



Seymour River Rockslide Mitigation



**Seymour Salmonid Society
PO Box 52221
North Vancouver, BC
V7J 3V5**



**Final Report
January 4, 2015**

Notification

This document has been prepared by Northwest Hydraulic Consultants Ltd. and BGC Engineering Inc. in accordance with generally accepted engineering and geoscience practices and is intended for the exclusive use and benefit of Seymour Salmonid Society for whom it was prepared and for the particular purpose for which it was prepared. No other warranty, expressed or implied, is made.

Northwest Hydraulic Consultants Ltd. and BGC Engineering Inc. and their officers, directors, employees, and agents assume no responsibility for the reliance upon this document or any of its contents by any party other than the Seymour Salmonid Society, for whom the document was prepared, and directly related to the rockslide mitigation concepts on the Seymour River, North Vancouver.

Citation

Northwest Hydraulic Consultants Ltd. and BGC Engineering Inc. 2016. Seymour River Rockslide Mitigation. Prepared for Seymour Salmonid Society. 04 January 2016.

Certification

Report prepared by:

Sam Fougère, M.Sc., P.Geo.

Barry Chilibec, M.A.Sc., P. Eng.

Table of Contents

Background	1
Tasks	1
Slide Assessment.....	2
Impacts to Seymour River Steelhead and Salmon	2
Impacts to Lower Seymour Conservation Reserve (LSCR)	4
Impacts to River Flows and Water Levels	4
Rock Slide Stability and Geotechnical Aspects.....	8
Assessment of Mitigation Options.....	9
Proposed Options	10
Preferred Option.....	13
Proposed Mitigation Implementation.....	13
Approach	13
Safety and Constructability.....	14
Issues and Uncertainties.....	14
Implementation and Schedule.....	15
Project Costs	16
References	17

List of Tables

Table 1 Slide Mitigation Options Assessment	12
---	----

List of Figures

Figure 1 Seymour Rock Slide Location Map (base map from Google Maps).	3
Figure 2 NHC Rockslide Survey.	5
Figure 3 WSC 08GA030 Seymour River water level at Twin Bridges January 1 st to October 25 th 2015.	6
Figure 4 Seymour River Flows and Upstream Water Levels January 1 st to November 25 th 2015.....	7
Figure 5 Frequency Distribution of 2015 Seymour River Flows January 1 st to November 25 th 2015.	7
Figure 5 Project Schedule	16

Background

At 5:30 AM on December 7th 2014, a rock slide occurred within a canyon 0.5 km downstream from the Twin Bridges crossing and temporarily blocked the Seymour River, North Vancouver (**Figure 1**). The blockage created a dammed pool that varies from 13 to 25 meters deep, backwatering the river with elevated water levels extending 600 to 1,100 m upstream of the slide depending on river flow rate.

Precipitation due to storm events in the upper Seymour River resulted in two flood pulses releasing over the slide material on December 9th and 10th, 2014. These increases in flow mobilized and re-deposited finer rock slide debris downstream, resulting in settling of larger rock slide boulders (re-arrangement of loose rock boulders falling into space created by the removal and re-deposition of the finer debris). Based on data collected after the rock slide event and assessment of the expected extent and frequency of inundation at the Twin Bridges upstream of the rock slide, Metro Vancouver proactively deactivated and removed the Twin Bridges crossing on January 12th 2015. Access to the slide site and Fisherman's Trail were limited and the site was secured to limit public access and provide site safety.

Northwest Hydraulic Consultants Ltd. (NHC) and BGC Engineering Inc. (BGC) staff cooperatively assessed and monitored the slide in the days and week following the event. Both NHC and BGC prepared technical reports on the hydraulics and fluvial morphology, and geotechnical aspects of the slide for Metro Vancouver respectively (NHC, 2015; BGC, 2015).

Tasks

NHC and BGC were retained to assess short and long-term options to restore fish passage past the rock slide. These options would address key issues:

1. Public safety
2. Slide and slope stability
3. Hydraulic issues and impacts, and
4. Fish movement and migration.

The options assessment will look at mitigation activities and works, and develop conceptual costing based on previous project work and professional experience. The process started with a workshop meeting and discussion of ideas, which formed the outline of the work.

Both NHC and BGC visited the site and reviewed the historic and current conditions. NHC undertook a small site survey using an RTK GPS and total station on November 5th 2015. The site plans used in this report were developed from these data. BGC also visited the site with scaling and blasting contractors to discuss potential options and costs.

Currently the site is assessed and reviewed monthly, and water levels are monitored continuously both above the slide, at Twin Bridges by Water Survey Canada, and below the slide at Grantham Bridge at a gauge operated by the District of North Vancouver.

Slide Assessment

Impacts to Seymour River Steelhead and Salmon

The pre-slide river gradient through the slide area was approximately 2% to 4% and provided for salmon and steelhead movement to the upper river over a broad range of flows. Historically, some reported rock and boulder removal was undertaken to improve the hydraulics for pink salmon passage at low flows, and it is likely that extreme flood flows either prevented or hindered fish passage upstream. During extreme flows, salmon would likely hold in downstream pools and reaches waiting for flows to subside before attempting movement upstream.

The Seymour Salmonid Society (SSS) raises steelhead at a hatchery just below Seymour Falls Dam, and relies on escapement for broodstock for the summer and winter-run steelhead programs. Broodstock collection was limited to tangle net captures within the canyon below the barrier in 2015. Additional tagging was conducted on emigrating steelhead smolts, with no tags recorded at the downstream station indicating no fish passing over the slide during the assessment period. Through both biological monitoring and observations undertaken in 2015, the conclusion is that the slide is a complete barrier for upstream fish migration and limits or greatly reduce downstream smolt out-migration from the upper river.

The slide creates a permanent barrier to upstream fish movement and migration, blocking access to upriver habitats to pacific salmon: coho, chinook and pink salmon, and winter and summer-run steelhead. Summer and winter-run steelhead stocks were the first runs impacted by the slide in early 2015, with fall-runs of pink, coho and chinook affected in the fall of 2015.

In 2015, Fisheries and Oceans Canada (DFO), SSS, Tsleil-Waututh Nation (TWN) and Squamish Nation (SN) operated a system of hoop nets to capture and transport fall-run salmon over the barrier into the upper river. Ongoing fish trapping and a subsequent radio-tagging program provides insight into the movement behaviour of fish in the lower river and may benefit a longer-term trapping program if this is pursued.

