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Community Surficial Geology and Geohazards Map Series, Fort McPherson, Northwest Territories, Canada

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ABSTRACT
Permafrost degradation due to climate warming can impact building foundations, as well as nearby slopes whose stability often depends on permafrost remaining frozen. A set of community maps were compiled with the assistance and support of Ecology North, the Hamlet of Fort McPherson, and the Rat River Development Corporation Ltd. The map series for Fort McPherson, Northwest Territories, included surficial geology; geohazards, including permafrost-related geohazards; vegetation; and results of visual slope retrogression analyses and recommended setback lines.
The objectives of the project were to improve community understanding of local conditions, assist land management decisions, and provide baseline references for permafrost and slope stability conditions. These maps comprise one of several proposed adaptation strategies for climate change in Fort McPherson that require geotechnical engineering and permafrost expertise. A poster prepared for community outreach and capacity-building is presented and mitigation options are summarized.

RÉSUMÉ
La dégradation du pergélisol due au réchauffement climatique peut avoir un impact sur les fondations de bâtiments, ainsi que sur les pentes environnantes dont la stabilité est souvent tributaire du pergélisol. Un ensemble de cartes communautaires a été compilé avec l'aide et le soutien d'Ecology North, du hameau de Fort McPherson et de Rat River Development Corporation Ltd. La série de cartes pour Fort McPherson, aux Territoires du Nord-Ouest, comprenait la géologie des dépôts meubles; les géorisques, y compris les géorisques liés au pergélisol; végétation; et les résultats des analyses visuelles de la régression des pentes et des lignes de retrait recommandées.
Les objectifs du projet étaient d'améliorer la compréhension de la communauté sur les conditions locales, de faciliter la prise de décisions en matière de gestion des terres et de fournir des données de référence sur les conditions du pergélisol et de la stabilité de la pente. Ces cartes comprennent l'une des nombreuses stratégies d'adaptation proposées pour le changement climatique à Fort McPherson qui nécessitent une expertise en génie géotechnique et en pergélisol. Une affiche préparée pour la sensibilisation communautaire et le renforcement des capacités est présentée et les options d'atténuation sont résumées.

1 INTRODUCTION

The community of Fort McPherson, Northwest Territories is located on the east side of the Peel River, about 185 km southwest of Inuvik on the Dempster Highway 8. Inuvik is located about 115 air-km north-northeast of Fort McPherson. The Peel River flows north at Fort McPherson. The community is situated on a small plateau above the Peel River floodplain (Figure 1, within the townsite mapping area, outlined in purple). The plateau dips gently eastward and has a steep slope on its west side.

Nehtruh-EBA Consulting Ltd. (Nehtruh-EBA) prepared a series of terrain and geohazard maps, as well as a slope stability review and evaluation of stabilization options for the steep slope along the western edge of the townsite (Nehtruh-EBA 2019). This work was undertaken for the Rat River Development Corporation Ltd. (RRDC).

The overarching objective of the project was to contribute to the preparation of climate change adaptation strategies for Fort McPherson, tying in with other efforts by Ecology North towards the same goal.

The goal of the terrain and geohazard mapping was to produce a series of maps that will be useful in land use planning within the municipal boundaries. The goal of the slope stability review was to evaluate possible unstable portions of the slope along the western edge of the townsite.

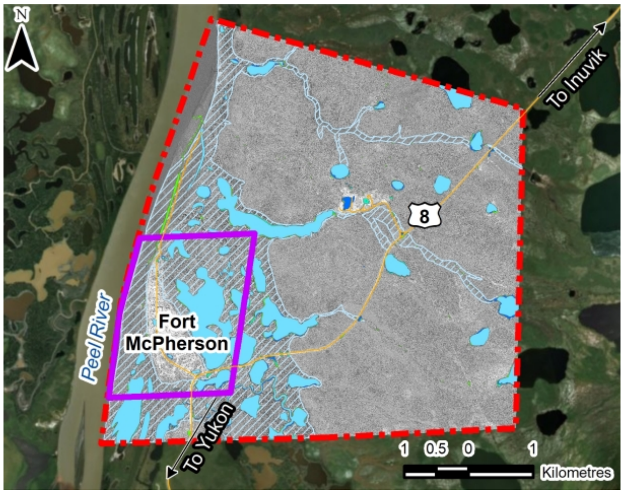

Figure 1. Community mapping overview at Fort McPherson, NT. The regional project mapping area is outlined in red.

