GEOTECHNICAL INVESTIGATION
SLOPE STABILITY
AND
STREAMBANK EROSION ANALYSIS
2935 & 2955 MISSISSAUGA ROAD
MISSISSAUGA, ONTARIO

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1. INTRODUCTION

Terraprobe Limited was retained by G. Merulla Inc. c/o Beacon Planning Services to conduct a slope stability and streambank erosion study for a property located in the southeast quadrant of the intersection of Mississauga Road and Dundas Street West, in the City of Mississauga, Ontario.

The subject property is bounded by Mississauga Road on the west and Credit River on the east side. There is a drainage channel located on the north side of the property followed by Dundas Street West. The west and south portions of the property are densely vegetated and includes a drainage ditch located approximately along the west and south property boundary. It is understood that the study area consists of two adjoining land parcels (2935 - 2955 Mississauga Road). The subject site currently consists of a relatively flat tableland surrounded by vegetated/forested areas located along the north, south and west property boundaries, and the Credit River valley slope located along the east property boundary. The property is currently vacant, however, includes remnants of previous development (abandoned swimming pool, concrete pad and a portion of the concrete foundation of a former dwelling) located on the south parcel (2935 Mississauga Road).

This report includes the results of a detailed slope stability and streambank erosion study based on a site specific borehole investigation, which was conducted to assess the long-term stability and erosion risks of the valley slope located within the study area. The study provides geotechnical engineering recommendations with respect to the long-term stability of the site slope including applicable stability and erosion setbacks.

2. SITE AND PROJECT DESCRIPTION

The site is located at a short distance south of the intersection of Mississauga Road and Dundas Street West, in the City of Mississauga, Ontario. The property fronts on Mississauga Road and extends east to Credit River which is located at the toe of the valley slope along the east property boundary. The municipal address of the property is 2935 - 2955 Mississauga Road, Mississauga, Ontario. The legal description of the property is "Part of Lots 3 and 4, Range 1, South of Dundas Street Racey Tract, City of Mississauga, Regional Municipality of Peel". The general location of the property is shown on Figure 1. An aerial view of the site (2006 Aerial Photograph, Source City of Mississauga) is enclosed as Figure 2. For the purpose of site discussion, the orientation of Mississauga Road is assumed to be aligned in a north-south direction.

The subject property is roughly rectangular in shape and consists of two adjoining land parcels fronting on Mississauga Road. Portions of the property located along the west, north and south property boundaries currently consists of densely vegetated/forested areas. The property includes a relatively flat tableland surrounded by these vegetated/forested areas and the Credit River valley slope located along the east property boundary. The property is currently vacant except for the remnants of a previous development located on the south parcel. The current site topography consists of a relatively flat to gently sloping ground except for the easterly portion of the property which consists of a relatively steep slope associated with Credit River watershed.

The prominent feature of the site, pertaining to the slope stability and erosion risks, consists of a relatively high and steep valley slope located within the easterly portion of the site adjoining Credit River. This slope distinctively extends from the north property boundary to almost to the two-third length of the property along Credit River. The northerly portion of this slope (close to Borehole 1 and Section 1) is about 6 m to 8 m in height. The slope becomes progressively higher as it extends further south, becoming as high as about 11m for the remaining portion of the slope (in the area of Boreholes 2 & 3 and Sections 2 & 3), except for the southerly portion (south of Section 3 to the existing swimming pool) where it decreases in height to about 6 m to 3 m close to the southerly edge of the swimming pool. The watercourse (Credit River) is located at the toe of the slope in this area. The proximity of the river to the slope has resulted in active toe erosion and over-steepening of the lower portion of the slope which consists of shale (Bedrock of Geogian Bay Formation). The slope located further south of the swimming pool, within the study area, gradually diminishes as the ground becomes relatively flat and the river gradually meanders away.

It is noted that the rear (west) portion of the high (middle) slope, behind the top of bank, extending from about Section 1 to approximately to the middle of Sections 2 and 3, has been disturbed and re-graded. The area to the rear (west) of the top of bank currently consists of a relatively narrow and level plateau (about 1 m to 3 m) wide, followed by a drop of about 2 m to 3 m. It appears that the ground behind the top of bank, in this area, has been lowered and re-graded.

There are densely vegetated/forested areas located along the north, west and south property boundaries. The topography of these areas generally varies from relatively flat to gently sloping. The majority of the vegetated area along the west property boundary (Mississauga Road) is generally flat to gently sloping and includes a relatively small ditch. The ditch continues along the south property boundary located within the southerly vegetated area. This area extends across the width of the property to Credit River. The topography of this southerly vegetated area is also relatively flat to gently sloping except for a couple of localized relatively steep areas (Sections 4 and 5). The northerly vegetated area also consists of gently sloping ground and includes dense vegetation.

