COPY

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VGES DEDICATED SERVICE 12 YEARS 1995-2007

31 October 2008

Cultus Country Investments
#216 – 3388 Rosemay Heights Crescent
Surrey, BC V3S 0K7

Attn: **Mr. Jon Van Geel**

Re: **Geotechnical Investigation & Report**
Proposed 42 Lot Development
Lot 3 – 1760 Columbia Valley Highway, Chilliwack, BC
Lot 4 – 1536 Frost Road, Chilliwack, BC
Lot 2 – 1766 Columbia Valley Highway, Chilliwack, BC
VGES Project No. 42906-04

In accordance with your request, Valley Geotechnical Engineering Services Ltd. (VGES) have completed a geotechnical soils investigation and report for the above referenced project. The following report outlines geotechnical recommendations pertinent to the proposed site development and includes identifications of geotechnical hazards within the area and slope stability analyses.

Based upon our work, we conclude that the proposed 42 lot development at the above referenced site is feasible from a geotechnical standpoint provided that the recommendations given below are incorporated in the design and followed during construction. Valley Geotechnical Engineering Services Ltd. estimate that the likelihood of a landslide occurring and affecting the proposed development is low based on a probability of less than 10 percent in 50 years.

Based on the site's proximity to Frosst Creek and its alluvial fan, flooding events causing erosion and deposition in the low lying areas of the site have a low probability based on the 200-year design flood. This flooding hazard results in a Flood Construction Level (FCL) of 0.6m above finished final grade (Northwest Hydraulic Consultants, 2006). We therefore conclude that the site may be used safely for its intended use provided recommendations in this report are followed.

This report was completed in accordance with the following documents:

- British Columbia Building Code 2006
- Fraser Valley Regional District (FVRD) - Community Charter, Section 56
- Association of Professional Engineers and Geoscientists of British Columbia – Guidelines for Legislated Landslide Assessments for Proposed Residential Development in British Columbia, March 2006

The following reports/documents were reviewed in preparation of this report:

- VGES, December 2007. *Geotechnical Investigation & Report – Proposed 218 Holiday Cottage Lot Development, Cultus Country Resort.* Prepared for OPD Ventures Ltd.
- VGES, November 2007. *Geotechnical Investigation & Report – Waste Water Treatment Plant, Cultus Country Resort.* Prepared for OPD Ventures Ltd.
- VGES, March 2007. *Addendum: Geotechnical Recommendations for Proposed Water Reservoir, 1800 Block of Columbia Valley Highway, Cultus Lake, BC.* Prepared for OPD Ventures Ltd.10
- Northwest Hydraulic Consultants, March 2006. *Frosst Creek Fan Hazard Zones, Cultus Lake, BC Final Report.* Prepared for Fraser Valley Regional District.
- Hay & Company Consultants Inc, July 1992. *Flood Construction Level for Subdivision 3, Section 15, Township 22, Portion W½, NWD – Frosst Creek Fan.* Prepared for Mr. Wes Friesen.
- Cave, Peter. February, 1991, revised November 1993. *Hazard Acceptability Thresholds for Development Approvals by Local Government.* Regional District of Fraser-Cheam.

1. SITE DESCRIPTION

The site consists of three lots, Lots 2, 3 and 4, and is located on the south side of the 1700 Block of Columbia Valley Highway in Chilliwack, BC. The area is proposed to be developed into 42 lots for and will contain an approximate area of 3.73ha. Overall, the site is irregular in shape with its widest dimensions of approximately 169m north to south and 394m west to east. The legal description of the site is as follows:

- Subdivision 3, Section 15, Township 22, Rem. W½, New Westminster District
- Subdivision 4, Section 15, Township 22, Rem. E½, New Westminster District

Currently, the site is densely covered with forest vegetation consisting of a variety of trees and shrubs. Generally, the site slopes up from north-east to south-west at grades varying from relatively flat up to 36 percent. The steepest portions are located towards the south-central portion of Lot 4 (south-west area of the site). The site borders Columbia Valley Highway to the north, Frost Road to the west, and various lots to the south and east.

2. SITE TERRAIN AND SURROUNDING AREAS

An extensive topographic survey was completed by Butler Sundvick & Associates Professional Land Surveyors of the site in 2008. Please note that this survey was limited to the extents of the site. Topographic information beyond the site boundaries were obtained from CanMap, Topo Canada Version 2.0.

As previously stated, the site generally slopes up from north-east to south-west. These slopes range from relatively flat, near Columbia Valley Highway, to grades up to 36 percent towards the south-west side of the site. Approximately 160m south of the rear property line the topography flattens out to a plateau where the Cultus Lake Holiday Park development is located. Offset approximately 1100m from the Cultus Lake Holiday Park is the base of Isar Mountain. Directly south of the base is a north-west ridge of Isar Mountain that extends from an elevation of approximately 210m up to 980m, geodetic.

Based on a review of the Geological Survey of Canada Map 1485A, the site, along with the plateau, is Sumas Drift material. This material consists of recessional glacial deposits including sand and gravel channel and floodplain deposits laid by proglacial streams. This material is typically between 5 to 25m but can be up to 40m thick. Beyond the plateau, Isar Mountain consists of bedrock including sedimentary, volcanic, granitic, and metamorphic rocks of Mesozoic and Upper Paleozoic ages. Overlying the bedrock is between 1 to 5m thick of glacial, colluvial, and eolian sediments.

Based on a qualitative analysis of the global area around the site, we conclude that landslide potential including debris flows from Isar Mountain is low. Please note that our qualitative analysis was based on the subsurface conditions encountered during our test pit investigation, review of the Geological Survey of Canada Maps, and topographic information provided. The attached Section 1 in Appendix C shows the generalized topography and subsurface conditions from the north-west Isar Mountain Ridge to the valley floor.

Frosst Creek is located up to approximately 160m from the north-west corner of the site. Over the period of thousands of years this creek has formed an alluvial fan, which remains active. This fan starts at the mouth of the valley to the north-west of the site and terminates at the south-end of Cultus Lake. Based on our review of the 2006 Northwest Hydraulics (NWH) report, our site is located outside the southern edge of the Frosst Creek alluvial fan boundaries. On the inside of this fan boundary, the recommended Flood Construction Level (FCL) is 0.6m above finished final grade.

On the basis of our review of the NWH report along with topographic information provided for this site, the north-east low lying area could be susceptible to a low probability of flooding due to overbank flows. The remainder of the site would not be susceptible to flooding.

Review of the 1992 Hay & Company report shows that a previously constructed home on the east side of the site was recommended to be constructed 1.0m above final finished grade due to flooding potential. Please note that since this report, additional reviews have been completed on the surrounding area, including the 2006 NWH report, as well as construction and repair of existing dikes.

Based on the above, we conclude that the lower portion of the site, outlined on the attached site plan in Appendix B, is susceptible to a low probability of a flooding hazard. We therefore recommend that the proposed buildings in the lower portions of the site be constructed at the FCL of 0.6m above final finished grade. Please note the underside of the main floor joists should be constructed at or above this FCL. Please also note that this report, as well as the NWH, March 2006, report was completed based on the 200-year flood event.

3. PROPOSED DEVELOPMENT

As previously stated, the site is proposed to be developed into 42 lots. The development is proposed to include 1 main roadway with 3 cul-de-sacs. The main roadway will stem from Columbia Valley Highway at the north-east side of the site and connect to Frost Road. The existing buildings on the east and south-west corners of the site are proposed to remain in-place. Please note that at the time of writing this report, no detailed design drawings were provided to us. Upon completion, VGES will review the final drawings to confirm that the recommendations outlined in this report are followed. If required, additional recommendations would be submitted in an addendum report.

Cuts and minor structural fill will be necessary to achieve suitable grades for the lots and roads. For recommendations pertaining to site preparation, cuts, and fills see *Section 6: Conclusions and Recommendations.*

4. FIELD INVESTIGATION

VGES carried out a test pit investigation on 16 June 2008 using a light, track-mounted excavator. The test pit investigation included excavating a total of 14 test pits, designated as TP1 to TP14. The test pits were excavated to depths ranging between 2.4 to 3.6m below existing grade. The investigation was conducted throughout the general area of the site and included minor clearing of vegetation with the excavator.

The field work was carried out under full-time supervision of a member of our engineering staff who logged the soil and groundwater conditions encountered, and collected representative soil samples for detailed examination and soil classification. No underground services were disturbed due to our investigation. Following completion of logging, the test pits were backfilled with the disturbed soils and loosely compacted using the excavator bucket. The attached site plan in Appendix A provides locations of the test pits.

5. SUBSURFACE CONDITIONS

During our geotechnical investigation, the subsurface conditions encountered were relatively consistent throughout the site. The surface soils generally consisted of surficial topsoil, fill, and organic material ranging between minor cover to up to 1.15m in thickness at TP2. Underlying the topsoil material was brown, grey, and black silty sand and sand and gravel. This material was encountered over the entire site and extended beyond depths of discontinuity of the test pits. The gravel particles encountered were elongated and sub-angular to round. Based upon our recent work, as well as work completed for the reservoir and the investigation completed for the 218 lot subdivision below, we have concluded that these materials comprise of colluvium which originated from upslope bedrock and is generally loose to compact.

The topsoil, fill, and organic material encountered are deemed unsuitable for typical footing bearing and should be removed and replaced prior to foundation construction. See *Section 6: Conclusions and Recommendations* for details.

Although some soils encountered onsite were moist, no free water was encountered to the depths explored. Based on our soils investigation, we are of the opinion that the subsurface materials are relatively free draining. See Appendix A for test pit logs and location plan for details of the subsurface conditions encountered.

Based on our soils investigation and the 2006 BC Building Code, the classification of seismic site response for the site is Site Class D.

6. CONCLUSIONS AND RECOMMENDATIONS

Based on the soil and ground water conditions found, along with our review of reports previously mentioned, we consider that the proposed development is feasible from a geotechnical standpoint provided that the recommendations given in this report are followed. We conclude that the potential hazards of the site include landslides, debris floods, and flooding. The following sections provide conclusions and recommendations regarding slope stability, flood construction levels, liquefaction, site preparation including cuts and fills, foundations, drainage, pavements, and retaining walls.

6.1 SLOPE STABILITY ANALYSES

Two geotechnical computer modeling programs; GSLOPE and GeoStudio 2007 with Slope/W were used to conduct our slope stability analyses of the site. These computer models were used to conduct limit equilibrium slope stability analyses using Bishop's Modified and Morgenstern-Price Methods. Both shallow and deep-seated failures were considered under static and seismic conditions.

Four sections were modeled for our analyses: Sections A-A and B-B were completed for our March 2007 Water Reservoir report and includes the steep slopes through Lot 3. Sections C-C and D-D were completed for Lot 4 and included analyses for the steepest gradients of the site. As previously stated, a qualitative analysis was completed for the area outside of the site boundaries including the north-west Ridge of Isar Mountain. See Section 1 for details of our qualitative analysis in Appendix 1.

The stratigraphy used in our analyses was inferred from our soils investigations along with the topographic information provided by Butler Sundvick & Associates Professional Land Surveyors and CanMap, Topo Canda Version 2.0. The stability calculations were performed using the following parameters:

Seismic Acceleration		0.21g
Minimum Factors of Safety	Static:	1.5
	Seismic:	1.1

Please note that our analyses were completed in accordance with APEGBC's Legislated Landslide Assessments for Proposed Residential Development in BC of March 2006. The seismic acceleration used was based on a design event with a 10 percent probability being exceeded in 50 years. See the attached site plan and sections for details of our slope stability analyses in Appendix B and C, respectively. The results of the stability analyses are summarized in the following table:

Section	**Lowest FS**	**FS req.**	**FS > FS req.**
A-A - *Static*	2.6	1.5	Y
A-A - **Seismic**	**1.3**	1.1	Y
B-B - *Static*	2.3	1.5	Y
B-B - **Seismic**	**1.2**	1.1	Y
C-C - *Static*	2.6	1.5	Y
C-C - **Seismic**	**1.5**	1.1	Y
D-D - *Static*	2.3	1.5	Y
D-D - **Seismic**	**1.3**	1.1	Y

Based on our qualitative analysis along with our computer modeling of the site we conclude that adequate factors of safety are present for the site slopes provided excessive fill is not placed on the slopes. The slopes above and within the proposed development site are therefore stable under both static and seismic conditions under the 2006 BC Building Code and APEGBC's Legislated Landslide Assessment of March 2006. The risk of landslides affecting the proposed development is low. The site may therefore be used safely for the intended purpose.

Please note that the APEGBC Landslide Assessment Statement is attached at the end of this report in Appendix D.

6.2 FLOOD CONSTRUCTION LEVELS

As previously stated, we conducted a review of topographic site information, as well as a review of the NWH 2006 Frosst Creek Fan Hazard Report. We conclude that the lower, flatter area of the site on the east side is susceptible to a low probability of flooding hazard from the Frosst Creek Alluvial Fan. We therefore recommend that the proposed buildings in the low portions of the site be constructed at the FCL of 0.6m above final finished grade. Please note the underside of the main floor joists should be constructed above this FCL. See Appendix B for areas showing where the FCL is required to be met.

6.3 LIQUEFACTION

The subsurface conditions encountered onsite determined that the native soils are relatively clean, sand and gravel with some areas of silty sand. Based on the low silt content through the majority of the site, this material may be susceptible to liquefaction if a seasonally high water table does exist. However, please note that the site is on a slope and the subsurface materials are relatively free-draining and therefore we do not expect a high water table.

For our December 2007 report on the lower 218 lot development, we monitored the water table levels throughout the site. Based on our monitoring and analysis of the subsurface conditions, the probability of punching failure of the foundations was determined to be low for the design earthquake. Our monitoring and previous drilling of the low lying 218 lot development site showed that the water table was deeper than 3.0m below grade during the wet season.

Based on the above, as well as our knowledge of sites in the near vicinity of the area, we are of the opinion that the potential for building collapse due to the design earthquake is low. Please note that these buildings are not considered post disaster structures and distortion of these buildings is allowed provided that people can egress from the building.

6.4 SITE PREPARATION

Site preparation should include removal of all organic soil and materials considered unsuitable within the zone of influence of the buildings, driveways, and roads. The zone of influence is a 1 horizontal to 1 vertical (1H:1V) projection taken 1.0m offset horizontally from the outside footing or pavement edge. If unsuitable material extends below the design elevation of the proposed buildings, it should also be removed and either disposed offsite or stockpiled for use in nonstructural areas, such as landscapes. During site preparation, the subgrade should be shaped and graded slightly to prevent ponding of water. For further recommendations regarding drainage, see Section 6.8.

Based on the relatively shallow depth to the inorganic sand and gravel material, we expect that the bearing surface for the buildings would consist of the native loose to compact sand and gravel material with adequate bearing capacity. We do however recommend that the exposed sand and gravel surface be compacted with a heavy vibratory roller prior to forming or placement of fill where required. As previously stated, no detailed design drawings were provided to us at the time of writing this report.

6.5 CUTS

If the native sand and gravel material is exposed, we recommend that permanent cut slopes be no steeper than 2H:1V. Temporary cut slopes, where required, should be no steeper than 1H:1V. Please note that VGES should be onsite to review cut slopes to ensure that the site is safe for workers.

At the time of our test pit investigation, no free water was encountered. However; if ponding water is found during excavation, we expect that de-watering by conventional sump and pump methods would be sufficient.

6.6 FILLS

Fill, where required to achieve suitable grades should consist of VGES approved, free-draining granular material, placed in maximum 300mm lifts. This material should be compacted to at least 95 percent of the materials Standard Proctor density (SPD) to achieve building grades and to at least 95 percent of the material's Modified Proctor density (MPD) for road areas.

VGES should be present to review all cuts, fills, and fill material placed to ensure that work is being completed in accordance with our recommendations.

6.7 FOUNDATIONS

Footings can either be constructed on the exposed, compacted, and approved native sand and gravel or alternatively on VGES approved structural fill, which may be required to achieve design footing elevation for the buildings.

The footings can be designed based upon an unfactored allowable soil bearing pressure of 96kPa (2000 psf). The ultimate soil bearing pressure at failure of the material is 286kPa (6000 psf). Using a geotechnical resistance factor of 0.5 for bearing of shallow foundations, the ultimate limit state bearing pressure is 140 kPa (3000 psf).

The following geotechnical design parameters are to be used for design:

Ultimate Limit State (ULS)	140 kPa (3000 psf)
Serviceability Limit State (SLS)	96 kPa (2000 psf)
Site class	D (50kPa $<$ su $<$ 100kPa, $15<N_{60}<50$)
Peak ground acceleration (PGA)	0.35g
Acceleration-based site coefficient (F_a)	1.2
Velocity-based site coefficient (F_v)	1.2
Modulus of subgrade reaction	80MPa/m (300pci)

As previously stated, the exposed native sand and gravel should be compacted with a heavy vibratory roller, prior to forming or placement of fill where required. All fill material should also be compacted to at least 95 percent SPD and can be designed for the same allowable bearing pressure. A minimum of 450 mm of soil cover is required for all exterior footings for frost protection.

6.8 DRAINAGE AND SLAB LEVEL

We recommend that final grades be chosen so as to shed water away from driveways and building structures. Trenches should be used during construction to rid low-lying areas of storm water.

Buildings with slabs below surrounding grade should be provided with perimeter drains constructed at the footing levels. The drains should consist of a perforated pipe surrounded with drain-rock, encapsulated in a non-woven, needle punched filter fabric and backfilled with granular free draining soil. For buildings constructed as slab-on-grade above surrounding grade, no perimeter drains will be required.

Roof run-off must not be tied to the perimeter drainage system but should be directed to a sump which collects both roof and perimeter drain waters. This water should then either be directed it by gravity to the storm water connections or be directed into a rock pit, whichever is preferred by the FVRD. If requested, VGES may provide rock pit design drawings.

The FCL for the low lying area to the east of the site may be susceptible to flooding with a low probability for the design flood. We recommend that underside of the main floor joists be constructed at least 0.6m above finished grade. Please note that any mechanical equipment place below this level would be susceptible to damage during flooding.

6.9 PAVEMENT SECTION

Site preparation should be undertaken in accordance with recommendations provided in the previous sections. The following minimum pavement section is recommended over the prepared native sand and gravel or VGES approved 95 percent MPD compacted structural fill sub grade:

- 300 mm of compacted 75mm minus sand or sand & gravel sub base
- 100 mm of 19 mm minus crushed gravel base
- 80 mm of asphalt

The sub grade must be approved by VGES prior to sub base placement and pavement section must be placed in accordance with municipal standards.

6.10 RETAINING WALLS

Based on the slopes onsite, we expect that retaining walls may need to be incorporated to achieve lot and road grades. These walls may be the most effective way to utilize the area of the site while providing final grades which satisfy the development.

Adequate drainage must be provided behind all retaining walls, irrespective of their height, to ensure that hydrostatic pressures do not develop behind these walls. Also, the retaining walls must be constructed on a VGES approved compacted base. In addition, the global stability of these walls should be reviewed by a qualified geotechnical engineer to confirm that the minimum factors of safety under both static and seismic loading conditions are met.

Several different types of retaining walls may be considered. Engineered retaining walls could include Lock Block, Allan Block, cast in-place concrete, living/green walls, and/or shotcrete. In any event, the height of wall, even with terracing, may be limited by the FVRD specifications. Following a review of the final design, VGES can provide design details for the retaining walls.

6.0 CLOSURE

It is recommended that VGES be retained to carry out a geotechnical review of the design drawings to ensure compliance with the recommendations set forth in this report. Additional recommendations upon review of the final design, if required, would be provided in an addendum report. In addition, VGES should be retained to carry out field reviews and testing during site preparation to confirm that the subsurface conditions do not differ from that anticipated in this report and that our recommendations have been followed.

We trust that this letter with the attached provides the required information. If you have any questions, please call.