2 PROJECT OBJECTIVES

The map series encompassed the production of desktop-level maps that would accomplish the following goals:

- Help the community better understand the soils, bedrock and permafrost conditions around them, including geohazards related to those conditions;
- Provide a tool to assist land managers with land use and development, that is, to determine the preferred areas for building and avoid areas unsuitable for future development. Identification of areas with high ice content and/or organic soils, issues with water on site, thaw settlement, and slope instabilities were to be identified for this purpose; and
- Provide a baseline reference for monitoring potential permafrost degradation or large-scale changes in permafrost conditions and/or slope stability, resulting from climate change and/or human-induced impact.

3 SCOPE OF WORK

The project comprised five main tasks:

- Prepare a series of surficial geology and geohazard maps;
- Execute a site investigation to collect ground-truthing data for the mapping and to collect information on various slope sections in the community;
- Review slope stability and related mapping to determine possible contributing factors to slope instabilities on the western edge of the townsite;
- Provide options to mitigate or eliminate those factors, thus helping to reduce the likelihood and magnitude of possible future slope failures; and
- Prepare a poster for community outreach and capacity-building.

4 METHODS

4.1 Mapping

The geotechnical and air photo review portion of the evaluation included:

- Review of geotechnical reports from numerous community developments, and geological maps.
- Acquisition of high-resolution digital stereo pair air photos from the National Air Photo Library in Ottawa (1950, 1990) and from the Government of the Northwest Territories (2004), a 2D DigitalGlobe satellite image from 2017 from Harris MapMart, and a 2D DigitalGlobe colour satellite image from 2012 from ESRI.
- Initial geohazard and surficial geology mapping was completed directly using PurVIEW™ by means of standard stereo air photo analysis. This software allows the mapper to not only view the photos in 3D on a computer screen with the aid of specialized 3D glasses, but also to zoom in and out of the images. Scales as large as 1:3,000 to 1:5,000 were used, allowing for the delineation of otherwise difficult-to-identify features with greater accuracy than is possible with a standard stereoscope and hard-copy air photos.
- Mapping was completed for an area that encompasses the community of Fort McPherson, outlying areas such as the piped sewage lagoon, the trucked sewage lagoon, and the solid waste site east of Fort McPherson. Additional large-scale maps were developed to provide more detail within the community itself, and along its western edge, where slope stability concerns had been noted.
- The terrain mapping included surficial materials, terrain and geomorphic processes. It was refined using existing geotechnical data, observations and information from community representatives, as well as ground-truthing for specific terrain units.
- A visual slope retrogression analysis was carried out along the western edge of the townsite, using the available air photo coverage. The goal was to determine whether a progression of slope movements or permafrost thaw might have occurred, and whether or not that progression appeared to have been accelerating in recent years.

4.2 Field Checking

Nehtruh-EBA's site investigation in 2018 was directed by the findings of the geotechnical data and air photo review. Reconnaissance work and additional testhole locations were selected to focus on key infrastructure, slopes and selected terrain unit types, especially units or locations not already documented by previous site investigations.

Nehtruh-EBA monitored the drilling of two boreholes to evaluate the subsurface conditions near St. Matthews Anglican Church and Cemetery. The holes were drilled by the Hamlet of Fort McPherson using a 20 cm diameter solid-stem auger on a track-mounted Bobcat E63. A drill depth of 1.8 m was achieved in each borehole.

An additional 13 boreholes were drilled with the assistance of Ecology North using a hand-held Edelman auger, with depths ranging from 0.4 to 1.5 m, to the maximum depth of the auger, or to refusal on frozen soil or suspected cobbles or boulders. Three testpits to 0.3 m depth were advanced on the slope using hand tools.

4.3 Slope Stability Review

When the mapping and field work was completed, Nehtruh-EBA carried out a qualitative slope stability assessment. This work included an assessment of risk factors, a slope retrogression analysis, and an evaluation of the likelihood of future slope movements and estimated possible future rates of slope movements. From the anticipated rates of future slope movements, 30-year and 50-year setback lines were estimated.

A series of historical photographs was also obtained to provide an overview of the series of church buildings constructed over the years at St. Matthew's Anglican Church, as well as the performance of the slope below the church buildings and points north along the Peel River.

Based on the findings, Nehtruh-EBA prepared some options to reduce slope-related risks, for consideration by RRDC and the community of Fort McPherson.

