# Report

Associated Engineering
GLOBAL PERSPECTIVE.
LOCAL FOCUS.

# City of Coquitlam

## Qualitative Partial Risk Slope Analysis, Chines Escarpment and Corona Crescent Areas

**June 2013**

Associated Engineering | GLOBAL PERSPECTIVE. LOCAL FOCUS.

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June 20, 2013
File: 2013-2355.000

Jozsef Dioszeghy, P.Eng.
Consultant
City of Coquitlam
500 Mariner Way
Coquitlam, B.C.
V3K 7B6

**Re: Final Report: Qualitative Partial Risk Slope Analysis, Chines Escarpment and Corona Crescent Areas**

Dear Mr. Dioszeghy:

Associated Engineering and Summit Environmental Consultants Inc. are pleased to present you with our final report for the above-noted study.

We trust this completes the assignment to your satisfaction. Please call or e-mail if you have any questions.

Yours truly,

*Submitted Digitally*

Joe Alcock, P.Geo.
Geoscientist

Dr. Brian Guy, P.Geo., P.H.
Senior Geoscientist

# Executive Summary

## 1 INTRODUCTION

Metro Vancouver, the City of Coquitlam and the City of Port Moody engaged Associated Engineering to complete an Integrated Stormwater Management Plan (ISMP) for the Chines Escarpment and Corona Crescent areas. A Landslide Risk Management Procedure was initiated as part of this ISMP, consisting of:

Phase 1: Development of a Landslide Risk Analysis Methodology (completed in 2011); and
Phase 2: Implementation of a Landslide Partial Risk Analysis (this report).

The Phase 2 goals were to:

1. Determine qualitative hazard ratings at specific residential properties located at ravine crests in the Chines Escarpment and Corona Crescent areas, based on site inspections and existing topographic, geological, hydrological and other information;
2. Evaluate the spatial probability of a landslide impacting a downslope house, and complete a qualitative partial risk analysis for those specific ravine crest properties (Figure 1-2);
3. Determine where geotechnical engineering assessment is recommended to confirm the risk evaluation and develop comprehensive mitigation recommendations (Phase 3); and
4. Review the current development requirements of the Cities of Coquitlam and Port Moody for slope hazard lands and provide comments and recommendations.

The Phase 2 results are not intended to provide detailed, property-specific, full risk assessments, but rather to identify the properties requiring further geotechnical assessment.

The project area consists of the Chines Escarpment and Corona Crescent areas. Residential properties were developed in the 1940s through 1980s adjacent to the upper ravine crests and at the bottoms of slopes before modern steep land development requirements were in place, and before modern landslide risk analysis procedures were in use.

During the Phase 2 field work, the top ravine edge and slopes were examined for evidence of potential landslide initiation conditions. Previously documented landslide headscarps were reviewed. Potential landslide initiation locations were investigated at fill deposits. Some specific properties downslope of the key landslide initiation zones in the Corona Crescent area were also investigated.

## 2 RESULTS

Qualitative partial risk analysis was completed on 108 properties located along the Chines Escarpment and in the Corona Crescent area using the methodology developed by Wise *et al.* (2004). This is a well-accepted methodology in B.C. for conducting partial risk analyses for landslides. The analysis provides an estimate of the combined probability that a landslide will occur and that it will reach a downslope element at risk (i.e. a house).

Site-specific information was collected to estimate the qualitative probability that a landslide would originate at the property. The spatial probability of a landslide impacting a house or other element was identified through inspection of downslope and downstream features. A further 10 properties at the base of the ravines and steep slopes were also inspected to determine the exposure to potential landslide impacts from upslope.

The analysis identified 7 High and Very High Risk properties. A further 30 properties were indicated as being Moderate Risk. The remaining 71 properties were determined to be Low or Very Low Risk. In the Corona Crescent area, 10 houses on Park Crescent were identified which are open to landslide risk from properties above and are rated as Exposed. Other recommendations to address landslide risk for specific properties are provided in the report and on the property sheets in Appendix B .

Partial risk analysis of retrogressive landslides at the ravine crests for the 108 properties was conducted. The analysis indicated one very high and two high risk properties, due to houses constructed very close to the ravine crest.

Properties along the west side of Schoolhouse Creek ravine were noted to have fill along the crest and upper ravine slope. The City of Coquitlam’s consultants have previously conducted geotechnical investigations, piezometer monitoring and drain installation in this area.

The City of Coquitlam and City of Port Moody by-laws and planning requirements were reviewed in regard to development near steep slopes and construction of retaining walls. Recommendations were provided for specific bylaw and planning issues.

## 3 RECOMMENDATIONS

Risks from landslides cannot be reduced to zero but managed through control of land development, drainage improvements and bylaws restricting actions which increase landslide risk. Recommendations for individual properties are provided on the property sheets in Appendix B, and for the specific sites in the City of Coquitlam and the City of Port Moody in the main report. These recommendations will assist with reduction of the landslide risks. Selected higher priority recommendations are listed below.

1. The 7 identified High and Very High risk properties on Corona Crescent and Thermal Drive and the slopes leading down from them should have Phase 3 geotechnical assessments completed. This work may include a preliminary visual assessment, and sub-surface geotechnical investigations

through test pits, drilling and in-situ soil testing. It would allow individual geotechnical assessments, slope "factor of safety" calculations and seismic stability assessments to be completed for the High and Very High risk rated properties.

Other Moderate risk properties in the Corona Crescent area may be considered for Phase 3 geotechnical assessments based on the potential for landslides to reach downslope houses on Park Crescent. Certain Moderate risk properties in the Schoolhouse Creek ravine area with historic slope and drainage issues should be considered for further geotechnical and drainage assessment.

2. For properties with Moderate or High or Very High risk, there are steps that the property owners and the City of Coquitlam can take to reduce the landslide risk, including:

    i. Discontinue placing new fill at the crest and upper ravine slope areas, and remove previously placed fill from those locations.

    ii. Roof, foundation and driveway water drainage should be directed to the storm sewer system and not disposed of onto the ravine slopes.

    iii. New retaining walls at the ravine crests should be permitted through the by-law process, designed and constructed by qualified professionals, and inspected and maintained. Non-engineered retaining walls at the ravine crest should be decommissioned or re-constructed under professional guidance.

    iv. The property owners and the Cities must ensure that street drainage is captured by the stormwater system. Street drainage should not be allowed to drain into driveways and toward the ravine slopes.

    v. The City water mains and storm and sanitary sewer pipes should be inspected and maintained to reduce the risk of broken or leaking pipes adding water to ravine crest areas.

3. Large fill deposit sites on Wyvem Avenue and Northview Place should be monitored and have geotechnical investigations conducted if significant subsidence and potential landslide initiation conditions are noted.

4. Metro Vancouver staff and their consultants should continue visually checking slope stability and drainage conditions in the ravines where previous landslides or water erosion have occurred.

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# 1 Introduction

## 1.1 PROJECT GOALS

Metro Vancouver, the City of Coquitlam (Coquitlam) and the City of Port Moody (Port Moody) engaged Associated Engineering (AE) to complete an Integrated Stormwater Management Plan (ISMP) for the Chines Escarpment area. The Suter Brook area in Coquitlam (i.e. the Corona Crescent area) was later added onto the ISMP area.

A Landslide Risk Management Procedure was initiated as part of this ISMP, consisting of:

- Phase 1: Development of a Landslide Risk Analysis Methodology; and
- Phase 2: Implementation of Landslide Partial Risk Analysis (this report).

Summit Environmental Consultants Inc. (Summit), the environmental sciences division of AE, completed the Phase 1: Development of a Landslide Risk Analysis Methodology in 2011 (AE 2011).

This Phase 2 Partial Risk Analysis work builds on the Phase 1 report, which should be reviewed in conjunction with this report. The Phase 2 field and property evaluations were completed in June 2012 and March 2013. The landslide partial risk analysis was conducted in the Chines Escarpment and Corona Crescent areas which together form the project area (Figures 1-1 and 1-2).

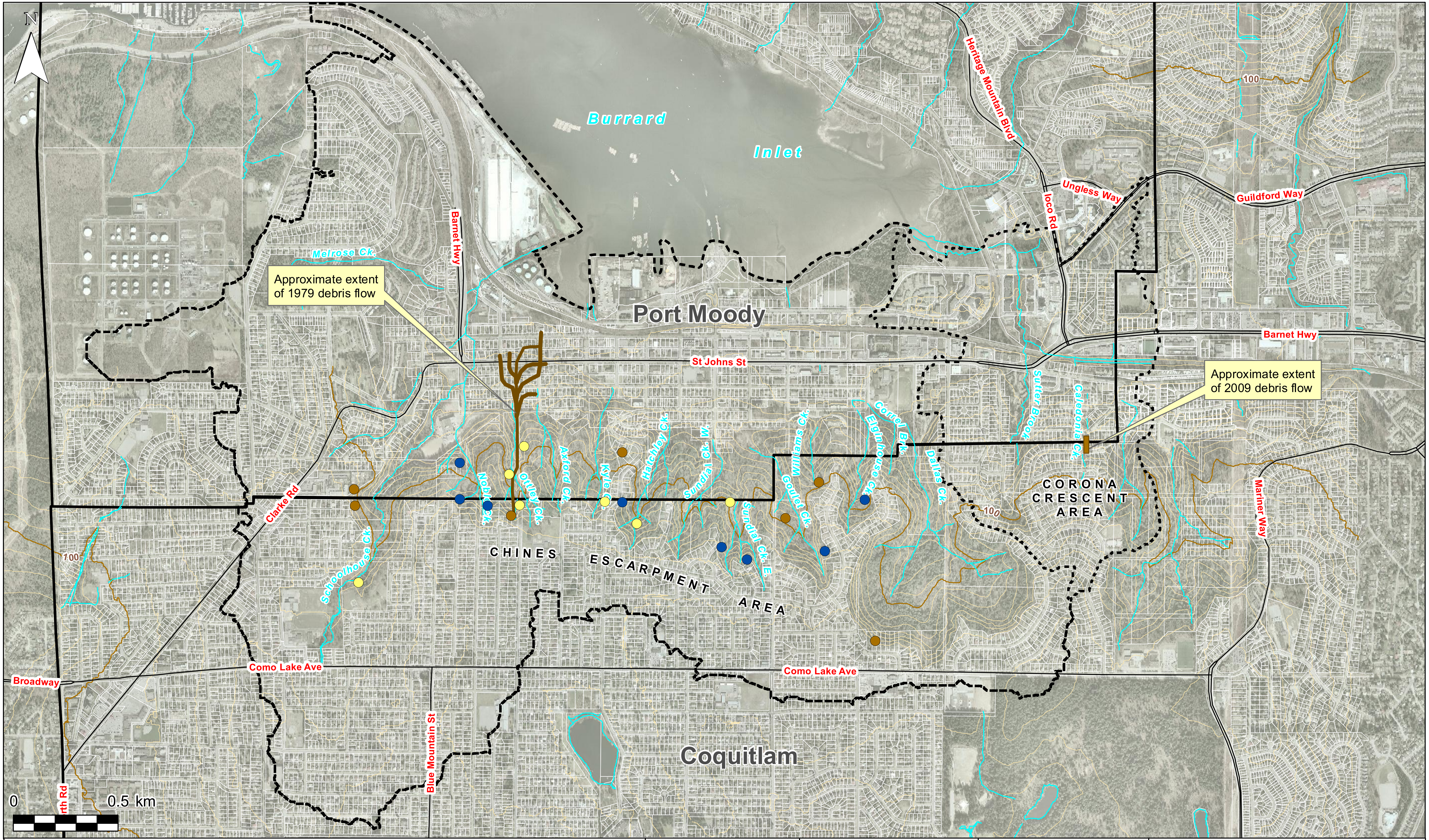
The goals of Phase 2 were to:

1) Determine qualitative hazard ratings at specific residential properties, located at ravine crests in the Chines Escarpment and Corona Crescent areas, based on site inspections and existing topographic, geological, hydrological and other information;
2) Evaluate the spatial probability of a landslide impacting a house or other element at risk and complete a qualitative partial risk analysis for those specific ravine-crest properties (Figure 1-2);
3) Determine where geotechnical engineering assessment is recommended to confirm the risk evaluation and develop comprehensive mitigation recommendations (Phase 3); and
4) Review the current development requirements of the Cities of Coquitlam and Port Moody for slope hazard lands and provide comments and recommendations.

**<u>The Phase 2 results are not intended to provide detailed, property-specific full risk assessments, but rather to identify the sites requiring further geotechnical assessment.</u>**

## 1.2 PROJECT AREA SETTING

The Chines Escarpment area in Coquitlam and Port Moody consists of 13 steep-sided stream ravines, draining generally north, cut into the edge of an upland about 100 m high. In Port Moody, north of the ravines, are lowlands that descend to Burrard Inlet. The ravines have dense second growth deciduous and coniferous forest, old logging trails, some stormwater infrastructure above and below ground, and foot trails.




- Major Roads
- Stream
- Project Area Boundary
- December 1979, Reported by Eisbacher and Clague, 1981
- Various Years, Reported by Thurber 1983, 1988
- Various Years, Summit and Other

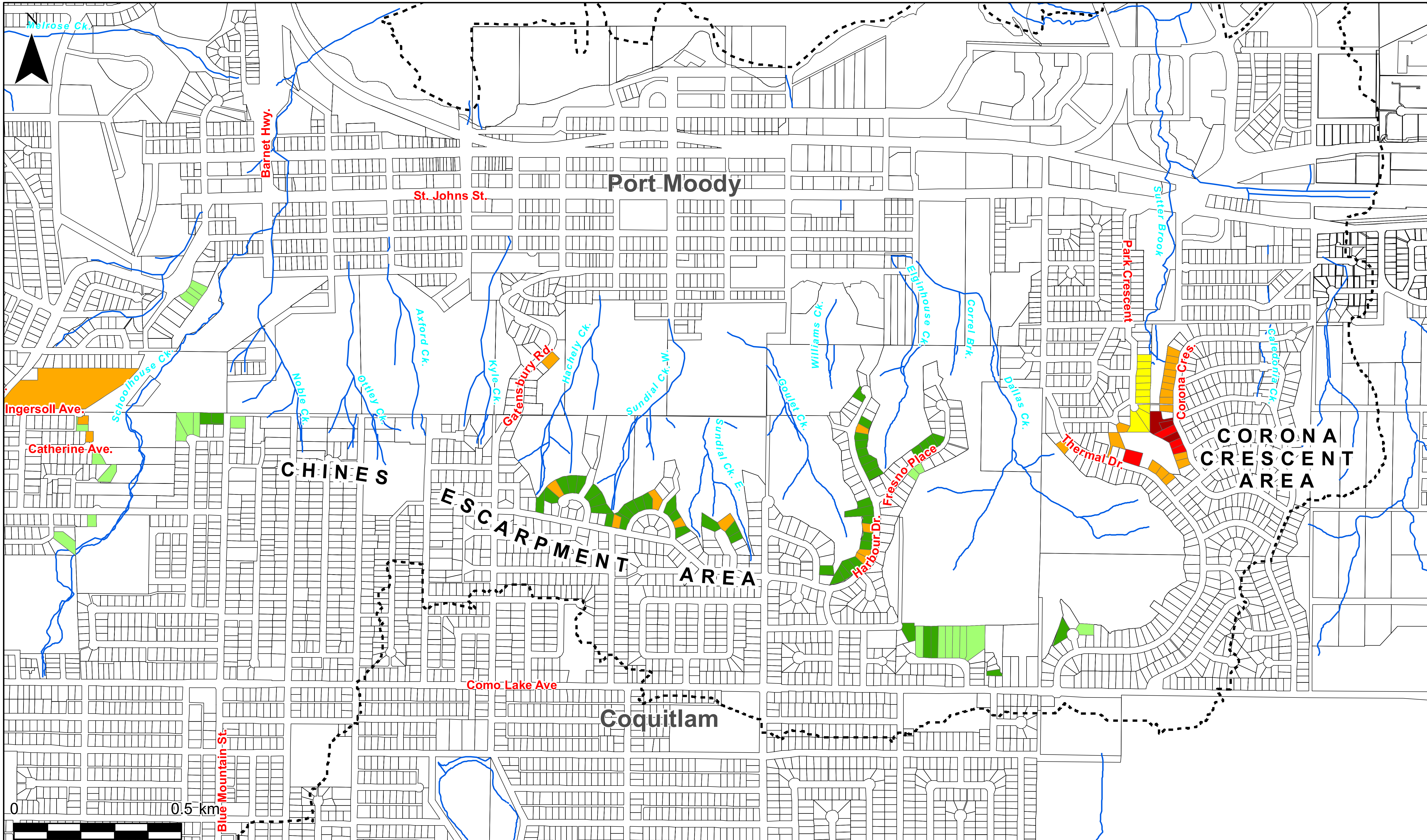
SUMMIT ENVIRONMENTAL CONSULTANTS INC.
A Member of the Associated Engineering Group of Companies

metro vancouver | Port Moody City of the Arts | Coquitlam

| | |
|---|---|
| PROJECT: | 2011-2817.010 |
| DATE: | January 2013 |
| DRAWN BY: | DA |

**PORT MOODY COQUITLAM DRAINAGE AREA ISMP**

**Figure 1-1: Project Area and Landslide and Erosion Events**




Municipal Boundary
Stream
Project Area Boundary
Exposed Properties

**Partial Risk Rating at Properties**

Very Low
Moderate
Very High
Low
High

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Coquitlam

| | |
|---|---|
| PROJECT: | 2013-2355.000.003 |
| DATE: | May 2013 |
| DRAWN BY: | DA |

**PORT MOODY / COQUITLAM DRAINAGE AREA ISMP**

**Figure 1-2: Qualitative Partial Risk Ratings At Private Properties Assessed**

Thermal Drive cross where the escarpment is less well expressed. Overhead power lines with cleared Only Gatensbury Road crosses the main escarpment area in a north-south direction. Clark Drive and rights-of-way also cross some parts of the escarpment area. The escarpment area includes several city parks and natural areas. Over the past several decades, residential areas have been developed adjacent to the ravine crests in Coquitlam and on four post-glacial fans and the lowlands below the ravine mouths in Port Moody.

The Corona Crescent area consists of the steep slopes at the head of Suter Brook ravine and adjacent lower areas along Park Crescent. This area also has an irregular upper ravine edge. The ravine slopes have lower relief to the north. Suter Brook sources from several ravine seepages and stormwater drainage outlets. Most of the steepest slope areas are included in Chineside Ravine and Natural Area Park.

The ravines generally have very steep upper slopes (>80%) at the headward ends, middle sections with more moderate slopes (about 20 to 60%) and lower sections with moderate to gentle slopes (about 5 – 40%). The old coalescing fans beyond the ravine mouths slope north (about 10 – 15%). The south (i.e. upstream) ends of the ravines generally have the steepest slopes, the most recent natural slope instabilities (as shown by sharp ridges and headscarps), and the most recent water erosion (where upland streams enter the ravines).

Due to long term stream and ravine slope erosion, the upland edge is very irregular in form. A road system was developed adjacent to this complex upland edge and residential lots were developed in the 1940s, 1950s and 1960s extending up to the ravine edges, to maximize the number and area of the lots beside the ravine park land. Houses were also built at the top (Corona Crescent) and bottom (Park Crescent) of ravine slopes in the 1970s and 1980s in the eastern part of the study area.

Excavation of basements, garages and driveways created about 100 to 200 cubic metres of soil spoils per lot. It is inferred, based on the surface features, that most of these spoils were spread around the backyard and ravine crest areas and not trucked offsite. The excavated soil was sand and gravel from Capilano Sediments, or silt, sand and gravel from Vashon Drift till, or silt, sand and clay from Quadra Sands. The surficial geologic units are discussed in Section 3.

# 2 Methodology

## 2.1 SELECTION OF PROPERTIES FOR ASSESSMENT

In the project area, we chose which residential properties to assess through interpretation of topographic, and cadastral mapping, previous geotechnical reports, historic aerial photographs loaned by City of Coquitlam, and images on the City of Coquitlam mapping web site (QtheMap™), and on GoogleEarth™ and on Bing Maps™ web sites. The residential properties identified for evaluation included:

- Properties located at the top of steep slopes over 20 m long and more than 10 m high, where there are houses below.
- Properties close to historic landslide and stormwater erosion sites (referenced in Thurber (1983, 1988); Eisbacher and Clague (1981); Evans and Savigny (1994)).
- Properties located at the top of steep ravine slopes, where the ravine continues for up to several hundred metres downstream and outlets in Port Moody.
- Properties located close to slopes with possible landslide headscarp features (based on contour pattern).
- Properties with evidence of disturbance at the crest (e.g. bare soil, fill disposal, removal of trees and deciduous vegetation).
- Properties consisting of small lots between roads and steep slopes, where we suspected that the back yards had been enlarged by fill placement.
- Properties with water mains and storm and sanitary sewer pipes located near the ravine crests.
- Properties near large fill dumping sites (referenced in Thurber (1983, 1988) and visible on early aerial photographs).
- Properties with retaining walls, swimming pools or garages near the crest.
- Properties near storm sewer outfalls into steep ravines.
- Properties near sites with previous erosion caused by burst water supply or storm sewer pipes.

