GEOHAZARD RISK STUDY
WHITEHORSE ESCARPMENT

Whitehorse, Yukon
October, 2002

EBA File: 0201-1200002

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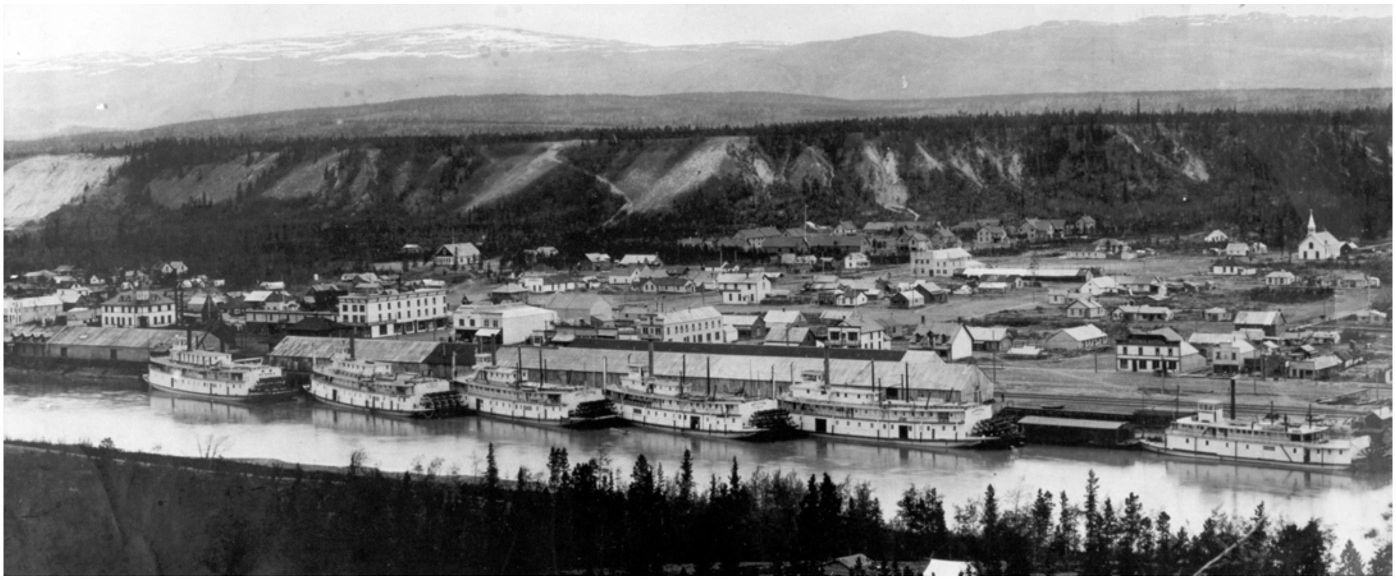
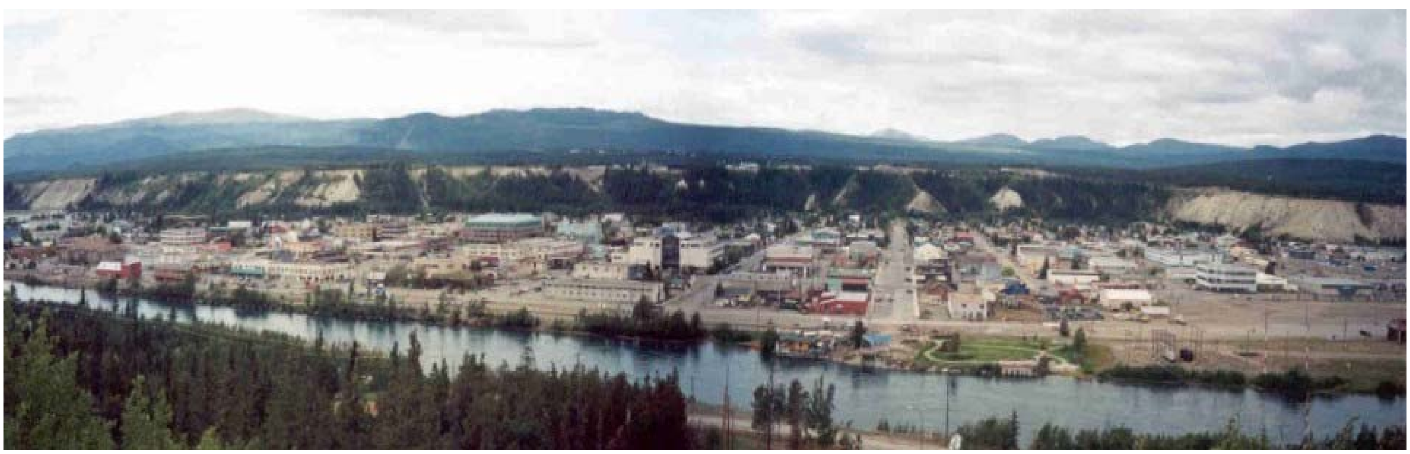


Whitehorse, 1913



Whitehorse, 2002

submitted to:

City of Whitehorse

prepared by:

EBA Engineering Consultants Ltd.

Whitehorse, Yukon

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EXECUTIVE SUMMARY AND CONCLUSIONS

Detailed terrain analysis, assessment of mass movement processes, hazard interpretation, consequence evaluation, risk assessment, slope stability analysis to incorporate seismic loading, and a review of previous studies and historic records have been completed to evaluate the slope stability of the Whitehorse Escarpment. The project was completed to evaluate the suitability of the present set-forward line and to provide recommendations for planning guidelines for development near the toe of the escarpment.

The Whitehorse escarpment is a 60 m high natural scarp of glaciolacustrine silt formed by down-cutting of the Yukon River into glacial lake sediments. The escarpment has a long history of slope instability involving shallow surface flows. These have resulted in severe impacts to private property and development infrastructure. The greatest impacts from mass movement mechanisms on the escarpments have occurred since the development of the airport and associated infrastructure. The removal of forest cover is one aspect of airport development that may have contributed to an increase in the activity rate of erosional processes on parts of the escarpment.

Four fundamental surficial materials were mapped in the study area: glaciolacustrine silts with some clay, eolian sands, fluvial sand and gravel, and colluvium. Five mass movement mechanisms (progressive deformation by seasonal thawing of saturated silt, toppling, debris flows, slumps and earthflows and slow mass movement) were characterized as being active or potentially active within the study area. This included some processes that were observed in similar terrain on parts of the escarpment outside the study area.

The study area was sub-divided into eight management zones with similar terrain characteristics, slope movement mechanisms and slope process phase (i.e., active, inactive). The methodology was developed to enable more precise management of lands near the escarpment in the future, and to facilitate the determination of criteria for development planning near the escarpment.

Evaluation of slope stability also included the measuring of deflection in the single remaining operative slope indicator casing originally installed in 1970, located above the west end of Main Street. The new data was compared with that collected in 1971. The data suggests that the variations between the two data sets were not significant, and there was no strong evidence to suggest that quantifiable deep-seated movement had occurred at this location. The precision of the data was considered too unreliable to detect incremental movement due to the condition of the station, the long time frame between data sets (32 years) and the potential for variance in the data between different instrumentation. The escarpment is judged to be stable with respect to deep-seated failures (large landslides) but is subject to shallow failures.

The quantitative analysis of slope stability using SLOPE/W indicates that although the Whitehorse Escarpment is considered stable for deep-seated failures in the static case, earthquake loading reduces the Factor of Safety to less than desirable levels. This effect is offset somewhat by the apparent carbonate cementation of the soils, however, the potential for deep seated failure during design earthquake events cannot be negated.

The last comprehensive report (EBA, 1971) that was completed on the stability of the escarpment concluded that an adequate factor of safety exists [greater than 1.2] against an overall massive landslide. Shallow failures possess significantly lower factors of safety than do overall deep-seated failures and recent slope movement observed has been restricted to surface sloughing. Thermocouple readings indicate that frost penetration depth is in the order of 1.0 m to 1.5 m on the escarpment face. The face of the escarpment is subject to rapid regression (about 0.3 m per year).

Interception ditches and settling ponds, which have been constructed at the toe of the escarpment in areas subject to annual deposition from mud flows, appear to have been effective in controlling one of the chief consequences of the stability and erosion problems of the escarpment. The successful control of deposits accumulating from the constant advance of small debris flows, combined with some degree of effort to reduce the hazard, will affect land use considerations near the toe of the escarpment.

A specific recommendation in a previous report (EBA, 1971) to reduce the hazard by loading the failing areas of thawing silt with non-cohesive material has not been implemented. This recommendation is validated by the results of this study, and it would be of potential benefit to both the City – to reduce the impacts from present mass movement processes – and to the Airport Authority – to reduce the rate of regression and loss of land from ongoing erosion. The cost benefits of applying effort to reduce the hazard verses ongoing maintenance of the consequence should be considered.

The rate of sloughing and erosion on the escarpment is expected to be proportional to precipitation rate and frequency. Periods of elevated precipitation have been linked to increased stability problems. Cumulative departure from the mean analysis using 60 years of climate data indicates a 10 % probability in 50 years of a monthly rainfall of 190 mm (6.4 times the average) for the summer months (May to August).

Hazard and consequence assessment was carried out to complete a risk analysis. The results were applied to delineate High, Moderate and Low risk zones that may be used to guide development planning. The zonal concept provides an opportunity to carry out detailed geotechnical assessments on specific properties. The results of these detailed geotechnical assessments could justify moderation of development restrictions based on site-specific recommendations, e.g., special building design, or placement of engineered structures to reduce the impact of potential landslide depositions near the base of the escarpment.

A number of recommendations were formulated based on the result of the study. A hazard mitigation program should be initiated to reduce or arrest the ongoing erosion and regression. A management plan for the escarpment should be developed to manage slope processes and develop the area for public use. Programs to monitor the sub-surface conditions and to monitor regression should be initiated. A study to inventory and evaluate the stability of the existing trail system, to assess the impact on slope stability by recently constructed trails that have undercut steep slopes, and to provide recommendations to reduce the potential impact of trail construction should be instigated. Recommendations should be developed to design suitable engineered structures to control or reduce the impact of potential landslides.

1.0 INTRODUCTION

EBA Engineering Consultants (EBA) was retained to conduct a slope stability hazard evaluation and risk assessment of the Whitehorse Escarpment between Robert Service Way and Baxters Gulch in the City of Whitehorse, Yukon (Baxters Gulch [Figure 2] is a deep gully that incises the escarpment approximately 150 m north of Baxter Street). The project was requested by the City of Whitehorse to aid the City in its determination of a rationale to assess whether or not the present escarpment protection boundary [set-forward line] for the Whitehorse escarpment in downtown Whitehorse, as shown on the Official Community Plan, is appropriate. The report will aid the development of acceptable and unacceptable land use activities for the zone created between the set-forward lines and the escarpment crest.

The scope of work for this project was presented in a proposal prepared by EBA and submitted to the City on January 22, 2002. The work was approved by Mr. Wayne Tuck, P.Eng., City Engineer, on February 1, 2002 under contract number 34660.

2.0 SCOPE OF WORK

The two-phase project was designed to deliver a risk assessment to aid in the determination of the positioning of the set-forward line. It includes an assessment of the active and dormant slope movement mechanisms, and reviewing the mass wasting history of the escarpment based on data that is currently available. The study area was defined as that area of the escarpment located behind the downtown area, between Robert Service Way and the mouth of Baxters Gulch.

The scope of work for this project consisted of the following:

- Assemble and review previous reports and mapping. Existing in-house information included several generations and scales of air photos, the Southern Lakes Terrain Mapping, previous EBA geotechnical reports, and other studies.
- Conduct detailed air photo interpretation of recent (August, 2001) aerial photographs to delineate polygons with different geomorphologic processes, terrain characteristics and terrain stability hazards. Delineate mappable active mechanisms of slope movement.
- Use historic air photographs and review development history to understand the evolution of slope processes on the Whitehorse escarpment.
- Prepare base maps of the study area to show the results of the terrain and slope stability mapping and the risk assessment.
- Conduct Phase 1 fieldwork to map potential hazards and movement mechanisms within the study area. The fieldwork will also be used to verify terrain mapping, assess processes and investigate features identified through the air photograph interpretation. Carry out further fieldwork (Phase 2) to assess consequences based on the previous work to complete the risk assessment.

- Locate and take readings from existing slope indicators installed during a previous study.
- Review stability analyses that were previously completed by EBA in 1971, and update with pseudostatic techniques to consider the seismic loading case.
- Review the drainage infrastructure of the Whitehorse International Airport to identify discharge points and their impact on the stability of the slope.
- Arrange for an EBA senior geohazard specialist (Mr. Nigel Skermer, P.Eng.) to review the terrain mapping and other analyses completed, participate in the risk assessment, recommend guidelines for development along or near the toe of the escarpment, and provide technical consultation during the analyses and reporting phases of the work.
- Prepare a report to present a description of the work completed, including terrain/hazard mapping of the study area, results of all completed stability analyses including pseudostatic analyses to consider the seismic loading case, a discussion of the implications of soil movement mechanisms identified, and a description of the methodology and results of the risk assessment and recommendations regarding the set-forward lines.

The evaluation is based on surficial observations, air photograph interpretation and a review of previous work. The detailed geotechnical evaluation of soil properties is based on previous studies and testing of the escarpment. No subsurface evaluation beyond re-testing of existing slope stability indicators was to be completed to facilitate this evaluation. Some discussion of relevant slope processes outside the study area is included; however, the hazard analysis and slope classification is mainly limited to the defined study area.

3.0 PROJECT BACKGROUND

The study area is a segment of the Yukon River Valley escarpment located behind downtown Whitehorse between Mud Hill adjacent to Robert Service Way to the south and the First Nation cemetery, at the entrance to Baxters Gulch, to the north (Figure 2). The present set forward line, or "escarpment protection boundary" (Figure 2), which is understood to have been established in the early 1970's, is located beyond the toe of the slope in this area. The present "escarpment protection boundary" (set-forward line) is pre-dated by a line shown on a plan of the city by Yukon Electric Co. Ltd. (September 25, 1961), behind which "further development [was] discouraged" (Appendix D).

