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Project No. 0378-002-01
January 3, 2008

Mr. James Whyte, AScT.
Director, Provincial Operations
Provincial Emergency Program
Emergency Management British Columbia
455 Boleskine Road
Victoria, British Columbia
V8Z 1E7

Re: Cohoe Creek Landslide and Landslide Induced Wave (Seiche) at Chehalis Lake

Dear Sir:

BGC Engineering Inc. (BGC) was retained by the Provincial Emergency Program (PEP) on December 10, 2007, to conduct a preliminary assessment of the Cohoe Creek landslide and slide induced wave on Chehalis Lake, which is believed to have occurred on or about December 4, 2007 (Pattle, 2007). This letter report provides the results of that assessment. Photographs and figures referred to in the text appear in Appendix I. Resource materials are listed in Appendix II.

1.0 BACKGROUND

A rock slide from the west slope of Chehalis Lake occurred on or about December 4, 2007. The lake is approximately 8 km long and has an average width of about 1 km. The slide occurred approximately 1 km from its north end.

Debris entering the lake caused a large wave that is generally referred to as a seiche. This inundated many kilometres of the lake shoreline eliminating most trees in the run-up zone and badly damaging three campgrounds on the lake. Campgrounds are located at the north end and south end of the lake, as well as on the Skwellepit Creek fan on the west side of the lake. The slide and wave run-up impacts along the shoreline generated a significant amount of large woody debris (LWD) that is presently floating in the lake, including a large debris mat at the lake outlet.

Two concerns prompted PEP to contact BGC: First, the potential for the woody debris to enter Chehalis River and impact infrastructure on its alluvial fan due to log jams forming and diverting flows; and second, the potential for additional instability of the landslide headscarp.

BGC conducted a one-day site visit on December 11, 2007. Both authors of this letter participated. The area was accessed by helicopter out of Agassiz, leaving at about 09:00 and returning at 14:00. Savigny examined the landslide and Weatherly looked at the hydrology and fluvial geomorphology aspects of the lake shoreline and lower Chehalis River. The work included:

- aerial inspections of the rock slide and the damage around Chehalis Lake;
- a ground inspection of the slide headscarp;
- ground inspections of the campgrounds at both ends of the lake and on the Skwellepit Creek fan, including estimates of wave run-up;
- an aerial and ground inspection of the large debris mat that has developed at the lake outlet; and
- an aerial inspection of lower Chehalis River from the lake outlet down to the mouth of the river at the confluence with Harrison River.

2.0 SCOPE OF WORK

The BGC scope of work was outlined in your email of December 10, 2007 (Whyte to Jakob) and in a telephone conversation (Savigny with Whyte) on December 13, 2007. Following are the items that were requested:

1. Assess the landslide area to see if there are any obvious signs of potential additional slope failure.
2. Examine the outlet of the lake and the debris mat to determine if the debris mat has grounded on the shallow area of the lake.
3. Provide a relative assessment of the likelihood that woody debris could enter the river and either constrict the flow, cause elevated water levels, or otherwise create a potential hazard on the river.
4. Provide a report that identifies any issues that could result in an imminent threat to public safety

3.0 FACTUAL INFORMATION

Following is a summary of the factual information assembled as part of our scope of work. This forms the basis of our assessment. We assume it to be correct for purposes of this preliminary assessment.

3.1 Cohoe Creek Landslide

3.1.1 General Description

The landslide developed on the left side of Cohoe Creek as shown in Photo 1. The highest headscarp elevation is approximately 843 m, which is 648 m vertically above Chehalis Lake (elev. ~235 m) as shown in Figure 1. The source area extends from the headscarp down to approximately elevation 444 m (Photos 2 and 3), an on-slope distance of ~675 m. The total on-slope distance affected between the headscarp and the lake is ~1,130 m and the line-of-sight angle over this distance is between 31° and 32°. The total extent of debris runout into Chehalis Lake is unknown.

3.1.2 Geological Setting

The rock mass comprising Mt. Orrock is quartz diorite belonging to the Coast Plutonic Complex. No regional faults are identified on the most recent published geological map of the area (Roddick, 1965). No earthquakes were recorded in the area around the time of the landslide based on communication with the Pacific Geoscience Centre in Sydney, British Columbia. Evidence of pre-existing landslide headscarps is shown on Photo 2. These had approximate headscarp elevations of 600 m.

3.1.3 Geological Controls – Slide Surface

The slide surface is exposed along the upper left lateral margin of the slide immediately below the headscarp (Photo 4). Here it was found to be controlled by pervasive planar surfaces (Photo 5), some of which are tectonic faults with several centimetres of plastic gouge and slickensides (Photos 6 and 7). These slide surfaces trend into the slope at the bottom of the headscarp, which averages in the order of 50 m high. Groundwater discharges at the bottom of the headscarp where these planar surfaces crop out (Photo 4).

3.1.4 Geological Controls - Headscarp

Evidence of fresh joint dilation is common behind the headscarp (Photos 8 and 9). The maximum setback distance of observed dilation is ~21 m. The left lateral margin of the landslide has no headscarp as the slide surface daylights.