The review of information used in property selection was limited where:

- The slope details and landslide headscarps on aerial photographs were hidden by vegetation, shadows and landscaping.
- The available topographic mapping was generalized compared to the actual slope complexity.
- Recent land changes were not represented on available aerial photographs or mapping.

Based on these assessments, 108 properties were identified in various locations along the ravine crests and below the ravine slopes which warranted on-site evaluation (Appendix A). This list was provided to the Cities of Coquitlam and Port Moody in order that the property owners could be contacted to obtain access permission.

The selection of properties for on-site evaluations was based on the available information. Even with review of topographic and aerial photograph information, reports by other consultants, landslide records and other information, it is possible that other properties exist in the project area which were not assessed but where landslides may start. The site evaluations were only completed at the reported locations and cannot be applied elsewhere.

## 2.2 AUTHORIZATION FROM PROPERTY OWNERS

The procedures used for property owner contact and authorization to enter private property are outlined in Appendix A. The City of Coquitlam and City of Port Moody staff contacted property owners by letter, phone and in person to order to gain authorization for access. Notifications were posted where no contact was established after several attempts. In all cases, the privacy and security of the property owners was treated as paramount. Slope investigations were conducted to ensure that no damage occurred to landscaping or underground pipes or wires.

## 2.3 FIELD ASSESSMENT

The residential properties were assessed in the field and information recorded through use of property sheets and by photography. The information collected included:

- Residential address, approximate house age, general foundation conditions, key site features including retaining walls;
- Photographs of the house back yard, crest and ravine slopes below;
- Distance from the slope crest to the back of the house;
- Slope gradients on the upper ravine slopes and in the backyard;
- Slope deformation evidence at and below the slope crest;
- Condition of the yard near the slope crest, including surface subsidence, wet areas and presence of old drainage pipes and rock pits;
- Subsurface soil and water information collected at key locations from shallow shovel test pits, soil auger holes (the pits and holes were refilled afterwards) and excavation exposures;
- The estimated fill thickness and composition at the slope crests and downslope of the crest, through visual estimation, shovel test pits, hand augering and probing with a metal rod;
- Evidence of previous landslides and water erosion;
- The natural and constructed drainage, including roof and foundation drains and their disposal sites;
- Evidence of creep or subsidence in the house, fences, retaining walls and outbuildings;
- Evidence of groundwater seepage on the ravine slopes; and
- The form and condition of immature and mature trees and old stumps at the crest and downslope, indicative of the original ground surface, previous slope instability or unstable substrate.

The field assessments were conducted by Joe Alcock, M.Sc., P.Geo., with assistance from Amanda Klein, B. Tech. in June 2012 and March 2013. The property sheets are compiled in Appendix B.

## 2.4 PARTIAL RISK ANALYSIS

The partial risk analysis methodology and results are described in Section 5.0.

# 3 Previous Studies

Previous surficial geology studies and landslide events are summarized below to provide background information for the evaluation of slope conditions and landslide hazards at the residential properties.

## 3.1 SURFICIAL GEOLOGY

The surficial geology of the project area was previously mapped (Armstrong and Hicock (1980); Armstrong (1984); Clague (1994)). This information is compiled in Table 3-1.

**Table 3-1 Surficial Geologic Units In The Project Area**

| Unit Name | Depositional Environment and Sediment Type | Approximate Age (years before present) |
|---|---|---|
| Modern deposits | Present day shore, stream and slope deposits. | Less than 10,000 |
| Salish Sediments, Stream Sediments | Marine shore and stream deposits of sand, gravel, silt. | 10,000 – 11,000 |
| Capilano Sediments | Beach gravel and sand;<br>Glaciomarine stony silt to clay from glacier melt in shallow ocean; and<br>Intertidal sands. | 11,000 - 13,000 |
| Vashon Drift (Fraser Glaciation) | Subglacial till;<br>Glaciomarine waterlain tills of stony clay, silt and sand composition;<br>Glacial outwash sands and gravels. | 13,000 - 18,000 |
| Quadra Sand | Stream, shore and nearshore fine to coarse sand, minor silt and gravel; and<br>Interbedded silt, fine sand and minor peat. | 18,000 - 24,000 |
| Cowichan Head Formation [Not exposed in project area] | Sand and silty sand; and<br>Silt, clay, sand, peat beds. | 24,000 - >62, 000 |

Sources: Armstrong and Hicock (1980); Armstrong (1984); Clague (1994)

The Chines Escarpment area consists of an upland surface in the south, stream ravines with steep slopes in the central part, and gentle gradient lowlands to the north near Burrard Inlet (Figure 1-1). The upland is formed of three superimposed surficial units. From the base to the top these consist of Quadra Sand; Vashon Drift; and Capilano Sediments.

The Quadra Sand unit consists of silt, sand and clay layers, some with gravel. Where exposed at stream and slope erosion sites, it consists of dense, rhythmically-layered clayey silt. This unit has been consolidated by over-riding glacier ice and long-term natural consolidation. The Quadra Sand generally underlies the steep mid to lower ravine slopes but is infrequently exposed.

Overlying the Quadra Sand unit are the Vashon Drift subglacial and waterlain tills. These dense, cobbly silty to clayey sand tills are present on the upland surface, on the upper ravine slopes, and underlie most of the areas of upland residential development. The tills were consolidated by over-riding and overlying glacial ice.

Overlying the Vashon Drift in some locations is the Capilano Sediments unit. The Capilano Sediments occur as pockets and thin sheets of beach or nearshore sands with pebbles on the upper and middle ravine slopes. The Capilano Sediments may represent sand and gravel from wave washing of the till during late glacial submergence in a marine environment. The lowlands north of the escarpment (outside the main project area) are underlain by Salish Sediments, where it locally occurs as a thick sand unit.

The ravine slopes are generally covered with a 0.2 to 0.5 m thick layer of recent colluvium of intermixed silt, sand and organic materials. Where slope erosion has previously occurred, or on the steepest slopes, only thin forest soil or surface organic layers are present over the dense Quadra Sand or Vashon Drift.

The overall escarpment form, with narrow steep ridges between deep stream ravines, suggests much of the slope form depends on the underlying consolidated Quadra Sand unit and the consolidated Vashon Drift till units, and the headward erosion of streams from surface runoff and groundwater outflow at the ravine heads. The upper ravine edges are generally eroded into the till units in the upland area. Lower on the slope, such as lower Harbour Drive, Corona Crescent and Thermal Drive areas, the ravines are eroded into silt, sand and clay of the Quadra Sand unit.

In the project area, the overburden-bedrock interface is estimated to be more than 100 m below surface and thus has little influence on slope stability and drainage.

## 3.2 PREVIOUS LANDSLIDE EVENTS

The Phase I report (Table 3-15 therein) provided an inventory of recorded landslide events based on Thurber (1983, 1988), Eisbacher and Clague (1981) and Golder (2007). The locations of these previously reported slides are indicated on Figure 1-1. This information has been compiled with additional information regarding new landslides, landslide triggers and the spatial aspects of deposition zones in Table 3-2.

One pre-historic and two historic landslide events in the Chines Escarpment and Corona Crescent areas have implications for the risk analysis and are described below. The two historic landslides impacted houses and came close to injuring people. Both were human-induced landslides, where large quantities of water were added to fill and natural surficial deposits and caused debris flows, which started in steep source areas and descended to and deposited on the gentle slopes below where houses were located.

## Table 3-2 Previous Landslides, Chines Escarpment and Corona Crescent Areas

| Month/Year of Event | Event Description | Event Trigger | Spatial Extent of Transport and Deposition |
|---|---|---|---|
| Unknown, possibly late 1970s | Gully erosion and landslides at Mayfair Court, Poirier Street, Canyon Court and Gatensbury Road (three locations) in Coquitlam (Thurber 1983). | Inferred to be from stormwater flow erosion, groundwater seepage and stream erosion. | Landslides on ravine slopes travelled to base, no report of debris flow transport beyond. Water erosion and deposition continued downstream. |
| Dec. 1979 | Three small landslides/washouts, upper Noble Creek, one small landslide west side of Hachley Creek, one small landslide upper Goulet Creek, and one small landslide east side Elgin House Creek (Thurber 1988; Eisbacher and Clague 1981). | High rainfall and wet soil conditions | Washouts or landslides on ravine slopes travelled to base of slope, no report of debris flow transport beyond. Water erosion and deposition likely continued downstream. |
| Dec. 1979 | In Ottley Creek ravine, a large debris flow occurred which reached the residential area below and damaged several residences, structures and cars, and put several lives in danger (Thurber 1988; Eisbacher and Clague 1981). | Failure of a large soil fill pile on a steep hillside due to toe erosion, wetting from surface and groundwater, combined with high stormwater flow in the steep ravine. | The debris flow travelled over 600 m down the steep ravine and about 700 m beyond the ravine mouth through a residential neighbourhood. Downslope, the debris flow lobe and accompanying water became channelized along roads and ditches. |
| Dec. 1979 | One landslide on natural ravine slopes in Kyle Creek. Two landslides from fill areas. The landslide from fill in Dallas Creek ravine partially blocked a stream. The landslide from fill near Williams Creek ravine travelled downslope, but did not combine with a stream. | High rainfall . presence of fill and wet soil conditions. | The landslide from ravine slope travelled to base, no report of debris transport beyond. The landslides from fill travelled as possible debris flows downslope to more gentle gradient slopes. The one near Williams ravine travelled about 125 m downslope. |
| Dec. 1979 | Significant fill subsidence occurred beside Schoolhouse Creek ravine near Ingersoll Ave. (not classified as a landslide). Fill also subsided or moved at Adiron and Wyvem locations. | High rainfall and surface drainage onto large fill deposit areas. | No reported movement of fill much beyond original footprint. |
| Unknown, possibly 2006 | Shallow landslides in Ottley Creek and East Sundial Creek ravines (Golder Associates 2007). | Ottley landslide triggered by active groundwater seepage near headscarp. East Sundial landslide #1 triggered by failure of stormwater pipe. East Sundial landslide #2 triggered by active groundwater seepage near headscarp. | Ottley landslide had 10 m high headscarp, extended about 82 m down to the creek on slopes of 40 to 20% where there was a deposit, and possible creek bank erosion from blockage. East Sundial landslide #1 had a track about 60 m long below a headscarp 5 to 8 m wide. This landslide deposited in a 500 $m^2$ area in the ravine bottom at the base of slope. East Sundial landslide #2 had a track about 65 m long with a 40 m wide headscarp, and was about 1 m deep. |

## Table 3-2 Previous Landslides, Chines Escarpment and Corona Crescent Areas, continued

| Time of Event | Event Description | Event Trigger | Spatial Extent of Transport and Deposits |
|---|---|---|---|
| Unknown, possibly 2008 | Creek bank erosion at the head of Schoolhouse Creek tributary below a storm drain, now rehabilitated with armour rock cover and slope reinforcing. | High streamflow after rainfall where the creek was less armoured and where it flows beside erodible slopes. | Creek bank erosion later armoured. Creek ravine widened and deepened by a few metres. |
| Unknown, possibly 2008 | A small shallow slide in middle Ottley Creek ravine. | Inferred to be due to groundwater seepage reducing colluvial soil strength. | Deposition at base of feature. |
| December 16, 2009 | Debris flow in 1000 block of Corona Crescent, from fill deposits below a road which crosses a small ravine (Braun 2010). | Debris flow caused by water main failure and rapid saturation of steep fill deposits. | Debris flow travelled about 80 m from headscarp, deposited in yards. |
| Unknown, possibly 2011 | A small shallow debris flow in fill or previous landslide deposits in upper Ottley Creek ravine. | Inferred to be due to stream erosion of previous deposits, undercutting the toe. | Debris collected within several metres of base of steeper slope section. |

### 3.2.1 Large Pre-historic Landslide North of Correl Brook Ravine

Armstrong (1984) described evidence suggesting a large, pre-historic landslide had occurred north of Correl Brook ravine. At the Port Moody works yard, a pre-1984 excavation discovered buried trees which had been sheared off at the trunk, underlying a layer of younger sediment. No dating was conducted and little geologic information is available. Armstrong interpreted that a pre-historic landslide issued from the Correl Brook ravine which damaged and covered a post-glacial forest.

No other landslides have been identified which compare in size and travel distance to this event. Further study of this pre-historic landslide would be worthwhile for estimating its date of occurrence, and the risk exposure for developed areas below the Correl Brook ravine. This landslide could be up to thousands of years old.

### 3.2.2 Ottley Creek Ravine Debris Flow, 1979

In December 1979 at the head of Ottley Creek ravine, a large fill deposit (estimated at about 4,000 $m^3$) on a steep slope failed due to erosion from high stormwater flow after several days of heavy rainfall (Eisbacher and Clague (1981); Thurber (1988); Evans and Savigny (1994)) (Figure 1-1). The fill consisted of mineral soil from construction excavations and wood debris from land clearing. The failure resulted in a large debris slide into the creek, which temporarily blocked the creek. This debris slide then developed into a channelized debris flow, which moved rapidly down Ottley Creek ravine, incorporated additional soil, wood debris and water, exited the ravine and spread over the residential area below as an unconfined debris flow. Mixed soil, wood debris and sorted gravels were deposited at the ravine mouth and sediment trails were deposited along the water tracks. There is anecdotal evidence that the debris flow traveled in pulses.

The outer fringe of the debris flow, with high water content and some sediment, may have continued as a debris flood, with slower transport of high sediment content water. The event was estimated to have transported about 8,000 $m^3$ of debris in total.

The debris flow damaged several residences, structures and vehicles, and put lives in danger (Figure 1-1; Eisbacher and Clague (1981); Thurber (1988)). This debris flow nearly caused serious injury to four people - a house with three residents was impacted by the debris and knocked off its foundation, and a basement apartment with one resident was rapidly inundated. The people managed to escape the affected houses, and no serious injuries occurred (Eisbacher and Clague (1981); Thurber (1988); Evans and Savigny (1994)).

### 3.2.3 Corona Crescent Debris Flow, 2009

On the evening of December 16, 2009, a water main burst in the 1000 block of Corona Crescent in Coquitlam. The location was at a steep City-owned land parcel in a ravine, where Corona Crescent crosses Caledonia Creek. The pipe was located on the downslope side of a cast-in-place concrete retaining wall, with up to 3 m of fill on the downslope side, consisting of granular material, organic silt and sand, roots, wood fragments and construction debris over top of previous topsoil and native silt (Braun 2010). The pipe burst caused a high volume of water flow onto the fill and down the steep slope. This resulted in a small debris flow which descended the ravine and deposited onto Brookmount Avenue and onto the driveways and yards of two adjacent private properties about 60 to 80 m below, located in Port Moody. The debris was later removed and the headscarp and track rehabilitated by the City of Coquitlam.

This landslide has been classified as a debris flow as it consisted of soil and water, was laterally confined and travelled rapidly. It is understood that some of the steep headscarp was on City land in the ravine and some was on private property.

There were concerns regarding the foundation stability of the adjacent house on Corona Crescent, where a paving stone patio built on fill had been partly eroded away; however, the house was reviewed (Braun 2010) and has remained stable since that time.

After the debris flow occurred, groundwater seepage was later noted coming from the base of the track. The slope below the retaining wall was evaluated as marginally stable due to the over-steepened condition, which during earthquake shaking would likely become unstable (Braun 2010). Recommendations to improve the embankment stability were provided, including fill removal, maintenance of the concrete retaining wall drainage, construction of stable slopes below the wall and revegetation of the slopes.

The City of Coquitlam aerial photography and topographic maps indicate that, before the debris flow, the slope had some deciduous and coniferous trees, deciduous underbrush and slopes of about 18% to 40%. When viewed in June 2012, the headscarp and erosion scar had been rehabilitated, with large armour rock placed along the stream channel, deciduous trees and bushes planted on the slope, and the slopes seeded with grass (Photos 1 to 5, Appendix C). Some remaining small deciduous trees west of the headscarp are tilted into the slope, indicating the soils have moved or otherwise provide little support (Photos 5 and 6, Appendix C).

#### 3.2.4 Metro Vancouver Ravine Inspections

Since the major erosion events in December1979, seasonal checking of landslides, slope stability and drainage conditions from ravine access trails has been conducted by Metro Vancouver and their geotechnical consultants for ravines where previous slope failures or water erosion had occurred. A number of geotechnical assessment reports have been prepared based on the landslide investigations (e.g. Golder 2007) which provide valuable background information on landslide location, activity and stability.

# 4 Landslide Types, Indicators and Frequency

Coquitlam and Port Moody initiated a landslide risk analysis program as part of the overall ISMP due to the potential for landslides initiating in the Chines Escarpment and Corona Crescent areas to cause damage, injury or death.

For the Chines Escarpment and Corona Crescent areas, the natural surficial deposits, the steep ravine slopes, the slope stability, the presence of soil fill, and the surface and subsurface drainage conditions are complex and similar to other steep slope areas in the Vancouver area (Eisbacher and Clague 1981). In the Chines Escarpment area, there are no houses immediately below the ravine slopes but rather at the outlets of the ravines leading down from the escarpment. In the Corona Crescent area, however, there are houses at the slope bottom near Park Crescent which would be exposed to potential landslides or debris flows from above.

## 4.1 POTENTIAL LANDSLIDE TYPES AND TRIGGERS

Previous studies of landslides in the project area (Thurber (1983, 1988); Eisbacher and Clague (1981)) have identified several landslide types, potential start zones on natural steep slopes and fill sites, and various potential triggers (Table 3-2).

The type, size and nature of potential landslides in the project area were determined through:

- Review of background reports and research articles;
- Interpretation of historical aerial photographs and modern orthophotographs;
- Field review of ravine crests, slopes and bottoms; and
- Field review of residential properties above and below the ravine slopes.

Based on the surficial geology, the surface and groundwater regimes, and the history of landslide events, the following types of landslides have likely occurred since deglaciation:

- Debris or earth falls and debris avalanches;
- Debris or earth slides;
- Debris or earth flows;
- Debris floods;
- Shallow-seated slumps; and
- Deep-seated slumps.

The landslide terminology of Cruden and Varnes (1996) has been generally followed in this report. In the Cruden and Varnes (1996) scheme, where the soils are predominantly fine, the term “earth” is used, and where the soils are predominantly coarse, “debris” is used. For simplicity in this report, the term “debris” is preferentially used.

Evidence of slope creep was noted in most parts of the project area but does not constitute a type of landslide. Evidence of fill subsidence was noted in the project area, but this is also not considered a type of landslide, only a possible precursor to landslide activity.

Potential triggers for landslide initiation include:

- Heavy winter rainfall over several days, leading to high soil water content (increased soil mass, reduced soil strength, higher water pressure in fractures) and high surface runoff and streamflow;
- Stream undermining of steep slopes;
- Failure of oversteepened slopes created by uncontrolled stormwater flow;
- Groundwater outflow, leading to high soil water content;
- Placement of mineral soil or organic waste fill on slopes with marginal stability;
- Misdirection of surface drainage onto steep slopes;
- Failure of water main or storm sewer pipes, releasing large quantities of water near the slope crest;
- Uncontrolled water drainage down ravine slopes;
- Old logging trail cuts destabilizing ravine slopes;
- Failure of retaining walls, releasing fill and water onto steep slopes below;
- Failure of swimming pools (in-use or decommissioned in place);
- Failure of large fill piles due to misdirected water, loss of soil strength; or addition of new fill;
- Earthquake shaking and resulting soil strength and water drainage changes; and
- Rotting of wood embedded in soil fill or failure deposits.

Not all of these potential landslide triggers have been recognized as causing landslides in the project area, but based on the site conditions, these triggers could initiate landslides.

## 4.2 LANDSLIDE AND SLOPE INSTABILITY INDICATORS

Section 4.2.1 addresses landslide indicators derived from aerial photographs; and the subsequent sections address various indicators derived from other information sources (previous reports, our field investigations in 2011, 2012 and 2013, and discussions with City staff and local residents.

### 4.2.1 Historical and Modern Aerial Photographs

To assess historic landslide activity, aerial photographs from 1954, 1963, 1969, 1974 and 1979 were loaned by the City of Coquitlam for stereoscopic interpretation (Table 4-1). Orthophotographs from 2003, 2006, 2009 and 2012 were also viewed at the Coquitlam City web site (Qthemap™). Other recent orthophotographs were viewed at the GoogleEarth™ and Bing Maps™ web sites.

The 1954 and 1963 aerial photographs provide evidence of trail building and logging on forested slopes, initial residential land development, the use of fill disposal sites and later residential land development at the ravine crests. In most cases, the deciduous forest canopy obscures surface details such that landslide scars, streams, slopes and stormwater erosion tracks are not visible.

