FISH LAKE MITIGATION FLOW - APPENDIX 2.7.2.4B-D

Prepared for:

Taseko Mines Limited
300 - 905 West Pender St.
Vancouver, BC V6C 1L6
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Abstract

As a measure to ensure the viability of the resident Rainbow Trout population in Fish Lake, the New Prosperity Mine Development Plan proposes to recirculate water from the outlet of the lake to the two Fish Lake tributaries that are known to support spawning fish. To investigate the overall volume of recirculation that will be required to maintain adequate flow depth, Manning's discharge equation was employed with reported channel characteristics in the tributaries. The results of these calculations suggest the recirculation system will be required to deliver up to 0.735 m^3/sec of water during the Rainbow Trout spawning period to maintain a spawning depth of 0.20 m in both tributaries. The required volume drops to between 0.1 and 0.3 m^3/sec during other periods outside the spawning period when the required water depths decrease to 0.10 m deep. Through the maintenance of the required mitigation flow and the remaining habitat it is estimated that the tributaries will support a spawning population of 6,200 Rainbow Trout.

The implications of this proposed flow recirculation to the stream temperatures and dissolved oxygen concentrations were evaluated using a weighted average mixing model. Results from this model suggest that, as expected, the temperatures in the tributaries are anticipated to closely reflect the ambient temperatures in Fish Lake. The model suggests that water temperatures in the tributaries will increase during the winter months. During the spring and summer months water temperatures in the tributaries are anticipated to decrease, while the fall period temperatures will increase over baseline. The predicted changes will be on average less than 6°C from baseline and should therefore be considered within the range of natural temperatures.

The advantages of mixing epilimnetic and hypolimnetic water to optimize temperatures for developing Rainbow Trout is demonstrated with a mixing scenario that includes 50% epilimnion water and 50% hypolimnion water. This scenario suggests that tributary water temperatures may decrease from a baseline average of approximately 15°C in July to an average of 12°C and in doing so more closely approximate the optimal temperatures for developing Rainbow Trout embryos (8.5 to 11°C as in Reed et al., 2003).

Predictions pertaining to the end-of-pipe dissolved oxygen concentrations in the tributaries suggest that concentrations will be influenced strongly by lake water concentrations. During the stratified winter and summer periods the predicted average concentrations will range between 4 and 6 mg/L, below the applicable guidelines for aquatic life. During the spring and fall turnover periods end-of-pipe concentrations will be close to the theoretical saturation level of 10 mg/L on average. This situation will require ongoing monitoring and potentially artificial aeration strategies to ensure rapid equilibration with atmospheric conditions a short distance from the end-of-pipe.

Overall the maintenance of year round flow in the tributaries is expected to have advantages to the overall health of the tributary and lake ecology. Currently, the tributaries are ephemeral and provide little in the way of habitat during the fall and winter. Year round flow will ensure that juvenile Rainbow Trout as well as other aquatic organisms will be sustained over the fall and winter. Additionally, the increased dissolved oxygen contributions from the tributaries during the winter months could maintain refuge habitat in the event of depleted winter concentrations.

1.0 Introduction

Maintenance of a healthy, sustainable population of Rainbow Trout (*Oncorhynchus mykiss*) in Fish Lake is a key objective outlined in the New Prosperity Mine proposal. This document describes the mitigation measures being proposed to maintain suitable stream flows during the critical spawning and egg incubation periods in Fish Lake Tributary 1 and Fish Creek Reach 8.

Physical Habitat Criteria for Rainbow Trout Spawning Habitat

Rainbow Trout spawn in small tributary streams to lakes and larger streams during the mid March to late June period (Lindsey et al., 1959; Hartman et al., 1962; Scott and Crossman, 1973). Spawning generally occurs when water temperatures are between 10.0 and 15.5°C (Scott and Crossman, 1973). Redds are built in clear, silt-free water near vegetated banks (Ford et al., 1995) over fine gravel in riffles above pools (Scott and Crossman, 1973).

Rainbow Trout spawn in coarse sand-cobble substrates ranging in size from 0.5 cm to 5.1 cm (Bernstein and Montgomery, 2008). Spawning typically takes place in lotic habitat but can occur in littoral areas in the absence of stream-type habitat, inlets, or outlets. The preferred water velocity for spawning ranges from 0.3 to 0.9 m/s in depths from 0.15 to 2.5 m (Bernstein and Montgomery, 2008; Ford et al., 1995). Rainbow Trout alevin emergence from the redd takes four to seven weeks (mid June to mid August; Scott and Crossman, 1973; Ford et al., 1995).

1.1 Baseline Conditions in Middle and Upper Fish Creek

The Fish Lake watershed supports a monoculture population of Rainbow Trout consisting of approximately 85,000 adult, sub-adult, and juveniles residing in Fish Lake, 5,000 fish in Little Fish Lake, and 75,000 Rainbow Trout in Fish Creek and lake tributaries (Triton, 1999). With the exception of a few tributaries, the majority of the instream habitat occurs in Fish Creek, reaches 4 through 8, and in Fish Lake Tributary 1. Refer to Figure 1.1 in Appendix 2.7.2.5A for the location of the tributaries and reaches. Combined, these two creek sections provide 52,138 m^2 of instream habitat at bankfull conditions, of which 47,246 m^2 (91%) is classified as fish bearing (Table 1; Triton, 1997). Refer to Figure 2.6.1.5-1 in the New Prosperity EIS for a map of the baseline fish distribution.

Table 1. Baseline conditions for Rainbow Trout habitat in Middle and Upper Fish Creek

Reach	Flow Type[1]	Fish Status[2]	Bankfull Channel Dimensions[3]		
			Length (m)	Width (m)	Area (m^2)
Fish Creek Mainstem					
4	continuous	FB	1,705	4.2	7,161
5	continuous	FB	3,221	4.5	14,495
6	continuous	FB	1,072	4.0	4,288
8	intermittent	FB	5,565	2.9	16,139
Totals/Averages			**11,563**	**3.9**	**42,083**
Fish Lake Tributary No.1					
1	continuous	FB	1,761	2.5	4,403
Trib B2D	intermittent	FB	400	1.9	760
2	continuous	NFB	118	2.7	319
2	intermittent	NFB	2,371	1.6	3,794
3	ephemeral	NFB	557	1.4	780
Totals/Averages			**5,207**	**2.0**	**10,056**
Grand Totals			**16,770**		**52,138**

Modified from Appendix 5-3-A Fish Creek Fish and Fish Habitat Surveys (Summer 1996 and 1997)
[2] **FB**: fish-bearing; **NFB**: non fish-bearing
[3] **Bankfull** channel width and area measurements reflect maximum values

Within the mainstem reaches, Reach 8 contains 16,139 m^2 of instream habitat, all of which is fish bearing. Fish Lake Tributary 1 provides 10,056 m^2 of instream habitat, of which 5,163 m^2 (51%) is fish bearing.

The TSF main embankment will be located approximately 2.5 km upstream from Fish Lake; this installation will eliminate fish bearing habitat in the upper sections of mainstem Reach 8 and non-fish bearing habitat in Fish Lake Tributary 1 (Reaches 2 and 3). Fish bearing reaches and habitat downstream of the TSF will not be physically affected by the Project. However, the location of the TSF is anticipated to result in reduced flows to the lower sections of Reach 8 and Fish Lake Tributary 1 (Reaches 1 and 2). To address this reduction in flow in the lower sections of Reach 8 and Fish Lake Tributary 1 (Reach 1 and 2) and to maintain the productive capacity of this habitat, flow augmentation is planned. Details regarding the water management plan and predicted natural flows are contained within EIS Section 2.7.2.4.

Physical habitat surveys conducted in 1996 and 1997 (Triton, 1999) assessed the amount of potential spawning habitat in Fish Creek watershed as determined by the presence (percentage) of gravel-bottom substrates and riffle-type habitat (Table 2). Based on 29% occurrence of gravel-bottom substrates and 17% riffle habitat type composition, it was determined that the remaining (conserved) instream habitat in Reach 8 and Fish Lake Tributary 1 will provide 5,118 m^2 and 3,000 m^2 respectively, of potential spawning habitat. As the amount of riffle habitat varies with flow/season, the occurrence of gravel bottom substrates was considered the more accurate of the two estimates to describe potential spawning habitat area.

Table 2. Estimates of potential Rainbow Trout spawning habitat in Fish Creek mainstem Reach 8 and Fish Lake Tributary 1, downstream from the TSF main embankment

Reach	Baseline Bankfull Area (m^2)	Bankfull Area Downstream from TSF (m^2)	Potential Gravel Spawning Habitat (m^2)[1]	Potential Riffle Spawning Habitat (m^2)[2]
Reach 8 (fish bearing)	16,139	9,513	2,759	1,617
Fish Lake Tributary 1 (fish bearing; includes Trib. B2D)	5,163	5,163	1,497	878
Fish Lake Tributary 1 (non-fish bearing	4,893	2,972	862	505
Totals	26,195	17,648	5,118	3,000

[1] based on 29% gravel substrate composition; downstream from TSF
[2] based on 17% riffle habitat type composition; downstream from TSF

In 1997, a total of 14,741 mature Rainbow Trout migrated from Fish Lake into Fish Creek inlet (Reach 8; 4,593 spawners) and outlet (Reaches 6 and 5; 10,148 spawners; Triton, 1999). This population spawned over an estimated 12,332 m^2 gravel substrates in those reaches which resulted in a spawner density of 1.2 fish/m^2 gravel habitat. The majority (80%) of the migration from the lake into the inlet and outlet spawning areas occurred between May 8 and June 6, while an outmigration of juveniles from inlet and outlet reaches into the lake was largely (80%) complete by July 22. In 1997, a small number of Rainbow Trout were also observed migrating into Fish Lake Tributary 1 (Triton, 1999).

The calculated spawner density (1.2 fish/m^2 gravel habitat) is somewhat lower than values described by others. For example, Zimmerman and Reeves (2000) recorded average Rainbow Trout redd dimensions of 1.5 m long and 0.86 m wide. Assuming that the shape was elliptical these measurements would equate to a total redd area of 1.01 m^2 and a potential spawner density of approximately 1 pair per m^2 without any superimposition of redds. Other authors report much smaller average Rainbow Trout redds (0.2 m^2) and increased spawning densities per Rainbow Trout pair (1 pair per 0.80 m^2; cited in Bernstein and Montgomery, 2008). These data suggest that not all gravel bottom habitat in Reaches 4 to 6 and 8 were utilized by spawning Rainbow Trout.

1.2 Predicted Project Effects on Spawning Habitat in Middle and Upper Fish Creek

In total, the Project is predicted to affect approximately 46,485 m^2 fish bearing and 21,000 m^2 non-fish bearing stream habitat in Middle and Upper Fish Creek, primarily as a result of the TSF construction and operations and open-pit developments (Table 3). This includes direct effects (Harmful, Alteration, Disruption or Destruction; HADD) under jurisdiction of the *Fisheries Act* and the Metal Mining Effluent Regulations (MMER) and indirect effects under the *Fisheries Act*. (see Section 2.7.2.5 of the EIS).

Table 3. Summary of predicted effects on instream Rainbow Trout habitat in Middle and Upper Fish Creek

Category	Direct Effects (HADD; m2)	Direct Effects (MMER; m2)	Indirect Effects (HADD; m2)	Total (m2)
Fish Bearing Stream	12,367	5,794	28,324	46,485
Non-Fish Bearing Stream	2,772	14,468	3,756	20,996
Stream Total	15,139	20,262	32,080	67,481
Lake	0	66,000	0	66,000
Riparian (Stream and Lake)	199,170	195,400	0	394,570

Adapted from Section 2.7.2.5 of the EIS

The development of the open pit in Reach 6 and upper Reach 5, and flow reductions in lower Reach 5, will directly and indirectly affect all of the approximately 7,552 m^2 of Rainbow Trout spawning habitat in Fish Lake outlet (Table 4). Construction of the TSF is currently predicted to reduce surface flow in Reach 8 by 54%. Similar flow reductions are predicted in Fish Lake Tributary 1. If these Project effects were not addressed, little to no suitable spawning habitat would be available to the resident Rainbow Trout population in Fish Lake.

Natural discharge in Reach 1 of Fish Lake Tributary 1 comprises surface flow from tributary B2D and sub-surface flow from Reach 2. The general arrangement of the TSF and other infrastructure will not affect the discharge in tributary B2D. Refer to Figure 2.7.2.5-1b of the EIS for the site arrangement in relation to fish habitat. Currently, fish migration into Reach 2 of Fish Lake Tributary 1 is prevented by a 200 m section of sub-surface flow located approximately 200 m downstream of the established reach break between Reaches 1 and 2. The proposed excavation/daylighting and complexing (e.g., gravel additions as/if required) of this 200 m section, in addition to upstream flow augmentation, is expected to provide an additional 1,600 m^2 of fish habitat in Fish Lake Tributary 1. Refer to Figure 2.7.2.5-2 in the New Prosperity EIS for the proposed arrangement of the flow augmentation and the Tributary 1 enhancement.

Table 4. Summary of predicted effects on Rainbow Trout spawning habitat in Middle and Upper Fish Creek before mitigation

Mainstem Reach	*Baseline Spawning Habitat (m^2)*	*Effects (m^2)*	*Remaining Spawning Habitat (m^2)*
5	6,523	6,523 (direct effect from pit development in upper reach and indirect effect from flow reduction in lower reach)	0
6	1,029	1,029 (direct effect from pit development	0
8	4,680	4,680 (indirect effect from flow reduction in lower 2.5 km of reach, downstream from the TSF)	0
Total Mainstem	12,332	9,702	0
Fish Lake Tributary 1			
Reach 1	1,365	1,365 (indirect effect from TSF and sub-surface flow reduction)	
Total Tributary	**1,365**	**1,365**	**0**
SOURCE: modified from Appendix 5-3-A. Fish Creek Fish and Fish Habitat Surveys (summer 1996 and 1997) Note: potential spawning habitat (m^2) in Tributary B2D (Fish Lake Tributary 1 tributary) and Fish Lake Tributary 3 are not included as theses streams will not be affected by Project activities			

2.0 Mitigation Plan

Details of the flow augmentation plan are presented in the water quantity evaluation in Section 2.7.2.4A of the New Prosperity Environmental Impact Statement (EIS). Generally speaking, the plan will involve recirculating water from the outlet of Fish Lake back into two of the lake's inlet tributaries. This recirculation will accomplish two primary objectives:

1. Provide sufficient flow and therefore availability of spawning habitat to exceed the minimum genetically viable population of Rainbow Trout, estimated to be around 1,900 spawning pairs or 3,800 mature individuals (Reed et al., 2003)
2. Provide meaningful enhancement to available ephemeral habitat by maintaining continuous recirculation of the water

Water recirculation will involve pumping from near the outlet of Fish Lake to the uppermost extent of the undisturbed channels of Fish Creek Reach 8 and Fish Lake Tributary 1, immediately downstream of the seepage collection ponds (New Prosperity EIS Figure 2.7.2.5-2). The exact location of the withdrawal is still uncertain and may require several kilometres of pipeline to be installed. A portion of this new pipeline will likely follow the right-of-way of the tailings pipeline. The withdrawal structure at the lake will be designed as a multi-depth withdrawal, to provide some control over circulating water temperatures. The pumping volumes and the spawning areas required for both of the creeks were calculated based on the observed baseline conditions and are discussed in detail below.

Currently, both of the identified streams flow ephemerally which could lead to reduced spawning success under temporary wetted conditions and possible stranding of juvenile fish. By maintaining flow throughout the year with consistent recirculation, the survival and recruitment of the Rainbow Trout population in Fish Lake and the reaches of its remaining tributaries is expected to contribute to the sustainability of resident Rainbow Trout in Fish Lake. While the recirculation of lake water into upper Fish Creek and Fish Lake Tributary 1 to replicate their natural hydrographs during spring-summer is considered mitigation (Section 2.7.2.5), the additional pumping in fall-winter and therefore extended habitat availability is considered as partial compensation for Project effects.

In the event mitigation is not successful, the Proponent has identified several potential options that would be considered for implementation. The success of the mitigation measures will be monitored as part of an overall adaptive management plan and the results of that monitoring would be used to refine and implement mitigation where and when needed. Given the plans to recirculate water it will be possible to modify flows at any point during the Project to optimize flows in the tributaries. Flow manipulation will also enable water temperatures to be adjusted during the Project to ensure optimal conditions for all life stages in the streams. In the event the amount of habitat is found to be inadequate, additional channel complexing can occur to expand the total quantity of available habitat. Finally, in situations where spawning in the tributaries is not occurring as envisioned, other strategies including operation of a hatchery (i.e., Hanceville Hatchery) and outplants to barren lakes could be considered for implementation (see non-MMER Fish and Fish Habitat Compensation Plan for more detail – App. 2.7.2.5-A1 *Fisheries Act* Compensation).

2.1 Estimated Spatial Requirements

Baseline instream habitat conditions are compared to operational (post-construction) conditions in Table 5. Of particular note is the additional 2,972 m^2 of habitat area that will become fish bearing following the daylighting/complexing of the current 200 m of subsurface flow in Fish Lake Tributary 1. Post-construction instream areas as they relate to spawning habitat are presented in Table 6.

Table 5. Post-construction (operational) instream habitat predictions in tributaries to Fish Lake

	Baseline Area				
	Reach	***Baseline Channel***	***Baseline Length (m)***	***Width (m)***	***Baseline Area (m^2)***
Fish Creek Inlet (Reach 8; fish bearing)	8	Continuous	5,565	2.9	16,139
Fish Lake Tributary 1 (fish bearing)	1	Continuous	1,761	2.5	4,403
Tributary B2D (fish bearing)	1	Intermittent	400	1.9	760
Fish Lake Tributary 1 (non-fish bearing)	2	Continuous	118	2.7	319
Fish Lake Tributary 1 (non-fish bearing)	2	Intermittent	2,371	1.6	3,794
Total			**10,215**		**25,415**
	Operational Area				
	Reach	**Baseline Channel**	**Remaining Length (m)**	**Width (m)**	**Remaining Area (m^2)**
Fish Creek Inlet (Reach 8; fish bearing)	8	Continuous	3,280	2.9	9,513
Fish Lake Tributary 1 (fish bearing)	1	Continuous	1,761	2.5	4,403
Tributary B2D (fish bearing)	1	Intermittent	400	1.9	760
Fish Lake Tributary 1 (non-fish bearing)	**2**	**Continuous**	**118**	**2.7**	**319**
Fish Lake Tributary 1 (non-fish bearing)	**2**	**Intermittent**	**1,658**	**1.6**	**2,653**
Total			**7,217**		**17,648**

Shaded text represents additional habitat that will be created by daylighting the current 200 m section of sub-surface flow and augmenting the flow.

The New Prosperity Mine developmeScootnt plan will retain over 17,600 m^2 of instream habitat in Upper Fish Creek and Fish Lake Tributary 1. Of this, 54% of the available habitat is located in Upper Fish Creek (Reach 8). Fish Lake Tributary 1 will require that roughly 200 m of currently subsurface channel be excavated to allow for fish migration into Reach 2. In doing so, roughly 2,972 m^2 of new habitat will be available to Rainbow Trout. Refer to Figure 2.7.2.5-2 in the New Prosperity EIS for details.

Based on the percentage of instream habitat that contains suitable spawning gravels (29%), it is estimated that 5,118 m^2 of the channel will be suitable for Rainbow Trout spawning (Table 6). Based on the existing spawner density of 1.2 fish/m^2, the habitat is predicted to provide adequate spawning area for about 6,200 individuals (3,100 pairs), greater than the minimum viable population of 3,800 individuals (Reed et al., 2003; see Section 2.7.2.5 for discussion).

