Cheakamus Project Water Use Plan

Monitoring Program Terms of Reference

- **Cheakamus River Juvenile Salmonid Outmigrant Enumeration Monitoring**
- **Cheakamus River Chum Salmon Escapement Monitoring and Mainstem Spawning Groundwater Survey**
- **Trout Abundance Monitor in Cheakamus River (Daisy Lake Dam to Cheakamus Canyon)**
- **Cheakamus River Steelhead Adult Abundance, Fry Emergence-timing, and Juvenile Habitat Use and Abundance Monitoring**
- **Monitoring Stranding Downstream of Cheakamus Generating Station**
- **Monitoring Stranding Downstream of Daisy Lake Dam**
- **Monitoring Groundwater in Side Channels of the Cheakamus River**
- **Cheakamus River Benthic Community Monitoring**
- **Monitoring Channel Morphology in Cheakamus River**
- **Cheakamus River Recreational Angling Access Monitoring**

Revision 1: **February 2007**
1st Submission: **November 2006**

Terms of Reference for the Cheakamus Water Use Plan Effectiveness Monitoring Program

Overview

This document presents Terms of Reference (TOR) for the effectiveness monitoring programs for the Cheakamus Water Use Plan (WUP). These programs will monitor outcomes of the recommended operational changes, and provide information on which to base future operating decisions.

The first submission of the TOR was in November 2006 for the Cheakamus River Juvenile salmonid outmigrant enumeration monitoring program. This document is Revision 1 and provides detailed Terms of Reference for the following programs:

1a) Cheakamus River Juvenile salmonid outmigrant enumeration monitoring: A five-year monitoring program to enumerate juvenile salmonid outmigration from the Cheakamus River mainstem and key side channels. Previously submitted to the Comptroller of Water Rights on 20 November 2006; leave to commence was received 28 November 2006.

1b) Cheakamus River chum salmon escapement monitoring and mainstem spawning groundwater survey: A five-year monitoring program to enumerate chum spawning escapement and examine groundwater in mainstem spawning areas

2) Trout abundance monitor in Cheakamus River (Daisy Lake Dam to Cheakamus canyon): A five-year monitoring program for rainbow trout in the non-anadromous section of the Cheakamus River.

3) Cheakamus River steelhead adult abundance, fry emergence-timing, and juvenile habitat use and abundance monitoring: A five-year monitoring program to examine the effects of mainstem flows on steelhead production.

4) Monitoring stranding downstream of Cheakamus generating station: A three-year monitoring program to examine stranding downstream of the Cheakamus generating station tailrace on the Squamish River.

5) Monitoring stranding downstream of Daisy Lake Dam: A one-year monitoring program to monitor fish stranding downstream of Daisy Dam.

6) Monitoring groundwater in side channels of the Cheakamus River: A five-year program to monitor the effect of Cheakamus mainstem flows on groundwater-fed side channels.

7) Cheakamus River benthic community monitoring: A three-year monitoring program and modelling exercise to examine the effects of mainstem flows on the benthic community.

8) Monitoring channel morphology in Cheakamus River: A five-year monitoring program to examine the effects of flows on channel morphology in the Cheakamus River mainstem.

9) Cheakamus River recreational angling access monitoring: A one-year monitoring program to examine the benefits to recreational angling access (available angling locations) of the 1 January to 31 March 5.0 $m^3 \cdot s^{-1}$ minimum flow release from Daisy Lake Dam.

Cheakamus WUP Monitoring Program #1a: Cheakamus River Juvenile Salmonid Outmigrant Enumeration Monitoring

1.1 Monitoring Program Rationale

1.1.1 Background

The Water Use Plan (WUP) for the Cheakamus River (BC Hydro 2005) includes a flow regime for the Cheakamus River designed to balance environmental, social and economic values. One of the fundamental objectives of the Cheakamus River WUP was to maximize wild fish populations, and the WUP recommended an operating alternative and associated river flow regime based in part on expected benefits to wild fish populations. However, the benefits to fish populations from the new river flows were uncertain because benefits were modelled based on uncertain relationships between fish habitat and flow, and assumed relationships between fish habitat and fish production (Marmorek and Parnell 2002). To help reduce this uncertainty and help determine the impacts of the new flow regime on salmon populations, the WUP Fisheries Technical Committee recommended that the outmigration of juvenile salmon be monitored.

The monitoring program outlined in this Terms of Reference has been developed to examine the effects of the WUP flow regime on the production of juvenile salmonids from the mainstem of the Cheakamus River and major side channels. The program is a continuation and expansion of a program initiated during the consultative process to monitor juvenile outmigration. Operation of two Rotary Screw Traps (RSTs) at River Kilometre 5.5 commenced in the spring of 2000 and is ongoing. This Terms of Reference (TOR) outlines the study plan that has been developed and refined over six years of operation, and includes a number of refinements to increase the precision and accuracy of outmigration estimates, and improve crew safety and fish catches during high water operation. Data from this study will be used in conjunction with data from other monitoring programs to develop stock-recruitment relationships that are critical for separating effects of spawning escapement from flow-related changes in survival during incubation and freshwater rearing (Bradford et al. 2005).

1.1.2 Management Questions

Important management concerns are the effects of discharge on:

i) The production of juvenile salmonids, defined as the total smolt outmigration.

ii) Productivity, defined as the number of smolts per adult spawner at low spawner abundance (i.e., slope of stock-recruitment relationship).

iii) Habitat capacity, defined as the maximum production (outmigration) that the habitat can produce (i.e., asymptote of a stock-recruitment relationship).

The new flow regime is expected to affect habitat capacity and productivity, and hence affect juvenile production. Thus, the key management questions addressed by this monitor are:

1) What is the relation between discharge and juvenile salmonid production, productivity, and habitat capacity of the mainstem and major side channels of the Cheakamus River?

2) Does juvenile salmonid production, productivity, or habitat capacity change following implementation of the WUP flow regime?

1.1.3 Hypotheses

The key ecological null hypotheses examined by this monitor are:

H_1: Flow does not affect smolt production.

$H_{1.1}$: Flow does not affect productivity

$H_{1.2}$: Flow does not affect habitat capacity

H_2: Smolt production does not change following implementation of the WUP operations.

$H_{2.1}$: Productivity does not change following implementation of the WUP operations

$H_{2.2}$: Habitat capacity does not change following implementation of the WUP operations

Discharge can affect many components of salmonid lifehistory in freshwater, such as the quantity and quality of spawning and incubation habitat, and the availability of food and space for rearing. Thus, the new flow regime can affect all species of anadromous salmonids in the Cheakamus River. These hypotheses will be examined for each species for which sufficient data are available (Table 1a-1).

Table 1a-1: Data Sources Available to Examine Hypotheses #1 and 2.

Lifestage	Expect a reasonably precise mainstem estimate?	Expect a reasonably precise side-channel estimate?	Data source
Chum fry	Yes, outmigrants	Yes, outmigrants	This program
Chum spawners	Perhaps, spawners	Perhaps, spawners	Chum escapement, program #1b
Chinook fry	Yes, outmigrants	N/A	This program
Coho smolt	Yes, outmigrants	Yes, outmigrants	This program
Pink fry	Yes if abundant, outmigrants	Yes, outmigrants	This program
Chinook smolt	No, outmigrants	N/A	This program
Steelhead smolt	No, outmigrants	N/A	This program
Steelhead parr (index of late-freshwater production)	Perhaps, spring 'pre-migrants'	N/A	Steelhead abundance, program #3
Steelhead adults	Yes, spawners	N/A	Steelhead abundance, program #3

This juvenile outmigration program is expected to provide reasonably precise mainstem estimates of the chum fry, Chinook fry (age 0 spring outmigrants), pink fry, and coho smolt outmigrations; it has been a challenge to obtain precise estimates of Chinook smolt (age 1 or older spring outmigrants), and steelhead smolt outmigrations (Table 1a-1; Melville and McCubbing 2005). Thus, using the data from this program it should be possible to examine the hypotheses for mainstem juvenile production and habitat capacity for chum fry, Chinook fry, pink fry, and coho smolts, as well as the hypotheses for chum productivity ($H_{1.1}$) using spawner escapement data from the "Cheakamus River chum salmon escapement monitoring and mainstem spawning groundwater survey (#1b)". There may not be sufficient data from the mainstem to examine hypotheses for the other species and lifestages, though the "Cheakamus River steelhead adult abundance, fry emergence-timing, and juvenile habitat use and abundance monitoring (#3)" will examine flow effects on steelhead stock recruitment. Information on steelhead outmigrants from this outmirgration program will provide companion data to support the steelhead program (#3). As such, estimates of steelhead smolt outmigrants will be provided annually to program #3 for use in subsequent analyses.

1.1.4 Key Water Use Decision Affected

The key water use decision that would be informed by the results of the monitoring program would be the flow release from the Daisy Lake Dam. Such changes would affect social and environmental values, and power production in the system.

1.2 Monitoring Program Proposal

1.2.1 Objective and Scope

The objective of this monitor is to collect the data necessary to estimate the annual outmigration of juvenile salmonids from the Cheakamus River mainstem and key side channels. The species of interest are: chum and pink fry, and coho, steelhead and Chinook smolts, though it can be a challenge to obtain precise mainstem estimates for each species (Table 1a-1). In-stream movement of other species and life-stages captured will also be documented, including steelhead parr, coho fry, coast range sculpin (*Cottus aleuticus*) and the Pacific lamprey (*Entophenus tridentatus*).

Juvenile outmigration for all salmonid species will be enumerated with traps and counters at the outlets of key side channels. To provide data to test the hypotheses for Program #6 (Monitoring groundwater in side channels of the Cheakamus River), juvenile outmigration will also be enumerated from groundwater-only fed channels (which for some channels can be considered "tributaries" to larger channel complexes; Figure 1a-2). Based on the species use of individual channels, the outmigration of either fry, smolts or both will be enumerated from select channels.

Fry migration will be monitored as individual estimates at two groundwater channels (Upper Paradise, Kisutch) in order to meet the objectives of Program #6. As well, the entire Upper Paradise/Kisutch/Gorbushca complex will be assessed for fry production. This will be accomplished by using a series of fyke nets and mark-recapture methodology in the side channels to obtain and estimate the contribution to fry production in the Cheakamus.

Juvenile smolt outmigration from side channels will be monitored using manual traps or traps equipped with automated counters at five locations. Juvenile outmigration will be monitored at four ground water only fed channels; Kisutch, BC Rail channels and Tenderfoot channels by automated counter as well a manual trap which will be operated at a new site on Upper Paradise channel upstream of the confluence with Farpoint (which is flow through). This assessment of productivity in groundwater-only channels will meet objectives Program #6. In addition a manual trap will be operated at a new location downstream of the confluence of all channels in the Upper Paradise/Gorbushca area of restoration. This trap has a dual purpose: to monitor production from all channels that enter the Upper Paradise outflow above the RST site (Gorbuschca complex, Kisutch, Upper Paradise, Sue's and Far Point complex) and to provide coho smolts for marking groups required to provide recaptures at the RST site and a subsequent coho smolt production estimate for all the watershed area above the RST site.

The scope of the monitoring, based on the objectives outlined above, is as follows:

- The geographic scope of the monitoring includes the Cheakamus River mainstem and key side channel habitats upstream from river Kilometre 5.5. RSTs will be operated at the site currently being utilized, 5.5 km upstream of the confluence with the Squamish River (Melville and McCubbing 2004) due to various logistics that make this site the most feasible, and for comparison with the previous data available at this location.

- RSTs will attempt to obtain mainstem population estimates (i.e., total outmigration) for: chum fry, pink fry, coho smolts, steelhead smolts, and Chinook smolts. As such, data collection at RSTs will occur during the juvenile outmigration, which occurs from approximately 15 February and 15 June based on historic run timing (as defined by Melville and McCubbing 2000). Total outmigration will be estimated using the mark recapture methodology as developed by Melville and McCubbing 2005 and appropriate analytical methods. It is expected that improvement to the marking and sampling techniques (noted in section 1.2.3) relative , and associated analytical methods (see Task 4 of section 1.2.3) will be explored to attempt to improve population estimates, while ensuring that estimates can be compared with those from previous years.

- Side channel traps will enumerate the same species and life-stages as RSTs. As such, data collection at the side channels will occur from approximately 15 February to 15 June. Total outmigration from each channel will be estimated based on estimates of fence and counter efficiency.

- All species captured in the RSTs and in side channel traps will be documented.

- Monitoring is scheduled to occur annually for five years.

1.2.2 Approach

The monitoring approach is to annually estimate the total juvenile outmigration for each salmon species using downstream trapping methods. This time series of data will be used to examine the effects of flow on juvenile production, productivity, and habitat capacity by comparing variation in juvenile production and discharge. It is anticipated that both differences in the pre-WUP and WUP flow regime, as well as the natural annual variation in seasonal discharge will provide good contrast in flow to examine the effects of discharge on spawning, egg incubation, juvenile rearing, and ultimately juvenile production. Juvenile production is a useful measure that integrates the effects of flow over these many life stages.

The monitoring approach is based on sampling methodologies developed and refined on the Cheakamus River (i.e., Melville and McCubbing 2005), as well as recommendations from quantitative reviews of the program sampling design (Parnell et al. 2003, Bradford et al. 2005).

Separate estimates of production from the Cheakamus River mainstem and key side channels will be used to compare relative production between mainstem and side channel habitats, as well as variation in production between these habitats that may be related to mainstem discharge.

1.2.3 Methods

Task 1: Project Coordination

Project coordination involves the general administrative and technical oversight of the program. This will include but not be limited to:

1) Budget management.

2) Staff selection.

3) Logistic coordination.

4) Technical oversight in field and analysis components.

5) Liaison with regulatory agencies and other stakeholders.

Coordination with WUP Monitoring and Other Monitoring Programs

To help answer high-level questions regarding the relation between Cheakamus River discharge and fish production, data from this juvenile downstream migrant program will ultimately be used in combination with data from the adult chum escapement program (Program #1b), the steelhead monitoring program (#3), the groundwater in side channels monitoring program (#6), and possibly other WUP monitoring programs. Therefore, it is critical that data collection is coordinated among programs.

To ensure that data collection is coordinated among the inter-related monitoring programs for the Cheakamus WUP, an important task for this program is to develop and maintain communication with project leads for the other monitoring programs.

This communication could involve a workshop at the start of the field season to ensure that the trapping locations and methodologies will meet the data requirements of the other programs, and vice-versa. Logistical changes within the scope of the monitoring program may be required.

To help distinguish between natural and hatchery production, the proponent will maintain communication with hatchery staff (i.e., Tenderfoot hatchery, North Vancouver Outdoor School hatchery) to determine and coordinate with the location and timing of hatchery releases, and determine if modifications to the trapping methodology are needed distinguish downstream migration of hatchery and naturally produced fish. At a minimum, annual reporting will summarize data on hatchery releases, the ability to distinguish hatchery and wild juveniles, and the influence of these releases, if any, on catches and abundance estimates for wild fish. To date, hatchery releases have not affected outmigration estimates for the key species of interest noted in Table 1a-1 (Melville and McCubbing 2005).

Task 2: Mainstem RST Trapping

RST Installation and Removal

To date temporary cableways and winch systems have been installed attached to large cottonwoods on the right bank and a fairly mature cedar on the left bank. A breakaway on the left bank is part of the cable system as a safety in case of cable failure. At the present discharge curve traps can be operated safely at a maximum of 70 $m^3 \bullet s^{-1}$. As well there is the risk of the mature cottonwoods failing. Therefore, permanent mooring points to operate three RSTs and with larger cable to withstand higher discharge will be designed and installed. This mooring will increase operation safety as well as the ability to fish in higher flows (>50 $m^3 \bullet s^{-1}$), thus improve the accuracy and precision of population estimates. Design and installation of the moorings is a priority and should commence in the first year of the monitor.

Two RSTs have previously been fished in this program and the minimum use of two RSTs will continue under this TOR. In addition, to increase capture efficiency during higher discharge, and thus confidence in population estimation, a third RST will be installed and operated when the flows and wetted width permit. This would increase the number of fish caught (for marking Steelhead/Chinook) and recaptured.

Note: The bank full width (~40m) would preclude the operation of more than three RSTs at this site.

Annual RST installation at the North Vancouver Outdoor School Site will commence on approximately 10 February in order for trapping to commence on 15 February. This will include installing the cable systems and replacing any worn components to ensure they are sound and assembly of all traps. Two RST will be installed at the start of trapping and the third will be added as warranted when discharge increases. Annual removal of all traps and cable ways would be completed by 30 June.

RST Operation

The RSTs will be positioned in the channel to maximize fish capture, as in previous years (e.g., Melville and McCubbing 2005). Particular emphasis is placed on sampling locations and velocities for steelhead smolt capture during their migration.

The RSTs will be monitored every day throughout the sample period. All fish will be counted, marked (where appropriate, see Task #4 below) and biological data collected. Each trap will be checked again in the late afternoon/evening for debris build up, if warranted. Further checks or continuous monitoring will be undertaken during high water events this requirement being determined by the onsite supervisor. Sampling and marking of juvenile salmonids at the RST site will be undertaken as per previous study years. Debris will be removed on all checks.

A temperature logger will be installed at the RST site from 15 February to 15 June, as well as a permanent manual water gauge to assist with monitoring discharge instantaneously for operational decisions. Hourly discharge measurements from the Water Survey of Canada (WSC) for the Cheakamus River at Brackendale (WSC 08GA043), located 100 m upstream of the trap site will be utilized for data analysis.

A set of drums for the RSTs with a larger mesh size than previously used (Melville and McCubbing 2005) will be installed at higher discharges to reduce water resistance, thus increasing the ability to operate the traps during the peak of smolt migration. These drums would be exchanged with the existing drums on or about 30 April when the majority of the fry migration (chum, pink and chinook) is complete and the smolt migration is beginning to increase (run-timing information from 2000-2005 reports). This will increase smolt capture as discharges increase (Figure 1a-1) by reducing the effects of algal blooms that typically clog small meshed drums, reducing attractive flow and fish capture.

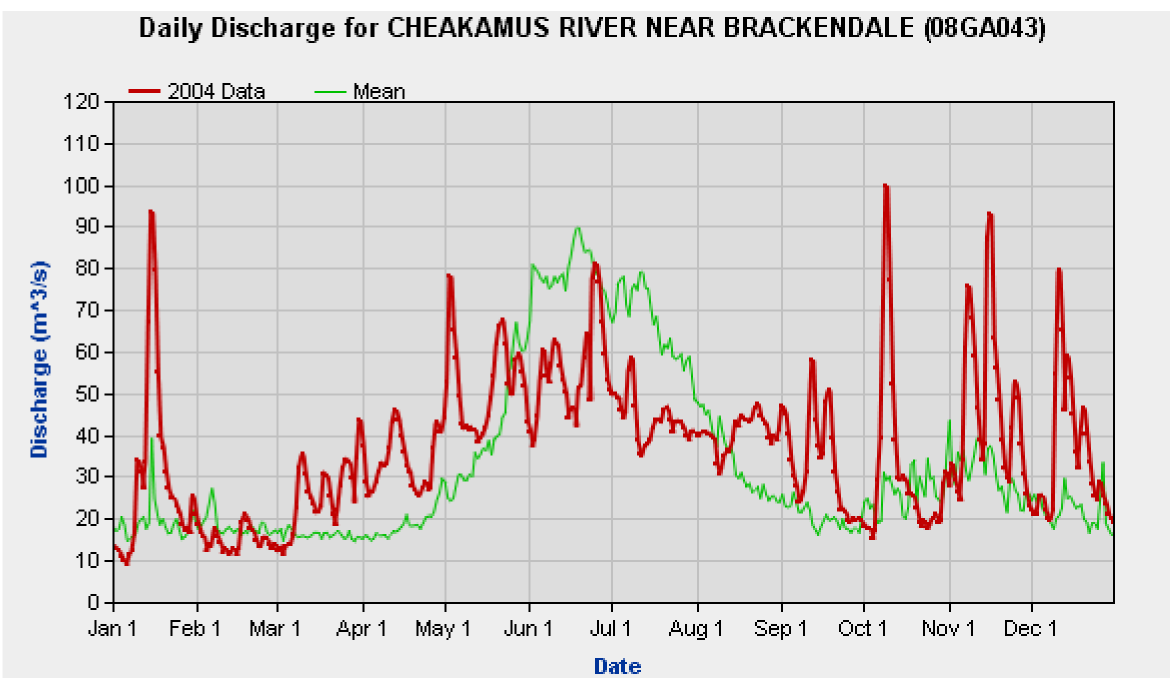

Figure 1a-1: Daily Discharge for the Cheakamus River near Brackendale in 2004, and the Average Over the Period of Record

Task 3: Side Channel Trapping

Fry Trapping, Installation and Removal

Based on historic outmigation timing of chum, pink and chinook fry, fyke nets will be installed in Upper Paradise, Kisutch. and Gorbushca such that they can begin operation 15 February to enumerate fry outmigrations.

To provide data for Program #6 (Monitoring groundwater in side channels of the Cheakamus River) enumeration of fry from groundwater-only side channels (Upper Paradise, and Kisutch) will be undertaken. Two fyke nets will be installed in each of these channels (fyke net sites a to d in Figure 1a-2) in order to estimate fry production utilizing mark-recapture methodology as described in Melville and McCubbing 2004. Briefly; an upstream fyke net and trap box will be used to capture fish for marking using Neutral Red dye, these fish will then be released for recapture in the downstream trap on each groundwater channel and a mark-recapture population estimate will be calculated for each channel (Figure 1a-2).

To enumerate total fry production of the Upper Paradise/Gorbushca channel complex two additional fyke nets (e and f in Figure 1a-2) will be installed; one in Gorbushca channel and one at the new diversion weir. The Gorbushca fyke will be used to obtain fry for marking as described above and the fyke located just upstream of the new Upper Paradise/Gorbushca diversion weir will be used to estimate total fry production from the entire side channel complex (Figure 1a-2).

Fry species will be determined manually at each trap site where fish are being processed by field personnel. The fry enumeration in side channels will continue until numbers drop to near zero, normally 30 April 30.

Tenderfoot Creek will not be enumerated for fry as confounding factors from hatchery influences and logistical issues (higher flows, hatchery releases) are likely not conducive to successful fry enumeration.

1. Smolt Trapping Installation and Removal:

Side channel full span diversion weirs will be operated to enumerate smolt outmigrations from the Upper Paradise/Gorbushca, BC Rail and Tenderfoot channels. Based on historic run timing (Melville and McCubbing, 2005) traps will be installed such that enumeration of smolts can commence on 1 April. As part of Program #6 groundwater-fed sections of the Kisutch channel and Upper Paradise channel will also be monitored, for a total of five smolt trapping locations (Figure 1a-2).

Trap designs will be site specific (Table 1a-2) but will consist of a full span diversion weir that directs all smolts to a holding box for subsequent manual counting and or passive electronic enumeration. Fence and trap box efficiency will be periodically checked by release of marked fish upstream of the trap location (McCubbing and

Ward 2004). Counter efficiency will be assessed through video validation with digital video equipment (Galesloot 2004). Species identification will be conducted manually for smolts at Upper Paradise and Upper Paradise/Gorbushca Channels, and by video and sub sampling at Kisutch, BC Rail and Tenderfoot Channels.

Site 1: Upper Paradise/Gorbushca

The new trapping site on the Upper Paradise/Gorbushca Restoration Channel will be located below the confluence of all the channels that exit via Upper Paradise (Figure 1a-2) and would also be utilized by the adult Chum enumeration monitor (Chum Escapement Program #1b). The location will facilitate the enumeration of all juvenile species form this large network of channels and increase fish numbers available for marking for the RST efficiency estimate of coho smolts (see Melville and McCubbing 2005), and a similar opportunity will be explored for steelhead smolts. It will consist of a concrete sill and full span diversion weir into a trap box.

Site 2: New Upper Paradise

This site will be located upstream of the confluence of Farpoint channel and Upper Paradise, and upstream of the new ‘Emerson’ channel proposal. Data collection will be linked to Program #6 (Ground water side channel study). This trap will also be a secondary marking location for smolts, mitigating the loss of fish available to mark by the occasional backwatering of Site 1 (occurs at ~100 $m^3 \cdot s^{-1}$ see Figure 1a-1). It will consist of a sill and full span diversion weir into a trap box.

Sites 3, 4 and 5: Kisutch, BC Rail, and Tenderfoot Creek

At Kisutch, BC Rail and Tenderfoot Channel automated counters (Logie 2100C, Aquantic Ltd. or comparable counter) will be used for the enumeration of coho and other (few previously observed <0.1% total production) smolts. Counter efficiency will be validated using digital VCR. The diversion design will incorporate the option to trap and mark a portion of the smolt outmigration if required for RST monitoring and/or species partitioning. The Tenderfoot trap will not be operated during smolt hatchery releases. Resistivity tube counters have been proven to accurately assess fish migrations within acceptable efficiencies, >90% accuracy (Galesloot 2004, McCubbing et al. 1999). The counter infrastructure required will be the same as used in adult chum monitoring program (program 1b), except for the “leads” tube sensors and trap boxes, which will be of a size suitable to pass chum fry but divert smolts. Four tubes will be utilized to enumerate coho and other smolts at each site, with sub-sampling or video utilized to separate species. All side channel traps will be removed commencing 15 June.

Table 1a-2: Summary of Trap Sites and Methods for Juvenile Salmonids on the Cheakamus River Mainstem and Side Channels. Trap numbers correspond to Figure 1a-2.

Trap	Design	Target Species	Enumeration Method	Channel Type	Data Requirement
Upper Paradise/ Gorbushca	Full span diversion and trap	Coho smolts and other smolts (few)	Total count manual (trap efficiency check)	Groundwater and mainstem intake	Side channel production and RST marking site
Smolts and fry (#1 and e-f)	Partial Fry Trap utilizing fyke nets	All fry	Mark recapture estimate		
Upper Paradise	Full span diversion and trap	Coho smolts and other smolts (few)	Total count manual (trap efficiency check)	Groundwater	Ground water side channel production and back-up for smolt mark-groups
Smolts and fry (#2 and a-b)	Partial Fry Trap utilizing fyke nets	All fry	Mark recapture estimate		
Kisutch Smolts and fry (#3 and c-d)	Diversion fence box and counter tubes	Coho smolts and other smolts (few)	Total count manual (trap efficiency check)	Groundwater	Side channel production and Ground water
	Partial Fry Trap utilizing fyke nets	All fry	Mark recapture estimate		
BC Rail Smolts only (#4)	Diversion fence box and counter tubes	Coho smolts and other smolts (few)	Total count corrected for efficiency	Groundwater	Side channel production and Ground water
Tenderfoot Smolts only (#5)	Diversion fence box and counter tubes Partial Fry Trap utilizing fyke nets	Coho smolts and other smolts (few)	Total count corrected for efficiency	Groundwater (and other source?)	Side channel production and Ground water but hatchery influence
RST Site All species and age	RST (3)	All smolts and fry	Mark recapture estimate	Not applicable	Mainstem estimator

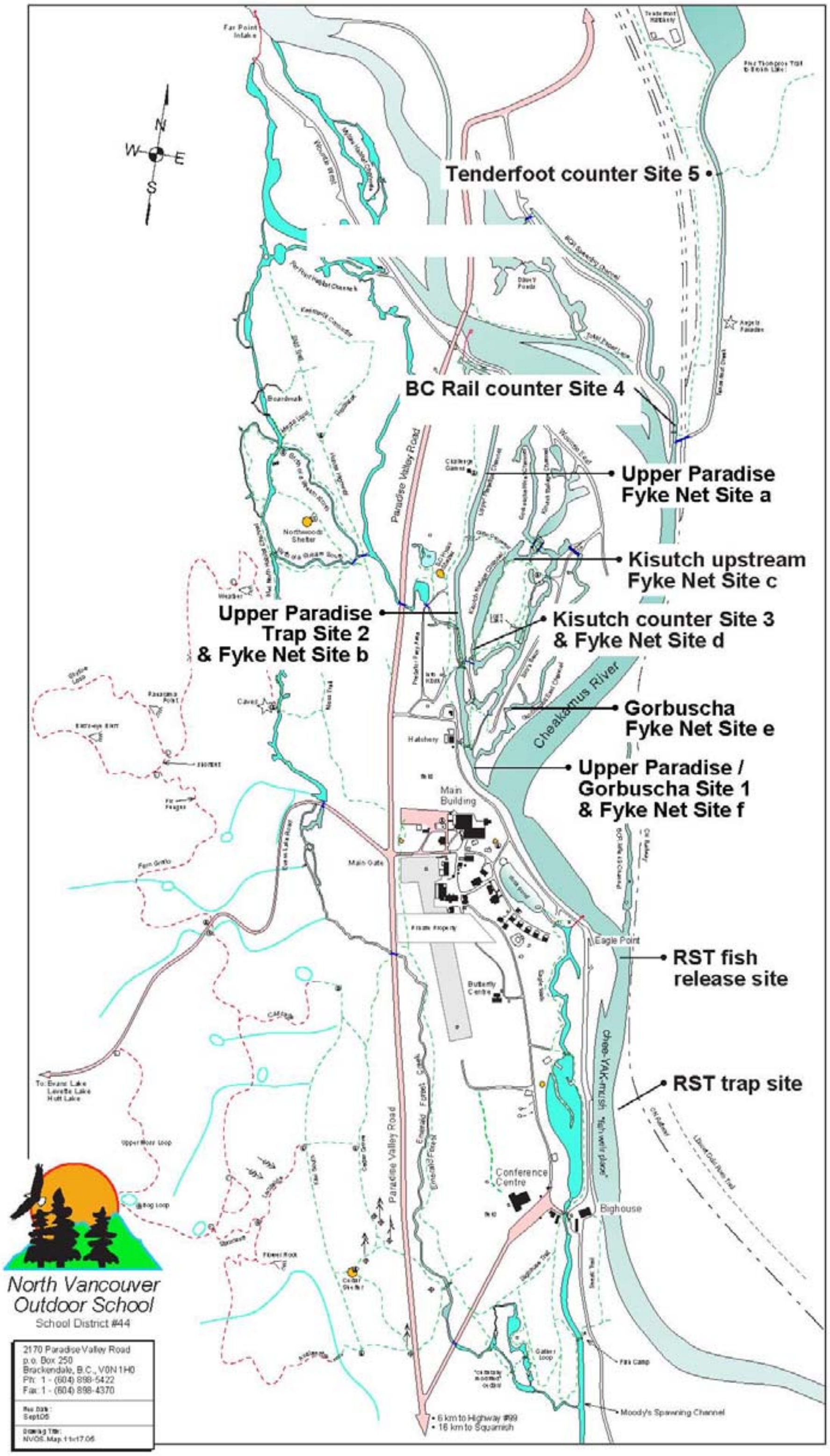

Figure 1a-2: Trapping and Release Sites for the Cheakamus River Juvenile Monitoring Program

Task 4: Trap Operation, Mark Group Methodology and Biosampling

Methodologies for developing mark groups for population estimation are site specific to the Cheakamus and have been developed over six years of operation (Melville and McCubbing 2005), and these methods are outlined briefly below. These methods are assessed as the best methods available taking into account, fish health, site logistics/access, crew safety and to full-fill the assumptions of mark-recapture methodology as outlined in Seber (1982).

Fry

Based on observations of fry mortality and recapture the following method of marking and release is utilized.

In order to assess catch efficiency of salmonid fry at the RST site a percentage of fish captured in each trap will be marked in the late afternoon/early evening and released immediately ~500 m upstream of the capture site. The percentage marked is based on sampling logistics and in-season professional opinion. Pink, chum and chinook fry will be marked for four consecutive days each week by immersion in aerated Bismark Brown Y dye at a concentration 1:100,000, for one to two hours depending on the number of fry and the water temperature. In order to separate release groups into weekly marking strata (Melville and McCubbing 2005), a three-day period with no marking and releases will follow the four consecutive days of marking and release.

Estimates of side channel fry production will be calculated using the methods prescribed in McCubbing and Melville 2004. Briefly, fry will be captured in upstream fyke nets and will be marked in the late afternoon/early evening and released immediately at the upstream fyke net site (a minimum of 100+ m upstream of downstream recapture site). Pink, chum and chinook fry will be marked as described for RST fry, except the dye utilized will be Neutral Red. The ratio of marked to unmarked fry at the downstream fyke nets will be used through statistical analysis to estimate total fry yield for each channel as described in Section 2.3.3.

