TETRA TECH EBA

CLIMATE CHANGE VULNERABILITY ASSESSMENT DEMPSTER HIGHWAY, YT/NT

PRESENTED TO

Government of Northwest Territories

DEPARTMENT OF TRANSPORTATION

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EXECUTIVE SUMMARY

The Dempster Highway is the only road connection to the western Arctic, linking southern Canada through the northern Yukon (Dawson City) to the Northwest Territories communities of Fort McPherson, Tsiigehtchik and Inuvik. It was designed and constructed in the 1970's, and opened to traffic in 1978. It traverses 730 km of highly varied subarctic and arctic terrain, including three mountain ranges. Permafrost conditions vary with latitude and elevation from sporadic discontinuous at the Klondike Highway to continuous at Inuvik.

In this region of northern Canada, climate warming has been observed since about 1970, and ground temperatures in the permafrost are increasing. This report is the first phase of a study to assess the vulnerability of the Dempster Highway in YT and NT to the potential impacts of current and future climate warming.

A primary purpose of the study was to determine if there is sufficient recent and historic information to conduct a PIEVC assessment of the highway. The first step was to review available information to establish data gaps and deficiencies. A second objective was to determine feasibility and associated scope for a systematic vulnerability assessment that could form a subsequent phase of the project and what its value might be to improve highway management. A third objective was to develop a scope for future maintenance management that will relate current and future maintenance practices to addressing the impact of climate change on the highway.

Information from a driving trip along the highway is presented, with specific reference to maintenance requirements related to climate change. An attempt was made to separate these from normal highway maintenance operations. The maintenance personnel from each section of highway attended the site visit and provided valuable information to the team. A summary workshop was held at the conclusion of the field trip, to present and discuss the information obtained.

The route was divided into seven terrain regions for this project, each with identified priorities relative to maintenance activities that could be linked to climate change effects. Environmental factors that drive the vulnerability show clear linkages to natural hazards directly related to surface water extreme runoff events and permafrost that has a high component of ground ice.

The PIEVC process was developed for infrastructure at discrete locations. It is not well suited for linear infrastructure where the environmental parameters and geotechnical conditions vary along its length. A PIEVC vulnerability study may be effective for a particular terrain segment along the Dempster highway.

The greatest hazards for both highway safety and maintenance relate directly to thaw of fine-grained permafrost foundation soils that have a high proportion of ground ice and a higher frequency of extreme weather events both precipitation and winter snow storms. Those factors that should be addressed in future upgrades to operating and maintenance procedures include:

- Documentation of locations with vulnerable permafrost topography, such as ice-wedges, that have a potential to affect the embankment integrity.
- Identification and monitoring of locations where thermokarst features are threatening embankment integrity.
- Review of all culvert installations for bypass erosion, cover integrity and hydraulic effectiveness.
- Document where sinkholes that threaten embankment safety form, include conditions at the time. Identify a probable cause and document the mitigation procedures adopted. This activity can evolve into a small database that will help recognize vulnerable locations and improve our understanding of the collapse mechanisms.
- Identify locations where embankment sideslopes are progressively failing and evaluate the risk of overall rapid slope failure. Adopt a proactive mitigation procedure, such as berm construction (Photo 18), that can be applied as and where required to protect the road from sudden collapse.

Current information from locations along the highway pertaining to climate, ground temperatures and surface water hydrology from which extreme runoff events can be deduced is lacking or non-existent. A plan for future data collection and management should consider the following recommendations.

- Install a weather station at each maintenance shop and provide the data in a useful format for planning.
- Install ground temperature monitoring stations into terrain flagged as sensitive to small changes in ground temperature. There were four sites installed in 2014, but the authors have not seen any of the data.
- Support research on the effects that snow drift accumulation on exposed sideslopes accelerates permafrost thaw and contributes to sideslope instability. Examine practical mitigation measures such as slope flattening, berms and removal of brush that traps snow.
- Install slope indicators and ground temperature cables into a few deep fills that appear to be subject to creep displacements to confirm the embankment temperatures and lateral deformations. Collect and test soil samples to confirm engineering properties of the construction materials.
- Map surface conditions and soil types near locations where thaw-flow slides could jeopardize the embankment.
- Install runoff monitoring stations on key rivers and streams and carry out a regional hydrological assessment that can be updated as new data is collected.
- Continue to monitor culvert performance and effectiveness of erosion mitigation structures.

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LIMITATIONS OF REPORT

This report and its contents are intended for the sole use of the Government of the Northwest Territories and their agents. Tetra Tech EBA Inc. (Tetra Tech EBA) does not accept any responsibility for the accuracy of any of the data, the analysis, or the recommendations contained or referenced in the report when the report is used or relied upon by any Party other than Government of the Northwest Territories or for any Project other than the proposed development at the subject site. Any such unauthorized use of this report is at the sole risk of the user. Use of this report is subject to the terms and conditions stated in Tetra Tech EBA's Services Agreement. Tetra Tech EBA's General Conditions are provided in Appendix A of this report.

1.0 INTRODUCTION

1.1 Purpose and Scope

The Dempster Highway is the only road connection to the western Arctic, linking southern Canada through the northern Yukon (Dawson City) to the Northwest Territories communities of Fort McPherson, Tsiigehtchik and Inuvik. It was designed and constructed in the 1970's, and opened to traffic in 1978. The design and construction were managed by Public Works Canada, with a number of private contractors providing construction services for different sections. This was the second major highway across the permafrost regions of northern Canada. Experience with construction and operation of the Alaska Highway in the 1940's provided an earlier precedent for construction of linear infrastructure over permafrost terrain, as did the Hudson Bay Railway. The original design intent was to maintain the permafrost by providing a minimum fill thickness as an insulating cover, together with flatter road embankment sideslopes.

In this region of northern Canada, climate warming has been observed since about 1970, and ground temperatures in the permafrost are increasing. This report is the first phase of a study to assess the vulnerability of the Dempster Highway in YT and NT to the potential impacts of current and future climate warming.

A primary purpose of the study was to determine if there is sufficient recent and historic information to conduct a formal vulnerability assessment of the Dempster Highway. The first step was to review available information in order to establish data gaps and deficiencies. A second objective was to determine feasibility and associated scope for a systematic vulnerability assessment that could form a subsequent phase of the project and what its value might be to improve highway management. A third objective was to develop recommendations that could enhance current and future maintenance practices on the highway by addressing climate change.

2.0 PROJECT TASK SUMMARY

The following tasks were completed as part of this study:

1. Collected existing information from available sources;
2. Organized and hosted a project planning meeting in Edmonton on August 8, 2013 to present initial findings, and prepare plans for a route reconnaissaance/driving trip;
3. Completed a route reconnaissance/driving trip from Inuvik to Dawson and then on to Whitehorse to examine the existing condition of the Dempster Highway, and obtain feedback about seasonal operational issues from NT and YT Highways maintenance personnel;
4. Organized and facilitated a workshop held in Whitehorse on December 12, 2013 to present the findings of the reconnaissance/driving trip, along with initial assessment of principal factors affecting vulnerability to climate change. This one-day session provided a unique opportunity for the project team to obtain feedback from YT and NT highways maintenance personnel on their views of existing and future climate change effects on highway maintenance requirements; and
5. Prepared a draft and final report on the study.

One additional meeting was held in November 2013 when project personnel were gathered in Yellowknife for a permafrost seminar, hosted by others. That meeting provided an opportunity to refine the scope for the workshop, and to finalize the workshop date, agenda, and invitation list.

2.1 Collection of Existing Information

The first component of the study was to gather existing information related to soil and permafrost conditions, as well as historic ground temperature to determine where data gaps are evident. The Tetra Tech EBA offices in Whitehorse, Yellowknife, and Edmonton conducted an internal records search and project files with relevant data were set aside.

Tetra Tech EBA contacted the Government of Yukon's Department of Highways and they located "as built" drawings for most of the Yukon section of the highway that showed vertical and horizontal geometry of that road segment including borrow pits and culvert installations immediately post-construction, but no detailed descriptions of permafrost and/or ground temperatures.

Dr. Chris Burn and Brendan O'Neill from Carleton University provided a spreadsheet summarizing sites near the Dempster on the Peel Plateau where thermistor cables are installed as part of their ongoing permafrost research work.

In addition to these resources, Tetra Tech EBA searched the Arctic Science and Technology Information System (ASTIS) provided by the Arctic Institute of North America at the University of Calgary for any published reports containing information related to soil conditions, permafrost, and ground temperature along the Dempster Highway.

Tetra Tech EBA's Yellowknife Office contacted the GNWT Department of Transportation and obtained copies of several reports on the NT section of the highway.

Personnel in the Federal Department of Public Works and Government Services Canada who were involved with highway design or construction management were identified and an effort made to contact certain people. However, none of these people could be located or contacted during this time period.

Maps 1, 2 and 3 are overview level airphoto maps of the Dempster Highway showing the location, where available, of the data collected as background information for this study, and Appendix B contains a tabular summary of the report/reference data for each of the Yukon and Northwest Territories sections of the highway.

2.2 Planning Meeting

A project initiation meeting was held in Tetra Tech EBA's Edmonton Office on August 8, 2013 with representatives of Tetra Tech EBA, both YT and NT Highways, and Dr. Chris Burn from Carleton University (science advisor retained by GNWT). In addition to the presentation of background information that had been collected to that date (and obtaining information on other possible sources) the meeting focused on identifying the various sections of the highway that had similar geomorphology, permafrost and climate conditions. This meeting also provided an opportunity to plan the reconnaissance trip that was scheduled for the end of August 2013.

It was noted at the meeting that Northwestel was collecting climate and ground temperature data at a dozen or so of their sites adjacent to the Dempster Highway in YT/NT, and arrangements were made by Tetra Tech EBA through Yukon College and Northwestel to obtain access to these data for use in the vulnerability assessment.

2.3 Field Trip

A trip driving down the Dempster Highway from Inuvik to Dawson City was completed between August 24 and 27, 2013. Participants in the trip are summarized in the following Table. One of the purposes of the trip was to meet with the maintenance personnel responsible for various sections of the highway, and obtain their input and visit specific sites where they were experiencing excessive or recurring maintenance that may be caused by climate change effects.

Table 1: Participants in August 2013 Driving Trip – Dempster Highway

Tetra Tech EBA Inc.	Carleton University	Government of NT, Department of Transportation	Government of YT, Transportation Engineering
Richard Trimble, P.Eng. Tetra Tech EBA Project Manager, Permafrost Engineer	Dr. Chris Burn – Advisor, Permafrost Science	Greg Cousineau – Transportation Planner, Project Manager	Sandra Orban, P.Eng. – Regional Program Manager[2]
Don Hayley, P.Eng., (Hayley Arctic Geoconsulting Ltd.) – Advisor, Permafrost Engineering		Steve Kokelj, Permafrost Scientist[1]	
		Gurdev Jagpal, Regional Superintendent, Inuvik[1]	
		Arvind Vashishtha, Project Engineer[1]	

[1] Only for NT section of the highway

[2] Only for YT section of the highway

The drive started in Inuvik NT and finished three days later in Dawson City YT. A total of eleven stops of significance were made along the NT section, with thirteen stops in the Yukon section. Observations are presented in subsequent sections of this report. Initially, a list of potential stops was prepared at the kickoff meeting, subsequently augmented by the Tetra Tech EBA Project Manager, and then augmented again through discussions with highways personnel on the trip, as well as the local maintenance personnel met during the trip.

2.4 Workshop

A one-day workshop was held at the Whitehorse office of Tetra Tech EBA on December 12, 2013. It was attended primarily by those on the August field trip, with the addition of several maintenance supervisors from both the YT and NT sections of the highway. The morning was spent summarizing the findings from the field trip, and presenting climate, surficial geology, permafrost and ground temperature data collected during and after the trip. In addition, a presentation was made on the challenges of highway construction and maintenance across regions of ice-rich permafrost.

