Stantec

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Reference: Desktop Geotechnical Overview – Ladue South, Town of Faro, Yukon.

1. INTRODUCTION

Stantec Consulting Ltd. (Stantec) was contracted by the Government of Yukon's Land Development Branch (LDB) to provide a geotechnical overview of the area known as 'Ladue South' within the Town of Faro (TOF), Yukon. The purpose of the geotechnical overview was to assess the suitability of developing the Study Area for residential use. It is understood that the TOF is updating the Official Community Plan (OCP); the results of the feasibility study will be integrated into the OCP as development designations.

Ladue South is defined by the LDB in the Scope of Work as being situated along Ladue Drive, between Golf Course Road (unsurveyed) and Sheldon Road. It includes 10 lots, one of which is partly bisected by Golf Course Road and would require realignment of Golf Course Road with the lot in question (Lot 210); the TOF has indicated they are willing to realign the road. The 10 lots are understood to be currently of mixed ownership (TOF and Yukon Government) and zoning ('Residential – Single' and 'Residential – Multiple'). Two lots are situated on the north side of Ladue Drive are the remaining 8 are on the south side of the road.

For the purpose of this assessment, we have defined the Study Area as the Ladue South 'envelope' defined by the LDB (comprising the ten lots) and a 250 m buffer extending on all sides of the envelope. Although outlying hazards are considered beyond the buffer, we have focused data collection, including geotechnical borehole data review, on the Study Area. An overview of the Study Area is shown on Figure 1.

Stantec has also been retained to complete a Geotechnical Overview Assessment of a separate study area known as the 'Light Industrial Feasibility Area' within the Town of Faro. A separate deliverable has been prepared for this area, using the single Scope of Work document issued by the LDB.

2. SCOPE OF WORK

According to the issued scope of work by the LDB, the desktop geotechnical overview is comprised of a 'foundations report that specifies the suitability of residential development consistent with the TOF zoning'. To meet the needs of the foundation report, we have undertaken the following tasks, in line with similar reporting completed for the Government of Yukon Land Development Branch and other community development projects in Northern Canada:

1. Compilation and review of background information (geographical data, climate data, bedrock and surficial geology maps, existing geotechnical reports, permafrost-related publications, etc.).
2. Using data obtained from the above-listed activities, evaluate the suitability of developing the site from a geotechnical hazard perspective.
3. Develop a Desktop Geotechnical Overview report that includes the following sections:

- General site and terrain conditions, including surficial materials and topography;
- Anticipated soil conditions (soil types, drainage);
- Groundwater;
- Bedrock (depth);
- Seasonal frost and permafrost;
- Terrain hazards and constraints for development; and
- Comments on the overall construction suitability.

Figure 1 - Overview of the Study Area within the Town of Faro, Yukon, facing due north. It is comprised of ten lots of mixed ownership (municipal vs. territorial government) on Ladue Drive and a 250 m buffer represented by the black polygon.

3. SITE CONDITIONS

3.1 DATA SOURCES

Findings of this geotechnical suitability assessment are based on professional judgment, publicly available literature, maps and reports, third-party geotechnical data (cited) as well as observations compiled by Stantec working in similar latitudes subject to permafrost. Data sources used in this investigation include:

- GeoYukon, interactive mapping application;
- Yukon Geological Survey for bedrock and surficial geology mapping and datasets;
  - Surficial Geology, Faro Region, Yukon, parts of NTS 105K/3, 4, 5, & 6 (Turner, Bond, & Lipovsky, 2014)
  - Geological map of Anvil District (Pigage, 2004)
- Faro Landscape Hazards study Yukon (Benkert, et al., 2015)
- Yukon Permafrost database (Yukon Geological Survey, 2023);
- Government of Yukon water well registry online ArcGIS application (Government of Yukon, 2023);
- Geotechnical borehole data from the online Yukon Permafrost database
- Government of Yukon Light Detection and Ranging (LiDAR) collection (a total of 7 LAS datasets surveyed in 2019 by McElhanney) (Government of Yukon, 2023)
- Canadian Climate Normals, 1981-2010 for Faro A (Airport) Station (Environment and Climate Change Canada, 2023)

The Faro Landscape Hazards study is frequently cited in this report due to its relevancy, recency, and valuable case studies contained within. The results of the field investigation for the Del Van Gorder school and baseball diamond area, situated ~250 m south of the corner of Ladue Drive (within the Study Area) are particularly useful for this desktop assessment. The results have been compared to older geotechnical borehole records from 1980 for the Study Area.

3.2 EXPECTED SITE CONDITIONS

Based on our review of the information detailed above, the following conditions are expected within the Study Area (subject to confirmation through field investigation):

3.2.1 Topography

Faro is located in the Tintina Trench of the Cordillera physiographic region, situated between the Pelly Mountains (west) and the Yukon Plateau (east) (Bostock, 1967). The Study Area is located on a glaciofluvial terrace; the terraced topography of the area is characterized by broad benches and short but moderate to steeply sloping scarps. These scarps vary between 30% and 80% near the Study Area, over horizontal slope distances ranging from 8 m to 40 m. Lot 202, which is not part of the Study Area (and understood to have not been consolidated with Lot 203 as was originally believed) features short scarps on the northwest and southwest sides.

