Watershed Assessment
Chapman and Gray Creek community watersheds

11 March 2014

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Acknowledgements

The author is grateful to Dave Lasser, RPF for project coordination on behalf of the Sunshine Coast Community Forest; to Warren Hansen RPF of Chartwell Consultants Ltd for his help with spatial data and his assistance with field access; to the other GIS wizards of Chartwell Consultants Ltd. for their patience and skill in processing spatial data; to Tom Lamb of Coast Power Sports for making a side-by-side all-terrain vehicle available on short notice; and to Rent-it Canada and Dagan Benner for transporting the ATV also at short notice and even when inconvenient for them. The author is especially indebted to Dr. Bruce Thomson P. Geo. and Dr. Brent Ward, P. Geo. for time spent searching for ancient data and maps; to Denny Maynard, P. Geo. for his expert interpretation of surficial geology and terrain stability; to Brian Carson, P. Geo. for sharing his extensive knowledge of the Chapman Creek watershed; and to Allan Chapman, P. Geo. for his hydrological analysis and insight on climate and stream flow trends.

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1. INTRODUCTION

Sechelt Community Projects Inc. (SCPI) has commissioned a watershed assessment for the Gray Creek and Chapman Creek community watersheds. Both are water supply areas for the Sunshine Coast Regional District (SCRD) in the vicinity of Sechelt (Figure 1). Chapman Creek is the primary supply; Gray Creek is currently an emergency supply only.

SCPI has a forest harvesting tenure in the form of a Community Forest Agreement to manage the Sunshine Coast Community Forest (SCCF). SCCF tenure includes 40% of the Chapman Creek community watershed area and 72% of the Gray Creek community watershed area.

The purpose of the assessment is to determine the present physical condition of the community watersheds and the extent of recovery from past disturbance; and to make recommendations to SCPI for forest management for the SCCF tenure in the watersheds with specific regard for water quality for community water supply. In particular, SCPI asked that risk zones be delineated for sediment events that could affect water quality, to inform SCCF forest management planning.

2. ASSESSMENT TEAM

Glynnis Horel, P. Eng. of G.M. Horel Engineering Ltd. completed assessments of hydrologic change, sediment sources and stream channels. Allan Chapman, P. Geo., provided analyses and interpretation of trends in stream flow and climate cycles. Denny Maynard, P. Geo. undertook refinement of existing mapping of terrain units (surficial geology) and terrain stability hazard classes; this work provided the basis for delineating risk zones. Chartwell Consultants Ltd. provided technical support and processing of spatial data.

3. INFORMATION AVAILABLE

The following information was available for this assessment.
Imagery:

- Black and white airphotos for 1972, 1985, 1994, 1996, 1998
- Colour airphotos for 2003
- Orthos flown in 2009 and 2010 (also in the Google Earth imagery)

Spatial data:

- LIDAR[1] products – orthophotos, bare-earth hillshade images, 1 m and 5 m contours, slope classes, tree heights. The LIDAR was flown in 2009 and 2010 for SCRD and SCPI.
- TRIM streams, revised in this project to align with the orthos
- B.C. government roads (several sources)
- Property ownership and parks
- B.C. government vegetation inventory (VRI Rank 1, downloaded September 2013).

[1] LIDAR – "light detecting and ranging" technology

Figure 1

Location

- B.C. government digital bedrock geology at 1:250,000
- B.C. government database for licensed water intakes, provincial parks and forest tenures
- Provincial parks
- Watershed boundaries from B.C. Corporate Watershed Base (CWB)
- Terrain polygons from B. Thomson, P. Geo. for Chapman Creek watershed digitized in 1997 from manuscript photomapping prepared in 1984
- Terrain mapping as microstation files for the SCCF portion of Gray and Chapman watersheds from D. Maynard dated 1994

Other information in the public domain:
- ClimateWNA – UBC climate model
- Climate data from Environment Canada
- Hydrometeorological data from Water Survey of Canada

Reports
- Comprehensive Regional Water Plan – Final. June 2013. Report by Opus DaytonKnight Consultants Ltd. to Sunshine Coast Regional District.
- Chapman Creek Source Assessment Response Plan (SARP). August 2012. Report by Urban Systems Ltd. to Sunshine Coast Regional District
- Chapman Creek Watershed Drinking Water Source Assessment Final report. July 2006. Report by Triton Environmental Consultants Ltd. to Sunshine Coast Regional District
- Watershed Assessment for Chapman Creek and Gray Creek, Sechelt, B.C. December 2000. Report by EBA Engineering consultants Ltd. to International Forest Products Ltd., Campbell River Operations
- Cumulative Summary Report, Watershed Monitoring Program for Chapman and Gray Creeks (1995 through 2000). April 2000. Report by Brian Carson, P. Geo. to International Forest Products Ltd., funded by Forest Renewal B.C.
- Chapman Creek Hydrology Data Summary and Analysis. May 1991. Report by A.R. Chapman, P. Geo. and D.E Reksten, P. Eng., Ministry of Environment, Water Management Division, Hydrology Section.
- Chapman Creek Landslide Inventory. 1987. Bruce Thomson, P. Geo., Ministry of Environment and Parks, Recreational Fisheries Branch

4. METHODS

Watershed boundaries in the provincial Corporate Watershed Base (CWB) were delineated from TRIM 20 m contours. For this project LIDAR 1 m contours were available and so were used to refine the watershed boundaries. This has resulted in slightly different boundaries than presented in other reports which used the BC government watershed boundaries available at the time. Thus, the areas reported here are slightly different than areas given in those reports.

Road locations were refined to fit the orthos. Linework for major streams (from the TRIM base) was revised to fit the orthos and the LIDAR contours. There was a slight shift between the orthos and LIDAR contours; for this project the orthos took precedence. Stream gradients were measured using LIDAR 5 m contours; for gradients less than 5%, 1 m contours were used.

Road spatial data was created by merging two existing government spatial data sets and fitting the linework to the 2009/2010 orthos. New linework was created for roads within the watershed areas that were visible on the orthos but were not in the spatial data sets. Road status (e.g. active, inactive, permanently deactivated, seasonally deactivated) is based on accessibility encountered in our field reconnaissance and, in the case of permanent deactivation, the appearance of roads on the 2009/2010 orthos and Google Earth images. The accuracy of the deactivation status is therefore limited by what can be seen on the orthos.

Identification of stream channel types was based on LIDAR contours, orthos, bare-earth imagery and field observations. Channel gradients and widths at the field stops were measured from the ortho and using 1 m LIDAR contours. Stream profiles were constructed using LIDAR 5 m contours and at low gradients, 1 m contours.

The 1994 microstation terrain files were converted to polygons by Chartwell Consultants Ltd.; polygon boundaries and terrain classifications were refined in this project by D. Maynard, P. Geo. from the field reconnaissance and using LIDAR bare-earth images and LIDAR-generated slope classes.

The 1987 Thomson landslide inventory was originally created using 13 separate airphoto series taken between 1946 and 1982; and field reconnaissance in 1984. For this project, the Thomson inventory was digitized as point shapefiles from the original hardcopy map. Chartwell Consultants Ltd. processed the spatial data. Where more recent landslides were observed by Maynard or Horel on imagery or on the heli flights they have been added to the spatial inventory.

Field reconnaissance was done the week of August 19-23, 2013 by vehicle for roads that were driveable; by side-by-side ATV for roads that were not driveable; and by helicopter (two flights). A second field visit was made on November 20, 2013. Numerous fallen trees over the road limited ATV access past Field Stop #33 (Appendix B) on the Sechelt Dakota Forest Service Road (FSR) on the west side of Chapman Creek; we walked from there to the upper bridge crossing (Field Stop #27). We walked old roads on the east side of Chapman Creek from the end of the driveable road down to the old stream crossings (Field Stops #2 and #3). Field visits August 19-20 and November 20 were with D. Lasser, RPF; August 21 with W. Hansen RPF; and August 22-23 with D. Maynard, P. Geo. Heli flights were conducted on August 19 with D. Lasser, RPF and on August 23 with D. Lasser RPF and D. Maynard, P. Geo. Photos from field stops and helicopter flights are in Appendix B.

5. WATER SUPPLY SYSTEM

The SCRD water supply system for the Regional Water Service Area (RWSA) is described in detail in the Comprehensive Regional Water Plan report (Opus DaytonKnight 2013). In brief, Chapman Creek supplies 10,000 connections plus bulk supply to Gibsons (SCRD does not manage water distribution at Gibsons). It is the largest water system in the RWSA, supplying 90% of the residents and businesses within the RWSA. Gray Creek, which formerly supplied domestic water to residents of Sandy Hook and Tuwanek during summer high-demand periods (Triton report 2006), is now an emergency supply only (Opus DaytonKnight report 2013). Gray Creek has a chlorination facility only (Field stop #6), not a water treatment plant and does not currently meet treatment requirements for surface water sources.

The Chapman Creek intake is 7.5 km upstream from the ocean at an elevation of 174 m (from 1 m LIDAR contours); Gray Creek intake is 2.7 km upstream from the ocean at an elevation of 192 m. The water intakes in Chapman and Gray Creeks are similar structures, located in bedrock reaches (See Field Stops #2 and #7). They are robust concrete and steel structures that appear well suited to these high-energy streams that transport logs and boulders.

Chapman Lake and Edwards Lake are the largest headwater lakes in the Chapman and Gray Creek drainages; both have control gates to allow water storage for controlled release during low streamflow periods. Edwards Lake naturally outlets to the Gray Creek watershed but an excavated channel and control gate (Figure 2) allows discharge into the Chapman Creek watershed. Because of this, Edwards Lake and its drainage area are delineated as a separate watershed unit in this report.

Figure 2. Channel and control gate that allows diversion of flow from Edwards Lake into Chapman watershed. Photo date August 18, 2013.

Carson (2000) relates that the major concern on Chapman Creek is centred on the watershed's ability to deliver water during the summer-autumns season after a period of extended drought. He notes that annual water yield is more than 20 times the amount of water licensed for used by SCRD; the watershed is not limited by total water production. However, the watershed, including Chapman and Edwards Lakes, has inadequate storage capacity. Low summer-autumns flows depend mainly on meltwater from late-persisting snowpacks, supplemented from groundwater and with flow released from Chapman and Edwards Lakes. Low-water concerns are expected to be exacerbated in future as climate warming trends cause declines in summer snowpacks and higher rates of evapotranspiration.

Climate and stream flow trends are discussed further in Section 8 below.

Fish and fish habitat are not in the scope of this assessment. However I note that several of the documents listed in Section 3 above indicate that the recommended minimum flows to sustain fish populations downstream of the SCRD intake are not always met.

6. WATER QUALITY

Carson (2000), Triton (2006) and Opus DaytonKnight (2013) discuss water quality in depth. Raw water quality parameters in Chapman Creek identified by Triton (2006) as potential concerns include pH, turbidity, colour, total organic carbon and faecal coliform. Opus DaytonKnight (2013) notes that "*processes at the Chapman Creek water treatment plant [commissioned in 2004] include coagulation, flocculation, DAF clarification, filtration, and UV primary and chlorine gas secondary disinfection. The treatment processes comply with the "B.C. Drinking Water Protection Regulation" and the treated water consistently meets guidelines (despite operation in excess of design capacity)*". In short, the treatment facility is robust and capable of handling all normal water quality concerns, including occasional landslide events (personal communication B. Carson 28 Nov 2013).

Carson (2000) presents results and analyses for water quality monitoring for 1995 – 2000 for the Chapman and Gray Creek watersheds. A summary of his significant findings relevant to this assessment is as follows:

<u>Turbidity – Chapman Creek</u>

- Large numbers of landslides associated with historic logging, mainly from forest roads, had created long standing concerns for degradation of water quality in Chapman Creek. More than 250 landslides have been documented in upper Chapman Creek that have occasioned severe impacts to the channel and to water quality. Beginning in 1992, watershed restoration projects were undertaken to stabilize and deactivate old logging roads. The main objective was preventative, to reduce the potential for landslides to continue to occur. Because of these efforts, many potential failure initiation sites have been stabilized and no longer pose a long term threat to the watershed.

- The road network was not a major supplier of sediment in the major events monitored between October 1995 and March 2000.

- Not all landslides from roads or other hillslope areas enter the channel. Some are captured on run-out slopes.

- The sand gullies with unvegetated slopes between km 17 and 19 [my Field Stops #20-23 and heli photo site C-01] are now only occasionally an important sediment source to Chapman Creek.

- The majority of suspended sediment to the channel is generated below the km 16 sampling site. Unstable eroding channel banks are the dominant contributor of sediment, and will continue to be so indefinitely.

<u>Total Organic Carbon (TOC)</u>

- TOC levels are highest in fall storms and lowest during summer low flows. This is believed to be associated with the relative contributions to stream flows between the seasons. In fall storms, higher concentrations of TOC arise from flushing of leaves and forest floor litter by surface runoff. In summer, groundwater is a major contributor to stream flow.

- Deciduous trees (alder, maple) generate more TOC than conifers, and can create tannin levels as much as 20 times higher than those provided by fir and cedar (comments in Carson 2000 on unpublished data). The increase in deciduous vegetation in the riparian zone following historic logging [Figure 3] is likely to have influenced TOC levels in Chapman Creek.

- TOC levels vary substantially from place to place in the watershed. TOC concentrations were found to be highest in tributaries such as Tsawcome Creek which drains a considerable portion of the wet uplands of Chapman watershed where natural organic compounds are common in surface water [see images, Appendix C].

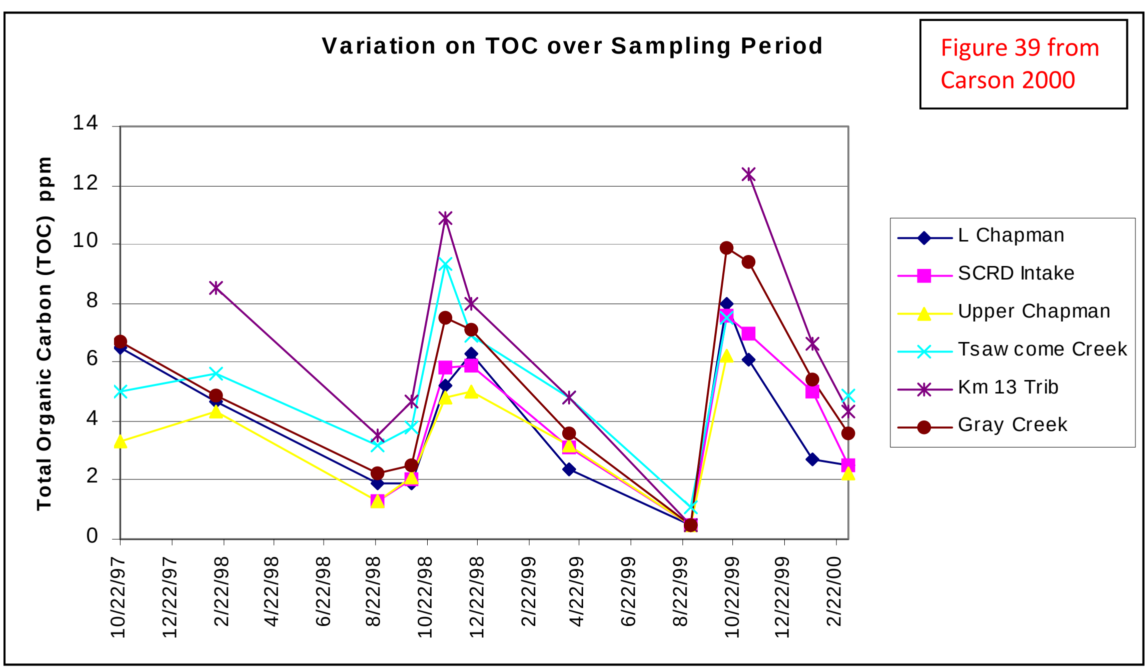
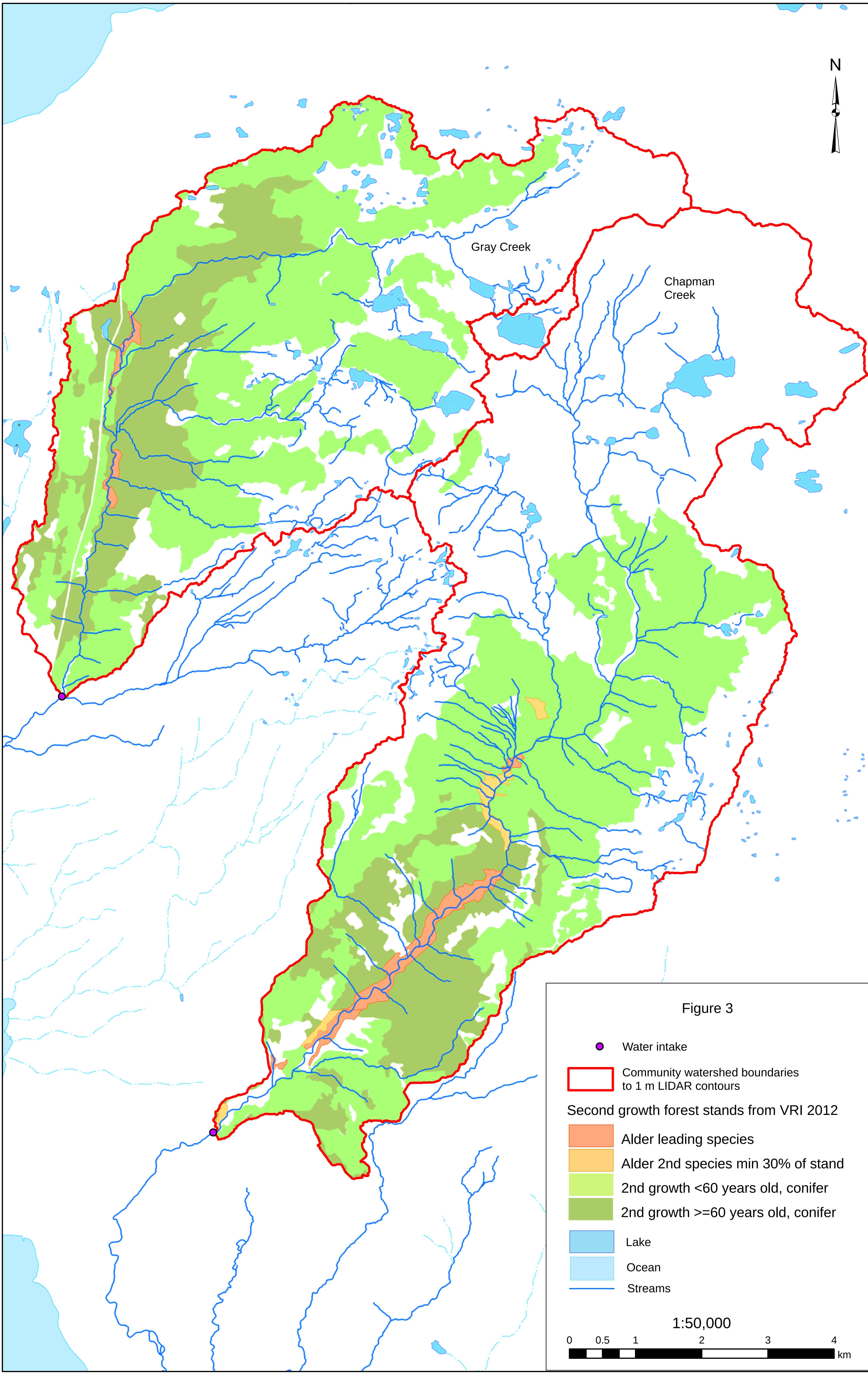


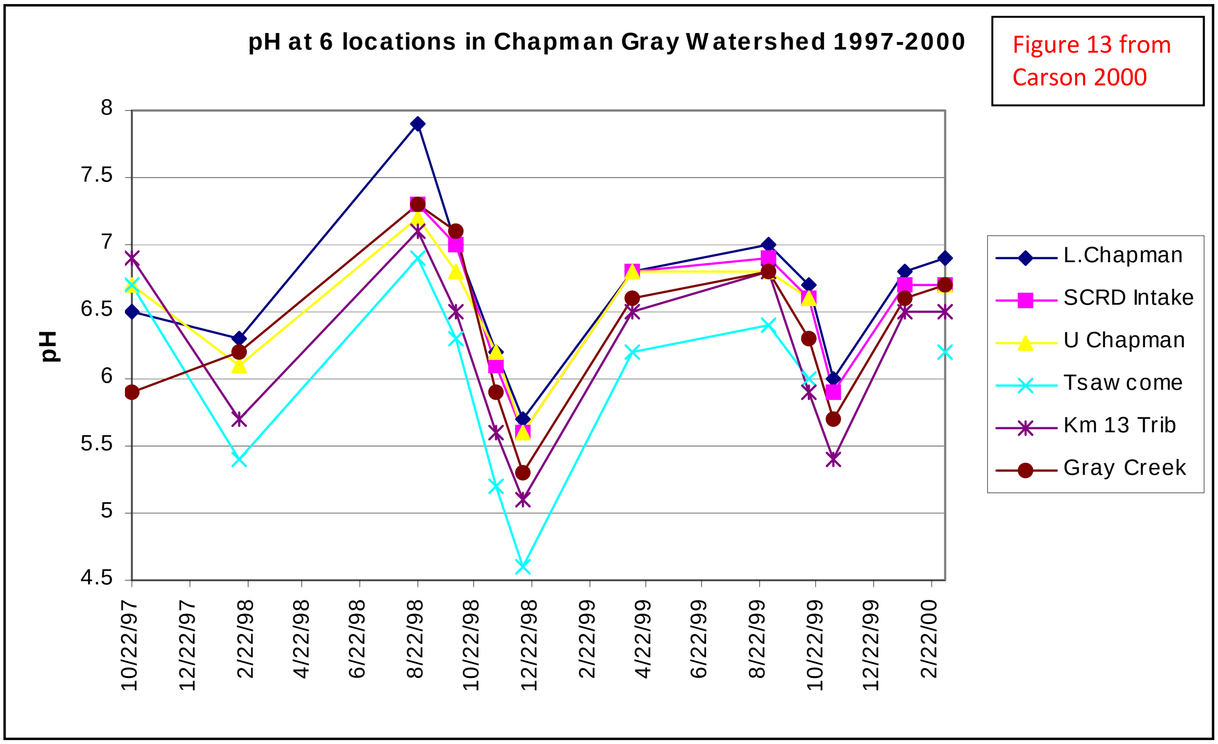
Figure 39 from Carson 2000


N
Gray Creek
Chapman
Creek
Figure 3
Water intake
Community watershed boundaries
to 1 m LIDAR contours
Second growth forest stands from VRI 2012
Alder leading species
Alder 2nd species min 30% of stand
2nd growth <60 years old, conifer
2nd growth >=60 years old, conifer
Lake
Ocean
Streams
1:50,000
0
0.5
1
2
3
4
km

pH

- Water in both Chapman and Gray Creeks tends to be acidic (low pH) and therefore somewhat corrosive. pH is commonly highest (less acidic) in summer and lowest (more acidic) during high flows in fall and winter. Reasons postulated for this are changes in relative contributions of groundwater (less acidic); loading [from contaminants] in the atmosphere during heavy rainfall in fall and winter, and organic acid additions as rainwater passes through forest soils. [Note: a pH of 7 is neutral. pH greater than 7 is basic, pH less than 7 is acidic.]

- In most cases in Chapman Creek, pHs rise as one moves downstream. Lowest pHs are found in small tributaries such as Tsawcome Creek which drain upper montaine catchments with wetlands and extensive organic soil horizons. There appears to be a correlation between pH and TOC but the specific cause is not known.



True colour

- Colour (arising mainly from dissolved or colloidal organic material, and most commonly tannins and lignins) varies most dramatically with season and discharge, and less with location. Colour levels are lowest in summer and highest in autumn, when concentrations of organic material are increased by rainwater washing through leaf litter and forest decomposition.

Garbage dumped on the trails and roads at the west boundary of Chapman watershed above the intake (Field Stops #28 and #29) was not identified as a significant threat to water quality in the reports listed in Section 3; but given the difficulty of extracting contaminants once they have entered the groundwater system, SCRD should take steps to discourage garbage dumping.

6.1 Conclusions on water quality

- The most significant effect on water quality from past forest development has been turbidity events from landslides. The potential for future development-related landslides has been substantially reduced by extensive road deactivation carried out since the early 1990's; and by forest regeneration on steep hillslopes. While the road network was found not to be a major supplier of sediment or turbidity, it should be noted that there was no active hauling during the period monitored.

- Conversion of the riparian forest from conifer to deciduous along Chapman Creek following historic logging of the valley floor is likely to have increased TOCs. Even so, the highest TOCs were from Tsawcome Creek which has minimal deciduous forest along the riparian zone, but drains uplands with wetlands and organic soils.

- It cannot be presumed that turbidity or the other water quality parameters discussed above can be controlled by maintaining mature forest throughout the watershed in future. The monitoring data suggest that, with remediation of the old roads, the concentrations of these parameters are primarily the result of natural instability and erosion of stream escarpments; and the extent of wetlands and organic soil horizons.

7. WATERSHED DESCRIPTIONS

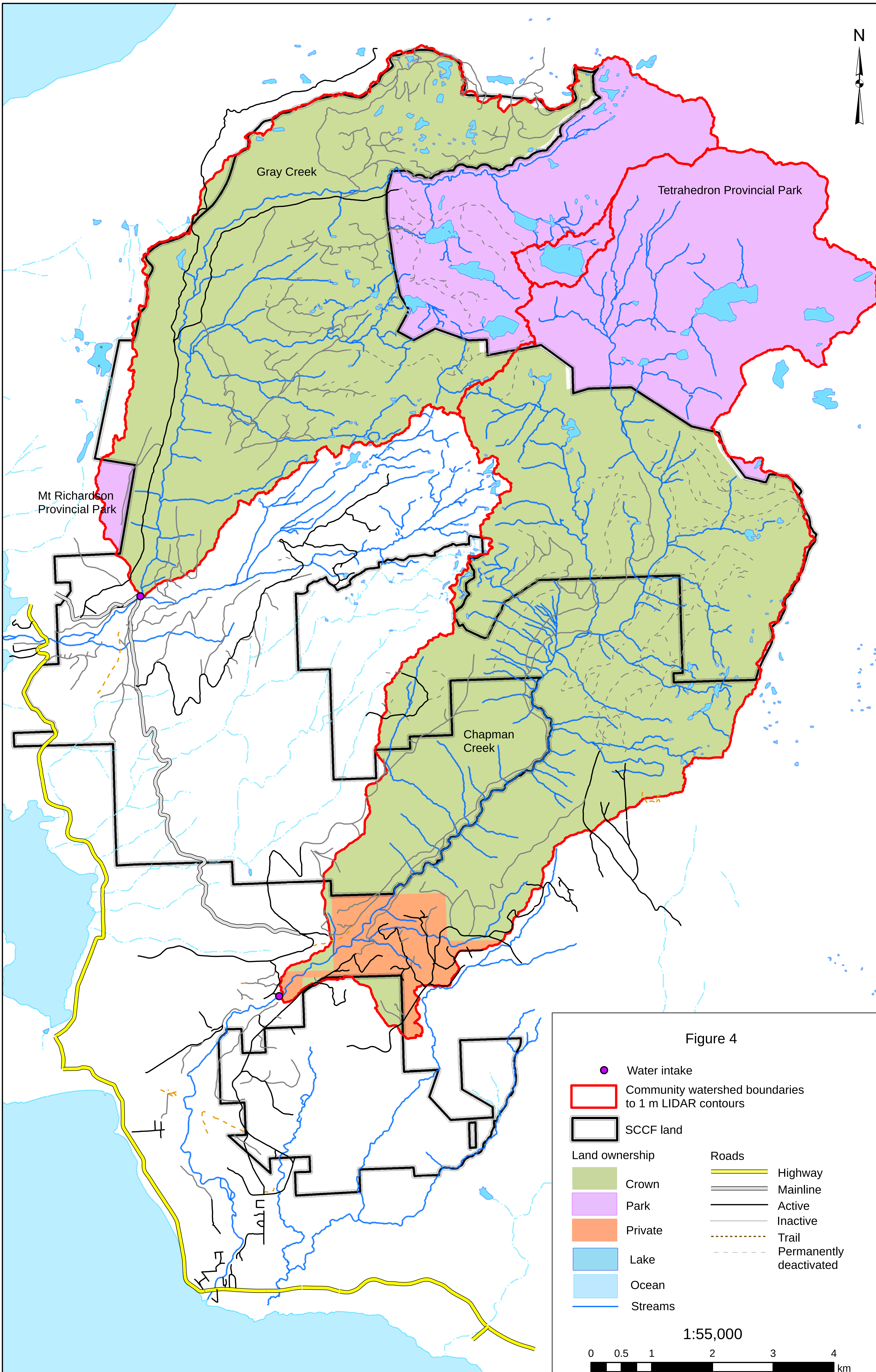
Unless otherwise indicated, distances in km indicated in this report refer to distance along the mainstem channels of Chapman and Gray Creeks, measured upstream from the ocean. See map and stream profiles, Appendix E.

7.1 Land ownership and tenure

The distribution of land ownership and tenure within the community watersheds is shown in Table 1 and Figure 4.

7.2 Bedrock geology

Chapman Creek community watershed is primarily underlain by granitic intrusive rocks of the Coast Range Plutonic Complex – late Jurassic granodioritic rocks in the lower watershed and mid-Cretaceous quartz dioritic rocks in the upper watershed (Figure 5). Lower Cretaceous marine sedimentary and volcanic rocks of the Gambier Group occur at the northern limit of the watershed, north of Chapman Lake. There is a suggestion of lower to middle Jurassic Bowen Island Group sedimentary rocks at the eastern drainage divide; however, this was not field-verified and I note that the unit boundaries of the 1:250,000 geological mapping may not be accurate at the scale of Figure 5 (1:60,000).


N
Gray Creek
Tetrahedron Provincial Park
Mt Richardson
Provincial Park
Chapman
Creek
Figure 4
Water intake
Community watershed boundaries
to 1 m LIDAR contours
SCCF land
Land ownership
Crown
Park
Private
Lake
Ocean
Streams
Roads
Highway
Mainline
Active
Inactive
Trail
Permanently
deactivated
1:55,000
0 0.5 1 2 3 4
km

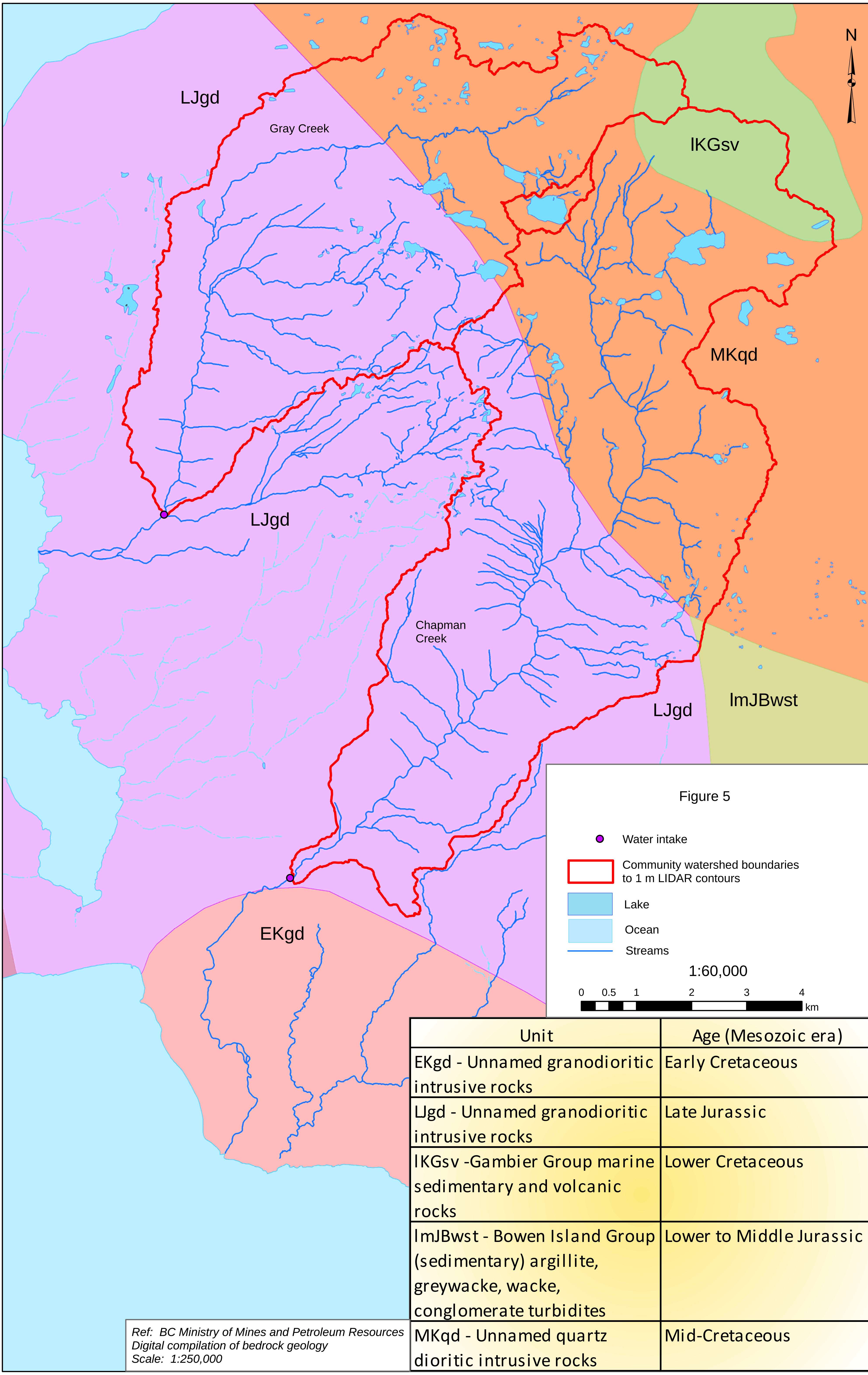


Figure 5

Unit	Age (Mesozoic era)
EKgd - Unnamed granodioritic intrusive rocks	Early Cretaceous
LJgd - Unnamed granodioritic intrusive rocks	Late Jurassic
lKGsv -Gambier Group marine sedimentary and volcanic rocks	Lower Cretaceous
lmJBwst - Bowen Island Group (sedimentary) argillite, greywacke, wacke, conglomerate turbidites	Lower to Middle Jurassic
MKqd - Unnamed quartz dioritic intrusive rocks	Mid-Cretaceous

Ref: BC Ministry of Mines and Petroleum Resources
Digital compilation of bedrock geology
Scale: 1:250,000

Gray Creek community watershed is underlain by granitic intrusive rocks of the Coast Range Plutonic complex – late Jurassic granodioritic rocks in the lower watershed (see Field Stops #37 to 40); and mid-Cretaceous quartz dioritic rocks in the upper watershed (see Field Stops #11 to 16).

Table 1 – Land ownership within community watersheds (CWS)

	Chapman Creek CWS		Gray Creek CWS		Edwards Lake	
	Area, ha	% of CWS	Area, ha	% of CWS	Area, ha	% of CWS
Crown-outside of park	4262	68%	3145	73%	0	0%
Private	330	5%	0	0%	0	0%
Park (crown)	1645	26%	1170	27%	97	100%
Total area	6237	100%	4314	100%	97	100%
SCCF (crown)	2483	40%	3104	72%	0	0%

7.3 Chapman Creek

Chapman Creek flows southward into the Strait of Georgia, entering the Strait approximately 4 km southeast of Sechelt. It is an elongate watershed trending northeast-southwest with a single dominant mainstem; tributaries are small drainages generally without well-developed valley forms. In the community watershed, elevation ranges from 174 m at the intake to 1664 m (from LIDAR 1 m contours) at the drainage divide northeast of Chapman Lake.

The lower 9 km of Chapman Creek is incised into, and in places cut down through, a large glaciofluvial fan formed at the mouth of the main Chapman Creek valley. There are large commercial quarrying operations in the gravel deposits on this fan. The bottom 1 km of channel is through an urban area; Carson (2000) notes alterations that have been made to the channel through this area. From 1 km to 3.8 km Chapman Creek has an alluvial channel in a contemporary floodplain up to 275 m wide; there are side channels in this reach at 2.0 – 2.5 km. Above 3.8 km to the fan apex at 9 km, the channel is mainly confined with several short alluvial reaches; bedrock is apparent in numerous places (Field Stop #4) where the stream has completely penetrated the glaciofluvial deposits.

The SCRD intake is located at 7.5 km in a bedrock reach within the upper part of the glaciofluvial fan. From the fan apex at 9 km to the confluence with Tsawcome Creek at 17.1 km, Chapman Creek has a glacially scoured U-shaped valley form with steep upper valley walls that break to gently sloping upland plateaux on both sides of the valley (Figure 6, Figure 9). The upland plateaux have numerous small lakes, ponds and wetlands. The mid and lower valley slopes and valley floor have deep tills with occurrences of glaciofluvial and glaciolacustrine deposits. The stream is incised into these deposits in an inner trench with steep escarpments adjacent to the channel. There is active bank erosion and slumping where the stream impinges on these escarpments (heli sites C-02, C-07, C-08, C-09, C-10). Numerous landslides occurred in this part of the watershed following historic logging of steep slopes (see Section 11).

Figure 6. Looking north along Chapman valley from approximately 9 km. Photo date: August 18, 2013.

There are several alluvial reaches where the valley floor widens locally up to 300 m. Channel gradients in these reaches range from 2% to 7% and are most commonly 5-7%. The floodplain deposits comprise mainly cobbles and boulders with cascade-pool or step-pool morphology and appear to be glaciofluvial deposits being reworked by the present stream. Large wood debris (LWD) is scarce to absent (Figure 7). Between the alluvial reaches the channel is mainly non-alluvial boulder step-pool or bedrock controlled and has several sets of falls (Figure 8 – see also stream profile Appendix E). The entire mainstem below Chapman Lake is a high energy stream with high transport potential.

Alluvial reaches in Chapman Creek below Tsawcome Creek (17.1 km) have regenerated extensively to alder stands, which are less suitable than conifers for resisting bank erosion and supplying functional large wood debris (LWD). However, the absence of LWD may be more a function of stream energy than LWD supply, as LWD is being introduced at eroding and slumping escarpments. Stream channels in these reaches are generally stable at present.

Above Tsawcome Creek the valley form changes abruptly to a dissected landscape with irregular hummocky to ridged bedrock-dominated terrain (Figure 9); surficial materials are mainly colluvial and till veneers to blankets and there are numerous bedrock exposures. The channel is mainly non-alluvial; there are short alluvial reaches at local widenings where the stream becomes unconfined.

Figure 7. Looking north from 11.4 km along alluvial reach of Chapman Creek. Cobble-boulder substrate. Photo date: August 23, 2013.

Figure 8. Looking north along Chapman Creek at falls at 12.6 km. Photo date: August 23, 2013.

There are numerous small headwater lakes, ponds and wetlands in the upper watershed; the largest waterbody is Chapman Lake (35 ha). The headwater basins of Chapman Lake, in Gambier Group sedimentary and volcanic rocks, have steep slopes and avalanche paths.

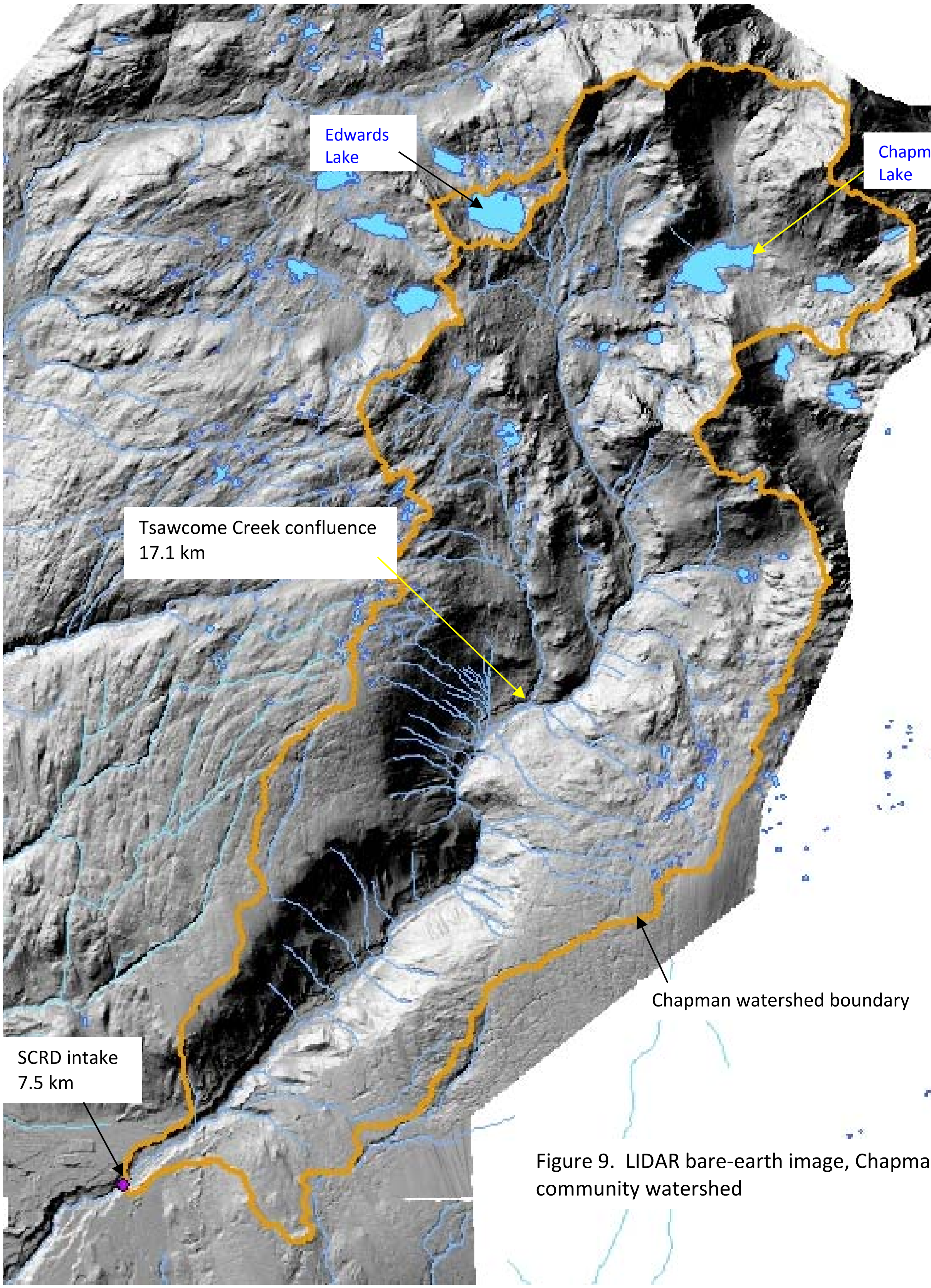


Figure 9. LIDAR bare-earth image, Chapman community watershed

7.4 Gray Creek

Gray Creek flows into the east side of Sechelt Inlet at Tuwanek. The lower 2.7 km of Gray Creek is incised into deep glaciofluvial deposits formed below the confluence of the main valley and the valley of its largest tributary (which is outside the community watershed). The stream has formed an active fan in the lower part of these deposits. Above 2.7 km, the drainage area is asymmetric; stream alignment and drainage patterns appear strongly controlled by structure in the underlying bedrock. From 2.7 km to 10 km the mainstem extends almost due north and lies along the west edge of the watershed. Past 10 km the channel curves to turn eastward in the upper part of the watershed, extending east-west along the north side of the watershed to the top of the mainstem at 17 km (Figure 10).

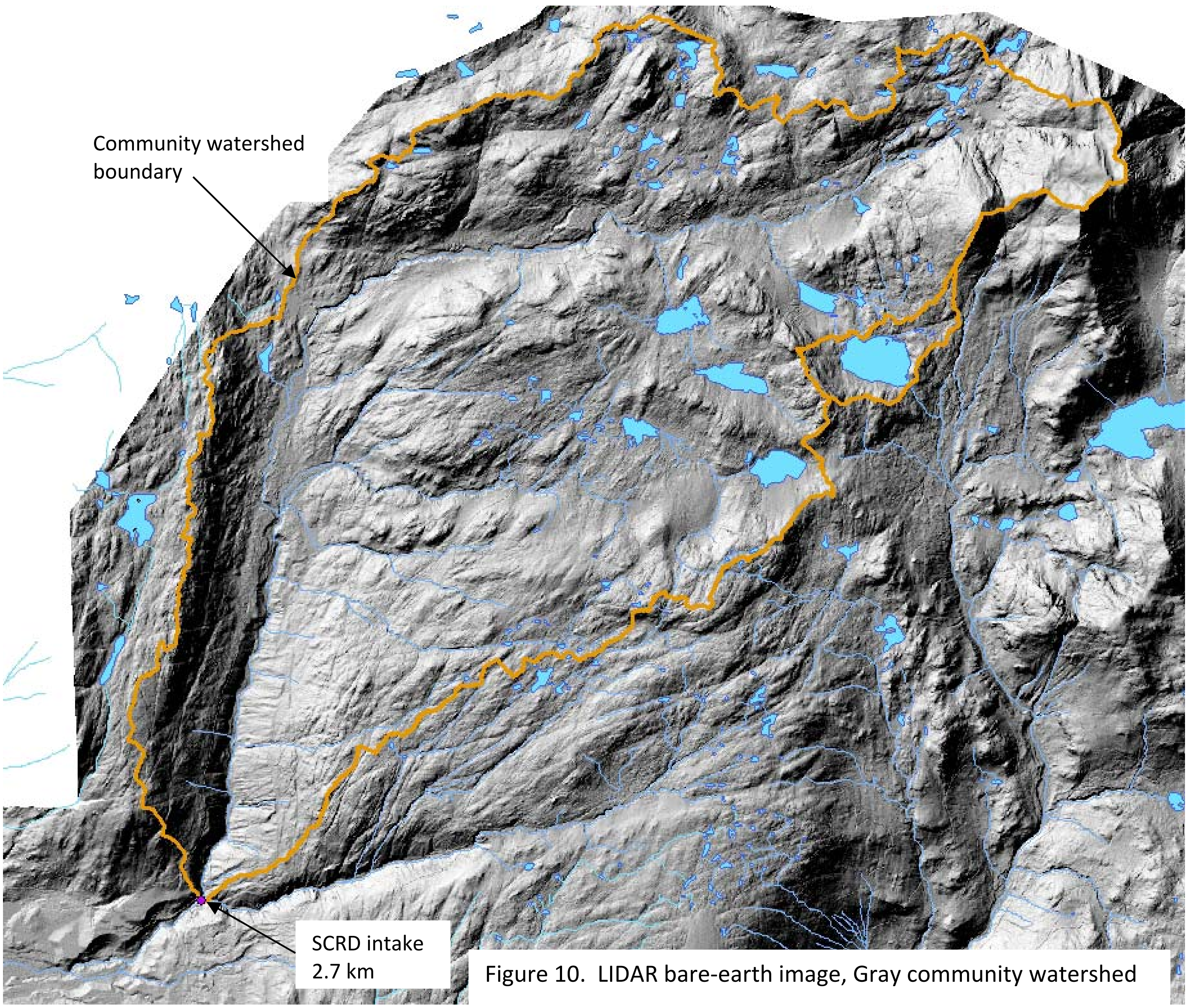


Figure 10. LIDAR bare-earth image, Gray community watershed

In the community watershed, elevation ranges from 192 m at the intake to 1655 m (from LIDAR 1 m contours) at the northeast drainage divide to Chapman watershed. From 2.7 km to 7.3 km Gray Creek has a V-shaped valley form with moderate to steep slopes (Figure 11). Upper slopes have veneers to blankets of till and colluvium over rock, with frequent bedrock exposures. Mid and lower slopes have deep till and glaciolacustrine deposits; there are extensive continuous exposures of glaciolacustrine deposits in road cuts along the Gray Creek FSR (Field Stop #41). These deposits are no longer visible at Field Stop #42 (2.7 km).

The inner trench is deepest at the south end becoming shallower to the north (upstream). The mainstem is incised in a steep-sided inner trench and has a moderate to steep gradient non-alluvial channel. This reach has a high energy stream with unsorted boulder substrate and mainly step-pool morphology; LWD is virtually absent (Figure 12). This valley was logged in the 1940's and 1950's. There are numerous vegetated landslide paths on the valley sidewalls, suggesting a high rate of landslides associated with the original logging. A number of landslides occurred from the road (Gray Creek FSR); others are in Class 5 terrain (unstable – see definitions, Appendix G), primarily in gullied till and glaciolacustrine deposits.

On the west side of this valley the drainage divide lies along the top of the valley wall at the break in slope. On the east side, the valley wall breaks to upland with irregular hilly, hummocky to ridged, bedrock-dominated terrain with till and colluvial veneers to blankets, dissected by numerous small streams (Figure 13).

At 7.3 km the inner trench disappears. The valley floor widens; from 7.8 km to 9.6 km Gray Creek has an alluvial channel in a floodplain up to 300 m wide with channel gradients 2-3% and mainly riffle-pool morphology (Figure 14). LWD is visible in the channel (Figure 15), and overflow channels are evident on the floodplain in several places. Logged in the early 1950's, the riparian forest is now well advanced second growth. Parts of this reach have regenerated to alder stands, which are less suitable than conifers for resisting bank erosion and supplying functional LWD. Overall, this reach is stable and in good condition.

At 9.6 - 11.1 km the valley floor narrows, the stream is entrenched in a steep-sided gully, and has a steep-gradient bedrock-boulder channel. At 11.1-12.8 km the valley floor in the trench widens to a floodplain up to 100 m wide and the channel becomes unconfined. The floodplain deposits appear to be coarse glaciofluvial deposits being reworked by the present stream; the channel has a cobble-boulder substrate with mainly step-pool morphology and gradients of 5-10%. LWD is scarce to absent (Field Stop #10). Stream escarpments at the trench sidewalls are steep with numerous old landslide scars, mostly vegetated; and some recent small landslides (heli sites GR-03, GR-04).

From 12.8 km to 14.9 km the valley floor narrows; the stream is mainly confined semi-alluvial or non-alluvial with short alluvial or wetland reaches at local widenings. At 14.9 – 15.6 km the trench disappears; the stream is an unconfined alluvial channel in a floodplain up to approximately 100 m wide, with a gravelly substrate, gradients of 1-5%, and mainly riffle-pool morphology. Much of this reach has wetlands adjacent to the stream. From 15.6 km to the top of the mainstem at 16.9 km the stream is mainly confined semi-alluvial with short non-alluvial reaches; and wetland or alluvial reaches at local widenings. The surrounding terrain has numerous small wetlands; the mainstem drains from headwater wetlands and shallow lakes (Appendix C).

Figure 11. Looking north at Gray Creek valley from 2.3 km. Photo date: August 23, 2013.

