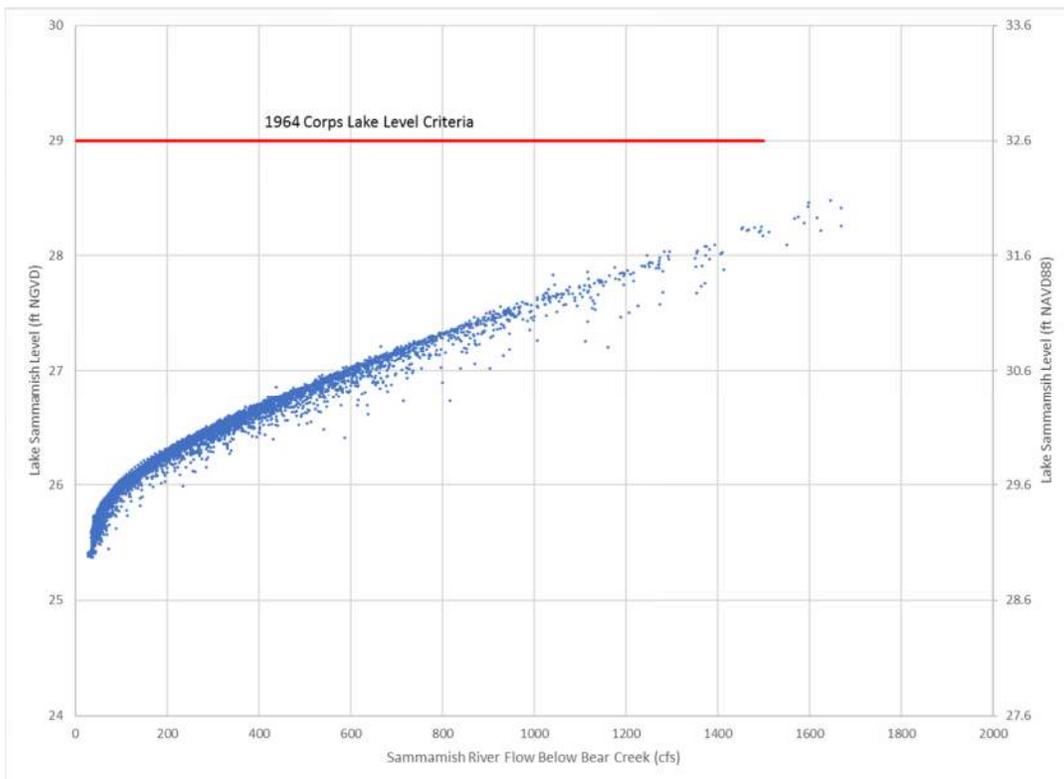


Figure 10. Alternative 1 Daily Lake Sammamish Level vs. Sammamish Average Daily River Flow

### 5.3.2 Alternative 2: Fixed Weir - Habitat

Alternative 2 performance is shown in Alternative 1 performance is shown in Table 3 through Table 6. This alternative meets all evaluation criteria except the number of days lake level was above threshold elevations increased to 10 days on average per year for elevation 27.0 NGVD29 and 0.8 days on average per year for elevation 28.0 feet NGVD29.

Overall, this alternative showed an increase in the average daily lake level in the winter/spring months and about 0.2-foot reduction in the summer. Long-term average daily lake level is shown in Figure 11 and average daily Sammamish River flow in Figure 12.

This alternative meets the Corps requirement for minimum summer lake level and the lake level/flow criteria. Figure 13 shows a plot of the daily paired lake level/river flow.

This alternative matched targets for all other evaluation criteria.

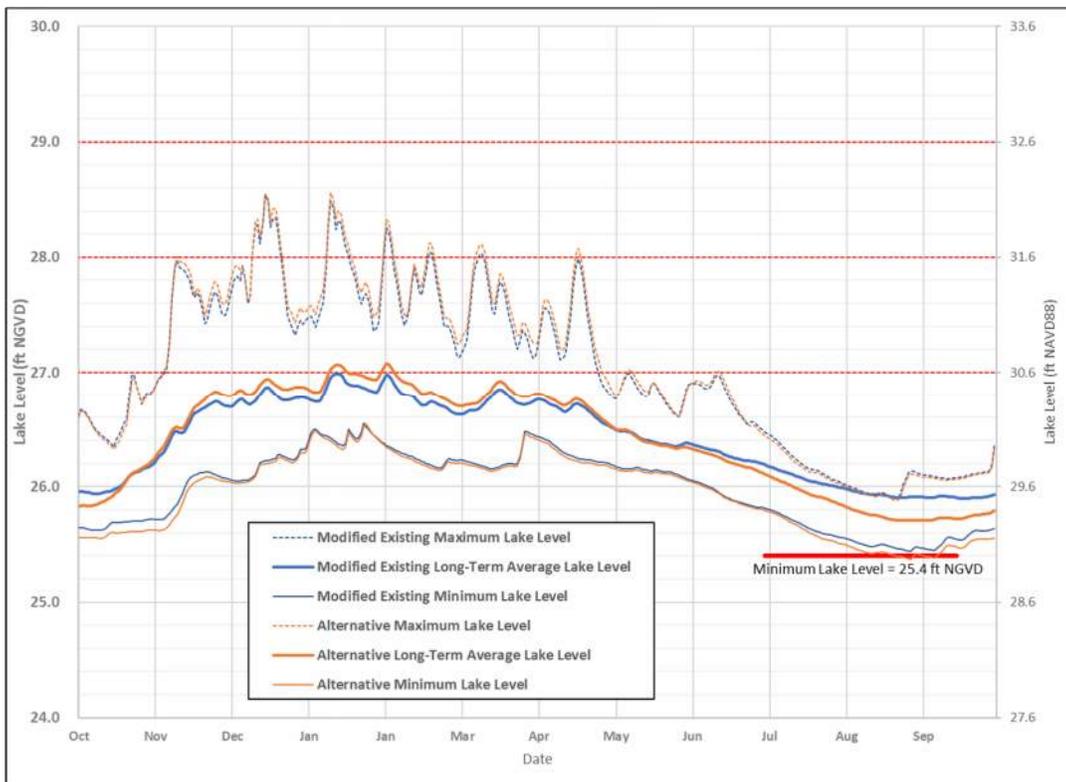


Figure 11. Alternative 2 Average Daily Sammamish Lake Level

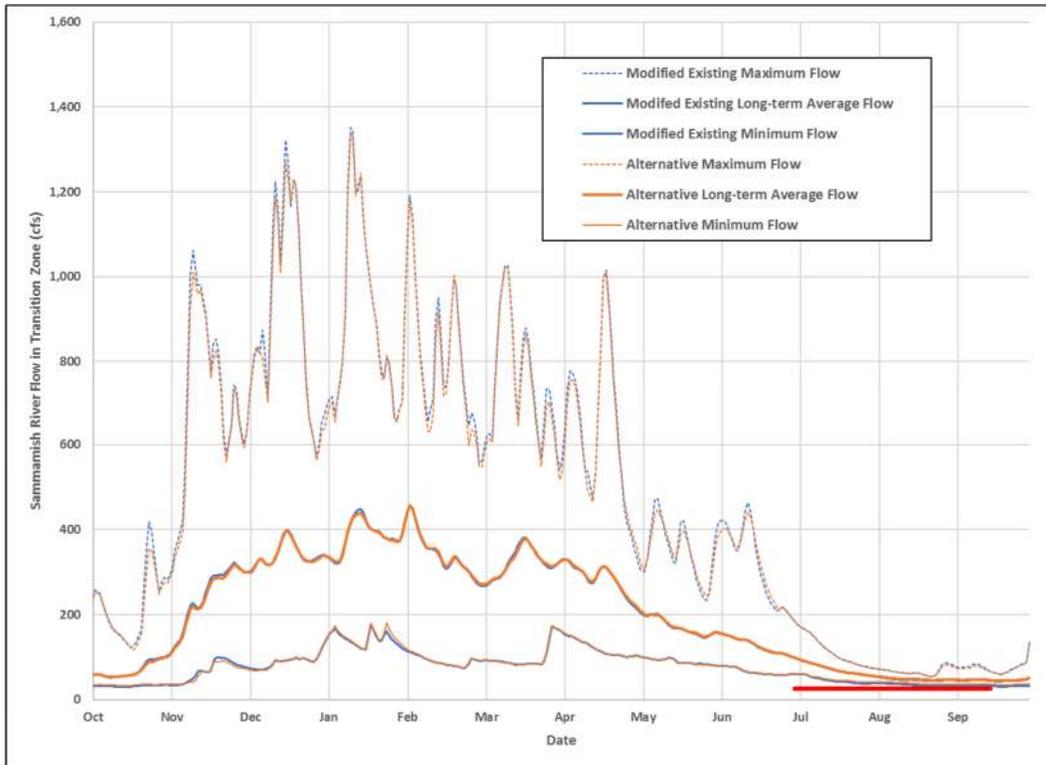


Figure 12. Alternative 2 Average Daily Sammamish River Flow in Transition Zone

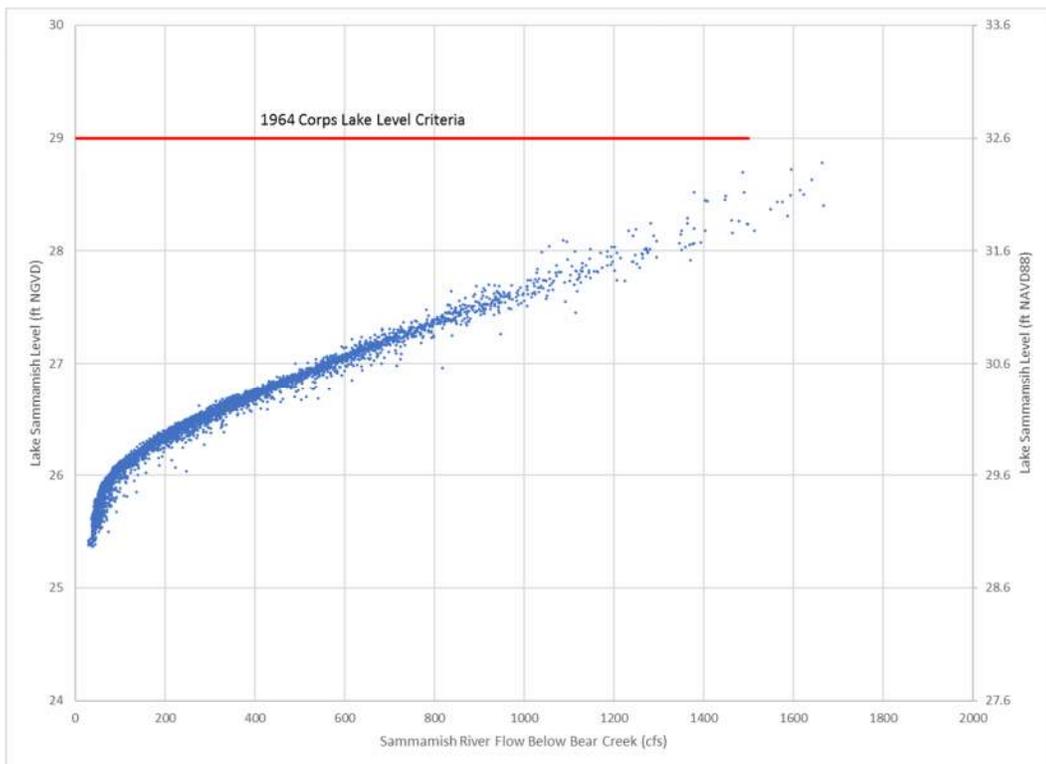


Figure 13. Alternative 2 Daily Lake Sammamish Level vs. Sammamish Average Daily River Flow