Yours very truly;

Narayan Abhyankar, P. Eng.
Principal Geotechnical Engineer   Oct 31/08

Nate Stevens, Dipl.T.
Geotechnical Engineering Technologist

Attachments:

- Appendix A – Test Pit Logs and Location Plan
- Appendix B – Site Plans
- Appendix C – Slope Stability Cross Sections
- Appendix D – APEGBC Landslide Assessment Statement

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APPENDIX A

Test Pit Logs and Location Plan

VGES Project No. 42906-04

TABLE 1

SUMMARY OF TEST PITS LOG

Project: 43906-04
Address: Lots 2, 3, &4 - Columbia Valley Hwy, Chilliwack, BC
Client: Cultus Lake Investments
Date of Investigation: June 16, 2008

Test Hole No.	Depth m	Soil Conditions
1	0 – 1.20	Brown, compact, SAND and gravel, elongated, sub-angular to rounded
No GPS info.	1.20 – 1.50	Dark grey, compact, clean, medium SAND
	1.50 – 2.40	Dark grey, compact, course, silty SAND with gravel, elongated, sub-angular to sub-rounded
	2.40 – 3.00	Dark grey, moist, compact, silty SAND with trace gravel with pockets of clayey fine sand
		Discontinued @ 3.00 m and no free water encountered
2	0 – 1.15	Black organic SILT (topsoil)
No GPS info.	0.15 – 1.50	Dark brown, compact, silty SAND and gravel, elongated, sub-angular to rounded
	1.50 – 2.70	Dark grey, compact, course SAND with silt to sandy gravel with silt, well graded, sub-angular to sub-rounded cobbles
	2.70 – 3.30	Dark brown, poorly graded GRAVEL with sand, sub-angular to rounded
		Discontinued @ 3.30 m and no free water encountered

3 49°01'58.7" 122°01'26.5"	0 – 0.15 0.15 – 1.80 1.80 – 3.30	Black organic SILT (topsoil) Light brown, compact, loamy silty SAND with rounded gravel Dark grey, compact, medium SAND progressing to course sand and gravel to sandy gravel, elongated, sub-rounded to sub-angular Discontinued @ 3.30 m and no free water encountered
4 49°01'57.3" 122°01'28.8"	0 – 0.90 0.90 – 3.00 3.00 – 3.15	Brown, compact, SAND and gravel, heavy root structure Brown, compact, well graded GRAVEL with sand and silt, elongated, rounded to sub-angular Gray to black, compact, poorly graded medium SAND with gravel, rounded Discontinued @ 3.15 m and no free water encountered
5 49°01'57.5" 122°01'30.5"	0 – 0.15 0.15 – 0.90 0.90 – 3.60	Black organic SILT (topsoil) Brown, compact, loamy silty SAND Gray to black, compact, clean SAND with GRAVEL, rounded to sub-angular, 0.45m cobble noted Discontinued @ 3.60 m and no free water encountered
6 49°01'55.8" 122°01'30.1"	0 – 0.15 0.15 – 1.50 1.50 – 2.40	Black organic SILT (topsoil) Brown, compact, silty SAND with gravel, elongated, rounded to sub-angular Dark grey, poorly graded GRAVEL with sand and silt, sub-angular to sub-rounded Discontinued @ 3.41 m due to hole collapse and no free water encountered
7 49°01'55.8" 122°01'28.7"	0 – 0.15 0.15 – 2.50	Black organic SILT (topsoil) Brown, compact, silty SAND and gravel, sub-rounded to sub-angular Discontinued @ 2.50 m and no free water encountered

8 49°01'54.8" 122°01'27.3"	0 – 0.15	Black organic SILT (topsoil)
	0.15 – 1.50	Brown, compact, silty SAND and gravel, sub-angular to sub-rounded
	1.50 – 2.10	Dark grey, silty SAND with gravel to course sand and gravel, sub-angluar
	2.10 – 2.40	Black to brown, moist, compact , silty SAND
		Discontinued @ 2.40 m due to large cobble and no free water encountered
9 49°01'54.4" 122°01'27.4"	0 – 0.15	Black organic SILT (topsoil)
	0.15 – 1.20	Brown, compact, silty SAND and gravel
	1.20 – 2.70	Dark brown, compact, well graded, layered silty sandy GRAVEL with 0.30m minus cobbles, sub-angular
		Discontinued @ 3.10 m and no water encountered
10 49°01'53.6" 122°01'25.9"	0 – 0.15	Black organic SILT (topsoil)
	0.15 – 0.60	Brown to light brown, compact, loamy silty SAND
	0.60 – 1.50	Brown, silty SAND and gravel, sub-rounded
	1.50 – 1.95	Dark grey, compact, course, sandy GRAVEL with 0.30m sub-angular cobbles
	1.95 – 2.40	Brown, compact, silty SAND with gravel
		Discontinued @ 2.40 m due to hole collapse and no free water encountered
11 49°01'53.8" 122°01'24.1"	0 – 0.15	Black organic SILT (topsoil)
	0.15 – 0.45	Brown to light brown, compact, loamy silty SAND
	0.45 – 1.20	Brown, silty SAND and gravel, sub-rounded
	1.20 – 2.40	Dark grey, compact, course, sandy GRAVEL, with 0.30m sub-angular cobbles
		Discontinued @ 2.40 m and no free water encountered

12 49°01'55" 122°01'23.4"	0 – 0.15 0.15 – 1.50 1.50 – 3.30	Black organic SILT (topsoil) Brown, silty SAND and gravel, sub-rounded Dark grey, compact, course, well graded, silty sandy GRAVEL, with 0.30m sub-angular cobbles Discontinued @ 3.30 m and no free water encountered
13 49°01'55.8" 122°01'22.4"	0 – 0.15 0.15 - 1.20 1.20 – 2.55	Black organic SILT (topsoil) Brown, compact, silty to sandy GRAVEL Dark grey, compact, moist, sandy GRAVEL, elongated, sub-angular Discontinued @ 2.55 m and no free water encountered
14 49°01'54.4" 122°01'19.5"	0 – 0.45 0.45 – 1.80 1.80 – 2.70 2.70 – 3.00	Black organic SILT, fill (topsoil) Brown, compact, sandy GRAVEL, sub-angular to sub-rounded with 0.30m cobbles Brown, compact, moist, silty SAND with gravel Brown, compact, sandy SILT Discontinued @ 3.30 m and no free water encountered

Note: See attached plans for test pit locations

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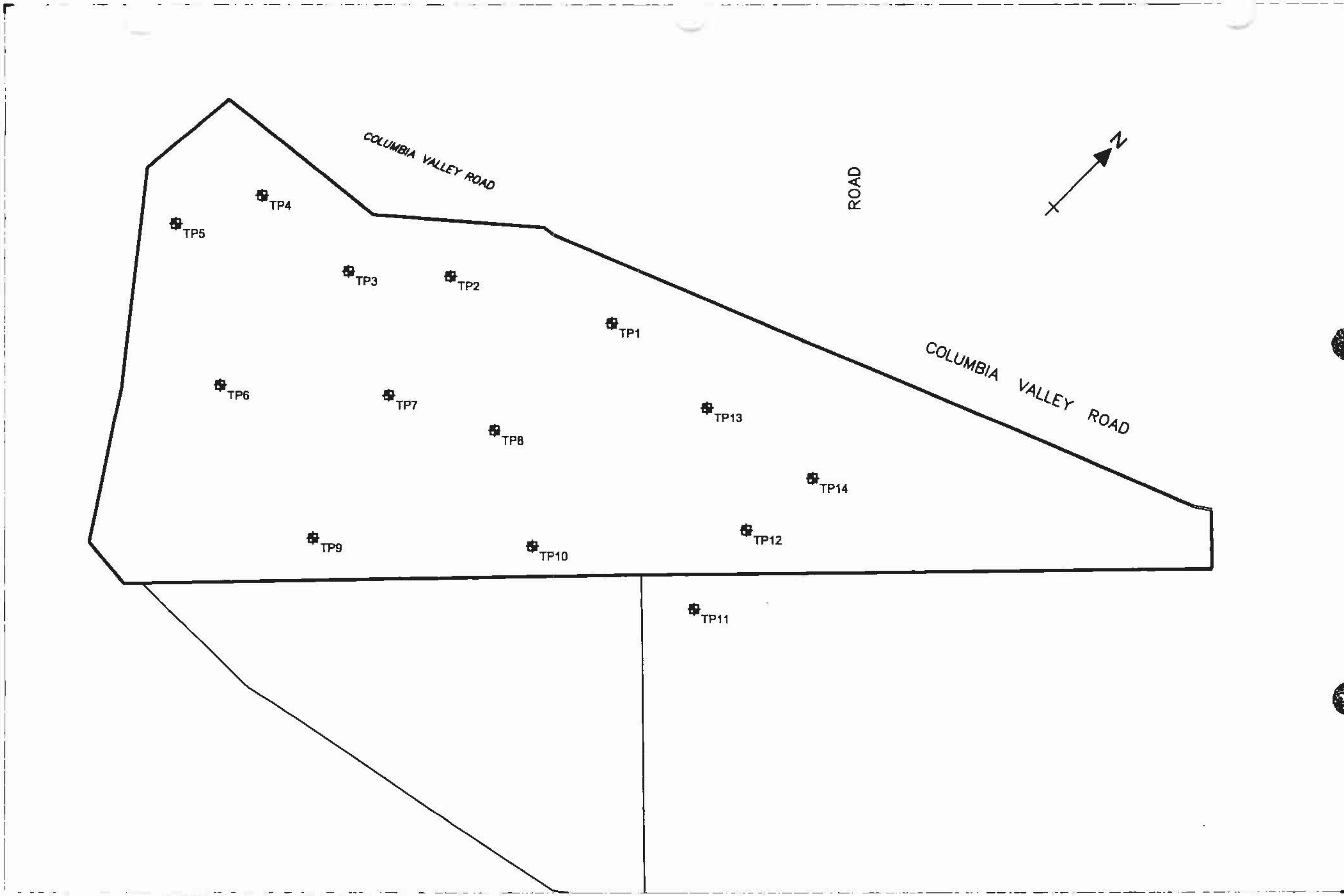

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Client:	Cultus Country Investments	Title:	Test Pit Location Plan		
Location:	1700 Block of Columbia Hwy, Chilliwack, BC	Scale:	NTS	Proj. No:	42906-04
Description:	Proposed Subdivision	Drawn:	NS	Date:	June 26, 2008
		Checked:	NA	Rev. #: 0	Sheet: 1 of 1

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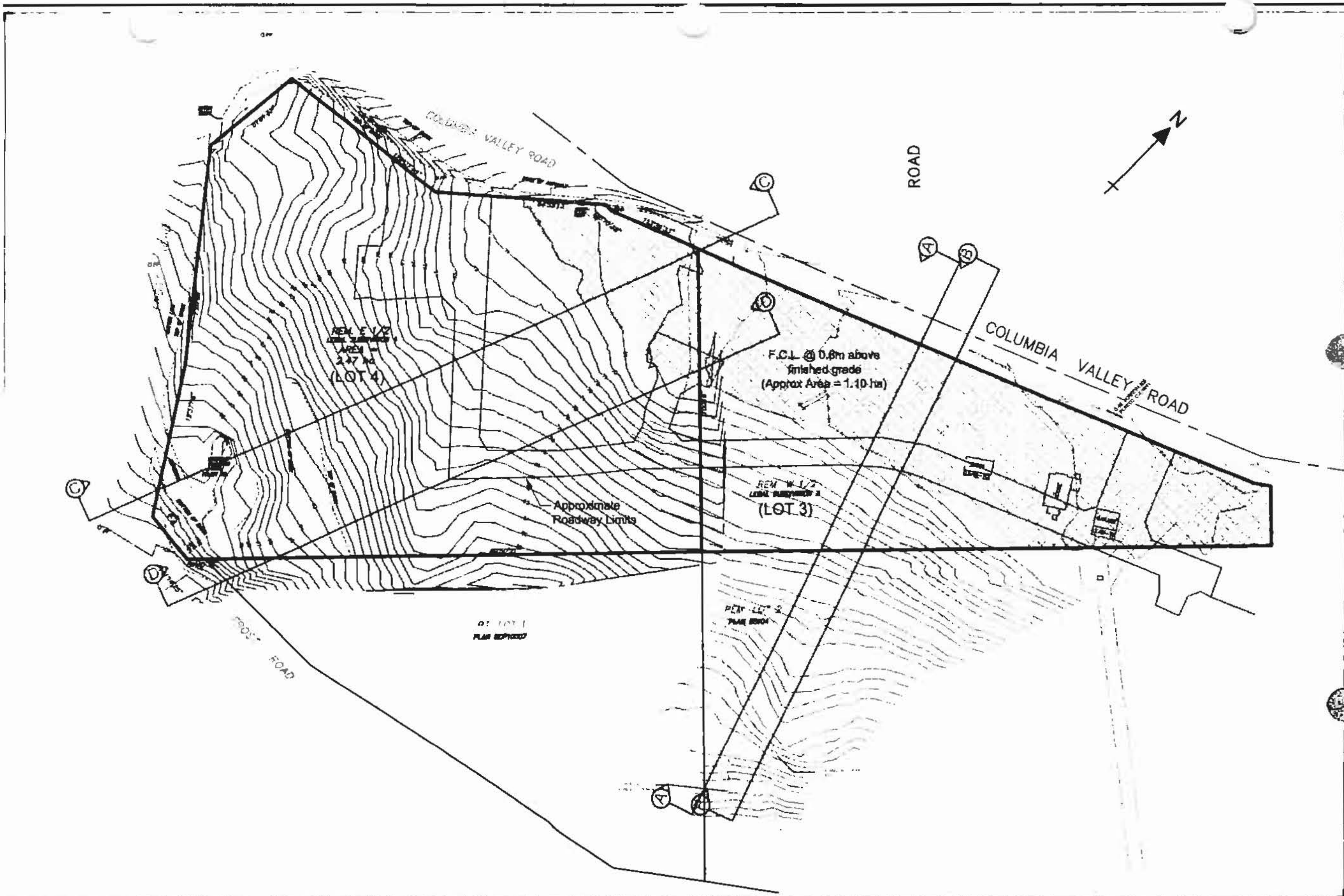
APPENDIX B

Site Plans

VGES Project No. 42906-04



Client:	Cultus Country Investments	Title:	Cross Section Location Plan		
Location:	1700 Block of Columbia Hwy, Chilliwack, BC	Scale:	NTS	Proj. No:	42906-04
Description:	Proposed Subdivision	Drawn:	NS	Date:	June 26, 2008
		Checked:	NA	Rev. #: 0	Sheet: 1 of 2

Valley Geotechnical Engineering Services Ltd.

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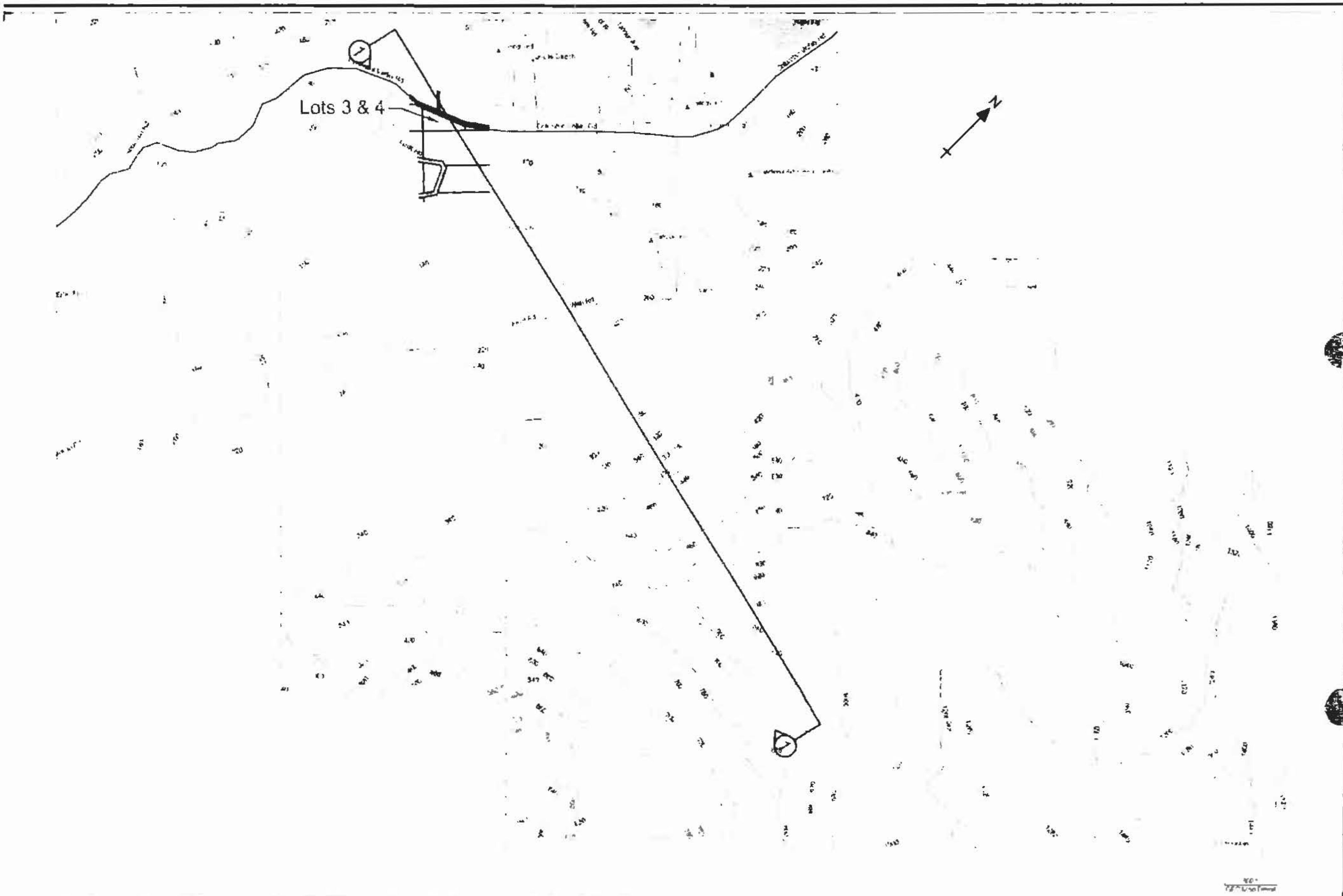

VALLEY GEOTECHNICAL ENGINEERING SERVICES LTD.