Table 6. Spawning potential area and population

	Reach	Baseline Channel	Remaining Area (m^2)	Spawning Area (m^2)[1]	Predicted number of spawners[2]
Fish Creek (Inlet)	8	Continuous	9,513	2,759	3,311
Fish Lake Tributary 1	1	Continuous	4,403	1,277	1,532
Tributary B2D (fish bearing)	1	Intermittent	760	220	264
Fish Lake Tributary 1	2	Continuous	319	93	112
Fish Lake Tributary 1	2	Intermittent	2,653	769	923
Total			**17,648**	**5,118**	**6,142**

[1] based 29% gravel substrate composition through the channel length

[2] based on baseline spawner density of 1.2 fish/m^2

3.0 Estimated Flow Requirements

The hydrology of the Fish Creek watershed is dominated by snowmelt and precipitation generated spring freshet, followed by rapidly declining flows throughout the summer and a precipitation event-driven fall freshet. During winter, stream reaches provide limited usable habitat as many are either dry or frozen. Reach 1 of Fish Lake Tributary 1 remains flowing during winter, primarily as a result of tributary B2D and sub-surface flow contribution from Reach 2 in that drainage. Reach 8 (Fish Lake inlet) has negligible (intermittent) flow during winter (most instream habitat is frozen substrate-to-surface). Fish Creek Reaches 4 to 6 (Middle Fish Creek) flow throughout the winter.

To predict flow regimes required to support a viable Rainbow Trout population during mine operations, the following parameters and methodology were utilized:

1. Mean Annual Unit Runoff (MAUR)
2. Watershed area
3. Channel characteristics
4. Manning Equation

An important component of the annual water balance is runoff, which is defined here as flow in streams and rivers expressed on a per unit area basis (Mean Annual Unit Runoff – MAUR). The predicted Project effects on surface water flows were assessed against baseline conditions of Fish Creek Reach 8 and Fish Lake Tributary 1 (Table 7). The runoff estimates presented here are considered conservative (i.e., may underestimate actual flows) given they do not include contributions that will be diverted around the TSF or overflow water from the TSF during post-closure. For this assessment they are considered adequate as initial estimates for facilitating the design for pumping capacity and requirements for optimizing seasonal volumes. In the likely event actual runoff into the creeks is greater than estimates shown in Table 7, pumping volumes would simply be adjusted to maintain suitable volumes.

Spawning flow requirements for Fish Lake Tributary 1 and Reach 8 were estimated using the Manning Formula (Cuenca, 1989). Channel shape and size values were gathered from the Fish and Fish Habitat Study (Triton, 1999) and were used to calculate cross-sectional area, wetted perimeter, channel roughness, and channel gradient. The specific spawning requirements of Rainbow Trout were used to establish suitable water depths and velocities required for habitat design and flow requirements.

Table 7. Estimated runoff values for Fish Creek Reach 8 and Fish Lake Tributary 1

	Fish Creek Reach 8			***Fish Lake Tributary 1***		
	Surface Water (m^3/sec)			***Surface Water (m^3/sec)***		
Month	**Baseline**	**Operations**	**Closure**	**Baseline**	**Operations**	**Closure**
January	0.004	0.001	0.001	0.002	0.001	0.001
February	0.003	0.000	0.000	0.001	0.001	0.001
March	0.010	0.002	0.000	0.005	0.002	0.002
April	0.280	0.038	0.040	0.109	0.057	0.057
May	0.780	0.107	0.110	0.304	0.159	0.159
June	0.260	0.036	0.040	0.103	0.054	0.054
July	0.140	0.019	0.020	0.055	0.029	0.029
August	0.100	0.013	0.010	0.038	0.020	0.020
September	0.110	0.015	0.010	0.042	0.022	0.022
October	0.160	0.022	0.020	0.063	0.033	0.033
November	0.030	0.004	0.000	0.012	0.006	0.006
December	0.010	0.001	0.001	0.003	0.002	0.002
Annual	**0.160**	**0.020**	**0.020**	**0.060**	**0.030**	**0.030**

Values assume that no diverted surface water from the TSF enters the streams and that no overflow occurs from the TSF during closure.

The Manning Equation:

$$V = \frac{R^{2/3} s^{1/2}}{n} \qquad Q = VA$$

Where:

V = flow velocity
R = cross-sectional area divided by the wetted perimeter
s = hydraulic gradient (slope of the channel)
n = roughness coefficient of the channel
Q = volumetric flow
A = cross-sectional area

Assumptions made during the water volume calculations include:

1. Uniform flow;
2. Consistent channel gradient; and
3. Rectangular channel cross section.

Manning’s “n” is a coefficient representing the roughness or friction applied to the flow by the channel. Manning’s n-values are pre-calculated for different surfaces/materials. The roughness value with the most similarity to the study area was assumed to be 0.0325. The desired water depth during the spawning period was set at 0.2 m based on mean HSI values for Rainbow Trout spawning (Ford et al., 1995).

Calculations of supplemental flow requirements (discharge required to maintain suitable spawning water velocity and depth), shown in Table 8, range from 0.12 to 0.41 m^3/s in Reach 8 and from 0.07 to 0.32 m^3/s in Fish Lake Tributary 1. Water velocities were calculated secondarily using the calculated discharges and channel area.

Table 8. Example supplemental flow calculations using channel characteristics for Fish Creek Reach 8 and Fish Lake Tributary 1

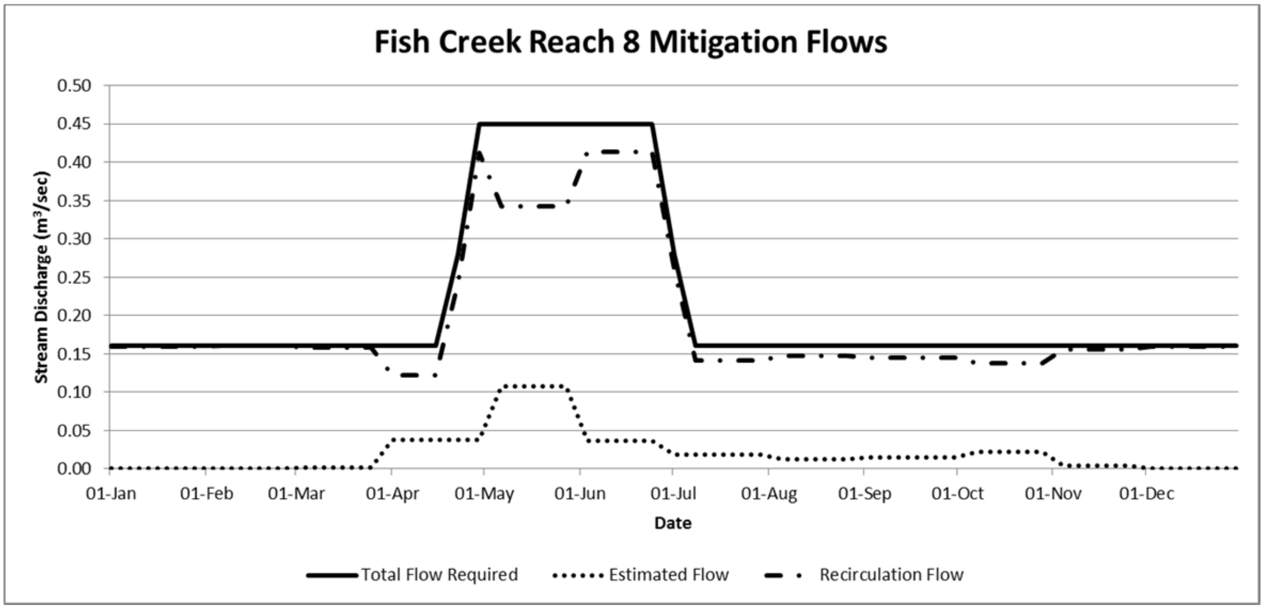
Stream	Depth (m)	Required Flow (m^3/sec)	Estimated Natural Flow (m^3/sec)	Supplemental Flow (m^3/sec)	Flow velocity (m/sec)
Fish Creek Reach 8	0.10	0.160	0.038	0.122	0.55
	0.15	0.280	0.038	0.242	0.70
	0.20	0.450	0.038	0.412	0.84
Fish Lake Tributary 1	0.10	0.130	0.057	0.073	0.55
	0.15	0.240	0.057	0.183	0.70
	0.20	0.380	0.057	0.323	0.83

Supplemental flow requirements for Fish Creek Reach 8 and Fish Lake Tributary 1 are illustrated in Figures 1 and 2 respectively. In general, the hydrologic intervals were established to simulate the natural hydrograph of the area. This involved dividing the supplementary flow requirements into four distinct periods:

- Pre-spawning period (April 8 to May 5)
- Spawning period (May 6 to June 30)
- Incubation and emergence (July 1 to August 25) – This is consistent with a 56 day incubation and emergence period (at 11°C the time is reported to be 18 to 50 days; Raleigh et al., 1984)
- Overwintering habitat (September to March)

During these periods, supplemental flows were determined by the water depths required by the different life stages of Rainbow Trout that are anticipated to be present. During the pre-spawning period, water depth will gradually increase from 0.10 to 0.20 m deep to allow for migration of fish and staging within the channels. During the spawning periods water depths will be maintained at 0.20 m (Stefferud, 1993; Muhlfeld, 2002). During the incubation and emergence periods water levels will be gradually reduced from 0.20 to 0.10 m deep, where they will stay for the overwintering period.

Figure 1. Fish Creek Reach 8 mitigation flows

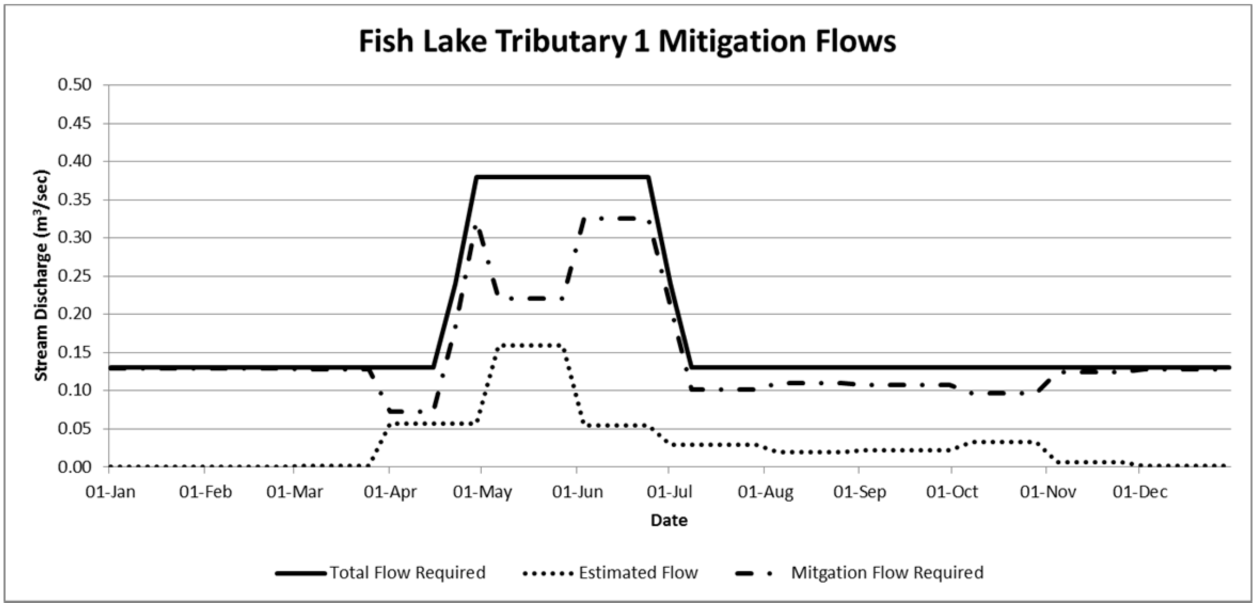


At peak discharge in April and June, approximately 0.41 and 0.32 m^3/sec of water will be recirculated into Fish Creek Reach 8 and Fish Lake Tributary 1, respectively. This will result in water depths of at least 0.20 m in both creeks, well within the range identified by Ford et al. (1995) for Rainbow Trout spawning. The estimated velocities associated with these flows are predicted to range up to 0.84 m/sec, which is at the high end of the velocity envelope specified for Rainbow Trout. However, as stated earlier these velocities are based upon a straight, featureless channel, which will not be the case for the remaining natural channel.

Throughout the low flow fall and winter periods, water levels in Fish Creek Reach 8 and Fish Lake Tributary 1 will be maintained at 0.10 m deep; this translates into sustained discharges of 0.16 and 0.13 m^3/sec, respectively. By maintaining these flows, overwintering and rearing habitat will be available to juvenile Rainbow Trout, whereas none currently exists in Reach 8 and an unknown amount is in Fish Lake Tributary 1.

As a result of unknown/unmeasured contributions of groundwater/sub-surface flow to these mitigation tributaries, there remains some uncertainty with respect to the volumes that will be required for recirculation. Monitoring of instream flows will be undertaken and through an adaptive management approach flows would be adjusted to reflect contributions from unquantified groundwater and/or subsurface flow. The proposed duration of recirculation would be year-round with a minimum flow of approximately 0.15 m^3/s, depending on the tributary.

Figure 2. Fish Lake Tributary 1 mitigation flows



4.0 Temperature Considerations

4.1 Introduction

Fish Lake is a dimictic (fully mixes twice per year, once in the fall and once in spring after ice has left the lake), mesotropic lake displaying high concentrations of nutrients and associated high biomass production (Appendix 2.7.2.4B-A and Appendix 2.7.2.4B-C). Biological activity peaks during the spring and summer when photosynthetic activity is driven by high solar radiation. High levels of primary productivity during this period, in conjunction with thermal stratification, can translate into the depletion of dissolved oxygen concentrations during both the summer and winter periods. In the spring, fall and winter periods Fish Lake tends to exhibit uniform, well-mixed conditions throughout the water column.

Both temperature and dissolved oxygen concentrations will be important considerations when it comes to recirculating water to the mitigation habitat. Discharge temperatures will be actively managed to maintain optimal conditions for the life stages present in the streams. Management will be accomplished by controlling the depth of water withdrawal through a multiport water intake. This management would be most effective during stratified periods; during unstratified periods, discharge temperatures will be representative of the surface water temperature in the lake (i.e., below 10°C). During periods of high water temperatures, the lake would be stratified, allowing temperature optimization in the tributaries for all lifestages of Rainbow Trout.

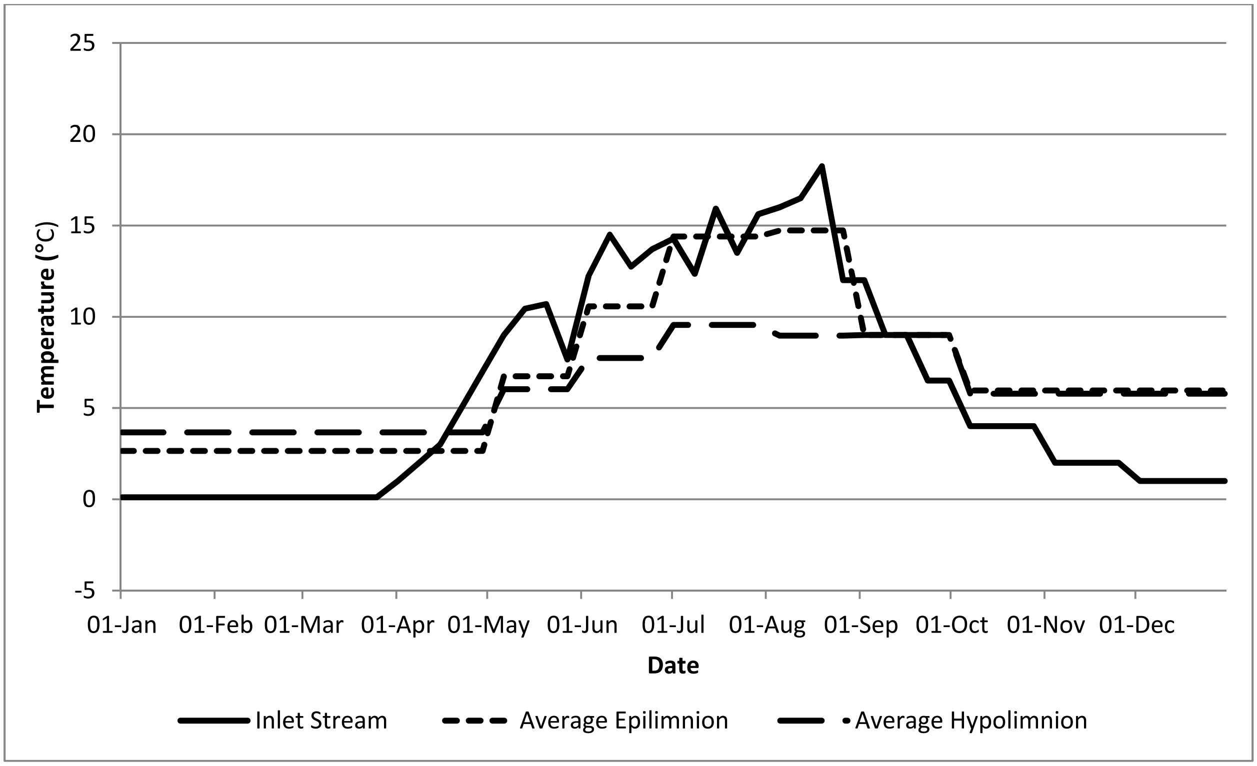
In order to evaluate how the proposed mitigation flows could affect the fish habitat in the identified spawning tributaries, a weighted average mixing model was applied for both water temperature and dissolved oxygen concentrations.

4.2 Data Sources

4.2.1 Lake Water

Lake water temperatures used in the mixing model were based on temperature profile data and Fish Creek Reach 8 data collected onsite between 1994 and 2012, (Presented in March 2009 EIS Appendix 5-2-A(v2) and Appendix 2.7.2.4B-C) graphically presented in Figure 3.

Figure 3. Predicted temperature in Fish Lake Tributary 1, based upon recirculation containing 50% epilimnion water and 50% hypolimnion water in July



The data were divided into 7 distinct time periods over the period of a year:

- Winter (January, February, March, April)
- May
- June
- July
- August
- September
- Fall (October, November, December)

Water temperatures from the lake consisted of profiles gathered at 1 m intervals across the entire depth of Fish Lake. The water temperatures observed during the 7 distinct time periods were fairly uniform within the periods; however the sampling instances were not uniformly distributed amongst the periods (observations concentrated during the months of May and June). Temperature observations in the profiles were divided into epilimnion (≤6 m) and hypolimnion (>6 m).

Temperature profile data confirmed Fish Lake was stratified during the months of July and August at a depth of approximately 6 m (March 2009 EIS Appendix 5-2-A(v2)). No data were available for the month of September, and measurements from mid October confirmed the lake was isothermal (same temperature from surface to bottom) also indicating it had been completely mixed (Appendix 2.7.2.4B-C). For the purposes of developing the mixing model, September water temperatures in both the epilimnion and hypolimnion were assumed to be equal to Fish Lake inlet temperatures.

During the winter, spring, and fall, lake water temperatures were based on limited data collected during supplementary limnological sampling (Appendix 2.7.2.4B-C). While the lake was not stratified during these periods, to remain consistent with stratified periods, average water temperatures were calculated for the epilimnion (≤6 m) and hypolimnion (>6 m) (Figures 4 and 5, Table 9).