Figure 12. Gray Creek channel at 3.4 km. Photo date: August 23, 2013.

Figure 13. Looking east at hummocky upland terrain east of Gray Creek in the southern half of the Gray Creek valley. Photo date: August 23, 2013.

7.5 Edwards Lake

This drainage unit consists of Edwards Lake and the area draining into the lake. Edwards Lake is not strictly speaking a watershed; it is delineated separately in this assessment because its natural outlet is into Gray Creek, but flow is diverted into Chapman Creek.

It is a high-elevation drainage, ranging from 1070 m at the control gate to a maximum 1355 m elevation where the drainage area tapers out on the slope northeast of the lake. The total drainage area is 97 ha; it is entirely within Tetrahedron Provincial Park and has never been logged. At one time a road was constructed into the basin on the west side of the lake; on the ortho it appears to be debuilt (this was confirmed by D. Lasser, personal communication Nov 29, 2013).

Figure 14. Alluvial reach of Gray Creek at 8.0 km. Photo date: August 23, 2013

Figure 15. Google Earth image of alluvial reach of Gray Creek at 8.7 km. LWD visible in channel.

8. CLIMATE AND STREAMFLOW TRENDS

Analysis of streamflow data for Chapman Creek has been undertaken in previous studies (Chapman and Reksten 1991, Carson 2000); and Opus DaytonKnight (2013) presents a drought risk analyses for community water supply. For this assessment, a review of climate and streamflow *trends* has been undertaken by A. Chapman, P. Geo. The purpose was to determine whether there are identifiable climate patterns in the long-term precipitation data; and if such patterns are discernible, whether shifts in these patterns have had a statistically significant effect on stream flows. Chapman's report with accompanying tables and figures is in Appendix A. His significant findings are as follows; the figures referred to in this section are in Chapman's report in Appendix A.

Annual precipitation *(Figures A-1 to A-4)*

- Two full Pacific Decadal Oscillation (PDO) cycles are evident in the past century: "cool/wet" PDO regimes prevailed from 1890-1924 and from 1947-1976, while "warm/dry" PDO regimes dominated from 1925-1946 and from 1977 through to the mid 1990's. There is a belief that the PDO has shifted back to the cool phase beginning in the early 2000's. In particular, PDO has a strong effect on winter snow accumulation and subsequent spring runoff.

- The annual precipitation record at Gibson's Gower Point over the past 51 years manifests a slight downward trend, but not statistically significant *(Figure A-3)*.

Monthly and seasonal precipitation *(Figures A-5 to A-8)*

- Most precipitation in the study area occurs from October to March; for the 1961-2012 period of record at Gibsons Gower Point, 72 percent occurred during this period. November, December and January are the wettest months *(Figure A-5)*.

- Over the period of record at Gibson's Gower Point, for the winter period (October to March) there is a slight but not statistically significant downward trend in total precipitation *(Figure A-6)*.

- Spring precipitation (April to June) exhibits a statistically significant increasing trend. Over the 61 year period of record, spring precipitation has increased 28% *(Figure A-7)*.

- Summer precipitation (July to October) over the 61 year period of record has declined steadily and substantially, by about 40%, from an average of about 198 mm to 119 mm. The same decline has been documented in other climate stations across the south coast of B.C. *(Figure A-8)*.

Annual streamflow *(Figures B-1 and B-2, Appendix A)*

- The stream flow analyses looked at both a composite record from the three Chapman Creek gauges (1959-1970, 1970-1988 and 1993-2003 – *Figure B-1, Appendix A*), and from the Roberts Creek gauge which has a good long-term record (1960-2011).

- There is a slight downward, but not statistically significant, trend in annual runoff *(Figure B-2, Appendix A)* and in winter runoff for Chapman Creek, consistent with the slight decline in annual precipitation seen at Gibsons Gower Point. Roberts Creek showed a similar trend: slight but not statistically significant decline in annual runoff and winter runoff *(Figures B-4 and B-5, Appendix A)*.

Monthly streamflow *(Figure B-3, Appendix A)*

- Highest average monthly runoff occurs in May and June, but on occasion large "Pineapple Express" or "Atmospheric River" storms cause very large runoff events at other times. The largest monthly runoff of record occurred in October 1962.

- Lowest average monthly runoff typically occurs in August. Summer droughts can on occasion extend through October. In 26 of 42 years of record (62%), the recorded discharge in August was not sufficient to meet the full SCRD licenced demand. [Note: The composite record created by Chapman, Appendix A, assumed that for the two gauges below the intake, the maximum licensed volume was extracted every day. He notes that this is not likely to be the case.]

- The composite Chapman Creek record is not amenable to examination of monthly or seasonal trends, and is confounded by storage and release of water from Chapman and Edwards Lakes. The Roberts Creek record however, is useful for regional trend analysis. Roberts Creek manifests a substantial and statistically significant decrease in summer runoff (July to September – *Figure B-6, Appendix A*). Summer runoff has decreased about 35% from 1960 to 2011. This is consistent with the reduced summer rainfall reflected in the Gibsons Gower Point climate station and other coastal climate stations.

Peak flows

- Annual peak flows typically occur between October and March, although two have occurred in July (1972 and 1974) from unusual summer storms. Peak flows occur most commonly from October to December *(Figure B-7, Appendix A)*.

- The two largest peak flows in Chapman Creek occurred in 1962 and 1968; the peak flow of record was in October 1962.

- While the composite record for Chapman Creek must be interpreted with caution, there appears to be a significant and substantial downward trend to decreasing peak flow magnitudes over the period of record. No similar significant trend in magnitude of peak flows is apparent in Roberts Creek flows *(Figures B-8 and B-9, Appendix A)*.

It might be postulated that the difference in trend is related to factors affecting flow generation at the high elevation zones in Chapman Creek, such as variations in extent of snowpack during peak flow storm events. (Roberts Creek extends to a maximum elevation of 1129 m, whereas Chapman Creek reaches 1665 m). If the difference is in peak flows generated at high elevation, there may be an influence by the control gates on Chapman and Edwards Lakes. Another possibility is that peak flows in Chapman Creek are declining as a consequence of hydrologic recovery in stands logged in the rain-on-snow zone (Section 10).

ClimateWNA predicted climate variables for high elevations in Chapman watershed in October indicate an average daily minimum temperature of 1.5^{o}C and about 11% of total precipitation falling as snow. This suggests peak flows in October are more likely to be rain-generated whereas peak flows occurring in November to March would typically be rain-on-snow.

While declining summer runoff is consistent with declining precipitation trends, increased evapotranspiration in the regenerating second growth stands might be a contributing factor.

9. BACKGROUND – HYDROLOGIC CHANGE AS A CONSEQUENCE OF FOREST DEVELOPMENT

This section discusses factors affecting hydrologic change that are relevant to Chapman and Gray Creek watersheds. For more extensive background, refer to the information sources listed at the end of this report.

Streamflow response in a watershed involves a complex interaction between climatic conditions, physical watershed characteristics and land use. Factors influencing stream flow response can include:

- Regional climate
- Vegetation (distribution of forest and non-forest areas)
- Dominant peak flow regime (snow melt, rain, rain-on-snow)
- Topographic relief
- Aspect and wind exposure
- Surface catchment size
- Soil depth and permeability
- Bedrock permeability and structure
- Subsurface groundwater catchment
- Water storage (lakes, wetlands, icefields, late-persisting snowpacks)
- Roads
- Non-forest development (agriculture, urban, industrial)
- Artificial flow controls or diversions
- Groundwater or surface water extraction

9.1 Forest removal

Trees intercept some portion of rainfall and snowfall; and draw water from the ground and release it into the air by evapotranspiration. Canopy density, tree type and degree of canopy closure determine the extent of interception. When forests are removed, the loss of interception means that all precipitation hits the ground directly. This can result in increased runoff or infiltration and increased snowpack depth. The extent to which this affects stream flows depends on stand characteristics; in the case of rainfall interception, on antecedent moisture in the canopy; on the nature of the particular storm event; and on other watershed factors as listed above.

Increases in snowpack depth can have the effect of increasing the total water yield from a watershed. Vegetation removal can increase snowpack exposure to wind; and also changes snowpack albedo[2], which can change the rate and timing of snowmelt.

Forest removal can elevate groundwater levels because of the loss of evapotranspiration (Hetherington 1987). This effect is most pronounced in summer when transpiration rates are highest. Water uptake by large trees is considerable. For example, at a study site in western Washington, Martin et al. (1997) determined that their research stand of *A. amabilis* stored an average of 12.6 kg/tree of water, or 27.2 mm, which they equated to approximately 8 days of transpiration. Water taken up by trees that is not consumed in photosynthesis is transpired into the atmosphere. During periods of extreme drought, transpiration ceases and trees become dormant to preserve stored water.

In rain-dominated climate zones photosynthesis and evapotranspiration continue in the winter months although at a reduced rate. Researchers have found winter evaporation rates to be 20-30% of summer rates (Murakami et al. 2000, Humphreys et al. 2003). Hence, in winter, with reduced evapotranspiration coupled with high seasonal rainfall, the difference in soil moisture content between forested and clearcut sites would be correspondingly reduced and might be eliminated.

9.2 Stream flow effects of harvesting

In snowmelt peak flow regimes, typical of interior watersheds, high rates of cut can result in significant increases in snowpack, and consequent significant increases both in annual discharge and in spring peak flow events. Because of other changes such as greater exposure to wind, spring melt rates can be higher, and peak flow events may occur sooner.

In rain and rain-on-snow peak flow regimes, the influence of harvesting is far more variable. Forest canopies have finite ability to intercept rain, so in large storms much of the rain goes through the canopy. In small storms occurring on a dry canopy (such as summer storms), a high percentage of the rain may be retained in the canopy, then subsequently evaporate without reaching the ground. Thus, stream flows from small storms can be significantly increased by forest removal.

The influence of forest removal diminishes with increasing basin size, with the largest increases recorded in watersheds of less than 100 ha. One such study was conducted in Roberts Creek (Hudson 2001), where small (S6[3]) streams were found to experience large flow increases in rain-on-snow events. In large watersheds, especially those of high relief, there is greater potential for variation in other factors that influence runoff such as precipitation, snow accumulation, aspect, topography, vegetation, wind conditions, temperature, soil thickness and permeability, storage in lakes, ponds or wetlands; and therefore greater opportunities for “desynchronizing” of runoff. Studies in large watersheds have recorded smaller to no increase in peak flows after harvesting, or

[2] Albedo is the fraction of solar energy reflected back from the surface.
[3] S6 – non-fish-bearing stream 3 m or less in width. Ref. Forest Practices Code Riparian Management Area Guidebook, Dec 1995.

even decreases; but predicting responses in large watersheds tend to be less certain because there are few studies on large watersheds.

The current state of science does not allow a quantitative estimate of stream flow changes as they relate to ECAs. There is no simple relationship between the factors noted above and streamflow change; each watershed has a unique response. Numerical modeling methods such as the DHSVM[4] that attempt to incorporate all the variables affecting watershed hydrologic response are elaborate and costly, and at present are mainly a research application. For this assessment we consider qualitatively the factors that affect stream flow response, draw from the observed trends in climate and stream flows; and make a best judgment on how stream flows may have been or could be affected by harvesting.

9.3 Hydrologic recovery

As forests regenerate, the canopy functions with respect to rain and snow interception start to recover. Hydrologic recovery, as the term is generally used in B.C. studies and in this report, is an indicator of how a regenerating stand compares to a reference stand (typically a natural stand) with respect to snowpack development and rainfall interception (Hudson and Horel 2007). Equivalent clearcut area (ECA) is determined by applying hydrologic recovery models to individual harvested stand areas, and cumulating these stand areas for the total watershed.

Rainfall interception in different ages of forests has been studied at research sites in Upper Gray Creek and on Vancouver Island (Hudson 2003). The rainfall interception curves presented in Hudson 2003 are based on these data. Ten snow courses were also established in Upper Gray Creek to study snowpack development and recovery in clearcuts and regenerating forests; these data are the basis of the snowpack recovery curves in Hudson 2000.

ECA gives only an indication of potential streamflow change based on the extent of forest modification. An ECA of 50% does not mean that stream flows may have changed, or recovered, by this amount. In particular, ECA is not an indicator of watershed or stream condition.

Confusion arises over the use of the term “hydrologic recovery” because it is used several ways in the scientific literature. For example, in the U.S., “hydrologic recovery” is often used to mean the return of a watershed to the pre-disturbance hydrologic regime. Used in this context, it includes other complex physical processes. Evaluating hydrological recovery in this sense usually involves a suite of indicators representing various watershed processes. To avoid confusion it is preferable to use the term “watershed recovery” to describe recovery of these multiple processes or condition at the watershed scale. Similarly, the term “hydrologic function” is used to compare current condition to a target condition and in the literature, may refer to an entire watershed or to an individual stream reach. ECA is not an indicator of watershed recovery, or of hydrologic function at either the watershed or stream scale.

The term “hydrologic recovery” should not be confused with “sufficiently restocked” or “greened up”. “Sufficiently restocked” means that a harvested area has met the stocking standard and the

[4] Distributed hydrology-soil-vegetation model

seedlings or small trees are free from direct competition from other trees, shrubs, grasses or herbaceous plants. This typically means a tree height of 1.3 m. "Green-up" means that a stand is determined to be adequately stocked and the tallest 10% of trees are at least 3 m in height[5]. "Green-up" does not mean hydrologic recovery.

ECA limits and rate of cut restrictions are sometimes sought as a means of restricting harvesting in order to protect forest values other than watershed hydrology; for example, old forest attributes, terrestrial habitat or viewscapes. ECAs are not intended for this purpose and should not be used in this way. Other forest values should be addressed on their own merits and by the appropriate means.

10. HARVEST-RELATED STREAM FLOW CHANGE IN CHAPMAN AND GRAY CREEKS

The oldest logging indicated in the VRI Rank 1 in Gray Creek CWS was in 1913, and in Chapman Creek CWS was in 1916. The lower to mid valleys in both watersheds were extensively logged in the 1940's and 1950's (Figures 16 and 17). The greatest rate of logging in Chapman Creek was from 1970 to 1979 and in Gray Creek from 1980 to 1989.

Hydrologic recovery is well advanced in the older logged areas; some stands are over-recovered (Figure F-2, Appendix F). "Over-recovery" means that the second growth forest canopy is denser than an old-growth canopy and intercepts more rain (Hudson 2003). The effects of over-recovery are expected to disappear over time as mature second growth stands begin to develop old forest characteristics. In calculating ECAs, over-recovery is taken into account in the rainfall zone and for the rain component in the transient snow zone (rain-on-snow zone).

ECAs determined using LIDAR tree heights (LIDAR flown in 2009 and 2010) are in Table 2. Criteria used to calculate ECAs are described in Appendix F. The negative values in Table 2 arise from second growth stands which have achieved over-recovery with respect to rainfall interception.

Only 2% of Chapman community watershed area and less than 1% of Gray community watershed area is in the rainfall zone (elevation band 1 – Table 2 below and Figure F-1, Appendix F). In Chapman Creek, 27% of the watershed area is in the transient snow zone (elevation band 2) and 71% is in the snow accumulation zone (elevation bands 3 and 4). In Gray Creek, 33% is in the transient snow zone and 72% is in the snow accumulation zone. The influence of snowpack in both watersheds should therefore be a significant factor in total annual discharge, monthly discharge and most peak flows.

We would expect that high ECAs in the transient snow and snow accumulation zones in these watersheds would cause increases in annual discharge, increases in spring runoff and increases in magnitude of peak flows generated by rain-on-snow events. Not all annual peak flows are rain-on-snow events; peak flows occurring in October would normally be rain-generated. Peak flows occurring from November to March would normally be rain-on-snow events. The extent to which peak flows are enhanced by snowmelt contribution depends on conditions at the time of the event.

[5] FRPA, Forest Planning and Practices Regulation s65 (3).

A cold rain-on-snow event may produce very little snowmelt; rain water may be absorbed by the snowpack. Temperature and wind are the most significant factors affecting rate of snowmelt; melt rates are significantly increased by warm windy conditions.

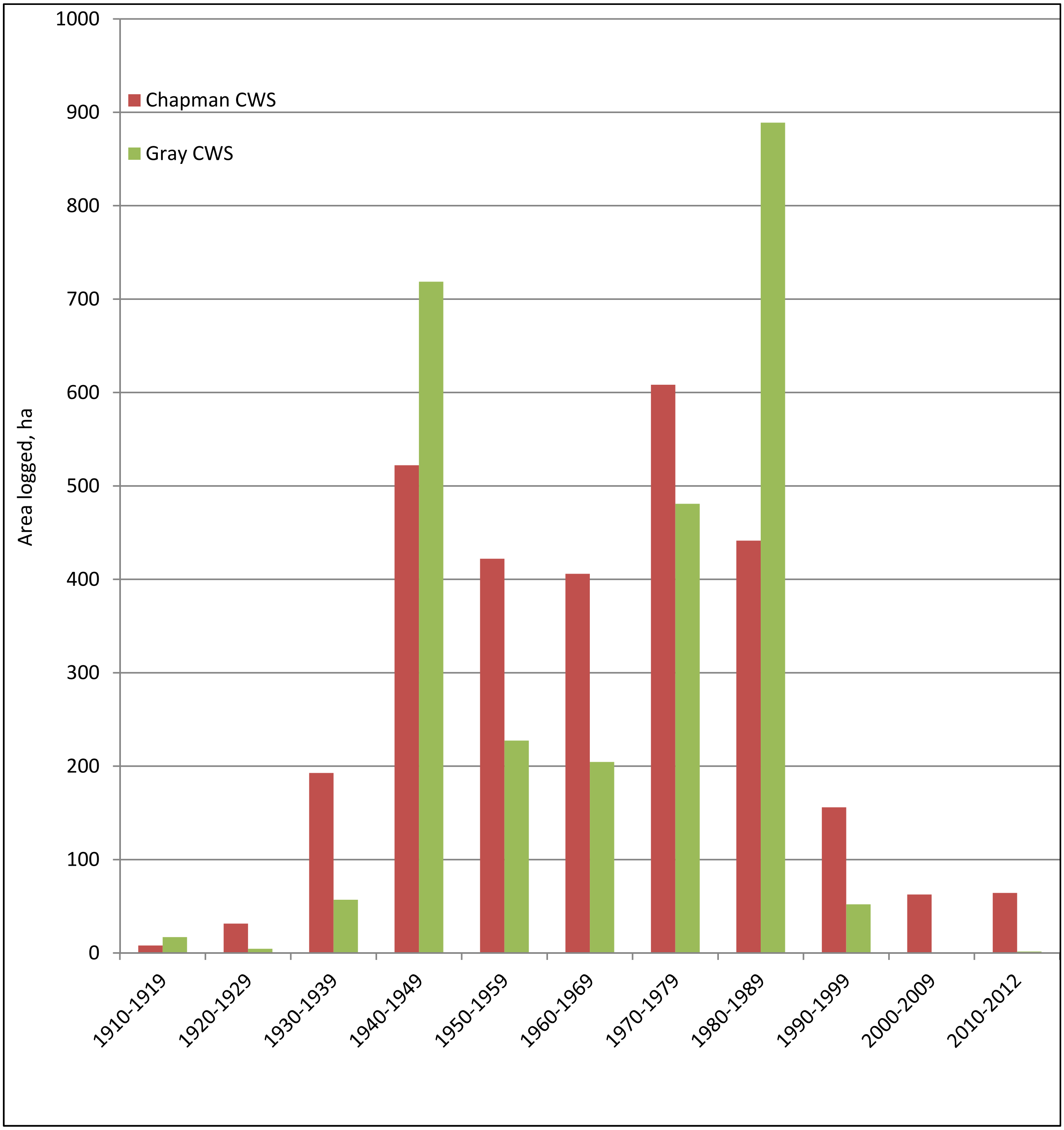


Figure 16. Rate of logging in Chapman and Gray Creek community watersheds, from VRI Rank 1 to 2012.

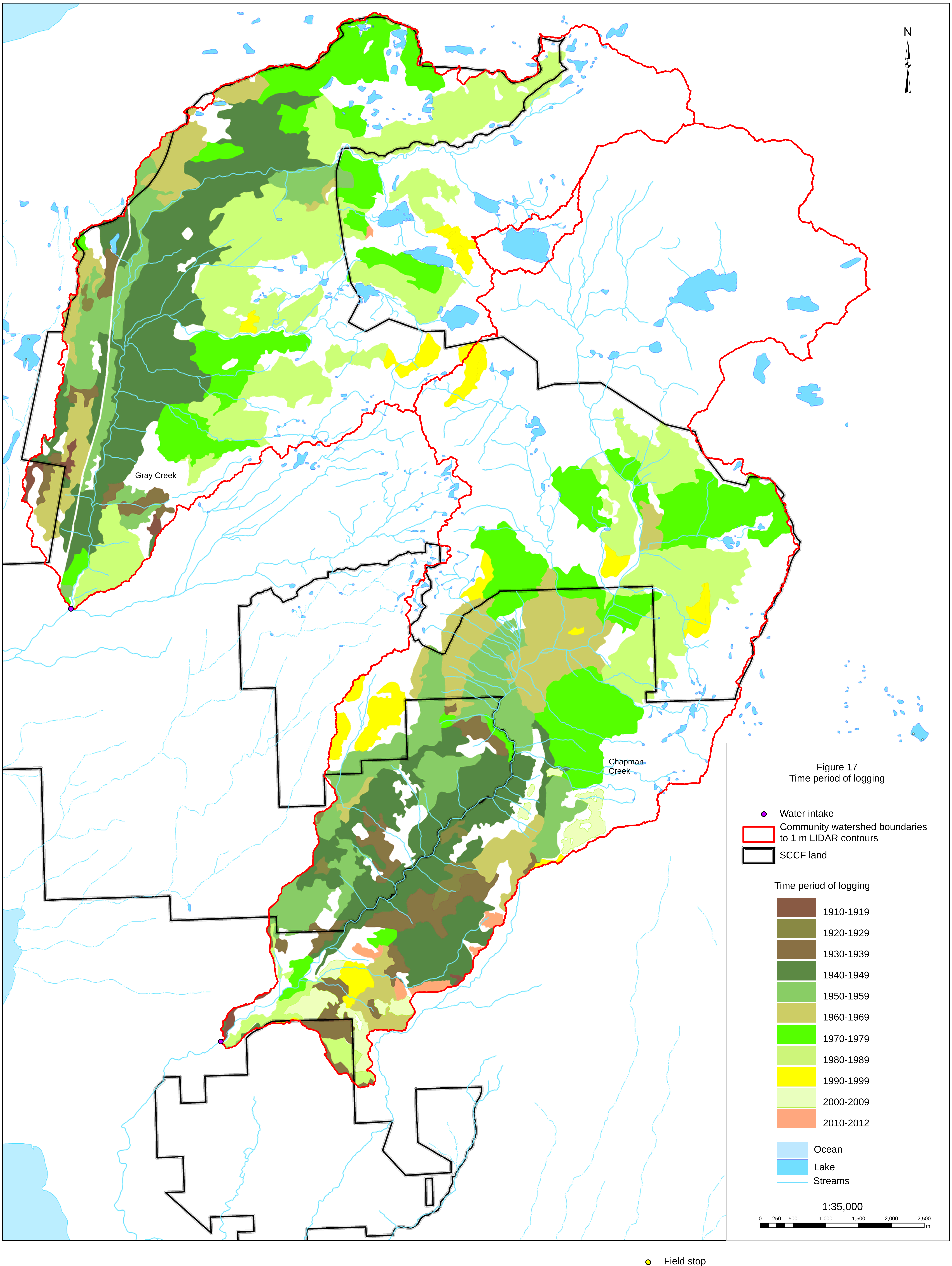


Figure 17
Time period of logging

Table 2 – Equivalent Clearcut Area – 2009/2010 LIDAR tree heights

Community watershed	Elevation band	Elevation range	Total Area		Equivalent Clearcut Area*	
			ha	%	ha	%
Chapman	1	<300 m	102	2	32	12%
	2	300-800 m	1705	27	113	2%
	3	800-1200 m	3725	60	546	15%
	4	1200-1664	705	11	35	5%
			6237	100	726	12%
Edwards	3	1070-1200 m	93	96	0	0
	4	1200-1361	4	4	0	0
			97	100		0
Gray	1	<300 m	17	0.4	-1	-7%
	2	300-900 m	1417	33	-20	-3%
	3	900-1200 m	2624	61	879	33%
	4	1200-1658	256	6	9	3%
			4314	100	866	20%

**Negative ECA values are due to stands that have achieved over-recovery with respect to rainfall interception; that is, they have denser canopies than old growth stands.*
Mature stands with alder as the leading species (>50%) are assumed to be maximum 50% recovered.

The expected trends of increased annual and peak flows are not apparent in the stream flow records. Chapman (Appendix A) found a slight decline (but not statistically significant) in annual stream discharge in Chapman Creek over the period of record. From Figure 17, significant harvesting in the rain-on-snow zone had already taken place before records were kept. We may postulate that flow increases had already occurred by the time flow measurements began. Chapman also found a statistically significant decline in peak flows over the record. We may further speculate that this may reflect hydrologic recovery in the regenerating stands. As noted in Section 8, there might be other causes related to climate factors in the transient snow and snow accumulation zones; for example, changes in snowpack distribution at the time of storm events that cause peak flows. There are insufficient data to draw conclusions about the causes of this trend. If the difference is due to climate-driven changes, such as timing of snowpack accumulation relative to storms causing peak flow events, there may be smaller effects within that trend, such as from hydrologic recovery or enhanced drainage from roads. It is not possible to discern these effects from the existing data.

Carson (2000) observed that in Chapman Creek increased snowpack depth from harvesting was unlikely to help sustain summer flows because the watershed zone where snowpack depths may have increased was melted off by late spring. Carson further noted that climate warming trends could hasten snowmelt in early spring, exacerbating the decline of summer low flows.

Loss of evapotranspiration and consequent elevation of groundwater tables following harvesting can increase summer low flows, and this may have occurred when the valley floor and lower slopes were initially logged. Those areas now have well advanced second growth; and evapotranspiration rates would be largely re-established, or in over-recovered stands, may exceed the evapotranspiration rates of the original forests. The current trend to decreasing low flows in Chapman Creek is clearly related to the same trend in summer precipitation (Chapman, Appendix A); but increased evapotranspiration in the regenerating forests might also be a factor.

Summer low flows are also a function of the groundwater storage capacity which is related to the combined factors of soil depth, soil permeability and slope steepness. For example, watersheds with extensive glaciofluvial deposits, or watersheds with extensive deep tills and low relief, may have high rates of infiltration and high groundwater storage capacity, which sustain base flows in the summer time. Both Chapman and Gray Creeks have low base flows, reflecting generally high runoff as opposed to infiltration, and relatively low groundwater storage capacity.

10.1 Roads

Roads can affect hydrologic processes in several ways and can have greater effects on stream flows than forest removal (Grant et al. 2008):

- Compact road surfaces reduce infiltration and increase runoff.
- Road cuts intercept shallow subsurface groundwater flows and bring it to the surface.
- Road ditches can act as a secondary drainage network, concentrating flows to streams and altering drainage patterns.

These effects can increase stream flows from groundwater brought to the surface and conducted via ditches to streams; and reduce concentration times so that streams peak faster.

Roads on steep slopes with thin soils are more likely to intercept subsurface seepage and increase surface flows than roads on gentle slopes. Cuts on steep slopes are higher, and more likely to intercept seepage; cuts on gentle slopes may be minimal. On gentle slopes with deep permeable surficial deposits, subsurface flows may predominantly be beneath the road, and not intercepted in road cuts. In Chapman and Gray Creeks, roads cross many kinds of slope conditions; there is sufficient road length on moderate to steep slopes for interception of seepage and enhanced stream flows from road drainage to have occurred.

Good culverting practices, such as maintaining natural surface drainage courses across the road and cross-culverting to discharge ditchwater onto the forest floor, can help to mitigate the influence of roads on stream flows by dispersing and slowing surface flows. The degree to which ditchwater culverts mitigate intercepted seepage depends on distance to streams, slope steepness below the road, soil depth and soil permeability. Ditchwater discharged from roads close to streams onto steep slopes with thin soils may remain as surface flow until it reaches the stream system. Ditchwater discharged distant from streams onto deep permeable soils is more likely to re-infiltrate.

Similarly, cross ditching for road deactivation helps but may not be completely effective for the same reasons that cross-culverting may not be completely effective. Complete debuilding and recontouring of roads is more effective at restoring hillslope drainage patterns; however, Carson (2000) observed that even with recontoured roads, some intercepted seepage continued to flow as surface streams in cross-ditches. This may diminish as roads become overgrown. See images, Appendix D.

Most roads in Chapman watershed and many roads in Gray watershed have had some level of deactivation. Figure D-1 (Appendix D) shows the extent of road deactivation, as visible on the 2009/2010 orthos; but may not show the full extent of debuilt roads because of the limitations of viewing the roads on the orthos.

From the trend in declining peak flows we may speculate that either peak flows were not significantly increased by the road network; or that the deactivation measures have been effective at diminishing the effects of the roads; or that larger effects from climate trends mask the effects of roads.

11. LANDSLIDES AND SEDIMENT SOURCES

Chapman and Reksten (1991), EBA (2000), Triton (2006) and Carson (2000) discuss logging-related landslides in Chapman Creek in detail. There are natural landslides in both Chapman and Gray watersheds on steep unstable terrain and at stream escarpments in the inner trenches. The rate of landslides was greatly accelerated by historic logging. During that time, logging-related landslides were the largest sediment sources in both watersheds.

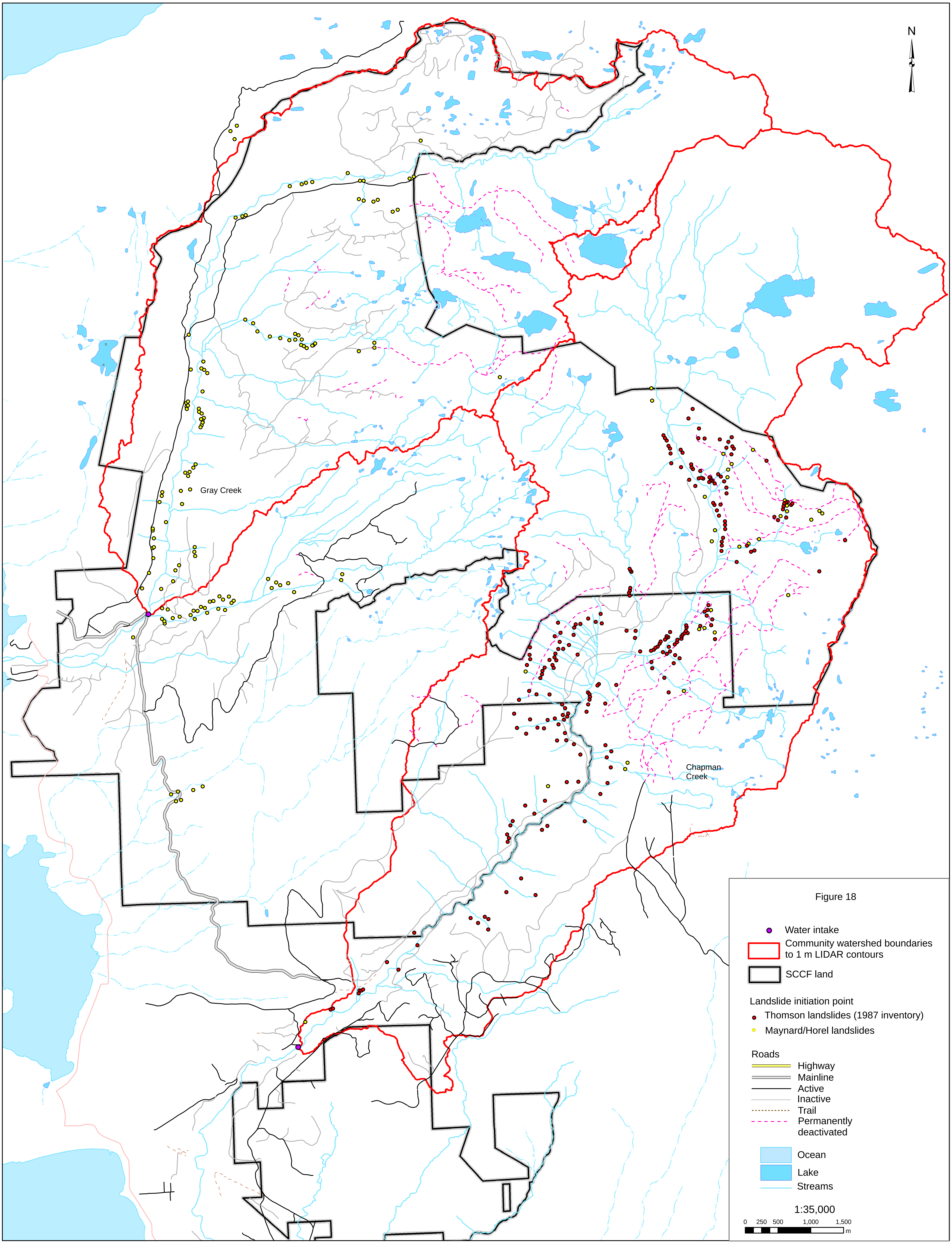
Logging-related landslides included:
- Landslides from unstable sidecast road fills
- Progressive failures in large cutslopes
- Landslides initiating on steep slopes below roads, triggered by road drainage
- Landslides in logged gully sidewalls and stream escarpments
- Post-harvesting open-slope failures (many of these may have been caused by road drainage)

<u>Potential sediment sources from roads</u>
Maps displaying road status, road grades steeper than 10%, road fill stability hazard and risk of landslides to Chapman and Gray Creek from roads are in Appendix D.

These road attributes are from a planning level assessment using LIDAR contours, bare-earth images, orthos and slope mapping. No field investigation of the road system was done for this assessment other than the field stops and helicopter overview flights.

11.1 Chapman Creek

The 1987 Thomson inventory recorded 246 landslides in the Chapman watershed, with concentrations on both sides of the valley at 14-18 km, and on the east side of the valley at 19-21 km (Figure 18) [*this project digitized the Thomson inventory*]. EBA (2000) note that they recorded a


N
Gray Creek
Chapman
Creek
Figure 18
Water intake
Community watershed boundaries
to 1 m LIDAR contours
SCCF land
Landslide initiation point
Thomson landslides (1987 inventory)
Maynard/Horel landslides
Roads
Highway
Mainline
Active
Inactive
Trail
Permanently
deactivated
Ocean
Lake
Streams
1:35,000
0 250 500 1,000 1,500
m

further 22 landslides dating between 1984 and 2000. The historic landslide tracks are now mostly vegetated (Figure 19). Some are still minor or occasional sediment sources.

Figure 19. Looking northwest at west side of Chapman valley at 16.5 km. Numerous old landslide tracks visible. 2010 Google Earth image.

Several recent small landslides were noted during the helicopter flights on the east valley sidewalls of Chapman Creek between 9 km and 14 km. These initiated in steep slopes in mature second growth timber and extended to the stream channel. Recent small landslides have also been observed in the slopes above the Sechelt Dakota FSR on the west side of Chapman Creek; these did not extend past the road. There are active slumps in the stream escarpments where the stream is undercutting the toe of the slope.

The gullies at Field Stops #20 – 23 (heli site C-01) logged in the 1950's still have areas of bare unstable slopes and according to Carson (2000) are still occasionally a sediment source. The logged gully sidewalls at heli sites C-03, C-04 and C-05 are still unstable and well connected to stream channels; the tributary at heli sites C-03 and C-04 joins Chapman Creek at 19 km. The gullies and tributary appear to be seasonal streams; these sites are expected to be sediment sources during high flows.

Roads

The Sechelt Dakota FSR (formerly called East Main) is the original access into the west side of Chapman Creek valley. It is an old road, built in the 1940's to 1960's, probably by bulldozer. This road is gated at the entrance to private land in the vicinity of the watershed boundary. ATVs bypass the gate by means of a trail. From the gate to the upper bridge crossing, a distance of 8 km, the road is inactive and seasonally deactivated. Drainage structures are still in place, backed up by shallow cross-ditches. The road surface is becoming vegetated (Field Stop #33) and producing very little sediment at the present time. The road is kept passable by recreationists for ATVs but not for vehicles; it is obstructed by numerous windthrown trees. Most road cuts are in deep silty to sandy tills. Glaciofluvial and glaciolacustrine deposits were noted in the vicinity of the large gullies (Field Stops #20 to #23); raveling unstable cutslopes have over-run the road surface there. A recent small landslide was noted off the frontal slope of the landing at Field Stop #23, directly above the Chapman Creek channel. Remedial works such as stacked rock fills and rock-wall cutslope support have been undertaken at a number of sites to improve road stability (Field Stops #19/35, #23). Even so, oversteepened fill sections and unstable cuts remain.

The SARP makes recommendations for remedial work at several locations on this road. Before any of this work is carried out, there should be a detailed geotechnical assessment done of the entire road length that is not currently permanently deactivated, including examination of fillslopes, cutslopes and drainage onto slopes below the road. An assessment should consider disturbance that would be created in order to carry out any proposed remedial works. If remedial work is to be undertaken, a sediment control plan should be in place before the work commences.

I note that the SARP erroneously describes the spur road at their Field Site 2 (Field Stop #18, Appendix B in this report) as being within the SCCF tenure. This spur road is in fact on AJB's land (Figure 4). Clearing for this spur road encroached into SCCF land at the junction. The SARP describes a slope failure in this clearing. No sign of movement was evident during our field visits. The uprooted stumps and logs appear to be from clearing for the spur road. Minor erosion is occurring on the road surface, however little sediment is currently being carried to the ditch which extends across the spur road at the junction (see photos, Field Stop #18). The spur road is not in active use and is an insignificant sediment source at the present time.

The bridge across Chapman Creek at 17.2 km has been removed and the entire road system beyond the crossing has been permanently deactivated (Figure D-1). Many of the roads are becoming overgrown; some roads still have unvegetated road surfaces and cross ditches. Road deactivation has substantially limited the potential for future landslides to occur off old roads although events occasionally occur; a recent landslide was noted at a gully crossing on a deactivated road (heli site C-05). This landslide would have produced a sediment pulse at the time it occurred and may continue to be a minor source of sediment at high flows.

An old connector road crossed Chapman Creek at 10.9 km (Field Stop #3). The bridge has been removed, the road has been abandoned and is becoming overgrown. The road on the east side is mainly on private land. A section of this road descends the escarpment of the inner trench, crossing steep unstable slopes in till with inclusions of glaciolacustrine deposits. Some cuts and fills on this road are still unstable (heli site C-09, Field Stop #44) and are active sediment sources. The stream is eroding the toe of the slope here.

The road at the upper drainage divide on the west side of Chapman Creek (Field Stops #30 and #31) has been deactivated (but not debuilt) with structures removed, and is becoming overgrown. There is minimal sediment production from this road.

There are few active roads in Chapman watershed at present and most of those are on the east side of the watershed. The Sechelt-Wilson FSR, an active road with regular traffic that accesses the Dakota Ridge recreation area, twice crosses the tributary that joins Chapman Creek at 9.2 km (which is 1.7 km above the intake). The crossings are near the 6 km and 8 km posts on this road (Field Stops #45 and #46). The structures (corrugated steel pipes) at both crossings are in good condition and adequately armoured. However, at both locations the ditches discharge flow directly into the stream. There are no sediment control measures in the ditches at either location. There was considerable flow in the ditch entering the stream at the 6 km crossing at the time of our site visit. Traffic on this road during wet weather is likely to generate muddy runoff that would carry down this tributary to Chapman Creek.

Stream escarpments and channel banks

Heli sites C-02, C-07, C-08, C-09, C-10 show sites observed during the helicopter reconnaissance of active bank erosion and instability where Chapman Creek impinges on the escarpments of the inner trench. These eroding and slumping escarpments are chronic sediment sources, directly exposed to erosive stream flow.

Heli sites C-02, C-07, C-08 along Chapman Creek are above 16 km; and heli sites C-03, C-04, C-05 are in the tributary that joins at 19 km. Heli sites C-09 and C-10 are below 16 km. From the sites observed, it would appear that these sites occur throughout the length of the inner trench; but Carson 2000 found that the greatest contribution to turbidity is below 16 km. It would seem that either there are a greater number of these sites below 16 km than above 16 km; or that the surficial deposits in the sites below 16 km are finer textured and would yield higher suspended sediment when eroded. The fine-textured till and glaciolacustrine deposits observed at Field Stop #44 suggest the latter.

To be certain, identifying all sites along the channel would require walking the channel, as it is difficult to see these sites any other way. Tree cover limits the ability to see these sites even by helicopter. However, there is unlikely to be any practicable remedy for eroding stream escarpments other than to treat turbidity at the intake.

Summary of sediment sources in Chapman Creek watershed

- The rate of natural landslides was greatly accelerated by historic logging and road building on steep slopes.
- The logging-related landslides are largely revegetated by advanced second growth forests or mitigated by road deactivation.
- There continue to be intermittent landslides and minor erosion events from deactivated roads that are not yet revegetated.
- Landslides (natural or development-related) connected to stream channels cause large sediment events at the time of occurrence, and may thereafter for a number of years continue to be progressively diminishing sediment sources from erosion of the unvegetated landslide surface and retrogression of the headscarps.

- There are several destabilized gullies that are not yet revegetated and are probably sediment sources during peak flows.
- There are numerous sites along the escarpments of the inner trench where bank erosion, undercutting and slumping are occurring. These are chronic sources that are directly connected to the Chapman Creek channel and are the most significant on-going sources of turbidity in the watershed. In the upper watershed, above 16 km, the sites observed were in till. Carson's (2000) findings suggest that either there are many more of these eroding escarpments below 16 km; or more likely, that the lower sites are in finer textured deposits which would have a higher yield of fine sediment when eroded. There is unlikely to be any practicable remedy for these sites other than to treat turbidity at the intake.
- Active haul roads connected to streams have the potential to cause or contribute to turbidity events when subject to heavy traffic in wet weather. Roads were not found to be significant contributors of sediment in Carson's monitoring program but there were no active haul roads during the monitoring period and therefore the relative importance of turbidity from muddy road runoff could not be evaluated.
- There are potential sediment sources (steep fillslopes, roads with steep grades) on roads that have not been permanently deactivated. The sections of the Sechelt Dakota FSR on the west side of Chapman Creek shown on Figure D-4 have a high likelihood of delivering sediment directly into the Chapman Creek channel if a landslide occurred.

11.2 Gray Creek

Numerous landslides followed logging and road construction in the 1940's and 1950's on the steep valley sidewalls between 2.7 km and 7.3 km. Landslide paths are most prevalent in the lower valley slopes in deep till and lacustrine deposits. The old landslide tracks are now vegetated (e.g., heli site GR-05) and the rate of landslides has decreased substantially with the advanced second growth on these slopes.

As with Chapman Creek, bank erosion, undercutting and slumping are occurring in places at the escarpments along the inner trenches (e.g., heli sites GR-03 and GR-04), although there appear to be fewer of these sites than in Chapman Creek. The small landslide into the channel at heli site GR-03 appears recent; there are older ones in the escarpment nearby. The landslides at GR-04 might be related to road fills or road drainage from the Gray Creek FSR directly upslope. Carson 2000 reports that turbidity was monitored less in Gray Creek than in Chapman Creek; of the data available, turbidity readings were typically lower in Gray Creek.

Unstable gully sidewalls are sediment sources in some of the tributary drainages (heli sites GR-01 and GR-02). Heli site GR-02 is a recent landslide in an older landslide path that appears to have originated from a road fill (the road has since been debuilt). The new landslide initiates at the break in slope at the top of the stream escarpment.

<u>Roads</u>
The Gray Creek FSR was not active for industrial use at the time of this assessment but receives regular vehicle use as it is the access to Tetrahedron Provincial Park. There are steep fills along much of the main valley from 2.7 km to 7.3 km and many old landslide paths (now vegetated) from

this road. One section crosses the top of a rock bluff. Over-steepened fills directly above the Gray Creek channel were also observed at Field Stop #38, and are apparent at heli site GR-04. There are also short sections of over-steepened fills exhibiting tension cracks in places along the roads on the north side of Gray Creek in the upper watershed (Field Stops #13 and #14; Figure D-3, Appendix D).

There are minor erosion sites on inactive roads that have been cross-ditched but with structures left in place, e.g. collapsing fill over culvert at Field Stop #40.

<u>Summary of sediment sources in Gray Creek watershed</u>

- Natural landslides occur intermittently, mainly on steep slopes in till and glaciolacustrine deposits of the lower valley slopes between 2.7 km and 7.3 km.
- The rate of landslides was greatly accelerated by logging and road construction in the 1940's and 1950's, mainly in the steep valley slopes between 2.7 km and 7.3 km. These landslides are largely revegetated and the rate of landslides has declined to a more natural level.
- In the Gray Creek channel there are chronic sediment sources in eroding or slumping channel banks, and occasional small landslides in steep stream escarpments.
- There are unstable and eroding gully sidewalls in some tributary streams that are sediment sources during peak flows.
- There are minor sediment sources on existing roads, particularly at stream crossings that have not been deactivated.
- Potential landslide hazards at over-steepened road fills were noted along Gray Creek FSR and on the main access road on the north side of Gray Creek in the upper watershed.

12. STREAMS

In this assessment, stream channels are categorized into three physical types based on characteristics relevant to forest management of coastal streams. The main distinction between the types is susceptibility to channel bank and bed erosion and channel disturbance. See descriptions of channel types in Appendix E. Maps displaying stream channel types, stream gradients and streams on fans are in Appendix E.

"Alluvial" streams as used here are low-gradient streams with flanking floodplains, even though the extent of the floodplain beyond the active channel may be quite narrow. "Semi-alluvial" streams are low-gradient streams in confined channels with fluvially transported bed material but no flanking floodplain beyond the seasonally active channel. "Non-alluvial streams" are those with primarily bedrock or boulder dominated channels and no flanking floodplain. Channel types were identified mainly by stream gradient and terrain characteristics as visible on imagery; and checked at field stops. Confined low gradient streams that were not clearly visible on imagery or seen at the field stops were classified as semi-alluvial based on gradient; some of these may actually be non-alluvial channels.

Clearcutting in an active or "wet" floodplain can lead to channel instability which, in large streams, can take many years to stabilize. A "wet" floodplain is the portion of a floodplain that experiences overbank flow or flow in flood channels frequently, typically within 5 years. Figure E-5 shows alluvial stream reaches that may have flanking floodplains.

Distribution of channel types are summarized in Table 3. Many small streams are not mapped. The main valleys of both Gray and Chapman Creek have mature second growth forests and the channels are stable. The characteristics and condition of the Gray and Chapman mainstem channels are described in Sections 7.3 and 7.4.

Table 3 – distribution of stream channel types

Watershed unit	Length of channel type for mapped streams, km				
	Alluvial	Semi-alluvial	Wetland	Non-alluvial	Total
Chapman CWS	16.9	15.2	0.9	88.3	121.2
Edwards	0.2	0.1	0.2	0.1	0.6
Gray CWS	15.2	8.6	2.9	37.5	64.2

Some tributaries have entrenched reaches with eroding or slumping sites in gully sidewalls and are locally aggraded, contributing sediment pulses to the stream system (heli site GR-01 and GR-02 at 7.3 km tributary in Gray Creek; heli site C-03 and C-04 at 19.4 km tributary Chapman Creek).

13. RISK ZONES

The risk zones identified in this project show the potential for landslides to cause turbidity events at the SCRD intakes in Chapman and Gray Creeks. The purpose of these risk zones is to inform SCCF forest planning and risk management in the community watersheds. Maps showing terrain stability hazard classes and risk zones are in Appendix G.

Delineation of risk zones for harvesting made use of the following planning-level information:

- Thomson's 1987 landslide inventory in Chapman watershed, with the addition of more recent events that were noted in this project
- Landslides identified from 2003 airphotos and the orthos in Gray watershed
- Slope mapping generated from LIDAR data
- Bare-earth images generated from LIDAR data
- Terrain mapping with terrain classification, stability hazard classes and sediment delivery potential attributes, completed by D. Maynard, P. Geo.

In addition to the risk from landslides associated with forest removal, forest development planning needs to consider risk associated with roads needed for access. Maps showing road stability hazard sections (identified from planning-level assessment) are in Appendix D. As discussed in Section 11.1, the Sechelt-Dakota FSR on the west side of Chapman Creek, currently inactive, is a high risk road for sediment delivery to Chapman Creek. While considerable work has been done to improve fillslope stability (by means of stacked rock fills) and cutslope stability (by means of rock buttressing), this road continues to have sections with significant stability hazards, many of which have high potential for sediment delivery to Chapman Creek. As well, if the road were to be used for active hauling, there is a high potential for muddy runoff to enter Chapman Creek via drainage courses that cross the road.

Gray Creek FSR also has sections with stability hazards that have high potential for sediment delivery to Gray Creek. However, this road receives on-going public traffic for access to Tetrahedron Provincial Park and although it currently has wilderness (unmaintained) status, is essentially a permanent active road.

14. RECOMMENDED MANAGEMENT PRACTICES IN COMMUNITY WATERSHEDS

The main objective for forest management in the community watersheds is to not cause turbidity events that could affect water quality at the SCRD intakes. The greatest potential cause of turbidity events associated with forest development is landslides. Carson (2000) was unable to evaluate the relative importance of turbidity from muddy road runoff because there was no active hauling at the time of sampling. The suspended sediment likely to enter Chapman Creek from muddy road runoff or ditch erosion may be small relative to the sediment recruited from eroding channel banks, but could accelerate turbidity events especially in rainstorms that happen during seasonally low flows.

The maps in Appendices D, E and G are meant to assist with forest management of roads and streams.

14.1 Roads

At the present time, SCPI does not have active road permits in either Gray or Chapman watersheds. Road permits for active roads are held by others including SCRD. D. Lasser, RPF, advises that SCPI obtains road permits as needed for specific forest development activities.

These recommendations are for the purpose of controlling sediment from roads that could cause turbidity, from landslides, ditchline erosion or muddy runoff from hauling.

<u>Road inspections</u>

- When a road is under an active road permit, SCCF should carry out and document inspections, with particular attention to road sections connected or potentially connected by surface flow to existing streams. Inspections should focus on potential stability hazards, roads with steep grades, roads across fans, condition of drainage structures and sediment control in ditchlines.

<u>Design and construction of new roads</u>

- Road locations closely adjacent to streams should be avoided to the extent practicable. It is highly desirable to provide buffers between roads and streams in order to capture road-generated flow before it reaches a stream.

