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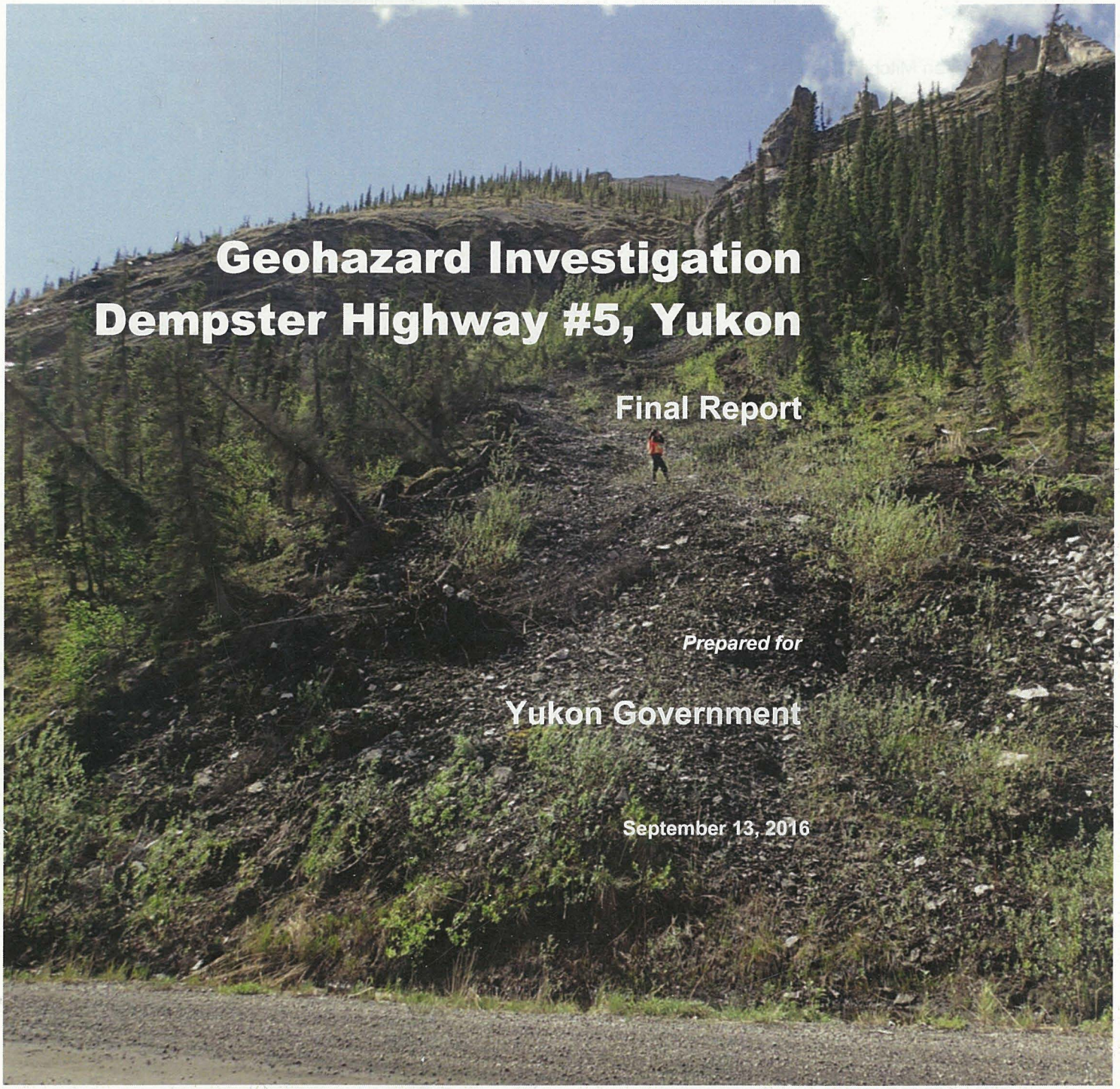

Geohazard Investigation Dempster Highway #5, Yukon

Final Report

Prepared for

Yukon Government

September 13, 2016

GR-05-047

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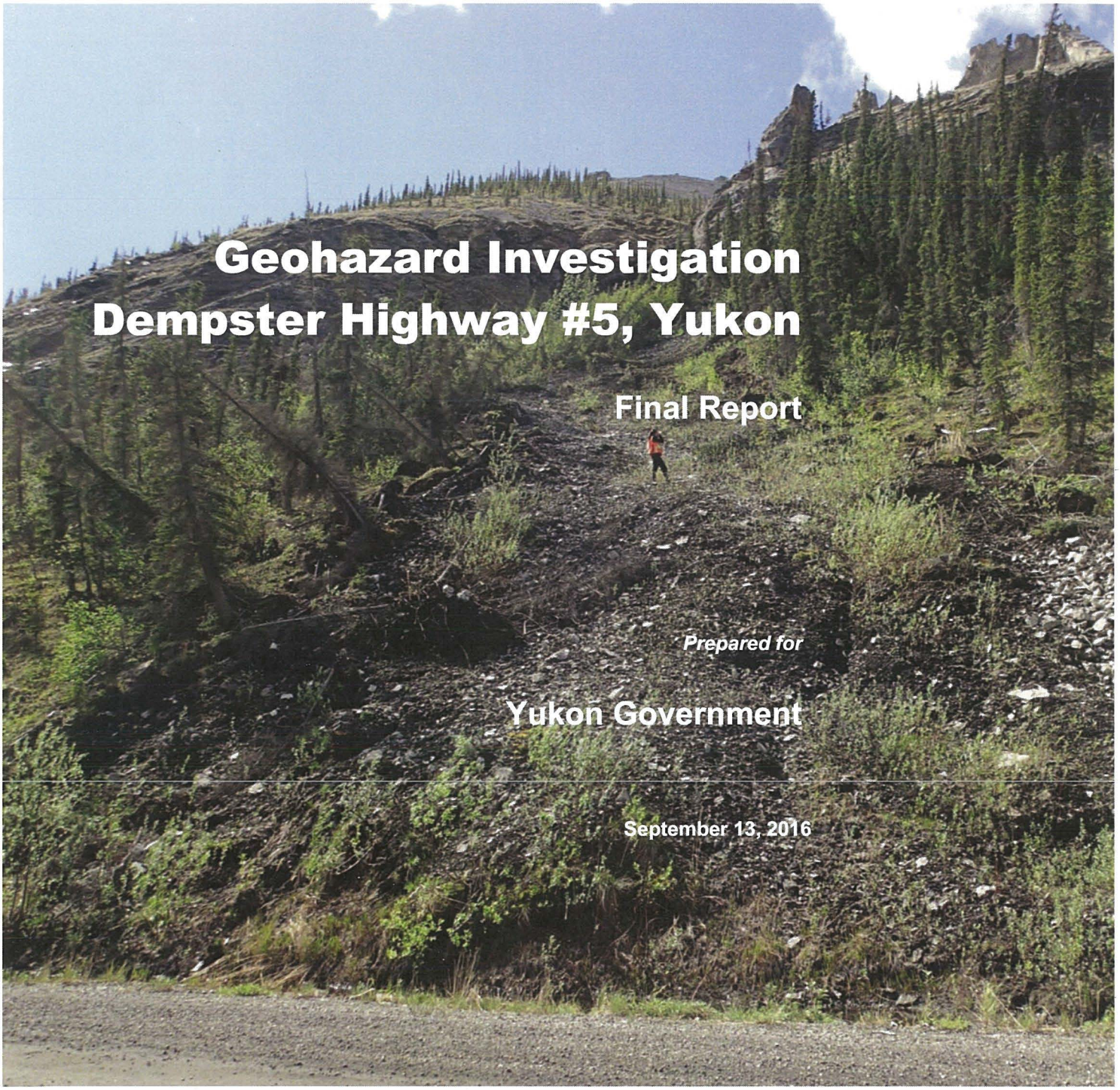

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September 13, 2016

Mr. Lekan Mitchell, E.I.T.
Engineer-in-Training
Transportation Engineering, W-13
Yukon Government
Box 2703
Whitehorse, Yukon Y1A 2C6

Dear Mr. Mitchell,

Re: Final Report – Geohazard Investigation Dempster Highway #5, Yukon

Kryotek Arctic Innovation Inc. and Palmer Environmental Consulting Group Inc. are pleased to submit the enclosed Final Report to Yukon Department of Highways and Public Works – Transportation Engineering Branch presenting the results of our investigation of mass movement and meander migration hazards along Yukon's portion of the Dempster Highway. This report has been updated based on your feedback.

Through systematic desktop-based analysis, field reconnaissance investigations and data interpretation, we have identified, delineated and characterized 54 existing or imminent mass movements that pose very low to very high risks to the highway, considering the likelihood and consequence of occurrence.

We have also completed detailed assessments of meander migration hazards at 26 of 102 identified encroachment sites, where progressive bank erosion has the potential to undermine adjacent highway embankments without intervention. Thousands of cubic metres of riprap are estimated to be required over the next 25 years to mitigate risk to highway stability.

Should you have any questions, please do not hesitate to contact Jim Coates at 867-336-1597 or jcoates@kryotekinc.com, or Robin McKillop at 604-629-9075 (ext. 106) or robin@pecg.ca.

We appreciate the opportunity to work with you on this fascinating project.

Yours truly,

Kryotek Arctic Innovation Inc.

Jim Coates, M.Sc.
President, Permafrost Specialist

Palmer Environmental Consulting Group Inc.

Robin McKillop, M.Sc., P.Geo.
Partner, Geomorphologist

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Revision Log

Revision #	Reviewed By	Date	Issue / Revision Description
1	Robin McKillop	August 5, 2016	Senior Review
2	Jim Coates	August 8, 2016	PM Review
3	Lekan Mitchell	August 30, 2016	Client Review

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Executive Summary

Yukon Department of Highways and Public Works – Transportation Engineering Branch (HPW-TEB) has initiated a geohazard investigation aimed at identifying sections of the Dempster Highway corridor that are susceptible to soil and rock mass movements with the potential to impact the highway. Its objective is to prioritize high-risk sites for more detailed investigation, guide planning decisions for future remediation works, and ultimately design and implement measures to mitigate risk to the highway. Kryotek Arctic Innovation Inc. (Kryotek) and Palmer Environmental Consulting Group Inc. (PECG) were retained by HPW-TEB to complete the geohazard investigation within 1 km of either side of Yukon's entire 465 km-long portion of the highway, based on desktop analyses and field reconnaissance investigations.

Kryotek and PECG applied a systematic, five-phase approach to the identification, delineation and characterization of mass movement geohazards within the study area. Through an initial background review (Phase 1), we enhanced our understanding of bedrock and surficial geology, Quaternary history and permafrost conditions, and established the distribution of previously mapped mass movements. Building on the results of this review, we completed a preliminary desktop-based assessment of potential mass movement geohazards and meander migration hazards (Phase 2). More than 100 possible mass movements were identified, many conservatively, for field inspection. A total of 102 meander-highway encroachments sites with the potential for future highway impact was also identified. Detailed meander migration assessments were completed at 26 encroachment sites prioritized for follow-up analysis based on indications of progressive bank erosion or localized failure of existing riprap protection (Phase 3). Truck-based field reconnaissance investigations were completed along the highway in early June 2016 from km 0 to km 465 (Phase 4). Field inspections ranging from visual observation and photography to investigation of failure morphology and materials were completed at nearly 200 sites. Data analysis and interpretation incorporating field observations enabled refinement and updating of the mass movement geohazard inventory, including the prioritized meander migration hazard site characterizations (Phase 5). A risk evaluation of each mass movement geohazard site was also completed.

The desktop analyses and field reconnaissance investigations culminated in the identification, delineation and characterization of 54 mass movement geohazards with the potential to impact the highway, mostly within the Ogilvie highway maintenance section. The inventoried geohazards, from most to least common, include active layer detachments, retrogressive thaw slumps, rockfall, thermokarst subsidence, debris flows, thermokarst gullies and debris slides. Fifty percent of the 54 mass movement geohazards pose only low or very low risks to the highway, due to their modest possibility for only temporary (<1 day) and/or partial (single-lane) closure for maintenance. Thirteen percent represent high or very high risks to the highway, including some rockfall slopes and retrogressive thaw slumps, due to their relatively high likelihood of impact necessitating localized road reconstruction. Key site and mass movement characteristic statistics have been summarized graphically to support any future predictive terrain stability mapping along the highway corridor.

Detailed assessment of meander morphology and dynamics at prioritized meander-highway encroachment sites determined continued meander migration is likely to impact the highway embankment at 19 of the 26 sites within approximately 25 years, without intervention. Six of these 26 sites have

already been impacted or may be impacted within as few as 5 years. We have forecasted requiring 100 to 5,390 m^3 of riprap at each site to mitigate risk to the highway and have identified sites where alternative erosion protection measures warrant consideration.

Based on the results of this geohazard investigation, several recommendations are provided for HPW-TEB's consideration. Predictive terrain stability mapping should be completed along the highway corridor in order to identify terrain where mass movements may occur but where none has been documented through this inventory. It would also be worth updating this geohazard inventory every 5 to 10 years given the short periods over which wildfire and climate change can affect permafrost and ground stability. In order to maintain an accurate forecast of hazards and riprap requirements associated with meander migration, a monitoring plan should be developed and implemented, reassessment should be completed every 5 to 10 years, and detailed assessments should be completed at encroachment sites outside the original priority study area.

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1 Introduction

Kryotek Arctic Innovation Inc. (Kryotek) and Palmer Environmental Consulting Group Inc. (PECG) are pleased to provide Yukon Department of Highways and Public Works – Transportation Engineering Branch (HPW-TEB) with the final results of our investigation of mass movement and meander migration hazards along Yukon's 465 km-long portion of the Dempster Highway. We have identified, delineated and characterized 54 existing or imminent soil and rock mass movement geohazards that pose very low to very high risks to the highway or its embankments/ditches (hereinafter referred to more simply as "the highway"). We have identified an additional 102 sites at which meander encroachment may pose a hazard to highway embankment stability within the coming decades, without intervention, especially where systematic migration toward the highway has been documented.

Following provision of important background information (Section 1), we provide an overview of the physical setting of the region traversed by the Dempster Highway (Section 2). In Section 3, we describe the systematic methods used to assess each mass movement and meander-highway encroachment site. The results of the mass movement and meander migration hazard assessments are presented in Section 4, with reference to summary figures (including site plans and photographs) provided in appendices. Section 5 interprets and discusses the results, and acknowledges important assumptions and limitations. Key conclusions and recommendations are identified in Section 6. A statement of limitations is provided in Section 7, prior to a list of all cited references (Section 8).

Appendices A to **E** contain information pertaining to the mass movement geohazard assessment work, and **Appendices F** to **J** include information pertaining to the meander migration hazard assessment work.

1.1 Background

Kryotek and PECG understand that HPW-TEB is interested in identifying sections of the Dempster Highway corridor that are susceptible to soil and rock mass movements with the potential to impact the stability, operation or maintenance of the highway. Primarily during the snow-free season, mass movements along the highway corridor necessitate temporary closure of the highway, emergency remediation, and management of waste material in an economical and environmentally responsible manner. Various forms of landslides and related mass movements are common, most of which are influenced by permafrost (e.g., **Figure 1-1**). Permafrost terrain exhibits unique slope instabilities from thawing of frozen ground on slopes and under the highway subgrade, and several retrogressive thaw failures have occurred since the highway was constructed. The ongoing responsibility for maintaining a safe and reliable highway creates challenges for HPW-TEB with respect to its annual budgeting and resource allocation. With an improved understanding of the distribution and characteristics of different geohazards along each of its maintenance sections, HPW-TEB will be better positioned to prioritize high-risk sites for more detailed, follow-up investigation, guide planning decisions for future remediation works, and ultimately design and implement measures to mitigate risk to the highway.

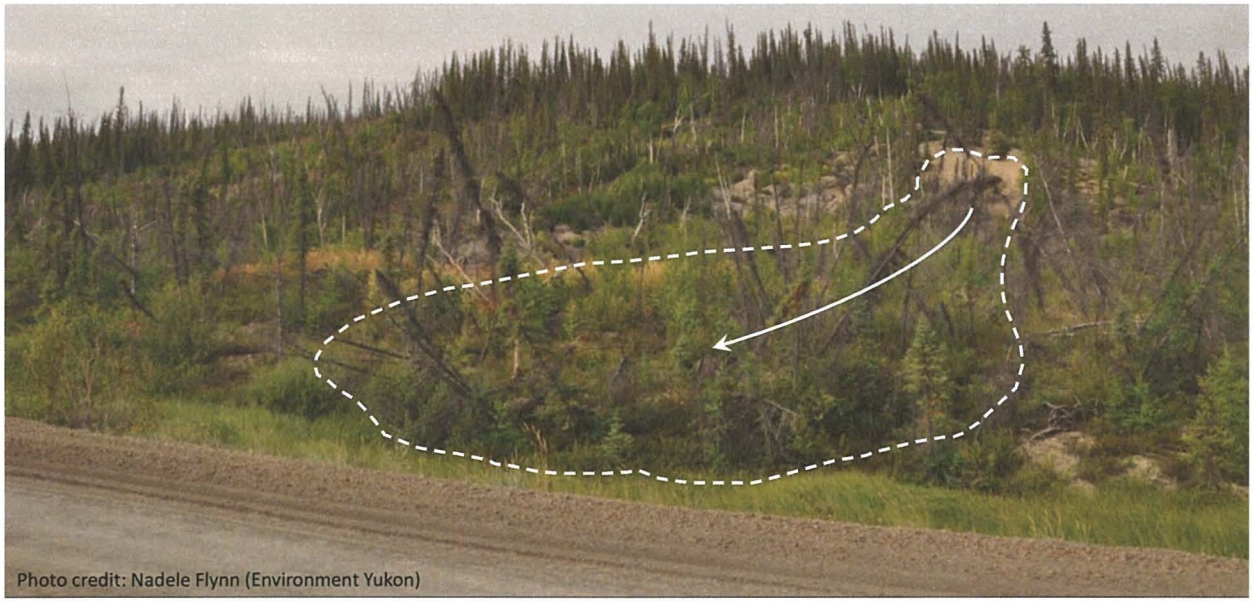


Figure 1-1. Active Layer Detachments on Burned Valley Side of Eagle River (km 379)

A number of case studies and regional inventories of landslides in Yukon that have been conducted in recent decades contributed important background information and guidance for this project. Huscroft et al. (2004) published a regional characterization of landslides along the Alaska Highway corridor, in which they describe the settings, causes and geological controls (including permafrost) of landslides within five distinct physiographic zones along the highway corridor. In addition to identifying hundreds of landslides within each zone, a select few of which are described in detailed case studies, they describe the potential impacts of climate change on landslide hazards. Building on this work, Blais-Stevens et al. (2010) completed a more comprehensive inventory of mass movements along the Alaska Highway corridor that includes terrain hazards such as rock glaciers and solifluction slopes, in addition to various types of landslides. Using aerial photograph analysis, satellite imagery and visual inspection from a fixed-wing aircraft, Lipovsky and Huscroft (2007) identified over 100 permafrost-related landslides in the Pelly River watershed. The overall characterization of their source-area settings, triggers, high mobility and longevity of activity is directly applicable to the hazard evaluations completed in this project. Coates' (2008) M.Sc. research highlights the role of forest fires in the initiation of landslides (active layer detachments) and the failure mechanisms and geometries associated with this dominant type of mass movement in unglaciated central Yukon. One of the distinct and widespread landform-soil types identified in unglaciated Yukon by McKillop et al. (2013), "landslide-affected colluvial veneer" (LST4), is typified by its history of active layer detachments.

Fewer research projects on landslides or other mass movement processes along the Dempster Highway have been conducted, largely because of its remoteness and lower usage in comparison to the Alaska Highway. Major landslides and related geomorphological processes are included in the continuous mapping of surficial geology completed by the Yukon Geological Survey (YGS) and Geological Survey of Canada (GSC) in the region traversed by the Dempster Highway (Lipovsky and Bond, 2014). The original 1:50,000-scale Quaternary geology mapping completed by Ricker (1968) in association with his M.Sc. thesis for the North Klondike and upper Blackstone river systems provides broad delineations of

mass movements such as large landslides and rock fall areas (talus slopes), rock glaciers and solifluction slopes. Notes on hazard associations in each surficial geology unit are provided on an accompanying "terrain classification, sensitivity and engineering legend" (Ricker, 1977). Richardson and Sauer (1975) completed a detailed terrain classification from km 267 (Mile 166) to km 468 (Mile 290.5) of the Dempster Highway, in part to investigate the potential effects of highway construction on the physical environment. Notably, they identify five vegetation associations indicative of distinct geotechnical conditions. More recently, investigations into the effects of climate change on permafrost and road stability along the Dempster Highway have been undertaken (e.g., EBA, 2013; Burn et al., 2015).

1.2 Scope

The project described herein fills an important gap in landslide inventories in Yukon. Our team has mapped and characterized soil and rock mass movements that pose a hazard to the Dempster Highway, based on desktop analysis and field reconnaissance investigations. In order to focus attention on the mass movement processes most likely to affect highway stability, namely all forms of landslides, we have deliberately excluded other forms of mass movements from our analysis that are less likely to result in sudden and/or significant highway impacts. The processes of solifluction (soil creep on permafrost table), slopewash (combined sheetwash, piping and frost heave displacement on permafrost table) and inactive or minor (<1 m of relief) thermokarst (subsidence due to thawing of underlying ice-rich permafrost) are so commonplace along the highway corridor that special management of the comparatively minor hazards they pose is not feasible. Debris flood hazard, which is more of a fluvial hazard than a mass movement hazard, is not explicitly identified. Small anthropogenic slopes (e.g., road cuts) prone to ongoing, minor sloughing or raveling, which may necessitate attention and periodic maintenance, are also excluded from this hazard-focused inventory (as described further in Section 5.3). We have additionally focused attention on identifying the hazard posed by meander migration alongside the highway, given its widespread role in triggering failures within the highway embankments through scour and undercutting.

Another important clarification is how the objectives of this assignment differ from those in a terrain stability mapping project. The focus of this inventory-style assignment, in accordance with HPW-TEB's original request-for-proposal (RFP), is on identifying existing or imminent, discrete mass movement sites with the potential to impact the highway. Some of the mass movement sites exhibit recurrence, posing an ongoing risk to the highway, while many are defined by a single event that may only be subject to lower-risk, post-failure modification (e.g., minor sloughs or flows). For example, a large active layer detachment that crosses the highway would necessitate road closure to clear debris and may require localized reconstruction, but the risk its scar poses to the highway would generally be much lower and solely reflect the potential implications of post-failure modification. Terrain stability mapping, beyond the scope of this project, involves the predictive delineation of unstable or potentially unstable slopes based on an expectation for landsliding triggered by surface disturbance. No slope disturbance is proposed in association with this project, although it should be noted that natural surface disturbance caused by wildfire may compromise slope stability on slopes that are currently stable. Ongoing climate change may also degrade permafrost such that slopes or ice-rich lowlands become unstable. As elaborated below (Section 5.1), the insights gained through this project can be used to guide and help calibrate more predictive mapping of potentially hazardous terrain that currently exhibits no existing or imminent mass movements.

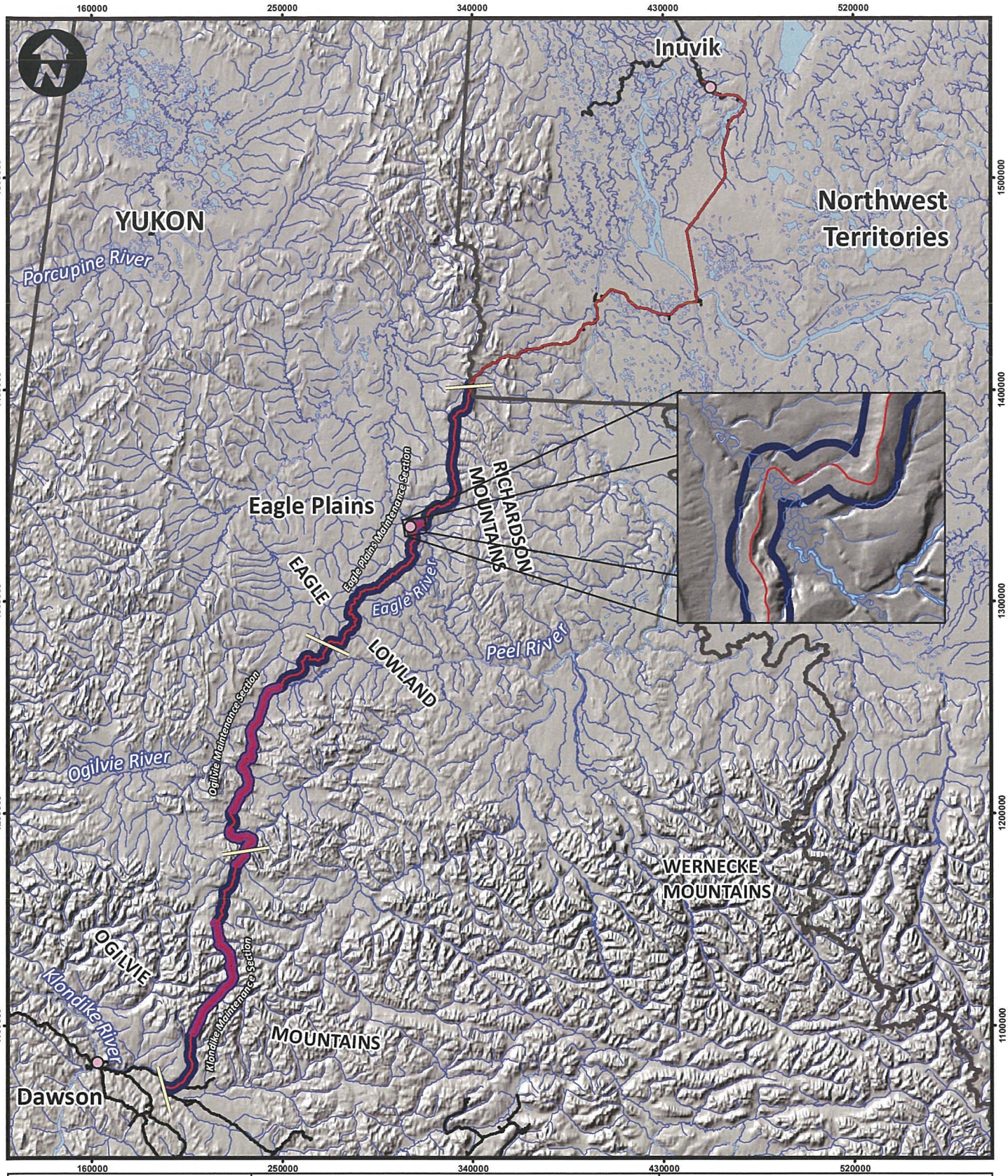
1.3 Study Area

Four sections of Yukon's portion of the Dempster Highway were originally prioritized by HPW-TEB for investigation due to the relative frequency and severity of soil and rock mass movements within each section (shown in purple on **Figure 1-2**): km 34.0 – km 98.0 (Klondike maintenance section); km 129.5 – km 160.0 (Klondike/Ogilvie maintenance section); km 170.0 – km 245.0 (Ogilvie maintenance section); and km 373.5 – km 382.0 (Eagle Plains maintenance section). The study area was subsequently expanded to include Yukon's entire 465 km-long portion of the Dempster Highway, from the junction with the North Klondike Highway (km 0) to the border with the Northwest Territories (km 465).

Mass movement and meander migration hazard sites with the potential to impact the highway were mapped within 1 km of either side of the highway centreline. The limits (including initiation zones) of all mass movements with the potential to impact the highway were fully encompassed by this 2 km-wide corridor. Mass movements within the 2 km-wide study corridor that are unlikely to impact the highway have not been identified or assessed.

1.4 Objective

The objective of this assignment is to help HPW-TEB prioritize geohazard sites along the Dempster Highway corridor for detailed investigation, analysis and remediation, based on site-specific risk to the highway. Our work will also support the evaluation of the structural stability of the highway and help guide future planning decisions. Key to achieving this objective are the identification, delineation and characterization of soil and rock mass movement geohazards, as well as potential meander migration hazards, based on desktop interpretation and field reconnaissance investigations.



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Legend

- Place Names
- Watercourses
- Territorial Boundary
- Roads
- Dempster Highway
- Original Priority Study Corridor (km 34-98, 129.5-160, 170-245, 373.5-382)
- Final Study Corridor (km 0-465)
- Highway Maintenance Sections

Project Number: 14132

Title: Geohazard Investigation
Dempster Highway #5

Study Area

Figure 1-2

Data notes: Digital Elevation Model and base data provided by Geomatics Yukon via online source (www.geomaticsyukon.ca) Yukon Albers NAD83 1:2,500,000 Drawn by: CEB Checked by: RM 08/08/2016

2 Physical Setting

2.1.1 Physiography

The Dempster Highway traverses several distinct physiographic regions within Yukon (Mathews, 1986). From its junction with the North Klondike Highway (km 0), the Dempster Highway immediately leaves the 'Klondike Plateau' and crosses the Klondike River within the narrow, northwest-southeast-trending 'Tintina Trench'. It climbs through the 'Southern Ogilvie Mountains' and traverses the 'Eagle Lowland', which extends to the border with the Northwest Territories (km 465). Physiographic information within the region traversed by the Dempster Highway are provided by Smith et al. (2004), who summarize topographic, drainage and climatic data for each of three ecoregions that encompass nearly all of Yukon's portion of the highway: Mackenzie Mountains (approx. km 35 to km 85), North Ogilvie Mountains (approx. km 85 to km 220) and Eagle Plains (approx. km 220 to km 430). Summaries for each ecoregion are provided in the following paragraphs.

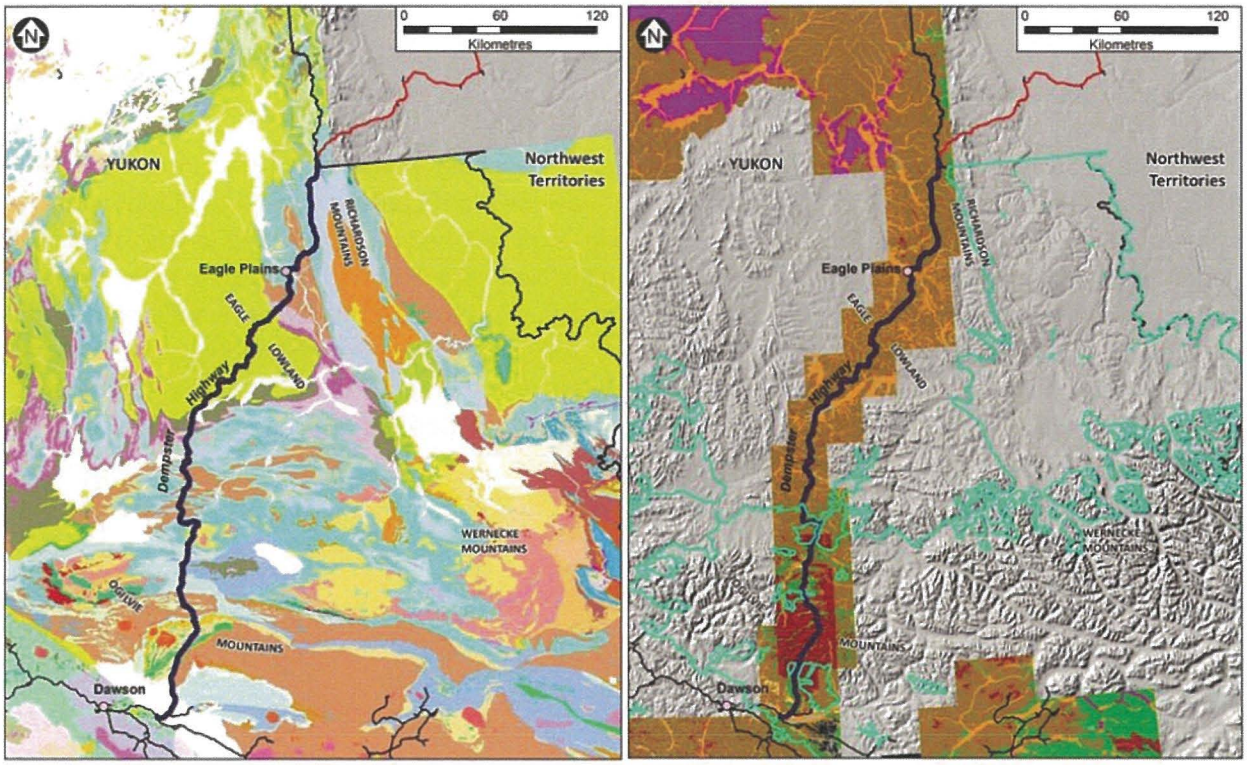
The Mackenzie Mountains ecoregion, which includes the South Ogilvie, Wernecke and much of the Mackenzie Mountains themselves, has elevations ranging from 400 m to 2,750 m but generally between 750 m and 1500 m (YEWG, 2004a). Mean annual temperature is approximately -6ºC, with comparatively subdued seasonal variability in temperatures due to the high, mountainous terrain (YEWG, 2004a). Mean annual precipitation is generally between 450 and 600 mm, most of which falls in the summer and autumn months (YEWG, 2004a). Extreme recorded temperatures range from approximately -50ºC to 30ºC, but this range is likely smaller, -35ºC to 15ºC, at the highest elevations in this ecoregion (YEWG, 2004a). The drainage divide between the Peel and Yukon Rivers is located within this ecoregion. Rock glaciers, solifluction, soil creep, rotational slumps, debris flows, and large rock slides are all present in this region, which includes the boundary between continuous and discontinuous permafrost (YEWG, 2004a).

In the unglaciated North Ogilvie Mountains ecoregion, elevations range from 280 m to 1,860 m and mean annual precipitation is in the order of 300 to 450 mm, most of which falls as rain during the summer months (YEWG, 2004b). Mean annual temperatures are generally -7ºC to -10ºC, and extreme temperatures can range from -60 to 30ºC (YEWG, 2004b). There are no major rivers in this ecoregion; water ultimately drains into the Yukon, Porcupine or Peel River basins through smaller tributaries (YEWG, 2004b). Permafrost is continuous within this ecoregion, except in the immediate vicinity of some larger watercourses (YEWG, 2004b).

Elevations in the Eagle Plains ecoregion range from 250 m to 1,110 m, with most of the region between 300 and 600 m (YEWG, 2004c). Annual precipitation is in the order of 400 mm, most of which falls as rain in the summer. Mean annual temperatures are approximately -7.5ºC, but this ecoregion experiences marked seasonal variation: extreme temperatures can range from -60 to 30ºC (YEWG, 2004c). Drainage from this ecoregion is generally into the Porcupine River via its numerous tributaries, including the Eagle River (YEWG, 2004c). This region is underlain by continuous permafrost, within which ground ice has commonly been encountered during construction and maintenance of the highway (YEWG, 2004c).

2.1.2 Bedrock geology

The bedrock geology along the Dempster Highway is complex (**Figure 2-1**). The highway crosses the basinal and shelf facies of the western margin of Ancestral North America (Gordey and Makepeace, 1999). From km 0 to km 240, the highway crosses Proterozoic to Paleozoic clastic to carbonaceous rocks, including chert, sandstone, shale, conglomerate, limestone and quartzite, with minor amounts of volcanics, phyllite and felsic instrusives. The rocks from km 240 to km 344 are dominantly Cretaceous fine-grained clastic rocks, such as mudstone, shale, and sandstone. The rest of the highway, from km 344 to km 464, crosses Silurian to Carboniferous shale, sandstone, siltstone, and limestone.



Regional Bedrock Geology
Refer to Gordey and Makepeace (1999) for bedrock geology legend (http://www.geology.gov.yk.ca/mapgallery/203.html). Study area shown as navy.

Regional Surficial Geology
Surficial geology simplified from Lipovsky and Bond (2014). Maximum northwestern limit of glaciation (light blue-green) from Duk-Rodkin (1999). Surficial geology polygons are colour-coded by dominant surficial material: till (green), colluvium (brown), bedrock (red), glaciofluvial (orange), glaciolacustrine (purple), organic (grey), eolian (beige), and anthropogenic (black). Study area shown as navy.

Figure 2-1. Regional Geology

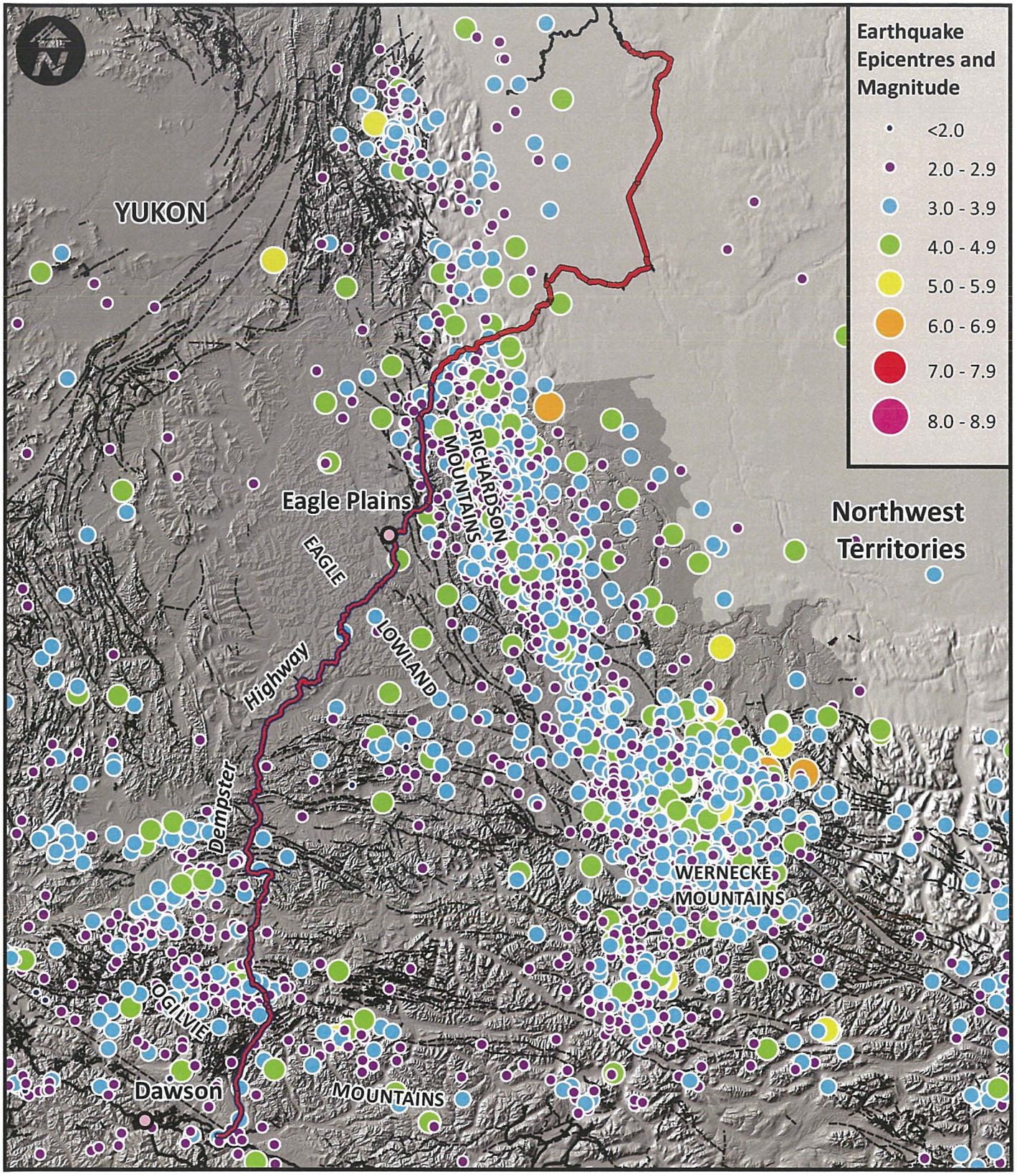
The study area of this project is generally outside areas of high seismicity, except where the highway passes through the Ogilvie and Richardson Mountains (**Figure 2-2**). Approximately 130 segments of faults identified in data from Geomatics Yukon intersect the study corridor, the vast majority of which are generally west-east or northwest-southeast trending, unnamed, defined thrust, reverse or normal faults. The southern half of the route is intersected by the east-west trending Tombstone, North Fork, Dawson,

and Soldier thrust faults; the northwest-southeast trending dextral Tintina Fault; and the northeast-southwest trending Robert Service thrust fault. Only unnamed faults intersect the northern half of the route, north of the Ogilvie River, and the vast majority of these are defined normal or reverse faults.

2.1.3 Surficial geology

Parts of Yukon were repeatedly glaciated during the past ~2.6 million years. These events have left a wide range of surficial materials of varying ages across the region crossed by the Dempster Highway (**Figure 2-1**). The wide range in ages of the glacial and non-glacial surficial materials in Yukon results in a difference in the weathering depth of soils across the region crossed by the Dempster Highway. In this part of Yukon, there are three distinct glacial limits, each representing a surface with a unique weathering history. In order of youngest to oldest, these limits are the McConnell (~10 thousand years old), the Reid (~200 thousand years old) and the Pre-Reid (~2.6 million years old) (for clarity, only the maximum limit of glaciation is depicted on **Figure 2-1**).

The entire study corridor is covered by surficial geology mapping at scales ranging from 1:50,000 to 1:125,000 (Lipovsky and Bond, 2014). The highway traverses large areas mapped as fluvial materials, surrounded by slopes comprising colluvium mantling exposed bedrock. Isolated areas of thick till deposits are scattered throughout regions surrounding the North Klondike and Blackstone rivers. North of the maximum glacial limit, where the highway enters the Engineer Creek valley, surficial materials comprise a similar distribution of broad fluvial areas surrounded by colluvial materials, with sporadic bedrock outcrops. The long, rounded ridge complexes in the Eagle Plains area are dominated by weathered bedrock, locally veneered by fine-textured colluvium. Colluvial and periglacial processes are widespread throughout the study area.



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KRYOTEK

PALMER ENVIRONMENTAL CONSULTING GROUP INC.

Legend

- Study Corridor
- Dempster Highway
- Faults
- Watercourses
- Roads

Project Number: 14132
Title: Geohazard Investigation Dempster Highway #5

Regional Seismicity 1897 - 2014

Figure 2-2

Data notes: Digital Elevation Model, base data, and seismic data provided by Geomatics Yukon via online source (www.geomaticsyukon.ca) Nad83 Zone 17 N 1:2,500,000 Drawn by: CEB Checked by: RM 07/07/2016

2.1.4 Permafrost

2.1.4.1 Distribution

Permafrost is ground that remains below 0°C for more than one year. Its distribution along the Dempster Highway relates to latitude and elevation, at a regional scale, and to a variety of factors including aspect, surficial material, micro-topography and vegetation, at a local scale (Williams and Burn, 1996; Bonnaventure et al., 2012; McKillop et al., 2013). The highway transitions from a region of extensive discontinuous permafrost (50-90% areal coverage) as it ascends the North Klondike River valley through North Fork Pass, to a region of continuous permafrost (90-100% areal coverage) north of the Ogilvie Mountains and continuing beyond Eagle Plains (Heginbottom et al., 1995). Permafrost, identified based on the presence of visible ground ice, was encountered at all sites in the Eagle Lowland that were examined for granular material in association with construction and maintenance of the Dempster Highway (EBA, 1990), as cited by YEWG (2004c).

2.1.4.2 Active Layer Thickness

The active layer is the upper layer of ground that freezes and thaws seasonally above the permafrost table. It may be restricted to soils and unconsolidated surficial materials, or it may extend into underlying, weathered or intact bedrock. The active layer varies spatially at regional and local scales. At a local scale, its thickness primarily depends on elevation, aspect, soil texture, drainage, snow pack, vegetation cover and wildfire history (Williams and Burn, 1996; Bonnaventure et al., 2012; McKillop et al., 2013). The active layer is generally 1 to 2 m thick along the Dempster Highway, becoming thinner to the north. Exceptional active layer thicknesses of up to about 3 m occur in areas severely burned by wildfire and/or altered by unmitigated disturbances. Well drained, coarse-grained soils tend to have thicker active layers than poorly drained and fine-grained areas. In areas of thick, mossy organic cover, permafrost may be encountered at depths as shallow as just a few tens of centimetres.

Active layer thickness also varies seasonally and in response to natural and anthropogenic disturbances. Each year active layer thickness increases following spring snowmelt and typically peaks in late summer. During the 2 to 3 months when the active layer is unfrozen, snowmelt and rainfall can infiltrate the ground until they reach the permafrost table. Groundwater perched on the permafrost table moves slowly through the active layer, in some cases entering streams, until the active layer re-freezes in the autumn and groundwater flow ceases. Active layers thicken appreciably following wildfire, which burns most or all of the insulating surface organic mat, reduces interception of snow by trees (where present), lowers the surface albedo, increases exposure to solar radiation and decreases evapotranspiration (e.g., Burn, 1998). The permafrost responds immediately by thickening its active layer, commonly by up to several times its original thickness (Burn, 1998; Smith et al., 2015). Yoshikawa et al. (2003) estimate natural wildfire recurrence of 50 to 300 years in the boreal forest of interior Alaska. Smith et al. (2015) documented stabilization of post-fire active layer thickening within approximately 5 years in an area of extensive discontinuous permafrost in the central Mackenzie Valley.

2.1.4.3 Ground Ice

Permafrost may or may not contain ice, depending primarily on the material within which it exists and its hydro-geomorphic setting. Most commonly, ice is restricted to the pores within unconsolidated surficial materials or the voids and fractures within weathered bedrock. These conditions are widespread in areas of exposed or shallow bedrock, along ridges of residual soils and weathered bedrock, and on well drained colluvial slopes. In their 1:1,000,000-scale mapping of permafrost and ground ice conditions in northwestern Canada, Heginbottom and Radburn (1992) indicate volumetric ice contents range from "nil to low" to "low to moderate" along a broad corridor encompassing the Dempster Highway. Local experience has demonstrated that ice contents are generally highest in valley bottoms with fine-grained soils. In wetlands, across broad floodplains and on gentle slopes blanketed in fine-textured colluvium, permafrost may be ice-rich, containing seams, lenses or massive bodies of ice. Ice wedges, which can be several metres deep and more than a metre wide, occur in some areas alongside the Dempster Highway. On well-drained, southerly aspects with convex slopes, permafrost (if present) is generally ice-poor.