Client:	Cultus Country Investments	Title:	Global Stability Cross Section Location Plan
Location:	1700 Block of Columbia Hwy, Chilliwack, BC	Scale: NTS	Proj. No: 42906-04
Description:	Proposed Subdivision	Drawn: NS	Date: June 26, 2008
		Checked: NA	Rev. #: 0 / Sheet: 2 of 2

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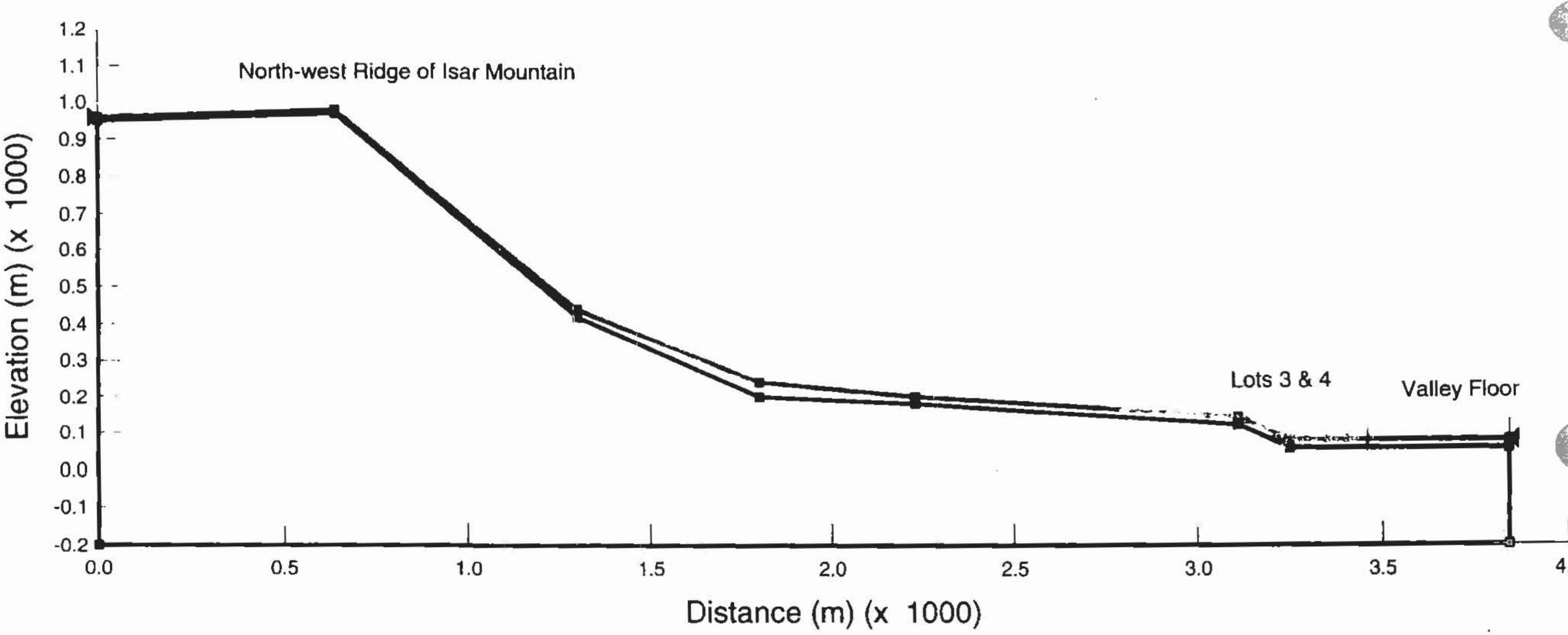
APPENDIX C

Slope Stability Cross Sections

VGES Project No. 42906-04

Section 1 - Qualitative Analysis



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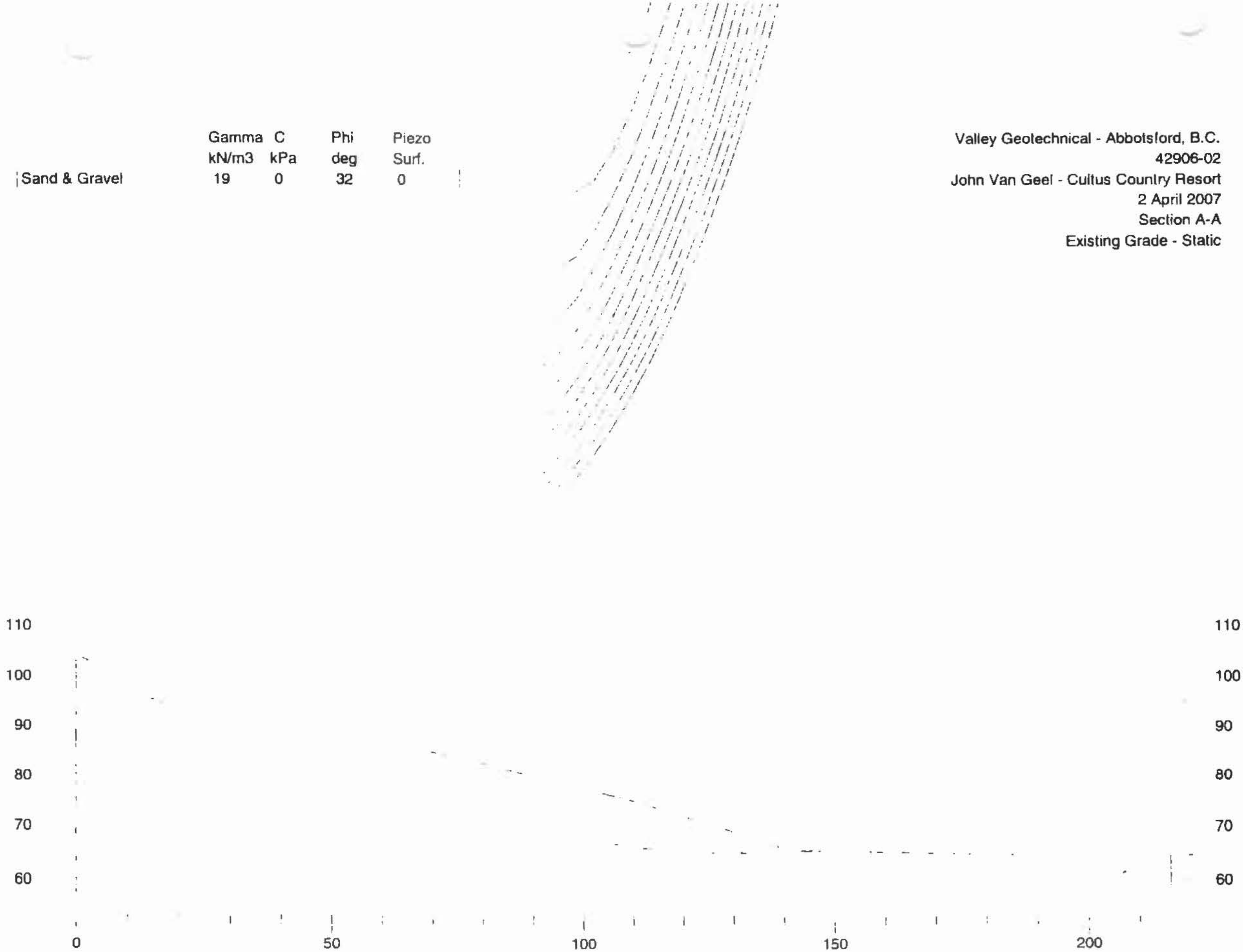
42906-02
John Van Geel - Cultus Country Resort
2 April 2007
Section A-A
Existing Grade - Static



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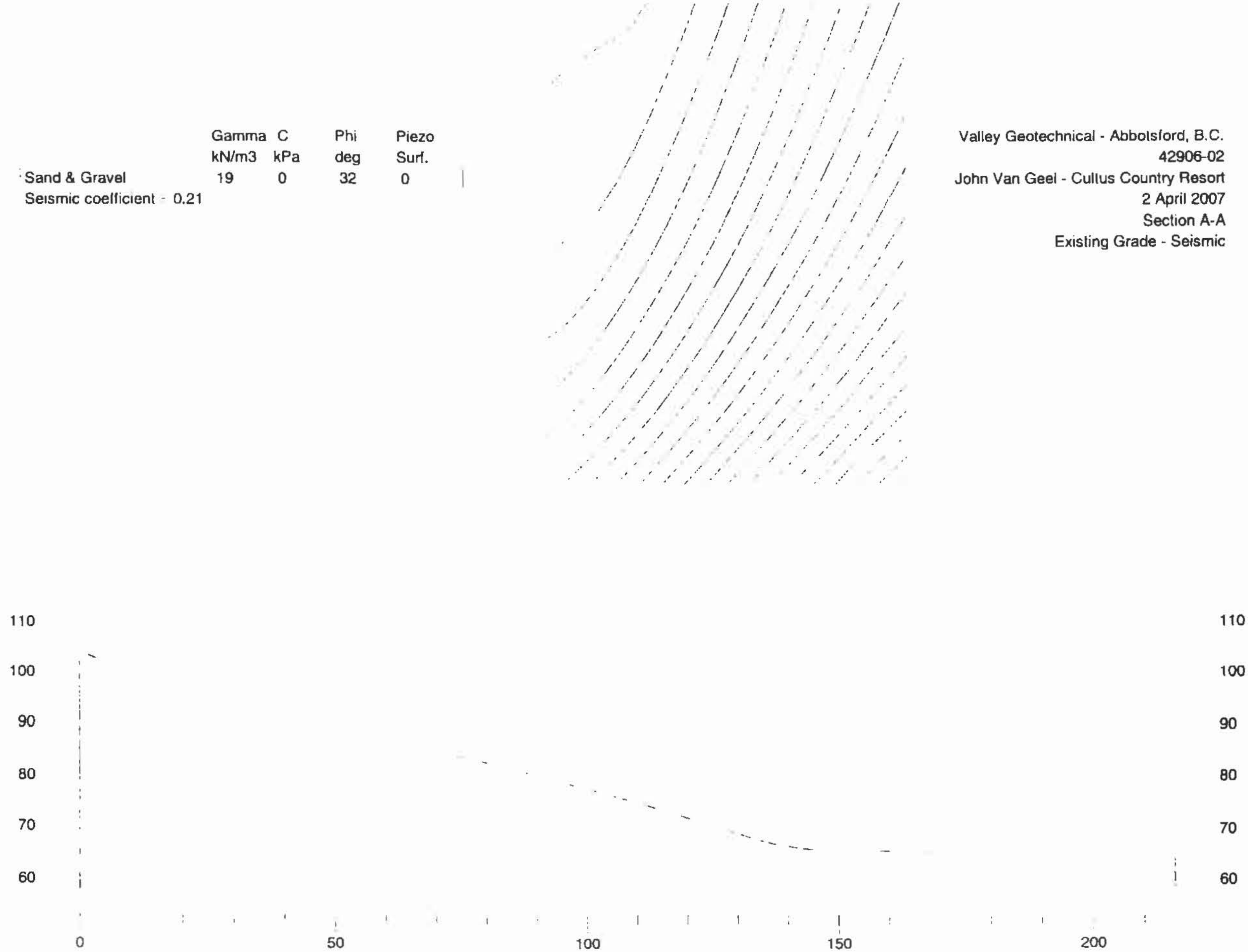
Sand & Gravel	19	0	32	0

Seismic coefficient - 0.21

Valley Geotechnical - Abbotsford, B.C.
42906-02
John Van Geel - Cultus Country Resort
2 April 2007
Section A-A
Existing Grade - Seismic



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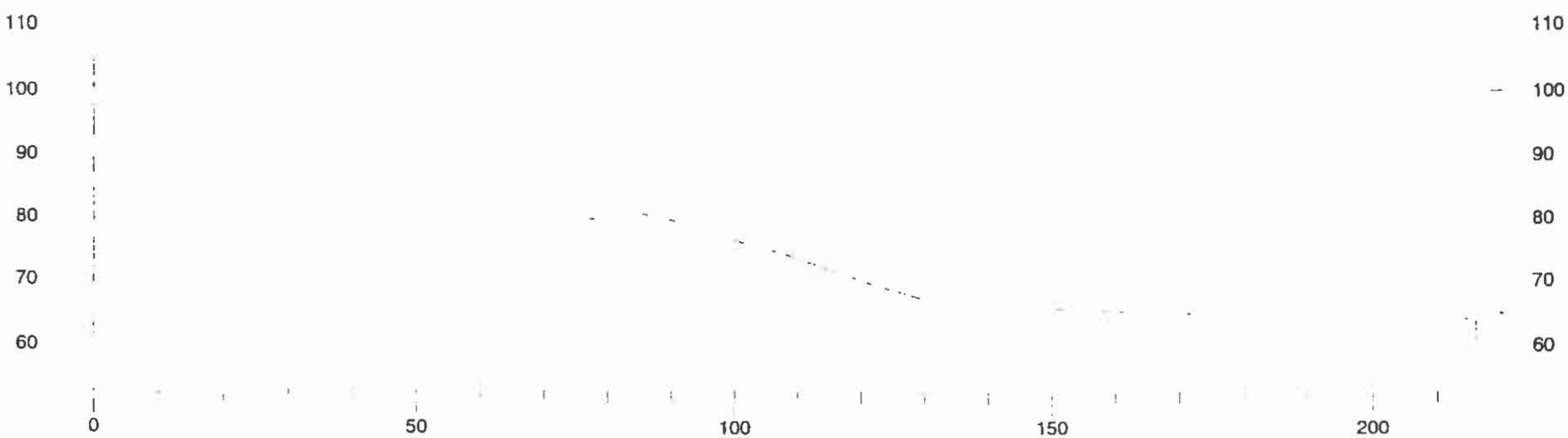
42906-02
John Van Geel - Cultus Country Resort
12 March 2007
Section B-B
Existing Grade - Static



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Sand & Gravel	19	0	32	0

Seismic coefficient = 0.21

Valley Geotechnical - Abbotsford, B.C.
42906-02
John Van Geel - Cultus Country Resort
12 March 2007
Section B-B
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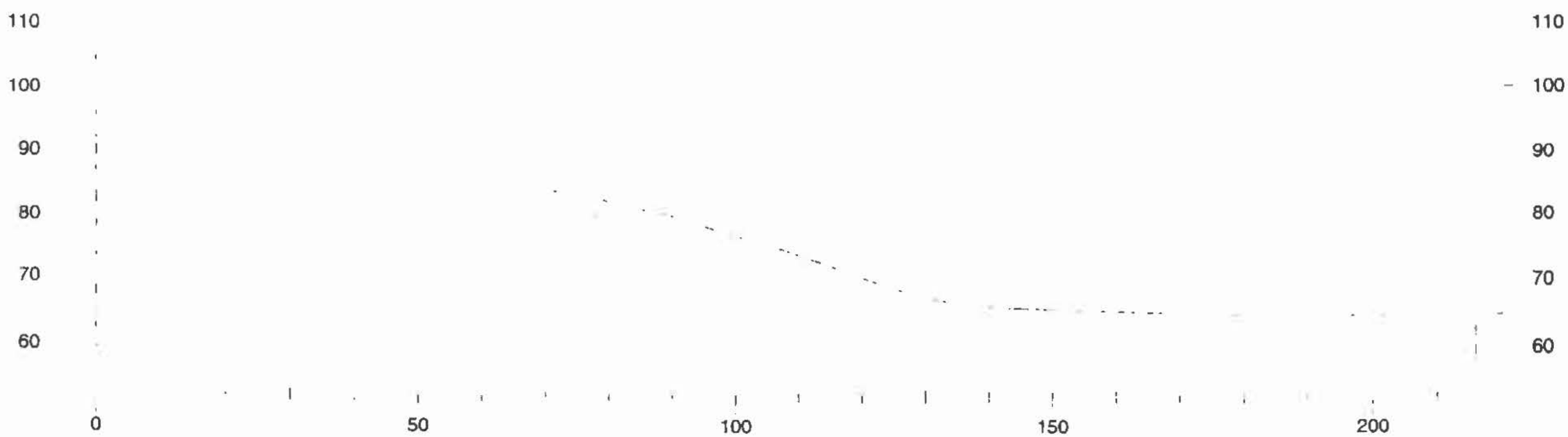

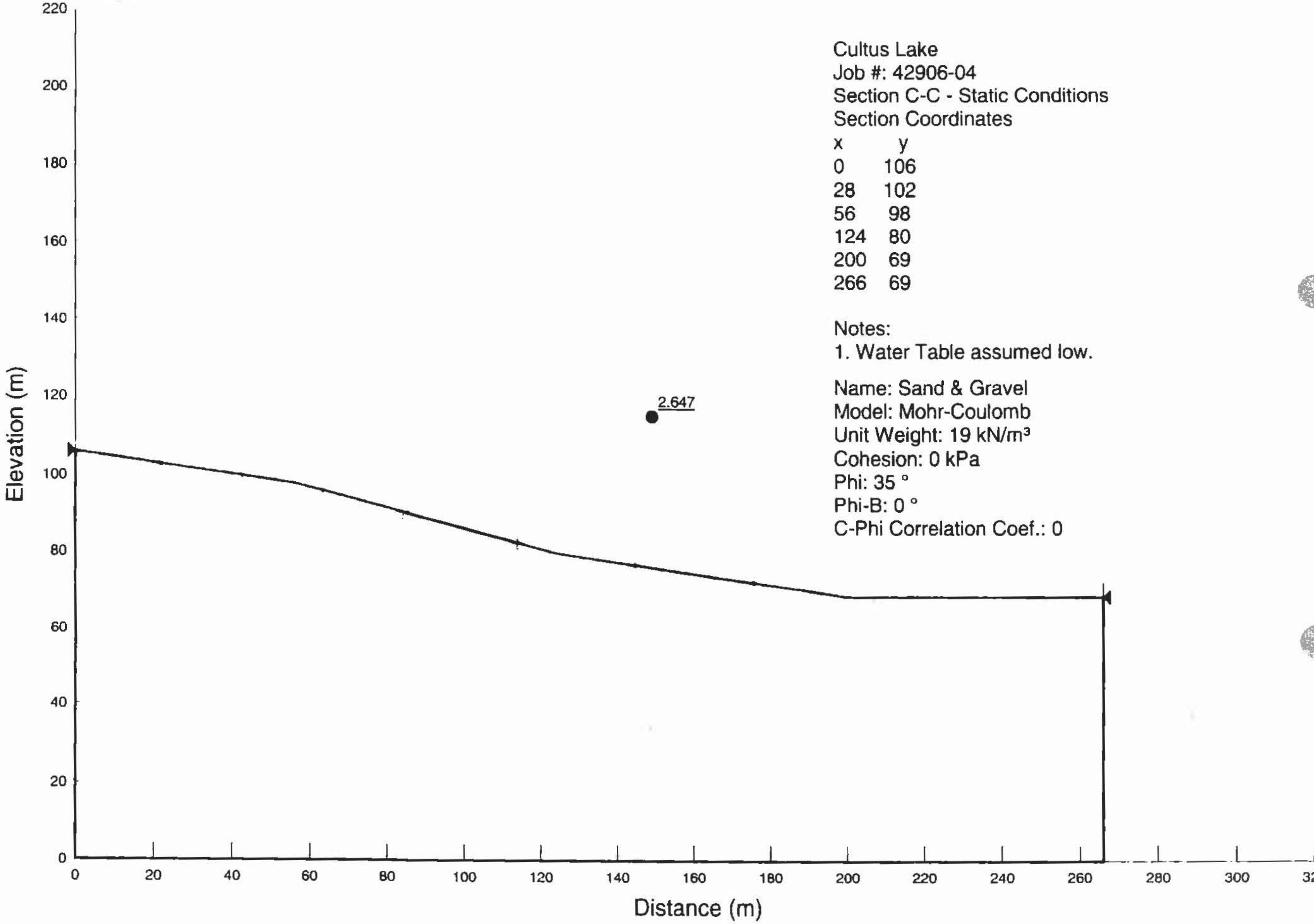
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Job #: 42906-04
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28 102
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124 80
200 69
266 69
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Model: Mohr-Coulomb
Unit Weight: 19 kN/m³
Cohesion: 0 kPa
Phi: 35 °
Phi-B: 0 °
C-Phi Correlation Coef.: 0
2.647
Elevation (m)
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140
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280
300
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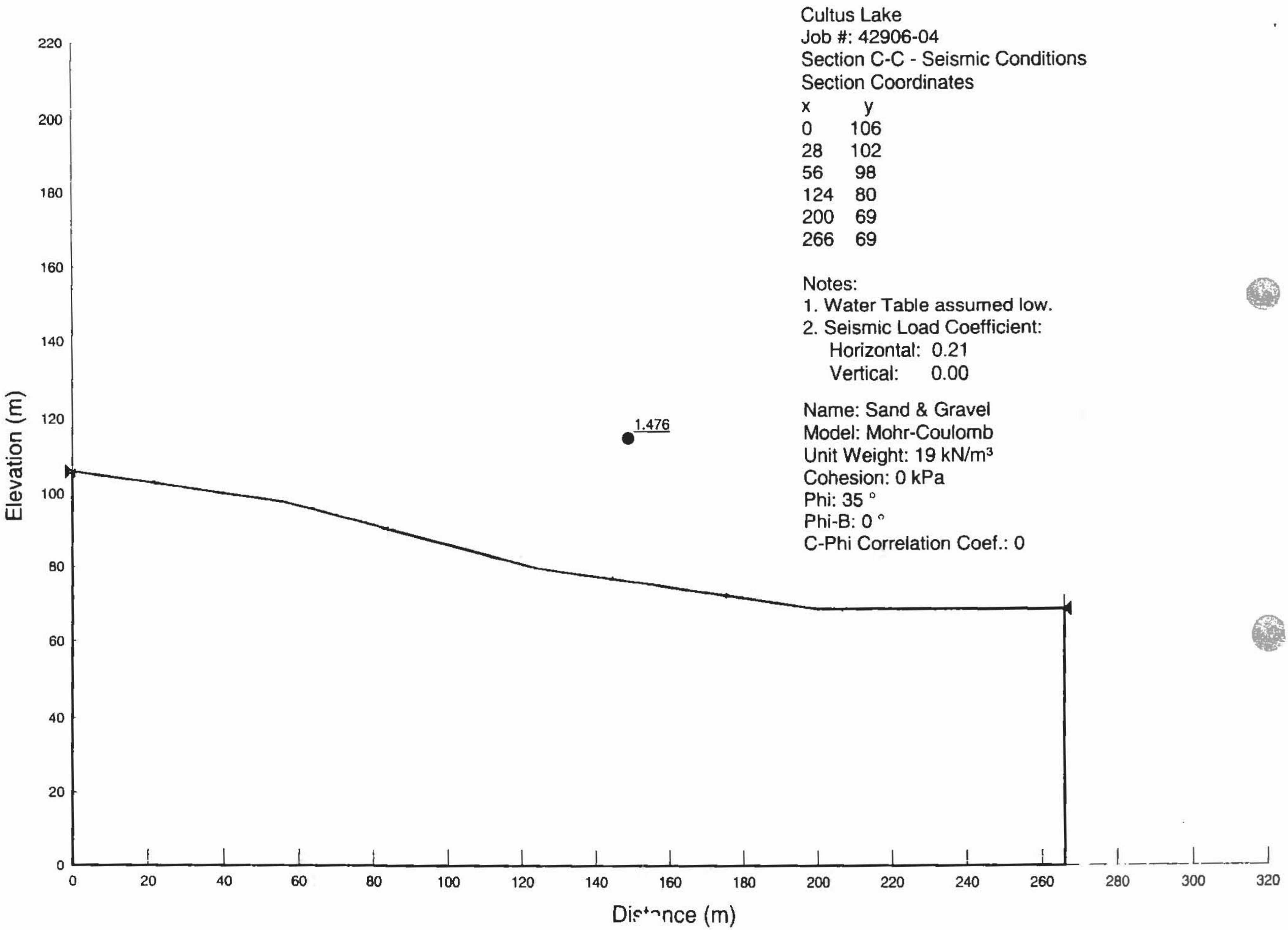
Cultus Lake
Job #: 42906-04
Section C-C - Seismic Conditions
Section Coordinates
x y
0 106
28 102
56 98
124 80
200 69
266 69
Notes:
1. Water Table assumed low.
2. Seismic Load Coefficient:
Horizontal: 0.21
Vertical: 0.00
Name: Sand & Gravel
Model: Mohr-Coulomb
Unit Weight: 19 kN/m³
Cohesion: 0 kPa
Phi: 35 °
Phi-B: 0 °
C-Phi Correlation Coef.: 0
1.476
Elevation (m)
Distance (m)
220
200
180
160
140
120
100
80
60
40
20
0
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320