- Road design should incorporate measures to control erosion and sediment transport. Examples include:
  - Planning vertical alignments at stream crossings to avoid muddy road surface runoff draining toward and into streams

- Adequate cross-drain culverts so that ditch water is discharged onto the forest floor and not into streams
- Armouring around culvert inlets and outlets to prevent fill erosion
- Seeding of cutslopes, fillslopes and ditchlines in fine-textured soils to establish good grass cover
- Applying clean surface ballast to roads close to streams or at stream crossings
- Use of check dams, catchbasins and other measures to limit ditch erosion and to settle or filter muddy runoff

- Road construction should be planned to take place outside of the normal wet season (October to March) as much as possible. Actual weather conditions vary from year to year, and climate trends show that dry weather is more frequently continuing into October. When dry weather persists into the autumn, activities could continue; but at the onset of wet weather, road construction should be curtailed for the season, and sediment control measures implemented to protect against erosion over the winter.

- Wet weather can occur through the spring and summer months as well. Road construction plans should include sediment management to control sediment during construction.

<u>Road maintenance for roads under permit</u>

- A water quality concern with local bedrock is the occasional occurrence of pyrites in the different granodiorites (noticeable as rust coated rocks in the rock quarries). Pyrites can generate acid drainage, which, along with their associated heavy metals, can be a significant issue for water treatment. Use of rock containing pyrites for road surfacing should be avoided for road sections where road drainage may reach streams. [Personal communication B. Carson Nov 28, 2013.]

- Except for emergency repairs, culvert replacements at stream crossings should be done when weather is sufficiently dry that the stream is either dry or at seasonally low levels.

- Grading is most effectively done when road surfaces are damp, such as during or following a light rain. However, grading should not be done when conditions are so wet that muddy runoff is leaving the road surface and flowing in ditches. Grading should not be done if heavy rain is forecast.

- Grader operators should maintain crowned roads wherever road conditions permit and avoid leaving continuous berms that concentrate road runoff towards streams.

- Clean ditches and sumps in summer, and seed ditchlines and sumps promptly so that grass cover is well established before the onset of fall rains. Do not clean ditches in the wet season unless urgently needed to clear blockages and restore drainage.

- Avoid placing ditchspoil on the road shoulder on steep slopes, which will surcharge the shoulder and could cause instability. This is particularly important for old roads with steep fills.

- For roads not in active use, either drainage structures should be removed or "fail-safed" with cross-ditches; or the roads should receive frequent inspections.

Hauling

- Active forest roads subject to regular traffic during wet weather have the potential to generate many times the amount of fine sediment (turbidity) than inactive roads. Normal road surface erosion under traffic is chronic and cumulative. Every small site adds to the problem and can result in deteriorated water quality. A sediment control plan should be completed for any road placed under permit for the purpose of industrial use, before heavy traffic commences.

- If the Sechelt-Dakota FSR (west) was to be re-opened for active use, muddy runoff could enter Chapman Creek via the tributary creeks and ditchwater culverts. Before this road is considered for active industrial use, a detailed geotechnical assessment should be done of the road section proposed for use including examination of fillslopes, cutslopes and drainage onto slopes below the road. A sediment control plan should be in place before any remedial work commences or before the road is used for industrial traffic.

- In addition to the sediment management measures described above for road construction and maintenance, it is recommended to cease hauling when conditions are sufficiently wet that muddy runoff is leaving the road surface and flowing in ditches, unless sufficient sediment control measures are in place so that muddy ditch water does not enter streams.

14.2 Terrain stability management

Terrain stability assessments (TSAs) should be done by qualified registered professionals and should be carried out according to the APEGBC/ABCFP "Guidelines for professional services in the forest sector – terrain stability assessments" (2010) or its subsequent revisions.

The terrain and landslide information in this project should be made available to terrain specialists undertaking TSAs in these watersheds.

TSAs should be undertaken for proposed harvesting or road construction in moderate or higher hazard terrain (Stability Class 3, 4 or 5) where there is a potential for a landslide to enter a stream that could conduct turbid water to the Gray or Chapman mainstems. TSAs should address the hazard of post-harvesting open-slope landslides; and if roads are proposed, should address potential landslides from roads and from drainage onto slopes below roads. TSAs for proposed cutblocks should address the potential effects of forest removal on stability and the effects on terrain stability of adjacent slopes if boundary-edge windthrow was to occur. TSAs should estimate the likelihood of landslides occurring (hazard) and the size ranges of possible landslides; and should describe the probable paths that landslides could take, down to the terminus (geomorphic extent).

14.3 Streams, fans and floodplains

Before harvesting next to alluvial streams, the extent of the wet floodplain should be identified, and harvest strategies selected that will not destabilize the floodplain or cause increased channel bank erosion. Clearcutting on wet floodplains should be avoided. Windthrow assessments should be done for cutblocks bordering alluvial streams, and management strategies employed so that riparian functions are not lost due to windthrow. The alluvial reaches and floodplains at 7.8 – 9.6 km and 14.9 – 15.6 km in Gray Creek watershed are especially sensitive.

Similarly, clearcutting the active portion of a fan can cause the fan to destabilize. Roads located across a fan without regard to fan behaviour can result in long-term road maintenance problems and contribute to fan instability. There are several small fans in the Gray and Chapman community watersheds; Figure E-5, Appendix E shows streams on fans. The geomorphically active zones of fans should be delineated before logging or road building on fans.

If seasonal or perennial S4 or S6 streams are not addressed by buffer requirements in a Forest Stewardship Plan, then the following should apply. Cross-stream yarding should be avoided; and, subject to windthrow considerations, these streams should have buffers and machine-free zones of minimum 5 m width. Perennial streams are those that flow year round except for the driest parts of the summer; seasonal streams are those that flow continuously for at least 2 months.

14.4 Windthrow management

These watersheds are exposed to storm winds that can cause windthrow. Windthrow assessments should be completed for proposed harvest areas next to streams, or near breaks to steep terrain. Harvest strategies should include windthrow management strategies where needed to protect terrain stability and long-term riparian functions. Windthrow assessments should be carried out by qualified professionals with expertise in this field.

15. WATERSHED MONITORING AND NEXT ASSESSMENT

SCPI is advised to monitor and record the following on the SCCF tenure in Chapman and Gray watersheds:

- Any new landslides, and waterbodies affected by them
- Windthrow, particularly along any new cutblock boundaries adjacent to streams or at breaks to stream terrain
- Any stability or erosion concerns identified on roads under permit, and remedial work undertaken to address them
- The effectiveness of sediment management plans prepared for active roads that are placed under permit to SCPI. The FREP water quality protocol is an example of a suitable monitoring protocol.

Because of limited road access, especially in Chapman watershed, a helicopter overflight once a year, or after extreme storms, may be the most effective way to undertake watershed inspections. Watershed conditions should be reassessed at intervals of approximately 10 years, or sooner if extreme storms have caused significant change. New imagery at approximately 10 year intervals would help to track landslide occurrence and trends in watershed condition.

16. USE AND LIMITATIONS

This assessment has been undertaken in accordance with generally accepted methods of watershed assessment for forestlands in coastal British Columbia. No other undertaking is given. No portion of this report may be extracted and used independently; it is meant to be read and used in its entirety.

This report is for the sole use of Sechelt Community Projects Inc. for the purpose of forest management and harvest planning in the Sunshine Coast Community Forest tenures in Gray Creek and Chapman Creek watersheds. It is not for use by any other party or for any other purpose.

Glynnis Horel, P. Eng.

PROFESSIONAL PROVINCE OF G. M. HOREL BRITISH COLUMBIA ENGINEER

Citations and other information sources

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Appendix A

Trends in Precipitation and Runoff

A. Chapman, P. Geo.

Chapman and Grey Creek – Patterns in Precipitation and Runoff

Report to: Dave Lasser, RPF
Operations Manager
Sunshine Coast Community Forest
Sechelt, BC

Prepared by: Allan Chapman, MSc, PGeo
Chapman Geoscience Ltd.
Victoria, BC

Date: October 31, 2013

A. Precipitation:

Annual Precipitation

The Chapman Creek watershed ranges in elevation from sea level to nearly 1,670 metres above sea level, with a watershed drainage area of 6,800 hectares (68.0 km^2). The Grey Creek watershed ranges in elevation from sea level to 1,670 metres above sea level, with a watershed drainage area of 5,890 hectares (58.9 km^2). Annual precipitation increases substantially with elevation, as a result of the orographic effect of the Coast Mountains (Chapman and Reksten, 1991).

The long-term climate record from the Environment Canada climate station Gibsons Gower Point (station ID 1043152) provides a good record of the magnitude and variability of precipitation near sea level. For the 51-year period of 1962-2012, average annual precipitation was 1,332 mm (standard deviation = 199 mm) (Figure A-1). The wettest year in the record was 1968, with 1,695 mm of precipitation, while the driest year was 2002, with only 715 mm of precipitation (due to some missing data in June and September that were back-filled with data from Sechelt, this value is an estimate). The deviation in annual precipitation from one year to the next is shown in Figure A-2. For the 51 years of record, the range was from 27 percent greater than average (in 1968) to 46 percent less than average (in 2002). Most of the precipitation at sea level occurs as rain, with snow occurring only infrequently. At Gibsons Gower Point, about 3.6 percent of the average annual precipitation is associated with snow.

The magnitude of precipitation at sea level does not reflect high elevations in the watersheds. There are no long-term climate records at high elevation to analyze, so high elevation precipitation must be inferred. Chapman and Reksten (1991) suggested annual precipitation of 3,000 mm at high elevations in the Chapman Creek watershed, and a mean annual precipitation across the watershed of about 2,800 mm. The recent development of the Climate Western North America (ClimateWNA) (Wang et. al, 2006), provides better accuracy of precipitation estimates across the watersheds. ClimateWNA is a gridded climate product that interprets monthly and annual climate variables across the landscape, using the PRISM data from Daly et. al., 2002). ClimateWNA provides an estimate of 3,700 for average annual

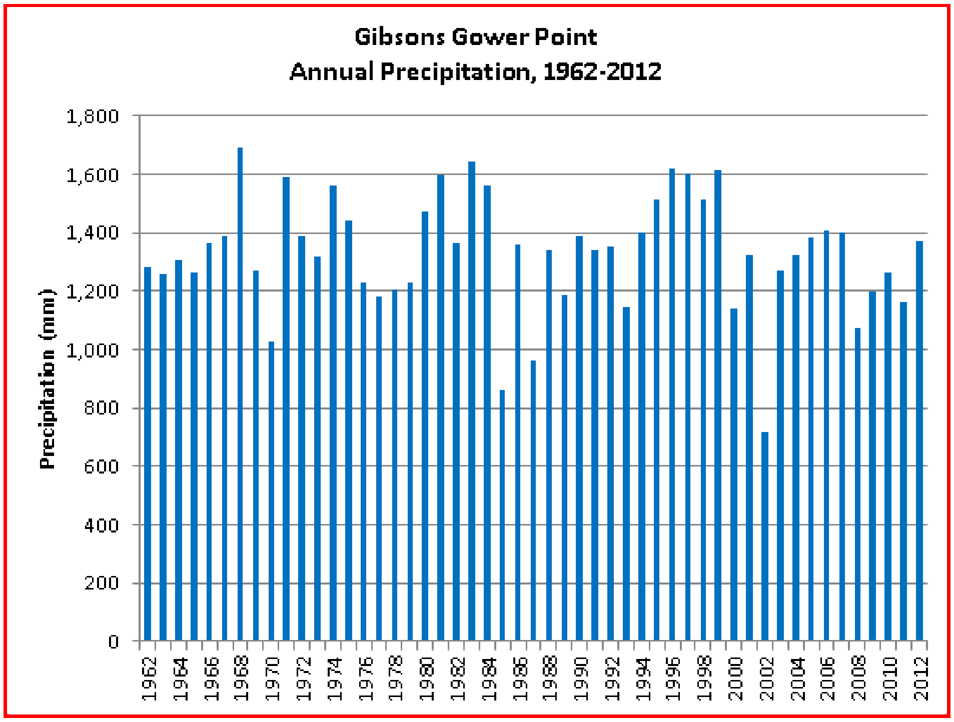

Figure A-1. Annual precipitation at Gibsons Gower Point (1043152), 1962-2012

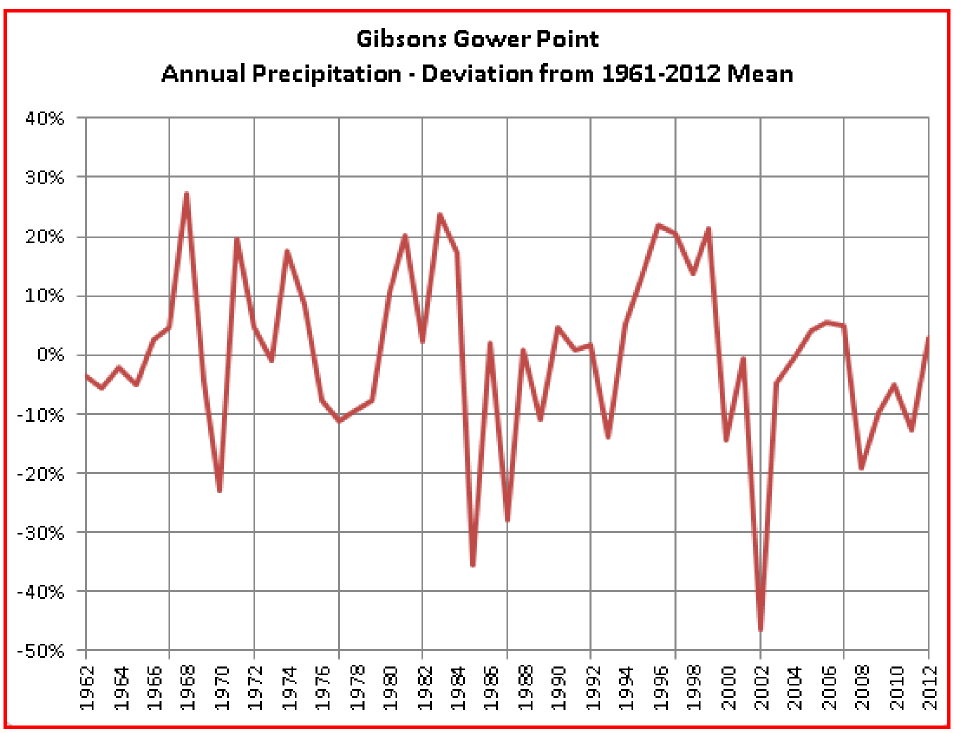

Figure A-2. Deviation in annual precipitation from the mean of 1,332 mm, at Gibsons Gower Point (1043152), 1962-2012.

precipitation at the high elevations of Chapman and Grey creeks, and an average of about 3,300 mm for the entire watershed.

Trends in Annual Precipitation

A number of factors can affect annual precipitation from one year to the next, or over multi-decadal time periods. First, there is natural variability in weather-producing conditions. Much of the precipitation that occurs along the Sunshine Coast is produced from frontal storm systems that arise off the Pacific Ocean, and variability in those storm systems from one year to the next produces most of the variability in annual precipitation. In addition, however, there are climate "forcings" related to ocean temperature that can produce significant effect on local weather along the BC coast. These are the Pacific Decadal Oscillation (PDO), and the En Niño Southern Oscillation (ENSO). The PDO is strongly related to sea surface temperatures in the North Pacific, affecting weather patterns across north-west North America. Shifts in the PDO from "warm/dry" to "cool/wet" occur over multi-decadal periods (20-30 years). ENSO is related to sea surface temperatures in equatorial regions, but with a persistence of only 6-18 months. Two full PDO cycles are evident in the past century: "cool/wet" PDO regimes prevailed from 1890-1924 and again from 1947-1976, while "warm/dry" PDO regimes dominated from 1925-1946 and from 1977 through to the mid-1990's. There is belief that the PDO has shifted back to the cool phase, beginning in the early 2000's. Analysis of temperature, precipitation, snow and streamflow data for British Columbia shows a strong statistical relationship with these climate forcings (MOE 2007). In particular, the PDO has a strong effect on winter snow accumulation and subsequent spring runoff. In addition to the natural variability and the PDO/ENSO climate forcings, general climate warming (i.e., "climate change") over the past few decades is now being reflected in weather patterns across coastal BC.

The annual precipitation record at Gibsons Gower Point over the past 51 years manifests a slight downward trend (Figure A-3). The magnitude of the trend is small, and is not statistically significant (i.e., it is overwhelmed by the inter-annual variability). Figure A-4 shows the annual precipitation in 5-year periods, with the average values of the 5-year periods varying from a high of 1,440 mm (1997-2001) to a low of 1,220 mm (2002-2006).

The Chapman and Grey creek watersheds are believed to be geologically "tight", with no significant loss of water to deep, bedrock groundwater. The greatest loss of water in the watersheds is due to evapotranspiration (the combined transpiration from vegetation, and evaporation from soil and surface water). Annual evapotranspiration for the watersheds is estimated to be approximately 600-650 mm (Thorthwaite, 1964).

Monthly and Seasonal Precipitation

Most of the precipitation that falls on Chapman Creek and Grey Creek occurs during the fall and winter period of October to March. Of the 1,332 mm of annual precipitation measured at Gibsons Gower Point over the 1961-2012 period, 72 percent (966 mm) occurred during October to March (Figure A-5).

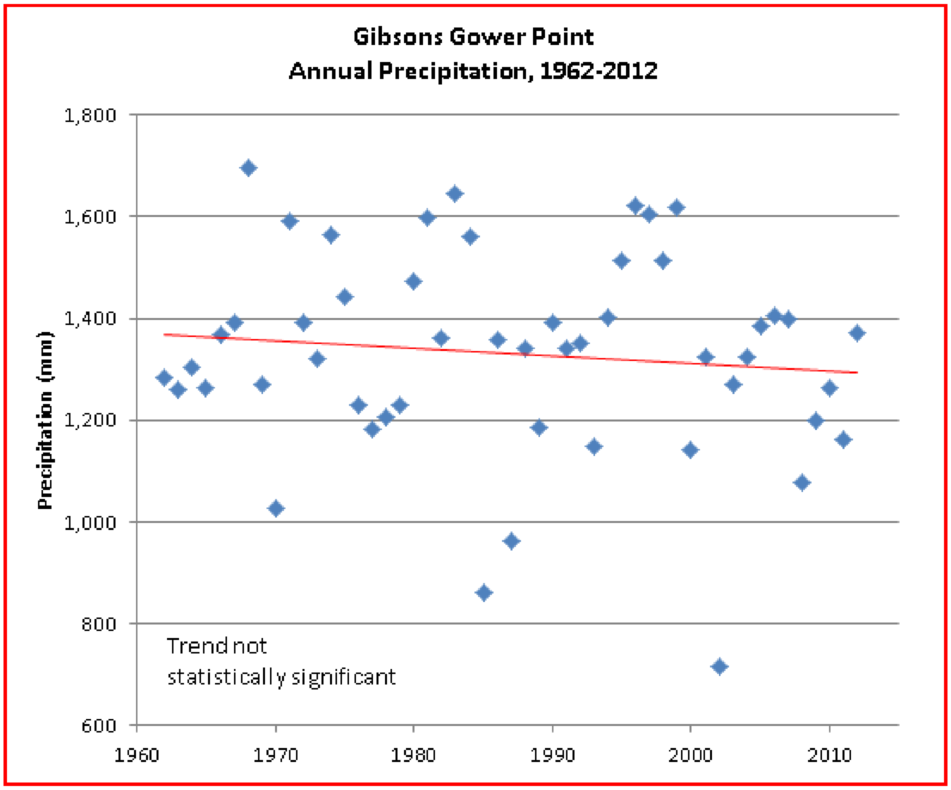

Figure A-3. Trend in annual precipitation at Gibsons Gower Point (1043152).

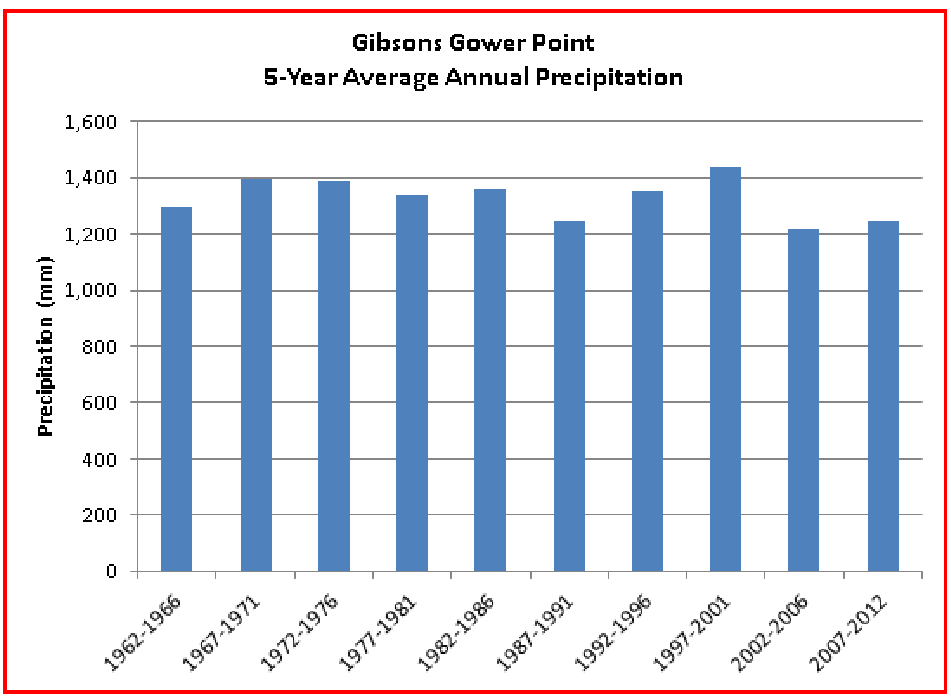

Figure A-4. 5-Year average annual precipitation at Gibsons Gower Point (1043152).

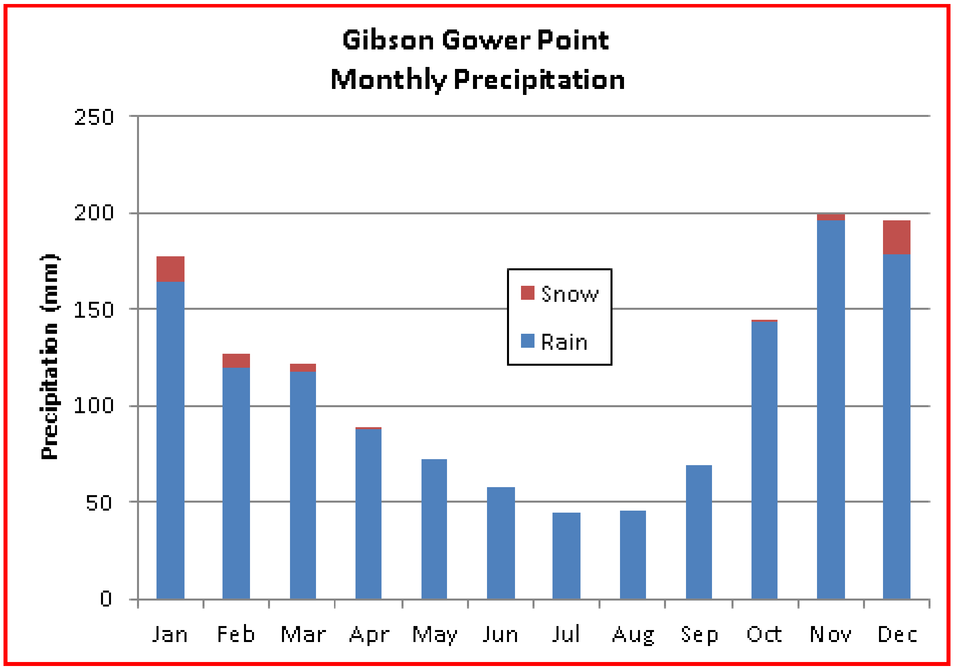

Figure A-5. Monthly precipitation at Gibsons Gower Point (1043152).

November, December and January are the wettest months, with about 200 mm of precipitation each. This precipitation results from frontal storms that develop over the Pacific Ocean and move across the BC coast from the west. Occasionally, a very strong frontal storm system with a connection to a moisture feed in the subtropical western Pacific brings in very large amounts of precipitation over a few days. These storms are referred to as a “Pineapple Express” or an “Atmospheric River” storm, and can produce 100+ mm of rain over 2-3 days at sea level, and 200-300+ mm of rain at high elevation.

At sea level, most of the precipitation occurs as rain. With increased elevation in the watersheds, though, temperatures cool and winter precipitation occurs as snow, allowing a snowpack to accumulate over the winter to melt in the spring. The 300-900 metre elevation zone is typically considered to be a “transient snow zone” (Hudson 2003), with the local snow line rising and falling in response to varying weather conditions. Above approximately 900 metres elevation, a snowpack will typically establish and accumulate during the winter. The BC Ministry of Environment operated a manual snow survey station in the Chapman Creek watershed, at an elevation of 1022 metres (Chapman Creek snow course, 3A22), for the 1993 to 2002 period[1]. At the peak of the winter snow accumulation near April 1st, over the 10 year period, an average of 1,344 mm of water equivalent, with an average snowpack depth of 3.1 metres, had accumulated (Table 1). At higher elevations in the watershed, the winter snow accumulation will be greater. This accumulated winter snow then melts over the spring and early

[1] BC Snow Survey Archive: http://a100.gov.bc.ca/pub/mss/stationlist.do

summer, and is critical to maintaining stream flows in Chapman and Grey creeks during the dry summer period.

Trends in Monthly and Seasonal Precipitation

Analysis of the monthly precipitation record for Gibsons Gower Point for the past 61 years indicates that significant changes in the precipitation regime have occurred, and are likely continuing to occur. Figures A-6, A-7 and A-8 display the 61-year trend in precipitation for the winter (Oct-Mar), spring (Apr-Jun) and summer (Jul-Oct) periods, respectively. For the winter period, there is a slight (but not statistically significant) downward trend in total precipitation. In general, winter precipitation has remained largely unchanged over the past 61 years, except for the natural variability around the average of 966 mm. Spring precipitation, on the other hand, displays an increasing trend (statistically significant). Over the 61-year period, spring precipitation has increased about 28 percent, from an average of about 190 mm to about 240 mm. Summer rainfall, however, exhibits the most profound change, with implications for streamflow and water supply. Over the 61-year period, summer precipitation has declined steadily and substantially, by about 40 percent, from an average of about 198 mm to 119 mm. This reduction in summer precipitation has been documented at other climate stations across the south coast of BC, and is likely to be manifested in decreasing summer streamflow in Chapman and Grey creeks over the same time period.

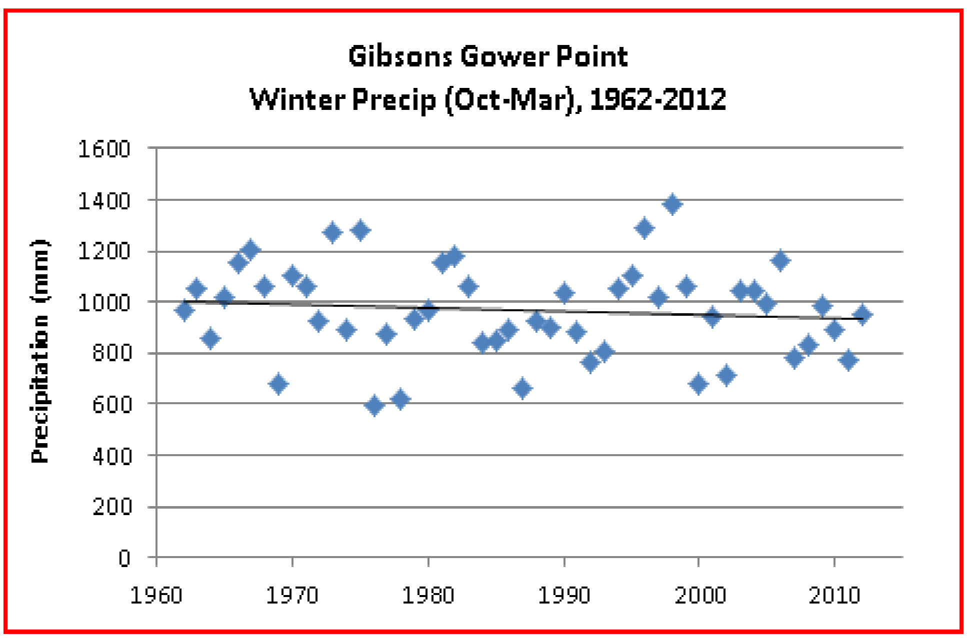

Figure A-6. Trend in winter precipitation at Gibsons Gower Point (1043152).

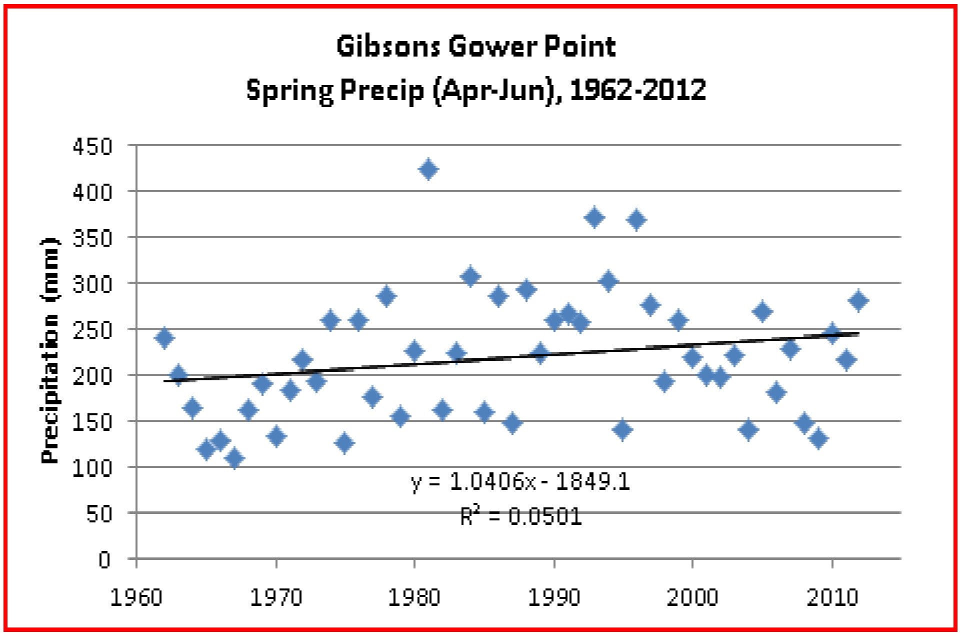

Figure A-7. **Trend in spring precipitation at Gibsons Gower Point (1043152).**

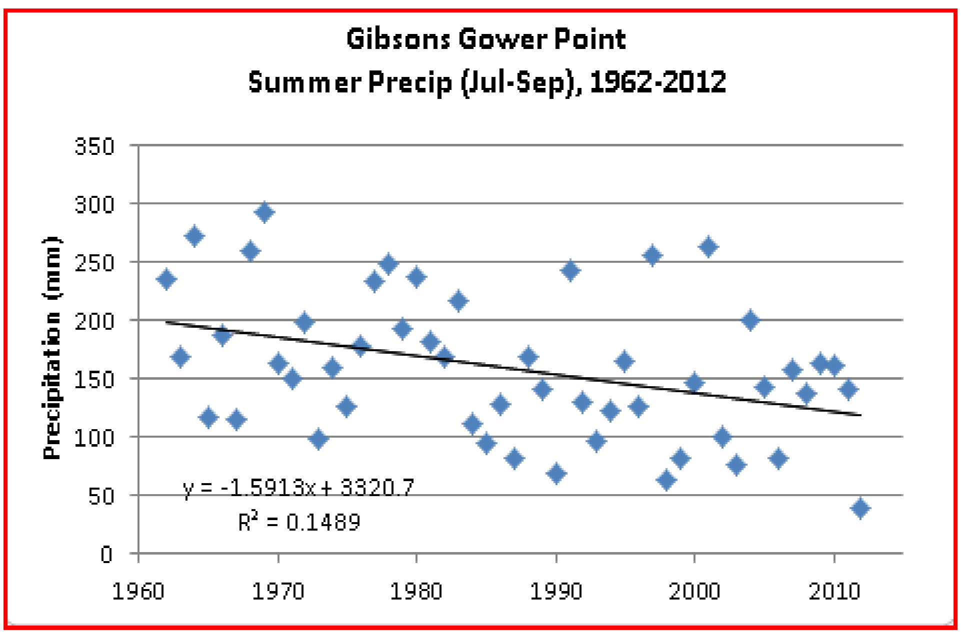

Figure A-8. **Trend in summer precipitation at Gibsons Gower Point (1043152).**

B. Streamflow

Three hydrometric stations operated by the Water Survey of Canada have operated on Chapman Creek over the 1959-2003 period (Table 2). Gauges 08GA046 (1959-1070) and 08GA078 (1993-2003) are both located downstream of the water intake operated by the Sunshine Coast Regional District (SCRD), and so their flow record is affected by water extraction. To produce a composite flow record encompassing the three gauges, the monthly records of gauges 08GA046 and 08GA078 were adjusted and "naturalized". The record for 08GA060 was not adjusted. The adjustments consisted of:

- Adjusting the two gauges by the ratio of their drainage areas to the drainage area of 08GA060;
- Adjusting the two gauges by the maximum possible diversion allowed under the SCRD water licences (Table 3). For 08GA047, for the period of 1959-1970, the adjustment was 0.112 m^3/s, while for 08GA078, for the period of 1993-2003, the adjustment was 0.238 m^3/s. The adjustment assumes that the maximum licensed volume was withdrawn every day. It is not likely to be the case that the maximum volume was withdrawn every day.

Table 2. Water Survey of Canada stream flow gauges.

Gauge #	Gauge Name	Period of Record	Drainage Area (km^2)	Latitude	Longitude	Regulation
08GA046	Chapman Creek near Wilson Creek	1959-1970	71.5	49°26'31" N	123°43'14" W	Regulated - below SCRD diversion
08GA060	Chapman Creek above Sechelt Diversion	1970-1988	64.5	49°28'56" N	123°42'39" W	Natural
08GA078	Chapman Creek below Sechelt Diversion	1993-2003	65.8	49°28'56" N	123°42'39" W	Regulated - below SCRD diversion
08GA047	Roberts Creek at Roberts Creek	1959-2011	32.6	49°25'15" N	123°38'24" W	Regulated

Annual Streamflow

The adjusted annual streamflow record is shown in Figure B-1. Mean annual "naturalized" discharge for the period of gauge record is calculated to be 4.66 m^3/s, with a mean annual runoff of 2,277 mm. The largest measured annual discharge was in 1968 (7.66 m^3/s, 3452 mm), while the lowest annual runoff was in 1985 (2.95 m^3/s, 1441 mm).

There is a slight downward trend in annual runoff for Chapman Creek (Figure B-2). While the trend is not statistically significant (it is small in relation to the natural year-to-year variability in streamflow), it is consistent with declining trend of annual precipitation reported for the Gibsons Gower Point climate data.

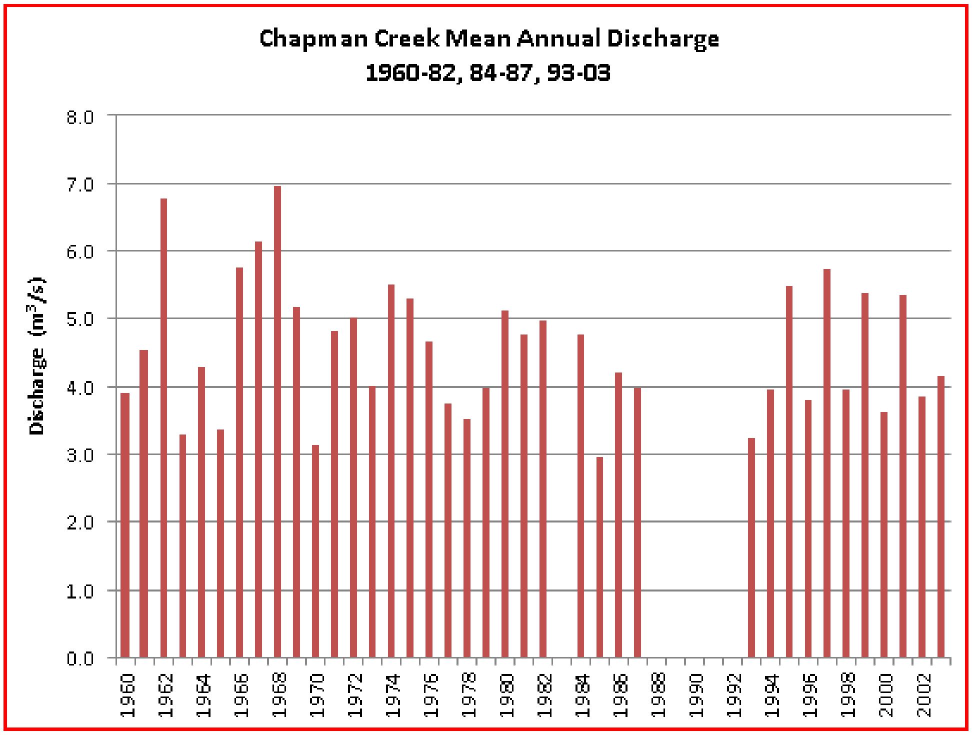

Figure B-1. Mean annual discharge for Chapman Creek measured at three Water Survey of Canada gauges (08GA046 - Chapman Creek near Wilson Creek, 1960-1970; 08GA060 - Chapman Creek above Sechelt Diversion, 1971-1987; 08GA078 - Chapman Creek below Sechelt Diversion, 1993-2003).

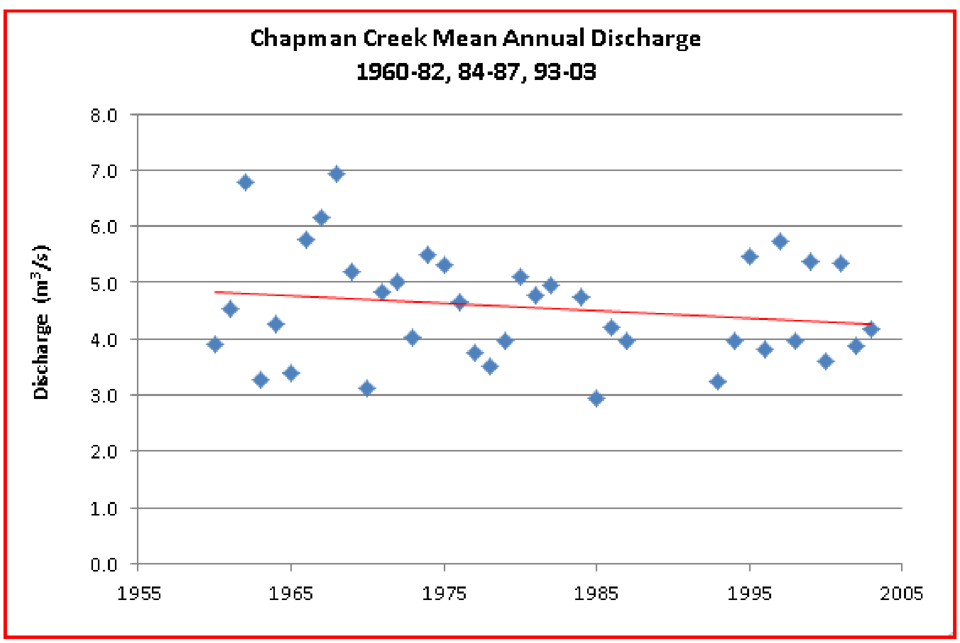

Figure B-2. Trend in mean annual discharge for Chapman Creek.

Using a simple water balance equation of P = Q – Et, where Q = Discharge, P = Precipitation, and Et = Evapotranspiration, mean annual precipitation across the Chapman Creek watershed is estimated to be approximately 2,900 mm (2,280 mm annual runoff + 620 mm Et). This estimate is lower than the watershed-average precipitation of 3,300 mm derived from the ClimateWNA data. The reasons for the difference aren't readily apparent, although it is possible that ClimateWNA may be over-estimating the high elevation precipitation.

Table 3. Licensed water use for Chapman Creek (data from the Ministry of Forests, Lands and Natural Resource Operations).

Licence No	Stream Name	Purpose	Quantity	Units	Licensee	Priority Date
C016599	Chapman Creek	Waterworks Local Auth	8,297	m^3/year	SUNSHINE COAST REGIONAL DISTRICT	19450426
C022345	Chapman Creek	Waterworks Local Auth	33,186	m^3/year	SUNSHINE COAST REGIONAL DISTRICT	19540830
C050724	Chapman Creek	Storage-Non Power	906,608	m^3/year	SUNSHINE COAST REGIONAL DISTRICT	19670713
C065258	Chapman Creek	Waterworks Local Auth	2,986,781	m^3/year	SUNSHINE COAST REGIONAL DISTRICT	19670713
C069217	Chapman Creek	Waterworks Local Auth	497,797	m^3/year	SUNSHINE COAST REGIONAL DISTRICT	19290603
"	Chapman Creek	Waterworks Local Auth	497,797	m^3/year	SUNSHINE COAST REGIONAL DISTRICT	19290603
C069999	Chapman Creek	Waterworks Local Auth	2,986,781	m^3/year	SUNSHINE COAST REGIONAL DISTRICT	19880623
C107474	Chapman Creek	Waterworks Local Auth	995,594	m^3/year	SUNSHINE COAST REGIONAL DISTRICT	19670713
C114222	Chapman Creek	Conserv.-Construct.Works	0.170	m^3/s	ENVIRONMENT MINISTRY OF	19990304
C121468	Chapman Creek	Irrigation	12,335	m^3/year	CANADIAN FOREST PRODUCTS LTD	19700730
C129269	Chapman Creek	Ponds	0.283	m^3/s	SUNSHINE COAST SALMONID ENHANCEMENT SOC.	19840526

Monthly Streamflow

Average monthly runoff is shown on Figure B-3. The highest average monthly runoff occurs in May and June, as a result of spring snowmelt. Although the spring snowmelt freshet produces the highest average monthly runoff, on occasion large fall and winter rainstorms can produce very substantial runoff volumes. These storms are the large "Pineapple Express" or Atmospheric River" frontal storms, that occur every few years. The largest monthly runoff during the period of record occurred in October 1962.

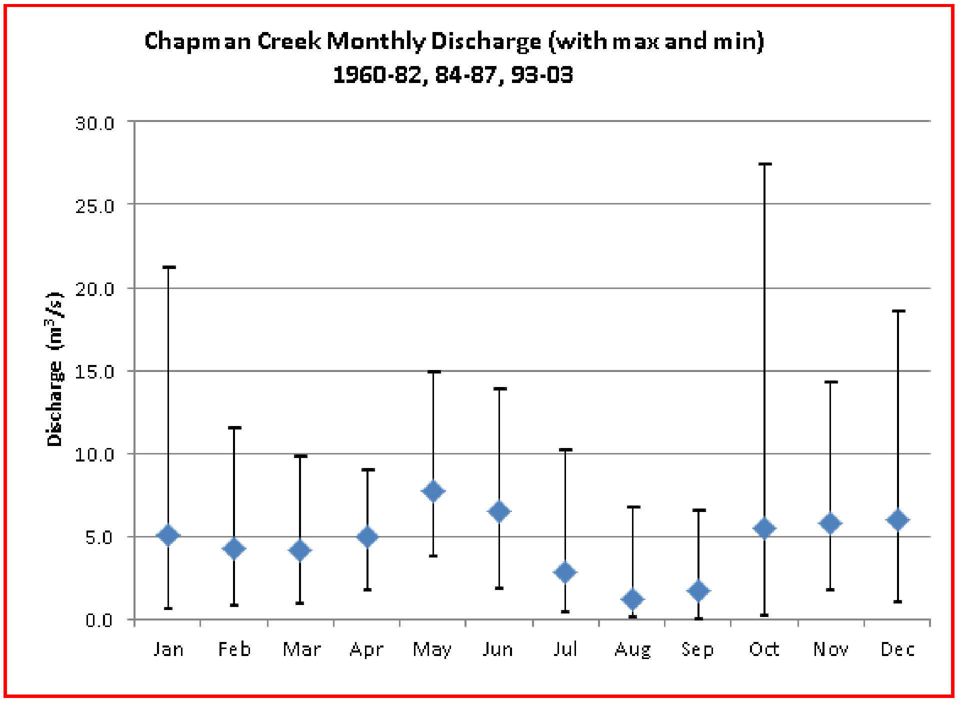

Figure B-3. Average monthly runoff (with maximum and minimum of record) for Chapman Creek.

The lowest average monthly runoff typically occurs in August (average = 1.20 m^3/s) during the dry summer period. Summer "droughts" can, on occasion, persist into the autumn period, with very low stream flows lasting through October. The Sunshine Coast Regional District stores water in Chapman Lake and Edward Lake, located in the upper Chapman Creek watershed. Water is released from the lakes during the summer and fall low flow season, when needed, to maintain sufficient water for the municipal water supply. Information on the quantity and timing of water releases from the two lakes is not available. However, the water releases will be reflected in the discharge record at the flow gauges.

There is a total licenced water demand of about 0.691 m3/s on Chapman Creek (0.238 m3/s for the Sunshine Coast Regional District water supply – this is considered a "consumptive" use; and a further 0.453 m3/s licensed to the Ministry of Environment and Sunshine Coast Salmonid Enhancement Society for instream "non-consumptive" uses) (Table 3). The SCRD waterworks licenses have priority (as determined by the date of the licence) over the MoE and salmon enhancement licences. In 26 of 42 years of record (62 percent), the recorded discharge in August would not have been sufficient to meet the full licenced demand, even with the releases of water from Chapman and Edward lakes[2,3]. Over the

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[2] The actual volumes of stored water that has been released from the lakes over the period of stream flow record was not evaluated.

[3] It is likely that the volume of water actually withdrawn from Chapman Creek under the SCRD water licences was less than the potential maximum approved withdrawal in some years.

1993 to 2003 period, the maximum SCRD withdrawals would consume 50 percent or greater of the discharge in 50 percent of the years.

The adjusted and "naturalized" stream flow record produced from the composite Chapman Creek gauges is not amenable to showing trends on monthly streamflow over time. However, Roberts Creek (WSC gauge 08GA047), located close to Chapman Creek and subject to similar climate and hydrology conditions, has a good long-term flow record (1960-2011) and is useful for regional trend analysis. Similar to Chapman Creek, the Roberts Creek flow record shows a slight decline in annual runoff (Figure B-4). It also shows a slight decline in winter (Oct-Mar) runoff (Figure B-5). However, neither of the trends in annual or winter runoff is statistically significant. Roberts Creek, on the other hand, does manifest a substantial and statistically significant decrease in summer runoff (Jul-Sep) (Figure B-6). Summer discharge has decreased about 35 percent, from 0.240 m^3/s in 1960 to about 0.175 m^3/s in 2011, on average. It is possible that water extraction from Roberts Creek has a small effect on summer stream flow reduction over time, but it does not appear to be a significant effect. There are currently only five active water licences for Roberts Creek, with a total demand of 12.7 m^3/day (0.0001 m^3/s). The trend in reduced summer runoff over the last few decades is consistent with the trend of reduced summer rainfall, as reflected in the Gibsons Gower Point climate station, and other climate stations across the south coast. These trends are broadly regional in nature, and appear related to changes in summer weather patterns (drier, and possibly warmer), and are expected to be reflected in reduced runoff in Chapman and Grey creeks. Beaulieu and Schreier (2011) document the role of late season snow in maintaining summer discharge at a site on the Sunshine Coast, and comment on the anticipated effect of lower summer discharge as a result of diminished snowpacks due to climate warming.

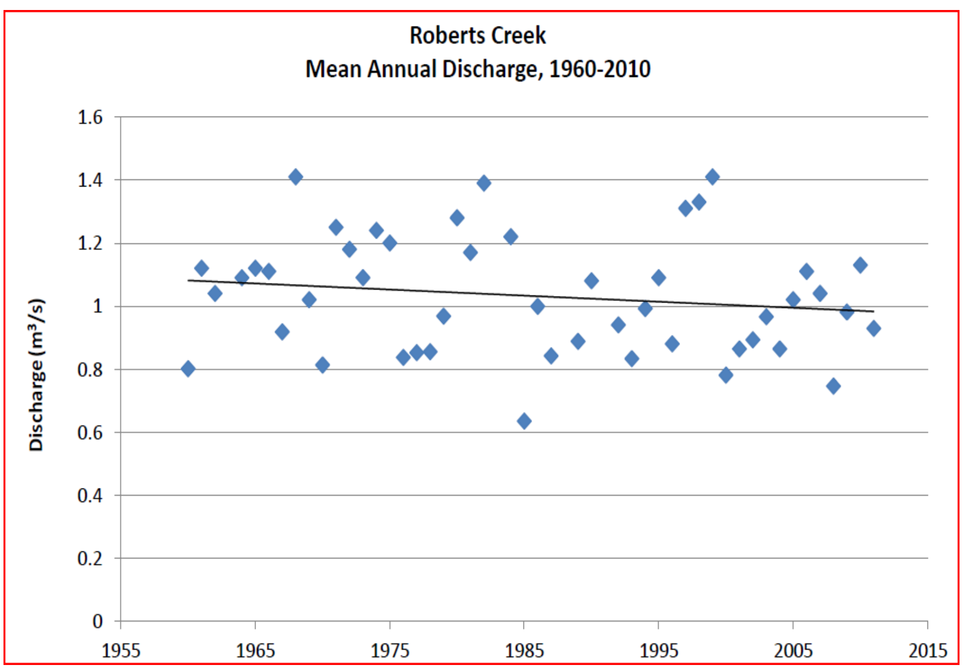

Figure B-4. Mean annual discharge for Roberts Creek (08GA047), with trend line.

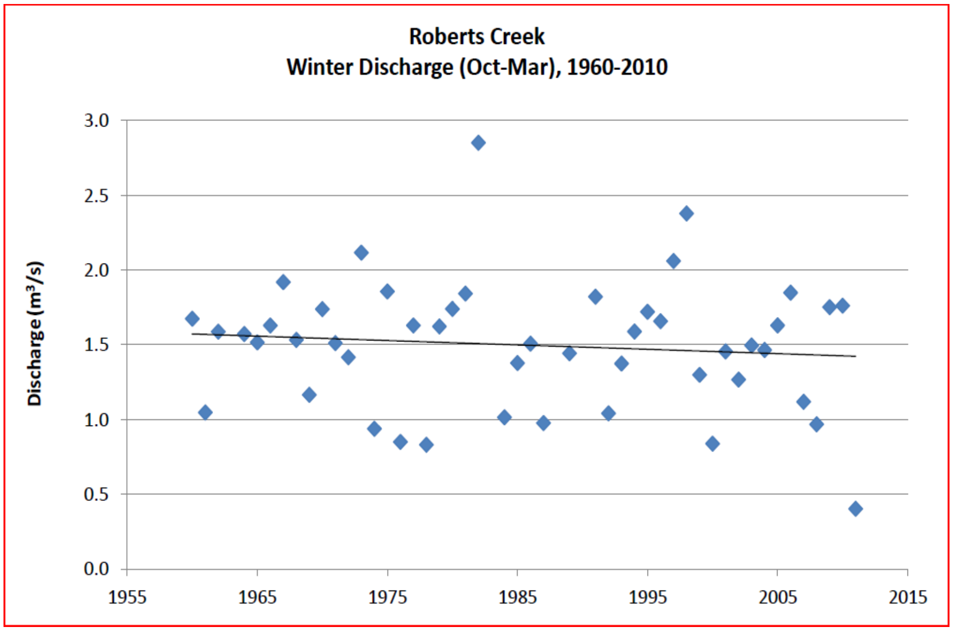

Figure B-5. Trend in winter discharge for Roberts Creek (08GA047).

