Mosquito Creek Ravine East Bank Assessment

Completed by

WESTREK
Geotechnical Services Ltd.

For the

City of North Vancouver
141 14th Street
North Vancouver
B.C. V7M 1H9

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Project #: 005-051

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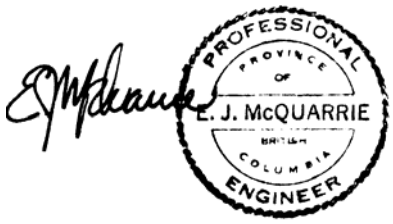
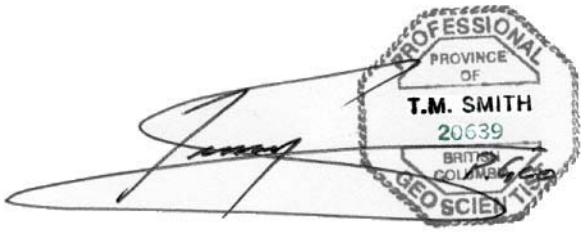
Prepared By: -





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1.0 INTRODUCTION

The objective of this study is to conduct a landslide risk assessment for the eastern slopes in the Mosquito Creek ravine, with specific consideration for the buildings and underground services located near the crest. The risk assessment also considers the potential impacts on the water quality and fish habitat in Mosquito Creek, and the potential impacts on the recreational trail and its users.

The study does not address the risk associated with debris floods or debris flows that initiate upstream from the study area. The City of North Vancouver (the City) informed us that this work has been completed in several reports submitted by Kerr Wood Leidal Associates Ltd., (KWL) that are detailed in Section 3.1.

The details of this study are described in the "Request for Proposal, Mosquito Creek Ravine Stability Study" submitted the City.

2.0 THE WATERSHED AND SITE DESCRIPTION

The Mosquito Creek watershed is approximately 9 km long and 1 to 3 km wide and drains from the headwaters located between Grouse Mountain and Mount Fromme. The total drainage area is 15.5 km^2 and two significant tributaries join the stream: Thain Creek (within the District of North Vancouver limits) and Wagg Creek (within the City of North Vancouver limits).

The channel gradients in the headwaters are generally moderately steep, with gradients varying from 20 to 30%. The gradients in the tributaries to these reaches are much steeper. The study area is located within the upper part of the lower reach where the stream is well confined with channel gradients that generally vary from 5 to 8%.

The headwaters of the watershed (adjacent to the Grouse Mountain ski area) are prone to debris flows and debris floods; however, the runout potential significantly diminishes within the City limits. Kerr Wood Leidal (2000) suggests that a moderate debris flood hazard exists within the study area.

The study area covers the slopes on the eastern side of Mosquito Creek from Highway 1 downstream to West 17th Street (refer to Plate 1). This fish-bearing stream is deeply incised into the Capilano Sediments, comprised of marine and glaciomarine deposits. There is a history of instability along these slopes, including three failures since 1999. Most of the creek gully is located within a municipal park and a gravel trail follows the toe of the slope. The trail is approximately 3 m wide and groomed up to at least West 19th Street, while a less groomed or unofficial trail (i.e. single track) continues northward almost up to the highway overpass.

The east slope gradually increases in height northward or upstream. Also, surface drainage conditions appear to worsen northward, particularly north of West 22nd Street where groundwater discharge from the slope flows over the trail during much of the year.

The crest of the slope borders residential development and several houses are located fairly close to the crest and, in a few cases, beyond the crest. Other elements at risk located near the crest of the slope include a sanitary sewer main behind the houses at 1931 to 2015 Westview Drive (roughly between West 19th Street and West 20th Street), both a storm sewer and water main at the corner of Bewicke Avenue and West 19th Street, an isolated storm sewer main in the laneway between West 23rd and West 22nd Streets and a sanitary sewer and water main on West 23rd Street..

Plate 1: The approximate location of the study area depicted on the 1996 air photo. The approximate extent of the study reach of Mosquito Creek is depicted by the blue line. North is to the top of the page.

3.0 INVESTIGATION

3.1 Background Research

Prior to the field assessment, the following documents provided by the City were reviewed.

i. "Westview Drive and 21st Street North Vancouver" report from Cook Pickering & Doyle Ltd. (CPD) dated May 21st 1976.

ii. "Drainage at 2101 and 2103 Westview Drive" memorandum from F. S. Morris (Director Permits and Licenses) to T. J. Scott (City Engineer) dated December 21st 1977.

iii. "Property Development - 21st and Westview Drive" memorandum from F. S. Morris to C. E. Hjorth (City Building Inspector) dated December 21st 1977.

iv. "Procedures for Drainage Checks" memorandum from F. S. Morris to C. E. Hjorth, R. J. Foster, R. E. Erlandsen, P. Timms and R. J. Mearns dated December 21st 1977.

v. A letter from C. A. Boom Engineering Ltd. (CABEL), to Mr. E. Hjorth regarding engineering supervision on 3 homes for Mr. C. Stirskey of West Vay developments on Westview Drive and 21st Street dated July 20th 1977.

vi. "2101 and 2103 Westview Drive, North Vancouver" letter from F. S. Morris to Fraser Valley Financial Services Ltd. dated January 16th 1978.

vii. "Storm Connections – Westview & 21st Street Vicinity" memorandum from E. D. Bridgman to the Director of Permits & Licenses dated February 2nd 1978.

viii. A memo from CABEL to City of North Vancouver Building Inspector regarding formwork and reinforcing inspection of the foundation at 20069 Westview Drive dated February 7th 1978.

ix. "Subdivision of Lot A, Block 201, D. L. 544, Plan 15673, being the northerly portion of what was formerly 2105 Westview drive, North Vancouver, B. C." from W. A. Marsh to Amata Engineering Ltd. (Amata) dated March 9th 1978.

x. "Homes at 2101 and 2103 Westview Drive, North Vancouver, B. C." letter from CABEL to Russ Foster (Building Inspector) dated March 15th 1978.

xi. "Property immediately North of Lots C & D, Block 201, DL 544, Plan 16126 Westview drive near 21st Street, North Vancouver" report from CPD dated March 22nd 1978.

xii. "Subdivision of Lot A, Block 201, D. L. 544, Plan 15673, being the northerly portion of what was formerly 2105 Westview drive, North Vancouver, B. C." from Amata to F. S. Morris dated March 28th 1978.

xiii. "Supervision of Construction of the Reparations to the Upper Terrace Slope and House Foundations of Lot A, Block 201, D. L. 544, Plan 15673, being the northerly portion of what was formerly 2105 Westview drive, North Vancouver, B. C." from Amata to E. Hjorth dated March 28th 1978.

xiv. A letter from CABEL to E. Hjorth regarding the retaining walls at 2101 and 2103 Westview Drive dated April 14th 1978.

xv. A letter from CABEL to E. Hjorth regarding the properties at 2101 and 2103 Westview Drive dated May 15th 1978.

xvi. “Lots 10 & 11, Resub A, Block 1, D. L. 547 – (2009 Westview Drive)” memorandum for record purposes from E. D. Bridgman dated June 15th 1978.

xvii. “Lot 19, Block 201A, D. L. 544, Plan 1364” letter from E. D. Bridgman to Crest Realty Ltd., dated September 12th 1978.

xviii. “Lot 19, Block 201A, D. L. 544 (Preliminary Building Plan Check Comments)” memorandum from E. D. Bridgman to building inspectors dated February 8th, 1979.

xix. “Lot 19 – 22nd Street west of Westview Drive North Vancouver, B.C.” report from CPD dated January 23, 1980.

xx. “Letter from A. Stephens and others re: Erosion of the Bank of Mosquito Creek in the 600 Block West 19th and 20th Streets” to Mayor and Council from the City Engineer dated July 15th, 1980.

xxi. “Bank Stability West of Westview Drive from 17th Street to 24th Street – Effect of New Construction”, memorandum from Mr. F. S. Morris, Director Development and Licensing Services to all plumbing and building inspectors and plan checkers dated March 28th, 1983.

xxii. “”Damage to sanitary main serving 2009 and 2105 Westview Drive, North Vancouver” letter (WITHOUT PREJUDICE) from the Corporation of the City of North Vancouver to Mr. G. Foster dated April 7th 1983.

xxiii. “Disposal of Storm Water from Junction Box – 2015 Westview, North Vancouver.” letter from D. O. Olsen Plumbing & Gas Inspector to G. Foster dated May 4th 1983.

xxiv. “Building Permit No. A2521, One Family Dwelling – 2009 Westview Drive, North Vancouver, B. C. Lot 10 of Subdivision “A”, Block 1, D. L. 547, Plan 4195” letter from C. E. Hjorth City Building Inspector to Gary Everett MacDougall and Kathy MacDougall dated June 28th 1983.

xxv. “Soil Investigation Residential Lot Adjacent to 622 West 22nd Avenue North Vancouver, British Columbia”, report by Robinson Dames and Moore (RDM) dated April 27th, 1984.

xxvi. “Building Permit Application – 626 West 22nd Street (Lot 19, Block 201A, D. L. 544)” memorandum from Deputy City Engineer to the Chief Building Inspector dated November 2nd 1984.

xxvii. “Proposed Dwelling at 626 West 22nd Street, North Vancouver, B.C. Lot 19, Block 201A, D. L. 544, Plan 1363” letter from the Corporation of the City of North Vancouver to Mr. M. Pazdera dated February 15th 1985.

xxviii. “Lot 19, Block 201A, D. L. 544 (Proposed Dwelling for 626 West 22nd Street)” memorandum from the Deputy City Engineer to the Chief Building Inspector dated April 3rd 1985.

xxix. “Permission to Construct Works on Street Allowances Under Authority of By-Law 4949” permit from the Corporation of the City of North Vancouver to Mr. M. Pazdera dated September 10th 1985.

xxx. “Preliminary Geotechnical Study, Mosquito Creek, North Vancouver, BC”, report by MacLeod Geotechnical Ltd. (Macleod) dated May 6, 1987.

xxxi. “Mosquito Creek Ravine Slope at 19th and Bewicke”, report by MacLeod dated February 17, 1988.

xxxii. Test Hole Logs and Location Plan for the highway interchange from the BC Ministry of Transportation and Highways from 1994.

xxxiii. “19th & Bewicke Ave. Slope Stabilization”, report by MacLeod dated October 30, 1995.

xxxiv. “Overview Report on Debris Flow Hazards” by KWL to the District of North Vancouver dated April 1999.

xxxv. “Mosquito Creek Flood & Erosion Study”, draft report by KWL dated January 2000.

xxxvi. “Mosquito Creek Slide, North Vancouver”, report by EBA Consultants Ltd. to KWL dated May 2, 2000.

xxxvii. “Mosquito Creek Debris Slide”, report by KWL dated May 3, 2000.

xxxviii. “Westview Interchange – Proposed Subdivision, Slope Stability and Set-back Assessment”, report by Thurber Engineering Ltd. (Thurber) to BC Transportation Financing Authority dated January 24, 2001.

xxxix. “Westview Interchange Development Review of Civil Design”, memo by Thurber dated April 1, 2002.

xl. “Debris Flood Study and Risk Mitigation Alternatives for Mosquito Creek” report by KWL to the District of North Vancouver dated December 2003.

xli. “Mosquito Creek Ravine – Slope Instability”, proposal by Thurber dated September 2, 2004.

xlii. “Mosquito Creek – East Flank Ravine Slope Instability” by KWL dated October 19, 2004.

xliii. “Westview Interchange Development Slope Setback Assessment”, letter by Thurber dated November 15, 2004.

xliv. “Proposed Westview Interchange Development, Review of Civil and Landscape Design”, memo by Thurber dated November 19, 2004.

xlv. “Landslide – 625 W23rd St.” by KWL dated March 12, 2004.

xlvi. “Lot 8 – 625 West 22nd St., North Vancouver, B.C.” report from Fieber Rock Engineering Services (Fieber) to Mr. Dave. Harper dated November 2nd 2005.

xlvii. “Rock Pit Storm Water Disposal System 6625 West 22nd St., North Vancouver, B. C.” letter from Fieber to Colleen Perry (Supervisor, Parks and Environment) dated April 6th 2006.

