# WILLOWMOOR COLD-WATER SUPPLEMENTATION CONCEPTS

June 2014

Department of Natural Resources and Parks

King County

KING COUNTY FLOOD CONTROL DISTRICT

Water and Land Resources Division
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# WILLOWMOOR COLD-WATER SUPPLEMENTATION CONCEPTS

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King County

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# Executive Summary

Water quality in the project area is poor. High water temperature is the most serious concern for fish and the aquatic ecosystem in the project area. Water temperatures are regularly above 20° C (68° F) from May through October and can exceed 25° C (77° F) daily during July and August. The Washington Department of Ecology (Ecology) standards are 16° C (61° F) for core summer rearing habitat for salmonids and 17.5° C (64° F) for salmon migration. Observations of adult Chinook salmon mortality during particularly hot summers such as 1998 have prompted concerns that high water temperatures in the river can substantially reduce fish survival and lower reproductive success. A variety of studies have indicated that temperatures in the range of 21° C (70° F) are an incipient lethal threshold for adult salmon (Bell 1990; USEPA 2003).

This technical memorandum describes the results of a conceptual level analysis of six cold-water supplementation options for the Upper Sammamish River in Marymoor Park. The following options are evaluated:

1. Hypolimnetic withdrawal of 20 cfs from Lake Sammamish (10 cfs also evaluated)
2. Groundwater well discharge (~1 cfs) into transition zone
3. Shallow groundwater trench concentration (~1 cfs) into transition zone
4. Potable water source and discharge into transition zone (1-2 cfs)
5. Heat exchange system for 5 cfs of upper river flow
6. Groundwater infiltration gallery for 5 cfs of upper river flow

Different volumes could be used for options 1, 5, and 6, but as evaluated they bracket the range of feasible flow volumes that could be used.

The estimated conceptual level implementation and life-cycle costs of anticipated operation and maintenance (net present value over 50 years) are summarized below in Table ES-1.

**Table ES-1. Estimated conceptual level implementation and life cycle costs for six concept alternatives.**

| Concept Alternative | Implementation Cost ($) | Life-Cycle Cost (50 years; $) | Cfs Supplied[1] | $/cfs[2] |
|---|---|---|---|---|
| Concept 1-Hypolimnetic Withdrawal from Lake Sammamish | $6,959,000 | $197,000 | 10, 20 | $358,000[3] |
| Concept 2-Pumped Groundwater | $2,160,000 | $145,000 | 1 | $2,305,000 |
| Concept 3-Shallow Groundwater Trench | $752,000 | $23,000 | 1 | $775,000 |
| Concept 4-Purchase Potable Water | $850,000 | $4,457,000 | 1 | $5,307,000 |
| Concept 5-Pump Lake Water to Heat Exchange System | $2,603,000 | $142,000 | 5, 10, 20 | $549,000 |
| Concept 6-Pump Lake Water to Hyporheic Discharge | $1,950,000 | $62,000 | 5, 10, 20 | $402,000 |

[1] – Concepts 5 and 6 only evaluated for 5 cfs in this memo. The potential for 10 or 20 cfs will be explored further in design.

[2] – Cost per cfs based on sum of implementation cost plus life-cycle cost.

[3] – Cost for 20 cfs

Based on the potential feasibility, cost, temperature benefits, and other factors, we recommend that Concepts 1, 5 and 6 should be considered for a more detailed feasibility study. The following matrix in Table ES-2 summarizes how each concept alternative compares to each other.

**TABLE ES-2. Alternative Matrix**

TETRA TECH

| | Hypolimnetic Withdrawal | Pump Deeper Groundwater | Shallow Groundwater Trench Consolidation | Purchase Potable Water | Heat Pump Exchange | Hyporheic Flow |
|---|---|---|---|---|---|---|
| **Key Features** | Withdraw water from 35 to 49 foot depth in Lake Sammamish | One or two 40-60 foot deep wells near transition zone | Pipe trench to intercept shallow groundwater | Connect to existing City water line at W Lake Sammamish Pkwy | Pump near rowing club to buried heat exchange mechanical system | Pump near rowing club to discharge to gravel trenches near Transition Zone |
| | ~16,000 LF submerged pipeline -- discharge at weir | ~1,300 LF of pipeline -- discharge to Transition Zone or new channel | ~3,000 LF of pipeline -- discharge to Transition Zone or new channel | ~3,000 LF of pipeline -- discharge to Transition Zone or new channel | ~1,100 LF of pipeline & ~1,500 LF heat exchanger--discharge to Transition Zone or new channel | ~2,800 LF of pipeline -- discharge to Transition Zone or new channel(s) |
| **Planning Level Construction Costs** | $7.0 million total cost | $2.2 million total cost | $800k total cost | $900k total cost | $2.6 million total cost | $2.0 million total cost |
| **Net Present Value, Operation and Maintenance Over 50 Years** | $197k NPV for O&M (over 50 years) | $145k NPV for O&M (over 50 years) | $23k NPV for O&M (over 50 years) | $4.5 million NPV for O&M (over 50 years) | $142k NPV for O&M (over 50 years) | $62k NPV for O&M (over 50 years) |
| **Water Quality of Source** | Temperature average = 13C | Temperature average = 10C | Temperature average = 10C | Temperature average = 10C | Temperature average = 18C (after cooling) | Temperature average = 18C (after cooling) |
| | DO average = 5 mg/l | DO average = <1 mg/l; requires aeration | DO average = <1 mg/l; requires aeration | DO average = <1 mg/l; requires aeration | DO average = 8 to 9 mg/l | DO average = <1 mg/l; requires aeration |
| | Phosphorus = <0.01 mg/l; however may want to consider treatment for phosphorus | Phosphorus = no data | Phosphorus = no data | Phosphorus = no data | Phosphorus = <0.01 mg/l | Phosphorus = <0.01 mg/l |
| | Need to identify aeration options prior to discharge below weir in river. | Need to identify aeration options prior to discharge to pools | Need to identify aeration options prior to discharge to pools | Need to identify aeration and chlorine removal options prior to discharge to pools | Need to identify if further cooling is feasible, such as to 10C | Need to identify aeration oprtions prior to discharge to pools and if further cooling is feasible |
| **Water Quantity** | 20 cfs (10 cfs also evaluated) | 1-2 cfs based on estimated yield from City of Redmond wells | Less than 1 cfs; no data available | 1 cfs assumed since City water supply would be limited | 5 cfs (may be possible to scale up to 10, or 20 cfs) | 5 cfs (may be possible to scale up to 10, or 20 cfs) |
| | Costs assume 60 days of pumping (July 15-Sept 15) | Costs assume 60 days of pumping (July 15-Sept 15) | Need further information on water availability during summer | Costs assume 60 days of purchase (July 15-Sept 15) | Costs assume 60 days of pumping (July 15-Sept 15) | Costs assume 60 days of pumping (July 15-Sept 15) |
| **Temperature Cooling Effect and Distance Downstream** | Cooling to 17.5C for 5,000 to 25,000 square feet when lake temperature is 24 or 20C (for 20 cfs) | Cooling by 0.5C or less within pool | Cooling by 0.5C or less within pool | Cooling by 0.5C or less within pool | Create thermal refuge(s) in Transition Zone at less than 21C lethal limit | Create thermal refuge(s) in Transition Zone at less than 21C lethal limit |
| | Cooling of river to 17.5C for ~800 feet downstream of weir or 2000 feet remaining less than 21C (for 20 cfs) | Provides small area of refuge | Provides small area of refuge | Provides small area of refuge | | |
| **Change in Index of Thermal Stress** | 20 cfs reduces thermal stress by 88% and 100% for 16 and 21C thresholds; 10 cfs by 61% and 95%, respectively | Negligible | Negligible | Negligible | Reduces thermal stress by 12% and 85% for 16 and 21C thresholds, upper river only | Reduces thermal stress by 12% and 85% for 16 and 21C thresholds, upper river only |
| **Habitat and Water Quantity Effects of Construction Activities** | Wetlands = less than 1/2 acre impact | Wetlands = 1 acre impact | Wetlands = 1 acre impact | Wetlands = 1 acre impact | Wetlands = 1 acre impact for trench-scale, could be 5-10 acres for larger area of exchange | Wetlands = 1 acre impact for short trench, could be 5-10 acres or more for larger channel system |
| | Tree Removal = ~16-20 (pump and discharge locations) | Tree Removal = ~6-8 (pipe trenching) | Tree Removal = ~25 (install pipe trench) | Tree Removal = ~6-8 (pipe trenching) | Tree Removal = ~6-8 (pipe trenching) | Tree Removal = ~6-8 (trenching) |
| | Fish screen required for intake | N/A | N/A | N/A | Fish screen required for intake | Fish screen required for intake |
| | No effects to groundwater table (replaces existing volume of surface outflow from lake) | Need to evaluate effects to groundwater table | Need to evaluate effects to wetlands from draining (up to 9 acres) | Need to evaluate effects on City water supply | Likely no effect to groundwater table | Need to evaluate potential effects (raising and/or lowering) on groundwater table and residence time |
| **Constructability** | Easy to moderate -- sink pipeline to bed of lake/river | Easy to moderate -- trenching in wetland soils | Moderate -- large trench in wetland soils | Easy to moderate -- trenching in wetland soils | Moderate to difficult -- Much larger scale than normal heat pump systems; unproven to work at this scale | Moderate -- trenching in wetland soils |
| **Operation and Maintenance** | Moderate -- annual pump maintenance and 60 days of electricity | Limited -- infrequent well pump maintenance and 60 days of electricity | Essentially none | Extensive -- high potable water purchase costs | Moderate to extensive -- Piping may need periodic clean-out; annual pump maintenance and electricity | Moderate -- annual pump maintenance and electricity; infrequent clean-out of gravel trenches |
| **Additional-Qualitative Disadvantages** | Need for navigation buoys and signage | Water rights need review/approval | Likely not a reliable water source | Water rights or other City approval | Unproven as to feasibility on this large of a scale | Potentially too short residence time to cool water |
| **Additional-Qualitative Advantages** | Highest volume for maximum temperature reduction | | Only "natural"-type solution, no mechanical/electrical required | | Could potentially cool as low as 10C (similar to natural groundwater) | Gravel trenches will also passively convey cooler ambient groundwater to resting pools |
| | High reliability for source water | High reliability for source water | | If confirmed with City, reliable water source | High reliability for source water | High reliability for source water |
| **Bottom Line** | Highly effective, high cost | Limited effectiveness, moderate cost | Limited effectiveness, low cost | Limited effectiveness, high cost | Moderate effectiveness, moderate cost | Moderate effectiveness, moderate cost |

# Introduction

King County and the King County Flood Control District seek to improve flood control and habitat conditions in the Sammamish River Transition Zone in Marymoor Park. The Transition Zone is located in the upper portion of the Sammamish River immediately downstream of the Sammamish Weir structure that controls lake levels during low flows (Figure 1). The Transition Zone was constructed as part of the overall Sammamish River Improvement Project in the 1960s by the U.S. Army Corps of Engineers in cooperation with King County. The Transition Zone as currently constructed has required increasingly intensive and costly maintenance including regular mowing, trimming and removal of the vegetation and removal of accumulated sediments and organic material in the channel. These actions adversely affect water quality and habitat and conflict with Federal, state and local efforts to protect and enhance riverine habitat and recover ESA listed salmon species. Additionally, property owners around Lake Sammamish have expressed concerns about springtime lake levels and that further maintenance should be conducted in the Transition Zone. Consequently, reconfiguration of the Transition Zone is necessary to:

- Provide necessary lake level control, flow conveyance, and downstream flood control;
- Reduce costs, complexity and ecological impacts of maintenance;
- Enhance habitat conditions in the river channel and adjacent tributaries and wetlands to benefit ESA listed Chinook and other species.

## Project Area

The project area includes the outlet of Lake Sammamish down to the end of the Transition Zone and the associated King County owned lands to the south of the river (Figure 2). This distance encompasses approximately 4,500 feet of channel from Lake Sammamish to the end of the Transition Zone and approximately 90 acres south of the channel. Of interest, although outside of the project area is the Sammamish River downstream to the confluence with Bear Creek, a distance of approximately 2,200 feet.

## Contents of this Memo

This memo describes the six conceptual alternatives for cold-water supplementation that have been evaluated relative to their construction cost, life-cycle costs, potential benefits to temperature, and other considerations. Recommendations are provided for a feasibility-level analysis of the two most promising options.

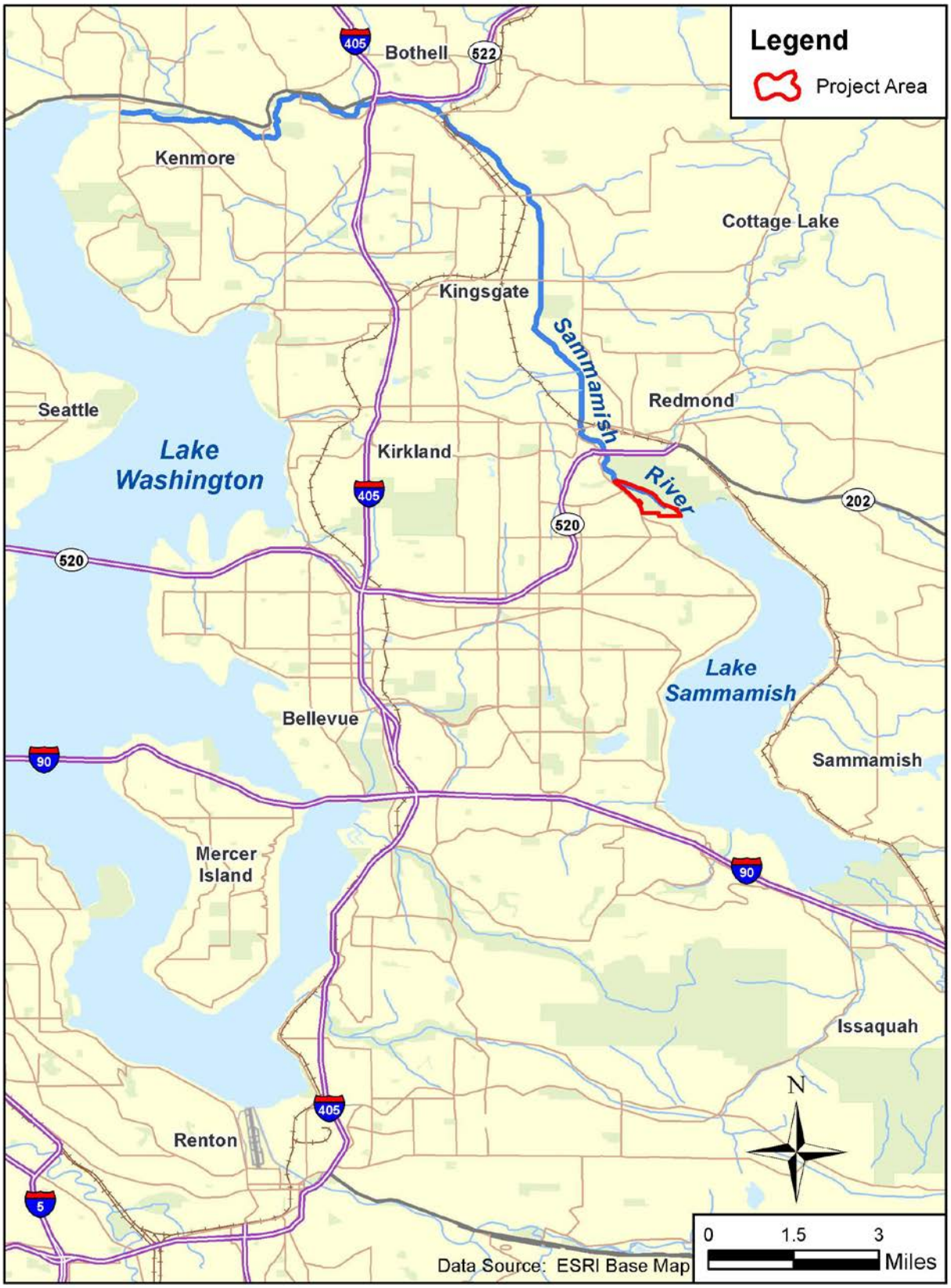



Figure 1. Vicinity Map.

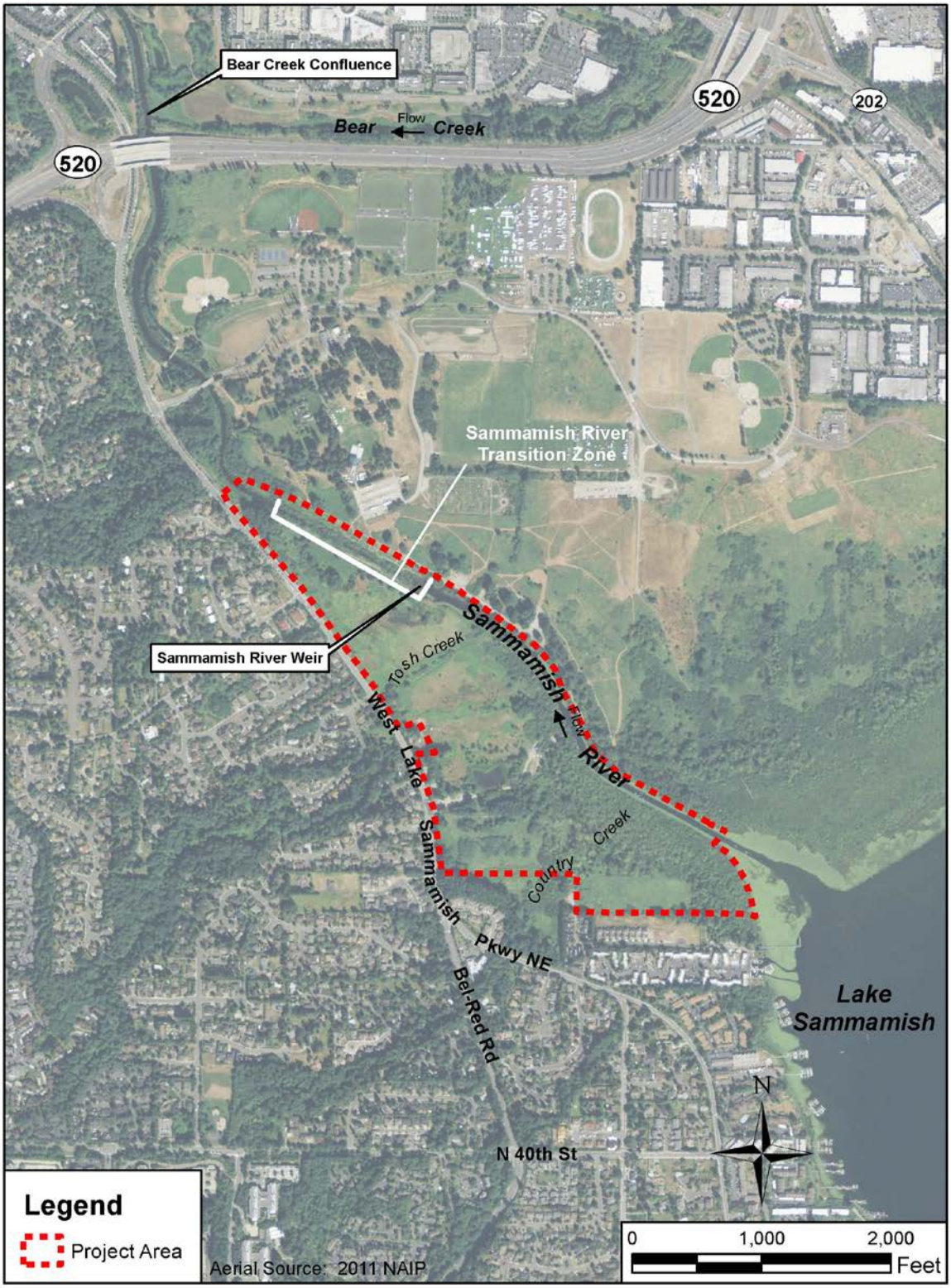



**Figure 2. Project Area.**

## Summary of Water Temperature Problems

Water quality in the project area is poor. High water temperature is the most serious concerns for fish and the aquatic ecosystem in the project area. Gage data is available for the project area (at the weir) and downstream in the Sammamish River, as well as in Lake Sammamish (Figure 3).

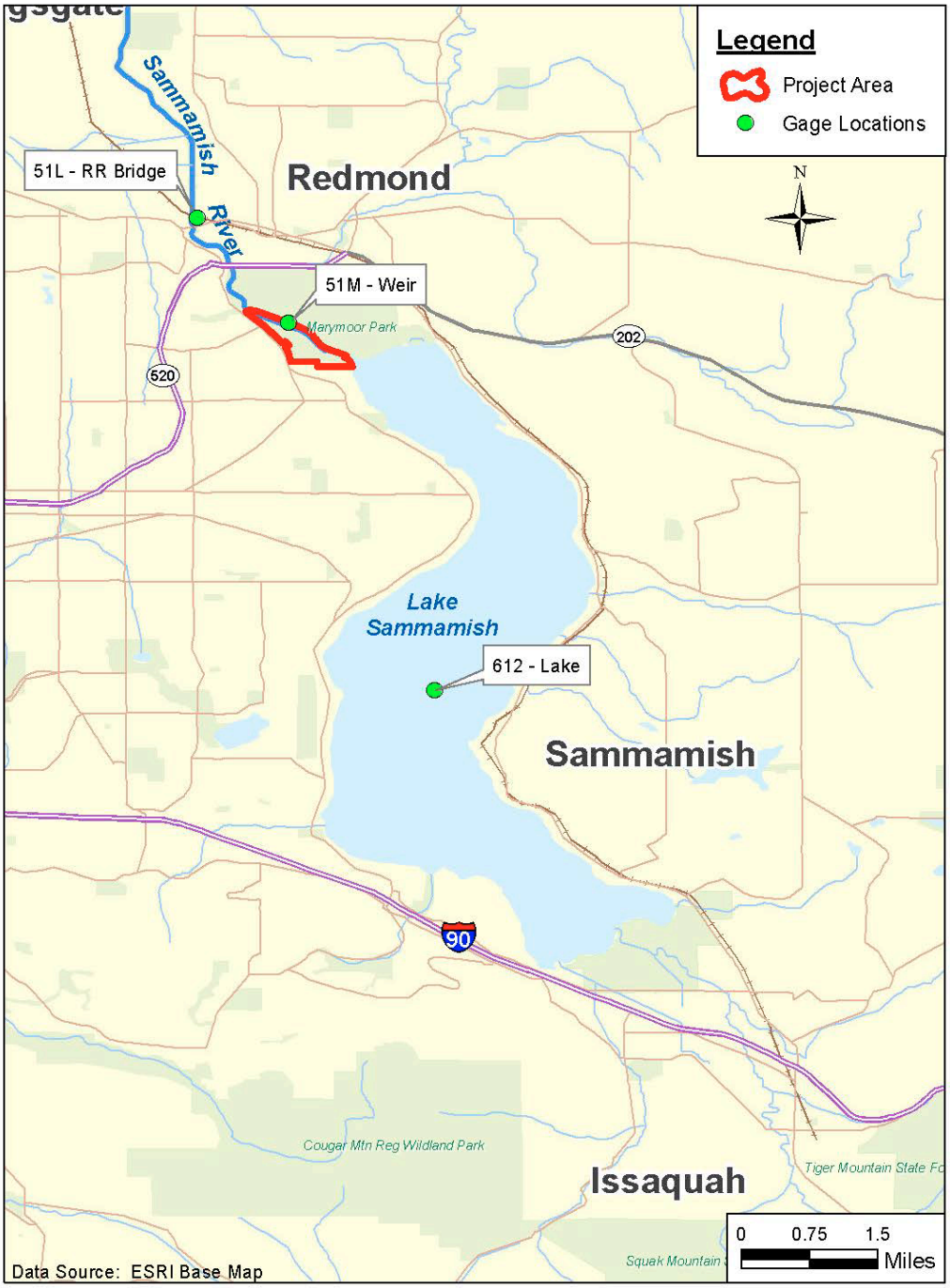



**Figure 3. Locations of King County gages discussed in this report.**

Water temperatures as high as 27° C (80° F) have been measured in the project area during late July (King County gage data); water temperatures are regularly above 20° C (68° F) from May through October and can exceed 25° C (77° F) daily during July and August (Figure 4). As the discharge from the lake that enters the Sammamish River is from the surface, the river temperatures are naturally seasonally high. Figure 4 shows the monthly mean, mean maximum, and mean minimum Sammamish River water temperatures (at the weir, Gage 51M, and near the railroad bridge downstream of Bear Creek, Gage 51L). Even with cooler Bear Creek water flows, temperatures downstream of Bear Creek are still high, but reduced by approximately 2° C (3.6° F) as compared to temperatures near the weir.

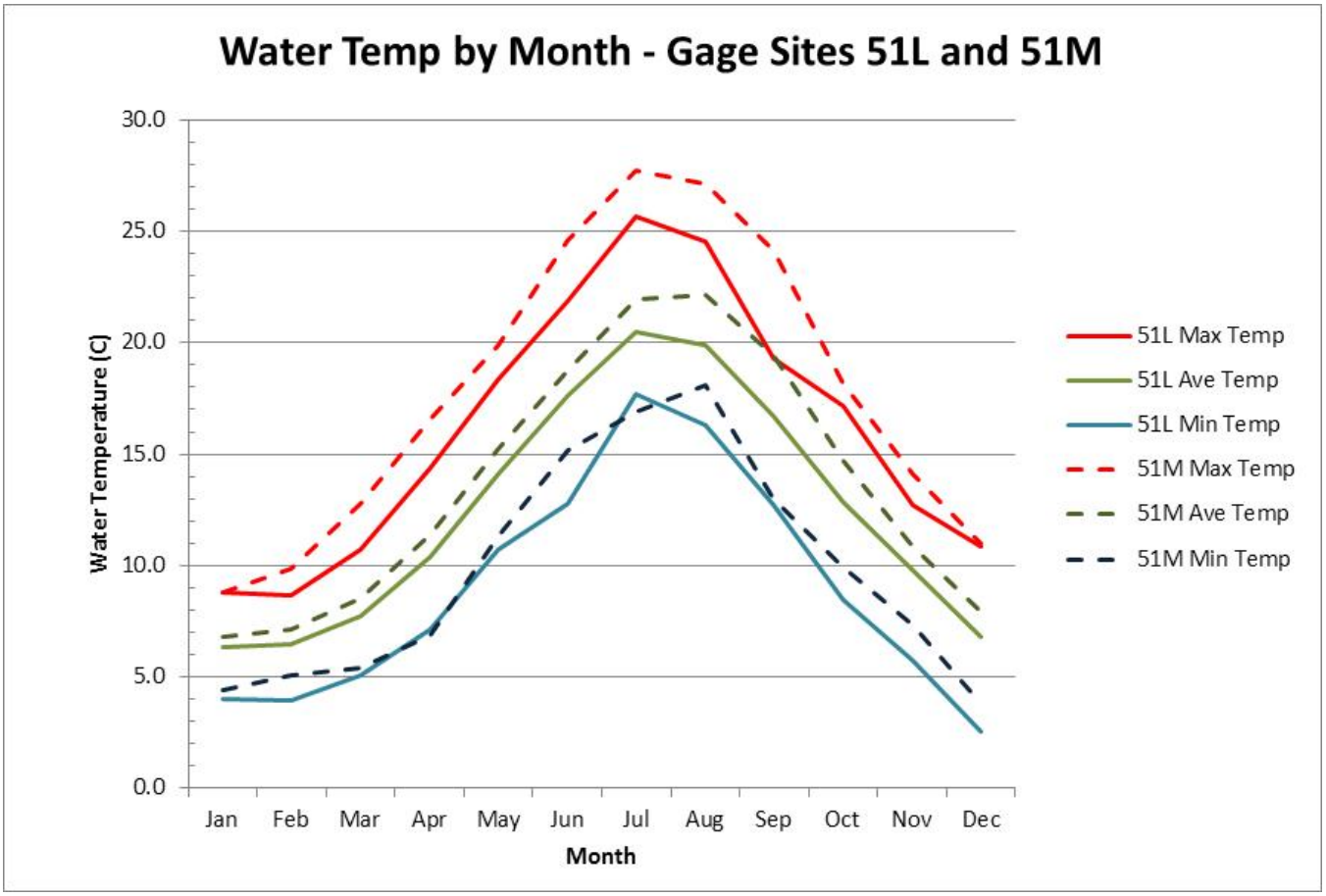



**Figure 4. Monthly mean, maximum, and minimum water temperatures in Sammamish River at Weir (Gage 51M) and railroad bridge (Gage 51L) for period of record (51M, 1995-2014; 51L, 2001-2014).**

Temperature modeling of the Sammamish River has been conducted by King County and others (King County 2009, 2001; Buchak, et al. 2001; Jain, et al. 2000) previously to evaluate existing conditions and potential scenarios for reducing temperatures. Additional modeling was conducted for this study and is discussed later for specific cold-water alternatives. A key concept developed with this earlier modeling was an "index of thermal stress" that is a calculation similar to degree-days – the amount of time that water temperatures are above 17° C (for example 2 hours of 19C water would result in 2/24 * (19-17) = 0.168 degree-days above the threshold), determined at the time as the upper end of preferred or suitable temperatures for adult Chinook salmon. As summarized in King County (2001), under existing conditions there is a thermal stress on average of 1.35 degree-days above 17° C during the August to October timeframe analyzed for the project area[1]. Since this is an average exceedance, the maximum thermal stress (hottest day) during this time period is often several degrees higher – the maximum thermal stress is 7.02 degree-days (i.e. an average of 7.02 degrees above 17° C). A number of scenarios for reducing temperatures were evaluated and compared to existing conditions (base case) and the only scenarios that were likely to significantly reduce water temperatures in the upper river were the engineered solutions of withdrawing 10 or 20 cfs from deep in Lake Sammamish (in the hypolimnion where temperature are quite cold). Other scenarios such as riparian restoration were likely to provide cumulative benefits to the river and reduce water temperatures in the lower river (by preventing solar heating in the upper river), but were not likely to substantially reduce temperatures in the upper river. While flows out of Lake Sammamish have likely always been high, under historic conditions, the extensive shading and groundwater and tributary inputs would likely have moderated the high temperature flows fairly quickly so there would not have been large expanses of hot water. As the historic conditions are not reasonably restored, a more engineered solution to more specifically cool the upper river is necessary to effectively address high temperatures – shading and pool creation do not significantly reduce water temperatures.

The current Washington Department of Ecology (WDOE) water temperature standard is for a maximum 7-day moving average temperature of 17.5° C (63.5° F) for salmonid spawning, rearing and migration (September 16 to June 14) and 16° C (60.8° F) for core salmonid summer habitat (June 15 to September 15; WDOE 2012). The 16° C standard applies to the project area during the summer months. Figure 5 shows the Sammamish River water temperatures along with the general timing of salmon presence in the river, and the WDOE temperature standards. Water temperatures exceed WDOE water temperature standards during the months of July and August, even the minimum (nighttime) temperatures. The mean monthly maximum temperatures exceed WDOE standards from April through October (Figure 5).

[1] For example, the water temperature exceeds 17° C by an average of 1.35 degrees over a 24 hour day, which does not mean that the temperature is 18.35°C, but represents the average of both higher and lower temperatures throughout the day and the cumulative average temperature for the whole day is 1.35 degrees above preferred temperatures for a cold-water species such as Chinook salmon.

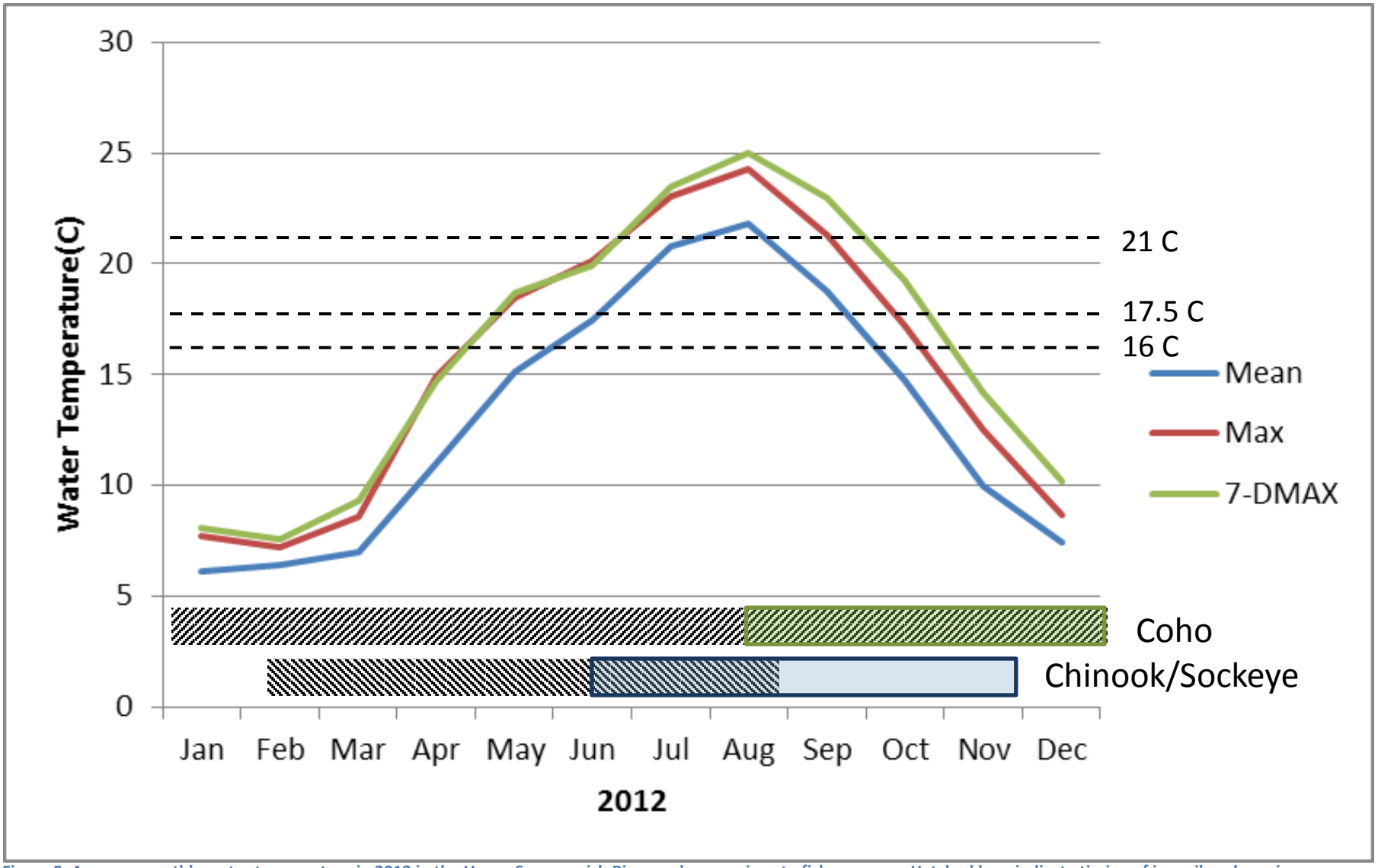



**Figure 5. Average monthly water temperature in 2012 in the Upper Sammamish River and comparison to fish presence. Hatched bars indicate timing of juvenile salmon in the watershed; solid bars indicate timing of adult salmon from entry at the locks through spawning.**

## Conceptual Alternatives

Because water temperature has potentially a large effect on salmon survivability and use of the project area, six conceptual alternatives were developed at a preliminary level and evaluated. The following sections describe these six alternatives.