The right lateral margin of the landslide headscarp developed approximately parallel to and coincident with the thalweg of Cohoe Creek. An extensive tract between elevations ~600 m and ~740 m, and possibly more, is controlled by subvertical northwest-trending joints. Some combination of shearing and up thrusting occurred along the joints to facilitate slide movement, thus capturing/deepening the thalweg of Cohoe Creek by as much as 10 m over the same elevation range (Photos 3 and 10). The thalweg of Cohoe Creek below approximately 740 m elevation is somewhat deeper and marked by a precipitous right slope into the creek. The precipitous relief increases below approximately 600 m elevation and continues as low as approximately 444 m elevation, which may indicate that the previous instability reported above had similar characteristics.

3.1.5 Thalweg of Cohoe Creek

As indicated in the previous paragraph, the thalweg elevation of Cohoe Creek appears to have been deepened by the landslide. However, the authors emphasize that the actual path of Cohoe Creek was not visible across the landslide scar on December 11, 2007. Rather, the creek flow disappeared into the debris at approximately 740 m elevation and no single breakout location was visible. On a December 21, 2007, return visit courtesy of B.C. Hydro, the creek flow appeared to break out over a wide area at approximately 400 m elevation along the right (south) half of the slide scar. Here it caused shallow instability that extended all the way down to the lake shore.

3.2 Climate

The exact time of the landslide is not known but it likely occurred late on December 3 or on December 4. Climate stations in the vicinity of Chehalis Lake are located at Mission West Abbey and Agassiz CDA: both gauges are maintained by Environment Canada. Precipitation and temperature data for the period December 1 to 5, 2007 are summarized in Table 1.

Table 1: Regional Climate Data – December, 2007

Day	Mission West Abbey			Agassiz CDA		
	Precipitation (mm)	Avg Temp (^{o}C)	Max Temp (^{o}C)	Precipitation (mm)	Avg Temp (^{o}C)	Max Temp (^{o}C)
Dec 1, 2007	5.4	-3.0	-1.0	30.0	-1.0	-1.0
Dec 2, 2007	73.0	-0.5	6.0	65.6	-0.8	4.0
Dec 3, 2007	34.2	5.8	15.5	27.0	3.5	10.5
Dec 4, 2007	18.0	12.0	13.5	30.6	7.0	12.0
Dec 5, 2007	0	5.8	7.0	2.8	5.3	7.5

Table 1 indicates there was significant precipitation in the form of snow on December 1 and 2: 96 mm of precipitation was recorded at Agassiz and 78 mm at Mission. Lesser amounts of precipitation fell on December 3 and 4, but this system (a Pineapple Express) was associated with subtropical moisture flow and unseasonally high temperatures that melted all of the accumulated snow. During the helicopter flight, only a dusting of snow was observed in the vicinity of the landslide. The total precipitation between December 1 and 4 was 131 mm at Mission and 153 mm at Agassiz. It is likely that significantly more and higher intensity precipitation fell at higher elevations of Chehalis Lake due to orographic effects (data are available from BC Hydro climate stations that could be used to better estimate the orographic effects). It is not known whether snow had accumulated in the vicinity of the lake prior to December 1. Regardless, the timing of the landslide is coincident with a significant amount of runoff.

3.3 Chehalis Lake Shoreline

The large volume of rock entering the lake and its extremely rapid velocity generated a large wave. Landslide-generated waves have been well-documented in the scientific literature and their hazard potential has been identified in numerous studies. The wave impacted both the east and west shorelines north of and including the Skwellepit Creek fan. A wave run-up of 22 to 23 m[1] was measured on the west shoreline at the north end of the lake, while a 5 m high wave impacted the adjacent campground (Photos 11 and 12). This north campground was completely destroyed by the wave. Opposite the landslide, the wave run-up was about 30 m, while on the fan of Skwellepit Creek the run-up was approximately 7 to 9 m.

South of Skwellepit Creek the wave run-up on the west and east shores was significantly less, as indicated by a general lack of disturbance to the shoreline vegetation (Photo 13). However, a significant wave did propagate down the lake. A wave run-up of 5 to 6 m was measured at the campground at the south end of the lake. The campground is located in the southeast corner of the lake, to the immediate east of the lake outlet. Damage at this campground was generally restricted to the deposition of woody debris and existing infrastructure, such as picnic tables and outhouses, being moved.

3.4 Chehalis River

Downstream of the lake outlet, Chehalis River is mostly confined in a canyon down to the fan apex, a distance of about 12 km. A wave with a height of 3 to 4 m did enter the river, as indicated by scour marks immediately downstream of the lake outlet (Photo 14). However, the wave appears to have attenuated fairly rapidly based on channel observations from the helicopter (i.e. a lack of high water marks, fresh log jams in the canyon or obvious scour).

