Knowledge Synthesis and Re-Establishment Plan for Coquitlam Reservoir Sockeye Salmon

Prepared for

The Kwikwetlem Salmon Restoration Program

Prepared by

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EXECUTIVE SUMMARY

Sockeye Salmon were extirpated from Coquitlam Lake and the whole Coquitlam Watershed in 1914 with the completion of the Coquitlam Dam at its current height. The Kwikwetlem Salmon Restoration Program (KSRP) has led the efforts to re-introduce and re-establish a sustainable Sockeye Salmon population into Coquitlam Reservoir for the last 12 years. Through these efforts, a knowledge base about current conditions and future directions for the Coquitlam Reservoir Sockeye Salmon re-introduction and population establishment has been built. This report summarizes current conditions and future direction and gives recommendations for decision points to initiate the next steps in establishing a self-sustaining Sockeye Salmon population.

The main obstacle to Sockeye re-establishment is the inability to allow significant numbers of Kokanee smolts to survive leaving the reservoir. The probable reasons for this are: 1) injury or mortality when passing through the Low Level Outlets (LLOs) into the tunnel and the Lower Coquitlam River, 2) lack of surface current to attract Kokanee smolts into the dam forebay and Sluice Tower area, and 3) inability of smolts to find the LLOs in the dam Sluice Tower.

Smolt outmigration numbers could be boosted using two approaches, as follows:

1. Reservoir elevation and discharge volume through the LLO could be optimized for the month of May by creating smolt attracting surface current by increasing LLO discharge to >6 m^3/s and by lowering the reservoir elevation to <144 m to decrease the distance to and flow velocity through the LLOs for out bound smolts. To support safe smolt passage from the LLOs into the tunnel it will be necessary to remove a rock outcropping from the tunnel ceiling and rock debris from the tunnel floor and these tunnel modification will be costly. For now, tunnel modifications will divert funding from measures that should have higher chances of success in boosting the numbers of Kokanee smolts that leave the reservoir.
2. Smolt numbers can be boosted through hatchery intervention using wild Coquitlam Reservoir Kokanee Salmon as broodstock. DFO has agreed to provide approved space at Rosewall Creek Hatchery on Vancouver Island for incubating 10,000–50,000 wild Kokanee eggs and rearing juveniles to smolt stage for imprinting and release into the Lower Coquitlam River. Concurrently with this hatchery program, a floating smolt surface collector should be considered. The collector system should create considerable current to attract smolts to the forebay area, collect smolts and transport them past the dam. Costs for supplying and operating this collector should be compared to costs for improving tunnel passage.
   Larger smolt numbers resulting from hatchery enhancement and the smolt collector system should lead to larger returns of adult Sockeye to the dam which will require the optimization of the current trapping and trucking operation to transport fish to the reservoir.

In addition, predation by river otters must be reduced or eliminated by “otter proofing” the trap and possibly the encouragement of salmon to enter the trap in warm and lower water conditions. This could involve small (> 0.5m^3/s increase) pulse discharges from Coquitlam Reservoir to increase flows and thus

encourage salmon to move out of otter exposed holding areas into the “otter-proof” fish trap. Environmental, public safety concerns and the effectiveness of such pulse flows should be reviewed.

If smolt to adult survival is found to be in line with, or higher than, other Lower Fraser Sockeye stocks (>1%) and Sockeye Salmon returns increases to more than 500 fish, consideration can be given to replacing the surface smolt collection system with a surface fish passage facility. Once a larger number of Sockeye Salmon is regularly transported above the dam, their offspring should have a higher propensity to leave the reservoir and the need for further hatchery enhancement is hoped to be eliminated. To facilitate large numbers of smolts to leave the reservoir and to accommodate larger (>1,000) Sockeye Salmon escapements, a complete fish ladder should be added to the Coquitlam Dam structure. The optimization of discharge to accommodate smolt outmigration will be directly negotiated with BC Hydro within the operational framework for Coquitlam Reservoir. Funding for the investigation of smolt movement in the spring and the hatchery program will be applied for through Fish and Wildlife Compensation Program (FWCP) on an annual basis. The more costly construction and operation of a surface fish passage way for smolts and/or a fish ladder for adults will need to be supported directly by BC Hydro.

The fish ladder and the increasing numbers of Sockeye returning to the reservoir will hopefully increase the escapement to the dam to >1,000 fish and allow for unassisted migration into and out of Coquitlam Reservoir. In addition, a fish ladder would also likely lead to the establishment of populations of Coho Salmon and Steelhead Trout above the dam.

If implemented sequentially as proposed, these measures will address the primary difficulties to be resolved to restore a Sockeye Salmon population above the dam.

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The KSRP members have spent many hours to fulfill the dream of Sockeye, Coho and Steelhead re-introduction into Coquitlam Reservoir and worked together with the Kwikwetlem First Nation and the Watershed Watch Salmon Society to commission the writing of this report. Craig Orr helped to write the proposal for this report. Norm Fletcher gave valuable advice with regards to the Coquitlam Dam History and construction detail and provided a summary of the Al Grist Memorial Hatchery operations.

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Other KSRP members that shaped this initiative over time are Tony Matahlija, Diane Ramage as well as Margaret Birch (City of Coquitlam) and Steve Brown (City of Port Coquitlam).

Many others that are not named in this report contributed to the KSRP initiative over time and the authors apologize for the omission of their names and contributions.

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INTRODUCTION

Report Background and Objectives

All salmon and other anadromous species were wiped out from upstream areas, as access to spawning and rearing habitat was blocked when Coquitlam Dam was completed in 1914, as part of the Coquitlam Hydroelectric Project. At the same time, a population of Kokanee (landlocked Sockeye) survived in Coquitlam Reservoir, which is much larger than natural Coquitlam Lake (Figure 6). Small numbers (generally <1,000 smolts) of Kokanee smolts have been escaping from the reservoir, returning as adult Sockeye and presenting opportunities for restoring sustainable populations of Sockeye Salmon if favourable conditions can be provided. Restoring salmon populations and fish passage to Coquitlam Reservoir and its tributaries has been the subject of many studies and meetings involving First Nations, BC Hydro and Metro Vancouver for the last 12 years.

Although most, if not all, species of Pacific salmon were present, Sockeye Salmon was the main anadromous species known to have inhabited the lake (Koop 2001). Very little is known regarding the historical population of Sockeye Salmon. What is known, is that Coquitlam Sockeye Salmon migrated into the Coquitlam River and Lake in April and May of each year (Koop 2001) and that these salmon were very important to the Kwikwetlem First Nation. Alouette River Sockeye, also extirpated by hydroelectric development, also returned at this time of year. In addition to Sockeye Salmon, Kwikwetlem people also fished for Coho, Chum and Chinook Salmon at the mouths of tributaries to Coquitlam Lake (G. Chaffee, pers. comm.). Re-introduction of Sockeye Salmon into Coquitlam Reservoir is also of high interest to Metro Vancouver as the reservoir provides approximately one-third of the domestic water supply for the Metro Vancouver area.

The Kwikwetlem Salmon Restoration Project (KSRP) has evolved from the Kwikwetlem Sockeye Restoration Project (KSRP) that was founded by representatives of Kwikwetlem First Nation, DFO, Metro Vancouver, BC Hydro, Watershed Watch Salmon Society and smaller volunteer community groups to restore salmon stocks in Coquitlam Reservoir. The KSRP has been involved in many studies and meetings over the past 12 years. These efforts have focused on Sockeye as does this report.

This report summarizes the results of all studies undertaken for the KSRP over the last 12 years. Recommendations are made on steps for restoring a Sockeye Salmon population that will produce escapements of more than 500 fish/year (a stock establishment phase). Based on this plan, the report also suggests measures that are meant to restore a self-sustaining Sockeye Salmon population in a self-sustaining phase with intervention and the end goal of the establishment of an unassisted and self-sustaining Sockeye Salmon population.

The five main objectives of this report are:

1. To review the results of the studies and work completed to date under the KSRP umbrella to determine all known critical factors and to identify remaining key uncertainties;
2. To define and articulate the goals, criteria and metrics of success for a plan which will result in restoration of primarily a Sockeye Salmon stock in Coquitlam Reservoir;

3. To define and develop plans for Sockeye smolt production and outmigration that will increase returns of adult Sockeye to the reservoir;
4. To identify monitoring requirements and adaptive management opportunities including decision points for achieving plan goals; and
5. To present this plan to KSRP members, the Fish and Wildlife Compensation Program (FWCP) and to BC Hydro for approval.

Restoring anadromous fish access to Coquitlam Reservoir is a complex matter. 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.

The writing of this report aligns with the “Design Establishment Phase of Fish Passage” step in BC Hydro's Fish Passage Decision Framework (Figure 1) and is a necessary step toward the successful restoration of Coquitlam Lake salmon stocks.

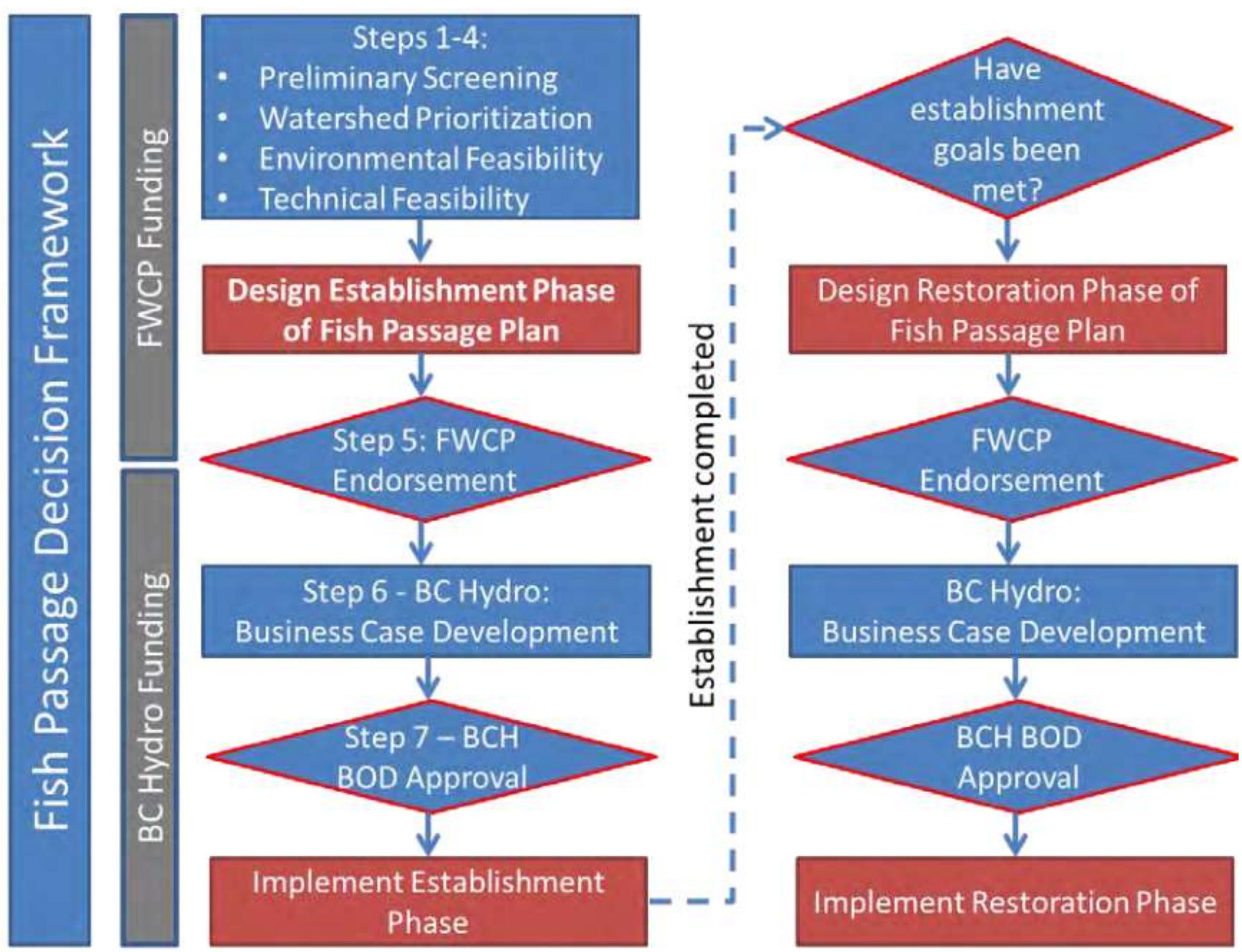

Figure 1 Decision process for “phased” approach to designing and implementing a fish passage plan for the Coquitlam watershed.

Coho and Steelhead salmonid stocks will also benefit from the facilities developed to restore Sockeye Salmon when access is provided to suitable spawning habitats above the dam. In addition, Chinook, Chum and Pink Salmon may also benefit but these species typically spawn in river areas downstream from lakes. Migratory Cutthroat Trout and Bulltrout may also take advantage of the reservoir and its tributaries for rearing and spawning should a fish ladder be built. To account for outstanding uncertainties and the transition to more targeted actions, an adaptive management approach is recommended. By incorporating this approach, future information, gained as part of the KSRP process, can be incorporated in stride to reduce uncertainties and guide decisions going forward. The benefits of this report are anticipated to be:

1. Development of a Stock Establishment Plan;
2. Identification of future actions required; and
3. Continuation of the collaborative framework for investigating and implementing fish passage facilities at Coquitlam Dam.

Physical Setting and Existing Hydro Facilities

The Coquitlam Watershed is located in the lower mainland of British Columbia, about 30 km northeast of Vancouver, in the southernmost extension of the Pacific Ranges of the Coast Mountains. It is 253 km^2 in area (193 km^2 or 76% above the dam and 60 km^2 or 24% below) and ground elevations range from 153 m to over 2000 m. All of the Sockeye Salmon spawning and rearing habitat in the watershed exists above the dam. The Coquitlam River flows from the Coastal Mountains through the cities of Coquitlam and Port Coquitlam and from there into the Fraser River. Coquitlam Dam which was built in 1904–1905 was upgraded to its current 30 m height in 1914. Coquitlam Reservoir was created by and is located above the Coquitlam Dam (Figure 2) and is part of the BC Hydro Coquitlam-Buntzen hydro- generating system (Figure 3, Figure 4) and the Metro Vancouver drinking water system.

Water for generating power flows from the reservoir via a 3.9 km tunnel to Buntzen Reservoir where 530 m and 170 m penstocks lead to powerhouses located on the Indian Arm of Burrard Inlet (BCRP 2000) (Figure 3).

The Coquitlam basin is open to south-westerly flows of warm, moist air, which bring heavy rainfall. Approximately 50% of annual precipitation normally falls between October and January. Average precipitation in November is 600 mm; however, it can reach levels of 1,000 mm or more (FWCP 2011). The high precipitation of the area results in a high flushing rate typical of coastal lakes. The lake has a volume of 1,044,000 m^3, a mean depth of 87 m and a surface area 12 km^2. The annual inflow of 725,000 m^3 results in a water exchange rate of 0.69 times per year or a complete exchange time of 1.4 years using full pool volume (Nordin and Mazumder 2005).

Figure 2 Picture of Coquitlam Dam (Stuart 2010).

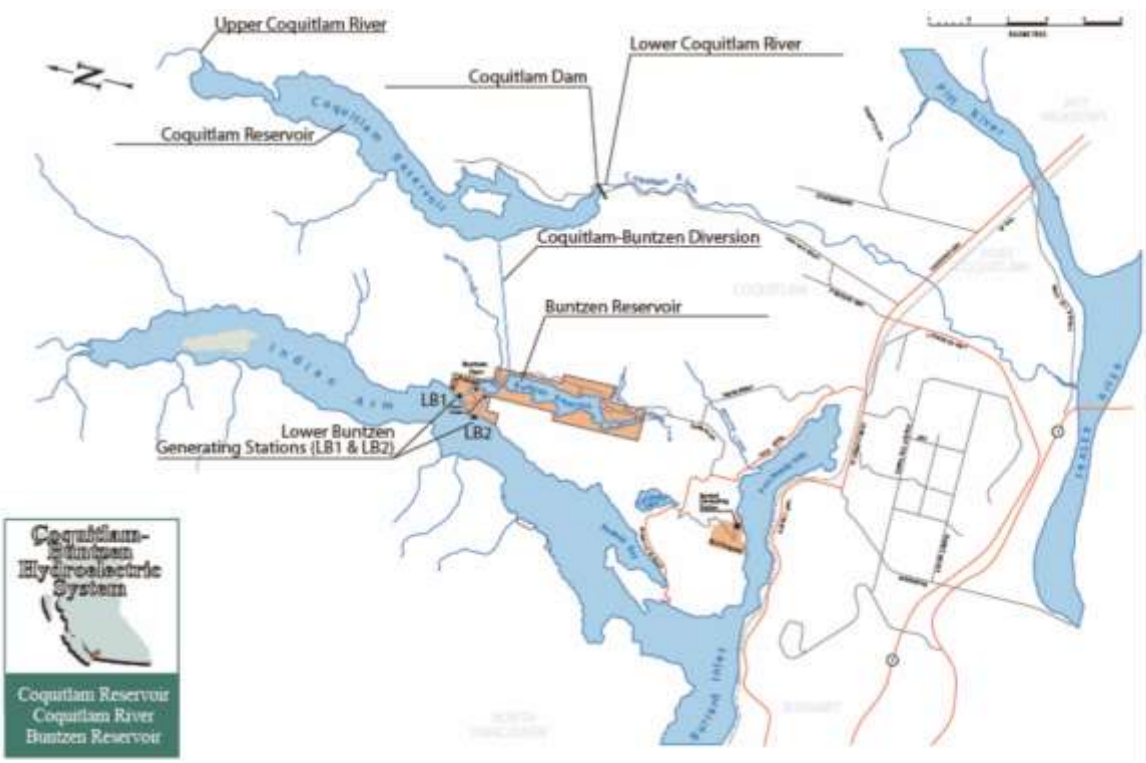

Figure 3 Coquitlam-Buntzen hydro generating complex (KSRP Committee).

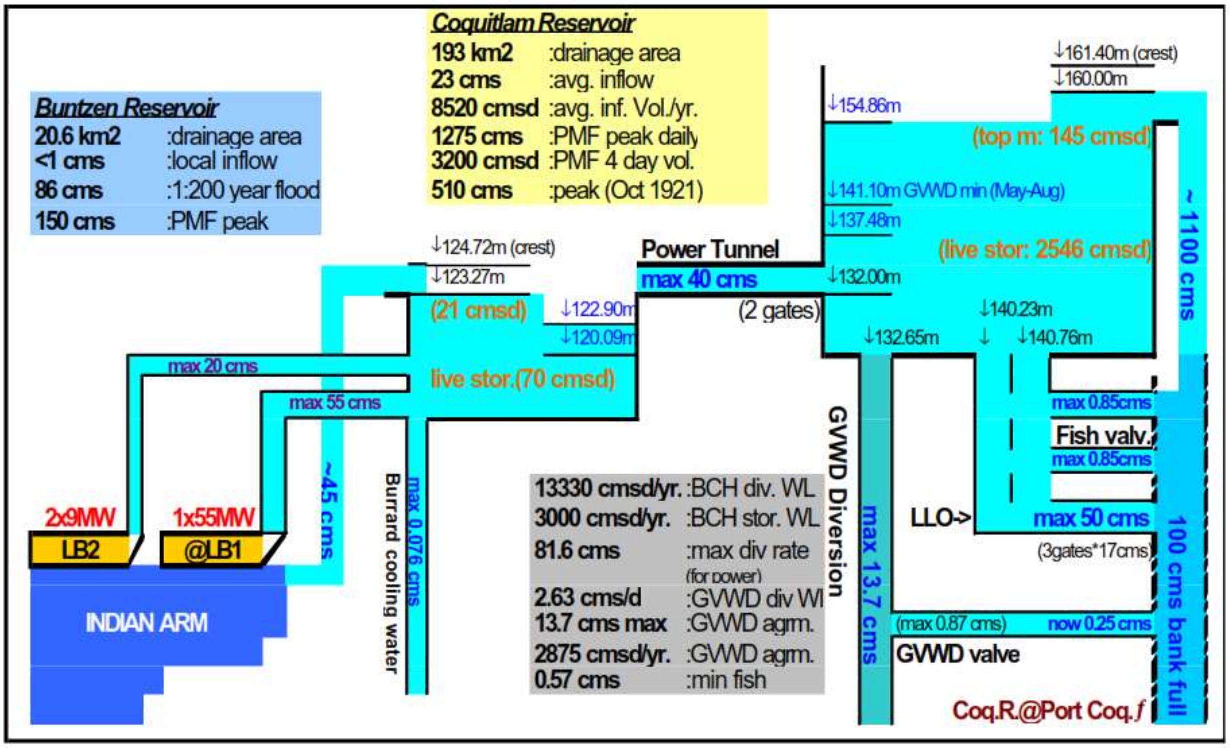

Figure 4 Coquitlam-Buntzen system diagram (Bocking and Gaboury 2003).

Coquitlam Reservoir has a maximum depth of approximately 187 m (Stockner 2003). It has steep rocky shores on the east shores of the central main basin and on the shallower secondary basin at the north end. Coquitlam Dam is located at the south end of the main basin (Figure 2). The tunnel to Buntzen Reservoir is located on the south west shore of the main basin. The main tributaries to Coquitlam Reservoir are the Upper Coquitlam River and Alpine Creek at the north end, Harmony Creek entering the central basin from the west, Falls Creek and Cedar Creek entering the central basin from the east and Beaver Creek entering the reservoir from the southwest.

Before inundation, Coquitlam Lake was shorter on the shallow north and south ends and did not inundate the area east of the main island and the mouth of Cedar Creek (Figure 6).

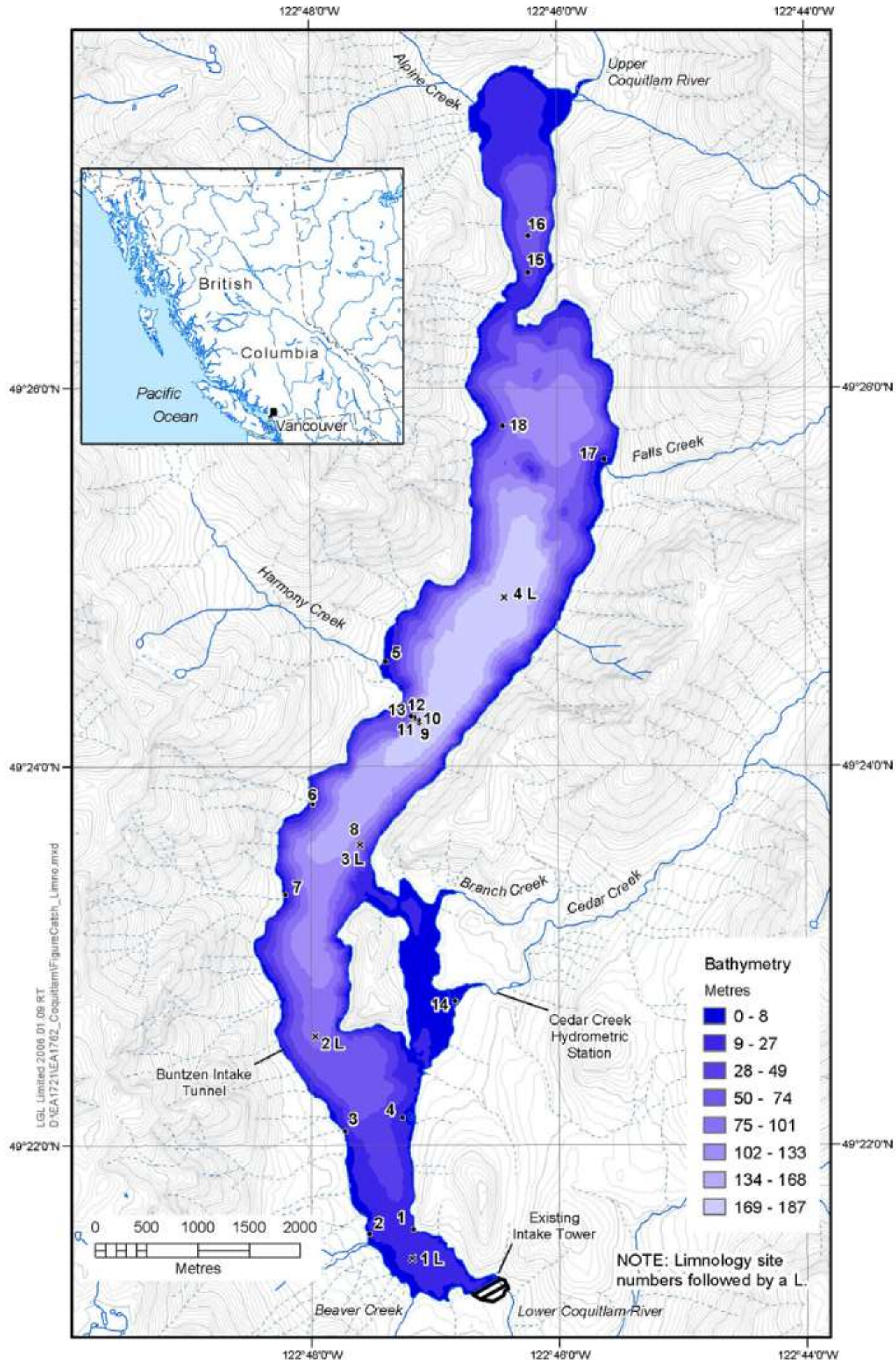

Figure 5 Bathymetry of Coquitlam Reservoir with water sampling station numbers (Bussanich et al. 2006a).