2.1.5 Mass Movement Processes

Mass movements involve the downslope transport of material, such as soil and/or rock, under the influence of gravity. Mass movements may or may not be associated with water, snow or ice. Along the Dempster Highway, landslides, whether rapid or slow, are the dominant mode of mass movement. Landslide terminology used in this report follows the standards defined by Hungr et al. (2014), a recent update to the classic classifications established by Varnes (1978) and Cruden and Varnes (1996), which describe the process as well as the type of material involved in the mass movement. The terminology also aligns with the classification system outlined in the guidance document, *Geohazards and Risk: A Proponent's Guide to Linear Infrastructure* (Guthrie and Cuervo, 2015). Where two modes of failure contribute to movement, the landslide type is assigned based on the apparent dominant mode. The landslide terms applied in this report are illustrated schematically in **Figure 2-3**.

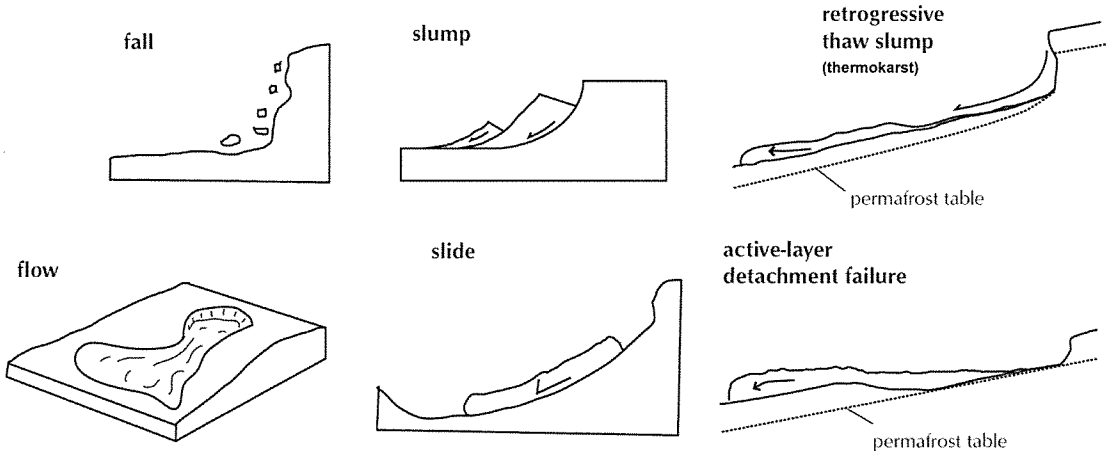


Figure 2-3. Landslide Terminology Used in this Report (adapted from Huscroft et al., 2004)

Where more accurate representation of the role of permafrost is required, refinements to standardized landslide terminology are made based on the *Multi-language glossary of permafrost and related ground-ice terms* (van Everdingen, 2005), which is consistent with the approach applied in the regional characterization of landslides along Yukon's Alaska Highway corridor (Huscroft et al., 2004). "Active-layer failures" (referred to herein as active layer detachments, for consistency with local nomenclature) describe flows and/or slides of material in which failure occurs at the interface of a frozen substrate, and "retrogressive thaw slumps" describe mass movements that enlarge upslope through the repeated fall, slide or flow of material from a steep, thawing headscarp (**Figure 2-3**). Rock glaciers have been excluded from this inventory, despite their local presence alongside the highway and their inclusion in Blais-Stevens' (2010) landslide inventory along the Alaska Highway corridor, because their snouts are inactive and do not pose a risk to the highway. The prevalence of highway instability caused by erosion along the outer banks of migrating stream meanders also warranted separately identifying sites exposed to mass movement failures due to meander migration.

Understanding the type and distribution of mass movements along the Dempster Highway requires an appreciation for the physiographic, geological and permafrost-related factors that govern instability, each of which has been characterized in the preceding sections. Within its Yukon extent, the Dempster Highway traverses major valleys, mountain passes and subarctic plains. In addition to differences in topography, differences in the weathering (glaciated vs. unglaciated) and permafrost conditions south of, within and north of the Ogilvie Mountains impart important differences in the occurrence, characteristics and detection of ground instability.

Most mass movements along the Dempster Highway corridor are influenced, either directly or indirectly, by permafrost or related periglacial processes. Climatic warming is contributing to the degradation (thaw) of permafrost, especially on southerly aspects and in broad valley bottoms exposed to prolonged sunlight during the summer. Permafrost degradation results in an increase in active layer thickness, which increases the volume (mass) of surficial material available for downslope transport and degree of soil saturation provided by the release of water from thawing ground ice. Shallow landsliding (e.g., active layer detachment) occurs once the shear stress exceeds the shear strength of the material. Thermokarst subsidence and gullying may occur in gentler terrain. Deep-seated failures within thick overburden or weathered bedrock occur in response to failures of weak layers or thawing of ice bodies at depth. Deep-seated permafrost failures may result from movement of groundwater within unfrozen zones (taliks) in or beneath permafrost.

The most common triggers for both shallow and deep-seated failures are extreme rainfall or heat events (i.e., intense or prolonged) and wildfires (**Figure 2-4**). Seasons of increased geohazard activity include the period from late July to early September, when active layers are deepest, permafrost is warmest and rainfall is greatest, as well as late May or early June, when erosion during snowmelt freshet freshly exposes permafrost to fluvio-thermal erosion and slumping. Slopes underlain by permafrost that have not experienced recent wildfires are more prone to active layer detachments immediately following a fire.

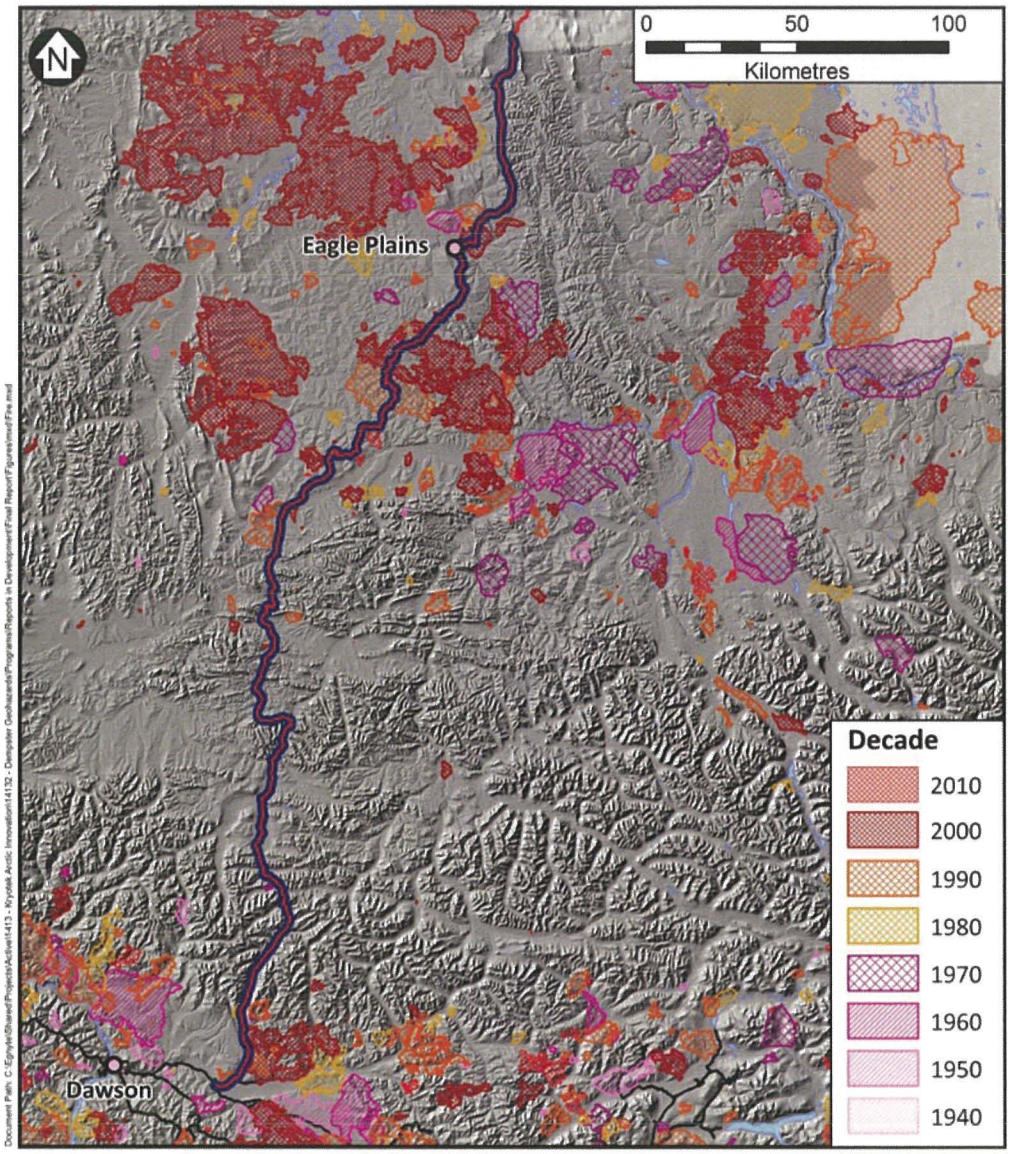


Figure 2-4. Regional Wildfire History along the Dempster Highway

2.1.5.1 Meander Migration

Meander migration is one of the principal factors contributing to mass movements alongside sections of the highway that parallel (or cross) rivers within major valleys along the Dempster Highway. Commonly, the progressive encroachment of a meander alongside the highway through sequential bank undercutting and collapse leads to exposure and accelerated thaw of ice-rich permafrost, and over-steepening of slopes adjacent to the highway embankment. Sudden bank collapses can result in metres of loss of highway embankment, as illustrated recently along Engineer Creek at km 182 (**Figure 2-5**). There are essentially three main river-highway encroachment scenarios that warranted consideration as part of this overall hazard assessment (**Figure 2-6**).

Figure 2-5. Meander-induced Mass Movement of Highway Embankment along Engineer Creek at km 182

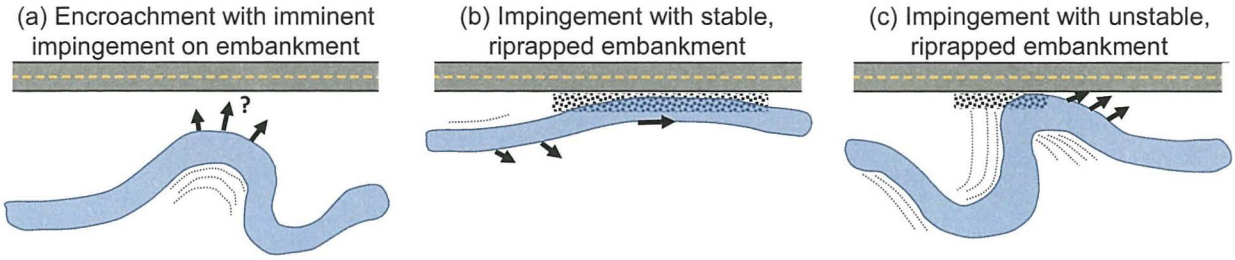


Figure 2-6. Three Main Meander-Highway Encroachment Scenarios

2.1.6 Fluvial Geomorphology

The Dempster Highway follows valley bottoms along most of its southern half within Yukon. As such, it parallels and crosses several large, meandering creeks and rivers. From km 0 at the North Klondike Highway, the Dempster Highway ascends the west side of the North Klondike River valley until km 67 where it crosses to the east side and climbs over North Fork Pass in the Ogilvie Mountains. The highway then descends along the west side of East Blackstone River to its confluence with the main branch of Blackstone River at Chapman Lake (km 115). The highway follows the west side of the Blackstone River valley until km 146, where it turns westward to climb over a low divide into the headwaters of Engineer Creek. The highway generally parallels the west side of Engineer Creek to its confluence with Ogilvie River, at km 195. From there, the Dempster Highway follows the Ogilvie River valley until approximately

km 246, where it ascends the valley side to gain a long ridge system continuing northward toward Eagle Plains. North of Eagle Plains to the border with the Northwest Territories, the highway traverses the gentle, lower, western slopes of the Richardson Mountains. Only headwater tributaries are crossed along this northernmost section of the study area.

All of the large creeks and rivers that the Dempster Highway follows exhibit characteristics typical of watercourses that drain mountainous terrain in subarctic environments: relatively high bedloads, mixed single- and multi-thread channel reaches, and vegetation patterns diagnostic of ice effects. Their morphologies are somewhat modified by the presence of extensive discontinuous permafrost, which locally affects bank stability and hydrological processes (Scott, 1978). Of the five major watercourses along this study corridor, North Klondike River exhibits the greatest stability, particularly in its upper reaches. Overall, the river exhibits a partly confined, irregular meandering with localized multi-thread reaches more similar to a wandering planform. A number of large, incised alluvial fans at the mouths of tributaries are a testament to the period of increased sediment supplies following glaciation of the Ogilvie Mountains.

East Blackstone River exhibits a wandering to irregularly meandering pattern within a U-shaped valley. Glacial drift is relatively thick, contributing high amounts of sediment from erosional scarps along the outside banks of meanders. Meanders are commonly incised deeply through morainal debris and fluvial terraces, where they exhibit a relatively stable planform.

Blackstone River exhibits a dominantly wandering pattern, with localized braided and meandering reaches. Moderately high and steep mountains overshadow Blackstone River as it flows, partly confined, along a flat valley bottom. In places, the highway follows a toe slope along which the river encroaches. Large point and side bars are indicative of high sediment loads and relatively rapid meander migration; channel avulsions are also common.

Engineer Creek drains a range of moderately steep mountains veneered by talus. Periglacial processes compound the effects of normal colluvial activity and deliver large volumes of coarse sediment into V-shaped, headwater tributaries that join the upper reaches of Engineer Creek. Debris floods are likely common, based on the extent and uniformity in age of gravel deposits. The high sediment loads delivered to the gentler main branch of Engineer Creek are less readily transported, resulting in frequent and locally dramatic morphological adjustments along the wandering, multi-thread channel. Of all the watercourses along the study corridor, Engineer Creek exhibits the greatest instability in the form of meander migration, channel avulsions and bed level changes. Ice-rich permafrost comprising some of the banks is susceptible to thermal erosion, in addition to fluvial erosion, which reduces resistance to morphological change.

Ogilvie River exhibits an irregularly meandering to wandering channel pattern, with several reaches confined between steep mountainsides along narrow valley bottoms. Riprap has been applied to a significant proportion of the highway embankment where it is confined against the toe of the mountainside by the wide, sinuous channel. In sections of broader valley bottom, there are commonly two dominant, meandering channels separated by vegetated islands. Meander cut-offs and other channel avulsions can have dramatic geomorphological consequences.

2.1.7 Highway Infrastructure

The Dempster Highway and its embankments/ditches, drainage culverts, bridges and riprap revetments represent the principal infrastructure potentially at risk from mass movements and meander migration. Evaluating the risk requires an understanding of the ways in which geohazards can impact highway infrastructure. **Figure 2-7** depicts a schematic representation of the four main 'pathways' for geohazards to impact the highway.

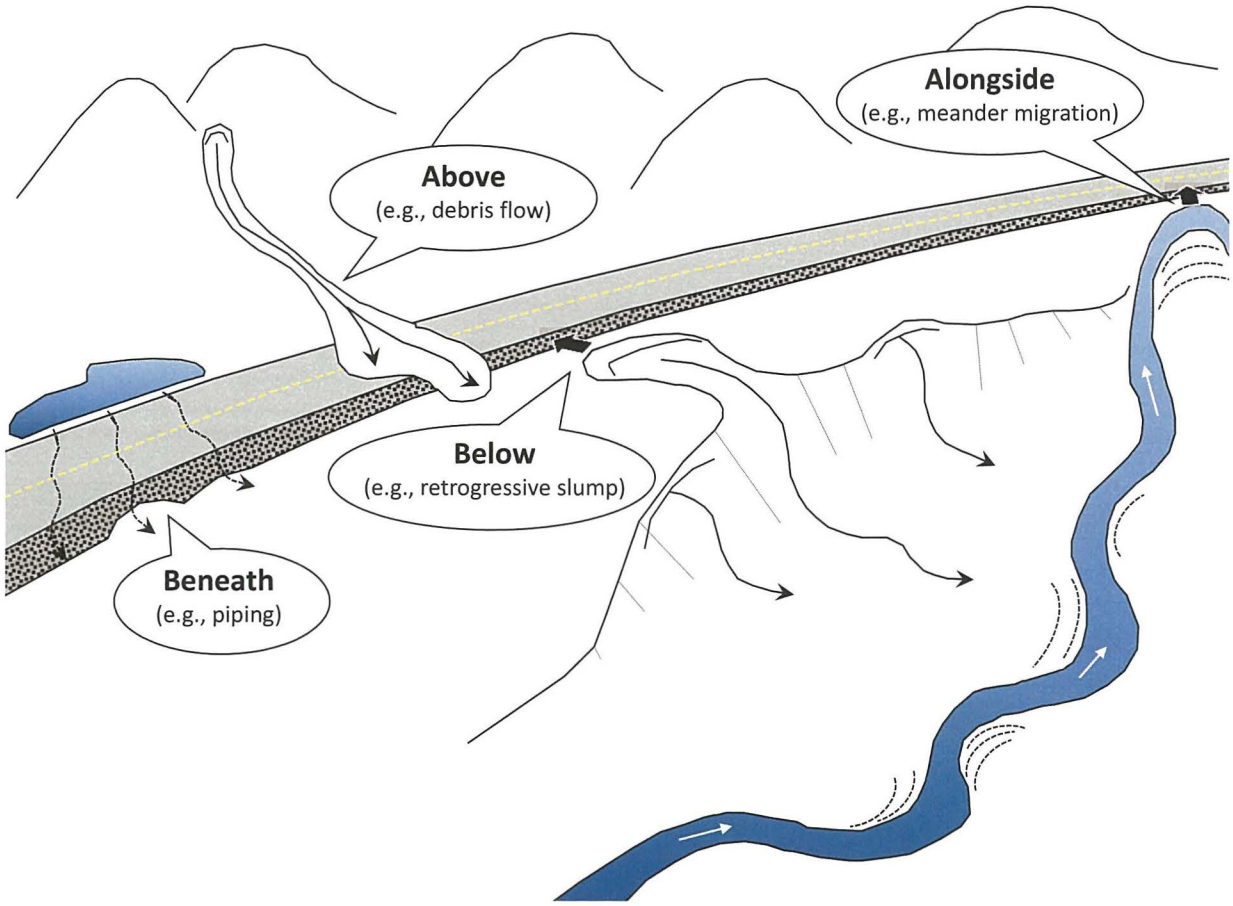


Figure 2-7. Schematic Representation of Different Modes of Highway Impact

1. Mass movement initiated **above** the highway, whether from natural or anthropogenic causes, travels downslope against, onto or across the highway. This may result in severance or burial, both of which block vehicle traffic and require remediation.
2. Mass movement initiated **below** the highway, whether from natural or anthropogenic causes, travels upslope through retrogressive erosion to or beyond the highway. This may result in undermining, settlement and ultimately severance, blocking vehicle traffic and requiring remediation.

3. Mass movement initiated **beneath** the highway, whether from natural or anthropogenic causes, typically occurs as a result of thermokarst and/or piping within underlying materials. This may result in differential subsidence and potentially collapse of the highway, either slowing or blocking traffic and requiring remediation.
4. Mass movement initiated **alongside** the highway (or bridge abutments) commonly occurs due to encroachment of a stream meander. This may result in undermining and collapse (slumping) of the highway embankment, such as occurred at km 182 due to encroachment of Engineer Creek (**Figure 2-5**).

Also important to consider in the evaluation of potential impacts from mass movements is the local manner in which the highway has been constructed. A section of highway entirely built up on an embankment may respond to mass movement processes differently from a cut-slope section with side-cast and a cut-slope section without any side-cast. The height and steepness of the embankments must also be considered. With respect to meander migration hazard, the presence, extent and size of riprap protection affect the level of risk.

3 Methods

Kryotek and PECG applied a systematic, five-phase approach for assessing soil and rock mass movement and meander migration hazards along the Dempster Highway corridor based on desktop analysis and field reconnaissance investigations. The methods used in each phase of work are outlined in the following sections.

3.1 Phase 1 – Background Review

3.1.1 Data Compilation and Review

Our team completed a background review, building on that completed in support of our previous rock quarry evaluation project for HPW-TEB (Kryotek and PECG, 2015), in order to search publications for geohazard sites already identified through previous studies, consult with local experts on the occurrence of landslides and permafrost-related instability along the highway, and establish a project-specific understanding of the site conditions most commonly associated with mass movements. The insight we gained through this methodical review enabled us to optimize the identification of mass movement geohazards along the highway corridor, based on even subtle diagnostic features.

As noted previously in Section 1.1, relatively large landslides and other terrain hazards had been identified along portions of our study through YGS and GSC surficial geology mapping compiled by Lipovsky and Bond (2014), M.Sc. research on the Quaternary geology of the North Klondike and upper Blackstone river systems investigations (Ricker, 1968; 1977), a highway-focused terrain evaluation crossing Eagle Lowland (Richardson and Sauer, 1975), and permafrost studies conducted by EBA (2013) and Burn et al. (2015). In addition to identifying geohazards that may be of relevance to this project,

these studies improved our team's understanding of the combination of site conditions most prone to different modes of mass movement.

Kryotek and PECG reviewed data from additional sources to enhance our understanding of the geologic, topographic and permafrost settings of mass movements along the Dempster Highway:

- Yukon's bedrock geology mapping compilation (Gordey and Makepeace, 1999), providing insight on the regional distribution of rock masses prone to different forms of instability, and surficial geology mapping compilation (Lipovsky and Bond, 2014), providing insight on the regional distribution of different types, textures and thicknesses of surficial materials (as well as major landslides);
- Permafrost probability mapping of southern Yukon (Bonnaventure et al., 2012) to support our interpretations of permafrost conditions within the southern Ogilvie Mountains;
- Glacial limits mapping (Duk-Rodkin, 1999) to help distinguish zones with different depths and severities of weathering;
- YGS Open File outlining diagnostic characteristics in aerial photographs of permafrost-related mass movements including active layer detachments, and thermokarst-induced subsidence and gullying (McKillop et al., 2013);
- Existing National Topographic System (CanVec) GIS base data, including digital elevation models, watercourses, waterbodies, topographic contours and transportation corridors, accessed from Geomatics Yukon;
- 500 to 600 m-wide corridor[1] of high-resolution, colour orthophotography from 2013/2014, provided by HPW-TEB;
- 600 to 2,000 m-wide corridor[2] of LiDAR survey data from 2013/2014, provided by HPW-TEB, and subsequently processed by our team to produce high-resolution, bare-earth hillshade models for the full (variable) width of data coverage available;
- Seamless mosaics of high-resolution satellite imagery covering the 2 km-wide study corridor from 2007/2008 (Quickbird) and September 2010 (GeoEye), provided by Geomatics Yukon;
- Territory-wide wildfire mapping, by decade (from Geomatics Yukon), as a basis for contributing to the understanding of the lag between wildfire and landsliding;
- Mapping of significant earthquakes and seismic hazard in Yukon (Hyndman et al., 2005; Lamontagne et al., 2007; GSC and YGS, 2009), given its potential to partly explain the distribution and timing of landslides;

[1] Narrower coverage than the approximately 500 m buffer (1,000 m total width) HPW-TEB indicated was available, and not always centred along the highway centreline

[2] Mostly narrower coverage than the approximately 500 m buffer (1,000 m total width) HPW-TEB indicated was available, and not always centred along the highway centreline, with areas of wider coverage discovered through our team's initial background review

- Peer-reviewed literature on permafrost-related slope hazards including those by Ward et al. (1992), Dyke (2004), Coates and Lewkowicz (2005), Lewkowicz and Harris (2005) and Lipovsky et al. (2006);
- As-built drawings and relevant sections of geotechnical reports for the Dempster Highway (e.g., SRK Consulting (Canada) Inc., 2014), provided by HPW-TEB; and
- Colour, 1:45,000-scale aerial photography stereo-pairs along the highway corridor from 1977, as well as black-and-white, 1:20,000-scale aerial photography from 1989 covering sites of detailed meander migration assessment (Section 3.3) (**Table 3-1**).

Table 3-1. List of Historical Aerial Photographs Reviewed along Dempster Highway

Roll	Photographs	Date	Nominal Scale
A37497	1 – 26, 50 – 145	1977	1:45,000
A37499	1 – 20	1977	1:45,000
A27498	141, 144, 158-159, 161-162, 167-168, 176, 178-180, 184-187, 194-199, 211, 214, 217-218, 220, 244, 262-265	1989	1:20,000

3.1.2 Consultation

In order to gain additional insight beyond what is available in regional-scale mapping and publications, Kryotek and PECG consulted senior YGS and Yukon Energy, Mines and Resources (EMR) staff on their local knowledge of permafrost-related landslides (Panya Lipovsky, Surficial Geologist), surficial materials (Jeff Bond, Manager, Surficial Geology), local bedrock characteristics (Tiffani Fraser, Bedrock Geologist), variability in permafrost conditions (Sarah Laxton, Permafrost Geologist) and permafrost degradation and recovery at past disturbance sites (Kirstie Simpson (EMR Senior Advisor, Sustainable and Integrated Resource Management). The staff shared photographs, pertinent field observations (e.g., active layer thicknesses) and locations of areas prone to certain geohazards. We also spoke with Dr. Chris Burn, Canada's leading researcher on permafrost distribution and conditions in Yukon, about his permafrost experience along the Dempster Highway. Further information on the history of maintenance along problematic sections of the Dempster Highway was gained through discussions with HPW-TEB staff and maintenance personnel, including foremen and equipment operators at Ogilvie Camp with experience along the highway corridor.

3.2 Phase 2 – Preliminary Desktop-Based Mapping

3.2.1 Preliminary Mass Movement Geohazard Identification, Delineation and Characterization

Kryotek and PECG conducted a systematic review of available spatial data layers to preliminarily identify and delineate mass movement hazards within the study corridor. Mass movements were identified primarily through the combined interpretation of HPW-TEB's high-resolution orthophotography and LiDAR-derived hillshade and slope models from 2013/2014, with or without the 1 m topographic contours

overlaid, and historical aerial photography (Section 3.1.1). Field photographs to which our team already had access helped calibrate our interpretations.

We deliberately adopted a conservative approach in the desktop-based identification of mass movements, knowing that active layer detachments can initiate and runout on very gentle slopes. We correctly anticipated that field reconnaissance would enable us to confirm certain features terminated sufficiently far from the highway to not pose a threat or were merely regenerating anthropogenic disturbances as opposed to regenerating landslide scars.

The existing and/or projected limits of each geohazard were preliminarily delineated (two dimensions) while viewing the base data sets at a large scale (approx. 1:2,000). Projected runout limits were estimated based on local topography and morphologic evidence from similar, nearby mass movement events. Particular attention was given to analyzing areas adjacent to obvious slope failures as well as areas exhibiting characteristics most similar to the failure-initiation settings described in other landslide studies in Yukon (e.g., Huscroft et al., 2004; Lipovsky and Huscroft, 2007).

Each identified geohazard was preliminarily classified according to standardized landslide terminology, as outlined above in Section 2.1.5. Characterizations at this stage of desktop study were deliberately kept to a minimum level of detail, recognizing that field work would enable removal of a number of conservatively identified sites. Site-specific attributes, in addition to the type of mass movement, included position relative to the highway (above, below or beneath) and a prioritization for field reconnaissance investigations. The final database of mass movement geohazard attributes, updated following field reconnaissance (as described below in Section 3.5.1), is provided in **Appendix A**.

3.2.2 Basic Potential Meander Migration Hazard Identification

Sections of highway with existing or suspected imminent encroachments of a meandering channel were identified using a similar interpretation of multiple data layers to that used in the development of the main mass movement inventory. A standard ellipse was drawn to identify the encroachment site, approximately encompassing the area already or potentially exposed to mass movements induced by continued bank erosion (**Appendix F**). Meander-highway encroachments with separations of more than about 35 m were considered sufficiently far to exclude them from the inventory. Sections of highway already fully or partially 'protected' with riprap were included in the hazard identification if there was reasonable potential for future undermining and failure of the riprap to re-expose erodible soils (or the highway embankment itself) and again destabilize the highway. Riprapped (or unprotected) encroachment sites where the channel approximately parallels the highway, thereby minimizing the scour potential along the embankment, were generally excluded from the hazard inventory but may require periodic maintenance of riprap and highway embankment material.

A modest level of assessment was completed for each meander-highway encroachment site (**Appendix F**). We documented the following site-specific attributes: proximity (m) of the channel bank to the near edge of the highway, trajectory of meander migration (compass direction, e.g., NW), and riprap presence (yes, no, partial). We prioritized sites for more detailed, follow-up assessment, based on a holistic

interpretation of the relative hazard of continued bank erosion posed to the highway (based on indicators of meander migration such as meander scrolls, oxbows, large point bars, vegetation patterns, etc.).

3.3 Phase 3 – Detailed Meander Migration Hazard Assessment

Of all the meander-highway encroachment sites identified through the initial hazard review, only those deemed to have the greatest potential for impact to the highway were prioritized for more detailed, follow-up assessment (**Appendix G**). Prioritized sites generally exhibited evidence of relatively rapid meander encroachment alongside the highway, with trajectories directed roughly perpendicularly toward the highway, and may also have had minor separation with no or incomplete riprap protection. The following sections outline the methods completed at each of these detailed assessment sites.

3.3.1 Initial Imagery/LiDAR Interpretation

The imagery and LiDAR-derived topographic data sets identified above in Section 3.1.1 provided a basis for evaluating meander dynamics at each of the prioritized encroachment sites based on a comparative overlay analysis (Section 3.3.4) (**Appendix H**). The historical aerial photography was georeferenced to the 2013/2014 orthophotography using standard ArcGIS georeferencing tools. Approximately five control points were used to optimize the spatial match within the immediate vicinity of the valley bottom encroachment site, where relief and relative image distortion are low. Resultant errors in comparison to the 2013/2014 orthophotography were ±3 m (1989) and ±4 m (1977). The orthorectified 2007/2008 Quickbird imagery exhibited an error of approximately ±3 m in comparison to the 2013/2014 orthophotography.

At each encroachment site, important attributes were measured (quantitative) or interpreted (qualitative) from the imagery and elevation data sets, as well as from pertinent local information (**Appendix G**). Each of the site, channel, meander and riprap requirement attributes documented on the site-specific summary figures for each encroachment site (**Appendix H**) is defined in **Table 3-2**. Distance, or length or width, attributes were determined using the ArcGIS 'measure' tool; height, or elevation differences, were determined based on querying the high-resolution, LiDAR-derived DEM; and embankment slopes and lengths were calculated based on trigonometric relations. A number of qualitative attributes were interpreted from the imagery and elevation data sets based on diagnostic features and professional experience along the Dempster Highway and elsewhere in central Yukon. The relative depth and ice content of permafrost in banks and valley bottoms, for example, were interpreted based on consideration of vegetation type, density and growth habitat; slope position and morphology; surficial material properties; and nearby surface expressions of ice-rich permafrost (e.g., thermokarst ponds and gullies, ice-wedge polygons).

Table 3-2. Definitions of Key Attributes of Prioritized Meander-Highway Encroachment Sites (reported in Appendices G and H)

	Abbrev. Heading	Full Heading	Description
SITE	Section	Highway maintenance section	Highway maintenance section
	Watercourse	Watercourse name	Watercourse name
	Riprap history	Riprap history	Year(s) of riprap application (if known), based on HPW-TEB consultation, highway as-built drawings and imagery interpretation
	Hwy-watercourse proximity (m)	Highway-watercourse proximity (m)	Shortest distance (m) between channel and toe of highway embankment at encroachment site
	Position in meander belt	Position within meander belt	Position of encroachment site within meander belt (i.e. corridor within which lateral channel adjustments typically occur) – within or at edge
CHANNEL	Setting	Topographic and surficial setting	General characterization of landform between channel and highway at encroachment site
	Permafrost	Permafrost characteristics	Relative depth (near-surface (<0.4 m), shallow (0.4-1 m), deep (>1 m)) and ice content (ice-rich (massive ice), ice-moderate (segregated ice), ice-poor (minimal visible ice)) of permafrost
	Bank height (m)	Channel bank height (m)	Approximate height (m) of channel bank at encroachment site estimated from bottom-of-bank (water surface) to top-of-bank (commonly different from bankfull depth)
	Low-flow width (m)	Low-flow channel width (m)	Approximate wetted width (m) of low-flow channel visible in imagery
	Bankfull width (m)	Bankfull channel width (m)	Approximate width of active channel, measured between tops of bank, including the low-flow channel and adjacent unvegetated or recently scoured areas
MEANDER	1° migration rate (m/yr)	Primary erosion migration rate (m/yr)	Primary rate of meander migration (m/yr) at encroachment site
	1° trajectory	Primary erosion migration trajectory	Primary trajectory of meander migration at encroachment site (N, E, S, W, etc.)
	2° migration rate (m/yr)	Secondary erosion migration rate (m/yr)	Secondary rate of meander migration (m/yr) at encroachment site
	2° trajectory	Secondary erosion migration trajectory	Secondary trajectory of meander migration at encroachment site (N, E, S, W, etc.)
	Confinement	Existing channel confinement at encroachment site	Presence of an anthropogenic or natural topographic feature that restricts meander movement (unconfined, naturally confined (e.g., scarp, hillside), or confined by highway (e.g., riprapped or suspected to be riprapped))
RIPRAP REQUIREMENTS	Timeframe until impact (yr)	Estimated riprap embankment requirement time (yrs)	Estimated period (yrs) from 2016 field reconnaissance within which continued meander migration is likely to impact highway embankment, without intervention
	Lateral extent (m)	Estimated riprap embankment requirement length (m)	Estimated lateral extent (m) of impact zone along highway embankment where riprap protection may be required
	Slope length (m)	Estimated riprap embankment slope length (m)	Estimated slope length (m) of required riprap embankment extending from toe of highway embankment down to elevation 1 m below adjacent channel bottom-of-bank
	Thickness (m)	Assumed riprap thickness (m)	Assumed thickness (m) of Class II riprap application on embankment
	Volume (m^3)	Estimated riprap embankment volume (m^3)	Estimated volume (m^3) of riprap required to protect impact zone along highway embankment

3.3.2 Riprap Placement History

Riprap placement year and volume at each encroachment site, as identified in **Table 3-3**, were determined from HPW-TEB records, aerial imagery and Dempster Highway as-built drawings.

Table 3-3. Riprap Placement Year and Volume Estimates

km	Placement Year	Volume (m^3)	Notes
52.3	No riprap		
54.9	No riprap		Riparian vegetation and channel dynamics suggest riprap could be present
55.9	No riprap		
88.0	No riprap		
131.4	2004	300	
136.1	Unknown	Unknown	Riprap observed in aerial imagery
138.5	No riprap		
147.6	No riprap		
170.9	No riprap		
172.9	2016	Unknown	
175.2	Unknown	Unknown	Riprap observed in aerial imagery
180.7	Unknown	Unknown	The embankment is sparsely riprapped as observed in aerial imagery
181.5	No riprap		
182.1	2010, 2015	800, 500	
183.3	No riprap		
185.8	No riprap		
188.6	1971, 2015	2,000, 800	
189.4	1998	2,100	
195.1	1971	Unknown	Riprap visible on west bank in aerial imagery. It is unclear if riprap is present on the east bank.
202.5	No riprap		
221.1	1969	Unknown	Determined from as-built drawings
221.3	No riprap		Channel dynamics suggest riprap could be present
232.0	No riprap		
236.3	No riprap		
239.5	No riprap		
243.8	1991, 1996, 2013, 2015	10,000, 2,000, 2,500, 900	

Note: Based on consultation with HPW-TEB, review of highway as-built drawings, and interpretation of imagery

3.3.3 Hydrological Assessment

Changes in hydrological parameters, particularly peak flows, could result in significant morphological restructuring within the study area. Discharge data from two Water Survey of Canada (WSC) gauges were analyzed to identify any systematic changes in hydrology since 1977 (earliest set of aerial photography). The two gauges were located along North Klondike River and Blackstone River. There are no WSC gauges on Engineer Creek or Ogilvie River. The Eagle River gauge data were not analyzed because no significant meander-highway encroachment sites were identified in the region. Station information for each analyzed gauge is summarized in **Table 3-4**.

Table 3-4. WSC Stream Gauge Information

Watercourse	North Klondike River	Blackstone River
WSC Station ID	09EA004	10MA003
Location	64° 00' 07" N 138° 35' 46" W	64° 54' 05" N 138° 16' 33" W
Period of Record	1974 – 2015	1984 – 2015
Drainage Area (km^2)	1,090	1,180

Historical mean annual discharge data were analyzed (regression) to determine if there have been systematic temporal changes in the annual volume of water conveyed by each watercourse. Changes in mean annual discharge or total water volume could have implications for sediment transport and channel migration potential. However, these morphological processes depend on threshold conditions, and the exceedance of these thresholds cannot be determined from the mean annual flow data.

Most morphological restructuring occurs during flood conditions. Changes in the timing and values of peak flows could result in appreciable changes in channel cross-sectional area, longitudinal profile and/or planform geometry (i.e., lateral and longitudinal migration). Historical maximum daily discharge data were analyzed (regression) at each site to highlight systematic changes in the magnitude of peak flows. The maximum instantaneous discharge records had significant data gaps and thus were not used in the peak flow analysis.

3.3.4 Migration Rate Estimation

As a basis for estimating rates and trajectories of meander migration, both banks of the main channel and any major side channels were delineated based on each year of imagery. The banks were delineated at a sufficiently large scale to take advantage of detail available in the high-resolution imagery but not so large that the patterns and spatial relations could be missed (e.g., 1:2,500 to 1:5,000). Top-of-bank position was typically based on an obvious change in vegetation corresponding to a scour limit and/or a prominent slope-break visible in the DEM hillshade models. Channel thalwegs, which are typically the deepest portion of a channel, were also delineated in order to support interpretations of patterns in bank

erosion and meander dynamics. They were generally delineated as a centreline to the low-flow channel visible in the imagery.

In order to assess meander dynamics in the vicinity of each encroachment site, the delineated channel banks and thalwegs were analyzed in conjunction with reach-scale imagery coverage. Most meanders were dynamic and exhibited migration along multiple trajectories. However, only migration trajectories (and their associated migration rates) toward the Dempster Highway were studied in this assessment. For each site that exhibited some form of systematic migration, a *primary* migration rate and trajectory was determined. For sites with more than one migration trajectory toward the highway, a *secondary* migration rate and trajectory was measured. Migration rates were not calculated for encroachment sites that exhibited no systematic change in bank position over the period of record.

In order to predict when a migrating channel may impact the Dempster Highway, a time-averaged migration rate is required. Migration rates were calculated by dividing the total migration distance along a given trajectory by the elapsed time period between imagery years. Exactly which time period was appropriate for estimating the migration rate was determined on a site-by-site basis. Some sites exhibited systematic migration from the earliest photographic record (1977) to the most recent imagery (2013/2014); migration rates, therefore, were based on the full period of record (1977 to 2013/2014). Migration rates were estimated based on shorter periods of record (e.g., 1989 to 2013/2014) at sites exhibiting irregular or unsystematic migration, or where avulsions had made former patterns and rates of bank erosion unrepresentative. Avulsions or other forms of significant morphological restructuring that occurred in the vicinity of encroachment sites in the past 20 years typically precluded the use of the earlier imagery (i.e., 1977 and 1989) in the estimation of migration rates.

3.3.5 Forecasting Riprap Requirements

In order to support HPW-TEB's budget and resource allocation for highway maintenance, and inform its prioritization of new rock quarries for riprap production, we analyzed the migration rate and trajectory data (Section 3.3.4) to estimate approximately when and how much riprap protection would be required in order to mitigate risk to the highway. Riprap requirements at each encroachment site were forecasted based on the estimated near-future (<25 years) upstream and downstream limits of meander encroachment alongside the highway embankment in the absence of any proactive mitigation.

3.3.5.1 Timeframe until Impact

The predicted timeframe until meander migration impacts the highway embankment was determined by measuring the distance between the 2013/2014 delineated bank and the highway embankment *along the meander migration trajectory* and dividing that distance by the time-averaged migration rate. The predicted timeframes were confirmed or updated based on the channel bank position observed during field reconnaissance completed in June 2016 (**Appendices G** and **H**). Channel migration at a given site is an episodic process and is dependent on many environmental factors such as flow conditions, bar morphology and distribution, thawing of permafrost in banks, and ice scour. However, a time-averaged migration rate provides the best estimate of migration potential at a given encroachment site.

The timeframe until impact estimates are reported as 5-year intervals (except for <2 years and 2-5 years) to accommodate annual deviations from the time-averaged migration rate and avoid misrepresenting the accuracy of such estimates. Sites that exhibited an estimated timeframe until impact greater than 25 years were reported together as a single category (>25 years), as the reliability of predictions beyond 25 years is compromised by unforeseen avulsions, anthropogenic disturbance and the varied effects of climate change.

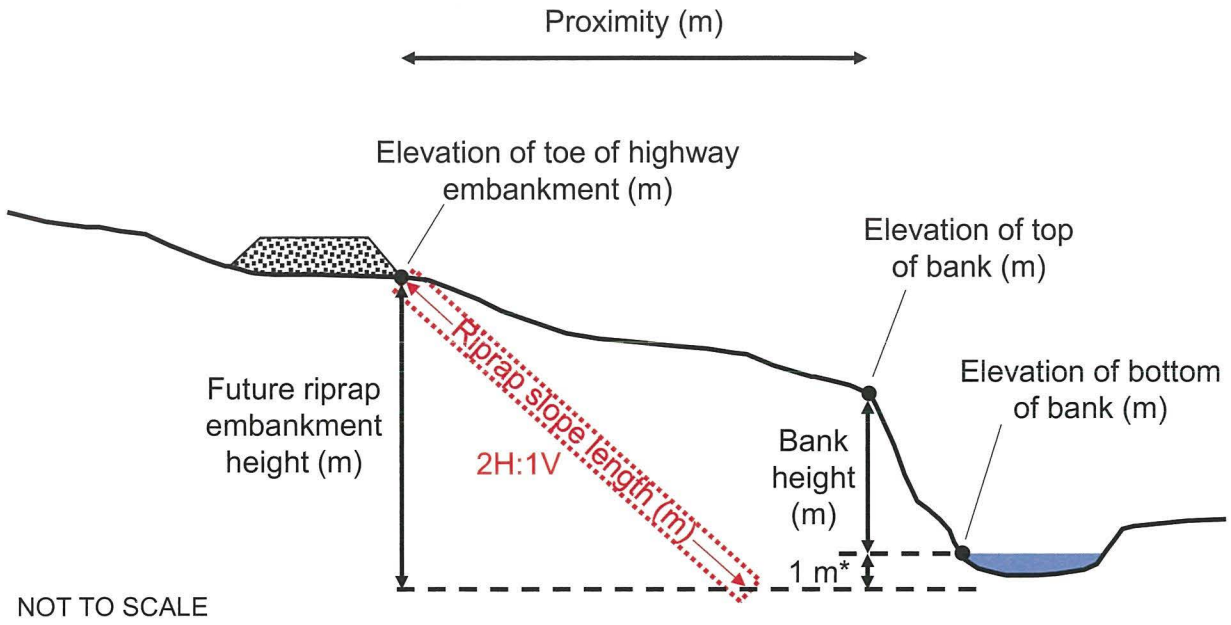
The timeframe until impact estimates are based on the assumption that *proactive* erosion protection measures are not implemented to stop meander encroachment from reaching the toe of the highway embankment.

3.3.5.2 Extent and Volume

The prediction of the lateral extent of impact of meander migration along the highway embankment was based primarily on local meander geometry and trajectories of migration. For the purposes of estimating the necessary lateral extent of riprap, approximately 5 to 10 m was added to this initial extent prediction to allow for localized scour at the upstream and downstream limits. This resultant value is reported in **Appendices G** and **H**.

The required riprap embankment slope length (perpendicular to the highway) was estimated from the elevation difference between the toe of the highway embankment and the bottom of the channel bank (**Figure 3-1**). This elevation difference was determined from the LiDAR-derived DEM (Section 3.1.1). An additional 1 m was added to this measured height to account for channel depth not measurable below the water surface (LiDAR cannot penetrate water) and accommodate some toe scour[3]. Using this more conservative future riprap embankment height, a 2H:1V slope was calculated to determine the required riprap slope length. A 2H:1V slope was used because it is generally stable and requires less material in comparison to gentler embankment slopes (e.g., 3H:1V). If HPW-TEB prefers to use a gentler embankment slope than 2H:1V, such as may be appropriate for banks underlain by ice-rich permafrost, the ultimate volume estimates could easily be recalculated.

[3] This allowance is generalized for the purposes of this predictive study; site-specific assessments and/or modelling are required to more accurately estimate necessary allowances for scour at the base of riprap.



* Approx. allowance for water depth (not penetrated by LiDAR) and scour

Figure 3-1. Schematic Representation of Riprap Embankment Measurement and Estimation Parameters

The required thickness of riprap placement on the embankment is largely based on the grain size diameter of the riprap. A stable riprap gradation is best determined through hydraulic modelling or applicable empirical guidelines (e.g., as reported by the Transportation Association of Canada (TAC), 2004). For the purposes of this assessment, a 1.0 m riprap thickness was assumed. Through previous correspondence with HPW-TEB, it was determined that Class II riprap is most commonly applied at encroachment sites along the Dempster Highway. Class II riprap has a median grain size diameter (D_{50}) of 0.5 m and a maximum grain size diameter (D_{100}) of 0.8 m. A 1.0 m thickness is two times greater than the D_{50} and 1.25 times greater than the D_{100}, which aligns with standard protocols (e.g., Ontario Ministry of Transportation, 1995; Province of British Columbia, 2000; TAC, 2004). HPW-TEB may prefer a thicker cover of riprap to allow for localized effects of ice build-up, scour and plucking, for example based on tests conducted by Sodhi et al. (1999), in which case the ultimate riprap volume estimates could easily be recalculated.

The total volume of riprap required at each encroachment site was calculated as the product of the predicted embankment lateral extent, its 2H:1V slope length, and its assumed riprap thickness (1.0 m). The riprap volume estimate is based on the predicted lateral extent of impact, as described above, and does not account for additional riprap that may be required for maintenance or to mitigate downstream (or upstream) erosion due to longitudinal migration. The riprap volume estimates assume proactive erosion protection measures are not implemented and the embankment will not be riprapped until immediately before impact.

Extents of impact and associated riprap requirements were not provided for encroachment sites exhibiting no systematic migration over the period of record, due to the unreliability of predicted upstream and downstream limits of impact.

3.3.6 Alternative Erosion Protection Measures

Despite its widespread application along the banks of large creeks and rivers that parallel the Dempster Highway, riprap can have a number of negative consequences for channel morphology and aquatic ecology of which HPW-TEB should be aware (Reid and Church, 2015): (1) reduction of local sediment supply; (2) substrate coarsening; (3) channel incision and/or longitudinal migration; (4) localized bank scour at the upstream and downstream limits of riprap; and (5) reduction in organic input, including large woody debris, from the riparian zone.