Smolts

Capture efficiency for smolts at the RSTs will be assessed using smolts from two sites. The first will be unmarked smolts captured at the RST site, these smolts will be marked (please see below for marking procedure) at the morning trap check. The RST marked fish will then be transported upstream ~500 m to a holding box and released at dusk. The second group will be captured at the Upper Paradise/Gorbushca trap, marked as above, with a different distinguishing mark that will differentiate side channel marked fish from RST marked fish. These fish will be held in a holding box until dusk and released. Smolt marking will be undertaken on a minimum of six groups of fish stratified by run time and strength. Marking of smolts will occur seven days per week. Recaptures and fish not used for mark groups will be recorded and released ~300 m downstream of each RST trap and immediately downstream of side channel traps.

Smolt marks (unique to each release group) refer to a combination of caudal fin mark(s) and the subdermal injection of a coloured dye using a jet inoculator (Hart and Pritcher, 1969). Prior to dye marking, smolts will be anaesthetized. Caudal fin clips will be of two types: upper caudal (UC) and lower caudal (LC). The caudal fin will be cut dorso-ventrally at a point approximately one-fourth the distance from the tip of the lobe to the caudal peduncle. Coloured dye will be applied either to the upper or lower caudal peduncle, or the pectoral fin with a jet inoculator. The mark is a line on the fin ray approximately 3–4 mm long. Coho and steelhead parr and smolts along with all age classes of chinook will be marked individually, using this method.

Rotary Trap Efficiencies and Population Estimate Calculations

A key challenge in estimating outmigration from the Cheakamus river is the decreasing catchability as flows increase during the spring, often at the same time as outmigration for some species is expected to peak. Historical estimates of run size from Cheakamus River outmigrant data have been calculated using the unstratified Petersen or the temporally-stratified Darroche methods as implemented in SPAS (Arnason et. al. 1996). The unstratified estimates of population size are likely quite biased because capture efficiency can change dramatically over the sampling period. The stratified estimator can be difficult to implement using data from the Cheakamus because there are sometimes very low or zero recaptures in some strata when trap efficiency is low and/or the amount of fish available to mark within a stratum is small. Reducing the number of strata through pooling may alleviate this problem but can lead to the same biases and uncertainty associated with the unstratified estimator. A new statistical methodology is being developed which the proponent will use for estimating run size and timing from stratified mark-recapture data. The new method will assume that the numbers of fish migrating past a trapping location over successive strata are not independent, but instead exhibit a temporal pattern in abundance determined by a run-timing curve. This assumption can be supported from a meta-analysis of outmigrant data derived from downstream weirs where the numbers of migrating fish are reliably determined. The new method will fit a run-timing curve to the mark-recapture data using Bayesian estimation with priors for run timing and process variation in the run-timing curve developed from the meta-analysis.

Discharge data required for these calculations can be obtained from BC Hydro, WSC gauges, and the inflow monitoring component of the channel morphology monitoring program (#8).

Note: Minor changes in marking methodology outlined above (i.e., the number of mark groups/strata) may be warranted as an improved estimation methodology is developed.

Bio-sampling

For chum, pink, chinook and coho fry a maximum of 25 of each species will be sampled for length and weight bi-weekly at the RST site and Upper Paradise/Gorbushca site.

For coho, chinook and steelhead parr and smolts approximately twenty per cent of the day’s catch up to 25 per day of each will be sampled for length to the nearest millimetre. Twice weekly each species will also be sampled for weight to the nearest tenth of a gram. Scale samples will be taken stratified by migration timing and size for each species (Ward et al. 1989), and aged. Bio sampling will be undertaken at the RST site and the Upper Paradise/Gorbushca trap site.

Modifications to sampling regime in consultation with the contract monitor may be made in-season based on numbers of fish captured.

Task 5: Temperature Logging

A need to have annual temperature logger stations on the Cheakamus River to meet the needs of the various ongoing environmental studies has been identified. As the juvenile downstream migrant study has a large daily field component it has been decided to include the collection and distribution of annual river temperature data within the TOR.

Five sites will be monitored for temperature:

1) Between Daisy Dam and Rubble Creek.
2) Between Rubble Creek and the Cheakamus Canyon.
3) Downstream of the Cheakamus Canyon and upstream of Culliton Creek.
4) Rotary Screw Trap Site.
5) Downstream of Cheekye River.

Two loggers will be installed at each site (as back up) and temperature will be logged hourly, 365 days per year. The loggers will be downloaded bimonthly. Data will be made available to the Project Biologist for all other BC Hydro monitoring studies.

Task 6: Data Analysis and Reporting

Different analytical models with different assumptions are available to calculate the total outmigration. In addition, new analytical tools are being developed (see Task 4) that may be more suitable for challenging conditions on the Cheakamus River of decreasing catchability with increasing discharge. Hence, a component of the data analysis in Year 1 will be to hold a workshop with regulatory agencies and interested parties to review the analytical methods, discuss the assumptions for each method, and ultimately determine the most appropriate analytical method to use for this program.

A report will be prepared annually that:

a) Re-iterate the objective and scope of the monitor.
b) Presents the methods used for data collection.
c) Describes the compiled data set and presents the results of all analyses, including;
    - Biophysical data.
    - Biological data – length, weight, age, condition, length at age.
    - Run timing data – capture through time.

- Fry and smolt yield estimate– Peterson estimates, and associated precision. Also a comparison with previous data collection.
- Mainstem and side channel production.
- Hatchery vs. wild production.
- Operational difficulties.

d) Discusses the consequences of these results as they pertain to the current WUP operation.

A key deliverable of the project each year will be the raw data complied in a standardized database.

In addition, the raw data, data summaries and data analyses from the groundwater-fed channels will be provided annually and in a timely manner to the implementers of the "Groundwater in side channels" monitoring program (#6).

1.2.4 Interpretation of Monitoring Results

The management questions and hypotheses in Sections 1.2 and 1.3 will be examined for each species and life stage for which reasonably precise outmigration estimates can be obtained (see Table 1a-1). Management Question 1 and Hypothesis 1 address specific relations between seasonal discharge and smolt production. As such, ecologically relevant metrics of discharge (i.e., peak discharge during chum egg incubation, minimum weekly discharge during the coho growing season) will be calculated for use in subsequent correlation analyses with smolt outmigration. Such analyses may provide a useful diagnostic tool to examine flow effects. Management Question 2 and Hypothesis 2 address the more general trends in smolt production following implementation of the WUP flow regime, and as such analyses will follow a general before-after approach using the outmigration data collected prior to implementation of the WUP flow regime.

The sampling and subsequent analytical challenges outlined above for obtaining precise outmigrant estimates for some species (Table 1a-1) in the Cheakamus River may limit the strength of the inferences that can be drawn from the monitoring data, or increase the duration of monitoring required to determine the effect of flow (Bradford et al. 2005). Refinements to the sampling and analytical techniques outlined in these Terms of Reference should help to address these challenges. Despite these challenges, a quantitative review (Parnell et al. 2003) of the sampling for the analytical components that involve a general before-after approach found that the program had reasonable statistical power to detect large-scale changes in the order of a 50% decrease in coho production or a 100% increase in chum production, given the relatively precise outmigration estimates for these species (Melville and McCubbing 2005).

Information from this program will also be used in combination with data from other monitoring programs to help answer high-level questions regarding the relation between Cheakamus River discharge and fish production (see the "Project Coordination" section above). Data from each program will provide multiple lines of evidence with which to evaluate ecological hypotheses and contribute to continued quantitative and qualitative learning on the response of fish to flow in the Cheakamus River.

Analyses and interpretations from the side channel data will consider any physical alterations or expansions of these channels that may occur in the future.

1.2.5 Schedule

Data will be collected annually for five years. Trapping is scheduled to occur from 15 February to 15 June. Water temperature in the Cheakamus River will be logged year-round and downloaded every second month. The specific timing for individual tasks is described in the Methods section above.

1.2.6 Budget

Table 1a-3 outlines the estimated cost for the monitoring program. The budget assumes that the two RSTs currently (2006) used in the program will be available for use.

Table 1a-3: Cost Estimate for the Cheakamus River Juvenile Salmonid Outmigrant Enumeration Monitoring

Task	Labour	Daily rate	Units					Total Cost
			Yr 1	Yr 2	Yr 3	Yr 4	Yr 5	
Project Coordination	Project Biologist	$600	10	10	10	10	10	$30,000
Installation & removal of cables	Rigging Technicians	$600	10	10	10	10	10	$30,000
Trap installation	Project Biologist	$600	4	4	4	4	4	$12,000
(RST and side channel)	Technician 1	$300	4	4	4	4	4	$6,000
	Technician 2	$300	4	4	4	4	4	$6,000
	Technician 3	$300	4	4	4	4	4	$6,000
	Technician 4	$300	4	4	4	4	4	$6,000
RST & side channel trap operation	Project Biologist	$600	90	90	90	90	90	$270,000
(Feb 15 to Jun 15)	Technician 1	$300	100	100	100	100	100	$150,000
	Technician 2	$300	100	100	100	100	100	$150,000
	Technician 3	$300	70	70	70	70	70	$105,000
	Technician 4	$300	70	70	70	70	70	$105,000
Trap removal	Project Biologist	$600	2	2	2	2	2	$6,000
	Technician 1	$300	2	2	2	2	2	$3,000
	Technician 2	$300	2	2	2	2	2	$3,000
	Technician 3	$300	2	2	2	2	2	$3,000
	Technician 4	$300	2	2	2	2	2	$3,000
Temperature logger downloads	Project Biologist	$600	4	4	4	4	4	$12,000
	Technician 1	$300	4	4	4	4	4	$6,000
Data entry	Project Biologist	$600	15	15	15	15	15	$45,000
	Technician 1	$300	10	10	10	10	10	$15,000
Data analysis and reporting	Analyst	$750	15	5	5	5	5	$26,250
	Project Biologist	$600	15	15	15	15	15	$45,000
	Technician 1	$300	3	3	3	3	3	$4,500
	Contingency	10%	$45,971	$23,121	$24,621	$25,871	$24,621	$144,205
		Subtotal	*$261,521*	*$231,171*	*$232,671*	*$233,921*	*$232,671*	*$1,191,955*
	Expenses	Unit Price						
	Construction of new RST moorings	$50,000	1					$50,000
	Large mesh drums for RST	$7,000	3					$21,000
	RST purchase / replacement	$20,000	1			1		$40,000
	RST maintenance & re-screening	$5,000	2		3		3	$40,000
	Side channel traps	$9,500	5					$47,500
	Side channel trap maintenance	$500		5	5	5	5	$10,000
	Automated counters	$20,000	3					$60,000
	VCR validation equipment	$2,500	3					$7,500
	Fyke net purchase / replacement	$2,000	3			3		$12,000
	Temp loggers & accessories	$1,500	1			1		$3,000
	Field supplies	$4,000	1	1	1	1	1	$20,000
	Mileage	$0.56	11000	11000	11000	11000	11000	$30,800
	Lodging and meals (month)	$2,500	4	4	4	4	4	$50,000
	Report preparation	$500	1	1	1	1	1	$2,500
		Subtotal	*$244,160*	*$23,160*	*$38,160*	*$50,660*	*$38,160*	*$394,300*
	Future Inflation	2%	$10,114	$10,275	$16,577	$23,459	$28,188	$88,613
		Total	**$515,795**	**$264,606**	**$287,408**	**$308,040**	**$299,019**	**$1,674,868**

1.2.7 References

Arnason, A.N., C.W. Kirby, C.J. Schwarz, and J.R. Irvine. 1996. Computer analysis of data from stratified mark-recovery experiments for the estimation of salmon escapements and other populations. Can. Tech. Rep. Fish. Aquat. Sci. 2106 37p.

BC Hydro 2005. Cheakamus Project Water Use Plan – Revised for acceptance by the Comptroller of Water Rights. Prepared by BC Hydro October 1, 2005.

Bradford, M.J., Korman, J., and P.S. Higgins. 2005. Using confidence intervals to estimate the response of salmon populations (*Oncorhynchus* spp.) to experimental habitat alterations. Can. J. Fish. Aquat. Sci. 62:2716-2726.

Marmorek, D. and L.J. Parnell. 2002 Cheakamus River Water Use Plan. Report of the Consultative Committee. Prepared by Essa Technologies Ltd. Vancouver BC. on behalf of the Cheakamus River Consultative Committee. Vancouver, BC. 234pp

McCubbing, D.J.F., and B.R. Ward. 2004. Adult Steelhead Trout and Salmonid Smolt Migration at the Keogh River, B.C. during Winter and Spring 2003. Habitat Conservation Trust Fund Contract Number: CBIO4051. 43p

McCubbing, D.J.F, B.R. Ward, and L. Burroughs. 1999. Salmonid escapement enumeration on the Keogh River: a demonstration of a resistivity counter in British Columbia. Province of British Columbia Fisheries Technical Circular Number 104: 25p.

Melville, C.C. and D. McCubbing. 2000-2005. BC Hydro reports on juvenile chum production – data on file.

Parnell I.J., D.R. Marmorek, B. Lister and J. Korman. 2003. Cheakamus Water Use Plan: Quantitative evaluation of the statistical and cost performance of alternative salmonid monitoring design options. Final report prepared by ESSA Technologies Ltd., Vancouver, BC. for BC Hydro, Burnaby, BC. 81 pp.

Seber, G.A.F. 1982. The estimation of annual abundance and related parameters. 2nd Ed. London: Griffin.

Cheakamus River Monitoring Program #1b: Cheakamus River Chum Salmon Escapement Monitoring and Mainstem Spawning Groundwater Survey

1.1 Monitoring Program Rationale

1.1.1 Background

The Water Use Plan (WUP) for the Cheakamus River (BC Hydro 2005) includes a flow regime for the Cheakamus River designed to balance environmental, social and economic values. One of the fundamental objectives of the Cheakamus River WUP was to maximize wild fish populations, and the WUP recommended an operating alternative and associated river flow regime based in part on expected benefits to wild fish populations. However, the benefits to fish populations from the new river flows were uncertain because benefits were modelled based on uncertain relationships between fish habitat and flow, and assumed relationships between fish habitat and fish production (Marmorek and Parnell 2002). To reduce this uncertainty, the Cheakamus WUP Consultative Committee recommended a number of environmental monitoring programs.

The Cheakamus River chum salmon population was identified during the consultative process as a key-stone indicator species, and the effect of flow on chum salmon spawning and incubation was of particular concern. To reduce this uncertainty, one recommendation was to link adult chum salmon spawner escapement and juvenile out migration data, and use the resultant spawner-fry index (H') as an indicator of flow effects. The potential value of this index was highlighted during an exercise that modelled alternative monitoring designs (Parnell et al. 2003). BC Hydro has monitored Cheakamus River juvenile chum fry outmigration for the last seven years (see Melville and McCubbing 2000-2005) and monitoring of outmigration is planned to continue (see Program #1a). However no accurate adult chum salmon spawner escapement data exists for the Cheakamus watershed and the linkages between adult escapement and juvenile outmigration are currently poorly understood.

Another important uncertainty during the consultative process was the relation between river discharge and groundwater upwelling in mainstem spawning areas. The effective spawning area Performance Measure for chum salmon and other salmon species was influential in the selection of flow alternatives during the consultative process. The performance measure was calculated using a model based on River 2-D simulations, depth, velocity and substrate preference curves, and redd stranding calculations. This model identifies those areas where spawning is likely or unlikely to occur based on depth, velocity and substrate criteria, and thus the approach will overestimate the area of spawning habitat relative to empirical measures (Marmorek and Parnell 2002, Appendix 8, #5). The model does not predict the precise location of spawning. Thus, the model is useful for comparing alternative flows, but does not provide precise measures of spawning habitat. Modelling suggested that lower and more stable flows during the fall (relative to the existing Interim Flow Order) would provide both a larger area suitable for spawning that would also remain wetted during incubation, resulting in relatively greater effective spawning area. This finding, and the modelling approach in general, was uncertain because chum spawning habitat selection can also be driven primarily by groundwater upwelling, and not the surface flow characteristics of water depth/velocity and spawning gravel suitability. It was suggested that lower flows during the fall spawning period would result in reduced surface water-to-groundwater exchange, reduced upwelling, poorer spawning site selection and thus lower chum egg to fry survival, and that the River 2-D modelling had greatly overestimated suitable spawning area under low flows.

The monitoring program outlined in this Terms of Reference has been developed to examine the effects of the WUP flow regime on chum salmon spawning and incubation in the mainstem of the Cheakamus River and major side channels. Monitoring will include two components:

i) Estimating annual escapement of adult chum salmon in the Cheakamus River.

ii) Examining the relation between discharge, groundwater upwelling, and the selection of spawning habitat by chum salmon in the mainstem.

Data from this study will also be used in conjunction with data from other monitoring programs to develop stock-recruitment relationships that are critical for separating effects of spawning escapement from flow-related changes in survival during incubation (Bradford et al. 2005).

1.1.1 Management Questions

The key management questions are:

1) What is the relation between discharge and chum salmon spawning site selection and incubation conditions?

2) Do the models used during the WUP to calculate effective spawning area (based on depth, velocity and substrate) provide an accurate representation of chum salmon spawning site selection, and the availability of spawning habitat?

3) Are there other alternative metrics that better represent chum salmon spawning habitat?

Here, incubation will be measured by as the number outmigrant fry per adult spawner.

1.1.2 Summary of Alternative Hypotheses

The primary null hypotheses (and sub-hypotheses) associated with these management questions are:

H_1: Discharge during the chum salmon spawning and incubation period does not affect productivity, measured as the number of fry per spawner in the mainstem.

This first hypothesis is general, and the specific hypotheses below will assist in diagnosing some likely reason(s) for any observed patterns.

H_2: Spawning chum salmon do not select areas of upwelling groundwater for spawning in the mainstem.

Hypothesis 2 will be tested by overlaying mapping of chum salmon spawning distribution at a site with mapping of water upwelling to determine will determine whether chum salmon spawn more frequently in upwelling areas.

H_3: Discharge during the chum salmon spawning and incubation period does not affect the upwelling of groundwater in mainstem spawning areas.

This third hypothesis examines the link between discharge and surface-subsurface groundwater exchange.

Appropriate, ecologically based metrics of discharge during the incubation period that would be used to test these hypotheses might include peak discharge or minimum weekly discharge.

1.1.3 Key Water Use Decision Affected

The key water use decision that would potentially be affected by the results of the monitoring is the seasonal flow release from the Daisy Dam, in particular, releases during the chum spawning and incubation period. Such changes would affect power generation and other social and environmental values in the Cheakamus River.

1.2 Monitoring Program Proposal

1.2.1 Objective and Scope

The objectives of the program are:

1) Using a stratified marking and recapture regime obtain annual chum salmon spawning escapements for the Cheakamus River upstream of the established juvenile out migration monitoring station.

2) Conduct preliminary surveys to determine if groundwater flows though chum spawning grounds are related to river discharge.

The geographic scope of the monitoring of chum salmon escapement is the anadromous section of Cheakamus River mainstem, and key side channels for chum salmon spawning. The geographic scope of the mainstem spawning groundwater component is selected key spawning areas in the mainstem of the Cheakamus River.

1.2.2 Approach

Chum Adult Escapement Study

Proposals for annual chum escapement estimation should use standardized techniques to allow for robust inter-annual comparisons that will minimize the risk of incorrectly inferring significant changes have occurred to the Cheakamus River chum population as a result of water use.

There are many challenges to estimating chum escapement and spawning distribution in the Cheakamus watershed as there is considerable downstream movement of spawned-out moribund fish among mainstem spawners and low visibility with poor access to all river reaches and side channel complexes when river discharges are high (see Melville and McCubbing 2000; Korman et al. 2002). These conditions create challenges for traditional visual tag mark recapture approaches that are commonly employed in smaller coastal systems. Traditional visual mark recapture escapement surveys involve tagging salmon with external tags followed by detailed foot carcass surveys of all possible spawning grounds. To be robust, this type of survey generally requires tagging upwards of 10 per cent of the total estimated population (current estimated at 80,000 chum, DFO data on file; DFO 1957) to be tagged during the monitor.

For the present monitor a passive mark recapture technique is proposed in place of a traditional mark recapture carcass recovery or visual estimation study. This passive tag recovery approach involves the use of fixed location resistivity fish counters on side channels coupled with PIT (Passively Integrated Transponder) tag readers. PIT tags are small sealed electronic modules with unique identification codes that can be implanted in, or externally attached to juvenile and adult fish. Fixed station river antennas passively monitor movements of fish with tags and record data with logging equipment.

PIT technology has many advantages over externally mounted visual tag techniques and has been extensively used as an accurate adult and juvenile salmonid monitoring tool since the mid 1980s in the Columbia River basin (e.g.. Prentice et al. 1986; Prentice et al. 1990; McCutcheon et al. 1994; Downing et al. 2001; Matter and Stanford 2003) and is currently used in a wide variety of aquatic and terrestrial monitoring programs worldwide (see: www.biomark.com/reference.htm for a bibliography and Thorsteinsson (2002) for additional references).

Stratified tag application of seine net captured chum adults would occur at a single location in the lower mainstem with subsequent detections at all side channels complexes with sizable chum spawning habitat. Radio telemetry will be used to determine spawner distribution upstream and downstream of the current juvenile outmigration monitoring site and residence time during the initial four years of the monitor. This approach will simultaneously parse mainstem and individual side channel spawning populations based on the ratio of tagged fish detections to untagged fish detections and will allow for detailed collection of run time data in each side channel complex (see section the Methods section below for a simplified numerical example).

Development of mark recapture study design and analytical methodology will be set as Task 2 in the first year of the monitor. Models deriving optimal spatial and temporal mark recapture stratification will refine the monitoring fidelity and provide inference about appropriate sample sizes. The benefits and disadvantages of tagging different sex ratios (e.g., tagging females only) will also be examined during this design phase. Efficiency estimates for the resistivity counters, PIT readers and tag retention, are required prior to monitor implementation.

Chum Spawning Habitat Groundwater Selection Study

The approach in this pilot study is to:

i) Map the distribution chum spawning at a site.

ii) Measure and compare and contrast river water downwelling, groundwater upwelling, and other physical characteristics at areas selected and not-selected for spawning.

iii) Measure ii under a range of available discharges to determine the relation between discharge and upwelling.

1.2.3 Methods

Task 1: Project Coordination

Project coordination involves the general administrative and technical oversight of the program. This will include but not be limited to:

1) Budget management.

2) Staff selection.

3) Logistic coordination.

4) Technical oversight in field and analysis components.

5) Liaison with regulatory agencies.

Coordination with WUP Monitoring and Other Monitoring Programs

To help answer high-level questions regarding the relation between Cheakamus River discharge and fish production, data from this chum escapement program will ultimately be used in combination with data from the juvenile outmigration (Program #1a), the groundwater in side channels monitoring program (#6), and possibly other WUP monitoring programs. For instance, physicochemical and other data collected under Task #3 of program #6 will provide useful comparisons for data collected at spawning sites in this program. Therefore, it is critical that data collection is coordinated among programs.

To ensure that data collection is coordinated among the inter-related monitoring programs for the Cheakamus WUP, an important task for this program is to develop and maintain communication with project leads for the other monitoring programs. This could involve a workshop at the start of the field season to ensure that the trapping locations and methodologies will meet the data requirements of the other programs, and vice-versa. Logistical changes within the scope of the program may be required.

Task 2: Chum Adult Escapement

The proportion of total escapement upstream of the current juvenile monitoring station located at the North Vancouver Outdoor School facility will be determined on a year-to-year basis. Differentiation of escapement will allow the monitoring program to accurately calibrate the fry-per-spawner index H' among years and will provide inference about density dependent linkages and their possible affects on the distribution of spawning fish. Mark recapture tagging will be conducted in the lower reach of the Cheakamus River 1–2 km downstream of the Cheekye River confluence and prime spawning habitat to ensure marked fish distribute themselves randomly throughout the spawning reaches.

- Six stratified weekly tagging sessions of 200 (100 each male/female) fresh chum spawners with PIT tags and 20 radio tags will occur at a mainstem river site downstream of the major spawning grounds in early October through mid November. A total of 1200 spawners will be tagged with PIT tags, of which 120 will also be implanted with radio tags. All pit tagged fish will be externally tagged with dorsal Floy tags or other permanent mark to help test PIT tag retention (assumption #3 below).

- PIT tag detection/logging equipment at side channel enumeration sites including Tenderfoot Creek (operated by Tenderfoot Hatchery), BC Rail Creek, Upper Paradise spawning channel (operated in conjunction in NVOS), and Moodies spawning channel (operated in conjunction with Squamish Nation) will monitor upstream spawners. A resistivity type fish counter (e.g., Aprahamian et al. 1996) will be set up concurrently with the pit tag reader and will monitor the total number of upstream fish, including those with PIT tags at all the above channels with the exception of Tenderfoot Creek where fish are manually enumerated by DFO staff.

- Three mainstem directional fixed station radio receivers and one mobile radio tracking unit will be used to survey the side channels and mainstem habitats to determine spawner distribution and to obtain residence time data. Fixed station logging receivers will be located at the juvenile monitoring site, at the bailey bridge, and downstream of the Cheekye River confluence near the Sunwolf recreation centre. Occasional mobile tracking by foot and raft of the Cheakamus may be needed to assess possible downstream movements of fish out of the Cheakamus River. Radio tagging surveys will be scaled back after four years once clear run times and spawner distribution can be established.

- Enumeration confidence will be linked to resistivity counter efficiency (estimated at >90 per cent ; McCubbing et al. 1999), PIT tag detection efficiency (>95 per cent) and tag loss. Foot surveys of side channel complexes with mobile PIT detectors will be completed to compare PIT detection, fish counts, and to derive tag retention estimates in the first two years of the monitor.

A total of 1200 chum spawners will be PIT tagged in lower reaches 1 October through 15 November. PIT tags detectors and resistivity counters monitor side channels for each fish entering the spawning habitat. Telemetry data provides inference on spawner distribution and offers an independent verification of spawner distribution between mainstem and side channel spawning areas, which is used in the calculation of spawner escapement (Table 1b-1).

Table 1b-1: Numerical Example to Illustrate the Monitoring Approach and Calculations Used in the Population Estimate. PIT detections per count represent the number of unique PIT tags detected at a site from the total number of fish enumerated though the site.

Moodies spawning channel	45 PIT detections per 1,500 counts
BC Rail Creek	50 PIT detections per 2,600 counts
Tenderfoot Creek	178 PIT detections per 12,000 counts
Upper Paradise spawning channel	276 PIT detections per 22,000 counts

Total of 549 PIT detections per 38,100 spawners = 69 spawners per detection
Assume equal mix of 69 spawners per PIT tagged spawner in side channel and mainstem
1200 – 549 = 651 PIT tagged individuals not detected in side channel complexes
651 x 69 = 44,919 mainstem fish
Total population estimate: 38,100 side channel + 44,919 mainstem = 83,019 spawners

Assumptions:

1. The population is closed during the period of the study. For adult spawners, this implies that there is no recruitment nor immigration to the spawning population, that death and emigration affect tagged and untagged fish equally, and that all components of the population are vulnerable to either capture or recapture. For this assumption to be valid, it is critical that marks be applied throughout the entire period of adult migration, and that tagged individuals are well mixed within the population at time of recapture.

2. Tagged and untagged fish are correctly identified. If tagged or untagged fish are not detected, the proportion of tagged fish is underestimated in recapture samples, and population abundance is overestimated. Detection efficiency of resistivity counters is >90 per cent in several other river systems in British Columbia (McCubbing et al. 1999; McCubbing and Ignace 1999) and PIT read detection efficiencies ranging from 88 to 100 per cent, have been reported in the literature with efficiency largely dependant on antenna design and migration aperture and most studies observed detection efficiencies of >95 per cent (Prentice et al. 1990; McCutcheon et al. 1994; Castro-Santos et al. 1996).

3. No tags are lost. If tags are lost (due to poor application technique or aggressive behaviour during spawning), the proportion of tagged fish will be also underestimated in the recapture samples, and population abundance will be

overestimated. For visual tags, Schubert et al. (1996) found loss rates from 0 to 2.7 per cent from adult pink salmon, but tag loss of up to 30 per cent has been documented in adult chum salmon (Lister and Harvey 1969). Retention of PIT tags is usually extremely high (96.6 per cent in juvenile *Salmo trutta*, Ombredanne et al. 1998; 99 to 100 per cent in Chinook salmon, *Oncorhynchus tshawytscha*, Prentice et al. 1990). Most salmonid studies indicate PIT tag loss is lowest (< 2 per cent) when tags are properly positioned in the peritoneal cavity. (Prentice et al. 1990; McCutcheon et al. 1994; Buzby and Deegan 1999; Dare 2003) and recent advances in radio frequency identification (RFID) technology have produced larger glass encapsulated tags that might be capable of oral-gastric placement similar to radio tags used in telemetry surveys.

4. Tagging does not change the availability of fish for detection. The stress of capturing, holding and marking fish could lead to behavioural changes which affect a fish's ability to swim upstream, change its availability for detection, or in some cases even cause mortality. Such effects would again cause an underestimate of the percent of fish tagged, and an overestimate of population abundance.

5. Tagged and untagged fish have an equal probability of initial capture and detection. This assumption is generally violated to some extent in all mark-recapture studies (Otis et al. 1978), but can be minimized by making tag application and recovery as representative as possible, through standardized effort and the use of gear with minimal selectivity.

Task 3: Spawning Habitat Groundwater Selection Study

The literature has indicated that chum and other salmonids, in some cases, preferentially select river mainstem spawning areas characterized by directional groundwater (Geist et al. 2002; Salo 1991; Baxter and McPhail 1999). A two-year pilot study is therefore proposed to determine:

i) The extent to which spawning chum select sites with directional groundwater movement.

ii) If changes in intragravel flow conditions through redds are related to river discharge.

Site Selection

Two pairs of mainstem chum spawning areas will be selected where down welling versus upwelling are suspected as indicated by physical features described by Vaux (1968). Given the pilot nature of this component and the limited scope of site selection, the program is not designed such that results can be extrapolated to all mainstem spawning.

Mapping Chum Salmon Spawning

At each area, chum salmon spawning distribution will be mapped by GPS. The timing of spawning at each location will be recorded or estimated, and the corresponding discharge at the time of spawning will be inferred from discharge records.

Physical Characteristics

This study would involve placement of piezometers and temperature recorders (six per study site) and monthly documentation of water levels, temperature and chemistry over the incubation period to identify the strength and direction of intragravel water flows. This monitoring would be conducted between spawning (November) and later stages of incubation (March). These measurements are not expected to be sufficiently sensitive to identify specific groundwater types or sources, such as deep phreatic groundwater versus river water upwelling/downwelling.

Task 4: Analyses

Chum Escapement

Annual escapement estimates for mainstem and side channel spawning areas will be calculated as outlined in Section 1.2. These estimates will be used in conjunction with data from the juvenile outmigration programs (Program #1a) to calculate fry-per-spawner. Once a sufficient time-series of fry-per-spawner has been developed, the analyst will perform further analyses to examine patterns in the data, such as flow or spawner density-dependents effects. Flow data for these analyses can be obtained from Daisy Lake Dam releases (available from BC Hydro Generation Operations), the Water Survey of Canada gauge at Brackendale, and the channel morphology monitoring program (Program #8).

Groundwater and Spawning

Analyses for this component will include mapping of the spawning sites, mapping of areas of upwelling and downwelling under various flows, and analyzing the relation between discharge and the physical measures that indicate directional water exchange. Overlaying the spawning and upwelling / downwelling mapping will determine whether chum salmon are selecting upwelling / downwelling areas. If so, the relation discharge and directional water exchange will be used to meet the study objective of determining if groundwater flows though chum spawning grounds are related to river discharge.

Task 5: Reporting

Following each year of data collection, a data report will provide the background, methods, and results to date. It will also discuss suitability of these novel sampling techniques being employed to the collect the data required. Annual reports will include an Executive Summary outlining the data collected to date, and the status of the program. In addition, the raw data, data summaries, and data analyses for side channel escapement will be provided annually and in a timely manner to the implementers of the "Groundwater in side channels" monitoring program (#6).

Following completion of the groundwater component in Year 3, detailed reporting on this component will be prepared and include:

a) An executive summary of the entire component.
b) A data summary.
c) The analytical procedures.
d) A detailed summary of the findings as they relate to the ecological hypotheses and the key management questions.
e) A summary of remaining uncertainties with respect to the relation between discharge, groundwater flow, chum spawning habitat selection and subsequent incubation survival.
f) The applicability of these techniques to reduce uncertainties in e).

