TETRA TECH

April 20, 2023

ISSUED FOR USE
FILE: 704-ENG.WARC04345-01
Via Email: matt.ball@yukon.ca

Government of Yukon
Energy, Mines and Resources
Land Management Branch (K320)
PO Box 2703
Whitehorse, YT Y1A 2C6

Attention: Matt Ball
Director, Land Management

Subject: Updated Geohazard Study (Rev 1)
5th Avenue and Rogers Street – Whitehorse, Yukon

1.0 INTRODUCTION

Tetra Tech Canada Inc. (Tetra Tech) was retained by the Government of Yukon, Energy, Mines and Resources, Sustainable Resources Division (YG) to conduct an updated site-specific geohazard study for the land parcel (Block 340, 105331 CLSR YT) at 5th Avenue and Rogers Street (the parcel), located in the downtown area of Whitehorse, Yukon, as shown on Figure 1.

Approval of this work was provided by Heather Mills through a signed contract C00069005 dated January 3, 2023.

This report includes findings from an updated site-specific slope geohazard assessment using historical air photo and LiDAR analysis supplementing the most recent report on the parcel completed by Tetra Tech in May 2016. The 2016 report summarized the results of recent site visits and studies regarding the terrain and slope stability of the escarpment (EBA 2012, Tetra Tech EBA 2014) and reviewed previous reports on terrain stability in the area (EBA 2002 and 2012).

1.1 Project Background

Tetra Tech understands that YG is preparing to sell the parcel to a buyer from the private sector, who will develop the land for mixed residential and commercial use. The parcel is mostly undeveloped, measures approximately 200 m long by 100 m wide with a total area of about 2.1 hectares, and is bounded by Hoge Street to the south, 5th Avenue to the east, the rear of residential properties along Hawkins Street to the north, and the toe of the Whitehorse escarpment to the west (Figure 1).

The Whitehorse escarpment (the Escarpment) is a steep slope, about 60 m high, consisting of a natural bluff of glaciolacustrine sediment formed by down-cutting of the Yukon River into glacial lake sediments that runs in a roughly north-south direction along the western edge of downtown Whitehorse. It separates downtown Whitehorse from the airport terrace, a plain of fluvial/deltaic sand blanket overlying the glaciolacustrine sediment (EBA 2012). Landslides and other types of mass movement events are common on the Escarpment and have been observed throughout the history of Whitehorse. Tetra Tech (formerly EBA Engineering Consultants) has completed geohazard mapping of the Escarpment, including a geohazard study of the entire escarpment in 2002, which was subsequent to an earlier investigation conducted on the Escarpment in 1971 (EBA 1971); and an updated geohazard study of the southern part of downtown Whitehorse, between Robert Service Way and Lambert Street, in 2012 (Tetra Teach 2012).

Tetra Tech completed a desktop geotechnical site evaluation and a site-specific terrain stability assessment of the subject site in 2016, which included a preliminary design for an interceptor berm to retain landslide debris and reduce the probability of the site being impacted.

A slope stability monitoring report for the Escarpment was prepared for the 2021 season by Tetra Tech and was issued in 2022 (Tetra Tech 2022). That report was prepared for the City of Whitehorse (the City) after a Spring 2021 letter prepared by Tetra Tech (Tetra Tech 2021) recommended monitoring key escarpment areas for slope stability issues which were anticipated to occur during spring freshet 2021.

Severe widespread mass movement activity occurred on the Escarpment in Spring 2022, with large landslides developing in several locations. As a result of the mass movement activity observed on the Escarpment in Spring 2022, the City of Whitehorse retained Tetra Tech to carry out an updated landslide hazard assessment, to update the previous studies done in 2002 and 2012. This assessment was in progress at the time of preparation of this report.

Based on the 2002 geohazard risk study, approximately half of the parcel was identified within the Low Hazard Zone. A narrow (about 12 m wide and 100 m long) section along the northwest boundary of the parcel was located within the High Hazard Zone and the balance, about half the parcel, within the Moderate Hazard Zone (EBA 2002).

2.0 METHODOLOGY

2.1 Geotechnical Desktop Evaluation

The previously mentioned reports were referenced in this updated geohazard assessment. Site visits were performed by the author in late May to early June 2022 as part of emergency slope monitoring work requested by the City, however no field visits we completed specifically for this site-specific geohazard study at the 5th and Rogers parcel.

2.2 Helicopter Based Aerial LiDAR and Orthoimagery

Pioneer Exploration Consultants Ltd. (Pioneer) conducted a helicopter-based aerial LiDAR and orthophoto scan of the entire Escarpment on September 14, 2022 using a Phoenix Ranger XL LiDAR system at a resolution of 250-300 pts/m^2.

The 2022 LiDAR and orthoimagery data (5 cm) was provided to Tetra Tech by Pioneer in October 2022. Tetra Tech reclassified the data to fine-tune the ground classification parameters and created a 20-cm-resolution Digital Elevation Model (DEM). The orthoimagery is seen on Figure 1 and hillshade DEM on Figure 2.

LiDAR and Orthoimagery from 2013 and 2019 was provided to Tetra Tech by the City and was sourced from GeoYukon – the Government of Yukon's digital map data. The City granted permission to use this data for this site-specific landslide hazard update.

2.3 GIS (Geographic Information System) Analysis

GIS processing of Pioneer's data was conducted by Tetra Tech and included creating ortho mosaics of the recent imagery; 0.25 m, 0.5 m, and 1.0 m raster surfaces of the digital surface model and the digital elevation models. The ArcGIS Pro environment allows for creation of 3D visual models by draping orthoimagery onto LiDAR data to aid in detecting problem areas.

2.3.1 Elevation Change Detection Analysis

Elevation change detection analysis was completed between years 2013 to 2019 and 2019 to 2022 using the available LiDAR data and the following techniques:

- Define borders for gain/loss polygons to calculate areas and max/min elevation differences. The threshold for polygon size was set at 10 m^2 to reduce excessive points, anomalous results, and possible noise in data;
- Used 0.3 m elevation difference for determining elevation gain/loss (vertical accuracy of data is a few centimetres, horizontal is 0.20 m); and
- Evaluating results with reference to known earthworks activities like berm construction to determine validity of the models. It was determined that some "random" unexpected results or polygon errors can be attributed to misclassification of previous years' LiDAR data by third parties.

2.3.2 Landslide Susceptibility Model

Landslide susceptibility modelling using GIS is a widely used approach for analyzing landslide-prone areas. GIS-based modelling allows the integration of different data layers including topography, geology, soil type, land use, and rainfall data to identify areas with a higher likelihood of experiencing slope failure. Eight factors that control mass movement were used in the modelling, these include: slope angle, altitude (elevation), aspect, topographic position index (TPI), landform, surficial geology, distance from tension cracks, and the height of vegetation. Climate variables such as spring freeze/thaw cycles, snowfall accumulation, and total spring precipitation and their influence on historical mass movement events identified in air photos would be great resources to use, but due to budget and time constraints, these variables were not included in this analysis. The factors have been transformed into raster data using GIS for use in the modelling environment. The slope angle and other terrain factors were extracted from the most recent (2022) LiDAR data DEM (0.2 m).

The eight factors that control mass movement were subdivided into the following zones or classes:

1. Slope angles were divided into six zones: 0˚ to 2˚, 2˚ to 5˚, 5˚ to 10˚, 10˚ to 20˚, 20˚ to 30˚, and greater than 30˚.
2. Altitude was classified into eight classes using 10 m elevation intervals between 628 m and 708 m above sea level.
3. Slope aspect was classified into eight cardinal directions (North, Northeast, East, Southeast, South, Southwest, West, Northwest) and flat; so, a total of nine classes were used.
4. Topographic Position Index (TPI) was calculated following Gessler et al. (1995) and were classified into three classes (less than -0.2, -0.2 to 0.2, and greater than 0.2).
5. Landform classification consisted of 10 classes: canyons/deep incised streams, mid-slope drainages/shallow valleys, upland drainages/headwaters, U-shaped valleys, small plains, open slopes, upper slopes, local ridges/hills in valleys, mid-slope ridges/small hills in plains, and mountain tops/high ridges.

6. Surficial geology layers from the previous studies were used where classes were based off a combination of dominant sediment types, geomorphology, and textures. There were 12 classes found and used. Where no data was available, an additional “unknown” class was used.

7. Tension cracks delineated during the terrain and slope instability hazard assessment were used with a combination of five length classes (0 to 50 m, 50 to 100 m, 100 to 200 m, 200 to 400 m and >400 m).

8. Vegetation height was determined from the Canopy Height Model (CHM) from the LiDAR data. Five classes were used for the vegetation height variable: less than 0.2 m, 0.2 to 2 m, 2 to 5 m, 5 to 20 m, and greater than 20 m.