The Whitehorse escarpment is a 45 m to 60 m high natural slope along the west side of the Yukon River floodplains which are occupied by the Downtown and Marwell areas of Whitehorse. The escarpment leads up to a prominent terrace, which was almost totally deforested to develop the present airport. The slope was formed from the down-cutting of the Yukon River into thick glaciolacustrine sediments.

Historically, the construction of the Whitehorse Airport and the expansion of the downtown area of Whitehorse away from the banks of the Yukon River (towards the toe of the Whitehorse escarpment) both led to development that encroached upon the Whitehorse escarpment. In particular, a number of airport buildings were located near the crest of the escarpment (referred to as the "east camp"), and roads and service lines passed up the slope itself. A viewpoint on a recreational trail above the foot of Hawkins Street has been developed on a remnant section of the former east airport road. In the downtown area, residential buildings encroached up to the toe of the escarpment and in some cases onto fans or other colluvial deposits that occur at its base.

Although some natural erosion processes on the escarpment were evident in historic photographs, slope stability problems intensified during the onset of development of airport facilities in the 1930's. This development led to extensive deforestation of both the plateau above the escarpment (Whitehorse Airport) and to sections of the escarpment slope itself. In the ensuing years, an apparent increase in the rate of erosion and slide frequency was attributed to this development. "Damage to the vegetal cover of the escarpment appears to have started [with] extensive construction work at the airport site [east of the runway] and construction of a new road on the face of the escarpment for access." (Legget, 1959). Deforestation can increase the rate of run-off from the plateau by reducing the rate of evapotranspiration and increasing the likelihood of concentrated runoff directed onto sensitive terrain. Deforestation has been implicated to contribute to instability in other jurisdictions.

Extensive development during the 1940's notably destabilized the escarpment face, leading to incidents of mass movement. Primarily, the mass movement took the form of shallow earth flows and debris flows of saturated sediments, although landslides and earth slumps were also reported. Formal assessments of these mass movements identified the association of the instability with development and recommended the removal of the east airport buildings and associated infrastructure that had been allowed to expand near the crest of the escarpment.

Ongoing stability problems on the escarpment, including numerous mud flows that deposited material onto private property in the city, prompted the Government of Canada (Department of Transport) to request a comprehensive slope stability evaluation. This was conducted by EBA in 1971. The EBA study concluded that the escarpment was stable in respect to deep-seated failures (large landslides) but was subject to shallow failures. This study did not consider the case of seismic loading (effect of earthquakes) on the escarpment. A variety of mitigative measures were recommended in the study to control or reduce the shallow failures; however, EBA is not aware which, if any, of these measures were enacted. The report (EBA, 1971) provides practical geotechnical information, summaries of pertinent records from other reports and includes a thorough analysis of soil stratigraphy and material properties. Mitigative measures recommended in the 1971 report are reproduced in Appendix C of this report.

In recognition of the real or perceived risks associated with slope failures and mass movements on the escarpment, the City of Whitehorse developed and implemented a set-forward development line in the downtown area. At the time the line was developed there likely existed some rationale that on one side of the line the risks were acceptable whereas on the other side the risks were not acceptable. The existence of a record of the actual rationale utilized to position the line (thereby defining development limits near the escarpment) could not be confirmed. EBA was not involved in any way with the concept, design or establishment of this set-forward line, which is assumed to have been designed in the early 1970's.

The set-forward line, which isolates in the order of 133 potential lots from consideration for further development, runs in what casually appears to be a random fashion along road and lot boundaries from the southern end of the downtown area, north to Lot 314 (opposite the intersection of 2nd Avenue Extension and 4th Avenue). Over its length the set-forward line ranges from being coincident with the toe of the escarpment to as much as 120 m from the toe. It is suspected, but not specifically known, that the position of the line was influenced as much by land ownership issues as by engineering judgment at the time the line was established (Figure 2).

In the nearly 30 years since the set-forward line was assumed to have been established, mass wasting activity (erosion, toppling failures, earth flows) has continued to occur to some degree along the escarpment. Protective measures have been developed by the City to intercept mud flows along the most active zones. Bermed interception ditches have been constructed along the toe of the escarpment slope west of Main and Elliot Streets to divert silt-laden run-off and low-volume debris flows into a series of settling ponds, which are separated by concrete baffles. The settling ponds are periodically excavated to remove collected silt, which is stockpiled adjacent to the ponds and removed by Public Works when required. The ditches and settling ponds, which are located behind the cemetery at the west end of Steele Street (Photographs 1, 20 and 21; Figures 1 and 2), have apparently been effective in reducing the consequence of the hazards. However, there have been no measures enacted to mitigate or control the mechanisms that are the source of the ongoing erosion and deposition.

A ditch was also constructed between private property and the escarpment beyond the west ends of Elliot and Hanson Streets along part of the old airport road that was abandoned after 1953. A lower section of the abandoned road now acts as an interception berm to divert and de-energize flows initiated at the active headscarp areas on upper escarpment slopes. No settling ponds have been constructed in this area and the material is dispersed behind the old roadbed.

A history of development on or adjacent to the escarpment is summarized in Appendix A.

4.0 METHODOLOGY

The project was completed in 2 phases. Phase 1 consisted of a detailed terrain study and a slope stability and hazard evaluation. Phase 2 included a consequence investigation (to complement the hazard assessment of Phase 1), a Risk Assessment and the subsequent advance of development planning zones. Figure 1 illustrates the conclusions of the Risk Assessment and delineates High, Moderate and Low Risk zones for development planning. The set-forward line set out on earlier planning maps is precluded by 2 lines that delineate an area in which further detailed geotechnical evaluation is recommended prior to development. The results of the terrain mapping and hazard evaluation are presented on Figure 2.

Preliminary site visits were conducted in the fall of 2001. Review of previous reports was carried out in March and April 2002. Detailed fieldwork for Phase 1 was completed during May 2002 and for Phase 2 on August 17-19, 2002.

The study was initiated with a review of previous reports that evaluate slope stability on the Whitehorse Escarpment. These reports provided useful analyses of soil stratigraphy and material properties (EBA, 1971) and insight into the history of stability problems and development that affected the escarpment (Legget, 1959).

Preliminary terrain mapping and hazard assessment of the study area was done by air photo interpretation of 1:10,000 scale, black and white air photographs A28473 Nos. 080 to 086 (Geographic Air Survey Ltd.) flown in August 2001. The landscape was divided into polygons with similar terrain characteristics (Figure 2). Polygons were labeled with a preliminary terrain symbol, drainage symbol and slope stability (hazard) class, and mass movement processes (landslides) were identified. Slope stability classifications indicate the likelihood of instability resulting from natural slope processes and take into account slope gradient and the presence and type of geomorphological processes (Table 7.1). A detailed legend of terrain symbols used is included as Appendix B.

A review of historic air photographs (1994, 1993, 1992, 1990, 1971, 1965, and 1962) was carried out to evaluate early mass movement processes and to study the rate of regression.

Fieldwork was conducted to evaluate the following aspects of the project:

- Verify terrain and hazard mapping by confirming soil conditions, terrain characteristics and geomorphological processes mapped during the air photograph interpretation.
- Map potential hazards and movement mechanisms within the study area.
- Evaluate landslides both within and outside the study area.
- Locate and take readings from existing slope indicators installed during previous studies.
- Identify any drainage structures that presently impact the escarpment.

- Conduct a consequence assessment and evaluate the conceptual design of the preliminary hazard lines for development planning purposes.

Exploratory traverses were conducted in the fall of 2001 and in April 2002. Fieldwork was conducted in May 2002, immediately following the loss of snow cover and during ground-thawing conditions. This is the period when the erosional mechanisms are most active, particularly thawing of seasonally frozen, ice-rich silt below the eolian sand mantle. In the absence of high levels of precipitation, thawing is associated with minor sloughing, small debris flows that cause rilling, shallow gullying and deposition of sediments along the base of the escarpment. Active areas of instability on the escarpment were categorized by the operative mechanism(s). Representative landslides and erosion processes were evaluated in detail in the field.

Four of the six slope indicator casings installed in 1970 were located. Only one of these was operative (Photograph 4), and slope indicator readings were recorded from May 22 to June 3, 2002. Duplicate readings were required to verify the initial data. The data from the initial readings in 1971 were re-entered, and compared to the 2002 data, as shown on Figure 3.

In the absence of established survey points to provide controlled monitoring stations, it was necessary to devise a method to provide a rough estimate of the recent rate of regression. The present position of a prominent concrete foundation located at the escarpment crest was compared to its image on a large-scale (1:2000) 1990 air photograph (Photograph 1). Distances from various points on the foundation to the crest of the escarpment were measured on May 30, 2002.

Planning boundaries were established to delineate zones of differing risk levels (Figure 1). These zones are defined to provide geotechnical guidelines for development planning. The specific placement of the set-forward lines resulted from the culmination of data from a variety of sources, including observations and conclusions from the hazard study, terrain mapping, fieldwork observations, previous reports on the stability of the escarpment, assessment of landslide mechanisms on the escarpment outside the study area, experience from similar terrain in other jurisdictions and guidelines for development near hazardous terrain by other municipalities. The placement of development planning zone boundaries is addressed in Section 8.0.

5.0 SURFICIAL GEOLOGY and STRATIGRAPHY

The unconsolidated sedimentary deposits of the Yukon River Valley at Whitehorse were laid down during the retreat of the Cordilleran ice-sheet, probably between 35,000 and 12,000 years ago. Surficial deposits in the Whitehorse area were laid down through a variety of de-glacial processes. Gravel deposits beside and underlying the Alaska highway next to the Whitehorse airport are remnants of a glacial-outflow delta that likely has an irregular contact with deep lacustrine silts that underlie the plateau of the Whitehorse airport. These more or less homogenous stratified layers of silt accumulated in a long narrow proglacial lake, which was created behind a dam of terminal moraine and/or ice, probably located near the present mouth of the Takhini River. A well sorted eolian sand mantle overlies the thick glaciolacustrine silt.

Down-cutting of the Yukon River into the thick glaciolacustrine silts created the present steep-sided escarpment. Most of the escarpment was forested prior to airport-related development, with the exception of Mud Hill at the southern end of the study area and the silt cliffs south of the entrance to Baxters Gulch (Figure 2). At Mud Hill the glaciolacustrine silt bank is over-steepened, initially from active erosion of the river channel meander, and subsequently by development of the Whitepass and Yukon Route Railway right-of-way at the toe of the escarpment. In 1997, material at the toe of the section of the escarpment referred to as Mud Hill was removed to facilitate improvements to Robert Service Way.

Since the early 1950's, slope stability studies have been conducted to evaluate the potential causes of mass movement processes that have impacted development on or near the escarpment. The description of stratigraphy and texture of materials that form the escarpment are well documented in these earlier reports. Extensive drilling programs were conducted to evaluate the nature of the contact between the non-cohesive eolian sands that mantle the surface of the airport plateau and the underlying cohesive glaciolacustrine silts of unknown thickness.

The stratigraphy is well defined as a mantle of fine, well sorted sand, ranging in thickness from approximately 1 m to 9 m, overlying thick glaciolacustrine silt. The depth of the eolian mantle is greatest in the southeast corner of the airport plateau, capping the area of the escarpment known as Mud Hill, which separates the airport from Robert Service Way (Figure 2). The glaciolacustrine silt unit is stratified with thin layers of fine sand, clay, or sorted silt in beds from 2 cm to 8 cm thick, but in most sections appears massive. Occasional scattered pebbles are found throughout, as are discontinuous thin lenses of sand. Grain size analysis (Table 6.1) indicates that the two distinct units are each well-sorted. The overlying unit is sand with trace gravel; the underlying unit is silt with some clay and fine sand.

Permafrost was not encountered during the extensive drilling programs undertaken in the area and is not thought to be a contributing factor to the slope stability problems. However, seasonally frozen ground, which may persist into the summer, is a principal element of the most active erosion mechanisms on the escarpment.

6.0 RESULTS and DISCUSSION

An abundance of historical and geotechnical information is available from previous studies of the stability of the Whitehorse escarpment. Leggett (1959) reported anecdotal information by “old-time Yukoners” that stability problems were negligible on the escarpment prior to airport development and most of the slope was forested. However, research of historic photographs (dated 1900, 1902, 1913 and 1914) carried out for this study show a number of openings on the escarpment that appear to be the result of landslides or active erosion. The density of these openings is greatest in an area that remains the most active today, between Hanson and Steele Streets. Early photographs appear to confirm that the area to the south, where the bridle path was located and where the east airport road was constructed, was free of active slides and covered by forest and/or grasses prior to development.

A comprehensive geotechnical evaluation of the escarpment was completed by EBA in 1971. To conduct their analyses, 8 piezometers, 5 thermocouples and 6 slope indicator wells were installed in November 1970. Today, only one slope indicator well, located at the escarpment crest above the west end of Main Street, was capped and operable. The other instrumentation infrastructure from the 1970 study is either missing or disabled. The report identified the significant process leading to instability as the nearly saturated “clayey-silt” exposed on steep gradient slopes and subject to freezing conditions.

Significant conclusions of the EBA (1971) report include:

- “The analysis of slope stability has indicated that an adequate factor of safety exists [greater than 1.2] against an overall massive landslide providing the piezometric level is below the base of the slope”;
- “Shallow failures possess significantly lower factors of safety than do overall deep-seated failures”;
- The observed slope movement has been restricted to surface sloughing;
- Thermocouple readings indicate that frost penetration depth is in the order of 1.0 m to 1.5 m on the escarpment face; and
- The face of the escarpment is subject to rapid regression (about 0.3 m per year).