### Hypolimnetic Withdrawal of Cold Water from Lake Sammamish

This concept is to withdraw either 10 or 20 cfs of cold water from Lake Sammamish at an approximate depth near 15 meters (49 feet) and pump it via a pipeline to discharge at or near the Sammamish Weir. The lake is stratified during the spring to fall months with high temperatures near the surface and cold temperatures below the thermocline in the hypolimnion. Below 10 meters (33 feet) and nearer to 15 meters (49 feet) is where water temperatures average less than 55° F (13° C) during the July to October time period, dissolved oxygen levels are typically 8 mg/l near 10 meters but drop below 4 mg/l at 15 meters, and phosphorus levels are not elevated above 0.01 mg/l (similar to surface conditions; see Figures 6 and 7). The cold water discharge would passively replace 10 or 20 cfs of outflow from the lake during the critical high temperature time period (assumed as July 15 to September 15 for concept purposes).

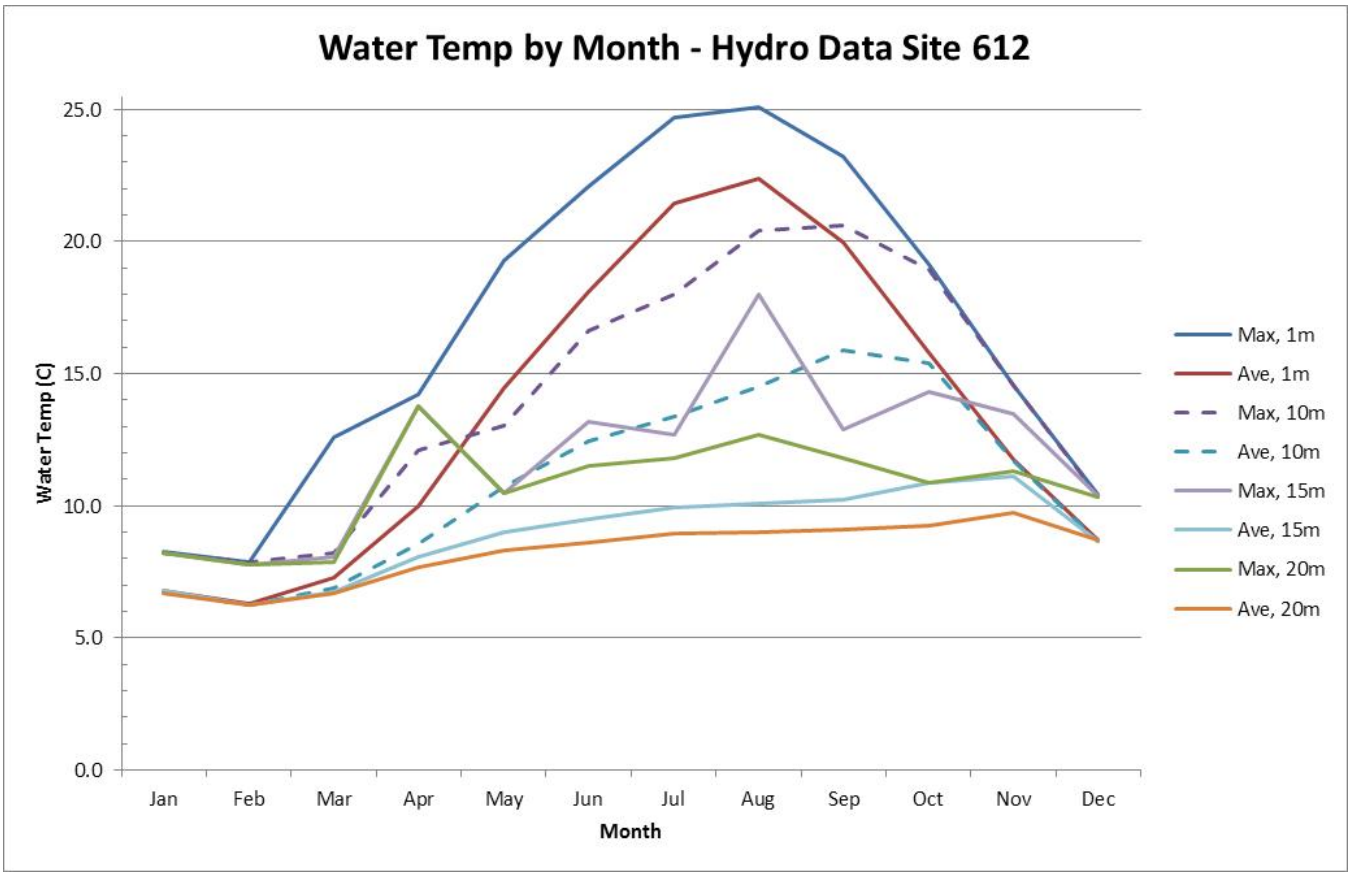



**Figure 6. Monthly maximum and mean water temperatures at Lake Sammamish Hydro Data Site 612 at 1, 10, 15, and 20 meter depths**

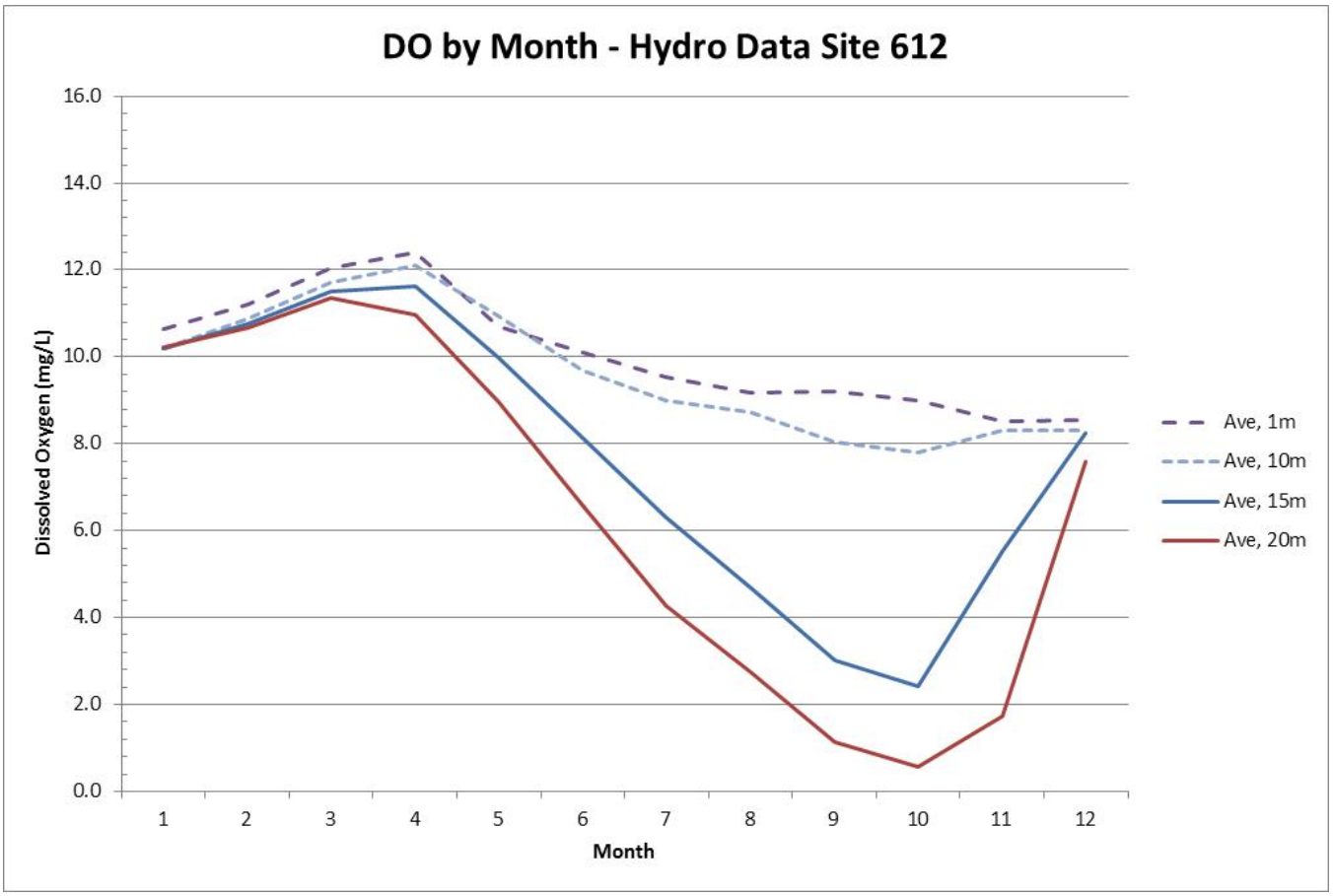



**Figure 7. Monthly mean dissolved oxygen concentrations at Lake Sammamish Hydro Data Site 612 at 1, 10, 15, and 20 meter depths**

The north end of Lake Sammamish is very shallow, so in order to withdraw water from a depth up to 49 feet, the intake would need to be located where the lake is deeper than 50 feet.

Primary features of this alternative include:

- Submerged intake and 16,000 linear feet (LF) 36-inch pipeline (20 cfs) or 30-inch pipeline (10 cfs) on Lake Sammamish bottom (50-60 foot depth).
- Submerged 2,000 LF 36-inch pipeline (20 cfs) or 30-inch pipeline (10 cfs) on Sammamish River bottom from the lake outlet to the pump station.
- Upland pump station proposed near Sammamish Rowing Association river access for existing power and access purposes.
- Submerged 2,000 LF 24-inch pipeline (20 cfs) or 18-inch (10 cfs) on Sammamish River bottom from pump station to discharge at existing weir.
- Elevated discharge over existing weir to aerate discharge and mix with weir outflow and cool the overall river temperatures. The 20 cfs would be approximately 40% of the discharge, since current mean monthly discharge during July, August and September is approximately 50 cfs.

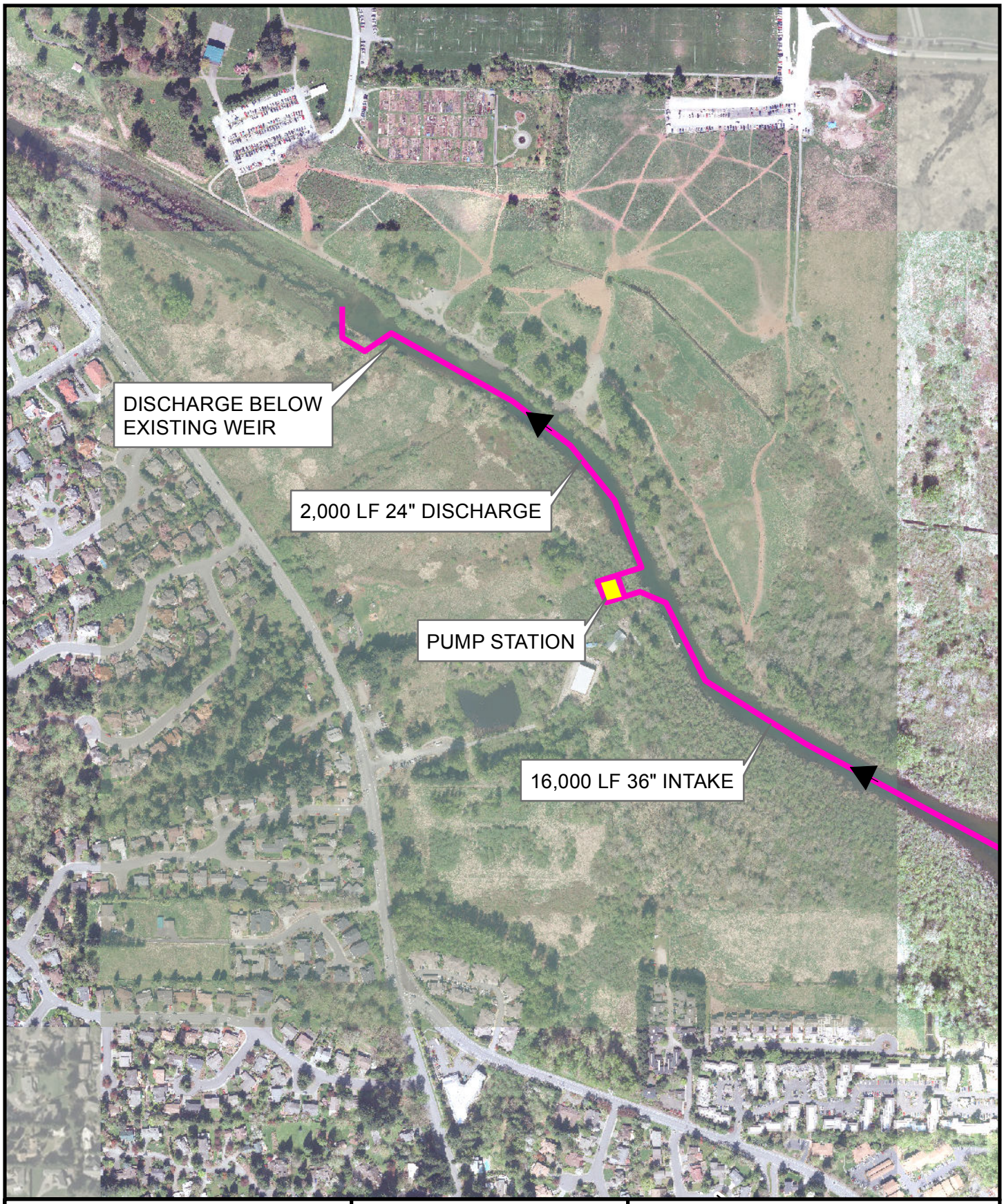
The potential temperature benefits of this alternative were evaluated by an empirical analysis (Appendix A) and further river temperature modeling (Appendix B). Results show that both the 10 and 20 cfs options provide the potential for several degrees (°C) cooling of river temperatures for several hundred feet downriver. The empirical analysis indicates that the discharge of 20 cfs, which could represent approximately 30 – 50% of the mean monthly discharge of the river during the month of August, could cool river temperatures down to the 63.5° F (17.5° C) standard in a downstream plume for an area of 5,000 to 25,000 square feet, equivalent to the majority of the river from the weir downstream for 100 to 300 feet. The input of 10 cfs influences about half the area and distance downstream, as would be expected. These areas and distances depend on what the lake outlet temperature is; the warmer the water, the less area/distance of cooling that can be achieved. But, perhaps more importantly, it is possible to reduce temperatures below the 21° C incipient lethal threshold for several hundred feet downstream (varies from 800 feet to nearly 2000 feet for the 20 cfs option). As Bear Creek also cools river temperatures by approximately 3.6° F (2° C) on average, the cumulative cooling benefit could substantially reduce the thermal stress on migratory salmon for further distances downstream.

Modeling (Appendix B) results show that the 20 cfs option could reduce average thermal stress on salmon by 88% (using a 16C threshold) and by 100% for the 21C threshold. The 10 cfs option could reduce average thermal stress on salmon by 61% and 95%, for the 16C and 21C thresholds, respectively. The temperature can also be reduced much further downstream to at least North Creek, although by a less significant amount. In combination with riparian restoration measures, the distance of cooling effects could likely be extended further downstream as shading helps prevent temperature increases due to solar radiation.

Additionally, this alternative requires very little construction work on land or in wetlands; the pipelines and concrete anchors would be assembled on land, floated into the lake as it is assembled, positioned via barge or work boats, and then sunk to the bottom. The only land elements are the pump station and the discharge. Consideration can be given during final design to a variable speed pump system, as compared to delivering a 20 cfs or 10 cfs discharge presented here. Variable speed systems have advantages, but are typically more expensive and pump selection can be more difficult, given head losses for the different flow rates using the larger pipe diameters sized for the higher flows.

Potential concerns or risks of this alternative include the potential effects to navigation from having a 36 or 30-inch diameter pipeline running along the bed of the lake outlet channel upstream of the weir. The bathymetry of the existing Sammamish River is not known, but we assume the depth to be in the range of 6-10 feet, so a submerged pipe is considered feasible and also reduces wetland disturbance of an upland trench alignment. Another constraint to this alternative is the fish screen at the intake that will be elevated off the lake bottom would need detailed sizing / design, along with a cleaning mechanism.

The planning level cost estimate for the 20 cfs alternative is $7.0 million, for the 10 cfs alternative would be approximately $5 million. Operation and maintenance (life-cycle) requirements would include electricity for pumping and annual start-up/maintenance/shut-down labor and equipment costs for the pump. An estimated net present value of operation and maintenance is $197,000 over fifty years. The following table provides the planning level cost estimate for this alternative.




Proposed System

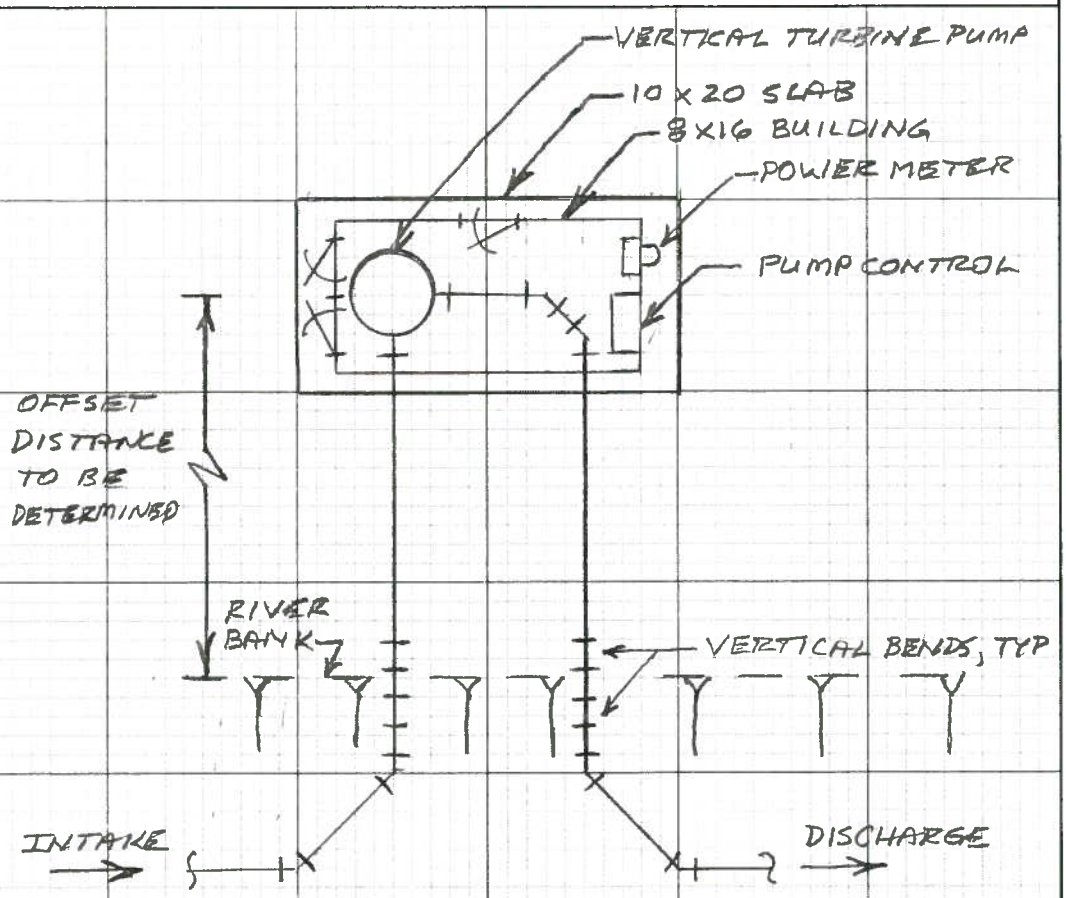
King County

N

0 500 Feet

WILLOWMOOR PARK
CONCEPT 1
HYPOLIMNETIC WITHDRAWAL
FROM LAKE SAMMAMISH

| CLIENT: KING COUNTY | PROJECT: WILLOWMOOR |
|---|---|
| SUBJECT: CONCEPT 1 | |




PUMP STATION - PLAN

| TETRA TECH | | HOPKINSON | 12/11/13 | |
|---|---|---|---|---|
| | JOB NO. | BY | DATE | SHEET NO. |

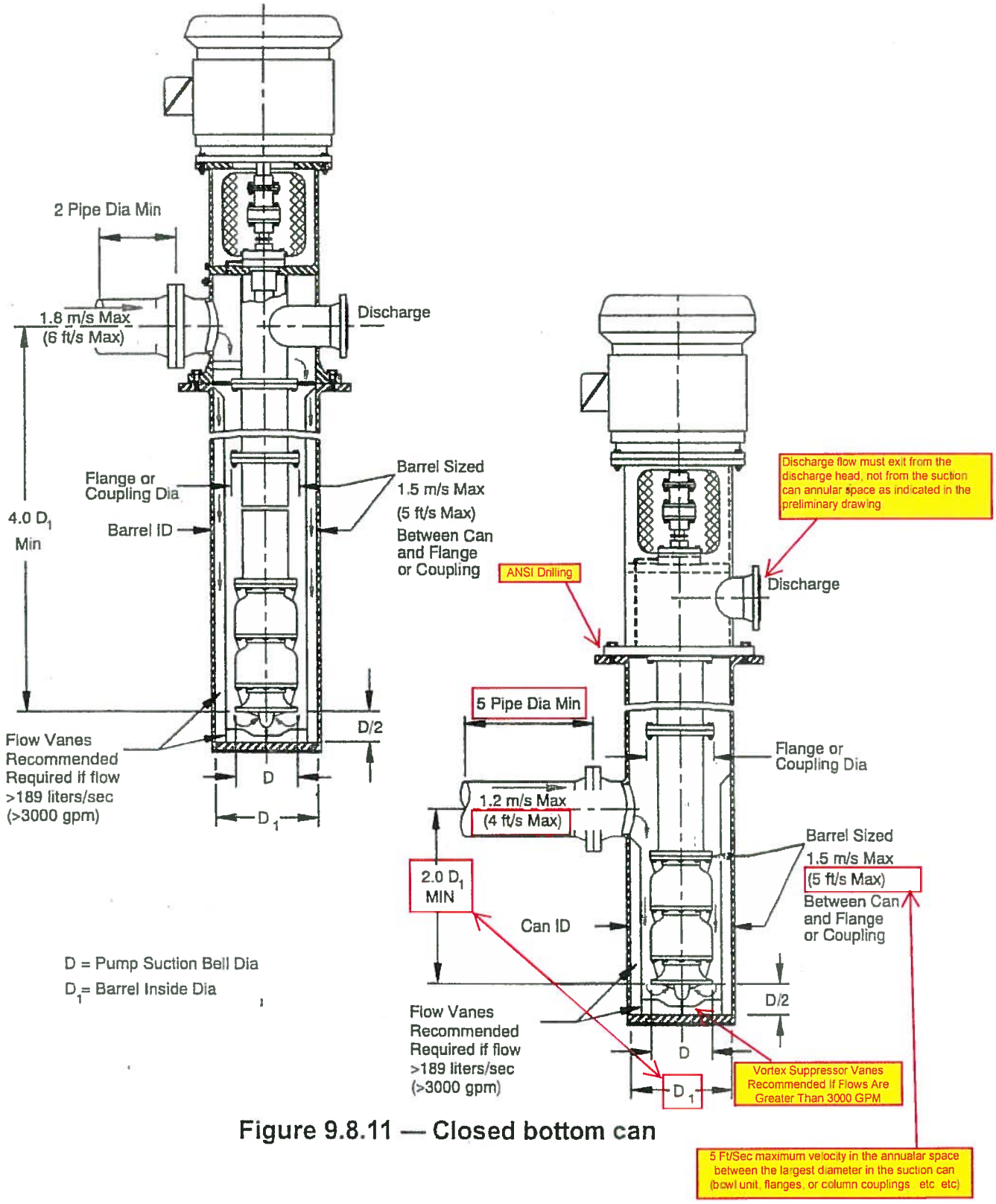
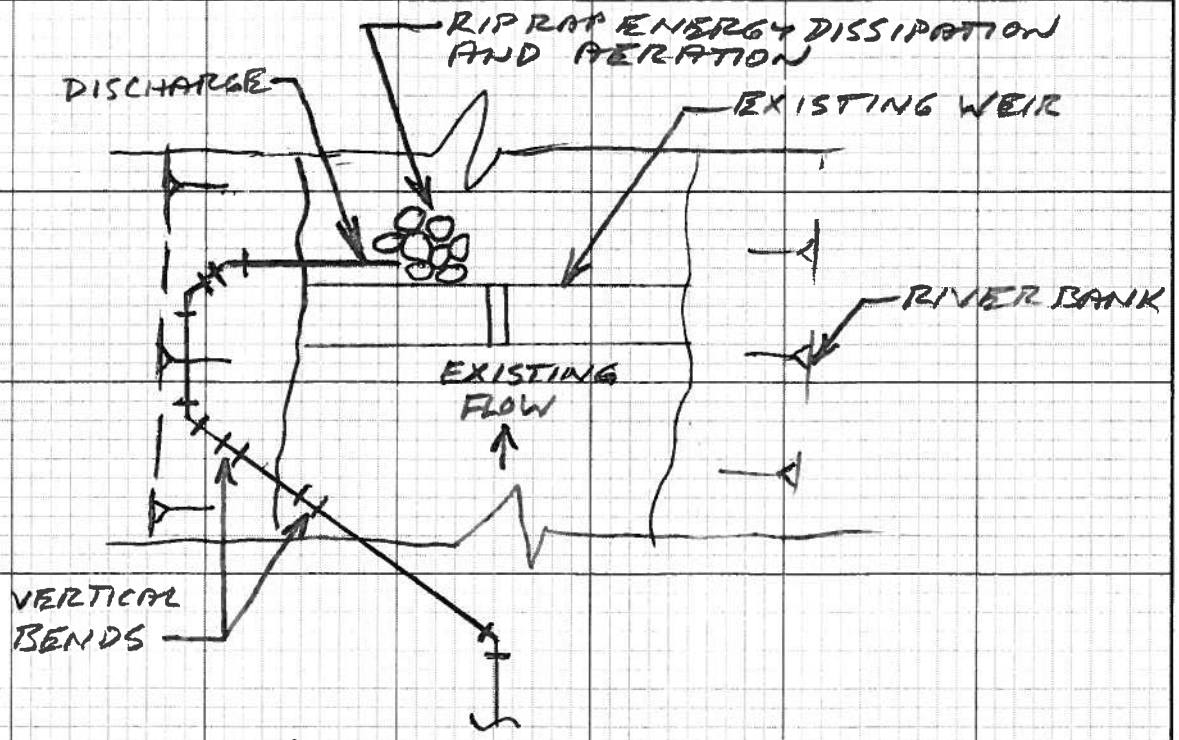



**Figure 9.8.11 — Closed bottom can**

CLIENT: KING COUNTY | PROJECT: WILLOWMOOR

SUBJECT: CONCEPT 1




DISCHARGE AT WEIR – PLAN

| TETRA TECH | | HOPKINSON | ~~12/11/13~~ 6/6/14 | |
|---|---|---|---|---|
| | JOB NO. | BY | DATE | SHEET NO. |

**T31746 King County - Willowmoor**
**Task 6 Cold Water Supplementation**
**Concept Alternative Cost Estimate Details**
**Concept 1-Hypoliminetic Withdrawal From Lake Sammamish (20 cfs)**
**Date : 6-Jun-14**

TETRA TECH

| Item | Description | Quantity | Unit | Unit cost, $ | | Cost, $ |
|---|---|---|---|---|---|---|
| **1** | **Mobilization/Demobilization/Testing** | | | | | |
| | Assume 8% of subtotal for items 2-5 | 1 | ls | $242,300 | **$** | **242,300** |
| **2** | **Sitework** | | | | | |
| | Pump Site | | | | | |
| | Archaeological monitoring (SHPO standards) allowance | 1 | ls | $10,000 | $ | 10,000 |
| | Erosion control | 1 | ls | $5,000 | $ | 5,000 |
| | Clear & grub | 1 | ls | $5,000 | $ | 5,000 |
| | Excavation - Pipelines | 640 | cy | $15 | $ | 9,600 |
| | Excavation - Pump station | 40 | cy | $20 | $ | 800 |
| | Turbidity Curtain | 200 | lf | $15 | $ | 3,000 |
| | Haul waste to disposal | 1,300 | ton | $10 | $ | 13,000 |
| | Imported fill - Pipeline & Pump Station | 1,300 | ton | $15 | $ | 19,500 |
| | Trench shoring | 1 | ls | $5,000 | $ | 5,000 |
| | Dewatering for pipeline and pump station | 5 | days | $200 | $ | 1,000 |
| | Crushed Surfacing Base Course | 100 | cy | $30 | $ | 3,000 |
| | Discharge Site At Weir | | | | | |
| | Archaeological monitoring (SHPO standards) allowance | 1 | ls | $10,000 | $ | 10,000 |
| | Erosion control | 1 | ls | $2,000 | $ | 2,000 |
| | Clear & grub | 1 | ls | $2,000 | $ | 2,000 |
| | Excavation - Pipelines | 210 | cy | $15 | $ | 3,200 |
| | Turbidity Curtain | 200 | lf | $15 | $ | 3,000 |
| | Haul waste to disposal | 400 | ton | $10 | $ | 4,000 |
| | Imported fill - Pipeline | 400 | ton | $20 | $ | 8,000 |
| | Trench shoring | 1 | ls | $2,000 | $ | 2,000 |
| | Dewatering for pipeline construction | 2 | days | $200 | $ | 400 |
| | Rip Rap Energy Dissipation | 30 | ton | $40 | $ | 1,200 |
| | Weir retrofit contingency allowance | 1 | ls | $5,000 | $ | 5,000 |
| | **Subtotal, Sitework** | | | | **$** | **115,700** |

| Item | Description | Quantity | Unit | Unit cost, $ | | Cost, $ |
|---|---|---|---|---|---|---|
| **3** | **Piping** | | | | | |
| | Intake To Pump Station | | | | | |
| | HDPE Intake MH & Cone Style Fish Screen | 1 | allow | $50,000 | $ | 50,000 |
| | 36" HDPE DIPS DR 21 Intake Pipe | 16,000 | lf | $141 | $ | 2,256,000 |
| | 36" Precast Pipe Anchors | 640 | ea | $300 | $ | 192,000 |
| | 4 - work boats for pipe positioning | 1 | ls | $10,000 | $ | 10,000 |
| | 30" HDPE DIPS DR 21 PS Transition Pipe | 150 | lf | $105 | $ | 15,800 |
| | 30" Valve | 1 | ea | $25,000 | $ | 25,000 |
| | 30" 45 Deg Bend | 4 | ea | $732 | $ | 2,900 |
| | 36x30 Reducer | 1 | ea | $1,000 | $ | 1,000 |
| | Discharge From Pump Station | | | | | |
| | 18" HDPE DIPS DR 21 PS Transition Pipe | 150 | lf | $42 | $ | 6,300 |
| | 18" Valve | 1 | ea | $20,000 | $ | 20,000 |
| | 18" 45 Deg Bend | 8 | ea | $224 | $ | 1,800 |
| | 24x18 Reducer | 1 | ea | $500 | $ | 500 |
| | 24" HDPE DIPS DR 21 Discharge Pipe | 2,000 | lf | $69 | $ | 138,000 |
| | 24" Precast Pipe Anchors | 80 | ea | $300 | $ | 24,000 |
| | Discharge Site At Weir | | | | | |
| | 24" HDPE DIPS DR 21 PS Transition Pipe | 150 | lf | $69 | $ | 10,400 |
| | 24" 45 Deg Bend | 5 | ea | $371 | $ | 1,900 |
| | **Subtotal, Piping** | | | | **$** | **2,755,600** |
| **4** | **Structural and Architectural** | | | | | |
| | Pump Station | | | | | |
| | Slab on grade (10'x20'x8") | 5 | cy | $250 | $ | 1,200 |
| | Pump building (timber frame, 8'x16') | 128 | sf | $200 | $ | 25,600 |
| | **Subtotal, Structural and Architectural** | | | | **$** | **26,800** |
| **5** | **Mechanical** | | | | | |
| | Pump Station | | | | | |
| | Vertical Turbine Pump (single pump, with no backup pum | 1 | ea | $126,000 | $ | 126,000 |
| | Building space heater and passive ventilation | 1 | ls | $5,000 | $ | 5,000 |
| | **Subtotal, Mechanical** | | | | **$** | **131,000** |

| Item | Description | Quantity | Unit | Unit cost, $ | | Cost, $ |
|---|---|---|---|---|---|---|
| **6** | **Electrical** | | | | | |
| | Pump Station | | | | | |
| | Pump station power and control panel | 1 | allow | $100,000 | $ | 100,000 |
| | 2-3" PVC direct bury conduit | 500 | lf | $20 | $ | 10,000 |
| | Power extension to pump station | 500 | lf | $20 | $ | 10,000 |
| | Meter & shutoff | 1 | ls | $500 | $ | 500 |
| | Electrical contingency allowance | 1 | ls | $2,500 | $ | 2,500 |
| | **Subtotal, Electrical and Control** | | | | **$** | **123,000** |
| **7** | **Intrumentation and Control** | | | | | |
| | Included in electrical in section 6 | | | | **$** | **-** |
| | **Subtotal, Intrumentation and Control** | | | | **$** | **-** |
| **8** | **Site Restoration** | | | | | |
| | Pump Station | | | | | |
| | Site landscaping | 1 | ls | $2,000 | $ | 2,000 |
| | Discharge Below Existing Weir | | | | | |
| | Key Logs | 3 | ea | $500 | $ | 1,500 |
| | Imported topsoil | 100 | cy | $15 | $ | 1,500 |
| | Wetland landscaping | 1 | ls | $2,000 | $ | 2,000 |
| | **Subtotal, Site Restoration** | | | | **$** | **7,000** |
| | Total Estimated Direct Costs (Rounded) | | | | $ | 3,401,000 |
| | General Contractor Overhead and Profit | 15.0% | | | $ | 510,000 |
| | Subtotal | | | | **$** | **3,911,000** |
| | Contingency | 30.0% | | | $ | 1,173,000 |
| | Sales Tax (City of Redmond) | 9.5% | | | $ | 483,000 |
| | Subtotal | | | | | **$5,567,000** |
| | Engineering (Design and Construction) | 15.0% | | | $ | 835,000 |
| | Administration | 10.0% | | | $ | 557,000 |
| | **Alternative 1 - Total Estimated Project Costs** | | | | | **$6,959,000** |

## Pump Deeper Groundwater to Transition Zone

This alternative would include installing a well to a depth of 30-50 feet on the south side of the river and pumping well water (assumed temperature of 10° C or 50° F) into pools or other locations downstream of the weir in the Transition Zone or designated locations for any proposed new channel. It is recommended that a new well be drilled south of the river to be out of the wellhead protection zone for the City of Redmond's water system in Marymoor Park. Based on withdrawal rates for the City's well system, it is assumed that up to 1 cfs could be pumped from the well on a sustained basis during the July 15 to September 15 time period. Monitoring data from the existing wells in Marymoor Park indicate that groundwater levels vary from approximately 5 to 11 feet below the ground surface over the year (King County 2013). Dissolved oxygen (DO) levels are likely to be low, so at discharge, this water would need to be aerated.