Figure 4. Seasonal distribution of observed epilimnetic temperatures in Fish Lake

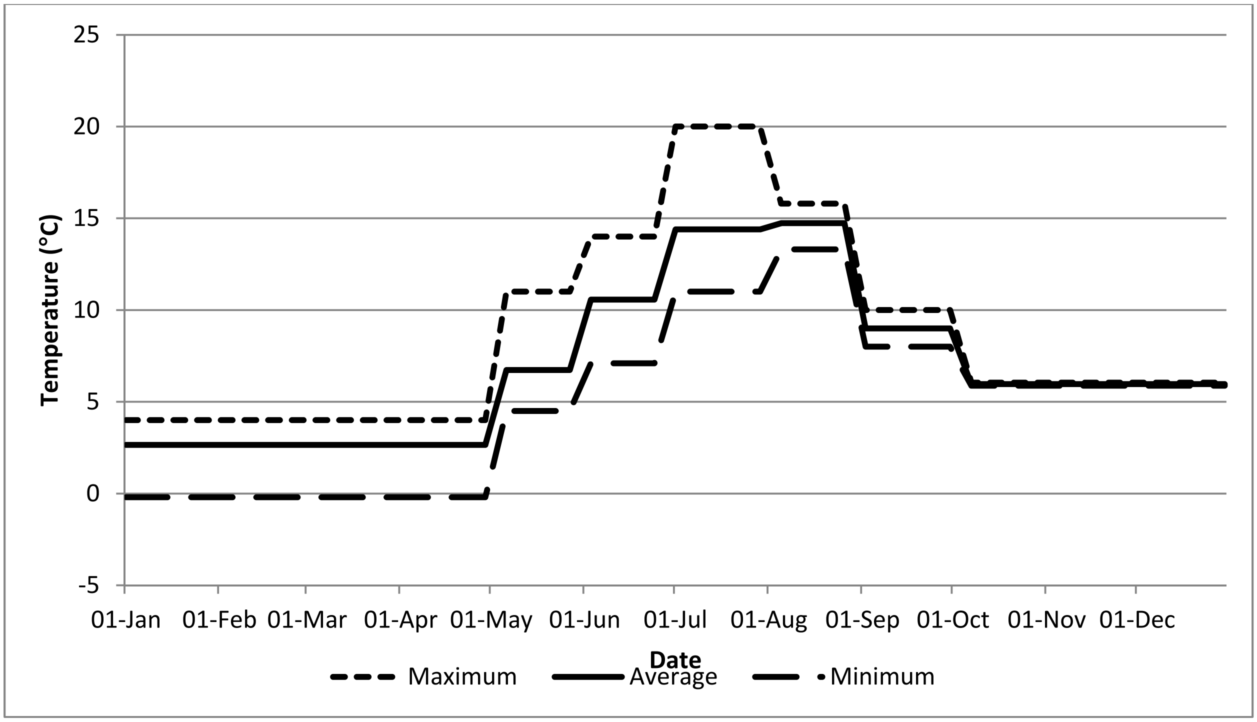
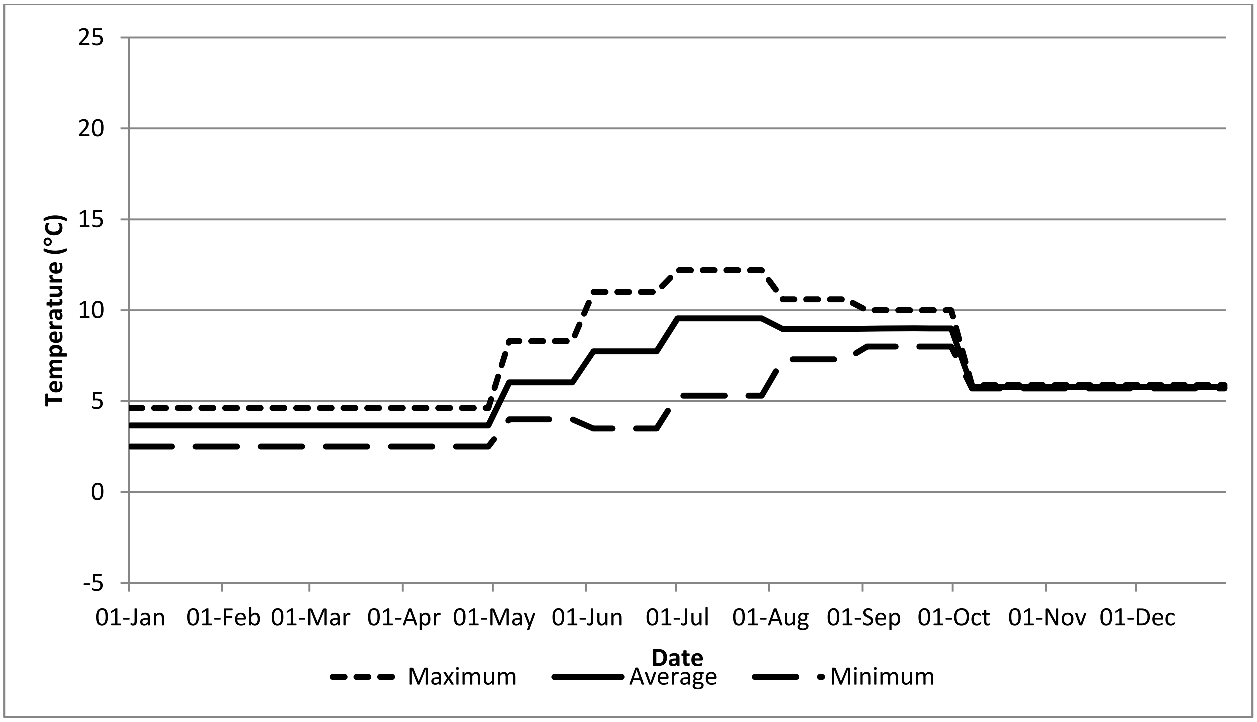


Figure 5. Seasonal distribution of observed hypolimnetic temperature in Fish Lake



4.2.2 Inlet Water Temperature

Temperatures in Fish Creek Reach 8 are well documented throughout typical spawning periods of May, June, July, and August (Triton, 1997). These data consist of daily temperature observations gathered between May 13 and August 15, 1997. For the purpose of this assessment these data were averaged on a weekly basis and used in the mixing model. Throughout the remainder of year, spot measurements (detailed in Appendix 2.7.4.2B-C) were utilized to produce seasonal averages. The following water temperature predictions assume the observed baseline temperatures in the inlet and lakes will be reflective of the temperatures following the development of the Project.

Table 9. Calculated average, maximum, and minimum temperatures from Fish Lake and Fish Creek Reach 8

Period		Epilimnion Temp. (°C)	Hypolimnion Temp. (°C)	Number of Profiles	Inlet Temperature (°C)
Winter	Average	2.65	3.66	4	1.07
	Maximum	4.00	4.62		7.00
	Minimum	-0.20	2.50		0.10
May	Average	6.73	6.03	16	9.45
	Maximum	11.00	8.30		10.70
	Minimum	4.50	4.00		7.66
June	Average	10.57	7.73	10	13.3
	Maximum	14.00	11.00		14.50
	Minimum	7.10	3.50		12.25
July	Average	14.39	9.55	6	14.34
	Maximum	20.00	12.20		15.93
	Minimum	11.00	5.3		12.35
August	Average	14.73	8.96	1	15.69
	Maximum	15.80	10.60		18.25
	Minimum	13.30	7.30		12.00
September	Average	8.00	8.00	0	8.00
	Maximum	12.00	12.00		12.00
	Minimum	6.50	6.50		6.50
Fall	Average	5.96	5.78	1	2.23
	Maximum	6.04	5.88		4.00
	Minimum	5.88	5.70		1.00

4.2.3 Habitat Requirements for Rainbow Trout

The optimal habitat requirements for Rainbow Trout life stages are summarized in Table 10. The most sensitive stage for Rainbow Trout (i.e., lowest temperature threshold) appears to be the embryonic development stage with an optimal temperature envelope of between 11 and 8.5°C. Within the Fish Lake mitigation streams, Rainbow Trout at the embryonic development stage are present for a period of roughly 40 days past the bulk of the Rainbow migration into a particular spawning area (Ford et al., 1995). Triton (1997) reported that 80% of the Rainbow Trout migration into Fish Creek Reach 8 occurred between May 8 and June 6. This would correspond to a critical embryonic development period lasting to approximately July 20.

Table 10. Optimal thermal conditions for various life stages of Rainbow Trout

Stage	Minimum optimal Temperature (°C)	Maximum optimal Temperature (°C)
Embryonic Development	8.5	11
Fry	13.8	19
Juvenile	10.0	22.2
Adult	10.0	21.1

Source: Ford et al. (1995)

4.3 Mixing Model

The weighted average model that was applied to the temperature analysis is similar to the mass balance mixing model used to predict water quality in the neighbouring watercourses and lakes.

$$T_{new} = \frac{(Q_{recirculated} * T_{recirculated}) + (Q_{natural} * T_{natural})}{(Q_{recirculated} + Q_{natural})}$$

This model does not take into account the difference in specific heat capacity related to changes in water density. Within the anticipated range of potential temperatures (4.21 kJ/kg K at 0.01°C and 4.18° kJ/kg K at 25°C), the maximum variance in specific heat capacity can be expected to vary 0.03 kJ/kg K, which would account for less than a 1 percent difference between upper and lower limits. Based upon this justification this model does not consider variability in specific heat capacity. The model assumes there is no loss or gain of thermal energy as the recirculated water travels through the pipe and that no change in phase occurs during the mixing process (i.e., water to vapour). Predicted temperatures represent the instantaneous temperature at the point of mixing and may not represent actual temperatures along the entire length of the mitigation habitat. The model does, however, provide a tool to assess the overall patterns and consequences of recirculating and mixing lake water with natural runoff.

4.4 Results

Based on the measured and predicted temperatures, lake water temperature is predicted to be greater than that of the inlets throughout the cooler fall and winter months. This is expected, as the lake has a greater volume and greater capacity to retain heat compared with the tributaries. During the summer, temperatures in both the inlet stream and the lake increase, however the temperature in the inlet increases earlier and more rapidly than in the lake (Figure 4). By the second week of June the temperature in the inlet averaged approximately 13°C while the surface water in the lake remained below 10°C (Figure 4). By July 1 the temperatures in the epilimnion and the inlet were approximately equal to the inlet temperatures (approx. 15°C). During August the epilimnion temperatures remained at approximately 15°C, while the inlet stream increased to average weekly temperatures between 16 and 18°C. Overall, the baseline data confirm that the temperature in the inlet stream is equal to or greater than that of the epilimnion during the summer stratified periods. During the summer, temperatures in the hypolimnion remained slightly below 10°C. Outside of the summer period, temperatures in the surface water of the lake appear to be between 3 and 5°C warmer than that observed in the inlet.

The estimated natural and recirculated flow volumes for Fish Creek Reach 8 and Fish Lake Tributary 1 are detailed in Tables 7 and 8 as well as in Figures 2 and 3. These flows are combined with the baseline temperature data in Table 9 into a weighted average model to predict end-of-pipe temperatures in the tributaries (Table 11). The first scenario of this model consisted of the measured maximum, minimum, and average temperatures in the epilimnion of the lake and the average weekly temperatures measured in the inlet (Figures 7 and 8).

Table 11. Average case scenario inputs and outputs from the Fish Creek Reach 8 mixing model based on 100% epilimnetic recirculation

Period	Natural Runoff (m^3/sec)	Average Weekly Inlet Temperature (°C)	Recirculated Runoff (m^3/sec)	Average Epilimnion Temperature (°C)	Resulting Temperature (°C)
January 1 – Mar 31	0.001	0.1	0.159	2.65	2.63
April 1 – April 7	0.038	1	0.122	2.65	2.26
April 8 – April 14	0.038	2	0.122	2.65	2.49
April 15 – April 21	0.038	3	0.122	2.65	2.73
April 22 – April 28	0.038	5	0.242	2.65	2.97
April 29 – May 5	0.038	7	0.412	2.65	3.01
May 6 – May 12	0.107	9.0	0.343	6.73	7.27
May 13 – June 2	0.107	7.66 – 10.70	0.343	6.73	6.95 – 7.61
June 3 – June 30	0.036	12.25 – 14.50	0.414	10.57	10.70 – 10.88
July 1 – July 7	0.019	14.28	0.261	14.30	14.38
July 8 – Aug 4	0.019	12.35 – 15.93	0.147	14.30	14.15 – 14.57
Aug 5 – Aug 25	0.013	12.00 – 18.25	0.147	14.73	14.51 – 15.02
Aug 26 – Sept 1	0.013	12.00	0.147	14.73	14.51
Sept 2 – Sept 8	0.015	12.00	0.145	9.00	9.28
Sept 9 – Sept 22	0.015	9.00	0.145	9.00	9.00
Sept 23 – Oct 6	0.015	6.50	0.145	9.00	8.77
Oct 7 – Nov 3	0.022	4	0.138	5.96	5.69
Nov 4 – Nov 24	0.004	2	0.156	5.96	5.86
Nov 25 – Dec 31	0.001	1.0	0.159	5.96	5.93

Based on the average conditions in the epilimnion, the predicted temperatures in the creeks stayed at or below 15°C (Table 11). The maximum temperature scenario exhibited predicted temperatures up to approximately 20°C (Figures 6 and 7). Overall, these values are within the baseline temperature range observed in Fish Creek Reach 8 and are within the optimal temperature range for all Rainbow Trout life stages with the exception of embryonic development.

Embryonic development is estimated to take place in Fish Creek Reach 8 between approximately May 8 and July 20. Under average conditions, the predicted end-of-pipe temperatures between May 8 and July 1 fall within the optimal temperature range of 8.5 to 11.0. Between July 1 and August 1, the predicted temperatures increase to between 15 and 20°C under average and maximum temperature conditions, respectively. While these temperatures are greater than the optimal temperature specified for embryonic development (Table 10), they are within the natural baseline temperature range (Table 9). Consequently, no adverse effects on Rainbow Trout production are anticipated, even at maximum observed temperatures.

Figure 6. Predicted stream water temperatures in Fish Creek Reach 8, based on epilimnetic recirculation

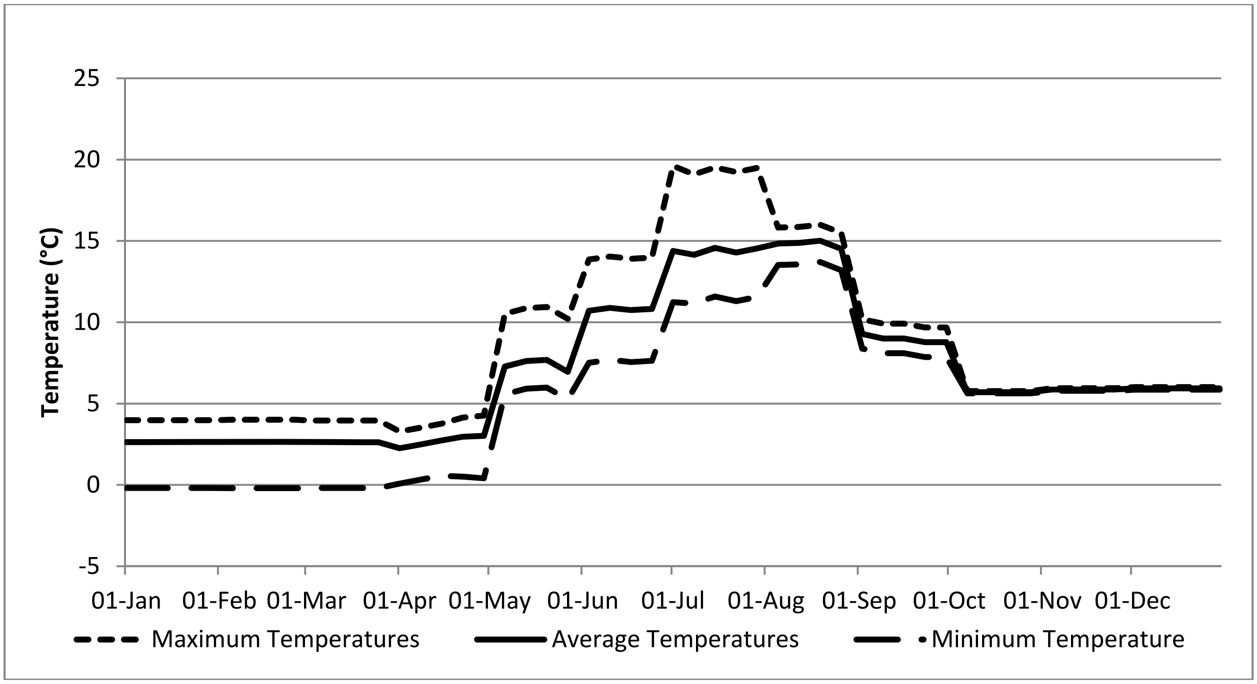
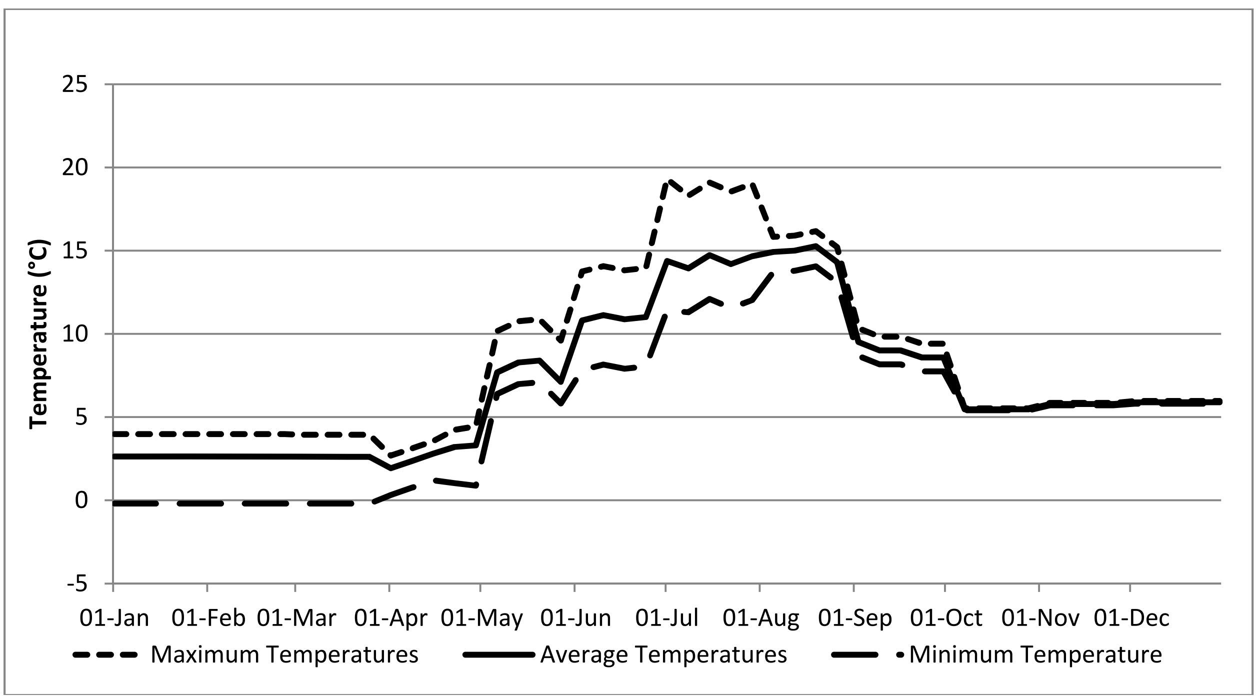


Figure 7. Predicted stream water temperatures in Fish Lake Tributary 1, based on epilimnetic recirculation



The second scenario considered involved recirculating a mixture of water from both the epilimnion and hypolimnion through a multiport withdrawal in order to reduce predicted temperatures for the embryonic Rainbow Trout during July (Figures 8 and 9).