A key recommendation of the report was to initiate a test program to place a granular blanket over the sloughing areas that would provide a surcharge load to consolidate the saturated clayey-silt upon thawing. This recommendation was never followed.

Previous studies of the escarpment, (EBA, Legget) identified factors contributing to the significant amount of mass wasting in the 1950's and 1960's. Many of these factors were anthropogenic in nature and significant progress has been made to reverse the influence of development on escarpment stability. All buildings on the east side of the airport have been removed and the airport fence is moved away from the escarpment crest. Moreover, natural revegetation of deforested sections of the escarpment has progressed to some degree since the 1970's and this has had a beneficial influence on the stability of the escarpment slope.

To aid in the assessment of the progression of mass movement processes on the escarpment, high level stereo air photographs from 1962 to the present were reviewed, and landscape photos from archival records were compared. Photographs dated 1900 and 1913 indicate that some erosional processes on the escarpment were active, but on a much smaller scale and in more limited areas than that occurring after airport development. The original bridle path trail is shown crossing both forested and grass covered slopes with no evidence of slope failures. Increased activity on and near the escarpment, such as the clearing and development along the crest and the construction of the airport access road across the bridle path route, appear coincident with increased evidence of erosion and mass movement activity.

The active progressive erosion processes on the escarpment appear to be the result of previous mass movement events. No recent openings in previously forested areas were observed within the study area. Some of the historically active areas remain quite active and some are wholly or partially re-vegetated. Considerable revegetation of the slides at the east airport road area suggests that mitigative measures, such as removal of the east airport buildings, have been effective in some areas. The most active zones, both historically and recently, are the large headscarps between Lambert Street and Wood Street. In May and June, these areas produce a slurry of material as the upper silt unit seasonally thaws. Erosion and transport of fine-grained soil is further aided by deep pockets of melting, windblown snow that have accumulated in the headscarp bowls over the winter. The largest landslide that is known to have occurred within the study area, which took out a section of the airport access road at the west end of Hoge Street, is partially re-vegetated.

6.1 Terrain and Terrain Stability Mapping

6.1.1 Surficial Materials

Four fundamental surficial materials were mapped in the study area: glaciolacustrine silts with some clay, eolian fine sands, fluvial sand and gravel, and colluvium. The mass of the escarpment is lacustrine in origin, capped by a thick mantle of eolian sand. Colluvial deposits occur mostly along the base of the escarpment. A discontinuous thin mantle of fluvial sand and gravel was observed near the plateau surface at the northern extent of the study area (Zone I, Figure 2). Some minor anthropogenic material was also observed at the south end of the study area.

The middle to upper slopes of the escarpment are generally well drained, with some poorly drained areas in the headscarp bowls of saturated silts that are undergoing progressive deformation by seasonal thawing. The lower slopes are typically moderately drained.

Glaciolacustrine Materials

Glaciolacustrine materials consist of fine sediments produced by glacial abrasion that were transported to proglacial lakes by meltwater streams. Finer sediments tend to remain suspended in the lake, and then slowly settle to the lake bottom. These glaciolacustrine sediments typically consist of stratified silt, clay, and fine sand. Dropstones transported on floating ice, ranging up to boulder size, may be embedded in the finer material. The sediments are usually slowly permeable to impermeable and are generally moderately to highly cohesive, depending on the amount of clay. The texture of the glaciolacustrine material that forms the Whitehorse Escarpment is quite consistent: silt with some clay and fine sand (Table 6.1). Some thin beds of fine sand or clayey silt occur.

Table 6.1

Summary of Grain Size Analyses, Previous Studies

		DEPTH (m) from	DEPTH (m) to	% CLAY	% SILT	% SAND FINE	% SAND MEDIUM	% SAND COARS	GRAVE
EBA 1971	Sand	1.2	1.7	0	0	4	56	35	5
		3	3.5	0	0	7	81	10	2
	Silt	4.3	4.7	12	79	9			
		9.1	9.6	15	75	10			
		13.4	13.9	11	85	4			
		18.3	18.7	12	87	1			
DBR-NRC 1954			0.3	17	68	15			
			0.8	14	60	26			
			1.1	14	65	21			
			1.8	16	75	9			
DBR-NRC 1957			3.2	14	71	15			
			1.2	21	75	4			
			3.2	17	70	13			
			2.8	17	81	2			
Mean: silt unit				15	74	11			
Mean: sand unit						5.5	68.5	22.5	3.5

Given the history of the escarpment, it appears there may be an apparent cohesion of the silt deposit increasing its strength characteristics against a deep-seated failure. A synopsis of evidence for elevated cohesion of the silt due to cementation, explaining the apparent competence of the silt bluffs that often form steep cliffs with gradients of 60 degrees, was compiled in the report: Robert Service Way Slope Stability Review and Risk Assessment (EBA, 1997). The assumption of additional strength to resist shallow based failures is not considered valid, due to the previously described causes of these failures.

Eolian Sediments

Eolian sediments are transported and deposited by wind. They are usually found near extensive exposures of fine-grained sediments, for example, scarps in glaciofluvial and glaciolacustrine sediments. They typically occur as a thin capping over other materials, but may locally thicken to a blanket or dunes. Eolian sediments are loosely packed and well sorted, with textures in the coarse silt to medium sand range. Eolian deposits may be characterized by small- scale cross-bedding, which was observed during the field studies in August. Where these sediments are un-vegetated they are highly susceptible to surface erosion. The eolian sands that cap the Whitehorse escarpment form a mantle of coarse-sandy, medium sand with trace fine sand (Table 6.1).

Fluvial Material

Large deposits of fluvial gravels, sand and silt were deposited by pro-glacial streams and rivers. Some smaller deposits are the result of recent stream activity. These sediments are loose, non-cohesive and highly porous and permeable. Associated landforms, such as floodplains (**Fp, FAp**) and parts of fans that are close to stream-level, typically have high water tables and are moderately to imperfectly drained. Fluvial material is a minor component of the study area. The thin mantle observed near-surface along the northern end of the plateau was probably deposited by a historic stream, possibly prior to the development of Baxters Gulch.

Colluvium

Colluvial materials have accumulated during post-glacial time as a result of gravity-induced slope movement, such as soil creep and landslides. Geomorphological processes active on the escarpment have created colluvial deposits along the toe. The physical characteristics of colluvium are closely related to the parent material, but may vary with mode of deposition. Geomorphological processes that result in the deposition of colluvium in the study area are discussed in detail in Section 6.4 of this report.

Anthropogenic Material

Anthropogenic materials are geological materials so modified by human activities that their original physical properties (e.g., structure, cohesion, compaction) have been drastically altered. They are typically formed by the removal of material from an original site followed by deposition elsewhere.

A low relief (up to 3 m) ridge of native material mixed with organics was mapped on the crest of Mud Hill (Figure 2). This may be the result of an early dumpsite of cleared material deposited during the initial development of the airport.

6.1.2 Terrain Stability (Hazard) Interpretation

Hazard or Terrain Stability classifications indicate the likelihood of gravitationally induced mass movements, such as slumps, slides, debris flows and earthflows. For this study, terrain stability classes range from Class **I** (stable) to Class **V** (unstable) (Table 6.2) and indicate the likelihood of instability resulting from disturbance due to development or other impacts such as anomalous climatic influences. The terrain stability class is based on terrain characteristics that include slope gradient, material type and texture, drainage and geomorphological processes. Management implications of Terrain Stability Classes are summarized in Table 6.2. Given the potentially high consequence areas near the base of the escarpment, any development, including recreational trail construction, should heed the inherent recommendations of Table 6.2.

6.2 Climatic Influence

The rate of regression in the areas of active sloughing probably has a strong association with climate. The rate of sloughing and erosion is expected to be proportional to precipitation rate and frequency. Periods of elevated precipitation have been linked to increased stability problems. Large slides and increased mud flow activity were reported in the spring of 1953, when the precipitation for June exceeded 90 mm. The average June precipitation for the period of record is 30.1 mm.

Cumulative departure from the mean analysis was developed using 60 years of climate data (1942 to 2001) for the summer months (May to August). The results of the analysis indicate that there is a 10 % probability in 50 years of a monthly rainfall of 190 mm. This is 6.4 times the average monthly rainfall for the summer months (29.9 mm). In 1953, when large slides occurred below the east airport area, the average monthly rainfall for the summer months was 54.4 mm. June 1953 rainfall was 92 mm and the August total was 64.5 mm. In the last 25 years, monthly rainfall exceeded 60 mm 6 times, with a high of 109.6 mm in July 1988.

Table 6.2
Management Implications of Terrain Stability Classes

Class	Rating	Implication
I	Negligible	No significant stability problems exist. The area is typically vegetated with coniferous trees and there are no visible signs of mass movement activity or erosion.
II	Very Low	There is a very low likelihood of landslides. Some minor erosion from freeze-thaw processes and rilling or washing on small exposed areas may occur. No history of mass movement is known. Landslide initiation in these areas would not be expected to occur as a matter of course due to natural processes, but may occur as a result of disturbance, e.g., from trail construction, excavation at base, heavy use that eroded vegetation, re-direction of concentrated run-off from above onto the slope, or excessive saturation of soil resulting from unprecedented weather conditions.
III	Low	Minor stability problems can develop. Vegetation removal could reduce terrain stability. Vegetation removal, e.g., to construct trails, may be mitigated by the application of conscientious geotechnical practices to reduce the probability of landslide. Deposits of material at the base of slope from erosional processes or minor landslides may be present, but typically do not extend far beyond the base of slope and may be partially stabilized by vegetation (i.e., they may be only intermittently active).
IV	Moderate	Expected to contain areas with a moderate likelihood of mass movement initiation. This would typically be naturally occurring, seasonal activity. Extreme climatic conditions with excessive precipitation combined with snow melt and or ground-thawing conditions could initiate landslides and/or heavy erosion. Terrain is sensitive to anthropogenic disturbance or influence from adjacent disturbed areas. Repetitious access routes or trails are not recommended. However, if these areas cannot be avoided, some access trails may be possible if they are located and designed by suitably trained terrain stability professionals. Active, typically un-vegetated deposits of material have accumulated at the base of slope from seasonal mass movement and/or erosional processes.
V	High	Expected to contain areas with a high likelihood of mass movement initiation. This would typically be naturally occurring, seasonal activity. Extreme climatic conditions with excessive precipitation combined with snow melt and or ground-thawing conditions would typically initiate landslides and/or heavy erosion. Terrain is extremely sensitive to anthropogenic disturbance or influence from adjacent disturbed areas. These areas should be reserved as "no disturbance" zones, i.e., no trails should be constructed and repetitious access to existing trails or routes should be curtailed. Active, typically un-vegetated deposits of material have accumulated at the base of slope from seasonal mass movement and/or erosional processes. Engineered solutions to reduce or slow mass movement in active erosion areas, and/or control the impact of the resultant deposition should be considered.

6.2.1 Regression

A previous study (Enns, 1969) reported a surface retreat due to sloughing at the rate of about 30 cm per year. Rudimentary measurements of an abandoned foundation from the east airport development, located at the edge of the escarpment crest, were compared with relative points on a large scale (1:2000) air photograph taken in August, 1990 (Photograph 1). There is some indication that the rate of erosion in this area may be less than 30 cm per year. Further study using surveyed control points is necessary to accurately monitor regression rates.

The regression rate is strongly linked to climate and is unlikely to occur uniformly every year. A 5-year comparison of positions along the crest of slope in an active area of the Takhini escarpment to the north of the study area found a regression rate of 50 cm per year (Lidgren, 1990).

6.2.2 Drainage Infrastructure

Development of water and sewer infrastructure at the airport impacted the stability of the escarpment, particularly in the area of the east camp, the east airport road and Pucketts Gulch. Clearing and excavation below east camp and in Pucketts Gulch was carried out to install water and sewer lines. Early plans show culverts at the escarpment crest that directed concentrated run-off to Pucketts Gulch, to a point above Main Street and near the east access road. Early reports record significant washout and erosion from a sewer outfall at Pucketts Gulch. A remnant of a wooden culvert may be observed near the viewpoint above the foot of Hawkins Street. It is assumed that this culvert was installed under the historic road to collect water from an inside ditch, which is presently filled with silt that buries the culvert inlet.

In 1944, a system of septic tanks and disposal fields installed in 1941 were abandoned. There is no record that this system was dismantled when the buildings were subsequently connected to a collection system, or when the buildings were later removed.

Only two intact culvert outlets were discovered within the study area. Two metal, 600 mm diameter culverts are located at different elevations at the head of Pucketts Gulch. Both are filled with soil and are apparently inoperative. The only known culvert that directs run-off to the escarpment is located near the head of Baxters Gulch (outside of the study area). A large diameter culvert connects to a run-off collection ditch at the northwest corner of the airport. An incised channel carries intermittent flow from this culvert towards the floor of Baxters Gulch.

No recent impacts from active drainage infrastructure discharge points were observed within the study area.

6.3 Slope Stability Analyses

As previously stated, the stability analysis completed in 1971 was to be reviewed and updated with pseudostatic techniques to consider the seismic loading case. Slope stability analyses were conducted using the computer program SLOPE/W, which uses limit equilibrium to solve the factor of safety.

6.3.1 Previous Slope Stability Evaluation

In 1971, a comprehensive slope stability evaluation was conducted by EBA on behalf of the Government of Canada (Department of Transport). The EBA analyses were conducted to evaluate the stability of the Whitehorse Escarpment following the documented earth flows and slope failures that resulted in damage to infrastructure located on the escarpment and to buildings located near the toe of the escarpment in the downtown area in the 1950's and 1960's.

An average cross-section of the escarpment was used for the analysis, along with material properties based on laboratory testing conducted at the time and those previously reported by the Department of Transportation. Varying piezometric levels were also included to show the effects of a high groundwater table. The results of the analyses were that the escarpment was stable in respect to deep-seated failures (large landslides) but was subject to shallow failures. At the time of the report, no consideration for a seismic loading case of the escarpment was made.

