

Cheakamus/Squamish Powerhouse Channel Pilot LWD Project

2009 PROJECT FINAL REPORT



prepared for:

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prepared with financial support of:

"BC Hydro Bridge Coastal Fish and Wildlife Restoration Program"

BCRP Project # 09.CMS.05

BCCF Report # 05-2009



**British Columbia
Conservation
Foundation**



GREATER GEORGIA BASIN
STEELHEAD Recovery Plan
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EXECUTIVE SUMMARY

Due to the artificial constructed nature of the Powerhouse Channel, minimal fish habitat value in the form of physical stream characteristics exist. This channel is used throughout the year by numerous trout and salmon species, including all juvenile salmon species and steelhead, cutthroat and char, mainly for rearing, as there are limited productive spawning areas. Through this project, habitat restoration prescriptions that focus primarily on increasing habitat through the design of vertical piling woody debris structures (similar to engineered log jams), were developed. These structures have been designed to respond to the varying flow levels of the Powerhouse Channel and provide refuge during high stream flow events, provide immediate refuge areas for protection from predators, and act as a substrate medium ideal for lower trophic level community adherence and growth.

Professional biologists and engineers conducted a field survey and used aerial photography, literature review and correspondence with key stakeholders to develop prescriptions that identified seven suitable sites within a 1 km reach of the channel. The structure design that was developed is a vertical log structure consisting of seven trees with rootwads anchored with ballast boulders and piles driven into the streambed. The estimated cost for this fish enhancement works is \$80,000 (with contingency \$130,000).

Funding for this initial design stage of the project was provided by the Bridge Coastal Fish and Wildlife Restoration Program and Living Rivers – Georgia Basin/Vancouver Island.

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1 INTRODUCTION

1.1 Background

The Squamish Powerhouse Channel is a simplified channel which conveys water from the penstock of the BC Hydro - Squamish Powerhouse to the mainstem Squamish River. Water from the Cheakamus/Daisy Reservoir makes its way from the Cheakamus to the Squamish watershed and into the Powerhouse Channel via an 11 km long tunnel that has been bored through Cloudburst Mountain.

Hydro-electricity is created at the Squamish Powerhouse, situated to the east of the Squamish mainstem. The Cheakamus/Squamish hydro-electric facility was constructed by BC Electric and became operational circa, 1957. As per BC Hydro's *Strategic Plan*, a water license which allows diversion of 27cms, and a low fish flow requirement of 5cms has been permitted.

Due to the substantial length and overall wetted area provided by the Powerhouse Channel, it is believed to be an extremely valuable side-channel used heavily by fishes during the volatile winter precipitation run-off or spring freshet events that occur annually in the Squamish mainstem. The Powerhouse Channels' connectivity with several other natural and constructed side-channels and ponds increases its importance to overall Squamish watershed fish sustainability. In the Cheakamus River, extensive habitat restoration efforts have provided approximately 56,000m² of rearing habitat through side-channel construction, known as the Dave Marshall Salmon Reserve. Albeit significantly more complexed with a diversity of hydraulic and physical parameters than that of the Powerhouse Channel, this side-channel complex was said to provide approximately 45% of the total coho smolt production leaving the Cheakamus River (Juvenile counts undertaken by BC Hydro and DFO in the spring of 2001 (Melville and McCubbing, 2000)). The importance of the large body of water from the Powerhouse Channel should not be underestimated as a significant refuge area and contributor to the overall Squamish watershed fish stocks.

1.2 Statement of Need

Steelhead populations in the Squamish River are at historical lows according to the steelhead harvest analysis and reports from local anglers. Low ocean survival combined with a reduction in stable freshwater habitat, resulting from riparian disturbance, are major contributors to the population decline. Numerous recovery programs have prioritized the protection/development of stable off-channel habitat in the Squamish as a strategy for recovery of steelhead trout and salmon in the watershed. The Squamish River Watershed Salmon Recovery Plan, prepared by the Pacific Salmon Foundation, states that the Squamish watershed was chosen for intense recovery strategy development because of: past and future land development and human population pressures on the ecosystem; past fish and wildlife habitat impacts; a high potential for recovery; and fish species diversity (Golder 2005). The Greater Georgia Basin Steelhead Recovery Plan considers steelhead trout to be in an '*extreme conservation*

concern population status (Lill, 2002), and identifies the restoration of productive side-channels as a recovery strategy. Also, stated as the third *'fish restoration objective'* in the *BCRP - Cheakamus Watershed Plan* (BCRP - Volume 2: Cheakamus River Watershed) is the need to *'improve habitat conditions for fish stocks using the Squamish River side-channel below the tailrace'*.

The Powerhouse Channel hosts a diversity of anadromous and non-anadromous fish stocks including cutthroat trout, steelhead trout, char, and all species of pacific salmon, as well as various other fish species (ie. sculpins and stickleback). Impacts to fish, associated with the Cheakamus/Daisy Reservoir to Squamish hydro-electric diversion operations include; entrainment of fish through the penstock from Daisy Reservoir; potential for elevated short-term TGP (total gas pressure) events; and adverse affect of flow fluctuations on spawning salmon (BCRP - Volume 2: Cheakamus River Watershed). BC Hydro is, however, addressing many of these operational issues.

In addition to the impacts noted in the Cheakamus Watershed Plan, other concerns from stakeholders include: the absence of stream characteristics suitable for fish sustainability resulting from limited/no natural recruitment of sediment (i.e. cobbles and gravels) or large woody debris; fish stranding/mortalities when spilling ceases; temperature variability as a result of the source waters originating from a foreign watershed; and regulated water level variability creating temporary adverse fish habitat conditions and non-natural flow regimes.

Due to the artificial constructed nature of the Powerhouse Channel, minimal fish habitat value in the form of physical stream characteristics exist, albeit a significant estimated wetted area of 55,000 m² is available for fish use. This channel is used throughout the year by numerous trout and salmon species, including all juvenile salmon species and steelhead, cutthroat and char, mainly for rearing, as there are limited productive spawning areas (M. Foy, DFO, pers. comm.).

2 GOALS AND OBJECTIVES

The overall goal of this project is to develop habitat restoration prescriptions that focus primarily on increasing habitat through the design of vertical piling woody debris structures (similar to engineered log jams) that are able to respond to the varying flow levels of the Powerhouse Channel.

Using a unique concept of pile driving wood stems into the channel bed and integrating woody debris in a matrix, fish habitat capacity will be improved at all flow levels. Because of the unpredictable changes in water levels and substrate composition within the channel, the traditional triangular LWD structures may not be suitable. Large multi-log structures that can be attached to stable pilings and offer ideal habitat over the entire vertical height of the structure are preferred. The design will adopt a concept that will function at varying water levels, as this regulated channel frequently experiences low water conditions. In addition, methods will be explored to generate greater rearing area during minimum flow levels; this will be addressed in an attempt to mitigate the issue of fish stranding in select reaches. The woody debris structures will not only provide immediate refuge areas for protection from predators, but also a substrate medium ideal for lower trophic level community adherence and growth. The proposed woody debris placement will provide salmonid and non-salmonid habitat features in a man-made channel which exists with limited ability of natural recruitment of woody debris.

Specific objectives to reach these goals include:

- Gathering background information on the Powerhouse Channel regulated operations to help develop a habitat restoration project which integrates with fluctuating aquatic habitat conditions of this channel,
- Integrating key stakeholders into project discussions, and project design,
- Collecting field parameters then design a large woody debris habitat project that will increase habitat capacity and function at all water levels, and
- Designing a fish habitat restoration project which can respond to a unique water resource environment, and one that will attract partnership funding for implementation.

3 STUDY AREA

The Powerhouse Channel is accessed off the Sea-to-Sky (Highway 99) north of the Lower Mainland (Figure 1). After passing through the city of Squamish, turn west and head along the Squamish Valley Road for about 23 km. Once the paved road gives way to gravel, travel another 3.5 km and you will cross a bridge over the upper portion and the beginning of the Powerhouse Channel. The Powerhouse Channel flows south for more than 1.5 km before its confluence with the Squamish River (Table I).