Figure 8. Predicted temperature in Fish Creek Reach 8, based on recirculation containing 50% epilimnion water and 50% hypolimnion water in July

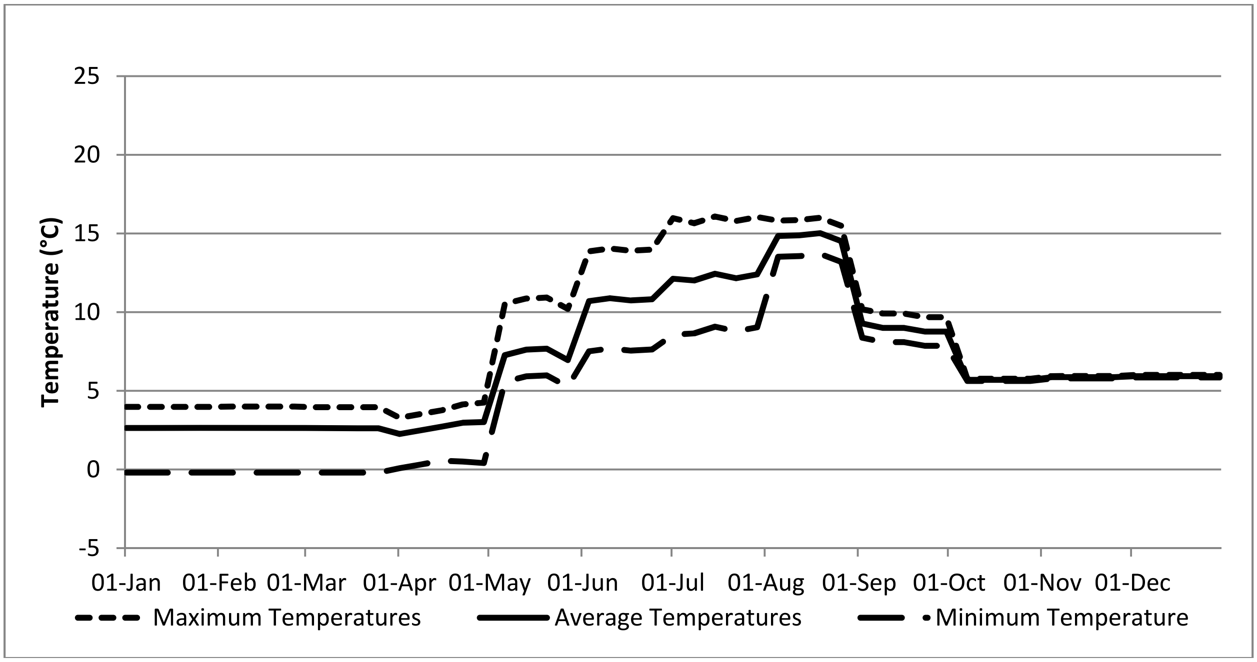
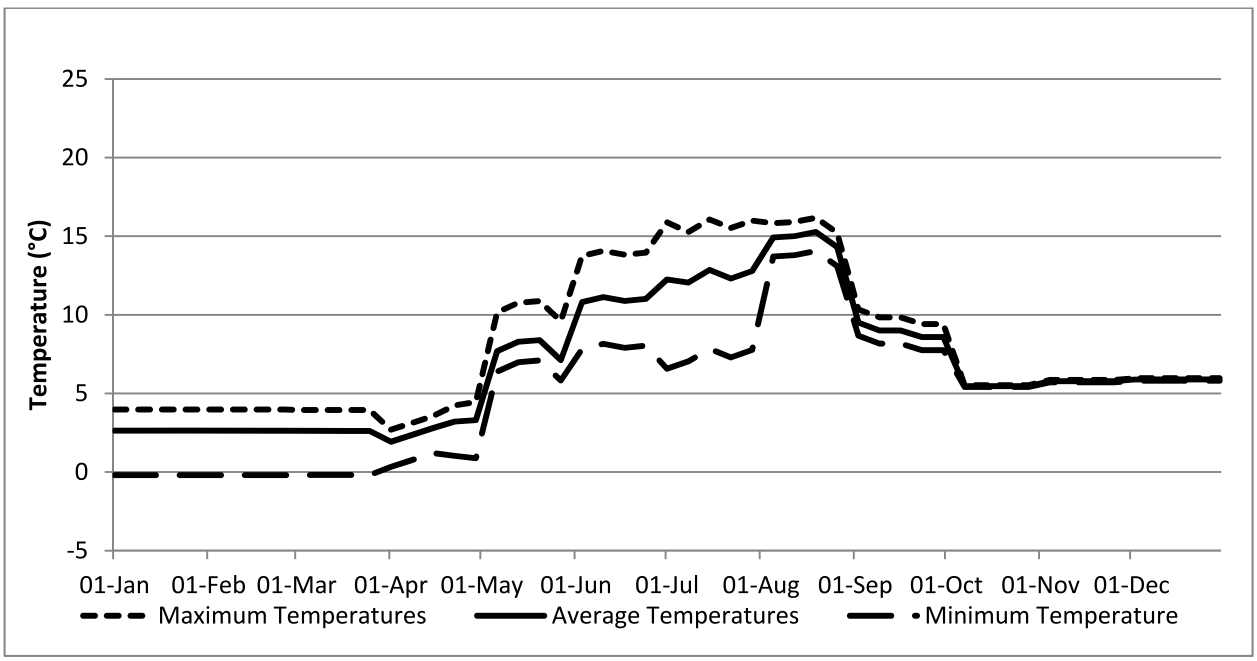


Figure 9. Predicted temperature in Fish Lake Tributary 1, based upon recirculation containing 50% epilimnion water and 50% hypolimnion water in July



The construction of a multiport intake for the recirculation pump will provide the option to withdrawal water from either the epilimnion or the hypolimnion to manipulate end-of-pipe temperature. This form of manipulation has been used extensively in reservoirs discharging to rivers and creeks. Water temperature predictions suggest that with the exception of the month of July, 100% of the recirculation water may be withdrawn from the epilimnion, without excursions away from the optimal temperatures for developing Rainbow Trout.

Results from the second scenario predict average and maximum temperatures in the mitigation streams would remain between 12.5 and 16°C respectively (Figures 8 and 9) with 50% of the recirculation water coming from the hypolimnion and 50% coming from the epilimnion. These values are closer to the optimal embryonic development temperatures identified in Ford et al. (1995). Following the month of July, stream temperatures would increase back to between 14 and 16°C for the month of August. In both scenarios, the mitigation flow temperatures through fall, winter, and spring are close to the surface water temperatures in the lake.

Implementation of a multiport withdrawal system would provide a management tool for ensuring adequate temperatures will be available for maintaining and sustaining Rainbow Trout throughout the Project. The amount of cooler hypolimnetic water available for withdrawal during the warmer months is of concern, given its importance for sustaining fish. Based on the estimated recirculation volumes and the distribution between epilimnetic water and hypolimnetic water modelled in scenario 2, the total volume of water required was calculated (Table 12).

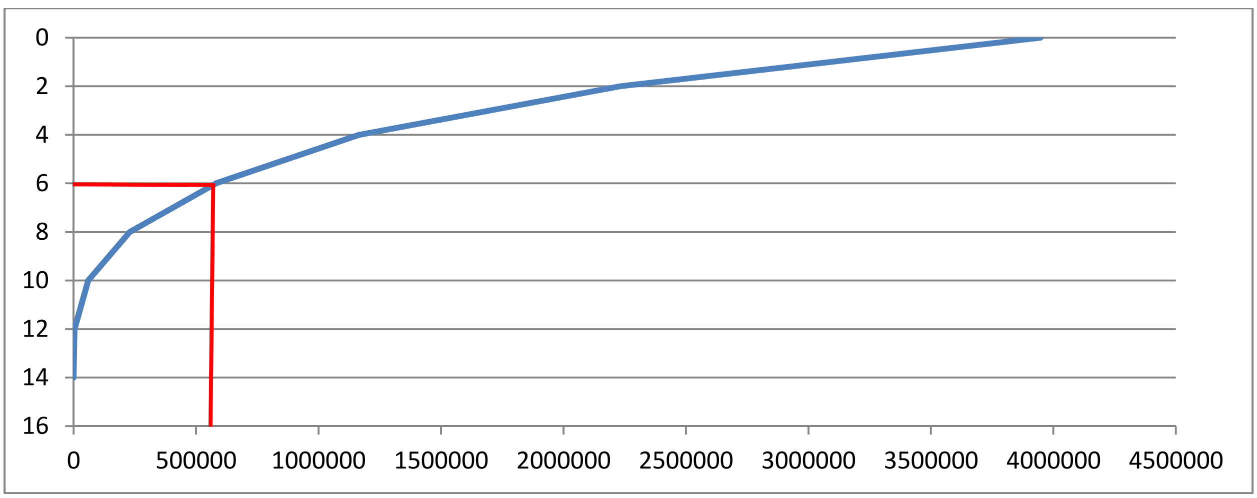
Table 12. Estimated volume of water required for mitigation flow recirculation based on recirculation containing 50% epilimnion water and 50% hypolimnion water in July (Scenario 2)

Period	Recirculated Runoff Fish Lake Tributary 1 (m^3/sec	Recirculated Runoff Fish Lake Tributary 1 (m^3/sec)	Percentage Epilimnion	Percentage Hypolimnion	Epilimnion Volume Recirculated (m^3/day)	Hypolimnion Volume Recirculated (m^3/day)
January 1 – Mar 31	0.129	0.160	100	0	24,970	
April 1 – April 7	0.073	0.122	100	0	10,541	
April 8 – April 14	0.073	0.122	100	0	10,541	
April 15 – April 21	0.073	0.122	100	0	10,541	
April 22 – April 28	0.183	0.242	100	0	36,720	
April 29 – May 5	0.323	0.412	100	0	63,504	
May 6 – May 12	0.221	0.343	100	0	48,730	
May 13 – June 2	0.221	0.343	100	0	48,730	
June 3 – June 30	0.326	0.414	100	0	63,936	
July 1 – July 7	0.211	0.261	50	50	20,390	20,390

Period	Recirculated Runoff Fish Lake Tributary 1 (m^3/sec	Recirculated Runoff Fish Lake Tributary 1 (m^3/sec)	Percentage Epilimnion	Percentage Hypolimnion	Epilimnion Volume Recirculated (m^3/day)	Hypolimnion Volume Recirculated (m^3/day)
July 8 – Aug 4	0.101	0.147	50	50	10,713	10,713
Aug 5 – Aug 25	0.110	0.147	100	0	22,205	
Aug 26 – Sept 1	0.108	0.147	100	0	22,032	
Sept 2 – Sept 8	0.108	0.145	100	0	21,859	
Sept 9 – Sept 22	0.108	0.145	100	0	21,859	
Sept 23 – Oct 6	0.108	0.145	100	0	21,859	
Oct 7 – Nov 3	0.097	0.138	100	0	20,304	
Nov 4 – Nov 24	0.124	0.156	100	0	24,192	
Nov 25 – Dec 31	0.124	0.159	100	0	24,451	

Baseline data (Appendix A, B and C) suggest that the lake currently stratifies at a depth of approximately 6 m. The hypsographic Fish Lake basin data suggest that this equates to 582,128 m^3 of water lying below 6 m (Figure 10).

Figure 10. Hypsographic volume data for Fish Lake



Note: Horizontal red line represents the depth of stratification while the vertical red line indicates the estimated basin volume below the stratification depth

Table 13. Estimated total volume of water (m^3/year) required to maintain recirculation based on recirculation containing 50% epilimnion water and 50% hypolimnion water in July (Scenario 2)

Period	Epilimnion Volume Recirculated (m^3/day)	Hypolimnion Volume Recirculated (m^3/day)	Total Epilimnion Volume Recirculated (m^3/period)	Total Hypolimnion Volume Recirculated (m^3/period)
January 1 – Mar 31	24,970		2,247,300	
April 1 – April 7	10,541		73,787	
April 8 – April 14	10,541		73,787	
April 15 – April 21	10,541		73,787	
April 22 – April 28	36,720		257,040	
April 29 – May 5	63,504		444,528	
May 6 – May 12	48,730		341,110	
May 13 – June 2	48,730		1,023,330	
June 3 – June 30	63,936		1,790,208	
July 1 – July 7	20,390	20,390	142,730	142,730
July 8 – Aug 4	10,713	10,713	299,964	299,964
Aug 5 – Aug 25	22,205		466,305	
Aug 26 – Sept 1	22,032		154,224	
Sept 2 – Sept 8	21,859		153,013	
Sept 9 – Sept 22	21,859		306,026	
Sept 23 – Oct 6	21,859		306,859	
Oct 7 – Nov 3	20,304		568,512	
Nov 4 – Nov 24	24,192		508,032	
Nov 25 – Dec 31	24,451		904,687	
Total			**10,135,229**	**442,694**

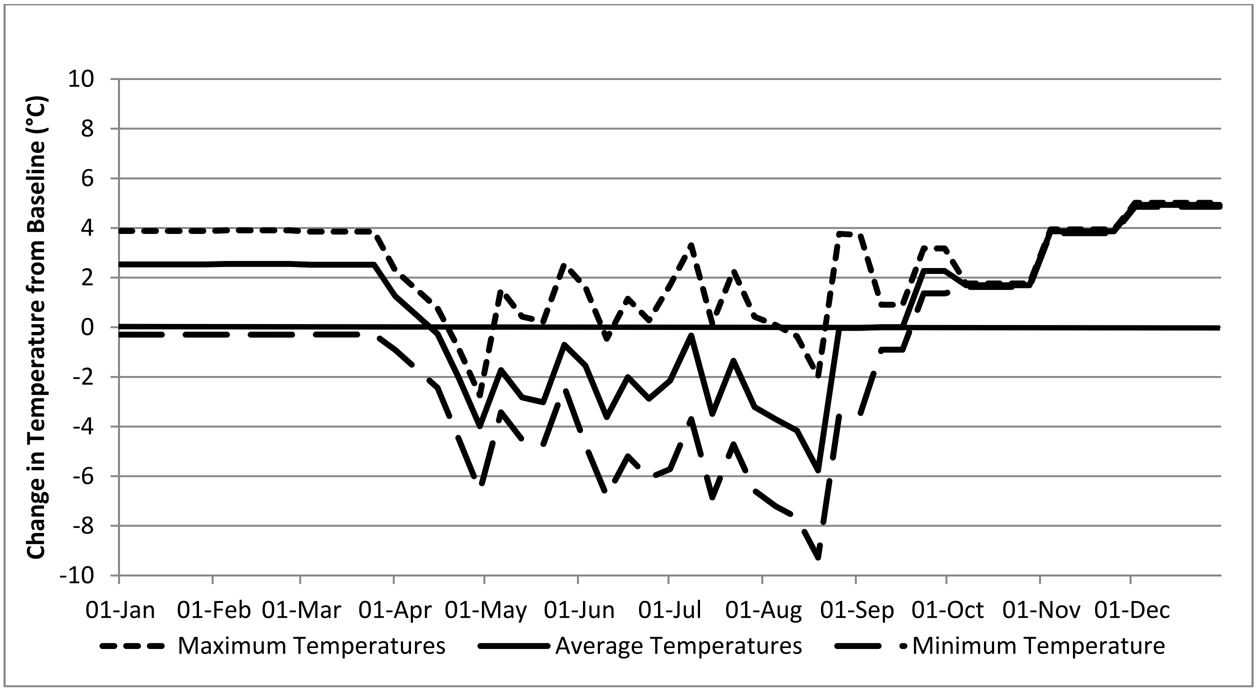
Daily recirculation estimates from Table 12 were extended to calculate water recirculation volumes at various periods over a typical year (Table 13). The results indicate over 10,100,000 m^3 of water will be recirculated from the top 6 m of Fish Lake. Pumping 50% of the July recirculation volume from the hypolimnion of the lake will require an additional 442,000 m^3 of water. Based on an estimated hypolimnetic volume of 582,128 m^3, this would equate to roughly 75% of the total hypolimnetic volume.

4.5 Water Temperature Discussion

A weighted average mixing model was used to predict the end-of-pipe temperatures based on the proposed mitigation flows. The initial modelling scenario involved recirculating surface and epilimnetic water to the mitigation streams. The results of this analysis suggest that the average temperatures at the end-of-pipe will be within the optimal temperature range for every Rainbow Trout life stage, with the exception of embryonic development during the month of July. This was partially addressed in the second scenario when the water temperature predictions were made using 50% epilimnetic water and 50% hypolimnetic water for the July recirculation period.

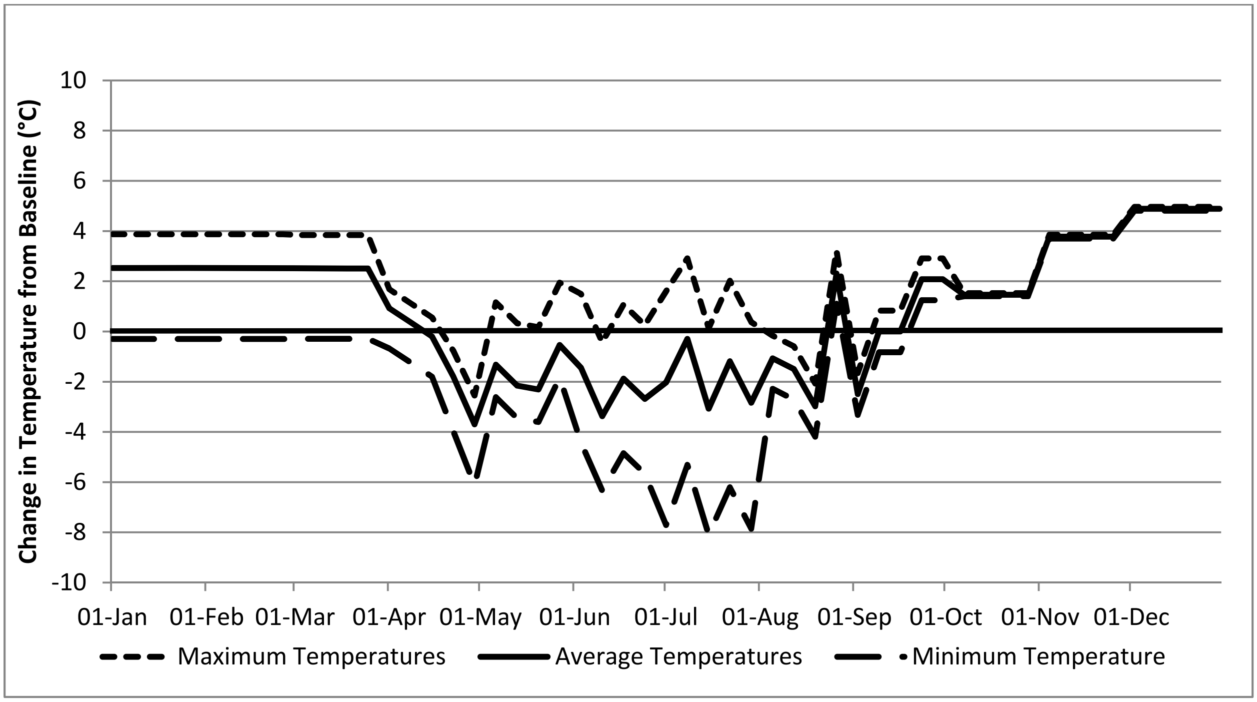
The results from the second scenario indicate that the end-of pipe temperatures can be maintained between 12 and 13°C through the month of July under average conditions, close to the optimal embryonic development temperatures.

Figure 11. Comparison of predicted Fish Creek Reach 8 temperatures with the observed baseline temperatures based on recirculation containing 50% epilimnion water and 50% hypolimnion water in July (Scenario 2)



Following the discharge of water from the recirculation pipe and the mixing with the natural stream flow, the water will be in contact with the atmosphere and will hence be able to gain or lose energy. This would result in the predicted water temperatures naturally adjusting toward the ambient conditions.

Figure 12. Comparison of predicted Fish Lake Tributary 1 temperatures with the observed baseline temperatures based upon recirculation containing 50% epilimnion water and 50% hypolimnion water in July



When the predicted water temperatures are compared against the baseline inlet water temperatures, several patterns are evident (Figures 11 and 12). Firstly, the end-of-pipe temperatures in the creeks during the winter months will be increased over baseline. This however, is somewhat misleading because the tributaries have little to no flow during the winter months and baseline tributary temperatures are based upon spot measurements in isolated pools. By the beginning of April the difference between the predicted temperatures and the baseline temperatures begins to decrease and by the beginning of May the predicted temperatures are below the baseline inlet temperatures. This reflects the fact that the lake will warm up slower than the inlet streams due to the large difference in volume and heat capacity.

During the migration, spawning, and embryonic development periods (May, June, July) the predicted end-of-pipe water temperatures in both Fish Creek Reach 8 and Fish Lake Tributary 1 will range between 0 and 2°C below the observed baseline temperatures. Based on the optimal temperature data reported in Ford et al. (1995), the predicted temperatures are within or slightly above the optimal range for all Rainbow Trout life stages. Some temperature optimization will be realized with the use of the multiport water withdrawal system incorporating cooling hypolimnetic water during the month of July. During the late summer and early fall periods the predicted temperatures are close to baseline temperatures. During the late fall and early winter the predicted mitigation flow temperatures are once again greater than the baseline temperatures. However, as with the winter temperatures, these are somewhat misleading because baseline flows are greatly reduced or absent.