The [EBA] 1971 report stated that erratic groundwater levels were reported from piezometers installed at that time and that piezometers with tips located at or near the sand-silt interface recorded a perched water table at various times of the year. Furthermore, for a significant proportion of the escarpment, no piezometric head was noted at the sand-silt interface. Two cases, assuming a groundwater table at elevations 649.2 m and 664.5 m respectively, were analyzed to show the effect of a high ground water table on the Factor of Safety. Details of the assumptions are shown on Figure 2 and further discussed in the following sections.

Slope stability analyses were also conducted for a portion of the escarpment slope adjacent to Robert Service Way (EBA, 1997).

6.3.2 Assumed Input Parameters for 2002 Analysis

For the present study, slope stability analyses were conducted using the same typical cross-section and material properties that were established in the [EBA] 1971 report. The material properties used for the analyses are presented in Table 6.3 and the typical cross-section used is presented in Figure 2. The three piezometric levels addressed in the 1971 report were also analyzed.

Table 6.3
Assumed Material Properties

Material	**Density (kN/m^3)**	**Angle of Friction (°)**	**Cohesion (kPa)**
Sand (cap)	18.4	35	0
Silt, with some clay	18.9	35	0
Remoulded silt with some clay (at escarpment toe)	18.9	11	0

To evaluate the factor of safety due to a seismic event, pseudostatic analyses were conducted by applying a seismic acceleration to the design section. A peak horizontal ground acceleration of 0.10 g for a 10% probability of exceedence in 50 years was used based on previous studies completed by EBA in the City of Whitehorse. This ground acceleration value corresponds to the National Building Code of Canada (1990), which states that Whitehorse is in Seismic Acceleration Zone 2, with peak ground accelerations ranging from 0.08 g to 0.11 g for a 10% probability of exceedence in 50 years.

6.3.3 Slope Stability Evaluation

Using the assumed input parameters as outlined in Section 6.2.2, Factors of Safety were calculated and are presented in Table 6.4.

Table 6.4
Factors of Safety

Water Table Elevation	Factor of Safety			
	Minimum		Select[1]	
	Static	Pseudostatic	Static	Pseudostatic
below toe of escarpment	1.29	1.00	1.31	1.04
649.2 m	1.12	0.81	1.31	0.98
664.5 m	0.55	0.38	0.91	0.70

[1] Select slip surfaces represent moderately deep-seated failures with slip surfaces starting from near the escarpment crest.

The calculated Factor of Safety for the static state corresponds with the calculations presented in the [EBA] 1971 report. For water elevations below the toe and the 664.5 m case, the minimum slip surface represents surface sloughing, which is documented in previous literature as a frequent occurrence. For the 649.2 m water elevation case (below the toe), the minimum slip surface results in a surface starting approximately two thirds down from the crest of the slope and travels through the base of the remolded saturated silt. This is a result of the assumed water elevation. The select slip surfaces were calculated to present more of a deep seated failure with the surface beginning near the crest of the escarpment.

As discussed in previous reports (EBA 1971, EBA 1997), a perched water table within the overlying sand layer and the silt deposit immediately beneath the sand-silt interface has been observed throughout the time of study. This perched water table condition has also been supported by the observation of seepage to be exiting at the sand-silt interface particularly during the spring thaw and following periods of heavy rainfall. The source of the perched water table is likely from infiltration of direct precipitation and/or surface runoff throughout the plateau that lies above the slope crest.

The location of the regional ground water table within the slope has not been determined. Previous studies have assumed that the regional ground water table is below the toe of the slope. The lack of seepage from the slope face except at or near the sand-silt interface supports this assumption. Therefore, the water table elevations shown above, at 649. 2 m and 664.5 m, and corresponding lower factors of safety, demonstrate the sensitivity of the piezometric level on the calculated Factor of Safety.

As presented in Table 6.4, updating the 1971 stability analysis with pseudostatic techniques to consider the seismic loading case lowers the factor of safety from about 1.3 down to 1.0 for all assumed failure surfaces. This assumes that the regional ground water table is below the toe of the slope.

6.3.4 Subsequent Slope Stability Analysis Evaluation

The Whitehorse escarpment has had a history of surface sloughing and mud flows generally associated with the spring thaw season and groundwater runoff; however, no reference to a deep-seated or large scale failure of the slope has been noted in the available information even following earthquakes experienced in the Whitehorse area. The Takini East debris slide involved the mobilization of an estimated 3000 m^3; however, it is still considered a shallow landslide (Photographs 10-12).

Given the history of the escarpment, it appears there may be an apparent cohesion of the silt deposit increasing its strength characteristics against a deep-seated failure. This assumption of additional strength to resist shallow based failures is not considered valid, due to the previously described causes of these failures.

EBA's 1997 report evaluated the strength parameters for the silt and determined that a certain amount of cohesion is apparent in the soil depending on the structure of the silt unit. It was concluded that on slopes exhibiting extremely steep gradients it is generally noted that the silt has a desiccated, blocky structure and areas that do not have such high slope gradients almost always exhibit an amorphous structure and higher apparent moisture content. Furthermore, the blocky silt exhibits greater cohesion through both soil suction and by a water-soluble cementing agent, possible unsaturated clay particle coatings or calcium carbonate derived from limestone formations surrounding Whitehorse (EBA, 1997).

EBA believes that it is reasonable to adopt the use of an apparent cohesion to account for the strength increase of the Whitehorse escarpment silts to resist a deep-seated failure. The value of the apparent cohesion cannot be quantitatively determined; however, to illustrate the affects of cohesion of the silt, the typical cross-section was evaluated with the water table below the toe of the slope with varying amounts of cohesion for the static and pseudostatic case. Results are presented in Table 6.5.

Table 6.5
Assumed Cohesion Effects on Factors of Safety

Cohesion Silt with some clay (kPa)	Factor of Safety			
	Minimum[1]		Select[2]	
	Static	Pseudostatic	Static	Pseudostatic
0	1.29	1.00	1.31	1.04
5	1.43	1.17		
10	1.54	1.21		
20	1.70	1.37		

Notes: [1] When the silt has cohesion, the minimum slip surface is a deep failure, similar to the "select" slip surfaces chosen for the case where no cohesion was assumed.
[2] Select slip surfaces represent moderately deep seated failures with slip surfaces starting from near the escarpment crest.

6.3.5 Slope Indicator Readings

A total of six slope indicators were installed in 1970 along the study area of the Whitehorse escarpment. Of these six, only one indicator has remained operational over the last 32 years and was able to be used for the current evaluation (Photograph 4). Two consecutive sets of readings were taken on June 3, 2002 to check the consistency in the data, to reinitialize the instrument, and to ensure that an accurate set of readings are available for future study. At the time of this report, EBA is unaware of any additional sets of data recorded for SIB-02 excluding the two sets taken in the spring of 1971 and reported in EBA 1971. The June 3 data, along with the February 23, 1971 data, was imported into a computer program for comparison.

An incremental deflection of approximately ± 10 mm is present throughout the data. These deflections could be attributed to or at least partially attributed to variations in equipment used, orientation of equipment, or equipment accuracy. Without additional data, conclusions regarding any apparent movement are unable to be formulated with a suitable degree of confidence.

Presently, the ground elevation at SIB-02 is approximately 1.0 m below the original ground elevation present during the installation in 1970. This is due to surface sloughing occurring since the original installation. Furthermore, following the final set of readings and upon disassembling the equipment, it was determined that the upper 9 m of instrument has no backfill present between the slope indicator pipe and drill hole side wall. Although the slope indicator pipe was fixed at the ground elevation during the recording of the two sets of readings, the readings taken between 0.6 m and 9 m are suspect.

Should this instrument be used in the future, it will require proper backfill, and two initial sets of readings will be required to reinitialize it and provide base readings for comparison of future data.

It is difficult to make valid observations of any apparent incremental movement due to the limited amount of data present. With only two sets of data over a thirty-one year time period, slight changes in inclination or small movement trends are unable to be established. However, the fact that the probe (inclinometer) traveled all the way to the base of the casing indicates that there has been no deep-seated instability at this location. Deep-seated movement would be expected to shear, or at least significantly deform, the casing, and thus restrict the movement of the probe.

6.4 Mass Movement Processes and the Implications on the Whitehorse Escarpment

Slides have occurred at various times and in various magnitudes on the escarpment over the past century. Debris slides and mudflows are mass movement processes that have had foremost impact. There are no records of deep-seated failures on the escarpment behind the present downtown area.

Mass movement mechanisms or active geomorphological processes observed on the escarpment were characterized as:

1. Progressive deformation by seasonal thawing of saturated silt (Photographs 3-9);
2. Toppling (Photographs 15, 18);
3. Rilling erosion and shallow gullying;
4. Debris slides and debris flows (Photographs 2, 10 - 12);
5. Slumps and earthflows (includes mud flows) (Photograph 19);
6. Slow mass movement;
7. Gullying (Photograph 17); and
8. Seepage (Photographs 6 - 9, 19).

6.4.1 Progressive Deformation by Seasonal Thawing of Saturated Silt

Progressive deformation by seasonal thawing of the saturated surface of the silt unit, aided by melting snow, is the most widespread, active and problematic erosional process in the study area. It presently generates the greatest impact to lands located at the base of the escarpment (Photographs 3 to 9).

The sand layer on the surface of the airport site promotes downward percolation of precipitation and precludes run-off and evaporation. This condition is amplified by the absence of forest cover. The top of the underlying silt unit, being less pervious than the loose sand unit, becomes saturated to some degree as it slows the vertical percolation rate and increases the rate of lateral ground water flow.

On the face of the escarpment, the saturated silt is exposed to seasonal freezing. Frost penetration on the escarpment face is in the order of 1 m to 1.5 m (EBA, 1971). Freezing of the silt results in ice lensing or segregation. Thawing of the exposed face in the spring and early summer results in sloughing of the material. The thawed material fails constantly on the underlying frozen surface, which also prevents drainage through the soil.

As the material thaws, slumping and sloughing at the headscarps generate a series of small mud flows that transport the material downslope. This process causes shallow gullying of the lower escarpment slopes, the development of broad colluvial fans beyond the escarpment toe and may result in larger flows or slides during periods of extreme rainfall. Periodically, larger blocks of material will slough or slide into the headscarp bowl, a result of the undermining and over-steepening of the overlying sand unit by successive thawing and sloughing of mostly saturated silt. Ditching and settling ponds (Photographs 20, 21) constructed along the base of slope at particularly troublesome areas have been effective in controlling the deposition by ongoing mud flows during typical or average climatic conditions.

Given the nature of the process and the texture of the material, the fans created by this activity tend to have very flat gradients and result in the deposition of material a considerable distance from the toe of the slope. In severe precipitation events, the volume of the mud flows or debris slides may have the potential to cause considerable damage to private property in its path.

6.4.2 Toppling

Toppling of small blocks from sub-vertical cliffs of compact silt on upper escarpment slopes is common in the study area. This process involves the release of relatively small masses (e.g., up to a few cubic metres) of dry, cohesive silt blocks and movement downslope by free fall, rolling and bouncing. Small blocks of recently toppled material were observed at Baxters Gulch and north of Pucketts Gulch (Photographs 15, 18) and involved small blocks that broke up into smaller particles upon impact with the middle slopes. Infrequently, large blocks (greater than 5 m^3) can be severed from the upper slopes by the combined influence of erosional processes, such as freeze-thaw wedging and swelling of clay from saturation.

Debris from smaller toppled blocks typically rolls down the lower slopes to settle on or near the toe of the slope. It is conceivable that toppling of larger blocks, e.g., from “hoodoos” such as those developed in Zone I above Baxter Street (Photographs 14, 16), could occur infrequently and would have a more extensive deposition zone. This could be initiated by an anomalous incident such as a severe climate event or seismic activity.

The extent of the deposition zone from smaller toppled blocks does not typically extend beyond 2 m from the toe. Moderate sized blocks of compact silt toppled from sub-vertical pillars observed within Baxters Gulch deposited material up to 10 m out from the toe of the slope. A large toppled block would have a more extensive deposition zone of larger debris, and could have the potential to cause damage to private property in its path.

6.4.3 Rilling Erosion and Shallow Gullying

Rilling erosion and shallow gullying are geomorphological processes caused by water, e.g., from run-off or seepage, moving downslope. Rilling results in a pattern of fine parallel furrows created by the surface erosion of fine textured soils from flowing water. Scouring during rilling erosion and shallow gullying will contribute suspended sediment to the silt-laden water and mudflows. This process is not typically a concern for generating rapid impact to downslope areas. However, if not controlled it can lead to extensive deposition over time and may develop into deep gullying and destabilization of the slope. Diversion and collection structures, such as ditches, berms and frequently maintained settling ponds, if properly engineered, can be effective in controlling the deposition from these processes.

6.4.4 Debris Slides and Debris Flows

Debris slides are a variety of landslide. They occur when a mass of glacial drift or colluvium becomes detached from a hillside and moves rapidly downslope by sliding along a shear plane. Debris slides are initiated on steep hillsides by the sliding of weathered till and/or colluvium along a shear plane that often coincides with the contact between weathered till (i.e., pedogenic soil) and unweathered till, or between colluvium and till, or between any of these materials and bedrock. Slides may be triggered by heavy rain, water from snow melt, and/or rain on snow events, and can result from loss of soil strength due to high pore water pressure. During wet conditions, slides are also triggered by wind stress on trees, tree throw, impact of falling rocks from up slope, and vibrations due to earthquakes or human activity. Concentrated drainage diverted onto steep slopes can initiate a slope failure and may initiate landslides some distance downslope.

