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Geotechnical Evaluation
Geohazard Assessment
Block 4 - North End Subdivision
Dawson City, Yukon – 2017

Prepared For: **City of Dawson**

Date : **June 30, 2017**

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1.0 INTRODUCTION

Chilkoot Geological Engineers Ltd. was retained by the *City of Dawson* to conduct a geotechnical evaluation of the Block 4 - North End Subdivision located in Dawson City, Yukon. The purpose of the evaluation was to identify potential geohazards which may impact the subdivision. The location of the study area has been illustrated in Figure 1. The configuration of the residential subdivision has been attached as Figure 2.

Authorization to proceed with the work was granted on April 10th, 2017 by *City of Dawson – Community Development Officer* Mr.Micah Olesh. The field work was conducted between May 16th & 18th, 2017 in accordance with our March 29th, 2017 Proposal. Our preliminary findings were presented in a Letter Report dated May 29th, 2017.

A description of our methodology and findings have been provided below.

2.0 SCOPE-OF-WORK

The intent of our geotechnical evaluation was to identify potential geohazards which may impact the subdivision and provide recommendations for mitigation where hazards were identified. These anticipated potential hazards would be related to surface drainage, rockfall, erosion susceptibility, potential for localized slope failure and other similar types of geotechnical liabilities considering the subdivision is located within the limits of a former quarry.

Our evaluation was to focus upon Lots 15 & 16 (as steeper slopes are prevalent within this area), Lots 1, 2, 4 & 6 to a lesser extent and upslope regions (within ~ 100 m) of the subdivision limits. Geohazards (beyond the 100 m upslope boundary) were to be identified where readily evident, however it was beyond our scope-of-work to assess the degree to which they may impact the subdivision. In addition, it was beyond our scope-of-work to assess individual lot upgrades within the subdivision where they have been privately developed.

The hazard potential was to be assessed on a case-by-case basis such that the probability of occurrence and level of risk (severity) they may pose can be assessed from a qualitative standpoint.

- The probability of occurrence for each of the hazards was to be classified as either probable, remote, extremely remote, extremely improbable or combination thereof,
- The severity was to be classified as either being catastrophic, hazardous, major, minor, having no effect or combination thereof.

3.0 METHODOLOGY

Our methodology was comprised of a literature review as well as a site reconnaissance.

3.1 Literature Review

A literature review was conducted prior to the field work program to better evaluate the regional conditions and detail the field work programs. While our firm requested ancillary information relating to the subdivision such as site grading and drainage plans, the *City of Dawson – Community Development Officer* indicated they were unaware of the existence of any such plans.

The following sources of information were reviewed;

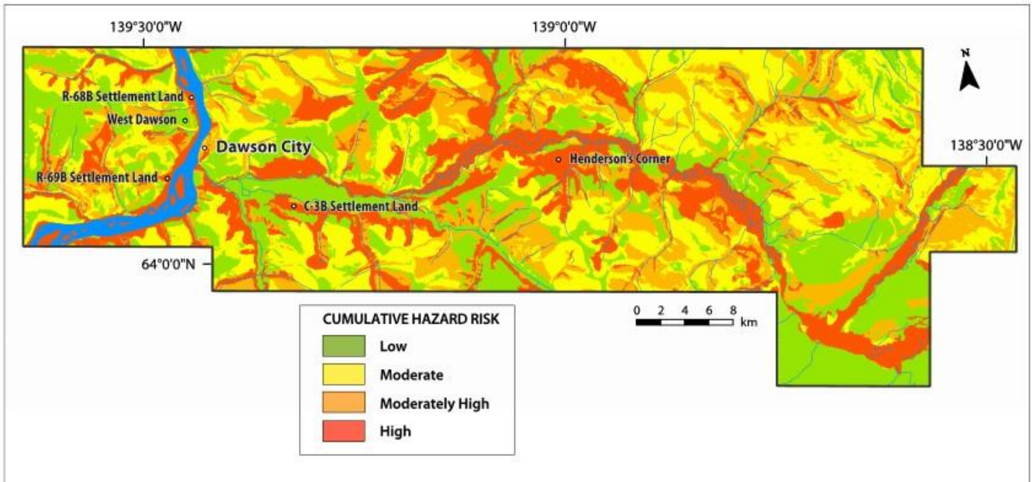
Technical Reports

- Dawson Natural Landscape Hazards – Geoscience Mapping for Climate Change Adaptation Planning prepared by the *Northern Climate ExChange – Yukon Research Center – Yukon College* - B.Benkert, K.Kennedy, D.Fortier, A.Lewkowicz, L.Roy, K.Grandmont, I.de Grandpre, S.Laxton, L.McKenna and K.Moote, 2015.

  This report was compiled to serve as a baseline to allow for climate change adaptation planning as adverse effects of a warming environment have become a reality in northern Yukon. The intent was to generate a hazards map to help identify the potential for permafrost thaw, landslides and flooding. Their study area paralleled the limits of a 1:25,000 surficial geology map (Open File 2014-12) which has been described below.

  The hazards report indicated that an approach was generated to consider local community concerns and infrastructure, disturbance history, permafrost distribution and characteristics, surficial geology conditions, hydrology and projections of future climate. Following the retention of scientific information and case studies, data related to slope angle, slope aspect, surficial materials and permafrost probability were input into a raster comprised of pixels which each represented 30 m^2. The hazard potential relative to each of these criteria was assigned and a map based upon a cumulative weighted risk was generated. The report was clear to indicated that while the hazard map can serve as an initial guide to local conditions, there are limitations due to site specific conditions and so detailed site studies (e.g., geotechnical or engineering studies) would still be required.

A copy of the hazard map which was generated during the work has been attached below.



The limits of the study area have been superimposed on the hazards map and has been attached as Appendix A for reference purposes.

- <u>The Dawson City landslide (Dawson map area, NTS 116B/3), central Yukon</u> prepared by M.Brideau, D.Stead, V.Stevens, C.Roots, P.Lipovsky and P.VonGaza, 2007.

  This technical paper describes the slide and established a series of arrays and differential global positioning system (DGPS) pins which would allow for annual monitoring of slide movements to accuracies of < 1 cm as the slide debris is known to be moving.

  The pre-historic slide is described as having occurred in altered ultramafic rocks. Although the mechanisms of movement are described as rock glacier or earth flow processes, these mechanisms could not be confirmed during the study which was undertaken. While the initial failure was thought to have a been a catastrophic rock slide, their observations suggest that only small-magnitude mass movement events have occurred in the last century. Rockfall has been ongoing since the initial event to this day, as the upper part of the original debris field has since been buried by rock talus. The study noted recent signs of movement of a block of terrain located upslope of the headscarp and within central portions of the slide debris where split trees provided visual indicators of slope movement. As such, monitoring stakes and DGPS pins were established to allow for annual monitoring of the slide. The rate of movement in the central and lower portions of the slide debris were calculated to be ~ 4.5 cm/year.

The paper indicated that the lower realms of the debris slide had been re-contoured in the early 1980's following quarry operations.

- Geotechnical Evaluation – Proposed North End Subdivision – Dawson City, Yukon dated September 18, 2016 compiled by our firm for *Yukon Government – Energy, Mines and Resources*.

  The purpose of the evaluation was to characterize the local conditions to allow for residential development of the proposed (infill) subdivision. The work involved a site reconnaissance, drilling and laboratory work programs. In brief, the study suggested that the site conditions would allow for infilling however additional geotechnical evaluation would be required to better assess the regional geohazard potential. Geotechnical setbacks from the toe of the slide and Yukon River were identified.

In addition to these documents, during our time onsite, the subdivision developer provided us with a geotechnical evaluation report which was prepared for the subdivision.

- The December 3rd, 2013 report was entitled, Geotechnical Evaluation – Proposed Residential Subdivision North End of 5th Avenue, Dawson City, Yukon and was prepared by *EBA – A TetraTech Company* for the *City of Dawson*.

  The report provided geotechnical recommendations for access roads, building foundations and the installation of municipal (sewer/water) infrastructure. During the evaluation, seven (7) test pits were excavated within the limits of the proposed subdivision to retain soil samples to allow for laboratory analysis. Bedrock samples were also retained to allow for asbestos content analysis. The analysis verified that naturally occurring asbestos was present within the soils and bedrock located at the site. The test pits encountered a combination of colluvial deposits and fill. The evaluation presented geotechnical parameters in order to assist in the development of the subdivision while understanding the health risks associated with the presence of the potential asbestos.

A copy of the *EBA* Geotechnical Evaluation Report has been attached in Appendix C.

Surficial Geology Map

A 1:25,000 surficial geology map (Open File 2014-12) entitled Surficial Geology, Dawson Region, Yukon – Parts of NTS 115O/14 & 15 and 116B/1, 2, 3 & 4 compiled by K.McKenna and P.Lipovsky - *Yukon Geological Survey* was reviewed to provide insight into the regional geomorphology. In brief, the map indicated that the subdivision lies in a region dominated by colluvial deposits.

A portion of this map and the corresponding limits of the study area have been provided in Figure 3 – Surficial Geology.

Bedrock Geology Map

A bedrock geology map, available through the *Yukon Geological Survey*, identified the regional bedrock types and characteristics within the study area. The map was entitled *Yukon Bedrock Geology Map* – *Yukon Geological Survey* – Open File 2016-1 - 1:1,000,000 scale compiled by M.Colpron, S.Israel, D.Murphy, L.Pigage, and D.Moynihan. A more detailed delineation of these contacts was found on the *Yukon Geological Survey* website.

A portion of the website map, which illustrates the bedrock located in the region of the study area, has been attached as Figure 4 – Bedrock Geology.

Topographical Information

Our firm obtained a topographical map of the subdivision and local area through YG/*Underhill Geomatics Ltd*. The topographical map was compiled through recent Lidar data and has been attached as Figure 5.

Archives

A hand drawn picture of Dawson entitled 'Birdseye view of Dawson' drawn by Dr.J.Bell in 1903, was obtained following a search of *YG's – Department of Tourism and Culture - Yukon Archives*. The picture depicts Dawson as it was viewed from West Dawson on the north bank of the Yukon River and has been attached as Figure 6 - Historical Setting.

Aerial Photographs

A selection of aerial photographs which were obtained from the *YG – EMR Library*, were reviewed to assess the historical development of the study area. Our observations of the respective air photos which were reviewed were noted as follows;

1951 – *A13139* – Although the airphoto is of poor resolution (as it lies in the shadow of Midnight Dome), the prominent slope located north of present day Lot 18 can be seen. Some lighter tones can also be noted directly south of this area.

1960 – *A17155* - No photos of the study area were noted within the flight line.

1970 – *A22199* – Quarry activities can be noted within Lots 15/16 & 18. The activities appear to comprised of bull-dozer pushes which originate immediately beyond the north-east corner of Lot 15/16. A cul-de-sac trail terminates in the area of Lot 18.

