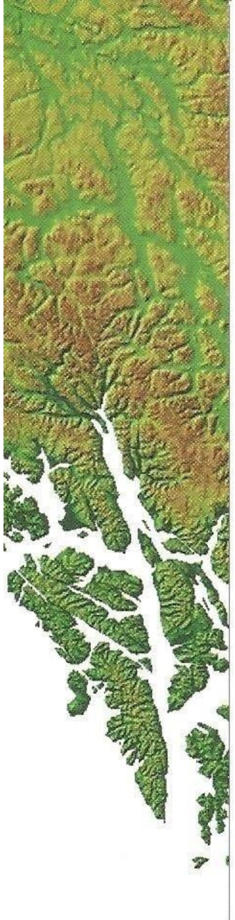

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Geotechnical Evaluation
Proposed North End Subdivision
Dawson City, Yukon – 2016

St.Mary's Church & Hospital - *Circa 1901*
With permission from *Jim Robb collection*

Prepared For: **Yukon Government – Energy, Mines and Resources**

Date : **September 18, 2016**

EXECUTIVE SUMMARY
Geotechnical Evaluation
Proposed North End Subdivision
Dawson City, Yukon – 2016

Chilkoot Geological Engineers Ltd. was retained by the *Yukon Government – Energy, Mines and Resources – Lands Management Branch* to conduct a geotechnical evaluation for the proposed North End Subdivision located in Dawson City, Yukon. While this region was once a vibrant part of Dawson City which was utilized for residential, commercial and industrial purposes during the Gold Rush Era, it has lain essentially dormant since the 1940's with the exception of a sporadic assemblage of residential houses which have been constructed over the years.

Given the time span the area lay dormant, the intent of our evaluation was to determine the geotechnical feasibility of residential development within the study area and retain site specific information through drilling methodologies from the western (Yukon River) half of the study area. Beyond near surface samples, subsurface information from the eastern half of the study area was not retained as additional planning consideration was required to allow for access to the lots and subsurface utility routes in this region. This region was however incorporated into a literature review and site reconnaissance which was conducted to allow for a preliminary assessment. Collectively, this information allowed us to formulate geotechnical recommendations from a regional perspective to assist in the design and construction of subsurface utilities, surface roads and buildings within the study area.

In addition, as portions of the study area lie within the limits of a pre-historic landslide known as the Moosehide Slide (*Ëddhä dädhëchą* in Gwich'in), we also summarized readily available technical information pertaining to the failure and provided preliminary discussions regarding the potential hazards that may exist in the region. It was beyond our scope-of-work however to conduct a natural hazards assessment.

In brief, our evaluation determined that the terrain and soil conditions which were encountered within the study area will generally be suitable for residential subdivision development. However, as some of the regions are inaccessible or will otherwise need to be utilized as geotechnical setbacks/buffers (as a precaution for potential natural hazards which were identified), some restrictions upon development will apply.

Our evaluation found that of the ~104 lots which were evaluated, approximately 40 of them were deemed suitable for development. Rezoning, lot amalgamation and adjustments to the lot lines will be required to maximize the development potential of the area.

The presence of both fluvial and colluvial deposits (as well as fills) which are prevalent throughout the study area, will require engineering design consideration if development is to occur as these materials are predominately frozen and are undergoing periglacial, mass wasting and/or thaw-degradation processes. Any development will need to minimize the thermal and physical disturbances that construction will have upon these materials and processes. The design will need to accommodate movements that may result from fluctuations in the underlying soil volumes and/or slope movements. While these soil types and conditions will pose additional geotechnical challenges relative to standard infrastructure design and construction, their presence shouldn't prohibit development. In fact, the majority of the town-site has already been developed upon these very deposits and site conditions.

As permafrost is prevalent throughout the study area, it's critical that a proper drainage regime is established in order to protect the permafrost and maximize the life of the subdivision. As such, in addition to upgrading the roads and infrastructure within the study area, the individual granular building pads and lot accesses should be carefully established. This will allow for proper (local and regional) drainage and thus greatly assist in the long-term stability of the region.

While individual residences will need to be constructed utilizing cribbing and ventilated crawlspace foundation systems (as is the standard in the northern regions of Dawson), consideration should be given to developing a multi-story public use building (on Front Street) which is founded upon a concrete slab-on-grade type of foundation system as the subsurface conditions are favorable in this area.

Given the nature of historical development and the serpentinization of the parent rock (and hence the potential for asbestos occurrences), an environmental site assessment of the study area should be conducted to better assess the potential environmental hazards.

While it's understood that annual displacement monitoring of Moosehide Slide is being conducted by the *Yukon Geological Survey*, a natural hazards assessment should also be conducted to better characterize the potential hazard that the slide may pose upon the study area.

A supplemental geotechnical evaluation should be conducted once a conceptual design has been determined to verify the geotechnical parameters which have been outlined herein.

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Dawson City, Yukon – 2016

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1.0 INTRODUCTION

Chilkoot Geological Engineers Ltd. was retained by the *Yukon Government (YG) - Energy Mines and Resources* to conduct a geotechnical evaluation for the proposed North End Subdivision located in Dawson City, Yukon. The location and limits of the study area have been illustrated in Figures 1 and 2, respectively.

The purpose of the evaluation was to determine the development potential of terrain located within the study area from a geotechnical perspective with the intent to develop residential lots and supporting infrastructure.

Authorization to proceed with the work was granted on July 19th, 2016 by *YG - Energy, Mines and Resources - Lands Management Branch - Program Manager*, Mr.K.Fisher. The field work was conducted between July 20th & 28th, 2016 in accordance with our May 30th, 2016 Proposal.

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

2.0 SCOPE-OF-WORK

The intent of our evaluation was to determine the residential development feasibility of the study area and retain site specific geotechnical information through drilling methodologies from regions within the western half of the study area. The drilling allowed for detailed characterization of the soil conditions such that geotechnical parameters for subsurface utility installations and road construction could be identified in the western regions. Subsurface geotechnical information was not retained from the eastern half of the study area as additional planning considerations would be required to allow for lot access and utility routing in this region. Although subsurface geotechnical information (beyond depths of 1 meter) was not retained from any of the building lots (due to the presence of dense foliage), sufficient information was retained through a literature review and site reconnaissance to allow for an assessment of the residential development potential of these regions.

Although portions of the study area lie within the limits of the Moosehide Slide it was beyond our scope of work to conduct a risk analysis to quantify the potential hazards that the slide may pose. However, we have provided preliminary discussions regarding the potential natural hazards and the risks they may present relative to site development based upon the information which was reviewed.

3.0 METHODOLOGY

Our methodology was comprised of a literature review as well as field and laboratory work programs.

3.1 Literature Review

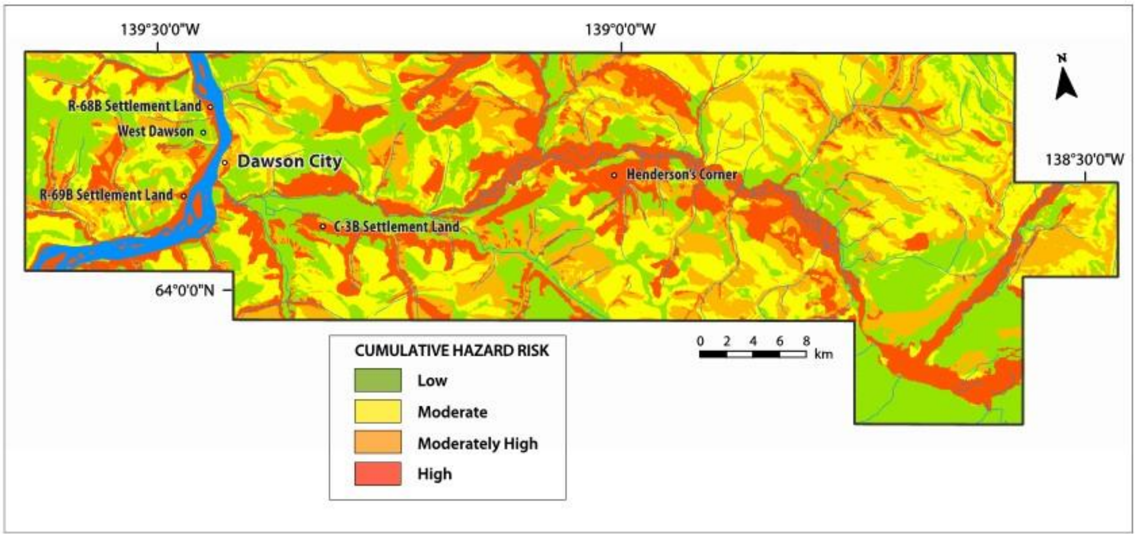
A literature review was conducted prior to the field work program to better evaluate the regional conditions and detail the field work programs. The following sources of information were reviewed;

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) will 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.

The Dawson City landslide (Dawson map area, NTS 116B/3), central Yukon 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 rock 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 be re-contoured in the early 1980’s following quarry operations.

Ongoing displacement monitoring at the Dawson City landslide (Dawson map area, NTS 116B/3) prepared by M.Brideau, D.Stead, C.Roots and P.Lipovsky, 2012.

This work summarized five (5) years of slide observations which were taken since the establishment of monitoring arrays described above in the 2007 paper.

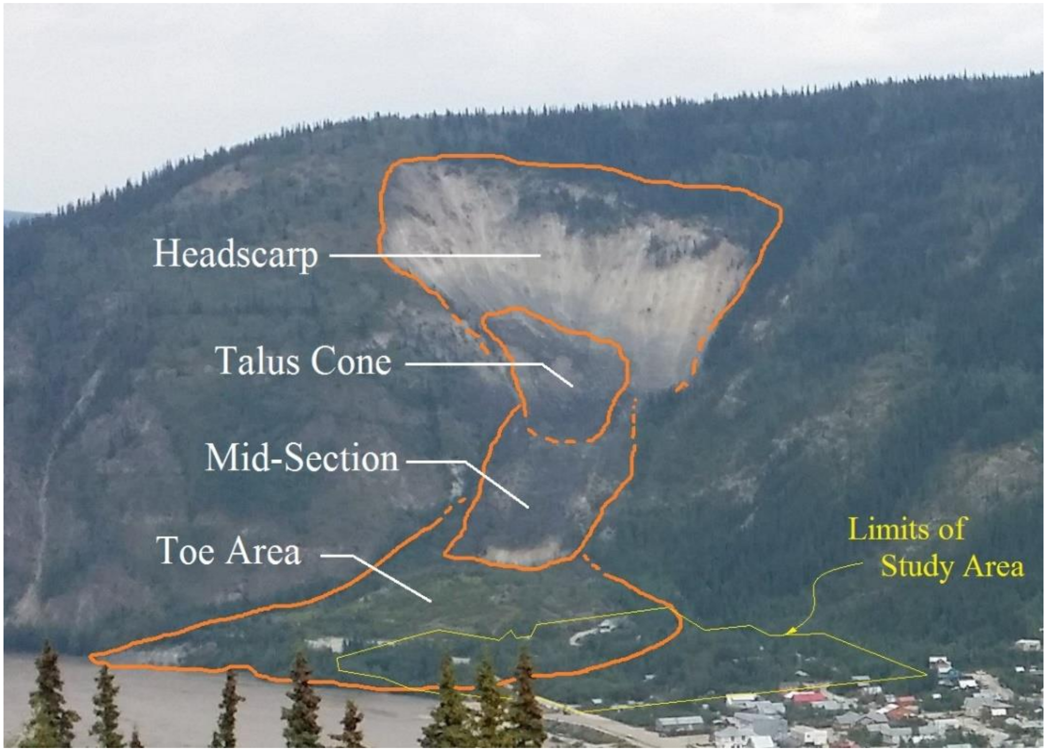
The study separated the slide into four (4) distinct areas comprised of;

a headscarp,

an upper talus slope/cone (which is an accumulation of rockfall),

a central moving section, and

a lower (toe area) zone of re-contoured debris.



View of slide and study area facing north-east. Photo taken from road to Sunnydale in West Dawson.

The paper indicated that five (5) years of monitoring was not long enough to identify trends and so the risks associated with the unstable block (identified in 2007) above the headscarp, could not be determined. However, the paper quantified the volume of the unstable block which lay above the headscarp as measuring roughly between 10,000 and 50,000 m^3. For comparison purposes, our firm estimated that the volume of the original slide may have been in the order of 500,000 to 750,000 m^3.

The data noted movements within the headscarp which ranged between 4.3 and 11.9 cm/year and movements in the central section which ranged between 8.5 and 20 cm/year.

It's understood that annual monitoring of the slide is ongoing.

<u>Geotechnical Evaluation – Proposed 2nd Avenue Upgrades - 2014</u> dated September 30th, 2014 prepared by our firm for *YG – EMR*.

The purpose of the evaluation was to characterize the sub-surface conditions along 2nd Avenue and assess the regions overall feasibility to allow for;

- an extension of 2nd Avenue subsurface utilities from Edward Street to Judge Street,
- road upgrades, and
- future lot development on either side of the avenue assuming engineered cribbing types of foundation systems.

A total of four (4) boreholes were advanced during the evaluation at the locations noted in Figure 2. BH 1-14 and BH 2-14 were advanced within fluvial deposits. BH 3-14 encountered colluvial slide deposits which overlay these fluvial deposits. BH 4-14, which was advanced at higher elevations, encountered predominately colluvial slide deposits.

In brief, the evaluation determined that the subsurface conditions encountered at the site will be suitable to allow for road upgrades and installation of sub-surface utilities. While deemed feasible, the residential development potential will vary along 2nd Avenue.

The geomorphic conditions supported the construction of standard PWF cribbing and ventilated crawlspace types of residential foundation systems founded upon structural granular pads, however, additional assessment would be required on a case-by-case basis once the individual building sites have been identified.

<u>Geotechnical Investigation – Proposed 7th Avenue Utility Expansion, Dawson City, Yukon – 2009-2010</u> dated March 16, 2010 prepared by our firm for the *City of Dawson*.

The purpose of the evaluation was to characterize the sub-surface conditions along portions of 7th Avenue and assess the regions overall feasibility to allow for an extension to subsurface utilities.

The originally proposed expansion was to extend the existing 7th Avenue utilities from King Street to Albert Street and then progress along Albert Street to 6th Avenue. However, following site reconnaissance work, the proposed route was modified to tie-in to the 6th Avenue utility along Duke Street as the region between Duke and Albert Street (along 7th Avenue) appeared to be bedrock controlled. The scope-of-work was expanded on October 1, 2009 following discussions with the *City of Dawson*, CAO to include a separate expansion area at the corner of 8th Avenue and Queen Street to facilitate service upgrades to potential building lots in the area.

Envisioned 7th Avenue utility expansion.

A total of five (5) boreholes were advanced during the work through predominantly colluvial apron deposits as described below.

The borehole soil logs and a site plan denoting the approximate borehole locations have been attached in Appendix B for reference purposes.

Based upon the information obtained during the investigation, the installation of sub-surface (sanitary and water) utilities through conventional excavation/backfill construction methodologies will be feasible at the proposed development areas, However, additional consideration may be required if permafrost is encountered at the installation depth. In addition, the evaluation determined that there is a potential for encountering bedrock.

<u>Geotechnical Evaluation – Lot 8 – Block 2, Dawson City, Yukon – 2014</u> dated August 19, 2014 prepared by our firm for *YG – EMR.*

The evaluation was conducted to determine the feasibility of developing the lot for residential purposes. In brief, a borehole was advanced on 2nd Avenue through frozen fluvial deposits as access to the lot was restricted due to the presence of heavy vegetation. The evaluation determined that residential construction would be feasible utilizing a cribbing and ventilated crawlspace type of foundation system founded upon a granular pad.