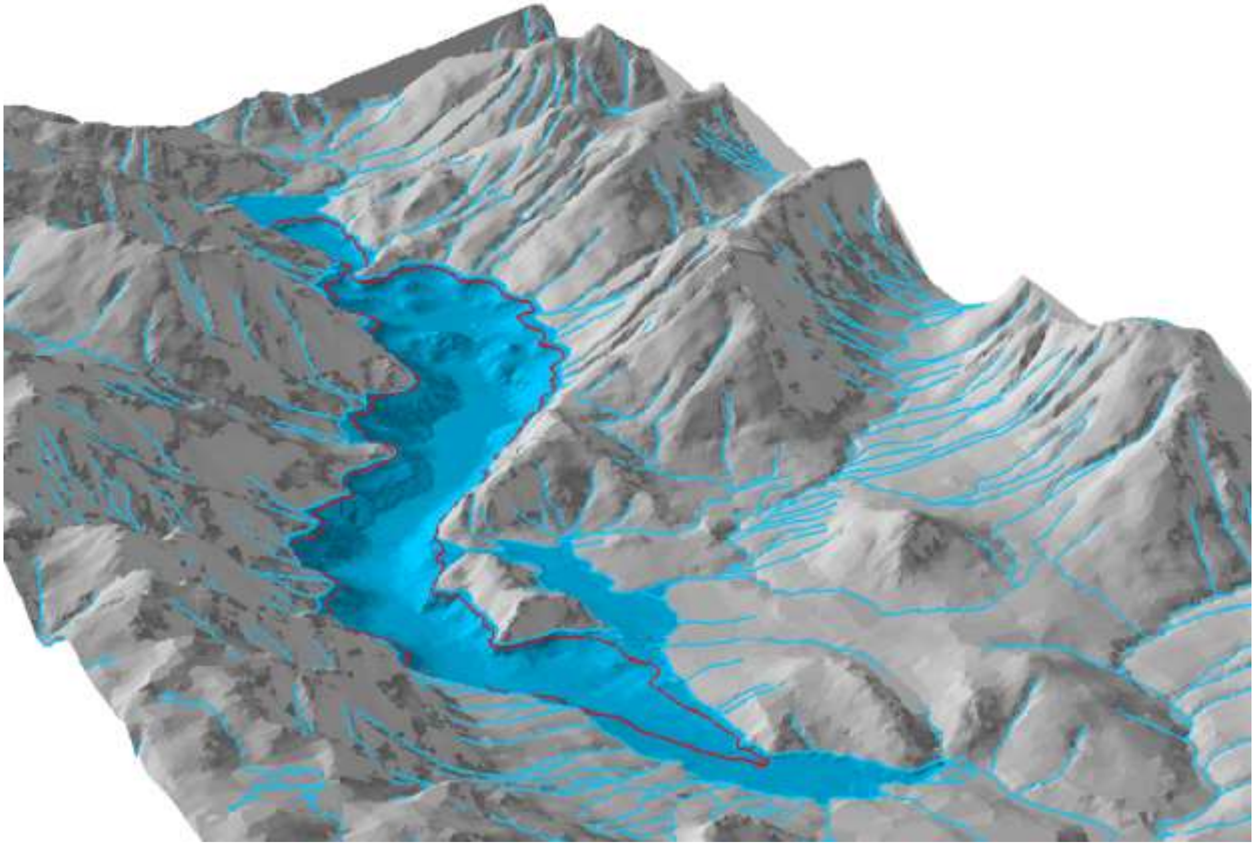

Figure 6 Two-dimensional map of Coquitlam Lake showing the shore of Coquitlam Lake before inundation as a red line and the current lake shore at the edges of the blue area (Metro Vancouver).

In total, Coquitlam Reservoir has four outlet structures. The largest of these in terms of release magnitude is a free crest weir located on the east side of the dam, which is capable of releasing roughly 1100 m^3/s at probable maximum flood. The spillway is carved into the bedrock to the left of Coquitlam Dam when looking downstream and is positioned above a tunnel that delivers the discharge from a Sluice Tower adjacent to the dam. The Sluice Tower is the second largest outlet and it can deliver a maximum of 52 m^3/s to the Coquitlam River. The Sluice Tower has 5 outlets (two fish flow valves (FV), each capable of delivering a maximum of 0.85 m^3/s, and three Low Level Outlets (LLOs) capable of delivering 17 m^3/s each at maximum flow). In 2008, one of the LLOs (LLO3) was retrofitted with a new "knife gate valve" style gate to allow for finer flow adjustments and deliver larger volumes of water with less wear to the gate infrastructure (Figure 7).

Figure 7 Knife gate valve installed in 2008 at one of the LLOs in the Coquitlam Dam gatehouse (BC Hydro Engineering 2009).

Since 2008, the LLO3 with newly installed knife valve has been the principal structure delivering downstream flow releases to the Coquitlam River (Figure 7). The FVs are now rarely used.

The third outlet is a tunnel located roughly 3.4 km upstream of the dam (about a quarter of the way up the reservoir) that is capable of delivering a combined maximum discharge of 40 m^3/s through two separate gates into the neighboring Buntzen Reservoir. The Buntzen Reservoir diversion intake is located at elevation 130 m, which is 20 m below the full-inundation level of 150 m and 10.2 m below the LLO at the Coquitlam Dam gatehouse. Once in Buntzen Reservoir, these inflows are used to supply the Buntzen generating stations situated on the shores of Indian Arm. On rare occasions, the water can also be used to supply cooling waters for the Burrard Thermal Generating Station located on the shores of Burrard inlet or up to 45 m^3/s can be spilled directly into Indian Arm.

The last of the four outlet structures is an intake tower that supplies domestic drinking water to Metro Vancouver. The structure has three rotating screened (screen size 1 cm^2) intakes located at different elevations. Combined, these three intakes are capable of delivering a total of 13.7 m^3/s to Metro Vancouver's drinking water system (Lewis et al. 1996). The Metro Vancouver intake structure is also equipped with a diversion pipe and valve system capable of diverting up to 0.87 m^3/s to the Coquitlam River downstream of the dam. However, the diversion pipe is no longer in use but remains functional. The Metro Vancouver diversion pipe may represent a suitable water supply structure to deliver ample gravity fed water to a potential fish hatchery below Coquitlam Dam. Coquitlam Reservoir has been used for domestic water supply for Metro Vancouver since the early 1900s and is a dedicated drinking water reservoir with restricted public access since the early 1980s.

The maximum possible annual draw down through the four outlet structures is about 13 m (low of 137 m, high of 150 m) and represents about half of the reservoir's maximum storage volume.

Another structure of note is a gravity fed adult salmon trapping facility located immediately downstream of the dam. Outflows from the trap serve as the headwaters for the Grant's Tomb side channel and rearing pond.

Coquitlam Reservoir Hydro Operations

Coquitlam Lake Reservoir operations can be described as having two phases during the Sockeye data collection period (2005 to present). During the pre-Water Use Plan (WUP) phase, water releases from the Sluice Tower to the Lower Coquitlam River were delivered through two smaller "Fish Flow Valves" (FVs) that were kept fully open year round. Starting with the WUP phase and the installation of the new LLO3, Sluice Tower discharges followed monthly flow release targets set by the WUP. If water was in short supply, only a minimum discharge of 1.1 m^3/s was maintained into the Lower Coquitlam River (Table 1). The initial FVs, as well as the later modified LLO3 outlet, are located in three sluiceways, all of which can be opened to allow for larger releases of water.

Discharge through the FVs to the Coquitlam River during the pre-WUP phase averaged 1.0 m^3/s, and typically ranged from 0.4 to 1.5 m^3/s during non-outage periods depending on reservoir elevation. In addition to these releases, the Greater Vancouver (later Metro Vancouver) Water District (GVWD) provided a minimum of 0.25 m^3/s of water to supply the Grant's Tomb channel network on the lower river. These pre-WUP releases ended on October 21, 2008, when flows to the Coquitlam River were switched over to the new LLO structure and began to follow the WUP release schedule (Figure 8).

Table 1 Monthly targeted flow releases from Coquitlam Reservoir to the Coquitlam River as described in the system's Coquitlam Buntzen Project Water Use Plan (BC Hydro 2005).

Month	LLO Release (m^3/s)		Month	LLO Release (m^3/s)	
	Target	Minimum		Target	Minimum
Jan 1 - 15	5.90	3.60	Jul	1.20	1.10
Jan 16 - 31	2.92	2.92	Aug	2.70	1.10
Feb	2.92	2.92	Sep	2.22	1.10
Mar	4.25	1.77	Oct	6.07	3.59
Apr	3.50	1.10	Nov	3.96	1.49
May	2.91	1.10	Dec	5.00	2.51
Jun	1.10	1.10			

Of particular note in Figure 8 for the FV and LLO releases are two years where short-term flow pulses were delivered downstream during the April 1–June 15 Sockeye smolt monitoring period. In 2010, a single 7-day, 6 m^3/s flow pulse was delivered starting May 12, while in 2011, two such pulses were released: one starting April 27 and the other May 13. In both years, the pulse releases were an attempt to increase Sockeye smolt output by increasing attraction flows to the LLO3. Also of note were the high releases in 2009, where LLO discharge averaged 5.5 m^3/s throughout the migration period.

In addition to the FV and LLO controlled releases, there were a number of sluice valve spills, many of which reached 40 to 45 m^3/s in magnitude (Figure 9). The sluice valves, LLOs and FVs are inside the Sluice Tower and only LLO3 and FVs are used on a regular basis. LLO3 is a throttleable sluice gate that can provide flows of 0 to 9m^3/s. All sluice gate releases occurred during the pre-WUP phase of facility operations during the fall and winter months, of particular note were a series of small spills that occurred during the Sockeye smolt outmigration period. The first was a 7-day spill in 2005 that started April 22 and had a magnitude of approximately 5.2 m^3/s. This was followed by another test spill in 2006 when sluice gate spill duration was increased to 21 days. For this release, the start date was a day earlier as the previous year (April 21) and discharge averaged 5.0 m^3/s. The last trial sluice gate spill occurred in 2008, when the duration was cut back to 7 days. The start date was moved to April 29, and the average discharge increased to 8.4 m^3/s. Also of note, no sluice gate spill occurred in 2007 during the Sockeye out migration period; however, there was a significant sluice gate release that started several weeks earlier on March 16. Peak discharges approached 40.5 m^3/s and the spill lasted to April 2. Unlike other spills, the 2007 event was not intended as an experimental trial to increase Kokanee smolt outmigration. Rather it was related to flood risk management. Throughout these sluice gate spill events, the FV gates were also fully opened and added roughly 1 m^3/s to the total discharge into the Lower Coquitlam River.

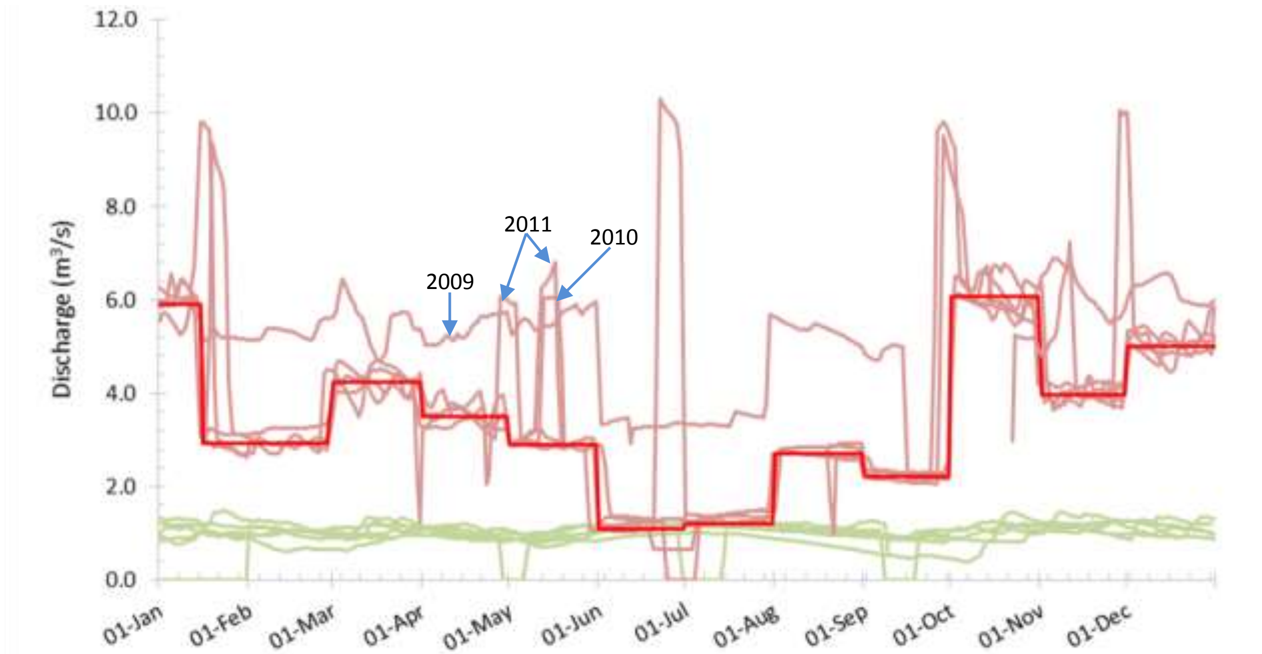

Figure 8 Plot of Coquitlam Dam releases (m^3/s) to the Lower Coquitlam River from 2003 to 2013. During pre-WUP releases (up to October 2008, green lines), FVs were fully open year round to deliver downstream flows based on prevailing reservoir elevation. Post WUP implementation discharges (2008 onward, burgundy lines) through the new LLO mostly followed a specified monthly WUP target (red line).

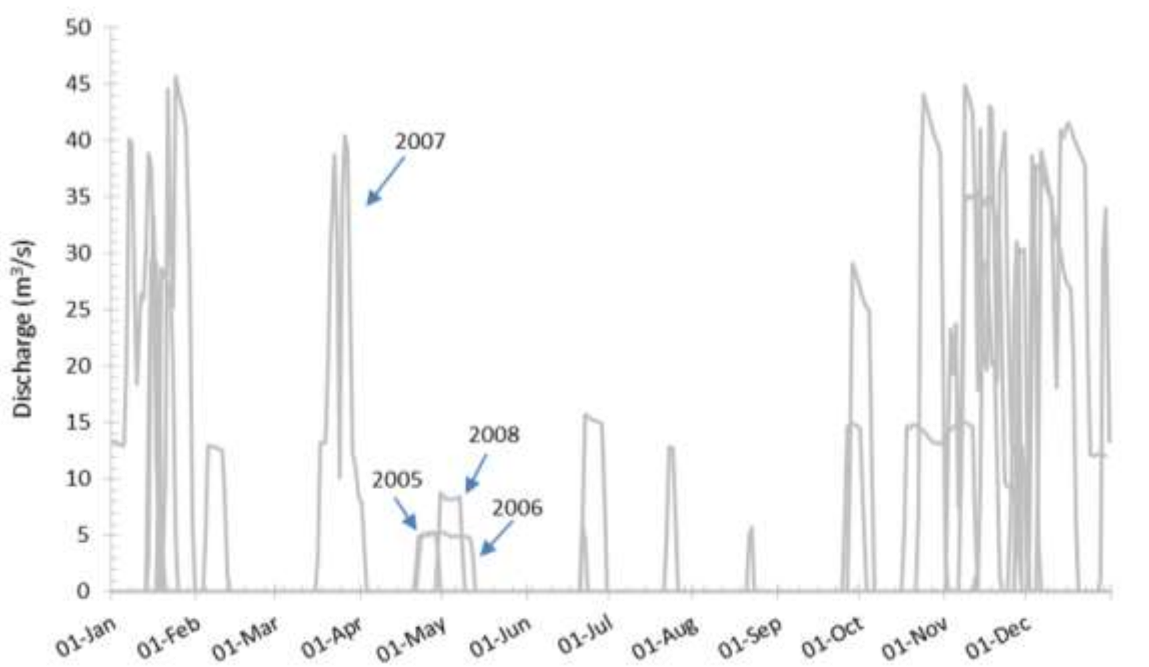

Figure 9 Sluice gate discharges from 2003 to 2008. Of particular note are pulse flow trials of 2005, 2006 and 2008, and the natural spill of 2007, all of which occurred either just before or during the smolt outmigration monitoring period of April 1–May 31.

The water releases through the FVs, the LLOs, and the spill sluice valves in combination with releases through the Buntzen Tunnel, determine the elevation of Coquitlam Reservoir. Reservoir elevations were highly variable during the 2003–2013 period (Figure 10). There are two time periods to consider. Prior to 2008, reservoir elevation was managed to 149 m above sea level (all elevation levels are listed as above sea level or “asl” for standardization) due to dam safety concerns. After the new dam was constructed this constraint was removed. Overall, elevations ranged from 141.25 to 152.42 m and at no time did they converge to a narrow band between years (signifying a constraint in operations). The only consistent pattern was a tendency for elevations to reach their yearly lows in April and to increase as a result of spring freshet over the course of the following two months. Reservoir elevation tended to drop thereafter to another seasonal low by the end of September, after which it fluctuated wildly in response to fall and winter rain storms. Spring freshet flows have made it difficult to maintain a steady low reservoir elevation during the smolt outmigration period. From the April low, elevations typically rose 2−4 m by the end of June. An additional 4–6 m of elevation change could be attributed to between year differences in the seasonal April low values. Overall, reservoir elevations could be expected to be anywhere within a 5 m range (145–150 m) during the main smolt outmigration period in May and depended largely on the timing and magnitude of yearly inflows and the releases out of all four reservoir outlets.

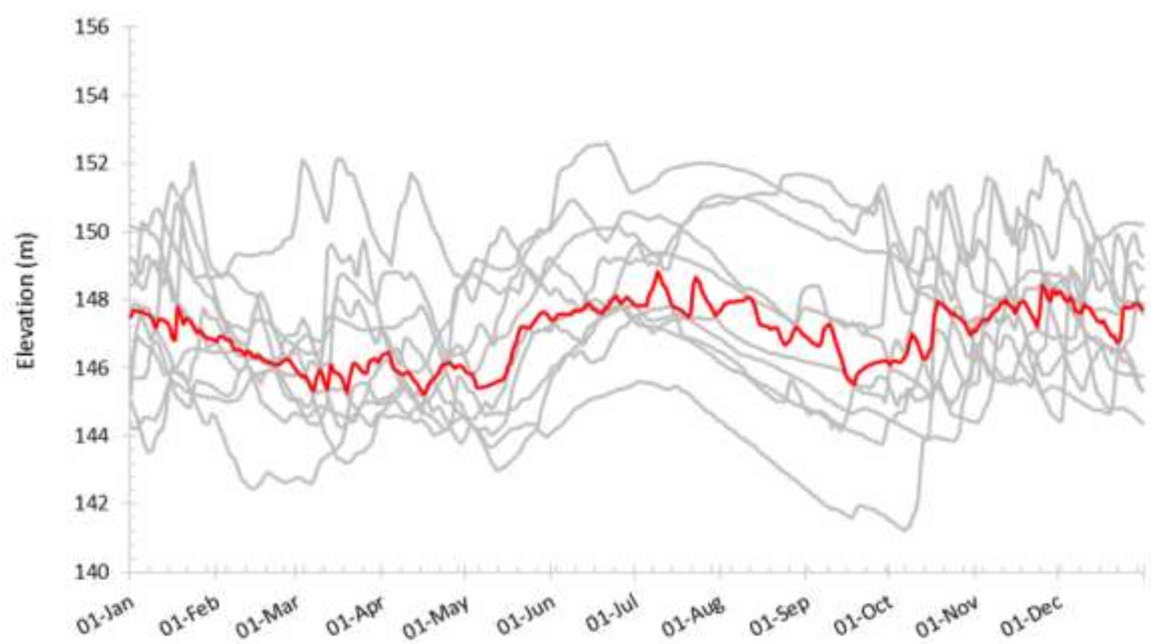

Figure 10 Plot of Coquitlam Lake Reservoir daily average water surface elevations from 2003 to 2013.

It should be noted that pre-2008 fluctuations in reservoir elevation had the potential to directly impact hydraulic conditions in the FVs because FVs were kept fully open year round and changes in elevation determined the discharge out of these structures. Higher elevations created greater discharges and higher velocities through the FVs and increased the distance between the water surface and the intake structures, thus reducing the potential for fish attracting surface flows. The higher velocities in turn likely led to higher mortalities in outmigrating smolts. This fish unfriendly scenario was typical for pre-

WUP operations at the Coquitlam Dam Sluice Tower. After implementation of the WUP-discharges and the installation of the new LLO3, outlet openings were changed to accommodate the changes in water elevation. This in turn led to changes in accompanying velocities in the LLO. For example, a given discharge at high reservoir elevation required a smaller gate opening and hence a faster velocity through the LLO. At low reservoir elevations, a wider LLO opening was required to deliver the targeted discharge, hence lowering velocity through the LLO. The acceleration and turbulence created by changing velocity conditions through the LLO was likely a factor determining the condition and/or extent of mortality in out-migrating smolts. During high velocities through the LLO the plume of water entering the tunnel to the Coquitlam River hits the far wall before cascading to the tunnel floor and then downstream out into the river. This scenario is a source of smolt injury and/or mortality during outmigration. Nevertheless, it appears that low reservoir levels and higher discharges through the new LLO may be the most favourable condition for smolt out migration, especially if the survival through the LLO can be improved through structural changes.

The effects of variable reservoir elevations are not restricted to FV and LLO hydraulics, but have upstream implications as well. The entrance to the forebay, the narrowest spot between the reservoir and the dam outlet, is located about 300 m upstream from the Sluice Tower. Only at low reservoir elevations and high sluice discharges are any fish attracting surface flows possible at the forebay entrance. During high reservoir elevations and low discharges, no surface flows are noticeable and therefore likely no smolt attracting surface flows exist. It has been shown that Sockeye smolts use velocity gradients and that they are negatively rheotactic (Hartman et al. 1967) as a means to detect lake outlets. In the case of Coquitlam Reservoir, the morphology of the forebay and targeted discharges do not create detectable currents to attract out-migrating smolts.

Of all the discharge facilities on the reservoir, water extraction for the GVWD (now Metro Vancouver) drinking water has always been the most stable within a given year and the most consistent between years. From 2003 to 2013, daily median discharge typically centered around 4 m^3/s for much of the year, the only exception being a near doubling of outflow during the summer months (Figure 11). The GVWD water supply intakes are well screened to prevent debris and other organic matter form entering the system. As a result, this outflow has generally been considered to not impact on Sockeye smolt outmigration.

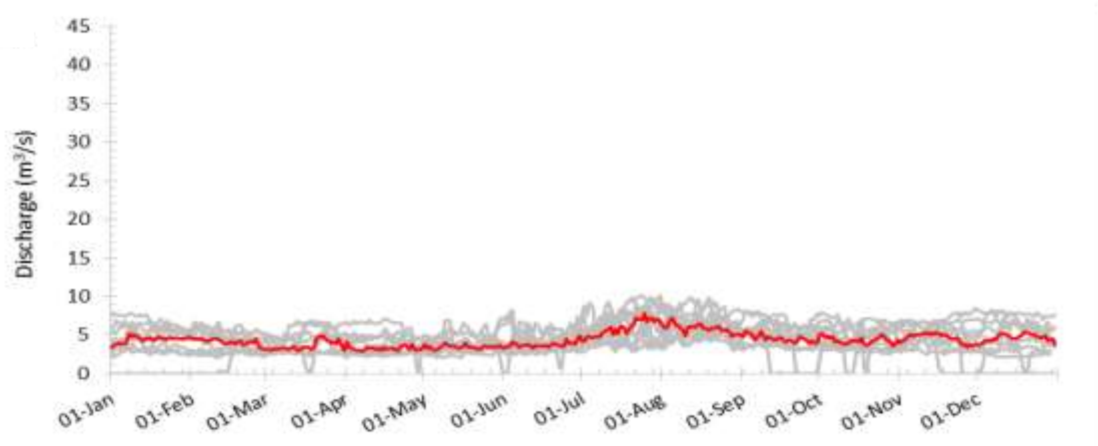

Figure 11 Discharges from the Coquitlam Lake Reservoir, 2003–2013, illustrating the relative constancy and small volume of GVWD extractions (red line, average values over the 2003–2013 period).

Kwikwetlem Salmon Restoration Program (KSRP)

The initial priority of the KSRP is to commence restoration of the Sockeye Salmon run to Coquitlam Reservoir by utilizing the BC Hydro Fish Passage Framework. The KSRP was founded in 2003 and its core team members are representatives of the Kwikwetlem First Nation, Department of Fisheries and Oceans, Metro Vancouver, City of Coquitlam, BC Hydro, the Watershed Watch Salmon Society and the British Columbia Ministry of Environment. Many other organizations have contributed over the years. The KSRP core team meets as required to plan upcoming studies and coordinate the submission of proposals for project funding. The KSRP team partners with local volunteer organizations and consulting companies to build the knowledge base for re-introduction of Sockeye and other salmon species into the reservoir. In addition, the KSRP seeks advice through other subject experts and is supported by many hours of voluntary contribution.