### 5.3.3 Alternative 3: Manually Operated Weir

For all evaluation criteria, Alternative 3 met lake level and flow targets. Alternative 3 performance is shown in Table 3 through Table 6. This alternative showed a nearly 0.1-foot reduction in average daily lake level in the winter, slight increase or no change in the spring months and about a 0.1-foot reduction in the summer. Long-term average daily lake level is shown in Figure 14 and average daily Sammamish River flow in Figure 15.

This alternative meets the Corps requirement for minimum summer lake level and the lake level/flow criteria. Figure 16 shows a plot of the daily paired lake level/river flow.

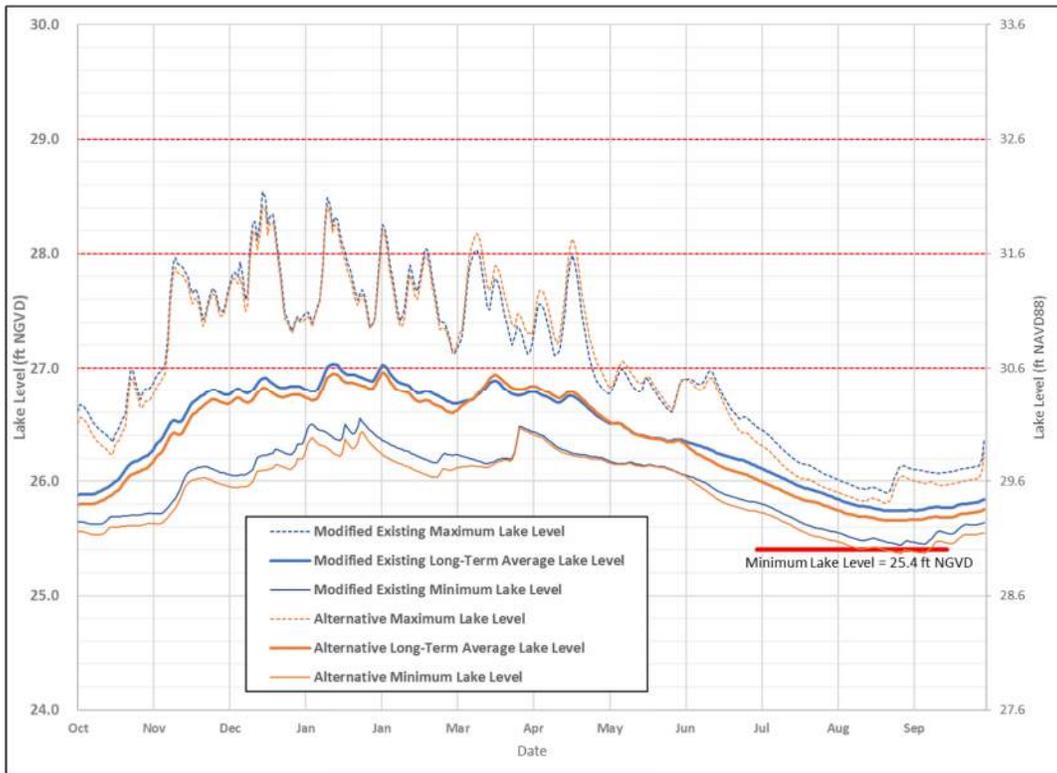


Figure 14. Alternative 3 Average Daily Sammamish Lake Level Sammamish River Flow in Transition Zone

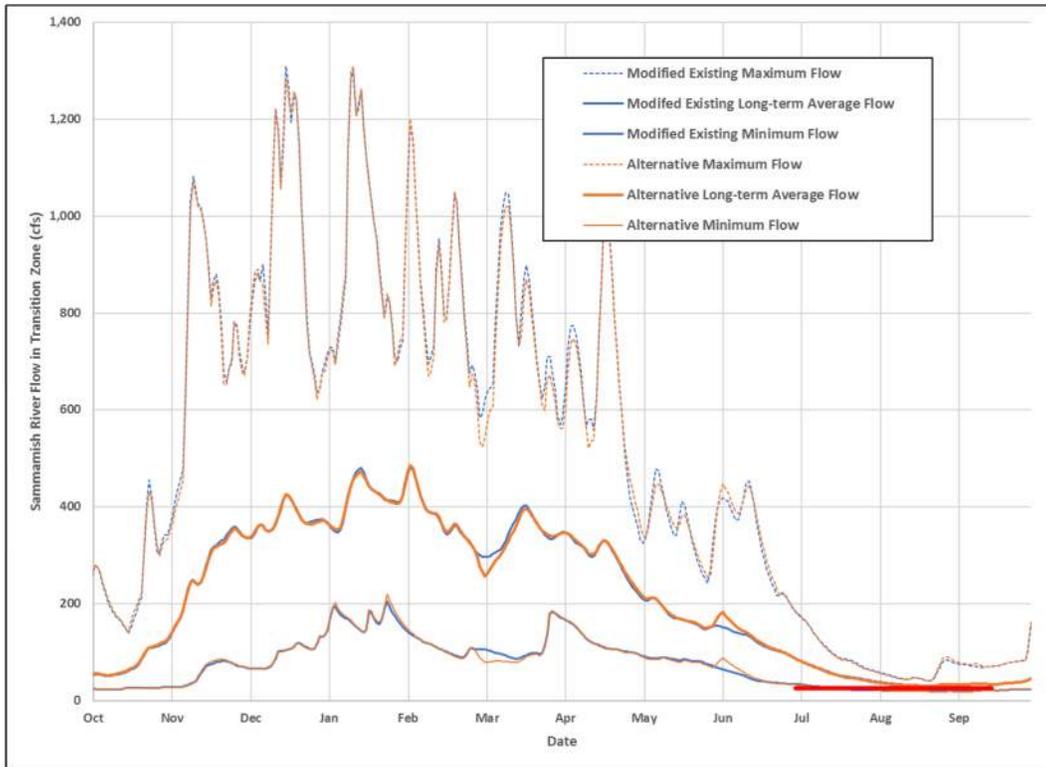


Figure 15. Alternative 3 Average Daily Sammamish River Flow in Transition Zone

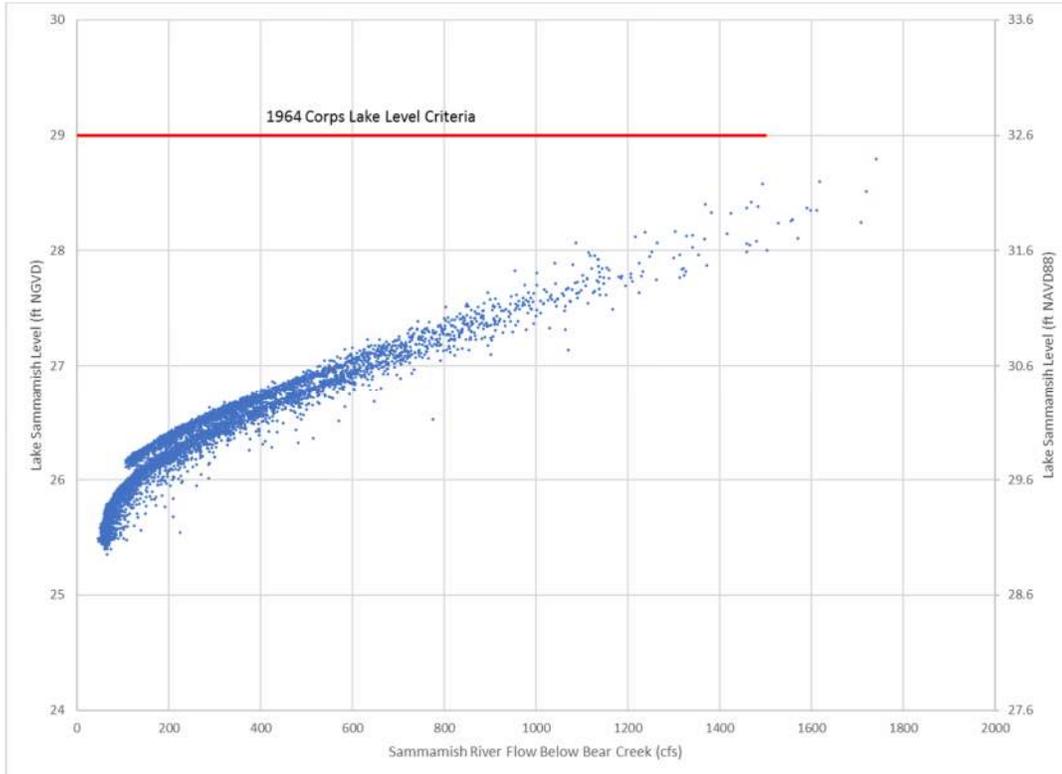


Figure 16. Alternative 3 Daily Lake Sammamish Level vs. Sammamish Average Daily River Flow

### 5.3.4 Summary

The analysis of weir/side channel alternatives showed that the side channel could be accommodated with minor modifications to the TZ weir and still meet the flow and stage evaluation criteria specified in the Corps GDM. However, the fixed weir/side channel configurations were not able to balance the competing evaluation criteria for winter stage reduction and wetland preservation. To meet both criteria, an adjustable weir (e.g. stoplogs) would need to be installed during February through June. Regardless of whether a fixed or seasonally adjusted weir is selected, it would be advantageous to construct the weir with an adjustable configuration to tune the weir operation to match design condition. An adjustable weir would provide flexibility to adapt to altered flow and climate conditions that are likely to occur in the future. Table 6 provides a summary of alternative performance.