The borehole soil log (1-14 – Lot 8) has been attached in Appendix B for characterization purposes. The location of the borehole has been denoted on Figure 2 – Study Area, Borehole and Hand Auger Locations.

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.

We have included a portion of this map and have denoted the limits of the study area in Figure 3 – Surficial Geology.

The map indicated that the study area lies in a region dominated by colluvial deposit, however, fluvial deposits were also identified in the south-western quadrant.

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. In addition, 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.

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 5- Historical Setting.

The locations of the former roads which were once utilized in the study area (but which have now become overgrown) were superimposed onto a *Google Earth* map of the study area to better illustrate the past use of the region. This imagery has been attached as Figure 6 – Historical Development.

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* - Poor resolution but Front Street, 2nd Avenue and the three roads east-west (Edward, George and Judge Streets) can be noted. 5th/6th Avenue quarry is visible along with the quarry located north of the slide region. A road along the Yukon River at the toe of the slide is clearly visible. A large building is located between Front Street and 2nd Avenue and Edward and George Street.

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

1970 – *A22199* - Moderate intensity quarry operations at the slide area and 5th

Avenue. Edward Street cleared from Front Street to 3rd Avenue. Steele Street established to Judge. A flat clearing has been established in the toe of the slide area.

1977 – *A24708* – A trail on George Street, which extends to the east beyond Steele Street has been established. High intensity quarry operations are occurring at the 5th Avenue Quarry. Quarry operations are ongoing at the slide area.

1984 – *NW9584* – The north-east corner of Judge Street has not yet been established. High intensity quarry operations are occuring on the slide area. The region between 2nd Avenue and Steele Street cleared from Albert Street to Edward Street.

1987 – *WP8718* Judge Street has been extended east to the present day north/south alignment. Present day road alignments essentially established. Old warehouse/building between Front Street and 2nd Avenue and Edward and George Street has been removed. Quarry at slide area has been reclaimed and a prominent line of boulders established at the toe of the slope has been established to prevent site access.

1990 – *A27664* – Moderate intensity quarry operations are ongoing at 5th/6th Avenue Quarry.

1993 – *A27857* - Quarry operations at 5th/6th Avenue Quarry appear to have ceased.

2004 – *G0307068* – The southwestern region of the study area has been essentially cleared from the intersection of 4th Avenue and Albert Street diagonally to the intersection between George Street and 2nd Avenue and then advances towards Front Street along George Street. Much of this area has since become overgrown.

The locations of the former roads and trails which were once utilized in the study area (but have now become overgrown) were superimposed onto a

Google Earth map of the study area to better illustrate the past use of the region. This imagery has been attached as Figure 6 – Historical Development.

A selection of the above noted aerial photographs have been attached in Figure 7 – Selection of Air Photos.

Sub-surface Utility Plans

The *City of Dawson – Public Works Department* was contacted to obtain plans which denoted the locations of nearby sub-surface utilities which were comprised of sanitary and water lines as well as storm water drainage systems.

The sub-surface utility plans noted the presence of (200 mm Ø) sanitary and water lines within the extreme southern realms of the study area extending into 2nd Avenue and Judge Street as noted in Figure 8a.

The storm water drainage system noted the presence of a catch basin (on Front Street) and several area culverts as illustrated in Figure 8b. The plan also shows *City of Dawson – Public Works Department* hand written comments regarding (essential requirements for) envisioned culverts and ditches to assist in regional drainage.

From discussions with *Public Works Department* personnel, it was understood that newer sub-surface utilities are encased in corrugated steel pipe (CSP) culverts such that a more robust 'super-pipe', which can accommodate considerable ground movement, is created. From our discussions, it was understood that relative to the colluvial and fluvial deposits where utilities have been installed, more maintenance appears to be required in zones where installations are embedded within the fluvial deposits.

3.2 Field Work Program

The field work program was comprised of a site reconnaissance, utility locates and drilling program.

Site Reconnaissance

A site reconnaissance was conducted between July 20th to 28th, 2016 to note the field conditions and geological features within (and just beyond) the study area. The exception to this were regions where residences were established within the study area 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.

Site Reconnaissance - Conditions along Steele Avenue

Utility Locates

Utility locates were conducted prior to drilling in order to confirm that the proposed borehole locations were clear of potential underground hazards. This involved contacting *Northwestel*, *Yukon Energy Corporation Ltd (YECL)*, and the *City of Dawson*.

In brief, *Northwestel* and *YECL* indicated that their infrastructure was comprised of overhead lines. The *City of Dawson* indicated that sanitary, water and storm water drainage lines were located as noted in Figures 8a & 8b. It was understood that the existing sanitary and water utilities are located in the order of 3 meters below the existing road grades.

In general, the proposed borehole locations were clear of underground utilities. Of note however, it became apparent during the evaluation that there were some locations within the study area where local residents have installed miscellaneous infrastructure such as septic fields/tanks, seasonal subsurface water lines and subsurface electrical lines and so onsite precautions during the field work program were taken.

Drilling Program

The drilling program was conducted on July 25th and 26th, 2016 by *Donjek Drilling* utilizing a CME-750 drill mounted on a 3-ton 4-wheel drive truck. The drill was employed under the direction of our firm.

Drilling BH 3-16

The program was comprised of advancing six (6) boreholes in order to obtain soil samples and characterize the subsurface conditions utilizing both 150 mm Ø solid-stem and 200 mm Ø hollow-stem continuous flight augers. The 200 mm Ø hollow-stem continuous flight augers allowed for standard penetration test (SPT) methodologies to be employed.

The SPT's allowed for an assessment of the relative density of sub-surface soils by measuring the number of blows (N-value) required to drive a 50 mm diameter uncased sampler tube a distance of 300 mm utilizing a 63.5 kg hammer dropped from a height of 760 mm. These 'N' values allowed for correlation of the noted resistance relative to the materials density/consistency where thawed materials were encountered. The approximate correlation has been presented on the '*Notes on Soil Logs'* enclosed in Appendix B. In addition to assessment of the materials relative density, the testing allowed for the

SPT @ BH 4-16

retention of relatively undisturbed samples to allow for more a more accurate characterization of the soil conditions.

The boreholes were advanced to an average depth of 8.50 meters but varied between 5.94 meters (BH 4-16) and 10.67 meters (BH 6-16).

The approximate locations of the boreholes have been plotted on Figure 2 relative to prominent site features. In addition, the figure denotes the locations of the boreholes which were advanced during the 2nd Avenue and Lot 8, Block 2 - Geotechnical Evaluations for ease of reference.

Borehole and Site Survey

Following completion of the drilling, the elevations of the boreholes were surveyed relative to the intersection of Edward Street and 2nd Avenue, utilizing a (*Leica LR Rugby*) laser level. The road surface at this location was utilized as the benchmark during the 2nd Avenue Geotechnical Evaluation and so was given the same arbitrary elevation of 100.00 meters such that a comparison between the borehole elevations and stratigraphycould be made. A level survey noted a vertical relief of ~ 10 meters along 2nd Avenue between Edward and Judge Streets. The elevations of the boreholes have been noted on the Borehole Soil Logs enclosed in Appendix B.

A cross-sectional survey was also conducted between the low lying areas immediately north of George Street and the Yukon River. In brief, the following elevations were noted;

Cross sectional survey – Yukon River to lots north of George Street

Location	***Elevation (m)***
Edge of Slide just north of George St.	101.92
Ground Surface @ Auger Hole No. 4	100.33
Low region (north of George St. & east of Front Street)	99.97
Centerline of George and Front Street	100.99
Toe of Dike – Front Street side by BH 3-16	100.27
Top of Dike @ George Street	101.60
Toe of Dike - Yukon River side	98.31
Yukon River	96.20

Borehole Soil Logs

During drilling, field soil logs were maintained by the undersigned to record the stratigraphy of the soils that were encountered. The logs recorded the following information;

Soil description

(depths, color, relative moisture content and density, gradation/plasticity, inclusions, oxidation, transition zones)

Sample depths and types

Temperatures -

Intermittent temperature readings were recorded utilizing a digital-thermometer (TPI Model 342, Type K Thermo-coupler).

Unconfined Compressive Strength -

A *Humboldt Manufacturing Ltd*. pocket penetrometer was intermittently utilized on cohesive (fine-grained) soils to provide relative estimates (in kg/cm^2) of the materials unconfined compressive strength.

Material Classification -

The results of the laboratory analysis formed the basis of the material classification, however, field and laboratory observations were also utilized.

Depth of groundwater

Other pertinent geotechnical information

Comments regarding drilling effort

The above noted information was utilized along with visual observations and results of the laboratory analysis in order to compile the Borehole Soil Logs which have been enclosed in Appendix B.

The appendix also includes '*Notes on Soil Classification'* which provides additional information regarding the nature of the soil log descriptions. A copy of the *'Unified Soil Classification System'* and the *'Classification for Frozen Soils (adapted by Linnell and Kaplar, 1966)'*, which were utilized to classify thawed and frozen soils respectively, have also been attached at the beginning of the appendix for reference purposes.

Sampling Program

Soil samples were retained at regular intervals (approximately 2 samples per 1.5 meters) during the field work by obtaining grab samples directly from the auger flighting.

A total of sixty-three (63) soil samples were retained during the drilling program.

Once the samples were retained, they were described on the field soil logs. Each sample was subsequently sealed in air-tight plastic bags and numbered consecutively. The samples were subsequently transported to our Whitehorse laboratory facilities to undergo more detailed examination and analysis as described in Section 3.3, below.

Borehole Termination

The boreholes were terminated at an average depth of 8.50 meters below the existing ground surface, but varied between 5.94 meters (BH 4-16) and 10.67 meters (BH 6-16). Refusal was encountered in BH 2-16 at a depth of 8.23 meters and BH 4-16 at a depth of 5.64 meters, after encountering a possible boulder and extremely dense soil conditions respectively.

The solid-stem boreholes were backfilled with the auger cuttings approximately 15 minutes following completion of drilling. This allowed for time to estimate rates of groundwater seepage or borehole collapse (to assess the relative degree of soil densities). Seepage was not noted in any of the boreholes during this elapsed time frame. However, borehole collapse was noted in all four (4) of the solid-stem boreholes upon auger withdrawal. The amount of collapse varied depending upon the soil types encountered at the depth of borehole termination. Where fluvial deposits were encountered (BH 1-16, BH 2-16 & BH 6-16) the average amount of collapse was noted to be 0.44 meters (with a standard deviation of 0.15 meters). Borehole BH 5-16, which was terminated in decomposed serpentine rubble/(possible bedrock), experienced 3.82 meters of collapse. The final elevation of collapse in this borehole roughly coincided with the interface between the decomposed serpentine and the overlying slide rubble.

A 1.0 meter thick zone of bentonite was established at the interface between the fills and organic strata (or in their absence at a depth between ~ 1 and 2 meters) in accordance with good drilling practices where solid-stem boreholes were advanced.

Monitoring Well Installations

2" diameter ABS monitoring well were installed in BH 3-16 and BH 4-16 to depths of approximately 5.93 meters and 5.77 meters below the existing ground surface, respectively. The wells will allow for future monitoring of the local groundwater conditions.

The lower 3.1 meters of the wells were slotted. This portion of the wells were covered with a silt sock to minimize the influx of fines and extend the life of the wells. The annular space was backfilled with imported filter sand. The exception to this was above the slotted portions of the pipe where a 1.0 meter thick bentonite plug was installed to seal the annular space in accordance with good installation practices. A second 1.0 meter thick bentonite seal was established at a depth between ~ 1 and 2 meters.

Access to the wells were restricted through 4" diameter lockable steel casings which extended approximately 0.8 meters above the existing ground surface. The well casings were painted in a high visibility paint for protective purposes.

Photographs

Photos were taken during the work to document the field work program, laboratory soils samples and site conditions.

Hand Sampling Program

As much of the study area is treed and thus inaccessible to the drill rig, a hand sampling program was conducted through hand excavation methodologies in order to access select regions in the study area. In all, a total of ten (10) locations were sampled (A1 through A10) as noted in Figure 2. The sample locations were recorded utilizing a hand-held GPS unit.

During this time, a total of sixteen (16) soil samples were retained. In general, two soil samples were retained from each sampling location unless shallow refusal was encountered. The first of the two samples was generally obtained through use of a shovel from depths of approximately 0.1 to 0.2 meters. The second sample (at each of the sampling locations) was obtained from the bottom 0.1 meters of the respective sampling locations, following hand auger advancement.

The depth of hand auger advancement varied. Refusal was obtained in all ten (10) of the sampling locations at an average depth of 0.43 meters but varied between 0.1 meters (BH 4-16 & BH 6-16) and 0.85 meters (BH 3-16).

Once the soil samples were retained, they were described on the field soil logs. The soil samples were then sealed in air-tight plastic bags and numbered consecutively in order to allow for subsequent laboratory analysis.

A summary of the soils which were encountered along with the results of the laboratory work program have been presented in Table I.

Auger Hole No.2

3.3 Laboratory Work Program

A laboratory work program was conducted in order to characterize the index properties and conditions of the retained soil samples.

The analysis was conducted between August 2nd and 12th, 2016 at our Whitehorse laboratory facilities.

In brief, the analysis was comprised of natural moisture content determination and visual laboratory classification of all seventy-nine (79) retained soil samples. The moisture content analysis was conducted in accordance with ASTM D 2216-92. The results of the analysis have been denoted as 'MC' (⦿ - Symbol) on the Soil Logs enclosed in Appendix B.

Twenty-three (23) of the samples were analyzed in greater detail through grain size distribution (in accordance with ASTM D 422-633) in order to classify the soil utilizing the *Unified Soils Classification System*. The results of the analysis have been summarized on the Borehole Soil Logs enclosed in Appendix B and in the Stratigraphic Summary in Table I, with the percent composition of fines (silt & clay), sand and gravel denoted with the symbols - ▲, ● & ■ respectively.

4.0 SITE CONDITIONS

4.1 Study Area

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

The study area lies in a region of Dawson which was once historically developed during the gold rush era but has since lain predominantly dormant relative to housing development. The 1903 drawing by Dr.Bell (enclosed as Figure 5) shows that historically, the study area was a vibrant part of Dawson which was once comprised of houses, sternwheeler docks, industrial warehouses, St.Mary's Catholic church, hospital and school and numerous wall tents. It's understood from the information provided in the The Dawson City landslide (2007 – Brideau et al) technical paper that the three story wooden hospital located on the level portions on the toe of the slide was run between the early 1900's and 1940's. These structures were all situated on a well-developed system of roads. Some of these roads (such as Steele Avenue) have since become fully overgrown with vegetation.

St.Mary's Church & Hospital – circa 1901
With permission from Jim Robb collection

While many of the lots within the study area are undeveloped, local residential infilling has occurred. Some of these infilled lots may have been the result of squatting as many of the dwellings in the area encroach upon lot lines, roads, alleyways, etc. Well established residences are also however, present within the study area along with various historical structures (such as the *Father Judge Cabin*). The remainder of the area is generally treed and harbors a willow/alder bush understory.

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.

Regionally, the vegetation is predominately comprised of sparse boreal forest. Black spruce and birch dominate regions underlain by permafrost. The understory consists of a variety of lichen, mosses, willow, alders and shrubs. Scrub birch and willows are also prevalent from low-lying regions to areas well above the treeline. Eutric brunisols soils developed on loamy colluvial materials are prevalent throughout the region. Permafrost is extensive, discontinuous and overlain with turbic cryosols.