The remainder of the property, surrounded by these vegetated areas and the relatively steep slope along Credit River on the east, currently includes a relatively flat and clear area which was cultivated and reportedly supports a barley crop.

3. FIELD PROCEDURE

The field investigation of the site was conducted on August 14, 2008, and consisted of drilling and sampling a total of four (4) exploratory boreholes extending to depths of about 7.4 m (Boreholes 2 and 4) to 9.2 m (Boreholes 1 and 3) below existing ground surface.

The borehole locations were established and finalized in the presence of the client and a representative of Beacon Planning Services. The boreholes were staked out in the field by Terraprobe Limited. Various public utility agencies were contacted to clear borehole locations of possible underground plants. The ground surface elevations at the borehole locations were measured by Tarasick McMillan Kubicki Limited, OLS, and are referenced to the geodetic datum. The approximate locations of the boreholes are presented on Figure 3.

The borings were made using a continuous flight power auger machine (track-mounted) equipped with conventional soil sampling and testing tools. The drilling was observed and recorded by a member of our field engineering staff on a full time basis, who also logged the boring and examined the samples. The results of the borehole are recorded in detail on the accompanying borehole logs.

Representative disturbed samples of the strata penetrated were obtained from the boreholes using a split-barrel sampler advanced by a 63.5 kg hammer dropping approximately 760 mm. The results of the Penetration Tests are reported as "N" values on the borehole logs at the corresponding sampling depths.

Samples obtained from the boreholes were inspected in the field immediately upon retrieval for type, texture, colour and odour. The samples obtained were then sealed in clean plastic containers and transferred to the Terraprobe laboratory where the samples were examined by a geotechnical engineer to verify the accuracy of the initial soil descriptions, and to select appropriate samples for laboratory testing. Laboratory testing consisted of water content determination on all samples, while a sieve and hydrometer analysis was carried out on selected samples (Borehole 1, Sample 4; Borehole 2, Sample 6; Borehole 3, Sample 3; Borehole 3, Sample 6; and Borehole 4, Sample 2). Atterberg Limits tests were also conducted on four selected samples (Borehole 1, Sample 4; Borehole 2, Sample 6; Borehole 3, Sample 6; and Borehole 4, Sample 2). The measured natural water content for individual samples are plotted on the corresponding borehole logs at respective sampling depths, and the results of the grain size analysis are appended.

Water levels were monitored in the open boreholes upon completion of drilling. Standpipe type piezometer consisting a PVC tubing were installed in Boreholes 1, 3 and 4 to facilitate shallow ground water monitoring. The PVC tubing was saw slotted near its base and fitted with a bentonite clay seal as shown on the accompanying borehole logs. The results of ground water monitoring are summarized in a subsequent section of this report.

4. SUBSURFACE CONDITIONS

The results of the borehole are summarized below and recorded on the accompanying Borehole Logs. This summary is intended to correlate this data to assist in the interpretation of the subsurface conditions encountered at the site.

It should be noted that the soil conditions are confirmed at the borehole locations only and may vary between and beyond the borehole locations. The stratigraphic boundaries as shown on the logs and sections represent an inferred transition between the various strata, rather than a precise plane of geologic change.

In summary, the borehole encountered an overburden predominantly comprising undisturbed glacial till deposit underlain by shale bedrock of Georgian Bay Formation. A layer of topsoil was encountered in Borehole 4 at the ground surface.

4.1 Topsoil

A topsoil layer (about 200 m thick) was encountered at the ground surface in Borehole 4. The topsoil was dark brown to black in colour and predominantly consisted of a clayey silt matrix. A distinct layer of topsoil was not encountered at other borehole locations.

It must be noted that the topsoil thickness is confirmed at the borehole location only, and may vary beyond the borehole location. This information is not considered to be sufficient for estimating topsoil quantities and associated costs.

4.2 Earth Fill

A relatively thin layer of earth fill materials (about 0.8 m thick) was encountered at the ground surface in Borehole 3. The earth fill materials consisted of clayey silt with trace amounts of sand and gravel. The earth fill materials also included trace amounts of organic.

The Standard Penetration Test result (‘N’ Value) obtained from the earth fill layer was 10 blows per 300 mm of penetration, suggesting a stiff consistency. Measured moisture content of the earth fill sample was 13 percent by weight, indicating a moist condition.

4.3 Native Soils

Native glacial till deposit was encountered at the ground surface in Boreholes 1 and 2, and beneath the earth fill and topsoil layers at Boreholes 3 and 4 respectively. The native soils predominantly consisted of silt to clayey silt till deposit with embedded sand and gravel. This deposit was underlain by bedrock of Georgian Bay Formation which extended to the full depth of investigation at every borehole location. At Borehole 2, a silt and sand layer was penetrated at a depth of 3.0 m below grade, embedded within the silt/clayey silt till deposit. Similarly, a sand and silt to silty sand layer was encountered overlying the silt/clayey silt till deposit (underlying the surficial earth fill layer) at Borehole 3 extending to a depth of about 2.3 m below grade.