An analysis of historic airphotos was also completed using the following airphotos:

i. 1996 airphotos BCC96081, #97 to #98 and #120 to #122;
ii. 1992 airphotos BC92018, #80 and #81;
iii. 1982 airphotos BC82059, #23 to #27;
iv. 1980 airphotos BCC239, #100 to #102;
v. 1979 airphotos BC79047, #97, #98, #132 and #133;
vi. 1976 airphotos BC5721, #148, #149, #206 and #207;
vii. 1968 airphotos BC7105, #29 and #30;
viii. 1963 airphotos BC5059, #221 and #222;
ix. 1957 airphotos BC2351, #66 and #67; and
x. 1952 airphotos BC1456, #14 and #15.

Other background information included:

- *Surficial Geology of Vancouver, Map 1486A* by Armstrong, J.E. and Hicock, S.R., published by the Geological Survey of Canada in 1979;
- *The Geology of Vancouver West Half and Mainland Part of Alberni* by Roddick, J. A. and C. J. Woodsworth published by the Geological Survey of Canada in 1979 (OF 611).
- A topographic plan showing property boundaries, addresses, and municipal underground services in the area provided by the City.
- The Sanitary Sewer Plan for Mosquito Creek at 20th Street provided by the City.
- City of North Vancouver Embankment Drainage – Dispersal Box Detail.

3.2 Site Reconnaissance

The east slope of Mosquito Creek was traversed in a systematic manner. First, a base line was established and stationed along the trail. Then cross-sections were traversed up and down the slope every 50 m using a hipchain and clinometer. Traverse notes included the following:

- Slope.
- Soil exposures or apparent composition.
- Groundwater discharge or concentrated surface runoff.
- Wet site indicators (i.e. hydrophitic vegetation).
- Signs of surface erosion or shallow slope movement.
- The presence of retaining walls.

- An estimate on the magnitude and runout from the observed slope instabilities.

The crest of the slope was traversed where accessible to measure the setback of the house and deck from the crest of the slope and to check for tension cracks, pipe outlets (from roof or foundation drains), areas of tree removal, and areas where extensive garden waste has been cast over the slope. However, some areas near the crest were not accessible due to fences or inhospitable vegetation such as thick blackberry.

3.3 Subsurface Investigation

A total of 3 test holes were drilled using solid stem augers combined with Dynamic Cone Penetration Tests (DCPTs) to determine the subsurface conditions. These test holes were drilled at the following locations:

- TH05-1 on Bewicke Avenue near West 19th Street.
- TH05-2 near the slope crest at the west end of West 22nd Street, and
- TH05-3 near the slope crest at the west end of the alley between West 22nd Street. and West 23rd Street.

The auger test holes and DCPTs were advanced to practical refusal at depths ranging from 8.8 m in TH05-1 to 13.9 m in TH05-2.

The original plan was to use a Sonic drill to obtain continuous sampling with less soil disturbance; however, the day before drilling, the Sonic drill rig became unavailable due to mechanical failure. Drilling would have been delayed by at least 1 week while awaiting repairs. Since the underground services were already checked, the neighbours notified and “no parking” signs posted at the drill sites, the decision was made to change the drilling method and maintain the original schedule.

The soil conditions were logged in the field by the project engineer and selected samples were obtained. Laboratory tests consisted of confirmatory identifications and soil classifications. More detailed tests were originally planned but the change in drilling method prompted changes to the testing plan as well. The level of disturbance on the auger samples precluded direct shear tests. Instead, the soil strength parameters were determined from the insitu DCPTs.

The results of the drilling and insitu testing are summarized on the test hole logs in Appendix C. The test hole locations are shown on the location map in Appendix D.

3.4 Instrumentation

Standpipe piezometers were installed in TH05-1 and TH05-3 to monitor the groundwater table. A piezometer could not be installed in TH05-2 because the hole would not remain open long enough. The slotted tips of the piezometers

were installed to depths of 6.1 m in TH05-1 and 10.7 m in TH05-3. The objective was to install the slotted tips within the sandy silt layer, which forms the bottom of the unconfined aquifer.

The water levels in the piezometers were measured between January 12 and 14, 2006 during a period of prolonged rainfall. Rain had fallen each day for more than 24 days prior to these water level measurements. The measured water levels are shown on the test hole logs in Appendix C.

4.0 SOIL & GROUNDWATER CONDITIONS

Based on the drilling results and surface exposures along the valley walls, the soil conditions along the crest of the slope generally consist of a fining downwards sequence. Surficial sand and gravel overlies sand, then silty sand, silt and then clayey silt to silty clay. The groundwater forms an unconfined aquifer on top of the clay. All three test holes found similar soil conditions, but at different depths.

In TH05-1, the sandy silt was found below 3.0 m depth while the silty clay begins at 6.7 m depth. Refusal was encountered at 8.8 m depth, likely in very dense till or till-like material. The groundwater level measured in the piezometer was at 3.7 m depth within the sandy silt.

In TH05-2 and TH05-3, the sandy silt begins at 5.5 to 5.8 m depth while the clay begins at 9.1 to 10.1 m depth. Refusal occurred between 13.3 and 13.9 m depth, again likely on very dense till or till-like material. The groundwater level in TH05-3 was measured at 6.0 m, again in the sandy silt.

These soil conditions are part of the Capilano Sediments, comprised of marine and glaciomarine deposits. The sediments were deposited between 10,500 and 13,000 years ago when the sea level was much higher than at present. As the sea level gradually lowered (due to isostatic rebound), the deposition environment gradually changed from sea bottom to beach or deltaic. The resulting geologic sequence consists of marine and glaciomarine clays and clayey silts overlain by beach and deltaic sands and gravels. The result is a coarsening upwards or fining downwards sequence in the soil profile.

These deposits are all near-normally consolidated, meaning they have not been glacially overridden or subject to much more pressure than at present. Therefore, the granular deposits are generally loose near the ground surface becoming loose to compact at depth as the confining stress increases. The silt is firm to stiff while the silty clay is firm with low plasticity.

The groundwater level in the unconfined aquifer will fluctuate in response to rainfall and snowmelt. The surficial sand and gravel is relatively permeable; therefore, surface runoff will tend to infiltrate into the ground relatively quickly. The result is a groundwater peak that likely occurs during January and early February after prolonged rainfall.

5.0 SITE HISTORY

The history of development and slope stability problems along the eastern slopes of the Mosquito Creek ravine was determined from historic airphotos and the reports provided by the City. The scale and clarity of the older airphotos was quite poor; therefore, details were often limited.

5.1 Development

The initial phase of development along the east crest of the gully was during the 1950s and 1960s, before the highway crossing was constructed at the north end of the project area. However, development was at a much lower density than at present. Several houses at the north end of the project area were demolished between 1963 and 1968, although the highway interchange was not constructed until between 1968 and 1976. The watermain crossing the gully at the end of West 23rd Street was installed in the late 1960s about the same time as the powerlines crossing the gully at West 21st Street.

5.2 Channel

The north reach of the creek (within the study area) is still in its natural state and does not appear to have undergone any man-made channel modifications. Recent erosion at the base of the slopes between West 22nd Street and West 23rd Street was noted in the 1976 airphotos, possibly due to flooding. Fresh toe erosion was noted north of West 21st Street between 1979 and 1982, possibly due to more flooding and City records indicate flooding in 1955 caused extensive erosion to the slope between West 19th Street and West 20th Street.

The south reach of the Mosquito Creek underwent channel improvements in the early 1960s and more improvements in the early 1970s. These improvements straightened and channelized the flow to reduce flooding. Up to 1992, the creek appears to have experience episodes of heavy sediment transport. The airphotos show a reduction in active sediment load after 1992, possibly due to improvements farther upstream within the District of North Vancouver. The City has suggested that this could also be as a result of the District of North Vancouver culverting Mosquito Creek from Evergreen Place to Queens Street. This has not been confirmed in this study.

5.3 Eastern Slopes of the Ravine

The gully banks do not appear to have been logged for close to 100 years and disturbances on these slopes are generally small-scale. The 1963 airphotos show a small failure or fresh scouring near the crest of the slope south of West 19th Street (probably behind 1845 Bewicke Avenue) and the house was noted to be fairly close to the edge of the slope. More disturbance in the same general area was noted in 1979 and 1980, probably related to fill placement behind 1805 to 1821 Bewicke Avenue.

The 1979 and 1980 airphotos show slope disturbance, probably due to fill dumped over the slope below the end of West 20th Street. Just south of West 20th Street, the existing vertical scarp created by flooding in 1955 is visible in the airphotos dating back to at least 1963. MacLeod noted this feature in 1987. This vertical scarp is prone to raveling and slabbing, including a small failure reported in October 2004 behind 1945 Westview Drive (KWL, October 19, 2004).

Fill placed over the slope or near the crest has caused damage to many of the properties in the past. The original house at 2009 Westview Drive was reported to have settled 0.3 m at the back in 1978. Excavated material from construction of the existing houses at 2009 and 2015 Westview Drive was reportedly placed overtop of the sewer main at the back of the properties and the resulting slope movement damaged the main in 1983.

Fill placed on the slope below the end of West 19th Street had experienced some stability problems (MacLeod 1988). This slope was subsequently reconstructed as an engineered fill and a partial Lock-block wall. Based on the report by MacLeod in 1995, the slope below 626 West 19th Street has been stabilized.

In 1999, a small slide below 632 West 23rd Street was investigated by EBA (2000). The slide was reportedly 30 m wide by 20 m high and the report concluded that the house at 632 West 23rd Street did not have adequate set-back from the slope. Thurber (2002) refers to “a large slough” at this same location.

On March 6, 2004, a watermain failure along Westview Drive triggered a debris slide below 625 West 23rd Street and the alley between West 22nd Street and West 23rd Street (KWL, March 12, 2004). The slide was reportedly 9 m wide, 16 m long, and extended 2 m back from the original crest. Recommendations were made to stabilize this slope and protect the house at 625 West 23rd Street. Thurber (2004) suggested this slide was still active several months later. The City has indicated that this site was remediated in the fall/winter of 2004, with revegetation completed in the spring of 2005.

Mosquito Creek has been subject to past debris flows and debris floods; however, Westrek understand that none of the recent bank failures are related to either hazard.

6.0 DETAILED SITE DESCRIPTION

The following descriptions are based on the field reconnaissance conducted in late November, 2005. Cross-sections were measured at 50 m intervals. Slope conditions between the cross-sections are extrapolated from the sections on either side. The setbacks for the houses were measured (±1 m) only where the rear yards were readily accessible while setbacks for the others are only estimates.

6.1 North of West 22nd St to Highway 1.

The properties contained within this section of the study area include: 626 and 622 West 22nd Street, 625 and 632 West 23rd Street and the proposed new sub-division adjacent to the Highway.

The vertical shape of the slopes to the west of these properties is concave and the gradients vary from 30 to 40% at the base, to 60 to 80% in the upper section near the crest. The length of these moderate to steep slopes varies from 30 to 70 m, with the longer slopes present at the northern end (i.e. near Highway 1). The trail at the base of these slopes is located on a 20 to 30 m wide, gently sloping bench that forms part of the confined floodplain of Mosquito Creek. The trail at the base of these slopes is “single track” and hummocky.

A relic, erosional scarp approximately 20 m long and 8 to 10 m high is located at the base of the slopes near Sta. 0+750 (i.e. to the northwest of 626 West 22nd Street). A relic channel is situated at the base of this scarp. The slopes above this feature are moderately steep for approximately 30 m slope length.

The house at 632 West 23rd Street is located approximately 4 m back from the crest of the moderate to steep slopes. The house at 625 West 23rd Street is set back approximately 10 m from the crest except where a recent slide has encroached on the property. Here, the house is set back 6 to 8 m from the headscarp.

The house at 626 West 22nd Street is founded on and downslope from the crest of moderately steep (i.e. 45%) slopes above the relic scarp, and the house at 622 West 22nd Street is set back 2.5 m from the crest of these slopes. The house foundation at 626 West 22nd Street has been engineered and bears on steel pipe piles driven into the slope and tied together with cross-bracing and grade beams. The geotechnical report by RDM (1984) identified at least 1.5 m of fill near the crest of this slope, reportedly from construction of the older house at 622 West 22nd Street.