The afternoon session focused on bringing forward for discussion feedback from the highway personnel, specifically related to climate change effects. The intent was to identify changes in performance of water management structures and road embankment that have been observed and to discuss these within the context of the terrain sensitivity and engineering practice past and present.

The group identified nine specific hazard types that are considered to have a linkage to climate change both trends and extremes. Those nine hazards were then ranked in severity using a simple scale 1 to 5 for each of seven physiographic regions the highway crosses between the Klondike Highway and Inuvik. The discussion resulted in a clear consensus as to the relative importance of each hazard type in the respective region. That matrix is presented and discussed in Section 4 of this report.

3.0 INFORMATION PRESENTATION

3.1 Summary of Regions/Geomorphic Conditions Along the Highway

The Dempster Highway terrain has commonly been divided into seven regions of similar geomorphology, permafrost, and climate conditions based on experience of the project team. Those regions are generally consistent with most published literature such as the "Dempster Highway Travelogue, a joint Yukon, Northwest Territories travel document. These regions were adopted for this study and are summarized in Table 2 and shown on Figure 1.

Table 2: Study Regions along the Dempster Highway, YT/NT

Region	km post range	Territory
North Klondike	0 – 80	Yukon km 0 in Yukon is at the junction with the North Klondike Highway about 40 km south of Dawson City, YT
Blackstone Uplands	80 – 156	Yukon
Ogilvie River	156 – 260	Yukon
Eagle Plains	260 - 406	Yukon
Richardson Mountains	406-465 (YT)+ 0 27 (NT)	Yukon and Northwest Territories (note km 465 is the Yukon /NT border where the km posts are re-set to zero for NT section).
Peel Plateau	27 – 74	Northwest Territories
Mackenzie Lowlands	74 - 272	Northwest Territories km 272 is at Navy Road, Inuvik, NT

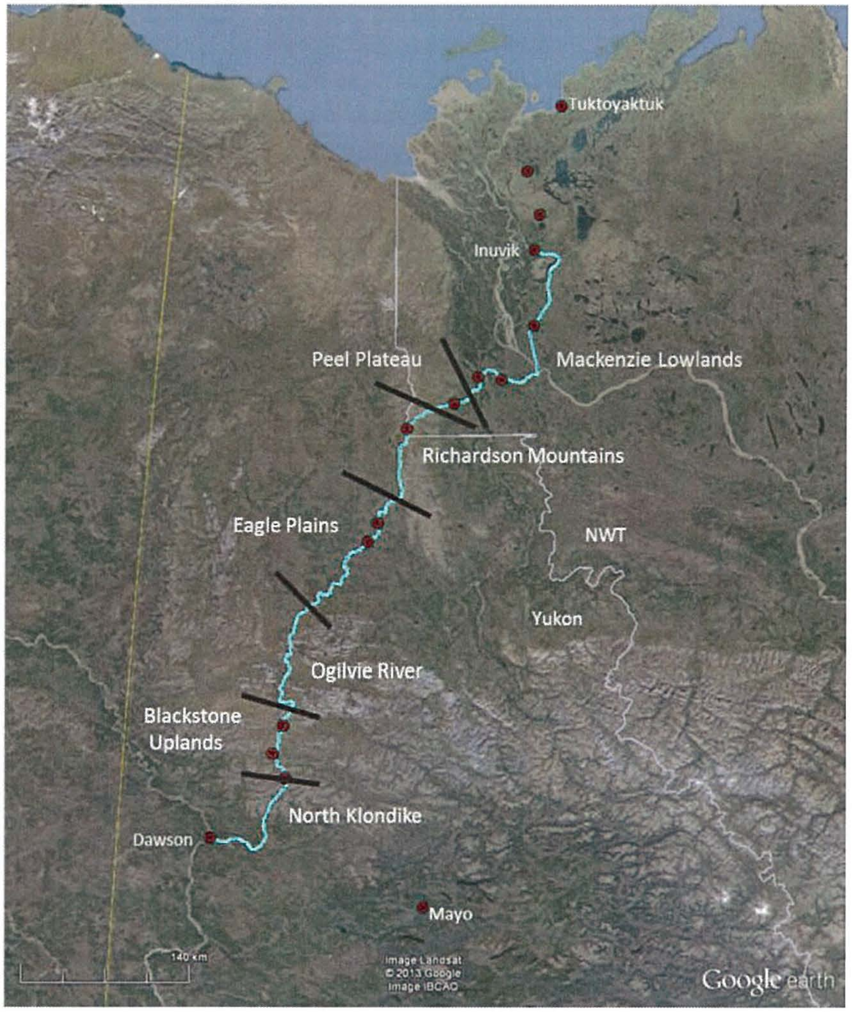


Figure 1: Locations of Study Regions along the Highway

Detailed information obtained from the field trip is presented in the following sections:

3.1.1 North Klondike Segment (km 0-80)

No maintenance issues that are believed sensitive to climate change were observed along this section of the highway during the field trip, or pointed out to the field crew by YT maintenance personnel. This region follows the North Klondike River Valley and is predominantly granular alluvial valley deposits with minor (if any) permafrost features on the route. There are numerous culvert crossings, but no significant erosion or stability issues were noted.

3.1.2 Blackstone Uplands Segment (km 80-156)

This is generally an unglaciated (i.e. not in the most recent period of continental glaciation) ice-rich permafrost area characterized by broad valleys and numerous areas of both ice-wedge polygons and thermokarst lakes. However, the highway crosses a short section of glaciated terrain near km 109 that has deposited steep sided moraine on both sides of the highway.

Observations from the driving trip are presented as follows:

Photo 1 shows degraded ice-wedge polygons adjacent to the highway at about km 96. Natural undulations in the terrain adjacent to the highway are about 2 m and are indicative of thaw of ice-wedge polygons.

Photo 1:
Degraded ice-wedges adjacent to the highway embankment, km 96 (August 27, 2013)

Several large thermokarst lakes are also present adjacent to this section of highway – the largest being Chapman Lake and Two Moose Lake. These lakes have increased in size since the highway was constructed, and are now adjacent to and potentially encroaching on the highway embankment.

Photo 2:
View across Two Moose Lake where permafrost thaw is threatening the stability of the road embankment (August 27, 2013)

The short glaciated area that the highway passes through is centered on about km 109 – the moraine in this area is ice-rich, and has recently started to exhibit minor slope instabilities (surface flow slides) related to increased active layer thickness, and possibly increased rainfall. None of these slides have affected the highway yet, but are very close to the ditches in some areas.

Photo 3:
Shallow flowslide in glacial moraine near km 109 (August 27, 2013)

Erosion from the Blackstone River has affected the highway at about km 122, necessitating a realignment. The highway was moved away from the river, but reconstruction included a minor cut section that has created ongoing permafrost thaw-settlement issues and initiated progressive instability that requires regular maintenance.

Photo 4:
Erosion at toe of highway embankment by the Blackstone River (August 27, 2013)

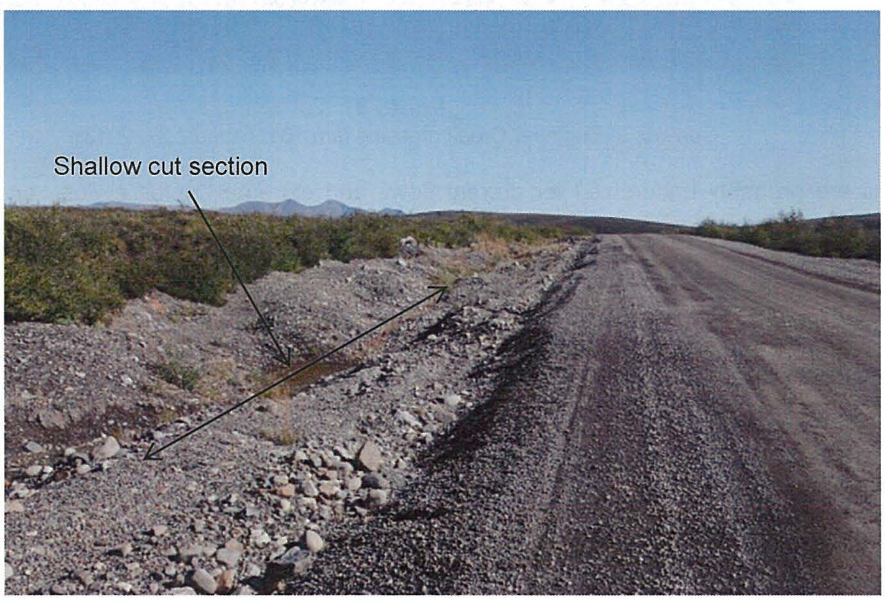


Photo 5:
New alignment further away from Blackstone River, But the shallow cut section has created thaw settlement problems in the left shoulder, km 122 (August 27, 2013)

3.1.3 Ogilvie River Segment (km 156-250)

The highway in this area generally follows Engineer Creek to its junction with the Ogilvie River, and from there follows the Ogilvie River valley until it starts to climb up to the Eagle Plain. The southern section is underlain by permafrost, but after crossing the Ogilvie River the highway is generally founded on unfrozen alluvial deposits adjacent to steep valley sideslopes underlain by permafrost.

The highway in this segment crosses Engineer Creek twice, and increased flows and winter icing have continued to cause maintenance issues at those crossings.

Photo 6:
Culverts at Engineer Creek crossing (km 161) (August 27, 2013)

These culverts are probably undersized for current flows and extreme rainfall events, and maintenance crews indicate that they ice up most winters. The culvert installations are not consistent with current design practice as the overlying fill is too thin to effectively dissipate the load from heavy vehicles

Increased flows in Engineer Creek have also created highway instability by eroding the toe of the embankment. This has necessitated several repairs by highways crews after extreme rainfall events (see Photo 7).

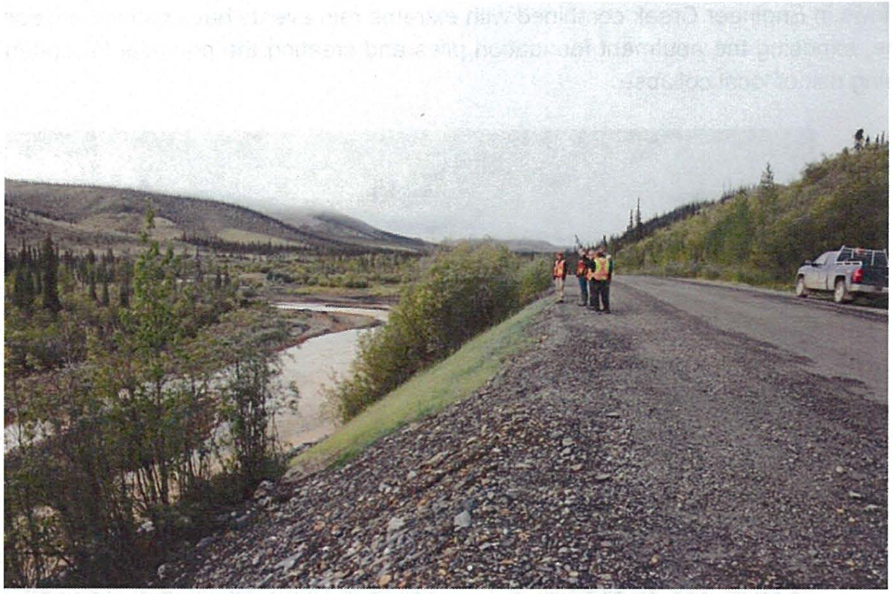


Photo 7:
View of successful erosion repair adjacent to Engineer Creek, km 177 (August 27, 2013)

The black shale used for embankment construction material has decomposed into clay minerals, and absorbed heat that has accelerated permafrost thaw and settlement.