Over time, the forest had more second-growth coniferous trees regrow which block surface details in all seasons.

The 1969 aerial photographs indicate sediment deposition along some creeks in the ravine bottoms, likely related to erosion below stormwater pipe outlets at the ravine crest and upper slopes. The 1974 aerial photographs have evidence of a landslide (likely a debris fall or avalanche) on a ravine wall near the north end of Poirier Street. The trigger for this landslide is not known.

Pre-1950s aerial photographs are mainly of small scale (1:40,000 or less), and taken in summer with full vegetation cover, and therefore small slope features such as landslides are generally not visible. Aerial photographs from the 1950s and 1960s are useful for indicating logging, fill deposition sites, and other disturbance features, but due to the forest canopy are not useful for determining the location and cause of any landslides.

The Chines Escarpment ravines were logged over an extended period starting in the early part of the 20$^{th}$ century, with some late harvest in the 1950s in the Dallas Creek area, and the 1960s near Ottley Creek. As indicated on the aerial photographs, logging involved construction of trails angling across the ravine slopes and up the ridge crests between ravines. These trails connected to the ends of city streets in many cases. Some shallow debris slides below the trails in the 1950s and 1960s are suggested by wider areas of bright reflectance on the historic aerial photographs. No active debris slides from logging were noted during the ravine assessments but old logging trails with gaps were noted in several of the ravines (Correl Brook, Ottley Creek).

## Table 4-1 Historical Aerial Photograph Interpretation and Comments

| Year | Roll, Numbers | Scale | Comments |
|---|---|---|---|
| 1954 | BC1676: 5,6,7,8;<br>BC1676: 56,57,58,59,60 | About<br>1:20,000 | • In the base of Correl Brook ravine, widespread evidence of logging where logs were dragged to a central point.<br>• Fill from road construction visible downslope of future Seaforth Way.<br>• Forest clearing along tops of slopes, Schoolhouse Creek ravine, Kinsac, and Blue Mountain areas.<br>• Off end of Ingersoll Ave., large bare soil area in ravine. Possible placed fill or cleared area. Bare tote roads lead in to this area.<br>• Off edge of Adiron, large bare soil area, possible fill, extends into Schoolhouse Creek ravine. |
| 1963 | BC5061: 123,124,125,<br>126 127 | About<br>1:20,000 | • Edge of Schoolhouse Creek ravine and west side of Gatensbury Road now have residential development.<br>• Possible fill area off end of Ultra Court off Thermal Drive.<br>• Logging trails, bare soil, between Lillian St. on top and Henry St. below, and between Kyle and Axford Creeks.<br>• Trace bare soil below ends of Ingersoll and Catherine – former bare area now partly covered by vegetation.<br>• Housing developed on Harbour Dr. and Thermal Dr. A trail connects north end of Harbour Dr. to streets downhill.<br>• Trails present in Correl Brook ravine base. |
| 1969 | BC5323: 73,74,75,76,<br>77,78 | About<br>1:20,000 | • Logging trails visible between Lillian and Henry Streets (between Kyle and Axford Creek ravines), possible small shallow debris failures below.<br>• Trail leads from end of Bend Court to lower town area. Wide bare soil patch along trail.<br>• Deposition of gravel bars along West and East Sundial Creeks likely from stormwater erosion of slopes.<br>• Deposition of sediment below head of gully at upstream end of Hachley Creek.<br>• Failures below city road and gully formed, on west side of Thermal, south of Park Crescent – possibly related to stormwater drainage off the road.<br>• Recent trails and harvest in Correl Brook ravine, eastern side, northern end.<br>• At head of Suter Brook, one area above west part of Park Drive has indication of soil removal to create a flat building spot.<br>• Suter Brook has gravel bars deposited from active stream transport, below Park and Corona Crescents. |
| 1974 | BC5574: 31,32,33,34 | About<br>1:40,000 | • Most upland residential housing built, back yards extend to ravine crests.<br>• Most of slope crests hidden by canopy and shadow. Some fill deposition sites visible.<br>• Large ravine slope failure visible, west of north end of Poirier St. in East Sundial ravine. Bare soil, concave headscarp. Cleared right-of-way extends north from Poirier St. to lower part of city – trees removed, ridged, no landslides. |

## Table 4-1 Historical Aerial Photograph Review and Comments, continued

| Year | Roll, Numbers | Scale | Comments |
|---|---|---|---|
| 1979 | BC79046: 225,226,227,228,229,230<br>BC79046: 2,3,4,5,6,7,8 | About 1:20,000 | • Dense forest canopy at slope crest. No landslide features visible. |
| 2003 | Q the Map, City of Coquitlam | About 1:564 | • Deciduous trees in leaf. No landslide features visible. |
| 2006 | Q the Map, City of Coquitlam | About 1:564 | • No leaves on deciduous trees. No landslide features visible. |
| 2009 | Q the Map, City of Coquitlam | About 1:564 | • No leaves on deciduous trees. No landslide features visible. |
| 2012 | Q the Map, City of Coquitlam | About 1:564 | • No leaves on deciduous trees. No landslide features visible. |

### 4.2.2 Landslide and Slope Instability Indicators on Natural Slopes

During the Phase 1 field assessment in June and August 2011, most of the ravine bottoms and streams were traversed on the access trails and some ravine slopes were examined along the midslopes and top edges. Several small previously documented landslide headscarps, tracks and deposits were reviewed. The stream intervals were examined for evidence of landslide deposits, debris flow levees and deposits, and stream sediment deposits possibly eroded from landslides. Only Ottley Creek ravine was noted to have levee deposits along the stream from the 1979 debris flow. Most streams showed evidence of erosion, downcutting, sediment aggradation and armouring from the high volumes of stormwater which were directed to the ravine slopes in the 1960s and 1970s.

During the Phase 2 site assessments on residential properties in 2012 and 2013, the top ravine edge and upper slopes were examined. Some previously documented landslide headscarps were reviewed.

The ravine head areas had more frequent landslide erosion sites than elsewhere. Near vertical bare soil faces up to several metres high and wide were noted in the dense upper Vashon till and the dense lower Quadra Sand deposits. It is interpreted that these are former debris fall/avalanche or debris flow headscarps, or have resulted from stream erosion at the base of the slope. These faces can maintain a very steep slope, have periodic spalling of thin layers from the lack of lateral support, and would be susceptible to surface water erosion. Steep faces in till were observed near the heads of most ravines, but particularly in West and East Sundial Creeks and tributaries, Kyle Creek, Elgin House Creek and Goulet Creek.

Vertical faces in Quadra Sands up to a few metres high and wide were observed in many lower ravine sections where stream or slope erosion had occurred into horizontally laminated silts and clays. These vertical faces also showed spalling of thin slabs where groundwater outflow occurred and lateral support had been removed. These erosion surfaces are being colonized by pioneer vegetation. These scars were located in the mid to lower ravine slopes, several tens of metres downslope from the crests, and are not considered to affect the ravine crest stability above. The instabilities were indicated to be slow and self-limiting, where fallen debris supported the lower part of the erosion face.

Small, amphitheatre-shaped headscarps with trees or deciduous vegetation were present along the top ravine crest, likely from landslides from 100 or more years ago. On these headscarps, there was no sign of modern translational movement or creep, tension cracks, sagging slopes or other instability indicators. No deposits were located at the ravine bottom underneath these headscarps, suggesting that very low volume erosion events occurred, or the failure occurred and then was washed away by succeeding streamflow over a long period of time. The absence of mature or young conifers in these headscarps suggested that tree growth had been prevented by wet soil conditions, or by moving surface colluvium which prevented rooting. A few instability indicators in native soils or fill below the slope crests were found where previous uncontrolled stormwater flow had occurred and resulted in erosion or landslide activity, such as at Poirier Street.

Most ravine slopes are covered with a layer of colluvium mixed with organic material about 0.2 to 0.5 m thick, which shows active shallow downslope creep. This thin colluvium allows rapid water infiltration and subsurface flow downslope. The colluvium obscures many surface features (surficial geological unit contacts, shallow landslide scars, groundwater seepages). Where landslides have previously occurred, this surface colluvium is generally missing.

The historical landslide scars near the upper ravine slopes were field reviewed. Inactive landslide scars are difficult to see after 10 to 20 years due to soil sloughing and revegetation. Where the landslide volume was small, there are often no lobate or mounded deposits visible. Where recent landslides had been rehabilitated and revegetated, no significant instability indicators were observed.

Many cedar and Douglas fir stumps up to 2 m diameter are present on the ravine bottoms, slopes and near the upper crests, indicating little surface change over a few hundred years. After logging, many of the slopes regrew with deciduous tree species, and coniferous trees will likely grow in later as part of natural succession. Areas of previous landslides or erosion, or groundwater outflow areas, generally had thick deciduous brush grow back (e.g. salmonberry, thimbleberry), with no mature trees present.

The mature trees along the crest and on the ravine slopes were checked for indications of slope movement. The common tree species are big leaf maple, Douglas fir, cedar, and hemlock. Only a few deciduous trees showed a bent trunk shape (“pistol butt”) that is indicative of previous slope movements or poor rooting or damage from bulldozers or fill dumping. Most coniferous trees do not develop pistol butt but some have curved lower trunks indicative of slope creep. Where the coniferous trees are slowly creeping downslope, the whole trunk is generally curved. Shallow-rooted trees were noted leaning where previous slope movement had occurred.

Active shallow creep was indicated by the build-up of litter and colluvial soil on the upslope side of the trunks and loss on the downslope side, such that tops of roots became exposed. Development of thicker stronger, roots on the downslope side (buttress roots) was noted on many coniferous trees on steep slopes.

While there was a general association noted between groundwater outflow zones and small slope instabilities, no large slope instabilities related to groundwater outflow were noted. Groundwater seepage at upper, mid, and lower slope positions indicates high soil moisture conditions which could reduce soil strength and stability. The groundwater outflow zones were difficult to spot when the whole surface was wet or where invasive species covered the slopes. The slopes were also examined for patches or strips of water-loving plants from groundwater seepage and downslope flow. Most of the private properties along ravine crests have Vashon Drift till or Capilano Sediments present at surface, which can have local perched water tables.

At many top of slope locations below former stormwater outlets, there are eroded water tracks, small gullies and enlarged stream courses with eroded vertical banks. Such features resulted from uncontrolled stormwater outflow after the original upland stormwater system was installed during initial land development in the 1960s and 1970s. These water erosion features, in places, have had slowly enlarging headscarps in mid and lower ravine slope locations. These features are generally not impinging on or destabilizing upper ravine slope areas. A small gully in sandy deposits from original stormwater erosion near the top of Gatensbury Road was rehabilitated in the past by end dumping in large rock pieces but there is still some minor bank sloughing. Other stormwater erosion site rehabilitation is described in Thurber (1983). Since the late 1970s, Coquitlam and Port Moody have installed an extensive system of corrugated and solid plastic pipes to conduct stormwater from the upland down to the ravine bottom streams, in order to prevent ravine slope erosion and stream incision.

### 4.2.3 Fill Deposit Instability Indicators

Six characteristic situations were found in the Chines Escarpment and Corona Crescent areas where fill was placed on or near the ravine crests behind houses. These fill deposits were examined for instability indicators.

1. On individual lots with large back yards, the soil from basement, swimming pool or garage excavation was sometimes disposed of by spreading the soil to form a gently outsloping back yard. Some fill was also placed at the slope crest in order to extend the backyard. This material was generally local mineral soil, excavated boulders and occasional stumps, placed in a layer about 0.3 to 1 m thick. This mineral soil layer, estimated to be about 40 to 60 years old now, has partially settled and consolidated. Where fences, garden walls and structures were founded in this fill, often there are creep indicators, with fences and walls which lean very slightly downslope.

   In recent years, at some residential properties being re-developed, local mineral soil from swimming pool and garage excavations, deck and patio construction and lot landscaping has been placed as fill at the ravine crest.

   At 990 Corona Crescent, the backyard swimming pool and patios had evidence of fill subsidence in the past, which produced extensive cracking, which was later repaired. The large concrete retaining wall supporting the swimming pool and patio on the downslope side was vertical, not cracked, had integrated drainage, and had likely been engineered.

   In some back yards on Ingersoll Avenue, Canyon Court, Harbour Drive and Ultra Court, small fill areas near the crest showed evidence of 0.1 to 0.3 m of subsidence.

2. Where there was little area to spread the excavated material, rounded piles and lobes of fill were placed along and below the crest, generally extending about 3 to 8 m downslope. Subsidence indicators are present where rot of buried wood debris and soil consolidation

occurred. Where this fill had a smooth surface, it is interpreted that it may have been bladed and packed by a bulldozer or backhoe.

3. Unofficial fill and waste dumping occurred where streets ended at the ravine crests (e.g. near the ends of Porter and Poirier Streets, near the ends of Ingersoll and Catherine Avenues and other locations). This material on surface was generally a mix of mineral soil, wood debris, concrete and asphalt pieces and some domestic waste, likely end-dumped from trucks along the crest, forming an apron downslope. It is estimated that this fill and domestic waste were placed about 40 to 60 years ago.

4. Established fill dumping locations were found where large fill aprons were extended into the ravines (i.e. off Wyvem Street, Miller Avenue, Adiron Avenue, and Northview Place in Coquitlam, and off Seaforth Way in Port Moody). These fill deposits may have been shaped and packed by a bulldozer. The material on surface was a mix of mineral soil, boulders, concrete and asphalt slab waste, and some larger domestic garbage. It is estimated to have been placed about 40 to 60 years ago. Indications of minor instability such as subsided areas or lower slope bulges were noted. No tension cracks or failures were observed in these large fill deposits.

5. At a few properties, fill has been deposited in back yards against wooden retaining walls erected at the downslope edge. During the period of high rainfall in February-March 2013, the fill deposited in back yards at three residential properties had subsidence, tension cracks form (two locations) and partial failure of the retaining walls through vertical post failure, horizontal tie failure or minor wall displacement. This is discussed in Section 7.7.

6. Fill may have been placed underneath or beside City roads which adjoin the ravine slopes (i.e. 1060 Block Gatensbury Road, 970 Block Thermal Drive, and 960 Block Seaview Drive). This fill may form parts of the road subgrade and may have undergone subsidence and lateral creep. This is discussed further in Section 7.7.

In some locations, where growing conditions are optimal, conifers up to 0.3 to 0.5 m diameter are growing in the 40 to 60 year old fill along the slope crest. At other locations, small conifers, deciduous trees and dense deciduous brush (e.g. blackberry, thimbleberry and salmonberry) are present, obscuring the fill material and preventing visual assessment of the slope stability and drainage conditions.

#### 4.2.4 Surface Drainage At Properties Affecting Slope Stability

At the residential properties assessed, only a few cases were found where it would be possible for street drainage to enter driveways and hence flow to back yards and ravine slopes. At one property on Chines Crescent, a possible landslide scarp was located below a ravine crest where street water may have drained down a driveway. The Cities of Coquitlam and Port Moody monitor street drainage and infrastructure actively to ensure the road water is properly directed to stormwater infrastructure.

At most residential properties along the ravine crests, back-of-house roof drainage was directed to subsurface pipes and hence to just below the ravine crest area. At many locations, the front of house roof drainage also went to the ravine. In a few cases, there is likely some patio or driveway drainage also being captured by the pipes and directed to the ravines.

Water erosion tracks or small slope failures were noted below some drainage pipe outlets on the upper ravine slopes. It is understood that many of the houses were originally built with foundation drains of clay or concrete weeping tile pipe which carried foundation and roof water to underground rock pits for water disposal. Most houses have had the roof and foundation drainage upgraded in the past 20 years, as the clay and concrete pipes failed. Plastic PCV pipes, of solid or perforated form, now carry water to the ravine crests.

At a number of locations, swimming pool water was drained down the ravine crest, which caused slope erosion and shallow slope failures which deposited into streams. The debris deposits caused stream diversion and minor erosion on the opposite bank where the stream was diverted around the deposit.

## 4.3 LANDSLIDE FREQUENCY

Determination of landslide frequency allows a better understanding of the landslide hazard and the triggers.

Previous inventories of landslides in the project area indicated a total of 22 events have occurred since about 1970 (AE 2011). These landslides were generally small with only local effects. The recent landslide frequency rate for the project area, including all types, would therefore be about 22 events in about 43 years, or about 0.5 events/year.

This 43 year period does not represent an adequate record from which to develop long-term landslide frequency values. Many small landslides were never identified or recorded and are now impossible to identify, so the calculated recent landslide frequency represents a minimum rate of occurrence.

Many of the landslides which occurred in December 1979 were related to stormwater erosion impacts from early urban development. These stormwater erosion sites have since been rehabilitated, and water erosion mitigated through improved stormwater control and water conveyance in pipes to the ravine bottoms. Conveying drainage water to the slope bottom has likely reduced the natural rate of headward ravine erosion by streams. Landslide frequencies would also be lower since the 1960s due to the diminished effects from the historic logging and trail building on the ravine slopes. Accordingly, there has been an apparent reduction in landslide frequency after about 1979.

Since there has been an incomplete recording of landslide events along the Chines Escarpment, and because the two known modern events caused no injury or death, the landslide frequency cannot be directly related to risk tolerance levels.

The landslide frequency rate of about 0.5 events/year of mainly small events appears to reflect the conditions along the Chines Escarpment, where large landslides, debris flows or debris floods are uncommon (Thurber 1988), and few that caused damage have ever occurred, under the conditions prevailing from about 1970 to 2013. Small landslides with local deposition occur but do not have impacts outside the immediate ravine area.

Coquitlam has specific bylaws and a development permit process to control land development and re-development along the ravine crests. However, some human-induced landslides may possibly occur in future, given that isolated examples were noted where new fill was deposited at the ravine crest, non-engineered retaining walls were constructed near the crest; and roof and yard drainage pipes were installed which drain to the ravines.

The Vashon Drift till and Quadra Sand are the natural surficial deposits from which the Chines Escarpment and Corona Crescent landslides may originate. Both deposits have been glacially consolidated, have low hydraulic conductivity, may have perched water tables and generally have a surface mantle of weathered soil material, mixed with organic material. The Vashon Drift till and Quadra Sand were observed to fail in shallow vertical layers along planes of weakness parallel to the slope surface. While the original failure volumes may not be large, estimated at from several to several tens of cubic metres from headscarps perhaps 20 m wide and 2 m deep, the descent of a landslide might accumulate additional colluvial material from the slopes. In summary, the Vashon Drift till and Quadra Sand may produce many small landslides with local impacts, but large damaging landslides are uncommon and usually result from human-influenced conditions such as misdirected stormwater flow and erosion of large fill deposits.

There are too few data on which to base a magnitude-frequency analysis of the landslides and debris flows in the Chines Escarpment and Corona Drive areas. This landslide frequency analysis does not consider earthquake-generated landslides as these could not be separately identified. Seismic risk analysis was not completed given the absence of the sub-surface soil strength properties, soil depth, and groundwater data that are required to carry out this analysis. These data will likely become available in future phases of geotechnical investigation.

# 5 Qualitative Partial Risk Analysis

A qualitative partial risk analysis was used for the landslide risk analysis for the Chines Escarpment and Corona Crescent areas. Section 5.1 describes the landslide risk scenarios identified in the project area. The risk analysis methodology is then outlined in Section 5.2 and applied in Sections 5.3 and onward.

## 5.1 LANDSLIDE RISK SCENARIOS

In Phase 1 (AE 2011), two landslide risk scenarios were defined, based on an office review of previously reported landslides and erosion events, and the field investigations in the project area. Some similar landslide types were grouped for these two scenarios. After the more extensive Phase 2 field review, additional individual landslide risk scenarios were developed, with examples, which are listed in Table 5-1. These landslide risk scenarios describe a series of connected slope processes which could cause soil, water and woody debris to reach and impact houses.

## 5.2 QUALITATIVE PARTIAL RISK METHODOLOGY

A qualitative partial risk analysis was completed for the 108 identified properties along the ravine crests using the site information and available topographic and infrastructure mapping. The partial risk analysis methodology of Wise *et al.* (2004) was used, which is a well-accepted methodology in B.C. for conducting partial risk analyses for landslides. A partial risk analysis evaluates the probability of occurrence of a specific hazardous landslide and the probability of that landslide reaching or affecting an element at risk (i.e. a house). This partial risk analysis does not explicitly evaluate the vulnerability of the element (e.g. a large family house would be more vulnerable to a landslide impact than a single person house) and therefore is not a complete estimate of risk.

For the District of North Vancouver private properties, a full risk analysis framework was used by BGC Engineering (2006a, 2006b; 2007 and 2010), adapted from concepts outlined in Wise *et al.* (2004). BGC's application of this risk analysis framework involved a multi-year phased approach of geotechnical investigation and analysis, probability analysis and reporting for several areas of the District. This method of risk analysis was first considered for the Chines project area (AE 2011). Later evaluation indicated that a partial risk analysis method was more suitable given the limited amount of subsurface soil and water information available, and the lack of information regarding the structural conditions at downslope houses.