Riprap embankments also commonly require maintenance or local reconstruction due to partial or complete failure by undermining or dislodgment, entrainment of stone by water or rafted ice, or thawing of underlying permafrost. Depending on the frequency and cost of maintenance, alternative erosion protection measures may prove more cost-effective in the long-term. The relative rarity along the Dempster Highway of bedrock sources suitable for the production of Class II or III riprap further increases costs associated with riprap revetments, due to hauling and quarry development limitations, in comparison to other available techniques.

In addition to default estimation of riprap requirements, Kryotek and PECG considered whether alternative erosion protection measures may warrant consideration at at-risk encroachment sites. Implementation of alternative erosion protection measures would generally necessitate rock placement, cut/fill or restoration beyond the 30 m highway right-of-way within which HPW-TEB is permitted to work, so additional approval may need to be sought if such works are pursued. The following subsections provide an overview of alternative erosion protection measures that HPW-TEB could consider using instead of, or in addition to, riprap, depending on site-specific conditions.

3.3.6.1 River Training Structures

General consideration was given to the appropriateness and benefits of using river training structures to mitigate the risk of highway embankment erosion at each encroachment site. River training structures are designed to shift the thalweg from its current alignment within the channel in order to reduce erosion along a bank and/or deliberately increase scour elsewhere within the channel (e.g., to erode a medial bar that is concentrating flow along a bank). They can be used in the absence of riprap bank protection, where conditions and proximities to the highway permit, or in addition to riprap bank protection. River training structures may provide a means of preserving natural riparian habitat and creating more diverse in-stream habitat features.

Two of the most common and effective types of river training structures are bendway weirs and flow retarding bars, or 'hockey stick' weirs. Bendway weirs, originally developed to improve navigation along the Mississippi River (Derrek, 1994), are linear rock structures that project slightly upstream from a channel bank aimed at shifting the erosive energy of flow away from the bank. Hockey stick weirs, in

contrast to bendway weirs, are linear rock structures designed to project slightly downstream from a channel bank with the same objective of shifting the thalweg away from the bank. The principal difference in form is that bendway weirs are typically designed with a crest just below normal water level, whereas hockey stick weirs are typically designed with a crest approximately coincident with bankfull stage. The term 'hockey stick' relates to the resemblance of the weir, in plan view, to a hockey stick. An abrupt bend at its end is designed to direct toe scour away from the base of the main weir structure.

River engineering manuals (e.g., HEC-23, 2001) and related publications (e.g., Derrick, 1995; Saele and Fripp, 2005) outline a number of criteria for the design of bendway weirs and other river training structures. For example, guidelines are typically provided for weir height, width, angle, surface slope, length, spacing, key depths and stone sizes. Rarely, however, are equally important geomorphological considerations in the siting and design of river training structures identified. The effectiveness of river training structures contemplated for use along the large creeks and rivers alongside the Dempster Highway would depend on whether their implementation considered unanticipated lateral or vertical channel adjustments, irregular sediment transport patterns, unfavourable interactions with ice cover, and/or accelerated thawing of permafrost within the banks.

In identifying encroachment sites where river training structures may be more effective than riprap alone, or may replace the need for riprap, Kryotek and PECG considered a number of geomorphological parameters at a preliminary level: channel pattern and avulsion history; meander geometry and channel width; and implications of hillslope processes. Additional assessment is required of sediment transport and gravel bar dynamics, potential river ice interactions, bank composition and permafrost, and implications for fish habitat.

For the purposes of facilitating high-level cost comparisons between riprap and river training structures, we assumed that river training structures would generally require similar volumes of riprap-caliber rock as those required for standard riprap bank protection. For example, if 1,000 m^3 of riprap was required for bank protection along the outer bank of a particular meander, approximately 1,000 m^3 would likely be required to construct river training structures at that site (instead of, or in addition to, placing riprap along the bank). The predicted benefit would be a reduction in long-term maintenance requirements if the river training structures are designed appropriately. If both riprap bank protection and river training structures were deemed necessary, for example due to a propensity for scour and undermining, the volume of rock required at that site would double (i.e., a total of approximately 2,000 m^3 would be required based on the example above). More detailed assessment and design development would be required to accurately determine rock volume requirements for different erosion protection measures.

3.3.6.2 Bioengineering Techniques

Kryotek and PECG gave consideration to the use of bioengineering techniques for more natural bank stabilization at select encroachment sites where the highway embankment is not at immediate risk of impact. Bioengineering should only be considered as a form of bank stabilization at sites along small (low-energy) channels with low, permafrost-free (or ice-poor) banks and little to no history of migration toward the highway. The documented effectiveness of bioengineering techniques in such northern environments with discontinuous permafrost, extensive wintertime ice cover, prolonged topographic

shading and short growing seasons should be further investigated prior to developing site-specific designs.

Three of the most common and straightforward types of bioengineering for bank stabilization include brush mattresses, brush layers and anchored large woody debris. A *brush mattress* consists of layers of living branches of willows, for example, laid in a criss-cross pattern against a channel bank to form a living ground cover. The integrity of the mattress itself provides short-term stability until the shoots from the branches root and establish a shrubby bank cover. Brush mattresses inhibit erosion of exposed soils due to rainsplash and low to moderate flows. *Brush layers* are living branches placed in several layers along a channel bank, interbedded with soil and projecting into the channel edge. Brush layers are effective for filling and stabilizing small scour holes or shallow sloughs in banks, and they can dramatically reduce shear stresses along the bank once the shrubs (e.g., willows) comprising each of their layers become established. *Anchored large woody debris* has been used to stabilize channel banks, naturalize sediment transport patterns, and diversify aquatic habitat particularly in watersheds that have been clear-cut in association with forest harvesting. Large woody debris gets embedded and anchored into the banks, typically using boulders and cables or anchor logs in addition to the weight of overlying soil, with its rootwad projecting into the edge of the channel. The rootwad inhibits bank scour while promoting localized scour pool formation with benefits for aquatic habitat. Anchored woody debris must be positioned carefully and secured well in order to minimize the potential for outflanking or dislodgment.

Kryotek and PECG deemed bioengineering worthy of HPW-TEB's consideration at select sites due to the significant cost savings for implementation and improved public perception. Most if not all material necessary for the suggested bioengineering techniques can likely be sourced on site at least at certain times of year (i.e., dormant periods of shrub growth). Due to the relative lack of large woody debris (>30 cm diameter), this material would need to be sourced off-site or replaced with several logs bound together to produce a similar diameter and effect. Additional supervision may be required during the implementation of bioengineering measures if equipment operators are not experienced in their installation.

3.3.6.3 Channel and Floodplain Modification

Kryotek and PECG considered opportunities to modify the channel or its adjacent floodplain as a means of mitigating erosion of the highway embankment. Possible modifications to a channel include resculpting its cross-sectional shape to increase hydraulic capacity and reduce shear stresses along the eroding bank, although careful consideration must be given to meander geometry and the potential for the channel to readopt its existing form. Local channel realignment was also considered. Channel realignment would only warrant consideration for a side channel or narrow section of a creek, where there is little potential for subsequent avulsion and readoption of its current planform. Channels are realigned regularly and successfully in areas of resource and urban development, using natural channel design principles aimed at mimicking the form and function of the existing channel.

Localized and deliberate excavation of a floodplain can also be used to reduce the shear stress exerted along the outer bank of a meander. For example, a floodplain could be terraced such that local bankfull width increases but bankfull depth (which drives scour potential) decreases. A flood swale could also be

excavated in the surface of a floodplain to convey a portion of flow once water level surpasses a certain elevation and height on the bank. Such a channel may require armouring in order to inhibit incision and unintended avulsion.

In most cases, the cost of channel or floodplain modification likely exceeds the cost of riprap protection and other alternative erosion protection measures. Such modifications also may necessitate a more rigorous approvals process, in accordance with the temporary disturbance they could have on in-stream and riparian habitat. Approximate volumes of possible cut-and-fill were specified at applicable encroachment sites, but detailed field investigations and follow-up analyses are required to accurately determine volumes and design parameters.

3.4 Phase 4 – Field Reconnaissance Investigations

3.4.1 Mass Movement Geohazard Sites

Field reconnaissance investigations were completed for three main reasons: (1) to 'ground truth' desktop-based interpretations and determine which of the conservatively identified geohazard sites could be excluded from the inventory; (2) to collect additional, site-specific observations and measurements of each mass movement to support its more refined characterization and risk evaluation; and (3) to identify any new mass movement geohazards that have occurred since the 2013/2014 orthophotography and LiDAR data were acquired.

Field work was completed within one week in early June 2016, during which weather was mostly a mix of sun and cloud with isolated showers. Two crews each comprising two staff from Kryotek and PECG conducted truck-based field reconnaissance in a convoy from km 0 to km 465, with accommodation at Ogilvie Camp or in Dawson. All work was conducted in accordance with our team's project-specific safety plan approved in advance by HPW-TEB.

The nature of investigative work completed at each mass movement geohazard depended on its type, proximity and complexity, and was generally commensurate with the need for field observation and measurement to supplement desktop-based analysis methods. Field equipment available to each crew included a shovel (spade), hand auger, frost probe, measuring tape, clinometer, laser rangefinder, knife, trowel, hand lens, camera, handheld GPS, compass and increment borer. Kryotek's backpack-portable auger drill and electrical resistivity equipment were also available for use where critical to better understand failure mechanisms in areas of ice-rich permafrost.

Field observations were recorded directly on field maps, in field notebooks or on GPS-enabled smartphones loaded with the geoPDF field maps. Brief comments at each inspection site were compiled in **Appendix B**. If a preliminarily identified site warranted exclusion from the inventory, a simple 'not a hazard' note was made along with a brief justification. At a minimum, photographs were taken of all geohazard sites to support subsequent desktop-based analyses. Observations and measurements were made, as appropriate, of site topography, surficial materials, permafrost conditions[4], evidence of instability

[4] Active layer thicknesses were very shallow (commonly only 10 cm) due to the early June reconnaissance period and not representative of late-summer thicknesses, so few were recorded.

and failure geometry. No samples of soil or rock were collected, as the analysis of such material would offer little additional insight to reconnaissance-level investigations of mass movement processes. Evidence of the recency or recurrence of certain mass movements was collected, where possible, using basic dendrochronological techniques. Small cores from trees on, or immediately adjacent to, the mass movement were extracted using an increment borer.

3.4.2 Prioritized Meander Migration Hazard Sites

Field inspections were completed at all of the prioritized meander migration hazard sites for which a detailed desktop-based assessment had been completed (Section 3.3). Representative photographs were taken (**Appendix I**), and observations were made of channel bank and floodplain conditions. Measurements of the proximity between the channel bank and the toe of the highway embankment were completed to confirm that the value measured from the 2013/2014 imagery is still representative of site conditions (within a margin of error of about 3 m). Any significant failures of the highway embankment or existing riprap were noted.

Although field inspections were not systematically made at all non-prioritized sites, incidental observations of maintenance concerns (e.g., sloughing highway embankment, failing riprap) were recorded where noted (**Appendix B**). A number of meander-highway encroachment sites outside the original study area exhibit similar characteristics to those prioritized ones and, therefore, warrant a similar level of more detailed, follow-up assessment (as recommended below in Section 6 and in **Appendix F**).

3.5 Phase 5 – Data Analysis and Interpretation

3.5.1 Updated Mass Movement Geohazard Identification, Delineation and Characterization

All preliminarily identified mass movement sites determined not to represent hazards to the highway for one reason or another were removed from the inventory. All field-confirmed and newly identified hazards were carefully re-analyzed with reference to field photographs and notes. The limits of each hazard were refined, where necessary, and well-defined transitions between initiation and transport, or transport and runout, were delineated. Key linear features associated with each hazard, such as headscarps or tension cracks, were added. Failure geometries were carefully measured based on the imagery and LiDAR-derived topographic data, with confirmatory comparisons to site-specific field measurements, in order to ensure the final values are fully representative of the feature (ground-based measurements are commonly inaccurate due to view obstructions and poor spatial context).

Standardized summary figures, including site plans, field photographs and key data, were prepared for each of the final mass movement geohazards (**Appendix C**). The standardized data table included in these summary figures has been modified slightly for thermokarst features (subsidence or gully) to ensure the most important information is effectively communicated. Each of the site, process, geometry and implications attributes documented on each summary figure is defined in **Table 3-5**. Additional attributes documented at each site to support interpretations, along with a metadata table of attribute definitions, are provided in **Appendix A**.

Table 3-5. Definitions of Key Attributes of Mass Movement Geohazard Sites (reported in Appendices A and C)

	Abbrev. Heading	Description
SITE	Section	Highway maintenance section
	Proximity (m)	Proximity, or shortest distance (m), between nearest limit of geohazard and toe of highway embankment
	Aspect (°)	Average aspect of mass movement slope (0-360°)
	Surficial material	Dominant surficial material involved in mass movement (e.g., gszFAp), based on field-checked surficial geology mapping, coded with texture (gsz: silty sandy gravel), genetic material (FA: active fluvial) and surface expression (p: plain) according to YGS' adaptation of Howes and Kenk (1997)
	Permafrost	General permafrost characteristics on mass movement slope, such as approximate depth (active layer thickness) and/or ground ice conditions
PROCESS	Type	Classification of dominant mass movement process according to Hungr et al. (2014), with permafrost-related refinements based on van Everdingen (2005)
	Position	General position of mass movement relative to highway
	Causes	General factors contributing to mass movement, considering both natural and anthropogenic influences
	Triggers	Potential mechanisms for actual mass movement initiation
	Timing	General timing of occurrence, or recurrence, of mass movement based mainly on historical imagery and/or dendrochronological analysis
GEOMETRY	Elevation (m)	Approximate elevation above sea level (m) of centroid of delineated mass movement polygon
	Initiation slope (°) [a]	Approximate angle (°) of mass movement initiation zone
	Runout slope (°) [a]	Approximate angle (°) of mass movement runout zone
	Average slope (°)	Approximate average angle (°) of mass movement (fahrböschung, from crest of source to toe of deposit, for slope processes; from upslope to downslope limits for thermokarst features)
	Dimensions (L/W/D) (m) [a]	Approximate dimensions (m) of mass movement: total length (L), width at highway (W), and depth (thickness) (D)
	Length (m) [b]	Approximate total horizontal length (m) of thermokarst feature
	Width (m) [b]	Approximate width (m) of thermokarst feature (top width for gullies; cross-slope width for subsidence)
	Depth (m) [b]	Approximate depth of thermokarst feature (vertical depth for gullies; local (internal) relief for subsidence)
IMPLICATIONS	Likelihood	Projected frequency of impact to highway based on current conditions
	Consequence	Projected severity of impact to highway based on current conditions
	Risk	Relative (qualitative) risk of highway impact, considering both likelihood and consequence, based on current conditions (as defined in the risk evaluation matrix (Section 3.5.2); note: km post text box in bottom-right corner of summary figures in **Appendix C** colour-coded according to risk
	Mitigation	General insight with respect to the nature of processes requiring management in order to mitigate risk to the highway
	Comments	Any additional noteworthy comments specific to the geohazard site

Notes:

[a] Presented for slope processes (including retrogressive thaw slumps) only

[b] Presented for thermokarst subsidence and gullies only

3.5.2 Evaluation of Risk to Highway

Evaluation of the risk posed by each mass movement geohazard to the highway provides a basis for HPW-TEB to make site-to-site comparisons with respect to potential highway implications. Kryotek and PECG developed a qualitative 'risk matrix' to evaluate each geohazard's risk by considering its likelihood and potential consequence of occurrence (**Figure 3-2**). The relative thresholds of 'likelihood' and 'consequence' have been established with practical implications in mind, enabling HPW-TEB to more effectively prioritize sites for follow-up investigation and mitigation. The likelihood classes consider expected, approximate timeframes within which a particular mass movement may occur (or recur); the consequence classes consider general implications for highway maintenance and closures. The risk evaluation completed for each site incorporated insight from both the desktop interpretations and the field reconnaissance investigations.

RISK EVALUATION MATRIX			CONSEQUENCE		
			Low	Moderate	High
			Highway ditch/edge maintenance, necessitating <1 day or partial (single-lane) closure	Highway coverage/settlement, necessitating ≥1 day closure	Highway damage/collapse, necessitating local road reconstruction
LIKELIHOOD	High	<2 years	Moderate	High	Very High
	Moderate	2-10 years	Low	Moderate	High
	Low	>10 years	Very Low	Low	Moderate

Figure 3-2. Mass Movement Geohazard Risk Evaluation Matrix

A careful review and basic statistical analysis of key characteristics of each mass movement geohazard along the Dempster Highway was completed in an effort to establish correlations among geohazard characteristics that best explain the distribution and general magnitude of their occurrence (or recurrence). Such analysis may help reveal project-specific topographic, geomorphological or permafrost-related criteria that can be used to evaluate hazard and risk levels and predict sites of future instability. Summary graphs were prepared for HPW-TEB's future reference and planning applications.

3.5.3 Updated Prioritized Meander Migration Hazards

A comparison was made between field observations and the desktop-based delineations and interpretations to ensure conditions are still represented well by the 2013/2014 bank position and morphology. For sites with meander-highway proximities that had been reduced through bank erosion by more than about 3 m (the approximate margin of error), the proximities and estimated timeframes until impact were updated accordingly (i.e., final estimates of timeframes until impact are from 2016). No changes to estimated riprap volumes were required.

4 Results

The main results of the mass movement geohazard identification, delineation and characterization, including a site plan and field photographs of each hazard, are provided in **Appendix C**. Site plans and basic information about each of the originally identified meander-highway encroachment sites are compiled in **Appendix F**; stand-alone summary figures presenting the results of the detailed meander migration hazard assessments are provided in **Appendix H**. The following sections report summaries of key results of both the mass movement and meander migration hazard assessments.

4.1 Mass Movement Hazards

Field reconnaissance investigations along the Dempster Highway culminated in the identification of 54 mass movement geohazards (**Appendix D**). Basic observations made at each of nearly 200 inspection sites are tabulated in **Appendix B**. Where applicable, reference is made to more detailed, site-specific information provided in the summary figures for each mass movement geohazard (**Appendix C**).

Seven classes of mass movement geohazards were identified and included in the final inventory (from most to least common): active layer detachments, retrogressive thaw slumps, rockfall, thermokarst subsidence, debris flows, thermokarst gullies and debris slides. Eight of the 54 geohazard sites exhibit more than one mass movement process (e.g., both rockfall and debris slides). **Figure 4-1** summarizes the total number of each identified hazard class within the entire study area. The active layer detachment form of debris slide is by far the most common type of identified mass movement (20 of 54). Fewer than ten occurrences of each of the other six types of mass movements were identified, including the second-most common: retrogressive thaw slumps (9 of 54). The identification of only one regular (permafrost-free) debris slide in **Figure 4-1** is misleading, as debris slides occur at some of the multiple process sites.

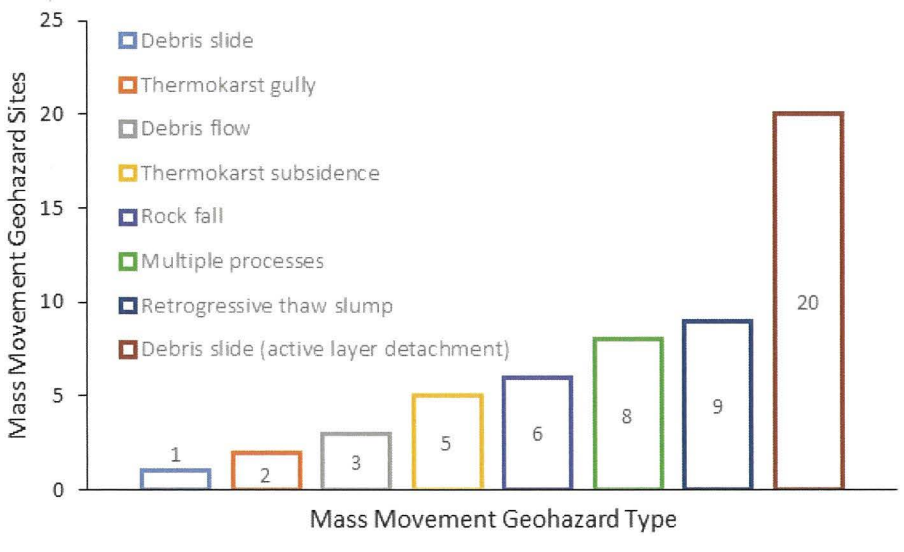


Figure 4-1. Total Number of Mass Movement Geohazards, by Class

The majority of mass movement geohazards occur within the Ogilvie highway maintenance section (38 of 54) (**Figure 4-2**, **Appendix D**) due to its relatively high relief and slope-toe highway alignment. The greatest concentration of mass movement geohazards is located at the base of a high mountainside between km 212 and km 214. The Ogilvie maintenance section also exhibits the greatest diversity of mass movement geohazards (**Appendix D**). All 11 mass movement geohazards within the Klondike maintenance section are related to permafrost, with a notable concentration of retrogressive thaw slumps near Chapman Lake (**Appendix D**). Comparatively few mass movements pose a risk to the highway within the Eagle Plains maintenance section (5 of 54), despite it being the longest section (**Appendix D**). The Eagle Plains maintenance section owes its relative paucity of mass movement geohazards to the rounded ridge crest and gentle, lower mountain slopes the highway traverses.

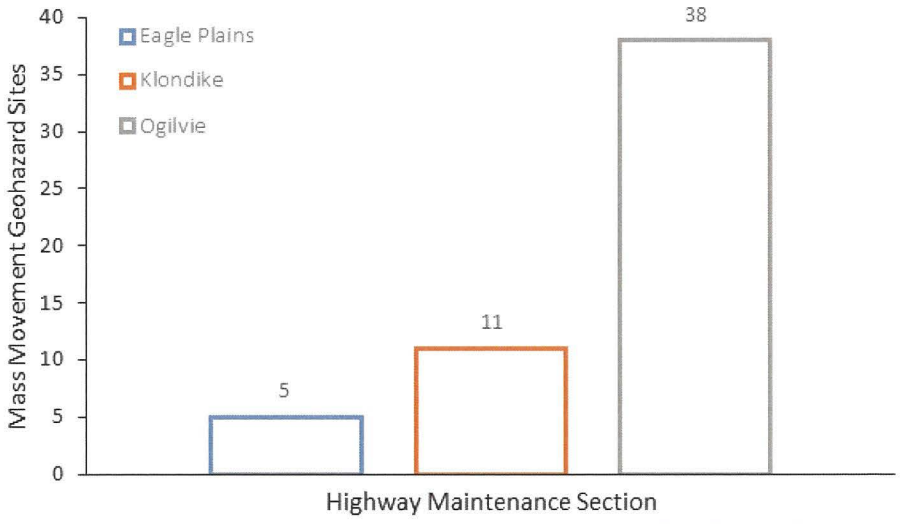


Figure 4-2. Total Number of Mass Movement Geohazards, by Maintenance Section

Of the 54 mass movement geohazards, more than three-quarters (41) originated **above** the highway (**Figure 4-3**). Some of these terminate at the edge of the highway embankment, while others have existing or projected limits that extend onto or across the highway. Mass movement failures originating **below** the highway, but with the potential to impact the highway through retrogressive erosion, represent nine of the identified geohazards; some of these have already extended upslope and crossed the highway. Mass movement geohazards **beneath** the highway (e.g., thermokarst subsidence) were only identified in four locations.

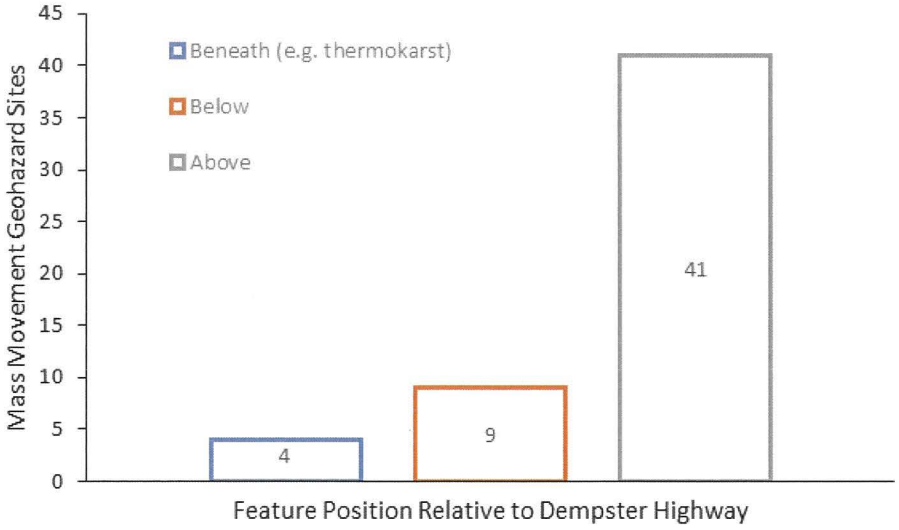


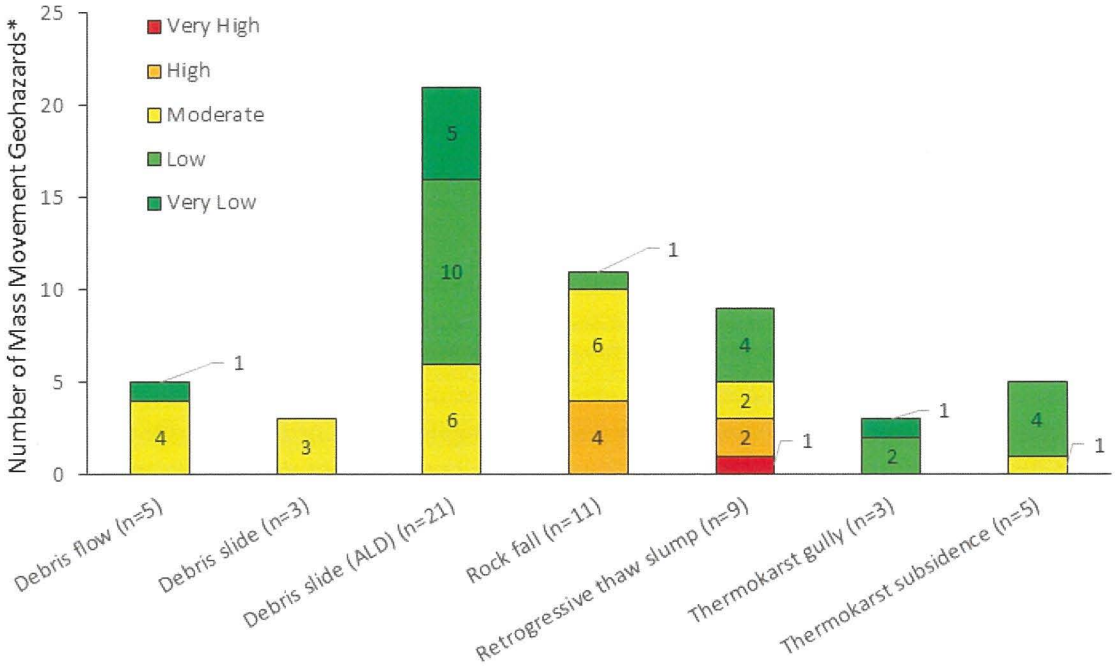
Figure 4-3. Total Number of Mass Movement Geohazards, by Position Relative to Highway

Although 54 mass movement geohazard sites were inventoried along the Dempster Highway, exactly half (27, or 50%) of these represent low or very low risk to the highway (**Table 4-1**, **Appendix E**). Such sites were included in the final inventory given their potential requirement for periodic maintenance or to ensure recognition of the possibility of impact at the site, however slight. Seven, or 13%, of mass movement geohazard sites represent a high or very high risk to the highway. Four of these are rockfall (km 224.7 and km 176.5) or rockfall/debris slide (km 212.5 and km 212.8) slopes well known to HPW-TEB. The other three are retrogressive thaw slumps that have developed on the river-cut scarp on the southeast side of the highway near Chapman Lake. The retrogressive thaw slump at km 116.2 earned the very high risk rating, according to the evaluation matrix of likelihood and potential consequence (Section 3.5.2), and already appears to have necessitated a shift in the alignment of the highway. Continued retrogression of the multi-headscarp feature has occurred in recent years, based on comparative overlay analysis of available imagery and the identification of fresh tension cracks well back from the headscarps. The retrogressive thaw slumps at km 115.6 and km 115.9 exhibit fewer signs of activity near or beyond their headscarps, but they have the potential to evolve into similarly active features. Water ponding along the base of the northern highway embankment at km 115.9, in an area of degrading ice-wedge polygons, may enlarge in extent and depth and help to accelerate retrogression on the opposite side of the highway.

Table 4-1. Summary Distribution of Mass Movement Geohazard Risk Ratings

Risk Rating	Number of Geohazard Sites	Percentage of Geohazard Sites
Very High (VH)	1	2%
High (H)	6	11%
Moderate (M)	20	37%
Low (L)	21	39%
Very Low (VL)	6	11%
Total:	**54**	**100%**

Figure 4-4 indicates that the second- and third-most common mass movement geohazards identified along the highway, rockfall and retrogressive thaw slumps, respectively, generally represent the highest risks. Despite the widespread distribution and visual impressiveness of active layer detachments, most of those included in the inventory only pose a risk in association with post-event, modifying sloughs or flows. Accumulation of material in the ditches or at the edge of the highway would likely necessitate short-duration (<1 day) or partial (1 lane) highway closure. Active layer detachments within a particular slide path (i.e., delineated geohazard polygon), at the scale of the original event, are non-recurrent within timescales relevant to highway operation and maintenance (i.e., recurrence within a given scar typically necessitates full recovery of vegetation and surface organics, which may take more than a century).



* Separately counts geohazards at multiple-process sites, hence total >54

Figure 4-4. Total Number of Mass Movement Geohazards, by Risk Rating

4.1.1 Retrogressive Thaw Slump Case Study

One of the mass movement processes most likely to necessitate localized reconstruction if it reaches the highway is retrogressive thaw slumps. Kryotek's backpack-portable auger drill was used to assess ground (permafrost) conditions conducive to retrogressive thaw slumps at a relatively small, recently developed retrogressive thaw slump on the west side of the highway at km 93.6 (**Appendices C** and **D**). The slump had developed in silty to sandy, inactive fluvial deposits on nearly level ground, at the edge of a shallow drainage swale that enters the East Blackstone River shortly after crossing the highway. Field investigations confirmed the desktop-based interpretation of ice-wedge polygons in the area; an ice wedge at least 2 m wide was exposed within the ablating headscarp of the retrogressive thaw slump

(**Figure 4-5**). Five shallow (<1 m) auger boreholes drilled in undisturbed ground within 10 m of the headscarp intersected ice-rich silt and very fine sand beneath about 15 cm of surface organics. Ground ice was present in pores and segregated seams, in addition to the ice wedges. Meltwater and rainwater ponded at the edge of the drainage swale, at the toe of the retrogressive thaw slump, appears to be contributing to the thawing of the underlying, ice-rich soils.

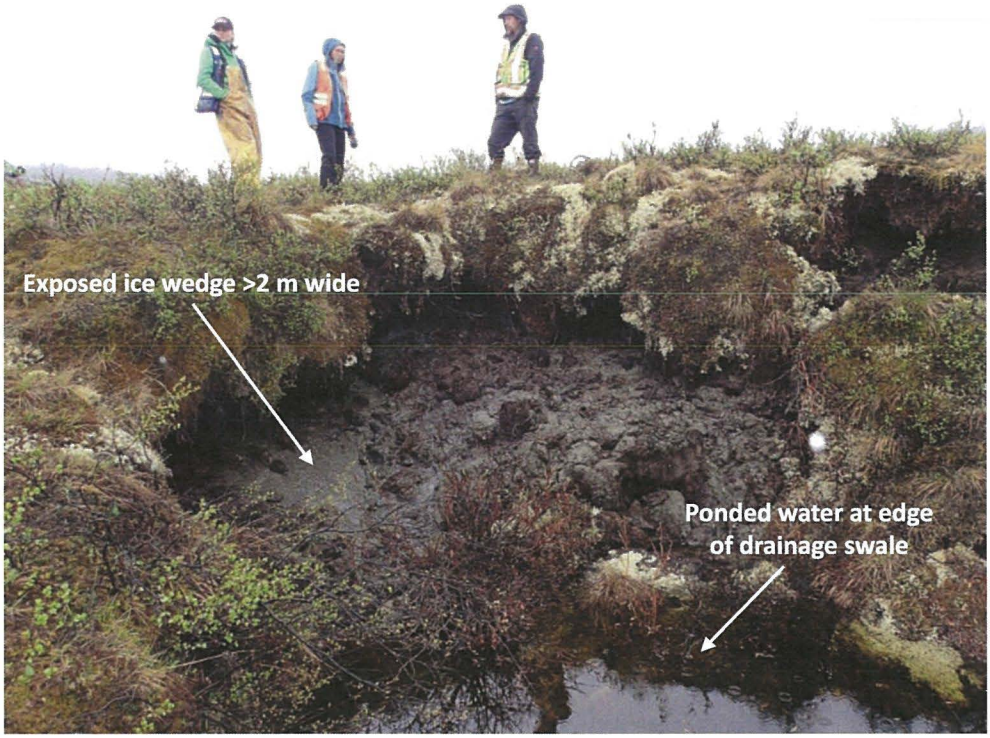


Figure 4-5. Ice-rich Permafrost in Headscarp of Retrogressive Thaw Slump at km 93.6

4.2 Meander Migration Hazards

A total of 102 meander-highway encroachment sites with the potential for migration-induced undercutting and collapse of the highway embankment was identified within the Klondike and Ogilvie highway maintenance sections (**Appendices F** and **J**). The greatest concentration of encroachment sites occurs along Engineer Creek, which transports considerable volumes of bedload along its unstable, wandering channel bound by banks comprising ice-rich permafrost. No potential meander migration hazard sites were identified within the Eagle Plains maintenance section, within which the highway mostly traverses a ridge or crosses headwater tributaries at the base of the Richardson Mountains. The tortuously meandering Eagle River, itself, exhibits a high degree of channel instability but currently does not encroach alongside the highway.

Figure 4-6 summarizes the findings of meander migration hazard mapping, grouped by proximity of the channel bank to the nearest edge of the Dempster Highway. The vast majority of encroachment sites (79 of 102) have proximities of 10 m or less, 45 of which exhibit no (0 m) separation and may be only partly

protected by riprap, with a risk of future instability through scour or undermining of the riprap (**Figure 4-6**). It is important to note that the proximity is a useful, comparative reference, but it is not necessarily indicative of the hazard or risk posed to the highway. The results of a more thorough assessment of potential meander migration hazards at 26 encroachment sites prioritized following initial desktop-based identification are provided in the following sections.

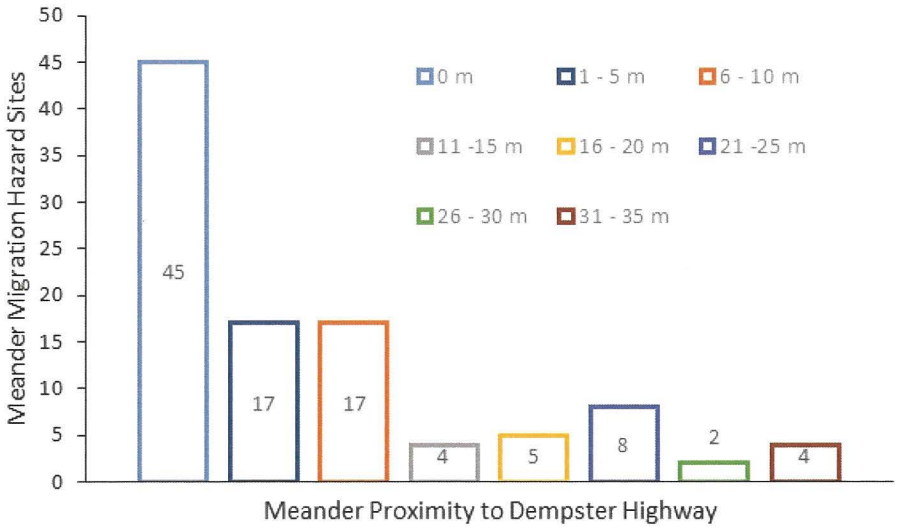


Figure 4-6. Total Number of Meander-Highway Encroachment Sites, by Proximity

4.2.1 Hydrological Assessment

As outlined above in Section 3.3.3, a hydrological assessment was completed to inform interpretations of detailed assessment of prioritized meander migration hazards along the Dempster Highway. Regression analyses suggest there was a very slight decrease in mean annual flow along North Klondike River and a very slight increase along Blackstone River over the period of record (**Figure 4-7**). As expected, there was considerable variability in the mean annual data at both sites. The magnitudes of annual flood events do not appear to systemically increase or decrease (**Figure 4-8**). The negligibility of temporal change in mean annual flow and maximum daily discharge data suggests, at a regional scale, the flow regime did not systematically change over the period of photographic record (1977 to 2013/2014).

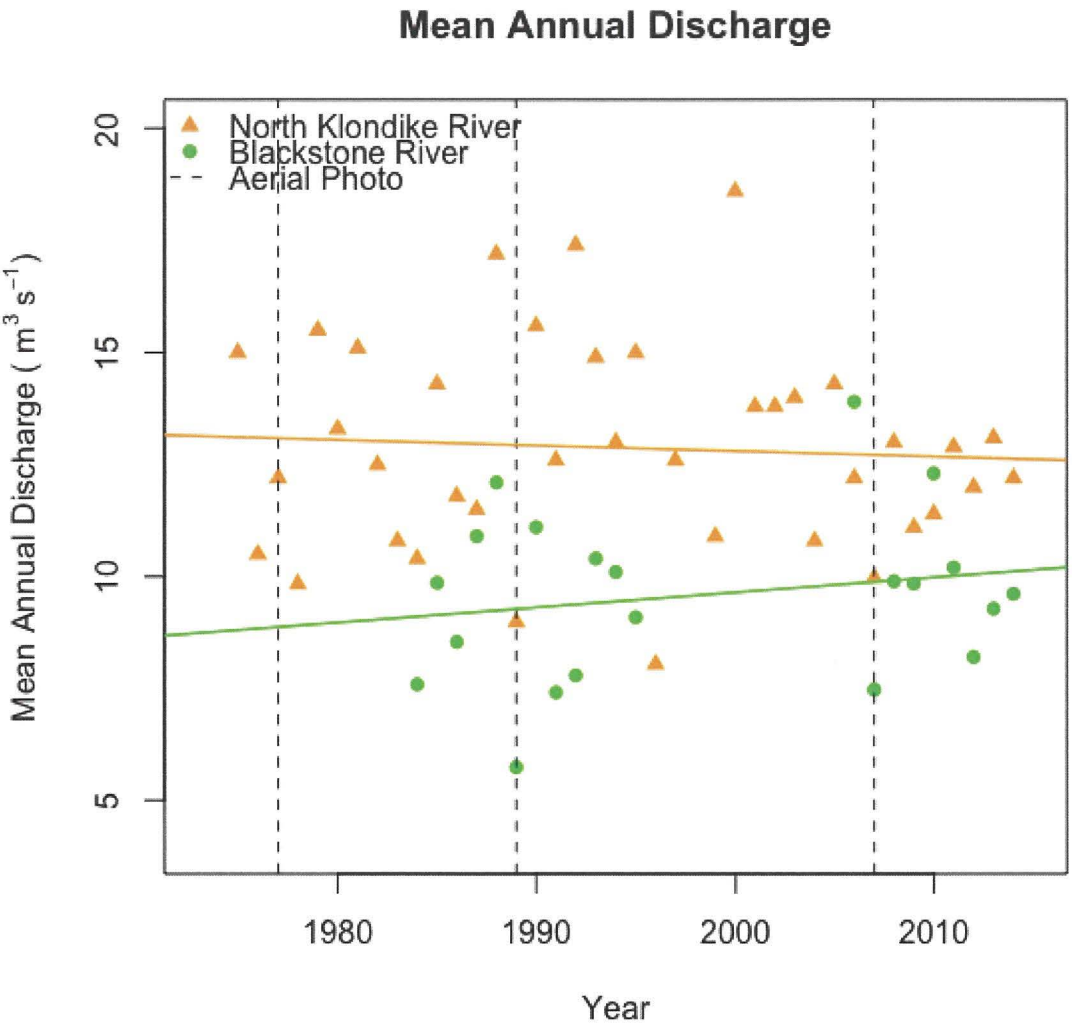


Figure 4-7. Mean Annual Discharge along North Klondike River (WSC 09EA004) and Blackstone River (WSC 10MA003)

One noteworthy finding is the magnitude of the annual flood event at Blackstone River in 1993. The maximum daily discharge (534 m^3/s) in 1993 was considerably greater than both the average peak discharge (127 m^3/s) and the second largest recorded flood (138 m^3/s). This 1993 flood, assuming its documented magnitude is accurate, was likely caused by a large rain-on-snow event and would have led to considerable morphological restructuring along the channel. Climatic data to confirm a large precipitation event and/or snow melt from a nearby weather station were not found, and accessible weather records in Dawson are only complete as far back as 1995. The annual flood on Peel River, into which Blackstone River flows, was recorded on the same day but was not anomalously high (10^{th} largest flood in a 40-year record).

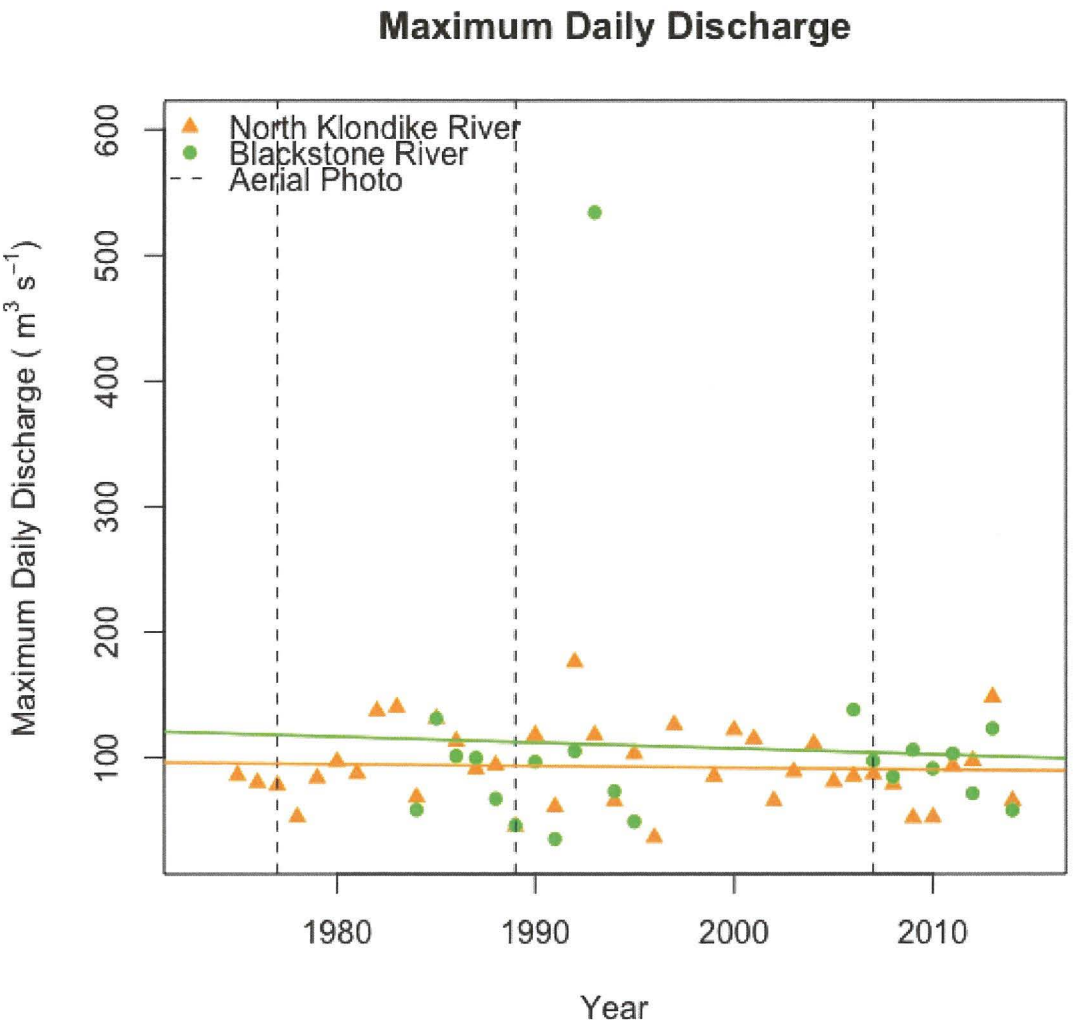
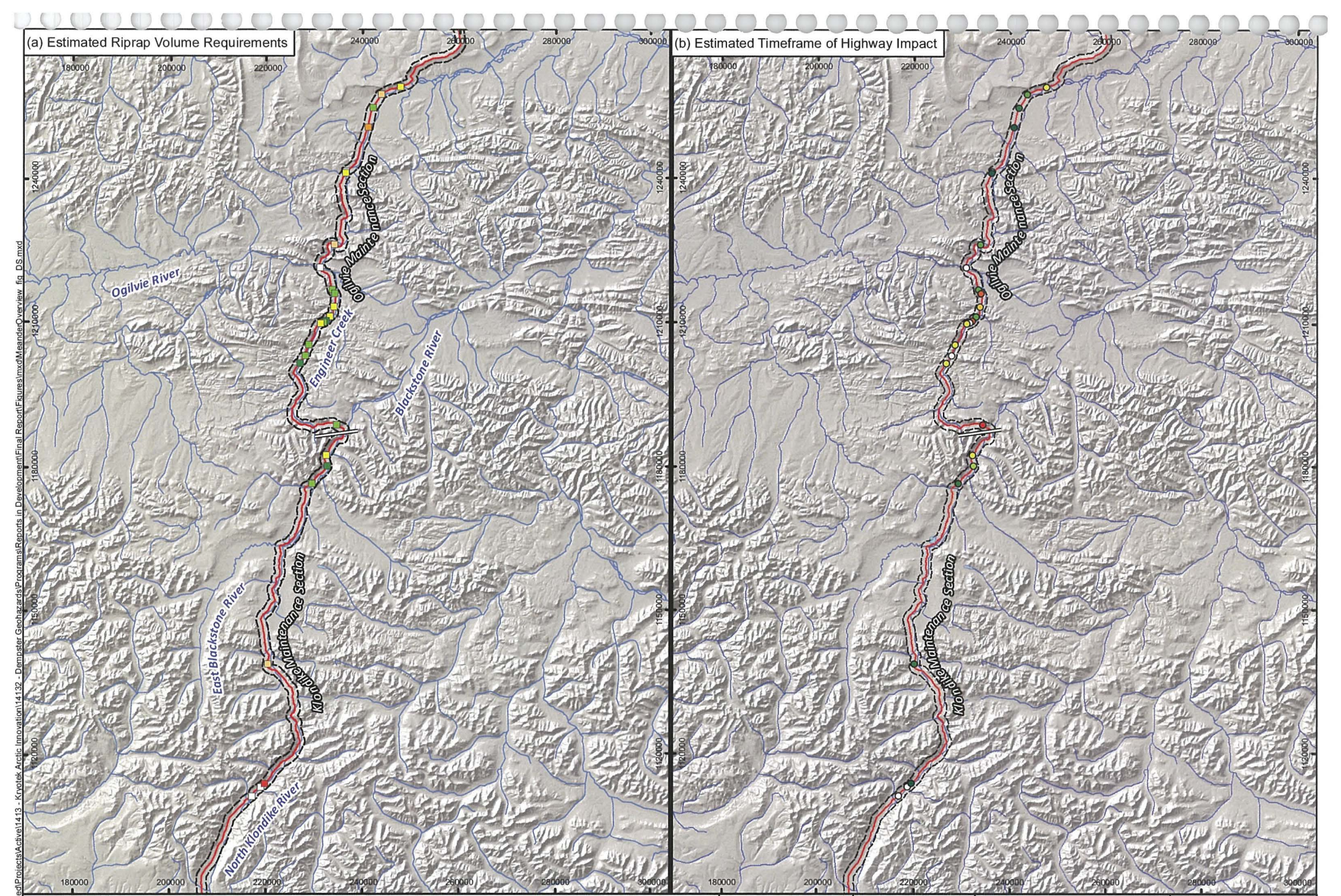


Figure 4-8. Maximum Daily Discharge along North Klondike River (WSC 09EA004) and Blackstone River (WSC 10MA003)

4.2.2 Forecasted Riprap Requirements

The migration rate analyses resulted in a broad distribution of estimates of timeframe until impact and riprap requirements. The spatial distribution of timeframe until impact and riprap volume requirements is presented in **Figure 4-9**. The number of encroachment sites and total estimated riprap requirements corresponding to each timeframe until impact are presented in **Table 4-2**. The highway embankment has already been impacted at three sites and will likely be impacted at two more sites within 2 years. Furthermore, it will likely be impacted at eight sites within the next 10 years.