Primary features of this alternative include:

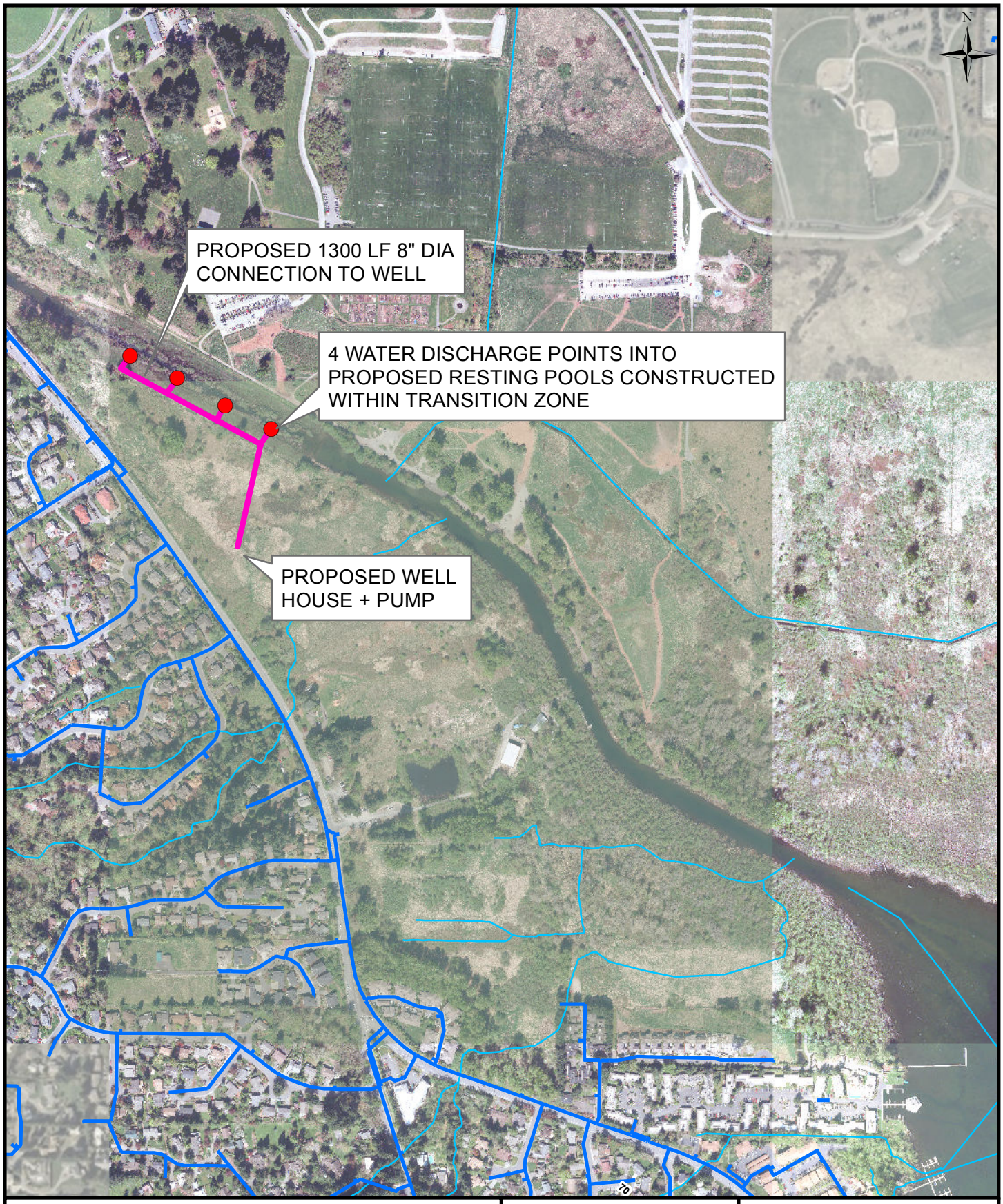
- Supply up to 1 cfs of groundwater to resting pools in July and August.
- Well house and pump south of the Sammamish River Transition Zone and outside the wellhead protection zone for the City of Redmond's water system.
- 1,300 LF of 8-inch pipe to deliver groundwater from well house to distribute within the Transition Zone.

The potential temperature benefits of this alternative are likely to be minimal as less than 1 cfs discharge to each pool could not likely provide any substantial cooling of the overall river temperatures as it would represent approximately 1-2% of the river flow and measurements of actual temperatures measured at the confluence of small tributaries to the Sammamish River in 2010 (R2 2010) with flows less than 1 cfs (tributary temperature approximately 17°C)indicated less than 0.5° C drop in temperature in the immediate vicinity of the tributary confluence. While a constructed pool could help to reduce the rate of mixing with river water, the potential cooling effect is still likely to be less than 1° C. See Appendix A, the temperature benefit is likely to be minimal, but could provide a small cooler water refuge for migrating fish.

All proposed features for this alternative would be located within King County-owned property (within Marymoor Park) and thus could easily be constructed and maintained. This concept could be implemented in conjunction with any proposed other restoration measures or channel reconfigurations and would likely be more sustainable if constructed on the outside of a meander bend in association with large wood to promote continued scour of the pools. Construction methods required for this concept are straight-forward and easy to build.

Potential risks or challenges of this concept include obtaining approval from the Department of Ecology and the City of Redmond to pump groundwater. Key risks include the potential effects on the City's water supply and whether 1 cfs could be sustainably pumped during the July-September time period. Discharge will need to be aerated to increase DO levels. Also, potential effects on wetlands should be evaluated, particularly for a well on the south (west) bank of the Sammamish River.

The planning level cost estimate for this concept is approximately $2.2 million, which includes the cost of drilling a new well. If the new well was drilled on the south (west) bank of the Sammamish River, there would be reduced costs for piping as compared to the distance from the existing wells on the north (east) bank. Operation and maintenance needs would include electricity for pumping and periodic maintenance of the pump, although well pumps are durable and long-lasting with minimal maintenance. The estimated net present value of operation and maintenance activities is $145,000 over 50 years.




Proposed Pools
Proposed Well
Proposed Pipe
Streams
Existing Water Line

King County

0 600 Feet

WILLOWMOOR PARK
CONCEPT 2
CONNECT TO
PROPOSED WELL

**Client:** T31746 King County - Willowmoor
**Project:** Task 6 Cold Water Supplementation
**Subject:** Concept Alternative Cost Estimate Details
Concept 2-Pumped Groundwater to Pools
**Date :** 6-Jun-14

TETRA TECH

| Item | Description | Quantity | Unit | Unit cost, $ | | Cost, $ |
|---|---|---|---|---|---|---|
| 1 | **Mobilization/Demobilization/Testing** | | | | | |
| | Assume 8% of subtotal for items 2-5 | 1 | ls | $70,800 | **$** | **70,800** |
| 2 | **Sitework** | | | | | |
| | Well Site | | | | | |
| | New well | 1 | ls | $50,000 | $ | 50,000 |
| | Site fencing, landscaping, driveway etc | 1 | ls | $75,000 | $ | 75,000 |
| | Erosion control | 1 | ls | $2,000 | $ | 2,000 |
| | Trench shoring | 1 | ls | $10,000 | $ | 10,000 |
| | Dewatering for pump station wet well | 14 | days | $500 | $ | 7,000 |
| | Transition Zone Pools | | | | | |
| | Transition Zone Resting Pools - sitework by others during channel reconfiguration project | | | | $ | - |
| | | | | | **$** | **144,000** |
| 3 | **Piping** | | | | | |
| | 8" HDPE pipe | 3,500 | lf | $30 | $ | 105,000 |
| | Pipe valves and appertenances | 1 | ls | $15,000 | $ | 15,000 |
| | Excavation Pipe Trench | 4,000 | cy | $20 | $ | 80,000 |
| | Pipe Trench Bedding | 2,500 | cy | $35 | $ | 87,500 |
| | Trench Restoration - Hydroseed | 0.75 | ac | $5,000 | $ | 3,800 |
| | River outfall locations energy dissipation & pool excavation | 1 | ls | $50,000 | $ | 50,000 |
| | 36" PVC C905 DR 25 Gravity Sewer | 0 | lf | $250 | $ | - |
| | **Subtotal, Piping** | | | | **$** | **341,300** |
| 4 | **Structural and Architectural** | | | | | |
| | Pump Builiding | 1 | ls | $300,000 | $ | 300,000 |
| | **Subtotal, Structural and Architectural** | | | | **$** | **300,000** |
| 5 | **Mechanical** | | | | | |
| | Pump 25 hp w/ controls, electric hook up, plumb, mech for pump | 1 | ls | $100,000 | $ | 100,000 |

| Item | Description | Quantity | Unit | Unit cost, $ | | Cost, $ |
|---|---|---|---|---|---|---|
| | **Subtotal, Mechanical** | | | | **$** | **100,000** |
| **6** | **Electrical** | | | | | |
| | Pump station power and control panel | 1 | allow | $100,000 | $ | 100,000 |
| | **Subtotal, Electrical and Control** | | | | **$** | **100,000** |
| **7** | **Intrumentation and Control** | | | | | |
| | Included in electrical in section 6 | | | | **$** | **-** |
| | **Subtotal, Intrumentation and Control** | | | | **$** | **-** |
| **8** | **Site Restoration** | | | | | |
| | Included in Section 3 pipe and Section 2 well site, above | | | | $ | - |
| | Transition Zone Resting Pools - restoration by others during channel reconfiguration project | | | | $ | - |
| | **Subtotal, Site Restoration** | | | | **$** | **-** |
| | Total Estimated Direct Costs (Rounded) | | | | $ | 1,056,000 |
| | General Contractor Overhead and Profit | 15.0% | | | $ | 158,000 |
| | Subtotal | | | | **$** | **1,214,000** |
| | Contingency | 30.0% | | | $ | 364,000 |
| | Sales Tax (City of Redmond) | 9.5% | | | $ | 150,000 |
| | Subtotal | | | | | **$1,728,000** |
| | Engineering (Design and Construction) | 15.0% | | | $ | 259,000 |
| | Administration | 10.0% | | | $ | 173,000 |
| | **Alternative 2 - Total Estimated Project Costs** | | | | | **$2,160,000** |

## Shallow Groundwater Trench Consolidation

This alternative is to concentrate shallow groundwater (less than 8 feet below ground surface) into a trench and/or perforated pipe, backfilled with high porosity fill, to discharge into constructed pools in the Transition Zone. Based on withdrawal rates from the City's water well system in Marymoor Park, it is assumed that the volume of shallow groundwater available is likely to be less than 1 cfs. Shallow piezometers have been installed by King County on the south (west) bank of the Sammamish River and monitoring data indicates that groundwater levels fluctuate from approximately 5 to 12 feet below ground surface (King County 2013). Groundwater temperatures are generally 10-11° C and DO levels are low (about 1 mg/l; King County monitoring data from 2013), so the discharge would need to be aerated.

Primary features of this alternative include the following:

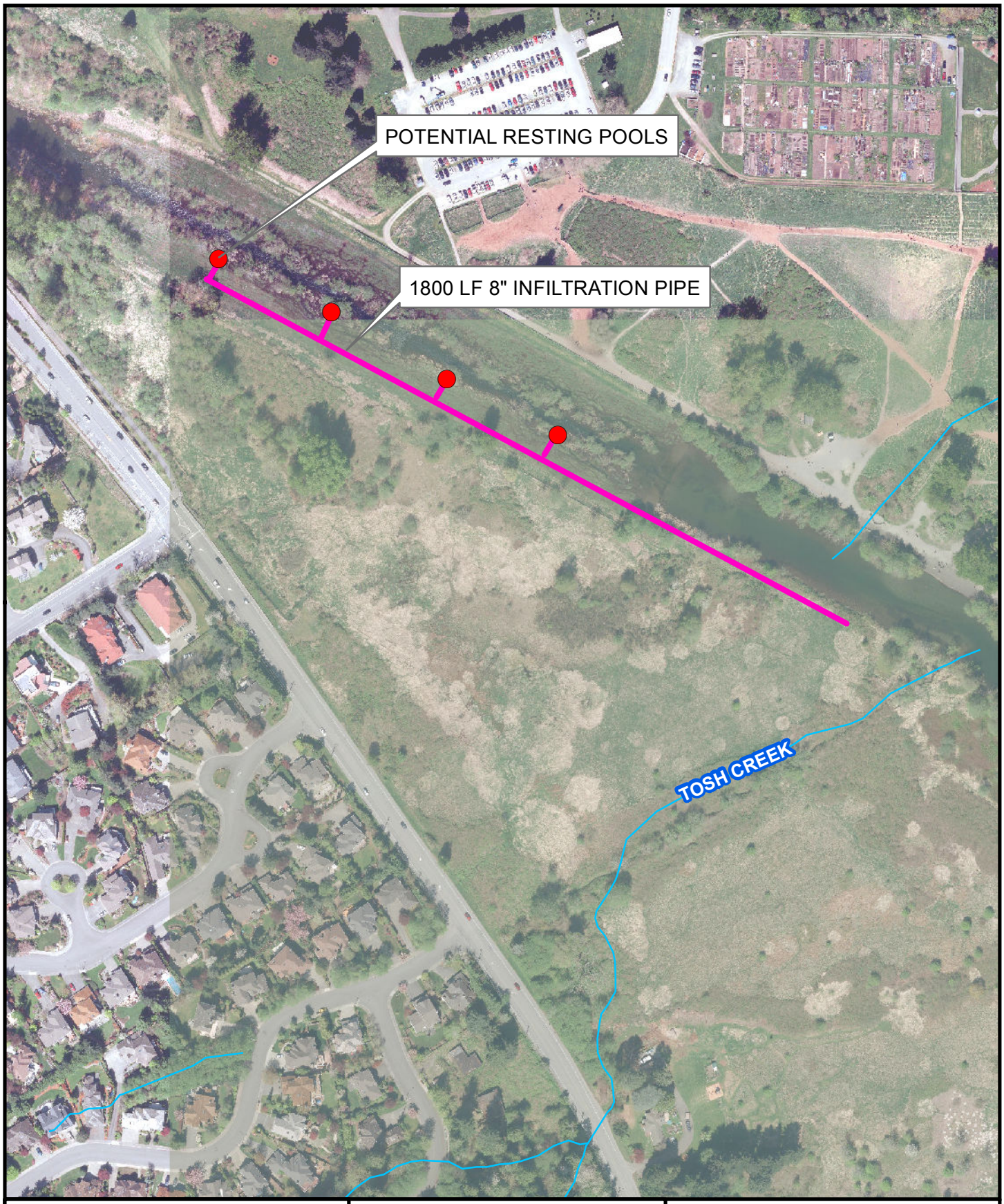
- Gravity discharge flows to resting pools.
- 1,800 LF 8-inch groundwater interception and infiltration piping.

The potential temperature benefits of this alternative are likely to be minimal as less than 1 cfs discharge to each pool could not likely provide any substantial cooling of the overall river temperatures as it would represent approximately 1-2% of the river flow and measurements of actual temperatures measured at the confluence of small tributaries to the Sammamish River in 2010 (R2 2010) with flows less than 1 cfs (tributary temperature approximately 17°C)indicated less than 0.5° C drop in temperature in the immediate vicinity of the tributary confluence. While a constructed pool could help to reduce the rate of mixing with river water, the potential cooling effect is still likely to be less than 1° C. See Appendix A, the temperature benefit is likely to be minimal, but could provide a small cooler water refuge for migrating fish.

All proposed features for this alternative would be located within King County-owned property (within Marymoor Park) and thus could easily be constructed and maintained. This concept could be implemented in conjunction with any proposed other restoration measures or channel reconfigurations and would likely be more sustainable if constructed on the outside of a meander bend in association with large wood to promote continued scour of the pools. Construction methods required for this concept are straight-forward and easy to build.

Potential risks or challenges of this concept include likely effects to wetlands on the south (west) bank of the Sammamish River. This concept could potentially "drain" wetlands by promoting and speeding up groundwater discharge to the river. At this time it is estimated that up to 9 acres of wetlands could be affected. A feasibility study to evaluate potential effects to wetlands is recommended. As there is also surface discharge of stormwater to the area, wetland hydrology is not entirely driven by groundwater levels. The discharge would need to be aerated to increase DO levels.

The planning level cost estimate for this concept is approximately $800,000. Operation and maintenance needs would include periodic removal of sediment/silt from the perforating pipes. The estimated net present value of operation and maintenance activities is $23,000 over 50 years.




Proposed Pools

Proposed Pipe

Streams

N

King County

0 250 Feet

WILLOWMOOR PARK
CONCEPT 3
SHALLOW GROUNDWATER
TRENCH TO POOLS

**T31746 King County - Willowmoor**
**Task 6 Cold Water Supplementation**
**Concept Alternative Cost Estimate Details**
**Concept 3-Shallow Groundwater Trench(es) to Pools**
**Date : 6-Jun-14**

| Item | Description | Quantity | Unit | Unit cost, $ | | Cost, $ |
|---|---|---|---|---|---|---|
| **1** | **Mobilization/Demobilization/Testing** | | | | | |
| | Assume 8% of subtotal for items 2-5 | 1 | ls | $26,900 | **$** | **26,900** |
| **2** | **Sitework** | | | | | |
| | Groundwater Trench(es) | | | | | |
| | Archaeological monitoring (SHPO standards) allowance | 1 | ls | $20,000 | $ | 20,000 |
| | Erosion control | 1 | ls | $2,000 | $ | 2,000 |
| | Clear & grub | 1 | ls | $2,000 | $ | 2,000 |
| | Excavation - Pipelines | 4,300 | cy | $15 | $ | 64,500 |
| | Haul waste to disposal | 8,000 | ton | $10 | $ | 80,000 |
| | Imported free draining fill - Pipeline | 8,000 | ton | $15 | $ | 120,000 |
| | Trench shoring | 1 | ls | $2,000 | $ | 2,000 |
| | Dewatering during trench work | 7 | days | $200 | $ | 1,400 |
| | Transition Zone Pools | | | | | |
| | Transition Zone Resting Pools - sitework by others during channel reconfiguration project | | | | $ | - |
| | **Subtotal, Sitework** | | | | **$** | **291,900** |
| **3** | **Piping** | | | | | |
| | Intake System | | | | | |
| | Transiton zone discharge assembly | 4 | ea | $250 | $ | 1,000 |
| | 8" perforated pipe | 2,000 | lf | $20 | $ | 40,000 |
| | Cleanouts | 5 | ea | $200 | $ | 1,000 |
| | Tosh Creek intake assembly | 1 | ea | $2,000 | $ | 2,000 |
| | **Subtotal, Piping** | | | | **$** | **44,000** |

| Item | Description | Quantity | Unit | Unit cost, $ | | Cost, $ |
|---|---|---|---|---|---|---|
| 4 | **Structural and Architectural** | | | | | |
| | Not applicable - no structures | | | | $ | - |
| | **Subtotal, Structural and Architectural** | | | | **$** | **-** |
| 5 | **Mechanical** | | | | | |
| | Not applicable - no mechanical system | | | | $ | - |
| | **Subtotal, Mechanical** | | | | **$** | **-** |
| 6 | **Electrical** | | | | | |
| | Not applicable - no electrical system | | | | $ | - |
| | **Subtotal, Electrical and Control** | | | | **$** | **-** |
| 7 | **Intrumentation and Control** | | | | | |
| | Not applicable - no I&C system | | | | **$** | **-** |
| | **Subtotal, Intrumentation and Control** | | | | **$** | **-** |
| 8 | **Site Restoration** | | | | | |
| | Surface restoration & landscaping | 1 | ls | $5,000 | $ | 5,000 |
| | Transition Zone Resting Pools - restoration by others during channel reconfiguration project | | | | $ | - |
| | **Subtotal, Site Restoration** | | | | **$** | **5,000** |
| | Total Estimated Direct Costs (Rounded) | | | | $ | 368,000 |
| | General Contractor Overhead and Profit | 15.0% | | | $ | 55,200 |
| | Subtotal | | | | **$** | **423,000** |
| | Contingency | 30.0% | | | $ | 127,000 |
| | Sales Tax (City of Redmond) | 9.5% | | | $ | 52,000 |
| | Subtotal | | | | | **$602,000** |
| | Engineering (Design and Construction) | 15.0% | | | $ | 90,000 |
| | Administration | 10.0% | | | $ | 60,000 |
| | **Alternative 3 - Total Estimated Project Costs** | | | | | **$752,000** |

## Potable Water to Discharge to Transition Zone

This alternative would include the purchase of potable City of Redmond water and pipe to discharge to pools constructed in the Transition Zone.

Primary elements of this alternative include:

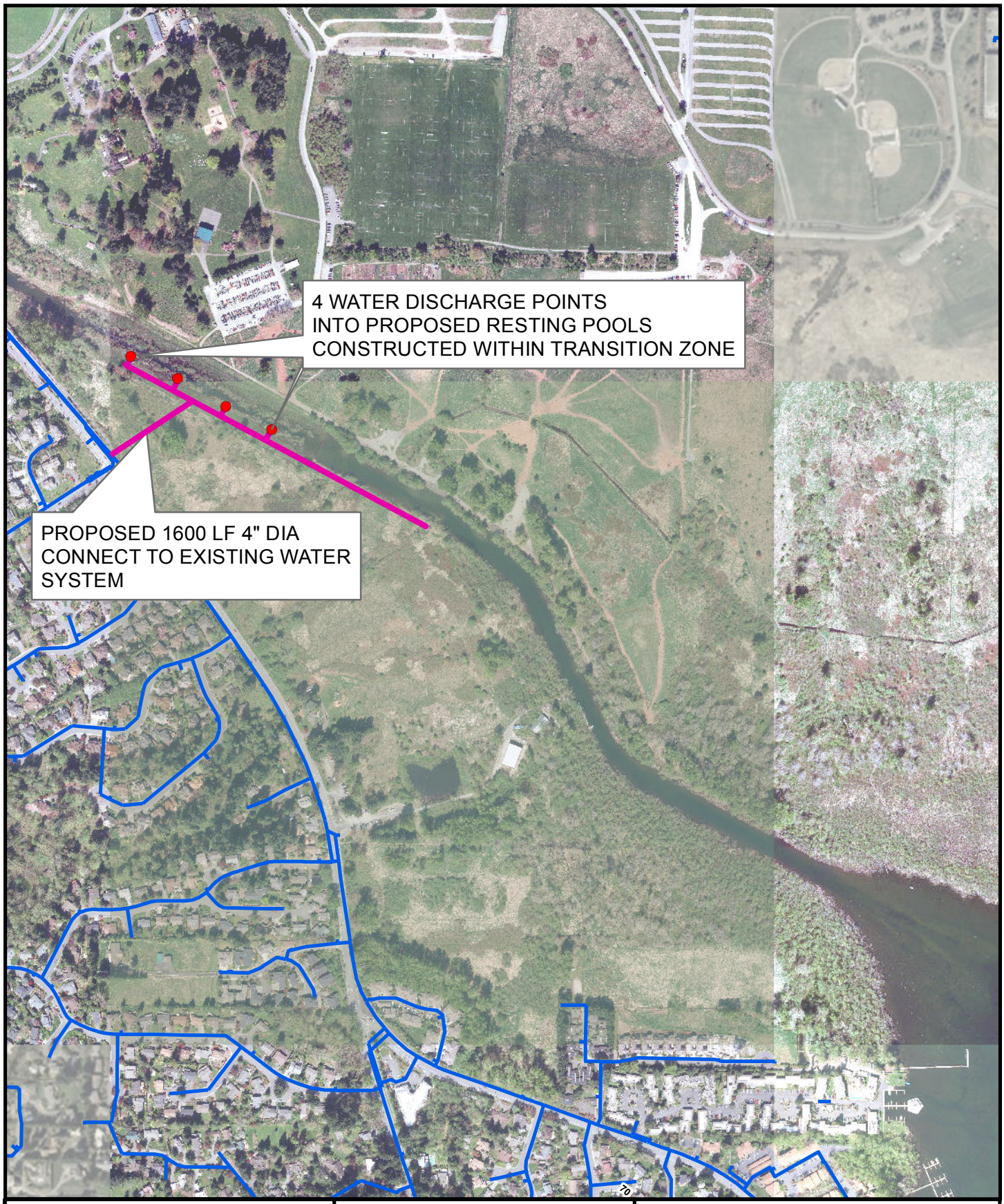
- Provide connection to potable water line in West Lake Sammamish Parkway.
- Install water meter box, 1,600 LF of 4-inch diameter pipe, and appurtenances to provide water to four pools within the transition zone of the Sammamish River.
- Supply up to 1 cfs of potable water (assume 10°C temperature) to resting pools in July and August.

The potential temperature benefits of this alternative are likely to be minimal as less than 1 cfs discharge to each pool could not likely provide any substantial cooling of the overall river temperatures as it would represent approximately 1-2% of the river flow and measurements of actual temperatures measured at the confluence of small tributaries to the Sammamish River in 2010 (R2 2010) with flows less than 1 cfs (tributary temperature approximately 17°C)indicated less than 0.5° C drop in temperature in the immediate vicinity of the tributary confluence. While a constructed pool could help to reduce the rate of mixing with river water, the potential cooling effect is still likely to be less than 1° C. See Appendix A, the temperature benefit is likely to be minimal, but could provide a small cooler water refuge for migrating fish.

All proposed features for this alternative would be located within King County-owned property (within Marymoor Park) and thus could easily be constructed and maintained. This concept could be implemented in conjunction with any proposed other restoration measures or channel reconfigurations and would likely be more sustainable if constructed on the outside of a meander bend in association with large wood to promote continued scour of the pools. Construction methods required for this concept are straight-forward and easy to build.

Potential risks or challenges of this concept include the high cost of potable water and whether 1 cfs could be reasonably provided by the City in the critical time period when other City water demands are high. Also, as potable water is treated for human consumption, chlorine and other constituents may be present – would likely need to remove via filtration or aeration prior to discharge to the river.

The planning level cost estimate for this concept is approximately $900,000. Operation and maintenance needs would include purchasing potable water for 60 days each year at commercial rates. The estimated net present value of operation and maintenance activities is $4.5 million over 50 years.




Proposed Pools

Proposed Pipe

Existing Water Line

King County

N

0 600 Feet

WILLOWMOOR PARK
CONCEPT 4
CONNECT TO EXISTING
WATER SYSTEM

**T31746 King County - Willowmoor**
**Task 6 Cold Water Supplementation**
**Concept Alternative Cost Estimate Details**
**Concept 4-Purchase Potable Water & Pipe To Pools**
**Date : 6-Jun-14**

TETRA TECH

| Item | Description | Quantity | Unit | Unit cost, $ | Cost, $ |
|---|---|---|---|---|---|
| 1 | **Mobilization/Demobilization/Testing** | | | | |
| | Assume 8% of subtotal for items 2-5 | 1 | ls | $30,800 | **$ 30,800** |
| 2 | **Sitework** | | | | |
| | Water Meter 4" | 1 | ls | $10,000 | $ 10,000 |
| | City of Redmond Connection Fee | 1 | ls | $155,000 | $ 155,000 |
| | Trench shoring | 1 | ls | $5,000 | $ 5,000 |
| | Dewatering for pipeline construction | 30 | days | $500 | $ 15,000 |
| | Transition Zone Pools | | | | |
| | Transition Zone Resting Pools - sitework by others during channel reconfiguration project | | | | $ - |
| | **Subtotal, Sitework** | | | | **$ 185,000** |
| 3 | **Piping** | | | | |
| | 4" HDPE | 2,000 | lf | $15 | $ 30,000 |
| | Pipe valves and appertenances | 1 | ls | $15,000 | $ 15,000 |
| | Excavation - Pipe Trench | 2,500 | cy | $20 | $ 50,000 |
| | Backfill Pipe Bedding | 1,500 | cy | $35 | $ 52,500 |
| | Trench Restoration - Hydroseed | 0.50 | ac | $5,000 | $ 2,500 |
| | River outfall locations energy dissipation & pool excavatio | 1 | ls | $50,000 | $ 50,000 |
| | **Subtotal, Piping** | | | | **$ 200,000** |
| 4 | **Structural and Architectural** | | | | |
| | Not applicable - no structures | | | | $ - |
| | **Subtotal, Structural and Architectural** | | | | **$ -** |
| 5 | **Mechanical** | | | | |
| | Not applicable - no mechanical system | | | | $ - |
| | **Subtotal, Mechanical** | | | | **$ -** |

| Item | Description | Quantity | Unit | Unit cost, $ | Cost, $ |
|---|---|---|---|---|---|
| **6** | **Electrical** | | | | |
| | Not applicable - no electrical system | | | | $ - |
| | **Subtotal, Electrical and Control** | | | | **$ -** |
| **7** | **Intrumentation and Control** | | | | |
| | Not applicable - no I&C system | | | | **$ -** |
| | **Subtotal, Intrumentation and Control** | | | | **$ -** |
| **8** | **Site Restoration** | | | | |
| | Included in Section 3 piping | | | | $ - |
| | Transition Zone Resting Pools - restoration by others during channel reconfiguration project | | | | $ - |
| | **Subtotal, Site Restoration** | | | | **$ -** |

| | | |
|---|---|---|
| Total Estimated Direct Costs (Rounded) | | $ 416,000 |
| General Contractor Overhead and Profit | 15.0% | $ 62,400 |
| Subtotal | | **$ 478,000** |
| Contingency | 30.0% | $ 143,000 |
| Sales Tax (City of Redmond) | 9.5% | $ 59,000 |
| Subtotal | | **$680,000** |
| Engineering (Design and Construction) | 15.0% | $ 102,000 |
| Administration | 10.0% | $ 68,000 |
| **Alternative 4 - Total Estimated Project Costs** | | **$850,000** |

## Heat Pump Exchange System

This alternative would withdraw 5 cfs (10 or 20 cfs could also be considered, but is not analyzed here) of water from the lake outlet channel above the weir and pump it into a heat pump exchange system in the ground for cooling and then pipe to discharge at the weir outlet. The discharge (assumed at this time to be cooled to 18° C) would generally replace 5 cfs of passive outflow from the Lake, 24 hours per day, during the critical time period (July to September). Concept feasibility of maximizing the contact time with cooler groundwater was initially explored at 5 cfs to limit the number and system head loss of parallel pipes in the proposed system and limit the extent of wetland construction disturbances. It is likely that this alternative could be scaled up to 10 and possibly 20 cfs, and potentially greater cooling could also be achieved.

Primary features of this alternative include:

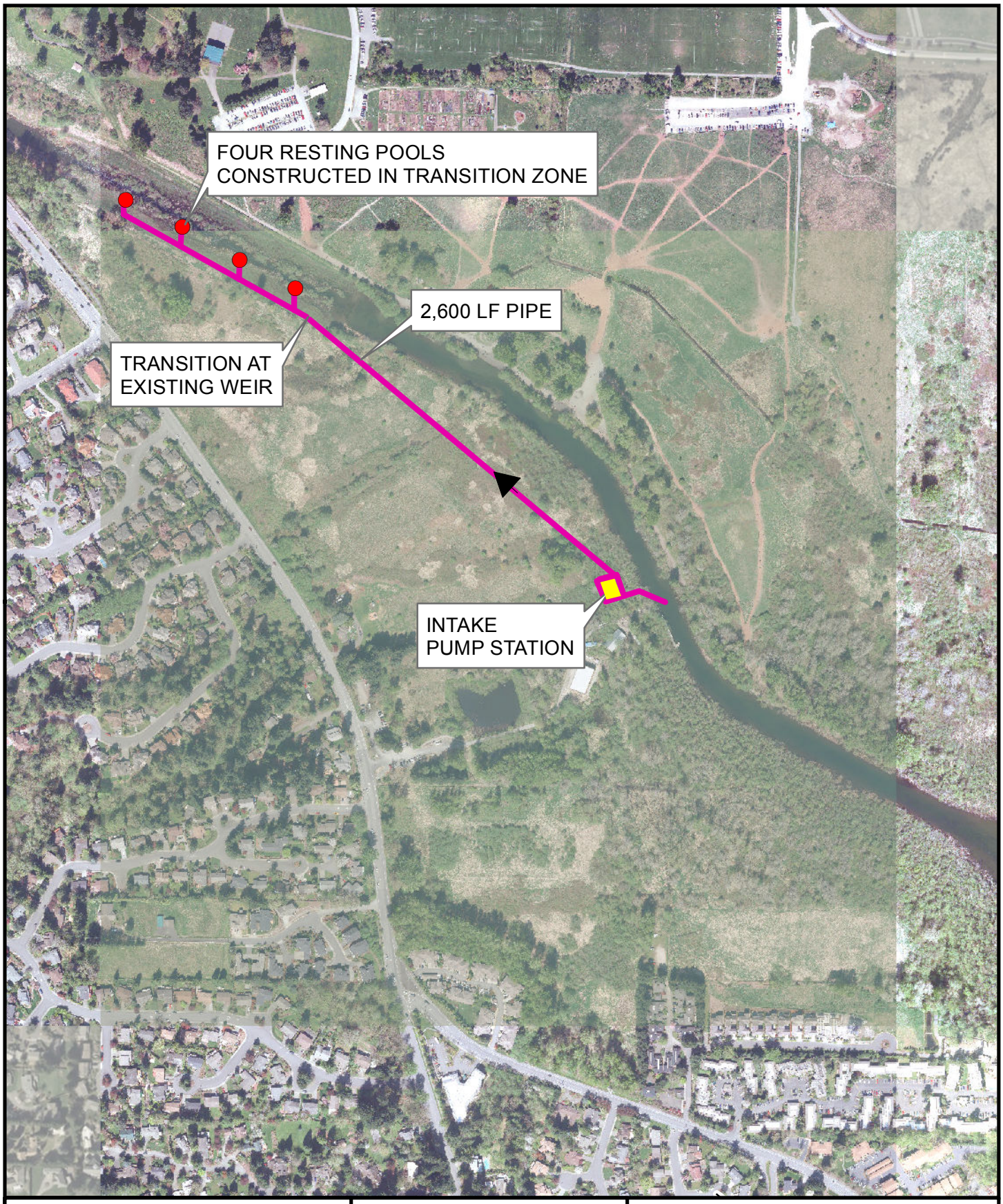
- Submerged intake with upland pump station proposed near Sammamish Rowing Association river access for existing power and access purposes.
- Upland discharge piping with trench construction to heat exchange transition structure to split flow into 1500 LF of heat exchange with colder ambient groundwater conditions.
- Heat exchange system constructed in excavated trench with 4 x 3 cross section of 6-inch pipelines, backfilled with high porosity fill, to second transition structure before continuing as single pipe trench construction downstream.
- Four pipes convey cooled water to below grade discharge at constructed resting pools.

The potential temperature benefits of this alternative are likely to be moderate. Modeling of 5 cfs of cold input (Appendix B) could reduce the average thermal stress in the upper segment (above Bear Creek) by 12% (16°C threshold) and 85% (21°C threshold). This provides substantial cooling in the upper river, but effects are negligible further downstream because of the low volume.

All proposed features for this alternative would be located within King County-owned property (within Marymoor Park) and thus could easily be constructed and maintained. This concept could be implemented in conjunction with any proposed other restoration measures or channel reconfigurations as the discharge could occur at the existing or a reconfigured weir for the low-flow channel. Construction methods required for this concept would necessitate excavation for the heat exchange system and piping which could affect existing wetlands and trees.

Potential risks or challenges of this concept include potential construction and pump operation disturbances at the rowing club, wider construction disturbances for heat exchange piping across the existing wetlands, and a moderate to high level of operation and maintenance activities and costs.

The planning level cost estimate for this concept is approximately $2.6 million. Operation and maintenance needs would include electricity for pumping and annual pump start-up/maintenance/shut-down and flushing of the heat exchange piping and periodic sediment removal from pipe transitions. The estimated net present value of operation and maintenance activities is $142,000 over 50 years.