The downslope elements at risk considered for this analysis are downslope houses, multi-family residences and occupied buildings. These buildings are fixed location elements and therefore always exposed to any hazards.

## Table 5-1 Landslide Risk Scenarios

| Risk Scenario | Landslide Initiation and Impacts | Trigger Mechanism | Examples |
|---|---|---|---|
| 1) Debris Flow | Open slope landslide starts in large volume fill at a slope crest or on the upper slope due to addition of stormwater, becomes channelized, mixes with additional sediment and water and rapidly descends as a channelized debris flow to residential areas. | High rainstorm runoff misdirected by poor drainage control at top of slope onto fill with poor stability characteristics. Weather controlled. | Coquitlam/Port Moody 1979 (Ottley Ravine debris flow). Coquitlam 1979 (debris flow from end of Harbour Drive near Williams Creek ravine). |
| 2) Debris Flow | Open slope landslide starts in native soil or minor fill at a slope crest or on the upper slope due to addition of large volumes of water due to failure of adjacent infrastructure (i.e. storm sewer, water main or swimming pool). Becomes channelized and then rapidly descends as a debris flow to residential areas. | Sudden release of large quantities of water from infrastructure pipes at the slope crest, onto soil or fill with poor stability characteristics. Debris flow occurrence depends on infrastructure failure, and slope and soil conditions. | Coquitlam/Port Moody 2009 (Corona Crescent). Harbour Drive area, 1980s (year approximate). |
| 3) Debris Flow | Open slope landslide starts in native soils due to rainfall or seepage, reaches the ravine bottom, combines with streamflow and debris and continues down the ravine as a channelized debris flow to residential areas. | Large rainstorm, input of soil water and groundwater seepage onto soil with poor stability characteristics. Weather controlled. | Coquitlam/Port Moody 1979. (Goulet ravine debris flow did not reach houses). The pre-historic debris flow from Correl Brook ravine may have been of this type. |
| 4) Debris Slides, Falls and Avalanches | Open slope landslide starts in native soil or fill due to loss soil strength and toe support and falls to the lower part of the slope or ravine bottom or potentially to residential areas. | Runoff from large rainstorms, groundwater seepage, slope loading from addition of fill, removal of toe support by stream erosion. Weather and erosion controlled. | Coquitlam 1979 (Kyle ravine event did not reach houses). |
| 5) Debris Floods | Soil and organic debris are transported down the ravine by high stream flow and reach residential areas. | Large rainstorm runoff misdirected by poor drainage control at top of slope. Weather controlled. | Coquitlam/Port Moody 1979 (Outer fringe of Ottley ravine event) |
| 6) Shallow and Deep-Seated Slumps | A coherent mass of soil fails along a rupture surface. This may lead to an open slope landslide which descends to a lower slope location or into a ravine bottom and becomes a debris flow. | Large rainstorm, removal of slope toe support by stream erosion. | Possible in project area but none found or previously described. |

Partial risk can be calculated by:

**Partial Risk = $P_{HA} = P_H \times P_{S:H} \times P_{T:S}$**

**$P_{HA}$**: The probability of occurrence of a specific hazardous landslide reaching a downslope element at risk.
**$P_H$**: The probability of occurrence of a specific hazardous landslide over a 100 year period.
**$P_{S:H}$**: The probability that a landslide will impact an element at risk, given that a landslide occurs.
**$P_{T:S}$**: The temporal probability of landslide impact.

For this project, the temporal probability of landslide impact has the value 1 as the elements at risk (houses) are at permanent locations and therefore exposed to the hazard at all times.

The partial risk equation therefore simplifies to:

**Partial Risk = $P_{HA} = P_H \times P_{S:H}$**

or in general terms, Partial Risk is the product of Landslide Hazard and Spatial Probability.

This partial risk analysis procedure was applied to the properties along the top ravine crest, with risk ratings developed ranging from Very Low to Very High. Properties along the slope base which might be affected by landslides from upslope are categorized as “Exposed”.

The partial risk analysis was completed with the understanding that the future Phase 3 geotechnical investigation (described in Section 6) could obtain detailed topographic mapping through surveys, subsurface soil composition and strength through test pits or geotechnical drilling, and groundwater information from piezometers such that slope stability modelling, factor of safety calculations and seismic analyses could also be completed. The structural characteristics and vulnerability of houses could also be determined. A full risk analysis may then be possible in future with the additional site information. Currently, little specific information is available about the subsurface conditions in the project area and the vulnerability of the elements at risk.

The partial risk analysis was completed separately for the Chines Escarpment area (Section 5.3) and the Corona Crescent area (Section 5.4), due to the differences in the ravine forms, landslide processes, and spatial effects and therefore the landslide hazards and spatial probabilities.

A partial risk analysis was also completed for the upper ravine edges for both the Chines Escarpment and Corona Crescent areas, in regard to potential effects from retrogression of landslide headscarps toward the upslope houses and City pipe infrastructure (Section 5.5).

Based on the inventoried landslides (Table 3-2) and the landslide risk scenarios (Table 5-1), we have grouped the various landslide types into two key types, in order to effectively conduct the partial risk analysis. The $P_H$ rating has been developed based on the two component landslide types occurring in succession – i.e. an open slope landslide which descends to the ravine and becomes channelized into a debris flow and travels downslope to the ravine mouth.

The hazard from open slope landslides is presented as $P_{H1}$

The hazard from debris flows is presented as $P_{H2}$

The resultant hazard from the two contingent landslide types is the product of the individual hazards, so that:

$$\mathbf{P_H = P_{H1} \times P_{H2}}$$

The $P_{H1}$ and $P_{H2}$ categories and their product $P_H$ are listed in Table 5-2. As these hazards are qualitative categories based on site conditions, and the two hazard categories are multiplied, the resultant hazard will be one of three categories listed.

**Table 5-2 Resultant Hazard $P_H$, Based on $P_{H1}$ and $P_{H2}$**

| $P_H = P_{H1} \times P_{H2}$ | | $P_{H1}$ Category | | |
|---|---|---|---|---|
| | | **Low** | **Moderate** | **High** |
| $P_{H2}$ Category | **Low** | Low | Low | Moderate |
| | **Moderate** | Low | Moderate | High |
| | **High** | Moderate | High | High |

## 5.3 CHINES ESCARPMENT AREA, PARTIAL QUALITATIVE RISK

### 5.3.1 Hazard Probability ($P_H$)

For the Chines Escarpment area, the hazard probability can be determined through the component open slope landslide partial risk and channelized debris flow partial risk, as described in Section 5.2.

In the Chines Escarpment area, the recorded landslide characteristics (Table 3-2) indicate that most landslides originating from native soils due to natural rainstorm trigger events generally travelled only a few tens of metres before deposition. Debris flows travelled about 125 m where the landslide was confined and water was mixed with the soil. Debris flows with large volume and long travel distance (>200 m) were generally initiated only where piped stormwater was directed onto large fill areas.

#### 5.3.1.1 Open Slope Landslide Hazard

At each upslope residential property, the likelihood that an open slope landslide would initiate was estimated based on the site factors at and below the ravine crest and in the back yard immediately adjacent, with particular attention paid to slope gradient, drainage, instability indicators, presence and thickness of soil fill and presence of nearby subsurface water mains and storm and sanitary sewer pipes (Table 5-3; Appendix B: Property Sheets).

The slopes below the ravine crests are generally planar to slightly convex. Most of the residential properties do not have gullies with confined conditions directly below. The confined conditions occur instead at the ravine bottom where the stream channel is present.

The hazard probability was estimated qualitatively as High, Moderate or Low, according to the criteria in Table 5-3.

## Table 5-3 Qualitative Hazard Probability ($P_{H1}$), Open Slope Landslide Events

| | Qualitative Hazard Rating | Criteria From Field and Background Information | Estimated Probability of Occurrence in Any 100 year Period |
|---|---|---|---|
| **Probability of Open Slope Landslide $P_{H1}$** | **High** | • Slopes below crest greater than 80% with weathered till/waterlain deposit, or colluviated till/waterlain deposit.<br>• Presence of fill > 2 m thick at and below crest.<br>• Past landslide or slope instability indicators present: landslide headscarps, previous slope erosion sites, tension cracks, impacted vegetation.<br>• Groundwater seepage present.<br>• Normal soil profile missing, suggests removal by erosion.<br>• Water mains and storm and sanitary pipes near crest.<br>• Presence of fill at the slope crest held by a non-engineered retaining wall or unmaintained engineered retaining wall. | >0.01 |
| | **Moderate** | • Slopes below crest between 60% and 80% with weathered till/waterlain deposit, or colluviated till/waterlain deposit.<br>• Presence of minor fill < 2 m thick at crest.<br>• Minor slope instability indicators and impacted vegetation.<br>• Little groundwater seepage.<br>• Normal soil profile present.<br>• Either water mains or storm or sanitary sewer pipes near crest.<br>• Presence of fill at slope crest held by an engineered and maintained retaining wall. | 0.002 to 0.01 |
| | **Low** | • Slopes below crest are less than 60% with weathered till/waterlain deposit, or colluviated till/waterlain deposit.<br>• Little (<1 m) or no fill present.<br>• No slope instability indicators.<br>• Presence of old stumps on slope, full soil profile, no human disturbance.<br>• No groundwater seepage.<br>• Normal soil profile present.<br>• No water mains or storm or sanitary sewer pipes near crest.<br>• No fill held by a retaining wall at slope crest. | <0.002 |

#### 5.3.1.2 Debris Flow Hazard

The likelihood that a debris flow would initiate from the landslide debris reaching the ravine bottom and travel to the ravine mouth was estimated based on the ravine site factors to produce the hazard rating. The likelihood of debris flow initiation was estimated based on research by VanDine (1996), Millard (1999) and Ministry of Forests (2001), which is incorporated in Table 5-4.

**Table 5-4 Qualitative Hazard Probability ($P_{H2}$), Initiation and Transport of a Channelized Debris Flow**

| | Qualitative Hazard Rating | Criteria From Field and Background Information | Estimated Probability of Occurrence in Any 100 year Period |
|---|---|---|---|
| **Probability of Channelized Debris Flow Initiation after Landslide Reaches Ravine Bottom**<br>**$P_{H2}$** | **High** | • Ravine base greater than 47% ($25^o$).<br>• Presence of thick accumulated slope or stream debris in ravine bottom.<br>• Past debris flow indicators present: levees, large channel deposits, old log jams, impacted vegetation (trim line).<br>• Stream flow present. | >0.01 |
| | **Moderate** | • Ravine base between 25% ($47^o$) and 18% ($10^o$).<br>• Some accumulated debris in ravine bottom.<br>• Rare indicators of past debris flows.<br>• Stream flow seasonal. | 0.002 to 0.01 |
| | **Low** | • Ravine base less than 18% ($10^o$)<br>• Little accumulated debris in ravine bottom.<br>• No indicators of past debris flows.<br>• Little or no stream flow present. | <0.002 |

### 5.3.2 Spatial Probability ($P_{S:H}$) in the Chines Escarpment Area

Consistent with the spatial probability ($P_{S:H}$) previously defined (Wise *et al.* 2004),we define $P_{S:H}$ here as the probability that a landslide and subsequently initiated debris flow will reach a house, when a specific hazardous landslide and subsequent debris flow are initiated.

For the Chines Escarpment area:

> $P_{S:H}$: The probability that a debris flow travels or deposits in the residential area beyond the ravine outlet and impacts houses.

In the Chines Escarpment area, for any landslide to reach a house below, it has to travel down the ravine slope, then transform into a debris flow in the ravine bottom (these two processes are represented by $P_H$), and then travel to the ravine mouth. The potential to impact the residential area beyond is the spatial probability ($P_{S:H}$).

Any debris flow which reaches the ravine mouth would likely impact houses beyond if there were no control structures. However, Metro Vancouver has constructed control structures such as collection basins, debris racks and dewatering structures at the ravine mouths except for Schoolhouse Brook, Correl Brook and Dallas Creek. These control structures were noted during the field assessments. These control structures were designed by Metro Vancouver's geotechnical consultants and constructed in the 1980s. The control structures for Noble Creek and Ottley Creek have subsequently been redesigned and re-constructed.

The analysis of $P_{S:H}$ in the Chines Escarpment area was completed using the criteria presented in Table 5-5.

In the Chines Escarpment area, the areas downslope and downstream of potential debris flow initiation points include the ravines and lowland areas in Port Moody extending from Schoolhouse Creek east to Correl Brook. Thurber (1988) previously evaluated which of the Chines escarpment ravines would tend to have debris flows, debris floods or water floods. Debris flow and debris flood potential zones were defined by Thurber (1988) at the ravine mouths of Noble, Ottley, Axford, Kyle, Hachley, the combined Sundial West and Sundial East, Williams, Elgin House, and Dallas Creeks. Goulet Creek and Correl Brook had water flood potential zones defined. No debris flow or debris flood zones were identified at Schoolhouse Brook as mainly water floods were predicted in this larger stream ravine which was wider and lower gradient.

Thurber (1988) determined which ravines would tend to have debris flows based on a simple rating for the individual ravine, where the width × length ÷ ravine floor slope generated an index number. Values over 15 (Schoolhouse Creek and Correl Brook) were inferred to have high sediment storage and low sediment transport potential. Values of less than 7 were inferred to have low sediment storage and high sediment transport potential, and thus would favour debris flows. Thurber (1988) noted that Schoolhouse Creek and Correl Brook had low overall gradients of about 7% while the other smaller ravines were steeper and ranged from 9 to 14%.

**Table 5-5 Qualitative Spatial Probability ($P_{S:H}$), Chines Escarpment Area**

| $P_{S:H}$ | Qualitative Spatial Probability Rating | Criteria From Field and Background Information |
|---|---|---|
| **Probability Of Debris Flow Interaction Beyond Ravine Mouth** | **High** | • Element within 100 m of ravine mouth in runout zone.<br>• Steep ravine gradient (15% or greater).<br>• No catch basin or control structure at mouth of small, steep ravine.<br>• No available in-ravine storage for debris flow deposits. |
| | **Moderate** | • Element between 100 to 200 m beyond ravine mouth in runout zone.<br>• Moderate ravine gradient (8 – 14 %).<br>• Presence of catch basin or control structure at mouth of small steep ravine.<br>• Presence of structure of unknown capacity to capture or detain debris flows<br>• Some available in-ravine storage for debris flow deposits and water floods. |
| | **Low** | • Element more than 200 m from ravine mouth beyond runout zone.<br>• Low ravine gradient (7% or less).<br>• Catch basin or control structure at ravine mouth.<br>• The ravine is wide and has large volumes of available storage for debris flow deposits and water floods. |

Based on Thurber (1988) and our calculations, we conclude that Schoolhouse Creek and Correl Brook have a low probability of debris flow transport beyond the mouth. The other small, steeper ravine watersheds have the potential for debris flows and runout to residential properties beyond the mouth, except for the presence of collection basins and other structures.

In future, debris flow initiation, travel, deposition and runout modelling could be completed using the available programs (UBCDFlow from UBC Civil Engineering, or FLO-2D, a commercial software product) if estimates for debris flow initiation and runout are required. This detailed modelling was not requested for the present analysis.

### 5.3.3 Partial Risk Determination

The partial risk ratings were derived from Table 5-6 using the combined landslide and debris flow $P_H$ (hazards) and the $P_{S:H}$ (spatial probabilities) for both the Chines Escarpment area. The partial risk results for the individual properties are presented in Table 5-7. For example, a Moderate landslide hazard combined with a Low debris flow hazard, together with a Moderate spatial likelihood of debris flow impact would produce a Low partial risk.

The partial risk rating results and site specific recommendations are also included on the individual property sheets (Appendix B). All site information relevant to the hazard analysis is recorded on the property sheets.

**Table 5-6 Qualitative Partial Risk Matrix**

| $P_{HA} = P_H \times P_{S:H}$ Probability of a specific hazardous landslide reaching a downslope house. | | $P_{S:H}$ Probability that a landslide will reach a house, given that a landslide occurs. | | |
|---|---|---|---|---|
| | | **Low** | **Moderate** | **High** |
| $P_H$ Probability of occurrence of a specific hazardous landslide over a 100 year period. | **Low** | Very Low | Low | Moderate |
| | **Moderate** | Low | Moderate | High |
| | **High** | Moderate | High | Very High |

## 5.4 CORONA CRESCENT AREA - QUALITATIVE PARTIAL RISK ANALYSIS

The Corona Crescent area has two types of potential landslide events which could impact houses downslope because of the steep slopes and the coalescing ravine system which opens to the residential area below.

- An open slope landslide could travel a short distance (<100 m) downslope to the houses below.
- An open slope landslide could descend to the ravine bottom, a debris flow could develop, and then travel a short distance (<200 m) down ravine to the houses.

We reviewed the general soil, surface water and stream conditions, the slope forms and gradients, and the confined ravine bottom conditions, to determine which Corona Crescent area residential properties would likely produce an open slope landslide which could become a channelized debris flow.

We also noted the general wet slope conditions, the slope gradients and forms that indicated where open slope landslides would likely travel to the ravine bottom and transform into a debris flow and move down the main Suter Brook ravine or a tributary ravine to the houses.

Since the debris flow occurrence depends on the initial landslide, the two individual hazards ($P_{H1}$ open slope landslide; and $P_{H2}$ debris flow) are multiplied together to get the total hazard ($P_H$) at the mouth of the ravine. Where only an open slope landslide would impact a house, $P_H = P_{H1}$.

The landslide and debris flow hazards and the spatial probabilities are outlined in the sections below.

**Table 5-7 Qualitative Partial Risk Analysis for Individual Properties, Chines Escarpment Area**

| | Port Moody Address | $P_{H1}$ Open Slope | $P_{H2}$ Channelized | Total $P_H$ | $P_{S:H}$ | Qualitative Partial Risk | Receiving Ravine |
|---|---|---|---|---|---|---|---|
| 1 | 994 Seaforth Way | Low | Low | Low | Low | Very Low | Schoolhouse |
| 2 | 998 Seaforth Way | Low | Low | Low | Low | Very Low | Schoolhouse |
| 3 | 1000 Seaforth Way | Low | Low | Low | Low | Very Low | Schoolhouse |
| | | | | | | | |
| 4 | 910 Ingersoll Ave. | High | Moderate | High | Low | Moderate | Schoolhouse |
| | | | | | | | |
| 5 | 1037 Gatensbury Dr. | Moderate | Moderate | Moderate | Moderate | Moderate | Hachley |
| | **Coquitlam Address** | **$P_{H1}$ Open Slope** | **$P_{H2}$ Channelized** | **Total $P_H$** | **$P_{S:H}$** | **Qualitative Partial Risk** | **Receiving Ravine** |
| 6 | 824 Ingersoll Ave. | Low | Low | Low | Low | Very Low | Schoolhouse |
| 7 | 826 Ingersoll Ave. | Low | Low | Low | Low | Very Low | Schoolhouse |
| 8 | 830 Ingersoll Ave. | High | Low | Moderate | Low | Moderate | Schoolhouse |
| | | | | | | | |
| 9 | 845 Catherine Ave. | High | Low | Moderate | Low | Moderate | Schoolhouse |
| 10 | 858 Catherine Ave. | Low | Low | Low | Low | Very Low | Schoolhouse |
| | | | | | | | |
| 11 | 841 Wyvem Ave. | Low | Low | Low | Low | Very Low | Schoolhouse |
| 12 | 824 Miller Ave. | Low | Low | Low | Low | Very Low | Schoolhouse |
| 13 | 796 Adiron Ave. | Low | Moderate | Low | Low | Very Low | Schoolhouse |
| | | | | | | | |
| 14 | 992 Kinsac St. | Low | Low | Low | Low | Very Low | Schoolhouse |
| 15 | 994 Kinsac St. | Low | Low | Low | Low | Very Low | Schoolhouse |
| 16 | 996 Kinsac St. | Low | Low | Low | Low | Very Low | Schoolhouse |
| | | | | | | | |
| 17 | 1010 Blue Mountain St. | Moderate | Low | Low | Low | Very Low | Schoolhouse |
| 18 | 1015 Blue Mountain St. | Low | Low | Low | Low | Very Low | Schoolhouse |
| 19 | 1020 Blue Mountain St. | Moderate | Low | Low | Low | Very Low | Schoolhouse |
| | | | | | | | |
| 20 | 925 Selkirk Cres. | Low | Moderate | Low | Moderate | Low | Goulet |
| | | | | | | | |
| 21 | 1361 Chine Cres. | Low | Moderate | Low | Moderate | Low | Hachley |
| 22 | 1363 Chine Cres. | Moderate | Moderate | Moderate | Moderate | Moderate | Hachley |
| 23 | 1369 Chine Cres. | Low | Moderate | Low | Moderate | Low | Hachley |
| 24 | 1371 Chine Cres. | Low | Moderate | Low | Moderate | Low | Hachley |
| 25 | 1373 Chine Cres. | Low | Moderate | Low | Moderate | Low | Hachley |
| 26 | 1377 Chine Cres. | Low | Moderate | Low | Moderate | Low | West Sundial |
| 27 | 1381 Chine Cres. | Low | Moderate | Low | Moderate | Low | West Sundial |
| 28 | 1385 Chine Cres. | Low | Moderate | Low | Moderate | Low | West Sundial |
| | | | | | | | |
| 29 | 1445 Harbour Drive | Low | Moderate | Low | Moderate | Low | West Sundial |
| 30 | 1455 Harbour Drive | Moderate | High | High | Moderate | Moderate | West Sundial |