Table 3. Summary of Comparative Evaluation Criteria

	Modified Existing Condition <sup>a</sup>	Alternative 1: Fixed Weir – Flood		Alternative 2: Fixed Weir - Habitat		Alternative 3: Manually Operated Weir	
		Result	Change in Percentage from Existing	Result	Change in Percentage from Existing	Result	Change in Percentage from Existing
<b>3. Sammamish River Flow Frequency (% Time Exceeded)</b>							
<b>1500 cfs</b>	0.2%	0.2%	0.0%	0.2%	0.0%	0.2%	0.0%
<b>1000 cfs</b>	2.6%	2.5%	-0.1%	2.5%	-0.1%	2.5%	-0.1%
<b>7. Number of Days in a Year on Average Elevation Exceeded in Winter and Spring</b>							
<b>EI. 29.0 ft NGVD29</b>	0	0.0	0.0	0	0.0	0.0	0.0
<b>EI. 28.0 ft NGVD29</b>	2.3	2.2	-0.1	3.1	0.8	2.3	0.0
<b>EI. 27.0 ft NGVD29</b>	47.0	45.2	-1.8	56.8	9.8	46.7	-0.3
<b>Yellow shading indicates criteria not met.</b>							

a. Number of days per year exceeding a give lake stage shown here will differ than those provided to represent “Existing Conditions” as part of the *Concept Design Summary Report (King County, 2015)*. This is primarily driven by use of a single rating curve, indicative of recent (2014-2017) TZ vegetation management practices, to represent conveyance through the TZ, within this analysis (See Appendix “A”). Previous analyses incorporated rating curve information representing previous TZ maintenance practices.

Table 4. Summary of Single Value Criteria

	Target	Alternative 1: Fixed Weir – Flood		Alternative 2: Fixed Weir - Habitat		Alternative 3: Manually Operated Weir	
		Result	Diff. from Target	Result	Diff. from Target	Result	Diff. from Target
<b>4. Minimum Summer Low Flow (cfs)</b>	26	26	0	28	2	26	0
<b>6. Average Winter Base Lake Level (ft NGVD29)</b>	26.83	26.77	-0.06	26.85	0.02	26.74	-0.09
<b>9. Minimum Summer Lake Level (ft NGVD29)</b>	25.40	25.40	0.0	25.40	0.0	25.40	0.0
<b>Yellow shading indicates criteria not met.</b>							

Table 5. Summary of Wetland Criteria

	Target	Alternative 1: Fixed Weir – Flood		Alternative 2: Fixed Weir - Habitat		Alternative 3: Manually Operated Weir	
		Result	Diff. from Target	Result	Diff. from Target	Result	Diff. from Target
Annual Average Continuous Days of Inundation at El. 26.63 feet NGVD29 (30.2 feet NAVD88) During Growing Season	48	37	-11	48	0	48	0
Annual Average Continuous Days of Inundation at El. 27.03 feet NGVD29 (30.6 feet NAVD88) During Growing Season	10	11	1	17	7	14	4
Annual Average Total Number of Days of Inundation at El. 27.03 feet NGVD29 (30.6 feet NAVD88) During Growing Season	18	18	0	23	5	21	3
Maximum Continuous Days of Inundation at El. 27.43 feet NGVD29 (31.0 feet NAVD88) During Growing Season	16	16	0	17	1	17	1
Yellow shading indicates criteria not met.							

Table 6. Alternative Performance Summary

No. <sup>a</sup>	Alternative 1: Fixed Weir – Flood	Alternative 2: Fixed Weir - Habitat	Alternative 3: Manually Operated Weir
<b>GOAL #1: Ensure the Transition Zone’s capability to provide necessary lake level control, flow conveyance, and downstream flood control.</b>			
3 - Minimize impacts on tributary drainage systems along downstream river corridor	Yes	Yes	Yes
6 - Reduce average winter base lake level.	Yes	No – Negligible increase.	Yes
7 - Reduce frequency and duration of high winter and spring lake levels relative to current conditions	Yes	No – Increase in days above 27 and 28 feet NGVD29	Yes
8 - Keep lake levels at or below 29.0 feet NGVD29 (1964 Corps lake level criteria) up to the 40-year spring/10-year annual peak flow as identified in the Corps’ 1962 General Design Memo.	Yes	Yes	Yes.
9 - Maintain minimum lake levels through summer as identified in the Corps’ 1962 General Design Memo.	Yes	Yes	Yes
<b>Goal #2: Enhance habitat conditions in the river channel, floodplain, buffers, associated tributaries and adjacent wetlands for ESA-listed Chinook, steelhead, kokanee, and other fish and wildlife species.</b>			
4 - Maintain discharge at or above minimum existing summer flows for fish use.	Yes	Yes	Yes
Maintain existing hydrology of lakeshore fringe wetlands.	No – Wetland criteria not met for the minimum inundation level.	Yes	Yes

a. Goals and are taken from the *Concept Design Summary Report* (King County, 2015)

## 6.0 REMOTELY OPERATED DYNAMIC TZ WEIR

A remotely operated dynamic weir (remotely operated weir) was evaluated to determine its ability to reduce lake level in advance of a large inflow event. This type of facility would use information on Lake Sammamish inflow and weather forecast information to pre-release water from Lake Sammamish to draw down the lake level in advance of a large inflow event.

### 6.1 WEIR OPERATION PROTOCOL AND ANALYSIS

The routing model was used to evaluate performance of a remotely operated weir for three discrete events extracted from the modified existing conditions time-series to depict a range of operating conditions during the winter (see Table 7):

- An early-winter event when lake level and outflow to the Sammamish River are relatively low
- A mid-winter event when lake level is high and outflow to the river is also high
- A late-winter event with lake level and outflow in between the early- and mid-winter conditions.

Table 7. Events for Remotely Operated TZ Weir Analysis

	Early-Winter Event	Mid-Winter Event	Late-Winter Event
<b>Date of Peak Inflow</b>	12/13/2010	1/8/2009	1/30/2004
<b>Starting Lake Level (feet NGVD29, feet NAVD88)</b>	26.53, 30.10	27.01, 30.58	26.84, 30.41
<b>Outflow Prior to Event (cfs)</b>	~100	~450	~300
<b>Event Duration</b>	8 days	11 days	8 days
<b>Event Volume</b>	14,100 acre-feet	14,400 acre-feet	10,700 acre-feet
<b>Peak Inflow</b>	2,300 cfs	2,900 cfs	2,400 cfs

The weir operating protocol used in the analysis was to release water from Lake Sammamish for a defined release period prior to a peak inflow event. The defined release period ranged from one to three days, based on the assumption that weather forecast accuracy diminishes beyond three days. The Northwest River Forecast System uses a 4- to 10-day forecast at Issaquah; however, the forecast point is based on model guidance only. The release period was assumed to end the day of the peak inflow. The end day was selected based on the assumption that streams that are tributary to the Sammamish River would be peaking at the same time and extending the release would exacerbate downstream flooding.

The combined flow from the adjustable weir and side channel at the downstream end of the Transition Zone was assumed to be maintained at 750 cfs during the release period. The design release rate was based on limiting peak flows in the Sammamish River downstream of Bear Creek to less than 1,500 cfs for the events analyzed. A flow rate of 1,500 cfs is known to be within the capacity of the Sammamish River channel (King County, 2015).

This relatively simple protocol assumes that a system can be designed to accurately predict inflow to Lake Sammamish based on uncertain weather forecasting. There is a risk that an incorrect forecast would lead to unnecessary release of water from Lake Sammamish, which could have a detrimental effect on wetland inundation and the volume of water available for the summer low-flow period. A

complex and sophisticated flow prediction system would need to be designed and calibrated to control the operation of this structure. It likely would require human interaction to operate correctly.

## 6.2 WEIR PERFORMANCE

The results of the adjustable weir analysis are shown in Table 8 and Figure 17. The largest reduction in lake elevation would occur during the early-winter event, when the downstream channel has more capacity available for release flows than it does during the mid-winter and late-winter events. Conversely, the mid-winter event showed the smallest reduction due to limited capacity for release flows in the transition zone. As would be expected, longer release periods resulted in larger reductions in lake level.

Table 8. Modeled Event Parameters and Reduction in Peak Lake Level with Remotely Operated TZ Weir

Scenario	Early Winter Event		Mid-Winter Event		Late Winter Event	
	Stage NGVD29 (NAVD88)	Difference	Stage NGVD29 (NAVD88)	Difference	Stage NGVD29 (NAVD88)	Difference
<b>Modified</b>	28.57 (32.14)	NA	28.52 (32.09)	NA	28.28 (31.85)	NA
<b>1-Day Release</b>	28.37 (31.94)	0.20	28.5 (32.07)	0.02	28.21 (31.78)	0.07
<b>2-Day Release</b>	28.26 (31.83)	0.31	28.42 (31.99)	0.10	28.13 (31.7)	0.15
<b>3-Day Release</b>	28.15 (31.72)	0.42	28.34 (31.91)	0.18	28.06 (31.63)	0.22
<b>Alternative 1</b>	28.49 (32.06)	0.08	28.51 (32.08)	0.01	28.28 (31.85)	0.00
<b>Alternative 2</b>	28.58 (32.15)	-0.01	28.59 (32.16)	-0.07	28.36 (31.93)	-0.08
<b>Alternative 3</b>	28.45 (32.02)	0.12	28.45 (32.02)	0.07	28.23 (31.8)	0.05