4.3 Site Description

The study area encompasses the most northern region of Dawson City which is accessible by roads originating from the town proper. While these roads allow for access to the majority of the study area, the steepness of the terrain along the eastern limits of the site along (the north-south portion of) Judge Street generally prohibits direct vehicular access onto most of these lots. The local residents have constructed an access trail to their residences in this area.

Lower portions of Moosehide Slide, which is the remnants of a prehistoric landslide, are located within the north-western realms of the study area. The approximate limits of the slide and contacts between the surficial deposits have been denoted on the surficial geology map enclosed as Figure 3 and Figure 10 – Development Potential.

Surface drainage through the study area is poor and generally undefined. Ditches were absent and there were only a few (essentially dysfunctional) culverts present. The prevailing elevations suggests that the regional drainage is towards the south-west and west. Shallow erosion channels were observed in the region immediately east of George Street suggesting considerable seasonal water flow through this area. It is understood that this water originates at the (north-east) corner of Judge Street on a seasonal basis in the spring. Standing water can be expected in local depressions in the spring and summer months.

The study area is well treed with spruce, birch and the odd poplar. The understory is comprised of willow bush and alder.

Local site development and residential construction is occurring on a number of properties just south of the study area on 2nd Avenue and Judge Street. The developments appear to be comprised of granular fill placement upon which cribbing and residential houses are being constructed. Given the historical development, it can be expected that the study area harbors buildings remnants and other miscellaneous debris.

The elevations in the region of the study area vary. In general, the region south of George Street and west of 2nd Avenue was considered predominately level. Higher elevations are encountered as one traverses to the north and east beyond these roadways. An elevation difference of approximately 10 meters was noted following a survey of the boreholes between the Edward Street region (which was near the local benchmark - arbitrary elevation of 100.0 m) and Judge Street (elevation 109.45 m @ BH 4-16) to the north. Slightly higher magnitudes of relief were noted east-west between Front Street and Judge Street. Beyond Judge Street to the east, steeper slopes (in the order of 25-30°) and higher elevations were noted.

The Yukon River, which flows to the north along the western periphery of the study area, lies at a relative elevation of ~ 96.2 meters. By comparison, the top of the dike at George Street was noted to be ~ 101.6 meters. Low lying regions which were encountered just north of George Street and along the periphery of the block encompassed by Front Street and 2nd Avenue and between George and Edward Street were noted to lie in the order of 1 meter below the adjacent roadways.

Geodetic elevations within the study area range from approximately 320 meters (near Albert Street) to 340 meters (beyond Judge Street). The Yukon River lies at an elevation of approximately 316 meters. The top of the dike was constructed to a geodetic elevation of approximately 321 meters. The prominent headscarp lies at elevations of 660 meters. The highest point above the study area is the Midnight Dome at 880 meters.

Panoramic view of study area from intersection of Front and Edward facing north-east. BH 3-16 well on lhs

4.4 Geomorphology

Soil Deposits

The composition and geomorphology of the soil deposits located within the study area varies. The lower elevations (< ~ 101 m) are dominated fluvial deposits. In regions of higher elevations, these deposit are overlain by colluvial apron deposits, generally east of 2nd Avenue. The terrain becomes bedrock controlled further east near Judge Street and beyond where colluvial fan deposits dominate. Slide debris/rubble overlies (and has disturbed) the fluvial deposits north of George Street and generally west of 2nd Avenue.

The distribution of these deposits has been illustrated in the Surficial Geology map enclosed as Figure 3 and in Figure 10 – Development Potential.

Glaciation

Evidence shows that the Dawson area and Klondike Plateau have probably not been 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 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 permafrost is generally widespread throughout the study area.

Watercourses

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

Groundwater

Groundwater was encountered in BH 3-16 at a depth of 4.18 meters (elevation 96.09 meters). This elevation coincides with fine grained fluvial channel deposits which have been described in Section 3.7, below and the elevation of the Yukon River.

Observations of the monitoring wells installed in BH 4-16 and BH 3-14, noted dry conditions.

Perched groundwater conditions would likely prevail at higher elevations due to the presence of underlying fine grained materials and other impermeable boundaries (i.e. bedrock, permafrost, etc.).

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 (which are common in Dawson City) do not appear to 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 and with building density.

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 (as described below) 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. The presence of saturated fine grained soils would make regions more susceptible to this type of hazard.

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.

The prominent Moosehide Slide, the toe of which is located within the study area, is thought to have occurred in the order of 1700 years ago as the result of two (2) separate geological events. The failure is thought to have occurred at/near a contact between serpentine and metasedimentary rocks as the result of high pore-water pressures and seismic activity (Brideau, et al, 2012). The structural geology suggests the headscarp, located ~ 600 meters north of the study area, is near the intersection of a normal and (several) thrust faults as noted in Figure 4 – Bedrock Geology.

Continued slope instability has been recorded in the headscarp, mid-section and toe areas of the slide. The 2012 study suggests the headscarp is moving at rate of 4-12 cm/year while the mid-section of the landslide deposit is moving at higher rate of 9-20 cm/year (Brideau, et al, 2012). The movement is thought to be through either rock glacier (on interstitial ice) or earth flow (on saturated interstitial silt and clays) mechanisms (Brideau, et al, 2007). The upper realms of the failure would be more susceptible to rockfall while the lower toe area would be prone to creep.

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

Typical tree trunk deformation.

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 1-2 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. While these hazards generally originate from the slide headscarp and accumulate in the upper talus zone, they may also originate from and impact lower elevations.

Floods

As with the majority of Dawson, the lower realms of the study area would be prone to flood events if it were not for the protective dike which was established in the 1980's. The higher elevations in the region of the study area will make these areas less susceptible to flood events in the event of overtopping or else rise in groundwater levels.

The lower elevation of the study area would have been previously flooded prior to the establishment of the dike given its proximity to the Yukon River. Historically, flood events in Dawson have stemmed from the formation of ice dams located upstream of the townsite in either the Klondike or Yukon Rivers.

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 and fluvial materials. The colluvial materials are located in regions where higher elevations prevail. These materials are differentially weathered and unsorted. The fluvial materials are generally comprised of deposits which are derived from more recent depositional events. These deposits accumulate in lower elevations, near valley (creek/river) bottoms.

Both types of materials are geomorphologically modified through various mechanisms such as erosional, fluvial, mass movement and/or periglacial processes such as cryoturbation and permafrost processes.

The surficial geology map (Open File 2014-12) described the colluvial and fluvial materials as follows;

Colluvium

"Material transported and deposited by down-slope, gravity driven processes such as creep, solifluction, landslides and snow avalanches. Colluvium is the dominant surficial material in the uplands north and south of the Klondike River and west of the Yukon River as most of these areas escaped Pleistocene glaciation. It commonly has a stratified structure with a highly variable texture and composition controlled by the parent material, transport mechanism and travel distance. Colluvium on uplands and slopes is generally derived from weathered bedrock and loess, resulting in a silt-rich diamicton containing angular, local bedrock clasts. On steeper slopes, colluvium is generally coarser grained, as it has been deposited by rapid mass wasting processes such as rock fall, debris flow and avalanches. Slower processes such as sheetwash, solifluction and creep occur on gentler slopes, which in conjunction with greater accumulations of loess and the presence of near-surface permafrost, result in finer grained colluvium. Colluvial aprons found on lower slopes and the uphill sides of terraces are commonly ice-rich and are primarily composed of re-sedimented loess and peat (muck). North of the Klondike River, Pre-Reid morainal deposits have been extensively modified by slope movement (colluviation) and solifluction and are mapped as complexes of colluvial and morainal deposits."

Fluvial

"Sediments transported and deposited by modern streams and rivers, found in floodplains, fans and terraces. Fluvial materials may be subject to occasional flooding, sudden stream migration and/or inundation. Fluvial deposits typically consist of well-sorted stratified sand and gravel comprising subangular to rounded clasts. Thicknesses up to 10 meters are common. Low order streams in unglaciated areas are confined to very narrow V-shaped valleys and their fluvial deposits are generally not mapped due to scale limitations. Fluvial fans (Ff), or complexes of coalescing fan-shaped landforms (Fa) are found at the mouths of tributary streams. Where smaller streams enter the Klondike River Valley, fluvial deposits usually consist of large amounts of resedimented silt and sand primarily derived from loess with minor gravels derived from colluvial or glaciofluvial materials. These fans, though still active, likely formed relatively quickly after the McConnell glaciation. They may be ice-rich and contain ice wedges, especially where they are north-facing. Active fluvial (FA) materials primarily consist of sand and gravel and are subject to regular flooding."

The fluvial deposits noted in the Dawson area are comprised of Klondike River Valley Deposits. These deposits are characterized by organics/peat which overlie fine grained fluvial materials ranging from sands to silts with minor amounts of gravel. These materials overlie predominately coarse grained materials (where the tailings are derived). Based upon the undersigned's past experience in the Dawson area, it is anticipated that these soils are clean and contain high percentages of cobble to boulder sized materials. They are known to be thaw stable.

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

<u>Fill</u>

Due to the poor founding nature of the soils located in the Dawson area, considerable amounts of fill have been imported into the townsite to facilitate both historical and recent development. The fills may overlie the above noted deposits and are typically coarse grained but may also contain an appreciable amount of fines and deleterious organic materials.

In brief, the surficial geology map indicated that four (4) types of deposits are present within the study area. This includes;

Colluvial Slide Deposits (drzCh-RX) which are hummocky and comprised of mixed fragments, rubble and silt materials which are 'transported by down-slope, gravity-driven processes such as creep, solifluction, landslide and snow avalanches' (as described in the Surficial Geology Map) and Bedrock. Permafrost is widespread throughout these deposits.

These deposits were predominately encountered north of George Street and west of 2nd Avenue.

Fluvial Plain Deposits (szgFp-X) which are comprised of sands, silts and gravels. These materials have been deposited by modern rivers and are subject to frequent flooding. Permafrost is widespread throughout these deposits.

These deposits were predominately encountered south of George Street and west of 2nd Avenue.

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 were predominately encountered between 2nd Avenue and (N-S) Judge Street and south of Judge Street.

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 were predominately encountered east of Judge Street.

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.

<u>Slide Mountain Terrane</u>

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

4.7 Subsurface Conditions

Soil Stratigraphy

Detailed descriptions of the soil stratigraphy that was encountered have been provided on the Borehole Soil Logs attached in Appendix B and in the Stratigraphic Summary attached as Table I. In general, the subsurface soil units which were encountered during the drilling program were classified as either fluvial deposits, colluvial slide debris or combinations thereof. These materials were overlain by fill materials.

A summary of the soil units which were encountered during the drilling program has been described as follows.

<u>Fill (Unit # 1)</u>

Fill was encountered in each of the six (6) boreholes at the ground surface.

The fill is comprised of predominately coarse grained granular materials but may also contain deleterious materials such as wood chips, organic inclusions and silt nodules. As with all fills, it may contain rubble, scrap steel, high levels of fines/organics and/or other deleterious materials. Varying amounts of sawdust, scrap lumber and wood chips may also be encountered within the fill as the study area is located just north of (and partially within) the historical Sawmill District.

The fill materials have been utilized to construct the road base and in some locations (such as central portions of Lots 1-10, Block B between Front Street and 2nd Avenue), lot fill.

Based upon the results of grain size distribution analysis conducted on four (4) samples of the fill, it was on average classified as a Sandy Gravel with some Silt. One of the samples was classified as Silty Sandy Gravel as it contained 21.6% silt. The average moisture content was noted to be 4.9% (by weight) but varied between 2.6% to 6.8%.

The average thickness of the fill measured 0.69 meters but varied between 0.45 meters (BH 5-16) to 1.1 meters (BH 6-16).

Fluvial Deposits (Units # 2, # 3 & # 4)

A sequence of fluvial deposits was encountered in four (4) of the boreholes which were advanced from elevations lower than 106 meters. The stratigraphy of the fluvial deposits in these boreholes was comprised of;

Unit # 2 – Peat/Organic Stratum

which are wet and rich in organics and organic silt, overlying;

Unit # 3 – Alluvial Channel Deposits

which are predominately silty in nature, but may contain finer clay sized materials and/or coarser granular materials, overlying;

Unit # 4 – Alluvial Valley Deposits

which are predominately clean, coarse grained and contain cobble and possibly boulder sized materials.

Unit # 2 –Peat/Organic Stratum;

The peat/organic is comprised of a veneer of organics and rootlets which overlie and are entrained within organic rich silt. These soils are moist to wet and compressible in nature. They serve as an insulating layer to underlying frozen soils and are themselves partially frozen at some locations.

The average moisture contents of the peat/organic statum was noted to be 70.9% but varied between 32.2% and 116.0%. The higher moisture contents are indicative of their frozen nature.

On average, this soil unit measured 0.51 meters thick but measured up to 0.92 meters thick in BH 6-16. These deposits were noted to be thicker towards 2nd Avenue and may be thicker in the regions where undeveloped lots are encountered. The thickness of this deposit in BH 3-14 (advanced during the 2014 2nd Avenue Geotechnical Evaluation), was however ~ 2.9 meters.

The peat/organic stratum underlay the fill (and rubble at BH 6-16) at an average depth of 0.96 meters but varied between 0.61 meters (BH 1-16) and 1.52 (BH 6-16). These depths corresponded to an elevation of 99.53 meters (with a standard deviation of 0.30 meters).

This soil unit overlay;

Unit # 3 – Fluvial Channel Deposits;

The fluvial channel deposits were comprised of sequences of fine grained non-plastic grey silts which contained varying amounts of sand and gravel or else dark grey low-plastic clayey silt to sandy silty clays. On average, the grey silts were classified as sandy silt which contained up to some gravel.

Organics (Unit #2) over Fluvial silt (Unit #3)

Due to the nature of channel deposition, this deposit was noted to grade coarser with depth although it may also contain regions of organic deposits (or other deleterious materials) which would result from channel infilling. Cobbles and possibly boulder sized materials are generally encountered near the base of this deposit. Refusal was encountered at BH 2-16 at a depth of 8.23 meters within these soils.

The moisture contents of these soils varied. The average moisture content of the grey silt was noted to be 31.3 % but varied between 15.1% and 38.7%. The average moisture content of the dark grey clay silt to silty clay was noted to be 44.1% but varied between 35.2% and 55.5%.

The thickness of this soil unit was noted to average 7.02 meters with a standard deviation of 0.31 meters.

This deposit was encountered at an average depth of 1.62 meters but varied between 0.9 meters (BH 1-16) and 2.44 meters (BH 6-16). These variable depths however corresponded to an elevation of 98.87 meters with a standard deviation of only 0.06 meters. By comparison, these deposits were encountered at similar elevations of 99.26 meters along 2nd Avenue.

This soil unit was noted to be frozen at an average depth of 2.18 meters (excluding BH 3-16). In BH 3-16, this deposit was noted to be permanently frozen at greater depths of ~ 5.5 meters, likely due to the thermal influence of the Yukon River.

This soil unit overlay;

Unit # 4 – Fluvial Valley Deposits;

The fluvial valley deposits were comprised of clean coarse grained granular deposits which are known to contain cobbles and boulders. These deposits are extremely dense and are generally known to be frozen and thaw stable. These materials comprise a base gravel unit upon which the overlying compressible and unstable thaw susceptible (Unit # 2 and # 3) materials lie.