5 RESULTS

The results of the surficial geology and geohazard mapping were provided to RRDC as a map atlas series (Nehtruh-EBA 2019), which is too large to include here. Instead, we provide selected excerpts from the mapping, along with the community outreach poster, *Fort McPherson, NT, Surficial Geology and Geohazards Mapping.* The following discussion summarizes the surficial geology for the regional project area and then focuses on the geohazard findings within the townsite of Fort McPherson. Some typical mitigation options that were considered appropriate for the project areas are summarized.

5.1 Surficial Geology

Most of the eastern portion of the regional project area (Figure 1) was mapped by Duk-Rodkin and Hughes (1992) as consisting of flat to gently-sloping till deposits 1 to 3 m thick with abundant bogs and fens, while the area traversed by Highway 8 at the southern edge of the study area was noted as the same till, but without wetlands. The till comprised silt, sand, clay and gravel.

In general, areas mapped as till by Duk-Rodkin and Hughes (1992) were confirmed as till by our study, with some refinements for fluvial and organic deposits visible at finer scales within those areas.

Duk-Rodkin and Hughes concluded that the townsite, the areas surrounding the townsite and those flanking the river were part of the Peel River floodplain. The floodplain deposits were described as sand, silt and minor gravel with thermokarst depressions. At the finer scale of our analysis, however, some significant refinements in the mapping were made. It was determined that the community of Fort McPherson is located on a bedrock upland covered with till, that forms an "island" within the fluvial deposits of the Peel River, as shown in Figure 2. A steep slope on the upland's western side is covered with colluvial deposits of unknown thickness. The mapping was further refined by using the information from previous geotechnical site investigations and the data from the site investigation for this study. Testhole locations, including those executed for this study, are shown in Figure 2.

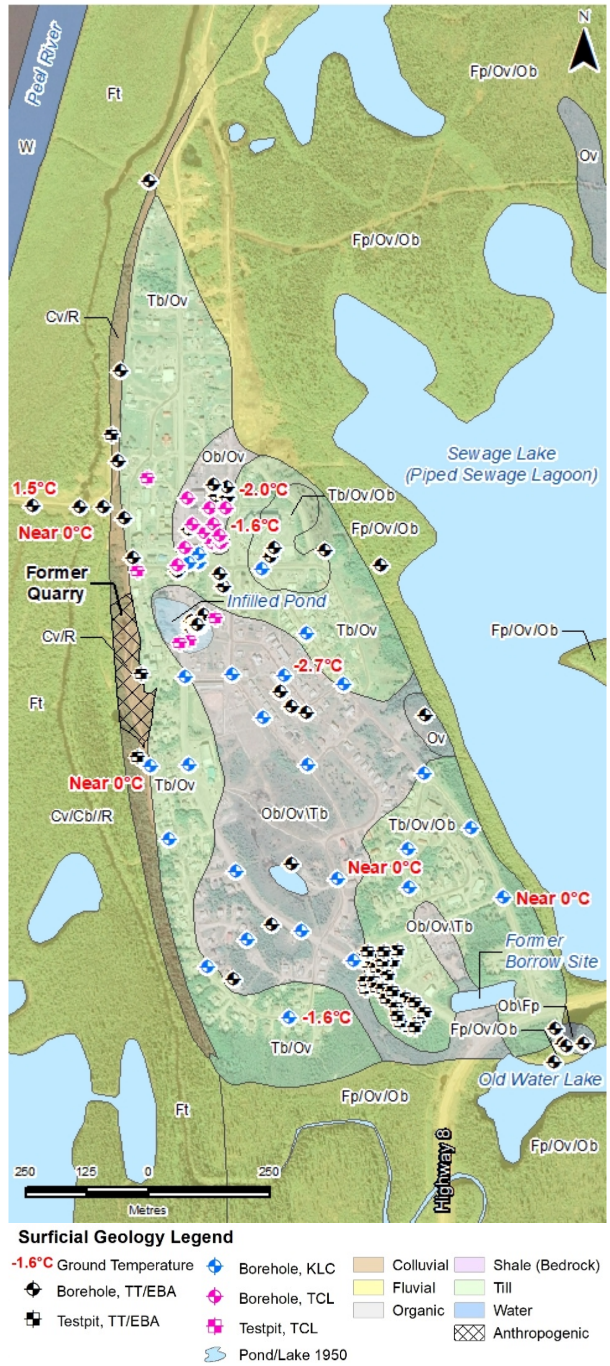

Figure 2. Surficial geology mapping, Fort McPherson, NT.

