Cheakamus Project Water Use Plan

Monitoring Stranding Downstream of Cheakamus Generating Station

Implementation Year: 4

Reference: CMSMON-4

Fish and Hydrological Assessments Summary Report

Study Period: 2011

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FISH AND HYDROLOGICAL ASSESSMENTS SUMMARY REPORT

BC Hydro Cheakamus Generating Station Stranding Study

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REPORT

Executive Summary

The Squamish River contains numerous fish species that use the Cheakamus Generating Station (CGS) Tailrace Channel (TC) and Lower Squamish River Side-channel (LSRS) for spawning, rearing, holding, migrating, and/or overwintering (Troffe and Melville, 2004). The Cheakamus Water Use Planning (WUP) process involved discussions by the Fisheries Technical Committee (FTC) concerning the hypothesis that fluctuating water levels in the CGS TC and LSRS could strand juvenile fish or redds. During the WUP process the FTC recommended development of a monitoring program; the aims of the monitoring being to test the fish stranding hypothesis, and to provide more information to the next WUP process. Operations management of the CGS requires information about the magnitude of the stranding risk in the TC and LSRS at various times throughout the year, to reduce impacts to fish populations. This report provides a summary of the methods, observations, and constraints of the fish survey and hydrology assessment programs conducted for the monitoring program.

Previous stranding studies in the CGS TC and LSRS were reviewed and the results synthesized to form the basis for developing sampling protocols. Fish sampling sites were determined from previous similar studies conducted within the TC and LSRS and additional sites were selected to represent the variety of habitat conditions present. General channel morphology, channel in-flows, and instream and stream-bank habitat characteristics of the TC and LSRS were measured to determine if they influence water quality parameters and fish use and presence.

Site visits as part of the fish assessment programs were conducted from September 22, 2008 to December 18, 2009 and eight different fish species were captured and/or observed. Six of these species were salmonids: Coho Salmon (*Oncorhynchus kisutch*), Chinook Salmon (*Oncorhynchus tshawytscha*), Chum Salmon (*Oncorhynchus keta*), Pink Salmon (*Oncorhynchus gorbuscha*), Rainbow Trout (*Oncorhynchus myskiss*), and Dolly Varden (*Salvelinus malma*). The majority of the fish observed were Coho Salmon, which made up roughly half of the recorded fish (48%, 393 individuals), whereas Chum made up the least number of fish (1%,10 individuals). Adult Chinook, Coho, Pink, and Chum salmon, and resident adult trout (Dolly Varden, Rainbow Trout) were primarily observed in the fall (based on eight sampling events from September to November in 2008 and 2009). Juvenile salmon (Chinook and Coho), and juvenile and adult resident species (Dolly Varden, Rainbow Trout, sculpins [*Cottus* sp.], and Threespine Stickleback [*Gasterosteus aculeatus*]) were observed during every season with winter providing the least number captured/observed. Approximately two-thirds of individuals identified were juveniles, being either fry or parr.

Stranding surveys were conducted after decreases in water levels, or in anticipation of decreased water levels that exposed the TC and LSRS to stranding risk. Stranding events were noted at Sites 2, 5, 6, 7, 8, and 12 and included six salmonids, three stickleback (i.e., a total of nine individual fish were stranded), and a deposit of eggs found behind some rip-rap. Sites 8 and 12 are wide gravel areas where stranded fish were located on sandy or gravel areas. Sites 6 and 7 both have banks with relatively steep shelves that provide some instream cover in the form of depressions or woody debris when flows are high.

To relate the fish stranding observations to the hydrologic conditions in the TC and LSRS, the relationship between the flows and water levels in the TC and LSRS was established. The hydrology of the Upper Squamish River Side-Channel (USRS), TC, and LSRS is complex, with interaction between the various inflows, time lags and backwatering effects. A hydraulic model, River2D, was used to estimate the water level within the TC and LSRS using records from CGS turbine discharge and Squamish River water level at Ashlu Bridge, and estimated USRS and Highfalls Creek flows. Sixty model scenarios were developed to represent the likely range of CGS turbine discharge and Squamish River stage conditions. The fish stranding observations and corresponding boundary conditions were linked to a modelled threshold rate of water level change. The area of the modelled elements exceeding the threshold rate of water level change were summed as the area of potential stranding risk, and compared amongst the different scenarios.

Population-level effects of stranding were not determined within the scope of this monitoring program. Instead, the program aimed to provide a generalized index of stranding risk based upon observations under the various operational and seasonal conditions. The five management questions developed in the Terms of Reference (TOR) of this monitoring program are to address the stranding risk and are outlined below with Golder's approach and answers:

1) **What is the magnitude of stranding risk in the TC and LSRS downstream of the CGS and at what time of the year is it at its highest level?**

Based on the observation of only ten stranded fish on six sampling occasions, the overall magnitude of stranding observed for all fish species is considered low. A low magnitude of standing risk may, however, be significant to fish populations that are already understood to be threatened, such as Chinook Salmon.

Due to the lack of detailed bathymetric data, it was not possible to accurately model variations in water level on a site-specific basis. Therefore, it was not possible to establish an absolute magnitude of stranding risk within the Monitor. Generalized observations were made by interpreting the model results in terms of the relative variations in the amount of area of potential stranding risk when comparing different modelled scenarios. It was observed that regardless of the CGS turbine ramp-down mode, the area of potential stranding risk decreased with higher Squamish River flows and water levels. Therefore, the ramp-down scenarios with the highest potential for creating areas of stranding risk were those that occurred during low flows and water levels in the Squamish River. Low flow in the Squamish River typically occurs from December to April, and also around September.

A stranding risk index ratio of 0.05 was estimated based on the stranding observations and modelled operational and seasonal conditions. The stranding risk index suggests that if 100 fish were observed within the channels then an average of 5 fish may be observed stranded following a ramp-down event. This value was determined by dividing the number of fish observed stranded during each survey by the number of fish observed not stranded during each survey. Golder and Squamish Nation conducted a stranding study downstream of Daisy Dam on the Cheakamus River which found 35 fish stranded after the flow ramp down event on November 1, 2008 (Golder 2009). This study had defined a minimal acceptable level of stranding through consultations with Fisheries and Oceans (DFO) and the Ministry of Environment (MoE) to be "dozens of fish stranded" and therefore determined the levels of stranding observed during the November 1 ramp down event to be within the tolerable limits set (Golder 2009).

The relative magnitude of stranding risk in the TC and LSRS habitats is less than the stranding observed below Daisy Dam during the November 1 ramp down and less than the stranding risk deemed acceptable for the Daisy Dam November ramp down. The diversity of fish species in the TC and LSRS is greater than below Daisy Dam as anadromous salmonids are able to access the TC and LSRS. Therefore, even though the total number of stranded fish may be lower at TC and LSRS habitats, the level of stranding could potentially be significant to salmonids that are returning to spawn. Chinook Salmon are of particular concern as these species have been observed spawning in the TC and are not known to spawn in surrounding streams or channels.

The stranding index is at best a qualitative indicator of stranding potential, as the numbers of fish found stranded and observed do not represent the entire number of fish both stranded and inhabiting the TC and LSRS habitats, and underestimates the actual numbers. This index has a high uncertainty due to the potential biases with the ability to observe fish and stranding correlating positively or negatively with the variable hydraulic conditions that are associated with increased or decreased stranding rates.

2) What is the aerial extent of the stranding impact should it occur?

The aerial extent of stranding impact varies depending on the ramp-down mode and the Squamish River water level. The generalized relative risk of potential stranding under the modelled scenarios suggests:

- For all analyzed CGS turbine ramp-down modes, the area of potential stranding risk increased with a lower flow/water level at Squamish River at Ashlu Bridge;
- For periods of low flows in the Squamish River (i.e., water level below 32.4 m at Ashlu Bridge), the study results indicate that the risk of stranding was the highest for the 55-0 m^3/s ramp-down mode, followed by the 25-0 m^3/s ramp-down mode. The 55-25 m^3/s ramp-down mode resulted in the lowest relative risk of stranding; and
- Although the total aerial extent of stranding could not be calculated due to the limitations in the bathymetric data, the relative extent of observed stranding covered a small area compared to the size of the TC and LSRS.

3) Does a peaking operation at the powerhouse prevent juvenile salmonids from colonizing habitats that are prone to dewatering?

The analysis of whether the duration of peaking operations is enough to limit or prevent fish colonization of habitat that will become dewatered incorporates minnow trap (MT) catch-per-unit-effort (CPUE) data. The MT CPUE data indicates fish move into these temporarily available habitats during peaking operations and that fish occupy this habitat between peaking operations, provided the habitat remains wetted. The data suggest that peaking operations do not prevent colonization of habitats prone to dewatering.

4) What is the stranding risk to spawning adults and resulting redds when in the TC and LSRS?

Stranding of adult salmonids within the TC and LSRS is considered lower than the mean stranding risk index, as the stranding incidents that included adult salmonids occurred during one event, on September 22, 2008. The stranding risk index for that survey event was determined to be 0.03 compared with the mean stranding risk index of 0.05 fish observed stranded / fish observed not stranded. Though the hydraulic model cannot be used to quantify the stranding risk to redds, observations of redds in the TC and LSRS suggest these areas would be potentially at risk of stranding eggs in the redds when ambient flows lessen and operations of the CGS significantly reduce flows. During such instances the large gravel area is left almost entirely dewatered, except for the narrow thalweg channel on the left downstream bank, and this may strand a considerable proportion of eggs in any established Pink or other salmon redds. Chinook Salmon adults and redds are sensitive to stranding, particularly in the area immediately below the CGS, where adults have been observed holding and displaying spawning behaviour. The significance of such stranding is that it would be estimated to be greater in the TC and LSRS than in the Squamish River main channel.

5) If the rate of stranding is found to be significant, what kind of actions can be taken to mitigate the impact?

The rate of stranding within the TC and LSRS was not found to be substantial due to the relatively low value of the mean stranding risk index (0.05 fish observed stranded / fish observed not stranded) and subsequently the overall low potential stranding risk relative to that observed in the Cheakamus River below Daisy Dam (Golder 2009). The potential for stranding would have unequal impacts among different species, as species which have lower population numbers and longer periods between spawning events would potentially be more greatly affected by low numbers stranding, compared to fish species that reproduce more quickly and have greater local populations. The types of mitigation measures that could be employed to reduce the numbers of fish that become stranded are:

- Seasonally altering ramping rates based on Squamish River water levels and operational conditions;
- Fish barriers for adults to prevent spawning in specified high-risk stranding areas;
- Reshaping the channel to limit access to high-risk areas where dewatering occurs; and
- Redd salvage operations.

By addressing the five management questions above the Monitor aimed to provide information to either satisfactorily reject or fail to reject the Stranding Impact Hypothesis defined in the TOR:

- That the stranding rate of juvenile and adult fish does not exceed the threshold value judged to be harmful to local fish populations.

Although a threshold value of stranding risk was not specifically determined for the TC and LSRS, the management questions do indicate that the stranding risk index is relatively low downstream of the CGS in comparison to a “minimum acceptable level of stranding” determined for the Daisy Lake Dam November 1 ramp down event, and the actual observed stranding below Daisy Dam (Golder 2009). Therefore, the Monitor suggests that the Stranding Impact Hypothesis would likely fail to be rejected and that the observed stranding rate would be determined as not harmful to local fish populations.

Study Limitations

This report was prepared for the exclusive use of BC Hydro, their assignees and representatives, and is intended to provide an assessment of relative stranding risk to fish within the Cheakamus Generating Station Tailrace Channel (TC) and the Lower Squamish River Side-channel (LSRS). The scope of work for the stranding study was described in Golder's proposal. The terms and conditions outlined in that proposal apply to this report. This report is not intended to identify or evaluate potential effects outside of the area of the TC and LSRS.

The stranding study is based on data and information, obtained from a review of available literature and during the documented investigations within the TC and the LSRS, which included twelve sampling sites, and is based solely on the site conditions observed during these investigations.

This report was prepared, based in part, on information obtained from BC Hydro. In evaluating the subject project area, Golder has relied in good faith on information provided. We accept no responsibility for any deficiency or inaccuracy contained in this report as a result of our reliance on the aforementioned information.

The findings and conclusions documented in this report have been prepared for the specific application to this project, and have been developed in a manner consistent with that level of care normally exercised by environmental professionals currently practicing under similar conditions in the jurisdiction. Golder makes no warranty, expressed or implied, and assumes no liability with respect to the use of the information contained in this report at the subject site, or at any other site, for other than its intended purpose.

Any use which a third party makes of this report, or any reliance on, or decisions to be made based on it, are the responsibilities of such third parties. Golder accepts no responsibility for damages, if any, suffered by any third party as a result of decisions made or actions based on this report.

Acronym Glossary

BO - Boulder

BS – Beach seine

CC - Consultative Committee

CC – Sculpin species

CCME – Canadian Council of Ministers for the Environment

CGS - Cheakamus Generating Station

CH – Chinook Salmon

CM – Chum Salmon

CB – Cobble

CO – Coho Salmon

CO_2 – Carbon Dioxide

CPUE - Catch per unit effort

DEM – Digital elevation model

DFO – Fisheries and Oceans Canada

DHI – Defense Hydrographic Initiative

DN – Dip-netting

DO - Dissolved Oxygen

DV – Dolly Varden

EF – Electrofishing

FDIS – Fisheries Data Information System

FTC - Fisheries Technical Committee

GR – Gravel

HEC – Hydrologic Engineering Center

LOD – Large organic debris

LSRS - Lower Squamish River Side-channel

LUB – Left upstream bank

MoE – (British Columbia) Ministry of Environment

MPS – Multiprobe System

MT - Minnow Trap

NAD – North American Datum

O – Organics

OV – Overhanging vegetation

PK – Pink Salmon

RAS – River Analysis System

RB – Rainbow Trout

RIC – Resource Inventory Committee

RR – Rip-rap

RUB – Right upstream bank

S – Silt

SS – Snorkel surveys

TC - Tailrace Channel

TOR - Terms of Reference

TSB – Threespine Stickleback

UNSA – Unknown salmon

USRS - Upper Squamish River Side-channel

UTM – Universe Transverse Mercator

VO – Visual observations

WSC - Water Survey of Canada

WUP - Water Use Plan

YSI – Yellow Springs Instruments

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1.0 INTRODUCTION

1.1 Background

In May 1999 a Water Use Planning (WUP) process was initiated by BC Hydro for the Cheakamus Generating Station (CGS). To administer the planning process a Consultative Committee (CC) was formed in June 1999. The CC established a Fisheries Technical Committee (FTC) to review fisheries matters related to the Daisy Lake Dam water management plan. As part of the planning process, a Water Use Plan was developed for the Cheakamus River below the Daisy Lake Dam to balance environmental, social, and economic values by including an appointed flow regime (BC Hydro 2005). In February 2006 this WUP was put into effect.

The CGS is supplied from the Daisy Reservoir located upstream of the Cheakamus River canyon via a 16 km diversion tunnel through Cloudburst Mountain (Appendix C). Discharge from the CGS is managed through a facility operation model that follows the operational constraints of the Water Use Plan. The CGS normally operates as a peaking plant during the daytime to accommodate increased consumer demands in Squamish and surrounding areas. It is often shut down at night, as reservoir inflows and flow release requirements to the Cheakamus River leave insufficient water to run the plant continuously. This occurs particularly during the winter when inflows are low (WUP 2005), but can occur during any season. During the spring freshet when inflows are high, CGS typically runs at full capacity around the clock. CGS can also be shut down for scheduled maintenance. Low water levels in both the Tailrace Channel (TC) and the Lower Squamish River Side-channel (LSRS) as a result of nightly shut down can impact water temperature, dissolved oxygen, and increase the risk of fish stranding.

The Cheakamus WUP process involved discussions by the FTC concerning the hypothesis that fluctuating water levels in the CGS TC and downstream SRS could strand juvenile fish or redds (spawning sites). The Squamish River contains numerous fish species that use the CGS TC and LSRS for spawning, rearing, holding, migrating, and/or overwintering (Troffe and Melville, 2004). Both adult and juvenile fish may move into and colonize habitat at differing rates and numbers throughout the year during peak operation of the CGS. These movements likely depend on a variety of factors including life history and habitat requirements. Fish colonizing habitats prone to dewatering, or spawning redds located in such habitats, are at risk of stranding when discharge from the CGS is stopped or reduced. The fish stranding hypothesis resulted from anecdotal observations of stranding of fish while CGS turbines were shut down following extended periods of sustained operation that coincided with low flows from the Squamish River (BC Hydro 2007).

During the WUP process the FTC recommended a monitor of stranding downstream of the Cheakamus Generating Station (referred to hereafter as the “Monitor”) be developed, which would better inform the fish stranding hypothesis. The inclusion of the hypothesis in the current WUP process was therefore postponed until it could be re-examined at the next WUP review process when the Monitor was anticipated to have provided more information with which to make a decision.

Operations management of the CGS requires information as to the magnitude of the stranding risk in the TC and LSRS at various times throughout the year to reduce impacts to fish populations. In response to these concerns, BC Hydro initiated the monitor to address these potential impacts downstream of CGS. Golder Associates Ltd. (Golder) was retained by Squamish Nation to assist with conducting BC Hydro’s monitoring program within the CGS TC and the adjacent and downstream SRS. The program was designed to address the management concerns of stranding risk to adult and juvenile fish. This report provides a summary of the methods, observations, and constraints of the fish survey programs and the hydrological monitoring and modelling programs conducted over the durations of the Monitor.

1.2 Study Location

The CGS discharges into a relatively short Tailrace Channel, located on the eastern bank of the Squamish River, which connects to a side channel from the Squamish mainstem (Squamish River Side-channel) and runs roughly 1.7 km downstream before reconnecting to the Squamish River (Figure 1). The study area for this Monitor includes both the Tailrace Channel and the Lower Squamish River Side-channel (TC and LSRS). The LSRS is defined as the section of channel immediately downstream of the confluence of TC and USRS up to the location where the LSRS rejoins with the Squamish mainstem.

1.3 BC Hydro Terms of Reference – Objectives

The Terms of Reference (TOR: dated February 22, 2007) developed by BC Hydro and with input from fisheries agencies, local First Nations, and stakeholders, for monitoring stranding downstream of the CGS outlines its objective as collecting data necessary to address the following management questions:

1) What is the magnitude of stranding risk in the TC and LSRS downstream of the CGS, and at what time of the year is it at its highest level?

2) What is the aerial extent of the stranding impact should it occur?

3) Does a peaking operation at the powerhouse prevent juvenile salmonids from colonizing habitats that are prone to dewatering?

4) What is the stranding risk to spawning adults and resulting redds when in the TC and LSRS?

5) If the rate of stranding is found to be significant, what kind of actions can be taken to mitigate the impact?

By addressing these questions above the Monitor aims to provide information to either satisfactorily reject or fail to reject the Stranding Impact Hypothesis defined in the TOR:

- That the stranding rate of juvenile and adult fish does not exceed the threshold value judged to be harmful to local fish populations.

Although a threshold value of stranding risk was not specifically determined for the TC and LSRS, the management questions do indicate that the stranding risk index is relatively low downstream of the CGS in comparison to the “minimum acceptable level of stranding” during the November 1 ramp down event below the Daisy Dam, as well as the actual observed stranding below Daisy Dam (Golder 2009). Therefore, the Monitor suggests that the Stranding Impact Hypothesis would fail to be rejected.

1.4 Purpose and Objectives

To address the management questions data was collected over a four year period. The purposes of the data collection was to provide information to assess the fisheries resources and to conduct a hydrological analysis to identify and characterize both the habitat use by fish and the hydraulic conditions that have the potential to strand fish. Year 1, from September 2008 to June 2009, and Year 2, from July to December 2009, was spent collecting fish data and hydrological data was collected during Year 1, Year 3, from January to October 2010, and Year 4, from November 2010 to October 2011. The objectives and tasks through the duration of the project consisted of the following components:

1) Review existing studies of stranding in the CGS TC and LSRS;

2) Assess fish use (determine fish species presence/absence and life history phases) within the CGS TC and LSRS;

3) Assess colonization of juvenile fish into the TC and the LSRS during a range of available flows;

4) Record water quality (temperature and dissolved oxygen) within segments of the TC and LSRS;

5) Conduct periodic stranding surveys to identify incidents of stranding;

6) Monitor water levels in the TC and LSRS, and flows in the USRS and High Falls Creek;

7) Monitor and analyse the discharge volumes from the CGS into the TC, Squamish River water levels, flows in the USRS and High Falls Creek; and

8) Construct a two-dimensional hydraulic model of the TC and LSRS to assess stranding risk.

2.0 METHODS

2.1 Hydrologic and Hydraulic Analysis

To relate the fish stranding observations to the hydrologic conditions in the TC and LSRS during Cheakamus Generating Station (CGS), the relationship between the flows and water levels in the TC and LSRS was established. The hydrology of the USRS, TC, and LSRS is complex, with interaction between the various inflows, time lags and backwatering effects. The water level is not only influenced by the CGS turbine discharge, but also by the USRS flows, Highfall Creek flows, and the Squamish River water level. The conventional water level estimate approach using stage-discharge rating curve is unsuitable for this project, as there is no unique water level associated with a specific flow. A hydraulic model was used to estimate the water level under a range of Squamish River stage and CGS turbine discharge conditions. The hydrologic and hydraulic analysis carried out in this report includes the following work:

- Data Collection;
- Hydraulic Model Development;
- Modelling Scenario Development;
- Simulated Stranding Threshold; and
- Model Interpretation.

These are discussed in more detail in the following sections.

2.2 Data Collection

To identify and characterize the CGS turbine ramp-down conditions that have the potential to strand fish, hydrologic and hydraulic analysis was undertaken to estimate the water levels in the TC and LSRS. The analysis required the collection of the following data:

- Bathymetric data;
- Flow data; and
- Water level data.

The following sub-sections discuss the data collected for the hydrologic and hydraulic analysis.

2.2.1 Bathymetric Data

The River2D model was used to simulate the flow regime in the CGS TC and LSRS. River2D is a two-dimensional, depth-averaged, finite element numerical model that was developed by the University of Alberta. To develop the bathymetry for this 2-dimensional model, Golder carried out manual cross-section surveys along the TC and LSRS in August 2010. The manual level and rod survey work was performed over a period of three days, and 19 cross-sections were surveyed at locations selected from site reconnaissance and review of aerial photographs. These cross-sections spanned over approximately 1.5 km in the TC and LSRS, and the distance between the cross-sections varies between 7 m and 250 m.

The survey work was performed as an alternative source of bathymetric data, due to the poor quality of the original bathymetric data that was provided to Golder. The bathymetric data quality issue is discussed in the next section.

2.2.1.1 Bathymetric Data Issues

Accurate representation of the physical features of the river channel bed is a crucial factor in successful hydraulic modelling. Golder initially attempted to construct the two-dimensional hydraulic model based on sounder bathymetric data provided by BC Hydro. However, upon further examination, the data was of inadequate resolution or accuracy to be suitable for the intended use.

The issue with the provided bathymetric data was identified when a topographic survey, intended to reconcile the datum and provide several controlled reference points overlapped with the provided bathymetric data. The surveyed elevations of the reference points were compared to the elevations of the corresponding points on the provided bathymetry. The variation between the surveyed reference point elevations and the provided bathymetric data ranged from -1.04 m to 0.78 m (total range of 1.82 m). Given that the channel is generally less than 3 m in depth at bank full flow, this variation was considered significant. The provided bathymetric data generally lacked measurements between the thalweg and the top of bank along the edges of the channel, resulting in poor resolution in the portions of the TC and LSRS most susceptible to stranding risk. In addition, discussion with BC Hydro staff indicated that the datum used in the development of the provided bathymetric data was the water surface elevation at one point within the LSRS, without taking into account the slope of the water surface. Sounding data collected from a boat was subtracted from the water surface elevation at the singular reference point to estimate bed elevations along the channel thalweg. This methodology resulted in bathymetric data which were not suitable for hydraulic modelling. Golder attempted to correct the provided bathymetric data using manually surveyed cross-section data. However, the attempted correction did not result in a reasonable representation of the channel geometry, and the final analysis was based only on the surveyed cross-sections.