Fluvial valley deposits (Unit # 4) BH 1-16

Where samples of this deposit were retained (in BH 1-16), the average moisture content was noted to be 7.5% but varied between 4.4% and 9.9%. A representative sample (No.11) was classified as a poorly graded sandy gravel.

These deposits were encountered at an average depth of 8.70 meters (in BH 1-16, BH 2-16 & BH 6-16) which equates to an elevation of 91.79 meters (standard deviation of 0.26 meters). The deposits were not encountered where auger advancement ceased at shallower elevations. By comparison, these deposits were encountered at shallower depths of 4.27 (along BH 1-14 & 2-14) on 2nd Avenue. This depth equates to elevations of ~ 95.81 meters along 2nd Avenue. As such, it appears the base gravel dips towards the west and drops approximately 4 meters in elevation.

Based upon the elevations at which the gravel stratum was encountered, it appears that the gravel profile remains relatively unchanged throughout the contact between the Yukon River and the townsite.

Colluvial Slide Debris (Unit # 5a and # 5b)

The composition of the slide debris/rubble (which was encountered BH 4-16 through BH 6-16) varied. The slide debris was comprised of rubble (# 5a) classified as coarse grained sandy silty gravel which generally overlay decomposed rubble (# 5b) which was classified as silty gravelly sand. The exception to this was BH 6-16 where a 0.42 meter thick layer of coarse grained rubble (# 5a) overlay organics (Unit # 2) and the remaining sequence of fluvial deposits (Units # 3 & # 4), as described above. The rubble at this location was likely utilized as fill during historical development of the study area. While a similar stratigraphic sequence was encountered in BH 3-14, the 2.59 meter thickness and elevations suggest that the slide debris in this area was deposited at the time of the (2nd) failure.

The decomposed slide rubble (# 5b) may be the remnants of the 1st slide event. The overlying coarse grained rubble (# 5a) is likely the remnants of the 2nd slide event.

In general, the rubble was noted to be dense to very dense and likely contains cobble to boulder sized materials. The gravel sized materials within the rubble was comprised of fractured serpentinized rock. The fine grained constituents of the slide debris was fibrous in nature and may contain asbestos (as is common in serpentinized rock).

As the elevation at which Unit # 3 fluvial channel deposits were encountered was consistent (@ 98.87 meters), it suggests that the slide thickness increases as one progresses upslope towards the north. The organic mat (Unit # 2) and portions of the fluvial channel deposits (Unit # 3) appear to have been scoured away at some locations (as noted in BH 5-16), as a result of the slide dynamics. These fluvial deposits appear to have been scoured to depths of ~2 meters (into the Unit # 3 - silt deposits) to elevations of ~ 97 meters.

Although the (2007 & 2012) technical papers (by Brideau et al) suggest that the toe of the slide lies north of Judge Street, our observations suggest that the toe is located approximately 15 meters north of George Street as was identified in the surficial geology map (Open File 2014-12). Our observations were verified as slide debris was encountered south of Judge Street as noted in the borehole soil logs.

Unit # 5a – Coarse Grained Slide Rubble

The coarse grained slide rubble was encountered in BH 4-16 through BH 6-16 immediately below Unit # 1 fill materials at an average depth of 1.02 meters.

BH 4-16 - Sample No.33 – Unit # 5a Colluvial Slide Debris

The moisture content of the rubble averaged 5.8% (but varied between 2.8% and 10.1%), indicating generally damp conditions.

The thickness of this upper rubble deposit averaged 2.57 meters but varied between 0.42 meters (BH 6-16) and 4.85 (BH 5-16).

Unit # 5b – Decomposed Slide Rubble

The fine grained decomposed slide rubble was encountered in BH 4-16 and BH 5-16 immediately below Unit # 5a rubble at an average depth of 4.73 meters. This is similar to BH 4-14 (advanced on 2nd Avenue) where the decomposed slide rubble was encountered at a depth of 5.51 meters.

BH 4-16 – Sample No.34 – Unit # 5b Colluvial Slide Debris

Excluding Sample No.48, the average moisture content of the decomposed rubble was 9.9% (but varied between 2.4% and 14.2%), indicating generally moist conditions. The 64.5% moisture content of Sample No.48 indicated that this sample was likely frozen.

Sample No.42, which was located at the interface with the overlying coarse grained slide rubble, was a diamicton classified as a gravelly silty sand and may be remnants of colluvial apron materials which were deposited between the 1st and 2nd slide events. The depth of this sample may coincide with the base of the 2nd slide event.

BH 5-16 – Sample No.42
Remnants of Colluvial Apron Deposits

Sample No. 49, which was retained from the base of BH 5-16, was classified as a silty sand with some gravel and may also be remnants of the original native deposits intermixed with the slide rubble from the 1st slide event.

Sample No. 47, 48 & 49

Unit # 6 – Colluvial Apron Deposits

Excluding the slide debris, colluvial (apron or fan) deposits were not encountered during borehole advancement. These types of soils were however encountered during our (2009-2010) geotechnical investigation of 7th Avenue where similar elevations and slope aspects exist.

In brief, the boreholes soil logs from this evaluation indicated that the colluvial apron deposits were comprised of a mixture of silt, sand, gravel, organics and fractured detritus. The deposits were noted to be frozen and contained ice lenses up to 80 mm thick. The colluvial deposits were encountered below the road fills and extended to the termination depth of each borehole (~ 6 meters).

Groundwater

Groundwater was encountered in BH 3-16 at a depth of 4.18 meters (elevation 96.09 meters). This elevation coincides with fine grained fluvial channel deposits which have been described in Section 3.7, below and elevation of the Yukon River (elevation~96.2 meters).

Observations of the monitoring wells installed in BH 4-16 and BH 3-14 (on 2nd Avenue), noted dry conditions.

Perched groundwater conditions would likely prevail at higher elevations due to the presence of underlying fine grained materials and other impermeable boundaries (i.e. bedrock, permafrost, etc.).

Permafrost

Permanently frozen soils were noted in each of the boreholes except BH 4-16. Three (3) of the ten (10) hand auger holes also encountered frozen materials.

Boreholes (BH 1-16, BH 2-16 & BH 6-16) encountered frozen (Unit #3) soils an average depth of 2.18 meters (with a standard deviation of 0.32 meters). This depth is similar to the 2.20 meter average depth where frozen materials were encountered on 2nd Avenue. BH 3-16, located at the toe of the dike, encountered frozen soils at depths > 5.02 meters. The higher degree of thaw is likely a result of the thermal influence of the Yukon River.

Of the two boreholes which were advanced through predominately slide debris (BH 4-16 & BH 5-16), an indication of permanently frozen soils was only observed in BH 5-16 at a depth of 8.52 meters. This indication was noted in the form of the higher moisture contents in Sample No.48. The soils at BH 4-16 are however, likely frozen at depth.

The frozen soils (Unit # 3 & # 4) were classified in accordance with the *National Research Council* Classification System, as;

Nbn – indicating segregated ice not visible by eye, well bonded with no excess ice.

Vs – indicating stratified or distinctly oriented ice formations (visually estimated to contain up to 10% ice by volume).

Vx – indicating individual ice crystals or inclusions < 1 mm in size and approximately 1 % ice saturation by volume.

Seasonal Frost

The surficial soils would generally be exposed to seasonal frost to depths of approximately 1.8 meters. This depth of penetration would vary depending upon the thickness of the organic strata (Soil Unit # 2) and overlying fills which act as insulation for the underlying soils.

Cobbles and Boulders

Cobbles and potential boulders would be present within;

the base of the fluvial channel deposits (Unit # 3),

throughout the underlying fluvial valley deposits (Unit # 4), and

within the slide debris/rubble.

The odd surficial boulder was noted along the Yukon River (west of Front Street and north of George Street) and near Judge Street.

Boulder along Judge Street – Area 26

Bedrock

There was no indication of bedrock within any of the boreholes which were advanced. Locally however, bedrock may be present near (north-south) Judge Street where the topography appears to be bedrock controlled.

View of north-east corner of Judge Street facing north.

While the depth to bedrock will vary, it is understood that it may be encountered in the order of 20 meters in the region of Front Street. Bedrock may be encountered at shallower depths in regions where higher elevations are present.

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.

5.0 DISCUSSIONS

5.1 General Overview

Development Potential

In general, the terrain and soil conditions encountered within the study area will be suitable for residential subdivision development. However, as some of the regions are inaccessible or else will need to be utilized as geotechnical buffers, there will be some restrictions upon development.

A site plan which illustrates the approximate regions of the study area which should be suitable for residential building development has been attached as Figure 10 – Development Potential.

Geomorphic Considerations

As with most residential developments in Dawson City, the subsurface conditions will pose geotechnical challenges relative to standard residential design and construction practices.

The presence of fluvial and colluvial deposits and fill, will require additional consideration as these materials are undergoing periglacial processes or else may be susceptible to thaw-degradation (where frozen) due to climate change and anthropogenic activities. In addition, 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 rock glacier, earth flow and creep mechanisms.

While efforts will need to be undertaken to minimize both the thermal and physical impacts development may have upon these deposits, the presence of these soils will not prohibit development. In fact, the majority of the town-site has been developed upon these very soils.

Site Development

It's critical to control surface drainage to protect the permafrost in order to assist in 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 prior to residential building construction. This work should be carefully orchestrated and monitored by regulatory authorities in order to control surface drainage and minimize disturbance to the thermal regime.

Development by individual homeowners may otherwise become liabilities if not properly established or maintained.

Permafrost Protection

As the permafrost which is prevalent throughout the study area is susceptible to undesirable thaw-degradation, engineering considerations will be required during infrastructure design and construction.

Subsurface utilities and trenches will need to be well insulated in order to minimize their thermal influence upon the adjacent permafrost.

Clearing will need to be staged such that it is conducted immediately prior to road and granular building pad construction as the loss of shade will induce thaw. Clearing beyond regions of infrastructure development should be discouraged.

Building structures will need to be constructed upon cribbing and ventilated crawlspace foundations such that impact of the heat from the building upon the permafrost is minimized.

Foundation Types

Light residential building(s) should be supported by standard (PWF) cribbing and ventilated crawlspace foundation systems founded on approved granular pads which measure no less than 1.8 meters thick and are placed upon undisturbed native deposits. This type of foundation system has proved to be a suitable foundation option as it can be re-levelled on an as needed basis.

In general, the use of standard concrete footing and/or slab-on-grade foundation systems will not be feasible due to the presence of underlying permafrost and compressible soils. However, slab-on-grade concrete foundations can be considered in regions where fluvial deposits are present so long as cut/fill construction methodologies that incorporate thermal protection measures are employed. This type of foundation will be well suited for commercial/public use facilities as they are less susceptible to seismic impacts or thaw degradation and can support heavier loads.

Maintenance

As with all dwellings constructed on cribbing in Dawson City, periodic re-levelling of residential structures will be required to accommodate fluctuations in underlying soil volumes. As this task is often ignored over time due to human nature, home owner incentives should be established in order to encourage active monitoring and re-levelling of residences and maintenance of surface drainage courses. These tasks should be verified by regulatory authorities such as the building inspector or else similar entity.

In general, where residences and infrastructure are established in regions which may be undergoing slope movements (through creep and other slide mechanisms), a higher frequency and degree of maintenance should be anticipated.

Surface Utilities

The roads within the study area will require upgrading, realignment and road widening. New roads (between 2nd Avenue and Judge Street) may also need to be constructed to re-establish Steele Avenue.

Culverts and ditches will need to be established to better control regional surface drainage. 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 movement.

Although shallow sliver fills (< 0.25 m) should be incorporated, where possible, road construction should be accomplished entirely through means of fill operations.

Sub-surface Utilities

The installation of sub-surface utilities through conventional excavation/backfill construction methodologies will be feasible in the western half of the study area (Front Steet & 2nd Avenue). While additional investigation will be required east of 2nd Avenue (along Steele Avenue) to verify the extent and conditions of the colluvial apron deposits, the presence of these materials should also allow for sub-surface utility installation.

As with all sub-surface utilities in Dawson City, maintenance will be required intermittently to accommodate changes in the sub-surface conditions.

Differential and Total Movements

Everything in Dawson moves. As such, the primary challenge during development will be to minimize both differential and long-term movements such that infrastructure can be developed. The nature and magnitudes of these movements will vary depending upon the geomorphology and constructed conditions.

Differential movements will generally prove to be higher in transitional zones between the varying deposits which were identified. As both surface roads and sub-surface utilities will need to traverse these deposits, additional consideration will need to be provided during the design phases in anticipation of crossing these transitional zones. By contrast, residences should not be constructed above these transitional zones.

As the subsurface utilities will traverse the various deposits, the utility pipes will be subjected to a component of the relative movements as described below. However, given the nature of the uniform granular trench backfill (within which the utilities are embedded), the horizontal movements of the colluvial deposits will not likely translate directly to the utilities. Generally, where trenches are excavated (and backfilled) through the colluvial deposits, deformation to the upslope side of the trench sidewall should be expected over time.

While it’s common practice to discuss movements relative to the vertical axis, the nature of the deposits located within the study areas requires additional discussion relative to a horizontal component of displacement.

Horizontal Displacement

Literature suggests that the rate of movement will vary between the colluvial deposits as follows;

Colluvial Slide Deposits

The colluvial slide deposits are moving at a rate which may range between 4 to 20 cm/year in the central regions of the slide. From a conservative standpoint, assuming that these rates are comparable in the regions of the slide located within the limits of the study area, portions of the colluvial apron deposits may be moving down-slope (towards the south/south-west) at a rate as high as 20 cm/year. However, our observations suggest that this rate of movement is not linear throughout the cross-section of the slide. Specifically, as the toe of the slide appears to be anchored to some degree in the region just north of George Street, the higher rates of movement are likely concentrated in regions where higher elevations prevail. This suggests that the nature of the movement in this region may be through predominately plastic deformation.

Colluvial Apron & Fan Deposits

As movements are dominated by potential creep through predominately cryoturbation/nivitation mechanisms, the rate of movement would be in the order of 1-5 cm/year. The direction of movement within these soils would be down-slope (generally towards the west).

Vertical Movement

Differential movements in the order of (+/-) 25 mm may occur with the proposed cribbing and ventilated crawlspace foundation system. Periodic adjustment to the cribbing system should be anticipated throughout the life of the structure to accommodate differential and total settlements.

If a uniform granular pad thickness cannot be maintained (such as in the region between 2nd Avenue and Judge Street), then a difference in total settlement between the thicker and thinner sides of the pad should be anticipated. While the magnitude of these movements would depend upon the site and as-built conditions, a greater degree of settlement should be anticipated on the downslope side of the structure.

Environmental Considerations

As the western portion of the study area lies in a region of Dawson which was once utilized for industrial purposes and as the slide debris is comprised of predominately serpentinized rock which may harbor occurrences of asbestos, additional consideration will be required as determined through an environmental site assessment(s).

Natural Hazards

A detailed description of the potential natural hazards which may be associated with the study area have been provided in Section 4.4 – Geomorphology. Although several technical reports (which were referenced in the Dawson Natural Landscape Hazards report prepared by the *Northern Climate ExChange*) characterized the nature of the Moosehide Slide and its potential failure mechanisms, none of the studies appeared to have assessed the impacts a potential failure may have upon the town-site, if any. As such, a natural hazards assessment should be conducted.

Geotechnical Setbacks

Geotechnical setbacks will need to be observed within the limits of the study area to allow for a factor of safety from potential long-term geotechnical hazards related to slope movements of the slide debris and potential rockfall hazards.