2.3.2.1 Frequency Ratio Model

The frequency ratio model is a statistical method used to assess the susceptibility of slopes to landslides. It assumes that the frequency of landslides is related to the spatial distribution of conditioning and triggering factors. The model calculates the frequency ratio (FR) of landslides in relation to each factor, which represents the ratio of the number of landslides that occur in areas with a certain factor to the number of landslides that occur in areas without that factor. The FR values are then combined using a weighted sum to obtain an overall susceptibility score for each area. The slope stability classes evaluated from the landslide hazard rating (unstable) was used in absence of historical landslide data to provide this comparison.

The eight conditioning factors discussed above were considered in the frequency ratio. The FR model has been widely used in landslide susceptibility mapping studies in different regions and at various scales. It has been shown to be a reliable and effective method for identifying areas with high landslide susceptibility and can provide useful information for land use planning and disaster risk reduction.

There are several studies that have applied the FR model for landslide susceptibility mapping, for example, Althuwaynee et al. (2012), Ayalew et al. (2005), and Ohlmacher et al. (2003). The landslide parameters were processed as raster files at 0.2 m resolution. Following the methods discussed in the literature above, the final outputs have been presented in Figure 5, Frequency Ratio Slope Susceptibility Model.

2.3.2.2 Machine Learning Generalized Linear Model

Generalized Linear Models (GLMs) have been a useful machine learning (ML) method for predicting slope stability and widely used in various studies including Bui et al., 2018, Fabbrocini et al., 2016, Kim et al., 2017, Liu et al., 2019 and Park et al., 2019. The methodology adapted in this study follows the same principals. In slope stability analysis, the goal is to predict whether a slope will fail or remain stable under certain conditions. GLMs can be used to model the relationship between predictor variables (such as slope, distance to tension cracks, landform, etc.) and the response variable (slope stability). GLMs are a flexible and powerful tool for this type of prediction because they can accommodate a wide range of data distributions and can handle both continuous and categorical predictor variables. Additionally, GLMs allow for the incorporation of prior knowledge and can handle missing data. In this project all eight variables described above were used as predictor variables. R Studio with multiple ML packages like ‘caret’ and ‘randomForest’ was used. The number of points used for creating the model at 0.2 m interval was too heavy on processing and consisted of 4 million points, resampling was done down to 2 m resolution, reducing the total data processing points to approximately 1 million, allowing the models to run successfully.

The resulting model was then used to predict the probability of slope failure under specific conditions. The output from the GLM model for the parcel is presented in Figure 6.

2.4 Mapping of Terrain, Slope Instability Features, and Landslide Hazard Designation

Previous landslide hazard designation mapping by EBA (2002) was updated using all available information from the desktop evaluation, landslide susceptibility modelling, and GIS analysis. Field data collected during the 2022 landslide emergency response work was also used in the landslide hazard designation mapping.

Tetra Tech's methodology and scope of work for the terrain and slope instability and landslide hazard designation mapping update was as follows:

- Obtain and review available information for the Escarpment and the parcel site, including air photos, LiDAR data, historical geohazard maps, surficial geology mapping, and previous geotechnical reports;
- Map terrain and slope instability features using ArcGIS Pro software, which allows digital air photos to be viewed in 3D. Terrain geohazard features that are difficult to see at smaller scales using the standard stereoscope method and hard copy photographs are easy to identify and map using ArcGIS Pro's zooming feature;
- Map terrain features and geomorphic processes that are indicative of slope instability, including mass wasting and gully erosion features, groundwater seepage locations, and/or surface water drainage paths over the slopes;
- Identify and map natural and human-induced changes over time between the selected air photo date sets in the parcel area. The base mapping was founded on the 2002 air photos. Each iteration of the mapping updated the base map to account for changes noted in each year of imagery reviewed (2013, 2019, and 2022). These maps were used to assist in delineating geohazard designation boundaries and slope instability features and how those boundaries and features may have changed over time;
- LiDAR data available from the City or the Yukon LiDAR Collection was analyzed, including an ArcGIS-based change detection analysis between 2013 and 2022 to assist with landslide hazard feature mapping in ArcGIS Pro. Bare-earth hillshade models from LiDAR allow the ability to distinguish features that might otherwise be difficult to identify in areas that are vegetated; and
- Review and refine, if required, the landslide hazard designation zones delineated as low, moderate, or high. Each landslide hazard rating has a specified land use guideline (development planning guideline) which are abbreviated from the 2002 geohazard risk study and are presented in Table 2-1, and within the legend on Figures 1 to 4.

Table 2-1: Landslide Hazard Ratings and Land Use Guidelines

LANDSLIDE HAZARD RATING	LAND USE GUIDELINES
LOW HAZARD	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. Residential foundation walls facing the Escarpment should be designed to withstand a potential surcharge of 3'x130 pcf or 390 psf and the lower sill of windows are not recommended below 1 m above grade.
MODERATE HAZARD	Could be subject to direct or indirect impact from slide run-out, mudflow or silt fall. Building development is generally not recommended 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 and reinforced concrete basement walls.
HIGH HAZARD	Geohazards are judged too severe to permit any building development or major use, with the exception of limited recreational access trails, properly sited, engineered and constructed. Disturbance to the slope would not be allowed, either to the soil or vegetation.

*Abbreviated from Geohazard Risk Study, EBA, 2002 (Table 8.1).

3.0 SLOPE INSTABILITY FEATURE MAPPING RESULTS

The area upslope of the proposed development parcel hosts multiple, active mass movement processes in relic headscarps (Tetra Tech 2022). These erosional processes include seasonal freeze/thaw cycles, groundwater seepage, slumping and sloughing of saturated soil, gullying, debris flows, and mud slides. Materials transported from these processes form low gradient colluvial depositional fans (runout accumulations) that extend along the length of the Escarpment.

Much of the Escarpment is forested, with the exception of the historical landslide scars, recent active headscarps, and slide transport and deposition (runout) zones downslope. No monitoring stakes were installed upslope of the parcel area during the 2021 monitoring work since no significant, active mass movement was observed on the Escarpment in this area at that time (Tetra Tech 2022).

Erosion and mass movement on the Escarpment are directly related to infiltration of surface water on the airport plateau and surface and groundwater flow from other areas further upgradient. Vertical percolation through the sand blanket that caps the plateau becomes horizontal where it is restricted by the underlying contact with the relatively impermeable glaciolacustrine deposit, resulting in groundwater outflow from the base of the sand, located approximately 3 m to 5 m below the Escarpment crest (Tetra Tech 2016a).

The active mass movement and erosion mechanisms on the Escarpment including active debris flows, flow directions, and gullying are discussed in more detail in Tetra Tech's (formerly EBA) previous reports and are summarized in Table 3-1 below. The table is sourced from the 2002 report and has been updated to show active processes and mechanisms of slope movement and erosion observed specifically at the 5th and Rogers parcel between 2013 and 2022. Mechanisms are ordered from most to least common. The rates of erosion and shallow soil stability could increase during periods of high precipitation or rapid snow melt.

As discussed in detail in the 2002 report, there are no records of deep-seated failures on the Escarpment behind the present downtown area.

Table 3-1: Mechanisms of Slope Movement on the Whitehorse Escarpment (from EBA 2002)

Mechanism	Details	Active between 2013 and 2022 at the 5th and Rogers parcel
Seepage/Flow	Most active during seasonal thawing, snowmelt, and/or during storms with high levels of rain. The thawing of mostly saturated sediment at the confluence of a permeable substrate with a less permeable one contributes to the most active slope mechanism in the study area. The sand layer on the surface promotes downward percolation of precipitation and flows along the top of the underlying glaciolacustrine unit which, being less pervious than the top looser sand unit, becomes saturated and increases rate of lateral ground water flow.	Yes
Progressive deformation by seasonal thawing of saturated silt	Saturated glaciolacustrine soil can develop ice lenses during the winter months, and during thawing, these soils can collapse and generate a small mudflow that transports material downslope.	Yes
Gullying	Gullies are small, V-shaped ravines that form by erosion caused by water flow. They are a conduit for concentrated linear mass movement – Debris flows or slides. Can be fast flowing and hazardous.	Yes
Rilling erosion and shallow gullying	These occur due to run-off or seepage or water flowing down the slope, causing well-defined channelized erosion features extending downslope across the Escarpment face. If loose sediments exist within the path of the flowing water, sediment-laden water can develop into a mudflow. Developing features that require erosion control.	Yes
Debris slides and debris flows	Debris slides occur when a mass of colluvium becomes detached from a hillside and moves rapidly downslope by sliding along a shear plane. These slides may be triggered by heavy rain, water from snowmelt, and/or rain on snow events. 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.	Yes
Slow mass movement	Slow mass movement along the Escarpment have rates from very slow (centimetres per year) to extremely slow (millimetres per year).	Yes

A summary of results of the updated slope stability mapping at the parcel and key differences compared to the previous studies are discussed in the following sections.