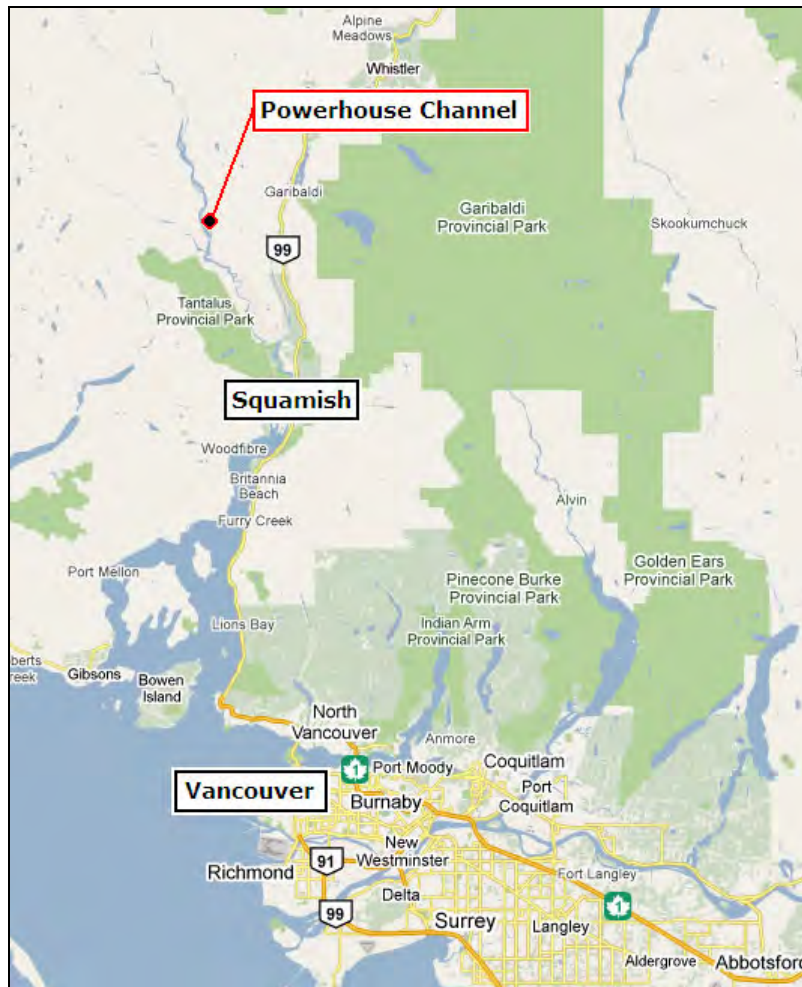


Figure 1: Overview map highlighting the location of the Powerhouse Channel in relation to Squamish, Vancouver, and the Lower Mainland. (Figure adapted from Google Earth.)

Table I: Additional information for the Powerhouse Channel.

Gazetted Name:	Unnamed	Origination	Daisy Lake Reservoir
Watershed Code:	900-097600-42312	Stream Length:	1.65 km
Stream order:	1	Confluence:	Squamish River

4 METHODS

On March 17, 2010, a survey was conducted on the Powerhouse Channel by a biologist from LGL Limited Environmental Research Associates (LGL), professional engineers from Kerr Wood Liedal Associates Ltd. (KWL), and a fish habitat technician from the BC Conservation Foundation. Collaboration and discussion on the available habitat, hydrological features and needed restoration techniques were discussed. In addition, aerial photography was used to assist in determining channel characteristics and identifying viable structure sites. GPS coordinates (Table II), digital photography (Appendix IV), and field observations were recorded.

Table II: UTM coordinates (NAD 1983 geodetic reference system) for landmarks/features collected during the March 17, 2010 survey.

Feature	UTM Coordinates
Bridge crossing channel (survey start)	10 U 539842 5466860
High Falls Creek confluence	10 U 539875 5466774
Tributary from DFO restoration ponds	10 U 539941 5466521
Gravel pad (access across channel)	10 U 539765 5465860
Sharp channel turn (survey end)	10 U 539592 5465639

Starting at the upstream portion of the Powerhouse Channel at the bridge crossing the channel, approximately 1 km was surveyed. At the 1 km point, the channel makes a hard turn, deflected by rip-rap armoring of the Squamish Valley Road. It was collaboratively determined that structures constructed from this point downstream posed a potential risk of eroding the road during extreme flow events. The survey ended here as no restoration techniques would have been recommended for this section (Figure II).

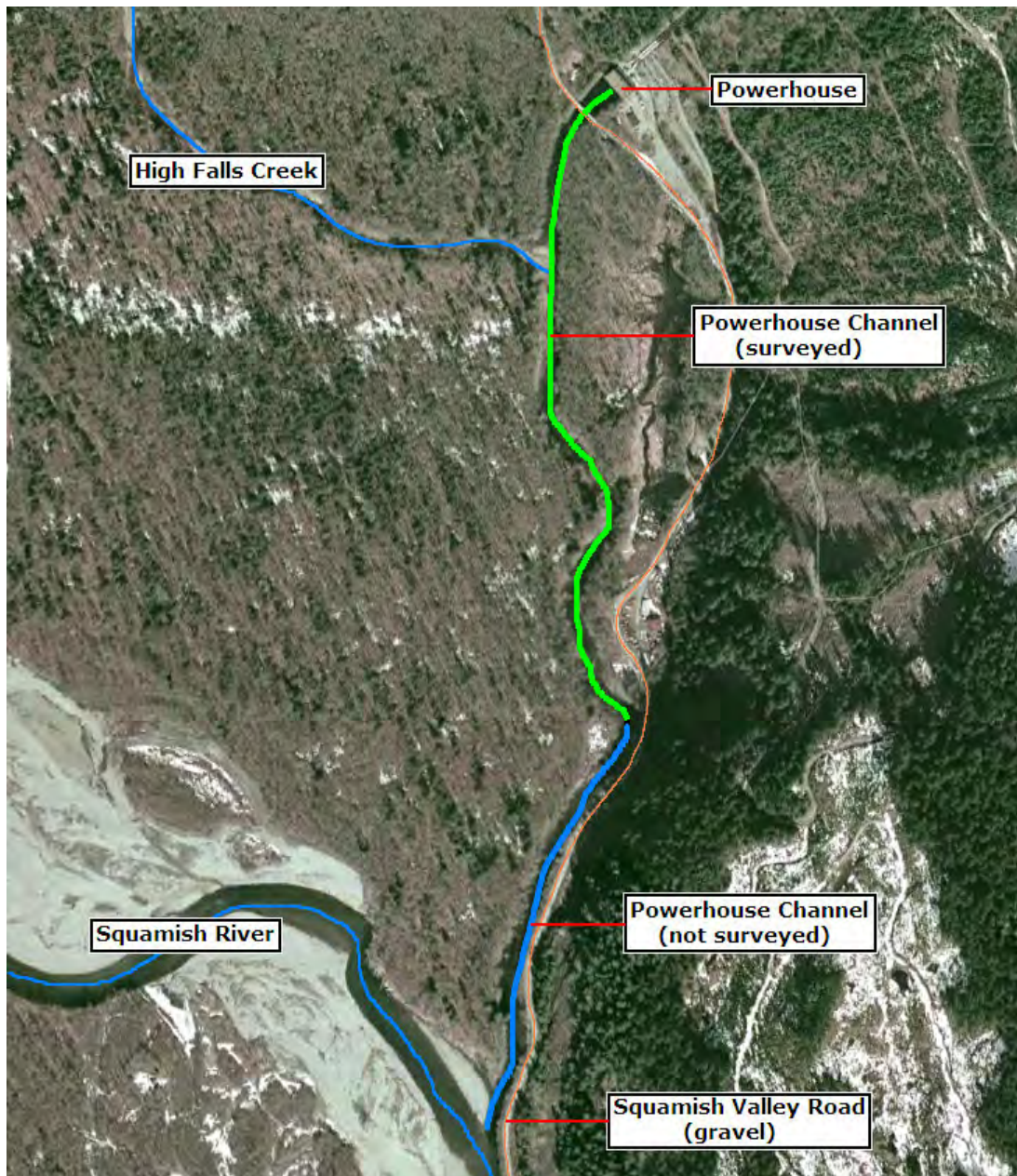


Figure 2: Detailed aerial view of Powerhouse Channel highlighting local landmarks. (Figure adapted from Google Earth.)