The Past of Coquitlam Reservoir Salmonids from Oral History, Written History and Genetic Results

Archeological evidence suggests the deep-rooted connection of the Kwikwetlem First Nation to the Coquitlam Watershed dates back thousands of years (Koop 2001) and the literal translation of the word “Kwikwetlem” is “red fish up the river”. Therefore, although never scientifically enumerated, the historical Sockeye Salmon runs to the Coquitlam Lake were likely substantial.

Coquitlam Lake, before the construction of the Coquitlam Dam, was also the home to at least three other anadromous salmon species. While Sockeye migrated into the system early from April to July, Coho Salmon entered in October and Chum Salmon and Steelhead Trout were also found in the lake and its tributaries but their migration timing is unknown (Koop 2001). In addition to Kwikwetlem First Nation oral history, the same four species were mentioned by federal and provincial governments in the late 1800s and the early 1900s in context with Coquitlam Lake (Koop 2001).

Although Sockeye Salmon were extirpated from the Coquitlam River watershed following construction of the Coquitlam Dam, a Kokanee population persists to this day in the reservoir. This Kokanee population is likely the offspring of the now extinct anadromous form of Sockeye Salmon and not a "true" or sympatric Kokanee population that co-existed with the anadromous Sockeye. Evidence for this theory is based on genetics and fish morphology. Given the easy access into Coquitlam Lake prior to the construction of the dam coupled with the low productivity of Coquitlam Lake, and the dull coloration at maturity, it is likely that the current Kokanee are direct descendants of the original anadromous Sockeye form. In addition, the genetic fingerprint and morphometric traits (gill raker length and number) of Coquitlam Kokanee are very similar to the ones found in the Sockeye-Kokanee hybrid stock of Alouette Reservoir (Bussanich et al. 2006b; Nelson and Wood 2007). Godbout et al. (2011) also found that re-anadromized Coquitlam Sockeye had low genetic diversity, a typical sign of a population that had survived a genetic bottleneck or originated from very few individuals.

STUDIES ON COQUITLAM SALMON SPECIES HISTORY AND CURRENT ESCAPEMENT

Sockeye Salmon

The primary species of interest for re-establishment into Coquitlam Reservoir is Sockeye Salmon. Sockeye Salmon were (and continue to be) highly valued by the Kwikwetlem First Nation members as a significant portion of their diet (G. Joe, Kwikwetlem First Nation. pers. comm.). Sockeye Salmon also have the greatest biomass production potential as evidenced by the existing Kokanee biomass in the reservoir (Bussanich et al. 2006a; Plate et al. 2011; Plate et al. 2012). Re-establishment of a self-sustaining population of Sockeye Salmon would be considered as part of a corrective action to offset damage done by the construction of the dam, described as a critical footprint impact on the Coquitlam River system (FWCP 2011).

Sockeye Salmon can occur as three distinct ecotypes:

1. An anadromous lake type which rears in lakes as a juvenile before emigrating to the ocean to grow and mature then return to freshwater to spawn and die;
2. An anadromous sea or river type which rears in rivers as a juvenile before emigrating to the ocean to grow and mature then return to freshwater to spawn and die; and
3. A non-anadromous type called Kokanee which spends its entire life cycle in fresh water (Godbout et al. 2011).

The Coquitlam watershed originally supported a run of Sockeye Salmon (Bengeyfield at al. 2001; Koop 2001; Godbout et al. 2011) that returned to the lake in late spring (from April to July). Therefore Gaboury and Bocking (2004) proposed that the probable run timing of Coquitlam Sockeye would be a return of adults from April through July with subsequent spawning from September through November. This timing would lead to egg incubation and in-gravel rearing of alevins from September to March. Smolt migration would likely occur from April to mid-June. It is now known that Coquitlam Sockeye return to the Coquitlam River from July through August, which is later than the historically reported run timing. Migration timing for the re-introduced Coquitlam Sockeye is therefore expected to be similar to the timing for Alouette Reservoir and Pitt Lake Sockeye stocks, which is in line with other Early Fraser River Sockeye stocks (Figure 12).

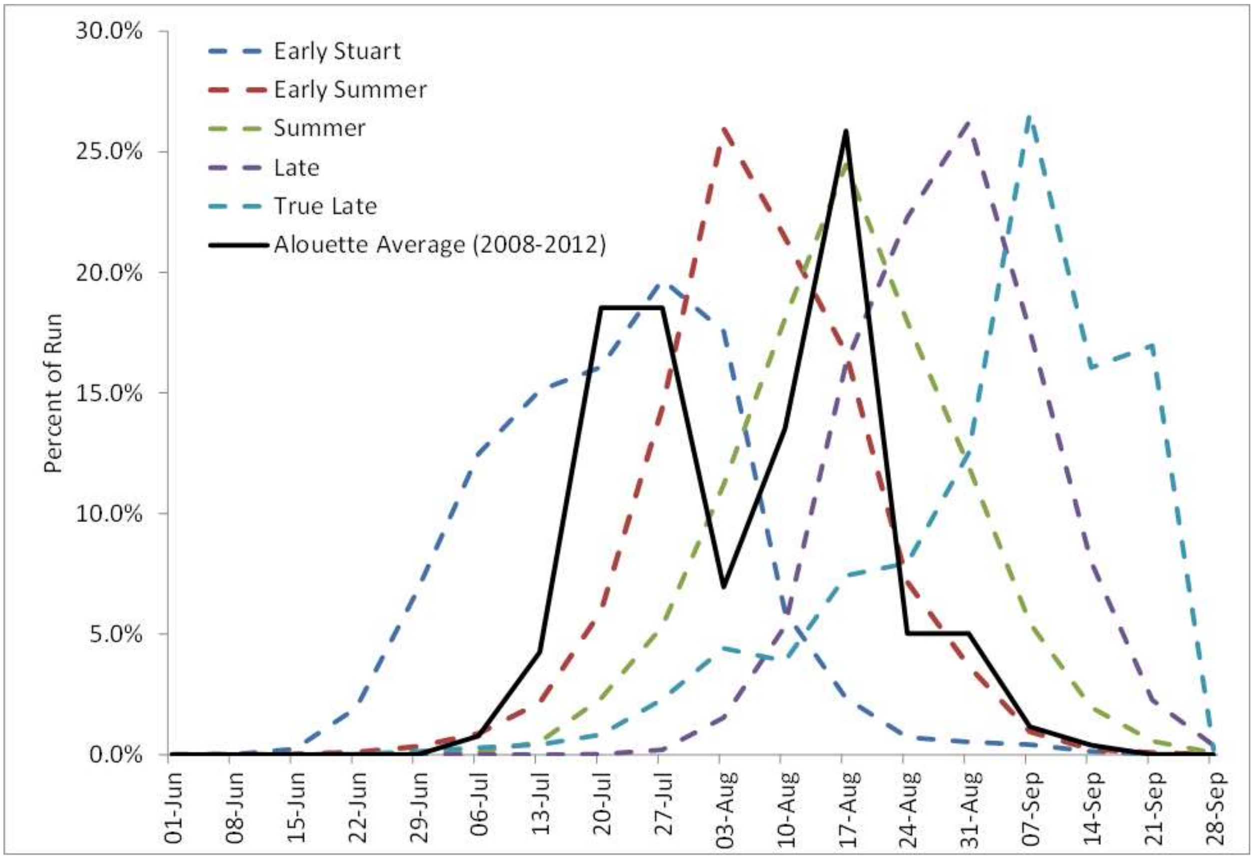

Figure 12 Relative arrival timing of Alouette Sockeye at the ALLCO fish fence in comparison to timing through the lower Fraser River for the main Fraser River run timing groups (02-09 average) (Noble 2011; Plate and Bocking 2013).

Since the return of adult Sockeye to the Coquitlam Reservoir has been monitored starting in 2007, annual return totals have ranged from 11 fish in 2008 to 1 fish in 2009 (Figure 27). While Sockeye movement has not been tracked in the reservoir, it is known that Coquitlam Reservoir Kokanee spawn in October (Plate et al. 2011, 2012) and it is assumed that their direct anadromous descendants would spawn at the same time. Alouette Sockeye descendants from Kokanee showed this behavioural pattern (Plate and Bocking 2010, 2011, 2013).

While Sockeye smolt outmigration from Coquitlam Reservoir since 2005 has been highly variable and at lower levels than have been experienced at Alouette Reservoir the migration timing appears to be similar. Typically, Alouette Sockeye smolts migrate from mid-April until late May or early June (Baxter and Bocking 2006; Humble et al. 2006; Mathews and Bocking 2007, 2009, 2010, 2011; Mathews et al. 2012, 2013, and 2014 *In Press*). Coquitlam smolt estimates at the Rotary Screw Trap (RST) site 3, approximately 1.6 km downstream of Coquitlam Dam, have ranged from a minimum of 19 smolts in 2008 to a maximum of 1,531 smolts in 2005 (Table 5).

Prior to the construction of Coquitlam Dam, anadromous Sockeye Salmon likely spawned along the shores of Coquitlam Lake and in its adjoining tributaries. Current studies have been researching the genetic linkage between the recent observations of Kokanee Salmon (Sockeye Salmon) smolts migrating from the Coquitlam Reservoir and the returning Sockeye Salmon adults. These studies have determined that the outmigrating smolts were the progeny of the Coquitlam Reservoir Kokanee Salmon population (Nelson and Wood 2007; Godbout et al. 2011). These genetic investigations also suggest that the Coquitlam Kokanee Salmon population originated from relatively few anadromous individuals that residualized after their downstream migration was blocked (Nelson and Wood 2007; Godbout et al. 2011).

Coho Salmon

Coho Salmon likely used several Coquitlam Lake tributaries for spawning prior to dam construction and entered the system annually in October (Koop 2001). The lower reaches of Cedar Creek, Beaver Creek, and the lower reaches of the Upper Coquitlam River, all now inundated, appeared to have been used by Coho Salmon for spawning (Koop 2001; Bocking and Gaboury 2003). The number of Coho Salmon returning to any tributary before dam construction is undocumented but the timing of different life stages currently found in the Lower Coquitlam River was likely the timing for the same stages in the reservoir tributaries before the dam was built. Coho Salmon currently start to enter the river in late October to spawn in November and December and their eggs incubate until April–May (Figure 13). Typically, following a one year freshwater residence, Coho smolts leave the system from April to June.

Following dam construction, Chum, Coho, Steelhead and Pink Salmon continued to return the Coquitlam River below the dam in substantial numbers until the mid-1950s after the results of a large landslide and flood control dredging and channelling damaged much of the river bed. While some records of escapement numbers exist for the period between dam construction and 2001, reliable escapement numbers for all salmon species and Steelhead trout were gathered from 2002 through 2012 as part of COQMON-7, the “Lower Coquitlam River Fish Productivity Index” (Schick et al. 2013).

Based on fish counts and subsequent Area Under the Curve (AUC) estimates in combination with mark recapture experiments carried out by Schick et al. between 2002 and 2011, Coho escapement to the lower Coquitlam River ranged from 878 fish in 2008 to 12,338 fish in 2010 (36–480 females/km) (Figure 14) with a decadal average of 4253 (±3,556 STDEV) (Schick et al. 2013). Within this range, the three largest escapements were estimated for the last three years of data available from 2010 to 2012.

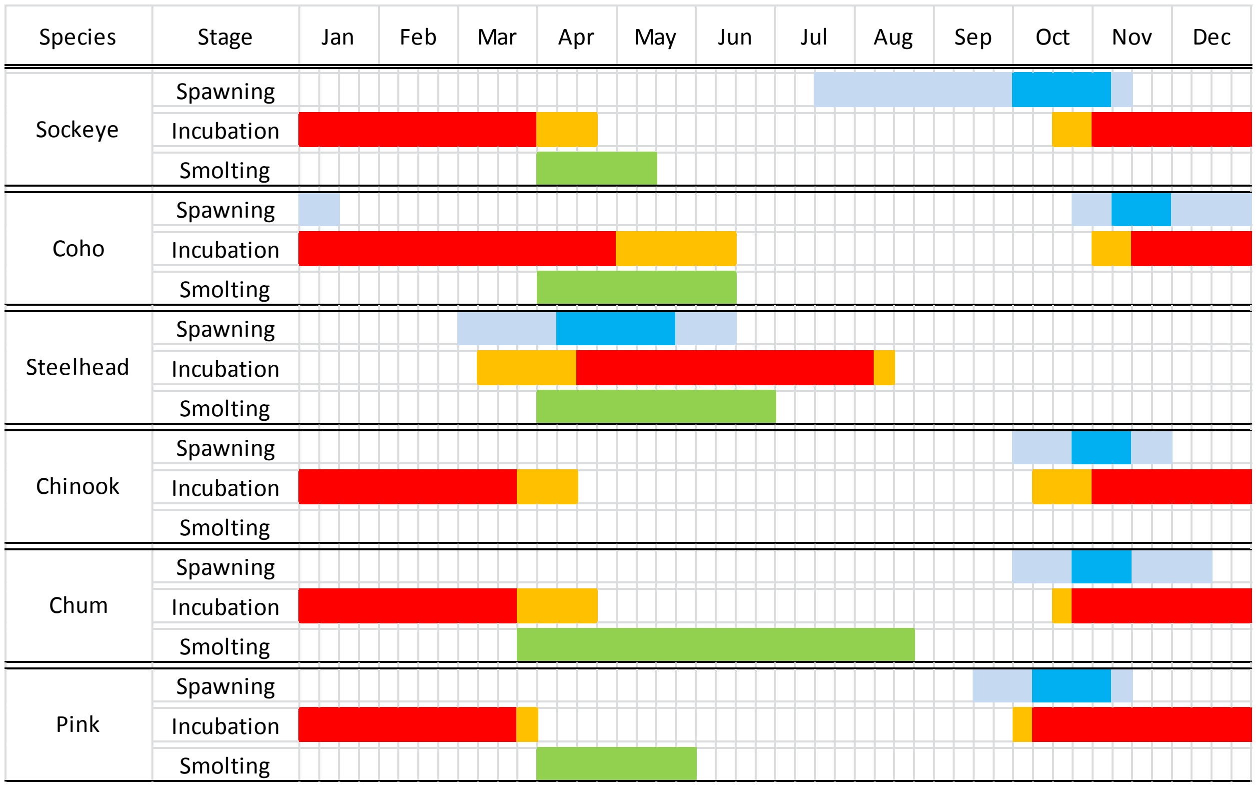

Figure 13 Timing of Coho, Steelhead, Chinook, Chum and Pink Salmon spawning, incubation and smolting in the Lower Coquitlam River based on COQMON-7 and assumed timing for the same stages for Sockeye (Data: Bocking and Gaboury 2003; Schick et al. 2013).

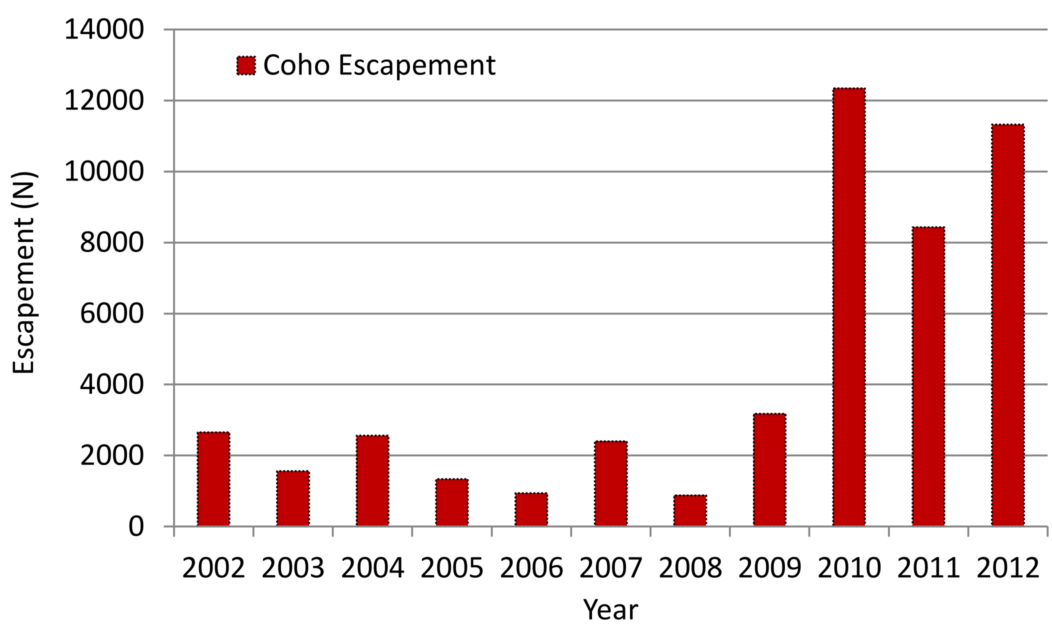

Figure 14 Coho escapement into Coquitlam River below Coquitlam Dam from 2002 to 2012 based on AUCs and mark recapture experiments (Data: Schick et al. 2013 COQMON-7).

For Coho Salmon, passage from the Lower Coquitlam River into Coquitlam Reservoir would increase the available spawning and rearing habitat. The amount of this spawning and rearing habitat, without further intervention, would likely only support several hundred female Coho (Gaboury and Murray 2006) as most of the historic habitat is now inundated. For a more accurate estimate of the habitat that would be available above Coquitlam Dam for Coho Salmon, further field work would need to be carried out.

Steelhead

Steelhead used the habitat upstream of Coquitlam Dam before its construction but escapement numbers or knowledge about the historic system entry timing are unknown (Koop 2001). Current timing for all freshwater life stages in the Lower Coquitlam River (Schick et al. 2013) below the dam may still reflect historic timing of stages in the habitat above the dam. Steelhead enter the Lower Coquitlam River in early February to spawn in April and May (Figure 13). Their eggs incubate from March to early August and following a 1–3 year freshwater residence, Steelhead smolts leave the system from April to June for the ocean. Steelhead restoration above Coquitlam Dam cannot be addressed until two way fish passage exists to accommodate out migrating kelts (spawned out adults).

From 2002 to 2011, Steelhead escapement to the Lower Coquitlam River was assessed annually as part of COQMON-7 and the results are shown in Figure 15 (Schick et al. 2013). Steelhead escapement ranged from a minimum of 225 fish in 2009 to a maximum of 868 fish in 2006 (Figure 15). The average escapement for the period was 395 fish with a standard deviation of ± 218 fish.

Steelhead trout are not known for beach spawning in lakes so their historical spawning locations were likely in the lower reaches of Beaver Creek, Cedar Creek, the Upper Coquitlam River. The majority of these reaches was inundated when the reservoir was created. Therefore the amount of available spawning and rearing habitat without further intervention appears to be small and likely supports less than 100 female Steelhead (Gaboury and Murray 2006). To confirm the suitability for Steelhead re-establishment into these systems additional study may be required.

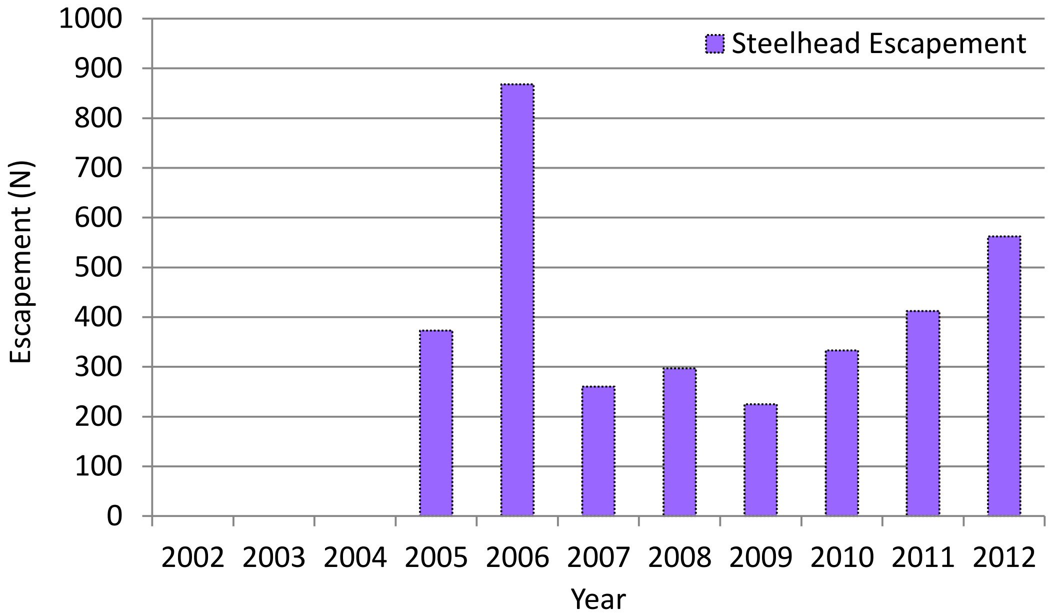

Figure 15 Steelhead escapement into Coquitlam River below Coquitlam Dam from 2002 to 2012 (Data: Schick et al. 2013).

Chum and Pink Salmon

Neither Chum nor Pink Salmon were reported to historically have spawned above the Coquitlam Dam before its construction (Koop 2001) but they still spawn in good numbers downstream of the dam.

Chum and Pink escapements to the Lower Coquitlam River were estimated from 2002 to 2011, as part of COQMON-7. Based on fish counts and subsequent Area Under the Curve (AUC) estimates in combination with mark recapture experiments carried out by Schick et al. (2013) between 2002 and 2011, Chum escapement ranged from a minimum of 6,931 fish in 2010 to a maximum of 51,860 fish in 2006 (Figure 16). The average escapement for the period was 22,132 fish with a standard deviation of ± 12,416.

Larger numbers of Pink Salmon only enter the Coquitlam River in odd numbered years and their escapement ranged from a minimum of 2,944 fish in 2007 to a maximum of 10,598 fish in 2009 (Figure 17). The average escapement for the period was 6,733 fish with a standard deviation of ± 3,560.

It is unknown whether Chum or Pink Salmon would take advantage of fish passage over Coquitlam Dam if it were re-established based on their typical occupation of the lower reaches of many coastal rivers.

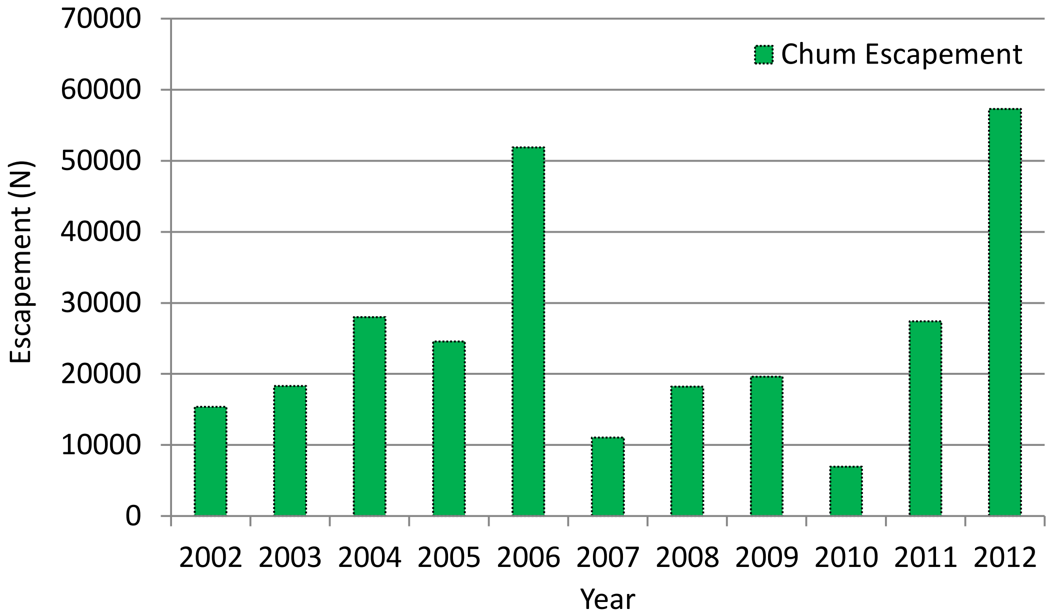

Figure 16 Chum escapement into Coquitlam River below Coquitlam Dam from 2002 to 2012 (Data from: Schick et al. 2013).