**Table 5-7 Qualitative Partial Risk Analysis for Individual Properties, Chines Escarpment Area**

| | Coquitlam Address | $P_{H1}$ Open Slope | $P_{H2}$ Channelized | Total $P_H$ | $P_{S:H}$ | Qualitative Partial Risk | Receiving Ravine |
|---|---|---|---|---|---|---|---|
| 31 | 1501 Marine Cres. | Low | Moderate | Low | Moderate | Low | West Sundial |
| 32 | 1507 Marine Cres. | Low | Moderate | Low | Moderate | Low | West Sundial |
| 33 | 1513 Marine Cres. | Low | Moderate | Low | Moderate | Low | West Sundial |
| 34 | 1519 Marine Cres. | Low | Moderate | Low | Moderate | Low | West Sundial |
| 35 | 1525 Marine Cres. | Low | Moderate | Low | Moderate | Low | West Sundial |
| 36 | 1531 Marine Cres. | Moderate | Moderate | Moderate | Moderate | Moderate | West Sundial |
| 37 | 1537 Marine Cres. | Low | Moderate | Low | Moderate | Low | East Sundial |
| 38 | 1543 Marine Cres. | Low | Moderate | Low | Moderate | Low | East Sundial |
| 39 | 1553 Marine Cres. | Moderate | Moderate | Moderate | Moderate | Moderate | East Sundial |
| 40 | 1563 Marine Cres. | Low | Moderate | Low | Moderate | Low | East Sundial |
| | | | | | | | |
| 41 | 937 Canyon Court | Low | Moderate | Low | Moderate | Low | East Sundial |
| 42 | 941 Canyon Court | Low | Moderate | Low | Moderate | Low | East Sundial |
| 43 | 944 Canyon Court | Low | Moderate | Low | Moderate | Low | East Sundial |
| 44 | 945 Canyon Court | Moderate | Moderate | Moderate | Moderate | Moderate | East Sundial |
| | | | | | | | |
| 45 | 1335 Harbour Drive | Low | Moderate | Low | Moderate | Low | Hachley |
| 46 | 1769 Harbour Drive | Low | Moderate | Low | Moderate | Low | Goulet |
| 47 | 1773 Harbour Drive | Low | Moderate | Low | Moderate | Low | Goulet |
| 48 | 1777 Harbour Drive | Low | Moderate | Low | Moderate | Low | Goulet |
| 49 | 1781 Harbour Drive | Low | Moderate | Low | Moderate | Low | Goulet |
| 50 | 1785 Harbour Drive | Moderate | Moderate | Moderate | Moderate | Moderate | Goulet |
| 51 | 1789 Harbour Drive | Moderate | Moderate | Moderate | Moderate | Moderate | Goulet |
| 52 | 1791 Harbour Drive | Low | Moderate | Low | Moderate | Low | Goulet |
| 53 | 1793 Harbour Drive | Low | Moderate | Low | Moderate | Low | Goulet |
| 54 | 1797 Harbour Drive | Moderate | Moderate | Moderate | Moderate | Moderate | Goulet |
| 55 | 1801 Harbour Drive | Low | Moderate | Low | Moderate | Low | Goulet |
| 56 | 1805 Harbour Drive | Low | Moderate | Low | Moderate | Low | Goulet |
| 57 | 1807 Harbour Drive | Low | Moderate | Low | Moderate | Low | Goulet |
| 58 | 1822 Harbour Drive | Low | Moderate | Low | Moderate | Low | Elgin House |
| 59 | 1826 Harbour Drive | Low | Moderate | Low | Moderate | Low | Elgin House |
| 60 | 1830 Harbour Drive | Low | Moderate | Low | Moderate | Low | Elgin House |
| 61 | 1834 Harbour Drive | Low | Moderate | Low | Moderate | Low | Elgin House |
| 62 | 1838 Harbour Drive | Low | Moderate | Low | Moderate | Low | Elgin House |
| 63 | 1842 Harbour Drive | Low | Moderate | Low | Moderate | Low | Elgin House |
| 64 | 1846 Harbour Drive | Moderate | Moderate | Moderate | Moderate | Moderate | Elgin House |
| 65 | 1850 Harbour Drive | Low | Moderate | Low | Moderate | Low | Elgin House |
| 66 | 1861 Harbour Drive | Low | Moderate | Low | Moderate | Low | Williams |
| | | | | | | | |
| 67 | 921 Fresno Place | Low | Low | Low | Low | Very Low | Dallas |
| 68 | 925 Fresno Place | Low | Low | Low | Low | Very Low | Dallas |
| 69 | 928 Fresno Place | Low | Moderate | Low | Moderate | Low | Elgin House |

**Table 5-7 Qualitative Partial Risk Analysis for Individual Properties, Chines Escarpment Area**

| | Coquitlam Address | $P_{H1}$ Open Slope | $P_{H2}$ Channelized | Total $P_H$ | $P_{S:H}$ | Qualitative Partial Risk | Receiving Ravine |
|---|---|---|---|---|---|---|---|
| 70 | 932 Fresno Place | Low | Moderate | Low | Moderate | Low | Elgin House |
| 71 | 936 Fresno Place | Low | Moderate | Low | Moderate | Low | Elgin House |
| 72 | 940 Fresno Place | Low | Moderate | Low | Moderate | Low | Elgin House |
| | | | | | | | |
| 73 | 1904 Bowman Ave. | Moderate | Low | Low | Low | Low | Dallas |
| | | | | | | | |
| 74 | 1919 Custer Court | Low | Low | Low | Low | Very Low | Dallas |
| 75 | 1927 Custer Court | Moderate | Low | Low | Low | Very Low | Dallas |
| 76 | 1933 Custer Court | Moderate | Low | Low | Low | Very Low | Dallas |
| 77 | 1943 Custer Court | Low | Low | Low | Low | Very Low | Dallas |
| 78 | 1953 Custer Court | Low | Low | Low | Low | Very Low | Dallas |
| 79 | 1963 Custer Court | Low | Low | Low | Low | Very Low | Dallas |
| 80 | 1973 Custer Court | Low | Low | Low | Low | Very Low | Dallas |
| 81 | 1975 Custer Court | Low | Low | Low | Low | Very Low | Dallas |
| | | | | | | | |
| 82 | 805 Northview | Moderate | Low | Low | Low | Very Low | Dallas |
| 83 | 830 Ultra Court | Moderate | Low | Low | Low | Very Low | Dallas |
| 84 | 838 Ultra Court | Low | Low | Low | Low | Very Low | Dallas |

### 5.4.1 Hazard Probability

Some properties on the west side of Corona Crescent in the 900 and 1000 blocks and on Thermal Drive in the 800 and 900 blocks are located above steep slopes leading down to ravine bottoms which lead to houses on Park Crescent below. Some of the Corona Crescent and all the Thermal Drive properties are located above Chineside Ravine and Natural Park Area, which contains three small, steep, wet ravines which join just above Park Crescent.

#### 5.4.1.1 Open Slope Landslide Hazard

The open slope landslide hazard, $P_{H1}$ for the Corona Crescent upslope properties was determined using the previously developed Table 5-3.

In the Corona Crescent area, the ravine slopes are steep immediately below the crest (50 – 80%) but more gentle (20 – 30%) near the downslope houses. Potentially, the slopes immediately above the Park Crescent houses may be gentle enough to allow some landslide deposition to occur before runout reached the houses; however this has not yet been tested by landslide modelling or observance of actual occurrences.

#### 5.4.1.2 Debris Flow Hazard

The likelihood that a debris flow would initiate from the landslide debris reaching the ravine bottom and then travel to the ravine mouth was estimated based on the ravine site factors to produce the hazard rating using the previously developed Table 5-4.

Just above Park Drive, Suter Brook and its tributary stream enter underground stormwater pipes with small debris fences above the inlets. Suter Brook flows through stormwater pipes to Suter Park where it re-emerges. It is envisioned that any debris flows travelling down upper Suter Brook ravine would be detained at the end of the ravine near or at the house at 2242 Park Drive.

On the slopes below Corona Drive are some small streams draining from City stormwater pipes, and some small seepages which may be natural or from roof or foundation drainage. These small streams and seepages would increase the likelihood of debris flow initiation and travel at these locations.

For the Corona Crescent area, there are a number of debris flows which can be used to evaluate potential runout distance where there are no control structures. The 1979 Ottley Creek ravine debris flow (described in Section 3.2.2) descended from the creek headwaters to the lowlands during a major rainstorm. The gradient from the head to the end of the debris fan was about 12% (derived from Eisbacher and Clague (1981)). To the outside limit of the debris fan, the gradient was about 11%. The debris flow had a run out distance of about 700 m beyond the ravine mouth, mostly over City land and streets as water and sediment.

The 2009 Corona Crescent debris flow (described in Section 3.2.3) descended a slope and deposited near houses. The initiation point was on a steeper slope of about 50 - 60% in a shallow gully. The overall gradient of this debris flow path, from initiation point to deposition edge was about 20% (about 11.9$^o$). The deposition area was on gently-sloped land. The slope gradient from initiation point to deposition area is considered representative of the Corona Crescent project area slopes. It is inferred that potential debris flows could initiate, travel downslope, and reach houses where the slope gradients are about 25% or higher at the initiation point.

Other reported debris flows in the Chines Escarpment area are less well documented; however photographic and field information suggests similar slope gradients for debris flow initiation and runout (Thurber (1988); Eisbacher and Clague (1981)).

### 5.4.2 Spatial Probability

Slope gradients and morphology and the specific location of downslope houses were assessed to determine whether a landslide or debris flow could reach a house ($P_{S:H}$) according to Table 5-8.

### 5.4.3 Qualitative Risk Analysis at Corona Crescent Residential Properties

Slope gradients and morphology and the specific location of downslope houses were assessed to determine whether a landslide or debris flow could reach a house ($P_{S:H}$) according to Table 5-8.

There are 7 properties in the Corona Crescent – Thermal Drive area with a High or Very High risk rating (Figure 1-2). This means that there is at least a High risk that a landslide or debris flow could be initiated at these properties and reach a downslope house.  Several other properties in this area have more gentle ravine slopes below, less fill and fewer instability indicators, but are still of Moderate risk.

### Table 5-8 Qualitative Spatial Probability, Corona Crescent Area

| Qualitative Spatial Probability Rating | Criteria From Field and Background Information |
|---|---|
| **High** | • Element is within estimated travel distance (<150 m) of landslides or debris flows.<br>• Element is near or within a ravine bottom which could direct falling, sliding or flowing soil material and logs from above toward the element;<br>• No shape features on the slope offer protection from falling, sliding or flowing soil material and logs travelling toward the element. |
| **Moderate** | • Element is at outer estimated travel distance (200 to 500 m) of landslides or debris flows.<br>• Element is near edge of a ravine bottom which could direct debris movement toward the element.<br>• Some slope features offer protection from falling, sliding or flowing soil material and logs from above.<br>• Ridges and hollows direct some water or debris away from the element. |
| **Low** | • Element is beyond estimated travel distance (>500 m) of landslides or debris flows.<br>• Element is well outside ravine bottom which would direct falling, sliding or flowing soil material and logs from above toward the element;<br>• Element is protected by the shape of the slope above. |

**Table 5-9 Partial Risk Analysis for Identified Properties, Corona Crescent Area**

| | Coquitlam Address | $P_{H1}$ Open Slope | $P_{H2}$ Channel-ized | Total $P_H$ | $P_{S:H}$ | Qualitative Partial Risk | Receiving Ravine or Street | Downslope or Downstream Affected Properties or Features |
|---|---|---|---|---|---|---|---|---|
| 85 | 967 Thermal Drive | Low | Moderate | Low | High | Moderate | Suter | 2242 Park Cres. |
| 86 | 969 Thermal Drive | Low | Moderate | Low | High | Moderate | Suter | 2242 Park Cres. |
| 87 | 971 Thermal Drive | Low | Moderate | Low | High | Moderate | Suter | 2242 Park Cres. |
| 88 | 977 Thermal Drive | Moderate | Moderate | Moderate | High | High | Suter | 2242 Park Cres. |
| 89 | 983 Thermal Drive | Low | Moderate | Low | High | Moderate | Suter | 2242 Park Cres. |
| 90 | 1000 Thermal Drive | High | Moderate | High | Low | Moderate | Dallas | Dallas Creek |
| | | | | | | | | |
| 91 | 968 Corona Cres. | Low | Moderate | Low | High | Moderate | Suter | 2242 Park Cres. |
| 92 | 972 Corona Cres. | Low | Moderate | Low | High | Moderate | Suter | 2242 Park Cres. |
| 93 | 976 Corona Cres. | Moderate | Moderate | Moderate | High | High | Suter | 2242 Park Cres. |
| 94 | 980 Corona Cres. | Moderate | Moderate | Moderate | High | High | Suter | 2242 Park Cres. |
| 95 | 984 Corona Cres. | High | Moderate | High | High | Very High | Suter | 2242 Park Cres. |
| 96 | 988 Corona Cres. | Moderate | Moderate | Moderate | High | High | Suter | 2242 Park Cres. |
| 97 | 990 Corona Cres. | High | Moderate | High | High | Very High | Suter | 2242 Park Cres. |
| 98 | 992 Corona Cres. | High | N/A | High | High | Very High | Park Cres. | 2244, 2242 Park Cres. |
| 99 | 998 Corona Cres. | Low | N/A | Low | High | Moderate | Park Cres. | 2246, 2247 Park Cres. |
| 100 | 1000 Corona Cres. | Low | N/A | Low | High | Moderate | Park Cres. | 2247, 2251, 2255 Park Cres. |
| 101 | 1004 Corona Cres. | Low | N/A | Low | High | Moderate | Park Cres. | 2255, 2259 Park Cres. |
| 102 | 1008 Corona Cres. | Low | Moderate | Low | High | Moderate | Park Cres. | 2263, 2267, 2271 Park Cres |
| 103 | 1012 Corona Cres. | Low | Moderate | Low | High | Moderate | Park Cres. | 2271 Park Cres |
| 104 | 1016 Corona Cres. | Low | Moderate | Low | High | Moderate | Park Cres. | 2271 Park Cres |
| 105 | 1020 Corona Cres. | Low | Moderate | Low | High | Moderate | Park Cres. | 2271 Park Cres |
| 106 | 1024 Corona Cres. | Low | Moderate | Low | High | Moderate | Suter | Suter Brook |
| 107 | 1028 Corona Cres. | Low | Moderate | Low | High | Moderate | Suter | Suter Brook |
| | | | | | | | | |
| 108 | 2234 Park Cres. | Low | Moderate | Low | High | Moderate | Park Cres. | 2242 Park Cres. |

N/A: Not applicable

**N.B.: Downslope properties exposed to landslides are indicated on Figure 1-2 as "Exposed".**

Ten specific properties on Park Crescent have been identified that are located downslope of Corona Crescent and Thermal Drive properties and could be impacted by landslides originating from these properties. These properties are highlighted on Figure 1-2 as “Exposed” and discussed in Section 6.3.

Based on the risk value and site visit, brief recommendations are provided on the property sheets for monitoring or future geotechnical evaluation.

## 5.5 QUALITATIVE PARTIAL RISK ANALYSIS FOR RETROGRESSIVE LANDSLIDES AT THE RAVINE CREST

At the 108 residential properties, it is possible that a retrogressive landslide (one that causes a headscarp notch into the upland edge) may initiate at the ravine crest and the resulting soil loss undermine or displace the house foundations or City pipe infrastructure. The qualitative partial risk analysis follows the procedure defined previously.

### 5.5.1 Ravine Crest Retrogressive Landslide Hazard

The landslide hazards previously estimated for open slope failures (Table 5-3) are used for the hazard component of the risk analysis.

### 5.5.2 Ravine Crest Spatial Probability

The spatial probability is rated as Low, Moderate or High, based on the estimated retrogression of the headscarp toward the existing houses or City pipe infrastructure (Table 5-10).

It was observed that the upper slope crest was not scalloped or notched due to landslide headscarp retrogression into the upland edge. The ravine crests are formed of over-consolidated Vashon glacial till or Quadra Sands (waterlain sediments) which generally do not exhibit retrogressive failures The upslope spatial hazard ratings (Table 5-10) reflect this observed spatial effect.

### 5.5.3 Ravine Crest Retrogressive Landslide Risk Analysis

The risk analysis for retrogressive landslides at the ravine crest is presented in Table 5-11. Three properties were determined to have High or Very High risk based on the landslide hazards and the spatial probabilities:

- 1037 Gatensbury Road, Port Moody
- 845 Catherine Ave, Coquitlam
- 1000 Thermal Drive, Coquitlam

**Table 5-10 Spatial Probability for Retrogressive Landslides, Chines Escarpment and Corona Crescent Areas**

| $P_{S:H}$ | Qualitative Spatial Probability Rating | Criteria From Field and Background Information |
|---|---|---|
| **Probability Of Interaction At Ravine Crest** | **High** | • Elements at risk less than 3 m behind estimated landslide headscarp.<br>• House foundations or pipes set back less than 3 m so that remedial measures could not be completed before impacted. |
| | **Moderate** | • Elements at risk 3 to 7 m behind estimated landslide headscarp.<br>• House foundations or pipes set back sufficiently that remedial measures could be completed before impacted. |
| | **Low** | • Elements at risk at least 7 m behind estimated landslide headscarp.<br>• House foundations or pipes set back sufficiently that remedial measures could be completed before impacted. |

In addition, 944 Canyon Court is rated as Moderate and is located close (about 3 m) to the ravine crest where some minor subsidence was noted.

The 1037 Gatensbury Road location has patio and possibly house foundations close to the crest.

Since the slope assessments, further engineering works have been completed at 1000 Thermal Drive which are understood to have reduced the overall risk (Horizon Engineering 2013). At 845 Catherine Avenue, the slopes have had previous geotechnical assessment by Golder Associates (1996, 1998 and 1999).

The High and Very High risk ratings indicate that potential ravine crest retreat may result in partial loss of house or City pipe infrastructure foundation support, requiring a geotechnical assessment. Any foundation engineering reports prepared for the owners of the three locations should be shared with the respective City.

