BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CITY OF NORTH VANCOUVER

GEOTECHNICAL STABILITY STUDY

PRELIMINARY PARTIAL RISK ANALYSIS

FINAL

PROJECT NO: 0600-001
DATE: APRIL 24, 2009

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April 24, 2009
Project No. 0600-001

Mr. Tony Barber
Manager, Engineering Planning and Design
City of North Vancouver
141 West 14th Street
North Vancouver, B.C. V7M 1H9

April 24, 2009

Dear Mr. Barber:

Re: Geotechnical Stability Study: PRELIMINARY PARTIAL RISK ANALYSIS

Please find attached two copies of our above referenced report, dated April 24, 2009.

Should you have any questions or comments, please do not hesitate to contact me at the number listed above.

Yours sincerely

BGC ENGINEERING INC.
per:

ORIGINAL SIGNED BY

Michael Porter, P.Eng.
Senior Geotechnical Engineer

MJP/mj/mz

EXECUTIVE SUMMARY

BGC Engineering Inc. (BGC) was retained by the City of North Vancouver (CNV) to conduct an assessment of the geotechnical stability of creek ravines with the objective of determining preliminary landslide partial risk ratings on select slope areas within CNV's boundaries. The objectives of this preliminary study were to help CNV prioritize areas for follow-up risk assessment and, if necessary, risk reduction. The preliminary study focused on areas where buildings or civil infrastructure are located adjacent to slopes that were identified as hazards or potential hazards. It satisfies the requirements of the Preliminary Analysis phase of a risk management program as defined by the Canadian Standards Association (CAN/CSA Q850-97).

With respect to landslide risk management, Preliminary Analysis involves the identification and characterization of landslide hazards and their potential consequences, and using risk scenarios to assign a course of action:

- immediate action if an imminent hazard with high anticipated consequences is identified;
- follow-up investigation, landslide risk assessment, and/or monitoring on a prioritized basis; or
- terminate the risk management process as the potential risks are likely not an issue.

An assessment of surficial geology, development history, historical landslide activity, and current conditions along potentially hazardous slopes was completed through review of maps, aerial photographs, engineering reports, and brief field reconnaissance. Sites were prioritized for follow-up assessment based on qualitative estimates of partial risk, including an assessment of the likelihood of landslide activity and the proximity of inhabited structures to the crest of the ravine slopes.

During the course of BGC's assessment, areas of imminent risk requiring immediate action were not identified. One location classified as 'very high' partial risk was identified (2052 Mackay Avenue) and we recommend that further investigation and risk assessment be completed at this site within one year of the release of this report. Sixteen locations were classified as having 'high' partial risk. The risks at these sites may be deemed tolerable, but recommendations for further investigation and mitigation have been provided in the case that CNV and the affected property owners wish to reduce these risks further. We recommend that these studies be completed within three years of release of this report. Twenty-six locations were classified as having 'moderate' partial risk. Specific recommendations have not been provided for these locations, though CNV might consider conducting geotechnical re-inspections at one to five year intervals at these sites to confirm that slope stability conditions do not worsen over time. No further action is recommended at sites rated as 'low' or 'very low'.

As a general recommendation, BGC noted several locations where it appears home storm drains are not currently connected to CNV's storm sewer system. This increases the potential for storm water to infiltrate the soils near potentially hazardous slopes and may contribute to ongoing erosion, settlement, and slope instability. It is recommended that all homes along ravine crests connect to the storm sewer system. Evidence of ongoing placement of fill and lawn cuttings along parts of the study area was also noted. Over time these practices can oversteepen the slopes, damage vegetation that would otherwise help to stabilize the slope, trap moisture, and increase the potential for slope instability. We recommend CNV take action to ensure its residents discontinue these practices.

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LIMITATIONS OF REPORT

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

As a mutual protection to our client, the public, and ourselves, all reports and drawings are submitted for the confidential information of our client for a specific project. It is understood that the City of North Vancouver will make this report and drawings available to the community for the sole purpose of conveying current information about landslide risk management as limited in paragraph one, above. Anyone in the community receiving a copy of this report and drawings is urged to recognize that these documents represent an interim step in the risk management process as defined by Canadian Standards Association Guidelines.

Authorization for any use and/or publication of this report or any data, statements, conclusions or abstracts from or regarding our reports and drawings, through any form of print or electronic media, including without limitation, posting or reproduction of same on any website, is reserved pending BGC's written approval. If this report is issued in an electronic format, an original paper copy is on file at BGC Engineering Inc. and that copy is the primary reference with precedence over any electronic copy of the document, or any extracts from our documents published by others.

1.0 INTRODUCTION

This report summarizes the observations and conclusions made by BGC Engineering Inc. (BGC) as part of a geotechnical study of areas of potential slope instability within the City of North Vancouver (CNV).

The terms of reference for this assessment were originally defined by CNV in a Request for Proposals for the Study of Geotechnical Stability of Creek Ravines, and in BGC's proposal dated December 6, 2007. BGC's study was authorized by CNV on February 15, 2008. The original study included creek ravines within CNV boundaries.

Following review of BGC's draft report dated October 27, 2008, CNV requested that the project scope be expanded to include slopes around portions of Low Level Road and Grand Boulevard. BGC provided a cost estimate for the expanded scope on January 7, 2009, which was authorized by CNV on January 13, 2009.

2.0 SCOPE OF WORK

2.1 Areas of Interest

The Areas of Interest included: portions of Mackay Creek, Thain Creek, Wagg Creek, Mission Creek and Mosquito Creek north of West 23rd Street that lie within CNV's boundaries; slopes above Low Level Road between St. Patricks Avenue and Heywood Street; and slopes above and below Grand Boulevard between East 19th Street and East 23rd Street. Areas of Interest are shown on Figure 1.

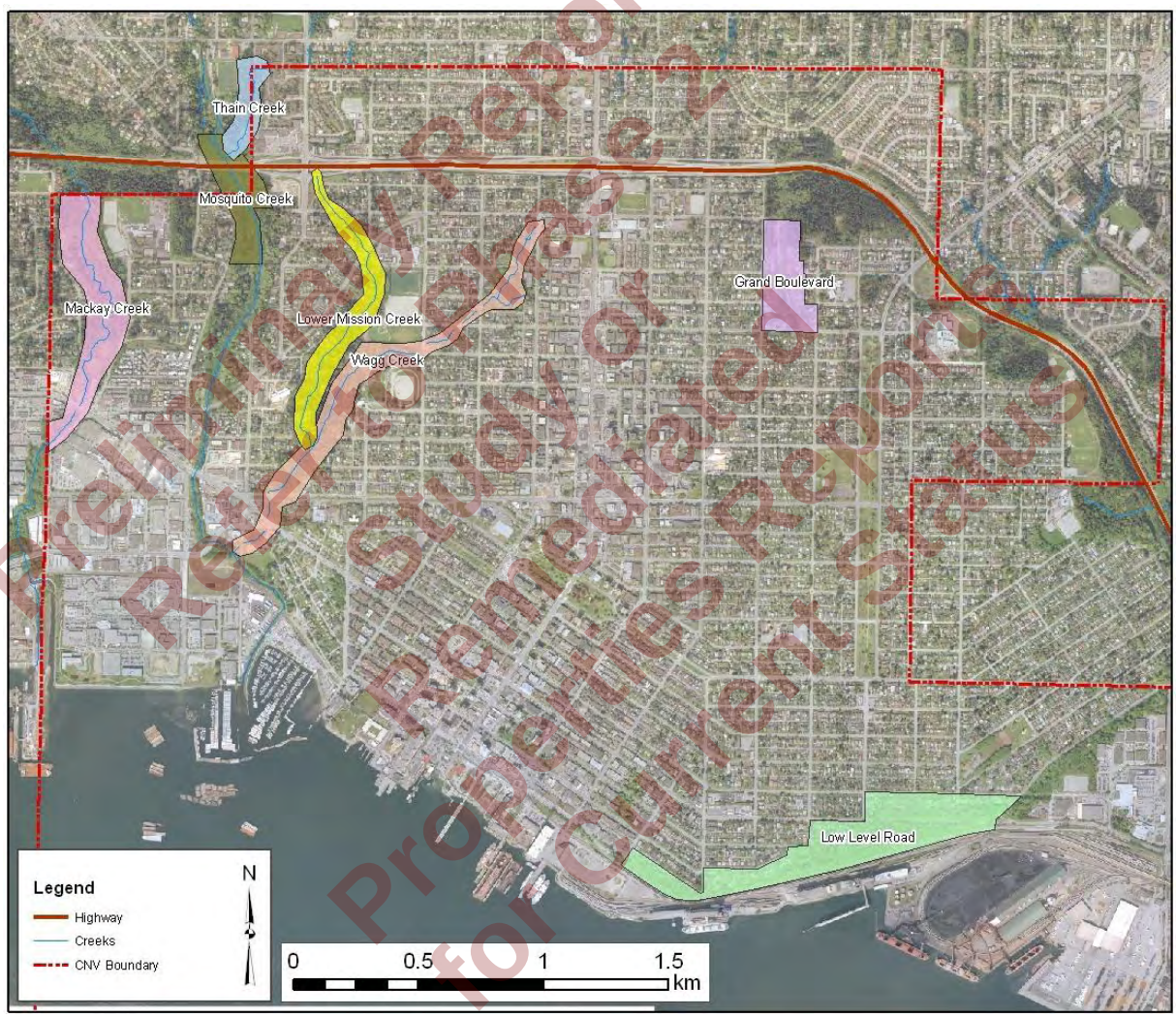


Figure 1: Study Area Map

2.2 Study Objectives

BGC understands CNV's ultimate objective for the proposed study and follow-up works is the systematic management of landslide hazards using an accepted risk-based approach. Borrowing heavily from Canadian Standards Association (CSA) guidelines, BGC assisted the District of North Vancouver (DNV) with the development and implementation of a suitable

framework for this type of risk management program following a fatal landslide in 2005. As illustrated in Figure 2, the framework comprises six steps and represents an ongoing cycle of assessment, mitigation, monitoring and communication.

The purpose of the CNV study was to conduct a preliminary partial risk analysis associated with slope stability hazards within the Areas of Interest described above. The study was intended to satisfy the "Preliminary Analysis" and, in part, the "Risk Estimation" steps of the Risk Management Decision-Making Process, modified after CAN/CSA-Q850-97 (Canadian Standards Association, 1997), and illustrated in Figure 2. Partial risk is defined in Section 5.0.

According to CSA guidelines, preliminary analysis involves the identification and characterization of hazards using risk scenarios. In the case of landslides, this involves developing an understanding of where previous landslides have occurred, their causal factors, typical magnitude, velocity and runout behaviour, and likely consequences. With this information, risk scenarios can be used in conjunction with a preliminary landslide hazard assessment to determine an appropriate course of action for each element at risk. The methodology was tailored to meet CNV's requirements and to be compatible with landslide hazard assessments recently completed along other ravines within the City (Westrek, 2006 and 2007).

The risk terminology used in this report is consistent with definitions provided by CSA (1997), Wise et al. (2004) and Fell et al. (2005). Risk is defined as the product of the probability or likelihood of occurrence of a hazard and the consequence of that hazard's occurrence. Hazards considered in this study include harmful or potentially harmful landslides. Consequence is the change, loss or damage to elements at risk (i.e. humans, property, the environment or other things of value) resulting from hazard occurrence, and is the product of spatial probability ($P_{S:H}$ – the potential of a landslide to reach or affect the space occupied by the element), temporal probability ($P_{T:S}$ – the potential of a mobile element to be at the site affected by the hazard at the time of its occurrence), vulnerability (V – the ability of the element to resist change or harm if impacted by the hazard) and the value or worth of the element.

Partial risk (P_{HA}) is the product of hazard likelihood (P_H) and spatial probability ($P_{S:H}$) only. Elements at risk included in this study are habitable structures, including single and multi family residences and public buildings like schools and recreational structures. Temporal probability is not a factor for non-mobile elements such as homes and public buildings. Because this study is a preliminary analysis intended to prioritize subsequent studies, evaluations of vulnerability and element values were not necessary.

It is important to note that facilities, improvements or natural areas other than the elements at risk identified above were not included in the partial risk analysis. These may include roads, trails, playing fields, natural areas and the users thereof; above-ground or underground

utilities; or plant or animal habitat. Consequences that may arise from landslides occurring within the Areas of Interest that do not affect the elements at risk identified above may include, but are not limited to: damage to private property or public facilities; reductions in property values; losses associated with service interruptions along transportation, utility or communication infrastructure; environmental damage; or combinations of the above. Risk associated with these other consequences was not evaluated as part of this study.

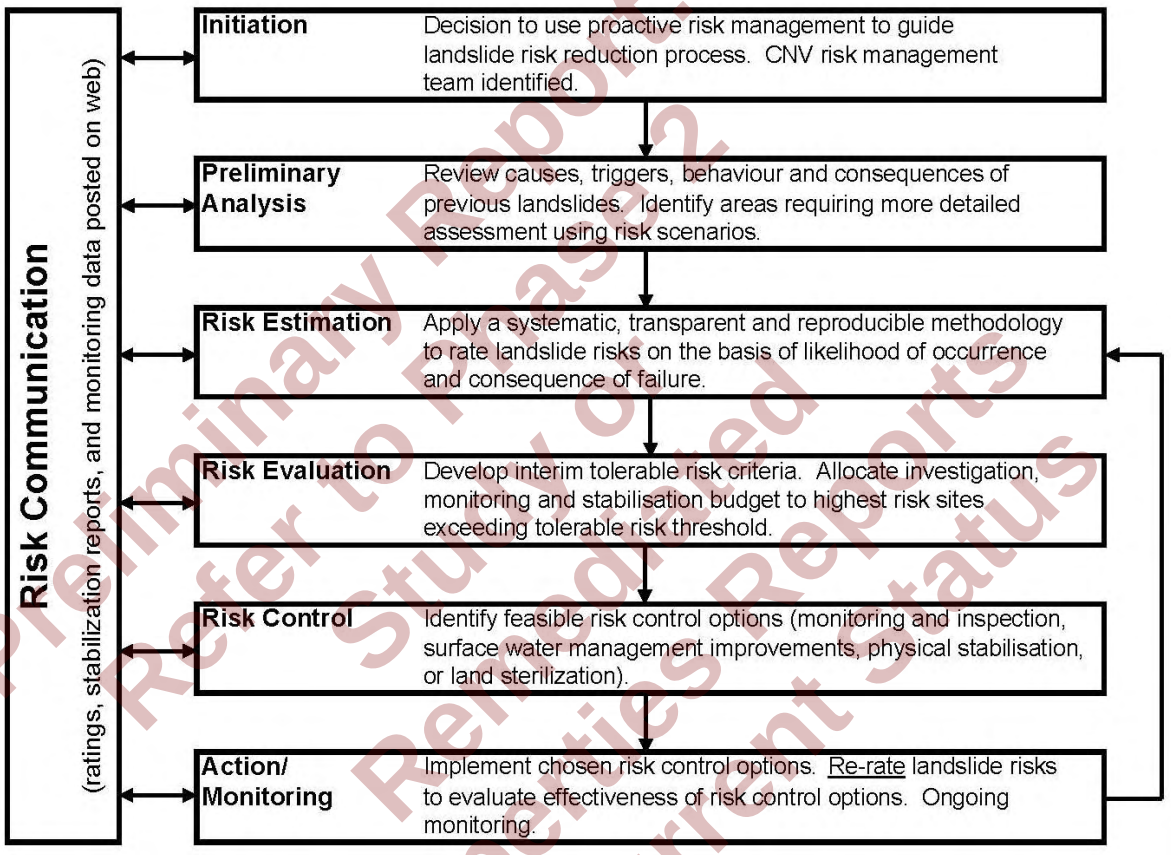


Figure 2: Landslide Risk Management Program (after CAN/CSA Q850-97)

3.0 STUDY METHODOLOGY

3.1 Project Meeting

The first task was a meeting with CNV representatives to review the project requirements, the landslide causal factors that we proposed to consider, the end use of the study results, and other relevant information CNV had on file. Risk scenarios for the range of possible consequences of a landslide, should one occur, were developed and discussed with CNV.