5.2 Site Specific Considerations

The following discussions have been provided relative to the areas noted in Figure 9 to address site specific observations which were made during the course of our evaluation.

Some adjustment to the lot boundaries may be required due to encroachment and (intended) lot usage issues.

Area 1

This use of this area, located on the toe of slide, should continue to be utilized as an intermittent public use area. While public washrooms or storage sheds could be constructed, permanent public use structures should not be constructed in this area as it is located in a slide/rockfall run-out zone.

View of Area # 1 facing east and Area # 3.

The historical Father Boyds Cabin is located in the western half of this area. St.Mary's church, school and hospital were also once located in this area just north of the cabin.

Father Judge Cabin facing north-west.

Area 2

Located on the slope overlooking Area 1, development should not be allowed in this region as it too is located in a slide/rockfall run-out zone. The south-eastern periphery and regions north-east of this area could allow for areas where rockfall deflection berms and interceptions mounds could be constructed as precautionary measures, if deemed necessary.

Area 3

Permanent structures should not be allowed in this area as it may be located in a slide/rockfall run-out zone.

Area 4

The road right-of-way would need considerable re-alignment to allow for road access to Area 1 if it is to be utilized.

Area 5

These two lots would be suitable for residential use.

Area 6, 7 & 9

These areas are comprised of backslopes and should not be developed. They could be attached to residential lots located to their south to serve as lot extensions. The existing trees should not be removed as they may serve as protection from potential rockfall hazards.

View of study area facing south-west. Area # 9 in foreground.

Area 8

Although this area appears to be a road extension to 2nd Avenue, it could be rezoned and utilized as a residential lot. Development should be limited to the southern realms of site as the northern realms are comprised of a backslope where rockfall hazards may exist. Additional assessment will be required to assess the use of this area as it appears to be predominately comprised of a yard belonging to a residence located to the west.

View of Area # 8 facing north.

Area 9

See Area 6 above.

Area 10

These lots will not be suitable for residential use as there is no access to them from the south. These slide deposits are undergoing considerable movement as noted from deformation in trees located on the lots.

Area 11

This area denotes a 30 meter wide geotechnical setback from the toe of the slide debris and Yukon River. Development should not be allowed in this region. Extension cracks and tree trunk deformation indicating active slope movement were noted along the trail which traverses the area.

Extension crack along Area # 11

View of slide and study area from West Dawson facing east.

Area 12

Although a rental cabin is located in one of the southern lots in this area, permanent structures should not be permitted given its proximity to the top edge of the slope located to the west. This area however would be suitable for temporary seasonal vendors which could allow for light commercial operations.

Area 13, 15 & 25

These roads would require road upgrading include regrading, realignment, road widening, ditch construction and culvert installations. Some residences (and potentially other structures) appear to encroach upon these roadways.

Area 14

As residences have been established in this region on the slide debris for some time future development should not be restricted. The exception to this would be on the two southern-most (Lot 3 & Lot 12) as they are located near the leading edge of the slide debris.

Area 15

See Area 13.

Area 16

Residential development should not be allowed on the lot as it is located just north of/on the leading edge of the slide debris.

Area 17

These lots will not be suitable for development given the steepness of the slope. It's understood from local residents that a seasonal spring flows through this area towards the south-west.

Area 18

This area delineates a 30 meter wide geotechnical setback from the toe of slide. Development should not be allowed in this region as the toe of the slide will encroach into this zone over time. Based upon the higher rates of movement which were estimated to be in the order of 20 cm/year, the setback should allow for ~150 years of movement (at the current rate). Tree trunk deformations, indicating active slope movement through potential creep mechanisms, were noted sporadically within the area.

A shallow lined and armored ditch (or French drain) should be constructed along the entire toe of the slide debris to channel surface water from Area 17 through the geotechnical setback to allow for its discharge towards Front Street.

Area 19

This area should re-zoned to allow for construction of a roadway (and cul-de-sac) to access lots located east of 2^{nd} Avenue. The access to some of these lots may otherwise prove difficult given the differences in elevation between the lots and Judge Street.

The (north-south) alleyway at this location was once known as Steele Avenue according to the historical 1903 illustration by Dr.Bell. This road could be extended to Area 32 to the south to access lots in this area.

Site conditions near Auger Hole No.9

Additional consideration will be required if road access will advance through the above noted areas as a side-cut into the up-slope (east) side of the road should be avoided. A cut into the slope will increase the rate of movement of soils which are undergoing creep. If possible, the road should be constructed entirely through fill placement. The side-slopes of the roadway should be well armored to allow for the flow of surface waters as ditches should not be excavated into the colluvial deposits.

Area 20

There were two cabins and an outhouse (which appeared to be of historical value) located on these lots. The western portions of the lot could allow for visitor parking from the Steele Avenue cul-de-sac described in Area 19. Lot 10 Block F in this area will otherwise be suitable for residential construction.

View of cabins in Area # 20 facing north-west.

Area 21

Residential development should not be allowed on these lots (# 2 & # 13 – Block C) as it is located near the leading edge of the slide debris where movement through creep (or other mechanisms) will be pronounced. The lot could however allow for similar light commercial operations as per Area 12 so long as permanent structures are not constructed. Caution should be exercised such that the leading edge of the slide is not disturbed.

Area 22

As these lots (# 1 & # 14 – Block C) are located at the toe of the slide and within the geotechnical setback limit described in Area 18, above, residential development should be prohibited. These lots could be utilized for parking or else park (or similar type of non-permanent structure) usage. Caution should be exercised such that the toe of the slide is not disturbed.

Area 23

The eastern half of this area (Lots # 1 and # 2 Block C) should be suitable for residential development. Development of the western halves of these lots should be restricted to non-permanent structures as they lie within the limits of the geotechnical setback described in Area 18. Additional consideration may be required as to the use of Lot # 1 Block C and Lot # 1 Block F, as the southern portions of these lots may need to be utilized to allow for (Area 19) road construction.

Area 24

These lots will be suitable for residential lot development. The lots located on the east side of this area may be accessible from Judge Street depending upon residential building design and site access requirements. Several residences located in other regions of Dawson have accommodated these sloping areas through the construction of elevated walkways.

Residence access along 8th Avenue.

Area 25

As per the other roads in the study area, Judge Street will require upgrading to residential standards. Several residences utilize this roadway for lot access.

View of Judge Street facing south.

Area 26

The lots located in this area have poor access from Judge Street as they are situated approximately 5-10 meters above the prevailing road elevations. The western half of the area is comprised of a steep slope. Residential development of these lots would not be readily feasible without a substantial amount of lot and infrastructure development.

Area 27

This area is comprised of a backslope that lies above a residence. While it could serve as a lot extension, residential development would not be readily feasible due to poor lot access. The presence of potential near surface bedrock may require additional consideration.

Area 28

This road right-of-way could be re-zoned to allow for residential development although a trail which allows for local residential access bisects the site.

Area 29

Although this area partially lies amidst a backslope, the road right-of-way could be re-zoned to allow for residential lot development. The presence of potential near surface bedrock may require additional consideration as would be the lack of municipal sub-surface utilities. As this area is located near a known cemetery, additional heritage assessment may be required to verify that there are no grave sites located on these lots.

Area 30

The soil conditions in this area parallel those located below the Dawson City Offices and Fire Hall, where a concrete slab-on-grade was constructed upon an engineered granular pad. As the foundation has performed well since being established in 1999, construction of a similar type of structure in this area utilizing similar cut/fill construction methodologies should be considered.

As the structure would be constructed on essentially the last remaining empty city block available on the riverfront, it would be well suited to allow for construction of a multi-story public use facility. The building would need to be constructed upon a concrete slab-on-grade founded upon structural fill which extends to the underlying fluvial valley deposits (Unit # 4). The structure could allow for commercial operations, offices, multi-use community rooms and other similar types of pubic usage.

More detailed assessment and recommendations will need to be provided if this option is to be considered. While these lots will otherwise be suitable for residential development, a supplemental geotechnical evaluation should be conducted in this area to verify the continuity, thickness and quality of the granular fill which was encountered in the central regions during the auger hole program. The intent would be to verify whether or not the existing fills could be utilized as structural granular pads for residential building construction.

Area 31

These lots are suitable for residential development. Access to the lots located on the east side of this area will need to be considered if Area 32 is not developed as a roadway.

Area 32

As referenced in Area 19 above, this region can become an extension to the roadway (and allow for access to lots located in this area) as well as serve as part of a subsurface utility right-of-way (stemming from Area 39).

Otherwise, this area could be utilized for residential development so long as road access is available.

Area 33

Although bisected by a local trail which is utilized by nearby residents, these lots are suitable for residential development.

Area 34

Comprised of colluvial fan materials which may be bedrock controlled, the southern realm of this area is known as the Typhoid Cemetery. While a geophysical survey through means of ground penetrating radar (or other methodologies) would be recommended to delineate its extent, we would not recommend residential development in this area given poor site access. The two blocks located upslope from this area were once utilized as cemeteries as noted in Dr.Bell's 1903 illustration enclosed as Figure 5 and as denoted in Figure 6.

Area 35

Although delineated as untitled Commissioners Land, Edward Street should be upgraded to current road standards. The lot could otherwise be utilized for residential purposes so long as there is sufficient access to region due to the loss of Edward Street.

Area 36

This western half of this area is suitable for residential development. The eastern half of this area is comprised of colluvial deposits which may be undergoing movement through creep mechanisms. As such, residential development on (or near) the eastern half of the lot is not recommended.

Area 37

This lot is suitable for residential development.

Area 38

These lots are not readily suitable for residential development as the terrain slopes steeply towards the west. This are can however be considered for use as a subsurface utility corridor to allow for installation between Area 32 and Area 39. Additional consideration will be required to assess the excavation side-slope configuration and stability relative to routing sub-surface utilities through this area, particularly as nearby residences are located just east of the area.

Area 39

This area serves as a road junction (between Judge Street and a local residential trail) and terminus to the existing subsurface utilities. A fire hydrant is located in this area.

Area 40

This lot should be rezoned as a roadway such that Area 39 and Area 25 of Judge Street remain functional.

Area 41

The lots located in this area have poor/no access from Judge Street. Residential development of these lots would not be readily feasible without a substantial amount of lot and infrastructure development. In addition, given their proximity to Typhoid Cemetery, additional assessment would be required to verify whether or not grave sites may be present in the area.

Area 42

This lot is suitable for residential lot development.

Area 43

This lot was assessed during a 2014 geotechnical evaluation and was deemed suitable for residential development.

Area 44

This lot could serve as an extension to the lot on Area 43 as access is not otherwise readily feasible. The eastern half of this area is comprised of steeply sloping colluvial deposits which may be undergoing movement through creep mechanisms and so residential development on (or near) the eastern half of the lot is not recommended.

Area 45

Permanent developments should be restricted within this geotechnical setback area as a precaution against potential rockfall which may orginate from the slide area.

6.0 RECOMMENDATIONS

The following recommendations have been provided to allow for design and construction of residential building pads, roads and subsurface utilities. These recommendations have been provided further to site specific discussions which should also be considered as described in Section 5.0 – Discussions.

6.1 Residential Foundations - (PWF) cribbing and ventilated crawlspace

Geotechnical Evaluations

A geotechnical evaluation should be conducted to verify the soil conditions within the perimeter of any proposed building load envelope once conceptual designs have been formulated. The sub-surface conditions should be assessed on a case-by-case basis to verify the suitability of the recommendations which have been provided herein.

Clearing Operations

As clearing operations will induce thaw due to the loss of shade, clearing should only be conducted immediately prior to granular pad construction. Construction of the granular pad will help protect the underlying permafrost due to its insulating capabilities once completed.

Clearing beyond the regions of the building pad should be discouraged.

Structural Granular Pad

Residences should be founded upon structural granular pads comprised of an approved, clean, inorganic, well graded sand and gravel mixture which measures no less than 1.8 meters thick.

The structural granular pad should be constructed as follows;

Structural Granular Pad

UNIT	THICKNESS[A, B]	COMPACTION [C]	COMPOSITION
Base	150 mm	100 %	20 mm minus crushed granular aggregate, overlying
Sub-base	450 mm	98 %	80 mm minus sub-base course aggregate, overlying
Sub-base	1200 mm	95 %	150 mm minus and/or Class I Rip-Rap sub-base course aggregate, overlying
Geotextile Fabric[D]	NA	NA	Non-woven filter fabric
Sub-grade	NA	95 %	undisturbed surficial organic materials

Notes;

[A] – The prepared surface of the granular backfill should be level in the region where PWF pads are to be placed. The granular pad should extend a minimum of 2.0 meters beyond the edge of the pad at these locations.

[B] – The thickness of this unit should be uniform through-out the building load envelope where possible. The intent is to construct a granular pad which measures no less than 1.8 meters thick and lies above the organic soil stratum or colluvial deposits.

[C] – Indicates percent compaction relative to the materials Proctor maximum dry density at (or near, ± 2%) its optimum moisture content. Caution should be exercised during compaction as the underlying sub-grade materials are moisture sensitive and subject to a loss of strength if disturbed.

All materials should be placed in uniform, level lifts that do not exceed 150 mm thick, as measured following compaction. The exception to this would be if Class I Rip-Rap (or equivalent coarse) materials are utilized. Typically, these materials are placed in 0.5 meter thick lifts prior to leveling and static rolling.

D – The use of a bedding sand leveling course should be placed immediately below the geotextile fabric.

The recommended fills should conform to the grain size distribution specified in Appendix C.

If the underlying organic soil unit is disturbed, then consideration should be given to replacing the soil unit with an equivalent level of thermal protection through the use of SM Styrofoam.

Allowable Bearing Pressure

The allowable bearing pressure for light residential building structures should not be greater than 105 kilopascals for a cribbing and ventilated crawlspace foundation system constructed on the structural granular pad described herein.

This figure includes the total of all live and dead loads.

Differential and Total Movements

Differential movements in the order of (+/-) 25 mm may occur with the proposed foundation system. Periodic adjustment to the cribbing system should be anticipated throughout the life of the structure in order to accommodate the movements when these limits are exceeded or if gross settlement/heave occurs. Additional measures should be considered to allow for long-term thaw-consolidation of regions where residential building construction is to be considered.

If a uniform granular pad thickness cannot be maintained (as in the region between 2nd Avenue and Judge Street), then a difference in total settlement between the thicker and thinner sides of the pad should be anticipated. The magnitude would depend upon the site and as-built conditions.

Structural Breaks & Reinforcing

Structural breaks and reinforcement should be integrated into the building design to allow for differential movements caused by soil volume changes of the underlying soils.

Cribbing & Crawlspace

Cribbing should be constructed utilizing robust PWF wood placed upon constructed pads. A system of adjustable screw jacks, which are incorporated into the cribbing, should be considered to readily allow for re-levelling of the structure.

A ventilated crawlspace should be incorporated into the foundation design. Specifically, this would involve skirting the building perimeter with a sub-wall which incorporates a wire mesh or lattice work such that air flow below the structure is unrestricted during the winter months. The openings should be configured in such a manner that they can be opened during the course of the winter to allow for building heat to escape from beneath the structure. These openings should subsequently be closed in the summer months to prevent exterior (warmer) air from impacting the constructed granular base and underlying permafrost.

Crawlspaces must be protected from rain, snow and the ingress of surface and groundwater at all times.

Site Drainage

The granular pad construction and surrounding areas should be graded to direct surface water away from the building structure. Typically, a 4 percent slope will be suitable for this purpose.