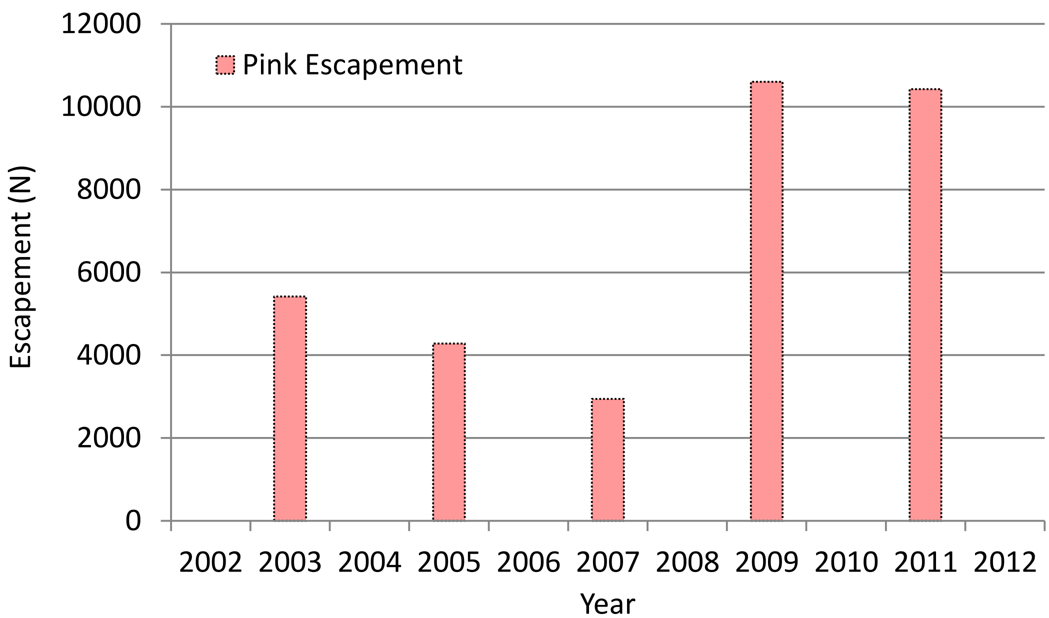

Figure 17 Pink escapement into Coquitlam River below Coquitlam Dam from 2002 to 2012 (Data from: Schick et al. 2013).

Chinook Salmon

Chinook Salmon were not reported to have spawned above the Coquitlam Dam before its construction (Koop 2001) but their escapement to the lower Coquitlam River, due to enhancement efforts, has recently increased.

As part of COQMON-7, Chinook escapement to the Lower Coquitlam River was estimated for four years from 2008 to 2011 (Schick et al. 2013) and the results are shown in Figure 18. Escapement ranged from a minimum of 952 fish in 2008 to a maximum of 8,018 fish in 2010 and the average escapement was 3,854 fish with a standard deviation of ± 3,281.

Chinook Salmon are typically main stem spawners that do not migrate through lakes to reach tributaries for spawning. It is therefore unlikely that Chinook would take advantage of fish passage over Coquitlam Dam should it be re-established. Even if Chinook would use a fish ladder the amount of spawning habitat available to them would be small.

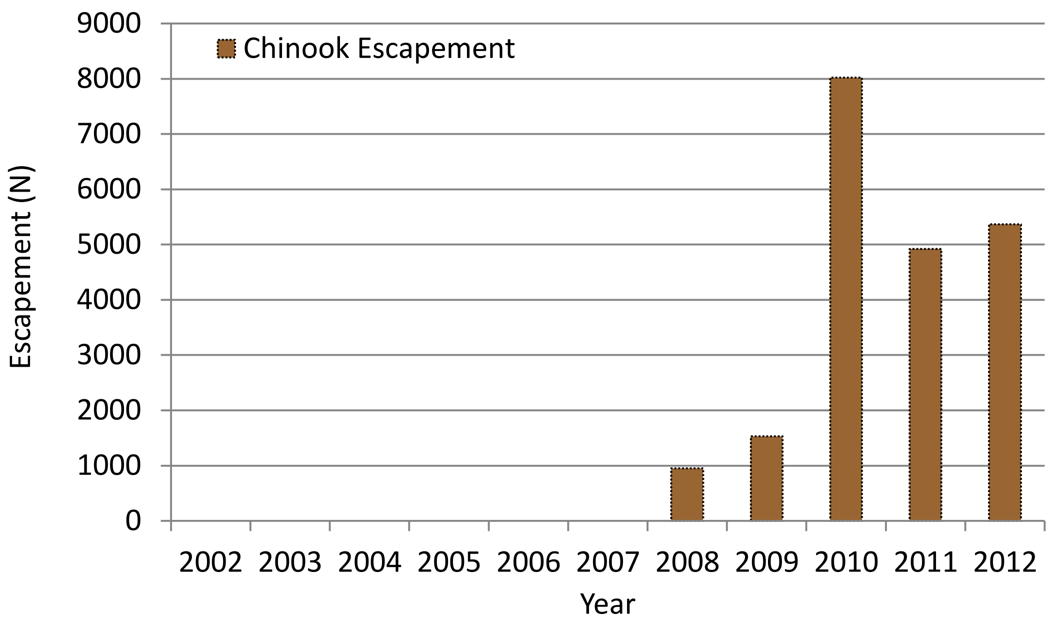

Figure 18 Chinook escapement into Coquitlam River below Coquitlam Dam from 2002 to 2012 (Data from: Schick et al. 2013).

LOWER COQUITLAM RIVER HABITAT ENHANCEMENT

Over the last 30 years many habitat improvement projects have been started or completed in the Coquitlam River Watershed below Coquitlam Dam. The funding for these projects was provided as compensation for loss of habitat or access to stream areas as a result of initial damming for hydropower generation and later use of the reservoir as a drinking water source. In addition compensation funding was provided to mitigate urban development leading to encroachment on the Coquitlam Watershed. Moreover, all of these initiatives were supported by DFO working with many volunteers that contributed many hours of labour to re-create a total of >30,000m² of formerly lost spawning and rearing habitat that support tens of thousands of Coho, Chum, Pink, Steelhead and Cutthroat Trout. Table 2 summarizes these habitat improvement projects and the benefit they provided to the Lower Coquitlam River and its tributaries.

Table 2 Summary of Coquitlam River and tributaries habitat improvement projects (from: Coquitlam River Watershed 2013).

Project Name and Installation Year	Funders and Volunteers	Project Location and Type	Habitat Creation or Improvement
Swoboda Channel, (mainstem)	BC Hydro, Community Fisheries, DFO	Below Coquitlam Dam, spawning channel	Ideal spawning habitat for salmon and trout
Grant's Tomb Project, 1993 (mainstem)	DFO, BC Hydro, Port Coquitlam Hunting and Fishing Club	Below Coquitlam Dam, pond with small dams	Juvenile salmon rearing habitat for 2,200 Coho smolts
Large Woody Debris Placement, 1998−1999 (mainstem)	DFO	Upper Coquitlam Park	Stream cover and scour pools for juvenile Coho and Steelhead rearing
Orr Creek Channel and Ponds (tributary)	DFO, BC Hydro, Port Coquitlam Hunting and Fishing Club, BC Watershed Restoration Program	Orr Creek, stabilization of logging affected banks and building of rearing ponds	Decrease siltation in Coquitlam River, create rearing and 3,000 m² of spawning habitat for 3,000 Coho smolts, 25,000 Chum fry
Slade Creek Fish Ladder and Ponds Habitat Compensation (tributary)	DFO	Slade Creek, fish ladder, rearing ponds	Facilitate access to Coho spawning habitat and provide juvenile Coho rearing habitat
Archery Range Improvements, 1994 (mainstem)	City of Coquitlam, DFO, BC Hydro	Archery Range, rearing ponds, spawning habitat	Create rearing habitat for juvenile Coho and Steelhead
Overland Off-Channel Habitat, 2002 (mainstem)	Port Coquitlam District Hunting and Fishing Club, DFO, BC Hydro	100 m north of Pritchard Creek confluence, rearing ponds	Rearing habitat for juvenile Coho, Steelhead and Cutthroat, wetland habitat creation
Oxbow Lake, 2009 (mainstem)	DFO, BC Hydro, River Springs Strata, City of Coquitlam	River Drive, re-connection of lake to Coquitlam River	Creation of 2,600 m² of juvenile rearing habitat and 5,000 m² of spawning habitat
Grist Channel, 1997 (tributary)	DFO, Maple Creek Streamkeepers	Grist Channel, Coquitlam River Park, channel rehabilitation and construction	Creation of 1,500 m² of spawning and 1,000 m² rearing habitat for Coho, Chum, Steelhead and Cutthroat

Project Name and Installation Year	Funders and Volunteers	Project Location and Type	Habitat Creation or Improvement
Maple Creek Well, 1997 (tributary)	DFO, Maple Creek Streamkeepers, Fisheries Renewal BC, Forest Renewal BC, BC Hydro	Maple Creek, well	Well to increase water flow at natural low flow periods, creation of 1,000 m² of rearing and 1,500 m² of spawning habitat for Coho
Riverview Sheep Paddock Pond, 2004 (mainstem)	North Fraser Salmon Assistance Program, DFO, Metro Vancouver, Burke Mountain Naturalists, Colony Farm Park Association	Colony Farm, pond and high tide water delivery system	Creation of 7,000 m² of salmonid rearing habitat for Coho smolts and 9,000 m² of wildlife habitat
Wilson Farm Habitat and Water Level Improvements, 2010 (mainstem)	Port Mann/Highway 1 Improvement Compensation Funding	Wilson Farm, ponds, water flow systems, native plantings	Creation of fish rearing as well as amphibian and other wildlife habitat
Various Ongoing Habitat Compensation Programs		Throughout the Lower Coquitlam River area	Creation of fish rearing and spawning habitat

COQUITLAM RESERVOIR STUDIES

Coquitlam Reservoir Productivity, Plankton and Water Chemistry

Over the last ten years several studies were carried out to investigate the Coquitlam Reservoir productivity. The following three main studies summarize those efforts:

- Bussanich et al. (2005, 2006a) assessed water chemistry and primary productivity as well as phyto- and zoo-plankton abundance and composition to determine whether the re-introduction of Sockeye Salmon would be rearing limited.
- Nordin and Mazumder (2005) undertook a study to determine whether the lack of salmon derived nutrients following dam completion can be seen in changes to the nutrient composition of bottom cores.
- Stockner and Vidmanic (2014) investigated the phyto- and zoo-plankton community to assess the ongoing suitability of Coquitlam Reservoir as a drinking water source and its suitability for Sockeye re-introduction.

The current plankton biomass levels and plankton densities place Coquitlam Reservoir among the lowest recorded in the Canadian aquatic science literature for north temperate lakes (Stockner and Vidmanic 2014). In this ultra-oligotrophic state, phytoplankton communities are dominated by small pico-cyanobacteria and mobile flagellates. These phytoplankton species are characterized by rapid growth rates, rapid nutrient recycling in fast-flushing, low production ecosystems (Stockner and Vidmanic 2014).

The zooplankton community in Coquitlam Reservoir is dominated by cladocerans, notably Daphnia, and copepods and their overall densities are lower than in fertilized reservoirs in British Columbia (Figure 19) but in line with other ultra-oligotrophic reservoirs in coastal British Columbia such as Capilano and Seymour Reservoirs (Stockner and Vidmanic 2014) and ultra-oligotrophic lakes in Alaska (Kyle et al. 1988). In summary, while low, the zooplankton productivity of Coquitlam Reservoir would likely not be a limiting factor for the production of Sockeye smolts that would support a Sockeye spawner population of 2,000–15,000 fish.

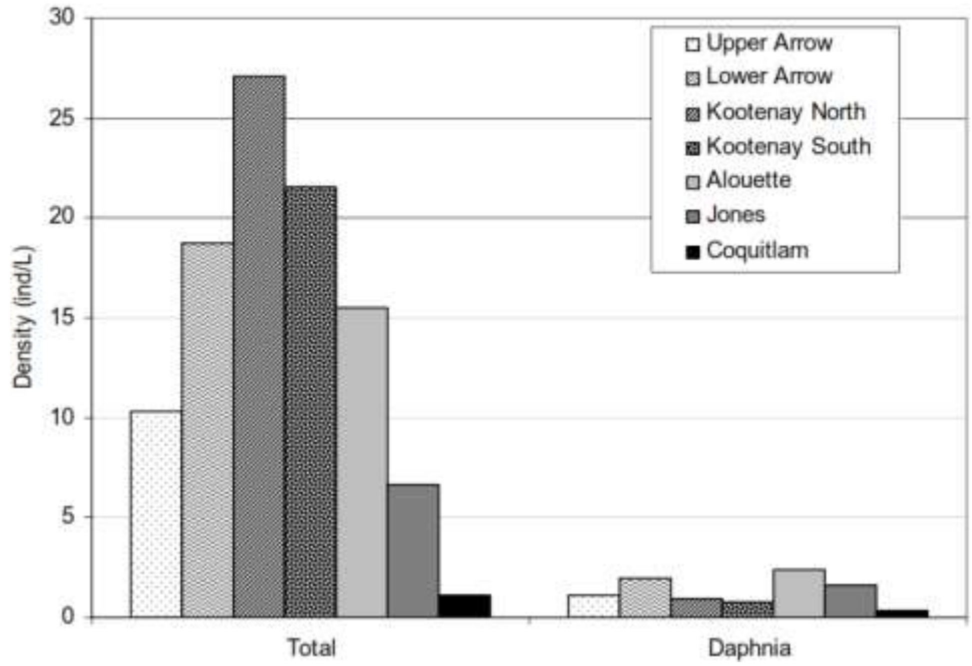

Figure 19 Zooplankton densities in fertilized BC reservoirs in comparison to the unfertilized Coquitlam Reservoir (Presentation Dr. John Stockner 2014, Eco Logic).

The reasons for low primary productivity include the interactive effects of climatic, hydrologic and biogeographic conditions. Perhaps the most important of these being high rainfall events that create rapid flushing, and short water residence times, resulting in a large export of biogenic production. The rapid flushing also leads to very low sedimentation rates of pelagic material (<1 mm/year) and little storage of nutrients in the benthos. The high proportion of granitic bedrock and shallow, organic and till soils will assure the perpetuation of this ultra-oligotrophic condition. Therefore Coquitlam Reservoir Total Phosphorus (TP) and Total Nitrogen (TN) concentrations are very low ranging from 2–3 µg/L and 100–200 µg/L, respectively (Bussanich et al. 2006a). As a consequence of such low nutrient availability, Chlorophyll a summer concentrations are also very and low with <0.5 µg/L (Mavinic et al. 2012) but in line with other ultra-oligotrophic reservoirs such as Capilano or Seymour (Stockner and Vidmanic 2014).

In addition, acid rain falling on poorly buffered bedrock gradually creates acidity within the reservoir and the pH in the summer months during high biological demand for HCO_3^- can be as low as pH 5.5 to 6.0. The low summer pH values also present ideal conditions for the phytoplankton dominance of *Merismopedia*, a colonial acidophilic blue-green algae (Figure 20). *Merismopedia* is not grazed by zooplankton and therefore represents a nutrient sink. *Merismopedia* dominance prevents the transfer of part of the reservoir nutrients into higher trophic organisms such as fish.

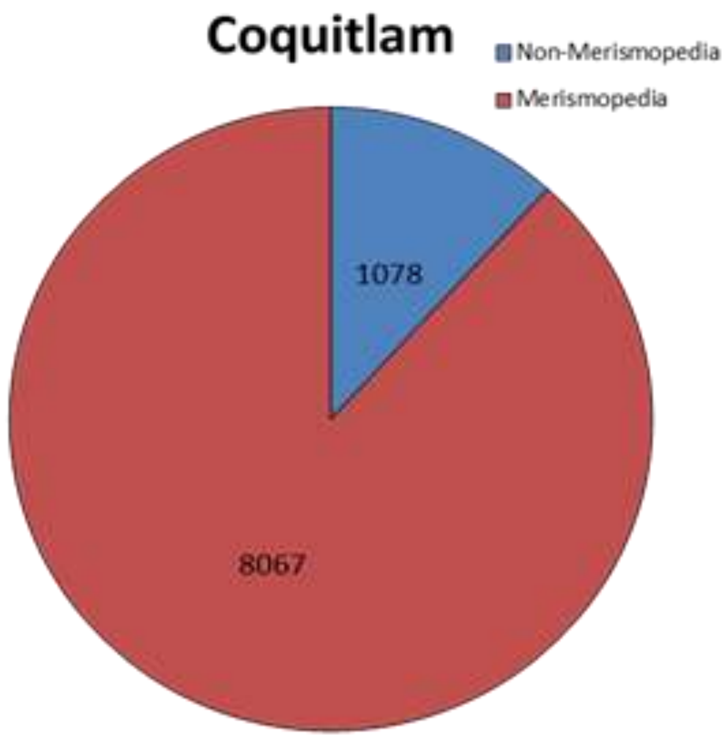

Figure 20 The proportion of average cell density (cells/mL) for *Merismopedia* and non-*Merismopedia* organisms in Coquitlam Reservoir (Stockner and Vidmanic 2014).

In addition to the aforementioned studies on productivity, bottom coring was carried out to assess whether the lack of marine nutrients from salmon imported to the reservoir following dam construction was visible in the benthic nutrient and phytoplankton record. This paleolimnological work showed that there had been no major shift in productivity over the 200 year period covered by the core samples (Donald et al. 2012). The only change in the record was the small and gradual increase in lake productivity that began at the time of dam construction in the early 1900s until 2011. Ocean derived salmon nutrients therefore never had a significant role in the lake's nutrient budget prior to impoundment. This aligns well with the Sockeye smolt and adult biomass estimates produced in this report and the hydroacoustic estimates of the current Kokanee smolt and spawner biomass.

Coquitlam Reservoir Drinking Water and Salmon Re-Establishment

The ultra-oligotrophic and clear water of Coquitlam Reservoir is used as the source of approximately one-third of Metro Vancouver's domestic drinking water. The potential of degradation of the drinking water quality by re-introduced salmon was investigated in several studies. Perrin et al. (2007) evaluated the hypothesis that the re-establishment of a large Sockeye run may lead to changes in quality of water that is withdrawn into the distribution system of Metro Vancouver through 5 major pathways: 1) an increase in nutrient loading from decomposition of salmon and a subsequent increase in algal biomass, 2) an increase in the incidence of pathogens (bacteria, viruses, protozoans, Giardia, Cryptosporidium and various parasitic worms) from salmon and from wildlife that feed on spawning salmon or salmon carcasses, 3) an increase in the concentrations of marine derived contaminants that are carried into the reservoir by salmon, 4) an increase in concentrations of disinfection by-products and odour producing compounds caused by organic matter from salmon decomposition combined with chlorine at the treatment plant, and 5) an increase of turbidity caused by physical disturbance of substrates during salmon spawning.

Several studies were funded over the last ten years to investigate the potential for changes to the drinking water quality by salmon nutrient addition. The following two studies summarize those efforts:

- Perrin et al. (2007) assessed the potential consequences of salmon re-introduction for drinking water quality.
- Donald et al. (2012) reported on a series of studies carried out by a drinking water expert panel assembled by Metro Vancouver. In these studies a combination of desk-top and field work was undertaken to suggest the consequences of marine nutrient addition for different sizes of re-established Sockeye runs.

The conclusion from both reports is that none of the five pathways of change will affect drinking water quality in Coquitlam Reservoir for the following reasons (Perrin et al. 2007; Donald et al. 2012):

Pathway (1) Nutrient contribution from a Sockeye population of <20,000 fish will only add 11% of Total Dissolved Phosphorus (TDP) and therefore not lead to algae blooms or change the ultra-oligotrophic state of Coquitlam Reservoir. This assumption was agreed to by Metro Vancouver.

Pathway (2) No additional pathogens from fish predators such as bears are expected if all Sockeye are deep water reservoir spawners similar to the Kokanee that they are direct descendants of. Predators cannot reach spawners in deep water and following spawning all Kokanee sink right to the bottom of the reservoir. The same is expected for post-spawn Sockeye.

Pathway (3) The concentrations of added contaminants from Sockeye carcasses will be so minimal that it will be several orders of magnitude below detection threshold and therefore not influence drinking water quality.

Pathway (4) Disinfection by-products to deal with added organic fish matter would not be created since all of the organic matter would be readily taken up by the natural micro-flora of the reservoir. In addition, an experiment showed that added nutrients did not lead to the creation of toxic disinfection by-products.

Pathway (5) The potential for an increase in turbidity by physical disturbance during spawning was also categorized as low unless Sockeye would spawn close to the water intake and would dig redds rather than broadcast spawn without any red digging. At this point, no Kokanee spawning activity has been observed close to the drinking water intake and it is expected that Sockeye do not deviate from this behaviour.

Coquitlam Reservoir Fisheries Productivity

The fisheries productivity and rearing capacity of Coquitlam Reservoir for juvenile Kokanee and Sockeye Salmon is crucial information for setting realistic escapement goals for a re-introduced Sockeye population. Rearing capacity can be estimated using:

1. **Euphotic zone depth** as an indirect measure of primary productivity based purely on potential photosynthetic activity in the light penetrated layer of the lake (Koenings and Burkett 1987). Aside from light penetration, primary productivity is also based on nutrient availability and therefore this model typically overestimates primary productivity and fish rearing capacity in nutrient poor, clear and ultra-oligotrophic lakes such as Coquitlam Reservoir.
2. **Zooplankton biomass** (Koenings and Kyle 1997) as an indirect measure of primary productivity based on the secondary trophic level or zooplankton. Total Sockeye smolt biomass and seasonal mean macro-zooplankton biomass for the growing season (May–October) preceding smolting have been shown to be highly correlated for Sockeye lakes ($r^2 = 0.92$; Koenings and Kyle 1997). Koenings and Kyle (1997) determined that, for 18 BC and Alaskan Sockeye lakes, Sockeye smolt biomass (kg/km^2) was 2.11 times seasonal mean macro-zooplankton biomass (mg/m^2). Applying this relationship (Zooplankton Biomass Model) to Coquitlam zooplankton data for 2004 and 2005, it is possible to predict total sockeye biomass at smolting. If, for any reason, the flow of nutrients from the primary trophic level or phytoplankton to the secondary trophic level or zooplankton is limited, this model will overestimate fish rearing capacity. In Coquitlam Reservoir, the blue-green algae *Merismopedia* represents the dominant phytoplankton species and *Merismopedia* is not grazed upon by zooplankton organisms and therefore represents a nutrient sink. Therefore, the zooplankton biomass model likely overestimates the fish rearing capacity of Coquitlam Reservoir.
3. A simple application of typical **smolt biomass** in ultra-oligotrophic coastal lakes to Coquitlam Reservoir (K. Hyatt, DFO PBS Nanaimo, pers. comm.). This approach is based on empirical fish biomass data collected in environments with physical and biological characteristics similar to the ones found in Coquitlam Reservoir and should therefore be well suited to estimate smolt rearing capacity in Coquitlam Reservoir. K. Hyatt (pers. comm.) suggested that non-glacial, coastal oligotrophic lakes could produce between 1.5 and 5.0 kg/ha of Sockeye fry biomass in the fall with typical values between 2.0 and 3.0 kg/ha. For Coquitlam Reservoir, likely the lower end of the spectrum applies.
4. **Direct measure of fish biomass** using hydroacoustic surveys that were carried out in Coquitlam Reservoir in 2005 (Bussanich et al. 2006a), 2010 (Plate et al. 2011) and 2011 (Plate et al. 2012). The signal strength of the targets detected in those surveys can be translated into fish length and with knowledge of the fish species composition and their lengths at age, the biomass or number of Kokanee smolts can be estimated. Since Coquitlam Reservoir is a drinking water source for Metro Vancouver and access to it is restricted, no fishing pressure exists and its fish biomass should only be limited by natural factors such as food availability, spawning habitat availability and predation. How these factors play together to determine rearing capacity is unique to each body of water and therefore the current biomass or number of Kokanee smolts should be a realistic indicator for Sockeye smolt rearing capacity in the future.

The results of the application of all four methods to estimate rearing capacity of Kokanee and/or Sockeye in Coquitlam Reservoir are summarized in Table 3.

Each estimate of smolt biomass was converted to numbers of smolts by dividing by the mean weight of smolts. Although there are no data available for what the average weight of a Coquitlam sockeye smolt might be, a suitable proxy is the average weight of 4.5 g for Kokanee 1+ 'smolts' that emigrated from the Alouette Reservoir (Mathews et al. 2013).

In summary, the rearing capacity estimates for Coquitlam Reservoir Age 1+ Kokanee smolts range from 39,000–411,000 (Table 3). Kokanee smolt numbers based on hydroacoustic surveys over three years ranged from 39,000–82,000 standing stock of Kokanee smolts in Coquitlam Reservoir. The latter number of Kokanee smolts is currently produced within the limitations of the reservoir and will therefore likely represent the future smolt production for Kokanee and/or Sockeye well. Assuming that all smolts produced in the reservoir would outmigrate and applying the Alouette survival of 1% from smolt to adult, Coquitlam Reservoir would produce a Sockeye escapement of 390–820 fish from its current Age 1+ smolts. These numbers would likely be supplemented by similar numbers of Age 2+ smolts to produce a total escapement of 780–1,640 fish based on the current proportions of Age 1+ and Age 2+ Kokanee (Plate et al. 2011, 2012).

Survival from smolt to adult stage in the reservoir is expected to be higher than in the ocean based on fewer predators and more evenly distributed food but individual fish are expected to be much smaller at spawning in the reservoir based on a much smaller amount of food available. Based on hydroacoustic survey estimates, Kokanee escapement (Age 3+ and 4+) was much higher (14,560 fish) than the suggested Sockeye escapement (780-1,640 spawners) in 2005, but was similar to the suggested Sockeye escapement (1,880 fish) in 2010 and (2,520 fish) in 2011. Based on these numbers it appears realistic to suggest a carrying capacity range of 1,880–14,560 Kokanee and a range of 2,000–15,000 Sockeye spawners based on the models summarized in Table 3.

Table 3 Comparison of three model estimates of Sockeye smolt biomass, smolt numbers and required spawners compared to 2005, 2010 and 2011 Kokanee fall fry (Age 0+ and 1+) standing crop estimates from hydroacoustic surveys in Coquitlam Reservoir.