The scarps and channels formed when meandering streams eroded through the glaciofluvial terrace and underlying glaciolacustrine sediments that were deposited during the most recent glaciation. These scarps are readily visible on hillshade imagery produced from the LiDAR point data obtained from the Yukon Government open data website (Figure 2). Many of these scarps appear to have been excavated (disturbed) to create level building areas when the town was developed and were possibly also used for aggregate sources (e.g., for road surfacing and fills). A prominent, disturbed glaciofluvial scarp is situated approximately 130 m east-northeast from Lot 210. From toe to the top of scarp, the elevation difference is approximately 14 m. A gravel road has been constructed at the top of this feature.

From the LiDAR data, the elevation profile through Lots 203 and 210 from southwest to northeast is approximately 727 to 732 m above sea level (asl); there is an overall slope downwards towards the southwest at Lot 203. Lots 175 and 176 on the north side of the street feature little elevation difference, at 726 m asl, but also slope southwesterly. These two lots are situated at slightly lower elevation than Lot 203 (~1.5 – 2 m). They feature short but steep scarps just outside the rear lot lines. A plain hillshade figure with the lot lines overlain in shown on Figure B.1 in Appendix B.

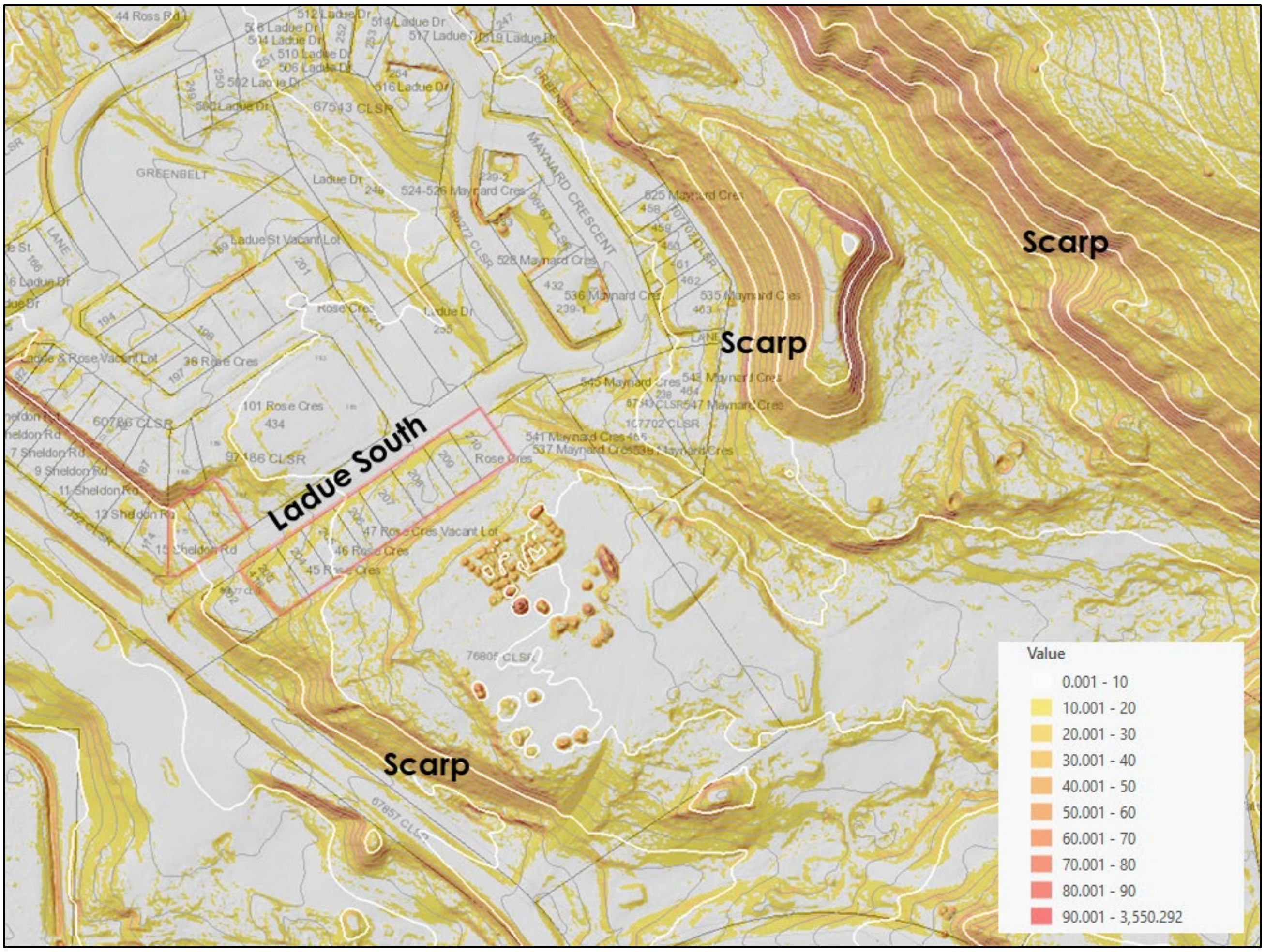

Figure 2 - Slope and contour map generated from LiDAR data for the Study Area. Note the southwest slope trend for the Ladue South area, as indicated by the contours, and surrounding scarps created by streams incising through the terrace and fans.

3.2.2 Surficial Materials and Soils

Surficial geology mapping by the Yukon Geological Survey indicates that the Study Area is a glaciofluvial terrace containing predominantly sand and gravel and minor cobbles and boulders, and overlies a glaciolacustrine plain containing finer sediments, namely silt, clay, and sand (Turner, Bond, & Lipovsky, 2014). Channel features (most of which are now dry) formed when meandering streams cut through the terrace and glaciolacustrine deposits well after the end of the last glaciation. The glaciolacustrine sediments were deposited by glacial lakes during the Wisconsinan McConnell glaciation (the last glaciation before the current Holocene epoch). More detailed surficial geology mapping is shown on Figure B.2 in Appendix B.

