FEASIBILITY ASSESSMENT OF KOKANEE
RE-ANADROMIZATION AND PLANNING OF FISH
PROPAGATION FOR RE-INTRODUCTION OF
SOCKEYE SALMON IN COQUITLAM RESERVOIR

Prepared for:

BC Hydro Bridge Coastal Fish and Wildlife Restoration Program
6911 Southpoint Drive (E14),
Burnaby, BC V3N 4X8

BCRP Report No. 05.Co.08

March 2006
FEASIBILITY ASSESSMENT OF KOKANEE RE-ANADROMIZATION AND PLANNING OF FISH PROPAGATION FOR RE-INTRODUCTION OF SOCKEYE SALMON IN COQUITLAM RESERVOIR

Prepared by:

R. Bussanich and R.C. Bocking\(^1\)
R. Nelson\(^2\) and C. Wood\(^3\)

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\(^1\) LGL Limited environmental research associates, 9768 Second Street, Sidney, BC, V8L 3Y8
\(^2\) Seastar Biotech Inc., 32056-3749 Shelbourne Street, Victoria, BC, V8P 5S2
\(^3\) Fisheries and Oceans Canada, Pacific Biological Station, 3190 Hammond Road, Nanaimo, BC, V9R 5K6
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EXECUTIVE SUMMARY

An assessment of propagation strategies was implemented for re-introducing Coquitlam sockeye salmon, with the goals to determine whether or not resident kokanee and neighbouring sockeye populations could be used as donor stock for sockeye recovery initiatives, determine the best strategy using conventional hatchery practices or captive broodstock technology, and identify candidate sites and resource needs for future program development.

The need for a supplementation or captive broodstock program as part of a re-introduction program depends on a number of factors; the ability of Coquitlam kokanee to re-anadromize, the feasibility of using a donor stock, the ability of Coquitlam kokanee to migrate volitionally or with assistance (e.g. trapping) from the reservoir in sufficient numbers, and the timeframe and benchmarks (abundance) desired for re-introduction. The preferred and most cost-effective program would see Coquitlam kokanee allowed to migrate from the reservoir and re-anadromize volitionally. However, supplementation or captive broodstock program may be considered to fast track re-introduction or meet abundance goals that cannot be achieved without such intervention.

A total of 198 specimens were collected from kokanee and sockeye populations in Coquitlam Reservoir, Widgeon Slough, Alouette River, Pitt Lake, Cultus Lake, Harrison River, and Harrison Lake for genetic analysis. The study demonstrated that kokanee in the Coquitlam Reservoir share many of the same genetic characteristics as neighbouring populations of sockeye and kokanee, at least since the time of dam construction. Coquitlam kokanee appear to be closest genetically to Pitt Lake sockeye and Alouette Lake kokanee. Analysis of Coquitlam kokanee gill raker length and number were similar to cultured experiments of sockeye-kokanee hybrid crosses and supported the genetic results that the local kokanee stock are likely from recent descendents of sockeye. However, the observation that no novel haplotypes were observed in Coquitlam Reservoir, and that all haplotypes are present nearby in the region suggests that the Coquitlam nerkids have not been isolated from the other populations for an extensive period of time. From a gene purity perspective, it would be preferable to re-anadromize the Coquitlam kokanee population rather than introduce a separate gene pool to the reservoir, if stock supplementation proceeds.

An assessment of implementing a multi-year captive broodstock or supplementation program was completed. Based on the information gathered, a supplementation strategy is preferable to a captive broodstock strategy at Coquitlam reservoir. In the short-term, Rosewall Creek Hatchery was determined to be the best choice as an egg incubation and rearing facility, followed by Inch Creek. Preventive measures include culturing sockeye at two facilities, redundant water deliver systems, emergency response readiness (standby staff), site security and operational protocols that minimize disease outbreaks. The ALLCO hatchery site at Alouette River was also identified as a suitable site for developing a long-term program. This site would have the added advantage of simultaneously servicing two sockeye re-introduction initiatives, at Coquitlam and Alouette.
The successful development and operation of a supplementation program will require a long term commitment, a multi-disciplinary team of experts, and community consultation at critical stages. This report supports ongoing feasibility assessments regarding the Coquitlam re-anadromization program, and describes options for stock augmentation of sockeye salmon into the Coquitlam Reservoir.
1 INTRODUCTION

The goal of the Coquitlam Salmon Recovery Program (CSRP) is to return Coquitlam Lake Reservoir sockeye to the status of a viable, self-sustaining and genetically robust wild population that will contribute to its ecosystem and have the potential to support sustainable use. The long term initiative of reintroducing sockeye to Coquitlam Reservoir and increasing salmon production to its pre-dam construction historical levels is currently funded by the Bridge Coastal Restoration Program (BCRP).

The Coquitlam hydroelectric project was completed in 1914. The dam impounded the waters of the Coquitlam River watershed, creating Coquitlam reservoir. As a result, access to what was formerly known as Coquitlam Lake was blocked for all anadromous fish. The question of restoring fish passage to Coquitlam Reservoir and its tributaries has been the subject of intense debate among resource users and BC Hydro in recent years. Although most if not all species of Pacific salmon were present, sockeye salmon was the main anadromous species known to inhabit the lake. What is known is that they were important to the Kwikwetlem First Nation (KFN) and migrated into the Coquitlam River and lake in April and May of each year (Koop 2001). Alouette River sockeye, also extirpated by hydroelectric development, also return at this time of year. Kwikwetlem people also fished for coho, chum, and Chinook salmon at the mouths of tributaries to Coquitlam Lake (George Chaffee, KFN, pers. comm.).

The question of restoring anadromous fish access to Coquitlam reservoir is a complex one. Bocking and Gaboury (2002) established a framework for the evaluation of restoring fish passage for anadromous species upstream of hydroelectric dams. The framework addresses key biological, physical, operational, and structural issues related to restoring fish passage. While there remains considerable uncertainty regarding the potential success, Bocking and Gaboury (2003) found that there appears to be no serious impediments to the re-introduction of sockeye salmon and other salmon species such as coho to the Coquitlam Reservoir. Preliminary research suggests that the reservoir has the capacity to support a spawning population of between 5,000 and 10,000 female sockeye and around 200 coho (Nordin and Mazumder 2005, Bussanich et al 2006, Bocking and Gaboury 2003). Re-introduction of sockeye salmon to the Coquitlam Reservoir will require propagation of the stock, while coho salmon, steelhead, Dolly Varden, and anadromous cutthroat would likely colonize the watershed naturally over time.

Consultations with professionals and interested parties were held throughout the development of this report. Telephone interviews and meetings were convened from April 2005 to January 2006. Appendix A contains a list of all persons and organizations consulted.

This report will support the decision to either resume or suspend re-anadromization programs and studies, and recommend a strategic plan for stock augmentation of sockeye salmon into the Coquitlam Reservoir.
1.1 OBJECTIVES

Three objectives associated with the study are, as follows:

1. Investigate the evolutionary history of Coquitlam kokanee by using mitochondrial DNA analysis, gill raker analysis, and developmental characteristics in common garden experiments to measure genetic differentiation from adjacent sockeye populations; re-anadromization is believed to be feasible if genetic differentiation is small or undetectable, as expected if isolation has been recent (e.g. since dam construction);
2. Artificially propagate Coquitlam kokanee and sockeye for a candidate donor population at the Rosewall Creek Experimental Hatchery to assess the feasibility of maintaining a captive broodstock or hatchery program to support the CSRP by monitoring survival, growth, and maturation rates under controlled fish culture conditions; and
3. Produce smolts large enough to be acoustically tagged and tracked during seaward migration after release in to the Coquitlam River and allow researchers to monitor salmon migration along the Pacific Coast of North America (http://www.postcoml.org).

The specific objectives that support the above overarching objectives are:

1. Assessment of the evolutionary history of Coquitlam Kokanee.
   a. Evaluation of genetics from the local kokanee population broodstock or from neighbouring sockeye populations to re-seed the Coquitlam reservoir;
   b. Evaluation of gill raker differences between kokanee and sympatric sockeye populations to assess the extent of genetic differentiation and the likelihood of re-anadromization.

2. Assessment of implementing a multi-year captive broodstock or supplementation program for CSRP, should re-anadromization appear feasible based on the results of Objective 1.
   a. Evaluation of current captive broodstock and hatchery programs local to the Pacific Northwest;
   b. Determination of available donor stock sockeye juveniles to support releases starting in 2007 until 2016;
   c. Identification of partnerships with existing public, First Nations, and commercial programs;
   d. Determination of approximate program costs, timelines, and infrastructure requirements;
   e. Recommendations and options for future stock augmentation and fishery management.

1.2 PHYSICAL SETTING

Coquitlam Reservoir in southwest British Columbia is a major source of water for domestic water consumption to the Greater Vancouver region and covers approximately 1200 ha (Figure 1). The area is characterized by west coast maritime air with cool wet winters and warm dry summers.
The Coquitlam Reservoir is located above the Coquitlam Dam and is part of the Coquitlam-Bunzten hydro-generating system. The dam was first built in 1904-05 and then reconstructed and raised to its current height of 30 m in 1914. Power is generated by diverting flow from the reservoir via a 3.9 km tunnel to Bunzten Lake reservoir where 530 m and 130 m penstocks lead to power houses located on the shoreline of the Indian Arm in Burrard Inlet (BCRP 2000). The Coquitlam Reservoir has also been used for domestic water supply for Greater Vancouver since 1902.

The reservoir has a mean and maximum depth of approximately 71 and 187, respectively, at a pool elevation of 152 m, with single period of complete mixing between November and March. The reservoir is approximately 12 km long and has an average width of roughly 1 km. Coquitlam Reservoir is classified as a monomictic reservoir type, with an oligotrophic trophic status (Wetzel 2001). Bocking and Gaboury (2003) describe the reservoir characteristics in detail.
2 ASSESSMENT OF THE EVOLUTIONARY HISTORY OF COQUITLAM KOKANEE

The different life forms of *O. nerka* that characterize the species consist of the larger anadromous sockeye (> 1.5kg), that emigrate to sea as yearlings and return as adults just before spawning, and the smaller (<1 kg) resident kokanee that remains in the lake and matures in the
lake. Offspring of kokanee are typically resident fish, although they are capable of producing migrants that return as anadromous adults (Foerster 1947). Kokanee may colonize new areas, but their origin is commonly from the sympatric native anadromous sockeye population. Anadromous sockeye populations often produce a portion of “residuals” that remain in the lake and complete their life cycle in freshwater. A portion of residual will conform to the anadromous life history pattern and we may expect a portion will become the progenitors of kokanee. By recent origin, the residual nerka will be genetically indistinguishable from their anadromous parents.

The following information is relevant to two key questions that must be addressed for the CSRP:

1. Are Coquitlam kokanee reproductively isolated from their ancestral sockeye parents and neighbouring sockeye populations? And;

2. If Coquitlam kokanee are given the opportunity to out-migrate volitionally or are artificially reared and released, can these fish successfully return as adults (i.e., re-anadromize)?

The theory of anadromous sockeye originating from seaward drift kokanee is not a new concept. Kokanee have successfully out-migrated and returned as sea-run adults in other lake systems (Foerster 1947, Mullan 1986, Kaeriyama et al. 1992, Urawa 1991). Bocking and Gaboury (2003) reviewed examples of re-anadromization, and the performance of these cases in Canada, USA, and Japan. The extent to which seaward migrating, juvenile Coquitlam kokanee would return as adults is unknown, and it would take a substantial number of emigrants over many generations to establish a run of sockeye.

2.1 DEFINITIONS

A compilation of scientific terms is provided for the reader’s convenience.

**allopatric** - separated and not interbreeding: describes species or populations that do not interbreed because they are geographically isolated from one another

**anadromous** - returning to rivers to breed: describes fish such as salmon and shad that return from the sea to the rivers where they were born in order to breed.

**asynchronism** - occurrence at different times: in computing and electronics, the occurrence of two or more processes at different times

**cytochrome b** - protein-containing compound: a protein belonging to the b group that contains iron and plays a role in cell respiration

**deme** - population of related species: a local population of closely related interbreeding species
**deoxyribonucleic acid (DNA)** - substance carrying organism's genetic information: a nucleic acid molecule in the form of a twisted double strand double helix that is the major component of chromosomes and carries genetic information. DNA, which is found in all living organisms except some viruses, reproduces itself and is the means by which hereditary characteristics pass from one generation to the next.

**fitness** - ability to reproduce successfully: the ability of an organism to produce offspring that survive and reproduce

**haplotype** - linked gene variations inherited together: a segment of DNA containing closely linked gene variations that are inherited as a unit

**homogeneity** -
1. quality of being same: the quality of being of the same or a similar nature
2. quality of being uniform: the quality of having a uniform appearance or composition

**restriction fragment length polymorphism** - differences in DNA fragment lengths: a variation between individuals in the length of the DNA fragments produced by a specific restriction enzyme. They are caused by mutations and can be used to detect genetic anomalies.

**mitochondrial DNA** - DNA molecule outside cell nucleus: a small circular DNA molecule found in the mitochondria of a cell. Mitochondrial DNA is inherited only from the mother.