The Standard Penetration Test results (‘N’ Values) obtained from the silt/clayey silt till deposit generally varied from 21 blows to 78 blows per 300 mm of penetration and 50 blows per 50 mm to 150 mm of penetration, suggesting a very stiff to hard consistency (typically hard). Measured moisture contents of the samples of these soils typically ranged between 4 percent to 14 percent by weight, indicating a damp to moist condition.

The Standard Penetration Test results (‘N’ Values) obtained from the silt and sand to silty sand layers varied from 17 blows per 300 mm of penetration and 50 blows per 100 mm to 150 mm of penetration, suggesting a compact to very dense relative density (typically very dense). Measured moisture contents of these soil samples typically ranged between 6 percent to 13 percent by weight, indicating a moist to very moist condition.

4.4 Geotechnical Laboratory Test Results

The geotechnical laboratory testing consisted of water content determination on all samples, while a sieve and hydrometer analysis was carried out on selected native soil samples (Borehole 1, Sample 4; Borehole 2, Sample 6; Borehole 3, Sample 3; Borehole 3, Sample 6; and Borehole 4, Sample 2). Atterberg Limits test was also conducted on four selected native soil samples (Borehole 1, Sample 4; Borehole 2, Sample 6; Borehole 3, Sample 6; and Borehole 4, Sample 2). The measured natural water content for individual samples are plotted on the borehole logs at respective sampling depths, while the results of the sieve and hydrometer analysis as well as Atterberg Limits are appended and summarized below.

Borehole No.	Sample No.	Depth	Gravel (%)	Sand (%)	Silt (%)	Clay (%)
1	4	2.3 m BG	19	17	45	19
2	6	4.5 m BG	6	26	49	19
3	3	1.5 m BG	13	45	35	7
3	6	4.5 m BG	10	8	63	19

Borehole No.	Sample No.	Depth	Gravel (%)	Sand (%)	Silt (%)	Clay (%)
4	2	0.8 m BG	8	11	54	27

BG = Below Grade

The results of the Atterberg Limits tests were plotted on A-Line Graph (refer to enclosed figures, Atterberg Limits Test Results). The following table presents a summary of Atterberg Limit tests:

Borehole No., Sample No.	Depth	Liquid Limit (WL)	Plastic Limit (WP)	Plasticity Index (IP)	Natural Water Content (WN)	Compressibility	Plasticity
BH 1, Sa 4	2.5 m BG	25.8	15.9	9.9	6	Slight or Low	Slightly Plastic
BH 2, Sa 6	4.6 m BG	22.4	14.7	7.7	8	Slight or Low	Slightly Plastic
BH 3, Sa 6	4.7 m BG	21.9	13.8	8.1	9	Slight or Low	Slightly Plastic
BH 4, Sa 2	1.0 m BG	34.2	20.7	13.4	10	Moderate or Intermediate	Slightly Plastic

The results of the Atterberg Limits Tests classify the soil samples analyzed as an inorganic clay of slight plasticity with a slight or low compressibility except for Borehole 4, Sample 2 which has a moderate or intermediate compressibility.

4.5 Bedrock

The glacial till overburden is underlain by bedrock of the Georgian Bay Formation. The interpreted elevations at which the inferred bedrock surface was identified, are tabulated below:

	BH 1	BH 2	BH 3	BH 4
Inferred Bedrock Surface Elevation (m)	97.6	98.7	97.2	96.2

The bedrock of the Georgian Bay Formation is a deposit predominantly comprising thin to medium bedded grey shale of Ordivcian age. The shale contains interbeds of grey calcareous shale, limestone and calcareous sandstone which are discontinuous and nominally 50 to 300 mm thick. Experience from other previous investigations conducted in the general area indicated that there may be thicker limestone layers present in the formation.

There is typically a zone of weathering at the contact between the rock of the Georgian Bay Formation and the glacial soil overburden. In the Ontario Ministry of Transportation and Communications document RR229, *Evaluation of Shales for Construction Projects,* there is reproduced from Skempton, Davis and

Chandler, a *typical weathering profile of a low durability shale,* that characterizes the shale surface into three grades of weathering and four zones described as follows:

	Zone	Description	Notes
Fully Weathered	IVb	soil like matrix only	indistinguishable from glacial drift deposits, slightly clayey, may be fissured
Partially Weathered	IVa	soil like matrix with occasional pellets of shale less than 3 mm dia.	little or no trace of rock structure, although matrix may contain relic fissures
	III	soil like matrix with frequent angular shale particles up to 25 mm dia.	moisture content of matrix greater than the shale particles
	II	angular blocks of unweathered shale with virtually no matrix separated by weaker chemically weathered but intact shale	spheroidal chemical weathering of shale pieces emanating from relic joints and fissures, and bedding planes
Unweathered (Sound)	I	shale	regular fissuring

The surface of the rock having been scoured and involved by the base of glacial ice, Shale Zone III and IV are not present in an identifiable form. At the base of the Glacial Till deposit there is sometimes found a zone of silt and fragmented shale that can be interpreted as the lowest portion of the till or as partially weathered rock of Zone III. The distinction is subjective and depends on the investigator. The differences between the partially weathered classes of rock is not profound.

4.6 Ground Water

The depth of ground water seepage was measured in open boreholes upon completion of drilling. Water levels were also measured on August 28, 2008 in the standpipe piezometer installed in Boreholes 1, 3 and 4. The water level measurements in the open boreholes and standpipe piezometers are summarized below:

Borehole No.	Depth of Boring	Depth to Cave	Unstabilized Water Level Depth / Elevation at the time of drilling	Water Level Depth/ Elevation on August 28, 2008
1	9.2 m BG	open	dry	6.1 m / 96.0 m
2	7.4 m BG	open	dry	NP
3	9.2 m BG	open	dry	7.5 m / 97.3 m
4	7.4 m BG	open	dry	2.2 m / 96.3 m

BG = Below Grade
NP = Piezometer not installed

It should be noted that the ground water levels indicated above may fluctuate seasonally depending on the amount of precipitation and surface runoff.

4.7 Visual Slope Inspection

A visual inspection was conducted of the subject slope area on August 28, 2008. General information pertinent to the existing slope features such as slope profile, slope drainage, watercourse features, vegetation cover, structures in the vicinity of the slope, erosion and slope slide features, was obtained during this inspection. A brief summary of the results of the visual inspection is presented below.

A topographic survey of the property was provided by Tarasick McMillan Kubicki Limited and is enclosed (Figure 3). A total of six (6) cross sections were derived from the topographic information provided to prepare slope models for the long-term slope stability analysis. The cross-sections were selected on the basis of the slope height and inclination to represent the critical slope conditions present within the study area. The sections included a portion of the tableland and extended across the slope down to the slope toe and watercourse if applicable. The locations of the selected slope cross-sections are presented on Figure 3, and the details of the slope profile are presented on Figures 4A and 4B.

The subject property includes a relatively flat tableland surrounded by densely vegetated/forested areas located along the west, east and south property boundaries, and the Credit River valley slope located along the east property boundary. The current site topography consists of a relatively flat to gently sloping ground except for the easterly portion of the property which consists of a relatively steep slope associated with Credit River.

The prominent valley feature present within the study area consists of a relatively high and steep valley slope located within the easterly portion of the site adjoining Credit River. This slope extends from the north property boundary to almost to the two-third length of the property along Credit River. The slope height increases as it extends south and then gradually decreases after the high point (ridge). The slope becomes relatively gentle and gradually diminishes as it extends further south of the highest slope area, and towards the south property boundary (refer to Figure 3). The overall slope height within the northerly portion (close to Borehole 1 and Section 1) is about 6 m to 8 m. As noted before, the slope becomes higher as it extends further south becoming as high as about 11 m (in the area of Boreholes 2 & 3 and Sections 2 & 3). The slope height gradually decreases as it extends further south of the highest slope area (southerly portion, south of Section 3 to the existing swimming pool) where it decreases in height to about 6 m to 3 m close to the southerly edge of the swimming pool. The slope further south of the swimming pool, within the study area, gradually diminishes as the ground becomes relatively flat.

The valley slope located along the east property boundary (Credit River) is among the steepest and highest within the study area. The lower portion of the slope comprises shale bedrock which underlies the overburden. The inclination of the lower shale portion of the slope is relatively steep and near vertical at locations. It generally varies from about 0.3 to 0.8 (horz.) to 1 (vert.) or locally steeper. The upper (overburden) potion of the slope is relatively less steep compared to the lower shale portion. The overall average inclinations of the overburden portion of the slope vary from about 1.1 (horz.) to 1 (vert.) at Section 3 to about 1.6 (horz.) to 1 (vert.) at Section 1. The overburden slope, close to Borehole 3, is also at locally near vertical inclination and appeared to be unstable. Please refer to enclosed sections (Figures 3, 4A and 4B) and photographs for details.