Lower Chehalis River is gauged by the Water Survey of Canada (WSC) (#08MG001) at the fan apex. Here the upstream drainage area is 383 km^2. Gauge stage records were obtained by BGC from the WSC for the period December 3 to 6, 2007. The resulting data do not show an obvious flood wave that could be attributed to the landslide (Figure 2). However, data are

[1] All wave run-up heights reported by BGC are vertical heights.

only recorded every half hour, so a flood wave would not necessarily be recorded (particularly as a flood wave associated with the landslide event would likely last less than a couple of minutes).

The landslide and shore damage from wave run-up generated a significant amount of large woody debris (LWD) that is presently floating in the lake, including a large debris mat at the lake outlet. The debris mat there is about 200 m wide and 100 m long (Photo 15). A similar area of debris is distributed in a number of mats that are located in the middle of the lake between the landslide and Skwellepit Creek (Photo 13). The LWD at the lake outlet appears to have grounded in relatively shallow water. During the site visit, water depths at the lake outlet were less than 1 m (Photo 16). While water depths increase rapidly away from the outlet, water depths at the lake outlet are the ultimate control for downstream transport of LWD. During spring runoff or a large rainstorm, water depths would likely be sufficiently deep to transport the logs into the canyon section.

A minimal amount of LWD appears to have been transported down Chehalis River as a result of the waves generated by the landslide. No fresh log jams were observed between the lake outlet and the fan apex. On the fan of Chehalis River, one fresh log jam was observed about half way down the main channel (Photo 17). Compared to older log jams on the fan, the fresh deposit represents a small percentage. A lack of downstream transport of LWD during the rock slide is not surprising, as the initial wave that moved down the lake would not have been carrying a surge of wood.

4.0 ASSESSMENTS

4.1 Cohoe Creek Landslide

The in situ volume of rock in the source area is estimated at 2.8 Mm^3. Applying a bulking factor of 30%, the mobile volume estimate becomes approximately 3.7 Mm^3. The volume of bulked debris entering Chehalis Lake is estimated to have been approximately 2.9 Mm^3 and the volume of fresh debris left on the slide track is estimated at approximately 800,000 m^3. The initial landslide movement is classified as a rock block slide although it also had wedge characteristics given the joint control described above along the right lateral margin. The initial movement quickly disintegrated and gained velocity becoming what is commonly referred to as a rock avalanche.

In the two hours spent traversing the headscarp area on December 11, small rock falls were virtually continuous. This was, in part, because of diurnal warming.

It is estimated that rock falls from the headscarp will continue for many years. Those with in situ volumes up to approximately 10,000 m^3 are likely to occur at least once annually. They will be the full height of the headscarp (50 m) and joint controlled both laterally and at distance behind the headscarp. Debris from these events is not expected to reach more than a few hundred metres from the headscarp.

Larger fault-controlled rock block slides and/or wedges encompassing the full height of the headscarp, spanning most of its width and taking up most of the 21 m wide dilated zone can be expected to have in situ volumes of between 100,000 and 200,000 m^3. The annual probability of occurrence is estimated at between 0.1 and 0.01. Computer modelling would be required to predict how much of the debris, if any, would reach the pre-failure location of the forestry road (Figure 1) and enter the lake.

The following observations suggest that another landslide comparable in scale with the recent one is possible:

- the fault surface observed to trend beneath the headscarp;
- the presence of clay gouge on the fault surface;
- the extent to which the fault surface and ones like it control groundwater;
- the steep configuration of the headscarp; and
- evidence of recurring instability on the slope

The probability of an event equal to or greater than the recent one is considered to be between 0.01 and 0.001 on the basis of available information.

In addition to the landslide hazards described above, there exists a landslide hazard related to remobilization of the landslide debris. This is because of the infiltration of Cohoe Creek flow into the debris. The hazard may also extend into colluvium, glacial drift or rock underlaying the slide debris.

4.2 Chehalis River

The present concern is that the LWD mat at the lake outlet could be transported into the canyon and cause problems downstream. It is very unlikely that the entire debris mat would be transported downstream during a single rainstorm or spring runoff, as the tendency is for the LWD to cluster rather than disperse thus reducing its mobility. However, over a number of years, the debris mat will progressively break-up and send waves of LWD downstream. High winds from the north would increase the mobility of the LWD. While it is not known how much lake levels fluctuate, water depths will be sufficient deep to transport logs during rainstorms and spring runoff (as evidenced by an older log jam located immediately below the lake outlet, Photo 14). There are two concerns associated with the LWD.

First there is significant potential for large log jams to form downstream of the lake outlet, particularly where bedrock exposures constrict the channel. For example, the channel width is constricted to less than 10 m in two locations in the initial kilometer downstream of the lake

(Photos 18 and 19). Log jams several metres in height or higher could easily form at these constrictions and provide a barrier to fish migration. Coho and an introduced run of summer steelhead move through the canyon reach to use tributary streams, Chehalis Lake, and the upper section of the river above the lake. Resident rainbow trout, cutthroat trout, as well as anadromous Dolly Varden char are also known to use the watershed. Log jam barriers could have significant negative impacts to these fish.