A detailed report for the chum escapement component will be prepared after data collection in Year 5:

a) An executive summary of the entire component.
b) A data summary.
c) The analytical procedures.
d) A detailed summary of the findings as they relate to the ecological hypotheses and the key management questions.
e) Discusses the consequences of these results as they pertain to the current WUP operation.
f) Future monitoring of chum escapement, if any, required to address the management questions and ecological hypotheses.

All reports will be provided in Microsoft Word and Adobe Acrobat (*.pdf) and all maps and figures will be provided in their native format either as embedded objects in the Word file or as separate files. All data collected will be submitted annually in a Microsoft Access Database. The raw data is a key deliverable of this project.

1.2.4 Interpretation of Monitoring Results

Chum Escapement

Escapement estimates for mainstem and side channel spawning areas will be calculated as outlined in Section 1.2. These estimates will be used in conjunction with data from the juvenile outmigration programs (Program #1a) to calculate fry-per-spawner. A stock-recruitment modelling analytical approach that account for spawner density dependent effects will be used to test H_1. While the same WUP base flow regime (BC Hydro 2005) will likely be in place for the duration of monitoring, natural variation is discharge across years is expected to provide the contrast in flow conditions, such as the frequency and duration of discharges greater than the WUP minimum flows, needed to examine the hypotheses and management questions.

Groundwater Spawning

Results from the groundwater component will provide information to future WUP reviews that may help guide future data collection on chum spawning, and may ultimately be used to refine calculations of spawning and incubation performance measures, e.g., by incorporating measures of groundwater-surface water interactions.

1.2.5 Schedule

The chum salmon escapement component is scheduled to occur annually over five years. Given the novel techniques employed in the chum escapement program, the initial two years will involve some “pilot” testing to standardize methodologies and the index sites.

The chum salmon mainstem spawning and groundwater component is scheduled to occur over two years (i.e., two spawning-incubation periods) and is scheduled to begin in Year 2 following implementation of the WUP monitoring programs. This program is essentially a pilot study designed to provide information for use in future WUP reviews. The need for future groundwater monitoring will be determine during these future planning processes.

The specific seasonal timing for each task is described in the Methods section

1.2.6 Budget

Tables 1b-2 to 1b-4 outline the estimated budget for this program.

Table 1b-2: Budget Estimate for the Cheakamus River Chum Salmon Escapement Monitoring and Mainstem Spawning Groundwater Survey, Summary of the Two Components (See Tables 1b-3 and 1b-4 for more detailed breakdowns)

Task								Total Cost
	Labour		Yr 1	Yr 2	Yr 3	Yr 4	Yr 5	
	Contingency	10%	$31,126	$21,360	$19,725	$15,601	$11,451	**$99,261**
		Subtotal	$128,626	$142,960	$126,375	$89,851	$85,701	**$573,511**
	Expenses							
		Subtotal	*$213,756*	*$91,996*	*$90,596*	*$81,756*	*$40,256*	**$518,360**
	Future Inflation	2%	*$6,848*	*$9,492*	*$13,280*	*$14,146*	*$13,110*	**$56,876**
		Total	*$349,229*	*$244,448*	*$230,251*	*$185,753*	*$139,066*	**$1,148,747**

Table 1b-3: Budget Estimate for the Cheakamus River Chum Salmon Escapement Monitoring and Mainstem Spawning Groundwater Survey, Chum Salmon Escapement Component

Task	Labour	Daily rate	Units					Total Cost
			Yr 1	Yr 2	Yr 3	Yr 4	Yr 5	
Project Coordination	Project Biologist	$600	7	7	7	7	7	$21,000
Design and analytical methodology	Analyst	$750	15	5				$15,000
Install counter / tag readers	Project Biologist	$600	2	2	2	2	2	$6,000
	Technician 1	$300	2	2	2	2	2	$3,000
PIT tagging	Project Biologist	$600	24	24	24	24	24	$72,000
	Technician 1	$300	18	18	18	18	18	$27,000
	Technician 2	$300	18	18	18	18	18	$27,000
	Technician 3	$300	18	18	18	18	18	$27,000
Counter / PIT data collection	Project Biologist	$600	25	25	20	20	20	$66,000
	Technician 1	$300	25	25	20	20	20	$33,000
	Technician 2	$300	25	25				$15,000
Remove counter / tag readers	Project Biologist	$600	1	1	1	1	1	$3,000
	Technician 1	$300	1	1	1	1	1	$1,500
Data entry	Project Biologist	$600	10	10	10	10	10	$30,000
	Technician 1	$300	8	8	8	8	8	$12,000
Data analysis and reporting	Analyst	$750	5	5	5	5	5	$18,750
	Project Biologist	$600	10	10	10	10	10	$30,000
	Technician 1	$300	2	2	2	2	2	$3,000
	Contingency	10%	$31,126	$17,176	$15,951	$15,601	$11,451	$91,303
		Subtotal	*$128,626*	*$107,176*	*$90,201*	*$89,851*	*$85,701*	*$501,553*
	Expenses	Unit Price						
	Side channel traps	$11,750	4					$47,000
	PIT tag readers	$5,500	4					$22,000
	Mobile PIT Tag reader	$5,500	1					$5,500
	Telemetry fixed receivers	$13,500	4					$54,000
	Radio Tags	$375	120	120	120	120		$180,000
	PIT Tags	$15	1200	1200	1200	1200	1200	$90,000
	Floy Tags	$2.50	1200	1200	1200	1200	1200	$15,000
	Capture Nets	$3,500	1		1		1	$10,500
	Snorkel equipment	$2,000	1	1	1	1	1	$10,000
	Raft rental (telemetry study)	$150	10	10	10	10	10	$7,500
	Mileage (per km)	$0.56	7600	7600	7600	7600	7600	$21,280
	Field supplies	$2,500	1	1	1	1	1	$12,500
	Lodging and meals (month)	$2,500	2	2	2	2	2	$25,000
	Report preparation	$500	1	1	1	1	1	$2,500
		Subtotal	*$213,756*	*$81,756*	*$85,256*	*$81,756*	*$40,256*	*$502,780*
	Future Inflation	2%	$6,848	$7,633	$10,739	$14,146	$13,110	$52,475
		Total	**$349,229**	**$196,564**	**$186,196**	**$185,753**	**$139,066**	**$1,056,808**

Table 1b-4: Budget Estimate for the Cheakamus River Chum Salmon Escapement Monitoring and Mainstem Spawning Groundwater Survey, Chum Salmon Mainstem Spawning Groundwater Component

Task	**Labour**	Daily rate	Units		Total Cost
			Yr 2	Yr 3	
Project Coordination	Project Biologist	$600	4	3	$4,200
Field sampling	Groundwater expert	$700	10	10	$2,800
	Project Biologist	$600	10	10	$2,400
	Technician 1	$300	10	10	$1,200
Travel / mobilization	Groundwater expert	$700	2	2	$14,000
	Project Biologist	$600	2	2	$12,000
	Technician 1	$300	2	2	$6,000
Data analysis and reporting	Groundwater expert	$700	10	12	$15,400
	Project Biologist	$600	5	5	$6,000
	Contingency	10%	$4,184	$3,774	$7,958
		Subtotal	*$35,784*	*$36,174*	*$71,958*
	Expenses	Unit Price			
	Piezometers and temperature loggers	$100	24		$2,400
	Disolved oxygen and conductivity meters	$2,500	1		$2,500
	Mileage (per km)	$0.56	1500	1500	$1,680
	Field supplies	$1,000	1	1	$2,000
	Lodging (night)	$100	30	30	$6,000
	Report preparation	$500	1	1	$1,000
		Subtotal	*$10,240*	*$5,340*	*$15,580*
	Future Inflation	2%	$1,859	$2,541	$4,400
		Total	**$47,883**	**$44,055**	**$91,938**

1.2.7 References

Aprahamian, M.W, Nicholson S.M, McCubbing, D.J.F and Davidson I. 1996 The use of resistivity fish counters in fish stock assessment. In Stick Assessment in Inland Waters ed I. Cowx Chapter 3, 27-43.

Baxter, J. S., and J. D. McPhail. 1999. The influence of redd site selection, groundwater upwelling, and over-winter incubation temperature on survival of bull trout (*Salvelinus confluentus*) from egg to alevin. Can. J. Fish. Aquat. Sci. 77:1233–1239.

Buzby, K., and L. A. Deegan. 1999. Relative retention of anchor and passive integrated transponder tags in arctic grayling. N. Amer. J. Fish. Man. 19:1147-1150.

Castro-Santos, T., A. Haro, and S. Walk. 1996. A passive integrated transponder (PIT) tagging system for monitoring fishways. Fish. Res. 28: 253–261.

Dare, M. R. 2003. Mortality and long-term retention of passive integrated transponder tags by spring chinook salmon. N. Amer. J. Fish. Man. 23: 1015-1019.

Department of Fisheries, Canada. 1957. A report on the fisheries problems related to the power development of the Cheakamus River system. Vancouver, B.C. 39p. + appendices.

Downing, S. L., E. F. Prentice, B. W. Peterson, E. P. Nunnallee, B. F. Jonasson. 2001. Development and evaluation of passive integrated transponder tag technology: annual report, 1999 to 2000. Report to the U.S. Department of Energy, Bonneville Power Administration, Division of Fish and Wildlife, Contract 307-00001, Project No. 83-319, 31 p.

Geist, D.R., T.P. Hanrahan, E.V. Arntzen, G.A. McMichael, C.A. Murray, and V.J. Chen. 2002. Phsicochemical characteristics of the hyporheic zone affect redd site selection by chum salmon and fall chinook salmon in the Columbia River. N. Amer. J. Fish. Man. 22: 1077-1085.

Korman, J., R.N.M. Arhens, P.S. Higgins, and C.J. Walters. 2002. Effects of observer efficiency, arrival timing, and survey life on estimates of escapement for steelhead trout (*Oncorhynchus mykiss*) derived from repeat mark-recapture experiments. Can. J. Fish. Aquat. Sci. 59: 1116-1131.

Lister, D.B., and R.A.L. Harvey. 1969. Loss of Petersen disk tag estimates from spawning chum salmon (*Oncorhynchus keta*). Can. Fish Culturist 40: 33-40.

Matter, A. L. and B. P. Sandford. 2003. A comparison of migration rates of radio- and PIT-tagged adult Snake River chinook salmon through the Columbia River hydropower system. N. Amer. J. Fish. Man. 23: 967-973.

McCubbing,D.J.F and D. Ignace. 1999 Salmonid Escapement Estimates on the Deadman River, resistivity counter video validation and escapement estimates. MEOLP Project Report. 45p.

McCubbing, D.J.F, B.R. Ward, and L. Burroughs. 1999. Salmonid escapement enumeration on the Keogh River: a demonstration of a resistivity counter in British Columbia. Province of British Columbia Fisheries Technical Circular Number 104: 25p.

McCutcheon, C. S., E. F. Prentice, and D. L. Park. 1994. Passive monitoring of migrating adult steelhead with PIT tags. N. Amer. J. Fish. Man. 14: 220-223.

Melville, C.C. and D. McCubbing. 2000-2005. BC Hydro reports on juvenile chum production – data on file.

Otis, D., K. Burnham, G. White, and D. Anderson. 1978. Statistical inference from capture data on closed animal populations. Wildl. Monogr. No. 63.

Parnell I.J., D.R. Marmorek, B. Lister and J. Korman. 2003. Cheakamus Water Use Plan: Quantitative evaluation of the statistical and cost performance of alternative salmonid monitoring design options. Final report prepared by ESSA Technologies Ltd., Vancouver, BC. for BC Hydro, Burnaby, BC. 81 p.

Prentice, E., C. McCutheon, T. Flagg, D. Park. 1986. Study to Determine the Biological Feasibility of a New Fish Tagging System. Bonneville Power Administration. Report DOE/BP-11982-2. 99 p.

Prentice, E. F., T. A. Flagg, C. S. McCutcheon. 1990. Feasibility of using implantable passive integrated transponder (PIT) tags in salmonids. Amer. Fish. Soc. Symp., 7:317-322.

Salo, E.O. 1991. Life history of chum salmon, *Oncorhynchus keta*. In C. Groot and L. Margolis (editors), Pacific salmon life histories, p. 231-309. Univ. B.C. Press, Vancouver, B.C.

Schubert, N.D., T.R. Whitehouse and A.J. Cass. 1997. Design and evaluation of the 1995 Fraser River pink salmon (*Oncorhynchus gorbuscha*) escapement estimation study. Can. Tech. Rep. Fish and Aquat. Sci. 2178: 75 p.

Thorsteinsson, V. 2002. Tagging Methods for Stock Assessment and Research in Fisheries. Report of Concerted Action FAIR CT.96.1394 (CATAG). Reykjavik. Marine Research. Institute Technical Report (79). 179 pp.

Vaux, W.G. 1968. Intragravel flow and interchange of water in a streambed. Fish. Bull. 66: 479- 489.

Cheakamus River Monitoring Program #2: Trout Abundance Monitor in Cheakamus River (Daisy Lake Dam to Cheakamus Canyon)

1.1 Program Rationale

1.1.1 Background

The upper part of Cheakamus River between the anadromous fish barrier and Daisy Lake Dam is known to support a resident rainbow trout population. Char and sclupin are also present. An important uncertainty in the Cheakamus WUP process was the relationship between discharge from Daisy Dam and the quantity of resident trout habitat, and the resulting trout abundance. The impact of the change of the WUP flow regime on the rainbow trout population was uncertain because: i) the actual differences in discharge downstream of Daisy Dam between the WUP and pre-WUP flow regime are uncertain, and ii) the impact of the pre-WUP operation is uncertain. Limited sampling has been done in the past, nor were any field studies been done during the WUP process, that evaluated the status of this population and how it may be impacted by Daisy Lake Dam operations. The only study done during the WUP that pertains to this population of trout was an air photo interpretation exercise that qualitatively rated the value of hydraulically unique habitats identified from photos taken at different dam discharges. This analysis produced a "Rated Usable Area" statistic that summarized the quantity of habitat in terms of equivalent prime habitat units (ha) and how this quantity changes with river flow. This statistic was used as the foundation for a performance measure designed to track changes in habitat (and by association fish abundance) when modelling alternative operations. Because no fish density or abundance data were collected to support this habitat rating scheme, the value of the habitat rating scheme, and hence of the performance measure, was deemed questionable by some CC members. This created considerable uncertainty in the outcome of any change to the operating regime from the existing pre-WUP operations.

The abundance of resident trout downstream of Daisy Dam was considered by the CC to be a critical component in the WUP trade-off process. There were two reasons for this importance. First, was resident trout's inherent value to CC members who consider it to be an indicator of ecological health. The second and probably more important reason was because there was a general perception among CC members that trout abundance was highly susceptible to changes in Daisy Lake Dam flow releases, particularly relative to pre-WUP dam operations. Because of its relative importance and a WUP fish management objective, as well as the high level of uncertainty surrounding the consequence of flow regime changes, the CC members recommended that a monitor be carried out to track the status of rainbow trout populations. The purpose of the monitor would be to relate changes in trout abundance to changes in Daisy Lake Dam operations if such a relation exists.

1.1.2 Management Questions

Table 2-1 outlines the minimum flow requirements for the WUP flow regime and pre-WUP flow regime. The flow releases from Daisy Dam are based on the minimum flow requirement from Daisy Dam, additional flow requirements downstream at the

Brackendale gauge, and during periods of high inflows such as during the spring snowmelt, the inflows to Daisy Reservoir. Changes in flow required to maintain the minimum flow at Brackendale are unpredictable and can create variability in the flow regime experienced by the resident trout population. Of particular concern is the fact that these changes will follow a pattern that is opposite of the system's prevailing hydrology (higher releases at times when flows are naturally low). However, hydrological modelling exercises have found that the magnitude of these changes are relatively small, and may be "masked" by the influence of local inflows from Rubble Creek immediately downstream of the dam. As a result, the impact of these short-term fluctuations is not expected to be biologically important, particularly when one considers that such fluctuations in flow are well within the range found in the natural environment. For this reason, the monitor will only be concerned with the impact of changes to the base flow release on the resident trout population, and that short-term fluctuations in flow will be largely ignored. The only exception will be flood flow releases, which could have an impact. Such events will be noted and incorporated in the interpretation of study result, but studies specifically design to identify flood-related impacts will not be carried out because the ability to regulate flows is limited during floods.

Table 2-1: Overview of Minimum Flow Release Requirements Prior to the Water Use Plan and Under the Water Use Plan Flow Regime

	Pre-WUP ($m^3 \cdot s^{-1}$)	WUP ($m^3 \cdot s^{-1}$)
Minimum flow from Daisy Dam		
Jan 1 to Mar 31	5	5
Apr 1 to Oct 31	5	7
Nov to Dec 31	5	3
Additional flow releases	Based on inflows to Daisy Reservoir	Based on flow requirements at Brackendale Gauge

Thus, the consequence of the WUP change in Dam releases is uncertain, largely because the impact of the current regime is unknown. If one were to assume that habitat and flow are positively correlated, then one would expect a potential reduction in habitat during the 3 $m^3 \cdot s^{-1}$ base release, and a potential increase in summer rearing habitat with the 7 $m^3 \cdot s^{-1}$ base flow. This change in base flow leads to the following fish management question:

1) Do Daisy Lake Dam releases affect the resident rainbow trout population located immediately downstream of Daisy Lake Dam? The parameters of interest include fish density or relative abundance, age class distribution, size-at-age, and relative condition.

1.1.3 Summary of Impact Hypotheses

The management question outlined above will be addressed through a test of four impact hypotheses. The impact hypotheses relate to three key phases in the life history of rainbow trout; spawning success, summer rearing (growth and survival), and over-wintering survival. Direct measures of these parameters are outside the scope of this monitor and therefore, the monitor relies on the use of indicator variables to test these hypotheses. Relative spawning success will be measured in terms of inter-annual variability in fry abundance, while relative rearing success will be explored through tests of size-at-age and relative condition and relative abundance data, and over-wintering survival will be noted by tracking the ratio of age-class specific densities. These variables will be tested using the following impact hypotheses:

H_O1: Relative spawning success, as indicated by fry density at the time of sampling, is not correlated with average (or some other summary statistic) discharge during the spawning, incubation, emergence, and early rearing phases of development.

It should be noted that test of this hypothesis will require some measure of adult spawner abundance to account for inter-annual differences in egg deposition.

H_O2: Relative rearing success, as indicated by relative condition, size-at-age, and abundance, is not correlated with average (or some other summary statistic) discharge during the summer growth season.

The summer low flow period is generally considered to the standard time during which population censuses are taken for inter-annual or treatment related comparisons. As result, test of H_O2 with respect to abundance will also lead to an indirect test of general population success. In should be noted that density measurements may have to be corrected for local habitat quality constraints (a covariate) if between-site or between-system, or between-treatment comparisons are to be made.

Test of H_O2 will rely on inter-annual variability of Daisy Lake Dam releases in response to downstream requirements at the Brackendale stream flow gauge to provide the necessary range of flow treatments. At this time, it is unknown to what extent flows in the upper reaches of the Cheakamus River will vary, though it is not expected to be very large. As a result, it may be possible that the range of annual flow treatments may be too small to create the contrast needed to test for a measurable effect. Furthermore, confounding factors unrelated base flow levels might also mask the treatment effect. For these reasons, tests of the hypotheses above are not expected to uncover relationships unless there are clear and very strong responses to small changes in base flow conditions.

In addition to the impact hypotheses above, there will also be a general test of the assumption that resident trout populations are not impacted by the change to WUP based operations. The general compliance based hypothesis will make use of the fish abundance and morphology data collected for hypotheses H_O1 to H_O3 by examining the data set for temporal trends. The impact hypotheses are as follows:

H_O3: Relative spawning success, as indicated by fry density at the time of sampling, remains stable or increases through time following implementation of the WUP.

H_O4: Relative rearing success, as indicated by relative condition, size-at-age, and abundance, remains stable or increases through time following implementation of the WUP.

The test of these hypotheses assume that the current flow regime out of Daisy Lake Dam is superior to the WUP for promoting trout population growth and that the current status of the population is at or near its maximum potential given the non-operational constraints in the system. Like hypotheses H_O1 and H_O2, these will be low power tests because of many confounding factors.

1.1.4 Key Water Use Decision Affected

The key water use decision that could be informed by results of the monitoring would be the seasonal flow release from Daisy Lake Dam. The WUP flow regime from Daisy Lake Dam will change considerably from the pre-WUP regime, where releases were governed by the flow requirements at the Brackendale stream flow gauge. Flow releases from Daisy Dam under the WUP are likely to be lower during November to December, and possibly higher during April to October. This change was recommended during the WUP primarily to benefit salmonids in the lower reaches of the river, and was assumed not to impact resident trout populations. The only evidence available to support this assumption was the relatively insensitive RUA performance measure (PM) used in the trade-off analysis (Marmorek and Parnell 2002). There was considerable uncertainty in the validity of the PM because it relied primarily on air photo interpretation techniques that have yet to be tested for robustness, accuracy, and predictive capability. This uncertainty was one of the factors that lead to a division among CC members regarding the appropriateness of various flow regime options and their consequences to the resident trout population. Results of the monitor will reduce this uncertainty and will provide information to inform future decisions.

1.2 Program Proposal

1.2.1 Objective and Scope

The objective of this monitor is to collect the data necessary to test the Impact Hypotheses outlined above and hence, address the Management Questions. The following aspects define the scope of the study:

a) The study area will be restricted to the upper section of Cheakamus River bounded by Daisy Lake Dam at its upstream end and the start of the canyon reach.

b) The resident rainbow trout population will be the focus of monitoring, and all species captured will be documented.

c) The monitor will be carried out annually for five years.

d) Sampling will be carried out over a two-week period at a standardized time of the year.

e) A data report will be prepared annually summarizing the year’s findings.

1.2.2 Approach

The general approach to the monitor will be to carry out annual fish population censuses to track changes through time and whether inter-annual differences are related to prevailing hydrological conditions. The census variables of interest include juvenile abundance, adult abundance, size at age, and relative condition. These variables collectively allow testing of hypotheses concerning rearing success, and spawning success.

The monitor does not incorporate a before-after WUP implementation comparison in its design, nor are there target values set for specific population characteristics. This monitor is designed strictly as a tracking process to ensure that the resident fish population does not deteriorate through time as was assumed by some members during the WUP. The other design aspect of the monitor is to ensure that sufficient data are collected to determine whether the cause of a decline, if one is detected, can be attributed to the new operations.

It should be noted that the population census data is to be collected by sampling techniques that are prone to error when applied to large river situations such as the Cheakamus River. As a result, the ability for the monitor to detect statistically significant differences through time is relatively low unless the magnitude of change among the population variables is very large. It is unlikely that subtle changes in population character will be detected. Inherent in the design of the monitor is the assumption that such small changes in population character do not have an impact of its persistence or resilience.

To help minimize error, all sampling will be carried out at a standardized time of the year and over a short period of time (maximum two weeks) to minimize the effect of within-year differences in population character. Fish sampling will be carried out primarily by multiple removal using BC Resource Inventory Standards Committee standard electrofishing techniques. The only exception will be the adult fish census, which will rely on angling or another suitable technique for sampling since the areas these fish are likely to reside (i.e., deeper faster waters) are too dangerous to fish by electroshocker. Also, the adult fish census, designed as an indicator of the spawning fish population, may be sampled at a different time of the year than the juvenile fish census.

To overcome high variance in the data due to sampling error, the monitor will have to be carried out annually for the full duration of the WUP implementation period so as to maximize the number of sampling periods. This will maximize the resolving power of the statistical tests to detect differences in the population data over time.

1.2.3 Methods

Task 1: Project Coordination

Project coordination involves the general administrative and technical oversight of the program. This will include but not be limited to:

1) Budget management.

2) Staff selection.

3) Logistic coordination.

4) Technical oversight in field and analysis components.

5) Liaison with regulatory agencies.

Coordination with WUP Monitoring and Other Monitoring Programs

To help answer high-level questions regarding the relation between Cheakamus River discharge and fish production, data from this resident trout program will ultimately be used in combination with data from the steelhead monitoring program (#3), the benthic community monitoring program (#7), the channel morphology and hydrology program (#8), and possibly other WUP monitoring programs. For example, the benthic community monitoring program will require that juvenile specimens be collected under this program and Program #3, and sent to the benthic program for analyses of stomach contents. Therefore, it is critical that data collection is coordinated among programs.

To ensure that data collection is coordinated among the inter-related monitoring programs for the Cheakamus WUP, an important task for this program is to develop and maintain communication with project leads for the other monitoring programs. This could involve a workshop at the start of the field season to ensure that the trapping locations and methodologies will meet the data requirements of the other programs, and vice-versa. Logistical changes within the scope of the program may be required.

Task 2: Field Methods

Pilot snorkel survey

In the first year, one or two snorkel surveys covering the area from Daisy Dam downstream to the start of the canyon will provide information on the general distribution of each rainbow trout lifestage that may assist in site selection. In addition, this snorkel may provide an index of adult abundance that can be compared with the information from the angling sampling of adults (see below). The most appropriate seasonal and diel timing for this survey(s) will be determined. Late winter may provide suitable sampling conditions for adult enumeration.

Information Review and Site Selection

Site selection for electrofishing will occur during the first year of the monitor. A first step in site selection will be to review existing fish sampling data upstream of the Cheakamus Canyon (e.g., Clark 1989; contact Ron Ptolemy, BC Ministry of Environment), to determine if sampling can correspond to existing sites. Site selection should reflect the general character of the river, and include both high and low quality habitats. To assist with comparisons with data collected under this program, the information review will include a summary of quantitative data from previous fish sampling.

Once selected, the location of each site will be marked by flagging and/or wood stakes, including the position of all nets used during the sampling procedure. GPS co-ordinates will also be collected for each site and net location so that they may be documented on maps and air photographs for future reference.

A minimum of ten sites will be selected for sampling. This assumes that a single three-person crew is capable of sampling at least two sites per day. The actual number of sites selected however will depend on several factors, including the degree of difficulty to access the site, the time it takes to set up nets and a fish processing centre, the level of effort to measure habitat quality, and the number fish caught at each site. Although total effort is by project scope, it can be spread over a two-week period to accommodate challenges with field logistics. All sites are to be sampled during the same two-week period each year so that the data can be directly compared between years.

Fish Capture

Fish capture will be carried out using two different methods. A multi-pass electroshocking program will be used to estimate juvenile abundance, which will be reported as a density value (i.e., fish•m^{-2}). Adult abundance will be reported in terms of Catch per Unit Effort (CPUE) which will be based on a targeted angling program. Details of the two programs are as follows:

Electroshocking Program

Sampling will be done by a three-person crew equipped with a fish electroshocker and appropriate stop nets. A minimum of two passes will be done for each site, which is to be enclosed by nets if possible and passes should be separated by a minimum of 30 minutes. Fish captured during each pass will either be immediately processed before starting the next pass, or will be stored in separate containers until all passes are completed. The total number of passes done at each site should be sufficient to ensure that population estimates have a CV of less than 0.2. This will require that the analysis of electroshocking data be done in the field.

During the first year, details of the fish capture methodology used at each site will be clearly documented so that it can be accurately repeated in subsequent years. Some of the parameters to be recorded include; the duration of each pass, voltage level and pulse rate of the unit, the use of stop nets and their location, the time between passes, the anode and cathode arrangement, position of netting crew, total area of the electroshocked site, and a general sketch of the anode sweep pattern.

Electroshocking results will be verified by snorkel at each site, where feasible, to confirm the fish distribution within and around the shocked site.

The benthic community monitoring program (#7) will require that juvenile salmonids be sampled, sacrificed and sent to Program #7 to examine stomach contents. For efficiency, theses samples will be collected under this program and/or the steelhead production program (Program #3). Stomach samples from 15 juvenile salmonids for each stream-rearing salmonid species of interest will need to be collected from near the benthic invertebrate sampling sites (i.e., 15 samples per species in each of the years of benthic sampling, in Years 2 and 3, for a total of 30 individuals per species). Subject to sampling permit approval and conservation concerns, species collected for the benthic program would include rainbow trout/steelhead, coho salmon, Chinook salmon and bull trout. Coordination of the collection of stomach samples will be determined through communication under Task #1.

Adult Enumeration

Enumeration of adult rainbow trout will be carried out by team of competent fly-fishers working in tandem in an upstream direction. Sampling will begin at the downstream end of the study section, and proceed upstream to the confluence of Rubble Creek. Total level of effort is not to exceed 24 hours (i.e., a crew of two anglers working six hours per day for two days). Like the electroshocking program, the adult survey is to be carried out at the same time of year each year, and preferably with the same anglers. The time of year that the survey is to be carried out will depend on when trout reach maturity. Pilot surveys, including the snorkel surveys described above, may be necessary during the first year to determine when that is.

Fish Morphology

Captured juvenile fish will be anaesthetized, enumerated, and its taxon identified to the nearest species. They will also be measured to the nearest 1 mm for fork length and wet weighed to the nearest 1 g. In addition scale samples will be collected and stored on slides for future reference. Once processed, the anaesthetized fish will be allowed to recover and then released.

Adult fish caught by fly-fishing are only to be measured for fork length so as to minimize handling. In addition, scale samples from a total of ten adult fish will be taken over the course of the sampling period to assess the age structure of the spawning population. These fish will be selected through a systematic sampling paradigm based on the rate of adult fish capture.

Habitat Assessment

Habitat assessments will be carried out at all electrofishing sites. These assessments will consist of standard descriptions that use RIC standard measurement procedures and definitions for substrate composition, cover availability, and flow metering for depth and velocity transects.

Task 3: Data Analysis

All data will be entered into a common database in a standard format for subsequent analysis. This will ensure that the data collected over the years are compatible and can be extracted and compared without transformation.

Fish Density Estimates

Fish density estimates will be calculated from the multi-pass electroshocking data using the maximum likelihood estimation procedures. If the pattern of removal departs significantly from expected values, then a Bayesian approach to the analysis should be used as it tends to be more accurate in such cases (e.g., Mantyniemi et al. 2005 and references therein). If the Bayesian approach is needed, a uniform prior capture probability of 0.5 should be used. Regardless of the techniques used, fish density estimates should be calculated separately for all age classes and reported to include estimates of standard error (or equivalent).

As indicated in the Habitat Assessment sub-section above, it may be necessary to qualify the density measurements by considering habitat quality as a covariate in analyses. Discriminant function analysis will be used to develop a habitat-rating scheme for this purpose that is based on the substrate, cover, average depth and velocity data collected at each site. Alternative analytical approaches to developing such rating scheme maybe used as necessary.

Additional inferences will be derived from comparing densities with theoretical maximum densities calculated from a provincial model of electrofishing data that uses measures of water chemistry (for application to the Cheakamus River, see notes in Ptolemy and Wilson 2006).

Adult Abundance

Adult abundance will simply be reported as CPUE value calculated by dividing the total catch by the total level of fishing effort (rod hours).

Size at Age

Fish age will be determined by length frequency analysis using common applications (program MIX www.math.mcmaster.ca/peter/mix/mix.html or similar) and validated with the scale ageing. Size at age will be calculated by averaging the fork lengths of all fish of the same age class. Regression analysis will be used to estimate the average annual growth rate of each age class.

Relative Condition

Relative condition of each fish will be calculated using standard formulae and then averaged for each age class. Fish condition will be used to examine $H_0 4$. Differences in condition between age classes, as assessed by ANOVA, will indicate age specific limitations to growth and perhaps survival.

Relative Spawning Success

Relative spawning success will be reported as an indicator variable calculated as the average density of fry corrected by the relative abundance of adult fish. Though the result will resemble an actual measure of spawning success, it should not be interpreted as such. The variable will have little value in the short term, but as the data set increases with the number of years, between year comparisons can be made.

Between Year Comparisons

Between year comparisons of variables above will be the means by which hypotheses $H_O 1$ to $H_O 4$ are tested. Such comparisons will take on two forms. In the first form, inter annual differences will be explored by regression analysis on hydrology related parameters, including average discharge at key times of the year, the occurrence of flood events, and exceedence probabilities of key discharge values. The intent of such analyses is to establish correlations, if not a causal relationship, between annual hydrological events and the population parameter of interest. It is through these correlation analyses that hypotheses H_O1 and H_O2 are tested.

The other type of between year comparison will be an exploration of annual trends. In this case, regression analysis is used to examine the likelihood that the population parameter of interest increases, decreases or remains the same over time. It will be through this trend analysis that hypothesis H_O3 and H_O4 will be tested.