Cultus Lake
Job #: 42906-04
Section D-D - Static
Section Coordinates

x	y
0	108
18	106
37	97
72	91
101	82
192	68
237	68

Name: Sand & Gravel
Model: Mohr-Coulomb
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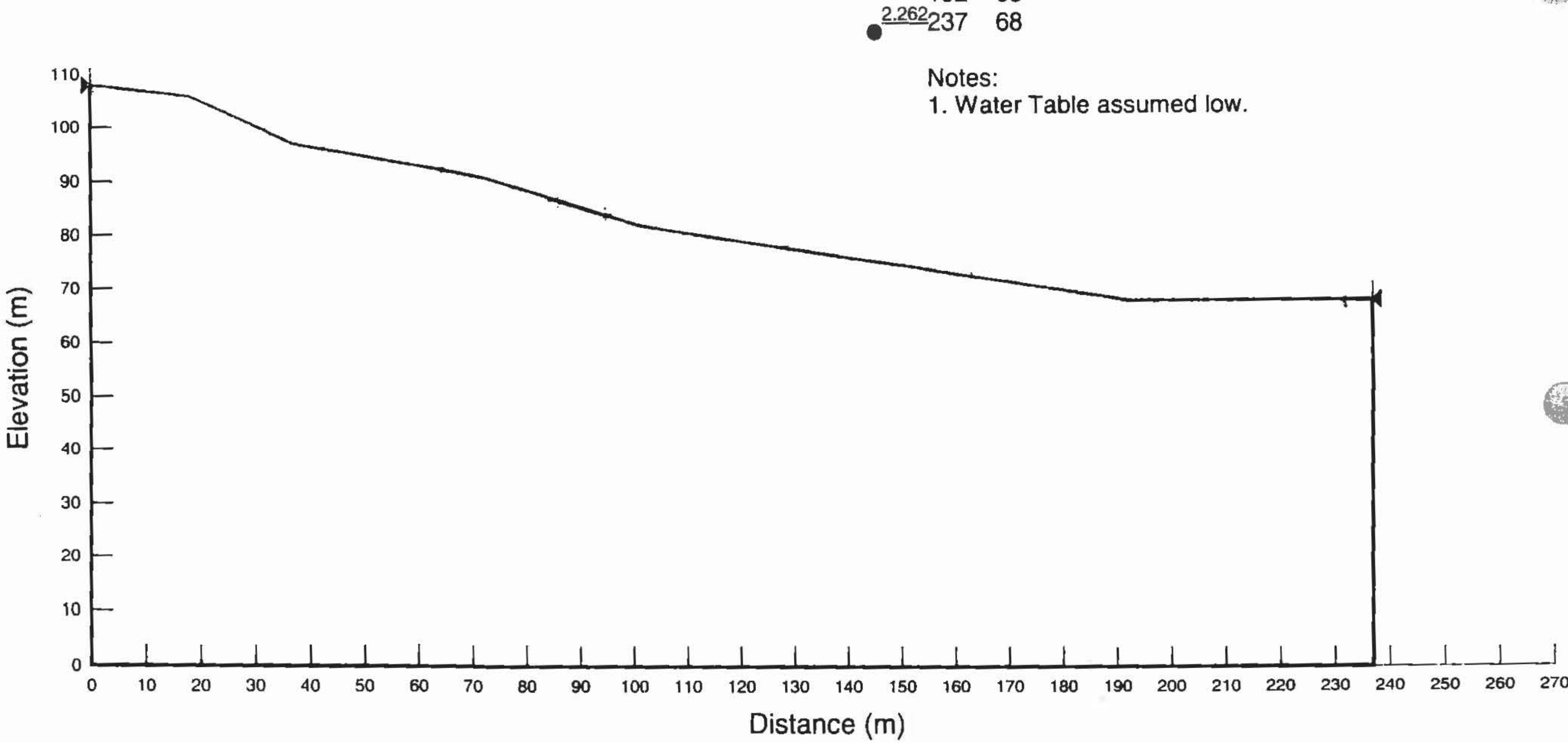
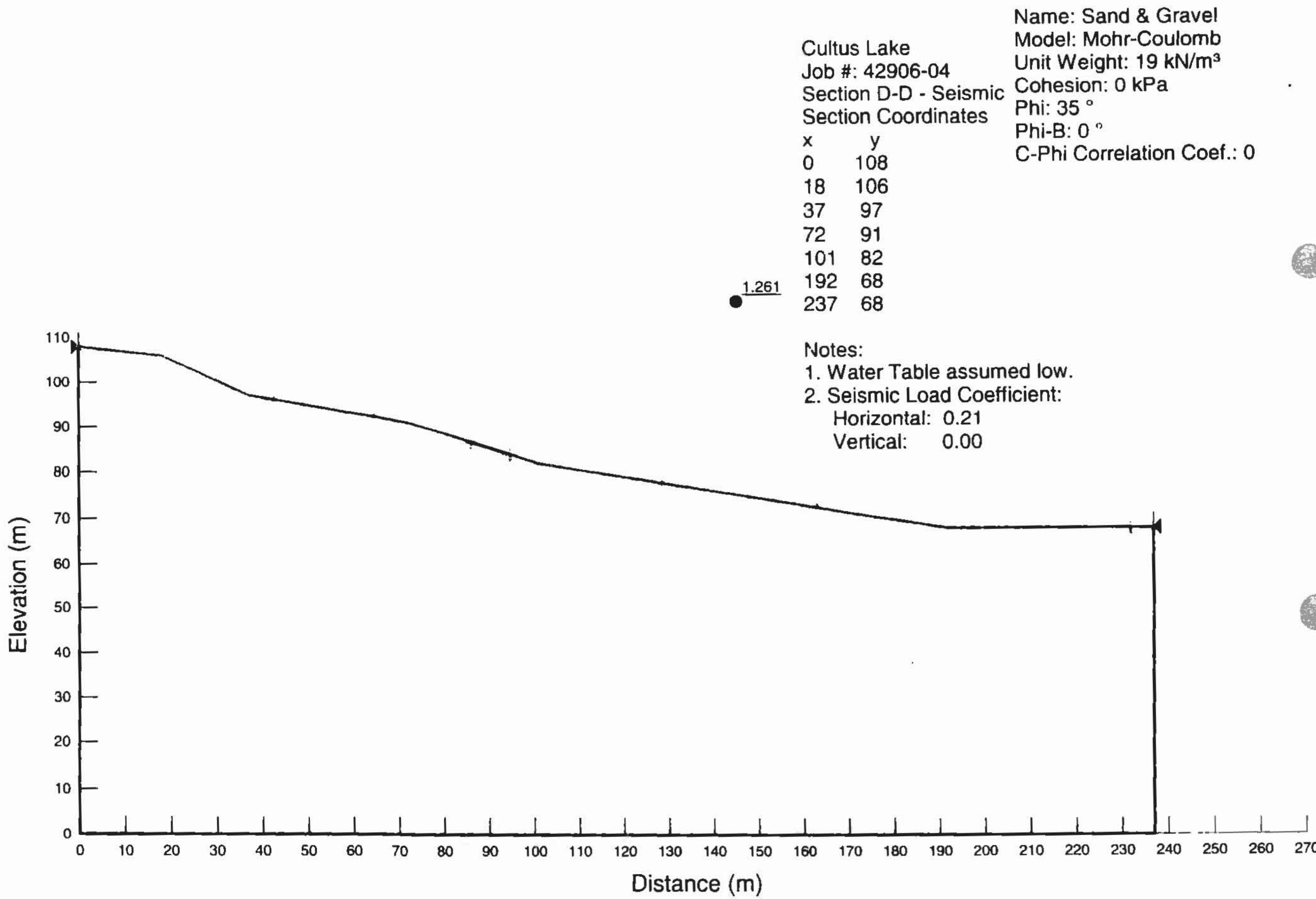
Phi-B: 0 °
C-Phi Correlation Coef.: 0

Notes:
1. Water Table assumed low.





Cultus Lake
Job #: 42906-04
Section D-D - Seismic
Section Coordinates
x y
0 108
18 106
37 97
72 91
101 82
192 68
237 68
Name: Sand & Gravel
Model: Mohr-Coulomb
Unit Weight: 19 kN/m³
Cohesion: 0 kPa
Phi: 35 °
Phi-B: 0 °
C-Phi Correlation Coef.: 0
1.261
Notes:
1. Water Table assumed low.
2. Seismic Load Coefficient:
Horizontal: 0.21
Vertical: 0.00
Elevation (m)
Distance (m)
0 10 20 30 40 50 60 70 80 90 100 110
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200 210 220 230 240 250 260 270

APPENDIX D

APEGBC Landslide Assessment Statement

VGES Project No. 42906-04

APPENDIX D: LANDSLIDE ASSESSMENT ASSURANCE STATEMENT

Note: This Statement is to be read and completed in conjunction with the *APEGBC Guidelines for Legislated Landslide Assessments for Proposed Residential Development in British Columbia*, 2006 (*"APEGBC Guidelines"*) and is to be provided for *landslide assessments* for the purposes of the *Land Title Act, Community Charter* or the *Local Government Act*. Italicized words are defined in the *APEGBC Guidelines*

To: The *Approving Authority* Date: 14 July 2008

Fraser Valley Regional District
[illegible] Cheam Ave, Chilliwack BC
Jurisdiction and address V2P 1N6

With reference to (check one):

- ☐ Land Title Act (Section 86) – Subdivision Approval
- ☐ *Local Government* Act (Sections 919.1 and 920) – Development Permit
- ✓ Community Charter (Section 56) – Building Permit
- ☐ *Local Government* Act (Section 910) – Flood Plain Bylaw Variance
- ☐ *Local Government* Act (Section 910) – Flood Plain Bylaw Exemption

For the Property: Subdivision 3, Sec 15, Twn 22, Rem W½, NWD
1760 Columbia Valley Hwy, Chilliwack, BC
Legal description and civic address of the Property

The undersigned hereby gives assurance that he/she is a *Qualified Professional* and is a *Professional Engineer* or *Professional Geoscientist.*

I have signed, sealed and dated, and thereby certified, the attached *landslide assessment* report on the Property in accordance with the *APEGBC Guidelines*. That report must be read in conjunction with this Statement. In preparing that report I have:

Check to the left of applicable items

✓ 1. Collected and reviewed appropriate background information

✓ 2. Reviewed the proposed *residential development* on the Property

✓ 3. Conducted field work on and, if required, beyond the Property

✓ 4. Reported on the results of the field work on and, if required, beyond the Property

✓ 5. Considered any changed conditions on and, if required, beyond the Property

6. For a *landslide hazard analysis* or *landslide risk analysis* I have:

✓ 6.1 reviewed and characterized, if appropriate, any *landslide* that may affect the Property

✓ 6.2 estimated the *landslide hazard*

✓ 6.3 identified existing and anticipated future *elements at risk* on and, if required, beyond the Property

✓ 6.4 estimated the potential *consequences* to those *elements at risk*

7. Where the *Approving Authority* has adopted a *level of landslide safety* I have:

✓ 7.1 compared the *level of landslide safety* adopted by the *Approving Authority* with the findings of my investigation

✓ 7.2 made a finding on the *level of landslide safety* on the Property based on the comparison

___7.3 made recommendations to reduce *landslide hazards* and/or *landslide risks*

8. Where the *Approving Authority* has **not** adopted a *level of landslide safety* I have:

___8.1 described the method of *landslide hazard analysis* or *landslide risk analysis* used

___8.2 referred to an appropriate and identified provincial, national or international guideline for *level of landslide safety*

___8.3 compared this guideline with the findings of my investigation

___8.4 made a finding on the *level of landslide safety* on the Property based on the comparison

✓___8.5 made recommendations to reduce *landslide hazards* and/or *landslide risks*

✓___9. Reported on the requirements for future inspections of the Property and recommended who should conduct those inspections.

Based on my comparison between

Check one

☑ the findings from the investigation and the adopted *level of landslide safety* (item 7.2 above)

☐ the appropriate and identified provincial, national or international guideline for *level of landslide safety* (item 8.4 above)

I hereby give my assurance that

Check one

☐ for subdivision approval, as required by the Land Title Act (Section 86), "that the land may be used safely for the use intended"

Check one

☐ with one or more recommended registered *covenants.*

☐ without any registered *covenant.*

☐ for a development permit, as required by the *Local Government* Act (Sections 919.1 and 920), my report will "assist the *local government* in determining what conditions or requirements under [Section 920] subsection (7.1) it will impose in the permit"

☑ for a building permit, as required by the Community Charter (Section 56), "the land may be used safely for the use intended"

Check one

☐ with one or more recommended registered *covenants.*

☑ without any registered *covenant.*

☐ for flood plain bylaw variance, as required by the "Flood Hazard Area Land Use Management Guidelines" associated with the *Local Government* Act (Section 910), "the development may occur safely."

☐ for flood plain bylaw exemption, as required by the *Local Government* Act (Section 910), "the land may be used safely for the use intended."

NARAYAN ABHYANKAR

Name (print)

Signature

Date

15-62 FAWCETT ROAD

Address

COQUITLAM, BC V3K 6V5

(604) 527-8475

Phone

(Affix Professional seal here)

If the *Qualified Professional* is a member of a firm, complete the following.

I am a member of the firm VALLEY GEOTECHNICAL ENGINEERING SERVICES LTD
and I sign this letter on behalf of the firm. (Print name of firm)

APPENDIX D: LANDSLIDE ASSESSMENT ASSURANCE STATEMENT

Note: This Statement is to be read and completed in conjunction with the *APEGBC Guidelines for Legislated Landslide Assessments for Proposed Residential Development in British Columbia*, 2006 ("*APEGBC Guidelines*") and is to be provided for *landslide assessments* for the purposes of the *Land Title Act*, *Community Charter* or the *Local Government Act*. Italicized words are defined in the *APEGBC Guidelines*.

To: The *Approving Authority* Date: 14 JULY 2008

FRASER VALLEY REGIONAL DISTRICT
45950 CHEAM AVE CHILLIWACK, BC
Jurisdiction and address V2P 1N6

With reference to (check one):

- ☐ Land Title Act (Section 86) – Subdivision Approval
- ☐ *Local Government* Act (Sections 919.1 and 920) – Development Permit
- ☑ Community Charter (Section 56) – Building Permit
- ☐ *Local Government* Act (Section 910) – Flood Plain Bylaw Variance
- ☐ *Local Government* Act (Section 910) – Flood Plain Bylaw Exemption

For the Property: SUBDIVISION 4, SEC 15, TWN 22, REM E½, NWD
1536 FROST ROAD, CHILLIWACK, BC
Legal description and civic address of the Property

The undersigned hereby gives assurance that he/she is a *Qualified Professional* and is a *Professional Engineer* or *Professional Geoscientist.*

I have signed, sealed and dated, and thereby certified, the attached *landslide assessment* report on the Property in accordance with the *APEGBC Guidelines*. That report must be read in conjunction with this Statement. In preparing that report I have:

Check to the left of applicable items

✓ 1. Collected and reviewed appropriate background information

✓ 2. Reviewed the proposed *residential development* on the Property

✓ 3. Conducted field work on and, if required, beyond the Property

✓ 4. Reported on the results of the field work on and, if required, beyond the Property

✓ 5. Considered any changed conditions on and, if required, beyond the Property

6. For a *landslide hazard analysis* or *landslide risk analysis* I have:

✓ 6.1 reviewed and characterized, if appropriate, any *landslide* that may affect the Property

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7. Where the *Approving Authority* has adopted a *level of landslide safety* I have:

✓ 7.1 compared the *level of landslide safety* adopted by the *Approving Authority* with the findings of my investigation

✓ 7.2 made a finding on the *level of landslide safety* on the Property based on the comparison

___7.3 made recommendations to reduce *landslide hazards* and/or *landslide risks*

8. Where the *Approving Authority* has **not** adopted a *level of landslide safety* I have:

___8.1 described the method of *landslide hazard analysis* or *landslide risk analysis* used

___8.2 referred to an appropriate and identified provincial, national or international guideline for *level of landslide safety*

___8.3 compared this guideline with the findings of my investigation

___8.4 made a finding on the *level of landslide safety* on the Property based on the comparison

___8.5 made recommendations to reduce *landslide hazards* and/or *landslide risks*

✓ 9. Reported on the requirements for future inspections of the Property and recommended who should conduct those inspections.