The second potential impact is immediately downstream of the fan apex, where the Chehalis Indian Band has recently constructed a $3M dyke on the left bank. The dyke is offset from the main channel except at its upstream end, where the formation of a large log jam could divert flows directly against the dyke. While log jams naturally form downstream of this location where the river is less confined and wider, a log jam could form on the right bank at the location indicated on Photo 20. Flows would then be diverted against the left bank and recently constructed dyke. Log jams further downstream could also encourage increased lateral instability on the left bank despite the dyke offset. While the alluvial fan of the Chehalis River is characterized by naturally high lateral instability, the potential volume of LWD that could be introduced to the fan (albeit episodically and over a period of many years if not decades) would likely increase bank erosion rates considerably.

Given these two concerns, it is recommended that the floating LWD in the lake be removed. It is important to note that there is limited equipment or vehicle access to the river between the lake outlet and the fan apex. It would be very difficult to extract logs from a major log jam in the canyon once it establishes.

Log jams in the canyon could also impound significant volumes of water, if they developed to a height in excess of 4 to 5 m during a storm event. An outburst flood could then potentially occur if the log jam failed catastrophically. It is possible that the resulting peak flow could be in excess of the 200-year return period flow, for which it is assumed that the Chehalis dyke has been designed. The potential for such an event is beyond the scope of this assessment. However, log jams are most likely in the upper half of the canyon reach and any dam outbreak flood would have a significant distance over which to attenuate.

4.3 LWD Removal

During the site visit, Hamish Weatherly of BGC met with Jeff Ladd of the BC Ministry of Forests and Brian Radke of the BC Ministry of Tourism at the lake outlet. Mr. Ladd was accompanied by a contractor experienced with log boom construction.

As an interim measure, it was suggested that a log boom be set-up immediately upstream of the lake outlet. This initial log boom would prevent any LWD from being transported downstream into the canyon in the short-term. However, at this location, water levels are too shallow for a boom boat to operate and remove the woody debris. A second log boom will be required further upstream where water depths are greater than 2 m. The contractor indicated that Canfor used to operate a log boom at the lake outlet about 200 to 300 m upstream of the lake outlet. These operations were carried out from a boat launch on the east side of the lake. This boat launch is currently used by recreational boat users. The location of the log boom is indicated on Figure 3, which is a bathymetric map of the lake.

5.0 SAFETY ISSUES THAT WARRANT FOLLOW-UP STUDY

The probability of future landslide events affecting the Cohoe Creek headscarp is estimated in Section 4.1. The BGC scope of work excluded consideration of attendant risks. Our understanding is that other stakeholders will be encouraged to address the risks and develop their risk management strategies.

The assessment reported in Section 4, particularly the ongoing landslide hazards, is the result of very limited field and office work. Nevertheless, we emphasize that the threat of landslide recurrence is significant and should be evaluated in much more detail after the winter of 2007-08. In particular, this undertaking should be completed as part of medium to long-term planning for:

- re-opening of the forestry road across the Cohoe Creek landslide (if required);
- allowing winter use of the re-opened road in view of an elevated snow avalanche hazard;
- commercial use of the lake (logging, etc.); and
- recreational use of the lake and its shoreline area.

The focus of follow-up landslide hazard and risk assessment should include, as a minimum:

1. Obtain new stereo aerial photographs or Lidar imagery of the slide area and other east-southeast facing slopes overlooking Chehalis Lake.
2. Completion of detailed topographic mapping from the new photography/imagery.
3. Detailed geological mapping of the headscarp area with focus on the orientation(s) of faults trending under the headscarp of the Cohoe Creek landslide, and determination of the physical properties of fault gouge(s).
4. Establish a magnitude-frequency relationship for recurring events.
5. Determine the minimum size of a rock slide that will reach the logging road and enter the lake based on runout modelling.
6. Calibrate a hydrodynamic transient wave model against available observations reported here or obtained from follow-up mapping in 2008.
7. Use the calibrated model together with the results from steps 4 and 5 as a basis for risk management.
8. Investigate the potential for other rock avalanches sources along Chehalis Lake based on air photographs and analysis and limited field work.

6.0 CLOSURE

BGC Engineering Inc. (BGC) prepared this report for the account of the Provincial Emergency Program (PEP). The material in it reflects the judgment of BGC staff in light of the information available to BGC at the time of report preparation. Any use which a third party makes of this report or any reliance on decisions to be based on it are the responsibility of such third parties. BGC accepts no responsibility for damages, if any, suffered by any third party as a result of decisions made or actions based on this report.

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We trust that this letter report meets your present requirements. If you have any questions ore comments, please contact the undersigned at (604) 684-5900.