Eaves troughs should be incorporated into the roof structures. The discharge/outflows should extend a minimum of 3 meters away from the building perimeter. Care should be taken to direct this flow of water around the perimeter of the structure and ensure that the discharge does not cause erosion.

While local elevations will need to be considered, residential granular pads should be constructed such that the pad surface is no less than 1 meter higher than the prevailing road grades.

6.2 Roads

Structure

The structure of the roadway will be dependent upon the condition and composition of the sub-grade materials and expected traffic loading. However, as a minimum, the road structure should be comprised of;

Material [A]	**Thickness (mm)**	**Compaction [B]**
Base 20 mm minus	200 [C]	98 %
Granular Sub-Base 80 mm minus	200	98 %
Granular Pit Run 150 mm minus [D]	400 [E]	95 %
Geotextile Fabric [F]	As required	NA
Approved Sub-grade [G]	NA	As directed

[A] - The surfaces of the granular courses should be shaped with a 3% crown to promote drainage.

[B] - Indicates percent compaction relative to the materials Proctor maximum dry density at (or near, ± 2%) its optimum moisture content. All materials should be placed in uniform, level lifts that do not exceed 200 mm thick, as measured following compaction.

C - The thickness of this granular course can be reduced to 100 mm in regions where parking areas are to be constructed.

D - This sub-base layer should extend approximately 1 meter beyond the edge of the overlying sub-base layer where new roads are constructed.

E - This granular course should be utilized where new roads (or parking areas) are constructed or where re-alignments of existing roads extend beyond the existing limits of the roadways. While the thickness of this granular course should be adjusted to attain required design elevations it should not measure less than 200 mm thick. The thickness of this granular course can be reduced in parking areas as determined in the field depending upon the sub-grade conditions and design elevations

F - The use of a geotextile fabric (which is underlain by a levelling course) will be required at the sub-grade interface where roads are advanced into undisturbed regions (ie, Steele Avenue area).

G - Where new roads are constructed at the locations of pre-existing ones, the former roads should be scarified to ensure a good bond is attained between the two road structures.

The recommended fills should conform to the grain size distribution specified in Appendix C.

If the existing roadways are to be widened to allow for re-alignment, then the road structure should be placed utilizing sliver fill construction methodologies. Specifically, the newly constructed areas should be keyed into the existing road structure.

Culverts

Corrugated steel pipe (CSP) culverts should be incorporated into the road design and lot accesses to maintain positive drainage.

The culverts should be placed upon a layer of bedding sand which measures no less than 150 mm thick. CSP’s should be encased by a 300 mm thick zone of bedding sand which surrounds the sides and top of the pipe. All materials should be placed in uniform, level lifts that do not exceed 150 mm thick and are compacted to no less than 95 % of the materials corresponding maximum Proctor value at (or near) its optimum moisture content. Culverts should have a minimum soil cover of 300 mm.

Ditches

While ditches should be incorporated into the design, additional consideration will be required in regions where colluvial deposits prevail. Specifically, as cuts into the colluvial deposits should be avoided where possible (so as not to induce or increase rates of creep) the side slopes of the roadways should be lined with rip-rap such that they serve as ditch sidewalls where the topography is favorable.

Otherwise, where ditches cut into the colluvial deposits, consideration should be given to lining them with perforated drain pipe encased in clear stone drainage rock wrapped in geotextile fabric. This will allow for some degree of lateral support to the ditch cut-slopes and thus decrease the potential for movement, particularly where creep mechanisms may be occurring within these deposits.

Maintenance

As with all gravel roadways, regular maintenance will be required during its life-span. Maintenance may include placement/compaction of additional surfacing materials, removal of bedload from erosion control structures, grading and winter sanding operations and other similar types of operations.

6.3 Sub-surface Utilities

As sub-surface utilities will be installed at depths in the order of 3 meters, the trench base materials will be comprised of predominately fluvial channel deposits of silt (Unit # 3) or else colluvial slide/apron deposits (Units # 5a and Unit # 6).

Proposed Construction Materials & Backfill

The proposed utilities should be comprised of heavy duty HDPE pipe and utilize electro-fusion type connections. The pipes should be well insulated to prevent freezing by means of soil cover (no less than 2.1 meters), physical coating, heat trace or combinations thereof. The utility pipes should be well insulated to minimize thermal impacts to the adjacent native soils.

Utility pipes should be encased in CSP culverts such that a more robust pipe which can withstand soil movements is created.

Underground utilities should be placed on no less than 300 mm of bedding sand (or else 10 mm minus clear stone) which conform to the gradation specified in Appendix C – Imported Fill. A minimum cover of 300 mm. of bedding material should be established on all sides of the pipe to protect the utility from oversize materials and potential damage during backfill.

All bedding materials and trench backfill should be placed in uniform, level lifts that measure 150 mm thick (following compaction). The lift thickness can approach 300 mm if the sub-grade conditions are considered poor by the retained geotechnical consultant so long as adequate densities are achieved.

The bedding sand and trench backfill should be compacted to 95 percent of its maximum Proctor density at (or near) the materials optimum moisture content.

Underground utilities should be situated outside of building perimeters to allow for ease of maintenance. If utility trenches are located within a building load envelope, then the granular backfill materials should be compacted to 98% of the materials maximum Proctor density at (or near) the materials optimum moisture content.

If soft, compressible materials, groundwater or frozen soils are encountered at the base of the trench excavation, then an open graded clear stone should be utilized to bridge these areas. The clear stone should be fully encased in filter fabric to prevent to the influx of fines from the adjacent soils and subsequent backfill. The clear stone fill should be compacted to the satisfaction of the geotechnical consultant. Caution should be exercised such that the underlying sub-grade materials are not disturbed.

As the insulating capabilities of the organic soils (which will be removed from within the utility trench) will be lost, (SM) Styrofoam should be placed across the entire trench width near the base of the active layer (~ 2 m depth), so as to protect the underlying permafrost. The thickness of the Styrofoam should be in the order of 100 mm. If the utilities are not well insulated or if heat trace is utilized, then a layer of Styrofoam should be placed at the base (and sidewalls) of the trench (below the utilities) in order to minimize the thermal influence of the utilities upon the permafrost.

Trench plugs should be utilized in regions were moderate installation grades are required by the design.

Staged Excavation/Backfill Operations

The installation of the water and sanitary utilities in separate trenches should be considered to protect the water-line from potential contamination in the event of a break in the sanitary line. As a minimum, if placed in the same trench, the water line should be placed above the sanitary line.

Given the presence of permafrost and its susceptibility to thaw, excavation and backfill operations should be staged such that the length of exposed trench at any given time is minimized. Concurrent excavation and backfill operations should be considered.

The length of exposed trench would be dependent upon the proposed construction methodology, work effort employed and sub-surface conditions encountered at the proposed installation depths. These lengths should be determined prior to the time of construction but in general should measure no more than 60 meters in length.

Installation of sub-surface utility pipe should be initiated from regions of lower elevations and progress to regions where higher elevations are present.

Proposed Schedule

Given the presence of permafrost conditions near/at the proposed installation depths, we recommend that utilities be installed in the spring or fall to minimize degradation of the native soils. Additional consideration may however be required as inclement weather may be encountered during these seasons.

6.4 Earthworks

Deleterious Materials

Excavated soils which are frozen, have a high moisture content or are saturated, will not be suitable for re-use and so should be hauled to waste. In addition, given the historical development, buildings remnants and other deleterious debris should be anticipated and likewise removed from structural envelopes.

While Unit # 5a of the slide debris will be geotechnically suitable for trench backfill where thawed, it (and Unit # 5b) should also be hauled to waste (utilizing adequate precautionary measures) where encountered, as it harbors asbestos fibers and thus would otherwise pose a hazard to the workers during backfill operations.

The fills (Unit # 1) and colluvial materials (Unit # 6) will generally be suitable for use as trench backfill so long as these materials are thawed. The use of the organics (Unit # 2) for trench backfill can be considered on a case-by-case basis so long as its use does not impede subsequent trench backfill compaction efforts. The organics should be placed near the base of the trench at a depth no greater than 300 mm above the top of the utilities.

Excavations

Excavations should be conducted utilizing a heavy tracked excavator (equipped with a clean-up bucket) to minimize disturbance to the sub-grade materials. While excavation difficulties are not expected, hard digging will be encountered where frozen soils are encountered. A digging/frost bucket may be required in these frozen zones above the sub-grade. However, caution should be exercised such that loose, disturbed, remolded or slough materials do not remain in the excavation. If a prepared founding surface cannot be prepared through mechanical means, then hand cleaning may be necessary.

If permafrost is exposed during excavation, it should be protected from degradation by implementing an accelerated work program, utilizing insulated tarps and/or scheduling the project at times so as to minimize thaw.

Construction Operations

As clearing operations (which may be required to prepare the Steele Avenue roadway and building lots) will induce thaw due to the loss of shade, it should be staged in order to minimize the detrimental impacts. While the schedule for staging will vary depending upon the construction methodologies, in general, the first stage of clearing should be conducted immediately prior to road construction as the placement of fills will assist in insulating the native deposits. Subsequent stages of clearing should be conducted as building sites are developed.

The sub-grade is moisture sensitive and subject to a loss of strength if disturbed. As such, caution should be exercised during construction particularly where vibrations are induced (i.e. during compaction). Wheeled equipment should not be allowed on any sub-grade surface.

If the sub-grade is exposed, it should be covered to minimize degradation and protect it from precipitation as it is moisture sensitive.

Compaction operations should be limited to static rolling in regions which are underlain by colluvial deposits so as not to increase rates of (or induce) slope movement.

Fills should be placed and compacted utilizing bottom-up construction methodologies. Top-down placement (and compaction) of successive lifts of fill, should be avoided.

The contractor should be prepared to adjust their construction methodology and excavation profiles as soil and site conditions dictate.

Filter Fabric

Geotextile filter fabric should be utilized where fills are placed upon native deposits or to assist in bridging soft compressible areas where subsurface utilities may need to be installed.

If successive pieces are required, they should be either sewn or overlapped by a minimum of 1.5 meters. The overlap should be in the direction of the prevailing gradient such that the downhill piece lies below the uphill piece. Caution should be exercised such that the fabric is not torn or compromised during aggregate placement.

Inclement Weather

Excavations, sub-grade and construction materials should be protected from drying, freezing, snow and surface/groundwater at all times. Special attention should be given during construction operations that occur during periods of heavy precipitation and other inclement weather that may have an effect upon construction and subsurface conditions. Any water, snow or ice that accumulates in the excavation(s) should be removed immediately.

Temporary Excavations & Worker Safety

Worker safety is paramount.

Excavations

Temporary excavations to conventional depths at this site should comply with current regulations under the *Yukon Workers Compensation Board* **-** *Occupational Health & Safety Act*.

The excavation sidewall (slope) stability will be dependent upon the material characteristics, configuration of the excavation, length of exposure, presence of groundwater and other similar factors which should be evaluated at the time of construction. Additional caution may be required as cobbles (and potential boulders) may be present in the materials. If large cobbles or boulders are encountered in the trench sidewalls or slopes within the native deposits, they should be removed to allow for safe working conditions.

Slope stability will be poor where soft, wet/saturated materials, fills or recently dewatered materials are encountered and more gradual cut slopes (in the order of 2 to

1, horizontal to vertical) may be required in these areas to minimize the potential for slope failure.

Where frozen materials are encountered, trench sidewalls will be relatively stable although some slumping and surface degradation will occur if the material is allowed to thaw.

ACM Hazards

Given the serpentinized nature of the colluvial deposits, precautions should be taken to protect workers from potential asbestos which may be entrained within these materials as they may present a potential respiratory hazard. As such, where work is conducted with the colluvial deposits, standard asbestos containing material (ACM) precautions should be taken.

Surface and Groundwater

Surface and groundwater should be removed from excavations and working areas at all times to ensure a dry working area.

As groundwater may be encountered during construction, the Contractor should be prepared to conduct construction dewatering operations throughout the course of sub-surface utility installations.

The contractor should be aware of potentially undesirable effects that may be caused by dewatering, particularly if groundwater influx is considerable. These effects may include slumping of excavation sidewalls and settlement of surrounding areas (structures) due to a decrease in pore water pressures.

Local areas should be graded to direct drainage away from excavations and temporary stockpiles. The base of any excavation should be prepared in such a manner that positive drainage is maintained.

Temporary Stockpiles

Stockpiled materials that may be utilized during construction should be protected from segregation and the ingress of snow, rain and surface waters.

Frozen materials which are excavated during the work will not be suitable for re-use and should be hauled to waste. These materials should not be stockpiled onsite as they will liquefy as they thaw and will become difficult to handle.

Erosion Control

Measures should be established during construction to minimize the impacts of erosion. This can be accomplished through the combined use of silt fencing/rock baffle construction and placement of protective rip-rap armor in regions where regions of high flow velocities or susceptible soils are identified. Grass and other types of vegetation should be utilized to stabilize exposed soils (such as ditches and granular pad side slopes) as deemed appropriate.

The frequency and locations where these erosion control features should be installed will have to be assessed on a case-by-case basis once a conceptual subdivision design has been established and during construction. These (and additional) erosion control measures may be required as the drainage regime stabilizes following construction.

Design Considerations

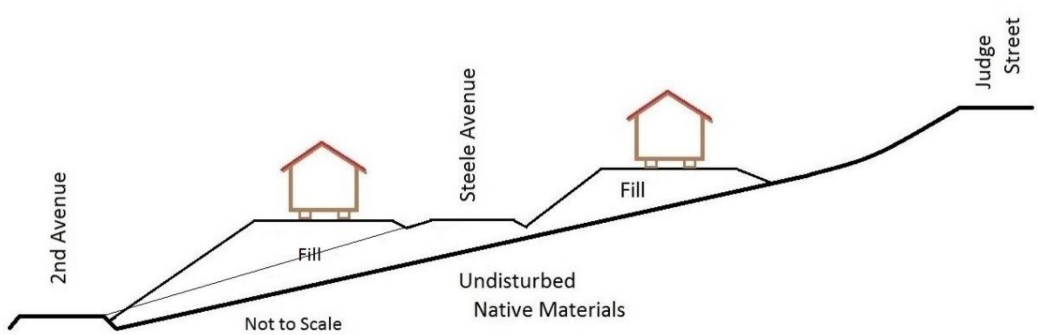
As long-term creep and other movements are likely, the sub-surface utility design should incorporate measures which will allow for generally north to south movements (between the colluvial slide and fluvial deposits) and west to east movements (between the colluvial apron and fluvial deposits).

As long-term sidewall deformation to the upslope side of the trench sidewall(s) should be anticipated in the colluvial deposits, utilities should be offset towards the downslope side of the trench (away from the side of the anticipated deformation) to increase their life-span.

Additional measures should be incorporated to accommodate differential and total movements where individual lot services connect to the residences.

The construction of junction boxes, which can be utilized to allow for maintenance of subsurface compression/extension sleeves, should be considered. These utility access points/wells should be situated where transitional zones between the varying deposits are located as determined in the field. Additional consideration may be required as to the configuration and composition of the utility wells, as the soils encountered at the founding elevations are generally not be suitable to support concrete structures. Reinforced wooden PWF structures should be considered otherwise a reduction in the design life of the concrete manhole structures should be anticipated. Provisions should be included in the design such that the utility wells do not adversely impact the pipes as considerable differential movements between these components should be anticipated.

A conceptual plan which illustrates the envisioned nature of the structural pads and road fills in the region between 2nd Avenue and Judge Street has been provided below.