Task 4: Reporting

Project reporting will consist of annual data reports and a final report at the conclusion of the monitor. The annual data reports will summarize the year's findings and include a short discussion of how the year's data compare to that collected in previous years. It will include a brief description of methods, present the data collected that year, and report on the results of all analyses.

Every five years, a summary report will be prepared that summarizes all the results to date and discusses in detail the results as they pertain to the impact hypotheses, and more importantly, as they pertain to the management question in Section 1.2.

At the conclusion of the monitor, a final comprehensive report will be prepared from all of the annual reports written to date that:

a) Re-iterates the objective and scope of the monitor.
b) Presents the methods of data collection.
c) Describes the compiled data set and presents the results of all analyses.
d) Presents a summary of quantitative fish data from previous historic sampling (as described in the Information Review section above)
e) Discusses the consequences of these results as they pertain to the current WUP operation, and the necessity and/or possibility for future change.

1.2.4 Interpretation of Monitoring Results

The implications of the monitoring program to the WUP and its potential for change in the future is linked to the outcome of the hypothesis tests outlined above. Rejection of hypotheses H_O1 would suggest a causal link between the year's prevailing hydrology and spawning success. Similarly, rejection of H_O2 would suggest a causal link between the prevailing hydrology and rearing success. In each case, for the causal link to be associated with WUP operations, it must be demonstrated that the observed pattern in hydrology was caused by dam operations, and in particular the flow regime dictated by the WUP. Because there are several major local inflow sources immediately downstream of the dam, it is possible that the potential causal link is natural in nature.

Where hypotheses H_O1 and H_O2 deal with immediate (i.e., same year) responses to differences in hydrology, tests of H_O3 and H_O4 are designed to explore the potential for a delayed gradual response to the WUP. Rejection of the latter two hypotheses (which have be stated as a one tailed test) would suggest a negative impact to the resident fish population and that it took more than one year or one generation for it to materialize. If the population response is dramatic, then it may be necessary to modify WUP operations to prevent further decline. The data collected to date would form the basis from which such an alternative WUP operating strategy would be developed.

By combining results of all hypotheses, it may be possible to determine whether the observed pattern is the result of WUP operations, or some other environmental factor. Rejection of all null hypotheses would suggest a very strong relationship between WUP based operations and resident fish populations, particularly if it can be shown that the hydrological events impacting the population are of WUP origin. Alternatively, if all null hypotheses are not rejected, then it may be concluded that WUP-based operations had no measurable effect on the population and that observed variance in population character is natural in origin. In between these two "extreme" outcomes, are 14 other patterns of hypothesis rejection, each leading to a unique conclusion regarding in the influence of WUP operation on the resident fish population.

1.2.5 Schedule

Monitoring is scheduled to occur annually for five years. At the conclusion of the monitor, a final report will be prepared that discusses the overall findings of the monitor.

1.2.6 Budget

Table 2-2 outlines the estimated cost for this program.

Table 2-2: Cost Estimate for the Trout Abundance Monitor in Cheakamus River (Daisy Lake Dam to Cheakamus Canyon)

Task	**Labour**	Daily rate	Units					Total Cost
			Yr 1	Yr 2	Yr 3	Yr 4	Yr 5	
Project Coordination	Project Biologist	$600	6	4	4	4	4	$13,200
Pilot snorkel	Project Biologist	$600	2					$1,200
	Technician 1	$300	2					$600
	Technician 2	$300	2					$600
Electroshocking	Project Biologist	$600	6	6	6	6	6	$18,000
	Technician 1	$300	6	6	6	6	6	$9,000
	Technician 2	$300	6	6	6	6	6	$9,000
Angling	Technician 1	$300	2	2	2	2	2	$3,000
	Technician 2	$300	2	2	2	2	2	$3,000
Data Entry	Project Biologist	$600	4	2	2	2	2	$7,200
	Technician 1	$300	3	3	3	3	3	$4,500
Data Analysis	Project Biologist	$600	2	2	2	2	7	$9,000
	Technician 1	$300	4	4	4	4	4	$6,000
Reporting	Biologist	$600	4	4	4	4	10	$15,600
	Technician 1	$300	6	6	6	6	15	$11,700
	Contingency	10%	$3,184	$2,644	$2,644	$2,644	$3,574	$14,688
		Subtotal	*$27,484*	*$22,144*	*$22,144*	*$22,144*	*$32,374*	*$126,288*
	Expenses	Unit Price						
	Mileage (per km)	$ 0.56	3500	3500	3500	3500	3500	$9,800
	Lodging (day)	$ 100	18	18	18	18	18	$9,000
	Meals	$ 50	28	22	22	22	22	$5,800
	Electroshocker	$ 75	5	5	5	5	5	$1,875
	Nets (x3)	$ 30	5	5	5	5	5	$750
	Scale ageing	$ 25	10	10	10	10	10	$1,250
	Dry suit rental	$ 50	12	6	6	6	6	$1,800
	Field supplies	$ 500	1	1	1	1	1	$2,500
	Report reproduction	$ 500	1	1	1	1	1	$2,500
		Subtotal	*$7,535*	*$6,935*	*$6,935*	*$6,935*	*$6,935*	*$35,275*
	Future Inflation	2%	$700	$1,175	$1,780	$2,397	$4,091	$10,143
		Total	**$35,719**	**$30,253**	**$30,858**	**$31,476**	**$43,400**	**$171,706**

1.2.7 References

BC Hydro 2005. Cheakamus Project Water Use Plan – Revised for acceptance by the Comptroller of Water Rights. Prepared by BC Hydro October 1, 2005.

Clark, B.J. 1989. The assessment of the recreational fishery potential of the Cheakamus River upstream of the anadromous barrier: Progress in 1988. Regional Report LM037. Ministry of Environment, Surrey, B.C.

Mäntyniemi, S., Romakkaniemi, A., and Arjas, E. 2005. Bayesian removal estimation of a population size under unequal catchability. Can. J. Fish. Aquat. Sci. 62: 291-300.

Marmorek, D. R. and I. Parnell. 2002. Cheakamus River water use plan: report of the Consultative Committee. BC Hydro. Burnaby, B.C. 235p.

Ptolemy, R.A., and Wilson, G. 2006. BC Ministry of Environment comments on the Cheakamus Water Use Plan monitoring program. Correspondence dated December 6 2006.

Cheakamus River Monitoring Program #3: Cheakamus River Steelhead Adult Abundance, Fry Emergence-timing, and Juvenile Habitat Use and Abundance Monitoring

1.1 Program Rationale

1.1.1 Background

The Water Use Plan (WUP) for the Cheakamus River (BC Hydro 2005) includes a flow regime for the Cheakamus River designed to balance environmental, social and economic values. The effect of the flow regime on the Cheakamus River steelhead population is uncertain. A fundamental debate in the Cheakamus WUP was associated with the importance of the natural hydrograph to juvenile steelhead and salmon production. The pre-WUP flow release was based on releasing from Daisy Dam into the Cheakamus River the greater of 5 $m^3 \bullet s^{-1}$ or 45% of the previous seven days average inflows to the reservoir. Proponents of the existing flow regime argued that both seasonal and daily elements of the hydrograph could be important to juvenile salmonid production and that higher flows will provide benefits in off-channel rearing areas that were not accounted for in the WUP modelling (Marmorek and Parnell 2002). Proponents of the recommended flow regime defined during the WUP consultative process (Marmorek and Parnell 2002) had more confidence in the fish habitat modelling, which suggested that dam operations do not affect the mainstem or side channel juvenile rearing area for salmon or steelhead except at very low dam releases. In addition, discussions after the consultative process recommended higher flows (38 vs. 20 $m^3 \bullet s^{-1}$ at Brackendale) during July and August to benefit recreational rafting, however, fisheries regulators raised concerns that these flows could be detrimental to emerging steelhead fry.

The monitoring program outlined in this Terms of Reference has been developed to examine the effects of the flow regime on the abundance and survival of key steelhead life-stages, and ultimately the production of steelhead smolts in freshwater. The steelhead parr indexing program that is outlined in this TOR may be the only method of determining freshwater steelhead production in the Cheakamus River. Reliable escapement estimates, and estimates of Young of Year (YoY) and parr steelhead abundance will help to identify potential population bottlenecks (i.e., extent of summer feeding and over-winter habitat for parr) and determine the extent to which flow regulation determines steelhead production in freshwater. This study provides information on habitat use and discharge that will be useful for developing testable hypotheses around the effects of high flows during steelhead emergence. The data from this study will be used to develop stock-recruitment relationships that are critical for separating effects of spawning escapement from flow-related changes in freshwater survival rates on juvenile steelhead production (Bradford et al. 2005).

1.1.2 Management Questions

This project addresses four management questions related to the Cheakamus WUP. The first is whether increased flows during July and August will negatively affect emergent steelhead Young of Year (YoY). The hypothesis put forward by fisheries regulators is that higher flows during the steelhead emergence period will displace

YoY from preferred habitats or interrupt their normal ontogenetic movement pattern to deeper and higher velocity habitats, leading to decreased survival rates and ultimately, a decline in freshwater production. The hypothesis is based in part on the observation of late fry emergence during a year with very high and sustained freshet flows, and the likely associated colder water temperatures. Since the habitat requirements of emergent fry change as they grow (deeper, faster and larger "territories") and since available fry habitat differs between of 38 vs. 20 $m^3 \cdot s^{-1}$ (at Brackendale), discharge during emergence can affect steelhead fry.

The second question addressed by the monitor is a more general one to evaluate how changes in flow effect habitat use of steelhead YoY and parr. The displacement hypothesis of Question 1 is only one of many possibilities describing how flow and flow changes limit the survival and growth of juvenile steelhead. For example, flow-through side channels have been shown to be preferentially used by steelhead parr (Bruce 2001), and decreases in flow likely reduce the availability of such habitats. Thus, maintaining higher flows in the late summer and early fall may have an overall benefit to juvenile production. A better understanding of preferred habitat use of both steelhead YoY and parr in the Cheakamus River is required to develop a more complete set of hypotheses. This information will also be invaluable for interpreting the response of annual indices of steelhead abundance and production to variation in discharge.

The third question of the monitor is whether an annual index of parr abundance will provide a more robust estimate of steelhead production in the Cheakamus River relative to the current downstream migrant trapping program. The trapping program catches very few steelhead smolts leading to very uncertain estimates of the total number of outmigrants (Melville and McCubbing, 2004). The juvenile visual assessment technique recently developed on the Thompson system (Hagen et al. 2005) could be used on the Cheakamus River to provide a reliable annual index of the abundance of steelhead parr. Boat electrofishing may also be feasible. Parr abundance provides an index of potential smolt production, or an index late-freshwater production.

The fourth question addressed by the monitor is whether flow affects juvenile steelhead production. As for the other annual abundance estimation programs supported by BC Hydro on the Cheakamus River, changes in parr density over time will be related to differences in discharge to evaluate the effects of the flow regime recommended in the WUP. The data would allow the development of stock-recruitment relationships between escapement (e.g., Korman et al. 2005) and parr abundance. In addition, continued collection of both YoY and parr densities could be used to develop a YoY-to-parr stock recruitment relationship which would be very helpful for determining whether changes in YoY density (related to Question 1) translate into changes in parr abundance, or whether any gains or losses in YoY are compensated by density-dependent changes in survival rate.

1.1.3 Detailed Hypotheses about the Effects of Discharge on Juvenile Steelhead

The hypothesis associated with Management Question 1 is that higher flows during the steelhead emergence period will displace YoY steelhead from preferred habits or interrupt their normal ontogenetic movement pattern to deeper and higher velocity habitats, leading to a decrease in survival and a decline in freshwater production. To test this hypothesis directly, estimates of the survival rate of YoY in the late summer and fall need to be compared under both high and low flow discharges, and changes in survival would need to be compared to subsequent production levels. It is not feasible to directly measure YoY survival rates in the Cheakamus River, so the hypothesis can only be qualitatively evaluated by comparing the seasonal declines in density and length-frequency shifts over the critical period. Even if the seasonal declines in density are greater at higher flows, it will be uncertain as to whether survival rates were actually lower, or whether the fish were simply displaced out of the study area but survived at equivalent rates. Given this uncertainty, limited effort is devoted to this question, and sampling will confirm emergence timing.

The hypothesis associated with Question 2 is a very general one regarding how discharge or changes in discharge affect habitat use of juvenile steelhead. Comparisons of relative densities among habitats and years with different discharge (owing to natural variation in seasonal discharge) will be helpful in determining the linkage between flow and changes in indices of juvenile steelhead abundance over time. As well, data collected in the early years of the study will be used to develop more specific hypotheses to be tested in later years.

There is no formal scientific hypothesis that is applicable to Question 3. At issue here is whether a parr indexing program is feasible on the Cheakamus River.

The hypothesis associated with Question 4 of this study is that discharge in the Cheakamus River effects juvenile steelhead production. This hypothesis will be tested by obtaining reliable indices of spawner, YoY, and parr abundance, and relating changes in abundance and deviations from the stock-recruitment relationships to specific aspects of the flow regime. Although the Cheakamus WUP has no experimental flow element, it is very likely that natural interannual variation in the hydrograph will provide useful contrasts.

1.1.4 Key Water Use Decision Affected

The key water use decision that would be informed by the monitoring program is the seasonal discharge from Daisy Lake Dam, particularly the minimum flows from 1 July to 31 August during fry emergence.

1.2 Monitoring Program Proposal

1.2.1 Objective and Scope

The primary objective of the monitor is to improve our understanding of the effects of flow on steelhead production in the Cheakamus River. The population bottlenecks limiting freshwater production and their relationship with flow are uncertain. The monitor therefore indexes the abundance of four life stages; spawners, YoY in the fall shortly after emergence, YoY in the spring when the fish are approximately nine months old from date of hatch; and parr in the spring that are 1.9 years and older (1+, 2+, and 3+ parr). Data will be used to describe habitat use during these times that in turn will be useful to develop more detailed hypotheses. Stock-recruitment relationships between spawners and YoY, spawners and parr, and YoY and parr will be used to assess population bottlenecks. Over time, deviations from these stock-recruitment relationships can be compared to particular flow events to improve our understanding of how flow affects steelhead juvenile production.

The monitor includes the entire anadromous reach of the Cheakamus River from the Squamish River (approximately 18 km). Mainstem, constructed side channel, and natural side channels are included in the sampling. A small amount of sampling will also be conducted in Brohm River, a small tributary of the Cheekye that is known to be highly productive for steelhead.

1.2.2 Approach

The monitoring approach is to collect steelhead abundance indices for four life stages to identify:

i) Periods of low survival.

ii) The habitats used during these periods.

iii) The effects of flow on these habitats.

Once a long-term time series has been collected, the effects of flow on survival during distinct periods can be confirmed by examining the relationship between discharge and residuals from life-stage specific stock recruitment models.

The monitoring program consists of enumerating adults using snorkel counts in the spring, sampling YoY steelhead during the emergence and post emergence periods in the summer and fall by backpack/shore-based electrofishing, and sampling larger YoY and parr by electrofishing and snorkel-based surveys during the early spring (see table below). The summer/fall electrofishing data will be used to evaluate the effects of flow on displacement of YoY (Question 1). In the first year of the study, sequential sampling at a limited number of mainstem sites in reaches where spawning occurs will be used to document emergence timing, and analysis of the sequential pattern of density and size will provide an index of mortality or movement out of the sample site. A repeated measures design based on a random selection of sites in each habitat strata will be used in all years used to describe YoY and parr habitat use in the fall and spring (Question 2). Parr data collected in the spring will be used as an annual index of parr abundance (Question 3). Young-of-year data will help identify bottlenecks in production between egg deposition (indexed by spawner abundance) and smolt production, indexed by springtime parr abundance or outmigrant smolts. Representative sampling required for Questions 2 and 3 requires the development of a habitat map and database to select sites using a random habitat-stratified sampling scheme.

The use of alternative sampling techniques to estimate parr abundance is based on uncertainty in the habitats used by steelhead parr in the Cheakamus River, and thus: 1) uncertainty in the ability to effectively sample parr using standard enclosed backpack/shore-based electrofishing, and 2) the associated implicit assumption that steelhead parr are not abundant in habitats that cannot effectively be sampled by standard enclosed backpack/shore-based electrofishing. Calibrated snorkel assessments and boat electrofishing will be used to examine these assumptions and help better understand the habitat use by parr in the Cheakamus River.

Life Stage	Sample Strategy	Gear Type
Spawners (spring)	Repeated counts over freshwater residence period	Snorkelling (Task #2)
YoY Emergence Timing (summer/fall)	Sequential sampling, 1-yr. only	Backpack/shore-based electrofishing (Task #3)
YoY Abundance (fall)	Random habitat-stratified sampling, every yr.	Backpack/shore-based electrofishing (Task #5)
Parr Abundance (fall)	Random habitat-stratified sampling, every yr.	Backpack/shore-based electrofishing (Task #5)
YoY Abundance (spring)	Random habitat-stratified sampling, every yr.	Backpack/shore-based electrofishing (Task #5) and snorkelling and/or boat electrofishing (Task #6)
Parr Abundance (spring)	Random habitat-stratified sampling, every yr.	Snorkelling and/or boat electrofishing (Task #6)

1.2.3 Methods

Task 1: Project coordination

Project coordination involves the general administrative and technical oversight of the program. This will include but not be limited to:

1) Budget management.

2) Staff selection.

3) Logistic coordination.

4) Technical oversight in field and analysis components.

5) Liaison with regulatory agencies.

Coordination with WUP Monitoring and Other Monitoring Programs

To help answer high-level questions regarding the relation between Cheakamus River discharge and fish production, data from this program will ultimately be used in combination with data from the juvenile outmigration program (Program #1a), the groundwater in side channels monitoring program (#6), and possibly other WUP monitoring programs. For example, the benthic community monitoring program will require that juvenile specimens be collected under this program and Program #2, and sent to the benthic program for analyses of stomach contents. Therefore, it is critical that data collection is coordinated among programs.

To ensure that data collection is coordinated among the inter-related monitoring programs for the Cheakamus WUP, an important task for this program is to develop and maintain communication with project leads for the other monitoring programs. This could involve a workshop at the start of the field season to ensure that the trapping locations and methodologies will meet the data requirements of the other programs, and vice-versa. Logistical changes within the scope of the program may be required.

Coordination with Hatchery Programs

To help distinguish between natural and hatchery production, the proponent will maintain communication with hatchery staff (i.e., Tenderfoot hatchery) to determine and coordinate with the location and timing of hatchery releases, and determine if modifications to the sampling methodology are needed distinguish hatchery and naturally produced fish (juveniles and returning adults). At a minimum, annual reporting will summarize data on hatchery releases, the ability to distinguish hatchery and wild juveniles and adults, and the influence of these releases, if any, on catches and abundance estimates for wild fish.

Task 2: Spawner Escapement

Spawner abundance will be estimated following the methodology that has been established and refined for the Cheakamus River (Korman et al. 2005). Repeated snorkel swims over the period of freshwater residence (spawning period) will enumerate steelhead over the entire length of the adult study section, which has been defined as the upper watershed from 0.5 to 14.5 km downstream of the anadromous barrier. All char and resident rainbow >20 cm fork length will also be recorded. Diver horizontal visibility (Korman et al. 2005) will be measured during each swim at appropriate locations along the study section. Discharge data will be obtained from the Water Survey of Canada gauge near Brackendale (WSC 08GA043).

Total escapement estimates and confidence bounds will be calculated using the analytical methods and maximum likelihood estimation procedure of Korman et al. 2002, as adapted in Korman et al. 2005. Briefly, escapement is calculated by:

a) Estimating observer efficiency using established relationships between observer efficiency, horizontal visibility, and discharge.
b) Expanding individual counts by the estimated observer efficiency.
c) Computing maximum likelihood estimates of escapement using a model that combines data from the expanded individual counts (b) with information on timing of river entry and departure (i.e., entry timing dependent survey life). Parameters for this model have been estimated using historic snorkel and radio telemetry data from the Cheakamus River.

Task 3: Emergence Timing

During the period of 1 July to 30 September an assessment of steelhead fry emergence timing will be conducted by backpack/shore-based electrofishing the same six sites every two weeks. This sequential sampling will only be conducted in the first year of study to verify estimates of emergence timing calculated based on estimates of spawn timing from historic radio telemetry (Korman et al. 2005) and hatch dates calculated based on accumulated thermal units. Emergence timing will be determined based on the change in length-frequencies and densities across the sample period.

Sites will be enclosed by stop nets and will be >75 m^2. Three-pass depletion utilizing a backpack/shore-based electroshocker will be conducted. Lengths and weights will be measured for all fish that are captured. The same six sites sampled by McCubbing et al. (2005) will be sampled in this monitor to maintain continuity. Three closed sites will be sampled per day by a three-person crew. Six person-days are required to sample all six sites in a week, requiring a total of 30 person-days of field effort across the five weeks sampled between 1 July and 30 September.

Task 4: Habitat Survey

In the first year of study, a habitat survey will be conducted at a discharge range of 15-25 $m^3 \bullet s^{-1}$ at Brackendale. The objective of the survey is to develop a map of the river that denotes areas that can be effectively sampled by backpack/shore-based electrofishing, boat electrofishing, or snorkeling, or that cannot be sampled by either technique and therefore excluded from the sampling universe. The total length of both riverbanks and side channels will be classified into a set of habitat type-gear type categories as in the following example:

Habitat Type	Gear Type
Low angle cobble bar (mainstem)	Backpack/shore-based electrofishing
Side channel (backwater)	Backpack/shore-based electrofishing
Side channel (flow-through)	Backpack/shore-based electrofishing
Steep bank in riffle/run	Snorkelling/boat electrofishing
Steep bank in pool	Snorkelling/boat electrofishing
Rapid	Excluded
Steep bank in fast run	Excluded

The survey will be conducted by raft. A unique identifier for each section of bank will be recorded, the length of each habitat unit will be measured with survey tape or laser range finding binoculars, and qualitative appraisal of habitat quality for steelhead fry and steelhead parr will be assessed. Sampling sites for fish surveys will be selected using a repeated measures design based on a random selection of sites in each habitat strata. The same sites will be sampled during the fall and spring in all years of study. Hence, annual variation in fish abundance can be examined using ANOVA with a proposed model form of $F_{ij} = \mu + Y_i + S_j + e_{ij}$, where, F_{ij} = fish density in year i at site j; μ is the mean density; Y_i is a random year effect; S_j is a random site effect; and residual variation. Further stratification by reach (see Fig. 1.2 of CC report) may assist with the design.

The total length of mainstem to be surveyed covers the entire anadromous length of the Cheakamus River which is approximately 18 km. There is likely an additional 5–10 km of side channel habitat for a total survey length of approximately 25 km. Assuming 2.5 km can be surveyed per day, a total of ten days of field time for a project biologist and river guide is required. Two sets of recent air photographs will be acquired from existing provincial or BC Hydro archives. Habitat units will be marked on the air photographs and denoted using a sensible unique ID system. Lengths will be measured in the field at the time of the survey using a laser range-finder. Site identifiers and lengths will be entered in an Excel spreadsheet. An Excel macro will be programmed to randomly select a subsample of sites from each habitat and gear strata.

Task 5: Fall and Spring Backpack/Shore-Based Electrofishing Surveys

To estimate fall parr and YoY abundance, habitat use, and to help infer subsequent survival, fall electrofishing at a representative set of sites will be conducted annually between 15 September and 15 October. A total of 15 enclosed sites will be sampled each year using multi-pass depletion.

To estimate spring parr and YoY abundance, habitat use, and infer survival since the previous fall, electrofishing in the spring will follow the same protocols and sample the same sites, as for the fall sample (Section 2.2.3). Sampling will occur from mid-March to mid-April when water temperatures generally exceed 5-6 C and discharges are still moderate (15-25 $m^3 \cdot s^{-1}$).

Fifteen closed sites will be sampled, assuming eight days of effort with a three-person crew (ca. two sites/day). Sites will be accessed by boat or truck depending on location. The length and species of all fish captured will be recorded. A random selection of 25 per cent of the fish captured at each site will be weighed. Scales will be taken from a length-stratified subsample of 100 juvenile steelhead to develop a year-specific size classification to segregate YoY, and age 1 and older parr. Scale data will be used to validate aging from length frequency analysis, that will be done using common applications (program MIX www.math.mcmaster.ca/peter/mix/mix.html or similar). Site area, dominant and sub-dominant substrate classes, instream and overhead cover types, and depth and velocity characteristics will be recorded, as per standard provincial protocols.

Age-specific densities will be calculated from the depletion data using Maximum Likelihood or similar techniques. To facilitate comparisons with historic data and data from other systems, densities of YoY will also be adjusted for depth and velocity preferences (hydraulic suitability) using HSI curves, and expressed as abundance per 100 m^2 of hydraulically suitable habitat.

The benthic community monitoring program (#7) will require that juvenile salmonids be sampled, sacrificed and sent to Program #7 to examine stomach contents. For efficiency, theses samples will be collected under this program and/or the trout abundance program in the non-anadromous reach (Program #2). Stomach samples from 15 juvenile salmonids for each stream rearing salmonid species of interest will need to be collected from near the benthic invertebrate sampling sites (i.e., 15 samples per species in each of the years of benthic sampling, in Years 2 and 3, for a total of 30 individuals per species). Subject to sampling permit approval and conservation concerns, species collected would include rainbow trout/steelhead, coho salmon, Chinook salmon and bull trout. Coordination of the collection of stomach samples will be determined through communication under Task #1.

Task 6: Springtime Parr Surveys

Parr in the Cheakamus River utilize habitats that are too deep or fast to be effectively sampled by backpack/shore-based electrofishing. To estimate spring abundance and habitat use by larger parr, these habitats must be sampled by snorkeling using methods developed by on the Thompson River and its tributaries (Hagen et al. 2005), or by boat electrofishing. Either method requires relatively good water clarity and low discharge (15-25 $m^3 \cdot s^{-1}$), which limits sampling to the mid-March to mid-April period. Suitable sampling conditions may also occur in late fall, however timing fall surveys would be challenging given fall storms and high density of spawning pink and chum salmon that likely displace juvenile fish and increase health risks to divers. The spring snorkel-based approach will be evaluated in Year 1 of the monitor and boat electrofishing will be evaluated in Year 2. The sampling method in subsequent years will be determined based on a comparison of the two methods.

Surveys will be conducted at 40 sites (20 sites per habitat type) at night. Sites will be 25 (snorkel) or 50 (boat electrofishing) meters in length. Divers will move in an upstream direction enumerating all species and age classes (defined as either YoY or parr) within a wetted width of 4 m from the shoreline. Site length, area, substrate, and cover types, and depth and velocity characteristics will be recorded. Boat electrofishing will be conducted in a downstream direction with the boat controlled using an outboard jet motor, oars, or a hand-line, depending on the depth and velocity characteristics of the site.

To calibrate the snorkel and boat electrofishing sampling, mark-recapture experiments will be conducted at 10 of the 40 sites (five per habitat type) over two nights. On the first night, fish will be enumerated, captured, marked, and released back into the site. For snorkel surveys, fish will be captured by dip net by the divers after conducting the first pass. The crew will return to the site the next night and enumerate the number of fish with and without marks. Catchability will be determined based on the ratio of marked and unmarked fish. Scales will be taken from a length-stratified subsample of 100 juvenile steelhead captured on the first night to develop a year-specific size classification to segregate YoY, age 1, and age 2+ parr.

Estimates of YoY and parr steelhead densities will be derived by converting indices of density at open sites to actual densities based on estimated catchabilities derived by mark-recapture. Catchability estimates will be calculated using standard mark-recapture estimates assuming a closed population and no mark loss or mortality.

For the snorkel surveys, a three-person crew consisting of two divers and one river guide is required. A total of six sites will be sampled per night, requiring seven nights of effort to complete all 40 sites. An additional six nights of effort will be required for the mark-recapture experiments for a total of 13 nights or 39 person-days of sampling effort. All sites will be accessed by raft. The work must be conducted by biologists with experience enumerating salmonids by visual methods in rivers at night.

Boat electrofishing consists of a two-person crew. A river guide/ technician will operate the raft and electrofisher and a second technician/biologist will capture stunned fish by dip net. The budget includes the labour to specify and rent equipment and rig a relatively specialized boat electrofisher that is required for the Cheakamus River. An inflatable boat with rowing frame, an outboard jet motor, hard floor, 5000 Watt generator, Smith-Root boat electrofishing equipment, holding tub, and lights will be required.

Task 7: Reporting

All data collected will be submitted annually in a Microsoft Access Database. Data from all years of study will be compiled annually into a single database (Excel or Access) to facilitate multi-year analyses. The raw data is a key deliverable of this project.

An annual report documenting methods, results, and conclusions from all aspects of the program will be provided. Reports will include an Executive Summary outlining the data collected to date, and the status of the project. As the project progresses, reporting must include results from individual years as well as a synthesis of results from all previous years of study.

Following the final year of data collection, a final report will be prepared that will include:

a) An executive summary of the entire project.

b) A data summary.

c) The analytical procedures.

d) A detailed summary of the findings as they relate to the ecological hypothesis and the key management questions.

e) Recommendations for future monitoring, if any, needed to understand better the effects of flow on steelhead production.

All reports will be provided in Microsoft Word and Adobe Acrobat (*.pdf) and all maps and figures will be provided in their native format either as embedded objects in the Word file or as separate files.

1.2.4 Interpretation of Monitoring Program Results

Emergence timing of steelhead fry will be determined through examination of length-frequency histograms for each week of the five-week program. Emergence timing estimated from the catch data should be compared to estimates derived from a multi-year estimate of spawn timing from historical telemetry data (Korman et al. 2005), the required number of accumulated thermal units for emergence (Jensen et al. 1992), and year-specific water temperature data being collected under the Cheakamus WUP salmon outmigration monitoring program (Program #1a).

Results from habitat mapping will be compared with historic habitat mapping work (see summary in Ptolemy and Wilson 2006). River and reach-wide estimates of fry and parr abundance in the spring and fall will be determined by scaling up the site-specific densities using the habitat survey data.

Reporting in Year 2 must include a comparison of densities and catchabilities between snorkel and boat electrofishing methods, the within and among crew replicability of the estimates for each method, and a recommendation regarding which method, or combination of methods, should be used in future years of sampling. The relationship between YoY and parr density and site characteristics must be described.

As data accumulates in the latter years of the study, the relationship between habitat use and flow must be described. Spawner-to-YoY, YoY-to-parr, and spawner-to-parr relationships must be developed in the final years of study. An analysis of the relationship between residuals from these curves and discharge must be conducted. Reporting in latter years of the study must include both year-specific information as well as a synthesis of results across all years of study to address the management questions and hypotheses outlined above. Steelhead smolt outmigration estimates collected and calculated under the Juvenile Oumigrant program (#1a) will provide companion data for stock-recruit analyses and to support inferences drawn from the adult and juvenile data collected under this program. Program #1a will provide the steelhead smolt outmigration estimates to this program annually, for use in subsequent analyses. Hence, the first year of reporting for this program will include a review of these historic steelhead smolt outmigration estimates and their precision (see Melville and McCubbing 2006), how they relate to the subsequent adult escapements (e.g., Korman et al. 2005), and the inferences on the “capacity” of the system that can be drawn from these data (see Ptolemy and Wilson 2006). Inferences on capacity will include comparisons of juvenile abundance per unit area relative to other systems and water quality-based predictions of maximum biomass. Reporting in subsequent years will update this review.

Additional companion data may support the inferences drawn from this monitoring. Common measures of discharge during the critical periods identified by the monitoring will be calculated and compared with historic discharge records and common habitat benchmarks, such as the proportion of Mean Annual Discharge.

1.2.5 Schedule

Timing for field sampling for individual components is described in detail in the Methods section and is summarized in the table below.

Adult snorkel surveys will occur from February to June. Sampling for emergence timing will occur on a bi-weekly basis between 1 July and 30 September and only in Year 1 of the study. The habitat survey must be conducted at a discharge range of 15-25 $m^3 \bullet s^{-1}$. Flows in this range occur frequently during February and March. Fall backpack/shore-based electrofishing surveys will be conducted between 15 September and 15 October. Snorkel- or boat electrofishing-based parr surveys and backpack/shore-based electrofishing YoY surveys will be conducted between 15 March and 15 April.

Reports will be prepared annually. Ideally, annual reports would cover a “biological year”, and summarize adult escapement (calendar year t), subsequent YoY fall abundance (calendar year t), and the subsequent YoY and parr abundance the following spring (calendar year t+1).