**morph** - transform quickly: to cause something to change its outward appearance completely and instantaneously, or undergo this process

**nerkid** – belonging to the genus and species *Onchorhyncus nerka.*

**nucleotide** - structural unit of nucleic acids: a component of RNA and DNA, consisting of a nucleoside linked to a phosphate group

**polymerase chain reaction** - technique to replicate DNA sequence: a technique used to replicate a fragment of DNA and produce a large amount of that sequence

**polymorphism** -
1. existence in different forms: the characteristic of existing in different forms
2. difference in DNA sequence: a difference in DNA sequence between individuals

**propagation** - reproduce organism: to reproduce a plant or animal, or cause one to reproduce

**restriction fragment length polymorphism** - differences in DNA fragment lengths: a variation between individuals in the length of the DNA fragments produced by a specific restriction enzyme. They are caused by mutations and can be used to detect genetic anomalies.

**selection** - survival of fittest: the process by which organisms that adapt well to their environment produce offspring, while those that do not adapt die out, resulting in gradual
changes in a species. Selection may take place naturally or artificially as the result of breeding for specific characteristics.

**supplementation** - an addition to something to increase its size or make up for a deficiency.

**sympatric** - living nearby without interbreeding: describes species that occupy roughly the same area of land but do not interbreed

### 2.2 METHODOLOGY

**2.2.1 Genetic Analysis**

Techniques developed by Dr. John Nelson and Dr. Chris Wood (Nelson and Beacham 1999; Nelson et al. 1998) were used for genetic analysis of Coquitlam kokanee and neighbouring kokanee and sockeye populations in the Lower Fraser River.

**Sample Collection**

A total of 198 specimens were collected from kokanee and sockeye populations in Coquitlam Reservoir, Widgeon Slough, Alouette River, Pitt Lake, Cultus Lake, Harrison River, and Harrison Lake for genetic analysis (Table 1, Figure 2). Samples were stored in ethanol or frozen for storage prior to analysis.

![Figure 2. Genetic sample collection sites for the Coquitlam re-anadromy study.](image)
Table 1. Samples collected and analyzed by RFLP method.

<table>
<thead>
<tr>
<th>Name</th>
<th>type</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coquitlam Reservoir (CQR)</td>
<td>kokanee</td>
<td>21</td>
</tr>
<tr>
<td>Widgeon Slough (WDS)</td>
<td>sockeye</td>
<td>58</td>
</tr>
<tr>
<td>Pitt Lake (PL)</td>
<td>sockeye</td>
<td>30</td>
</tr>
<tr>
<td>Alouette River (ALR)</td>
<td>kokanee</td>
<td>16</td>
</tr>
<tr>
<td>Cultus Lake (CL)</td>
<td>sockeye</td>
<td>25</td>
</tr>
<tr>
<td>Harrison River (HR)</td>
<td>sockeye</td>
<td>25</td>
</tr>
<tr>
<td>Harrison Lake (HL)</td>
<td>sockeye</td>
<td>23</td>
</tr>
</tbody>
</table>

**DNA extraction and PCR**

DNA was extracted from either fin, or muscle samples as described by Nelson et al. (1998). Each polymerase chain reaction (PCR) required from between 1 to 10µls crude DNA extract depending on sample type and sample quality. PCR amplification of mitochondrial genes NADH-dehydrogenase subunit 1 (ND1) and cytochrome b (cytb) was accomplished with primers pairs LGL 290, LGL 560 and LGL 287 and LGL 765 respectively. PCR was carried out in 96 well microtiter plates with a MJ PTC-100 thermal cycler (MJ research, Watertown, MA). 50 µl PCR reactions contained 10pmol (0.4µM) of each primer, 80µM of each nucleotide, 20mM tris-pH 8.8, 2mM MgSO4, 10mM KCl, 0.1% triton X-100, 10mM (NH4)SO4, 0.1 mg/ml bovine serum albumin with the extension and denaturation at steps being 30 long at 72 C and 94 C respectively. The annealing temperature for both primers sets was 48 C. The cytb PCR product was approximately 1300 bp while the amplified segment of the ND1 gene was approximately 859 base pairs. PCR products for both genes were pooled and purified away from PCR buffer components using Qiaquick 96 PCR purification plates (Qiagen Corp.).

**RFLP assay**

The eluate from the Qiaquick plates was split four ways and subjected to restriction digestion with Apal, Bfal, BstI1I and RsaI according to the enzyme supplier's instructions. After digestion the fragments were electrophoresed on a 1.5% agarose gel. All gels contained 0.5X TBE Buffer and were of a 3:1 ratio of metaphor agarose (Mandel Scientific Corp.) to standard grade agarose. Samples were electrophoresed and 100 V for three hours and stained with ethidium bromide. Band patterns from each enzyme were scored separately and band size was determined from a 1-kb ladder (Gibco-BRL Corp.). The enzymes Apal, Bfal, BstI1I and RsaI produced patterns including 7, 5, 2 and 8 different bands, respectively. Each fish in the analysis was scored for individual enzymes and assigned one of 21 possible composite haplotypes.

**Statistical Analysis**

To judge the relationship among the samples, a test of genetic homogeneity was conducted in pair-wise fashion to determine which samples could be judged different. Also, pair-wise $F_{ST}$ was calculated to get a quantitative sense of the relationship among the samples; these tests were performed with ARLEQUIN (Schneider et al. 1999). A neighbour joining tree
was generated using PHYLIP version 3.5c (Felsenstein 1995) to gain an overall understanding of the relationship among the samples.

2.2.2 Gill Raker Assessment

Gill rakers of Coquitlam kokanee collected during the May 2005 fish population survey from Coquitlam were assessed using techniques developed by Foote et al (1999).

2.3 RESULTS

2.3.1 Genetic Analysis

Five different haplotypes were found in the seven samples examined. The frequencies of each haplotype found in each sample are shown in Table 2. Three different haplotypes (1, 3, 6) were found in the sample from Coquitlam Reservoir, all of which were found among some other samples in this study, but all three were not found in the nearest sites sampled (Widgeon Slough and Alouette Lake). This suggests, not surprisingly, that kokanee in the Coquitlam Reservoir have been reproductively isolated from neighbouring populations of sockeye and kokanee, at least since the time of dam construction. However, the observation that no novel haplotypes were observed in Coquitlam Reservoir, and that all haplotypes are present nearby in the region suggests that the Coquitlam nerkids have not been isolated from the other populations for an extensive period of time. Further supporting this suggestion, haplotype 3 is the most prevalent haplotype found in Coquitlam Reservoir (86%) and this haplotype is also the most prevalent haplotype found in the nearby populations of Widgeon Slough, Pitt Lake, and Alouette River.

Table 2. Haplotype frequencies of nerkid populations in the lower Fraser River.

<table>
<thead>
<tr>
<th>Haplotype</th>
<th>N</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
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<tbody>
<tr>
<td>Coquitlam Reservoir</td>
<td>21</td>
<td>0.095</td>
<td>0.857</td>
<td></td>
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<td>0.048</td>
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<tr>
<td>Widgeon Slough</td>
<td>58</td>
<td></td>
<td>1</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Pitt Lake</td>
<td>30</td>
<td>0.167</td>
<td>0.167</td>
<td>0.667</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alouette River</td>
<td>16</td>
<td></td>
<td></td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cultus Lake</td>
<td>25</td>
<td>0.2</td>
<td>0.24</td>
<td>0.56</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Harrison River</td>
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<td>0.52</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Harrison Lake</td>
<td>23</td>
<td>0.13</td>
<td>0.13</td>
<td>0.522</td>
<td>0.13</td>
<td></td>
<td>0.087</td>
</tr>
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</table>

The statistical tests performed in this report are subject to the limitation of small samples size of Coquitlam Reservoir and Alouette River samples. With this limitation in mind, the tests performed are consistent with the hypothesis that Coquitlam Reservoir has not been unusually isolated from nearby nerkid populations. Pair-wise tests of genetic homogeneity (Table 3) shows that the null hypothesis of genetic homogeneity could not be rejected for tests of Coquitlam
Reservoir with Pitt Lake, Alouette River, and Harrison Lake. Examination of pair wise $F_{ST}$ (Table 4) shows that the Coquitlam Reservoir is closest genetically to Pitt Lake, and Alouette River as $F_{ST}$ values with these two populations were low (0.04 and 0.05 respectively) and not statistically significant. The average pair wise $F_{ST}$ for Coquitlam Reservoir was 0.19, while the average pair wise $F_{ST}$ for the other samples ranges from 0.16 to 0.4; again suggesting that Coquitlam is not remarkably isolated among the samples examined. The neighbour joining tree (Figure 3) shows that the Coquitlam Reservoir samples were most similar to Pitt Lake, Widgeon Slough and Alouette River.

Table 3. Test of genetic homogeneity of nerkid populations in the lower Fraser River.

<table>
<thead>
<tr>
<th></th>
<th>CQR</th>
<th>WDS</th>
<th>PL</th>
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<th>CUL</th>
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<tr>
<td>HL</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>-</td>
</tr>
</tbody>
</table>

Note: reject homogeneity test

Table 4. Pairwise Fst test of nerkid populations in the lower Fraser River.

<table>
<thead>
<tr>
<th></th>
<th>CQR</th>
<th>WDS</th>
<th>PL</th>
<th>ALR</th>
<th>CUL</th>
<th>HR</th>
<th>HL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coquitlam Reservoir</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Widgeon Slough</td>
<td>0.16</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pitt Lake</td>
<td>0.04</td>
<td>0.31</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alouette River</td>
<td>0.05</td>
<td>0</td>
<td>0</td>
<td>0.16</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cultus Lake</td>
<td>0.44</td>
<td>0.72</td>
<td>0.3</td>
<td>0.54</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Harrison River</td>
<td>0.33</td>
<td>0.64</td>
<td>0.13</td>
<td>0.45</td>
<td>0.25</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Harrison Lake</td>
<td>0.1</td>
<td>0.41</td>
<td>0</td>
<td>0.23</td>
<td>0.15</td>
<td>0.1</td>
<td>0</td>
</tr>
</tbody>
</table>

Note: significant at $a = 0.05$
2.3.2 Gill Raker Assessment

Kokanee collected at Coquitlam Reservoir, 15-17 May 2005, had an average 34.8 gill rakers (± 2.2 SD, n = 58). The range of counts was 30 to 39 gill rakers. Mean gill raker length was 5.8 mm (± 0.9 SD, n = 60).

2.4 DISCUSSION

2.4.1 Evaluation of genetics from the local kokanee population broodstock or from neighbouring sockeye populations to re-seed the Coquitlam reservoir

Generally, genetic similarity of *O. nerka* stocks between closely positioned lakes suggest common ancestry. Genetic analysis will determine whether broodstock from the local kokanee population can be used to re-seed the Coquitlam Reservoir or whether it would be more appropriate to use broodstock from neighbouring sockeye populations from neighbouring stocks. The genetic analysis will determine whether the kokanee population in the Coquitlam is a recent
event (since dam construction) or anciently (over thousands of years) isolated from nearby anadromous sockeye populations (Taylor et al. 1996, Withler et al. 2000). If kokanee and sockeye have been isolated for a very long time, it is assumed that re-anadromization of local kokanee is less feasible than using neighbouring stocks (Foote et al. 1994). There are genetic implications from these two options. From a gene purity perspective, it would be preferable to re-anadromize the Coquitlam kokanee population rather than introduce a separate gene pool to the reservoir.

Additional samples are required to complete analysis of the evolutionary relationship among sockeye and kokanee populations of this region. Besides increasing the sample size of the Coquitlam Reservoir and Alouette River samples, we recommend analysis of samples of kokanee from the different spawning sites within Coquitlam Reservoir, kokanee from Alouette reservoir, and the “volitional smolt” samples found in the Coquitlam River. The results analyzed to date however suggest that the Coquitlam Reservoir nerkids share many of the same genetic characteristics found in the region suggesting that the population is not remarkably isolated. This increases the likelihood and feasibility of re-anadromization of the resident nerkids. From a genetic conservation perspective, this is a desirable route to take because we have examined no other sample that is genetically identical to the nerkids found in Coquitlam Reservoir indicating that it would be advisable to not transfer fish from proximal anadromous populations to re-establish an anadromous run in the Coquitlam watershed.

2.4.2 Genetic Tissue Sample Quality

Careful storage and handling of tissue specimens is needed to avoid release of cellular enzymes which destroy the DNA. Tissue quality of frozen samples was compromised due to freeze-thaw events. Among a variety of methods used to preserve DNA, placing the sample in 95% ethanol immediately after sampling is preferred (www.absc.usgs.gov/research/genetics/sampling.pdf; www.pac.dfo-mpo.gc.ca/sci/mgl/StockID/SalmonSampleProtocol011005.pdf). Preserving a piece of operculum and adipose fin tissue approximately the size of a pencil eraser is sufficient.

2.4.3 Gill Raker Assessment

Morphological differences between kokanee and sympatric sockeye populations can be used by researchers to assess the extent of genetic differentiation and the likelihood of re-anadromization. Foote et al (1999) demonstrated that the number and length of gill rakers is a reliable indicator for differentiating sympatric anadromous and nonanadromous morphs of sockeye salmon. Kokanee demonstrated significantly more gill rakers (39 vs. 36) and shorter gill rakers (< 19%) than sockeye. Under controlled conditions, reciprocal hybrids (sockeye x kokanee) were more similar to each other than their parents (sockeye x sockeye, or kokanee x kokanee). Gill raker characteristics of Coquitlam kokanee were comparable with sockeye hybrids from the literature.