Proposed Pools

Proposed Pipe

King County

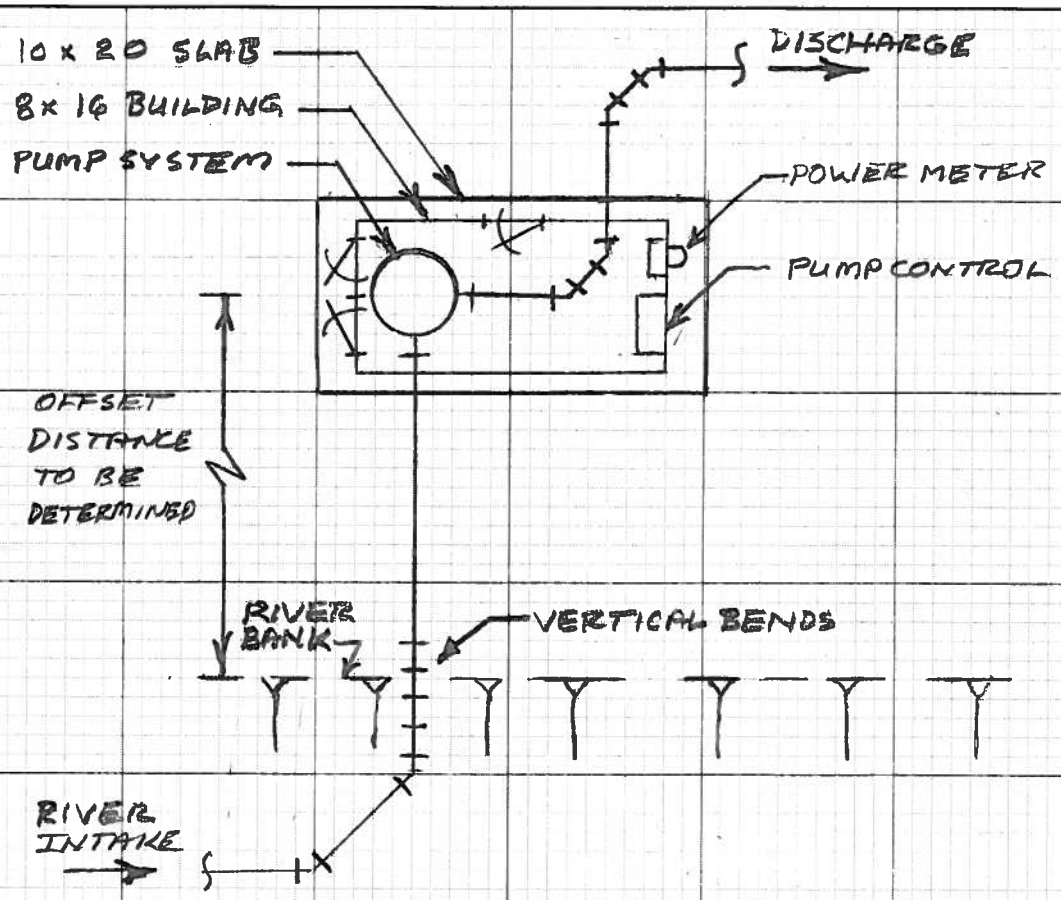
N

0 500 Feet

WILLOWMOOR PARK
CONCEPT 5
HEAT EXCHANGE SYSTEM

CLIENT: KING COUNTY | PROJECT: WILLOWMOOR

SUBJECT: SAMMAMISH RIVER INTAKE PUMP STATION

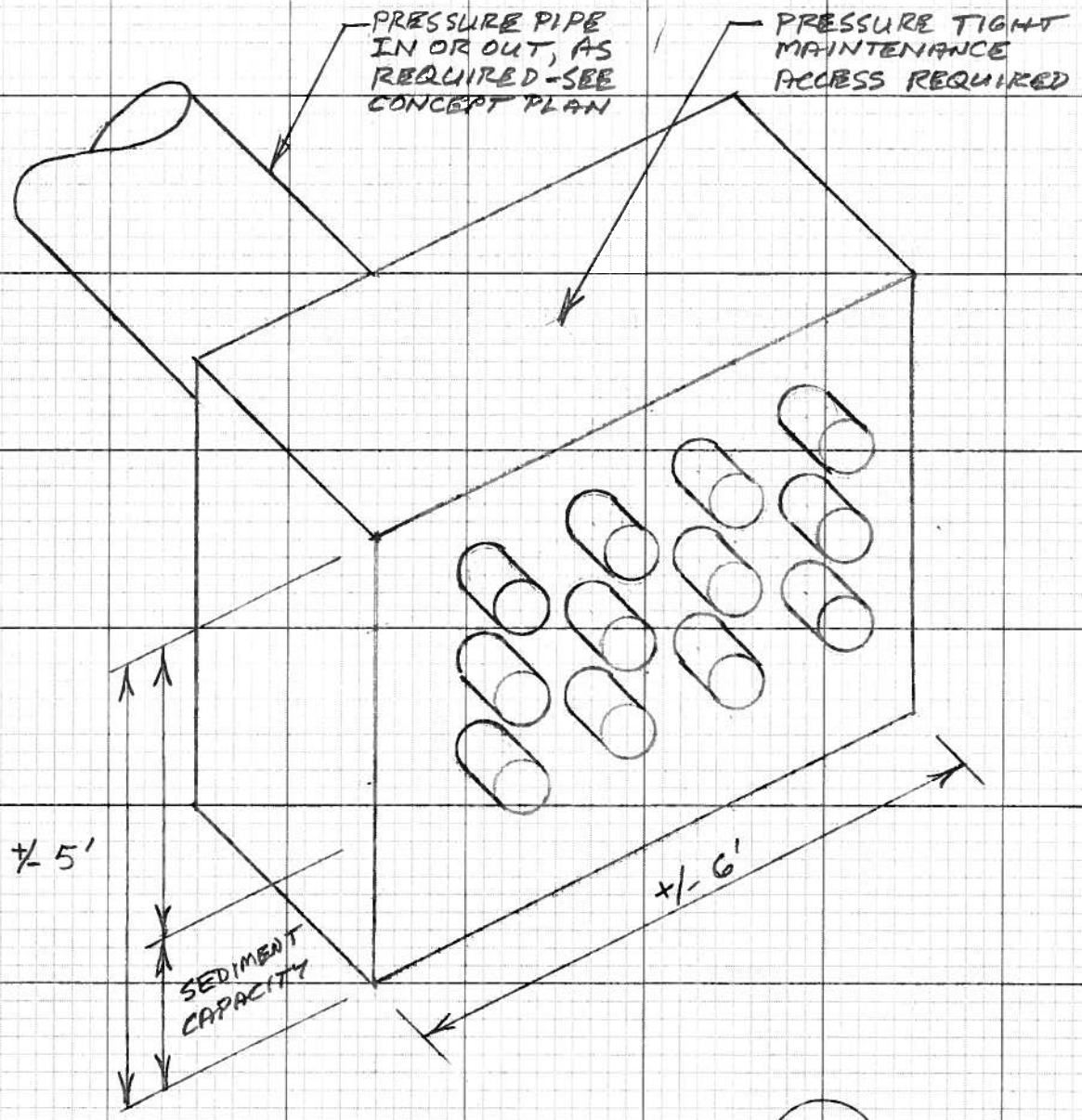



PUMP STATION - PLAN

| TETRA TECH | T31746 | HOPKINSON | 3/14 | |
|---|---|---|---|---|
| | JOB NO. | BY | DATE | SHEET NO. |

| CLIENT: KING COUNTY | PROJECT: WILLOWMOOR |
|---|---|

SUBJECT: HEAT EXCHANGE TRANSITION STRUCTURE




CONCEPT SKETCH
NTS

| TETRA TECH | T31746 | HOPKINSON | 3/14 | |
|---|---|---|---|---|
| | JOB NO. | BY | DATE | SHEET NO. |

**T31746 King County - Willowmoor**
**Task 6 Cold Water Supplementation**
**Concept Alternative Cost Estimate Details**
**Concept 5-Pump Lake Water To Heat Exchange System**
**Date : 6-Jun-14**

| Item | Description | Quantity | Unit | Unit cost, $ | | Cost, $ |
|---|---|---|---|---|---|---|
| **1** | **Mobilization/Demobilization/Testing** | | | | | |
| | Assume 8% of subtotal for items 2-5 | 1 | ls | $86,100 | **$** | **86,100** |
| **2** | **Sitework** | | | | | |
| | Pump Site | | | | | |
| | Archaeological monitoring (SHPO standards) allowance | 1 | ls | $10,000 | $ | 10,000 |
| | Erosion control | 1 | ls | $5,000 | $ | 5,000 |
| | Clear & grub | 1 | ls | $5,000 | $ | 5,000 |
| | Trench shoring | 1 | ls | $5,000 | $ | 5,000 |
| | Excavation - Pipelines | 640 | cy | $15 | $ | 9,600 |
| | Excavation - Pump station | 40 | cy | $20 | $ | 800 |
| | Turbidity Curtain | 200 | lf | $15 | $ | 3,000 |
| | Haul waste to disposal | 1,300 | ton | $10 | $ | 13,000 |
| | Imported fill - Pipeline & Pump Station | 1,300 | ton | $15 | $ | 19,500 |
| | Dewatering for pipeline and pump station | 5 | days | $200 | $ | 1,000 |
| | Crushed Surfacing Base Course | 100 | cy | $30 | $ | 3,000 |
| | Upland Pipe From Pump Station To Heat Exchange To Transition Zone Discharge | | | | | |
| | Archaeological monitoring (SHPO standards) allowance | 1 | ls | $10,000 | $ | 10,000 |
| | Erosion control | 1 | ls | $2,000 | $ | 2,000 |
| | Clear & grub | 1 | ls | $2,000 | $ | 2,000 |
| | Trench shoring | 1 | ls | $2,000 | $ | 2,000 |
| | Excavation - Conveyance Pipelines | 2,300 | cy | $15 | $ | 34,500 |
| | Excavation - Heat Exchange Pipe Trench | 3,200 | cy | $15 | $ | 48,000 |
| | Haul waste to disposal | 10,200 | ton | $10 | $ | 102,000 |
| | Imported fill - Pipeline | 10,200 | ton | $15 | $ | 153,000 |
| | Dewatering for pipeline construction | 2 | days | $200 | $ | 400 |
| | Transition Zone Pools | | | | | |
| | Transition Zone Resting Pools - sitework by others during channel reconfiguration project | | | | $ | - |
| | **Subtotal, Sitework** | | | | **$** | **428,800** |

| | | | | | | |
|---|---|---|---|---|---|---|
| **3** | **Piping** | | | | | |
| | Intake To Pump Station | | | | | |
| | Fish Screen Assembly | 1 | ls | $2,000 | $ | 2,000 |
| | 16" HDPE DIPS DR 21 Intake Assembly | 1 | ls | $3,000 | $ | 3,000 |
| | 16" HDPE DIPS DR 21 Intake Pipe | 130 | lf | $66 | $ | 8,600 |
| | 36" Precast Pipe Anchors | 2 | ea | $240 | $ | 500 |
| | Work boat for pipe intake positioning | 2 | day | $200 | $ | 400 |
| | 16x12 Reducer | 1 | ea | $1,575 | $ | 1,600 |
| | 12" HDPE DIPS DR 21 PS Transition Pipe | 20 | lf | $35 | $ | 700 |
| | 12" Valve | 1 | ea | $5,400 | $ | 5,400 |
| | 16" 45 Deg Bend | 4 | ea | $1,575 | $ | 6,300 |
| | Upland Pipe From Pump Station To Heat Exchange To Transition Zone Discharge | | | | | |
| | 12" HDPE DIPS DR 21 PS Transition Pipe | 20 | lf | $35 | $ | 700 |
| | 12" Valve | 1 | ea | $5,400 | $ | 5,400 |
| | 16x12 Reducer | 1 | ea | $1,575 | $ | 1,600 |
| | 16" 45 Deg Bend | 4 | ea | $1,575 | $ | 6,300 |
| | 16" HDPE DIPS DR 21 Discharge Pipe | 1,100 | lf | $66 | $ | 72,600 |
| | Heat Exchange Pipe Transition | 2 | ea | $5,000 | $ | 10,000 |
| | 6" Heat Exchange Pipe | 18,000 | ea | $15 | $ | 270,000 |
| | Transition Zone Pipe Discharge to Pools | | | | | |
| | 16x6 Wye | 4 | ea | $1,575 | $ | 6,300 |
| | 16" Cleanout/Blowoff | 1 | ea | $1,575 | $ | 1,600 |
| | 6" Valve | 4 | ea | $1,300 | $ | 5,200 |
| | 6" Distribution Pipe | 600 | lf | $15 | $ | 9,000 |
| | **Subtotal, Piping** | | | | **$** | **415,200** |
| **4** | **Structural and Architectural** | | | | | |
| | Pump Station | | | | | |
| | Slab on grade (10'x20'x8") | 5 | cy | $250 | $ | 1,200 |
| | Pump building (timber frame, 8'x16') | 128 | sf | $200 | $ | 25,600 |
| | **Subtotal, Structural and Architectural** | | | | **$** | **26,800** |

| | | | | | | |
|---|---|---|---|---|---|---|
| **5** | **Mechanical** | | | | | |
| | Pump Station | | | | | |
| | Pump System | 1 | ea | $200,000 | $ | 200,000 |
| | Building space heater and passive ventilation | 1 | ls | $5,000 | $ | 5,000 |
| | **Subtotal, Mechanical** | | | | **$** | **205,000** |
| **6** | **Electrical** | | | | | |
| | Pump Station | | | | | |
| | Pump station power and control panel | 1 | allow | $75,000 | $ | 75,000 |
| | 2-3" PVC direct bury conduit | 500 | lf | $20 | $ | 10,000 |
| | Power extension to pump station | 500 | lf | $20 | $ | 10,000 |
| | Meter & shutoff | 1 | ls | $500 | $ | 500 |
| | Electrical contingency allowance | 1 | ls | $2,500 | $ | 2,500 |
| | **Subtotal, Electrical and Control** | | | | **$** | **98,000** |
| **7** | **Intrumentation and Control** | | | | | |
| | Included in electrical in section 6 | | | | **$** | **-** |
| | **Subtotal, Intrumentation and Control** | | | | **$** | **-** |
| **8** | **Site Restoration** | | | | | |
| | Pump Station | | | | | |
| | Site landscaping | 1 | ls | $2,000 | $ | 2,000 |
| | Upland Piping | | | | | |
| | Surface restoration & landscaping | 1 | ls | $10,000 | $ | 10,000 |
| | Discharge Site | | | | | |
| | Transition Zone Resting Pools - restoration by others during channel reconfiguration project | | | | $ | - |
| | **Subtotal, Site Restoration** | | | | **$** | **12,000** |

| | | | |
|---|---|---|---|
| Total Estimated Direct Costs (Rounded) | | $ | 1,272,000 |
| General Contractor Overhead and Profit | 15.0% | $ | 191,000 |
| Subtotal | | **$** | **1,463,000** |
| Contingency | 30.0% | $ | 439,000 |
| Sales Tax (City of Redmond) | 9.5% | $ | 181,000 |
| Subtotal | | | **$2,083,000** |
| Engineering (Design and Construction) | 15.0% | $ | 312,000 |
| Administration | 10.0% | $ | 208,000 |
| **Alternative 1 - Total Estimated Project Costs** | | | **$2,603,000** |

## Pump Lake Outlet Water to Hyporheic Flow System

This alternative would pump 5 cfs of water from the lake outlet channel to a gravel infiltration gallery/trench system for return via gravel-filed channels (i.e. hyporheic flow) to pools constructed in the Transition Zone. This alternative could be scaled up to higher volumes (for example 10 cfs, or possibly 20 cfs) that could provide more cooling effects.

Primary features of this alternative include:

- Submerged intake with upland pump station proposed near Sammamish Rowing Association river access for existing power and access purposes.
- Submerged discharge piping in Sammamish River to upland trench transition at existing weir.
- Trench excavation of 800 LF of pipeline from the river to constructed infiltration trenches.
- Excavate 4 gravel backfilled infiltration trenches for flow to pools within the Transition Zone

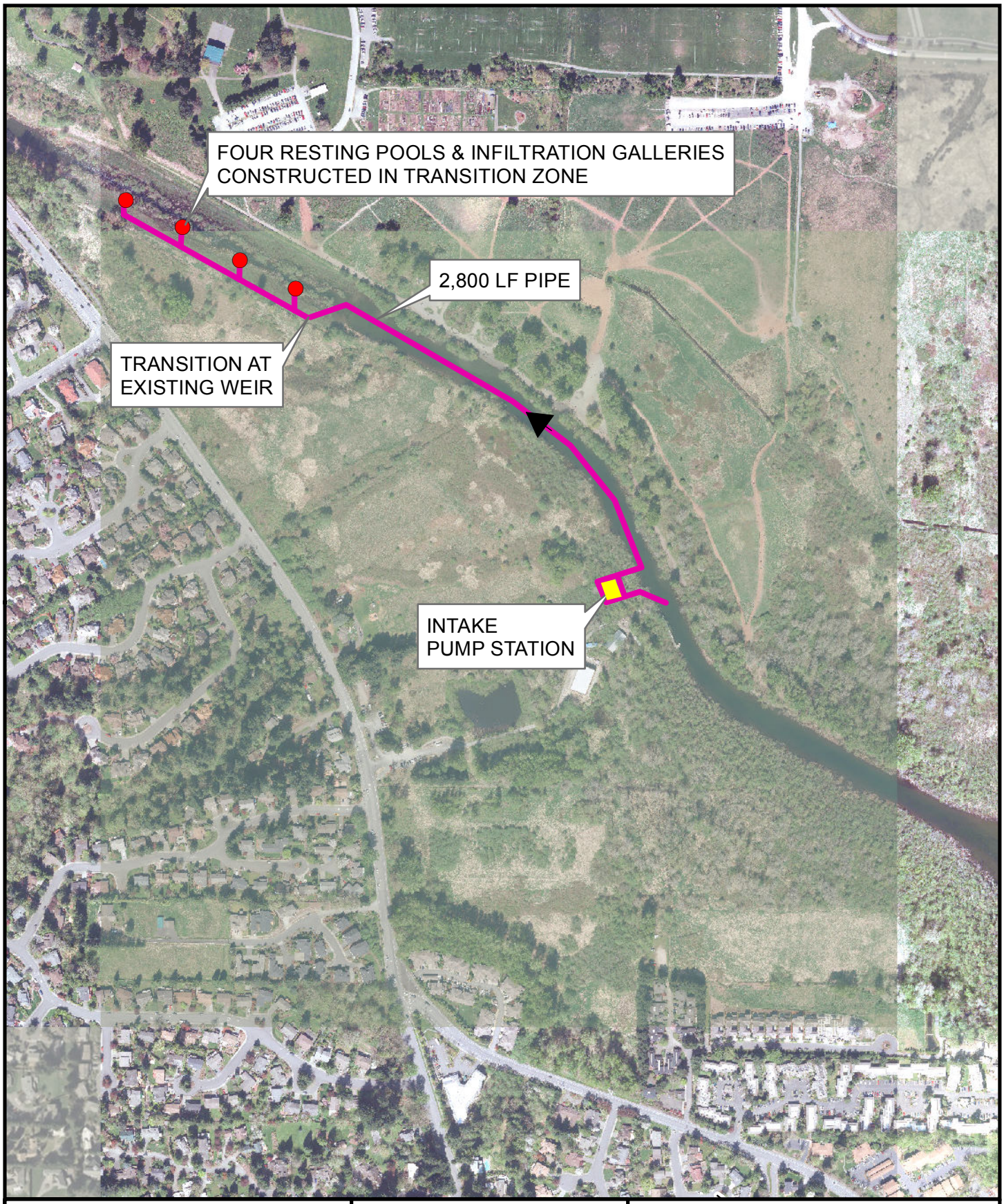
The potential temperature benefits of this alternative are likely to be moderate. Modeling of 5 cfs of cold input (Appendix B) could reduce the average thermal stress in the upper segment (above Bear Creek) by 12% (16°C threshold) and 85% (21°C threshold). This provides substantial cooling in the upper river, but effects are negligible further downstream because of the low volume. Investigations of hyporheic cooling from gravel bars in the Clackamas River (Grant et al. 2006) indicated residence time of only 12 hours could provide approximately 3°C of cooling; however, the scale of the flow going through the gravel bars was less than 0.5% of the river flow and did not provide any substantial cooling of the river. Based on the results considered for the 10 cfs discharge in Alternative 1, there is the potential to reduce overall river temperatures below 20°C for a few hundred feet. Particularly if this alternative was combined with a secondary channel/pool system in the floodplain, the extensive shading from the riparian zone could extend this benefit further downstream. The gravel trenches are also likely to provide a pathway for discharge of existing groundwater to the pools, essentially concentrates groundwater similar to Concept Alternative 3. Another variation that could be evaluated is the extension of the hyporheic concept, perforated pipe discharging to gravel trenches, the full length of the conveyance piping parallel to the Transition Zone. The intent would be to combine the benefits of the Concept 6 pumped flow with the passive groundwater collection of Concept 3 and provide more contact time with cooler groundwater.

All proposed features for this alternative would be located within King County-owned property (within Marymoor Park) and thus could easily be constructed and maintained. This concept could be implemented in conjunction with any proposed other restoration measures or channel reconfigurations as the discharge could occur at pools in the Transition Zone or to pools in the floodplain in a multiple channel plan. Construction of a submerged pipe in the river and trench excavation in non-wetlands would reduce environmental impacts; could also easily be constructed as a buried pipe via trench through uplands as an alternative.

Potential risks or challenges of this concept include the possibility that more than a minor amount of the pumped volume discharges into the groundwater table and does not readily return to the river (or returns after the critical time period). A feasibility analysis of residence time and potential losses into

the natural floodplain soils is recommended. The trenches might provide a conduit for natural groundwater flow into the pools, although potential effects to wetlands could also occur from more rapid draining.

The planning level cost estimate for this concept is approximately $2.0 million. Operation and maintenance needs would include pumping costs (electricity), periodic pump maintenance, and periodic clean out of fine sediments or organic material that may accumulate in the gravel trenches. The estimated net present value of operation and maintenance activities is $62,000 over 50 years.




Proposed Pools

Proposed Pipe

King County

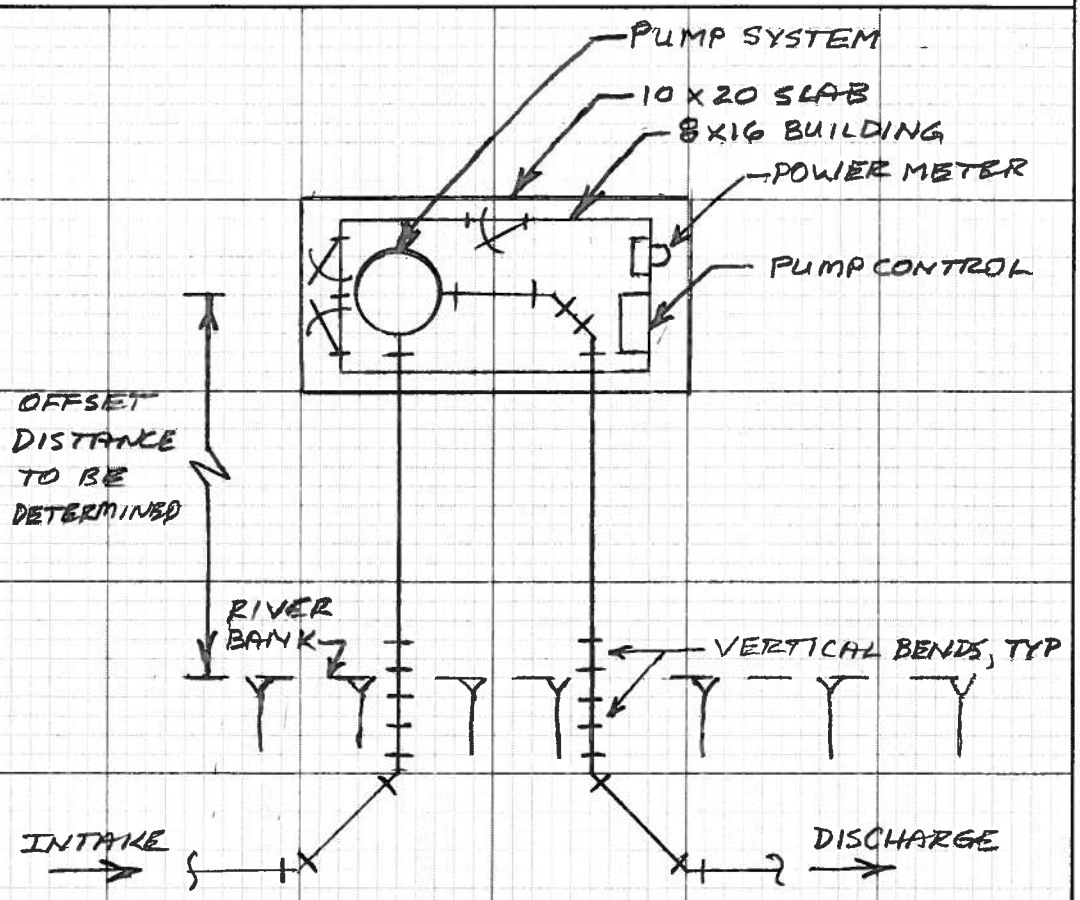
N

0 500 Feet

WILLOWMOOR PARK
CONCEPT 6
INFILTRATION GALLERY /
HYPOPHERIC DISCHARGE

| CLIENT: KING COUNTY | PROJECT: WILLOWMOOR |
|---|---|

SUBJECT: SAMMAMISH RIVER INTAKE PUMP STATION

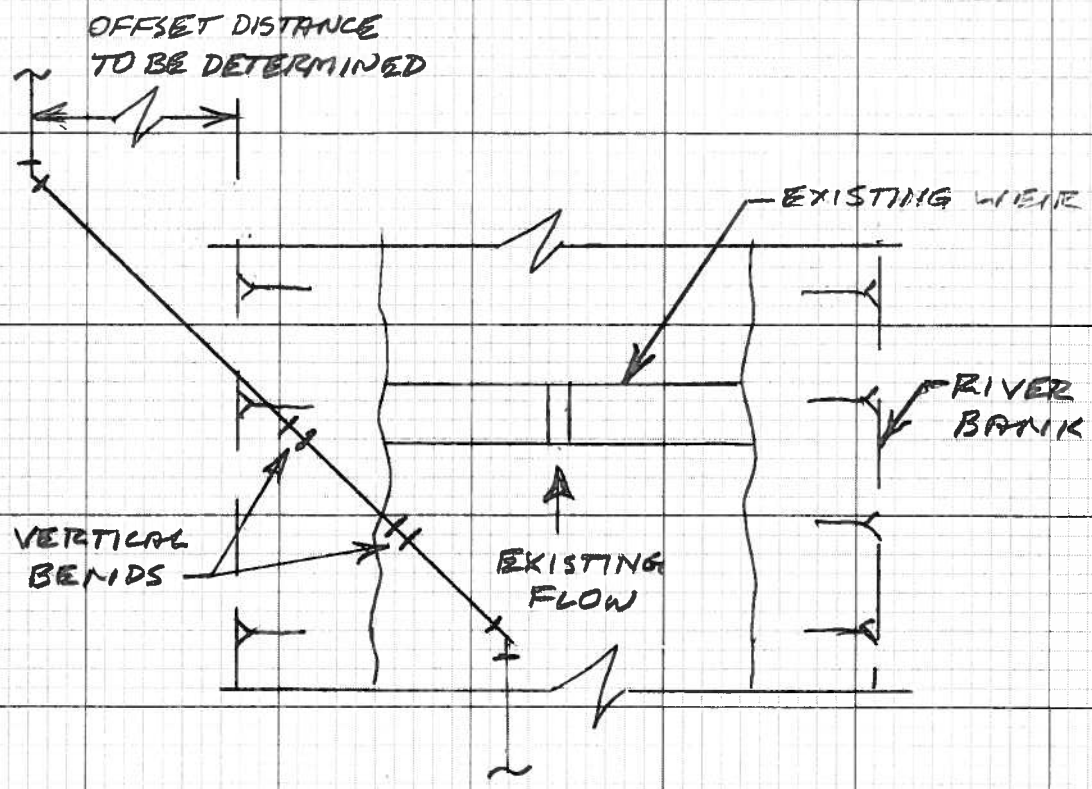



PUMP STATION - PLAN

| TETRA TECH | T31746 | HOPKINSON | 3/14 | |
|---|---|---|---|---|
| | JOB NO. | BY | DATE | SHEET NO. |

| CLIENT: KING COUNTY | PROJECT: WILLOWMOOR |
|---|---|

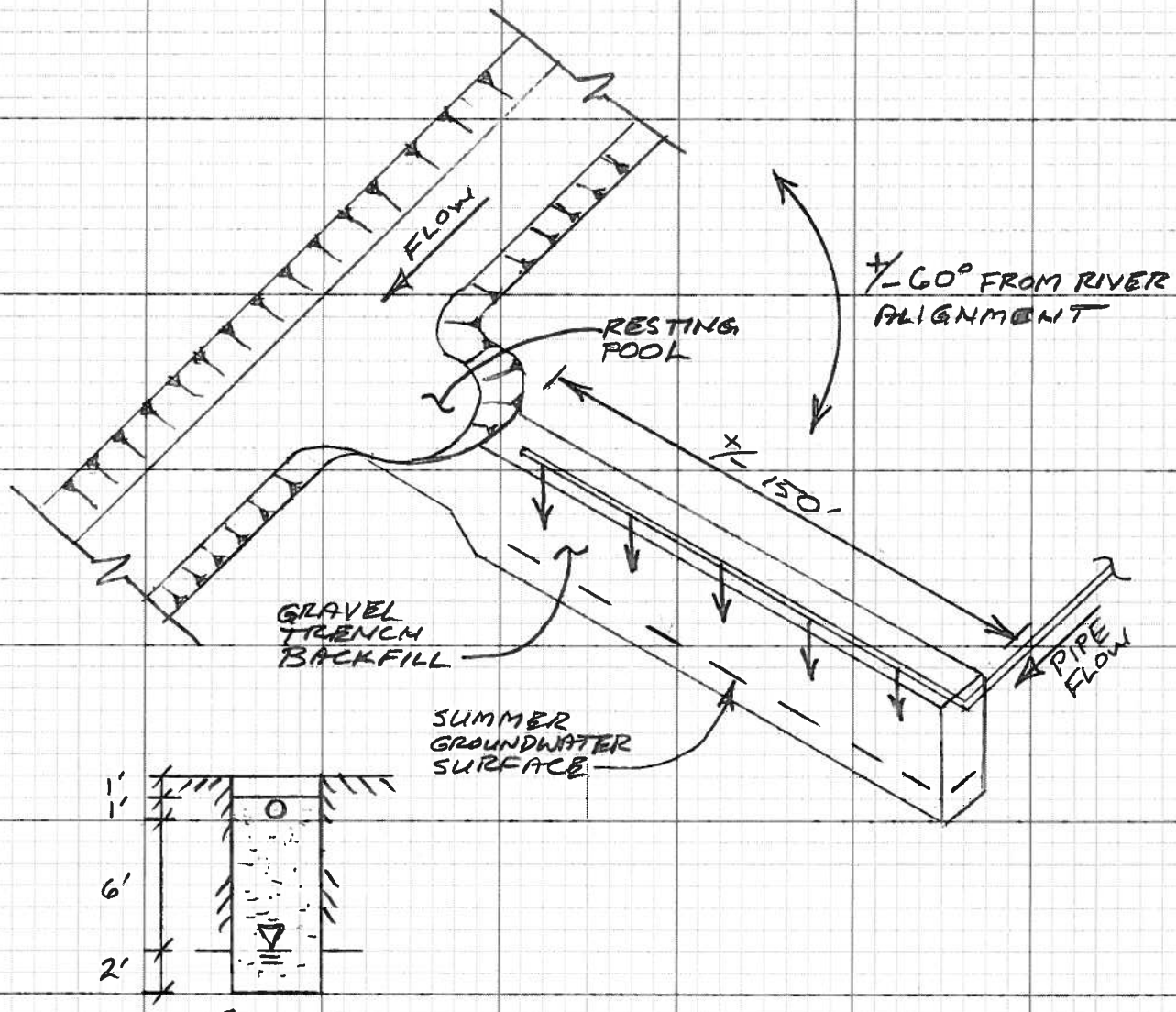
SUBJECT: IN RIVER TO UPLAND TRANSITION




PIPE TRANSITION AT WEIR - PLAN

| TETRA TECH | T31746 | HOPKINSON | 3/14 | |
|---|---|---|---|---|
| | JOB NO. | BY | DATE | SHEET NO. |

| CLIENT: KING COUNTY | PROJECT: WILLOWMOOR |
|---|---|
| SUBJECT: HYPORHEIC DISCHARGE CONCEPT | |







SECTION

CONCEPT SKETCH
NTS

| TETRA TECH | T31746 | HOPKINSON | 3/14 | |
|---|---|---|---|---|
| | JOB NO. | BY | DATE | SHEET NO. |

**T31746 King County - Willowmoor**
**Task 6 Cold Water Supplementation**
**Concept Alternative Cost Estimate Details**
**Concept 6-Pump Lake Water To Hyporheic Discharge**
**Date : 6-Jun-14**

TETRA TECH

| Item | Description | Quantity | Unit | Unit cost, $ | Cost, $ |
|---|---|---|---|---|---|
| **1** | **Mobilization/Demobilization/Testing** | | | | |
| | Assume 8% of subtotal for items 2-5 | 1 | ls | $62,800 | **$ 62,800** |
| **2** | **Sitework** | | | | |
| | Pump Site | | | | |
| | Archaeological monitoring (SHPO standards) allowance | 1 | ls | $10,000 | $ 10,000 |
| | Erosion control | 1 | ls | $5,000 | $ 5,000 |
| | Clear & grub | 1 | ls | $5,000 | $ 5,000 |
| | Trench shoring | 1 | ls | $5,000 | $ 5,000 |
| | Excavation - Pipelines | 640 | cy | $15 | $ 9,600 |
| | Excavation - Pump station | 40 | cy | $20 | $ 800 |
| | Turbidity Curtain | 200 | lf | $15 | $ 3,000 |
| | Haul waste to disposal | 1,300 | ton | $10 | $ 13,000 |
| | Imported fill - Pipeline & Pump Station | 1,300 | ton | $15 | $ 19,500 |
| | Dewatering for pipeline and pump station | 5 | days | $200 | $ 1,000 |
| | Crushed Surfacing Base Course | 100 | cy | $30 | $ 3,000 |
| | Upland Pipe From Weir To Transition Zone Discharge | | | | |
| | Archaeological monitoring (SHPO standards) allowance | 1 | ls | $10,000 | $ 10,000 |
| | Erosion control | 1 | ls | $2,000 | $ 2,000 |
| | Clear & grub | 1 | ls | $2,000 | $ 2,000 |
| | Trench shoring | 1 | ls | $2,000 | $ 2,000 |
| | Excavation - Pipelines | 1,700 | cy | $15 | $ 25,500 |
| | Haul waste to disposal | 3,100 | ton | $10 | $ 31,000 |
| | Imported fill - Pipeline | 3,100 | ton | $20 | $ 62,000 |
| | Dewatering for pipeline construction | 2 | days | $200 | $ 400 |
| | Transition Zone Infiltration Trenches & Resting Pools | | | | |
| | Archaeological monitoring (SHPO standards) allowance | 1 | ls | $20,000 | $ 20,000 |
| | Erosion control | 1 | ls | $5,000 | $ 5,000 |
| | Clear & grub | 1 | ls | $5,000 | $ 5,000 |
| | Excavation shoring | 1 | ls | $2,000 | $ 2,000 |
| | Excavation - Infiltration Trenches | 1,600 | cy | $20 | $ 32,000 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | Haul waste to disposal | 3,000 | ton | $10 | $ | 30,000 |
| | Imported gravel backfill - Infiltration Trenches | 3,000 | ton | $20 | $ | 60,000 |
| | Transition Zone Resting Pools - sitework by others during channel reconfiguration project | | | | $ | - |
| | **Subtotal, Sitework** | | | | **$** | **363,800** |
| **3** | **Piping** | | | | | |
| | Intake To Pump Station | | | | | |
| | Fish Screen Assembly | 1 | ls | $2,000 | $ | 2,000 |
| | 16" HDPE DIPS DR 21 Intake Assembly | 1 | ls | $3,000 | $ | 3,000 |
| | 16" HDPE DIPS DR 21 Intake Pipe | 130 | lf | $66 | $ | 8,600 |
| | 36" Precast Pipe Anchors | 2 | ea | $240 | $ | 500 |
| | Work boat for pipe intake positioning | 2 | day | $200 | $ | 400 |
| | 16x12 Reducer | 1 | ea | $1,575 | $ | 1,600 |
| | 12" HDPE DIPS DR 21 PS Transition Pipe | 20 | lf | $35 | $ | 700 |
| | 12" Valve | 1 | ea | $5,400 | $ | 5,400 |
| | 16" 45 Deg Bend | 4 | ea | $1,575 | $ | 6,300 |
| | Discharge From Pump Station | | | | | |
| | 12" HDPE DIPS DR 21 PS Transition Pipe | 20 | lf | $35 | $ | 700 |
| | 12" Valve | 1 | ea | $5,400 | $ | 5,400 |
| | 16x12 Reducer | 1 | ea | $1,575 | $ | 1,600 |
| | 16" 45 Deg Bend | 10 | ea | $1,575 | $ | 15,800 |
| | 16" HDPE DIPS DR 21 Discharge Pipe | 2,930 | lf | $66 | $ | 193,400 |
| | 24" Precast Pipe Anchors | 100 | ea | $240 | $ | 24,000 |
| | Transition Zone Infiltration Trenches | | | | | |
| | 16x6 Wye | 4 | ea | $1,575 | $ | 6,300 |
| | 16" Cleanout/Blowoff | 1 | ea | $1,575 | $ | 1,600 |
| | 6" Valve | 4 | ea | $1,300 | $ | 5,200 |
| | 6" Perforated Distribution Pipe | 600 | lf | $15 | $ | 9,000 |
| | **Subtotal, Piping** | | | | **$** | **289,500** |
| **4** | **Structural and Architectural** | | | | | |
| | Pump Station | | | | | |
| | Slab on grade (10'x20'x8") | 5 | cy | $250 | $ | 1,200 |
| | Pump building (timber frame, 8'x16') | 128 | sf | $200 | $ | 25,600 |
| | **Subtotal, Structural and Architectural** | | | | **$** | **26,800** |

| | | | | | | |
|---|---|---|---|---|---|---|
| **5** | **Mechanical** | | | | | |
| | Pump Station | | | | | |
| | Pump System | 1 | ea | $100,000 | $ | 100,000 |
| | Building space heater and passive ventilation | 1 | ls | $5,000 | $ | 5,000 |
| | **Subtotal, Mechanical** | | | | **$** | **105,000** |
| **6** | **Electrical** | | | | | |
| | Pump Station | | | | | |
| | Pump station power and control panel | 1 | allow | $75,000 | $ | 75,000 |
| | 2-3" PVC direct bury conduit | 500 | lf | $20 | $ | 10,000 |
| | Power extension to pump station | 500 | lf | $20 | $ | 10,000 |
| | Meter & shutoff | 1 | ls | $500 | $ | 500 |
| | Electrical contingency allowance | 1 | ls | $2,500 | $ | 2,500 |
| | **Subtotal, Electrical and Control** | | | | **$** | **98,000** |
| **7** | **Intrumentation and Control** | | | | | |
| | Included in electrical in section 6 | | | | **$** | **-** |
| | **Subtotal, Intrumentation and Control** | | | | **$** | **-** |
| **8** | **Site Restoration** | | | | | |
| | Pump Station | | | | | |
| | Site landscaping | 1 | ls | $2,000 | $ | 2,000 |
| | Upland Piping & Infiltration Trenches | | | | | |
| | Surface restoration & landscaping | 1 | ls | $5,000 | $ | 5,000 |
| | Discharge Site | | | | | |
| | Transition Zone Resting Pools - restoration by others during channel reconfiguration project | | | | $ | - |
| | **Subtotal, Site Restoration** | | | | **$** | **7,000** |

| | | | |
|---|---|---|---|
| Total Estimated Direct Costs (Rounded) | | $ | 953,000 |
| General Contractor Overhead and Profit | 15.0% | $ | 143,000 |
| Subtotal | | **$** | **1,096,000** |
| Contingency | 30.0% | $ | 329,000 |
| Sales Tax (City of Redmond) | 9.5% | $ | 135,000 |
| Subtotal | | | **$1,560,000** |
| Engineering (Design and Construction) | 15.0% | $ | 234,000 |
| Administration | 10.0% | $ | 156,000 |
| **Alternative 1 - Total Estimated Project Costs** | | | **$1,950,000** |

## Comparison of Alternatives

The concept alternatives have been compared by considering costs (both initial construction and life-cycle costs), the estimated temperature and other water quality factors of the source water to be used, water quantity/volume scale, the potential temperature benefit that could be achieved, habitat and other environmental effects, constructability and operation and maintenance considerations, and any other qualitative advantages or disadvantages that could be identified. Table ES-2 provides a summary of these key considerations for each alternative.