Figure 1 Seymour Rock Slide Location Map (base map from Google Maps).



Both the steelhead and salmon trap-and-haul programs initiated after the slide were successful in terms of broodstock and transporting limited numbers of fish to ensure some wild production in the upper river. However, these programs were intensive in terms of effort and resources. They also rely on access to the river, which is flow-dependent and hence can be limited. The programs are unlikely to be viable at higher flows in the late fall or early spring. Trapping and handling of fish also exposes animals to shock and stress, and incurs losses. Further, these programs are unable to handle and transport the run sizes of fall-run salmon, or be efficient in the capture of low-run size winter and summer-run steelhead.

At the slide, the primary physical barrier is a 7 m high “chimney” under a primary approximately 1,000 m³ boulder (Sta. 0+55 Profile Section, **Figure 2**). At lower flows (less than 4 m³/s) there is a hydraulic disconnection as the flows seep through the porous dam crest. At flows exceeding 4 m³/s, the river spills over the crest and downstream underneath this boulder chimney. At these intermediate flows, fish cannot access nor ascend the chimney and may be sustaining damage attempting passage. As flows further increase, the hydraulic capacity of the chimney is exceeded and flows spill over the top of the large boulder and overtop the entire slide. At these high flows the hydraulics are extreme and highly aerated with excessive velocities preventing fish passage.

Impacts to Lower Seymour Conservation Reserve (LSCR)

The slide caused a hydraulic barrier and backwatering of the river that increases static and flood water levels along the Seymour River upstream past Twin Bridges. Riparian areas and vegetation are flooded with large trees dying, Twin Bridges access bridge has been removed, trail systems have been changed and access to the LSCR is affected. Metro Vancouver is in the process of assessing and designing new access at Twin Bridges, and proposes to proceed with implementation of the new bridge and trail system in 2016. The bridge removal in early 2015 and subsequent Twin Bridges re-construction in 2016/17 has significant costs.

Impacts to River Flows and Water Levels

Following the initial rock slide and debris re-distribution on December 9th and 10th 2014, no other significant debris accumulation has been observed on the upstream face or crest of the slide deposit. On the downstream face of the slide deposit, materials have been washed out and distributed in the downstream channel. Debris and trees carried by the Seymour River have washed over or broken up on the slide.

Some limited monitoring is ongoing. Water Survey Canada (WSC) has re-installed a temporary hydrometric station on the upstream pool at Twin Bridges, and NHC continues to monitor Seymour River flows via a gauge at Grantham Bridge downstream of the slide. Metro Vancouver monitors flows and water levels upstream of the rock slide at Spur 4 and the Seymour Falls Dam. WSC data from the Twin Bridges site indicates that flows in the Seymour River have resulted in several “high water” events at the slide. This is largely due to the restricted slide crest width and hydraulic effect. In the past 11 months, 10 discrete river flow events in excess of 100 m³/s have occurred (**Figure 3**).

Note that the slide has no effects on run-off, and does not modify the hydrology of the river. The small amount of flow storage provided in the pool behind the slide does not modify downstream flood flows to any measureable extent.

Figure 2 NHC Rockslide Survey.