Photo 1. Gill sample of a Coquitlam Reservoir kokanee.
2.4.4 Potential Coquitlam Kokanee Smolt-to-Adult Performance

The genetic analysis and gill raker characteristics supports the concept that reversion to anadromy is likely. It was demonstrated at Coquitlam and Alouette Reservoir in spring 2005 that juvenile kokanee out-migrated when given the opportunity to ‘volitionally’ emigrate from the reservoir. A total juvenile kokanee population of 3,500 (averaging 5 g and 80 mm) was estimated to have out-migrated from Coquitlam Reservoir in 2005 (Alf Leake, pers. comm.). We would expect adult sockeye from these releases in fall 2007 (i.e., age-3 males), 2008, and 2009, numbering less than 75 adults in any year, using a smolt-to adult survival rate of 1-5 %, and three marine-age classes (i.e., 1-marine, 2-marine, and 3-marine rearing). Several researchers have provided evidence that kokanee may at times go to sea, survive ocean life and return to spawn in freshwater. Smolt-to-adult recruitment rates of seaward kokanee have generally been less than 1% (Foerster 1947, Ricker 1972, Kaeriyama et al. 1992).

Behavioural, physiological, and genetic studies among sockeye, kokanee, and reciprocal crosses demonstrated that sockeye were able to adapt to a 24-hour saltwater challenge 3 to 6 weeks sooner than the other *O. nerka* due to faster growth rates, but survival rates and migratory behaviour was not significantly different between all *O. nerka* forms (Danner 1994). Danner (1994) concluded that kokanee maintain their propensity and capacity for smoltification. Taylor and Foote (1991) compared swimming performance and morphology of sockeye, kokanee, and hybrid juvenile and demonstrated that juvenile sockeye salmon are stronger swimmers than kokanee or kokanee x sockeye hybrids. Similar comparisons of development rate, ontogeny of seawater adaptability, and growth and onset of maturity between these forms, indicated that progeny of hybrid crosses may be less successful than pure cross progeny of either type in their respective environments (Wood and Foote 1990, Foote et al 1992, Wood and Foote 1996).

2.5 RE-ANADROMY RECOMMENDATIONS

- We recommend an additional year of sampling and analysis of kokanee from different spawning sites within Coquitlam Reservoir, kokanee from Alouette reservoir, and the “volitional smolt” samples found in the Coquitlam River to increase sample sizes and increase confidence in the results.

- From a gene purity perspective, it would be preferable to re-anadromize the Coquitlam kokanee population rather than introduce a separate gene pool to the reservoir, if stock supplementation proceeds.

- Monitor and collect biological data of returning adult sockeye salmon populations at the Coquitlam River and Alouette River between 2007 and 2009.

- If supplementation proceeds, continued genetic sampling and monitoring changes in genetic fitness should be evaluated by comparing the relatedness of the parents (the broodstock) to the fitness of their offspring (the returning adults). This would help us understand of the effects of population reduction on genetic traits that affect survival.
3 ASSESSMENT OF IMPLEMENTING A MULTI-YEAR CAPTIVE BROODSTOCK OR SUPPLEMENTATION PROGRAM FOR CSRP

Since re-anadromization of Coquitlam kokanee appears plausible from the genetic analysis, a comparison of propagation techniques is needed for further planning if sockeye are to be re-introduced. The need for propagation to assist in the re-introduction of sockeye to Coquitlam Reservoir depends on a number of factors; the ability of Coquitlam kokanee to re-anadromize, the feasibility of using a donor stock, the ability of Coquitlam kokanee to migrate volitionally or with assistance (e.g. trapping) from the reservoir in sufficient numbers, and the timeframe and benchmarks (abundance) desired for re-introduction. The preferred and most cost-effective program would see Coquitlam kokanee allowed to migrate from the reservoir and re-anadromize volitionally. This is currently being evaluated at the Coquitlam and Alouette (Baxter and Bocking 2005). However, even if volitional re-anadromy is successful, a supplementation or captive broodstock program may be considered to fast track re-introduction or meet abundance goals that cannot be achieved without such intervention.

Conventional supplementation uses hatcheries to incubate fertilized eggs taken from returning adults, after which juveniles are released to the wild as fry or smolts. Commonly, large numbers of fish are incubated and raised in hatcheries for less than two years and are released to the wild as juveniles. The size and time of release is normally synchronized to match the size and behaviour of wild fish. These are labeled ‘enhancement’ or ‘supplementation’ programs. The fish then grow and mature in the ocean and return to spawn in natural habitats in the system from which they originated, thus integrating with and contributing to the recovery or maintenance of the wild population. Key practices such as the use of native spawners, prescribed spawner collection methods and spawning practices, and evaluation of subsequent survival help to maintain the genetic characteristics of the parent wild population.

A captive broodstock program is a more intensive method than conventional supplementation with the key difference being the length of time in captivity. Captive broodstock may be collected from the natural habitat as adults, as deposited eggs, or as juveniles, reared throughout their whole life, and spawned to produce offspring for the purpose of supplementation (and released to the wild). The strategies applied to salmon recovery in the Pacific Northwest, include (Pollard and Flagg, 2004):

1. Rearing the population to maturity in a hatchery and releasing the first or second generation offspring into ancestral lakes or streams at one or more juvenile life stages (e.g., fry, parr, or smolt); or
2. Rearing the broodstock to adulthood in captivity, and then releasing the adults back into their natural habitats to spawn naturally.

Conventional supplementation and captive broodstock programs can result in potential complications and risks. These programs have been criticized for not addressing the underlying causes to endangerment (Meffe 1992). The potential genetic and environmental hazards of using captive culture (inbreeding, genetic drift, domestication, selection, behavioural conditioning, and exposure to disease) and possible negative interactions between hatchery and wild fish are well
documented (Tave 1993, Waples 1999). Captive breeding may also be less cost effective in the long term than in-situ preservation. Most fisheries researchers and managers recognize that habitat improvements may take several-to-many generations to complete. The decision to use captive broodstock is made when the risk of extinction in waiting for habitat recovery via habitat improvements is greater than the risk to the population from hatchery intervention.

Although specific concerns have been expressed about the potential genetic and environmental drawbacks of captive breeding, most of these can be alleviated by carefully designed mating strategies (Hard et al. 1992). Genetic concerns about a small founder population (potential inbreeding depression leading to loss of genetic diversity) are alleviated by using a breeding plan that actually increases genetic diversity. The increased survival inherent in captive brood programs also decreases the potential loss of genetic diversity in hatchery fish compared to wild fish. The main positive feature of this method is the enormous increase in egg-to-adult survival (more than a thousand-fold), thereby permitting the rapid recovery of the population. Such projects are usually regarded as methods of last resort, an experimental approach to be used only as part of an integrated recovery plan in situations where the natural population is at risk of extirpation.

The following report provides an overview and evaluation of current captive broodstock and hatchery programs local to the Pacific Northwest, identifies available donor stock sockeye juveniles to support releases starting in 2007, and determines approximate program costs, timelines, and infrastructure requirements and potential partners in the process.

3.1 METHODOLOGY

3.1.1 Data Collection

All relevant environmental, design and operational data pertinent to assessing the feasibility of developing a hatchery or captive broodstock program were collected by literature review, personal communication, questionnaire, collection of unpublished data, and a pilot study for collection of kokanee broodstock at Coquitlam Reservoir.

3.1.2 Literature Review

A review of documents related to sockeye/kokanee supplementation, captive broodstock, and re-anadromy was completed. A computer-based literature search was used to retrieve the most up-to-date information. Government reports, published and unpublished, were reviewed, as were proceedings from pertinent conferences, workshops and meetings.

3.1.3 Personal Communication

To understand the nature of developing a Coquitlam sockeye hatchery program, discussions were supplemented with interviews with members of government agencies, academic institutions and other interested individuals. Experts in sockeye biology, reservoir
ecology, sockeye culture, fish diseases, and genetics were contacted by electronic mail, and telephone.

The people and agencies that provided personal communications are outlined in Appendix 1.

3.1.4 Questionnaire

Managers of existing and prospective hatchery facilities were requested to fill out and return a questionnaire similar in design to that used by IHOT 1995. Audit information included operational repair/maintenance needs, disease management issues, water quantity/quality characteristics (influent and effluent), feed management strategies, fish transportation and handling processes, and emergency plans.

3.1.5 Unpublished Data

Several agencies were approached for base line and anecdotal data including (but not limited to):

- Department of Fisheries and Oceans
- Northern Southeast Regional Aquaculture, AK
- Ministry of Agriculture, Food and Fisheries
- BC Ministry of Environment
- Environment Canada
- Greater Vancouver Regional District
- Natural Resources Canada
- Office of the Provincial Veterinarian,
- University of Guelph, ON (Alma Aquaculture Research Station)

3.1.6 Site Selection

Guidelines by Fisheries and Oceans Canada (Cultus Lake Sockeye Recovery), Environment Canada, National Oceanic and Atmospheric Administration (Redfish Sockeye Recovery), and Alaskan Department of Fish and Game were used to assess the feasibility and cost of developing a sockeye hatchery program for the CRSP (Doug Lofthouse, Fisheries and Oceans, Vancouver, BC, pers. comm., Cultus Sockeye Recovery Team 2004, Pollard and Flagg 2004, Environment Canada 2001, IMST 2000, Flagg and Nash 1999, IHOT 1995, McDaniel et al. 1994).

Each site was evaluated using the following criteria:

1. Ground water supply (pathogen, toxin, heavy metal free water);
2. Water supply is gravity fed with system controls (and alarms);
3. Integrated water treatment system in compliance with effluent regulations;
4. Incidence of disease absent or very low, using proper screening and prevention steps (pathogen free water);
5. State-of-the art security system: site totally enclosed/fenced, monitored (24/7) using video surveillance, and alarmed;
6. Qualified fish culture personnel with > 5 years sockeye rearing experience, proper
treatment of disease, immunization against disease, use of hormone controlling
therapeutics to manage maturation rates, and breeding strategies for maximum genetic
variability;
7. Proximity to Coquitlam Reservoir – Recommended donor stock and fish reared in natal
water (same stream, watershed, geographical area);
8. An Emergency Response Program with < 20 min response time when water flow
interrupted;
9. Available rearing space and containers for 1 stock and more than 1 brood;
10. Age of facility and estimated repair costs (capital investments and operating/maintenance
expenses);
11. Readiness of operation 2005-2009; and
12. Willingness to disseminate information and transfer technology to interest groups.

3.1.7 Kokanee Broodstock Collection Feasibility Study

A fall survey was implemented to assess spawner distribution and timing, develop a
protocol for handling fish, and collect biological data (i.e., age-length, sex, fecundity, spawner
behaviour). Foot surveys were conducted at Upper Coquitlam River, and Cedar Creek to
determine the presence and absence of spawners in tributaries. Survey days were selected based
upon the best conditions for viewing fish (i.e., low water and very good water clarity). Visual
counts were conducted by a two-person crew walking upstream through the site, or navigating
the shoreline by boat 500 m in proximity of the mouths of the survey tributaries, always in sight
of the bed substrate. High probability spawning areas in the reservoir were determined by
gillnetting at tributary fans and identifying concentrations of pre-spawning or spent kokanee.
Broodstock collection and adult biological data collection was implemented during 31 October –
3 November. Mature adult kokanee were held for 24 hours to assess post-handling survival, and
sacrificed to examine for internal injury and general health. Shoreline sites with concentrations
of kokanee were then assessed using a towed underwater video system or Seabed Imaging and
Mapping System (SIMS) to determine the distribution and habitat characteristics of these
potential spawning sites and their spawning limitations. Shoreline kokanee spawning habitat
assessments were implemented during 15 November and the results are summarized in a
companion report by Gaboury and Murray 2006.

3.2 RESULTS & DISCUSSION

3.2.1 Overview of Pacific Northwest Captive Broodstock Programs

In the United States, the U.S. Fish and Wildlife Service (USFWS) has used captive
broodstock to enhance over 30% of the nonanadromous fish species listed under the U.S.
Endangered Species Act (ESA) using captive broodstock techniques (Johnson and Jensen 1991,
Andrews and Kaufman 1994, Hendry et al. 2000). Captive broodstock programs have been in
development by the Northwest Power Planning Council’s Columbia River Basin Fish and
Wildlife Program since the 1990’s. The performance of captive broodstock programs in terms of
growth, survival, and reproductive performance has been variable (Flagg and Mahnken 1995, Schiewe et al 1997, Berejikian et al. 1997, 2001, Berejikian 2001). Key biological performance measures included:

1. Egg-to-adult survival was highly variable. For example, sockeye (0% - 88%), Chinook (2% - 78%), and coho (3% - 80%);
2. Age and size of mature captive brood adults was generally less than wild cohorts;
3. The viability of eggs from captive broodstock (30%-70%) was less than natural fish (75%-95%); and
4. Actively reared adults released to spawn in the natural environment may have lower breeding success than wild cohorts.

The performance of captive broodstock programs in terms of economic viability has also been variable (Table 5).

Table 5. Summary of Anadromous Salmon Captive Broodstock Programs in North America.