2.2.2 Flow Data

Flow data was collected for this project to establish the upstream boundary conditions for the River2D hydraulic model. Two types of flow data were collected for this study for use as upstream boundary conditions in the hydraulic model: Cheakamus Generating Station (CGS) turbine discharge records, and USRS flows.

2.2.2.1 Cheakamus Generating Station Turbine Discharge Records

Golder was provided with hourly CGS turbine discharge records between 1967 and 2011. Only the turbine discharge records between 2004 and 2011 were used, to coincide with the available water level records from Squamish River at Ashlu Bridge which were used to establish the model's downstream boundary conditions.

2.2.2.2 Upper Squamish River Side Channel Manually-Measured Flows

The USRS is the section of the Squamish River side-channel located upstream of the confluence with the TC, and its flows, together with the CGS turbine discharge, were used to establish the model's upstream boundary conditions. Flows in the USRS are mainly based on two input sources: The Squamish River, and High Falls Creek. Part of the flow in the USRS comes from the Squamish River, whenever the Squamish River water level rises above a certain threshold elevation and starts to contribute flows into the USRS. The other part of the USRS flow comes from High Falls Creek, which is not influenced by the Squamish River, but a function of local surface runoff associated with precipitation events. Golder provided training for Squamish First Nation personnel to conduct manual stream flow measurements using a chain and a flow meter, at the mouth of the High Falls Creek and at a section of USRS located just upstream of High Falls Creek. Approximately eight flow measurements were taken at each site during the monitoring period.

2.2.3 Water Level Data

Two types of water level data were collected for this study: Squamish River water level at Ashlu Bridge, and water level within the TC and LSRS.

2.2.3.1 Water Level Data for the Squamish River

Water level data was collected at the Ashlu Bridge crossing of the Squamish River to establish the downstream boundary conditions for the River2D hydraulic model. The Squamish River water level was recorded every hour at a location approximately 100 m downstream of Ashlu Bridge (this location is hereafter referred to as Squamish River at Ashlu Bridge). Ashlu Bridge is located on the Squamish River, approximately 700 m downstream of the confluence between the Squamish River and the LSRS. The hourly water level record between 2004 and 2011 was provided by VIA-SAT Data Systems Inc. (2012). There were some missing records in 2005, 2006, and 2011.

2.2.3.2 TC and LSRS water level records

In September 2008, Golder installed three stage recording stations (hereon referred to as Stage Recording Station) along the TC and LSRS to continuously monitor the water levels, which were planned for model calibration use. The locations of the Stage Recording Stations are shown in Figure 1. Each station consists of two staff gauges and two non-vented pressure transducers. The transducers were installed in pairs to provide redundancy in the data collection system. Two barometric pressure transducers were also installed within the study area. The data collected by the barometric pressure transducers was used to compensate for the variations in atmospheric pressure recorded by the underwater pressure transducers at each of the Stage Recording Stations.

The pressure transducers recorded pressure at 15 minute intervals from September 2008 to October 2011. Golder provided training for Squamish First Nation personnel for collecting the data from these Stage Recording Stations.

Doug Bush Survey Services Ltd. was retained in August 2009 to carry out a topographic survey to establish the position and elevation of each of the Stage Recording Stations. In addition, two BC Hydro hydrometric stations located downstream from Ashlu Bridge and by the CGS were also surveyed. This survey provided a common coordinate system (UTM NAD 83) for the topographic, bathymetric, and hydrometric data used for the hydrologic and hydraulic analysis. The water surface elevation was also recorded during the survey.

Because the pressure transducers are located at the base of the channel, direct measurement of the transducer’s elevation was not possible. The datum for the transducers was calculated by surveying the water surface and subtracting the recorded depth reported by the transducer at the time of the survey. In addition to the 2009 Doug Bush works, the water surface elevation was observed during Golder’s various field visits. The water surface elevation was periodically re-checked using the installed staff gauge at each site.

Periods of water level records were missing for the Squamish River at Ashlu Bridge in 2005, 2006, and 2011. CGS turbine flow data for these periods were available, but data analysis was not performed because the flow data must be examined along with the coincident Squamish River water level data in order to establish useful boundary conditions.

The pressure transducers Golder installed at the three Stage Recording Stations recorded water levels in the TC and LSRS from September 2008 to October 2011. Due to technical issues and human errors, data between February 2009 and October 2009 were missing for most of the Stage Recording Stations. Furthermore, there were intermittent equipment issues with the Stage Recording Station after October 2009. These periods were excluded from the data analysis.

A summary of the available pressure transducer data from the three monitoring stations is shown in Table 1. Periods with data are highlighted in yellow.

Table 1: Stage Recording Station Data Summary

	Stage Recording Station #1		Stage Recording Station #2		Stage Recording Station #3	
Transducer#	**1**	**2**	**1**	**2**	**1**	**2**
Sept-08	🟨	🟨	🟨	🟨	🟨	🟨
Oct-08	🟨	🟨	🟨	🟨	🟨	🟨
Nov-08	🟨	🟨	🟨	🟨	🟨	🟨
Dec-08	🟨	🟨	🟨	🟨	🟨	🟨
Jan-09	27-Jan-09 13:30[2]	🟨	🟨	🟨	27-Jan-09 13:30	🟨
Feb-09		17-Feb-09 12:45	17-Feb-09 12:45	17-Feb-09 13:00		17-Feb-09 13:00
Mar-09						
Apr-09	08-Apr-09 14:49[3]					
May-09	🟨					
Jun-09	🟨					
Jul-09	🟨					
Aug-09	🟨					

	Stage Recording Station #1		Stage Recording Station #2		Stage Recording Station #3	
Transducer#	**1**	**2**	**1**	**2**	**1**	**2**
Sep-09	22-Sept-09 6:34					
Oct-09	30-Oct-09 12:10	30-Oct-09 12:01		30-Oct-09 14:15		30-Oct-09 15:45
Nov-09	🟨	🟨		🟨		🟨
Dec-09	🟨	🟨		🟨	09-Dec-09 13:15	🟨
Jan-10	🟨	🟨		🟨	🟨	🟨
Feb-10	🟨	🟨		🟨	🟨	🟨
Mar-10	🟨	🟨	12-Mar-10 15:51	🟨	🟨	12-Mar-10 17:15
Apr-10	🟨	🟨	🟨	🟨	🟨	
May-10	🟨	🟨	🟨	🟨	19-May-10 5:00	
Jun-10	🟨	🟨	🟨	🟨	03-Jun-10 14:43	03-Jun-10 14:30
Jul-10	🟨	🟨	🟨	🟨	🟨	🟨
Aug-10	🟨	🟨	🟨	🟨	🟨	🟨
Sep-10	🟨	🟨	🟨	🟨	🟨	🟨
Oct-10	🟨	🟨	🟨	🟨	🟨	🟨
Nov-10	🟨	🟨	🟨	🟨	09-Nov-10 11:07	🟨
Dec-10	🟨	🟨	🟨	🟨	17-Dec-10 11:56	🟨
Jan-11	🟨	🟨	🟨	🟨	🟨	🟨
Feb-11	🟨	🟨	🟨	🟨	🟨	🟨
Mar-11	🟨	🟨	🟨	🟨	🟨	🟨
Apr-11	🟨	🟨	🟨	🟨	🟨	🟨
May-11	🟨	🟨	🟨	🟨	🟨	🟨
Jun-11	🟨	🟨	🟨	03-Jun-11 11:58	🟨	🟨
Jul-11	🟨	🟨	🟨		🟨	🟨
Aug-11	🟨	🟨	🟨		🟨	🟨
Sep-11	🟨	🟨	🟨		🟨	🟨
Oct-11	🟨	🟨	🟨		🟨	🟨

1) Transducers 🟨 = available water level record
2) Date = last available time BEFORE data gap
3) Date = first available time AFTER data gap

2.3 Hydraulic Model Development

The complex interaction between Squamish River water level, CGS turbine discharge, and USRS flows made estimating water level using stage-discharge rating curves non-feasible. Therefore, a hydraulic model was used to estimate the water levels in the TC and LSRS. River2D is a two-dimensional, depth-averaged, finite element numerical model that was developed by the University of Alberta. The model has built-in capability for fish habitat evaluation studies based on the concepts developed by Leake (2004).

The use of the River2D model for this project involved three programs: R2D_Bed, R2D_Mesh and River2D. These programs are typically used in succession. The normal modelling process would involve using R2D_Bed to create a preliminary bed topography file from the raw field data and then edit and refine the topography. The resulting bed topography file is imported into R2D_Mesh, where a computational mesh is draped over the topography to create it and then refined for computational stability. River2D is then used to solve for the water depths and velocities throughout the discretized mesh.

The River2D model consists of two analysis modes: steady-state analysis and transient analysis (also known as unsteady state analysis). Steady-state modelling does not account for the change of variables (e.g., flow velocity and depth) over time, and assumes that the parameters that govern the physical processes are constant during the simulation period. Transient analysis allows dynamic simulation of temporally variable physical processes. A dynamic solution is required if the boundary conditions vary considerably with time. Since the evaluation of fish habitat presented in this study is based on the estimated change in water level during the CGS turbine ramp-downs, the River2D transient analysis was used for the model run. The steady-state analysis was used for the calibration of model parameters.

The following tasks were carried out in the development of the River2D model:

1) Develop channel bed file and model mesh file based on the available bathymetric data;
2) Establish model boundary conditions using the available flow and water level records described in Section 2.2.2 and 2.2.3; and
3) Calibration and validation of model parameters by comparing modelled water levels to that of the available data.

These steps are described in more detail in the following sections.

2.3.1 Bathymetry Development

2.3.1.1 R2D_Bed

R2D_Bed was designed for editing bed topography data. Accurate representation of the physical features of the river channel bed is a crucial component in river flow modelling. To develop the model bed file, the model bathymetry was based on the 19 surveyed cross-sections as discussed in Section 2.2.1. These cross-sections span over a reach of approximately 1.5 km, with the distance between them varying between 7 m and 250 m.

In additional to the 19 surveyed cross-sections, additional interpolated sections were generated to smooth the cross-sectional transition. The purpose of the interpolated sections was to add details related to the channel width and bank positions inferred from aerial photographs and to reduce the abrupt change in cross-sectional flow area in the model bathymetry that may result in computational instability. Two models, HEC-RAS (developed by US Army Corps of Engineers) and Mike 11 (developed by DHI Software), were used to create the interpolated bathymetry.

Typically, linear interpolation ignores the spatial trend by weighting point data equally based on distance from the interpolated value. However, for the purpose of establishing the bathymetry between the surveyed cross-sections in this project, the linear interpolation was manually guided along the direction of the spatial trend (i.e., flow direction of the tailrace channel). Between each surveyed cross-section, the interpolated bank contours were also manually adjusted to follow the shape of the bank limits visible from available aerial photographs and large scale mapping. In some areas, it was necessary to raise the banks artificially, as River2D model requires the modelled flow to be within the confines of the modelled bathymetry. The interpolated bathymetry was extracted into nodes using a 0.5 m x 0.5 m raster and imported into a R2D_Bed file.

In addition to the nodal information, the model also requires input for bed resistance. River2D uses bed roughness height, K_s, a parameter calculated from Manning's roughness, n, and hydraulic radius, R, which was approximated by the flow depth to the free surface in two-dimensional open channel flow (Steffler 2002). For the TC and LSRS, an initial roughness height was assigned for the channel based on field observations and then calibrated using water level records. The roughness height calibration is discussed in Section 2.3.3.

2.3.1.2 R2D_Mesh

The R2D_Mesh program is used for the development of a computational mesh for input to River2D. The bed file prepared using R2D_Bed was used as an input to R2D_Mesh to generate mesh for the River2D model.

The final finite element mesh for modelling the study area had the following characteristics:

- The bank boundary nodes had a fine enough resolution to ensure that the resulting boundary elements follow the banks as closely as practical;
- Relatively small element sizes (about 2 m by 2 m) were used in the areas near the upstream and downstream boundary, and in areas with large velocity change and rapid elevation change (e.g., steep banks); and
- Relatively larger element sizes (about 5 m by 5 m) were used in the areas where flow velocity varied gradually.

In addition, the mesh sizes were based on the following criteria, to achieve a balance between model computational efficiency and model accuracy:

- A minimum of 8 to 10 mesh elements across the channel;
- A minimum of 20 mesh elements near the model open boundaries;
- Relatively smooth transition between meshes of different size (i.e., no abrupt size change between neighbouring meshes); and
- A minimum mesh Quality Index of 0.3. The mesh quality is a parameter that is related to model computation efficiency. It is defined as the ratio of triangle area to circumcircle area (the circle which passes through the three points defining the triangle) normalized to the corresponding ratio for an equilateral triangle.

The final finite element mesh used in the River2D model has a total of 10,881 nodes and 20,295 triangular elements for simulating the conditions in the TC and LSRS.

2.3.2 Model Boundary conditions

Boundary conditions were required in River2D to model the TC and LSRS water levels. In this project, the left and right banks along the TC and LSRS were treated as no-flow boundaries. The upstream and downstream boundary was set to be approximately 50 m downstream of CGS, and approximately 150 m upstream of the LSRS and Squamish River confluence, respectively. The works involved in establishing the upstream and downstream boundary conditions are discussed in the following sections.

2.3.2.1 Upstream Boundary conditions

The upstream boundary conditions for the River2D model were estimated using the CGS hourly turbine discharge records and the estimated flows from the USRS and High Falls Creek. As noted in Section 2.1.2, manual flow measurements were taken at High Falls Creek and a section of the USRS. Eight flow measurements taken from each site during the various site visits. These data were used to inform and bound the development of a relationship between the Squamish River flow and flows in the USRS.

To estimate the USRS flow, a generalized relationship between the USRS flow and the Squamish River water level at Ashlu Bridge was established. This involved adjusting the contribution of flow from the USRS under specifically selected Squamish River water level conditions until the TC and LSRS modelled water levels were close to the observed water levels. This task was performed as a part of model calibration, discussed in more detail in Section 2.3.3.2.

To estimate the flow contribution from High Falls Creek, a regional analysis was carried out using nearby gauged watersheds. After reviewing the available gauged watersheds near the project area, Water Survey of Canada (WSC) Mashiter Creek hydrometric station near Squamish (8GA057) was selected as a representative hydrometric station. Mashiter Creek is located approximately 26 km southeast of High Falls Creek and has similar watershed area and mean basin elevation to that of High Falls Creek, as shown in Table 2.

Table 2: Regional Analysis to Establish Normal Annual Flow for High Falls Creek

Stream Name	Period of Record	Watershed Area (km^2)	Mean Basin Elevation (m)	Mean Annual Precipitation (mm)
Mashiter Creek near Squamish River (WSC #8GA057)	1966 to 1981	38.9	1,150	2,149
High Falls Creek	n/a	30.5 (estimated)	1,100 (estimated)	n/a

n/a = Not applicable

Based on Mashiter Creek's mean annual flow and monthly flow distribution from the BC Streamflow Inventory (Coulson, 1998), the watershed areal transfer methodology was used to estimate the mean annual flow and the monthly average flow of High Falls Creek, as shown in Table 3.

Table 3: Estimated Mean Annual Flow and Monthly Flow for High Falls Creek

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean Annual
Flow (m^3/s)	1.8	1.8	1.8	1.8	3.1	3.6	2.3	1.3	1.0	2.3	2.6	2.3	2.1

The above monthly flow from High Falls Creek, combined with the USRS flows in Section 2.3.3.2 that varies with the Squamish River water level, and the CGS flows, form the upstream boundary conditions.

2.3.2.2 Downstream Boundary conditions

The downstream boundary conditions were estimated using the water level record from Squamish River at Ashlu Bridge. This water level record was collected approximately 800 m downstream of the mouth of the LSRS.

The River2D model's downstream boundary is approximately 150 m upstream of the LSRS and Squamish River confluence (Stage Recording Station #1). The Ashlu Bridge water level records were transferred to this location. The transfer of the water level between the two locations was based on the concurrent records at Squamish River at Ashlu Bridge, and at the Stage Recording Station #1.

The water level at Stage Recording Station #1 is not only dependent on the water level at Squamish River at Ashlu Bridge, it is also dependent on the flows in the LSRS. In the LSRS, the CGS turbine discharge is typically the most dominant flow, compared to that of the USRS and High Falls Creek. Therefore, when the water levels from Stage Recording Station #1 and Squamish River at Ashlu Bridge were plotted, three distinctive curves were observed as shown in Chart 1. The three curves correspond to the three dominant CGS turbine discharge modes, estimated to be approximately 55 m^3/s, 25 m^3/s, and no flow.

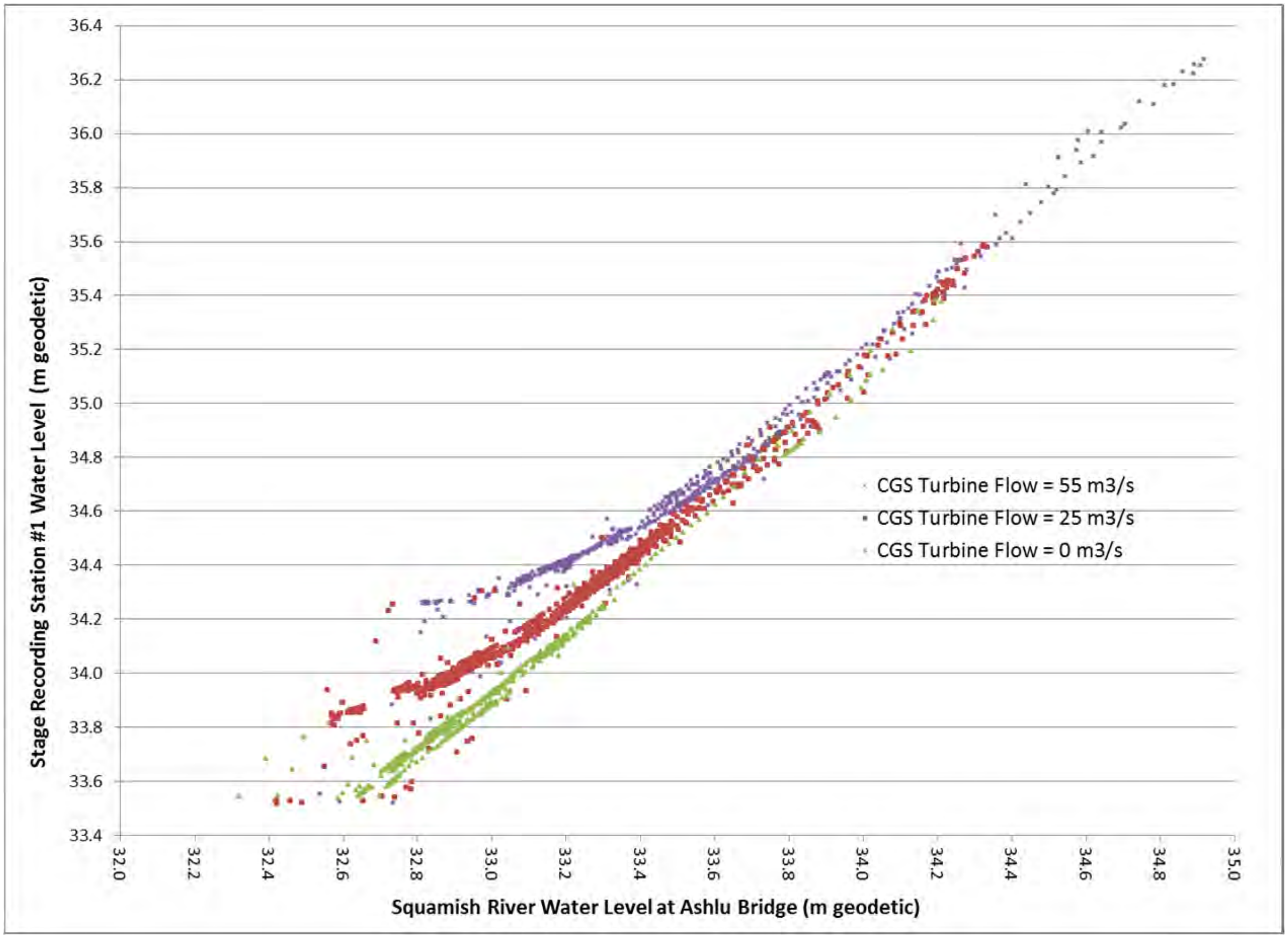

Chart 1: Squamish River water level at Ashlu Bridge versus Stage Recording Station #1 water level (2008 dataset)

Based on the observed relationships in Chart 1, the hourly water level at Stage Recording Station #1 was estimated using the 2008 and 2009 Squamish River water level at Ashlu Bridge. Due to the elevation of the Stage Recording Station #1 pressure transducers, water level record below 33.5 m was not readable (i.e., the water level is below the transducers). Therefore, below this elevation, the water level relationship between Stage Recording Station #1 and Squamish River at Ashlu Bridge was extrapolated. Using the relationship in Chart 1 and the aforementioned extrapolation, the average absolute error of the transferred water level in 2008 and 2009 was approximately 0.06 m, validating the suitability of this approach. Therefore, the water level transfer approach was used to establish the model's downstream boundary conditions corresponding to the modelled range of Squamish River water levels and CGS flows.

2.3.3 Model Calibration

The model was calibrated to minimize the difference between the modelled water levels and the water levels observed at the Stage Recording Stations in the TC and LSRS. The bed roughness height and the USRS flows were the primary calibration variables and are discussed in the next sections.

2.3.3.1 Bed Roughness Height

River2D uses bed roughness height, K_s, to represent the bed resistance. K_s was calculated from Manning's roughness, n, and hydraulic radius approximated by the flow depth (Steffler 2002).

The calibration of K_s started with an initial estimated average flow depth and Manning's n, based on site observations of bed material size and channel geometry. River2D steady-state analysis was performed using CGS discharge records and the corresponding Squamish River water level records at Ashlu Bridge. This was performed during periods where there was no significant fluctuation in either the CGS discharge or the Squamish River water level allowing steady state modelling to be used. The bed roughness was adjusted to minimize the difference between the modelled and the observed water levels at Stage Recording Stations #2 and #3. It was observed that the under most conditions the modelled water levels at Stage Recording Stations #2 and #3 were not very sensitive to the change in bed roughness height. Based on the calibration works, two roughness heights were used in the model. A roughness height of 0.21 m was applied for the upstream half of the model domain (i.e., the TC and LSRS), and a roughness height of 0.43 m was applied for the downstream half of the model domain.

2.3.3.2 USRS Flow

The USRS was anecdotally known to have significant flows during periods of high Squamish River water level. The first step undertaken was to establish a stage-discharge relationship between the USRS flow and the Squamish River water level at Ashlu Bridge. It was necessary to isolate the flow contribution from High Falls Creek, however, and High Falls Creek flows are independent of the Squamish River water level. High Falls Creek flow is dominated by surface runoff in response of precipitation events. In order to minimize the influence of High Falls Creek from the contribution from the Squamish River, the initial calibration of the USRS flow was completed for periods when low precipitation was recorded. The selected periods for USRS calibration were the month of August. The High Falls Creek contribution was assigned the monthly average August flow based on the regional analysis in Section 2.3.2.1.

The relationship between the USRS flow and Squamish River water level at Ashlu Bridge was determined iteratively. Various CGS turbine discharges and Squamish River water levels were used for the calibration work. After the initial bed roughness height calibration, the USRS flow was adjusted to minimize the difference between the modelled and observed water levels at Stage Recording Stations #2 and #3.

The result of the calibration is plotted in Chart 2, with the x-axis being the LSRS flows and the y-axis being the water level at the Stage Recording Station #2 and Stage Recording Station #3. Based on the calibration runs, the variation between the modelled and observed water level at Stage Recording Station #2 is between -0.14 to 0.25 (total range of 0.39 m), and the variation between the modelled and observed water level at Stage Recording Station #3 is between -0.22 to 0.09 (total range of 0.31 m).