5.2 Geohazards

5.2.1 Thermokarst

The permafrost nature of the landscape suggested that thermokarst lakes and ponds were likely present. Evidence supporting this inference was given by Sewage Lake, which serves as the piped sewage lagoon for the hamlet. The lake has expanded to capture two smaller circular and oval lakes at the southeastern and northern ends of the lake (Figures 1 and 3). These conditions were already present in 1950.

Between 1950 and 1990, the creek south of town expanded somewhat, but a number of lakes and ponds within and surrounding the townsite mapping area did not expand at all (Figure 3). Those that did grow, expanded mostly on the southern shore, by amounts of 10 to 22 m, perhaps due to prevailing northerly winds in summer resulting in extra wave activity that caused thermal erosion of the southern shores. A 22 m expansion over 40 years amounts to an approximate widening of about 55 cm/year.

From 1990 to 2004, lake expansions were on the order of 10-12 m, and directions of expansion were more random (Figure 3). Rate of widening was approximately 79 cm/year for this shorter time frame. Again, some lakes did not expand at all, and the majority of those that did are located on the Peel River floodplain deposits. This may indicate that the floodplain sediments are more ice-rich than the till uplands. The findings of EBA (1977) appear to corroborate this, as ice layers were found within the floodplain deposits. However, other studies indicate that the till uplands can also contain ice-rich layers or massive ice (KCL 1978; EBA 1992).

In 2017, river water levels were high – a tributary on the sand bar north of town appeared to be bank-full for the first time. Some of the apparent stream expansion south of town at this time may simply have been due to high water conditions. Some lake expansion occurred between 2004 and 2017. Expansions of about 10 m occurred mainly on the southern and western sides of the lakes in the floodplain zone (Figure 3). The widening rate was similar to the rate in the previous time frame, at about 77 cm/year.

5.2.2 Flooding

Flooding can occur anywhere within the Peel River floodplain and, to a lesser extent, in areas of thinner fluvial deposits. Potential flood zones are shown on Figure 3. Disturbances including mud deposits and possible scouring along the slopes as a result of flooding were visible in some areas on the 2012 satellite image (Figure 4). The creek at the toe of slope on the western edge of the community is connected to the Peel River south and north of the community. It acts as an overflow channel during high water.

5.2.3 Gullies

Gullies are natural features formed by water erosion. These are shown on Figure 3. Figure 4 shows an enlargement of the north end of the townsite. Most of the gullies are located on the steep slope along the western edge of the community, though a few gullies also drain to Sewage Lake. Soil erosion is a concern within gullies.