The large diameter water main (operated by the Greater Vancouver Water District) runs down the slope in a shallow draw directly below the end of West 23rd Street. According to the design drawings, this pipe is encased in concrete however the depth of burial is unknown. Slope angles in this draw are 60% on the upper half and 40% on the lower half, and are flatter than the adjacent slopes.

A buried sanitary sewer pipe is located near the crest of the slope at the west end of West 23rd Street. The City also maintains a buried water main (150 mm diameter) on the north side of West 23rd Street and the west end of the pipe is located next to the slope crest. A fire hydrant is also situated at the slope crest.

An isolated storm sewer pipe (i.e. not connected to the overall system) is located in the laneway at the rear of 625 West 23rd Street. This pipe drains to a buried rock pit adjacent to the slope crest.

A detention pond, left from the upgrading of the Westview interchange on Highway 1, is located immediately south of the highway bridge on the proposed sub-division of West 24th Street. The City has indicated that the base of this pond was not lined with an impermeable barrier.

A band of seepage is present on these moderate to steep slopes approximately 1/3rd of the way up from the gentle slopes at the base. The seepage emanates from the interface of the firm, fine-grained, sandy silt overlying a firm, grey silty clay. A veneer of organic-rich, weathered colluvium was noted on the lower slopes. The impermeable clay layer creates a perched groundwater table, causing the groundwater to flow horizontally and discharge from the slope at the seepage zones. Seepage zones were also noted on the upper slopes below 632 West 23rd Street. The seepage flows across the slopes and ponds on the trail (at the base) at several locations.

Evidence of recent and historic, small, shallow landslides was found on these slopes, with the headscarps generally located around the seepage zones. These slides deposited on the gently sloping bench at the base and in several cases crossed the trail. The magnitude of most events is likely less than 100 m^3 and the majority of the slides ran out less than 15 m beyond the concave break at the base of these slopes without reaching the channel of Mosquito Creek. Remnants of the 1999 slide reported by EBA (2000) were no longer distinguishable from the older slides on this same slope. The scars are now overgrown with vegetation.

A recent, larger landslide (approximately 200 m^3) was triggered on the slopes to the west of 625 West 23rd Street in March 2004. The City indicated this failure may have been triggered by the surface runoff from a ruptured water main. The runout was arrested on the gentle to moderate slopes next to the trail. The City has inidicated that this landslide was stabilized by them in 2004.

The trees on the slopes in this section are predominantly coniferous; however, a significant number of deciduous trees are present on the slopes adjacent to 626 West 22nd and 625 West 23rd Streets. The deciduous trees are primarily situated on the slopes where the earlier slope failures have occurred. The conifers are approximately 80 to 100 years old. Hydro-phytic plants (i.e. horse-tail, etc) are located in and around the seepage zones and landslide debris piles on the lower slopes.

A veneer of unconsolidated fill is scattered across the crest of the moderately steep to steep slopes in this area. Debris and yard waste is mixed in with this fill, which is oversteepened at several locations and shows signs of shallow downslope movement (or creep).

6.2 South of West 22nd Street to 2117 Westview Drive

The properties contained within this section of the study area include: 625 West 22nd Street and 2117 and 2121 Westview Drive.

The vertical shape of the slopes to the west of these properties is concave and the morphology is benchy to uniform and straight with gradients varying from 80 to 85% at the base (for approximately 16 m), 25 to 30% in the mid-slope region (for up to 12 m) and 65% up to the rear of the building envelope (for up to 12 m) at 625 West 22nd Street. The floodplain at the base of the slopes is gently sloping (0 to 5%) for approximately 25 m out to the channel of Mosquito Creek. The channel bank is 30 to 50% for 7 m. The trail at the base of these slopes is "single track".

At the time of the fieldwork, the building envelope at 625 West 22nd Street was recently excavated, exposing the underlying native soils. The edge of the excavation is setback 3 m from the crest of the moderately steep slopes; however, the underside of the footings is located 1 to 2 m below the original ground surface.

The houses at 2121 and 2117 Westview Drive are setback more than 12 m from the crest of the slope. The yards at the rear of these houses have an average slope of 40% to the crest of the moderately steep slopes to the west.

The surficial geology consists of bedded Capilano Sediments as encountered in TH 05-02, situated to the north of 625 West 22nd Street. This test hole found:-

(a) Topsoil overlying loose to compact gravelly sand to 3.7 m depth; overlying

(b) Compact silty fine grained sand with a trace of gravel to 5.5 m depth. Lenses of clean sand and gravel were present in this unit; overlying

(c) Firm sandy silt to 9.1 m depth; overlying

(d) Firm, grey silty clay to 13.9 m depth; overlying

(e) A very dense deposit (likely till or till-like material) that could not be penetrated with the auger drill.

The natural slopes are covered by a thin, loose, organic-rich, sandy colluvial veneer. No seepage was observed on the slopes below 2121 and 2117 Westview Drive; however, seepage was noted on the slopes adjacent to the relic erosional scarp (to the northwest of 625 West 22nd Street).

The back yards of 2121 and 2117 Westview Drive have been leveled by placement of a thick terrace of uncontrolled fill. This fill extends beyond the yards and onto the upper slopes where debris and yard waste was found mixed in with this fill. The fill material is oversteepened at several locations and shallow downslope movement (or creep) was noted. Fill was also noted on the slopes below West 22nd Street and around the house at 626 West 22nd Street.

No recent landslides were noted on the moderately steep to steep slopes in this area. The trees on these slopes are both coniferous and deciduous.

6.3 2103 to 2041 Westview Drive

The properties contained on the slopes within this section of the study area are: 2103, 2101, 2069, 2059, 2049 and 2041 Westview Drive. A B.C Hydro "right of way" is located to the south of 2101 Westview Drive.

The vertical shape of the slopes to the west of these properties is concave and the morphology is generally uniform and straight. The gradients vary from 70 to 90% in the middle to upper segments (for 20 to 25 m) and 30 to 40% on the lower segments (for approximately 20 m). The floodplain at the base of these slopes is gentle (5 to 10%) for approximately 20 m to the edge of the stream channel. The trail at the base of these slopes is “single track”.

A thin veneer of weathered colluvium with some organics drapes the moderately steep to very steep slopes in this area. The underlying material exposed at several locations is composed of firm to stiff, sandy silt with a trace to some gravel (likely part of the Capilano sediments). No seepage was noted on these slopes and the trees are both coniferous and deciduous.

A thin veneer of unconsolidated fill mixed with debris and yard waste is scattered across the crest of the moderately steep to very steep slopes behind 2103 and 2101 Westview Drive. The fill material is oversteepened at several locations and evidence of small, shallow landslides was observed. The runout from these events traveled 5 to 10 m downslope.

The houses at 2103 and 2101 Westview Drive are set back 3 to 5 m from the crest of the steep to very steep slopes. The deck posts at 2101 are founded at the crest of the slope and show signs of displacement, while the deck at 2103 is cantilevered from the main structure (refer to Plate 2). Geotechnical reports by CPD in 1976 and 1978 identified surficial fill over “native hard clayey silt” and recommended the footings bear on native soil. Constructed in 1978, the foundations were reportedly inspected by CABEL and are presumably founded on native soil.

The roof and foundation drains at 2103 and 2101 Westview Drive lead to concrete catch basins located near the crest of the slope. It is not clear if this then drains to the City stormwater system or leads to the base of the slope in solid pipe and drains into Mosquito Creek.

City records show CABEL also inspected construction of the houses at 2049, 2059 and 2069 Westview Drive. The deck at the rear of the house at 2049 Westview Drive is located 3 to 4 m back from the slope crest and the main structure is setback 7 m. A timber crib, retaining wall, approximately 1.5 m high, is located at the crest on this property. While some timbers are missing, this wall was still functional and appears to be stable in the short-term. This wall supports fill placed to level the back yard, which shows signs of significant settlement.

The deck at the rear of 2059 Westview Drive is situated 2 to 3 m from the slope crest and the corner post has been displaced laterally. This displacement is evidence of shallow creep or settlement of the soils supporting the deck foundation. The fill placed along the slope crest also shows signs of significant settlement.

Plate 2: Note the displacement of the post supporting the deck on this structure (thought to be at 2101 Westview Drive). The crest of the ravine is located next to the base of these posts. The BC Hydro RoW is in the background of the picture.

The house at 2069 Westview Drive is setback a little farther from the slope. Fill in this backyard also shows signs of settlement but does not appear to have directly impacted on the house. The right-of-way at the end of West 21st Street is heavily covered with blackberry obscuring this slope.

The City has noted that the property at 2041 Westview is not connected to the stormwater network. The location of the rockpit may be at the crest of the slopes or is not known. The City introduced a policy to require new developments along the crest of this slope to place their rock pits at the base of the slope sometime between 1978 and 1983. This house predates this policy and is probably connected to rock pit beneath the back yards.

6.4 South of 2041 Westview Drive to 1957 Westview Drive.

The properties contained on the slopes within this section of the study area are: 2017, 2015, 2009 and 1957 Westview Drive.

The vertical shape of the slopes to the west of these properties is concave and the morphology varies from uniform and straight to irregular and hummocky. The gradients generally range from 60 to 75% for approximately 20 to 25 m, although some steeper sections are present (i.e. 100 to 120%). The floodplain at the base of the slopes is 5 to 10% for 25 to 30 m. A relic stream channel is located 11 m from the base of the slopes on the west side of the trail. The trail at the base of these slopes is no longer single track and is approximately 3 m wide.

The surficial material on these slopes is generally composed of a veneer of weathered, organic-rich colluvium overlying the undisturbed Capilano sediments. A considerable amount of unconsolidated fill material, with debris and yard waste mixed in, is present on these slopes. The fill material is oversteepened at several locations. The vegetation at the crest of these slopes is thick blackberry, which obscures the view of the slope and limits access.

Several recent landslides have occurred on these slopes with the runout reaching the gentle terrain at the base. These failures are mainly contained within the unconsolidated fills. Several debris snouts (i.e. associated with the landslide runout) cross the trail at the base of these slopes. The trees on these slopes are mainly deciduous (estimated to be 25 to 35 years old), which is likely associated with the landslide activity.

The house at 2017 Westview Drive is situated more than 10 m from the slope crest but the houses at 2015 and 2009 Westview Drive are closer to the slope. An old timber crib retaining wall at the slope crest next to 2015 Westview Drive supports sandy, organic fill placed in the backyard. This wall has settled and shifted forward at least 0.3 m creating a vertical scarp in the soil behind the wall (refer to Plate 3). The footings for the sundeck are setback approximately 7 m from the top of the retaining wall, while the house foundation is setback 10 m from the wall. The house at 2009 Westview Drive has a similar setback and neither house appears to have suffered damage due to the slope movement.

The house at 1957 Westview Drive is located approximately 12 m back from the crest of the moderately steep slopes. The slope below this property appears to be natural, without the thick fills found to the north.

The City's plans show a sanitary sewer line across the crest of the slope between 2015 and 1957 Westview Drive. The sewer location plan locates the pipe at least 10 m back from the crest of the slope behind 1957 Westview Drive but it is shown at or within 2 m of the crest behind 2009 and 2015 Westview Drive and 5 m back from the crest where the connecting pipe extends to Westview Drive. The sewer main was reportedly damaged in 1983 during construction of the houses at 2009 and 2015 Westview Drive due to fill placement near the crest of the slope. The

slope movement appears to be active or recent, suggesting that the sewer main could be damaged again.

Plate 3: The separation behind the face of the retaining wall.

City records indicate that the houses at 2009 and 2015 Westview Drive are connected to rock pits located at the base of the slope. A 150 mm diameter PVC pipe was found in the surficial materials at the base of the slope behind 2015 Westview Drive. No flow was observed in this pipe, which, since the field study occurred in late November, could indicate that it was severed by one of the slope failures and may be discharging flow into the surficial materials present on these slopes. Anecdotal information suggests that a previous owner of this lot extended the yard by filling onto the slopes with old cars and multiple loads of wood chips.