Based upon the key elements described in the matrix in the Executive Summary, we are providing the following recommendations:

1. Eliminate the low volume (~1 cfs) alternatives (groundwater or potable water) from further consideration. The potential temperature benefits are negligible, and while better than no cooling at all are generally not worth the potential cost or further evaluation. The potential to reconfigure the Transition Zone for other habitat and flow purposes would allow the potential for passively intercepting groundwater flows without any explicit piping or pumping.
2. All three higher volume alternatives are definitely worth evaluating in more detail (hypolimnetic withdrawal, heat exchange, and hyporheic flow). These alternatives provide the scale of potential temperature benefits that could actually make a difference in reducing thermal stress to salmon and could also affect temperatures, at a minimum down to Bear Creek, and potentially in the river on a broader scale. Any of these alternatives could fit well within the context of other restoration and flood management measures being considered in the project area. The heat exchange or hyporheic alternatives should be considered for scaling up to 10 or 20 cfs if possible.

Of key consideration for the hypolimnetic withdrawal alternative is whether the large-scale pumping that is proposed could have any unintended effects on lake processes (stratification, nutrient cycling, etc.)? There could also be minor effects to navigation both in the lake and the lake outlet channel resulting from the pipe intake and submerged pipe. However, these features would certainly not preclude navigation, but would need appropriate signage and warning buoys to prevent accidental vessel grounding and damages to the pipeline.

The heat exchange option does not require nearly the scale or cost of infrastructure, although it does require similar pumping capabilities. Additional analysis of scaling this option to larger volumes, and the potential for greater cooling (such as to 10°C, similar to groundwater temperatures) is warranted. Expanding this option would likely require more substantial grading and cultural resources could be encountered.

The hyporheic option also does not require nearly the scale or cost of infrastructure, although it does require similar pumping capabilities. Additional study is required to fully identify the feasibility such as conducting test pumping and infiltration on both existing soils and a small-scale gravel trench to identify losses to groundwater, residence time, potential effects to the groundwater table and wetlands, potential effects to cultural resources, and to confirm the cooling potential based on these factors.

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# APPENDIX A

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# Technical Memorandum

Date: June 6, 2014 Project Number: 2040.01/MM101

To: Merri Martz (Tetra Tech)

From: Paul DeVries, Ph.D., P.E. and Clair Yoder, P.E.

Subject: Analysis of thermal habitat refuge availability for adult Chinook salmon associated with various cold water supplementation strategies in the upper Sammamish River, between Lake Sammamish and Bear Creek

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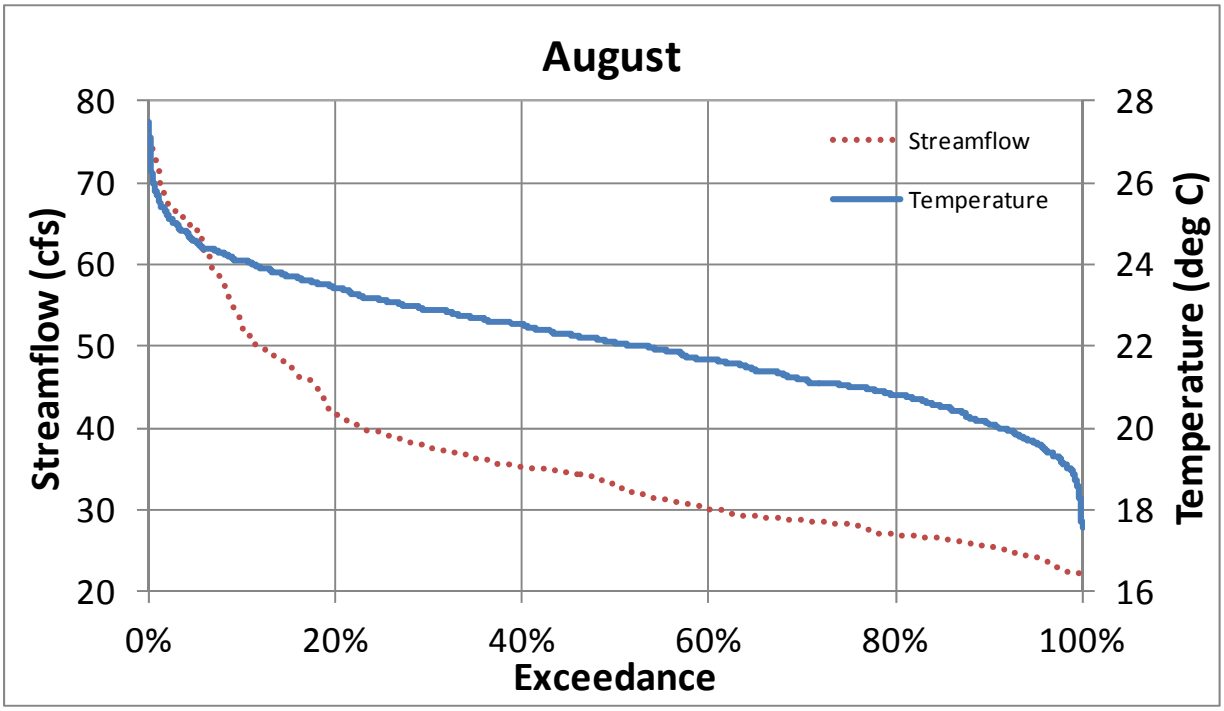
## 1.0 BACKGROUND

King County is investigating options for providing thermal refuge habitat in the upper Sammamish River for adult migrant Chinook salmon (*Oncorhynchus tshawytscha*) during the warm summer and fall months when water temperatures can frequently exceed water quality criteria. Tetra Tech is presently assisting the County with developing conceptual plans for cold water supplementation strategies within the upper river. The study area extends from the outlet of Lake Sammamish downstream to Bear Creek. R2 was subcontracted via Tetra Tech to perform scoping level temperature modeling and analysis to evaluate various cold water supplementation strategies under consideration and estimate the spatial extent of the cold water influence for each.

R2 was initially contracted to perform a screening-level analysis involving the setting up and running of a computer numerical water quality model (CE-QUAL-W2) for the Sammamish River that was developed originally in 2005-6 and later revised by King County (DeGasperi 2009). R2 reviewed the revised model to see if it could be used to evaluate mixing processes in the context of this project, and concluded it could not without significant revision. King County and R2 consequently agreed that resolving the problems with the CE-QUAL-W2 model were beyond the project scope at this time. As a result, R2 and King County agreed to modify the scope and instead expand on a set of simplified, screening level mixing analyses, relying heavily on work performed previously in 2010 for the Muckleshoot Indian Tribe (R2 2010).

### *1.1 Sammamish River Baseline Conditions*

Temperature and streamflow conditions in the Sammamish River vary from year to year depending on many factors including rainfall and weather conditions. Exceedance of water quality criteria typically occur in the warm summer and fall months. King County gage 51m has been collecting data for temperature since 1995 and streamflow since 2001. Flow and temperature duration curves were developed for August and September (Figure 1) when temperatures are generally highest and adult Chinook salmon begin to move up through the river (Fresh et al. 1999). These curves defined the general range of inflow and environmental conditions that would most frequently influence the extent to which water temperatures could be cooled in the Sammamish River. In general, the higher the inflow discharge rate and water temperature from Lake Sammamish, and/or the higher the air temperature during the day, the smaller the potential area of cooling associated with any given option for providing thermal refuge habitat.



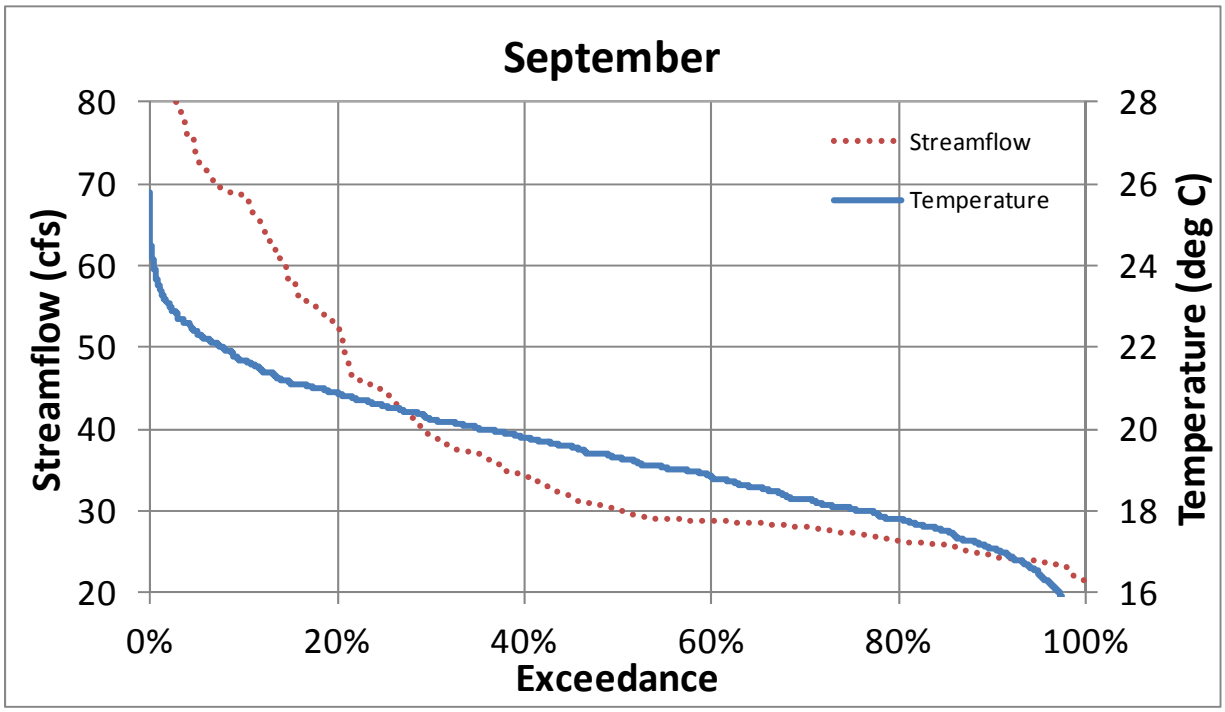




Figure 1. Sammamish River flow and temperature duration curves for the month of August (top) and September (bottom), calculated using King County gage 51m.

### *1.2 Overview of Analyses*

Three scenarios were identified by King County for evaluation, including:

- **Scenario 1**: Replace 20 cfs of water in the Sammamish River below the Marymoor weir with cooler 13°C water.
- **Scenario 2**: Replace 10 cfs of water in the Sammamish River below the Marymoor weir with cooler 13°C water.
- **Scenario 3**: Supplement the Sammamish River with 1 cfs of 10°C water discharged into 4 pools in the transition zone. This would include four releases of 0.25 cfs at different points along a 2,000 foot reach just below the Marymoor weir.

These scenarios represent a wide range of thermal mixing conditions, where Scenario 1 represents between ~25%-100% flow replacement at the injection point during the critical high temperature period, and Scenario 3 represents ~0.3%-1% replacement at each injection point.

R2 performed three independent types of analyses to evaluate the cold water supplementation scenarios, where each analysis provided a different perspective of mixing processes associated with the range of proposed replacement and characteristic river flows:

1. A theoretical one-dimensional mixing analysis (R2 2010)

2. Comparing empirical volume data collected in 2010 (R2 2010) at tributary confluences with flows and temperatures associated with a scenario.

3. Application of SSTEMP, a simplified one-dimensional reach scale heat transport computer model, to evaluate temperature increases (i.e., reheating) downstream of the mixing zone, extending to the confluence with Bear Creek. For reasons given later, this analysis was only performed for Scenario 2 (10 cfs replacement).

The results of each analysis were evaluated, and general conclusions regarding scenario effectiveness were inferred from the collective impacts. In addition, the theoretical and SSTEMP analyses were combined in an effort to estimate distances downstream that a specific temperature contour might extend. There were two primary temperature levels identified by the County as targets for assessment:

1. The Washington State water quality standards identify a criterion corresponding to a 7-day average of the daily maximum (7DADM) for salmonid spawning, rearing, and migration equal to 17.5°C.

2. An incipient lethal limit of 21°C for Chinook salmon.

On hot summer days, each scenario replaces warmer water with cooler water and therefore represents a degree of cooling over baseline conditions, which initially might be interpreted as a benefit. However, from a biological perspective, the benefits of each action are only effective for volumes with temperatures that are biologically suitable according to the above levels. Results from each of the three scenarios were therefore referenced against these levels to evaluate effectiveness.

The approach and results of each analysis are described sequentially in the next four sections below. The independent results are then integrated in the summary section.

## 2.0 THEORETICAL 1-D TRANSVERSE MIXING ANALYSIS

### *2.1 Methods*

We performed a simplified, first order analytical assessment of depth-averaged temperature gradients across the channel (i.e., 'transverse mixing') of a plume that extends in the downstream direction following methods of Fischer et al. (1979; see Appendix A for details). The purpose of the mixing analysis was to approximate the area of water downstream of an injection point possessing a temperature less than a specified level. In all cases, it was assumed that the replacement water had a temperature of 13°C, representing water taken from the Lake Sammamish hypolimnion. All calculations were performed in a spreadsheet.

The exact location of the cool water injection point remains to be identified at this stage of the project. Consequently, we note that there are effectively two sub-reaches within the study reach that have characteristically different slopes, channel roughness, and thus depths and velocities at low summer flows. These different characteristics would influence the intensity of mixing across the channel, as reflected by the width of the cooler water plume at different cross-section locations. The two reaches identified are:

- An upper reach located just downstream of the Marymoor weir, which is shallower with a higher gradient slope and faster velocity.
- A lower reach located downstream of the higher gradient, upper reach, which is deeper with a lower gradient and slower velocities.

Since it was not clear which reach would be the better location for flow injection, both were analyzed. The width and depth of the Sammamish River were approximated for each reach from previous results of a low flow simulation using a version of the County's Flood Insurance Study (FIS) HEC-RAS model that R2 modified for evaluating flows associated with a side channel reconnection project in Bothell. Manning's *n* roughness values for the main channel portion of each cross-section were increased to simulate low flows (i.e., to account for expected increase in relative roughness with decreasing flow).

Temperature calculations were performed for a range of expected Sammamish River temperatures and stream flows typical in the month of August. August was selected because it is the month when water temperatures are typically the warmest. Flows tend to be comparable in September but temperatures are lower, thus August is generally the critical month for temperature modification. The records indicate that stream flow in August generally ranges

between 20-80 cfs and temperature ranged mostly between 18-26°C, exceeding 24°C approximately 10% of the time (Figure 1).

We evaluated more commonly elevated levels of Sammamish River water temperatures corresponding to 20°C, 21°C, 22°C, 23°C, and 24°C, and a varying range of flows between 20-80 cfs in the mixing analysis. The analysis does not consider the warming influence of air temperature in the downstream direction. Only Scenarios 1 and 2 were evaluated because the 2010 empirical data indicate that Scenario 3 (4 x 0.25 cfs discharge points) would be associated with negligible benefits (see next section). Scenario 3 represents the release of a small flow directly into a small pool, where mixing processes are influenced by local microtopography and potentially vertical stratification. A total of 128 simulations were performed with varying combinations of initial Sammamish River temperature, Sammamish River streamflow, replacement water amount (i.e., Scenario 1 or 2), and reach segment conditions.

### *2.2 Results*

Using this analysis, suitable habitat area was delineated by temperature contours ('isotherms') within the mixing zone. Figure 2 depicts an example calculation result for a total 40 cfs in the Sammamish River with a Lake outflow temperature of 22°C, and a 10 cfs replacement flow at 13°C (i.e., Scenario 2). This figure shows isotherms for selected temperature levels within the mixing zone depicted relative to the centerline of the river, from which the area within each contour can be calculated. Similarly appearing curves were obtained for the other 127 combinations.

As a way of succinctly presenting the results of 128 simulations, curves were prepared relating available suitable thermal habitat area to the ratio of water replaced under different temperature conditions. The area within each isotherm was calculated in a spreadsheet for each simulation as an estimate of the habitat area for the specified replacement and inflow discharge rates and water temperature. This was done for the range of temperatures and Sammamish River flows identified above. The resulting curves provide an approximate indication of the variability in area of cooler water habitat that might be provided with variation in ambient water conditions, referenced to the two target temperature levels evaluated. Figures 3 and 4 accordingly depict the estimated area of the plume containing water with temperatures less than or equal to 17.5°C for Scenarios 1 and 2, respectively. Figure 5 depicts analogous results for the estimated area of the plume containing water with temperatures less than or equal to 21°C. Results are presented for the upper (higher gradient) reach and lower (lower gradient) reaches.

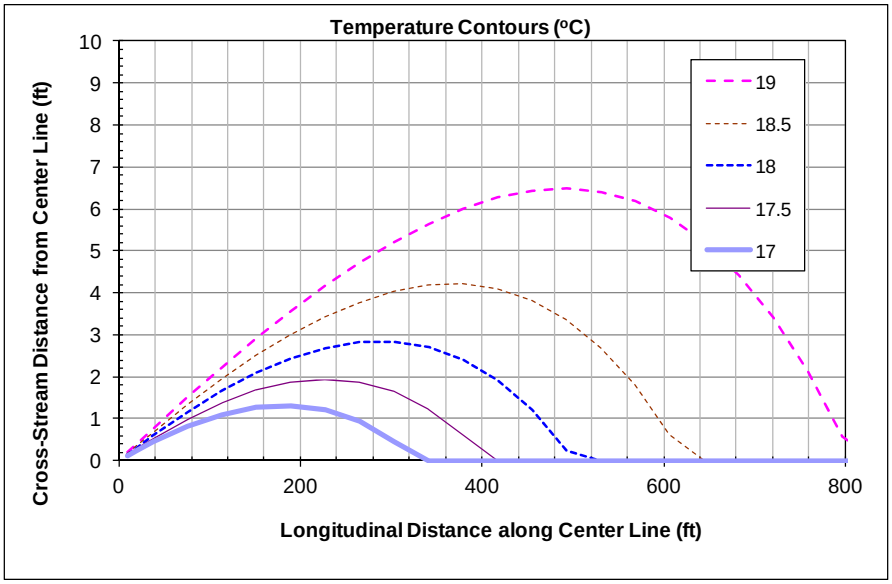



Figure 2. Example calculation of temperature contours for a simplified representation of the Sammamish River with a point source located at the axes origin which is aligned with channel center line. River flow direction is from left to right, replacement source flow (10 cfs) is 25% of the total flow (40 cfs), and mainstem/replacement water temperatures = 22°C/13°C, respectively.

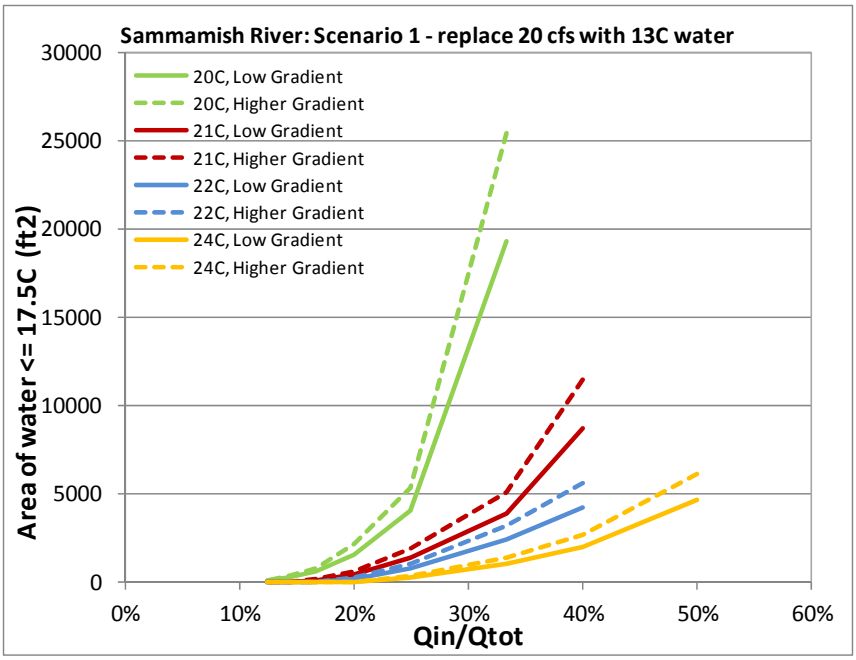



Figure 3. Area of the cooler water plume with temperature less than 17.5°C as a function of replacement water flow percentage for Scenario 1; curves are presented for different inflow temperatures in the upper ('Higher Gradient') and lower ('Low Gradient') reaches.

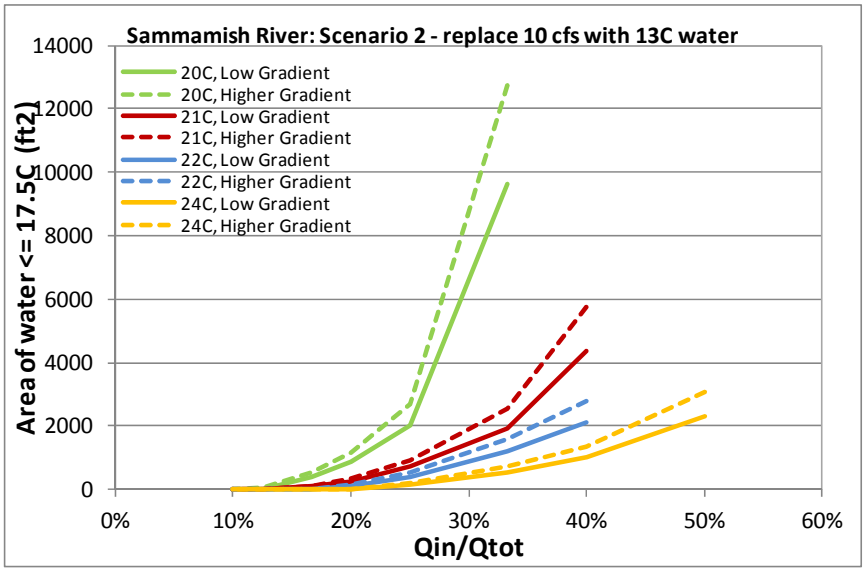



Figure 4. Area of the cooler water plume with temperature less than 17.5°C as a function of replacement water flow percentage for Scenario 2; curves are presented for different inflow temperatures in the upper ('Higher Gradient') and lower ('Low Gradient') reaches.

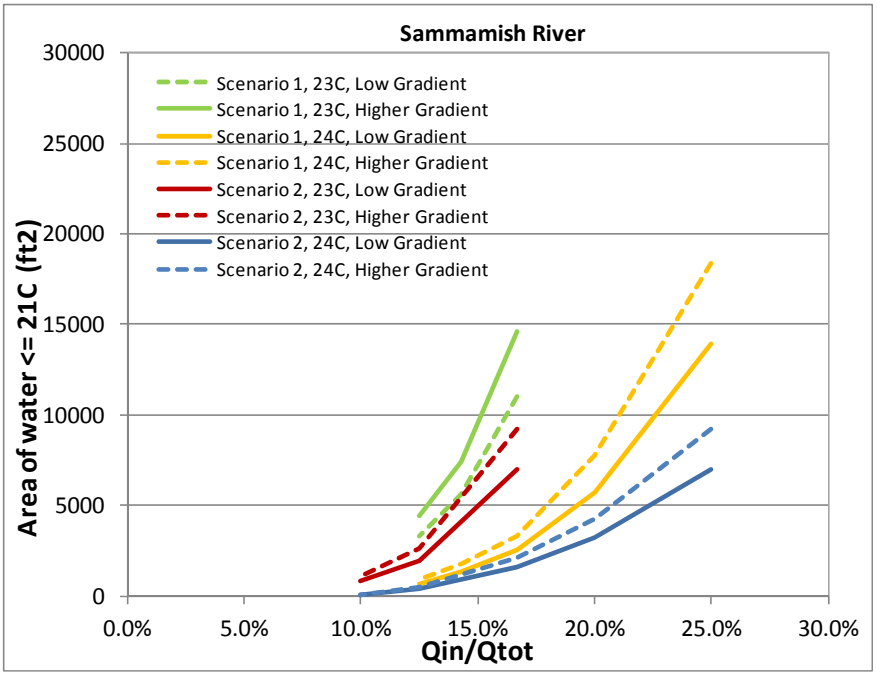



Figure 5. Area of the cooler water plume with temperature less than 21°C as a function of replacement water flow percentage for Scenarios 1 and 2; curves are presented for different inflow temperatures in the upper ('Higher Gradient') and lower ('Low Gradient') reaches.

These figures lead to the following general observations:

1. As expected, the cooler water plume area decreases for higher initial temperatures in the Sammamish River, and Scenario 1 with a replacement of 20 cfs was associated with a larger cooler water plume than Scenario 2 with a replacement of 10 cfs
2. Replacement inflows of 13°C water would need to constitute more than 10% of the total flow to ensure temperatures did not exceed 21°C most of the time.
3. Replacement inflows of 13°C water would need to constitute more than 30% of the total flow on days when Sammamish Lake surface water temperatures exceed about 24°C.
4. As the ratio of the replacement water to total water in the Sammamish River increases, the area of the cooler water plume increases nonlinearly, suggesting an asymptotic criterion might be discernible with more detailed modeling analysis. However, the asymptotic (or, threshold) flow value varies with receiving water temperature and target temperature. The worst case condition would be when both receiving water temperatures and total flow rates are high. This condition generally occurs when flows below the weir exceed 60 cfs, which in August occurs approximately 6% of the time (cf. Figure 1).
5. The higher gradient reach was associated with a slightly larger predicted plume area than the lower gradient reach for the same flow and temperature boundary conditions. We interpret this to mean that the higher velocity in this reach has a stronger influence than the higher transverse mixing coefficient where the water travels farther before it has had a chance to fully mix from the source to the banks. Combined with better turbulent exchange of oxygen, this result suggests the steeper gradient reach may be a reasonable location for the 10 cfs and 20 cfs scenarios.

It should be noted that the analysis is best applied to low to moderate flow ratios where the ≤17.5°C plume does not reach the channel margins. Analyses of thermal refuge habitat area provided via larger flow inputs become more complicated when the isotherm of interest reaches the channel margins. When this happens, the downstream extent of temperature change is then controlled by heat input from the atmosphere and radiation, which the local dispersion analysis does not address.

<u>Summary of Mixing Analysis Findings</u>:

- Scenario 1: Pronounced cooling effect possible dependent on river conditions.
- Scenario 2: Cooling effect possible dependent on river conditions.
- Scenario 3: Mixing analysis not applicable due to localized influence of bathymetry and release location.

## 3.0 COMPARISON WITH EMPIRICAL THERMAL HABITAT VOLUME DATA COLLECTED IN 2010

### *3.1 Methods*

Thermal mixing zones were mapped spatially by R2 (2010) throughout the water column on 1-2 occasions below each of nine tributary confluences in the summer of 2010. The collective data were combined in that study to develop 3-dimensional surface response curves of habitat volume (vertical z-axis) as a function of (i) temperature differential relative to the incoming cooler water (horizontal y-axis) and (ii) tributary inflow relative to Sammamish River inflow (horizontal x-axis). Data were sparse for temperature differences greater than 4°C and inflows greater than 12% of the Sammamish River total flow rate, however, such that the data from that study could not be used to directly evaluate volumes and temperatures in this assessment. Moreover, the distribution of data was limited by a relatively small number of tributaries and narrow ranges of flows and temperatures that year, such that the results were 'clumped' with large gaps in the X- and Y-axis plane of the surface response curve. This resulted in a somewhat irregular surface response curve in the original study.

The 2010 data were reanalyzed for this assessment, where the limited number of measured flow percentage data points corresponding to a flow contribution greater than about 12% were excluded. In addition, because the shape of the surface response curve can vary strongly depending on the mathematical method used to interpolate between irregularly spaced data (called more formally a 'gridding algorithm'), we compared the results from a variety of alternative methods to see which smoothed out observed irregularity of the data the best. A radial basis function method was ultimately used for gridding the filtered data, with greater interpolation weight placed along the temperature axis than the flow axis. The results were extrapolated to a 5°C temperature differential, which encompasses comparing a 13°C release against both the 17.5°C DOE criterion. The corresponding percent flow coordinates for each alternative scenario were calculated as:

$$\%\,Flow = \frac{Replacement\ Flow}{Total\ Flow}$$

### *3.2 Results*

The surface response curve created by this analysis is presented in Figure 6. This figure shows the available habitat volume as a function of the percent of total flow and temperature

differential. As implied in the previous paragraph, it should be pointed out that the surface response curve in Figure 6 is just one possible approximation that depends on the gridding algorithm used. The resulting surface response curve is somewhat irregular and 'humpy' because there were no data points for flows between 7-10 percent. However, a general trend is apparent where habitat volume increases more substantially with increasing flow percentage above about the 5% level. Following the surface along the 4.5°C temperature difference coordinate plane (i.e., 17.5°C - 13°C = 4.5°C), suggests that an inflow of 13°C water would need to account for somewhere between at least 4%-8% of the total flow rate in August in order to have a more substantial effect on the volume of water with temperature equal to or less than 17.5°C. This result is consistent with the more general findings of the 2010 study.

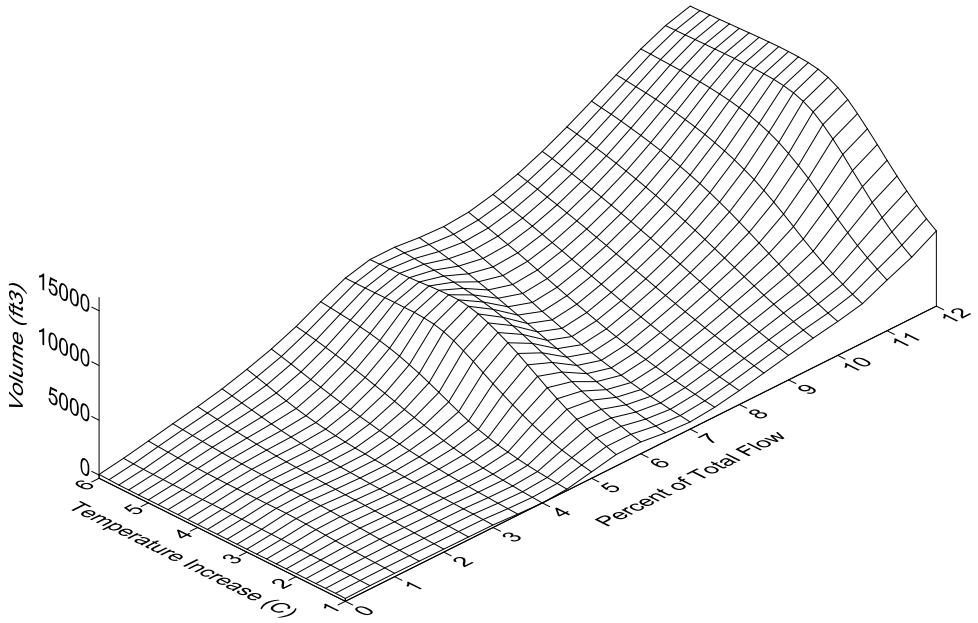



Figure 6. Surface response curve generated for measured available habitat volume as a function of temperature contour (expressed as increase over tributary inflow temperature) and the ratio of tributary inflow to Sammamish River flow upstream of confluence. Note that the 'hump' in the middle of the surface response curve is likely an artifact of a concentration of data around the 5%-6% flow range, and none in the 7%-10% range

Scenario 3, with a release of 1 cfs, represents only 3% of the 50% exceedance flow in August (~33 cfs) and only 1.5% of the 5% exceedance flow (~65 cfs). The empirical data suggest that Scenario 3 does not have the potential to appreciably reduce river temperatures. Note that the 12% flow level is exceeded essentially all of the time in August when the replacement inflow is approximately ≥9 cfs; the 5% level is similarly exceeded in August when inflow is approximately ≥4 cfs.