1977 – *A24708* – Quarry activities can be noted in Lots 8-16 & 18. The bull-dozer activities which were noted in the 1970 airphoto to the north-east appear to have ceased.

The area is now partially overgrown with vegetation.

There two prominent areas located within the southern half of the subdivision where borrow activities are being conducted.

The western borrow area (accessed from the end of 5th Avenue) appears to have been cut to an elevation near those present at the intersection between Albert Street and 5th Avenue. This area appears to encompass present day Lots 8 & 11, along with western portions of Lots 10 & 12 and eastern portions of Lot 9.

The eastern borrow area (accessed from either 5th or 6th Avenue) appears to have been cut to slightly higher elevations (near those present at the intersection between Albert Street and 6th Avenue). This area appears to encompass present day Lots 13- 16 & 18, along with eastern portions of Lots 10 and 12.

1984 – *NW9584* – Quarry activities have extended to the north-west portions of the subdivision. All of the present day subdivision lots have been impacted by quarry operations. The slopes which extend to the north-east beyond the subdivision limits have all been cleared of vegetation to the present day alignment of the 9th Avenue Trail. The northern limits of the borrow pit extend approximately 25 meters north of the subdivisions northern extent (beyond Lots 1 & 2). It appears the primary operations are comprised of bulldozing material from the Lots 2, 4 & 5 towards the south. This material appears to have been pushed over the slope and onto (predominately) Lots 8 & 10, entirely filling the western borrow excavation described above in the 1977 airphoto. The slough from this fill extends to the south onto Lots 9 and 11-14.

The region located south-east of the present day subdivision limits have been cleared. This area coincides with the houses currently located immediately east of 6th Avenue.

The region located north-east of Lots 15/16 has also been cleared to the previous 1970 limits.

1987 – *WP8718* Quarry operations appear to be limited to southern realms of the present day subdivision. Material is being sourced from the eastern side of Lot 16. The back-slope regions have been cleared up to 20 meters east of Lot 16. The region immediately south of Albert Street and west of 6th Avenue appears to have been excavated to its present day elevations.

1990 – *A27664* – Borrow operations appear to be limited to the south-eastern realms of the subdivision and nearby adjacent areas. The remainder of the subdivision appears to have been configured to its present day topography. Borrow operations have proceeded north from the end of 7th Avenue. Vegetation has covered over central portions of the site, particularly along Lots 6, 8 & 10. Vegetation has re-established itself along portions of the exposed slope located north-east of the subdivision (south-west of the 9th Avenue Trail).

1993 – *A27857* – Borrow operations appear to have ceased. The region located immediately east of 6th Avenue has been excavated to allow for residential building construction in this area.

2004 – *G0307068* – Other than continued revegetation, the subdivision area appears to be unchanged from the 1993 airphoto.

A selection of the above noted aerial photographs has been attached as Appendix B – Selection of Air Photos.

3.2 Site Reconnaissance

A site reconnaissance was conducted over the course of three days between May 16th to 18th, 2017. During this time, the region was traversed on foot such that field conditions and geological features within (and just beyond) the study area could be observed. The exception to this were regions where residences were established within the study area (Lots 3, 5 & 14) as traversing these lots was considered intrusive.

Our observations were documented through a combination of field notes, GPS waypoints and photographs. These observations have been summarized in Section 4.0 – Site Conditions, below.

4.0 SITE CONDITIONS

4.1 Study Area

The study area is located within the municipal limits of Dawson City, Yukon. Dawson City is located within Tr'ondëk Hwëch'in Traditional Territory. The location and limits of the study area has been illustrated in Figures 1 & 2, respectively.

The 1903 drawing by Dr.Bell (enclosed as Figure 6) shows that historically, the study area was once a residential part of Dawson comprised of houses and wall tents. These structures were all situated on a well-developed system of roads. Otherwise, since then, the area appears to have lain dormant relative to housing development.

4.2 Physiographic Region

The study area is part of the Boreal Cordillera Ecozone and lies within the Klondike Plateau immediately south-west of the Tintina Trench. The mountains in the region are of the Dawson Range, a sub-range of the Yukon (Mountain) Range which dominate much of central Yukon and eastern Alaska. These mountains rise to elevations in the order of 1500 meters. The terrain can be described as smooth, rolling, unglaciated terrain, which is incised by narrow, deep, V-shaped valleys.

Permafrost is extensive, discontinuous and overlain with turbic cryosols.

4.3 Site Description

The residential subdivision is located within the limits of a former quarry. As colluvial materials dominate the area, the area was likely a rock quarry which was utilized to supply general fill around the Dawson town-site. The odd surficial boulder in size to 1.5 meters was noted within the subdivision.

While the roadways were established, subdivision development was ongoing at the time of our assessment. Specifically, houses had already been constructed on Lots 3, 5 and 14. These house were constructed on cribbing and ventilated crawlspace types of foundations which were established on granular pads.

A granular building pad had been constructed on Lot 6. The western side of this lot had been constructed utilizing a series of gabion baskets such that a steep slope could be constructed. It’s understood that the gabion wall was engineered in order to avoid

encroaching on municipal infrastructure located at the base of the slope. The remaining undeveloped lots within the study area are generally vegetated with a variety of grasses, willow bush and the odd birch tree.

The remnants of cut-slopes which were likely created by a bulldozer were noted on Lots 2 & 4. These lineation features were oriented approximately north-south and measured in the order of 1.0-1.5 meters in height. The tree trunks in this region were noted to be slightly deformed, suggesting slope movement (possibly comprised of creep).

The subdivision is accessed through a primary and a secondary road which each connect to Albert Street. The primary road bisects the central and upper realms of the site. The secondary road allows for access to lots located at lower elevations as noted in Figure 2.

While the topography within the limits of the subdivision varies, regionally the terrain ascends towards the north-east. The subdivision lies at elevations which range between approximately 322 meters to 360 meters as noted in Figure 5. The Midnight Dome lies approximately 1.3 km north-east of the site at an elevation of approximately 880 meters. The Yukon River lies at an elevation of approximately 316 meters.

Surface drainage through the subdivision is poorly defined. Although shallow swales were established along the upper road (adjacent to Lots 3 to 6), ditches and culverts within the subdivision were not present.

Generally surface waters flow from regions of higher elevations onto regions of lower elevations towards the south-west. This surface flow is generally contained at higher elevations to rudimentary swales which are present in areas where the building lots are located at higher elevations relative to the primary road (namely Lots 1-6). Otherwise where building lots are located at lower elevations, the surface waters flow off the road shoulders onto the side slopes of the road embankment and onto the building lots. Erosion rills have formed along the roadway embankment at some of these locations (such as Lots 8 and 15).

Prominent slopes lie above and extend into Lots 15 and 16. These slopes measured approximately 20 meters in height and had grades in the order of 40°. Considerably steeper slopes are located west of these lots immediately north of Lot 18. While these slopes are predominately comprised of native colluvial deposits, some regions of fill, remnant from quarry operations were noted to overlie portions of Lot 15 and Lot 18. Cobbles which had fallen down the slopes were noted along the toes of these slopes.

The 9th Avenue Trail lay directly above the steep portion of the slope and traverses the approximate north-eastern limits of the subdivision. The back-slope conditions beyond the 9th Avenue Trail alignment were dominated by a well-established forest comprised of predominately spruce trees. Thick moss and lichen were present throughout the area along with stands and lineations of willow bush.

Some historical remnants (in the forms of empty cans and miscellaneous debris) were noted in this region. There were no signs of slope movement, run-off or erosion in the back-slope area. Permafrost is likely present throughout this area based upon the types of vegetation which was present.

4.4 Geomorphology

Soil Deposits
The composition and geomorphology of the regional soil deposits are comprised of colluvial fan and apron deposits. These soils have been quarried and disturbed within the limits of the subdivision and so fills comprised of these materials and possible organics are also present.

The terrain in the region of building lots located at higher elevations is likely bedrock controlled.

The distribution of these deposits has been illustrated in the Surficial Geology map enclosed as Figure 3.

Glaciation
Evidence shows that the Dawson area and Klondike Plateau have probably not been glaciated since Pre-Reid advances (2.65 Ma to > 200 Ka).

Permafrost
Dawson (and the study area) lies within the zone of extensive discontinuous permafrost (50-90%). The permafrost in this zone can vary from poorly bonded soils with non-visible ice to massive ice lenses ranging in size to tens of meters.

Regionally the permafrost is probably more than 100 m thick with taliks (thawed subsurface) present beneath large rivers and lakes and beneath south-facing slopes.

While thawed areas may also be encountered where the region has been previously cleared, regionally permafrost is generally widespread. Permafrost may be present at lower elevations within the subdivision.

Watercourses
The Yukon River flows to the north along the western periphery of the study area.

Groundwater
Shallow groundwater would be expected in the form of seepage zones and sheet-wash flows give the nature of the terrain and anticipated soil types.

Natural Hazards
The Dawson Natural Landscape Hazards report provided a description of the types of natural hazards in the Dawson region. These hazards were classified as being related to either seismicity, mass wasting, floods and/or permafrost related processes.
A description of each of these hazards has been summarized as follows;

Seismic Events
According to the *National Building Code*, Dawson City lies within a region classified as having a moderate potential for seismic activity.

> While the classification is given relative to the potential for damage to one and two-story dwellings, the impacts of utilizing cribbing types of foundation systems would not have been considered. The use of these types of foundation systems would in general make structures more susceptible to damage in the event of severe seismic occurrences. The degree to which these structures may be prone to damage will vary on a case-by-case basis.

The report indicated that *Natural Resources Canada* (2013) had recorded thirty-four (34) earthquakes $\leq$ a magnitude of 4.0 within 50 km of Dawson since 1980. Larger earthquakes were not observed over this time frame.

Aside from seismic accelerations which will impact infrastructure that result from earthquakes, they may also induce landslides and cause liquefaction to occur.

> *Liquefaction*
> Liquefaction is a condition whereby the soil mass loses its strength due to an increase in pore water pressures. While the presence of saturated fine grained

soils would make some regions in Dawson susceptible to this type of hazard, liquefaction would not likely occur in the subdivision given the coarse grained nature of the colluvial deposits and fill materials.

Mass Wasting

Mass wasting is the result of downslope movement of rock, debris and soil caused by gravity. These slope movements occur when the shear stress exceeds the shear strength of materials over an essentially continuous failure surface. The process may be either extremely rapid or else take place over the course of years to centuries. The affected materials will move along either a shallow or else potentially deep seated failure zone.

Slope movements can occur through falls, topples, landslides, lateral spreads, flows (which include avalanches, solifluction, slope wash and creep) mechanisms or else combinations thereof. Once the failed materials come to rest, the resulting slope is generally more stable than that which had existed prior to the failure.

A description of the prominent failure modalities which may be present within the region have been described as follows;

Landslides

Landslides are the result of rapid downslope movement of rock, debris and soil which is driven by gravity. They are commonly associated with steep to moderately steep slopes and can be triggered as a result of seismic activity, permafrost degradation, increase in pore water pressure from surface and/or groundwater, forest fires, formation of ice lenses and extension cracks and other similar types of factors.