LEGEND

- Dempster Highway
- Watercourses
- Study Corridor
- Maintenance Section Break

Riprap volume (m3) - Figure (a)

- N/A (no systematic erosion toward hwy)
- 0 - 500
- 501 - 1000
- 1001 - 1500
- 1501 - 2000
- 2001 - 2500
- 2501 +

Timeframe of impact (yr) - Figure (b)**

- N/A (no systematic erosion toward hwy)
- >25 yrs
- 21 - 25 yrs
- 16 - 20 yrs
- 11 - 15 yrs
- 6 - 10 yrs
- 2 - 5 yrs
- <2 yrs
- 0 yrs

**Estimated timeframe of impact from 2016 field reconnaissance

0 10 20 km

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Yukon Government

Project: Dempster Meander Migration Hazards
Project number: 14132
Client: Yukon Government

KRYOTEK

PALMER ENVIRONMENTAL CONSULTING GROUP INC.

Distribution of Riprap Requirements at Priotitized Meander Encroachment Sites

Figure 4-9

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Data notes: Digital Elevation Model and base data provided by: Geomatics Yukon via online source (www.geomaticsyukon.ca)

Table 4-2. Estimated Riprap Requirements by Timeframe until Impact

Timeframe until Impact (from 2016)	No. of Sites	Total Volume of Required Riprap (m^3)
Channel has impacted highway embankment	3	2,150
<2 yrs	2	1,350
2-5 yrs	1	1,460
6-10 yrs	5	4,920
11-15 yrs	1	100
16-20 yrs	4	5,230
21-25 yrs	3	2,860
>25 yrs	3	8,780
No systematic migration	4	0
Total:	**26**	**26,850**

The number of encroachment sites at which impacts are forecasted within each time period is summarized for each studied river system in **Table 4-3**. The majority of encroachment sites along North Klondike River and Ogilvie River are unlikely to require erosion protection measures within the next 20 years. This contrasts with encroachment sites along Engineer Creek, 8 of 10 which will likely require erosion protection measures within 10 years.

Table 4-3. Number of Sites per Timeframe until Impact for Each River System

Timeframe until Impact (from 2016)	No. of North Klondike River Sites	No. of Blackstone River Sites	No. of Engineer Creek Sites	No. of Ogilvie River Sites
Channel has impacted highway embankment		1	2	
<2 yrs			2	
2-5 yrs			1	
6-10 yrs		1	3	1
11-15 yrs		1		
16-20 yrs			2	2
21-25 yrs		2		1
>25 yrs	2			2
No systematic migration	1			2
Total:	**3**	**5**	**10**	**8**

The estimated total riprap requirements for each river system are presented in **Table 4-4**. Engineer Creek and Ogilvie River will likely require considerably more riprap than North Klondike River and Blackstone River. This disparity in estimated riprap requirements is likely due to differences in the number of encroachment sites along each river system, not necessarily the severity of future impact at individual sites.

Table 4-4. Estimated Riprap Requirements for Each River System

System	Estimated Riprap Requirement (m^3)
North Klondike River	5,390
Blackstone River	4,000
Engineer Creek	8,920
Ogilvie River	8,540
Total:	**26,850**

5 Discussion

5.1 Spatial Associations of Mass Movement Geohazards

Understanding the commonalities of sites where mass movement geohazards were identified can help provide insight into possible controlling mechanisms and enables prediction of similar processes in nearby (adjacent or separate) terrain undisturbed at present. Potential correlations in site characteristics can also aid in the prediction of mass movement initiation zones, runout limits and dimensions. Summary charts have been generated to show the average, maximum and minimum values, for each type of inventoried mass movement geohazard, for initiation angles (**Figure 5-1**), runout angles (**Figure 5-2**) and average (fahrböschung) angles (**Figure 5-3**).

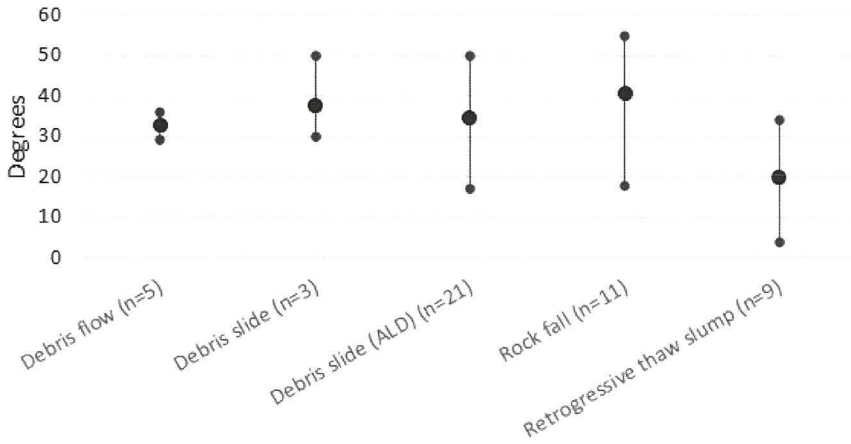


Figure 5-1. Average, Maximum and Minimum Mass Movement Geohazard Initiation Angles, by Class

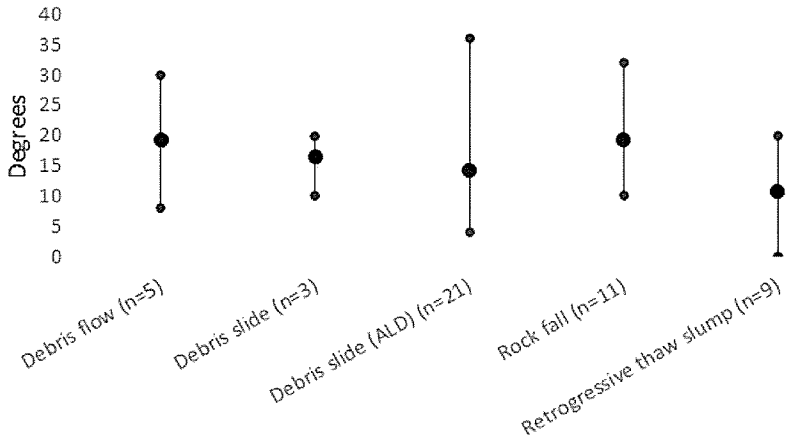
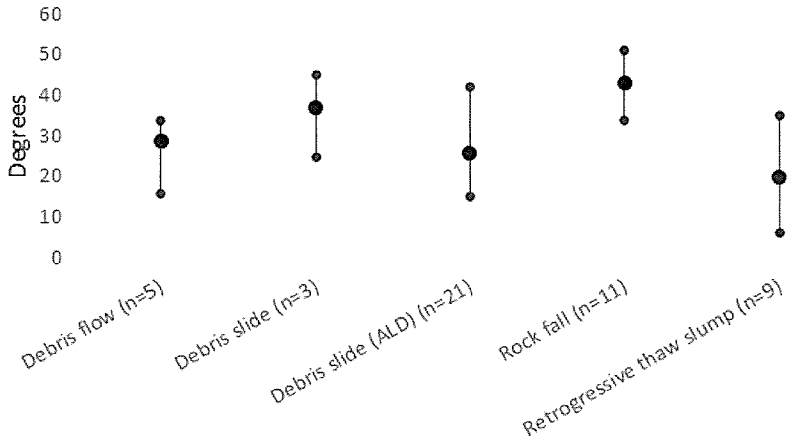


Figure 5-2. Average, Maximum and Minimum Mass Movement Geohazard Runout Angles, by Class



Note: The fahrböschung (average 'angle of reach') does not apply to retrogressive thaw slumps, strictly speaking, but it is included for comparative reference.

Figure 5-3. Average, Maximum and Minimum Mass Movement Geohazard Fahrböschung, by Class

Each inventoried type of mass movement geohazard along the Dempster Highway, on average, has a slightly different initiation angle (**Figure 5-1**). Their minima and maxima commonly at least partly overlap. Rockfall has the steepest initiation angle (41°, on average). Regular (permafrost-free) debris slides, which are commonly associated with rockfall-dominated slopes along the highway, have similarly steep initiation angles of 38° (on average). Active layer detachments may initiate on comparatively gentler slopes (35°, on average), largely due to the dramatic reduction in shear strength that occurs when water becomes perched on the permafrost table. Retrogressive thaw slumps require little relief to form, as HPW-TEB is aware through its regular maintenance of "sinkholes", having an average initiation angle of just 20°.

The average runout angles are lowest for retrogressive thaw slumps (11°) and active layer detachments (14°), both of which typically involve the transport of saturated, organic-rich debris (**Figure 5-2**). Active layer detachments tend to runout on slopes gentler than their permafrost-free debris slide equivalents (17°). The similarity between the comparatively steep average runout angles for rockfall and debris flows (both about 19°), in this study area, is because they commonly occur on the same mountainsides and are dominated by coarse rock debris.

The fahrböshung, or average 'angle of reach' of a mass movement from the crest of its source to the toe of its deposit, is a measure of the relative mobility of a landslide. Mass movements with low fahrböschung are considered highly mobile. Apart from retrogressive thaw slumps, which are less meaningfully represented by the fahrböschung due to their incremental rather than sudden runout, active layer detachments exhibit the lowest fahrböschung – highest mobility – within the study area (26°, on average) (**Figure 5-3**). The few regular (permafrost-free) debris flows that occur along the highway are also highly mobile, with an average fahrböschung of 29°. Rockfall debris remains comparatively close to its source, with an average fahrböschung of 43°, largely due to the relatively low height of source bluffs and small size of detached fragments.

Graphical representations of the mean, maximum and minimum lengths and widths (at the highway) of each mass movement geohazard, by class, have also been prepared (**Figures 5-4** and **5-5**). Insights from these charts can provide a general expectation for the relative magnitude of different mass movement processes that can be expected in areas along the highway not already affected. By far, debris flows exhibit the longest average total lengths (i.e., from crest to toe) of any of the mass movement processes along the Dempster Highway (480 m) (**Figure 5-4**). Such lengths are explained by the effects of pre-existing gullies (transport zones) on pore water pressure, bulking potential and energy dissipation. Even the longest-travelled mass movement geohazard (debris flow) along the Dempster Highway had a total length of nearly 700 m, well within the 1,000 m study corridor buffer width. All other forms of mass movement geohazards exhibit average total lengths less than 120 m.

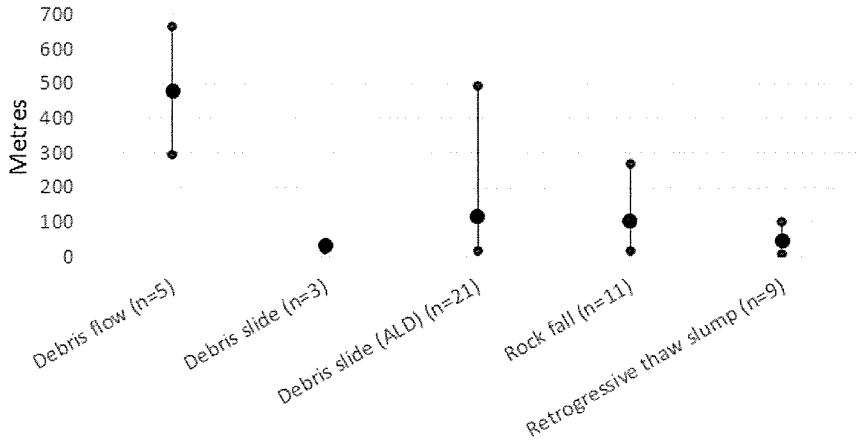
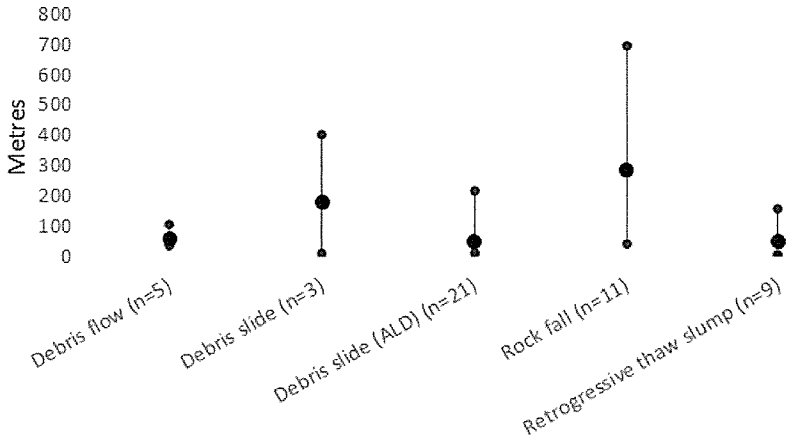


Figure 5-4. Mass Movement Geohazard Lengths, by Class



Note: Widths are provided for comparative reference and to provide an indication of the extent of highway exposed to the process, but caution is required in interpretation as some of the mass movement geohazard sites (polygons) have been delineated to include multiple event occurrences (smaller constituent widths) where contiguous or overlapping.

Figure 5-5. Mass Movement Geohazard Widths at the Highway, by Class

The mass movement geohazard width comparison (**Figure 5-5**) is provided for comparative reference, and to provide an indication of the extent of highway exposed to the process, but the values are not all directly comparable. Rockfall widths represent the total width of the slope prone to rockfall, not necessarily the width of an individual rockfall event on that slope, whereas most active layer detachment widths are based on delineation of discrete (individual) events. Most importantly, rockfall slopes pose a risk to the longest segments of highway, with average and maximum widths of 287 and 695 m, respectively. In contrast, debris flows pose a risk to narrow segments of highway (38 m, on average, with a maximum debris fan width of 105 m).

Several more general spatial associations of mass movements within the study area warrant acknowledgment:

- *Qualitative spatial associations of mass movement geohazards* – Regular (permafrost-free) debris slides are most commonly associated with slopes that are blanketed in colluvial soils. They are commonly associated with rockfall slopes, in some cases initiating in former rockfall debris. Active layer detachments occur mainly on moderately steep slopes with shallow permafrost (<1 m), and may be prevalent on a given slope immediately following wildfire. The occurrence of an active layer detachment on a given slope is a testament to the susceptibility of that broader slope to similar types of failures. On well-defined scarps, active layer detachments may evolve into retrogressive thaw slumps, especially where ponded or flowing water continually removes runout debris. Debris flows initiate in high basins thickly mantled in rubbly colluvium derived from weathered underlying and upslope bedrock. Their runout limits are distinguished by conspicuous debris fans or cones, which may or may not have natural levees. Rockfall is most frequent and widespread on steep, unvegetated slopes below rugged bedrock bluffs with lithologies prone to frost shattering. Abundant talus is an inconclusive indicator of rockfall hazard because, in this landscape of periglacial activity, it commonly accumulates and slowly creeps downslope posing little to no hazard to the highway below. Thermokarst subsidence is most widespread in areas of ice-wedge polygons, particularly where thawing due to natural processes

or anthropogenic disturbance. Well-drained, granular surface soils exhibiting collapse hollows and mounds are likely underlain by finer-textured (e.g., siltier) material containing massive ice. Thermokarst gullying occurs naturally in the landscape, but those instances included in this inventory are at least partially initiated by anthropogenic concentration of surface runoff (e.g., in culverts).

- *Influence of anthropogenic disturbance on mass movements* – Some form of anthropogenic disturbance was noted in association with about half of all mass movement geohazard sites (as noted under 'Causes' in **Appendices A** and **C**). There are three main ways in which anthropogenic disturbances appear to have increased the likelihood and/or size of mass movements within the study area. First, surface runoff that concentrates on the highway surface or within culverts crossing beneath the highway can affect the stability immediately downslope by elevating pore water pressure (and reducing shear strength) of the soils and/or by accelerating the depression and thaw of permafrost. Thermokarst gullying and retrogressive failures may result. Second, cut-slopes formed on the upslope side of the highway, during its construction, commonly undermine and oversteepen slopes that may have otherwise self-stabilized over millennia. Raveling, slumping and/or sliding may result. Third, unnatural blockages to surface and shallow subsurface drainage that result in ponding, such as highway embankments crossing slopewash runnels or thawing ice-wedge polygons, can locally accelerate permafrost degradation, piping and differential settlement.
- *Bedrock lithology not a reliable indicator of mass movements* – Mass movements were identified in nearly all mapped bedrock units traversed by the four study area sections, which are underlain by sedimentary and volcanic rocks, or unconsolidated Quaternary deposits (i.e., bedrock buried deeply and of unknown lithology). There are no apparent relationships between individual bedrock units (lithologies) and a higher overall occurrence of failures, or between the type of mass movement and the associated mapped bedrock unit.
- *Local seismicity not a reliable indicator of mass movements* – Although certain sections of the study area are seismically active (**Figure 2-2**), there is no obvious relationship between the occurrence of mass movements and the proximity, magnitude or concentration of past earthquake epicentres.
- *Influence of wildfires on mass movements* – The pronounced influence of wildfire on the stability of slopes underlain by permafrost is well established (e.g., Coates and Lewkowicz, 2005; Coates, 2008). However, the spatial association of wildfires and landslide occurrence may not be discernible based on territory-wide, publicly available data. Only four mapped fires intersect the study sections: one in the Ogilvie section (no associated failures) and three in the Eagle Plains section. In one of these three areas of wildfire, recent active layer detachments may have been triggered by a 6 ha fire that occurred in 2007.

The various spatial associations described above provide a basis for calibrating and improving predictions of the occurrence (distribution and timing) and relative magnitude of different mass movement processes on slopes undisturbed at present. For planning purposes, it is reasonable to assume that particular slopes or lowlands exhibiting one or more occurrences of a particular type and size of mass movement may experience additional, similar failures in the future. The closer a particular undisturbed site is in both proximity and characteristics to sites of existing or imminent mass movement geohazards, the more

representative those geohazards are likely to be of future potential mass movements. Terrain stability mapping, as a means of predicting other areas of instability along the highway corridor, would require extrapolation from the findings of this study and consideration of existing and potential future conditions (e.g., wildfire, climate change).

5.2 Key Findings from Meander Migration Hazard Assessment

The time-transgressive analysis of meanders at each of the 26 prioritized encroachment sites has documented widespread bank erosion that is likely to impact sections of the highway in the near future without intervention. Several important findings of the detailed migration assessments warrant discussion:

- *Wandering, gravel-bed channels* – All of the large creeks and rivers paralleled and crossed by the Dempster Highway exhibit at least some reaches with a wandering, gravel-bed pattern. By definition, wandering channels are unstable. They typically have abundant side channels, or split main channels, and are subject to frequent and dramatic avulsion. Wandering channels transport large volumes of coarse bedload, which is temporarily stored in large bars before being redistributed farther downstream. The distribution, morphology and mobility of gravel bars must be considered in site-specific risk assessments and the design of erosion protection measures.
- *Unstable Engineer Creek* – Engineer Creek exhibits far greater instability than any other watercourse alongside the Dempster Highway. Relatively rapid meander migration, disproportionately large gravel bars, and frequent channel avulsions suggest there has been a disturbance to the flow and/or sediment supply regime. Continued morphological adjustments are anticipated to accelerate bank erosion in some areas, including new sites not currently being eroded, and abandon eroding highway-edge channels in others. Given the rapidity of change, regular (e.g., annual or biannual) field reconnaissance is required to reassess each site and verify that the predictions made based on the 2013/2014 imagery and 2016 field inspections are still accurate.
- *Period of greatest migration* – In general, the most significant channel adjustments at unconfined encroachment sites occurred between 1989 and 2007/2008. This observation could explained by this time interval being longer than the other imagery-based intervals (i.e., 1977 to 1989, 2007/2008 to 2013/2014). However, it could suggest the channels became increasingly unstable during this time period. Channel instability could be a result of perturbation to flow regime or sediment supply, as well as changing permafrost conditions. Channel instability and restructuring could also be the result of an anomalously large flood event (e.g., 1993 flood on Blackstone River) (Section 4.2.1).
- *Riprap placement considerations* – At many encroachment sites, previous riprap applications have had insufficient extents to accommodate continued meander migration. Particularly along Engineer Creek, the 2013/2014 imagery and 2016 field inspections revealed upstream limits of riprap at risk of outflanking and the extension of erosion beyond the downstream limits. Future riprap placement should extend well upstream and downstream of the actual limits of the impact zone to inhibit anomalous scour at tie-in points and allow for accelerated longitudinal migration. The failure of riprap embankments constructed on banks with ice-rich permafrost demonstrates

the importance of understanding site-specific subsurface conditions in addition to fluvial processes. At encroachment sites most prone to scour along the base of the embankment, riprap may need to be embedded more deeply into the channel bed and over-sized relative to empirical hydraulic relations.

- *Validation of predictions* – According to HPW-TEB, riprap was applied to two encroachment sites (km 182.1 and km 188.6) in 2015. Based on the most recent imagery available in our study (2013/2014), we predicted each of these sites would be impacted by continued migration within 2 years. This helps validate the predictions, at least in the short-term, and retrospectively demonstrates how advance knowledge of future riprap requirements can optimize HPW-TEB's allocation of resources.
- *Reassessment and monitoring* – The rapidity of morphological changes documented through this assessment underscores the need to repeat a similar assessment in 5 to 10 years, updating baseline conditions established herein. At sites where recent avulsions have been identified, earlier reassessment may be warranted. HPW-TEB may want to consider implementing an 'encroachment site monitoring plan', developed by a fluvial geomorphologist familiar with northern environments, in order to track continued encroachment and identify triggers for instability (e.g., nearby avulsions, reworked gravel bars, etc.). Monitoring should ideally be completed by HPW-TEB staff each year or two, as well as after any anomalously large flood events or rapid ice break-up. Encroachment sites where no systematic migration toward the highway has occurred should not be excluded from follow-up consideration. In most of those cases, the proximity between the channel and highway is low and even a slight change in the distribution of bars or woody debris could initiate an undesirable morphological response.
- *Alternative erosion protection measures* – Alternative erosion protection measures warrant consideration at several of the 26 encroachment sites. Preference should be given to sites with sufficient channel-highway separation that minor unforeseen adjustments in bank morphology can be accommodated, especially if the alternative measure is used without any riprap placement along the eroding bank. A site-specific cost-benefit analysis that accounts for long-term maintenance requirements in addition to capital construction costs would be worthwhile in the planning stages of site prioritization. As a starting point, it is reasonable to assume a similar volume of riprap would be required to construct river training structures as would be required to riprap the corresponding bank. The cost of more significant modification of the channel or floodplain would need to consider additional approvals processes that are likely also required.

5.3 Terrain Considerations for Highway Maintenance

Over the course of this project, it became apparent that a distinction had to be made between processes that necessitate ongoing highway ditch or edge maintenance (perhaps monthly, during the snow-free season), and processes that constitute discrete mass movement geohazards to the highway. A decision was made to exclude minor processes with negligible impact potential that occur solely in areas of anthropogenic disturbance, such as small road cuts, even though summertime maintenance may be required (Section 1.2). The ongoing raveling and sloughing of road cuts, such as shown in **Figure 5-6**, were not considered to be geohazards or the focus of this assignment. For instabilities in anthropogenic disturbances to be included in the mass movement geohazard inventory, they had to pre-date the

anthropogenic disturbance or extend (e.g., initiate) beyond the limits of the disturbance, in addition to having the potential to actually impact the highway. A number of road cuts with crests that appeared to have been migrating upslope through mass movements (e.g., active layer detachments) that initiated above were deemed geohazards and included in the inventory (e.g., km 219.3).

Figure 5-6. Example of a Road-cut Slough Excluded from the Geohazard Inventory

Minor (<1 m) thermokarst subsidence is ubiquitous in areas of thawing ice-wedge polygons around Chapman Lake and alongside the section of highway approaching the border with the Northwest Territories. Such occurrences are so widespread that discrete delineation as part of a geohazard study for the benefit of highway maintenance planning was deemed inappropriate. A separate mapping exercise, such as that completed jointly by PECG and Yukon College for Northwestel's proposed fibre optic line along the Dempster Highway (McKillop et al., 2016), better addresses questions of minor thermokarst activity or potential. For thermokarst processes to be included in the geohazard inventory, they had to exhibit active mass wastage (e.g., tension cracks, slumping, etc.) and subsidence or gullying with local relief of more than 1 m.

The highway traverses slopes prone to solifluction and slopewash, both of which can affect highway conditions through incremental (mm/yr), downslope movement of fine sediments. Although slopes exhibiting such processes were excluded from this geohazard inventory, they may necessitate periodic maintenance of downslope ditches and drainage culverts. The approximate distribution of such mass movement processes was mapped by McKillop et al. (2016) in support of the proposed fibre optic line along the Dempster Highway.

5.4 Approach, Assumptions and Limitations

Kryotek and PECG applied a systematic approach to identifying, delineating, characterizing and evaluating risk at mass movement and meander migration sites along the Dempster Highway. However, several important assumptions and limitations of this investigation should be acknowledged:

- **Project scale and objective** – The purpose of this project was to identify existing or imminent soil and rock mass movements with the potential to impact the highway along Yukon's entire 465 km-long portion of the highway (within 1 km of the highway centreline). Small failures, such as sloughs restricted to a highway cut-slope, have not been included in our inventory (Sections 1.2 and 5.3). Minor instabilities hidden beneath a tree canopy may also have been missed in the desktop-based interpretation and drive-by observation. Reconnaissance-level investigations were completed in the field at mass movement geohazard sites, in accordance with HPW-TEB's RFP. More detailed mapping and modelling of failure geometry and geotechnical properties were not completed, as such in-depth characterizations would have little additional benefit for HPW-TEB's highway maintenance planning.
- **Principal data sources** – Geohazard characterizations and risk assessments were based on a combination of desktop analysis and a single reconnaissance-level field investigation. Although excellent orthophotography and LiDAR-derived elevation data were available to support preliminary and final assessment, corresponding stereo-imagery was not available for review. Sites first identified using the imagery and/or LiDAR-derived elevation data *following* the field program, upon a better-calibrated review of the spatial data, were necessarily characterized only through desktop analysis.
- **Meander migration hazard predictions** – The limitations of the meander migration hazard assessment must be considered when evaluating its results and implications. All predictions of future channel geometry and estimates of riprap requirements are based solely on desktop assessment. Errors inherent in the georeferencing and orthorectification processes to which each imagery source was subjected can slightly bias the results, especially where the amount of change (e.g., migration distance) is small. Furthermore, the comparative overlay analysis we applied facilitates time-averaged estimation of meander migration, assuming progression at a uniform rate. Bank erosion is more likely to occur episodically in response to extreme flows, thalweg adjustments in association with avulsions or bar redistribution, upstream ice jam breaching, and accelerated thaw of ice-rich permafrost in the banks. A time-averaged rate effectively reduces the 'noise' represented by localized and episodic adjustments, but such adjustments become more important and have greater implications as channel-highway separation decreases. A single flood could trigger the collapse of several metres of undercut bank. The estimation of future riprap requirements, in the absence of proactive intervention, makes assumptions with respect to the lateral extent, slope length (including steepness) and thickness of riprap. More detailed analysis is required to accurately determine appropriate allowances for scour and stone sizing, which in turn influences total volume requirements.

6 Conclusions and Recommendations

Several key conclusions of the investigation of mass movement geohazards along the Dempster Highway warrant highlighting:

- A total of 54 mass movement geohazards were identified, delineated and characterized within the study area based on systematic interpretation of high-resolution orthophotography and LiDAR-derived hillshade and slope models, followed by field reconnaissance investigations.
- Fifty percent of the 54 mass movement geohazards pose only low or very low risks to the highway, due to their modest possibility for only temporary (<1 day) and/or partial (single-lane) closure for maintenance. Thirteen percent represent high or very high risks to the highway, including some rockfall slopes and retrogressive thaw slumps, due to their relatively high likelihood of impact necessitating localized road reconstruction.
- Permafrost, or degrading permafrost, is a factor in more than three-quarters of mapped mass movement geohazards. Active layer detachments (debris slides), which occur on slopes with shallow permafrost, are the most common and geographically widespread mass movement hazard.

Meander migration alongside the Dempster Highway is one of the most widespread catalysts of highway instability, especially where exacerbated by the repeated exposure of ice-rich permafrost in slumping banks. A total of 102 meander-highway encroachment sites with the potential for future highway impact was identified. Detailed desktop analyses and follow-up field inspections were completed at 26 prioritized sites, yielding the following key results:

- The highway has been already been impacted by a watercourse at three sites and, without intervention, highway impact is likely at two additional sites within two years. Furthermore, the highway will likely be impacted by a migrating watercourse at eight sites within the next 10 years.
- Four encroachment sites exhibit no systematic migration of meanders toward the highway over the period of record. Furthermore, the watercourse is unlikely to impact the highway embankment within 25 years at an additional four encroachment sites. Notwithstanding these findings, documentation of widespread channel avulsions within the study reaches underscores the need for reassessment and monitoring to ensure predictions are still valid.
- Engineer Creek is a dynamic channel with high migration rates and frequent avulsions. Eight encroachment sites along Engineer Creek will likely require erosion protection measures within the next 10 years.
- The majority of encroachment sites along North Klondike River and Ogilvie River are unlikely to require erosion protection strategies within the next 20 years. The timeframes until impact along Blackstone River, from 2016, range from 6-10 years to 21-25 years.

- Minimal migration has occurred over the period of record at highway encroachment sites that are naturally confined by hillslopes or scarps. Monitoring confined sites for evidence of change is just as important as monitoring unconfined sites, given the potential for undercutting of the slope toe to trigger mass movement failures with the potential to impact the highway above.

Insights gained through the completion of this project justify several recommendations for HPW-TEB's consideration in association with both mass movement and meander migration hazards:

- **Mass movement geohazard study recommendations** – If HPW-TEB is interested in strengthening its understanding of terrain susceptible to soil and rock mass movements where none has been documented through this inventory of existing or imminent geohazards, it should consider having predictive terrain stability mapping completed within a continuous mapping corridor along the highway. Due regard should be given to the potential implications of wildfire and climate change on mass movement potential. The spatial associations and related findings of this investigation would be invaluable in the calibration of terrain stability interpretations. Updating the inventory presented in this report in 5 to 10 years may also be worthwhile, given the relatively short periods during which new mass movements occur in response to wildfire, anthropogenic disturbance or climate change.
- **Meander migration hazard study recommendations** – HPW-TEB should consider (1) developing and implementing a monitoring plan for tracking changes at encroachment sites with the greatest risk to highway stability, or with the greatest potential for continued morphological change; and (2) reassessing the encroachment sites (and any new ones) every 5 to 10 years to update the baseline conditions and predictions established through this study. In line with this second recommendation, Kryotek and PECG recommend detailed (desktop-based) meander migration assessments be completed at meander-highway encroachment sites at km 104.6, km 105.2, km, km 107.7, km 108.8, km 111.9 and km 165.5 (**Appendix F**), all of which are outside the original priority study area from which the 26 sites for detailed assessment were selected. Such follow-up assessments would help explain instabilities observed in the field and forecast future riprap requirements.

7 Statement of Limitations

This report has been prepared by the Consultants (Kryotek Arctic Innovation Inc. (Kryotek) and Palmer Environmental Consulting Group Inc. (PECG)) for the benefit of the Client (Yukon Government) in accordance with the agreement between Consultant and Client, including the scope of work detailed therein (the "Agreement"). The report and the information it provides may be used and relied upon only by Client, except (1) as agreed to in writing by Consultant and Client, (2) as required by-law, or (3) to the extent used by governmental reviewing agencies for the purpose of obtaining permits or approvals.

The extent of this study was limited to the specific scope of work for which we were retained and that is described in this report. Kryotek and PECG have assumed that the information and data provided by the client or any secondary sources of information are factual and accurate. Kryotek and PECG accept no responsibility for any deficiency, misstatement or inaccuracy contained in this report as a result of omissions, misinterpretations or negligent acts from relied-upon data. Judgment has been used by Kryotek and PECG in interpreting mass movement and meander migration hazards based on desktop analyses and field reconnaissance investigations (at many but not all sites).

Kryotek and PECG are not guarantors of site conditions, projected characteristics of mass movements or predicted channel adjustments at meander-highway encroachment sites (which are based primarily on imagery and elevation data only as current as 2013/2014), but warrants only that our work was undertaken and our report prepared in a manner consistent with the level of skill and diligence normally exercised by competent geoscience professionals practicing in Yukon. Our findings, conclusions and recommendations should be evaluated in light of the limited scope of our work.

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Appendix A

Attributes of Mass Movement Geohazards

- **Attributes of Mass Movement Geohazards**
- **METADATA for Attributes of Mass Movement Geohazards**

Appendix B

Field Site Inspection Comments

Appendix C

Summary Figures of Mass Movement Geohazard Assessment Results

Appendix D

Distribution and Classification of Mass Movement Geohazards

Appendix E

Distribution and Risk of Mass Movement Geohazards

Appendix F

Summary Results of Meander-Highway Encroachment Site Identification

Appendix G

Attributes of Prioritized Meander-Highway Encroachment Sites

- **Attributes of Prioritized Meander-Highway Encroachment Sites**
- **METADATA for Attributes of Prioritized Meander-Highway Encroachment Sites**

Appendix H

Summary Figures of Prioritized Meander Migration Hazard Assessment Results

Appendix I

Field Photographs of Prioritized Meander-Highway Encroachment Sites

Appendix J

Distribution and Proximities of Meander-Highway Encroachment Sites

Appendix A. Attributes of Mass Movement Geohazards

KM_POST	SECTION	TYPE	POS_TO_HWY	PROXIMITY	ELEV_CNTR	ASPECT	SURF_MAT	PERMAFROST	FIRE	VEGETATION	IMG_1977	IMG_07-08	IMG_13-14	TIMING	LENGTH	DEPTH	WIDTH_MAX	WIDTH_MIN	WIDTH_HWY	ELEV_CREST	ELEV_RUNT
60.7	Klondike	TKg	below	10	933	120	szcFa	Shallow permafrost, likely locally ice-rich	-	stunted black spruce	inconclusive	y	y	Ongoing/episodic, likely initiated following highway construction							
85.5	Klondike	TKs	beneath	0	1180	240	dszMu	Shallow, ice-rich permafrost in area of degrading ice-wedge polygons	-	subalpine shrubs	y	y	y	Ongoing/episodic, likely exacerbated by highway construction							
86.2	Klondike	DS (ALD) & TKg	above	0	1170	15	dszMa	Shallow, ice-rich permafrost in area of degrading ice-wedge polygons	-	subalpine shrubs	possibly	y	y	Ongoing/episodic, likely exacerbated by highway construction							
93.6	Klondike	RTS	below	10	1124	330	sgzFGt	Shallow, ice-rich permafrost in area of degrading ice-wedge polygons; 2 m of exposed ice wedge plus seams/lenses	-	subalpine shrubs	inconclusive	inconclusive	y	Ongoing/episodic, possibly exacerbated by highway construction	13	2	22	6	6	1126	1123
96.8	Klondike	TKs	beneath	0	1106	55	zsgFf	Shallow, ice-rich permafrost (silt/organics) in area of degrading ice-wedge polygons	-	subalpine shrubs	possibly	y	y	Ongoing/episodic, possibly exacerbated by highway construction							
97.1	Klondike	TKs	beneath	0	1106	60	zsgFf	Shallow, ice-rich permafrost (silt/organics) in area of degrading ice-wedge polygons	-	subalpine shrubs	inconclusive	y	y	Ongoing/episodic, possibly exacerbated by highway construction							
115.4	Klondike	DS (ALD)	below	10	988	140	szdMa	Shallow, ice-rich permafrost on river-cut scarp adjacent to degrading ice-wedge polygons	-	subalpine shrubs, deciduous trees	n	n	y	Single event (2007-2013) with potential to initiate retrogressive thaw slump	48	2.5	26	23	26	1001	980
115.6	Klondike	RTS	below	3.5	989	155	gszFt\szdMa	Shallow, ice-rich permafrost on river-cut scarp adjacent to degrading ice-wedge polygons	-	subalpine shrubs, deciduous trees	possibly	y	y	Ongoing/episodic, possibly exacerbated by highway construction	23	2.4	88	60	60	997	981
115.9	Klondike	RTS	below	5	986	135	gszFt\szdMa	Shallow, ice-rich permafrost on river-cut scarp adjacent to degrading ice-wedge polygons	-	subalpine shrubs, deciduous trees	possibly	y	y	Ongoing/episodic, possibly exacerbated by highway construction	45	4.5	117	90	90	998	978
116.2	Klondike	RTS	below	0	989	135	gszFt\szdMa	Shallow, ice-rich permafrost on river-cut scarp adjacent to degrading ice-wedge polygons with lake on opposite, upslope side of highway	-	subalpine shrubs, deciduous trees	y	y	y	Ongoing/episodic, possibly exacerbated by highway construction; rapid retrogression 2007-2013 (~1 m/yr)	50	3	175	155	155	998	979
116.7	Klondike	TKs	beneath	0	998	160	gszFt	Shallow, ice-rich permafrost in area of ice-wedge polygons	-	subalpine shrubs, deciduous trees	y	y	y	Ongoing/episodic, likely initiated by clearing for borrow pit							
173.7	Ogilvie	DS (ALD)	above	0	724	110	szrCv	Shallow permafrost	-	stunted black spruce	n	n	y	Single event (2007-2013) with potential for post-failure sloughs/flows	54	0.9	27	18	27	746	720
176.5	Ogilvie	RF	above	0	752	120	R	Permafrost, likely ice-poor, deep within weathered bedrock	-	mostly unvegetated	y	y	y	Recurrent (likely annual)	231	n/a	420	234	420	858	700
177.6	Ogilvie	RF & DS	above	0	708	107	rszCv	Permafrost, likely ice-poor, relatively deep within colluvial rubble or weathered bedrock	-	mostly unvegetated	y	y	y	Recurrent (likely annual)	41	n/a	406	176	406	736	695

Note: Field headings and abbreviations defined in metadata table that follows

Appendix A. Attributes of Mass Movement Geohazards

KM_POST	SECTION	TYPE	POS_TO_HWY	PROXIMITY	ELEV_CNTR	ASPECT	SURF_MAT	PERMAFROST	FIRE	VEGETATION	IMG_1977	IMG_07-08	IMG_13-14	TIMING	LENGTH	DEPTH	WIDTH_MAX	WIDTH_MIN	WIDTH_HWY	ELEV_CREST	ELEV_RUNT
189.4	Ogilvie	RTS	above	0	636	70	zsgFt	Shallow, likely ice-rich permafrost above terrace scarp beside highway	-	stunted black spruce	y	y	y	Ongoing/episodic, possibly exacerbated by old winter trail upslope of highway	100	4.3	53	11	53	643	623
191.6	Ogilvie	DS (ALD)	above	0	635	85	szrCv	Shallow permafrost	-	stunted black spruce	y	y	y	Single event (likely slightly pre-dates highway construction) with minimal remaining potential for post-failure sloughs/flows	168	2.2	40	5	40	701	619
193	Ogilvie	RTS	above	0	605	60	zsrCa	Shallow permafrost with segregated ice (lenses/seams)	-	stunted black spruce	inconclusive	inconclusive	y	Ongoing/episodic, likely exacerbated by concentrated drainage along ditch at slope toe	8	1.5	15	7	15	609	604
205	Ogilvie	RF	above	0	581	115	R	Permafrost, likely ice-poor, relatively deep within colluvial rubble or weathered bedrock	-	shrubs and deciduous trees	y	y	y	Recurrent (likely annual)	44	n/a	132	120	132	602	572
209.5	Ogilvie	DS (ALD)	above	0	578	70	dszCv	Shallow permafrost	-	stunted black spruce and deciduous trees	n	n	y	Single event (2007-2013) with potential for post-failure sloughs/flows	52	1	52	16	52	602	566
209.6	Ogilvie	DS (ALD)	above	0	569	80	dszCv	Shallow permafrost	-	stunted black spruce and deciduous trees	n	n	y	Single event (2007-2013) with potential for post-failure sloughs/flows	67	<1	63	39	63	599	564
209.7	Ogilvie	DS (ALD)	above	0	566	85	dszCv	Shallow permafrost	-	stunted black spruce and deciduous trees	n	n	y	Single event (2007-2013) with potential for post-failure sloughs/flows	66	<1	54	5	54	611	560
210.9	Ogilvie	RF	above	0	590	165	R	Permafrost, likely ice-poor, deep within bedrock	-	mostly unvegetated	y	y	y	Recurrent (likely annual)	45	n/a	41	17	41	602	561
212.5	Ogilvie	RF & DS	above	0	622	70	R	Permafrost, likely ice-poor, relatively deep within colluvial rubble or weathered bedrock	-	mostly unvegetated	y	y	y	Recurrent (likely annual)	208	n/a	453	345	453	738	554
212.7	Ogilvie	DF	above	0	652	70	rszCv	Permafrost, likely ice-poor, relatively deep within colluvial rubble or weathered bedrock	-	mostly unvegetated	y	y	y	Recurrent (likely decadal)	294	n/a	38	3	38	755	553
212.8	Ogilvie	RF & DS	above	0	615	65	R/rszCb	Permafrost, likely ice-poor, relatively deep within colluvial rubble or weathered bedrock	-	mostly unvegetated	y	y	y	Recurrent (likely annual)	220	n/a	196	158	165	740	554
212.95	Ogilvie	DF & RF	above	0	805	60	rszCv	Permafrost, likely ice-poor, relatively deep within colluvial rubble or weathered bedrock	-	mostly unvegetated	y	y	y	Recurrent (likely decadal)	666	n/a	135	5	105	980	552
213	Ogilvie	DS (ALD)	above	0	575	60	rszCv	Permafrost, likely ice-poor, relatively deep within colluvial rubble or weathered bedrock	-	stunted black spruce	n	n	y	Single event (2007-2013) with potential for post-failure sloughs/flows	142	0.5	22	9	22	630	553

Note: Field headings and abbreviations defined in metadata table that follows

Appendix A. Attributes of Mass Movement Geohazards

KM_POST	SECTION	TYPE	POS_TO_HWY	PROXIMITY	ELEV_CNTR	ASPECT	SURF_MAT	PERMAFROST	FIRE	VEGETATION	IMG_1977	IMG_07-08	IMG_13-14	TIMING	LENGTH	DEPTH	WIDTH_MAX	WIDTH_MIN	WIDTH_HWY	ELEV_CREST	ELEV_RUNT
213.05	Ogilvie	DS (ALD)	above	10	573	55	rszCv	Shallow permafrost	-	stunted black spruce	n	n	y	Single event (2007-2013) with potential for post-failure sloughs/flows	64	<1	28	20	28	604	555
213.1	Ogilvie	DF	above	0	594	60	rszCv	Permafrost, likely ice-poor, relatively deep within colluvial rubble or weathered bedrock	-	stunted black spruce and deciduous trees	y	y	y	Recurrent (likely decadal)	295	n/a	44	4	44	730	552
213.15	Ogilvie	DS (ALD)	above	0	564	60	rszCv	Shallow permafrost	-	stunted black spruce and deciduous trees	n	n	y	Single event (2007-2013) with potential for post-failure sloughs/flows	43	0.5	19	7	19	585	555
213.2	Ogilvie	DS (ALD)	above	0	556	45	rszCv	Shallow permafrost	-	stunted black spruce and deciduous trees	n	n	y	Single event (2007-2013) with potential for post-failure sloughs/flows	33	<1	17	13	17	571	555
213.35	Ogilvie	DF	above	0	810	55	rszCv	Permafrost, likely ice-poor, relatively deep within colluvial rubble or weathered bedrock	-	mostly unvegetated	y	y	y	Recurrent (likely decadal)	654	n/a	130	4	45	920	552
213.4	Ogilvie	DS (ALD)	above	10	576	30	rszCv	Shallow permafrost	-	stunted black spruce and deciduous trees	n	n	n	Single event (2013-2016) with potential for post-failure sloughs/flows	43	0.6	19	9	9	596	557
218.1	Ogilvie	DS (ALD)	above	0	553	45	rszCv	Shallow permafrost	-	stunted black spruce and deciduous trees	n	n	y	Single event (2007-2013) with potential for post-failure sloughs/flows	73	<1	86	50	86	587	541
219.3	Ogilvie	RF & DS (ALD)	above	0	550	105	rszCv/R	Permafrost, likely ice-poor, relatively deep within colluvial rubble or weathered bedrock	-	mostly unvegetated	y	y	y	Recurrent (likely annual)	32	n/a	500	410	500	579	541
221.5	Ogilvie	RF	above	0	544	120	R	Permafrost, likely ice-poor, relatively deep within colluvial rubble or weathered bedrock	-	mostly unvegetated	y	y	y	Recurrent (likely annual)	17	n/a	88	86	86	560	538
221.6	Ogilvie	RTS	above	0	555	145	dszCv	Shallow, likely ice-rich permafrost above slope-toe scarp beside highway	-	stunted black spruce	inconclusive	y	y	Ongoing/episodic, possibly exacerbated by highway construction	49	3	21	3	15	562	538
221.7	Ogilvie	RF	above	0	551	130	R	Permafrost, likely ice-poor, relatively deep within colluvial rubble or weathered bedrock	-	mostly unvegetated	y	y	y	Recurrent (likely annual)	30	n/a	130	96	130	570	539
221.8	Ogilvie	RTS	above	0	563	110	dszCv	Shallow, likely ice-rich permafrost above slope-toe scarp beside highway	-	stunted black spruce	inconclusive	y	y	Ongoing/episodic, possibly exacerbated by highway construction	99	3	45	3	45	570	538
221.9	Ogilvie	DS & RF	above	0	549	145	dszCv/R	Shallow permafrost areas remaining within slope otherwise underlain by permafrost relatively deep within colluvium or weathered bedrock	-	mostly unvegetated	y	y	y	Recurrent (likely annual)	30	<1	130	106	130	562	537
224.7	Ogilvie	RF	above	0	635	150	R	Permafrost, likely ice-poor, relatively deep within colluvial rubble or weathered bedrock	-	mostly unvegetated	y	y	y	Recurrent (likely annual)	270	n/a	695	650	695	840	524