A debris flow is a shallow landslide on a steep hill slope involving rapid translational displacement of material that typically results in a deposition zone extending well beyond the toe of the slope. It is characterized by the rapid flow of a mass of viscous material, consisting of water, mud, sand, stones, and organic debris. Large debris flows often are channeled within gullies and may move downslope for several hundred metres or more before depositing on gentler terrain. Debris flows are significant potential sources of stream sediment and a hazard to activities or structures located in run-out zones.

No evidence of large debris flows was observed in the study area. However, a debris flow (the Takini East Slide)—with an estimated volume of 3,000 m^3—occurred in July 2000 on a section of the escarpment located 1.5 km north of Baxters Gulch, below the Department of Fisheries and Oceans compound in the Takhini subdivision (Photographs 10 to 12). This slide was evaluated on May 8, 2002 and it was confirmed that the soil conditions and depositional environment at this location are the same as that within the study area. No observable depression in the plateau above the slide could be determined that would cause concentration of surface run-off at this location. However, the large storage yard of a light industrial development is situated as close as 4.5 m to 12.5 m from the crest of the escarpment. This is the only place along the escarpment in this area where the vegetation has been removed and replaced by an open storage yard. Along the rest of the escarpment in this area, no development occurs beyond an estimated minimum 50 m of the crest, and is separated from the escarpment by a buffer of forested or grassed terrain.

Debris flows typically result in a deposition zone extending well beyond the toe of the slope. The deposition zone of the Takhini East slide was estimated to be 30 percent longer than the height of the transport zone. In this case the deposition zone extended 65 m from the slope through a forested area (Photographs 10, 11). The deposition zone would likely have extended further if the path of deposition were unforested. The Takini East Slide occurred in July, 2000, which recorded rainfall of 40 mm, only 25% above average (see Section 6.2).

6.4.5 Slumps and Earthflows

Slumps and earthflows often involve combined processes of earth movement (rotation of a block of overburden over a broadly concave slip surface, or slump) and result in the downslope transport of the resulting mass, either by a flow or a gliding displacement of a series of blocks (earthflow). Slumps and earthflows vary greatly in size. Rates of movement range from extremely slow (millimetres per year) to rapid (metres per second). Creep activity is a common precursor to slumps and earthflows. Slumps and earthflows are commonly, but not necessarily, associated with seepage.

Slumps and earthflows from seepage on lower escarpment slopes were not observed within the study area. However, this process was noted at two nearby areas of the escarpment, in Baxters Gulch (Photograph 19) and south of Mud Hill (Figure 2). The volume of material moved by these processes was observed to be relatively small. At upper Baxters Gulch, the tongue of deposition material has a slope gradient of 15 percent and extends 40 m downslope from the base of the 6 m high headscarp.

6.4.6 Slow Mass Movement

Slow downslope movement of masses of surficial material by creeping, flowing or sliding (denoted by F" in the terrain stability mapping symbols) was observed in the study area. Rates of movement are very slow (centimetres per year) to extremely slow (millimetres per year).

Slow mass movement on the escarpment is typically associated with other slope movement mechanisms observed on the upper slopes. It was observed in active areas of progressive erosion, where the seasonal thawing and sloughing of mostly saturated silt undermined the surficial material on the slope above. Generally, this process appears to involve small blocks of material moved downslope initially at a slow rate, eventually sliding rapidly into the headscarp below.

Slow movement was observed above the recent (July 2000) Takhini debris flow where a wide tension crack has formed (Photograph 13). The block of material immediately upslope of the headscarp of the Takhini slide is creeping towards the void left by the slide.

There was no evidence observed to indicate that large isolated blocks of material were undergoing measurable slow movement. The probability of extensive damage to property beyond the toe of the escarpment slope as a direct result of slow mass movement is judged to be low.

6.4.7 Gully Erosion

Gullies are small ravines with V-shaped cross sections that typically form in either glacial drift or bedrock. Gullied terrain is an indicator of either former or active erosion, and the symbol serves to identify material that is potentially subject to erosion or mass movement. Gully side slopes and steep headwalls are common sites of slope failures and are classed as unstable (Class **V**). Gullying (moderate to deep) on the Whitehorse escarpment was observed to be caused by run-off, seepage, thawing, flooding or concentrated drainage from the plateau (Photograph 17).

An example of the impacts of concentrated runoff on sensitive terrain may be observed at an active gully south of the study area, above a baseball field on Robert Service Way (Figure 2). The top of a narrow, dry gully links directly to a wide swale, sloped towards the escarpment. The swale is approximately 50 m wide and 75 m long, and may have been created during the clearing of the plateau. Although there is no stream channel developed on the plateau, the gully is clearly periodically active, probably during periods of elevated rainfall.

6.4.8 Seepage

Seepage is typically most active in spring during seasonal thawing, snowmelt and/or during storms with high levels of rain. This commonly occurs on slowly permeable or impermeable units, such as consolidated till or bedrock, and on lower slopes where shallow subsurface water is received from a relatively large catchment area further upslope. It may also occur where groundwater is concentrated at the surface by a physical conduit such as a geological fault. Such moist sites appear to be indicated by gaps in the forest canopy and the presence of deciduous vegetation (e.g. willow, alder).

Seepage was observed on the upper face of the escarpment at and immediately below the glaciofluvial sand / glaciolacustrine silt contact (Photographs 6 to 9, 19). It is the thawing of frozen seepage and mostly saturated silt at this confluence of a permeable substrate with a less permeable one that contributes to the most active slope mechanism in the study area. Seepage was noted on a small scale on lower escarpment slopes in two areas outside the study area: on the north slope of Baxters Gulch; and south of Mud Hill (Figure 2).

6.5 Slope Process Management Zones

The study area was segmented into zones characterized by similar terrain characteristics and consistent slope movement processes at an analogous stage of activity. For the purposes of the risk assessment, the consequence of mass movement activities within each zone is expected to be similar. The results are summarized in the following table, which is also reproduced on Figure 2.

Table 8.4 Slope Process Management Zones

ZONE	SOIL MOVEMENT MECHANISMS*	DESCRIPTION
A_1	**1, 3**	Active area; An interception ditch has been excavated along part of the toe of slope to intercept mudslides.
B	**1, 2, 3**	Mud Hill. Type 1 slides have not developed into deeply scalloped headscarps; the slope is capped with a high berm of fibric soil; toe of slope is over-steepened by railway/road right-of-way cut slope; toppling is a minor component as toppling blocks are small.
C	**1, 4**	Slide zones have been less active in recent times and are partially re-vegetated.
A_2	**1**	Active area; most mudflow deposits settle on low gradient fans. No interception ditches have been constructed.
D	**1, 4**	The most active area of the escarpment. Headscarps are deeply scalloped; interception ditches and settling ponds have been constructed along the toe of the slope.
E	**1** (inactive)	This mainly forested section has some old slide paths that are re-vegetated.
F	All; (deposition zone)	Fans and depositional zones of mass movement activity from upper slopes; most of material is deposited from mud flows with some toppling debris.
G	**1, 4, 9** (inactive)	Pucketts Gulch. No active areas of mass movement; previous areas of instability are re-vegetated with grasses or trees.
H	inactive	Forested; some old slide paths or gullies are re-vegetated.
I	**2, 3**	Small toppling failures; some rilling and shallow gullying; un-vegetated;

* **1** progressive deformation by seasonal thawing of saturated silt; **2** toppling; **3** rilling erosion and shallow gullying; **4** debris slides and debris flows; **5** slumps and earthflows (including mud flows); **6** slow mass movement; **7** gullying

Zone I differs significantly from the rest of the study area in that it has much reduced seepage emitting from the face of the escarpment. The escarpment face appears dry and more cohesive, which is manifested by the lack of vegetation and sub-vertical bluffs formed on the upper slopes. The difference in hydrological conditions in this section of the escarpment may be partially attributable to the better drainage allowed by Baxters Gulch immediately to the north, and to the forest cover that has been allowed to remain on the plateau above the slope.

7.0 RISK ANALYSIS

7.1.1 Hazard Assessment

Hazard represents the probability and magnitude of a slope failure occurrence and is derived from the terrain stability analysis (Section 6.1). It is rated as low (L), moderate (M) or high (H) (Figure 2). Hazard is a function of numerous factors, including soil and drainage characteristics, climate, vegetation and the influence of previous development. This definition includes the magnitude of a landslide and the extent of the area influenced by debris deposition. The potential damage that may result is considered part of the impact, or consequence. Terrain polygons mapped with a high hazard of slope movement form a continuous zone behind the developed area of the downtown core within the study area (Figure 2). The terrain stability Section 6.1.2 presents a more comprehensive definition of hazard.

7.1.2 Consequence Assessment

The assessment of consequence involves an evaluation of the potential impact to private property, utilities, the public and other values. These values are typically located at the lower elevation extent of the escarpment in the potential deposition zone of mass movement mechanisms initiated within a hazardous area.

Rather that assigning a consequence value to individual polygons, consequence was assessed in zones situated sub-parallel to the escarpment terrain, and positioned relative to terrain characteristics, hazard assessment, historic mass movement activity, identified slope processes, experience with similar silt escarpments of other jurisdictions and other conditions. A High consequence is assigned if there is a high likelihood of significant impact from slide debris and transport and/or deposition within the zone. A Moderate consequence is assigned if there is a moderate likelihood of significant impact from slide debris and transport and/or deposition within the zone, and where impact from landslides may be potentially reduced with the construction of protective, properly engineered structures. A zone extending farther from the base of the escarpment, where the impact from mass movement activity on the escarpment would likely be limited to flooding and deposition of fine sediments at a relatively slow rate, is assigned a Low consequence.

7.1.3 Risk Assessment

The level of risk depends on both the degree of hazard and the potential consequence (Table 7.1). The values of hazard, consequence and risk are qualitative, and no quantitative or numerical values are attached to the terms low, moderate and high. This system of relative risk allows comparison between areas of different assigned risk and the development of appropriate management practices for each risk area.

There are residual uncertainties inherent in any investigation of complex natural phenomena. Lack of subsurface geologic information and the lack of certainty as to future climatic inputs limits certainty in terrain analysis, and implies some residual risk associated with all development within or near unstable terrain.

Table 7.1: Risk Rating: Risk = Hazard X Consequence

Hazard Rating	Consequence Rating		Risk Rating
High	High	=	Very High
High	Moderate	=	High
Moderate	High	=	High
High	Low	=	Moderate
Moderate	Moderate	=	Moderate
Low	High	=	Moderate
Moderate	Low	=	Low
Low	Moderate	=	Low
Low	Low	=	Low

8.0 DEVELOPMENT PLANNING ZONES

The foregoing terrain analysis and risk assessment was integrated to develop the primary aim of the study, which was to determine a rationale to assess the appropriateness of the previous set-forward line, and to make recommendations to aid in the determination of the positioning of development planning boundaries to replace the previous set-forward line. The City may also refer to development planning boundaries as “escarpment protection boundaries” in other applications. Development Planning Zones were created to delineate High, Moderate and Low risk zones that may be used to guide proposed development. The zonal concept provides an opportunity to carry out detailed geotechnical assessments on specific properties. The results of these detailed geotechnical assessments could justify moderation of development restrictions based on site-specific recommendations, e.g., special building design, or placement of engineered structures to reduce the impact of potential landslide depositions near the base of the escarpment. The implications of the Development Planning Zones are summarized on Table 8.1.

Table 8.1 Development Planning Guidelines

GEOHAZARD RATING ZONES	LAND USE GUIDELINES
Zone 1 LOW HAZARD	Under existing conditions the observable geohazards pose a low level of risk. Chance of occurrence is judged to be 10% or less in 50 years, or only minor nuisance arising from some overland run-out of silt laden floodwater. Building development should be acceptable without further geohazard investigation. Mitigative structures in place up-gradient, such as ditches and berms draining to settling areas or ponds, should substantially reduce the risk of nuisance flooding. In this zone, maintenance (i.e., clean-up by Public Works crews) may be required following extreme precipitation events, excessive erosion and/or landslides.
Zone 2 MODERATE HAZARD	Buildings and other property could be subject to direct or indirect impact from slide run-out, mudflow or silt fall with a chance of occurrence considerably greater than 10% in 50 years. Building development is generally not recommended in this area, but may be permissible subject to modifications and/or mitigation techniques detailed by an adequately trained, qualified geotechnical engineer or geoscientist in a detailed site specific study, acceptable to the City, prepared on behalf of the property owner. The risk may be acceptable under existing conditions at certain locations with mitigative measures such as, but not limited to, construction of deflection berms, reinforced concrete basement walls, and/or slope restoration on the escarpment face. Restricted land use as is, such as parks, community gardens, parking lots or other recreational, casual use, may be permissible.
Zone 3 HIGH HAZARD	Geohazards are judged to be too severe in potential magnitude and frequency to permit any building development or major use, with the exception of limited recreational access trails to viewing sites at the top of the bluffs. Such trails would be properly sited, engineered and constructed. Many of the present trails would not qualify. Disturbance to the slope would not be allowed, either to the soil or vegetation. No development to be allowed on airport land near the crest of the slope. The chance of occurrence of a damaging event could be as high as 10% in 1 year. Loss of life and injury is implicit.

The low hazard/moderate hazard boundary line varies in distance from the toe of the escarpment slope. In general, the distance of this boundary from the toe of the escarpment has a direct relationship with the degree of risk and hazard on the adjacent escarpment slope. The analyses of slope processes and description of hazard for the various areas along the escarpment are described in Sections 6.4 and 6.5 and shown on Figure 2.

Risk zone boundaries (Figure 1) were developed from the analysis of slope processes, hazard assessment, field observations of slope characteristics and landslides within and outside the study area, historical activity, and from generally accepted practices employed in other jurisdictions with similar terrain. The lines have been created for development planning purposes. Detailed geohazard evaluation of the slope above specific properties or locations may conclude that the line can be adjusted. This evaluation would be carried out by a geotechnical professional – hired by the developer – and it would be reviewed by the City and its consultants.