3.1 Terrain Conditions and Slope Instability Features

Newly-mapped 2022 slope instability features, along with any changes between 2013 and 2019 were identified using historical air photos and LiDAR data records. The 5th and Rogers parcel can be separated into two areas divided by Rogers Street; the more active northern section towards Hawkins Street, and less active southern section towards Hoge Street. The recent 2022 landslide activity south of Hoge Street towards Jeckell Street is also referenced in this report.

3.1.1 Northern Section of 5th and Rogers Parcel (Hawkins Street to Rogers Street)

Much of the slope instability activity identified along the Escarpment occurs in the area between Hawkins and Rogers streets.

Backscarp regression of approximately 2.6 m (between 2013 to 2019) and 5.7 m (between 2019 to 2022) was identified through historical LiDAR and air photo analysis, approximately halfway upslope at the northwestern edge of the parcel, above the former east airport access road (EAAR), which is currently used as a recreational walking path (Figures 1 and 2).

Numerous small (<10 m^3) earth flows occurred across the exposed area, and slumping was observed in some locations on the downslope side of the trail. A run-off interceptor ditch is located upslope of the EAAR, directing flow down to the dog park located at the west end of Main Street.

This analysis also determined that the Escarpment toe at this location has transitioned eastwards by up to approximately 50 m since 2019. Although the area is still vegetated, given the nature of the process and texture of the material, the fan is accumulating material by continual seepage from upslope backscarp faces. Significant flow of sediment-laden water is visible flowing down the slope and into the west side of the subject site during the spring. Significant precipitation events may have the potential to increase the volume of material and possibly cause damage to property.

3.1.2 Southern Section of 5th and Rogers Parcel (Rogers Street to Hoge Street)

Historical comparative analysis of the LiDAR data (from 2013 to 2022) does not show significant changes to the toe of the Escarpment at the middle or southern sections of the parcel between Rogers Street and Hoge Street. Although there has been some slow mass movement occurring at these locations between 2013 and 2022, there was no detectable change to the existing backscarps, landslide scars, or the crest of the Escarpment directly upslope of this southern section of the 5th and Rogers parcel (Figures 1 to 4). Most of this section of the slope is vegetated, which suggests it being stable.

3.1.3 South of the 5th and Rogers Parcel (Hoge Street to Jeckell Street)

A large landslide (referred to as the "Jeckell Street slide" or "Cliffside slide"), which initiated from the tension cracks observed behind Cliffside Park a year earlier, occurred to the south of the parcel on May 28, 2022. The runout zone of this landslide encroached on most of Cliffside Park, and almost extended across to the opposite side of 6th avenue, approximately 45 m from the toe of the Escarpment. The accumulation of water and saturated sediment behind a silt fence at the toe of the slope added to the runout distance at this location (Figures 1 to 4). The runout material extended approximately halfway into the moderate hazard zone, which is consistent with the expected material movement within the moderate hazard zone and associated land use guidelines prepared for the 2002 report. This landslide was anticipated by Tetra Tech, the pre-failure tension crack was identified and monitored during the 2021 slope inspection work (Tetra Tech 2022). The slide was captured by a trail camera set up by the Yukon Geological Survey (https://fb.watch/diMqWC2h3K/).

The thickness of material loss from the 2022 Cliffside slide averaged approximately 2.5 m and was up to 7.1 m, given the size of the area (approximately 1,750 m^2) this loss represents a volume of approximately 4,400 m^3. A tension crack developed into a headscarp (identified as Headscarp 6 in the 2021 report) on June 18, 2021, upslope of the St. Elias adult group home between Jeckell and Hoge Streets, to the south of the parcel. Although it was difficult to make valid determinations of the headscarp movements using previously installed instrumentation, it did not appear to show significant detectable movement based on observations during the Spring 2022 emergency inspections. This headscarp is located upslope of the landslide interception berm constructed west of the St. Elias adult group home near the foot of Hoge Street and is south of the 5th and Rogers parcel. The berm is a segment of a proposed continuous berm that was recommended in a previous Slope Stability Study (Tetra Tech EBA 2012) and adopted by the City for development in the south downtown area of Whitehorse.

3.2 Elevation Change Detection Analysis Results

The results of the elevation change detection analysis between the 2013 and 2019, and 2019 and 2022 LiDAR-derived DEMs are illustrated in Figures 3 and 4, respectively. Regions of yellow to red represent apparent subsidence and are indicative of slumping/ erosion or backscarp face regression. Areas of green to blue indicate apparent accumulation of the surficial material. Some anomalous results of the elevation change detection analysis can be attributed to misclassification or slightly different classification of LiDAR data results by third parties. The elevation change detection analysis generally corresponds with the expected mass movement activities and helped refine and confirm the mapped instability features and how they have been altered. Elevation changes due to cut (red) and fill (blue) of the ground for the construction of the St. Elias adult group home and fill placement (blue) for the interception berm west of the home were detected by the analysis and are clearly visible on Figure 3.

In general, much of the Escarpment slope above the 5th and Rogers parcel has not experienced much elevation change between 2013 and 2022. Most of the material movement is seen at the headscarp located at the top of the Escarpment immediately west of the area between Rogers and Lowe Streets. The average thickness of material loss from the headscarp erosion is approximately 0.93 m between 2013 and 2019 and 0.68 m between 2019 and 2022. Given the size of the area (approximately 900 m^2) this loss represents volumes of 840 m^3 and 610 m^3, respectively. The material flows down the gully and drainage paths and accumulates at the toe of the Escarpment. Accumulation of material averaging 0.5 m in thickness was identified at this location. Saturated ground surface conditions are evident at the Escarpment toe in this location throughout the spring and summer months.

3.3 Landslide Susceptibility Modelling Results

The model outputs are presented on Figures 5 and 6. The FR and GLM model outputs are consistent with the geohazard assessments done with other methods. Among the two methods the FR method is more of a statistical method and since the processing can be done directly using raster analysis, a 0.2 m raster resolution is kept. The GLM method required a model to be created using individual data points and it was necessary to reduce the model resolution to 2 m; the outputs appear relatively coarse; the results should not be affected by this processing alteration.

The cutoff thresholds for the index values are relative and have been determined based off the visual inspection of the model outputs. These threshold values will differ from site to site or project to project, but a single value has been used across the entire escarpment for consistency.

The landslide susceptibility model looks at the areas that are susceptible to slide but does not consider potential impacts to downslope areas. The geohazard study done with hazard designation zones identified provides a more realistic picture of the areas that are likely to be affected by a landslide.

The models are dynamic in nature. For example, if a new tension crack is found on the slope, it can be added to the model and updated outputs can be produced. Similarly, if any alteration to the slope is performed, the alteration can be modeled and the outputs from both models can be updated. One important item that should be kept in mind is that like with any other model, the model is as good as the input data. Eight different variables are used as input to both the susceptibility models. These do not include any climate variables or historical landslide data. The training dataset provided is the geohazard assessment conducted for this study. This is something that can be taken up as a part of larger study to expand the model to include other variables including climate change. Such a study requires more time to collect and process the data and is beyond the scope of this project.

In general, most of the Escarpment slope above the 5th and Rogers parcel is within the low and moderate slope susceptibility hazard model indices using both FR and GLM outputs. The slopes at the northern (north of Rogers Street) and southern (south of Lowe Street) extents of the parcel area show high susceptibility, corresponding to terrain conditions and slope instability feature mapping described in section 3.1. High susceptibility hazard was modeled at the sand/silt interface, approximately three quarters of the way up the Escarpment, extending downwards to approximately the middle of the Escarpment, and is generally focused within historic headscarps.

3.4 Updated Geohazard Assessment

As with Tetra Tech's 2012 study, this historical air photo and LiDAR interpretation study coupled with elevation change detection analysis have determined that no changes are warranted to the 2002 Landslide Hazard zones at the 5th and Rogers parcel. The Escarpment slopes continue to show expected active thaw-flow slides and erosion and mass movement are ongoing at a manageable and predictable rate that reflects the landslide hazard zone and land use guidelines developed by EBA in 2002.

The parcel at 5th and Rogers is located mostly within the Low Hazard Zone (50% of parcel area) and Moderate Hazard Zone (46% of parcel area), with the exception of the northwestern corner that is at the boundary of the High Hazard Zone (4% of parcel area).

4.0 POTENTIAL SINKHOLE ACTIVITY

YG has advised that a potential sinkhole is present at the site. Tetra Tech completed a site visit on March 2, 2023 to observe the potential sinkhole and review its origin. The hole is located in a stand of trees, approximately in the centre of the parcel. The hole was mostly obscured by snow at the time of the site visit and was surrounded by fencing, as shown in the photos below.