Note: Field headings and abbreviations defined in metadata table that follows

Appendix A. Attributes of Mass Movement Geohazards

KM_POST	SECTION	TYPE	POS_TO_HWY	PROXIMITY	ELEV_CNTR	ASPECT	SURF_MAT	PERMAFROST	FIRE	VEGETATION	IMG_1977	IMG_07-08	IMG_13-14	TIMING	LENGTH	DEPTH	WIDTH_MAX	WIDTH_MIN	WIDTH_HWY	ELEV_CREST	ELEV_RUNT
241.9	Ogilvie	DS (ALD)	above	0	509	170	szrCb	Shallow permafrost	Possible fire influence	stunted black spruce and deciduous trees	n	y	y	Single event (1977-2007) with minimal remaining potential for post-failure sloughs/flows	173	0.5	24	9	24	537	490
242	Ogilvie	DS (ALD)	above	0	534	170	szrCb	Shallow permafrost	Possible fire influence	stunted black spruce and deciduous trees	n	y	y	Single event (1977-2007) with minimal remaining potential for post-failure sloughs/flows	338	1	30	11	28	610	490
242.2	Ogilvie	DS (ALD)	above	0	495	170	rszCb	Moderately deep permafrost in original road cut area	-	deciduous trees	n	n	y	Single event (2007-2013) with potential for post-failure sloughs/flows	19	1	27	12	27	503	495
244	Ogilvie	DS (ALD)	above	8	495	165	szrCv	Shallow permafrost	-	stunted black spruce	inconclusive	y	y	Single event with potential for post-failure sloughs/flows	104	<1	55	16	17	523	487
244.1	Ogilvie	DS (ALD)	above	6	505	145	szrCv	Shallow permafrost	-	stunted black spruce	inconclusive	y	y	Single event with potential for post-failure sloughs/flows	115	<1	150	113	150	540	486
244.25	Ogilvie	DS (ALD)	above	30	488	120	szrCv	Shallow permafrost	-	stunted black spruce	n	n	y	Single event (2007-2013) with potential for post-failure sloughs/flows	100	<1	35	26	26	518	485
244.3	Ogilvie	DF & DS (ALD)	above	46.6	560	135	szrCv	Shallow permafrost	Possible fire influence	stunted black spruce	n	n	y	Single event (2007-2013) with potential for post-failure sloughs/flows	493	n/a	57	5	57	630	486
273.1	Ogilvie	DS (ALD)	above	0	854	150	rszCv	Shallow permafrost	-	black spruce	n	n	y	Single event (2007-2013) with potential for post-failure sloughs/flows	33	0.3	49	19	49	860	850
301.4	Eagle Plains	TKg	below	0	607	175	rszCb	Shallow permafrost	-	stunted black spruce	inconclusive	inconclusive	y	Ongoing/episodic, likely initiated following highway construction							
378.8	Eagle Plains	DS (ALD)	above	0	339	210	szdCv	Shallow, likely ice-poor permafrost	Burned most recently in 2007	stunted black spruce and deciduous trees	inconclusive	y	y	Single event with potential for post-failure sloughs/flows	217	1	217	160	217	385	329
432.7	Eagle Plains	DS	below	0	549	45	A	Permafrost likely relatively deep within highway embankment or underlying weathered bedrock	-	deciduous trees	n	inconclusive	y	Single event with potential for post-failure sloughs and gradual retrogression	25	0.5	18	7	10	556	545
453.9	Eagle Plains	TKs	above	3	653	285	szxCb	Shallow, ice-rich permafrost in area of degrading ice-wedge polygons	-	subalpine shrubs	n	y	y	Ongoing/episodic, possibly exacerbated by highway construction							
462.3	Eagle Plains	RTS	below	7	796	20	szrCb	Shallow, likely ice-rich permafrost	-	subalpine shrubs	inconclusive	y	y	Ongoing/episodic, possibly exacerbated by highway construction	47	2	48	22	13	800	795

Note: Field headings and abbreviations defined in metadata table that follows

Appendix A. Attributes of Mass Movement Geohazards

KM_POST	SLOPE_INIT	SLOPE_RUNT	SLOPE_AVG	TK_LENGTH	TK_WIDTH_T	TK_WIDTH_B	TK_WIDTH_H	TK_DEPTH	TK_ELEV_CR	TK_ELEV_RT	TK_SLOPE	LIKELIHOOD	CONSEQ	RISK	CAUSES	TRIGGERS	MITIGATION	COMMENTS
60.7				113	12	2	12	3	939	931	4	L	M	L	concentrated drainage	intense rainfall/snowmelt	Management of surface runoff from culvert	
85.5				360	235	n/a	235	<2	1190	1172	3	M	L	L	alteration to surface organic cover, alteration to drainage, permafrost degradation	intense rainfall/snowmelt or heat	Management of ground settlement	Differential settlement expected to continue affecting hwy embankments
86.2				55	480	n/a	420	2	1180	1166	14	M	L	L	disturbance and possible over-steepening of slope toe, permafrost degradation	intense rainfall/snowmelt or heat	Management of runout debris	Minor slope deformation expected to continue as ice-wedge polygons thaw
93.6	11	9	11									L	H	M	alteration to drainage pattern (unnatural impoundment), permafrost degradation	intense rainfall/snowmelt or heat	Management of ground settlement	Dominant trajectory of retrogression subparallel to, rather than toward, hwy
96.8				518	95	55	95	2.5	1111	1102	1	L	M	L	permafrost degradation	intense rainfall/snowmelt or heat	Management of ground settlement	Area of severest subsidence activity southwest of hwy
97.1				170	25	12	25	2	1109	1102	2	L	M	L	permafrost degradation	intense rainfall/snowmelt or heat	Management of ground settlement	Active subsidence limited to area immediately west of hwy
115.4	36	10	24									M	M	M	incremental undercutting of slope toe by river, permafrost degradation	intense rainfall/snowmelt or heat	Management of ground settlement if/when feature retrogresses toward hwy	Potential for feature to evolve into retrogressive thaw slump
115.6	29	0	35									M	H	H	disturbance to surface organic cover, alteration of drainage pattern, permafrost degradation	intense rainfall/snowmelt or heat	Management of ponding adjacent to hwy and ground settlement if/when feature retrogresses toward hwy	Ponding north of hwy may exacerbate failure to south
115.9	29	11	24									M	H	H	alteration of drainage pattern, permafrost degradation	intense rainfall/snowmelt or heat	Management of ground settlement and slope failures if/when feature retrogresses toward hwy	
116.2	4	20	20									H	H	VH	disturbance to surface organic cover, alteration of drainage pattern, permafrost degradation	intense rainfall/snowmelt or heat	Management of ground settlement and slope failures if/when feature retrogresses toward hwy	Significant risk to hwy, especially given lake to north and relatively rapid retrogression (up to ~1 m/year); potential for future lake drainage
116.7				147	200	n/a	200	1.5	1010	997	5	M	M	M	disturbance to surface organic cover, alteration of drainage pattern, permafrost degradation	intense rainfall/snowmelt or heat	Management of ground settlement	Differential settlement expected to continue affecting hwy embankments
173.7	32	4	26									M	L	L	oversteepened slope toe, permafrost degradation	intense rainfall/snowmelt or heat	Management of debris accumulation in ditch	Runout limits approximate due to clearing of former debris accumulation
176.5	44	17	34									H	M	H	steep rock bluffs	freeze/thaw, intense rainfall/snowmelt	Management of rockfall debris in ditch and on hwy	Runout limits approximate due to clearing of former debris accumulation; risk greatest downslope of prominent rock bluffs
177.6	50	20	45									H	L	M	oversteepened slope toe	freeze/thaw, intense rainfall/snowmelt	Management of rockfall debris in ditch and on hwy	Runout limits approximate due to clearing of former debris accumulation

Note: Field headings and abbreviations defined in metadata table that follows

Appendix A. Attributes of Mass Movement Geohazards

KM_POST	SLOPE_INIT	SLOPE_RUNT	SLOPE_AVG	TK_LENGTH	TK_WIDTH_T	TK_WIDTH_B	TK_WIDTH_H	TK_DEPTH	TK_ELEV_CR	TK_ELEV_RT	TK_SLOPE	LIKELIHOOD	CONSEQ	RISK	CAUSES	TRIGGERS	MITIGATION	COMMENTS
189.4	5	13	11									M	L	L	permafrost degradation	intense rainfall/snowmelt or heat	Management of debris accumulation in ditch	
191.6	39	15	26									L	L	VL	permafrost degradation	intense rainfall/snowmelt	None expected to be required	Mostly stabilized through natural revegetation
193	28	15	28									M	L	L	fluvio-thermal erosion of slope toe, permafrost degradation	intense rainfall/snowmelt or heat	Management of surface runoff and debris accumulation in ditch	
205	27	15	34									M	L	L	steep rock bluff	freeze/thaw, intense rainfall/snowmelt	Management of rockfall debris in ditch and on hwy	Runout limits approximate due to clearing of former debris accumulation
209.5	29	24	35									M	M	M	disturbance and possible over-steepening of slope toe, permafrost degradation	intense rainfall/snowmelt or heat	Management of runout debris	Runout limits approximate due to clearing of former debris accumulation
209.6	42	17	28									M	M	M	disturbance and possible over-steepening of slope toe, permafrost degradation	intense rainfall/snowmelt or heat	Management of runout debris	Runout limits approximate due to clearing of former debris accumulation
209.7	50	14	37									M	M	M	disturbance and possible over-steepening of slope toe, permafrost degradation	intense rainfall/snowmelt or heat	Management of runout debris	Runout limits approximate due to clearing of former debris accumulation
210.9	46	17	42									H	L	M	steep rock bluff	freeze/thaw	Management of rockfall initiation and/or debris in ditch and on hwy	Runout limits approximate due to clearing of former debris accumulation
212.5	35	27	42									H	M	H	steep rock bluffs	freeze/thaw, intense rainfall/snowmelt	Management of rockfall/debris slide debris in ditch and on hwy	Runout limits approximate due to clearing of former debris accumulation; risk greatest downslope of prominent rock bluffs; small debris slides
212.7	32	19	34									L	H	M	saturation of colluvial debris in headwater basin, gully channelization	intense rainfall/snowmelt	Management of runout debris	
212.8	36	31	40									H	M	H	steep rock bluffs	freeze/thaw, intense rainfall/snowmelt	Management of rockfall/debris slide debris in ditch and on hwy	Runout limits approximate due to clearing of former debris accumulation; small debris slides
212.95	36	30	33									L	H	M	saturation of colluvial debris in headwater basin, gully channelization	intense rainfall/snowmelt, freeze/thaw	Management of runout debris	
213	38	10	29									M	L	L	permafrost degradation	intense rainfall/snowmelt or heat, possible rockfall onto slope	Management of debris accumulation in ditch	Runout limits approximate due to clearing of former debris accumulation

Note: Field headings and abbreviations defined in metadata table that follows

Appendix A. Attributes of Mass Movement Geohazards

KM_POST	SLOPE_INIT	SLOPE_RUNT	SLOPE_AVG	TK_LENGTH	TK_WIDTH_T	TK_WIDTH_B	TK_WIDTH_H	TK_DEPTH	TK_ELEV_CR	TK_ELEV_RT	TK_SLOPE	LIKELIHOOD	CONSEQ	RISK	CAUSES	TRIGGERS	MITIGATION	COMMENTS
213.05	48	33	37									M	L	L	permafrost degradation	intense rainfall/snowmelt or heat	Management of debris accumulation in ditch	
213.1	31	23	31									L	H	M	saturation of colluvial debris in headwater basin, gully channelization	intense rainfall/snowmelt	Management of runout debris	
213.15	37	15	35									M	L	L	disturbance and possible over-steepening of slope toe, permafrost degradation	intense rainfall/snowmelt or heat	Management of debris accumulation in ditch	Runout limits approximate due to clearing of former debris accumulation
213.2	43	5	25									M	L	L	disturbance and possible over-steepening of slope toe, permafrost degradation	intense rainfall/snowmelt or heat	Management of debris accumulation in ditch	Runout limits approximate due to clearing of former debris accumulation
213.35	36	16	29									L	H	M	saturation of colluvial debris in headwater basin, gully channelization	intense rainfall/snowmelt	Management of runout debris	
213.4	41	36	42									M	L	L	permafrost degradation	intense rainfall/snowmelt or heat	Management of debris accumulation in ditch	
218.1	40	25	32									M	L	L	permafrost degradation	intense rainfall/snowmelt or heat	Management of debris accumulation in ditch	Runout limits approximate due to clearing of former debris accumulation
219.3	47	13	50									H	L	M	oversteepened slope toe, steep rock bluffs	freeze/thaw, intense rainfall/snowmelt	Management of debris accumulation in ditch	Runout limits approximate due to clearing of former debris accumulation
221.5	55	14	51									H	L	M	steep rock bluff	freeze/thaw, intense rainfall/snowmelt	Management of debris accumulation in ditch	Runout limits approximate due to clearing of former debris accumulation
221.6	34	11	26									M	L	L	disturbance and possible over-steepening of slope toe, permafrost degradation	intense rainfall/snowmelt or heat	Management of debris accumulation in ditch	
221.7	18	32	46									H	L	M	steep rock bluff	freeze/thaw, intense rainfall/snowmelt	Management of debris accumulation in ditch	Runout limits approximate due to clearing of former debris accumulation
221.8	31	12	18									M	L	L	natural concentration of runoff, permafrost degradation	intense rainfall/snowmelt or heat	Management of debris accumulation in ditch	
221.9	33	10	40									H	L	M	disturbance and possible over-steepening of slope toe, steep rock bluffs	freeze/thaw, intense rainfall/snowmelt	Management of debris accumulation in ditch	Runout limits approximate due to clearing of former debris accumulation
224.7	55	16	49									H	M	H	steep rock bluffs	freeze/thaw, intense rainfall/snowmelt	Management of rockfall debris in ditch and on hwy	Runout limits approximate due to clearing of former debris accumulation; risk greatest downslope of prominent rock bluffs

Note: Field headings and abbreviations defined in metadata table that follows

Appendix A. Attributes of Mass Movement Geohazards

KM_POST	SLOPE_INIT	SLOPE_RUNT	SLOPE_AVG	TK_LENGTH	TK_WIDTH_T	TK_WIDTH_B	TK_WIDTH_H	TK_DEPTH	TK_ELEV_CR	TK_ELEV_RT	TK_SLOPE	LIKELIHOOD	CONSEQ	RISK	CAUSES	TRIGGERS	MITIGATION	COMMENTS
241.9	22	7	15									L	L	VL	permafrost degradation, possible fire	intense rainfall/snowmelt or heat	None expected to be required	Mostly stabilized through natural revegetation
242	29	14	19									L	L	VL	permafrost degradation, possible fire	intense rainfall/snowmelt or heat	None expected to be required	Mostly stabilized through natural revegetation
242.2	33	4	23									M	L	L	oversteepened slope toe	intense rainfall/snowmelt or heat	Management of debris accumulation in ditch	Runout limits approximate due to clearing of former debris accumulation
244	39	13	19									M	L	L	permafrost degradation	intense rainfall/snowmelt or heat	Management of debris accumulation in ditch	
244.1	24	16	25									M	L	L	permafrost degradation	intense rainfall/snowmelt or heat	Management of debris accumulation in ditch	
244.25	36	5	18									L	L	VL	permafrost degradation	intense rainfall/snowmelt or heat	Management of debris accumulation in ditch of staging area	
244.3	29	8	16									L	L	VL	permafrost degradation, possible fire	intense rainfall/snowmelt or heat	Management of debris accumulation in ditch or staging area	Special case of recurrent runout of debris from multiple active layer detachment sources
273.1	17	17	16									M	M	M	oversteepened slope toe, permafrost degradation	intense rainfall/snowmelt or heat	Management of runout debris	Reactivation possible
301.4				86	8	2	5	1	610	604	5	L	L	VL	concentrated drainage	intense rainfall/snowmelt	Management of surface runoff from culvert	
378.8	20	5	15									M	M	M	fire, permafrost degradation	intense rainfall/snowmelt or heat	Management of runout debris	
432.7	30	20	25									M	M	M	concentrated drainage in hwy ditch undercutting embankment	intense rainfall/snowmelt	Management of runoff in hwy ditch	
453.9				78	70	n/a	70	<1	656	653	2	L	M	L	possible disturbance to surface organic cover, permafrost degradation	intense rainfall/snowmelt or heat	Management of ground settlement	Potential for feature to evolve into retrogressive thaw slump
462.3	8	5	6									M	M	M	alteration of drainage pattern, permafrost degradation	intense rainfall/snowmelt or heat	Management of surface runoff and ground settlement	Dominant trajectory of retrogression parallel to, rather than toward, hwy

Note: Field headings and abbreviations defined in metadata table that follows

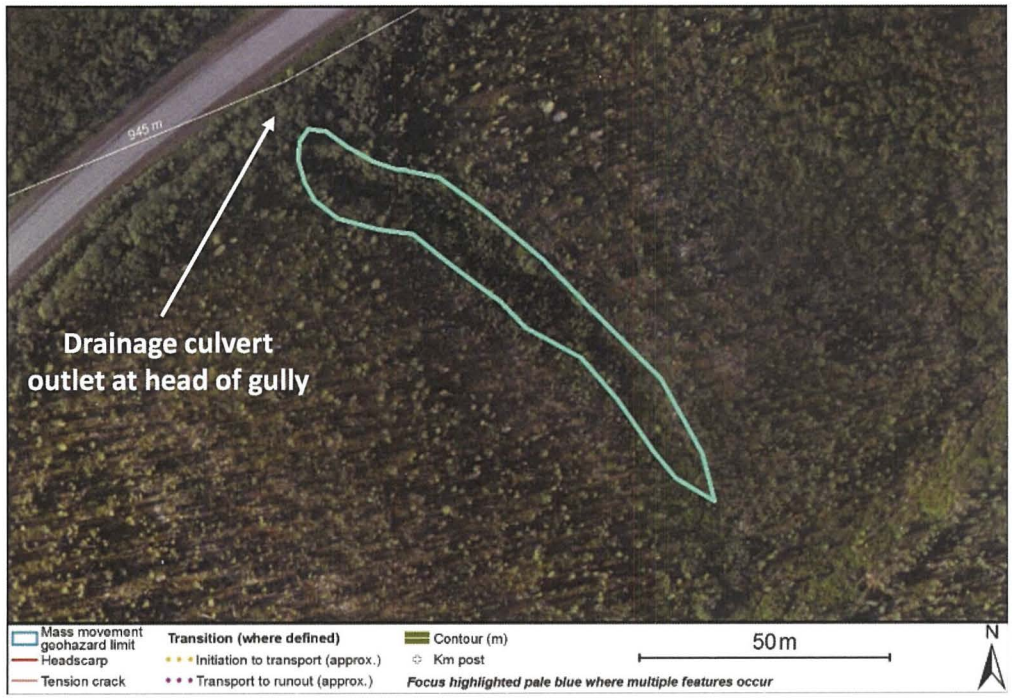
Appendix A. METADATA of Attributes of Mass Movement Geohazards

Field Heading	Full Field Heading	Description	Possible Values
KM_POST	Kilometre post	Approximate highway kilometre (unique identifier for mass movement site)	Numerical
SECTION	Highway maintenance section	Highway maintenance section	Klondike, Ogilvie, Eagle Plains
TYPE	Type of mass movement	Classification of dominant mass movement process according to Hungr et al. (2014), with permafrost-related refinements based on van Everdingen (2005)	DS: debris slide, DS (ALD): debris slide (active layer detachment), RTS: retrogressive thaw slump, RF: rockfall, DF: debris flow, TKs: thermokarst subsidence (active, >1 m relief), TKg: thermokarst gully (active, >1 m relief)
POS_TO_HWY	Position relative to highway	General position of mass movement relative to highway	above, below, beneath
PROXIMITY	Proximity (m)	Proximity, or shortest distance (m), between nearest limit of geohazard and toe of highway embankment	Numerical
ELEV_CNTR	Elevation (m)	Elevation above sea level (m) of centroid of delineated mass movement polygon	Numerical
ASPECT	Aspect (°)	Average aspect of mass movement slope (°)	0-360°
SURF_MAT	Surficial material	Dominant surficial material involved in mass movement (e.g., gszFAp), based on field-checked surficial geology mapping, coded with texture (gsz: silty sandy gravel), genetic material (FA: active fluvial) and surface expression (p: plain) according to YGS' adaptation of Howes and Kenk (1997)	Based on Howes and Kenk (1997)
PERMAFROST	Permafrost	General permafrost characteristics on mass movement slope, such as approximate depth (active layer thickness) and/or ground ice conditions	Text
FIRE	Fire	Potential influence of fire history on mass movement	Text
VEGETATION	Vegetation	General vegetation dominating the area encompassing the mass movement	Text
IMG_1977	1977 imagery	Presence of mass movement in 1977 imagery	y: yes, n: no, possibly, inconclusive
IMG_07-08	2007/2009 imagery	Presence of mass movement in 2007/2008 imagery	y: yes, n: no, possibly, inconclusive
IMG_13-14	2013/2014 imagery	Presence of mass movement in 2013/2014 imagery	y: yes, n: no, possibly, inconclusive
TIMING	Timing	General timing of occurrence, or recurrence, of mass movement based mainly on historical imagery and/or dendrochronological analysis	Text
LENGTH	Length (m)	Approximate total horizontal length (m) of mass movement	Numerical
DEPTH	Depth (m)	Approximate depth (thickness) (m) of mass movement	Numerical
WIDTH_MAX	Maximum width (m)	Approximate maximum width (m) of mass movement	Numerical
WIDTH_MIN	Minimum width (m)	Approximate minimum width (m) of mass movement	Numerical
WIDTH_HWY	Width at highway (m)	Approximate width (m) of mass movement at or near highway	Numerical
ELEV_CREST	Elevation (m) at crest	Approximate elevation (m) at crest of mass movement	Numerical
ELEV_RUNT	Elevation (m) at runout	Approximate elevation (m) at termination of runout (toe of deposit)	Numerical
SLOPE_INIT	Initiation slope (°)	Approximate angle (°) of mass movement initiation zone	0-90°
SLOPE_RUNT	Runout slope (°)	Approximate angle (°) of mass movement runout zone	0-90°
SLOPE_AVG	Average slope (°)	Approximate average angle (°) of mass movement (fahrböschung, from crest of source to toe of deposit)	0-90°
TK_LENGTH	Length (m)	Approximate total horizontal length (m) of thermokarst feature	Numerical
TK_WIDTH_T	Thermokarst top width (m)	Approximate top (gullies) or cross-slope (subsidence) width (m) of thermokarst features	Numerical
TK_WIDTH_B	Thermokarst bottom width (m)	Approximate bottom width (m) of thermokarst gullies	Numerical
TK_WIDTH_H	Thermokarst width at highway (m)	Approximate top (gullies) or cross-slope (subsidence) width (m) of thermokarst features at or near highway	Numerical
TK_DEPTH	Thermokarst depth (m)	Approximate depth of thermokarst feature (vertical depth for gullies; local (internal) relief for subsidence)	Numerical
TK_ELEV_CR	Thermokarst elevation at crest	Approximate elevation (m) at upslope limit of thermokarst feature	Numerical
TK_ELEV_RT	Thermokarst elevation at runout	Approximate elevation (m) at downslope limit of thermokarst feature	Numerical
TK_SLOPE	Thermokarst average slope (°)	Approximate average angle (°) of thermokarst feature, from upslope to downslope limits	0-90°
LIKELIHOOD	Likelihood	Projected frequency of impact to highway based on current conditions	L: low, M: moderate, H: high
CONSEQ	Consequence	Projected severity of impact to highway based on current conditions	L: low, M: moderate, H: high
RISK	Risk	Relative (qualitative) risk of highway impact, considering both likelihood and consequence, based on current conditions (as defined in the risk evaluation matrix (Section 3.5.2); note: km post text box in bottom-right corner of summary figures in Appendix C colour-coded according to risk	VL: very low, L: low, M: moderate, H: high, VH: very high
CAUSES	Causes	General factors contributing to mass movement, considering both natural and anthropogenic influences	Text
TRIGGERS	Triggers	Potential mechanisms for actual mass movement initiation	Text
MITIGATION	Mitigation	General insight with respect to the nature of processes requiring management in order to mitigate risk to the highway	Text
COMMENTS	Comments	Any additional noteworthy comments specific to the geohazard site	Text

KM_approx	Comment	Id	YukAlb83_E	YukAlb83_N
11.1	Deep gully at culvert outlet but not in permafrost and has self-stabilized bed	182	204002	1075030
20.2	Anthropogenic disturbance - not hazard-related	181	206917	1083138
26.8	Anthropogenic disturbance - not hazard-related	180	206543	1089361
39.4	Minor rockfall/talus slope well back from hwy	0	209584	1100885
39.7	Anthropogenic disturbance - not hazard-related	1	210089	1100979
43.5	Anthropogenic disturbance - not hazard-related	2	211623	1104663
45.2	No feature of relevance	3	212027	1106174
48.7	No feature of relevance	4	214375	1108816
52.3	Detailed Meander Assessment Site - see details in report	5	216824	1111085
53.2	Beaver-dammed oxbow; no major hwy embankment effects	7	217411	1112030
53.3	No feature of relevance	6	217348	1112091
54.9	Detailed Meander Assessment Site - see details in report	8	218790	1113039
55.4	Anthropogenic disturbance - not hazard-related	9	219130	1113404
55.5	Anthropogenic disturbance - not hazard-related	10	219188	1113425
55.9	Detailed Meander Assessment Site - see details in report	77	219500	1113653
56.0	Anthropogenic disturbance - not hazard-related	78	219480	1113703
59.6	No feature of relevance	11	221516	1116560
60.1	No major seepage, no slumping banks	79	221973	1116811
60.7	Mass Movement Geohazard Site - see details in report	12	222364	1117209
60.9	12 m nearest rockfall debris, low source bluff, mossy rock debris	80	222464	1117471
61.7	Anthropogenic disturbance - not hazard-related	81	222904	1118033
64.4	Mature trees and no evidence of instability in association with possible old rock glacier or landslide	82	225084	1119613
68.1	No evidence of instability at snout of rock glacier, and local bedrock control	83	226973	1122716
69.1	Beaver-dammed side channel, no obvious slumping	13	226359	1124417
72.2	Anthropogenic disturbance - not hazard-related	14	226222	1126547
75.4	Rock cut in bedrock, no evidence of significant instability	15	225762	1128926
76.1	Top of gullied slope at hwy edge, but hwy founded on bedrock or thin, coarse material	16	225789	1129652
76.9	No evidence of active instability, also anthropogenic disturbance in area	86	225662	1130421
77.3	Only minor sloughing of engineered fill in road cut	17	225478	1130618
82.9	Only minor sloughing of road cut	18	223599	1135639
83.1	Anthropogenic disturbance - not hazard-related	85	223410	1135808
85.5	Anthropogenic disturbance to ice-rich permafrost has led to differential settlement in borrow pits adjacent to hwy	20	221601	1137460
86.2	Anthropogenic disturbance to ice-rich permafrost in road cut has led to small failures that terminate before hwy	19	220956	1137492
88.0	Detailed Meander Assessment Site - see details in report	21	220124	1138698
89.7	Small creek with bank scour at outlet of culvert beneath hwy	84	220455	1140427
91.2	Only minor settlement within ice-rich permafrost, and no evidence of significant active instability	22	219765	1141847
93.6	Mass Movement Geohazard Site - see details in report	23	219448	1144118
94.3	Only minor settlement within ice-rich permafrost, and no evidence of significant active instability	24	219363	1144787
94.4	Only minor settlement within ice-rich permafrost, and no evidence of significant active instability	25	219353	1144877
96.8	Mass Movement Geohazard Site - see details in report	26	218876	1147302
97.1	Mass Movement Geohazard Site - see details in report	27	218802	1147601
97.2	Only minor settlement within ice-rich permafrost, and no evidence of significant active instability	87	218785	1147668
97.3	Only minor settlement within ice-rich permafrost, and no evidence of significant active instability	88	218747	1147783
103.7	Well vegetated, relatively stable, high bank, with little to no evidence of meander migration	76	221314	1152936
104.6	Active gullying and slumping of hwy embankment at several locations along meander	179	221101	1153720
105.2	Well vegetated bank with no significant erosion, but proximity is 2 m	75	221065	1154390
107.7	Active gullying and slumping of hwy embankment within and above small riprap at several locations along meander	178	221942	1156669
108.8	Recently repaired riprap embankment with no new signs of instability	74	222606	1157392
109.4	Active layer detachments terminate at base of slope, well back from hwy	177	222654	1157863
109.7	Active layer detachments terminate at base of slope, well back from hwy	176	222650	1158200
110.0	Active layer detachments terminate at base of slope, well back from hwy	73	222490	1158480
111.9	Well vegetated bank with no significant erosion, but proximity is <3 m	62	222510	1160289
116.7	Mass Movement Geohazard Site - see details in report	175	224183	1163921
119.2	Only minor settlement within ice-rich permafrost, and limited evidence of active instability	174	225786	1165645
119.6	Thermokarst activity concentrated west of hwy, with no obvious affect on hwy itself	173	225940	1165978
123.1	Well vegetated, high bank with 22 m between meander and highway, but underlain by ice-rich permafrost exhibiting thermokarst subsidence	72	227153	1169354
123.2	Thermokarst in ice-rich permafrost (10 cm lens visible) west of hwy, with initiation of westward-retrogressing thaw slump	89	227163	1169395
131.4	Detailed Meander Assessment Site - see details in report	90	229281	1176476
136.1	Detailed Meander Assessment Site - see details in report	71	232388	1179937
136.7	Road cut in bedrock, with no significant instability	68	232202	1180522
138.5	Detailed Meander Assessment Site - see details in report	70	232117	1182258
142.1	Solifluction into western road ditch, with some minor water outflow onto hwy	69	234069	1185308
143.5	Minor ravelling of road cut into toe of talus-creep slope	91	235342	1185709
144.3	Tension cracks and small slumps in hwy embankment above recently placed, small riprap	61	235737	1186259
147.6	Detailed Meander Assessment Site - see details in report	92	234338	1188551
153.1	No feature of relevance	67	229214	1188100
153.2	Anthropogenic disturbance - not hazard-related	65	229236	1188154
154.6	Anthropogenic disturbance - not hazard-related	66	227921	1188656
155.1	Debris flood fan terminates at valley-bottom creek, which is highly disturbed (anthropogenically) in the confluence area	172	227484	1188628
156.0	Minor rockfall/creep on northern hillside terminates at base of slope, back from hwy	63	226510	1188849
157.7	Minor rockfall/creep on eastern hillside terminates at base of slope, back from hwy	64	225336	1189862
165.6	Recently riprapped embankment intact, but potential for erosion at southern limit	60	227081	1196916
166.4	Recently riprapped embankment intact, but potential for erosion at southern limit	57	226618	1197791
168.3	Two adjacent springs at base of slope west of hwy	58	225525	1199706
170.9	Detailed Meander Assessment Site - see details in report	93	226672	1201407
171.3	Possible minor active layer detachment terminates well back from hwy	94	226976	1201819
172.9	Detailed Meander Assessment Site - see details in report	95	227812	1203058
173.6	Debris slides and active layer detachments terminate well back from hwy	97	227861	1203790
173.7	Mass Movement Geohazard Site - see details in report	96	227947	1203844
175.4	Detailed Meander Assessment Site - see details in report	98	228623	1205335
175.5	Possible minor active layer detachment terminates well back from hwy	99	228653	1205477
176.3	Anthropogenic disturbance - not hazard-related	51	229136	1206141
176.5	Mass Movement Geohazard Site - see details in report	55	229226	1206372
177.5	Mass Movement Geohazard Site - see details in report	54	229641	1206967
177.6	Mass Movement Geohazard Site - see details in report	53	229681	1207120
177.8	Mass Movement Geohazard Site - see details in report	52	229752	1207348
179.0	No feature of relevance	50	229906	1208456
180.7	Detailed Meander Assessment Site - see details in report	100	230989	1209737
181.4	Detailed Meander Assessment Site - see details in report	101	231605	1209933
182.1	Detailed Meander Assessment Site - see details in report	102	232180	1210256
183.3	Detailed Meander Assessment Site - see details in report	103	232950	1211193
183.6	Outcrop of weathered bedrock upslope	56	233089	1211434
183.9	Minor rockfall from small outcrop terminates back from hwy	48	233430	1211610
185.1	Minor rockfall terminates back from hwy	49	233557	1212632
185.3	Scoured area at culvert outlet	183	233634	1212806
185.8	Detailed Meander Assessment Site - see details in report	104	233791	1213216
188.6	Detailed Meander Assessment Site - see details in report	105	233900	1215949
189.4	Detailed Meander Assessment Site - see details in report	106	233401	1216626

Appendix B. Field Site Inspection Comments

KM_approx	Comment	Id	YukAlb83_E	YukAlb83_N
191.6	Mass Movement Geohazard Site - see details in report	59	232924	1218719
191.7	Colluvial fan likely formed by a variety of mass movement processes long before hwy construction	47	232925	1218817
193.0	Mass Movement Geohazard Site - see details in report	46	232390	1219987
195.1	Detailed Meander Assessment Site - see details in report	107	230866	1221271
197.4	Minor rockfall terminates back from hwy	45	231426	1223326
197.9	Minor rockfall/creep terminates back from hwy	44	231822	1223481
200.1	Minor rockfall/creep terminates back from hwy	43	232504	1225104
202.4	Detailed Meander Assessment Site - see details in report	108	233791	1226170
202.5	Mass Movement Geohazard Site - see details in report	111	236248	1232952
203.7	No feature of relevance	41	234757	1225566
205.0	Mass Movement Geohazard Site - see details in report	42	235521	1226389
209.3	Possible minor active layer detachment terminates well back from hwy	40	235246	1230624
209.5	Mass Movement Geohazard Site - see details in report	188	235281	1230796
209.6	Mass Movement Geohazard Site - see details in report	189	235284	1230853
209.7	Mass Movement Geohazard Site - see details in report	39	235276	1230953
209.8	Localized failure of riprap/embankment, with largest 4 m high, 1.5 m deep and 10 m wide)	109	235335	1231098
210.2	Active layer detachment terminates well back from hwy	110	235587	1231311
210.9	Mass Movement Geohazard Site - see details in report	38	236275	1231602
212.7	Mass Movement Geohazard Site - see details in report	171	236213	1233148
212.8	Mass Movement Geohazard Site - see details in report	170	236147	1233233
212.9	Mass Movement Geohazard Site - see details in report	112	236093	1233401
212.9	Mass Movement Geohazard Site - see details in report	168	236114	1233342
213.0	Mass Movement Geohazard Site - see details in report	169	236038	1233446
213.1	Mass Movement Geohazard Site - see details in report	113	236033	1233495
213.1	Mass Movement Geohazard Site - see details in report	184	236017	1233532
213.2	Mass Movement Geohazard Site - see details in report	185	235998	1233571
213.3	Mass Movement Geohazard Site - see details in report	167	235913	1233716
213.4	Mass Movement Geohazard Site - see details in report	114	235881	1233772
213.7	No feature of relevance	115	235742	1234150
213.8	Minor rockfall/ravelling of road cut requiring periodic maintenance	166	235720	1234256
218.0	Possible small active layer detachment back from hwy	37	234962	1238298
218.1	Mass Movement Geohazard Site - see details in report	116	234946	1238404
219.3	Mass Movement Geohazard Site - see details in report	117	235347	1239381
219.5	Mass Movement Geohazard Site - see details in report	36	235382	1239632
219.7	Mainly road cut ravelling	118	235474	1239800
221.2	Detailed Meander Assessment Site - see details in report	119	236257	1241075
221.3	Detailed Meander Assessment Site - see details in report	120	236249	1241195
221.5	Mass Movement Geohazard Site - see details in report	192	236363	1241486
221.7	Mass Movement Geohazard Site - see details in report	35	236440	1241574
221.8	Mass Movement Geohazard Site - see details in report	190	236484	1241591
221.9	Mass Movement Geohazard Site - see details in report	191	236547	1241621
224.7	Mass Movement Geohazard Site - see details in report	28	238509	1243673
232.0	Detailed Meander Assessment Site - see details in report	121	240814	1250554
236.3	Detailed Meander Assessment Site - see details in report	122	241843	1254671
239.5	Detailed Meander Assessment Site - see details in report	123	243471	1257461
241.9	Mass Movement Geohazard Site - see details in report	126	245640	1258573
242.0	Mass Movement Geohazard Site - see details in report	124	245711	1258604
242.2	Mass Movement Geohazard Site - see details in report	34	245933	1258625
242.5	Minor rockfall/ravelling of road cut requiring periodic maintenance	33	246265	1258662
242.8	Possible old active layer detachment that terminates well back from hwy	125	246454	1258725
243.8	Detailed Meander Assessment Site - see details in report	127	247407	1259024
244.0	Mass Movement Geohazard Site - see details in report	30	247522	1259099
244.2	Mass Movement Geohazard Site - see details in report	186	247715	1259179
244.3	Mass Movement Geohazard Site - see details in report	29	247812	1259306
244.3	Mass Movement Geohazard Site - see details in report	187	247824	1259220
244.4	Active layer detachment terminates well back from hwy	31	247937	1259286
244.6	Active layer detachments terminate well back from hwy	32	248149	1259384
247.9	Only localized, minor gullying downstream of culvert	165	249756	1261338
248.1	Only localized, minor gullying downstream of culvert	164	249861	1261494
250.0	Only localized, minor gullying downstream of culvert	162	250798	1263081
250.5	Only localized, minor gullying downstream of culvert	161	251233	1263337
250.8	Only localized, minor gullying downstream of culvert	163	251564	1263465
258.4	Only minor creep of talus due to periglacial processes	160	258455	1266084
267.7	Only localized, minor gullying	159	260954	1273819
273.1	Mass Movement Geohazard Site - see details in report	158	264350	1272390
273.3	Predominantly minor creep of talus due to periglacial processes	157	264649	1272397
274.0	Predominantly minor creep of talus due to periglacial processes	156	265263	1272561
279.7	No feature of relevance	155	269516	1274173
279.9	No feature of relevance	154	269515	1274353
286.0	Only localized, minor gullying	153	271815	1279650
293.3	Only localized, minor gullying downstream of culvert	152	278072	1279899
298.2	Only localized, minor gullying downstream of culvert	151	279478	1284162
301.4	Mass Movement Geohazard Site - see details in report	150	281879	1286275
325.8	Anthropogenic disturbance - not hazard-related	149	286671	1302498
326.3	Only localized, minor gullying downstream of culvert	148	286845	1302911
342.9	Only localized, minor gullying downstream of culvert	147	299633	1310379
350.0	Mainly minor creep of talus in road cut due to periglacial processes	146	304244	1314064
350.9	Several old active layer detachments terminate well back from hwy	145	305041	1314466
353.7	Anthropogenic disturbance - not hazard-related	134	307058	1316327
358.8	Anthropogenic disturbance - not hazard-related	133	310743	1319150
365.5	Only minor creep of talus due to periglacial processes	132	310803	1324945
378.8	Mass Movement Geohazard Site - see details in report	131	313167	1336402
379.0	No feature of relevance	144	313310	1336314
381.3	Possible old active layer detachment terminates well back from hwy	143	315199	1336651
410.3	Only localized, minor gullying	130	332220	1352957
418.7	Only minor settlement and ponding adjacent to hwy, in area of ice-rich permafrost	142	330614	1360931
425.3	Only minor settlement and ponding adjacent to hwy, in area of ice-rich permafrost	141	330249	1367527
426.7	Only minor settlement and ponding adjacent to hwy, in area of ice-rich permafrost	140	330412	1368884
429.7	Only minor settlement and ponding adjacent to hwy, in area of ice-rich permafrost	138	331089	1371935
430.3	Only minor settlement and ponding adjacent to hwy, in area of ice-rich permafrost	139	331215	1372483
431.9	Only minor settlement and ponding adjacent to hwy, in area of ice-rich permafrost	137	331536	1373901
432.7	Mass Movement Geohazard Site - see details in report	128	331526	1374698
434.1	Only minor settlement and ponding adjacent to hwy, in area of ice-rich permafrost	129	331313	1376096
440.6	Only localized, minor gullying downslope of hwy	136	331957	1382574
440.7	Only localized, minor gullying downslope of hwy	135	331959	1382615



SITE	PROCESS	GEOMETRY	IMPLICATIONS
Section	**Type**	**Elevation (m)**	**Likelihood**
Klondike	thermokarst gully	933	L
Proximity (m)	**Position**	**Length (m)**	**Consequence**
10	below	113	M
Aspect (°)	**Causes**	**Width (m)**	**Risk**
120	concentrated drainage	12	L
Surficial material	**Triggers**	**Depth (m)**	**Mitigation**
szcFa	intense rainfall/snowmelt	3	Management of surface runoff from culvert
Permafrost	**Timing**	**Average slope (°)**	**Comments**
Shallow permafrost, likely locally ice-rich	Ongoing/episodic, likely initiated following highway construction	4	

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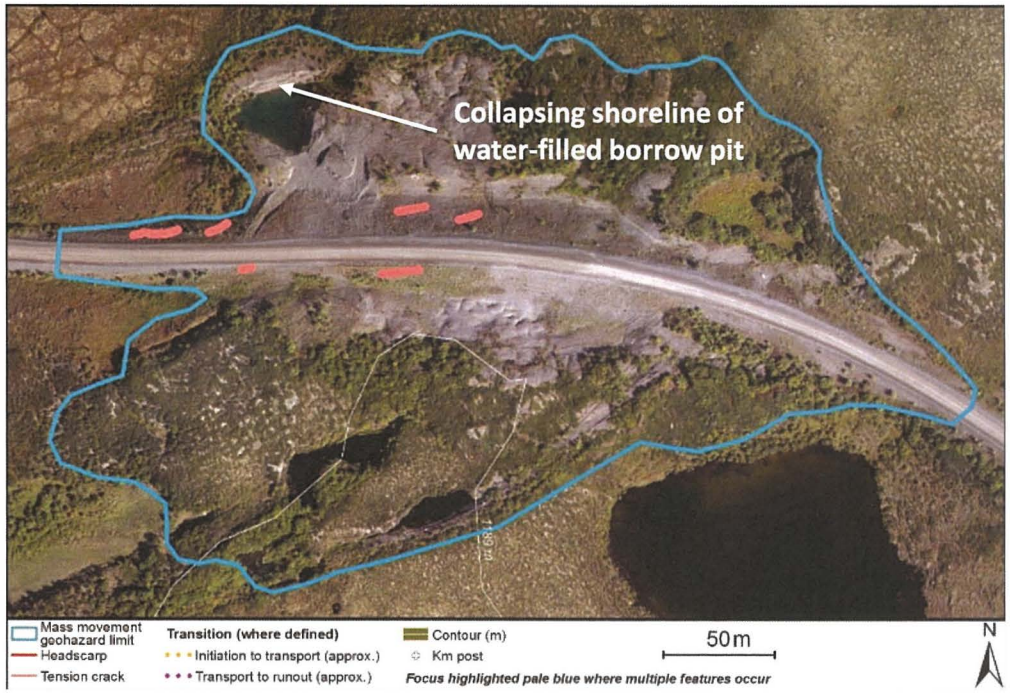

SITE	PROCESS	GEOMETRY	IMPLICATIONS

Section	Type	Elevation (m)	Likelihood
Klondike	thermokarst subsidence	1180	M

Proximity (m)	Position	Length (m)	Consequence
0	beneath	360	L

Aspect (°)	Causes	Width (m)	Risk
240	alteration to surface organic cover, alteration to drainage, permafrost degradation	235	L

Surficial material	Triggers	Depth (m)	Mitigation
dszMu	intense rainfall/snowmelt or heat	<2	Management of ground settlement

Permafrost	Timing	Average slope (°)	Comments
Shallow, ice-rich permafrost in area of degrading ice-wedge polygons	Ongoing/episodic, likely exacerbated by highway construction	3	Differential settlement expected to continue affecting hwy embankments

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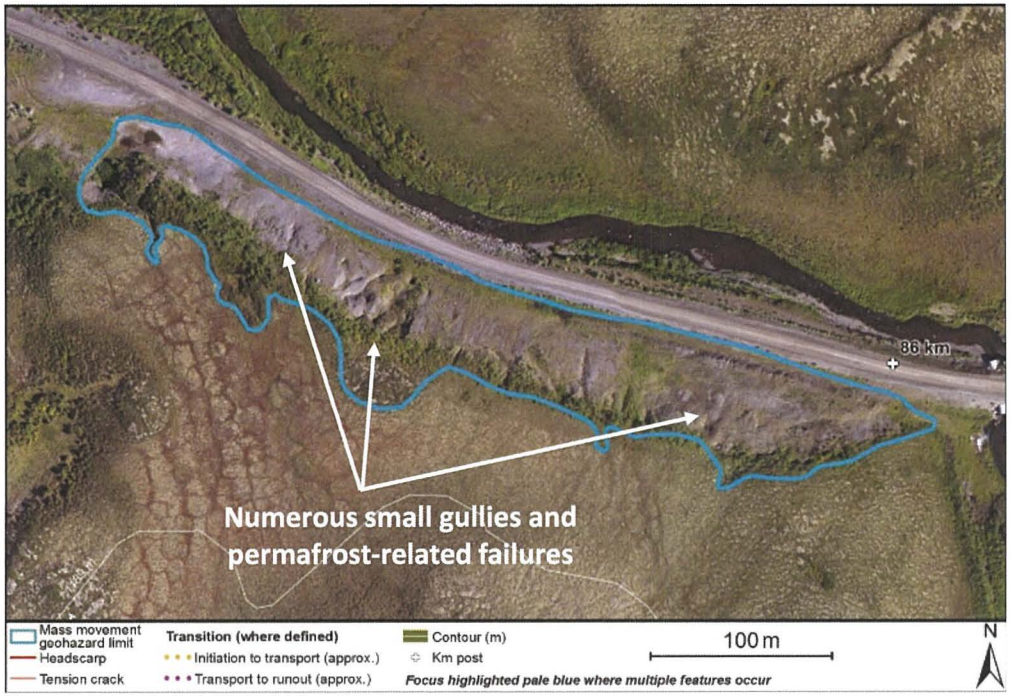