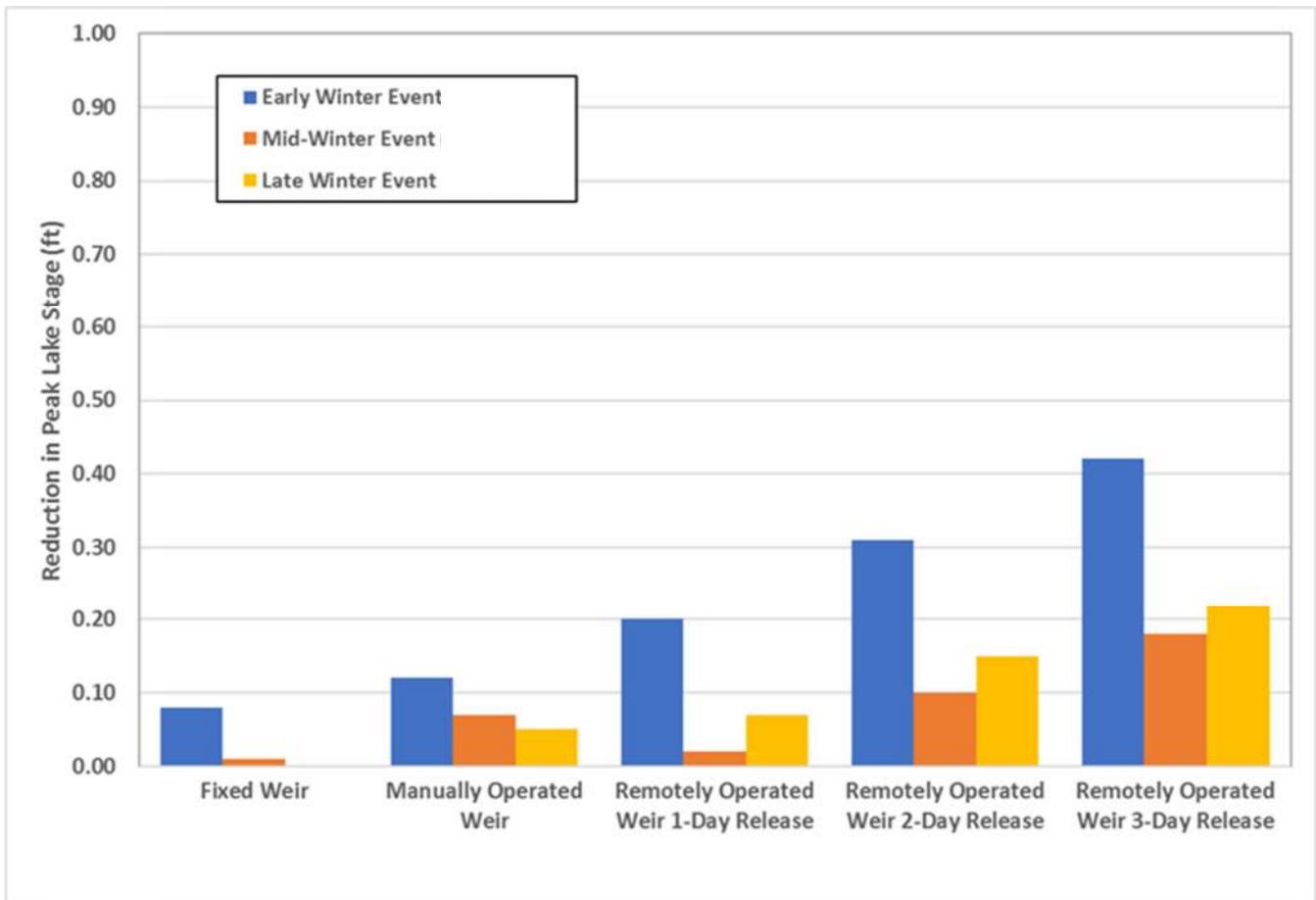


Figure 17. Reduction in Peak Lake Level for Adjustable Weir Scenarios and Alternative Configurations

For early- and late-winter events, the remotely operated weir performed slightly better at lowering lake level than the fixed and manually operated weir/side channel alternatives for a 1-day release scenario. Performance improved for longer release periods for these events. However, the fixed weir analysis showed that lowering lake level would negatively impact wetlands along the fringe of Lake Sammamish and the reduction in lake level with the remotely operated weir would likely result in similar impacts to wetlands. The continuous analysis performed for the fixed and seasonally adjusted weir/side channel alternatives would need to be performed on the remotely operated weir also to fully compare performance.

For mid-winter events, the fixed and manually operated weir/side channel alternatives showed nearly equivalent or better performance compared to a 1-day release for the remotely operated weir and only slightly worse for longer release periods.

## 7.0 BENEFITS AND COST

The benefits and costs of each alternative described in this technical memorandum are presented in this section. To focus on relative cost differences, costs are provided for the TZ weir only. It is assumed

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that the side channel configuration is so similar for all alternatives that the cost would be identical for all of them.

## 7.1 FIXED TZ WEIR

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As described in Section 5.2, Alternatives 1 and 2 utilize a fixed weir structure that remains at one elevation year-round. The TZ weir would be retrofitted as a multi-chamber flash-board structure with concrete, aluminum, or wooden stop logs between slotted piers. The piers would be attached to the upstream face of the existing TZ weir on an approximate 10-foot spacing. The construction cost for this structure is estimated to range from \$60,000 to \$90,000.

Advantages of the Fixed Weir:

- Minor retrofit to the existing structure.
- Able to tune weir if found to not meet design performance.
- Simple operation.

Disadvantages of the Fixed Weir:

- Intermediate piers holding flash-boards may collect debris.
- Regular inspection required to ensure integrity of post connections.

## 7.2 MANUALLY OPERATED TZ WEIR

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Alternative 3 is a variation on the fixed weir that incorporates a manual, seasonal adjustment to more precisely control lake levels during late winter and spring. This manually operated weir alternative would be nearly identical to the fixed weir alternatives and therefore would have the same construction cost. Stop logs would need to be inserted and removed once a year, which would increase maintenance costs. The construction cost for this structure is estimated to range from \$70,000 to \$100,000.

Advantages of the Manually Operated Weir:

- Minor retrofit to the existing structure.
- Able to adjust weir height as needed to meet flow targets.
- Simple operation.

Disadvantages of the Manually Operated Weir:

- Intermediate piers holding flash-boards may collect debris.
- Regular inspection required to ensure integrity of post connections.
- Additional maintenance activity required to adjust stop logs.

## 7.3 REMOTELY OPERATED TZ WEIR

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The remotely operated weir could be provided with a pneumatically actuated gate linked to a SCADA system for real-time control. This structure would use bottom-hinged metal plates along the sill of the

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TZ weir supported by an air bladder. The air bladder would inflate or deflate as needed to raise or lower the spill crest to meet flow targets. A concrete notch would still be provided and would be flanked by two adjustable weir structures. The construction cost for this structure is estimated to range from \$290,000 to \$390,000.

Advantages of the Remotely Operated Weir:

- Able to adjust weir height as needed to meet flow targets.
- Maintenance access not required to adjust weir.
- No intermediate piers required.

Disadvantages of the Remotely Operated Weir:

- Complex apparatus with many moving parts.
- Control panel in structure required on bank.
- Significant operational commitment.
- Uncertainty regarding jurisdictional authority. Some regional weirs with frequent adjustments operate under MOUs or sub-district agreements (Lake Ballinger and Lake Samish). A complex weir with uncertain adjustment periods may require a Habitat Conservation Plan agreement.
- Specialized skill required for maintenance.
- May require significant modification to the existing TZ weir.
- Weir setting relies on imprecise and uncertain weather forecasting.
- Increased pressure from outside public and private parties to participate in determination of day to day operation.
- Unattractive aesthetics.
- Highest cost alternative.
- Potential navigation hazard.
- Potential target for vandalism.

## 8.0 CONCLUSIONS

The analysis of the fixed and manually operated weir/side channel configuration showed that these types of facilities are able to meet most of the evaluation criteria. Incorporating a side channel appears to be achievable with minor modifications to the TZ weir. The controlling criteria were found to be the lake level reduction and wetland inundation criteria. However, the competing goals of these criteria at the 27.0 feet NGVD29 elevation limit the range of possible weir configurations.

A dynamic weir provides the flexibility to balance these competing goals. Both the manually operated and remotely operated weirs met all target criteria. The remotely operated weir has the potential to reduce lake level more than the manually operated weir during larger early winter events but did not show appreciable lake level reduction compared to the fixed and manually operated weir/side channel alternatives during mid-winter when there is limited release capacity to the Sammamish River. The performance of the remotely operated weir improved with longer release periods. The remotely operated weir does carry significant risks including unnecessarily releasing water due to uncertainty in weather forecasting and inflow prediction. The presence of the remotely operated weir could create a false sense of security against lake level rise due to a missed forecast for a large inflow event. This type of structure also requires complex and sophisticated infrastructure to operate, increasing risks associated with operation error and damage due to debris or vandalism. There are also several

intangible risks with the remotely operated weir related to jurisdictional authority and community expectations.

The County and Consultant project team recommends moving the alternatives analysis forward with a manually operated, seasonally adjustable weir configuration in both variations of the split channel alternative. The manually operated weir meets all required project criteria with lower operational risk and lower cost and complexity than the remotely operated weir. The weir would be configured with a multi-chambered flashboard structure to afford the ability to tune the weir after construction to reflect the design operation. Also, this structure would provide flexibility to change operation to adjust to future climate change or development conditions. Weir screening criteria are summarized in Table 9.

Table 9. Dynamic Weir Screening Criteria

Dynamic Weir Screening Criteria	Fixed Weir	Manually Operated Dynamic Weir	Remotely Operated Dynamic Weir 1-Day Release	Remotely Operated Dynamic Weir 3-Day Release
<b>Meets All Required Project Criteria</b>	No	Yes	Yes	Yes
<b>Operational Risk<sup>1</sup></b>	Low	Low	Medium-High	High
<b>Maximum Flood Benefit<sup>2</sup> (feet) Representative Early Winter Event</b>	0.08	0.12	0.20	0.42
<b>Maximum Flood Benefit (feet) Representative Late Winter Event</b>	0.00	0.05	0.07	0.22
<b>Range of Capital Cost</b>	\$60,000 - \$90,000	\$70,000 - \$100,000	\$290,000 – \$390,000	
<b>Amortized Annual Cost of O&amp;M</b>	\$2,900	\$7,700	\$62,800	
<b>Net Present Value of O&amp;M</b>	\$78,000	\$208,000	\$1,700,000	
<b>Range of Total Cost</b>	\$138,000-\$168,000	\$278,000-\$378,000	\$1,990,000 \$2,090,000	

1 – Operational risk is a qualitative value rated low to high and based on four factors; a) Predictability of technology performance, i.e. how well known and commonly utilized is the technology in similar conditions, b) Predictability of appropriate timing and magnitude of required weir adjustments, c) Risk of vandalism or mechanical failure interfering with weir performance, and d) Uncertainty around jurisdictional implementation authority.