Yours truly,
BGC Engineering Inc.
per:

K. Wayne Savigny, Ph.D., P.Eng., P.Geo.
Senior Geotechnical Engineer

Hamish Weatherly, M.Sc., P.Geo.
Senior Fluvial Geomorphologist

HW/kws

APPENDIX I

PHOTOGRAPHS and FIGURES

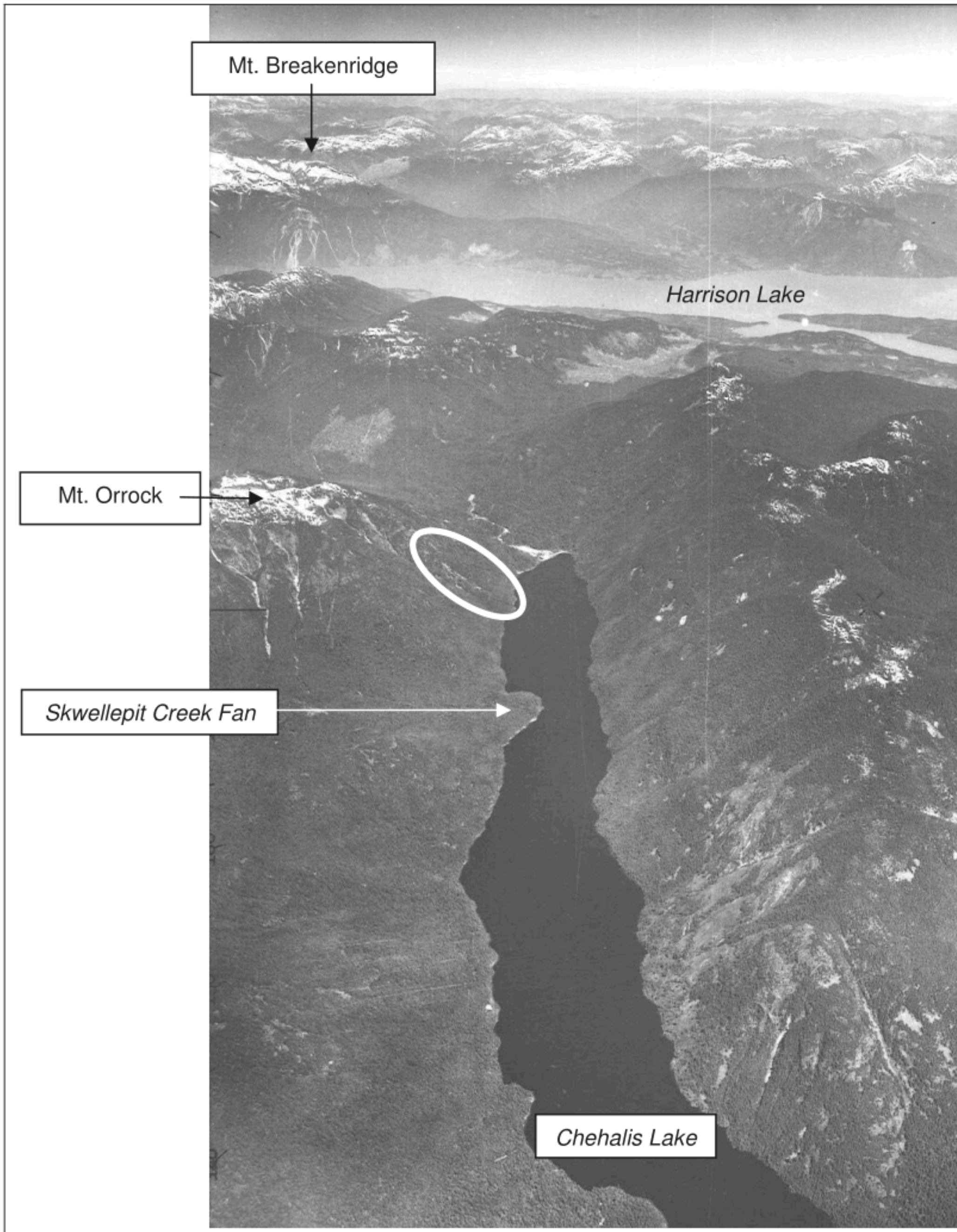

Photo 1: View north-northeast along Chehalis Lake with Harrison Lake and Mt. Breakenridge in the background. The location of the Cohoe Creek landslide is indicated by the ellipse. (B.C. Government oblique air photo BC499-99, taken June 20, 1948)