3.2 Background Research

BGC reviewed the following documents, provided by CNV.

Kerr Wood Leidal Associates Ltd. April 1994. Thain Creek Ravine Stability Assessment. Project No. 99.012K.

Kerr Wood Leidal Associates Ltd. October 2, 1997. Inventory of Environmentally Sensitive Areas. File 99.021.

EBA Engineering Consultants, Ltd. February 10, 2006. Investigation of Foundation Distress, Unit 815 – Cypress Garden, North Vancouver. File 7825444.

Westrek Geotechnical Services Ltd. July 19, 2006. Mosquito Creek Ravine East Bank Assessment: Project # 005-051.

Westrek Geotechnical Services Ltd. May 8, 2007. Mosquito Creek East Ravine Landslide Risk Analysis, Phase II – Detailed Study. Project # 006-002.

EBA Engineering Consultants, Ltd. November 29, 2007. Slope Stability Monitoring and Analysis, Cypress Garden, North Vancouver, B.C. File V13100029.

EBA Engineering Consultants, Ltd. February 2000. Low Level Road Risk Management Study. File no. 99-86071.

SNC-Lavalin. July 15, 2008. North Shore Trade Area Study Geotechnical Report. Project no. 017920.

CNV also provided BGC with geospatial data for the project, including layers with LiDAR-derived topography, stream centre lines, building footprints, property lines, roads and storm drains.

Other published reports and maps, and unpublished work by BGC for DNV, are cited in the References section, below.

3.3 Screening Study

A screening process was conducted to determine which properties were to be included in the air photo and field verification phase of the study. The purpose of the screening was to employ conservative assumptions to determine which slope segments might produce landslides that could result in significant structural damage and possible impact to habitable structures (the elements at risk). Structures captured by the screening process were included in the field verification phase of the study.

3.4 Aerial Photograph Review

BGC reviewed historical aerial photographs in stereo to: investigate the occurrence and location of previous landslides; develop an appreciation for historical landslide frequency for slope segments in the study area; and document the development history around the study area, including fill placement. Sufficiently large and well-defined slide areas were mapped (Drawings 1 through 7). Observations of causal factors for landslides, including stream erosion, saturated ground, steep slopes and surface erosion, were compiled. Table 1 contains a list of aerial photographs reviewed by BGC.

Table 1: List of Aerial Photographs Used in this Study

Date	Flight	Photos	Nominal Scale
1926	BA.23	6-11, 56-59	1:10,000
1949	BC 729	19-23, 43-45, 88-91	1:10,000
1957	BC 2351	66-67, 71-74	1:15,840
1961	A17427	36-38	
10-Apr-63	BC 5060	11-14	1:12,000
28-Apr-63	BC 5059	220-223, 236-238	1:12,000
13-Mar-69	BC 5325	98-99, 180-184, 196-198	1:16,000
21-Mar-74	BC 5573	154-155, 231-233	1:12,000
12-Jun-74	BC 5591	283-287	1:12,000
15-Jul-76	BC5721	124-126, 149-150	
1979	BC 79047	63-65, 97-98, 131-136	1:25,000
22-Jan-80	30BCC239	80-81; 99-104; 133-136	1:6,000
1984	A 26511	73-75, 100-102	1:10,000
1987	FF 8727	194-195	
1987	FF 8727	125-126	
29-Jul-92	30 BCB 92018	6-7, 78-81	1:15,000
1996	30 BCC 96129	25-26	
22-Jul-96	30 BC 96081	97-99, 120-122	1:15,000
27-Sep-96	FFC 96000	13-14	
2-Apr-04	SRS 6929	116-117, 147-150	1:20,000

3.5 Field Verification

BGC visited sites flagged by the screening study to determine whether each site warranted inclusion in the risk analysis and reporting phases, and collect basic information in a systematic manner suitable for input into a geohazards database at a later date. This information included slope angles, drainage characteristics, evidence of slope deformation, and proximity of the hazards to elements at risk. BGC visited the creek ravine Areas of Interest in May of 2008, and the Low Level Road and Grand Boulevard Areas of Interest in February of 2009.

3.6 Risk Analysis and Reporting

A partial risk analysis was carried out on the elements identified by the screening study and field verification, based on criteria developed from BGC's experience with similar conditions in DNV (BGC Engineering Inc., 2006). BGC's partial risk ranking scheme is outlined in Section 5.0.

BGC prepared this report that includes our observations, conclusions and recommendations, based on the risk ratings assigned to each element at risk. The results of the partial risk analysis undertaken by BGC are broadly comparable with results of a similar study performed by Westrek in July of 1996 along the east bank of Mosquito Creek.

3.7 Project Personnel

Michael Porter, P.Eng., acted as project manager and field-reviewed select sites. The office and field investigations were coordinated and carried out by Martin Zaleski, CEG (California), with assistance from Sam Fougere, P.Geo., Andy Jamieson, EIT, and Matthew Buchanan. Michael Beaupre assisted with data entry. Matthew Buchanan and Ken Sam assisted with geospatial analyses and map compilation. Matthias Jakob, P.Geo., provided senior review.

4.0 BACKGROUND INFORMATION

4.1 Physiographic Setting

The study area comprises a series of terraces that descend southward from the Coast Ranges down to Burrard Inlet. The terrace surfaces are gently southward-sloping, but are separated from adjacent terrace surfaces by steeper slopes. The terraces are dissected by steep-sided ravines. Southward-flowing streams occupy the ravine bottoms.

Elevations range from 10 to 90 m above sea level across the study area. The highest elevation is located atop a terrace near the intersection of Westview Drive and West 28th Street, at the north end of the study area. The lowest elevation is in the Wagg Creek thalweg near the intersection of West 2nd Street and West 3rd Street, at the south end of the study area.

On average, the study area slopes southward at about 2˚. Many steeper slopes, with heights of up to 30 m, and slope angles exceeding 35˚ in places, are present between terraces and along ravine side slopes. Average channel angles are between 1˚ and 2˚, although short segments of the channels are steeper.

4.2 Climate and Vegetation

The Köppen-Geiger classification of the local climate is *Cfb* (sometimes *Csb*), or temperate without a dry season (sometimes with a dry season) and with warm summers (Peel et al., 1997). The study area is within the Coastal Western Hemlock biogeoclimatic ecosystem (Meidinger and Pojar, 1991). Average annual precipitation is approximately 1300 mm, of which 96% occurs as rainfall, and 71% occurs between the months of October and March (Environment Canada, 2007).

Second-growth forest covers most of the ravines within the study area. The forest consists of a mixture of coniferous (mostly hemlock, fir and cedar) and deciduous (maple and alder) trees. Some old-growth cedar stumps are present. Brush and ground cover includes native species such as skunk cabbage, nettles and ferns; and invasive blackberry, ivy, holly, clematis, lamiastrum and periwinkle. Most areas atop the terraces are landscaped.

4.3 Geologic Setting

The basement rock beneath the study area includes mid-Cretaceous quartz diorite of the Coast Plutonic Complex. Beneath about the southwestern ¾ of the study area, these intrusive rocks are unconformably overlain by Mid-Cretaceous Nanaimo Group coarse clastic sedimentary rocks (BCGS, 2005). Bedrock outcrops were not found in the study area.

During the Late Pleistocene, the study area was covered by glaciers. Repeated glacial advances and retreats in the Lower Mainland, occurring between 18,000 and 12,000 years before present (bp), left relatively compact, complex interlayered proglacial and glacial deposits, lying unconformably atop the bedrock. Known collectively as Vashon Drift

(Armstrong, 1984), these deposits include tills, glaciofluvial sands and gravels, and glaciolacustrine silts and clays.

As the last of the ice sheets melted and retreated, the study area experienced isostatic rebound. The relative sea level around the Lower Mainland was up to 200 m higher during deglaciation than at present (Clague, 1989), as evidenced by the presence of elevated shorelines, seaward-tilted terraces, and raised marine, deltaic and fluvial deposits. Known as Capilano Formation sediments, these deposits are around 13,000 to 10,500 years old, and comprise deep water marine silts and clays overlain by up to 15 m of sand to coarse cobble channel-fill and deltaic sediments. The Capilano Formation comprises raised deltaic and channel fill deposits lying atop deeper-water silts and clays beneath glaciomarine terraces within the study area (Armstrong, 1984).

After the uplands emerged, streams eroded rapidly downward and headward through the relatively unconsolidated glacial sediments, and more slowly through the more-consolidated bedrock. The rapid erosion, which continued through the Holocene epoch to the present day, produced steep-sided creek ravines incised into the Capilano and Vashon sediments. Reworked sediments were deposited as Holocene deltaic deposits in the lowlands south of Marine Drive, consisting mostly of sands and gravels, and reaching 15 m in thickness.

Throughout the Holocene (or Postglacial) Era, the steep ravine slopes have experienced mass movement, ranging from slow creep through to rapid earth slides and flows. As a result of mass movement and soil development processes, ravine side slopes are mostly covered with a veneer of colluvium, with some areas mantled with thicker colluvium as landslide debris. Discontinuous Holocene floodplains are present along many parts of the ravine bottoms.

Human settlement and development in the last 150 years has produced significant changes in Metro Vancouver urban ravine environments. Many ravines have been filled with a mix of excavation material and undifferentiated fill and channelled through culverts to allow for denser development. Aerial photographs suggest that many residential neighbourhoods on the upland terraces in the study area are built upon infilled stream channels. Where stream channels and ravines remain unfilled, they are often modified by grading along their side slopes. Common scenarios include dumping construction debris or yard waste into ravines behind properties, placing fill on steep ravine slopes to enlarge usable yard space, or directing drainage toward the crests of ravine slopes. Often, such practices increase the likelihood of slope failures.

4.4 Groundwater and Hydrology

Most precipitation falling on the study area infiltrates into the soil and either flows as seepage through the soil and colluvium, or enters the local groundwater flow network by infiltrating site soils.

Many small seeps and springs were observed across the study area, in particular near ravine bottoms. Nearby soil exposures suggest that relatively impermeable marine silts and silty clays or tills are present near many ravine bottoms where seepage is observed. Groundwater probably flows relatively freely through the sandy to gravelly, raised channel and deltaic deposits that cap the terraces adjacent to the ravines, and perches atop the less permeable soils that underlie them. Aquifers in the raised channel and deltaic deposits may be hydraulically connected to source areas located some distance from the ravine.

5.0 PARTIAL RISK ANALYSIS

As stated previously in this report, BGC's investigation was to satisfy the requirements of a "Preliminary Analysis", as defined by CSA (1997), and illustrated in Figure 2. This Preliminary Analysis is intended to prioritize areas for subsequent action, including follow-up monitoring, detailed investigations, mitigation or land sterilization. As such, a partial risk analysis, incorporating hazard likelihood and spatial probability, satisfies these requirements where habitable structures are the elements at risk. The subsequent phases of the Landslide Risk Management Program would deal with site-specific investigations and mitigation, where prudent.

At CNV's request, the partial risk analysis procedures employed by BGC are intended to produce results that are broadly comparable with those obtained by Westrek (2006) in their analysis of partial risk along the east bank of Mosquito Creek.

5.1 Hazard Likelihood

Hazard likelihood, P_H, is a qualitative measure of the likelihood of occurrence of a harmful or potentially harmful landslide. BGC provided qualitative hazard likelihood estimates for each property based on evidence for past failures or adverse slope conditions, as observed in aerial photographs, documented in other reports, or observed in the field. Table 2 shows hazard likelihood ratings and criteria used in this study.

Table 2: Qualitative Landslide Hazard Likelihood Ratings for Potentially Hazardous Slopes

Factor	Rating	Criteria
Hazard Likelihood (P_H)	High	Evidence of active or historical landslides or slope deformation, regardless of slope angle or height - landslide scarps containing exposed soil or re-vegetated with deciduous trees or young conifers - visible settlement in fills, retaining walls
	Moderate	Adverse slope conditions, but no evidence of historical landslides or slope deformation - slopes steeper than 35° and more than 3 m high - presence of random fills or yard waste - presence of un-engineered retaining walls - abundant seepage or surface erosion
	Low	Favourable slope conditions and no evidence of historical landslides or slope deformation - slopes less steep than 35° - slopes less than 3 m high - engineered fills or retaining walls (if present)
	Not Rated	Slopes less steep than 25° with no evidence of historical landslides, slope deformation or adverse ground conditions

The hazard likelihood ratings shown in Table 2 were applied to potentially hazardous slopes, as identified by a screening study and field verification described in Section 6.0.

5.2 Spatial Probability

Spatial probability, $P_{S:H}$, refers to the potential of a landslide to reach or affect a habitable structure. BGC provided qualitative estimates of spatial probability that were based on field measurements between potentially hazardous slopes and habitable structures (including any structurally attached decks, garages, etc.). Hazards situated more than 10 m laterally (i.e. along contour, as opposed to directly upslope or downslope) from an element at risk were considered unlikely to impact that element. Lower bound criteria for spatial probability were developed to clearly identify properties worth including in the partial risk assessment: these criteria are presented below and discussed in detail in Section 6.2.

5.2.1 Spatial Probability for Upslope Elements

Habitable structures were present only above ravine crests within the Mackay Creek, Mosquito Creek, Thain Creek, Lower Mission Creek, Wagg Creek and Low Level Road areas. Consequently, spatial probability ratings for upslope elements were applied exclusively in these areas. Ratings and criteria for spatial probability for upslope elements ($P_{S:H;\ CREST}$) are shown in Table 3.

Table 3: Qualitative Spatial Probability Ratings for Upslope Elements

Factor	Rating	Criteria
Spatial Probability for Homes At or Near Crest of Slope ($P_{S:H;\ CREST}$)	High	Home or attached deck < 3 m from crest of slope - high likelihood of initial landslide impacting the element(s) at risk
	Moderate	Home or attached deck 3 to 6 m from crest of slope - initial landslide or subsequent erosion or landslide retrogression could impact the element(s) at risk
	Low	Home or attached deck 6 to 10 m from crest of slope - initial landslide or subsequent erosion or landslide retrogression unlikely to impact the element(s) at risk
	Not Rated	Home or attached deck > 10 m from crest of slope

5.2.2 Spatial Probability for Downslope Elements

Homes are present both above and below potentially hazardous slopes in the Grand Boulevard study area. Therefore, downslope elements at risk are present in addition to upslope elements at risk within that area. Table 4 describes the spatial probability ratings and criteria for downslope elements ($P_{S:H;\ BASE}$).