<table>
<thead>
<tr>
<th>Species</th>
<th>River/Lake origin</th>
<th>Region</th>
<th>No. stocks</th>
<th>Year Initiated</th>
<th>Est. Year of Termination</th>
<th>Est. Annual Budget ($ x 1000)</th>
<th>Annual Escapement (1994-2003) $ per Recruit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sockeye</td>
<td>Redfish Lake</td>
<td>Stanley Basin, ID</td>
<td>1</td>
<td>1992</td>
<td>2021</td>
<td>$$$$$</td>
<td>1,725</td>
</tr>
<tr>
<td></td>
<td>Sakinaw Lake</td>
<td>Georgia Strait, BC</td>
<td>1</td>
<td>2000</td>
<td>2009</td>
<td>$$</td>
<td>500</td>
</tr>
<tr>
<td></td>
<td>Cultus Lake</td>
<td>Fraser River, BC</td>
<td>1</td>
<td>2000</td>
<td>2009</td>
<td>$$</td>
<td>500</td>
</tr>
<tr>
<td></td>
<td>Skaha Lake</td>
<td>Okanagan Basin, BC</td>
<td>1</td>
<td>2004</td>
<td>?</td>
<td>$$</td>
<td>240</td>
</tr>
<tr>
<td>Coho</td>
<td>Scott Creek</td>
<td>Central Coast, CA</td>
<td>1</td>
<td>2003</td>
<td>?</td>
<td>?</td>
<td>?</td>
</tr>
<tr>
<td></td>
<td>Dry Creek</td>
<td>Russian River, CA</td>
<td>1</td>
<td>2001</td>
<td>2003</td>
<td>?</td>
<td>?</td>
</tr>
<tr>
<td>Chinook</td>
<td>Sacremento River</td>
<td>Central, CA</td>
<td>1</td>
<td>1991</td>
<td>2006</td>
<td>$$$$</td>
<td>1,000</td>
</tr>
<tr>
<td></td>
<td>Tucannon River</td>
<td>Columbia River, WA</td>
<td>1</td>
<td>1997</td>
<td>2011</td>
<td>$$$$</td>
<td>250</td>
</tr>
<tr>
<td></td>
<td>Dungeness River</td>
<td>East Staits-Juan de Fuca, WA</td>
<td>1</td>
<td>1992</td>
<td>2003</td>
<td>$$</td>
<td>?</td>
</tr>
<tr>
<td></td>
<td>Grand Rhone River trib</td>
<td>Snake River, OR</td>
<td>3</td>
<td>1998</td>
<td>?</td>
<td>$$$</td>
<td>950-1455</td>
</tr>
<tr>
<td></td>
<td>Salmon River trib</td>
<td>Snake River, ID</td>
<td>3</td>
<td>1991</td>
<td>?</td>
<td>$$$</td>
<td>810</td>
</tr>
<tr>
<td></td>
<td>Puntledge River</td>
<td>Vancouver Island, BC</td>
<td>1</td>
<td>1997</td>
<td>2007</td>
<td>$$</td>
<td>150</td>
</tr>
</tbody>
</table>

The goal of any captive broodstock program would be to mimic the natural life-cycle of the fish but such a regime may not be attainable in practice. While recent technological advancements in husbandry, nutrition, genetics, and fish health have improved the performance standards of captive broodstock programs in North America, captive broodstock programs should be viewed as a short-term measure in assisting stock recovery and never as a substitute for naturally spawning fish to the watershed. Captive broodstock programs can provide a quick-start to recovery, but these efforts must go hand in hand with habitat improvements.

Emerging DFO policies for the use of captive breeding include limiting the technology to the recovery of endangered populations, the use of mating strategies that minimize the potential loss of genetic variability in captivity and the use of the technology for no longer than is...
necessary to fulfill stated recovery goals. The following interim guidelines have been used by DFO (Cultus Sockeye Recovery Team 2004, Flagg and Mahnaken 1995):

- The objective is to produce 500 breeding adults each year for two consecutive cycles (eight years), followed by a full review of the program after five years;
- Only wild spawners will be used, and those fish will not be counted as part of the naturally breeding population when evaluating progress toward recovery;
- When adults produced from the captive spawners are themselves spawned in captivity, they will not be counted as part of the natural breeding population when evaluating recovery. Their progeny that are released into the wild and return to spawn naturally, however, will be included;
- All fish produced in the program and released to the wild will be marked with an adipose fin clip. An awareness program will be mounted to ensure that harvesters understand the difference between a marked sockeye (which must be released) and a marked coho (which can be retained).

There are operational risks associated with hatcheries, including the possibility of mechanical failure and disease. Preventive measures include culturing sockeye at two facilities, redundant water delivery systems, emergency response readiness (standby staff), site security and operational protocols that minimize disease outbreaks (McDaniel et al. 1994). Implementation of design and operation must be reviewed with Canadian agency experts, particularly those familiar with sockeye enhancement. Furthermore, hatchery managers would need authorization to acquire eggs in excess of those required to produce 500 spawners under average survival conditions. Any production above the needs of the captive breeding project would be planted in the lake as fry or smolts to supplement the wild population.

Other considerations when implementing captive broodstock programs are as follows:

1. plant fish at the earliest life stage possible;
2. maintain fish at low rearing densities;
3. maintain high numbers of brood fish (effective population numbers);
4. equalize the genetic contribution of all parental fish to the next generation;
5. capture brood fish throughout the spawning season;
6. spawn all mature adults available;
7. avoid selection of brood fish and progeny based on physical appearance and captive performance; and
8. juveniles from captive-bred fish should be reared under conditions that mimic the natural environment (i.e., cover, substrate and structure complexing).

The important decision points that must be considered when proposing to use captive broodstock as a tool for stock recovery are outlined in Pollard and Flagg (2004), and include the following process steps:

1. Consider the alternatives - captive broodstock is recommended as the final option;
2. Evaluate the status of the population and goals of the proposed program;
3. Design the program using operational guidelines;
4. Develop a detailed hatchery and genetic management plan; and
5. Evaluate potential hazards and benefits.

By following these steps, decision makers will be able to demonstrate rationale for the
program, manage risks, coordinate with overall fisheries management goals, and increase
likelihood of program success in terms of budgets and scheduling.

3.2.2 Case Studies of Sockeye Recovery Initiatives & Propagation Techniques

3.2.2.1 Redfish Lake Sockeye Case Study

Precipitous declines of Snake River sockeye salmon led to their federal listing as
endangered in 1991. In that same year, the Idaho Department of Fish and Game began the
captive brood program to preserve the existing population and prevent their extinction. The fish
are unique because they are the only population of sockeye salmon in the Snake River drainage.
They are distinguished for traveling farther than any other North American sockeye population—
1500 km—to reach the ocean; they travel to the highest elevation; and they are the most
southerly population of sockeye in North America.

The ultimate goal of the program is to re-establish sockeye salmon runs to Stanley Basin
with interim recovery targets of 1500 sockeye to the Sawtooth Valley Basin. In the near-term,
the program is focused on preventing further decreases to sockeye salmon populations,
maintaining genetic diversity, and increasing species abundance (Willard et al. 2004).

To date, the program has returned nearly 350 anadromous sockeye salmon to Idaho
(Flagg et al 2004). In 1999, the first hatchery-produced sockeye salmon returned to the Stanley
Basin. That year, seven adults returned to spawn. In 2000, the program experienced its first
significant return of hatchery-produced adults. Two hundred fifty-seven sockeye salmon
returned to collection facilities on Redfish Lake Creek and the upper Salmon River at the IDFG
Sawtooth Fish Hatchery, and the majority of those adult returns were released to the system for
natural spawning. Hatchery-produced adult returns to collection facilities in Stanley Basin,
(Flagg et al 2004, The Times News Twin Valley Idaho 29 September 2005
(www.magicvalley.com), NW Fishletter November 2003 (www.news-data.com), Seattle Times 1
September 2004 (www.bluefish.org)). The Redfish Lake sockeye returns have varied in smolt-
to-adult return rates (SAR) from 0.05% to 0.5%, while other supplemented sockeye stocks (i.e.,
Lake Wenatchee) had SAR’s from 0.7 to 2.1% (Chuck Peven, Chelan PUD, Wenatchee, WA,
NWFishletter NWF.170/Nov.2003).
3.2.2.2  **Cultus Lake Sockeye Case Study**

The captive breeding and supplementation projects for Cultus Sockeye have been underway since 2000. A supplementary project has been the *ex situ* collection of cryopreserved sperm that began in 1995 and has continued as part of the captive breeding project.

The captive breeding project began on an *ad hoc* basis in 2000 when very few spawners returned to the Sweltzer Creek fence and those that did were in very poor condition. Five females and six males were captured and the survivors were spawned, with the progeny incubated and reared at the Cultus Lake Laboratory over the next 18 months. Because the small number of spawners limited genetic diversity, all of these fish were marked with an adipose clip and released as smolts; they were replaced by wild smolts emigrating through Sweltzer in the spring of 2002. These fish were moved to the Chilliwack River Hatchery for disease screening and parasite removal (they suffered high mortality from parasitic copepods), and subsequently to the Rosewall Creek Hatchery.

A small number of adults was captured in 2001, and experienced high pre-spawn mortality (PSM). They were incubated and initially reared at Cultus Lake, then transferred to the Chilliwack River Hatchery for disease screening and parasite removal and finally to the Rosewall Creek Hatchery on Vancouver Island for rearing to maturity. Juveniles that were surplus to the requirements of the captive breeding project were released into Cultus Lake as fry in the fall of 2002 and as smolts in the spring of 2003. Ninety percent of the released fish had their adipose fin clipped. Also in the spring of 2003, 881 wild smolts were retained for captive breeding to broaden the genetic diversity of the captive population. These fish were moved to the Inch Creek Hatchery for disease screening and parasite removal (there was very little mortality thanks to lessons learned with the 2000 brood year smolts) and subsequently to the Rosewall Creek Hatchery.

In the fall of 2002, the project was redesigned, with larger brood stock targets to permit testing various methods to maximize subsequent survivals. The egg-take used a matrix spawning technique to produce almost 500 separate mating families and over 400,000 eggs. Both pre-spawn and incubation mortality were much lower than in the previous two years. Ten eggs selected from each mating were retained in the captive breeding project; the remainder (227,000 4 g fry) were incubated and reared at the Inch Creek Hatchery before release into Cultus Lake as marked fry in October.

In the fall of 2003, 2004, and 2005, large egg-takes permitted about 500 mating families. Adults and juveniles have been reared at Inch Creek hatchery and Rosewall Creek Hatchery. Again, fish in excess of the requirements of the captive breeding project will be released into Cultus Lake in 2006.

3.2.2.3  **Skaha Lake Sockeye Case Study**

The Okanagan Nation Alliance Fisheries Department ONAFD has been actively involved in the conservation, protection, restoration, and enhancement of the Okanagan River
salmon stocks. The Okanagan River sockeye population is one of only two remaining populations of sockeye salmon in the international Columbia River Basin. Construction of dams, channelization, urban encroachment, water management practices and predation have all contributed to depletion and extinction of salmon stocks within the Okanagan River basin.

In 1997, under the direction of elders, the Okanagan Nation Alliance (ONA) Fisheries Department began work to bring sockeye salmon back into Okanagan Lake. The ONA met with staff from Fisheries and Oceans Canada (DFO), and the BC Ministry of Water, Land and Air Protection (MWLAP) to discuss the goal of re-introducing sockeye into the Upper Okanagan. The ONA and Colville Confederated Tribes, with project funding provided by the Bonneville Power Administration, have completed a three-year risk assessment from 2000-2003. During this time, members of the Canadian Okanagan Basin Technical Working Group (COBTWG), fisheries agency staff, and other independent experts have provided annual technical review and assessment of project design, methodology, and results.

At the end of the three-year risk assessment it was determined that, with proper project design, reintroducing sockeye salmon into Skaha Lake posed little threat to resident fish stocks, and the COBTWG supported the ONA’s initiative to proceed with an experimental fry re-introduction program. Introduction of juvenile sockeye directly into Skaha Lake is the option with least risk and the greatest learning benefit, as:

- There is no risk of exotic species or fish disease being introduced;
- There is an ability to mark a controlled number of fry which facilitates monitoring of in-lake kokanee and sockeye interactions and;
- Opportunity to assessment growth, development and survival of the treated fish.

With annual project monitoring, this method will yield significant information on the survival of kokanee and sockeye at various life history stages and on their interactions within Skaha Lake, and assist in sockeye and kokanee stock management. With approvals provided by the Federal-Provincial Introductions and Transfers Committee under the Federal Fisheries Act, the ONA moved forward with implementation planning. In October 2003, the Okanagan Nation Alliance proceeded with a small Okanagan sockeye broodstock collection and egg take, raised the eggs in a hatchery, and released 352,500 sockeye fry into Skaha Lake. This marked a historic occasion, where, for the first time in over 50 years, sockeye salmon were able to occupy their historic habitat within Skaha Lake.

The fall of 2004 began Year 1 of the 12-Year Program for Reintroduction of Sockeye Salmon into Skaha Lake. Sockeye adults were collected on the spawning grounds in October 2004, and approximately 1.6-million eggs were transported to the Shuswap River Hatchery in Lumby, where they were disinfected, fertilized and incubated over the winter of 2004/2005. In May 2005, the surviving fry were released into the Okanagan River at Penticton. The monitoring and evaluation component of the program, developed with the technical expertise of the ONA, DFO and MWLAP, is designed to assess the affects of the reintroduction on life history stages, growth and development of the sockeye and kokanee in Skaha Lake.
Major components of the 12-year reintroduction plan include:

- Retain the existing upstream migration barrier into Skaha Lake until the end of the 12-year plan;
- Collect sockeye broodstock from the Okanagan River spawning grounds downstream of McIntyre Dam;
- Fertilize and incubate sockeye eggs at a fish hatchery, fry identification marking, and release of sockeye fry into Skaha Lake;
- Annual monitoring and evaluation of sockeye juveniles and all age classes of resident fisheries in Skaha Lake;
- Annual lake limnology monitoring; and
- Monitor sockeye juvenile downstream out-migration.