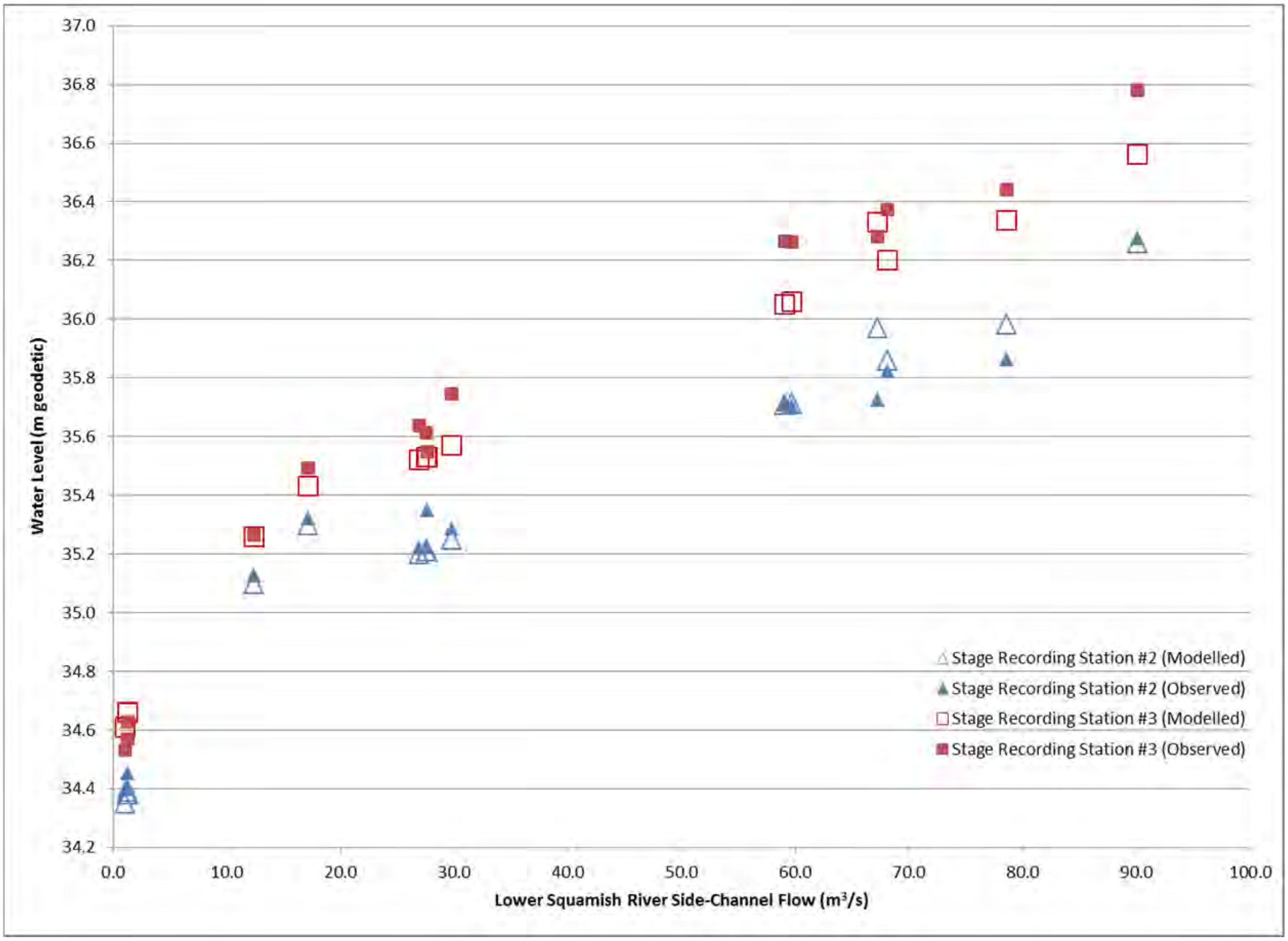

Chart 2: Model Calibration Results

2.4 Hydraulic Modelling Scenarios

The terms of reference for this study included performing River2D transient analysis using 40 years of simulated CGS turbine release and Squamish water level data. This approach was later determined to be ineffective for achieving the goal of the study, and also unfeasible due to the extremely long model computation time required. A scenario-based modelling approach was proposed in which various scenarios would be created to represent the current CGS ramp-down discharge protocols and the anticipated range of Squamish River water levels. In total, 60 modelling scenarios were developed for this study, based on the observation of the existing data that yielded 3 modes of CGS ramp-down rates and 20 categories of Squamish River flows and associated water levels.

Three generalized turbine ramp-down discharge modes were observed from the recorded hourly CGS turbine discharge records:

- 55-0 m^3/s;
- 25-0 m^3/s; and
- 55-25 m^3/s.

For each of the three ramp-down modes, over 50 random samples of ramp-down events were taken from the CGS hourly discharge records between 2004 and 2011. From these samples, the ramp-down event with the fastest rate of change was selected as a conservative representation for each of the three ramp-down modes; they are: 40.1 m^3/s/hour, 21.4 m^3/s/hour, and 25.8 m^3/s/hour for the 55-0 m^3/s, 25-0 m^3/s, and 55-25 m^3/s modes, respectively. It was also observed that the most significant rate of water level change occurred within the first hour of the ramp-down. The study focused on water level changes within the first hour of each ramp-down, as this was considered the critical period. It was noted that the definition of the critical boundary conditions were limited by the temporal resolution of the CGS flow provided, which was hourly.

The Squamish River water level records at Ashlu Bridge between 2004 and 2011 were reviewed. The maximum range of water level fluctuation observed during this period was 3.8 m, between the geodetic elevation of 32.0 m and 35.8 m. This range was divided into 20 bins of 0.2 m intervals, from 32.0 m to 36.0 m.

The size of the mesh elements and the anticipated flow speed within the modelled system influence the selection of the time step of the model. In this study, the time step was selected to be 50 seconds.

2.5 Simulated Stranding Threshold

To link the modelled results to scenarios that have the potential for fish stranding, a threshold rate of water level change associated with potential fish stranding events was estimated based on the reviewed fish stranding observations at 12 assessments sites.

As shown in Table 6 (Section 2.9.1), fish assessment field visits were carried out between September 2008 and December 2009, with a total of 20 visits. Twelve potential stranding assessment sites were identified along the TC as shown in Figure 1. Stranding was observed during 6 of the site visits, as shown in Table 10 (Section 3.1.4).

Based on the field visit records, fish stranding was observed during 55-0 m^3/s ramp-down and the 25-0 m^3/s ramp-down. For each of these ramp-down modes, the downstream boundary conditions (Squamish River water levels at Ashlu Bridge) corresponding to the fish stranding observations were plotted against the assessment site number as shown in Chart 3 and Chart 4. River2D model was then run using the corresponding boundary conditions, and the resulting rates of water level change at each observation site were reviewed. The slowest rate of water level change which resulted in stranding was selected as a conservative threshold to represent a potentially fish-stranding condition in the TC and LSRS. These results indicated that a rate of water level change (i.e., water level drop) of 0.36 m or more per hour had the potential to result in stranding conditions.

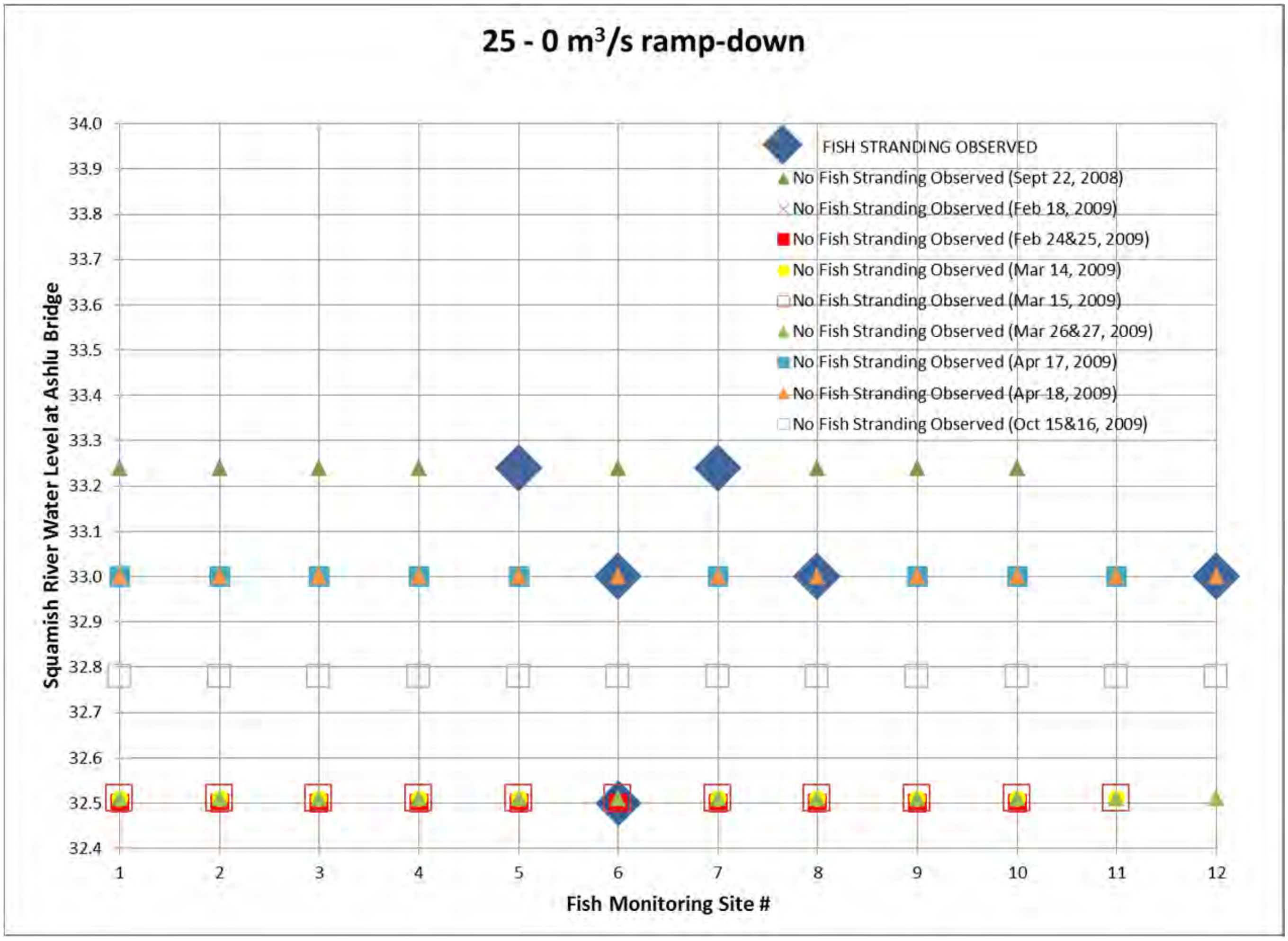

Chart 3: Fish stranding observation results, 25-0 m^3/s ramp-down.

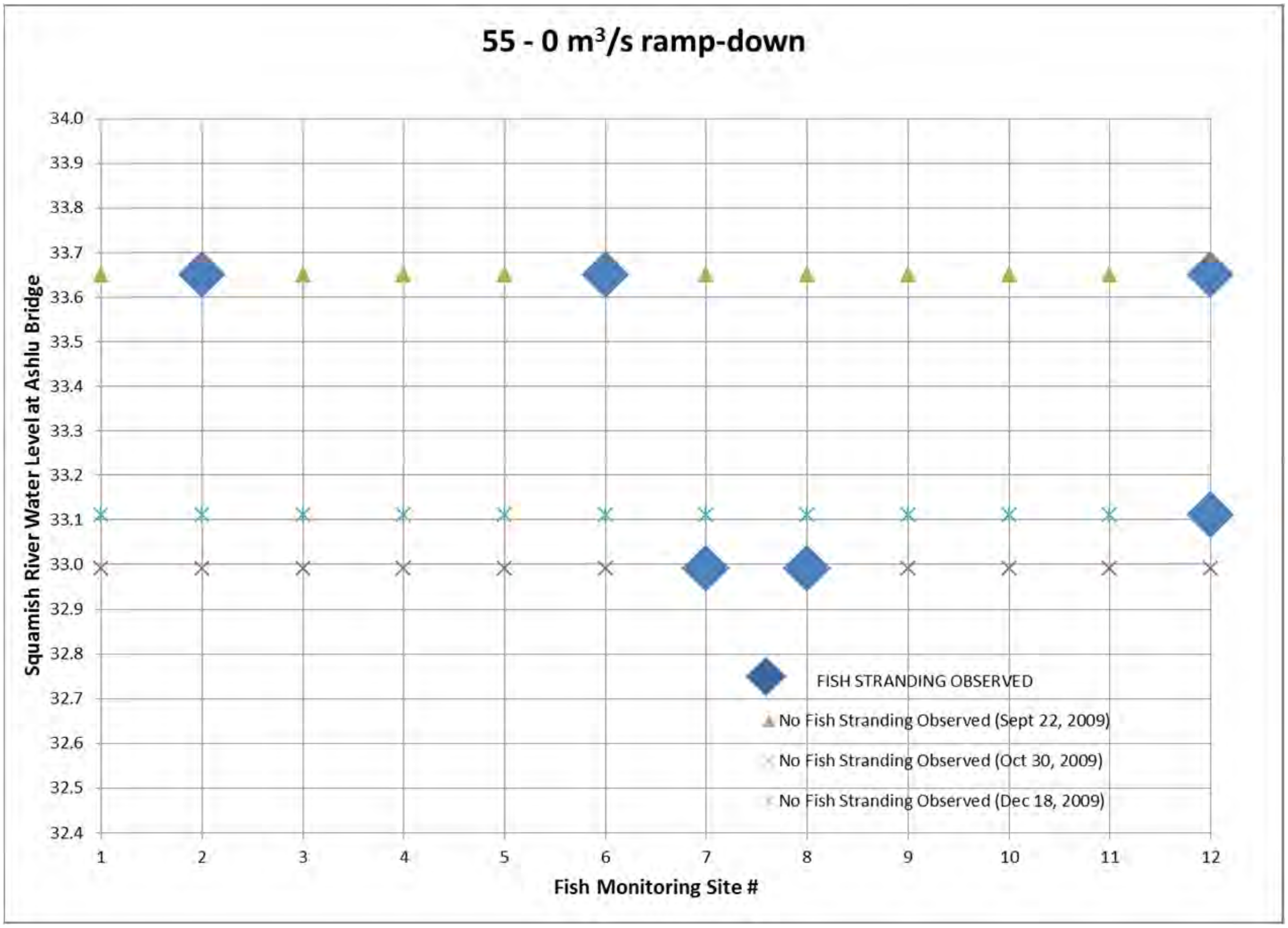

Chart 4: Fish stranding observation results, 55-0 m^3/s ramp-down.

2.6 Hydraulic Model Interpretation

Using threshold rate established in Section 2.5, the relative significance of the potential risk for fish stranding water inferred for each of the 60 modelled scenarios. In each model scenario, the model mesh elements that dried during the first hour of the ramp-down were flagged. Flagged elements with a water level drop that met or exceeded the threshold value (i.e., 0.36 m/hour) were identified, and the areas of these elements were summed. The relative significance of stranding for each scenario was estimated by comparing the areal sums of the identified elements, hereafter referred to as the area of potential stranding risk. The results are shown and discussed in Section 3.3.

2.7 Information Review

Stranding in the CGS TC and LSRS has been examined in previous studies (*e.g.,* Melville 2002; Troffe and Melville 2004; Tantalus Consulting and Geostreams Consulting 2005; Sigma 1996). This information was reviewed and the results synthesized to form the basis for developing sampling and monitoring protocols that were used to collect the required data to address the management questions of this Monitor.

2.8 Fish Sampling Site Selection

The locations of the sampling sites were determined from previous similar studies conducted within the TC and LSRS (Troffe and Melville 2004). Additional sites were selected within the TC (Site 10) and in the LSRS (Site 11 and Site 12) to better represent the different habitat conditions in the channels. Selection of these sites was based upon the suitability of the habitat for fish use, accessibility, and location along the channel. Locations sampled during the fisheries assessment of this Monitor are shown in Figure 1 and in Appendix A (Photographs 1 to 24) and described in Table 4.

Table 4: Sampling locations in the BC Hydro Cheakamus Generating Station Tailrace Channel and the Squamish River Side-channel.

Site #	Description[1]	Site Type[2]	GPS Location	Photograph # (Appendix A)
1	Glide/pool directly by outlet of generator 1, CB/BO substrate, RR/OV cover, RR/CB bank	Tailrace, LUB	10U 479079, 5531295	1
2	Glide/pool between Site 1 and bridge, CB/BO substrate, RR/OV cover, RR bank	Tailrace, LUB	10U 479074, 5531832	2
3	Pool directly by outlet of generator 2, CB/BO substrate, RR/OV cover, CB/BO bank	Tailrace, RUB	10U 479111, 5531264	3,5
4	Glide between Site 3 and bridge, GR/BO substrate, RR/OV cover, BO/O,CB,GR bank	Tailrace, RUB	10U 479065, 5531251	4,5
5	Glide immediately downstream of bridge, CB/GR/BO substrate, BO/OV cover, CB/GR bank	Tailrace, LUB	10U 479035, 5531224	6,7,8,9
6	Glide/pool downstream of Site 5, O substrate, LOD/OV cover, O bank	Tailrace, LUB	10U 479004, 5531139	10
7	Glide at confluence of side channel and tailrace, S/LOD substrate, LOD cover, S/LOD bank	Tailrace, LUB	10U 479000, 5531054	11, 12
8	Pool/glide across from Shop 2, GR/LOD substrate, GR/LOD cover, O bank	Side-channel, RUB	10U 479054, 5530523	13, 14
9	Glide/pool upstream from confluence with Squamish River mainstem, GR/CB/O/S substrate, LOD/pool cover, GR/CB,O,S bank	Side-channel, RUB	10U 478989, 5530052	15, 16,
10	Glide immediately downstream of bridge, GR substrate, GR/OV cover, CB/BO,GR bank	Tailrace, RUB	10U 479042, 5537200	17, 18
11	220m upstream of Site 8, GR/CB,S substrate, LOD/BO cover, O/OV bank	Side-channel, RUB	10U 479035, 9530779	19,20,21,22
12	35m downstream of side channel and tailrace confluence, GR/CO,S substrate, LOD/OV,CB cover CB/BO,O bank	Side-channel, LUB	10U 479016, 5530908	23, 24

1) BO=boulder; CB=cobble; GR=gravel; LOD=large organic debris; O=organics; OV=overhanging vegetation; RR=rip-rap; S=silt.
2) LUB=left upstream bank; RUB=right upstream bank.

The boundaries of the TC and LSRS were consistent with previous studies (Troffe and Melville 2004) based on the site locations along the channel. Sites located upstream of the TC and LSRS confluence were identified as being within the TC and those sites located downstream of the confluence were identified as being within the SRS. Defining the TC and LSRS sections allows comparison between these two sections to determine if differences in general channel morphology, channel in-flows, and instream and stream-bank habitat characteristics influence water quality parameters and fish use and presence in the TC and LSRS. The sampling sites comprising the TC and LSRS are presented in Table 5.

Table 5: Tailrace Channel and Lower Squamish River Side-channel fish sampling sites.

	Tailrace Channel	Lower Squamish River Side-channel
Site ID #	1, 2, 3, 4, 5, 6, 10	7, 8, 9, 11, 12

2.9 Fish Survey and Capture

2.9.1 Fish Use Assessments and Juvenile Colonization Surveys

BC Hydro's TOR suggested conducting juvenile fish use assessments by on-shore visual observations. Visual Observations (VO) were conducted for the first two surveys (Table 6: September 22 and November 17, 2008) to assess juvenile fish use in the TC and LSRS; however, this method proved to be of limited use for surveying juvenile fish due to poor water clarity and visibility limitations, difficult access to shoreline areas, and variable flows, so other methods needed to be explored. Visual observations were conducted on an *ad hoc* basis in Year 1 of the Monitor when site conditions proved suitable. In Year 2, there was an attempt to schedule VO and stranding surveys primarily when water flows were low following high flow events and when water clarity was suitable for observing juvenile fish.

Other sampling methods for fish were explored in Year 1 and consisted of minnow trapping (MT), beach seining (BS), snorkel surveys (SS), and dip-netting (DN). Electrofishing (EF) was also considered but all permit applications made to Fisheries and Oceans Canada (DFO) requesting electrofishing as a method were declined due to concerns over potential impacts to other life stages (e.g*.,* eggs in redds). Visual observation was deemed more appropriate for adult surveys within limitations of flow and water clarity. While an effort was made to maintain consistency in the methods used over all survey dates, some deviations were necessary which reflected changes in the CGS's level of operation, and the water flow within the TC and LSRS. Of the sampling methods employed in Year 1 it was determined MT and VO were the most effective: These methods were employed through Year 2 whereas BS, SS, DN, and EF were abandoned as sampling options. Sampling dates and methods, operation of the CGS, and channel flow conditions during the fish assessment are presented in Table 6.

Fish assessment surveys were conducted by the Squamish Nation and Golder.

Table 6: Summary of sampling dates, Generating Station operation, flow conditions, and sampling methods.

Field Visit	Date	Season	Gen Stn Operation	Flow Condition		Method[1]				
				Day	Night	VO	MT	SS	BS	DN
1	Sept 22/2008	Fall	Operating	Low	N/A	Y				
2	Nov 17/2008	Fall	Operating	High	N/A	Y				
3	Feb 18/2009	Winter	Lock-out	Low	N/A		Y	Y		
4	Feb 24-25/2009	Winter	Lock-out	Low	Low		Y		Y	
5	Mar 14-15/2009	Winter	Lock-out	Low	Variable		Y	Y	Y	
6	Mar 26-27/2009	Winter	Lock-out	Low	Low		Y	Y	Y	
7	Apr 17-18/2009	Spring	Lock-out	Low	Low	Y	Y	Y	Y	
8	May 6-7/2009	Spring	Must-run	High	Variable	Y	Y	Y		
9	May 20-21/2009	Spring	Must-run	High	Variable	Y	Y	Y		
10	June 3-4/2009	Summer	Must-run	High	High	Y	Y			Y
11	July 21-22/2009	Summer	Must-run	High	High	Y	Y			
12	Aug 6-7/2009	Summer	Must-run	High	High	Y	Y			Y
13	Aug 20-21/2009	Summer	Must-run	High	High	Y	Y			Y
14	Sept 16/2009	Summer	Must-run	High	N/A	Y				
15	Sept 22/2009	Fall	Lock-out	Low	N/A	Y				
16	Oct 2-3/2009	Fall	Partial-run	Low	Low	Y	Y			
17	Oct 15-16/2009	Fall	Lock-out	Medium	Medium	Y	Y			
18	Oct 30/2009	Fall	Lock-out	Medium	N/A	Y				
19	Nov 17-18/2009	Winter	Must-run	High	High	Y	Y			
20	Dec 18/2009	Winter	Lock-out	Medium	N/A	Y				

1) VO=visual observation; MT=minnow trap; SS=snorkel survey; BS=beach seine; DN=dip net

2.9.1.1 Minnow Trap

Minnow traps were employed as a fish sampling method during Year 1 site visits conducted from February to June 2009 and Year 2 site visits conducted from July to December 2009. Minnow traps were placed along the banks of the TC and LSRS within both shallow and deep areas of the sampling sites (e.g., Appendix A; Photograph 1). Minnow traps were baited with procured trout roe placed in perforated zip-lock bags and individually secured to a line anchored at a fixed location on the bank. Minnow trapping methods were based off of those outlined in Conlin and Tutty (1979).

Two to four MTs were set at each of the twelve sampling sites during low flows in the TC and LSRS while the CGS Units were under a lock-out. Minnow traps were set in these conditions to determine juvenile fish presence and use within the channels at low flow. When both CGS Units were operating at full discharge, under a “must-run,” sampling with MT was conducted at only eight sites: Sites 1, 2, 3, and 4, between the CGS and the Forest Service Road bridge, were avoided during a “must-run” due to BC Hydro Health and Safety Regulations concerning Safe Work Procedures in the TC. The purpose of setting MT at high flows was to gather information related to fish presence and use in recently and intermittently wetted areas.