Summary of Empirical Data Findings:

- Scenario 1: Provides more substantial cooling effect in August.
- Scenario 2: Provides substantial cooling effect in August.
- Scenario 3: Does not provide much cooling effect.

The 10 cfs replacement flow scenario appears to be a reasonable approximation of the minimum flow needed to provide a substantial cooling effect at all times in August.

## 4.0 SSTEMP ANALYSIS OF DOWNSTREAM RE-HEATING

### *4.1 Methods*

SSTEMP was used to evaluate temperature conditions from the fully mixed Sammamish River and replacement water (i.e., starting downstream of the cross-channel mixing zone) until it reaches Bear Creek. Bear Creek is located approximately 1.6 miles downstream from the Marymoor weir, and thus there is opportunity during daytime hours for the river water temperature to increase due to radiation and convection from the sun and air. This warming limits the downstream extent to which a cooling effect may be observed. The SSTEMP model is a scaled down version of the Stream Network Temperature Model (SNTEMP; Theurer et al. 1984). The model can be used to estimate average (across the channel) downstream changes in water temperature associated with changing riparian shade, physical features of a stream, stream withdrawals, and other factors on instream temperature. The model analyzes single stream segments for a single time period (Bartholow 2002), so we defined a simulation reach extending downstream to the confluence with Bear Creek, where the tributary inflow provides thermal refuge habitat (R2 2010).

The results in Section 3.2 indicated Scenario 2 (= a replacement rate of 10 cfs at 13°C) was a reasonable approximation of the smallest replacement flow providing a substantial increase in habitat volume. SSTEMP accordingly was set up to simulate this scenario to provide an indication of the variability of temperatures arriving at the Bear Creek confluence depending on river flow and air temperature. The Bear Creek confluence is an historically important thermal refuge area, thus it is instructive to evaluate the extent to which holding conditions might be improved between there and the lake. Temperature increases were modeled for a range of Sammamish River inflow rates versus a range of (i) air temperatures and (ii) Sammamish River inflow temperatures. Based on the theoretical mixing analysis of section 2, it was estimated that a fully mixed system would be attained within 1000 feet of the Marymoor weir. This distance was subtracted off of the total distance from the weir to Bear Creek for an analysis reach length of approximately 1.4 miles long. The SSTEMP input parameters include hydrology, geometry, meteorology, and shade conditions. Representative climatologic and hydraulic parameter values were developed based on information representing August conditions that was extracted from meteorological data at SeaTac and the Sammamish River HEC-RAS model (see Appendix B, which is a screen shot of the program input window values). A value of Manning's n = 0.07 was assumed based on typical values for sluggish, weedy pools (Chow 1959). Default shading parameters were used, but they were kept the same for all calculations and thus did not influence the comparative results.

Two sets of simulations were conducted. The first set varied both the air temperature (21-35°C; 70-95°F) and the Sammamish River flow (20-100 cfs) while keeping the Sammamish River inflow water temperature constant at 22°C to estimate water temperature arriving at Bear Creek. The second set of simulations varied both the Sammamish River inflow water temperature (20-24°C) and the Sammamish River streamflow (20-100 cfs) while keeping the air temperature constant at 32°C (90°F) to estimate water temperature arriving at Bear Creek. Contour plots were developed showing the range in temperature at Bear Creek as a function of total river flow, river inflow temperature, and air temperature. These plots present the estimated average temperature in the river just upstream of the Bear Creek confluence for each set of simulations.

### *4.2 Results*

Figure 7 shows the range of water temperature estimated at Bear Creek under Scenario 2 for an example case where river inflow temperature is 22°C. Note that while the 10 cfs replacement flow is predicted to have a significant temperature reduction effect locally when the total river flow is near the low end, the mixing zone is shorter and the results depicted in Figure 7 indicate that atmospheric warming is greater for lower flows such that substantial warming can occur between the downstream end of the mixing zone and Bear Creek during hotter days.

Most importantly, Figure 7 illustrates that water temperatures downstream can vary considerably depending on air temperature, inflow temperature, and whether flows in the Sammamish River are low or high for the summer season. Accordingly, the distance downstream that a given scenario provides suitable habitat for Chinook salmon adults will vary depending on these three factors, which reflects variation in time of day and season, hydrology, climate, and other factors. The results show that identifying which replacement flow rate is best is not necessarily a simple matter using SSTEMP without first more specifically identifying the key conditions of concern.

One inference on outcome that can be made from the figure is that higher river flows tend to reduce the impact of the cooling flow by the time water arrives at Bear Creek, or in other words, the length of the cool water zone is shorter for higher flows. This is intuitive because the relative thermal mass contribution of the cooling water is smaller as river flow increases. This is evaluated in greater detail in the next section.

<u>Summary of SSTEMP Analysis Findings</u>:

- Scenario 1: Not evaluated with SSTEMP (recommend waiting until target design and evaluation criteria are more specifically defined; 10 cfs result provides reasonable indication of range of effects).

- Scenario 2: Length of the cooler water plume can reach Bear Creek, but frequency of occurrence depends on factors including total river flow, river inflow temperature, and air temperature.
- Scenario 3: Not evaluated with SSTEMP (spatial scale too small).

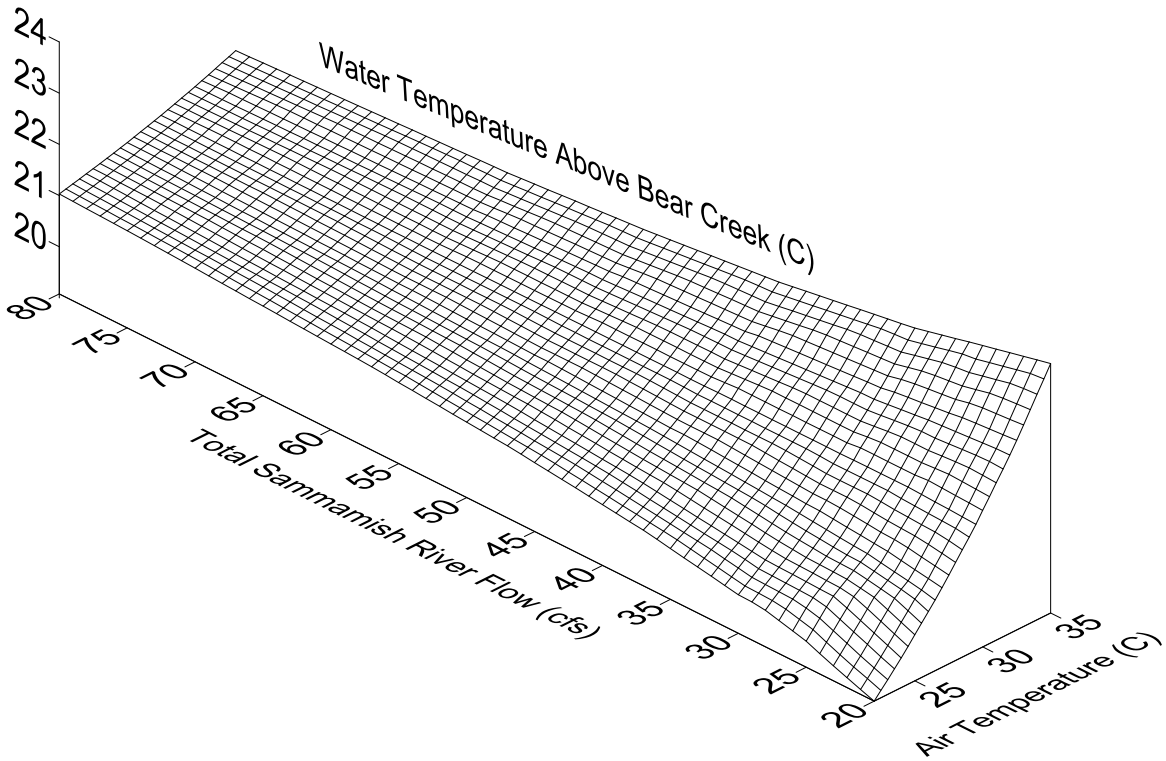



Figure 7. Range of temperatures estimated to occur in the Sammamish River upstream of the Bear Creek confluence (=contour levels) under Scenario 2 as a function of air temperature and total river flow with an inflow river temperature = 22°C. For this scenario, air temperature has a greater warming influence at low flow, and the effect of the replacement flow becomes less pronounced with increasing total river flow.

# 5.0 COOLING DISTANCE COMPARISON ANALYSIS

## *5.1 Methods*

A combination of the mixing analysis and SSTEMP methods were used to evaluate and compare the downstream distance of potential temperature reduction for the case where cool water was added to the steep upper reach below the weir. The mixing analysis methodology (described in Section 2 above) was used first to compare the longitudinal distance of a given temperature contour for (i) a specific replacement scenario with varying conditions of Sammamish River inflows and temperatures, and (ii) a specific inflow condition under different replacement scenarios. In most cases, the downstream extent of the temperature contour could be estimated using just the mixing analysis results. In a few cases where the replacement flow thermal volume was large relative to total flow, the fully mixed temperature was less than the value of the temperature contour being evaluated. As a consequence, insolation and air temperature then became the primary factors in determining a downstream warming rate. SSTEMP was used in these cases to iteratively estimate the additional distance downstream before the fully mixed water reached the temperature threshold of interest (i.e., 17.5°C, 21°C). SSTEMP was simulated in those cases assuming an air temperature of 32°C (90°F), and the length of the analysis segment was modified iteratively until the downstream temperature predicted by SSTEMP matched the target temperature contour. Simulations were conducted involving a Sammamish River total flow of 65 cfs (approximately the 5% exceedance flow for August, which represents a worst case flow condition) under varying Sammamish River inflow temperatures.

## *5.2 Results*

Figure 8 shows the resulting 17.5°C contour for scenario 1 (top) and Scenario 2 (bottom) for Sammamish River inflow temperatures of 24°C, 22°C, 21°C, and 20°C. These plots illustrate that as the Sammamish River inflow temperature increases and/or the replacement flow rate decreases, the 17.5°C contour moves upstream and the area benefitting from cool water replacement shrinks. For example, the 17.5°C contour extends over 1,200 feet downstream when inflow temperature is at 21°C, but extends just over 700 feet when inflow is at 24°C under Scenario 1. As another example, the 17.5°C contour extends over 1,200 feet under Scenario 1 while it extends only 100 feet under Scenario 2 when the inflow temperature is 21°C. It should be noted that under Scenario 2 when the inflow is at 24°C, the area of the 17.5°C contour is so small that it shows effectively as a horizontal line running along the abscissa axis in the bottom graph of Figure 8. As expected, Scenario 1 with a higher release rate of 13°C water has a larger impact on both the total area and distance downstream.

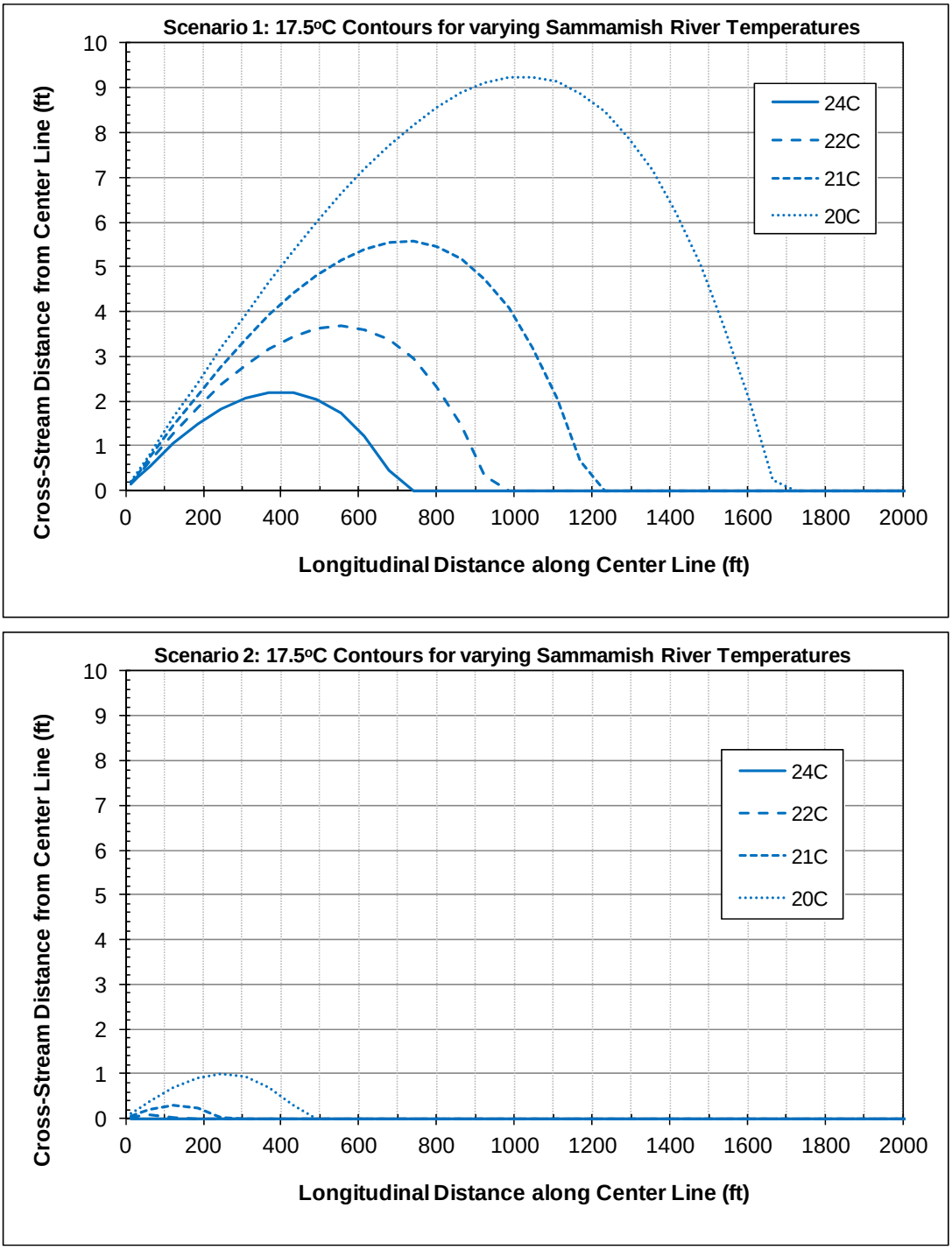



Figure 8. Comparison of 17.5°C contours under scenario 1 (top) and scenario 2 (bottom) for a Sammamish River flow of 65 cfs and various Sammamish River temperatures.

In a second analysis, the longitudinal distance of the temperature reduction was compared between the three scenarios using the same total flow rate and initial condition temperature for a representative worst case condition. Figure 9 depicts the resulting 17.5°C and 21°C contours for the three scenarios assuming a Sammamish River total flow of 65 cfs and temperature of 24°C. Under these approximate worst case conditions, the replacement flow rate is 31% of total for Scenario 1, 15% for Scenario 2, and 1.5% for Scenario 3. In this case, Scenario 2 has a relatively small thermal refuge benefit, and appears to provide habitat area with temperatures mostly above 17.5°C and below 21°C. Scenario 3 is predicted to have an imperceptible impact, as indicated by the line plotting along the abscissa axis in Figure 9.

Summary of Cooling Distance Comparison Findings:

- Scenario 1: Pronounced cooling effect possible dependent on river conditions
- Scenario 2: Localized cooling effect possible dependent on river conditions
- Scenario 3: Cooling effect limited to small microhabitat area.

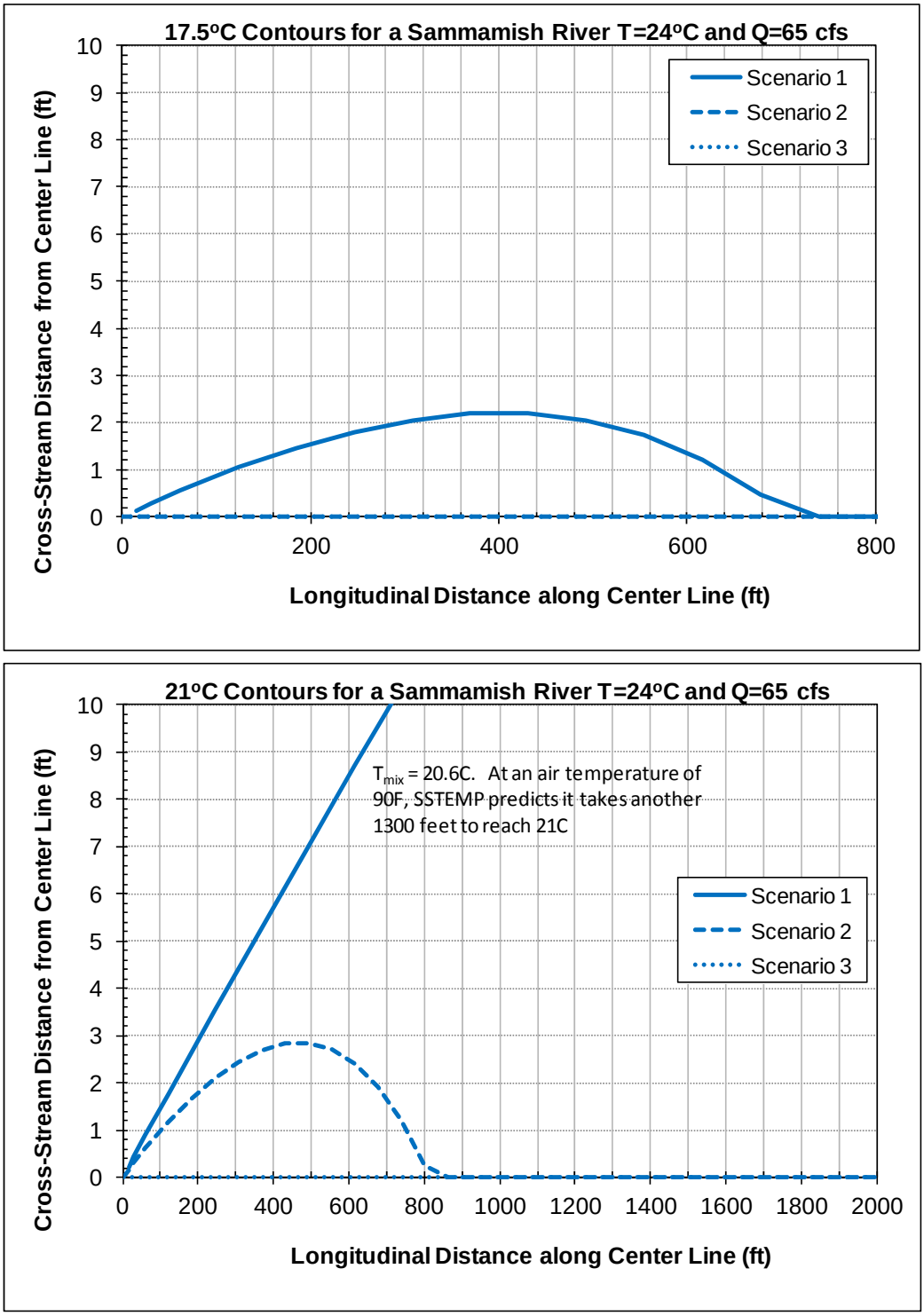



Figure 9. 17.5°C (top) and 21°C (bottom) contour comparison between the three scenarios assuming a Sammamish River flow of 65 cfs and temperature of 24°C.

## 5.0 SUMMARY CONCLUSIONS

An important point that became clear during this screening level analysis is that the quantity (i.e., spatial extent) and quality (degree of cooling) of thermal refuge habitat provided by a given flow supplementation scenario in the Sammamish River can vary substantially depending on boundary conditions set by the inflow rate and temperature from Lake Sammamish and by air temperature. A set of representative conditions should be developed that narrow the range of conditions to be analyzed during the design phase. What those conditions should be will require input from fisheries managers. For example, the beneficial effect of adding cooler water is reduced when both flows and water temperatures in the river are high compared with other times. We evaluated a 5% exceedance flow for August and a 24 C inflow temperature to approximate worst case conditions as part of our screening level assessment of potential benefits. Analogous flow and temperature duration parameters would be useful as design criteria and help focus the identification of desired target conditions and development of designs.

The following specific conclusions are drawn from this screening level analysis:

1. Based on work performed previously investigating tributary thermal mixing zones in the Sammamish River, a replacement flow of 1 cfs at 13°C is unlikely to provide significant biological benefits to adult Chinook salmon.
2. While not analyzed specifically here, the results suggest strongly that none of the scenarios evaluated would create much if any core summer salmonid habitat with temperatures below 16°C except when water temperatures and flows exiting Lake Sammamish are low relative to worst case conditions that could occur in August and September.
3. Replacement or augmentation inflows should exceed more than 10-12% of the total flow rate in the reach for there to be a reasonable expectation of providing a significant amount of habitat under 21°C for Chinook salmon adults under most flow conditions. The analysis suggests that a 9 cfs or greater inflow could achieve this, a level above which marginal increases in habitat volume are larger per cfs added than when the inflow is less than this. Albeit less, some benefit may also be realized if inflows were between 4-9 cfs, however.
4. The 10 cfs replacement flow of Scenario 2 may not provide extensive thermal refuge habitat (i.e., <17.5°C) during worst case conditions in August, but can provide some local cooling to keep temperatures below the approximate incipient lethal level of 21 °C.

5. Based on analytic mixing analysis equations, the steeper reach below the weir appears to be a suitable location for a discharge point, (although more detailed numerical modeling should be performed to confirm this).

In summary, Scenarios 1 and 2 are expected to have an identifiable impact while Scenario 3 is unlikely to have any measurable impact beyond providing a small thermal microhabitat area. Scenario 2 appears to be about the smallest flow replacement rate recommended based on this analysis. A more detailed and extensive analysis may be necessary if a more accurate evaluation of the downstream extent of thermal benefits of scenario 1, 2 or other flow rate is desired.

Once a preferred alternative is identified, it should be feasible to analyze specific designs using a simplified 3-dimensional numerical model. Based on our results, it appears that the model domain should extend at least 1500 ft downstream of the release point to allow simulation of water temperatures under a range of boundary flow and temperature conditions.

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# Appendix A: Transverse Mixing Analysis Details

For simplicity, the release of cooler water was represented as a point source in the middle of the river. It was assumed that the temperature mixing zone increased linearly in width across the channel until it reached the bank. The corresponding length of channel between the point source and the point where the mixing zone reached the bank was set as the mixing length L. To permit rapid solution in a spreadsheet, the cross-section distribution of temperature across the mixing zone was simplified as a triangular approximation (as opposed to a Gaussian distribution; Fischer et al. 1979). The temperature along the channel centerline for a given distance downstream was estimated using an analogous relation for concentration described in Fischer et al. (1979):

$$\frac{T_{center}}{T_{source}} = fn\left(x' = \frac{x\varepsilon_t}{\bar{u}W^2}\right)$$

where $x$ = distance downstream from the point source, $\varepsilon_t$ = transverse mixing coefficient (ft$^2$/s), $\bar{u}$ = mean streamwise velocity (ft/s), and $W$ = width (ft). Applying the temperature equation to the cross-stream distribution allowed calculation of the approximate location of the temperature contour at any point across the mixing zone. The transverse mixing coefficient value was based on theoretical estimates. The input parameters for the analysis are summarized in Table A-1.

Table A-1. Mixing analysis input parameters characterizing summer flow (~20-80 cfs) conditions in the Sammamish River below the weir at Marymoor Park.

| Input Parameter | Higher Gradient Reach | Lower Gradient Reach | Source |
|---|---|---|---|
| Slope | 0.42% | 0.03% | Estimated from HEC-RAS model |
| Transverse mixing coefficient | 0.3d$u$* | 0.15d$u$* | Calculated theoretical |
| Width | 45 ft | 45 ft | Estimated from HEC-RAS model |
| depth | 1.6 ft | 4.1 ft | Estimated from HEC-RAS model |

For the lower gradient upper reach, the transverse mixing coefficient was estimated using the approximation of a rectangular channel as (Fischer et al, 1979 equation 5.4):

$$\varepsilon_t = 0.15du*$$

where $d$ = depth (ft) and $u^*$ = shear velocity (ft/s). The shear velocity was estimated as (Fischer et al, 1979 equation 5.1):

$$u^* = \text{sqrt}(gdS)$$

where $g$ = acceleration due to gravity (32.2 ft/s$^2$) and $S$ = streamwise slope.

For the higher gradient upper reach, the transverse mixing coefficient was estimated using the approximation of a natural stream with variable cross-section profile and roughness (Fischer et al, 1979 equation 5.6):

$$\varepsilon_t = 0.6du^* \pm 50\%$$

A value of 0.3d$u^*$ was used for the calculation of the transverse mixing coefficient in this study because the steeper reach morphologically lies somewhere between a rectangular channel and a rough bed, meandering stream. This corresponds to using the minus 50 percent value, or roughly twice the lower value used downstream. We believe this is a reasonable representation of characteristic differences in mixing properties in the two reaches, and the values are within comparable ranges determined in other studies (e.g., Webel and Schatzmann 1984; Boxall and Guymer 2003).

# Appendix B: SSTEMP Model Input Parameters

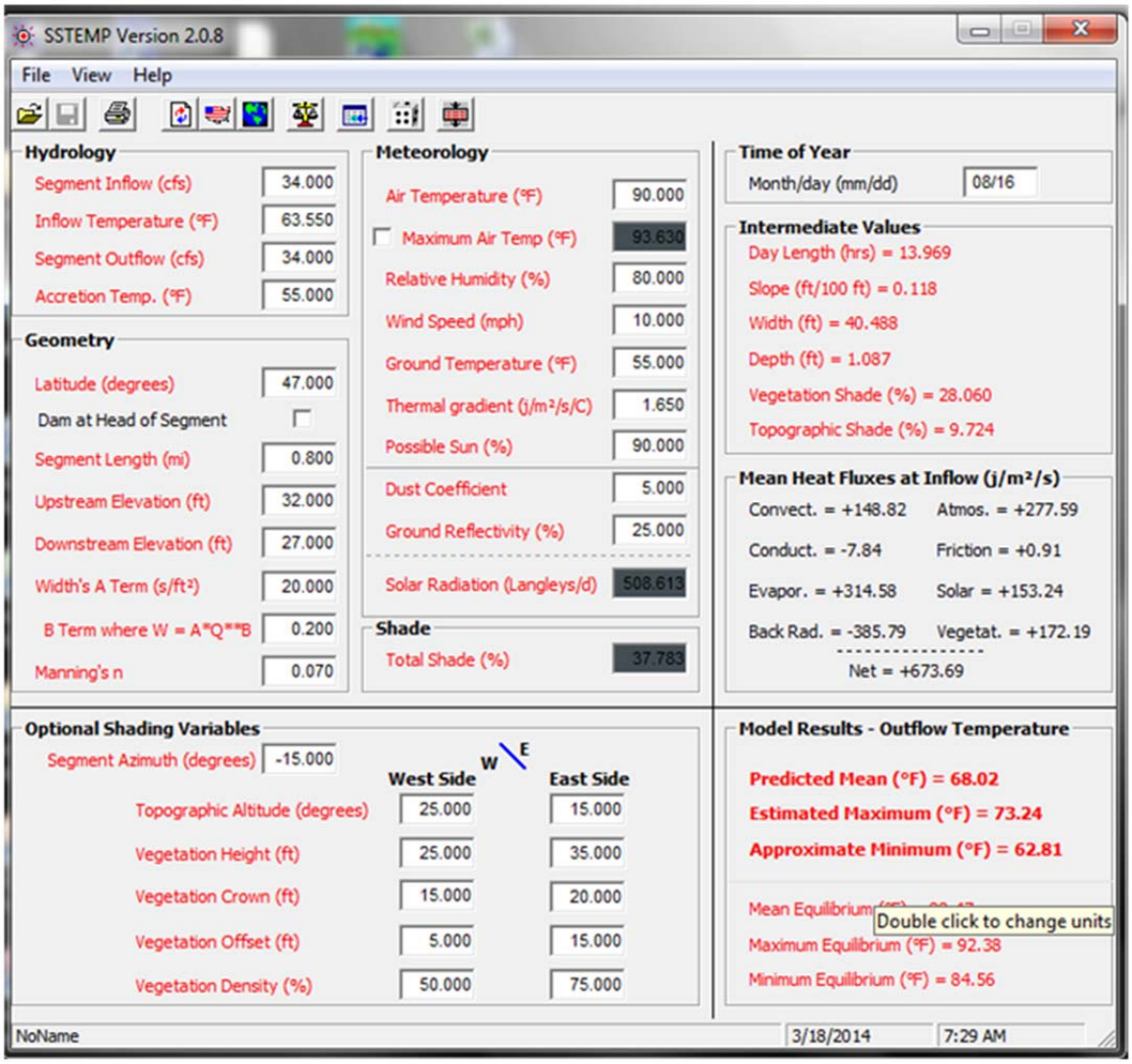


Figure B-1. Screen snapshot of an example of SSTEMP model input parameters used in the analysis.

# APPENDIX B

# Sammamish River Temperature Modeling of Selected Cold-Water Supplementation Concepts

June 2014

King County

Department of Natural Resources and Parks
Water and Land Resources Division
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# Sammamish River Temperature Modeling of Selected Cold-Water Supplementation Concepts

**Prepared for:**

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# EXECUTIVE SUMMARY

Insert executive summary text here.

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# 1.0 INTRODUCTION

Listing of Puget Sound Chinook under the federal Endangered Species Act (ESA) has triggered an intensive effort to identify causes of salmon population declines and measures that can be taken to maintain or improve existing conditions. The King County Flood Control District is investigating options to improve summer temperature conditions in the upper Sammamish River that would potentially benefit adult Chinook migrating through the river to spawn in the Big Bear Creek basin, tributaries to Lake Sammamish (including Issaquah Creek) or return to the hatchery on Issaquah Creek.

Summer temperature conditions in the upper Sammamish River consistently exceed the applicable state standard of 16 $^{o}$C[1] as well as temperature thresholds considered to be potentially lethal to salmonids (e.g, 21 $^{o}$C). Extremely high river temperatures in 1998 were believed to have contributed to Chinook pre-spawn mortality observed in the river that year (Fresh et al. 1999, Martz et al. 1999). It has also been suggested that the generally higher pre-spawn mortality rate of Chinook observed in Bear and Issaquah creeks relative to pre-spawn mortality in the Cedar River between 2002 and 2005 may be due in part to the relatively high temperatures experienced by fish migrating through the river (Berge et al. 2006). Fresh et al. (1999) suggested that the upper reach of the Sammamish River (perhaps exacerbated by high temperatures in the Ship Canal) represented a significant impediment to the passage of adult Chinook destined to spawn in the Issaquah Creek basin affecting the long-term viability of the population.

This report describes the results of the application of an existing river temperature model developed for the Sammamish River to evaluate three temperature management scenarios relative to a **Baseline** model run representing existing thermal conditions in the river. The three management alternatives were as follows:

- **5 cfs Augmentation Flow** - Add 5 cfs (not replacing any weir flow) to the most upstream model segment with a constant temperature of 18 $^{o}$C for the period July 15 – September.
- **10 cfs Hypolimnetic Withdrawal** - Replace 10 cfs of flow to river at weir boundary with lake hypolimnetic water (temperature based on historical data from 15 m depth in lake used in Sammamish River Corridor Action Plan study) for the period July 15 – September 15.
- **20 cfs Hypolimnetic Withdrawal** - Replace 20 cfs of flow to river at weir boundary with lake hypolimnetic water (temperature based on historical data from 15 m depth in lake used in Sammamish River Corridor Action Plan study) for the period July 15 – September 15.

[1] The Sammamish River is designated as core summer salmonid habitat with a standard of 16 $^{o}$C based on the 7-day moving average of the daily maximum temperature (Chapter 173-201A of the Washington Administrative Code).

## 1.1 Background

Observed pre-spawn mortality of adult Chinook in the Sammamish River led water quality managers to initiate a temperature monitoring and modeling investigation of the river (Martz et al. 1999). Following the initial investigation, the monitoring program and model were refined, and the model was updated to version 3.0 by JEEAI (Jain et al. 2000, Buchak et al. 2001). The model developed by JEEAI was further modified to improve the model calibration and provide for extended (multi-year) simulations. This version of the model was then used to evaluate several temperature management scenarios in support of the Sammamish River Corridor Action Plan (USACE and King County 2002).

## 1.2 Objectives

The overall objective of the work described in this report was to use the existing Sammamish River temperature model to evaluate three temperature management alternatives currently under consideration as part of the King County Flood District's Willowmoor Floodplain Restoration Project.

Specific tasks to meet these objectives were:

- Revise input files as needed to create the three temperature management scenarios.
- Revise model output locations and temperature thresholds for calculation of the Index of Thermal Stress at each river assessment point (six locations in total).
- Summarize results in tabular and graphical format and include an assessment of the reduction in the 7-day moving average of the daily maximum temperature.

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# 2.0 METHODS

For information on the development and testing of the model, the reader is referred to King County (2001). In general, statistical comparisons of model output to observed temperatures indicated reasonably low bias and error. Bias ranged from -0.12 to 0.17 $^{o}$C and the root mean square error (RMSE) ranged from 0.32 to 0.58 $^{o}$C for the period June through October 1999 at observation locations along the river from the Redmond Railroad Bridge to Blyth Park in Bothell. These error statistics are similar to many other well calibrated temperature models surveyed by Arhonditsis and Brett (2004). The ultimate acceptance of a model requires the evaluation of a host of factors and no specific pass/fail criteria exist. In general, model performance was considered adequate for conducting the alternatives analyses described in this report.

## 2.1 7-Day Moving Average of the Daily Maximum Temperature

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The 7-day moving average of the daily maximum temperature (7-DMAX) was calculated to facilitate direct comparison of model results to the state temperature standard. Washington State has established water quality standards to protect designated uses for aquatic life, including temperature standards for the protection of uses by salmon. The designated use of the Sammamish River by salmon is:

- **Core summer salmonid habitat** – This use protects summer season (June 15 through September 15) salmonid spawning or emergence, or adult holding; use as important summer rearing habitat by one or more salmonids; or foraging by adult and sub-adult native char. Other common characteristic aquatic life uses for waters in this category include spawning outside of the summer season, rearing, and migration by salmonids. The aquatic life temperature criterion for this use is 16 $^{o}$C (60.8 $^{o}$F). This is the designated use and applicable criterion to the Sammamish River.

Other use protections in the state water quality standards include, **salmonid spawning, rearing, and migration**. The key identifying characteristic of this use is salmon or trout spawning and emergence that only occurs outside of the summer season (September 16 - June 14). Other common characteristic aquatic life uses for waters in this category include rearing and migration by salmonids. The aquatic life criterion for this use is 17.5 $^{o}$C (63.5 $^{o}$F).

Washington State uses the designated uses and criteria described above to ensure that where a water body is naturally capable of providing full support for its designated aquatic life uses, that condition will be maintained. The standards (the combination of use and criteria) recognize, however, that not all waters are naturally capable of staying below the fully protective temperature criteria. When a water body is naturally warmer than the above-described criteria, the state provides an allowance for additional warming due to human activities. In this case, the combined effects of all human activities must also not

cause more than a 0.3°C (0.54°F) increase above the naturally higher temperature condition.