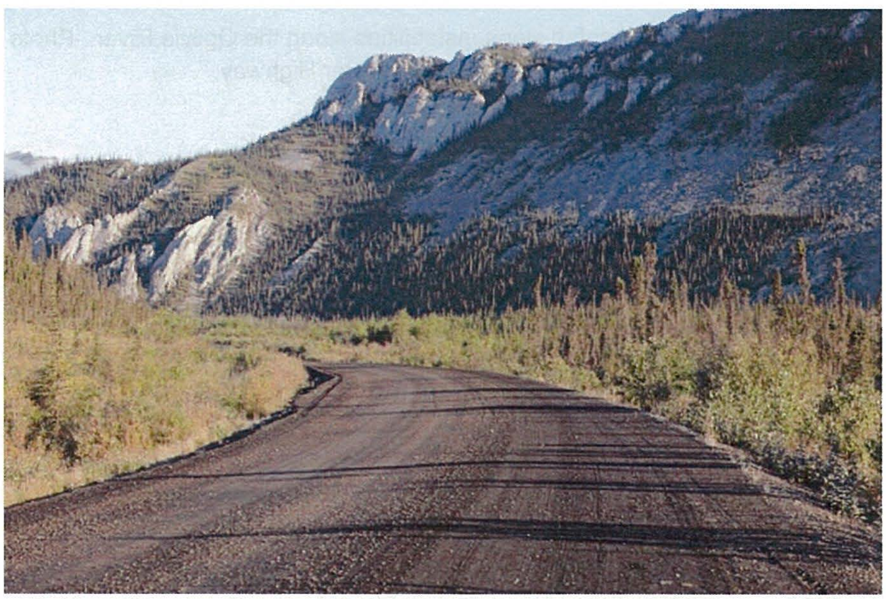


Photo 8:
Black shale embankment showing settlement at km 192 just south of Engineer Creek Bridge (August 27, 2013).

The original shale embankment fill has produced a matrix of fine clay and silt by freeze-thaw action. The black surface increases heat absorption, further deepening the active layer resulting in progressive settlement into the surrounding wetland tundra.

Increased flows in Engineer Creek combined with extreme rain events have caused erosion of the Engineer Creek at the bridge, exposing the abutment foundation piles and creating the potential for undermining of the abutment and increasing risk of local collapse.

Photo 9:
Erosion at abutment of bridge crossing Engineer Creek, km 195 (August 27, 2013)

Extreme rainfall events have also created slope instabilities along the Ogilvie River. Photo 10 shows a debris flow at about km 244, the toe of which came close to the Dempster Highway.

Photo 10:
Minor Debris flow along highway beside Ogilvie River km 244 (August 26, 2013)

Higher flows in the Ogilvie River may also have contributed to the requirement for additional or increased riprap protection along the toe of the road embankment next to the Ogilvie River.

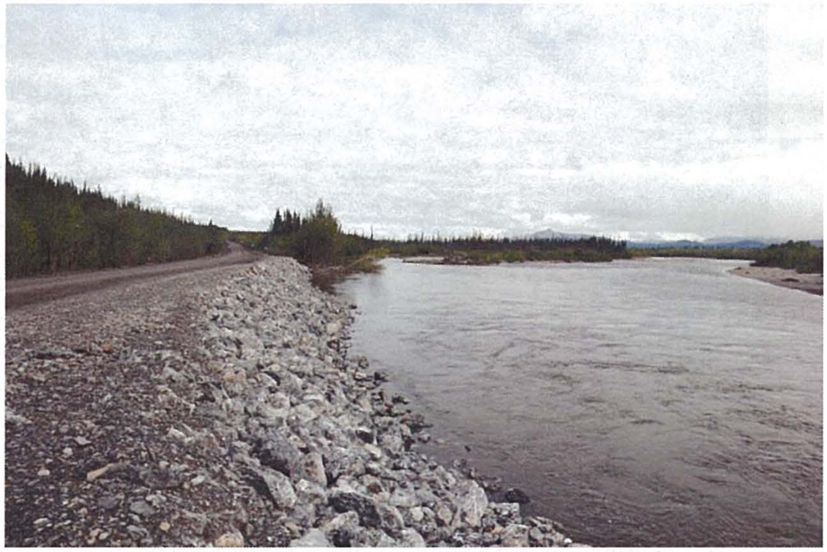


Photo 11:
Improved erosion protection required along Ogilvie River km 245 (August 26, 2013)

3.1.4 Eagle Plains Segment (km 260 – 406)

The highway climbs out of the Ogilvie River Valley just before km 250, and above this, minimal maintenance issues were observed as the road essentially follows bedrock cored ridges to the Richardson Mountains. Two unexplained "sinkhole" locations in fill areas at about km 372 and 394 were identified by the local maintenance foreman, but no photos were taken and not much could be seen as these were filled in shortly after they were observed. There was no clear reason for sinkhole formation at the locations as no permafrost-related features were observed in the adjacent landscape. One location (km 372) was adjacent to a cut into hard rock. It appeared that the material removed from the cut was the fill used at the sinkhole site and that it was very coarse rock -- possibly 0.6 m and larger boulder sizes. One hypothesis for the sinkhole at that location was loss of surface fines into the voids of the underlying rock fill. It will be necessary to investigate further by selective investigation of the nature of fill materials at sinkhole locations and the contribution of water movement initiating internal erosion. No information was provided about the sinkhole observed and repaired at km 394.

Several areas of slope instability were noted on the north side of the Eagle River valley, possibly related to forest fire and/or increased precipitation, or both – see Photo 12.

Photo 12:
Slope instability on the north side of the Eagle River Valley km 379 (August 26, 2013)

3.1.5 Richardson Mountains Segment (km 406 (YT) – 27 (NT)

The Richardson Mountains are a range of the Canadian Rocky Mountains that parallels the northernmost part of the boundary of the Yukon and Northwest Territories. Trending northwest-southeast, the Richardson Mountains are the northern extremity of the Rockies.

Increased rainfall and possibly undersized culverts have created road instabilities through washouts adjacent to culverts in some sections of the highway. Photo 13 shows culvert distress affecting the road surface at about km 415.

Photo 13:
Flow next to and around a culvert creating road instability km 415 (August 26, 2013)

The thaw of ice-wedges in the permafrost has affected the highway on the NT side in the vicinity of km 8.5 since about 1984 when there was a fatal accident at this location caused by road collapse into a thawed ice-wedge void. Photos 13 and 14 below, show continuing distress to both sides of the highway embankment at this location caused by thaw near the toe of the fill.

Photo 14:
Ice-wedge thaw near toe of embankment creating road instability at km 8.5 NT (August 25, 2013)

Photo 15:
Ice-wedge thaw (and ponded water) near toe of embankment creating road instability at km 8.5 NT (August 25, 2013)

3.1.6 Peel Plateau Segment (NT km 27 – 74)

The landscape in this segment is almost entirely shaped as result of the most recent (Laurentide) glaciation, along with subsequent post glacial fluvial and other geomorphological processes. Continuous thick permafrost is present throughout to a depth close to 300 m (Geological Survey of Canada, unpublished data). Retrogressive thaw-flow slides are common where ground ice has been exposed in glaciolacustrine deposits by forest fires, debris flows and regressive erosion.

These thaw slumps are one of the most active geomorphic features within this segment and they are all situated within the maximum westward extent of the Laurentide Ice Sheet.

The Peel Plateau is particularly susceptible to the effects of a warming climate as it contains a significant amount of ice-rich permafrost. Instability at km 27 related to thaw of ice-rich near surface soils on both banks of a surface drainage course has affected the toe of the highway embankment.

Photo 16:
Thaw and slumping of near surface ice-rich permafrost is creating instability at km 27 NT (August 25, 2013)

Thaw at the toe of the embankment, possibly combined with creep of ice-rich permafrost has created tension cracks and instabiity at km 30.

Photo 17:
Road instability related to tension cracks and slumping on a deep fill at km 30 NT (August 25, 2013)

Toe berms have been used successfully at several locations to mitigate the effects of tension cracks and sideslope slumping in thick fills over culverts.

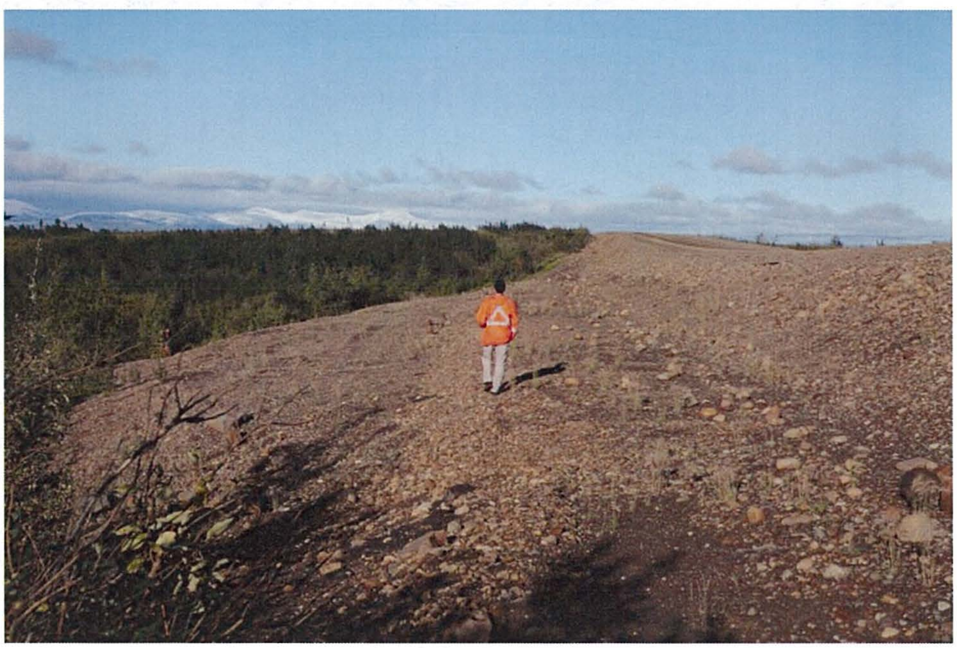


Photo 18:
Successful application of a toe berm to stabilize road embankment km 51 NT (August 25, 2013)

Thaw at the toe of the embankment, possibly combined with creep of ice-rich permafrost has created tension cracks and instabiity at km 53 and 59.

Photo 19:
Road instability related to tension cracks and slumping at km 53 NT (August 25, 2013)

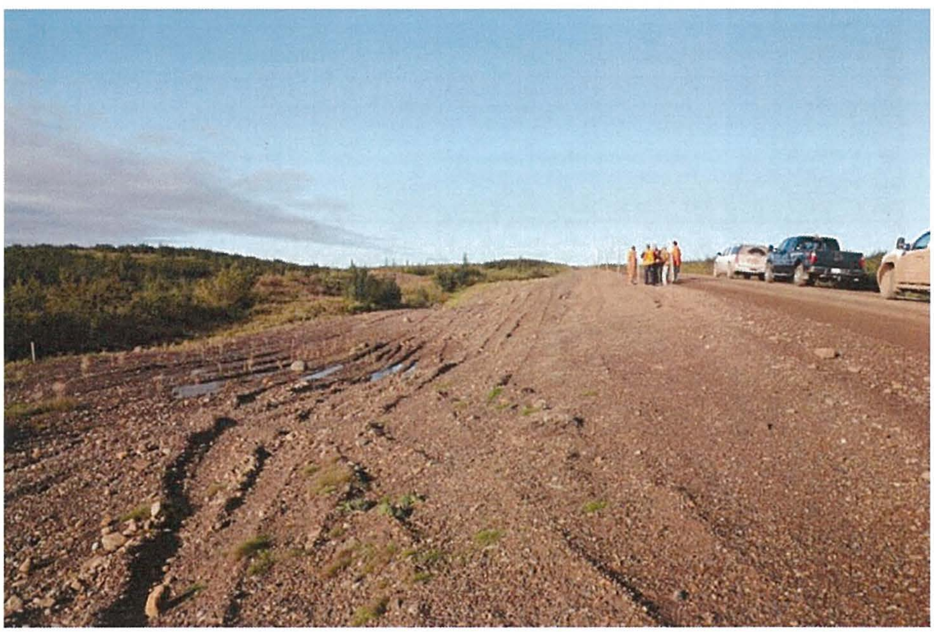


Photo 20:
Road instability related to tension cracks and slumping at km 59 NT (August 25, 2013)

3.1.7 Mackenzie Lowlands (km 74 – 272)

This section of highway from the Peel River to Inuvik is generally flat and contains significant areas of standing water (swamps) connected by small drainage courses. In general, the swamps are shallow and freeze to the bottom every winter, preserving the permafrost. In some sections of the highway, ponded water combined with significant embankment settlement has created deep water that probably doesn't freeze every winter. This has created ongoing permafrost thaw and resulting culvert and highway distress.