5 RESULTS, DISCUSSION & RECOMMENDATIONS

LGL, with editing and information inputs from KWL and BCCF, compiled the information gathered through the field survey, correspondence with stakeholders, and literature review into a technical document titled:

Conceptual Design for Habitat Enhancement Works in Squamish Powerhouse Channel

The covering letter and technical document are located at the end of this report in Appendix V. In summary, the document details the location, number, and design of the proposed habitat enhancement works. The document also outlines the anchoring of the structures, estimated budget (with contingency), and recommendations prior to commencing the construction stage.

6 ACKNOWLEDGEMENTS

BC Hydro – Bridge Coastal Fish and Wildlife Restoration Program is recognized for funding this project along with Living Rivers – Georgia Basin/Vancouver Island. This project would not have gotten off the ground without the commitment and hard work of Mark Gaboury from LGL Limited Environmental Research Associates. Dave Murray and Sarah Lawrie from Kerr Wood Leidal Associates Ltd. are recognized for their contributions towards the technical memo. Also, Alexis Hall from BC Hydro assisted in gathering information on the Powerhouse Channel.

7 REFERENCES

- Golder Associates Ltd. 2005. Squamish River Watershed Salmon Recovery Plan: Final Report. Prepared for the Pacific Salmon Foundation. 187p.
- Lill, A.F. 2002. Greater Georgia Basin Steelhead Recovery Action Plan. Prepared for the Pacific Salmon Foundation. AF Lill and Associates Ltd. North Vancouver, BC. 107p.
- Melville, C. and D. McCubbing. 2000. Assessment of the 2000 Juvenile Salmon Migration from the Cheakamus River, Using Rotary Traps. Prepared for B.C. Hydro by Instream Fisheries Consultants.

APPENDIX I: Financial Statement



Project #09.CMS.05

Financial Statement Form

	BUDGET		ACTUAL	
	BCRP	Other	BCRP	Other
INCOME				
<i>Total Income by Source</i>	4925	4925	4925	7620.12
Grand Total Income (BCRP + other)	9850		12545.12	
EXPENSES	Note: Expenses must be entered as negative numbers (e.g. – 1000, etc.) in order for the formulas to calculate correctly.			
Project Personnel				
Wages (BCCF)	-2625	-2625	-954.12	-1471.96
Consultant Fees:				
• LGL & KWL	-2000	-2000	-3858.88	-4850.95
Materials & Equipment				
Equipment Rental				
Materials Purchased				
Travel Expenses (fuel)	-300	-300	-112	
Permits				
Per diem				-12.75
Administration				
Office Supplies				
Photocopies & printing				
Postage				
Admin fee				-1284.46
Total Expenses	-4925	-4925	-4925	-7620.12
Grand Total Expenses (BCRP + other)	-9850		-12545.12	
BALANCE (Grand Total Income – Grand Total Expenses)	<i>The budget balance should equal \$0</i> 0		<i>The actual balance might not equal \$0*</i> 0	

APPENDIX II: Performance Measures – Actual Outcomes

Project #09.CMS.05

Project Type	Primary Habitat Benefit Targeted of Project (m ²)	Primary Target Species	Habitat (m ²)									
			Estuarine	In-Stream Habitat – Mainstream	In-stream Habitat – Tributary	Riparian	Reservoir Shoreline Complexes	Riverine	Lowland Deciduous	Lowland Coniferous	Upland	Wetland
Impact Mitigation												
Fish passage technologies	Area of habitat made available to target species											
Drawdown zone revegetation/stabilization	Area turned into productive habitat											
Wildlife migration improvement	Area of habitat made available to target species											
Prevention of drowning of nests, nestlings	Area of wetland habitat created outside expected flood level (1:10 year)											
Habitat Conservation												
Habitat conserved – general	Functional habitat conserved/replaced through acquisition and mgmt											
	Functional habitat conserved by other measures (e.g. riprapping)											
Designated rare/special habitat	Rare/special habitat protected											
Maintain or Restore Habitat forming process												
Artificial gravel recruitment	Area of stream habitat improved by gravel plmt.											
Artificial wood debris recruitment	Area of stream habitat improved by LWD plcmt	Adult and juvenile salmonids						Proposed 1575m ²				
Small-scale complexing in existing habitats	Area increase in functional habitat through complexing											
Prescribed burns or other upland habitat enhancement for wildlife	Functional area of habitat improved											
Habitat Development												
New Habitat created	Functional area created											

APPENDIX III: Confirmation of BCRP Recognition

The goal of this project was to develop a suitable design to address the goals outlined in Section 2 of this report. While considerable time and effort was spent gathering data in the field at the site, there was limited opportunity for media involvement at this stage of the project. Future stages will involve ground-breaking and the construction of the LWD structures at the proposed sites. In these later stages, when there is a product to show to the public and the press, we will take steps to highlight BCRP's financial contribution through various media such as inclusion of the project completion report on the Living Rivers – Georgia Basin/Vancouver Island website, through invitations to local newspaper companies, through on-site signage, and particularly through presentations routinely given to angling and stewardship groups. Prior to the construction stage of this project, this project completion report will be submitted to Living Rivers to add to their website as they provided partnership funding, along with BCRP, for this project.



Presentations to angling and stewardship groups are used to highlight our funding partners, discuss past project and identify upcoming projects. For example, a presentation was given to 40 members of the Kingfishers Rod and Gun Club on February 3, 2010.



On-site signage is an effective way to inform river users of project objectives and to highlight funding partners. The typical project sign measures 36" X 60" and is made of a laminated high resolution vinyl graphic wrapped over aluminum. Signs are positioned at high-use areas at the project site to inform river users of the project objectives and funding partners.

APPENDIX IV: Photo Documentation



Figure 3: Upstream end of Powerhouse Channel, also the starting point of the field survey performed on March 17, 2010.

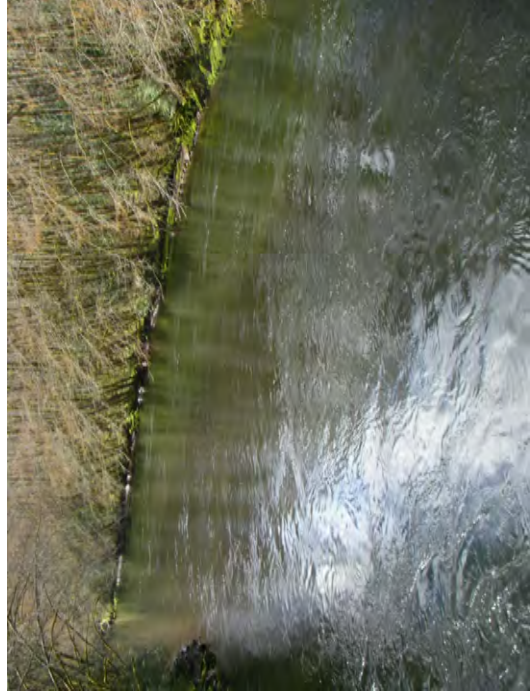


Figure 5: Looking downstream at proposed LWD sites #1 (foreground on right bank or river when facing downstream) and site #2 (background on right bank).



Figure 4: Pilings evident beneath bridge spanning Powerhouse Channel as well as piling remnants from a historical bridge crossing on right and Powerhouse visible in the background.



Figure 6: Looking across at the confluence of High Falls Creek and proposed LWD site #3 (foreground on left bank).

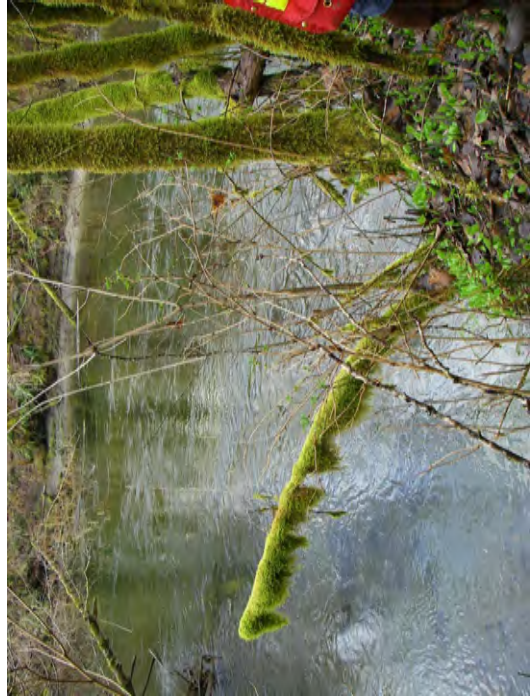


Figure 7: Looking across at proposed LWD site #4 (foreground on right bank).