Rock Glacier

Rock glaciers are generally lobes or tongues of rock which are frozen along with interstitial ice, ice lenses and fine grained debris. Although the mechanisms of movement are poorly understood, it’s thought that movement is the result of plastic deformation.

Earth Flow

Earthflows are the rapid to slow downslope viscous movement of generally fine grained plastic to non-plastic materials. The rates of movement within earth flows are higher than that of creep.

Creep

Creep is caused by the repeated expansion and contraction of the upper part of the regolith (weathered bedrock surface) or other colluvial derived materials through repeated freeze/thaw and/or wetting/drying cycles. Combined with gravitational forces, this intermittent/seasonal process results in slope movement in generally steep terrain, although even shallow angled slopes may exhibit this behavior. While the rate of movement in colluvial materials is almost imperceptible (in the order of 1-5 cm/year), its effects can be seen in the form of tilted/deformed tree trunks, tilting fences and other similar types of indicators. The movement commonly occurs across the entire slope and does not extend much greater than 1 meter below the ground surface. The movement can be exaggerated in regions of permafrost which are undergoing thaw degradation as water cannot drain through the underlying frozen soils thus increasing pore water pressures and the potential for movement. Undercutting the toe features of these failures can increase the rate of movement significantly.

Rockfall

Rockfall results from the release of rocks from a competent mass which progresses down-slope due to gravity. These hazards generally originate from steep slopes.

Floods

Historically, flood events in Dawson have stemmed from the formation of ice dams located upstream of the town-site in either the Klondike or Yukon Rivers.

Unlike the remainder of Dawson proper (which is albeit protected by a dike established in the 1980's), the study area would not be prone to flood events given the local elevations.

Permafrost

As permafrost is prevalent throughout the region, thaw degradation due to climate change and anthropogenic processes impacts the soil stability, particularly in regions where the soils are ice rich and not thaw stable.

4.5 Surficial Geology

The distribution of the surficial deposits within the study area have been illustrated in the surficial geology map of Dawson (Open File 2014-12) enclosed as Figure 3. The map described the deposits within the study area as being comprised of colluvial materials.

The colluvial materials are geomorphologically modified through various mechanisms such as erosional, mass movement and/or periglacial processes such as cryoturbation and permafrost processes. These materials are differentially weathered and unsorted.

In brief, the surficial geology map indicated that two (2) types of colluvial deposits are present within the study area. This includes;

> Colluvial Apron Deposits (zdsCa-X) which are comprised of silt, mixed fragments and sand colluvium. The surficial geology map describes colluvial aprons as being found on lower gentle slopes where slower mass wasting processes such as sheetwash, solifluction and creep occur. These regions are commonly fine grained and ice-rich. Permafrost is widespread.
>
> These deposits would be encountered in the south-western region of the subdivision near Lot 17.
>
> Colluvial Fan and Apron Deposits (rCfa) which are comprised of colluvial rubble. As these deposits are found on moderate slopes, the material is 'generally derived from weathered bedrock and loess, resulting in a silt-rich diamicton containing angular, local bedrock clasts' (as described in the Surficial Geology Map). These deposits are encountered throughout the majority of the subdivision.

In addition to the above noted native deposits, fills were also noted within the study area as described below;

> Fill
>
> Fills are present within the subdivision area as identified in the geotechnical report prepared by *EBA*. Based upon the airphotos, Lots 8 and 10 are predominately comprised of colluvial (and potentially organic) fill materials which have been pushed off the slope from regions located north of these lots.

4.6 Bedrock Geology

The regional geology in the Dawson area is comprised of two complex assemblages comprised of the Intermontane (Yukon-Tanana) and Slide Mountain Terrane as illustrated in Figure 4. These assemblages consist of an intensely deformed, variably metamorphosed and sheared group of ultramafic, igneous and metamorphosed rocks which include serpentine, diorite, amphibolites and schist (Yukon-Tanana) and a weakly deformed assemblage comprised of shale, siltstone and sandstone which contains some phyllite (Slide Mountain).

The corresponding rock assemblages are described in the Yukon Bedrock Geology Map (Open File 2016-1) legend, as;

Yukon Tanana Terrane

DMF3 - Finlayson – assemblage of minor quartzite, metavolcaniclastic rocks

PK2 - Klondike Schist – felsic metavolcanic rocks intercalated with metaclastic rocks.

Slide Mountain Terrane

CPSM4 – Slide Mountain - oceanic assemblage of chert, argillite, minor sandstone and variably serpentinized ultramafic rocks; metapyroxenite, dunite and harzburgite.

With the exception of the prominent rock feature located immediately north of Lot 18, there were no signs of competent bedrock outcrops. While we classified the rock feature as possible bedrock, it could simply be a large boulder. The terrain in regions of higher elevations within the subdivision however, is likely bedrock controlled as evidence by the composition of the exposed colluvial ground surface.

Regionally, the surface of the bedrock is known to be fractured and in a state of decomposition due to weathering and periglacial processes. The degree of fracturing and decomposition varies depending upon the origin of the parent rock and local setting.

4.7 Subsurface Conditions

The subsurface conditions have been described in the *EBA* Geotechnical Evaluation Report attached in Appendix C.

5.0 DISCUSSIONS

5.1 General Overview

There are geohazard liabilities associated with the slopes which overlie and extend into the subdivision as it appears the quarry was not closed in accordance with current standards and hence steep slopes are present. These features create potential liabilities which are related to erosion, rockfall and a potential for slope failure. In addition, as per all other residential areas located at higher elevations in Dawson, the subdivision roads (and adjacent areas) are susceptible to erosion during the time that surface drainage is being established.

While a detailed description of other potential natural hazards which may be present from a regional perspective have been provided in Section 4.4 – Geomorphology, based upon our observations, further to the geohazards noted above, the primary natural hazards associated with the subdivision area would be related to creep and earthquakes.

Considering that quarry operations ceased by 1993, in general, given the elapsed period of time since then, the slopes present within (and adjacent to) the subdivision appear to be relatively stable as signs of mass erosion and utterly failed slopes were not identified. That said, there were signs that rockfall has been occurring (especially in the region of Lot 15, 16 & 18) and an extension crack (indicative of slope movement) was observed on Lot 16.

While municipalities typically establish minimum development setbacks of 30 meters from the crests and toes of slopes in order to provide a factor of safety relative to potential risks associated with the terrain, in the case of Block 4, the adjacent slopes in fact extend into some of the properties (Lots 1, 2, 4, 5, 15, 16 and 18).

The presence of colluvial deposits and fill will require additional consideration as these materials are undergoing periglacial processes or else may be susceptible to thaw-degradation. These deposits will induce movements upon the infrastructure due to fluctuations in the underlying soil volumes (particularly where permafrost is exposed to thaw-degradation) and slope movements (within the colluvial deposits) through earth flow and creep mechanisms.

As with all subdivisions and developed areas, it’s important to control surface drainage to protect the long-term stability of the region. As such, the establishment of granular building pads, lot accesses and local drainage regimes should be carefully considered. This work should be carefully orchestrated and monitored by regulatory authorities in order to control surface drainage and minimize disturbance to the thermal regime.

5.2 Site Specific Considerations

Discussions pertaining to each of the individual geohazard liabilities which have been identified at the subdivision have been provided as follows;

Surface Drainage

Propability of Occurance: Probable
Level of Risk: Minor

The topography of Block 4 and surrounding areas does not allow for proper surface drainage. Specifically, surface drainage progressively flows from (municipal) regions of higher elevations onto (private Block 4) lots located at lower elevations. As such, individual property owners should be made aware of this regime such the surface drainage in the area is properly managed and the potential impacts are recognized.

The surface drainage along some portions of the road would be considered poor, particularly where the road has been established at higher elevations relative to adjacent lots. Erosion rills were noted in the road side slopes along Lots 8, 10, 15 & 16.

As such, Lots 15 and 16 could be filled to prevent surface water from impacting the lots and road side-slopes. As the topography will not allow for this at Lots 8 and 10, the road side-slopes should instead be armored with drain rock if seeding is not sufficient to prevent erosion. The water at the base of the side-slopes in Lots 8 and 10 (amongst others) would need to be redirected and managed accordingly.

Rockfall

Propability of Occurance: Probable to Remote
Level of Risk: Minor to Catastrophic

Rockfall is occurring where steeper slopes are present above Lots 15, 16 & 18. Rockfall is more likely in these areas during poor weather (rain/precipitation) and the spring freshet and so exposure to regions located at the toe of these slopes should be minimized during these times. While most of the rockfall would present only a minor hazard (relative to building structures), the risk factor would increase significantly relative to the size of the rock or if people are directly exposed.

While it appears the majority of the rockfall is being restrained by the presence of trees located at the toes of the respective slopes, fences should be established along Lots 15, 16 & 18 as an added precaution. Ideally, the trees located along the toe of these slopes should not be removed given the protection they afford.

The use of fences along Lots 2, 4 and 5 should be considered on a case-by-case basis depending upon the nature of lot development.

The fences should be robust and tall enough to minimize the impacts of rockfall. Chain-link fences are commonly ideal for this purpose.

While the *City of Dawson* could establish a fence on the upslope side of the subdivision to reduce the impacts of rockfall which originates from municipal land, as the slopes continue onto the lots, the risks from rockfall still remains. As such, the fence(s) on Lot 15 and 16 should be established near the toe of the slope(s). Large boulders or concrete lock blocks could be utilized in the Lot 18 area given its use as overflow parking.

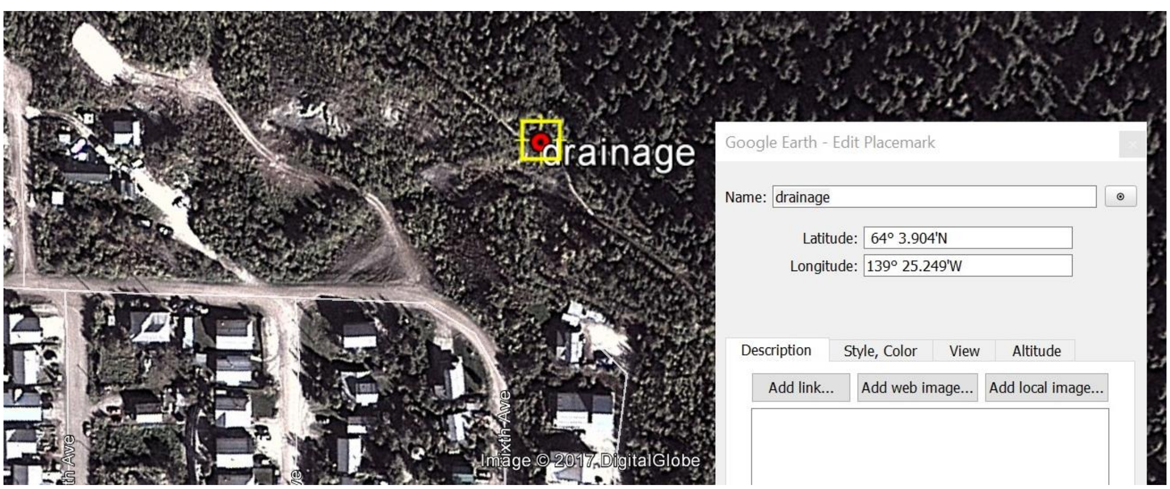
Additional effort should be employed to plant birch or other local trees immediately downslope of any boulders which may pose a hazard such as the one located just east of Lot 16. The purpose would be to establish a barrier which has the potential to prevent the boulders from progressing downslope in the event they are dislodged due to erosion, ice-jacking, etc. The approximate location of the boulder has been illustrated in Figure 7.