Photo 21:
Ponded water has created permafrost thaw, culvert distress, and road instability at km 90 NT
(August 24, 2013)

Some sections of the road in this area are through shallow cuts, sometimes exposing ice-rich permafrost at depth. One of these cuts at km 227 just south of Inuvik exhibits a large thaw settlement depression requiring the addition of fill to keep it from becoming a hazard.

Photo 22:
Thawing ground ice in permafrost adjacent to highway at km 227 NT (August 24, 2013)

4.0 INFORMATION ANALYSIS

The information obtained from the driving trip, along with some subsequent analysis of ground temperature and climate data was presented at the workshop to representatives from both YT and NT highways, along with other members of the team. The presentations included highlights from technical papers and information gleaned from construction records. The following sections include information presented at the workshop, along with other climate and temperature data collected to assist in the interpretation of the effects of climate change on the Dempster Highway.

4.1 Terrain

An elevation profile of the Dempster Highway is presented in Figure 2. As can be seen from this information, there is a significant amount of relief along the highway that affects air temperature, precipitation, and ground temperature. The nature of the slopes, soil type and permafrost conditions are all climate related and vary substantially in response to the terrain elements. As shown on Figure 2, the elevation of the Dempster Highway ranges from just above sea level to over 1200 m at its highest point in the Yukon.

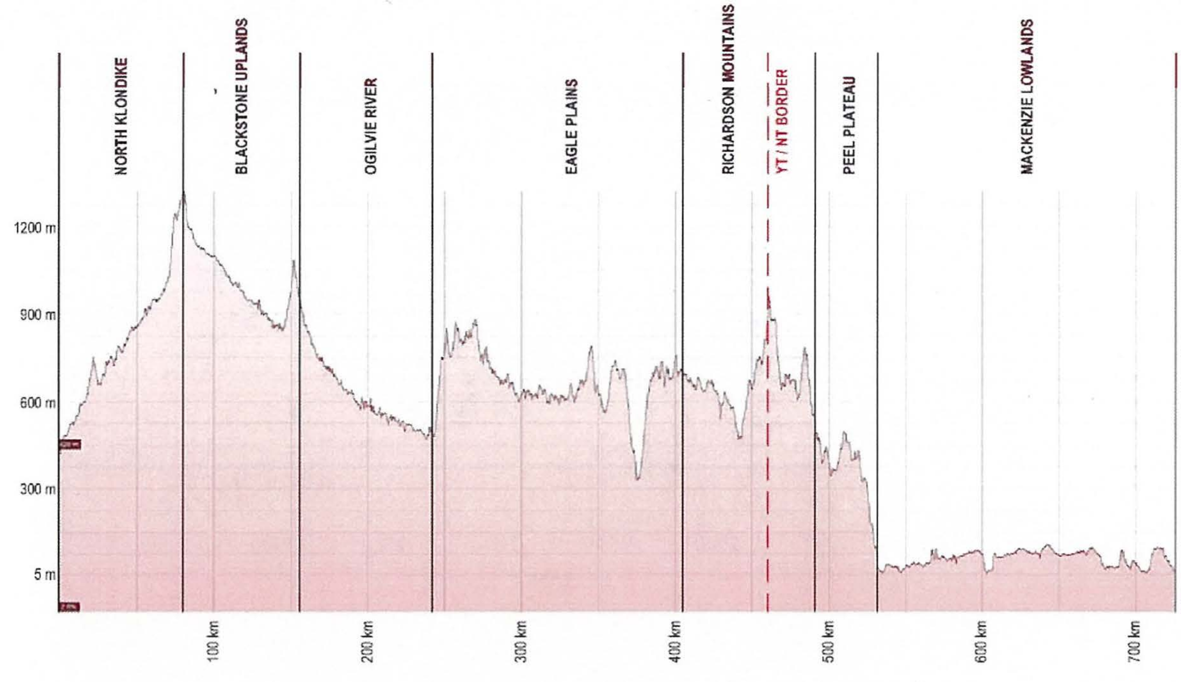
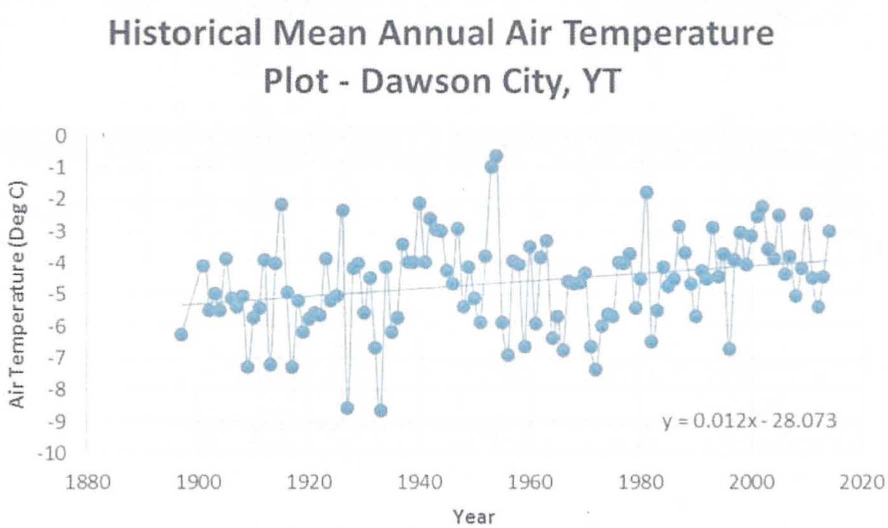
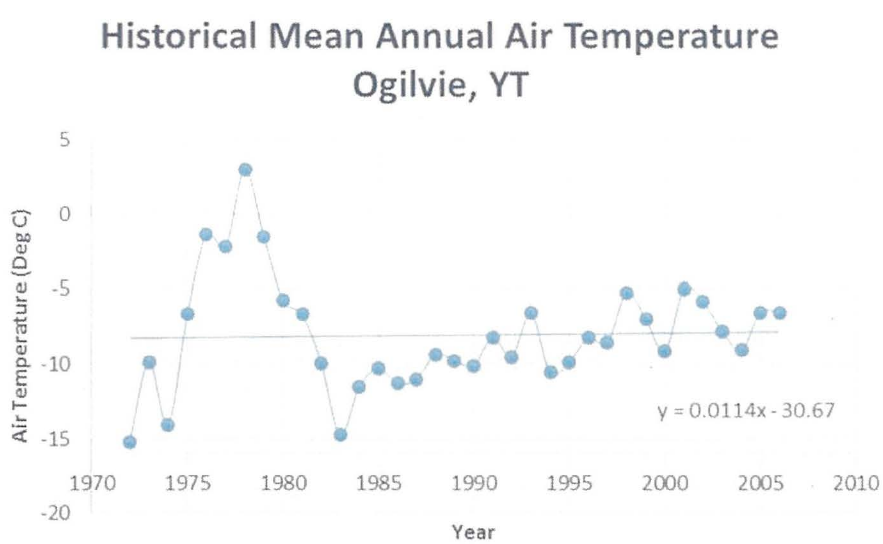


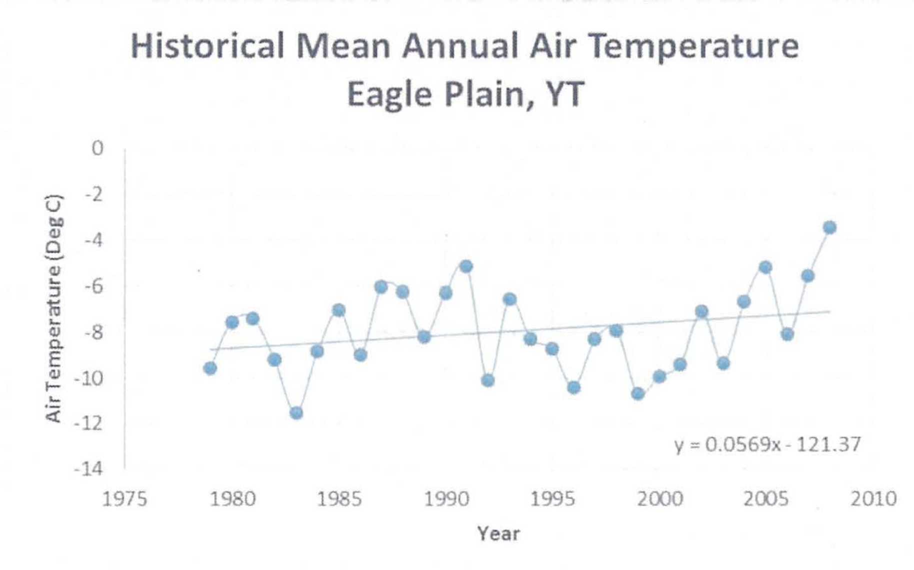
Figure 2: Elevation Profile of the Dempster Highway Showing Study Areas

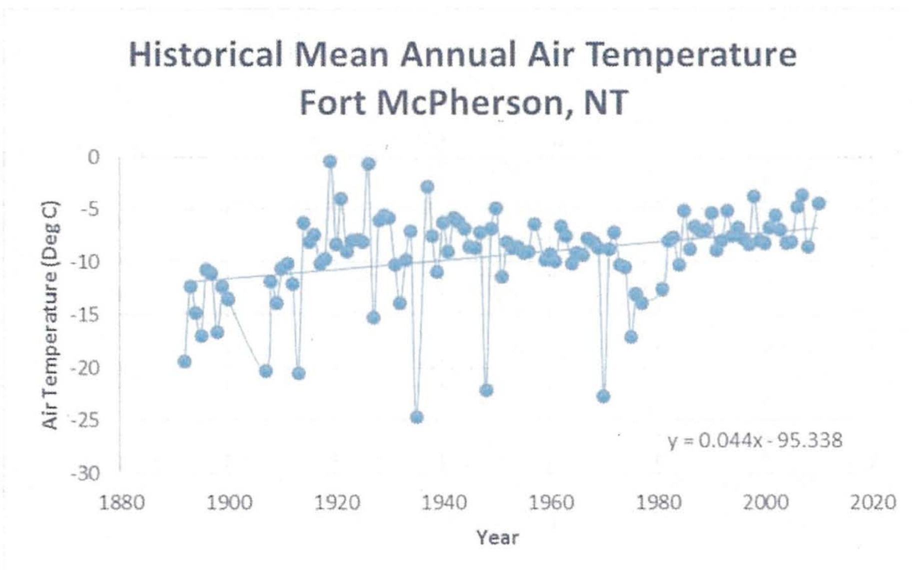
4.2 Climate

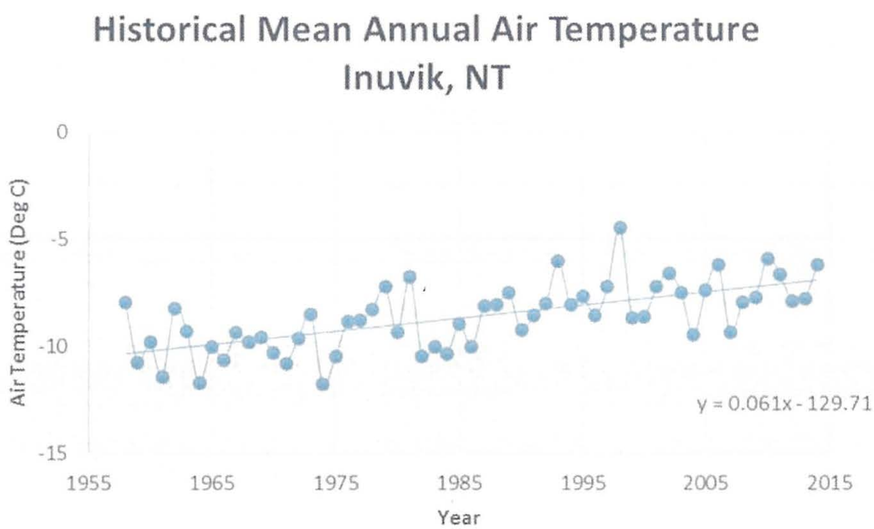
The climate along the highway is affected by mountains and valleys, local micro-climate, as well as ocean storms in the northern section. However, the Mean Annual Air Temperature (MAAT) trend for locations at both ends (Dawson City, Inuvik) and along the highway (Ogilvie, Eagle Plain, and Fort McPherson) is warming. The following plots summarize the data and show trend lines of MAAT at locations along the highway.