Based on my comparison between

Check one

☑ the findings from the investigation and the adopted *level of landslide safety* (item 7.2 above)

☐ the appropriate and identified provincial, national or international guideline for *level of landslide safety* (item 8.4 above)

I hereby give my assurance that

Check one

☐ for subdivision approval, as required by the Land Title Act (Section 86), "that the land may be used safely for the use intended"

Check one

☐ with one or more recommended registered *covenants*.

☐ without any registered *covenant*.

☐ for a development permit, as required by the *Local Government* Act (Sections 919.1 and 920), my report will "assist the *local government* in determining what conditions or requirements under [Section 920] subsection (7.1) it will impose in the permit"

☑ for a building permit, as required by the Community Charter (Section 56), "the land may be used safely for the use intended"

Check one

☐ with one or more recommended registered *covenants*.

☑ without any registered *covenant*.

☐ for flood plain bylaw variance, as required by the "Flood Hazard Area Land Use Management Guidelines" associated with the *Local Government* Act (Section 910), "the development may occur safely."

☐ for flood plain bylaw exemption, as required by the *Local Government* Act (Section 910), "the land may be used safely for the use intended."

NARAYAN ABHYANKAR
Name (print)

Signature

Date

15-62 FAWCETT ROAD
Address
COQUITLAM, BC V3K 6V5

604 527-8475
Phone

(Affix Professional seal here)

If the *Qualified Professional* is a member of a firm, complete the following.

I am a member of the firm VALLEY GEOTECHNICAL ENGINEERING SERVICES LTD.
(Print name of firm)
and I sign this letter on behalf of the firm.

575

See attached update from NHC

FROSST CREEK FAN HAZARD ZONES
CULTUS LAKE, BC
FINAL REPORT

Prepared for:

Fraser Valley Regional District
45950 Cheam Avenue
Chilliwack, BC
V2P 1N6

Prepared by:

northwest hydraulic consultants
30 Gostick Place
North Vancouver, BC
V7M 3G3

March 2006

nhc 3-4320

DISCLAIMER

This document has been prepared by **northwest hydraulic consultants** in accordance with generally accepted geoscience and engineering practices and is intended for the exclusive use and benefit of the Fraser Valley Regional District and their authorized representatives for specific application to flood hazard assessments at or near Frosst Creek, near Cultus Lake, BC. The contents of this document are not to be relied upon or used, in whole or in part, by or for the benefit of others without specific written authorization from **northwest hydraulic consultants**. No other warranty, expressed or implied, is made.

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Report prepared by

Derek Ray, P.Geo.

DAR
14 MAR 2006

Report reviewed by

BM Chilibeck

Barry Chilibeck P.Eng.

PROVINCE OF BRITISH COLUMBIA
B. M. CHILIBECK
14 MAR 06
ENGINEER

EXECUTIVE SUMMARY

Frosst Creek Fan drains a watershed area of approximately 30 km^2, and forming an alluvial fan terminating in Cultus Lake near Chilliwack, B.C. Past flooding events on the fan have resulted in significant erosion and sediment deposition that has had a negative impact on the residents and landowners on the fan. Past studies have focused on the mechanics of flood events in relation to a system of ad hoc dikes that have been built on one or both sides of the channel over the length of the fan. The purpose of the present study is to delineate relative hazard zones on the fan for the purposes of establishing flood construction levels.

The upper portion of the Frosst Creek watershed is steep, heavily logged and unstable. Abundant sediment and woody debris is supplied to the channel from the banks and hillslopes. Morphometric analysis of the basin indicates that debris flow events are possible, however the extended length of lower-gradient channel immediately upstream of the fan precludes debris flows from reaching the fan apex. Secondary hydrogeomorphic events, such as debris floods are possible however, and the recent history of flooding events suggests that they are relatively common in this watershed.

Relative hazard zones are delineated in Figure 3 and summarised in Table 4. Vertical construction elevations have been established based on a potential breach in the existing dike or in spilling of flow, debris, and sediment from the existing channel. An acceptable freeboard has been added to the calculated heights to account for expected large amounts of sediment and woody debris that would be discharged during the design flood event. Conceptual on-site floodproofing designs are provided, but based on the wide range of risk factors, site-specific assessment and design is recommended for the area.

This study considered alluvial debris flood and channel avulsion hazards based on *in situ* conditions. Hillslope hazards, such as landslides, originating from the adjacent steep slopes have not been assessed. The 1994 MELP hazard assessment provided an elevation estimate to mitigate potential flooding caused by Cultus Lake. We recommend that a study be undertaken to determine the 200-year water level of Cultus Lake and update this elevation. The value of 46.5 m geodetic as determined in the 1994 study should be used until an updated 200-year elevation is calculated.

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1 INTRODUCTION

1.1 BACKGROUND

Frosst Creek is a steep mountain stream draining an area of approximately 30 km^2 and forming an alluvial fan at its mouth terminating at the southwest end of Cultus Lake near Chilliwack, BC. The fan has historically been subject to a variety of natural hazards, including flooding and debris floods, which have negatively impacted the recreational and residential properties located on the fan.

The airphoto record indicates that the fan was cleared prior to 1940. Development on the fan has historically been limited to agriculture, with recreational uses such as golf course, campgrounds and seasonal recreational dwellings becoming important since the 1950s. In recent years there has been an increase in pressure to construct year-round dwellings or upgrade the existing buildings for year-round use. This has resulted not only in a greater investment value of properties on the fan, but has increased the human life exposure to natural hazards.

Development in this area is under the jurisdiction of the Fraser Valley Regional District (FVRD). Northwest Hydraulics Consultants (**nhc**) have been contracted to delineate alluvial fan hazard zones for eventual incorporation into the regional bylaws. The majority of previous studies to date have focused on the issue of flooding originating from Frosst Creek and the problem of containing the flood flows and deposits of sediment within the orphan dike system that extends along the length of the lower channel. The present study will examine the suite of hydrogeomorphic hazards affecting the fan and delineate relative hazard zones.

1.2 SCOPE

The purpose of this study is to delineate relative hazard zones on the Frosst Creek Fan relating to hydrogeomorphic events, such as flooding and debris floods, originating from Frosst Creek. This study will not consider hillslope hazards, such as landslides, originating from the adjacent steep slopes, nor does it incorporate a 200-year water level of Cultus Lake, although a 1994 Ministry of Environment, Lands and Parks (MELP) provides an estimate of this value.

Flooding on Frosst Creek Fan has been the subject of numerous studies in the last few decades, constituting a considerable body of knowledge. Where possible, these past studies have been reviewed and the pertinent information included in the present report.

In addition to delineating the relative hazard zones, we have provided recommendations for mitigating the identified hazards through zoning mechanisms such as restricting the intended property use and setting construction standards for new structures.

1.3 Study Limitations

The present study has exclusively considered hydrogeomorphic hazards originating from Frosst Creek and Watt Creek. The active alluvial fan of Frosst Creek may be subject to other hazards associated with hillslope processes, such as landslides and slumps, however these hazards have not been considered.

The boundary of Frosst Creek Fan and the relative hazard zones have been mapped at a scale of 1:6,000 using recent (2004) ortho-corrected airphotos and contours derived from 1:20,000 TRIM mapping with a contour interval of 20 m. The use of these data and the scale of mapping necessarily impose a limit on the accuracy of the boundaries that are represented on the maps included in this report. There should be no attempt at gaining a greater level of accuracy or precision by magnifying or otherwise increasing the scale of the hazard maps.

2 Overview

2.1 Study Area

Frosst Creek drains an area of approximately 30 km^2 in the Cascade Mountains, near Chilliwack, BC. The upper portion of the watershed, representing approximately half the basin area, extends southward and spans the international border with the United States, resulting in markedly different land-use patterns on either side of the border. The portion of the watershed in Washington State has been heavily logged over the past two decades (nhc, 1999) resulting in a considerable amount of slope instability in the form of gullying of tributaries and mass wasting on the open slopes. The portion of the watershed in British Columbia has not been logged to the same extent, though there is evidence of past landslide activity there as well.

From the international border, Frosst Creek flows for approximately 3 km to the north and then westwards in a confined, steep valley with channel gradients of over 50%. Downstream of the confined valley the channel flows across an alluvial terrace for a distance of almost 3 km. The terrace lies approximately 100 m above the elevation of the lower fan and the channel is incised into it by up to 80 m. The average channel gradient is between 3 to 4% and the channel is mostly confined in the bottom of this valley with a limited floodplain having been developed, indicating that the rate of incision has likely stabilised.

Frosst Creek is supplied with an abundance of sediment and woody debris along the length of its watershed. The heavily logged upper watershed has numerous slide paths and unstable gullies that terminate in the creek channel. Slide paths and gullies also exist on the steep valley side slopes north of the international border and the channel in the incised reach is well charged with sediment and debris in storage.

2.2 Frosst Creek Fan

Frosst Creek Fan has formed at the base of the raised alluvial terrace, with the head of the fan in the mouth of the incised valley and extending northeastwards to terminate at Cultus Lake. The community of Leisure Valley is located on the left bank of Frosst Creek at the fan apex and Lindell Beach is located along the fan margin. The channel length across the fan is approximately 1.6 km with an average gradient of approximately 3% at the top of the fan decreasing to approximately 1.2% on the lower fan.

A steep scarp along the base of the upper alluvial terrace forms the south-western boundary of the fan while to the north the fan is confined by the lower slopes of Vedder Mountain. A much steeper fan formed by Watt Creek encroaches on the southeastern corner of the fan with Spring

Creek, which drains down the middle of the golf course, marking the approximate boundary between Watt Creek and Frosst Creek Fans (Figure 1).

At the apex of fan the channel is located on the right side of the valley, with a relatively wide section of alluvial sediments on the left side of the channel occupied by the community of Leisure Valley. Downstream of the Columbia Valley Road Bridge the channel flows across to the left side of the fan to run along the base of the steep valley slopes to the lake.

The majority of the original vegetation has been removed from the fan and the fan surface has been converted to various recreational, agricultural and residential uses. The community of Lindell Beach occupies the lower portion of the fan along Cultus Lake with a portion of the community extending south onto the lower edges of the Watt Creek Fan. Upslope of Lindell Beach a recreational camp ground and golf course occupy the middle portion of the fan with cattle pastures and farm dwellings occupying the upper portion of the fan below the road.

2.3 WATT CREEK FAN

Watt Creek is a small steep catchment flowing to the northwest from a basin area of a few square kilometres in the northern Cascade Mountains. The creek has built a steep fan terminating in Cultus Lake, adjoining Frosst Creek Fan at its northeastern terminus. Bedrock geology mapping indicates an abundance of soft, readily weathered rock in the basin including shale and turbidite. The steep channel sideslopes and valley walls of the fan and lower watershed are composed of thick deposits of soft, loose, small-grained material. Numerous open slopes are ravelling into the channel, providing an abundant supply of sediment.

Columbia Valley Road crosses the fan approximately 550 m upstream of Cultus Lake. Upstream of the crossing the channel is deeply incised into the fan surface by up to 30 to 40 m in some places. Furthermore, from the apex of the fan, the channel is located on the east side of the fan centreline, away from Frosst Creek fan. There is virtually no potential for avulsion or transfer of hazard to the west side of the fan originating in this reach.

Downstream of the bridge the channel becomes much less incised and at many locations there are levies that have formed on the bank tops. Immediately downstream of the bridge the left (west) bank is quite low and there is evidence that debris floods have spilled out onto the fan from this point.

Past flooding events include a large flood in the early 1980s that deposited a large amount of sediment and organic debris on the Cultus Lake Provincial Park picnic area (Jim Wiebe, pers. comm.). The fact that this watershed has in the past experienced high-magnitude hydrogeomorphic events, indicates that there is a real potential for future events to occur.

Furthermore, the fan surface shows evidence of long-term aggradation. Many of the older trees lack root flare at the base of the trunk, indicating partial burial. As well, there are numerous buried and partially buried stumps that represent either trees killed by burial, or buried stumps left over from past logging.

2.4 Existing Dike System

An ad hoc or orphan dike system has been constructed along one or both banks of Frosst Creek over the majority of the length of the active fan. This dike has been constructed using locally sourced material, most of which has been excavated from the creek channel during or immediately after flood events. There has been no formal design approval or supervision associated with the existing dikes. The existing system is to be upgraded to provincial flood protection standards and maintained by the FVRD through formation of a service area, Studies have been recently completed that identify deficiencies in terms of dike height and armouring for 200-year flood estimates. In addition to improving the dikes, the reports also make recommendations for installing sediment traps to manage the long-term aggradation of the channel.

We understand that FVRD is engaged in a planning process to complete the recommended works. Completion of these works would reduce a large portion of the risk and potential damages associated with the flood hazards on Frosst Creek Fan. However, areas behind these works will still be subject to some risk of a flood or debris flood event that breaches the system of dikes and sediment traps and causes flood damage.

2.5 Previous Studies

The **nhc** report ***Frosst Creek, Assessment of Potential Flooding and Sedimentation*** (March, 1999) contains a comprehensive review of past flooding studies of Frosst Creek. This review includes the following:

Frosst Creek Flood Mitigation Study – prepared by B.R.W. McMullen, P.Eng. of the B.C. Ministry of Environment (MOE), 1988. Includes an estimate of design flood based on regional hydrology as well as cost estimates and recommendations for upgrading the existing dikes.

Frosst Creek – Update to 1988 Flood Mitigation Study – prepared by Hay & Company Consultants for Fraser-Cheam Regional District, 1994. Report regarding additional flooding in 1989 and 1990 with calculations of bedload transport from re-surveyed cross sections. Includes recommendations and cost estimates for upgrading the existing dikes.

Review of Floodproofing Requirements Frosst Creek Lindell Beach area – January 1994 – memo to file prepared by B.C. Ministry of Environment, Lands and Parks, file # 35150-30 13 0 E, January 14, 1994. Memo establishes safe building elevations for the community of Lindell Beach. Includes map of Lindell Beach showing various hazard level zones.

Frosst Creek – November 1995 Flood Damage Restoration – prepared by Bland Engineering for B.C. Ministry of Environment, Lands and Parks, 1996. Report examining the long-term options for sediment management. Deposition volumes were calculated for the period from 1979 to 1996 with a recommendation made for excavating the delta as the best management option.

Since the 1999 report was prepared by **nhc** there have been a number of additional studies prepared examining the problem of flooding at Frosst Creek Fan. These include:

Frosst Creek Assessment of Potential Flooding and Sedimentation – Update of Flood Mitigation Works – prepared by **nhc** for Viva International Business Center Ltd, 2001.

Frosst Creek Sediment Control Works for Flood Management – prepared by **nhc** for Viva International Business Center Ltd, 2002.

Lindell Beach – Frosst Creek – Information Gathering for Dikes with no Local Authority – prepared by AMEC Earth & Engineering and BC Rivers Consulting for B.C. Ministry of Water, Land and Air Protection, 2002.

Frosst Creek – Channel Erosion and Debris Deposition During October 21, 22, 2003 Rainstorm – memo prepared by **nhc** for Fraser Valley Regional District, 2003.

Emergency Response to October 16-18 Landslide and Flood Events near Cultus Lake and in Hatzic Valley – prepared by Thurber Engineering Ltd., 2003.

Frosst Creek, B.C. – An Update of Sediment Control Works for Flood Management – prepared by **nhc** for 5228 Investments Ltd., 2003.

Frosst Creek Flood Mitigation Works – Operation and Maintenance Manual – prepared by nhc, 2004.

3 ALLUVIAL FAN HAZARDS

3.1 FAN MORPHOLOGY

Alluvial fans are depositional features formed over time spans of thousands, to tens of thousands of years where steeper, confined valleys open out onto larger, broader valleys or bodies of water. Channels on undisturbed fans would naturally experience cycles of infilling and avulsion so that over time the channel would occupy all portions of the fan, broadcasting sediments in a radial pattern resulting in a cone-shaped feature. Channel infilling occurs because the capacity of the channel to carry sediment decreases from the confined valley to the fan. This is partly because of a decrease in gradient but also because of the unconfined environment caused by the fan shape.

The convex-up cross profile shape of an alluvial fan results in an unconfined channel environment, whereby the ground level is generally decreasing away on all sides of the channel. This means that overbank flow does not generally return to the channel downstream but rather flows radially towards the fan margin. In contrast, a floodplain in a confined valley is generally level or increasing in height away from the channel so that overbank flows will return to the channel further downstream. Water escaping the channel on a fan causes a reduction in the sediment-carrying capacity. At Frosst Creek an ad hoc dike system serves to keep all but the largest flows from spilling out of the channel, however a reduction in down-fan gradient continues to cause net deposition in the channel.

In British Columbia a relatively recent history of glacial activity has resulted in the formation of 'paraglacial' fan features. This concept was introduced by Ryder (1971) to explain the relatively slow contemporary fan-building processes compared to what must have been very rapid fan building immediately after deglaciation when runoff and sediment availability were both very high. There is therefore a potential disconnect between the processes that built the fan initially and the modern day processes affecting the fan. Prior to making a determination of potential hazards, it is therefore necessary to carefully assess the present-day processes.

3.2 GENERAL HAZARDS

Typical hydrogeomorphic hazards affecting alluvial fans include floods, channel erosion, channel avulsions, debris floods and debris flows. These are natural events comprising the suite of processes that serve to build and maintain fan features. We have included a brief description of these hazards in order to clarify discussion:

Flood – an unusually large volume of water flowing in the channel, a portion of which may flow overbank. Floods are associated with other hazards such as channel erosion and avulsion.

Channel Erosion – refers to lateral migration of a stream channel, generally occurring during a large flow event. Channel erosion can result in loss or damage to adjacent property, or damage to the foundations or supports of buildings adjacent to the channel.

Channel Avulsion – abandonment of a channel course to occupy a different position on the alluvial fan. Avulsion of a large creek can pose serious risk to property or buildings while avulsion of a small stream channel, or a partial avulsion of a larger channel may only result in minor erosion.

Debris Flood – a large flood event associated with an unusually high amount of sediment movement consisting of coarse bedload material, suspended material and organic material such as trees and logs. Due to the high concentration of sediment, the flow characteristics are altered and debris floods are capable of transporting much larger sizes and volumes of rock and debris than a clear water event. There is no well-established threshold that separates debris floods from debris flows

Debris Flow – a rapid, channelised, fluid transport of water-saturated debris. Transport generally initiates in steep gullies and is conveyed downslope at high velocity and has the potential to inflict serious damage to mature forest and human development, as well as create life threatening situations for the occupants of a building. Damage from this process is not limited to impact from the main transport of debris since after flows can carry finer sediment downslope once the main lobe has deposited.

The above list of potential hazards is listed in approximately increasing degree of severity in terms of potential damage to buildings and property or loss of human life. In order to develop a comprehensive picture of potential flood hazards affecting Frosst Creek it is necessary to determine which of the above-listed hazards might occur, as well as their magnitude and period of recurrence.

3.3 Historical Events

In order to more accurately predict the likelihood of future events, it is helpful to understand the history of past events. There have been numerous recorded flooding events in the past several decades originating from Frosst Creek. Serious flooding occurred in 1986, 1989, 1990, and 1995 (**nhc**, 1999). A significant flood was also reported to have occurred in the 1940s. A large flood occurred in 2003, although it did not result in actual damage to property, it deposited significant amounts of sediment and debris on channel bars and on the delta. Details of these floods have not been reported or quantified so it is not clear whether these events were associated with heavy rainfall, a rain-on-snow event or some sort of landslide dam outburst event.

It has been reported that these floods were associated with the rising of the creek bed due to deposition of bedload, which causes bank erosion along specific reaches, as well as avulsions. Most of these events were also associated with the transport and deposition of large amounts of organic material including logs and uprooted trees, which is consistent with a debris flood but does not have the severity of a debris flow. Extensive historical logging in the upper watershed has destabilised the slopes and generated an abundance of sediment and organic debris that caused a significant increase in debris and related flooding in the 1980s and 1990s. There is no evidence to suggest that this present sediment supply is limited or exhausted.