SITE	PROCESS	GEOMETRY	IMPLICATIONS

Section	Type	Elevation (m)	Likelihood
Klondike	debris slide (active layer detachment) & thermokarst gully	1170	M

Proximity (m)	Position	Length (m)	Consequence
0	above	55	L

Aspect (°)	Causes	Width (m)	Risk
15	disturbance and possible over-steepening of slope toe, permafrost degradation	420	L

Surficial material	Triggers	Depth (m)	Mitigation
dszMa	intense rainfall/snowmelt or heat	2	Management of runout debris

Permafrost	Timing	Average slope (°)	Comments
Shallow, ice-rich permafrost in area of degrading ice-wedge polygons	Ongoing/episodic, likely exacerbated by highway construction	14	Minor slope deformation expected to continue as ice-wedge polygons thaw

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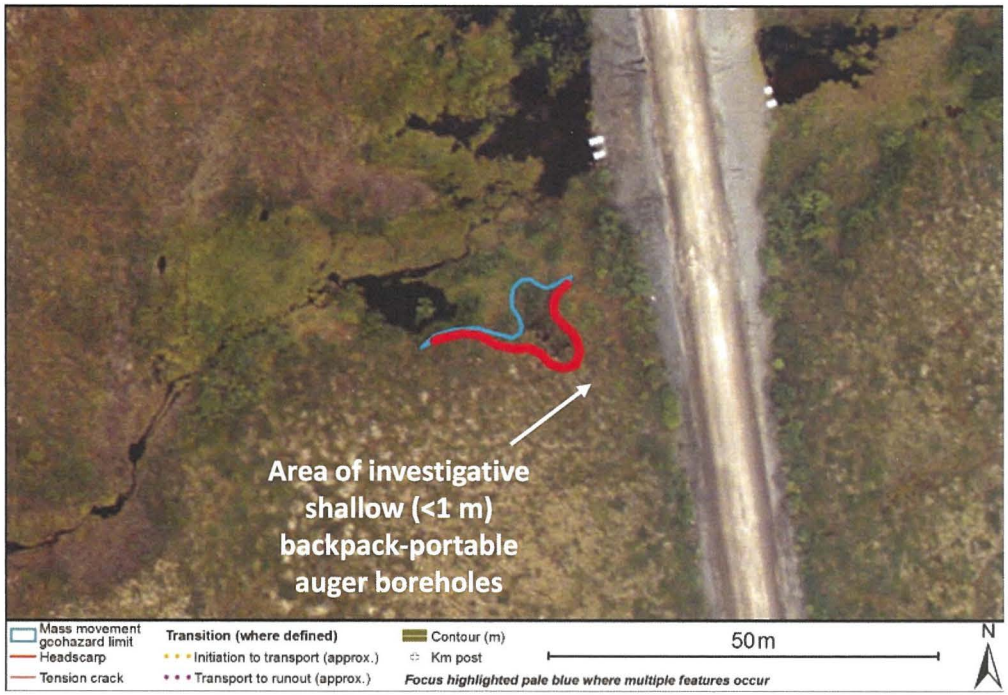

SITE	PROCESS	GEOMETRY	IMPLICATIONS
Section	**Type**	**Elevation (m)**	**Likelihood**
Klondike	retrogressive thaw slump	1124	L
Proximity (m)	**Position**	**Initiation slope (°)**	**Consequence**
10	below	11	H
Aspect (°)	**Causes**	**Runout slope (°)**	**Risk**
330	alteration to drainage pattern (unnatural impoundment), permafrost degradation	9	M
Surficial material	**Triggers**	**Average slope (°)**	**Mitigation**
sgzFGt	intense rainfall/snowmelt or heat	11	Management of ground settlement
Permafrost	**Timing**	**Dimensions (L/W/D) (m)**	**Comments**
Shallow, ice-rich permafrost in area of degrading ice-wedge polygons; 2 m of exposed ice wedge plus seams/lenses	Ongoing/episodic, possibly exacerbated by highway construction	13 / 6 / 2	Dominant trajectory of retrogression subparallel to, rather than toward, hwy

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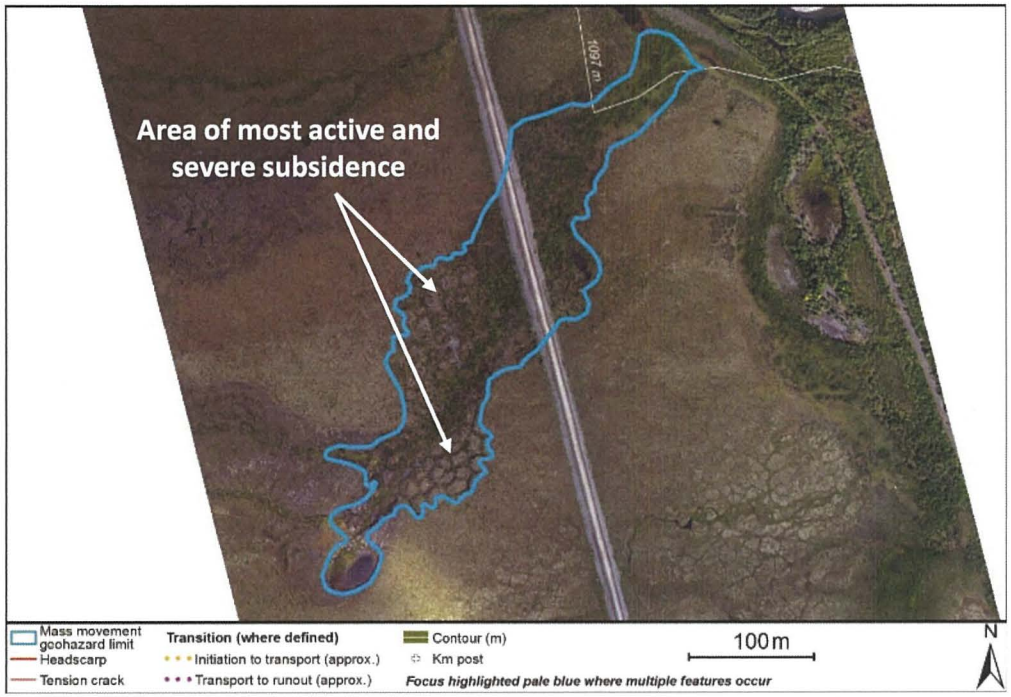

SITE	PROCESS	GEOMETRY	IMPLICATIONS

Section	Type	Elevation (m)	Likelihood
Klondike	thermokarst subsidence	1106	L

Proximity (m)	Position	Length (m)	Consequence
0	beneath	518	M

Aspect (°)	Causes	Width (m)	Risk
55	permafrost degradation	95	L

Surficial material	Triggers	Depth (m)	Mitigation
zsgFf	intense rainfall/snowmelt or heat	2.5	Management of ground settlement

Permafrost	Timing	Average slope (°)	Comments
Shallow, ice-rich permafrost (silt/organics) in area of degrading ice-wedge polygons	Ongoing/episodic, possibly exacerbated by highway construction	1	Area of severest subsidence activity southwest of hwy

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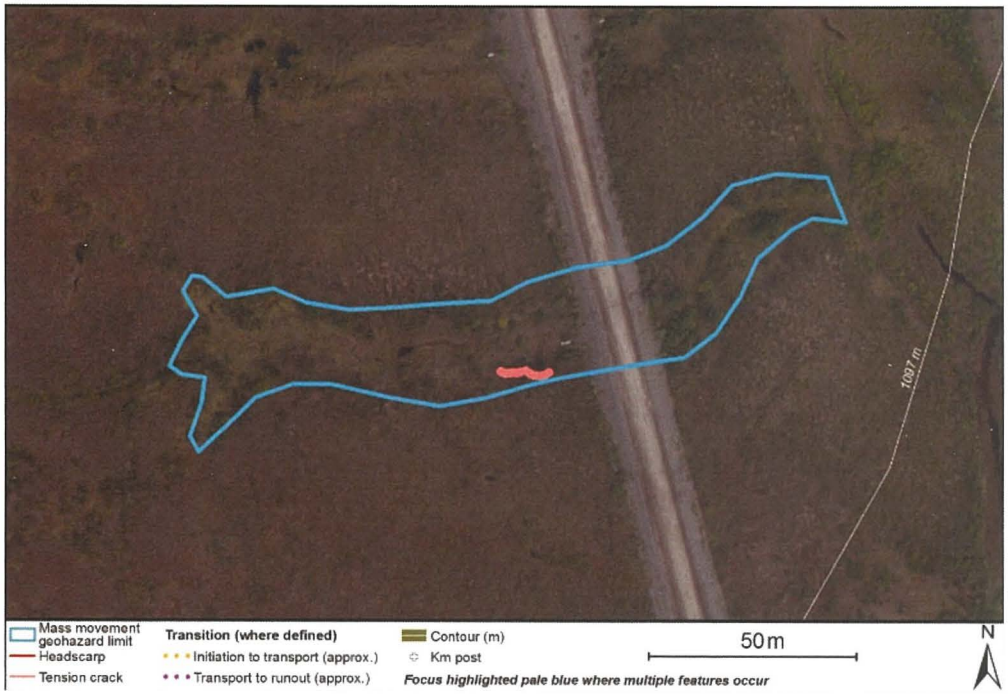

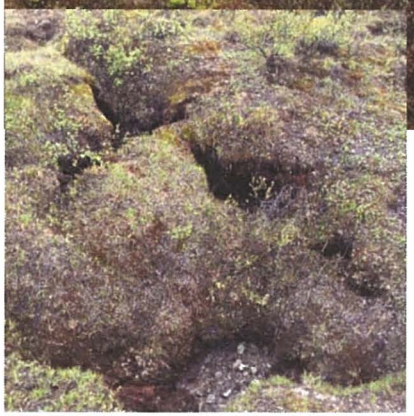

SITE	PROCESS	GEOMETRY	IMPLICATIONS
Section	**Type**	**Elevation (m)**	**Likelihood**
Klondike	thermokarst subsidence	1106	L
Proximity (m)	**Position**	**Length (m)**	**Consequence**
0	beneath	170	M
Aspect (°)	**Causes**	**Width (m)**	**Risk**
60	permafrost degradation	25	L
Surficial material	**Triggers**	**Depth (m)**	**Mitigation**
zsgFf	intense rainfall/snowmelt or heat	2	Management of ground settlement
Permafrost	**Timing**	**Average slope (°)**	**Comments**
Shallow, ice-rich permafrost (silt/organics) in area of degrading ice-wedge polygons	Ongoing/episodic, possibly exacerbated by highway construction	2	Active subsidence limited to area immediately west of hwy

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SITE	PROCESS	GEOMETRY	IMPLICATIONS
Section	**Type**	**Elevation (m)**	**Likelihood**
Klondike	debris slide (active layer detachment)	988	M
Proximity (m)	**Position**	**Initiation slope (°)**	**Consequence**
10	below	36	M
Aspect (°)	**Causes**	**Runout slope (°)**	**Risk**
140	incremental undercutting of slope toe by river, permafrost degradation	10	M
Surficial material	**Triggers**	**Average slope (°)**	**Mitigation**
szdMa	intense rainfall/snowmelt or heat	24	Management of ground settlement if/when feature retrogresses toward hwy
Permafrost	**Timing**	**Dimensions (L/W/D) (m)**	**Comments**
Shallow, ice-rich permafrost on river-cut scarp adjacent to degrading ice-wedge polygons	Single event (2007-2013) with potential to initiate retrogressive thaw slump	48 / 26 / 2.5	Potential for feature to evolve into retrogressive thaw slump

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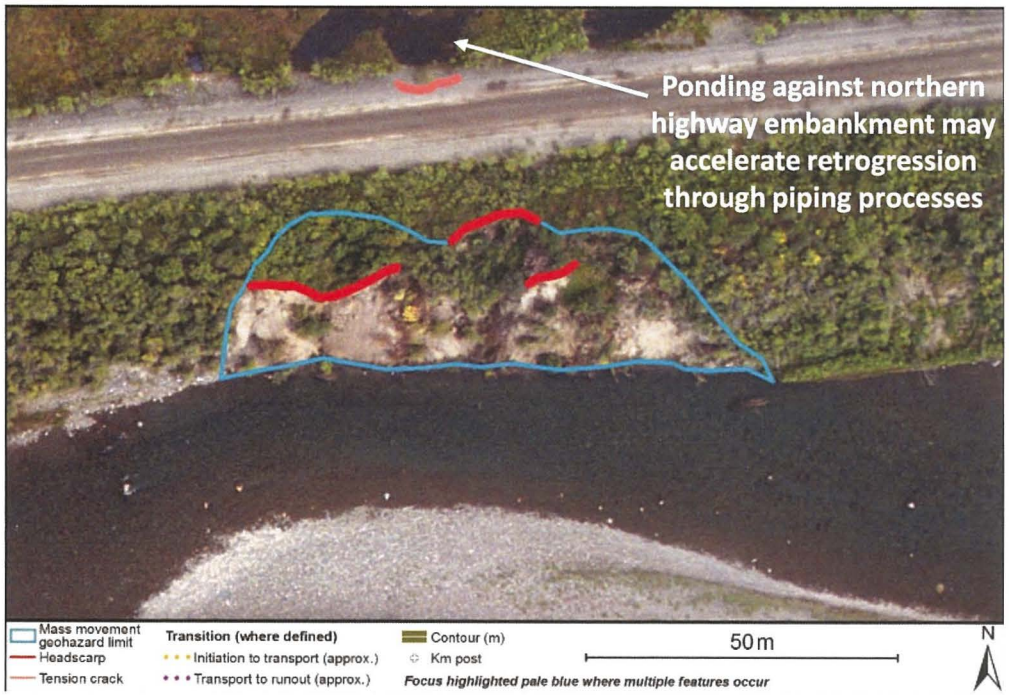

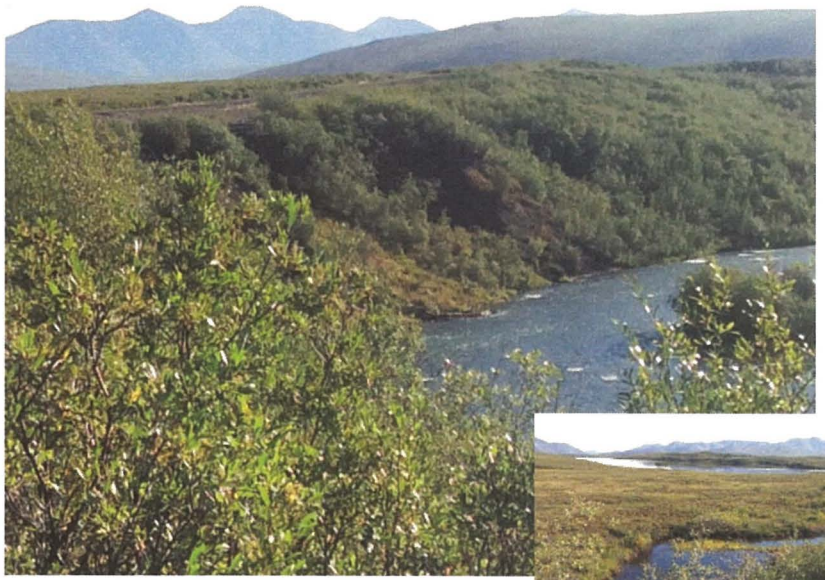

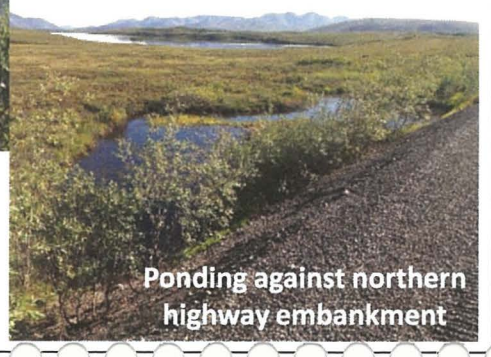

Photo credits: Lekan Mitchell

SITE	PROCESS	GEOMETRY	IMPLICATIONS
Section	**Type**	**Elevation (m)**	**Likelihood**
Klondike	retrogressive thaw slump	989	M
Proximity (m)	**Position**	**Initiation slope (°)**	**Consequence**
3.5	below	29	H
Aspect (°)	**Causes**	**Runout slope (°)**	**Risk**
155	disturbance to surface organic cover, alteration of drainage pattern, permafrost degradation	0	H
Surficial material	**Triggers**	**Average slope (°)**	**Mitigation**
gszFt\szdMa	intense rainfall/snowmelt or heat	35	Management of ponding adjacent to hwy and ground settlement if/when feature retrogresses toward hwy
Permafrost	**Timing**	**Dimensions (L/W/D) (m)**	**Comments**
Shallow, ice-rich permafrost on river-cut scarp adjacent to degrading ice-wedge polygons	Ongoing/episodic, possibly exacerbated by highway construction	23 / 60 / 2.4	Ponding north of hwy may exacerbate failure to south

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SITE	PROCESS	GEOMETRY	IMPLICATIONS

Section	Type	Elevation (m)	Likelihood
Klondike	retrogressive thaw slump	986	M

Proximity (m)	Position	Initiation slope (°)	Consequence
5	below	29	H

Aspect (°)	Causes	Runout slope (°)	Risk
135	alteration of drainage pattern, permafrost degradation	11	H

Surficial material	Triggers	Average slope (°)	Mitigation
gszFt\szdMa	intense rainfall/snowmelt or heat	24	Management of ground settlement and slope failures if/when feature retrogresses toward hwy

Permafrost	Timing	Dimensions (L/W/D) (m)	Comments
Shallow, ice-rich permafrost on river-cut scarp adjacent to degrading ice-wedge polygons	Ongoing/episodic, possibly exacerbated by highway construction	45 / 90 / 4.5	

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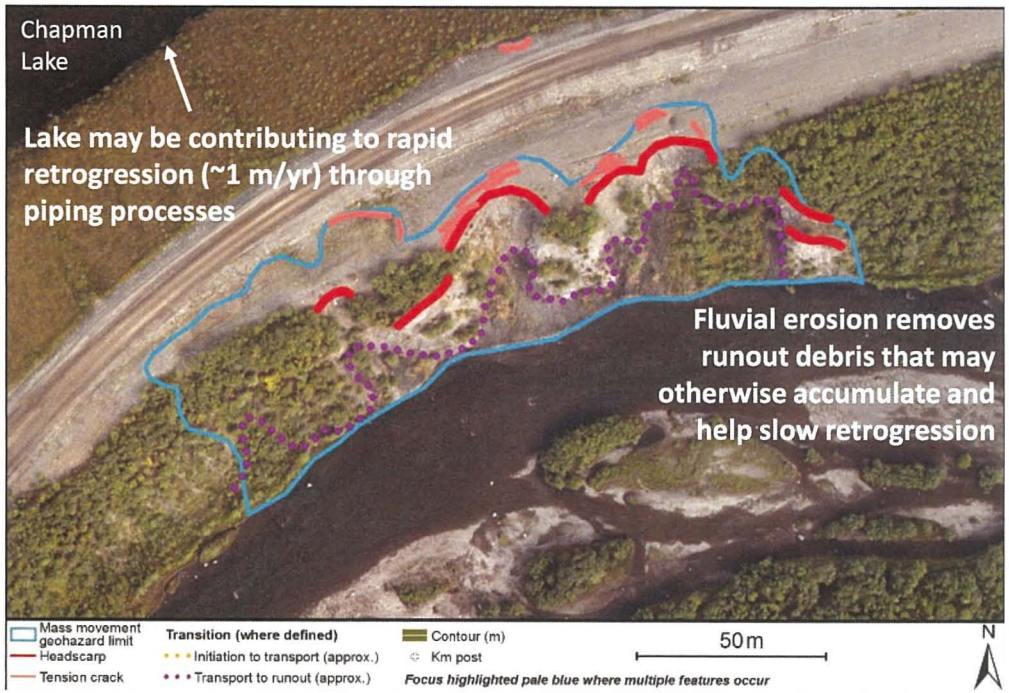

Photo credits: Lekan Mitchell

SITE	PROCESS	GEOMETRY	IMPLICATIONS
Section	**Type**	**Elevation (m)**	**Likelihood**
Klondike	retrogressive thaw slump	989	H
Proximity (m)	**Position**	**Initiation slope (°)**	**Consequence**
0	below	4	H
Aspect (°)	**Causes**	**Runout slope (°)**	**Risk**
135	disturbance to surface organic cover, alteration of drainage pattern, permafrost degradation	20	VH
Surficial material	**Triggers**	**Average slope (°)**	**Mitigation**
gszFt\szdMa	intense rainfall/snowmelt or heat	20	Management of ground settlement and slope failures if/when feature retrogresses toward hwy
Permafrost	**Timing**	**Dimensions (L/W/D) (m)**	**Comments**
Shallow, ice-rich permafrost on river-cut scarp adjacent to degrading ice-wedge polygons with lake on opposite, upslope side of highway	Ongoing/episodic, possibly exacerbated by highway construction; rapid retrogression 2007-2013 (~1 m/yr)	50 / 155 / 3	Significant risk to hwy, especially given lake to north and relatively rapid retrogression (up to ~1 m/year); potential for future lake drainage

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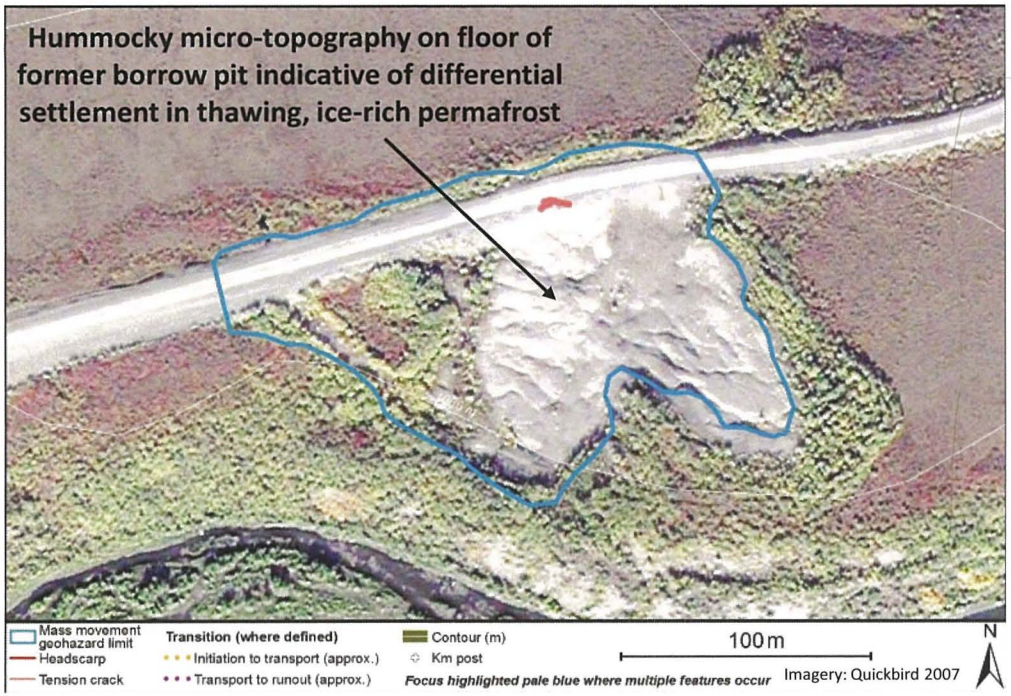

SITE	PROCESS	GEOMETRY	IMPLICATIONS
Section	**Type**	**Elevation (m)**	**Likelihood**
Klondike	thermokarst subsidence	998	M
Proximity (m)	**Position**	**Length (m)**	**Consequence**
0	beneath	147	M
Aspect (°)	**Causes**	**Width (m)**	**Risk**
160	disturbance to surface organic cover, alteration of drainage pattern, permafrost degradation	200	M
Surficial material	**Triggers**	**Depth (m)**	**Mitigation**
gszFt	intense rainfall/snowmelt or heat	1.5	Management of ground settlement
Permafrost	**Timing**	**Average slope (°)**	**Comments**
Shallow, ice-rich permafrost in area of ice-wedge polygons	Ongoing/episodic, likely initiated by clearing for borrow pit	5	Differential settlement expected to continue affecting hwy embankments

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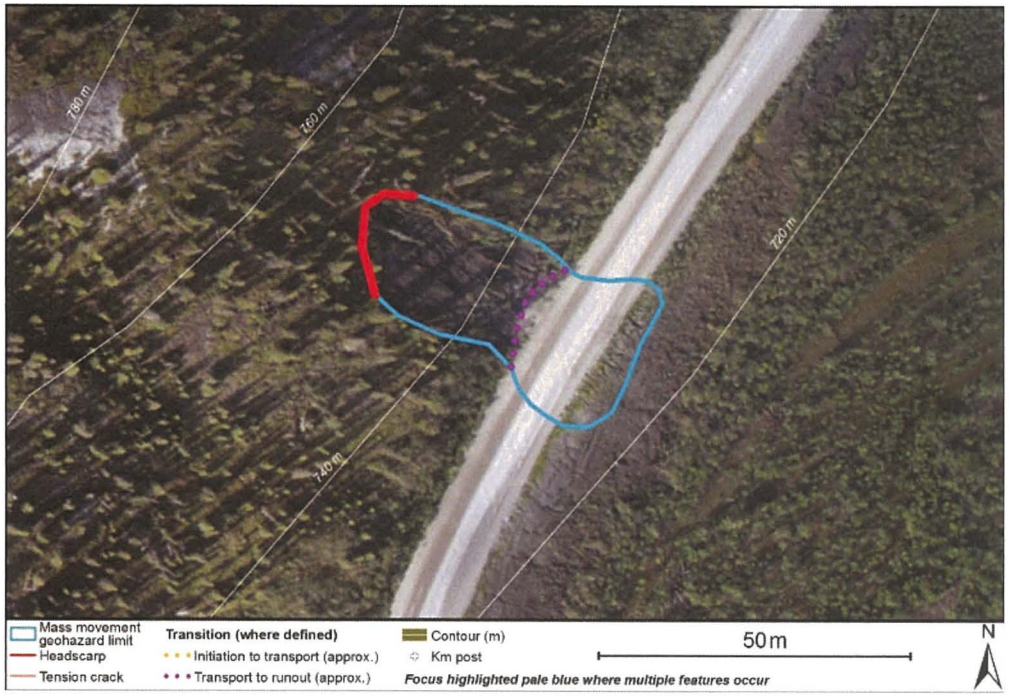

SITE	PROCESS	GEOMETRY	IMPLICATIONS
Section	**Type**	**Elevation (m)**	**Likelihood**
Ogilvie	debris slide (active layer detachment)	724	M
Proximity (m)	**Position**	**Initiation slope (°)**	**Consequence**
0	above	32	L
Aspect (°)	**Causes**	**Runout slope (°)**	**Risk**
110	oversteepened slope toe, permafrost degradation	4	L
Surficial material	**Triggers**	**Average slope (°)**	**Mitigation**
szrCv	intense rainfall/snowmelt or heat	26	Management of debris accumulation in ditch
Permafrost	**Timing**	**Dimensions (L/W/D) (m)**	**Comments**
Shallow permafrost	Single event (2007-2013) with potential for post-failure sloughs/flows	54 / 27 / 0.9	Runout limits approximate due to clearing of former debris accumulation

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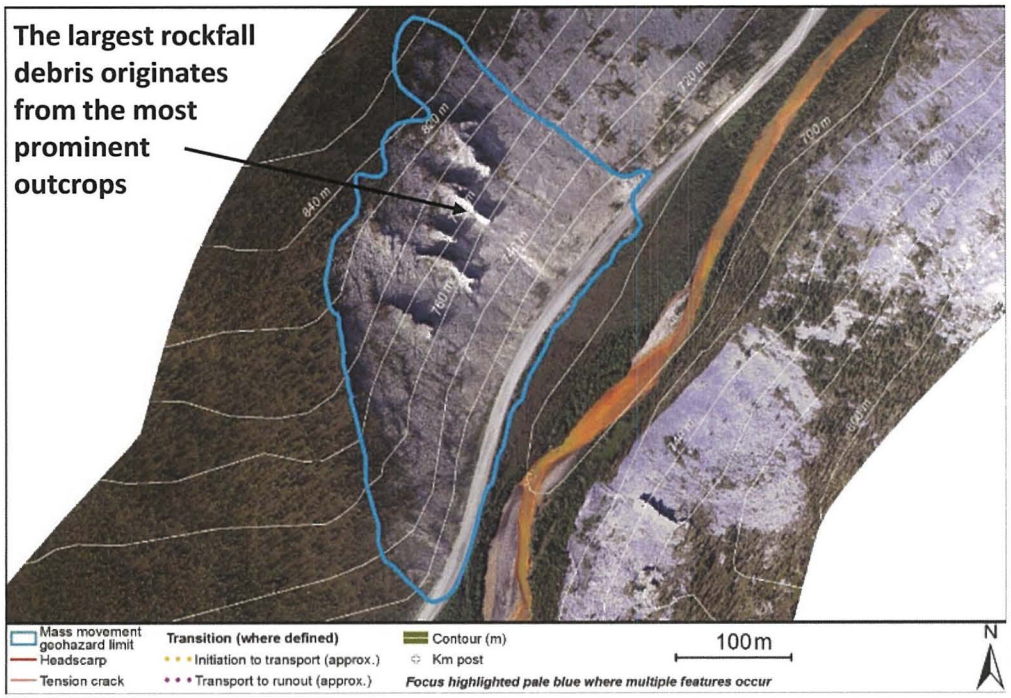

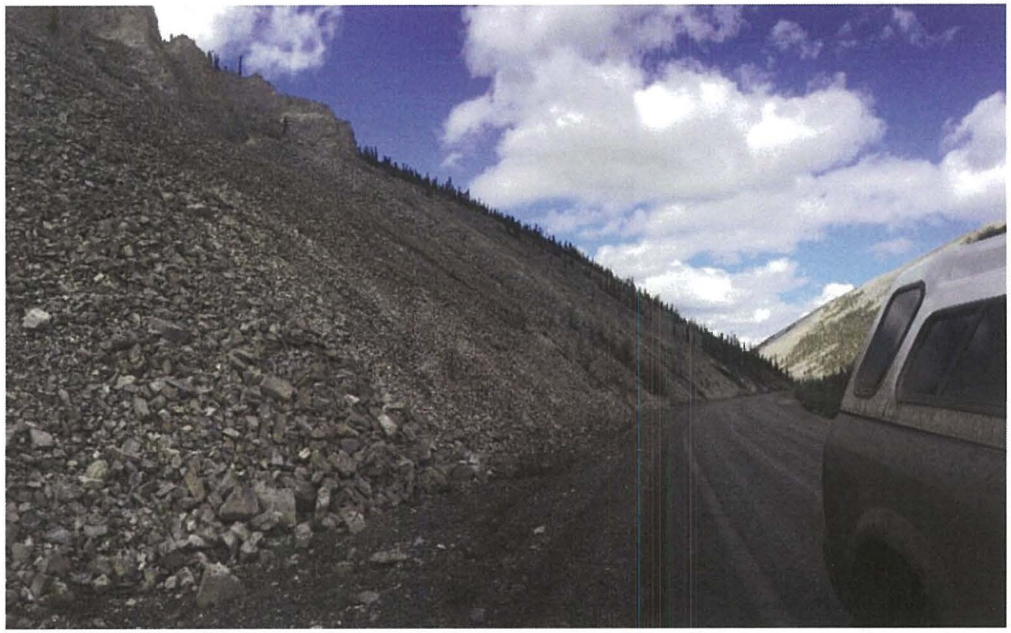

SITE	PROCESS	GEOMETRY	IMPLICATIONS
Section	**Type**	**Elevation (m)**	**Likelihood**
Ogilvie	rockfall	752	H
Proximity (m)	**Position**	**Initiation slope (°)**	**Consequence**
0	above	44	M
Aspect (°)	**Causes**	**Runout slope (°)**	**Risk**
120	steep rock bluffs	17	H
Surficial material	**Triggers**	**Average slope (°)**	**Mitigation**
R	freeze/thaw, intense rainfall/snowmelt	34	Management of rockfall debris in ditch and on hwy
Permafrost	**Timing**	**Dimensions (L/W/D) (m)**	**Comments**
Permafrost, likely ice-poor, deep within weathered bedrock	Recurrent (likely annual)	231 / 420 / n/a	Runout limits approximate due to clearing of former debris accumulation; risk greatest downslope of prominent rock bluffs

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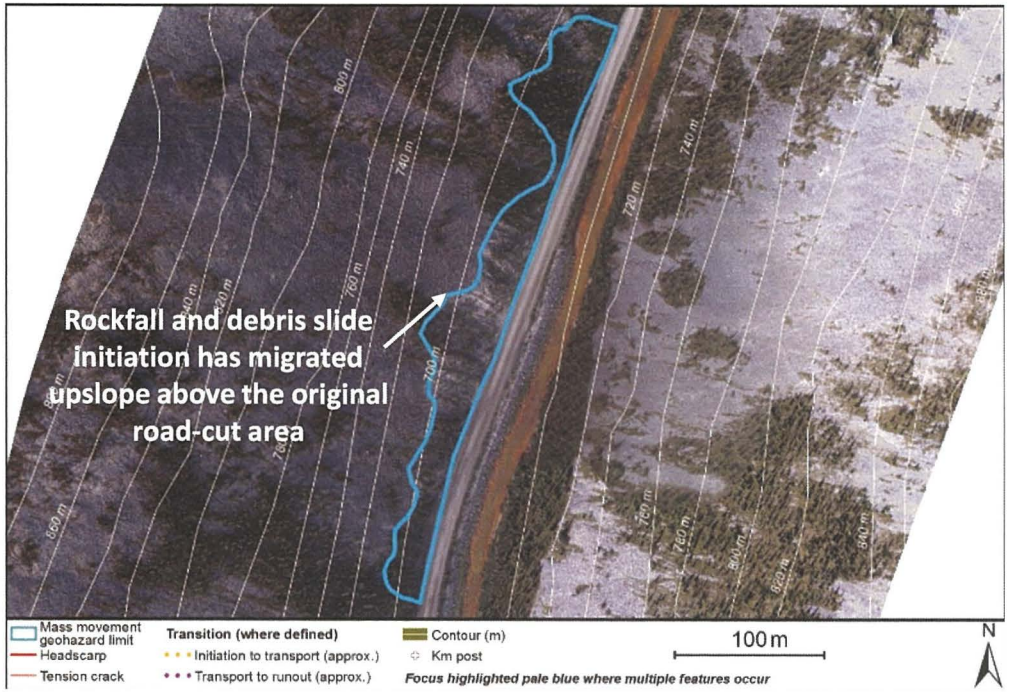

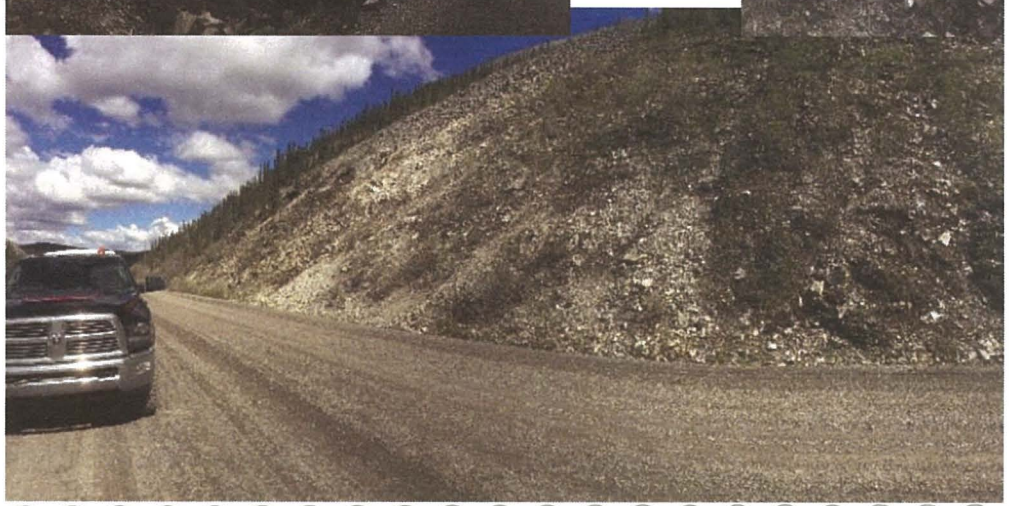

SITE	PROCESS	GEOMETRY	IMPLICATIONS
Section	**Type**	**Elevation (m)**	**Likelihood**
Ogilvie	rockfall & debris slide	708	H
Proximity (m)	**Position**	**Initiation slope (°)**	**Consequence**
0	above	50	L
Aspect (°)	**Causes**	**Runout slope (°)**	**Risk**
107	oversteepened slope toe	20	M
Surficial material	**Triggers**	**Average slope (°)**	**Mitigation**
rszCv	freeze/thaw, intense rainfall/snowmelt	45	Management of rockfall debris in ditch and on hwy
Permafrost	**Timing**	**Dimensions (L/W/D) (m)**	**Comments**
Permafrost, likely ice-poor, relatively deep within colluvial rubble or weathered bedrock	Recurrent (likely annual)	41 / 406 / n/a	Runout limits approximate due to clearing of former debris accumulation

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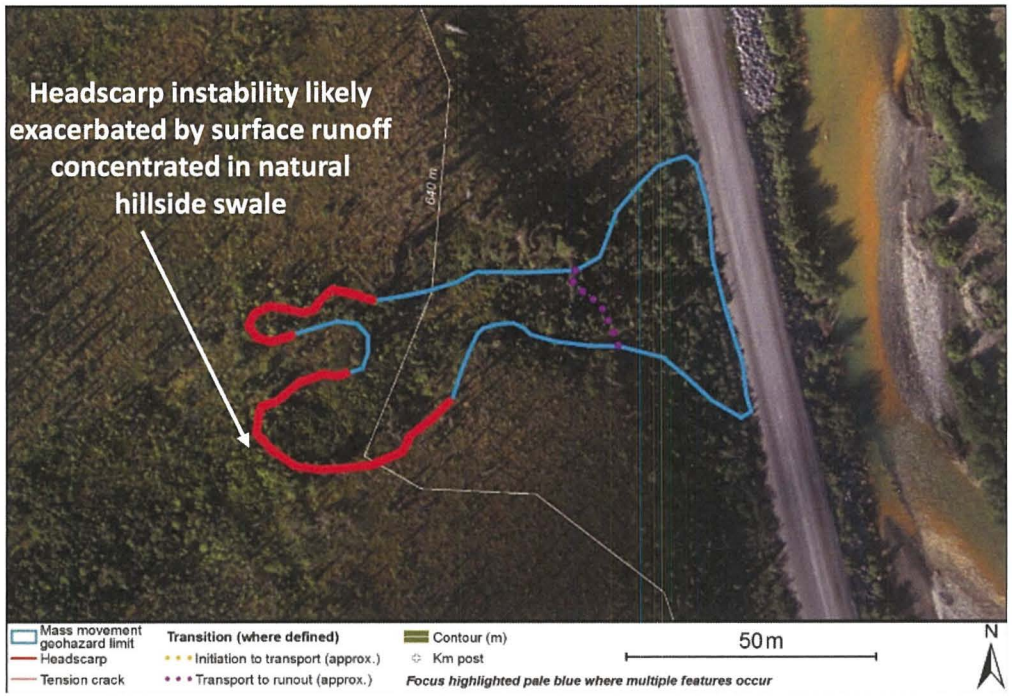

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SITE	PROCESS	GEOMETRY	IMPLICATIONS

Section	Type	Elevation (m)	Likelihood
Ogilvie	retrogressive thaw slump	636	M

Proximity (m)	Position	Initiation slope (°)	Consequence
0	above	5	L

Aspect (°)	Causes	Runout slope (°)	Risk
70	permafrost degradation	13	L

Surficial material	Triggers	Average slope (°)	Mitigation
zsgFt	intense rainfall/snowmelt or heat	11	Management of debris accumulation in ditch

Permafrost	Timing	Dimensions (L/W/D) (m)	Comments
Shallow, likely ice-rich permafrost above terrace scarp beside highway	Ongoing/episodic, possibly exacerbated by old winter trail upslope of highway	100 / 53 / 4.3	

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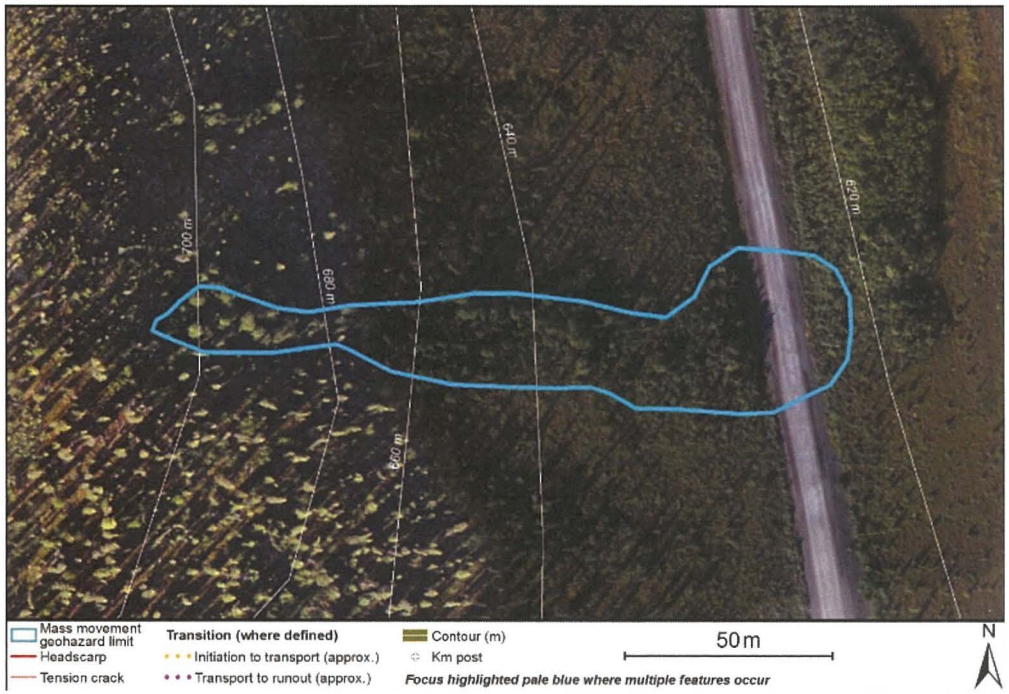

No field photographs available

SITE	PROCESS	GEOMETRY	IMPLICATIONS
Section	**Type**	**Elevation (m)**	**Likelihood**
Ogilvie	debris slide (active layer detachment)	635	L
Proximity (m)	**Position**	**Initiation slope (°)**	**Consequence**
0	above	39	L
Aspect (°)	**Causes**	**Runout slope (°)**	**Risk**
85	permafrost degradation	15	VL
Surficial material	**Triggers**	**Average slope (°)**	**Mitigation**
szrCv	intense rainfall/snowmelt	26	None expected to be required
Permafrost	**Timing**	**Dimensions (L/W/D) (m)**	**Comments**
Shallow permafrost	Single event (likely slightly pre-dates highway construction) with minimal remaining potential for post-failure sloughs/flows	168 / 40 / 2.2	Mostly stabilized through natural revegetation

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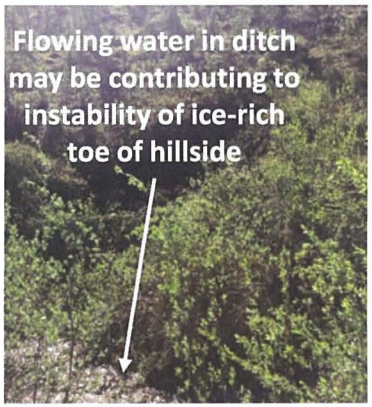
Project number: 14132
Client: Yukon Government

KM 191.6



SITE	PROCESS	GEOMETRY	IMPLICATIONS
Section	**Type**	**Elevation (m)**	**Likelihood**
Ogilvie	retrogressive thaw slump	605	M
Proximity (m)	**Position**	**Initiation slope (°)**	**Consequence**
0	above	28	L
Aspect (°)	**Causes**	**Runout slope (°)**	**Risk**
60	fluvio-thermal erosion of slope toe, permafrost degradation	15	L
Surficial material	**Triggers**	**Average slope (°)**	**Mitigation**
zsrCa	intense rainfall/snowmelt or heat	28	Management of surface runoff and debris accumulation in ditch
Permafrost	**Timing**	**Dimensions (L/W/D) (m)**	**Comments**
Shallow permafrost with segregated ice (lenses/seams)	Ongoing/episodic, likely exacerbated by concentrated drainage along ditch at slope toe	8 / 15 / 1.5	

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Project number: 14132
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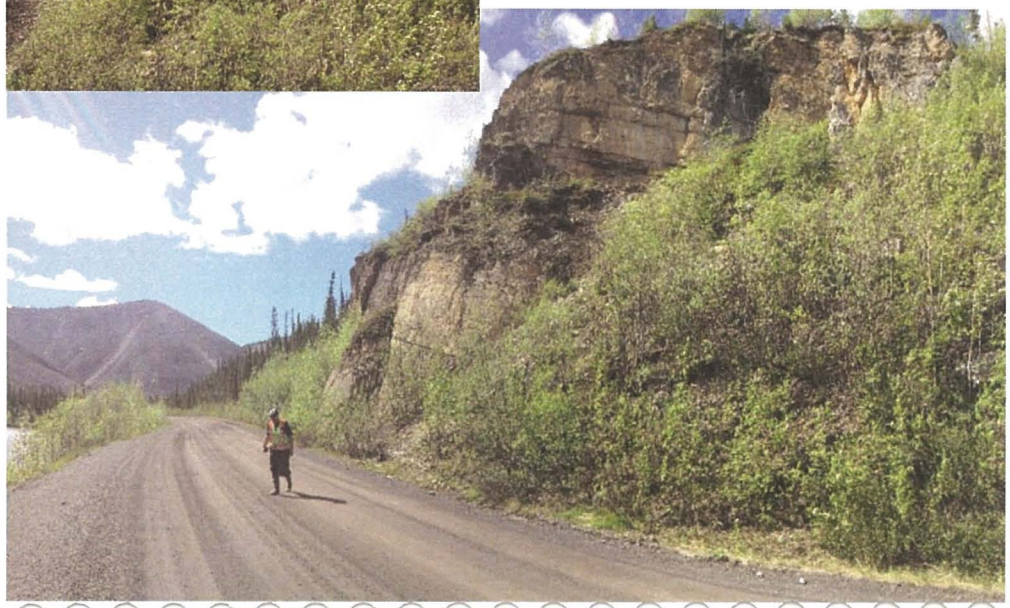
KM 193