Figure 9: Looking downstream at proposed LWD site #6 (on left bank).



Figure 8: Looking upstream at proposed LWD site #5 (on right bank).



Figure 10: Looking downstream at proposed LWD site #7 (on right bank)

APPENDIX V: Covering Letter & Technical Document



March 31, 2010

Mr. Dave Harper
Fisheries Technician
BC Conservation Foundation
#206 - 17564 56A Ave.
Surrey, BC, V3S 1G3

Dear Dave:

Re: Report on Conceptual Design for Habitat Enhancement Works in Squamish Powerhouse Channel

LGL Limited and Kerr Wood Leidal Associates Ltd. have prepared this letter report that describes a conceptual design for habitat enhancement works in the Squamish Powerhouse Channel. The enhancement works involve the installation of seven large woody debris structures at seven sites that were identified in the site visit of 17 March 2010. Material specifications for the woody debris structures and a cost estimate for construction of the works have been provided.

Please contact the undersigned at mgaboury@lgl.com or 250-758-1264 if you have any comments or questions on the report.

Sincerely yours,

A handwritten signature in blue ink that reads 'Marc Gaboury'. The signature is written in a cursive style.

Marc Gaboury MSc
Senior Fisheries Biologist
LGL Limited

cc: Dave Murray, Kerr Wood Leidal Associates Ltd.
Sarah Lawrie, Kerr Wood Leidal Associates Ltd.

Conceptual Design for Habitat Enhancement Works in Squamish Powerhouse Channel

Prepared by:

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Prepared with financial assistance from:

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

BCRP Report No. 09.CMS.05

March 2010

Background

The Squamish Powerhouse Channel is a simplified channel which conveys water discharged from the Cheakamus generating system to the mainstem Squamish River. The Cheakamus generating system is comprised of the Daisy Lake Dam and Reservoir, the 157 MW Cheakamus Powerhouse in the Squamish Valley, and a connecting tunnel through Cloudburst Mountain (Figure 11; BC Hydro 2005). Water for generating electricity is drawn from Daisy Lake Reservoir via a canal under the Sea-to-Sky Highway into Shadow Lake where it enters a 5.5 m diameter, 11 km long tunnel that runs through Cloudburst Mountain to the Squamish Valley. Twin penstocks carry the water from the tunnel exit to the Cheakamus generating station after which it is discharged into the Squamish River. The maximum flow from the generating station is 65 m³/s.

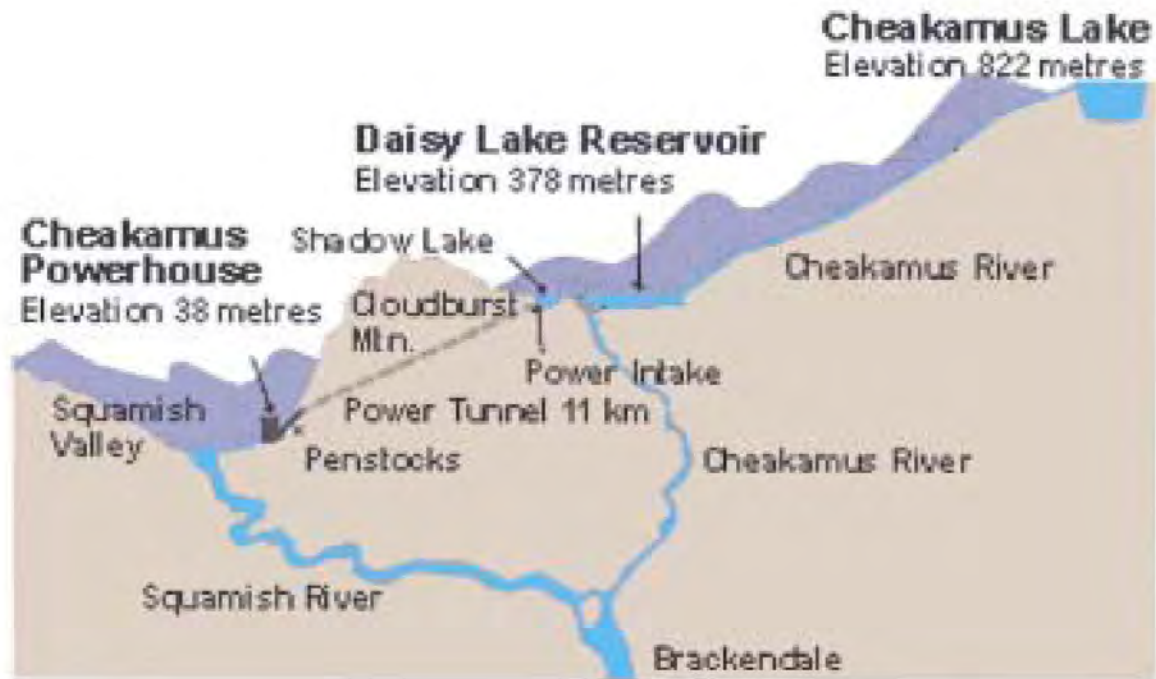


Figure 11. Map of Cheakamus generating system (reproduced from BC Hydro 2005).

The Squamish Powerhouse Channel (Figure 12) is used throughout the year by numerous trout and salmon species, including all juvenile salmon species and steelhead, cutthroat and char, mainly for rearing (M. Foy, DFO, pers. comm.). According to Fish Wizard (Freshwater Fisheries Society of BC 2010; <http://www.fishwizard.com/default.htm>), the Squamish River is inhabited by Atlantic salmon, Chinook, chum, coastal cutthroat trout, coastrange sculpin (formerly Aleutian sculpin), coho, cutthroat trout, cutthroat trout (anadromous), Dolly Varden, green sturgeon, lamprey (general), mountain whitefish, pink salmon, rainbow trout, sockeye, steelhead, and threespine stickleback.



Figure 12. Location map of Squamish Powerhouse Channel. Modified from Google Earth image.

Due to the substantial length and overall wetted area (estimated at 55,000 m²; C. Hryhorczuk, BCCF pers. comm.) provided by the Powerhouse Channel, it is believed to be an extremely valuable side-channel used heavily as refuge by fishes during the winter and spring freshets that occur in the Squamish mainstem. The Powerhouse Channels’ connectivity with several other natural and constructed side-channels and ponds increases its importance to overall Squamish watershed fish sustainability.

Impacts noted in the Cheakamus Water Use Plan (BC Hydro 2005) and other concerns from stakeholders include: limited natural recruitment of spawning substrate (i.e., cobbles and gravels) or Large Woody Debris (LWD) into the Powerhouse Channel; variation in releases from the Cheakamus Powerhouse causing large water level fluctuations and resulting in fish stranding and mortalities; and temperature variability as a result of the source waters originating from Daisy Lake.

Daily water levels in the Powerhouse Channel, immediately downstream of the Cheakamus Powerhouse, are monitored continuously by BC Hydro. In 2008, the mean change in daily water level was 0.6 m with a maximum daily change of 1.8 m and a minimum daily change of 0.001 m (Figure 13).