3.4 Morphometric Analysis

A useful tool to determine the potential of a drainage basin to generate high-energy hydrogeomorphic events is to examine morphometric characteristics, such as basin relief and basin size. Debris flows are initiated in steep terrain, are transported across intermediate terrain and begin to deposit at slopes below approximately 20%. Based on gradient and the generally high level of sediment generation, both the upper watershed of Frosst Creek and the middle canyon reach have the potential to generate debris flows (Figure 2).

The low-gradient reaches flowing across the upper alluvial terrace for a distance of approximately 3 km are well below the gradient threshold for transportation of debris flows. The valley side-slopes in the confined upper terrace reach are quite steep but the main process of instability appears to be landslides. It therefore appears to be nearly impossible that a debris flow would be delivered to the top of the Frosst Creek Fan. Debris flows occurring in the upper watershed would be attenuated and would appear as debris floods, which are a serious hazard (see Section 3.2).

3.5 Review of Historical Airphotos

Historical airphotos were reviewed for this study (Table 1) covering a time span of over 60 years with photos from each decade. The photos are in general clear, taken at a large scale, and of good quality.

Table 1 Airphoto History

Date			Roll #	Photo #
Year	Month	Day		
1930	5	11	A 2240	36
1940	7	17	BC 208	102
1954	5	14	BC 1789	86
1963	5	18	BC 5072	242, 244, 258, 260
1974	6	12	BC 5591	201, 202, 205
1979	3	23	BC 79004	38, 40, 208, 210
1981	10	14	BCC 304	32 - 36
1983	7	22	BC 83014	80, 184
1987	6	14	BC 87019	180 - 186
1988	7	7	BC 88007	122
1993	8	1	BC 93026	22, 48
2004	4	2	SRS 6912	50, 51, 69

The 1930 photo shows that recent logging had resulted in the removal of vegetation from the majority of the fan surface, including large portions of the scarp and upper alluvial terrace. The 1940 photo covers the area immediately upstream of the fan while the 1954 photo shows the fan itself. Both show that the Frosst Creek channel appears to be historically active, with established bars in the channel and an active delta terminating in the lake. The delta itself has grown considerably in the last 60 years, presumably in response to the documented increased rate of sediment supply (**nhc**, 1999), and displays frequent channel shifting on the delta surface. Significant flooding events and human intervention have resulted in obvious lateral channel migration and channel straightening. However, there is no evidence that actual channel avulsion has occurred. Rather, overbank flooding has resulted in erosion and sediment deposition of the fan adjacent to the channel.

Watt Creek Fan and portions of the lower watershed are visible in many of the photos, though the channel is not clearly visible due to tree cover. The location of the main channel on the fan has remained stable throughout the period of airphoto record, with no evidence of avulsion or channel shifting. Sediment deposited in the lake at the fan margin indicates that a large flow event may have broadcast sediment across the fan, spilling into the lake. There is no evidence of flows crossing the southwestern side of the Watt Creek Fan to reach the Frosst Creek Fan.

3.6 Relative Hazard Zones

The probability of impact from hazards is not equal in all areas of the alluvial fan. Areas that are in closer proximity to the existing channel, as well as lower areas representing former channel scars, would be expected to be at greater risk from hazards. On the other hand, areas of higher elevation and areas that are further away from the active channel should have a lower exposure to hazards.

3.7 Hydrology

Estimates of the magnitude of the daily and instantaneous flood at 50-, 100- and 200-year return intervals were calculated based on regional hydrology by McMullen of the B.C. Ministry of Environment (1988). These values have been adopted for all subsequent studies and are reproduced in Table 2. A preliminary analysis made using more recent updated regional flow records confirms that these estimates are conservative and likely do not need to be updated. For the purposes of this study we will assume a design debris flood of 77 m^3/s.

Table 2 Estimated magnitude of floods of various return periods (from MOE, 1988).

Return Period (years)	Estimated Peak Flow (m^3/s)	
	Daily	Instantaneous
500	30	55
100	36	66
200	43	77

4 ALLUVIAL FAN HAZARD ZONES

4.1 ACTIVE FAN BOUNDARY

The boundary of the active alluvial fan is shown in Figure 1. This boundary also represents the limits of this study. The head of the fan is located immediately upstream of the community of Leisure Valley. The steep scarp forming the right side of the river valley at the fan head veers to the east along Columbia Valley Road, forming the southern boundary of the fan. The steep scarp and Columbia Valley Road diverge at approximately the point where Watt Creek alluvial fan converges with the alluvial fan formed by Frosst Creek. The boundary between these two fans roughly coincides with Spring Creek, which flows across the Cultus Lake Golf Park. To the north the fan is bounded by the lower slopes of Vedder Mountain while to the east the fan terminates at Cultus Lake.

Those lands located outside of the active alluvial fan have not been considered in the present hazards study. There may be additional hazards originating from valley side-slopes that have not been considered.

4.2 DESIGN FLOOD EVENT

The morphometric analysis and channel inspection have ruled out the potential for destructive debris flows impacting the Frosst Creek Fan. The 200-year maximum instantaneous design flood has been adopted as 77 m^3/s, based on the 1988 regional hydrological analysis prepared by the B.C. Ministry of Environment. The recent history of flood events indicates that most large flows carry large amounts of coarse sediment and woody debris. Our inspections indicate that the channel continues to be well supplied with both sediment and organics. It is useful to consider the character and behaviour of the design event in order to understand the nature of the hazard for the residents and infrastructure. The closest proxy we have to the design event are the past events, therefore we have assumed that the design flood would behave in much the same way as past events, though on a much larger scale.

The design flood in Frosst Creek would likely be generated by intense rainstorms following an extended period of wet weather, and probably also associated with a melting snowpack. The design flood would exceed the channel capacity in many locations in the watershed, spilling out onto the floodplain and floating woody debris into the channel. There would be general mobilisation of the bed material and extensive erosion of the banks. The flow in the creek on the fan would be fast, heavily charged with sediment, with large quantities of floating and submerged organic debris partly consisting of large logs and uprooted trees. The design flood may also be associated with a debris outburst flood.

The hydrodynamic model HEC-RAS was used most recently to update the flood profile for the purposes of dike upgrade construction planning (**nhc** 2004). The model results show that flow would go overbank through the community of Leisure Valley, however the design flood would pass underneath the Columbia Valley Road Bridge. On the left bank, flow would spread out from the channel at the downstream end of the left bank dike and inundate the low-lying area of treed land, including the pasture. The calculated flood profile indicates there is inadequate dike freeboard at several locations, particularly near the RV Park located west of Lindell Beach and at the northwest corner of the community of Lindell Beach itself.

4.3 NATURE OF THE HAZARD

4.3.1 FROSST CREEK

For the purposes of quantifying the potential hazard, we have assumed that a potential failure of the existing dike would result in a rapid discharge of up to 30% of the total flow carrying significant amounts of sediment and organic matter. At a breach in the dike, the flow velocities would initially be quite high with concentrated discharge resulting in localised erosion and scour. However as the flow moved across the fan it would spread, following low areas, and be diverted by road crests and buildings. As the flow spreads out, the depth and velocity would reduce and sediment and debris would deposit.

The main hazard is from flow overtopping or eroding the dike, and spilling out onto the fan. In our analysis we assumed a breach at various locations up the existing dike profile, however, based on the existing channel location, a breakthrough at turns and constrictions of the flood corridor are more likely, where sediment can accumulate and debris lodgement can occur. These locations are near Lindell Beach, where the original Frosst Creek channel was diverted to its present location, and mid-valley near the campground where the channel has historically deposited debris and sediment.

We have calculated the flow depths and velocities at various distances from the Frosst Creek channel. At the dike failure point, the flow would initially pour over the dike and downcut through the dike fill. Flow velocities would be very high, exceeding 2.5 m/s and causing significant scour until the flow energy was dissipated somewhat by hydraulic jumps and the flow spread out laterally.

For the purposes of calculating flow velocities and depths, we have assumed that the slope of the fan surface is similar to the channel slope. The channel slope on the upper portion of the fan, immediately downstream of the bridge crossing is approximately 3%, while further down on the fan the slope decreases to approximately 1.1%. In general the steeper the slope, the greater the flow velocity and the shallower the flow depth.

On the upper portion of the fan, at a distance of 25 m from the dike breach, the average flow depth would be approximately 0.3 m with a velocity of 1.7 m/s. At a distance of 50 m from the breach, the depth would be approximately 0.22 m and the velocity 1.4 m/s. On the lower portion of the fan, the flow depth and velocity would be approximately 0.4 m and 1.3 m/s respectively at a distance of 25 m from the breach, and 0.3 m and 1.1 m/s at a distance of 50 m from the breach (Table 3). These depths assume that there is no surging or ponding, and that there is no debris present in the flow.

Table 3 Estimated depth and velocity of overbank flow at various distances from a potential dike breach.

Distance from Breach	Depth (m)	Velocity (m)
(on lower portion of the fan)		
25	0.4	1.3
50	0.3	1.1
100	0.2	0.85
(on upper portion of the fan)		
25	0.3	1.7
50	0.22	1.4
100	0.16	1.1

4.3.2 Watt Creek

The hazards originating from Watt Creek fan include flooding, avulsion, debris floods, and a potential for debris flows. Any large flow event has the potential to deposit large amounts of fine-grained sediment and woody debris. The present assessment was conducted to determine the most westward extent of hazard potential originating from Watt Creek, which would threaten those areas located on the Frosst Creek fan.

Due to the incised nature of the channel upstream of the Columbia Valley Road Bridge and the position of the channel relative to the fan crest, it is highly unlikely that that any of the above-mentioned hazards would be transferred to the west side of the fan. Downstream of the bridge, however, the channel is much less incised and there is evidence that past events have deposited large amounts of debris. Flow escaping from the channel has the potential to travel northwestwards towards Lindell Beach and impact the most southerly property on the waterfront, which is not located on Frosst Creek fan. However, the relatively long distance that the expected flow would have to travel to reach this property would cause attenuation of the flow. We do not expect that the flow depth at the fan margin would exceed 0.3 m.

4.4 Hazard Zones

Relative hazard zones have been established based on a range of factors and are presented in Figure 3. Table 4 summarises the potential hazards for each zone.

Zone 'X' represents a zone of significant hazard from channel erosion or avulsion. These areas are not protected by existing dikes and are within the proposed flood corridor of Frosst Creek. High velocity flows with the potential for scour or deposition of significant quantities of sediment and organic material are possible within this zone. We do not recommend that development permits for construction of dwellings or structures for use or occupation be permitted within this zone.

Zone 'A' represents a zone where high velocity overbank flows are possible. The resulting damage could include scour or deposition of significant quantities of sediment or organic material. We have added a significant freeboard to the estimated flow depth and recommend that scour protection be required for the base of any foundation or raised building pad that would resist flow velocities of at least 1.8 m/s. The recommended elevation is set at 1.5 m above surrounding finished grade.

Zone 'B' represents a zone where overbank flows are possible but with less consequence of damage. Depths of flow and velocities in this zone are also shallower and slower than in Zone A and sediment deposition would be of much smaller size, most likely consisting of fine gravel, sand and fine organic material. The recommended elevation is 1.0 m above surrounding finished grade.

Zone 'C' represents a zone where overbank flows have a low probability and if they were to occur, would be shallow with low velocities. Inundation upslope of barriers such as roads or within low points in the ground is the primary hazard. The recommended FCL is 0.6 m above surrounding finished grade.

Table 4 Frosst Creek Fan Hazard Zones.

Hazard Zone	Hazard Severity	Comments
X	Very High	Significant channel avulsion and erosion hazard
A	High	High velocity overbank flows, scour, sediment and organic material deposition
B	Moderate	Medium velocity overbank flows, deposition of fine material
C	Low	Low probability of low velocity flooding, deposition of fine material

4.5 Hazard Mitigation

Site-specific hazard mitigation should be viewed in the context of a holistic, overall hazard mitigation strategy. The other hazard mitigation components at Frosst Creek include the proposed sediment traps and dike upgrades. No single structure should be relied upon to provide protection from the design event, especially where the potential hazard may pose a risk to human life. Dikes built to the Provincial standard of offering protection from the 200-year event carry with them an intrinsic limit to their effectiveness. Properly designed dikes will eliminate nuisance flooding from less than design events, however absolute reliance on their effectiveness for design, or greater than design events is not an accepted standard of practice.

4.5.1 General Hazard Mitigation

Site-specific hazard mitigation is designed to prevent serious damage to valuable structures such as homes, and to prevent loss of life from building failure. The most common method of mitigating against the potential hazards posed by overbank flooding is to ensure that a building is raised such that the lowermost portion of the lowest habitable floor is above an accepted elevation – this is generally called floodproofing. There are several practical methods of achieving this:

1. Constructing a raised concrete foundation with a sill elevation at or above an accepted relative or geodetic elevation, and
2. Building the structure on a raised fill pad at or above accepted relative or geodetic elevation.

Both of these methods may incorporate scour protection at their base or along the building footing to prevent loss of structural stability. Raised concrete foundation walls have the added benefit of having a smaller overall footprint. A raised building fill pad on the other hand, having a larger footprint, may serve to concentrate flows, intensifying the depths and velocities between neighbouring structures. We recommend that buildings in high-density areas utilize the raised cast-in-place concrete foundation option for floodproofing. Table 5 provides recommended minimum building elevations above existing ground elevations to minimize flood damage associated with potential events.

The intended use of the building may also be a factor in determining whether flood protection is required. No occupied portion of a residential or recreational dwelling should be below these elevations. However, the District may wish to consider some building uses for which these restrictions need not apply. These building uses include carports, garages and utility or storage buildings.

In addition to the elevations suggested above, it is advisable that any development area or permit adopt all relevant setback provisions of the FVRD Floodplain Management Bylaw (Bylaw No. 0681, 2005). In some developed areas, such as Lindell Beach, there are existing structures within that distance and a site-specific relaxation of these requirements may be required. However, in areas where new or "greenfield" development is occurring, these applicable provisions of the bylaw should be adopted in full.

Figure 4 provides a schematic drawing showing some typical options for scour protection around the base of a concrete foundation or raised earth-filled building pad.

Table 5 Minimum Building Elevations for Fan Hazards.

Hazard Zone	Hazard Severity	Recommended Site-Specific Hazard Mitigation
X	Very High	Development is not recommended
A	High	Construct 1.5 m above local finished grade and protect base of building pad or foundation from scour
B	Moderate	Construct 1.0 m above local finished grade
C	Low	Construct 0.6 m above local finished grade

4.5.2 Site-Specific Hazard Mitigation

This study provides overall fan hazard mitigation in the form of zones and construction elevations, as well as conceptual level mitigation for structures in these zones. The wide variety of accepted residential footing and building systems makes it impossible to pre-design all possible interpretations of these concepts for all hazard areas. Site-specific interpretation and designs will be required for dwellings and structures that cannot comply with the general mitigations. The FVRD may interpret variations of the general mitigations in order to accommodate development permits in between hazard zones or in special circumstance of existing use. These actions are acceptable as long as they meet the minimum conditions.

5 CONCLUSION

Frosst Creek Fan has a history of flooding and sedimentation issues. Plans have been developed to increase the level of flood protection by raising the existing ad hoc dike system and install sediment traps. The previous hazard guidance conducted by the Provincial Government set notional elevations based on conditions at the time of issue. These conditions may have substantially changed since that time, and these results reflect the current conditions, status of knowledge and standards of practice. We have assigned the relative hazard zones based on the potential failure of the existing dike and/or overtopping of creek banks.

5.1 RECOMMENDATIONS

Based on the analysis outlined in the sections above, we recommend the following actions with respect to building bylaws and development permits:

- building elevations for each hazard zone outlined in Section 4 – specifically Tables 4 and 5 – be used as a minimum standard for the purposes of mitigating fan hazards;
- foundations or building pads in Zone 'A' include scour protection around their bases designed by a qualified registered professional[1];
- site-specific interpretation of the minimum standards be undertaken by qualified registered professionals or the FVRD for site-specific requirements.

We recommend that the 200-year water surface elevation of Cultus Lake, estimated in the 1994 Ministry of Environment memo at 46.5 m (GSC datum), be adopted until a study can be completed to update this value. Currently, this value represents the estimate of the natural boundary plus 1.5 m elevation as specified in the FVRD Floodplain Management Bylaw.

Calculation of formal updated FCL (flood construction elevations) is not possible at this time as additional topographic data is required at various points across the fan to determine actual geodetic elevations and required elevations to mitigate combined flood, fan and lake hazards. If this data becomes available in the future, revised FCL can be estimated for the Frosst Creek fan area.

[1] For the purposes of floodproofing design, a qualified registered professional is a professional engineer registered with APEGBC with experience in flood protection works. For flood hazard assessment, a qualified registered professional is a professional engineer or geoscientist registered with APEGBC with experience in flood hazard assessment.