Component	Sampling Timing	Years Sampled
Adult escapement	February – June	Annually
Habitat survey	When discharge = 15-25 $m^3 \cdot s^{-1}$	Year 1 only
YoY emergence timing	July – September	Year 1 only
YoY abundance (fall)[a]	15 September – 15 October	Annually
Parr abundance (fall)[a]	15 September – 15 October	Annually
YoY abundance (spring)[a]	15 March – 15 April	Annually
Parr abundance (spring)[a]	15 March – 15 April	Annually

[a] Habitat survey must be completed prior to first sampling.

1.2.6 Budget

Table 3-1 outlines the estimated cost for the monitoring program. The cost of spring parr surveys in Years 1 and 2 are based on snorkel and boat electrofishing programs, respectively. The more expensive program (boat electrofishing) was used to estimate spring parr survey costs in subsequent years, although the actual method that is used will be determined based on a comparison of the two methods. This decision has a negligible influence on the total costs as the two components have similar costs.

Table 3-1: Cost Estimate for the Cheakamus River Steelhead Adult Abundance, Fry Emergence-timing, and Juvenile Habitat Use and Abundance Monitoring

Task	Labour	Daily rate	Units Yr 1	Yr 2	Yr 3	Yr 4	Yr 5	Total Cost
Project Coordination	Project Biologist	$600	10	10	10	10	10	$30,000
Emergence timing	Project Biologist	$600	10					$6,000
	Technician 1	$300	10					$3,000
	Technician 2	$300	10					$3,000
Habitat survey	Project Biologist	$600	10					$6,000
	River Guide	$300	10					$3,000
Fall and spring YoY & parr electrofishing	Project Biologist	$600	16	16	16	16	16	$48,000
	Technician 1	$300	16	16	16	16	16	$24,000
	Technician 2	$300	16	16	16	16	16	$24,000
Spring parr & YoY snorkel survey	Project Biologist	$600	13					$7,800
	Biologist 1	$500	13					$6,500
	Biologist 2	$500	13					$6,500
Spring boat electrofishing parr & YoY survey	Project Biologist	$600		13	13	13	13	$31,200
	Biologist 1	$500		13	13	13	13	$26,000
Adult surveys	Project Biologist	$600	10	10	10	10	10	$30,000
	Biologist 1	$500	10	10	10	10	10	$25,000
	Biologist 2	$500	10	10	10	10	10	$25,000
	Biologist 3	$500	10	10	10	10	10	$25,000
	Biologist 4	$500	10	10	10	10	10	$25,000
Travel / mobilization	Project Biologist	$600	7	7	7	7	7	$21,000
	Technician 1	$300	5	3	3	3	3	$5,100
	Technician 2	$300	5	3	3	3	3	$5,100
	Biologist 1	$500	4	4	4	4	4	$10,000
	Biologist 2	$500	4	4	4	4	4	$10,000
Data entry	Project Biologist	$600	17	12	12	12	12	$39,000
	Technician 1	$300	10	8	8	8	8	$12,600
Data management	Analyst	$750	5	5	5	5	5	$18,750
	Project Biologist	$600	5	5	5	5	5	$15,000
Algorithm for habitat unit site selection	Analyst	$750	1					$750
Data analysis and reporting	Analyst	$750	20	20	20	20	30	$82,500
	Project Biologist	$600	12	12	12	12	15	$37,800
	Contingency	10%	$19,673	$15,829	$15,829	$15,929	$16,759	$84,018
		Subtotal	*$166,773*	*$129,879*	*$129,879*	*$129,979*	*$140,109*	*$696,618*
	Expenses	Unit Price						
	Enclosure nets	$1,000	1			1		$2,000
	Backpack electroshocker (purchase)	$8,900	1					$8,900
	Backpack electroshocker (maintenance)	$500		1	1	1	1	$2,000
	Boat rental	$150	49	39	39	39	39	$30,750
	Electrofishing raft rental	$600		13	13	13	13	$31,200
	Air photos	$500	2					$1,000
	Scale ageing	$25	200	200	200	200	200	$25,000
	Dry suit rental	$50	76	76	76	76	76	$19,000
	Mileage (per km)	$0.56	17100	14800	14800	14800	14800	$42,728
	Field supplies	$1,000	5	5	5	5	5	$25,000
	Lodging and meals (month)	$2,500	3	3	3	3	3	$37,500
	Report reproduction	$500	1	1	1	1	1	$2,500
		Subtotal	*$49,626*	*$44,238*	*$44,238*	*$45,238*	*$44,238*	*$227,578*
	Future Inflation	2%	$4,328	$7,034	$10,657	$14,443	$19,187	$55,650
		Total	**$220,727**	**$181,151**	**$184,774**	**$189,660**	**$203,534**	**$979,846**

1.2.7 References

BC Hydro. 2005. Cheakamus Project Water Use Plan – Revised for acceptance by the Comptroller of Water Rights. Prepared by BC Hydro October 1, 2005.

Bradford, M.J., Korman, J., and P.S. Higgins. 2005. Using confidence intervals to estimate the response of salmon populations (*Oncorhynchus* spp.) to experimental habitat alterations. Can. J. Fish. Aquat. Sci. 62:2716-2726.

Bruce, J. 2001. Cheakamus River Water Use Plan: Habitat suitability weighting functions for juvenile, summer rearing salmonids. Draft report prepared by BC Hydro for Cheakamus Water Use Planning Fish Technical Committee.

Hagen, J., Decker, S., and R. Bison. 2005. Calibrated rapid assessment methods for estimating total steelhead parr abundance in the Thompson River system, British Columbia – 2004 interim report. Prepared for BC Ministry of Water, Land and Air Protection, Kamloops BC, and Habitat Conservation Trust Fund, Victoria BC.

Jensen, J.O.T., McLean, W.E., Rombough, P.J., and T. Septav. 1992. Salmonid incubation and rearing programs for IBM-compatible computers. Can. Tech. Rep. Fish. Aquat. Sci. 1878: 46 p.

Korman, J., Higgins, P.S., and C.C. Melville. 2005. Incorporating the effects of migratory behaviour and river conditions into estimates of steelhead escapement. Report prepared by Ecometric Research, Vancouver, BC, for BC Hydro.

Marmorek, D.R., and I. Parnell. 2002. Cheakamus River water use plan - Report of the consultative committee. Report prepared by ESSA Technologies Ltd., Vancouver, BC on behalf of the Cheakamus River Water Use Plan Consultative Committee, Vancouver, BC, 234 pp.

Melville, C.C., and D.J.F. McCubbing. 2004. Assessment of the 2004 juvenile salmon migration in the Cheakamus River, using rotary traps. Report prepared by Instream Fisheries Consultants, Vancouver, BC, for BC Hydro.

Melville, C.C., and D.J.F. McCubbing. 2006. Assessment of the 2006 juvenile salmon migration in the Cheakamus River, using rotary traps. Draft Report prepared by Instream Fisheries Consultants, Vancouver, BC, for BC Hydro.

McCubbing, D.J.F., Melville, C.C., Wilson, G., and M. Foy. 2005. Assessment of the CN Rail caustic soda spill August 5th, 2005 on the fish populations of the Cheakamus River. Report prepared by Instream Fisheries Research, Vancouver, BC.

Ptolemy, R.A., and Wilson, G. 2006. BC Ministry of Environment comments on the Cheakamus Water Use Plan monitoring program #1a, Cheakamus River Juvenile Salmonid Outmigrant Enumeration Monitoring. Correspondence dated November 7 2006.

Cheakamus River Monitoring Program #4: Monitoring Stranding Downstream of Cheakamus Generating Station

1.1 Program Rationale

1.1.1 Background

During the scoping phase of the Cheakamus River WUP process, the Fish Technical Committee (FTC) introduced and discussed the hypothesis that the peaking operations at the Cheakamus powerhouse (located on the eastern bank of the Squamish River) resulted in tailrace water level fluctuations that could strand redds or juvenile fish. The powerplant discharges into a relatively short tailrace channel, which joins a seasonally wetted side channel of the Squamish River, and ultimately joins the Squamish River[1], approximately 1727 m downstream of the powerplant (Fig. 4-1; Tantalus Consulting and Geostreams Consulting 2005). Small tributary streams enter these channels as well. The hypothesis of fish stranding stemmed from several recent, anecdotal observations of fish stranding when the powerhouse turbines were shut down following extended periods of sustained turbine flows, and at a time when Squamish River discharge was at a low level.

The results of a fish stranding assessment completed in 1995/96 (Sigma Engineering Ltd. 1996) and a site visit by FTC members lead the FTC to conclude that the frequency and severity of impact was insufficient to warrant further consideration during the decision making process of present WUP process. The decision was not to reject the hypothesis, but to postpone its inclusion in the present WUP until better data are available to parameterise the issue. To that end, the FTC recommended that a monitor be developed to address key uncertainties uncovered during their initial assessment of the impact hypothesis, and that the hypothesis be re-examined in light of this monitoring information at the next review process.

[1] For the purposes of the Terms of Reference, “Tailrace channel” will refer to the section from the powerplant to the confluence with the “side channel”, and “side channel” will refer to the entire side channel of the Squamish River (Fig. 4-1).

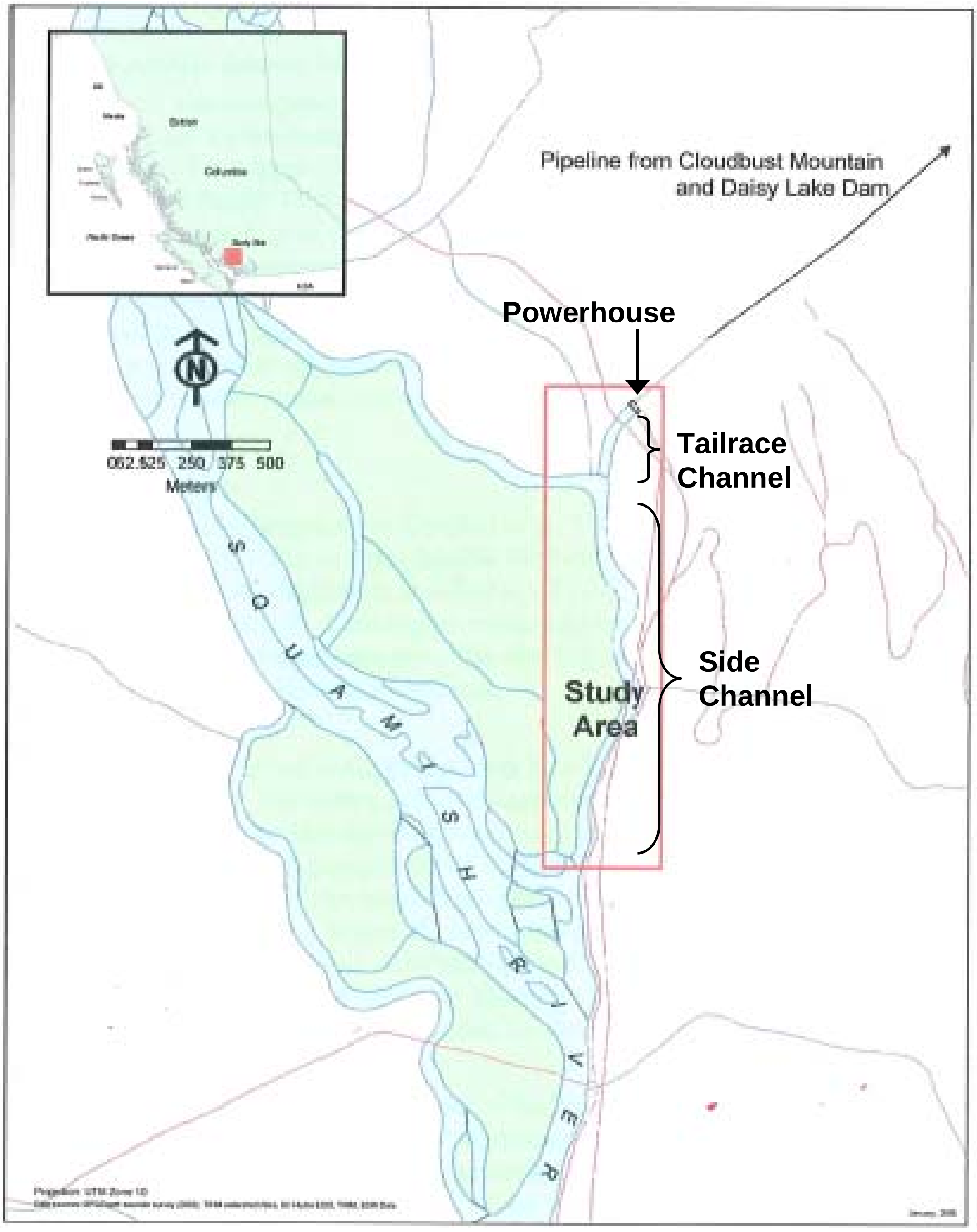

Figure 4-1: Cheakamus Generating Station, Tailrace Channel, and Side Channel. Modified From Tantalus Consulting and Geostreams Consulting (2005).

1.1.2 Management Questions

The uncertainties identified by the FTC in their assessment of the powerhouse-stranding hypothesis have lead to the following five management questions:

1) What is the magnitude of stranding risk in the tailrace channel downstream of the Cheakamus Generating Station, and at what time of the year is it at its highest level?

   Stranding risk refers to the number of fish stranded. Past attempts at quantifying this risk have met with limited success due to the unpredictable nature of Squamish River flows, as well as those from the powerhouse turbines. The reported low incidence of stranding may simply reflect the difficulty in identifying their occurrence, largely because of their stochasticity, short duration, and the logistical difficulties in organising surveys on short notice.

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

   Studies and anecdotal observations to date suggest that the extent of impact is relatively limited. However, the quantity and quality of data in support of that conclusion is relatively limited. Better data is needed to assess whether the impact is sufficient to harm wild fish populations in the watershed.

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

   There was a general belief among the FTC (supported by published literature) that the colonization of habitats by juvenile fish does not occur quickly and that it can take a fair amount of time for fish to seek and finally decide to defend relatively permanent feeding territories. The FTC hypothesized that peaking operations would disrupt this permanency behaviour and hence discourage re-colonization of such “risky” habitats.

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

   Observations to date would suggest that this risk is low, but this conclusion could simply reflect the low frequency at which the area is surveyed.

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

   For example, changing operations or physical alterations to the tailrace channel.

1.1.3 Summary of Impact Hypotheses

The monitor will test whether fish stranding in the tailrace channel, given the operation of the Cheakamus powerhouse turbines under WUP, is sufficient to affect fish populations, and therefore warrant mitigation. There are however, several difficulties in testing this hypothesis. Firstly, a threshold value of stranding needs to be defined that identifies events that are “harmful” to the population. This threshold value must be in units that are measurable under present conditions and will have to be set in consultation with appropriate fish agencies. The other difficulty is in actually quantifying the rate of stranding, particularly in light of the fact that stranding appears to occur only when certain flow conditions are present, that stranding cannot always be predicted in advance for planning purposes, and that field conditions make stranding very difficult to directly quantify.

The approach taken in this monitor to overcome this difficulty in measuring stranding rate is to rely on modelling techniques to identify those hydrological conditions that lead to dewatering and pool stranding events. In conjunction with the modelling work, studies will be carried out to identify the duration of sustained high flows (prior to the dewatering event) that are believed to be necessary to attract fish into the tailrace channel and then become stranded. This information is then incorporated into the model to properly identify conditions that could potentially result in stranding. Finally, to get a measure of stranding rate, the model is run with historical Squamish flow data and simulated turbine data (that used during the WUP process) to identify the average potential frequency and magnitude of stranding events each year given a WUP based operation. Explicitly stated, the impact hypothesis is as follows;

H_O1: Stranding rate of juvenile fish does not exceed the threshold value judge to be harmful to local fish populations.

Stranding rate is defined by the average annual frequency and magnitude of events where Squamish side channel inflow, turbine flow, and prior duration of sustained high flow combine to create stranding conditions. Stranding refers to both bar and pothole stranding (Higgins and Bradford 1996). Hypothesis 1 can be similarly stated for the occurrence of spawner or redd stranding.

1.1.4 Key Water Use Decision Affected

The WUP has no constraints for powerhouse turbine operations except for a 10 MW per five-minute turbine rampdown rate as the load drops from 40 to 10 MW. The lack of constraints was based on the assumption that spawning and rearing activities in the tailrace channel are limited and, therefore, the risk of stranding was minimal. However, anecdotal observations of both juvenile and spawner stranding puts the validity of this assumption into question. The monitor would help reduce this uncertainty and will provide the information necessary to review strategies to mitigate the impact should a significant stranding risk be found.

The key water use decision that would be informed by the results of this monitor would be the operation of the generating station, or physical changes to the channel in-lieu of such operational changes. Changes to turbine operation will be very costly, and will impact the flexibility needed to operate the powerhouse as a peaking facility. This was recognized by both the FTC and the CC when assessing the relative importance of the powerhouse-stranding hypothesis and contributed to the conclusion that the evaluation of the hypothesis be postponed until the next planning process. As a result, it is unlikely the monitor would lead to immediate changes to the WUP as they pertain to turbine changes. However, results of the monitor could help to formulate cost effective, physical works options if stranding were found to be a significant issue. The nature of these works would depend on the nature of the stranding impact.

1.2 Program Proposal

1.2.1 Objective and Scope

The objective of this monitor is to collect the data necessary to test the impact hypotheses outlined above and hence, address the management questions presented in Section 1.2. The following aspects define the scope of the study:

a) The study area will consist of the Cheakamus Generation Station tailrace channel. Though the entire length of the tailrace channel and side channel will be under investigation, particular attention will be focused on the tailrace channel, which is the section that lies between the powerhouse and the Squamish River side channel confluence.

b) The monitor is scheduled to be carried out over a period of three years.

c) The monitor is to include a workshop designed to set threshold values of stranding that identify those events deemed to be harmful to Squamish River fish populations.

d) A key component of the modelling is to develop a predictive model that identifies the frequency and duration of juvenile and adult fish stranding risk. Following a period of testing, the model will then be used to judge the severity of this risk as well as quantify/qualify its impact to Squamish River fish populations.

e) Should the level of stranding be deemed significant, a key deliverable of the monitor will be to develop potential mitigation options ranging from changes in turbine operation to extensive physical works (e.g., channel re-contouring) for future consideration.

1.2.2 Approach

Survey work in the tailrace channel, whether biological, physical or chemical sampling, poses considerable challenges. Work can only proceed safely and with accuracy when turbine releases are relatively low. Given the peaking nature of the powerhouse, this generally only occurs at night, though that may not always be the case. Furthermore, the conditions that could potentially lead to the stranding of either adult or juvenile fish tend to be stochastic in nature, thus making it difficult to organize and implement survey techniques. As result, the ability to directly observe stranding events, including the conditions that lead to them, is limited. To compensate, the monitor incorporates the use of many models (hydraulic, hydrological, turbine operations, etc.) to assess the stranding risk of juvenile and adult fish in the tailrace channel.

The monitor will be carried out over three years. The first year will focus on collecting hydrology, channel topography, and water chemistry data in the tailrace channel. Also included in Year 1 of the monitor is a general assessment of species and life history use. Year 2 of the monitor will focus on the hydrology and hydraulics of the tailrace channel with the aim of defining the combination of Squamish River and turbine flow conditions that lead to potential stranding events. This includes defining the length of time that constant flows must be sustained to encourage colonization of habitats prone to dewatering. In addition to the hydrology studies, Year 2 will also entail periodic surveys to identify incidents of stranding, as well as behavioural studies to identify colonization rates. The work done in the first two years of the monitor will be used to develop a predictive model of stranding events.

Year 3 will test the model to assess its predictive capability and accuracy. The assessment will consist primarily of comparisons between predicted and observed events. Once judged accurate, the model can be used to assess the average annual frequency and duration of events and therefore quantify the annual risk of stranding, a value needed to assess the relative importance of such events to the production of affected species. The assessment will be carried out using the modelled hydrology results developed during the WUP process. If impacts to fish populations are judged to be biologically important, the model and survey data collected during the monitor can then be used to develop cost effective mitigation activities that may be implemented in the future.

Table 4-1: Summary of Key Tasks and Annual Timing

Task	Timing (Y)
Information review	1
Topographical survey	1
Fish use assessment	1
System hydrology	1-3
Hydraulic model development	2
Periodic stranding surveys	2-3
Juvenile colonization rate	1-2
Stranding workshop	3

1.2.3 Methods

Task 1: Project Coordination

Project coordination involves the general administrative and technical oversight of the program. This will include but not be limited to:

1) Budget management.

2) Staff selection.

3) Logistic coordination.

4) Technical oversight in field and analysis components.

5) Liaison with regulatory agencies.

Coordination with WUP Monitoring and Other Monitoring Programs

To ensure that data collection is coordinated among the inter-related monitoring programs for the Cheakamus WUP, an important task for each program is to develop and maintain communication with project leads for the other monitoring programs. This communication could involve a workshop at the start of the field season to ensure that the sampling locations and methodologies will meet the data requirements of the other programs if needed, and vice-versa. While the data collected under this program in the Squamish River watershed may not be directly related to the data collection under the monitoring programs in the Cheakamus watershed, maintaining communication is important because the links between programs may not be immediately apparent (e.g., links with the stranding downstream of Daisy Dam, Program #5).

Discussions with projects leads for similar WUP stranding assessments in other watersheds may also beneficial (e.g., “Herrling Island Side Channel Chum Spawning Success Monitoring” under the Wahleach WUP, stranding programs under the Stave WUP).

Task 2: Data Collection

Year 1

Data collection in Year 1 of the monitor will consist primarily of topographical surveys, reconnaissance level fish use assessments, initial collating of Squamish River and tailrace channel water surface elevation data, and basic water chemistry analysis of stranding waters (potholes).

Review Existing Information

Several studies have examined stranding in the tailrace channel and side channel (e.g., Sigma Engineering Ltd. 1996; Melville 2002; Troffe and Melville 2004; Tantalus Consulting and Geostreams Consulting 2005; BC Hydro unpublished data). These studies were not necessarily coordinated. Therefore, the first step in the monitor is to review and summarize existing information on fish stranding and flows in the tailrace channel and side channel. This summary may result in modifications to the sampling.

Many of the tasks associated with Year 1 of the monitor were begun in September 2003 and completed in April 2004 (Troffe and Melville 2004; Tantalus Consulting and Geostreams Consulting 2005; BC Hydro unpublished data). An important remaining task is to develop a stage discharge curve for the tailrace channel. The tasks associated with Years 2 and 3 have yet to be started.

Topographical Survey

A topographical map of the tailrace channel will be developed at a resolution appropriate to help answer the management questions and test the hypothesis. A topographical survey of the tailrace channel can be carried out by depth sounder paired to a GPS unit to simultaneously track water depth and UTM position from a small boat. Areas not covered by water will be surveyed by transit and rod. All survey measurements will be relative to a local, permanent survey monument, preferably one with known UTM co-ordinates.

A topographical map of the tailrace channel has been produced (Tantalus Consulting and Geostreams Consulting 2005), and the information review task above will verify whether this map is appropriate for the study, or if further data collection and refinements are needed.

Fish Use Assessments

To add the information from the information review above, species and life history phases of fish that rear or spawn in the tailrace channel and side channel will be determined largely from on-shore foot surveys. Where possible, behavioural activities such as redd digging and feeding will be noted. All Incidents of stranding will be recorded. To help distinguish between stranding mortality and natural senescence, for spawning fish found stranded, gravid individuals will be reported separately. The stranding surveys will also distinguish between fish found stranded on gravel bars versus those trapped in isolated pools.

Logistical constraints and safety concerns may limit sampling to periods of low turbine discharge, which commonly occurs at night. Since much of this work will be carried out in areas where discharge can change rapidly with little notice, maintaining proper communication and coordination between facility operators and field crews will be critical for crew safety. Thus, these sampling constraints will be an important consideration for sampling planning.

Juvenile Colonization Rate

Another key task in Years 1 and 2 will be a study on the rate of colonization of juvenile fish into the tailrace channel. Sampling will examine a range of available flow conditions over these 2 years. It is currently believed that the variable flow conditions in the tailrace channel tend to exclude fish from the area as variable flows make rearing habitats too unstable to establish feeding territories. However, if high flows are sustained for a period of time, fish may become attracted to the area and begin to establish permanent territories. The clearer water discharged from the plant and from tributaries, relative to the frequently turbid waters of the Squamish mainstem may also attract fish. The duration of these periods of sustained tailrace flow that trigger this colonization response is unknown, and is a necessary parameter in order to define stranding risk.

The characterization of these colonization rates will be done in two ways, each designed to complement the other. The first method of will consist of periodic foot surveys where the presence/absence of fish will be noted from shore at key sites (a minimum of ten) along the length of the channel that are prone to dewatering when Squamish River flows are low. Depending on local fish behaviour, these surveys may have to be carried out at night with flashlights to detect their presence. Because this method may have limited observation efficiency, colonization data will also be collected by video camera (equipped with appropriate light for night-time viewing) installed at one of these sites. Over time (days to weeks) the camera will be relocated to other study sites as deemed necessary by the field crew. The general objective of both surveys is to quantify the presence of fish through time during periods of sustained turbine flow and hence develop duration criterion that signal the presence of fish that are at risk of stranding.

System Hydrology

The hydrology of the tailrace channel and side channel area is complex, with interactions between the many inflows, time lags and backwatering effects. Extensive efforts in previous attempts to correlate discharge have been generally unsuccessful. Thus, monitoring should focus on defining the key water levels (stage), locations and timings that are needed to make management decisions related to powerhouse operations, ramping and fish stranding.

The hydrology of the area will be captured by a series of water level recorders installed in the tailrace channel, side channel, and in the Squamish River.

1) Elaho and Squamish WSC gauges (Station No. 08GA071 and 08GA022 respectively). These data will be obtained from the WSC.

2) Tailrace stage at the powerhouse and turbine discharge. This data can be obtained from BC Hydro generation operations.

3) This program will install and maintain a gauge and datalogger on the Squamish River at or near the Ashulu Bridge, and in a location that provides the most suitable information for this program. This gauge will be operated for the duration of the monitoring program (three years). In addition, a staff gauge will be installed on or near the Ashulu Bridge as a backup for the continuous gauge. The installation and maintenance of these gauges at or near the Ashulu Bridge is an additional monitoring requirement of the WUP that will be covered under this program.

4) This program will install a network of gauges as needed in the tailrace channel, side channel, and key tributaries. The number and arrangement of the gauges will be determined under the information review task above.

Water level measurements for #3 and #4 will be logged at an appropriate interval (e.g., 15 min intervals). The water level recorders will be calibrated to datum so that all measurements are directly comparable to one another, and match up with the topographic survey,

Discharge at the Squamish River recorder (#3) will be interpolated from the data collected at the WSC stations. Discharge at the tailrace channel and side channel sites will be determined directly by a stage discharge curve. The stage discharge curve needed to calibrate flows will be developed using flow measurement gathered at a minimum of eight stage levels. For safety reasons, as well as problems with local turbulence, flow measurements using salt tracer technology may be appropriate. A saturated solution of salt water will be released upstream of the water level recorder and allowed to mix through out the water column. A salinity meter will then be used to record the passage of the salt plug as it moves by the recorder. The resulting salinity tracing will then be analyzed to estimate discharge (see Hudson and Fraser 2005 and references therein).

The inflow to the side channel (inflow from upstream of the tailrace confluence) from the Squamish River mainstem will be inferred from the network of gauges. The side channel flow data will then be linked to the Squamish River water level recorder to obtain a time sequence of side channels inflows. Inflows to the side channel from the Squamish mainstem only occur when the flows in the Squamish River reach a certain stage. Backwatering of the side channel and tailrace channel may also occur.

In addition to the measurements above, water level data will be collected at isolated pools to determine the rate of pool shrinkage and therefore obtain a measure of their persistence through time.

Water Quality

Water quality measurement will consist primarily of dissolved oxygen ($ml \bullet L^{-1}$) and temperature (°C) measurements taken over time at isolated pools. The temporal sequences will then be used to calculate the rate of DO deletion and temperature increase. Both factors can cause mortality in standing waters.

Year 2

Model development

In addition to the ongoing tasks (Table 4-1), year 2 will focus on developing a two-dimension flow model to identify the full range of Squamish River stage and powerhouse discharge conditions that cause stranding within the tailrace channel, as well as specific location of where the stranding would occur. The model will rely on the topographical data and hydrology data collected in Year 1 to generate a two dimension, finite element flow model of the channel to predict local water depth and velocity throughout the tailrace channel (Leake 2004). The model will also rely on the water level data collected within the tailrace channel for calibration purposes.

In addition to the modelling exercise, periodic surveys will be carried out to identify incidents of bar and pothole stranding as in Year 1. Where possible, these surveys will be co-ordinated with periods that are believed to be of high stranding risk (low Squamish River flows and no turbine discharge). With the development of the model, the timing of these surveys will become more effective as stranding conditions and locations become better defined.

Year 3

In addition to the ongoing tasks (Table 4-1), year 3 will include the following.

Stranding Workshop

A workshop will occur with key parties to set threshold values of stranding that identify those events deemed to be harmful to fish populations. The main goal of the workshop will be to achieve convergence of professional opinion towards a single threshold value. Good facilitation and an informed discussion of stranding events in the tailrace channel will be key to the success for this workshop.

Stranding Surveys

Periodic stranding surveys that note the incidence, location, and number of fish found stranded will be preformed in Year 3. These observations will be compared with model predictions to assess the validity and utility of the tailrace-stranding model. If found to be robust, the model will then be used to assess stranding risk based on WUP operations as it was modelled during the WUP process. If the model is not found to be sufficiently robust, it will be modified using the year's survey results.

Task 3: Data Analysis

All data will be entered into a common database in a standardized format. This will ensure that all data collected will be compatible to that of future studies. All survey data will be adapted to the UTM co-ordinate standard of measurement, and all references to water depth will be relative to data. The convention will ensure that the topographical data will be compatible will all GIS and modelling software packages currently used by BC Hydro.

Data analysis will consist primarily of two key activities, model development and hypothesis testing. Model development will follow all of the conventions, procedures modelling protocols as outlined by Leake (2004). Where possible the same software packages should be used to maintain consistency in the type and format of simulation results. Model accuracy and precision will be evaluated by comparing predictions of where and when stranding occurs [based on the topography of the channel (t), the duration of sustain high flow periods (Q_{dt}), rate of colonization by nearby resident fish (r), side channel flow (Q_{Sq}), and turbine flow (Q_t)] and a minimum subset of 20 actual observations of stranding. Discrepancies between the two sets of observations will be used to modify and improve the model if possible, but ultimately the differences will be used to quantify the distribution of model error.

Hypothesis testing will consist of comparing the probability that the stranding threshold is exceeded in any given year. To estimate the annual stranding risk, the stranding model will be run using 40 years of simulated WUP operations data to calculate the projected risk of stranding for each year of simulation. These simulation runs will incorporate the hydrology of Squamish River and the duration of sustained high flow periods into the model calculation. Model error will be incorporated into the probability distribution function through Monte Carlo simulation where the results of each yearly model run will be assigned a randomly drawn error factor.

$$P_{Stranding}\,[t, r, Qdt, Q_{Sq}, Q_t, yr] = P_{Stranding}[t, r, Qdt, Q_{Sq}, Q_t, yr] + P\,[error] \qquad \text{Eq. 1}$$

The threshold level of stranding will be determined in consultation with appropriate fish agencies, as will the critical probability level (alpha level).

Task 4: Reporting

Project reporting will consist of a series of annual data reports and a single final report at the conclusion of the monitor. The data reports will simply document the year's findings and conclusions, including a discussion on how the year's work improved the general understanding of stranding incidents in the tailrace channel. The annual reports will also summarize the progress made towards the development of a stranding model and present the results of pertinent tests of hypotheses.

At the conclusion of the monitor, a final report will be prepared that collates all of the observations collected to date and:

a) Re-states the objective and scope of the monitor.
b) Presents the method of data collection.
c) Describes the compiled data set and presents the results of all analyses.
d) Describes the stranding model in detail.
e) Discusses the consequences of these results, including those model simulations, as they pertain to the current WUP operation, and the necessity and/or possibility for future change.
f) Presents examples of mitigation options if stranding is found to be significant. The costs and effectiveness of each option should also be discussed.

1.2.4 Interpretation of Monitoring Results

Interpretation of the monitoring results will be straightforward. If we fail to reject the null hypothesis H_O1, then no further actions are required, including a review of the WUP as it pertains to tailrace stranding. If H_O1 is rejected, then tailrace stranding will be reviewed under the WUP review process.