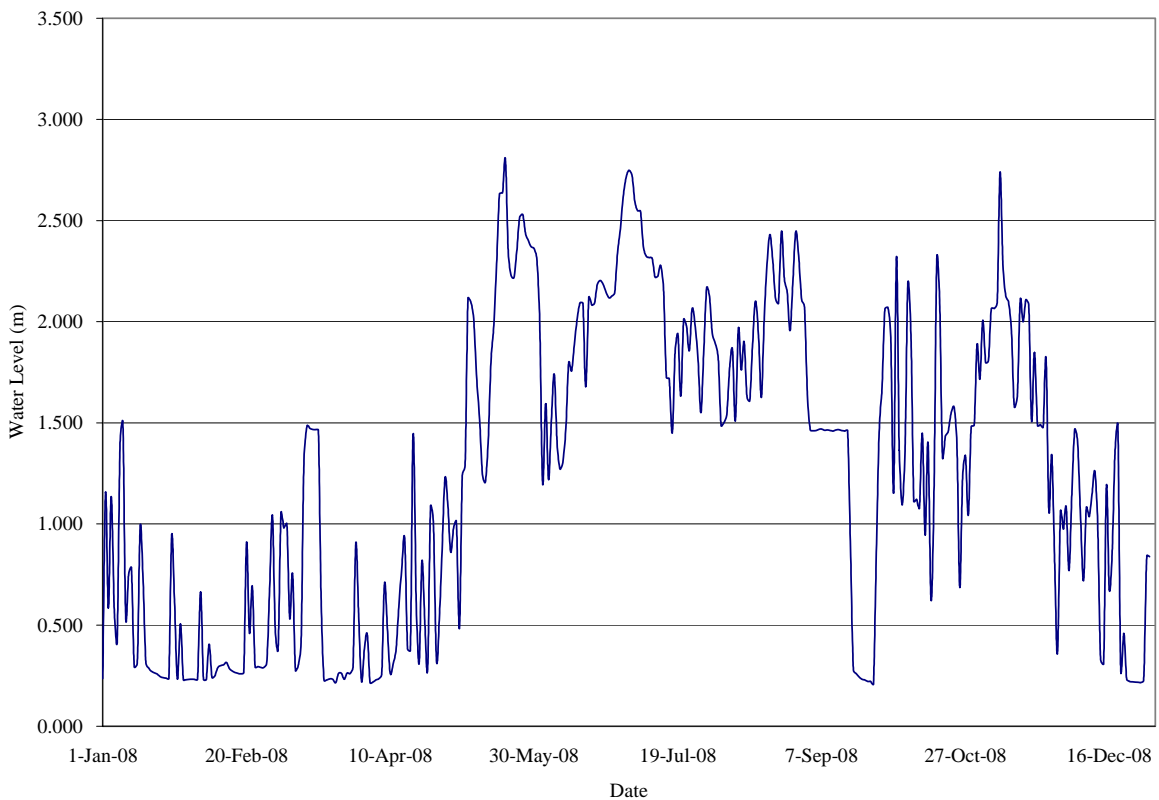


Figure 13. Daily water levels for the Squamish Powerhouse Channel, 2008 (BC Hydro unpubl. data).

The objective for this BC Hydro Bridge Coastal Fish and Wildlife Restoration Program (BCRP) project was to develop a conceptual habitat enhancement design to improve rearing

and overwintering habitat for native salmonids inhabiting the Squamish Powerhouse Channel. A key design criterion was that the enhancement structure remained functional at the varying flows and water levels experienced in the channel.

Powerhouse Channel Characteristics

The Squamish Powerhouse Channel is ~1650 m long with channel widths of ~30-40 m. The channel is primarily glide habitat at moderate flows with a constructed riffle structure at ~805 m downstream of the Powerhouse. An anabranch of the Squamish River enters the Powerhouse Channel at ~250 m downstream of Cheakamus Powerhouse. A gravel bar is evident at the confluence of the Powerhouse Channel and the Squamish anabranch. Substrate in the Powerhouse Channel is comprised primarily of sands and silts with localized gravel accumulations downstream of the confluence with the Squamish River anabranch. Visual estimates of near-bank water depths on 17 March 2010 at a staff gauge water level measurement of 1.58 m (staff gauge located at bridge crossing immediately downstream of the Powerhouse) ranged between ~1-1.5 m. Both banks sloped relatively steeply from the water's edge with bank heights of ~1-5 m above the water surface. Side slopes of the channel vary from near vertical to approximately 2V:1H. Riparian vegetation was comprised of primarily alder and cottonwood with a few Douglas fir trees.

Proposed Habitat Enhancement Works

As described below, enhancement works are proposed for seven sites in the Squamish Powerhouse Channel. The enhancement works will involve the construction of large woody debris (LWD) structures located in the thalweg of the channel. The enhancement works will primarily target rearing habitat for resident and anadromous salmonids.

Habitat Enhancement Objectives

Survival during early freshwater life stages is particularly critical for the maintenance of coho and steelhead populations, especially at the extremely low marine survival rates we are currently experiencing. Consequently, the proposed compensation measures are intended to provide high quality salmonid rearing and overwintering habitat for anadromous and as well as resident salmonids. For the proposed enhancement works, the biological objectives include:

- Improving overwintering and rearing habitat for native salmon and steelhead;
- Meeting density targets for coho and steelhead, relative to established biostandards (Koning and Keeley 1997) for LWD complexed sites that are:
 - Coho fry densities of ≥ 0.9 fry per m^2 ;
 - Steelhead fry densities of ≥ 0.3 fry per m^2 ;
 - Steelhead parr densities 0.2 to 0.3 parr/ m^2 ;
 - Rainbow trout fry and catchable-sized trout (≥ 15 cm) densities of ≥ 0.1 fish per m^2 ;

- Cutthroat trout fry densities of ≥ 0.1 fry per m^2 ; and
- Catchable-sized cutthroat trout densities of ≥ 0.06 fish per m^2 .

Habitat Enhancement Design

The proposed project would entail construction and installation of seven LWD jams suitably anchored with log piles and large boulder ballast within a ~780 m long section of the Powerhouse Channel (Table 3; Table 4 and Figure 14). The boulder ballast would counter buoyancy forces of the LWD and the piles would counter sliding forces on the structure. Each proposed LWD structure will be comprised of seven logs (Figure 15). It is anticipated that the logs with rootwads will have an average dbh of 0.5-0.6 m and range between 10-12 m long. Although some LWD is available currently at the proposed sites, it is assumed in the materials summary tables that all structure materials will be imported.

Due to the varying water levels in the Squamish Powerhouse Channel, the LWD structures will be placed in the thalweg of the channel to allow the scour pool associated with the structure to remain wetted and connected to the main watercourse, even at low water levels. At minimum water levels in the Channel a residual pool depth of ~0.6-0.8 m should remain in the scour pool of the structure. The residual pool will provide low flow refuge and should reduce fish stranding. Due to its vertical structure, the LWD design will function at varying water levels. The woody debris structures will not only provide immediate refuge areas for protection from predators, but also a substrate medium for periphyton and benthos.

Protection of the streambank nearest to the LWD structure will be required to reduce erosion. A shallow groyne that has a triangular shape in plan view with dimensions of ~6 m long by ~2 m high and ~2 m maximum width will be constructed of Class 250 kg riprap (Figure 15).

Table 3. Summary of materials required for LWD jam structures in Squamish Powerhouse Channel. Anchoring using log piles and boulder ballast. Locations within the specified reach as shown in Figure 14.

Site Number	Lat / Long Position	Structure Type	Right or Left Bank ¹	LWD Required	LWD Size (m)	LWD Ballast		Comments
						Boulders Required	Diameter (m)	
1	49°55'58.75"N 123°17'31.73"W	LogJam-7	Right	7	0.5 x 10	18	1.0	Seven logs with rootwads
2	49°55'56.60"N 123°17'32.00"W	LogJam-7	Right	7	0.5 x 10	18	1.0	Seven logs with rootwads
3	49°55'53.03"N 123°17'32.17"W	LogJam-7	Left	7	0.5 x 10	18	1.0	Seven logs with rootwads
4	49°55'44.44"N 123°17'32.27"W	LogJam-7	Right	7	0.5 x 10	18	1.0	Seven logs with rootwads
5	49°55'41.48"N 123°17'27.60"W	LogJam-7	Left	7	0.5 x 10	18	1.0	Seven logs with rootwads
6	49°55'40.02"N 123°17'28.08"W	LogJam-7	Left	7	0.5 x 10	18	1.0	Seven logs with rootwads
7	49°55'37.19"N 123°17'31.23"W	LogJam-7	Right	7	0.5 x 10	18	1.0	Seven logs with rootwads
Total						49	126	

Note: 1 - Right or Left Bank looking downstream

Table 4. Ballast requirements and boulder size options for the LWD jam structures in Squamish Powerhouse Channel. Anchoring using log piles and boulder ballast. Factor of Safety of Buoyancy=1.5; Ballast Factor = 1.