Historical Mean Annual Air Temperature
Eagle Plain, YT
Air Temperature (Deg C)
0
-2
-4
-6
-8
-10
-12
-14
1975
1980
1985
1990
1995
2000
2005
2010
Year
y = 0.0569x - 121.37


Historical Mean Annual Air Temperature
Fort McPherson, NT
Air Temperature (Deg C)
0
-5
-10
-15
-20
-25
-30
1880
1900
1920
1940
1960
1980
2000
2020
Year
y = 0.044x - 95.338



As can be seen by the plots, the air temperatures are warming at all locations, some more than others. Using the trend line data, the predicted air temperature in 2040 at each location is shown in Table 3.

Table 3: Predicted Air Temperatures along Dempster Highway based on Historical Data

Location	Predicted 2040 Air T based on Historical Trends	Annual Air T change since 1990
Dawson City	-3.6 °C	0.01 C° per year
Ogilvie	-7.4 °C	0.01 C° per year
Eagle Plain	-5.3 °C	0.05 C° per year
Fort McPherson	-5.6 °C	0.04 C° per year
Inuvik	-5.3 °C	0.06 C° per year

The Ogilvie data is the Yukon Governments highways maintenance yard at the Ogilvie River – it is located at the base of a steep sided valley, generally shaded from the sun, and represents a colder micro-climate in this section of the highway. This illustrates the effects of the terrain that the Dempster Highway traverses.

In addition to actual measured data, the mean annual air temperatures have also been modelled by others to make a prediction of what these may look like in 2040. The following Figure 3 shows these predictions for sites along the Dempster as well as at Tuktoyaktuk, NT. This information shows that winter air temperatures may rise as much as 2°C by 2040, with summer temperatures about the same as at present, and spring/fall temperatures about 1°C warmer.

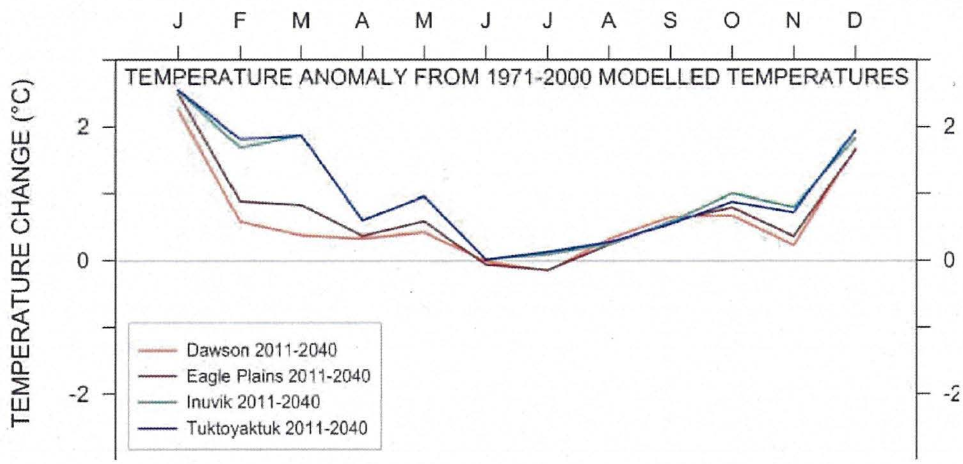


Figure 3: Predictions of Air Temperature Warming Based on Analysis of Current Trends

This information represents what residents of northern Canada have experienced – warmer winters with generally unchanged summers.

Specific data related to rainfall could not be located, however, the general experience of northern residents is that summers are wetter, with larger storm events becoming more common.

4.3 Permafrost

The permafrost temperature is directly related to air temperature, and based on the predictions of future air temperature, it can be expected that the mean annual ground temperature (MAGT) of the permafrost along the Dempster Highway will also gradually rise. As noted on Figure 4, those areas with a MAGT warmer than -2°C will likely experience extensive degradation of permafrost over the next 25 years (by 2040).

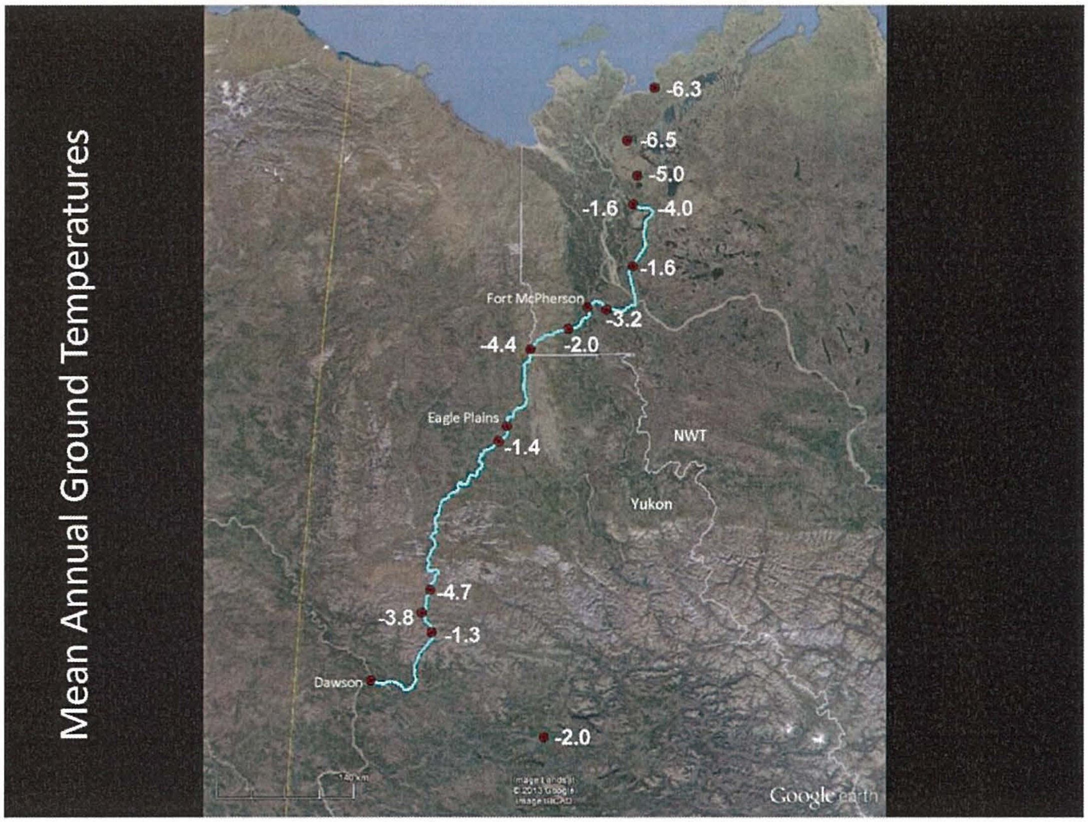


Figure 4: Recent Mean Annual Ground Temperatures Measured at Selected Locations along the Dempster Highway (2004 data from Chris Burn/Carleton University).

This information shows that several sections of the Dempster Highway constructed on warm permafrost are susceptible to thaw-settlement effects due to warming temperatures.

More background data on ground temperature along the Dempster Highway needs to be collected to verify these assumptions.

4.4 Ground Temperature Monitoring Locations

There are not a lot of historical ground temperature monitoring stations along the Dempster. In 1992, Northwestel constructed microwave towers along the highway to link Dawson City to Inuvik, and in 2009 weather instrumentation and ground temperature cables were installed at these sites, with data being recorded using dataloggers. Figure 5 shows the locations of these instruments along the highway. The data collected to date has been intermittent due to communication and power issues related to the remoteness of the sites; however, they should provide base data for future monitoring of the effects of climate change.

In addition, the Yukon and Northwest Territories governments, through their Highways departments installed four thermistor cables along with air temperature and wind monitors at km 124 and 421 (Yukon) and km 8.5 and 51.5 (NT). These locations are also shown on Figure 5.

The authors have not yet seen any of the data collected from these sites.

Figure 5: Locations of Ground Temperature Monitoring Stations (Yellow Circles-Northwestel (2009), White Diamonds-YT/NT Highways (2014)) Along the Dempster Highway

5.0 VULNERABULITY ASSESSMENT

5.1 The Applicability and Formal Approach of PIEVC

PIEVC is an initiative of Engineers Canada through their Public Infrastructure Engineering Vulnerability Committee (PIEVC) to develop a formal risk assessment process for evaluating the risks that climate change poses to public infrastructure in Canada. It is a five step process illustrated in Figure 6. It is a primary objective of this study to critically examine steps one, project definition and two, data gathering in order to determine if sufficient information exists at present and that conditions permit a formal vulnerability assessment.

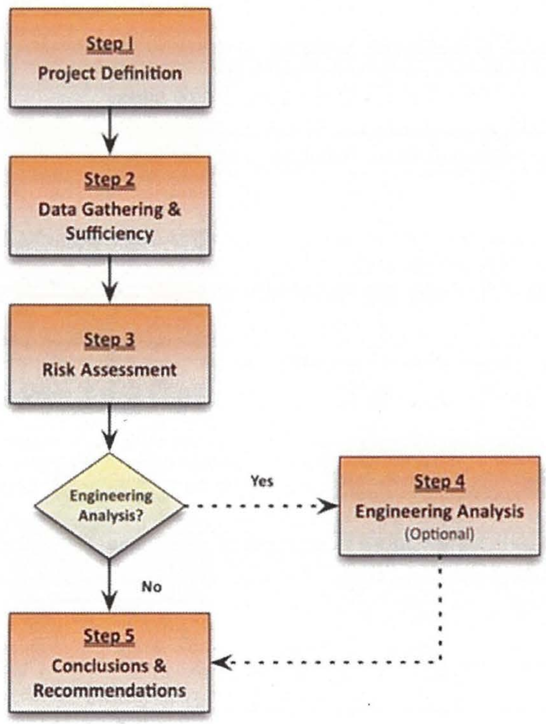


Figure 6: Steps to Complete a PIEVC Vulnerability Risk Assessment
Reference: http://www.pievc.ca/e/doc_list.cfm?dsid=43

The PIEVC process has been tested on at least two northern projects. The Highway 3, Vulnerability Assessment, carried out by BGC Engineering for GNWT-DOT (BGC, 2011) provided an insight into application of the protocol to a highway affected by permafrost. That study addressed 100 km of reconstructed highway between Behchoko and Yellowknife across a glaciolacustrine lake basin with frequent rock outcroppings. The climate was consistent and terrain conditions were relatively uniform with low relief. There was also some data on permafrost distribution and ground temperatures from the highway reconstruction over the past decade. One significant conclusion of the Highway 3 Vulnerability Study was that:

> "[1]Road embankment deformations due to warming of the permafrost subgrade are expected to result in loss of functionality as well as increased efforts to maintain and repair."