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FIGURES

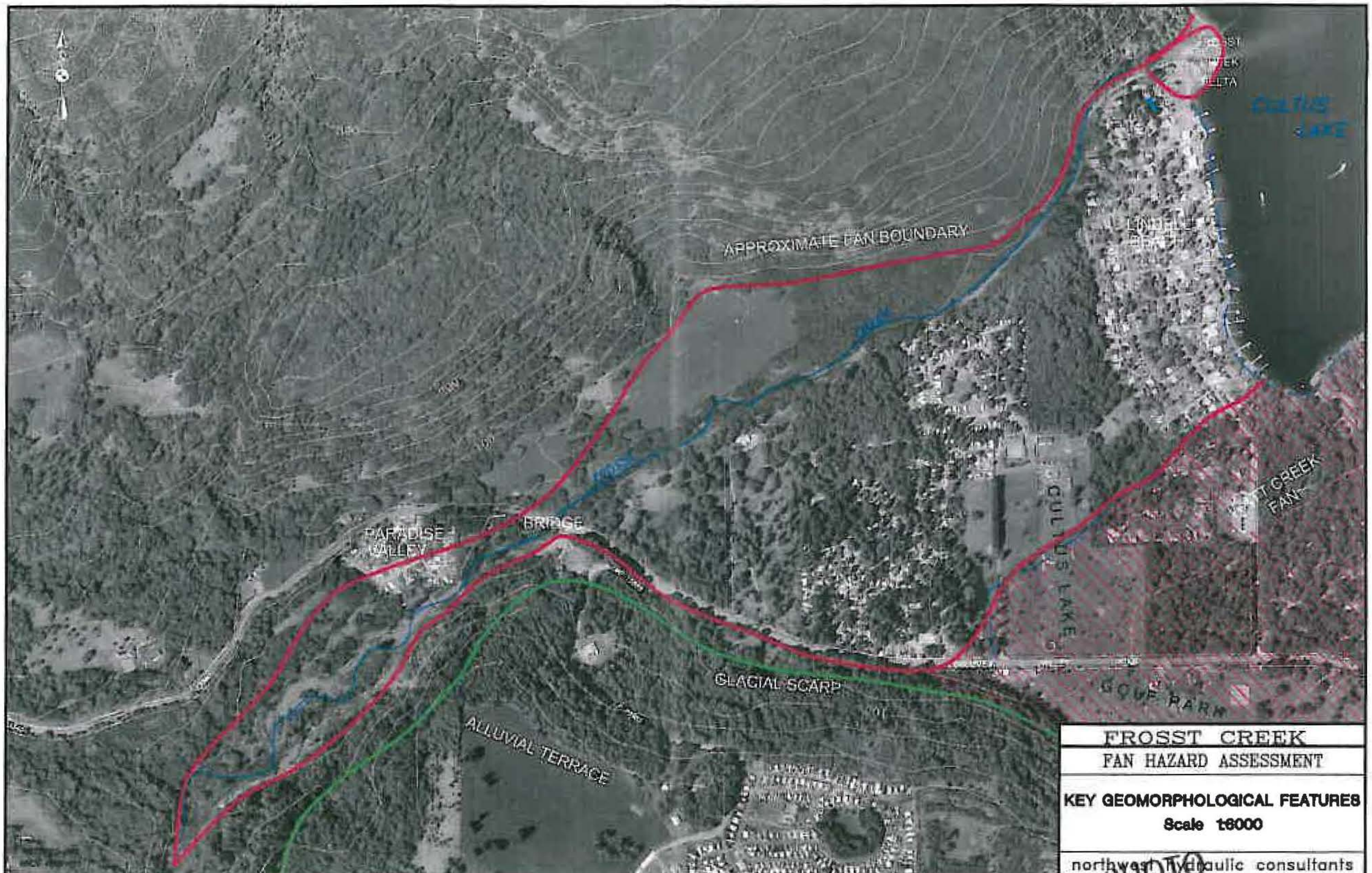
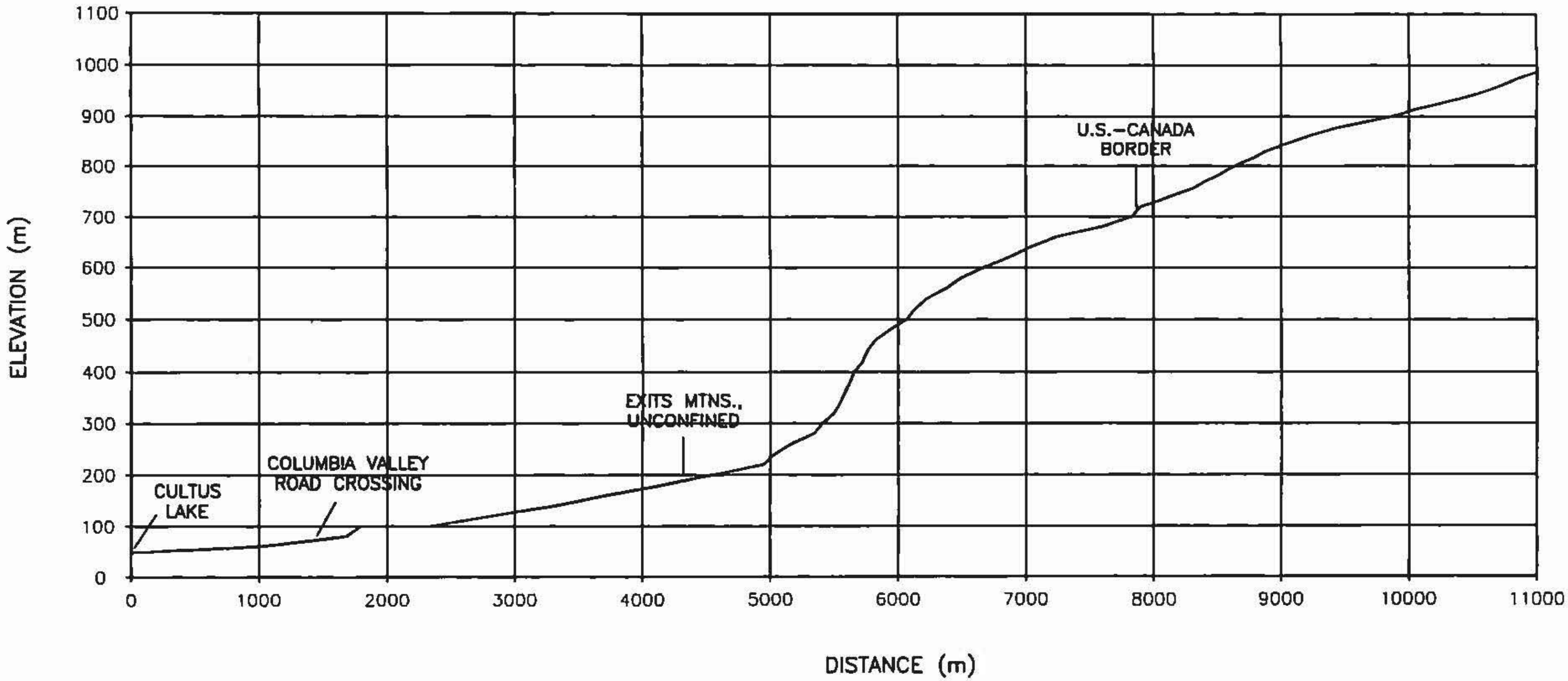


PHOTO REDUCED

FIGURE 1



HORIZONTAL SCALE 1:1
VERTICAL SCALE 1:4

Notes:

1) Longitudinal profile of channel located in British Columbia was calculated based on 1:20,000 TRIM mapping.
2) Longitudinal profile of channel located in Washington State was calculated based on a corrected image file of a 1;24,000 USGS topographic map.

TEST
NHCV 4320-002

FIGURE 2

FROSST CREEK

FAN HAZARD ASSESSMENT

FROSST CREEK

LONGITUDINAL PROFILE

Scale 1:50,000

northwest hydraulic consultants

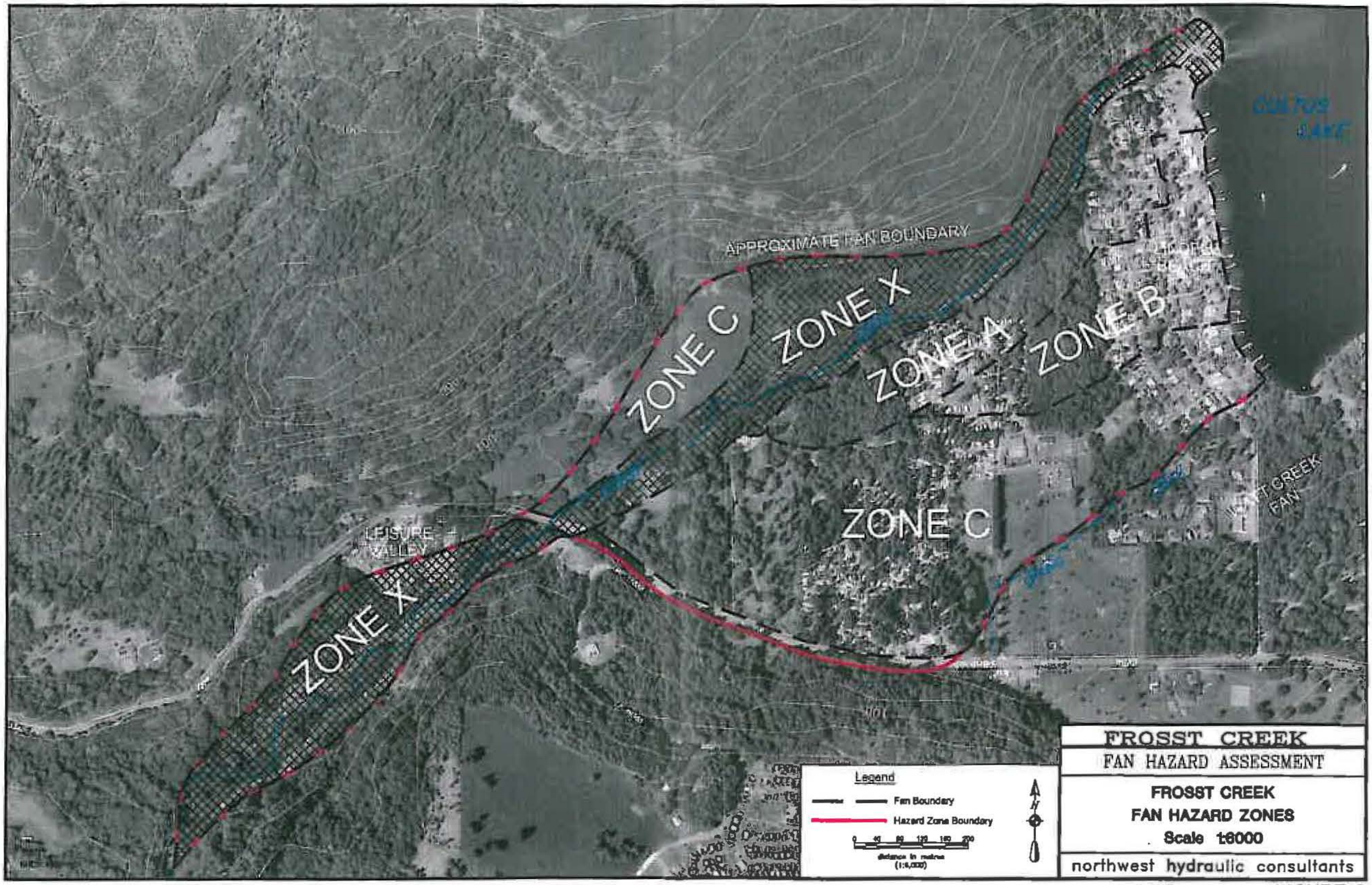
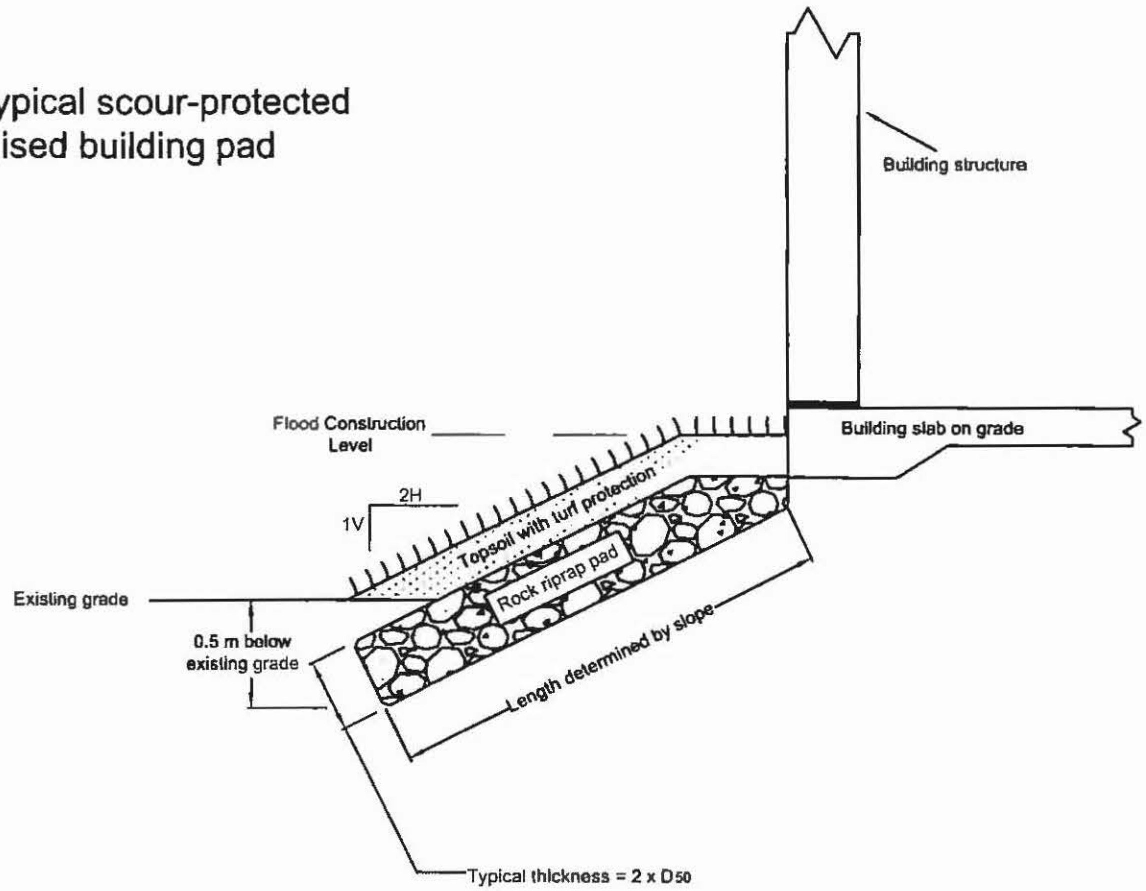


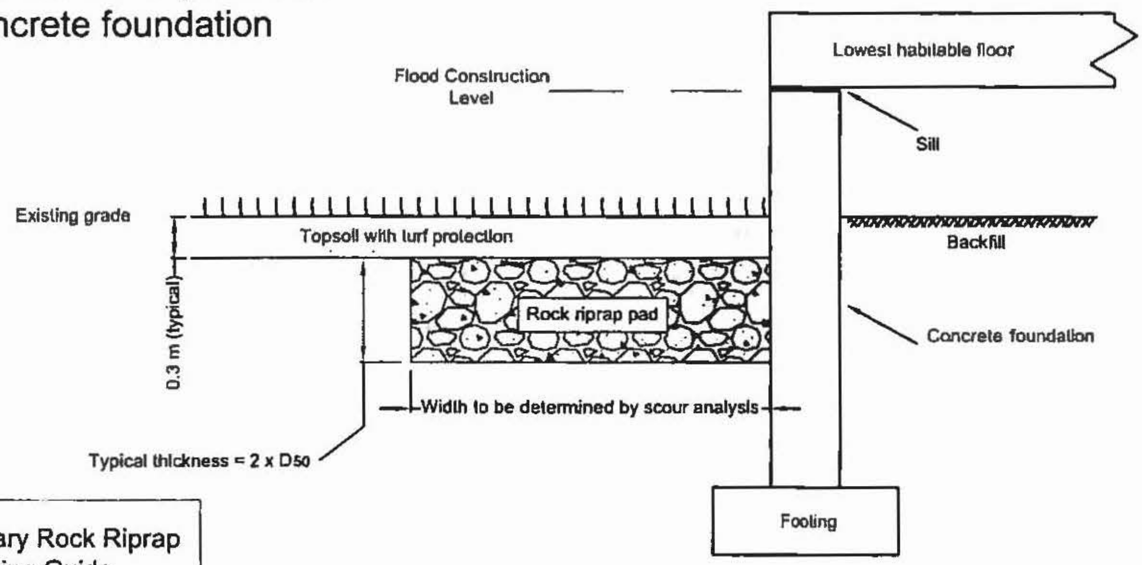
FIGURE 3

PHOTO REDUCED

Typical scour-protected raised building pad



Typical scour-protected concrete foundation



Preliminary Rock Riprap Sizing Guide

Velocity (m/s)	D_{50} (mm)
2	150
3	300
4	550
5	960
6	1300

FROSST CREEK FAN HAZARD ASSESSMENT

Typical Scour Protection

northwest hydraulic consultants

FIGURE 4

nhc
northwest hydraulic consultants

35712
July 25, 2011

Fraser Valley Regional District
Planning Department
45950 Cheam Avenue
Chilliwack, BC V2P 1N6

Attention: **Rick McDermid**
Manager of Development Approvals

Dear Mr. McDermid:

Subject: **2006 Frosst Creek Fan Hazard Zones**
Proposed Attachment:
Updated Hazard Zones at Lindell Beach

Northwest Hydraulic Consultants (NHC) has been engaged by the Fraser Valley Regional District (FVRD) to provide a professional opinion regarding development at Lindell Beach, which is located on the alluvial fan formed by Frosst Creek. NHC was previously engaged to conduct a study to delineate Fan Hazard Zones for the purposes of mitigating hazards to development (NHC, 2006). Since the study was completed, certain sections of the existing non-standard dikes separating Lindell Beach from Frosst Creek have been upgraded and a system is in place for conducting regular inspections and maintenance as required (NHC 2008; see also NHC 2002; 2001; 1999). As a result, FVRD would like to consider whether some portions of the so-called 'X Zone' may be suitable for development.

For the purposes of providing this opinion, we have considered only the portion of the 'X' Zone lying to the south of Frosst Creek and to the east of Vera Road.

1 BACKGROUND

The NHC (2006) report delineated four zones on the alluvial fan formed by Frosst Creek as shown on the attached figure (labelled **Figure 3** in the original report). Zone 'X' was originally defined as follows:

> Zone 'X' represents a zone of significant hazard from channel erosion or avulsion. These areas are not protected by existing dikes and are within the proposed flood corridor of Frosst Creek. High velocity flows with the potential for scour or deposition of significant quantities of sediment and organic material are possible within this zone. We do not recommend that development permits for construction of dwellings or structures for use or occupation be permitted within this zone. (p.15)

In drawing the boundaries of the 'X' Zone, the existing non-standard dikes were disregarded for the purposes of hazard planning. The reason for this was that the dikes were not known to be constructed to an elevation or standard based on engineering principles, nor were the dikes being inspected or maintained in any official capacity. The NHC (2008) document *Frosst Creek Flood Mitigation Works Operation and Maintenance Manual* describes the Flood Mitigation Works that have been constructed as well as spelling out the responsibilities for inspection, operation, and maintenance of the Flood Mitigation Works that have been adopted by the FVRD.

The Flood Mitigation Works include (NHC, 2008):

- 20,000 m^3 sediment-debris basin within the floodplain at river km 1+725 to 2+165,
- 5,000 m^3 sediment-debris basin within the floodplain at river km 0+795 to 0+928,
- Improvements to approximately 1,000 m of dike along the right bank of Frosst Creek from river km 0+000 to 1+125, and
- Flood and debris management activities within the 2,200 m flood corridor.

Zone 'A' is delineated within Lindell Beach abutting Zone 'X' and extending upstream to an area of slight channel incision. Zone 'A' is described within the original report as follows:

> Zone 'A' represents a zone where high velocity overbank flows are possible. The resulting damage could include scour or deposition of significant quantities of sediment or organic material. We have added a significant freeboard to the estimated flow depth and recommend that scour protection be required for the base of any foundation or raised building pad that would resist flow velocities of at least 1.8 m/s. The recommended elevation is set at 1.5 m above surrounding finished grade. (p.15)

The attached figure (originally **Figure 4** of the NHC, 2006 report) shows a typical scour protection schematic.

2 RECOMMENDATIONS

Since the 2006 NHC report was prepared, the current conditions at Frosst Creek have changed with regards to the level of protection from flood mitigation works. The dikes now meet a Provincial standard and are subject to regular inspection and maintenance. Furthermore, additional Flood Mitigation Works are in place to mitigate against the effects of sediment and debris accumulation in the channel. As a result it is reasonable to assume that lateral erosion or channel avulsion will be limited by the presence of the standard dike and that the Frosst Creek floodway is bounded on the right (south) bank by the presence of the standard dike. We therefore recommend that the boundary of the 'A' Zone within the community of Lindell Beach (ie. to the south of Frosst Creek and to the east of Vera Road) be defined by the landward toe of the dike.

Furthermore, we understand that future planning will consider upgrades and adoption of standard maintenance procedures for other portions of the existing non-standard dikes along Frosst Creek. It may be feasible to consider a similar re-definition of the 'X' Zone boundary within these areas in future.

For new development applications it is advisable that the FVRD, where practicable, maintain a suitable right of way (ROW) along the landward edge of the dike (toe) for the purposes of maintenance and inspection. We understand that the FVRD has a similar ROW provision included in existing bylaws governing development on the Fraser River floodplain. In addition to maintaining the existing ROW, where practicable, the FVRD should provide a suitable building setback from the toe which may allow future emergency works, as required, beyond the ROW. The District may wish to permit certain activities within the setback and existing ROW (such as landscaping, septic fields) or it may wish to prohibit all development.

3 CONCLUSION

Adoption of the recommendations outlined above would effectively negate the linework presented in **Figure 3** from the NHC (2006) report, but ONLY for the 'X' Zone/'A' Zone boundary within Lindell Beach lying to the south of Frosst Creek and to the east of Vera Road. The other boundaries shown on this figure remain valid until such time that the dike extending upstream of Vera Road is similarly upgraded to the required standard and a professional opinion regarding the advisability of reconsidering the boundary is obtained. The 'X' Zone/'A' Zone boundary within Lindell Beach would henceforth be defined by the physical extents of the existing dike.

4 REFERENCES

NHC, 2008. *Frosst Creek Flood Mitigation Works – Operation and Maintenance Manual*. Report prepared for Fraser Valley Regional District, Chilliwack, BC. Prepared by Northwest Hydraulic Consultants Ltd., North Vancouver, BC, April 2008, 25 pp + figs.