Southeast of the Study Area, where Golf Course Road meets Lorna Boulevard, the occurrence of "organic deposits" (accumulated organic matter in varying states of decomposition) and "permafrost processes" (i.e., processes controlled by the presence of permafrost and permafrost aggradation or degradation) are indicated by the surficial mapping. These deposits extend southeasterly into a low-lying, undeveloped area situated between Lorna Boulevard and Douglas Drive.

The Yukon Permafrost Database has geotechnical borehole records for the Study Area (Yukon Geological Survey, 2023). Approximately 12 boreholes intersect what are now the ten lots that comprise Ladue South; these were drilled in 1980 for what was then the Cyprus Anvil Mining Corporation ('Project Name: Proposed Basements for Mobile Home Park'). This project was presumably undertaken to develop housing for employees of the Faro Mine. In the southwest corner of the Study Area (towards Lot 203), drilling (GINT_2878-30) recorded 4.6 m of gravel and sand (occasional cobbles and boulders) overlying silt (some sand and gravel, trace pebbles) to 12.2 m. The silt unit is identified as glacial till, which disagrees with the 2014 Yukon Geological Survey surficial materials mapping of glaciolacustrine.

For the northeast end of the Study Area (near Lot 210), the borehole records similarly show 2.65 m of gravel and sand (glaciofluvial deposits) overlying silt to 6.4 m, where competent bedrock was encountered. The location of the 12 borehole records are shown on Figure B.3. in Appendix B (along with other surrounding borehole records and points).

From the LiDAR, surficial geology mapping, and imagery, we expect that the surface soils in proximity to the Study Area are well to rapidly-drained, coarse textured Regosols and possibly Brunisols that have developed from the glaciofluvial sand and gravel. Glaciolacustrine deposits in this area are indicated to contain silt, clay, and fine sand but are not encountered at depths above approximately 2.5 m. The glaciolacustrine deposits have likely not undergone pedogenic, or soil-forming processes and are therefore most likely to be unaltered parent materials residing above bedrock.

3.2.3 Groundwater

The online Government of Yukon water well registry has borehole records for groundwater monitoring and well installation in the outlying areas, specifically near the terminus of McQuest Road (northeast of the Study Area) and at the former Faro Hotel, near what is now the Yukon Housing Corporation on Campbell Street (Government of Yukon, 2023). For the area around McQuest Road, ten boreholes drilled in an unknown year for the purpose of installing wells extend between 6.7 and 13.7 m below ground surface (bgs) (Government of Yukon, 2023). The specific static water level is not indicated for any of these boreholes.

According to the registry and the accompanying Yukon Source Water Supply Protection Study, the Faro public water supply is via the underlying sand and gravel aquifer (an alluvial fan) that is recharged by both the Pelly River and Vangorda Creek (alternatively spelled Van Gorder creek on other maps) with variable recharge proportions depending on season (Tetra Tech, 2017). The registry shows the water supply wells are located approximately 1.4 km southwest of the Study Area. The town site was originally serviced via three wells (identified as wells 1, 2, and 3) that have since been decommissioned and assumed to have been replaced with two new wells (identified as wells 4 and 5) that were drilled in the summer of 2016 (pending as of the 2017 study). In wells 3 through 5, the static water level is reported at 2.75 and 4.14 m bgs (Tetra Tech, 2017).

Furthermore, the water supply study states that wells in Faro are relatively shallow (total depths of 12 m bgs), and cites a 2006 comprehensive study (prepared by Gartner Lee Limited – an online version of this report could not be located) for the town that found that the cone of depression from the wells extends to Vangorda Creek and groundwater velocities under pumping conditions are fast (may be less than 7 days travel time from Vangorda Creek) (Tetra Tech, 2017).

A separate 2003 report by Gartner Lee Limited (GLL) is referenced in the Faro Landscape Hazards Study; which again could not be located online, found that during periods of high flows in the Pelly River (e.g., during the spring freshet), groundwater recharge occurs to hydraulically connected aquifers which are expected to exist in the Faro town area (Benkert, et al., 2015).

From the limited information collected above, the regional water table in this area of the Faro townsite and potentially including the Study Area appears to be within 20 m of the ground surface via sand and gravel aquifers supplied by both Vangorda Creek and the Pelly River.

3.2.4 Bedrock

The Study Area is situated over metamorphic rock (quartzite, schist, eclogite) of the Snowcap Suite, which is part of the Yukon-Tanna terrane (Pigage, 2004).

The 1980 geotechnical borehole records available via the Yukon Permafrost Database for the Study Area show that bedrock is encountered at depths between 6 m and 12 m bgs. The shallowest bedrock was encountered in the northeast near Lot 210, at 6.4 m (GINT_2878-19).

From the LiDAR imagery, it is apparent that shallow bedrock (e.g., within 1-3 m) is not likely to be encountered within the Study Area or the immediate outlying areas on the glaciofluvial terrace. The surficial materials have blanketed the underlying bedrock by depths of more than 5 m, and as demonstrated by the geotechnical borehole records, by up to 12 m in the Study Area.