The predicted changes in the inlet stream temperatures and discharges could have a couple of important consequences to Fish Lake, especially near the mouths of the creeks. Firstly, consistently higher discharges during the ice covered period could maintain localized ice-free conditions at the immediate outlets. Overall, the mitigation flow temperatures are likely to have a small impact on the lake, as the predicted average end-of-pipe water temperatures at the head of the tributaries are anticipated to remain within 4°C on either side of the baseline (Figures 11 and 12) throughout the year. Additionally, water temperatures are expected to equilibrate with the ambient conditions of the period as it flows to the lake, further reducing any differences. It is possible that the lake temperature at the mouths of the tributaries could decrease during the winter months as the typically insulated lake water is exposed to the cold climate.

During the spring and summer periods the recirculation of water into the mitigation habitat could have a similar cooling effect on the lake, as the mixing model suggests the resulting water temperatures will be less than those observed naturally. During the fall, the predicted end-of-pipe temperatures again increase above the baseline temperatures. This could lead to a slight increase in thermal energy entering the lake, and potentially localized warming at the outlets (Figures 11 and 12).

Based on the predicted volumes necessary to maintain viable wetted habitat through the year, it is estimated a total of approximately 10,500,000 m^3 of water will need to be recirculated to the mitigation habitat over the course of the year (Table 13). During July, the predictions suggest that it may be beneficial to recirculate water both from the epilimnion and hypolimnion to maintain suitably cool water for Rainbow Trout embryo development. In order to maintain a 50:50 mixture of epilimnion and hypolimnion water during July a total of approximately 440,000 m^3 would be required from each level. It should be noted that the 50:50 ratio was chosen to demonstrate the ability to modify the end-of-pipe water temperature. In reality the system can be adjusted to any ratio to achieve desired temperature targets.

5.0 Dissolved Oxygen

5.1 Introduction

Like many eutrophic, dimictic lakes, Fish Lake naturally exhibits periods of depleted dissolved oxygen or anoxic conditions. This condition is especially prevalent during the winter ice-covered period when lake water is not in communication with the atmosphere and fluvial inputs are absent or reduced. This condition can cause high fish mortality during the winter, known as "winter kill" (Michaud, 1991).

During the ice-free period the dissolved oxygen (DO) concentration in the epilimnion will remain at or near saturation because of photosynthesis and atmospheric diffusion. Alternatively, beneath the thermocline (hypolimnion), DO concentrations will decline during the summer, because of microbial metabolism in the sediments, reduced photosynthetic contributions, and isolation from atmospheric contributions. If stratification persists long enough the entire hypolimnion can naturally become anoxic and unsuitable for fish. In the event recirculation water was to be withdrawn from the poorly oxygenated hypolimnion, low oxygen concentrations could pose a threat to stream-resident Rainbow Trout at the end-of-pipe discharge location. To evaluate the dissolved oxygen concentrations in the mitigation habitat a weighted average dissolved oxygen concentration model was applied (see Section 4.3). This model assumes no dissolved oxygen is gained or lost through the recirculation process and only provides a value for the end-of pipe concentrations. Following discharge into the mitigation streams it is expected contact with the atmosphere and turbulent mixing would bring DO concentrations into equilibrium with the water temperature.

5.2 Data Sources

Dissolved oxygen concentrations and profiles are well documented in Fish Lake through the open water periods of late spring and early summer (Appendix B and C). Profiles were conducted in conjunction with the profiles used for the temperature analysis. As with the temperature analysis the baseline data were divided into seven distinct periods and average values calculated for both the epilimnion (≤6 m) and hypolimnion (>6 m) (Table 14 and Figures 13, 14).

Table 14. Baseline dissolved oxygen conditions in Fish Lake and estimated values for the Inlet streams

Period		Epilimnion DO (mg/L)	Hypolimnion DO (mg/L)	Number of Profiles	Inlet DO (mg/L)
Winter	Average	4.18	0.63	4	11
	Maximum	9.93	1.56		
	Minimum	0.00	0.10		
May	Average	9.60	9.10	16	10
	Maximum	11.50	10.20		
	Minimum	7.30	2.40		
June	Average	10.30	8.14	10	10
	Maximum	13.50	11.60		
	Minimum	6.30	3.50		
July	Average	8.32	2.57	6	9
	Maximum	10.52	6.90		
	Minimum	3.80	0.40		
August	Average	6.42	6.41	1	9
	Maximum	8.04	6.52		
	Minimum	5.41	6.17		
September	Average	6.42	6.41	0	10
	Maximum	8.04	6.52		
	Minimum	5.41	6.17		
Fall	Average	10.08	9.02	1	10
	Maximum	10.57	9.70		
	Minimum	9.74	7.66		

As dissolved oxygen levels have not been measured at the lake inlet, estimates based on theoretical saturation concentrations at different temperatures were used. Winter dissolved oxygen concentrations were assumed to be 11 mg/L, which equates to 100% saturation at 11°C. Spring/fall and summer values were assumed to be 10 and 9 mg/L, which equates to 15 and 20°C respectively. While the predicted temperatures are generally below the assumed temperatures, these values are considered conservative to compensate for less than complete saturation conditions.

Figure 13. Observed average seasonal dissolved oxygen concentrations in the epilimnion (0 to 6 m) depths in Fish Lake

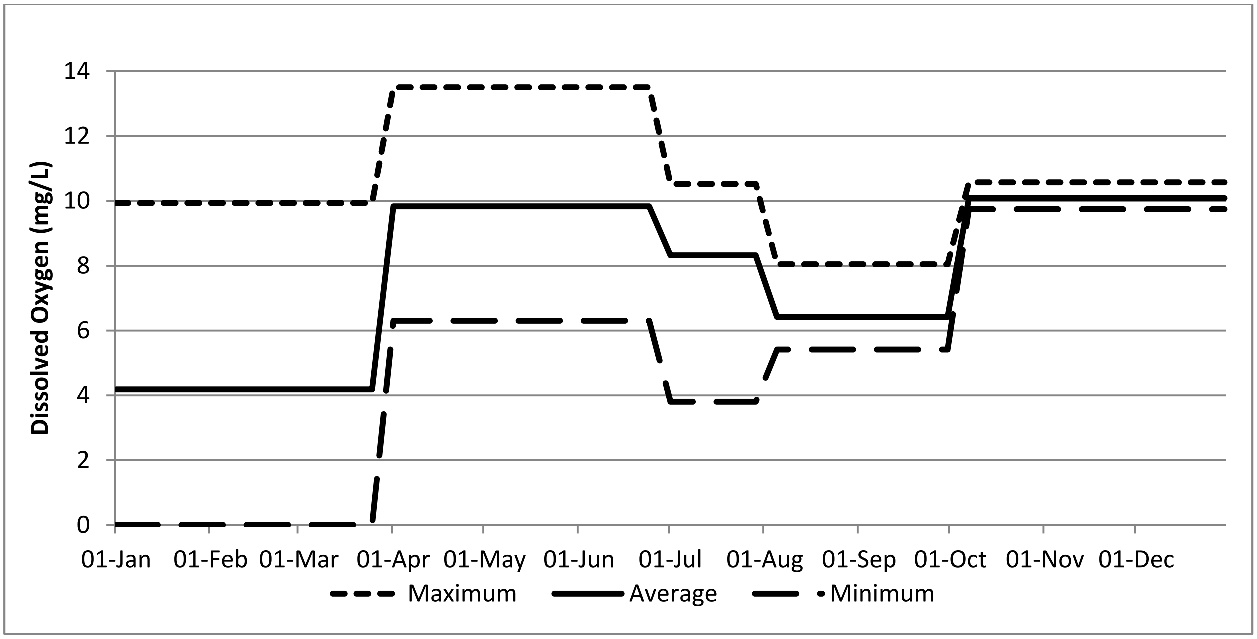
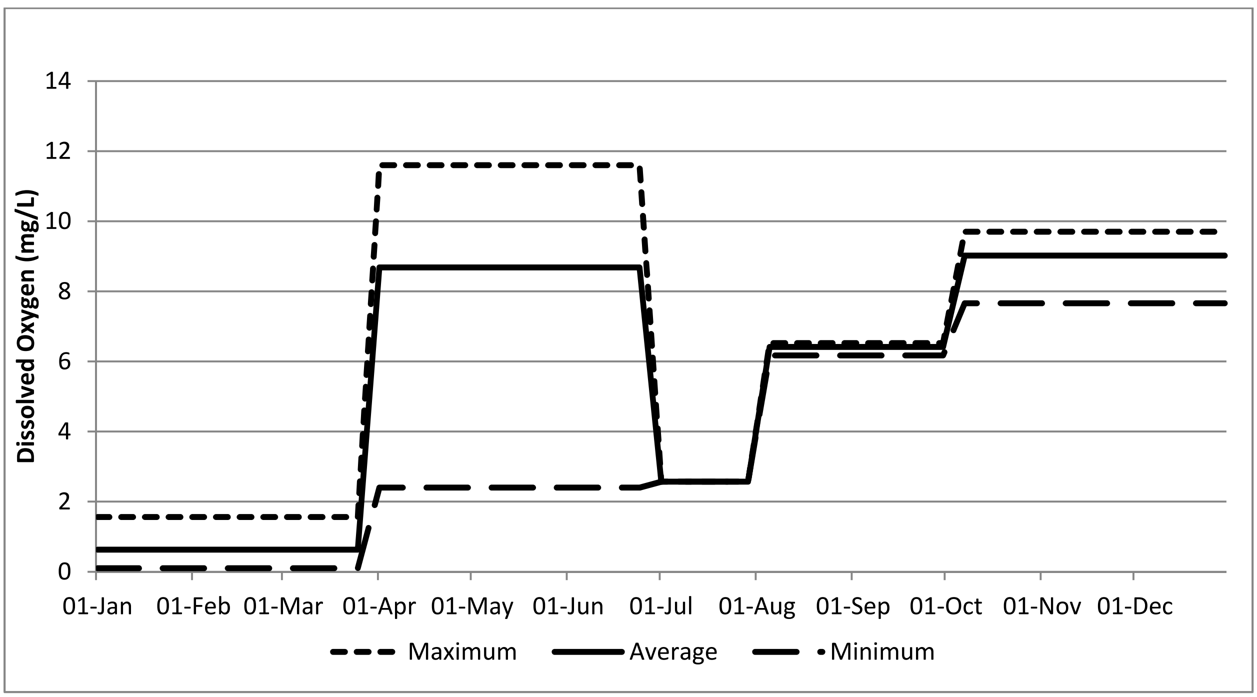


Figure 14. Observed average seasonal dissolved oxygen concentrations in the hypolimnion (>6 m) depths in Fish Lake



The British Columbian guidelines for the protection of aquatic life stipulate that the minimum instantaneous DO concentration to protect all life stages of fish with the exception of buried embryos is 5 mg/L; the equivalent 30-day average concentrations are 8 mg/L. When buried embryo stages are present in the streams, the minimum instantaneous water column concentrations are 9 mg/L and the 30-day average is 11 mg/L (BCMOE, 1997). The federal government specifies a minimum DO concentration for cold water species between 6.5 and 9.5 mg/L depending on the life stages present (CCME, 1999).

5.3 Results

The results of the mixing model suggest there could be a range of end-of-pipe DO levels during the ice-covered winter periods. Baseline DO values in the lake during this period ranged between 0 mg/L and 10 mg/L (Figures 13 and 14); based on the average observed DO concentrations in the epilimnion of the lake during this period the predicted end-of-pipe DO concentrations in the tributaries would be roughly 4.0 mg/L (Figures 15 and 16). Following ice-off and spring turnover, the predicted end-of-pipe dissolved oxygen concentrations would increase to levels more representative of the estimated baseline (~10 mg/L) as the lake water would be near saturation. This period coincides with the observed migration and spawning of the Fish Lake Rainbow Trout.

Following stratification of the lake in the summer the average end-of-pipe dissolved oxygen concentrations are expected to decline to between 6 and 7 mg/L. This reflects the contributions of cooler hypolimnetic water during the month of July and a reduction in dissolved oxygen capacity in the warm surface waters in August. Finally, the predicted dissolved oxygen concentrations during the late fall period would increase to near 10 mg/L as the lake surface water cools and turns over (Figures 15 and 16).

Figure 15. Predicted dissolved oxygen concentrations in Fish Creek Reach 8, based on recirculation containing 50% epilimnion water and 50% hypolimnion water in July

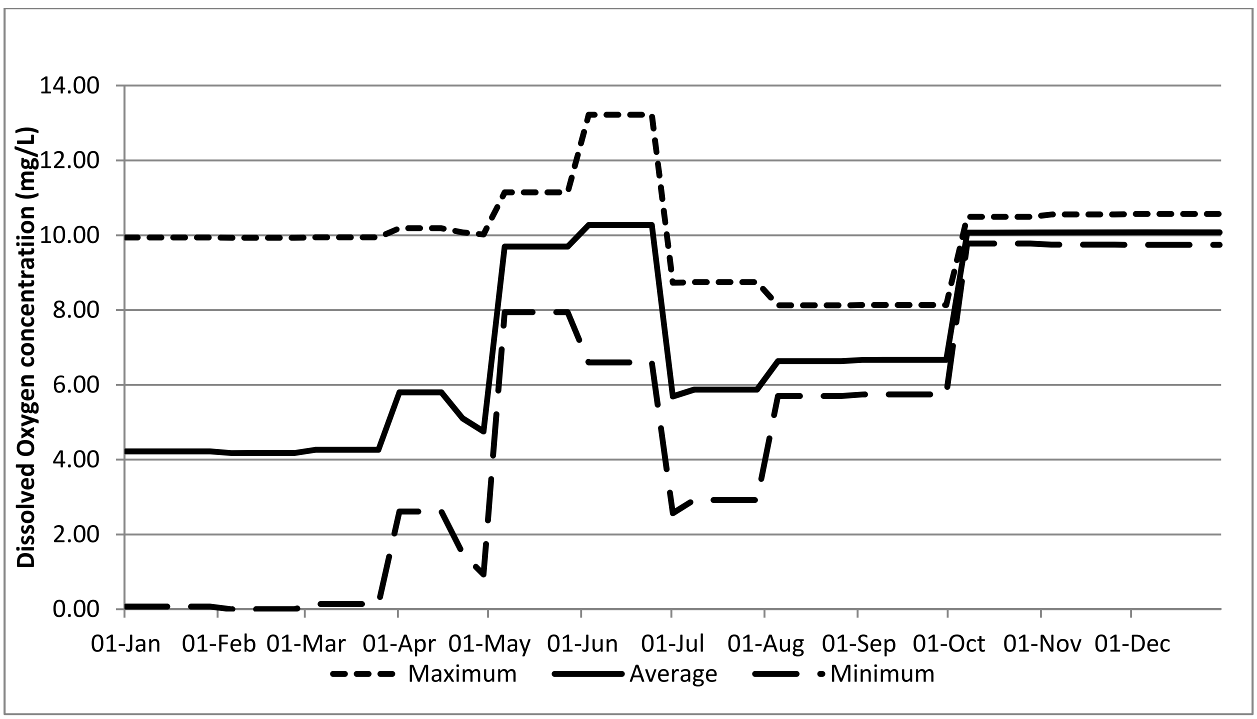
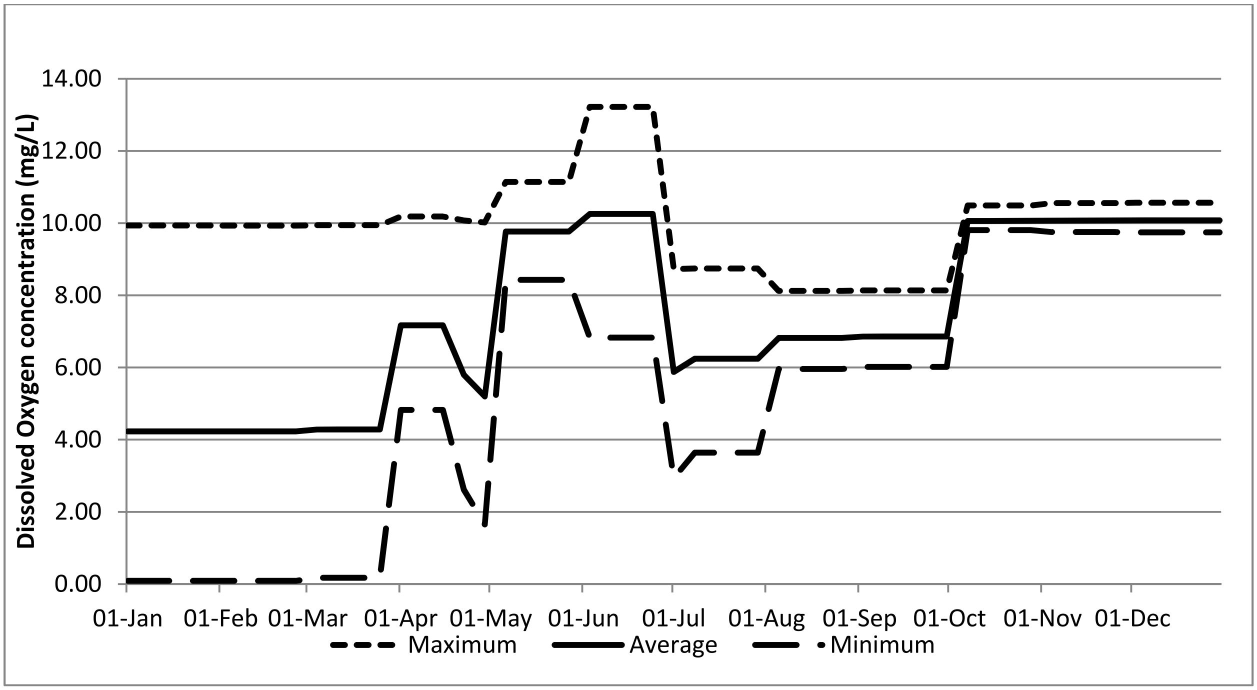


Figure 16. Predicted dissolved oxygen concentrations in Fish Lake Tributary 1, based on recirculation containing 50% epilimnion water and 50% hypolimnion water in July



5.4 Dissolved Oxygen Discussion

End-of-pipe dissolved oxygen concentrations during winter are predicted to be at or below the minimum instantaneous guidelines outlined in BCMOE (1997) and CCME (1999) under average case conditions. Similarly, concentrations of DO during the July embryonic development period are predicted to be below guideline criteria. In both situations it is anticipated that the DO concentrations would rapidly equilibrate with the atmosphere under the turbulent mixing conditions of the stream. However, this analysis suggests the situation may require additional aeration strategies (i.e., turbulent mixing features, oxygen diffusers) to ensure the DO concentrations increase to acceptable levels a short distance from the end of pipe. Regardless, the concentrations would be monitored throughout recirculation.

During the ice-free, unstratified periods (spring and fall) the dissolved oxygen concentrations at the end of pipe are predicted to be within the acceptable range for all life stages of Rainbow Trout, providing that recirculation occurs from the epilimnion. As with the other periods, it is anticipated that these concentrations would rapidly equilibrate to saturation levels as a result of the turbulent mixing.

Under a typical year the mitigation streams would flow ephemerally and would therefore not contribute a negligible amount of dissolved oxygen to the lake water during the late fall and winter period. This situation would do little to alleviate the natural oxygen depletion that occurs in the lake during this period. By maintaining year round flow in the tributaries, the enhancement program may supply dissolved oxygen to the lake via the inflow return to the lake.

Based on the flow regimes proposed here, 2,247,300 m^3 of water will be recirculated to the tributaries between the beginning of January and the end of March. Providing that all of this water equilibrates with the atmosphere to a dissolved oxygen concentration of 10 mg/L, the result would be an additional 2.247×10^{10} mg (22,473 kg) of dissolved oxygen entering the lake at the mouths of the creeks. This could provide valuable refuge habitat around the mouths of the creeks and largely offset the potential for winter kill.