Site	Structure Type	No. of Logs (0.5 m)	Average Submerged Length of Each Log (m)	Log	Rootwad	Total Mass of Ballast Required (kg)	Alternative Quantities for Each Boulder Diameter (m)				
							0.6 @ 300 kg	0.7 @ 480 kg	0.8 @ 700 kg	0.9 @ 1000 kg	1 @ 1400 kg
1	LogJam-7	7	10	21000	600 kg/log (1.5 m diameter)	25200	84	53	36	25	18
2	LogJam-7	7	10	21000	600 kg/log (1.5 m diameter)	25200	84	53	36	25	18
3	LogJam-7	7	10	21000	600 kg/log (1.5 m diameter)	25200	84	53	36	25	18
4	LogJam-7	7	10	21000	600 kg/log (1.5 m diameter)	25200	84	53	36	25	18
5	LogJam-7	7	10	21000	600 kg/log (1.5 m diameter)	25200	84	53	36	25	18
6	LogJam-7	7	10	21000	600 kg/log (1.5 m diameter)	25200	84	53	36	25	18
7	LogJam-7	7	10	21000	600 kg/log (1.5 m diameter)	25200	84	53	36	25	18

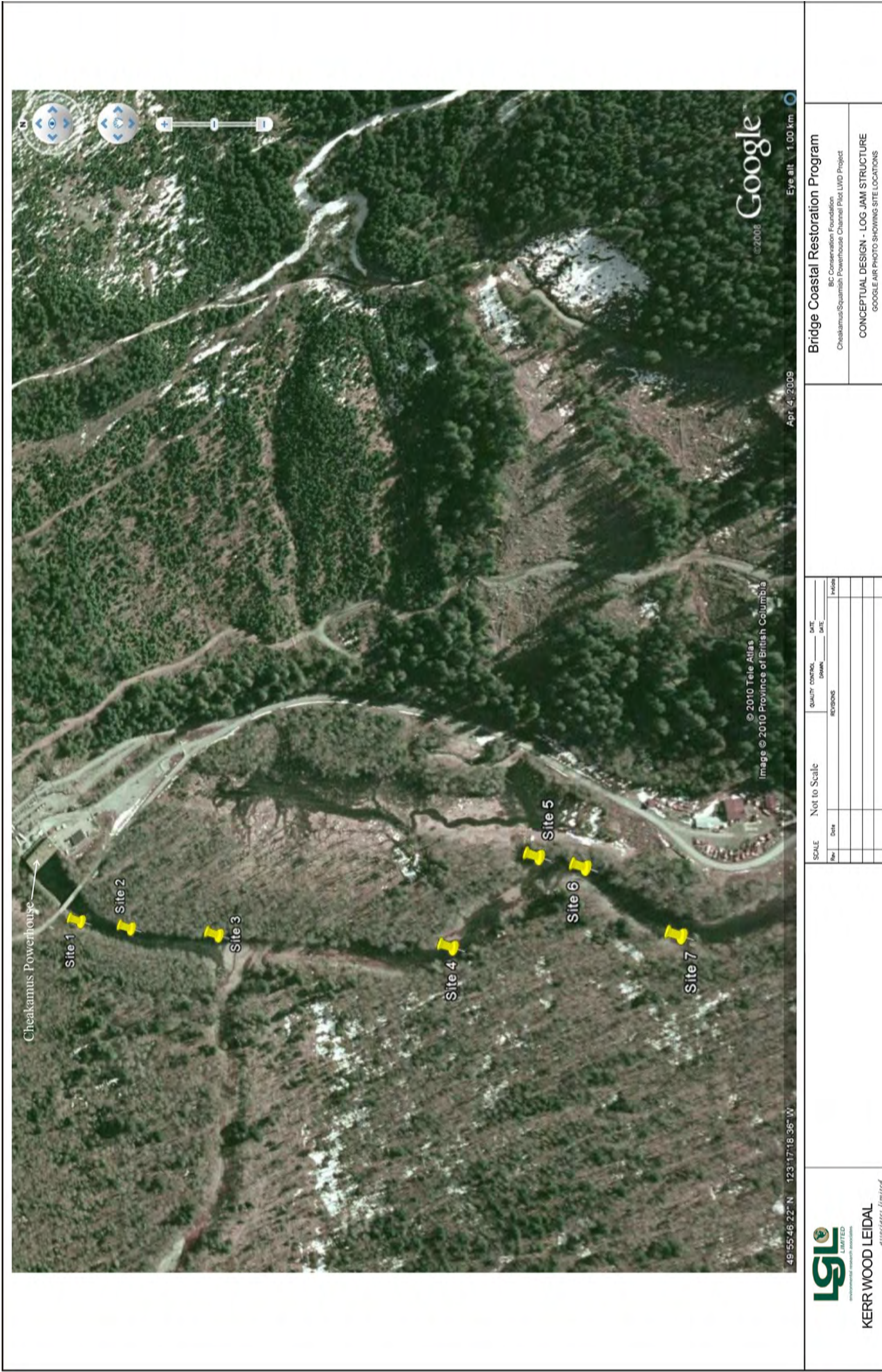


Figure 14. Google air photo showing locations of the proposed enhancement sites in the Squamish Powerhouse Channel.

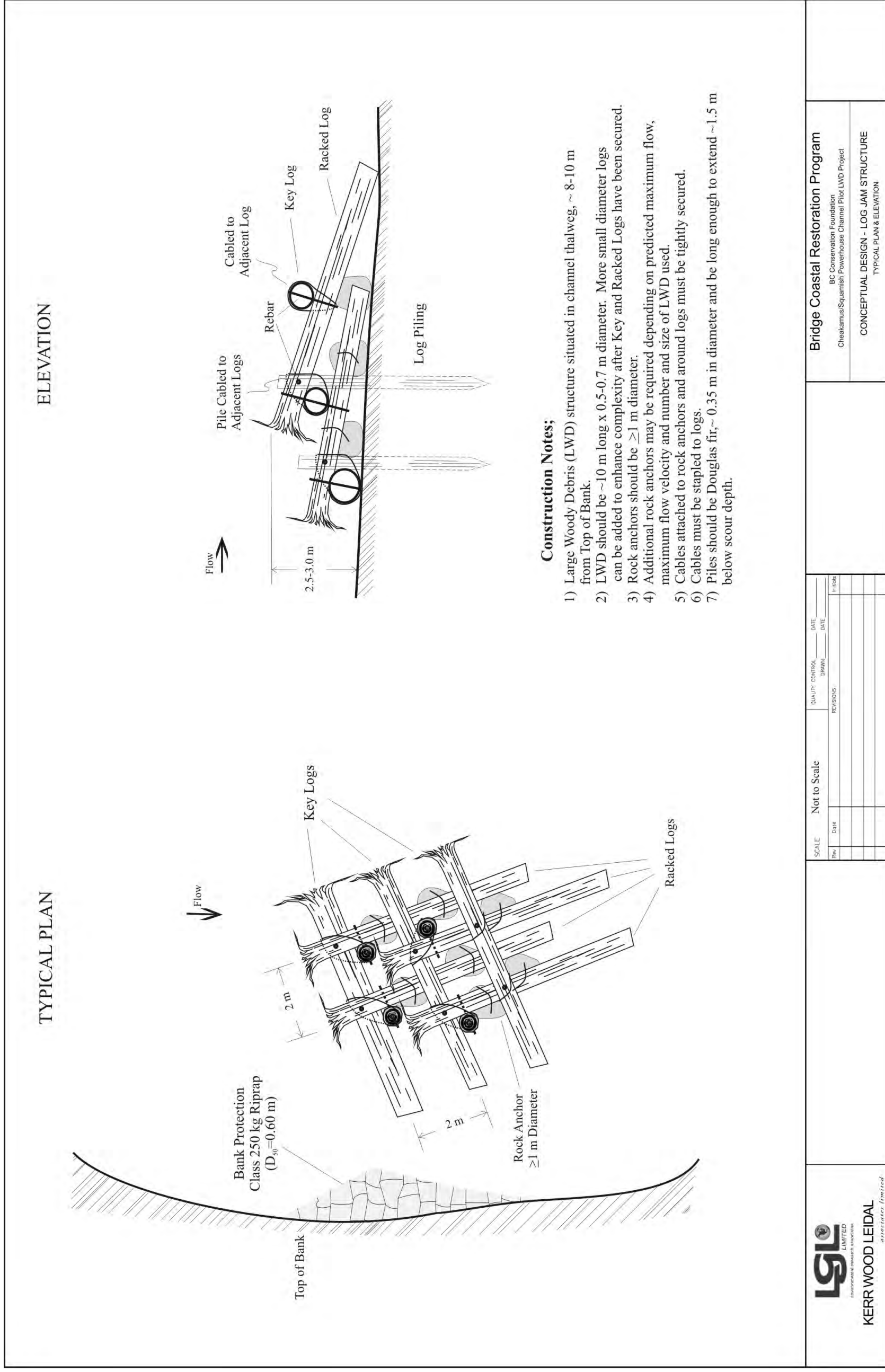


Figure 15. Conceptual design of log jam structure (Log Jam-7) for Squamish Powerhouse Channel.