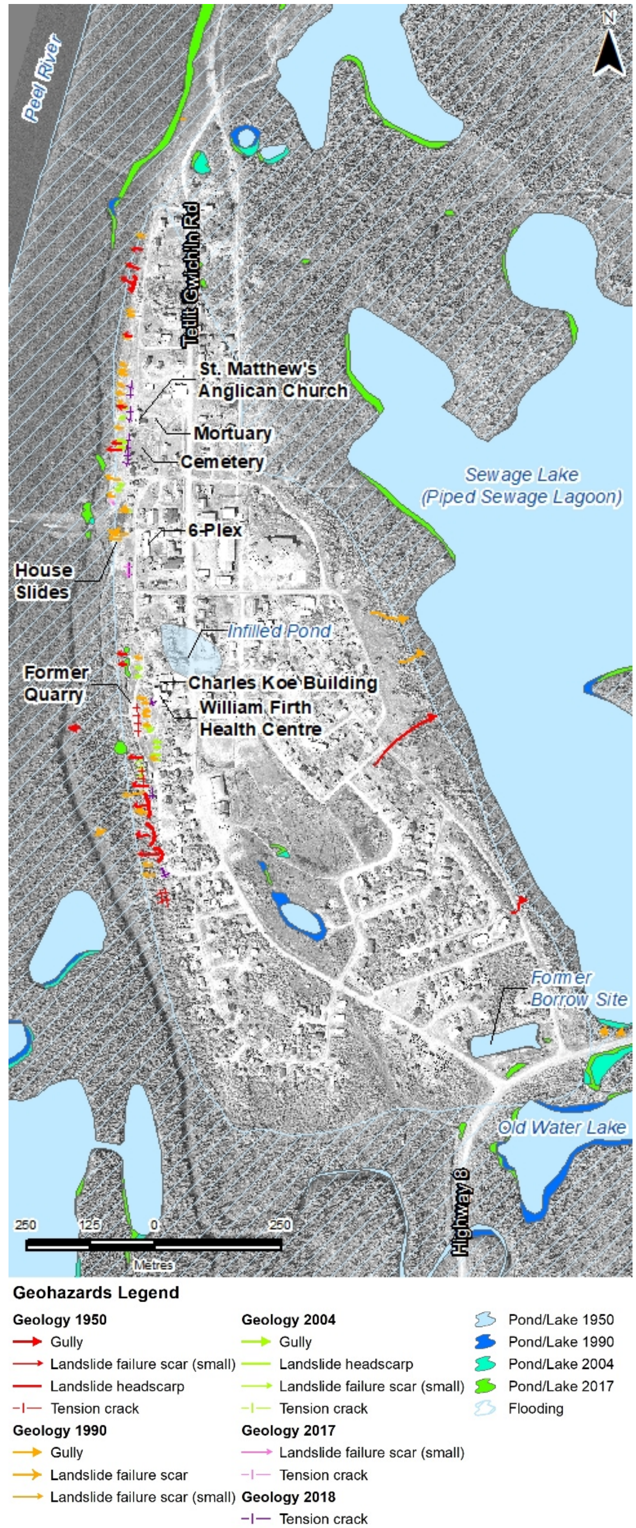

Figure 3. Geohazards mapping, with imagery from 2017.

Figure 4. Geohazards mapping, north end of townsite, with 2012 satellite image as background.

5.2.4 Debris Slides

Fresh debris slides were seen on the slope at the western edge of the town in 1950 (north end of current town extent, Figures 3 and 4). The remainder of the mapped debris slides and some possible tension cracks were vegetated and therefore formed at some time prior to 1950 (Figure 3).

Fresh debris slides were also found above and below roads and excavations in 1990 (Figures 3 and 4). These slides were induced by road-building and excavation. Other debris slides were vegetated or fresh.

Two apparent debris slides, on either side of and below a house (marked “House Slides” on Figure 4), might once have been trails, based on a 1930’s oblique photo (Figure 7). There was so much anthropogenic disturbance on the 1990 air photos that human clearing and construction activity might well have obscured other possible debris slides.

By 2004, there was a new debris slide on the slope below the north end of St. Matthew’s Anglican Church, notable due to being unvegetated (Figure 4). The section of the slope between the main river access road and the north end of the church appeared to be exceptionally active, with slides observed on all years of air photos reviewed. All other newer debris slides visible in 2004 were vegetated, except below and above the road descending the slope in the former quarry in the south part of town (Figures 3 and 4). The northerly of the “House Slides” had become an obvious trail by 2004, while the southerly slide appeared to have mostly grown over (Figure 4).

A few small slides were identified in 2017, although the resolution of the 2D black-and-white satellite image made it difficult to discern details in many areas. Numerous slides were visible during the fieldwork, along with several sets of tension cracks (Figures 3 and 4).

The cleared area marked as a “bladed trail” on Figure 4 was an active snowmobile trail in the winter of 2018-2019. However, a date for possible clearing or earthmoving in this area was unknown, and the feature could also be scour-related. Tension cracks were noted upslope of this area.

5.3 Vegetation Overview (Shrubs and Trees)

Figures 5 and 6 show the changes in shrub and tree cover on the slopes at the north end of the townsite. A significant increase in shrub growth, such as willow, had been noted by community members as becoming more prevalent after about the 1970’s. Trails that were once commonly used for hauling small boats between the townsite and the river are now so overgrown that they are no longer used.

Figure 5 suggests shrubs have been advancing upslope over time from the valley bottom, with lighter colours indicating younger growth. Figure 6, in contrast, shows some treed areas below John Tetlichi Drive (south of the main river access). South of the “House Slides,” a large area of trees on the slope was lost after 1950 (Figure 6). Several large trees located along the sides of the footpath between the crest of slope and the fenced churchyard and cemetery (identified by their shadows in Figure 6), were consistent with the 2018 field observations. Some smaller trees were also visible at the toe of slope in the 2012 satellite image (Figure 4), and confirmed in 2018.