**Table 5-11 Partial Risk Analysis for Retrogressive Landslides, Chines Escarpment and Corona Crescent Areas**

| | Port Moody Address | $P_H$ Upslope Effects | $P_{S:H}$ Upslope Effects | Qualitative Partial Risk |
|---|---|---|---|---|
| 1 | 994 Seaforth Way | Low | Low | Very Low |
| 2 | 998 Seaforth Way | Low | Low | Very Low |
| 3 | 1000 Seaforth Way | Low | Low | Very Low |
| | | | | |
| 4 | 910 Ingersoll Ave. | High | Low | Moderate |
| | | | | |
| 5 | 1037 Gatensbury Dr. | Moderate | High | High |
| | **Coquitlam Address** | **$P_H$ Upslope Effects** | **$P_{S:H}$ Upslope Effects** | **Qualitative Partial Risk** |
| 6 | 824 Ingersoll Ave. | Low | Low | Very Low |
| 7 | 826 Ingersoll Ave. | Low | Low | Very Low |
| 8 | 830 Ingersoll Ave. | High | Low | Moderate |
| | | | | |
| 9 | 845 Catherine Ave. | High | High | Very High |
| 10 | 858 Catherine Ave. | Very Low | Low | Very Low |
| | | | | |
| 11 | 841 Wyvem Ave. | Very Low | Low | Very Low |
| 12 | 824 Miller Ave. | Very Low | Low | Very Low |
| 13 | 796 Adiron Ave. | Low | Low | Very Low |
| | | | | |
| 14 | 992 Kinsac St. | Low | Low | Very Low |
| 15 | 994 Kinsac St. | Low | Low | Very Low |
| 16 | 996 Kinsac St. | Low | Low | Very Low |
| | | | | |
| 17 | 1010 Blue Mountain St. | Moderate | Low | Low |
| 18 | 1015 Blue Mountain St. | Low | Low | Very Low |
| 19 | 1020 Blue Mountain St. | Moderate | Low | Low |
| | | | | |
| 20 | 925 Selkirk Cres. | Low | Low | Very Low |
| | | | | |
| 21 | 1361 Chine Cres. | Low | Low | Very Low |
| 22 | 1363 Chine Cres. | Moderate | Low | Low |
| 23 | 1369 Chine Cres. | Low | Low | Very Low |
| 24 | 1371 Chine Cres. | Low | Low | Very Low |
| 25 | 1373 Chine Cres. | Low | Low | Very Low |
| 26 | 1377 Chine Cres. | Low | Low | Very Low |
| 27 | 1381 Chine Cres. | Low | Low | Very Low |
| 28 | 1385 Chine Cres. | Low | Low | Very Low |
| | | | | |
| 29 | 1445 Harbour Drive | Low | Low | Very Low |
| 30 | 1455 Harbour Drive | Moderate | Low | Low |

**Table 5-11 Partial Risk Analysis for Retrogressive Landslides, Chines Escarpment and Corona Crescent Areas**

| | Coquitlam Address | $P_H$ Upslope Effects | $P_{S:H}$ Upslope Effects | Qualitative Partial Risk |
|---|---|---|---|---|
| 31 | 1501 Marine Cres. | Low | Low | Very Low |
| 32 | 1507 Marine Cres. | Low | Low | Very Low |
| 33 | 1513 Marine Cres. | Low | Low | Very Low |
| 34 | 1519 Marine Cres. | Low | Low | Very Low |
| 35 | 1525 Marine Cres. | Low | Low | Very Low |
| 36 | 1531 Marine Cres. | Moderate | Low | Low |
| 37 | 1537 Marine Cres. | Low | Low | Very Low |
| 38 | 1543 Marine Cres. | Low | Low | Very Low |
| 39 | 1553 Marine Cres. | Moderate | Low | Low |
| 40 | 1563 Marine Cres. | Low | Low | Very Low |
| | | | | |
| 41 | 937 Canyon Court | Low | Low | Very Low |
| 42 | 941 Canyon Court | Low | Low | Very Low |
| 43 | 944 Canyon Court | Low | High | Moderate |
| 44 | 945 Canyon Court | Moderate | Low | Low |
| | | | | |
| 45 | 1335 Harbour Drive | Low | Low | Very Low |
| 46 | 1769 Harbour Drive | Low | Low | Very Low |
| 47 | 1773 Harbour Drive | Low | Low | Very Low |
| 48 | 1777 Harbour Drive | Low | Low | Very Low |
| 49 | 1781 Harbour Drive | Low | Low | Very Low |
| 50 | 1785 Harbour Drive | Moderate | Low | Low |
| 51 | 1789 Harbour Drive | Moderate | Low | Low |
| 52 | 1791 Harbour Drive | Low | Low | Very Low |
| 53 | 1793 Harbour Drive | Low | Low | Very Low |
| 54 | 1797 Harbour Drive | Moderate | Low | Low |
| 55 | 1801 Harbour Drive | Low | Low | Very Low |
| 56 | 1805 Harbour Drive | Low | Low | Very Low |
| 57 | 1807 Harbour Drive | Low | Low | Very Low |
| 58 | 1822 Harbour Drive | Low | Low | Very Low |
| 59 | 1826 Harbour Drive | Low | Low | Very Low |
| 60 | 1830 Harbour Drive | Low | Low | Very Low |
| 61 | 1834 Harbour Drive | Low | Low | Very Low |
| 62 | 1838 Harbour Drive | Low | Low | Very Low |
| 63 | 1842 Harbour Drive | Low | Low | Very Low |
| 64 | 1846 Harbour Drive | Moderate | Low | Low |
| 65 | 1850 Harbour Drive | Low | Low | Very Low |
| 66 | 1861 Harbour Drive | Low | Low | Very Low |
| | | | | |
| 67 | 921 Fresno Place | Low | Low | Very Low |
| 68 | 925 Fresno Place | Low | Low | Very Low |
| 69 | 928 Fresno Place | Low | Low | Very Low |
| 70 | 932 Fresno Place | Low | Low | Very Low |

**Table 5-11 Partial Risk Analysis for Retrogressive Landslides, Chines Escarpment and Corona Crescent Areas**

| | Coquitlam Address | $P_H$ Upslope Effects | $P_{S:H}$ Upslope Effects | Qualitative Partial Risk |
|---|---|---|---|---|
| 71 | 936 Fresno Place | Very Low | Low | Very Low |
| 72 | 940 Fresno Place | Very Low | Low | Very Low |
| | | | | |
| 73 | 1904 Bowman Ave. | Low | Low | Very Low |
| | | | | |
| 74 | 1919 Custer Court | Very Low | Low | Very Low |
| 75 | 1927 Custer Court | Low | Low | Very Low |
| 76 | 1933 Custer Court | Low | Low | Very Low |
| 77 | 1943 Custer Court | Very Low | Low | Very Low |
| 78 | 1953 Custer Court | Very Low | Moderate | Low |
| 79 | 1963 Custer Court | Very Low | Moderate | Low |
| 80 | 1973 Custer Court | Very Low | Low | Very Low |
| 81 | 1975 Custer Court | Very Low | Low | Very Low |
| | | | | |
| 82 | 805 Northview | Low | Low | Very Low |
| 83 | 830 Ultra Court | Low | Low | Very Low |
| 84 | 838 Ultra Court | Very Low | Low | Very Low |
| | | | | |
| 85 | 967 Thermal Drive | Low | Low | Very Low |
| 86 | 969 Thermal Drive | Low | Moderate | Low |
| 87 | 971 Thermal Drive | Low | Low | Very Low |
| 88 | 977 Thermal Drive | Low | Moderate | Low |
| 89 | 983 Thermal Drive | Low | Low | Very Low |
| 90 | 1000 Thermal Drive | High | Moderate | High |
| | | | | |
| 91 | 968 Corona Cres. | Low | Low | Very Low |
| 92 | 972 Corona Cres. | Low | Moderate | Low |
| 93 | 976 Corona Cres. | Low | Low | Very Low |
| 94 | 980 Corona Cres. | Low | Low | Very Low |
| 95 | 984 Corona Cres. | Low | Low | Very Low |
| 96 | 988 Corona Cres. | Low | Low | Very Low |
| 97 | 990 Corona Cres. | Low | Low | Very Low |
| 98 | 992 Corona Cres. | Low | Low | Very Low |
| 99 | 998 Corona Cres. | Low | Low | Very Low |
| 100 | 1000 Corona Cres. | Low | Low | Very Low |
| 101 | 1004 Corona Cres. | Low | Low | Very Low |
| 102 | 1008 Corona Cres. | Low | Low | Very Low |
| 103 | 1012 Corona Cres. | Low | Low | Very Low |
| 104 | 1016 Corona Cres. | Low | Low | Very Low |
| 105 | 1020 Corona Cres. | Low | Low | Very Low |
| 106 | 1024 Corona Cres. | Low | Low | Very Low |
| 107 | 1028 Corona Cres. | Low | Low | Very Low |
| 108 | 2234 Park Cres. | Low | Low | Very Low |

# 6 Phase 3 Geotechnical Assessment

## 6.1 INTRODUCTION

Phase 3 geotechnical assessment work should be considered at all properties identified herein with partial risk levels of High or Very High. The purpose of the Phase 3 geotechnical assessment will be to provide key site soil, water and spatial information for analysis and development of geotechnical recommendations.

The geotechnical assessment work could include an initial site walk-through to verify the requirement for a detailed assessment. The geotechnical professional may request a topographic survey to determine the locations and elevations of structures, the slope gradients, the location of tops and bases of slopes, the location of streams, seepage tracks and drainage infrastructure, and the location and elevation of survey markers for use during the geotechnical assessment.

The geotechnical professional would assess which properties and locations will require in-situ soil or fill identification and strength testing. A small geotechnical drill rig or backhoe could be used to work in the restricted backyard and slope areas. If thick and potentially unstable fill is present, the best method for removal or relocation would be determined.

The geotechnical reports held at the City Engineering Libraries at Coquitlam and Port Moody should be researched for previous drill testing, and other subsurface studies, which may provide additional background information and data for the test locations.

The following sections describe conditions at several sites in the Chines Escarpment and Corona Crescent areas where geotechnical assessment may be considered.

## 6.2 RECOMMENDATIONS FOR INDIVIDUAL PROPERTIES FOR MONITORING AND GEOTECHNICAL ASSESSMENT

Geotechnical investigations of soil and groundwater conditions at individual High and Very High Risk properties will take place, to allow individual geotechnical assessments, slope "factor of safety" calculations and seismic stability assessment.

Until the Phase 3 geotechnical investigations are initiated, recommendations are provided for property owners in Sections 6.2.1 to 6.2.3, for the various partial risk levels.

### 6.2.1 Recommendations for Low and Very Low Partial Risk Properties

These recommendations apply to the properties identified as "Low and Very Low Risk" in Tables 5-7 and 5-9.

**A geotechnical assessment is not required at this time. If there is any evidence of slope movement, water erosion or drainage problems on the property or nearby, we recommend that the property owner immediately contact the City and also immediately engage a geotechnical engineer to conduct an assessment.**

At the time of the site visit, there were no signs of imminent landslide initiation or erosion conditions that would require further assessment by a geotechnical engineer. If conditions change, and any of the following occurs: e.g. a landslide or water erosion, loss of ravine crest soil downslope, failure of fill, development of tension cracks, heavy slope seepage, subsidence or other conditions on or near the steep slope, then further assessment by a geotechnical engineer will be required immediately.

### 6.2.2 Recommendations for Moderate Partial Risk Properties

For Moderate partial risk properties, the property owner will need to take more pro-active action to determine the slope and water conditions, monitor these at critical times and take appropriate action if problems occur. The following recommendations apply to these sites:

**The City and the Property Owner should share relevant engineering and surveying reports.**

**The Property Owner must be pro-active and review the slopes and ravine crest area during and after times of heavy rainfall or snowmelt to monitor slope stability and check for erosion. If there is any evidence of slope movement, water erosion or drainage problems on the property or nearby, we recommend that the property owner immediately contact the City and also immediately engage a geotechnical engineer to conduct an assessment.**

In addition, we recommend geotechnical assessment of the slopes above the 10 properties on Park Crescent, where there is a Very High, High or Moderate risk at the properties above.

Additional site specific recommendations are provided on the individual property sheets.

### 6.2.3 Recommendations for High and Very High Partial Risk Properties

Recommendations for the property owners are provided on the property sheets for the High and Very High risk sites. These include:

**A geotechnical assessment of the slope stability is required.**
**In the Phase 3 geotechnical assessments, investigations of subsurface soil composition, distribution and strength, and water conditions, will be required.**

**The property owner should contact the City of Coquitlam or City of Port Moody and exchange any previous geotechnical engineering or other reports, construction designs, maps or letters, to ensure that the property boundaries, the nature of slope stability conditions and previous stability assessments are mutually understood.**

**The Property Owner must be pro-active and review the slopes and ravine crest area during and after times of heavy rainfall or snowmelt to monitor slope stability and check for erosion. If there is any evidence of slope movement, water erosion or drainage problems on the property or nearby, we recommend that the property owner immediately contact the City and also immediately engage a geotechnical engineer to conduct an assessment.**

Additional site specific recommendations are provided on the individual property sheets related to drainage, presence of fill and integrity of structures.

The City of Coquitlam has issued guides regarding Best Site Development Practices (City of Coquitlam 2005), and Retaining Wall Stability and Maintenance (City of Coquitlam 2008) which the property owners should consult. The property owner may choose to engage their own geotechnical engineer to determine the property risk conditions and what actions are required to ensure stability of the property and those lands and properties downslope and downstream.

## 6.3 CORONA CRESCENT – THERMAL DRIVE - PARK CRESCENT AREAS

In the Corona Crescent – Thermal Drive – Park Crescent areas, High and Very High partial risk results were obtained at a number of properties. Geotechnical assessment is recommended in Phase 3.

### 6.3.1 Corona Crescent Area

The fill areas located at and below the slope crest at the following six addresses should be investigated through a geotechnical assessment.

- 976 Corona Crescent
- 980 Corona Crescent
- 984 Corona Crescent
- 988 Corona Crescent
- 990 Corona Crescent
- 992 Corona Crescent

At these six properties, if significant thicknesses of fill with poor soil strength and drainage characteristics are found by visual assessment or hand augering, then geotechnical drilling or test pit excavation should be considered. If fill is found extending onto other nearby properties, this should also be assessed.

The fill deposited on City of Coquitlam land in Chineside Ravine and Natural Area Park off the 900 block of Thermal Drive should be assessed and if required, tested for thickness, composition and stability. This fill is located upslope of a ravine system leading down to several houses on Park Crescent near the head of Suter Brook. The fill exhibits subsidence features and downslope creep and is located above old natural ravines which had landslides in the distant past.

### 6.3.2 Park Crescent

Because of Very High, High and Moderate $P_{H:A}$ values at upslope properties, we recommend a geotechnical assessment upslope of the following 10 Exposed properties on Park Crescent:

- 2242 Park Crescent
- 2244 Park Crescent
- 2246 Park Crescent
- 2247 Park Crescent
- 2251 Park Crescent
- 2255 Park Crescent
- 2259 Park Crescent
- 2263 Park Crescent
- 2267 Park Crescent
- 2271 Park Crescent

Backhoe test pits may be considered at the lower slope above these Park Crescent properties in order to determine if deposits from previous landslides are present. The slope should also be tested and modelled for stability as it is located immediately above houses on Park Crescent. If slope conditions of concern are found extending onto other nearby properties, these should also be assessed.

At 2251 and 2259 Park Crescent, surface water flow was noted in late March 2013 which flowed downslope into back yards. This was after wet spring weather conditions where about 0.4 m rainfall occurred between about mid-February and mid-March 2013, as indicated by the nearby weather station at Como Lake Avenue (Environment Canada 2013). Some of this surface flow carried fine sediment which was deposited in the back yards. It is unknown if this surface water is from roof and foundation drainage from upslope properties, or from groundwater outflow, or from City pipe infrastructure. The City and property owners should work together to investigate and resolve these drainage issues.

At 2271 Park Crescent, a creek drains downslope to this property from steeper slopes above. The creek may source at an old City stormwater pipe outlet. The creek flows in a small gully on the slope, but appears poorly confined to the west where it flows north in a ditch across the east edge of 2271 Park Crescent, just below the hill slope. The creek did not have evidence of recent high volume or erosive water flows. It is understood that this surface water is added to Suter Brook north of the property. This creek should be assessed and monitored in regard to potential floods or slope stability issues.

The east slope of Suter Brook ravine below the residences at 976 through to 1000 Corona Crescent has seepage, seasonal surface streams, and some water-loving vegetation (skunk cabbage, maples, and others). This ravine slope area is a wet location below the ravine crest and beside and above other houses. It is unknown if this is an area of preferred groundwater outflow, an area where surface water flow is not captured by City infrastructure, or if there are infrastructure pipe leakage issues. The City should investigate the drainage conditions to determine the causes and possible resolutions to the seepage and wet soil conditions. This drainage investigation should be given high priority as this wet area has houses upslope of other houses. It is not known how this wet slope would behave during a strong earthquake. Consideration may be given to installation of horizontal drains into the slope, further surface drainage infrastructure or other drainage improvements. Slope stability modelling may be required.

### 6.3.3 Thermal Drive

The property at 977 Thermal Drive had a High risk rating due to steep slopes below the crest, and the routing of site drainage water (house roof, possible garage roof and driveway/patio surface) by at least two plastic drainage pipes to the steep slopes, which have evidence of surface water erosion and no armour at the pipe outlets. The property owner and the City of Coquitlam must work together regarding disposal of roof and foundation water as piping it to the steep slope is unsuitable and may lead to erosion or landslide conditions.

## 6.4 POTENTIAL RETROGRESSIVE LANDSLIDE SITES, GATENSBURY ROAD AND CANYON COURT

The property 1037 Gatensbury Road along the Chines Escarpment ravine crest has a high qualitative risk rating for retrogressive landslides and may require geotechnical assessment. In addition, the property 944 Canyon Court has a moderate risk but is within 3 m of the crest.

The high qualitative risk indicates that potential retrogression due to landslides at the ravine crest may result in partial loss of foundation support, requiring a geotechnical assessment of the house foundations and remediation measures.

The other high qualitative risk properties: 845 Catherine Avenue and 1000 Thermal Drive have already had geotechnical assessments.

While some other houses had foundations within 7 m of the ravine crest, it is estimated, based on the available evidence, that any potential landslide effect in the over-consolidated glacial till or waterlain sediments at the crest would not tend to undermine the house foundations. If some minor loss of the ravine crest occurred, the house foundations or City infrastructure pipes are set back sufficiently that geotechnical engineering remedial measures such as slope regrading, engineered retaining walls, soil nailing, drainage improvements or other remedial measures could be completed before impacts occur.

## 6.5 CATHERINE – INGERSOLL AVENUES AREA

Properties along the west side of Schoolhouse Creek were noted to have fill consisting of mineral soil and asphalt and concrete debris along the crest and upper ravine slope which was likely end-dumped from trucks during initial land development. The City of Coquitlam's consultants have previously conducted geotechnical investigations, piezometer monitoring and horizontal drain installation in this area.

Further geotechnical and surface drainage assessment is recommended. Test boreholes should be considered for the ravine crest in the Catherine – Ingersoll Avenue area to determine the extent, depth, and soil strength and groundwater characteristics of the fill deposits at the edge of the Schoolhouse Creek ravine. This would include the backyards of houses at 830 Ingersoll Avenue and 845 Catherine Avenue (Coquitlam), and the apartment parking lot edge at 910 Ingersoll Avenue (Port Moody). Piezometers and inclinometers could be installed to determine the seasonal groundwater changes and possible slow movement of fill into the ravine. The Golder Associates borehole installations from the 1990s and 2000s (Golder 1996, 1998, 1999, 2010) near Catherine Avenue may still be usable, and could form part of a network.

Drainage concerns at 910 Ingersoll Avenue must be addressed by the property owner and the City of Port Moody. Based on site evidence, we interpret that within the last several years, parking lot drainage water was diverted along the outer curb, and out onto the fill slope and native soils and caused a landslide or erosion feature several metres wide, two metres deep and over 20 m long. Other water erosion features are also present. Correction of the problem may require stormwater drainage planning, installation of suitable collection basins and stormsewer pipes, and landslide and erosion reclamation. The current elevations and locations of the drainage grates allow water to flow past and into the ravine.

## 6.6 LARGE FILL AREAS

Test boreholes should also be considered for the Seaview Drive, Wyvem Avenue, Miller Avenue, Adiron Avenue and Northview Place large fill disposal areas reviewed as part of this study. The fill depth and stability and the groundwater characteristics should be determined. These large fill sites sit above the larger and more gentle gradient Schoolhouse Creek and Correl Brook ravines.

Other large fill areas along the escarpment were mapped previously (Thurber 1988), including the north end of Kinsac Street, the north end of Poirier Street, and east of Ultra Court on Thermal Drive. Test boreholes should also be considered for these locations. Other large fill areas have been described by local residents and engineers (Now 2005), such as at the north end of Bend Court which was not assessed in this study.

## 6.7 1455 HARBOUR DRIVE

The City retaining wall and underground city storm sewer installation at 1455 Harbour Drive, at the head of West Sundial Creek, should be investigated through review of the installation reports and inspection of the current retaining wall and stormsewer pipe conditions. If necessary, geotechnical assessment of the retaining wall and the fill behind should be completed to assess the stability conditions. While the outside boulder and concrete wall has hairline cracks, some concrete panels above the wall have subsided several centimeters. Some minor subsidence has occurred in the fill soil above the stormwater pipe and it should be determined if water leakage is occurring.

## 6.8 CANYON COURT AND EAST SUNDIAL CREEK

Five properties on the north and east sides of Canyon Court were chosen for partial risk analysis based on the steep ravine slopes indicated on the topographic maps and aerial photographs.

During assessment of the properties, it was discovered that active slope erosion was occurring below 945 Canyon Court on the west side of the East Sundial Creek ravine, with evidence that similar erosion had occurred in the past just upstream. The active slope erosion was on a steep till slope where surface water flow and erosion had carried more than several cubic metres of sediment downslope, into East Sundial Creek and downstream for a distance. The source of the surface water flow was not obvious and the headscarp area was too dangerous and unstable to hike into for detailed examination. It is inferred that a subsurface drainage pipe collects water from roof, foundation and/or driveway areas and discharges at the top of a steep ravine slope about 20 m high, causing erosion.

The City and the private land owner should conduct a drainage assessment and determine options re: connecting the drainage pipes to a City stormsewer. Continued pipe drainage and erosion under the current arrangement will eventually cause the steep erosion headscarp to retrogress west into the back yard. Sediment should not be added to East Sundial Creek as this will cause further stream erosion, and it is likely the creek is fish-bearing in the lower reaches.

North of Harbour Drive in the uppermost part of the ravine, East Sundial Creek flows in a sub-surface stormwater pipe. Only a little surface flow is present in the ravine bottom, and this flow is not itself causing erosion and destabilization of ravine slopes. It appears that the ravine section on East Sundial Creek was previously eroded before the stormwater flow was piped, and that the erosion faces are still retrogressing up the ravine sides, towards the private property yards. In addition, the outlet and energy dissipater at the end of the stormwater pipe has fallen away from the pipe end, such that erosion is occurring into the local Quadra Sand unit from the water flow and spray.