Structure Anchoring

It is proposed that the large multi-log structures be anchored in the channel using log piles and large boulder ballast. Log piles will prevent the structure from sliding downstream on the channel bed and the boulder ballast will reduce structure buoyancy.

Piling is appropriate in streams with moderate to fine-sized bed material. Hard clays, cemented hardpan, bedrock and a high density of buried LWD will obstruct piling. Similarly, very coarse, cobble/boulder substrate will prove difficult for piling. We observed that log and concrete piles have been driven into the channel bed at the upstream end of the Powerhouse Channel for the current and previous bridge crossings.

Also, a recent project on the Cheakamus River by BCCF used piles to anchor a large 40 log structure. Douglas fir trees, averaging 35 cm in diameter and 8 m in length, were driven ~3 m into the streambed to resist hydraulic drag forcing acting on the structure during heightened stream flows. A Spyder excavator with an articulating clam-shell bucket positioned the piles while a 320 Cat excavator with a vibratory plate attachment was used to drive (or vibrate) the pile into the streambed (Photo 1 and Photo 2). A chainsaw was used to chisel one end of the pile to a 4-sided point to reduce resistance on the leading or driving end. A metal collar was welded onto the vibrating plate to prevent the vibrating plate from sliding off the top of the pile while forcing the pile downward. This structure site was located where a natural log jam had once been; several test digs revealed remnants of this historical log jam. If the pile met resistance against some buried obstacle (rock, wood or hard substrate), the angle was altered to continue past the obstruction. When the obstruction was not easily bypassed, a second machine was used to choke the log and apply additional downward force on the pile, effectively pushing through or past the obstruction. This technique allowed the pile to advance a few inches every minute, requiring, on average, 45 to 60 minutes to drive each pile.

Therefore, where pile-driving equipment access allows and soils are appropriate, we propose that the structures be anchored with piles. Pointed steel caps or sharpening one end of the log into a point will aid in driving the log piles into the channel bed.

Typical piling anchor designs require one-half to two-thirds of the pile's length to be buried below the streambed surface (Saldi-Caromile et al. 2004). This is critical for structures where the piles are located near or in the scour zone of the structure. Based on preliminary hydraulic analyses for this conceptual design, we estimate a potential scour depth of 4 m at the LWD structure. Further hydraulic analysis is required to confirm scour depth after topographic surveys and geotechnical assessments have been completed (see 'Recommended Assessments' section).

The log piles need to be long enough to extend below the estimated scour depth and resist all associated forces during maximum scour events. We recommend the log piles should extend a minimum of ~1.5 m below the scour depth. The total length of piles should therefore be ~8 m. The log piles should have a diameter of ~0.35 m. Two rows of piles should be driven into the streambed and brace logs (effectively key and racked pieces) should be anchored between them. The upstream row of piles is in the area of scour around the face of the logjam. Deeper

placement of the piles (~2 m below scour depth) into the channel bed is warranted for the upstream piles. The downstream row is positioned in the deposition zone, safe from the undermining effects of scour. Additional pilings away from the scour zone may also be considered. Pile types other than logs could potentially be used. The other types include steel H-pile, pipe or concrete.

A large excavator (Cat 330 or larger) mounted with a Vibratory Pile Driver is recommended for driving the piles into the streambed. Access by the excavator to each LWD site in the thalweg of the channel will require pre-planning, site preparation and coordination with BC Hydro. Timing of instream work by the excavator will need to be coordinated with BC Hydro to ensure no or minimal flow releases from the Powerhouse. Access by the excavator to each LWD site will likely require that a short access spur be constructed into the channel from the streambank. The access spur will ensure the excavator remains out of the water and on a stable surface while it is driving in the piles. The spur could be constructed of clean gravel to allow for placement in the channel when the spur is deactivated.



Photo 1. Vibratory Pile Driver attached to excavator (photo credit D. Harper, BCCF).



Photo 2. Driving piles using Vibratory Pile Driver attachment at LWD structure site in Cheakamus River, May 2010 (photo credit D. Harper, BCCF).

Pins (e.g., rebar or threaded rod) and cables are proposed to attach the logs together and to the pilings. Rebar pinning relies on shaft friction to maintain attachment. Using a cable clamp at one or both ends or bending the protruding rebar end will reduce the chance of pullout. When using threaded rods or bolts as connectors, large washers should always be used. Pilot holes are necessary for driving pins through large logs, and special, extended-shaft auger bits must be made for drilling through stacked logs.

Boulder ballast requirements for the LWD design have been determined using design charts that assume a factor of safety for buoyancy of 1.5 (D'Aoust and Millar 1999; Slaney et al. 1997). As an example, for a 0.5 m diameter log with attached rootwad, the total ballast required per metre of effective length would then be 130 kg/m, with a safety factor of ≥ 1.5 for buoyancy (D'Aoust and Millar 1999). Effective length refers to the length of log potentially submerged in the stream. Final boulder ballast requirements would be calculated during the detailed design stage of the project.

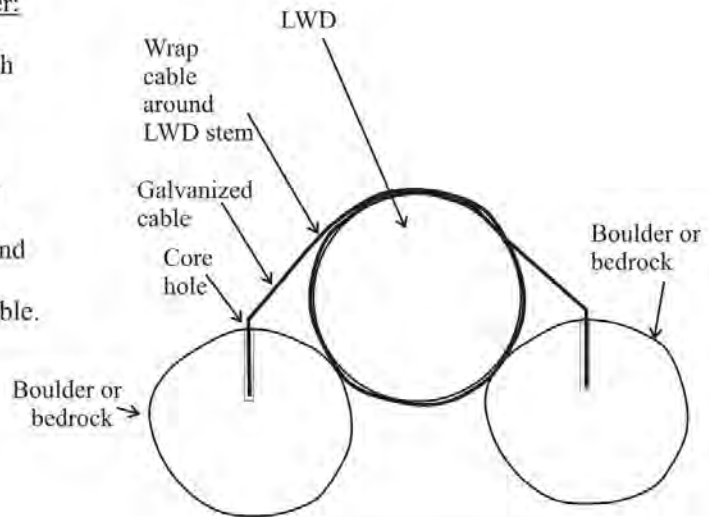
The ballast requirement for logs with rootwads attached would require conversion of the dimensions of the rootwad into an equivalent diameter and length of a log of equal mass. The total ballast requirement for the log with rootwad would be the sum of the individual ballast requirements determined for the bole and rootwad.

We recommend anchors of ≥ 1.0 m in diameter, based on a typical log diameter of 0.5 m. Except where noted, sufficient quantities of rock required to ballast the LWD structures are not available on site and would need to be brought to the proposed locations. LWD that are ballasted with boulders will be anchored by drilling 9/16-5/8" holes in the rock and using Epcon Ceramic 6 epoxy or equivalent and 1/2 inch galvanized cable (Figure 16). Two options for cabling of LWD to boulders are provided. The second option in Figure 16 provides a more natural appearance by minimizing exposure of the cable. Final sizing of the pins and cables should be confirmed after hydraulic analysis to determine design velocities, water levels, scour depths and drag forces has been completed (see 'Recommended Assessments' section).