Table 4: Qualitative Spatial Probability Ratings for Downslope Elements

Factor	Rating	Criteria
Spatial Probability for Homes At or Near the Base of Slopes ($P_{S:H;\ BASE}$)	High	Angle between home/habitable structure and crest of slope or source area > 23° - high likelihood of landslide debris impacting the element(s) at risk
	Moderate	Angle between home/habitable structure and crest of slope or source area between 21° and 23° - moderate likelihood of landslide debris impacting the element(s) at risk
	Low	Angle between home/habitable structure and crest of slope or source area between 19˚ and 21° - highly unlikely that landslide debris would impact the element(s) at risk
	Not Rated	Angle between home/habitable structure and crest of slope or source area < 19˚ - landslide impact on the element(s) at risk does not warrant analysis

5.3 Partial Risk

A qualitative estimate of partial risk (P_{HA}) for each element was determined by combining the hazard likelihood and spatial probability, as defined above, for each property. Qualitative partial risk ratings are defined in Table 5.

Table 5: Qualitative Partial Risk Matrix

$P_{HA} = P_H \times P_{S:H}$ Probability of a specific landslide impacting the identified elements at risk		P_H (Landslide Likelihood)		
		Low	Moderate	High
$P_{S:H}$ (Spatial Probability – highest risk of either $P_{S:H;\ CREST\ or\ BASE}$)	Low	Very Low	Low	Moderate
	Moderate	Low	Moderate	High
	High	Moderate	High	Very High

6.0 SITE SELECTION

This section outlines the two-step process for selecting properties for partial risk analysis. A screening study combined the results of seismic stability analyses with the study area topography to select properties for field verification. During field verification, additional criteria were applied to reduce the screening study selection set to properties with legitimate slope stability or landslide impact concerns. Appendix A shows properties selected by the screening study (Section 6.1), but not included in the partial risk analysis because of observations made during the field verification phase (Section 6.2).

6.1 Screening Study

Seismic stability analyses were run on hypothetical slopes, using conservative slope geometry, soil and groundwater properties from BGC's experience in DNV (BGC, 2006a). Two rounds of stability analyses were completed: Round 1 was intended to identify soils and groundwater conditions likely to produce significant deformation on commonly-observed ravine slope conditions; and Round 2 was to determine a lower bound slope angle for slopes with the potentially unstable soil and groundwater conditions identified in Round 1.

A 15 cm displacement has been identified by APEGBC's Task Force on Seismic Slope Stability (2008) as a limiting slope displacement for residential development suitability, and this value was adopted in BGC's analyses. A seismic coefficient corresponding with a 15 cm slope displacement, k_{15} (Bray & Travasarou, 2007; Task Force on Seismic Slope Stability, 2008), of 0.14 was employed based on a probabilistic spectral acceleration at 0.5 second period of 0.61 g and an earthquake magnitude of 7.0 (CBSC, 2005; Adams & Halchuk, 2003).

Round 1 was carried out on 35˚, 15 m high slopes. Groundwater conditions and soil properties were varied, with typical values taken from previous BGC work in DNV (BGC, 2006a). The results of Round 1 indicated that slopes underlain by saturated fill were likely to deform under seismic loading conditions, but that dry fill or saturated natural soils were unlikely to deform.

With this in mind, a stability model for Round 2 was constructed using the following assumptions:

- Slope height was kept constant at 15 m;
- The groundwater table was drawn 3 m below the slope crest, and intersecting the ground surface at the slope toe;
- The slope was assumed to be entirely underlain by fill derived from glaciomarine silt, with unit weight of 15.0 kN/m^3, cohesion of 6 kPa, and friction angle of 32˚.

By varying slope angles with each analysis, BGC determined that local slopes less steep than 14.5˚ were unlikely to deform more than 15 cm. By applying the results of this analysis to the site topography, BGC mapped potentially hazardous slopes across the study area (i.e.

slopes where it was possible to get 15 cm or more displacement if weak soils and high-groundwater conditions were present, during the design earthquake). Homes located within 10 m of these slopes were flagged for field verification.

The screening study identified 150 properties within the Areas of Interest that warranted field verification.

6.2 Field Verification

Field verification of the hazards identified by the screening process described above was undertaken to determine whether a property warranted a partial risk analysis. Lower-bound criteria were applied during the field verification phase of the study to decide which slopes were potentially hazardous, and which homes were sufficiently proximal to those slopes, to warrant inclusion, as described below:

1. Potentially Hazardous Slopes

   As described above, the screening process was based on stability analyses on slopes underlain entirely by saturated fill soil. Given the geologic environment and development history present within the study area, it is highly unlikely that such conditions exist. Although useful for screening purposes, these criteria are unsuitable for site-specific evaluations. Slopes lying at less than 25˚ were considered not potentially hazardous, except where signs of active seepage, past slope instability or other adverse ground conditions were observed. Only habitable structures near slopes exceeding 25˚ angles, or with adverse ground conditions, were considered to be elements at risk. These values correspond with screening criteria currently used by BGC in risk analyses for DNV.

2. Upslope Proximity

   Following criteria established by BGC for DNV (BGC, 2006a), it was considered unlikely that a single slope failure occurrence would extend more than 10 m behind the present slope crests. Habitable structures were included in the partial risk analysis only if those structures, or any structurally attached appurtenances (decks, carports, etc.) were located within 10 m of a slope crest, as measured in the field.

3. Downslope Proximity

   BGC's landslide runout evaluation work for DNV (BGC, 2006a and 2006b) suggested that damaging impact from landslides to homes below steep slopes was unlikely where the angle between the initiation zone and the home's foundation was less than 19˚. In this study, homes not located within the 19˚ shadow of potentially hazardous slopes were not included in the partial risk analysis.

Of the 150 properties identified in the screening study, 53 met the above-listed criteria for inclusion in the partial risk analysis. Three additional properties that were not identified in the screening study were added during the field verification phase: these properties were adjacent to other properties which had been identified in the screening study, and field

observations indicated that they also met the above-listed criteria. These three properties are 1980 Mackay Avenue, 1732 Wolfe Street, and 1601 Forbes Avenue. The remaining 97 properties (those not meeting the partial risk analysis criteria) are listed in Appendix A.

7.0 SITE EVALUATIONS

This section contains information on properties selected for partial risk analysis. Refer to Section 6.0 for a description of the procedure used to select properties for inclusion in the partial risk analysis.

Very high, high and moderate partial risk sites (marked by red, orange and yellow, respectively, on Table 5

Table 5: Qualitative Partial Risk Matrixand in Drawing 1) are described in detail in Sections 7.1 and 7.2, and select photographs are included. Recommendations are detailed after a description of each site. Moderate partial risk properties are tabulated in Section 7.3. A summary table for hazard and risk criteria and ratings is included in Appendix B.

Landslide terminology used in this report is in accordance with Cruden and Varnes (1996).

7.1 Very High Partial Risk Sites

One property was assigned to the very high risk category. BGC recommends that detailed investigations directed toward risk reduction be carried out within 1 year of the report date.

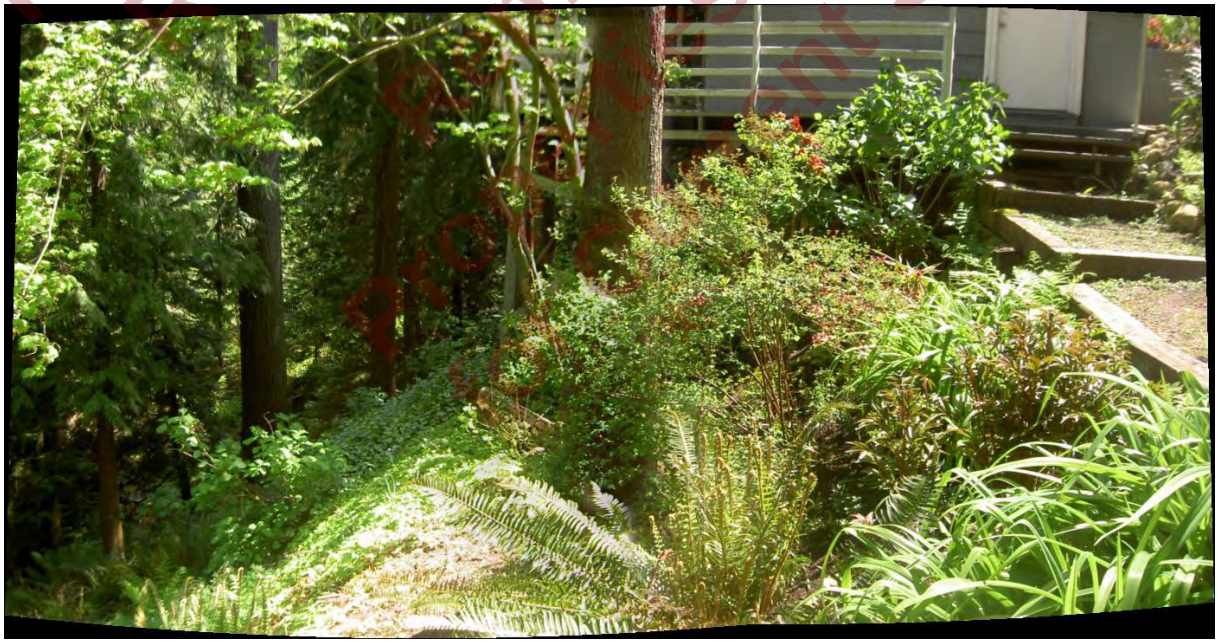
7.1.1 2052 Mackay Avenue

A single family residence is present near the slope crest, and a separate, detached accessory dwelling overhangs the slope crest. The accessory dwelling derives support from a concrete footing and from wood posts on shallow concrete piers. The accessory dwelling foundation lies atop fill placed at a 37˚ angle atop a natural 31˚ slope. The main residence is set back 2.1 m from the slope crest. The closest part of the slope to the main residence is retained by non-engineered wood lagging, concrete and river rock retaining walls.

No signs of slope instability were observed on aerial photographs covering the site. BGC observed signs of historic earth sliding on natural slopes north of the property; however, the closest proximity of slide features to any structures on site exceeds 10 m laterally. Recent ground deformation in fill was observed beneath the accessory dwelling, as discussed below. CNV mapping does not show a storm drain connection to the property.

At the time of BGC's site visits, the fill supporting the accessory dwelling foundation showed signs of settlement and slope deformation. Foundation and structural elements were displaced and damaged: the wood posts were out of plumb, displaced over 0.3 m downslope; and the concrete footings were cracked and settled (Photograph 1). The roof and floor were off-level, and walls, doors and windows were out of plumb (Photograph 2), probably owing to foundation displacement. Roof gutter downspout outlets from the accessory dwelling were directed onto the failing fill beneath the structure.

Photograph 1: Downslope Side of Accessory Dwelling Foundation, 2052 Mackay Ave.



Photograph 2: Accessory Dwelling Unit Overhanging the Top of Slope, 2052 Mackay Ave.

No deformation was observed at the main residence during BGC's site visits. BGC inferred that the northeast corner of the main residence was underlain by fill, retained by non-engineered wood lagging, concrete and rock retaining walls. This corner lies 2 m behind the slope crest. Renovations were underway at the main house at the time of BGC's site visits.

The property owner stated to BGC personnel that the accessory dwelling was used as a rental property, and was inhabited at the time of BGC's site visits.

The slope deformation in close proximity to the accessory dwelling unit warrants a high hazard likelihood (P_H) rating for this upslope element. The portion of the slope located within 3 m of the main residence does not show signs of significant settlement or deformation, but comprises non-engineered retaining walls, a slope angle steeper than 35° and probable random fills: consequently, P_H is moderate for this upslope element. The proximity to the slope warrants a high spatial probability ($P_{S:H}$) rating for both structures. A very high partial risk rating applies to the property as a whole; however, when considered separately, partial risk is high for the main residence and very high for the accessory dwelling unit.

BGC recommends that a detailed investigation be undertaken toward designing a slope or foundation repair intended to reduce risk to the accessory dwelling. Suitable repairs may include a deeper pier foundation deriving support from firm native soils, retaining walls supporting the fill or any combination thereof.

Removing the accessory dwelling may be considered as a risk reduction strategy. By removing this structure, the partial risk rating for the remainder of the property would be the high rating of the main residence. Following removal of the accessory dwelling unit, BGC's recommendations for the remaining main residence would include: tying runoff from paved surfaces and roof downspouts into CNV's storm drainage system to reduce groundwater levels near the slope; and completing a detailed investigation within 1 to 3 years, directed toward evaluating the stability of the slope so as to better assess risk and design suitable mitigation if necessary.

7.2 High Partial Risk Sites

High partial risk sites include properties where habitable structures are not likely to experience structural failure in the short term, but where conditions may warrant a detailed investigation within a three-year time frame to better characterize site hazards and design site mitigation. In the short term, the hazard likelihood can be reduced at most of the high risk sites by connecting roof and pavement runoff to CNV's storm drain system; however, the degree to which the hazard likelihood is reduced by these actions cannot be reliably estimated until a detailed investigation is completed. Table 6 contains a list of the 16 high partial risk sites identified in this study.

Table 6: High Partial Risk Sites

Site Address	P_H	$P_{S:H}$	Partial Risk
2048 Mackay Ave	MODERATE	HIGH	**HIGH**
2024 Mackay Ave	MODERATE	HIGH	**HIGH**
1928 Mackay Ave	HIGH	MODERATE	**HIGH**
1900 Mackay Ave	HIGH	MODERATE	**HIGH**
837-851 Westview Cres	HIGH	MODERATE	**HIGH**
825-835 Westview Cres	HIGH	MODERATE	**HIGH**
811-823 Westview Cres	HIGH	MODERATE	**HIGH**
1956 Wolfe St	HIGH	MODERATE	**HIGH**
1732 Wolfe St	HIGH	MODERATE	**HIGH**
1716 Wolfe St	HIGH	MODERATE	**HIGH**
660 W 3rd St	MODERATE	HIGH	**HIGH**
621 W 15th St	HIGH	MODERATE	**HIGH**
651 E 1st St	MODERATE	HIGH	**HIGH**
2116 Grand Blvd	MODERATE	HIGH	**HIGH**
2011 Grand Blvd	MODERATE	HIGH	**HIGH**

7.2.1 2048 Mackay Avenue

The single family residence at this property is located 4.3 m from the crest of a 38˚, 21 m high slope. An attached deck extends out from the home, ending 1.5 m from the slope crest. The site is not connected to the CNV storm drain system, and roof gutter downspouts were found to be discharging directly to the slope.

No instability was observed on historic aerial photographs of the slope near the residence. BGC did not find evidence for slope instability during the field reconnaissance. Some seepage was occurring at the slope toe.

This site was rated as having high partial risk because of the proximity of the attached deck (high spatial probability) to the slope (which has moderate hazard likelihood). In order to reduce the risk to a moderate level, BGC recommends that the deck be detached from the house, and derive all its support from piers and posts: this will lower both the spatial probability and partial risk ratings to “moderate”. Connecting the roof drainage to the CNV storm drain system will further reduce the likelihood of slope instability or erosion, and consequent headward retrogression of the slope crest. Alternatively, a detailed investigation that better assesses the landslide hazard can be undertaken.