As an initial guideline, the line separating the High Risk Zone from the Moderate Risk Zone was determined to be 26° (approximately 2:1 slope) from the crest of the escarpment. This guideline was used along most of the study area, and included those areas where previous slides had occurred, where there is active erosion and where seepage at the silt/sand contact was observed. This generalized location for the High/Moderate Risk line was adjusted following more detailed assessment of local terrain characteristics.

In some areas, moisture conditions on the escarpment were significantly drier where the slope is better drained. The escarpment between Cook Street and Baxter Street is an example, where the terrain forms a point between the escarpment and Baxters Gulch. Rapid drainage to Baxters Gulch, and to some extent the buffering of the rate of influx of precipitation to the ground by the forest cover in this area, account for the drier moisture conditions. In these areas, the High Risk/Moderate Risk line was guided by 30° gradient (approximately 1.75:1 slope) from the crest of the escarpment. Throughout the study area, this approach was used as an initial guideline. Adjustments to the line were made based on a host of factors, including local terrain conditions, the potential for channelization of landslide debris, the shape and extent of colluvial deposits at the foot of the slope, historical activity, evidence or reports of mud flows in specific areas and the scale of the present potential for mass movement and erosion activity.

9.0 RECOMMENDATIONS

The following recommendations are discussed in the subsequent sections.

1. Initiate a hazard mitigation program;
2. Develop a management plan for the escarpment;
3. Initiate a program to monitor the sub-surface conditions and rate of regression;
4. Instigate a study to inventory and evaluate the stability of the existing trail system, to assess the impact on slope stability by recently constructed trails that have undercut steep slopes, and to provide recommendations to reduce the potential impact of trail construction.
5. Create recommendations for suitable engineered structures to reduce the impact of potential landslides.

9.1 Hazard Mitigation

Hazard mitigation, if feasible, is generally a more favourable solution than consequence management. A key recommendation of the EBA 1971 report to apply granular material to load an active area of thawing silt may be a practical remedy to reduce the most active slope process. As recommended, placement of a surcharge load on the thawing silt face would result in an increase in total stress in the near surface silt to retain the thawing materials in place. The insulating quality of a blanket of material would also control the rate of thawing in the spring. This method of slope stabilization could be attempted in a small active area as a “test section” and expanded if successful. Aggressive re-vegetation of the applied material would promote success of the project. This hazard mitigation project could be a joint venture with the airport authority to arrest the silt deposition at the edge of the city and to prevent further regression of the airport plateau.

The concept to place a surcharge load on active area of thawing silt would employ a filter toe berm to retain the fill (Figure 4). The two principal requirements for a satisfactory filter are that it must be more pervious than the retained soil in order to act as a drain, and that it must be fine enough to prevent particles of the protected soil from washing into its voids. This could be achieved by zoning the core of the berm, i.e., with progressively graded material from fine (upslope) to coarse (downslope). Geotextile fabric could also be employed to achieve a barrier between finer textured fill and coarser-textured, better-drained toe berm material. The filter toe berm would be keyed to the slope on each side of the depression below the slide area being treated.

Hazard mitigation may also include actions to minimize potential soil movement, e.g., maintenance of vegetation along the crest of the escarpment, revegetation of slopes, management and maintenance of existing trails and developing guidelines for acceptable / non-acceptable access zones to the escarpment. Hand planting willows, benching, "bio-mat" placement to enhance revegetation, or a combination of bio-engineered rehabilitation methods are also options that may be considered.

Conscientious management of the lands on or above the escarpment is key to slope stability. The soil regime in the study area is sensitive to moisture and drainage. Ponding or holding of water on the airport site should not be allowed. Any alteration of the terrain on the airport site that would promote channeling and concentration of surface water should also be disallowed. Re-forestation of cleared areas that are not required for runway right-of-ways, e.g., outside of the fenced area along the crest of the escarpment, should be undertaken to increase the area of potential evapotranspiration from tree-cover.

9.2 Management Plan for the Escarpment

The escarpment is a visual icon of the city. There is great scope for enhancement of the escarpment as a prime attraction and at the same time addressing the need to mitigate the hazards and control the consequences. A management plan would focus on two main themes: management of slope processes, and development of the area for public use and visual quality. Management guidelines could include:

- Techniques to reduce the present hazards and slow or reverse present erosion processes
- Options for trail development
- Restricted use areas
- Engagement of public support for park development
- Suggestions for public participation in revitalization and mitigation projects to protect from further erosion and to reverse present erosion processes, and
- Integration of engineered consequence-control structures with public-friendly features – e.g., attractive settlement ponds to enhance a park setting.

9.3 Monitoring Program

A program to monitor the rate of regression should be initiated. Survey points along the crest of the escarpment at the identified active zones should be established and measured annually.

If funding permits, it may be useful to establish a program to monitor the subsurface soil and ground water conditions along the escarpment. Slope indicator casings could be installed in several locations near the escarpment crest, and monitored at least annually and following a seismic event. A monitoring schedule can be developed following installation. The results of the monitoring program would either provide confidence in the continued deep-seated stability of the escarpment, or give forewarning in the event movement was detected. All new installations should be deeper than the 1970 casings, which did not approach the base of slope elevation.

Several ground water monitoring wells should also be installed, to confirm the regional ground water elevation along the escarpment. This will assist in future analyses.

9.4 Recreational Development on the Escarpment

As recreation will likely be the main development strategy proposed by special interest groups within the high-risk area of the escarpment, it is prudent to develop a set of guidelines for trail construction. Some existing trails on the escarpment are located on particularly unstable slopes and/or have been created with poor construction methods that may have reduced slope stability. A gradual reduction of shear strength takes place following the creation of a new cut slope or construction along a slope. There is short to moderate-term stability immediately following the development, but not long-term stability. Cutting into unconsolidated material on a slope disturbs soil shear strength and a progressive reduction in strength upslope from the base may take place. Failure can occur a considerable time after construction.

A study to inventory and evaluate the stability of the existing trail system, to assess the impact on slope stability by recently constructed trails that have undercut steep slopes, and to provide recommendations to reduce the potential impact of trail construction, should be undertaken. This study would recommend which existing trails should be closed off and re-vegetated, which areas would be most suitable for the development of low impact trails, and site specific construction methodology to achieve this end.

9.5 Control Structures to Reduce Impacts from Ongoing Erosion

A study should be initiated to assess the suitability of the present silt collection ponds and ditch / berm system. Recommendations should be developed to better control those areas of the escarpment not presently protected by erosion control infrastructure.

10.0 CLOSURE

Conclusions and recommendations presented herein are based on observations of land-surface conditions, current understanding of slope processes and the review of previous geotechnical reports. This report has been prepared for use by the City of Whitehorse, which includes distribution as required for purposes for which this investigation was commissioned. This assessment has been carried out in accordance with generally accepted engineering and geoscience practice, and engineering/geoscience judgement has been applied in developing the recommendations in this report. The report incorporates and is subject to the General Conditions attached in Appendix F.

Respectfully submitted,
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FIGURES

PHOTOGRAPHS

APPENDIX A

Terrain Mapping with Air Photograph Mosaic, City of Whitehorse Engineering

APPENDIX B

Summary of Historic Development and Activity on the Escarpment

Appendix B

Summary of Historic Activity, Development and Stability Events on the Escarpment

- Prior to airport development, apart from a grass-covered meadow approximately 450 m back from the crest of the escarpment the entire plateau was covered with a moderately dense growth of pine and spruce and light underbrush.
- 1900 Much of the escarpment is reported to be mostly vegetated, covered with a moderately dense growth of pine and spruce and light underbrush [the bluffs above Ogilvie and Baxter Streets are assumed to have been un-vegetated also]. The "bridle path" up the face of the escarpment is reported to date back to this time. Early photographs show the area of the bridle path to be undisturbed, with forest and open grass-covered slopes. The "bridle path" is visible to the left of centre on the 1913 photograph reproduced on the frontispiece of this report.
- 1913 June 13. A photograph taken on this date shows the escarpment is mostly forested with some grass cover, with some minor evidence of possible mudflows.
- 1935 The main access road to the airfield was by way of Puckett's Gulch, a gully incised into the escarpment at the foot of Black Street. The bridle path to access the east airport area was a wide trail across both grass-covered and forested slopes.
- 1937 The Whitepass and Yukon Route Company (WPYR) construct an access road up to the airport following the "old bridle path". Original hangars and supporting buildings were located on the east side of the airfield.
- 1941 Buildings erected on east side of airport. It is reported that, prior to this time, mud flows similar to those that occur now did not exist on the escarpment.
- 1941-1942 The "bridle path" access road was improved by WPYR to replace the Puckett's Gulch road. A water line installed up the escarpment from town to east camp resulted in considerable disturbance to vegetation cover and slope.
- 1942, fall. Open drainage ditches excavated to drain into Puckett's Gulch. Minor sloughing reported on the "bridle path" road each year following [1941] construction.
- 1943-1945 Major construction phase on airfield included extensive surface drainage system of perforated pipes, all draining to Puckett's Gulch where the water spilled out into the gully. Storm sewers through the west camp area were connected to this system. Water and sewage installations were confused with no proper plan of compete system.

- 1944 Septic tanks and disposal fields that were installed in the east camp in 1941 did not function properly and were abandoned. The buildings were connected to a new collective system. It is not known if the old system was removed.
- 1945 Septic tanks and tile fields for sewage disposal at the east camp were abandoned.
- 1948 August storm water from the airfield flowed down the face of the escarpment through a culvert in the road just north of the northeast end of the cross-runway. Although there was not a large quantity of water, it washed a great deal of material down the slope, silting up portions of the cemetery, some yards and one basement. At the same time, erosion at the head of Puckett's Gulch occurred when a storm sewer undermined itself and the sanitary sewer, which broke. Other minor slides occurred along the face of the escarpment during this year.
- 1949, July Two serious landslides are reported. The headscarp of one is within 30 feet of an "east camp" building. Tension cracks indicate further potential for mass movement. A second slide occurred where the outfall sewer dropped down the escarpment. Serious sloughing on the escarpment prompts plans for drainage improvements created for RCAF and DoT. Monthly rainfall for June exceeded 3 inches, which occurred only 3 times (1949, 1953, 1961) in a 29 year period (1941-1970).
- 1949 summer and fall. Further slides reported. Seepage water reported flowing from the interface of sand and silt beds; slides block access road to east camp; icing of road in late fall; large tension cracks form at edge of road. Road is closed.
- 1949-1950 The road to airport east camp is closed due to slope stability problems and high maintenance frequency.
- 1950 Spring. Further sliding reported around sewer outfall [Puckett's Gulch]; slides reported at end of Hawkins Street, endangering several dwellings.
- 1950 Corrective drainage measures commenced. Considerable leakage of the water lines in the east camp reported.
- 1950-1951 A ditch is excavated to drain the south half of the west edge of the airstrip to the south. A storm water sewer previously emptying into Puckett's Gulch was reconstructed so that water is now carried north of the airfield in a buried line to the bottom of Baxter's Gulch.
- 1951 Extensive slides occurred along the escarpment. Access road to east camp requires continuous maintenance.

- 1953 The most serious slides in the history of the escarpment occur. In the spring of this year. Large quantities of "soupy" material flowed down into the town of Whitehorse causing considerable damage to private property. Very serious sloughing of the escarpment face caused damage to roads and buildings in Whitehorse and even to the graveyard at the foot of Steele Street. Cause cited as removal of vegetation and road construction across escarpment face. Deep frost penetration (due to a light snowfall) and excessive rainfall in the preceding winter and spring are also thought to have been major contributing factors. Sloughing and mudflows, with a wide range of deposition volumes depending on climate conditions, have occurred each year since. Monthly rainfall for June exceeded 3 inches, which occurred only 3 times (1949, 1953, 1961) in a 29 year period (1941-1970). Maintenance of the airport access road across the escarpment at the south end of town became futile, the road was considered unsafe for vehicle use and it was eventually abandoned.
- 1954 DoT carries out borehole program to evaluate the stratigraphy.
- 1957 May. A shallow ditch to drain surface water near east camp buildings is observed to have caused the bank to erode back 10 to 145 feet, carrying a good deal of material down the slope. It is observed that at no place on other escarpments in the Whitehorse area are mudflows evident similar to those on the airfield escarpment behind town.
- 1957 RCAF completes a test drilling program of 45 holes on a 500' grid to delineate the silt surface underlying the sand.
- 1958 Test drilling program of greater density than that completed in 1957 (520 holes, 200' grid) is carried out. Contour information presented in November. Serious consideration of revegetation is considered. An escarpment reforestation study is initiated.
- 1959 A comprehensive report on the stability of the Whitehorse Escarpment is issued by R.F. Leggett and G.H. Johnston for the National Research Council.
- 1969 Second Leggett report identified two silt dams constructed across Puckett's gulch, one close to the lower end and one approximately 2/3 up from the base. Dams were assumed to have been built to retain water and are identified as a serious hazard. The upper dam is reported as being approximately 8 m high.
- 1991 Construction of interception ditches and settlement ponds is completed at the toe of the escarpment near the end of Steele Street.