While the intent is to minimize disturbance to the underlying colluvial materials, so as not to induce (or increase rates of) creep, sliver fills should be incorporated at the interface between fill and native materials. Large side-cuts into the colluvial deposits (> 0.25 m) should however be avoided.

Clearing operations will need to be staged such that they are conducted immediately prior to road and granular building pad construction as the loss of shade will induce thaw. While the establishment of roads and building pads will help insulate the underlying permafrost, the construction of temporary structures which provide shade to the lots should be considered to assist in maintaining the lots prior to sale and residential building construction.

Clearing beyond regions of infrastructure development should be discouraged.

Construction Monitoring and Testing

During construction, qualified geotechnical personnel should monitor the excavation and side slopes and inspect all sub-grade surfaces prior to backfill to verify their suitability for use.

The suitability of proposed imported fills should be confirmed through laboratory testing. Field density (compaction) testing should be conducted to verify that adequate compaction has been attained during trench backfill placement and granular pad construction.

6.5 Additional Evaluations

Geotechnical Evaluation

A geotechnical evaluation should be conducted by means of test pit or drilling methodologies to better assess the soil conditions in the regions of Steele Avenue and Area 30 (Figure 9) if these areas are to be developed. The intent would be to characterize the sub-surface soil conditions in these areas as they were not readily accessible during our evaluation and as conceptual subdivision plans were not available at the time of our evaluation.

Phase I Environmental Site Assessment (ESA)

A Phase I ESA should be conducted to verify whether or not there may be potential environmental liabilities located within the study area.

Natural Hazards Assessment

A natural hazards assessment should be conducted to better characterize the potential risks that they may pose to proposed development areas.

Site Survey

A detailed topographical survey of the study area should be conducted to better assess development options.

Assessment of Existing Structures

The conditions of the existing structures should be well documented so their initial conditions prior to subdivision develop are known. This information may assist in the event of a claim (from pre-existing home owners) following subdivision development.

Seismic Considerations

Additional assessment would be required from a civil design standpoint to determine whether or not there should be limitations relative to building heights and/or configurations.

7.0 CONCLUSIONS

The geomorphic conditions within the study area will allow for residential subdivision development, however, geotechnical setbacks will need to be observed in select areas to allow for buffers from potential geotechnical hazards which were identified as movement of the slide debris (and potentially colluvial deposits) and rockfall.

Our evaluation revealed that of the ~104 lots which were assessed, approximately 40 of them were deemed suitable for development. Rezoning and lot amalgamation will be required to maximize the development potential of the area.

While the roads and subsurface utilities can be developed along the Front Street and 2nd Avenue road alignments in the western half of the study area, infrastructure development in the eastern half of the study area will require additional consideration as direct access to the lots in this region is generally restricted from Judge Street due to the steepness of the terrain. A new road and utility alignment, along what was once known as Steele Avenue, will allow for better access to this area.

Residences can be constructed utilizing PWF cribbing and ventilated crawlspace types of residential foundation systems founded upon structural granular pads as is standard practice in the northern regions of Dawson City. Consideration could be given to developing some lots (on Front Street) through cut/fill construction methodologies which would allow for the establishment of concrete slab-on-grade types of foundations. Additional assessment will be required on a case-by-case basis once individual building sites have been identified.

The establishment of granular building pads, lot accesses and local drainage regimes should be carefully considered prior to residential building construction. This work should be carefully orchestrated and monitored by regulatory authorities in order to control surface drainage and minimize disturbance to the thermal regime. Development by individual homeowners may otherwise become liabilities if not properly established or maintained.

An erosion control plan should be incorporated into the design as may be required.

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.

Given the nature of historical development and the serpentinization of the slide debris rock (and hence the potential for asbestos occurrences), an environmental site assessment of the study area should be conducted to better assess the potential environmental hazards.

A supplemental geotechnical evaluation should be conducted once a conceptual design has been determined to verify the anticipated site specific geotechnical parameters, particularly in the eastern regions of the study area where colluvial apron deposits are anticipated.

While its understood that annual displacement monitoring of Moosehide Slide is being conducted by the *Yukon Geological Survey*, a natural hazards assessment should also be conduct to better characterize the potential hazard that the slide region may pose upon the study area.

8.0 LIMITATIONS

This report is intended for the sole use of the *Yukon Government*. 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 subsurface conditions encountered at the time of our evaluation, current construction techniques and generally accepted engineering practices. The 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. A geotechnical evaluation and thermal assessment of any proposed building structure or infrastructure would need to be conducted if suitable founding conditions are to be assured.

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 previous studies. 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.

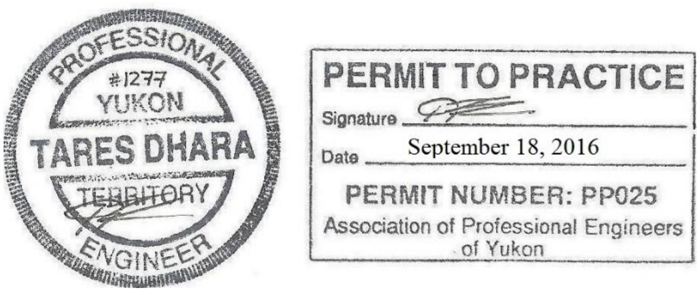
It is important to emphasize our evaluation is in fact, based upon random sampling and the results obtained at the borehole locations. Due to the geomorphological nature of the deposits encountered, interpolations of subsurface conditions between the borehole locations have not been made or been implied. 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 concerns.

Respectfully Submitted,

CHILKOOT GEOLOGICAL ENGINEERS LTD.



Tares Dhara, P.Eng.
Senior Geotechnical Engineer

TD/td

Geotechnical Evaluation
Proposed North End Subdivision
Dawson City, Yukon – 2016
Figure 1
Location of Study Area

Base map modified from *Google Earth* and *YG – Water Placer Atlas* Compiled Aug. 19th, 2016 by T.Dhara

Geotechnical Evaluation
Proposed North End Subdivision
Dawson City, Yukon – 2016

<u>Figure 2</u>

Study Area, Borehole and Hand Auger Locations

Base map supplied by *YG – Energy, Mines and Resources* Compiled by T.Dhara, Aug.18, 2016

Geotechnical Evaluation
Proposed North End Subdivision
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Figure 3

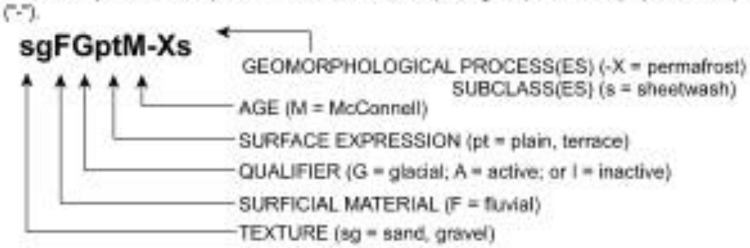
Surficial Geology, Dawson Region – Open File 2014-12

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

TERRAIN CLASSIFICATION SYSTEM

This surficial geology map was classified using the Terrain Classification System for British Columbia (Howes and Kenk, 1997), with minor modification to meet standards set by the Yukon Geological Survey. For example, we have added some permafrost process subclasses to accomodate the wider variety of permafrost features found in Yukon. We have also added an age classification to distinguish materials deposited during different Pleistocene glaciations.

A sample map unit label is shown below to illustrate the terrain classification system. Surficial materials form the core of the polygon map unit labels and are symbolized with a single upper case letter. Lower case textures are written to the left of the surficial material, and lower case surface expressions are written to the right. An upper case activity qualifier (A = active; I = inactive) may be shown immediately following the surficial material designator. The glacial qualifier "G" may alternatively be written immediately following the surficial material to indicate glacially modified materials. Age is indicated by a capital letter that follows the surface expression but precedes the process modifiers. Geomorphological processes (capital letters) and subclasses (lower case letters) always follow a dash symbol ("-").



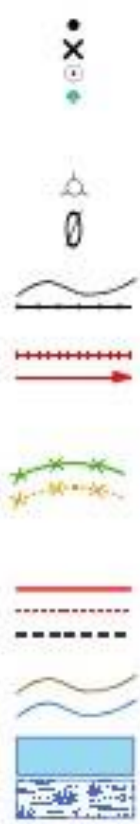
COMPOSITE SYMBOL DELIMITERS:

Due to scale limitations, up to 4 terrain units may be included in a single map unit label (e.g., sgFGptM.dsmMbM/xsCv\zcLGpM-XsV). Each component is separated by a delimiter that indicates relative proportions between the components (".", "/", "//") or a stratigraphic relationship "\").

"." - terrain units on either side of the symbol are of approximately equal proportion
"/" - terrain unit(s) before the symbol is more extensive than the one(s) following
"//" - terrain unit(s) before the symbol is considerably more extensive than the one(s) following
"\" - terrain unit(s) before the "\" symbol stratigraphically overlies the one(s) following

1st terrain unit (>50% of map unit) / 2nd terrain unit (30-49% of map unit) // 3rd terrain unit (10-29% of map unit) \ Underlying terrain unit

LEGEND



GROUND OBSERVATION SITES:

- field station
- stratigraphic section (labelled with site number)
- permafrost borehole
- electrical resistivity tomography (ERT) profile station

GEOLOGICAL FEATURES:

- collapsed open system pingo
- thermokarst pond
- geological boundary
- limit of mapping
- landslide escarpment
- direction of landslide movement

GLACIAL LIMITS:

- Reid (R), defined (after Duk-Rodkin, 1996)
- Pre-Reid (>R), assumed

TOPOGRAPHIC FEATURES:

- roads
- trails
- transmission line
- contours
- streams
- waterbodies
- wetlands

Information from Surficial Geology, Dawson Region map by *K.McKenna and P.Lipovsky*

SURFICIAL MATERIALS

F

FA

Holocene Fluvial: Sediments transported and deposited by modern streams and rivers, found in floodplains, fans, and terraces. Fluvial materials may be subject to occasional flooding, sudden stream migration, and/or inundation. Fluvial deposits typically consist of well-sorted stratified sand and gravel comprising subangular to rounded clasts. Thicknesses up to 10 m are common. Low order streams in unglaciated areas are confined to very narrow V-shaped valleys and their fluvial deposits are generally not mapped due to scale limitations. Fluvial fans (Ff), or complexes of coalescing fan-shaped landforms (Fa) are found at the mouths of tributary streams. Where smaller creeks enter the Klondike River valley, fluvial deposits usually consist of large amounts of resedimented silt and sand primarily derived from loess with minor gravels derived from colluvial or glaciofluvial materials. These fans, though still active, likely formed relatively quickly after the McConnell glaciation. They may be ice-rich and contain ice wedges, especially where they are north-facing. Active fluvial (FA) materials primarily consist of sand and gravel and are subject to regular flooding.

C

Colluvium: Material transported and deposited by down-slope, gravity-driven processes such as creep, solifluction, landslides, and snow avalanches. Colluvium is the dominant surficial material in the uplands north and south of the Klondike River and west of the Yukon River as most of these areas escaped Pleistocene glaciation. It commonly has a stratified structure with a highly variable texture and composition controlled by the parent material, transport mechanism, and travel distance. Colluvium on uplands and slopes is generally derived from weathered bedrock and loess, resulting in a silt-rich diamicton containing angular, local bedrock clasts. On steeper slopes, colluvium is generally coarser grained, as it has been deposited by rapid mass wasting processes such as rock fall, debris flows, and avalanches. Slower processes such as sheetwash, solifluction, and creep occur on gentler slopes, which in conjunction with greater accumulations of loess and the presence of near-surface permafrost, result in finer grained colluvium. Colluvial aprons found on lower slopes and the uphill sides of terraces are commonly ice-rich and are primarily composed of resedimented loess and peat (muck). North of the Klondike River, Pre-Reid morainal deposits have been extensively modified by slope movement (colluviation) and solifluction and are mapped as complexes of colluvial and morainal deposits.

R

Bedrock: Bedrock in the map area primarily consists of Yukon-Tanana terrane Paleozoic schist, quartzite, and gneiss older than 245 million years, as well as some Slide Mountain terrane greenstone, amphibolite, and serpentinized ultramafic rocks. Bedrock is exposed on steep cliffs and slopes along the Klondike and the Yukon river valleys, having been exposed by large landslides, glacial, or glaciofluvial erosion.

CITATION

McKenna, K.M. and Lipovsky, P.S., 2014. Surficial geology, Dawson region, Yukon; parts of NTS 115O/14 &15 and 116B/1, 2, 3 & 4. Yukon Geological Survey, Energy, Mines and Resources, Government of Yukon, Open File 2014-12, 1:25 000 scale.

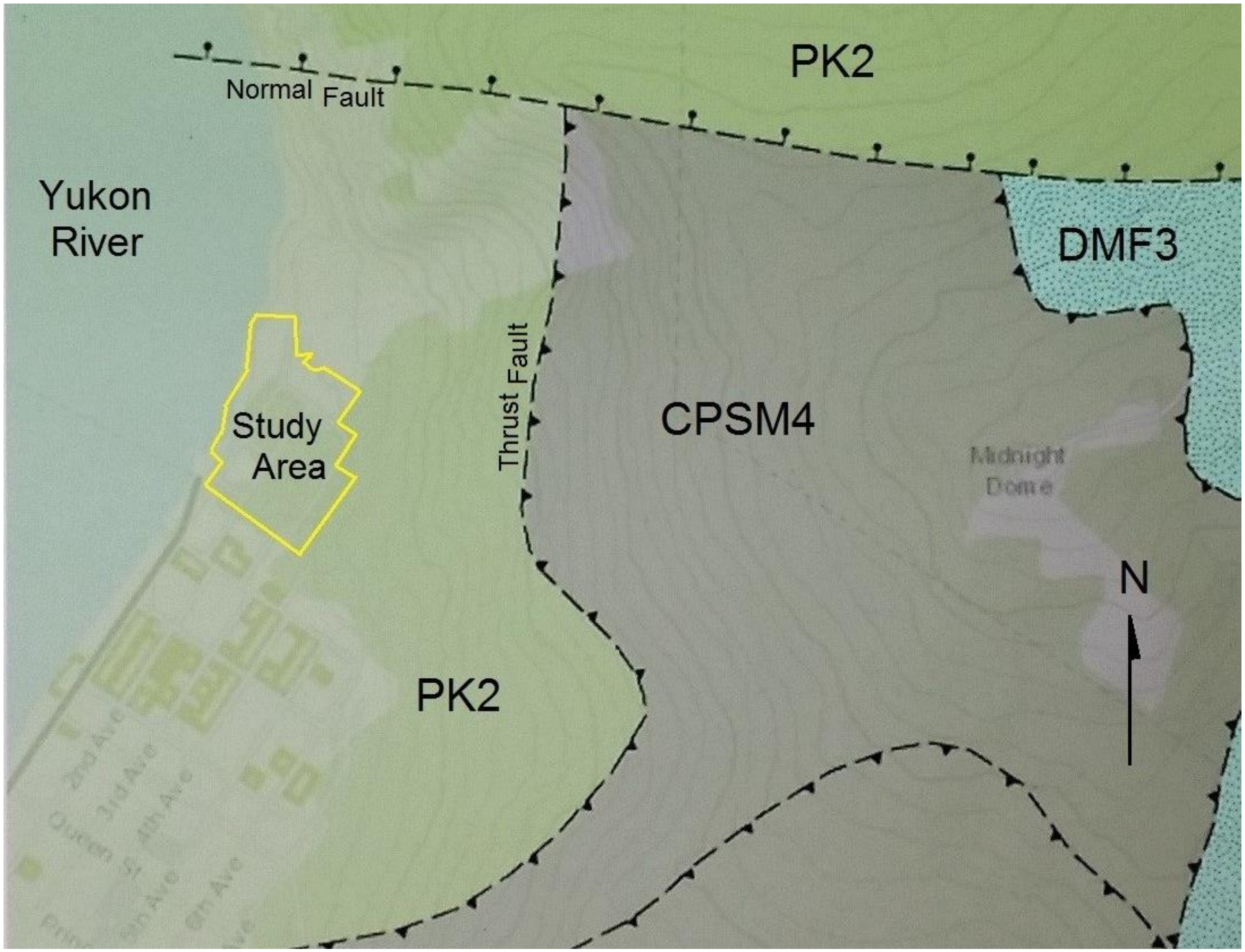
Information from Surficial Geology, Dawson Region map by *K.McKenna and P.Lipovsky*