The properties at 2017, 1957 and 1945 Westview Drive are not shown to be connected to the storm main and the location of the rock pits is not known. Only scattered seepage was noted on the slopes on these properties.

6.5 1945 to 1931 Westview Drive

The properties contained on the slopes within this section of the study area are: 1945, 1935 and 1931 Westview Drive.

A near-vertical scarp (approximately 10 to 12 m high) flanks the western edge of these properties (refer to Plate 4). The slopes below this scarp are moderately steep to very steep, with gradients that vary from 60 to 95% for 10 to 15 m slope length. The vertical shape of these slopes is concave and the morphology is

generally uniform and straight. The floodplain at the base of this scarp is approximately 20 to 25 m wide and extends out to the stream channel at approximately 5%. The trail at the base of these slopes is approximately 3 m wide.

A relic stream channel is located at the base of the scarp, which suggests that this feature was probably formed by erosional undercutting during periods of high flow. Cobbly boulders are present around the relic channel. City records indicate over-steepening of this feature may have been exacerbated during the 1955 flood event.

The house at 1945 Westview Drive is situated approximately 15 m back from the scarp while the other two houses are setback even farther.

Plate 4: Looking at the scarp in a southeasterly direction. Note the debris pile in the foreground of the picture from the recent landslide at the north end of the scarp. The adjacent properties are 1931 to 1945 Westview Drive.

The City's plans show a sanitary sewer line across the back of these properties, set back at least 10 m from the crest of the scarp.

The City has also indicated that rock pits are located at the rear of 1931 and 1935 Westview Drive near the slope crest. As discussed above, 1945 Westview Drive probably has a rock pit in the back yard above the slope.

The surficial material exposed in the scarp is: -

(a) A 0.5 to 1 m thick surface layer of loose to medium dense, weathered, silty sand with some gravel; overlying

(b) A 1 to 3 m thick layer of very stiff to hard silt with a trace of sand, clay and gravel. This layer has several very thin lenses of clean sand and gravel near the base. Seepage was emanating from these lenses; overlying

(c) A greater than 3 m thick layer of very dense, silty gravelly sand till-like material that may be over-ridden glacio-fluvial sediments as the gravel is rounded to sub-rounded in texture.

A veneer of weathered colluvial material with a trace to some organics drapes the moderately steep to very steep slopes at the base of the scarp. The colluvial material was generated from previous failures from the scarp above.

A recent, shallow landslide was noted on the northern edge of this scarp near 1945 Westview Drive. The runout from this event reached the gentle slopes at the base, near the trail.

Despite the over-steepened scarp, no tension cracks or slumped soil blocks were noted next to the crest of this scarp.

The trees on these slopes are mostly deciduous due to past slope disturbances.

6.6 West 19th Street to 1805 Bewicke Ave.

The properties contained on the slopes within this section of the study area are: 620 and 626 West 19th Street, 1845, 1821, 1815 and 1805 Bewicke Avenue.

An engineered fill slope and a 3.5 to 4 m high Lock-block retaining wall are located in this section of the study area. A single-track, access trail is located on the engineered slope that connects West 19th Street with the Mosquito Creek trail. The slopes on the engineered fill are moderately steep with gradients that vary from 50 to 75% for 25 m. The floodplain at the base of these slopes is gentle (~ 5%) for 7 to 10 m, then 45% for 5 m down to the stream channel. The slopes above the Lock-block wall are moderately steep to steep, with gradients that vary from 60 to 80% for 10 to 12 m. This slope was stabilized in 1985 following a series of slope failures within the pre-existing, over-steepened fill.

The property at 620 West 19th Street abuts the slope only in the northwest corner and the house is set well back from the slope. The northwestern corner of the house at 626 West 19th Street is setback 4 to 5 m from the crest of the slope above the Lock-block retaining wall. There is a 0.5 m high vertical scarp at the slope but according to MacLeod (1995), this scarp is a remnant of the wall stabilization work and the house is founded on dense native soils.

The slopes to the west of 1805 to 1845 Bewicke Avenue are steep to very steep with gradients that vary from 70 to 100% for approximately 15 to 20 m. The floodplain at the base of these slopes varies from 0 to 5% for 10 to 15 m, to the edge of the stream channel. The trail at the base of these slopes is approximately 3 m wide.

The northwest corner of the house at 1845 Bewicke Avenue is setback 4 m from the slope crest while the southwest corner is approximately 10 m back. The detached garage at this same property is setback about 2 m from the slope crest. The house has minor cracks in the foundation but is otherwise in good condition for a relatively old structure. Several small, over-steepened scarps are present on the slope below this property and are related to small, historic landslides.

Plate 5: The tension crack and slumping fills at the rear of the lots from 1805 to 1821 Bewicke Ave. The crest of the ravine slopes is adjacent to the fence on the left side of the picture.

The houses at 1805 and 1815 Bewicke Avenue are setback more than 10 m from the slope crest while the house at 1821 Bewicke Avenue is setback 8 to 10 m from the slope crest. A timber crib retaining wall along the slope crest behind 1821 Bewicke Avenue has settled significantly causing wall displacement and gaps in the timber ties. This wall is considered marginally stable and continues to

deteriorate. A small failure in the fill material was noted below 1821 Bewicke Avenue and the runout reached the gentle slopes at the base.

A significant volume of fill material was placed on the slopes to the west of the houses that extend from 1805 to 1821 Bewicke Avenue to level the yards. Tension cracks and significant slumping was noted in this fill (refer to Plate 5), which extends 5 to 6 m back from the slope crest to within about 6 m of the houses. The vertical displacement in the fill ranges between 150 and 300 mm while lateral movement has created bulges in this slope. A comment from one of the homeowners indicates that the fill may contain some sawdust, wood chips or other organic debris.

These properties are connected to storm mains beneath West 19th Street and Bewicke Avenue, with the possible exception of 1845 Bewicke Avenue. Built in 1951, this house predates the storm main and is probably connected to a rock pit. Considering the proximity of the house to the slope, the rock pit is probably very close to the slope.

The slope is covered by a veneer of either weathered colluvium or unconsolidated fill, comprised of silty sand with some gravel. Organic debris was found in the colluvium and yard waste and debris was mixed in with the fill material.

The surficial geology identified in Test Hole 05-01 (at the crest of the engineered slope) is described as: -

(a) A surface layer of loose to compact sand, sand and gravel and gravelly sand that becomes denser with depth. The thickness of this layer is approximately 2.5 to 3 m; overlying

(b) Compact/firm silty sand or sandy silt 3 to 4 m thick. The water table is situated around 3.7 m depth within this layer; overlying

(c) 2 to 2.5 m of soft to firm silty clay; overlying

(d) A very dense deposit (likely till) that could not be penetrated with the auger drill.

The trees on these slopes are both deciduous and coniferous.

No seepage was noted on these slopes despite the shallow groundwater table in Test Hole 05-01.

6.7 711 West 18th St. to 710 West 17th St.

The properties contained on the slopes within this section of the study area are: 711 West 18th Street and 710 West 17th Street, located behind 1709 to 1749 Bewicke Avenue. The lane between 1721 and 1737 Bewicke Avenue accesses these properties.

A moderately incised draw running northeast/southwest is located on the slopes to the west of these properties. Seepage was noted on the sides and in the base of

this draw causing minor erosional undercutting on the slopes flanking the draw. A ridge, probably formed by glacial meltwater, bounds the west side of the draw, separating this draw from the main floodplain of Mosquito Creek.

The slopes directly behind these properties (i.e. on the east side of the draw) are moderately steep (i.e. 70 to 75%) for approximately 12 to 15 m. The slopes on both sides of the ridge are moderately steep to very steep, with gradients ranging from 75 to 120%, and up to 10 m long.

The slopes northwest of 711 West 18th Street (adjacent to the vacant lot) are moderately steep, with gradients varying from 70 to 75% for 20 to 25 m. The vertical shape of these slopes is concave and the morphology is hummocky to irregular. Minor bulging was noted at the toe of these slopes. The floodplain next to this property is gentle sloping (i.e. 5%) for approximately 30 m to the edge of the stream channel.

The trail at the base of these slopes is approximately 3 m wide and set well back from the toe of the slope.

Both houses at these addresses are located approximately 6 m from the slope crest. The southwest corner of 710 West 17th Street is only about 3 m from the crest of a bowl-shaped feature on the slope, but the adjacent slope angle is about 60%. The end of the lane separating these properties is located at the crest. The City's plan shows the sanitary hook-up for 711 West 18th Street in the vacant lot to the north. The plan shows the end of this sewer main at least 10 m from the crest of the slope. The sanitary hook-up for 710 West 17th Street is to another vacant lot to the south. The end of this sewer main is shown to be 15 m from the crest of the bank. The City's records indicate that these houses are not connected to the storm main and probably have rock pits located at the rear of the lots to dispense runoff from the roof and the drain tile.

The undisturbed surficial material present on these slopes is composed of compact, fine grained sand with a trace of silt and gravel. A significant amount of yard waste and debris is located on the slopes to the west of these properties and the bulges in the slope are probably an indication of shallow slope movement in the waste material.

The trees on these slopes are both deciduous and coniferous.

6.8 South of West 17th Street.

No properties are located in this section of the study area, bound by a vacant park to the east and Larson Road to the southwest.

The slope in this section is moderately steep, with gradients varying from 55 to 65% for a slope distance of 20 to 25 m. The height of this slope diminishes to the southwest. The gentle floodplain at the base of this slope is approximately 50 m wide and houses a basketball court. The trail is roughly 35 m east of the toe of the slope and approximately 3 m wide.

The surficial material present on these slopes is composed of an unknown thickness of compact sand. This deposit appears to be native without any surficial fill. No seepage was noted on these slopes, and the trees are both deciduous and coniferous.

7.0 STABILITY ANALYSIS

Two-dimensional slope stability analyses were conducted using the soil stratigraphy found at each of the three test holes and the groundwater levels measured in the piezometers. The analyses were conducted at various slope angles measured during the field reconnaissance. The soil strength parameters were determined from the insitu testing and from back-analyses of the slopes adjacent to the test holes. The objectives of the analyses were to evaluate the relative stability of the embankment at various slope angles and soil stratigraphy, and to evaluate the probability of deep-seated failures that may have a greater impact on the adjacent structures.

The stability analyses conclude that the factor of safety along this embankment is generally far lower than normally acceptable for residential development. The normally acceptable factor of safety for residential structures is 1.5; however, most of the houses along the crest of the slope have a factor of safety less than 1.5. Developments close to a natural slope such as this must be prepared to accept a lower factor of safety or a higher risk of landslides than conventional residential developments. A factor of safety of 1.3 or less appears to be a better threshold for evaluating risk in this situation.

The factor of safety for the natural slopes is generally close to 1.0, meaning that at peak groundwater levels and soil moisture conditions, failures may occur on any slopes steeper than approximately 58%. Also, the potential for failure is greater in the upper valley (i.e. TH05-2 and TH05-3) compared to the lower valley (TH05-1) because the Capilano Sediments are much thicker. In all cases, the factor of safety is least for shallow surficial failures and increases for larger failures. When evaluating the risk to elements near the crest (i.e. houses or services), the proximity to the crest is a significant factor.

With most houses set back at least 6 m from the crest of the slope, a relatively large failure would be necessary to directly impact on the houses. In the lower valley (TH05-1), the factor of safety for such a large, deep-seated failure is greater than 1.3 for a 70% slope, but less than 1.3 for slopes steeper than 82%. In the upper valley, slopes steeper than 70% have a factor of safety less than 1.3 for massive failures extending 6 m back from the crest. In all cases, those elements within 2 to 3 m of the crest have the lowest factor of safety or are exposed to the greatest risk of failure. In other words, the most likely slope failure mechanism in the Capilano Sediments is a failure extending up to 2 to 3 m back from the crest.

The results of the stability analyses were incorporated into the risk analysis.