2 – Maximum flood benefit is defined as the maximum estimated reduction in Lake Sammamish stage relative to existing conditions found for each of the four weir management scenarios presented here.

## 9.0 REFERENCES

King County. 2013. Willowmoor Restoration Design Hydrology. Phase 1 – Hydrologic Characterization. Prepared by Northwest Hydraulic Consultants.

King County. 2015. Willowmoor Floodplain Restoration Project. Concept Design Summary Report. Prepared by Tetra Tech and Northwest Hydraulic Consultants.

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U.S. Army Corps of Engineers. 1962. General Design Memorandum, Channel Improvement, Sammamish River, Washington. Prepared by Seattle District.

## APPENDIX A. ANALYTICAL APPROACH

A spreadsheet routing model was developed to analyze the preliminary weir/side channel configurations. This reservoir routing method uses lake volume, weir discharge, and long-term flow and lake stage data to evaluate performance of weir and side channel configurations. An inflow time-series for the analysis was developed using observed lake elevation and outflow data from 2001 through May 2018. The analysis will be refined during the alternatives analysis phase using a longer-term inflow record based on a calibrated HSPF model and more robust routing with an unsteady HEC-RAS model currently in development.

### DATA SOURCES

Table A-1 lists data sources used in the preliminary weir analysis.

Table A-1. Data Sources Used in Preliminary Weir Analysis

Data Component	Type	Source
Lake Sammamish Level	2001 – 2018, 15-min., hourly, and daily (ft NAVD88)	USGS Gage 12122000
Sammamish River Flow	2001 – 2018, 15-min., hourly, and daily (cfs)	King County Gage 51m
Lake Sammamish Volume	Stage-volume Rating Table	King County
TZ Weir Flow	Stage-discharge Rating Table	King County

Notes: NAVD88 = North American Vertical Datum of 1988; cfs = cubic feet per second; USGS = U.S. Geological Survey; WSU = Washington State University

### SIGNIFICANT ASSUMPTIONS USED IN THE ANALYSIS

Key assumptions used in analytical approach are listed below:

- Average daily data are suitable for developing the inflow record and evaluating performance of alternatives.
- Lake level is adequately described using USGS Gage 12122000, Lake Sammamish at Redmond WA.
- Flat water surface for Lake Sammamish assumed for routing analysis.
- Volume associated with change in lake stage represents all sources of inflow to Lake Sammamish.
- The effects of wind set-up and other transient effects that could cause variations in water surface elevation across the lake were assumed to be negligible for this preliminary analysis.
- Surface water discharge to groundwater and consumptive water withdrawals from Lake Sammamish are negligible.
- Current TZ weir stage-discharge relationship is representative of the future maintenance condition in the transition zone.

Additional discussion on the assumptions used in the analysis is provided in the sections that follow.

## COMPUTATIONAL TIME STEP

Average daily flow and stage data were compared to 15-minute instantaneous flow and stage data at King County Gage 51m (Sammamish River at Marymoor) to evaluate the appropriateness of using daily data in the preliminary weir analysis. Using a daily time-step in the spreadsheet routing model shortens computation times for evaluating weir performance. Figure A-1 and Figure A-2 show flow and stage duration curves, respectively, for the average daily and 15-minute instantaneous data. Agreement between the 15-minute instantaneous data and the daily average data is good for both the flow curve and stage duration curve, indicating that the average daily data will be suitable for use in the preliminary weir analysis.

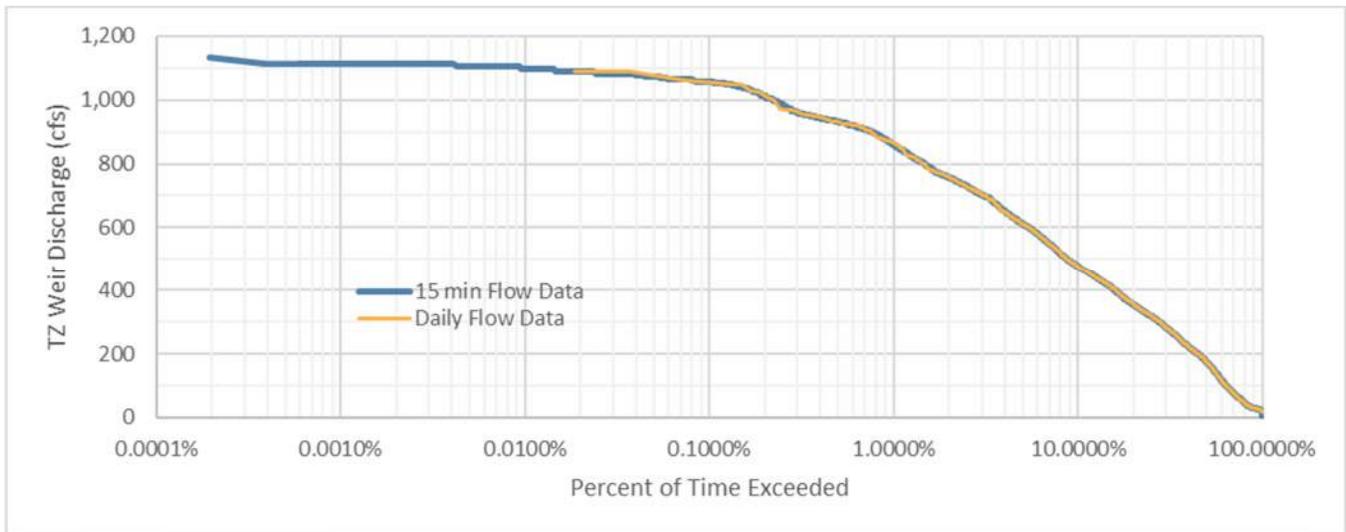


Figure A-1. Flow-Duration Curves for Average Daily and 15-Minute Instantaneous Discharge at the TZ Weir (2001 – 2018)

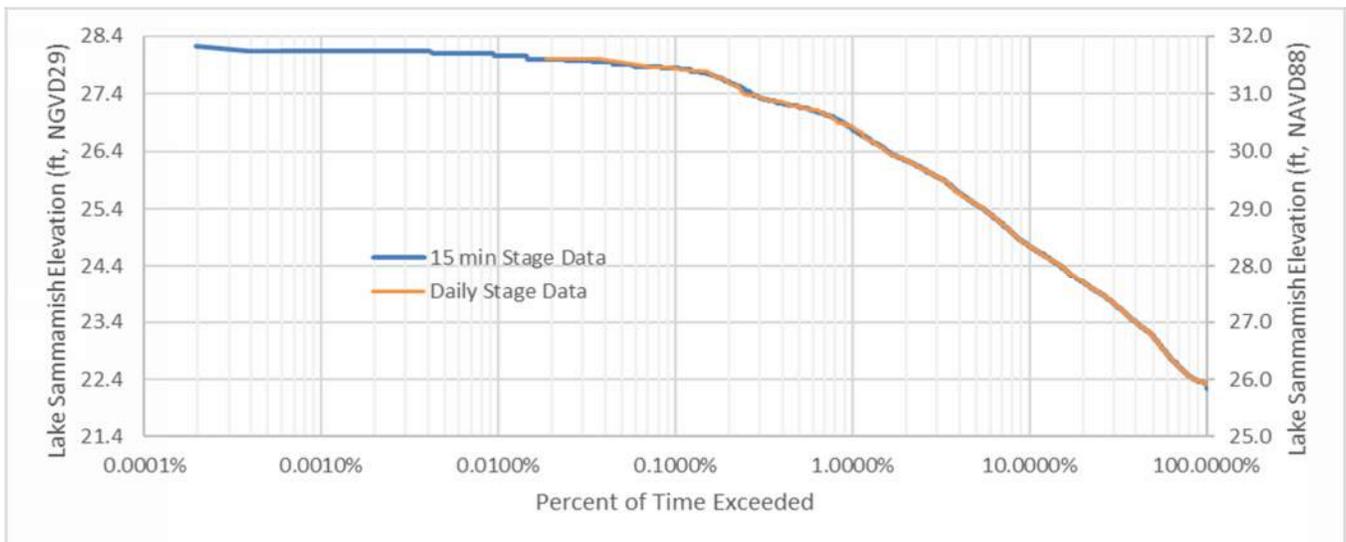


Figure A-2. Stage-Duration Curves for Average Daily and 15-Minute Instantaneous Discharge at the TZ Weir (2001 – 2018)

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## INFLOW TIME-SERIES

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The routing analysis requires an inflow time-series that represents all sources of inflow to Lake Sammamish including surface water from tributary streams, groundwater, rainfall and evaporation. To simplify the development of this time-series, a mass-balance approach based on change in lake storage was used to compute this inflow time-series. Inflow to the routing model was derived from lake stage and outflow to the Sammamish River measured by King County at the TZ weir. Inflow for the routing model was derived from the following equation:

$$I_i = (V_i - V_{i-1}) + O_i$$

Where:

I = Inflow (acre-feet/day)

V = Lake volume (acre-feet, calculated from stage data at USGS Gage 12122000)

O = Lake Sammamish outflow to Sammamish River (acre-feet/day, from King County Gage 51m)

i = Current time step (day)

Water level measured at USGS Gage 12122000, located approximately at the midpoint of Lake Sammamish, was assumed to provide a good representation of an average level across the lake. The effects of wind set-up and other transient effects that could cause variations in water surface elevation across the lake were assumed to be negligible for this preliminary analysis.

## MODIFIED EXISTING CONDITIONS MODEL

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The modified existing conditions time-series for Lake Sammamish stage and Sammamish River flow was computed using a variation on the standard reservoir routing model according to the relationships below:

$$\Delta V = I_i - O_{i-1}$$

$$V_i = V_{i-1} + \Delta V$$

$$S = f(V_i)$$

$$O = f(S_i)$$

Where:

I = Inflow (acre-feet/day, derived as shown above)

V = Lake volume (acre-feet)

O = Lake Sammamish outflow to Sammamish River (acre-feet/day) estimated using the current stage- discharge rating for the TZ weir provided by King County for Gage 51M. Stages were adjusted for Bear Creek inflows using the current adjustment table as provided by King County.