## 2.2 Index of Thermal Stress

Another scenario evaluation metric, the Index of Thermal Stress, was developed specifically for the evaluation of Sammamish River Corridor Action Plan temperature management scenarios (USACE and King County 2002). This metric was developed to provide a means of quantifying the exposure of salmon to heat stress. Daily temperature threshold exceedances were combined with the duration of the exceedances to provide an Index of Thermal Stress (ITS). This approach essentially produced a time-weighted average of the magnitude of exceedance of the temperature threshold each day. The temperature thresholds chosen for evaluation were 16, 17.5 and 21 $^{o}$C.

As a simple example, a one-hour exceedance at 20 $^{o}$C [1/24 x (20 – 16) = 0.167 degrees] would count the same as a two-hour exceedance at 18 $^{o}$C [2/24 x (18 – 16) = 0.167 degrees]. The calculation is illustrated graphically for a 16 $^{o}$C threshold in Figure 1.

## 2.3 Selected Locations for Management Evaluation

All scenarios evaluated for daily ITS were based on three thresholds (16, 17.5 and 21 $^{o}$C). Daily values of the ITS (based on the three thresholds) and daily maximum (and minimum) temperature were output for a 30 year simulation (conceptually representing weather experienced between 1970 and 1999)[2] at model segments 3, 6, 20, 25, 28 and 37. A plan and side view of the model geometry is shown in Figures 2 and 3, respectively.

These model segments represent the following locations:

- **Segment 3:** upstream of Big Bear Creek
- **Segment 6:** Redmond Railroad Bridge downstream of Bear Creek
- **Segment 20:** NE 145th Street Bridge (north end of the Agricultural Production District)
- **Segment 25:** just upstream of Little Bear Creek
- **Segment 28:** just upstream of North Creek
- **Segment 37:** Bothell/Blyth Park downstream of North Creek and upstream of Swamp Creek

Summary statistics included the mean and maximum ITS between July 15 and Sept 15 over the 30 year simulation. The mean and maximum 7-DMAX over the same time window was also summarized. The results are summarized in charts on the following pages.

[2] Note that the long-term model simulation results were based on synthetic tributary flow and temperature data. Therefore, the results are not intended to accurately represent temperature conditions in a particular year. The results are intended to capture the response of a number of temperature management alternatives under a wide variety of hydrologic and climatic conditions relative to the base case. Nonetheless, the base case results do provide a good indication of the magnitude and temporal variation of thermal stress experienced by migrating salmon.

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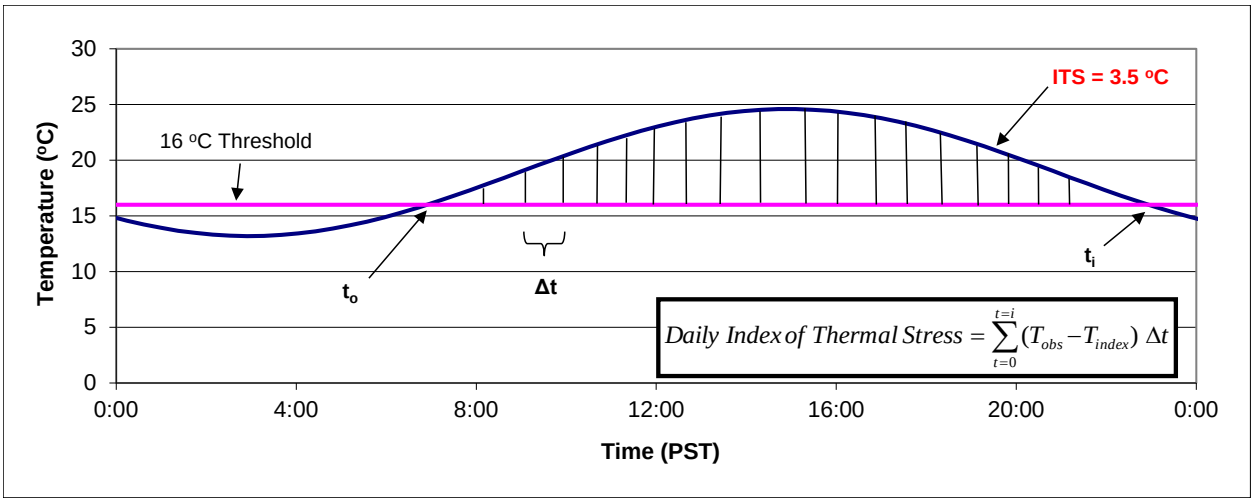


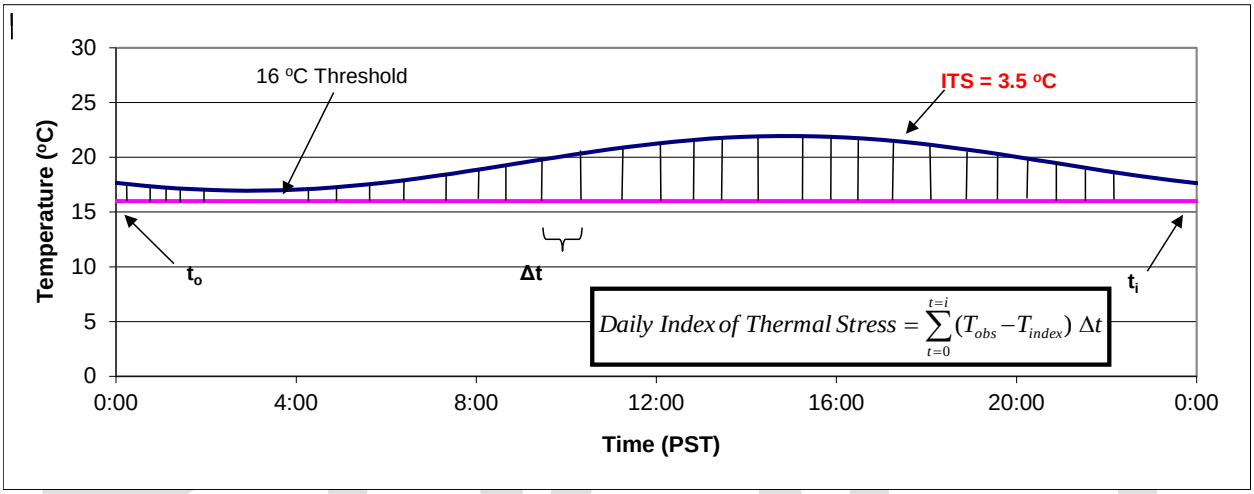


**Figure 1. Example Calculations of the Index of Thermal Stress Equal to an average exceedance of 3.5 °C over the course of the day based on a 16 °C temperature threshold.**

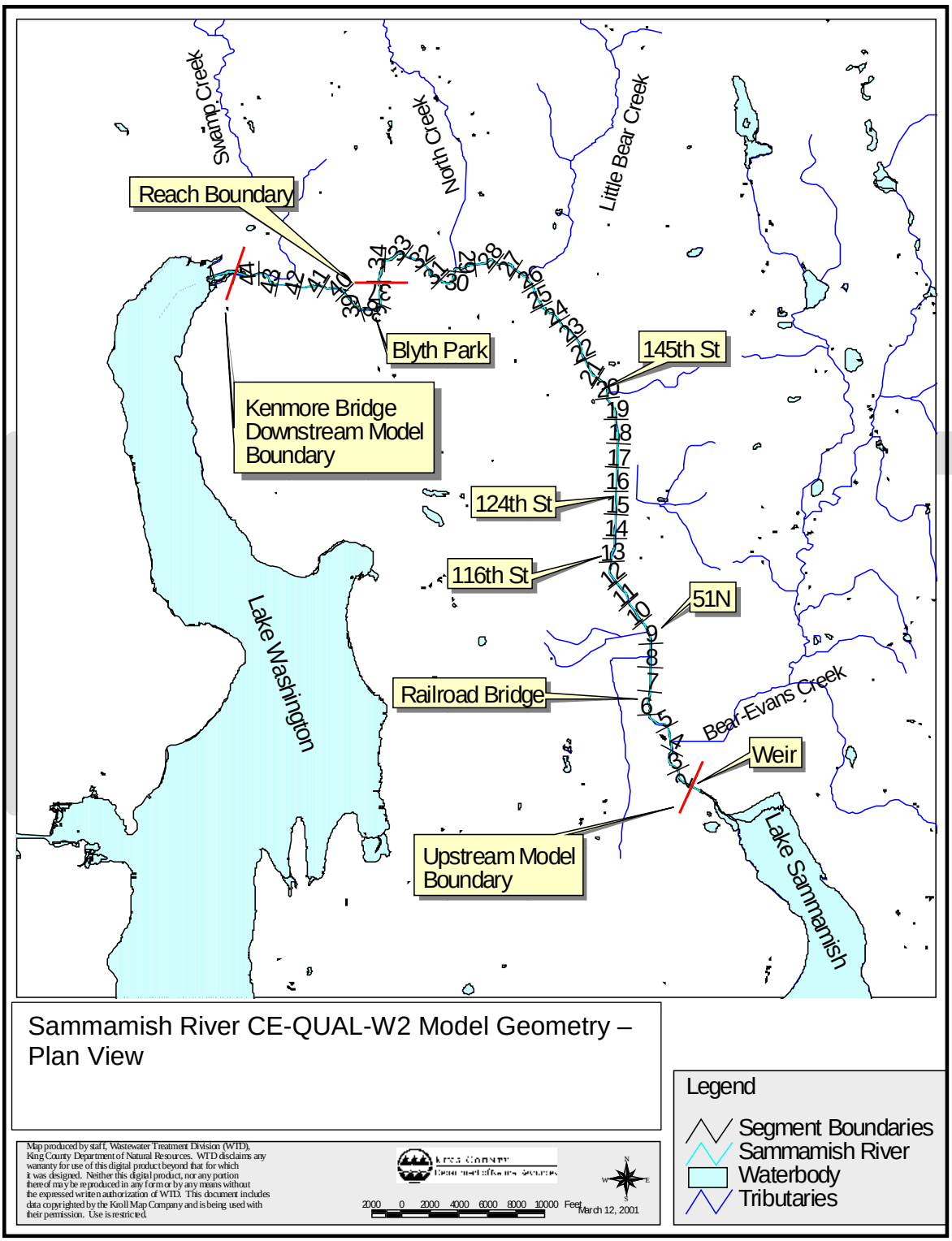


**Figure 2. Sammamish River CE-QUAL-W2 Model Geometry – Plan View.**

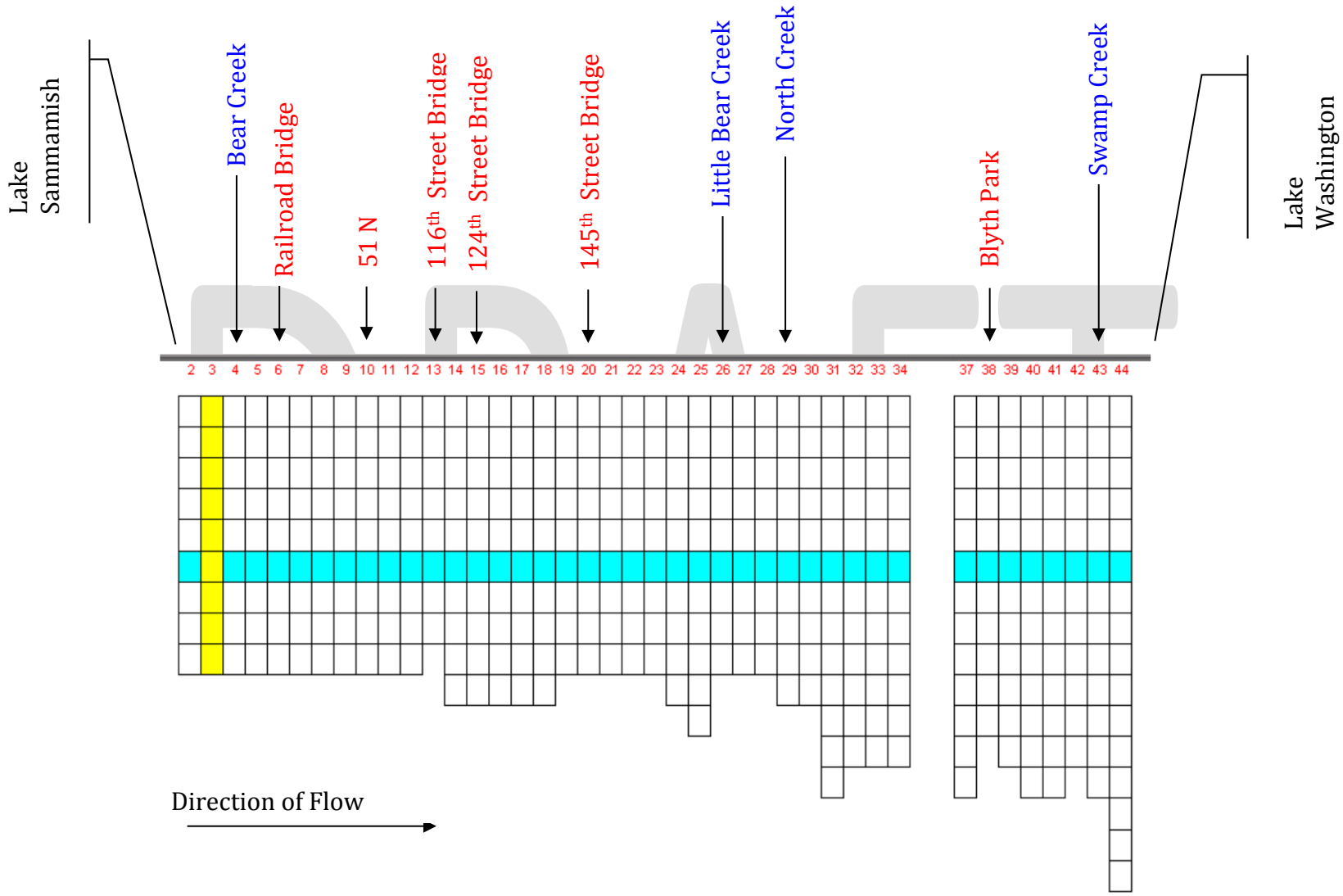


**Figure 3. Sammamish River CE-QUAL-W2 Model Geometry – Side View.**

## 2.4 Management Scenarios

As previously described above, a **Baseline** model run (a no action alternative) formed the basis of comparison to three temperature management scenarios. The modeled scenarios were as follows:

- **5 cfs Augmentation Flow** - Add 5 cfs (not replacing any weir flow) to the most upstream model segment with a constant temperature of 18 $^{o}$C for the period July 15 – September 15.
- **10 cfs Hypolimnetic Withdrawal** - Replace 10 cfs of flow to river at weir boundary with lake hypolimnetic water (temperature based on historical data from 15 m depth in lake used in Sammamish River Corridor Action Plan study) for the period July 15 – September 15.
- **20 cfs Hypolimnetic Withdrawal** - Replace 20 cfs of flow to river at weir boundary with lake hypolimnetic water (temperature based on historical data from 15 m depth in lake used in Sammamish River Corridor Action Plan study) for the period July 15 – September 15.

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# 3.0 RESULTS AND DISCUSSION

The results of the Baseline and three temperature management alternatives are presented below for average and maximum 7-DMAX and for average and maximum ITS.

## 3.1 Index of Thermal Stress

The results of the Baseline and three temperature management alternatives with respect to changes in the mean and maximum ITS between July 15 and September 15 over the 30-year period for the thresholds of 16, 17.5 and 21 °C are provided in Figures 4 through 9. The results for each scenario, including the Baseline model run are presented and discussed below. Tables summarizing the ITS results are provided in Appendix A.

### 3.1.1 Baseline

The Baseline results indicate that the greatest potential for thermal stress for salmonid migration occurs in the vicinity of the upstream boundary between the lake outlet at the weir and the confluence of Big Bear Creek. Upstream of the confluence with Big Bear Creek, the average temperature above 16 °C (i.e., ITS) for the period July 15-September 15 over the 30 year simulation was approximately 3.5 °C, while the maximum daily average exceedance was over 8.4 °C (Figures 4 and 5 and Tables A-1 and A-2). The maximum exceedance represents the highest daily ITS between July 15 and September 15 over the 30 year simulation. As the ITS temperature threshold increases (i.e., to 17.5 or 21 °C), the average and maximum ITS values decrease. Therefore, the average and maximum ITS at the upstream Segment 3 for the 21 °C threshold was about 0.2 and 3.4 °C, respectively.

Downstream of the confluence of Big Bear Creek, thermal stress decreases as a function of downstream distance (see Figures 4 through 9). The decline is due primarily to the input of cooler water from the major tributaries, including Big Bear, Little Bear and North creeks. This trend is consistent for all ITS threshold temperatures and is most evident for the ITS based on the 21 °C threshold (see Figures 8 and 9). The 21 °C threshold is not exceeded during the 30-year simulation at the most downstream Segment 37 between North Creek and Swamp Creek.

For comparison to the ITS values upstream of Bear Creek, the average temperature above 16 °C [ITS 16 °C) goes from 3.5 °C above Big Bear Creek to 2.2 °C downstream of Big Bear Creek to 0.7 °C near Blyth Park in Bothell between North Creek and Swamp Creek (see Figure 4 and Table A-1). The maximum ITS for the same 16 °C temperature threshold goes from 8.4 above Big Bear Creek to 6.8 °C downstream of Bear Creek to 3.8 °C between North and Swamp creeks.

### 3.1.2 5 cfs Augmentation Flow

The addition of 5 cfs of 18 °C water upstream of Big Bear Creek resulted in the largest reduction in ITS at the most upstream assessment Segment 3 just downstream of where this additional flow was placed. For the ITS based on the 16 °C threshold, the average ITS

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was reduced relative to the Baseline model by 12 percent and the maximum ITS was reduced by 24 percent at Segment 3 (see Figures 4 and 5 and Tables A-1 and A-2).

The most dramatic reduction predicted was for the average ITS based on a 21 °C threshold in Segment 3 – an 85 percent reduction (see Figure 8 and Table A-5). The reduction in the 21 °C ITS was also substantial for the maximum value – 58 percent at Segment 3 (see Figure 9 and Table A-6).

Much less reduction in ITS was predicted at assessment locations further downstream. At Segment 28 and 37, ITS was predicted to be essentially the same or somewhat higher than the Baseline ITS (see Tables A-1, A-3 and A-5). These small increases are due to increasing the volume of warmer river flow that is then less affected by the input from cooler tributaries.

### 3.1.3 10 cfs Augmentation Flow

The addition of 10 cfs of cold hypolimnetic water at the weir resulted in substantial reductions in ITS at the upstream Segment 3 (61 and 25 percent for the average and maximum ITS based on the 16 °C threshold) (see Figures 4 and 5 and Tables A-1 and A-2). Reductions in the ITS based on the 21 °C threshold were most dramatic with average and maximum ITS reductions of 95 and 61 percent, respectively, in Segment 3 (see Figures 8 and 9 and Tables A-5 and A-6).

Substantial reductions were also predicted at locations further downstream, although the relative reduction was predicted to decline as a function of downstream distance. For example, at the most downstream Segment 37, the ITS based on a 16 °C threshold was predicted to decrease by 18 and 4 percent for the average and maximum ITS, respectively (see Figures 4 and 5 and Tables A-1 and A-2).

### 3.1.4 20 cfs Augmentation Flow

The addition of 20 cfs of cold hypolimnetic water at the weir resulted in the largest reductions in ITS relative to the Baseline model at all assessment segments. The relative reduction in the 16 °C ITS was 88 and 42 percent for the average and maximum ITS at Segment 3 (see Figures 4 and 5 and Tables A-1 and A-2). The largest reductions were predicted for the ITS based on the 21 °C threshold in Segment 3 – average ITS was reduced 100 percent (i.e., to zero) and maximum ITS was reduced 93 percent (see Figures 8 and 9 and Tables A-5 and A-6).

As for the 10 cfs Hypolimnetic Withdrawal scenario, the relative reduction in ITS declined as function of distance downstream of the weir, with the relative differences in reduction between the two hypolimnetic withdrawal scenarios also decreasing with downstream distance. At the most downstream Segment 37, the average and maximum 16 °C ITS was reduced by 37 and 9 percent, respectively (see Figures 4 and 5 and Tables A-1 and A-2).

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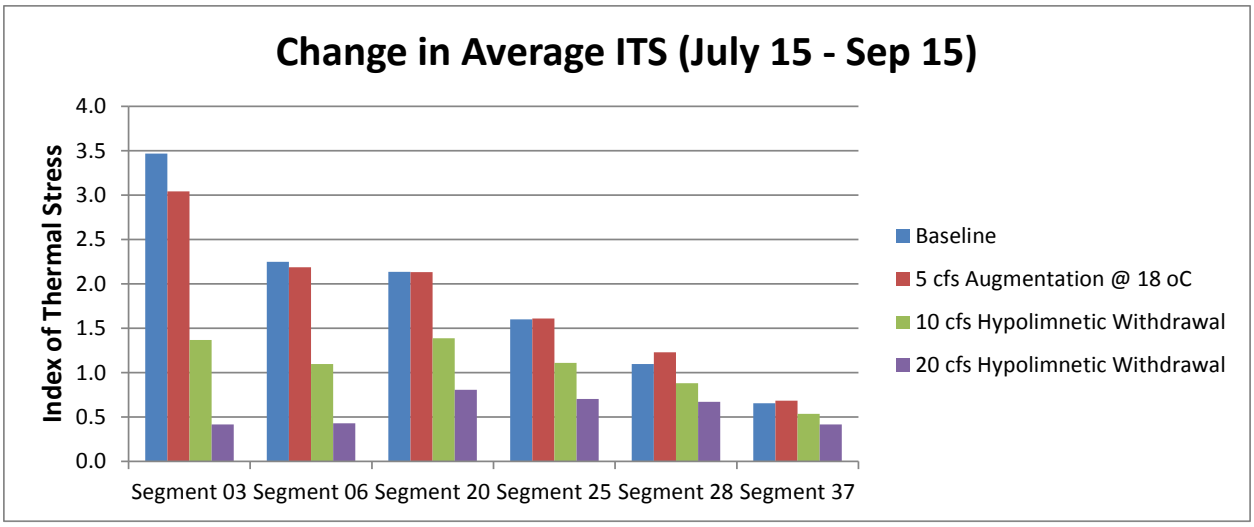


**Figure 4. Average Index of Thermal Stress (Jul 15-Sep 15) based on a threshold of 16 °C.**

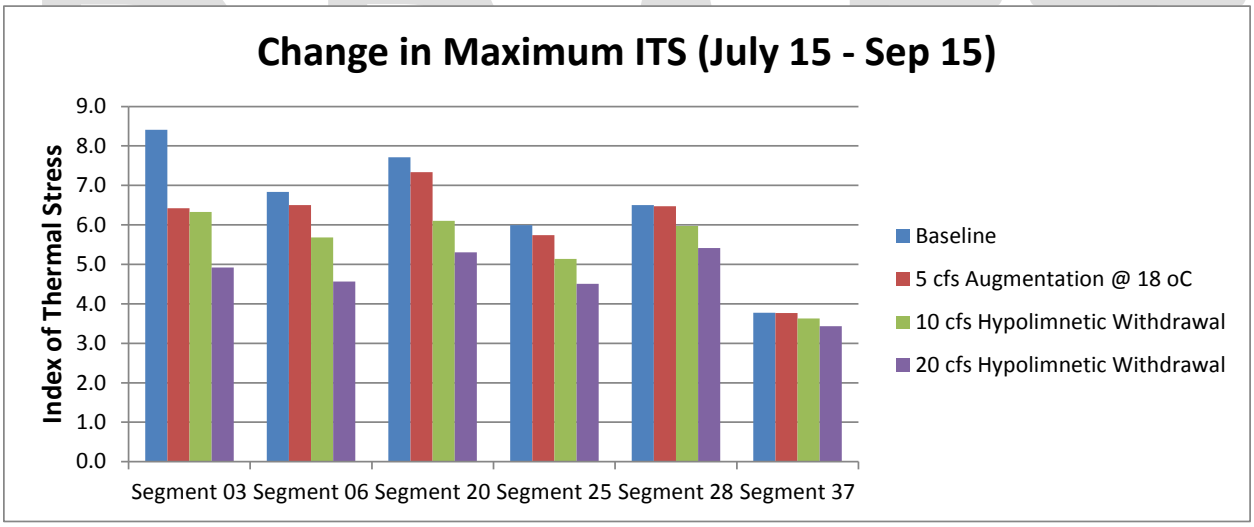


**Figure 5. Maximum Index of Thermal Stress (Jul 15-Sep 15) based on a threshold of 16 °C.**

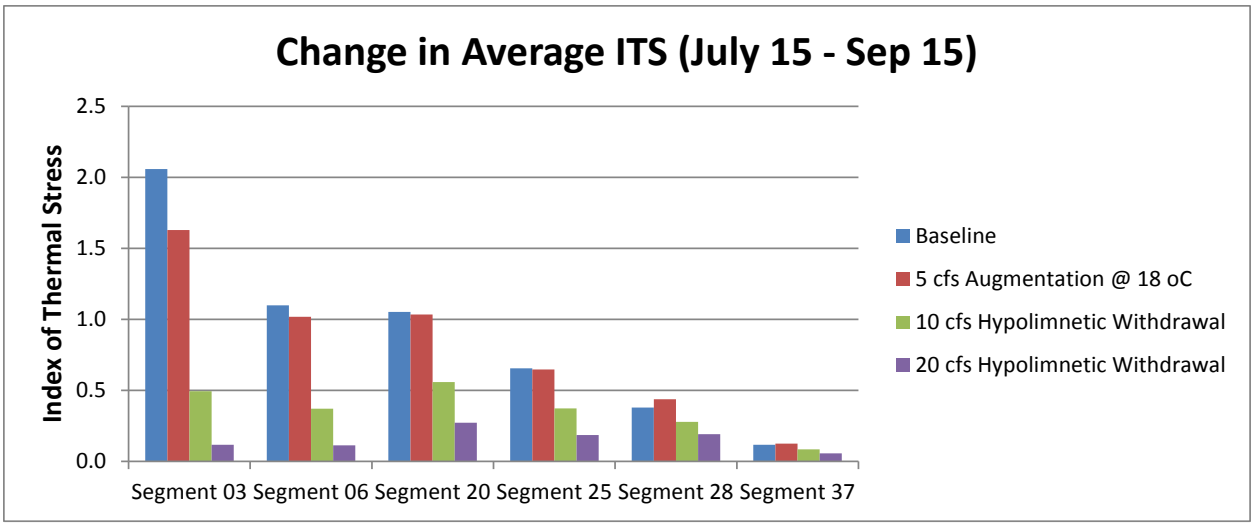


**Figure 6. Average Index of Thermal Stress (Jul 15-Sep 15) based on a threshold of 17.5 °C.**

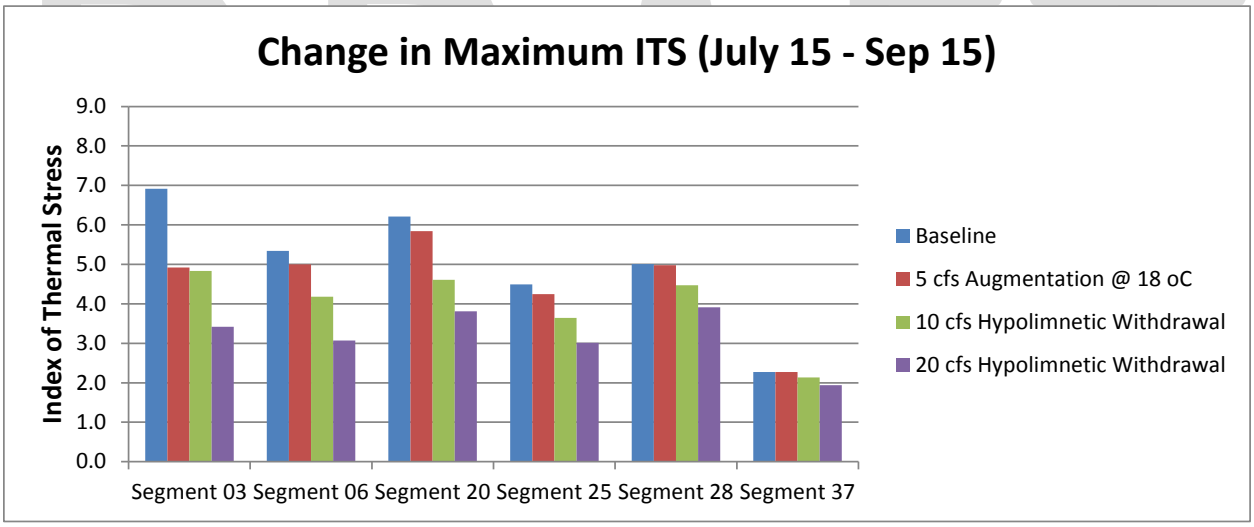


**Figure 7. Maximum Index of Thermal Stress (Jul 15-Sep 15) based on a threshold of 17.5 °C.**

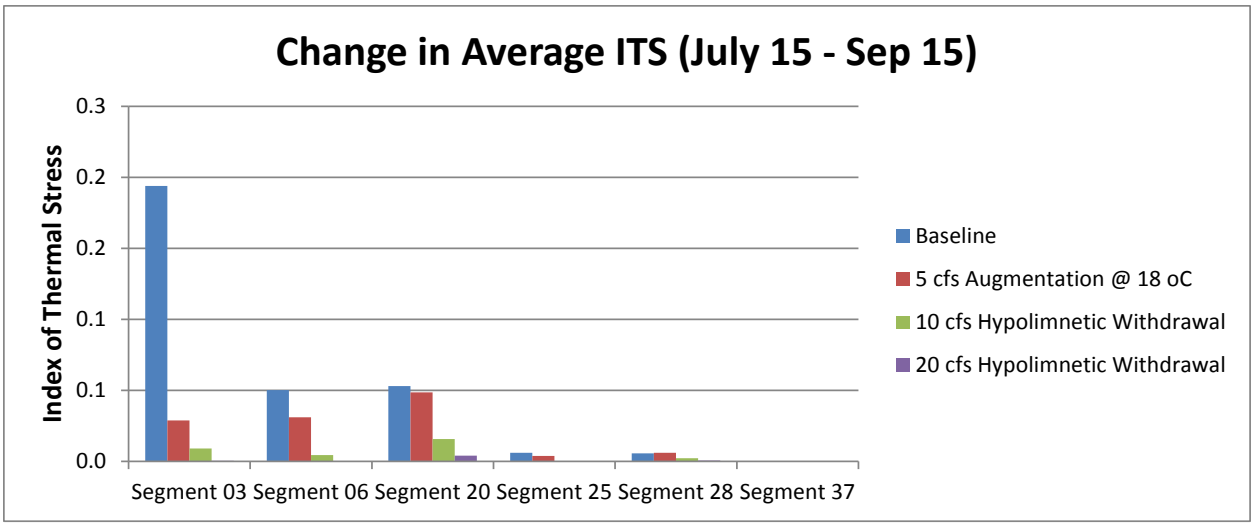


**Figure 8. Average Index of Thermal Stress (Jul 15-Sep 15) based on a threshold of 21 °C.**

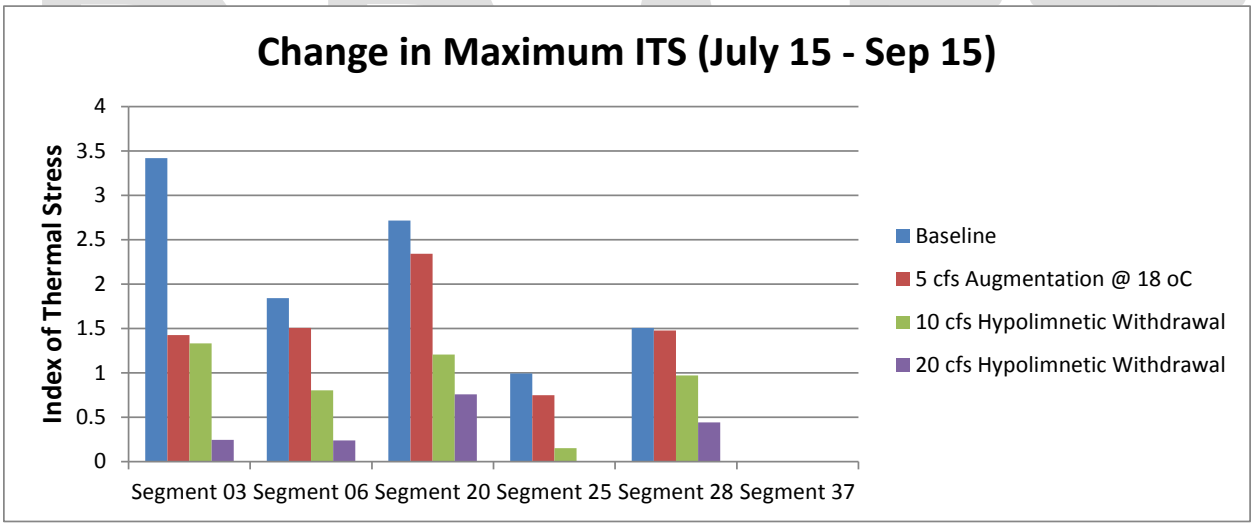


**Figure 9. Maximum Index of Thermal Stress (Jul 15-Sep 15) based on a threshold of 21 °C.**

### 3.1.5 Temporal Variation of the Index of Thermal Stress

The average and maximum values of the ITS over the 30 year simulations provide for relatively simple comparisons between management scenarios. However, the temporal variation of ITS over the course of any particular summer or among years is also relevant. The temporal variation is particularly important because the time when Chinook salmon migrate through the river is generally later than July 15th. Although a few Chinook are observed at the locks in June and July, the peak in the numbers of fish entering at the locks occurs in late August and early September (Berge et al. 2006). Fresh et al. (1999) reported that Chinook entered the Sammamish River at the end of August in 1998. Based on the Baseline temperature model run, ITS (for a 16 $^{o}$C threshold) is highest between mid-July and late August and generally begins a steady decline around August 15th (Figure 10).

The ITS (based on the 16 $^{o}$C threshold) above Big Bear Creek for the Baseline model run can be compared to the model-predicted ITS for the three management scenarios at the same upstream location (see Figure 10). The relatively more dramatic response to the two hypolimnetic withdrawal scenarios relative to the 5 cfs Augmentation flow scenario is apparent. The 20 cfs Hypolimnetic withdrawal scenario reduces substantially the number of years when temperatures would exceed 16 $^{o}$C at the most upstream segment after about August 15th.

Based on the Baseline model run ITS results for the 21 $^{o}$C threshold, temperatures in the river are routinely above 21 $^{o}$C from mid-July through mid-August, but the frequency of exceedances of the 21 $^{o}$C threshold decrease beginning in mid-August (Figure 11). The Baseline model run can be compared to the model-predicted ITS (21 $^{o}$C threshold) for the three management scenarios at the same upstream location (see Figure 11). Even the 5 cfs Augmentation scenario substantially reduces the occurrence of temperatures above 21 $^{o}$C beginning in mid-August and appears to practically eliminate exceedances of the 21 $^{o}$C threshold by late August. The Hypolimnetic Withdrawal scenarios also substantially reduce the risk of temperatures above 21 $^{o}$C throughout July and August (see Figure 11).