Geotechnical Evaluation

Proposed North End Subdivision – Dawson City, Yukon – 2016

Figure 4

Bedrock Geology



Based map from *Yukon Geological Survey* website

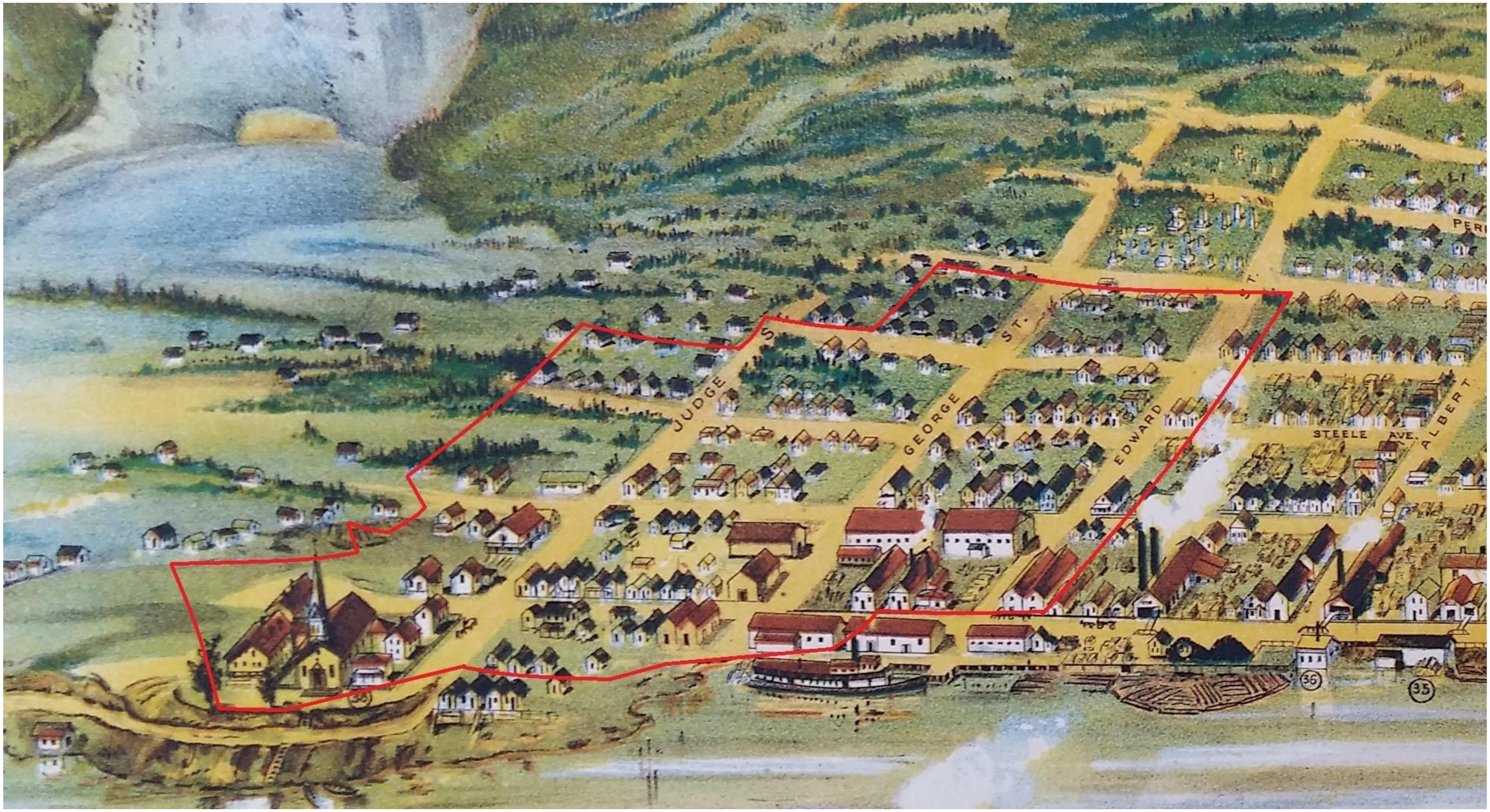
Compiled August 19, 2016 by T.Dhara

Geotechnical Evaluation

Proposed North End Subdivision – Dawson City, Yukon – 2016

Figure 5

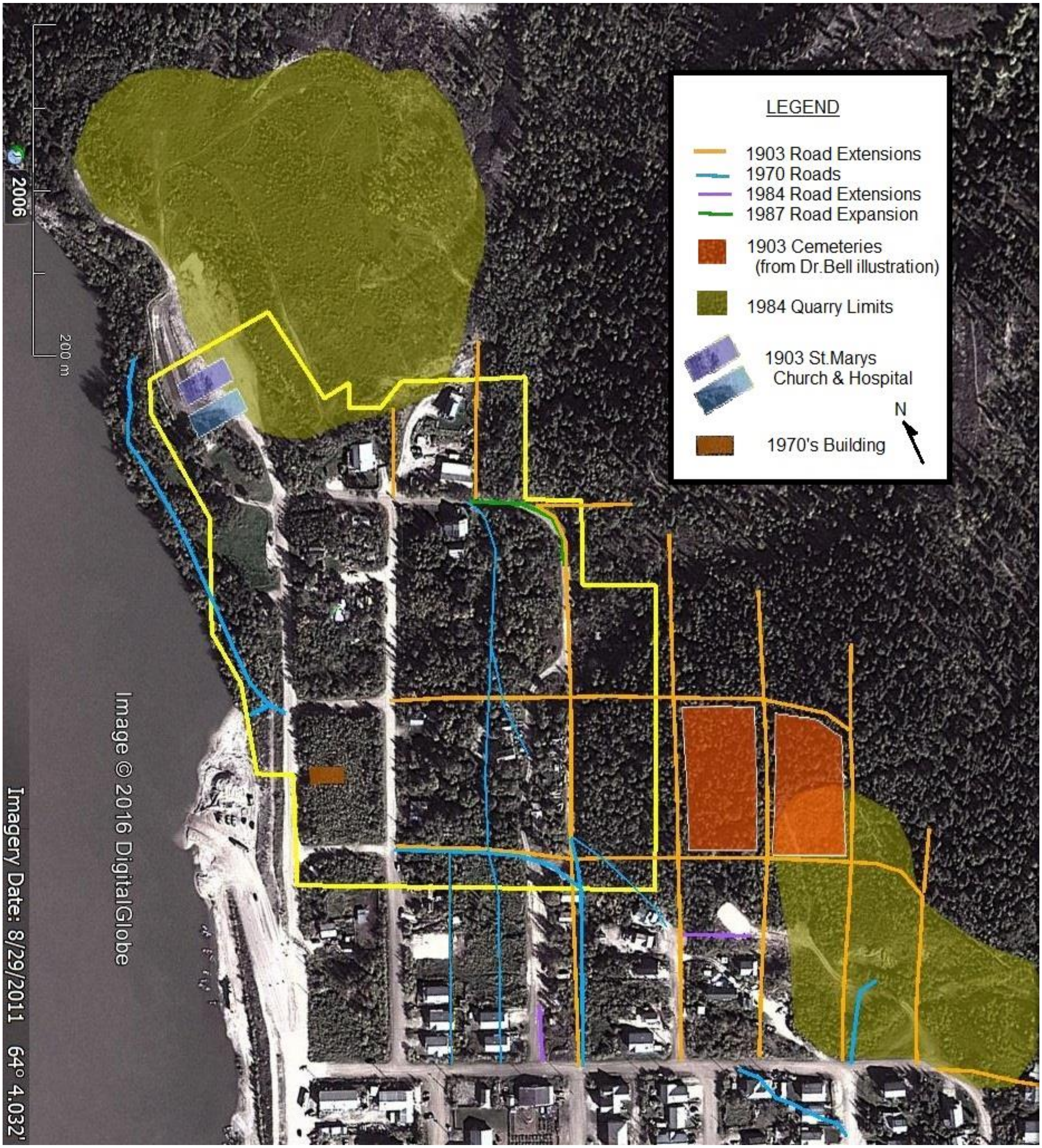
Historical (1903) Setting



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

Compiled August 18, 2016 by T.Dhara

Geotechnical Evaluation
Proposed North End Subdivision
Dawson City, Yukon – 2016
Figure 6
Historical Development



Base map from *Google Earth*

Compiled by T.Dhara, Aug.19, 2016

Geotechnical Evaluation
Proposed North End Subdivision
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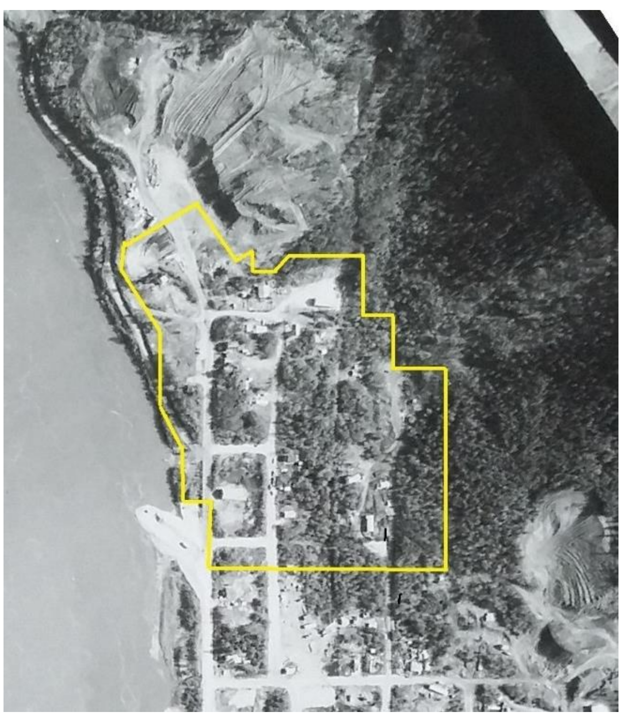
Figure 7
Selection of Air Photos

1970

1977



1984

1993

Air Photos from YG – EMR Library
Not to Scale – Limits are Approximate

Compiled August 19, 2016 by T.Dhara

Geotechnical Evaluation
Proposed North End Subdivision
Dawson City, Yukon – 2016
Figure 8 A
Utility Plan – Sanitary & Water

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

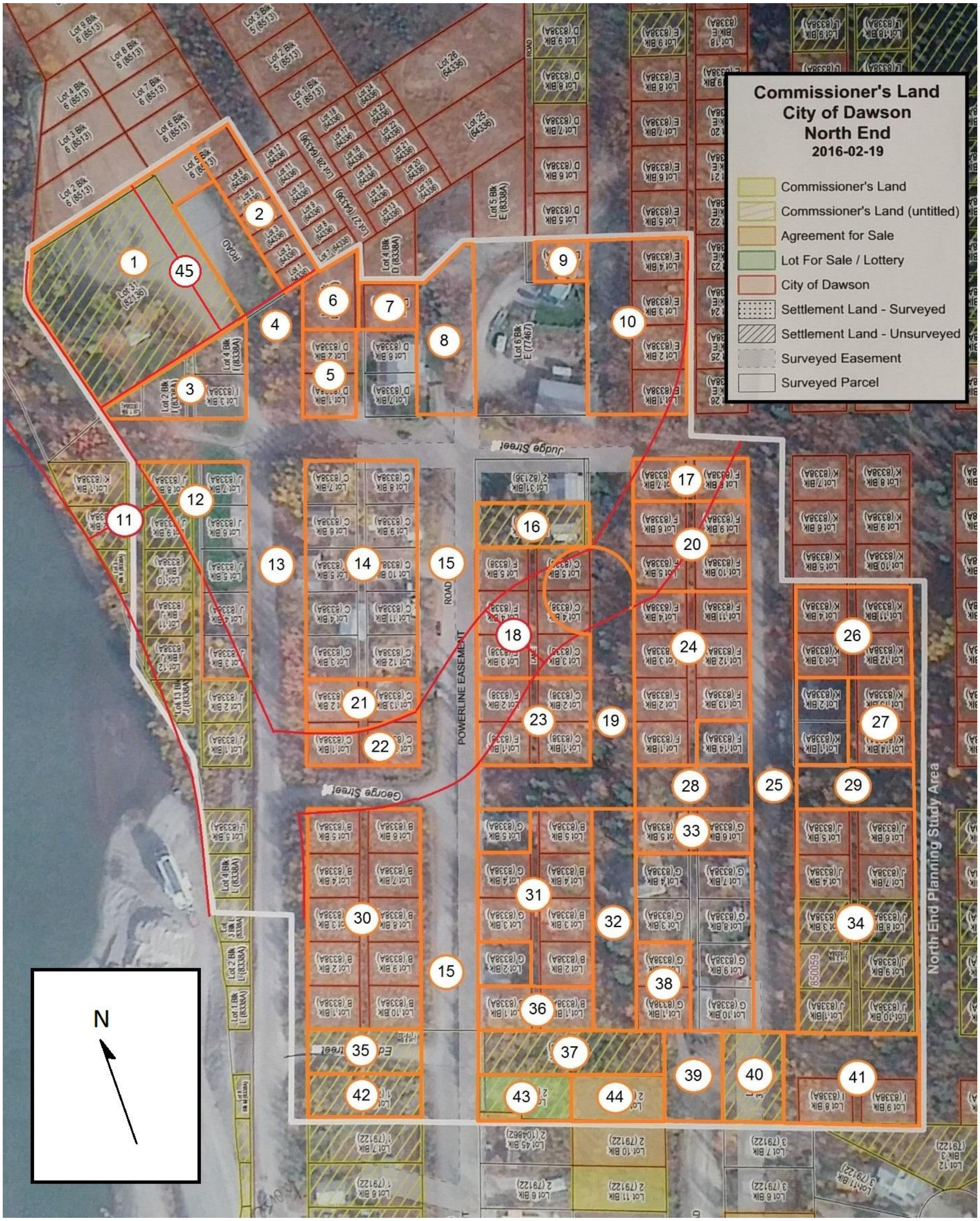
Compiled August 18, 2016 by T.Dhara

Geotechnical Evaluation
Proposed North End Subdivision
Dawson City, Yukon – 2016
Figure 8 B
Utility Plan – Storm Water Drainage

Base plan supplied by *City of Dawson* Compiled August 19, 2016 by T.Dhara

Geotechnical Evaluation
Proposed North End Subdivision
Dawson City, Yukon – 2016

Figure 9
Assessment Areas



Base map supplied by *YG – Energy, Mines and Resources*

Compiled by T.Dhara, Aug.29, 2016