Minnow traps were predominantly deployed overnight except for Site Visit 3, (February 18, 2009) when they were deployed in the morning and retrieved at the end of the sampling day, and during Site Visits 8 and 9 (May 6-7 and 20-21, 2009) where unexpected decreases in CGS flows necessitated pulling and resetting of some of the MTs.

2.9.1.2 Beach Seine

A BS was used in Year 1 to assess fish use of the TC and LSRS by adult and juvenile fish. The 8 m BS was used to sample along the near-shore and centre-channel habitats of the TC and LSRS. Near-shore and centre-channel habitats were sampled by pulling the BS out perpendicular to shore to a maximum wading depth (approximately 1.2 m) and seining downstream and back to shore in an arch where the BS was pursed and gathered up on shore (Appendix A, Photograph 25). Once beached the BS was opened up to determine if fish had been entrained and, once any entrained fish had been collected, the BS was flipped to determine if there were fish which remained entrained under the net or beached along the shore. The BS methods were based on those present in the Resource Inventory Committee’s (RIC) Fish Collection Methods and Standards (1997). The BS was employed during low flows due to the availability of access to the TC and LSRS habitats. During high flows both the effectiveness of the BS and the safety of the crew became issues that precluded use of the beach seining technique. Due to the challenge of deploying the BS under high flow conditions, and the relatively low catch-per-unit-effort, the BS method was not employed in Year 2 of the fish assessment.

2.9.1.3 Snorkel Survey

Snorkel surveys were conducted during site visits in Year 1 to make visual estimates of fish numbers along sampling sites in the TC and LSRS (Appendix A, Photograph 26). Selection of sites where SSs were conducted was based upon the level of flow at each particular site, and as such, some sites rarely had SSs conducted due to consistently low flow and suitable water levels. Prior to conducting each SS the sites were reviewed for hazards and potential risks, the routes and exit points planned and communicated, and a field staff member with throw-bags walked the shore slightly ahead of the snorkeler or waited at an agreed upon location downstream. Upon entering the water the snorkeler would note the visible distance through the water and proceeded downstream scanning side-to-side along the horizon and the bottom. The length of time and distance for each SS from commencement to completion was recorded by field staff on shore. Once the length of a site had been swum the snorkeler would exit the water and relay observations to field staff on shore. Snorkel surveys were conducted to assess fish use in the TC and LSRS by juvenile and adult fish and were not continued through Year 2 of the Monitor.

2.9.1.4 Dip Net

Dip netting was employed opportunistically at several sites during Site Visit 10 (June 3-4, 2009), Site Visit 12 (August 6-7, 2009) and Site Visit 13 (August 20-21, 2009) to collect juvenile fish that were clearly visible swimming near the surface of the TC.

2.9.2 Stranding Survey

Although BC Hydro's TOR stated that stranding surveys were to be conducted in Year 2 of the Monitor, periodic stranding surveys were conducted opportunistically in Year 1 immediately following and during partial and/or complete shut-down of the CGS while on site visits 1, 2, 7, and 8 (Table 6: Sept 22/08, Nov17/08, Apr 17-18/09, May 6-7/09), when water flows and clarity were suitable to visually observe juvenile fish. Stranding surveys were scheduled during Year 2 for site visits 14, 15, 18, and 20 (Table 6: Sept 16/09, Sept 22/09, Oct 30/09, Dec 18/09) primarily under lock-out conditions when flows had recently dropped.

Stranding surveys investigated dewatered areas throughout the sample sites for evidence of stranded fish by turning over rocks, checking underneath woody debris, and digging in and around shallow pools. Stranded fish were identified to species, counted, and their fork lengths measured. The habitat locations within each site where fish were observed were also identified and referred to as; bank, bar, isolated pool, pothole, shelf, and wetted channel. RIC (1998) methods were used to define these habitat locations as follows:

- **Bank** – Separated from wetted portion of TC and LSRS by presence of established vegetation and change in sediment texture and topography;
- **Bar** – Sediment deposit in the TC and LSRS that is generally larger than one particle diameter high or has lengths of the same order as the channel;
- **Isolated pool** – Wetted depression closed off from the main flow in the TC and LSRS with a depth to diameter ratio < 1:1;
- **Potholes** – Wetted depression in the TC and LSRS with a depth to diameter ratio of 1:1;
- **Shelf** – Distinct portion of TC and LSRS topography elevated from the thalweg channel; and
- **Wetted channel** – Areas within the TC and LSRS where water was continuous with main flow at the time of survey.

Any fish found alive during the stranding surveys were returned to the main-stem of the TC and LSRS after they were allowed to recover in a water-filled bucket.

2.9.3 Fish Processing

Juvenile fish captured by MT, BS, and DN methods were transferred and contained separately in a water-filled bucket for every haul or trap. Fish were placed anaesthetized (CO_2) on a fish measuring board and identified to the species level and their life stage estimated. Measurements of fish length were made to the nearest 1 mm fork length. Once processed, fish were placed in a second bucket and allowed to recover before being released in the location of their capture.

2.10 Fish Data Analysis

2.10.1 Data Management

Data were transferred from fish field cards and notes into an Access FDIS database developed by the BC Ministry of Environment (MoE) and excel spreadsheets developed by Golder. The Golder excel spreadsheets were used to determine the total numbers of fish observed and caught at each site, of each species, with each method and on each site visit. Excel was also used to calculate the catch per unit effort (CPUE) for each fish capture and survey method.

2.10.2 Catch per Unit Effort

Catch per unit effort was calculated to compare the level of effort required to capture fish under varying conditions and to be able to make comparisons between the TC and LSRS and between high and low flow conditions. CPUE was calculated for MT based upon the number of fish caught during the length of time in hours each trap was set (# fish/hour). CPUE was not calculated for the other methods employed due to limited success in capturing fish with those methods.

2.10.3 Stranding Risk

The Monitor aimed instead to provide an index of the number of fish that may become stranded under the various operational and seasonal conditions and the potential range of mortality that may occur to the fish or their eggs that are found in the area, using reasonable assumptions based on the literature, instead of determining the significance of stranding rates. This Monitor did not define the number of stranding fish deemed to be significant and therefore specific mitigation measures were not recommended to address fish stranding.

Stranding risk was estimated by comparing the number of fish found stranded to the number of fish observed within the study area to present a stranding index. This index is at best an indicator of stranding potential, given that numbers of fish found stranded and observed in the channels do not represent the entire number of fish both stranded and inhabiting channel habitats, and underestimates the actual numbers. However, the higher the ratio, the higher is the risk that stranding may impact the population. In the absence of abundance estimates using costly and intensive methods, such as telemetry, fence counts, or even mark/recapture, this index provides an inexpensive qualitative indicator as to the magnitude of stranding risk. However the index will have a high uncertainty due to potential biases, such as the ability to access the TC and LSRS to observe potential stranding correlating either positively or negatively with the variable hydraulic conditions which in turn may be associated with actual, and unobserved, increased or decreased stranding rates.

2.10.4 Data Comparisons

Box-whisker plots were used to compare CPUE values between low and high flows, and the TC and LSRS. These plots are useful when comparing groups of numerical data that have not been statistically analysed. The plots present the ranges of data collected, the mean, the median, and the range where 25% of the highest and lowest data are excluded.

2.11 Water Quality

Water quality measurements were recorded using a field multi-parameter instrument (YSI 556 MPS) at the sites within the TC and LSRS on each site visit of the fish assessment program. Meter measurements of water temperature and dissolved oxygen (DO) were recorded from the bank of the channel. Water quality measurements in isolated pools were limited primarily by a lack of observed isolated pools during low flow conditions in the TC and LSRS; shallow, isolated pools were only intermittently observed at Sites 8 and 12. These isolated pools are potentially areas of stranding risk to juvenile salmonids and smaller-sized adult fish, such as stickleback, based on low water levels and lack of suitable cover. Continuously monitoring temperature and DO in these isolated pools throughout a given field day was not logistically feasible due lack of time (field assessments needed to be conducted at the other 10 sites on the same day), and meeting health and safety requirements of BC Hydro operations (i.e., working within a set timeframe assigned by BC Hydro operations).

3.0 RESULTS

The following sections describe observations during Years 1 and 2 of the fish assessment and Years 1, 3 and 4 of the hydrological assessment, including the hydrological modelling, fish stranding surveys, and assessment of the management questions.

3.1 Fish Use Assessment

3.1.1 Fish Capture Methods

The number of fish captured and observed by each method on each site visit is shown in Table 7. Fish assessments were conducted by the VO method in Year 1 on the first two field visits (September 22 and November 17, 2008) and in Year 2 on field visits 14, 15, 18 and 20 (September 16, 22, October 30 and December 18, 2009). The September 22 field visits in both 2008 and 2009 were conducted during low flows whereas the field visits on October 30 and December 18, 2009 were conducted during medium flows and the November 17, 2008 and September 16, 2009 were conducted during high flows. Flows in the CGS TC and LSRS permitted safe use of the BS under low flow conditions at lock out during field visits 4, 5, 6, and 7 from February 24 to April 17, 2009. The most effective use of the BS method was limited to Sites 5, 6, 7, 8, 10, and 11. Over the course of these field visits there was a total of 14 fish successfully seined (Table 7). No fish were observed during any of the SS conducted either during low or high flow conditions. Snorkel surveys were not continued in Year 2 of the fish assessment.

Opportunistic use of DN was limited to occasions when fish were visible near the surface. This occurred only at Site 7 during Site Visit 10 on June 3-4, 2009, Site Visit 12 on August 6-7, 2009, and Site Visit 13 on August 20-21, 2009 when 62 unknown fry were observed and 1 Chinook fry was dip-netted, 3 Coho fry were observed and 1 dip-netted, and 1 Coho fry was observed and dip-netted, respectively.

The MTs were able to capture fish during all the site visits. They were used (at high and low flows) when no fish were captured/observed using the BS, DN or SS methods (Table 7).

Table 7: Total number of fish captured/observed (all species and life stages) by the different methods at each site for each field visit.

Field Visit	Date	Method	Site												
			1	2	3	4	5	6	7	8	9	10	11	12	All Sites
1	Sept 22/2008	VO	4	1	51	2	7	1	5	0	0	2	n/a[1]	n/a	73
2	Nov 17/2008	VO	0	0	0	0	0	0	5	0	0	0	n/a	n/a	5
3	Feb 18/2009	MT	0	0	2	0	0	0	0	0	1	0	n/a	n/a	3
		SS	n/a	n/a	n/a	n/a	0	0	n/a	n/a	n/a	0	n/a	n/a	0
4	Feb 24-25/2009	MT	3	3	3	11	1	4	4	7	2	0	n/a	n/a	38
		BS	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0	n/a	n/a	n/a	n/a	0
5	Mar 14-15/2009	VO	n/a	n/a	n/a	n/a	n/a	1	2	n/a	n/a	n/a	n/a	n/a	3
		MT	1	4	4	3	3	2	4	12	0	1	42	n/a	76
		SS	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0	n/a	n/a	0	n/a	0
		BS	n/a	n/a	n/a	n/a	1	0	2	0	n/a	0	1	n/a	4
6	Mar 26-27/2009	MT	1	5	1	4	1	3	1	2	0	2	3	27	50
		SS	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0	n/a	n/a	0	0	0
		BS	n/a	n/a	n/a	n/a	n/a	n/a	4	0	n/a	0	2	n/a	6
7	Apr 17-18/2009	VO	0	0	0	0	0	1	0	1	1	0	0	2	5
		MT	0	2	7	0	0	2	1	6	0	2	11	1	32
		SS	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0	n/a	n/a	0	n/a	0
		BS	n/a	n/a	n/a	n/a	n/a	n/a	2	1	n/a	n/a	1	n/a	4
8	May 6-7/2009	VO	n/a	n/a	n/a	n/a	0	0	0	0	0	0	0	0	0
8	May 6-7/2009	MT	n/a	n/a	n/a	n/a	5	0	1	0	0	0	0	0	6
		SS	n/a	n/a	n/a	n/a	0	n/a	n/a	0	n/a	n/a	n/a	n/a	0
9	May 20-21/2009	VO	n/a	n/a	n/a	n/a	0	0	0	0	0	0	0	0	0
		MT	n/a	n/a	n/a	n/a	0	0	0	0	0	2	0	0	2
		SS	n/a	n/a	n/a	n/a	0	0	0	0	n/a	n/a	n/a	n/a	0
10	June 3-4/2009	VO	n/a	n/a	n/a	n/a	2	0	62	0	0	0	0	0	64
		MT	n/a	n/a	n/a	n/a	1	0	0	2	0	1	1	0	5

Field Visit	Date	Method	Site												
			1	2	3	4	5	6	7	8	9	10	11	12	All Sites
		DN	n/a	n/a	n/a	n/a	n/a	n/a	1	n/a	n/a	n/a	n/a	n/a	1
11	July 21-22/2009	VO	n/a	n/a	n/a	n/a	0	0	0	0	0	0	0	0	0
		MT	n/a	n/a	n/a	n/a	1	6	1	2	1	2	0	0	13
12	Aug 6-7/2009	VO	n/a	n/a	n/a	n/a	0	0	3	0	0	1	0	0	4
		MT	n/a	n/a	n/a	n/a	1	0	0	1	4	6	0	3	15
		DN	n/a	n/a	n/a	n/a	n/a	n/a	1	n/a	n/a	n/a	n/a	n/a	1
13	Aug 20-21/2009	VO	n/a	n/a	n/a	n/a	0	0	2	0	0	0	0	0	2
		MT	n/a	n/a	n/a	n/a	0	0	1	4	2	0	0	8	15
		DN	n/a	n/a	n/a	n/a	n/a	n/a	1	n/a	n/a	n/a	n/a	n/a	1
14	Sept 16/2009	VO	0	0	0	0	1	0	3	0	1	0	0	0	5
15	Sept 22/2009	VO	1	1	0	1	0	1	11	5	0	6	12	27	65
16	Oct 2-3/2009	VO	n/a	n/a	n/a	n/a	1	0	1	1	2	0	1	0	6
		MT	n/a	n/a	n/a	n/a	14	53	28	5	1	9	9	2	121
17	Oct 15-16/2009	VO	1	1	2	3	3	0	0	4	0	1	4	2	21
		MT	7	7	18	14	5	8	3	10	3	11	15	6	107
18	Oct 30/2009	VO	0	0	0	0	0	0	3	5	0	0	0	2	10
19	Nov 17-18/2009	VO	n/a	n/a	n/a	n/a	0	0	0	0	0	0	0	0	0
		MT	n/a	n/a	n/a	n/a	8	19	3	1	1	10	4	1	47
20	Dec 18/2009	VO	0	0	0	0	0	0	0	0	0	0	0	2	2
All Field Visits		**All**	18	24	88	38	55	101	155	69	19	56	106	83	812

1) “n/a” indicates no sampling occurred.

3.1.2 Fish Abundance

Over the course of twenty field visits, conducted from September 22, 2008 to December 18, 2009, eight different fish species were captured and/or observed (Table 8) in the TC and LSRS. The numbers of fish species shown were collected using all methods employed during a field visit. Of the eight fish species listed there were six species of salmonids: Coho Salmon (*Oncorhynchus kisutch*), Chinook Salmon (*Oncorhynchus tshawytscha*), Chum Salmon (*Oncorhynchus keta*), Pink Salmon (*Oncorhynchus gorbuscha*), Rainbow Trout (*Oncorhynchus myskiss*), and Dolly Varden (*Salvelinus malma*) (Appendix A, Photographs 27 - 31). The two other fish identified were sculpin (*Cottus sp.*) and Threespine Stickleback (*Gasterosteus aculeatus*). The majority of the fish observed were Coho Salmon, which made up roughly half of the recorded fish (48%, 393 individuals), whereas Chum made up the least number of fish (1%, 10 individuals).

Table 8 presents the eight species of fish observed over Year's 1 and 2 of the fish assessment and their age class stages observed in the CGS TC and LSRS. Adult Chinook, Coho, Pink, and Chum Salmon, and resident adult trout (Dolly Varden, Rainbow Trout) were primarily observed in the fall (based on eight sampling events from September to November in 2008 and 2009). Juvenile salmon (Chinook and Coho), and juvenile and adult resident species (Dolly Varden, Rainbow Trout, sculpin, Threespine Stickleback) were observed during every season, with winter providing the least number captured/observed. The majority of individuals identified were juveniles, roughly two-thirds, being either fry or parr.

Observations of moving and jumping salmon adults were often unable to be positively identified by species or accurately counted. This was a result of often a combination of factors: turbid waters; deep, fast flowing water; indirect sighting on surfacing fish; and, distance from observer to fish. Table 9 below documents the number of observed "fin" and "roll" events counted and salmon unable to be positively identified during the fin or roll were recorded as "unknown salmon."

Table 8: Age class of documented fish in the CGS Tailrace Channel and Squamish River Side-channel.

Season	**Age Class**	**Species**									**CGS Tailrace Water Level**
		CO	**CH**	**CM**	**PK**	**UNSA**	**RB**	**DV**	**CC**	**TSB**	
Fall 2008	Fry / Parr	54	2								Low, high
	Adults			1		3	9	8	1		
Winter 2008/2009	Fry	29	1						3		Low
	Parr										
	Adult								7	1	
Spring 2009	Fry	120	16			2	3		5		High
	Parr						5	2			
	Adult								16	19	
Summer 2009	Fry	24	8			66					High
	Parr						4	3			
	Adult								9	7	

Season	Age Class	Species									CGS Tailrace Water Level
		CO	**CH**	**CM**	**PK**	**UNSA**	**RB**	**DV**	**CC**	**TSB**	
Fall 2009	Fry	161	82				4		1		Low, Medium, High
	Parr	1					1	2			
	Adult	4	20	7	64		1		30	4	
Winter 2009/2010	Fry										Medium
	Parr										
	Adult			2							
Total Number of Fish		**393**	**129**	**10**	**64**	**71**	**27**	**15**	**72**	**31**	

CO = Coho Salmon; CH = Chinook; CM = Chum; PK = Pink; UNSA = Unidentified Salmon; RB = Rainbow Trout; DV = Dolly Varden; CC = Sculpin sp.; TSB = Threespine Stickleback.

Table 9: Counts of adult fish “fins” and “rolls” observed in the Tailrace and Squamish River Side-channel.

Field Visit	Date	Fish Documented						
		CO	**CH**	**CM**	**PK**	**UNSA**	**RB**	**DV**
1 to 12	Sept 22/2008 to Aug 6-7/2009							
13	Aug 20-21/2009					2		
14	Sept 16/2009				89			
15	Sept 22/2009		5		31	11		
16	Oct 2-3/2009	8	10			82		
17	Oct 15-16/2009					10		
18	Oct 30/2009			1		2		1
19	Nov 17-18/2009					1		
20	Dec 18/2009							
Total Number of Observed Fish “Fin/Rolls”		**8**	**15**	**1**	**120**	**108**	**0**	**1**

CO = Coho Salmon; CH = Chinook; CM = Chum; PK = Pink; UNSA = Unidentified Salmon; RB = Rainbow Trout; DV = Dolly Varden.

3.1.3 Juvenile Colonization

Fish colonization of the TC and LSRS may occur during high flow `must-run' operations and/or as a result of backwatering from the Squamish River during freshet. Assessment of colonization was estimated by observing CPUE (calculated from minnow trap data) values at different flows and seasons. A review of CPUE throughout the year shows the highest values occur during the fall, specifically in October (Figure 2).

The collected fish data showed that CPUE was noticeably lower during high flow periods (mean of 0.05 fish/hr) than during low flow periods (0.10 fish/hr) (Figures 3). This difference in CPUE between high and low flow conditions may suggest juvenile fish were able to occupy, or colonize, recently wetted habitat areas. Mean CPUE in the TC was 0.06 fish/hr, which was double that in the LSRS at 0.03 fish/hr; however, median CPUE between the TC and LSRS was virtually identical, suggesting the difference observed in the means may be affected by one of two sites in the TC with high fish abundance that the other sites (Figure 4).

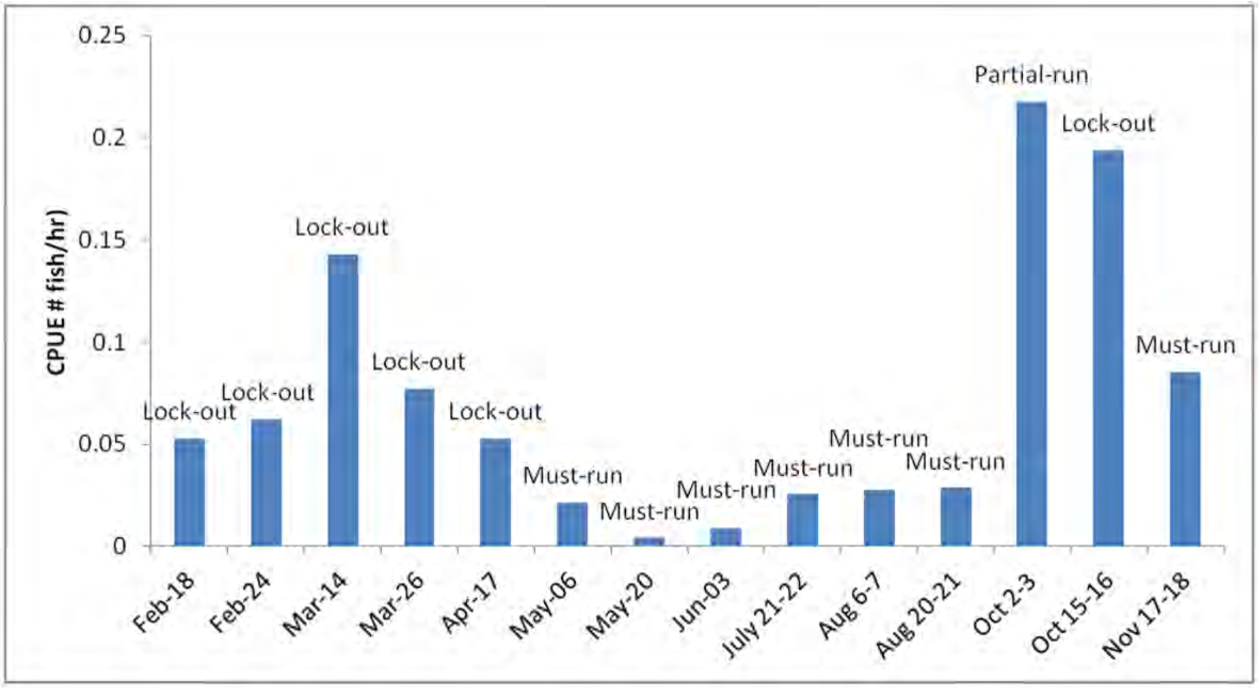

Figure 2: Minnow trap catch per unit effort by sampling date under lock-out and must-run operations.

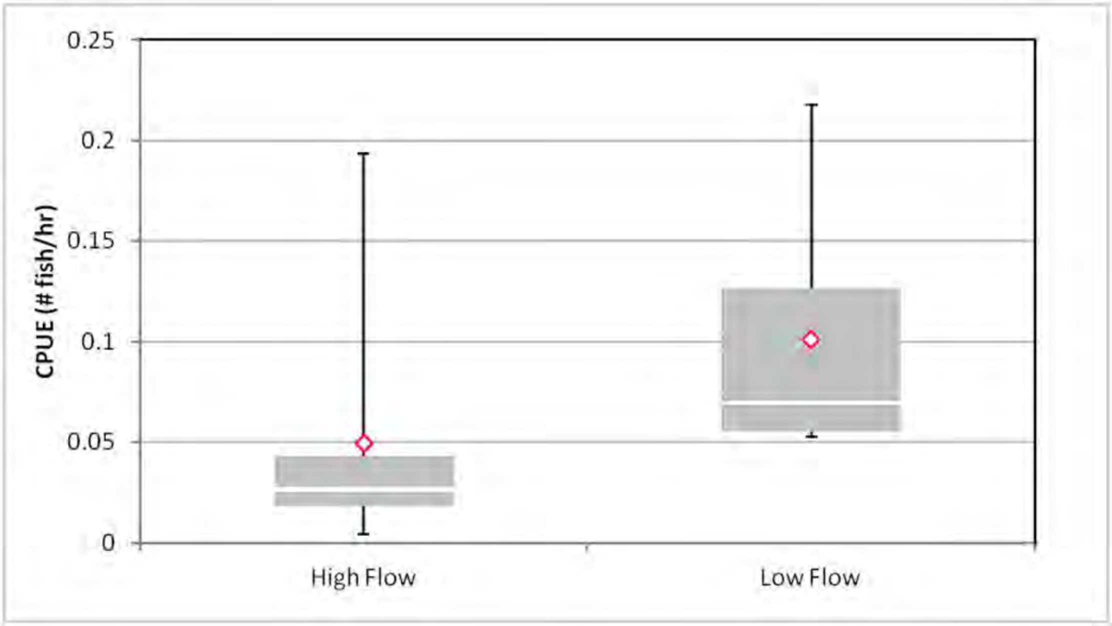

Figure 3: Box-Whisker Plot comparison of catch per unit effort during low and high flows in the Tailrace Channel and Squamish River Side-channel.