3.2.5 Climate & Seasonal Frost

The climate of Faro is characterized by short, cool summers and long, cold winters of the Boreal Cordillera ecozone (Environment Canada, 1999). The ecoregion is the Yukon Plateau North. The mean annual temperature of the interior subalpine is -0.7 to -0.3°C; average temperatures reach or exceed 10°C for only one month a year. The mean annual precipitation for this ecozone is 450 to 700 mm, of which between 35 and 60% falls as snow.

The nearest Environment Canada climate station is located at Faro Airport (Climate Reference ID: 2100517), approximately 3.8 km southwest of the Study Area at an elevation of 716 m above sea level (Environment and Climate Change Canada, 2023). For the thirty-year period spanning 1981-2010, average annual daily mean temperatures are -2.0°C. The lowest average daily winter temperatures generally occur in January (-20.1°C) while the warmest average daily summer temperatures occur in July (15.0 °C). The average annual precipitation is estimated on the order of 320 mm, with an average annual rainfall of 218 mm and average annual snowfall equivalent of 114 cm. The average freezing and thawing indices between 1981 and 2010 are 2468°C·days and 1792°C·days, respectively. For the thirty-year period of 1981 – 2010, the average frost-free period was 85 days, spanning on average between the dates of May 29 and August 23 (Environment and Climate Change Canada, 2023).

As Faro is situated in a valley bottom-trench, it experiences a slower rate of cooling with elevation; this is due to the pooling of cold air in the valley during the winter months (Benkert, et al., 2015). The area also tends to experience more variable temperatures in both summer and winter relative to areas to the south, in part due to its proximity to the St. Elias Mountains and distance from the Gulf of Alaska (Benkert, et al., 2015). Summers can be extremely warm, and winters can experience long cold periods.

3.2.6 Permafrost

According to the Permafrost Probability Model for Southern Yukon, Faro and the immediate surroundings have a 50-60% probability of extensive, discontinuous permafrost (Bonnaventure, Lewkowicz, Kremer, &

Sawada, 2012). The Study Area is broadly identified as having potential permafrost at depth in the Faro Landscape Hazards report (Benkert, et al., 2015).

Regionally, the Yukon Geological Survey Permafrost Database shows only a single temperature sensor (YGS_Faro) in Faro, which is located approximately 700 m southeast of the study area, in an undeveloped area 220 m southeast of Lorna Boulevard and 150 m southwest of Douglas Drive (Yukon Geological Survey, 2023). The cable was installed between 2007 and 2019 indicating permafrost within 4 m (the maximum depth of the temperature sensor) of the ground surface in the vegetated. There are no other temperature sensors located within the townsite.

Frozen soils are present in 8 of the 12 geotechnical borehole records (drilled 1980) available via the Yukon Permafrost Database (note that no permafrost records are available for the remaining 4 drill records within the Study Area – it is unknown if this is because no permafrost was present, no permafrost was assessed in the samples, or the records are incomplete or missing).

The depths to frozen soil range from 2.1 to 7 m bgs and occur in both the glaciofluvial and glaciolacustrine deposits. Ice with interstitial soil (silt) and ice without soil inclusions was observed in four of the borehole records, all on the south side of Ladue Drive (GINT_2878-14, -15, -19, and 20). Ice lenses were recorded up to 75 mm thick. Depths to ice range from 6.1 m to 9 m bgs, with visible ice (Vs) also present in two of the boreholes on this side of Ladue Drive. Ice is described when it meets the definition of being greater than 25 mm thick and without soil inclusions (Tart, 1996). On the northwest side of Ladue Drive around Lots 175 and 176, soils were found to be frozen at depths between 3.3 and 6.2 m bgs, with well-bonded to poorly-bonded soils with no visible ice to over 9 m bgs (GINT_2878-27, and -33).

Ice-rich permafrost is defined as 'thaw-sensitive permafrost containing excess ice' (Shur, Jorgenson, & Kanevskiy, 2011)'. It is further defined by having cryostructures that are lenticular, microlenticular, and layered (Benkert, et al., 2015). The ice is described in the borehole records as lenses that are 50-75 mm thick; this would meet the definition of ice-rich permafrost. In summary, the permafrost that was present in the Study Area in 1980 would be considered a mix of ice-poor and ice-rich, discontinuous permafrost given the information detailed in the records. The ice recorded in four of the boreholes all occurs in the silt horizon, which is considered highly frost-susceptible. From the Faro Landscape Hazards study, the silt horizons are typically ice-rich and mechanically unstable upon thawing if they are located at or below the permafrost table (Benkert, et al., 2015). If the permafrost has degraded in these deposits, poor-drainage may be observed due to thawing and release of water from the substrate in question.

The Faro Landscape Hazards study involved geophysical surveys of permafrost in five case study areas. For the Del Van Gorder School and baseball diamond site situated ~250 m south of Ladue Drive and Sheldon Road, the top of the permafrost was found 10-15 m deep in the south portion of the electrical resistivity tomography (ERT) profile near the school building. Permafrost was found to be deeper (15-25 m) northwards in the golf course area. From the geophysical survey, the report authors opined that the permafrost, which is upwards of 30-40 m thick between unfrozen ground (taliks and the active layer closer to the surface) is degrading, likely because of site disturbance (land and vegetation clearing, building construction). Similar degradation may have occurred in the permafrost that was present in the Study Area in 1980. In 2004 imagery, the Study Area was completely bare of vegetation, and has likely been disturbed (clearing, forest fire, fill placement) multiple times since the 1980 drilling.