Sinkholes form when subsurface voids collapse to create an open depression at the ground surface. Naturally occurring sinkholes are common in karst terrain areas that are underlain by soluble, carbonate rocks (e.g., limestone); voids form as the rocks are dissolved by groundwater and eventually collapse to form sinkholes. This type of process is not believed to be occurring at the subject site, since the bedrock beneath the site is understood to be granitic and not susceptible to karst processes. In urban environments and previously developed sites, such as the subject site, the most likely cause of sinkhole formation is the collapse of voids related to uncontrolled fill (e.g., loose fill with construction debris and large voids) or possibly abandoned underground utilities (e.g., old sewer lines).


Photo 1 (left): Potential sinkhole area in stand of trees near centre of the parcel, surrounded by fencing.
Photo 2 (right): Potential sinkhole mostly obscured by snow during the site visit on March 2, 2023.

The sinkhole should be checked in snow-free conditions to confirm its depth, which is likely no deeper than the maximum depth of ground disturbance from previous site developments.

New development at the subject site should include a geotechnical site investigation to determine the depth of potentially unstable soil, and site preparation procedures should be implemented to eliminate the risk of uncontrolled soil subsidence. Site preparation procedures generally consist of excavation to remove uncontrolled fill, old foundations, abandoned underground utilities, and other potentially deleterious materials. These should be replaced with fill that is placed in lifts and compacted to suit site development requirements.

5.0 RECOMMENDATIONS

Based on the findings of the updated site-specific slope hazard assessment described above, Tetra Tech considers that the recommendations given in the 2016 terrain stability assessment (Tetra Tech 2016a) remain valid and should be adhered to for development of the parcel at 5th and Rogers.

Key recommendations from the 2016 report include the following:

- An interceptor berm should be constructed along the lower slopes of the Escarpment, to reduce the potential for mass movements impacting the subject site and to control sediment-laden runoff from the slope. The interceptor berm should be tied into the existing berm to the south, behind the St. Elias group home.
- Foundations and/or basement walls on the Escarpment side of buildings should be designed to withstand loading from sediment accumulation. Basements are not recommended, but if basements are to be considered there should be no basement windows on the Escarpment side of the building, and any windows on the north or south sides of the building should be at least 0.75 m above surrounding finished grade.
- One or more collection/settling reservoirs should be constructed on the upslope side of the berm, to manage the considerable volume of sediment-laden runoff from the slope. Periodic cleanout of the reservoir(s) will be required as they become filled with sediment.
- Water exiting the collection/settling reservoirs must be discharged to a suitable receiving environment. Municipal storm sewer may be the most convenient option for disposal of water from the site, subject to obtaining permission from the City.

As noted above, Tetra Tech's recommendations given in 2016 with respect to the slope hazard assessment for the site remain valid. However, recommendations given in the 2016 site evaluation report (Tetra Tech 2016b) should be considered to be preliminary, and subject to confirmation and/or revision based on the specific details of the proposed developments at the site. For example, site preparation, foundation design, and seismic considerations discussed in the report will need to be reviewed and updated as necessary to suit the details of the proposed site developments, current code requirements, and/or other requirements as appropriate. The drawings showing a potential interceptor berm design are not for construction. It is expected that the design of the interceptor berm and collection/settling reservoir will require coordination and approval from the City, particularly with respect to the tie-in with the existing berm at the St. Elias group home and acceptable methods of disposal for water exiting the collection/settling reservoir.

6.0 LIMITATIONS OF REPORT

This report and its contents are intended for the sole use of the Government of Yukon and their agents. Tetra Tech Canada Inc. (operating as Tetra Tech) does not accept any responsibility for the accuracy of any of the data, the analysis, or the recommendations contained or referenced in the report when the report is used or relied upon by any Party other than the Government of Yukon, or for any Project other than the proposed development at the subject site. Any such unauthorized use of this report is at the sole risk of the user. Use of this document is subject to the Limitations on the Use of this Document attached in the Appendix or Contractual Terms and Conditions executed by both parties.

7.0 CLOSURE

We trust this document meets your present requirements. If you have any questions or comments, please contact the undersigned.

Respectfully submitted,
Tetra Tech Canada Inc.

REGISTERED PROFESSIONAL GEOSCIENTIST
E. PALCZEWSKI
LICENSEE
NT/NU
2023-04-20
FILE: 704-ENG.WARC04345-01
FILE: 704-ENG.WARC04345-01
FILE: 704-ENG.WARC04345-01

Prepared by:
Ernest Palczewski, B.Sc., P.Geo.
Geologist – Arctic Group
Direct Line: 587.460.3595
Ernest.Palczewski@tetratech.com

PROFESSIONAL ENGINEER
YUKON
ADAM W. WALLACE
TERRITORY
April 21, 2023
FILE: 704-ENG.WARC04345-01
FILE: 704-ENG.WARC04345-01
FILE: 704-ENG.WARC04345-01

Reviewed by:
Adam Wallace, M.Eng., P.Eng.
Geotechnical Engineer, Arctic Group
Direct Line: 867.668.9218
Adam.Wallace@tetratech.com

REGISTERED PROFESSIONAL GEOLOGIST
V. ROUJANSKI
LICENSEE
NWT/NU
2023-04-20
FILE: 704-ENG.WARC04345-01
FILE: 704-ENG.WARC04345-01
FILE: 704-ENG.WARC04345-01

Reviewed by:
Vladislav Roujanski, Ph.D., P.Geol.
Principal Specialist, Senior Geologist, Arctic Region
Direct Line: 587.460.3610
Vladislav.Roujanski@tetratech.com

PERMIT TO PRACTICE
TETRA TECH CANADA INC.
SIGNATURE
Date April 21, 2023
PERMIT NUMBER PP003
Association of Professional Engineers of Yukon

/cr

REFRENCES

Althuwaynee OF, Pradhan B, Park HJ. Landslide susceptibility mapping using frequency ratio, logistic regression, artificial neural network and their comparison: a case study from Malaysia. Environmental Earth Sciences. 2012;66(6):1743-1762. doi:10.1007/s12665-011-1418-2.

Ayalew L, Yamagishi H. The application of GIS-based logistic regression for landslide susceptibility mapping in the Kakuda-Yahiko Mountains, Central Japan. Geomorphology. 2005;65(1-2):15-31. Doi:10.1016/j.geomorph. 2004.06.010.

Bui DT, Tuan TA, Klempe H, et al. (2018) Landslide susceptibility assessment in the Hoa Binh province of Vietnam using machine learning algorithms. Catena 161: 68–80. DOI: 10.1016/j.catena.2017.09.004.

EBA, A Tetra Tech Company, 2012. *Downtown South Terrain Stability Assessments*. Report prepared for the City of Whitehorse, Engineering and Environment, April 2012. EBA file number W14101647.

EBA Engineering Consultants Ltd., 2002. *Geohazard Risk Study, Whitehorse Escarpment*. Report prepared for the City of Whitehorse, October 2002. EBA file no. 0201-01-1200002.

Elmer Brooker & Associates Ltd. (EBA), 1971. Soil and Foundation Investigation of Whitehorse Escarpment. Canada Department of Transport.

Fabbrocini A, Picarelli L, Santangelo M, et al. (2016) A comparison between logistic regression and artificial neural networks in landslide susceptibility mapping using GIS. Computers & Geosciences 95: 86-104. DOI: 10.1016/j.cageo.2016.07.001.

Gessler, P. E., Moore, I. D., McKenzie, N. J., & Ryan, P. J. (1995). Soil-landscape modelling and spatial prediction of soil attributes. International Journal of Geographical Information Systems, 9(4), 421-432.

Kim S, Oh HJ, Lee S (2017) Landslide susceptibility mapping using a Bayesian network and generalized linear models. Geomatics, Natural Hazards and Risk 8(1): 813-830. DOI: 10.1080/19475705.2017.1323562.

Liu K, Wang T, Wu F, et al. (2019) Landslide susceptibility assessment using a combination of generalized linear model and logistic regression models in Lishui City, China. Geocarto International 34(1): 1-19. DOI: 10.1080/10106049.2017.1396244.

Ohlmacher GC, Davis JC. Using multiple logistic regression and GIS technology to predict landslide hazard in northeast Kansas, USA. Engineering Geology. 2003;69(3-4):331-343. doi:10.1016/s0013-7952(03)00020-6.

Park S, Choi J, Kim J (2019) Comparison of generalized linear model and random forest for landslide susceptibility mapping in Korea. Geomatics, Natural Hazards and Risk 10(1): 1146-1162. DOI: 10.1080/19475705.2019.1647602.

Tetra Tech EBA Inc., 2014. *Terrain Stability Assessment, St. Elias Adult Group Home, Whitehorse, YT*. Letter report prepared for the Government of Yukon, October 15, 2014. Tetra Tech file no. W14103422-01.