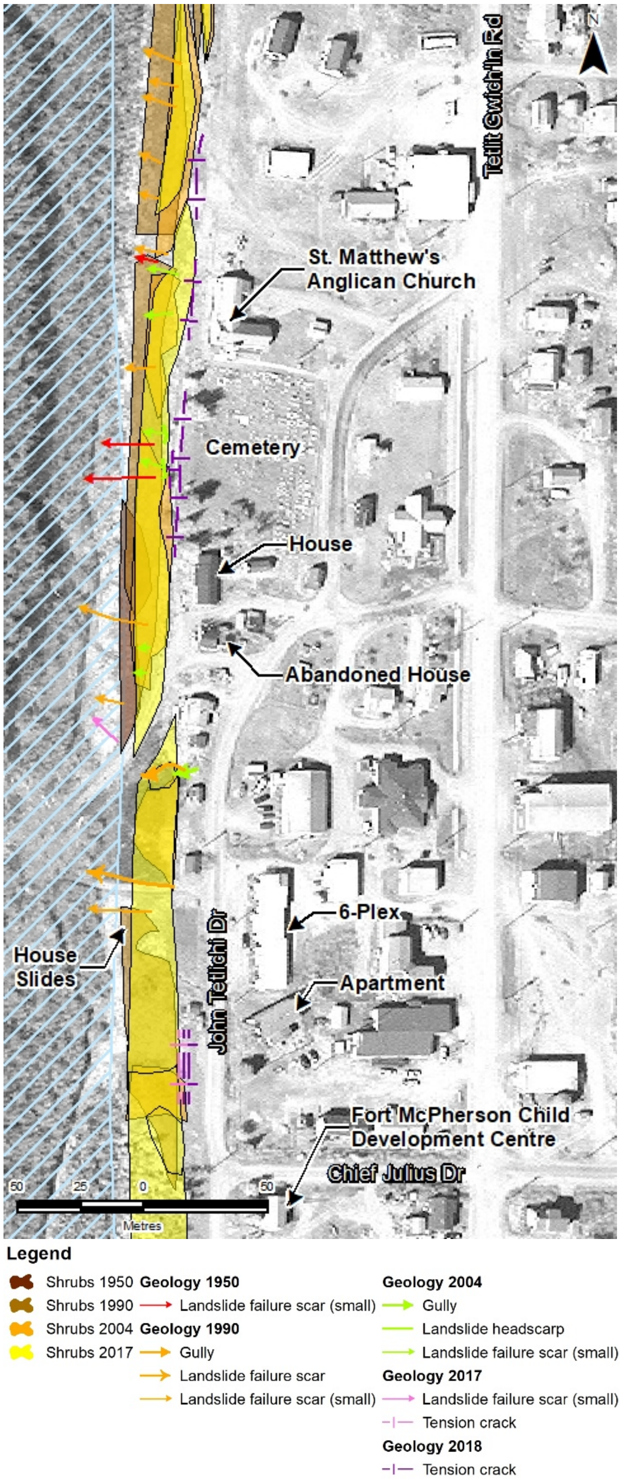

Figure 5. Mapping of shrub presence from several years of air photos indicates younger growth upslope.