S = Lake Sammamish stage (feet, NAVD88) estimated using the stage-volume relationship from the HEC- RAS model.

i = current time step (day)

The stage-discharge rating used in the preliminary weir analysis is shown in Figure A-3. A lake stage of 29 feet NAVD88 was set as the initial condition.

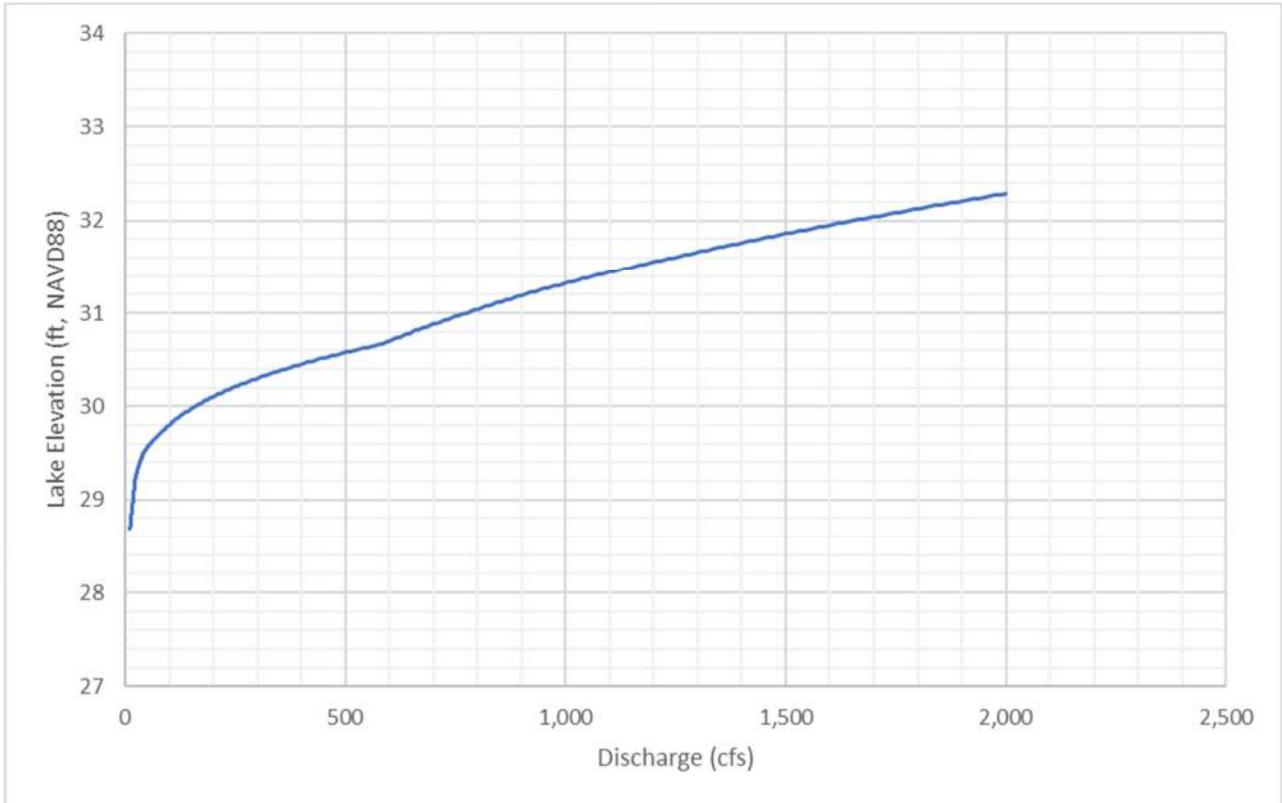


Figure A-3. Existing TZ Weir Rating Curve at King County Gage 51M Representing Full Maintenance Condition

The rating curve for the TZ weir has changed considerably over time due to vegetation and sediment management activities in the Transition Zone. To compensate for this change and to create a baseline time-series for evaluating the effectiveness of alternative weir/side channel configurations, modified existing-conditions lake stage and stream flow time-series were developed using the computed inflow time-series and the most recent TZ weir rating curve. The most recent rating was selected because it reflects the future maintenance condition after modification of the TZ weir.

The adjustment to account for the effect of Bear Creek backwater on flow at the TZ weir was based on historical average daily flow values for Bear Creek. Hourly peak flows can be up to 20 percent higher than the average daily flows, but the effects on lake level of those short-term higher flows are generally dampened as the backwater influence propagates through the TZ, the TZ weir and Lake Sammamish. Based on these findings, it was determined that use of average daily Bear Creek flows is appropriate for this analysis.

The stage-volume rating for Lake Sammamish used in the preliminary weir analysis is shown in Figure A-4. A lake stage of 29 feet NAVD88 was set as the initial condition. The stage-volume relationship for Lake Sammamish was validated and shown to provide a reasonable representation of lake volume. The surface of the lake was assumed to be flat for the routing analysis. This assumption is based on a comparison of coincident lake stages at the USGS and King County gage locations, which showed no appreciable difference between the two locations.

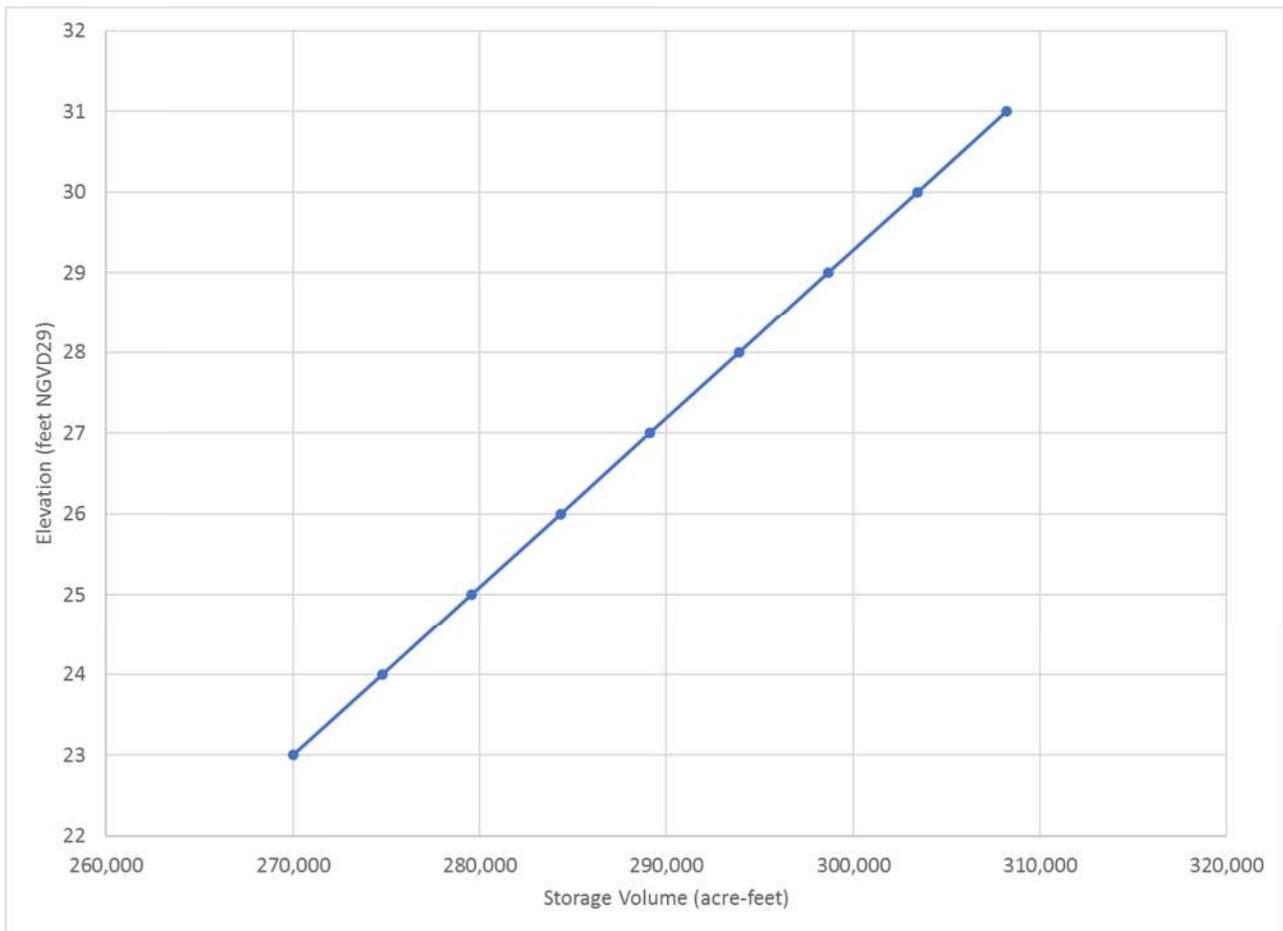


Figure A-4. Lake Sammamish Stage-Volume Relationship

A limitation of the spreadsheet-based approach is the inability to iterate a solution that uses inflow, lake level and outflow for the same day. To overcome this limitation, lake stage from the previous day is used to determine outflow. However, this approach can introduce errors in the long-term flow and stage computation. The potential for error was evaluated with a HEC-HMS model that uses a more robust lake routing routine that allows for iteration on a daily basis to represent stage and flow conditions more accurately. The HEC- HMS model used the same inflow, initial conditions, stage-storage rating, and weir rating as the spreadsheet routing analysis. Comparison to the HEC-HMS output showed that the spreadsheet routing model overestimates peak event flows by about 10%. Similar trends were noted for lake stage. Additional analysis showed that transforming the resulting modified existing-conditions time-series flow and stage data using a 4-day moving average (looking two days back and one day forward) compensated for the overestimation.

Figures A-5 through A-8 compare results for a representative event and flow duration for the three analytical approaches: unadjusted modified existing conditions, HEC-HMS, and the results of the modified existing conditions adjusted using a 4-day moving average. These figures show that adjusting the results of the modified existing conditions approach using a 4-day moving average provides a good fit to the HEC-HMS hydrograph for flow and stage values. The 4-day moving average approach was therefore used to adjust the results and evaluate performance of the TZ weir.