Tetra Tech Canada Inc., 2016a. *Terrain Stability Assessment Block 338, 103191 CLSR YT, Rogers Street to Hoge Street, Whitehorse, YT*. Prepared for the Government of Yukon. Submitted Issued for Use May 30, 2016. Tetra Tech file number ENG.WARC03041-01.

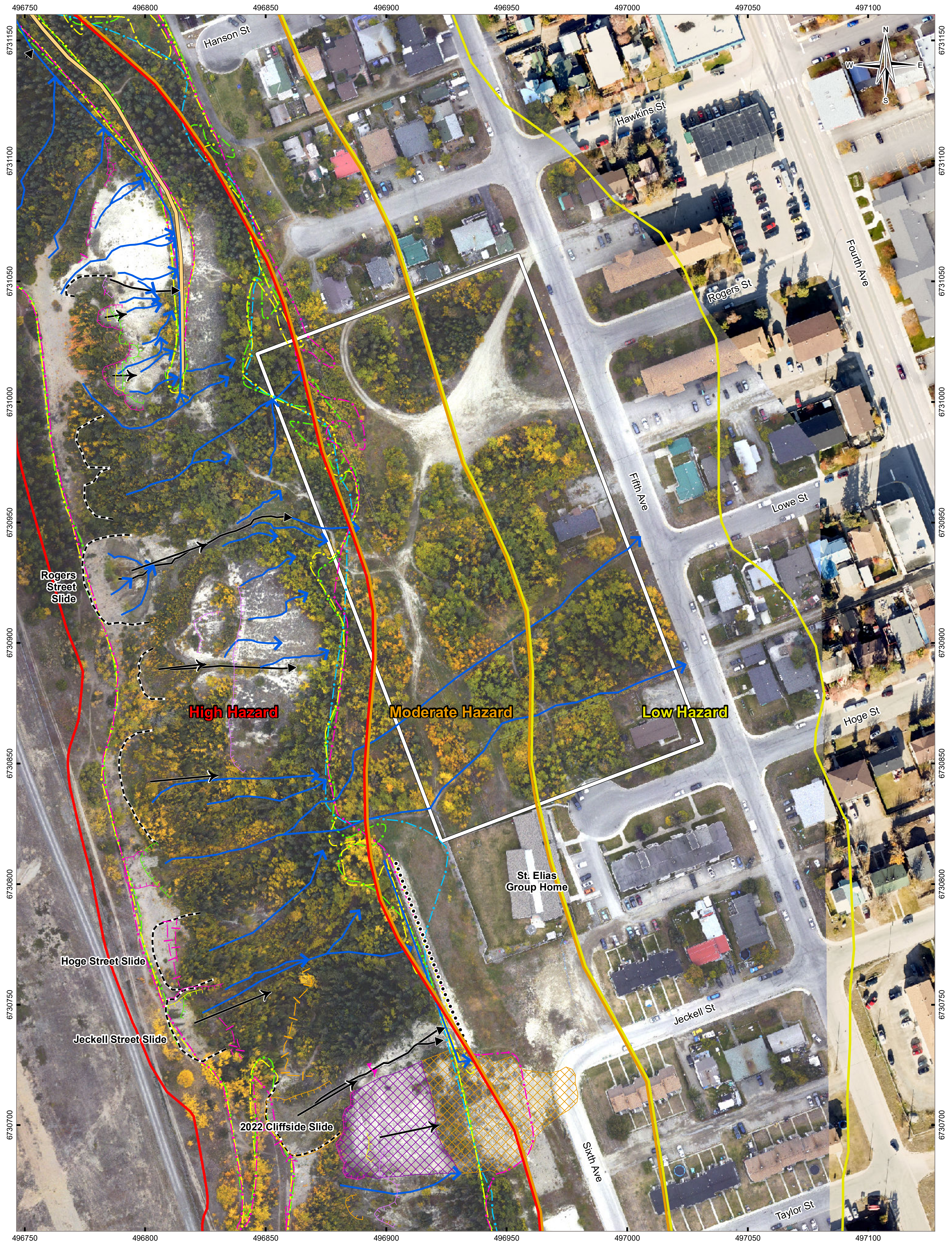
Tetra Tech Canada Inc., 2016b. *Desktop Geotechnical Evaluation, Slope Assessment, and Detailed Berm Design Block 338, Fifth and Rogers Street Property*. Prepared for the Government of Yukon, issued for Use May 30, 2016. Tetra Tech file number ENG.WARC03041-01

Tetra Tech Canada Inc., 2021. *Whitehorse Escarpment Seasonal Slope Assessment*. Letter report prepared for the City of Whitehorse, issued for use on April 21, 2021, Tetra Tech file no. 704-ENG.WARC03976-01.

Tetra Tech Canada Inc. 2022. *2021 Slope Stability Monitoring, Whitehorse Escarpment – Whitehorse, Yukon*. Tetra Tech file number ENG.WARC03976-02.

FIGURES

Q:\Edmonton\GIS\ENGINEERING\WARC\WARC04345-01\Maps\WARC04345-01_Figure01_HazardsImagery.mxd modified 2023-03-31 by megan.burns



LEGEND

Proposed Site Area
Existing Berm
Gully
Seepage
Toe/Crest of Slope

Mass Movement Features

Debris Flow Headscarp
Landslide Scar - Active
Headscarp - Historical
Tension Crack
Landslide (Purple is Initiation/Transition Zone and Orange is Runout Zone)

Year Feature Observed

2022
2021
2019
2016
2013
Pre 2013
Not Dated

Flow Direction
East Airport Access Road

Landslide Hazard Rating

High
Moderate
Low

NOTES
Base data source: 2022 LiDAR and orthoimagery collected by Pioneer Exploration Consultants Ltd. 2019 LiDAR and imagery from GeoYukon

STATUS
ISSUED FOR USE

**UPDATED GEOHAZARD STUDY
5TH AVENUE AND ROGERS STREET
WHITEHORSE, YUKON**

**2022 Imagery
Slope Instability Feature Interpretation
and Landslide Hazard Designation**

PROJECTION	DATUM	CLIENT
UTM Zone 8	NAD83	Yukon

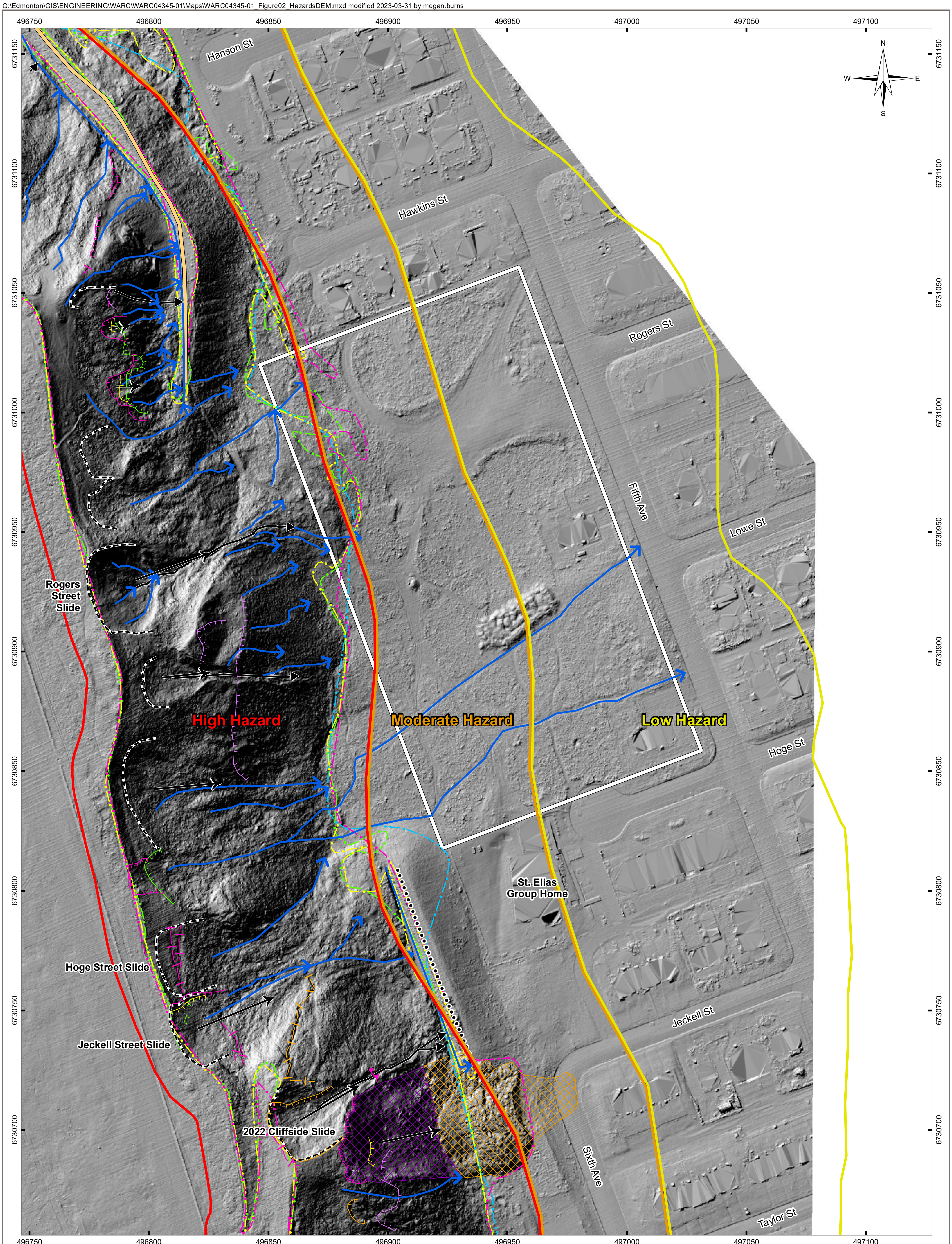
Scale: 1:1,500
20 10 0 20
Metres

TETRA TECH

FILE NO.				
WARC04345-01_Figure01_HazardsImagery.mxd				
OFFICE	DWN	CKD	APVD	REV
Tt-EDM	MRB	SL	EP	0
DATE	PROJECT NO.			
March 31, 2023	ENG.WARC04345-01			