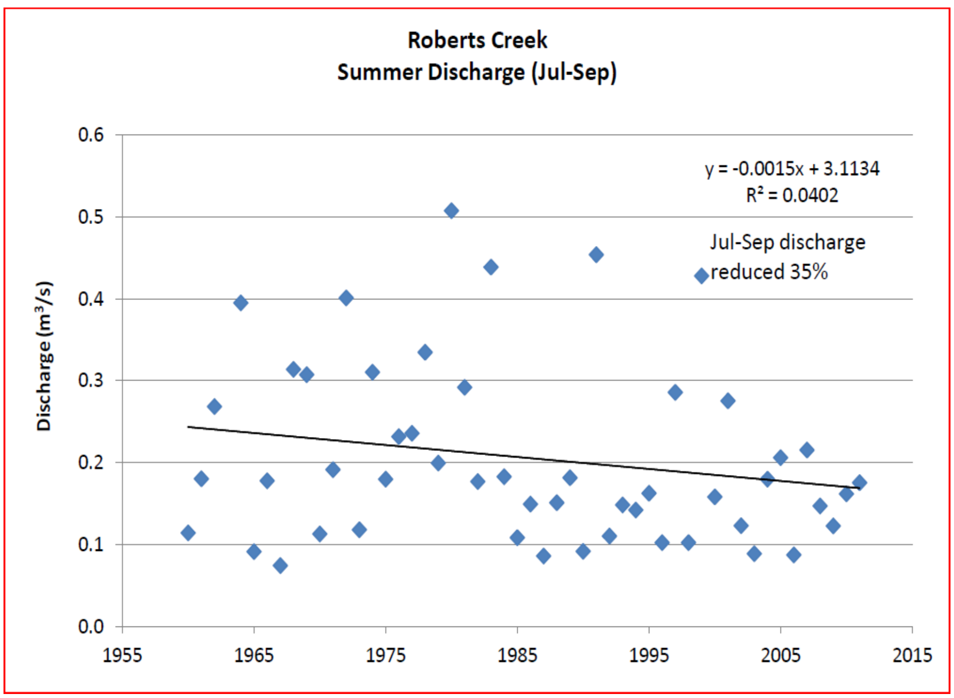

Figure B-6. Trend in summer discharge for Roberts Creek (08GA047). The 35% reduction in average summer runoff over the 52 year period is statistically significant.

Peak Flows

Although the largest volume of monthly runoff from Chapman Creek typically occurs in the spring, from melting snow, the largest daily or instantaneous peak flows occur between October and March, from large, short-lived frontal storms (Figure B-7). Of the 39 years of record from the three Chapman Creek hydrometric gauges, 27 years (69 percent) experienced the largest peak flow of the year in Oct-Dec. Another 10 years (26 percent) experienced the largest peak flow of the year later in the winter, during Jan-Mar. This is a typical coastal peak flow regime, where the peak flows result from intense, short-lived frontal rain and rain-on-snow storms (Grant et al, 2008; Moore and Wondzell, 2005). During the early part of the winter, the mid and high elevation snowpack in coastal watersheds is not yet well developed. "Pineapple Express" or "Atmospheric River" frontal storms bring heavy rainfall and warm air onto the BC coast from sub-tropical locations in the western Pacific. Rainfall of 100+ mm at sea level, and 200-300+ mm at higher elevations, over a two or three day period, is common. The warm air associated with the storm fronts causes the freezing elevation along the coastal mountains to rise, typically from <500 metres elevation to greater than 1000-1500 metres elevation. The warm air, combined with heavy rain, produces significant snowmelt, causing a "rain-on-snow" peak flow event. In the later part of the winter (Jan-Mar), the snowpack is heavier (e.g., usually 2+ metres deep at 1000 metres elevation in Chapman Creek), and is less capable of being melted and generating significant runoff by mid- and late-winter storms, due to the ability of a snowpack to store rain water.

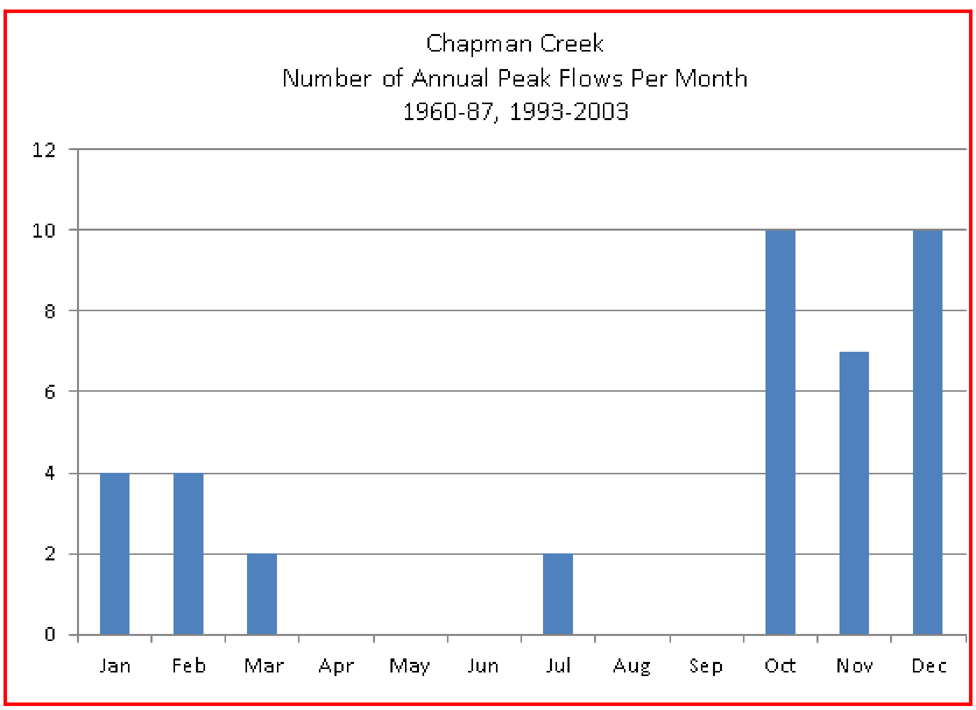

Figure B-7. Number of occurrences of maximum annual peak flow for Chapman Creek, 1969-1987, 1993-2003.

The magnitude of annual peak flows recorded at the three gauges has varied from (Figure B-8):

- Daily average peak flows: 20.8 – 193 m^3/s;
- Instantaneous peak flows: 35.7 – 148 m^3/s (unfortunately, the two largest peak flows measured were in the 1960-1969 period, where instantaneous peak flow values were not recorded).

Given that the peak flow record for Chapman Creek is derived from three stream flow gauges, it is difficult to infer a great deal. However, the record does show that:

- The two largest recorded peak flows occurred in 1962 (193 m^3/s) and 1968 (160 m^3/s);
- For the period 1969-2003, the largest daily average peak flow measured was 91.6 m^3/s (in 1983);
- There appears to be a general trend to decreasing peak flow magnitudes up to 2003.

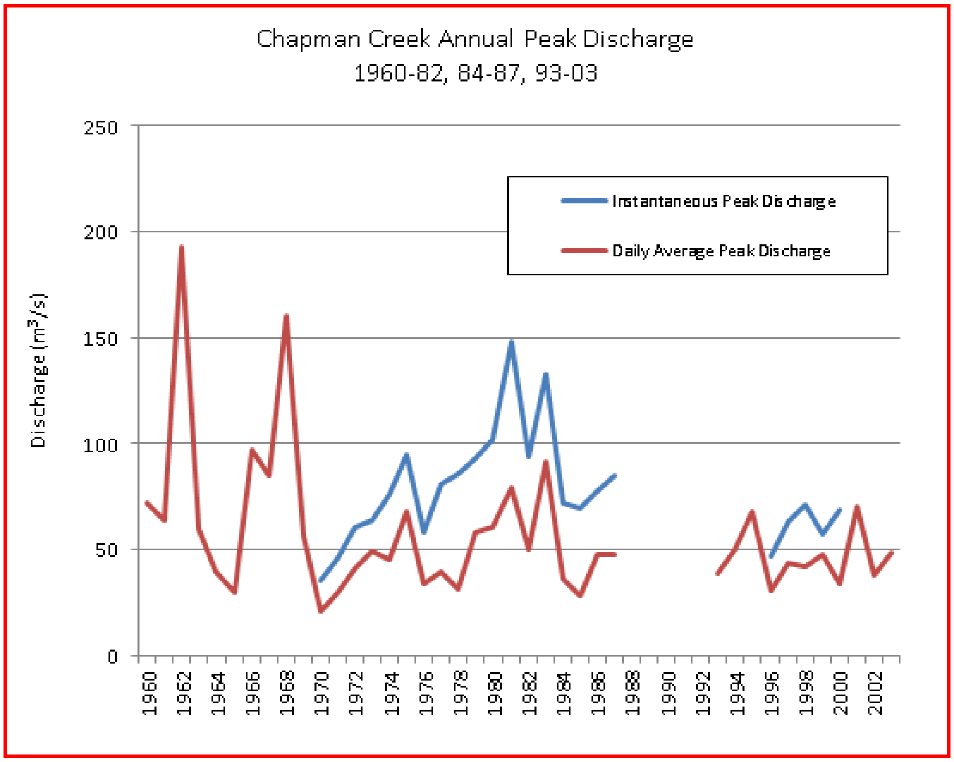

Figure B-8. Daily average and instantaneous peak flows measured on Chapman Creek, 1969-1987, 1993-2003.

Chapman Creek has experienced two annual peak flows in July (in 1972 and 1974), which is somewhat unusual in the flood record for coastal streams. Analysis of the rainfall records indicates that in both cases the high flows resulted from heavy, frontal rainfall. For the 1972 event, Gibsons Gower Point recorded 72 mm of rain over 2 days (July 11-12), which is approximately a 1-in-5 year rain storm (Chapman and Reksten, 1991). For the 1974 event, 100+ mm of rain was recorded in a few days in mid-July, leading up to the peak on July 17, on which a shorter duration but intense rain storm occurred. It is possible in both these years that some snowpack remained in the watershed at high elevation, and the intense, prolonged rain was augmented by snowmelt. Significant late summer mid and high elevation snowpack was observed in Chapman Creek by Brian Carson in 1999, and was noted to be contributing to maintaining summer discharge (Carson, 2000).

Given the paucity and inconsistency of the gauge data, however, it would be incautious to try to infer too much about the peak flow regime of Chapman Creek. The nearby Roberts Creek gauge provides a longer term, and more consistent peak flow record, and may be useful as a comparison. Figure B-9 shows the unit peak discharge (litres per second per km^2 of drainage area) for the three Chapman Creek gauges and for Roberts Creek.

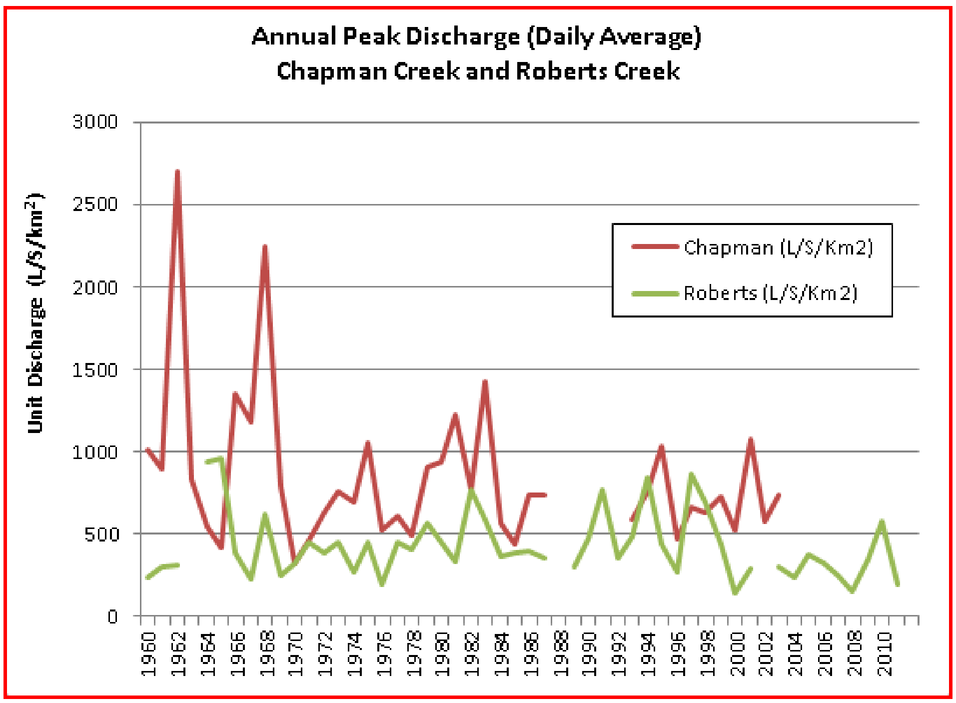

Figure B-9. Comparison of daily average unit peak flows (litres/second km^2) on Chapman Creek and Roberts Creek.

The comparison suggests some things:

- Chapman Creek tended to produce consistently higher peak flows, particularly in the 1960-1987 period;

- Chapman Creek and Roberts Creek produced similar unit peak flows for a short period of overlapping record from 1993-2002;
- There is no significant trend over time in the magnitude of the Roberts Creek peak flows, while the Chapman Creek peak flows demonstrate a significant and substantial downward trend in magnitude over the period of record.

The downward trend over time in measured peaks flows on Chapman Creek, from the early 1960s to 2003 may suggest (somewhat speculatively) that hydrological recovery has been occurring. Various reports have noted the logging history in the watershed. It can be hypothesized that the logging into the 1960s, possibly in the low and mid-elevation rain-on-snow zones, resulted in augmented peak flows, which have recovered over the decades that followed as forest canopy and natural runoff pathways and processes re-established (Grant et. al. 2008).

C. References

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Table 1. Chapman Creek snow course (3A26), 1993-2003, Elevation 1022 metres asl. Latitide 49-35, Longitude 123-34

	01-Feb				01-Mar				01-Apr				01-May			
Year	**Date**	**Snow (cm)**	**Water (mm)**	**Density (%)**	**Date**	**Snow (cm)**	**Water (mm)**	**Density (%)**	**Date**	**Snow (cm)**	**Water (mm)**	**Density (%)**	**Date**	**Snow (cm)**	**Water (mm)**	**Density (%)**
1993	01-Feb	194	722	37	25-Feb	168	732	44	31-Mar	200	862	43	30-Apr	202	946	47
1994	27-Jan	118	546	46	23-Feb	310	1023	33	29-Mar	291	1336	46	28-Apr	232	1176	51
1995	27-Jan	292	1250	43	27-Feb	293	1376	47	31-Mar	339	1660	49	26-Apr	338	1710	51
1996	01-Feb			51	27-Feb	204	662	32	28-Mar	168	704	42	06-May	170	756	44
1997	31-Jan	254	1010	40	01-Mar	254	1010	40	01-Apr	423	1648	39	01-May	328	1506	46
1998	02-Feb	217	862	40	27-Feb	370	1412	38	01-Apr	316	1580	50	01-May	271	1430	53
1999	01-Feb			53	01-Mar			53	01-Apr			53	01-May			53
2000	01-Feb			53	01-Mar			53	31-Mar	406	1728	43	01-May	406	1728	43
2001	01-Feb	406	1728	43	26-Feb	208	790	38	30-Mar	246	958	39	01-May	240	1018	42
2002	04-Feb	278	980	35	26-Feb	317	1274	40	28-Mar	387	1622	42	29-Apr	318	1658	52
2003	31-Jan	146	540	37	01-Mar			37	01-Apr			37	01-May			37
		Snow (cm)	**Water (mm)**	**Density (%)**		**Snow (cm)**	**Water (mm)**	**Density (%)**		**Snow (cm)**	**Water (mm)**	**Density (%)**		**Snow (cm)**	**Water (mm)**	**Density (%)**
Mean		238	954	40		265	1034	39		308	1344	43		278	1325	47
Normal		238	887	37		333	1268	38		344	1498	44		318	1594	50
Max		406	1728	46		370	1412	47		423	1728	50		406	1728	53
Min		118	540	35		168	662	32		168	704	39		170	756	42

Table 2. Water Survey of Canada hydrometric gauges.

Gauge #	Gauge Name	Period of Record	Drainage Area (km^2)	Latitude	Longitude	Regulation
08GA046	Chapman Creek near Wilson Creek	1959-1970	71.5	49°26'31" N	123°43'14" W	Regulated - below SCRD diversion
08GA060	Chapman Creek above Sechelt Diversion	1970-1988	64.5	49°28'56" N	123°42'39" W	Natural
08GA078	Chapman Creek below Sechelt Diversion	1993-2003	65.8	49°28'56" N	123°42'39" W	Regulated - below SCRD diversion
08GA047	Roberts Creek at Roberts Creek	1959-2011	32.6	49°25'15" N	123°38'24" W	Regulated

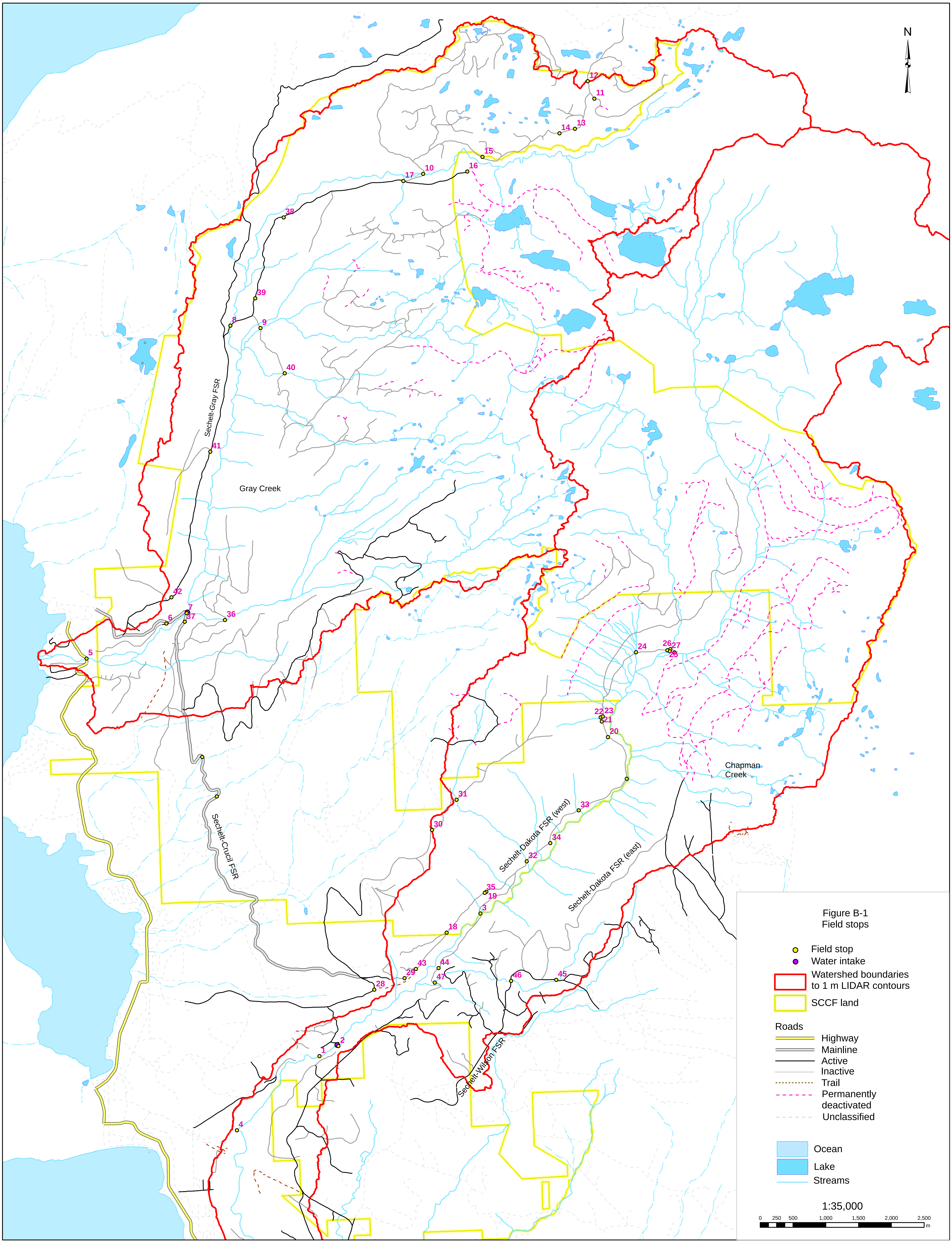
Table 3. Water licences for Chapman Creek (Ministry of Forests, Lands and Natural Resource Operations)

Licence No	WR Map/ Point Code	Stream Name	Purpose	Quantity	Units	Licensee	Priority Date
C016599	92.G.042.1.4 C (PD60277)	Chapman Creek	Waterworks Local Auth	8,297	m^3/year	SUNSHINE COAST REGIONAL DISTRICT	19450426
C022345	92.G.042.1.4 C (PD60277)	Chapman Creek	Waterworks Local Auth	33,186	m^3/year	SUNSHINE COAST REGIONAL DISTRICT	19540830
C050724	92.G.052 AA (PD61040)	Chapman Creek	Storage-Non Power	906,608	m^3/year	SUNSHINE COAST REGIONAL DISTRICT	19670713
C065258	92.G.042.3.4 K (PD45088)	Chapman Creek	Waterworks Local Auth	2,986,781	m^3/year	SUNSHINE COAST REGIONAL DISTRICT	19670713
C069217	92.G.042.3.4 H (PD45090)	Chapman Creek	Waterworks Local Auth	497,797	m^3/year	SUNSHINE COAST REGIONAL DISTRICT	19290603
"	92.G.042.3.4 K (PD45088)	Chapman Creek	Waterworks Local Auth	497,797	m^3/year	SUNSHINE COAST REGIONAL DISTRICT	19290603
C069999	92.G.042.3.4 K (PD45088)	Chapman Creek	Waterworks Local Auth	2,986,781	m^3/year	SUNSHINE COAST REGIONAL DISTRICT	19880623
C107474	92.G.042.3.4 K (PD45088)	Chapman Creek	Waterworks Local Auth	995,594	m^3/year	SUNSHINE COAST REGIONAL DISTRICT	19670713
C114222	92.G.042.1.4 (PD74424)	Chapman Creek	Conserv.-Construct.Works	0.170	m^3/second	ENVIRONMENT MINISTRY OF	19990304
C121468	92.G.042.1.4 D (PD60275)	Chapman Creek	Irrigation	12,335	m^3/year	CANADIAN FOREST PRODUCTS LTD	19700730
C129269	92.G.042.1.4 F (PD60276)	Chapman Creek	Ponds	0.283	m^3/second	SUNSHINE COAST SALMONID ENHANCEMENT SOC.	19840526

Summary		
Sunshine Coast Regional District Waterworks (for 1971-current)	7,508,436	m^3/year
	0.238	m^3/s
Sunshine Coast Regional District Waterworks (for 1959-1970)	3,526,061	m^3/year
	0.112	m^3/s
Canadian Forest Products Ltd.	12,335	m^3/year
	0.000	m^3/s
Ministry of Environment	0.17	m^3/s
Sunshine Coast Salmonid Enhancement	0.283	m^3/s
Total	**0.691**	**m^3/s**

Appendix B

B1 - Field stops
B2 - Heli photo sites


N
Sechelt-Gray FSR
Gray Creek
Chapman Creek
Sechelt-Crucil FSR
Sechelt-Dakota FSR (west)
Sechelt-Dakota FSR (east)
Sechelt-Wilson FSR
Figure B-1
Field stops
Field stop
Water intake
Watershed boundaries to 1 m LIDAR contours
SCCF land
Roads
Highway
Mainline
Active
Inactive
Trail
Permanently deactivated
Unclassified
Ocean
Lake
Streams
1:35,000
0 250 500 1,000 1,500 2,000 2,500
m

Field stop #01. Water pipeline crossing of Chapman Creek, below intake. August 19, 2013. Average width ~11 m; gradient 2%. Non-alluvial bedrock-boulder channel. No LWD in channel.

Photo 01. Looking west along water pipeline suspended above stream.

2010 ortho

Field stop #02. Dam and water intake on Chapman Creek, accessed from east side of channel. August 19, 2013. Bedrock channel at dam, falls below dam. Boulder-cobble channel U/S.

2010 ortho

Photo 02. Looking west at intake structure.

Field stop #02 cont'd. Dam and water intake on Chapman Creek. August 19, 2013.

Photo 03. Looking downstream at spillway and water pipeline.

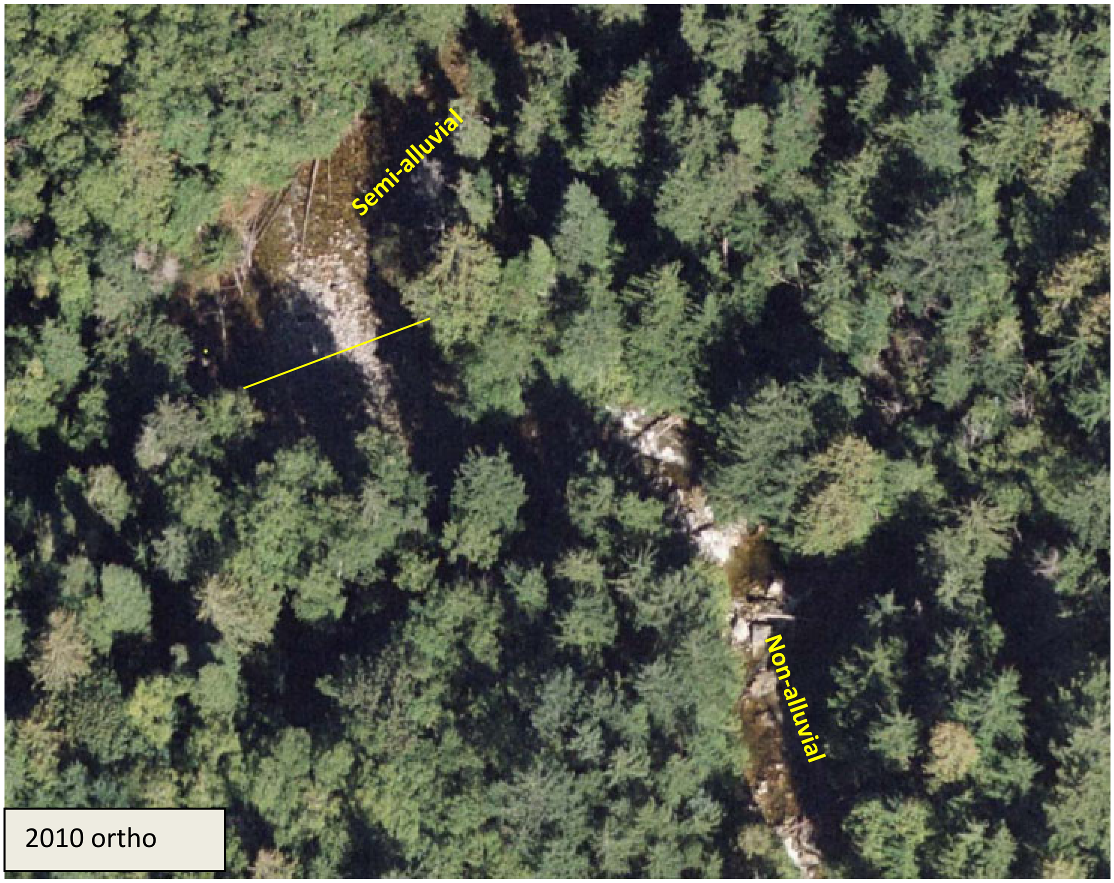
Photo 04. Looking upstream. Intake on left side of photo.

Field stop #03. Old road crossing, bridge removed. Boulder-cobble alluvial channel in narrow floodplain. Channel width ~13 m, gradient 3-4%. August 19, 2013.

Photo 05. Looking west across channel at old road. Bank armoured.

Photo 06. Looking downstream from east side of channel.

Field stop #04. U/S from bend: semi- alluvial channel with cobble boulder substrate, gradient 1-2%. D/S from bend: non-alluvial bedrock-boulder channel with pools, benchy gradient 3-4%. Channel width 18-20 m. Sparse LWD, non-functional. August 19, 2013.



2010 ortho

Photo 07. Semi-alluvial cobble-boulder channel upstream from bend.

Field stop #04 cont'd. August 19, 2013.

Photo 08. Non-alluvial channel downstream from bend.

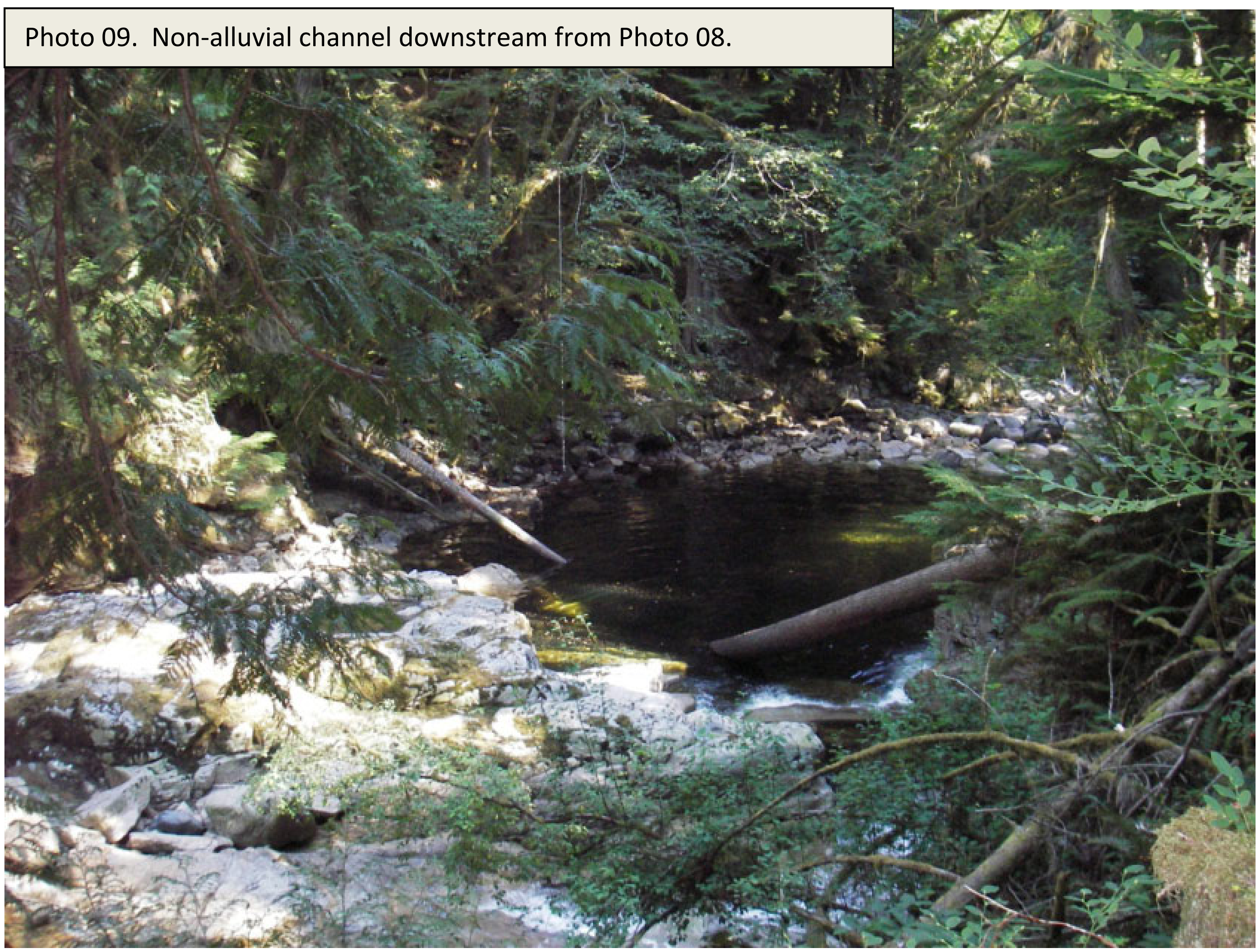


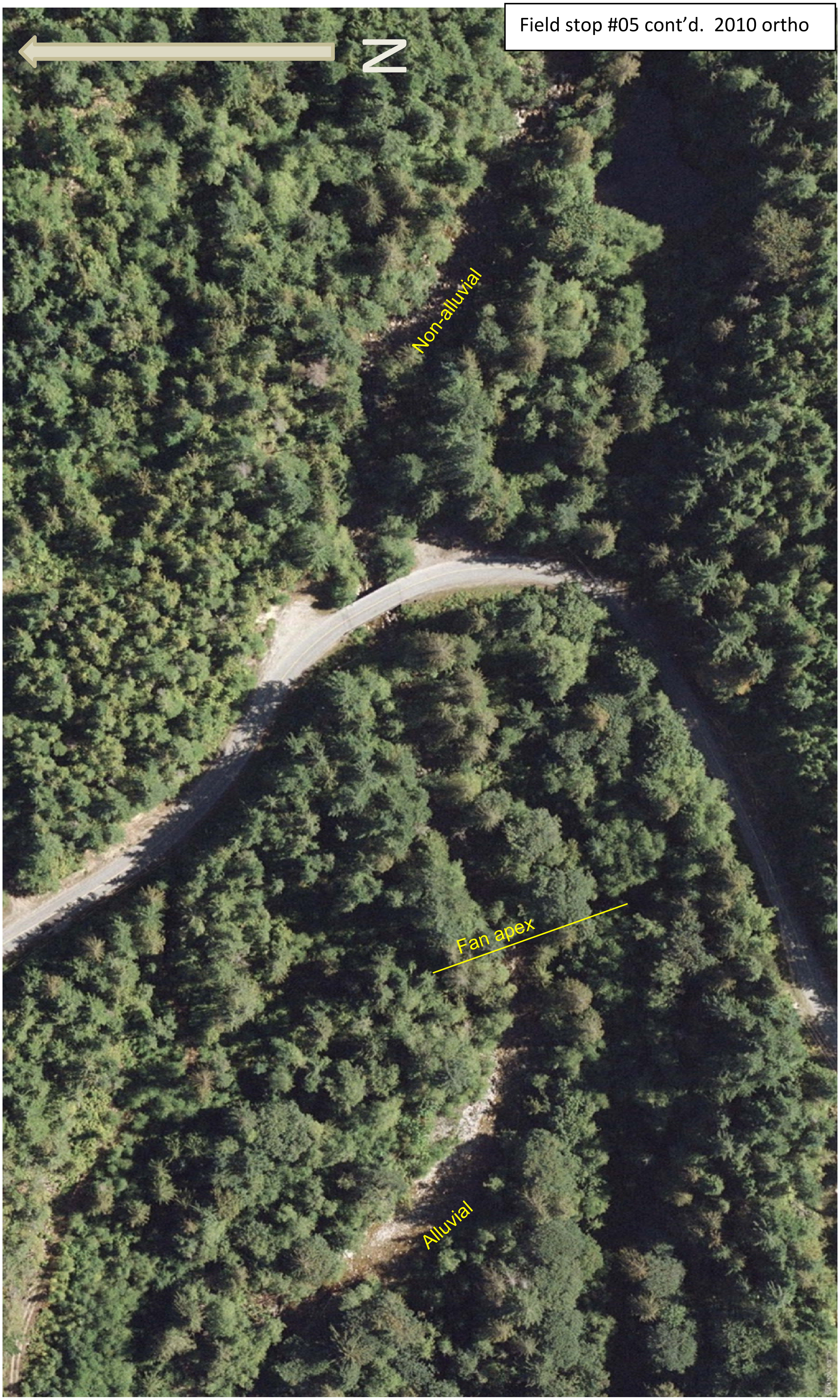
Photo 09. Non-alluvial channel downstream from Photo 08.

Field stop #05. August 20, 2013. Gray Creek at highway bridge, Tuwanek. Just above apex of alluvial fan. Channel width measured across bridge 13.2 m. Non-alluvial channel, gradient 7% U/S, 2% D/S; boulder substrate. No LWD.

Photo 10. Looking upstream from below bridge. Boulder step-pool channel.

Photo 11. Looking downstream from below bridge. Boulder cascade-pool channel.

Field stop #05 cont'd. 2010 ortho



Field stop #06. August 20, 2013. Water storage tank and chlorination plant downstream of Gray Creek intake.

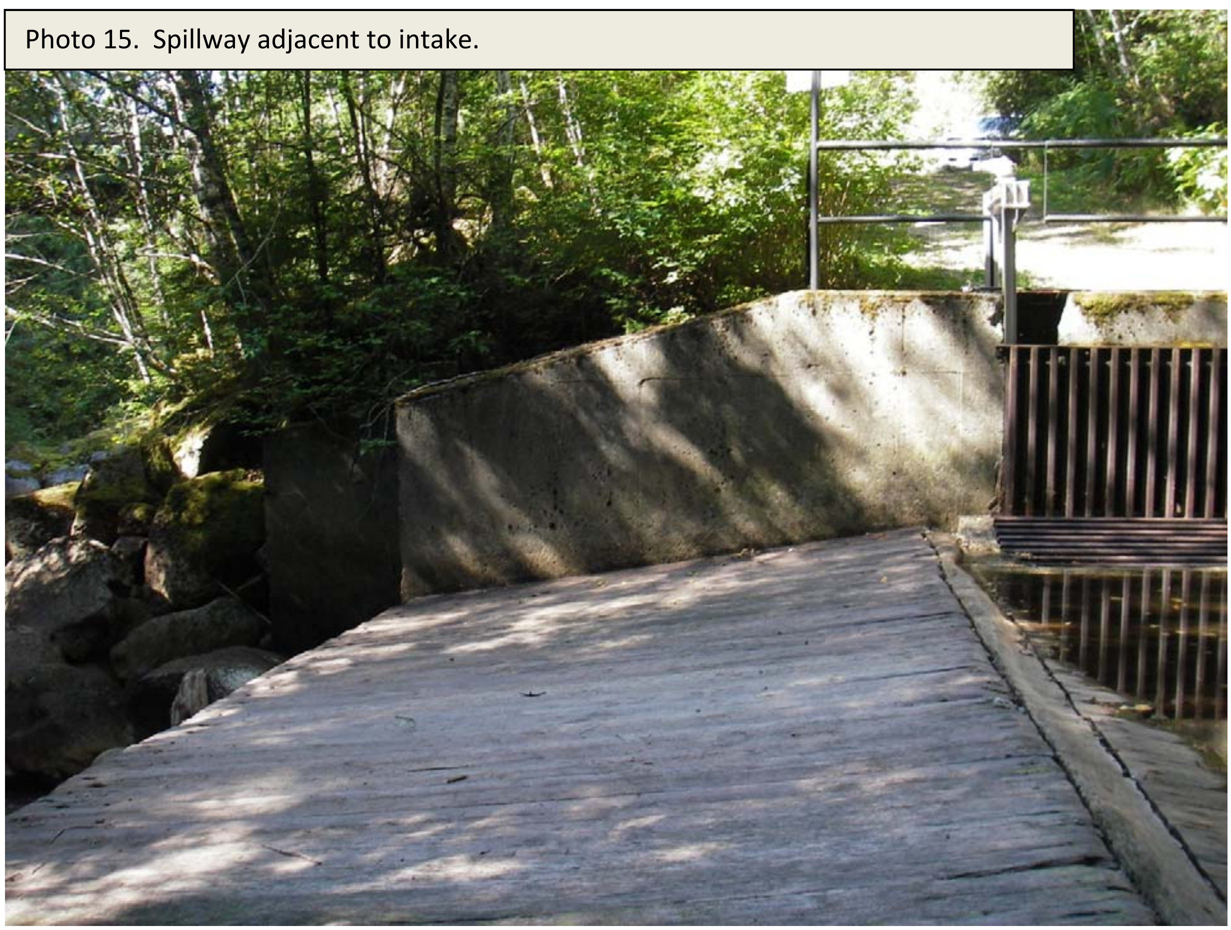
Photo 12. Grey Creek chlorination plant.

Photo 13. Water storage tank.

Field stop #07. August 20, 2013. Gray Creek water intake.

Photo 14. Gray Creek water intake structure.

Photo 15. Spillway adjacent to intake.



Field stop #07 cont'd. August 20, 2013. Gray Creek channel at intake. Non-alluvial bedrock boulder channel. Gradient benchy, 7-15%. Channel width measured across bridge 12.1 m. Confluence of 2 streams just above intake (not visible).

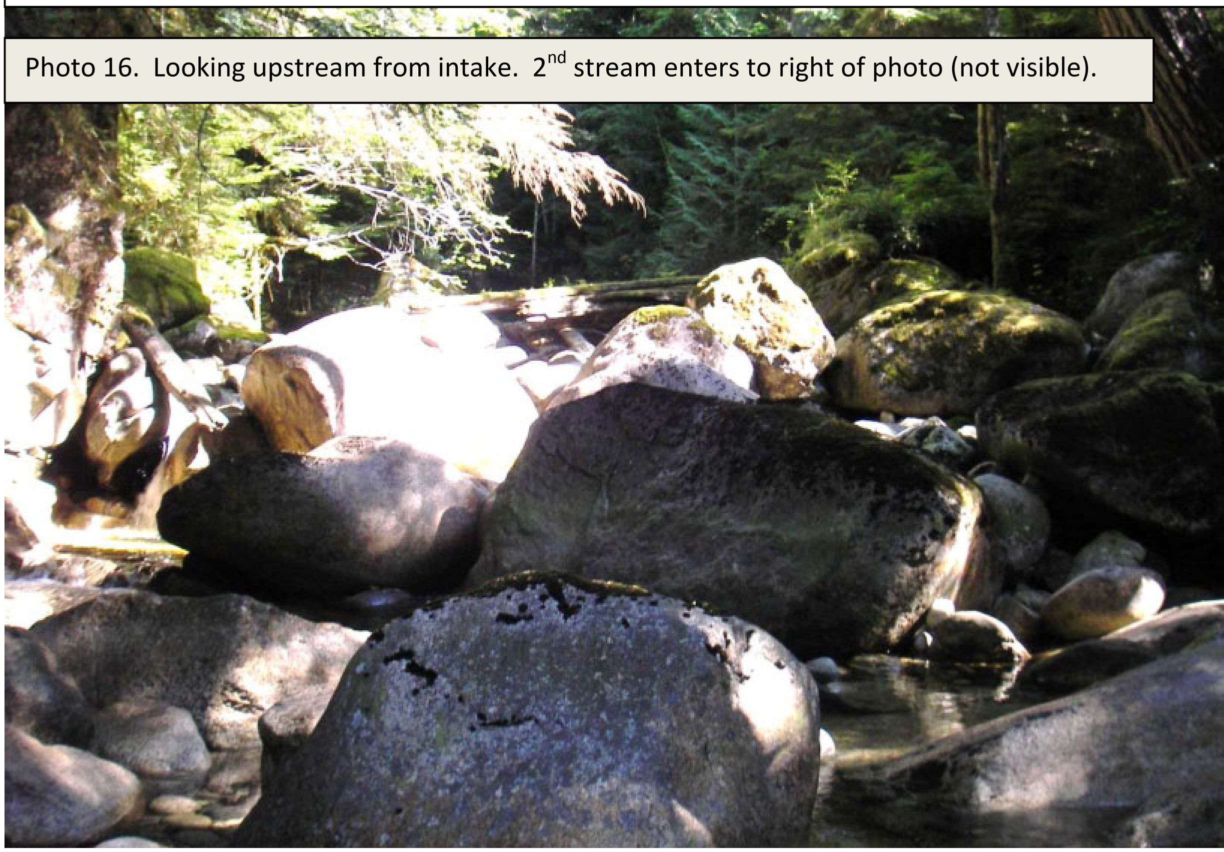


Photo 16. Looking upstream from intake. 2nd stream enters to right of photo (not visible).

Photo 17. Looking downstream from intake towards bridge.

Field stop #08. August 20, 2013. Bridge on Sechelt Gray Forest Service Road. Channel width 11 m measured across bridge. Alluvial channel U/S, gradient 1%. Sparse to no LWD.

Photo 18. Looking upstream from bridge. Alluvial channel, gradient 1%.

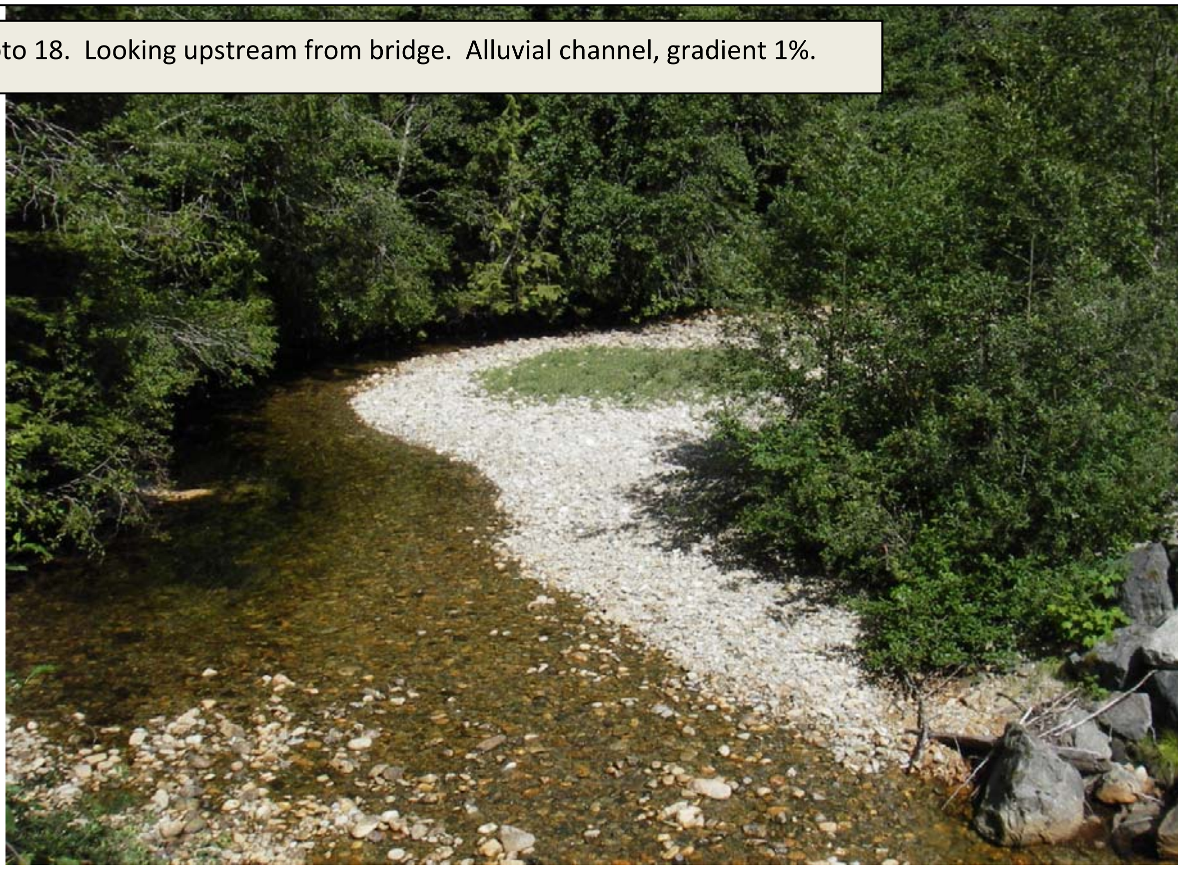
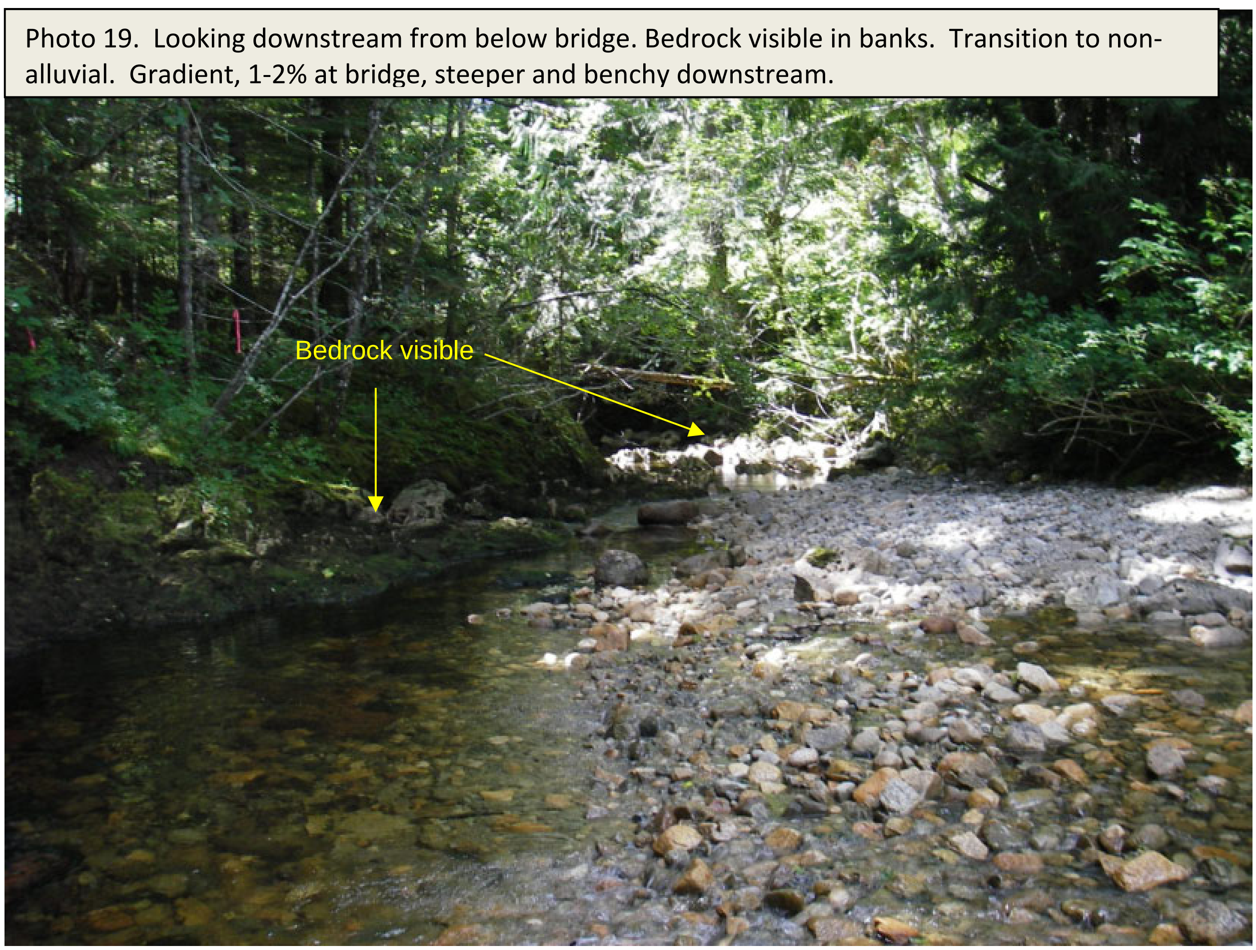


Photo 19. Looking downstream from below bridge. Bedrock visible in banks. Transition to non-alluvial. Gradient, 1-2% at bridge, steeper and benchy downstream.