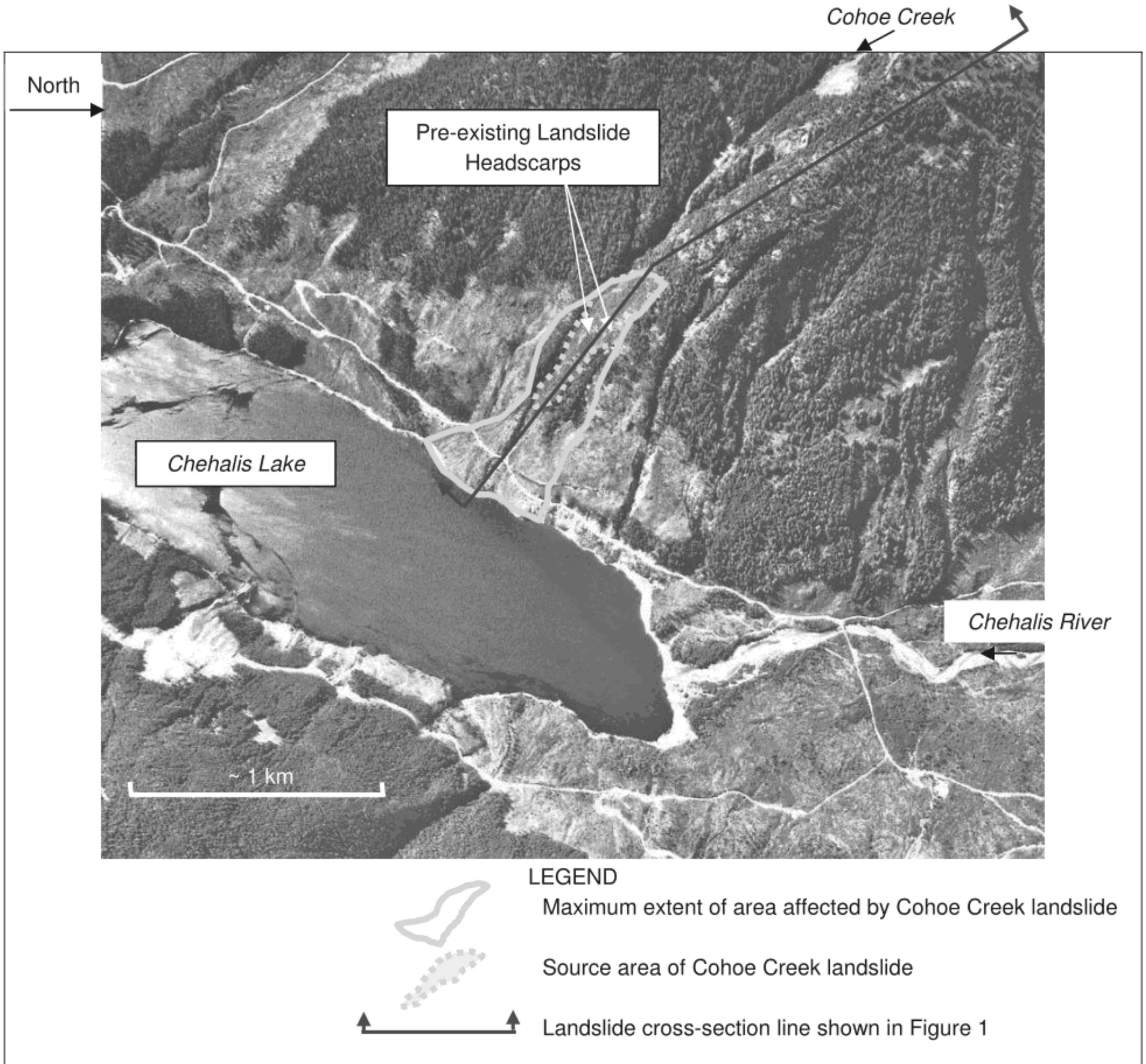

Photo 2: Cohoe Creek landslide. (B.C. Government air photo BC5214-208, taken September 4, 1966, original scale 1:31,680; reproduced scale shown with scale bar)

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Photo 10: View south from the upper left lateral margin of the Cohoe Creek landslide. The slide surface is visible in the foreground but debris covers it over most of the affected area. The thalweg of Cohoe Creek is present a short distance inside the debris relative to the disturbance limit in the forest across the top of the photo. The morphology of the upper right lateral margin along Cohoe Creek suggests the slide margin developed through some combination of shearing and up thrusting thereby accentuating relief by as much as 10 m along the pre-existing steep right lateral slope of the creek, a portion of which is indicated by the cliff face in the ellipse. Photo taken by K.W. Savigny on December 11, 2007.

Photo 11: 5 m high impact scars on trees located at the campground at the north end of Chehalis Lake.

Photo 12: Aerial view of damage caused to the campground at the north end of Chehalis Lake. The wave run-up measured on the shoreline at the far left of the above photo was 23 m.

Photo 13: Aerial view of damage looking down (south-southwest along) the lake. Note the general lack of shoreline damage to the south of Skwellepit Creek fan.

Photo 14: Downstream view of Chehalis River from the outlet of Chehalis Lake. Note the scour on the right bank adjacent to the log jam.

Photo 15: Debris mat at south end of Chehalis Lake.