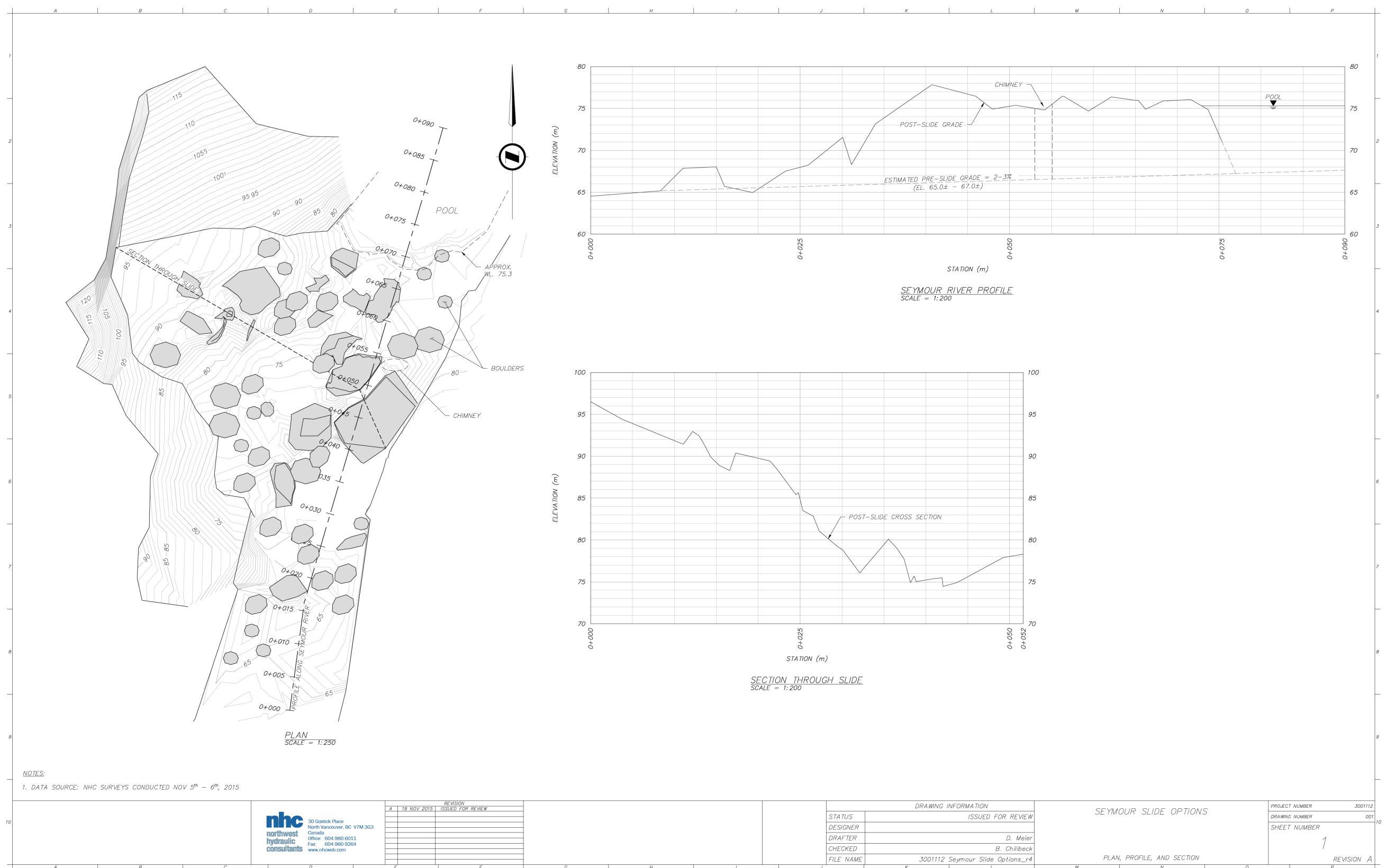
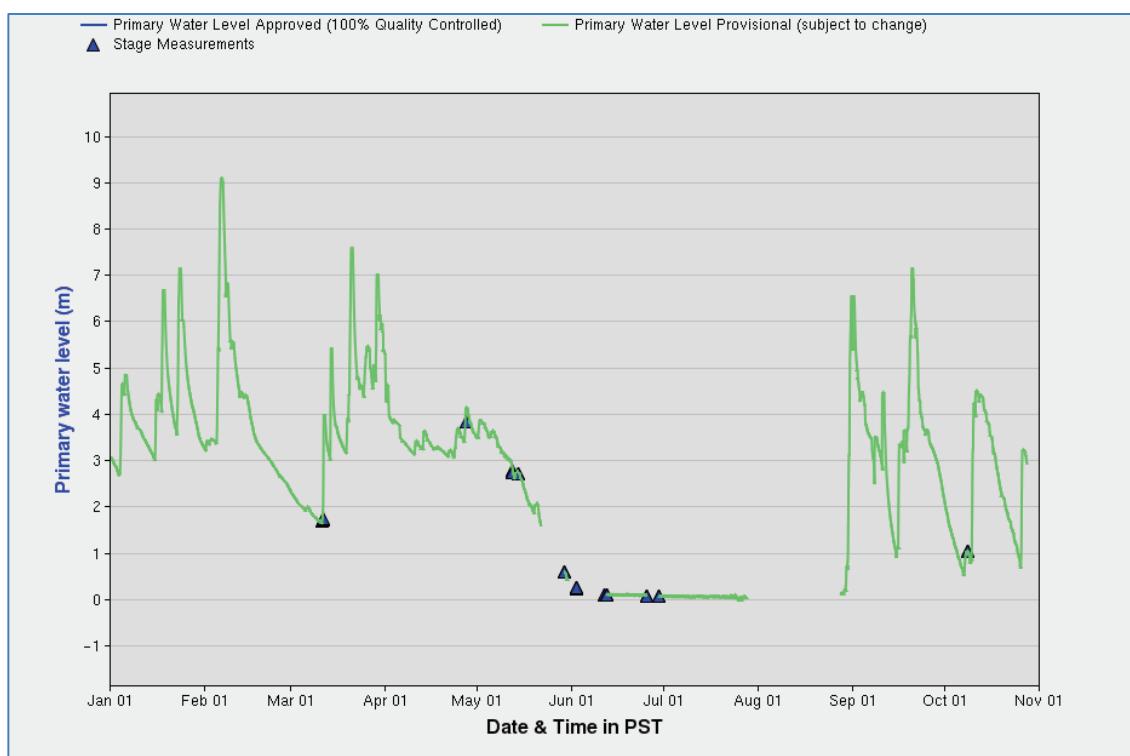


Figure 3 WSC 08GA030 Seymour River water level at Twin Bridges January 1st to October 25th 2015.



Corrected geodetic survey data from the slide was compared to upstream water levels to estimate geodetic water surface elevations and flows at the slide in 2015 (**Figure 4**). With this data the crest elevation was compared to discharge to identify at what discharge the slide would overtop – recognizing that flows through the slide occurred and at low flows water elevations upstream dropped below the crest of the slide. Based on a crest elevation of 74.8 m, a flow of 3.5 m³/s appears to be the cresting flow of the slide.

Frequency distribution of daily flows at the slide location indicates that the median flow was approximately 3.8 m³/s and the mean was 13.8 m³/s for 2015 (**Figure 5**). Flows exceeding 100 m³/s occur approximately 4% of the time, which concurs roughly with the 10 exceedance flood events on the hydrograph.

Figure 4 Seymour River Flows and Upstream Water Levels January 1st to November 25th 2015.