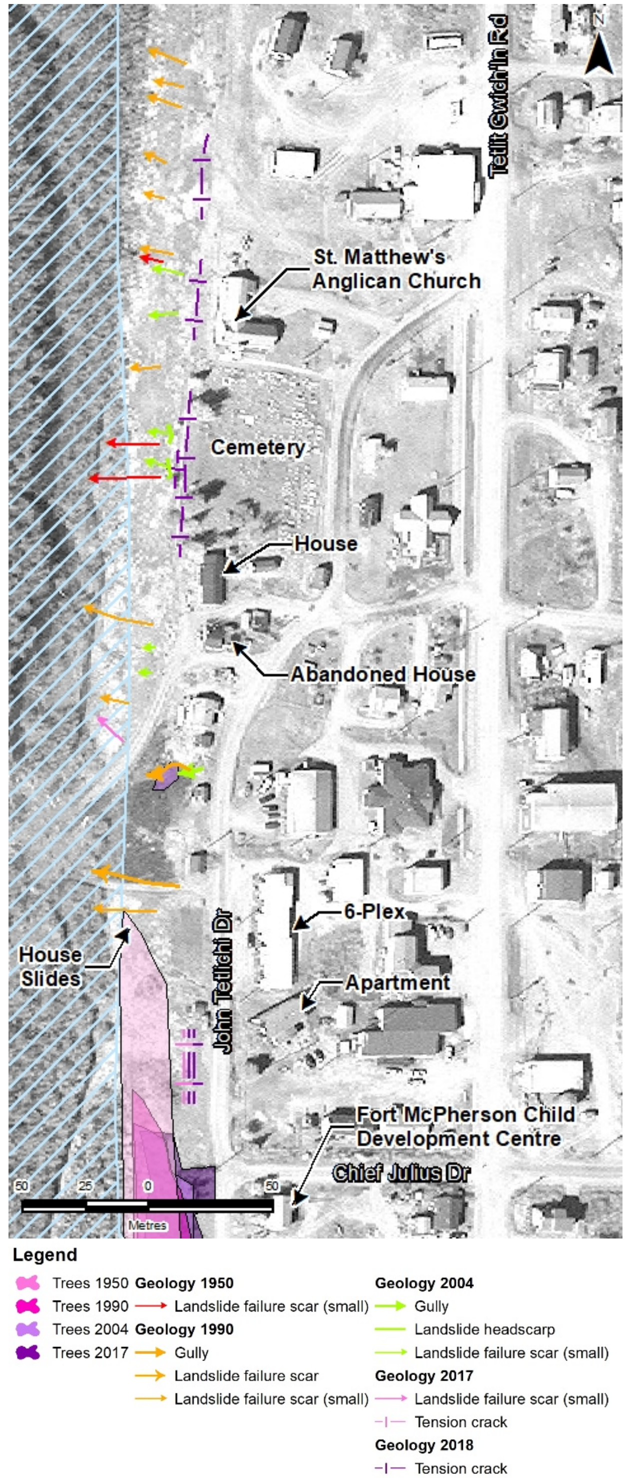

Figure 6. Mapping of tree presence from the air photos. Younger trees were higher on the slope than older trees.

So few trees were present on the slope below St. Matthew's Anglican Church and cemetery that they did not register in the mapping (Figure 6). A review of several historical site photos indicated that there might be more than one process taking place on the slope.

Figure 7 shows that the townsite and a significant proportion of the river slope was entirely lacking shrubs and trees in the 1930's, apparently due to site clearing. The reported increase in shrub growth since the 1970's could be related to climate change, but also to revegetation after site clearing. However, the community also noted that undesirable species (e.g., willow) comprised most of the regrowth, while preferred species were lacking (e.g. birch).

The general lack of trees below the church grounds appeared to be due to tree-cutting and brushing before the 1930's, as well as ongoing slope instabilities.

Figure 7. Looking north towards Fort McPherson in the 1930's. Note apparent removal of trees and shrubs in and below the developed part of the community, and the locations of overflow/creek channels in the floodplain. (Photo credits: Glenbow Archives NA-3844-92; or National Air Photo Library A2653-10; used with permission.)

5.4 Visual Slope Retrogression Analysis

Nehtruh-EBA conducted a qualitative slope stability assessment for the steep slope along the western edge of the community (Figure 8). Slope stability was evaluated based on the historical air photo/satellite image review, slope characteristics based on topographic mapping, measured slope angles at selected locations, and observations of soils in shallow boreholes at selected slope locations and in previously-drilled boreholes near the slope in the community. Exposed soils were logged at selected slope locations: two sites in the upper slope at observed slope instabilities, and one site at the toe of slope where the slope was likely undercut by high river flows or floodwater.

Definitions for hazard, likelihood, elements of value or elements at risk, consequence and risk were adapted from Wise et al. (2004) to create a matrix for assessing natural and man-made hazards at representative locations along the slope. Considerations and observations included:

- Observations of slope instabilities, particularly those that had caused damage to property on the slope or above the top of slope;
- Despite the increasing distance from the slope to the main channel of the Peel River since 1930, the toe of the slope was still subject to flooding, and frequency of slope instabilities did not appear to decrease over time;
- New slope failures below St. Matthew's Anglican Church and Cemetery could be due to periodic undercutting from scour; failures below top-of-slope roads further south could be due to pushing snow from the road over the bank; slope failures below other buildings could be due to the destabilizing effects of the former quarry; and
- The general lack of culverts along roads could mean that some overland drainage is now blocked by the roads, or concentrated where it does drain.

Figure 8 tracks the changes in slope crests and bases, showing the toe and top of slope lines used for analysis, for the three sets of air photos (1950, 1990 and 2004) for which stereo coverage was available. These mapped locations, along with topographic data from the Government of Northwest Territories, Department of Lands (2018), were used to estimate approximate rates of slope retrogression for representative slope sections.

5.5 Recommended Setbacks

Based on the estimated rates of slope retrogression, the recommended 30-year and 50-year setback lines were developed for use in land use planning (Figure 8).