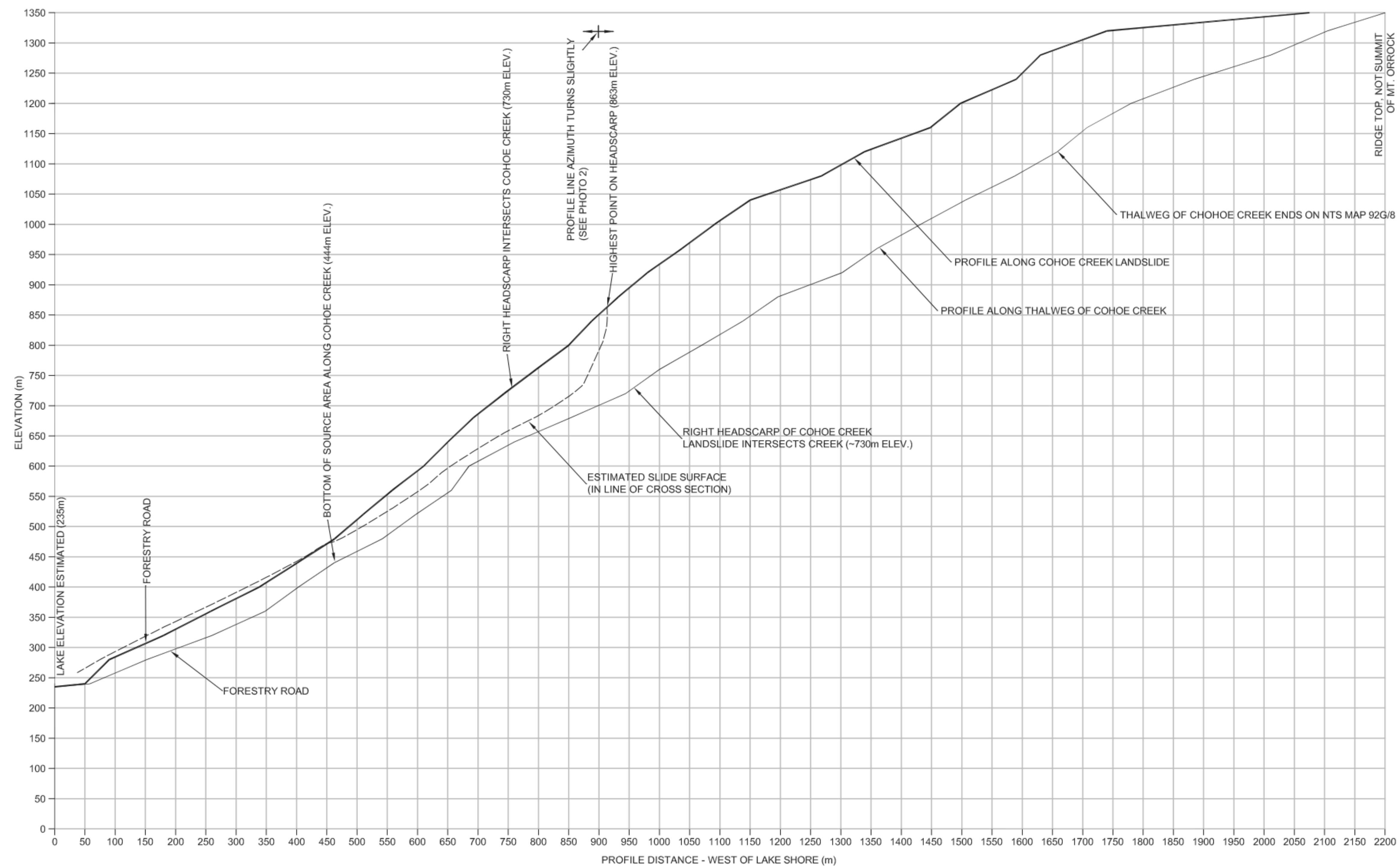
Photo 16: Lake outlet of Chehalis Lake. Note the shallow water at the outlet.

Photo 17: Upstream view of Chehalis River on the alluvial fan. The recently constructed dyke is visible on the right side and an arrow points to a log jam that is likely associated with the rock slide and/or recent storm.

Photo 18: Bedrock constriction of Chehalis River about 1.5 km downstream of the lake outlet. This crossing leads to the south campground on Chehalis Lake.

Photo 19: Existing log jam (that predates the rock slide) located about half way between Chehalis Lake and the alluvial fan.

Photo 20: Upstream view of Chehalis River at upper end of alluvial fan. A log jam could potentially form at the location indicated and direct flows against the recently constructed dyke (dashed red line).



NOTE: SEE LOCATION OF PROFILE ACROSS COHOE CREEK LANDSLIDE (HEAVY BLACK LINE) ON PHOTO 2

REV.	DATE	REVISION NOTES	DRAWN	CHECK	APPR.

