Cheakamus Project Water Use Plan

Monitoring Program Terms of Reference

- Cheakamus River Chum Salmon Escapement Monitoring and Mainstem Spawning Groundwater Survey

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 m³/s⁻¹ minimum flow release from Daisy Lake Dam.
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:

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

This first hypothesis is general, and the specific hypotheses below will assist in diagnosing some likely reason(s) for any observed patterns.
H₂: 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 whether chum salmon spawn more frequently in upwelling areas.

H₃: 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 through the site.

<table>
<thead>
<tr>
<th>Location</th>
<th>PIT detections per</th>
<th>Counts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moodies spawning channel</td>
<td>45</td>
<td>1,500</td>
</tr>
<tr>
<td>BC Rail Creek</td>
<td>50</td>
<td>2,600</td>
</tr>
<tr>
<td>Tenderfoot Creek</td>
<td>178</td>
<td>12,000</td>
</tr>
<tr>
<td>Upper Paradise spawning channel</td>
<td>276</td>
<td>22,000</td>
</tr>
</tbody>
</table>

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 through 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 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 H1. While the same WUP base flow regime (BC Hydro 2005) will likely be in place for the duration of monitoring, natural variation in 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

Total Program Cost: $1,148,747.
1.2.7 References