The stability analyses were conducted under static conditions. A sample analysis was also conducted under the National Building Code design earthquake conditions to provide an indication of the slope stability during such an earthquake. This cursory analysis suggests that most of the gully bank will experience numerous bank failures if a high magnitude earthquake occurs during the winter when groundwater levels are near their peak. However, detailed analyses of the seismic performance of this slope, including estimated slope movements and their potential impacts on existing structures is beyond the scope of work of this study. Suffice it to say that the probability of landslides throughout the study area increases substantially under seismic conditions.

8.0 RISK ANALYSIS

The initiation of this risk analysis followed the recognition by the City that some level of hazard and risk exists that may need to be managed, along with the identification of the elements present that could be at risk. The City determined that the risk (associated with ongoing landslides on the slopes on the east side of this ravine) should be assessed for the following elements: -

1. The houses at the crest of the slopes.

2. The City infrastructure located at the crest, base and on these slopes.

3. Public safety on the Mosquito Creek trail.

4. The fishery resource in Mosquito Creek.

The calculation of the partial risk, P (HA) was used in this study. This is described as the product of the probability of occurrence of a specific hazardous landslide (P (H)) and the probability of the event reaching or otherwise affecting the site occupied by a specific element (P (S: H)).

The partial risk is then mathematically expressed as:

$$P(HA) = P(H) \times P(S:H)$$

Partial risk does not consider the vulnerability of the element, and therefore is not a complete estimate of risk. An assessment of the temporal probability has not been completed.

In practice, partial risk is usually the preferred type of analysis when little is known about the vulnerability of the element or where an estimate of vulnerability is not required. The partial risk to these elements is presented in Tables 1, 2 and 3 in the attached appendices.

The partial risk has been presented qualitatively, using ratings such as *very high, high, moderate, low,* and *very low likelihood* of a specific hazardous landslide occurring. Objective criteria were set to determine the hazard ratings using a combination of site observations and the results from the stability analyses.

However, in the end, the meanings of these terms are somewhat subjective and are primarily intended to give a relative rating in order to prioritize future investigations and hazard mitigations.

The criteria used to reach the various hazard ratings are described in the table below: -

FACTOR	**RATING**	**CRITERIA**
Landslide Probability	Low	Slope 60% or flatter (F.O.S. > 1.3 under static conditions). No evidence of past landslides or surficial movement. Slope or retaining wall has been engineered.
	Moderate	Slopes 60 to 80% and: - no retaining wall - no random fill or yard waste - coniferous forest - no signs of slope movement or past landslides.
	High	Slopes steeper than 80%, or Slopes less than 80% and any of the following: - non-engineered retaining wall - random fill or yard waste on the slope or at the crest - primarily deciduous forest - signs of slope movement or past landslides. - considerable seepage present on the slopes.

Table 1: The definitions of the qualitative landslide probability ratings.

Probability of a Spatial Interaction P (S: H)	**RATING**	**CRITERIA**
Probability of an Upslope Interaction.	Very Low	Element at risk is so far back from the potential landslide headscarp that an impact is highly unlikely.
	Low	Element(s) at risk setback at least 5 m beyond anticipated landslide headscarp. Landslide in unlikely to impact the element(s) at risk and setback should be sufficient to allow remediation before any indirect impacts occur.
	Moderate	Element at risk setback 1 to 5 m beyond anticipated landslide headscarp. The initial landslide could impact the element(s) at risk directly. Subsequent settlement or landslide retrogression could also damage the element.
	High	Element(s) at risk setback less than 1 m beyond anticipated landslide headscarp. Initial landslide slide will likely impact the element(s) at risk.

Probability of a Spatial Interaction P (S: H)	**RATING**	**CRITERIA**
Probability of a Downslope Interaction.	Very Low	Element (s) at risk is well outside the potential runout zone and an impact is highly unlikely.
	Low	Element(s) at risk is at least 10 m but not 20 m beyond the anticipated runout and it unlikely there will be an impact. Sufficient buffer for creek to prevent siltation.
	Moderate	Element(s) at risk is less than 10 m beyond the anticipated runout zone. Direct impact could occur and subsequent events could also impact trail or cause siltation of creek.
	High	Element(s) at risk within the anticipated runout zone. Direct impact from landslide.

Table 2: The definitions of the qualitative spatial interactions (i.e. the P (S: H).

The partial risk ratings are determined from the landslide and spatial interaction probabilities using the following table:

P (HA) = P (H) x P (S: H), ***probability of occurrence of a specific hazardous landslide reaching or impacting the identified elements at risk.***		P(H) **Probability of occurrence of a specific hazardous landslide.**		
		Low	Moderate	High
P (S:H)**, likelihood that there will be a spatial interaction with the element(s) at risk, given that the landslide occurs**	Very low	***Very Low***	***Very low***	***Low***
	Low	***Very Low***	***Low***	***Moderate***
	Moderate	***Low***	***Moderate***	***High***
	High	***Moderate***	***High***	***Very High***

Table 3: The partial risk matrix showing the interaction of P (H) and P (S: H).

9.0 RECOMMENDATIONS

9.1 General Recommendations for New Development

The following recommendations are for new developments such as the proposed subdivision near the Westview Interchange and any infill housing elsewhere near the crest of the slope. Many of these recommendations are consistent with those by Thurber, the geotechnical engineers for the Westview Interchange subdivision.

i. Stormwater, including roof water, should be kept away from the slope.

ii. Stormwater should not be disposed of into the groundwater in any way. Rock pits or any other form of in-ground disposal of stormwater at the top of the ravine, or on the ravine slope itself, should not be used.

iii. If stormwater is contained within a surface pond, the pond should be set back at least 20 m from the slope crest and lined with an impermeable liner. Westrek understands that new sub-division between West 23rd and West 24th Streets will use the existing detention pond left from the Westview Interchange upgrade on Highway 1. This pond will require a liner to be installed.

iv. No in-ground sprinkler systems should be permitted within 30 m of the slope crest.

v. No fill placement should be permitted on the slope or within 3 m of the slope unless the slope is specifically assessed by a suitably qualified geotechnical engineer and the fill is designed so as not to impact on the natural slope stability.

vi. All new retaining walls within 3 m of the slope should be designed and inspected by a professional engineer. The preferred type of retaining wall is a mechanically stabilized earth (MSE) wall because the ability to distribute bearing pressures, accommodate settlement, and bridge minor erosion or failures.

vii. All retaining walls (including landscape walls) should be designed and inspected by a professional engineer.

viii. Minimum setbacks for new structures are difficult to apply because they depend on the foundation design. However, as a general rule, the City should require any new inhabited structure proposed within 10 m of the slope have a site specific risk analysis conducted by a suitably qualified geotechnical engineer and that the foundation be designed to reduce the potential slope hazard to an acceptable level.

9.2 General Recommendations for Existing Developments

This group of recommendations includes general recommendations for all existing developments along the eastern slopes of the Mosquito Creek Ravine.

i. The stormwater system should be reviewed. All rock pits and drain outlets discharging onto the slope should be abandoned. If possible storm drains should be connected to the City stormwater grid by gravity or sump pump. An alternative would be to extend the drains down to the bottom of the slope within solid pipe although this should be reviewed with the appropriate regulatory body that governs discharge in the riparian area for this stream.

Based on the City's records, this recommendation could affect: 632 West 23rd Street, 2041, 2017, 1957 and 1945 Westview Drive, 1845 Bewicke Avenue, 711 West 18th Street and 710 West 17th Street. The new house at 625 West 22nd Street was still under construction at the time of this study. Fieber has indicated that the rock pit for this structure was installed and functioning "as designed" on April 2006. Rock pits or any other form of in-ground disposal of stormwater at the top of the ravine, or on the ravine slope itself, should not be used.

The alley between West 22nd and West 23rd Streets appears to connect all properties on both sides to a storm main that discharges into a rock pit at the top of the slope. The presence of this pit near the scarp of a recent landslide is suspect and warrants a solid pipe connection to the bottom of the slope.

ii. All properties with rock pits located at the base of the slope should have the connecting pipes from the house to the pit inspected or tested for leaks. Any leaks should be repaired.

iii. All underground sprinkler systems installed in the rear yards backing onto the slope crest should be removed.

iv. The sanitary sewer mains behind 1931 to 2015 Westview Drive should be inspected or tested for leaks. Any leaks should be repaired.

v. Water mains (including the GVWD main on West 23rd Street) within 100 m of the slope should be tested for leaks and all leaks repaired.

vi. No fill, yard waste, or refuse should be disposed of onto the slope. All homeowners in the neighbourhoods bordering the slope should be notified of this and the reasons why. The City should review the existing by-laws and penalties and means of enforcement and strengthen them where necessary. Signs should be posted and barriers erected at the end of each street backing onto the slope.

vii. Household garbage, such as metal debris, should be removed from the slope.

viii. Yard waste and fill should be removed from the slope wherever it is suppressing the natural vegetation.

ix. Once the garbage, yard waste and fill are removed, a landscape architect should prepare a re-vegetation plan using natural species with strong root networks.

x. All new retaining walls within 3 m of the slope should be designed and inspected by a professional engineer. The preferred type of retaining wall is a MSE wall because the ability to distribute bearing pressures, accommodate settlement, and bridge minor erosion or failures.

9.3 Recommendations for Specific Properties

This group of recommendations is targeted at specific properties. Their urgency or priority depends on the risk ratings.

i. The trail on the east side of the creek should be permanently closed north of West 19th Street. The trail between 1805 Bewicke and West 19th Street should be closed seasonally (i.e. mid-November to mid-February) or during periods of heavy or prolonged rainfall.

ii. A berm should be constructed to buttress the slope below West 20th Street and 2015 Westview Drive to stabilize the potentially unstable slope where the sanitary sewer main is at risk. Further investigation is required for design of this berm, but the design could include flattening of the slope to 2H: 1V or reinforcing a steeper berm with geogrid. An MSE wall or reinforced earth slope are also options. This recommendation is of high priority.

    A similar berm should be constructed between 1931 and 1945 Westview Drive. This section of the berm would be a lower priority because the sanitary sewer main is less exposed to the potential slope hazard.

    Alternatively the City could relocate this sewer main away from the slope.

iii. The potentially unstable retaining walls at 1821 Bewicke Avenue, 2015 Westview Drive, and 2049 Westview Drive should be removed and either replaced with MSE walls or the upper slope flattened to remove the need for retaining walls. Replacement of the wall at 2015 Westview Avenue is of high priority because a failure could damage the sewer main. Replacement of the wall at 2049 Westview Avenue is of moderate to high priority because a failure could destabilize the footings supporting the sundeck. Replacement of the wall at 1821 Bewicke Avenue is of low priority because the wall only supports the back yard.

iv. The loose fill in the back of 1805 to 1821 Bewicke Avenue should be investigated further to determine if the displacement is simply due to settlement or due to slope movement. Stabilization of the slope would likely involve reconstructing the fillslope with geogrid reinforcement or simply flattening of the slope. This work is of low priority because the houses are not directly at risk. However, such a failure would place trail users at risk.

v. The owners of the properties classified as having a moderate, high or very high risk of damage to the house should be notified. The structures at risk should be individually assessed taking into consideration the structure's foundation design and the specific slope hazard. Some foundations may have been designed to withstand the potential slope movement. Others may warrant mitigative action such as:

    - slope reinforcement to reduce the probability of failure;

    - deepening or underpinning of the foundation onto more stable soil;

- replacement of older homes with newer structures constructed to manage the slope hazard (such as the recent construction at 625 West 22nd Street);

In some cases, the value of the existing structures will not warrant the cost of remediating the risk and decision will have to be made to either accept the risk or remove the house.

Prior to commencing this work, a more thorough geotechnical investigation of these lots must be completed.

10.0 LIMITATIONS

This study is intended for use by the City as a planning tool only. The study delineates the relative hazards on the east slope of Mosquito Creek and takes into consideration the proximity of the adjacent structures and services but does not include any assessment of the structural integrity of these structures or services. One objective of this study is to determine where site specific investigations are recommended, but this study itself should not be used as a site specific investigation or risk assessment. Such studies require specific evaluations of the structures and services.

The study is based predominantly on field reconnaissance with limited subsurface investigation. Three test holes are not adequate to accurately delineate the subsurface geology over such a large area. Variations in the soil conditions and groundwater levels will exist. Also, the field reconnaissance included cross-sections at 50 m intervals. Slope conditions between the cross-sections are extrapolated from the sections on either side. Some variations in the slope conditions may not have been detected.