1.2.5 Schedule

The monitor is to be carried out over three years. Timing for each task is outlined the Methods section above and summarized in Table 4-1.

1.2.6 Budget

Table 4-2 outlines the estimated cost for the monitoring program.

Table 4-2: Cost Estimate for Monitoring Stranding Downstream of Cheakamus Generating Station

Task	Labour	Daily rate	Units Yr 1	Yr 2	Yr 3	Total Cost
Project Coordination	Project Biologist	$600	6	4	4	$8,400
Topography GIS	GIS Technician	$500	4			$2,000
	Technician	$300	4			$1,200
Fish use, fish colonization, & water quality	Project Biologist	$600	20	10		$18,000
	Technician	$300	20	10		$9,000
Transducer installation	Geomorphologist	$700	4			$2,800
& flow measurements	Technician	$300	8			$2,400
	Technician	$300	8			$2,400
Transducer maintenance & downloads	Technician	$300	2	2	2	$1,800
	Technician	$300	2	2	2	$1,800
Stranding workshop	Project Biologist	$600			3	$1,800
	Technician	$300			3	$900
	Facilitator	$600			3	$1,800
Stranding Observations	Project Biologist	$600		10	10	$12,000
	Technician	$300		10	10	$6,000
Modelling	Analyst	$750		15	3	$13,500
Data analysis	Analyst	$750	2	10	5	$12,750
Reporting	Project Biologist	$600	4	4	4	$7,200
	GIS Technician	$500	3			$1,500
	Technician	$300	6	2	3	$3,300
	Analyst	$750		5	8	$9,750
	Contingency	10%	$7,236	$5,966	$3,983	$17,185
		Subtotal	*$48,036*	*$53,066*	*$36,383*	*$137,485*
	Expenses	Unit Price				
	Mileage (per km)	$ 0.56	6000	3500	3000	$7,000
	Lodging (night)	$ 100	32	22	16	$7,000
	Meals	$ 50	64	44	33	$7,050
	Transducers (Purchase / replacement)	$ 4,000	4	1		$20,000
	Installation materials	$ 200	4	1		$1,000
	Video equipment	$ 3,000	1			$3,000
	Field supplies	$ 1,500	1	1	1	$4,500
	Stranding workshop	$ 500			1	$500
	Report reproduction	$ 500	1	1	1	$1,500
		Subtotal	*$31,560*	*$12,560*	*$7,430*	*$51,550*
	Future Inflation	2%	$1,592	$2,651	$2,682	$6,925
		Total	**$81,188**	**$68,277**	**$46,495**	**$195,960**

1.2.7 References

Higgins, P.S., and Bradford, M.J. 1996. Evaluation of a large-scale fish salvage to reduce the impacts of controlled flow reduction in a regulated river. North American Journal of Fisheries Management. **16**:666-673.

Hudson, R., and Fraser, J. 2005. Introduction to salt dilution gauging for streamflow measurement part IV: the mass balance (or dry injection) method. Streamline Watershed Management Bulleting Volume 9 No. 1. Fall 2005. Available online: http://www.forrex.org/streamline/streamline.asp as accessed February 2006.

Leake, A. C. 2004. Campbell River flow-habitat modelling 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.

Melville, C. 2002. Field Observations from the Powerhouse on the Squamish River, Fall 2002.

Field report provided to BC Hydro, November 19, 2002. 18pp.

Sigma Engineering Ltd. 1996. Squamish River fall and winter flow ramping studies: fall and winter fish habitat use and fish stranding assessment. Prepared by Sigma Engineering Ltd. for BC Hydro. April 1996. 73 pp. + App.

Troffe, P., and Melville, C. 2004. Cheakamus generating station tailrace flow monitoring study biological sampling component, July 2003 – March 2004. Prepared for BC Hydro Power Facilities, Coastal Generation.

Tantalus Consulting and Geostreams Consulting 2005. CMS Tailrace flow and habitat analysis. Report prepared for BC Hydro. September 11 2005.

Cheakamus River Monitoring Program #5: Monitoring Stranding Downstream of Daisy Lake Dam

1.1 Program Rationale

1.1.1 Background

Implementation of the Cheakamus River WUP flow regime will result in several changes in flow regime experienced downstream of Daisy Lake Dam. Under the Interim Flow Agreement, discharge out of the dam fluctuated considerably over weekly periods to meet a release requirement equivalent to a percentage of the previous seven-day average inflow to Daisy Lake Reservoir, and the minimum release could not drop below a 5 $m^3 \bullet s^{-1}$ base flow. With the implementation of the WUP flow regime, dam releases will become much more stable. Though releases will continue to fluctuate, the magnitude of change will be much less as it is linked to the minimum flow requirements at the Water Survey Canada stream flow gauge at Brackendale. Also, the base flow release from Daisy Lake Dam will change, depending on the time of year, to 3, 5, or 7 $m^3 \bullet s^{-1}$.

Some concern has been raised by the Fisheries Technical Committee and others that the change in base flow prescribed in the WUP could lead to the stranding of resident trout rearing immediately downstream of the dam. This concern stems from the fact that under the WUP, flow conditions downstream of the dam will become more stable and have a slightly higher base level during the growing season, and hence may be more habitable to rearing fish. It has been hypothesized that a sudden drop in base flow following such stable growing conditions could lead to some stranding of these individuals. Such a drop would occur annually during the Nov 1st decrease in the minimum flow release requirement from 7 to 3 $m^3 \bullet s^{-1}$. The risk of stranding could be particularly high at this time of the year because local inflows to the Cheakamus River would typically exceed the minimum requirements at Brackendale, and thus only base flows would be released out of the dam. Given the low volume of water being released relative to the channels capacity, the drop in base flow could result in significant channel dewatering.

Downstream of Rubble creek, there are a number of local inflow sources, including that of Rubble Creek itself, which would attenuate the impacts of a change in base flow. Local inflows to the area typically exceed 5 $m^3 \bullet s^{-1}$ for much of the year and is often much higher in the weeks preceding the change in base flow. As a result, the only area of real concern for significant stranding lies immediately downstream of the dam and extends only to the confluence of Rubble Creek.

Given the expected small areal extent of suspected stranding, monitoring of one stranding event during Nov 1 decrease in minimum flow release was recommended to reduce uncertainty related to stranding.

1.1.2 Management Questions

The WUP includes a ramping rate protocol designed to minimize the risk of stranding when discharge form the dam is being reduced. The maximum rate of decrease changes depending on the discharge of out of the dam. For releases less than 10

$m^3 \cdot s^{-1}$, the range of interest here, the maximum rate of decrease is not to exceed 1 $m^3 \cdot s^{-1}$ per hour. The efficacy with which this ramping rate minimizes stranding is unknown and is therefore the subject of this monitor. The management question being addressed is as follows:

1) Is the prescribed ramping rate for flow less than 10 $m^3 \cdot s^{-1}$ is adequate to prevent fish stranding when the minimum release out of the Daisy Lake Dam is lowered on 1 Nov to 3 $m^3 \cdot s^{-1}$ from its high of 7 $m^3 \cdot s^{-1}$ during the preceding growing season?

Here, preventing stranding refers to a Minimum Acceptable Level of Stranding (MALS) that will be defined in consultation with regulatory agencies, as described in Section 1.1.3.

2) To what extent do the inflows of Rubble Creek impact the rate of stage change downstream of Rubble Creek, and do the inflows of other tributaries impact the rate of stage change at the Brackendale Gauge?

The rate of stage change during a flow reduction provides useful information. Fish stranding in other systems is dependent on the rate of stage change (i.e., $cm \cdot h^{-1}$). For example, a stage change less than 2.5 $cm \cdot h^{-1}$ was found not to require a fish salvage operation when applied to the Bridge and Seton river watershed (Hunter 1992; Bradford et al. 1995; Higgins and Bradford 1996; and Bradford 1997).

1.1.3 Summary of Impact Hypotheses

The development of a testable impact hypothesis requires that at minimum level of acceptable stranding (MALS) be defined. The development of such a threshold value should be done in consultation with regulatory agencies prior to the start of the monitor. Part of this consultation process should include the development of a formal definition of MALS so that it is measurable in the field and hence testable in a hypothesis-testing framework. Using the MALS threshold as a criterion of acceptance or rejection, the stranding hypothesis can be stated as follows:

H_O1: The rate of resident fish stranding immediately downstream of the dam does not exceed the MALS threshold value for this system when flows are reduced from 7 $m^3 \cdot s^{-1}$ to 3 $m^3 \cdot s^{-1}$ on 1 November of each year.

H_O2: The rate of stage change between Daisy Dam and Rubble Creek is less than 2.5 $cm \cdot h^{-1}$ when flows are reduced from 7 $m^3 \cdot s^{-1}$ to 3 $m^3 \cdot s^{-1}$ on 1 November.

1.1.4 Key Water Use Decision Affected

The key WUP decision affected by this monitor is the ramping rate during the Nov 1 decrease in the minimum flow release. If significant stranding is observed with the WUP operation, it may be necessary to re-examine the rate of maximum decrease or reconsider the 7 $m^3 \cdot s^{-1}$ to 3 $m^3 \cdot s^{-1}$ change in base flow. A change in ramping rate may necessitate further monitoring to ensure that the protocol performs as expected. Such a recommendation for further monitoring, if required, would be discussed by the Monitoring Advisory Committee. Alternatively, it may be necessary to carry out a fish salvage operation each time the change in base flow is made.

1.2 Program Proposal

1.2.1 Objective and Scope

The objective of this monitor is to collect the data necessary to test the Impact Hypotheses and hence, address the management questions presented above. The following aspects define the scope of the study:

a) The study area will be restricted to the upper section of Cheakamus River bounded by Daisy Lake Dam and the confluence of Rubble Creek.

b) Monitoring will focus on the reduction in flows from 7 $m^3 \bullet s^{-1}$ to 3 $m^3 \bullet s^{-1}$ on 1 November.

c) The monitor will be carried out for only one year unless the results show that the WUP ramping protocol is found to be inadequate to prevent significant stranding. Such a result and the need for further data collection would be discussed by the Cheakamus Monitoring Advisory Committee.

d) A small workshop will be held with regulatory agencies to define minimum acceptable level of fish stranding for Cheakamus River immediately downstream of the dam.

e) A final report will be prepared at the end of the monitor that summarizes the results of the entire monitoring program, discusses inferences that can be drawn pertaining to the impact of WUP over time, and presents conclusions concerning the impact hypotheses and the management question in Section 1.2.

1.2.2 Approach

The general approach to the monitor will be to base it on a standard fish salvage operation, the only difference being is that all occurrences of stranding will be documented for analysis. In order for hypothesis test to be carried out, it is necessary that a minimum acceptable level of fish stranding (MALS) be defined. This should be carried out in consultation with regulatory agencies in a small workshop setting. The objective would be to define the threshold value of MALS and to define the units of measurement such that it is testable given the data collected in the field. Ideally, this workshop should be held before the monitor is started.

The monitor is to be carried out for only one year. If significant stranding is found based on the definition of MALS, then changes to the ramping protocol may be necessary.

1.2.3 Methods

Task 1: Project Coordination

Project coordination involves the general administrative and technical oversight of the program. This will include but not be limited to:

1) Budget management.

2) Staff selection.

3) Logistic coordination.

4) Technical oversight in field and analysis components.

5) Liaison with regulatory agencies.

Coordination with WUP Monitoring and Other Monitoring Programs

To help answer high-level questions regarding the relation between Cheakamus River discharge and fish production, data from this stranding program will ultimately be used in combination with data from the resident fish population monitoring program (Program #2), and possibly other WUP monitoring programs. Therefore, it is critical that data collection is coordinated among programs.

To ensure that data collection is coordinated among the inter-related monitoring programs for the Cheakamus WUP, an important task for this program is to develop and maintain communication with project leads for the other monitoring programs. This communication could involve a workshop at the start of the field season to ensure that the sampling locations and methodologies will meet the data requirements of the other programs, and vice-versa. Logistical changes within the scope of the program may be required.

Task 2: Data Collection

Data collection will consist of a fish salvage operation where all occurrences of fish stranding are documented for analysis. The salvage operation will be carried out by a four-person crew. The crew will be teamed in pairs so that they work in tandem on either bank of the river. The salvage operation will begin immediately below the dam and proceed downstream to the confluence of Rubble Creek. As the teams survey the area, they will search for stranded fish (or possibly char redds) along the banks, noting their approximate size and age class. If the stranded individuals are alive, they will be immediately returned to the river. The teams will also note location of all isolated pools. Each team will be equipped with an electroshocker and dip nets so that they may test these pools for the presence of stranded fish and in turn rescue them if necessary. The size of each pool and the number of fish found in them will be noted for analysis. It is anticipated that the entire salvage operation can be completed on the same day that the change in base flow is made.

Prior to the commencement of the monitor, a minimum acceptable level of stranding (MALS) will be defined in consultation with regulatory agencies. This will be necessary in order to test the Impact Hypothesis outlined above.

In addition to the collection of fish stranding data, river stage during the rampdown should be logged (e.g., with a pressure transducer) and photodocumented at the following locations:

i) Immediately downstream of the dam.

ii) Immediately downstream of Rubble Creek

These data, along with the hourly data collected at the Brackendale stream gauge, will track the attenuation of the "rampdown wave" as it travels through the system.

Task 3: Data Analysis

All data will be entered into a common database in a standardized format. This will ensure that the data collected will be compatible that of future studies and can be easily extracted and compared without re-formatting the data structure or the use of transformation functions.

Data analysis will consist primarily of descriptive statistics that summarize the number of fish found stranded, the proportion found alive and returned to the mainstem channel, the proportion found in isolated pools, and the likelihood of stranding in relation to age class or size range.

Test of hypothesis H_O1 will consist of a direct comparison of measured rate of stranding with the MALS threshold (i.e., measured stranding rate < or > MALS). Test of H_O2 will be made by direct comparison of measured rates of stage change to the target rate. Results of the comparison stage comparison will be reported as a frequency of occurrence for each of the three test site.

Task 4: Reporting

At the conclusion of the monitor, a final report will be prepared that:

a) Re-states the objective and scope of the monitor.
b) Presents the method of data collection.
c) Describes the compiled data set and presents the results of all analyses.
d) Discusses the consequences of these results as they pertain to the current WUP operation, and the necessity and/or possibility for future change.

The report will be submitted to regulatory agencies for review and comment prior being finalised for general release. Of particular interest will be whether the monitor should be repeated to test an alternative ramping protocol if the WUP is found to cause significant stranding mortality.

1.2.4 Interpretation of Monitoring Results

Rejection of hypothesis H_O1 would indicate that the observed rate of stranding is beyond acceptable levels, and would thus trigger the need to re-examine the ramping protocol of dam releases less that 10 $m^3 \bullet s^{-1}$.

1.2.5 Schedule

The monitoring program is to commence the same year that the WUP is implemented. It is to be completed in one year, and a report is to be finalized within six months of the fish salvage operation.

1.2.6 Budget

Table 5-1 outlines the estimated cost for the monitoring program. The estimate includes time necessary to prepare and hold a small workshop to define minimum acceptable level of stranding.

Table 5-1: Cost Estimate for Monitoring Stranding Downstream of Daisy Lake Dam

Task	**Labour**	Daily rate	Units	Total Cost
			Yr 1	
Project Coordination	Project Biologist	$600	2	$1,200
MALS workshop	Project Biologist	$600	3	$1,800
Design and Logistics	Project Biologist	$600	2	$1,200
Install transducers	Project Biologist	$600	1	$600
	Technician 1	$300	1	$300
Electroshocking	Project Biologist	$600	1	$600
	Technician 1	$300	1	$300
	Technician 2	$300	1	$300
	Technician 3	$300	1	$300
Data Entry	Project Biologist	$600	1	$600
Data Analysis	Project Biologist	$600	1	$600
	Technician 1	$300	1	$300
Reporting	Project Biologist	$600	2	$1,200
	Technician 1	$300	4	$1,200
	Contingency	10%	$1,433	$1,433
		Subtotal	*$11,933*	*$11,933*
	Expenses	Unit Price		
	Mileage (per km)	$ 0.56	1100	$616
	Meals	$ 50	6	$300
	Electroshocker rental	$ 75	2	$150
	Nets	$ 30	2	$60
	Sampling Gear	$ 200	1	$200
	Hobo Pressure transducers / logger	$ 1,000	2	$2,000
	Report reproduction	$ 500	1	$500
		Subtotal	*$3,826*	*$3,826*
	Future Inflation	2%	$315	$315
		Total	**$16,074**	**$16,074**

1.2.7 References

Bradford, M. J., G. C. Taylor, et al. 1995. An experimental study of the stranding of juvenile coho salmon and rainbow trout during rapid flow decreases under winter conditions. North American Journal of Fisheries Management **15**:473-479.

Bradford, M. J. 1997. An experimental study of stranding of juvenile salmonids on gravel bars and in side channels during rapid flow decreases. Regulated Rivers **13**:95–401.

Higgins, P. S. and M. J. Bradford 1996. Evaluation of a large-scale fish salvage to reduce the impacts of controlled flow reduction in a regulated river. North American Journal of Fisheries Management **16**:666-673.

Hunter, M. A. 1992. Hydropower flow fluctuations and salmonids: a review of the biological effects, mechanical causes, and options for mitigation. Technical Report No. 119. State of Washington Department of Fisheries, Olympia.

Cheakamus River Monitoring Program #6: Monitoring Groundwater in Side Channels of the Cheakamus River

1.1 Program Rationale

1.1.1 Background

Both the Cheakamus River Water Use Plan (WUP) Consultative Committee (CC) and the Fisheries Technical Committee (FTC) have identified monitoring of groundwater side channels as a high priority for the system (Marmorek and Parnell 2002). Groundwater fed side channels play an important role in Cheakamus River salmonid production. Current research indicates that there is a very close connection between flows on the Cheakamus River mainstem and shallow groundwater systems in the vicinity of the North Vancouver Outdoor School (NVOS), for mainstem flows between 40 and 150 $m^3 \cdot s^{-1}$ measured at the Brackendale gauging station (Jordan-Knox 2003). However, there is no information available regarding these relationships for mainstem flows below 40 $m^3 \cdot s^{-1}$. As a result, it is uncertain whether the WUP mainstem flows will affect floodplain groundwater levels, and thereby potentially negatively affect salmonid side channel production near the NVOS and the Department of Fisheries and Oceans' Tenderfoot hatchery (TH). The WUP flow regime will, on average, have lower mainstem flows than existing operations during some seasons, but frequently higher during other seasons. To reduce the uncertainty with groundwater, this document outlines a shallow groundwater and side channel monitoring plan aimed at characterising the linkages between Cheakamus River mainstem flows, floodplain groundwater systems, and side channel upwelling.

1.1.2 Management Questions

Ground water-surface water interactions control the extent and character of floodplain hyporheic zones (subsurface zones where groundwater and surface water mix), and play an important role in the function of riparian ecosystems (Harvey and Bencala 1993, Winter et al. 1998, Bencala 2001). These interactions can dominate stream physiochemical gradients, base flow discharges and storm flow responses. Understanding stream and groundwater processes requires knowledge of the linkages between all of the interactions, and understanding these interactions has received new and growing interest for salmonid research and management in rivers. These process can be especially important in high-energy coastal watersheds, where highly permeable sediments and steep gradients encourage groundwater-surface water mixing (Edwards 1998). The lower Cheakamus River Valley is such a high-energy watershed in which effective management requires an understanding of Cheakamus River surface/groundwater interaction to maintain salmonid production, particularly in groundwater fed side channels.

The specific management questions are:

1) To what extent does seasonal NVOS and TH floodplain shallow groundwater flow direction, and selected water quality parameters (temperature, dissolved oxygen, and pH) vary in response to Cheakamus River mainstem flows ≤ 40 $m^3 \cdot s^{-1}$.

2) To what extent does seasonal NVOS and TH side channel hydrology depend on groundwater flow interactions with Cheakamus River mainstem flows ≤ 40 $m^3 \cdot s^{-1}$.

3) To what extent do key fish habitat variables related to flow (average depth, average velocity, discharge) and water quality (temperature, dissolved oxygen, and pH) in NVOS and TH side channels depend on groundwater flow interactions with Cheakamus River mainstem flows ≤ 40 $m^3 \cdot s^{-1}$.

4) To what extent does salmonid production vary in NVOS and TH side channels in relation to groundwater flow interactions with Cheakamus River mainstem flows ≤ 40 $m^3 \cdot s^{-1}$, and to what extent has the implementation of the WUP affected salmonid production in the NVOS and TH side channel habitats compared to the pre-WUP state.

1.1.3 Summary of Impact Hypotheses

The impact hypotheses tested in this monitor are grouped according to their corresponding management question. For the first management question that deals with the character of sub-surface flows and how it may change with fluctuations in Cheakamus River discharge, the null impact hypotheses are:

H_O1: The direction of ground water flow, as measured by pressure gradients in a network of piezometers, is not correlated with mainstem flows as they vary up to 40 $m^3 \cdot s^{-1}$.

If a correlation is found, then a model of an appropriate type (regression, optimization, etc) should be developed to characterize the relationship for predictive purposes.

H_O2: The water quality of subsurface flows, as determined by measures of water temperature (°C), dissolved oxygen (per cent saturation) and pH, is not correlated with mainstem flows as they vary up to 40 $m^3 \cdot s^{-1}$.

If correlations are found, then a model of an appropriate type (regression, optimization, etc) should be developed to characterize the relationship for predictive purposes.

The second management question deals with the hydrology of side channel habitats near NVOS and how it may vary with Cheakamus River flows. For Hypothesis 3, it is assumed that changes in side channel character are the result of groundwater influences that vary depending on mainstem flows. The null hypothesis is:

H_O3: The hydrology of the side channel near NVOS, as indicated by discharge measurements ($m^3 \cdot s^{-1}$), is not correlated with mainstem flows as they vary up to 40 $m^3 \cdot s^{-1}$.

If a correlation is found, then a model of an appropriate type (regression, optimization, etc) should be developed to characterize the relationship for predictive purposes.

The third management question deals with key fish habitat variables of side channels and how they may vary with Cheakamus River flows. Again, it is assumed that changes in side channel character are the result of groundwater influences that vary depending on mainstem flows. The null hypotheses are:

H_O4: The hydraulic character of the side channel habitats near NVOS, as indicated by average depth (m) and velocity ($m \bullet s^{-1}$) and wetted width (m) measurements, is not correlated with mainstem flows as they vary up to 40 $m^3 \bullet s^{-1}$.

If a correlation is found, then a model of an appropriate type (regression, optimization, etc) should be developed to characterize the relationship for predictive purposes.

H_O5: The water quality, as determined by measures of water temperature (°C), dissolved oxygen (per cent saturation) and pH, in side channels is not correlated with mainstem flows as they vary up to 40 $m^3 \bullet s^{-1}$.

If a correlation is found, then a model of an appropriate type (regression, optimization, etc) should be developed to characterize the relationship for predictive purposes.

The fourth management question examines the linkage between habitat quality, as defined by the parameters above, and the salmonid production of the channel. Production in this monitor will be defined as the capability for the network of side channels near NVOS to produce salmonid smolts. Production will be tested for correlations with habitat parameters, as well as directly with the hydrology of the Cheakamus River Mainstem. The null hypotheses are:

H_O6: Side channel production, as measured by annual counts of out migrating smolts from representative side channels, is not correlated with side channel character hydrology, hydraulic character or water quality.

The parameters to which the smolt counts will be regressed are that same ones that are to be tested in Hypotheses H_O3 to H_O5.

H_O7: Side channel production, as measured by annual counts of out migrating smolts from representative side channels, is not correlated with mainstem flows that fluctuate up to 40 $m^3 \bullet s^{-1}$.

Hypothesis 7 will be a direct test of the linkage between mainstem flow and side channel production. (A monitor result where Hypothesis H_O6 is rejected and H_O7 is accepted would suggest that there is indeed a mainstem linkage, but that the correlation is not brought about by mainstem influences on the measured habitat parameters.)

H_O8: Side channel use by spawning salmonids, as measured by the count of sexually mature salmonids migrating into representative the side channels, is not correlated with mainstem flows that fluctuate up to 40 $m^3 \bullet s^{-1}$.

Tests of Hypothesis 8 will be necessary to account for the possibility that variability in annual smolt counts is the result of year to year differences in escapement.

H_O9: Side channel production, as measured by annual counts of out migrating smolts from representative side channels, remains stable or increases over time (years) following the implementation of WUP operations.

All of the hypotheses will be tested with the assumption that there is sufficient seasonal and annual contrast in mainstem hydrology to illicit a side channel response on fish production if such a relationship exists.

1.1.4 Key Water Use Decision Affected

The key water use decision that may be affected by the results of this monitoring program is the seasonal flow release from Daisy Lake Dam. Uncertainty about the extent of connectivity between Cheakamus River mainstem flows and side channel functionality, and hence fish production, was an important uncertainty. The information on side channel connectivity available at the time of the WUP process was insufficient to determine impacts, particularly when mainstem flows were less than 40 $m^3 \bullet s^{-1}$. The purpose of the present monitor is to collect the information necessary to fill this data gap.

1.2 Program Proposal

1.2.1 Objective and Scope

The objective of this monitor is to collect the data necessary to test the impact hypotheses outlined in Section 1.3 and hence, address the management questions presented in Section 1.2. The following aspects define the scope of the study:

a) The study area will consist of groundwater linked/fed side channels in the lower Cheakamus River found between the confluences of Culliton and Cheekye creeks, particularly the restored channels in the vicinity of the North Vancouver Outdoor School.

b) Intensive monitoring will only be carried out on a select few side channels that are representative of the side channel network in the area. Functionality in other groundwater linked side channels will be inferred from these data.

c) Intensive groundwater monitoring will only be carried out in the immediate vicinity of the North Vancouver Outdoor School, and will include both sides of the Cheakamus River mainstem.

d) The monitor is to last for five years.

e) Data collection, data analyses and annual data reports will be done every year for the duration of the monitor.

f) A final report will be prepared at the end of the monitor that summarizes the results of the entire monitoring program, discusses inferences that can be drawn pertaining to the impact of WUP over time, and presents conclusions concerning the impact hypotheses and the management questions.

1.2.2 Approach

The approach to this monitor includes four linked components:

i) Measurements of groundwater levels, characteristics and horizontal gradients.

ii) Measurements of side channel hydrology.

iii) Measurements of side channel fish habitat, as it relates to flow and water quality.

iv) Measurement of fish production from side channels (note: fish will be enumerated under another monitoring program).

While these components are complimentary, the components also cover alternative approaches to address the issue, from trying to develop a mechanistic understanding of the relation between mainstem discharge and groundwater levels, to focusing on the consequences to a key endpoint of interest: fish production from side channels.

1.2.3 Methods

Task 1: Project Coordination

Project coordination involves the general administrative and technical oversight of the program. This will include but not be limited to:

1) Budget management.

2) Staff selection.

3) Logistic coordination.

4) Technical oversight in field and analysis components.

5) Liaison with regulatory agencies.

Coordination with WUP Monitoring and Other Monitoring Programs

To help answer high-level questions regarding the relation between Cheakamus River discharge and fish production, data from this monitoring program will ultimately be used in combination with data from the fish monitoring programs (Programs #1a, 1b and 3), and possibly other WUP monitoring programs. For example, adult escapement and juvenile outmigration data needed to test the hypotheses in this program will be collected by Programs #1a and 1b. Therefore, it is critical that data collection is coordinated among programs.

To ensure that data collection is coordinated among the inter-related monitoring programs for the Cheakamus WUP, an important task for this program is to develop and maintain communication with project leads for the other monitoring programs.

This communication could involve a workshop at the start of the field season to ensure that the sampling locations and methodologies will meet the data requirements of the other programs, and vice-versa. Logistical changes within the scope of the program may be required.

Task 2: Review Existing Data

To help guide data collection, an important first task is to review and summarize existing groundwater data for the area (i.e., Jordan-Knox 2003; BC Hydro unpublished data). A brief summary of existing data should be included in the introduction for the first year's report.

Task 3: Data Collection

i) Groundwater Hydrology and Water Chemistry

To understand groundwater dynamics, monitoring should occur at a number of locations in the floodplain, and at or near individual groundwater channels. Constructed groundwater side channels are frequently excavated to 1 m or more below the existing water table (e.g., Sheng et al. 1990, as reviewed in Lister and Finnigan 1997) and the elevation of the side channel bed can be lower than the adjacent river (mainstem) channel. Groundwater channels can drawdown groundwater levels immediately adjacent to the channel (scale of meters to 10's of meters from the channel). Thus, the arrangement of groundwater monitoring sites is important.

The following sections highlight existing monitoring locations and outline a potential sampling arrangement to characterize groundwater dynamics.

<u>NVOS floodplain, groundwater outside of side channels</u>: (Note: this section is piezometers on the land, not in the channels): To characterize seasonal groundwater levels and potential movement over an extensive floodplain area, a subset of the estimated existing 75 piezometers locations on the NVOS floodplain will be monitored periodically (e.g., bimonthly) for: groundwater level, pH, temperature DO, and other water chemistry measures used to differentiate water types. The review of existing information (Task 2) and results from the initial sampling will help focus the sampling on the most informative measures to continue to measure.

To characterize the temporal response of floodplain groundwater to mainstem flows, groundwater levels will be logged continuously at 3 piezometers, and the resulting horizontal gradients will be calculated from these data.

<u>NVOS side channels, groundwater near side channels</u>: (Note: this section is piezometers driven into or near the side channel streambed) To characterize groundwater levels at key groundwater side channels, one pair of piezometers will be installed in the Kisutch channel, and one pair in the Upper Paradise channel, and be logged continuously.

<u>Cheakamus mainstem water temperature and DO</u>: To help differentiate groundwater and surface water, measurements of Cheakamus River mainstem water temperature

and DO near the NVOS will be collected. Mainstem DO will be measured during each site visit of this program. Water temperature data will be obtained from #1a.

<u>Deep groundwater</u>: Regional groundwater flow can affect floodplain groundwater dynamics. Regional affects include climatic factors such as precipitation and snowpack levels, or human land use such as pumping from wells. To measure deep groundwater and regional effects, deep groundwater levels physicochemical measurements (as above) in two deep wells at Tenderfoot Lake (Tenderfoot hatchery abandoned well, and Tenderfoot Lake gallery well) will be monitored bimonthly. Additional inferences on regional groundwater effects will be assessed by obtaining climate data from a local climate station, such as the Squamish airport.

ii) Groundwater-fed Side Channel Hydrology and Water Chemistry

<u>NVOS groundwater-fed side channels</u>: (Note: this section is logging water that is actually in a channel) To measure physical characteristics of the water in groundwater-fed side channels, water level (stage), temperature, and DO will be logged continuously near the outlet of the Kisutch channel, and near the outlet of the Upper Paradise channel. In addition, to assist with the Habitat Quality component (below), water velocity will also be logged continuously using a Doppler-type velocity logger (6526 Starflow Ultrasonic Doppler Flow Recorder or similar) at a location in the Kisutch channel and in the Upper Paradise channel. Previous monitoring of groundwater channels during the WUP (BC Hydro unpublished data, contact James Bruce) noted that variation in discharge in the channels occurred largely due to changes in velocity, with little change in stage (depth).

iii) Fish Habitat Quality (Functionality)

Habitat quality will be characterized by a number of parameters, including average depth, average velocity, temperature, dissolved oxygen, and pH. Much of these data are collected under the components above. The values of each parameter will be compared to those that define species and life-stage specific optimum conditions, zone of tolerance and zone of resistance. The critical values will be determined from the literature in consultation with fish agencies, and other parties.

iv) Fish Production

Fish production will be assessed in terms of smolt outmigration from key groundwater-fed channels. For efficiency, the trapping and outmigration data will be collected under the “Juvenile salmonid outmigration enumeration monitoring”, Program #1a. As well, the adult escapement data needed to test Hypothesis 9 will be collected under the “Chum salmon escapement monitoring” Program #1b. Raw data, data summaries, and analyses will also be completed under Programs 1a and 1b and provided annually to this groundwater program, where additional analyses specific to the groundwater hypotheses and management questions of this program can occur if required.

Task 4: Cheakamus River Mainstem Discharge

Cheakamus River mainstem stage and discharge will obtained from: i) the Water Survey of Canada Brackendale Gauge, ii) flow releases from the Daisy Lake Dam will be obtained from BC Hydro generation operations, and iii) river stage will also be obtained from a water level gauge that will be installed and operated by this program in the vicinity of NVOS (e.g., near the Bailey bridge).