The lower bar notes the smallest observation, the bottom of the box notes the lower quartile, the line in the boxes notes the median, the red diamond notes the mean, the top of the box notes the upper quartile, and the upper bar notes the largest observation.

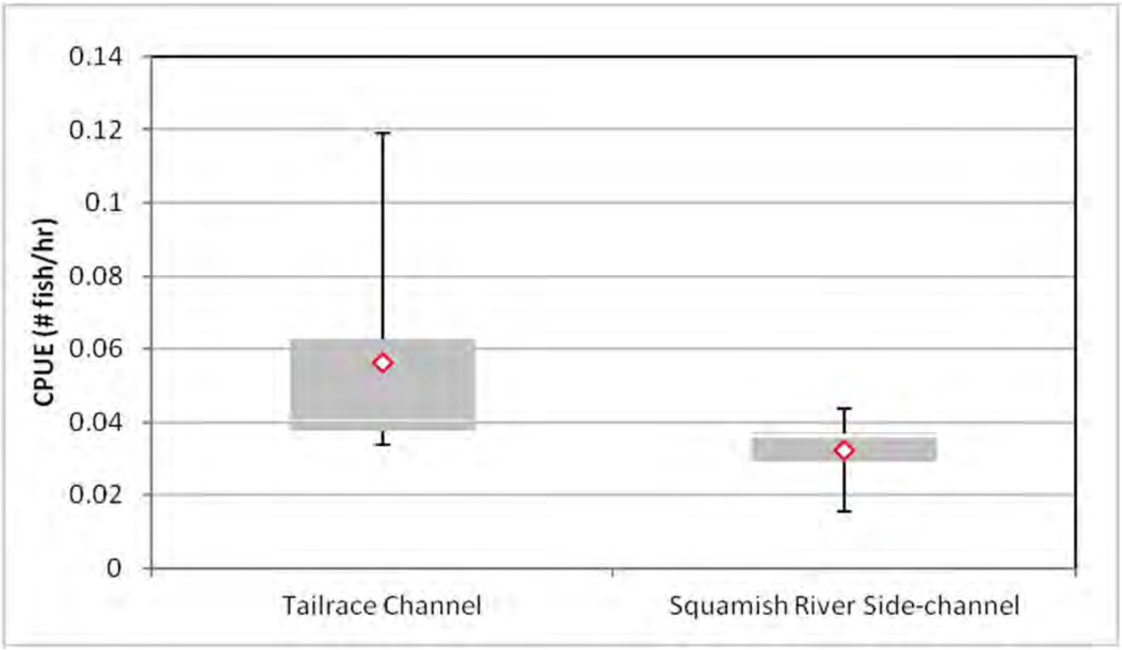

Figure 4: Box-Whisker Plot comparison of catch per unit effort in the Tailrace Channel and Squamish River Side-channel.

The lower bar notes the smallest observation, the bottom of the box notes the lower quartile, the line in the boxes notes the median, the red diamond notes the mean, the top of the box notes the upper quartile, and the upper bar notes the largest observation.

3.1.4 Fish Stranding Surveys

Stranding surveys were conducted after decreases in water levels, or in anticipation of decreased water levels, that exposed the TC and LSRS to increased stranding risk. Stranding surveys were conducted during Site Visits 1, 2, 7, 8, 14, 15, 18, and 20 on September 22 and November 17, 2008, and April 17, May 6, September 16 and September 22, October 30, and December 18, 2009, respectively. Details of fish observed during the stranding surveys are presented below in Table 10. Photographs of stranded fish can be found in Appendix A (Photographs 32 to 35).

A total of 12 individual stranded fish were observed, comprising six salmonid species and Threespine Stickleback. Stranding events were noted at Sites 2, 5, 6, 7, 8, and 12. One adult salmon was observed on the bank at Site 7 on September 22, 2008, however, this observation may have been a result of a spawned-out adult carcass having been pulled up the bank by a scavenger rather than a case of stranding, so it was not included in the stranding count. One Chinook adult was found stranded in the middle of a bar in Site 5 on September 22, 2008; one Chum fry was observed stranded on the bank at Site 6 on April 17, 2009; one Rainbow Trout parr was observed stranded on the bank at Site 8 on April 17, 2009 and another at Site 7 on October 30, 2009; one Coho fry was observed stranded on the bank at Site 6 on September 22, 2009; and, a Coho smolt was observed stranded on the bank roughly 30 m downstream of Site 8 on October 30, 2009. At Site 2 on September 22, 2009 a deposit of eggs was found stranded behind some rip-rap; the eggs looked purposely placed and Chinook Salmon had been observed in that section of the Tailrace Channel. Threespine Sticklebacks were also observed stranded along the bank at Site 12; two on April 17 and one on September 22, 2009.

Of the six sites where stranding was observed, Sites 8 and 12 both consisted of wide gravel areas which have small shallow pools and woody debris fish may get caught in. Fish found stranded in both these sites were located on the bank, on sandy or gravelled areas, as opposed to one of the small pools within the site. Sites 6 and 7 both had banks with relatively steep shelves that provide some instream cover in the form of depressions or woody debris while flows were high.

The scope of the Monitor does not determine the significance of stranding rates, though does provide an estimate of a stranding risk index, which could be used to estimate the number of fish that may become stranded as a result of CGS operating conditions. The stranding risk index was calculated by dividing the number of fish observed stranded by the number of fish observed using data collected at each stranding survey to produce date and condition-specific index values, and an overall index value, which are presented in Table 11. The highest rates of stranding were observed during lock-out conditions on October 30, 2009, and April 17-18, 2009, with calculated stranding indices of 0.20 and 0.10, respectively, compared to an overall average stranding index of 0.05.

Table 10: Fish visually observed during stranding surveys.

Field Visit	Date	Site ID	Species	# Fish[1]	Stage	Size (mm)	Stranded	Location	Comments
1	Sept 22/08	5	CH	1	Adult	400-500	Y	Mid-bar	Mortality
		7	Salmon sp	1	Adult	400-500	Y[2]	Bank	Spawned-out
2	Nov 17/08	No Stranding Observed							
5	Mar 14-15/09	6	TSB	1	Adult	60	Y	Bank	Alive – returned to Tailrace Channel
7	Apr 17-18/09	6	CM	1	Fry	38	Y	Bank	Mortality
		8	RB	1	Parr	211	Y	Bar	Mortality - Rigor mortis
		12	TSB	2	Adult	53-62	Y	Shelf	Live
14	Sept 16/09	No Stranding Observed							
15	Sept 22/09	12	TSB	1	Adult	52	Y	Bank, open mud	Mortality
		6	CO	1	Fry	28	Y	Bank	Mortality
		2	Salmon sp	100-200	Egg	10	Y	Behind large rock on bank	Mortality
18	Oct 30/09	7	RB	1	Parr	14	Y	Bank at side-channel confluence	Mortality
		8	CO	1	Smolt	20	Y	Bank, 30 m downstream of site	Mortality
20	Dec 18/09	No Stranding Observed							

1) CO = Coho Salmon; CH = Chinook; CM = Chum; PK = Pink; UNSA = Unidentified Salmon; RB = Rainbow Trout; DV = Dolly Varden; CC = Sculpin sp.; TSB = Threespine Stickleback.
2) This observation may be a result of a spawned out adult carcass being pulled up bank by a scavenger rather than a case of stranding.

Table 11: Stranding risk index by sampling date.

Field Visit	Date	# Fish Observed[1]	# Fish Stranded	Stranding Index
1	Sept 22/08	67	2	0.03
2	Nov 17/08	5	0	0.00
5	Mar 14-15/09	83	1	0.01
7	Apr 17-18/09	41	4	0.10
14	Sept 16/09	5	0	0.00
15	Sept 22/09	65	2	0.03
18	Oct 30/09	10	2	0.20
20	Dec 18/09	2	0	0.00
			Mean Stranding Index	0.05

1) The mean number of fish is presented when a range was recorded.

3.2 Water Quality

Water quality readings (DO, temperature) were taken during most site visits. During several visits, September 16 and 22 and October 16, 2009, water quality readings were not recorded due to multi-meters being unavailable for maintenance. Temperature and DO for the CGS TC and LSRS fluctuated over the course of the site visits but did not show substantial differences between these two sections (Figures 5 and 6, respectively). Raw temperature and DO data are provided in Appendix B.

During high flow sampling events, DO levels in the TC and LSRS ranged from 8.4 mg/L to 17.4 mg/L, with a mean of 12.5 mg/L (Appendix B). During low flow sampling events, DO levels ranged from 5.5 mg/L to 14.7 mg/L, with a mean of 11.1 mg/L. In the TC, DO levels ranged from 5.5 mg/L to 15.8 mg/L, with a mean of 11.5 mg/L; while in the LSRS DO ranged from 8.7 mg/L to 17.4 mg/L, with a mean of 12.4 mg/L. Ranges were similar to those observed by Troffe and Melville (2004).

These DO levels are well above those limits for the “lethal concentrations for BC juvenile and adult fish life stages” under the MoE Ambient Water Quality Criteria for Dissolved Oxygen (1997) and the Canadian Council of Ministers for the Environment (CCME) Dissolved Oxygen Guidelines for early and other fish life stages (1987). Overall, the observed DO levels in the TC and LSRS were above the “lethal concentrations for BC embryo and alevin fish life stages” under the MoE Ambient Water Quality Criteria for Dissolved Oxygen (1997). The exceptions to this was a low flow sampling event in the TC and LSRS on September 22, 2008, and in the TC at two sites on March 15 and one site on October 30, 2009, which all had recorded DO below the recommended 9 mg/L for buried embryo and alevin life stages in the water column. These measurements appear to be unusually low compared with the other recorded DO measurements, and they are less than the calculated means for both the TC and the LSRS, and at high and low flow events. It is therefore considered that the DO measurements recorded downstream of the CGS do not overall negatively impact fish populations.

Water temperature readings ranged from 2.9°C to 15.2°C and from 2.7°C to 15.2°C, in the TC and LSRS, respectively (Appendix B). At high flows water temperature ranged from 2.2°C to 15.2°C, with the mean value of 8.3°C; while at low flows water temperatures ranged from 2.3°C to 13.1°C, with a mean value of 5.9°C. There was no substantial difference in water temperature between the TC and LSRS nor under low flow and high flow conditions (Appendix B). Ranges were similar to those observed by Troffe and Melville (2004).

The observed upper temperatures are within the BC Water Quality Guidelines for Temperature (2001) regarding the rearing and migration of salmonids, and other cold water species, though they are too high for ideal incubation and spawning conditions. These warmer temperatures were observed in the TC in July through September and the LSRS in July and August. The lower range of the recorded temperature observed in the winter and spring, from November through to April, are outside the optimal temperature ranges for incubation, rearing, migration and spawning of salmonids. Spawning and incubation in the TC and LSRS may be limited in July through September and November through April by high and low temperatures, respectively. Although spawning behaviour, redds and the presence of juvenile and adult salmonids suggest that spawning and incubation may occur in the TC and/or the LSRS, the recorded temperatures indicate that these life-stages occur outside of the optimum temperature range. Despite the less than optimal temperature conditions within the TC and LSRS, the presence of juvenile and adult salmonids suggests that these fish are able to use the available habitats, potentially by altering their behaviour or incurring a high risk of mortality.

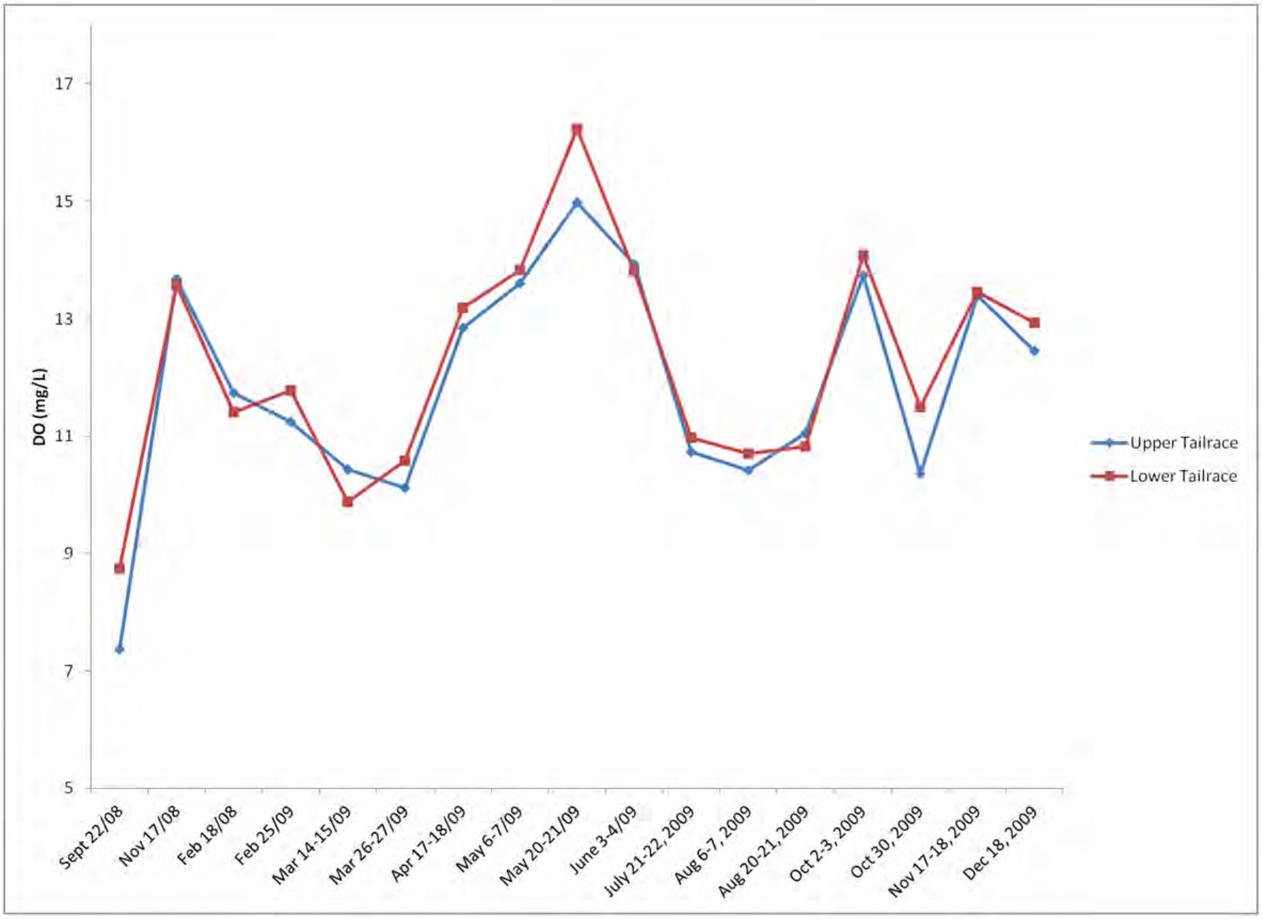

Figure 5: Dissolved oxygen in the Tailrace Channel and Squamish River Side-channel by sampling date.

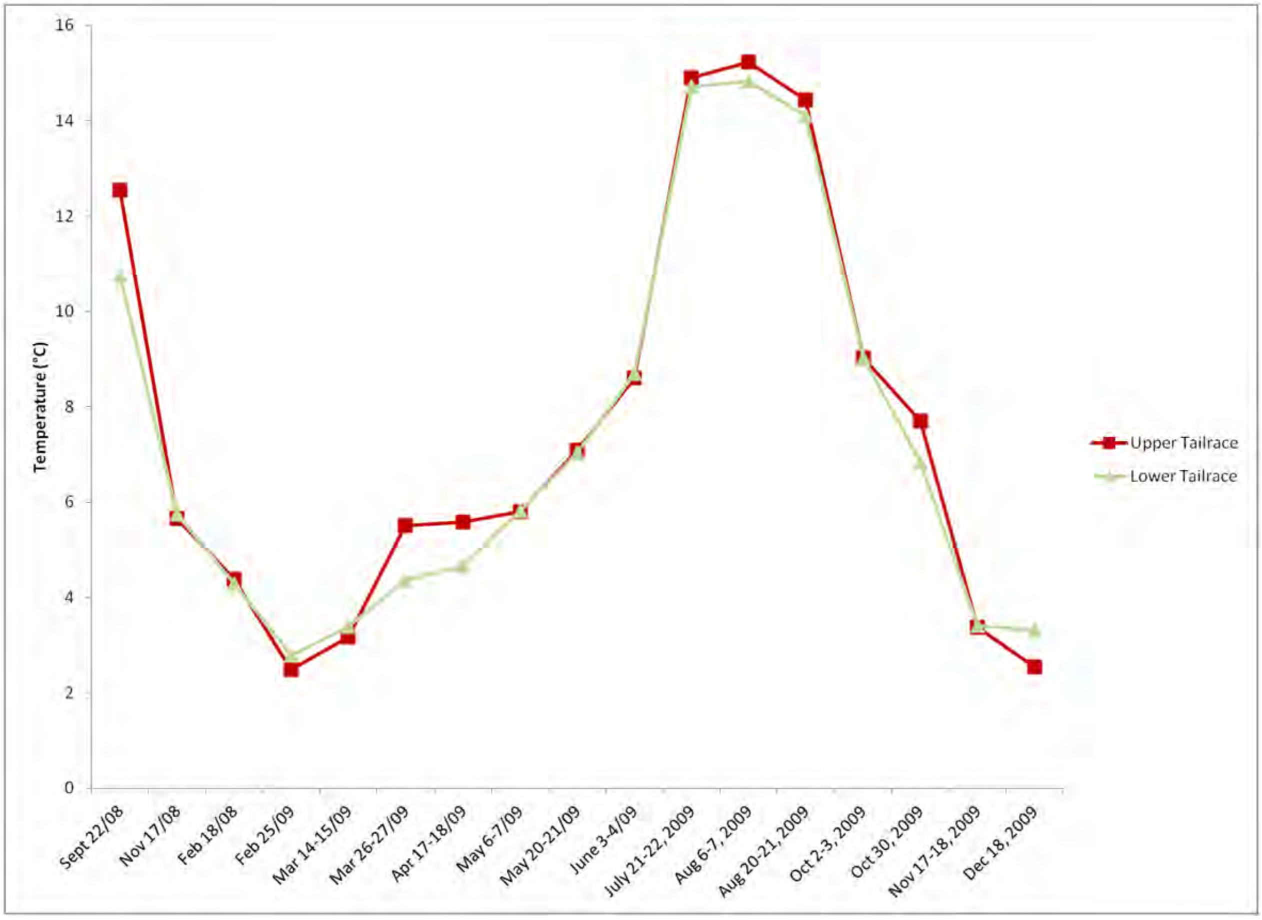

Figure 6: Water temperature in the Tailrace Channel and Squamish River Side-channel by sampling date.

3.3 Area of Potential Stranding Risk

Chart 5 shows the area of potential stranding risk versus the Squamish River water level at Ashlu Bridge for the three ramp-down modes.

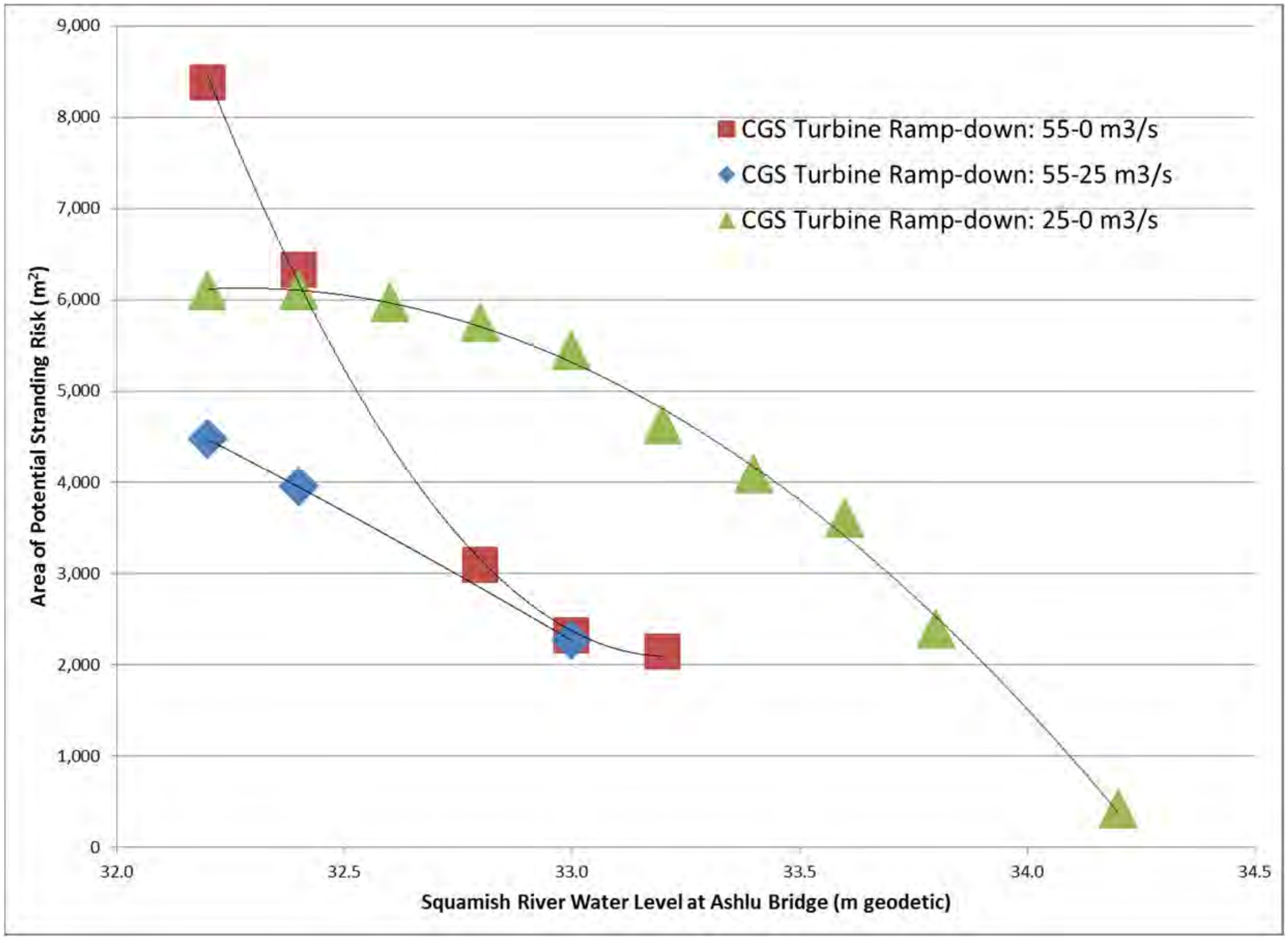

Chart 5: Area of potential stranding risk versus Squamish River water level at Ashlu Bridge.

The area of potential stranding risk is not an explicit identifier of stranding risk at any specific location; rather, it should be considered as a generalized indication of the likelihood of stranding under the modeled scenario relative to another scenario.

Based on Chart 5, the following trends were observed:

- For all ramp-down modes, the area of potential stranding risk increases with lower flows/water levels in the Squamish River; and
- For low flows/water levels in the Squamish River (i.e., Squamish River water level below 32.4 m at Ashlu Bridge), where fish stranding is more likely, the relative area of potential stranding risk was the highest for the 55-0 m^3/s ramp-down mode, followed by the 25-0 m^3/s and the 55-25 m^3/s ramp-down mode.