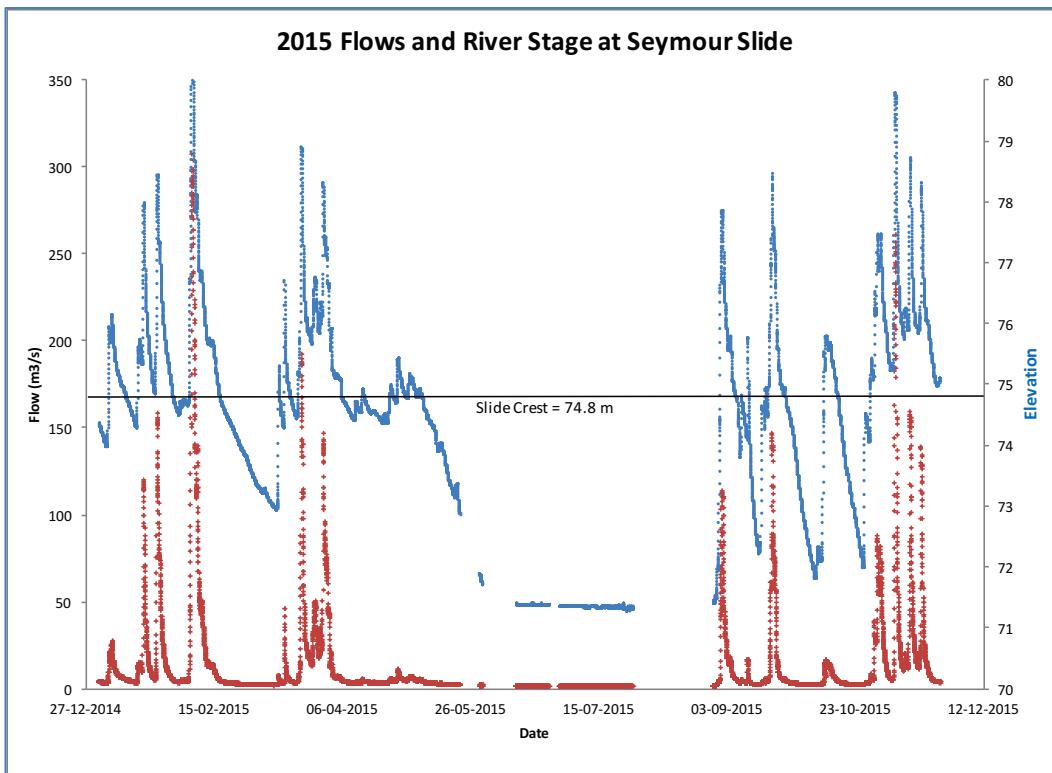
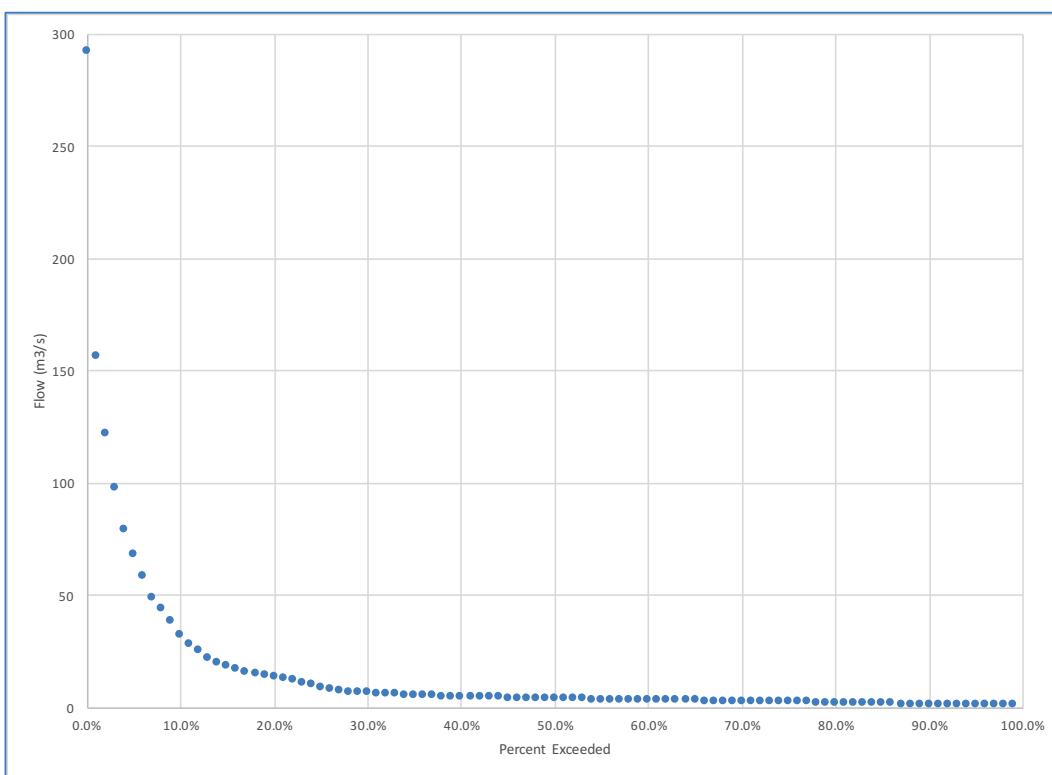


Figure 5 Frequency Distribution of 2015 Seymour River Flows January 1st to November 25th 2015.



Rock Slide Stability and Geotechnical Aspects

The rock slide released from a natural rock cliff along the western bank of the Seymour River canyon (BGC, 2015). In this reach of the river, the Seymour River flows through a 1.2 km long, 30 m to 45 m deep, linear canyon formed in bedrock along a regional rock fault structure. The rock slide ran out approximately 75 m from the crest of the slope, depositing 30,000 m³ to 50,000 m³ of debris into the Seymour River canyon below. This debris buttressed against the eastern bank of the canyon and partially blocked the Seymour River (flow over and through the rock slide debris was observed).

The shape and dimensions of the rock slide source area are controlled by three planar joint sets in very strong granodiorite bedrock. A planar sub-vertical release joint with a persistence of about 30 m trends parallel to the river, and forms the back scarp of the rock slide. From the crest of the slope to the base of the back scarp, there is evidence of a progressive joint weathering profile; from dark brown organic soil along the crest, through an iron-stained section, to fresh light grey surfaces towards the middle, representing locations of intact rock prior to failure. Another large joint dips into the canyon and downstream at about 40° to 50° and formed the basal failure surface for the rock slide. Lateral release of the rock slide was along a joint sub-orthogonal to the basal failure surface.

Since the rock slide in 2014, small (less than 1 m³) rock fall and debris slide events have occurred with loose material releasing from the back scarp or slope crest. The frequency of these rock and soil releases has decreased since the spring of 2015 and no larger-scale slope deformation of the back scarp has been observed. If mitigation work were to proceed, a danger-tree assessment, rock slope deformation monitoring, rock slope scaling, and potentially installation of rock fall catchment structures, may be required within the rock slide area depending on the option chosen.

On the upstream western slope of the canyon the rock bluffs reduce in height towards Twin Bridges and no slope deformation was observed. Access to view the eastern canyon wall is limited to the rock slide area. Downstream of the rock slide area, sections of the western canyon slopes can be viewed from Fisherman's Trail. The slopes are sub-vertical and consistently about 35 m high.

On December 22, 2015, a rockfall event of between about 50 to 400 m³ volume fell into the Seymour Canyon approximately 500 m downstream of December 2014 rock slide. The volume of this recent rockfall event is at least 100 times smaller than the December 2014 rockslide. Debris from the rockfall has formed a ponded area of approximately 50 to 100 m upstream. At other locations along the western canyon wall or on the slopes immediately upslope, the absence of large trees, mosses or lichens, indicates slope deformation on the scale of December 2015 has occurred previously. The December 2015 rockfall event and none of the other features indicating earlier slope instability along the canyon appear to be as large as the 2014 rock slide.