Field stop #09. August 20, 2013. Log bridge on tributary to Gray Creek. Rated at 5T in 2010. Channel width 10.5 m measured across bridge. Non-alluvial boulder step-pool channel, gradient 7-8%. No LWD.

Photo 20. Looking downstream toward bridge.

Photo 21. Looking downstream from bridge.

Field stop #10. August 20, 2013. Bridge on upper Gray Creek. Channel width 8.7 m measured across bridge. Non-alluvial boulder step-pool channel, gradient 7% D/S, 10% U/S. No LWD.

Photo 22. Looking downstream toward bridge.

Photo 23. Looking downstream from bridge.

Field stop #10 cont'd. August 20, 2013.

Photo 24. Looking upstream from bridge.

2010 ortho

Field stop #11. August 20, 2013.

Photo 25. Road becoming aldered. Semi-permanent deactivation.

Photo 26. Rock and silty colluvium in road cut.

Field stop #12. August 20, 2013. Road at Gray Creek drainage divide. Road becoming vegetated, cuts mainly rock.

Photo 27

Photo 28

Field stop #13. August 20, 2013. Rock cuts, flat road grade. Tension cracks in road shoulder. Steep slope below road.

Photo 29

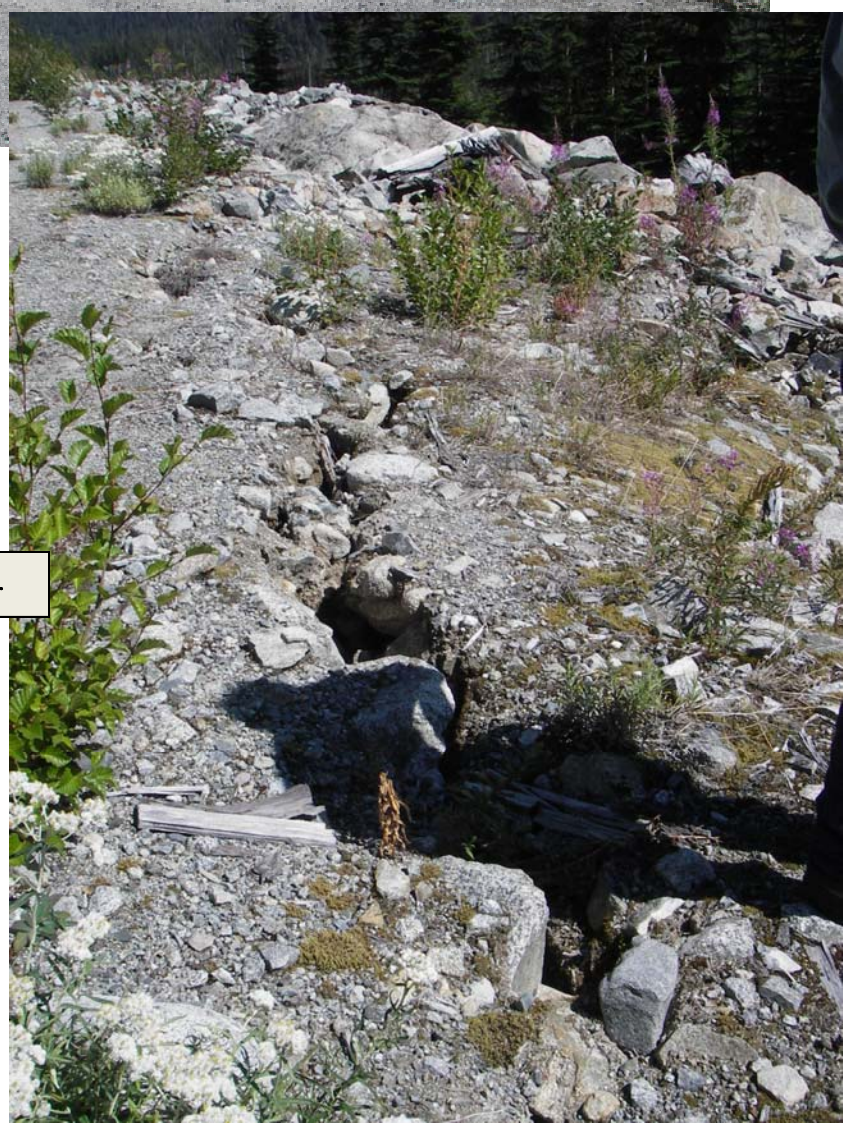


Photo 30. Tension cracks in fill shoulder.

Field stop #14. August 20, 2013. Rock cuts, flat road grade, steep fillslopes. Tension cracks in road shoulder. Steep slope below road.

Photo 31. Looking east.

Photo 32. Looking west. Tension cracks in fill shoulder.

Field stop #15. August 20, 2013. Culvert pipe still in place. Semi-permanent deactivation, culverts not removed. Road cross-ditched.

Photo 33. Looking west.

Photo 34. Looking west. Rock and silty colluvium in cuts. Cross-ditch to back up culvert.

Field stop #16. August 20, 2013. At upper parking lot for Tetrahedron Park

Photo 35. Looking east at start of park trail. Old forest road deactivated.

Photo 36. Looking west at high rock cut opposite parking lot.

Field stop #17. August 20, 2013. Bridge by lower parking lot for Tetrahedron Park trails.

Photo 37. Looking west at bridge.

Photo 38. Looking upstream at channel below bridge. Small steep non-alluvial stream.

Field stop #18. November 20, 2013. At junction of Sechelt-Dakota FSR and spur on AJB private land, west side of Chapman Creek.

Photo 39. Looking west at spur from Sechelt-Dakota FSR. Minor erosion of road surface. Steep grade around bend. Bedrock in road cut, top of bend.

Photo 40. Looking south along Sechelt-Dakota FST at spur junction. Ditch across spur junction, prevents vehicle access to AJB spur road.

Field stop #18. November 20, 2013. At junction of Sechelt-Dakota FSR and spur on AJB private land, west side of Chapman Creek.

Photo 40b. Looking west at cleared area north side of spur junction. Uprooted stumps, logs appear to be result of clearing for AJB spur road. Identified as slump in SARP; no sign of movement at time of our field visits. Bedrock visible at top of clearing.

Photo 40c. Looking east toward Sechelt-Dakota FST from bend on AJB spur road.

Field stops #19 and 35. August 21 and 22, 2013. On Sechelt Dakota Forest Service Road, Chapman watershed.

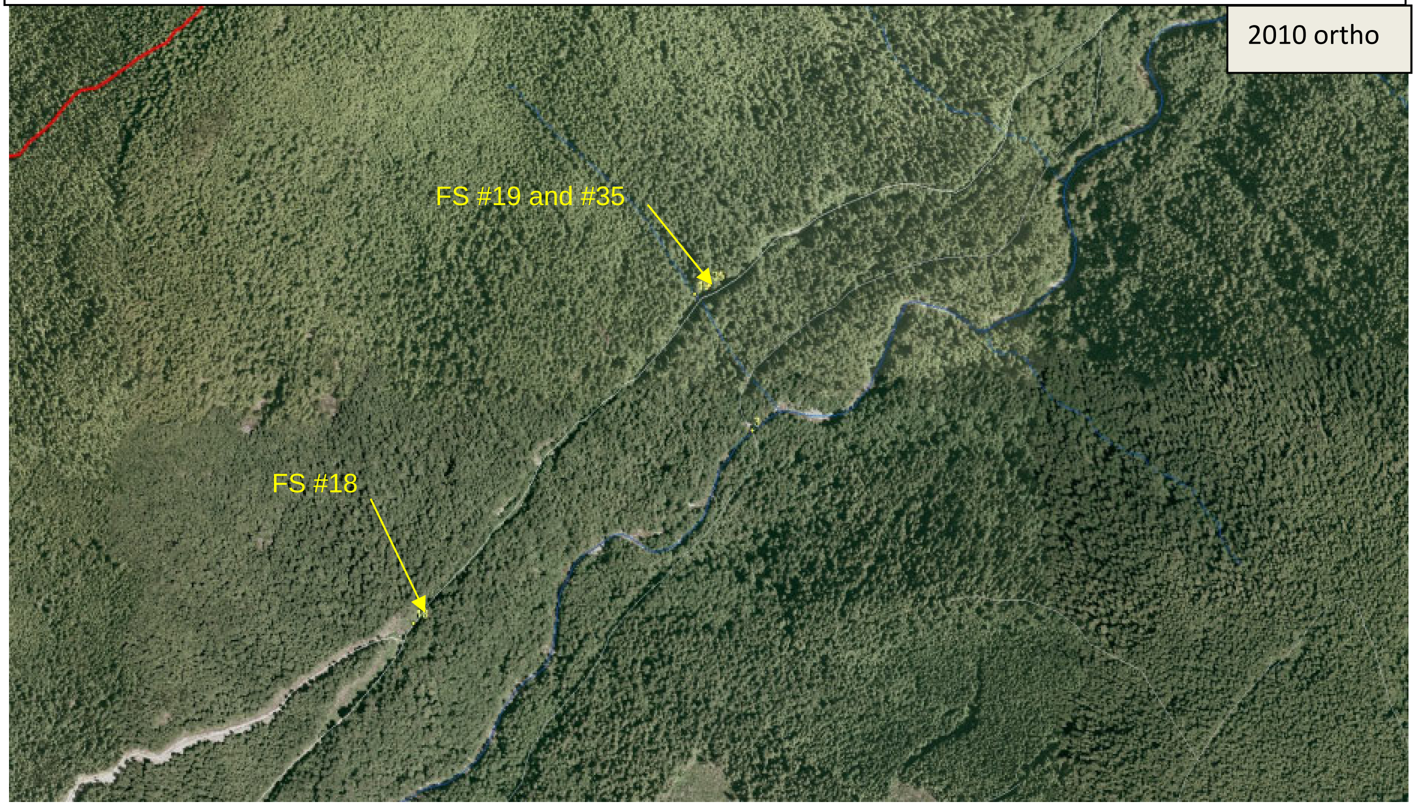


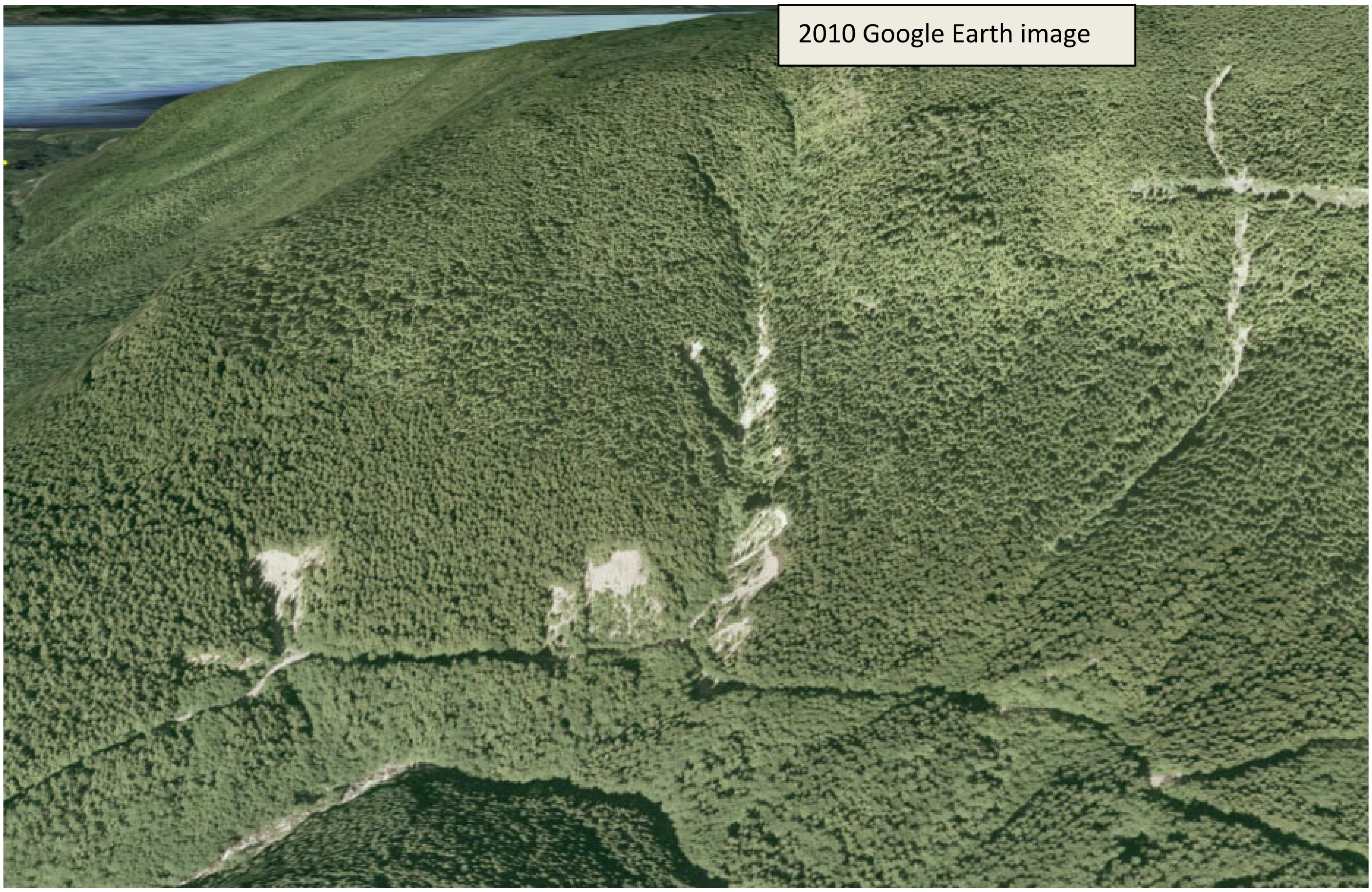
Photo 41. August 22, 2013. FS #19 and 35. Looking northeast at road shoulder. Stacked rock fill placed to stabilize road fill.

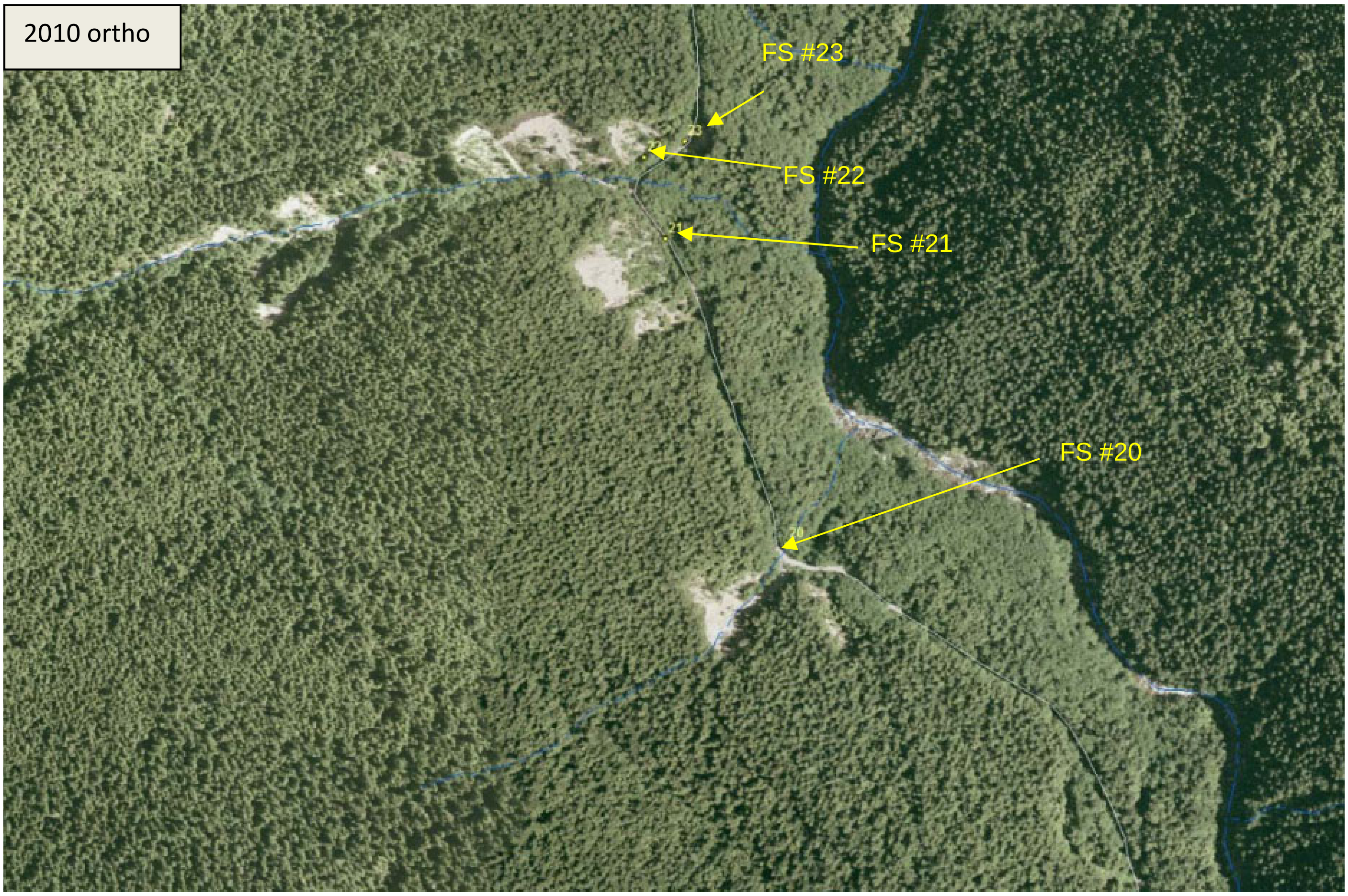
Field stops #19 and 35 cont'd.

Photo 42. August 22, 2013. FS #19 and 35. Looking southwest along Sechelt-Dakota FSR. Stacked rock wall built to support ravelling cut.

Photo 43. August 22, 2013. FS #19 and 35. Till exposed in scarp of cutslope.

Field stops #20 - 23. August 21, 2013. Area of chronic instability, west side of Chapman Creek valley.





Field stops #20 - 23. August 21, 2013. Area of chronic instability, west side of Chapman Creek valley.

Photo 44. FS #20. Boulders, rubble on road from ravelling slopes. Road not driveable.

Photo 45. FS #22. Trickle of flow in gully, cross-ditch across road.

Field stops #20 - 23. August 21, 2013. Area of chronic instability, west side of Chapman Creek valley.


Photo 46. Unstable cut at FS #22.

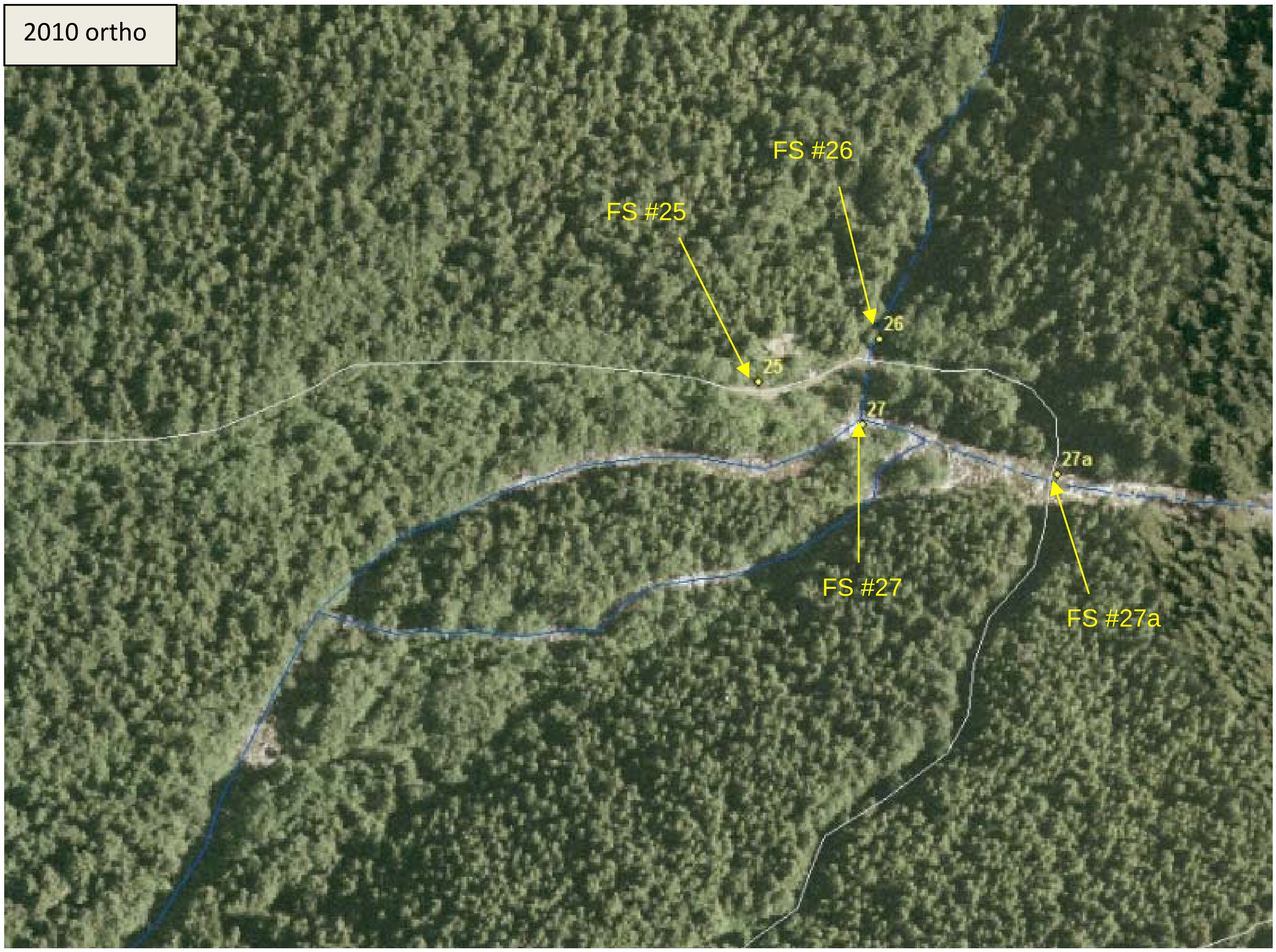

Photo 47. Unstable cuts at FS #22.

Field stop #23. August 21, 2013. Area of chronic instability, west side of Chapman Creek valley.

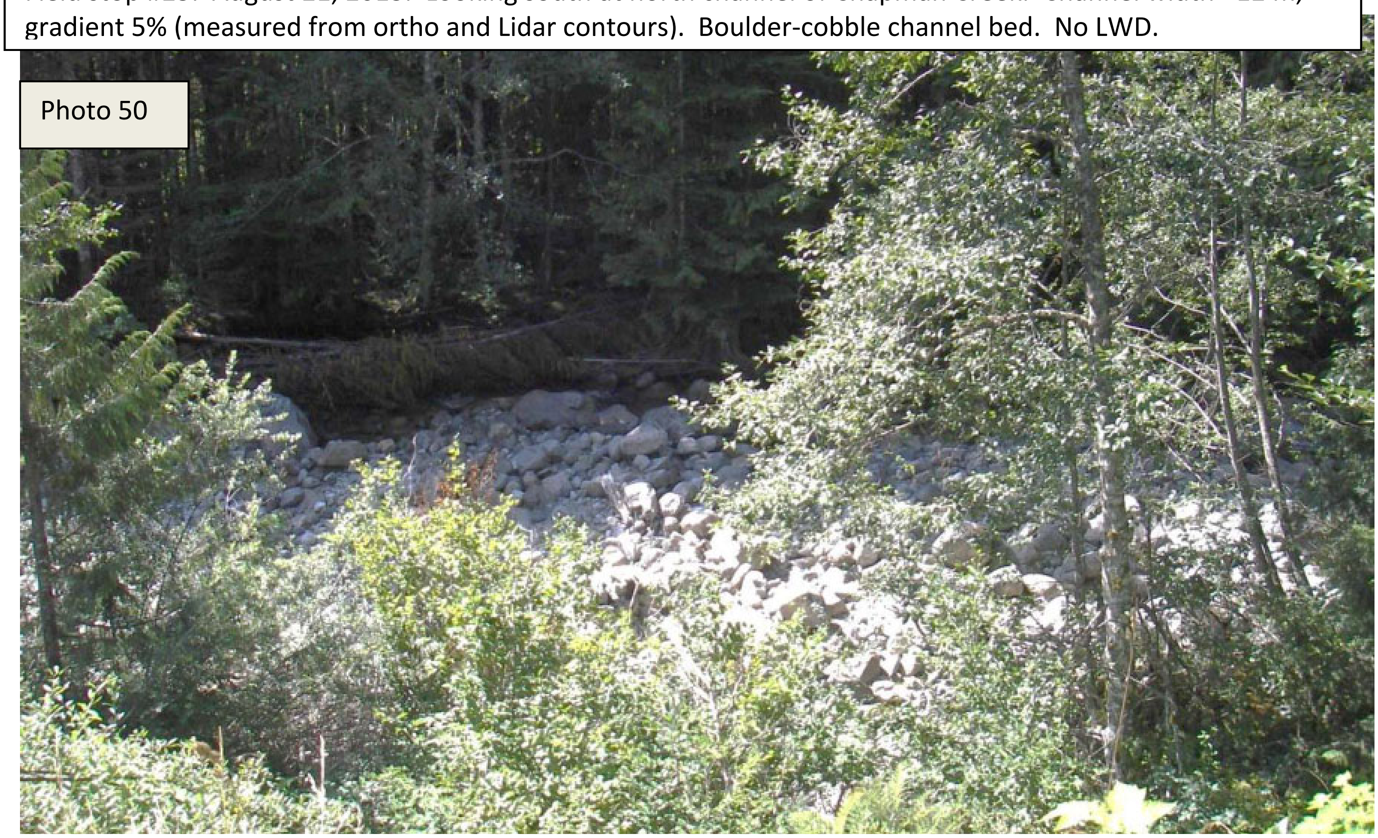
Photo 48. FS #23. Stacked rock wall built to support unstable cut in glaciolacustrine deposits.

Field stop #24. Tributary crossing. Bouldery non-alluvial channel, no flow at time of field visit. Gradient 20%.

Photo 49, looking upstream.



Field stop #25. August 21, 2013. Looking south at north channel of Chapman Creek. Channel width ~12 m, gradient 5% (measured from ortho and Lidar contours). Boulder-cobble channel bed. No LWD.



Field stop #26. August 21, 2013. Tributary of Chapman Creek at road crossing.

Photo 51. Looking downstream at tributary channel from old road crossing. Crossing structure removed. Non-alluvial boulder channel, gradient 15%, channel width 8-10 m.

Photo 52. Downstream of road crossing, looking towards Chapman Creek confluence. Fish in pools. Gradient 9% (from Lidar contours). Boulder step-pool channel.

Field stop #27. August 21, 2013. North channel of Chapman Creek at tributary confluence.

Photo 53. Looking downstream at north channel. Boulder step-pool channel in floodplain, possibly glaciofluvial. Gradient 5%, Channel width ~12 m. Sparse LWD, non-functional.

Field stop #27a. August 21, 2013. Chapman Creek at old bridge crossing, bridge removed. Channel width 16-18 m, single channel.

Photo 54. Looking upstream. Bedrock-boulder step-pool channel. No LWD.

Field stop #28. August 21, 2013. Garbage dumped beside trail just outside of watershed boundary.

Photo 55

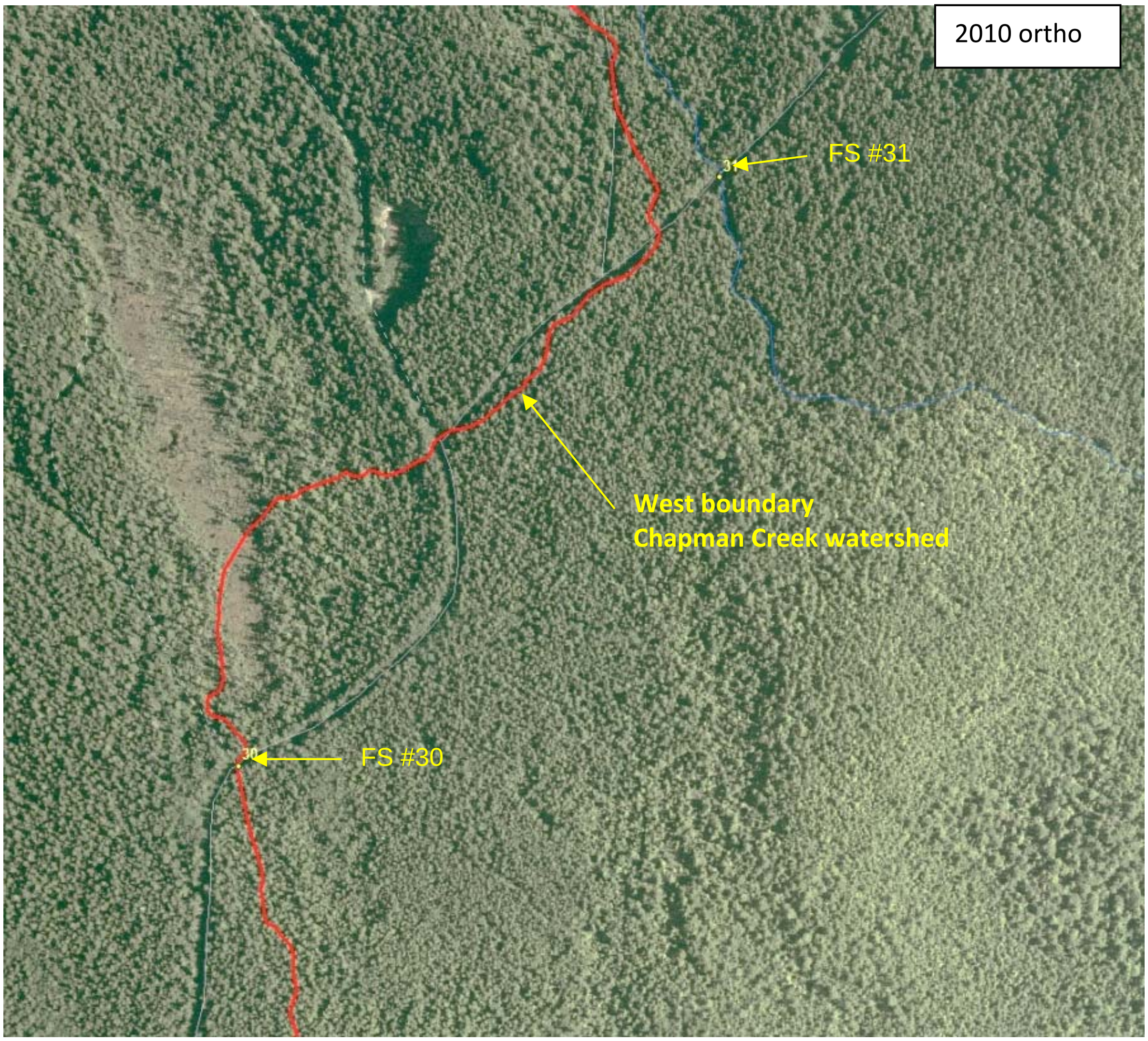
Field stop #29. August 21, 2013. Gate on Sechelt Dakota FSR at private property boundary. Garbage dumped in front of gate.

Photo 56

Field stop #29 cont'd. Garbage dumped on road leading up to gate.

Photo 57

Photo 58



Field stop #30. August 21, 2013. Upper road along Chapman watershed boundary.

Photo 59. Road becoming overgrown.

Field stop #31. August 21, 2013. Upper road. Stream crossing structure removed.

Photo 60. Looking northeast along road where structure removed.

Photo 61. Looking downstream at channel where structure removed. No erosion.

Field stop #32. August 22, 2013. Bridge on Sechelt –Dakota FSR, Chapman Watershed.

Photo 62. Looking downstream at left abutment.

Photo 63. Looking downstream at right abutment.

Field stop #32 cont'd. August 22, 2013

Photo 64. Looking upstream of bridge. Wood and boulders mossy, channel stable.

Photo 65. Looking downstream from below bridge. Channel armoured on both sides, armour extends well downstream of bridge. Boulders mossy, channel stable.

Field stop #33. August 22, 2013. On Sechelt-Dakota FSR, Chapman watershed.

Photo 66. Looking southwest. Road becoming overgrown. Small active failure above cutslope at this location, seeping. Minimal sediment production.

Photo 67. Looking southwest. Old landslide path from road fillslope, aldered.

Field stop #33 cont'd. August 22, 2013.

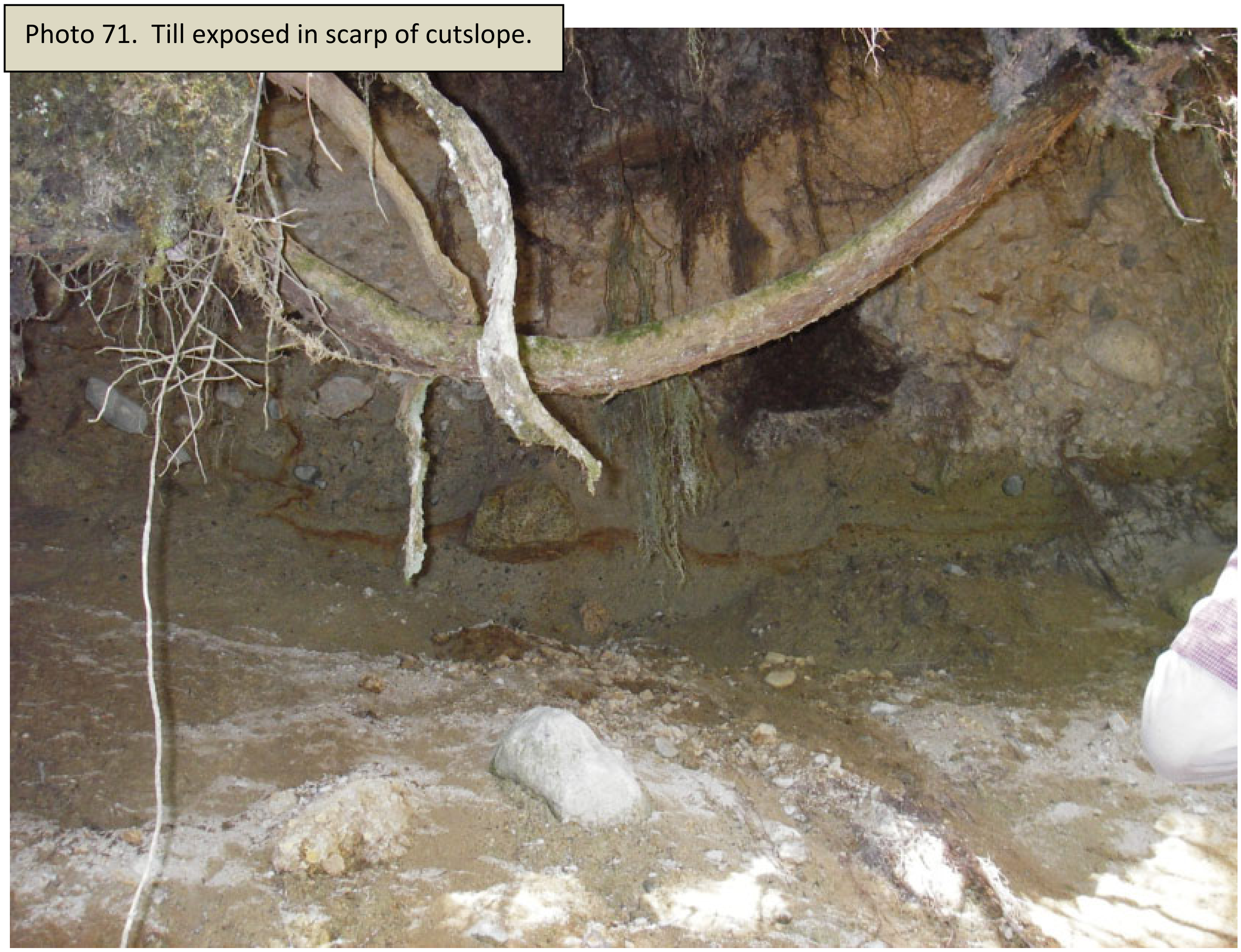
Photo 68. Looking upslope. Small active failure above cutslope, seeping, minor ravel.

Photo 69. Trickle of flow in cross-ditch below cutslope failure. Minimal sediment production.

Field stop #34. August 22, 2013. On Sechelt-Dakota FSR, Chapman watershed.

Photo 70. Ravelling cutslope with fallen trees.

Photo 71. Till exposed in scarp of cutslope.



Field stop #36. August 22, 2013. Old road crossing on tributary to Gray Creek. Bridge removed. Road becoming overgrown. Non-alluvial boulder-bedrock channel, width est. 8 m, gradient benchy, average 16% in vicinity of crossing (from Lidar 1 m contours.).

Photo 72. Looking downstream from old crossing site.

Photo 73. Looking upstream from old crossing site.

Field stop #37. August 22, 2013. Rock pit on Sechelt Crucil Forest Service Road. Altered granitic rock, minimal overburden.

Photo 74

Field stop #38. August 23, 2013. Rock pit on Sechelt Gray Creek Forest Service

Photo 75

Field stop #39. August 23, 2013. Rock pit on Sechelt Gray Creek Forest Service

Photo 76

Field stop #40. August 23, 2013. Rock pit at road crossing of Gray Creek tributary.

Photo 77

Field stop #40 cont'd. August 23, 2013. Stream crossing of Gray Creek tributary.

Photo 78. Road fill approaching stream crossing. Partial pullback of steep fills has been done.

Photo 79. Inlet end of wood box culvert.

Field stop #40 cont'd. August 23, 2013. Stream crossing of Gray Creek tributary.

Photo 80. Fill collapsing over top of wood box culvert.

Photo 81. Channel upstream of wood box culvert.

Field stop #41. August 23, 2013. Road cut on Sechelt Gray Creek Forest Service Road. Glaciolacustrine deposits visible for several km along road adjacent to powerline.

Photo 82 – laminated glaciolacustrine deposits

Field stop #42. August 23, 2013. Small gravel pit on Sechelt Gray Creek Forest Service Road.

Photo 83 – glaciofluvial ice contact deposits.

Field stop #43. November 20, 2013. At junction of Sechelt-Dakota FSR and short spur on AJB private land, west side of Chapman Creek.

Photo 84. Looking west at AJB spur from Sechelt-Dakota FSR. Minimal erosion.

Photo 85. Looking south along Sechelt-Dakota FST at spur junction. Ditch across spur junction, prevents vehicle access to AJB spur road. Minimal erosion or sediment deposition in ditch.

Field stop #44. November 20, 2013. Old road east side of Chapman Creek on AJB land.

Photo 86. Recent slump in cutslope. Till with inclusions of glaciolacustrine deposits. See also heli photo site C-09.

Photo 87. Road cut south of Photo 86. Till and glaciolacustine deposits.

Field stop #45. November 20, 2013. At 7 km Sechelt –Dakota FSR on east side of Chapman Creek.

Photo 88. Inlet end of culverts – 2-CMPs, well armoured.

Photo 89. Outlet end of culverts, well armoured. Erodible soils on road shoulder just above culverts, no erosion protection.

Field stop #45 cont'd. November 20, 2013. At 7 km Sechelt –Dakota FSR on east side of Chapman Creek.

Photo 90. Looking upgrade at ditch draining to inlet end of culverts . No check dams or sediment sumps to control sediment entering stream.

Photo 91. Outlet of ditchwater culvert approx. 200 m. from Field stop #45 (at about6.8 km). Extensive sediment deposition on forest floor.

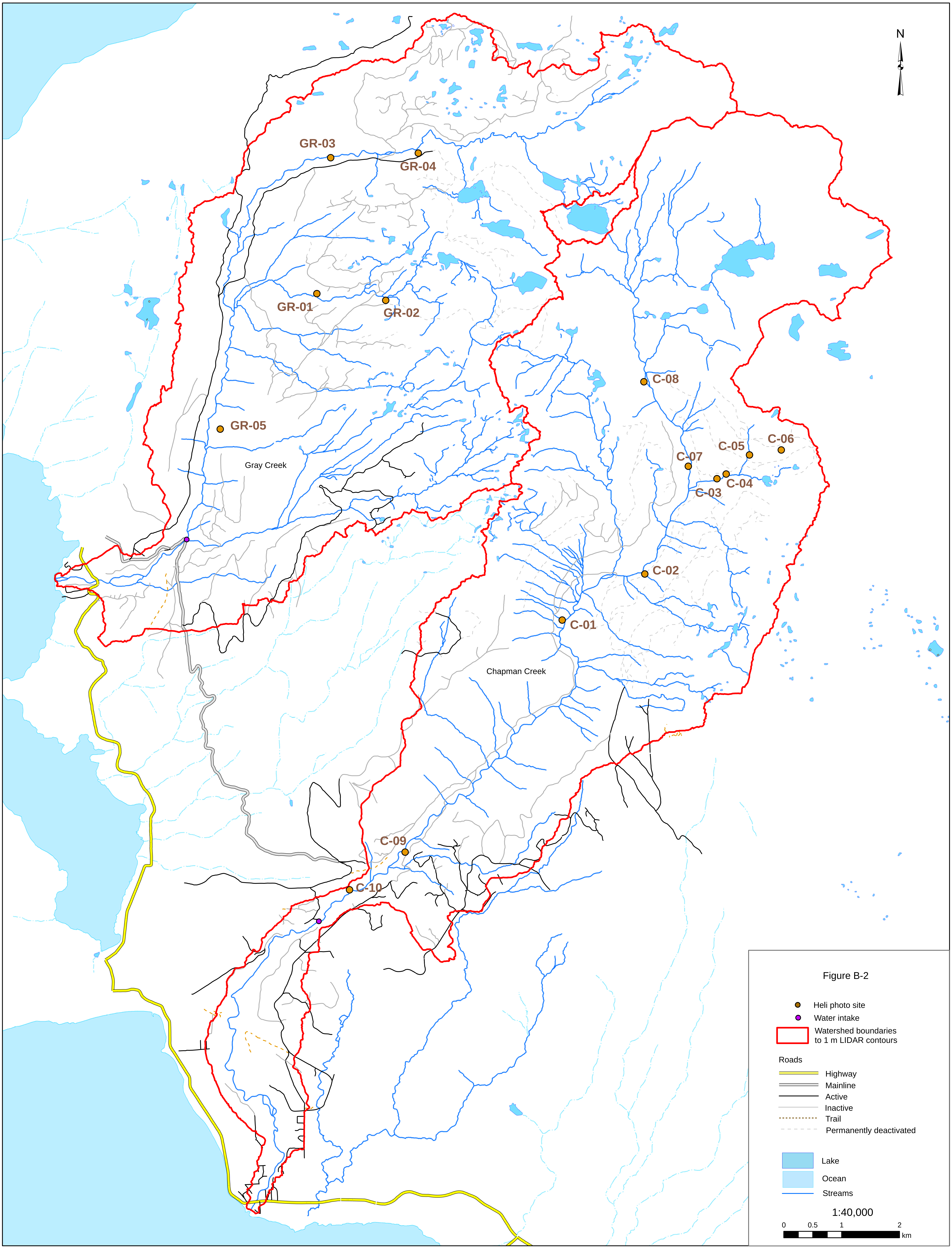
Field stop #46. November 20, 2013. Stream crossing at 6 km Sechelt –Dakota FSR, east side of Chapman Creek.

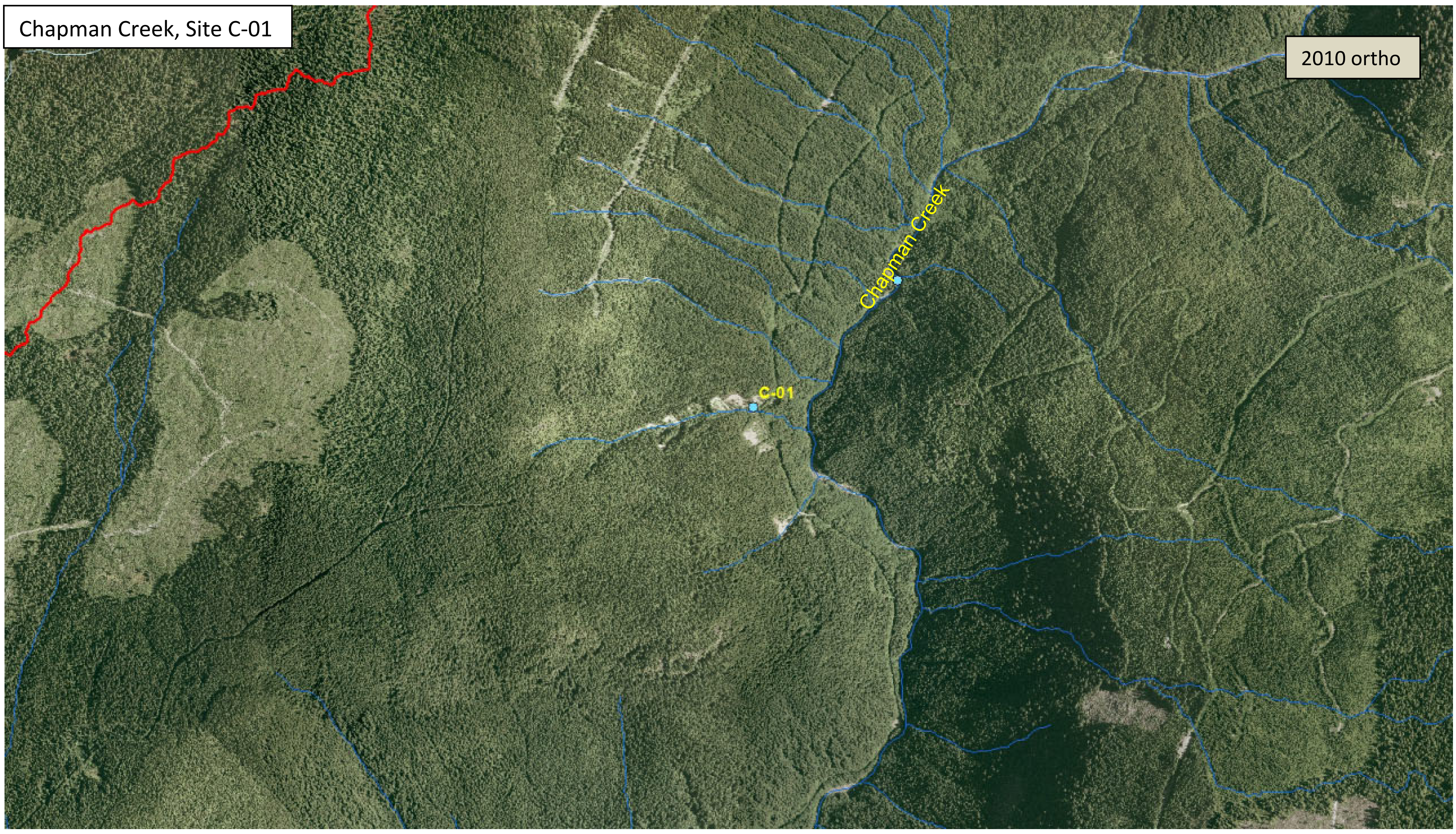
Photo 92. Outlet end of CMP at stream crossing. Pipe in good condition.

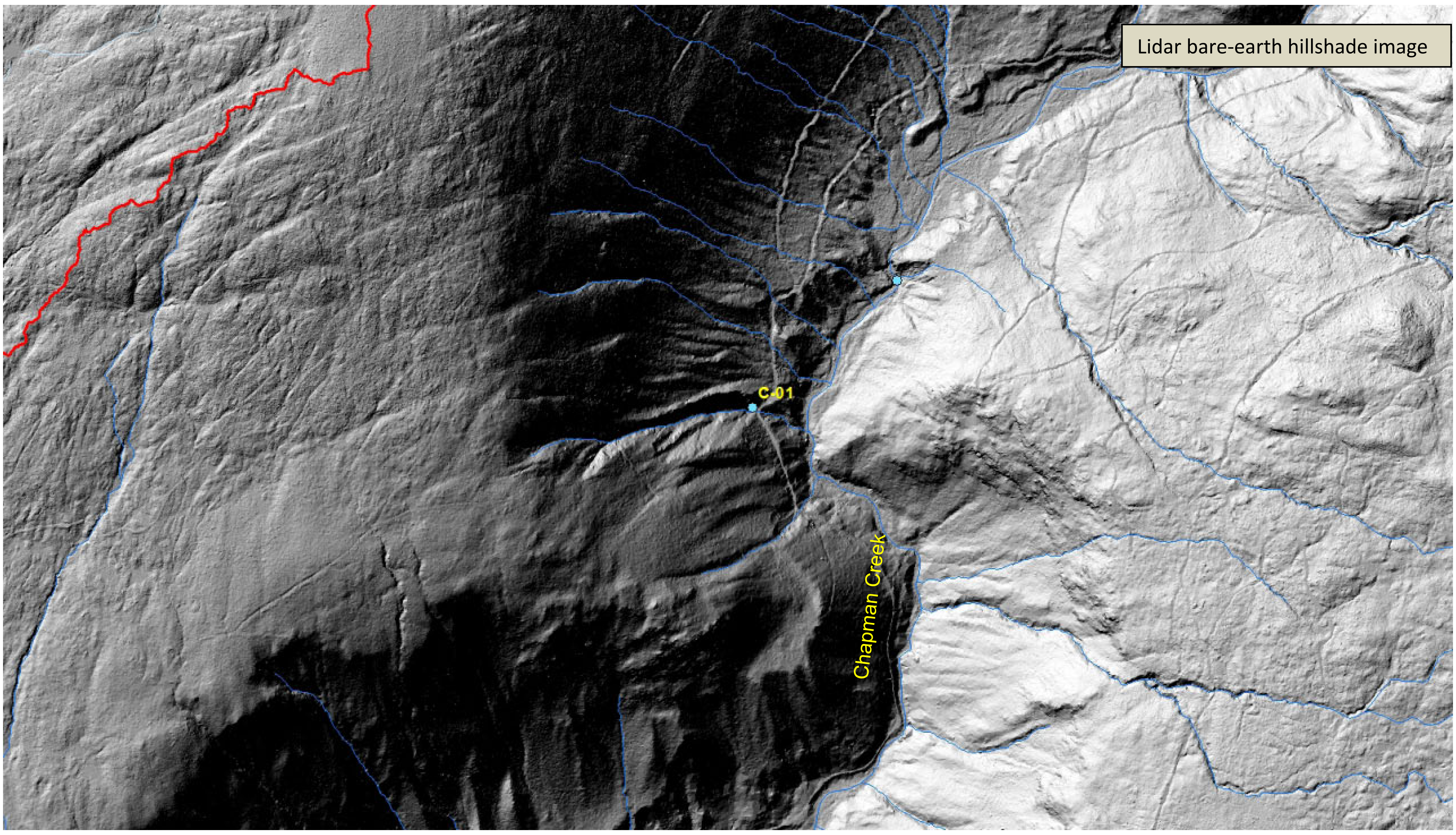
Photo 93. Looking down ditchline flowing to culvert inlet at stream crossing. Heavy ditchflow. Ditchwater crossdrain culvert needed to discharge flow away from stream.