3.2.7 Hazards and Terrain-Related Constraints

In the Faro Landscape Hazards report (Benkert, et al., 2015), the Study Area is situated within a MODERATE hazard zone due to potential permafrost at depth. The hazard is that 'moderate'[1] thaw settlement would occur due to permafrost degradation, which could damage structures and other infrastructure in this area. It is noted

[1] No definition is given for what is considered 'moderate' thaw either qualitatively or quantitively in the Faro Landscape Hazards report.

that dry or unsaturated frozen sediment does not present a hazard when thawed (Benkert, et al., 2015). Furthermore, the presence of ice-poor sediment in the overlying glaciofluvial deposits (which were found to be frozen in almost all borehole records for the site in 1980), may in fact translate to a condition of differential rates of thaw settlement, in which the upper ice-poor sediments thaw rapidly but with minimal thaw settlement, followed by slow but constant thawing of the underlying presumed ice-rich glaciolacustrine deposits. These ice-rich glaciolacustrine sediments, if super-saturated upon thawing (the volumetric water content of the ground is higher than the volume of soil pores when unfrozen) would result in severe surface settlement (Benkert, et al., 2015).

In the Faro Landscape Hazards report, the study area around the town site was divided into polygons based on terrain (surficial materials, slopes) and potential hazards. The following description of the Del Van Gorder School and baseball diamond case study site, situated approximately 250 m south of the Study Area and having similar topography and surficial materials, is relevant (**bolded** sections emphasized by Stantec):

> *"The area around Del Van Gorder School and the baseball diamond has been ranked as having moderate hazard risk. Glaciofluvial and glaciolacustrine sediments in the area include interbedded sand and silt,* ***which can be vulnerable to settlement as a result of permafrost thaw.*** *In addition, low-lying areas (like the baseball diamond) contain deposits that are fine-grained, wet, and organic-rich, which likely contributed to the growth of ice-rich permafrost in the past.*
>
> ***Notably, permafrost at this site is deeper than previously published values (30-40 m, rather than 10 m, as reported by EBA (1981)****)).* ***Considerable permafrost degradation has already occurred*** *in this area (e.g., visible as taliks in geophysical profiles, noted in the relatively shallow depth to the top of permafrost,* ***and the observed settlement-induced damage in the school and parking lot****), likely in response to the removal of vegetation as part of development. Given the amount of frozen ground still present at this site, it is likely that permafrost degradation at this location will continue for decades"* (Benkert, et al., 2015).

Glaciolacustrine sediments, independent of permafrost presence, also tend to be landslide-prone. This depends on several geotechnical properties of the deposits, ranging from the plasticity of the clay contained within (e.g., highly plastic clays with low residual strength), cementation, whether they are advance or retreat-phase lake sediments, and whether glacial-induced deformation and shearing occurred when overridden by glacial ice (Bishop, Evans, Petley, & Unger, 2008) (Geertsema & Cruden, 2008) (Froese & Cruden, 2001). Pre-sheared surfaces result in a reduction in strength to the materials and pre-conditions the slopes to failure, particularly if the slopes are disturbed through development or erosion by streams (Bishop, Evans, Petley, & Unger, 2008). It is noted in the Faro Landscape Hazard reports that no glaciolacustrine-related landslides have been observed in Faro in recent history (Benkert, et al., 2015).

From the LiDAR and imagery, the nearest landslides relative to the Study Area have occurred in the laterally extensive, exposed scarp that marks the modern floodplain limit of the Pelly River (north bank). The scarp is mostly unvegetated and shows signs of continuous raveling and gully erosion, with historic slumping and rotational landslides apparent from the LiDAR. Exposed glaciofluvial sediments overlying thick glaciolacustrine sediments (up to 40 m thick) are present in the scarps, with bluff exposures prominent on the west side of Mitchell Road where it passes the north side of the sewage lagoon (Benkert, et al., 2015). The top of this extensive scarp is situated approximately 700 m southwest of the edge of the Study Area from Lot 203 (closest distance). These scarp landslides do not pose a stability threat to the Study Area. Larger, more recent landslides are apparent along the Vangorda River ~ 900 m west of the Study Area; exposed glacial till up to 30 m high is present and most likely destabilized due to undercutting of the slope by Vangorda Creek (Benkert, et al., 2015).

Topographically, the area is situated on gentle ground that slopes approximately 3% southwest (as measured through Lots 210 to 203 via LiDAR and ESRI® ArcGIS Pro). As described above, there are moderate to steeply-sloping (i.e., >70%) scarps in the vicinity of the Study Area, specifically on the northwest and southwest sides of Lot 202 (not included in the potential development) and situated just outside the rear (northwest side) of Lots 175 and 176. These scarps are likely composed of coarse-textured (sand and gravel with minor cobbles and boulders) glaciofluvial sediments that may ravel when disturbed through cuts. It is likely that the lots have been graded already and no further cuts into these scarps will be necessary to facilitate development.

4. OVERALL DEVELOPMENT SUITABILITY

Qualitative development suitability within the study area is based on the overall site conditions, including the presence/absence of terrain constraints and potential geohazards. These terms are described as follows:

- Terrain constraints are naturally occurring features that have the potential to negatively affect the design, construction and maintenance of a community (e.g., slope steepness, drainage conditions, surficial material type, permafrost and periglacial features).
- Geohazards are terrain conditions that may lead to localized or widespread damage to property and threaten personal safety. Common examples of geohazards are landslides, gully erosion, ground subsidence and thermokarst, flooding, and thermo-erosion of permafrost.