The slope surface (including the lower shale and upper overburden portion) is generally bare with only minor patchy vegetation consisting of grass, weed and bush growth (refer to photographs). There are a few trees located at the slope crest in the area of the near vertical ridge, close to Borehole 3. As noted before, shale bedrock is exposed at the lower portion of the slope surface. Credit River is located at the slope toe and there is no floodplain separating the watercourse and the slope toe in this area. The water flow against the slope, the existing river contact with the slope, and stream bank conditions suggests ‘active toe erosion’ condition. The intermittent relatively harder limestone layers are visible in the bank erosion areas and are protruding out, at locations, from the slope surface. In general, the slope in this area appears to be over-steepened and unstable.

The slope located further south of the swimming pool, within the study area, gradually diminishes as the ground becomes relatively flat. The river meanders away from the slope in this area. The slope becomes relatively gentle and its height decreases significantly as it extends further south towards the south property boundary. The slope and the adjoining area are densely vegetated with grass, weed, brush and tree growth. There were no obvious slope instability and significant erosion issues identified in this area; and the area, in general, appeared to be stable.

It is noted that the rear (west) portion of the high (middle) slope area, behind the top of bank, extending from about Section 1 to approximately to the middle of Sections 2 and 3, has been disturbed and re-graded. The area to the rear (west) of the top of bank currently consists of a relatively narrow and level plateau (about 1 m to 3 m) wide, followed by a drop of about 2 m to 3 m. It appears that the ground behind the top of bank in this area has been lowered and re-graded.

As noted before, there are densely vegetated/forested areas located along the north, west and south property boundaries. The topography of these areas generally varies from relatively flat to gently sloping. The majority of the vegetated area along the west property boundary (Mississauga Road) is generally flat to gently sloping (with inclinations 3 to 5 horz. to 1 vert., or flatter) and includes a relatively small ditch. There are a few culverts located along Mississauga Road which drain into this ditch. The ditch continues along the south property boundary located within the southerly vegetated area. This area extends across the width of the property to Credit River. The topography of this southerly vegetated area is also relatively flat to gently sloping (typically 3 to 5 horz. to 1 vert., or flatter) except for a couple of localized relatively steep areas (Sections 4 and 5) with locally steeper inclinations approaching about 1.4 horz. to 1 vert. The overall elevation drop to the ditch level within the west and south vegetated areas vary from about 2 m to 4 m. These areas are densely vegetated with grass, weed, bush and a variety of young to mature trees. Only a few trees were noted to be leaning, while, the majority of the tree trunk growth was straight and upright (refer to enclosed photographs). The ditch was noted to be dry at the time of our site visit. These areas (except for the localized steep area at Sections 4 and 5) are relatively flat to gently sloping, and there were no obvious signs of any instability or erosion, and generally appeared to be stable. The area at Section 4 and 5 is locally relatively steep with inclination approaching about 1.4 horz. to 1 vert. However, the slope in this area is only about 3 m to 4 m high and there were no obvious signs of slope instability (i.e., tension cracks, slope slide, scarp, slump) and active erosion.

The northerly vegetated area (Section 6) also consists of gently sloping ground (typical inclination of a about 3 horz. to 1 vert.) with an overall drop of about 3 m to 4 m, and includes dense vegetation comprising grass, weed and tree growth. The tree trunk growth was noted to be generally straight and upright (refer to enclosed photographs). There were no obvious slope instability and erosion issues identified in this area; and the area, in general, appeared to be stable.

5. DISCUSSION AND RECOMMENDATIONS

The following discussion and recommendations are based on the factual data obtained from this investigation and are intended for use of the owner and the design engineer. Contractors bidding or providing services on this project should review the factual data and determine their own conclusions regarding construction methods and scheduling.

This report is provided on the basis of these terms of reference and on the assumption that the design features relevant to the geotechnical analyses will be in accordance with applicable codes, standards and guidelines of practice. If there are any changes to the site development features or any additional information relevant to the interpretations made of the subsurface information with respect to the geotechnical analyses or other recommendations, then Terraprobe should be retained to review the implications of these changes with respect to the contents of this report.

5.1 Slope Stability Analysis

A total of four boreholes were advanced along the east slope crest. The native soils (overburden) encountered in these boreholes predominantly consisted of hard/very dense native soils underlain by shale bedrock of Georgian Bay Formation.

A detailed engineering analysis of slope stability was carried out for selected slope cross-sections utilizing computer software (SLOPE/W, Geostudio 2004) and several standard methods of limit equilibrium analysis (Bishop's, Janbu, and Spencer). These methods of analysis allow the calculation of Factors of Safety for hypothetical or assumed failure surfaces through the slope. The analysis method is used to assess potential for movements of large masses of soil over a specific failure surface which is often curved or circular. The analysis involves dividing the sliding mass into thin slices and calculating the forces on each slice. The normal and shear forces acting on the sides and base of each slice are calculated. It is an iterative process that converges on to a solution.