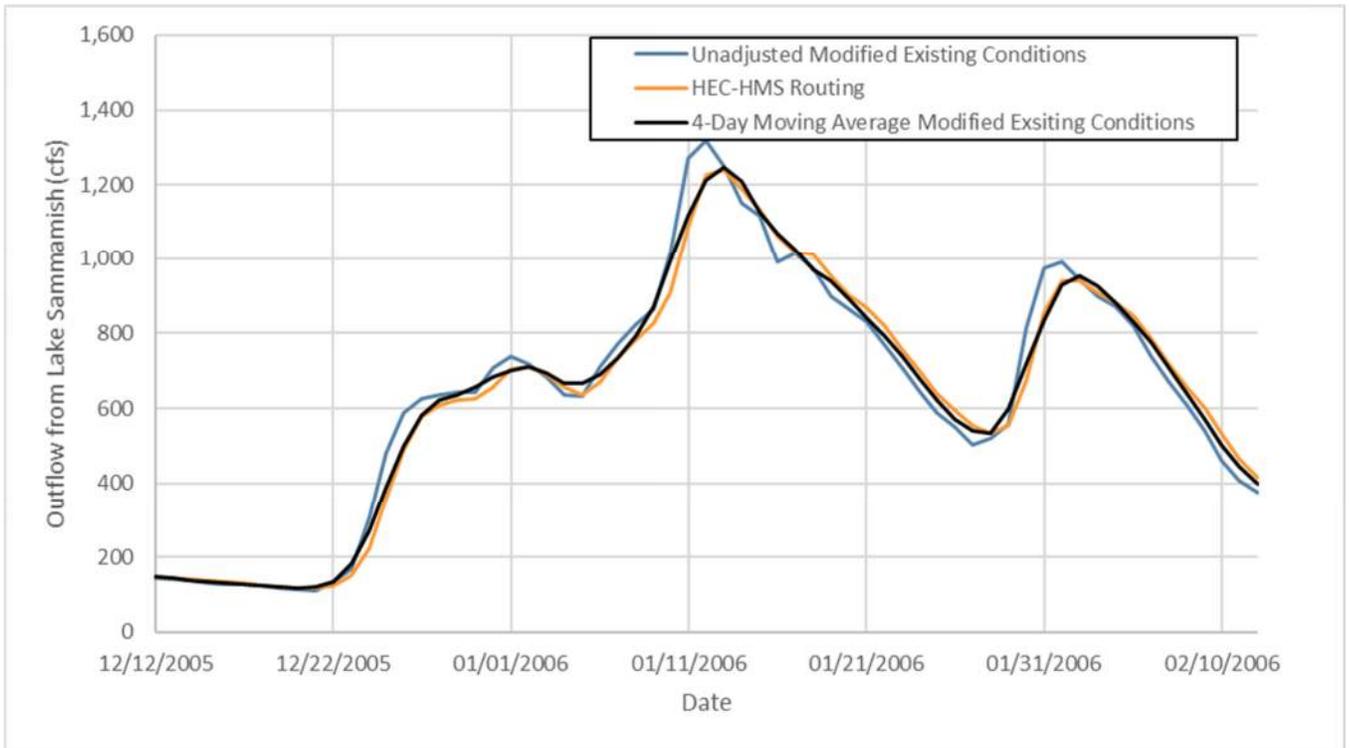


Figure A-5. Comparison of Modified Existing Conditions Model Results for Lake Sammamish Outflow

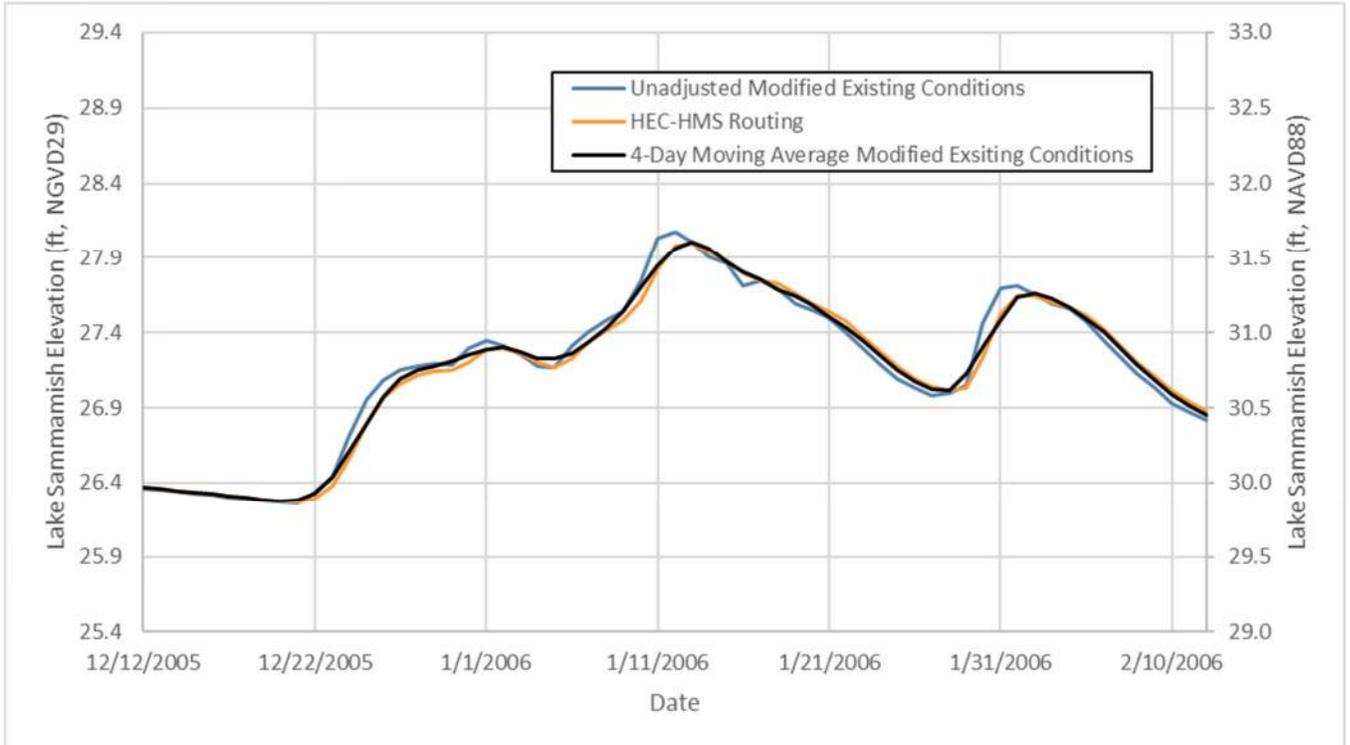


Figure A-6. Comparison of Modified Existing Conditions Model Results for Lake Sammamish Elevation

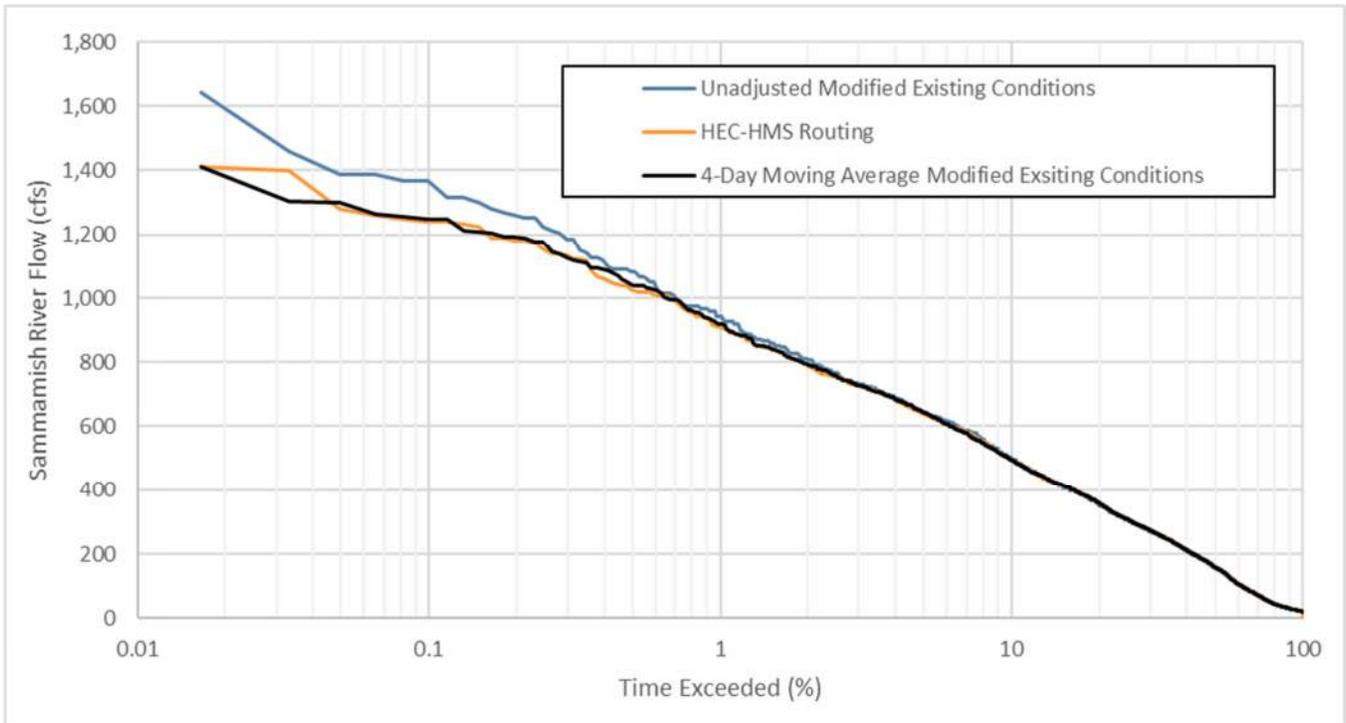


Figure A-7. Comparison of Modified Existing Conditions Model Results for Sammamish River Flow Duration