4.0 DISCUSSION

4.1 Summary of Hydrologic Modeling and Assessment

Hydrological analysis was performed to characterize the hydraulic conditions associated with the potential to strand fish in the CGS TC and LSRS. Variables that influenced hydraulic conditions in the TC and LSRS were selected for monitoring, and data was collected. Two-dimensional hydraulic modelling was performed using River2D based on the available bathymetric data and established boundary conditions. Sixty model scenarios were run, and the results were analyzed and summarized.

The site-specific potential of fish stranding could not be directly quantified using the hydraulic model due to the absence of detailed bathymetric data. The model results were analyzed in terms of the relative area of potential stranding risk associated with various combinations of CGS turbine ramp-down modes and Squamish River Water levels. The areal extent of potential stranding risk varied depending on the ramp-down mode and the Squamish River water level. The study results indicated that under the same ramp-down mode, a higher Squamish River water level resulted in a smaller area of potential stranding risk.

4.2 Fish Assessment

The following sections summarize results of the fish assessment program against the tasks laid out in BC Hydro's TOR.

4.2.1 Review Existing Stranding Studies in the Cheakamus Generating Station Tailrace Channel and the Squamish River Side-channel

The most complete and recent study examining stranding in the CGS TC and LSRS was conducted by Troffe and Melville (2004). The study focused on measuring water temperature and DO in the TC and LSRS from August to late September 2003. Troffe and Melville (2004) reported temperature and DO ranges of 12.6°C to 15.7°C and 4.8 mg/L to 10.3 mg/L, respectively. The extremes of these recorded parameters, observed during lock-out, were beyond the limits favourable for salmonid use such as for spawning (Troffe and Melville 2004).

Troffe and Melville (2004) also conducted monthly visits between August 2003 and March 2004 to assess fish species use by life history in the TC when tailrace flows were perceived to be critical. Visual observations (foot surveys) were used to observe and assess fish use at Sampling Sites 1 to 9. Adult Chinook used the TC for spawning in mid-August to early September, while Coho, Chum and Pink Salmon used the TC to migrate to spawning grounds located further upstream (i.e., High Falls Creek, Squamish River Side-channel). Observations of juvenile fish were limited to steelhead and Coho parr from August 2003 to October 2003; no juvenile fish were observed from November 2003 to March 2004.

Troffe and Melville (2004) reported that the critical time period for salmonids is likely in the late summer, early fall during salmon spawning periods when salmon densities are higher, flows from the Squamish River, generation and temperature are low, and DO demand is high. Installation of water quality data loggers and observations of salmonid behaviour during this critical period was therefore scheduled in this monitor.

Troffe and Melville (2004) reported difficulty observing adult Coho due to turbid and high water conditions in October. This was also found to be the case during our field visits to observe salmonids at the same time of year. It is likely that poor visibility and high water flows limited the ability to observe fish at other times of the study and may have contributed to not observing juvenile fish from November to March. We reviewed their approach and methodology prior to conducting our field surveys, and determined that visual observations were limited and the study objectives required another more consistent method for assessing fish use and juvenile colonization in the TC and LSRS. This modification of methods was essential given the highly variable conditions (i.e*.,* low vs. high flows, turbid water, Squamish River flow and seasonal visibility and available light). For these reasons, a combination of minnow traps, snorkel surveys, visual observations, beach seining and dip netting were employed in the fish assessment.

4.2.2 Assessment of Fish Use within the Cheakamus Generating Station Tailrace Channel and Squamish River Side-channel

Seasonal patterns in fish life history we observed followed our previous understanding of life history based on studies conducted in the TC and LSRS and in other systems in the Squamish River watershed (Golder 2008, Troffe and Melville 2004). Adult Coho, Chinook, Chum and Pink Salmon and juvenile Coho and Chinook salmon and various age classes of resident species (Dolly Varden, Rainbow Trout) were observed in the fall (based on sampling events in September into November in 2008 and 2009). Juvenile salmon (Chinook and Coho), and juvenile and adult resident species (sculpins, Threespine Stickleback) were observed during the winter and spring, with the exception of two adult salmon (Chum) in the winter. The majority of individual salmonids identified were juveniles, either fry or parr; however, all Pink and Chum Salmon observed were adults.

4.2.3 Assess the Colonization of Juvenile Fish into the Tailrace Channel and Squamish River Side-channel during a Range of Available Flow

Based on the fish assessment, colonization of previously dewatered areas in the CGS TC and LSRS by juvenile salmonids occurs to a limited extent during high flows of operational discharge from the CGS and/or from seasonal and weather influenced flows from the Squamish River mainstem entering into the side-channel. The extent and rate by which colonization may occur is thought to affect the risk of stranding of juvenile salmonids by sudden decreases in water levels due to CGS operations.

Minnow trapping data shows higher CPUE during low flows conditions compared to high flow conditions and higher CPUE within the TC compared to the LSRS. Colonization of recently watered habitats during fall high flow conditions occurred along the TC and LSRS, specifically in October, when the highest CPUE values occurred (Figure 2). This indicates that the greater apparent abundance of juvenile fish in the fall may be a result of flow conditions at this time of year contributing to higher catch efficiency and/or the timing of juvenile salmon moving into the channels. The TC had more juvenile fish and may potentially pose a greater risk of stranding than within the LSRS, especially during the fall. A key challenge for the interpretation of the MT data is that the effect of discharge on capture efficiency cannot be evaluated with the sampling approach and thus limits the inferences on colonization rates.

4.2.4 Record Water Quality in Isolated Pools in the Tailrace Channel and Squamish River Side-channel

Measurements in isolated pools of water quality parameters were limited due to the few shallow isolated pools being only intermittently observed within the TC and LSRS. Monitoring temperature and DO in these isolated pools over the course of a given field day was not logistically feasible due lack of time, and meeting health and safety requirements of BC Hydro operations. Further, the small size, height on the channel banks, and distance of several metres from the main channel, of the pools greatly limits the number and size of fish that would locate such shallow pools for cover during a ramp-down of the CGS to drop high flows to low.

Dissolved oxygen readings appeared to be lowest at the end of summer (September 2008), increased in the fall (November 2008), and then decreased through the winter (February and March 2009) (Figure 4). In the spring (late March, April and May 2009) DO readings started to increase again and peaked in late May and early June, 2009. Through the remainder of the summer (July and August 2009) DO readings decreased and then increased again in fall and winter (October, November, December 2009). The highest DO readings (November, May and June 2009) coincided with high flow must-run operations though not with the lowest, or even relatively low, temperature readings. Must-run conditions result in higher oxygenation of the water in the TC due to the operation of the turbines.

Dissolved oxygen readings also are generally negatively correlated with water temperatures in the TC and LSRS. The lowest DO readings were observed in September 2008 when water temperatures were highest, typical of late summer conditions. These conditions differed in late summer 2009 likely as a result of increased flows in the Squamish River due to considerable melting of freshet which maintained a relatively higher volume of water at a relatively lower temperature. During low flow conditions in February and March, temperatures decreased while DO levels increased. A steady increase in temperature was observed through April, May and June while DO levels also increased. Despite higher temperatures during these latter months, DO likely increases as a result of high-flow must-run conditions resulting from a high water volume caused by melting snow.

The higher levels of DO observed at differing times of the year (November, May, and June) are associated with high volumes of cool water in the TC and LSRS which resulted from the considerable melt of snow-pack in the warmer spring and summer months. Comparing the recorded DO levels to temperature through late spring (May) and into summer (June, July, August) show higher levels of DO than expected at these recorded temperatures: This may be due to super-saturation of the water as a result of the high flows from spring melt (freshet) and the CGS operations. Super-saturation, that occurs when water becomes highly concentrated with oxygen and other atmospheric gases beyond normal environmental conditions, has been well documented from dam turbine outages, spilling from dams, and spring freshet (Raymond 1979, Ryan and Dawley 1998, Weitkamp and Katz 1980). Super-saturation of the TC and LSRS was documented primarily in the spring and summer months during Site Visits 8 to 13, May 6-7 to August 20-21, 2009. As only oxygen was measured and not total dissolved gas pressure, there is uncertainty if these observed levels would reflect hazards to fish from gas bubble disease.

4.2.5 Periodic Stranding Surveys

Periodic stranding surveys were conducted through the fall of 2008 (September 22 and November 17, 2008) and the fall and early winter of 2009 (September 16 and 22, October 30, and December 18, 2009). Stranding surveys were scheduled to determine the incidence, number, and location of any fish found stranded during a reduction in water levels in the TC and LSRS as a result of CGS operations. Stranding surveys were generally initiated during low flow conditions when the CGS operations were reduced (fall 2008) or locked-out (fall and winter 2009). Surveys were scheduled for the late summer and into the fall, coinciding with adult salmon returning to spawn and the typically lower seasonal flows, when it was perceived the highest potential risk of stranding existed.

Over the course of six scheduled stranding surveys 10 fish were documented as stranded with one additional fish noted as potentially removed from the channel by scavengers. This suggests the WUP prescribed ramping rate did not completely prevent stranding from occurring, but did not result in large numbers of fish being stranded. Stranding surveys conducted during the time when adult salmon have been observed spawning or returning to spawn in the TC and LSRS (roughly August to December), did not indicate that any adults had become stranded prior to spawning.

An area within the LSRS of particular interest is located immediately downstream of the channel’s confluence with the TC, an area downstream of Site 7 extending to and including Site 12. At this location there is a large gravel area which has the potential to provide substrate for multiple redds. Coho and Chum salmon pass through the TC and LSRS to reach High Falls Creek to spawn, though while they were in the project area, no spawning activity from either of these species was observed (Golder 2008). The surveys did note adult Pink Salmon congregated in the large gravel area during September high flows and that redds were observed during low flows. Redd-guarding behaviour was observed by a female Pink Salmon in the thalweg adjacent to this large gravel area during low-flow lock-out conditions on October 15, 2009 (Photograph 40). This large gravel area would become exposed during periods of low flow. The potential risk of redd stranding could result from continual spilling of the CGS into the TC (must-run) attracting Pink Salmon to the available gravel area and then subsequently dewatering the area when CGS spilling operations reduces or discontinues (lock-out) for a period of time. Another area of interest is the rip-rap immediately below the CGS where deposited salmon eggs were found stranded behind a large rock. This area was observed to be frequented by Chinook Salmon, which may have established a redd in the rip-rap (Photographs 34 and 39). Chinook Salmon were also observed in the TC by a gravel area below the Forest Service Bridge and in the LSRS in a pool and riffle habitat constructed by the Squamish River Watershed Society in partnership with Fisheries and Oceans at Site 8 (Photographs 36 - 38). These areas pose challenges to manage and mitigate redd stranding, as ramping rates would not have a useful effect since dewatered areas would ultimately leave eggs in redds stranded regardless of the ramping rate, nor is it possible for the area to remain either watered or dewatered (to limit spawning adult access) through the duration of incubation and emergence. Both natural and CGS operational fluctuations of water levels within the TC and LSRS would not be consistent enough to maintain the gravel area as either watered or dewatered. During such instances the large gravel area is left almost entirely dewatered, except for the narrow thalweg channel on the left downstream bank, and this may strand a considerable proportion of eggs in any established Pink or other salmon redds. Potentially, during low flow and/or dry periods, CGS operations could spill long enough to provide sufficient moisture to the gravel area to prevent any deposited eggs from drying out. Research on dewatering of redds has shown that eggs from some salmonids (Chinook, Steelhead) can persist from one to five weeks as long as there is sufficient moisture retained in the gravel, either by capillary action of subsurface water and/or the proximity to groundwater (Becker et al 1982, Hawke 1978, Reiser and White 1983).

4.3 Hydraulic Model Limitations

The River2D model presented in this project had limitations due to the quality of bathymetric data that was available. Two-dimensional models and their computation results are highly sensitive to the quality of bathymetric input. In this project, the bathymetric data for approximately 1.5 km of TC and LSRS were based on 19 survey cross-sections, aerial photographs and large-scale mapping. The modeling results illustrated a general response to the flow change within the TC and LSRS but they should not be relied upon as accurate estimates of water level changes at specific locations. The model results were therefore of insufficient quality to evaluate site-specific fish stranding patterns, as these works required very detailed bathymetry that included features such as riffles and pools.

The model results were also limited by the vertical coverage of the surveyed cross-sections. When the TC and LSRS were surveyed, the survey limits were set at the top-of-bank for the left and right banks, and the low-lying overbank floodplain areas were not surveyed. Some modeling scenarios resulted in modeled water levels higher than the elevation of the surveyed top-of-bank. These scenarios were eliminated from the dataset as they were not representative of the actual conditions. These scenarios were associated with the highest Squamish River levels assessed, conditions which would result in the lowest relative stranding risk. Therefore, the elimination of these scenarios are considered to have no significant impact of the findings of this study.

4.4 Fish Capture Methods Evaluation

Visual observation alone was deemed to be an ineffective method to collect the required data to address the management questions of this Monitor, given the highly variable conditions and constraints of the two channels under different flow and seasonal conditions. Consequently, the beginning of Year 1 was spent assessing suitable fish capture methods. Constraints of the system such as variable channel flow and BC Hydro’s operations and safety concerns limited the ability to collect adequate data under certain conditions using the available sampling methods. Our approach was to employ a variety of capture methods to be able to effectively assess fish use, colonization and stranding under the varying conditions. The following provides a summary of some of the constraints encountered in conducting the field surveys.

Constraints with BC Hydro Operations:

- Ability of BC Hydro staff to attend to lock-out conditions at the CGS to meet the field survey requirements of this Monitor while also maintaining BC Hydro’s operational requirements;
- High water level conditions necessitating discharge from the CGS when lock-out conditions were required for sampling;
- Low water level conditions restricting scheduled CGS must-runs occurred when full discharge required for sampling;
- Optimum periods of power generation conflicted with sampling requirements during site visits; and
- Surveys limited to downstream of the Forest Service Road bridge during “must-run” conditions as a health and safety requirement of BC Hydro, thereby omitting the ability to survey Sites 1 to 4.

Constraints with Visual Observation Methods:

- Difficulty identifying juvenile fish due to poor water clarity at times;
- Difficult to standardize methods and quantify effort during high flows;
- Visibility changes occurred with season, weather, and flow conditions making it difficult to assess fish use consistently over the varying conditions; and
- Limited visibility over the full river width of the river.

Constraints with Beach Seining, Snorkelling and Minnow Trapping – High Flow Conditions:

- Seine – unable to access suitable terrain due to strength and depth of flow preventing entry to channels and pulling in the seine, water levels were too deep thereby limiting safe access by field crews and therefore limited seining to low flow conditions;
- Snorkel –higher turbidity observed during high flows reduced visibility in the water compared to low flow; health and safety risk of high flow conditions potentially resulting in snorkeler being swept away or coming into contact with debris drifting down stream; and
- Minnow Trap – in some areas flow may be too great for fish to access trap. In instances where variable flows occurred overnight due to operations, it was necessary to set traps farther out in the channel resulting in decreased ability to catch and reduced the effectiveness of the method to capture fish.

Constraints with Beach Seining, Snorkelling and Minnow Trapping – Low Flow Conditions:

- Seine – snagging seine on debris in channel bottom occurred; limited use of the shoreline area for pursing net collections and subsequent fish data collection;
- Snorkel – some areas of channel were too shallow to swim; resulting in increased swimming effort and decreased efficiency for snorkeler; and
- Minnow Traps – limited the size of fish captured and the traps were inaccessible if flows changed suddenly; requiring long set periods of stable flows that were often difficult to attain.

Visual observation is an efficient method to employ as it requires no specialized fishing gear, no permitting, and can be done from the edge of the bank. Despite these advantages of the VO method, it can be difficult to quantify observations of species and counts. For example, generally more fish were observed during site visits when flow volume in the TC and LSRS were low (September 22, 2008 and 2009) when compared with site visits that occurred when there were medium or high flow volumes (September 16, 2009, October 30, 2009, November 17, 2008, and December 18, 2009). It is unknown to what extent the differences in flow volume between dates of site visits may contribute to differences in numbers of fish observed.

Flows in the CGS TC and LSRS permitted safe use of the BS under low flow conditions at lock out during field visits 4, 5, 6, and 7 from February 24 to April 17, 2009. The most effective use of the BS method was limited to Sites 5, 6, 7, 8, 10, and 11. Despite the utility of the BS method to gather information about fish use and presence at some sites, the limitations of its use precluded its deployment over a variety of habitats and flow conditions, and therefore decreased its efficacy to assess fish use and presence in the TC and LSRS. For these reasons BS was not used during Year 2 of the fish assessment.

Snorkel surveys were not continued in Year 2 of the fish assessment. This was as a result of the lack of success in observing either juvenile or adult fish in the TC and LSRS during Year 1 of the Monitor. Factors that may have prevented fish sightings included the location of fish during the time of year of the sampling, lower fish activity during daylight hours (as opposed to night time surveys) when the SS were conducted, lack of adults during the time of year the SS was employed, and poor water clarity during high flow conditions.

The use of the DN to collect information on fish was employed opportunistically when fish were observed near the surface along the shore during both Year 1 and Year 2. As a regular method it is limited by these factors of effectiveness only near shore and deployed irregularly when opportunistic use was warranted, although DN is useful to obtain detailed information on fish species, size and age, due to its ease of deployment. Opportunistic use of DN was limited to occasions when fish were visible near the surface and within reach of the bank.

The use of MTs to assess fish proved to be the most reliable and consistent method under the varying conditions in the two channels. The MTs were able to capture fish during all the site visits they were used (at high and low flows) when no fish were captured/observed using either the BS, DN or SS methods (Table 7). Use of MT allowed for greater quantification and identification of fish, as the MTs were deployed overnight at a time of presumed greater fish activity, and deployment was for a longer period of time then the other methods.

Due to the constraints encountered with each of these methods and under different flow conditions, it was decided the combination of VO and MT methods would be suitable were used exclusively to assess fish use, colonization and stranding in the two channels during Year 2.

4.5 Management Questions

The Cheakamus Water Use Plan (WUP) TOR for this monitoring program (BC Hydro 2007) presented the concerns of the FTC regarding peaking CGS operations that would cause water levels in the TC and LSRS to fluctuate to an extent that could potentially strand redds and/or juvenile fish. The TOR noted that the risk of stranding is currently unknown and that the Monitor was intended to describe the level of fish use within the TC and LSRS, establish a threshold value of stranding deemed to be harmful to local fish populations, and determine whether the stranding rate observed and predicted exceeds the threshold value. The five management questions developed in the TOR of this monitoring program are to address the stranding risk and are outlined below with Golder’s approach and answers:

1) What is the magnitude of stranding risk in the TC and LSRS downstream of the CGS and at what time of the year is it at its highest level?

Based on the observation of only ten stranded fish on six sampling occasions, the overall magnitude of stranding observed is considered low. The greatest risk of stranding occurs during ramp downs when water levels in the Squamish River are typically low (e.g., from December to April, or around September during a year with low winter precipitation and low spring freshet). The observed low magnitude does not reflect an equally low potential risk of impact to all fish species populations, as the loss of relatively low overall numbers would impact populations differently, depending upon the species' local life history and relative abundance. A low magnitude of standing risk may be significant to fish populations that are already understood to be threatened, such as Chinook Salmon.

Due to the lack of detailed bathymetric data, it was not possible to perform accurate hydraulic modeling of the variations in site-specific water level. Therefore, it was not possible to establish an absolute magnitude of stranding risk within the Monitor. Generalized observations were made by interpreting the model results in terms of the relative area of potential stranding risk between different modelled scenarios. It was observed that regardless of the CGS turbine ramp-down mode, the area of potential stranding risk decreased with higher Squamish River flows and water levels. Therefore, the ramp-down scenarios with the highest potential for creating areas of stranding risk were those that occurred during low flows and water levels in the Squamish River. Low flow in the Squamish River typically occurs from December to April, and also around September.

A stranding risk index ratio of 0.05 was estimated based on the stranding observations and modelled operational and seasonal conditions. The stranding risk index suggests that if 100 fish were observed within the channels then an average of 5 fish may be observed stranded following a ramp-down event. This value was determined by dividing the number of fish observed stranded during each survey by the number of fish observed not stranded during each survey. Golder and Squamish Nation conducted a stranding study downstream of Daisy Dam on the Cheakamus River which found 35 fish stranded after the flow ramp down event on November 1, 2008 (Golder 2009). This study had defined a minimal acceptable level of stranding through consultations with Fisheries and Oceans (DFO) and the Ministry of Environment (MoE) to be "dozens of fish stranded" and therefore determined the levels of stranding observed during the November 1 ramp down event to be within the tolerable limits set (Golder 2009).

The relative magnitude of stranding risk in the TC and LSRS habitats is less than the stranding observed below Daisy Dam during the November 1 ramp down and less than the stranding risk deemed acceptable for the Daisy Dam November ramp down. The diversity of fish species in the TC and LSRS is greater than below Daisy Dam as anadromous salmonids are able to access the TC and LSRS. Therefore, even though the total number of stranded fish may be lower at TC and LSRS habitats, the level of stranding could potentially be significant to salmonids that are returning to spawn. Chinook Salmon are of particular concern as these species have been observed spawning in the TC and are not known to spawn in surrounding streams or channels.

The stranding index is at best a qualitative indicator of stranding potential, as the numbers of fish found stranded and observed do not represent the entire number of fish both stranded and inhabiting the TC and LSRS habitats, and underestimates the actual numbers. This index has a high uncertainty due to the potential biases with the ability to observe fish and stranding correlating positively or negatively with the variable hydraulic conditions that are associated with increased or decreased stranding rates.

2) What is the aerial extent of the stranding impact should it occur?

The aerial extent of stranding impact varies depending on the ramp-down mode and the Squamish River water level. The generalized relative risk of potential stranding under the modelled scenarios suggests:

- For all analyzed CGS turbine ramp-down modes, the area of potential stranding risk increased with a lower flow/water level at Squamish River at Ashlu Bridge;
- For periods of low flows in the Squamish River (i.e., water level below 32.4 m at Ashlu Bridge), the study results indicate that the risk of stranding was the highest for the 55-0 m^3/s ramp-down mode, followed by the 25-0 m^3/s ramp-down mode. The 55-25 m^3/s ramp-down mode resulted in the lowest relative risk of stranding; and
- Although the total aerial extent of stranding could not be calculated due to the limitations in the bathymetric data, the relative extent of observed stranding covered a small area compared to the size of the TC and LSRS.

3) Does a peaking operation at the powerhouse prevent juvenile salmonids from colonizing habitats that are prone to dewatering?

The analysis of whether the duration of peaking operations is enough to limit or prevent fish colonization of habitat that will become dewatered incorporates minnow trap (MT) catch-per-unit-effort (CPUE) data. The MT CPUE data indicates fish move into these temporarily available habitats during peaking operations and that fish occupy this habitat between peaking operations, provided the habitat remains wetted. The data suggest that peaking operations do not prevent colonization of habitats prone to dewatering.

4) What is the stranding risk to spawning adults and resulting redds when in the TC and LSRS?

Stranding of adult salmonids within the TC and LSRS is considered lower than the mean stranding risk index, as the stranding incidents that included adult salmonids occurred during one event, on September 22, 2008. The stranding risk index for that survey event was determined to be 0.03 compared with the mean stranding risk index of 0.05 fish observed stranded / fish observed not stranded. Though the hydraulic model is unable to quantify the stranding risk to redds, observations of redds in the TC and LSRS suggest these areas would be potentially at risk of stranding eggs in the redds when ambient flows lessen and operations of the CGS significantly reduce flows. During such instances the large gravel area at the confluence of the TC and the LSRS is left almost entirely dewatered, except for the narrow thalweg channel on the left downstream bank, and this may strand a considerable proportion of eggs in any established Pink or other salmon redds. Chinook Salmon adults and redds are sensitive to stranding, particularly in the area immediately below the CGS, where adults have been observed holding and displaying spawning behaviour. The significance of such stranding is that it would be estimated to be greater in the TC and LSRS than in the Squamish River main channel.