Erosion Susceptibility

Propability of Occurance: Probable
Level of Risk: Minor to Major

Loose fill materials which are remnants of the quarry operations were noted on the slopes which overlie Lots 15, 16 and 18. This material is unconsolidated and is undergoing erosion. As such, the lots which lie below these materials may be impacted from the downward migration of eroded materials. While eroded material will gravitate down-slope in minor amounts over time, the release of larger volumes of materials may occur and so this should be considered (see Landslides / Slope Failures below).

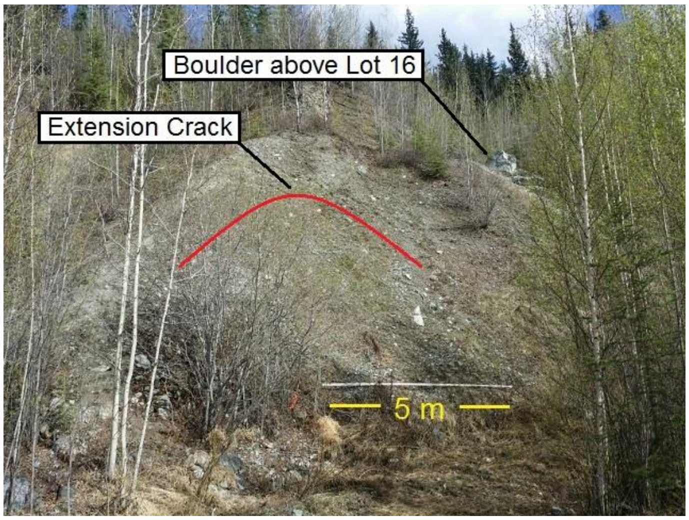
Portions of the 9th Avenue Trail above Lot 15 intercepted downslope surface drainage above the development and redirected the flow to the east. Future trail upgrades should consider managing this drainage accordingly to minimize down-slope impacts. This surface flow discharged from the trail at the approximate location noted below.

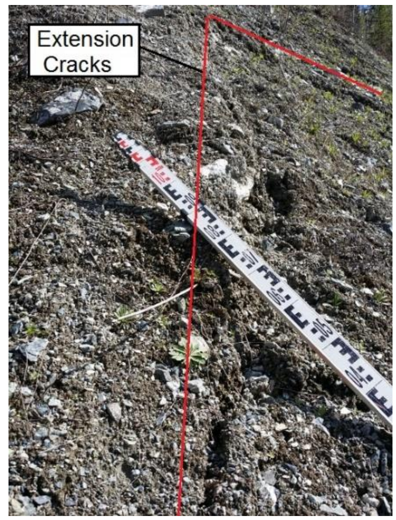


Landslide / Slope Failures

Propability of Occurance: Remote to Extremely Remote
Level of Risk: Hazardous to Catastrophic

Given the presence of steep slopes in the regions of Lot 15, 16 & 18, additional consideration will be required if these lots are to be utilized. Extension cracks (which are evidence of slope movement) are visible on the slope which lies on the boundary between Lots 15 & 16. These cracks were noted to be in the order of 3 cm wide and originate from a headscarp which measured in the order of 10 cm in height.





The location of these extension cracks has been noted in Figure 7.

As such, the residences on these two lots should be carefully situated to avoid the potential runout zone as follows;

<u>*Lot 15*</u>
The residence on Lot 15 should be located as far to the west as possible to allow for a buffer from the lot 15/16 boundary. This buffer is necessary to reduce the potential that debris from a slope failure would impact the residential structure.

<u>*Lot 16*</u>
The residence on this lot should be established close to Albert Street in order to provide a similar type of buffer from the lot 15/16 boundary and potential runout zone.

In addition, given the local elevations, the use of structural fill on Lots 15 and Lot 16 should be considered during building pad preparation. This will assist in redirecting surface drainage along the road shoulder and will assist in stabilizing the toe of the slope(s). Fill which intersects slopes should be keyed into the slope so as to reduce the potential of creating a potential slip surface.

Lot 18

As Lot 18 is being utilized for overflow parking, a simple barrier comprised of concrete lock blocks, jersey barriers or large (1.5 m +/-) boulders should be established at the base of the slope to reduce the risks which may be associated with failure/erosion of the slope in this region.

The slopes in these areas should be seeded on a regular basis until a cohesive vegetated cover has been established. This cover will help reduce the potential for rockfall, erosion and slope failure.

Excavation along the toe(s) of the existing slopes is not advised unless qualified geotechnical personnel are first consulted. The use of engineered gabion baskets walls to reinforce the toe of cut slopes could be considered on a case-by-case if excavation is required.

Creep

Propability of Occurance: Probable

Level of Risk: Minor to Major

Creep appears to be ongoing where steep slopes are present, particularly Lots 2, 4, 15 and 16. The impacts the 1-5 cm/year rates of movement will have upon infrastructure will vary over time.

Conditions on Lot 4 facing North. Note remnant cut slope from bulldozer and deformed tree trucks.

6.0 RECOMMENDATIONS

Our recommendations have been provided to assist in managing the geohazard risks which have been identified without having to re-contour the slopes located in the realm of the subdivision. While re-contouring could reduce some of the aforementioned risks, it would be a technically challenging undertaking. Additional evaluation would be required to assess the feasibility of this option particularly as disturbance to permafrost which may be present in the terrain which overlies the subdivision may in fact compromise regional stability and the drainage regime.

6.1 General

Roads, Foundations and Subsurface Infrastructure
Geotechnical recommendations for access road construction, house foundations and municipal sewer/water installations were provided in the December 3rd, 2013 Geotechnical Report prepared by *EBA – A TetraTech Company*.

Given the serpentinized nature of the colluvial deposits, precautions as identified in the *EBA* Geotechnical Report should be taken to protect workers from potential asbestos which may present a potential respiratory hazard.

Surface Drainage
Measures should be established to control surface drainage to minimize the impacts of erosion. This can be accomplished through the placement of protective rip-rap armor in regions where high flow velocities or soils susceptible to erosion have been identified or are noted. These armored areas could be underlain with impermeable liners to direct the flow as may be required. The use of silt fencing/rock baffles, culverts and ditches should also be considered.

Fencing
Fences should be established in regions where there is a potential for rockfall such as the northern side of Lot 15 and the eastern side of Lot 16. These fences should be established near the toe of the slope(s) and should be tall and robust enough to retain any potential rockfall. Typically, chain-link fences are suitable for this purpose.

Protective Barriers
Large boulders, concrete lock blocks or jersey barriers should be utilized along the north edge of Lot 18 and base of the steep slope located at the overflow parking area.

These items should form a continuous barrier as a precaution against rockfall and slope failures.

Signage
Rockfall signage should be established at the location of the overflow parking area to warn users of the potential hazard.

Vegetation
Grass and other types of vegetation should be utilized to stabilize exposed soils (such as steep slopes, road embankments and granular pad side slopes) as deemed appropriate. It may require several episodes of seeding/planting in order to establish a cohesive vegetative mat which will reduce the potential for erosion. Site specific plantings should be encouraged to reduce the associated risks with the rockfall potential.

Site Grading
Caution should be exercised in regions where colluvial materials are encountered as disturbance to these materials in regions which are undergoing creep will increase the rate of slope movement.

Additional Assessment
If there are concerns regarding the development of individual lots, the homeowner or developer should undertake a geotechnical evaluation to better characterize the site conditions and formulate site specific geotechnical parameters.

Building plans should be approved by civil/structural consultants to ensure any proposed structure conforms to required seismic parameters.

6.2 Site Specific Considerations

While site specific recommendations have been provided in Section 5.2, we have created a site plan illustrating some of the primary hazards and mitigation measures that should be considered during future development. While this plan should serve as a guideline, additional mitigation measures may need to be employed at other regions on a case-by-case basis. These other regions have not been identified due to the scale of mapping and as site conditions will change over time depending upon the nature of development and environmental factors.

This site plan has been attached as Figure 7 – Proposed Hazard Mitigation Plan.

6.3 Future Developments

We recommend that geohazard assessments, geotechnical evaluations and development plans (ie site grading, drainage, erosion control, etc.) should all be completed prior to approval of future subdivisions and lot developments as deemed appropriate by qualified personnel.

The need for these assessments, evaluations and plans should be outlined in guidelines and standard operating procedures established by the *City of Dawson* and other regulatory authorities as may be applicable.

7.0 CONCLUSIONS

General

There are geohazard liabilities associated with the slopes which overlie and extend into the Block 4 Subdivision as it appears the quarry (wherein the subdivision is located) was not closed in accordance with current standards.

Development upon (or near) steep slopes inherently increases the risks relative to geohazards. These terrain features create liabilities which are related to erosion, rockfall and potential slope failure. In addition, as per all other residential areas located at higher elevations in Dawson, the subdivision roads (and adjacent areas) are susceptible to erosion during the time that surface drainage is being established.

These risks and liabilities can however be managed through proper planning, engineering design and certified construction. As such, the associated liabilities and risks which have been identified herein should be considered during development of the individual lots and ancillary areas.

Development within the subdivision should be conducted in accordance with the December 3, 2013 geotechnical evaluation report prepared by *EBA* (*A Tetra Tech Company*) and our supplementary recommendations provided herein.

Notification

The subdivision developer, individual/future lot owners and the civil/structural design consultants should be made aware of the geotechnical evaluation report prepared by *EBA* and the findings of our geohazard assessment such that the liabilities and risks which have been identified can be considered.

Maintenance

As soil movements will occur due to the regional geomorphology, regular maintenance will be required to repair sub-surface utilities and re-level residential structures to ensure that movements are kept to within tolerable amounts. In general, where residences and infrastructure are established in regions which may be undergoing slope movements (through creep and other mechanisms), a higher frequency and degree of maintenance should be anticipated.

Subdivision Developments

As with all subdivisions and lot developments, geotechnical evaluations, geohazard assessments and development plans (ie site grading, surface drainage, erosion control, etc.) should be completed prior to granting development permits. Otherwise these developments may become liabilities in regions where geohazards are present or where surface drainage and site grading is not properly established or maintained.