The clear indication from the Highway 3 study is that certain factors related to climate change, such as warming of permafrost and increased precipitation have an overwhelming effect on linear infrastructure in regions of permafrost. Therefore, there is not a defined need for an extensive study of all possible variables and a risk assessment on the seven by seven matrix of probability and severity (consequence) as defined in the PIEVC protocol.

The Highway 3 study also concluded that:

> "There are limits to the protocol, particularly for roads that traverse varied terrain. It is impractical to isolate elements of a road individually because it is how these elements function together that governs its capacity."

This conclusion is amplified by an order of magnitude when applied to the Dempster Highway that is 737 km long and crosses three mountain ranges. It also makes the transition from continuous to widespread discontinuous permafrost terrain across mountainous terrain that has ground ice conditions uniquely related to an interpreted pattern of continental and valley glaciation.

It is clear that there is not sufficient fundamental data on soil type, ground temperature and ground ice, precipitation and runoff to apply the protocol and there probably never will be. However, the PIEVC process cannot be dismissed solely because there is little data to support the level of detail required. It has been dismissed primarily as not applicable to the widely varied conditions of climate, terrain and permafrost that are present along the route.

The concept of a vulnerability assessment for northern roads is a valid objective to manage future maintenance expenditures. The first step is to identify the relationship between the physical parameters of terrain and climate and performance of the road embankment and drainage structures. This step was taken by this project at the Whitehorse workshop in December, 2013. That process and what it achieved is described in Section 4.2

5.2 Hazard Assessment by Study Region

The project workshop provided an opportunity for the Project team to identify the hazards observed on the route reconnaissance and relate them directly with regular maintenance issues for each of the terrain segments identified in Section 3. Nine specific hazard types were identified that all workshop participants agreed represented significant maintenance issues that are probably related to climate change both warming trends and extreme occurrences. It was recognized that that there was no uniformity along the seven route segments identified in Section 3 therefore a relative severity factor that varied from 1 (least) to 5 (most) severe condition was applied for each segment. The results are presented in a matrix in Table 3 below.

[1] BGC Engineering Inc., Government of the Northwest Territories, Department of Transportation, Engineers Canada, Public Infrastructure Engineering Vulnerability Committee, *Climate Change Vulnerability Assessment for NWT Highway 3*, August 10, 2011

Table 4: Summary of A Hazard Severity (Scale 1 (low) to 5 (high)) in Study Regions of the Dempster Highway

Hazard	North Klondike	Blackstone Uplands	Ogilvie River	Eagle Plain	Richardson Mountains	Peel Plateau	Mackenzie Lowlands
Ground Ice (Thermokarst)	1	4	1	1	4	5	3
Sinkholes	4	5	1	2	3	5	3
Thaw Flowslides	0	2	0	0	3	5	0
Debris Flows	0	0	5	1	0	0	0
Extreme Floods	1	5	5	1	3	3	3
Erosion	1	3	5	1	4	1	2
Extreme Precipitation	1	2	5	1	3	4	1
Extreme Winter Storm	1	2	3	3	5	5	2
Icing	4	1	2	1	5	1	4
Totals	**13**	**24**	**27**	**11**	**30**	**29**	**18**

This summary, developed by the study group and maintenance personnel, indicates that the Richardson Mountains and Peel Plateau in the NT, as well as the Blackstone Uplands and Ogilvie River in YT have the highest hazard severity, and are considered to be the most vulnerable to climate change.

One item of significant interest to both YT Highways and NT Transportation was the continuing appearance of sinkholes along the highway. There has been no formal documentation of these events, as the holes are excavated and filled as soon as they are noticed. An example of sudden roadway collapse and its consequence was documented by Hayley and Bowen, in 1987. In late fall, 1985, a deep hole formed in the surface of the Dempster Highway, 8.5 km east of the NT-YT border in the Richardson Mountains Region, causing a fatal accident. Investigation showed that the surface grade had collapse suddenly into an open void in the foundation soils. The void was attributed to thermal erosion of one or more ice-wedges present beneath the embankment. Ice-wedges aligned perpendicular to the axis of the road offer a natural pathway for subsurface water at the time of warmest ground temperatures (late fall). Where natural cross-slope surface drainage is impeded by the embankment, a hydraulic gradient will feed a process of thermal erosion of the ice-wedge. That will usually remain unforeseen while the cavity enlarges until the bridging action of the embankment is unable to span and the roadway collapses into the void.

There are several potential causes for sinkhole development on the Dempster highway. Those that are most likely to be safety risks, in descending order of significance, include:

- Melting ground ice in the permafrost foundation soils, particularly over ice-wedge features
- Erosion next to existing culverts from bypass water
- Progressive migration of finer grained surface materials into voids of underlying coarse-grained rock basecourse materials
- Subsurface erosion through or below the embankment where there are no functional culverts
- Collapse of materials into old "peat bogs or dump sites" that may have been incorporated into the road embankment.

A road shoulder collapse/sinkhole development at km 82 in Yukon is shown in Photo 23.

Photo 23:
Sinkhole development near road shoulder at km 82 YT (June 2013, YG Photo)

The collapse occurred in June 2013 and the resulting cavity was sub-excavated then refilled before the site reconnaissance in August, 2013. A description of the excavation strongly suggests internal erosion as a likely cause but there was no documented geotechnical test data or observations. The surrounding terrain at this site, visited during the August 2013 reconnaissance trip did not appear to be affected by permafrost thaw and regression of ground ice.

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 Limitations of a Formal Climate Change Vulnerability Assessment

A primary objective of this project was to determine if there was sufficient information and data to conduct a formal climate change vulnerability study of the Dempster Highway. The methodology developed and applied elsewhere to public infrastructure in Canada was developed by the Public Infrastructure Engineering Vulnerability Committee of Engineers Canada (PIEVC). It has been identified as the most appropriate systematic approach to proceed with a formal vulnerability assessment. The first and second stages of a PIEVC assessment are to identify the project scope and the information currently available that could be useful to populate a seven by seven risk assessment matrix that is the core of the process.

The Dempster Highway from the Klondike Highway (km 0) to Inuvik traverses 730 km of highly varied subarctic and arctic terrain, including three mountain ranges. Permafrost conditions vary with latitude and elevation from sporadic discontinuous at the Klondike Highway to continuous at Inuvik. The route has been divided into seven terrain regions for this project, each with identified priorities relative to maintenance activities that could be linked to climate change effects. Environmental factors that drive the vulnerability show clear linkages to natural hazards directly related to surface water extreme runoff events and permafrost that has a high component of ground ice.

The PIEVC process was developed for infrastructure at discrete locations. It has been shown to work well for structures and earthworks such as airports and dams. It is not well suited for linear infrastructure where the environmental parameters and geotechnical conditions vary along its length. This was shown on the Highway 3 test case project that covered much more uniform terrain than the Dempster Highway. A PIEVC vulnerability study may be effective for a particular terrain segment along the Dempster highway. The Peel Plateau has been flagged as a vulnerable unit based on future maintenance and safety risk and would provide reasonably uniform conditions that drive environmental risks over sensitive ice-rich permafrost terrain.

A secondary but important consideration when assessing the feasibility of proceeding with a formal vulnerability study on a segmented basis is the lack of current geotechnical and environmental data along the entire route. Climatic data is elevation sensitive and very limited and geotechnical data representative of ground conditions at locations known to contribute to the greatest risk is very limited and probably out-of-date. The next logical step in pursuit of a clear understanding of the climate change vulnerability would be to initiate a focused instrumentation and monitoring program similar to that described in Subsection 5.3.

6.2 Guidance for Future Maintenance Management

The project has included an independent overview of the condition and maintenance issues currently affecting the Dempster Highway. The reconnaissance trip included two Geotechnical Engineers experienced with roads on permafrost terrain, two prominent permafrost scientists that have conducted research programs in the region and personnel from both Northwest Territories and Yukon government highway departments. The highway is unique in Canada given its length and the changing nature of permafrost terrain that it crosses. The categorization of hazards that will be affected by climate change in Table 3 and how they are distributed along the route provides insight into where the greatest challenges for future maintenance lie. These hazards (Table 3) do not include routine maintenance activities that are common to all gravel roads such as periodic resurfacing and patching potholes. Those activities will carry on and are more closely related to traffic frequency and type than to climatic parameters.

The greatest hazards for both highway safety and maintenance relate directly to thaw of fine-grained permafrost foundation soils that have a high proportion of ground ice and a higher frequency of extreme weather events both precipitation and winter snow storms. Those factors that should be addressed in future upgrades to operating and maintenance procedures include:

- Documentation of locations with vulnerable permafrost topography, such as ice-wedges, that have a potential to affect the embankment integrity.
- Identification and monitoring of locations where thermokarst features are threatening embankment integrity.
- Review of all culvert installations for bypass erosion, cover integrity and hydraulic effectiveness
- Document where sinkholes that threaten embankment safety form, include conditions at the time. Identify a probable cause and document the mitigation procedures adopted. This activity can evolve into a small database that will help recognize vulnerable locations and improve our understanding of the collapse mechanisms.
- Identify locations where embankment sideslopes are progressively failing and evaluate the risk of overall rapid slope failure. Adopt a proactive mitigation procedure, such as berm construction (Photo 18), that can be applied as and where required to protect the road from sudden collapse.

6.3 Future Data Collection and Management

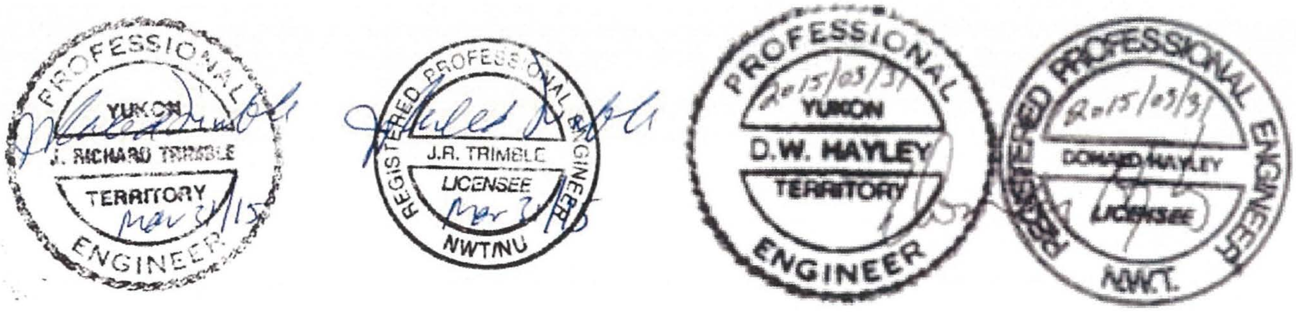
Current information is lacking or non-existent pertaining to climate, ground temperatures and surface water hydrology from which extreme runoff events can be deduced. A plan for future data collection and management should consider the following recommendations.

- Install a weather station at each maintenance shop and provide the data in a useful format for planning.
- Install ground temperature monitoring stations into terrain flagged as sensitive to small changes in ground temperature. There were four sites installed in 2014, but the authors have not seen any of the data.
- Support research on the effects that snow drift accumulation on exposed sideslopes accelerates permafrost thaw and contributes to sideslope instability. Examine practical mitigation measures such as slope flattening, berms and removal of brush that traps snow.
- Install slope indicators and ground temperature cables into a few deep fills that appear to be subject to creep displacements to confirm the embankment temperatures and lateral deformations. Collect and test soil samples to confirm engineering properties of the construction materials (NT Site at km 30, see Photo 17, would be a candidate site)
- Map surface conditions and soil types near locations where thaw-flow slides could jeopardize the embankment,
- Install runoff monitoring stations on key rivers and streams and carry out a regional hydrological assessment that can be updated as new data is collected.
- Continue to monitor culvert performance and effectiveness of erosion mitigation structures (Photo 7)

7.0 CLOSURE

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

Respectfully submitted,
Tetra Tech EBA Inc.