7.2.2 2024 Mackay Avenue

This property includes a single family residence, located 8 m from the slope crest, and a secondary detached structure overhanging the slope (Photograph 3). At the time of BGC’s site visit, the detached structure appeared to be a habitable structure, and is consequently considered as an element at risk. A storm drain connection was not mapped by CNV, and BGC found downspouts on the detached structure discharging to the slope crest.

The slope is inclined at a 39˚ angle, and is about 20 m high. No instability was observed in historic aerial photographs or by BGC personnel during the ground reconnaissance. Some seepage was observed at the toe of the slope. The slope was assigned as having moderate hazard likelihood due to the presence of seepage and the steep slope angle.

The property was assigned to the high partial risk category because of the proximity of the detached accessory dwelling to the slope (warranting a high spatial probability rating), and because of the assumption that this structure was inhabited. The main residence would receive a moderate spatial probability rating, and consequently be assigned moderate partial risk.

Photograph 3: Main and Accessory buildings at 2024 Mackay Ave.

BGC recommends proceeding with any one of the following options within a 1 to 3 year time frame, listed in order of least to greatest probable cost:

- If the detached structure is not inhabited, the homeowner should demonstrate this to the satisfaction of CNV. This information may already be on file with CNV.
- Remove the detached structure, or retrofit it so that it is not habitable, to the satisfaction of CNV.

- Conduct a detailed investigation to better assess slope stability hazards posed to the accessory dwelling unit. This investigation should include a determination of site stratigraphy (including mapping fill, if present), and conducting a slope stability analysis.

7.2.3 1928 Mackay Avenue

The single family residence at this site is set back 6 m from the crest of a 37˚, 18 m high slope. A deck between the residence and slope crest appears to be detached. The property is not connected to the CNV storm drainage system.

Photograph 4: View of damaged concrete block fence between 1900 and 1928 Mackay Avenue (shown by arrows).

Aerial photographs indicate that fill was placed across the top of the slope prior to 1949, associated with construction of the residence at 1900 Mackay Avenue (see Section 7.2.4, below). During the ground reconnaissance, BGC identified evidence for earth sliding or fill settlement, including: downslope tilting of a concrete retaining wall that extends from 1900 Mackay Avenue; horizontal and vertical separation of a concrete block fence between 1900 and 1928 Mackay Avenue (Photograph 4); and a series of depressions and concrete cracks that appear to line up with the cracked fence. The property owner indicated that the slope

crest had retrogressed up to one m over the past few years, and that active erosion was occurring beneath the thick brush obscuring the slope crest.

Because of the features discussed above, the hazard likelihood was judged to be high. The distance from the home to the slope crest warrants a moderate spatial probability, resulting in high partial risk to the residence.

BGC recommends conducting a detailed investigation to determine: how much fill underlies the area where settlement has been observed; whether the fill extends beneath the residence; and whether the native soils have deformed or are likely to deform in a way that would affect the residence. Subsurface investigations and a stability analysis should help resolve these issues, and better delineate the hazard at the site.

7.2.4 1900 Mackay Avenue

This property contains a single family residence set back 5 m from the slope crest, a swimming pool located about 5 to 6 m from the slope, and a hot tub at the crest. A concrete retaining wall extends across the slope crest, and continues northward to 1928 Mackay Avenue (see Section 7.2.3, above). Aerial photographs suggest the property was developed prior to 1949, and that significant fill was placed near the slope crest. The site is not connected to the CNV storm drainage system, and several drainage outlet pipes are located in the retaining wall.

BGC observed severe distortion in detached wood decks and fences between the residence and the slope crest (Photograph 5). The concrete patio around the pool is cracked in several places. No cracks were observed in the pool; however, this does not preclude the possibility of leakage from the pool or related plumbing. The concrete retaining wall is cracked in several places, and is tilted downslope. The deformation suggests that fill settlement, earth sliding or some combination of the two is occurring beneath the site.

Photograph 5: Distorted wood decks at 1900 Mackay Avenue.

Hazard likelihood is high, based on the recent deformation observed at the site. The distance from the residence to the top of slope warrants moderate spatial probability, resulting in high partial risk to the residence. BGC recommends conducting a detailed investigation within 1 to 3 years to determine the fill thickness and extent, whether fill underlies the residence, whether the observed damage is due to fill settlement or earth sliding, whether leakage from the pool is having an effect on stability, and whether future sliding is likely to impact the residence.

7.2.5 811-823 Westview Crescent (Cypress Gardens)

This row of townhouses was the subject of geotechnical reports addressing foundation distress at Unit 815. A test pitting investigation by EBA (2006) concluded that the settled foundation was underlain by unsuitable fill, which had been placed to fill in a previous stream channel. EBA (2007) installed an inclinometer near the site and conducted a stability analysis based on data from the inclinometer borehole. EBA concluded that the existing buildings were statically stable, but marginally stable under anticipated seismic loading.

Aerial photographs of the site did not reveal past instability on the slopes below these townhouse units, which suggests instability may be related to fill placement, with possible

deformation of underlying natural soils beneath the weight of the fill. CNV mapping shows storm drains beneath roads within the Cypress Gardens complex; however, CNV does not map connections to individual buildings, and BGC found an outlet pipe to the top of the slope from a downspout between Units 831 and 815 located atop a gabion wall. BGC does not, at present, have sufficient information to confirm this building is connected to the storm drain system. KWL (1994) stated that the wall was likely constructed in 1972 (Photograph 6). Engineering design drawings prepared by Swan Wooster in 1971 suggest that planned ravine stabilization works at the time included raising and lining the channel bed and re-grading the side slopes to 2:1 (horizontal:vertical); however, it is unlikely that the slope stabilization works were completed in conformance with the design (KWL, 1994).

Photograph 6: Gabion wall at top of slope, 811-821 Westview Cres.

The closest townhouse to the ravine slope is Unit 821, 5.3 m away. The slope ranges from 28˚ to 37˚ near these units, and is up to 10 m high. Some tension cracks were visible in concrete patios. The slopes below the gabion wall have consistently back-tilted alders, and probably comprise the same earth sliding that was observed immediately south of this site. Because recent landslide activity is present on the slope, hazard likelihood is rated high. Spatial probability is rated moderate; consequently, partial risk is high.

BGC recommends a detailed landslide hazard analysis across the Thain Creek slopes, which would include:

- a survey of the ravine slopes to document current conditions and evaluate changes since the last survey, undertaken in 1994;
- Mapping features related to landsliding and fill placement on the survey base;
- A review of slope indicator information, and consideration to installing an additional inclinometer below Unit 815, to locate landslide rupture surfaces and determine the activity level of landsliding;
- Subsurface investigations to characterize site soils, determine the location and thickness of fill, and evaluate groundwater conditions;
- Sampling and laboratory testing of site soils to obtain strength parameters; and
- Stability analyses under static and seismic conditions using updated information from the investigation steps listed above.

Risk to these townhomes can be better analyzed using the results of an updated landslide hazard analysis.

7.2.6 825-835 Westview Crescent (Cypress Gardens)

These townhomes are located as close as 5.3 m from the ravine slope, which has angles up to 50˚, and is up to 10 m high. Thain Creek is actively eroding the toe of the slope below the northwest part of this building (Units 833-835), which has produced the steepest slopes which, at the time of BGC's field reconnaissance, appeared to be undergoing active shallow landsliding. Fine grained soil is exposed in the creek bank at the toe of the slope: this soil may be glaciomarine clay, or it may be the till identified in a nearby borehole by EBA (2007). CNV mapping shows storm drains beneath roads within the Cypress Gardens complex, but does not show connections to individual buildings. BGC does not, at present, have sufficient information to confirm this building is connected to the storm drain system. BGC did not find any downspouts discharging toward the ravine slopes.

Because of the recent shallow earth sliding on the slope, hazard likelihood was characterized as high. Spatial probability is moderate, resulting in high partial risk to the townhomes. This risk level is applicable mostly to Units 833 and 835: the remaining townhomes in this building are adjacent to gentler slopes, and have been assigned to the same risk category because they are structurally attached to these two units. BGC recommends additional subsurface investigations and a stability analysis along a slope profile below Units 833 and 835, to better evaluate risk to those townhomes.

7.2.7 837-851 Westview Crescent (Cypress Gardens)

The active toe erosion identified below Units 833 and 835 (Section 7.2.6, above) continues upstream along the right bank of Thain Creek, below all the townhomes in this building. The inclinometer installed by EBA (2007), as described above (Section 7.2.6), is located near the

northwest corner of this building (Unit 851). Slope angles below this building are up to 50˚, and the slope is 5 to 10 m high. Unit 843 is the closest townhome to the slope crest, at 4 m.

During the field reconnaissance, BGC observed shallow earth sliding across the slope, below all the townhomes in this building. A concrete patio behind Unit 843 was cracked and downdropped up to 0.3 m. The resident of this unit stated that the offset had increased within the past two years. A new fence, installed in 2007, did not appear to be offset. CNV mapping shows storm drains beneath roads within the Cypress Gardens complex, but does not show connections to individual buildings. BGC does not, at present, have sufficient information to confirm this building is connected to the storm drain system. BGC did not find any downspouts discharging toward the ravine slopes.

EBA's (2007) report suggested fill was present at the slope crest; however, no fill was identified in the inclinometer borehole. Consequently, the ground deformation at the site cannot be conclusively attributed to the presence of fill. Because ground displacement is present, BGC assigned high hazard likelihood to the slope adjacent to this building. Spatial probability is currently rated moderate; however, headward retrogression, particularly near Unit 829, could cause that rating to increase. Partial risk is currently high.

Photograph 7: Shallow earth sliding and stream erosion below Units 837-851, Westview Cres.

BGC recommends continued inclinometer readings to determine the depth of deformation near the site. The stability analysis should be refined as results from inclinometer monitoring are obtained. Consideration should be given to conducting additional subsurface work to locate areas of fill and refine the understanding of the native soil stratigraphy, toward refining the stability analysis.

7.2.8 1956 Wolfe Street

This residence is set back 6 m from a 20 m high, 35˚ natural slope. The slope is vegetated with nettles, which indicates shallow groundwater. BGC did not observe evidence for past slope instability or significant grading and fill placement at the slope crest on aerial photographs. CNV's data indicates that the property is not connected to the storm drain network.

At the time of BGC's site visit, several large, fresh scarps and tension cracks were present along the top of the slope, approaching within 6 m of the residence (Photograph 8 and Photograph 9). These large scarps showed up to 0.5 and 0.2 m of vertical and horizontal separation, respectively, and could be followed for up to 20 m along the slope crest. A smaller step feature, defined by displaced patio stones, passed within 0.5 m of the residence (Photograph 10).

Photograph 8: View of Large Scarps along Crest of Slope, 1956 Wolfe St.

BGC interpreted these features as defining the crown of an active or suspended earth slide. The smaller step feature suggests that the crown may be retrogressing headward toward the residence. During BGC's site visits, there was no indication that the foundation was undermined: no structural distress was observed in the residence. Slide reactivation may begin to undermine the residence, particularly if headward retrogression extends beyond the smaller step.

Hazard likelihood was rated high, due to the presence of fresh landslide features on the slope. Spatial probability was rated moderate due to the 6.3 m distance between the residence and the top of the slope. Spatial probability is the factor most likely to change over the course of the next few years: if the landslide retrogresses toward the house, the top of slope measurement will decrease.

Photograph 9: Close-up of Large Scarp, 1956 Wolfe St.

Photograph 10: Small Scarp across Patio Stones, 1956 Wolfe St.

BGC recommends a detailed investigation to better define the landslide hazard and begin designing remedial measures, if the landslide investigations suggest that this is warranted. The detailed investigation should be carried out within one to three years, and should include: subsurface investigations to characterize site stratigraphy and groundwater conditions; detailed site mapping; slope profile measurements; and slope stability analyses. In the near term, BGC recommends connecting the roof downspouts and driveway drop inlets to the City's storm drain system, in order to reduce groundwater pressures and thereby lower the probability of landslide reactivation and retrogression.

7.2.9 1716 Wolfe Street

At this site, a single family residence is situated 3.2 m from a 37˚, 12 m high slope. No significant grading or past instability was observed in aerial photographs. CNV records do not show a connection to the storm drain system for the property.

Photograph 11: View along Slope at 1716 Wolfe Street.

During site visits, BGC observed suspended to dormant earth sliding, expressed as: tension cracks and shallow (up to 0.1 m deep) depressions extending across the top of the slope; displaced paving stones between the residence and top of slope; deck supports out of plumb (Photograph 11); and pistol-butted maple trees on the slope.

Hazard likelihood was rated high, due to the signs of recent instability discussed above. Spatial probability was rated moderate, due to the 3.2 m distance from the residence to the top of the slope. Consequently, partial risk was rated high. BGC recommends a detailed investigation within 1 to 3 years, directed toward better evaluating the nature of slope instability so as to better assess risk and design suitable mitigation if necessary.

7.2.10 1732 Wolfe Street

A deck attached to a single family residence is located 6 m from an 11 m high, 36˚ slope. The residence itself is another 4 m back from the slope crest. Aerial photographs indicate some grading at the ravine crest when the residence was constructed, some time between 1949 and 1957. CNV records do not show a storm drain connection to the property.

BGC observed suspended to dormant, earth slide related depressions and tension cracks extending across the property, between the deck and the top of the slope. These features coincide with those noted at 1716 Wolfe Street, to the south, and also line up with a section of fencing on the north property line that is pulled apart 3 cm and downdropped about 10 cm. The deck is out of level, which indicates that deformation exists beneath the deck posts. Photograph 12 shows damage to the deck and ground cracking immediately adjacent to it, and Photograph 13 shows relative locations of the house, deck and top of slope. The deformation observed on the ground roughly coincides with fill observed on aerial photographs of the site, and may be caused either by an earth slide related to an overloaded slope crest, or to settlement within the fill itself.

Hazard likelihood was rated high, due to the signs of recent instability discussed above. Spatial probability was rated moderate, due to the 6 m distance from the residence to the top of the slope. Consequently, partial risk was rated high. BGC recommends a detailed investigation within 1 to 3 years, directed toward better evaluating the nature of slope instability so as to better assess risk and design suitable mitigation if necessary. To reduce risk to the moderate category, the owner might consider either removing the deck or replacing it with a free-standing deck, not structurally attached to the residence.