There are large boulders at various intervals along the canyon between the 2014 rock slide debris and the canyon mouth (observed in Google Earth imagery). This suggests larger rockfall or rock slide events have occurred within the canyon but without further assessment of both canyon slopes an event frequency is difficult to determine. None of these large boulders block the Seymour River flow sufficiently to form large ponded areas similar to upstream of the 2014 rock slide.

The December 2014 rock slide debris formed a deposit that extends approximately 15 m above the existing canyon floor, and is comprised of boulders up to about 12 m maximum length, and an estimated average boulder diameter of 3 m to 5 m. Within the canyon, the rock slide deposit in the direction of the river flow is trapezoidal. The upstream face of the deposit is approximately 10 m high (above the existing stream channel elevation), about 30 m wide, and visible debris extends at least 70 m in length in the direction of river flow.

Larger boulders were surveyed and are shown on a plan (**Figure 2**). The previous level of the river invert and slope were estimated from the new survey data and existing pre-rock slide LiDAR data.

Assessment of Mitigation Options

To date, impacts of the rock slide on the Seymour River have been mitigated by removing infrastructure, installing fencing and safety notices and conducting trap-and-haul programs to move salmon and steelhead above the barrier. The current fish management practices are likely not sustainable, and long-term solutions are required.

A range of potential long-term options to mitigate the impacts of the rock slide on the river and fish passage have been reviewed below. These options are:

1. Do nothing.
2. Install and operate a temporary fish pass.
3. Install and operate a permanent open fishway.
4. Install a tunnel and slot fishway.
5. In-river fish capture and trap-and-haul program.
6. Permanent fish weir and trap-and-haul program.
7. Re-shape the slide debris pile with heavy construction equipment and conventional explosives.
8. Re-shape the slide debris pile with scaling crews, non-explosive or low-velocity explosive rock breaking to reduce block size, and harnessing river flows to transport the material.
9. Remove the slide debris with heavy construction equipment and conventional explosives.

Proposed Options

The options are further described below.

1. Option 1: Do nothing

No mitigation is applied to the slide and anadromous fish are limited to the lower Seymour River.

2. Option 2: Semi-permanent Denil or Steep-pass Fishway

A small section aluminum Denil or steep-pass fishway is installed along the western bank of the Seymour River on a semi-permanent basis, requiring 10, 10 m long 600 mm x 300 mm prefabricated steep-pass or Denil sections (20% slope) with 2 m x 2 m x 1 m deep resting pools every 2 to 3 runs. An intake control structure and barrier weir at the fishway entrance may be required, and upstream sections would be removed near the slide crest during winter conditions and re-installed annually. The fishway would be subject to potential flood and rockfall hazard.

Local Examples: Hadden Creek, Hoskins Creek

Costs: \$20k - \$40k per vertical meter (10 m fishway sections); Total \$0.75M - \$1.5M (by 2020)

3. Option 3: Open Vertical Slot Fishway

A 3 m x 3 m x 3 m deep vertical slot fishway installed on the left bank along a pre-constructed sloping rock cut ramping down to the river at a 10 to 15% grade (e.g. 135 m to 200 m total length). A single run or wrapped lay-out would require extensive excavations in the bedrock canyon wall (10,000 cu. m). The fishway would require a regulating intake, overflow control and rockfall protection, and a small barrier weir to guide fish at the entrance.

Local Examples: Hells Gate, Bonaparte River, Stamp River

Costs: \$100k - \$250k per vertical meter; Total \$1.9M - \$6.6M (by 2020)

4. Option 4: Tunnel and Slot Fishway

A 135 m to 200 m long, 3 m x 3 m wide tunnel section would be drilled at 10 to 15% slope from headwater to tailwater with 300 mm wide slots, 3 m high vertical slots, or 300 mm thick 1.5 m high weir sections installed at 3 m intervals. Lay-out could be wrapped or single run. A regulating intake is required at the intake, and a small barrier weir at the fishway entrance.

Local Examples: Browns River, Hells Gate, Castile Falls

Costs: \$75k - \$200k per vertical meter; not considered feasible

5. Option 5: In-river Trap / Floating Fence and Haul

In an annual program similar to 2015, in-river hoop and box traps or floating fence would be used to capture and haul live salmon and steelhead to the upper river, or for broodstock collection and rearing at the Seymour River Hatchery. Angling, broomstick fences, and trapping methods may be utilized through time.

Local Examples: local Community and DFO hatcheries

Costs: \$200k/year. Floating fence or traps costing \$100k - \$250k. Total \$1.1M - \$1.25 M (by 2020)

6. Option 6: Permanent Barrier Weir, Trap and Haul

Install a fish barrier or fence and collection facility at some location downstream of the slide on the lower Seymour River. Captured fish would be hauled to the upper river or collected for broodstock.

Local Examples: DFO's Capilano Hatchery or Puntledge River Hatchery

Costs: \$2.5m – \$4.0m capital construction and land; \$75k/year operations

7. Option 7: Re-shape the slide with heavy construction equipment and explosives

Construct access to the site. Heavy machinery access would be required across the Seymour River at the Twin Bridges site or at the end of Riverside Drive (over a new or temporary bridge at either site, or through the river at Twin Bridges during low flows). Walking trails may need to be widened to accommodate the heavy machinery and a machine access trail, large rock cut and work staging area to the rock slide area would be required through the forest. Extensive tree falling would be required. At the rock slide site conventional explosives and heavy equipment would be used to break up and re-distribute approximately 20,000 cu m. of slide material into a longer, milder gradient rock ramp.

Costs: \$1.0M - \$1.3M (by 2020)

8. Option 8: Re-shape the slide with scaling crews, non-explosive or low-velocity explosive rock breaking and river flows

Access to the site can be achieved with available infrastructure with only danger tree falling required. Utilize non-conventional rock breaking, limited equipment, and river hydraulics to redistribute 10,000 to 20,000 cu m. of slide material into a longer, milder gradient rock ramp.

Costs: \$0.45M - \$1.0M (by 2020)

9. Option 9: Remove the slide with heavy construction equipment and explosives.

As per Option 7 but including trucking the material out of the river canyon. Construct an access road to the site. Utilize conventional rock breaking, heavy equipment and off road trucks to remove 40,000 cu m. of slide material.

Costs: \$1.2M - \$2.0M (by 2020)

NHC and BGC assessed options through an options table (Table 1) that looked at the technical and ongoing operational issues, and expected construction and operational costs.