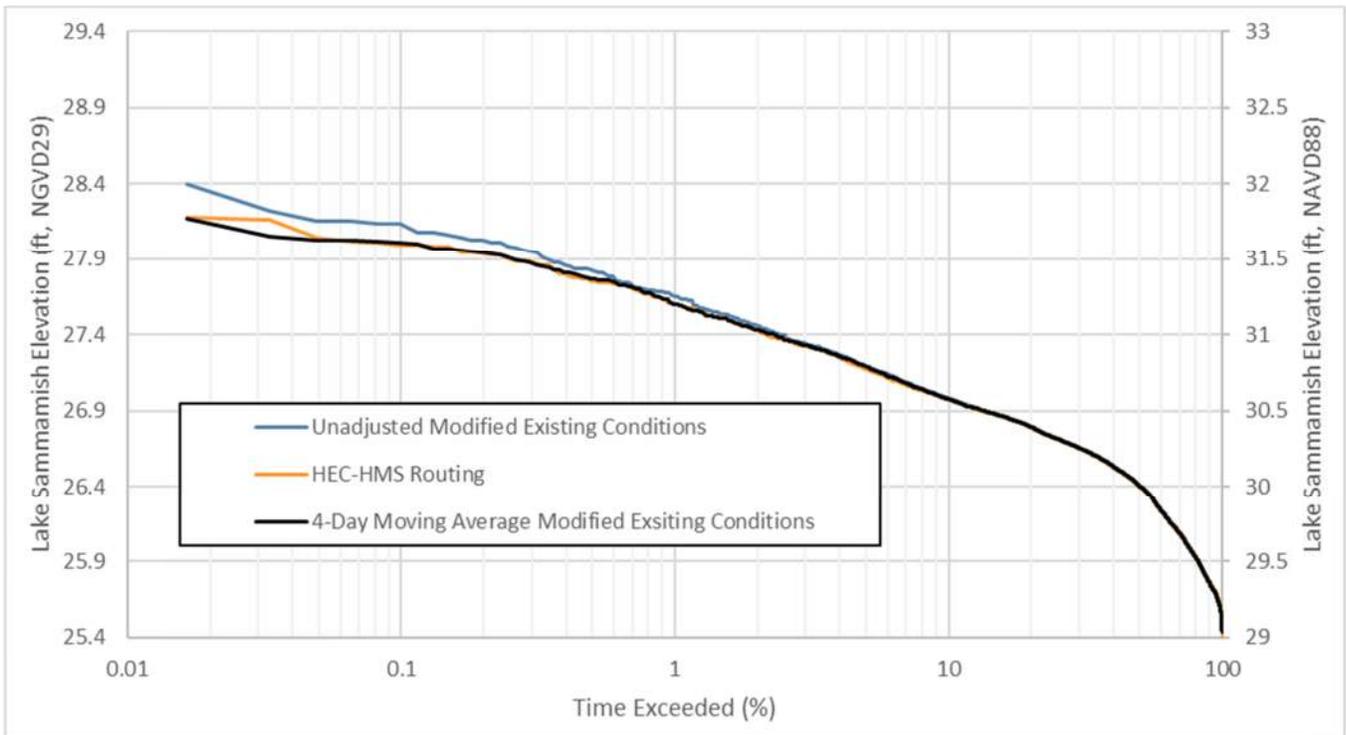


Figure A-8. Comparison of Modified Existing Conditions Model Results for Lake Sammamish Elevation Duration

The modified existing conditions time-series were also compared to observed lake elevations and Sammamish River discharge to validate their accuracy of the routing model. As shown in Figure A-9 and Figure A-10, there is generally good agreement between the model results and observed data, although the spreadsheet routing model tends to overpredict discharge during the winter compared to the observed data. The routing model was determined to provide a satisfactory prediction of lake elevation and Sammamish River discharge and to be suitable for use in assessing the performance of the weir/side channel alternatives.

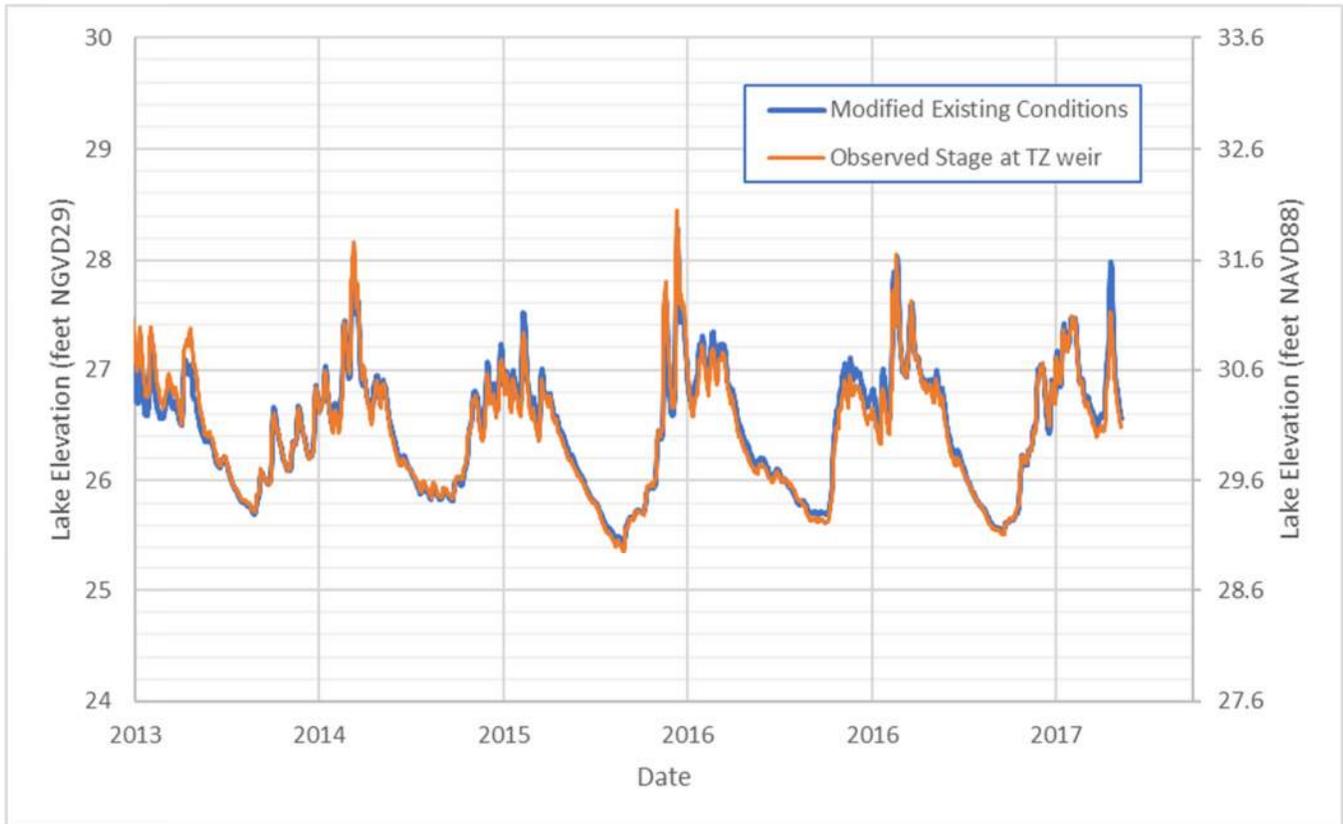


Figure A-9. Lake Sammamish Elevation Comparison Between Modified Existing Conditions and Observed at King County Gage 51M

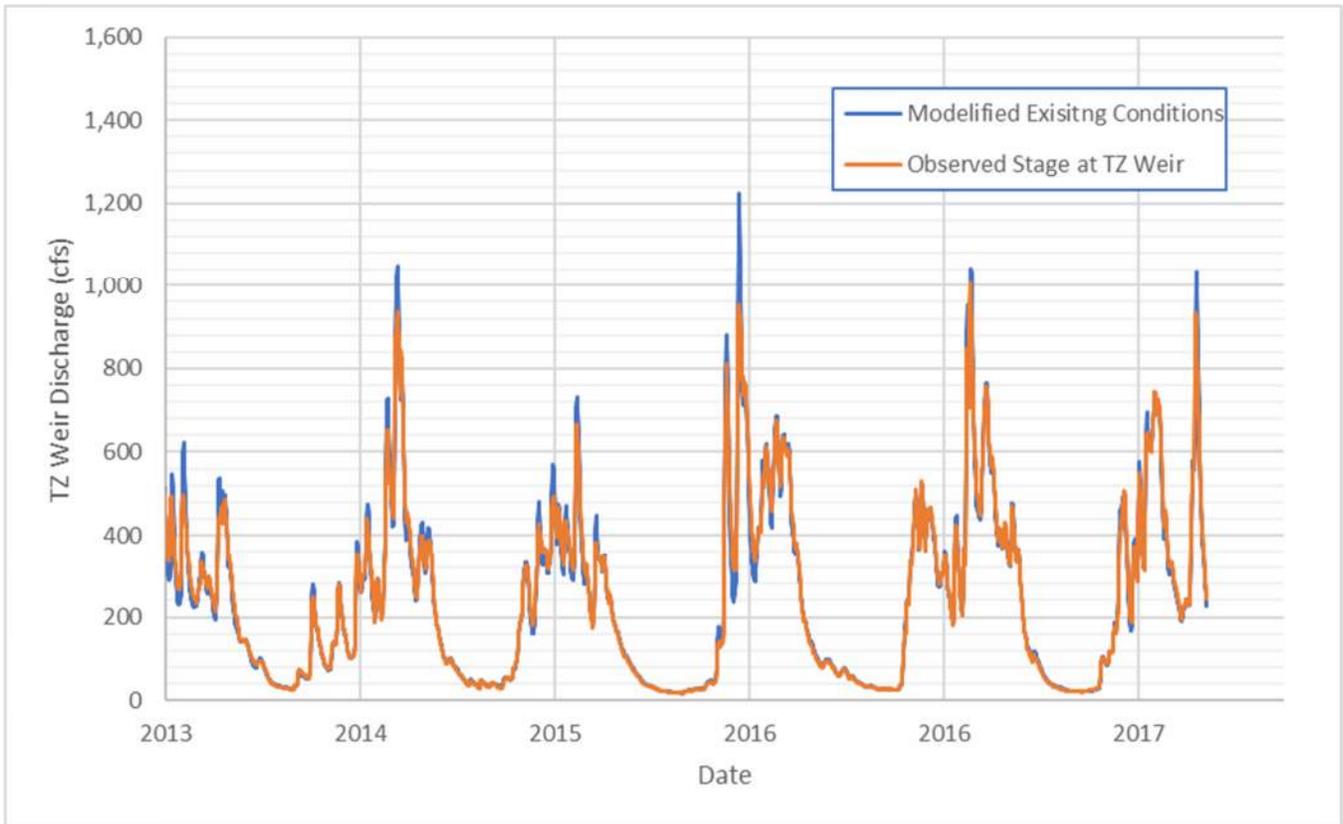


Figure A-10. TZ Weir Discharge Comparison Between Modified Existing Conditions and Observed at King County Gage 51M.