For a specific failure surface, the Factor of Safety is defined as the ratio of the available soil strength resisting movement, divided by the gravitational forces tending to cause movement. The Factor of Safety of 1.0 represents a "limiting equilibrium" condition where the slope is at a point of pending failure since the soil resistance is equal to forces tending to cause movement. It is usual to require a Factor of Safety greater than one (1) to ensure stability of the slope. The typical Factor of Safety used for engineering design of slopes for stability, ranges from about 1.3 to 1.5 for developments situated close to the slope crest. The most common design guidelines are based on a 1.5 minimum Factor of Safety.

Credit Valley Conservation (CVC) Policy Guidelines require a 1.5 minimum F.S. for slope stability for land development and planning. The guidelines stipulate that the slopes be provided with stability and erosion setbacks determined on the basis of various parameters, including height of slope, proximity of the slope toe to the watercourse, type of soils comprising slope, groundwater conditions, slope geometry, condition of vegetation etc. The CVC Policy Guidelines provide a generalized stability setback criteria based on the slope height and type of soil(s) comprising slope. In addition, it also stipulates a provision of a detailed investigation consisting of site specific boreholes and a slope stability analysis to refine/determine the safe stability setback distance.

The analysis was carried out by preparing a model of the slope geometry and subsurface conditions, and analyzing numerous different failure surfaces through the slope in search of the minimum or critical Factor of Safety for specific slope conditions. The pertinent data obtained from topographic mapping, slope profiles, slope mapping and the borehole information, were input for the slope stability analysis. Many calculations were carried out to examine the Factor of Safety for varying depths of potential failure surfaces. Based on the borehole results, the following average soil properties were utilized for the soil strata in the slope stability analysis:

Stratum	Unit Weight (kN/cu.m)	Angle of internal friction	Cohesion (kPa)
Silt to Clayey Silt (typically hard)	21	30°	6
Silt and Sand/Silty Sand (typically very dense)	21.5	36°	0

The above soil strength parameters are based on effective stress analysis for long-term slope stability. It is noted that these soil properties are relatively conservative, and the site soils are actually stronger. The ground water levels as measured in the standpipe piezometer in Boreholes 1, 3 and 4 were incorporated in the analysis.

The analysis was conducted for existing slope conditions for Sections 1, 2 and 3. These sections were selected based on the critical slope conditions present within the study area. The results of the slope stability analysis are presented on the enclosed figures, and are summarized as follow:

Section	Minimum Factor of Safety for Potential Slope Slides	Type of Slope Slide
Section 1	1.32	Overall Overburden Slope Slide
Section 2	1.28	Overall Overburden Slope Slide
Section 3	0.99	Overall Overburden Slope Slide

For residential developments, the MNR Policy Guidelines allow a minimum Factor of Safety of 1.3 to 1.5 for slope stability, as follows:

TYPE	LAND-USES	DESIGN MINIMUM FACTOR OF SAFETY
A	PASSIVE: no buildings near slope; farm field, bush, forest, timberland, woods, wasteland, badlands, tundra	1.1
B	LIGHT: no habitable structures near slope; recreational parks, golf courses, buried small utilities, tile beds, barns, garages, swimming pools, sheds, satellite dishes, dog houses	1.20 to 1.30
C	ACTIVE: habitable or occupied structures near slopes; residential, commercial, and industrial buildings, retaining walls, storage/warehousing of non-hazardous substances	1.30 to 1.50
D	INFRASTRUCTURE and PUBLIC USE: public use structures and buildings (i.e. hospitals, schools, stadiums), cemeteries, bridges, high voltage power transmission lines, towers, storage/warehousing of hazardous materials, waste management areas	1.40 to 1.50

Credit Valley Conservation Policy Guidelines require a 1.5 minimum F.S. for slope stability for land development and planning. The computed minimum factors of safety for Section 1, 2 and 3 for existing slope and ground water conditions, were 1.32, 1.28 and 0.99, respectively. These factors of safety are lower than the minimum required factor of safety of 1.5, and suggest that the east slope (along Credit River), in its current condition, is not stable in the long-term. The factor of safety obtained for Section 3 was 0.99 which indicates that the slope at this location is at pending failure and is likely deriving its current marginal stability from the vegetation root reinforcement which has not been taken into consideration in the slope stability analysis.

Therefore, additional slope stability analysis was carried out to determine the stable slope inclination for the subject slope. In order to establish the stable slope inclination, the most critical section (Section 3) with the least factor of safety (F.S. = 0.99) was selected and a number of representative trial profiles of the overburden slope with flatter inclinations but similar slope height and subsurface conditions as that of Section 3 were analyzed to obtain a minimum factor of safety of 1.5, in conformance to the policy guidelines.