SITE	PROCESS	GEOMETRY	IMPLICATIONS
Section	**Type**	**Elevation (m)**	**Likelihood**
Ogilvie	rockfall	581	M
Proximity (m)	**Position**	**Initiation slope (°)**	**Consequence**
0	above	27	L
Aspect (°)	**Causes**	**Runout slope (°)**	**Risk**
115	steep rock bluff	15	L
Surficial material	**Triggers**	**Average slope (°)**	**Mitigation**
R	freeze/thaw, intense rainfall/snowmelt	34	Management of rockfall debris in ditch and on hwy
Permafrost	**Timing**	**Dimensions (L/W/D) (m)**	**Comments**
Permafrost, likely ice-poor, relatively deep within colluvial rubble or weathered bedrock	Recurrent (likely annual)	44 / 132 / n/a	Runout limits approximate due to clearing of former debris accumulation

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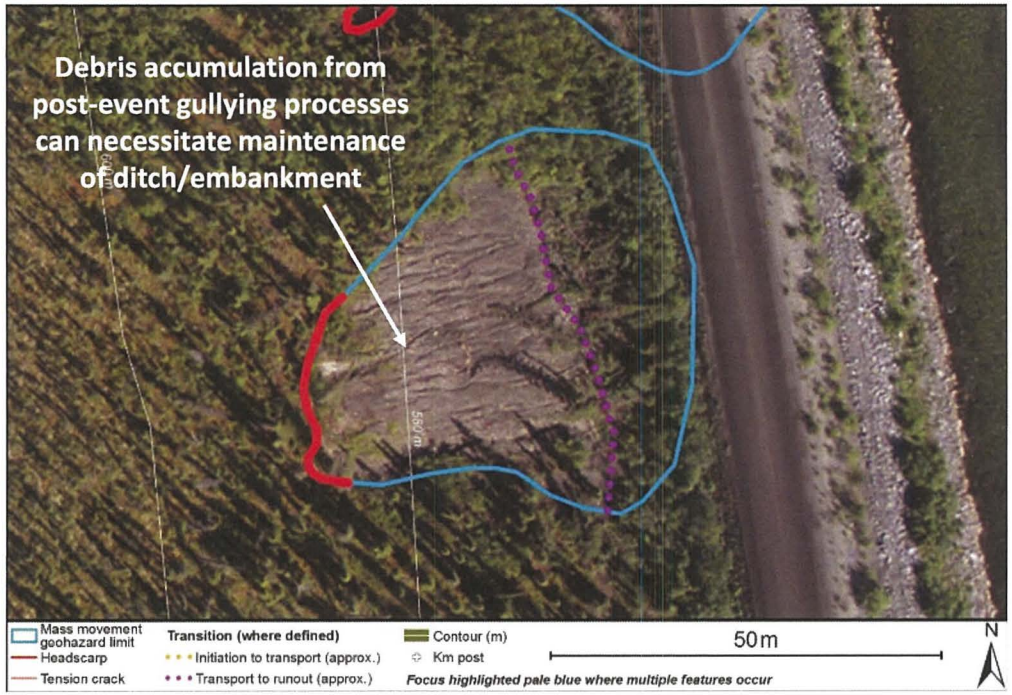
KM 205



SITE	PROCESS	GEOMETRY	IMPLICATIONS
Section	**Type**	**Elevation (m)**	**Likelihood**
Ogilvie	debris slide (active layer detachment)	578	M
Proximity (m)	**Position**	**Initiation slope (°)**	**Consequence**
0	above	29	M
Aspect (°)	**Causes**	**Runout slope (°)**	**Risk**
70	disturbance and possible over-steepening of slope toe, permafrost degradation	24	M
Surficial material	**Triggers**	**Average slope (°)**	**Mitigation**
dszCv	intense rainfall/snowmelt or heat	35	Management of runout debris
Permafrost	**Timing**	**Dimensions (L/W/D) (m)**	**Comments**
Shallow permafrost	Single event (2007-2013) with potential for post-failure sloughs/flows	52 / 52 / 1	Runout limits approximate due to clearing of former debris accumulation

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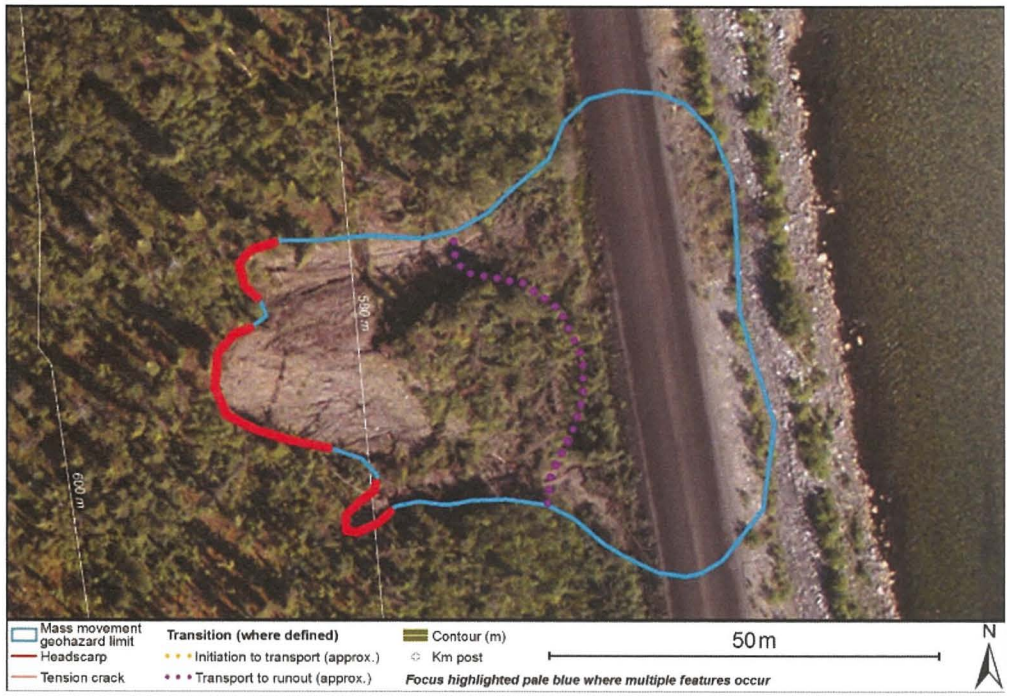
KM 209.5



SITE	PROCESS	GEOMETRY	IMPLICATIONS
Section	**Type**	**Elevation (m)**	**Likelihood**
Ogilvie	debris slide (active layer detachment)	569	M
Proximity (m)	**Position**	**Initiation slope (°)**	**Consequence**
0	above	42	M
Aspect (°)	**Causes**	**Runout slope (°)**	**Risk**
80	disturbance and possible over-steepening of slope toe, permafrost degradation	17	M
Surficial material	**Triggers**	**Average slope (°)**	**Mitigation**
dszCv	intense rainfall/snowmelt or heat	28	Management of runout debris
Permafrost	**Timing**	**Dimensions (L/W/D) (m)**	**Comments**
Shallow permafrost	Single event (2007-2013) with potential for post-failure sloughs/flows	67 / 63 / <1	Runout limits approximate due to clearing of former debris accumulation

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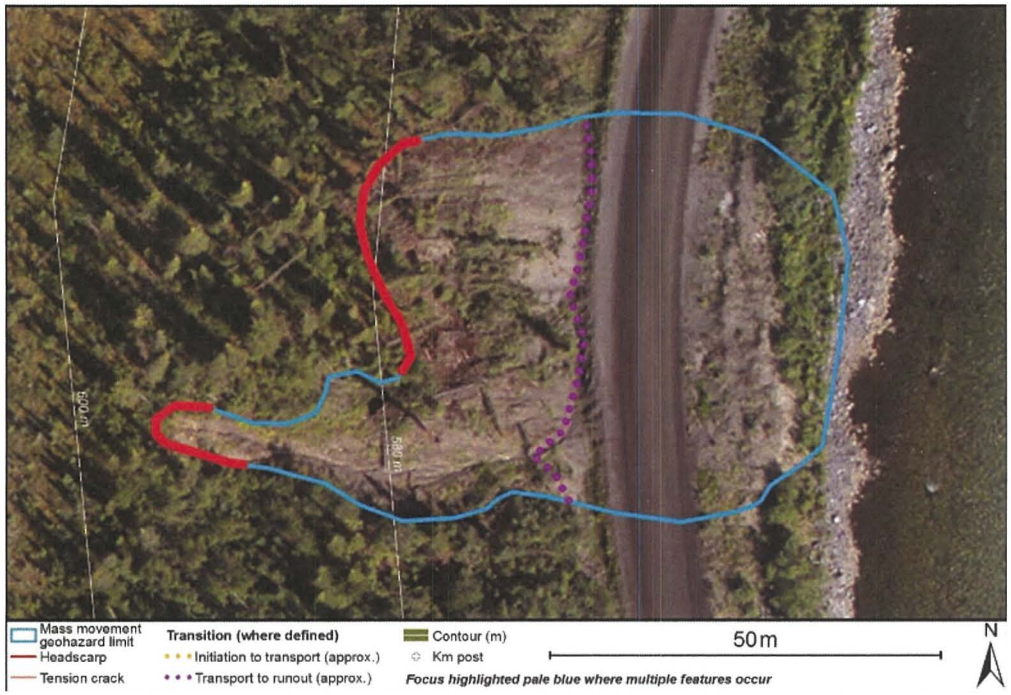
KM 209.6



SITE	PROCESS	GEOMETRY	IMPLICATIONS
Section	**Type**	**Elevation (m)**	**Likelihood**
Ogilvie	debris slide (active layer detachment)	566	M
Proximity (m)	**Position**	**Initiation slope (°)**	**Consequence**
0	above	50	M
Aspect (°)	**Causes**	**Runout slope (°)**	**Risk**
85	disturbance and possible over-steepening of slope toe, permafrost degradation	14	M
Surficial material	**Triggers**	**Average slope (°)**	**Mitigation**
dszCv	intense rainfall/snowmelt or heat	37	Management of runout debris
Permafrost	**Timing**	**Dimensions (L/W/D) (m)**	**Comments**
Shallow permafrost	Single event (2007-2013) with potential for post-failure sloughs/flows	66 / 54 / <1	Runout limits approximate due to clearing of former debris accumulation

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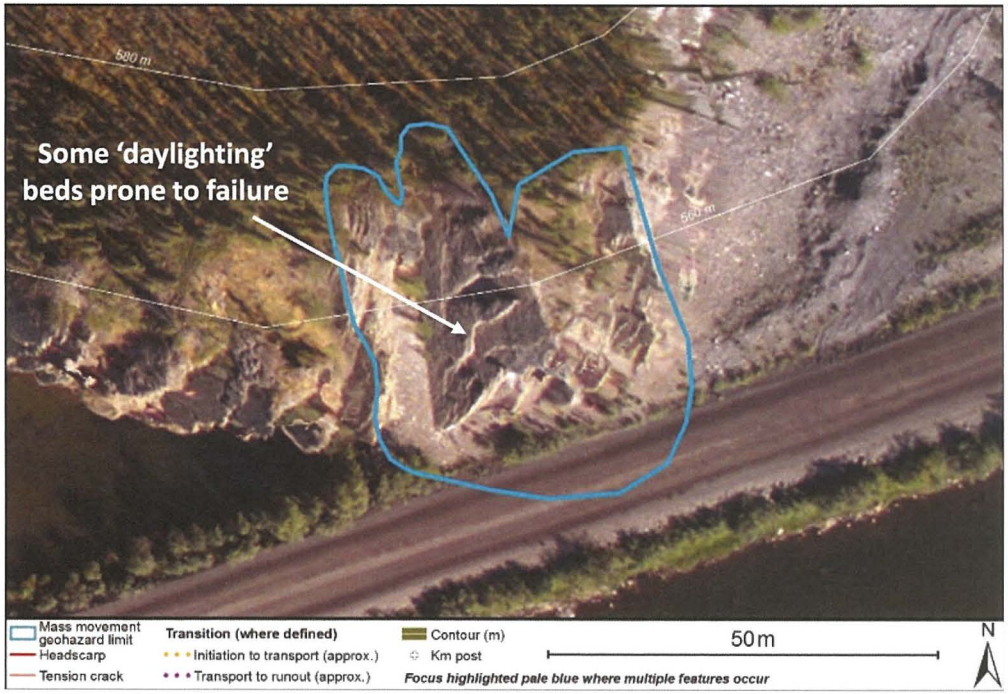

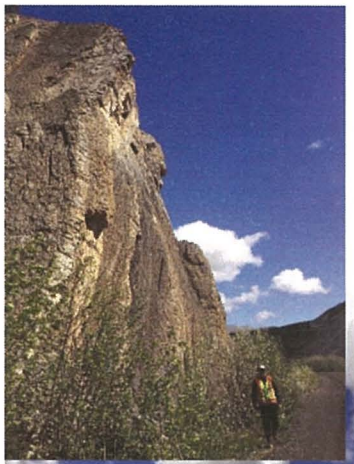

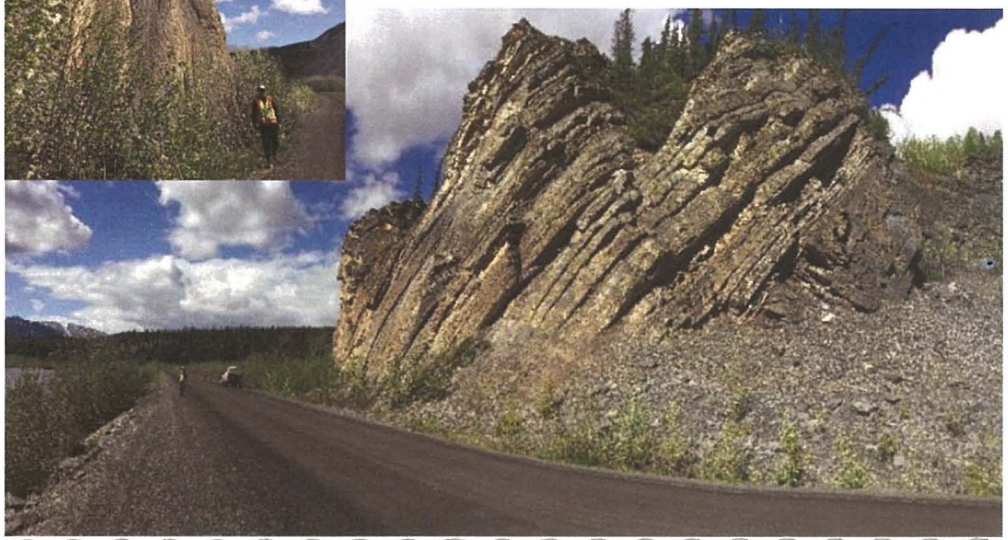

SITE	PROCESS	GEOMETRY	IMPLICATIONS
Section	**Type**	**Elevation (m)**	**Likelihood**
Ogilvie	rockfall	590	H
Proximity (m)	**Position**	**Initiation slope (°)**	**Consequence**
0	above	46	L
Aspect (°)	**Causes**	**Runout slope (°)**	**Risk**
165	steep rock bluff	17	M
Surficial material	**Triggers**	**Average slope (°)**	**Mitigation**
R	freeze/thaw	42	Management of rockfall initiation and/or debris in ditch and on hwy
Permafrost	**Timing**	**Dimensions (L/W/D) (m)**	**Comments**
Permafrost, likely ice-poor, deep within bedrock	Recurrent (likely annual)	45 / 41 / n/a	Runout limits approximate due to clearing of former debris accumulation

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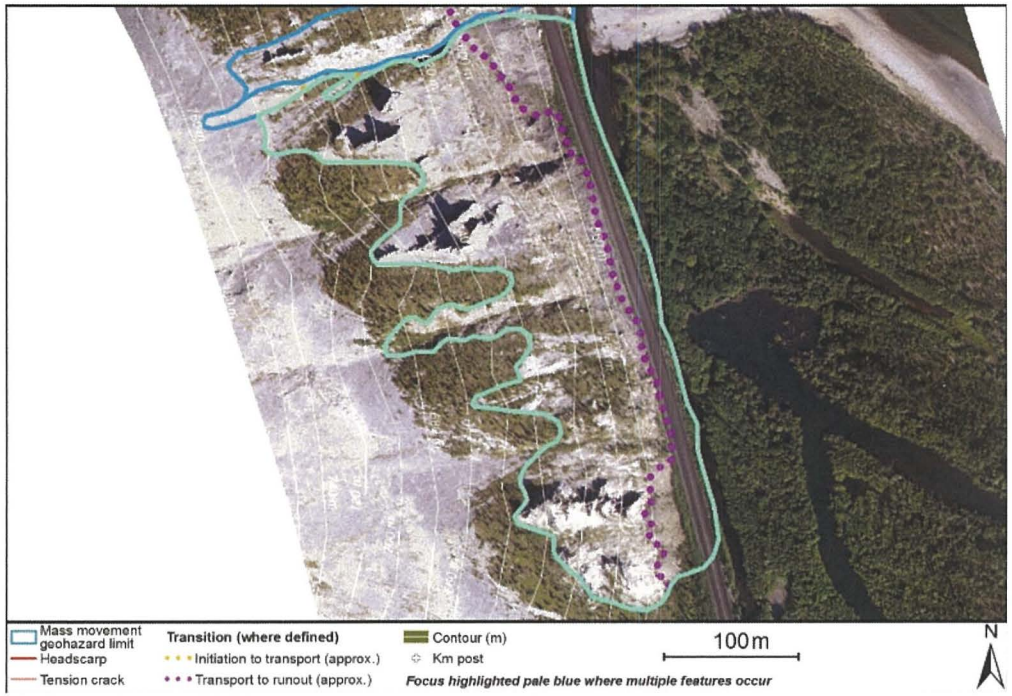
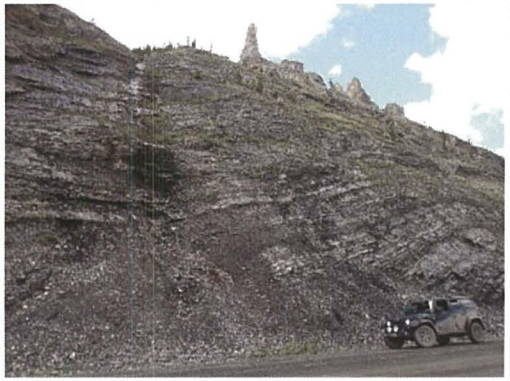
KM 210.9





SITE	PROCESS	GEOMETRY	IMPLICATIONS
Section	**Type**	**Elevation (m)**	**Likelihood**
Ogilvie	rockfall & debris slide	622	H
Proximity (m)	**Position**	**Initiation slope (°)**	**Consequence**
0	above	35	M
Aspect (°)	**Causes**	**Runout slope (°)**	**Risk**
70	steep rock bluffs	27	H
Surficial material	**Triggers**	**Average slope (°)**	**Mitigation**
R	freeze/thaw, intense rainfall/snowmelt	42	Management of rockfall/debris slide debris in ditch and on hwy
Permafrost	**Timing**	**Dimensions (L/W/D) (m)**	**Comments**
Permafrost, likely ice-poor, relatively deep within colluvial rubble or weathered bedrock	Recurrent (likely annual)	208 / 453 / n/a	Runout limits approximate due to clearing of former debris accumulation; risk greatest downslope of prominent rock bluffs; small debris slides

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Project number: 14132
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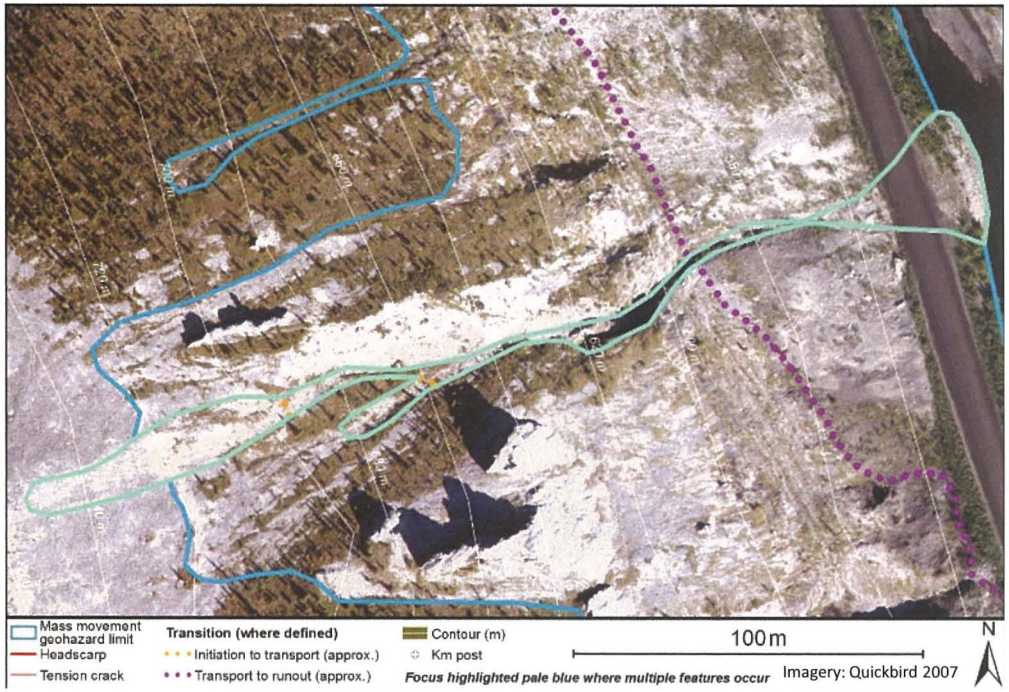
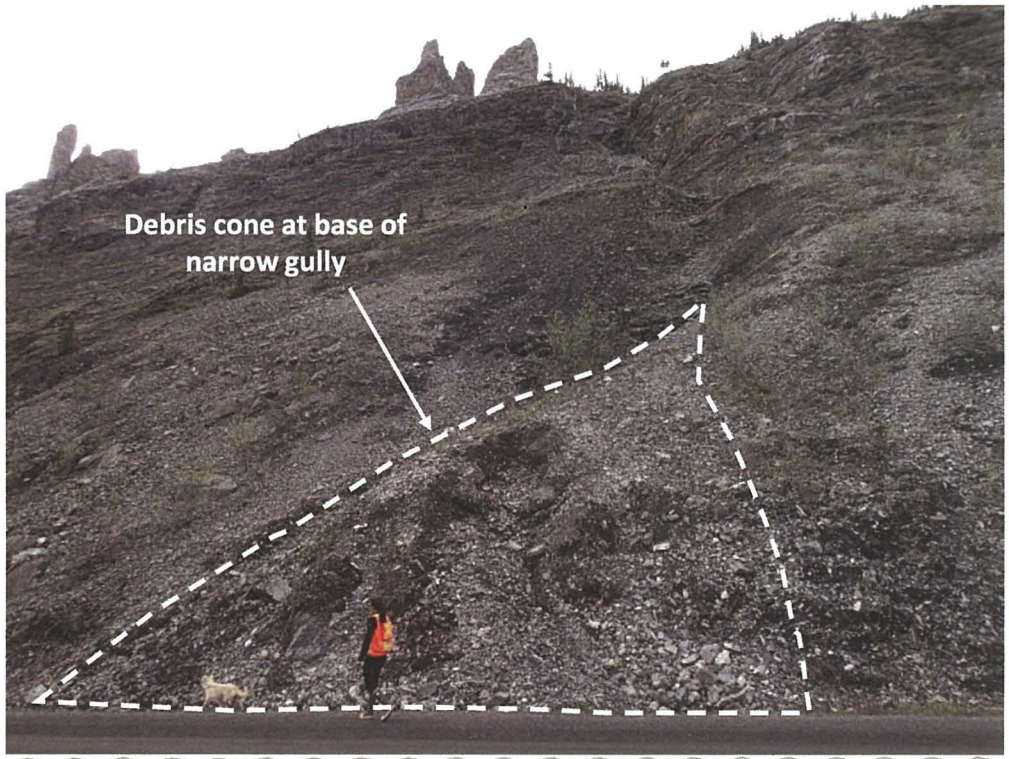
KM 212.5





SITE	PROCESS	GEOMETRY	IMPLICATIONS
Section	**Type**	**Elevation (m)**	**Likelihood**
Ogilvie	debris flow	652	L
Proximity (m)	**Position**	**Initiation slope (°)**	**Consequence**
0	above	32	H
Aspect (°)	**Causes**	**Runout slope (°)**	**Risk**
70	saturation of colluvial debris in headwater basin, gully channelization	19	M
Surficial material	**Triggers**	**Average slope (°)**	**Mitigation**
rszCv	intense rainfall/snowmelt	34	Management of runout debris
Permafrost	**Timing**	**Dimensions (L/W/D) (m)**	**Comments**
Permafrost, likely ice-poor, relatively deep within colluvial rubble or weathered bedrock	Recurrent (likely decadal)	294 / 38 / n/a	

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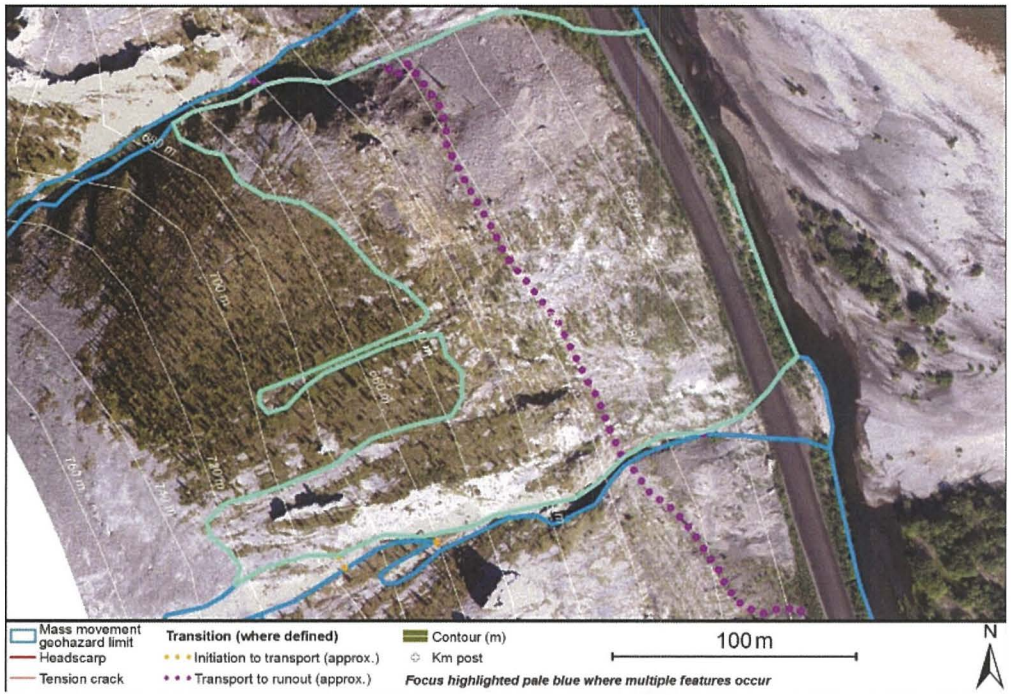

SITE	PROCESS	GEOMETRY	IMPLICATIONS
Section	**Type**	**Elevation (m)**	**Likelihood**
Ogilvie	rockfall & debris slide	615	H
Proximity (m)	**Position**	**Initiation slope (°)**	**Consequence**
0	above	36	M
Aspect (°)	**Causes**	**Runout slope (°)**	**Risk**
65	steep rock bluffs	31	H
Surficial material	**Triggers**	**Average slope (°)**	**Mitigation**
R/rszCb	freeze/thaw, intense rainfall/snowmelt	40	Management of rockfall/debris slide debris in ditch and on hwy
Permafrost	**Timing**	**Dimensions (L/W/D) (m)**	**Comments**
Permafrost, likely ice-poor, relatively deep within colluvial rubble or weathered bedrock	Recurrent (likely annual)	220 / 165 / n/a	Runout limits approximate due to clearing of former debris accumulation; small debris slides

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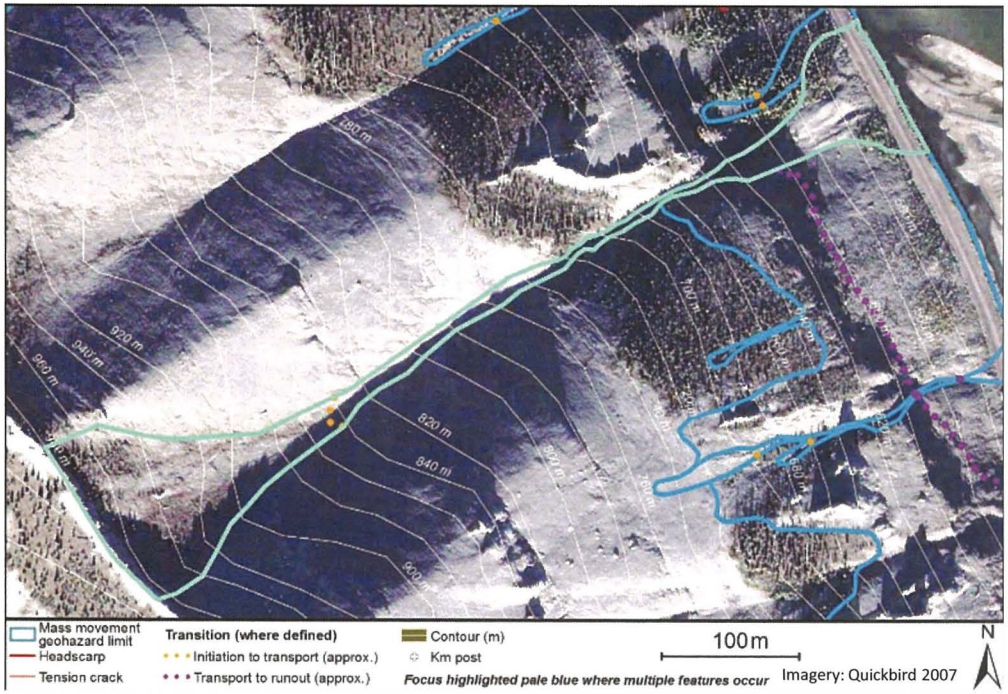
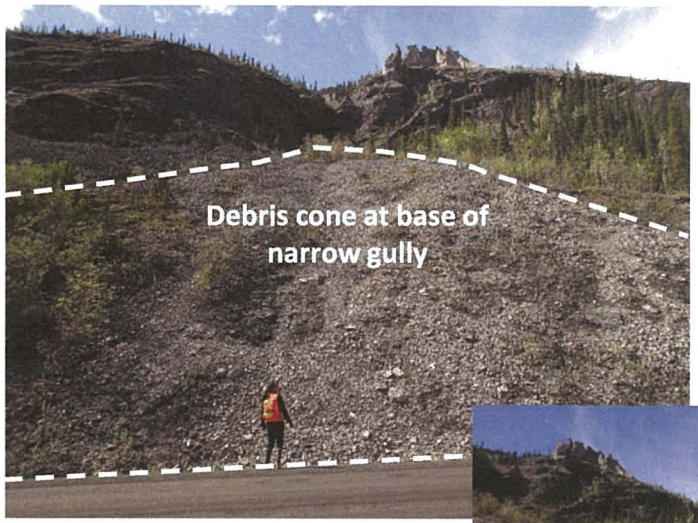
KM 212.8





SITE	PROCESS	GEOMETRY	IMPLICATIONS
Section	**Type**	**Elevation (m)**	**Likelihood**
Ogilvie	debris flow & rockfall	805	L
Proximity (m)	**Position**	**Initiation slope (°)**	**Consequence**
0	above	36	H
Aspect (°)	**Causes**	**Runout slope (°)**	**Risk**
60	saturation of colluvial debris in headwater basin, gully channelization	30	M
Surficial material	**Triggers**	**Average slope (°)**	**Mitigation**
rszCv	intense rainfall/snowmelt, freeze/thaw	33	Management of runout debris
Permafrost	**Timing**	**Dimensions (L/W/D) (m)**	**Comments**
Permafrost, likely ice-poor, relatively deep within colluvial rubble or weathered bedrock	Recurrent (likely decadal)	666 / 105 / n/a	

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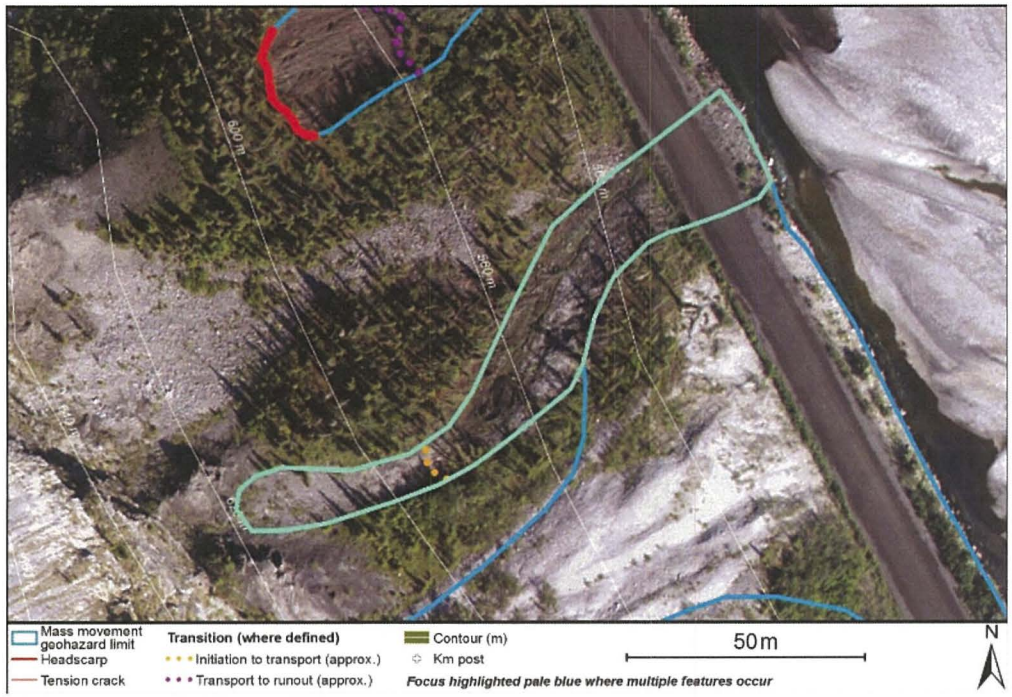
KM 212.95



SITE	PROCESS	GEOMETRY	IMPLICATIONS
Section	**Type**	**Elevation (m)**	**Likelihood**
Ogilvie	debris slide (active layer detachment)	575	M
Proximity (m)	**Position**	**Initiation slope (°)**	**Consequence**
0	above	38	L
Aspect (°)	**Causes**	**Runout slope (°)**	**Risk**
60	permafrost degradation	10	L
Surficial material	**Triggers**	**Average slope (°)**	**Mitigation**
rszCv	intense rainfall/snowmelt or heat, possible rockfall onto slope	29	Management of debris accumulation in ditch
Permafrost	**Timing**	**Dimensions (L/W/D) (m)**	**Comments**
Permafrost, likely ice-poor, relatively deep within colluvial rubble or weathered bedrock	Single event (2007-2013) with potential for post-failure sloughs/flows	142 / 22 / 0.5	Runout limits approximate due to clearing of former debris accumulation

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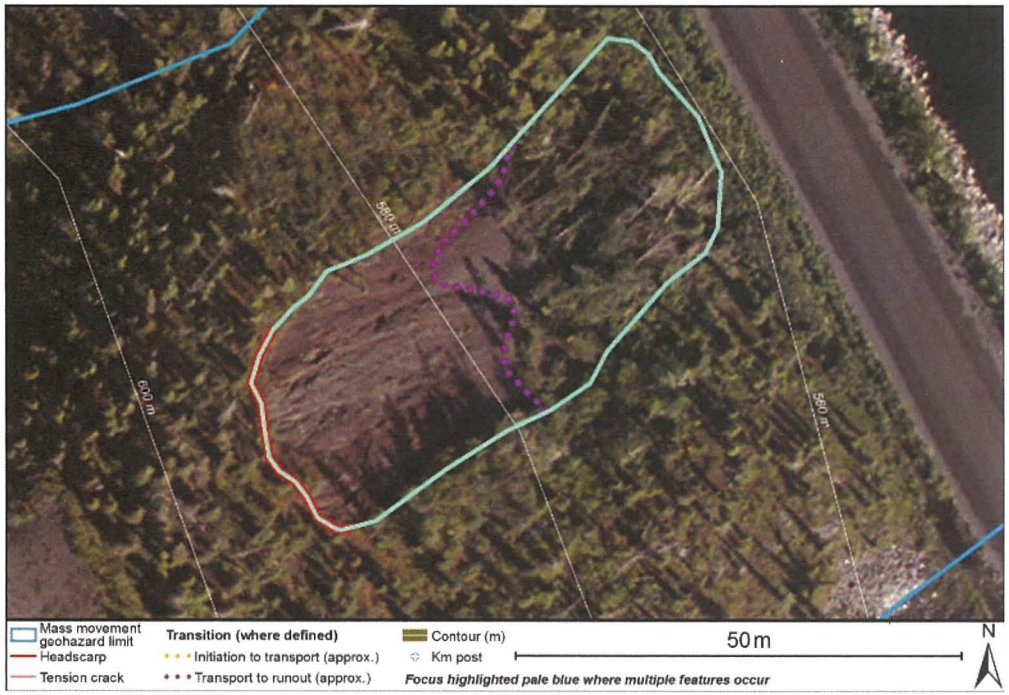
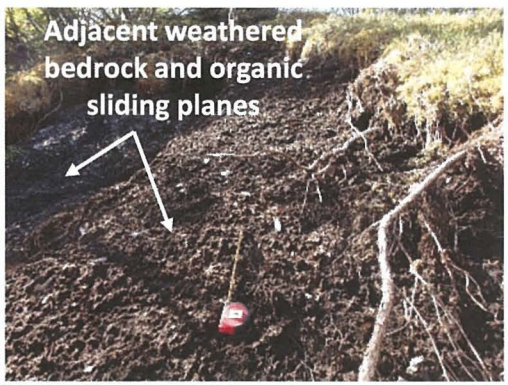
KM 213





SITE	PROCESS	GEOMETRY	IMPLICATIONS
Section	**Type**	**Elevation (m)**	**Likelihood**
Ogilvie	debris slide (active layer detachment)	573	M
Proximity (m)	**Position**	**Initiation slope (°)**	**Consequence**
10	above	48	L
Aspect (°)	**Causes**	**Runout slope (°)**	**Risk**
55	permafrost degradation	33	L
Surficial material	**Triggers**	**Average slope (°)**	**Mitigation**
rszCv	intense rainfall/snowmelt or heat	37	Management of debris accumulation in ditch
Permafrost	**Timing**	**Dimensions (L/W/D) (m)**	**Comments**
Shallow permafrost	Single event (2007-2013) with potential for post-failure sloughs/flows	64 / 28 / <1	

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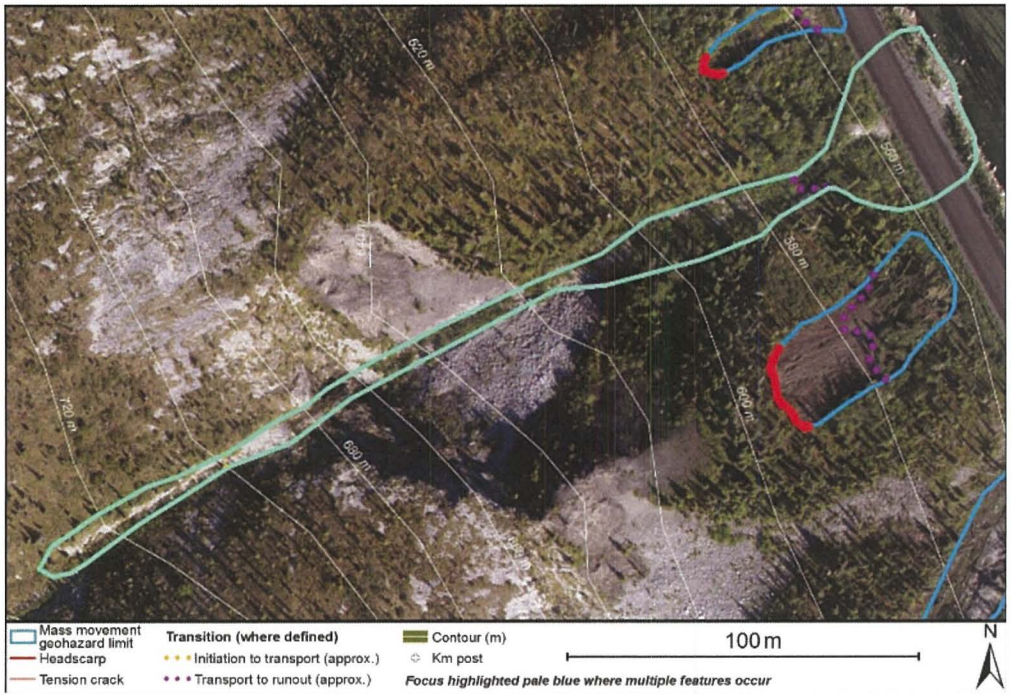
KM 213.05



SITE	PROCESS	GEOMETRY	IMPLICATIONS

Section	Type	Elevation (m)	Likelihood
Ogilvie	debris flow	594	L

Proximity (m)	Position	Initiation slope (°)	Consequence
0	above	31	H

Aspect (°)	Causes	Runout slope (°)	Risk
60	saturation of colluvial debris in headwater basin, gully channelization	23	M

Surficial material	Triggers	Average slope (°)	Mitigation
rszCv	intense rainfall/snowmelt	31	Management of runout debris

Permafrost	Timing	Dimensions (L/W/D) (m)	Comments
Permafrost, likely ice-poor, relatively deep within colluvial rubble or weathered bedrock	Recurrent (likely decadal)	295 / 44 / n/a	

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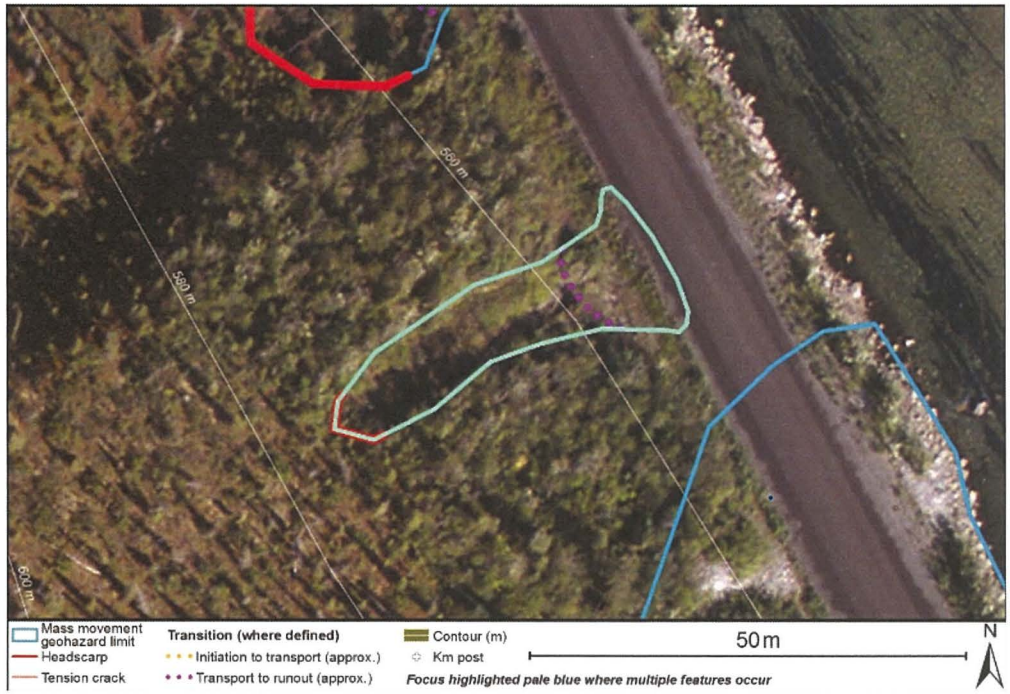
KM 213.1



Ogilvie	debris slide (active layer detachment)	564	M

Section	Type	Elevation (m)	Likelihood
Ogilvie	debris slide (active layer detachment)	564	M

Proximity (m)	Position	Initiation slope (°)	Consequence
0	above	37	L

Aspect (°)	Causes	Runout slope (°)	Risk
60	disturbance and possible over-steepening of slope toe, permafrost degradation	15	L

Surficial material	Triggers	Average slope (°)	Mitigation
rszCv	intense rainfall/snowmelt or heat	35	Management of debris accumulation in ditch

Permafrost	Timing	Dimensions (L/W/D) (m)	Comments
Shallow permafrost	Single event (2007-2013) with potential for post-failure sloughs/flows	43 / 19 / 0.5	Runout limits approximate due to clearing of former debris accumulation

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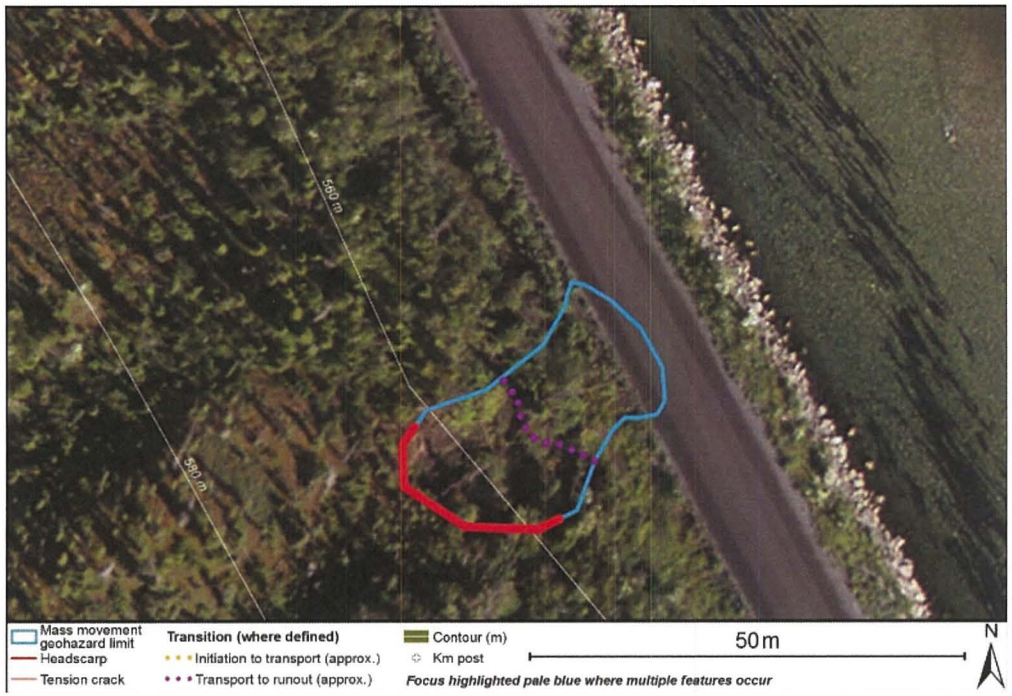
Client: Yukon Government