Figure 1

Q:\Edmonton\GIS\ENGINEERING\WARC\WARC04345-01\Maps\WARC04345-01_Figure02_HazardsDEM.mxd modified 2023-03-31 by megan.burns



LEGEND

Proposed Site Area
Existing Berm
Gully
Seepage
Toe/Crest of Slope

Mass Movement Features

Debris Flow Headscarp
Landslide Scar - Active
Headscarp - Historical
Tension Crack
Landslide (Purple is Initiation/Transition Zone and Orange is Runout Zone)

Year Feature Observed

2022
2021
2019
2016
2013
Pre 2013
Not Dated

Flow Direction
East Airport Access Road

Landslide Hazard Rating

High
Moderate
Low

NOTES
Base data source: 2022 LiDAR and orthoimagery collected by Pioneer Exploration Consultants Ltd. Digital elevation models by Tetra Tech Canada

STATUS
ISSUED FOR USE

UPDATED GEOHAZARD STUDY 5TH AVENUE AND ROGERS STREET WHITEHORSE, YUKON

2022 Bare Earth Shaded Relief Digital Elevation Model Slope Instability Feature Interpretation and Landslide Hazard Designation

PROJECTION	DATUM	CLIENT
UTM Zone 8	NAD83	Yukon

Scale: 1:1,500
20 10 0 20
Metres

TETRA TECH

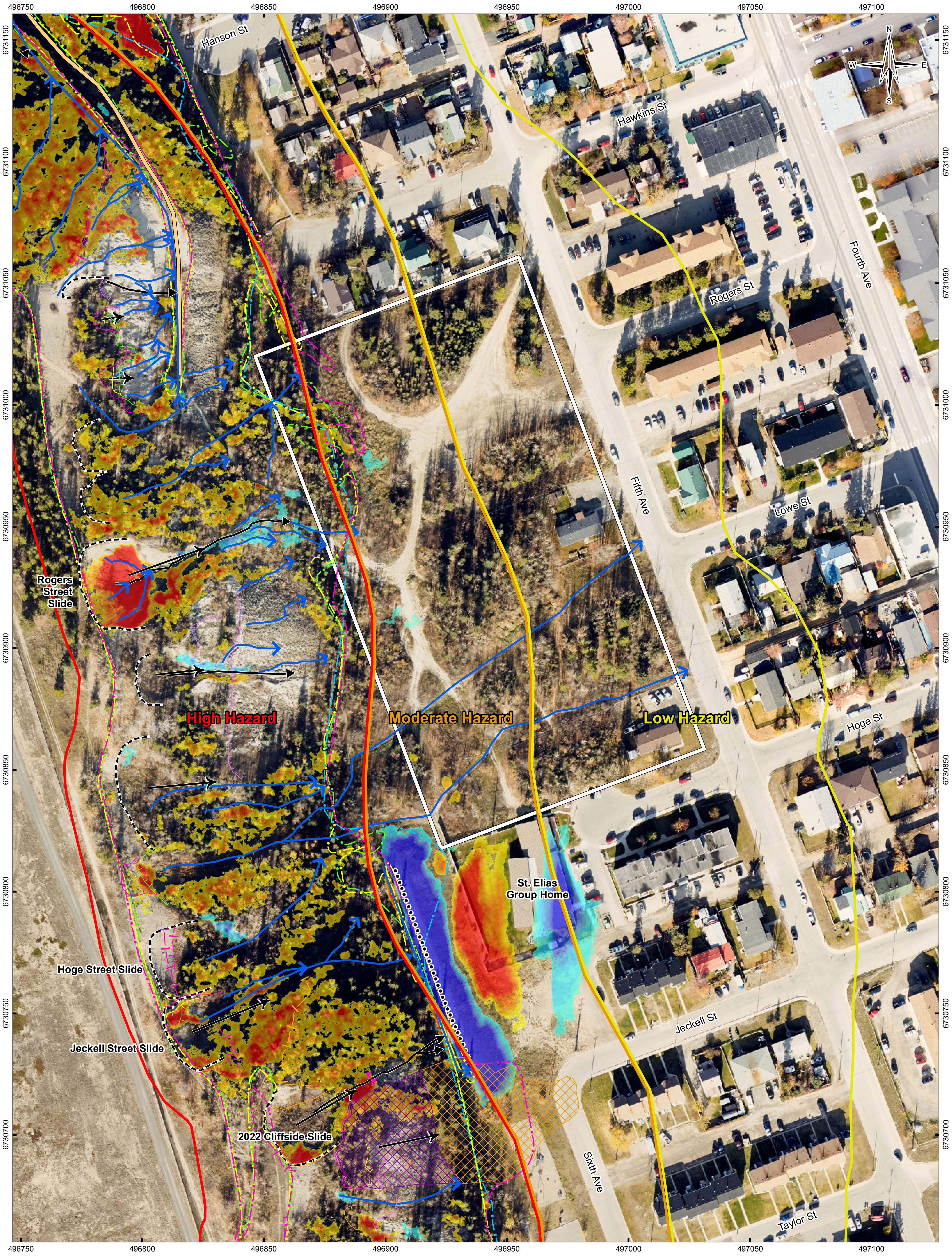
FILE NO.
WARC04345-01_Figure02_HazardsDEM.mxd

OFFICE	DWN	CKD	APVD	REV
Tt-EDM	MRB	SL	EP	0

DATE	PROJECT NO.
March 31, 2023	ENG.WARC04345-01

Figure 2

Q:\Edmonton\GIS\ENGINEERING\WARC\WARC04345-01\Maps\WARC04345-01_Figure03_HazardsChgDet.mxd modified 2023-03-31 by megan.burns



LEGEND

- Proposed Site Area
- Existing Berm
- Gully
- Seepage
- Toe/Crest of Slope

Mass Movement Features

- Debris Flow Headscarp
- Landslide Scarp - Active
- Headscarp - Historical
- Tension Crack
- Landslide (Purple is Initiation/Transition Zone and Orange is Runout Zone)

Year Feature Observed

- 2022
- 2021
- 2019
- 2016
- 2013
- Pre 2013
- Not Dated

- Flow Direction
- East Airport Access Road

Landslide Hazard Rating

- High
- Moderate
- Low

2013 to 2019 Surface Elevation Change (m)

> 1

< -1

NOTES

Base data source: 2013 and 2019 LiDAR and imagery from GeoYukon
Digital elevation models by Tetra Tech Canada