From the desktop review of imagery, LiDAR, and historical geotechnical borehole records and landscape hazard reports for the Town of Faro, the main geohazard to the Study Area is permafrost degradation resulting in thaw settlement, in agreement with the Faro Landscape Hazards report. At the time that the 1980 geotechnical boreholes were drilled, frozen soils were encountered between 2.1 and 7 m bgs and ice lenses 50-75 mm thick between 6.1 m and 9.0 m bgs. The ice lenses appear to have been hosted in the glaciolacustrine silt and clay horizon situated below the coarser (sand, gravel) glaciofluvial deposits, which in many of the drill records were also frozen but did not host ice.

Although these records are over 40 years old, and subsequent warming of the Arctic climate has likely resulted in a phase of permafrost degradation in this area (Benkert, et al., 2015), permafrost (intact or degraded) may still be present at depth in the Study Area and should be confirmed as such via field investigation (e.g. via auger drill and laboratory testing of ice content and soil characteristics).

The development suitability classification used for this assessment is based on the recently published Risk-Based Approach for Community Planning in Northern Regions – Requirements and Guidance (National Standard of Canada, 2023). A development suitability classification is specific to the site assessed; there is no “one-size fits all” classification system.

We have produced a development suitability classification that considers the terrain characteristics (including surficial material types, topography, terrain constraints and geohazards) and permafrost potential of the Study Area, as determined from the desktop geotechnical assessment (Table 1).

Table 1 - Criteria for estimating development suitability classes for the Study Area

Class Conditions
Terrain generally suitable for development (S) • Well-drained to imperfectly-drained soils. • Flat to very gently undulating topography with slopes under 10%. • Permafrost may be present, generally with low to medium volumetric ice content (<10% to 20% ground ice within 20 m from the surface) (Heginbottom, Dubreuil, & Harker, 1995) • No observed evidence of mass movement.
Terrain conditionally suitable for development (C) • Imperfectly to poorly drained soils. • Gently sloping topography with slopes between 10 to 20%. • Permafrost may be present, generally with medium to high volumetric ice content (10% to >20% ground ice within 20 m from the surface) • No observed evidence of rapid mass movement.
Terrain unfavourable for development (U) • Observed indicators of unstable terrain (e.g., ground settlement, thermokarst development, thermo-erosion of permafrost, gully erosion, landslide). • Poorly drained to very poorly drained soils. Surface seepage or drainage flow path generally present. • Slopes >20%. Surrounding area has steep scarps over 60%. • Thick organic soils, poorly-drained depressions. • Permafrost present with high ice content (ground ice >20% in the upper 10-20 m) • Sites with active mass wasting processes.

Based on the local surficial material type (i.e., glaciofluvial) and topography alone (slopes < 5%), the area could be classified as generally suitable for development. However, given the potential for ice-rich permafrost in the underlying glaciolacustrine silt, the study area needs to be classified as **conditionally suitable for development (C)**.

In summary, it is the permafrost susceptibility result that is calling for this specific classification, as potential ongoing and/or future permafrost degradation could have a negative impact on local development. Further investigating local permafrost conditions would require a geotechnical field investigation program.

5. RECOMMENDATIONS FOR DEVELOPMENT

General recommendations for development are outlined in the following subsections.

5.1 GEOTECHNICAL INVESTIGATIONS

Prior to development, a geotechnical field investigation should be carried out to inform the preliminary and detailed design. The geotechnical investigation requirements will be contingent based on the proposed development design, however it is generally anticipated the geotechnical investigation would require the following:

- Advancing approximately 5 to 10 boreholes throughout the development area. The boreholes should be advanced to depths of approximately 10 to 15 m below ground surface (depending on the proposed development design and soil conditions encountered). Soil samples should be collected from the boreholes and the ground ice conditions assessed.
- Carrying out laboratory testing on collected soil samples, including soil salinity, natural moisture content, particle size, and Atterberg limits.

- Install a series of thermistors in select boreholes and collect temperature readings to assess the ground thermal regime.
- Carrying out a thermal analysis to estimate the impact of the proposed development on underlying permafrost.
- Preparing a geotechnical investigation report, which documents the results of the investigation and provides geotechnical recommendations for detailed design such as:
    - Subsurface conditions including comments on the ground ice conditions.
    - Recommendations for foundation type, along with geotechnical ULS and SLS capacities for foundation design.
    - Thermal analysis and estimates of thaw settlement.
    - Recommendations for site preparation and material placement.

5.2 GENERAL DEVELOPMENT CONSIDERATIONS

Residential developments in the area should be designed while accounting for the potential effects of settlement due to permafrost thaw. This thaw could be generated both from impacts from development construction (e.g., excavation and removal of the vegetation to facilitate development, heat loss from building) or from naturally occurring process (e.g., climate change).

It is important to reiterate that site-specific baseline data relevant to permafrost is related to an investigation that took place over 40 years ago. Site conditions such as ground thermal regime, near surface permafrost ice-content or soil moisture regime may have changed since (i.e., possible increase in ground temperatures, reduction in ice-content, and possible deepening of the depth to permafrost). Design may need to account for recent and ongoing permafrost degradation, which could manifest as poorer site drainage (wet soils), uneven ground settlement, and a deeper permafrost table. An occurrence of permafrost degradation occurred within ~250 m of the Site around the Del Van Gorder school parking lot and baseball diamond, as described in the report by Benkert, et al., 2015.