If required, additional information on Cheakamus tributary inflows can be obtained from the channel morphology monitoring program (Program #8), and Cheakamus mainstem water temperatures can be obtained from the juvenile outmigration monitoring program (Program #1a).

Task 5: Data Analysis

Contour plots for various groundwater parameters will be developed to allow spatial analysis of groundwater gradients. Correlation analysis and other statistical techniques will be used to examine each hypothesis.

Task 6: Reporting

A report will be prepared annually that:

a) Re-iterate the objective and scope of the monitor.

b) Presents the methods used for data collection.

c) Summarizes pre-existing data, describes the compiled data set, and presents the results of all analyses.

d) Discusses the consequences of these results as they pertain to the current WUP operation.

A detailed report for the will be prepared following data collection in Year 5 that includes:

a) An executive summary of the entire component.

b) A data summary.

c) The analytical procedures.

d) A detailed summary of the findings as they relate to the ecological hypotheses and the key management questions.

e) Discusses the consequences of these results as they pertain to the current WUP operation.

f) Future monitoring of groundwater, if any, required to address the management questions and ecological hypotheses.

All reports will be provided in Microsoft Word and Adobe Acrobat (*.pdf) and all maps and figures will be provided in their native format either as embedded objects in the Word file or as separate files. All data collected will be submitted annually in a Microsoft Access Database. The raw data is a key deliverable of this project.

1.2.4 Interpretation of Monitoring Results

Each of the four management questions and associated hypotheses can be tested using the data collected under the four corresponding monitoring components:

i) Measurements of groundwater levels, characteristics and horizontal gradients.

ii) Measurements of side channel hydrology.

iii) Measurements of side channel fish habitat (as they relate to flow and water quality).

iv) Measurement of fish production from side channels.

Interpretation of monitoring results will also benefit from the linkage between the four key monitoring components. These results will provide information to guide future management decisions. As noted above, the monitoring components cover different approaches and endpoints of interest. Thus, future management decisions may depend on both the results from each component, and the relative merit and importance given to each approach and endpoint by scientists, managers and other parties.

<u>Components i) and ii): Groundwater levels and side channel hydrology</u>: The relation between groundwater parameters, side channel hydrology, and mainstem discharge (<40 $m^3 \cdot s^{-1}$) will be key to the interpretation of the physical results and the understanding of groundwater processes.

<u>Components iii) and iv): Fish habitat and production</u>: Fish production is the key biotic endpoint of interest, and the response of fish to potential changes in groundwater parameters will be an important driver in the interpretation of the ultimate impacts of mainstem discharge on groundwater. Data obtained for chum salmon will likely provide the most robust information to examine the fish production hypotheses. Reasonable estimates of chum salmon adult escapement and juvenile outmigration should be obtained from Programs 1a and 1b, and allow inferences of the effects of groundwater levels on the chum spawning and incubation (~October to March). While Programs 1a and 1b should obtain reasonable estimates of coho salmon juvenile outmigration and possibly adult escapement, given the seasonal migration patterns of juvenile coho salmon into and out of the channels, it will be more difficult to determine the effects of groundwater levels on coho survival at a seasonal timescale, especially the effects on summer rearing. Regardless, the relation between groundwater levels and a key measure of interest—total coho juvenile outmigration—can be examined.

1.2.5 Schedule

Monitoring is scheduled to occur annually for five years. The methods section above highlights the timing for each task.

1.2.6 Budget

Table 6-1 outlines the estimated cost for the monitoring program.

Table 6-1: Cost Estimate for Monitoring Groundwater in Side Channels of the Cheakamus River

Task	**Labour**	Daily rate	Yr 1	Yr 2	Units Yr 3	Yr 4	Yr 5	Total Cost
Project Coordination	Project Biologist	$600	4	4	4	4	4	$12,000
Install groundwater monitoring equipment	Groundwater Expert	$700	8	6	6	6	6	$22,400
	Technician 1	$300	8	6	6	6	6	$9,600
Download groundwater monitoring equipment	Groundwater Expert	$700	6	6	6	6	6	$21,000
	Technician 1	$300	6	6	6	6	6	$9,000
Mainstem stage	Groundwater Expert	$700	4	2	2	2	2	$8,400
	Technician 1	$300	4	2	2	2	2	$3,600
Habitat workshop	Groundwater Expert	$700	2					$1,400
	Project biologist	$600	2					$1,200
Data entry	Technician 1	$300	4	2	2	2	2	$3,600
Data analysis & reporting	Groundwater Expert	$700	10	5	5	5	10	$24,500
	Project biologist	$600	2	2	2	2	2	$6,000
	Technician 1	$300	2	2	2	2	2	$3,000
	Contingency	10%	$8,422	$3,101	$3,101	$3,101	$3,451	$21,176
		Subtotal	*$41,422*	*$25,401*	*$25,401*	*$25,401*	*$29,251*	*$146,876*
	Expenses	Unit Price						
	Mileage (per km)	$ 0.56	4500	3500	3500	3500	3500	$10,360
	Lodging (night)	$ 100	16	12	12	12	12	$6,400
	Meals	$ 50	16	12	12	12	12	$3,200
	Piezometers	$ 100	24	2	2	2	2	$3,200
	Data logger boxes	$ 100	7	1	1	1	1	$1,100
	Stilling wells	$ 200	5	1	1	1	1	$1,800
	Water level loggers	$ 1,450	8	1	1	1	1	$17,400
	Stage/temp/DO loggers	$ 2,900	5					$14,500
	Polycorder	$ 2,200	1					$2,200
	Velocity logger	$ 3,200	2					$6,400
	Meters	$ 2,000	1					$2,000
	Peristaltic pump	$ 1,500	1					$1,500
	Lab analysis	$ 500	3	1	1	1	1	$3,500
	Field supplies & maintenance	$ 2,000	1	1	1	1	1	$10,000
	Report reproduction	$ 500	1	1	1	1	1	$2,500
		Subtotal	*$51,220*	*$8,710*	*$8,710*	*$8,710*	*$8,710*	*$86,060*
	Future Inflation	2%	$1,853	$1,378	$2,088	$2,812	$3,951	$12,082
		Total	**$94,495**	**$35,489**	**$36,199**	**$36,923**	**$41,912**	**$245,018**

1.2.7 References

Bencala, K.E., 2000. Hyporheic hydrological processes. Hydrol. Process. 14: 2797-2798. Cheakamus Water Use Plan Fisheries Technical Committee, 2001. Annotated Draft Cheakamus Monitoring Plan.

Edwards, R.T., 1998. The Hyporheic Zone. River Ecology and Management. R. Naiman and R. Bilby (Eds). Springer, pgs: 399-429.

Harvey, J.W. and K.E. Bencala, 1993. The effect of streambed topography on surface-subsurface water exchange in mountain catchments. Water Resources Research 29:89-98.

Jordan-Knox, Q. 2003. Groundwater-surface water interactions in the lower Cheakamus Valley, British Columbia: an integrated investigation of a highly permeable coastal watershed. Thesis. Simon Fraser University.

Lister, D.B. and Finnigan, R.J. 1997. Rehabilitating off-channel habitat. Fish habitat rehabilitation procedures. P. A. Slaney and D. Zaldokas. Vancouver, B.C., B.C. Ministry of Environment, Lands and Parks, Watershed Restoration Program. Watershed Restoration Technical Circular No. 9.

Marmorek, D.R., and I. Parnell. 2002. Cheakamus River water use plan - Report of the consultative committee. Report prepared by ESSA Technologies Ltd., Vancouver, BC on behalf of the Cheakamus River Water Use Plan Consultative Committee, Vancouver, BC, 234 pp.

Sheng, M.D., M. Foy, and A.Y. Fedorenko. 1990. Coho salmon enhancement in British Columbia using improved groundwater-fed side channel. Canadian Manuscript Report of Fisheries and Aquatic Sciences 2071: 81 p.

Winter T.C., Harvey J.W., Franke O.L. and W.M. Alley, 1998. Ground Water and Surface Water – A Single Resource. US Geological Survey Circular 1139, 79 pp. http:/water.usgs.gov/pubs/circ/circ1139/

Cheakamus River Monitoring Program #7: Cheakamus River Benthic Community Monitoring

1.1 Monitoring Program Rationale

1.1.1 Background

The consultative process for the Cheakamus River Water Use Plan (WUP, Marmorek and Parnell 2002) considered operating alternatives to achieve objectives for water demand for power production, heritage and cultural values by First Nations, recreation, fish production, integrity of the aquatic ecosystem that supports the river food web and water quality, and flood control. The effects of flow regulation on the benthic community was an important uncertainty during this process. To reduce uncertainties, the CC unanimously endorsed implementation of a monitoring plan to fill in data gaps, reduce scientific uncertainty, and provide information to better inform the CC members during future planning processes (see BC Hydro 2005). One component of the monitoring plan was updated modelling to examine the importance of Cheakamus River flow on the abundance and composition of benthic communities that indicate "ecosystem health" and are fish food organisms. This document is a Terms of Reference (TOR) pertaining to the monitoring of benthic communities and habitat attributes that determine the composition and abundance of those communities in the Cheakamus River.

Benthic invertebrates are good indicators of water quality (Rosenberg and Resh 1993) and ecosystem health (Norris and Hawkins 2000), where the term "health" is useful for defining river condition that can be understood by the general public and resource managers (i.e., properly functioning condition). Good condition of the Cheakamus River can be defined by the presence of clean water and a functioning food web having a diversity of organisms that can support highly valued endemic fish species (mainly salmonids). Poorer condition following implementation of the new flow regime might include relatively low diversity and abundance of benthic organisms caused by an effect of altered release of water from the Daisy Dam that may modify the water chemistry, the availability of physical habitat, or hydrological regime. Because of continuous exposure to water flow, benthic biota provide an integrated record of physical and chemical environmental quality. They are ubiquitous, largely sedentary, and there are large numbers of species that can provide an integrated measure of response to stress. Their characteristics allow effective spatial and temporal analyses of disturbance among river reaches. The invertebrates act as a major food supply for fish, particularly salmonids that are sentinel species of the Cheakamus River, and provide an indication of food availability for fish populations through time and space. The result is that monitoring of benthic invertebrates can provide a sensitive indication of change in the chemical and physical attributes of the Cheakamus River.

The CC recognized this importance of the benthic community as an indicator of ecosystem function and endorsed a plan to build on earlier monitoring of the Cheakamus River (Perrin 2001). Biological and habitat data collected by Perrin (2001) in 1996 and again in 1999-2000 was used to examine the importance and effect of several hydrological variables on benthic invertebrate endpoints as indicators of "river health". A predictive model, hereafter referred to as the Cheakamus Benthos Model (CBM), was developed as part of this process. That model was later used to examine the effect of change in nutrient discharges from the Whistler Wastewater Treatment Plant that may be expected from future plant upgrades and water withdrawal scenarios on periphyton biomass in the Cheakamus River upstream of Daisy Reservoir.

The present monitoring design will focus on further development of the CBM to improve insight into effects of change in hydrological attributes on benthic invertebrate and periphyton composition and abundance. This TOR outlines the monitoring approach that will be required for continued development of the CBM to make it ready for application in the next WUP review.

1.1.2 Management Questions

The present CBM (Perrin 2001) showed that flow, variation in velocity, soluble phosphorus concentration, and distance from the dam were important predictors of benthic invertebrate biomass in the Cheakamus River. This model suggests that flow management can be an important driver of benthic invertebrate biomass. These predictors were found from only two years of monitoring in different seasons and can be considered preliminary due to a relatively small sample size (42 observations) that was used to identify the predictor variables. The WUP monitoring will provide approximately 80 new observations to be collected over four seasons to supplement the existing data and answer two management questions:

1) What habitat and flow attributes best determines the composition, abundance, and biomass of benthic invertebrates in the Cheakamus River?

2) Among all habitat and flow attributes, what is the relative importance and magnitude of effect of water release from the Daisy Dam in determining the composition, abundance, and biomass of benthic communities in the Cheakamus River?

The monitoring will be required over a wide range of flows and environmental conditions, among different seasons. Following data collection, various statistical modelling procedures including multiple regression analysis that is the basis of the present CBM and any supplemental analyses that are considered necessary by the project's lead biologist will be run. All statistical procedures will support development of a final predictive model that will be produced following the completion of data collection. That model will be used in future planning processes to explore the potential effects of water release alternatives on benthic indicators of ecosystem health and food availability for fish.

1.1.3 Summary of Alternative Hypotheses

The primary hypotheses (and sub-hypotheses) associated with these management questions and stated as if they were true (alternate hypotheses) are:

H_1: Flow and related hydrologic variables are important predictors of benthic community attributes.

> $H_{1.1}$: Variation in flow and related hydrological variables are important predictors of benthic community attributes.

H_2: Benthic invertebrate community diversity increases with increasing distance from the Daisy Dam.

$H_{2.1}$ Distance from the dam is an important predictor of benthic invertebrate community diversity.

H_3: Benthic invertebrate abundance increases with increasing distance from the Daisy Dam.

$H_{3.1}$ Distance from the dam is an important predictor of benthic invertebrate abundance.

H_4: Soluble phosphorus concentration is an important predictor of epilithic (i.e., on the surface of rocks) algae biomass in the Cheakamus River.

H_5: Soluble phosphorus concentration is an important predictor of benthic invertebrate biomass in the Cheakamus River.

H_6: Habitat attributes other than those described in H1 to H3 are not important predictors of benthic invertebrate composition.

H_7: Habitat attributes other than those described in H1 to H3 are not important predictors of benthic invertebrate abundance.

H_8: There is close similarity between the composition of prey that is ingested by fish in the Cheakamus River and composition of benthos that is produced in the Cheakamus River.

Each of these hypotheses will be examined as part of the main goal of further developing the CBM for use in future planning processes.

1.1.4 Key Water Use Decision Affected

The key water use decision that would potentially be affected by the results of the monitoring is the seasonal flow release from the Daisy Dam. The CBM will be a tool used to calculate various ecological performance measures, for use by technical committees to explore the potential consequences of change in strategies to release water from the Daisy Dam on indicators of river health and food availability for fish. The CBM will be regarded as a decision support tool, not a decision making tool. Use of the CBM for this purpose will contribute to future decisions on allocation of water for power production, heritage and cultural values by First Nations, recreation, fish production, integrity of the aquatic ecosystem that supports the river food web and water quality, and flood control. As part of this decision-making process in future planning, the CBM will quantify the importance of flow and flow related attributes in supporting a healthy river for multiple uses.

1.2 Monitoring Program Proposal

1.2.1 Objective and Scope

The objective of the benthos monitoring is to continue development of the CBM for use in evaluating river health among flow alternatives. River health will be indicated by attributes of the benthic invertebrate and periphyton communities. The model will be a decision support tool for future planning initiatives.

The geographic scope of the monitoring is the Cheakamus River mainstem downstream of Daisy Dam (Figure 7-1). The monitoring will occur at five sites that were sampled by Perrin (2001) in previous activities that supported initial water use planning and are located downstream of the Daisy Dam on the Cheakamus River (Figure 7-1). Those sites are called CH4 (approximately 200 m downstream of the Daisy Dam), CH5 (adjacent to highway sand sheds), CH6 (upstream of the Culliton Creek confluence), CH7 (downstream of the Culliton Creek confluence), and CH8 (downstream of the Cheekye Creek confluence). A wide range of environmental conditions will be captured in the sampling to facilitate development of the CBM using all possible physical and chemical conditions in the Cheakamus River. To meet this goal, data will be collected once during each season of the year. One sampling session will occur during each season of the year, for a total of four sampling sessions. This data collection is scheduled to occur over two calendar years (two separate seasons per year; see proposed schedule in Section 1.2.5). The resulting data will be appended to existing physical, chemical, and biological data that was used for preliminary model development by Perrin (2001). The final model will be compiled along with all statistical analyses in the year following completion of data collection.

The scope of work in this TOR is limited to provide the information needed to assess the effects of flow regulation on the aquatic ecosystem in the Cheakamus River downstream of the Daisy Dam. However, application of the CBM should be adaptable to consider other anthropogenic impacts in the watershed, should such data collection and analyses be requested as separate projects with additional funding, outside the scope of this TOR. For example, the model development should be sufficiently flexible to support additional monitoring at sites upstream of the reservoir that may be necessary to support interests of the Resort Municipality of Whistler, Whistler wastewater treatment plant. Such data would not be needed to assess flow effects downstream of Daisy Dam, of interest to the present TOR.

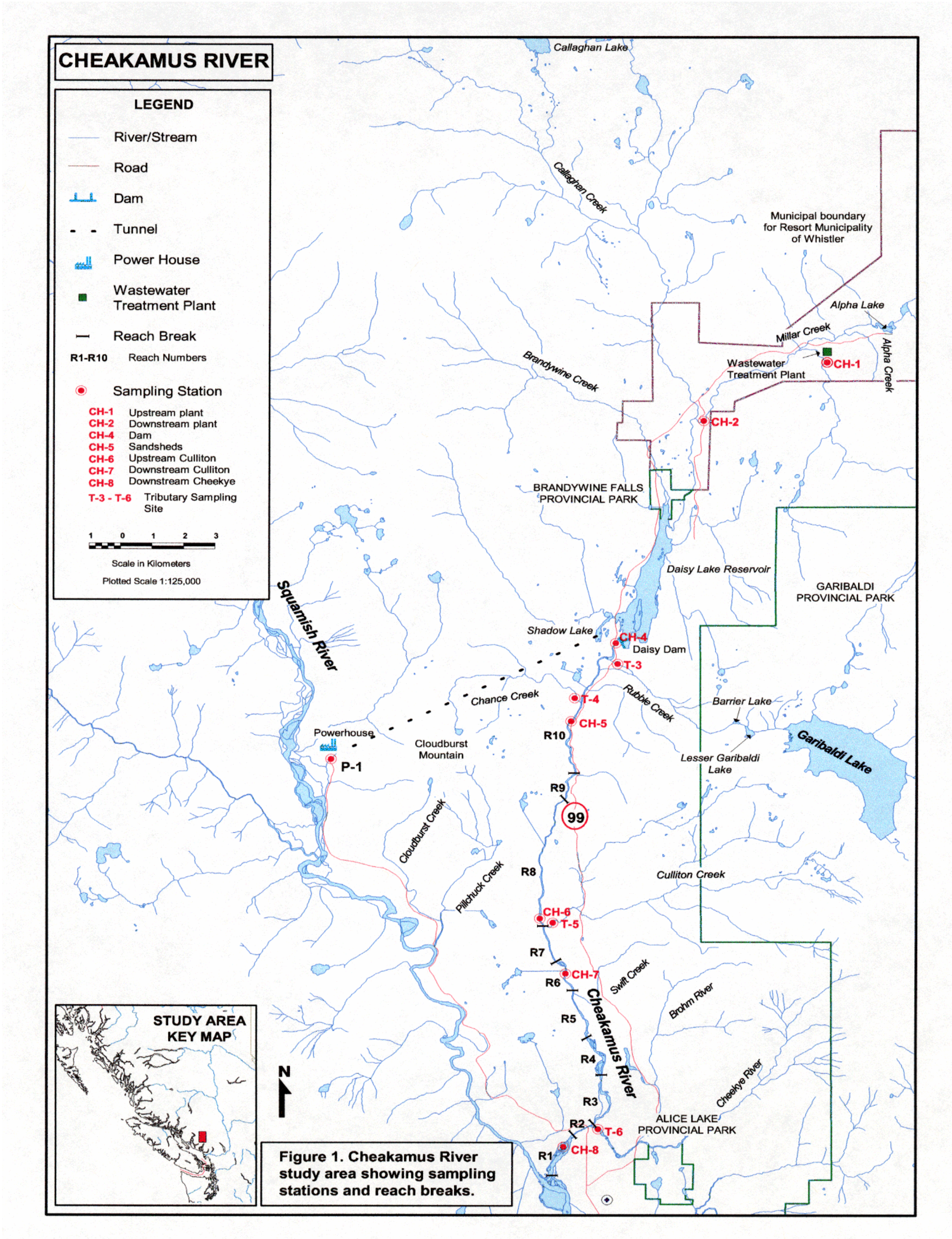

Figure 7-1: Cheakamus River Monitoring Sites as Defined from Previous Sampling by Perrin (2001). Sites CH-4, 5, 6, 7, and 8 are recommended for this TOR.

1.2.2 Approach

The monitoring approach is to collect physical and biological data from the river to add to an existing database of collected data, and use this expanded dataset to refine a model that predicts various benthic endpoints from the physical variables. The effect of flow variables on these benthic endpoints will be a key relationship examined.

The river monitoring will focus on benthic invertebrates and attributes of benthic habitats that support the invertebrates, including flow and related hydrological variables. Periphyton biomass and composition will be monitored for potential use as a predictor in the invertebrate modelling (as was found by Perrin 2001) but it will also to be available for any alternative modelling in which algal biomass and composition may form endpoints of interest. Perrin (2001) used benthic invertebrate biomass as the endpoint in the existing linear regression model but the project's lead biologist should not hesitate in running other endpoints (e.g., a diversity metric, abundance metrics, other measurement) to potentially produce more than one linear model corresponding to each endpoint of interest. Tools such as multidimensional scaling may assist in defining taxa or groups of taxa that are most important in discriminating between effects of location and time or other defined groups of samples. Combinations of those taxa may be most useful as final endpoints. In addition, consultation with members of the Cheakamus Water Use Plan monitoring committee may be useful to guide selection of endpoints that are most relevant to management of flows on the Cheakamus River. Effort should be made to limit analyses to not more than three regression equations. Any more may add complexity to eventual interpretations and potentially make results difficult to understand.

Analyses need not be restricted to application of regression modelling techniques. The compiled data will in fact be amenable to multivariate analysis and modelling that may also be suitable for addressing the hypotheses. Analyses and model selection will trade-off the increased predictive capability of more complex models with i) the ability to communicate the model and results to technical committees, and ii) the utility to managers and decisions makers who will ultimately use the model results.

Artificial substrata will be used for all measurements of periphyton and benthic invertebrate community composition, abundance, and biomass using hardware and procedures outlined by Perrin (2001). This approach will be consistent with the previous sampling methods, thus allowing data sets to be combined without confounding by method of collection. Because the samplers have a standardized substrate, particle size will be eliminated as a variable affecting benthic communities over space and time. The artificial substrata will facilitate sampling at wide ranging depths that is not possible with conventional samplers such as a Hess or Surber type of sampler. Use of artificial samplers requires installation of the hardware, a six to eight week period of incubation during which time a variety of physical and chemical measurements are made at each sampler or site as biological communities develop in the samplers, followed by harvest of the communities. The physical and chemical measurements will include but are not limited to several forms of nitrogen and phosphorus, water velocity, water depth, dissolved oxygen, conductivity, total dissolved solids, pH, turbidity, flow, continuous measurement of temperature, coding of ambient particle size distribution, and descriptions of other habitat conditions.

Laboratory work will follow to enumerate the benthic invertebrates, by genus, and the epilithic algae, by species, and to determine the biomass of the invertebrates and algae. The advantage of this approach is that it integrates community development processes over the time of installation of the samplers. The data are not strongly affected by episodic events that can introduce large variation in data from measurements made at discrete points in time.

In each of year of data collection, data will be compiled into a master file. To ensure that the data collected will be suitable for the extensive modelling exercise, and ensure that all data is formatted correctly and error free, it is recommended that following the first year of data collection, the data be read into statistical software, and that the CBM model be updated and re-run with the updated dataset. This exercise is not for application of the model, but to facilitate a quality check of the data and data collection. Final model development and reporting will occur in the year following the completion of data collection. No field sampling will be required in that year.

1.2.3 Methods

Task 1: Project Coordination

Project coordination involves the general administrative and technical oversight of the program. This will include but not be limited to:

1) Budget management.
2) Staff selection.
3) Logistic coordination.
4) Technical oversight in field and analysis components.
5) Liaison with regulatory agencies.

Coordination with WUP Monitoring and Other Monitoring Programs

To help answer high-level questions regarding the relation between Cheakamus River discharge and aquatic production at different trophic levels, data from this monitoring program will ultimately be used in combination with data from the fish monitoring programs (Programs #1, 2, and 3), the channel morphology and hydrology monitoring program (#8), and possibly other WUP monitoring programs. Therefore, it is critical that data collection is coordinated among programs.

To ensure that data collection is coordinated among the inter-related monitoring programs for the Cheakamus WUP, an important task for this program is to develop and maintain communication with project leads for the other monitoring programs. This could involve a workshop at the start of the field season to ensure that the trapping locations and methodologies will meet the data requirements of the other programs, and vice-versa. For example, Task 4 of this program requires that juvenile fish be obtained from one of the fish monitoring programs (Programs #1 to 3). Logistical changes within the scope of the program may be required.

Task 2: Site Selection and Field Preparation

Five sites in the Cheakamus River (CH4 to CH8 as shown in Figure 7-1) that were previously sampled by (Perrin 2001) will be sampled annually within a 40 – 50 day time series such that one sampling series in each season is completed. The result will be observations spanning a wide range of biological characteristics and habitat conditions from which the CBM will be developed. A field data sheet will be prepared in advance of each field session to ensure that all data needs are met. The form will contain the following data fields:

1. Survey information including date/time, predominant weather conditions, crew members, site name and number,

2. Installation details: georeferenced location for each site, site identification and configuration (photograph reference, sketch and/or description of site), details regarding the invertebrate collection baskets dimensions, installed substrate size, specifications of the periphyton plates, temperature logger identification,

3. Habitat descriptions and measurements that are consistent with modelling requirements and include but are not limited to flow, depth and velocity at each sampler, photosynthetically active radiation at the water surface and at each sampler, temperature, and check boxes to indicate the collection of samples for analysis of soluble reactive P (SRP), total phosphorus (TP), total dissolved P (TDP), ammonium ($NH4+$), nitrate ($NO3-$), total nitrogen (TN), total alkalinity, total dissolved solids, conductivity, pH, and turbidity (e.g. all potential predictor variables must be included),

4. Sampler removal data including date/time, predominant weather and site conditions, notes describing any sampler disturbance or movement, etc.

Task 3: Field Sampling and Analysis in Laboratories

Benthic invertebrates and periphyton will be sampled from artificial substrata installed over a time series of 40 – 50 days at each site in a different season within a scheduled two year period (see Section 1.2.5 for a proposed schedule). Four replicate benthos samplers and three replicate periphyton samplers will be installed and sampled at each site.

A periphyton sampler will consist of open-cell sheet Styrofoam mounted on a concrete patio block that is submersed in water depths of 8 – 50 cm in riffle or run habitat at each site. Once per week for at least six weeks a 2 cm diameter core of the Styrofoam and the adhered biomass will be removed using the open end of a 7 dram plastic vial and analyzed for chlorophyll-a concentration. Algal accrual on the plate is a function of cell settlement during a colonization phase, actual growth, and losses associated with insect grazing, scour from suspended particulates and sloughing. Colonization largely determines biomass in the first week of accrual but thereafter colonization is insignificant relative to growth. In this project, periphyton biomass is of particular interest because it is biomass that is available to higher trophic levels. Peak biomass (PB) measured during the accrual series is a function of actual growth and can be used in place of growth for spatial and temporal comparisons. PB will be the highest average concentration of chlorophyll-a attained on the replicate substrata on a given day during an accrual series. On the final sampling day of each series, one additional core will be removed from each substrate and preserved in Lugol's solution for taxonomic identification and enumeration.

Four replicate invertebrate substrata will be installed at each site at the same time that the periphyton substrata are installed. The substrata will be wire baskets (30 cm long x 14 cm wide x 14 cm deep) filled with gravel having a standard diameter of 2.5 – 3.5 cm. They will be placed in riffles or runs at each site in water depths of approximately 15 – 50 cm. The baskets will be embedded with the top surface flush with the top of the natural gravel. At the same time of final periphyton sampling, the baskets will be retrieved by placing a 250 μm mesh Nitex net around the basket and lifting the basket and net assembly out of the water and into a collection bucket. This retrieval method will prevent loss of animals. In the collection bucket, the baskets will be opened; the invertebrates will be brushed from the gravel and preserved in 10 per cent formalin. In the laboratory, all organisms retained on a 250 μm sieve will be identified to the lowest reliable taxonomic level, and counted. After enumeration, invertebrate biomass will be determined for each sample either using destructive procedures of drying and weighing or preferably with the use of length – weight regressions.

The installed colonization plates and baskets will be placed such that they will remain wetted under all flow conditions. Minimum flow conditions during the sampling period can be estimated based on the minimum flows outlined in Section 1.1.1 (above).

One water sample will be collected from each site at the start and finish of the sampler incubation period. All water samples will be analysed in the lab for a suite of parameters including soluble reactive P (SRP), total phosphorus (TP), total dissolved P (TDP), ammonium (NH_4^+), nitrate (NO_3^-), total N (TN), and alkalinity. The N:P ratio will be determined from molar concentrations of DIN and SRP, which are the forms of N and P that are considered biologically available.

On one day each week during the sampler incubation period, selected physical and chemical measurements will be made. Current velocity and water depth will be measured at each sampler using a velocity meter and meter stick respectively. Photosynthetically active radiation (PAR) will be measured at the water surface and at the sampler depth preferably using an irradiance meter that specifically measures PAR and is equipped with an underwater quantum sensor. Other weekly measurements will include total dissolved solids (TDS), conductivity, turbidity, dissolved oxygen, and pH using a water quality Sonde.

Temperature will be logged in hourly intervals over the complete sampling time series each year using a submersible temperature logger installed at each station.

The determination of flow for each sampling site will not simply be water released from the dam but must be specific to a given site. Flow metrics for use as predictors in the CBM may be average, maximum, or minimum flow for the period of sampler installation. Coefficient of variation of flow may also be a useful predictor. Power Records at BC Hydro can run calculations to provide daily mean flow at given locations in the river along with QAQC. There would be a fee billed to the project for this service. Alternatively the project's lead biologist can run the calculations independently. Which ever way this is done, the project implementers must include a fee in their cost estimate for determination of site-specific flow metrics. Inflows from major tributaries will also be logged continuously under the Cheakamus River

Channel Morphology monitoring program (Program #8), and data may be obtained from this program.

All data that is acquired in the field will be compiled on site forms that are described in Section 1.2.3.1. It is recommended that photos be taken on at least one visit to each sampling site during the sampling time series to illustrate the layout of samplers and ambient habitat characteristics. Any replacement baskets or plates required due to disturbance over the survey period must be documented on the field forms, as would any other changes to the sampling protocol.

Task 4: Fish Sampling and Analysis of Fish Diet

Composition of food that is ingested by fish in the Cheakamus River is needed to assist with the interpretation of the link between production of benthic invertebrates and food that is actually ingested by the fish. It is recommended that stomach samples from 15 juvenile salmonids be collected for each stream rearing salmonid species of interest (i.e., 15 samples per species in each of the years of benthic sampling, Years 2 and 3). Subject to sampling permit approval and conservation concerns, these species would include rainbow trout/steelhead, coho salmon, Chinook salmon and bull trout.

To enable cost efficiency, it is recommended that fish stomach samples be collected under the fish sampling Programs #2 (Trout abundance) and #3 (Steelhead production) and provided to this benthic program for lab analyses. Samples would be collected “opportunistically” from near the benthic sampling sites over the same timing window as the colonization baskets are in place. The samples must be enumerated to the lowest reliable taxonomic level in the laboratory.

Task 5: Analytical Methods

The present Cheakamus Benthos Model is a regression equation that can be used to predict benthic invertebrate biomass as a function of several habitat variables and to show the most important habitat attributes that determine the invertebrate biomass. As the new data are compiled from monitoring each year, the regression analysis should be run again using forward and backward stepping procedures. The result may be an annual change in predictor variables and statistics that indicate fit of the equation to the data and error rates as sample size is increased.

It is recommended that multivariate tools be run to reveal benthic indicators or metrics based on count data that may supplement the biomass model. For example, multidimensional scaling (MDS) may be used to identify groups of samples based on the Bray Curtis similarity of community groups. These groups may correspond to gradients downstream of the dam, time course change in composition and abundance of invertebrates, or both. A subsequent analysis in MDS that is also based on the Bray Curtis similarity measure may reveal what taxa are most important in contributing to those sample groups. Those taxa may be considered indicators of spatial and temporal variation in the Cheakamus River. Alternatively, combinations of taxa (e.g., all mayflies or mayflies plus stoneflies plus caddisflies) may be found to be good indicators. It is recommended that no more than three of these indicators be selected as supplemental endpoints for additional regression equations. These models in addition to the biomass model will then be available to support exploration of effects of water release strategies on biomass and on important metrics that are sensitive to flow manipulation during the subsequent Water Use Planning. All regression modelling must be accompanied by statistics showing variation in the dependent variable that is explained by the predictor variables, error rates, significance levels, distribution of residuals, etc., as diagnostic tools to decide on acceptance or rejection of the equations.