6.0 Risk and Associated Mitigation

The greatest risks associated with the proposed flow augmentation mitigation plan are primarily associated with mechanical failure of the pumps, loss of power, or damage to the pipelines which would affect the volume of water being transported to augment Reach 8 and Fish Lake Tributary 1 flows. Loss or reduction of augmentation flows could potentially result in fish stranding and mortality or desiccation of eggs depending on the time of year and severity of reduction. In order to mitigate the risk of mechanical or power failure, backup pumps and generators will be installed at all pump houses to provide backup pumping and power generating capabilities. In addition, the pipelines will be protected and right-of-ways clearly identified to limit the potential for disturbance associated with machinery and mine operation. Set-backs will be established and procedures put in place for regular inspection and maintenance. Pipe repair materials and replacement sections will be stockpiled onsite to minimize downtime associated with repairs. Lastly, a plan will be established for a fish salvage in the event of prolonged shutdown. This will include identification of all high risk stranding locations for prioritization of salvage efforts as well as safe release locations. Onsite staff will be trained in salvage procedures to ensure no delay in implementation.

Additionally, the predicted end-of pipe dissolved oxygen concentrations suggest that dissolved oxygen could be below the identified minimum concentrations required for aquatic life. It is anticipated that the dissolved oxygen concentrations would come into equilibrium rapidly with the tributaries. However, based upon the results of monitoring it may be necessary to adaptively manage the situation by encouraging dissolved oxygen solution through physical mixing or mechanical aeration.

Seasonal water temperatures in both Fish Lake and the tributaries will vary naturally from year to year. This variability will result in excursions from the predicted temperature values. To compensate for this, the complete different predictions for minimum, average, and maximum temperatures was included in this analysis. Despite this, the baseline values in the tributary were based on one season of data and likely do not reflect the full range of temperatures in the tributaries. Regardless of the potential for seasonal temperature variability, it is believed that the overall patterns predicted (i.e., warmer inlet temps in winter, cooler in spring and summer) would hold true. This is because the large volume of water in the lake will continue to heat slower than the tributaries in the summer and cool slower than the tributaries in the fall and winter.

It is expected that with effective onsite monitoring and the implementation of the proposed mitigation and adaptive management if required, the risk of failure of the proposed flow augmentation plan will be reduced to an acceptable level.

7.0 References

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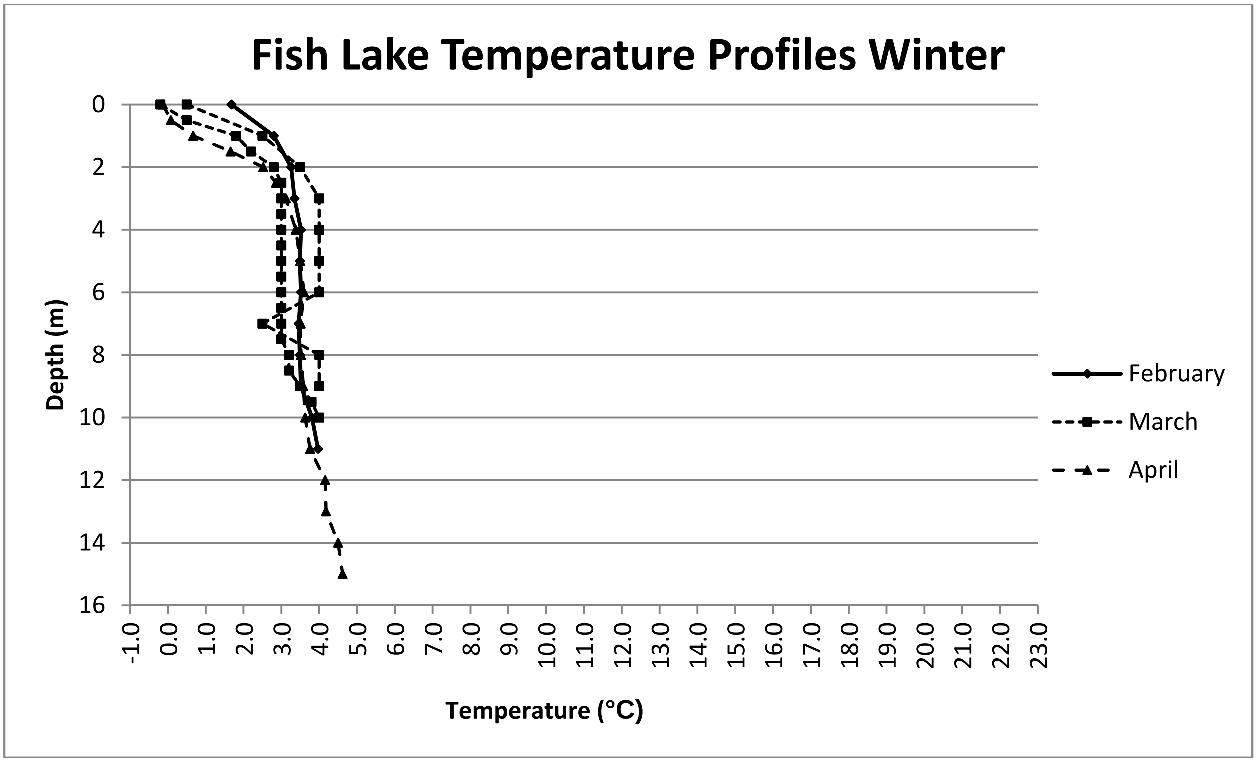
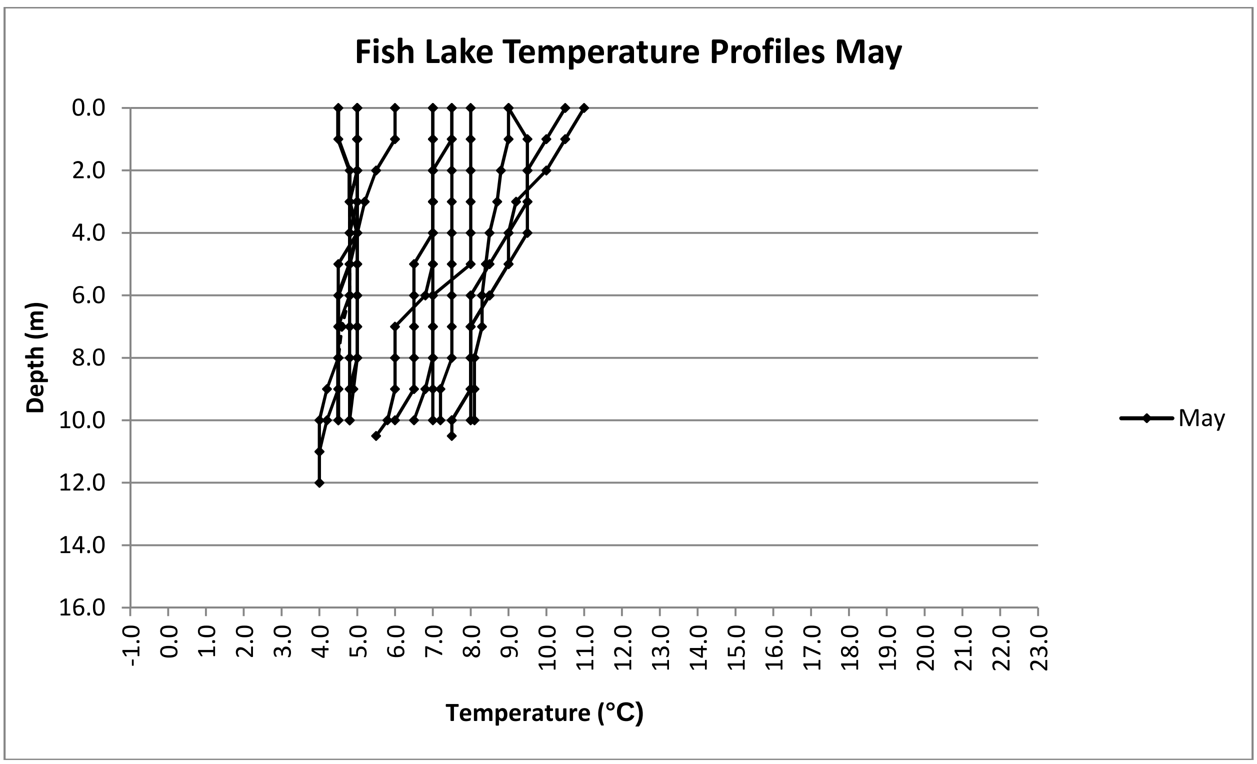
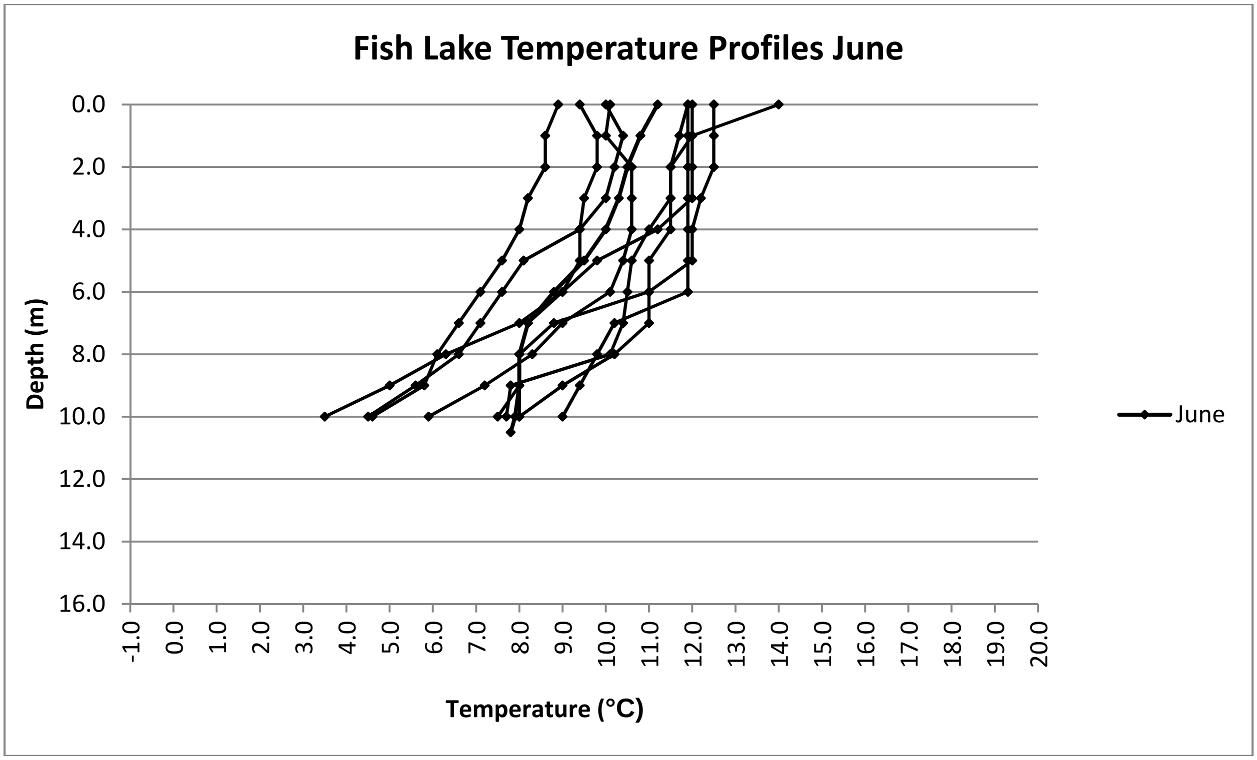
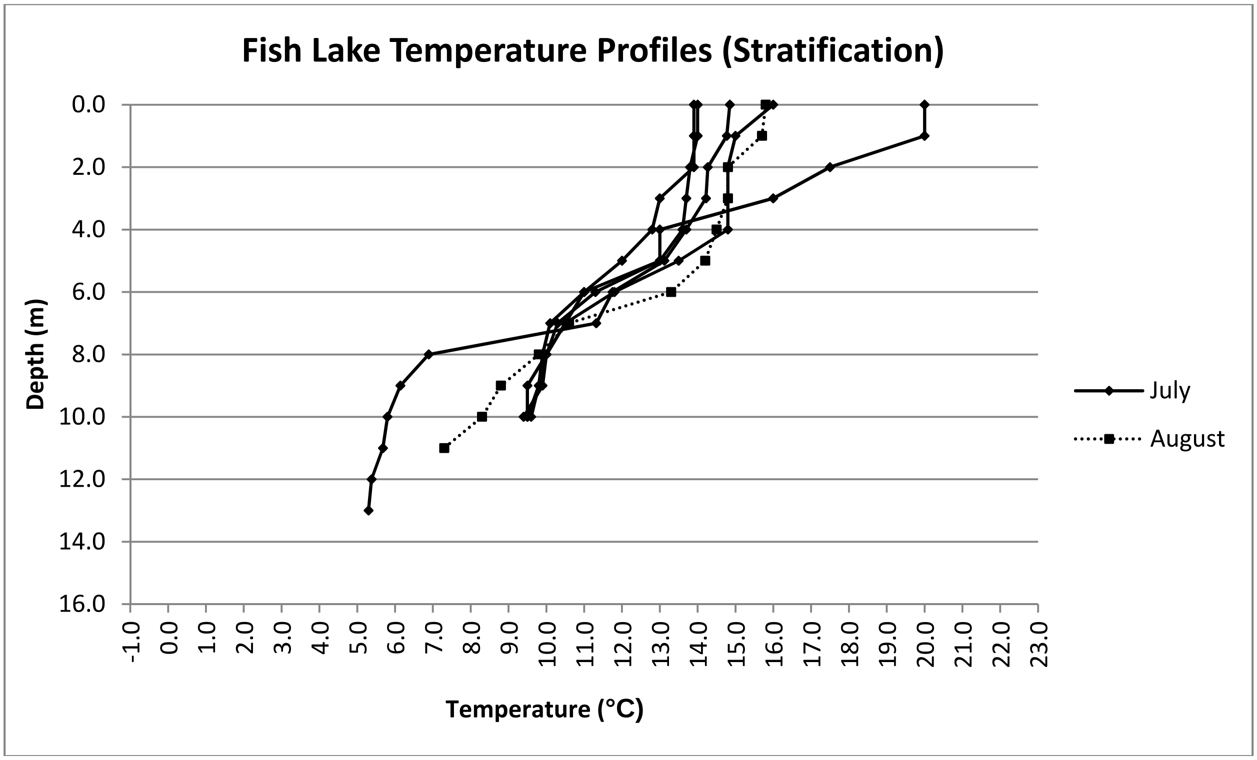
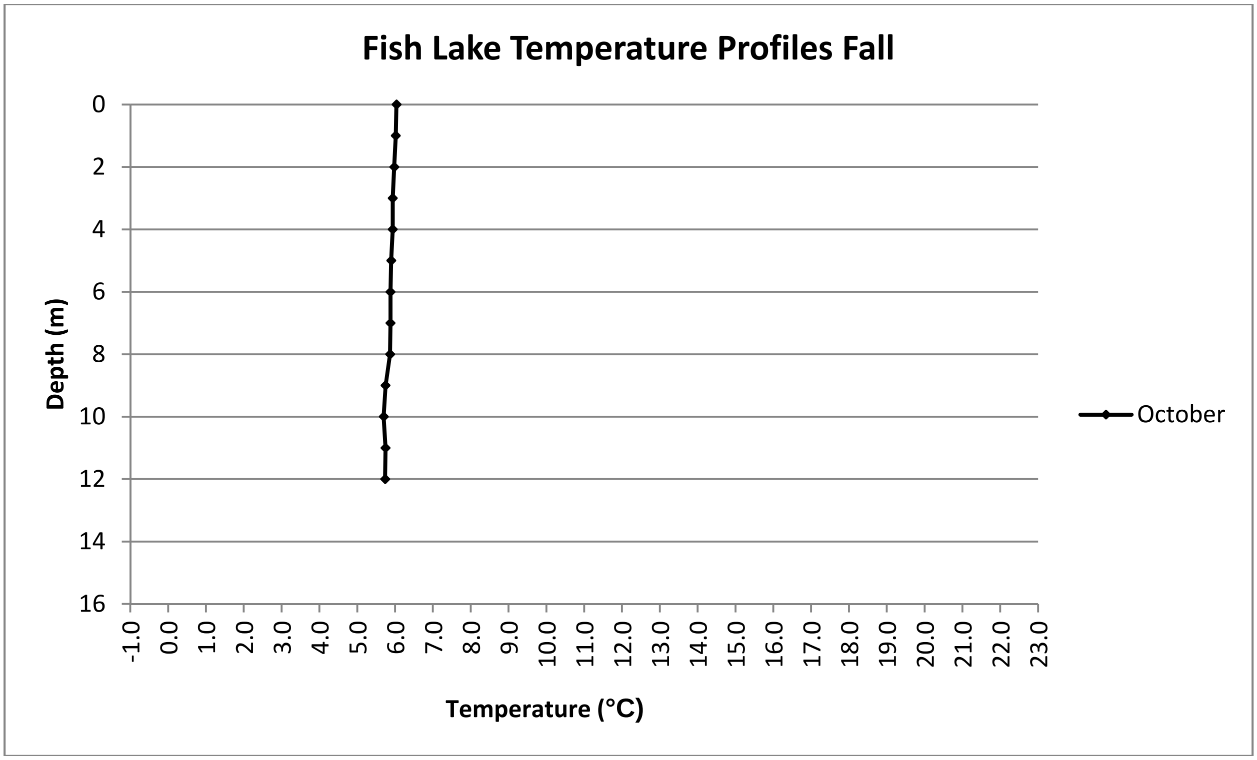
APPENDIX A – MONTHLY LAKE PROFILES


Fish Lake Temperature Profiles Winter
Depth (m)
0
2
4
6
8
10
12
14
16
-1.0
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
11.0
12.0
13.0
14.0
15.0
16.0
17.0
18.0
19.0
20.0
21.0
22.0
23.0
Temperature (°C)
February
March
April

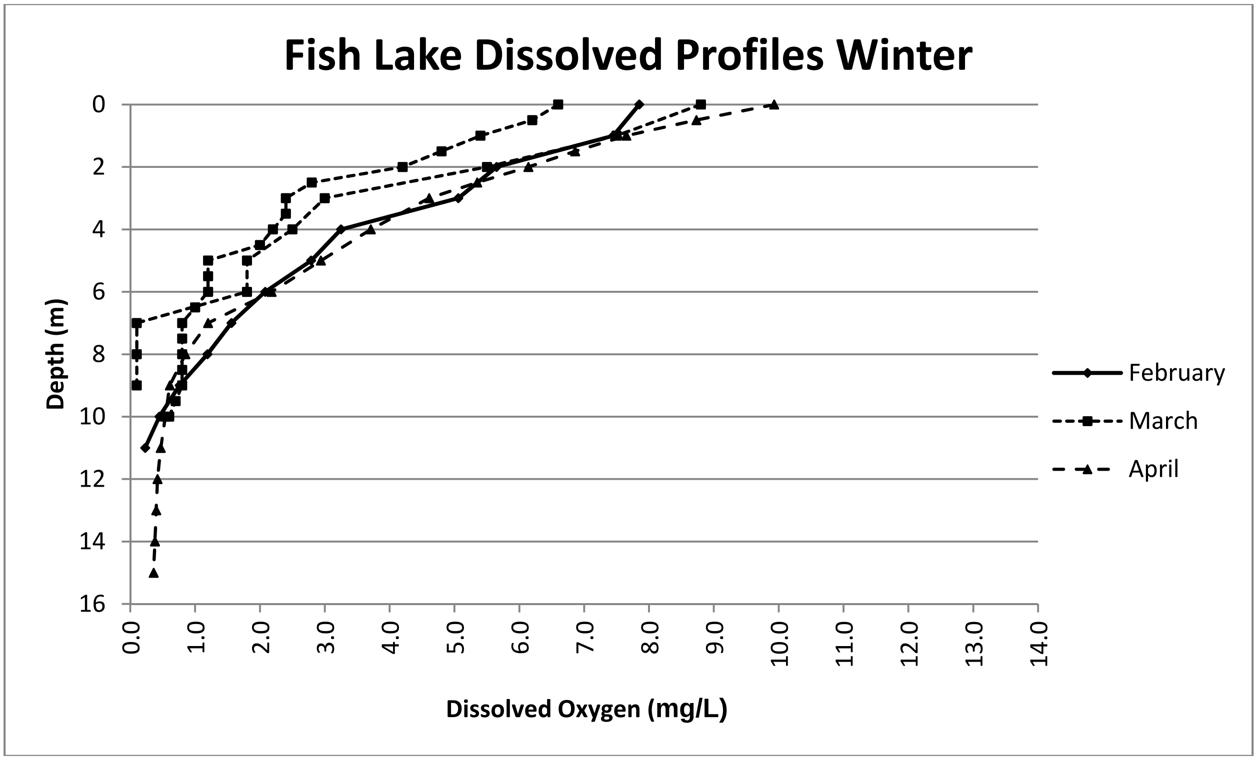

Fish Lake Temperature Profiles May
Depth (m)
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
-1.0
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
11.0
12.0
13.0
14.0
15.0
16.0
17.0
18.0
19.0
20.0
21.0
22.0
23.0
Temperature (°C)
May