Field stop #47. November 20, 2013. Stream crossing on old road, AJB land east side of Chapman Creek.

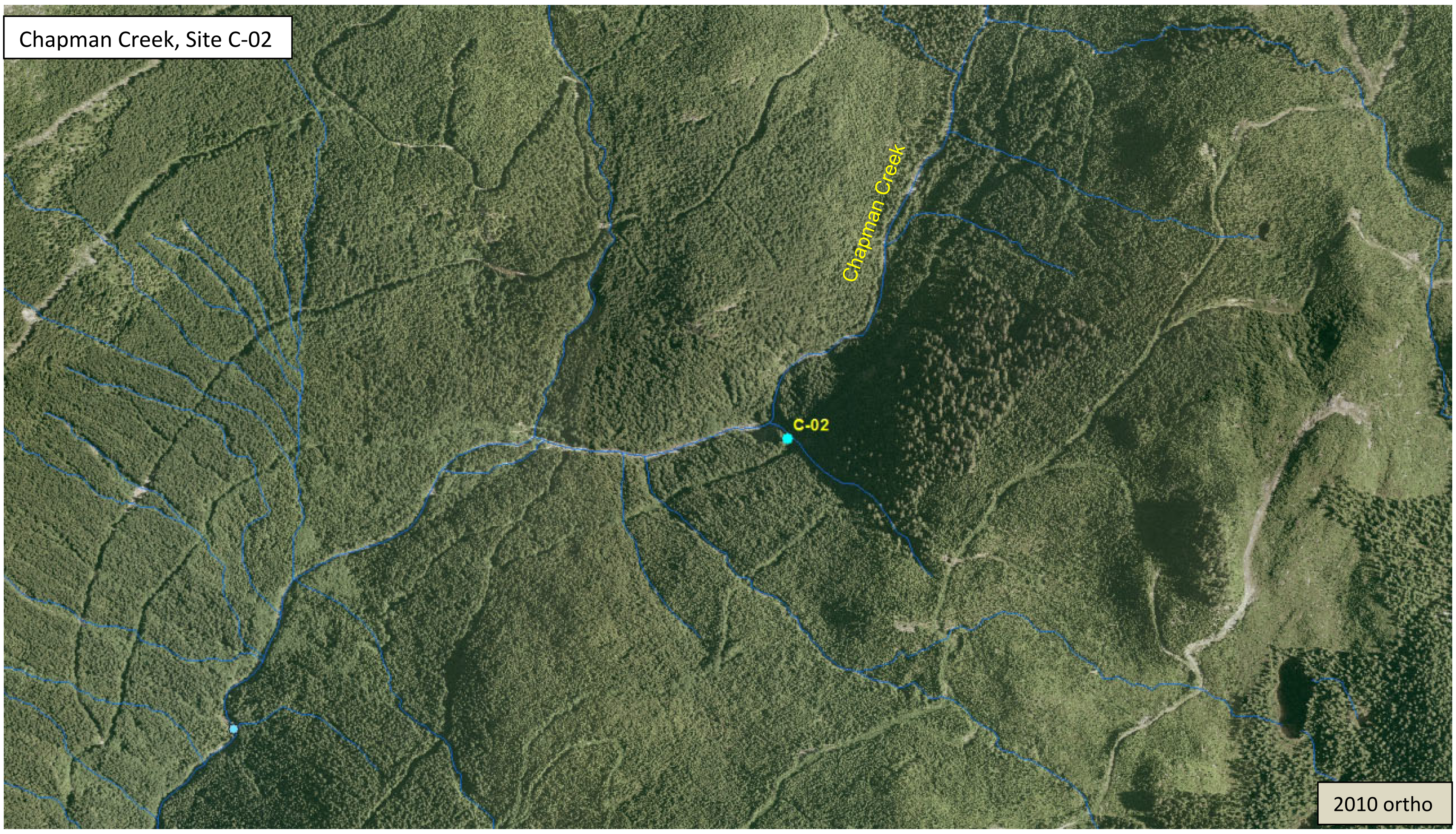
Photo 94. Looking upstream from old wood culvert, still in place. Channel mossy, stable, transports small wood debris, up to gravel size sediment.

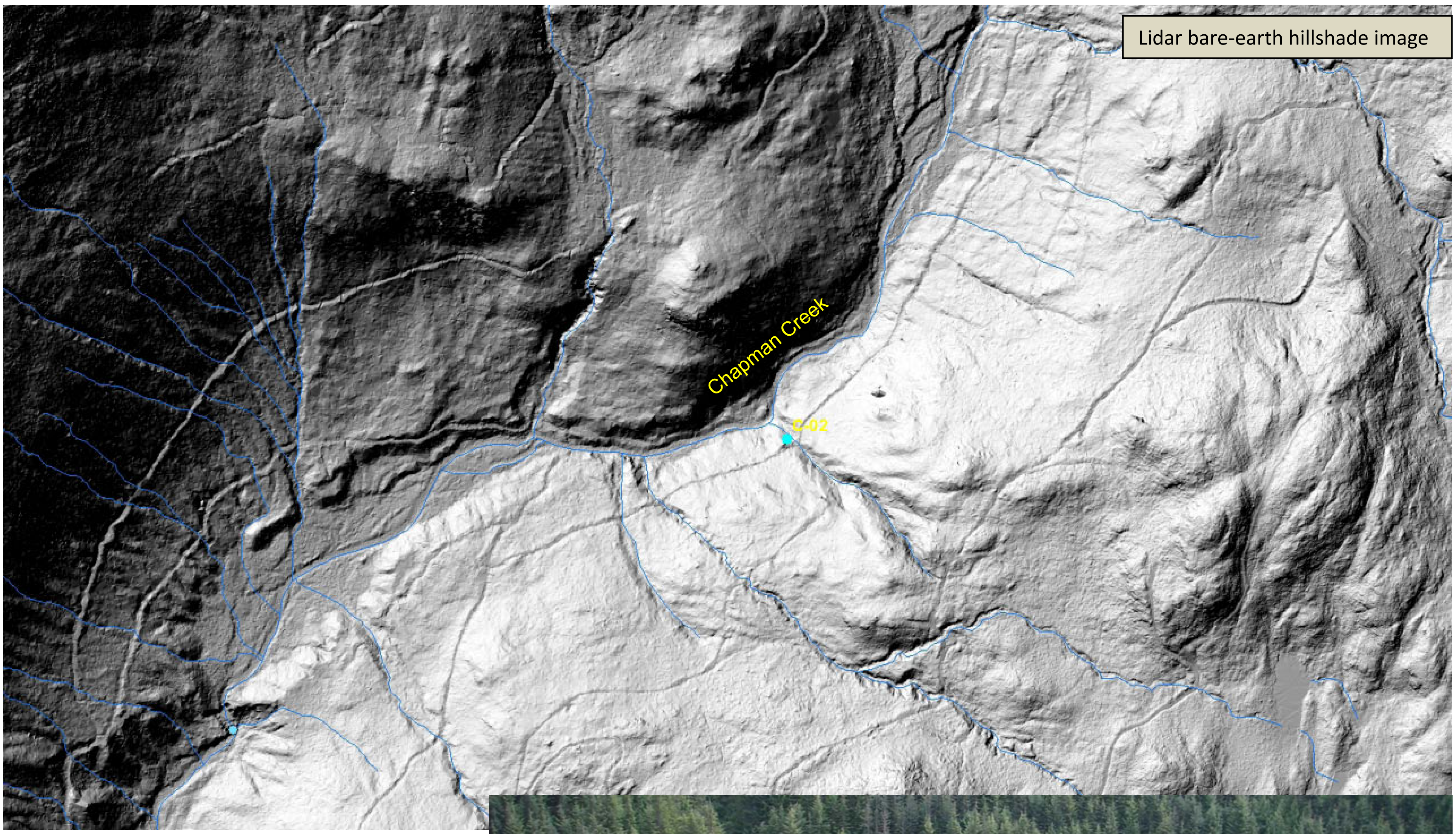

N
GR-03
GR-04
GR-01
GR-02
GR-05
Gray Creek
C-08
C-06
C-05
C-07
C-04
C-03
C-02
C-01
Chapman Creek
C-09
C-10
Figure B-2
Heli photo site
Water intake
Watershed boundaries to 1 m LIDAR contours
Roads
Highway
Mainline
Active
Inactive
Trail
Permanently deactivated
Lake
Ocean
Streams
1:40,000
0 0.5 1 2
km



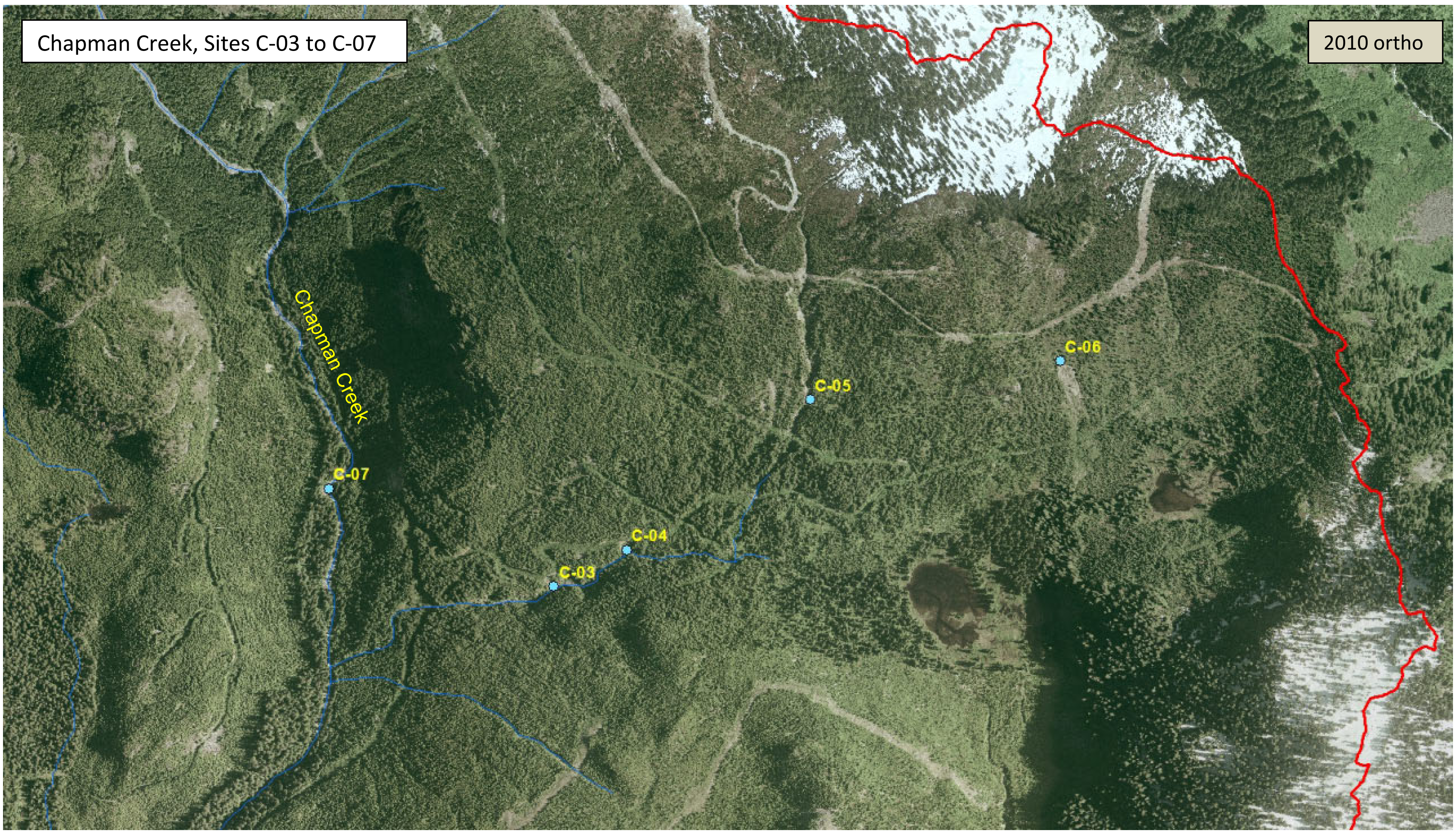


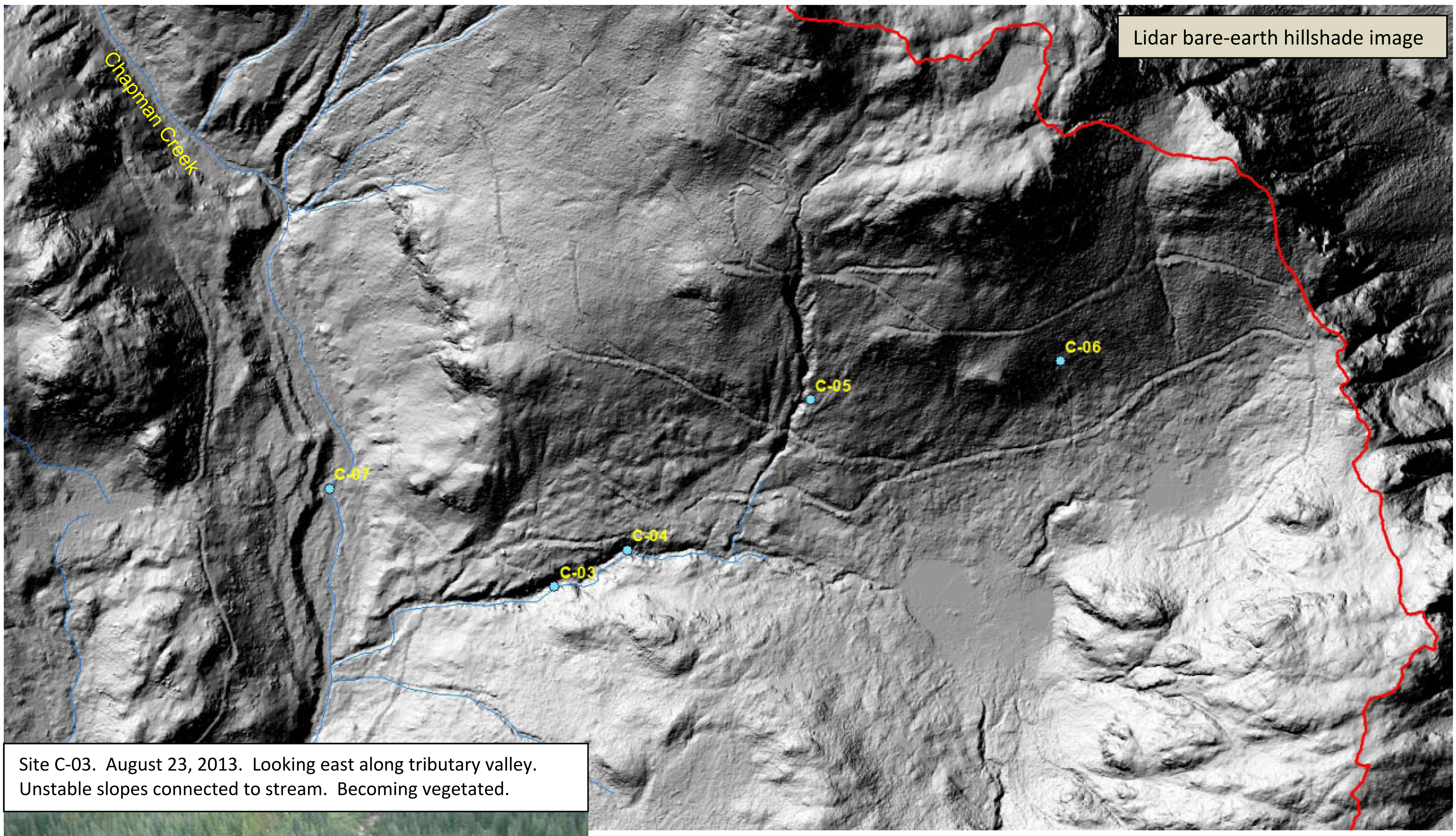
Site C-01. August 23, 2013. Looking west. Chronic unstable gully slopes in deep glaciofluvial deposits. See also Field Stops #20-23.



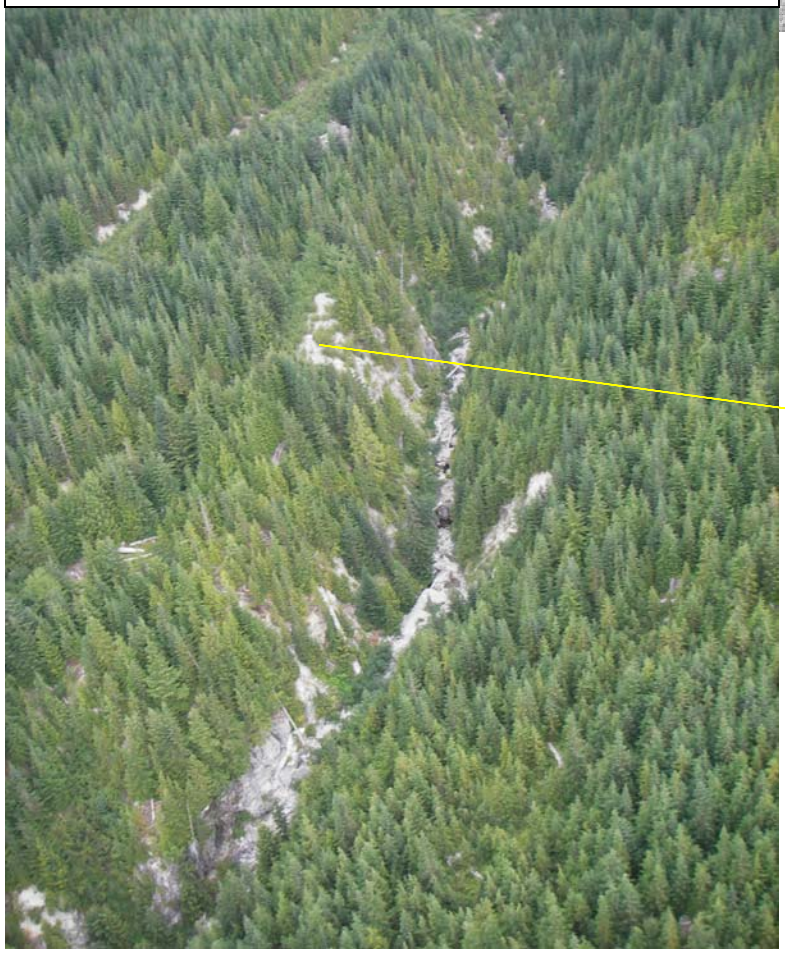


Site C-02. August 23, 2013. Looking southeast. Landslides initiating at break in slope above stream; connect to stream. Active erosion at toe of slope.





Site C-03. August 23, 2013. Looking east along tributary valley. Unstable slopes connected to stream. Becoming vegetated.



Site C-03. August 23, 2013. Looking north. Unstable slopes connected to stream. Becoming vegetated but still eroding, sloughing; stream aggraded.

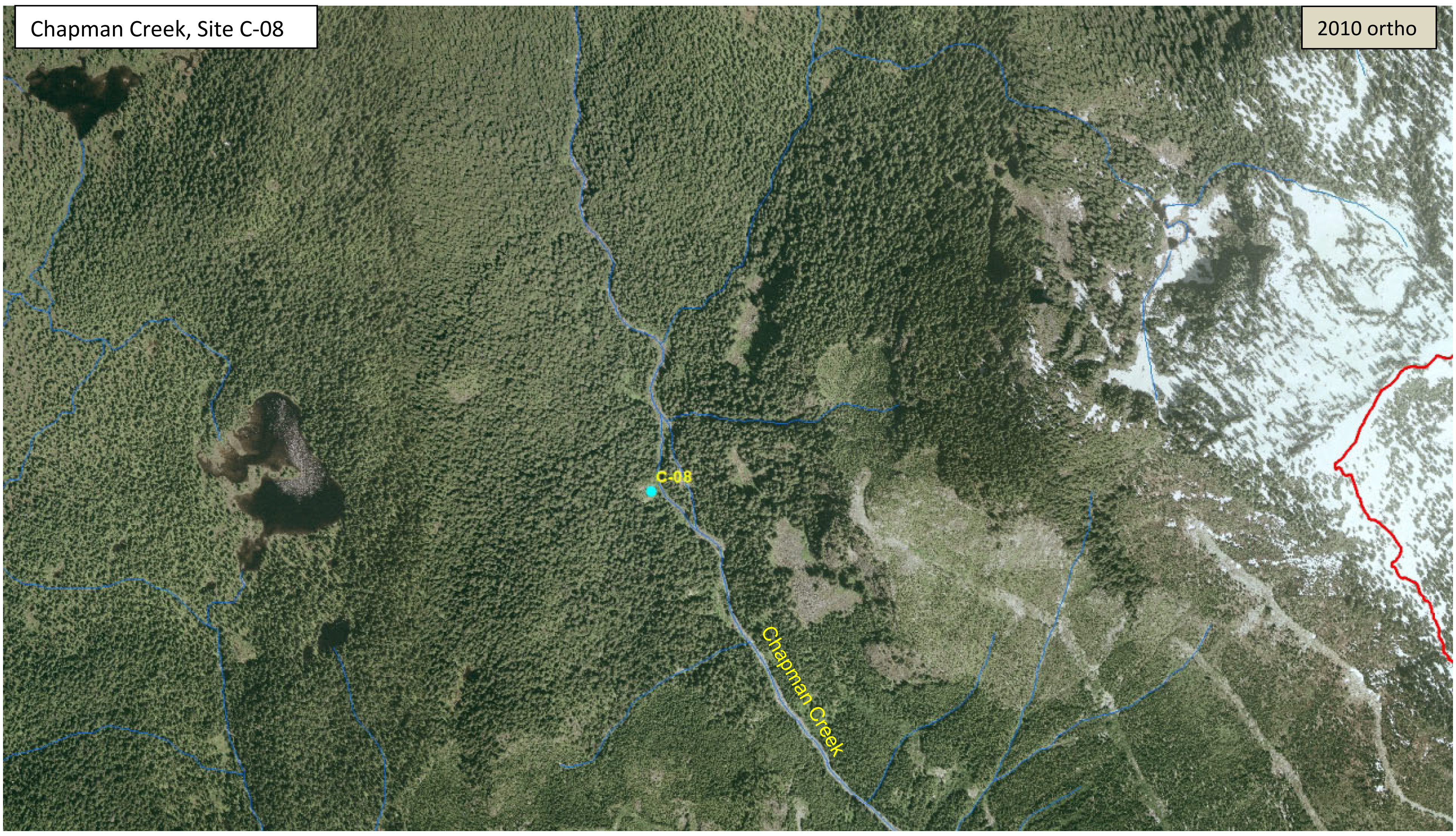
Site C-04. August 23, 2013. Tributary to Chapman Creek. Landslide in road fill and stream escarpment, becoming vegetated. Stream at toe of slope.

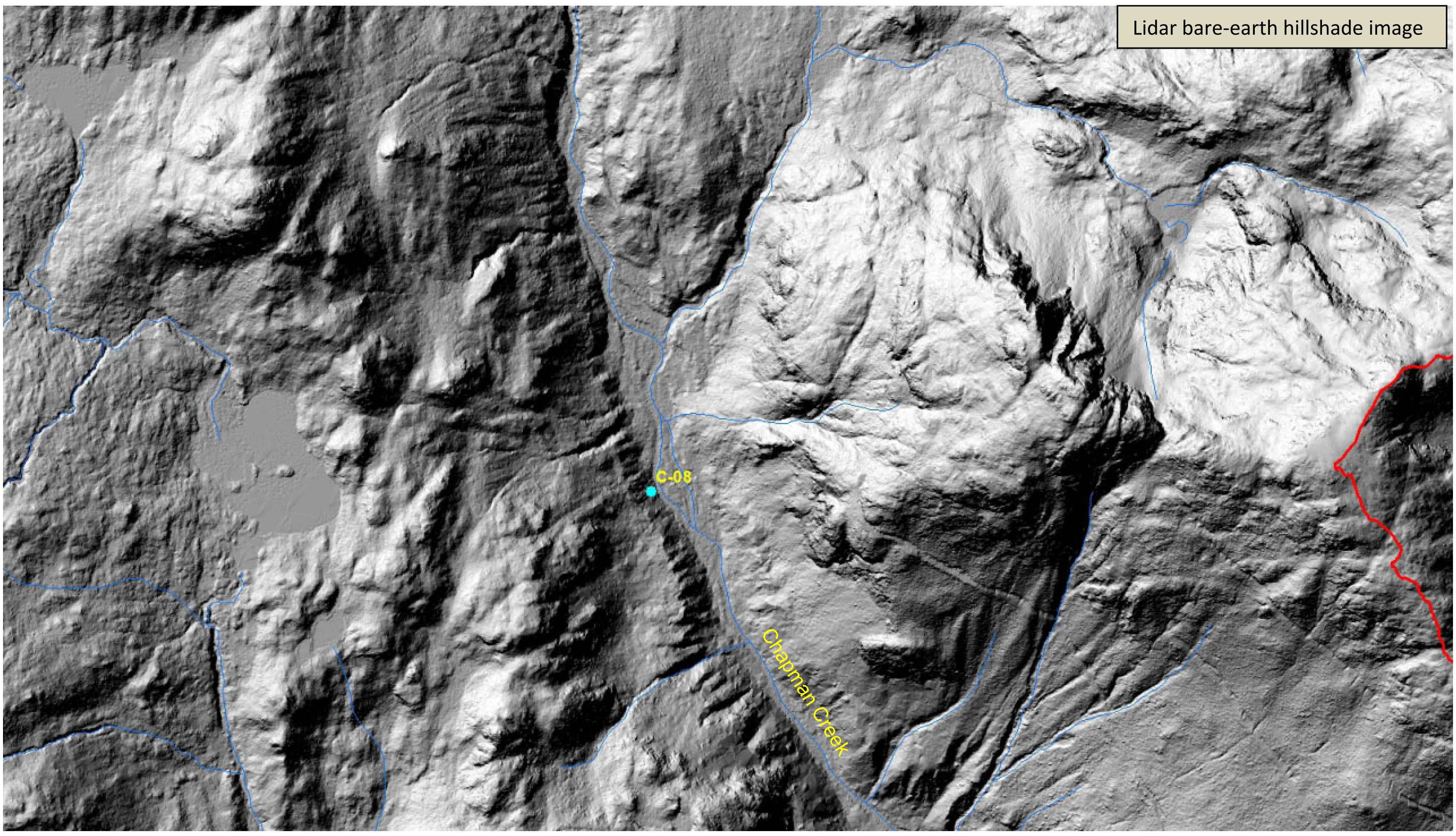
Site C-05. August 23, 2013. Ravelling unstable gully sidewalls. Becoming vegetated.

Site C-05 cont'd. 2010 Google Earth image. Recent landslide in deactivated road, unstable gully sidewalls. Logged 1973.

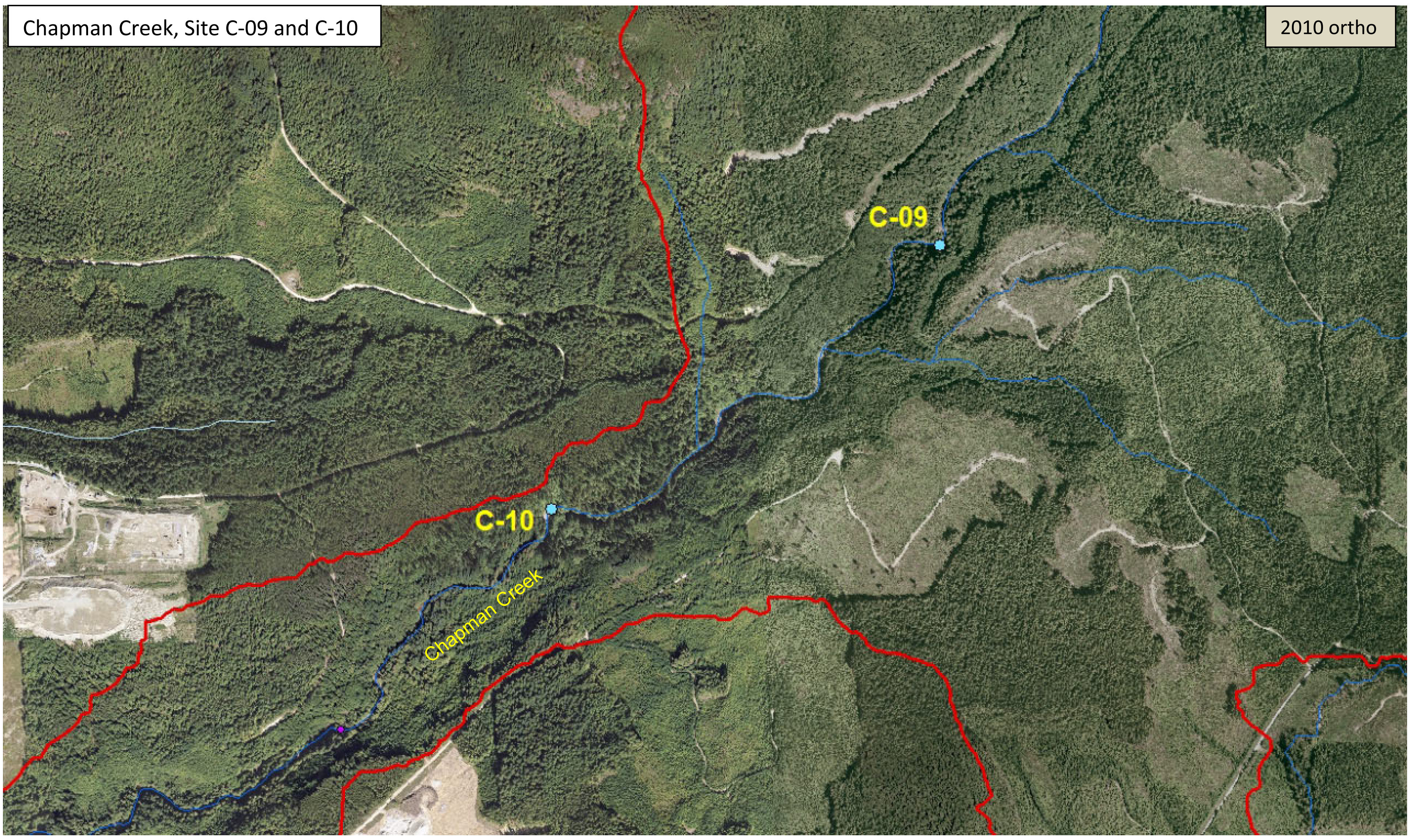
Site C-06. August 23, 2013. Looking north. Old landslide, becoming vegetated. Landslide runs out on toe slope, does not connect to stream.

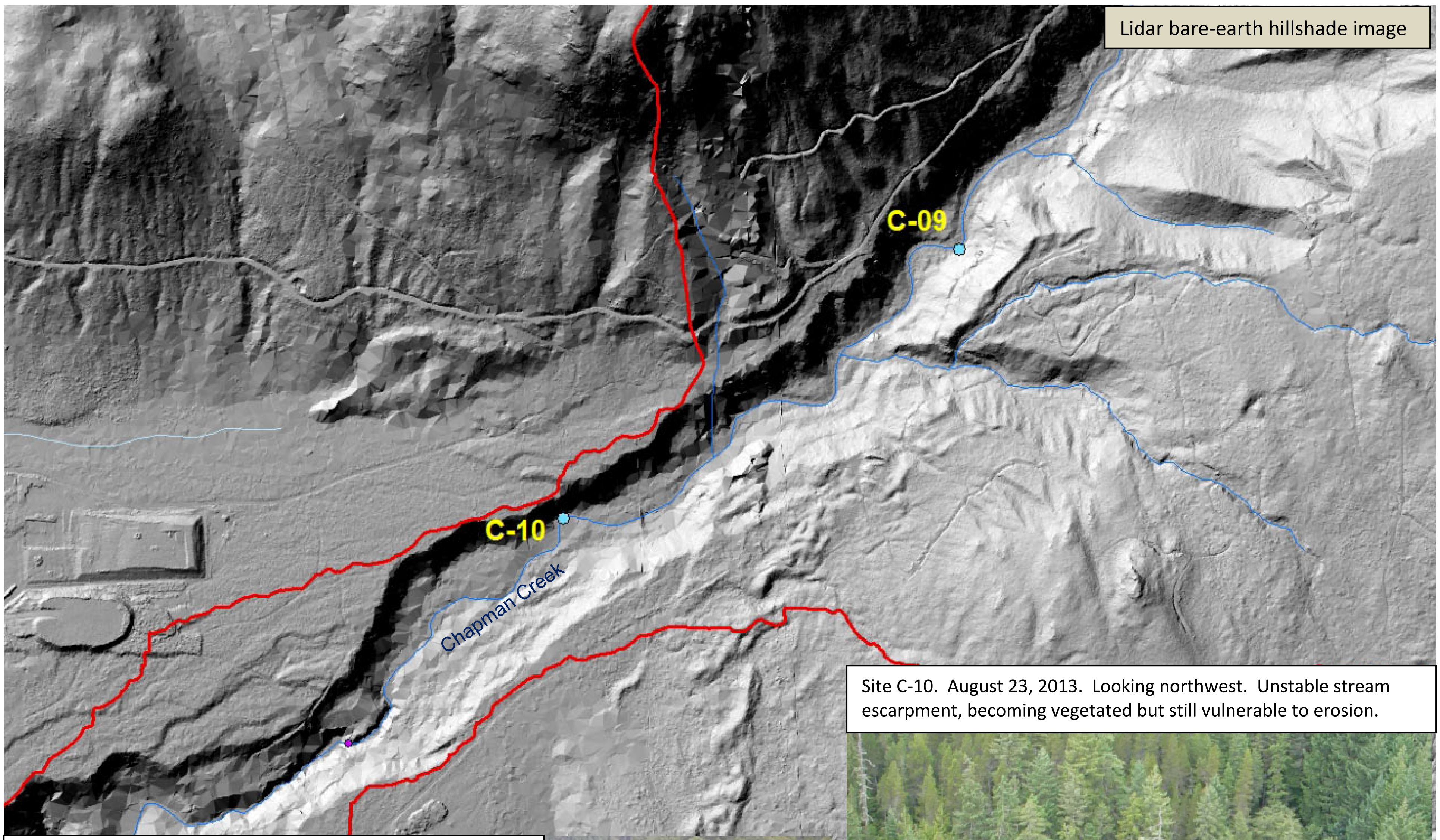
Site C-07. August 23, 2013. Looking west. Slumping till bank, undercut by stream, actively eroding. Unlogged riparian zone.





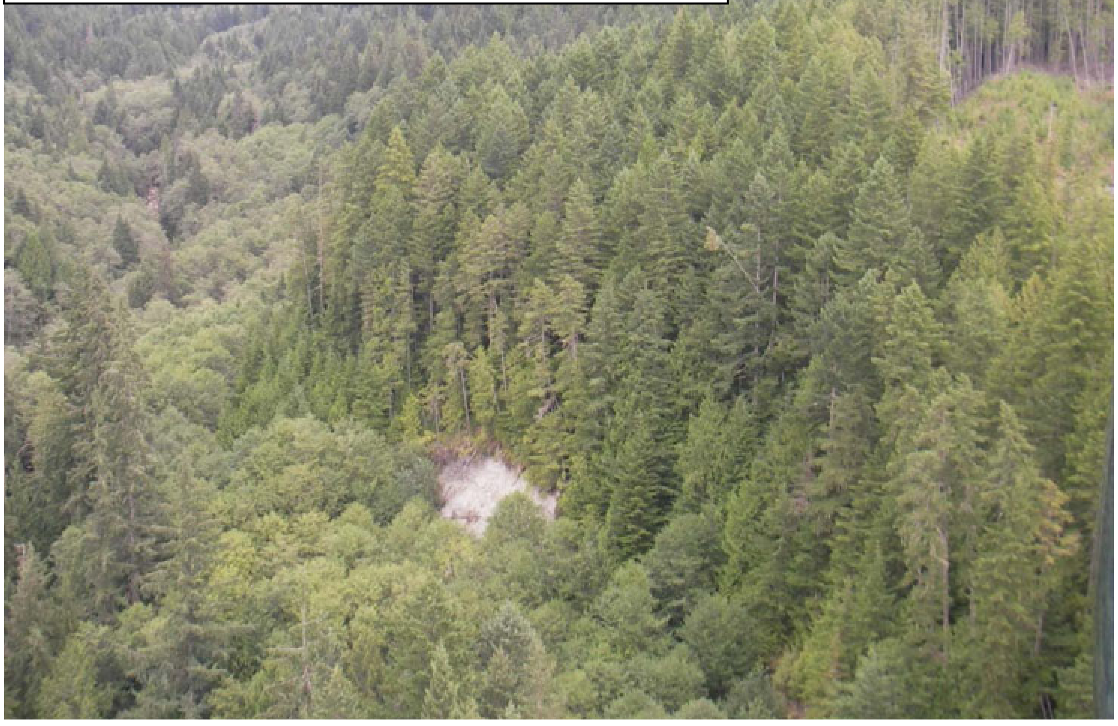
Site C-08. August 23, 2013. Looking northwest. Landslide in stream escarpment, undercut at toe. Becoming vegetated. Unlogged riparian zone.

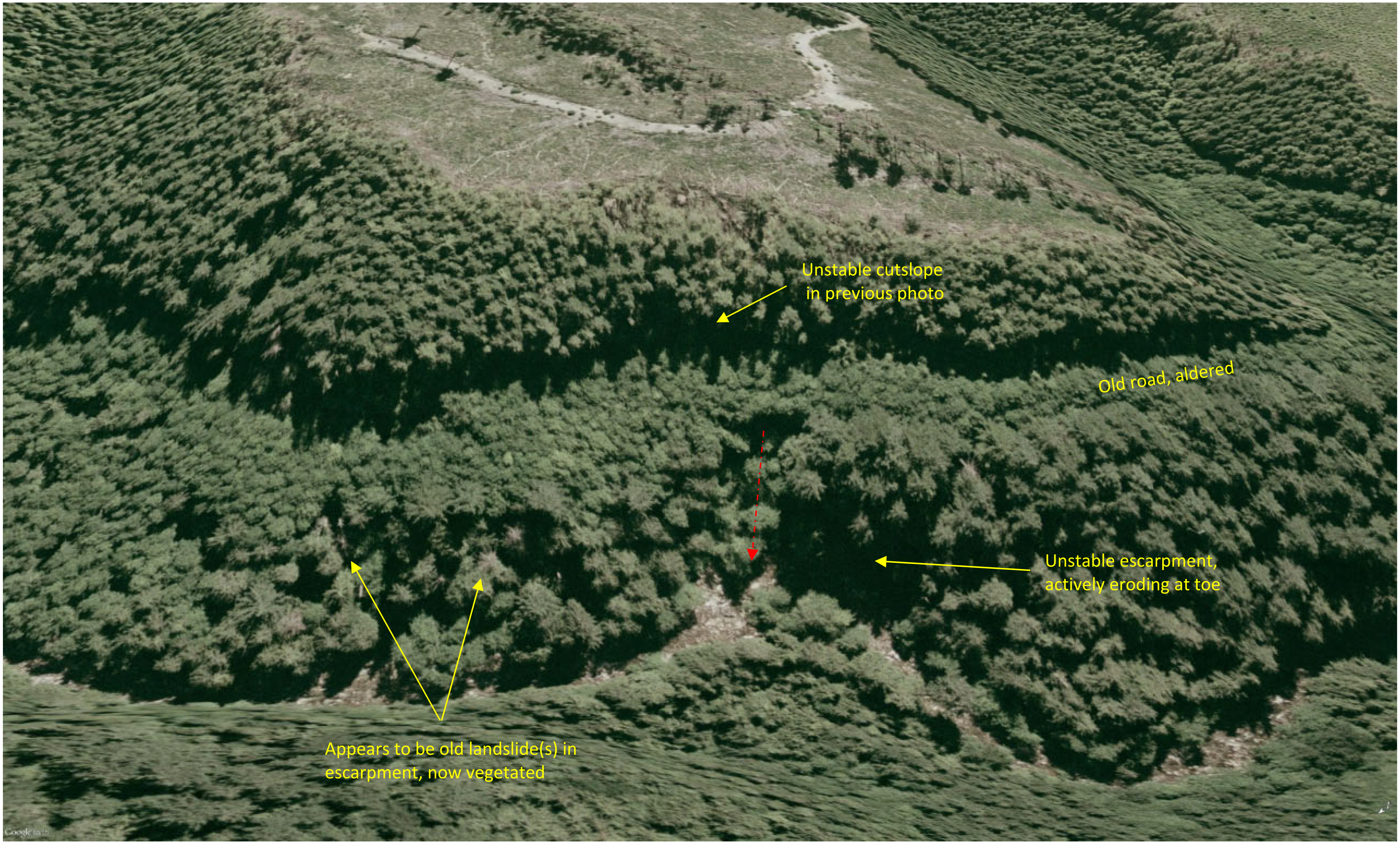




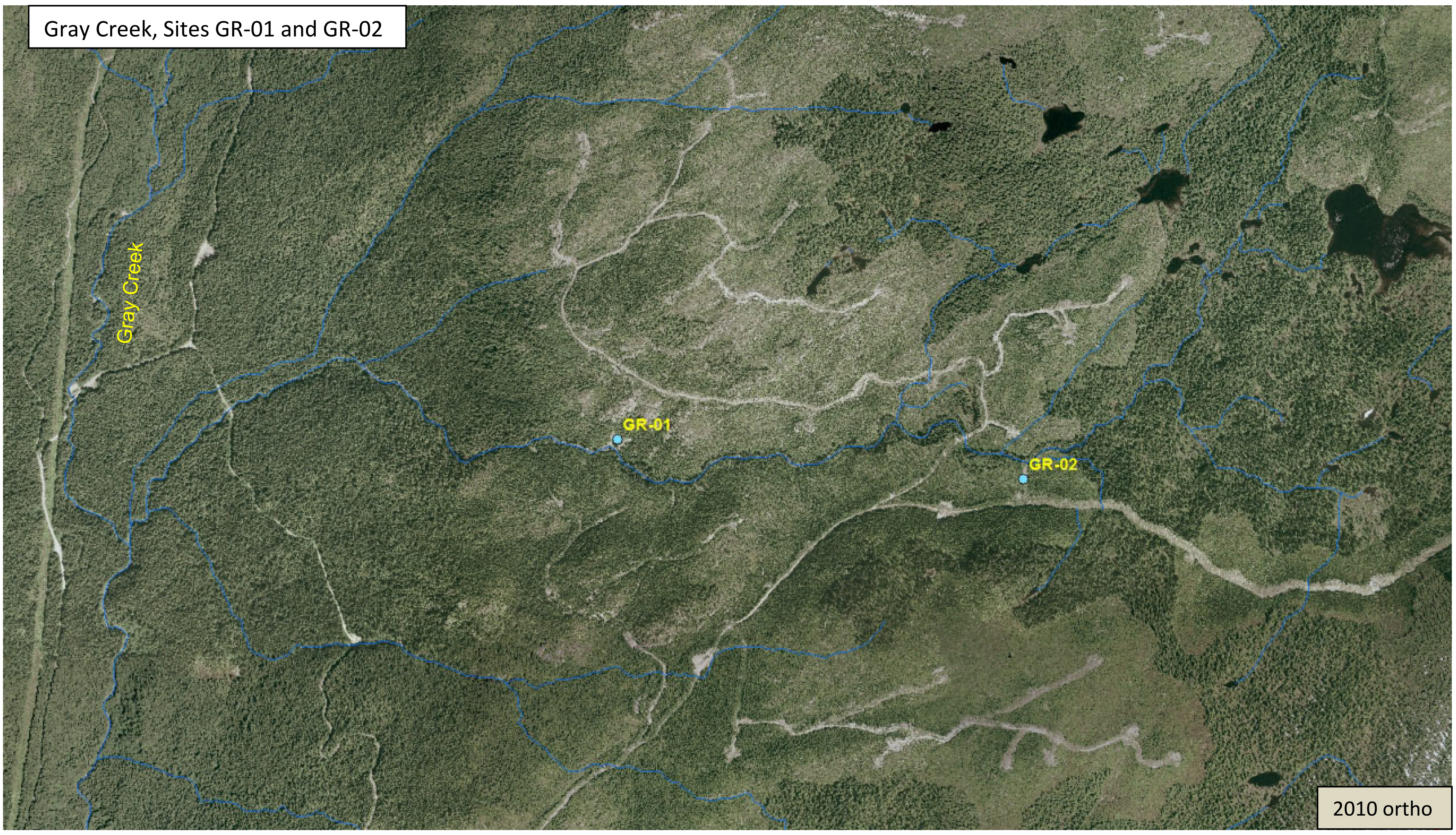
Site C-10. August 23, 2013. Looking northwest. Unstable stream escarpment, becoming vegetated but still vulnerable to erosion.

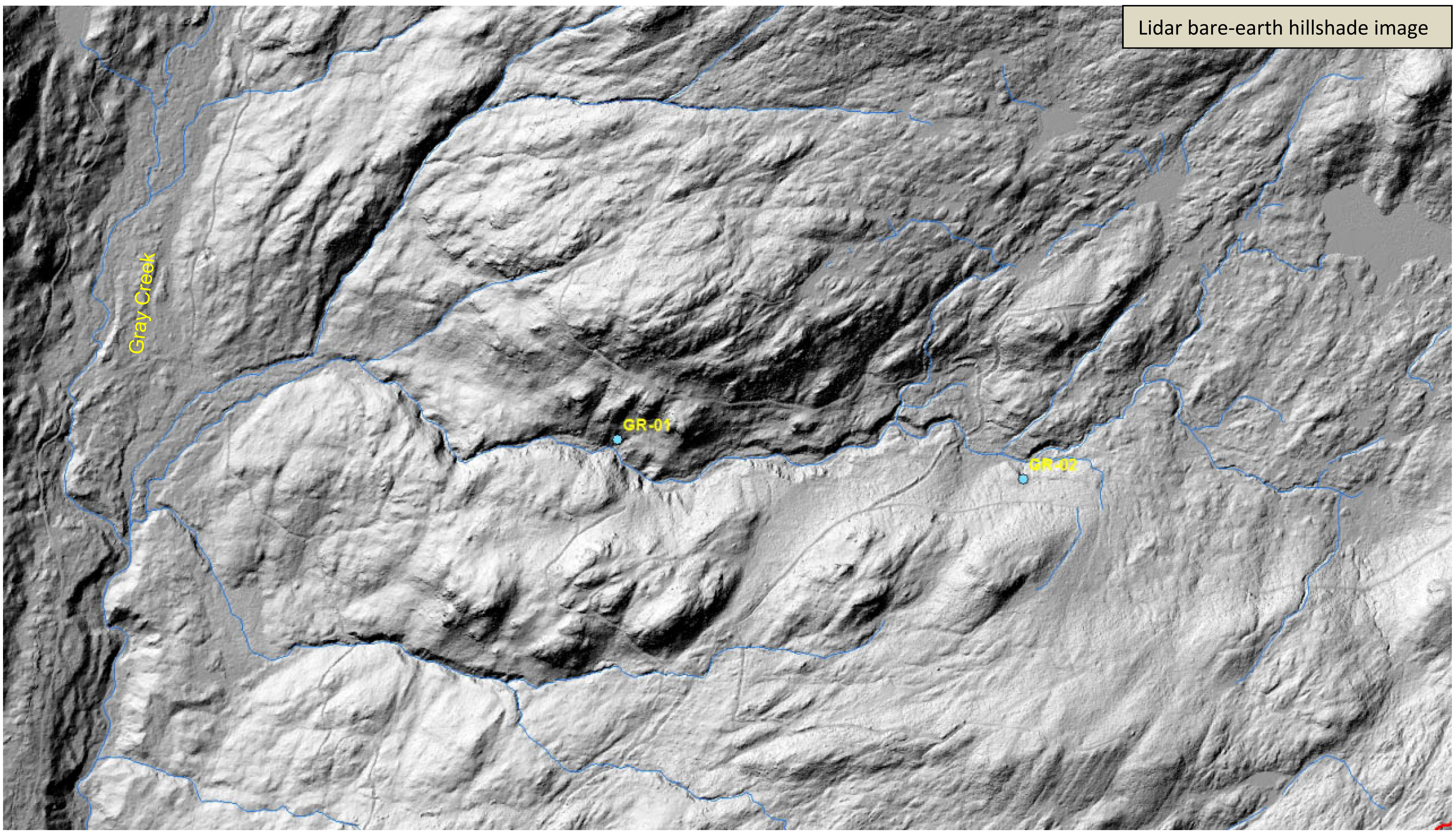
Site C-09. August 23, 2013. Looking northeast along Chapman valley. Unstable cutslope on old aldered road.





Site C-09 cont'd. 2010 Google Earth image. Unstable escarpments, actively eroding at toe, and possible old fillslope failures.