5) If the rate of stranding is found to be significant, what kind of actions can be taken to mitigate the impact?

The rate of stranding within the TC and LSRS was not found to be substantial due to the relatively low value of the mean stranding risk index (0.05 fish observed stranded / fish observed not stranded) and subsequently the overall low potential stranding risk relative to that observed in the Cheakamus River below Daisy Dam (Golder 2009). The potential for stranding would have unequal impacts among different species, as species which have lower population numbers and longer periods between spawning events would potentially be more greatly affected by low numbers stranding, compared to fish species that reproduce more quickly and have greater local populations. The types of mitigation measures that could be employed to reduce the numbers of fish that become stranded are:

- Seasonally altering ramping rates based on Squamish River water levels and operational conditions;
- Fish barriers for adults to prevent spawning in specified high-risk stranding areas;
- Reshaping the channel to limit access to high-risk areas where dewatering occurs; and
- Redd salvage operations.

By addressing the five management questions above the Monitor aimed to provide information to either satisfactorily reject or fail to reject the Stranding Impact Hypothesis defined in the TOR:

- That the stranding rate of juvenile and adult fish does not exceed the threshold value judged to be harmful to local fish populations.

Although a threshold value of stranding risk was not specifically determined for the TC and LSRS, the management questions do indicate that the stranding risk index is relatively low downstream of the CGS in comparison to a “minimum acceptable level of stranding” determined for the Daisy Lake Dam November 1 ramp down event, and the actual observed stranding below Daisy Dam (Golder 2009). Therefore, the Monitor suggests that the Stranding Impact Hypothesis would likely fail to be rejected and that the observed stranding rate would be determined as not harmful to local fish populations.

5.0 RECOMMENDATIONS FOR FUTURE WORKS

Due to the model limitations discussed in Section 4.3, the hydrologic analysis and the modeling work could not directly quantify the potential of fish stranding. However, the works completed have formed a basis should additional data be available in the future. The following are recommended for future works.

- Collection of detailed bathymetric survey data with consideration given to multi-beam data collection for detailed and site-specific habitat assessment;
- Recording of CGS discharge rates at a finer time step to better characterize ramp down modes;
- Continuous flow monitoring for the side-channel/High Falls Creek;
- Additional fish stranding observation during CGS ramp-down events;
- Fish capture efficiency assessment through use of mark recapture or radio telemetry; and
- Potentially include bed-slope and substrate composition analysis of identified key sites to determine a cumulative potential stranding area.

6.0 CLOSURE

We trust that the information contained in this report meets your requirements. Please contact the undersigned should you have any questions or comments.

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7.0 REFERENCES

BC Hydro. 2007. *“Cheakamus Project Water Use Plan – Monitoring Program Terms of Reference”.* Revision 1 - February 2007: 77-83.

Becker, C.D., Neitzel, D.A., and Fiskeisen,D.H. 1982. *“Effects of Dewatering on Chinook Salmon Redds: Tolerance of Four Developmental Phases to Daily Dewaterings”.* Transactions of the American Fisheries Society. 111:624-637.

Canadian Council of Ministers for the Environment (CCME). 1987. *“Canadian Water Quality Guidelines.”* Task Force on Water Quality Guidelines of the Canadian Council of Resource and Environment Ministers. 256 p.

Conlin, K., and Tutty, B.D. 1979. *“Juvenile salmonid field trapping manual (first ed.)”.* Fisheries and Marine Service Manuscript Report. #1530.

Coulson, C.H. and Obedkoff, W., 1998. British Columbia Streamflow Inventory

Golder Associates Ltd. (Golder). 2009. *“Cheakamus Project Water Use Plan: Monitoring Stranding Downstream of Daisy Lake Dam”.* Submitted to BC Hydro on behalf of Squamish Nation.

Golder Associates Ltd. (Golder). 2008. *“Annual Salmon Spawner Enumeration Program in the Squamish River Watershed”.* Prepared for the Squamish Nation and Fisheries and Oceans Canada.

Hawke, S.P. 1978. *“Stranded Redds of Quinnat Salmon in the Mathias River, South Island, New Zealand 1978”.* New Zealand Journal of Marine and Freshwater Research. 12:167-171.

Leake, A.C. 2004. *Campbell River flow-habitat modeling with River 2D*. Water Use Plan Technical Note WUP-JHT-TN-F03. Prepared for John Hart Water Use Plan Fisheries Technical Committee. June 11, 2004.

McMillan, Karen. 2012. Project Manager, Golder Associates Ltd. Conference call with Chris Coles, Rudy Sung, and Robert Harrison (Golder), Jeffery Walker, Darin Nishi (BC Hydro), and Randall Lewis, Squamish First Nation. July 13, 2012.

Melville, C. 2002. *“Field Observations from the Powerhouse on the Squamish River”.* Fall 2002. Prepared for BC Hydro.

Ministry of Environment (MoE). 2001. *“Water Quality Guidelines for Temperature: Overview Report.”* Water Management Branch, Environment and Lands Headquarters Division. Prepared pursuant to Section 2(e) of the Environment Management Act, 1981. August 22, 2001.

Ministry of Environment (MoE). 1997. *“Water Quality Ambient Water Quality Criteria for Dissolved Oxygen.”* Water Management Branch, Environment and Lands Headquarters Division. Prepared pursuant to Section 2(e) of the Environment Management Act, 1981. February 1997.

Raymond, H.L. 1979. *“Effects of Dams and Impoundments on Migrations of Juvenile Chinook Salmon and Steelhead from the Snake River, 1966 to 1975”.* Transactions of the American Fisheries Society. 108: 505-529

Reiser, D.W. and White, R.G. 1983. *"Effects of Complete Redd Dewatering on Salmonid Egg-Hatching Success and Development of Juveniles".* Transactions of the American Fisheries Society. 112:532-540.

Resources Inventory Committee of British Columbia (RIC). 1998. *"Reconnaissance (1:20,000) Fish and Fish Habitat Inventory: Standards and Procedures",* Version 1.1.

Resources Inventory Committee of British Columbia (RIC). 1997. *"Fish Collection Methods and Standards, Version 4.0",* Prepared by BC Ministry of Environment, Lands, and Parks, Fish Inventory Unit for the Resources Inventory Committee. January 1997..

Ryan, B.A. and E.M. Dawley. 1998. *"Effects of Dissolved Gas Supersaturation on Fish Residing in the Snake And Columbia Rivers, 1997".* Bonnevile Power Administration, Portland, Oregon. Available at http://pisces.bpa.gov/release/documents/documentviewer.aspx?doc=93605-2 (May 2010).

Sigma Engineering Ltd. (Sigma). 1996. *"Squamish River Fall and Winter Flow Ramping Studies: Fall and Winter Fish Habitat Use and Fish Stranding Assessment".* Prepared for BC Hydro Corporate Safety and Environment.

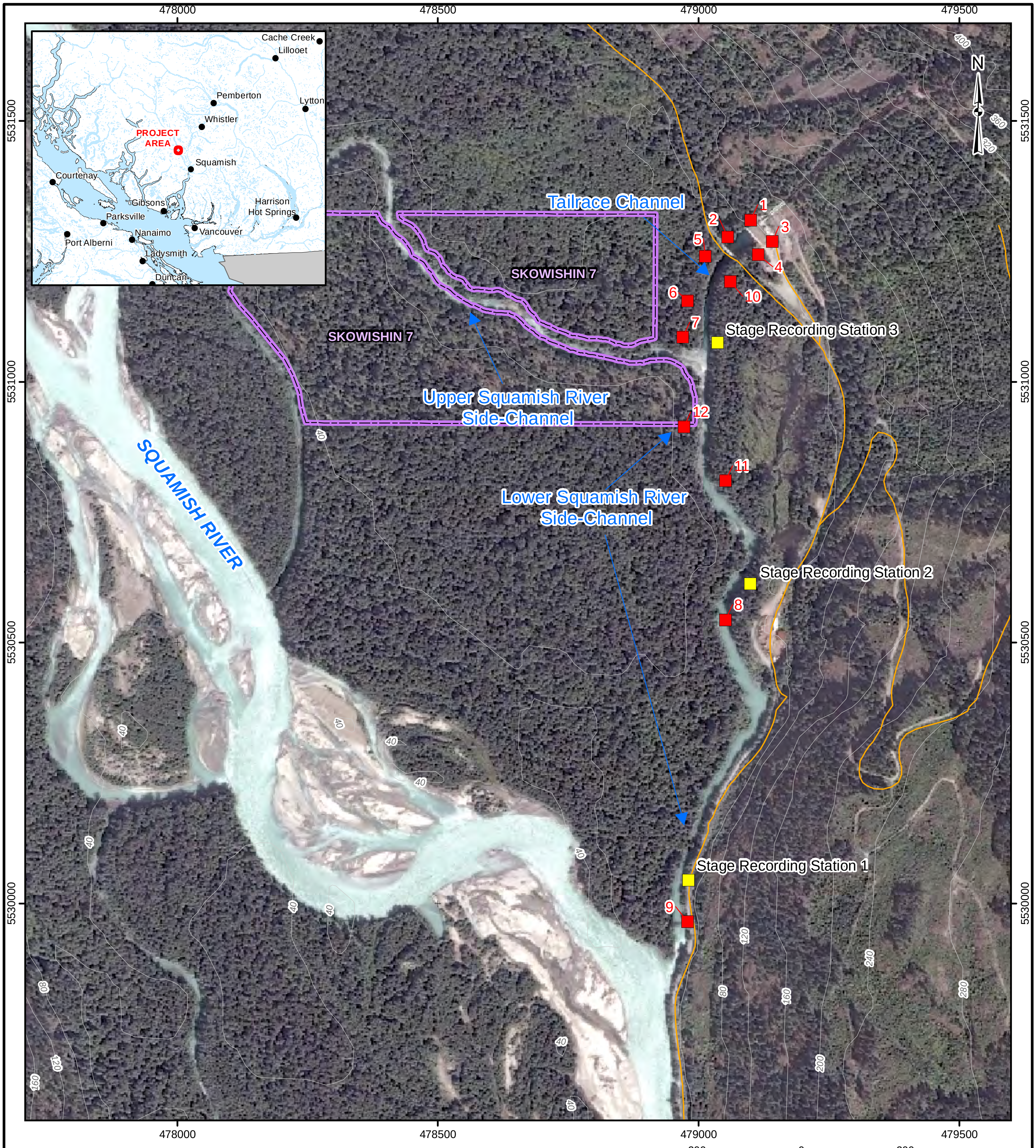
Steffler, P. 2002. *Bed Topography File Editor User's Manual*. University of Alberta. September, 2002.

Troffe, P.M. and C.C. Melville. 2004, *"Cheakamus Generating Station Tailrace Flow Monitoring Study Biological Sampling Component, July 2003-March 2004".* Instream Fisheries Research Inc. June 2004.

Tantalus Consulting and Geostreams Consulting 2005. *"CMS Tailrace Flow and Habitat Analysis".* Report prepared for BC Hydro. September 11, 2005.

VIA-SAT Data Systems Inc. (2012). Squamish River Water Level at Ashlu Bridge data received April 2, 2012 and July 26, 2012.

Weitkamp, D.E. and M, Katz. 1980. *"A Review of Dissolved Gas Supersaturation Literature".* Transactions of the American Fisheries Society. 109: 659-702.



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SCALE 1:50,000 KILOMETRES

LEGEND

🟨	Stage Recording Station
🟥	Fish Survey Field Site
—	Watercourse
—	Roads
	Contour (40m)
▭	Indian Reserve

REFERENCE

Imagery obtained from Bing Maps for ArcGIS published by Microsoft Corporation, Redmond, WA, May 2009. Indian reserve, road and watercourse data obtained from The Province of British Columbia. Contours obtained from Geogratis. Projection: UTM Zone 10 Datum: NAD 83

CLIENT

SN/MONITORING STRANDING/SQUAMISH

TITLE

SITE LOCATION

Golder Associates
Greater Vancouver Office, B.C.

PROJECT No. 08-1422-0007			PHASE No.	1000
DESIGN	RH	28JULY09	SCALE AS SHOWN	REV. -
GIS	JP	11MAR14	FIGURE 1	
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APPENDIX A

Photographs, Cheakamus Generating Station Stranding Study

Photograph 1: Site 1- Left Upstream Bank (LUB) directly below the Cheakamus Generating Station under lock-out. Allen Lewis II pulling a minnow trap (MT) from an over-night set, April 18, 2009.

Photograph 2: Site 2 - Right Downstream Bank (RDB) of the Tailrace Channel during lock-out, upstream of the bridge, March 27, 2009.

Photograph 3: Site 3 – Right Upstream Bank (RUB) directly in front of the Cheakamus Generating Station, during lock-out, April 18, 2009.

Photograph 4: Site 4 – Left Downstream Bank (LDB) upstream of the bridge at lock-out, April 18, 2009.

Photograph 5: Sites 3 & 4 on the RUB during a must-run, June 3, 2009.

Photograph 6: Site 5 – RDB of the Tailrace Channel downstream of the bridge, under lock-out, February 18, 2009.

Photograph 7: Looking downstream from Site 5 at the Tailrace Channel during high flow, May 20, 2009.

Photograph 8: View of RDB from Site 5 at high flow, May 6, 2009.

Photograph 9: View of RDB from Site 5 at partial flow during power generation ramp-down, May 6, 2009.

Photograph 10: Site 6 – RDB within the Tailrace Channel during lock-out, March 27, 2009.

Photograph 11: Site 7 – LUB at the confluence of the Squamish River Side-channel and the tailrace, low flow, March 27, 2009.

Photograph 12: Site 7 at confluence of side-channel and tailrace during high flow, June 3, 2009.

Photograph 13: Site 8 – RUB of the Squamish River Side-channel, low flow, February 25, 2009.

Photograph 14: View of Site 8 from RUB during high flow must-run, June 3, 2009.

Photograph 15: Site 9 – RDB in the Squamish River Side-channel during low flow conditions, April 18, 2009.

Photograph 16: High flow at Site 9, RDB, May19, 2009.

Photograph 17: Site 10 – LDB immediately downstream of the bridge, lock-out, February 18, 2009.

Photograph 18: View of Site 10 looking upstream from RUB during high flow must-run, June 4, 2009.

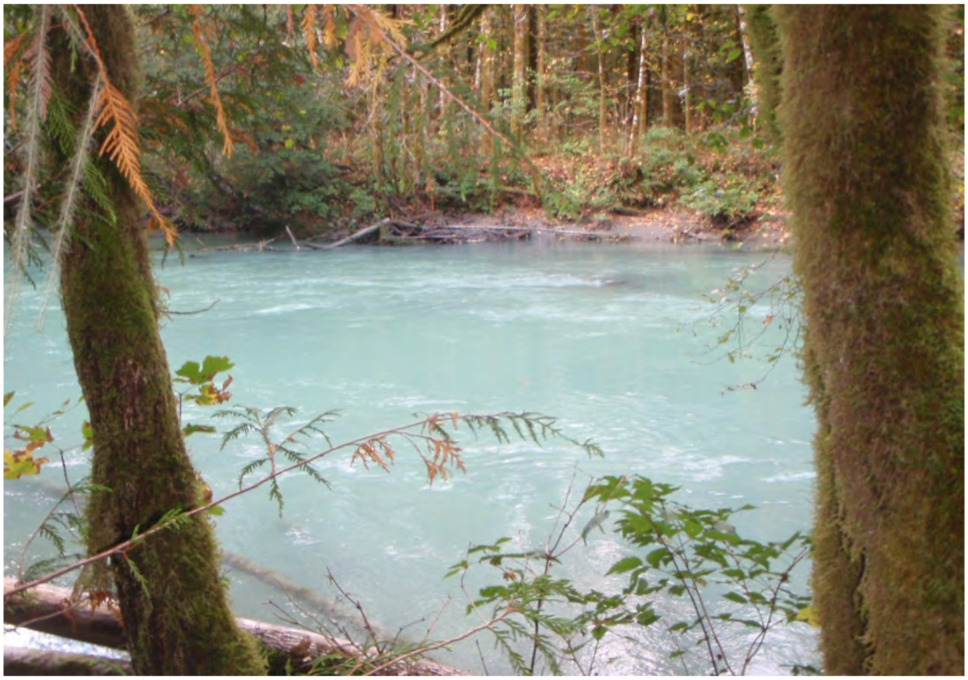
Photograph 19: Site 11 – LDB of Squamish River Side-channel during low flow, March 27, 2009.

Photograph 20: Low flow at Site11, view from RUB looking upstream, March 27, 2009.

Photograph 21: High flow at Site 11 during a power generation "must-run," view from RUB, May 6, 2009.

Photograph 22: Partial flow at Site 11 during power generation ramp-down, view from RUB looking upstream, May 6, 2009.

Photograph 23: Site 12 – RDB immediately below confluence of tailrace and Squamish River side-channel, looking downstream at low flow lock-out conditions, March 13, 2009.



Photograph 24: Site 12 – View from LDB across to RDB during high flow conditions, October 2, 2009.

Photograph 25: Use of Beach Seine (SN) at Site 10, March 26, 2009.

Photograph 26: Snorkel Swim (SW) at Site 8, April 18, 2009.

Photograph 27: Juvenile Coho salmon (Oncorhychus kisutch) caught in MT at Site 8, April 18, 2009.

Photograph 28: Juvenile Chinook salmon (Oncorhynchus tshawytscha) caught in MT at Site 6, November 18, 2009.

Photograph 29: Adult Pink salmon (Oncorhynchus gorbuscha) carcass observed at Site 7, September 22, 2009.

Photograph 30: Rainbow trout/Steelhead (Oncorhynchus mykiss) parr caught in MT at Site 12, March 27, 2009.

Photograph 31: Dolly Varden (Salvelinus malma) parr caught in MT at Site 4, March 27, 2009.

Photograph 32: Unidentified adult salmon species found dead instream, September 22, 2009.

Photograph 33: *Rainbow trout/Steelhead (Oncorhychus mykiss) parr found dead and stranded at Site 8, April 17, 2009.*

Photograph 34: *Salmon eggs found stranded behind large rock at Site 2, September 22, 2009.*

Photograph 35: Coho smolt (Oncorhychus kisutch) found dead and stranded downstream of Site 8, October 30, 2009.

Photograph 36: Adult Chinook salmon (Oncorhynchus tshawytscha) by gravel area at Site 10, October 15, 2009.

Photograph 37: Constructed riffle and pool habitat at Site 8, October 30, 2009.

Photograph 38: Adult Chinook salmon (Oncorhynchus tshawytscha) moving through constructed habitat at Site 8, October 15, 2009.

Photograph 39: Adult Chinook (Oncorhycus tshawytscha) below CGS at Site 3, October 15, 2009.

Photograph 40: Female Pink salmon (Oncorhychus gorbuscha) displaying redd-guarding behaviour towards an adult Steelhead (Oncorhynchus mykiss) at Site 12, October 15, 2009.

APPENDIX B

Water Quality Table

Table 1: Water Quality Readings from Upper and Lower Sections of the Tailrace Channel and Squamish River side-channel.

Field Visit	Date	DO (mg/L)		Temperature (°C)	
		Upper Channel	Lower Channel	Upper Channel	Lower Channel
1	September 22/2008	7.37	8.75	12.55	10.75
2	November 17/2008	13.68	13.58	5.65	5.74
3	February 18/2009	11.74	11.40	4.39	4.30
4	February 24-25/2009	11.25	11.78	2.49	2.79
5	March 14-15/2009	10.43	9.88	3.18	3.40
6	March 26-27/2009	10.12	10.58	5.51	4.37
7	April 17-18/2009	12.84	13.18	5.58	4.66
8	May 6-7/2009	13.61	13.83	5.81	5.83
9	May 20-21/2009	14.99	16.23	7.10	7.04
10	June 3-4/2009	13.94	13.81	8.61	8.69
11	July 21-22/2009	10.73	10.97	14.90	14.71
12	August 6-7/2009	10.41	10.71	15.22	14.82
13	August 20-21/2009	11.05	10.83	14.44	14.11
14	September 16/2009	n/a	n/a	n/a	n/a
15	September 22/2009	n/a	n/a	n/a	n/a
16	October 2-3/2009	13.75	14.09	9.02	9.02
17	October 15-16/2009	n/a	n/a	n/a	n/a
18	October 30/2009	10.36	11.50	7.71	6.83
19	November 17-18/2009	13.39	13.45	3.37	3.42
20	December 18/2009	12.46	12.93	2.54	3.33

n/a – Water Quality readings not taken

Table 2: Water Quality Readings from the sampling Sites in the Tailrace Channel and Squamish River side-channel.

Field Visit	Date	Water Quality Parameter	Site #											
			1	2	3	4	5	6	7	8	9	10	11	12
1	September 22/2008	DO (mg/L)	7.6	8.4	5.5	7.2	7.5	7.2	9.1	8.8	8.7	6.5	n/a[1]	n/a
		Temp (°C)	12.7	12.7	13.0	12.6	13.1	11.9	11.3	10.8	10.7	13.1	n/a	n/a
2	November 17/2008	DO (mg/L)	n/a	n/a	n/a	n/a	13.6	13.8	13.6	13.6	13.6	13.8	n/a	n/a
		Temp (°C)	n/a	n/a	n/a	n/a	5.6	5.7	5.6	5.7	5.8	5.7	n/a	n/a
3	February 18/2009	DO (mg/L)	n/a	n/a	11.2	11.2	13.0	n/a	12.3	n/a	11.4	10.9	n/a	n/a
		Temp (°C)	n/a	n/a	4.1	4.1	4.2	n/a	4.4	n/a	4.3	5.0	n/a	n/a
4	February 24-25/2009	DO (mg/L)	11.2	11.3	10.9	11.1	11.6	11.2	10.9	11.5	12.0	11.8	n/a	n/a
		Temp (°C)	2.5	2.5	2.5	2.5	2.5	2.5	2.3	2.7	2.8	2.5	n/a	n/a
5	March 14-15/2009	DO (mg/L)	10.3	11.2	8.5	11.1	11.1	8.3	11.3	9.0	10.0	11.8	10.6	n/a
		Temp (°C)	3.0	3.3	3.5	3.1	2.9	3.7	2.9	3.7	3.5	3.0	3.0	n/a
6	March 26-27/2009	DO (mg/L)	10.2	10.7	10.1	9.8	10.4	9.4	9.9	10.0	10.5	10.5	10.8	11.0
		Temp (°C)	5.4	5.7	5.4	5.4	5.4	5.5	5.6	4.4	4.4	5.7	4.1	4.5
7	April 17-18/2009	DO (mg/L)	12.7	12.7	12.1	12.8	13.1	13.5	13.4	13.3	13.3	12.2	10.4	n/a
		Temp (°C)	5.3	5.5	5.2	5.2	5.5	6.7	5.6	4.7	4.6	5.5	6.1	n/a
8	May 6-7/2009	DO (mg/L)	n/a	n/a	n/a	n/a	13.4	13.4	14.0	13.8	n/a	n/a	n/a	n/a
		Temp (°C)	n/a	n/a	n/a	n/a	5.8	5.8	5.9	5.8	n/a	n/a	n/a	n/a
9	May 20-21/2009	DO (mg/L)	n/a	n/a	n/a	n/a	14.1	15.8	15.7	16.4	15.9	14.4	16.0	15.5
		Temp (°C)	n/a	n/a	n/a	n/a	7.1	7.1	7.1	7.0	7.0	7.1	7.1	7.1
10	June 3-4/2009	DO (mg/L)	n/a	n/a	n/a	n/a	13.6	14.6	13.8	14.2	13.9	13.7	13.9	13.3
		Temp (°C)	n/a	n/a	n/a	n/a	8.7	8.6	8.4	8.6	8.6	8.7	8.7	8.8
11	July 21-22/2009	DO (mg/L)	n/a	n/a	n/a	n/a	10.8	10.8	10.5	11.1	11.1	10.8	11.1	10.6
		Temp (°C)	n/a	n/a	n/a	n/a	14.9	14.9	14.9	14.6	14.4	14.9	14.9	15.0
12	August 6-7/2009	DO (mg/L)	n/a	n/a	n/a	n/a	10.1	10.7	10.3	10.8	10.8	10.6	10.7	10.4
		Temp (°C)	n/a	n/a	n/a	n/a	15.2	15.2	15.2	14.6	14.3	15.2	15.2	15.2

Field Visit	Date	Water Quality Parameter	Site #											
			1	2	3	4	5	6	7	8	9	10	11	12
13	August 20-21/2009	DO (mg/L)	n/a	n/a	n/a	n/a	10.8	11.2	11.2	11.0	10.6	11.0	11.1	10.6
		Temp (°C)	n/a	n/a	n/a	n/a	14.4	14.4	14.4	13.9	13.6	14.5	14.4	14.4
14	September 16/2009	DO (mg/L)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
		Temp (°C)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
15	September 22/2009	DO (mg/L)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
		Temp (°C)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
16	October 2-3/2009	DO (mg/L)	n/a	n/a	n/a	n/a	14.0	13.6	13.5	14.0	13.8	13.9	14.3	14.3
		Temp (°C)	n/a	n/a	n/a	n/a	9.0	9.0	9.1	9.0	9.0	9.0	9.0	9.0
17	October 15-16/2009	DO (mg/L)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
		Temp (°C)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
18	October 30/2009	DO (mg/L)	10.1	10.9	8.4	10.5	11.0	10.7	11.2	11.6	11.4	10.0	11.3	11.6
		Temp (°C)	7.7	7.7	8.1	7.7	7.6	7.6	7.6	6.9	6.9	7.8	6.9	6.8
19	November 17-18/2009	DO (mg/L)	n/a	n/a	n/a	n/a	12.8	13.6	13.2	13.8	13.6	14.0	13.3	13.2
		Temp (°C)	n/a	n/a	n/a	n/a	3.4	3.3	3.3	3.5	3.0	3.4	3.7	3.5
20	December 18/2009	DO (mg/L)	13.1	13.5	10.8	13.1	13.3	12.6	10.0	13.3	13.5	13.3	12.8	12.2
		Temp (°C)	2.3	2.2	3.5	2.5	2.3	2.2	3.2	3.2	3.3	2.3	3.1	3.7

1) “n/a” indicates no readings were taken.