6 POSSIBLE MITIGATIONS

Mitigations proposed for management of existing or potential slope stability issues in Fort McPherson include the following main concepts:

Avoid the unstable terrain by using the setback lines to:

- Gradually move at-risk structures further away from the slope as the buildings reach the end of their service lives, replacing them with buildings in safer locations;
- Move serviceable but at-risk structures before the end of their service life; and
- Prevent the construction of new buildings within at-risk areas.

Reduce landslides by considering options to:

- Limit surface water runoff and infiltration by keeping water from either flowing downslope or infiltrating into the tension cracks;
- Prevent snow from being pushed over slopes or stored on tops of slopes to limit loading, water infiltration in spring, and insulation from snow over permafrost;
- Keep the ground frozen, thereby reducing the volume of soil that could fail; and
- Retain soil to keep the existing slope from failing, or build up a buffer area between the crests of slopes and the elements at risk, e.g. buttressing slopes that have been undercut by scour or quarrying.

Protect the elements at risk:

- For foundations at risk from slides or slumps, design remedial foundations so that slope failures would leave the foundation relatively unaffected, e.g. foundations to bedrock or mat slabs;

In general:

- Cost-benefit analyses could be applied to specific at-risk structures to determine if a specific structure should be moved, protected in place, or simply decommissioned and a new structure built elsewhere.

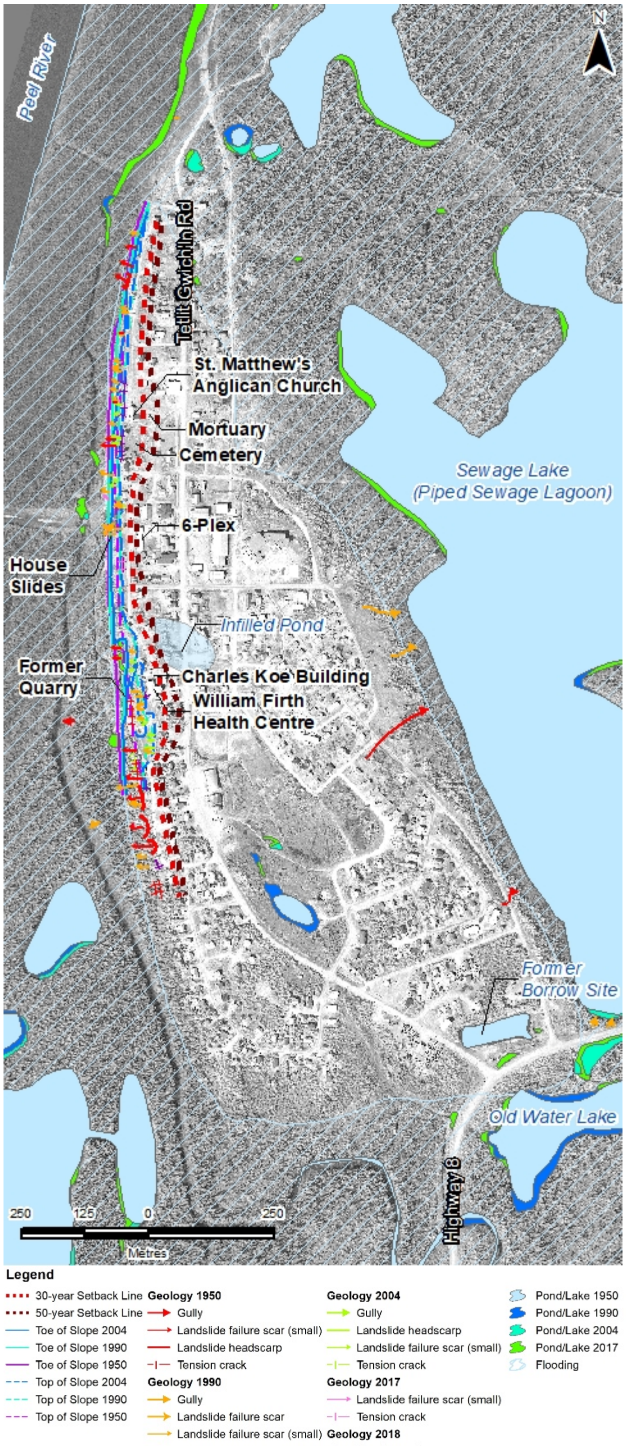

Figure 8. Visual Slope Retrogression Analysis and Recommended Setbacks.

- Similar considerations and solutions could be applied not just to structures but to other features of cultural or social importance, such as the cemetery at St. Matthew's Anglican Church, where numerous gravesites are at risk.

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A complete list of the references used for the project is provided on the accompanying poster.