Method	Year	Lake Area (ha)	Comments	Estimated Fall Smolt Standing Crop (kg)	Estimated Spring Smolt Standing Crop (kg)	Estimated Spring Smolt Numbers (N)	Estimated Eggs Required (N)	Estimated Female Spawners Required (N)	Estimated Male & Female Spawners Required (N)
Model based on Euphotic Zone Depth EZD=12 m (Bussanich et al. 2006) and 144 EV units (Koenings and Burkett 1987)		1,200		16,522	11,565	2,570,089	85,669,630	34,268	68,536
Model based on typical Sockeye smolt biomass (high 5 kg/ha, Low 1.5 kg/ha) in highly oligotrophic costal lakes (Hyatt, personal communication)		1,200	Low density estimate	1,800		280,000	9,333,333	3,733	7,467
Model based on zooplankton biomass (Koenings and Kyle 1997)	2004	1,200	Biomass 73 mg/m²	2,403	1,848	410,747	13,691,556	5,477	10,953
	2005	1,200	Biomass 45 mg/m²	1,481	1,139	253,200	8,440,000	3,376	6,752
Observed Coquitlam Reservoir 2005 Kokanee (Age 0+ and 1+) standing crop based on hydroacoustic surveys (Bussanich et al. 2006)	2005	1,200	Average smolt weight 4.5 g	529	370	82,289	2,742,963	1,097	2,194
Observed Coquitlam Reservoir 2010-2011 Kokanee (Age 0+ and 1+) standing crop based on hydroacoustic surveys (Plate et al. 2011; Plate et al. 2012)	2010	1,200	Average smolt weight 4.5 g	253	177	39,356	1,311,852	525	1,049
	2011	1,200	Average smolt weight 4.5 g	512	358	79,644	2,654,815	1,062	2,124
Mean of all estimates excluding EZD Model				1,163	779	190,873	6,362,420	2,545	5,090
Mean of all estimates based on empirical data				1,036	779	173,047	5,768,237	2,307	4,615
Mean of all estimates based on hydroacoustics				431	302	67,096	2,236,543	895	1,789

Coquitlam Reservoir Spawning Habitat Availability

In 2005 and 2006, qualitative surveys were carried out to assess spawning habitat in Coquitlam Reservoir and its tributaries, with the goal to determine whether or not re-introducing anadromous salmon upstream of the Coquitlam Dam would be constrained by available spawning capacity (Bussanich et al. 2005; Gaboury and Murray 2006). As part of these surveys, it was found that Kokanee did not appear to be using any tributaries for spawning and that instead all Kokanee spawning habitat was concentrated in certain areas of the reservoir shore in elevations between 144–125 m.

Beaver and Cedar creeks were found to provide approximately 1,000 m^2 of spawning habitat that would support about 600 female Sockeye but this habitat is not currently used by Kokanee and would realistically be better suited for Coho spawning.

Shoreline sites with concentrations of Kokanee were assessed using a towed underwater video system or Seabed Imaging and Mapping System (SIMS) to determine the distribution and habitat characteristics of potential lake spawning sites. Three creek fan sites were found to offer potential reservoir spawning habitat below the 140 m contour. The 140 m contour represents the reservoir depth with an eight out of ten year likelihood of inundation during all of the egg incubation period (based on 1984–2005 elevation data). Between the 125–140 elevation contours, the potential spawning capacity at the three fan areas was estimated at about 3,400 female Sockeye or Kokanee Salmon. For this number of spawners, it was assumed that fish broadcast-spawn over gravel, cobble and boulder substrates in addition to active red digging in smaller substrates.

Gaboury and Murray (2006) explored several options to provide additional spawning habitat through: 1) creation of spawning channels, 2) gravel addition to existing fans, or 3) by opening the higher quality spawning habitat above a natural fish barrier in Upper Coquitlam River. The best opportunity for effective lake spawning habitat enhancement through addition of spawning gravel was suggested for the fan at the mouth of Harmony Creek below the 140 m contour. The creation of stream spawning habitat using man-made side channels did not appear feasible due to site morphology paired with the widely fluctuating elevation changes of the reservoir.

Gaboury and Murray (2006) also suggested that establishment of fish passage over the natural fish barrier in the Upper Coquitlam River could open access to approximately 31,000 m^2 of additional spawning habitat for Sockeye and Coho Salmon as well as Cutthroat trout. Due to regulatory complexity, this option is not being pursued further at this time.

In summary, the combined spawning habitat capacity for Coquitlam Reservoir was estimated to be equivalent to that necessary to support the spawning of approximately 3,400 Sockeye females, or a total 6,800 Sockeye, without intervention. In addition, the reservoir tributaries offer spawning habitat for a smaller number of Coho and Steelhead without any intervention. The most promising options for habitat enhancement appear to be gravel addition in a few suspected spawning locations along the reservoir shoreline.

Non-Kokanee Resident Species

In addition to Kokanee, Cutthroat Trout (*Oncorhnychus clarki*), Large Scale Suckers (*Catostomus macrocheilus*), Northern Pikeminnow (*Ptychocheilus oregonensis*), Peamouth Chub (*Mylocheilus caurinus*), Redside Shiners (*Richardsonius balteatus*), Sculpin species (*Cottus spec.*) and Three-Spine Stickleback (*Gasterosteus aculeatus*) have been caught in gillnets in the Coquitlam Reservoir by Bussanich et al. (2006a) in 2004 and 2005, and by Plate et al. (2011, 2012) in 2010 and 2011. Smaller numbers of fish and fish species were also caught in other studies in the reservoir but the Bussanich et al. and Plate et al. fishing efforts were the most extensive. The typical relative species composition in Coquitlam Reservoir gillnet catch is shown in Figure 21.

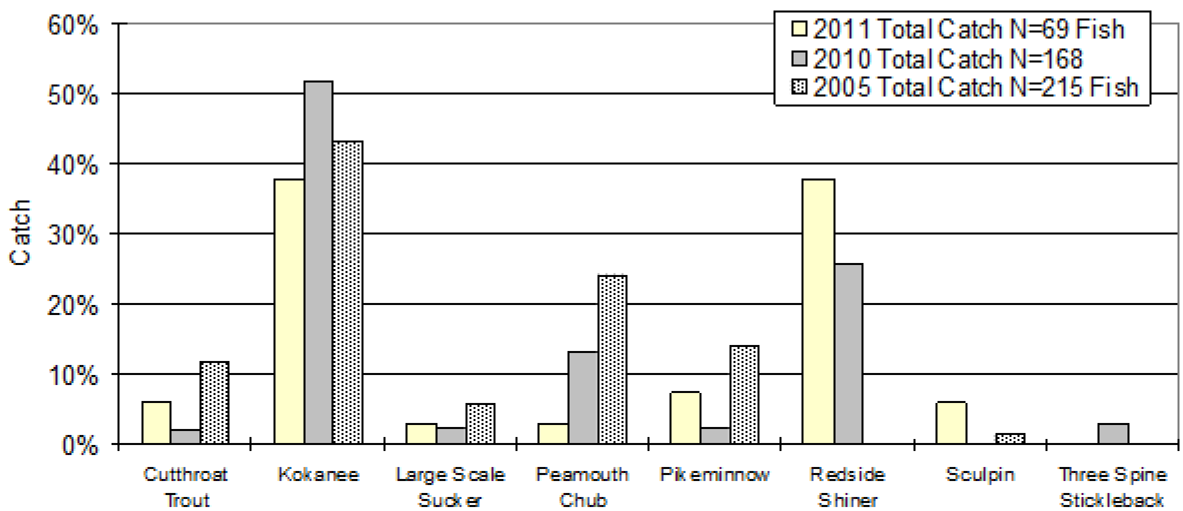

Figure 21 Percent of total catch in Coquitlam Reservoir by species (Plate et al. 2012).

Within the water column of Coquitlam Reservoir, Kokanee dominate the catch in the pelagic zone in all depths from 5–35 m (Plate et al. 2012). Peamouth Chub, Cutthroat Trout and Redside Shiners occupy the top 3 m of the water column and Northern Pikeminnow can be found throughout the water column to a depth of 25 m. Very few Three-Spine Stickleback were caught in all gillnet catches although mesh sizes small enough to catch Stickleback were used. Large Scale Suckers and Sculpin species were only caught when the net touched or was close to the bottom in the littoral zone (Plate et al. 2012). Therefore, Kokanee rearing habitat overlaps mainly with Northern Pikeminnow, a fish species that is well known to prey on juvenile salmonids. In support of this predator–prey relationship, Plate et al. (2012) found fish remains in the stomach of several dissected Northern Pikeminnow.

The stomach content of all age classes of Kokanee in Coquitlam Lake was almost entirely composed of small zooplankton organisms and very few larvae of terrestrial insects. Cutthroat Trout appeared to be feeding exclusively on terrestrial insects, similar to Peamouth Chub and Redside Shiners (Plate et al. 2012).

In summary, eight fish species appear to be rearing in Coquitlam Lake but competition for food between Kokanee and other fish species appear to be limited based on lake zones of occupation and stomach contents analysis. Juvenile Kokanee are likely prey items for Northern Pikeminnow based on lake zones of occupation and stomach contents analysis.

Introduction of Diseases into Coquitlam Reservoir

Transplantation of Sockeye Salmon eggs, fry or smolts from other watersheds would require Transplant Committee approval and pose a potential risk of introducing infectious hematopoietic necrosis (IHN), into the Coquitlam Reservoir and River. Thus, enhancement and hatchery culture of Sockeye in the Coquitlam system are planned to be based on local Kokanee broodstock which will not introduce new pathogens into the system.

Nevertheless, the culture of Sockeye Salmon should be carried out in a Sockeye dedicated hatchery or at least in separation from other salmon species. As a precaution, all female broodstock should be culled and disease screened. Eggs from each female should be kept separate until disease screening results are known to allow for the culling of egg batches of individual females should they be IHN carriers.

COQUITLAM SOCKEYE RE-INTRODUCTION STUDIES

Smolt Outmigration Studies

Sockeye Smolt Counts

Starting in the spring of 2000, a system of rotary screw traps (RSTs) has been operated in the Coquitlam River during the Kokanee smolt out-migrating period from late April to early June. Initially this project was designed to monitor outmigration of Coho Salmon and Steelhead Trout from the Lower Coquitlam River and consequently trapping operations started annually on April 1 and continued until mid-June. Sockeye smolts were added as a species of interest in 2005. The RST network consisted of four RSTs throughout the reaches of the Lower Coquitlam River. Particular fishing locations shifted over the years in response to changing river morphology and discharge characteristics.

During the early years of monitoring, no Sockeye smolts were captured in the RSTs. Although it is possible that during the early 2000s very few or no Sockeye smolts were present, it is also possible that Sockeye smolts were mis-identified as their presence was not expected and that such outmigrations have occurred since the dam was completed. The first large catch of 621 Sockeye smolts was registered in 2005 following a 7-day flow pulse when discharge was increased to 6.2 m^3/s from a base discharge of approximately 1 m^3/s by partial opening of one of the old LLO gates in addition to the FVs. Since that first outmigration event, Sockeye smolts have been captured every year at each of the RSTs, though in decreasing numbers. In 2013, the most recent year of available data, only 1 Sockeye smolt was captured. A summary of the RST catches since 2005 is provided in Table 4.

Table 4 Summary of RST data collected on the Lower Coquitlam River from 2005 to 2013. LLO Release refers to the duration that a Low Level Outlet was in use delivering a flow pulse >3 m^3/s. Capture efficiencies were those reported for Coho smolts caught in RST 3. Smolt abundance estimates were based on RST 3 catch data as well.

Year	LLO Release duration (days)	Catch				Capture Efficiency**	Smolt Abundance	Fork Length (%)	
		RST 4	RST 3	RST 2*	Total			< 100mm	> 100mm
2005	10	192	398	21	621	0.26	1531	85	15
2006	25	55	137	50	242	0.29	472	52	48
2007	0	-	54	72	126	0.28	193	100	-
2008	9	8	4	-	12	0.21	19	100	-
2009	60	71	50	9	130	0.2	250	53	47
2010	60	16	8	2	26	0.2	40	100	-
2011	63	107	21	14	142	0.19	111	99	1
2012	60	18	6	7	21	0.2	30	97	3
2013	60	1	-	-	1	-	-	-	1

* Sum of 2 RST's fished in tandem
** For RST3

In most years, the majority (>95%) of out-migrating smolts were less than 100 mm in length and were considered to be Age 1+ fish (having reared in freshwater for only a single summer) (Table 4). Average length of these smolts was 82.5 mm across all years and typically ranged from 60 to 100 mm. However, in 2006 and 2009 almost half of the fish were >100 mm and therefore considered to be Age 2+. Age data were not collected from scales of RST caught fish but calculated from the size at age data collected by Plate et al. (2011, 2012). It is interesting to note that the outmigration of the Age 2+ smolts only occurred in years 2005, 2006 and 2009, when the release regime consisted of an extended 5.5 to 6 m^3/s release of water through the LLOs and FVs.

In most years, too few Sockeye were captured to carry out mark-recapture trials to estimate total abundance with acceptable confidence intervals. Despite low catches, Sockeye capture efficiency (CE) was calculated for all years other than 2013 using the CE of the abundant Coho, which was found to be identical to Sockeye CE in 2005 and 2006. Only in 2005 and 2006, Sockeye CE could be calculated directly and was found to be 0.26 in 2005 and 0.29 in 2006 (Table 4).

<u>Sockeye Smolt Migration Timing</u>

Since 2009, the duration of Coquitlam Dam high spring flows (>3 m^3/s) increased from a few weeks to a total of 60 days (Table 4). This has provided opportunities to assess Sockeye Salmon outmigration timing. Outmigration started after April 15, peaking in most years in the middle of May, and ended by the end of May (Figure 22). The only exception to this pattern was 2011 when out migration peaked at the end of May. The cause for this late peak could not be determined given the limited data set. Overall, the data in Figure 22 show that Sockeye smolts are leaving the reservoir in a consistent pattern independent of the duration of higher discharges. This is consistent with typical Sockeye smolt outmigration behaviour (Groot 1965) and what has been observed in the Alouette River, suggesting that the outmigrating Sockeye’s ancestral migratory behaviour has been retained.

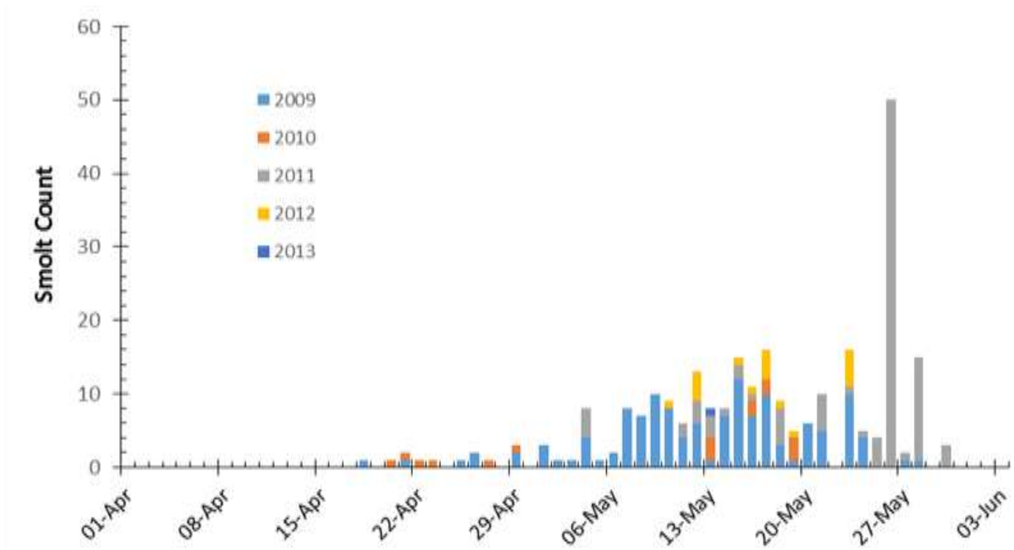

Figure 22 Daily smolt count for years 2009 to 2013 where LLO gate operations were not time constrained during the outmigration monitoring period (April 1 to May 31).

Sockeye Smolt Mortalities

Throughout the Sockeye smolt outmigration, mortalities were recorded in the RSTs, which were located 1.6 km downstream from the tunnel. The percentages of fish caught dead in the Lower Coquitlam River RSTs are shown in Table 4. Mortalities ranged from 11–61% of each year's total catch. These percentages can be considered high when compared to mortalities recorded for similarly sized Coho smolts (1–5%) caught in the same RSTs. Coquitlam Sockeye smolt mortality rates were also high when compared with Sockeye smolt mortality rates in RSTs operated on the neighboring Alouette River (M. Mathews, LGL Limited, pers. comm.) where mortalities were generally <0.1%. In the Coquitlam River, the highest mortalities occurred in 2011 with 61%. Some of the retrieved smolts showed evidence of physical trauma and scale loss (G. Lewis, pers. comm.). In contrast, the lowest mortality occurred in 2009 with 11%. In 2005 and 2006, when some of the Sockeye smolts were marked for re-capture, marked smolts did not show higher mortalities than unmarked fish, suggesting that handling was not a significant contributing factor. The damage and the high mortality rates experienced by the Sockeye smolts could only have occurred in their passage through the tunnel where high velocity contacts between discharge water flows and solid rock surfaces have recently been observed. These conditions have existed since the dam placed in service. The mortality rates reported may be understated because it is unlikely that all of the mortalities washed downstream and escaped predators to be counted at the RSTs.

Table 5 Annual RST trap mortality for out migrating Kokanee smolts, water release configurations and Coquitlam Reservoir elevations (2005–2013).

Year	Period Start	Period End	Duration	Coquitlam Dam Release (m^3/s)	Release Configuration	Reservoir elevation (m) Low	Reservoir elevation (m) High	Nerkid Captures	Smolt Estimate	Mortality (%)
2005	21-Apr	01-May	7	6.5	2FV + 1LLO (Partial)	146.0	147.7	621	1531	0.18
2006	22-Apr	17-May	21	6.1	2FV + 1LLO (Partial)	144.0	144.6	242	472	0.22
2007	-	-	0	1.0	2FV	144.5	145.6	126	193	0.24
2008	28-Apr	07-May	9	8.0	1LLO (full)	144.5	144.9	12	19	0.33
2009	01-Apr	31-May	60	5.5	1LLO (new)	145.1	149.0	130	250	0.11
2010	01-Apr	31-May	60	3.6	1LLO (new)	144.7	150.1	26	40	0.17
2011	01-Apr	03-Jun	63	3.9	1LLO (new)	145.8	150.1	142	111	0.61
2012	01-Apr	31-May	60	3.0	1LLO (new)	144.5	148.9	31	26	0.19
2013	01-Apr	31-May	60	3.3	1LLO (new)	147.9	151.7	1	-	-

* Based on Coho mark recapture trials

Based on the limited available data it appears as if there is no direct link between Kokanee smolt mortality and Coquitlam Dam discharge, release configuration or reservoir elevation. The lowest mortalities of 11% in 2009 occurred at a discharge of 5.5 m^3/s through the new LLO at reservoir elevations ranging from 145.1–149 m while the highest mortality of 61% occurred in 2011 at a discharge of 3.9 m^3/s through the new LLO at reservoir elevations ranging from 145.8–150.1 (Table 5). Similar discharges and reservoir elevations produced all other mortality rates between 11–61%. A slide show given by Brent Wilson (BC Hydro) at a KSRP meeting on July 31, 2014 provided more detail on the plume tunnel interface and Brent Wilson stated based on direct observations in the tunnel that the plume indeed hits the tunnel wall at about a 45° angle and is completely re-directed. A modification of the tunnel wall to allow for the plume to enter the water unobstructed would likely be costly and would need to go through a lengthy engineering and funding process. The outcome of this tunnel modification would likely not increase the numbers of Kokanee smolts that leave Coquitlam Reservoir by a large margin since it would only increase the number of smolts that survive LLO passage but not the number of smolts that enter the forebay or find LLOs. While a surface spill way is the more viable long-term solution to improve smolt outmigration, the option to use the tunnel can be re-considered after optimal operating conditions for smolt outmigration have been determined.

Smolt Behaviour Studies

Three separate studies have been carried out with readily available hatchery Coho smolts in an attempt to better understand the likely behaviour of Sockeye smolts in Coquitlam Reservoir at the time of outmigration. In the first study (Kintama Research Corporation 2005), 117 Coho smolts were implanted with acoustic telemetry tags and tracked using an array of receivers in the reservoir from April 15 to August 4, 2005. The objective was to determine whether the tagged Coho smolts were attracted to any one of the three possible outlets (the Buntzen Tunnel, the LLOs of the Coquitlam Dam gatehouse, the Metro Vancouver domestic water intakes) and determine whether outmigration occurred. Tracking results showed that the tagged Coho smolts tended to use the entire reservoir, with a tendency to prefer the southern end. None of the tagged smolts clustered in the vicinity of any of the outlet structures, and there was no evidence that any of the tagged smolts found their way out of the reservoir. This inability to find a suitable outlet for emigration was confirmed again in 2009 when 1,000 marked Coho smolts were released in the dam forebay on May 8 (no report was written but data is available from Matt Townsend) and a similar number of fish was released simultaneously at the tailrace below the dam. Over the following 5 weeks, a total of 536 (or 54%) tailrace marked smolts were captured at the RST located 1.6 km downstream of the dam. Two-thirds of the catch in the RST occurred on the same day of release in the tailrace and 95% of the catch was recorded over the following three day period. In contrast, only 50 (or 5%) of the reservoir forebay marked smolts were caught in the RST over the same 5 week period and the peak catch of 15 individuals occurred 3 days after the forebay release. As well, gillnet sets, beach seine trials and extensive snorkel swims failed to capture or find any of the marked fish in the forebay, suggesting that most, forebay Coho smolts had left the area or were predated (J. Greenbank, pers. comm.).

The Coho release experiment in the reservoir forebay was repeated in 2011, (no report was written but data was available from Matt Townsend) and, in addition, the effects of two LLO discharge scenarios were tested. For the first trial, LLO discharge was set to 3 m^3/s while LLO discharge for the second trial was set to 6 m^3/s. Although the results from this study were not available to the authors of this report, anecdotal evidence provided by the RST operators suggests that results were similar to the previous year and that the increased discharge did not lead to a higher number of smolts that left the reservoir through the LLO. The 2011 pulse trials were also preceded by a trash rack cleaning procedure at the LLO intakes to remove accumulated woody debris that may have hindered passage through the structure. Trash racks were cleaned immediately before the smolt release but did not appear to lead to higher passage rates through the LLO.

<u>The Numbers of Outmigrating Kokanee Smolt Linked to Coquitlam Reservoir Operations</u>

The relationship between Coquitlam Lake Reservoir operations and Kokanee smolt numbers in the Lower Coquitlam River was assessed by analysing the relationship between operational summary statistics and smolt numbers, as estimated from the Lower Coquitlam River Reach RST catch data (Table 8). In Figure 23, Kokanee smolt numbers appeared to be increasing with increasing discharge through the LLO into the Coquitlam River. However, this relationship appears to be very tentative and it may be confounded by other variables such as reservoir elevation and the release structure configuration.

The 2007 data point in Figure 23 indicates that no LLO release occurred during the smolt monitoring period yet an estimated 193 Sockeye left the reservoir. A likely explanation for this result may be that most of the smolts caught in 2007 left the reservoir during the LLO spill just prior to the start of the smolt monitoring period. Unfortunately, the timing of the 2007 smolt RST catch is unknown. It could have confirmed whether smolts moved out early during the monitoring period, indicating a link to the spill event, or later in the monitoring period aligning the movement with the typical out-migration period (Figure 5). In 2008, up to 8 m^3/s were released from the new LLO, yet only an estimated 19 Kokanee smolts left the reservoir. The 2008 LLO release, in late April, was only 7 days long. This occurred prior to the start of the typical migration period in May. In 2013, only 1 smolt was captured in the RST despite a LLO release of 3.3 m^3/s. The cause for such a poor outmigration is uncertain, although the average reservoir level in May of 2013 was approximately 2 m higher than in all other years and Kokanee smolts may not have been able to detect any attracting surface current or find the LLO at 140.2 m elevation when the reservoir surface was an average of 10 m higher (Table 5).