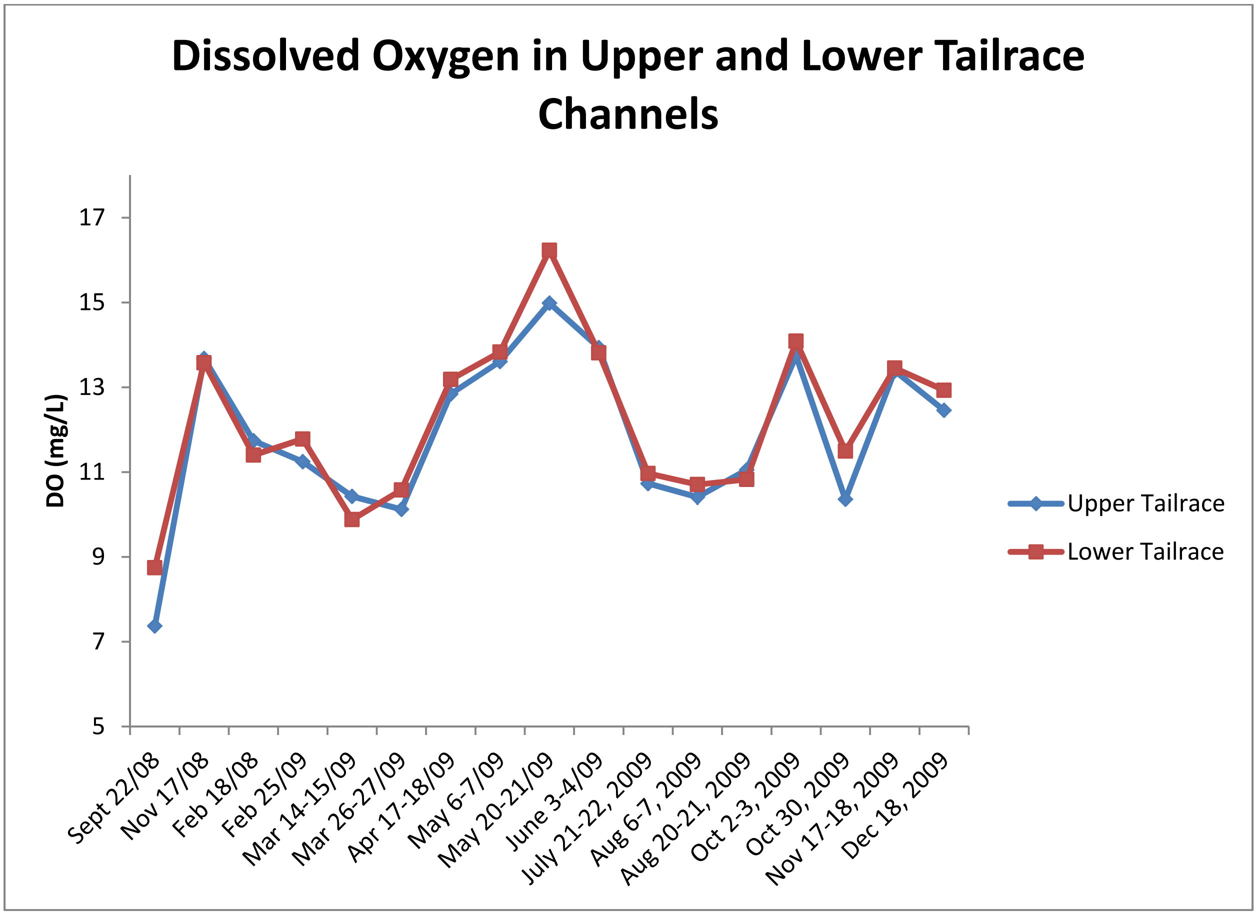


Figure 1: Dissolved Oxygen in Upper and Lower Sections of Tailrace Channel and Squamish River side-channel.

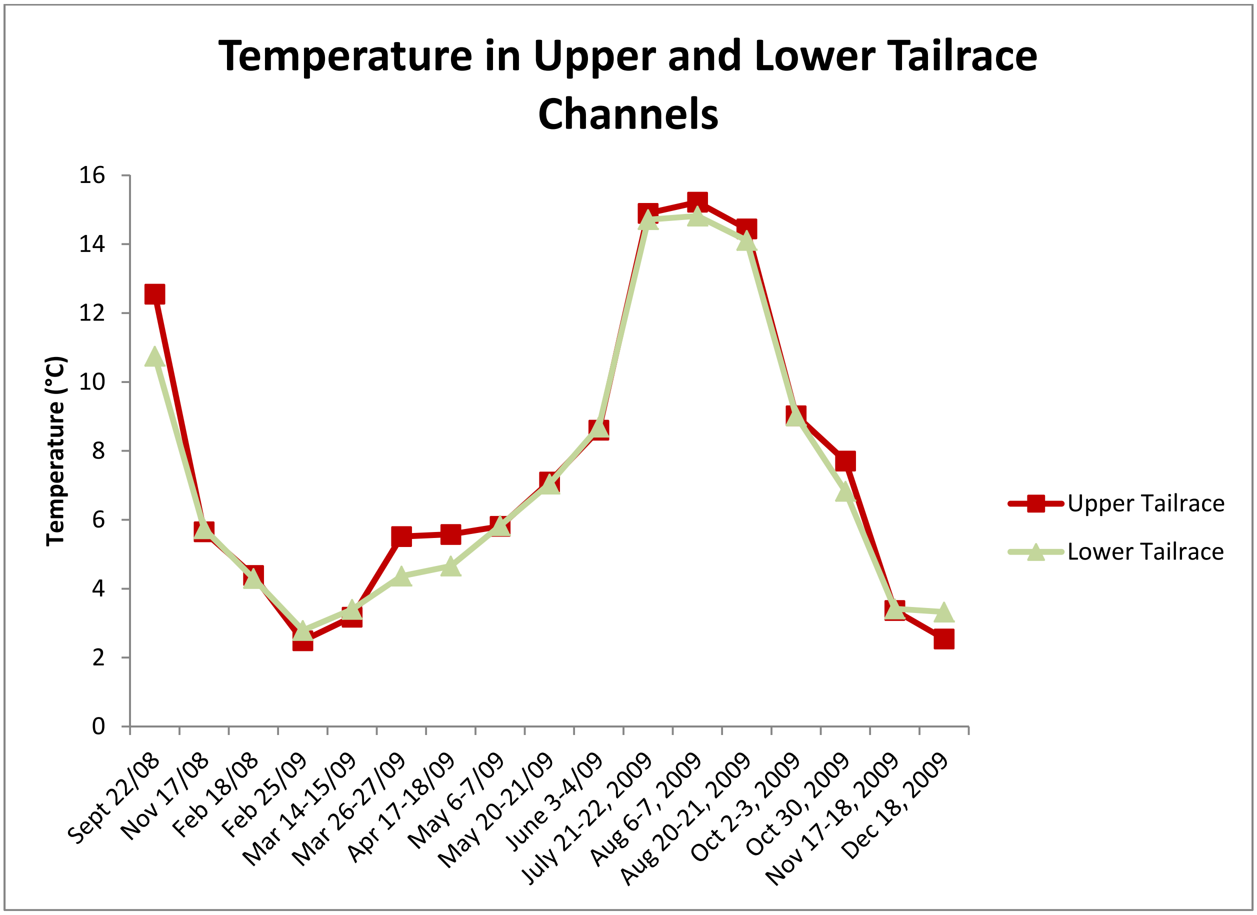


Figure 2: Water Temperature in Upper and Lower Sections of Tailrace Channel and Squamish River side-channel by Sampling Date.

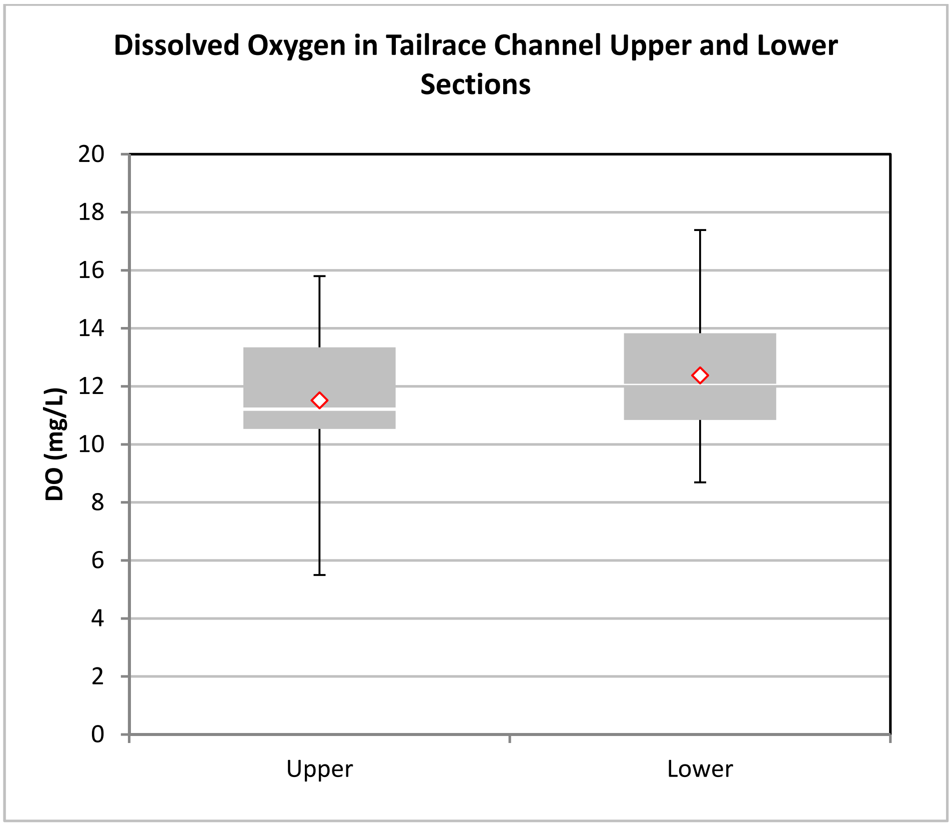


Figure 3: Dissolved Oxygen in Upper and Lower Sections of Tailrace and Squamish River side-channel.

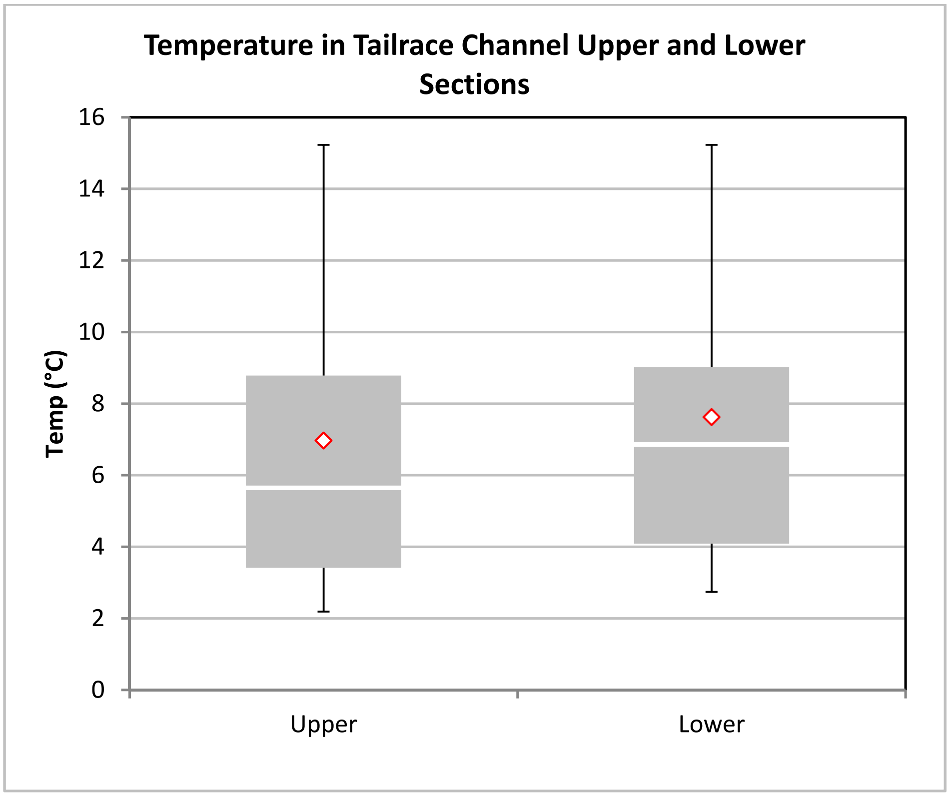


Figure 4: Water Temperature in Upper and Lower Sections of CGS Tailrace Channel and Squamish River side-channel.

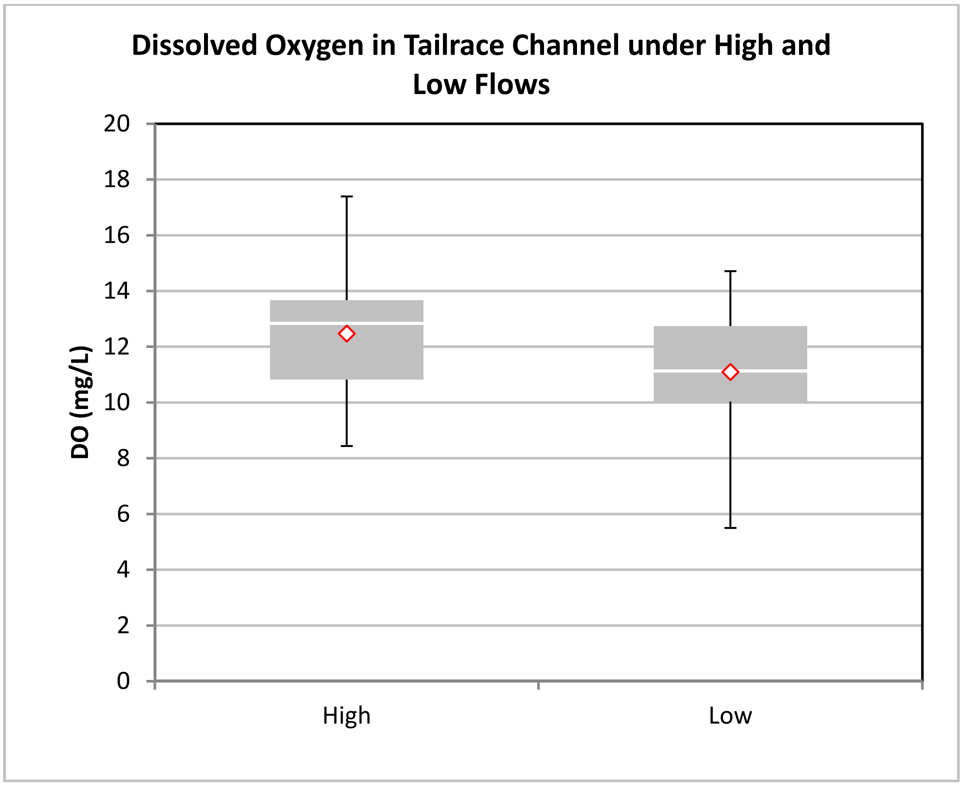


Figure 5: Dissolved Oxygen in the Tailrace and Squamish River side-channel at High and Low Flows Type.

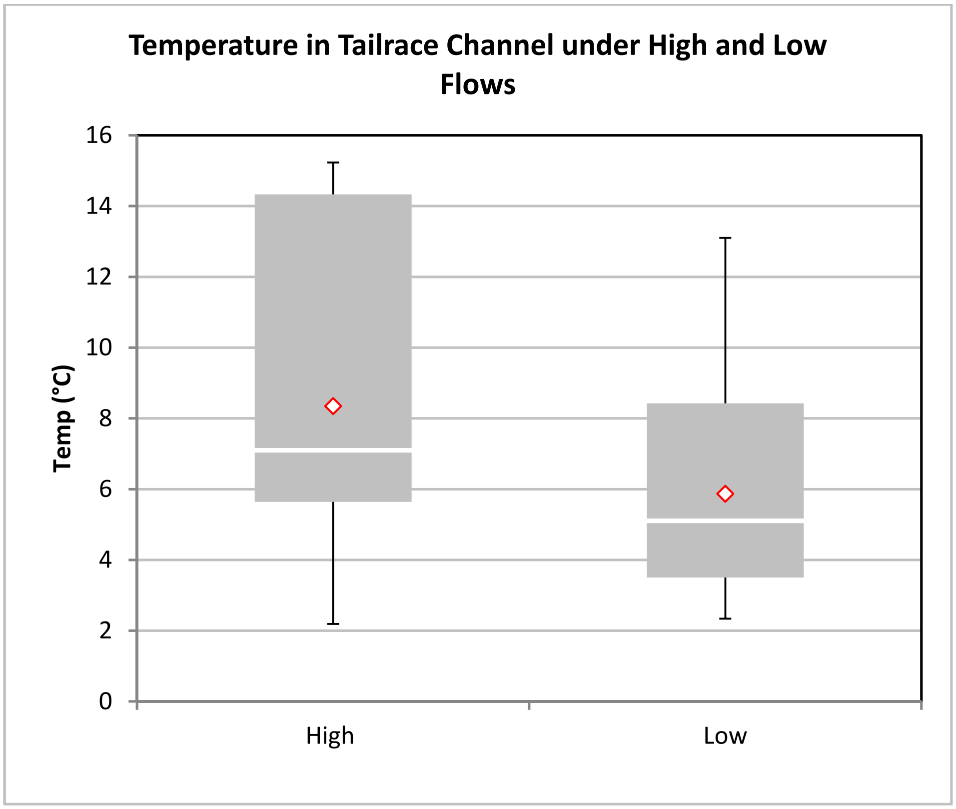


Figure 6: Temperature in the Tailrace and Squamish River side-channel at High and Low Flows.

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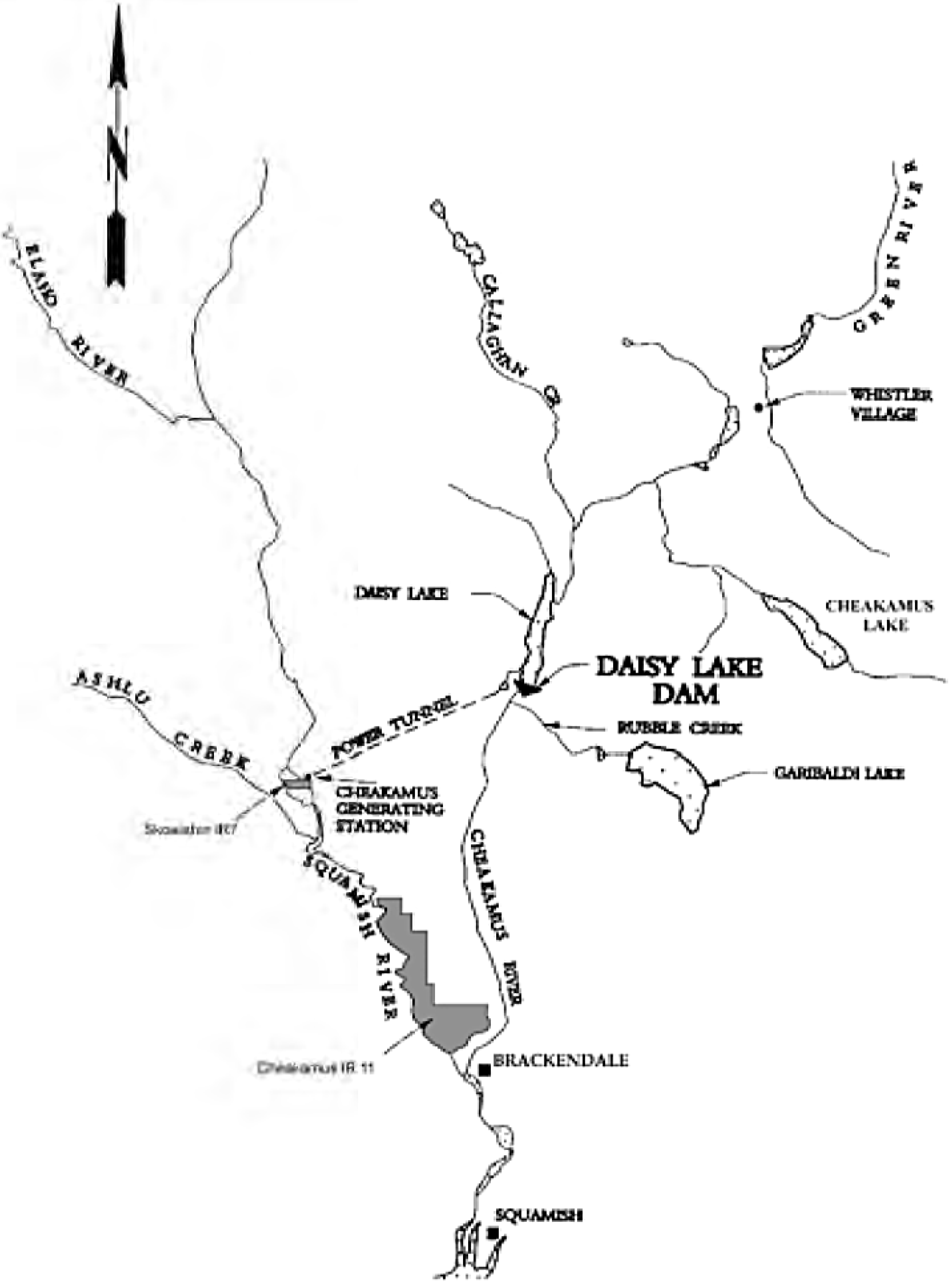
APPENDIX C

Daisy Lake Dam Map

N
ELAHO RIVER
CALLAGHAN
GREEN RIVER
WHISTLER VILLAGE
DAISY LAKE
CHEAKAMUS LAKE
DAISY LAKE DAM
ASHLU CREEK
POWER TUNNEL
RUBBLE CREEK
GARIBALDI LAKE
CHEAKAMUS GENERATING STATION
Skowishin IR7
SQUAMISH RIVER
CHEAKAMUS RIVER
Cheakamus IR 11
BRACKENDALE
SQUAMISH

KEY PLAN

NTS

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