The selection of foundation system(s) for the residential developments (e.g., surface pads, deep foundations, or foundations with heat exchangers) will be dependent on preliminary design requirements (e.g., settlement tolerance) of the the residences, and the geotechnical investigation results.

The design of buried utilities should consider their sensitivity to freezing. Utilities sensitive to freezing (e.g. water, sewer) must be protected from freezing conditions, including exposure to both permafrost and seasonal frost. Where utilities are located above the seasonal frost depth and/or in permafrost, freezing prevention measures should be explored; options include insulation, heat trace(s) etc. The utility designer should consult the manufacturer of the freezing prevention measures to determine the technical requirements of the system with special attention on the applicability of the system for use in areas of permafrost.

As a guide, key policy guidance documents have been developed in recent years in relation to reducing the overall vulnerability of infrastructure in northern communities. For the current study, four key documents developed as part of the Northern Infrastructure Standardization Initiative (NISI) provide standards and recommendations regarding proper evaluation, design, construction, operation and maintenance of new and existing infrastructures. They consist of the following:

- CAN/BNQ 2501-500 Geotechnical Site Investigations for Building Foundations in Permafrost.
- CAN/CSA-S503-15 Community drainage system planning, design, and maintenance in northern communities.
- CSA-S501-14 Moderating the effects of permafrost degradation on existing building foundations
- CSA PLUS 4011:19 Technical Guide: Infrastructure in permafrost: A guideline for climate change adaptation.

5.3 SITE DRAINAGE

Proper surface water drainage is essential for minimizing distress to new infrastructure. Drainage ditches or swales should not be excavated in ice-rich permafrost without detailed design unless proper measures are implemented in order to control erosion and prevent progressive permafrost degradation. Instead, ditches or swales should be formed within newly placed fill material, where the base of the ditches or swales matches the native ground surface (or above).

Existing preferential drainage flow paths should be maintained where possible to route water away from the development area while minimizing potential ground disturbance.

Culverts will need to be installed along new road segments and driveways, especially where flow paths have been identified (likely along Ladue Drive). It is recommended that the culverts be founded on structural backfill placed on native soil. In addition, care should be taken to avoid damage to permafrost during the installation of culverts. Finally, culvert inlets and outlets shall be designed to mitigate erosion of the surrounding area.

If Ladue Drive and Golf Course Road are improved as part of the residential development process, careful planning regarding spacing, position, and sizing of both ditches and culverts is needed with the southwest draining slope in mind.

Another development suitability consideration is that Lot 203, and Lots 175 and 176 are end-lots on a southwest-draining street. These lots will receive more surface runoff relative to the other properties, especially if there are surrounding impermeable surfaces and stormwater drainage from roofs and gutter systems.

6. CLOSURE

This report has been prepared for the sole benefit of the Government of Yukon's Land Development Branch (LDB) and its agents, and may not be used by any third party without the express written consent of Stantec Consulting Ltd. Any use, which a third party makes of this report, is the responsibility of such third party. Use of this report is subject to the Statement of General Conditions provided in **Appendix A**. It is the responsibility of LDB who is identified as "the Client" within the Statement of General Conditions, and its agents to review the conditions and to notify Stantec Consulting Ltd. should any of these not be satisfied.

The Statement of General Conditions addresses the following:

- Use of the report
- Basis of the report
- Standard of care
- Interpretation of site conditions
- Varying or unexpected site conditions
- Planning, design or construction.

We trust the above information meets with your present requirements. Should you have any questions or require further information, please do not hesitate to contact the undersigned.

Stantec Consulting Ltd.

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APPENDIX A

STATEMENT OF GENERAL CONDITIONS

STATEMENT OF GENERAL CONDITIONS

USE OF THIS REPORT: This report has been prepared for the sole benefit of the Client and may not be used by any third party without the express written consent of Stantec, which may be withheld at Stantec's discretion. Any use which a third party makes of this report is the responsibility of such third party.

BASIS OF THE REPORT: The information, opinions, and/or recommendations made in this report are in accordance with Stantec's present understanding of the specific site and project scope as described by the Client. The contents of this report are applicable only to the site conditions encountered at the time of the investigation or study. If the proposed project differs or is modified from what is described in this report or if the site conditions are altered, this report is no longer valid unless Stantec is engaged by the Client to review and revise the report to reflect the differing or modified project specifics and/or the altered site conditions.

STANDARD OF CARE: Preparation of this report, and all associated work, was carried out in accordance with the reasonable skill and diligence required by customarily accepted professional practices and procedures normally provided in the performance of such services at the time when and the location in which the services were performed. No other warranty is made.

INTERPRETATION OF SITE CONDITIONS: Soil, rock, and/or other material descriptions, and statements regarding their condition, made in this report are based on site conditions encountered by Stantec at the time of the work at specific field observation locations and/or through interpretation of both digital imagery and/or LiDAR data. Classifications and statements of condition have been made based on anticipated behavior of the materials or geomorphic processes and are interpretive in nature; no specific description should be considered exact, but rather should be considered reflective of the anticipated behaviour of materials or geomorphic processes. Extrapolation of in situ conditions can only be made to some limited extent beyond the observed locations. The extent depends on variability of the soil, superficial materials, bedrock, soil moisture and groundwater conditions as influenced by geological processes, construction activity, and land use.

VARYING OR UNEXPECTED CONDITIONS: Should any site or subsurface conditions be encountered that are different from those described in this report, Stantec must be notified immediately to assess if the varying or unexpected conditions are substantial and if reassessments of the report conclusions or recommendations are required. Stantec will not be responsible to any party for damages incurred as a result of failing to notify Stantec that differing site or sub-surface conditions are present.