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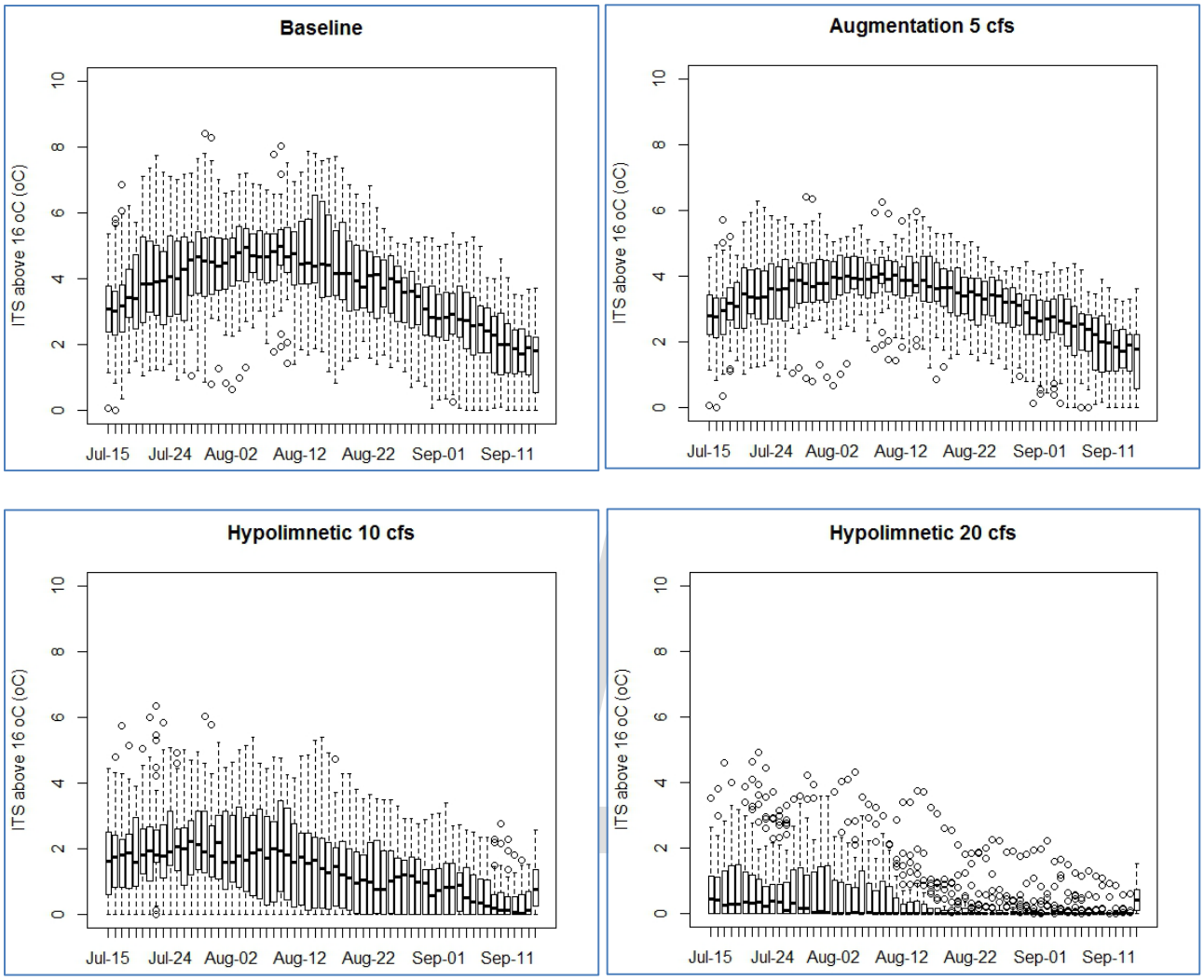


**Figure 10. Boxplot showing the daily ITS (based on a 16 °C threshold) above Big Bear Creek (Segment 3) for the period July 15 through September 15 over the 30 year simulation for the Baseline and three management scenarios.**

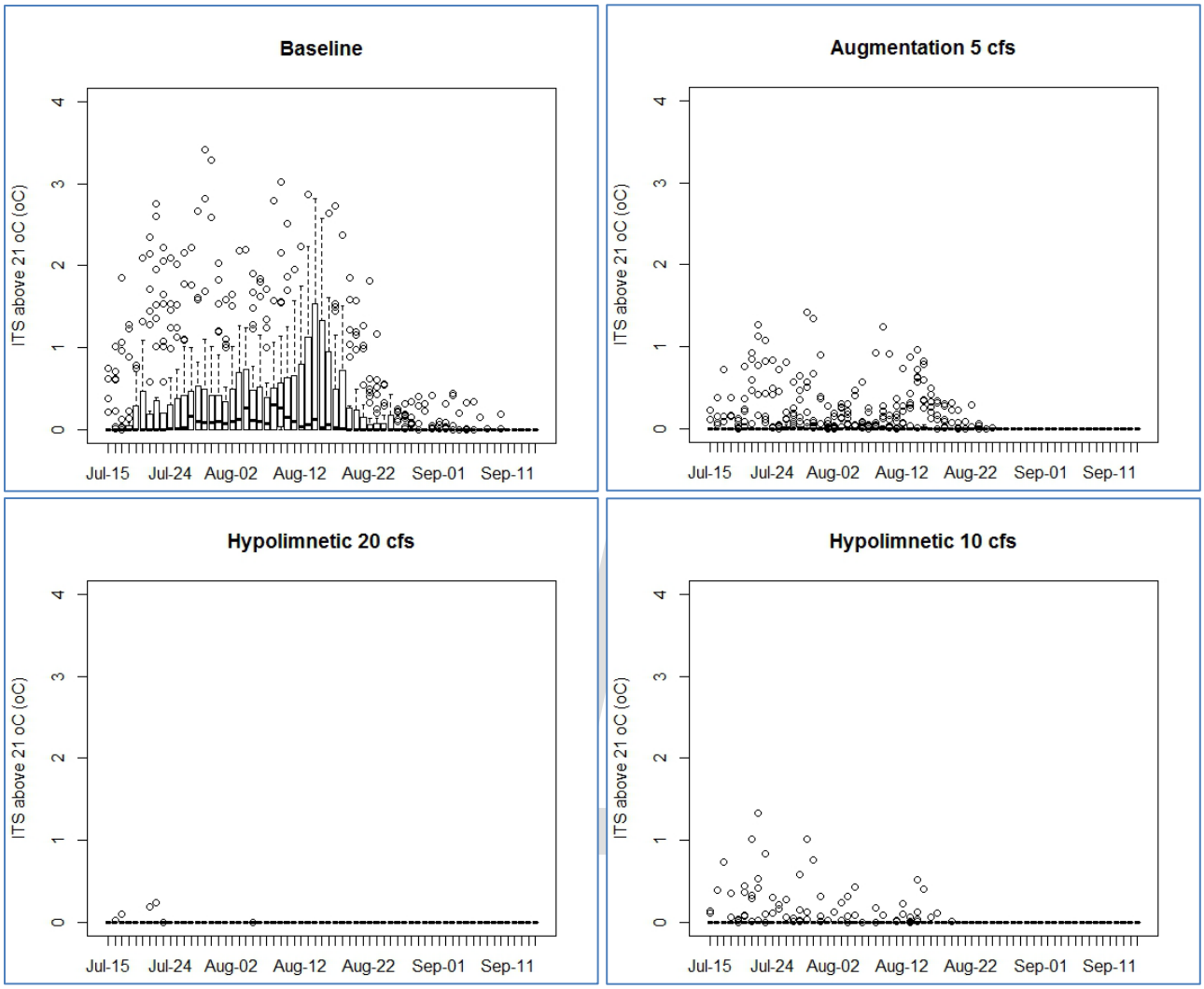


**Figure 11. Boxplot showing the daily ITS (based on a 21 °C threshold) above Big Bear Creek (Segment 3) for the period July 15 through September 15 over the 30 year simulation for the Baseline and three management scenarios.**

## 3.2 7-Day Moving Average of the Daily Maximum Temperature

The results of the Baseline and three temperature management alternatives with respect to changes in the mean and maximum 7-DMAX between July 15 and September 15 over the 30-year period are summarized in Figures 12 and 13. The results for each scenario, including the Baseline model run are presented and discussed below.

### 3.2.1 Baseline

The Baseline results for average and maximum 7-DMAX were consistent with the results for ITS that indicated the greatest thermal stress for salmonid migration in the vicinity of the upstream boundary. The average and maximum 7-DMAX then generally decrease as a function of downstream distance. As noted previously, the decline is due primarily to the input of cooler water from the major tributaries, including Big Bear, Little Bear and North creeks.

The average 7-DMAX between July 15 through September 15 over the 30-year simulation was not predicted to exceed 21 $^{o}$C at any of the assessment segments, although the average predicted for the most upstream Segment 3 was 20.5 $^{o}$C. The maximum 7-DMAX was predicted to exceed 21 $^{o}$C at all, but the most downstream Segment 37 at least once over the 30-year simulation period. The maximum 7-DMAX of 24.6 $^{o}$C was predicted to occur in the most upstream Segment 3 and slightly lower 7-DMAX values between 23.7 and 21.5 $^{o}$C between segments 6 and 28.

### 3.2.2 5 cfs Augmentation Flow

The addition of 5 cfs of 18 $^{o}$C water upstream of Big Bear Creek resulted in a 4 percent reduction in average 7-DMAX and an 8 percent reduction in maximum 7-DMAX in Segment 3.

Much less reduction in 7-DMAX was predicted at assessment locations further downstream. At Segments 25, 28 and 37; the average 7-DMAX was predicted to be essentially the same or somewhat higher than the Baseline. The small increases are due to increasing the volume of warmer river flow that is then less affected by the input from cooler tributaries.

### 3.2.3 10 cfs Augmentation Flow

The addition of 10 cfs of cold hypolimnetic water at the weir resulted in larger reductions in average 7-DMAX at the upstream Segment 3 (13 percent). Reductions in the maximum 7-DMAX at Segment 3 was the same as the prediction for the 5 cfs Augmentation Flow scenario (8 percent).

However, in contrast to the 5 cfs Augmentation Flow scenario, consistent, albeit smaller, reductions were predicted at locations further downstream. However, the relative reduction was predicted to decline as a function of downstream distance. For example, at

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the most downstream Segment 37, the 7-DMAX was predicted to decrease by 1 percent for both the average and maximum 7-DMAX.

### 3.2.4 20 cfs Augmentation Flow

The addition of 20 cfs of cold hypolimnetic water at the weir resulted in the largest reductions in 7-DMAX relative to the Baseline model at all assessment segments. Reduction in the average and maximum 7-DMAX at Segment 3 was 25 and 11 percent, respectively.

Similar to the 10 cfs Hypolimnetic Withdrawal scenario, consistent reductions were predicted downstream with the relative reduction declining as a function of downstream distance. The relative difference in reduction between the 10 and 20 cfs Hypolimnetic Withdrawal scenarios also decreased in the downstream direction. At the most downstream Segment 37, the 7-DMAX was predicted to decrease by 2 and 3 percent for the average and maximum 7-DMAX, respectively.

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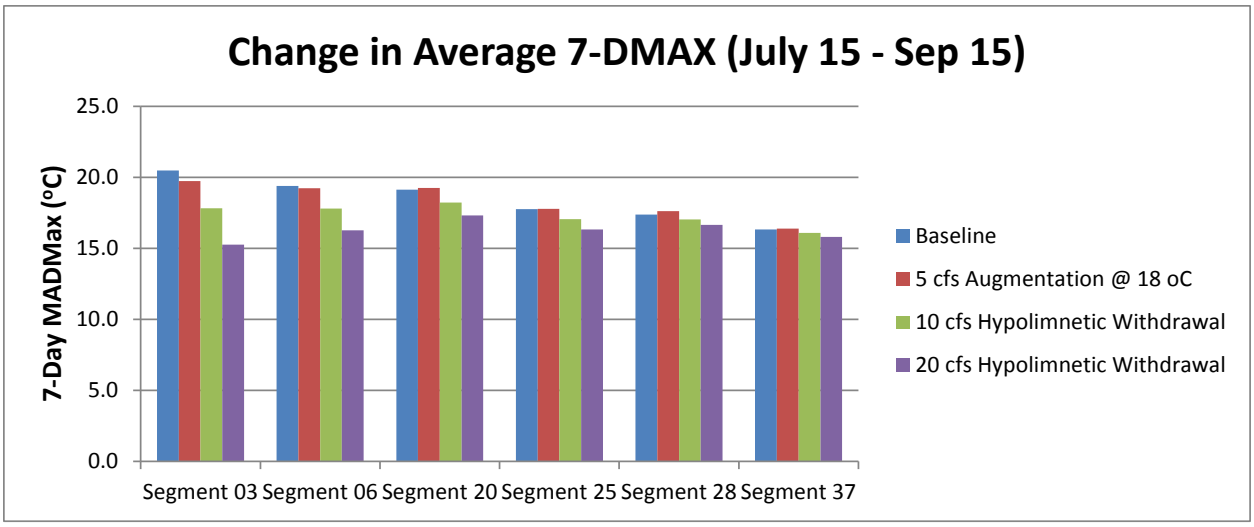


**Figure 12. Average 7-day moving average of daily maximum temperature (Jul 15-Sep 15).**

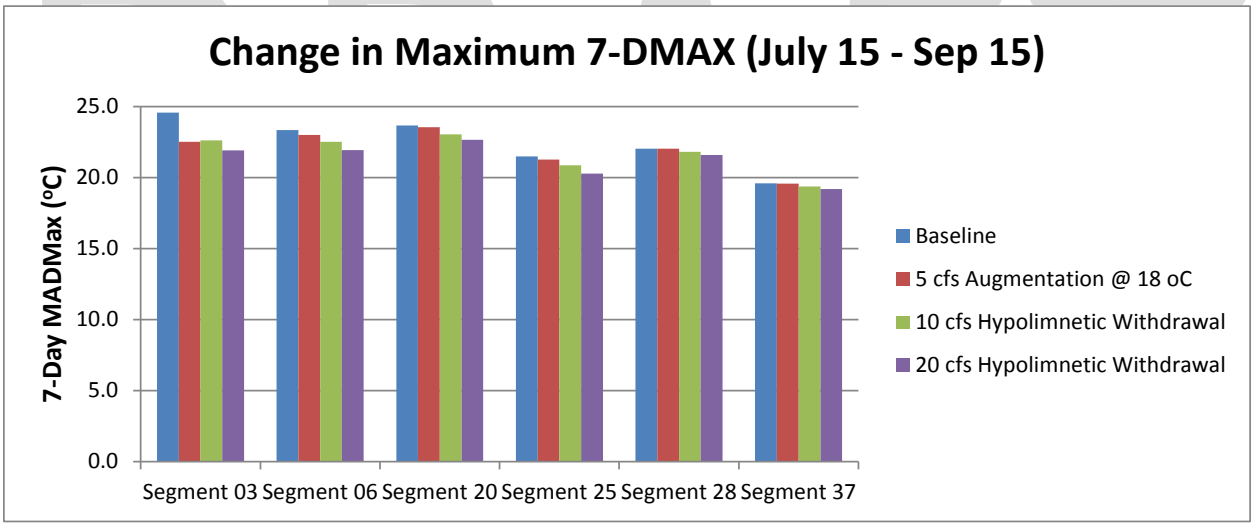


**Figure 13. Maximum 7-day moving average of daily maximum temperature (Jul 15-Sep 15).**

### 3.2.5 Time Series Plots of 7-DMAX

The average and maximum values of ITS and 7-DMAX provide metrics that allow comparisons to be made among various management alternatives. However, the water quality standards rely on comparison to time series plots of 7-DMAX. Because the outflow from the lake generally declines from mid-summer through fall, while the maximum lake (and river) temperatures generally occur mid-summer in late July or early August, the relative effect of various management scenarios changes from year to year and from day to day within any particular year. Ultimately, the relative reduction in thermal stress to migrating fish is also a function of the timing and duration of migration from the Ship Canal locks to spawning grounds.

In order to highlight the importance of variation in lake outflow and temperature in conjunction with the timing of Bear Creek and Lake Sammamish Chinook salmon, figures are presented that show the thermal response as measured by the 7-DMAX temperature at the most upstream Segment 3 (see Figures 14 and 15).

Figure 14 presents the 7-DMAX for the Baseline and three management scenarios for July 1st through September 30th in a year with a relatively high mean flow during the period July 15-September 15 (the third highest for the 30 year period), but a relatively low mean temperature of inflow from the lake (the sixth lowest). In a year like this, the maximum 7-DMAX is lower and the thermal response among the scenarios is not as dramatic as in the second example, which represents the year with the highest mean inflow temperature and an average inflow rate similar to the median for the 30-year period (Figure 15). Because the replacement flow is fixed and the temperature of the pumped hypolimnetic water is relatively constant (at least in these modeling scenarios), the effect of any particular scenario in any particular year or point in time during a summer will depend primarily on the inflow rate from the river and secondarily on the temperature of the inflow.

These figures also highlight the fact that the timing and duration of Chinook migration through the river will need to be considered more closely in more focused evaluations of the quantity and temperature of replacement flows delivered to the river, when the management alternative provides for such control.

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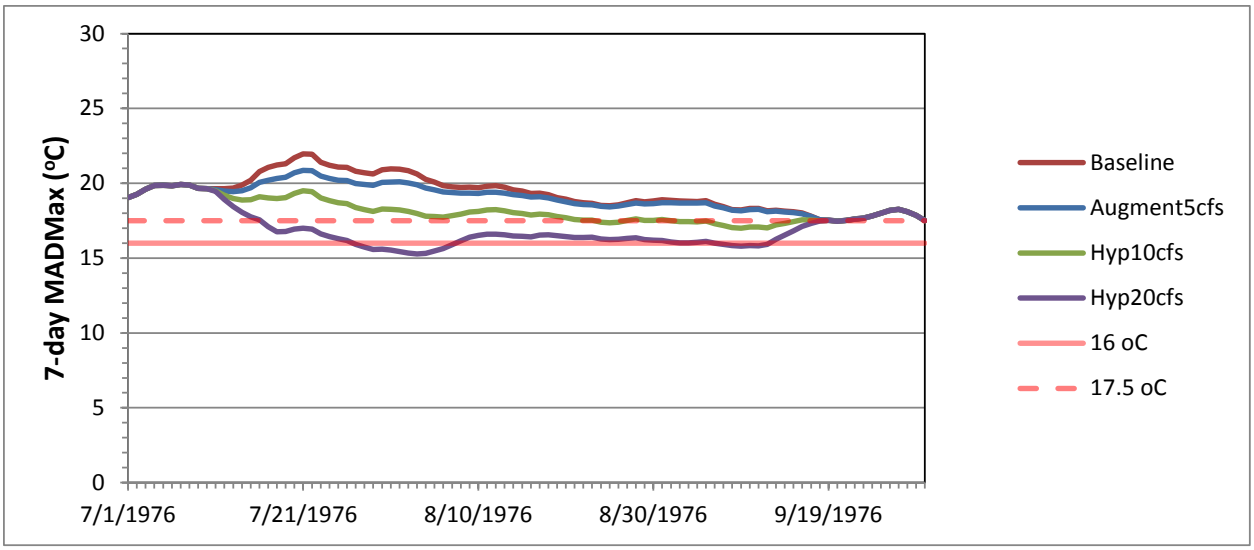


**Figure 14. Maximum 7-day Moving Average of Daily Maximum Temperature (Jul 15-Sep 15, 1976) in Segment 3 (downstream of weir and upstream of Big Bear Creek).**

*Note: This was a year with a relatively high mean flow during the period July 15-September 15 (the third highest for the 30 year period), but a relatively low mean temperature of the inflow from the lake (the sixth lowest). . Ecology's 16 and 17.5 ºC temperature standards are provided for comparison.*

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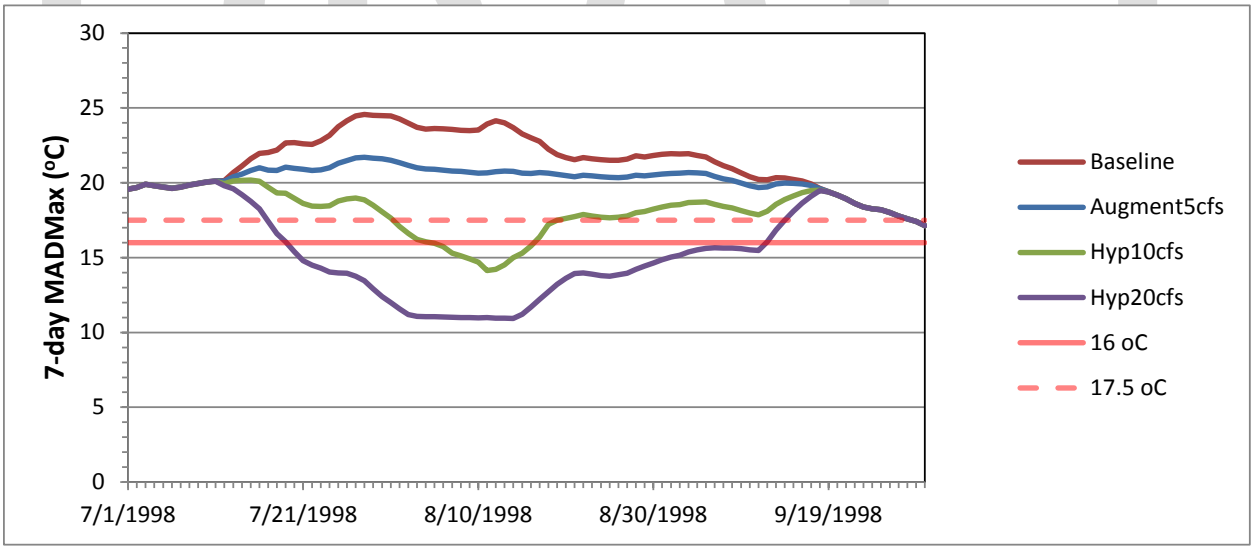


**Figure 15. Maximum 7-day Moving Average of Daily Maximum Temperature (Jul 15-Sep 15, 1998) in Segment 3 (downstream of weir and upstream of Big Bear Creek).**

*Note: This was the year with the highest mean inflow temperature and a flow rate similar to the median flow rate for the 30 year period. Ecology's 16 and 17.5 ºC temperature standards are provided for comparison.*

# 4.0 CONCLUSIONS AND RECOMMENDATIONS

Of the three river temperature management alternatives evaluated here, the Hypolimnetic Withdrawal scenarios are predicted to provide the greatest benefit where it is presumably needed most – in the most upstream reach the receives the warm surface water outflow from Lake Sammamish. The 20 cfs Hypolimnetic Withdrawal scenario performed better than the 10 cfs scenario, although the differences between these two alternatives were greatest at the upper most assessment segment and differences diminished as a function of distance downstream of the weir.

It should be noted that the 5 cfs Augmentation Flow scenario also indicated the potential to reduce thermal stress to migrating salmon, but the effectiveness was largely limited to the location just below the location where the additional 18 $^{o}$C flow was released.

The results of the modeling work presented here are also consistent with a parallel study that focused on nearfield effects of replacing 1, 10 and 20 cfs of summer lake surface outflow with much cooler water – nominally 10 $^{o}$C for the 1 cfs scenario and 13 $^{o}$C for the 10 and 20 cfs scenario (R2 Resource Consultants 2014). Their analyses suggested that a 9 cfs or greater replacement flow would provide a reasonable expectation of significant improvement in thermal refuge for migrating Chinook salmon. They also acknowledged that some benefit could be realized from replacement flows between 4 and 9 cfs.

To date, observed river temperatures and river temperature modeling of current conditions and potential conditions under various management scenarios has provided a reasonable approximation of the potential to improve the thermal conditions for fall Chinook migrating through the river. What has been lacking is a means to translate the spatial and temporal improvements in thermal regime into quantitative predictions in the migrating fish population given the potential for additional limiting factors such as spawning habitat impairment or loss, predation, harvest, hatchery selection and variability in ocean conditions. Perhaps most importantly from the perspective of improving the migratory corridor thermal regime is the potential compounding effect of thermal stress experienced as a result of passage through the Ship Canal to Lake Washington (USACE and SPU 2008). Monitoring of the thermal experience of migrating salmonids and monitoring of the health outcome of migrating is needed to better understand the impacts of thermal stress on Chinook reproductive success (e.g., Naughton et al. 2013).

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# APPENDIX A: SUMMARY TABLES OF INDEX OF THERMAL STRESS AND 7-DMAX RESULTS

**Table A-1 Summary of average ITS (degree-days above 16 °C) from July 15 to September 15 over the 30 year simulation at six selected locations along the Sammamish River.**

| Scenarios | Below Weir<br>Segment 3 | Downstream of Bear Creek<br>Segment 6 | NE 145th St Bridge<br>Segment 20 | Upstream of Little Bear Creek<br>Segment 25 | Upstream of North Creek<br>Segment 28 | Bothell Blyth Park<br>Segment 37 |
|---|---|---|---|---|---|---|
| | **Degree-days above 16 °C** | | | | | |
| Baseline | 3.5 | 2.3 | 2.1 | 1.6 | 1.1 | 0.66 |
| 5 cfs Augmentation @ 18 °C | 3.0 | 2.2 | 2.1 | 1.6 | 1.2 | 0.68 |
| 10 cfs Hypolimnetic Withdrawal | 1.4 | 1.1 | 1.4 | 1.1 | 0.88 | 0.54 |
| 20 cfs Hypolimnetic Withdrawal | 0.42 | 0.43 | 0.81 | 0.70 | 0.67 | 0.42 |
| | **Percent Reduction from Baseline** | | | | | |
| 5 cfs Augmentation @ 18 °C | 12 | 3 | 0 | -1 | 12 | 4 |
| 10 cfs Hypolimnetic Withdrawal | 61 | 51 | 35 | 31 | 19 | 18 |
| 20 cfs Hypolimnetic Withdrawal | 88 | 81 | 62 | 56 | 39 | 37 |

**Table A-2 Summary of maximum ITS (degree-days above 16 $^{o}$C) from July 15 to September 15 over the 30 year simulation at six selected locations along the Sammamish River.**

| Scenarios | Below Weir Segment 3 | Downstream of Bear Creek Segment 6 | NE 145th St Bridge Segment 20 | Upstream of Little Bear Creek Segment 25 | Upstream of North Creek Segment 28 | Bothell Blyth Park Segment 37 |
|---|---|---|---|---|---|---|
| | **Degree-days above 16 $^{o}$C** | | | | | |
| Baseline | 8.4 | 6.8 | 7.7 | 6.0 | 6.5 | 3.8 |
| 5 cfs Augmentation @ 18 $^{o}$C | 6.4 | 6.5 | 7.3 | 5.7 | 6.5 | 3.8 |
| 10 cfs Hypolimnetic Withdrawal | 6.3 | 5.7 | 6.1 | 5.1 | 6.0 | 3.6 |
| 20 cfs Hypolimnetic Withdrawal | 4.9 | 4.6 | 5.3 | 4.5 | 5.4 | 3.4 |
| | **Percent reduction from Baseline** | | | | | |
| 5 cfs Augmentation @ 18 $^{o}$C | 24 | 5 | 5 | 4 | 0 | 0 |
| 10 cfs Hypolimnetic Withdrawal | 25 | 17 | 21 | 14 | 8 | 4 |
| 20 cfs Hypolimnetic Withdrawal | 42 | 33 | 31 | 25 | 17 | 9 |

**Table A-3 Summary of average ITS (degree-days above 17.5 $^{o}$C) from July 15 to September 15 over the 30 year simulation at six selected locations along the Sammamish River.**

| Scenarios | Below Weir<br>Segment 3 | Downstream of Bear Creek<br>Segment 6 | NE 145th St Bridge<br>Segment 20 | Upstream of Little Bear Creek<br>Segment 25 | Upstream of North Creek<br>Segment 28 | Bothell Blyth Park<br>Segment 37 |
|---|---|---|---|---|---|---|
| | **Degree-days above 17.5 $^{o}$C** | | | | | |
| Baseline | 2.1 | 1.1 | 1.1 | 0.65 | 0.38 | 0.12 |
| 5 cfs Augmentation @ 18 $^{o}$C | 1.6 | 1.0 | 1.0 | 0.65 | 0.44 | 0.13 |
| 10 cfs Hypolimnetic Withdrawal | 0.5 | 0.37 | 0.56 | 0.37 | 0.28 | 0.08 |
| 20 cfs Hypolimnetic Withdrawal | 0.12 | 0.11 | 0.27 | 0.19 | 0.19 | 0.06 |
| | **Percent reduction from Baseline** | | | | | |
| 5 cfs Augmentation @ 18 $^{o}$C | 21 | 7 | 2 | 1 | -15 | -8 |
| 10 cfs Hypolimnetic Withdrawal | 76 | 66 | 47 | 43 | 26 | 27 |
| 20 cfs Hypolimnetic Withdrawal | 94 | 90 | 74 | 71 | 49 | 51 |

**Table A-4 Summary of maximum ITS (degree-days above 17.5 °C) from July 15 to September 15 over the 30 year simulation at six selected locations along the Sammamish River.**

| Scenarios | Below Weir<br>Segment 3 | Downstream of Bear Creek<br>Segment 6 | NE 145th St Bridge<br>Segment 20 | Upstream of Little Bear Creek<br>Segment 25 | Upstream of North Creek<br>Segment 28 | Bothell Blyth Park<br>Segment 37 |
|---|---|---|---|---|---|---|
| | **Degree-days above 17.5 °C** | | | | | |
| Baseline | 6.9 | 5.3 | 6.2 | 4.5 | 5.0 | 2.3 |
| 5 cfs Augmentation @ 18 °C | 4.9 | 5.0 | 5.8 | 4.2 | 5.0 | 2.3 |
| 10 cfs Hypolimnetic Withdrawal | 4.8 | 4.2 | 4.6 | 3.6 | 4.5 | 2.1 |
| 20 cfs Hypolimnetic Withdrawal | 3.4 | 3.1 | 3.8 | 3.0 | 3.9 | 1.9 |
| | **Percent reduction from Baseline** | | | | | |
| 5 cfs Augmentation @ 18 °C | 29 | 6 | 6 | 6 | 1 | 0 |
| 10 cfs Hypolimnetic Withdrawal | 30 | 22 | 26 | 19 | 11 | 6 |
| 20 cfs Hypolimnetic Withdrawal | 51 | 43 | 39 | 33 | 22 | 15 |

**Table A-5 Summary of average ITS (degree-days above 21 °C) from July 15 to September 15 over the 30 year simulation at six selected locations along the Sammamish River.**

| Scenarios | Below Weir<br>Segment 3 | Downstream of Bear Creek<br>Segment 6 | NE 145th St Bridge<br>Segment 20 | Upstream of Little Bear Creek<br>Segment 25 | Upstream of North Creek<br>Segment 28 | Bothell Blyth Park<br>Segment 37 |
|---|---|---|---|---|---|---|
| | **Degree-days above 21 °C** | | | | | |
| Baseline | 0.19 | 0.050 | 0.053 | 0.0060 | 0.0058 | 0.0000 |
| 5 cfs Augmentation @ 18 °C | 0.029 | 0.031 | 0.049 | 0.0038 | 0.0061 | 0.0000 |
| 10 cfs Hypolimnetic Withdrawal | 0.0091 | 0.0045 | 0.016 | 0.0002 | 0.0022 | 0.0000 |
| 20 cfs Hypolimnetic Withdrawal | 0.0004 | 0.0003 | 0.0041 | 0.0000 | 0.0007 | 0.0000 |
| | **Percent reduction from Baseline** | | | | | |
| 5 cfs Augmentation @ 18 °C | 85 | 38 | 8 | 37 | -7 | - |
| 10 cfs Hypolimnetic Withdrawal | 95 | 91 | 70 | 97 | 61 | - |
| 20 cfs Hypolimnetic Withdrawal | 100 | 99 | 92 | 100 | 88 | - |

**Table A-6 Summary of maximum ITS (degree-days above 21 °C) from July 15 to September 15 over the 30 year simulation at six selected locations along the Sammamish River.**

| Scenarios | Below Weir<br>Segment 3 | Downstream of Bear Creek<br>Segment 6 | NE 145th St Bridge<br>Segment 20 | Upstream of Little Bear Creek<br>Segment 25 | Upstream of North Creek<br>Segment 28 | Bothell Blyth Park<br>Segment 37 |
|---|---|---|---|---|---|---|
| | **Degree-days above 21 °C** | | | | | |
| Baseline | 3.4 | 1.8 | 2.7 | 1.0 | 1.5 | 0.0000 |
| 5 cfs Augmentation @ 18 °C | 1.4 | 1.5 | 2.3 | 0.75 | 1.5 | 0.0000 |
| 10 cfs Hypolimnetic Withdrawal | 1.3 | 0.81 | 1.2 | 0.15 | 1.0 | 0.0000 |
| 20 cfs Hypolimnetic Withdrawal | 0.25 | 0.24 | 0.75 | 0.0000 | 0.44 | 0.0000 |
| | **Percent reduction from Baseline** | | | | | |
| 5 cfs Augmentation @ 18 °C | 58 | 18 | 14 | 25 | 2 | - |
| 10 cfs Hypolimnetic Withdrawal | 61 | 56 | 56 | 85 | 36 | - |
| 20 cfs Hypolimnetic Withdrawal | 93 | 87 | 72 | 100 | 71 | - |

**Table A-7 Summary of maximum 7-DMAX from July 15 to September 15 over the 30 year simulation at six selected locations along the Sammamish River.**

| Scenarios | Below Weir<br>Segment 3 | Downstream of Bear Creek<br>Segment 6 | NE 145th St Bridge<br>Segment 20 | Upstream of Little Bear Creek<br>Segment 25 | Upstream of North Creek<br>Segment 28 | Bothell Blyth Park<br>Segment 37 |
|---|---|---|---|---|---|---|
| | **Degree-days above 21 $^{o}$C** | | | | | |
| Baseline | 24.6 | 23.3 | 23.7 | 21.5 | 22.0 | 19.6 |
| 5 cfs Augmentation @ 18 $^{o}$C | 22.5 | 23.0 | 23.5 | 21.3 | 22.0 | 19.6 |
| 10 cfs Hypolimnetic Withdrawal | 22.6 | 22.5 | 23.0 | 23.9 | 21.8 | 19.4 |
| 20 cfs Hypolimnetic Withdrawal | 21.9 | 21.9 | 22.7 | 20.3 | 21.6 | 19.2 |
| | **Percent reduction from Baseline** | | | | | |
| 5 cfs Augmentation @ 18 $^{o}$C | 8 | 1 | 1 | 1 | 0 | 0 |
| 10 cfs Hypolimnetic Withdrawal | 8 | 4 | 3 | 3 | 1 | 1 |
| 20 cfs Hypolimnetic Withdrawal | 11 | 6 | 4 | 6 | 2 | 2 |

**Table A-8 Summary of average 7-DMAX from July 15 to September 15 over the 30 year simulation at six selected locations along the Sammamish River.**

| Scenarios | Below Weir<br>Segment 3 | Downstream of Bear Creek<br>Segment 6 | NE 145th St Bridge<br>Segment 20 | Upstream of Little Bear Creek<br>Segment 25 | Upstream of North Creek<br>Segment 28 | Bothell Blyth Park<br>Segment 37 |
|---|---|---|---|---|---|---|
| | **Degree-days above 21 $^{o}$C** | | | | | |
| Baseline | 20.5 | 19.4 | 19.1 | 17.7 | 17.4 | 16.3 |
| 5 cfs Augmentation @ 18 $^{o}$C | 19.7 | 19.2 | 19.3 | 17.8 | 17.6 | 16.4 |
| 10 cfs Hypolimnetic Withdrawal | 17.8 | 17.8 | 18.2 | 17.1 | 17.0 | 16.1 |
| 20 cfs Hypolimnetic Withdrawal | 15.3 | 16.3 | 17.3 | 16.3 | 16.7 | 15.8 |
| | **Percent reduction from Baseline** | | | | | |
| 5 cfs Augmentation @ 18 $^{o}$C | 4 | 1 | -1 | 0 | -1 | 0 |
| 10 cfs Hypolimnetic Withdrawal | 13 | 8 | 5 | 4 | 2 | 1 |
| 20 cfs Hypolimnetic Withdrawal | 25 | 8 | 5 | 4 | 2 | 2 |