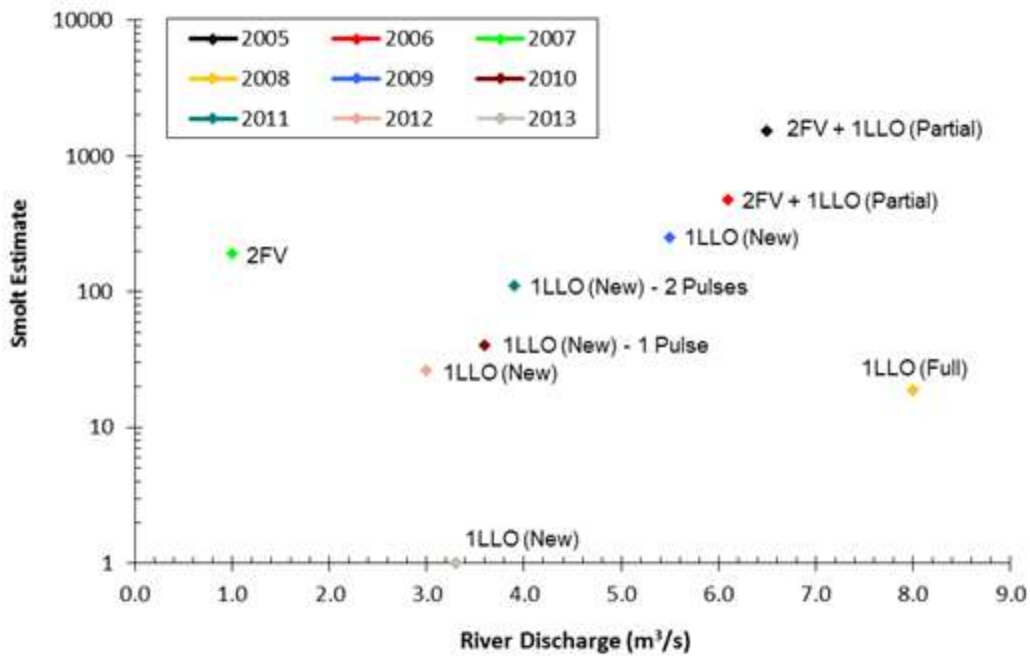

Figure 23 Plot of estimated smolt numbers based on RST catch data as a function of average total Sluice Tower LLO3 discharge. “LLO” refers to Low Level Outlet (No. 3), “FV” refers to fish flow valves, of which there are 2, “Pulse” refers to the addition of short term flow pulses of 6 m^3/s lasting 7 days, “New” refers to operations with the new LLO3 valve, and “Partial” or “Full” refers to gate operations with the old sluice valves in place.

When drawing a direct correlation between the timing of discharge pulses and catch of Sockeye smolts at the RST, it is apparent that increases in LLO discharges indeed lead to increases in Kokanee smolt numbers in the Lower Coquitlam River. This was found to be the case in 2010 and 2011 when LLO3 discharges were increased to 6 m^3/s for 7-day periods. In both years, the pulse releases were directly followed by increases in RST smolt capture (Figure 24). However in 2011, the smolt response was delayed when compared to 2010. In 2011, RST catch peaks occurred several days after the pulse release. This suggests that other unknown factors such as reservoir elevation may be involved. Figure 25 plots the range or reservoir elevations against the RST smolt catch and no available trend is visible. The highest RST Kokanee smolt catch occurred at medium reservoir elevations while the second highest Kokanee smolt RST catch occurred during very low reservoir elevations.

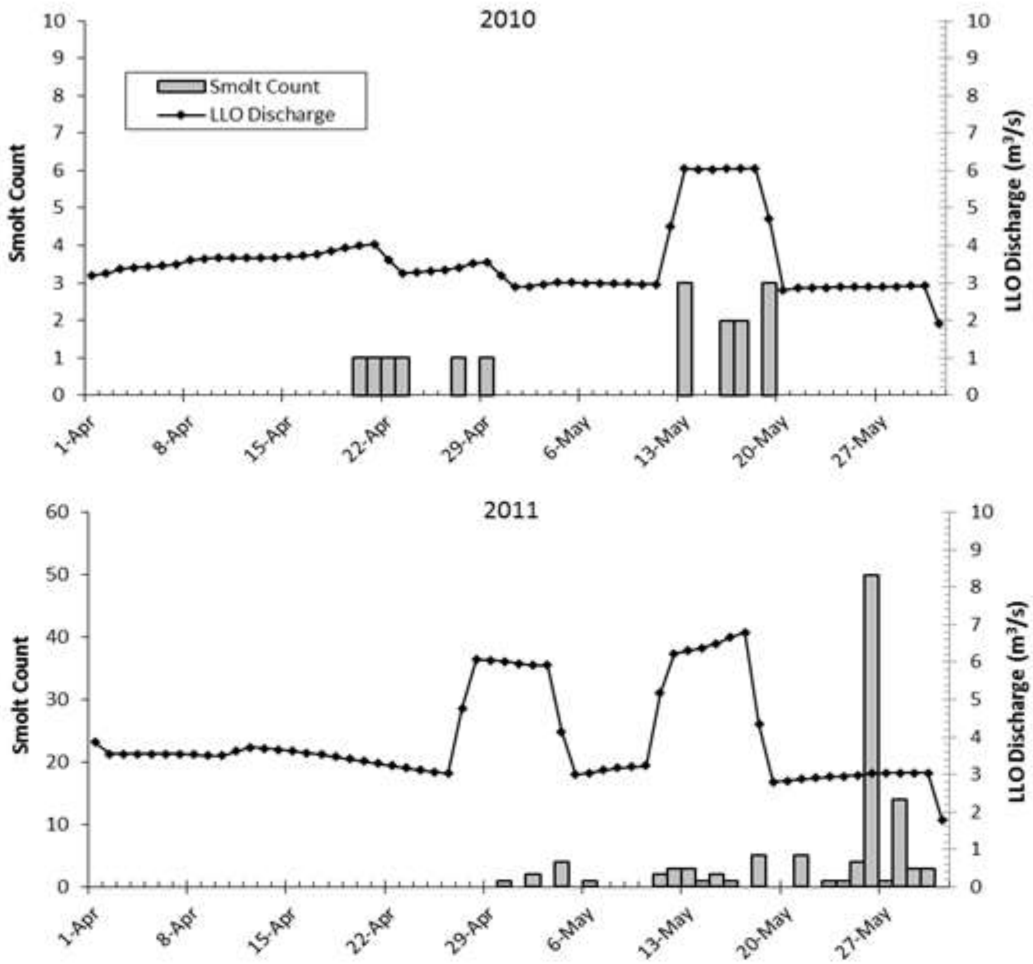

Figure 24 Plot of LLO discharge and RST smolt count showing the 7-day, 6 m^3/s pulse flow trials of 2010 (top chart) and 2011 (bottom chart).

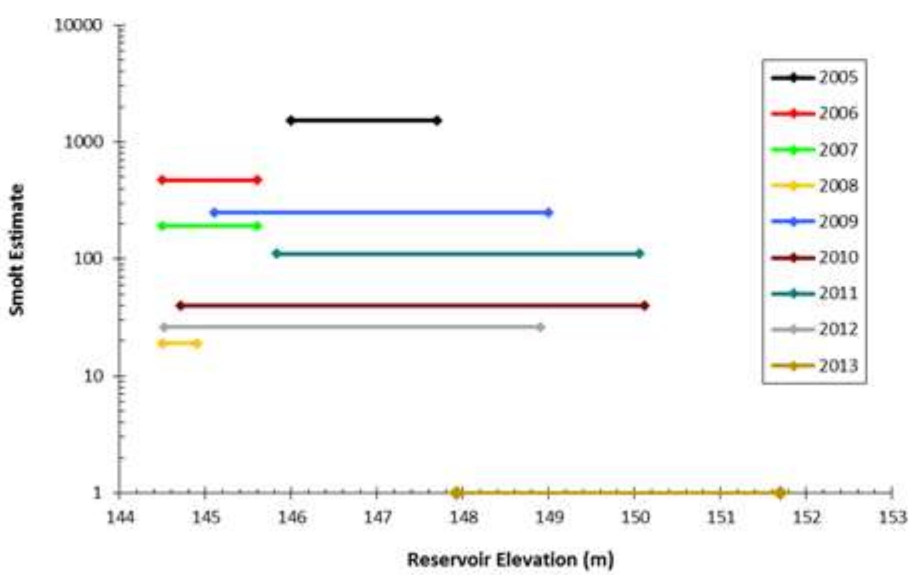

Figure 25 Plot of smolt abundance estimate based on RST catch data as a function of reservoir elevation range (denoted by horizontal line).

The outmigration of Kokanee smolts through the Coquitlam to Buntzen Tunnel has also been suggested as a possible factor reducing outmigration through the LLOs at the Coquitlam Dam gatehouse into the Lower Coquitlam River. Figure 26 indeed appears to be showing that higher use of the Buntzen Tunnel may be associated with low smolt output. This relationship is very tentative and only based on five years of data. It is very unlikely that Kokanee smolts find the Buntzen Lake tunnel entrance, that is located >10 m lower than the entrance to Coquitlam Dam LLOs, if they have difficulties finding the LLOs entrance. Real proof could be provided if Coquitlam Kokanee smolts could be caught in Buntzen Lake in May.

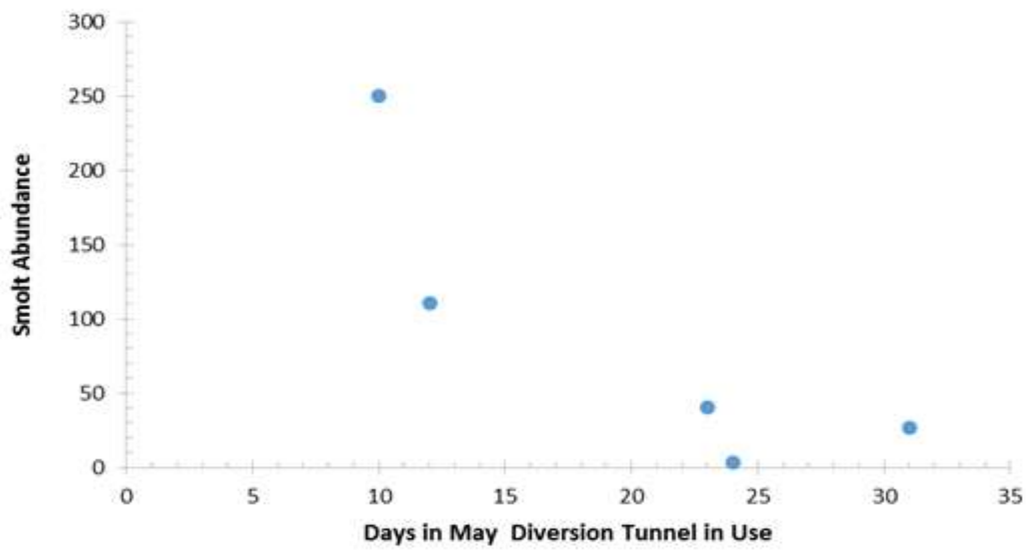

Figure 26 Kokanee smolt abundance (from RST catch) versus number of days the Buntzen Diversion Tunnel was in use during the month of May from 2008 to 2013.

Adult Sockeye Escapement Studies

Following their extirpation through the construction of Coquitlam Dam, the first officially recorded (unrecorded returns may have occurred before that) Sockeye adult returns to the Coquitlam River occurred in 2007 when two fish were found dead at the tunnel tailrace (dates of capture are unrecorded). The 2007 returns were followed by a 2008 return of 10 fish, of which nine were alive and trucked to Coquitlam Reservoir to complete the Sockeye life cycle for the first time in almost a century. DNA samples confirmed that all fish were offspring of Coquitlam Reservoir Kokanee. In 2008, scale samples were also collected from all captured fish, but only six were deemed readable. Five fish were determined to be Age 3+ fish. Of these five Age 3+ fish, three had reared in freshwater for one summer and two years in the ocean and the remaining two fish had reared in freshwater for two summers and in the ocean for one year. The last fish was determined to be an Age 2+ fish that spent one year each in freshwater and saltwater making it part of the 2007 cohort of smolts.

Since the 2008 peak catch, the numbers of adult returns have decreased (Figure 29) in line with the lower numbers of outmigrating Kokanee smolts (Table 5). In 2011, a total of six adults (three dead and three alive) were captured. Of the six 2011 adults, five were sampled for DNA and four originated from Coquitlam Reservoir and one fish was identified as a stray from Sakinaw Lake. BC. Straying was also detected in 2010, when two of the three fish caught in the trap were identified as being from Alouette Lake and the third fish was identified as a possible stray with unknown origin. Unfortunately, genetic ID information for the 2012 and 2013 Sockeye catches was not available at the time of this report. As a result, the persistence and extent of straying could not be evaluated except to note that it occurs in the Coquitlam River and may be a “natural” means of adding genetic diversification.

No scale data have been collected from the returning adult sockeye since 2008 and therefore there is no smolt year information for adults that returned after 2008.

Capture date data is not available for 2007 and 2008 return years. However, data from subsequent years showed that 12 of the 14 fish (85%) of returning adults were trapped during the month of August and that 2 arrived in the first two weeks of September. Since 2007, the latest adult Sockeye arrival date recorded for the Coquitlam system was October 26, 2010, well after trap operations had ceased in September. Unfortunately, this fish was not sampled for DNA and therefore its origins could not be determined. Based on this atypical late arrival timing it may have been a stray from another system.

Mortality for adult fish caught in the trap has tended to be high, largely due to predation by river otters. It is therefore also possible that more fish may have returned to the system than are recorded in the catch numbers. The trap was modified in 2013 to better prevent predator entry. The effectiveness of these measures continues to be untested. Regular snorkel counts and stream walks of the first 500 m of the Coquitlam River below the dam could be carried out throughout August to identify holding Sockeye. If Sockeye are found to hold below the fish trap, small (<0.5 m^3/s) increases in discharge through the LLO could attract Sockeye into the fish traps from where they could be transported into the reservoir. Discharge increases in August should be kept small since much of the lower river becomes a public beach during the summer months.

Scales should be taken from Sockeye when they are handled before being transported by truck over the dam. The scales can be used to age the fish, determine smolt outmigration year and check genetic stock ID.

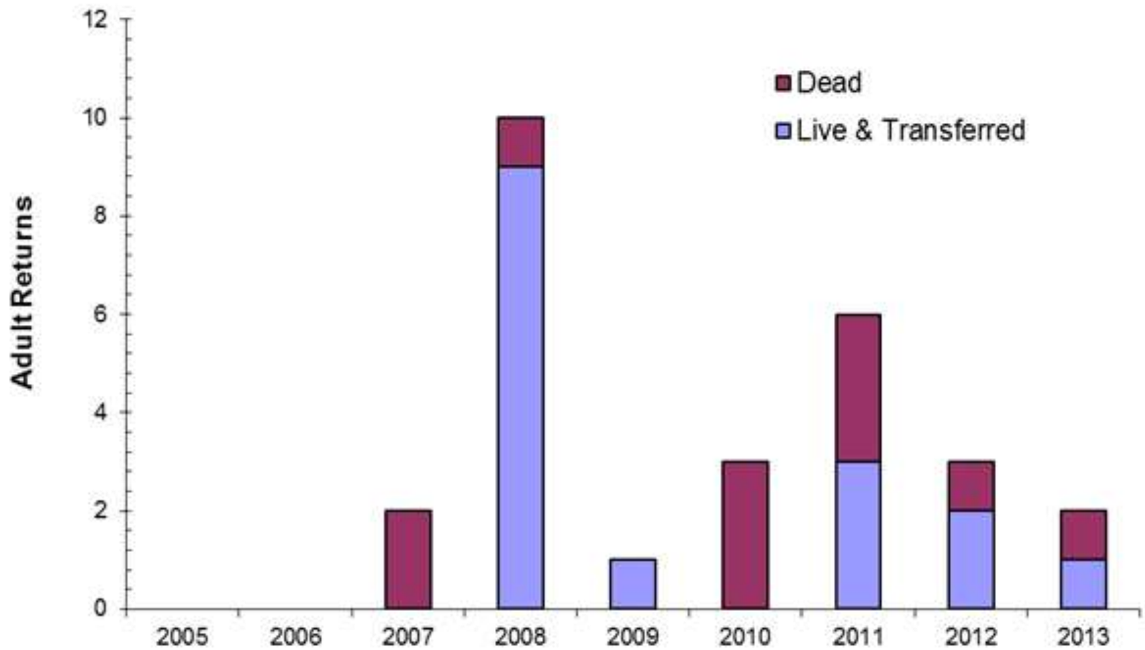

Figure 27 Count of captured adult Sockeye Salmon in the Coquitlam River. Live fish were trucked and released into the Coquitlam Reservoir. The majority of dead fish in the traps were the result of river otter predation.

Genetic Studies

Nelson and Wood (2007) investigated the genetic heritage of Kokanee in Coquitlam Reservoir and Kokanee smolts in Coquitlam River. They concluded that Kokanee smolts sampled in Coquitlam River are most likely smolts from Coquitlam Reservoir. Genetic stock identification checks supported the hypothesis that Coquitlam Reservoir Kokanee are recently derived from an anadromous Sockeye. Gill raker number and the length of Coquitlam Kokanee indicates that these fish have similar characteristics to Sockeye-Kokanee hybrids (Bussanich et al. 2006b) which supports the interpretation that Coquitlam Reservoir Kokanee are likely recent descendants of Sockeye Salmon. These results suggest that capability for re-anadromization likely exists in Coquitlam Kokanee populations and that it is feasible to pursue this objective.

SUMMARY OF FACTORS THAT AFFECT SOCKEYE RE-INTRODUCTION

A number of factors appear to be affecting Sockeye re-introduction effort. These factors and suggested mitigative measures are summarized in Table 6.

Table 6 Summary table for all factors that affect the Sockeye re-introduction into Coquitlam Reservoir and mitigative measures to respond to these factors.

Factors That Affect Sockeye Re-Introduction	**Evidence from Literature**	**Knowledge Gaps?**	**Funding for Studies**	**Suggested Mitigative Measures**	**Expected Outcome**
Very low primary productivity in Coquitlam Reservoir	Bottom coring (Donald et al. 2012)	No	N/A	None. Fertilization is not an option since the reservoir also serves as a drinking water source.	Bottom coring results suggested that historic salmon runs into Coquitlam Lake occurred at a low primary productivity regime similar to current conditions. Therefore the past and current trophic state of Coquitlam Reservoir does not appear to be a limiting factor for the establishment of a Sockeye spawner population of 2,000–15,000 fish.
Merismopedia as a nutrient dead end	Zooplankton and pH analysis (Stockner and Vidmanic 2014)	No	FWCP	None. Addition of Calcium Carbonate to increase pH and thus break the *Merismopedia* dominance is not an option because of drinking water quality concerns by Metro Vancouver.	Kokanee are currently surviving to adulthood and spawning under *Merismopedia* dominance and their growth until Age 2 is comparable to juvenile sockeye in more productive systems. Therefore action to break *Merismopedia* dominance is not necessary for Sockeye re-introduction.
Limits to re-introduction numbers based on models and standing Kokanee stocks	Application of productivity models and empirical data summarized in this report	No	FWCP	None.	Coquitlam Reservoir rearing capacity for juvenile Sockeye is estimated to produce an escapement in the range of 2,000–15,000 Sockeye spawners.

Factors That Affect Sockeye Re-Introduction	**Evidence from Literature**	**Knowledge Gaps?**	**Funding for Studies**	**Suggested Mitigative Measures**	**Expected Outcome**
Limits to re-introduction numbers based on spawning habitat availability	Limited Kokanee spawning habitat (Bussanich et al. 2005; Gaboury and Murray 2006)	No	N/A	Potential gravel addition is not a priority at this point.	Currently spawning habitat is limited to small areas suitable for lake spawning, tributaries are not used by Kokanee. Spawning appears to occur in small areas of gravelly lake bottom at elevations between 125–144 m. Based only on available spawning habitat, approximately 3,400 female Sockeye or a total population of 6,800 Sockeye can spawn in Coquitlam Reservoir. These numbers correspond well with the current standing stock of Age 3+ and Age 4+ Kokanee Salmon spawners.
Introduction of IHN		No	N/A	Use only Coquitlam Reservoir Kokanee broodstock as the basis for hatchery enhancement. Keep the eggs from each pairing separate and destroy eggs if females are tested positive for IHN.	No introduction of added IHN.
Smolts are not attracted to the LLO at the Coquitlam Dam Sluice Tower	Coho smolts released in the dam forebay distributed throughout the reservoir. Only 5% were recovered in RST below the dam (Kintama Research Corporation 2005, summary of results in this report)	Yes	FWCP	Option 1: Use low reservoir elevation (<144 m) and high LLO discharge (>6 m^3/s) for the month of May to improve surface flow and attract smolts. Option 2: Build a surface smolt passage way. Option 3: Build a surface current collection system that would pump Kokanee smolts from the surface of Coquitlam Reservoir over the dam and into the Lower Coquitlam River.	Option 1: The creation of surface current throughout the month of May could attract Kokanee smolts into the dam forebay and from there into the LLO for discharge into the Lower Coquitlam River. Option 2: The construction of the smolt fish passage way would lead to smolt attracting surface current and alleviate potential smolt mortality issues in the tunnel. The smolt passage way would also be the first step in building a complete fish ladder to provide two-way fish passage over the dam. Option 3: A surface collector could create surface current that might attract Kokanee smolts. This option could be a temporary measure to see how many smolts could be attracted into the forebay by surface current.

Factors That Affect Sockeye Re-Introduction	Evidence from Literature	Knowledge Gaps?	Funding for Studies	Suggested Mitigative Measures	Expected Outcome
Do large numbers of Kokanee smolts migrate into the Coquitlam Dam forebay and fail to find the LLO?	No	Yes	FWCP	Determine whether Kokanee smolts actively migrate to the Dam forebay in May in large numbers using a hydroacoustic approach. In combination with this study, a surface collector to create surface current could be installed to find out whether increased surface current will attract more smolts into the forebay.	If large numbers of smolts migrate to the forebay build the smolt passage way suggested in this report and allow the smolts to leave the reservoir to return as anadromous Sockeye. If small numbers of smolts migrate into the forebay, install a pump and a surface collector system and determine whether this attracts more smolts into the forebay.
Low numbers of Kokanee smolts leaving Coquitlam Reservoir	Low RST catches and estimates for Sockeye smolts in the Lower Coquitlam River (summarized in this report)	Optimal combination of LLO discharge and reservoir elevation for smolt outmigration	FWCP	Option 1: Increase the number of outmigrating Kokanee smolts through hatchery intervention using the dedicated Sockeye Hatchery at Rosewall Creek with Coquitlam Kokanee as broodstock. Option 2: Monitor smolt outmigration volume as well as injury and mortality incidence in the Lower Coquitlam River during a variety of reservoir elevations and discharges. Option 3: Install cameras in the tunnel below the LLO to monitor the response of the LLO water plume. Suggested optimal reservoir elevation <144 m and suggested discharge through LLO >6 m^3/s. Option 4: Build the Kokanee smolt passage way across Coquitlam Dam or improve fish passage conditions through the existing Sluice Tower and tunnel.	Option 1: The release of higher numbers of Kokanee smolts from Coquitlam Reservoir stock. Options 2 and 3: Find the optimal combination of reservoir elevation and LLO discharge to support Kokanee smolt outmigration through the LLO. For this work to go ahead, it has to be understood that a percentage of Kokanee smolts (average of 22%) will likely not survive the passage through the LLOs when hitting the tunnel wall. The cost of modifying the tunnel wall is currently unknown and needs to be determined before this option should be pursued. Tunnel modification will have uncertain success in allowing for more outmigration of Kokanee smolts. In addition, it may channel funding away from the better solution of a surface fish passage way. Option 4: Achieve natural outmigration of Coquitlam smolts.

Factors That Affect Sockeye Re-Introduction	Evidence from Literature	Knowledge Gaps?	Funding for Studies	Suggested Mitigative Measures	Expected Outcome
High Kokanee smolt mortalities in RST catch	High mortality rates in the Sockeye smolt RST catch (summarized in this report) and anecdotal evidence of physical trauma reported by RST operators	Yes	FWCP	Option 1: Install an independent wildlife monitoring digital camera at the LLO plume site and program it to take one picture every 6 hours throughout many discharge scenarios. Download the camera following deployment throughout the month of May and relate plume behaviour to reservoir elevation and discharge scenarios throughout the Sockeye smolt migration period. Option 2: Modify LLO flow or the tunnel ceiling to allow the LLO plume to fall freely into the tunnel without impacting rock surfaces.	Option 1: A decrease of Kokanee smolt mortality when migrating though the LLO. Option 2: The cost of modifying the tunnel wall is currently unknown and needs to be determined before this option should be pursued. Tunnel modification will have uncertain success in allowing for more outmigration of Kokanee smolts. In addition, it may channel funding away from the better solution of a surface fish passage way. It is therefore recommended to not pursue funding for this option at this time.
Predation on returning Sockeye spawners		Yes	FWCP	Option 1: Make the adult fish trap “otter proof” to avoid predation in the trap itself. Option 2: Carry out regular snorkel counts and steam walks throughout August to determine whether Sockeye are holding in the Lower Coquitlam River below the dam. Option 3: Increase discharge for short periods of time to initiate migratory behaviour and lead fish into the fish trap for transport into Coquitlam Reservoir. Option 4: In the step-wise fashion described in this report, build a fish ladder over Coquitlam Dam.	A reduction of otter predation on adult Coquitlam Sockeye in the fish trap and the river below the fish trap and dam.
No determination of recruitment success of emigrating Kokanee smolts		Yes	FWCP	Take scales of all fish that are transported over the dam to determine their age and smolt cohort year.	The determination of recruitment success of individual Kokanee smolt cohorts and their reservoir residency patterns.

ENHANCEMENT CONSIDERATIONS

While manipulating reservoir levels and discharges could increase outmigration of Kokanee smolts, a more efficient short-term measure would be hatchery enhancement, using fertilized eggs from netted Coquitlam Kokanee spawners. In this context, it needs to be mentioned that DFO has offered Sockeye hatching and rearing space at their Rosewall Creek hatchery. This will make larger numbers of Kokanee smolts available for release below the dam and should produce larger numbers of Sockeye adults for release into Coquitlam Reservoir. A portion of the returning adults would be used as broodstock for the next hatchery generation of smolts. Sockeye adults not required for broodstock would be trucked above the dam and released for spawning. Options for hatchery enhancement are further explored in this section of the report.