The City of Coquitlam should conduct a review of the stormwater infrastructure in this area and complete the necessary repairs or upgrades so that water control and erosion reduction are achieved.

## 6.9 1000 THERMAL DRIVE, 1553 MARINE CRESCENT AND 1904 BOWMAN AVENUE

At these three properties, the wood tie retaining walls have undergone partial failure of upright posts or lateral ties, such that the walls are bowed out, and further wall failure and soil loss are likely to occur unless the retaining walls are repaired or replaced.

At the direction of the City of Coquitlam, Horizon Engineering (2013) completed a geotechnical assessment of the 1000 Thermal Drive location, as the soil behind the wooden retaining wall had subsided and a tension crack formed in the back yard soil. There was another tension crack below the retaining wall in surface fill deposits on the south side of the property. Horizon provided several recommendations, which included fill removal, installation of a lock block retaining wall replace the wooden retaining walls, and other site repairs completed. We completed a partial risk analysis of this location, and observed the same slope instability features. The City indicates that the engineering recommendations had been carried out at the site.

At 1553 Marine Crescent, there was only a small amount of displacement visible in the wood retaining wall; however, a tension crack about 4 m long and 5 cm wide had formed in the backyard soil. As well, the retaining wall timbers showed water marks between the ties indicating seepage issuing out from behind the wall. The property owner must decide on repair, upgrading, replacement or removal of the retaining wall. A geotechnical assessment is recommended for this site; however, the City and property owner should discuss the course of action.

At 1904 Bowman Avenue, a long wood retaining wall has had a number of the upright posts break or the footing soils fail, resulting in displacement of some of the horizontal wood ties, and a bulging out of the wall. Inspection of the back yard and nearby slope area did not locate any tension cracks; however these may be obscured. It is recommended that the property owner have a geotechnical assessment completed for this site. The property owner must decide on repair, upgrading, replacement or removal of the retaining wall. The City and property owner should discuss the course of action for this site.

## 6.10 PORT MOODY DEBRIS FLOW HAZARD ZONES

Investigations by Thurber (1988) helped establish the debris flow and flood hazard zones used by Port Moody for development permit areas.

The catch basins, debris flow racks and dewatering structures at the ravine mouths should be reviewed as required for storage capacity, ability to contain debris flows or debris floods, ability to capture and dewater debris flows, and the need for removal of accumulated debris. The modelling of debris flows has progressed significantly since the structures were designed and constructed, and the capacities and function of the structures should be periodically reviewed.

## 6.11 CALEDONIA CREEK, CITY OF COQUITLAM

It is recommended that the City of Coquitlam engage a qualified professional to conduct a slope stability assessment of the City land west of the former 2009 Corona Crescent debris flow at Caledonia Creek to determine the cause of downslope leaning trees and a downslope bulge in the concrete retaining wall. This area sits a short distance uphill of houses in the City of Port Moody.

## 6.12 OUTBUILDING AND PATIO STABILITY, CITY OF COQUITLAM

The City and the property owners should have qualified professionals determine the foundation conditions and stability of wooden outbuildings located at 1363 Chines Crescent and 1563 Marine Crescent and a wooden patio located at 1785 Harbour Drive. These structures are atop or very near the ravine crest, with steep slopes immediately below. These buildings or patios are occupied by people for extended periods and any potential slope failures may cause the crest area to destabilize and the structure to fall or slide a long distance downslope.

# 7 Development Permit Requirements

## 7.1 COQUITLAM AND PORT MOODY DEVELOPMENT PERMIT REQUIREMENTS FOR HAZARDOUS OR STEEP LANDS

The Cities of Coquitlam and Port Moody have requirements in their Official Community Plans (OCPs) and through bylaws regarding development on hazardous and steep lands (City of Coquitlam 2005; City of Port Moody 2012). These requirements were reviewed in regard to this report's slope risk analysis results.

Coquitlam and Port Moody both require development permit applications and site assessments for development in specific areas to protect proposed houses and properties from hazardous conditions (landslides, erosion and other events). This is achieved through a permit process where verification of site suitability and identification of safeguards are necessary before council approval. The responsibility for the development permit and the supporting engineering and drainage studies, and the safety of the development and the liability arising from the development, rest with the property developer.

Coquitlam prepared a Guide to Best Site Development Practices (City of Coquitlam 2005) which consolidates City requirements regarding site development. For areas with slope hazards, the developer is required to have professionals conduct geotechnical and hydrogeological assessments in regard to subsurface soils, presence of fill, groundwater conditions, construction and building setbacks from slopes and ravines. The professionals must review the hazards above, below or beside the property which could adversely impact or be impacted by the proposed site development.

Coquitlam has issued a guide for residents regarding retaining wall development and maintenance (City of Coquitlam 2008). Several recommendations are provided in this document to improve slope safety near retaining walls, and advice is offered on what features might indicate slope, stability or drainage problems. Where problems are noticed, it is recommended that the property owner contact a structural or geotechnical engineer, and report problems on City property to the City. Where an older retaining wall was built without a building permit, the wall must be assessed and properly permitted to comply with current city bylaws. The City cautions that retaining walls constructed of wood (even treated wood) only last a limited time (Summit's estimate: 5 to 20 years) and require inspection and repairs or replacement. The responsibility for retaining wall monitoring and maintenance rests with the property owner where the wall is situated.

Port Moody has defined potentially hazardous lands which are presented as Maps 13 and 14 in the OCP, and Maps 5-1 and 5-2 in the Development Permit Guidelines. Port Moody requires in Steep Slope zones (>20% or $11^{o}$ for a minimum horizontal distance of 10 metres) a development application with a geotechnical report prepared by a professional engineer or geoscientist with expertise in slope stability.

In Port Moody, areas below the Chines Escarpment ravines have been defined in the OCP Hazardous Lands Map 13 as subject to direct debris flow (at the ravine mouths), indirect debris flow (just out from the ravine mouths),and floods (within about 4 blocks of the ravine mouths) (Port Moody 2012). We note that this zonation is in place even though catch basins and specialized drainage structures for floods and debris flows were installed at the ravine mouths in the 1980s.

The natural slope conditions which may represent higher risks include:

- Erosion and slope failures in the escarpment area;
- Debris flow or flooding risk at the outlets of the steep ravines, during major storms; and
- Soil susceptible to liquefaction during an earthquake.

Geotechnical investigations and reports are required for development permits for new houses and for construction that the City of Port Moody building inspector considers subject to flooding, debris flows, erosion, landsliding or other processes.

Where an application requires a geotechnical report, the application approval is subject to the submission of a covenant which can be registered in favour of the City, where the land owner agrees to use the land only in accordance to the covenant conditions and the geotechnical report, and the City is saved harmless from future natural hazard problems.

For Port Moody properties with development applications in these OCP defined hazard-zoned lands, a geotechnical report is required, which:

- Identifies and analyzes the specific risks at the site;
- Outlines mitigative measures in order to use the site safely, including setting the minimum elevation for habitable floor space; and
- Assesses how the development, the nearby drainage and the mitigative measures will affect risk at other nearby properties.

## 7.2 RECOMMENDATIONS FOR OFFICIAL COMMUNITY PLANS AND BYLAWS

1) Port Moody requires a development application with a geotechnical report in Steep Slope zones (>20%). In light of the present project's slope risk analyses, the 20% slope gradient appears to be a reasonable criterion in regard to potential landslide initiation, transport and deposition zones. This requirement should be continued.

2) For both Coquitlam and Port Moody, maintaining the existing library of previous geotechnical reports and allowing access to the collection for engineers and geoscientists conducting new investigations will allow more comprehensive assessments and recommendations, based on a better overall understanding of local soil, water, drainage and slope stability issues.

3) Both jurisdictions promote retention of natural vegetation and safe trees at development sites. This factor is important in maintaining the stability of the ravine crests and upper slopes near houses through maintenance of root strength, reduction of direct surface rainfall, and removal of some slope water by transpiration. Since the crests and slopes were in approximate equilibrium before

development while fully vegetated, removal of vegetation will tend to increase shallow slope movement, increase rainfall effects and reduce overall slope stability. There have been recent cases of tree topping and tree removal at the ravine crest and below which bylaw enforcement has dealt with. This should be monitored by bylaw staff.

4) For Coquitlam, specifications are given for “non-engineered” retaining wall construction up to 1.6 m high. Summit considers that these retaining wall specifications may be appropriate away from ravine areas, but we recommend that all retaining walls near ravines should be designed, constructed and maintained with engineer guidance. Provision of stable footings, drainage, stable fill and correct wall angle are very important where the site is subject to soil creep and focussed surface and subsurface drainage, such as near ravine crests. Large volumes of fill can be retained by a 1.6 m high retaining wall and the fill and retaining wall should not be exposed to slope and drainage conditions where initiation of a landslide may become possible.

5) Most geotechnical reports consider only the immediate development area and adjacent slopes but do not consider possible impacts on slopes some distance below. The OCPs and bylaws should direct the professional engineer/geoscientist to evaluate the entire downslope area of impact from possible water and landslide effects due to development at ravine crests.

6) The OCPs should require the geotechnical reports to outline where roof, driveway, patio and foundation drainage can be safely disposed of at sites where no stormsewer connection is available.

7) The OCPs should require the geotechnical reports to outline where previously-placed fill is located, assess if this fill should be removed from near and below the ravine crests during development or re-development and determine where the fill should be placed in a new stable location.

# 8 Summary and Recommendations

## 8.1 SUMMARY

A landslide partial risk analysis program was conducted for the Chines Escarpment and Corona Crescent areas in the Cities of Coquitlam and Port Moody in 2012 and 2013.

The goals were to:

1) Determine the probability that a landslide could occur at specific residential properties located at ravine crests, based on site inspections and existing topographic, geological, hydrological and other information;
2) Evaluate the spatial probability of a landslide impacting a house, and complete a partial risk analysis leading to a qualitative estimate of the risk associated with landslides;
3) Determine where geotechnical engineering assessment is recommended to confirm the risk analysis and develop more comprehensive mitigation recommendations (Phase 3); and
4) Review the current development requirements of the Cities of Coquitlam and Port Moody for slope hazard lands and provide comments and recommendations.

The partial risk analysis results are not intended to provide detailed, property-specific, full risk assessments, but rather to identify the properties requiring further geotechnical assessment.

Residential properties were developed in the 1940s through 1980s adjacent to the ravine crests and at the bottoms of slopes before modern steep land development requirements were in place, and before modern landslide risk analysis procedures were in use.

The residential properties to be assessed were chosen through interpretation of topographic and cadastral mapping, previous geotechnical reports, historic aerial photographs and modern orthophotographs. The properties assessed included:

- properties located at the top of steep ravine slopes where there are houses below;
- properties located close to historic landslide and stormwater erosion sites;
- properties near historic fill dumping sites;
- properties with soil fill or retaining walls near the crest; and
- properties with water mains or storm or sanitary sewer pipes near the slope crest.

Qualitative risk analysis was completed on 108 properties located along the Chines Escarpment and in Corona Crescent area. Site-specific information was collected to estimate the likelihood that a landslide would originate at the property. The spatial probability of a landslide impacting a house was identified through inspection of downslope and downstream features. A further 10 properties at the base of the ravines were also inspected to determine the exposure to potential landslide impacts from upslope.

The qualitative partial risk analysis used the methodology developed by Wise *et al.* (2004). This is a well-accepted methodology in B.C. for conducting partial risk analyses for landslides. The analysis provides an estimate of the combined probability that a landslide will occur and that it will reach a downslope house.

The analysis identified 7 High and Very High Risk properties. A further 30 properties were indicated as being Moderate Risk. The remaining 71 properties were determined to be Low or Very Low Risk. In the Corona Crescent area, 10 houses on Park Crescent were identified which are Exposed to landslide risk, based on the risk at upslope properties, and a slope morphology and threshold gradient review. Other recommendations to address landslide risk for specific properties are provided on property sheets in Appendix B.

The 7 High and Very High risk properties on Corona Crescent and Thermal Drive, and the slopes leading down from these properties should be evaluated by a geotechnical engineer during the future Phase 3 of this project. This geotechnical assessment work may include a preliminary visual assessment, and sub-surface soil and water geotechnical investigations.

Partial risk analysis of retrogressive landslides at the ravine crests was conducted for the 108 properties. The analysis indicated one very high, two high and three moderate risk properties. Previous geotechnical investigations had been completed at the very high risk site and one of the high risk sites. The remaining high risk site may require a geotechnical assessment.

Several large fill deposits and other smaller fill deposits in ravine parks and near roads were also investigated. Some properties along the west side of Schoolhouse Creek ravine have fill along the crest and upper ravine slopes. A slope erosion feature is present below a parking lot with drainage concerns. Geotechnical assessment and surface drainage review should be conducted at the noted sites.

The City of Coquitlam and City of Port Moody by-laws and planning requirements were reviewed regarding development near steep slopes and construction of retaining walls. Recommendations were provided for specific bylaw and planning issues.

## 8.2 RECOMMENDATIONS

As with all houses constructed above or below steep slopes, the risks from landslides cannot be reduced to zero, but only managed through control of land development. The following recommendations are provided for the City of Coquitlam and City of Port Moody in order to assist in management of the landslide risks:

1) The High and Very High partial risk sites on Corona Crescent and Thermal Drive, and certain of the Moderate partial risk sites in the Schoolhouse Creek ravine area should have Phase 3 geotechnical assessments completed as described in Section 7 and on the individual property sheets.

   The slopes below the High and Very High partial risk properties on Corona Crescent and Thermal Drive and above the 10 indicated Exposed properties on Park Crescent should have a geotechnical assessment re: landslide risk and exposure.

2) The fill deposit sites on Wyvem Avenue and Northview Place are large, and have steep slopes leading down to stream ravines (Schoolhouse Creek and Correl Brook, respectively) and should be monitored and have geotechnical investigations conducted if significant subsidence and imminent failure conditions are noted.

3) Seasonal visual checking of slope stability and drainage conditions from ravine access trails has been conducted by Metro Vancouver and their geotechnical consultants for ravines where previous slope failures or water erosion had occurred. These geotechnical reviews have high value and should continue. The access trails may require brushing and footpath reconstruction in order for staff to complete the slope and drainage reviews.

4) Where fill may have been placed to construct parts of the subgrade of City roads or widen road prisms which are beside ravine slopes (i.e. Gatensbury Road, Thermal Drive, Seaview Drive), some of this fill may have poor stability characteristics. The potential presence of fill beside and below the roads should be investigated, and any settling of fill should be monitored, especially where it is located above steep slopes. This fill may require removal.

5) For sites with Moderate, High or Very High risk, there are steps that the property owner and/or the Cities can take to reduce the risk, including:

   a) Discontinue placing new fill at the crest and upper ravine slope areas, and remove previously placed fill from those locations. If fill has been placed at the crest by the current owner, there are practical steps to reduce the risk of landslides, such as removal of the fill, relocation of fill to sites back from the crest, and better drainage and stabilization of the fill. If the fill was previously authorized by the City, the fill could be removed through property owner action or with City review and assistance. The assessment and removal of the fill should be conducted with review by a geotechnical engineer.

   b) Roof, foundation and driveway water drainage should ideally be directed to the storm sewer system and not disposed of onto the ravine slopes. In most locations, roof and foundation water is directed to the ravine crest through owner-installed plastic pipes. This may lead to erosion or wetting of slope soils and potential landslides. A program to upgrade property pipes to drain to the storm sewer system would reduce wetting and erosion of the ravine slopes.

   c) New retaining walls near ravine crests should be permitted through the by-law process, designed and constructed by qualified professionals, and inspected and maintained. Non-engineered retaining walls near the ravine crests should be inspected and repaired or removed if necessary.

   d) The street drainage should be directed away from the ravine slopes and collected in a stormwater management system. Street drainage should not be allowed to drain into driveways and toward the ravine slopes. The property owners and the Cities must ensure that street drainage is captured by the stormwater system.

e) The City water mains and storm and sanitary sewer pipes should be inspected and maintained to reduce the risk of broken or leaking pipes adding water to ravine slopes and causing landslides or erosion.

6) The 2011 Phase I field reviews outlined several locations where the corrugated plastic stormwater pipes which carry water down the ravine slopes were broken or disconnected. Previous landslides have occurred due to pipe failures near the crest. Inspections and replacement of the surface stormwater pipes should continue.

7) The Cities should act to limit causative factors for landslides related to water main and storm and sanitary sewer pipe conditions through inspection and maintenance of the pipes. The Cities should continue to implement the development permit process to guide construction of retaining walls and placement of fill on private property to reduce causative factors.

8) Three residential properties were identified where landslides originating at the ravine crest could remove soil from near or below house foundations, as the houses had been constructed at 2.5 m or less from the ravine crest. The property owners may have previously had engineering assessments prepared regarding the house foundations and soil conditions. Any recommendations therein should be implemented. For this project, it is recommended that these property owners take action to not direct drainage to near the ravine crest, not place further soil fill at the crest or below and engage a geotechnical engineer if any erosion, tension cracking, soil subsidence, slope seepage or other indicators of slope stability problems are observed. The respective City should be informed of any changes to the slopes near the house foundations.

# 9 Limitations

Subject to the following conditions and limitations, the investigation described in this report has been conducted in a manner consistent with a reasonable level of care and skill normally exercised by members of the B.C. geoscience profession currently practicing under similar conditions in the area.

1) The investigation described in this report has been limited to the scope of work described in the work program.

2) The findings and conclusions are valid only for the specific sites identified in the report.

3) Since site conditions may change over time, the report is intended for immediate use.

4) Subsurface soil and water conditions were inferred from surface observations. It is recommended that if subsurface soil or water conditions are encountered during construction excavations which are significantly different than those interpreted in this study, then a re-assessment of subsurface soil, drainage, slope stability, and proposed construction procedures should be completed by a qualified professional.

5) This Qualitative Partial Risk Analysis Report is based upon professional judgement and experience. Following the recommendations contained herein does not guarantee that landslides or floods will not occur. Natural variations are present in precipitation events, streamflow, groundwater flow, surficial material characteristics, surface and near surface soil water content, infiltration and drainage characteristics and other factors which may affect outcomes.

   This Qualitative Partial Risk Analysis is based upon landslides (e.g. open slope landslides and debris flows) occurring due to rainfall and snowmelt. Other processes such as liquefaction, earthquake-generated failures, soil excavations undermining slopes, or other processes are not included.

   This report is intended for the exclusive use of Metro Vancouver and the Cities of Coquitlam and Port Moody. It may not be used or relied upon in any manner whatsoever, or for any purpose whatsoever, by any other party. No other use and/or publication of information, data, statements, conclusions or abstracts regarding this report and data and cartographic results may be made without the written approval of Metro Vancouver and the Cities of Coquitlam and Port Moody. Associated Engineering makes no representation of fact or opinion of any nature whatsoever to any person or entity other than Metro Vancouver and the Cities of Coquitlam and Port Moody.

In accepting delivery of this report, Metro Vancouver and the City of Coquitlam and the City of Port Moody hereby agree that any and all claims which it may have against Associated Engineering or any of its servants, agents, or employees arising out of or in any way connected with the investigation described in this report or the preparation of this report, whether such claims are in contract or in tort, and whether such claims are based on negligence or otherwise, shall be limited to a total amount equal to the fees payable to Associated Engineering under our contract with Metro Vancouver.

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# A Appendix A - Investigation Methods

## A.1 PROPERTY ACCESS

In June 2012 and February/March 2013, the City of Coquitlam and the City of Port Moody delivered notification letters to the owners of the identified properties requiring slope assessment. The notices explained the program, indicated that slope assessment work was to be completed, and requested permission for property access. A page with Frequently Asked Questions and Answers was also provided. City staff also spoke in person with many of the residents to provide further information. In general, the property owners allowed access.

Where no permission for access had been granted, or where no contact had been achieved, the Cities conducted further discussions, and initiated legal notification to allow completion of the slope work. Slope assessment staff only entered private properties where permission had been given or where legal notification had been issued.

The slope assessments apply only to the specific sites visited or described, and not to other nearby properties which were not evaluated.

The slope assessments in June 2012 were conducted during full leaf-out of vegetation, which restricted viewing important surface details such as potential tension cracks, seepage sites, shallow landslide scars, and slope erosion problems. The slope assessments in March 2013 were completed before deciduous vegetation leaf-out, and the slopes and drainage were generally clearly viewed.

The list of properties identified for assessment is provided in Table A-1.

## A.2 RESIDENTIAL PROPERTY REVIEW

In advance of the 2012 slope assessments, Joe Alcock, P.Geo. met with Dana Soong, P.Eng. and Melanie Burton, A.Sc.T. of the City of Coquitlam on June 11, 2012 in the Chines Escarpment area to review the project goals, the methodology, and to discuss the assessment approach for the private residential land. Several other discussions were held to review access issues.