Table 1 Slide Mitigation Options Assessment

Seymour Rockslide Mitigation Options Assessment	Description	Investigation	Design	Construction			Investigation, Design and Construction Cost Estimate	Tree Falling	Fish Passage (assuming construction effort commences in 2015)			Annual Maintenance		Constructed Cost (excluding maintenance)	Total Cost Estimate by 2020 (5 Years from November 1, 2015)	Summary
		Site Investigation Effort	Design Effort	Construction Access & Footprint	Construction Safety Issues	Construction Feasibility			Fish Passage When Operational	Fish Passage Timeframe From November 1, 2015	Fish Life Cycle Affected	Annual Maintenance Short-Term (0 - 2 years)	Annual Maintenance Long-Term (>3 years)			
Option 1 - Do Nothing	Leave Seymour River rock slide debris undisturbed and let river flows erode and transport debris naturally.	Negligible (<\$5,000)	Negligible (<\$5,000)	Simple Access &/or Negligible Footprint	Negligible	Feasible	Low (<\$50,000)	Danger Trees	No	> 4 years	Yes	Negligible (<\$5,000)	Negligible (<\$5,000)	Low (<\$50,000)	Low (<\$50,000)	Unknown length of time before fish passage could occur naturally.
Option 2 - Aluminium Fish Ladder	Denil type fish ladder system attached to the western side of the Seymour River canyon wall: - construction access along Fisherman's Trail or from Twin Bridges, construction road from the trail to the rock slide area would include tree felling an access corridor and work area - review of bridge capacity at the end of Riverside Drive required if accessing site from that direction - site preparation, danger tree removal, rock-scaling, debris pile reshaping or removal, rock anchor preparation, rockfall protection fence installation - aluminium or steel structures anchored into the rock face - on-going maintenance.	Moderate (\$25,000 to \$50,000)	Considerable (>\$50,000)	Considerable Access Challenges &/or Large Footprint	Considerable (Rock fall exposure during installation)	Moderate or Considerable Technical or Safety Challenges	Very High (>\$250,000)	Large Area Tree Falling	Yes	0 - 2 years	Yes (0 - 2 years)	Considerable (>\$50,000)	Considerable (>\$50,000)	Very High (>\$250,000)	Very High (>\$500,000) (\$775,000 to \$1,475,000)	Temporary fish passage access in between high flow events. High flow events would likely cause significant maintenance challenges, and/or destroy the structures. Not considered a long-term viable mitigation option.
Option 3 - Concrete Fish Ladder	Fish ladder system constructed into rock of the eastern bank of the Seymour River: - construction access for heavy machinery, tree felling for access and construction corridor, grubbing, blasting, blasted rock removal, concrete structure placement and re-vegetation of the construction corridor.	Considerable (>\$50,000)	Considerable (>\$50,000)	Considerable Access Challenges &/or Large Footprint	Minor to Moderate (Rock fall exposure for installation)	Moderate or Considerable Technical or Safety Challenges	Very High (>\$250,000)	Large Area Tree Falling	Yes	0 - 2 years	Yes (0 - 2 years)	Minor (<\$5,000 to \$25,000)	Minor (\$5,000 to \$25,000)	Very High (>\$250,000)	Very High (>\$500,000) (\$1.9M to \$6.65M)	This option would result in significant rock cuts, tree removal, and site disturbance. A viable long-term mitigation option but expensive and resulting in extensive ground disturbance for site and construction access.
Option 4 - Tunnel and Slot Fishway	Tunnel through eastern side of Seymour River canyon wall: - if feasible to undertake a tunnel the following would be required. - construction access for site investigation, construction for construction areas, tree felling for access and construction corridor and laydown area, grubbing, stream flow diversion or coffer dam construction, tunnel portal preparation, blasting, blasted rock removal, tunnel support installation, slot fishway installation, on-going maintenance.	Considerable (>\$50,000)	Considerable (>\$50,000)	Extremely Difficult Access &/or Very Large Footprint	Considerable to Hazardous (Geotechnical Challenges)	Not Feasible	Very High (>\$250,000)	Large Area Tree Falling	No	Not Feasible	Yes	Moderate (\$25,000 to \$50,000)	Moderate (\$25,000 to \$50,000)	Very High (>\$250,000)	Very High (>\$500,000)	The tunnel component of this option is not considered a feasible option given the proximity of the regional fault along the canyon. Poor quality rock sections, challenges with portal preparations and site logistics suggest this option is not feasible, or cost prohibitive.
Option 5 - In-River Trap and Haul Program (Physical Fish Transportation)	As per 2015: - fish capture, fish extraction, fish relocation.	Negligible (<\$5,000)	Negligible (<\$5,000)	Minor or Moderate Access Effort &/or Moderate Footprint	Minor to Moderate	Feasible (Minor Safety or Technical Challenges)	High (\$100,000 to \$250,000)	Danger Trees	Yes (Moderate or Considerable Effort)	Immediate	No	Considerable (>\$50,000)	Considerable (>\$50,000)	Very High (>\$250,000)	Very High (>\$500,000) (\$1.1M to \$1.25M)	Fish passage only with human intervention. 2015 season demonstrated labour intensive process and low success rates and/or high levels of fish stress. Estimated costs approximately \$200,000 per annum. Not considered a long-term viable mitigation option.
Option 6 - Permanent Fish Weir and Trap and Haul Program (Physical Fish Transportation)	As per 2015 but with a permanent fish weir capture location: - fish capture, fish extraction, fish relocation.	Considerable (>\$50,000)	Considerable (>\$50,000)	Considerable Access Challenges &/or Large Footprint	Minor to Moderate	Feasible (Minor Safety or Technical Challenges)	High (\$100,000 to \$250,000)	Danger Trees	Yes (Moderate or Considerable Effort)	2 - 4 years	Yes (2 - 4 years)	Considerable (>\$50,000)	Considerable (>\$50,000)	Very High (>\$250,000)	Very High (>\$500,000) (\$2.5M to \$4M)	Fish passage only with human intervention. 2015 season demonstrated labour intensive process and low success rates and/or high levels of fish stress. Estimated costs approximately \$200,000 per annum. Not considered a long-term viable mitigation option.
Option 7 - Rockslide Debris Pile Reshaping - Excavators and Explosives	- Excavators and Explosives - similar to Option 9 without the rock transport component.	Minor (<\$5,000 to \$25,000)	Moderate (\$25,000 to \$50,000)	Considerable Access Challenges &/or Large Footprint	Minor to Moderate	Moderate or Considerable Technical or Safety Challenges	Very High (>\$250,000)	Large Area Tree Falling	Yes	2 - 4 years	Yes (2 - 4 years)	Minor (\$5,000 to \$25,000)	Negligible (<\$5,000)	Very High (>\$250,000)	Very High (>\$500,000) (\$0.96M to \$1.28M)	A viable long-term mitigation option but resulting in extensive ground disturbance for site and construction access.
Option 8 - Rockslide Debris Reshaping - Rock Scalers and Non-Explosive Rock Breaking Techniques	Rock Scalers and Non-Explosive Rock Breaking Techniques in the Seymour River Canyon. Rock breaking to sizes small enough to allow transportation of the material with the river flows. Repeat process until design grade achieved.	Minor (<\$5,000 to \$25,000)	Moderate (\$25,000 to \$50,000)	Simple Access &/or Negligible Footprint	Minor to Moderate	Feasible (Minor Safety or Technical Challenges)	Very High (>\$250,000)	Danger Trees	Yes	2 - 4 years	Yes (2 - 4 years)	Moderate (\$25,000 to \$50,000)	Minor (\$5,000 to \$25,000)	Very High (>\$250,000)	Very High (>\$500,000) (\$435,000 to \$935,000)	A viable long-term mitigation option with minimal ground disturbance for site and construction access.
Option 9 - Rockslide Debris Removal with Heavy Construction Equipment	Prepare construction access from Twin Bridges area through the Seymour River. Road construction from the Twin Bridges area to the rock slide area along Fisherman's Trail with capacity for semi-articulated 6 wheeled haul trucks. Construction of a road from the existing trail to the rock slide area and preparation of work area. Tree felling and grubbing required. Drill and blast work with conventional explosives to provide access to the canyon, drill and blasting of the large boulders. Loading blasted rock slide debris, hauling off-site and passing through the Seymour River at Twin Bridges each haul truck trip, or the addition of a temporary bridge. Repeating process until fish passage grades achieved.	Moderate (\$25,000 to \$50,000)	Moderate (\$25,000 to \$50,000)	Extremely Difficult Access &/or Very Large Footprint	Minor to Moderate	Moderate or Considerable Technical or Safety Challenges	Very High (>\$250,000)	Large Area Tree Falling	Yes	0 - 2 years	Yes (0 - 2 years)	Moderate (\$25,000 to \$50,000)	Minor (\$5,000 to \$25,000)	Very High (>\$250,000)	Very High (>\$500,000) (\$1.23M to \$2.03M)	A viable long-term mitigation option but resulting in extensive ground disturbance for site and construction access.