SCALE:	1:7500
DATE:	JAN 2008
DRAWN:	WKL
DESIGNED:	KWS
CHECKED:	KWS
APPROVED:	-

PROFESSIONAL SEAL:

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT: PROVINCIAL EMERGENCY PROGRAM

PROJECT: COHOE CREEK LANDSLIDE AND LANDSLIDE INDUCED WAVE (SEICHE) AT CHEHALIS LAKE

TITLE: COHOE CREEK THALWEG AND LANDSLIDE PROFILES

PROJECT No.:	FIGURE No.:	REV.:
0378-002	1	0

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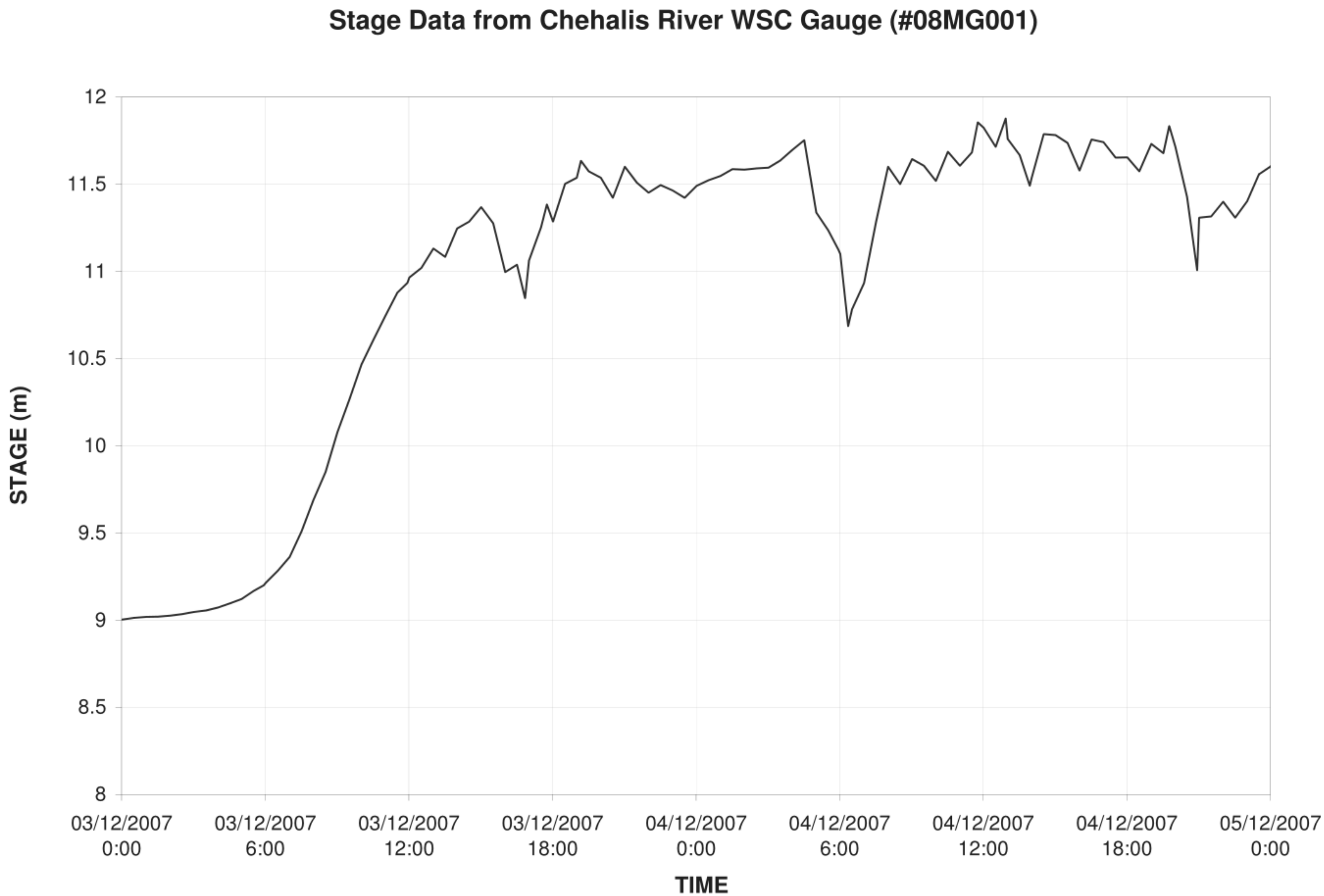

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Figure 2

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Figure 3. Bathymetric map of Chehalis Lake (obtained from http://www.AnglersAtlas.com).

APPENDIX II

RESOURCES USED FOR STUDY

Cited References

Pattle, J. 2007. Incident/Site Inspection Report – Chehalis Lake Landslide. Report prepared for the Provincial Emergency Program, dated December 7, 2007.

Roddick, J.A. 1965. Map 1151A, Geology, Pitt Lake (Vancouver, East Half) British Columbia. Geological Survey of Canada Map included in Memoir 335.

Aerial Photographs (borrowed from UBC, Dept. of Geography, Geographic Info. Ctr.)

Set 1: 1948 (June 20) Oblique B&W, BC499, nos. 98 & 99

Set 2: 1966 (Sept. 4) Vertical Stereo B&W, BC5215, nos. 207-209, scale ~1:31,680

Set 3: 1979 Vertical Stereo B&W, BC79194, nos. 10 & 11 (needed 12 also), scale ~1:20,000

Set 4: 1987 Vertical Stereo B&W, BC87098, nos. 186-188, scale ~1:85,000