In preparation for the 2013 slope assessments, several discussions by phone and e-mail were held with Jozsef Dioszeghy, P.Eng. of the City of Coquitlam and Pouya Behzadi, P.Eng. of the City of Port Moody. In addition, Dana Soong met with Joe Alcock and Amanda Klein on March 28, 2013 to review the general program results and discuss the schedule. Amanda Klein, B. Tech. of Summit assisted with field investigations on June 11 and 12, 2012, and March 27 and 28, 2013.

At residential addresses where written or verbal permission had been received from the private property owner, Summit staff conducted the following procedure:

- Attempt to contact the home owner. If they were home, introduce ourselves, offer a business card, describe the work, and get the homeowner's permission to enter and do work on behalf of the City. If no-one was in, a business card was left at the front door.
- Enquire with the owner, if available, as to the property history, the disposal of soil from excavations, any subsequent slope or water issues, how the roof and foundation are drained, and other relevant site information. Many of the property owners offered useful site history and development information.
- In all cases, conduct the work so as to protect the home owner's privacy and security and not damage the landscaping, yard features or underground water or electrical lines or drainage pipes.
- For confidentiality, only the house address is provided on the property sheets and tables of results.

## Table A-1 Residential Properties In Chines Escarpment Area Chosen For Assessment

| | Address | Reason for Assessment | Letter Request Outcome | Slope Assessment |
|---|---|---|---|---|
| 1 | 994 Seaforth Way | Possible fill below | Yes | Yes |
| 2 | 998 Seaforth Way | Possible fill below | Yes | Yes |
| 3 | 1000 Seaforth Way | Possible fill below | Yes | Yes |
| 4 | 910 Ingersoll Ave. | Fill mapped below apartments | Yes; conferred with site manager before entering. | Yes |
| 5 | 1037 Gatensbury | Possible fill, small lot between road and steep slope | Notice | Yes |
| 6 | 824 Ingersoll Ave. | Fill mapped below | Yes | Yes |
| 7 | 826 Ingersoll Ave. | Fill mapped below | Yes | Yes |
| 8 | 830 Ingersoll Ave. | Fill mapped below | Yes | Yes |
| 9 | 845 Catherine Ave. | Fill mapped below | Yes | Yes |
| 10 | 858 Catherine Ave. | Fill mapped below | Yes | Yes |
| 11 | 841 Wyvem Ave. | Fill mapped below | Yes | Yes |
| 12 | 824 Miller Ave. | Fill mapped below | Yes | Yes |
| 13 | 796 Adiron Ave. | Fill mapped below | Yes | Yes |
| 14 | 992 Kinsac St. | Fill mapped, steep slope below | Yes | Yes |
| 15 | 994 Kinsac St. | Steep slope below, fill nearby | Yes | Yes |
| 16 | 996 Kinsac St. | Steep slope below | Yes | Yes |
| 17 | 1010 Blue Mountain St. | Fill mapped, tall steep slope below | Yes | Yes |
| 18 | 1015 Blue Mountain St. | Possible fill nearby | Yes | Yes |
| 19 | 1020 Blue Mountain St. | Possible fill nearby | Yes | Yes |
| 20 | 925 Selkirk Cres. | Steep below | Yes | Yes |
| 21 | 1361 Chine Cres. | Steep below | Yes | Yes |
| 22 | 1363 Chine Cres. | Steep below | Yes | Yes |
| 23 | 1369 Chine Cres. | Old failure mapped nearby | Yes | Yes |
| 24 | 1371 Chine Cres. | Steep below | Yes | Yes |
| 25 | 1373 Chine Cres. | Fill indicated | Yes | Yes |
| 26 | 1377 Chine Cres. | Steep below | Yes | Yes |
| 27 | 1381 Chine Cres. | Steep below | Yes | Yes |
| 28 | 1385 Chine Cres. | Steep below | Yes | Yes |
| | | | | |

| | Address | Reason for Assessment | Letter Request Outcome | Slope Assessment |
|---|---|---|---|---|
| 29 | 1445 Harbour Dr. | Steep head of West Sundial ravine, retaining wall | Yes | Yes |
| 30 | 1455 Harbour Dr. | Steep below | Yes | Yes |
| 31 | 1501 Marine Cres. | Steep below | Yes | Yes |
| 32 | 1507 Marine Cres. | Steep below | Yes | Yes |
| 33 | 1513 Marine Cres. | Steep below | Yes | Yes |
| 34 | 1519 Marine Cres. | Steep below | Yes | Yes |
| 35 | 1525 Marine Cres. | Headscarp near back edge property | Yes | Yes |
| 36 | 1531 Marine Cres. | Steep below | Yes | Yes |
| 37 | 1537 Marine Cres. | Steep below | Notice | Yes |
| 38 | 1543 Marine Cres. | Steep below | Yes | Yes |
| 39 | 1553 Marine Cres. | Steep below | Yes | Yes |
| 40 | 1563 Marine Cres. | Steep below | Yes | Yes |
| 41 | 937 Canyon Court | Previous erosion nearby, steep slopes below | Yes | Yes |
| 42 | 941 Canyon Court | Previous erosion nearby, steep slopes below | Yes | Yes |
| 43 | 944 Canyon Court | Previous erosion nearby, steep slopes below | Yes | Yes |
| 44 | 945 Canyon Court | Previous erosion nearby, steep slopes below | Yes | Yes |
| 45 | 1355 Harbour Dr. | Fill nearby | Yes | Yes |
| 46 | 1769 Harbour Dr. | Steep below | Yes | Yes |
| 47 | 1773 Harbour Dr. | Steep below | Yes | Yes |
| 48 | 1777 Harbour Dr. | Steep below | Yes | Yes |
| 49 | 1781 Harbour Dr. | Steep below | Yes | Yes |
| 50 | 1785 Harbour Dr. | Steep below | Yes | Yes |
| 51 | 1789 Harbour Dr. | Steep below | Yes | Yes |
| 52 | 1791 Harbour Dr. | Steep below | Yes | Yes |
| 53 | 1793 Harbour Dr. | Pool near crest, steep below | Yes | Yes |
| 54 | 1797 Harbour Dr. | Failure nearby, pool near crest, steep below | Yes | Yes |
| 55 | 1801 Harbour Dr. | Steep below | Yes | Yes |
| 56 | 1805 Harbour Dr. | Steep below | Yes | Yes |

| | Address | Reason for Assessment | Letter Request Outcome | Slope Assessment |
|---|---|---|---|---|
| 57 | 1807 Harbour Dr. | House built close to steep slope | Yes | Yes |
| 58 | 1822 Harbour Dr. | House built close to steep slope | Yes | Yes |
| 59 | 1826 Harbour Dr. | House built close to steep slope | Yes | Yes |
| 60 | 1830 Harbour Dr. | House built close to steep slope | Yes | Yes |
| 61 | 1834 Harbour Dr. | House built close to steep slope | Yes | Yes |
| 62 | 1838 Harbour Dr. | House built close to steep slope | Yes | Yes |
| 63 | 1842 Harbour Dr. | House built close to steep slope | Notice | Yes |
| 64 | 1846 Harbour Dr. | House built close to steep slope | Yes | Yes |
| 65 | 1850 Harbour Dr. | House built close to steep slope | Yes | Yes |
| 66 | 1861 Harbour Dr. | Fill mapped, steep slope below | Yes | Yes |
| 67 | 921 Fresno Place | House built close to escarpment | Notice | Yes |
| 68 | 925 Fresno Place | House built close to escarpment | Yes | Yes |
| 69 | 928 Fresno Place | House built close to escarpment | Yes | Yes |
| 70 | 932 Fresno Place | House built close to escarpment, retaining wall | Yes | Yes |
| 71 | 936 Fresno Place | House built close to escarpment, retaining wall | Yes | Yes |
| 72 | 940 Fresno Place | House built close to escarpment | Yes | Yes |
| 73 | 1904 Bowman Ave. | Retaining wall | Yes | Yes |
| 74 | 1919 Custer Court | Steep slopes below | Yes | Yes |
| 75 | 1927 Custer Court | Steep slopes below | Yes | Yes |
| 76 | 1933 Custer Court | Pool at crest, steep below | Notice | Yes |
| 77 | 1943 Custer Court | Steep slopes below | Yes | Yes |
| 78 | 1953 Custer Court | Steep slopes below | Yes | Yes |
| 79 | 1963 Custer Court | Steep slopes below | Yes | Yes |
| 80 | 1973 Custer Court | Steep slopes below | Yes | Yes |
| 81 | 1975 Custer Court | Steep slopes below | Yes | Yes |
| 82 | 805 Northview Place | Fill mapped, steep slopes below | Yes | Yes |
| 83 | 830 Ultra Court | Fill nearby | Yes | Yes |
| 84 | 834 Ultra Court | Fill mapped, steep below | Yes | Yes |

## Table A-2 Residential Properties In Corona Crescent Area Chosen For Assessment

| | Address | Reason for Assessment | Letter Request Outcome | Slope Assessment |
|---|---|---|---|---|
| 85 | 967 Thermal Drive | Fill nearby, above other houses | Yes | Yes |
| 86 | 969 Thermal Drive | Fill nearby, above other houses | Yes | Yes |
| 87 | 971 Thermal Drive | Fill nearby, above other houses | Yes | Yes |
| 88 | 977 Thermal Drive | Fill nearby, above other houses | Notice | Yes |
| 89 | 983 Thermal Drive | Fill nearby, above other houses | Yes | Yes |
| 90 | 1000 Thermal Drive | Feb. 2013 fill settling, tension cracks | Yes | Yes |
| 91 | 968 Corona Cres. | Fill nearby, above other houses | Yes | Yes |
| 92 | 972 Corona Cres. | Fill nearby, above other houses | Yes | Yes |
| 93 | 976 Corona Cres. | Possible fill 1979 photos, steep slopes, above other houses | Yes | Yes |
| 94 | 980 Corona Cres. | Possible fill 1979 photos, steep slopes, above other houses | Yes | Yes |
| 95 | 984 Corona Cres. | Possible fill 1979 photos, steep slopes, above other houses | Yes | Yes |
| 96 | 988 Corona Cres. | Possible Fill 1979 photos, steep slopes, above other houses | Yes | Yes |
| 97 | 990 Corona Cres. | Fill nearby, steep slopes, above other houses | Yes | Yes |
| 98 | 992 Corona Cres. | Fill nearby, steep slopes, above other houses | Yes | Yes |
| 99 | 998 Corona Cres. | Fill nearby, steep slopes, above other houses | Yes | Yes |
| 100 | 1000 Corona Cres. | Fill nearby, steep slopes, above other houses | Yes | Yes |
| 101 | 1004 Corona Cres. | Fill nearby, steep slopes, above other houses | Yes | Yes |
| 102 | 1008 Corona Cres. | Fill nearby, steep slopes, above other houses | Yes | Yes |
| 103 | 1012 Corona Cres. | Fill nearby, steep slopes, above other houses | Yes | Yes |
| 104 | 1016 Corona Cres. | Fill nearby, steep slopes, above other houses | Yes | Yes |

| | Address | Reason for Assessment | Letter Request Outcome | Slope Assessment |
|---|---|---|---|---|
| 105 | 1020 Corona Cres. | Fill nearby, steep slopes, above other houses | Yes | Yes |
| 106 | 1024 Corona Cres. | Fill nearby, steep slopes, above other houses | Yes | Yes |
| 107 | 1028 Corona Cres. | Fill nearby, steep slopes, above other houses | Yes | Yes |
| 108 | 2234 Park Cres. | Steep slopes, other houses above | Yes | Yes |
| 109 | 2242 Park Cres. | Steep slopes, in ravine, other houses above | Yes | Yes |
| 110 | 2244 Park Cres. | Steep slopes, in ravine, other houses above | Yes | Yes |
| 111 | 2246 Park Cres. | Steep slopes and other houses above | Yes | Yes |
| 112 | 2247 Park Cres. | Steep slopes and other houses above | Yes | Yes |
| 113 | 2251 Park Cres. | Steep slopes and other houses above | Yes | Yes |
| 114 | 2255 Park Cres. | Steep slopes and other houses above | Yes | Yes |
| 115 | 2259 Park Cres. | Steep slopes and other houses above | Yes | Yes |
| 116 | 2263 Park Cres. | Steep slopes and other houses above | Yes | Yes |
| 117 | 2267 Park Cres. | Steep slopes and other houses above | Yes | Yes |
| 118 | 2271 Park Cres. | Steep slopes and other houses above | Yes | Yes |

# B Appendix B - Property Sheets

# C Appendix C - Overview Area Photographs

**1081 Corona Crescent – Site of 2009 Debris Flow**

Photo 1: View across headscarp area, now rehabilitated with grass and shrubs.

Photo 2: View down track of debris flow, now rehabilitated with grass, shrubs and small trees.

Photo 3: View up debris flow track with rock fill at culvert inlet.

## 1081 Corona Crescent – Site of 2009 Debris Flow

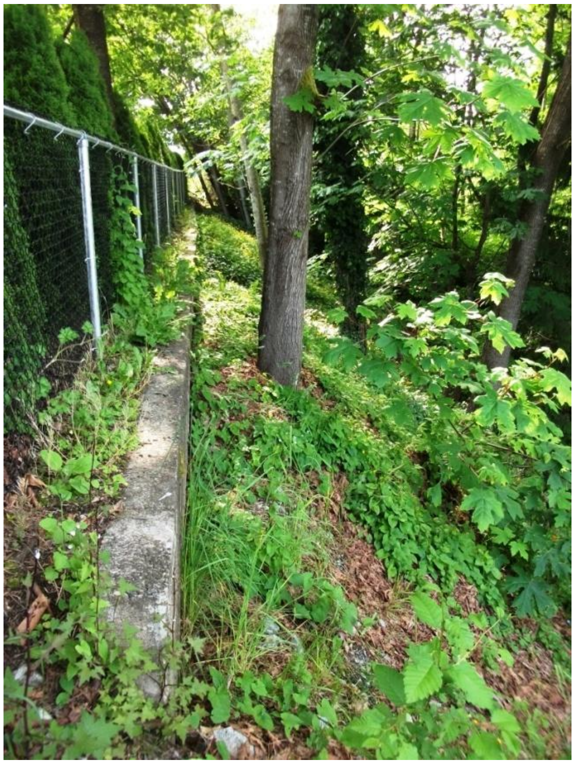

Photo 4: View along City concrete retaining wall above debris flow headscarp and below Corona Crescent. The wall is generally straight.

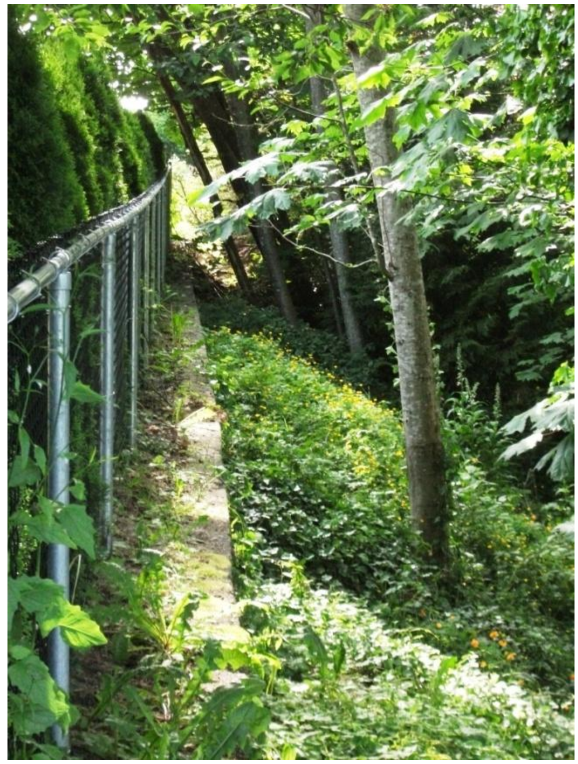

Photo 5: View along City concrete retaining wall with outward bulge, west along Corona Crescent from headscarp area. Small deciduous trees have tipped from shifted surface soils.

## Overview of Active Slope Sites – Corona Crescent Debris Flow Area


Photo 6: View over future debris flow track, pre 2009. The future headscarp is about at top centre. Some deciduous and evergreen trees were removed by the failure, with most depositing on a paved lane in the centre of photo. Photo from Bing Maps.

## Overview of Active Slope Sites – Schoolhouse Creek Ravine

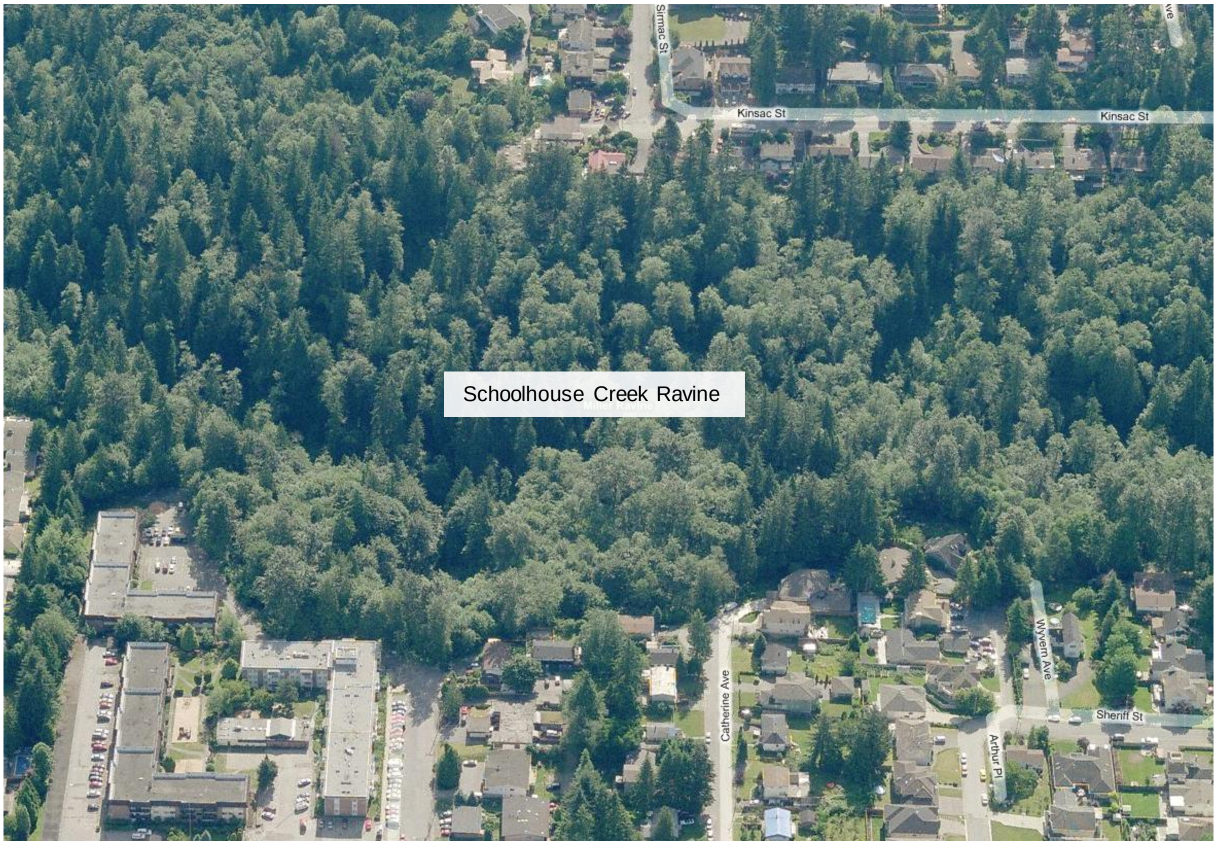


Photo 7: View of middle section of Schoolhouse Creek ravine, with 902 Ingersoll apartment building at lower left, houses at end of Catherine Street in lower centre, and property with large fill off Wyvem in lower right. Photo from Bing Maps.

## Overview of Active Slope Sites – Harbour Drive


Photo 8: View north to house at 1445 Harbour Drive (corner of Harbour and Crestwood) where a City stormwater pipe flows into the ravine on an armoured track, below a concrete retaining wall with some subsidence indicators. Photo from Bing Maps.

## Overview of Active Slope Sites – Harbour Drive and Fresno Drive


Photo 9: View south over Harbour Drive area, with steep natural slopes below houses left of centre, and below Selkirk Crescent and Porter Streets. Photo from Bing Maps.


Photo 10: View east over north ends of Harbour Drive and Fresno Place, with natural steep slopes below houses. Photo from Bing Maps.

## Overview of Active Slope Sites – Corona Crescent and Park Crescent


Photo 11: View south over Corona Crescent area, showing natural steep slopes below Corona Crescent and Thermal Drive, above houses on Park Crescent. Photo from Bing Maps.