STATUS
ISSUED FOR USE

UPDATED GEOHAZARD STUDY 5TH AVENUE AND ROGERS STREET WHITEHORSE, YUKON

2019 Imagery 2013-2019 Surface Elevation Change Detection Analysis

PROJECTION	DATUM	CLIENT
UTM Zone 8	NAD83	Yukon

Scale: 1:1,500
20 10 0 20
Metres

FILE NO.
WARC04345-01_Figure03_HazardsChgDet.mxd

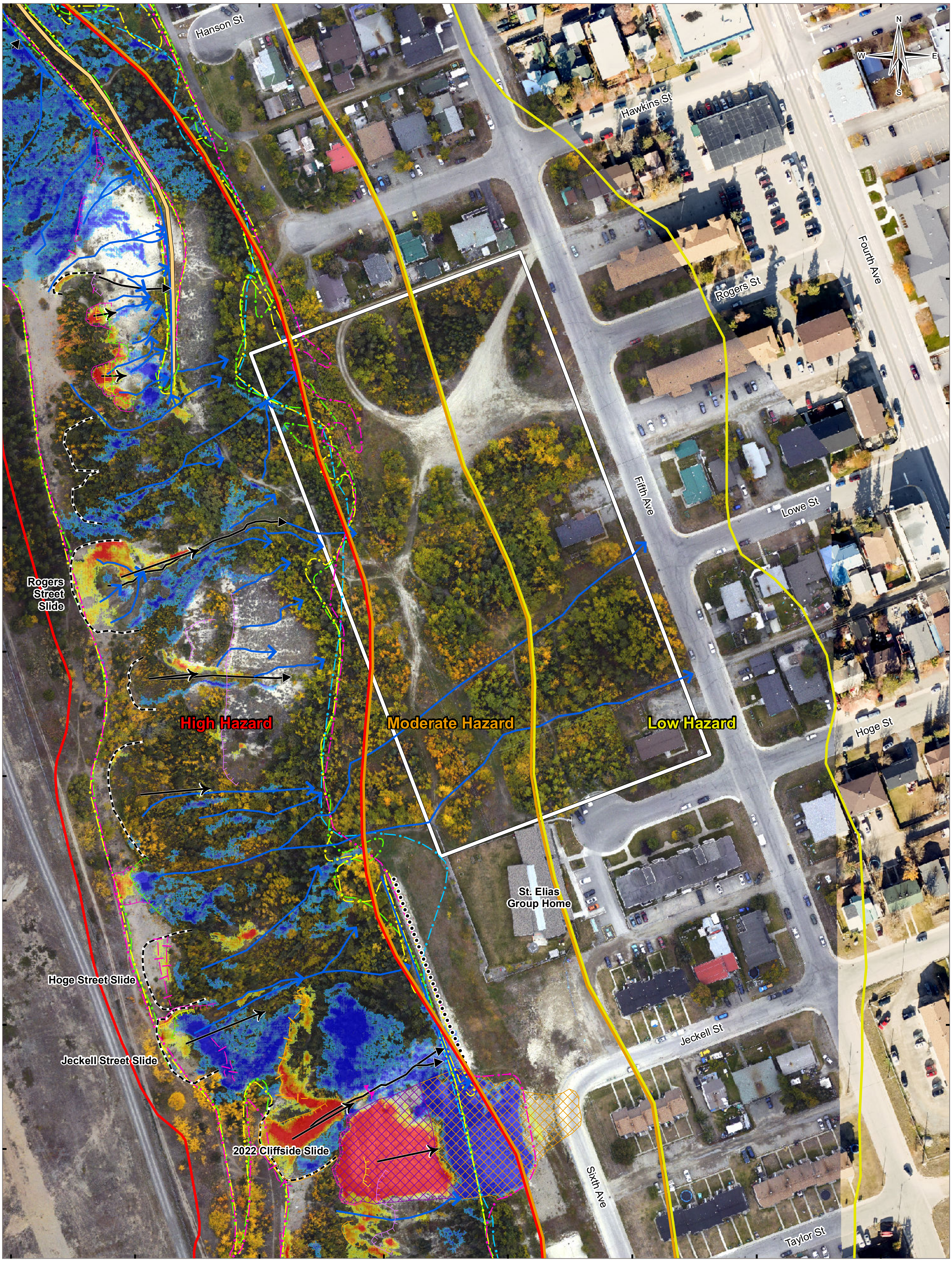
TETRA TECH

OFFICE	DWN	CKD	APVD	REV
Tt-EDM	MRB	SL	EP	0

DATE	PROJECT NO.
March 31, 2023	ENG.WARC04345-01

Figure 3

Q:\Edmonton\GIS\ENGINEERING\WARC\WARC04345-01\Maps\WARC04345-01_Figure04_HazardsChgDet.mxd modified 2023-03-31 by megan.burns



LEGEND

- Proposed Site Area
- Existing Berm
- Gully
- Seepage
- Toe/Crest of Slope

Mass Movement Features

- Debris Flow Headscarp
- Landslide Scar - Active
- Headscarp - Historical
- Tension Crack
- Landslide (Purple is Initiation/Transition Zone and Orange is Runout Zone)

Year Feature Observed

- 2022
- 2021
- 2019
- 2016
- 2013
- Pre 2013
- Not Dated

- Flow Direction
- East Airport Access Road

Landslide Hazard Rating

- High
- Moderate
- Low

2019 to 2022 Surface Elevation Change (m)

> 1

< -1

NOTES

Base data source: 2022 LiDAR and orthoimagery collected by Pioneer Exploration Consultants Ltd. 2019 LiDAR and imagery from GeoYukon Digital elevation models by Tetra Tech Canada

STATUS
ISSUED FOR USE

UPDATED GEOHAZARD STUDY 5TH AVENUE AND ROGERS STREET WHITEHORSE, YUKON

2022 Imagery 2019-2022 Surface Elevation Change Detection Analysis

PROJECTION	DATUM	CLIENT
UTM Zone 8	NAD83	Yukon

Scale: 1:1,500

20 10 0 20

Metres

TETRA TECH

FILE NO.
WARC04345-01_Figure04_HazardsChgDet.mxd

OFFICE	DWN	CKD	APVD	REV
Tt-EDM	MRB	SL	EP	0

DATE	PROJECT NO.
March 31, 2023	ENG.WARC04345-01

Figure 4

Q:\Edmonton\GIS\ENGINEERING\WARC\WARC04345-01\Maps\WARC04345-01_Figure05_FR_Model.mxd modified 4/3/2023 by javed.iqbal

LEGEND

- Proposed Site Area
- Existing Berm
- Gully
- Seepage
- Toe/Crest of Slope

Mass Movement Features

- Debris Flow Headscarp
- Landslide Scar - Active
- Headscarp - Historical
- Tension Crack
- Landslide (Purple is Initiation/Transition Zone and Orange is Runout Zone)

Year Feature Observed

- 2022
- 2021
- 2019
- 2016
- 2013
- Pre 2013
- Not Dated

- Flow Direction
- East Airport Access Road

Landslide Hazard Rating

- High
- Moderate
- Low

Frequency Ratio Slope Susceptibility Model

Hazard Index

- No (< 300)
- Low (300 - 400)
- Moderate (400 - 450)
- High (>450)

STATUS
ISSUED FOR USE

NOTES
Base data source: 2022 LiDAR and orthoimagery collected by Pioneer Exploration Consultants Ltd.
2019 LiDAR and imagery from GeoYukon
Digital elevation models by Tetra Tech Canada

UPDATED GEOHAZARD STUDY
5TH AVENUE AND ROGERS STREET
WHITEHORSE, YUKON

Frequency Ratio Slope Susceptibility Model

PROJECTION	DATUM	CLIENT
UTM Zone 8	NAD83	Yukon

Scale: 1:1,500
20 10 0 20
Metres

FILE NO.
WARC04345-01_Figure05_FR_Model.mxd

TETRA TECH

OFFICE	DWN	CKD	APVD	REV
Tt-EDM	JI	SL	EP	0

DATE	PROJECT NO.
April 3, 2023	ENG.WARC04345-01

Figure 5

Q:\Edmonton\GIS\ENGINEERING\WARC\WARC04345-01\Maps\WARC04345-01_Figure06_ML_GLM.mxd modified 4/3/2023 by javed.iqbal

LEGEND

- Proposed Site Area
- Existing Berm
- Gully
- Seepage
- Toe/Crest of Slope

Mass Movement Features

- Debris Flow Headscarp
- Landslide Scar - Active
- Headscarp - Historical
- Tension Crack
- Landslide (Purple is Initiation/Transition Zone and Orange is Runout Zone)

Year Feature Observed

- 2022
- 2021
- 2019
- 2016
- 2013
- Pre 2013
- Not Dated

- Flow Direction
- East Airport Access Road

Landslide Hazard Rating

- High
- Moderate
- Low

Machine Learning Model Hazard Index

- High (<2)
- Moderate (2 - 2.5)
- Low (> 2.5)

NOTES

Base data source: 2022 LiDAR and orthoimagery collected by Pioneer Exploration Consultants Ltd.
2019 LiDAR and imagery from GeoYukon
Digital elevation models by Tetra Tech Canada

STATUS
ISSUED FOR USE

UPDATED GEOHAZARD STUDY
5TH AVENUE AND ROGERS STREET
WHITEHORSE, YUKON

Machine Learning (GLM) Susceptibility Model

PROJECTION	DATUM	CLIENT
UTM Zone 8	NAD83	Yukon

Scale: 1:1,500

20 10 0 20

Metres

FILE NO.
WARC04345-01_Figure06_ML_GLM.mxd

TETRA TECH

OFFICE	DWN	CKD	APVD	REV
Tt-EDM	MRB	SL	EP	0

DATE	PROJECT NO.
April 3, 2023	ENG.WARC04345-01

Figure 6

APPENDIX A

TETRA TECH'S LIMITATIONS ON THE USE OF THIS DOCUMENT

LIMITATIONS ON USE OF THIS DOCUMENT

GEOTECHNICAL – YUKON GOVERNMENT

1.1 USE OF DOCUMENT AND OWNERSHIP

This document pertains to a specific site, a specific development, and a specific scope of work. The document may include plans, drawings, profiles and other supporting documents that collectively constitute the document (the "Professional Document").