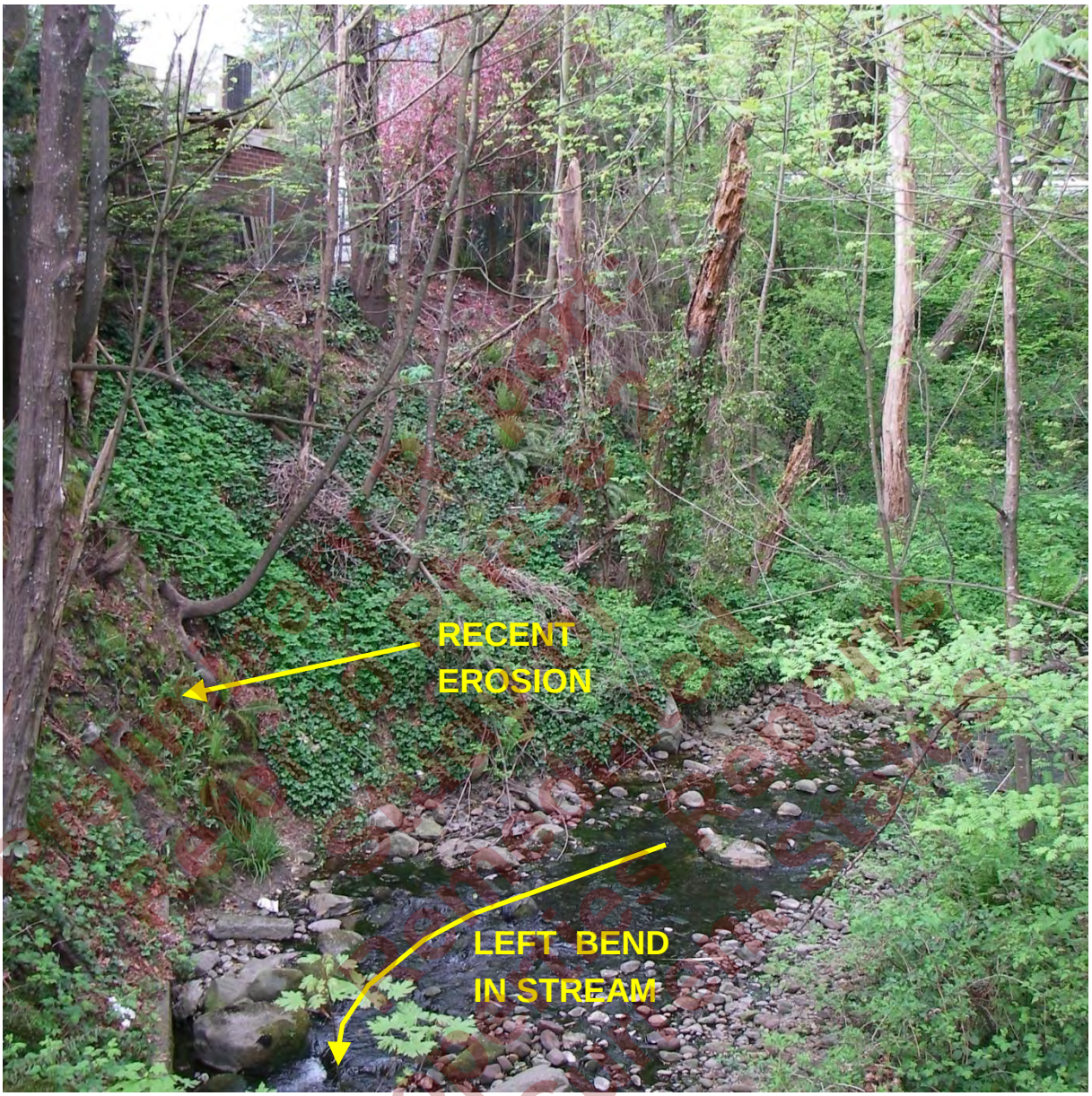
Photograph 12: Deck at 1732 Wolfe Street.

Photograph 13: View across back yard at 1732 Wolfe Street.

7.2.11 660 West 3rd Street

A Chevron gas station and convenience store occupies this property. The convenience store building is located 2 m from a 42˚, 7 m high slope. A left bend in Wagg Creek is present at the immediate toe of this slope, beneath the southeast corner of the store. Stream erosion at the slope toe and shallow surface water erosion on the slope was observed in aerial photographs of the site, and during BGC's ground reconnaissance (Photograph 14). No evidence for deeper-seated slope failures, or of damage to the structure, was observed. CNV has not mapped a storm drain connection to this property.

Hazard likelihood was rated moderate, owing to the steep slope angle and the presence of active erosion. The small distance between the store and the slope crest warrants a high spatial probability rating; consequently, the partial risk is rated high.



Photograph 14: View of Wagg Creek and slope below 660 West 3rd Street.

BGC recommends detailed study to determine whether the building or slope is underlain by fill. A slope stability analysis should also be undertaken, using site-specific material properties and slope profiles. The results of these studies should determine whether proactive mitigation should be recommended.

7.2.12 621 West 15th Street

The home at this site comprises one structure divided into two suites, and is set back 5 m from a 35˚, 14 m high slope. Aerial photographs taken in 1929 depict the residence. The owners indicated that no damage or settlement of the structure has been observed for as long as they have occupied it. Colour aerial photographs taken in January of 1980 show

brown-coloured ground below the slope crest, near the southeast corner of the residence: this colour may represent bare soil associated with slide activity, or simply dead brush and leaves on the non-landscaped slope. CNV has not mapped a storm drain connection to this property.

During the ground reconnaissance, BGC found benched ground and a series of scarps within a wide gully located southeast of the residence (Photograph 15), roughly coincident with the brown soil noted in the 1980 aerial photographs. BGC interpreted these features as representing suspended to dormant, shallow earth slide activity within the colluvium mantling the ravine slopes. Such activity is usually more likely to occur within gullies or hollows, owing to concentrated runoff. The closest distance between the crown of this slide area and the residence is 5 m.

Photograph 15: View across gully at 621 W 15th St.

A paved driveway and parking area extends over the slope crest near the northwest corner of the residence. BGC inferred that the parking area is built on fill placed at the slope crest, which may be up to 3 m thick, and is likely to be non-engineered. No signs of instability were observed associated with this wedge of fill.

Hazard likelihood was rated high, due to indications of past slide activity, and due to the presence of non-engineered fill. Based on the distance from the residence to the slope crest, spatial probability was rated moderate, resulting in a partial risk rating of high for this site.

BGC recommends a more detailed investigation at the site within 1 to 3 years. The investigation should focus on mapping and characterizing fill deposits at the crest, and determining whether fill underlies the residence.

7.2.13 651 East 1st Street

The single family residence at this property is situated 6 m from the crest of a 5 m high, 32˚ gully side slope. An attached deck approaches within 2 m of the slope crest. Minor fill and non-engineered unreinforced rock and masonry retaining walls, up to 1 m high, are present at the slope crest. No signs of past landsliding, significant settlement or foundation distress are present. CNV maps do not show a connection to the storm drain system.

Photograph 16: View facing south at 651 East 1st Street

The presence of non-engineered fill and retaining walls warrants a moderate hazard likelihood rating. Spatial probability is high based on the distance between the slope crest and attached deck. The resulting partial risk to the residence associated with the slope hazard is high.

The hazard rating could be reduced by removing the deck or modifying it so that it is not structurally attached to the home. Alternatively, a detailed investigation that better characterizes the landslide hazard on the property may produce a lower hazard rating and, accordingly, a lower partial risk rating.

7.2.14 2116 Grand Boulevard

The single family residence on this property is located 2 m from the crest of a 6 m high, 36˚ landscaped and terraced fill slope. Several unreinforced masonry and rock retaining walls, generally less than 1 m high, support small cuts and thin fills on the slope. The toe corresponds with an abandoned section of Grand Boulevard, which forms an 8 m wide bench about 5 m in elevation above the currently-used roadway. Some cracking and settlement was observed in these walls and in a rock-and-masonry fascia surrounding the home's foundation, but otherwise no signs of instability were observed. CNV maps do not show a connection to the storm drain system, though a main is located within the abandoned road grade below the home.

The presence of non-engineered fill and retaining walls on the slope warrants a moderate hazard likelihood rating. A high spatial probability rating is warranted by the proximity of the home to the slope crest. The resulting partial risk to this residence from potential landsliding on the slope below it is high.

BGC recommends that a detailed investigation be performed on the property, focused on better characterizing the landslide hazard below the home. If it can be demonstrated that the slope below the home is stable, or if engineered fill placement has been documented, a low hazard likelihood rating may be warranted, which would reduce the partial risk rating to moderate.

Photograph 17: View of landscaped fill slope beneath 2116 Grand Boulevard

7.2.15 2011 Grand Boulevard

A single family residence situated on this property is located about 10 m west of, and 6 m downslope from, the crest of the Grand Boulevard road embankment. The embankment is inclined at 25˚, and is presumed to be underlain by non-engineered fill. A small cut (<1 m high) is located at the toe of the slope, adjacent to the residence. Concrete block and river rock retaining walls, presumably non-engineered, provide support to the cut. No signs of past landsliding were observed on the slope, which is well vegetated with second-growth conifers and brush. CNV maps do not show a connection to the storm drain system.

The residence falls into the category of a downslope element at risk with respect to the road embankment slope. Hazard likelihood is rated moderate, due to the non-engineered fill presumed to underlie the slope crest. Spatial probability is rated high, as the angle from the slope crest to the closest part of the residence's foundation is 25˚.

BGC recommends a detailed geotechnical investigation be undertaken to determine the nature and extent of fill, if present, underlying the embankment slope, and to improve analyses of landslide hazard and risk to the residence.

7.3 Moderate Risk Sites

Moderate risk sites include those where a property is not likely to be affected by ravine slope stability hazards under current conditions, but where conditions may change to increase risk under reasonable circumstances. Moderate risk sites include those where:

- slope stability hazards are present, but the distance from hazards to elements at risk is relatively large, so it is unlikely that slope movement will affect habitable structures; or
- Elements at risk are relatively close to ravine slopes with relatively low slope hazards, so it is unlikely that slope movements will occur.

Twenty-six (26) moderate partial risk sites were identified. These are listed in Table 7. More detailed information for these sites is listed in Appendixes A and B. BGC recommends that moderate risk sites be inspected every 5 years. More frequent inspections may be warranted if a very large rainfall event is experienced, an earthquake occurs, or evidence of changed conditions is identified by residents or the qualified professional conducting the inspection.

Table 7: Moderate Partial Risk Sites

Site Address	P_H	$P_{S:H}$	Partial Risk
2030 Mackay Ave	MODERATE	MODERATE	**MODERATE**
2010 Mackay Ave	MODERATE	MODERATE	**MODERATE**
2000 Mackay Ave	MODERATE	MODERATE	**MODERATE**
1990 Mackay Ave	MODERATE	MODERATE	**MODERATE**
709 Westmoreland Cres	MODERATE	MODERATE	**MODERATE**
Westview Shopping Centre	HIGH	LOW	**MODERATE**
857-883 Westview Cres	LOW	HIGH	**MODERATE**
799-809 Westview Cres	HIGH	LOW	**MODERATE**
620 W 15th St	LOW	HIGH	**MODERATE**
1978 Wolfe St	HIGH	LOW	**MODERATE**
1704 Wolfe St	MODERATE	MODERATE	**MODERATE**
517 W 23rd St	MODERATE	MODERATE	**MODERATE**
Changing rooms, Mahon Park	MODERATE	MODERATE	**MODERATE**
9-12 - 601 W Keith St	MODERATE	MODERATE	**MODERATE**
2145 Chesterfield Ave	MODERATE	MODERATE	**MODERATE**
2059 Chesterfield Ave	MODERATE	MODERATE	**MODERATE**
1345 Delbruck Ave	MODERATE	MODERATE	**MODERATE**
1340 Delbruck Ave	MODERATE	MODERATE	**MODERATE**
643 E 1st St	MODERATE	MODERATE	**MODERATE**
647 E 1st St	MODERATE	MODERATE	**MODERATE**
665 E 2nd St	LOW	HIGH	**MODERATE**
863 E 4th St	MODERATE	MODERATE	**MODERATE**
2112 Grand Blvd	MODERATE	MODERATE	**MODERATE**
2140 Grand Blvd	MODERATE	MODERATE	**MODERATE**
2148 Grand Blvd	LOW	HIGH	**MODERATE**
2125 Grand Blvd	HIGH	LOW	**MODERATE**

7.4 Low and Very Low Partial Risk Sites

These sites include properties adjacent to ravines where slope hazards are relatively low and distances between ravine slopes and elements at risk are high. These sites are unlikely to experience damage from ravine slope stability hazards in the short- to medium-term. BGC recommends no further action for these sites, which are listed in Appendix B.

8.0 GENERAL RECOMMENDATIONS

Following are general recommendations for existing and new developments within the study area.

1. Storm water, including runoff from roofs, pavements, walkways and yards, should be captured by CNV's storm drainage system. Landscaped areas should be designed to direct runoff away from ravine slope crests. At no time should water be permitted to pond atop ravine slopes.
2. CNV should implement measures to prevent disposal or placement of non-engineered fill, yard waste or refuse onto ravine slopes. BGC understands that CNV's "Development Permit Area for Streamside Protection and Enhancement" regulations, and related information on CNV's website, partially fulfil this recommendation. CNV should ensure that the importance of proper maintenance of slope-side properties is communicated effectively to residents.
3. Existing deposits of non-engineered fill, yard waste or other refuse should be removed from ravine slopes.
4. New retaining walls or fills on ravine slopes or within 10 m of a ravine slope crest should be designed, inspected and approved by a Professional Engineer.
5. Foundations for new habitable structures located on a ravine slope or within 10 m of a ravine slope crest should be designed by a geotechnical engineer to manage slope hazards and risks.

9.0 CLOSURE

It is hoped that the foregoing satisfies the requirements of the assessment you requested. Please do not hesitate to contact the undersigned if you have any questions or require additional information.

Thank you for the opportunity to undertake this assessment.

BGC ENGINEERING INC.
Per:

ORIGINAL SIGNED BY

Michael Porter, M.Eng., P.Eng.
Senior Geological Engineer

ORIGINAL SIGNED BY

Martin Zaleski, PG, CEG (California)
Engineering Geologist

Reviewed by Matthias Jakob, Ph.D., P.Geo.
Senior Geoscientist

REFERENCES

Adams, J., & Halchuk, S. 2003. Fourth Generation Seismic Hazard Maps of Canada: Values for Over 650 Canadian Localities Intended for the 2005 National Building Code of Canada. Geological Survey of Canada.

Armstrong, J. E. 1984. Environmental and Engineering Applications of the Surficial Geology of the Fraser Lowland, British Columbia. Geological Survey of Canada.

B.C. Geologic Survey. 2005. BCGS Geoscience Map. Retrieved March 1, 2008, from http://www.em.gov.bc.ca/Mining/Geolsurv/MapPlace/maps.htm

BGC Engineering Inc. (BGC). 2006a. Berkley Landslide Risk Management, Phase 1 Risk Assessment, District of North Vancouver.

BGC Engineering Inc. (BGC). 2006b. Berkley Landslide Risk Management, Phase 2 Assessment of Risk Control Options, District of North Vancouver.

Bray, J. D., and Travasarou, T. 2007. Simplified Procedure for Estimating Earthquake-Induced Deviatoric Slope Displacements. Journal of Geotechnical and Environmental Engineering, 133 (4), 381-392.

Canadian Building Standards Commission. 2005. National Building Code of Canada.

Canadian Standards Association (CSA). 1997. Risk Management: Guideline for Decision Makers.

Clague, J. J. 1989. Quaternary Sea Levels. In R. J. Fulton (Ed.), Quaternary Geology of Canada and Greenland (Vol. 1). Geological Survey of Canada.