APPENDIX C

Detailed Legend for Terrain and Hazard Mapping (Figure 2)

APPENDIX C

LEGEND FOR TERRAIN SYMBOLS

(1) TERRAIN UNIT SYMBOLS

surficial material ↘ ↙ initiation zone
texture → **aCk – R"b** ← geomorphological process subclass
surface expression ↗ ↖ geomorphological process

Composite Units: Up to three letters may be used to describe any characteristic. Processes follow the dash ("-") symbol.

e.g. Mv.Rk indicates "Mv" and "Rk" are roughly equal in extent

Mv/Rk indicates "Mv" is more extensive than "Rk" (about 2/1 or 3/2)

Mv//Rk indicates "Mv" is much more extensive than "Rk" (about 3/1 or 4/1)

/Mw over Rk indicates "Rk" is partially buried by "Mw"

Stratigraphic Units: When one or more surficial materials overlie a different material or bedrock.

e.g. Mw over Rr indicates that "Mw" overlies "Rr"

(2) TEXTURE

c	clay	< 2 µm
z	Silt	2 – 62.5 µm
s	sand	62.5 µm – 2 mm
m	mud	mixture of sand (s) and silt (z)
f	fibric organic	the least decomposed of organic materials with >40 % preserved fibre

(3) MATERIALS

A	Anthropogenic materials	Artificial materials and materials modified by human actions such that their original physical appearance and properties have been drastically altered.
C	Colluvium	Products of gravitational slope movements; materials derived from local bedrock and major deposits derived from drift; includes talus and landslide deposits. Includes up to 20% bedrock.
E	Eolian sediments	Sand and silt transported and deposited by wind; includes loess.
F	Fluvial sediments	Sands and gravels transported and deposited by streams and rivers; floodplains, terraces and alluvial fans.
FA	"Active" fluvial sediments	Active deposition zone on modern floodplains and fans; active channel zone.
FG	Glaciofluvial sediments	Sands and gravels transported and deposited by meltwater streams; includes kames, eskers and outwash plains.
LG	Glaciolacustrine sediments	Fine sand, silt and clay deposited in ice-dammed lakes.
O	Organic materials	Material resulting from the accumulation of decaying vegetative matter; includes peat and organic soils.

4) SURFACE EXPRESSION

a	moderate slope(s)	predominantly planar slopes; 15-26º (28 - 49%)
b	Blanket	material >1-2 m thick with topography derived from underlying bedrock (which may not be mapped) or surficial material
c	Cone	a fan-shaped surface that is a sector of a cone; slopes 15º (27%) and steeper
d	Depression	enclosed depressions
f	Fan	a fan-shaped surface that is a sector of a cone; slopes 3-15º (5-27%)
h	Hummocky	steep-sided hillocks and hollows; many slopes 15º (27%) and steeper
j	gentle slope(s)	predominantly planar slopes; 4-15º (6 - 27%)
k	moderately steep slope	predominantly planar slopes; 26-35º (50 - 70%)
m	rolling topography	linear rises and depressions; < 15º (27%)
p	Plain	0-3º (0-5%)
s	steep slope(s)	slopes steeper than 35º (> 70%)
t	terrace(s)	stepped topography and benchlands
u	undulating topography	hillocks and hollows; slopes predominantly <15º
v	Veneer	material <1-2 m thick with topography derived from underlying bedrock (may not be mapped) or surficial materials; may include outcrops of underlying material
w	Mantle	surficial material of variable thickness
x	thin veneer	a subset of v (veneer), where there is a dominance of surficial materials about 10-25 centimetres thick

(5) GEOMORPHOLOGICAL PROCESSES

D	Deflation	Removal of sand and silt particles by wind action.
F	Failing	Slope experiencing slow mass movement, such as creeping, sliding or slumping
H	Kettled	Area includes numerous small depressions and/or lakes where buried blocks of ice melted.
L	Surface seepage	Zones of active seepage often found along the base of slope positions.
R	Rapid mass movement	Slope or parts of slope affected by processes such as debris flows, debris slides and avalanches, and rockfall
S	Solifluction	Slope modified by slow downslope movement of seasonally unfrozen regolith.
V	Gully Erosion	Modification of unconsolidated and consolidated surfaces by various processes such as running water, mass movement, resulting in the formation of parallel and sub-parallel long, narrow ravines.

Rapid Mass Movement (-R, -R") and Slow Mass Movement (-F, -F")

Where a double prime symbol (") is used with a mass movement process (e.g., **-R"s**, **-F"m**), slope failure has occurred within the polygon and the slope is classified as unstable. Landslide headscarps are located in these polygons.

Mass movement symbols without the double prime symbol (**"**) (e.g., **-Rb**, **-F**) indicate a polygon that contains the transport and/or deposition zone of landslides and debris flows. Although transportation zones are hazardous areas, they are generally not unstable and polygons will have a terrain stability class other than **V**.

Mass Movement Sub-Classes

-F"	slow mass movement - initiation zone
-Fc	soil creep: slow movement of soil
-Fe	earthflow: slow viscuous flow of material containing a high proportaion of silt and clay
-Fu	slump in surficial material along a slip plane that is concave upward or planar
-Fx	slump earthflow: combined slump (upper part) and earth flow (lower part)
-R	rapid mass movement
-R"	rapid mass movement - initiation zone
-Rd	debris flow: rapid flow of saturated debris
-Rf	debris fall: descent of a mass of surficial material by falling, bouncing or rolling
-Rn	Erosion of surficial materials by freeze-thaw processes and meltwater action.
-Rs	debris slide: sliding of disintegrating mass of surficial material.
-Rt	debris flood

(6) SOIL DRAINAGE CLASSES

r	rapidly drained	water is removed from the soil rapidly in relation to supply
w	well drained	water is removed from the soil readily but not rapidly
m	moderately well drained	water is removed from the soil somewhat slowly in relation to supply
i	imperfectly drained	water is removed from the soil sufficiently slowly in relation to supply to keep the soil wet for a significant part of the growing season
p	poorly drained	water is removed so slowly in relation to supply that the soil remains wet for a comparatively large part of the time the soil is not frozen
v	very poorly drained	water is removed from the soil so slowly that the water table remains at or on the surface for the greater part of the time the soil is not frozen

Where two drainage classes are shown:

- if the symbols are separated by a comma, e.g., "w,i", then no intermediate classes are present;
- if the symbols are separated by a dash, e.g., "w-i", then all intermediate classes are present

APPENDIX D

Remedial Measures and Benefits

Soil and Foundation Investigation of Whitehorse Escarpment

EBA, March, 1971

APPENDIX E

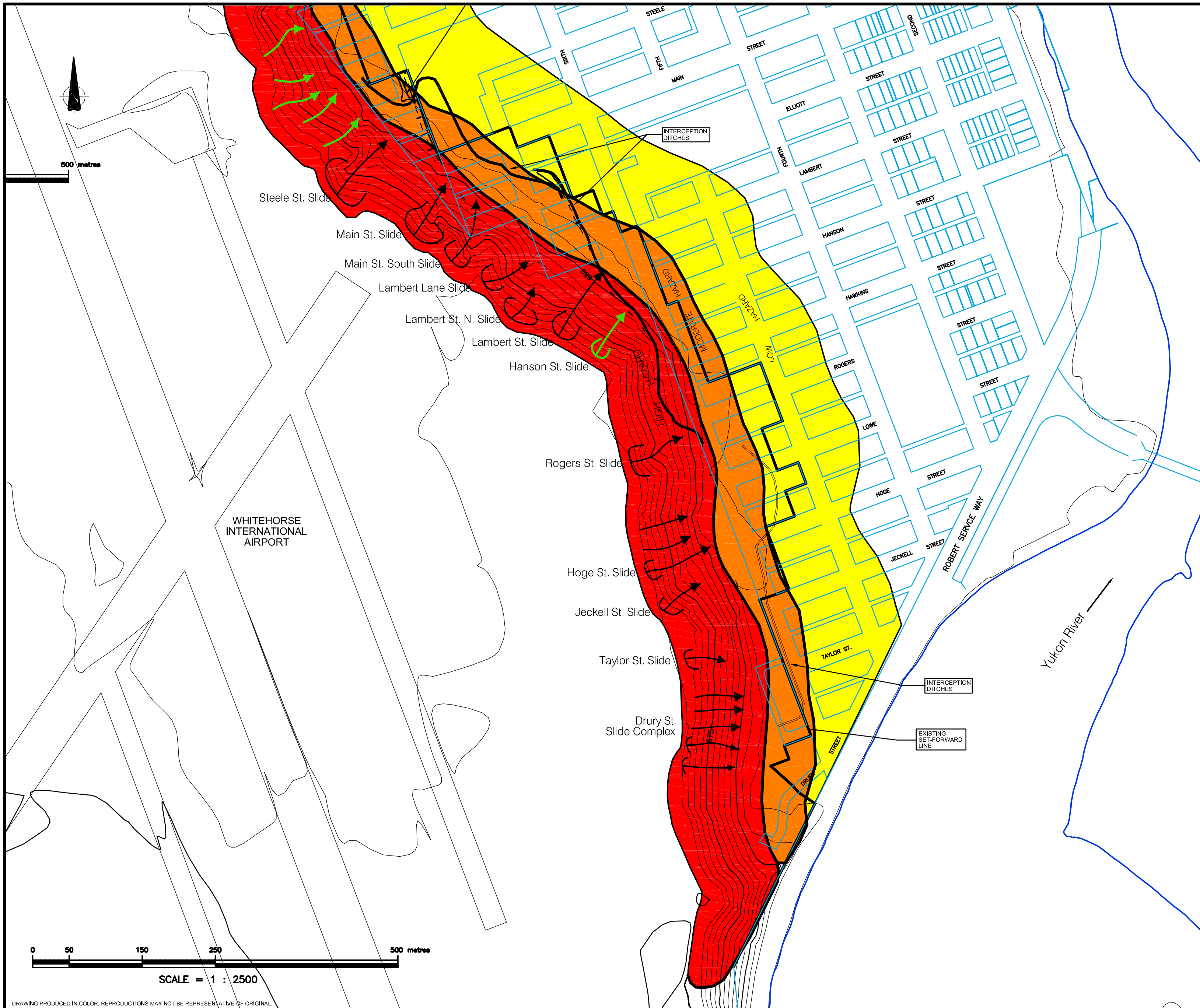
Early Set-Forward Line

Yukon Electric Co. Ltd.

1961

APPENDIX F

General Conditions



NOTES

GEOHAZARD RATING ZONES	LAND USE GUIDELINES
Zone 1 LOW HAZARD	Under existing conditions the observable geohazards pose a low level of risk. Chance of occurrence is judged to be 10% or less in 50 years, or only minor nuisance arising from some overland run-out of silt laden flood water. Building development should be acceptable without further geohazard investigation. Mitigative structures in place up-gradient, such as ditches and berms draining to settling areas or ponds, should substantially reduce the risk of nuisance flooding. In this zone, maintenance (i.e., clean-up by Public Works crews) may be required following extreme precipitation events, excessive erosion and/or landslides.
Zone 2 MODERATE HAZARD	Buildings and other property could be subject to direct or indirect impact from slide run-out, mudflow or silt fall with a chance of occurrence considerably greater than 10% in 50 years. Building development is generally not recommended in this area, but may be permissible subject to modifications and/or mitigation techniques detailed by an adequately trained, qualified engineer or geoscientist in a detailed site specific study, acceptable to the City, prepared on behalf of the property owner. The risk may be acceptable under existing conditions at certain locations with mitigative measures such as, but not limited to, construction of deflection berms, reinforced concrete basement walls, and/or slope restoration on the escarpment face. Restricted land use "as is", such as parks, community gardens or other recreational, casual use, may be permissible.
Zone 3 HIGH HAZARD	Geohazards are judged to be too severe in potential magnitude and frequency to permit any building development or major use, with the exception of limited recreational access trails to viewing sites at the top of the bluffs. Such trails would be properly sited, engineered and constructed. Many of the present trails would not qualify. Disturbance to the slope would not be allowed, either to the soil or vegetation. No development to be allowed on airport land near the crest of the slope. The chance of occurence of a damaging event could be as high as 10% in 1 year. Loss of life and injury is implicit.

LEGEND

- perennial stream
- ephemeral stream
- dry swale
- slide, active
- slide, active with headscarp area delineated
- slide, inactive, re-vegetated

CLIENT

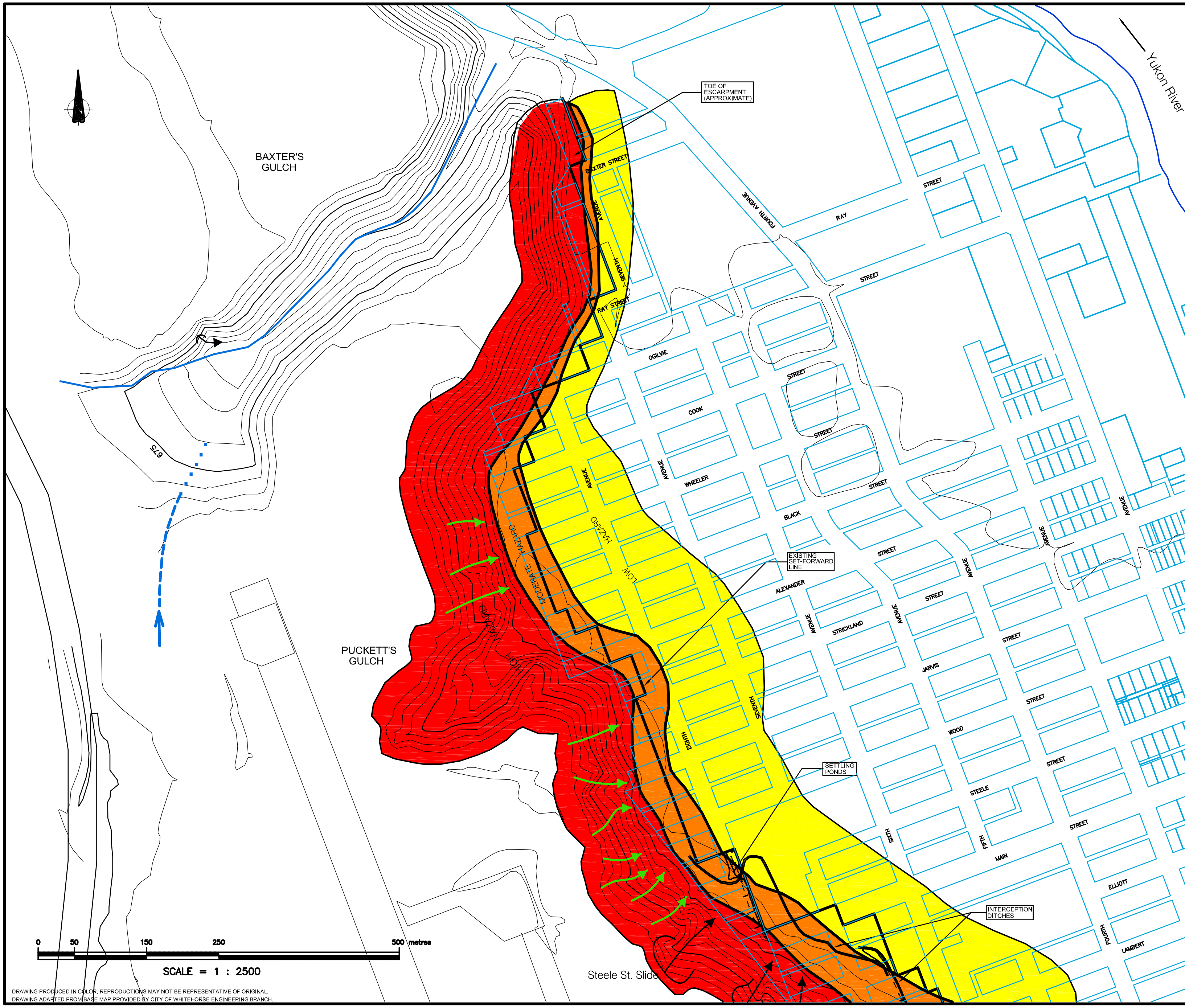
City of Whitehorse
ENGINEERING DEPARTMENT

No.	Revision/Issue	Date

EBA Engineering Consultants Ltd.