While subdivision development through a single developer should be encouraged (as it will be more cohesive), site development should follow approved plans.

The *City of Dawson* should verify the plans, site development and building construction within the subdivision complies with the *National Building Code of Canada* and accepted engineering practice. Otherwise proper measures should be undertaken to protect the residents and general public.

8.0 LIMITATIONS

This report is intended for the sole use of the *City of Dawson.*

No portion of this report may be used as a separate entity; it is intended to be read in its entirety.

Any use of this report by a third party is the responsibility of such third party.

The recommendations provided are based upon the site conditions encountered at the time of our evaluation, current construction techniques and generally accepted engineering practices. Our recommendations have been provided without considering the effects of deep and long-term thaw of local/regional permafrost which may stem from global warming, building/utility construction, or other causes.

The content within this report reflects our best judgment in light of the information available to our firm at the time of report preparation. The information presented herein should supersede information provided in our preliminary findings. The anticipated construction conditions have been discussed, but only to the extent that they may influence design decisions.

Any references to construction methods contained herein, express our opinion and are not intended to direct contractors on how to carry out construction. Prospective contractors should be aware that the data presented may not be sufficient to assess all factors that may have an effect upon construction.

It is important to emphasize our evaluation is in fact, based upon our literature review and site reconnaissance. Due to the geomorphological nature of the deposits encountered, interpolations of subsurface conditions have not been made or been implied. Should unexpected conditions be encountered during construction, our firm should be notified immediately in order to confirm the suitability of our recommendations. If required, our firm may alter or modify our recommendations and conclusions at such time.

9.0 CLOSURE

Thank you for allowing our firm to provide you with the above noted evaluation. While we trust the information will suit your purposes, please feel free to contact the undersigned if you have any questions or require clarification.

Respectfully Submitted,

CHILKOOT GEOLOGICAL ENGINEERS LTD.

PROFESSIONAL #1277 YUKON TARES DHARA TERRITORY ENGINEER

PERMIT TO PRACTICE
Signature
Date June 30, 2017
PERMIT NUMBER: PP025
Association of Professional Engineers of Yukon

Tares Dhara, P.Eng.
Senior Geotechnical Engineer

TD/td

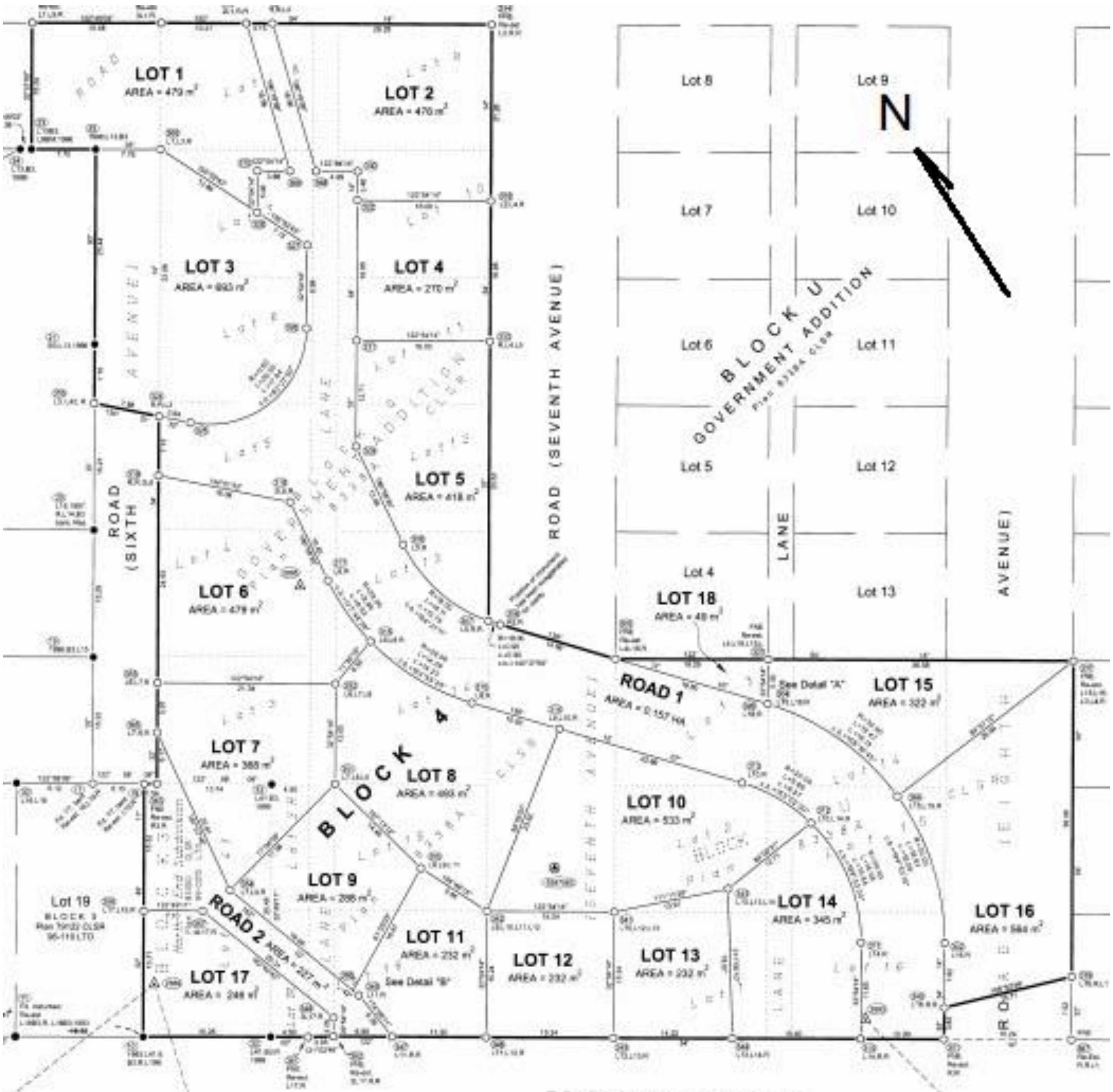
CHILKOOT GEOLOGICAL ENGINEERS LTD.

Geotechnical Evaluation – Geohazard Assessment
Block 4 North End Subdivision - Dawson City, Yukon - 2017
Figure 1 – Subdivision Location

Based map modified from Google Earth – Not to Scale – Locations are approximate.

Compiled March 25th, 2017 by T.Dhara

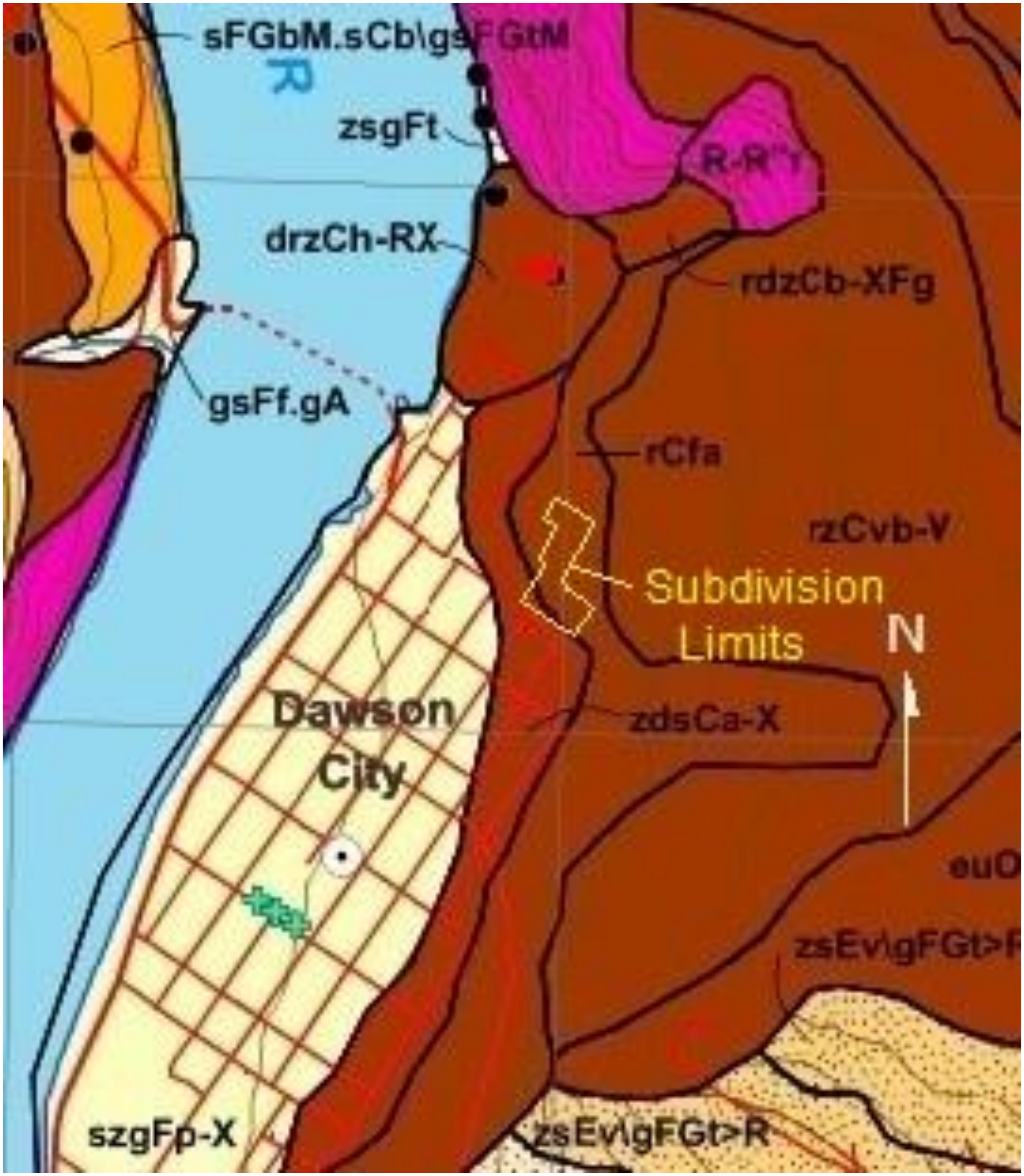
Geotechnical Evaluation – Geohazard Assessment
Block 4 North End Subdivision – Dawson City, Yukon – 2017
Figure 2 – Subdivision Lot Configuration



Geotechnical Evaluation – Geohazard Assessment
Block 4 - North End Subdivision - Dawson City, Yukon – 2017