Cruden, D. M., & Varnes, D. J. 1996. Landslide Types and Processes. In A. K. Turner, & R. L. Schuster (Eds.), Landslides: Investigation and Mitigation. Transportation Research Board, National Research Council.

EBA Engineering Consultants Ltd. 2006. Investigation of Foundation Distress, Unit 815 - Cypress Garden, North Vancouver.

EBA Engineering Consultants Ltd. 2007. Slope Stability Monitoring and Analysis, Cypress Garden, North Vancouver, B.C.

Fell, R., Ho, K.K.S., Lacasse, S., and Leroi, E. 2005. A Framework for Landslide Risk Assessment and Management. In O. Hungr, R. Fell, R. Couture, and E. Eberhardt (Eds.),

Landslide Risk Management. Proceedings of the International Conference on Landslide Risk Management, Vancouver, Canada, 31 May-3 June 2005.

Meidinger, D. V., & Pojar, J. 1991. Ecosystems of British Columbia. B.C. Ministry of Forests.

Peel, M. C., Finlayson, B. L., & McMahon, T. A. 1997. Updated World Map of the Koppen-Geiger Climate Classification. Hydrology and Earth System Sciences, 11, 1633-1644.

Task Force on Seismic Slope Stability. 2008. Methods of Seismic Slope Analysis. Association of Professional Engineers and Geoscientists of British Columbia.

Westrek Geotechnical Services Ltd. 2007. Mosquito Creek East Ravine Landslide Risk Analysis, Phase II - Detailed Study.

Westrek Geotechnical Services Ltd. 2006. Mosquito Creek Ravine East Bank Assessment.

Wise, M., Moore, G., & VanDine, D. 2004. Landslide Risk Case Studies in Forest Development Planning and Operations. Victoria: B.C. Ministry of Forests.

DRAWINGS

LEGEND

- LARGE LANDSLIDE BOUNDARY- INTERPRETED FROM AERIAL PHOTOGRAPHS
- LARGE LANDSLIDE BOUNDARY- OBSERVED DURING GROUND INSPECTION
- LARGE LANDSLIDE SCARP- INTERPRETED FROM AERIAL PHOTOGRAPHS
- LARGE LANDSLIDE SCARP- OBSERVED DURING GROUND INSPECTION
- SMALL LANDSLIDE SCARP AND TRACK- INTERPRETED FROM AERIAL PHOTOGRAPHS
- SMALL LANDSLIDE SCARP AND TRACK- OBSERVED DURING GROUND INSPECTION
- SURFACE WATER EROSION SCAR- INTERPRETED FROM AERIAL PHOTOGRAPHS
- SURFACE WATER EROSION SCAR- OBSERVED DURING GROUND INSPECTION
- CITY BOUNDARY
- STRUCTURE
- STRUCTURES FLAGGED FOR FIELD INSPECTIONS BY SCREENING STUDY
- VERY HIGH PARTIAL RISK STRUCTURE
- HIGH PARTIAL RISK STRUCTURE
- MODERATE PARTIAL RISK STRUCTURE
- FILL- INTERPRETED FROM AERIAL PHOTOGRAPHS
- FILL- OBSERVED DURING GROUND INSPECTION
- PROPERTY BOUNDARIES
- SPRING
- STREETS
- CREEKS
- MAJOR CONTOUR

SCALE:	NO SCALE	DESIGNED:	MZ
DATE:	APR 2009	CHECKED:	MP
DRAWN:	JCS, MIB	APPROVED:	MP

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT: City of North Vancouver

PROJECT: Geotechnical Stability Study, Preliminary Partial Risk Analysis

TITLE: Partial Risk Map Legend

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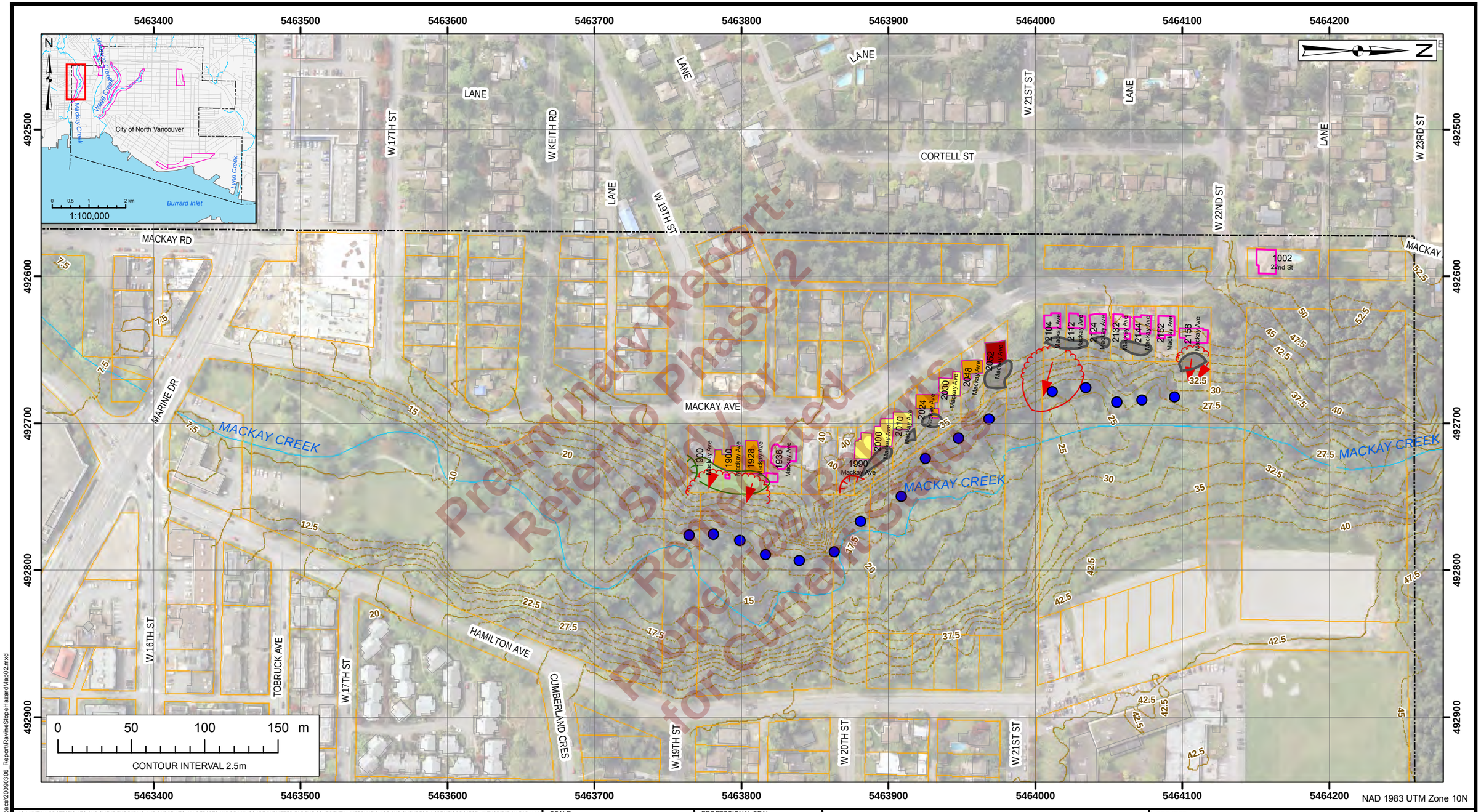

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DATE:	APR 2009
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DESIGNED:	MZ
CHECKED:	MP
APPROVED:	MP

PROFESSIONAL SEAL:

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT: City of North Vancouver

PROJECT: Geotechnical Stability Study, Preliminary Partial Risk Analysis

TITLE: Partial Risk Map
MacKay Creek

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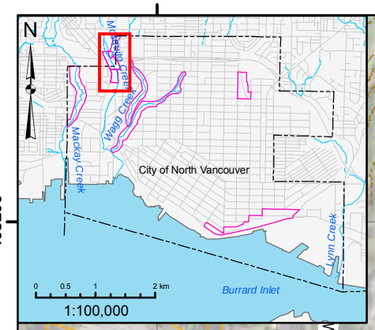

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APPROVED:	MP

PROFESSIONAL SEAL:

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT: City of North Vancouver

PROJECT: Geotechnical Stability Study, Preliminary Partial Risk Analysis

TITLE: Partial Risk Map
Mosquito Creek

PROJECT No.:	DWG No.:	REV.:
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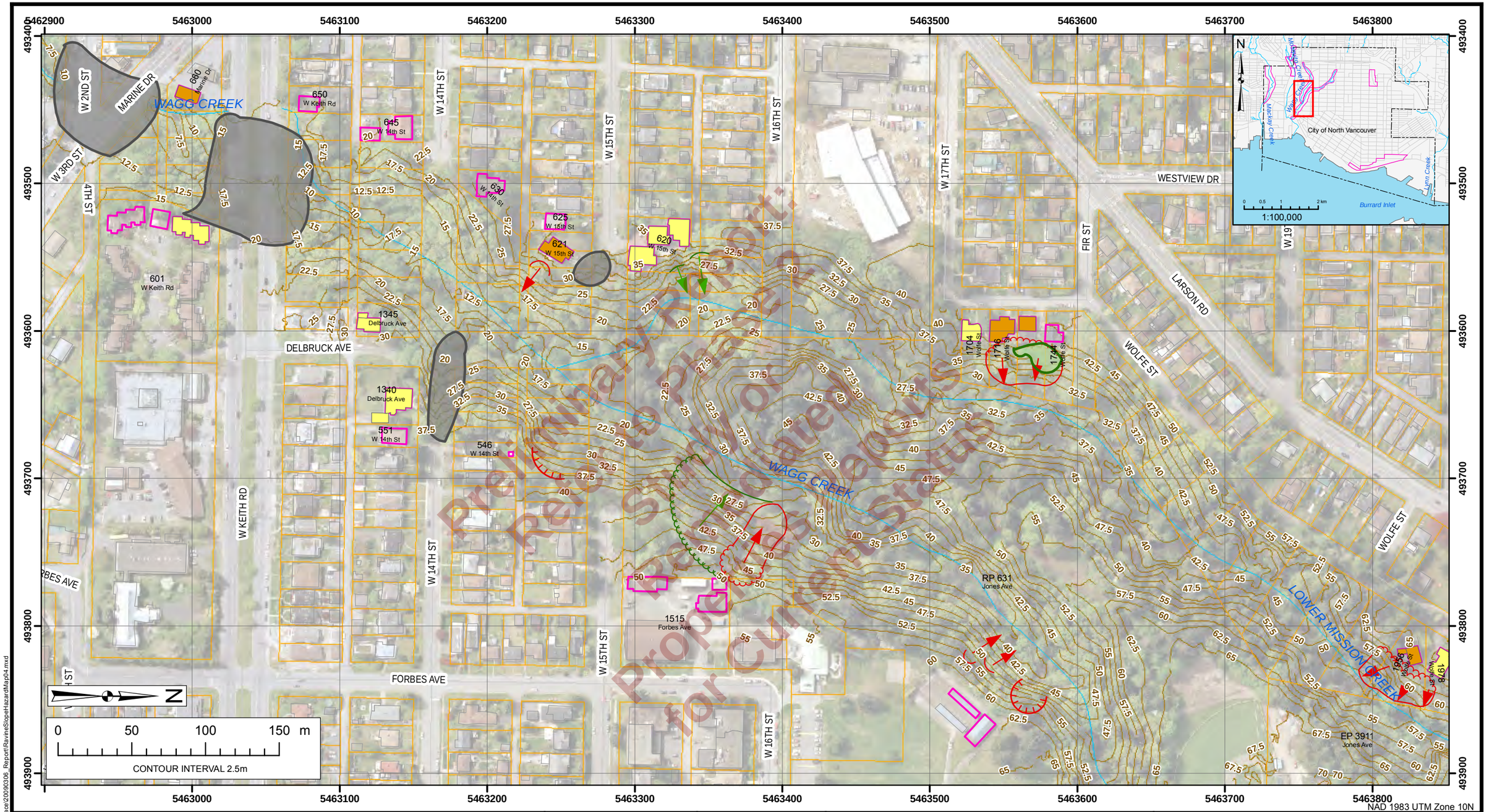

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APPROVED:	MP

PROFESSIONAL SEAL:

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT: City of North Vancouver

PROJECT: Geotechnical Stability Study, Preliminary Partial Risk Analysis

TITLE: Partial Risk Map
Wagg Creek South

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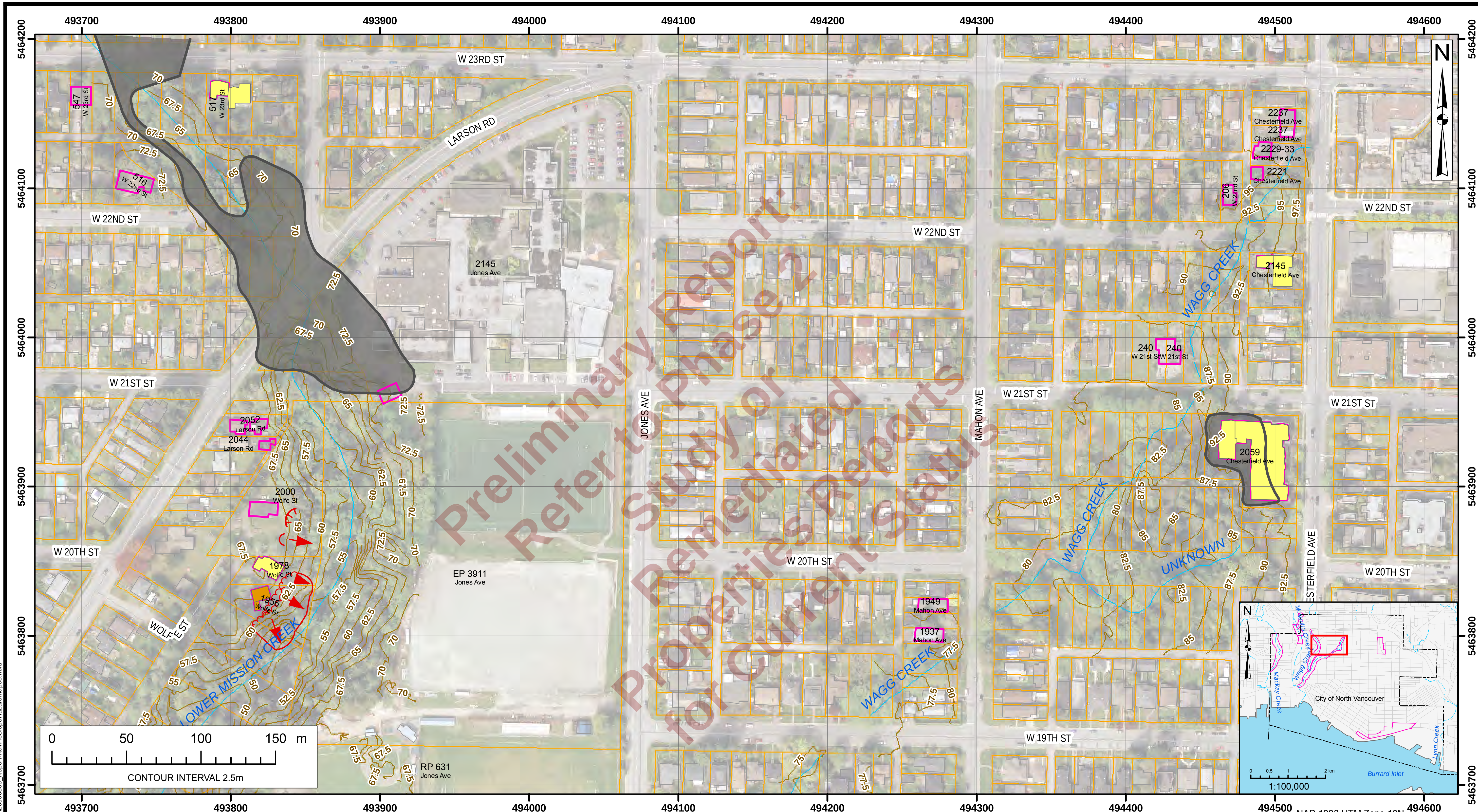