Existing Coquitlam River Hatchery Facilities

Three hatcheries currently enhance Coho, Chinook and Pink production for the Lower Coquitlam River and one of these has produced Steelhead in the past. Information about these hatcheries is summarized in Table 7.

In summary, the three Lower Coquitlam River hatcheries ensure enhanced returns of Coho and Chinook to the river. Their capacities are fully subscribed for this purpose and additional rearing capacity for Sockeye does not appear to be available. It is therefore recommended that Rosewall Creek Hatchery, a dedicated DFO Sockeye hatchery be used.

Table 7 Summary of information for Lower Coquitlam River hatcheries (Source: Coquitlam River Watershed 2012).

Hatchery Name, Location and Installation Year	Funders and Volunteers	Species Capacity for Individual Life Stages	Current Escapement Created
Al Grist Memorial Hatchery, on Coquitlam River just below Metro Vancouver gate, 1980	Port Coquitlam District Hunting and Fishing Club, Pacific Salmon Foundation, DFO	100,000 Coho fry, 23,000 Coho smolts (eggs from Coquitlam River broodstock), 50,000 Chinook smolts (egg import from Chilliwack DFO Hatchery); Past enhancement of Chum and Steelhead	Included in current total runs of Coho and Chinook
Hoy/Scott Creek Hatchery, Rearing Ponds and Habitat, on Hay Creek between Hoy Creek and Coquitlam Aquatic Centre, 1997	Hoy/Scott Creek Watershed Society, North Fraser River Salmon Assistance Project, Pacific Salmon Foundation, DFO	40,000 fed Coho fry and 5,000 Coho smolts (50,000 eggs from wild broodstock or 10,000 eggs from Al Grist Memorial Hatchery) , up to 250,000 unfed Pink fry (eggs form Chehalis River	?

		Hatchery using Harrison Watershed stock)	
River Springs Hatchery, Rearing Ponds and Habitat, downstream of Oxbow Lake by Lodge Street, early 1990s	River Springs Community, DFO	15,000 fed Coho fry (eggs from Coquitlam River wild broodstock or from Al Grist Memorial Hatchery)	?

A Captive Broodstock Program

In captive broodstock programs, wild spawners are captured and spawned in a hatchery. Their fertilized eggs are incubated and all of the subsequent life stages until maturity occur in a hatchery environment. Hatchery raised and mature adults are again spawned in a hatchery and thus a large number of eggs can be produced over two or three generations. Smolts or adults can be produced for re-introduction into the natural environment. The U.S. Fish and Wildlife Service has used captive broodstock techniques to enhance over 30% of the non-anadromous fish species listed under the U.S. Endangered Species Act (Johnson and Jensen 1991; Andrews and Kaufman 1994; Hendry et al. 2000). Captive broodstock programs require a large investment of time and money over a long period of time and have very variable success. Typically captive broodstock programs are highly variable in their egg-to-adult survival, their egg viability and the breeding success of adults released from such programs (Bussanich et al. 2006b). Such a program is not recommended for Coquitlam Reservoir because wild Kokanee spawners are consistently accessible in the reservoir and have been caught in high numbers by Plate et al. (2011, 2012). Therefore the rearing of Sockeye in captivity to maturity is unnecessary.

Wild Kokanee Broodstock Collection with Hatchery Rearing to Smolt Stage

Wild Kokanee that readily release eggs and sperm have been caught at two different locations in Coquitlam Reservoir for two consecutive years in 2010 and 2011 by Plate et al. (2011, 2012). It is therefore likely that wild Kokanee could be used as the broodstock for a Sockeye re-introduction program for Coquitlam Reservoir. All wild broodstock females should be culled and tested for IHN and the eggs of individual pairings should be kept separate until IHN testing results are known. Once IHN-free status has been determined, eggs from individual pairings can be pooled for incubation and reared into smolts at Rosewall Creek Hatchery. In their second spring, smolts would be imprinted near the downstream side of the Coquitlam Dam and released to avoid tunnel related mortalities. Adult Sockeye should return to their release location one to three years following the release of the smolts.

An average 1% survival from Sockeye smolt to adult has been estimated for returns from brood years 2005−2008 for the Alouette system and a similar survival rate can be expected for Coquitlam Sockeye. Using this survival rate, a smolt release of 10,000 fish would produce an escapement of approximately 100 adult fish under current low ocean productivity conditions. Based on results from studies carried out by Plate et al. (2011, 2012), female Coquitlam Kokanee produce an average of 200 eggs per female and likely closer to 100 eggs per female could be extracted in a wild broodstock egg take. Therefore approximately 100 mature females would need to be captured to take 10,000 eggs. This appears realistic, since more than 100 mature and readily egg and sperm releasing Kokanee were caught and released in 2011 and 2012 in two locations in Coquitlam Reservoir (Plate et al. 2011, 2012).

Approximately 50 of the 100 adult Sockeye Salmon that are hoped to return from the smolt release should be females. Part of these females and an equivalent number of males could be used as broodstock to provide eggs for rearing the next generation at Rosewall Creek Hatchery. The remaining fish could be released into Coquitlam Reservoir for natural spawning.

Ten to 20 Sockeye should produce 25,000–50,000 eggs and should be selected as broodstock for any additional hatchery enhancement since offspring from anadromous Sockeye may have a higher propensity for an anadromous life cycle than offspring from stationary Kokanee.

The hatchery enhancement should not be seen as a permanent solution to replace fish passage through Coquitlam Dam. Hatchery incubation and rearing over many generations can have deleterious genetic, anatomical and behavioural consequences (Berntson et al. 2011; Bingham et al. 2014; Chilcote et al. 2011; Pitcher and Neff 2007). The hatchery program should be seen as an initiative to test whether releases of larger numbers of Coquitlam Kokanee smolts will produce adult Sockeye escapements in line with other systems such as Alouette. After reasonable survival from smolt to adult stage has been proven and regular returns of more than 100 Sockeye adults have been established, hatchery intervention should either be stopped after three generations or be continued only with wild Kokanee broodstock.

If larger escapements are achieved through hatchery intervention, a fish ladder over Coquitlam Dam may become more desirable.

In summary, wild Kokanee broodstock could be used to produce 10,000 Kokanee smolts at Rosewall Creek Hatchery to determine their smolt to adult survival rate, to determine the most benign combination of water discharge and reservoir elevation for transit and to test the effectiveness of other smolt collection or dam passage options.

Since the discussion with Matt Foy (DFO) at the KSRP table, availability of Rosewall Creek Hatchery has been confirmed for incubating Coquitlam Sockeye to the smolt stage. In follow-up conversations with Mel Sheng (DFO Section Head Salmon Enhancement Program) and with Les Clint (DFO, Rosewall Creek Hatchery manager), it was clarified that space in the hatchery can be available this fall (2014) and that the rearing and maintenance costs for the small number of Sockeye Salmon expected for Coquitlam would be very reasonable. It is recommended that Rosewall Creek Hatchery will be used for this project and that discussions, paperwork and permitting to support the transfer of Coquitlam Kokanee eggs to Rosewall Creek will be started as soon as possible.

Eggs collection in Coquitlam Reservoir would likely span a period of several days to a week and eggs would be collected in small patches over the whole period. We therefore recommend daily shipments of the fertilized and water hardened eggs via an overnight courier to Rosewall Creek Hatchery.

Rosewall Creek Hatchery staff have been successfully working with Sockeye for over a decade as part of the Cultus Lake and Sakinaw Sockeye captive broodstock projects.

FISH PASSAGE ALTERNATIVES OVER COQUITLAM DAM

Current Smolt Outmigration

Currently, all Kokanee smolts that are leaving Coquitlam Reservoir to the Lower Coquitlam River have to navigate through the LLO at the Sluice Tower. This passage way has never passed smolt numbers to support significant returns of adult Sockeye. The LLO may be too deep to be found by smolts, and/or smolts are not guided to it by detectable surface current. The few smolts that find the LLO experience very high mortalities from 11–61% (26% average). The LLO therefore appears unsuitable for the passage of larger numbers of Kokanee and access to the LLO is a serious impediment to salmon re-introduction into Coquitlam Reservoir. An alternative smolt passage way is required to allow larger numbers of Kokanee to naturally leave the reservoir. This could be created by modifying the Sluice Tower/tunnel conditions or by a surface collection device.

A Floating Surface Smolt Collector as an Intermediate Way to Transport Smolts over Coquitlam Dam

A surface smolt collection system consists of a set of nets that guide fish to a floating pump intake box from which they can be pumped over the dam. The amount of water pumped over the dam must be sufficient to create a detectable surface current that will attract Kokanee. A very large version of such a device has been used successfully for several years to transport mainly Sockeye smolts over the Baker Lake Dam in Washington State, U.S.A. While the very large and highly technical Baker Lake surface collector version cost $US 50 Million, a smaller and manually operated prototype could be tested at Coquitlam Reservoir to create surface current and determine whether the surface current attracts smolts. Funding for this prototype may be provided through the FWCP but may also need additional funding directly from BC Hydro and may require the approval of BC Hydro Engineering or the BC Hydro Board of Directors. While a surface fish passage way still appears to be the better long-term solution, a surface smolt-collecting system that could be operated at all reservoir elevations could be an intermediate solution to allow more smolts to leave the reservoir. Such a system requires design services to provide information preparing cost estimates.

The success of the smolt surface collector could be determined in the annual RST counts of outmigrating Sockeye in the Lower Coquitlam River.

Modifications to Coquitlam Dam to Allow for Smolt Fish Passage

Consideration of both downstream movement (of smolts) and upstream movement of adult salmon need to be addressed in a stepwise approach for the re-introduction of a Sockeye Salmon population that can freely move between the Lower Coquitlam River and the reservoir. Presently, upstream movement over Coquitlam Dam is not possible, and downstream movement of smolts is seriously impeded. For movement of smolts downstream, the outflow from the reservoir should be near the water surface, and the flow should be large enough to attract smolts. Flows to the Coquitlam River are determined by the Water Use Plan, but how and where flows are released is not dictated.

The monthly flow targets for the Lower Coquitlam River identified in the Coquitlam-Buntzen Project Water Use Plan (2005) are listed in Table 8 below. Under drought conditions, the flows are lower for most months but never drop below the 1.1 m^3/s, the minimum fish flow.

Table 8 Monthly mean flow targets through the Coquitlam Reservoir LLO set by the Coquitlam Buntzen Project Water Use Plan (2005).

Month	Flow Target (m^3/s)
January	5.90
February	2.92
March	4.25
April	3.50
May	2.91
June	1.10
July	1.20
August	2.70
September	2.22
October	6.07
November	3.69
December	5.00

One option to promote successful smolt out migration from the reservoir is the construction of a surface fish passage. The smolt fish passage could consist of a channel cut through the bedrock with its base at a suitable elevation (possibly 145.0 masl) and incorporate suitable flow control to accommodate a wide range of reservoir elevations. The structure should also consider BC Hydro operations and public safety concerns. The length of the bedrock cut will be approximately 80–90 m. From late April to late May, a target flow in the range 1–2 m^3/s should be directed down the passage way. The details of this structure will need to be determined by BC Hydro Engineering.

While it appears technically feasible to build the rock cut based smolt passage way, pricing for this option is unknown.

BC Hydro power production and Metro Vancouver water supply would not be directly affected by the smolt passage way, as the discharge through the smolt passage way would be part of the WUP discharge requirements.

Post-construction biological assessments should include monitoring the Kokanee smolt abundances by direct counting of smolts passing through the fishway or the continuation of the annual RST smolt enumeration program in the Lower Coquitlam River.

In addition to the volitional outmigration of smolts, the proposed fish passage way can later be used as the upper part of a complete fish ladder that will allow the volitional upstream migration of adult salmon into Coquitlam Reservoir (Figure 28). The adult salmon fish ladder connecting the smolt passage way with the lower Coquitlam River could likely be built on the stable underlying bedrock.

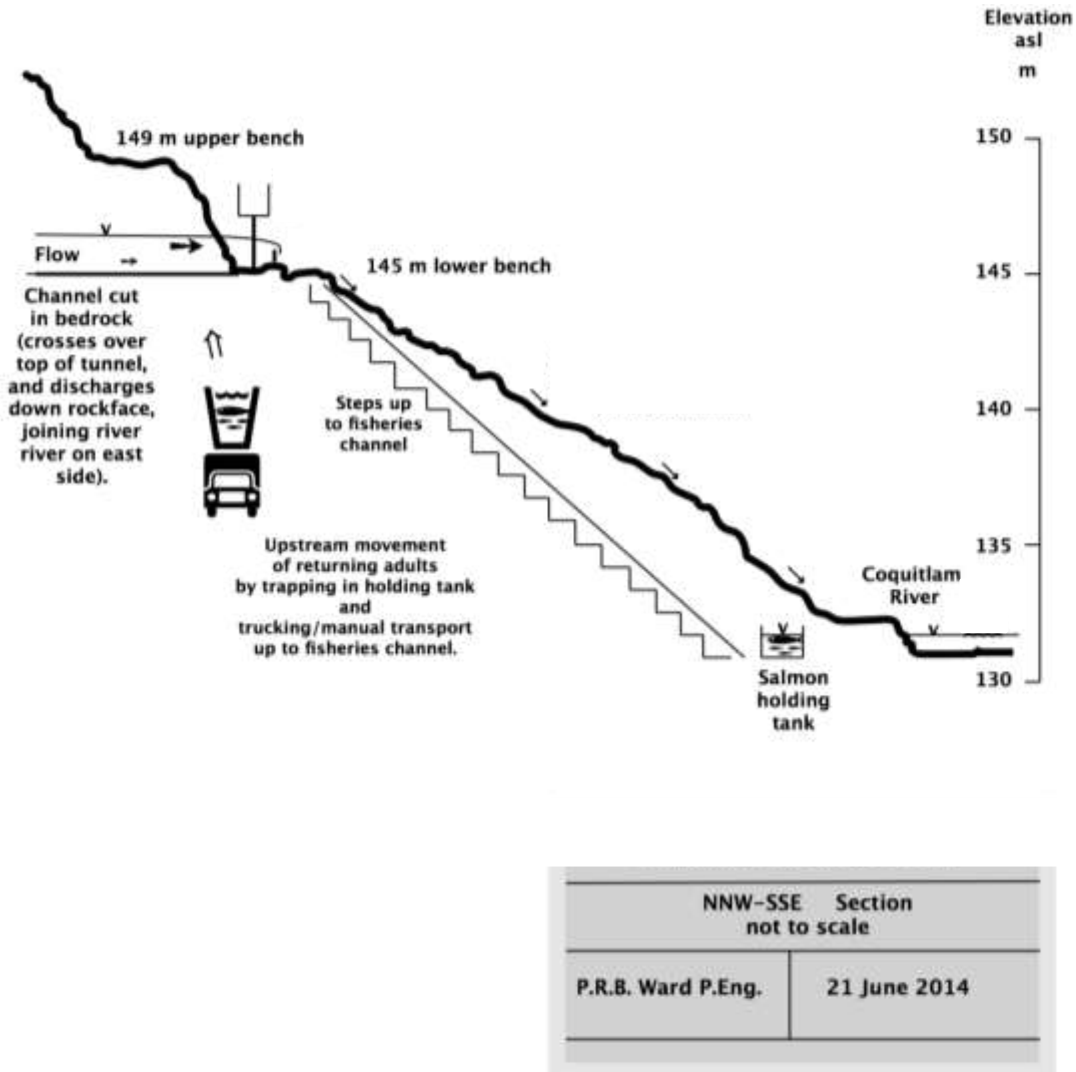

Figure 28 Coquitlam Dam surface smolt passage concept.

Adult Trapping and Trucking Operations

The current trapping and trucking operation aided by video surveillance, snorkel counts and fish attracting discharge pulses will likely have the capacity to transport up to 500-1,000 adult salmon above the dam. This initiative will need additional funding if Sockeye escapements in this range are expected. If escapements of more than 1,000 salmon are expected, the trapping and trucking approach would likely be overwhelmed and a fish ladder needs to be built to facilitate larger returns (Figure 28).

To coordinate fish transport and minimize predation losses, it is recommended that video surveillance be installed at the fish trap and monitored by Metro Vancouver security personnel at the watershed gate house.

FISHERIES MANAGEMENT CONSIDERATIONS

Fraser Management Objectives

Fraser Sockeye fisheries are managed by an international panel to achieve year-specific harvest rates or escapement goals for each of the four run-timing groups. The Canada/U.S. Pacific Salmon Treaty (1999 Revised Annex 4, Chapter 4, Section 3b) defines the spawning escapement objective for Fraser Sockeye as:

> *"…the target set by Canada including any extra requirements that may be determined by Canada and agreed to by the Fraser River Panel, for natural, environmental or stock assessment factors, to ensure the fish reach the spawning grounds at target levels. Any additional escapement amounts believed necessary by Canada for other than the foregoing will not affect the U.S. catch."*

From 1987 to 2002, escapement targets for Fraser Sockeye were based on the "Rebuilding Plan" developed in 1985 following the signing of the Pacific Salmon Treaty. The rebuilding strategy was "to increase annual escapement incrementally from historic levels" (Staley 2010).

In 2003, DFO conducted a review of the 1985 rebuilding strategy which resulted in the initiation of a new process, the Fraser River Sockeye Spawning Initiative (FRSSI), for setting annual escapement goals and target exploitation rates for Fraser Sockeye. A detailed description of the FRSSI process and models can be found in a number of DFO workshop reports (e.g., DFO 2009) and one published report (Pestal et al. 2008). Staley (2010) provides a review of the FRSSI process and the methods used to set the interim conservation benchmarks and Fraser Sockeye spawning targets for the 2007–2010 fishing seasons.

Wild Salmon Policy

Canada's Wild Salmon Policy (WSP) has identified the need to define lower benchmarks (LBs) and upper benchmarks (UBs) for each Fraser Sockeye stock. Holt et al. (2009) describe the methods that should be used to define these benchmarks and Grant et al. (2010) provided a range of estimates for each benchmark generated from alternative stock-recruitment models. However, the interim LBs and UBs defined through the FRSSI process and recent Canadian Science Advisory Secretariat (CSAS) working papers are fixed values intended to be compared with the 4-year average escapements for each stock or run-timing group (Staley 2010; Grant et al. 2010).

The Pitt River Sockeye Conservation Unit (Pitt-ES CU) is a reasonable indicator for assessing the environmental and fishing factors that might be affecting Coquitlam Sockeye survival and recruitment. Grant and Pestal (2012) assessed the status of the Pitt-ES CU and concluded that the current abundance (2005 onwards) relative to the previous three generations had declined by 54%, despite low exploitation rates (Figure 29). This was evident in the dramatic decline in productivity and the less than replacement returns per spawner since 2005 (Figure 29). As previously mentioned, the main factors influencing productivity are likely in the marine environment or the early river migrations by fry (Peterman and Dorner 2011). It should be noted that enhancement has likely been a factor in maintaining good abundances of Pitt River Sockeye Salmon numbers despite the current low survival and recruitment per spawner (see Grant and Pestal 2012 for abundance data).

Following the procedures used by Holtby and Ciruna (2008), Coquitlam Sockeye, if successfully established as a self-perpetuating stock, may become a new Conservation Unit under the Wild Salmon Policy. In time, benchmarks may need to be established for the Coquitlam River Sockeye CU and periodic status assessments may be required under the WSP (see for example, Grant and Pestal 2012).

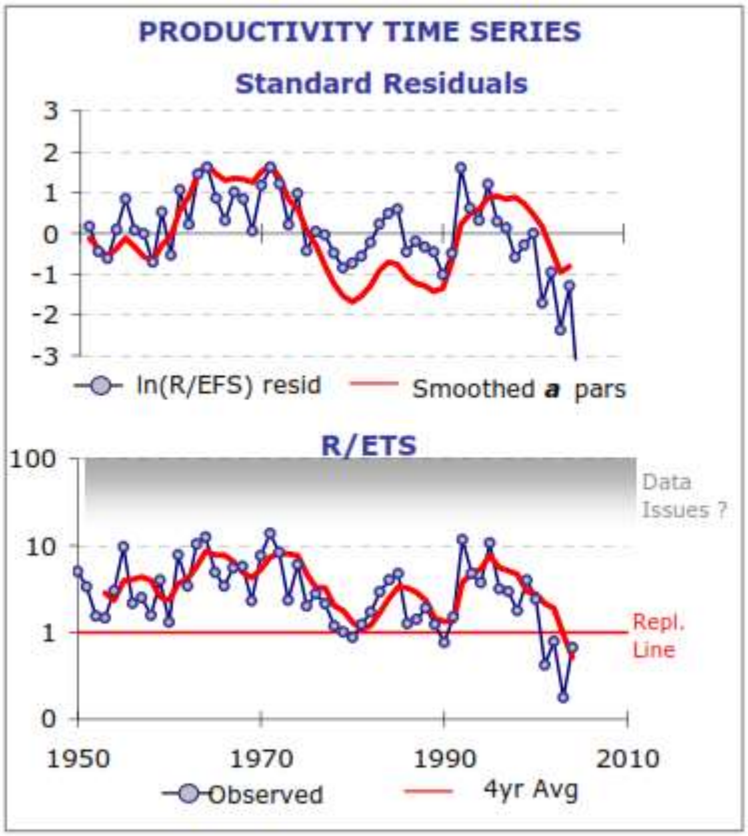

Figure 29 Productivity time series for Pitt River Sockeye and returns per spawner (Grant and Pestal 2012).

Management Goals for the Early Summer Stock Grouping

The Early Summer run timing group includes eight stocks: Bowron, Fennel, Gates, Nadina, Upper Pitt, Raft, Scotch, and Seymour, as well as variable contributions from miscellaneous populations. Coquitlam Sockeye Salmon are believed to have the same run timing as the Early Summer stock grouping. The 4-year average escapement for Early Summer Sockeye has been consistently above the Low Escapement Benchmark (LEB) or Limit Reference Point (LRP) since 1975 (Figure 30). There are no years since 1990 when the annual total escapement for this run-timing group has been less than the LEB. The Early Summer group includes eight indicator stocks with defined LEBs. Since the early 1980's, the 4-year moving averages of the annual escapement estimates have consistently exceeded the LEBs for each of the Early Summer indicator stocks, except for Bowron Sockeye. For Bowron, the 4-year moving average was consistently above the Bowron LEB prior to 2006 but lower than the LEB in 2007–2009. Fisheries were not permitted to target the Bowron stocks and other components of the Early Summer group in these years.

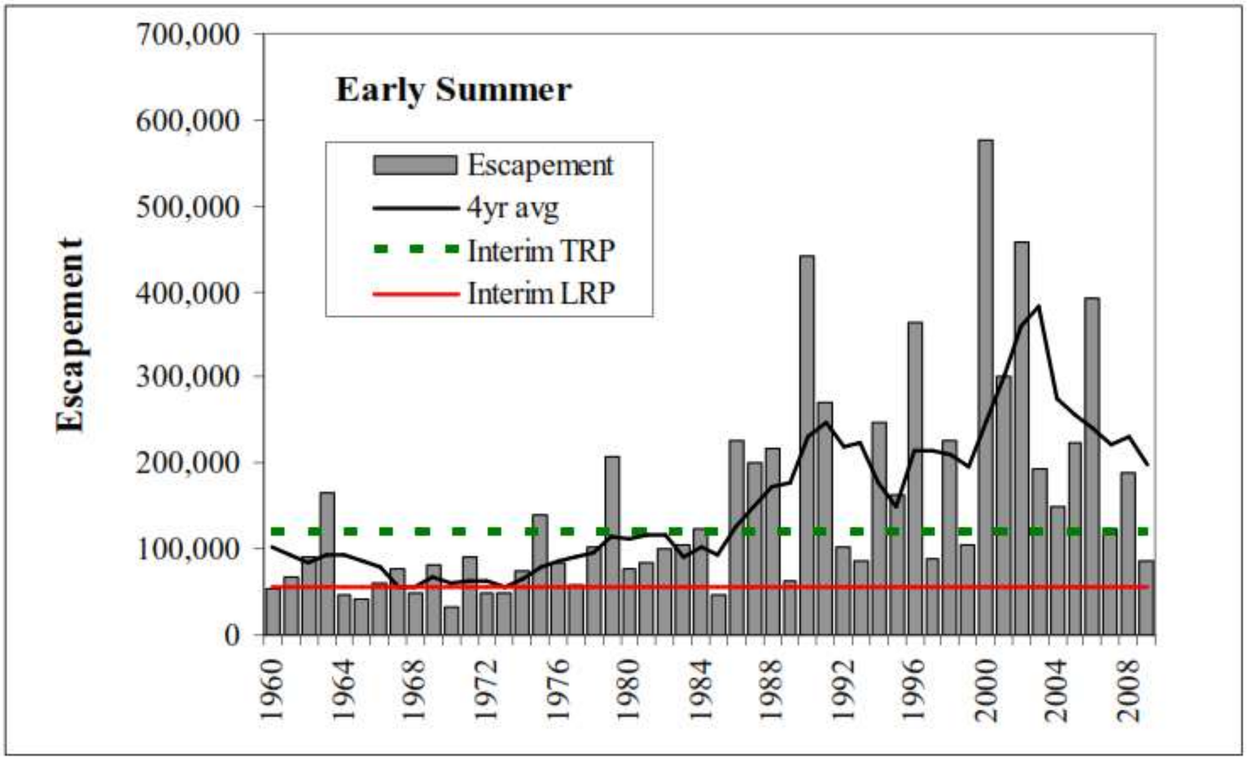

Figure 30 Escapement and operational reference points for Early Summer Sockeye (English et al. 2011a).