References to specific properties are based on the field reconnaissance, which occurred in the rear of the property. Addresses for some properties were verified at that time while others did not have ready access to the front of the property; therefore, the addresses were determined later. It is possible that a reference to a specific property in this report could be in error. If such an error is detected, the authors request notification so that the report can be corrected.

The setbacks for the houses were measured only where the rear yards were readily accessible while setbacks for the others are only estimates. Since many properties are fenced at the back, the accuracy of these estimates can vary.

Factual data and interpretation contained within this report were prepared specifically for the City with whom Westrek has entered a contract. No representations of any kind are made to any third parties with whom Westrek has not entered a contract.

Enc: Appendix A - Summary Tables (3); B - Slope Profiles (2); C – Test hole logs (3); D - Location map.

Appendix A.

Summary Tables.

Address	Year Existing House Constructed[1]	Engineering Review During Construction[2]	Landslide Probability	Estimated Runout Distance from Toe of Slope	Distance from Toe of Slope to Trail (m)[3]	Probability of Spatial Interaction with Trail	Partial Risk to Trail	Distance from Toe of Slope to Creek (m)[1]	Probability of Spatial Interaction with Creek	Partial Risk to Creek
710 West 17th Street	1955	No	Moderate	10	21	Low	**Low**	30	Very low	**Very low**
711 West 18th Street	1954	No	Moderate	10	12	Moderate	**Moderate**	21	Low	**Low**
1805 Bewicke Ave.	1986	No	High	20	14	High	**Very high**	20	High	**Very high**
1815 Bewicke Ave.	1985	No	High	20	14	High	**Very high**	20	High	**Very high**
1821 Bewicke Ave.	1974	No	High	20	14	High	**Very high**	20	High	**Very high**
1845 Bewicke Ave.	1951	No	High	20	4	High	**Very high**	12.5	High	**Very high**
Bewicke Ave @ West 19th Street	N/A	N/A	Low	15	0	High	**Moderate**	12	High	**Moderate**
626 West 19th Street	1969	No	Low	15	0	High	**Moderate**	12	High	**Moderate**
1931 Westview Drive	1989	No	High	10	0	High	**Very high**	10	High	**Very high**
1935 Westview Drive	1989	No	High	10	0	High	**Very high**	10	High	**Very high**
1945 Westview Drive	1949	No	High	10	0	High	**Very high**	10	High	**Very high**
1957 Westview Drive	1951	No	High	10	0	High	**Very high**	10	High	**Very high**
2009 Westview Drive	1982	No	Moderate	10	0	High	**High**	30	Very low	**Very low**

[1] Information provided by the City.
[2] Information provided by the City.
[3] The distance has been interpolated between the slope transects that were used to complete this assessment. The actual distance may differ.

Address.	**Year Existing House Constructed**[1]	**Engineering Review During Construction**	**Landslide Probability**	**Estimated Runout Distance from Toe of Slope**	**Distance from Toe of Slope to Trail (m)**	**Probability of Spatial Interaction with Trail**	**Partial Risk to Trail**	**Distance from Toe of Slope to Creek (m)**	**Probability of Spatial Interaction with Creek**	**Partial Risk to Creek**
2015 Westview Drive	1982	No	High	10	0	High	**Very high**	30	Very low	**Low**
2017 Westview Drive	1952	No	High	10	2	High	**Very high**	20	Low	**Moderate**
2041 Westview Drive	1953	No	High	10	3	High	**Very high**	20	Low	**Moderate**
2049 Westview Drive	1977	Yes	High	10	3	High	**Very high**	18	Low	**Moderate**
2059 Westview Drive	1978	Yes	High	10	3	High	**Very high**	18	Low	**Moderate**
2069 Westview Drive	1978	Yes	High	10	3	High	**Very high**	18	Low	**Moderate**
2101 Westview Drive	1978	Yes	High	10	5	High	**Very high**	25	Very low	**Low**
2103 Westview Drive	1978	Yes	High	10	5	High	**Very high**	25	Very low	**Low**
2117 Westview Drive	1979	Yes	High	10	5	High	**Very high**	25	Very low	**Low**
2121 Westview Drive	1979	Yes	High	10	5	High	**Very high**	25	Very low	**Low**
625 West 22nd Street	2006	Yes	Low	10	6	High	**Moderate**	30	Very low	**Very low**
626 West 22nd Street	1987	Yes	Moderate	10	15	Moderate	**Moderate**	30	Very low	**Very low**

Address	Year Existing House Constructed[1]	Engineering Review During Construction	Landslide Probability	Estimated Runout Distance from Toe of Slope	Distance from Toe of Slope to Trail (m)	Probability of Spatial Interaction with Trail	Partial Risk to Trail	Distance from Toe of Slope to Creek (m)	Probability of Spatial Interaction with Creek	Partial Risk to Creek
622 West 22nd Street	1968	No	Moderate	10	15	Moderate	**Moderate**	50	Very low	**Very low**
Laneway between West 23rd and West 22nd Streets.	N/A	N/A	Moderate	10	6	High	**High**	30	Very low	**Very low**
625 West 23rd Street	1965	Yes[4]	Moderate	15	15	High	**High**	50	Very low	**Very low**
West 23rd Street	N/A	N/A	Low[5]	10	7	High	**Moderate**	30	Very low	**Very low**
632 West 23rd Street	1931	No	High	20	7	High	**Very high**	30	Moderate	**High**

Summary Table 1: The partial risk to the trail and the channel of Mosquito Creek if a landslide originated from the slopes on the east side of the ravine. The partial risk is based on the probability of a spatial interaction only.

[4] Engineering review was not provided during construction, however an engineering assessment was completed following the landslide on the adjacent slopes.
[5] The probability of landslide occurrence on this slope is increased significantly it the buried services at the crest of this slope are leaking.

Address	Probability of a landslide	Estimated Size of Landslide	Distance from the Slope Crest to House[6]	Probability of a Spatial Interaction with the House	Partial Risk to the House	Distance to U/G Services[1]	Probability of a Spatial Interaction with the U/G Services	Partial Risk to U/G Services
710 West 17th Street	Moderate	8 x 3	6	Moderate	**Moderate**	N/A	N/A	**N/A**
711 West 18th Street/vacant lot	Moderate	5 x 2	6	Moderate	**Moderate**	15, Sanitary sewer.	Low	**Low**
1805 Bewicke Ave	High	10 x 6	> 10	Low	**Moderate**	N/A	N/A	**N/A**
1815 Bewicke Ave	High	10 x 6	11 to 12	Low	**Moderate**	N/A	N/A	**N/A**
1821 Bewicke Ave	High	10 x 6	10	Moderate	**High**	N/A	N/A	**N/A**
1845 Bewicke Ave	High	8 x 4	2 to 10	Moderate	**High**	N/A	N/A	**N/A**
Bewicke @ West 19thStreet	Low	10 x 3	N/A	N/A	**N/A**	5 (?), Sanitary sewer.	Moderate	**Low**
626 West 19th Street	Low	10 x 3	4	High	**Moderate**	N/A	N/A	**N/A**
1931 Westview Drive	High	10 x 3	>15	Very low	**Low**	5 (?) Sanitary sewer.	Moderate	**High**
1935 Westview Drive	High	10 x 3	>15	Very low	**Low**	5 (?) Sanitary sewer.	Moderate	**High**
1945 Westview Drive	High	10 x 3	15	Very low	**Low**	5 (?) Sanitary sewer.	Moderate	**High**
1957 Westview Drive	High	10 x 3	12	Very low	**Low**	5 (?) Sanitary sewer.	Moderate	**High**

[6] The distance has been interpolated between the slope transects that were used to complete this assessment. The actual distance may differ.

Address	Probability of a landslide	Estimated Size of Landslide	Distance from the Slope Crest to House (m)	Probability of a Spatial Interaction with the House	Partial Risk to the House	Distance to U/G Services (m)	Probability of a Spatial Interaction with the U/G Services	Partial Risk to U/G Services
2009 Westview Drive	Moderate	10 x 2	8	Low	**Low**	3 (?) Sanitary sewer.	High	**High**
2015 Westview Drive	High	10 x 2	7 to 10	Low	**Moderate**	2 (?) Sanitary sewer.	High	**Very high**
2017 Westview Drive	High	10 x 2	>10	Very low	**Low**	Not applicable (N/A)	N/A	**N/A**
2041 Westview Drive	High	10 x 2	8	Low	**Moderate**	N/A	N/A	**N/A**
2049 Westview Drive	High	10 x 2	3	High	**Very high**	N/A	N/A	**N/A**
2059 Westview Drive	High	10 x 2	2	High	**Very high**	N/A	N/A	**N/A**
2069 Westview Drive	High	10 x 2	4	Moderate	**High**	N/A	N/A	**N/A**
2101 Westview Drive	High	10 x 2	0	High	**Very High**	N/A	N/A	**N/A**
2103 Westview Drive	High	10 x 2	3	High	**Very high**	N/A	N/A	**N/A**
2117 Westview Drive	High	10 x 2	20 to 30	Very low	**Low**	N/A	N/A	**N/A**
2121 Westview Drive	High	10 x 2	20 to 30	Very low	**Low**	N/A	N/A	**N/A**
625 West 22nd Street	Low	N/A	3	Moderate	**Low**	N/A	N/A	**N/A**
626 West 22nd Street[7]	Moderate	8 x 2	0 (located on slope)	High	**High**	N/A	N/A	**N/A**
622 West 22nd Street	Moderate	10 x 2	2.5	High	**High**	N/A	N/A	**N/A**

[7] This property had geotechnical engineering design (from RDM) prior to construction, however no information was available on whether the final construction is in conformance with the design recommendations.

Address	**Probability of a landslide**	**Estimated Size of Landslide**	**Distance from the Slope Crest to House**	**Probability of a Spatial Interaction with the House**	**Partial Risk to the House**	**Distance to U/G Services**	**Probability of a Spatial Interaction with the U/G Services**	**Partial Risk to U/G Services**
625 West 23rd Street	Moderate	10 x 3	10	Low	**Moderate**	N/A	N/A	**N/A**
Laneway between West 23rd and West 22nd Streets.	Moderate	10 x 3	N/A	N/A	**N/A**	Possibly 2 m to storm sewer and rock pit.	High	**Very high**
West 23rd Street	Low[8]	10 x 2	N/A	N/A	**N/A**	0, GVWD Water main on slope, City watermain, fire hydrant and sanitary sewer main next crest.	High	**Moderate**
632 West 23rd Street	High	20 x 4	4	High	**Very high**	Unknown for water main and sanitary sewer main.	Unknown	**Unknown**

Summary Table 2: The partial risk to the house and/or U/G services on the properties at the slope crest if a landslide originated from the slopes on the east side of the ravine. The partial risk is based on the probability of a spatial interaction only.

[8] The probability of landslide occurrence on this slope is increased significantly it the buried services at the crest of this slope are leaking.