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DESIGNED:	MZ
CHECKED:	MP
APPROVED:	MP

PROFESSIONAL SEAL:

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT:
City of North Vancouver

PROJECT:
Geotechnical Stability Study, Preliminary Partial Risk Analysis

TITLE:
Partial Risk Map
Wagg Creek North

PROJECT No.:	DWG No.:	REV.:
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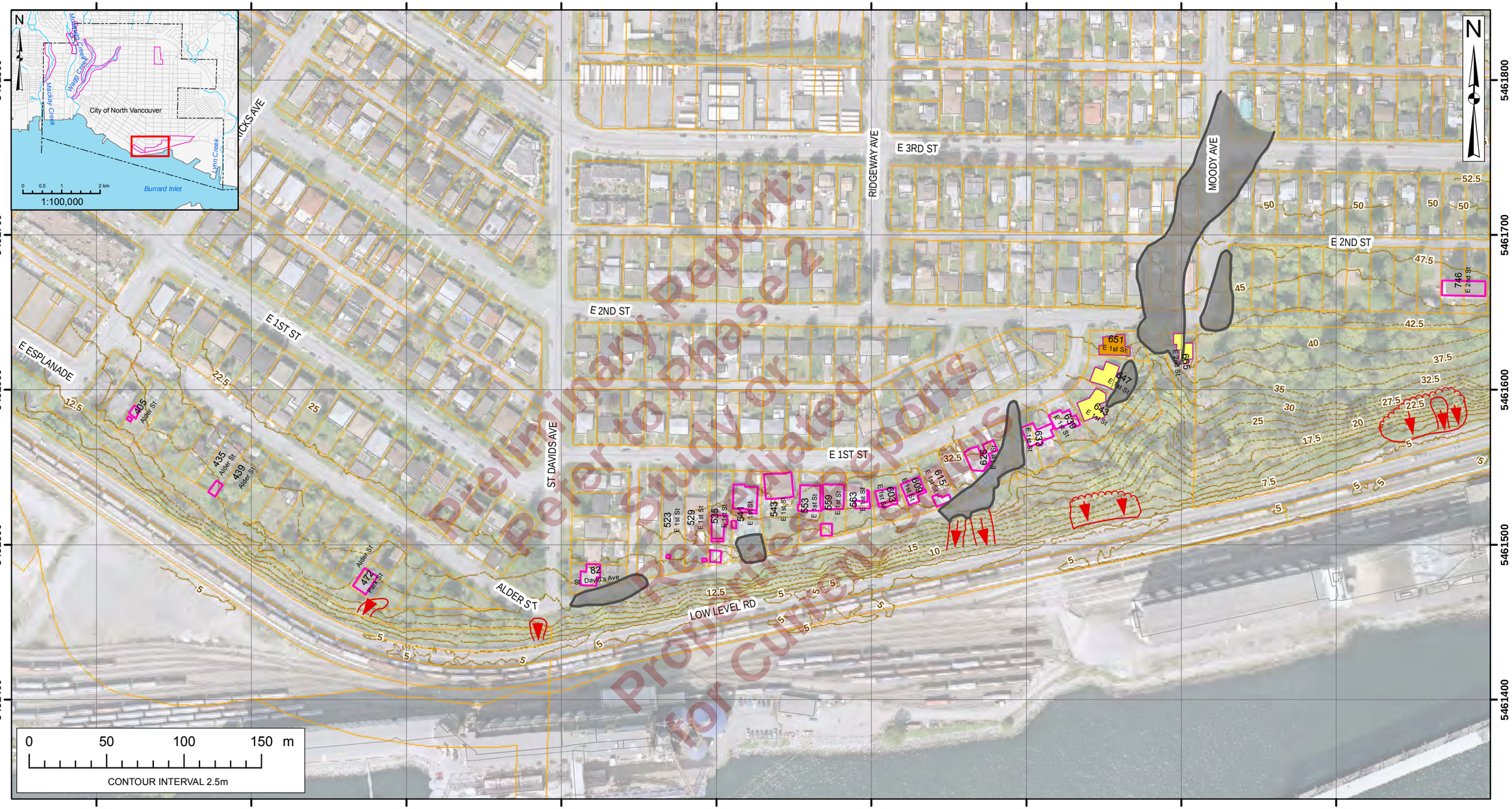

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CHECKED:	MP
APPROVED:	MP

PROFESSIONAL SEAL:

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT: City of North Vancouver

PROJECT: Geotechnical Stability Study, Preliminary Partial Risk Analysis

TITLE: Partial Risk Map
Low Level Road South

PROJECT No.:	DWG No.:	REV.:
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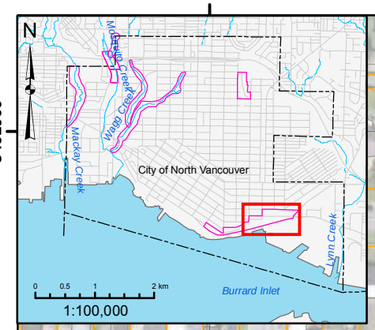

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APPROVED:	MP

PROFESSIONAL SEAL:

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT: City of North Vancouver

PROJECT: Geotechnical Stability Study, Preliminary Partial Risk Analysis

TITLE: Partial Risk Map
Low Level Road North

PROJECT No.:	DWG No.:	REV.:
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DESIGNED: MZ
CHECKED: MP
APPROVED: MP

PROFESSIONAL SEAL:

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT: City of North Vancouver

PROJECT: Geotechnical Stability Study, Preliminary Partial Risk Analysis

TITLE: Partial Risk Map
Grand Blvd

PROJECT No.: 0600-001
DWG No.: 8
REV.:

APPENDIX A

PROPERTIES IN AREAS OF INTEREST CAPTURED BY SCREENING STUDY AND NOT INCLUDED IN PARTIAL RISK ANALYSIS

Area	Address	Slope Angle, degrees	Distance to Crest, metres (Upslope Elements)	Angle to Initiation Zone, degrees (Downslope Elements)	Rationale for Exclusion from Partial Risk Evaluation
Mackay Creek	1002 W 22nd St	32	38	n/a	$P_{S:H;\ CREST}$: distance > 10 m; slope captured by screening study is a road cut
	1936 Mackay Ave	33	13	n/a	$P_{S:H;\ CREST}$: distance > 10 m; non-habitable shed < 10 m.
	2104 Mackay Ave	32	13	n/a	$P_{S:H;\ CREST}$: distance > 10 m
	2112 Mackay Ave	33	16	n/a	$P_{S:H;\ CREST}$: distance > 10 m
	2158 Mackay Ave	34	12	n/a	$P_{S:H;\ CREST}$: distance > 10 m
Mosquito Creek	2101 Fell St	20	30	n/a	P_H: slope angle < 25˚, predominantly native. $P_{S:H;\ CREST}$: distance > 10 m.
	2109 Fell St	20	15	n/a	P_H: slope angle < 25˚, predominantly native. $P_{S:H;\ CREST}$: distance > 10 m.
	2233 Alden Ln	35	12	n/a	$P_{S:H;\ CREST}$: distance > 10 m
	2245 Alden Ln	34	15	n/a	$P_{S:H;\ CREST}$: distance > 10 m
	2293 Alden Ln	38	31	n/a	$P_{S:H;\ CREST}$: No element at risk; structure identified by screening study was a non-habitable garage.
	632 W 23rd St	38	2	n/a	Excluded at CNV's request - addressed by Westrek (2006)
	706 Westmoreland Cres	35	14	n/a	$P_{S:H;\ CREST}$: distance > 10 m
	717 Westmoreland Cres	30	n/a	n/a	$P_{S:H;\ CREST}$: No element at risk: structure recently removed
	721 Westmoreland Cres	23	50	n/a	$P_{S:H;\ CREST}$: distance > 10 m
Thain Creek	876-980 Westview Cres	33	3	n/a	P_H: slope height <3 m
Lower Mission Creek	2044 Larson Crec.	45	21	n/a	$P_{S:H;\ CREST}$: No element at risk; structure identified by screening study was a non-habitable garage.
	2052 Larson Crec.	38	16	n/a	$P_{S:H;\ CREST}$: No element at risk; structure identified by screening study was a non-habitable shed.
	516 W 22nd St	41	3	n/a	P_H: slope height <3 m
	547 W 23rd St	15	3	n/a	P_H: slope angle < 25˚; soils predominantly native; no indications of past failure.
	Carson Graham School	35	28	n/a	$P_{S:H;\ CREST}$: no element at risk; building outline captured by screening study not present.

Area	Address	Slope Angle, degrees	Distance to Crest, metres (Upslope Elements)	Angle to Initiation Zone, degrees (Downslope Elements)	Rationale for Exclusion from Partial Risk Evaluation
Wagg Creek	1515 Forbes Ave	33	12	n/a	$P_{S:H;\ CREST}$: distance > 10 m; building outline captured by screening study not present.
	1744 Wolfe St	37	12	n/a	$P_{S:H;\ CREST}$: distance > 10 m
	1937 Mahon Ave	10	6	n/a	P_H: slope angle < 25˚ and < 3 m high.
	1949 Mahon Ave	10	26	n/a	P_H: slope angle < 25˚ and < 3 m high. $P_{S:H;\ CREST}$: distance > 10 m.
	2221 Chesterfield Ave	15	n/a	n/a	$P_{S:H;\ CREST}$: no structure on property.
	2229-33 Chesterfield Ave	15	4	n/a	P_H: slope angle < 25˚; slope recently re-graded. Current structures differ from those shown in building outline layer.
	2237 Chesterfield Ave	15	18	n/a	$P_{S:H;\ CREST}$: distance > 10 m
	240 W 21st St	15	6	n/a	P_H: slope angle < 25˚; engineered retaining wall protecting bank.
	546 W 14th St	70	17	n/a	$P_{S:H;\ CREST}$: distance > 10 m
	551 West 14th St	18	15	n/a	$P_{S:H;\ CREST}$: distance > 10 m
	625 W 15th St	42	20	n/a	$P_{S:H;\ CREST}$: distance > 10 m
	645 W 14th St	20	15	n/a	P_H: slope angle < 25˚, predominantly native. $P_{S:H;\ CREST}$: distance > 10 m.
	650 Keith Rd	10	25	n/a	P_H: slope angle < 25˚, predominantly native. $P_{S:H;\ CREST}$: distance > 10 m.
	Laundry - 601 W Keith St	21	3	n/a	P_H: slope angle < 25˚; soils predominantly native; no indications of past failure.
Low Level Road	405 Alder St	25	30	n/a	$P_{S:H;\ CREST}$: distance > 10 m; structure identified by screening study was a non-habitable shed.
	435 Alder St	26	20	n/a	$P_{S:H;\ CREST}$: distance > 10 m; structure identified by screening study was a non-habitable shed.
	472 Park St	40	18	n/a	$P_{S:H;\ CREST}$: distance > 10 m
	82 St. David's Ave	60	20	n/a	$P_{S:H;\ CREST}$: distance > 10 m
	535 E 1st St	45	25	n/a	$P_{S:H;\ CREST}$: distance > 10 m; structure identified by screening study was a non-habitable garage.
	541 E 1st St	45	40	n/a	$P_{S:H;\ CREST}$: distance > 10 m
	543 E 1st St	45	40	n/a	$P_{S:H;\ CREST}$: distance > 10 m
	553 E 1st St	40	30	n/a	$P_{S:H;\ CREST}$: distance > 10 m
	559 E 1st St	45	27	n/a	$P_{S:H;\ CREST}$: distance > 10 m; structure identified by screening study was a non-habitable garage.
	563 E 1st St	45	22	n/a	$P_{S:H;\ CREST}$: distance > 10 m

Area	Address	Slope Angle, degrees	Distance to Crest, metres (Upslope Elements)	Angle to Initiation Zone, degrees (Downslope Elements)	Rationale for Exclusion from Partial Risk Evaluation
Low Level Road	603 E 1st St	40	18	n/a	$P_{S:H;\ CREST}$: distance > 10 m
	609 E 1st St	35	16	n/a	$P_{S:H;\ CREST}$: distance > 10 m
	615 E 1st St	35	20	n/a	$P_{S:H;\ CREST}$: distance > 10 m; structure identified by screening study was a non-habitable garage.
	625 E 1st St	40	15	n/a	$P_{S:H;\ CREST}$: distance > 10 m
	633 E 1st St	30	18	n/a	$P_{S:H;\ CREST}$: distance > 10 m
	639 E 1st St	30	30	n/a	$P_{S:H;\ CREST}$: distance > 10 m
	746 E 2nd St	43	39	n/a	$P_{S:H;\ CREST}$: distance > 10 m
	808 E 3rd St	20	8	n/a	P_H: slope angle < 25˚, screen captured a small cut slope adjacent to E 3rd St
	819 E 3rd St	36	17	n/a	$P_{S:H;\ CREST}$: distance > 10 m
	827 E 4th St	<21	0	n/a	P_H: slope angle < 25˚, home situated on gently sloping ground, minor site grading
	833 E 4th St	<21	0	n/a	P_H: slope angle < 25˚, home situated on gently sloping ground, minor site grading
	839 E 4th St	<21	0	n/a	P_H: slope angle < 25˚, home situated on gently sloping ground, minor site grading
	845 E 4th St	<21	0	n/a	P_H: slope angle < 25˚, home situated on gently sloping ground, minor site grading
	849 E 4th St	<21	0	n/a	P_H: slope angle < 25˚, home situated on gently sloping ground, minor site grading
	903 E 4th St	>25	6	n/a	P_H: height < 3m, steeper slope segments are related to site grading and not to potentially hazardous slopes
	907 E 4th St	>25	6	n/a	P_H: height < 3m, steeper slope segments are related to site grading and not to potentially hazardous slopes
	911 E 4th St	>25	1	n/a	P_H: height < 3m, steeper slope segments are related to site grading and not to potentially hazardous slopes
	915 E 4th St	24	n/a	21	P_H: slope angle < 25˚, home situated on gently sloping ground, minor site grading
	923 E 4th St	>25	7	n/a	P_H: height < 3m, steeper slope segments are related to site grading and not to potentially hazardous slopes
	927 E 4th St	>25	5	n/a	P_H: height < 3m, steeper slope segments are related to site grading and not to potentially hazardous slopes
	933 E 4th St	>25	7	n/a	P_H: height < 3m, steeper slope segments are related to site grading and not to potentially hazardous slopes
	937 E 4th St	<21	0	n/a	P_H: slope angle < 25˚, home situated on gently sloping ground, minor site grading