Preferred Option

Selection of the preferred option was based on the collective assessment of the report authors and their professional experience. NHC and BGC considered the technical issues, and potential costs, effectiveness, and schedule of the various options. Key considerations included:

- Long-term costs of operation and public safety.
- Complete mitigation of other slide-related impacts.
- Effective movement of fish over a range of river flows.

The conclusion of the authors is that **Option 8: Re-shape the slide with scaling crews, non-explosive or low-velocity explosive rock breaking and river flows** is the preferred option.

Based on feedback from stakeholders we understand minimizing the construction footprint is also a key concern. Option 8 addresses this concern by requiring limited tree falling for danger trees, no site preparation for a lay-down or work area, and no additional physical access requirements (such as bridges, access roads, and access through the Seymour River). Equipment necessary, such as a compressor and associated tools and manual equipment, can be staged on Fisherman's Trail above the rock slide area. From this point compressor hoses will be extended to the rock slide area for the pneumatic drills and the site accessed would be by foot from Fisherman's Trail.

The following describes in further detail the approach and potential issues with this preferred option.

Proposed Mitigation Implementation

Approach

The proposed approach is that re-shaping of the debris pile through non-conventional rock breaking techniques would reduce block size sufficiently to allow the river hydraulics to re-distribute the rock slide debris into a longer, milder gradient profile at this section of river. The proposed rock-breaking and construction process would use pneumatic drills (mechanical drills powered by compressed air) to create drill-holes for either non-explosive rock breaking agents such as expandable grout, or boulder buster charges, or for low-velocity explosives. Access to the site for a compressor and the pneumatic drills and supplies would be with small vehicles (ATV's or Gators etc.) with equipment hand carried from existing trails down to the site.

The expected final slope of the modified slide deposit would have to be less than 10% and ideally between 5% to 7%, and the effective channel width would be around 15 m, to effect reasonable fish passage. The proposed slope shaping and treatment would require detailed and selected rock-breaking and shifting to managing the roughness and channel hydraulics to ensure smaller and weaker-swimming salmonids (e.g. pink salmon) could pass upstream.

Safety and Constructability

Prior to commencing work in the Seymour Canyon several safety areas require attention. Firstly, a danger tree assessment of the rock slide slope crest area, canyon slopes adjacent to the proposed work area, and the access route is recommended. This will result in some tree cutting along the crest of the failure for up to about 5 m back from the crest. Once this is complete, a check-scale of the rock slide scarp and adjacent escarpment slopes would be done for site safety. This will result in some additional soil and rock debris accumulation on the slide.

Several survey prisms or tell-tale crack meters would be placed on the upslope face of the rock slide escarpment and on larger boulders of the debris pile and be measured prior to entering the site each morning. Site access criteria would be reviewed each morning, based on rainfall, weather conditions, river flows, slope deformation rates, erosion of soil at the slope crest and review of the tree conditions.

Also, prior to any construction activity at the site, an evacuation plan would be prepared. A ‘spotter’ capable of warning all staff of slope instability or changes in site conditions would be used while construction activities are in progress. Only when exposure to potential upslope hazards has been minimized would the debris pile re-shaping begin.

Consultation each day between the hydraulic/geotechnical engineering team and the rock-scalers regarding the safest and most effective approach to achieve the objectives will be undertaken. In general, large boulders and/or areas of the channel will be prioritized and sequenced in a phased approach to get the river channel and profile to grade for fish passage. Once the profile is reached select boulders will be removed to allow fish passage at different flow regimes.