The 12-year phased program will span three sockeye, and four kokanee cycles, and feature adult capture, egg incubation and juvenile release. Due to conservation concerns, investigators have proposed that no fish should be removed for broodstock purposes, when runs are smaller than 10,000 sockeye at Wells Dam (Wright, 2003). The current goal is to incubate at least five million eggs, and be capable of rearing fry to 1.5 g for spring release thus permitting a maximum Skaha L. plant of approximately 1750 fry/ha annually (Howie Wright, Okanagan Nation Alliance Fisheries, Westbank, BC, pers. comm.). Among current options would be building a new hatchery, or upgrading Shuswap Falls hatcheries to a five-million egg capacity.

3.2.3  Assessment of captive broodstock and hatchery programs to support Coquitlam Salmon Recovery Plan (CSRP) studies.

3.2.3.1  Captive broodstock versus supplementation

Based on the information gathered, a supplementation strategy is preferred over a captive broodstock program should propagation be a desired tool to be used for re-introducing sockeye to Coquitlam reservoir. Costs and performance of various captive broodstock programs in the Pacific Northwest are summarized in Table 5. A significant capital investment and annual operating and maintenance costs is required for captive broodstock, with annual expenses ranging from $500,000 to $1,000,000 per year based on fiscal statements from Bonneville Power Administration (Portland, Oregon; www.cbfwa.org). Such programs are rare in BC and are used when the genetic integrity of a stock is at jeopardy in the wild (Photo Plate 2, Stu Barnston, Inch Creek Hatchery Manager, DFO, pers. comm.).
Donor Stock Locale and Availability

Based on genetic analysis and abundance estimates of adult kokanee at Coquitlam in 2004 and 2005, the existing kokanee population should be used as the donor stock for sockeye re-introduction. These studies support the concept of capturing up to 500 kokanee females (approximately 5% of the total adult population) and an equal number of males at Coquitlam Reservoir in fall (October-November) using tangle netting techniques for future re-anadromy experiments (Bussanich et al. 2006). Professional divers can be used to assess fish spawning condition/timing and assist capture by herding fish into a net. The extra effort to collect fish over a 2-3 week period will cost approximately $10,000 to $15,000. If necessary, mature adults would be held on-site in a floating ‘condo’ (estimated cost $2,500) at the Coquitlam North basin for 3-7 days following collection, males and females separated, and gamete collection coordinated between the fish collection team, DFO Community Advisor, local volunteers, and hatchery managers.

3.2.3.2 Identify potential hatcheries and facility locations for supplementation

Existing and prospective facilities involved with the sockeye culture within 300 km or (3 hours ground travel time) of the Greater Vancouver Regional District were reviewed. Twenty-eight hatchery operations were identified as operational (i.e., incubating or rearing salmon or trout) in the Greater Vancouver and Lower Fraser Valley. Of the total 28 freshwater operations, seven were federally operated, followed by one provincial facility, seven private facilities, and 13 non-government facilities. All operational freshwater finfish hatcheries in the regions are listed in Appendix 2.
Facilities experienced with culturing sockeye include: Inch Creek (Hatzic), Chilliwack (Chilliwack), Chehalis (Aggasiz), Weaver (Aggasiz), West Van Lab (West Vancouver), Cultus (Chilliwack), LSL Ltd (Aldergrove), ALLCO (Maple Ridge), Rosewall Creek (Qualicum), and Shadow Mountain Salmon Ltd (Chilliwack). Shadow Mountain Salmon Ltd is a commercial enterprise planning to culture juvenile and adult sockeye salmon using state-of-the-art technology, in 2006. In the short-term, Rosewall Creek Hatchery was determined to be the best choice as an egg incubation and rearing facility, followed by Inch Creek (Table 6). Despite ALLCO ranking 7th, this site is recommended for further consideration due to proximity, availability, and existing partnerships. We recommend upgrading existing facilities rather than developing a new hatchery.

Table 6. Decision matrix of candidate sockeye culture facilities and sites for Coquitlam re-anadromy feasibility study.

| Facility                  | Available Well Water - Gravity Fed | Technology Transfer Value to CSRP Partners | Available IHN-Free Well Water | Site Security (Fenced and Monitored) | Qualified Fish Culture Staff | Emergency response program (standby) | Captive Brood Experience | Available Rearing Capacity/Containers | Back-up Power/Water Delivery Systems | Proximity to Coquitlam Stock | Temperature Control | Facility Age/Reliability | Available Incubation Capacity/Containers | Cost to upgrade & operate (units x 1000) | Ready Fall 2006 | Ready Fall 2007 | Ready Fall 2008 |
|--------------------------|-----------------------------------|--------------------------------------------|--------------------------------|--------------------------------------|-------------------------------|-------------------------------------|-------------------------------|-------------------------------------|-------------------------------------|-----------------------------------|----------------|----------------|----------------|------------------------------------------------|-------------------------------|----------------|----------------|----------------|
| Rosewall Creek           | 100%                              | 10                                         | 10                             | 5                                    | 5                              | 5                                   | 5                            | 5                                   | 5                                   | 10                                | 2                                | Y/N                       | Y/N                       | Y/N                       |
| Inch Creek               | 84%                               | 5                                           | 10                             | 5                                    | 5                              | 5                                   | 5                            | 5                                   | 5                                   | 10                                | 2                                | Y/N                       | Y/N                       | Y/N                       |
| Chilliwack River         | 76%                               | 0                                           | 10                             | 5                                    | 5                              | 5                                   | 5                            | 5                                   | 5                                   | 10                                | 3                                | 3                        | 2                         | 75                         | N                 | N              | N              |
| Chehalis River           | 71%                               | 0                                           | 10                             | 5                                    | 5                              | 5                                   | 5                            | 5                                   | 5                                   | 5                                 | 0                                | 5                        | 2                         | 3                        | 2                         | 120               | N               | N              | N              |
| Weaver Creek             | 67%                               | 0                                           | 10                             | 5                                    | 5                              | 5                                   | 5                            | 5                                   | 5                                   | 5                                 | 0                                | 5                        | 2                         | 3                        | 2                         | 120               | N               | N              | N              |
| West Van Lab             | 65%                               | 5                                           | 10                             | 5                                    | 5                              | 2                                   | 5                            | 5                                   | 5                                   | 5                                 | 0                                | 0                        | 3                         | 2                        | 5                         | 5                  | 2              | 120             | N              |
| ALLCO                    | 64%                               | 5                                           | 10                             | 5                                    | 5                              | 2                                   | 0                            | 5                                   | 5                                   | 5                                 | 0                                | 5                        | 2                         | 3                        | 3                         | 2                  | 120             | N              | N              |
| Shadow Mountain Salmon   | 61%                               | 5                                           | 10                             | 5                                    | 3                              | 2                                   | 0                            | 5                                   | 0                                   | 5                                 | 0                                | 3                        | 5                         | 2                        | 3                         | 3                  | 2              | 150             | Y              |
| LSL Ltd                  | 60%                               | 5                                           | 10                             | 5                                    | 5                              | 3                                   | 2                            | 0                                   | 5                                   | 5                                 | 0                                | 3                        | 3                         | 3                        | 0                         | 3                  | 2              | 120             | N              |
| Cultus Lab               | 53%                               | 10                                          | 0                              | 5                                    | 0                              | 3                                   | 0                            | 5                                   | 5                                   | 5                                 | 3                                | 5                        | 3                         | 3                        | 0                         | 1                  | 2              | 25              | Y              |
|                           |                                    |                                             |                                |                                      |                                |                                      |                               |                                      |                                      |                                    |                                |                           |                           |                           |                             |                    |                 |                 |

3.2.3.3 Preliminary Audit of Potential Sites for Sockeye Culture and Estimate Costs

A preliminary audit of three existing facilities at Rosewall Creek, Inch Creek and Alouette River, and one development site (Shadow Mountain Salmon) was completed for short-term and long-term planning. The ‘pilot’ supplementation program would involve selecting two facilities to rear 100,000 to 125,000, each, for monitoring egg-to-smolt performance, while producing up to 225,000, 4-6 g smolts for mark and release at the Lower Coquitlam in the spring under the direction of Fisheries and Oceans. Two facilities would minimize the risk of production losses (i.e., disease outbreaks).
Rosewall Creek Hatchery (RCH) (Photo Plate 3)
Contact: Les Clint (Hatchery Manager, DFO, Qualicum)

Photo Plate 3. Rosewall Creek hatchery.

RCH (N 49°27'15", W 124°46'30") has been used by Fisheries and Oceans since 2001 for stock recovery and captive broodstock experimentation of Cultus Lake Sockeye, Sakinaw Lake Sockeye, Puntledge River Chinook, and for supplementation of Baynes Sound Pink salmon, and for cutthroat trout by the BC provincial government. The hatchery is owned by FOC and operated as a satellite facility to Qualicum Hatchery, and fed by the Rosewall Aquifer near the city of Qualicum. Rosewall Creek Hatchery has four deep wells supplying a near constant water temperature of 8°C, fish pathogen-free water. The hatchery is permitted to pump up to 4548 Lpm. Elevated concentration of CO₂ is suspected, however, no negative impacts on eggs or fish are known. Discharge from RCH complies with all Environment Canada standards and enters an isolated wetland pond and will not affect Rosewall Creek water quality. Water intake and outlet screens meet current screening guidelines and effluent discharge is monitored, reported, and currently complies with EC standards.

The RCH site contains: a food storage room, maintenance shop, associated storage, a wet laboratory, crew restrooms/wet gear storage, an electrical power room, a building heater-boiler room, and a standby generator room (Photo Plate 4). Visitation is restricted, and the site is not open to the public. Appendix 3 summarizes the current infrastructure status of the site and facility.
Photo Plate 4. Plastic circular containers at Rosewall Creek hatchery used for rearing sockeye.

Potential upgrades (estimated cost $) needed for the CSRP include:
- Well 1 needs upgrading ($250,000, cost shared among user groups)
- Degassing tower (Included with Well 1 upgrade)
- Alarm system ($50 per rearing unit)
- Circular fiberglass rearing containers with lids ($4000 per unit)
- Full spectrum lighting control to building ($1600)

Inch Creek Hatchery (ICH)
Contact: Stu Barneston (Hatchery Manager, DFO, Hatzic)

Inch Creek Hatchery (N 49°11'25", W 122°09'26") has been operated by Fisheries and Oceans since 1981 for supplementation of Inch Creek chum and Norrish Creek coho salmon, and since 2000 for stock recovery and captive broodstock experimentation of Cultus Lake Sockeye. The facility also serves to rear sturgeon by the BC provincial government, and serves as a satellite facility for supplementation of Pitt River sockeye. The hatchery is operated on the headwater of Inch Creek, a small groundwater fed tributary of Nicomen Slough near Dewdney. The hatchery is constructed on a 24 acre site and has an additional 6 acres available for development. The site has the potential for up to 16 million eggs and rearing 1-2 million 20 gram juvenile salmonids (i.e., coho, Chinook or trout) from nearby stocks (MacKinlay, 1985). Inch Creek Hatchery has two deep wells supplying variable water temperature ranging from 7.5 °C to 12 °C, fish pathogen-free water. The hatchery is permitted to pump up to 21,000 Lpm. The water from the wells at Inch Creek is quite soft and slightly acidic, typical of coastal aquifers. As is expected from well water, the gas pressures from the wells show nitrogen supersaturation and low oxygen. Degassing and aeration columns are used as mitigation measures. No negative impacts on eggs or fish from water quality are known. The ICH site contains: a food storage room, maintenance shop, vehicle storage, associated storage, a wet laboratory, crew restrooms/wet gear storage, crew living quarters, an electrical power room, a building heater-
boiler room, and a standby generator room. An administration building and visitor board is located on site, and an area for parking, including visitor buses. A complete description of the facility is outlined by MacKinlay (1985). Appendix 3 summarizes the current infrastructure status of the site and facility.

Upgrading the ICH facility to meet the schedule and production for CRP would include the following: drilling water supply (new wells), purchasing rearing containers, additional piping, and additional capacity for water effluent treatment. A hatchery system similar to the one constructed at Snootli Creek hatchery (FOC, Bella Coola) for recovery of Rivers Inlet (Owikeno Lake) sockeye stocks is suitable for raising up to 1 million sockeye eggs, and up to 800,000 sockeye smolts (@ 6 gram). This system is recommended for development at the ICH site for the long-term (Stu Barneston, Inch Creek Hatchery, pers. comm.). The concept of a mobile trailer equipped with rearing containers, and a closed, single pass water system needs further assessment. A mobile trailer was constructed by Shelter Industries (Aldergrove, BC) to house the incubators.

The total budget to engineer and construct the mobile hatchery was nearly $500,000. The conceptual design for an isolated trailer requires three components: an incubation system ($155,000), an aeration tower ($150,000), and rearing system ($135,000) (Wayne Krause, Sr. Engineer, Fisheries and Oceans, Vancouver, pers. comm.). Nearly fifty thousand dollars were expensed as overhead.