Exploitation Rates on the Early Summers

The total abundance for the Early Summer group was fairly consistent during the 1960–1989 period and higher but more variable from 1990–2009. Exploitation rates were relatively high (averaging 77%) from 1960−1989, and show a declining trend since 1993. Given the increasing trend in abundances observed in the 1998−2006 period when exploitation rates were in the 20–50% range, it is likely that many of the Early Summer stocks were overharvested during the 1960 to 1989 period (English et al. 2011a). This overharvesting was likely the result of run-timing overlap with fisheries targeting the more abundant Summer-run stocks. From 2007 to 2009, the Early Summer stock group had smaller returns and lower exploitation rates (Figure 31 and Figure 32).

Noble (2011) reconstructed exploitation rates for all Fraser River Sockeye stock units including the Pitt River, which historically had the same adult run timing as the Coquitlam Sockeye. For the period 2002 to 2009, exploitation rates in all fisheries on Pitt River Sockeye ranged from a low of 0.6% in 2009 to a high of 37.7% in 2004. The average exploitation rate over this period was 13.7%. Applying these exploitation rates for 2008 (8.2%) and 2009 (0.6%) returns of adult Sockeye Salmon to the Coquitlam River trap would indicate a total return (catch plus spawners) of 11 adults in 2008 and still one adult in 2009. Exploitation of Coquitlam River Sockeye was estimated to be 33% in 2010 when there was a significant commercial and First Nation fishery (harvest of approximately 1 million Early Summer Run Sockeye) and Sockeye returns were the largest ever recorded (English et al. 2011b).

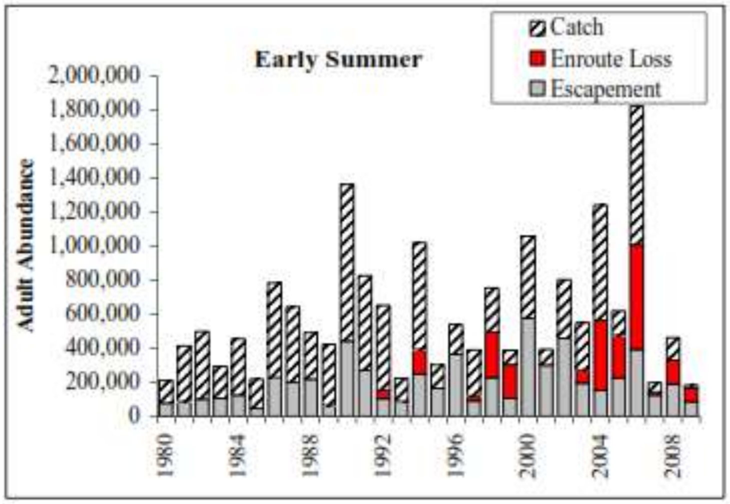

Figure 31 Estimates of total catch, escapement and en-route loss for Early Summer Fraser Sockeye, 1980–2009. En-route losses were not estimated prior to 1992 (English et al. 2011a).

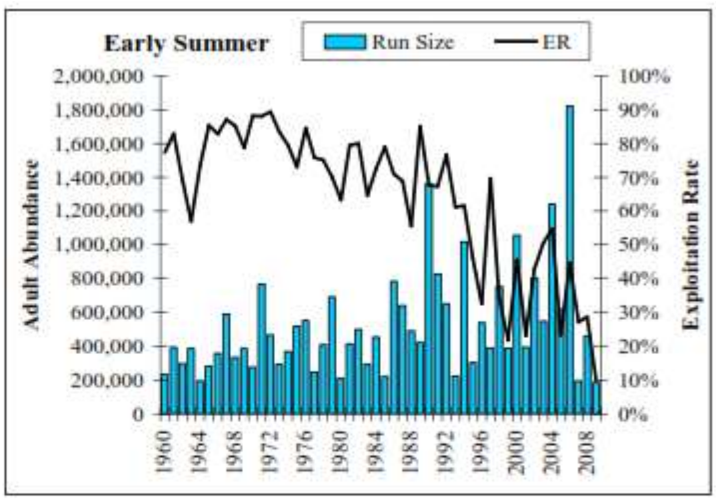

Figure 32 Estimates of total annual abundance and exploitation rates for Fraser Sockeye by run-timing group for the period 1980–2009 (English et al. 2011a).

Applying this exploitation rate to the large return of Sockeye to the Coquitlam in 2010 results in an estimated total return of four adults (catch plus escapement). Exploitation rates on Early Summer Sockeye were 35% and 15% for 2011 and 2012, respectively (DFO post-season review presentations).

Fraser Sockeye Productivity and Survival Rates

In this section, productivity refers to the number of returns per spawner. Historical data on survival rates of Fraser Sockeye stocks by life stage show that declines in total-life-cycle productivity from spawners to recruits have usually been associated with declines in juvenile-to-adult survival, but not the freshwater stage of spawner-to-juvenile productivity (Peterman and Dorner 2011). For most Early Summer stocks, productivity started a long downward trend in the 1960s and/or 1970s (Figure 33).

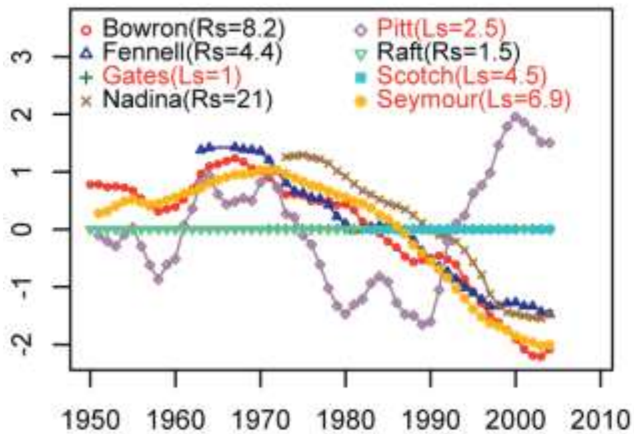

Figure 33 Comparison of time trends in scaled Kalman filter series for the Early Summer timing group, by brood year. To allow comparisons across stocks, each series is scaled to its own mean and is shown in standard deviation units from that mean (Peterman and Dorner 2011).

Current marine survival rates (smolt to adult) being experienced by Coquitlam and Alouette Sockeye (Table 9) are lower but in the same range as Chilko Lake Sockeye which has seen marine survivals less than 3.5% since the 2007 return year, and as low as 0.3% for the 2009 adult return year (2007 smolt year), respectively. Survival rates for other Fraser River Sockeye stocks, and in particular, the Pitt River and Early Summer run stock grouping are not available from Fisheries and Oceans. However, survival rates for Cultus Lake Sockeye which has undergone a re-building effort have also been poor in recent years (Figure 34; CSAS 2010).

Table 9 Smolt to adult return survival rates for Alouette Sockeye by year of smolting and year of brood (Bocking, unpublished data).

	Age at return								
Smolt Year	4.2	4.3	5.2	5.3	6.2	6.3	6.4	Total Return to Spawn (TRS)	Survival (Smolt to TRS)
2005	28	0	14	0	0	0	0	42	0.532%
2006	19	0	0	19	0	0	2	40	0.750%
2007	29	1	7	16	0	0		53	0.084%
2008	80	0	0	29	0	3		112	1.344%
TOTAL	**156**	**1**	**21**	**64**	**0**	**3**	**2**	**247**	

	Age at return							
Brood Year	4.2	4.3	5.2	5.3	6.2	6.3	6.4	Total Return to Spawn (TRS)
2003	28	0	14	19	0	0	0	61
2004	19	1	0	16	0	0	0	36
2005	29	0	7	29	0	3	0	68
2006	80	0	0		0	0	2	82
TOTAL	**156**	**1**	**21**	**64**	**0**	**3**	**2**	**247**

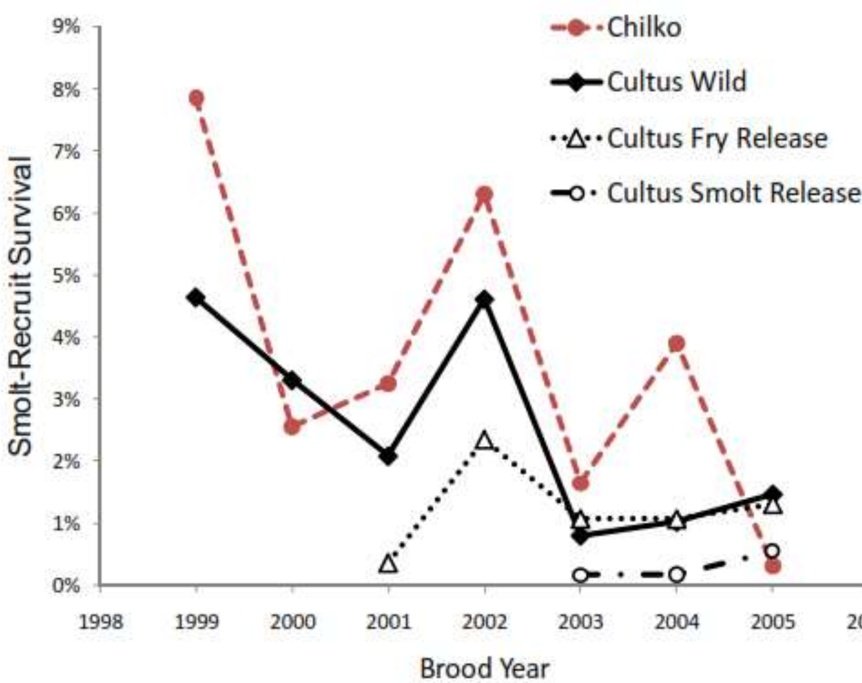

Figure 34 Recent smolt-recruit survival for Cultus Lake Sockeye Salmon, for wild smolts, smolts resulting from summer and fall fry releases to the lake, and from yearling smolt releases made in Sweltzer Creek, the outlet of Cultus Lake. Also shown are survival rates for Chilko Lake Sockeye Salmon, located in upper Fraser River basin (CSAS 2010).

Implications for Coquitlam Sockeye

Since Coquitlam Sockeye would be part of the Early Summer Sockeye timing group for the purposes of managing fisheries, there would be no requirements for special management considerations. Harvest rates on these stocks are currently below 40% and current abundances are constrained primarily by poor marine survival conditions. Several of the Early Summer Run stocks (e.g., Nahatlatch, Bowron) have been assessed as in the Red status zone under the Wild Salmon Policy (Grant and Pestal 2012). The WSP states that "*the presence of a CU in the Red zone will initiate immediate consideration of ways to protect the fish, increase their abundance, and reduce the potential risk of loss*". It is therefore reasonable to expect that harvest rates on these stocks will remain low for the foreseeable future. However, increasing the abundance of these stocks and Coquitlam Sockeye beyond current levels without enhancement intervention will not likely occur unless marine conditions improve. Should marine conditions improve and harvest rates remain low, there could be a considerable increase in Coquitlam Sockeye Salmon returns.

Management Goals for Coquitlam Sockeye

The long-term management goal for Coquitlam Sockeye should be to increase the stock to a self-sustaining level that it can withstand PSC and DFO managed harvest pressures. One indicator of success for this management strategy would be that the Coquitlam Sockeye returns co-varies with Pitt River Sockeye Salmon. Variable freshwater survival rates between the two stocks will produce noise in the co-variance and this should be accounted for.

Current and Future First Nation Fisheries for Coquitlam Salmon

Prior to dam construction, Kwikwetlem First Nation, Coquitlam River and Coquitlam Lake fisheries historically harvested Sockeye, Coho and Steelhead where fishing sites existed at various locations throughout the watershed (Koop 2001). This fishery is now gone and the current Section 35 right of First Nations to catch salmon for Food, Social and Ceremonial purposes is conducted in watersheds other than the Coquitlam.

First Nation fisheries targeting Fraser River Sockeye occur throughout the Fraser River watershed. However, future Coquitlam River Sockeye would only be vulnerable to First Nation fisheries occurring in marine waters and in the lower Fraser River mostly downstream of the Port Mann Bridge. The Port Mann Bridge is a First Nation fishery boundary for catch monitoring established by DFO. Catches of Sockeye Salmon within the Steveston to Port Mann Bridge (Area 29) stratum have been monitored over the years. Between 2002 and 2009, a total of 84,000 Sockeye have been harvested within the Steveston to Port Mann stratum (K. English, LGL Limited, pers. comm.). These fisheries would have been primarily targeted on the Summer Run and Late Run of Sockeye with limited harvests of the Early Summer run which includes the Pitt, the Alouette and likely the future Coquitlam stocks.

If a future harvest of the re-established Coquitlam Reservoir Sockeye will occur will be dependent on many factors and would be limited to years when escapement would exceed escapement goals and full habitat utilization.

Current and Future Commercial Fisheries for Coquitlam Salmon

Coquitlam River Coho, Chum and Pink Salmon are currently harvested in saltwater and lower Fraser River commercial fisheries (Gaboury and Bocking 2004). Future Coquitlam Sockeye might be part of the Early Summer Sockeye grouping where the majority of any harvesting would take place in Johnston Strait, Strait of Juan de Fuca and the lower Fraser River (downstream of Port Mann Bridge) gillnet and seine fisheries.

Current and Future Recreational Fisheries for Coquitlam Salmon

Historically, recreational fisheries in B.C. did not target Fraser River Sockeye but rather Chinook and Coho. Commencing in 1999, the DFO implemented a policy between 1999 and 2005 that recreational harvest of Sockeye would not exceed 5% of the commercial catch. Table 10 provides the annual estimates of the Canadian recreational and total Fraser Sockeye harvests from 1991 to 2009. Available catch estimates for the recreational fishery indicate that it accounts for less than 3.3% of the annual harvest of Fraser Sockeye with the majority of this occurring in the Strait of Georgia and the Fraser River.

Table 10 Estimates of Fraser Sockeye harvested in Canadian recreational fisheries by year and by region, 1986−2009 (Source: English et al. 2011a).

Year	Strait of Georgia	Johnstone Strait	West Coast Vancouver Island	Fraser River	Total Recreational	Total Catch	Percent Recreational
1991	23,521	2344	1056	*0*	26,921	9,037,000	0.30%
1992	6,745	2014	1360	*0*	10,119	4,671,000	0.22%
1993	23,600		1420	*0*	25,020	17,768,000	0.14%
1994	14,054		359	*0*	14,413	13,322,000	0.11%
1995	5,897		4	6,376	12,277	2,255,000	0.54%
1996	2,365		9	9,371	11,745	2,187,000	0.54%
1997	16,887		197	30,458	47,542	11,425,000	0.42%
1998	4,474		878	9,655	15,007	3,054,000	0.49%
1999	492	1538	51	1,913	3,994	561,000	0.71%
2000	6,367	744	0	24,075	31,186	2,463,000	1.27%
2001	3,219	0	182	41,773	45,174	1,604,000	2.82%
2002	5,133	62	216	125,040	130,451	4,223,000	3.09%
2003	2,918	384	310	73,393	77,005	2,346,900	3.28%
2004	3,340	1352	257	50,388	55,337	2,339,200	2.37%
2005	7,035	767	268	42,629	50,699	1,755,437	2.89%
2006	2,035	5445	794	134,292	142,566	5,427,000	2.63%
2007	192	76	58	11	337	375,620	0.09%
2008	79	10	26	16,344	16,459	573,595	2.87%
2009	0	48	304	0	352	124,341	0.28%
Average							
1992-00	8,987	1,432	475	9,094	19,034	6,411,778	0.49%
2001-09	2,661	905	268	53,763	57,598	2,085,455	2.26%
Percentages							
1992-00	47%	na	2%	48%	100%		
2001-09	5%	2%	0%	93%	100%		

GOALS AND METRICS FOR SOCKEYE RE-INTRODUCTION INTO COQUITLAM RESERVOIR

Based on the information in this report and the restrictive factors summarized in Table 6, the following metrics for the Sockeye re-establishment phases are suggested:

1. Establishment Phase:
   At current ocean survival, a minimum outmigration of 10,000 Kokanee smolts from Coquitlam Reservoir is required to create an escapement of >100 adult Sockeye. The minimum smolt numbers can be achieved through:
   a. hatchery intervention based on wild Kokanee broodstock and smolt release below the dam;
   b. parallel testing of a surface smolt collector in the forebay where a surface current would attract Kokanee smolts; and
   c. in addition, a meeting with BC Hydro Engineers to assess the feasibility and cost of tunnel modifications to increase smolt survival would be desirable.

   Of these three measures, the KSRP members agreed on measure a. hatchery intervention as the next step that should be taken followed by steps b. testing of a surface smolt collection system and c. a meeting with BC Hydro Engineering.

2. Self-Sustaining Phase with Continuing Intervention:
   At current ocean survival, a minimum of 50,000 Kokanee and Sockeye smolts should leave Coquitlam Reservoir to create an escapement of >500 adult Sockeye. This level of escapement can likely be achieved by:
   a. continuing measures 1a and 1b, above; and
   b. the construction of the smolt surface passage way.

3. Self-Sustaining Phase without Intervention:
   Returns of more than 1,000 Sockeye adults should require a 2 way fish ladder. This could be added to the downstream end of a trench smolt passage way. At least initially, the fish ladder construction may need to be supported by hatchery enhancement. The fish ladder will have to function for the range of reservoir elevations. It is expected that the fish ladder will also accommodate future Coho and Steelhead runs.

STEPWISE SUMMARY OF SOCKEYE AND OTHER SALMON SPECIES RE-ESTABLISHMENT OPTIONS

The details for Sockeye re-establishment to rearing capacity of Coquitlam Lake are described throughout this report. Here we provide a short and stepwise summary in key word form and a flow chart (Figure 35) for all options. The options are organized from least to most effort and funding and therefore also from least to most likelihood of success:

1. Determine and provide optimal LLO discharge and reservoir elevation for smolt outmigration success and consider to determine the options to modify the Sluice Tower and/or the tunnel to reduce smolt mortalities.
2. Try to determine what is required to attract large numbers of Kokanee smolts to migrate into the dam forebay and enter the LLOs.
3. Use temporary hatchery intervention based out of Rosewall Creek Hatchery to boost the number of outmigrating Kokanee smolts.
4. Install and operate a surface smolt collection system that transports smolts over the dam or through the tunnel.
5. Construct a smolt passage way to boost the number of outmigrating Kokanee smolts.
6. Construct a full fish ladder that allows for smolt outmigration and upstream migration of adult salmon.
7. Monitor smolt outmigration and adult upstream migration numbers to develop the salmon rearing capacity of the Coquitlam Reservoir to agreed production numbers or habitat capacity.

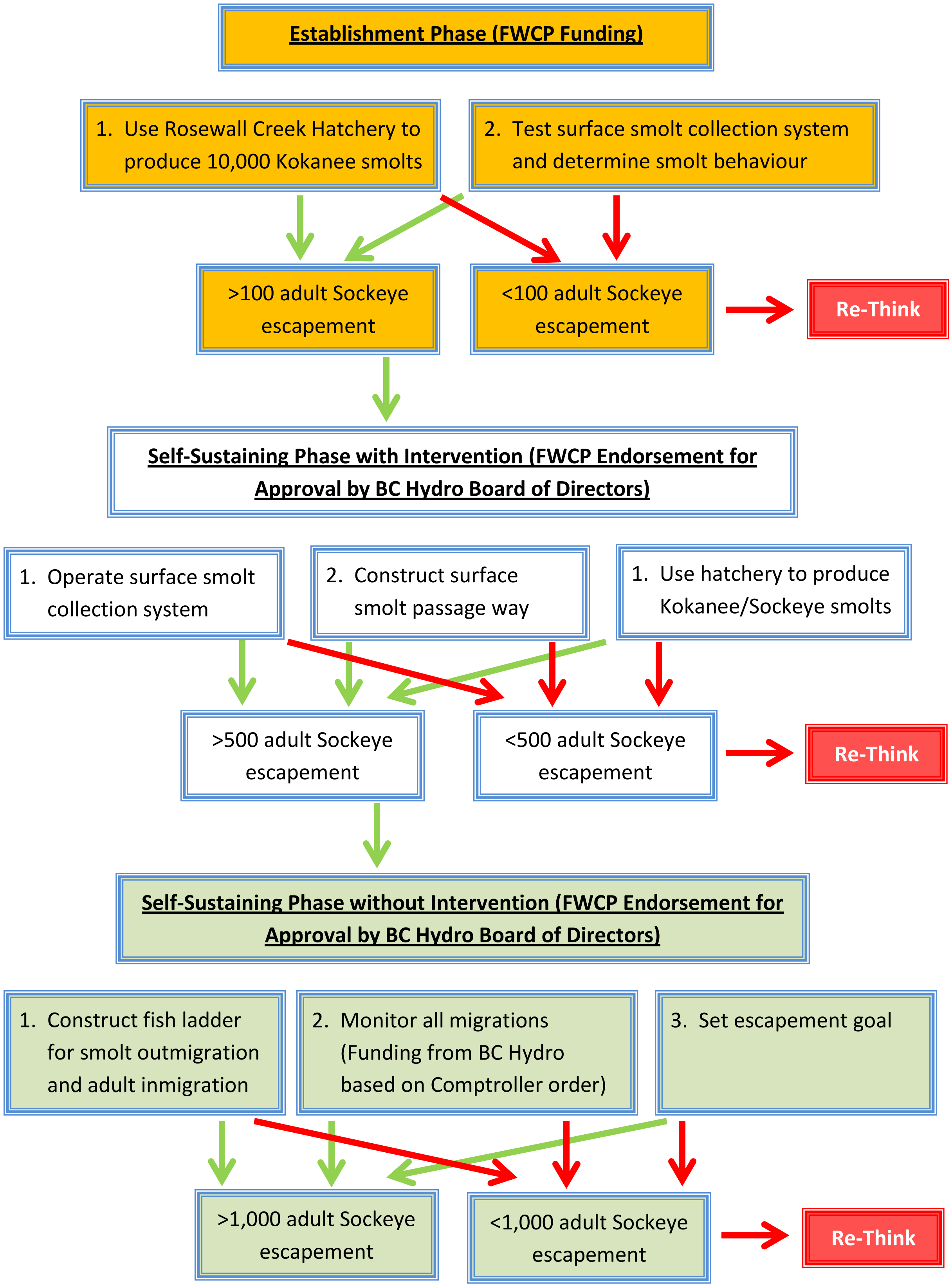

Figure 35 Flow chart for all steps of Sockeye re-establishment into Coquitlam Reservoir.

NEXT STEPS, DECISION POINTS FOR FUNDING APPLICATIONS

Referral of Plan to FWCP and BC Hydro

We suggest the following be presented to the FWCP and BC Hydro for implementation/funding from 2015 on:

1. FWCP funding: Capture and spawn a minimum of 100 female and 100 male Kokanee at Coquitlam Reservoir in the fall of 2014, 2015 and 2016 as broodstock for a hatchery intervention. Use Rosewall Creek Hatchery on Vancouver Island to raise 10,000–15,000 Kokanee smolts for release in 2016 to 2018. If so desired, 2,000 Kokanee smolts can be released at low reservoir elevation and high LLO discharge into the reservoir forebay or directly into the LLOs to determine their survival or less expensive and readily available Coho smolt could be considered for such high risk testing.
2. FWCP funding and potential FWCP endorsement for approval by BC Hydro Board of Directors: Concurrently with the 2015 hatchery program, develop, test and operate a floating surface smolt collection system through funding from FWCP to test whether surface current can attract smolts into the forebay. In conjunction with the surface collector testing, the approach behaviour of Coquitlam Kokanee Salmon smolts could be tested in hydroacoustic surveys.
3. FWCP endorsement for funding approval by BC Hydro Board of Directors: If larger numbers of smolts can be attracted to the forebay and if larger (>100) Sockeye escapements are achieved through the hatchery smolt release, build a smolt passage way. This will require separate applications to FWCP for endorsement of this measure and approval from the BC Hydro Board of Directors. Simultaneously apply for FWCP funding to establish a well-organized program for trapping and transporting adult Sockeye over the dam.
4. FWCP funding for smolt enumeration: If, based on a smolt surface collection system, more than 50,000 Kokanee smolts regularly leave Coquitlam Reservoir, cease the hatchery enhancement and rely on natural outmigration. All migration numbers need to be annually monitored. Based on review by the Provincial Comptroller of Water Rights, it is hoped that regular funding for migration enumeration will be provided by BC Hydro.
5. FWCP endorsement for funding approval by BC Hydro Board of Directors: If more than 1,000 adult Sockeye return, apply for funding to complete the fish passage facility to allow for unassisted Sockeye migration into the reservoir. Again, this measure will need to be endorsed by the FWCP Board to the BC Hydro Board of Directors for approval of business case development and implementation. If at any time, Coquitlam Sockeye escapement will overwhelm the truck and transport method, the construction of a fish ladder should be considered earlier in the process than suggested here.

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