PLANNING, DESIGN, OR CONSTRUCTION: Development or design plans and specifications should be reviewed by Stantec, sufficiently in advance initiating the next project stage (property acquisition, tender, construction, etc.), to confirm that this report adequately addresses the elaborated project specifics and that the contents of this report have been properly interpreted. Specialty quality assurance services (field observations and testing) during construction are a necessary part of the evaluation of sub-subsurface conditions and site preparation works. Site work relating to the recommendations included in this report should only be carried out in the presence of a qualified engineer or geoscientist; Stantec cannot be responsible for site work carried out without its representative being present.

APPENDIX B

FIGURES & MAPS

Figure B.1 - Overview of the Study Area with hillshade and lot lines (from the Government of Yukon property parcels data) shown. Lot 203 is not officially surveyed as being separate from Lot 202 (the corner lot in the southwest corner) but is understood to have never been consolidated wit Lot 203 and is not included in the feasibility study as per the Scope of Work.

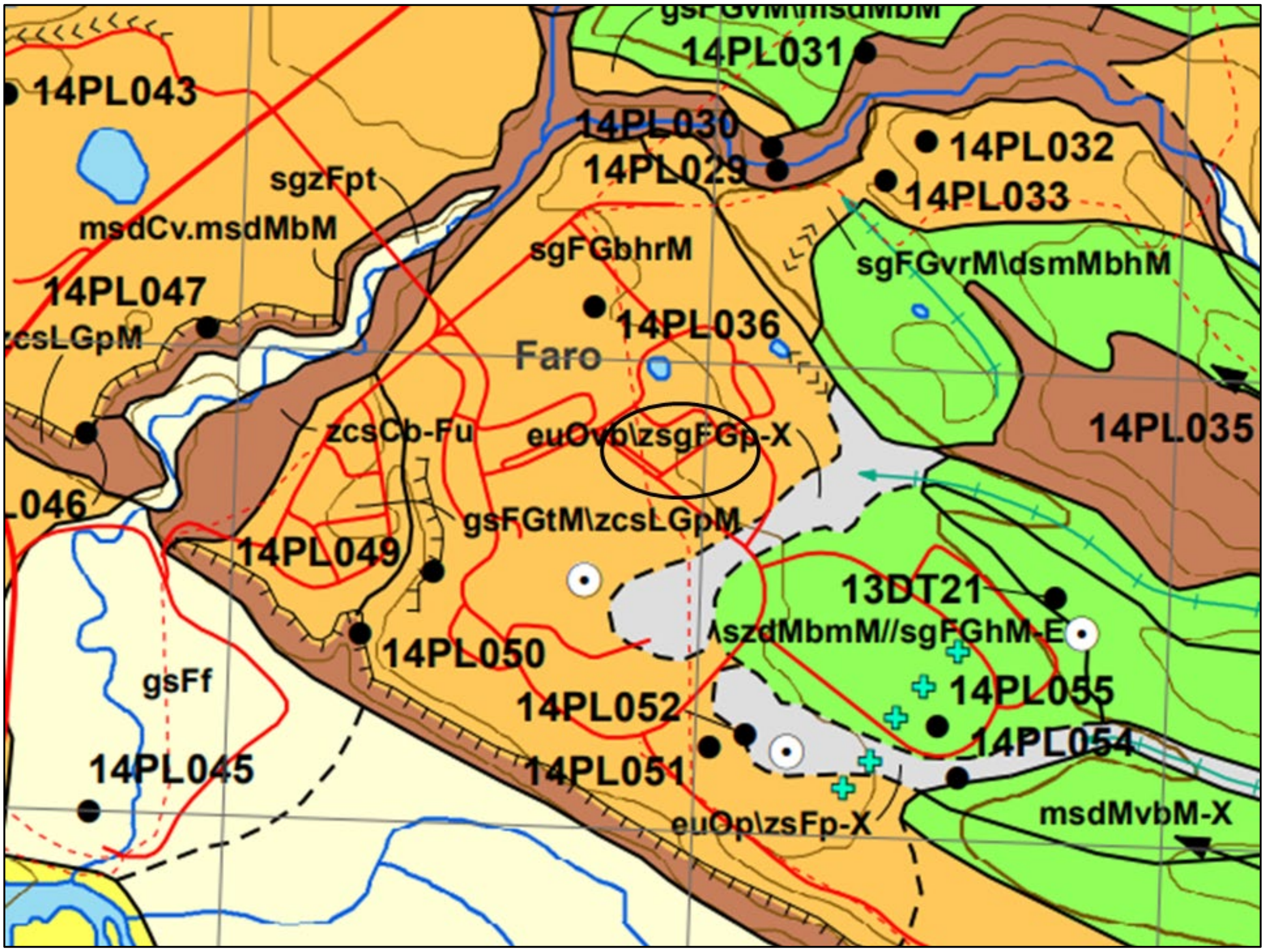

Figure B.2 - Surficial Geology of Ladue South – the Study Area is outlined by the black polygon. The correct terrain code is gsFGtM\zcsLGpM, which translates to glaciofluvial deposits overlying glaciolacustrine deposits. Mapping from Turner, Bond, & Lipovsky, 2014.

Figure B.3 – Geotechnical boreholes with drill records within the Study Area along Ladue Drive. The labels are the drill record number. There are 12 records within the planned lots; 8 of these had permafrost information. From Yukon Geological Survey, 2023.