As noted before, the borehole remained open and dry upon completion. Water levels in the standpipe piezometers (measured after about two weeks following the drilling) installed in Boreholes 1, 3 and 4 varied from about 2.2 m to 7.5 m below grade, located generally at or below the bedrock level. These water levels were incorporated in the slope stability analysis noted above. The site slope predominantly comprises glacial till overburden of relatively low permeability, underlain by shale bedrock. The formation of relatively high pore pressure in the overburden soil is not likely due to its composition and the slope configuration. However, conservatively, the potential effect of pore pressure on the long-term stability of the site slope was assessed to establish the long-term stable slope inclination, by incorporating an assumed elevated ground water level (within 1 to 2 m of the ground surface) to simulate short-term, temporary and infrequent elevated groundwater level condition due to the potential seasonal fluctuation in the groundwater table.

The results of the slope stability analysis conducted for a hypothetical slope profile with a flatter inclination of 1.8 horizontal to 1 vertical for the overburden soil with similar sub-surface conditions as that of Section 3, for both normal and elevated ground water conditions, are presented on the enclosed figures, and are summarized below:

Section	Assumed Overburden Slope Inclination	Minimum Factor of Safety for Potential Slope Slides		Type of Slope Slide
		Normal Ground Water (Normal Condition)	Elevated Ground Water (Temporary Condition)	
Section 3	1.8 H : 1V	1.53	1.31	Overburden Slope Slide

The above minimum computed factors of safety of 1.53 for the long-term (normal groundwater condition) and 1.31 for the short-term, temporary and infrequent condition (elevated groundwater level) are considered satisfactory and adequate. The remaining sections (Sections 1 and 2) were also re-analyzed with this flatter slope inclination of 1.8 to 1 (horizontal to vertical) to determine factors of safety against potential slope slides. The minimum factors of safety obtained for Sections 1 and 2 with a flatter inclination of 1.8 horizontal to 1 vertical for the overburden soil and with similar sub-surface conditions as that of the individual sections, were 1.67 and 1.71, which are considered to be satisfactory and adequate (refer to enclosed Slope Stability Analysis Figures).

Therefore, a slope inclination of 1.8 to 1 (horizontal to vertical) or flatter is required for the long-term stability of the overburden slope at this site. Based on the results of previous studies, and in conformance to CVC Policy Guidelines, a long term stable slope inclination of 1.4 horz. to 1 vert. is recommended for the slope portion comprising shale bedrock. Figure 3 and Figures 5A and 5B present the estimated location of the Long-term Stable Slope Crest in plan and sections. These figures delineate the location of the Long-term Stable Slope Crest where it is located behind the Physical Top of Bank (inland, towards the tableland) including both east and south slopes. In other areas, existing slope is considered to be stable in the long-term. Figure 6 presents the stable slope crest model to determine the long-term stable slope crest location based on applicable setbacks.

5.2 Toe Erosion Allowance

In addition to a stability set-back, a toe erosion allowance/setback is also recommended in areas where the watercourse position is within 15 m of the slope toe. A guideline table (MNR) recommended for estimating the toe erosion allowance is presented as follow:

Guideline Table

MINIMUM TOE EROSION ALLOWANCE - River within 15 m of Slope Toe *				
Type of Material Native Soil Structure	Evidence of Active Erosion** or Bankfull Flow Velocity > Competent Flow Velocity***	No evidence of Active Erosion** or Flow Velocity << Competent Flow Velocity***		
		Bankfull Width		
		< 5 m	5 - 30 m	> 30 m
1. Hard Rock (granite)	0 - 2 m	0 m	0 m	1 m
2. Soft Rock (shale, limestone) Cobbles, Boulders	2 - 5 m	0 m	1 m	2 m
3. Stiff/Hard Cohesive Soil (clays, clayey silt) Coarse Granular (gravels) Tills	5 - 8 m	1 m	2 m	4 m
4. Soft/Firm Cohesive Soil Fine Granular (sand, silt) Fill	8 - 15 m	1 - 2 m	5 m	7 m

* If a valley floor is > 15m width, still may require study or inclusion of a toe erosion allowance.

** Active Erosion is defined as: bank material is bare and exposed directly to stream flow under normal or flood flow conditions and, where undercutting, over steepening, slumping of a bank or high down stream sediment loading is occurring. An area may be exposed to river flow but may not display "active erosion" (i.e. is not bare or undercut) either as a result of well rooted vegetation or as a result of shifting of the channel or because flows are relatively low velocity. The toe erosion allowances presented in the right half of Table 2 are suggested for sites with this condition.

*** Competent Flow velocity; the flow velocity that the bed material in the stream can support without resulting in erosion or scour.
Consideration must also be given to potential future meandering of the watercourse channel.