GEOHAZARD DEVELOPMENT PLANNING ZONES
SOUTH HALF

DRWG.	FIGURE 1 - SHEET 2
EBA PROJECT NUMBER:	0201-1200002
DATE:	NOV. 2002
DRAWN BY:	J. BUYCK
CHECKED BY:	J. DENNETT/R. TRIMBLE
SCALE:	1:2500



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City of Whitehorse
ENGINEERING DEPARTMENT

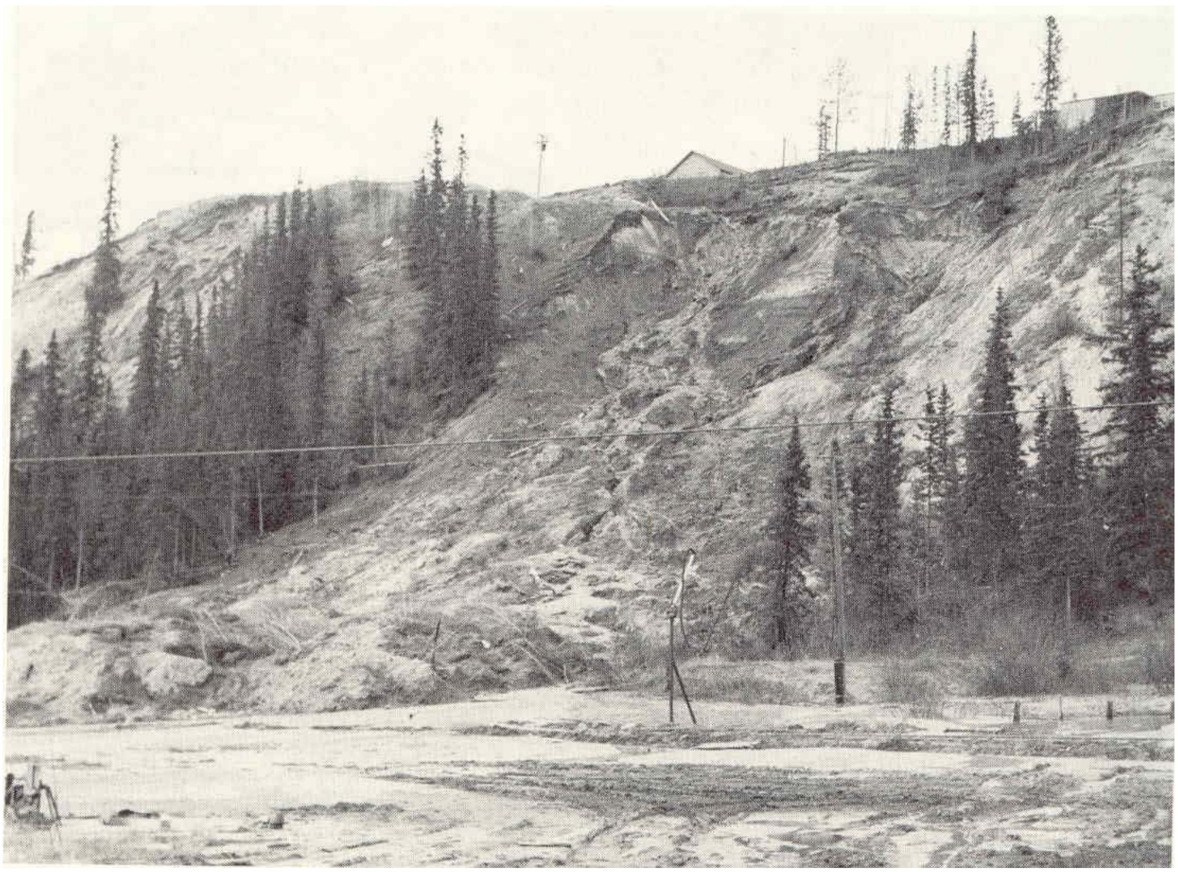
No.	Revision/Issue	Date

EBA Engineering Consultants Ltd.

GEOHAZARD DEVELOPMENT PLANNING ZONES
NORTH HALF

DRWG.	FIGURE 1 - SHEET 1
EBA PROJECT NUMBER:	0201-1200002
DATE:	NOV. 2002
DRAWN BY:	J. BUYCK
CHECKED BY:	J. DENNETT/R. TRIMBLE
SCALE:	1:2500

Photograph 1. August 1990. Aerial view of escarpment between Lambert Street and Steele Street.



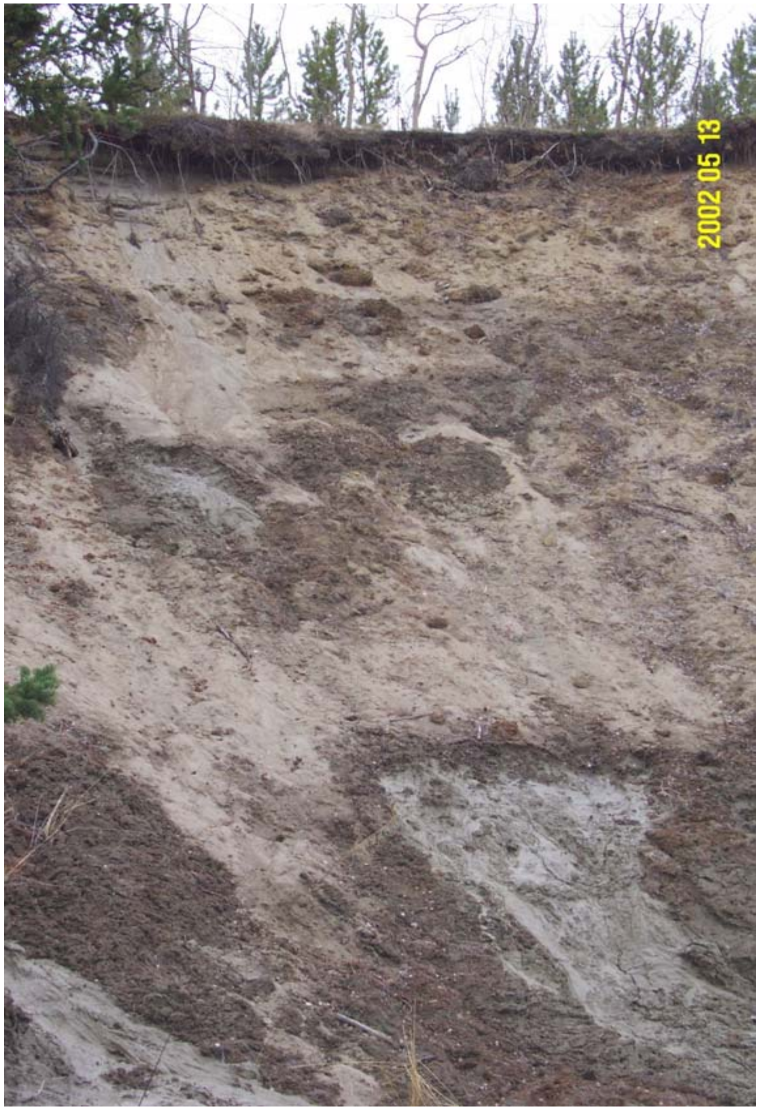
Photograph 2. [June] 1953. Landslide near Hoge Street (R.F. Legget).

Photograph 3. May 2002. Headscarp of Main Street Slide.

Photograph 4: May 2002. Main Street Slide. Melting snow in the headscarp contributes to the erosion process. The blue pipe stem to the left of centre is the slope stability indicator casing installed in 1970 and used for this study.

Photograph 5: May 2002. View from the crest of the active headscarp of the Lambert Street Slide.

Photograph 6: May 2002. Headscarp of an active area of thawing saturated silt below the eolian sand on the Lambert Street Slide. Detail of the specific active areas is shown on Photographs 7 and 8.



Photograph 7: May 2002. Details of thaw/flow zones within the active headscarp of the Lambert Street Slide.

Photograph 8: May 2002. Details of thaw/flow zones within the active headscarp of the Lambert Street Slide.

Photograph 9. May 2002. Active sloughing at thawing silt at contact with capping eolian sand within the Steele Street Slide headscarp.

Photograph 10: May 2002. The Takhini debris slide, which occurred in July 2000, is located on the escarpment that separates the Takhini subdivision from the Marwell Industrial Area. It occurred behind the Northerm Windows assembly plant on Copper Road. The toe of the deposition zone is close to a stream channel / drainage ditch (blue) and is within 50 m of private property.

Photograph 11: May 2002. View of the Takhini debris flow from the toe of the deposition zone.

Photograph 12: May 2002. Headscarp of the Takhini debris flow.

Photograph 13: May 2002. Tension crack formed upslope of the headscarp of the Takhini debris slide.

Photograph 14. August 2002. Sub-vertical silt bluffs on upper escarpment slope above Baxter Street.

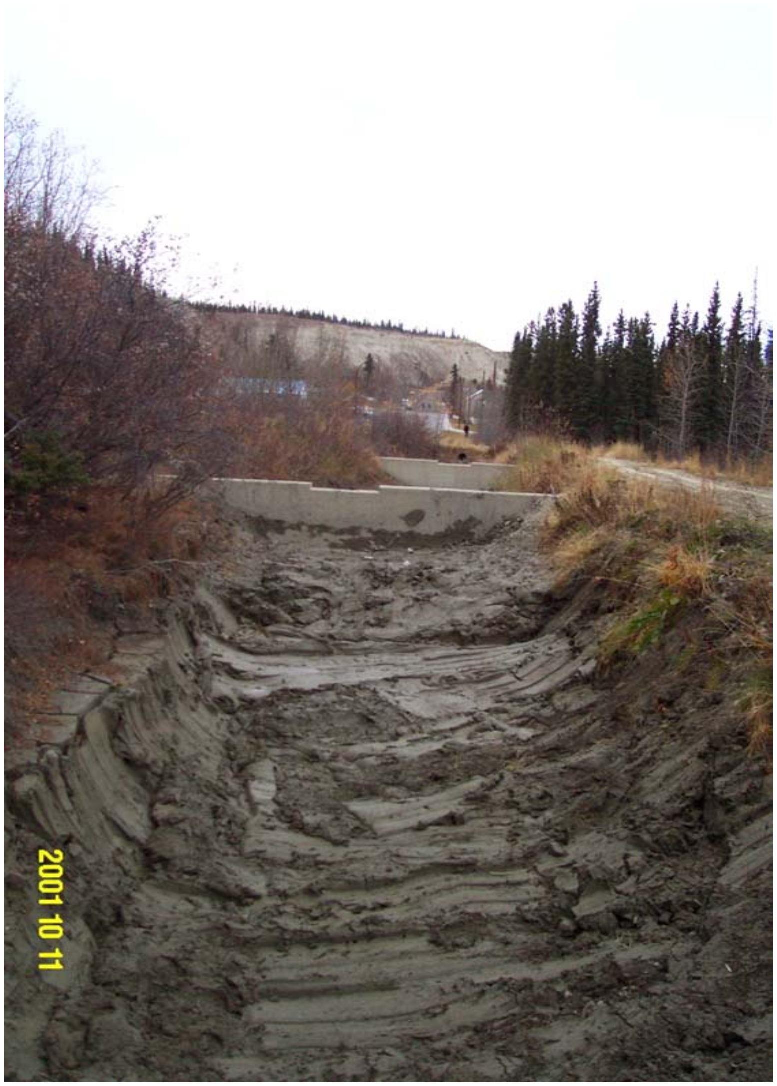
Photograph 15. August 2002. Sub-vertical silt bluffs with toppling debris at viewpoint on historic east airport road near Hawkins Street.

Photograph 16: May 2002. Sub-vertical bluffs of compact silt on the upper escarpment slopes above the end of Baxter Street

Photograph 17: May 2002. View up gully towards an active headscarp on the escarpment above the end of Main Street.

Photograph 18: April 2002. Toppled blocks of silt from sub-vertical bluffs within Baxter Gulch.

Photograph 19: April 2002. Slump and earthflow located at upper Baxters Gulch.



Photograph 20: September 2001. Baffled settling ponds located near the toe of the escarpment at the end of Steele Street. Silt has recently been removed.

Photograph 21. May 2002. Baffled settling ponds located near the toe of the escarpment at the end of Steele Street.