ALLCO Hatchery (ALLCO)
Contact: Jenny Ljunggren (Executive Director, Alouette River Management Society, Maple Ridge)

The lower ALLCO Hatchery (N 49°14’ 31”, W 122°31’ 57”) has been operated by BC Corrections with the assistance of Fisheries and Oceans Canada since 1979 for supplementation of the South Alouette chum, coho, pink, Chinook and other regional streams. Additional support was gained in 1980 from the province to rear cutthroat and steelhead for watersheds throughout the lower mainland. The lower hatchery is constructed on a 2 ha site located approximately 8 km from the Alouette dam reservoir on the South Alouette River. The lower ALLCO hatchery site is currently operated seven days a week by a inmate work crew of twelve and two fisheries instructors (Correctional Officers) rotating on a four and four shift. The site holds an office trailer, storage room, and incubation for up to 2.3 million eggs, 9 capilano troughs, two circular rearing troughs, and earthen ponds to hold up to 200,000 fish to smolt size (Photo Plate 5). The hatchery also has an onsite maintenance shop, vehicle storage, wet gear storage, crew lunch room, welding and woodworking shop, electrical power room, lights, pumps, a standby generator room and freezer/cooler for fish food storage.
Photo Plate 5. ALLCO grow-out ponds.

The Lower ALLCO Hatchery site has raised up to 2.3 million eggs a year and capacity for rearing for 200,000 juvenile salmonids (i.e., coho, Chinook, steelhead and trout) from Alouette stock. Pinks and Chinook eggs were transferred to ALLCO from Chilliwack/Harrison stocks for Alouette incubation and release. A unique fish fence for broodstock collection is installed each fall for broodstock capture and enumeration of returning salmonids.

The Upper ALLCO Hatchery (N 49° 14’ 57” W 122°31’ 40”’) was constructed in the mid 1990’s and initially built as a Research Hatchery with total independence from the lower hatchery. This hatchery is currently located on .5 ha, just up river from the lower hatchery. The Upper Allco Hatchery is also operated through a BC Corrections Inmate work program. This site contains incubation for up to 200,000 eggs, 6 capilano troughs to rear up to 100,000 fish to smolts. There is a potential for expansion to the north to four or more hectors of the current site, through permit from BC Parks, while still utilizing some of the existing infrastructure of the current site. In 2005 this hatchery held Alouette smolting kokanee, prior to tagging and release downstream for the POST program.

The Lower hatchery is supplied with water from South Alouette River via two river-water pumps, with additional water supplies coming from Mike Creek and an on-site well with a capacity of 1135 Lpm. A fourth water source comes from a licensed, spring-fed, groundwater collection system, available to both upper and lower hatcheries. This ground–fed supply ranges from 7.5 °C to 12 °C; (fish pathogen-free water). The two river pumps have a back-up generator and the water supplies are monitored with alarms. The security for this hatchery is maintained by BC Corrections 24/7.
Upgrading the Upper ALLCO facility to meet the schedule and production for CRP would be dependent on the anticipated number of fish to be reared. Costs associated with upgrading this Upper Hatchery could include the following: drilling a water supply (new well), purchasing rearing containers, additional piping, and additional capacity for water effluent treatment etc. An earthen pond system might also be recommended for development at the ALLCO site for the long-term use. ARMS, Corrections and the Department of Fisheries and Oceans are currently looking into the feasibility of expanding this upper hatchery, for rearing of Chinook and the possible return in 2007 of Alouette Sockeye that escaped this past spring during a BCRP project on the Alouette.

Outlines for a floor plan, site layout, and piping schematics for the CRSP project would be made available upon request. Prison industries have the capacity to build some of the equipment required for upgrading and have done so successfully in the past. The Rivers Heritage Centre, home to the Alouette River Management society, is available to the community for meetings and allowing on-site parking for visitors, including buses.

Shadow Mountain Salmon Ltd
Contact: Virginia Jacobsen (Principal, Shadow Mountain Salmon Ltd, Yarrow)
E-mail: shadowmountain@shaw.ca

Shadow Mountain Salmon Ltd is currently being developed for rearing sockeye salmon. The location is a privately owned 7 acre ALR property east of Yarrow, BC, on the north side of Cultus Lake on an aquifer fed from Cultus Lake. Two wells, one at 13.6 m and the other at 20 m, supply 10 °C water. Testing by Norwest Labs for water quality is planned for the fall 2005. The land based closed-loop aquaculture system will include a hatchery, nursery, and certified organic grow out operation as well as facilities to maintain Cultus Lake sockeye families. The owners are organizing a non-profit society and seeking opportunities with recovery programs specific to Lower Fraser salmon stocks.

Preliminary board advisors include:

Jens-Hugo & Virginia Jacobsen- Property Owners, 4843 Giesbrecht Road, Yarrow, B.C. V2R 4R1
Odd Grydeland – Aquaculture Consultant
Chief Larry Commodor - Chief of the Soowahlie First Nation
Nelson Kahama - Fisheries Councillor, Soowahlie First Nation
Dave Barnes - DFO Cultus Lake
Mark Johnson - DFO Cultus Lake

Initial feasibility funding required is an estimated $100,000. Estimated capital cost is $1.5 million. Some of the equipment and matching dollars has been offered by one aquaculture industry member.
3.2.3.4 Scope and schedule of services

The successful development and operation of a hatchery program will require a long term commitment, a multi-disciplinary team of experts, and community consultation at critical stages. Several critical stages need to be completed, as follows:

Stage 1. Planning & Design (2005 to 2012)
Stage 2. Site Development & Construction (2007 to 1012)
If stock abundance exceeds recovery reference point, then proceed to Stage 4.
Stage 4. Fisheries Management (2015 and beyond)
Regulatory agencies must develop short and long term management plans that include harvest rules and escapement policies for the sustainable use of Coquitlam sockeye.

A detailed recovery plan will need to be drafted with recommendations for fisheries management and hatchery supplementation. Interim criteria developed for Coquitlam sockeye recovery include:

1. Mean annual spawner abundance of 5,000 females over any 12 consecutive years;
2. A geometric mean of cohort replacement rate greater than 1 over those same years;
3. A system in place for estimating spawning run abundance with a standard error less than 25%.

Stage 5. Decommission Hatchery Program [2023 and beyond].
Once the population is recovered to a level of abundance that will support ecosystem function and sustainable use, the hatchery program could safely be stopped and thereby eliminate a source of genetic risk.

Stage I: Planning

The success of any hatchery program depends on defining the operational criteria, and conducting a site evaluation. A thorough review of these requisites is documented for completion of Stage 1: Planning. A tentative planning schedule is illustrated in Appendix 4. Stages 2 through 5 were beyond the scope of this report and are not reviewed. The development of the hatchery would be contingent on the results of ongoing kokanee volitional release experiments at Alouette Reservoir and Coquitlam reservoir. If BC Hydro repeats the ‘top spill’ experiment at Alouette each spring between 2006 and 2008 and modest returns of adult sockeye are observed then we would have greater confidence in pursuing propagation at Coquitlam. Similarly, returns from the 2005 volitional release of kokanee at Coquitlam should be monitored. A decision to proceed with propagation would be informed by the following:
• If no adults return to Alouette (or Coquitlam) following the 2005 to 2008 juvenile releases, then hatchery operations should be considered;
• If modest adults return (50-100 per year), then defer a decision regarding propagation; and
• If supplementation is desired, then we recommend a portion of the run be collected for broodstock and the remaining fish acoustic-tagged and tracked to final spawning destinations for assessing reproductive fitness.

Develop Design & Operational Criteria

Hatchery plans must be consistent with the recovery team’s goal and objectives and explicitly address uncertainties in population dynamics and management imprecision while protecting the population from unanticipated catastrophe (i.e., pre-spawning mortality).

Choosing an appropriate level of production capacity requires the weighing of scientific advice in the context of broad policy objectives for salmon management which often must consider conflicting societal values. This target level of capacity must reflect the unique characteristics of the Coquitlam population and its ecosystems, i.e., represent some reasonable proportion of the population’s productive capacity. Setting the target level of abundance is beyond the recovery team’s mandate and should be addressed by government policy-makers in consultation with the stakeholders. It is expected that the DFO’s Wild Salmon Policy will provide an appropriate framework.

The choice of a long-term target level of abundance must be based on our current understanding of the production dynamics of the Coquitlam population. Potential reference points include the following benchmarks, all of which should include:

• The abundance providing maximum sustainable yield ($S_{MSY}$) or some proportion of $S_{MSY}$;
• Some proportion of the productive capacity of the lake;
• Historic abundance; and
• The abundance at which ecosystem function is maintained.

Recent studies are addressing knowledge gaps related to historical and current production potential at Coquitlam Reservoir. Sediment core sampling indicated that the historical salmon population was less than 10,000 adults Nordin and Mazumder (2005). Gaboury and Murray (2006) indicated that tributaries to Coquitlam Reservoir that are accessible to adfluvial salmon do not appear to provide a significant amount of suitable spawning habitat. Based on the quality and quantity of spawning habitat in the accessible tributaries, it is not expected that significant numbers of re-introduced sockeye would utilize these streams for spawning. There appears to currently be sufficient lake shore habitat in the reservoir basin to support between 4,500 and 10,200 sockeye female spawners (Gaboury and Murray 2006). Based on limnological and fish population assessments in 2004 and 2005, Coquitlam Reservoir is likely to support a very low sockeye smolt production (< 5 kg/ha) (Bussanich et al 2006, Bussanich et al. 2005, Field et al.
2005). We would expect a smolt production of less than 1 million based on available spawning and rearing habitat information collected to date.

The best location and production targets for egg incubation and rearing facilities have yet to be identified. Based on global sockeye recovery initiatives and existing hatchery programs in the lower Fraser River, we recommend a relatively small scale hatchery program be developed based on a minimum capacity of 250,000 eggs, and rearing juveniles of optimal size (5 g) for spring release to the Lower Coquitlam River.

Site Evaluation

Concurrent with the volitional release experiments at Alouette Reservoir, we recommend a preliminary site assessment be completed at Rosewall Creek, Inch Creek, ALLCO to achieve the potential requirements of Coquitlam sockeye culture.

Water Supply Assessment:

Key to successful implementation of a hatchery is the water supply. We recommend a hydrogeological assessment be completed to determine the availability and/or constraints associated with development of the required water supply. Design parameters should include: required flow rate, redundancy, water quality and temperature.

Preliminary assessment of aquifer potential:

Based on hatchery information collected, an assessment of the local aquifer yield is needed. The following elements should be taken into account:

- the thickness and lateral extent of the producing aquifers (known or assumed);
- the present use of the aquifers and available monitoring data (in particular if trends indicative of lowering water tables that have been noticed or reported);
- the presence of other groundwater users that could be affected by the groundwater extraction;
- the estimated interaction between groundwater and surface water and the potential impact to local stream flows or surface water users; and
- long term drawdown estimates (20 years).

Existing hydrogeological information available for the Inch Creek, Rosewall Creek, and ALLCO needs to be reviewed. It is likely that groundwater source feasibility may be estimated from existing local wells, and historic and ongoing Provincial hydrogeological studies. Proper testing of the water supply is recommended before making the final decision on the site to be selected.
Water Quality Testing:

Where not available from existing hatchery records, representative water samples need to be collected and submitted for chemical analysis. Parameters to be analyzed should include: temperature, dissolved gases, water chemistry, turbidity, alkalinity/hardness, nitrite levels, and heavy metals.

If the deterioration of water quality versus time has been observed at the proposed sites, further assessment may indicate biofouling. Variation in iron and manganese concentrations (and other electron acceptors, too) can be most often attributed to bacterial activity occurring in the aquifer near the well screen (referred to as well biofouling).

Support Infrastructure Assessment

The support infrastructure available at the potential hatchery sites should be reviewed in detail, and improvement plans developed.

The infrastructure reviewed should include:

- water supply (available or requiring development, as discussed above);
- existing hatchery buildings and/or equipment, suitable and available for use by this program;
- land availability and tenure;
- availability of 3-phase power;
- availability of natural gas;
- effluent disposal and non-contamination issues; and
- site access.

In addition, opportunities and constraints for operations and supervisory personnel need to be reviewed. Capital and operational costs should be estimated for each site and gathered from: in-house costs from other projects, hatchery managers, DFO staff, equipment suppliers, and utility agencies.

3.2.3.5 Service Providers

This project requires the services of experienced professionals familiar with freshwater aquaculture development, sockeye aquaculture and hatchery operations, hatchery facilities, water supply, and groundwater potential and development. A list of qualified professionals is provided, by discipline in Appendix 5. The technical recovery team should be guided by Dr. Chris Wood (DFO, Conservation, PBS, Nanaimo, BC) and supported by Les Clint (Rosewall), Stu Barneston (Inch Creek), and Matt Foy (DFO).

Agencies currently involved in the program include: BC Hydro, Greater Vancouver Regional District, Kwiwetlem First Nation, MWLAP BC Province, North Fraser Salmon Assistance, University of British Columbia, and University of Victoria. Potential partnerships
could be expanded to include: ALLCO, Coquitlam River Watershed Society, Malaspina University-College, and BCIT.

3.2.3.6 Cost Estimation & Funding Sources

We estimate the development cost of a Coquitlam hatchery program from concept planning to an operational status would range between $750,000 and $900,000 using two facilities for egg incubation and juvenile grow-out (Table 7). Estimated planning and site development costs range from $50,000 to $70,000 and from $250,000 to $500,000, respectively. An annual operating and maintenance budget of over $200,000 would be required based on the proposed production targets (Table 8; Appendix 6).

Table 7. Estimated capital cost for Coquitlam Sockeye Hatchery Program.