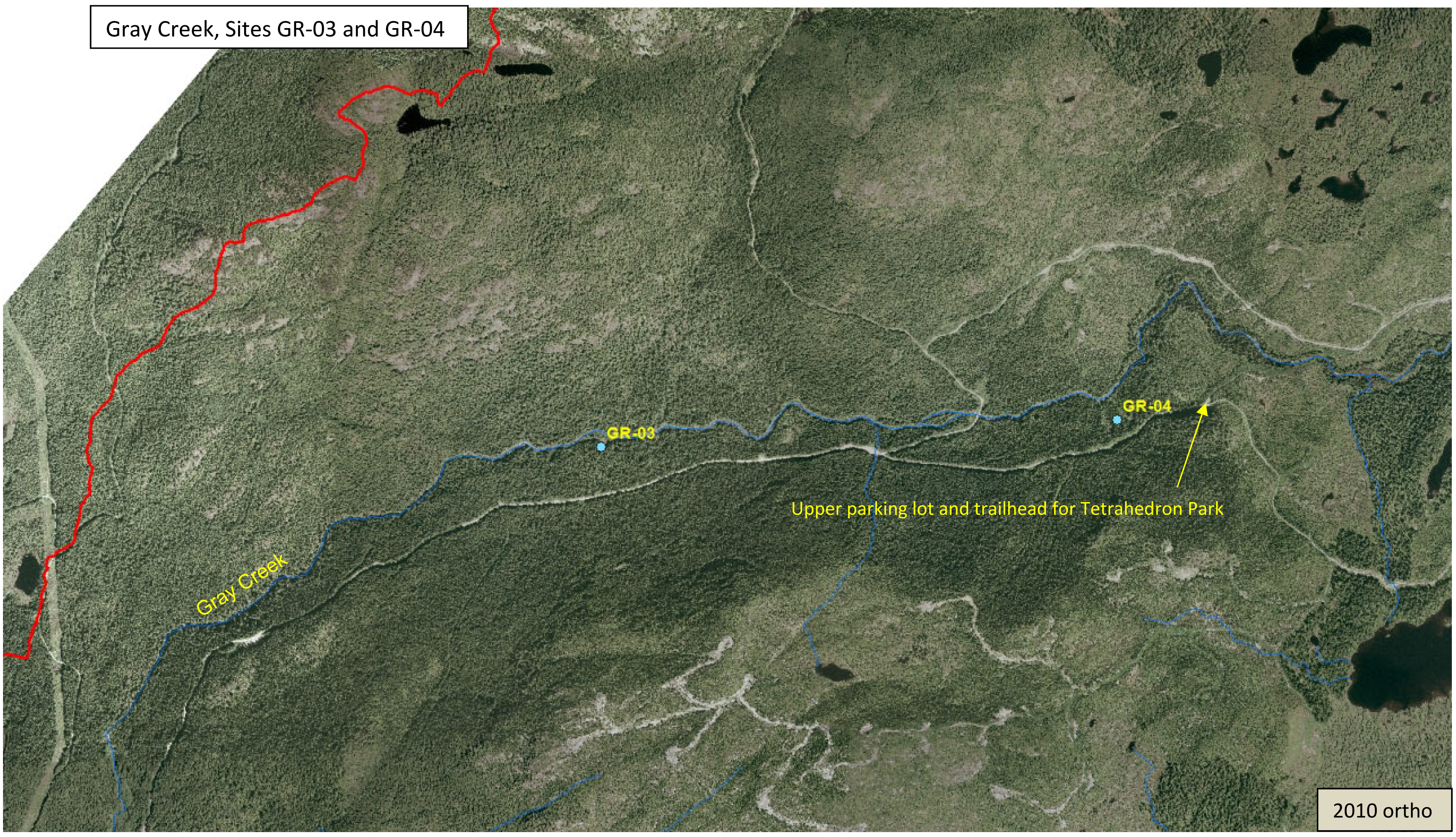
Site GR-01. August 23, 2013. Gray Creek tributary. Looking north at landslide in stream escarpment. Connects to stream at toe of slope, fresh sediment in channel.

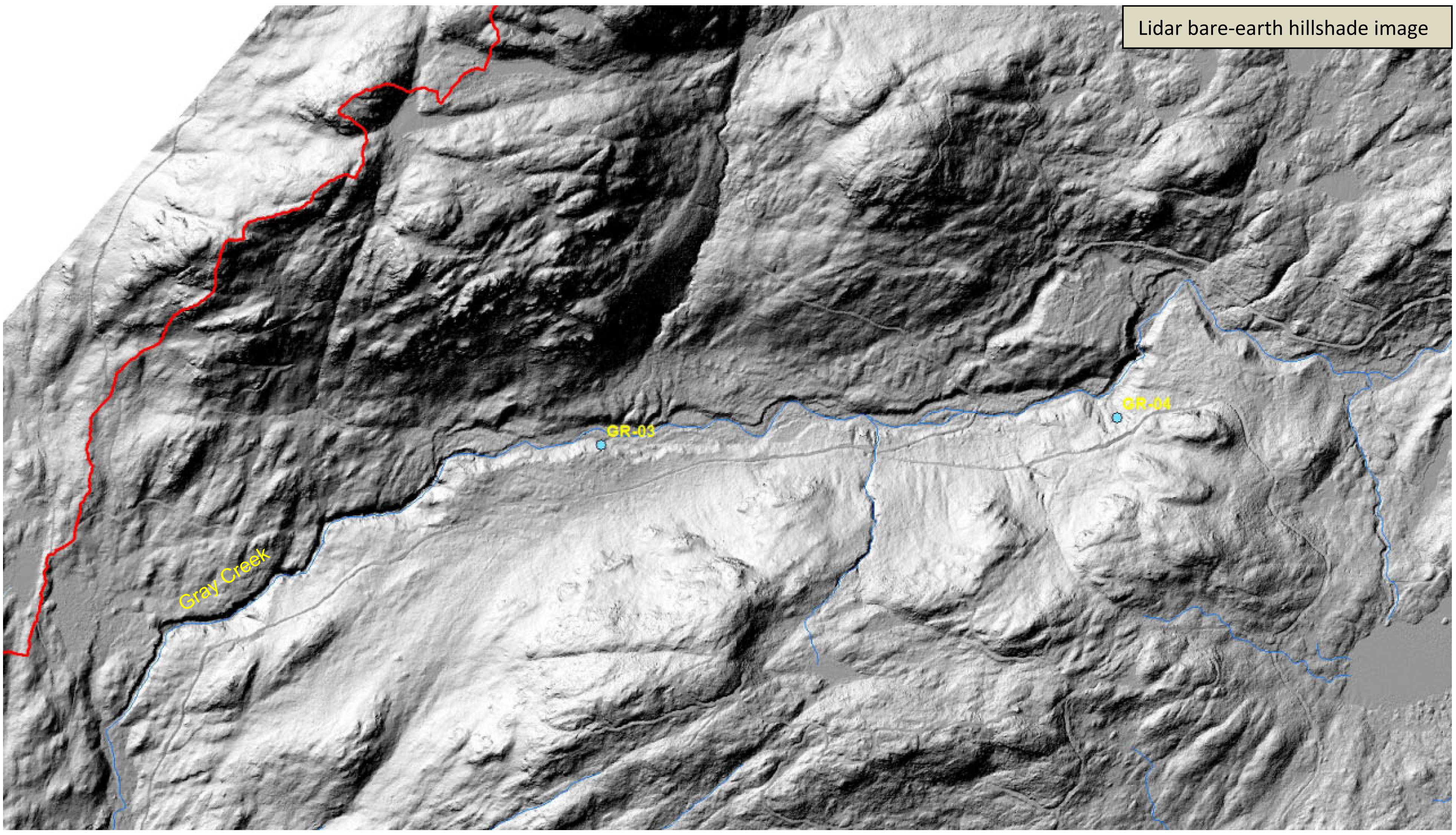
Site GR-02. August 23, 2013. Landslide at break in slope below deactivated road; connects to stream at toe of slope. Appears to have occurred in older landslide track (becoming vegetated) originating at road fill.

Site GR-01 cont'd. 2010 Google Earth image. Landslide paths connect to stream.

Site GR-02 cont'd. 2010 Google Earth image. Landslide path connects to stream.

Gray Creek, Sites GR-03 and GR-04





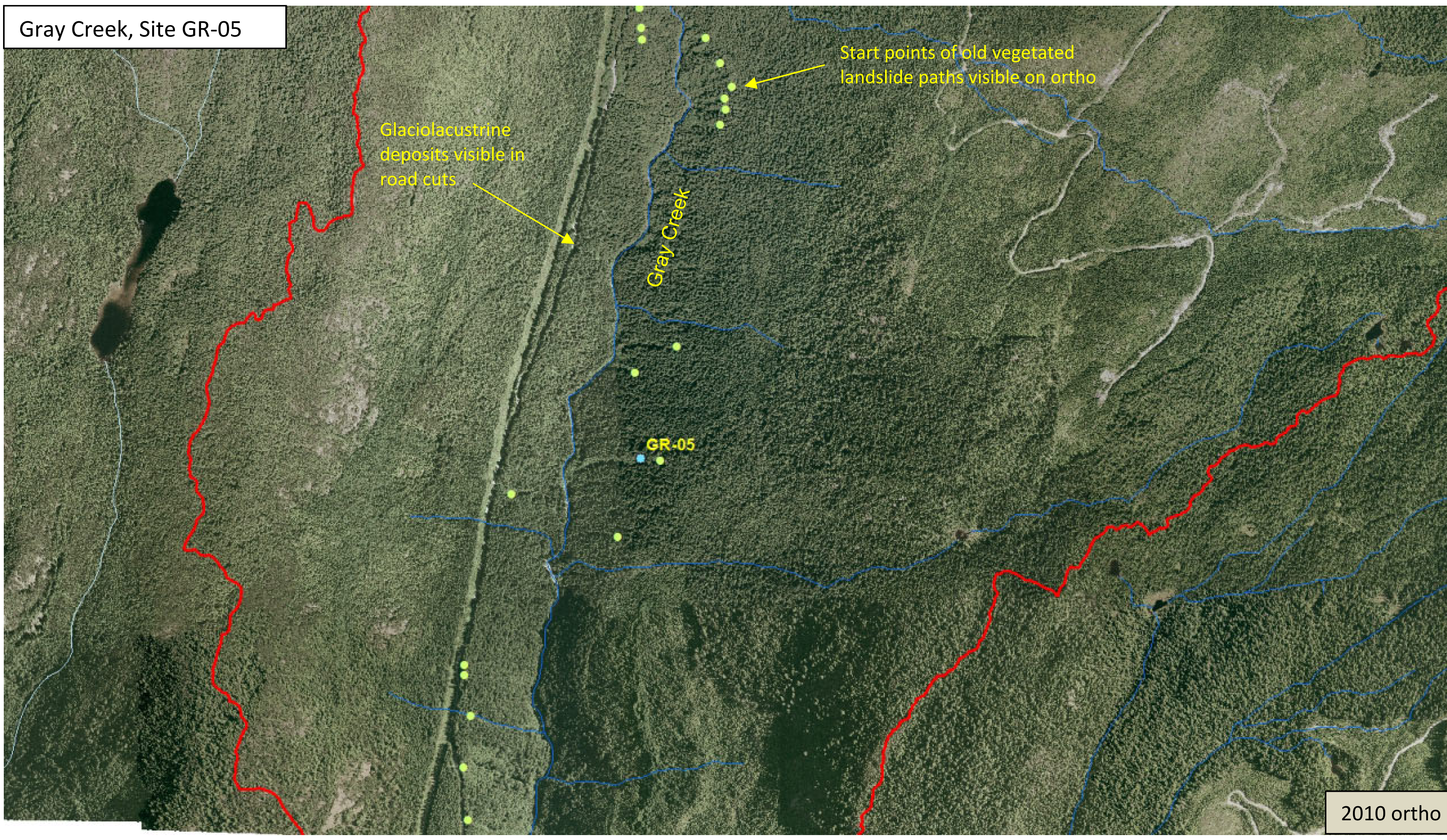
Site GR-03. August 23, 2013. Gray Creek. Looking south at recent landslide in stream escarpment. Connects to stream at toe of slope.

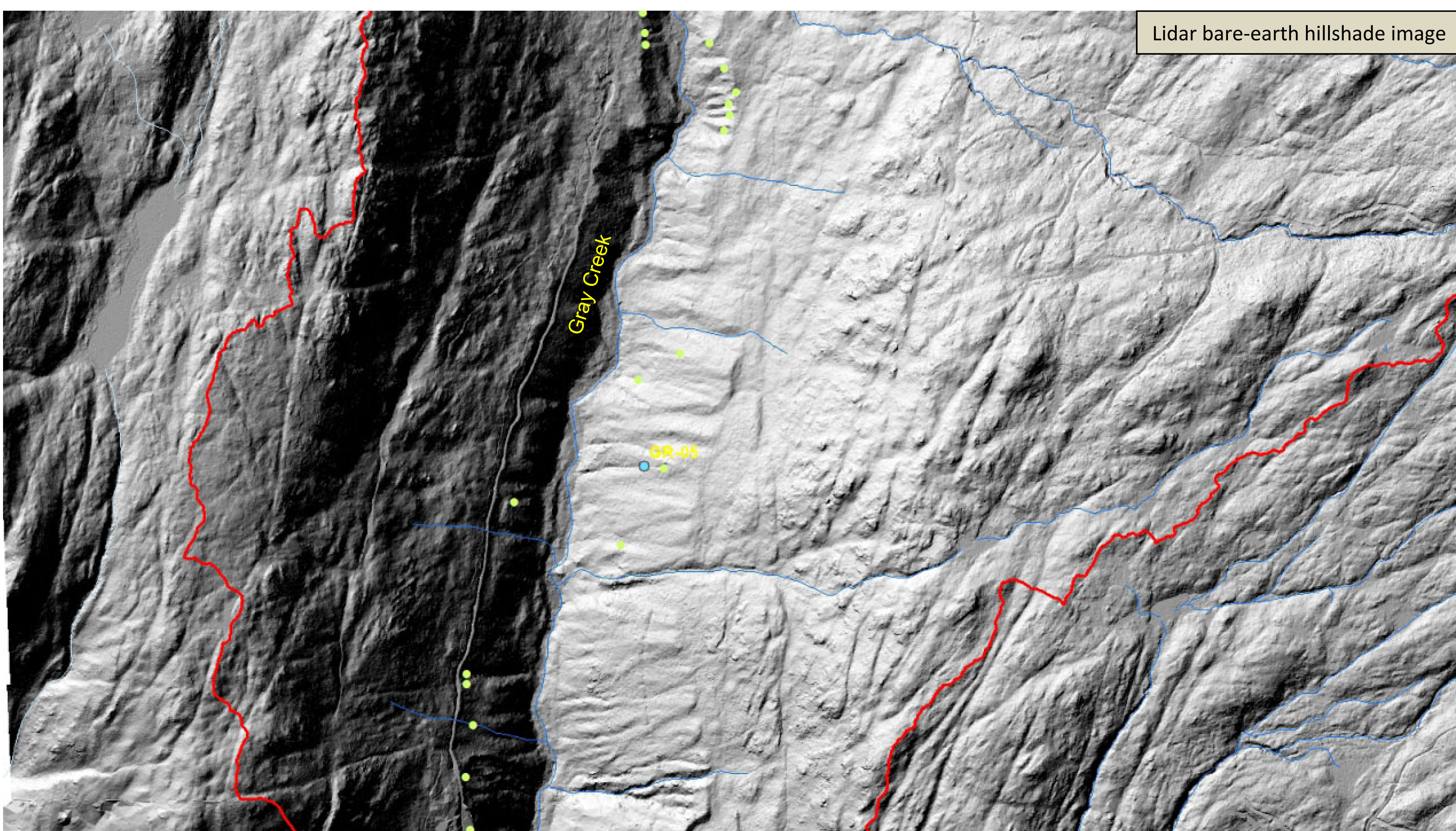
Site GR-04. August 23, 2013. Gray Creek. Looking south at landslides in stream escarpment below road.

Gray Creek, Site GR-03 cont'd. 2010 Google Earth image

Site GR-04 cont'd. 2010 Google Earth image

Gray Creek, Site GR-05



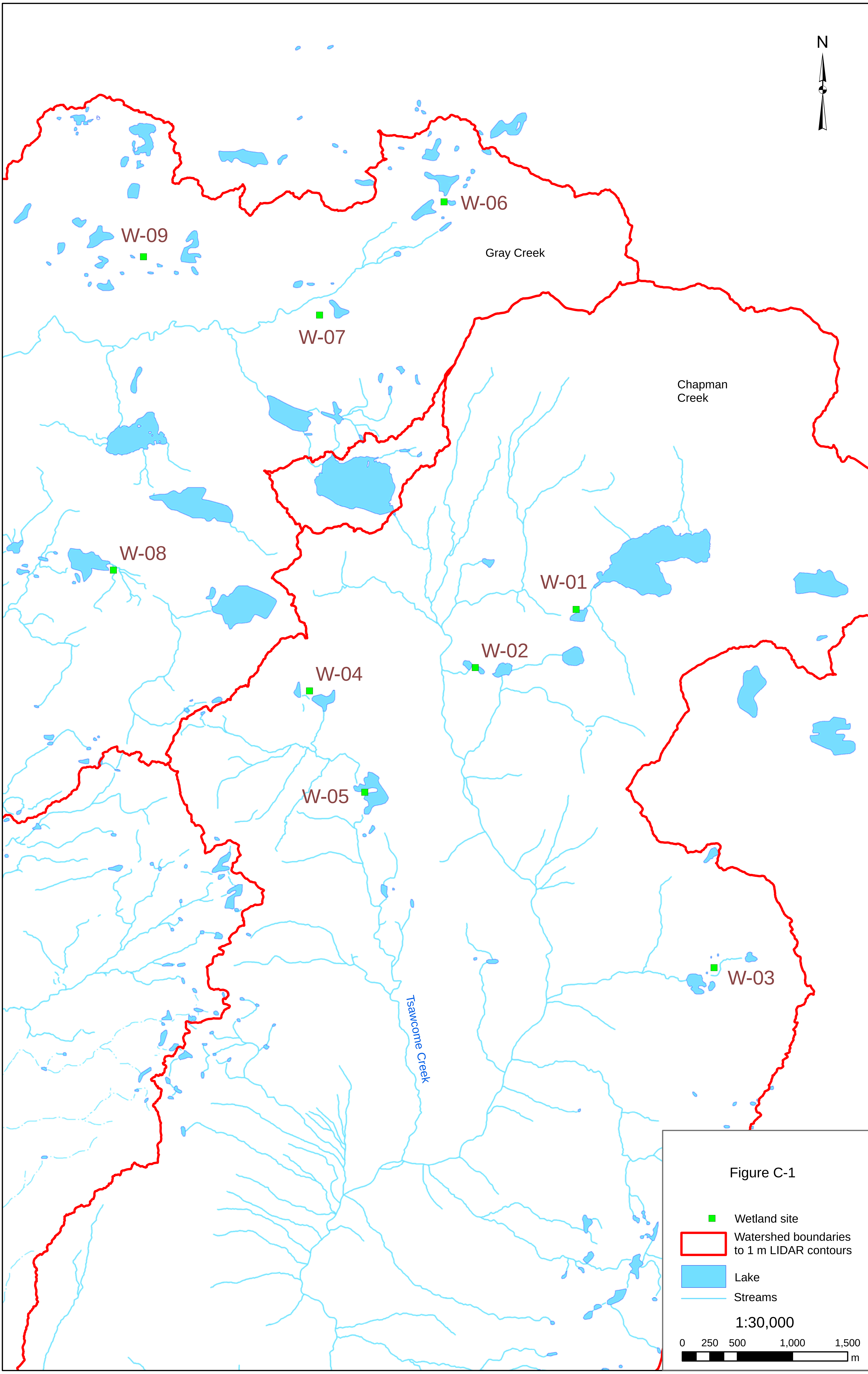


Site GR-05. August 23, 2013. Gray Creek. Numerous vegetated landslide paths visible in lower valley walls.

Site GR-05. August 23, 2013. Gray Creek. Looking east at vegetated landslide path on east side of Gray Creek.

Appendix C

Wetland images – upper Chapman and Gray watersheds


N
W-06
W-09
Gray Creek
W-07
Chapman
Creek
W-08
W-01
W-02
W-04
W-05
W-03
Tsawcome Creek
Figure C-1
Wetland site
Watershed boundaries
to 1 m LIDAR contours
Lake
Streams
1:30,000
0
250
500
1,000
1,500
m

Site W-01. Lakes and wetlands, Upper Chapman Creek Google Earth 2010 image

Control gate at outlet of Chapman Lake

Site W-04. Lakes, ponds and wetland terrain, headwaters of Tsawcome Creek. Google Earth 2010 image.

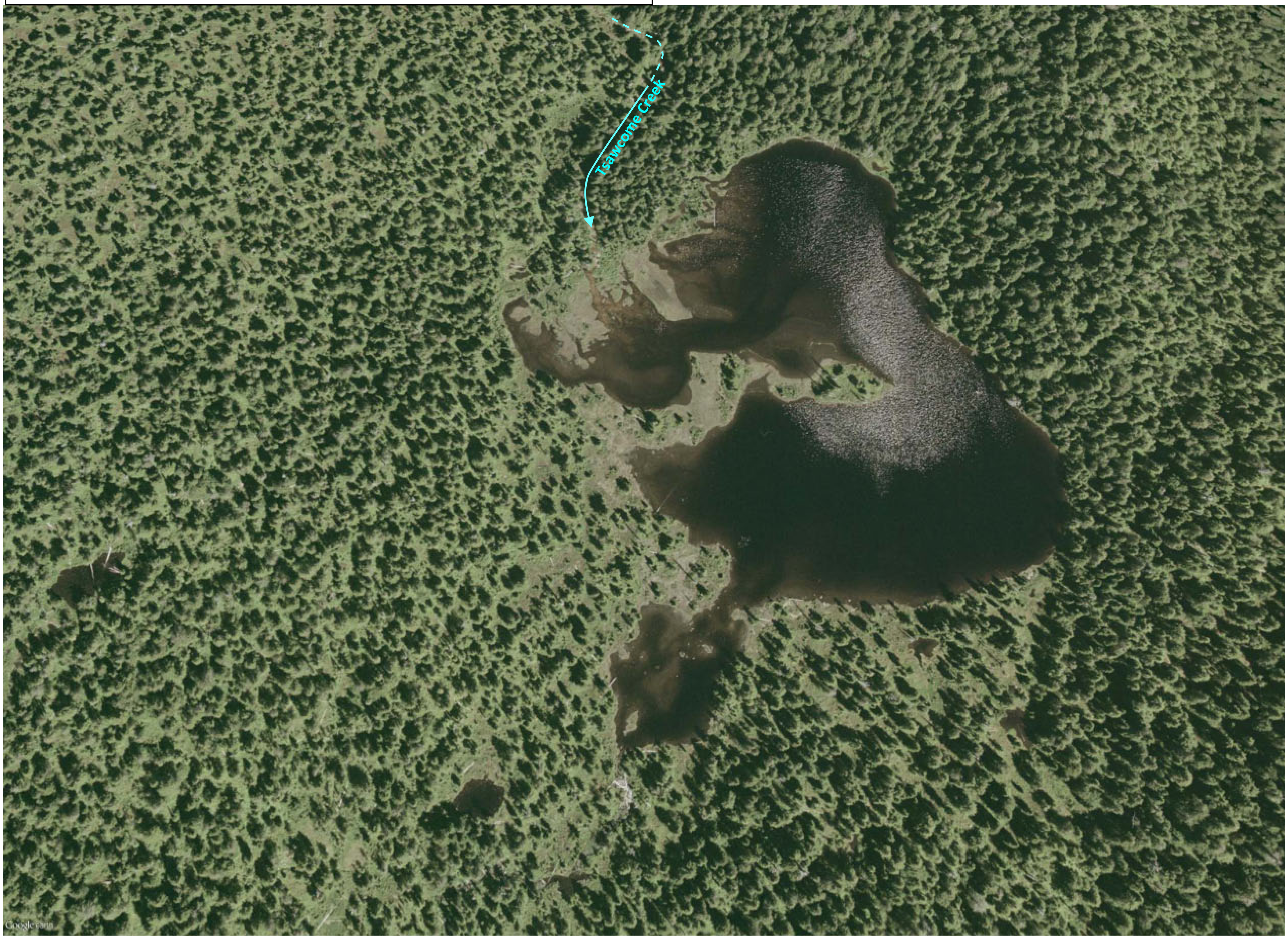
Site W-02. Shallow lakes and wetlands, upper Chapman Creek. Google Earth 2010 image.

Site W-02. Looking west at wetland adjacent to Chapman Creek channel. Photo date: August 23, 2013.

Site W-03. Shallow lakes and wetlands, headwaters of 19 km tributary, Chapman watershed. Google Earth 2010 image

Site W-03. Looking southwest at headwater lakes and wetlands, 19 km tributary, Chapman watershed. Photo date: August 23, 2013.

Site W-05. Lake and wetlands, Tsawcome Creek. Google Earth 2010 image.



Site W-07. Lakes, ponds and wetlands adjacent to Gray Creek, upper watershed. Google Earth image 2010.

Site W-06. Lakes and wetlands, headwaters of Gray Creek. Google Earth 2010 image.

Site W-06. Looking southwest at headwater lakes and wetlands, Gray Creek. Photo date: August 23, 2013.

Site W-08. Lakes, ponds and wetlands, upper Gray watershed. Google Earth 2010 image.

Site W-09. Lakes, ponds and wetlands, upper Gray watershed. Google Earth image 2010.

Appendix D

Roads

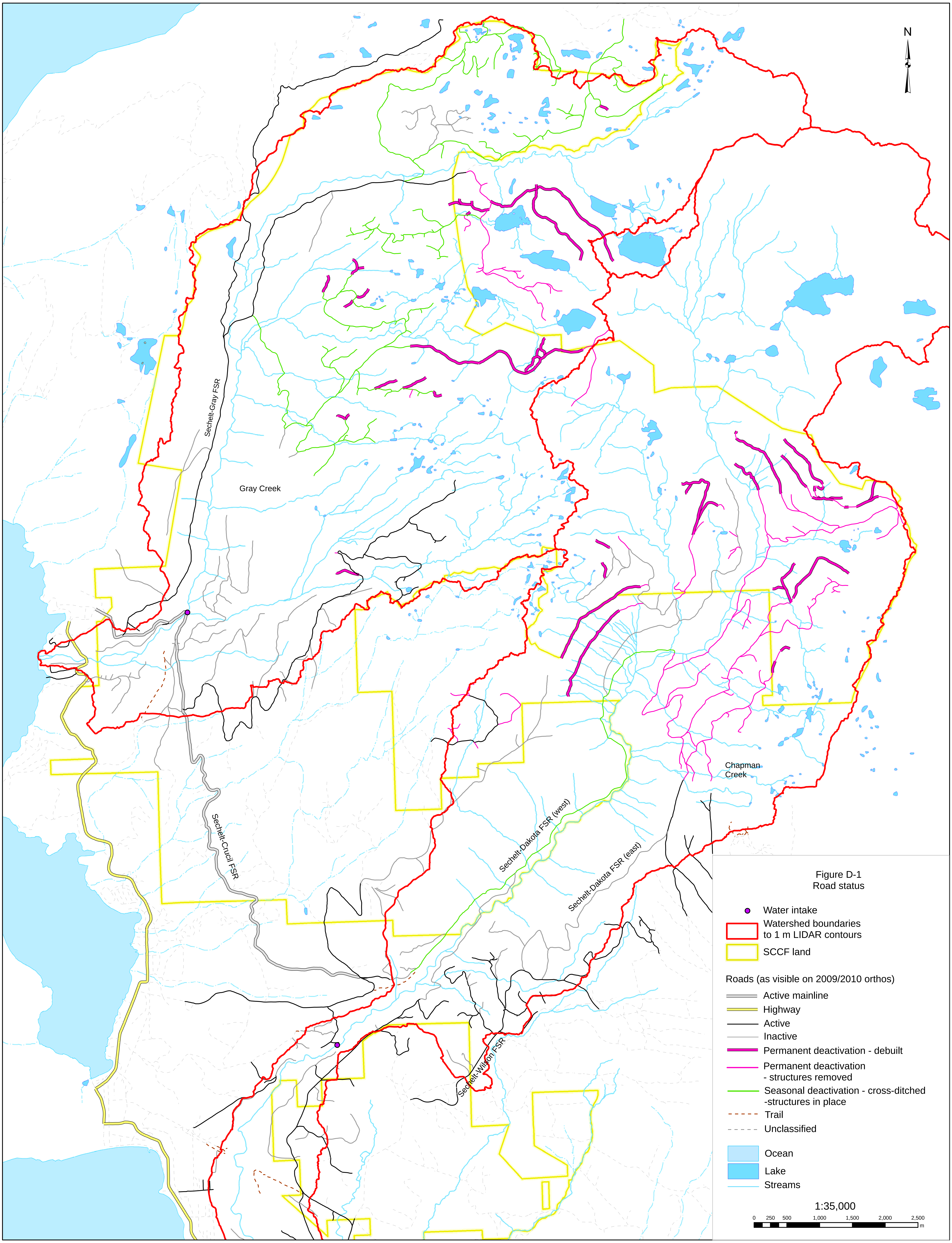
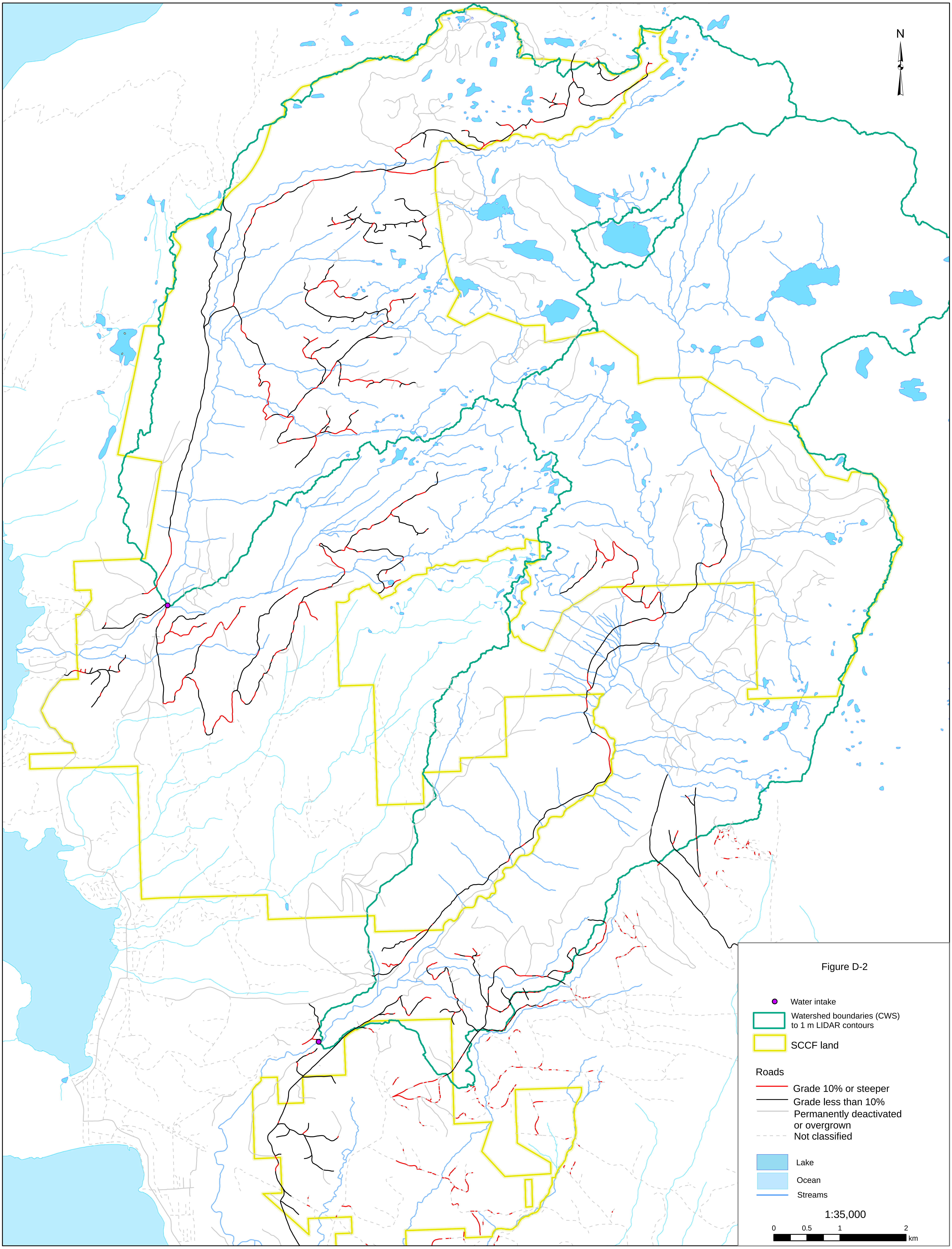
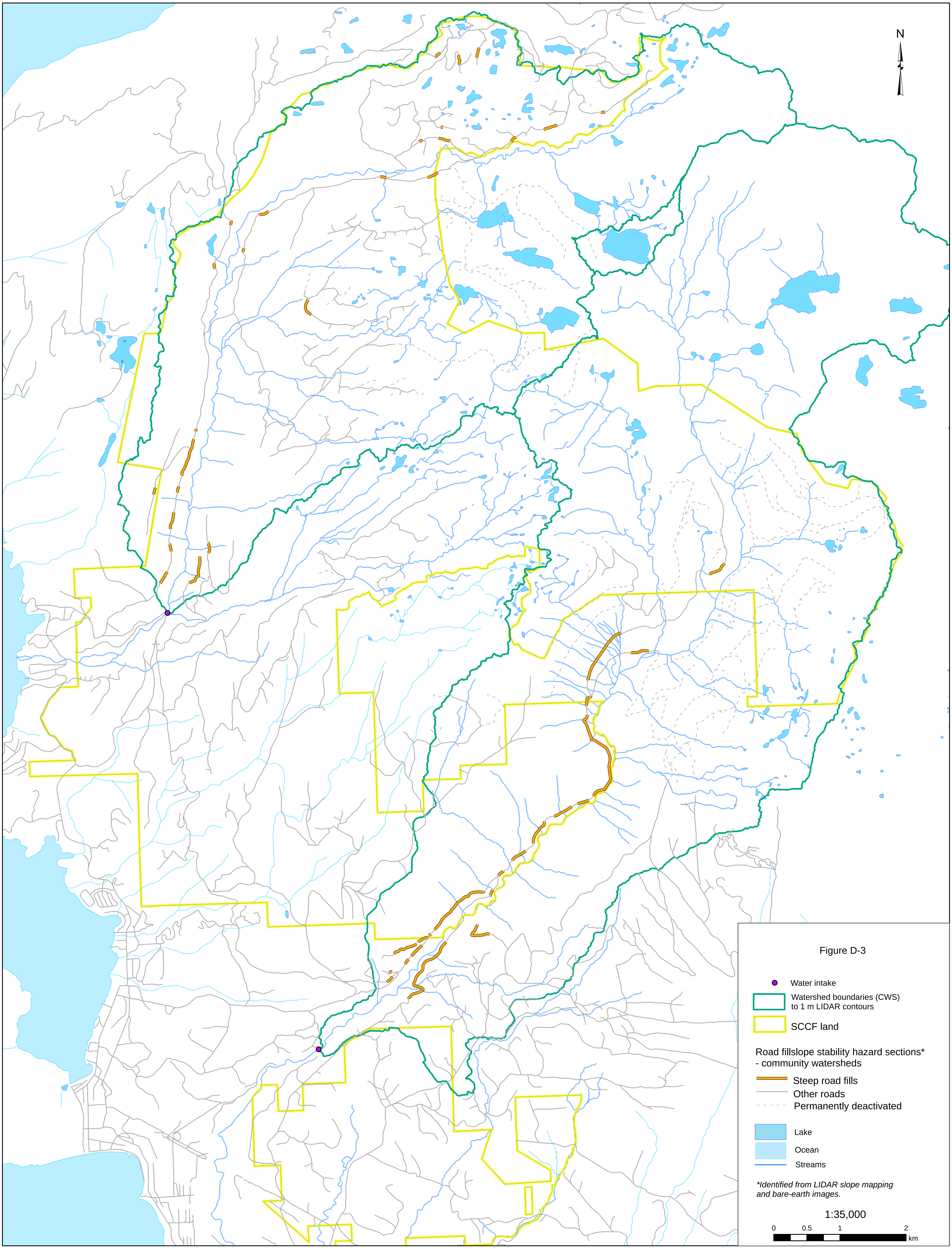
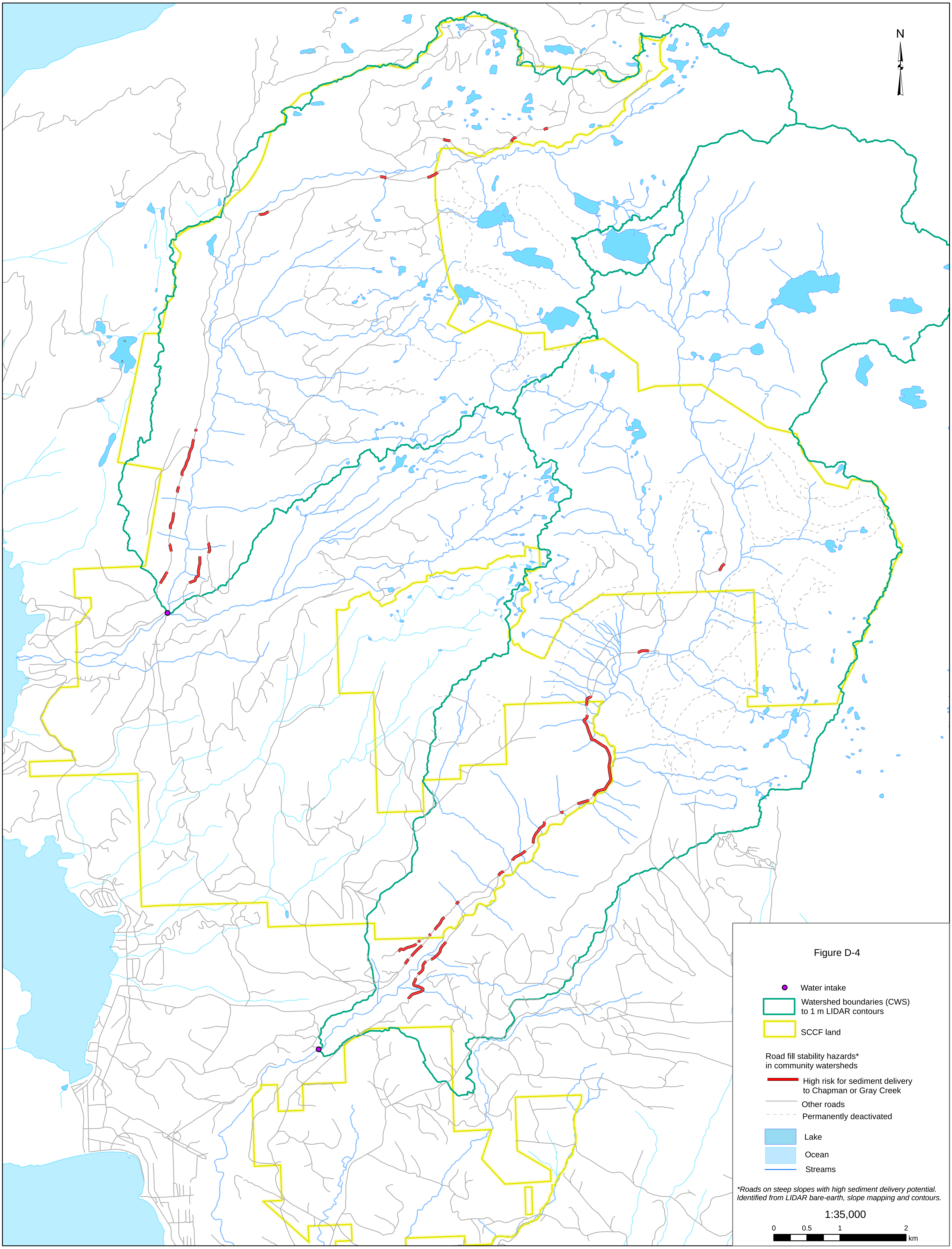
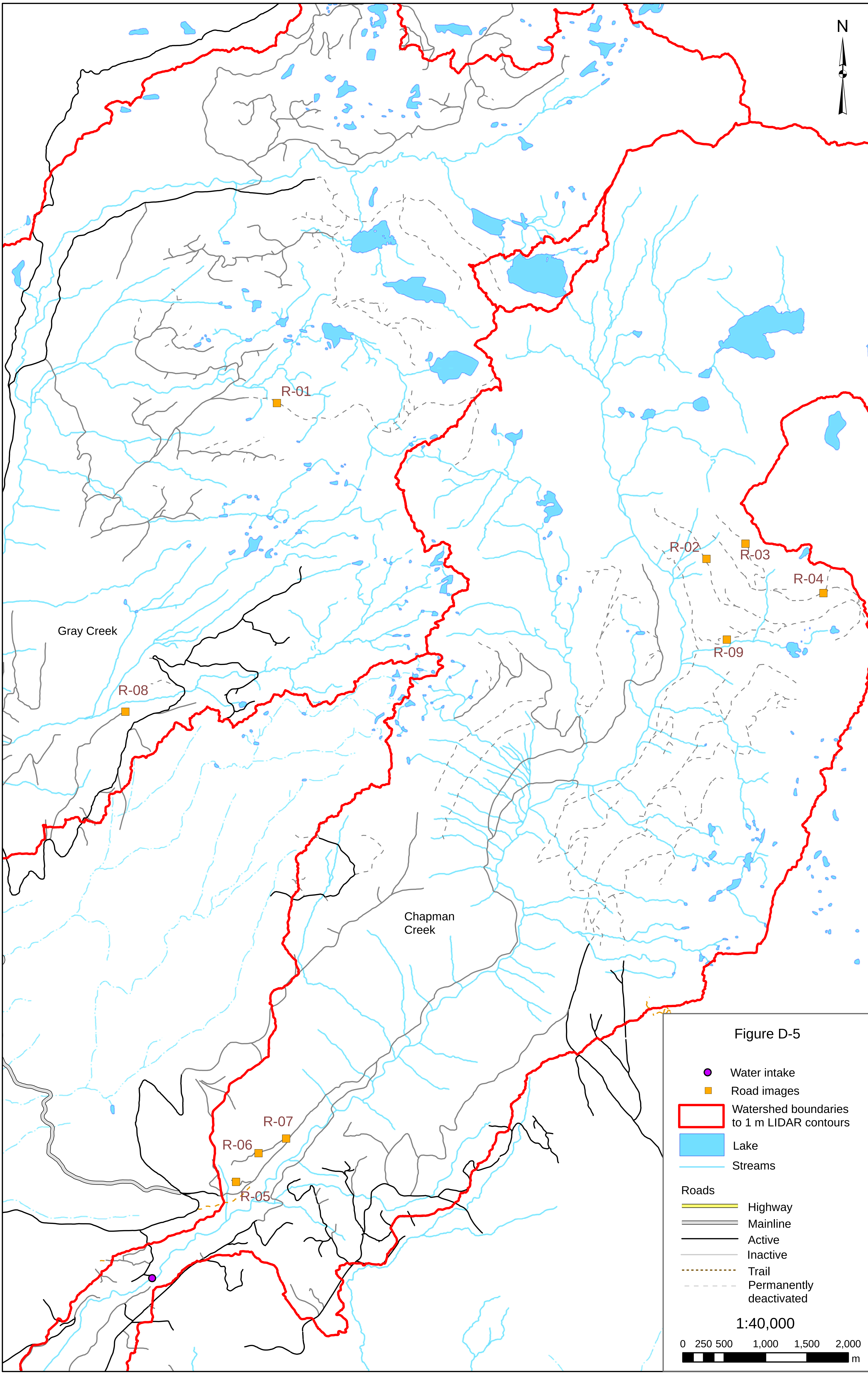


Figure D-1
Road status


N
Figure D-2
Water intake
Watershed boundaries (CWS) to 1 m LIDAR contours
SCCF land
Roads
Grade 10% or steeper
Grade less than 10%
Permanently deactivated or overgrown
Not classified
Lake
Ocean
Streams
1:35,000
0
0.5
1
2
km


N
Figure D-3
Water intake
Watershed boundaries (CWS) to 1 m LIDAR contours
SCCF land
Road fillslope stability hazard sections* - community watersheds
Steep road fills
Other roads
Permanently deactivated
Lake
Ocean
Streams
*Identified from LIDAR slope mapping and bare-earth images.
1:35,000
0
0.5
1
2
km


N
Figure D-4
Water intake
Watershed boundaries (CWS) to 1 m LIDAR contours
SCCF land
Road fill stability hazards* in community watersheds
High risk for sediment delivery to Chapman or Gray Creek
Other roads
Permanently deactivated
Lake
Ocean
Streams
*Roads on steep slopes with high sediment delivery potential. Identified from LIDAR bare-earth, slope mapping and contours.
1:35,000
0 0.5 1 2
km



N
R-01
R-02
R-03
R-04
R-09
R-08
Gray Creek
Chapman
Creek
R-07
R-06
R-05
Figure D-5
Water intake
Road images
Watershed boundaries
to 1 m LIDAR contours
Lake
Streams
Roads
Highway
Mainline
Active
Inactive
Trail
Permanently
deactivated
1:40,000
0 250 500 1,000 1,500 2,000
m

Site R-01. Debuilt road with cross-ditches, upper Gray Creek. Google Earth 2010 image.

Site R-02. Road deactivation, east side of Chapman Creek valley.   Google Earth image 2010.

Site R-03. Debuilt upper road section, east side of Chapman valley. Vertical logs erected for wildlife ("Woodhenge"). Google Earth 2010 image.

Site R-04. Debuilt road with crossditches, upper Gray watershed. Google Earth image 2010.

Site R-05. Spur road on AJB land, lower Chapman Creek. Google Earth 2010 image. See also Field Stop #43.

Site R-06. Spur road on AJB land, lower Chapman Creek. Google Earth image 2010.

Site R-07. Steep gradient section of spur road. Google Earth image 2010. See also Field Stop #18.

Photo R-08. Debuilt road in lower Gray Creek. Photo date: August 23, 2013.

Photo R-09. Overgrown road, km 19 tributary valley, Chapman Creek. August 23, 2013.

Appendix E

Streams

Stream channel types

"Alluvial" streams as used here are low gradient (less than 8%) with alluvial channel bed and bank material, where one or both banks are in alluvial deposits. Essentially, these are streams with flanking floodplains, even though the extent of the floodplain beyond the active channel may be quite narrow.

"Alluvial" as used in this assessment is consistent with "active fluvial units" in the CIT reports[1]. Fans may also be active fluvial units; there are several small fans in the community watersheds of Gray and Chapman Creek, and an active fan downstream of the SCRD intake in Gray Creek. Alluvial streams on active fans may have gradients steeper than 8%.

"Semi-alluvial" streams are low-gradient streams (less than 8%) in confined channels with fluvially transported bed material, and banks in non-alluvial deposits or in terraces (e.g. glaciofluvial) that rarely or no longer inundate (e.g., return interval more than 30 years).

"Non-alluvial" streams are typically steeper gradient streams (greater than 8%) that are bedrock or boulder controlled but may have forced alluvial or semi-alluvial morphologies at choke points ("vertical jams"); or have log steps that store sediment (upland or headwater streams). Low-gradient streams that have primarily bedrock or boulder-dominated channels are also non-alluvial streams.

In alluvial streams, the riparian forest has essential functions in controlling bank erosion, providing large wood debris (LWD) and maintaining channel processes. LWD is important in all sizes of alluvial streams. Loss of riparian forest can cause significant, and often long-term, channel impacts.

Riparian forest and understory vegetation on a floodplain provides surface roughness which slows overbank flows, promotes deposition of transported sediment, reduces channel erosion rates and increases flood elevations (source: Belt et al. 1992). Altering or removing the floodplain forest can cause changes to these processes. In large alluvial streams, LWD naturally accumulates in jams which can break up in peak floods, transport and reform as flow subsides. These jams dam sediment, cause flow diversions and create scour pools. They can cause major shifts in channel morphology (Montgomery et al. 2003) and increase flood elevations (Brummer et al. 2006). When a stream migrates away from a jam in response to wood and/or sediment accumulation, the jam may persist until it decays in place.

In small semi-alluvial and non-alluvial streams with low transport capacity, where LWD spans or nearly spans the channel, LWD from the riparian forest forms steps and plunge pools, influences flow patterns, limits sediment transport, dissipates energy and increases hydraulic variability; all of which results in complexity of aquatic habitat. Individual pieces entering the

[1] Coast Information Team – scientific advisory team for the central and north coast ecosystem-based management planning process.

stream can cause local scour or local stream bank erosion (Keller and Swanson 1979, Hassan et al. 2005).

In semi-alluvial and non-alluvial streams with high transport capacity, LWD often has limited to no geomorphic function. The importance of the riparian forest for these channels is primarily its influence on stability of the adjacent slopes, which depends on the slope conditions.

LWD in a stream reach can come from one or more of the following sources:

- Falling in from the adjacent riparian forest as a result of tree mortality, windthrow, bank erosion or failing escarpments
- Landslides or snow avalanches initiating upslope and entering the channel, either directly from the adjacent slope or indirectly via gully systems
- Fluvial transport into the reach from upstream sources

Most LWD contributed from the adjacent forest through tree mortality, windthrow or bank erosion comes from within 10 m of the stream. Studies in Southeast Alaska (Martin and Grotefendt, 2007) found that 95% of LWD in streams in buffered units was derived from within 30 m of the channel, whereas in unlogged stands, 96% of LWD was derived from within 20 m; and further, that 81% and 89% of LWD came from within 10 m of the channel for buffer and unlogged stands respectively. On steep slopes, trees will travel farther down the slope as they fall, and thus wood will be contributed from greater distances than on slopes where trees simply overturn (source: Belt et al. 1992) For streams that receive wood from logs that span the banks, the wood in the stream enters over prolonged periods of time (decades). In streams without sufficient energy to transport the size of wood in the stream, wood structures persist in-situ until they decay and break up (Bahuguna et al. 2010).