Figure 3

Surficial Geology, Dawson Region



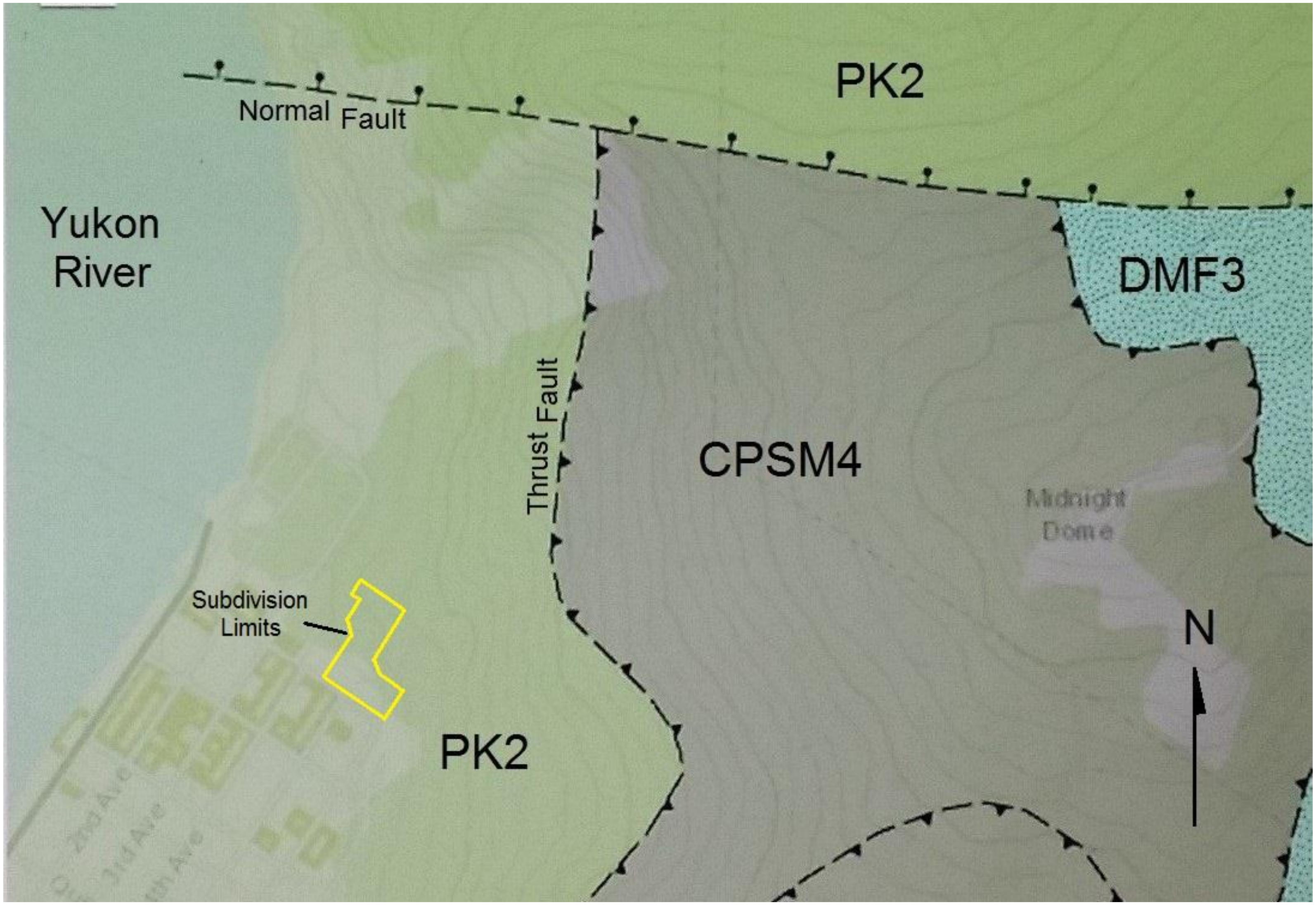
Base map modified from Surficial Geology, Dawson Region – Open File 2014-12
Map compiled by *K.McKenna and P.Lipovsky*

Geotechnical Evaluation – Geohazard Assessment

Block 4 - North End Subdivision – Dawson City, Yukon – 2017

Figure 4

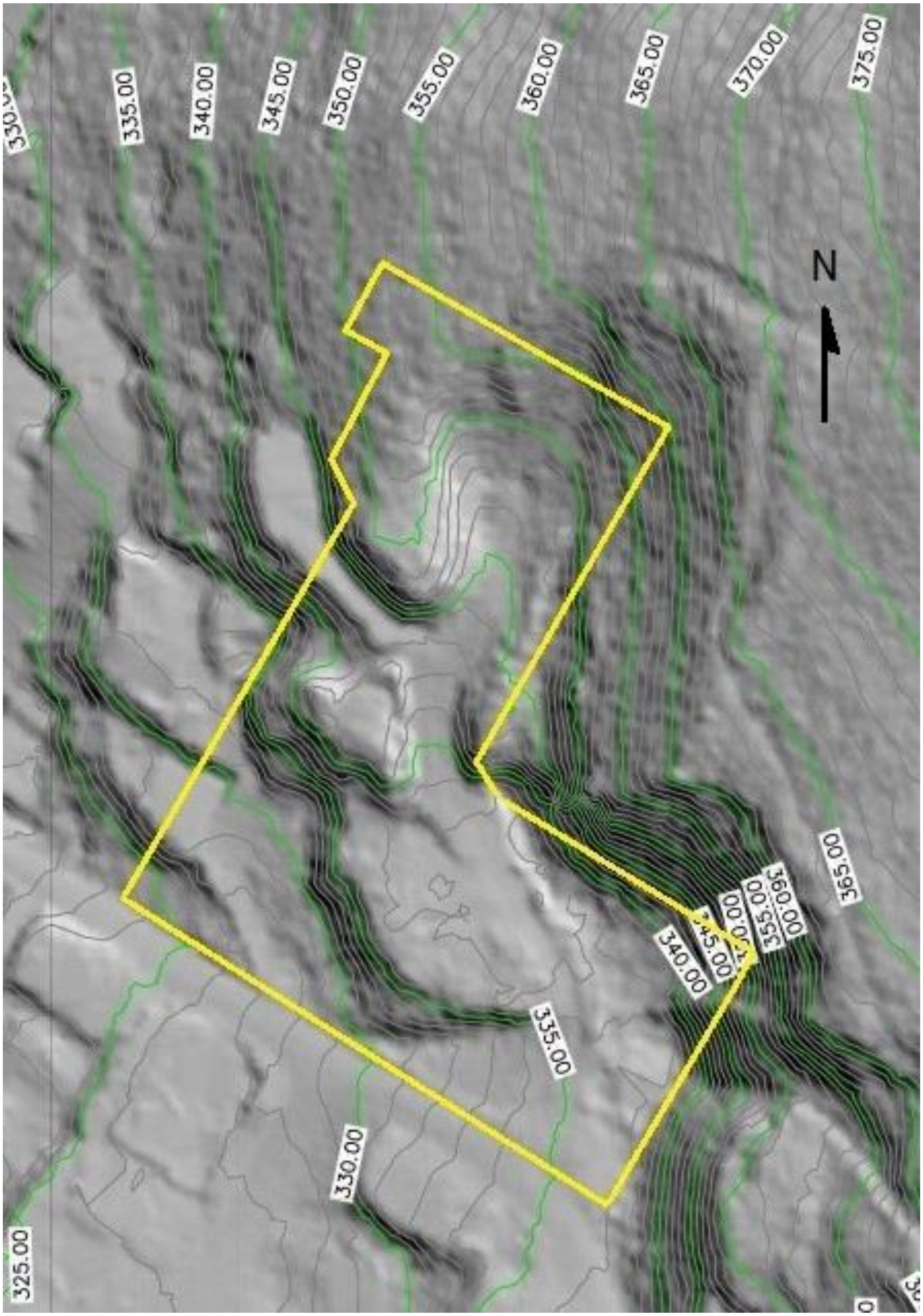
Bedrock Geology



Based map from *Yukon Geological Survey* website

Compiled June 22, 2017 by T.Dhara

Geotechnical Evaluation – Geohazard Assessment
Block 4 North End Subdivision – Dawson City, Yukon – 2017
Figure 5 – Local Topography – 2017 Lidar Survey



Base map supplied by YG through Underhill Geomatics Ltd. Compiled June 22nd, 2017 by T.Dhara, P.Eng.

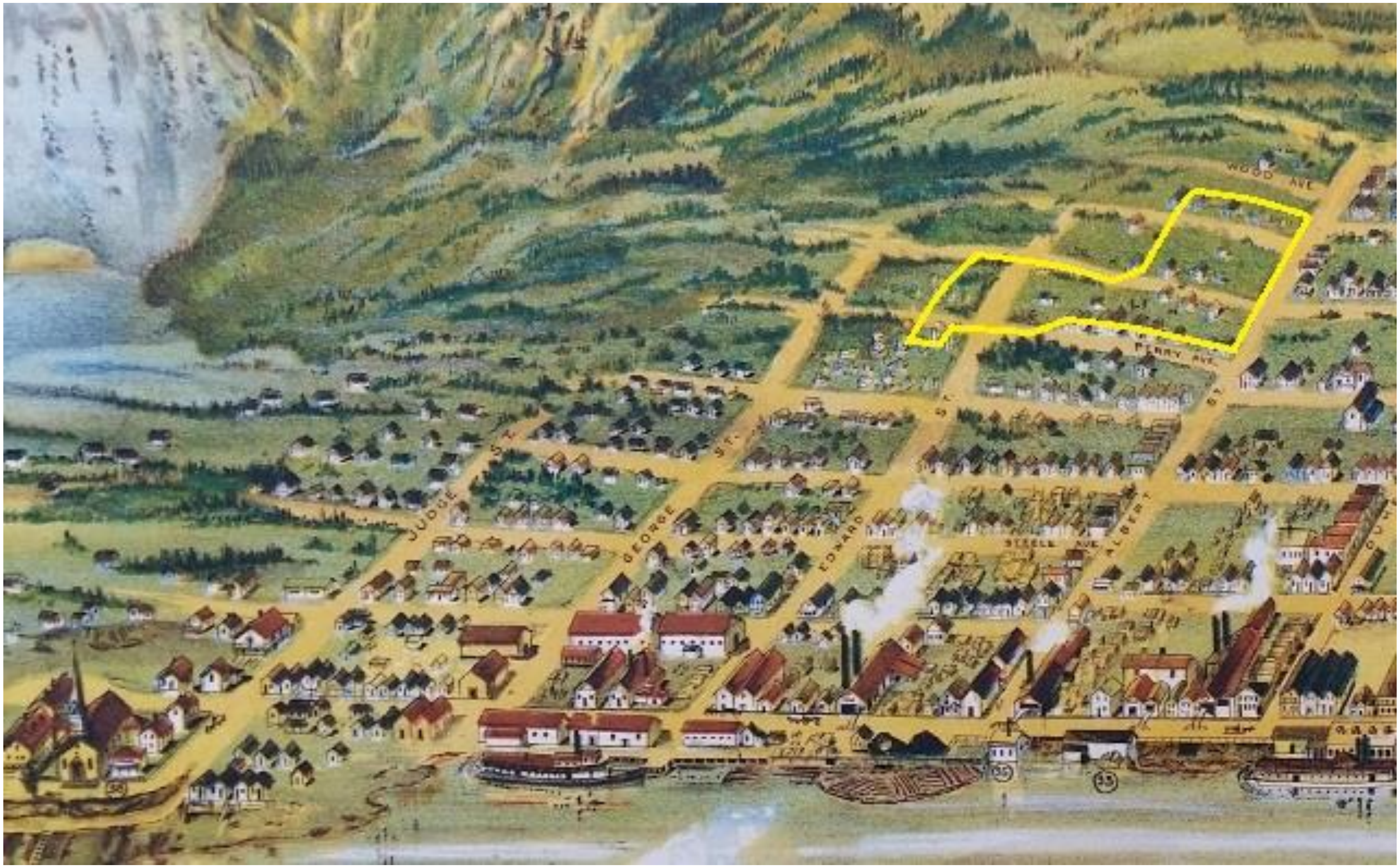
CHILKOOT GEOLOGICAL ENGINEERS LTD.