<table>
<thead>
<tr>
<th>Capital Investment Requirements</th>
<th>Life Cycle (Yr)</th>
<th>Estimated Cost ($)</th>
<th>Depreciation ($/Yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Land and Buildings</td>
<td>30</td>
<td>$575,000</td>
<td>$2,500</td>
</tr>
<tr>
<td>Total Site Developments</td>
<td>25</td>
<td>$54,500</td>
<td>$1,380</td>
</tr>
<tr>
<td>Total System Equipment</td>
<td>10</td>
<td>$237,500</td>
<td>$24,750</td>
</tr>
<tr>
<td>Total Transport Equipment</td>
<td>10</td>
<td>$24,000</td>
<td>$4,367</td>
</tr>
<tr>
<td>Gross Construction Cost</td>
<td></td>
<td>$891,000</td>
<td>$32,997</td>
</tr>
</tbody>
</table>

Table 8. Estimated operation and maintenance cost for Coquitlam Sockeye Hatchery Program.

<table>
<thead>
<tr>
<th>Operating and Maintenance Costs Per Annum</th>
<th>Estimated Cost ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Projected Direct Costs</td>
<td>$123,550</td>
</tr>
<tr>
<td>Total Projected Indirect Costs</td>
<td>$82,297</td>
</tr>
<tr>
<td>Gross Operating Cost</td>
<td>$205,847</td>
</tr>
</tbody>
</table>

Long-term funding is ‘key’ to successfully developing a hatchery program at Coquitlam. Potential sources of funding include:
• Bridge Coastal Restoration Program (BC Hydro; http://www.bchydro.com/bcrp/)
• Southern Boundary and Restoration Enhancement Fund (Pacific Salmon Commission; http://www.psc.org)
• Habitat Conservation Trust Fund (HCTF) http://www.hctf.ca/
• Pacific Salmon Endowment Fund, Fisheries and Oceans Canada; Administered by Pacific Salmon Endowment Fund Society; http://www.psf.ca/home.html
• Vancouver Foundation, http://www.vancouverfoundation.bc.ca/
• Mountain Equipment Coop (MEC) http://www.mec.ca/index.html
• Friends of the Environment Fund (FEF), Toronto Dominion Bank http://www.td.com/fef/
• Aquaculture Corporations: The Omega Salmon Group, parent company Pan Fish (Norway), Stolt Sea Farms (owned by Stolt-Nielsen), Pacific National Aquaculture (subsidiary of the parent company EWOS International and the Norwegian company Cermaq (previously Statkorn)), Marine Harvest (parent company Nutreco out of the Netherlands) is linked with Moore-Clark Canada.

Broodstock Abundance, Collection, and Handling

Studies in 2005 indicate that sufficient numbers of kokanee can be captured for broodstock (Bussanich et al 2006). The population of mature kokanee estimated to be present in the reservoir in November 2005 was 17,400. In 2005, 24% of the kokanee population were in their third or fourth year of life. The observed sex ratio in the age-2 and age-3 mature kokanee was 1.2 males to 1 female (n = 91). Of the age-2 and age-3 observed, 70% of the age-2 and 100% age-3 kokanee would spawn in November 2005. The estimated total female spawners for 2005 would be approximately 6,900 females (4,400 to 34,800 95% CI). The estimated total eggs deposited for 2005 would be approximately 2.62 million (observed 380 eggs per female in 2005).

Adult kokanee demonstrated good survival and no internal injury using gillnetting techniques. No mortalities were observed when mature kokanee were held for 24 hours at densities of 12 kg/m³ (i.e. 2 fish per 20 L tube). Scale loss ranged from 10% to 50%. Internal examination of muscles, organs, and gametes showed no hemorrhaging, discoloration, lesions, or bruising.

3.3 RECOMMENDATIONS

Donor Stock

Genetic analysis supports the initial conclusions of Bocking and Gaboury (2003) that the best chance for success lies with the re-anadromization of the existing kokanee stock in the reservoir.

Sufficient numbers of mature adult kokanee can be collected at the catch index sites identified by Bussanich et al (2006), during peak spawning in early November using 20-min gillnet sets at night, if artificial propagation is a desired method to augment sockeye recovery.
(i.e., catch per unit efforts ranging from 0.5 to 1.0 adult kokanee/90m²•hr, and a 50:50 sex ratio).

**Sockeye propagation**

The study findings support the initial conclusions of Bocking and Gaboury (2003) that reversion to anadromy is plausible and that the best strategy would be to:

1. continue the juvenile kokanee volitional release experiments at Alouette Reservoir. If the experiment demonstrates moderate returns of adults, then a ‘pilot’ supplementation program could be implemented for a minimum of one “sockeye” generation cycle at Coquitlam (and/or perhaps Alouette) reservoir (and monitor and evaluate the program performance to ensure the population is growing); otherwise,
2. defer propagation.

**ACKNOWLEDGMENTS**

The cooperation of many people was essential in meeting the objectives of this study. Special thanks to the Greater Vancouver Regional District, University of Victoria, Kwikwetlem First Nation, Chief and Elders, Fisheries and Oceans Canada, and to all whom assisted in the collection, processing, and analysis of the field data for this study. Technical assistance was provided by: Matt Foy, Doug Lofthouse, Stu Barneston, Al Stobart, Les Clint, Greg Bonnell, Wayne Krause, Maurice Coulter-Boisvert, Don MacKinley, Carol Cross, and Dorothee Keiser of Fisheries and Oceans Canada, Dr. Chris Foote (Malaspina University College), Alf Leake (BC Hydro), Geoff Clayton and Jennifer Ljunggren (ARMS), Virginia Jacobsen (Polderside Farms/Shadow Mountain Salmon Ltd), Kelly Field and Crystal Lawrence of the University of Victoria. From GVRD, Dave Dunkley, Ken Juvik, Heidi Walsh, and several Coquitlam Reservoir security personnel who offered technical assistance in the field. Thanks to George Chaffee, Nancy Joe (Kwikwetlem First Nation) for their support. Bruce Murray, Marc Gaboury, and Dorothy Baker (LGL) assisted with data collection, graphics and final reporting. Funding for this project was provided by the BC Hydro-Bridge Coastal Fish & Wildlife Restoration Program, Fisheries Oceans Canada, the National Science and Engineering Research Council of Canada, and the Greater Vancouver Regional District (GVRD),
REFERENCES


Bussanich, R., B. Murray, R. Bocking and D. Dunkley. 2005. Assessment of fish populations and lakeshore spawning habitat in Coquitlam Reservoir – Year 1 studies to address fish populations and reservoir ecology. Prepared for the BC Hydro Bridge Coastal Fish and Wildlife Restoration program. LGL Limited, Sidney BC. 38 p plus appendices.


Coastal Fish and Wildlife Restoration program. LGL Limited, Sidney BC. 35 p plus appendices.


Schneider, S., D. Roessli, and L. Excoffier. 1999. Arlequin ver. 2.0: A software for population genetic data analysis. Genetics and Biometry Laboratory, University of Geneva, Switzerland.


APPENDICES
Appendix 1. List of persons contacted for sockeye re-introduction feasibility study at Coquitlam Reservoir.

<table>
<thead>
<tr>
<th>Name</th>
<th>Organization</th>
<th>Telephone</th>
<th>Email</th>
</tr>
</thead>
<tbody>
<tr>
<td>Matt Foy</td>
<td>DFO, New Westminster</td>
<td>(604) 666-3678</td>
<td><a href="mailto:FoyM@pac.dfo-mpo.gc.ca">FoyM@pac.dfo-mpo.gc.ca</a></td>
</tr>
<tr>
<td>Doug Lofthouse</td>
<td>DFO, Vancouver</td>
<td>(604) 666-8646</td>
<td><a href="mailto:LofthouseD@pac.dfo-mpo.gc.ca">LofthouseD@pac.dfo-mpo.gc.ca</a></td>
</tr>
<tr>
<td>Stu Barneston</td>
<td>DFO, Inch Creek Hatchery</td>
<td>(604) 826-0244</td>
<td><a href="mailto:BarnetsonS@pac.dfo-mpo.gc.ca">BarnetsonS@pac.dfo-mpo.gc.ca</a></td>
</tr>
<tr>
<td>Al Stobbart</td>
<td>DFO, Inch Creek / Pitt River Hatchery</td>
<td>(604) 826-0244</td>
<td><a href="mailto:StobbartA@pac.dfo-mpo.gc.ca">StobbartA@pac.dfo-mpo.gc.ca</a></td>
</tr>
<tr>
<td>Les Clint</td>
<td>DFO, Rosewall Creek Hatchery</td>
<td>(250) 757-8412</td>
<td><a href="mailto:ClintL@pac.dfo-mpo.gc.ca">ClintL@pac.dfo-mpo.gc.ca</a></td>
</tr>
<tr>
<td>Greg Bonnell</td>
<td>DFO, Vancouver</td>
<td>(250) 363-3484</td>
<td><a href="mailto:BonnellG@pac.dfo-mpo.gc.ca">BonnellG@pac.dfo-mpo.gc.ca</a></td>
</tr>
<tr>
<td>Don MacKinlay</td>
<td>DFO, Vancouver</td>
<td>(604) 666-3520</td>
<td><a href="mailto:MacKinlayD@pac.dfo-mpo.gc.ca">MacKinlayD@pac.dfo-mpo.gc.ca</a></td>
</tr>
<tr>
<td>Wayne Krause</td>
<td>DFO, Engineer</td>
<td></td>
<td><a href="mailto:KrauseW@pac.dfo-mpo.gc.ca">KrauseW@pac.dfo-mpo.gc.ca</a></td>
</tr>
<tr>
<td>Maurice Coulter-Boisvert</td>
<td>DFO, Community Advisor</td>
<td>(604) 666-2870</td>
<td><a href="mailto:CoulterboisvertM@pac.dfo-mpo.gc.ca">CoulterboisvertM@pac.dfo-mpo.gc.ca</a></td>
</tr>
<tr>
<td>Carol Cross</td>
<td>DFO, Transplant Permitting</td>
<td>(250) 756-7069</td>
<td><a href="mailto:CrossC@pac.dfo-mpo.gc.ca">CrossC@pac.dfo-mpo.gc.ca</a></td>
</tr>
<tr>
<td>Dorothee Keiser</td>
<td>DFO, PBS, Fish Health</td>
<td></td>
<td><a href="mailto:KeiserD@pac.dfo-mpo.gc.ca">KeiserD@pac.dfo-mpo.gc.ca</a></td>
</tr>
<tr>
<td>Dr. Chris Foote</td>
<td>Aquaculture and Fisheries, Malaspina University-College</td>
<td>(250) 753-3245 ext. 2406</td>
<td><a href="mailto:footec@mala.bc.ca">footec@mala.bc.ca</a></td>
</tr>
<tr>
<td>Alf Leake</td>
<td>BC Hydro</td>
<td>(604) 528-1924</td>
<td><a href="mailto:Alf.Leake@bchydro.bc.ca">Alf.Leake@bchydro.bc.ca</a></td>
</tr>
<tr>
<td>Geoff Clayton</td>
<td>Alouette River Management Society</td>
<td>(604) 467-6401</td>
<td>Geoff Clayton&lt;<a href="mailto:gerclayton@shaw.ca">gerclayton@shaw.ca</a></td>
</tr>
<tr>
<td>Jenny Ljunggren</td>
<td>Alouette River Management Society</td>
<td>(604) 467-6401</td>
<td>Jenny Ljunggren <a href="mailto:arms@telus.net">arms@telus.net</a></td>
</tr>
<tr>
<td>Virginia and Jens Jacobsen</td>
<td>Shadow Mountain Salmon Ltd, Chilliwack</td>
<td>(604) 823-7324</td>
<td><a href="mailto:shadowmountain@shaw.ca">shadowmountain@shaw.ca</a></td>
</tr>
</tbody>
</table>
Appendix 2. Summary of existing freshwater hatcheries and grow-out operations of salmonids in Greater Vancouver and Fraser Valley Region.