The project's lead biologist is encouraged to explore other modelling alternatives. For example, multivariate modelling may be found to be more revealing and useful with fewer constraints than are found in multiple regression approaches. These approaches should be run and contrasted with application of the present CBM to eventually arrive at a final recommended model or group of models for future use in planning processes.

As in previous investigations (Perrin 2001), to control for Type I error rates, consideration should be given to the number of statistical test performed and should be limited to those required in the analysis.

Task 6: Performance Measure Development

Once data collection is concluded, appropriate performance measures (i.e., measures of the benthic community) can be selected, and the model will be finalized. The model can then be used during planning (outside the scope of this TOR) to calculate performance measures that can be used to examine the effect of flow on these benthic invertebrate endpoints. A final CBM will be the one supplied to an assigned technical committee to support future decisions on flows in the Cheakamus River.

Task 7: Reporting

Following the first year of data collection, a data report will provide the background, methods, and results date. Reports will include an Executive Summary outlining the data collected to date, the status of selected benthic invertebrate metrics across all sites, and the status of the CBM.

Once final analytical work has been completed in Year 4, a final report will be prepared that will include:

a) An executive summary of the entire project.
b) A data summary.
c) The analytical procedures.
d) A detailed summary of the findings as they relate to the ecological hypothesis and the key management questions.
e) The final recommended model or models for use in subsequent planning

All reports will be provided in Microsoft Word and Adobe Acrobat (*.pdf) and all maps and figures will be provided in their native format either as embedded objects in the Word file or as separate files. All data collected will be submitted annually in a Microsoft Access Database. The raw data is a key deliverable of this project.

1.2.4 Interpretation of Monitoring Results

The analytical methods and modelling exercise under Task 5 will inherently test Hypotheses 1 to 7, and address the two management questions. Hypothesis 8 will be examined under Task 4.

The final model(s) will provide value for future flow management decisions on the Cheakamus River by allowing users to explore ecological responses to various changes in flow that may be considered in future planning exercises.

All data that are collected during the years of monitoring and appended to existing data will also be available for other applications. The data will be a wealth of descriptive information for examining the ecological structure and function of the Cheakamus River.

1.2.5 Schedule

Field data is scheduled to be collected over two years, with final model development and reporting completed in the following year.

Table 7-1: Example Schedule for the Benthic Community Monitoring Program.

'Year' refers to the year following implementation of the Cheakamus monitoring programs, which is estimated to begin in 2007. Data collection during each season = 40-50 day sampling session. Winter = Jan-Mar, spring = Apr-Jun, summer = Jul-Sept, and fall = Oct-Dec.

	Year 2 (2008)				**Year 3 (2009)**				**Year 4 (2010)**			
	Winter	**Spring**	**Summer**	**Fall**	**Winter**	**Spring**	**Summer**	**Fall**	**Winter**	**Spring**	**Summer**	**Fall**
Data collection	■		■			■		■				
Final Analyses and reporting									■	■	■	■

Data collection is scheduled to begin in Year 2 after approval of the Cheakamus WUP monitoring programs, and the modelling and reporting completed in Year 4 following approval (Table 7-1). There is flexibility in the exact sequence in which the seasons are sampled. However, one constraint is that in order to sample a broad range of physical conditions, consecutive seasons should not be sampled (e.g., spring and summer in the same year).

1.2.6 Budget

Table 7-2 outlines the budget estimates for this program.

Table 7-2: Budget Estimate for the Cheakamus River Benthic Community Monitoring

Task	**Labour**	Daily rate	Units			Total Cost
			Yr 2	Yr 3	Yr 4	
Project Coordination	Project Biologist	$600	5	5	5	$9,000
Field sampling	Project Biologist	$600	35	35		$42,000
	Technician 1	$300	35	35		$21,000
Travel / mobilization	Project Biologist	$600	7	7		$8,400
	Technician 1	$300	7	7		$4,200
Data entry, analysis and reporting	Analyst	$750	20	20	35	$56,250
	Project Biologist	$600	10	10	20	$24,000
	Contingency	10%	$9,351	$9,351	$4,203	$22,905
		Subtotal	*$71,151*	*$71,151*	*$45,453*	*$187,755*
	Expenses	Unit Price				
	Mileage (per km)	$0.56	3500	3500	500	$4,200
	Field supplies[a]	$1,000	4	4		$8,000
	Lab	$20,000	1	1		$40,000
	Lodging (night)	$100	35	35		$7,000
	Meals	$50	35	35		$3,500
	Report preparation	$500	1	1	1	$1,500
		Subtotal	*$31,710*	*$31,710*	*$780*	*$64,200*
	Future Inflation	2%	$4,156	$6,296	$3,811	$14,263
		Total	**$107,017**	**$109,157**	**$50,044**	**$266,218**

1.2.7 References

BC Hydro 2005. Cheakamus Project Water Use Plan – Revised for acceptance by the Comptroller of Water Rights. Prepared by BC Hydro October 1, 2005.

Marmorek, D. R. and I. Parnell. 2002. Cheakamus River water use plan: report of the Consultative Committee. BC Hydro. Burnaby, B.C. 235p.

Norris, R.H. and C.P. Hawkins. 2000. Monitoring river health. Hydrobiologia. 435: 5-17.

Perrin, C.J. 2001. Trophic structure and function in the Cheakamus River for water use planning. Report prepared by Limnotek Research and Development Inc. for BC Hydro and Resort Municipality of Whistler. 67p.

Rosenberg, D.M. and V.H. Resh. (Ed). 1993. Freshwater biomonitoring and benthic macroinvertebrates. Chapman and Hall. New York.

Cheakamus River Monitoring Program #8: Monitoring Channel Morphology in Cheakamus River

1.1 Program Rationale

1.1.1 Background

The Cheakamus River FTC developed a suite of impact hypotheses related to impacts of Daisy Lake Dam operation on downstream fish and fish habitat. One of these hypotheses was that the pattern of release from the dam causes a change in the river's hydrology such that it alters its channel geomorphology. This in turn affects the quantity and quality of fish habitat in the system and hence, the number of wild salmon that it is capable of sustaining. Specifically, that habitat concerns were channel diversity, development and access to side channels, and the distribution and quality of substrates utilized by rearing and spawning salmonids.

To test this hypothesis, a study was carried out by Northwest Hydraulics Consulting (2000) that examined the role of Daisy Lake Dam and its historical operation on the present day morphology and sediment characteristics of the channel. The study found that channel morphology had indeed changed significantly since construction of the dam, including a general simplification of channel structure, reduction in the overall length and complexity of side channels, re-vegetation of gravel bars, and a general reduction in channel width. Coincident with these changes was a reduction in peak annual flow by roughly 20 per cent at Daisy Lake Dam. Modelling showed that operations could virtually eliminate the snowmelt freshet in a low inflow year. Though the authors concluded that the reduced freshet was most likely responsible for the rapid re-establishment of pioneer vegetation on bar surfaces, it was not the sole factor explaining the changes in channel morphology. Diking, bank protection, bridge placement, interception of large woody debris and sediments by Daisy Lake Dam, and the lost sediment supply from the Rubble Creek fan (due to bridge maintenance) were all thought to be important contributors. As a result, Northwest Hydraulics Consulting concluded that changes to Daisy Lake Dam operations alone would not be sufficient to reverse the morphological changes in the lower Cheakamus River.

Given the results of the channel morphology study, the FTC rejected the channel morphology hypothesis since Dam operations had little influence on the frequency, magnitude, or duration of very large flows that dramatically alter the channel. The FTC accepted the conclusions of the NWH study as they pertain to the general reduction in channel width, simplification of channel structure, and the vegetation of gravel bars. However, the FTC did identify uncertainties with respect to the role of Daisy Lake Dam operation on the frequency, magnitude and duration of intermediate flows that transport and re-distribute sediment input during large events, and effect other finer scale shaping of the channel and side channels; features that are important to biota. In particular, there was considerable uncertainty centred on the importance of substrate quality and quantity for salmonid species, and the effects of operation impacts, relative footprint effects and natural stochastic events (large floods), on their distribution and availability throughout the river. As well, recent changes in natural side channel access and availability since the implementation of the 45 per cent previous day's flow rule have prompted the question of whether base releases from Daisy Lake Dam could impact their availability and utility over time.

Therefore, the FTC recommended that these uncertainties be addressed in a monitoring plan. Some CC members also expressed concerns with channel morphology and recommended monitoring to support the technical conclusions of the FTC.

Coincident with these uncertainties is the relatively poor understanding of local inflows to the lower Cheakamus River and its contribution to the river's hydrology and hence habitat availability in the area.

It should be noted that the Northwest Hydraulics Consulting (2000) report did not address the consequences of the WUP specifically. Rather the study looked at changes in Daisy Lake Dam operations in general and as a result, the uncertainties identified by the FTC were in general as well. In this monitor however, inquiries addressing the uncertainties raised by the FTC will not be generalized in nature, but be examined solely in the context of the WUP operations. However, the results of the monitor may be extrapolated to other operating alternatives if they do not deviate dramatically from the present set of WUP constraints.

1.1.2 Management Questions

The uncertainties stemming from the Northwest Hydraulics Consulting (2000) report have lead to the following management questions:

1) Following implementation of the WUP, has there been a change in the overall availability of suitable fish spawning substrates from the present state? If so, can this change be clearly attributed to Daisy Lake Dam operations vs. other environmental or anthropogenic factor?
2) Following implementation of the WUP, has there been a change in the overall length, access and utility for fish of naturally occurring side channels from the present state? If so, can this change be clearly attributed to Daisy Lake Dam operations vs. other environmental or anthropogenic factors?
3) To what extent does the hydrology of Rubble Creek, Culliton Creek, and Swift Creek contribute to the general hydrology of lower Cheakamus River and how does it attenuate the effects of Daisy lake dam operations.

1.1.3 Summary of Impact Hypotheses

The management questions above will be examined in the context of a pre and post WUP comparison of survey data designed to test various impact hypotheses. Here, pre-WUP will be considered the first year of monitoring after implementation of the WUP flow regime in Feb 2006. Management questions #1 and 2 have an associated set of impact hypotheses that are testable with the data that is collected in the monitor, and the results of which can be used to draw inferences that collectively may answer the management question. Resolving whether changes that occur are the result of Daisy Lake Dam operations will require a further analysis and a weight of evidence approach.

In the case of the first management question, which deals with the availability of suitable substrate, the set of impact hypotheses is as follows:

H_O1: Total area (ha) of accessible substrate suitable for salmonid spawning has not changed since implementation of the WUP.

Tests of H1 are focused strictly on the distribution of substrate that is accessible to spawning fish at the most common flows in the system, which may be different for each species and may require separate tests. Tests of this hypothesis will use aerial estimates of suitable substrate measured at a coarse scale (i.e., predominantly gravel = suitable; predominantly large cobble = not suitable). Tests related to the utility of these substrates at different flows is the subject of monitor #1b.

For the management question related to the impacts on side channel utility, the impact hypotheses are:

H_O2: Total length (km) of connected side channel habitat wetted at typical flows has not changed since implementation of the WUP.

H_O3: The diversity of side channel habitat, as measured by the number and ratio of pool, run, and riffle habitats, has not changed since implementation of the WUP.

Test of all hypotheses above should incorporate an inventory of potential channel altering events (e.g., flood events, in stream physical works) that could have caused the observed changes, if any are detected. This inventory of events will be important in distinguishing whether the change is the result of Daisy Lake Dam operations, or some other event.

The tributary flow component of the monitor does not lend itself to the impact hypothesis paradigm. Rather, it is a data collection exercise designed to improve the present state of knowledge on tributary inflows to the system, and hence improve the accuracy of inferences drawn from all aspects of the Cheakamus River monitor.

1.1.4 Key Water Use Decision Affected

Results of the present monitor will not likely result in a significant change in decisions on flow release from Daisy Dam unless a clear and dramatic, operations-related, impact is detected. If such were the case, the WUP would have to be reviewed in its entirety because it’s unlikely that subtle changes in one or more operational constraints would alter the impact. An alternative may be to use instream physical works to mitigate the impact. Results of the monitor would aid in that respect as well, particularly the collection of air photos, which has recorded all channel changes through time. The conclusions resulting from these studies would also have an impact on the likelihood of reaching CC consensus in future WUPs. It will help reduce the uncertainty associated with the extent and nature of channel morphology changes arising directly from Daisy Lake Dam operations.

Results of the tributary flow monitor will improve the present state of knowledge on tributary inflows to the system, and hence improve the accuracy of inferences drawn from all aspects of the Cheakamus River monitor.

1.2 Program Proposal

1.2.1 Objective and Scope

The objective of this monitor is to collect the data necessary to test the impact hypotheses outlined in Section 1.3 and hence, address the management questions presented in Section 1.2. The following aspects define the scope of the study:

a) The study area will be encompass the entire length of Cheakamus River from Daisy Lake Dam to the confluence of Squamish River, excluding the canyon reach which is of limited value to fish and is impractical to survey.

b) The channel morphology component of the monitor will be carried out in Years 1 and 5, and will include the use of air photos, GIS technology, and a maximum of eight days of field ground truthing surveys. A data report will be prepared within one year following completion of the GIS and survey work.

c) The tributary flow component of the monitor will be carried out continuously at Rubble Creek, Culliton Creek, and Swift Creek until the next WUP review period. Each year a total of ten days will be dedicated to ensure that the resulting rating curves are appropriately calibrated. A data report will be prepared within three months of the end of each hydrological year.

d) A final report will be prepared at the end of the monitor that summarizes the results of the entire monitoring program, discusses inferences that can be drawn pertaining to the impact of WUP operations over time, and presents conclusions concerning the impact hypotheses and the management question in Section 1.2.

1.2.2 Approach

The monitoring approach is to use repeated air photo mapping and GIS analysis to monitor changes in channel morphology. This approach will provide information a resolution to detect coarse scale changes in the channel parameters of interest. This monitor will rely heavily on the use of air photographs and GIS technology to capture changes in channel morphology through time. In Years 1 and 5, at a standard discharge and time of the year, a set of air photographs will be taken at a scale of 1:5000 along the entire length of the river. These images will be scanned into computer and rectified across two dimensions (i.e., corrected for lens distortion) so as to create accurate photo mosaics. Using the original air photos, as well as ground truthing surveys, GIS tools will be used to mark the location and aerial extent of all features of interest, including the distribution of substrates and the location and character of side channels areas. The data and summary statistics gathered by GIS analysis will then be used to test the hypotheses outlined above. This approach is very similar to the approach taken to measure Rated Usable Area at different Daisy Lake Dam Discharges (Bruce 2001).

The other aspect of the monitor is the collection of hydrology data from the primary tributaries to the system. Because these tributaries are steep, comprised of coarse substrate and tend to be dynamic in nature, collection of this type of data will be difficult and prone to error. Rather than rely on standard approaches to collect such data, which rely on a stable channel shape and laminar flow condition for accurate measurement, an alternative will be used that incorporates the use of dye or salt tracers. With the recent development of portable and highly sensitive equipment, the use of tracers for this application has become a much more feasible option, and in this case, cost effective. Its use however, still requires the selection of a stable site for installing reference gauges for continued measurement.

1.2.3 Methods

Task 1: Project Coordination

Project coordination involves the general administrative and technical oversight of the program. This will include but not be limited to:

1) Budget management.
2) Staff selection.
3) Logistic coordination.
4) Technical oversight in field and analysis components.
5) Liaison with regulatory agencies.

Coordination with WUP Monitoring and Other Monitoring Programs

To help answer high-level questions regarding the relation between Cheakamus River discharge and fish production, data from this channel morphology program will ultimately be used in combination with data from the fish population monitoring programs (Programs #1,2,3,), the Cheakamus stranding program (#4), the benthic community monitoring program (#7), and possibly other WUP monitoring programs. Therefore, it is critical that data collection is coordinated among programs.

To ensure that data collection is coordinated among the inter-related monitoring programs for the Cheakamus WUP, an important task for this program is to develop and maintain communication with project leads for the other monitoring programs. This communication could involve a workshop at the start of the field season to ensure that the sampling locations and methodologies will meet the data requirements of the other programs, and vice-versa. Logistical changes within the scope of the program may be required.

Task 2: Field Data Collection

Air Photography and GIS Analysis

Air photos at a scale of 1:5000 will be taken along the entire length of the Cheakamus River in Years 1 and 5. Only those sections between the Squamish confluence and the bottom end of the canyon, and the top end of the canyon reach and Daisy Lake Dam will be developed for analysis.

The air photos will be scanned into a computer at maximum resolution and then corrected for lens distortion using appropriate software. The individual images will then be merged into a mosaic and properly scaled so that accurate topographical measurements can be taken. Once in this format, GIS tools will be used to create polygons of unique character based on the mosaic imagery and detailed air photo interpretation. With respect to the sediment related hypotheses, these polygons will reflect areas of similar substrate composition. For the side channel hypotheses, the polygons will reflect areas of unique character such as habitat type and will include such elements as the extent of connectivity to the mainstem and total length.

Once the initial GIS work is completed, a two person crew will be sent into the field to resolve uncertainties encountered during the air photo interpretation phase, verify the character of each polygon, and verify their boundaries. Corrections to the GIS database will then be made based on the field observations of the ground crew.

Tributary Flow Monitoring

Tributary flow monitoring will be carried out by flow salt tracer methodology. At each primary tributary, a site will be selected near the confluence to the Cheakamus River that is judged to be relatively stable through time – a bridge crossing would work well. At each of these sites, a staff gauge, pressure transducer and data logger will be installed in a permanently fixed housing structure. The staff gauge will be used to transform the pressure transducer measurements that are continuously recorded by data logger into a series of water depth measurements.

The depth measurements will be transformed to estimates of discharge using a flow-rating curve derived from flow measurements collected at specific intervals of water depth. Flow estimates will be obtained by salt tracer methodology where a known volume of a concentrated salt solution (salt plug) is released at a point upstream, allowed to mix thoroughly as it travels downstream, and then measured at regular intervals for salt concentration at the gauging site. The resulting sequence of salt concentration measurements is then integrated to over time (i.e., calculate the area under the curve), and then to compare it to the original salt plug concentration to estimate discharge. Details of the methodology can be obtained from several sources, including Hudson and Fraser (2005) and references therein, and in a monograph prepared by Turner Designs entitled “A Practical Guide to Flow Measurement” (available online at www.turnerdesigns.com).

Because these tributary systems are very dynamic, the flow rating curves will have to be re-calibrated every year to accommodate changes in channel morphology at the gauging site.

Task 3: Data Analysis

All GIS imagery and polygon data will be stored into a database in a standardized format for future retrieval and analysis. Similarly, all data related to the development of flow rating curves and their annual calibration will be stored in a common database and in a standardized format. The water level data at each site will be stored at hourly and daily average intervals. Each year, the data will be appended to the previous year’s data to create a singe data sequence for use in other monitors.

Hypotheses H_O1 to H_O4 will be tested using correlation analysis where the temporal sequence of all channel morphology data is examined for a significant increasing or decreasing trend. Both parametric and non-parametric tests will be used depending on the distribution of data.

The tributary flow data will not be subject to analyses other than the descriptive statistics noted above.

Task 4: Reporting

Project reporting will consist of a series of annual data reports and a single final report at the conclusion of the monitor. For the channel morphology component of the monitor a data report will be prepared once every five years and be complete within one year after the air photographs have been taken. The data report will simply document the findings of the year and will include a discussion on how the year's data compare with that collected in previous years. Included in this discussion will be the results of all pertinent hypothesis testing.

For the tributary flow monitor, the data reports will be prepared annually and will include a summary graph of daily average flow and pertinent summary statistics. These data will be incorporated into other monitors as necessary.

At the conclusion of the monitor, a final report will be prepared that collates all of the observations collected to date and:

a) Re-states the objective and scope of the monitor.
b) Presents the method of data collection.
c) Describes the compiled data set and presents the results of all analyses.
d) Discusses the consequences of these results as they pertain to the current WUP operation, and the necessity and/or possibility for future change.

1.2.4 Interpretation of Monitoring Results

The air photo mapping and GIS analysis should provide information at a resolution to detect coarse-scale changes in channel morphology. Rejection of any or all of the Hypotheses H_O1 to H_O3 would indicate some kind of change in channel morphology since implementation of the WUP. If the trend is towards increasing substrate availability and channel complexity, then the results are considered to be positive for fish. A negative trend would be interpreted as a loss of fish habitat. If a change has occurred, the next step in the interpretation is to determine whether the change is the result of Daisy Lake Dam operations or some other environmental or anthropogenic factor. Such a distinction will have to rely on a weight of evidence assessment using a database of known, potentially channel altering events in the river. If such events cannot reasonably explain the observed change in channel morphology, then the weight of evidence would default that the change is the result of Daisy Lake Dam operations. Whether the change would have occurred regardless of the WUP operations would remain uncertain.

1.2.5 Schedule

Monitoring is scheduled to occur for five years. The channel morphology component of the monitor will be carried out in Years 1 and 5. A data report will be completed within one year of starting the air-photo survey. The tributary flow measurements will be an ongoing component of the monitor. Annual data reports will be prepared within three months from the end of each hydrological year. At the conclusion of the monitor, a final report will be prepared that summarizes all findings to date.

1.2.6 Budget

Table 8-1 outlines the estimated cost for the monitoring program.

Table 8-1: Cost Estimate for Monitoring Channel Morphology in Cheakamus River

Task	**Labour**	Daily rate			Units			Total Cost
			Yr 1	Yr 2	Yr 3	Yr 4	Yr 5	
Project Coordination	Hydrologist	$700	8	3	3	3	4	$14,700
Airphoto interpretation	Geomorphologist	$700	5				5	$7,000
GIS data entry	GIS Sr. Technician	$500	20				20	$20,000
GIS Analysis	GIS Sr. Technician	$500	3				3	$3,000
Ground survey	Geomorphologist	$700	5				5	$7,000
	GIS Sr. Technician	$500	5				5	$5,000
Tributary site selection	Hydrologist	$700	2					$1,400
Transducer installation	Technician 1	$300	7					$2,100
	Technician 2	$300	7					$2,100
Transducer maintenance	Technician 1	$300	6	6	6	6	6	$9,000
	Technician 2	$300	6	6	6	6	6	$9,000
Tributary Data analysis	Hydrologist	$700	2	2	2	2	2	$7,000
Reporting	Geomorphologist	$700	2				12	$9,800
	GIS Sr. Technician	$500	4				12	$8,000
	Hydrologist	$700	4	2	2	2	6	$11,200
	Contingency	10%	$7,145	$1,164	$1,164	$1,164	$6,228	$16,864
		Subtotal	*$50,545*	*$9,664*	*$9,664*	*$9,664*	*$53,628*	*$133,164*
	Expenses	Unit Price						
	Mileage (per km)	$ 0.56	7000	1500	1500	1500	2500	$7,840
	Lodging (night)	$ 100	38	12	12	12	22	$9,600
	Meals	$ 50	38	12	12	12	22	$4,800
	Airphotos	$ 5,000	1				1	$10,000
	Survey gear	$ 10	5				5	$100
	Pressure transducer	$ 4,000	3				1	$16,000
	Installation materials	$ 125	3				1	$500
	Report preparation	$ 500	2	1	1	1	2	$3,500
		Subtotal	*$28,045*	*$3,140*	*$3,140*	*$3,140*	*$14,875*	*$52,340*
	Future Inflation	2%	$1,572	$517	$784	$1,055	$7,130	$11,058
		Total	**$80,161**	**$13,321**	**$13,588**	**$13,859**	**$75,632**	**$196,562**

1.2.7 References

Bruce, J. 2001. Cheakamus River Water Use Plan: Habitat suitability weighting functions for juvenile, summer rearing salmonids. Draft report prepared by BC Hydro for Cheakamus Water Use Planning Fish Technical Committee.

Hudson, R., and Fraser, J. 2005. Introduction to salt dilution gauging for streamflow measurement part IV: the mass balance (or dry injection) method. Streamline Watershed Management Bulleting Volume 9 No. 1. Fall 2005. Available online: http://www.forrex.org/streamline/streamline.asp as accessed February 2006.

Marmorek, D. R. and I. Parnell. 2002. Cheakamus River water use plan: report of the Consultative Committee. BC Hydro. Burnaby, B.C. 235p.

Northwest Hydraulic Consulting Ltd. 2000. Analysis of Channel Morphology and Sediment Transport Characteristics of the Cheakamus River. November 20, 2000.

Cheakamus River Monitoring Program #9: Cheakamus River Recreational Angling Access Monitoring

1.1 Monitoring Program Rationale

1.1.1 Background

The Cheakamus River Water Use Plan (WUP) considered operating alternatives to meet water demand for power generation, and several social and environmental objectives. With consideration of arguments from all participants, the Water Comptroller selected an operating regime similar to the one that was favoured by some members of the Consultative Committee (CC; Marmorek and Parnell 2002). To benefit recreational angling access, the flow regime selected by the Water Comptroller included a minimum flow from Daisy Dam of 5.0 $m^3 \cdot s^{-1}$ from 1 January to 31 March, rather than the 3.0 $m^3 \cdot s^{-1}$ minimum release during this period that was favoured by the Fisheries Technical Committee and some CC members. Recreational angling access refers to the availability of fishable locations under a given minimum flow release from Daisy Dam. The benefits to recreational angling access were uncertain, and the Water Comptroller ordered that these benefits be monitored. This document presents Terms of Reference for a program to monitor these benefits.

Under this operating regime, the minimum flow released from Daisy Dam during 1 January to 31 March will be determined either by (a) the 5.0 $m^3 \cdot s^{-1}$ requirement from Daisy Dam, or (b) the requirement to maintain 15.0 $m^3 \cdot s^{-1}$ downstream at the Brackendale gauge. The minimum flow release required to maintain 15.0 $m^3 \cdot s^{-1}$ at the Brackendale gauge is dependent on tributary inflows between Daisy Dam and the Brackendale gauge. Thus, the effective difference in flow releases under this higher minimum discharge requirement from Daisy Dam (3.0 $m^3 \cdot s^{-1}$ vs. 5.0 $m^3 \cdot s^{-1}$) is uncertain, may not occur continuously (i.e., during periods of low tributary inflow when >3.0 $m^3 \cdot s^{-1}$ would be released to maintain 15.0 $m^3 \cdot s^{-1}$ at Brackendale) and may vary with tributary inflows downstream of Daisy Dam. In addition, the effective difference in flow releases is expected to be of most consequence in river sections immediately downstream of the Dam, as the incremental discharge will become buffered by tributary inflows further downstream.

A performance measure for angling was developed by the recreation subgroup of the CC during the WUP. The performance measure examined was:

> "Number of days in the sport fishing season (mid March to 1 May; August to December) that the Brackendale gauge reading is between 19.4 cms (0.7 m) and 68.4 cms (1.2 m). (Note: sport fishing occurs from pre-dawn to post dusk. Steelhead = mid March to 1 May; salmon = August to December)." (from Appendix 2-C of Marmorek and Parnell 2002)

The flow release monitored under this program examines angling at a different time of year and at a different section of the river than that examined by the performance measure used during the WUP.

1.1.2 Management Questions

The key management questions are:

1) Does angling occur during this time of year in sections of the river that would be affected by this operation?

2) Is access to recreational angling locations during 1 January to 31 March improved under the 5.0 $m^3 \bullet s^{-1}$ minimum flow release from Daisy Dam relative to that which would occur with a 3.0 $m^3 \bullet s^{-1}$ minimum flow release?

1.1.3 Summary of Impact Hypotheses

There is one null hypothesis associated with the management question above:

H_O1: Access to recreational angling locations during 1 January to 31 March does not differ between a 5.0 $m^3 \bullet s^{-1}$ and 3.0 $m^3 \bullet s^{-1}$ minimum flow release requirement from Daisy Dam.

Again, a fundamental uncertainty is whether angling occurs during this time of year in sections of the river that would be affected by this operation.

1.1.4 Key Water Use Decision Affected

The key water use decision that would potentially be affected is the flow release from the Daisy Dam from 1 January to 31 March, a period of generally low inflows to Daisy Reservoir. This flow release can affect power production, heritage and cultural values by First Nations, recreation, fish production, integrity of the aquatic ecosystem that supports the river food web and water quality, and flood control.

1.2 Monitoring Program Proposal

1.2.1 Objective and Scope

The objective of the monitoring program is to collect the data necessary to answer the management questions and impact hypothesis. The geographic scope of the monitoring program will include the Cheakamus River from Daisy Dam to the start of the Cheakamus Canyon, since this minimum flow requirement is expected to affect flows in these upper reaches and have little effect in lower reaches where dam releases are buffered by tributary inflows. Data will be collected over one year.

1.2.2 Approach

The monitoring approach is to:

1) Characterize angling that occurs during 1 January to 31 March.

2) Identify important river sections for recreational angling during 1 January to 31 March.

The monitoring approach focuses on collecting and summarizing data on angler use of this river section during 1 January to 31 March. Inferences on the potential benefits to angling access will be based on this general information on angler use.

More detailed inferences on the benefits to angling access during 1 January to 31 March would be qualitative at best, because the flow regime selected by the Water Comptroller does not accommodate a direct comparison of angling access by sampling during 1 January to 31 March under both a 5.0 and the 3.0 $m^3 \bullet s^{-1}$ minimum flow release.

1.2.3 Methods

Task 1: Project Coordination

Project coordination involves the general administrative and technical oversight of the program. This will include but not be limited to:

1) Budget management.
2) Staff selection.
3) Logistic coordination.
4) Technical oversight in field and analysis components.
5) Liaison with regulatory agencies.

Coordination with WUP Monitoring and Other Monitoring Programs

Data from this program may be used in combination with data from the other monitoring programs, such as the channel morphology monitoring program (#8) to determine the benefits to angling. Therefore, it is critical that data collection is coordinated among programs.

To ensure that data collection is coordinated among the inter-related monitoring programs for the Cheakamus WUP, an important task for this program is to develop and maintain communication with project leads for the other monitoring programs. This communication could involve a workshop at the start of the field season to ensure that the sampling locations and methodologies will meet the data requirements of the other programs, and vice-versa. Logistical changes within the scope of the program may be required.

Task 2: Identify Angling Use

The proponent will determine angler use and important river sections for angling during 1 January to 31 March, through a review existing information such as creel survey data (if available for this time of year), interviews with anglers, and, if required, on the river counts. The objective is to obtain general information on the characteristics of angler use. A detailed, quantitative evaluation of determine metrics such as total angler-days is beyond the scope of this program.

Task 3: Reporting

A comprehensive report will be prepared following data collection that includes:

a) An executive summary of the entire project.
b) A summary of the methods used
c) A data summary.
d) A detailed summary of the findings as they relate to the ecological hypothesis and the key management question.

1.2.4 Interpretation of Monitoring Results

The key result of the monitoring will be angler use during this period. Inferences on the potential benefits to angling access will be based on this general information on angler use.

1.2.5 Schedule

Monitoring is scheduled to occur over one year. Monitoring is scheduled to begin two years (2008) after the implementation of the WUP flow regime (2006).

1.2.6 Budget

Table 9-1 outlines the estimated cost for the monitoring program.

Table 9-1: Cost Estimate for the Cheakamus River Recreational Angling Access Monitoring

Task	Labour	Daily rate	Units	Total Cost
			Yr 2	
Project Coordination	Project Biologist	$600	2	$1,200
Information review, interviews, and field counts	Project Biologist	$600	5	$3,000
	Technician 1	$300	5	$1,500
Travel	Project Biologist	$600	2	$1,200
	Technician 1	$300	2	$600
Data entry, analysis and reporting	Project Biologist	$600	4	$2,400
	Technician 1	$300	2	$600
	Contingency	10%	$1,206	$1,206
		Subtotal	*$11,706*	*$11,706*
	Expenses	Unit Price		
	Mileage (per km)	$0.56	1000	$560
	Field supplies	$500	1	$500
	Report reproduction	$500	1	$500
		Subtotal	*$1,560*	*$1,560*
	Future Inflation	2%	$536	$536
		Total	**$13,802**	**$13,802**

1.2.7 References

Marmorek, D. R. and I. Parnell. 2002. Cheakamus River water use plan: report of the Consultative Committee. BC Hydro. Burnaby, B.C. 235p.