Geotechnical Evaluation – Geohazard Assessment

Block 4 - North End Subdivision – Dawson City, Yukon – 2017

Figure 6

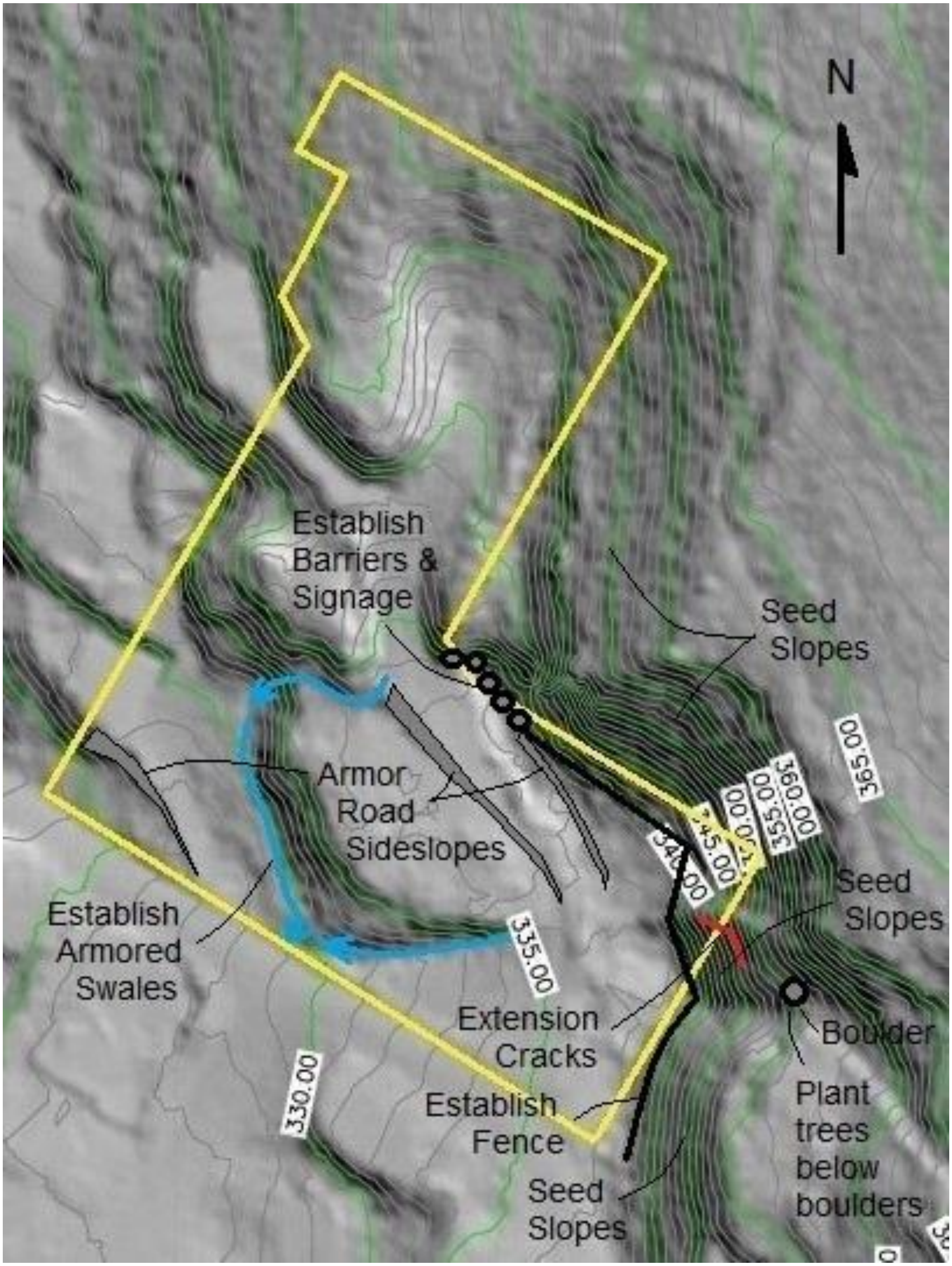
Historical (1903) Setting



Based map from 'Birdseye view of Dawson' by Dr.J.Bell – 1903

Compiled June 22, 2017 by T.Dhara

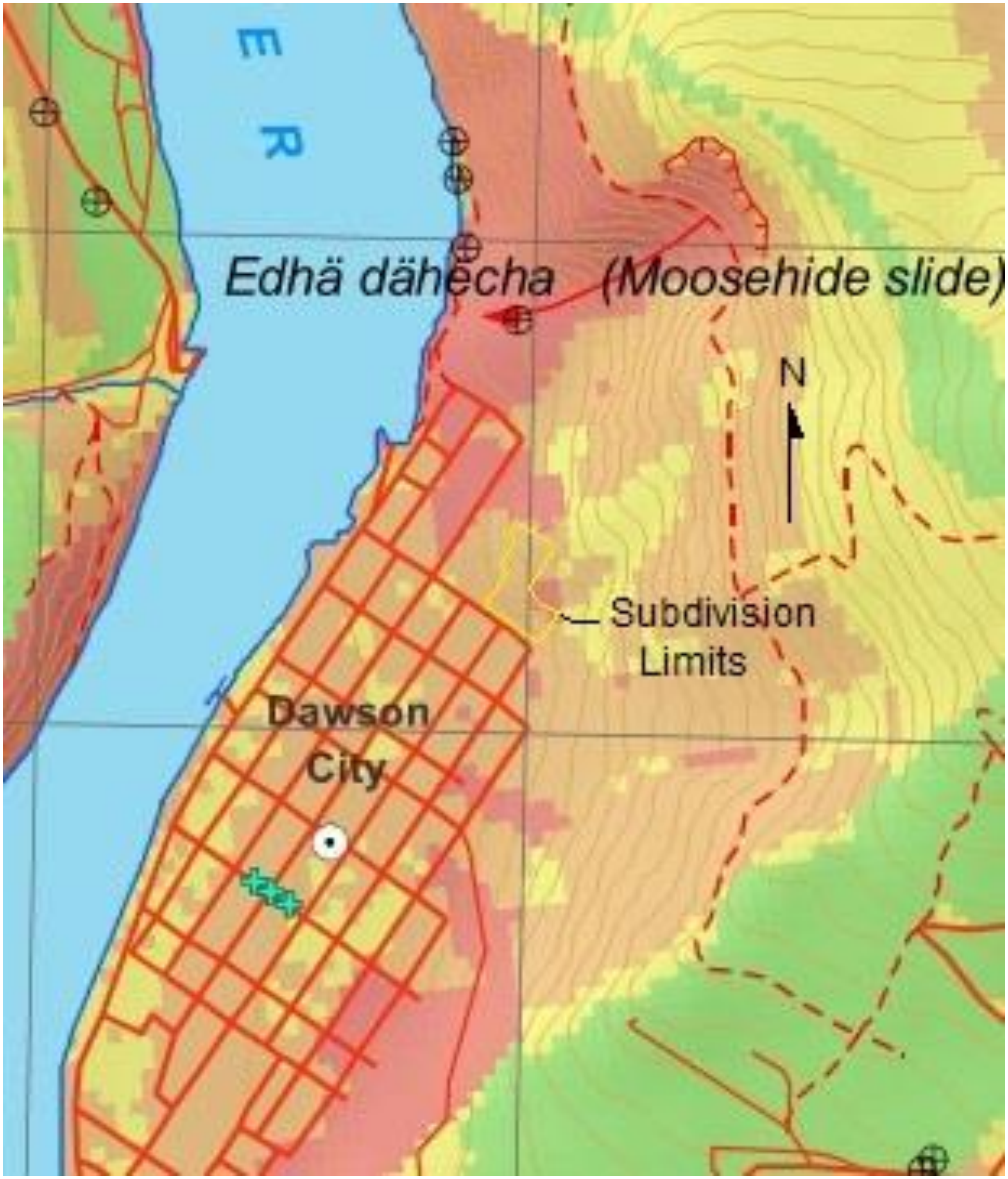
Geotechnical Evaluation – Geohazard Assessment
Block 4 North End Subdivision – Dawson City, Yukon – 2017
Figure 7 – Proposed Hazard Mitigation Plan



Base map supplied by YG through Underhill Geomatics Ltd.
Locations are approximate – Not to Scale

Compiled June 25th, 2017 by T.Dhara, P.Eng.

Geotechnical Evaluation – Geohazard Assessment
Block 4 - North End Subdivision
Dawson City, Yukon – 2017
Appendix A
Natural Hazard Risk Map from *North Climate ExChange*



Base map modified from Landscape Hazard Risk map compiled by *Northern Climate ExChange*

HAZARD CLASSIFICATIONS

Low risk. Characterized by flat to gently sloped terrain, with south and west-facing slopes. Low-risk terrain is found above modern floodplains, and is often comprised of well-drained gravel or weathered bedrock surface materials. Low-risk terrain may contain permafrost, but is less likely to be ice rich compared with more hazardous terrain.

Moderate risk. Characterized by gentle to moderate slopes, and occurs more commonly on west and south-facing slopes. Moderate-risk terrain is found on the steep edges and cold aspects of low-risk landforms (*i.e.* fluvial terraces and north-facing, high-elevation slopes). Moderate-risk terrain also occurs in coarse-grained (gravel) surficial materials that may be affected by ice-rich permafrost (*i.e.* downtown Dawson).

Moderately high risk. Characterized by moderate to steep slopes, and east to north-facing slopes. Moderately high-risk terrain is found on all aspects in the study area and is common in narrow, steep-sided valleys and on more gentle slopes where permafrost is more likely to be present. The difference between moderate and moderately high-risk terrain in the study area is often based on changes in slope angle and slope aspect.