<table>
<thead>
<tr>
<th>Facility *</th>
<th>Location</th>
<th>Organization b</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inch Creek Hatchery</td>
<td>Dewdney</td>
<td>DFO</td>
</tr>
<tr>
<td>Chehalis River Hatchery</td>
<td>Agassiz</td>
<td>DFO</td>
</tr>
<tr>
<td>Chilliwack River Hatchery</td>
<td>Chilliwack</td>
<td>DFO</td>
</tr>
<tr>
<td>Capilano River Hatchery</td>
<td>N. Vancouver</td>
<td>DFO</td>
</tr>
<tr>
<td>Weaver Creek</td>
<td>Harrison Mills</td>
<td>DFO</td>
</tr>
<tr>
<td>West Van Lab</td>
<td>Vancouver</td>
<td>DFO</td>
</tr>
<tr>
<td>Cultus Lab Research Facility</td>
<td>Chilliwack</td>
<td>DFO</td>
</tr>
<tr>
<td>ALLCO Hatchery</td>
<td>Maple Ridge</td>
<td>CSEP</td>
</tr>
<tr>
<td>Bell-Irving Kanaka Creek Hatchery</td>
<td>Maple Ridge</td>
<td>CSEP</td>
</tr>
<tr>
<td>Coquitlam River Hatchery</td>
<td>Port Coquitlam</td>
<td>CSEP</td>
</tr>
<tr>
<td>Stave Valley Salmonid Enhancement Society</td>
<td>Mission</td>
<td>CSEP</td>
</tr>
<tr>
<td>Port Moody Ecological Society</td>
<td>Port Moody</td>
<td>CSEP</td>
</tr>
<tr>
<td>Burrard Inlet Marine Enhancement Society</td>
<td>Port Moody</td>
<td>CSEP</td>
</tr>
<tr>
<td>Seymour Salmonid Society</td>
<td>N. Vancouver</td>
<td>CSEP</td>
</tr>
<tr>
<td>Vancouver Aquarium and Marine Science Centre</td>
<td>Vancouver</td>
<td>CSEP</td>
</tr>
<tr>
<td>Nicomekl Enhancement Society</td>
<td>Fort Langley</td>
<td>CSEP</td>
</tr>
<tr>
<td>Little Campbell River Hatchery</td>
<td>Surrey</td>
<td>CSEP</td>
</tr>
<tr>
<td>Steveston Salmon Hatchery</td>
<td>Richmond</td>
<td>CSEP</td>
</tr>
<tr>
<td>Tynehead Salmon Hatchery</td>
<td>Surrey</td>
<td>CSEP</td>
</tr>
<tr>
<td>Abbotsford Ravine Park Salmon Enhancement Society</td>
<td>Abbotsford</td>
<td>CSEP</td>
</tr>
<tr>
<td>Fraser Valley Trout Hatchery</td>
<td>Abbotsford</td>
<td>BC</td>
</tr>
<tr>
<td>Colebrook Trout Farm</td>
<td>Surrey</td>
<td>Private</td>
</tr>
<tr>
<td>Sun Valley Trout Farm</td>
<td>Mission</td>
<td>Private</td>
</tr>
<tr>
<td>Sun Valley Trout Farm</td>
<td>Hatzic</td>
<td>Private</td>
</tr>
<tr>
<td>West Creek Springs</td>
<td>Aldergrove</td>
<td>Private</td>
</tr>
<tr>
<td>Western Maple Holdings</td>
<td>Aldergrove</td>
<td>Private</td>
</tr>
<tr>
<td>LSL Ltd</td>
<td>Aldergrove</td>
<td>Private</td>
</tr>
<tr>
<td>Brumar Consulting Ltd</td>
<td>Agassiz</td>
<td>Private</td>
</tr>
<tr>
<td>Shadow Mountain Salmon Ltd</td>
<td>Chilliwack</td>
<td>Private</td>
</tr>
</tbody>
</table>

Sources:

Fisheries and Oceans Canada (DFO), DFO- Community Salmon Enhancement Program (CSEP), BC Fisheries (BC), Private (Industry)
Appendix 3. Existing hatchery infrastructure at Rosewall and Inch Creek hatcheries.

<table>
<thead>
<tr>
<th>Component</th>
<th>Feature</th>
<th>Rosewall Creek</th>
<th>Pitt Sockeye Satellite (Inch Creek)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Water Supply</strong></td>
<td><strong>Source</strong></td>
<td>Rosewall Aquifer</td>
<td>Norrish Aquifer</td>
</tr>
<tr>
<td>Available Water Flow (lpm)</td>
<td>Current: 1000 USGpm, Potential: All 4 wells (no back up) = 1500USGpm, or 3 wells = 1200 USGpm</td>
<td>Satellite: 750USGpm (Inch wells #1&amp;2 available for backup). Planned groundwater potential investigation (test well) to increase capacity to be undertaken within 30 days</td>
<td></td>
</tr>
<tr>
<td>Water quality constraints</td>
<td>Possible CO₂; Meets fish guidelines, Possible stressor for later adult stages</td>
<td>None</td>
<td></td>
</tr>
<tr>
<td>Condition of water supply lines</td>
<td>New</td>
<td>New</td>
<td></td>
</tr>
<tr>
<td>Year water supply lines installed</td>
<td>1990's</td>
<td>2003</td>
<td></td>
</tr>
<tr>
<td>Water treatment</td>
<td>No water treatment, to air tower, via gravity to ponds, effluent drum filter</td>
<td>No water treatment, via gravity to incubation/rearing</td>
<td></td>
</tr>
<tr>
<td><strong>Water Discharge</strong></td>
<td><strong>Receiving water</strong></td>
<td>Still pond wet land (biofilter)</td>
<td>Inch Creek</td>
</tr>
<tr>
<td>Number of discharge outlets</td>
<td>3 (1 main, 2 auxiliary)</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Total discharge flow (lpm)</td>
<td>Spec'ed to inflow</td>
<td>Spec'ed to inflow</td>
<td></td>
</tr>
<tr>
<td>Type of treatment</td>
<td>See above</td>
<td>Screened outlet (fry trap)</td>
<td></td>
</tr>
<tr>
<td><strong>Fish rearing facility</strong></td>
<td><strong>Type and description</strong></td>
<td>Circular tubs</td>
<td>Circular tubs and concrete channels (CCs)</td>
</tr>
<tr>
<td>m³ or ft³ capacity</td>
<td>0.3m³ to 42 m³</td>
<td>Tubs:0.7m³ &amp; 7.0m³ (77m³ total)</td>
<td>CCs:15m³ (150m³ total)</td>
</tr>
<tr>
<td>Condition of rearing tanks</td>
<td>Excellent</td>
<td>Excellent</td>
<td></td>
</tr>
<tr>
<td><strong>Hatching facility</strong></td>
<td><strong>Type and description</strong></td>
<td>Heath trays (100+) as required</td>
<td>Kitoi bulk incubators (10) Atikins Boxes (4) Heath stacks (48 trays)</td>
</tr>
<tr>
<td>Condition</td>
<td>Excellent</td>
<td>Excellent</td>
<td></td>
</tr>
<tr>
<td>Problems</td>
<td>None</td>
<td>None</td>
<td></td>
</tr>
<tr>
<td>Residence House</td>
<td><strong>Condition</strong></td>
<td>Excellent</td>
<td>Excellent</td>
</tr>
<tr>
<td><strong>Annual public visitations</strong></td>
<td># of FT employees</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td># of PT employees</td>
<td>2</td>
<td>0.7</td>
</tr>
<tr>
<td></td>
<td># volunteers</td>
<td>0 (quarantine facility), program volunteers vary</td>
<td>0 (quarantine facility)</td>
</tr>
<tr>
<td></td>
<td># of staff &gt; 5 years sockeye culture</td>
<td>0 (supported by Big Qualicum)</td>
<td>2 with 40 years combined sockeye experience (supported by Inch Creek)</td>
</tr>
<tr>
<td><strong>Electrical Supply</strong></td>
<td><strong>Three Phase</strong></td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td><strong>Annual Utility S estimate</strong></td>
<td>55k</td>
<td>55k</td>
</tr>
<tr>
<td></td>
<td><strong>Instrumentation condition</strong></td>
<td>Excellent</td>
<td>Excellent</td>
</tr>
<tr>
<td></td>
<td><strong>Generator condition</strong></td>
<td>Excellent</td>
<td>Excellent</td>
</tr>
<tr>
<td><strong>Site Conditions</strong></td>
<td><strong>Flooding in past</strong></td>
<td>None recorded</td>
<td>1983 (no infrastructure damage)</td>
</tr>
<tr>
<td></td>
<td><strong>Available space for expansion</strong></td>
<td>180 acres, 10 acres developed</td>
<td>Satellite facility in isolated compound with ~2 hectares available for expansion</td>
</tr>
<tr>
<td></td>
<td><strong>Suitable adjacent land for expansion</strong></td>
<td>Canadian Wildlife service, couple private farms, nature trust land owners (adjacent)</td>
<td>Ducks Unlimited, private farms</td>
</tr>
</tbody>
</table>
## Appendix 4. Template of hatchery renovation project flow chart for Coquitlam Reservoir sockeye re-introduction.

<table>
<thead>
<tr>
<th>Step</th>
<th>Product &amp; Deliverable</th>
<th>Task</th>
<th>Task description</th>
<th>Year 1</th>
<th>Year 2</th>
<th>Year 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Feasibility Study</td>
<td>1</td>
<td>Comprehensive engineering and planning report</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Pre-Concept Review</td>
<td>1</td>
<td>Define program requirements</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>Validate scope of work</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>Define fish production and hatchery goals</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>4</td>
<td>Review annual monitoring studies</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>5</td>
<td>Define water supply requirements and design coordination</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>6</td>
<td>Concept design of hatchery</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>7</td>
<td>Design options and alternatives</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>8</td>
<td>Identify permit requirements</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>9</td>
<td>Review codes and design recommendations</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>10</td>
<td>Review site and existing issues</td>
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<td>Inspect domestic water and wastewater, wells, and water supply</td>
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<td>2</td>
<td>Review contractors proposals</td>
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</table>
Appendix 5. List of service providers, by discipline, for sockeye re-introduction at Coquitlam Reservoir.

**Sockeye Genetics & Behaviour**
Dr. Chris Wood (DFO)
Dr. John Candy (DFO)
Dr. John Nelson (UVic)
Dr. Chris Foote (Malaspina University-College)

**Sockeye Disease Prevention**
Dorothee Keiser (DFO)

**Permitting for Transfer of Aquatic Organisms**
Carol Cross (DFO)

**Sockeye Enhancement Biologists & Hatchery Managers**
Stu Barnston (Manager, Inch Creek Hatchery, DFO),
Al Stobbart (Manager, Pitt Lake Hatchery, DFO),
Les Clint (Qualicum/Rosewall Hatchery, DFO),
Doug Lofthouse (DFO)
Szczepen Wolski (Manager, Shushwap Hatchery, Wolski Environmental),

**Salmon Hatchery Engineering**
Ken Woo (DFO),
Wai Leung (DFO)

**Environmental Site Assessment**
AMEC Earth & Environmental Limited, BC
EBA Engineering Consultants, BC
Golder & Associates, BC
Jacques Whitford Environmental Consultants, BC
LGL Research Associates Limited, BC

**Site & Facility Engineering**
AMEC Earth & Environmental Limited, BC
Canadian Aquaculture Systems Inc, ON
D.G.V. Engineering Services Ltd, BC
EBA Engineering Consultants, BC
FishPro, WA
Golder & Associates, BC
Jacques Whitford Environmental Consultants, BC
Kerr Wood Leidl Associates Ltd

**Groundwater Supply Specialists**
List of professionals available at www.bcgwa.org

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<tr>
<th>Capital Investment Requirements</th>
<th>Operating and Maintenance Costs Per Annum</th>
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<tr>
<td><strong>Life Cycle</strong></td>
<td><strong>Estimated Cost ($)</strong></td>
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<tr>
<td><strong>Depreciation ($/Yr)</strong></td>
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<td><strong>Total Land and Buildings</strong></td>
<td>500,000</td>
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<tr>
<td>Hatchery building</td>
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<td><strong>Site Developments</strong></td>
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<tr>
<td>Well</td>
<td>25 15,000</td>
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<tr>
<td>Power</td>
<td>25 2,000</td>
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<td>Natural gas</td>
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<td>Communication lines</td>
<td>25 500</td>
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<td>Effluent treatment system</td>
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<tr>
<td>Earthen Works</td>
<td>20,000</td>
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<td><strong>System Equipment</strong></td>
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<tr>
<td>Culture area (rearing tanks)</td>
<td>10 35,000</td>
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<tr>
<td>Backup generator</td>
<td>10 20,000</td>
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<tr>
<td>Mechanical filter</td>
<td>10 15,000</td>
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<td>CO2 stripping tower</td>
<td>10 10,000</td>
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<tr>
<td>Biological filter</td>
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<tr>
<td>Low head oxygenator</td>
<td>10 3,000</td>
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<tr>
<td>Oxygen concentration units</td>
<td>10 6,000</td>
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<tr>
<td>Plumbing</td>
<td>10 25,000</td>
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<td>Pumps</td>
<td>10 10,000</td>
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<tr>
<td>Hatchery equipment</td>
<td>10 5,000</td>
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<td>Fish handling, feeding, and husbandry equip.</td>
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<td>Heat exchanger</td>
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<td>UV unit</td>
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<td>Furnace</td>
<td>10 2,500</td>
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<td>Lighting and electrical</td>
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<td>Emergency alarm system</td>
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<td>Industrial tools (Heavy and Light)</td>
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<td><strong>Transport Equipment</strong></td>
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<td>Delivery vehicle</td>
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<td>Fuel storage tank</td>
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<td>Transport tank with air supply fittings</td>
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<td><strong>Total Land and Buildings</strong></td>
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<td><strong>Total System Equipment</strong></td>
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<td><strong>Total Transport Equipment</strong></td>
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| **Gross Construction Cost**     | **32,997**                                  |                                |
| **Gross Operating Cost**        | **205,847**                                 |                                |

**Key Assumptions:**
- Local contractor with limited room and board
- Estimates for construction cost only. No design, engineering, or administration costs included in estimate
- Process and water treatment equipment estimates provided by PRAqua Technologies Ltd
- All estimates quoted in 2005 dollars

**Projected Direct Costs**
- Egg Collection: 15,000
- Genetic Screening: 7,500
- Disease Screening: 5,000
- Feeds: 25,000
- Marking and tagging: 25,000
- Veterinary expenses: 500
- Telephone expenses: 3,000
- Power expenses: 10,000
- Natural gas expenses: 10,000
- Building repair and maintenance: 2,000
- Production system repairs and maintenance: 2,500
- Fuel and oil expenses: 10,000
- Vehicle repairs and maintenance: 600
- Vehicle license and insurance: 1,000
- General insurance and liability: 2,500
- Travel expenses: 250
- Small tools: 200
- Professional fees: 1,500
- Office expenses: 500
- Interest on operating: 1,500

**Projected Indirect Costs**
- Land taxes: 2,300
- Operating labour: 47,000
- Depreciation on buildings: 2,500
- Depreciation of developments: 1,380
- Depreciation on production system: 24,750
- Depreciation on fish delivery equipment: 4,367