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* * * * *

If you have any questions, please do not hesitate to contact me at 604.980.6011.

Sincerely,

northwest hydraulic consultants ltd.

original signed by

Derek Ray P.Geo.
Geomorphologist – Associate

Reviewed by Barry Chilibeck, P.Eng.
Principal

ENCLOSURES

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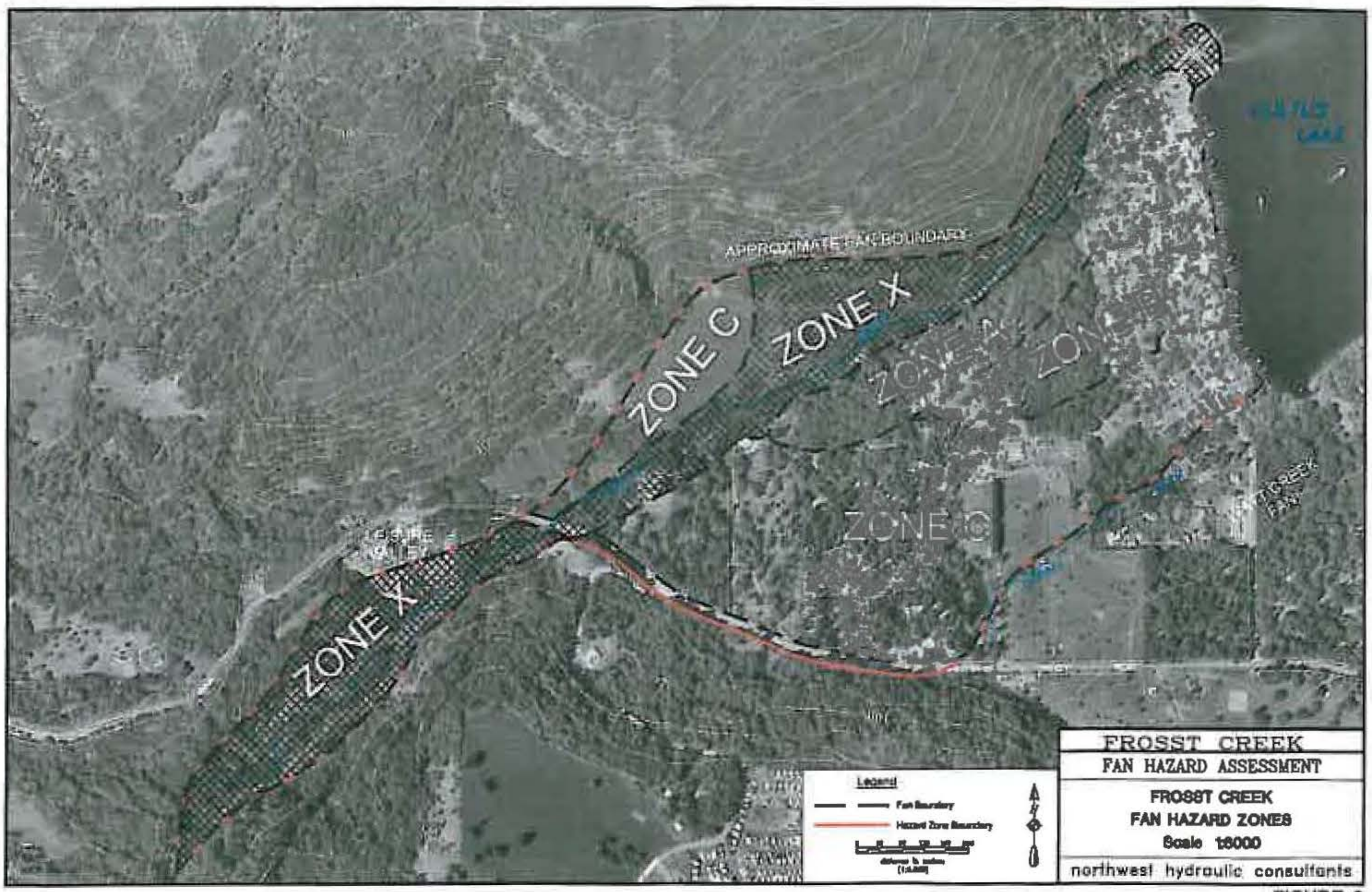
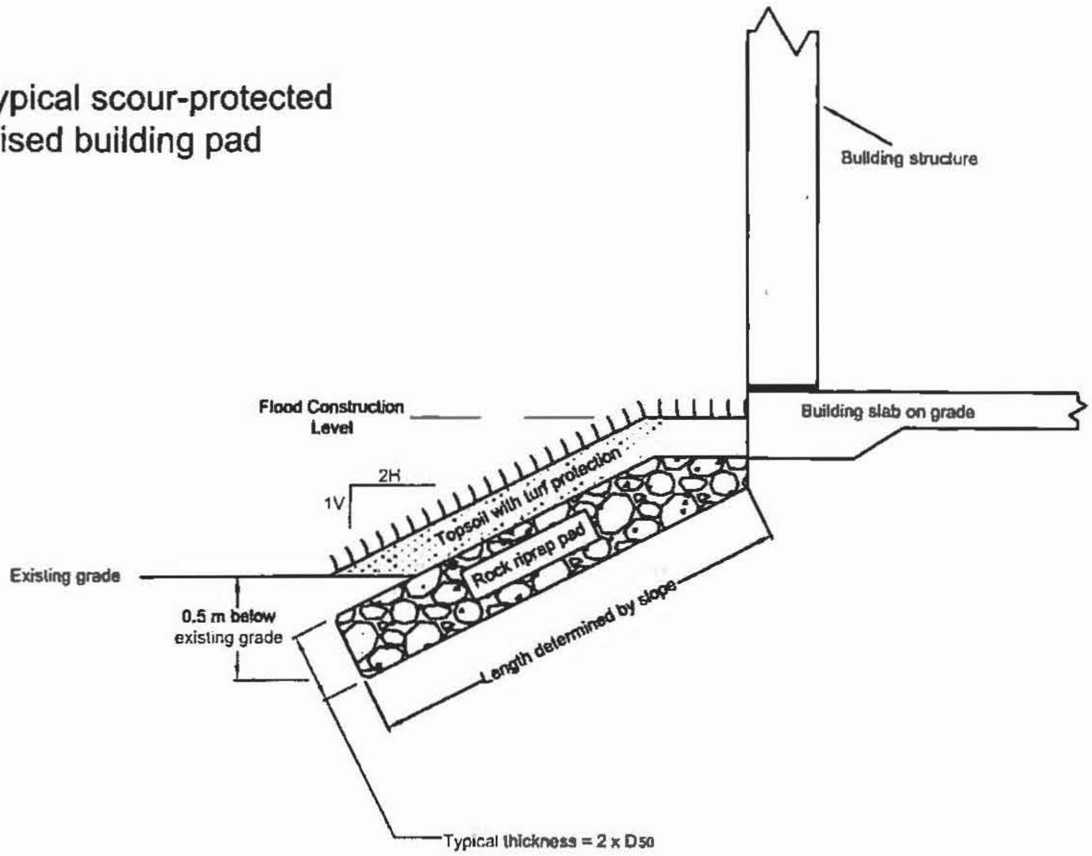
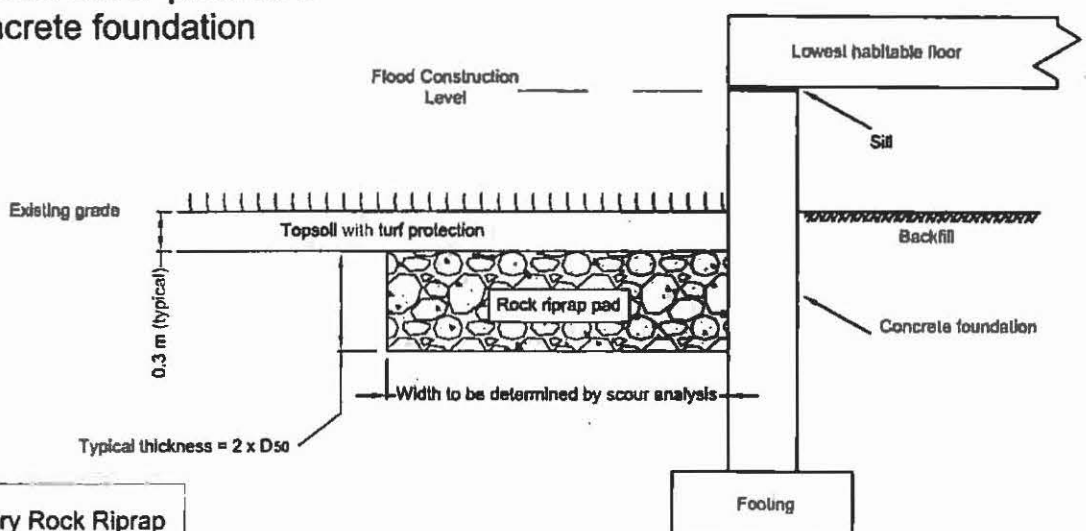

APPROXIMATE FAN BOUNDARY
ZONE C
ZONE X
ZONE X
ZONE C
Legend
Fan Boundary
Hazard Zone Boundary
N
FROSST CREEK
FAN HAZARD ASSESSMENT
FROSST CREEK
FAN HAZARD ZONES
Scale 1:6000
northwest hydraulic consultants

FIGURE 3

Typical scour-protected raised building pad



Typical scour-protected concrete foundation



Preliminary Rock Riprap Sizing Guide

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HAZARD ASSESSMENT

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Zone 'A' is delineated within Lindell Beach abutting Zone 'X' and extending upstream to an area of slight channel incision. Zone 'A' is described within the original report as follows:

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2 RECOMMENDATIONS

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Furthermore, we understand that future planning will consider upgrades and adoption of standard maintenance procedures for other portions of the existing non-standard dikes along Frosst Creek. It may be feasible to consider a similar re-definition of the 'X' Zone boundary within these areas in future.

For new development applications it is advisable that the FVRD, where practicable, maintain a suitable right of way (ROW) along the landward edge of the dike (toe) for the purposes of maintenance and inspection. We understand that the FVRD has a similar ROW provision included in existing bylaws governing development on the Fraser River floodplain. In addition to maintaining the existing ROW, where practicable, the FVRD should provide a suitable building setback from the toe which may allow future emergency works, as required, beyond the ROW. The District may wish to permit certain activities within the setback and existing ROW (such as landscaping, septic fields) or it may wish to prohibit all development.

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*   *   *   *   *

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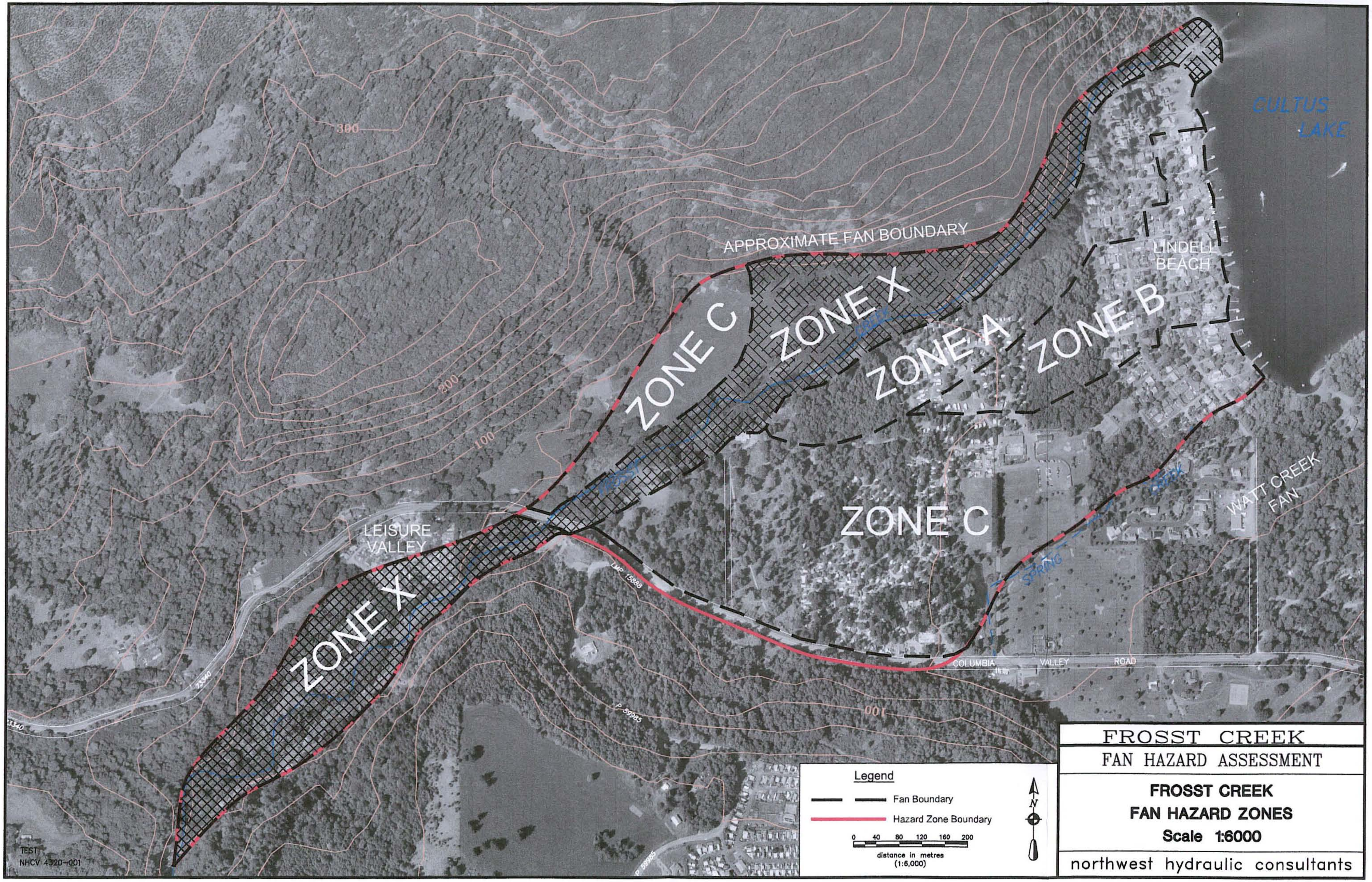


FROSST CREEK

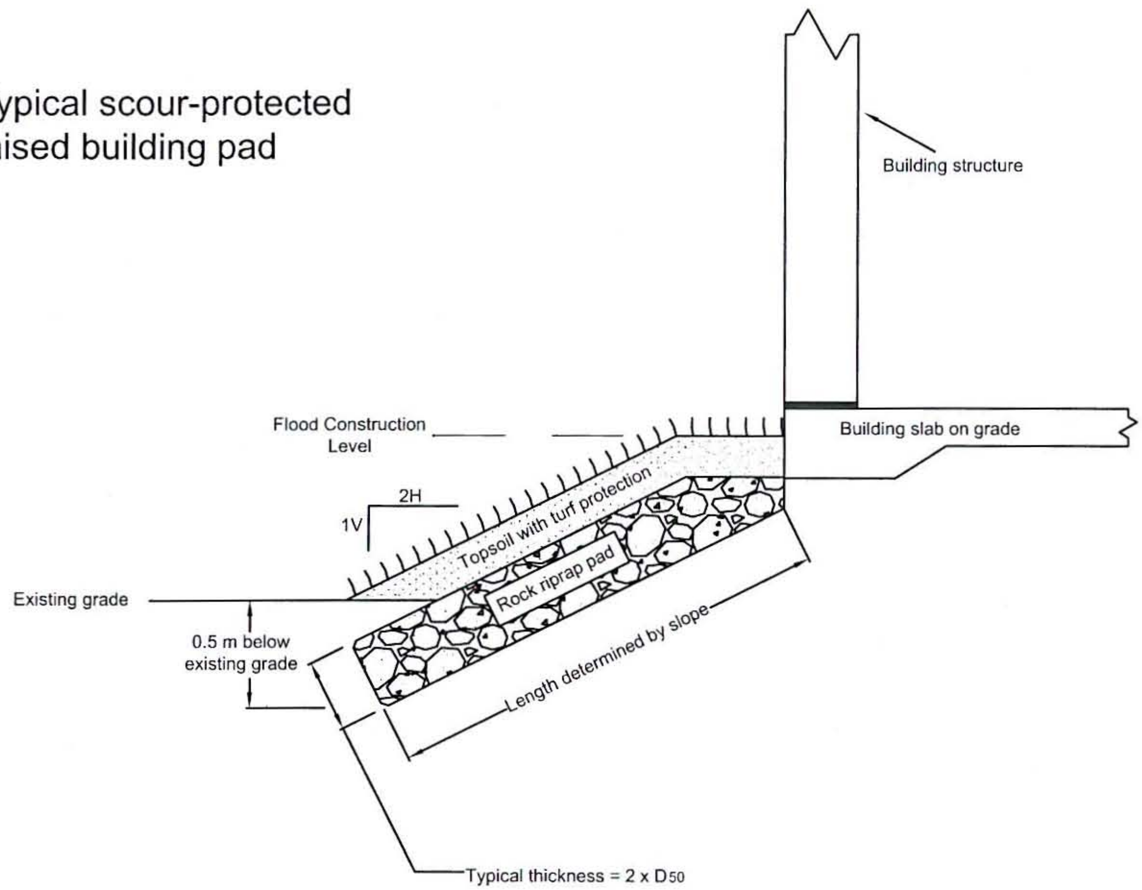
FAN HAZARD ASSESSMENT

FROSST CREEK
FAN HAZARD ZONES
Scale 1:6000

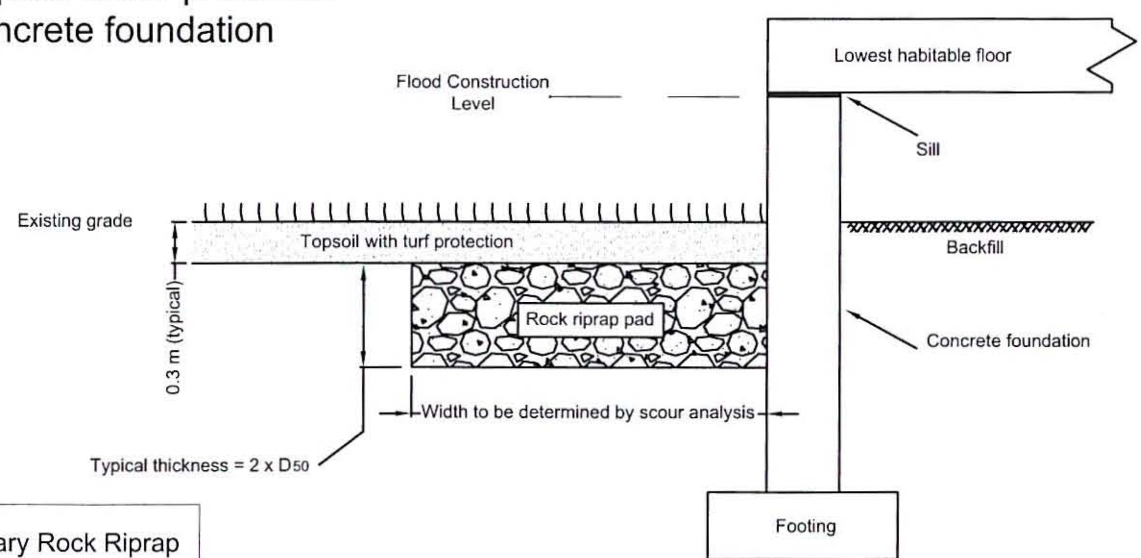
northwest hydraulic consultants

FIGURE 3

Typical scour-protected raised building pad



Typical scour-protected concrete foundation



Preliminary Rock Riprap Sizing Guide

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FROSST CREEK FAN HAZARD ASSESSMENT

Typical Scour Protection

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FIGURE 4