Source: Ontario Ministry of Natural Resources (2002), "Technical Guide River & Stream Systems: Erosion Hazard Limit, pp38

The MNR Guidelines "Geotechnical Principles for Stable Slopes" recommend an erosion setback where the watercourse is located within 15 m of the slope toe. The Guideline Table recommends different ranges of erosion setbacks based on the material comprising the slope toe, degree of erosion and watercourse characteristics.

The watercourse (Credit River) is located at the toe of the east slope, and there is no floodplain separating the slope toe and the watercourse. The proximity of the watercourse to the slope is resulting in active toe erosion at this location. The borehole data suggests that the subject slope predominantly comprises competent glacial till overburden underlain by bedrock of Georgian Bay Formation, and the slope toe in this area consists of shale bedrock. The MNR Guideline Table recommends a toe erosion allowance of 2 m to 5 m for these conditions.

However, the toe erosion setback for the subject site must be determined in accordance with the Credit Valley Conservation Authority document *Watercourse and Valleyland Protection Policies 1992*, which requires a 5 m toe erosion allowance in this case.

The relatively steep slope portion located within the southerly forested area (Sections 4 and 5) is located within 15 m of a ditch. This ditch was noted to be dry at the time of our inspection, and is understood to have only intermittent flow, generally originating from the discharge emanating from the existing culverts located along Mississauga Road. There was obvious evidence of active toe erosion at this location. According to the CVC Policy Guidelines, a toe erosion setback of 4 m was applied (based on cohesive clayey silt till soil composition comprising the slope toe, and a non-active erosion condition) at this location, to determine the location of the Long-Term Stable Slope Crest, in addition to the applicable stability setback.

The Long-term Stable Slope Crest location was calculated based on the applicable erosion and stability setbacks (stable slope inclination) in accordance with the CVC guidelines, as shown on the enclosed Long-Term Stable Slope Crest Model (Figure 6). As noted before, Figure 3 and Figures 5A and 5B present the estimated location of the Long-term Stable Slope Crest in plan and sections. These figures delineate the location of the Long-term Stable Slope Crest where it is located behind the Physical Top of Bank (inland, towards the tableland), including both east and south slopes. In other areas, existing slope is considered to be stable in the long-term. For planning purposes the long-term refers to a 100 year planning horizon.

5.3 Development Setback/Erosion Access Allowance

It should be noted that MNR and various Conservation Authority Policy Guidelines require that developments, dwellings, buildings, swimming pools or other structures should be further setback from the estimated long-term stable slope crest position. The development setback requirement varies for different authorities, and is also based on the development specifics. Typically, the CVC Guidelines stipulate a 5 m development setback.

6. SUMMARY

The borehole data indicates that the undisturbed native soils (overburden) comprising the subject slope consist of competent (typically hard/very dense) glacial till deposit. The glacial till overburden is underlain by shale bedrock which extended to the full depth of investigation.

Based on the results of the slope stability analysis, an inclination of 1.8 to 1 (horizontal to vertical) or flatter is required for the long-term stability of the overburden portion of the slope. A long term stable slope inclination of 1.4 horz. to 1 vert. is recommended for the underlying shale bedrock.

The watercourse (Credit River) is located at the toe of the east slope and the exposed bank conditions suggest 'active toe erosion' in this area. The lower portion of the slope (slope toe) in this area consists of shale bedrock, therefore a toe erosion allowance/setback of 5 m is recommended in conformance to CVC policy guidelines. A toe erosion allowance of 4 m is recommended at the localized steep slope portion situated within the southerly forested area (Section 4 and 5), located in a relative proximity of a ditch with intermittent flow.

Figure 3 and Figures 5A and 5B present the estimated location of the Long-term Stable Slope Crest in plan and sections. These figures delineate the location of the Long-term Stable Slope Crest where it is located behind the Physical Top of Bank (inland, towards the tableland), including both east and south slopes. In other areas, existing slope is considered to be stable in the long-term.

The following general constraints relating to the slope and erosion risks are recommended:

a) the site activities should be conducted in a manner which do not result in surface erosion of the slope. In particular, site grading and drainage should not be altered to result in a direct concentrated or channelized surface runoff from flowing directly over the slope, but a minor sheet flow may be acceptable,

b) the extent of the existing bare slope areas should be reduced by planting vegetation (where possible) using native non-invasive species. The vegetation growth will help reduce the surface erosion, particularly at the east slope, and

c) the configuration of the Credit River slope as well as other slopes located within the north, south and west vegetated/forested areas should not be altered without prior consultation with a geotechnical engineer and approval from concerned authorities. In particular, the slope should not be steepened and fill materials should not be placed on the slope or within 5 m of the slope crest.

It is recommended that any changes to site grading should only be carried out if approved by concerned authorities and a geotechnical engineer.

We trust the foregoing information is sufficient for your present requirements. If you have any questions, or if we can be of further assistance, please do not hesitate to contact us.

Yours truly,

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