Two Cabling Options

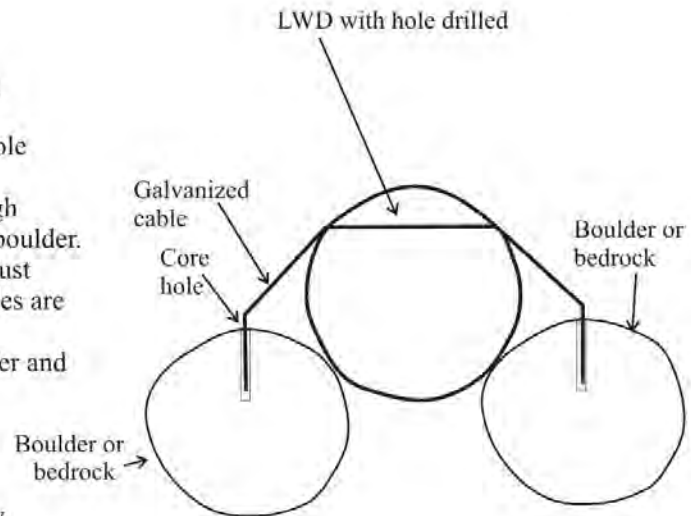
Attach cable to rock in following manner:

- 1- drill hole in rock 0.2-0.25 m deep with bit 1/16" larger in diameter than cable diameter (9/16" hole recommended).
- 2- clean holes thoroughly of dust using wire brush and water. Ensure holes are completely clean.
- 3- wrap cable (1/2" recommended) around LWD, and tighten.
- 4- squeeze epoxy into hole and insert cable.



Attach cable to rock in following manner:

- 1- drill a hole through the LWD using a hole diameter slightly larger than cable.
- 2- Pass the cable from one boulder, through the hole, and back down to the second boulder.
- 3- clean holes in boulders thoroughly of dust using wire brush and water. Ensure holes are completely clean.
- 4- squeeze epoxy into holes in each boulder and insert cable.



For additional information, refer to Slaney and Zaldokas (1997) WRP technical circular number 9, chapter 8, page 26.

Use Epcon Ceramic 6 epoxy or equivalent.

LGL Limited

Scale: Not to scale

Figure 16. Detail drawing for attaching boulders to LWD using cable and epoxy.

Fish Habitat Construction Timing Windows

The following table summarizes recommended timing windows for instream construction in the Squamish Powerhouse Channel based on the 'Fisheries Sensitive Zone Species Timing Windows' for Region 1 (Chilibeck et al. 1993). The preferred work window dates refer to the period when there are no fish eggs or alevins present in the substrates of the river or creek. Based on species distribution information for Squamish River (Fish Wizard: Freshwater Fisheries Society of BC 2010, <http://www.fishwizard.com/default.htm>), it is assumed that the Squamish Powerhouse Channel is inhabited by anadromous salmonids, including pink, chum, coho, Chinook and steelhead as well as rainbow trout, cutthroat trout and Dolly Varden.

Species	Construction Window
Chinook salmon	15 July - 15 Sep
Coho salmon	15 Jun - 15 Sep
Pink salmon	01 May - 15 Aug
Chum salmon	15 May – 15 Sep
Sockeye salmon	01 Jun - 15 Sep
Steelhead	01 Aug - 15 Nov
Rainbow trout (resident)	15 Aug - 15 Nov
Cutthroat trout (resident)	01 Aug – 30 Sep
Dolly Varden (resident)	01 Jun - 15 Sep
Whitefish	01 Jun – 15 Sep
Available Window	None Apparent
Least Risk Window	15 Aug – 15 Sept in Even Years

Based on the permissible work windows for pink salmon and rainbow trout, there appears to be no apparent work window in the Squamish Powerhouse Channel. Where no construction window is apparent based on individual 'Species Timing Windows', actual permissible windows will be determined by both federal and provincial fisheries staff. Tentatively, construction of the project is recommended during the least risk fisheries window of 15 August to 15 September in even years when spawning pink salmon are least abundant in the Squamish River.

Estimated Cost

The cost for construction of the enhancement works in the Squamish Powerhouse Channel has been estimated at ~\$130,000 (Table 5). Potential cost for the construction of the instream structures includes an appropriate contingency of +60% applied commensurate with the level of design and given the uncertainty of the local bidding climate and availability of qualified construction contractors. The estimated cost does not include the costs associated with the further work described in ‘Recommended Assessments’ below.

Table 5. Cost estimate for construction of the enhancement project in Squamish Powerhouse Channel.

			Squamish Powerhouse Channel		
Description	Unit	Unit Cost	Approx. Quantity	Cost	
Major Equipment:					
1	Excavator Cat 330 with Vibratory Pile Driver attached, all found	hour	\$180	90	\$16,200
2	Excavator Spyder, all found	hour	\$225	60	\$13,500
3	Excavators mob/demob.	lump sum	\$500.00	2	\$1,000
4	Dump Truck, all found	hour	\$145	30	\$4,350
5	Self-loading Logging Truck, all found	hour	\$140	40	\$5,600
Sub-total major equipment					\$40,650
Manpower:					
1	Project Coordinator (1 person)	pers-day	\$550	15	\$8,250
2	Semi-skilled Labour (2 people)	pers-day	\$250	10	\$2,500
Sub-total manpower					\$10,750
Light Equipment:					
1	Drilling Equipment Rental	week	\$500	2	\$1,000
Sub-total light equipment					\$1,000
Materials:					
1	LWD With Rootwads Attached	log	\$200	35	\$7,000
2	Log Piles (0.35 m diam x 8 m long)	pile	\$150	28	\$4,200
3	Ballast Rock (1.0 m) for LWD Structures	m ³	\$50	125	\$6,250
4	Riprap (Class 250 kg) for Groyne along streambank	m ³	\$50	84	\$4,200
5	Miscellaneous (epoxy, clamps, cable, etc)		\$1,000	5	\$5,000
Sub-total materials					\$26,650
				SUB-TOTAL	\$79,050
				Contingency (60%)	\$47,430
TOTAL ESTIMATED COST (Rounded to nearest \$10,000)					\$130,000
Total number of enhancement sites				7	

Recommended Assessments

Further assessments are required to allow the conceptual design to progress to the final design stage. Topographical surveys are required to obtain cross section and streambed profiles at each of the proposed enhancement sites. Substrate characteristics at each site should also be documented. A series of test digs should be performed with an excavator to see what the composition of the substrate is and whether it is suitable for pile driving. A request to BC Hydro would need to be made to terminate powerhouse releases so the channel access is possible for the excavator. With the cross section information, the effect of changes in water levels and depths at the proposed site locations can be assessed to refine the siting of the proposed LWD structures in the channel. Hydraulic analyses are required to determine channel velocities at maximum discharge and to determine the potential depth of scour at the LWD structures. The hydraulic analysis will allow log pile specifications and boulder ballast requirements to be refined.

In summary, the next steps in the design process include:

1. Topographic / bathymetric survey of LWD sites.
2. Test digs with an excavator to assess suitability of substrate for pile driving.
3. Geotechnical analysis to determine subsurface soils, pile size and required depth for scour and for stability.
4. Hydraulic analysis to determine design velocities, water levels, scour depths and drag forces, etc.
5. Preliminary design and application for Section 9 Water Act, Transport Canada (Navigable Waters), and DFO approvals.
6. Detailed design of structures including site plans, details and sizing of cables, ballast and other connections.
7. Implementation plan for construction access logistics and final cost estimate.

Site access and an implementation strategy to construct the structures within the channel need to be discussed with BC Hydro, Fisheries and Oceans Canada and BC Ministry of Environment. Minimizing the discharge through the Cheakamus Powerhouse during the construction period would facilitate access for machinery to work within the Powerhouse Channel. Work would need to be scheduled with BC Hydro to coincide with periods of low precipitation and river discharge, and possibly during powerhouse shutdown for maintenance or periods of low electrical demand.

Acknowledgments

Several people participated in one way or another in the completion of this study. We thank Dave Harper (BCCF) who provided administrative support and contract management. Alexis Hall and Ian Dodd of BC Hydro provided water level information for the Squamish Powerhouse Channel. Kerry Stratton coordinated the production of this report. The support of all these individuals is greatly appreciated. Financial support for this project was provided by BC Hydro Bridge Coastal Fish and Wildlife Restoration Program.

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