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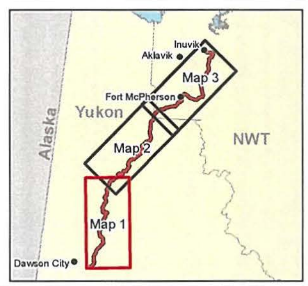
PERMIT NUMBER PP003
Association of Professional
Engineers of Yukon

PERMIT TO PRACTICE
TETRA TECH EBA INC.
Signature
Date
PERMIT NUMBER: P 018
NT/NU Association of Professional
Engineers and Geoscientists

LOCATION MAPS

LEGEND

- + km Station
- Existing Report
- Site with GTC
- Site With BH Log
- Community
- Demspter Highway
- Road
- Territorial Boundary



NOTES
Base data source: ESRI Basemap Imagery

STATUS
ISSUED FOR USE

CLIMATE CHANGE VULNERABILITY ASSESSMENT – DEMPSTER HIGHWAY, YT/NT

Study Area Overview

PROJECTION	DATUM	CLIENT
Yukon Albers	NAD83	Government of Northwest Territories Department of Transportation

Scale: 1:500,000

10 5 0 10

Kilometres

TETRA TECH EBA

FILE NO.
W14103156-01_Figure01_TT.mxd

PROJECT NO.	DWN	CKD	APVD	REV
W14103156-01	MEZ	KJ	RT	0

OFFICE	DATE
Tt EBA-VANC	March 31, 2015

Map 1

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LEGEND

- + km Station
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- Site with GTC
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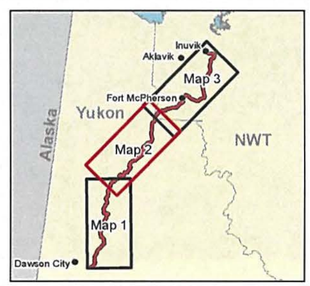
- Road
- Territorial Boundary



NOTES
Base data source: ESRI Basemap Imagery

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Yukon Albers	NAD83	Government of Northwest Territories Department of Transportation

Scale: 1:500,000

10 5 0 10

Kilometres

TETRA TECH EBA

FILE NO.				
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PROJECT NO.	**DWN**	**CKD**	**APVD**	**REV**
W14103156-01	MEZ	KJ	RT	0
OFFICE	**DATE**			
Tt EBA-VANC	March 31, 2015			

Map 2

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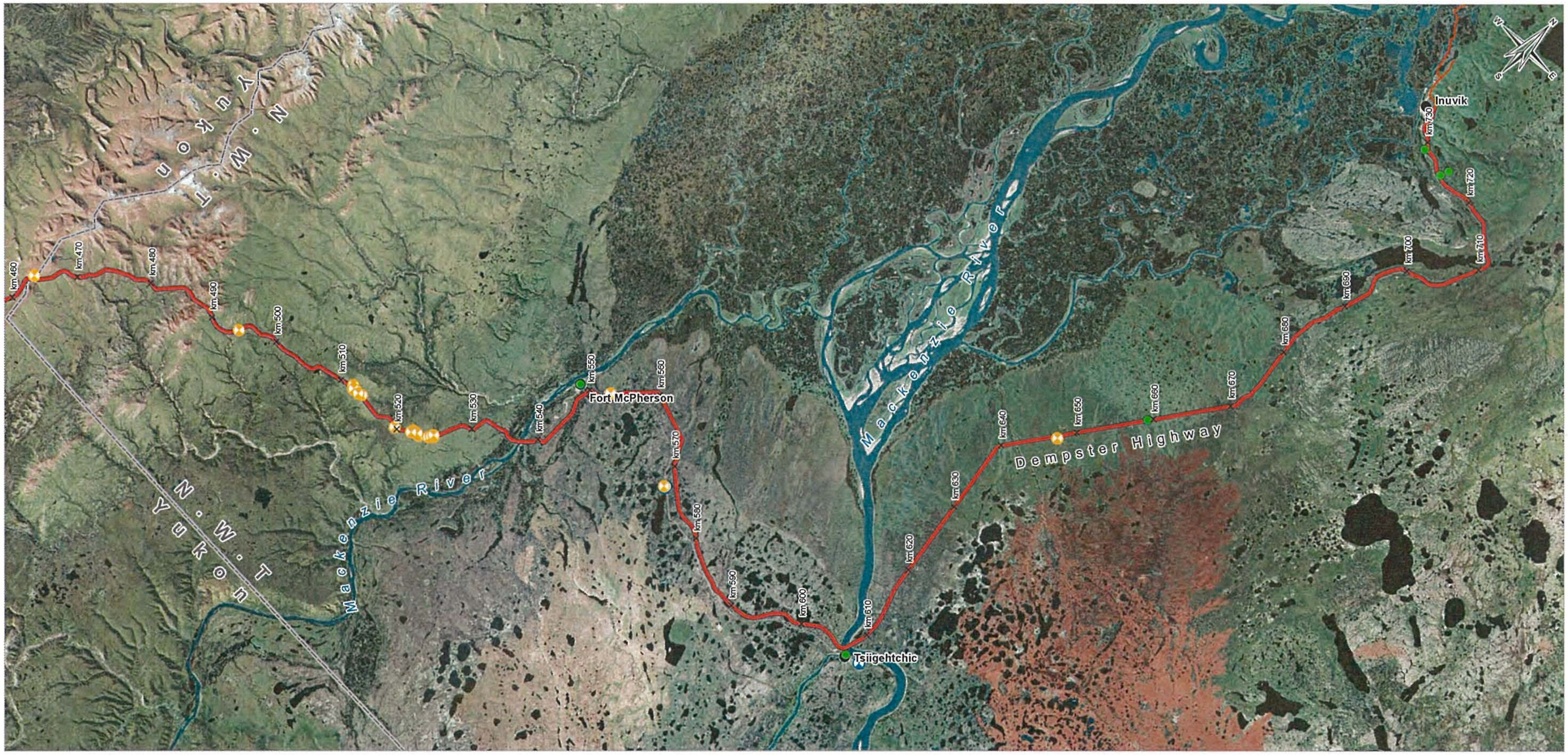

LEGEND

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- Site with GTC
- Site With BH Log
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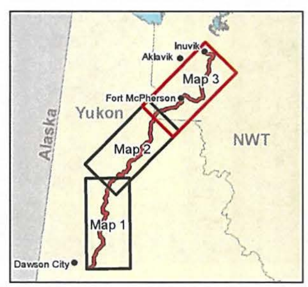
- Road
- Territorial Boundary



NOTES
Base data source: ESRI Basemap Imagery

STATUS
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CLIMATE CHANGE VULNERABILITY ASSESSMENT – DEMPSTER HIGHWAY, YT/NT

Study Area Overview

PROJECTION	DATUM	CLIENT
Yukon Albers	NAD83	Government of Northwest Territories Department of Transportation

Scale: 1:500,000
10 5 0 10
Kilometres

FILE NO.
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TETRA TECH EBA

PROJECT NO.	DWN	CKD	APVD	REV
W14103156-01	MEZ	KJ	RT	0

OFFICE	DATE
Tt EBA-VANC	March 31, 2015

Map 3

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APPENDIX A

TETRA TECH EBA'S GENERAL CONDITIONS

GENERAL CONDITIONS

GEOTECHNICAL REPORT

This report incorporates and is subject to these "General Conditions".

1.0 USE OF REPORT AND OWNERSHIP

This geotechnical report pertains to a specific site, a specific development and a specific scope of work. It is not applicable to any other sites nor should it be relied upon for types of development other than that to which it refers. Any variation from the site or development would necessitate a supplementary geotechnical assessment.

This report and the recommendations contained in it are intended for the sole use of Tetra Tech EBA's Client. Tetra Tech EBA does not accept any responsibility for the accuracy of any of the data, the analyses or the recommendations contained or referenced in the report when the report is used or relied upon by any party other than Tetra Tech EBA's Client unless otherwise authorized in writing by Tetra Tech EBA. Any unauthorized use of the report is at the sole risk of the user.

This report is subject to copyright and shall not be reproduced either wholly or in part without the prior, written permission of Tetra Tech EBA. Additional copies of the report, if required, may be obtained upon request.

2.0 ALTERNATE REPORT FORMAT

Where Tetra Tech EBA submits both electronic file and hard copy versions of reports, drawings and other project-related documents and deliverables (collectively termed Tetra Tech EBA's instruments of professional service), only the signed and/or sealed versions shall be considered final and legally binding. The original signed and/or sealed version archived by Tetra Tech EBA shall be deemed to be the original for the Project.

Both electronic file and hard copy versions of Tetra Tech EBA's instruments of professional service shall not, under any circumstances, no matter who owns or uses them, be altered by any party except Tetra Tech EBA. Tetra Tech EBA's instruments of professional service will be used only and exactly as submitted by Tetra Tech EBA.

Electronic files submitted by Tetra Tech EBA have been prepared and submitted using specific software and hardware systems. Tetra Tech EBA makes no representation about the compatibility of these files with the Client's current or future software and hardware systems.

3.0 ENVIRONMENTAL AND REGULATORY ISSUES

Unless stipulated in the report, Tetra Tech EBA has not been retained to investigate, address or consider and has not investigated, addressed or considered any environmental or regulatory issues associated with development on the subject site.

4.0 NATURE AND EXACTNESS OF SOIL AND ROCK DESCRIPTIONS

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

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

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

5.0 LOGS OF TESTHOLES

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

6.0 STRATIGRAPHIC AND GEOLOGICAL INFORMATION

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

7.0 PROTECTION OF EXPOSED GROUND

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

8.0 SUPPORT OF ADJACENT GROUND AND STRUCTURES

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

9.0 INFLUENCE OF CONSTRUCTION ACTIVITY

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

10.0 OBSERVATIONS DURING CONSTRUCTION

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

11.0 DRAINAGE SYSTEMS

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

12.0 BEARING CAPACITY

Design bearing capacities, loads and allowable stresses quoted in this report relate to a specific soil or rock type and condition. Construction activity and environmental circumstances can materially change the condition of soil or rock. The elevation at which a soil or rock type occurs is variable. It is a requirement of this report that structural elements be founded in and/or upon geological materials of the type and in the condition assumed. Sufficient observations should be made by qualified geotechnical personnel during construction to assure that the soil and/or rock conditions assumed in this report in fact exist at the site.

13.0 SAMPLES

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

14.0 INFORMATION PROVIDED TO TETRA TECH EBA BY OTHERS

During the performance of the work and the preparation of the report, Tetra Tech EBA may rely on information provided by persons other than the Client. While Tetra Tech EBA endeavours to verify the accuracy of such information when instructed to do so by the Client, Tetra Tech EBA accepts no responsibility for the accuracy or the reliability of such information which may affect the report.