The Professional Document is intended for the use of TETRA TECH's Client, its officers, employees, agents, representatives, successors and assigns (the "Client") as specifically identified in the TETRA TECH Services Agreement or other Contractual Agreement entered into with the Client (either of which is termed the "Contract" herein). TETRA TECH does not accept any responsibility for the accuracy of any of the data, analyses, recommendations or other contents of the Professional Document when it is used or relied upon by any party other than the Client, unless authorized in writing by TETRA TECH. Any changes to the conclusions, opinions, and recommendations presented in TETRA TECH's Professional Document must be authorized by TETRA TECH.

1.2 ALTERNATIVE DOCUMENT FORMAT

Where TETRA TECH submits electronic file and/or hard copy versions of the Professional Document or any drawings or other project-related documents and deliverables (collectively termed TETRA TECH's "Instruments of Professional Service"), only the signed and/or sealed versions shall be considered final. The original signed and/or sealed electronic file and/or hard copy version archived by TETRA TECH shall be deemed to be the original. TETRA TECH will archive a protected digital copy of the original signed and/or sealed version for a period of 10 years.

Electronic files submitted by TETRA TECH have been prepared and submitted using specific software and hardware systems, as per agreed project deliverable formats. TETRA TECH makes no representation about the compatibility of these files with the Client's future software and hardware systems.

1.3 STANDARD OF CARE

Services performed by TETRA TECH for the Professional Document have been conducted in accordance with the Contract, in a manner consistent with the level of skill ordinarily exercised by members of the profession currently practicing under similar conditions in the jurisdiction in which the services are provided. Professional judgment has been applied in developing the conclusions and/or recommendations provided in this Professional Document.

If any error or omission is detected by the Client or an Authorized Party, the error or omission must be brought to the attention of TETRA TECH within a reasonable time.

1.4 DISCLOSURE OF INFORMATION BY CLIENT

The Client acknowledges that it has fully cooperated with TETRA TECH with respect to the provision of all available information on the past, present, and proposed conditions on the site, including historical information respecting the use of the site.

1.5 INFORMATION PROVIDED TO TETRA TECH BY OTHERS

During the performance of the work and the preparation of this Professional Document, TETRA TECH may have relied on information provided by third parties other than the Client.

While TETRA TECH endeavours to verify the accuracy of such information, and subject to the standard of care herein, TETRA TECH accepts no responsibility for the accuracy or the reliability of such information even where inaccurate or unreliable information impacts any recommendations, design or other deliverables and causes the Client or an Authorized Party loss or damage, except where TETRA TECH has subcontracted for such information.

1.6 GENERAL LIMITATIONS OF DOCUMENT

This Professional Document is based solely on the conditions presented and the data available to TETRA TECH at the time the data were collected in the field or gathered from available databases.

The Client, and any Authorized Party, acknowledges that the Professional Document is based on limited data and that the conclusions, opinions, and recommendations contained in the Professional Document are the result of the application of professional judgment to such limited data.

The Professional Document is not applicable to any other sites, nor should it be relied upon for types of development other than those to which it refers. Any variation from the site conditions present, or variation in assumed conditions which might form the basis of design or recommendations as outlined in this report, at or on the development proposed as of the date of the Professional Document requires a supplementary exploration, investigation, and assessment.

TETRA TECH is neither qualified to make, nor is it making, any recommendations with respect to the purchase, sale, investment or development of the property, the decisions on which are the sole responsibility of the Client.

1.7 NOTIFICATION OF AUTHORITIES

In certain instances, the discovery of hazardous substances or conditions and materials may require that regulatory agencies and other persons be informed and the Client agrees that notification to such bodies or persons as required may be done by TETRA TECH in its reasonably exercised discretion.

1.8 ENVIRONMENTAL AND REGULATORY ISSUES

Unless stipulated in the report, TETRA TECH has not been retained to explore, address or consider and has not explored, addressed or considered any environmental or regulatory issues associated with development on the subject site.

1.9 NATURE AND EXACTNESS OF SOIL AND ROCK DESCRIPTIONS

Classification and identification of soils and rocks are based upon commonly accepted systems, methods and standards employed in professional geotechnical practice. This report contains descriptions of the systems and methods used. Where deviations from the system or method prevail, they are specifically mentioned.

Classification and identification of geological units are judgmental in nature as to both type and condition. TETRA TECH does not warrant conditions represented herein as exact, but infers accuracy only to the extent that is common in practice.

Where subsurface conditions encountered during development are different from those described in this report, qualified geotechnical personnel should revisit the site and review recommendations in light of the actual conditions encountered.

1.10 LOGS OF TESTHOLES

The testhole logs are a compilation of conditions and classification of soils and rocks as obtained from field observations and laboratory testing of selected samples. Soil and rock zones have been interpreted. Change from one geological zone to the other, indicated on the logs as a distinct line, can be, in fact, transitional. The extent of transition is interpretive. Any circumstance which requires precise definition of soil or rock zone transition elevations may require further investigation and review.

1.11 STRATIGRAPHIC AND GEOLOGICAL INFORMATION

The stratigraphic and geological information indicated on drawings contained in this report are inferred from logs of test holes and/or soil/rock exposures. Stratigraphy is known only at the locations of the test hole or exposure. Actual geology and stratigraphy between test holes and/or exposures may vary from that shown on these drawings. Natural variations in geological conditions are inherent and are a function of the historical environment. TETRA TECH does not represent the conditions illustrated as exact but recognizes that variations will exist. Where knowledge of more precise locations of geological units is necessary, additional exploration and review may be necessary.

1.12 PROTECTION OF EXPOSED GROUND

Excavation and construction operations expose geological materials to climatic elements (freeze/thaw, wet/dry) and/or mechanical disturbance which can cause severe deterioration. Unless otherwise specifically indicated in this report, the walls and floors of excavations must be protected from the elements, particularly moisture, desiccation, frost action and construction traffic.

1.13 SUPPORT OF ADJACENT GROUND AND STRUCTURES

Unless otherwise specifically advised, support of ground and structures adjacent to the anticipated construction and preservation of adjacent ground and structures from the adverse impact of construction activity is required.

1.14 INFLUENCE OF CONSTRUCTION ACTIVITY

Construction activity can impact structural performance of adjacent buildings and other installations. The influence of all anticipated construction activities should be considered by the contractor, owner, architect and prime engineer in consultation with a geotechnical engineer when the final design and construction techniques, and construction sequence are known.

1.15 OBSERVATIONS DURING CONSTRUCTION

Because of the nature of geological deposits, the judgmental nature of geotechnical engineering, and the potential of adverse circumstances arising from construction activity, observations during site preparation, excavation and construction should be carried out by a geotechnical engineer. These observations may then serve as the basis for confirmation and/or alteration of geotechnical recommendations or design guidelines presented herein.

1.16 DRAINAGE SYSTEMS

Where temporary or permanent drainage systems are installed within or around a structure, the systems which will be installed must protect the structure from loss of ground due to internal erosion and must be designed so as to assure continued satisfactory performance of the drains. Specific design detail of such systems should be developed or reviewed by the geotechnical engineer. Unless otherwise specified, it is a condition of this report that effective temporary and permanent drainage systems are required and that they must be considered in relation to project purpose and function.

1.17 DESIGN PARAMETERS

Bearing capacities for Limit States or Allowable Stress Design, strength/stiffness properties and similar geotechnical design parameters quoted in this report relate to a specific soil or rock type and condition. Construction activity and environmental circumstances can materially change the condition of soil or rock. The elevation at which a soil or rock type occurs is variable. It is a requirement of this report that structural elements be founded in and/or upon geological materials of the type and in the condition used in this report. Sufficient observations should be made by qualified geotechnical personnel during construction to assure that the soil and/or rock conditions considered in this report in fact exist at the site.

1.18 SAMPLES

TETRA TECH will retain all soil and rock samples for 30 days after this report is issued. Further storage or transfer of samples can be made at the Client’s expense upon written request, otherwise samples will be discarded.

1.19 APPLICABLE CODES, STANDARDS, GUIDELINES & BEST PRACTICE

This document has been prepared based on the applicable codes, standards, guidelines or best practice as identified in the report. Some mandated codes, standards and guidelines (such as ASTM, AASHTO Bridge Design/Construction Codes, Canadian Highway Bridge Design Code, National/Provincial Building Codes) are routinely updated and corrections made. TETRA TECH cannot predict nor be held liable for any such future changes, amendments, errors or omissions in these documents that may have a bearing on the assessment, design or analyses included in this report.