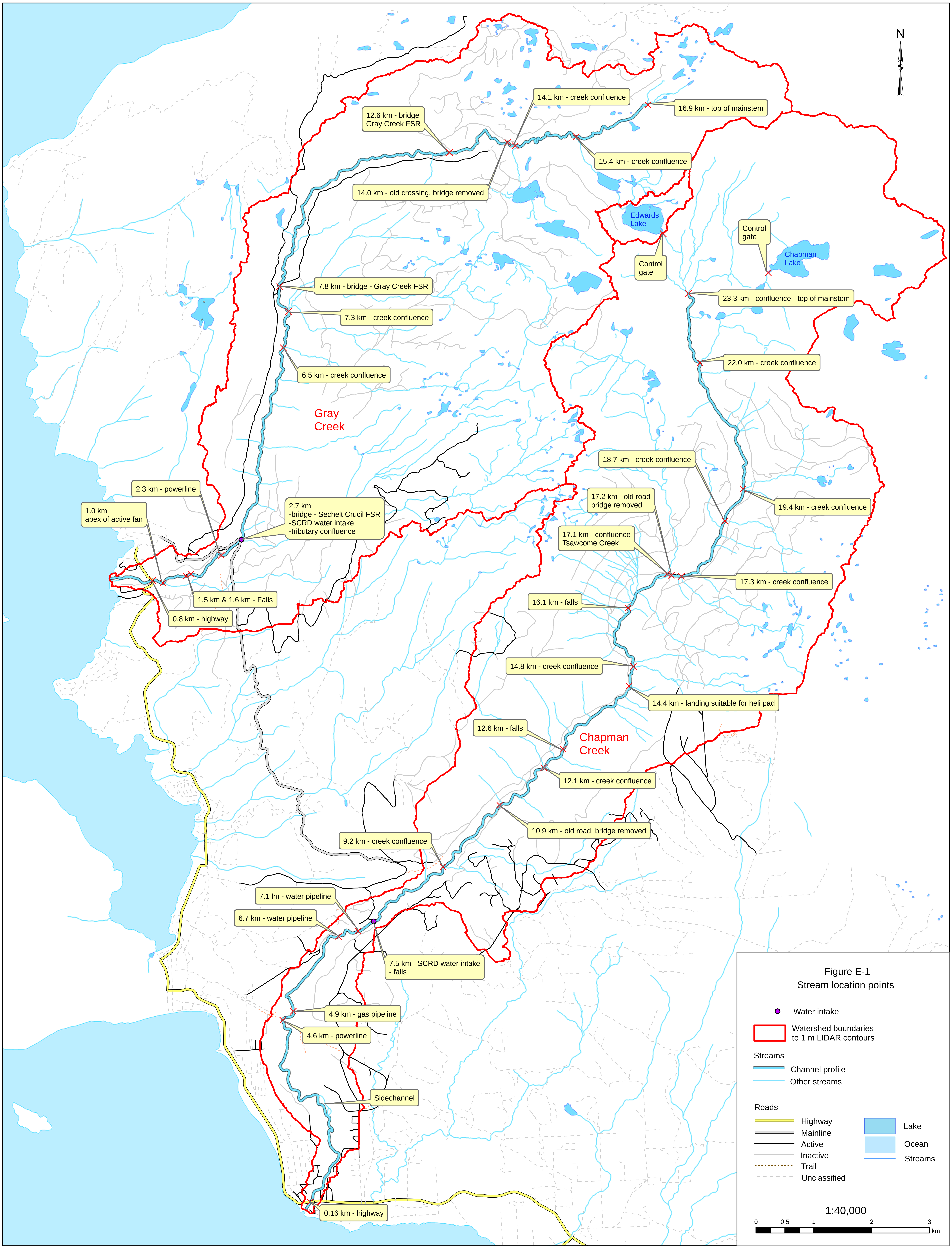


Figure E-1
Stream location points

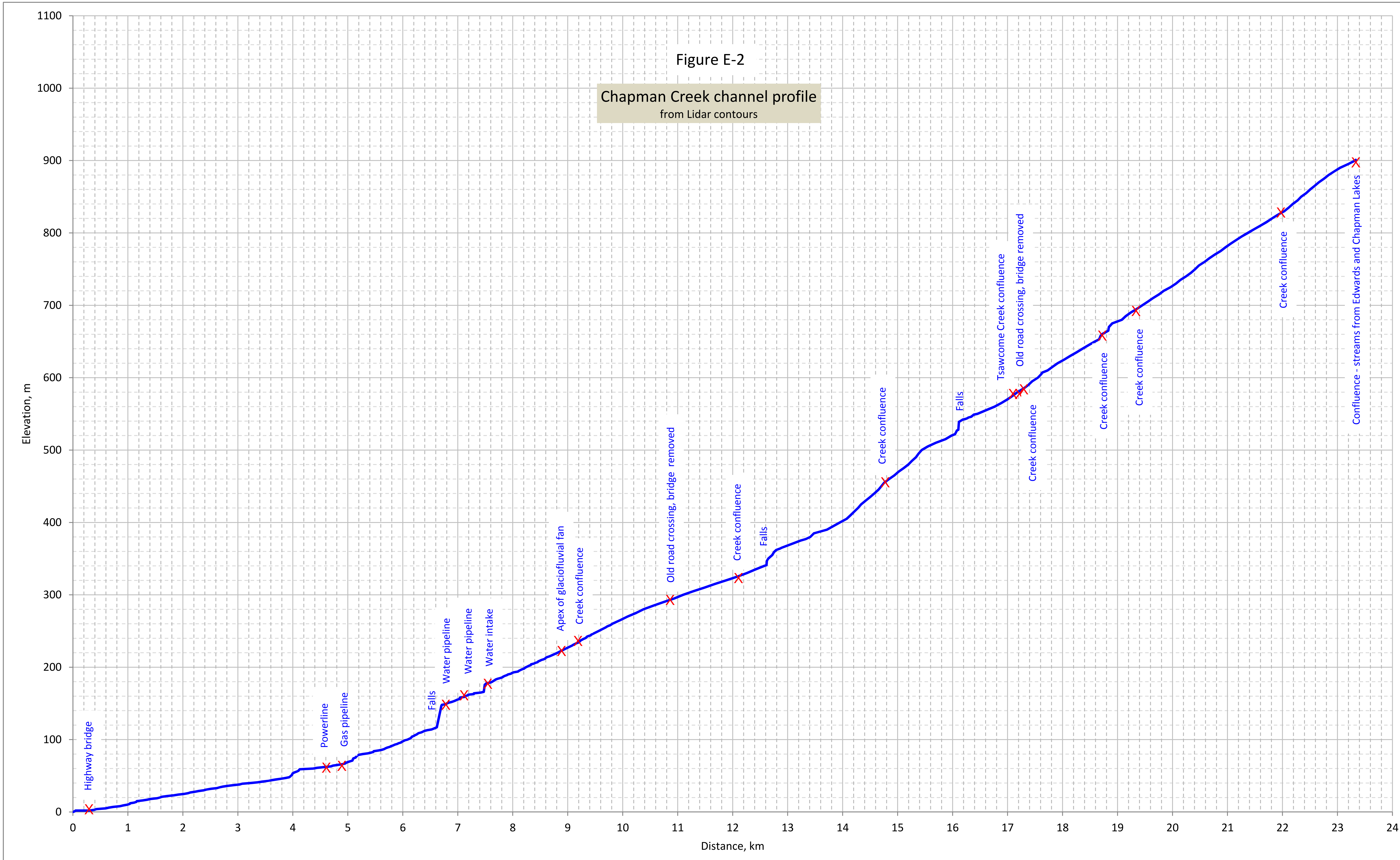


Figure E-2
Chapman Creek channel profile
from Lidar contours
Elevation, m
Distance, km
Highway bridge
Powerline
Gas pipeline
Falls
Water pipeline
Water pipeline
Water intake
Apex of glaciofluvial fan
Creek confluence
Old road crossing, bridge removed
Creek confluence
Falls
Creek confluence
Falls
Tsawcome Creek confluence
Old road crossing, bridge removed
Creek confluence
Creek confluence
Creek confluence
Creek confluence
Confluence - streams from Edwards and Chapman Lakes

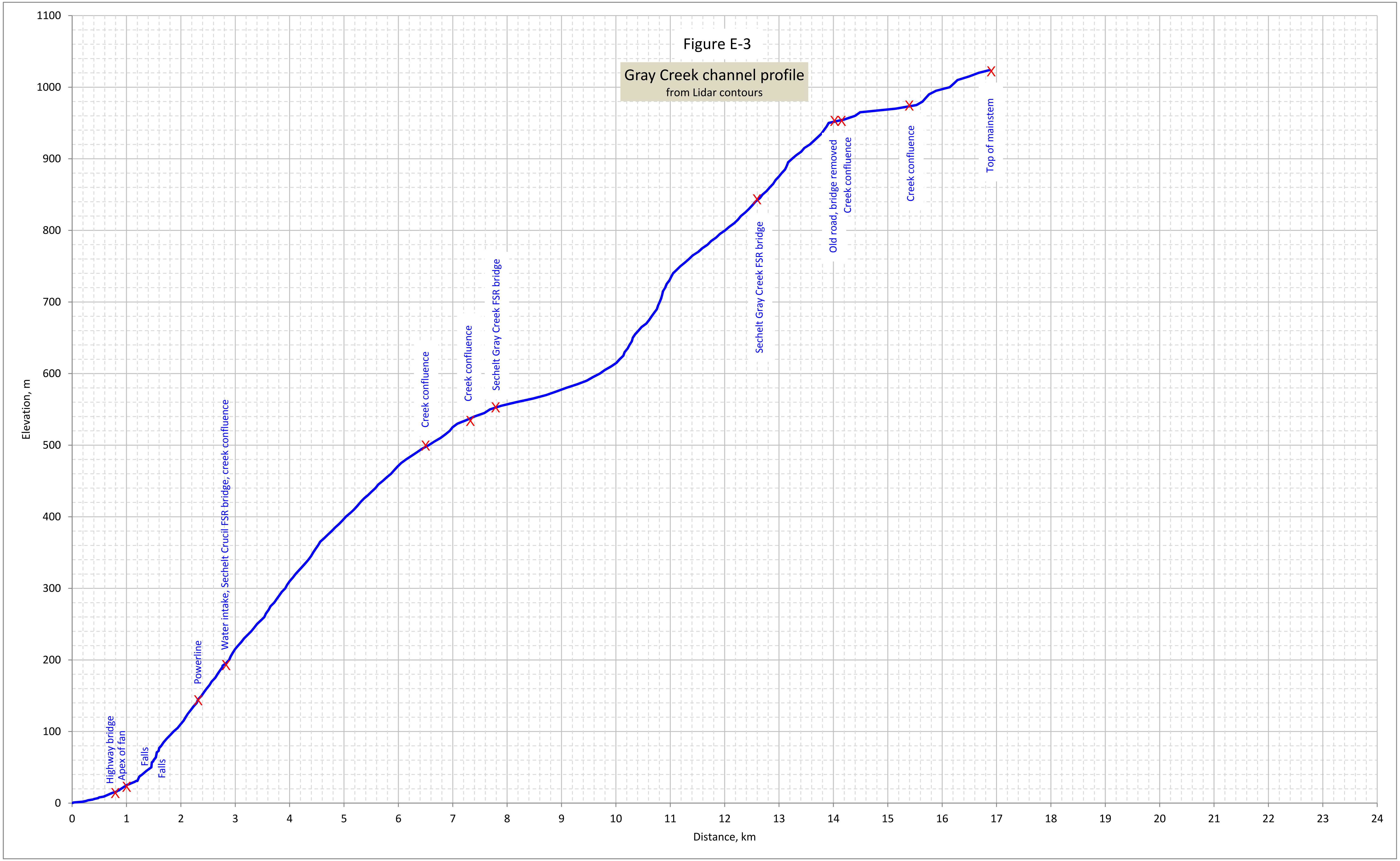


Figure E-3
Gray Creek channel profile
from Lidar contours
Elevation, m
Distance, km
Highway bridge
Apex of fan
Falls
Falls
Powerline
Water intake, Sechelt Crucil FSR bridge, creek confluence
Creek confluence
Creek confluence
Sechelt Gray Creek FSR bridge
Sechelt Gray Creek FSR bridge
Old road, bridge removed
Creek confluence
Creek confluence
Top of mainstem
0
100
200
300
400
500
600
700
800
900
1000
1100
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24

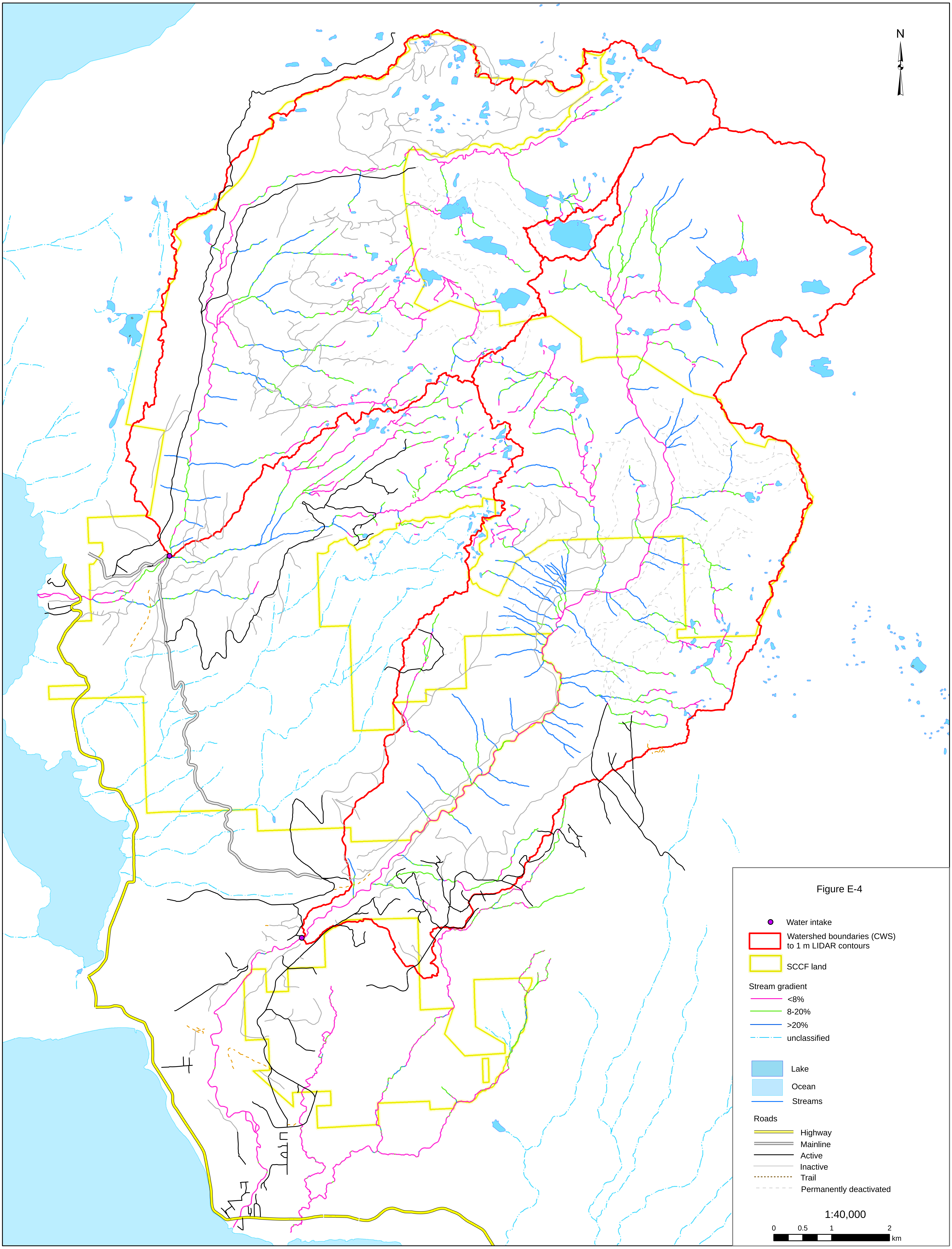
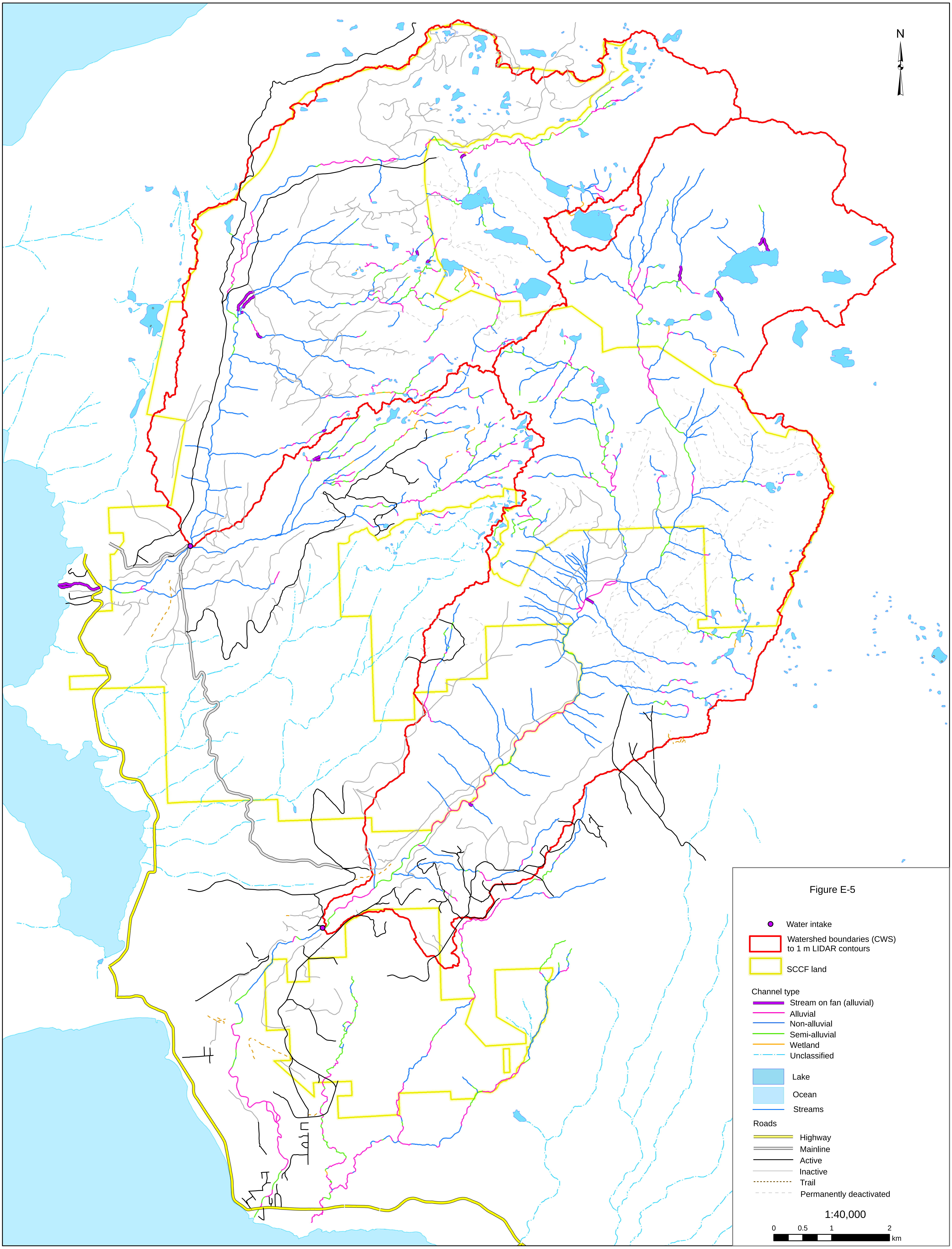

N
Water intake
Watershed boundaries (CWS)
to 1 m LIDAR contours
SCCF land
Stream gradient
<8%
8-20%
>20%
unclassified
Lake
Ocean
Streams
Roads
Highway
Mainline
Active
Inactive
Trail
Permanently deactivated
1:40,000
0 0.5 1 2
km

Figure E-4


N
Figure E-5
Water intake
Watershed boundaries (CWS) to 1 m LIDAR contours
SCCF land
Channel type
Stream on fan (alluvial)
Alluvial
Non-alluvial
Semi-alluvial
Wetland
Unclassified
Lake
Ocean
Streams
Roads
Highway
Mainline
Active
Inactive
Trail
Permanently deactivated
1:40,000
0 0.5 1 2
km

Appendix F

Hydrologic Recovery and Equivalent Clearcut Area

Determining hydrologic recovery and ECA

References:

- Hudson, R. 2000. *Assessing Snowpack Recovery of Watersheds in the Vancouver Forest Region.* Research Section, Coast Forest Region, B.C. Ministry of Forests, Nanaimo, B.C. Technical Report TR-004/2000.

- Hudson, R. 2003. *Using Combined Snowpack and Rainfall Interception Components to Assess Hydrologic Recovery of a Timber-Harvested Site: Working Toward an Operational Method.* Res.Sec. Coast For. Reg., BC Min. For., Nanaimo, B.C. Technical Report TR-027/2003.

- Hudson, R. and G. Horel. 2007. *An operational method of assessing hydrologic recovery for Vancouver Island and south coastal B.C*. Research Section, Coast Forest Region, B.C. Ministry of Forests, Nanaimo, B.C. Technical Report TR-032/2007.

This assessment uses the recovery models in TR032 (Hudson and Horel 2007) to determine hydrologic recovery and ECAs. TR032 has separate recovery curves for the rain, transient snow, and snow accumulation zones; and requires the selection of a design storm.

Elevation zones are shown on Figure F-1. Because trees have the greatest ability to intercept small storm events, selection of smaller design storms is more conservative (gives slower recovery) than large storms in the TR032 recovery models. Typically, a return period of 1.5-2 years is used because effects of this frequency are typically reflected in channel morphology of alluvial streams. Return periods of storm events are not available in the study area; from the available weather data at Sechelt and comparison to other sites with similar climates, a design storm of 35 mm was selected by the method shown below. ClimateWNA was used to adjust the design storm for higher elevation zones.

The regional snow zone mapping (Hudson 2004) indicates that most of Gray Creek is in Snow Zone 4 (the driest coastal zone) while the upper half of Chapman Creek is in Snow Zone 1, the wettest coastal zone. For the purpose of calculating recovery in the rain-on-snow and snow accumulation zones, the tree height thresholds for Snow Zone 1 were used in both watersheds, which are more conservative then tree height thresholds for Snow Zone 4. This may be conservative for Gray Creek.

Tree height is used as a surrogate for canopy density in most hydrologic recovery models, because tree height is routinely available in forest cover inventories, and is an easily repeatable measurement. Canopy density is not routinely available and is less repeatable in measurement.

Forest cover available for this assessment was VRI Rank 1 (2012). The forest cover polygon boundaries for logged areas were adjusted to better fit the 2009/2010 orthophotos and revised to account for recently harvested areas not reflected in the VRI Rank 1.

Tree heights for this assessment were obtained from LIDAR data. The median (rather than mean) tree height for each VRI stand was used in order to discount potential edge effects (from forest cover stand boundaries not being exactly coincident with actual stand areas as "seen" by LIDAR). The LIDAR heights have not been calibrated by field measurements. The LIDAR tree heights were compared to the available imagery (2009-2010) to check that they made sense and were adjusted where needed. Hydrologic recovery determined by the TR032 method is displayed on Figure F-2.

Selection of design storm for recovery criteria in rainfall zone and rainfall component of rain-on-snow zone (Elevation Bands 1 and 2)

Environment Canada climate station 1047170 – Sechelt B.C.
Period of record: 1927-1968 – not continuous, many years missing
Elevation: 23 m
Annual precipitation: 925.4 mm
Maximum 1 day rain of record: 68.1 mm on January 18, 1968

Return periods for Sechelt are not available, but from data at other coastal sites, return period of 1.5 years for 1 day rain is approximately half of the 1-day rain of record, or approximately 4% of the annual precipitation.

Half of 1-day rain of record = 34 mm
4% of annual precipitation = 37 mm
→use 35 mm

Adjustment of design storm for Elevation Bands 1 and 2 using ClimateWNA

Chapman Creek
EB1 - ClimateWNA average precipitation = 1790 mm -- 1.93x higher than Sechelt station
EB2 - ClimateWNA average precipitation = 3015 mm -- 3.25x higher than Sechelt station

	P_{DS}	P_E	CDR	I_{DS}	I_{OR}	P(s)
-->EB1 - increase P_{DS} and P_E x1.93:	68	83	0.65	128	0.58	
-->EB2 - increase P_{DS} and P_E x3.25:	114	140	0.65	215	0.65	0.15

Gray Creek
EB1 - ClimateWNA average precipitation = 2093 mm -- 2.26x higher than Sechelt station
EB2 - ClimateWNA average precipitation = 2999 mm -- 3.24x higher than Sechelt station

	P_{DS}	P_E	CDR	I_{DS}	I_{OR}	P(s)
-->EB1 - increase P_{DS} and P_E x2.26:	79.1	97.18	0.65	150	0.62	
-->EB2 - increase P_{DS} and P_E x3.24:	113.4	139.32	0.65	214	0.65	0.15

P_{DS} = design threshold storm, mm.
P_E = average of all storms exceeding threshold storm, mm. Source: CDCD data to 2004 (released 2007).
I_{DS} = design storm index = P_E/CDR.
CDR = canopy density ratio -- taken as 0.65
I_{OR} = over-recovery index = $0.65(1-e^{-0.04IDS})^{19.52}$
P(s) = proportion of snowmelt. Since P_{DS}>34 mm, then P(s) = $e^{(2.32+4.74/PDS)}$

Maximum over-recovery occurs at 25 m height:
O_{RSmax} at 25 m ht:

For S=0:	130.63
For S=1:	151.63

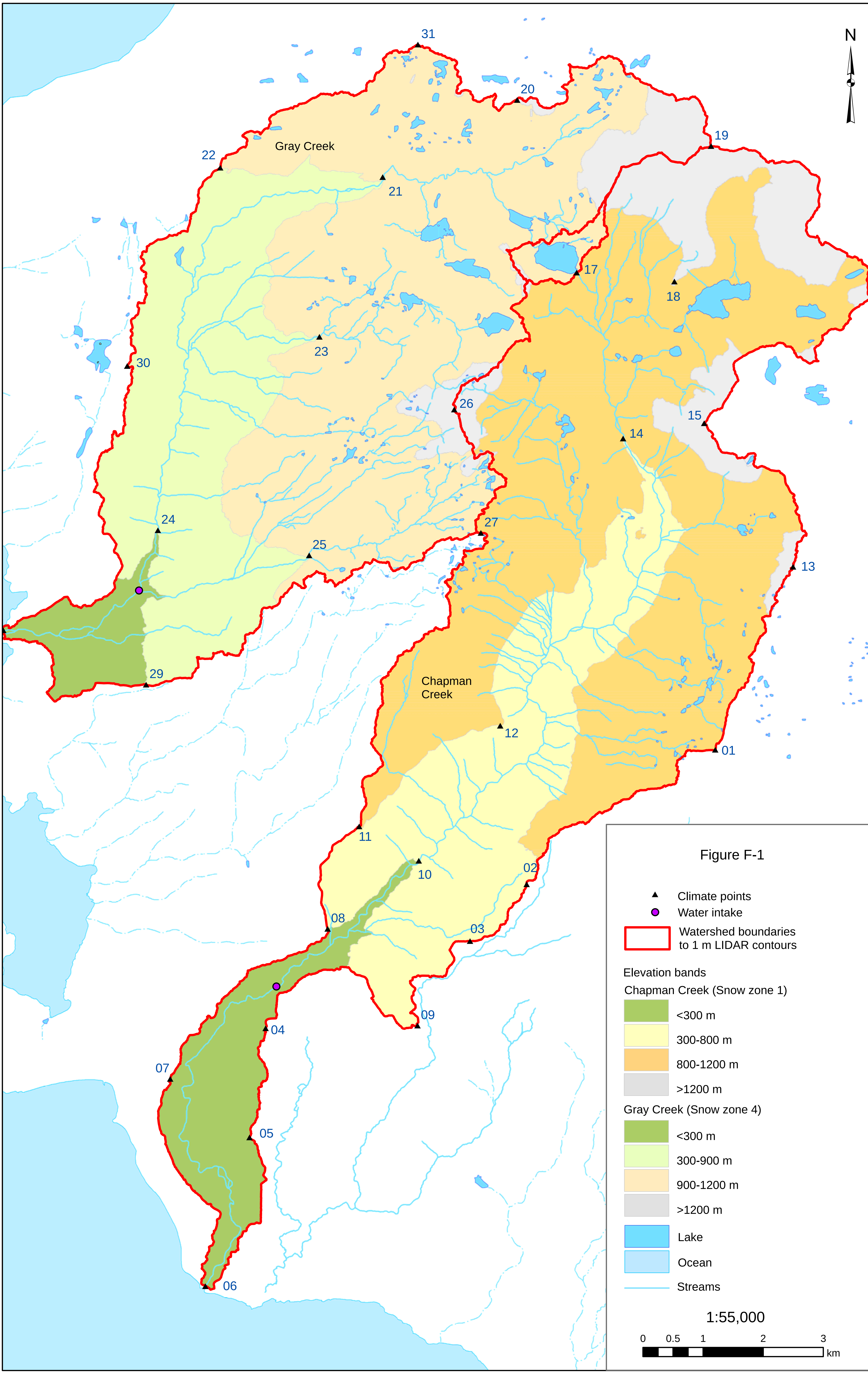
Tree height thresholds – snow accumulation zones

Ref.:
Snow course 3A26, upper Chapman Creek, elevation 1022 m
Period of record: 1993-2003
Maximum snow depth recorded: 423 cm

In EB2, tree height thresholds are determined as a function of elevation. In EB3 and EB4, tree height thresholds were assumed constant, and the tree height thresholds from TR-004 for Snow Zone 1 were used for both watersheds.

EB3: 800-1200 m elevation (Chapman Creek)
EB3: 900-1200 m elevation (Gray Creek)
EB4: >1200 m

Snow Zone 1
EB3: Tree height threshold = 4.2 m
EB4: Tree height threshold = 5.6 m


N
Gray Creek
Chapman Creek
31
20
19
22
21
17
18
23
30
26
15
14
24
27
25
13
29
12
01
11
10
02
08
03
09
04
07
05
06
Figure F-1
Climate points
Water intake
Watershed boundaries to 1 m LIDAR contours
Elevation bands
Chapman Creek (Snow zone 1)
<300 m
300-800 m
800-1200 m
>1200 m
Gray Creek (Snow zone 4)
<300 m
300-900 m
900-1200 m
>1200 m
Lake
Ocean
Streams
1:55,000
0 0.5 1 2 3
km

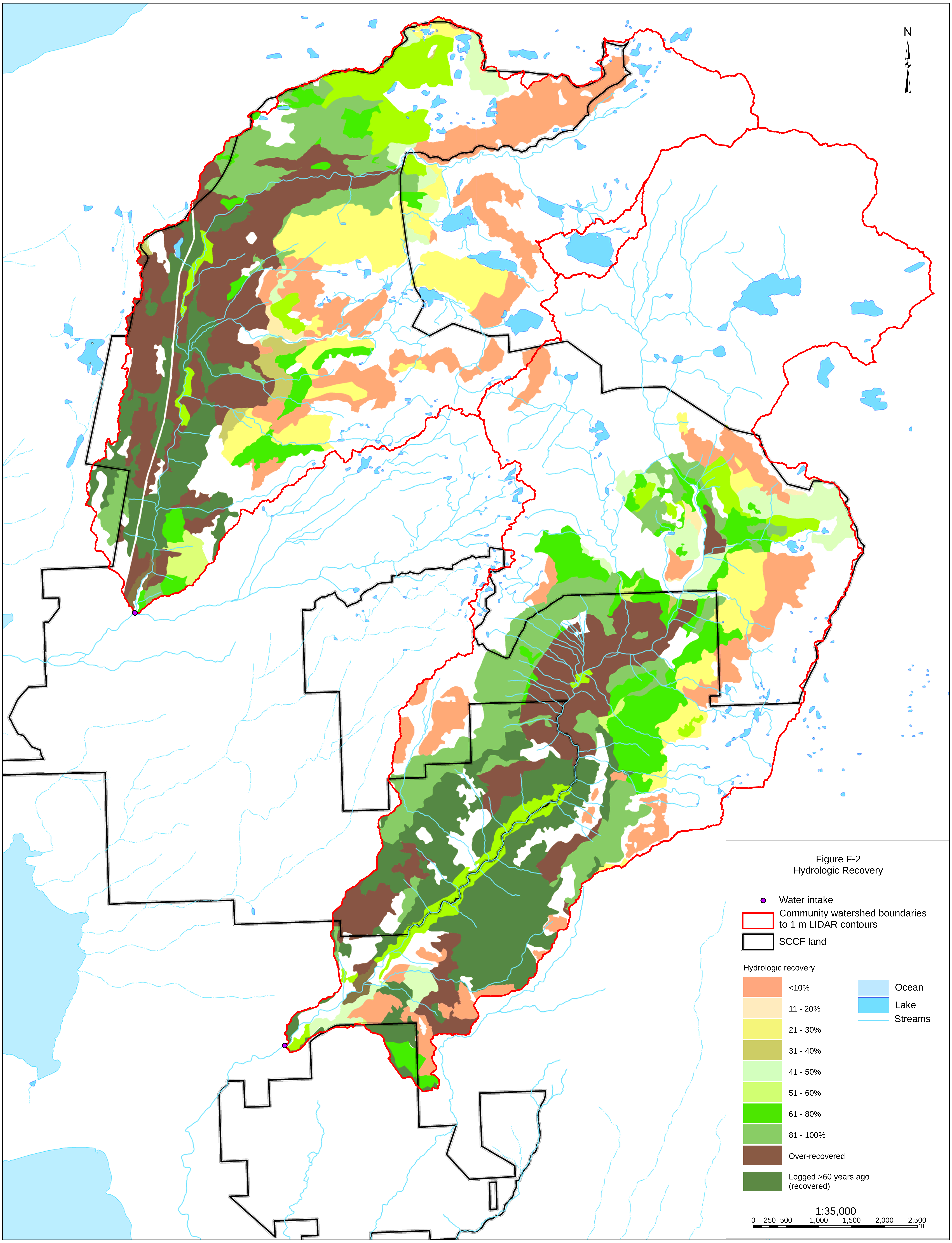

N
Figure F-2
Hydrologic Recovery
Water intake
Community watershed boundaries to 1 m LIDAR contours
SCCF land
Hydrologic recovery
<10%
11 - 20%
21 - 30%
31 - 40%
41 - 50%
51 - 60%
61 - 80%
81 - 100%
Over-recovered
Logged >60 years ago (recovered)
Ocean
Lake
Streams
1:35,000
0 250 500 1,000 1,500 2,000 2,500
m

Table F-1 - climate variables generated by ClimateWNA (UBC climate model)

Point	Latitude	Longitude	Elevation m	Mean annual precipitation, mm	Precipitation falling as snow, mm (water equivalent)	% of mean annual precipitation	Mean annual temperature, °C	Max summer temp, °C	Min winter temp, °C
01	49-31-02	123-36-09	1161	3638	1077	30%	4.9C	16.3	-3.9
02	49-29-53	123-38-48	743	2982	468	16%	6.6C	18.0	-2.2
03	49-29-23	123-39-37	552	2545	330	13%	7.0C	18.4	-1.8
04	49-29-40	123-42-28	209	2236	124	6%	8.9C	20.3	0.4
05	49-27-41	123-42-44	113	1688	75	4%	9.3C	20.4	0.9
06	49-26-22	123-43-24	0	1440	46	3%	10	20.7	1.7
07	49-28-14	123-43-48	110	1610	69	4%	9.4	20.4	1
08	49-29-32	123-41-34	300	2250	164	7%	8.3	19.7	-0.3
09	49-28-38	123-40-22	440	2216	218	10%	7.6	19.1	-1.1
10	49-30-07	123-40-17	300	2584	233	9%	7.8	19.1	-0.7
11	49-30-27	123-41-05	800	2645	495	19%	6.1	17.8	-2.8
12	49-31-19	123-39-06	800	3321	589	18%	6.3	17.5	-2.4
13	49-32-39	123-34-59	1280	4020	1283	32%	4.6	15.9	-4.1
14	49-33-51	123-37-16	800	3626	724	20%	5.9	16.9	-2.5
15	49-33-58	123-36-09	1485	3761	1591	42%	3.5	14.9	-5.4
16	49-35-03	123-33-47	1335	3589	1302	36%	4.1	15.5	-4.7
17	49-35-22	123-37-50	1070	3718	978	26%	5.2	16.7	-3.5
18	49-35-15	123-36-29	1200	3727	1106	30%	4.8	16.1	-3.9
19	49-36-28	123-35-55	1645	3675	1682	46%	3.2	15	-6
20	49-36-56	123-38-34	1200	3527	1111	31%	4.9	17.2	-4.5
21	49-36-16	123-40-28	800	3492	660	19%	6.4	18.7	-2.7
22	49-36-25	123-42-42	800	3014	584	19%	6.4	19.2	-2.8
23	49-34-52	123-41-25	800	3284	618	19%	6.4	18.8	-2.5
24	49-33-10	123-43-43	300	2695	163	6%	8.8	20.4	0.2
25	49-32-54	123-41-39	800	3395	487	14%	6.9	18.5	-1.9
26	49-34-10	123-39-35	1305	3890	1275	33%	4.6	16.3	-4.3
27	49-33-03	123-39-16	1200	3761	1124	30%	4.8	16.3	-3.9
28	49-32-19	123-45-54	0	1733	68	4%	9.6	20.8	1.2
29	49-31-47	123-43-57	300	2281	153	7%	8.5	20	-0.1
30	49-34-39	123-44-04	845	2934	394	13%	7.1	19.3	-1.8
31	49-37-28	123-39-55	1080	3201	1047	33%	4.9	17.9	-4.7
19	October - mean monthly variables			419	46	11%	4	7	2

Appendix G

Landslides, terrain stability and risk zones

Terrain classification, terrain stability classes and sediment delivery potential by D. Maynard, P. Geo.
Risk zones delineated by G. Horel, P. Eng.
Spatial data submitted separately.

TERRAIN STABILITY CLASSES

1 No significant stability problems expected, negligible likelihood of landslide initiation.

2 Very low likelihood of landslide initiation following timber harvesting or road construction.

3 Low likelihood of landslide initiation following timber harvesting or road construction. Minor stability problems may develop in some areas. Wet areas should be treated with caution. Sensitive micro-sites may require geotechnical review by a Qualified Professional.

4 Moderate likelihood of landslide initiation following timber harvesting or road construction. Terrain polygons include potentially unstable terrain. A field inspection by a Qualified Professional is required prior to development.

5 High likelihood of landslide initiation following timber harvesting or road construction. Terrain polygons include unstable terrain and/or areas of active instability. A field inspection by a Qualified Professional is required prior to development.

SEDIMENTATION POTENTIAL RATINGS

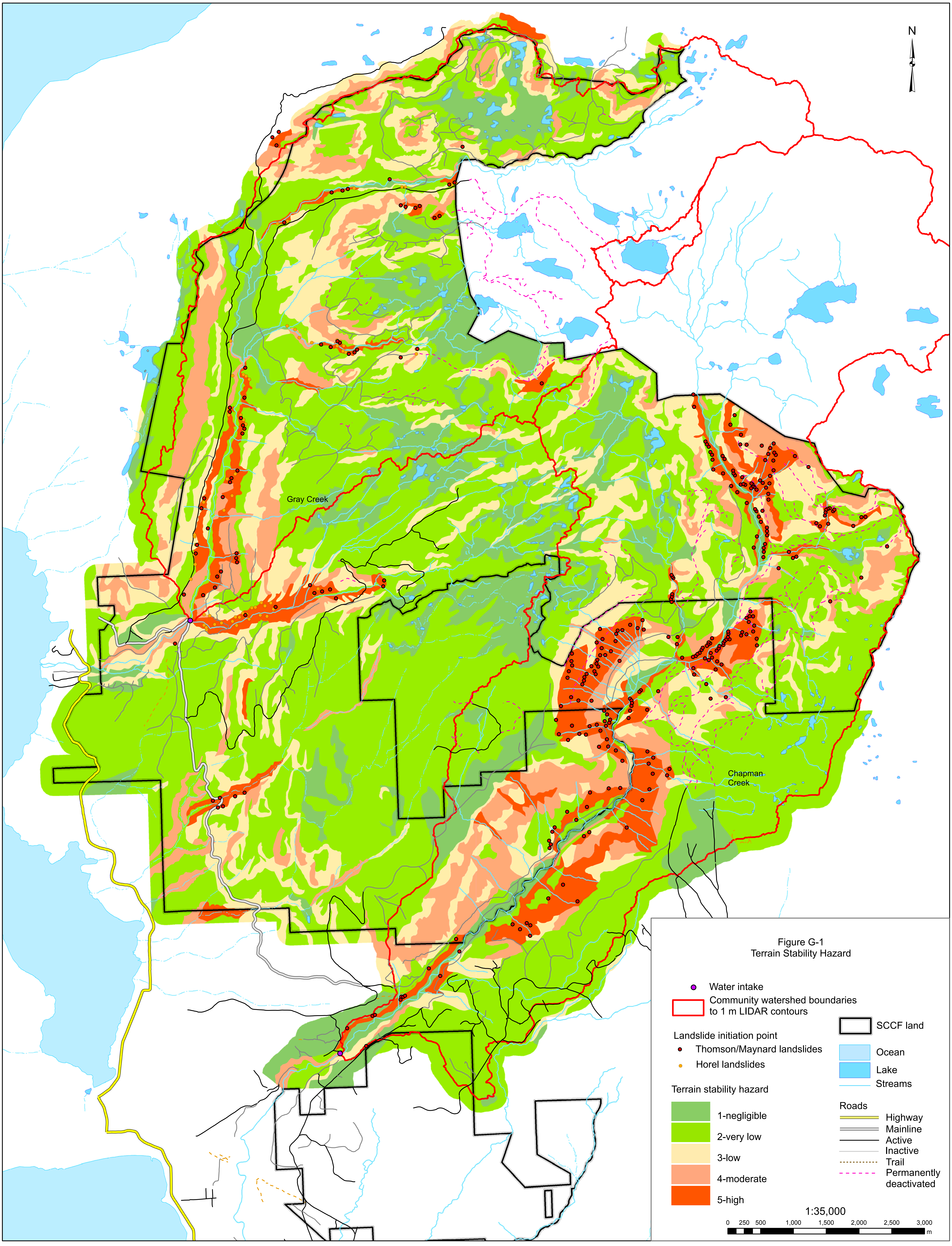
H High likelihood of landslide debris reaching a stream system if a landslide were to initiate in these terrain polygons. Most landslides occurring in these areas would be expected to directly enter a stream system.

M Moderate likelihood of landslide debris reaching a stream system if a landslide were to initiate in these terrain polygons. Some landslides would be expected to directly enter a stream system and some would likely deposit on the toe slope.

L Low to very low likelihood of landslide debris reaching a stream system if a landslide were to initiate in these terrain polygons. Few, if any, landslides occurring in these areas would be expected to directly enter a stream system. Also applied to any polygons where the likelihood of landslide occurrence is nil to very low (Stability class 1 terrain and most polygons where all the slopes are dry and less than 40% gradient).

\+ This symbol is attached as a modifier to indicate that the potential depositional area for any landslide debris could be a lake or large wetland that would act as a sediment sink. It is only applied for H and M ratings (e.g. M+).

Note: A stream system is assumed to include stream order one and two channels, gullies, and small lakes and wetlands that drain directly into main stream channels. Factors used to asses the potential impact of landslides on a receiving water body were based on criteria in *A Terrain Evaluation Method for Predicting Terrain Susceptible tp Post-Logging Landslide Activity* (Howes, 1987) and include: slope angle, the presence or absence of a runout zone, the length of the runout zone, and the presence of gullies that provide direct linkage between the slope and the valley floor.


N
Gray Creek
Chapman
Creek
Figure G-1
Terrain Stability Hazard
Water intake
Community watershed boundaries
to 1 m LIDAR contours
SCCF land
Landslide initiation point
Thomson/Maynard landslides
Horel landslides
Ocean
Lake
Streams
Terrain stability hazard
1-negligible
2-very low
3-low
4-moderate
5-high
Roads
Highway
Mainline
Active
Inactive
Trail
Permanently
deactivated
1:35,000
0 250 500 1,000 1,500 2,000 2,500 3,000
m

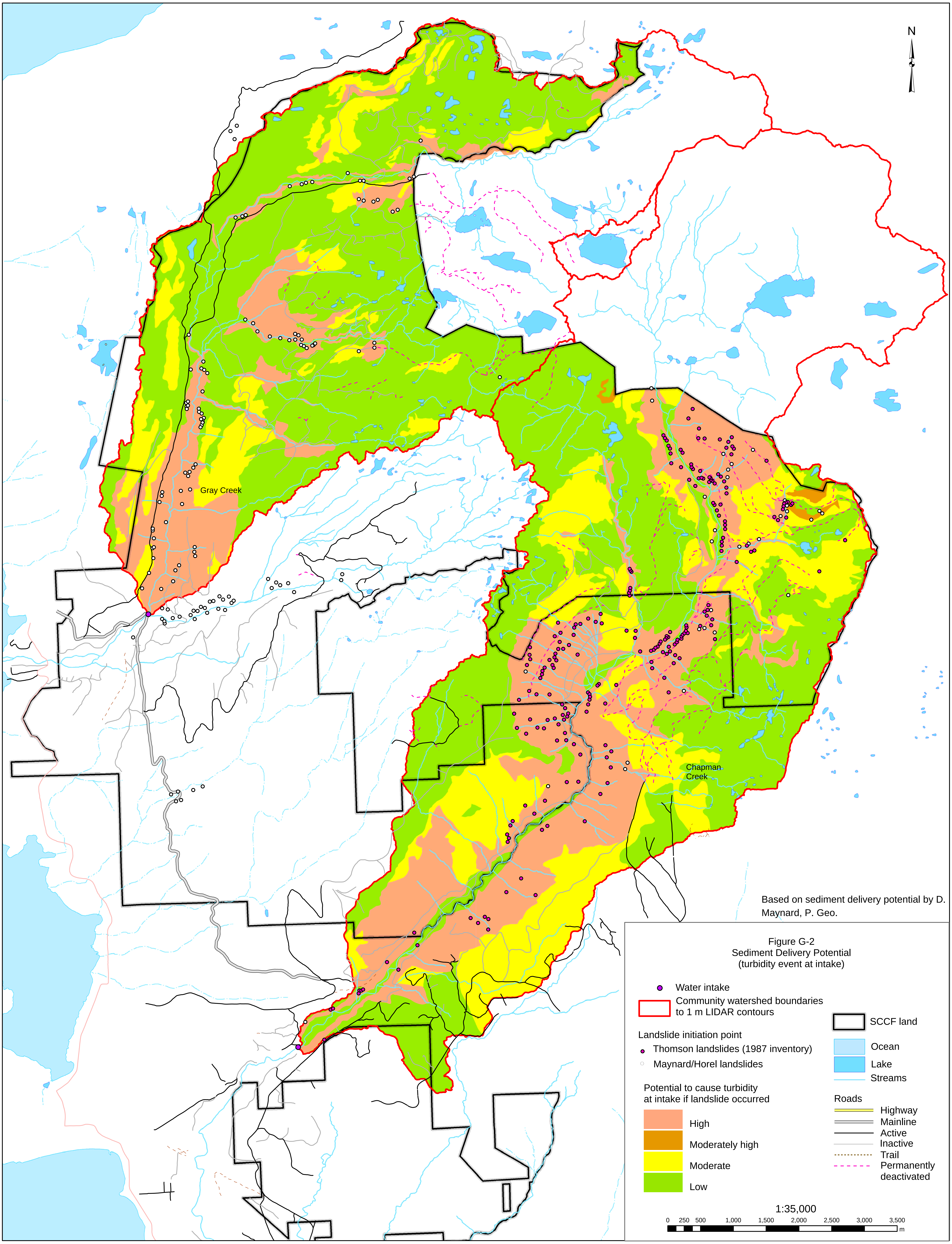
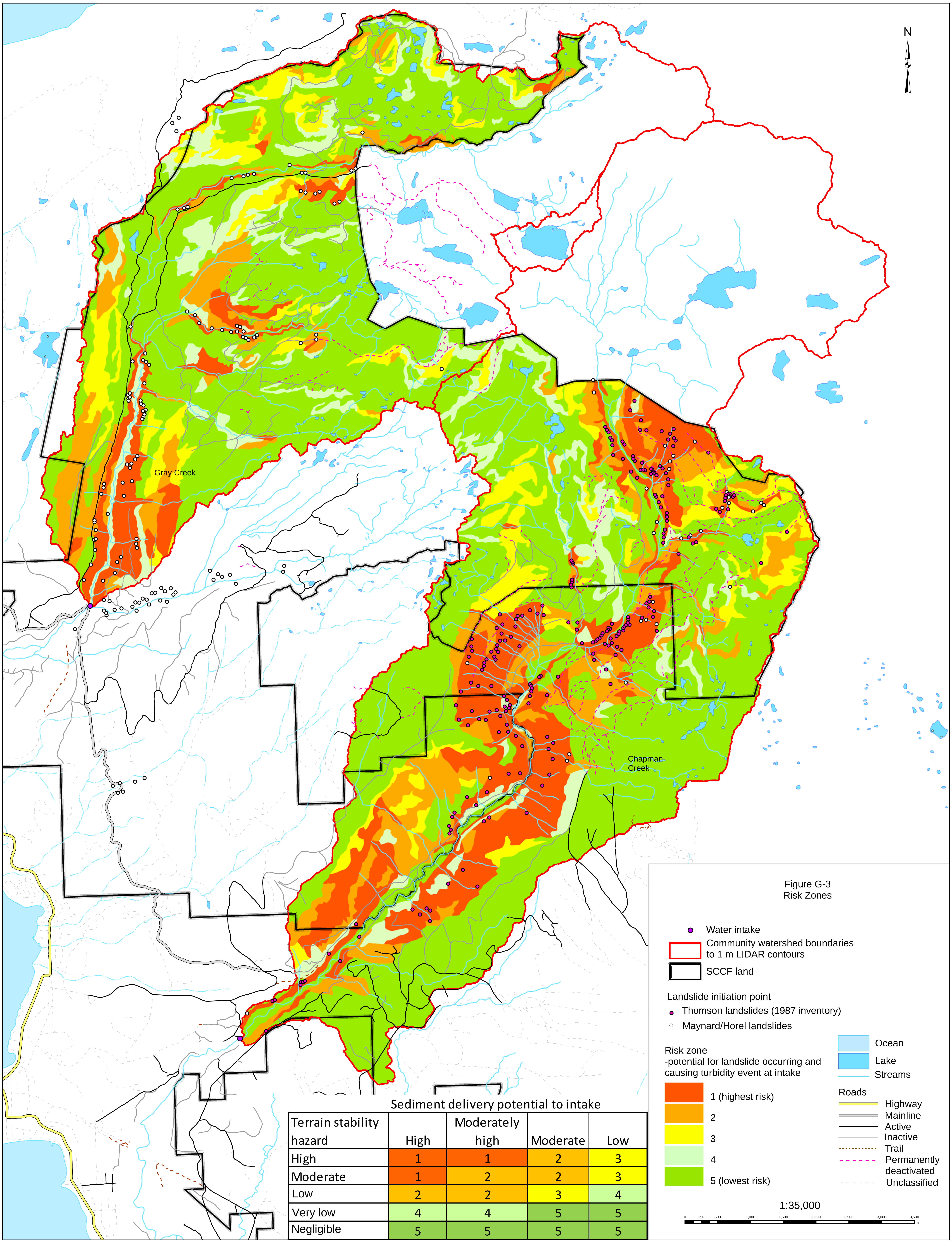


Figure G-2
Sediment Delivery Potential
(turbidity event at intake)



Sediment delivery potential to intake

Terrain stability hazard	High	Moderately high	Moderate	Low
High	1	1	2	3
Moderate	1	2	2	3
Low	2	2	3	4
Very low	4	4	5	5
Negligible	5	5	5	5