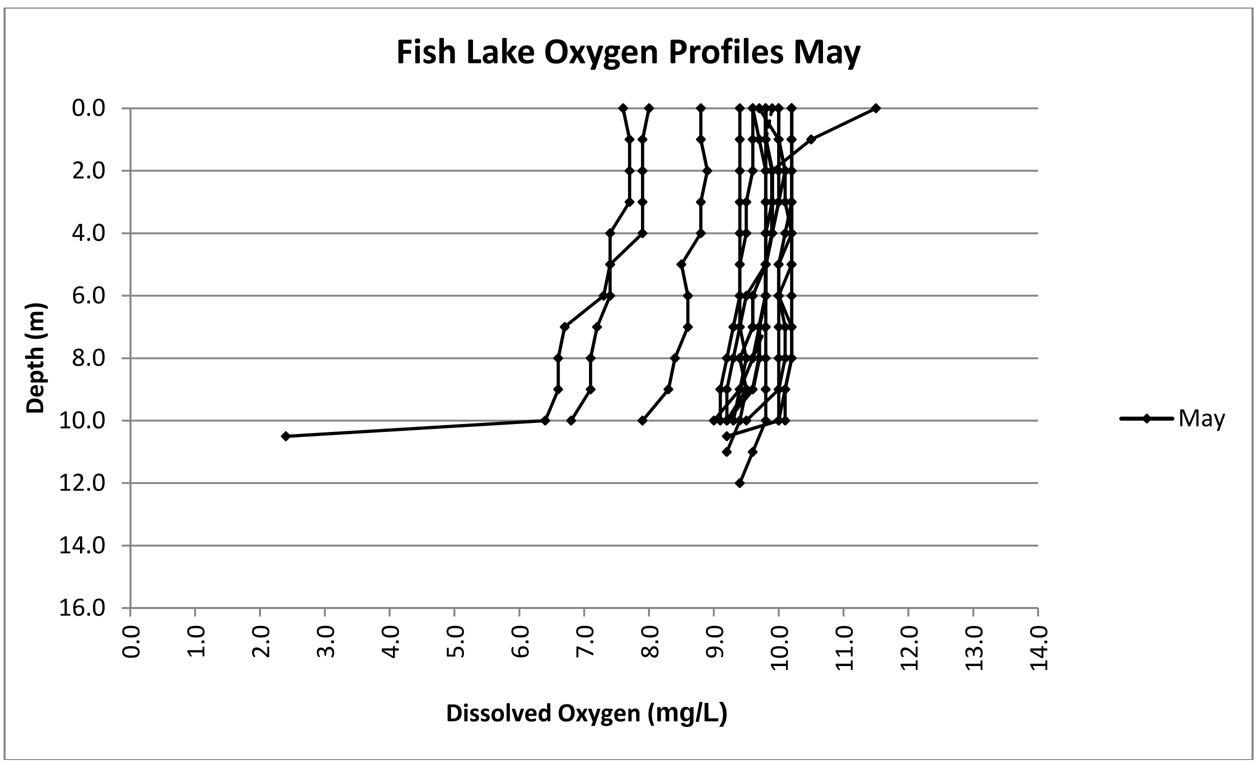

Fish Lake Temperature Profiles June
Depth (m)
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
-1.0 0.0 1.0 2.0 3.0 4.0 5.0 6.0 7.0 8.0 9.0 10.0 11.0 12.0 13.0 14.0 15.0 16.0 17.0 18.0 19.0 20.0
Temperature (°C)
June

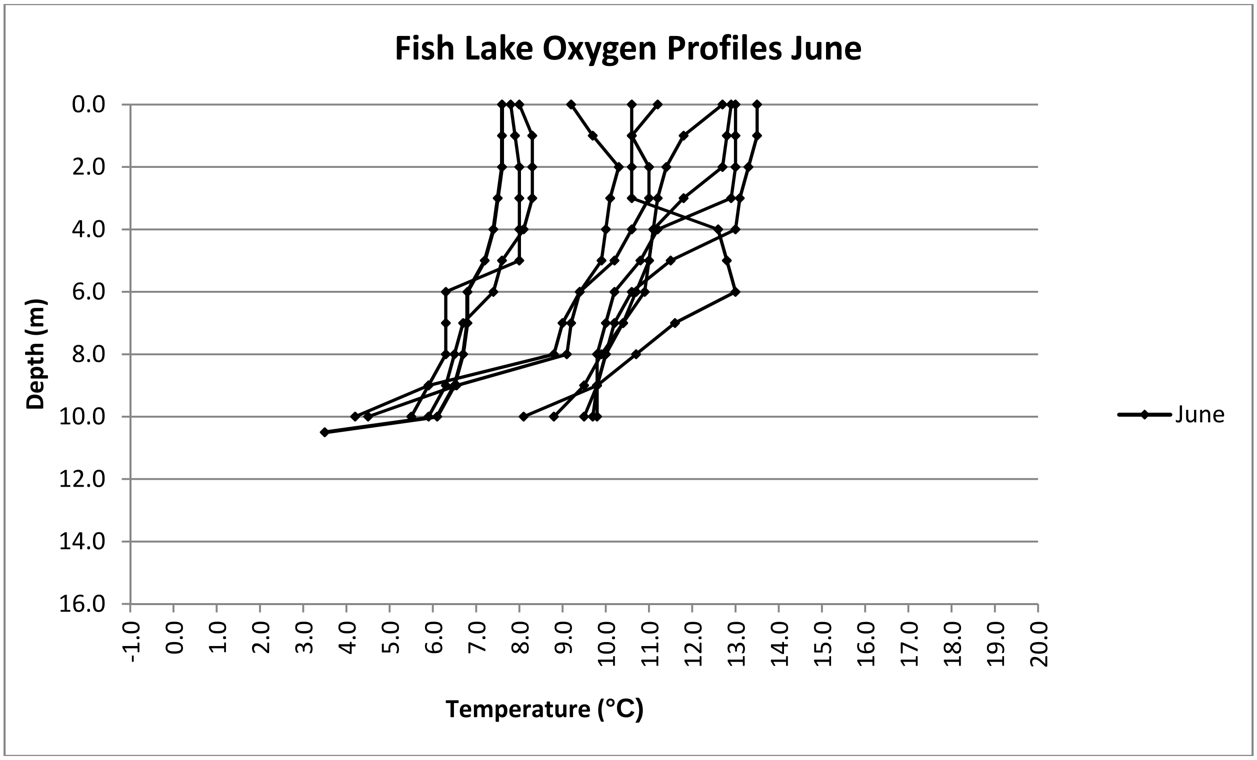

Fish Lake Temperature Profiles (Stratification)
Depth (m)
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
-1.0 0.0 1.0 2.0 3.0 4.0 5.0 6.0 7.0 8.0 9.0 10.0 11.0 12.0 13.0 14.0 15.0 16.0 17.0 18.0 19.0 20.0 21.0 22.0 23.0
Temperature (°C)
July
August

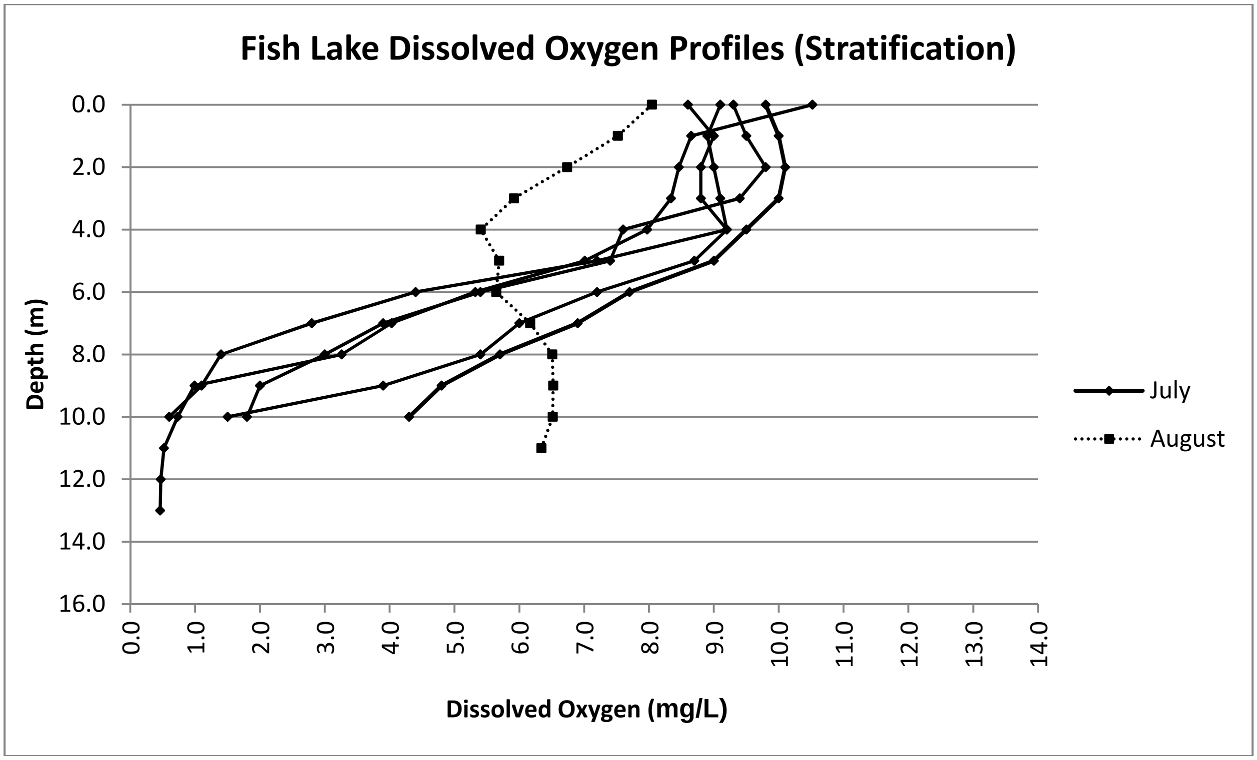

Fish Lake Temperature Profiles Fall
Depth (m)
0
2
4
6
8
10
12
14
16
-1.0
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
11.0
12.0
13.0
14.0
15.0
16.0
17.0
18.0
19.0
20.0
21.0
22.0
23.0
Temperature (°C)
October

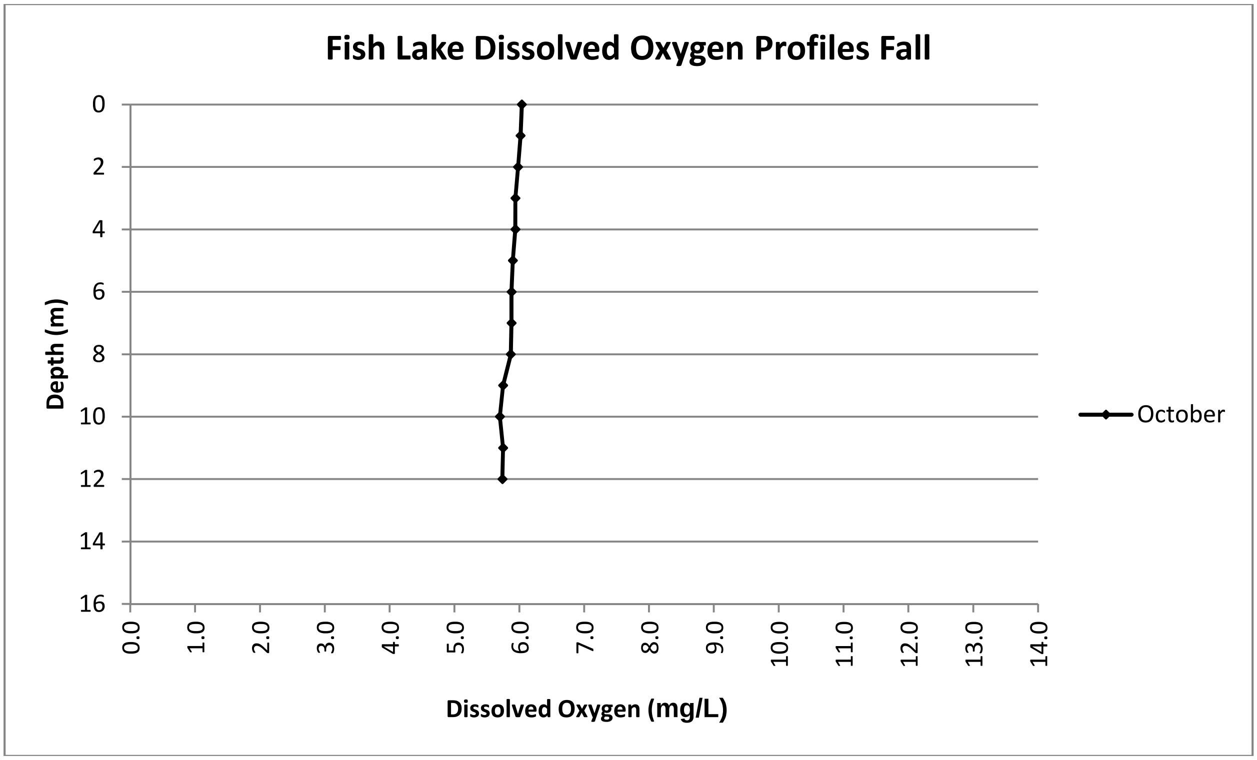
APPENDIX B – DISSOLVED OXYGEN PROFILES


Fish Lake Dissolved Profiles Winter
Depth (m)
0
2
4
6
8
10
12
14
16
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
11.0
12.0
13.0
14.0
Dissolved Oxygen (mg/L)
February
March
April


Fish Lake Oxygen Profiles May
Depth (m)
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
11.0
12.0
13.0
14.0
Dissolved Oxygen (mg/L)
May


Fish Lake Oxygen Profiles June
Depth (m)
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
-1.0
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
11.0
12.0
13.0
14.0
15.0
16.0
17.0
18.0
19.0
20.0
Temperature (°C)
June


Fish Lake Dissolved Oxygen Profiles (Stratification)
Depth (m)
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
11.0
12.0
13.0
14.0
Dissolved Oxygen (mg/L)
July
August


Fish Lake Dissolved Oxygen Profiles Fall
Depth (m)
0
2
4
6
8
10
12
14
16
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
11.0
12.0
13.0
14.0
Dissolved Oxygen (mg/L)
October

APPENDIX C – RAW PROFILE DATA

Date	Hour	Depth (m)	Oxygen (mg/l)	Temperature (°C)
26-Aug-94	1600	0	8.04	15.8
26-Aug-94	1600	1	7.52	15.7
26-Aug-94	1600	2	6.74	14.8
26-Aug-94	1600	3	5.92	14.8
26-Aug-94	1600	4	5.41	14.5
26-Aug-94	1600	5	5.69	14.2
26-Aug-94	1600	6	5.64	13.3
26-Aug-94	1600	7	6.17	10.6
26-Aug-94	1600	8	6.51	9.8
26-Aug-94	1600	9	6.52	8.8
26-Aug-94	1600	10	6.51	8.3
26-Aug-94	1600	11	6.34	7.3
06-Mar-96	-	0	8.80	0.5
06-Mar-96	-	1	7.50	2.5
06-Mar-96	-	2	5.50	3.5
06-Mar-96	-	3	3.00	4.0
06-Mar-96	-	4	2.50	4.0
06-Mar-96	-	5	1.80	4.0
06-Mar-96	-	6	1.80	4.0
06-Mar-96	-	7	0.10	2.5
06-Mar-96	-	8	0.10	4.0
06-Mar-96	-	9	0.10	4.0
02-May-96	1100	0.0	9.8	4.5

Date	Hour	Depth (m)	Oxygen (mg/l)	Temperature (°C)
02-May-96	1100	1.0	9.8	4.5
02-May-96	1100	2.0	9.9	4.8
02-May-96	1100	3.0	9.9	4.8
02-May-96	1100	4.0	9.9	5.0
02-May-96	1100	5.0	9.8	4.8
02-May-96	1100	6.0	9.8	4.5
02-May-96	1100	7.0	9.7	4.5
02-May-96	1100	8.0	9.7	4.5
02-May-96	1100	9.0	9.6	4.5
02-May-96	1100	10.0	9.2	4.5
02-May-96	1130	0.0	9.8	5.0
02-May-96	1130	1.0	9.8	5.0
02-May-96	1130	2.0	9.8	5.0
02-May-96	1130	3.0	9.8	5.0
02-May-96	1130	4.0	9.8	5.0
02-May-96	1130	5.0	9.8	4.5
02-May-96	1130	6.0	9.8	4.5
02-May-96	1130	7.0	9.8	4.5
02-May-96	1130	8.0	9.8	4.5
02-May-96	1130	9.0	9.8	4.2
02-May-96	1130	10.0	9.8	4.0
02-May-96	1130	11.0	9.6	4.0
02-May-96	1130	12.0	9.4	4.0

Date	Hour	Depth (m)	Oxygen (mg/l)	Temperature (°C)
04-May-96	1100	0.0	9.9	5.0
04-May-96	1100	1.0	9.8	5.0
04-May-96	1100	2.0	9.9	5.0
04-May-96	1100	3.0	9.9	4.8
04-May-96	1100	4.0	9.9	4.8
04-May-96	1100	5.0	9.8	4.8
04-May-96	1100	6.0	9.8	4.8
04-May-96	1100	7.0	9.8	4.6
04-May-96	1100	8.0	9.6	4.5
04-May-96	1100	9.0	9.4	4.5
04-May-96	1100	10.0	9.3	4.5
04-May-96	1115	0.0	11.5	5.0
04-May-96	1115	1.0	10.5	5.0
04-May-96	1115	2.0	9.9	5.0
04-May-96	1115	3.0	9.9	4.8
04-May-96	1115	4.0	9.8	4.8
04-May-96	1115	5.0	9.8	4.8
04-May-96	1115	6.0	9.6	4.8
04-May-96	1115	7.0	9.6	4.5
04-May-96	1115	8.0	9.4	4.5
04-May-96	1115	9.0	9.5	4.5
04-May-96	1115	10.0	9.4	4.2
04-May-96	1115	11.0	9.2	4.0

Date	Hour	Depth (m)	Oxygen (mg/l)	Temperature (°C)
06-May-96	1500	0.0	9.7	6.0
06-May-96	1500	1.0	10.0	6.0
06-May-96	1500	2.0	10.1	5.5
06-May-96	1500	3.0	10.0	5.2
06-May-96	1500	4.0	9.9	5.0
06-May-96	1500	5.0	9.8	5.0
06-May-96	1500	6.0	9.5	5.0
06-May-96	1500	7.0	9.4	5.0
06-May-96	1500	8.0	9.5	5.0
06-May-96	1500	9.0	9.4	4.9
06-May-96	1500	10.0	9.0	4.8
09-May-96	1020	0.0	10.2	5.0
09-May-96	1020	1.0	10.2	5.0
09-May-96	1020	2.0	10.2	5.0
09-May-96	1020	3.0	10.2	5.0
09-May-96	1020	4.0	10.1	4.8
09-May-96	1020	5.0	10.0	4.8
09-May-96	1020	6.0	10.0	4.8
09-May-96	1020	7.0	10.0	4.8
09-May-96	1020	8.0	10.0	4.8
09-May-96	1020	9.0	10.0	4.8
09-May-96	1020	10.0	10.0	4.8
11-May-96	1700	0.0	10.2	5.0