High risk. Characterized by moderate to steep slopes and coldest east and north-facing slopes. Much of the high-risk terrain in the study area is defined by geological boundaries containing high-hazard processes such as landslides, thermokarst, and active floodplains that may be subject to flooding. High-risk terrain in the study area occurs in valley bottoms (flood risk and high permafrost probabilities), on steep north-facing valley slopes, and where landslide processes have affected large areas of terrain (*i.e.* landslides on the north side of the Klondike Valley).

LEGEND

GROUND OBSERVATION SITES

geological field station
permafrost borehole
electrical resistivity tomography (ERT) profile station

GEOLOGICAL FEATURES

collapsed open system pingo
thermokarst pond

landslide escarpment
direction of landslide movement

TOPOGRAPHIC FEATURES

roads
trails
transmission line
limit of mapping

contours
streams

waterbodies

wetlands

Information from <u>Landscape Hazard Risk</u> map compiled by *Northern Climate ExChange*

METHODS

This map was produced for the purposes of community landscape hazard assessment and climate change adaptation planning for the Dawson region. An accompanying report provides additional detail on local surficial geology, stratigraphy, glacial history and landscape hazards (Benkert et al., 2015). The report is published by Yukon College's Northern Climate ExChange and is available for download at yukoncollege.yk.ca/research.

Landscape hazards for the Dawson region are modelled using a Geographic Information System (GIS) to generate an integrated risk ranking for each landscape 'unit' (defined by 30 m x 30 m pixels). Input data for the model include the following datasets: slope angle (steepness); slope aspect (directionality and exposure to sunlight); surface materials (derived from geological maps); and permafrost probability (see Benkert et al., 2015 for additional details).

Attributes of the individual datasets are classified on a 0-9 scale of potential risk, where zero represents low hazard risk and nine represents high hazard risk. High-risk areas include steep or unstable slopes, low-lying areas subject to flooding or inundation by water, and landscape units with a high likelihood of being affected by ice-rich or thaw-unstable permafrost. Low-risk areas are predicted to have favourable conditions for landscape development and include well-drained soils, gentle or moderate slopes, and a low likelihood of containing ice-rich or thaw-unstable permafrost.

Each of the input datasets is assigned a unique weighting value in the model that reflects the degree to which they control cumulative hazard risk. For this model, slope angle was given a weighting of 10%. Slope aspect was also given a weighting of 10%. Surface materials have a significant impact on landscape stability, and this input dataset was given a weighting of 50%. The likelihood of permafrost occurring on the landscape was given a relative weighting of 30% in the model (recognizing that slope aspect also contributes to permafrost presence).

Cumulative Ranking = 0.1(slope angle) + 0.1(slope aspect) + 0.5(materials) + 0.3(probability of permafrost)

By combining the individual rankings of each input raster according to their unique weighting, a cumulative risk ranking for each pixel in the map area is generated. Risk rankings range from 0 (low) to 9 (high). The cumulative rankings are reclassified into four categories (Low, Moderate, Moderately High and High) that represent potential hazard risk due to permafrost, slope stability, and flooding in the map area. The model represents current conditions, and does not integrate any potential changes to landscape stability associated with a changing climate.

LIMITATIONS TO THE MAP

The Dawson hazards map is meant to be used as a preliminary assessment of potential ground conditions in the study area, and does not replace detailed on-site investigations. Cumulative hazard rankings are highly dependent on rankings assigned to surface material units, and both the boundaries of the units and the materials assigned to those units are highly subjective and based on limited field checking conducted during surficial geological mapping studies (see map by McKenna and Lipovsky (2014) in Benkert et al., 2015 for more detail).

Additionally, flood hazard mapping does not yet exist for the study area and flood potential is based on geological units mapped as active floodplains or as being subject to periodic inundation. These units likely represent areas that are subject to regular annual or decadal flooding, but are unlikely to represent the highest and most catastrophic floods with lower recurrence intervals. See Figures 10 and 11 in Benkert et al. (2015) for preliminary flood risk mapping. (Note: this mapping has not been integrated into the hazard risk assessment presented here.)

Finally, the resolution of this map is limited by the 30 m x 30 m pixel size used to calculate slope, aspect, and permafrost probability, and the 1:25 000-scale mapping used to identify surficial materials and landforms. Local variations in all model inputs should be expected, and will be more pronounced for surface materials and permafrost probability.

It is important to note that cumulative hazard rankings are based on general observations of surface materials, drainage, slope angle, vegetation and the presence of permafrost landforms, as well as subsurface information provided by ERT and GPR profiles, drilling and probing of permafrost, and textural analyses of surficial and borehole samples. This has resulted in a projected risk ranking that will require geotechnical and/or engineering analyses to quantify.

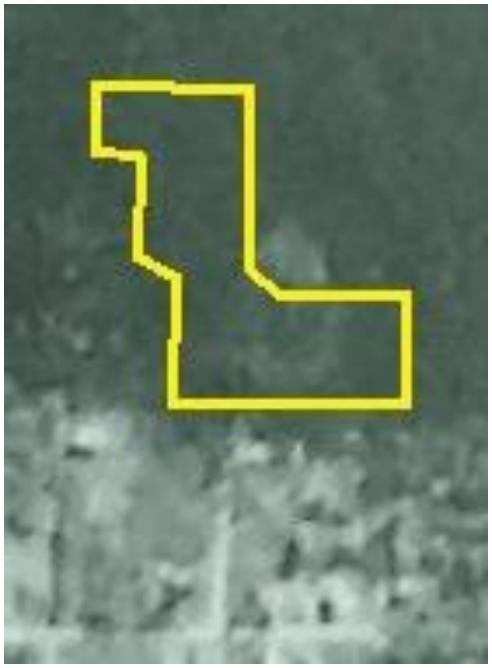
CITATION

Benkert B.E., Kennedy, K., Fortier, D., Lewkowicz, A.G., Roy, L.-P., Grandmont, K., de Grandpré, I., Laxton, S., McKenna, K., Moote, K., Bond, J., 2015. Dawson City Landscape Hazards: Geoscience Mapping for Climate Change Adaptation Planning. Northern Climate ExChange, Yukon Research Centre, Yukon College. 166 p and 2 maps.

Digital cartography and risk modeling by K. Kennedy, B. Elliot and P. Lipovsky, Yukon Geological Survey.

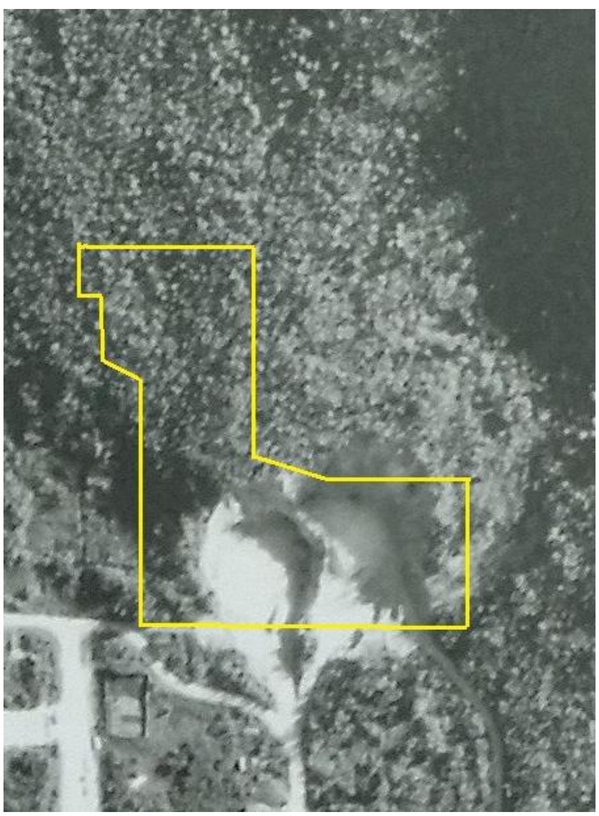
Information from Landscape Hazard Risk map compiled by *Northern Climate ExChange*

Geotechnical Evaluation – Geohazard Assessment
Block 4 – North End Subdivision
Dawson City, Yukon – 2017
Appendix B – Selection of Airphotos



1951

1970



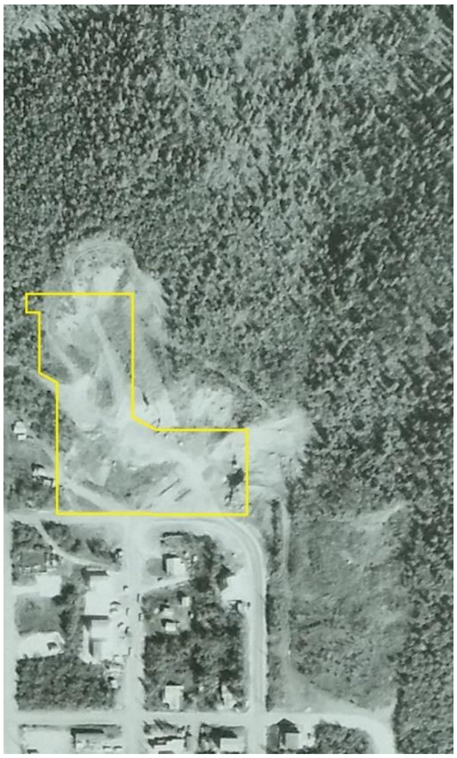
1978

1984

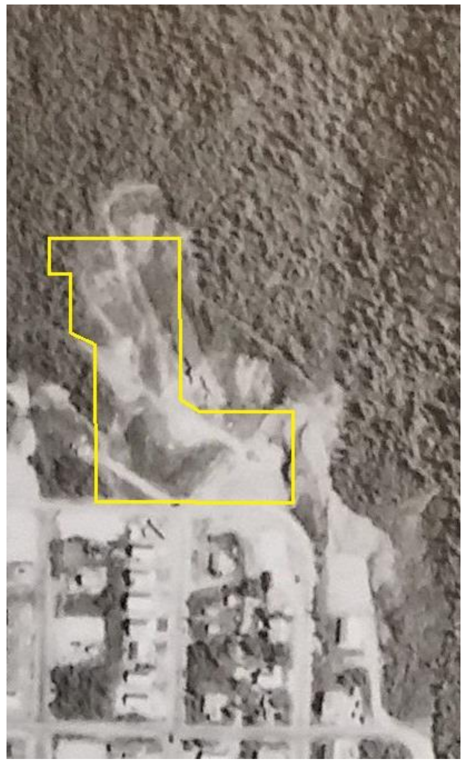
Site boundaries are approximate – Not to scale

Compiled June 17, 2017 by T.Dhara

Geotechnical Evaluation – Geohazard Assessment
Block 4 – North End Subdivision
Dawson City, Yukon – 2017
Appendix B – Selection of Airphotos



1987



1990

1993

2004

Site boundaries are approximate – Not to scale

Compiled June 17, 2017 by T.Dhara

Appendix C

EBA Engineering December 3rd, 2013

Geotechnical Evaluation Report

Attached separately due to file size