APPENDIX B

REFERENCE LIST (YT AND NT)

Dempster Highway - Reference List (Yukon)

	Document/Data			Description	Holder of Data	Reference/Catalogue Number	Digital Copy	Key Words	Map Reference		Comments
	Title	Author	Date						Northing	Easting	
1	GTC Installation Dempster Highway, Yukon and NWT	EBA	Dec 2008 - April 2009	Supply and install GTC at tower sites along Dempster Hwy for Northwestel	EBA	W14101221	Yes	Permafrost, Temperature, Towers, Climate	7097904	610059	
2	Geotechnical Evaluation - New Interpretive Centre	EBA	Jun-05	Drilling and recommendations for new interpretive centre	EBA	1200154		bearing capacity, drilling program, foundations, geotechnical assessment	7155990	633479	
3	Warm Storage Building - Ogilvie River Grader Station	EBA	Apr-03	Geotechnical to structural engineering regarding foundaiton design, borholes from 1987 project	EBA	0201-4652		shop/garage, foundations	7251200	625500	
4	Dempster Highway Interpretive Centre	EBA	Nov-92	Excavate testpits for Tombstone Interpretive Centre	EBA	0201-11103		Buildings, design/analysis, foundations, tourism development	7155750	633510	
5	Granular Source Investigations, Dempster Highway, Yukon	EBA	Jul-90	Dig testpits at 5 granular sources, test suitability for pit run	EBA	0201-10312		testpits, granular source, material testing	7106210	620275	
6	Final Report - Dempster Highway Grade Repairs	EBA	Dec-86	Design, construction planning for highway repairs	EBA	0201-4551					KM 8.5 and KM 50.9
7	Dempster Highway Claim- Mile 289.77-343.88	EBA	Jan-78	Contract claim for the Keen Construction Ltd section of Dempster	EBA	15-1888		grain size distribution			Mile 289.77 - 343.88
8	Geotechnical Evaluation - Tower Sites	EBA	Nov-03	Geotechnical evaluation for digital radio upgrade towers	EBA	1200032	Yes				
9	Geotechnical Evaluations of Proposed Quarry Sites	EBA	Feb-08	Quarry sites, all weather road construction	EBA	W14101001	Yes				
10	Subsoil Investigation: Fort McPherson, NWT	Klohn Leonoff Consultants Ltd.	Apr-78	Physical, subsoil and permafrost conditions in Fort McPherson	EBA	AL0914	Yes				
11	Geotechnical Investigation: Proposed Gymnasium, Arctic Red River, NWT	Thurber Consultants Ltd.	Nov-86	Geotechnical evaluation and recommendations with test hole logs	EBA	15-22-77	Yes				
14	The response of natural conditions and commodity flows to climate change in the Canadian North and Alaska - a PhD concept	Strutzke, A.; Opp, C.	Jun-10	Site-specific peculiarities of climate change effects and interactions with natural and infrastructure conditions	ASTIS	71461					
15	Permafrost investigations in western Arctic Canada	Burn, C.	Jun-05	Temperature in permafrost was measured in various depths of snow	ASTIS	61659					

	Document/Data			Description	Holder of Data	Reference/Catalogue Number	Digital Copy	Key Words	Map Reference		Comments
	Title	Author	Date						Northing	Easting	
16	Arctic timberline ecology	Broll, G.	Jun-05	Climate conditions, soil conditions and plant communities of the timberline at sites along the Dempster Highway	ASTIS	35832					
17	Permafrost and the Eagle River bridge, Yukon Territory, Canada	Johnston, G.H.	Jun-05	Permafrost conditions encountered at the bridge site	ASTIS	12252					
18	2004 Winter Field Geotechnical Investigation Program in the Gwich'in Settlement Area	Graburn, L.	Jun-05	65 boreholes drilled at 14 proposed borrow sources	ASTIS	61552					
19	Dempster Highway lateral drilling program	Klohn Leonoff Consultants Ltd.	Jul-78	Detailed testhole logs and lab data from drilling program between Carmacks and Inuvik	ASTIS	61080					
20	Proposed centreline and soil hole info. On abandoned line, mile 892-931		Jul-73	Gravel and shale holes indicating the presence of sand, gravel, silt, organics, ice, ice lenses	ASTIS	39790					
21	Dempster Highway drill logs	Public Works Canada	1969?	Descriptions of boreholes drilled along miles 0 to 64.5	ASTIS	37906					
22	Soil logs, Dempster mile 268.6 to 289.7	Public Works Canada	1972?	Soil logs for borholes drilled along miles 268.6 to 289.7	ASTIS	37904					
23	Dempster Highway relocation, mile 60-78: centerline drilling logs	Public Works Canada	Sep-74	Test hole logs and lab test data for holes drilled from mile 0 to 78	ASTIS	37898					
24	Culvert inspection report - Dempster Highway, NWT	NWT Department of Transportation	Jul-87	Findings from detailed culvert inspection	ASTIS	37891					
25	Geotechnical evaluation, Dempster Highway, NWT: selected sites	EBA	1985	Investigaiton along sites along the NWT portion of Dempster Highway: drilling	ASTIS	37886					
26	Preliminary Geotechnical Data and Construction Recommendations, Tuttle Airstrip, Eagle Plains, YT	EBA	Dec-87	Preliminary Geotechnical Data and Construction Recommendations, Tuttle Airstrip, Eagle Plains, YT	EBA	0201-4763		boreholes			

Dempster Highway - Reference List (Northwest Territories)

	Document/Data			Description	Holder of Data	Reference/Catalogue Number	Digital Copy	GTCs	Logs	Key Words	Map Reference		Comments / Locations
	Title	Author	Date								Northing	Easting	
1	Geotechnical Evaluation for Satellite Earth Station, Inuvik, NT	EBA	Jun-08	airtrack drilling, GTC installation	EBA	Y14101084	yes	yes	yes	permafrost, temperature, ice content, bedrock	7580110	560400	2 sites: Hidden Lake, just E of Inuvik; Airport site, 1.9 km NNW of end of Dempster
2	Site Investigation for Satellite Earth Station, Inuvik, NT	EBA	Mar-09	airtrack drilling, GTC installation	EBA	Y14101084.001	yes	yes	yes	permafrost, temperature, ice content, bedrock	7579026	560034	Just W of Environment Canada weather station, 1.2 km WNW of end of Dempster
3	Site Investigation at Culvert Locations, NWT Highway No. 8, km 195.3 and km 246.1	EBA	Feb-11	Watson 2100 drill to investigate obstructed/damaged culvert locations for proposed replacement structures - 3 BHs total	EBA	Y14101326.001	yes	no	yes	permafrost, ice content	7530170 7530121 7574909	557714 557667 552431	NWT Highway No. 8, km 195.3 and km 246.1
4	Community Permafrost Map, Tsiigehtchic, NT	EBA (INAC for INAC BHs & temp data)	Feb-11	Permafrost map based on air photo mapping and minor ground truthing, incl. 2 BHs by INAC (water-jetting)	EBA (INAC for INAC BHs & temp data)	Y14101275	yes	yes (INAC holes)	yes	permafrost, temperature, ice content, bedrock	7481292	553640	Various locations throughout community. Location noted is near top of thaw slump at steppe bison find.
5	Slope Stability Review and Evaluation of Stabilization Options, Church Hill, Tsiigehtchic, NT	EBA (INAC for INAC BHs & temp data)	Jun-11	slope evaluation based on site reconnaissance, small test pits and 1 BH advanced by INAC using water-jetting	EBA (INAC for INAC BHs & temp data)	Y14101275	yes	yes (INAC holes)	yes	permafrost, temperature, ice content, bedrock	7481292	553640	Various locations on slope. Location noted is near top of thaw slump at steppe bison find.
6	Geotechnical Evaluation for Heliport, Fort McPherson, NT	EBA	1992	geotechnical evaluation for heliport, 4 BHs	EBA	0701-92-10850	BHs - yes; report - unknown	yes	yes	permafrost, temperature, ice content, massive ice, bedrock			no UTMs on logs, need to locate site plan
7	Environmental Site Assessment Phase 1/2 at Former PPD Tank Farm, Tsiigehtchic, NT	EBA	Aug-01	ESA Phase 1/2 at former PPD Tank Farm - 19 hand-augered holes	EBA	0701-01-15143.2	BHs - yes; report - unknown	no	yes	basic soil statigraphy			no UTMs on logs, need to locate site plan
8	Geotechnical Evaluation for Power Station, Fort McPherson, NT	EBA	Nov-04	Geotechnical evaluation for power station, 4 BHs	EBA	1700107.001	BHs - yes; report - unknown	yes	yes	permafrost, temperature, ice content, bedrock			no UTMs on logs, need to locate site plan
9	Geotechnical Evaluation for Community Complex, Fort McPherson, NT	EBA	Apr-06	Geotechnical evaluation for community complex, 6 BHs	EBA	1700205 (desktop) 1700205.001 (site)	yes	yes	yes	permafrost, temperature, ice content, bedrock	7479919	505020	desktop has figure with old site investigation locations shown, site investigation report has figure with BHs (shows 8 BHs on figure, but only 6 logs; coordinates are for BH 1)
10	Geotechnical Evaluation for ENR and PWS Shops Buildings, Inuvik, NT	EBA	Jan-11	Geotechnical evaluation at ENR building at Shell Lake; 4 BHs	EBA	Y14101314 (desktop) Y14101314.001 (site investigation)	yes	yes	yes	permafrost, temperature, ice content, bedrock	7579799	556228	4 BHs at ENR site (UTM's for BH 1 shown)
11	Foundation Recommendations for Caribou Creek Bridge, NWT Hwy. No. 8 (Dempster Highway), km 220.8	EBA	Dec-07	Based on BH data from DOT, prepare foundation recommendations	EBA	Y14101057	yes	no	no	permafrost, ice content			tabulated lab results from borehole samples
12	Monitoring of Pile Installation for New Fire Hall, Fort McPherson, NT	EBA	Oct-07		EBA	Y14101036	yes	no	no	general stratigraphy			pile monitoring summary report
14	Foundations for CBC Tower, Fort McPherson, NT	EBA	Nov-77	Geotechnical evaluation of guy anchors and tower foundation.	EBA		yes	no	yes	stratigraphy			
15	Fort McPherson Water Intake Structure	EBA	Apr-00	Borehole logs and grain size results.	EBA	0701-00-14342	yes	no	yes	grain size results and stratigraphy	7477200	524800	
16	Geotechnical Evaluation for Proposed Seniors' Fourplex, Tsiigehtchic, NT	EBA	Jun-00	Geotechnical evaluation, adfreeze steel pipe piles.	EBA	1701-00-14480.2	yes	no	no	permafrost			100 km south of Inuvik

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	Title	Author	Date								Northing	Easting	
17	Contamination Delineation, Power Corporation, NWT	EBA	May-98	Borehole logs	EBA	0701-98-13813.2	yes	no	yes	borehole logs			Inuvik
18	Geotechnical Investigation Proposed Gymnasium, Arctic Red River, NT	EBA	Nov-86	Geotechnical investigation, evaluation, and recommendations.	EBA	15-22-77	yes	no	yes	borehole logs			Arctic Red River, NT
19	Geotechnical Evaluation, Dempster Highway, NT	EBA	Nov-93	Sections through centreline culverts, testholes	EBA	11300-04	yes	no	yes	borehole logs			Near km 10, Dempster Highway, NT
20	Chief Julius Elementary School, For McPherson, NT	EBA	Oct-74	Borehole logs	EBA	E960	yes	no	yes	borehole logs			Fort McPherson, NT
21	Phase II Environmnetal Site Assessment, Tetlit Gwichin Road, Fort McPherson, NT	EBA	Nov-08	Testpit logs	EBA	E22101904	yes	no	yes	testpit logs			Fort McPherson, NT
22	Development of the Dempster Highway north of the Arctic Circle	Huculak, Twach, Thomson, Cook	May-05	Design and construction techniques of the Dempster highway	EBA		no	no	no	Design of highway, construction techniques, embankment depth, surface treatment, photos			
23	Ground Ice in Continuous Permafrost: A Hazard to Safe Highway Operation	Hayley (EBA), Bowen (GNWT)	Jun-87	Paper on subgrade collapse due to ice wedges, remedial measures, grade reconstruction, and performance observations.	EBA		no	no	no	Subgrade collapse, ice wedges			
24	Geotechnical Evaluation Dempster Highway, NWT (selected sites)	EBA	Dec-85	drilling program, laboratory results, picture slides, borehole logs	EBA	0201-4426	no	no	yes	borehole logs, photos			KM 8.5, 18, 27.9 (NWT)