Date	Hour	Depth (m)	Oxygen (mg/l)	Temperature (°C)
11-May-96	1700	1.0	10.2	5.0
11-May-96	1700	2.0	10.2	5.0
11-May-96	1700	3.0	10.2	5.0
11-May-96	1700	4.0	10.2	5.0
11-May-96	1700	5.0	10.2	5.0
11-May-96	1700	6.0	10.2	5.0
11-May-96	1700	7.0	10.2	5.0
11-May-96	1700	8.0	10.2	5.0
11-May-96	1700	9.0	10.1	4.8
11-May-96	1700	10.0	10.1	4.8
13-May-96	2100	0.0	10.0	7.0
13-May-96	2100	1.0	10.0	7.0
13-May-96	2100	2.0	10.1	7.0
13-May-96	2100	3.0	10.1	7.0
13-May-96	2100	4.0	10.2	7.0
13-May-96	2100	5.0	10.2	7.0
13-May-96	2100	6.0	10.0	6.8
13-May-96	2100	7.0	10.2	6.0
13-May-96	2100	8.0	10.2	6.0
13-May-96	2100	9.0	10.1	6.0
13-May-96	2100	10.0	10.0	5.8
13-May-96	2100	10.5	9.2	5.5
15-May-96	1050	0.0	10.2	7.0

Date	Hour	Depth (m)	Oxygen (mg/l)	Temperature (°C)
15-May-96	1050	1.0	10.2	7.0
15-May-96	1050	2.0	10.2	7.0
15-May-96	1050	3.0	10.2	7.0
15-May-96	1050	4.0	10.2	7.0
15-May-96	1050	5.0	10.0	6.5
15-May-96	1050	6.0	10.0	6.5
15-May-96	1050	7.0	10.1	6.5
15-May-96	1050	8.0	10.1	6.5
15-May-96	1050	9.0	10.0	6.5
15-May-96	1050	10.0	9.5	6.0
17-May-96	1300	0.0	10.0	7.5
17-May-96	1300	1.0	10.0	7.5
17-May-96	1300	2.0	10.0	7.0
17-May-96	1300	3.0	10.0	7.0
17-May-96	1300	4.0	9.9	7.0
17-May-96	1300	5.0	9.8	7.0
17-May-96	1300	6.0	9.6	7.0
17-May-96	1300	7.0	9.6	7.0
17-May-96	1300	8.0	9.4	7.0
17-May-96	1300	9.0	9.5	6.8
17-May-96	1300	10.0	9.2	6.5
19-May-96	1600	0.0	9.6	8.0
19-May-96	1600	1.0	9.6	8.0

Date	Hour	Depth (m)	Oxygen (mg/l)	Temperature (°C)
19-May-96	1600	2.0	9.6	8.0
19-May-96	1600	3.0	9.5	8.0
19-May-96	1600	4.0	9.5	8.0
19-May-96	1600	5.0	9.4	8.0
19-May-96	1600	6.0	9.4	7.0
19-May-96	1600	7.0	9.3	7.0
19-May-96	1600	8.0	9.2	7.0
19-May-96	1600	9.0	9.1	7.0
19-May-96	1600	10.0	9.1	7.0
22-May-96	1915	0.0	9.6	7.5
22-May-96	1915	1.0	9.7	7.5
22-May-96	1915	2.0	9.8	7.5
22-May-96	1915	3.0	9.8	7.5
22-May-96	1915	4.0	9.8	7.5
22-May-96	1915	5.0	9.8	7.5
22-May-96	1915	6.0	9.8	7.5
22-May-96	1915	7.0	9.7	7.5
22-May-96	1915	8.0	9.6	7.5
22-May-96	1915	9.0	9.4	7.2
22-May-96	1915	10.0	9.3	7.2
25-May-96	1030	0.0	9.4	9.0
25-May-96	1030	1.0	9.4	9.0
25-May-96	1030	2.0	9.4	8.8

Date	Hour	Depth (m)	Oxygen (mg/l)	Temperature (°C)
25-May-96	1030	3.0	9.4	8.7
25-May-96	1030	4.0	9.4	8.5
25-May-96	1030	5.0	9.4	8.4
25-May-96	1030	6.0	9.4	8.3
25-May-96	1030	7.0	9.4	8.3
25-May-96	1030	8.0	9.3	8.1
25-May-96	1030	9.0	9.2	8.1
25-May-96	1030	10.0	9.2	8.1
27-May-96	1508	0.0	8.8	10.5
27-May-96	1508	1.0	8.8	10.0
27-May-96	1508	2.0	8.9	9.5
27-May-96	1508	3.0	8.8	9.5
27-May-96	1508	4.0	8.8	9.0
27-May-96	1508	5.0	8.5	9.0
27-May-96	1508	6.0	8.6	8.5
27-May-96	1508	7.0	8.6	8.0
27-May-96	1508	8.0	8.4	8.0
27-May-96	1508	9.0	8.3	8.0
27-May-96	1508	10.0	7.9	7.5
29-May-96	810	0.0	8.0	9.0
29-May-96	810	1.0	7.9	9.5
29-May-96	810	2.0	7.9	9.5
29-May-96	810	3.0	7.9	9.5

Date	Hour	Depth (m)	Oxygen (mg/l)	Temperature (°C)
29-May-96	810	4.0	7.9	9.5
29-May-96	810	5.0	7.4	9.0
29-May-96	810	6.0	7.4	8.5
29-May-96	810	7.0	7.2	8.0
29-May-96	810	8.0	7.1	8.0
29-May-96	810	9.0	7.1	8.0
29-May-96	810	10.0	6.8	8.0
31-May-96	1345	0.0	7.6	11.0
31-May-96	1345	1.0	7.7	10.5
31-May-96	1345	2.0	7.7	10.0
31-May-96	1345	3.0	7.7	9.2
31-May-96	1345	4.0	7.4	9.0
31-May-96	1345	5.0	7.4	8.5
31-May-96	1345	6.0	7.3	8.0
31-May-96	1345	7.0	6.7	8.0
31-May-96	1345	8.0	6.6	8.0
31-May-96	1345	9.0	6.6	8.0
31-May-96	1345	10.0	6.4	7.5
31-May-96	1345	10.5	2.4	7.5
02-Jun-96	1030	0.0	7.6	11.2
02-Jun-96	1030	1.0	7.6	10.8
02-Jun-96	1030	2.0	7.6	10.5
02-Jun-96	1030	3.0	7.5	10.3

Date	Hour	Depth (m)	Oxygen (mg/l)	Temperature (°C)
02-Jun-96	1030	4.0	7.4	10.0
02-Jun-96	1030	5.0	7.2	9.5
02-Jun-96	1030	6.0	6.8	8.8
02-Jun-96	1030	7.0	6.8	8.2
02-Jun-96	1030	8.0	6.7	8.0
02-Jun-96	1030	9.0	6.5	8.0
02-Jun-96	1030	10.0	6.1	7.9
02-Jun-96	1030	10.5	3.5	7.8
04-Jun-96	1215	0.0	8.0	14.0
04-Jun-96	1215	1.0	8.3	12.0
04-Jun-96	1215	2.0	8.3	12.0
04-Jun-96	1215	3.0	8.3	12.0
04-Jun-96	1215	4.0	8.1	11.2
04-Jun-96	1215	5.0	7.6	9.8
04-Jun-96	1215	6.0	7.4	9.0
04-Jun-96	1215	7.0	6.7	8.2
04-Jun-96	1215	8.0	6.5	8.0
04-Jun-96	1215	9.0	6.3	8.0
04-Jun-96	1215	10.0	5.9	8.0
07-Jun-96	1130	0.0	7.8	12.5
07-Jun-96	1130	1.0	7.9	12.5
07-Jun-96	1130	2.0	8.0	12.5
07-Jun-96	1130	3.0	8.0	12.2

Date	Hour	Depth (m)	Oxygen (mg/l)	Temperature (°C)
07-Jun-96	1130	4.0	8.0	12.0
07-Jun-96	1130	5.0	8.0	12.0
07-Jun-96	1130	6.0	6.3	11.0
07-Jun-96	1130	7.0	6.3	8.8
07-Jun-96	1130	8.0	6.3	8.0
07-Jun-96	1130	9.0	5.9	8.0
07-Jun-96	1130	10.0	5.5	7.5
11-Jun-96	1430	0.0	9.2	11.9
11-Jun-96	1430	1.0	9.7	11.7
11-Jun-96	1430	2.0	10.3	11.5
11-Jun-96	1430	3.0	10.1	11.5
11-Jun-96	1430	4.0	10.0	11.0
11-Jun-96	1430	5.0	9.9	10.6
11-Jun-96	1430	6.0	9.4	10.5
11-Jun-96	1430	7.0	9.2	10.4
11-Jun-96	1430	8.0	9.1	10.1
11-Jun-96	1430	9.0	6.6	7.8
11-Jun-96	1430	10.0	4.5	7.7
15-Jun-96	1800	0.0	11.2	11.9
15-Jun-96	1800	1.0	10.6	11.9
15-Jun-96	1800	2.0	10.6	11.9
15-Jun-96	1800	3.0	10.6	11.9
15-Jun-96	1800	4.0	12.6	11.9

Date	Hour	Depth (m)	Oxygen (mg/l)	Temperature (°C)
15-Jun-96	1800	5.0	12.8	11.9
15-Jun-96	1800	6.0	13.0	11.9
15-Jun-96	1800	7.0	11.6	10.2
15-Jun-96	1800	8.0	10.7	9.8
15-Jun-96	1800	9.0	9.8	9.4
15-Jun-96	1800	10.0	8.1	9.0
16-Jun-96	1300	0.0	10.6	12.0
16-Jun-96	1300	1.0	10.6	12.0
16-Jun-96	1300	2.0	11.0	11.5
16-Jun-96	1300	3.0	11.0	11.5
16-Jun-96	1300	4.0	10.6	11.5
16-Jun-96	1300	5.0	10.2	11.0
16-Jun-96	1300	6.0	9.4	11.0
16-Jun-96	1300	7.0	9.0	11.0
16-Jun-96	1300	8.0	8.8	10.2
16-Jun-96	1300	9.0	5.9	9.0
16-Jun-96	1300	10.0	4.2	8.0
21-Jun-96	1100	0.0	12.7	10.0
21-Jun-96	1100	1.0	11.8	10.4
21-Jun-96	1100	2.0	11.4	10.2
21-Jun-96	1100	3.0	11.2	10.0
21-Jun-96	1100	4.0	11.1	9.4
21-Jun-96	1100	5.0	11.0	9.4

Date	Hour	Depth (m)	Oxygen (mg/l)	Temperature (°C)
21-Jun-96	1100	6.0	10.7	9.0
21-Jun-96	1100	7.0	10.4	8.0
21-Jun-96	1100	8.0	9.9	6.3
21-Jun-96	1100	9.0	9.5	5.0
21-Jun-96	1100	10.0	8.8	3.5
24-Jun-96	1100	0.0	12.9	10.1
24-Jun-96	1100	1.0	12.8	10.0
24-Jun-96	1100	2.0	12.7	10.6
24-Jun-96	1100	3.0	11.8	10.6
24-Jun-96	1100	4.0	11.1	10.6
24-Jun-96	1100	5.0	11.0	10.4
24-Jun-96	1100	6.0	10.9	10.1
24-Jun-96	1100	7.0	10.4	9.0
24-Jun-96	1100	8.0	10.0	8.3
24-Jun-96	1100	9.0	9.8	7.2
24-Jun-96	1100	10.0	9.5	5.9
26-Jun-96	1100	0.0	13.0	8.9
26-Jun-96	1100	1.0	13.0	8.6
26-Jun-96	1100	2.0	13.0	8.6
26-Jun-96	1100	3.0	12.9	8.2
26-Jun-96	1100	4.0	11.2	8.0
26-Jun-96	1100	5.0	10.8	7.6
26-Jun-96	1100	6.0	10.2	7.1

Date	Hour	Depth (m)	Oxygen (mg/l)	Temperature (°C)
26-Jun-96	1100	7.0	10.0	6.6
26-Jun-96	1100	8.0	9.8	6.1
26-Jun-96	1100	9.0	9.8	5.8
26-Jun-96	1100	10.0	9.8	4.6
29-Jun-96	1115	0.0	13.5	9.4
29-Jun-96	1115	1.0	13.5	9.8
29-Jun-96	1115	2.0	13.3	9.8
29-Jun-96	1115	3.0	13.1	9.5
29-Jun-96	1115	4.0	13.0	9.4
29-Jun-96	1115	5.0	11.5	8.1
29-Jun-96	1115	6.0	10.6	7.6
29-Jun-96	1115	7.0	10.2	7.1
29-Jun-96	1115	8.0	10.0	6.6
29-Jun-96	1115	9.0	9.8	5.6
29-Jun-96	1115	10.0	9.7	4.5
02-Jul-96	1300	0.0	9.8	13.9
02-Jul-96	1300	1.0	10.0	13.9
02-Jul-96	1300	2.0	10.1	13.9
02-Jul-96	1300	3.0	10.0	13.0
02-Jul-96	1300	4.0	9.5	12.8
02-Jul-96	1300	5.0	9.0	12.0
02-Jul-96	1300	6.0	7.7	11.0
02-Jul-96	1300	7.0	6.9	10.1

Date	Hour	Depth (m)	Oxygen (mg/l)	Temperature (°C)
02-Jul-96	1300	8.0	5.7	9.9
02-Jul-96	1300	9.0	4.8	9.8
02-Jul-96	1300	10.0	4.3	9.6
05-Jul-96	1100	0.0	9.1	14.0
05-Jul-96	1100	1.0	8.9	14.0
05-Jul-96	1100	2.0	9.0	13.8
05-Jul-96	1100	3.0	9.1	13.7
05-Jul-96	1100	4.0	9.2	13.6
05-Jul-96	1100	5.0	8.7	13.0
05-Jul-96	1100	6.0	7.2	11.3
05-Jul-96	1100	7.0	6.0	10.3
05-Jul-96	1100	8.0	5.4	10.0
05-Jul-96	1100	9.0	3.9	9.9
05-Jul-96	1100	10.0	1.5	9.4
15-Jul-96	1600	0.0	9.3	20.0
15-Jul-96	1600	1.0	9.5	20.0
15-Jul-96	1600	2.0	9.8	17.5
15-Jul-96	1600	3.0	9.4	16.0
15-Jul-96	1600	4.0	7.6	13.0
15-Jul-96	1600	5.0	7.4	13.0
15-Jul-96	1600	6.0	5.4	11.0
15-Jul-96	1600	7.0	3.9	10.5
15-Jul-96	1600	8.0	3.0	10.0

Date	Hour	Depth (m)	Oxygen (mg/l)	Temperature (°C)
15-Jul-96	1600	9.0	2.0	9.5
15-Jul-96	1600	10.0	1.8	9.5
21-Jul-96	1200	0.0	8.6	16.0
21-Jul-96	1200	1.0	9.0	15.0
21-Jul-96	1200	2.0	8.8	14.8
21-Jul-96	1200	3.0	8.8	14.8
21-Jul-96	1200	4.0	9.2	14.8
21-Jul-96	1200	5.0	7.2	13.5
21-Jul-96	1200	6.0	4.4	11.8
21-Jul-96	1200	7.0	2.8	10.5
21-Jul-96	1200	8.0	1.4	10.0
21-Jul-96	1200	9.0	1.1	9.8
21-Jul-96	1200	10.0	0.6	9.5
27-Jul-96	-	0.0	8.5	19.5
27-Jul-96	-	1.0	8.4	18.0
27-Jul-96	-	2.0	8.4	17.8
27-Jul-96	-	3.0	8.3	16.0
27-Jul-96	-	4.0	7.5	15.0
27-Jul-96	-	5.0	6.7	14.2
27-Jul-96	-	6.0	3.8	12.2
27-Jul-96	-	7.0	1.9	11.0
27-Jul-96	-	8.0	1.0	10.2
27-Jul-96	-	9.0	0.6	10.0

Date	Hour	Depth (m)	Oxygen (mg/l)	Temperature (°C)
27-Jul-96	-	10.0	0.4	10.0
15-Mar-97	1310	0.0	6.6	-0.2
15-Mar-97	1310	0.5	6.2	0.5
15-Mar-97	1310	1.0	5.4	1.8
15-Mar-97	1310	1.5	4.8	2.2
15-Mar-97	1310	2.0	4.2	2.8
15-Mar-97	1310	2.5	2.8	3.0
15-Mar-97	1310	3.0	2.4	3.0
15-Mar-97	1310	3.5	2.4	3.0
15-Mar-97	1310	4.0	2.2	3.0
15-Mar-97	1310	4.5	2.0	3.0
15-Mar-97	1310	5.0	1.2	3.0
15-Mar-97	1310	5.5	1.2	3.0
15-Mar-97	1310	6.0	1.2	3.0
15-Mar-97	1310	6.5	1.0	3.0
15-Mar-97	1310	7.0	0.8	3.0
15-Mar-97	1310	7.5	0.8	3.0
15-Mar-97	1310	8.0	0.8	3.2
15-Mar-97	1310	8.5	0.8	3.2
15-Mar-97	1310	9.0	0.8	3.5
15-Mar-97	1310	9.5	0.7	3.8
15-Mar-97	1310	10.0	0.6	4.0
21-Jul-11		0.0	10.5	14.9

Date	Hour	Depth (m)	Oxygen (mg/l)	Temperature (°C)
21-Jul-11		1.0	8.7	14.8
21-Jul-11		2.0	8.5	14.3
21-Jul-11		3.0	8.3	14.2
21-Jul-11		4.0	8.0	13.7
21-Jul-11		5.0	7.0	13.1
21-Jul-11		6.0	5.3	11.8
21-Jul-11		7.0	4.0	11.3
21-Jul-11		8.0	3.3	6.9
21-Jul-11		9.0	1.0	6.1
21-Jul-11		10.0	0.7	5.8
21-Jul-11		11.0	0.5	5.7
21-Jul-11		12.0	0.5	5.4
21-Jul-11		13.0	0.5	5.3
19-Oct-11		0	10.57	6.04
19-Oct-11		1	10.28	6.02
19-Oct-11		2	10.19	5.98
19-Oct-11		3	10.01	5.94
19-Oct-11		4	9.95	5.94
19-Oct-11		5	9.80	5.90
19-Oct-11		6	9.74	5.88
19-Oct-11		7	9.66	5.88
19-Oct-11		8	9.70	5.87
19-Oct-11		9	9.46	5.75

Date	Hour	Depth (m)	Oxygen (mg/l)	Temperature (°C)
19-Oct-11		10	8.72	5.70
19-Oct-11		11	7.66	5.75
19-Oct-11		12	8.92	5.74
07-Apr-11		0	9.93	-0.13
07-Apr-11		0.5	8.73	0.08
07-Apr-11		1	7.65	0.67
07-Apr-11		1.5	6.86	1.66
07-Apr-11		2	6.14	2.52
07-Apr-11		2.5	5.35	2.86
07-Apr-11		3	4.61	3.12
07-Apr-11		4	3.71	3.38
07-Apr-11		5	2.94	3.50
07-Apr-11		6	2.18	3.60
07-Apr-11		7	1.20	3.51
07-Apr-11		8	0.85	3.52
07-Apr-11		9	0.61	3.58
07-Apr-11		10	0.54	3.63
07-Apr-11		11	0.47	3.76
07-Apr-11		12	0.42	4.16
07-Apr-11		13	0.40	4.18
07-Apr-11		14	0.38	4.50
07-Apr-11		15	0.36	4.62
26-Feb-12		0	7.85	1.68

Date	Hour	Depth (m)	Oxygen (mg/l)	Temperature (°C)
26-Feb-12		1	7.45	2.80
26-Feb-12		2	5.65	3.26
26-Feb-12		3	5.06	3.35
26-Feb-12		4	3.25	3.52
26-Feb-12		5	2.79	3.49
26-Feb-12		6	2.08	3.52
26-Feb-12		7	1.56	3.46
26-Feb-12		8	1.19	3.49
26-Feb-12		9	0.76	3.52
26-Feb-12		10	0.45	3.81
26-Feb-12		11	0.23	3.97