Area	Address	Slope Angle, degrees	Distance to Crest, metres (Upslope Elements)	Angle to Initiation Zone, degrees (Downslope Elements)	Rationale for Exclusion from Partial Risk Evaluation
Low Level Road	941 E 4th St	<21	0	n/a	P_H: slope angle < 25˚, home situated on gently sloping ground, minor site grading
	945 E 4th St	<21	0	n/a	P_H: slope angle < 25˚, home situated on gently sloping ground, minor site grading
	949 E 4th St	<21	0	n/a	P_H: slope angle < 25˚, home situated on gently sloping ground, minor site grading
	955 E 4th St	<21	0	n/a	P_H: slope angle < 25˚, home situated on gently sloping ground, minor site grading
Grand Blvd	2006 Grand Blvd	24	25	n/a	P_H: slope angle < 25˚, predominantly native. $P_{S:H;\ CREST}$: distance > 10 m.
	2010 Grand Blvd	30	30	n/a	$P_{S:H;\ CREST}$: distance > 10 m
	2042 Grand Blvd	30	14	n/a	$P_{S:H;\ CREST}$: distance > 10 m
	2052 Grand Blvd	35	12	n/a	$P_{S:H;\ CREST}$: distance > 10 m
	2104 Grand Blvd	33	1	n/a	P_H: slope height <3 m
	445 E 21st St	30	3	n/a	P_H: slope height <3 m, screen captured a minor fill slope adjacent to residence
	2004 Ridgeway Ave	<21	0	n/a	P_H: slope angle < 25˚, home situated on gently sloping ground, minor site grading
	2020 Ridgeway Ave	<21	0	n/a	P_H: slope angle < 25˚, home situated on gently sloping ground, minor site grading
	2028 Ridgeway Ave	<21	0	n/a	P_H: slope angle < 25˚, home situated on gently sloping ground, minor site grading
	2040 Ridgeway Ave	<21	0	n/a	P_H: slope angle < 25˚, home situated on gently sloping ground, minor site grading
	2048 Ridgeway Ave	<21	0	n/a	P_H: slope angle < 25˚, home situated on gently sloping ground, minor site grading
	2056 Ridgeway Ave	<21	0	n/a	P_H: slope angle < 25˚, home situated on gently sloping ground, minor site grading
	2106 Ridgeway Ave	<21	0	n/a	P_H: slope angle < 25˚, home situated on gently sloping ground, minor site grading
	2130 Ridgeway Ave	<21	0	n/a	P_H: slope angle < 25˚, home situated on gently sloping ground, minor site grading
	2200 Ridgeway Ave	22	6	n/a	P_H: slope angle < 25˚, no adverse ground conditions.
	1937 Grand Blvd	<21	0	n/a	P_H: slope angle < 25˚, predominantly native.
	1945 Grand Blvd	34	n/a	18	$P_{S:H;\ BASE}$: angle < 19˚
	2109 Grand Blvd	46	n/a	18	$P_{S:H;\ BASE}$: angle < 19˚
	2141 Grand Blvd	45	n/a	17	$P_{S:H;\ BASE}$: angle < 19˚

Area	Address	Slope Angle, degrees	Distance to Crest, metres (Upslope Elements)	Angle to Initiation Zone, degrees (Downslope Elements)	Rationale for Exclusion from Partial Risk Evaluation
Grand Blvd	2157 Grand Blvd	41	n/a	17	$P_{S:H;\ BASE}$: angle < 19˚
	422 E 19th St	<21	0	n/a	P_H: slope angle < 25˚, home situated on gently sloping ground, minor site grading
	426 E 19th St	<21	0	n/a	P_H: slope angle < 25˚, home situated on gently sloping ground, minor site grading
	428 E 19th St	<21	0	n/a	P_H: slope angle < 25˚, home situated on gently sloping ground, minor site grading
	434 E 19th St	<21	0	n/a	P_H: slope angle < 25˚, home situated on gently sloping ground, minor site grading
	450 E 21st St	<21	0	n/a	P_H: slope angle < 25˚, home situated on gently sloping ground, minor site grading
	417 E 20th St	<21	0	n/a	P_H: slope angle < 25˚, home situated on gently sloping ground, minor site grading
	418 E 20th St	<21	0	n/a	P_H: slope angle < 25˚, home situated on gently sloping ground, minor site grading

APPENDIX B

PARTIAL RISK ANALYSIS SUMMARY TABLE

Area	Address	Hazard Likelihood (P_H)									Spatial Probability for Upslope Elements ($P_{S:H;\ CREST}$)		Spatial Probability for Downslope Elements ($P_{S:H;\ BASE}$)		Partial Risk
				Low	Moderate			High							
		Slope Angle (°)	Slope Height (m)	Engineered Fills or Retaining Walls	Non-Engineered Fill or Yard Waste	Non-Engineered Retaining Walls	Seepage or Surface Erosion	Historic Landsliding (within 10 m laterally)	Visible Settlement or Damage to Structures	**Resulting $P_{(H)}$**	Distance to Home or Attached Structures (m)	**Resulting $P_{S:H;\ CREST}$**	Angle Between Home and Initiation Zone	**Resulting $P_{S:H;\ BASE}$**	P_{HA}
Mackay Creek	2152 Mackay Ave	34	16.8	NO	NO	NO	YES	NO	NO	MODERATE	8.2	LOW	N/A	N/A	**LOW**
	2144 Mackay Ave	38	17.2	NO	YES	NO	YES	NO	NO	MODERATE	10.0	LOW	N/A	N/A	**LOW**
	2132 Mackay Ave	36	16.5	NO	YES	NO	YES	NO	NO	MODERATE	9.2	LOW	N/A	N/A	**LOW**
	2124 Mackay Ave	31	18	NO	YES	YES	YES	NO	NO	MODERATE	7.5	LOW	N/A	N/A	**LOW**
	2052 Mackay Ave	37	24.1	NO	YES	YES	YES	YES	YES	HIGH	0.0	HIGH	N/A	N/A	**VERY HIGH**
	2048 Mackay Ave	38	20.9	NO	YES	YES	YES	NO	NO	MODERATE	1.5	HIGH	N/A	N/A	**HIGH**
	2030 Mackay Ave	37	19.3	NO	YES	YES	YES	NO	NO	MODERATE	3.1	MODERATE	N/A	N/A	**MODERATE**
	2024 Mackay Ave	39	20.1	NO	YES	YES	YES	NO	NO	MODERATE	0.0	HIGH	N/A	N/A	**HIGH**
	2010 Mackay Ave	42	20.7	NO	YES	YES	YES	NO	NO	MODERATE	5.6	MODERATE	N/A	N/A	**MODERATE**
	2000 Mackay Ave	42	18.7	NO	YES	NO	YES	NO	NO	MODERATE	4.0	MODERATE	N/A	N/A	**MODERATE**
	1990 Mackay Ave	43	19.1	NO	YES	YES	YES	NO	NO	MODERATE	5.0	MODERATE	N/A	N/A	**MODERATE**
	1980 Mackay Ave	35	17.2	NO	YES	NO	YES	NO	NO	MODERATE	10.0	LOW	N/A	N/A	**LOW**
	1928 Mackay Ave	37	18.1	NO	YES	YES	NO	YES	YES	HIGH	6.0	MODERATE	N/A	N/A	**HIGH**
	1900 Mackay Ave	38	17.9	NO	YES	YES	YES	YES	YES	HIGH	5.0	MODERATE	N/A	N/A	**HIGH**
Mosquito Creek	709 Westmoreland Cres	34	33.6	NO	YES	NO	NO	NO	NO	MODERATE	5.0	MODERATE	N/A	N/A	**MODERATE**
Thain Creek	Westview Shopping Centre	39	18.9	NO	YES	YES	YES	YES	YES	HIGH	8.0	LOW	N/A	N/A	**MODERATE**
	857-883 Westview Cres	42	13.4	YES	YES	NO	YES	NO	NO	LOW	2.0	HIGH	N/A	N/A	**MODERATE**
	837-851 Westview Cres	45	10.6	NO	YES	NO	YES	YES	YES	HIGH	4.0	MODERATE	N/A	N/A	**HIGH**
	825-835 Westview Cres	41	16.4	NO	YES	NO	YES	YES	YES	HIGH	5.3	MODERATE	N/A	N/A	**HIGH**
	811-823 Westview Cres	28	9.4	YES	NO	NO	YES	YES	YES	HIGH	5.3	MODERATE	N/A	N/A	**HIGH**
	799-809 Westview Cres	40	12.9	NO	YES	NO	YES	YES	NO	HIGH	8.8	LOW	N/A	N/A	**MODERATE**
Lower Mission Creek	620 W 15th St	39	9.4	YES	NO	NO	NO	NO	NO	LOW	3.0	HIGH	N/A	N/A	**MODERATE**
	2000 Wolfe St	40	16.1	NO	YES	NO	YES	NO	NO	MODERATE	10.0	LOW	N/A	N/A	**LOW**
	1978 Wolfe St	36	10	NO	NO	NO	YES	YES	NO	HIGH	6.5	LOW	N/A	N/A	**MODERATE**
	1956 Wolfe St	35	14.3	NO	YES	NO	NO	NO	YES	HIGH	6.0	MODERATE	N/A	N/A	**HIGH**
	1732 Wolfe St	36	11.2	NO	YES	NO	NO	YES	YES	HIGH	6.0	MODERATE	N/A	N/A	**HIGH**
	1716 Wolfe St	37	12.6	NO	YES	NO	NO	YES	YES	HIGH	3.2	MODERATE	N/A	N/A	**HIGH**
	1704 Wolfe St	40	12.9	NO	YES	YES	NO	NO	NO	MODERATE	3.1	MODERATE	N/A	N/A	**MODERATE**
	517 W 23rd St	38	3.7	NO	YES	YES	NO	NO	NO	MODERATE	5.0	MODERATE	N/A	N/A	**MODERATE**

Area	Address	Hazard Likelihood (P_H)									Spatial Probability for Upslope Elements ($P_{S:H;\ CREST}$)		Spatial Probability for Downslope Elements ($P_{S:H;\ BASE}$)		Partial Risk
		Slope Angle (°)	Slope Height (m)	Low: Engineered Fills or Retaining Walls	Moderate: Non-Engineered Fill or Yard Waste	Moderate: Non-Engineered Retaining Walls	Moderate: Seepage or Surface Erosion	High: Historic Landsliding (within 10 m laterally)	High: Visible Settlement or Damage to Structures	Resulting $P(_H)$	Distance to Home or Attached Structures (m)	Resulting $P_{S:H;\ CREST}$	Angle Between Home and Initiation Zone	Resulting $P_{S:H;\ BASE}$	P_{HA}
Wagg Creek	Changing rooms, Mahon Park	38	8.6	NO	NO	NO	YES	NO	NO	MODERATE	4.0	MODERATE	N/A	N/A	**MODERATE**
	660 W 3rd St	42	6.7	NO	YES	NO	YES	NO	NO	MODERATE	2.0	HIGH	N/A	N/A	**HIGH**
	630 W 14th St	30	5	NO	NO	NO	NO	NO	NO	LOW	6.0	MODERATE	N/A	N/A	**LOW**
	621 W 15th St	42	16.7	NO	YES	YES	NO	YES	NO	HIGH	5.0	MODERATE	N/A	N/A	**HIGH**
	206 W 22nd St	43	2.7	YES	NO	NO	YES	NO	NO	LOW	4.0	MODERATE	N/A	N/A	**LOW**
	Horseshoe Pit, Mahon Park	38	24.6	NO	YES	YES	YES	NO	NO	MODERATE	8.0	LOW	N/A	N/A	**LOW**
	9-12 - 601 W Keith St	34	9.5	NO	YES	NO	NO	NO	NO	MODERATE	5.0	MODERATE	N/A	N/A	**MODERATE**
	2145 Chesterfield Ave	30	5	NO	YES	YES	YES	NO	NO	MODERATE	4.0	MODERATE	N/A	N/A	**MODERATE**
	2059 Chesterfield Ave	38	4.9	NO	YES	NO	NO	NO	NO	MODERATE	6.0	MODERATE	N/A	N/A	**MODERATE**
	1601 Forbes Ave	30	20	NO	YES	NO	YES	NO	NO	MODERATE	10.0	LOW	N/A	N/A	**LOW**
	1345 Delbruck Ave	40	9.6	NO	YES	NO	NO	NO	NO	MODERATE	4.5	MODERATE	N/A	N/A	**MODERATE**
	1340 Delbruck Ave	42	3.3	NO	YES	YES	NO	NO	NO	MODERATE	5.1	MODERATE	N/A	N/A	**MODERATE**
	13-16 - 601 W Keith St	34	8.9	NO	NO	NO	NO	NO	NO	LOW	7.0	LOW	N/A	N/A	**VERY LOW**
Low Level Road	643 E 1st St	30	7.5	NO	YES	YES	NO	NO	NO	MODERATE	4.0	MODERATE	N/A	N/A	**MODERATE**
	647 E 1st St	30	7.5	NO	YES	NO	NO	NO	NO	MODERATE	4.5	MODERATE	N/A	N/A	**MODERATE**
	651 E 1st St	32	5.3	NO	YES	YES	NO	NO	NO	MODERATE	2.0	HIGH	N/A	N/A	**HIGH**
	665 E 2nd St	36	8.2	YES	NO	YES	NO	NO	NO	LOW	1.5	HIGH	N/A	N/A	**MODERATE**
	863 E 4th St	30	4	NO	YES	YES	NO	NO	NO	MODERATE	N/A	N/A	22	MODERATE	**MODERATE**
Grand Blvd	2112 Grand Blvd	34	4.5	NO	YES	NO	NO	NO	NO	MODERATE	4.5	MODERATE	N/A	N/A	**MODERATE**
	2116 Grand Blvd	36	5.9	NO	YES	YES	NO	NO	NO	MODERATE	2.3	HIGH	N/A	N/A	**HIGH**
	2128 Grand Blvd	30	10	YES	NO	NO	NO	NO	NO	LOW	6.0	MODERATE	N/A	N/A	**LOW**
	2140 Grand Blvd	33	7.6	NO	YES	NO	NO	NO	NO	MODERATE	4.2	MODERATE	N/A	N/A	**MODERATE**
	2144 Grand Blvd	40	7.7	YES	NO	NO	NO	NO	NO	LOW	3.3	MODERATE	N/A	N/A	**LOW**
	2148 Grand Blvd	26	10.5	YES	YES	NO	NO	NO	NO	LOW	2.3	HIGH	N/A	N/A	**MODERATE**
	2011 Grand Blvd	25	5.1	NO	YES	NO	NO	NO	NO	MODERATE	N/A	N/A	25	HIGH	**HIGH**
	2041 Grand Blvd	32	13.2	NO	NO	NO	NO	NO	NO	LOW	N/A	N/A	22	MODERATE	**LOW**
	2125 Grand Blvd	46	5.8	NO	NO	NO	YES	YES	NO	HIGH	N/A	N/A	20	LOW	**MODERATE**