ADDRESS	SITE DESCRIPTION & POTENTIAL HAZARD.											
	SLOPE HEIGHT (m)	UPPER SLOPE ANGLE (%)	FILL ON SLOPE (yes/no)	GROUND WATER SEEPAGE	ROCK PIT @ REAR OF LOT?[9]	SLOPE DEFORMATION	TIMBER TYPE	RETAINING WALL (yes/no)	WALL DEFORMATION (yes/no)	BACKYARD DEFORMATION (yes/no)	POSSIBLE LANDSLIDE TYPE	LANDSLIDE PROBABILITY
710 W17th	15	75	Yes	No	Rock pit @ crest of slope or unknown	Minor	Conifer + deciduous	No	-	No	Fill	Moderate
711 W18th/vacant lot	19	75	Debris yard waste	No	Rock pit @ crest of slope or unknown	Bulge	Conifer + deciduous	No	-	No	Fill	Moderate
1805 Bewicke	15	75	Yes	No	Storm drain connection	Bulge	Deciduous	No	-	Yes	Fill	High
1815 Bewicke	15	75	Yes	No	Storm drain connection	Bulge	Deciduous	No	-	Yes	Fill	High
1821 Bewicke	15	75	Yes	No	Storm drain connection	Bulge	Deciduous	Timber	Yes	Yes	Fill	High
1845 Bewicke	13	100	Yes	No	Rock pit @ crest of slope or unknown	Erosion	Conifer	No	-	Minor	Fill + natural	High
Bewicke @ W19th	12	50	Yes (eng)	No	N/A	No	none	No	-	No	Fill	Low
626 W19th	12	50	Yes (eng)	No	Storm drain connection	No	none	Lock-block	No	0.5 m scarp	Wall failure	Low
1931 Westview	~ 17	> 120	No	Minor seepage	Rock pit 25 m from crest	Ravel	none	No	-	Minor	Ravel/block	High
1935 Westview	~ 17	> 120	No	Minor seepage	Rock pit 25 m from crest	Ravel	none	No	-	Minor	Ravel/block	High
1945 Westview	~ 17	> 120	No	Minor seepage	Rock pit @ crest of slope or unknown	Ravel	none	No	-	Minor	Ravel/block	High
1957 Westview	15	110	No	Minor seepage	Rock pit @ crest of slope or unknown	No	Conifer	No	-	No	Natural	High
2009 Westview	15	100/60	Yes	No	Rock pit @ base of slope	Creep	Deciduous	No	-	No	Fill	Moderate
2015 Westview	15	100/60	Yes	No	Rock pit @ base of slope	Creep	Deciduous	Timber	Yes	Yes	Fill	High
2017 Westview	16	90	Yes	No	Rock pit @ crest of slope or unknown	Creep	Deciduous	No	-	Yes	Fill	High

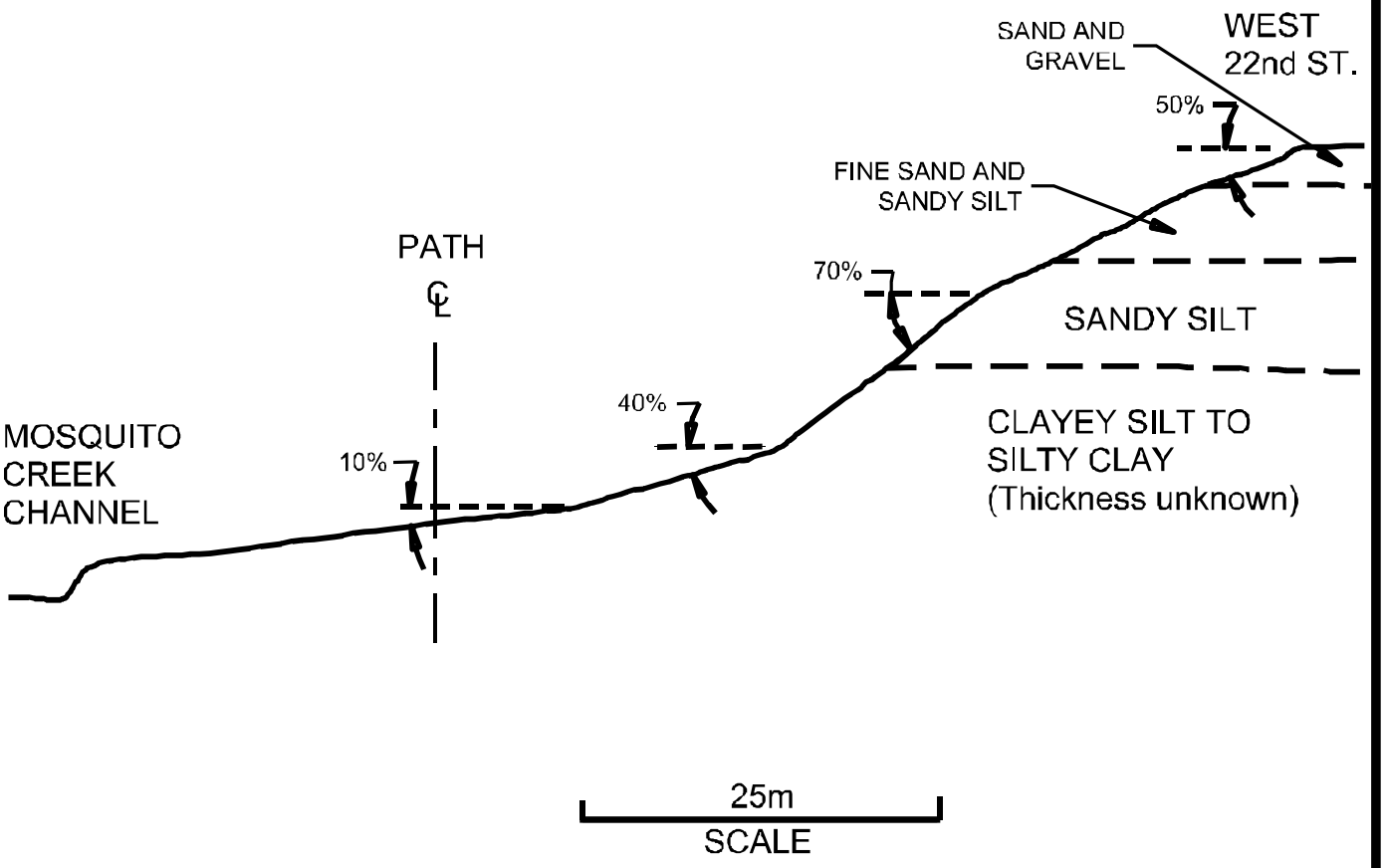
[9] Information provided by the City.

2041 Westview	16	90	Yes	No	Rock pit @ crest of slope or unknown	Creep	Deciduous	No	-	Yes	Fill	High
2049 Westview	17	90	Yes	No	Rock pit @ base of slope	Creep	Deciduous	Timber	Yes	Yes	Fill	High
2059 Westview	17	90	Yes	No	Rock pit @ base of slope	Creep	Deciduous	No	-	Yes	Fill	High
2069 Westview	17	90	Yes	No	Rock pit @ base of slope	Creep	Deciduous	No	-	Yes	Fill	High
2101 Westview	22	75/11	Yes	No	Storm drain connection (?), catch basin at rear of house.	Creep/slumping	Conifer + deciduous	No	-	Yes (sundeck)	Fill	High
2103 Westview	22	100/80/ 22	Yes	No	Storm drain connection (?), catch basin at rear of house.	Creep/slumping	Conifer	No	-	Yes	Fill	High
2117 Westview	22	75/22	Yes	No	Rock pit @ base of slope	Creep/slumping	Deciduous	No	-	Yes	Fill	High
2121 Westview	22	75/22	Yes	No	Rock pit @ base of slope	Creep/slumping	Deciduous	No	-	Yes	Fill	High
625 W22nd	19	60	No	No	Rock pit @ crest of slope or unknown	No	Conifer	No	-	No	Natural	Low
626 W22nd	19	58	Yes	Yes	Rock pit @ base of slope	No	Conifer	No	-	No	Natural	Moderate
622 W22nd	25	58	Unknown	Yes	Probably to storm drain	Creep	Deciduous + conifer	No	-	Minor	Fill	Moderate
625 W23rd	25	65 to 78	No	Yes	Storm drain connection	2004 landslide	None/ conifer	No	-	Part of landslide	Natural	Moderate
W23rd St	26	60	Yes	Yes	Storm drain	No	Conifer	No	-	No	Fill	Low
632 W23rd	30	70	Unknown	Yes	Unknown	1999 landslide	Conifer + deciduous	No	-	Slump	Natural	High

Summary Table 3: Site Observations and Landslide Probability.

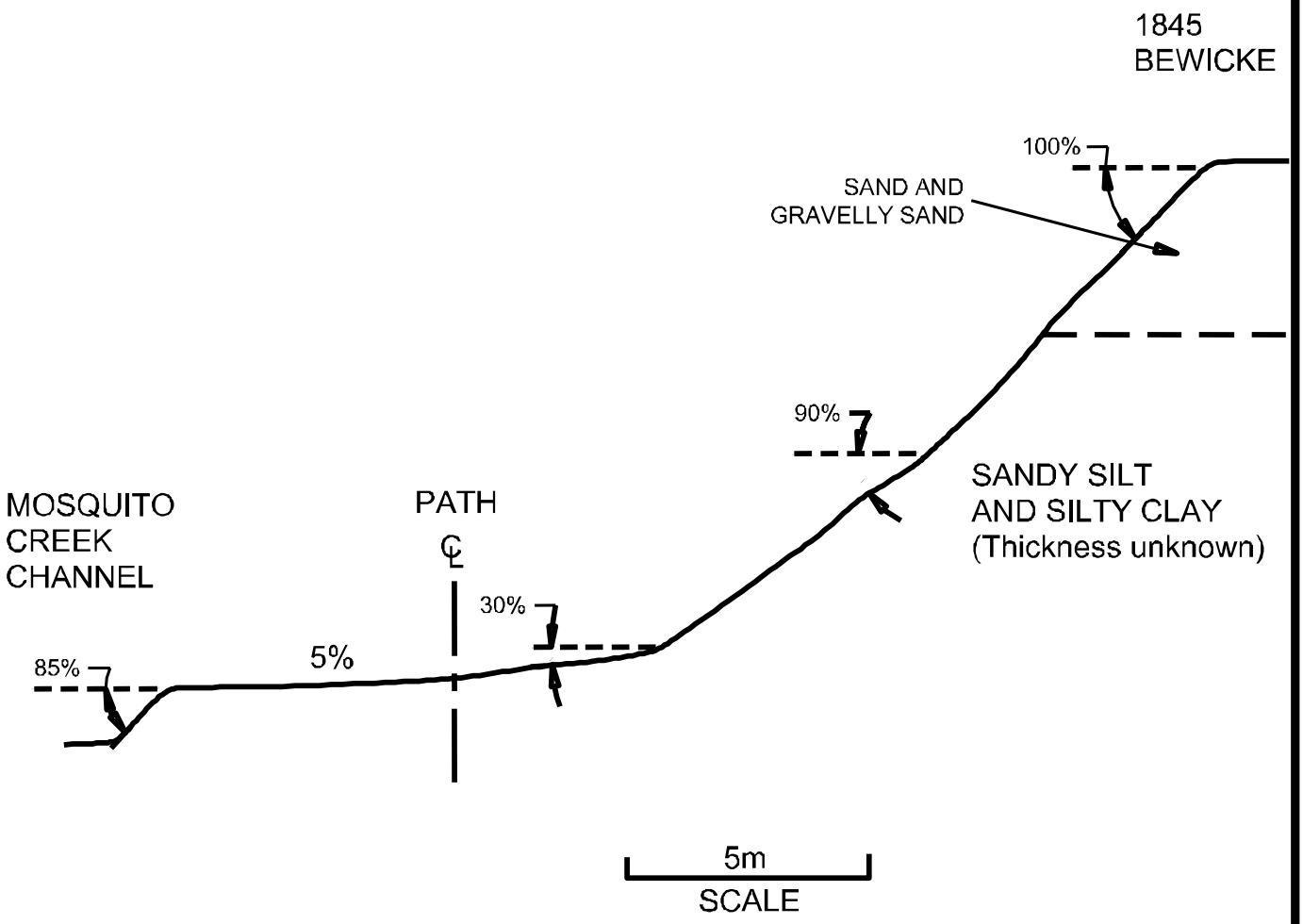
Appendix B.

Slope Profiles (2).



SLOPE PROFILE AT
STA. 0+700

WESTREK geotechnical services	CITY OF NORTH VANCOUVER				EAST BANK ASSESSMENT		
	MOSQUITO CREEK				SLOPE PROFILE, Sta. 0+700, TH05-3		
005-051	PTS	TS	TS	18/07/05	AS NOTED	1	



SLOPE PROFILE AT
STA. 0+250m

WESTREK geotechnical services	CLIENT: CITY OF NORTH VANCOUVER				TITLE: EAST BANK ASSESSMENT		
	PROJECT: MOSQUITO CREEK				SLOPE PROFILE, Sta. 0+250, TH05-1		
PROJECT no. 005-051	DRN. PTS	DSGN. TS	CHK. TS	DATE 18/07/05	SCALE AS NOTED	DWG no. 2	

Appendix C.