All boulders will be drilled in a pattern to allow effective control of the rock-breaking. This approach will require some trial and error for maximum effectiveness. Deflagration cartridges (low-velocity explosives) and boulder-busting techniques can be employed for the bulk of the debris re-shaping. Both techniques crack the rocks along pre-existing planes of weakness, or through intact rock. The use of deflagration cartridges allows for immediate review of results and the ability to re-drill and reset charges without delay. Boulder-busting of single boulders will shape the final channel profile and step and pool configuration.

Issues and Uncertainties

As with any innovative approach, there are issues and uncertainties that can only be addressed through further information and investigation. The proposed mitigation will require an adaptive approach with some professionally directed “trial and error” to confirm the treatment is effective but does not compromise worker or downstream safety.

The effectiveness of the proposed rock-breaking techniques, phasing of the rock-breaking in the canyon, and effectiveness of debris re-mobilization by the river will be managed by an observational approach using both survey and photometric techniques to quantify changes in the slide shape and volume. It is important to recognize that the process may be multi-stage as the final shape of the channel after rock breaking will be determined by the creek flood flow effects on the debris.

It is likely that an initial stage of rock breakage, followed by one or more higher river flow periods, may lead to a channel shape that requires further rock breakage and further river flow modification to achieve the objectives. In essence, the proposed method accelerates the natural erosion process on the debris, but the results will be somewhat dictated by the natural process of the river re-arranging the debris after the debris particle size is reduced.

Construction assumptions for re-shaping the rock slide debris pile assume:

- Bedrock canyon slopes extend to, or close to, the channel base.
- Rock slide debris is slightly weathered and adjacent to a regional fault zone, therefore likely fractured with pre-existing rock discontinuities.
- Rock slide debris below the surface is comprised of large boulders (>5 m max. length) because of the short run-out distance from the escarpment and limited chance of fragmentation (from fewer rock on rock run-out impacts).
- Hydraulic re-distribution and debris pile re-shaping will be effective (as noted, this may include several rock breaking episodes to reduce boulder sizes followed by river flow rearrangement, if required).
- Rock slope debris on the west side of the site may settle/deform into the channel as the debris pile is lowered.
- Some ongoing monitoring and manipulation of the channel surface may be required beyond the initial season of fish passage, or in response to extreme flood that may re-distribute the modified slide materials.

Implementation and Schedule

Construction of the modified channel section from the slide debris will be an iterative process. Several rock breaking-river flushing episodes may be required to re-shape the slide debris to allow fish passage. This would involve:

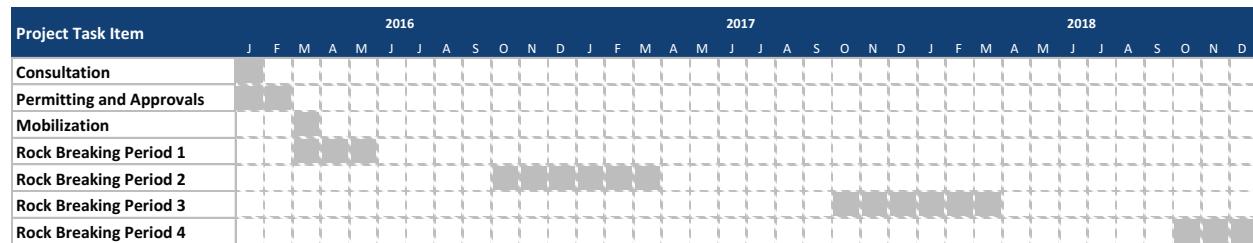
1. Assessing the existing boulder and slide materials, and expected movement and water flow paths.
2. Estimating the boulder diameters and masses that will mobilize at a range of Seymour River flood flows.
3. Determining the likely position and sequences of boulder movement and slide debris re-distribution that would occur for a sequence of drilling and rock-breaking undertaken during low flows between flood events.
4. Conducting a cycle of rock-breaking and scaling over a 3 to 7-day period.
5. Waiting for a high river flow period, then monitoring and assessing the rock and debris movement post-flood to determine the next sequence of rock breaking and slope adjustments required.
6. Assessing whether this method is providing effective results. If it is, repeat the process. If it is not, consult with the stakeholders for an alternative path forward.

7. Repeating the sequence until achieving the final channel slope, width and rock distribution.

Assuming that sizable flows will be required to move large boulders created during the scaling operations, approximately 6 to 10 suitable instream low flow work opportunities are likely available in a 12-month period. These low flow periods occur between large floods during the fall to spring period when rainfall and rain-on-snow generate large flows.

Based on assessment of the volume of slide debris and productivity of the rock-breaking and scaling, the reshaping process could take 2 to 5 years to complete – or a total of 20 to 40 “work events”. These work events would consist of 3 to 7 day periods when the scaling crew would drill and break rock in preparation for a large flood event. Mobilization for the work is expected to take a week, and could be initiated in early 2016, pending approvals and permitting as required. Remobilization for subsequent cycles of rock breakage, as needed, would have a lower mobilization time.

Figure 6 Project Schedule



At this time, permitting would be required from MFLNRO under the *Water Act* Section 9 “Works in and about a stream” (*Water Sustainability Act*; Section 11). Approvals from Fisheries and Oceans Canada would not likely be required. Community consultations, public and local government meetings may also be required.

Project Costs

The cost for the three-person scaling crew is estimated at \$5,000 to \$7,000 per day including materials. Assuming a 5-day work period per event and 8 instream work events per year, the estimated annual rockslide debris re-configuration costs are approximately \$240,000. Assuming as much as a 4-year program, the costs could approach \$1M. Additional costs for engineering and assessment would be required.

It is important to note that the cost is subject to the number of rock re-configuration cycles needed, which is subject to the effectiveness of each cycle. The effectiveness of the planned method is difficult to predict as it relies on the hydraulic power of the river. A few cycles of rock-breaking/river re-arrangement could be sufficient, or it could take many cycles. It is proposed to assess the effectiveness of the process after two to four cycles of work to confirm the planned approach is likely to achieve the results for an acceptable cost, including consideration of duration of the work and costs to maintain current fish management approaches during the work (e.g. costs of trapping and re-locating fish).

References

- NHC. 2015. Seymour River Rockslide Geomorphic and Hydrotechnical Assessment. Prepared for Metro Vancouver. 10 March 2015.
- BGC Engineering Inc. 2015. Seymour River Watershed December 7 2105 Rockslide – DRAFT. Prepared for Metro Vancouver Watershed Operations. 12 January 2015.