Test Hole Logs (3).

TEST HOLE 05-1

Project: Mosquito Creek Ravine East Bank Assessment		Client: City of North Vancouver	Date: November 29, 2005
Logged by: EJM	Elevation: Ground	Location: Bewicke Ave. near W19th St.	
Contractor: Downrite	Equip: Bombardier	Method: Solid Stem Auger / Dynamic Cone Penetration Test	

Depth (m)	Soil Description and Comments	Water Level	Sample Type	Sample #	DCPT (N)	Instrumentation	USC	Moist %	P.L.	L.L.
0.0	**SAND & GRAVEL: loose, grey, damp.**				6					
					13					
0.6	**SAND: loose, reddish brown, moist, organic, silty, gravelly**				2					
					6					
1.0	-becoming denser				37					
					39					
1.8	**Gravelly SAND: compact, grey, moist.**				25					
2.0					27					
2.4	**SAND: compact, grey, moist, trace of gravel.**				26					
	- silty layer from 2.7 to 3.0 m				15					
3.0	**Silty SAND to sandy SILT: compact, brown, wet, fine grained** - some sandier lenses				9					
					14					
		▼ 12/01/06								
3.7					11					
4.0					14					
					12					
			grab	1-1	16		SM-ML			
					11					
5.0										
5.2	**Sandy SILT: firm, grey, wet, fine grained sand**. - non-plastic				6					
					8					
					7					
6.0					8					
					10					
6.7	**Silty CLAY: firm, grey, wet.** - low plastic				5					

TEST HOLE 05-1

Sheet 2

Depth (m)	Soil Description and Comments	Water Level	Sample Type	Sample #	DCPT (N)	Instrumentation	USC	Moist %	P.L.	L.L.
7.0	**Silty CLAY: soft, grey, wet.** - low plastic		grab	1-2	5 3 4 5 6 100+		CL			
8.0										
8.8	Auger and DCPT refusal at 8.8 m depth End of Test Hole									
9.0										
10.0										
11.0										
12.0										
12.7										
13.0										
14.0										

INSTALLATIONS: Piezometer - 25 mm PVC. Solid pipe from 0 to 4.6 m; slotted pipe from 4.6 to 6.1 m. Bentonite seal from 1.5 to 2.2 m. Flush-mount cap.

TEST HOLE 05-2

Project: Mosquito Creek East Bank Ravine Assessment		Client: City of North Vancouver	Date: November 29, 2005
Logged by: EJM	Elevation: Ground	Location: West end of W22nd St.	
Contractor: Downrite	Equip: Bombardier	Method: Solid Stem Auger / Dynamic Cone Penetration Test	

Depth (m)	Soil Description and Comments	Water Level	Sample Type	Sample #	DCPT (N)	Instrumentation	USC	Moist %	P.L.	L.L.
0.0	**TOPSOIL: loose, dark brown, organic.**				6					
					6					
0.6	**SAND: loose, reddish brown, moist, gravelly**				3					
					4					
1.0					8					
1.5	**SAND: loose to compact, brown, moist, gravelly, clean**				8					
					8					
2.0					9					
					12					
					18					
3.0					15					
					21					
3.7	**SAND: compact, brown, silty, fine grained.** **Trace of gravel.**				23					
4.0	- 15 cm thick clean sand seam @ 4.0 m				21					
	- 15 cm thick clean sand seam @ 4.3 m				38					
					31					
5.0					14					
					19					
5.5	**Sandy SILT: compact, grey-brown, wet, fine grained sand**. - non-plastic				30					
			grab	2-1	24		ML			
6.0					38					
					55					
					30					

TEST HOLE 05-2

Sheet 2

Depth (m)	Soil Description and Comments23	Water Level	Sample Type	Sample #	DCPT (N)	Instrumentation	USC	Moist %	P.L.	L.L.
7.0	**Sandy SILT: compact, grey-brown, wet, fine grained sand**. - non-plastic				30					
					23					
	- finer grained with depth				12					
	- turns grey @ 7.9 m				15					
8.0					16					
			grab	2-2	15		ML			
					18					
9.0										
9.1	**silty CLAY: firm, grey, wet**. - low plastic				14					
					10					
					11					
10.0	- fine sandy seam				10					
					15					
					18					
11.0					9					
			grab	2-3	8		CL			
					10					
					11					
12.0					11					
					12					
					11					
13.0					12					
					13					
					100+					
13.9	Auger and DCPT refusal at 13.9 m depth **END OF TEST HOLE**									

INSTALLATIONS: No piezometer.

TEST HOLE 05-3

Project: Mosquito Creek East Bank Ravine Assessment		Client: City of North Vancouver	Date: November 29, 2005
Logged by: EJM	Elevation: Ground	Location: West end of alley between W22nd St. and W23rd St.	
Contractor: **Downrite**	Equip: Bombardier	Method: Solid Stem Auger / Dynamic Cone Penetration Test	

Depth (m)	Soil Description and Comments	Water Level	Sample Type	Sample #	DCPT (N)	Instrumentation	USC	Moist %	P.L.	L.L.
0.0	**SAND & GRAVEL(FILL): loose, grey, damp.**				13					
					9					
0.6	**SAND & GRAVEL: loose, dark brown, moist, some silt**				5					
					6					
1.0										
1.2	**SAND: compact, light brown, damp, some gravel, medium grain.**				45					
	- decreasing gravel content with depth									
	- cobble or small boulder				19					
					20					
2.0					25					
2.4	**Silty fine SAND to sandy SILT: compact, grey-brown, moist.**				19					
					24					
3.0					21					
					13					
					12					
4.0	- becomes wet, grey, and loose				18					
	- mostly SILT		grab	3-1	11		ML			
					9					
					9					
5.0										
5.2	- Sandier seam				17					
					31					
5.8	**Very fine sandy SILT: compact, grey, wet.**				23					
	- non-plastic									
6.0		▼ 14/01/06			42					
					39					
6.7					24					

TEST HOLE 05-3

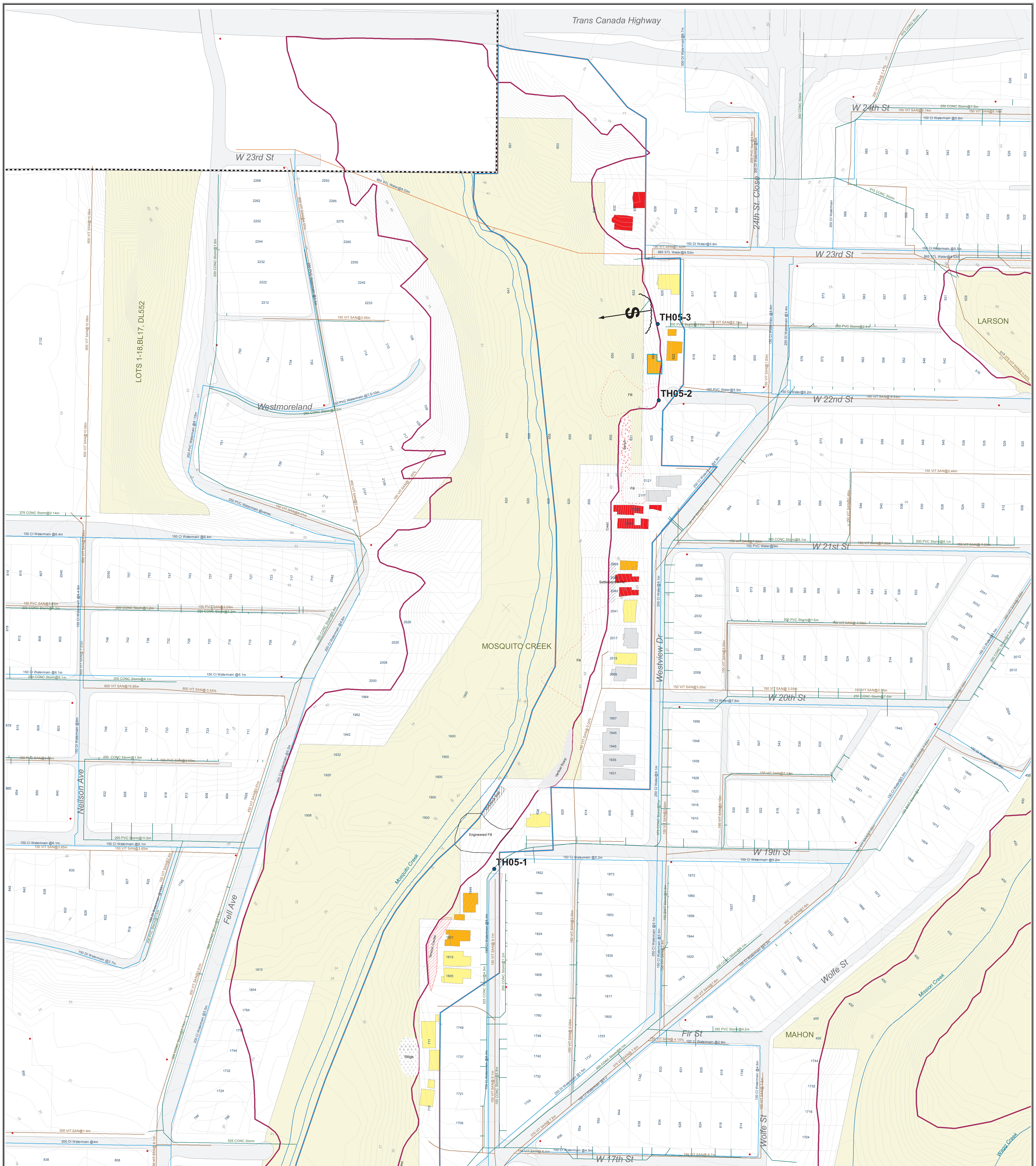
Sheet 2

Depth (m)	Soil Description and Comments	Water Level	Sample Type	Sample #	DCPT (N)	Instrumentation	USC	Moist %	P.L.	L.L.
7.0	**Very fine sandy SILT: compact, grey, wet.** - non-plastic				14					
					20					
					13					
					11					
8.0										
					16					
					13					
8.8			grab	3-2	15		ML			
9.0										
	- becoming finer grained and loose/firm.				10					
					10					
					8					
10.0										
10.1	**Clayey SILT to silty CLAY: firm, grey, wet.** - low plastic				11					
	- some thin sandy seams				20					
					13					
11.0					8					
					11					
					13					
					13					
12.0										
			grab	3-3	14		CL			
					19					
12.7										
					27					
13.0					44					
13.3	Auger and DCPT refusal at 13.3 m depth				100+					
14.0										

INSTALLATIONS: Piezometer - 25 mm PVC. Solid pipe from 0 to 9.1 m; slotted pipe from 9.1 to 10.7 m. Bentonite seals from 0.9 to 1.5 m and from 5.5 to 6.4 m. Flush-mount cap.

Appendix D.

Location Map (1).



City of North Vancouver

Mosquito Creek Ravine Study

Legend

- Sample Station
- Hydrant
- Test Hole
- Storm
- Ditch
- Sanitary
- Water
- GVRD Water Mains
- Contour (1m)
- Stream
- Top of Bank (2006)
- City Border
- Legal Parcel
- Study Area
- Park
- Road

Partial Building Risk

- Low
- Moderate
- High
- Very High

Slope Features

- Bench
- Crest
- Engineered Fill
- Fill
- Lockblock Wall
- Ridge
- Settlement In Fill
- Tension Cracks
- Vertical Scarp
- Slide

GIS Division, Information Technology,
City of North Vancouver

PLOTTED: Jul 18, 2006
FILE: G:\ArcMap_Projects_9.0\Engineering\Mosq_CkRavine2006v2.mxd
COORDINATE SYSTEM: NAD 83, UTM Zone 10

DISCLAIMER
This map was produced on the City of North Vancouver's Geographic Information System. Data provided herein is derived from sources with varying levels of accuracy and detail. The City of North Vancouver disclaims all responsibility for the accuracy or completeness of information contained herein.

0 50 100
Meters

N

2006