KM 213.15



SITE	PROCESS	GEOMETRY	IMPLICATIONS
Section	**Type**	**Elevation (m)**	**Likelihood**
Ogilvie	debris slide (active layer detachment)	556	M
Proximity (m)	**Position**	**Initiation slope (°)**	**Consequence**
0	above	43	L
Aspect (°)	**Causes**	**Runout slope (°)**	**Risk**
45	disturbance and possible over-steepening of slope toe, permafrost degradation	5	L
Surficial material	**Triggers**	**Average slope (°)**	**Mitigation**
rszCv	intense rainfall/snowmelt or heat	25	Management of debris accumulation in ditch
Permafrost	**Timing**	**Dimensions (L/W/D) (m)**	**Comments**
Shallow permafrost	Single event (2007-2013) with potential for post-failure sloughs/flows	33 / 17 / <1	Runout limits approximate due to clearing of former debris accumulation

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Project number: 14132
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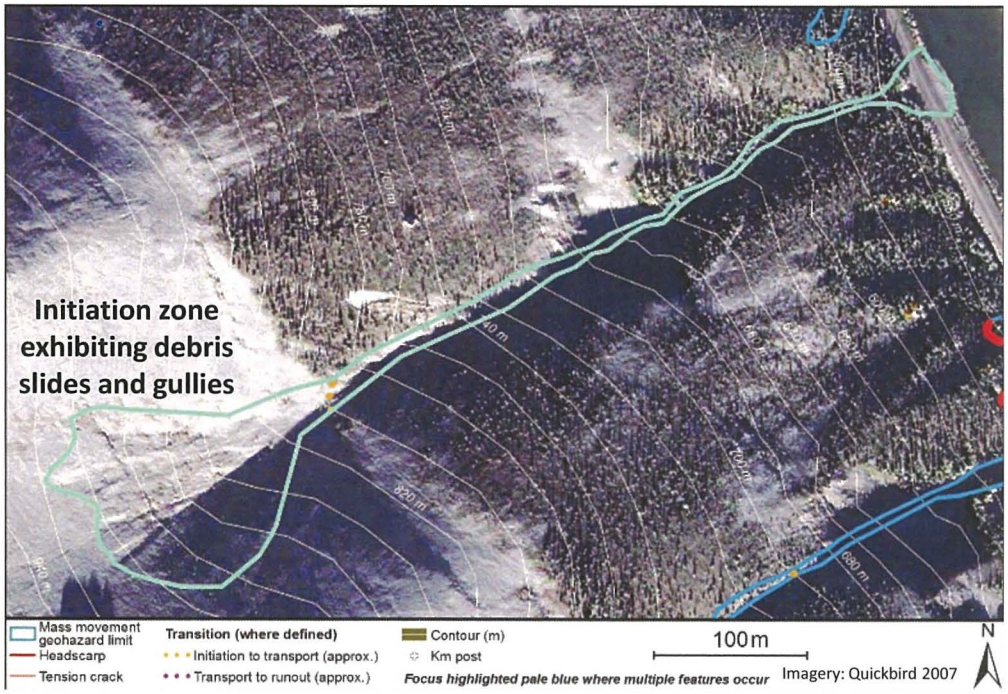
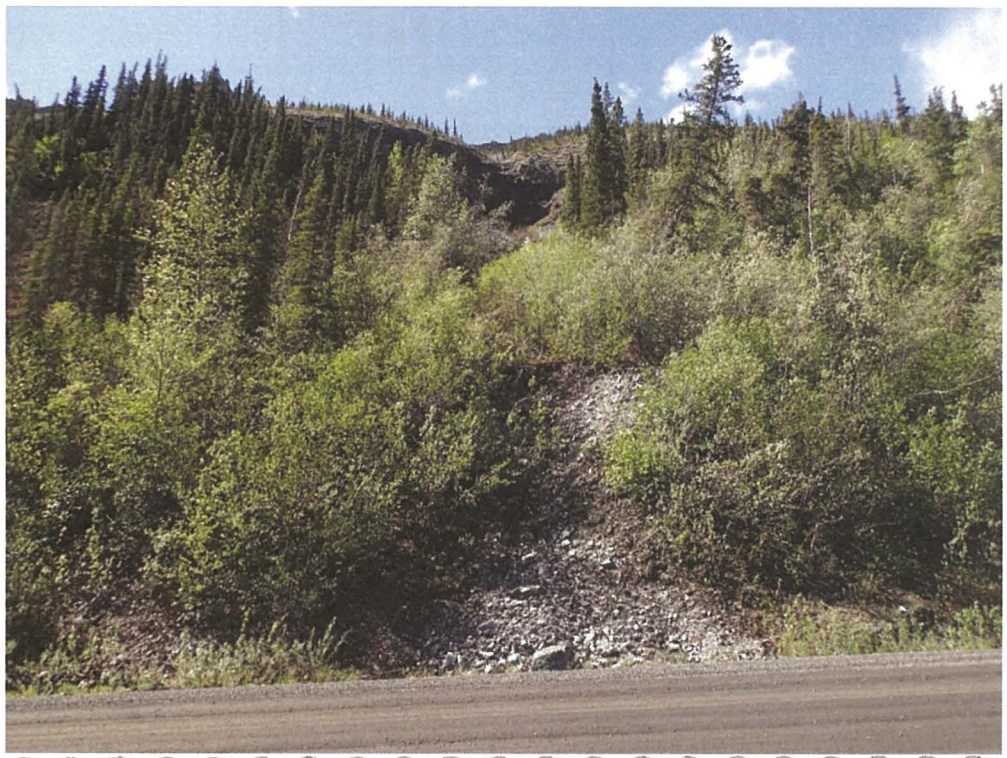
KM 213.2





SITE	PROCESS	GEOMETRY	IMPLICATIONS
Section	**Type**	**Elevation (m)**	**Likelihood**
Ogilvie	debris flow	810	L
Proximity (m)	**Position**	**Initiation slope (°)**	**Consequence**
0	above	36	H
Aspect (°)	**Causes**	**Runout slope (°)**	**Risk**
55	saturation of colluvial debris in headwater basin, gully channelization	16	M
Surficial material	**Triggers**	**Average slope (°)**	**Mitigation**
rszCv	intense rainfall/snowmelt	29	Management of runout debris
Permafrost	**Timing**	**Dimensions (L/W/D) (m)**	**Comments**
Permafrost, likely ice-poor, relatively deep within colluvial rubble or weathered bedrock	Recurrent (likely decadal)	654 / 45 / n/a	

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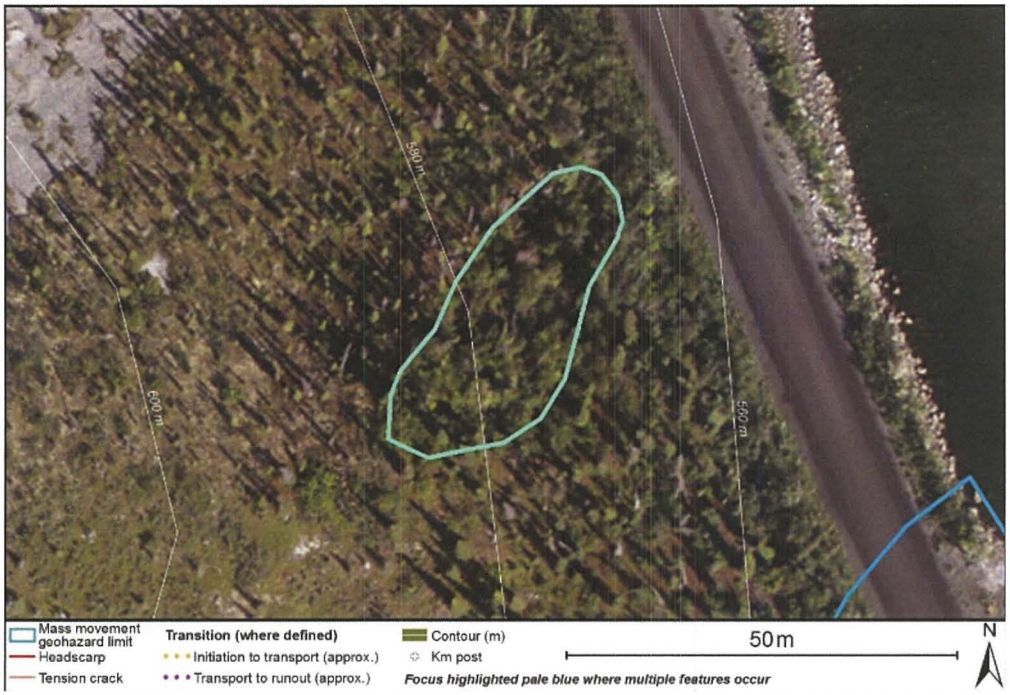
Project: Dempster Geohazard Investigation
Project number: 14132
Client: Yukon Government

KM 213.35



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SITE	PROCESS	GEOMETRY	IMPLICATIONS

Section	Type	Elevation (m)	Likelihood
Ogilvie	debris slide (active layer detachment)	576	M

Proximity (m)	Position	Initiation slope (°)	Consequence
10	above	41	L

Aspect (°)	Causes	Runout slope (°)	Risk
30	permafrost degradation	36	L

Surficial material	Triggers	Average slope (°)	Mitigation
rszCv	intense rainfall/snowmelt or heat	42	Management of debris accumulation in ditch

Permafrost	Timing	Dimensions (L/W/D) (m)	Comments
Shallow permafrost	Single event (2013-2016) with potential for post-failure sloughs/flows	43 / 9 / 0.6	

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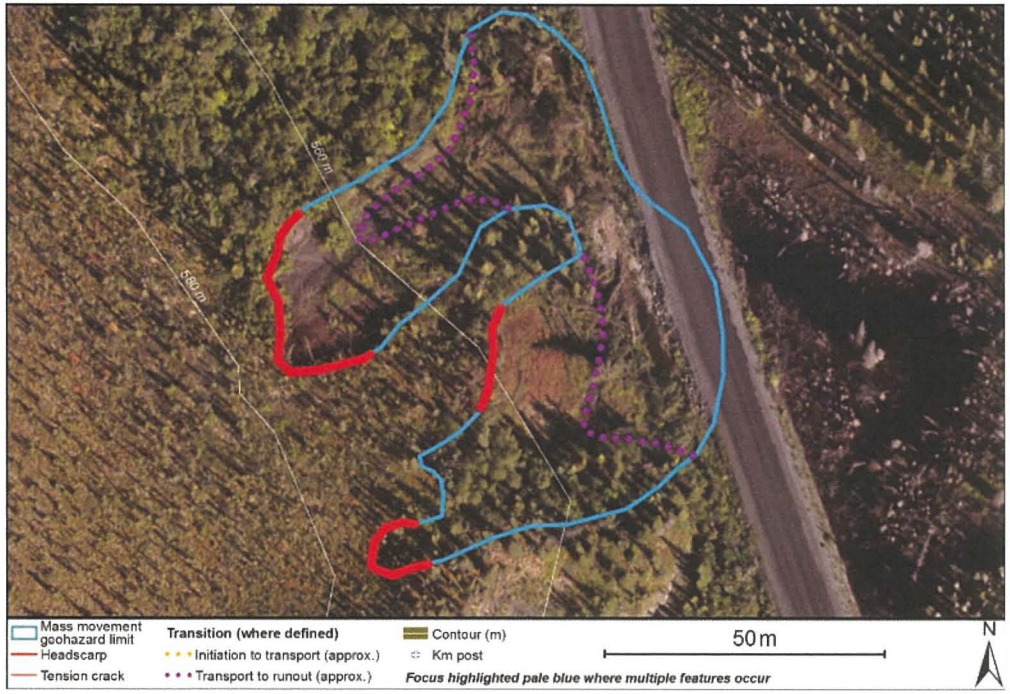
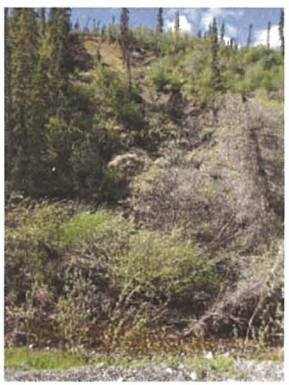
Project number: 14132
Client: Yukon Government

KM 213.4





SITE	PROCESS	GEOMETRY	IMPLICATIONS

Section	Type	Elevation (m)	Likelihood
Ogilvie	debris slide (active layer detachment)	553	M

Proximity (m)	Position	Initiation slope (°)	Consequence
0	above	40	L

Aspect (°)	Causes	Runout slope (°)	Risk
45	permafrost degradation	25	L

Surficial material	Triggers	Average slope (°)	Mitigation
rszCv	intense rainfall/snowmelt or heat	32	Management of debris accumulation in ditch

Permafrost	Timing	Dimensions (L/W/D) (m)	Comments
Shallow permafrost	Single event (2007-2013) with potential for post-failure sloughs/flows	73 / 86 / <1	Runout limits approximate due to clearing of former debris accumulation

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Project number: 14132
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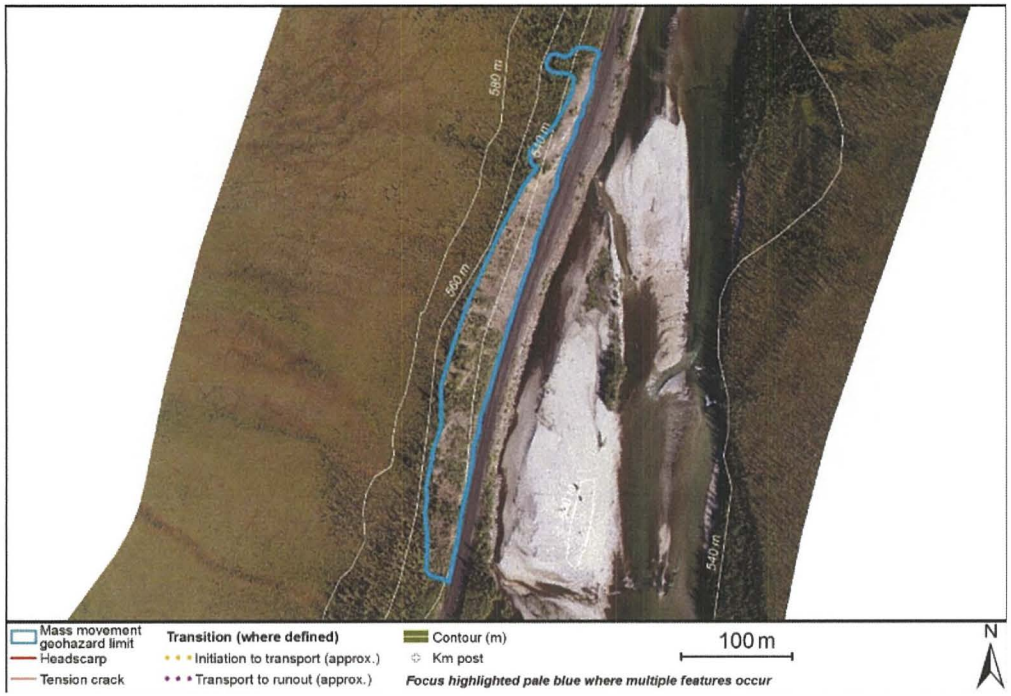
KM 218.1



SITE	PROCESS	GEOMETRY	IMPLICATIONS

Section	Type	Elevation (m)	Likelihood
Ogilvie	rockfall & debris slide (active layer detachment)	550	H

Proximity (m)	Position	Initiation slope (°)	Consequence
0	above	47	L

Aspect (°)	Causes	Runout slope (°)	Risk
105	oversteepened slope toe, steep rock bluffs	13	M

Surficial material	Triggers	Average slope (°)	Mitigation
rszCv/R	freeze/thaw, intense rainfall/snowmelt	50	Management of debris accumulation in ditch

Permafrost	Timing	Dimensions (L/W/D) (m)	Comments
Permafrost, likely ice-poor, relatively deep within colluvial rubble or weathered bedrock	Recurrent (likely annual)	32 / 500 / n/a	Runout limits approximate due to clearing of former debris accumulation

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Project number: 14132
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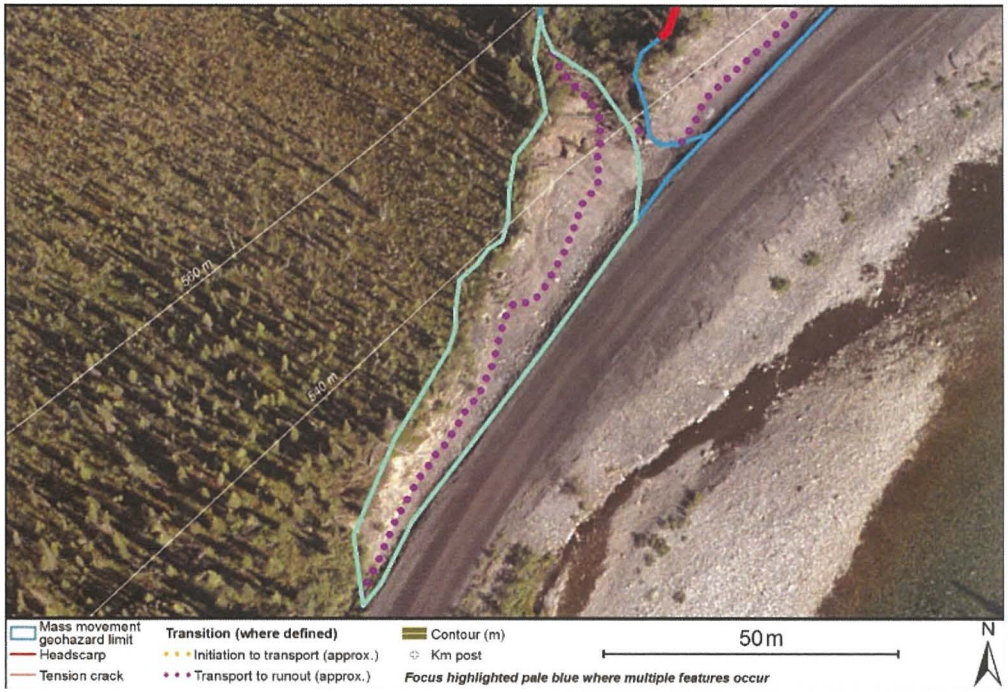
KM 219.3



SITE	PROCESS	GEOMETRY	IMPLICATIONS
Section	**Type**	**Elevation (m)**	**Likelihood**
Ogilvie	rockfall	544	H
Proximity (m)	**Position**	**Initiation slope (°)**	**Consequence**
0	above	55	L
Aspect (°)	**Causes**	**Runout slope (°)**	**Risk**
120	steep rock bluff	14	M
Surficial material	**Triggers**	**Average slope (°)**	**Mitigation**
R	freeze/thaw, intense rainfall/snowmelt	51	Management of debris accumulation in ditch
Permafrost	**Timing**	**Dimensions (L/W/D) (m)**	**Comments**
Permafrost, likely ice-poor, relatively deep within colluvial rubble or weathered bedrock	Recurrent (likely annual)	17 / 86 / n/a	Runout limits approximate due to clearing of former debris accumulation

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Project number: 14132
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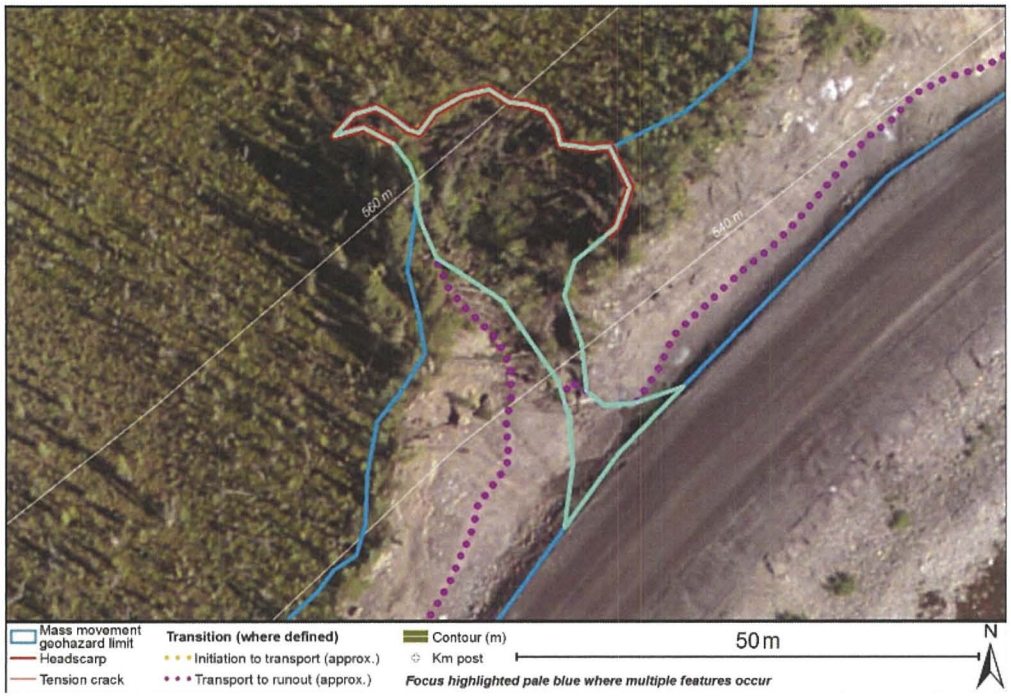
KM 221.5



No field photographs available

SITE	PROCESS	GEOMETRY	IMPLICATIONS

Section	Type	Elevation (m)	Likelihood
Ogilvie	retrogressive thaw slump	555	M

Proximity (m)	Position	Initiation slope (°)	Consequence
0	above	34	L

Aspect (°)	Causes	Runout slope (°)	Risk
145	disturbance and possible over-steepening of slope toe, permafrost degradation	11	L

Surficial material	Triggers	Average slope (°)	Mitigation
dszCv	intense rainfall/snowmelt or heat	26	Management of debris accumulation in ditch

Permafrost	Timing	Dimensions (L/W/D) (m)	Comments
Shallow, likely ice-rich permafrost above slope-toe scarp beside highway	Ongoing/episodic, possibly exacerbated by highway construction	49 / 15 / 3	

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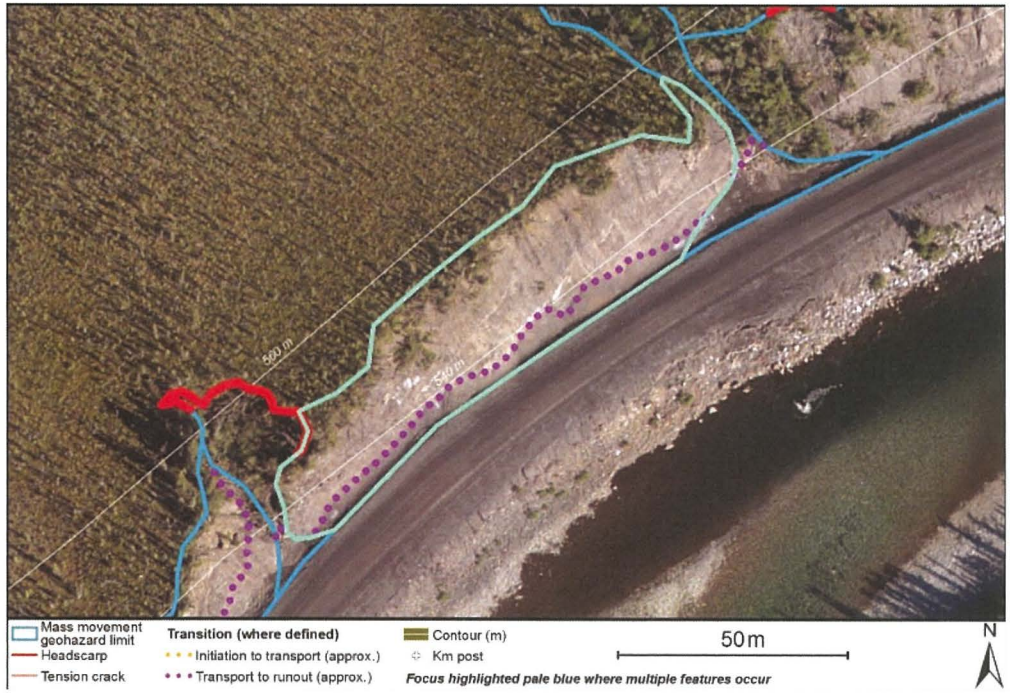
KM 221.6



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SITE	PROCESS	GEOMETRY	IMPLICATIONS
Section	**Type**	**Elevation (m)**	**Likelihood**
Ogilvie	rockfall	551	H
Proximity (m)	**Position**	**Initiation slope (°)**	**Consequence**
0	above	18	L
Aspect (°)	**Causes**	**Runout slope (°)**	**Risk**
130	steep rock bluff	32	M
Surficial material	**Triggers**	**Average slope (°)**	**Mitigation**
R	freeze/thaw, intense rainfall/snowmelt	46	Management of debris accumulation in ditch
Permafrost	**Timing**	**Dimensions (L/W/D) (m)**	**Comments**
Permafrost, likely ice-poor, relatively deep within colluvial rubble or weathered bedrock	Recurrent (likely annual)	30 / 130 / n/a	Runout limits approximate due to clearing of former debris accumulation

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Project number: 14132
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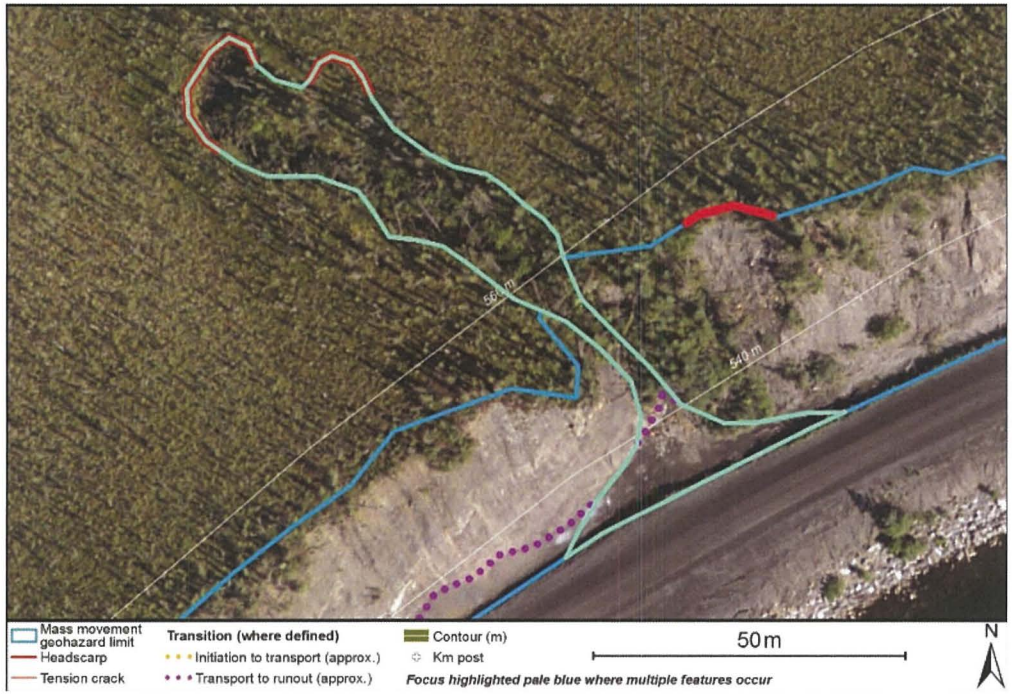

SITE	PROCESS	GEOMETRY	IMPLICATIONS
Section	**Type**	**Elevation (m)**	**Likelihood**
Ogilvie	retrogressive thaw slump	563	M
Proximity (m)	**Position**	**Initiation slope (°)**	**Consequence**
0	above	31	L
Aspect (°)	**Causes**	**Runout slope (°)**	**Risk**
110	natural concentration of runoff, permafrost degradation	12	L
Surficial material	**Triggers**	**Average slope (°)**	**Mitigation**
dszCv	intense rainfall/snowmelt or heat	18	Management of debris accumulation in ditch
Permafrost	**Timing**	**Dimensions (L/W/D) (m)**	**Comments**
Shallow, likely ice-rich permafrost above slope-toe scarp beside highway	Ongoing/episodic, possibly exacerbated by highway construction	99 / 45 / 3	

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Project number: 14132
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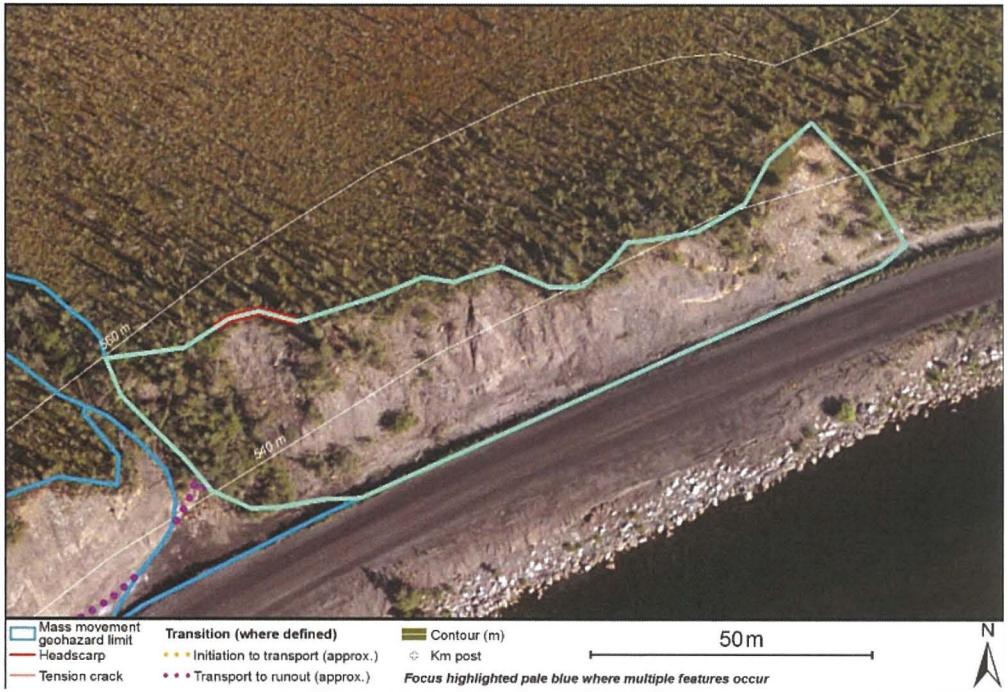

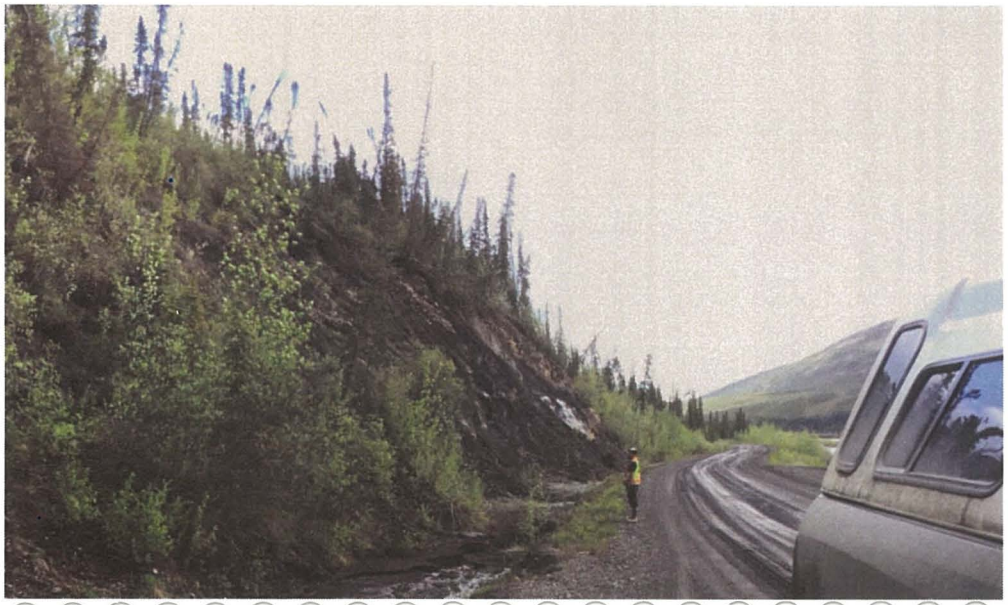

SITE	PROCESS	GEOMETRY	IMPLICATIONS
Section	**Type**	**Elevation (m)**	**Likelihood**
Ogilvie	debris slide & rockfall	549	H
Proximity (m)	**Position**	**Initiation slope (°)**	**Consequence**
0	above	33	L
Aspect (°)	**Causes**	**Runout slope (°)**	**Risk**
145	disturbance and possible over-steepening of slope toe, steep rock bluffs	10	M
Surficial material	**Triggers**	**Average slope (°)**	**Mitigation**
dszCv/R	freeze/thaw, intense rainfall/snowmelt	40	Management of debris accumulation in ditch
Permafrost	**Timing**	**Dimensions (L/W/D) (m)**	**Comments**
Shallow permafrost areas remaining within slope otherwise underlain by permafrost relatively deep within colluvium or weathered bedrock	Recurrent (likely annual)	30 / 130 / <1	Runout limits approximate due to clearing of former debris accumulation

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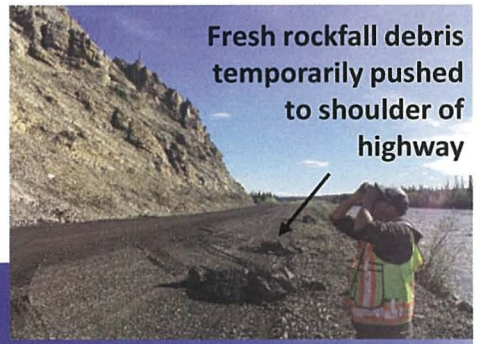
KM 221.9



SITE	PROCESS	GEOMETRY	IMPLICATIONS
Section	**Type**	**Elevation (m)**	**Likelihood**
Ogilvie	rockfall	635	H
Proximity (m)	**Position**	**Initiation slope (°)**	**Consequence**
0	above	55	M
Aspect (°)	**Causes**	**Runout slope (°)**	**Risk**
150	steep rock bluffs	16	H
Surficial material	**Triggers**	**Average slope (°)**	**Mitigation**
R	freeze/thaw, intense rainfall/snowmelt	49	Management of rockfall debris in ditch and on hwy
Permafrost	**Timing**	**Dimensions (L/W/D) (m)**	**Comments**
Permafrost, likely ice-poor, relatively deep within colluvial rubble or weathered bedrock	Recurrent (likely annual)	270 / 695 / n/a	Runout limits approximate due to clearing of former debris accumulation; risk greatest downslope of prominent rock bluffs

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Project number: 14132
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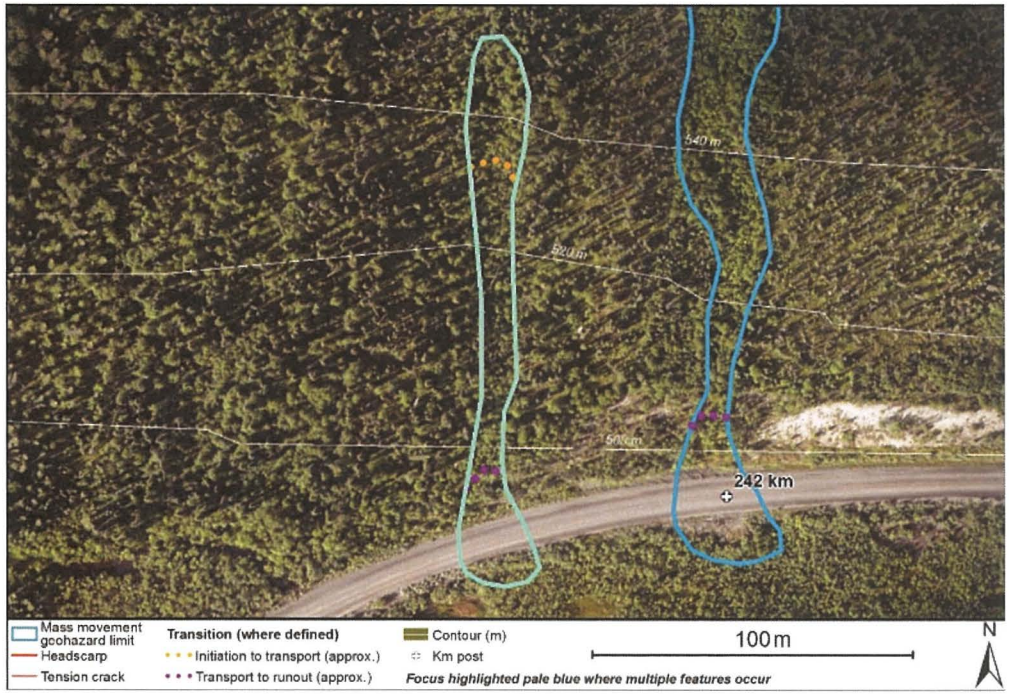
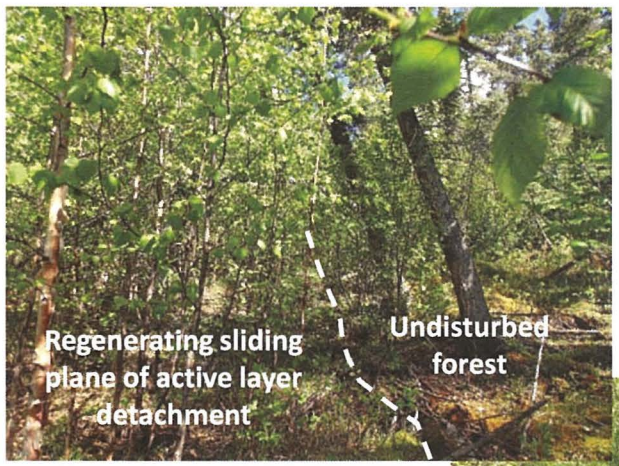
KM 224.7





SITE	PROCESS	GEOMETRY	IMPLICATIONS
Section	**Type**	**Elevation (m)**	**Likelihood**
Ogilvie	debris slide (active layer detachment)	509	L
Proximity (m)	**Position**	**Initiation slope (°)**	**Consequence**
0	above	22	L
Aspect (°)	**Causes**	**Runout slope (°)**	**Risk**
170	permafrost degradation, possible fire	7	VL
Surficial material	**Triggers**	**Average slope (°)**	**Mitigation**
szrCb	intense rainfall/snowmelt or heat	15	None expected to be required
Permafrost	**Timing**	**Dimensions (L/W/D) (m)**	**Comments**
Shallow permafrost	Single event (1977-2007) with minimal remaining potential for post-failure sloughs/flows	173 / 24 / 0.5	Mostly stabilized through natural revegetation

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Project number: 14132
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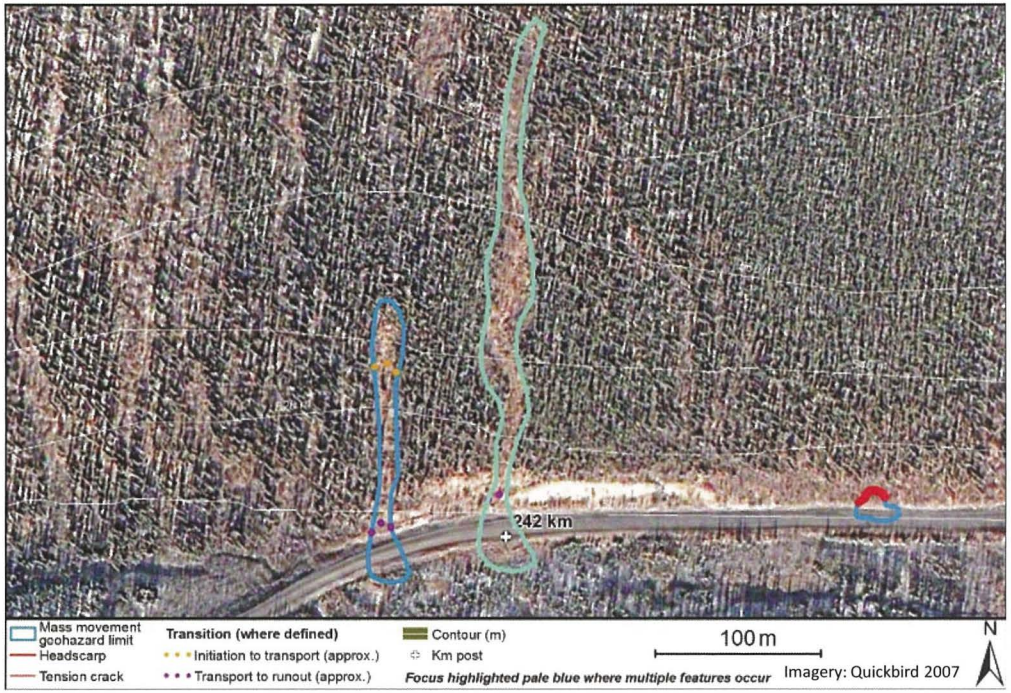
KM 241.9



SITE	PROCESS	GEOMETRY	IMPLICATIONS

Section	Type	Elevation (m)	Likelihood
Ogilvie	debris slide (active layer detachment)	534	L

Proximity (m)	Position	Initiation slope (°)	Consequence
0	above	29	L

Aspect (°)	Causes	Runout slope (°)	Risk
170	permafrost degradation, possible fire	14	VL

Surficial material	Triggers	Average slope (°)	Mitigation
szrCb	intense rainfall/snowmelt or heat	19	None expected to be required

Permafrost	Timing	Dimensions (L/W/D) (m)	Comments
Shallow permafrost	Single event (1977-2007) with minimal remaining potential for post-failure sloughs/flows	338 / 28 / 1	Mostly stabilized through natural revegetation

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Project number: 14132
Client: Yukon Government

KM 242

SITE	PROCESS	GEOMETRY	IMPLICATIONS
Section	**Type**	**Elevation (m)**	**Likelihood**
Ogilvie	debris slide (active layer detachment)	495	M
Proximity (m)	**Position**	**Initiation slope (°)**	**Consequence**
0	above	33	L
Aspect (°)	**Causes**	**Runout slope (°)**	**Risk**
170	oversteepened slope toe	4	L
Surficial material	**Triggers**	**Average slope (°)**	**Mitigation**
rszCb	intense rainfall/snowmelt or heat	23	Management of debris accumulation in ditch
Permafrost	**Timing**	**Dimensions (L/W/D) (m)**	**Comments**
Moderately deep permafrost in original road cut area	Single event (2007-2013) with potential for post-failure sloughs/flows	19 / 27 / 1	Runout limits approximate due to clearing of former debris accumulation

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Project: Dempster Geohazard Investigation
Project number: 14132
Client: Yukon Government

KM 242.2

No field photographs available

SITE	PROCESS	GEOMETRY	IMPLICATIONS

Section	Type	Elevation (m)	Likelihood
Ogilvie	debris slide (active layer detachment)	495	M

Proximity (m)	Position	Initiation slope (°)	Consequence
8	above	39	L

Aspect (°)	Causes	Runout slope (°)	Risk
165	permafrost degradation	13	L

Surficial material	Triggers	Average slope (°)	Mitigation
szrCv	intense rainfall/snowmelt or heat	19	Management of debris accumulation in ditch

Permafrost	Timing	Dimensions (L/W/D) (m)	Comments
Shallow permafrost	Single event with potential for post-failure sloughs/flows	104 / 17 / <1	

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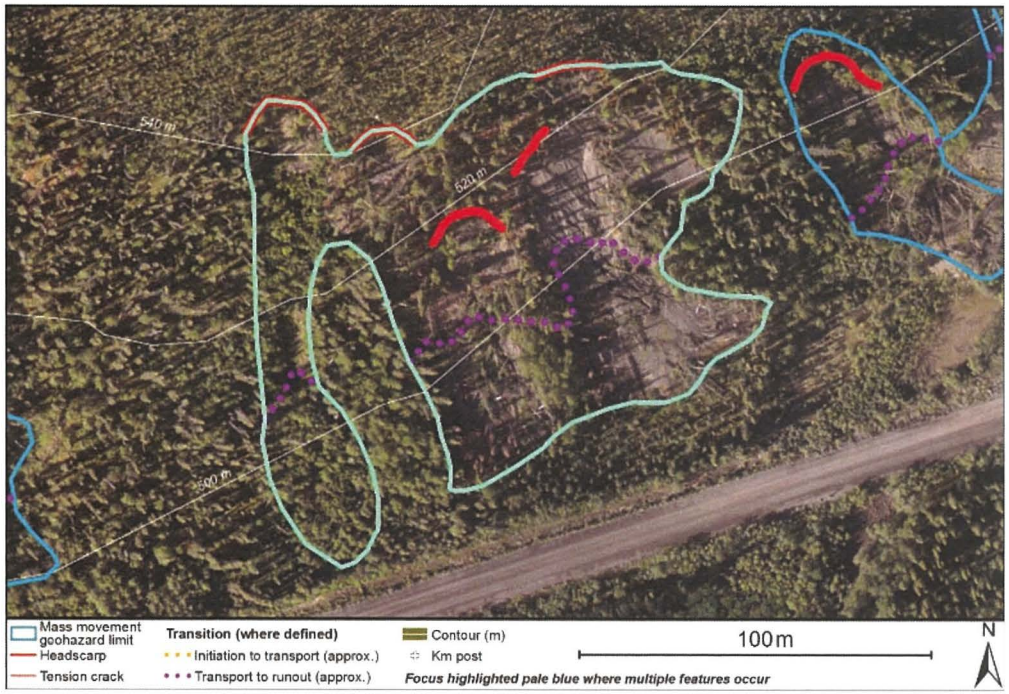
Project number: 14132
Client: Yukon Government

KM 244



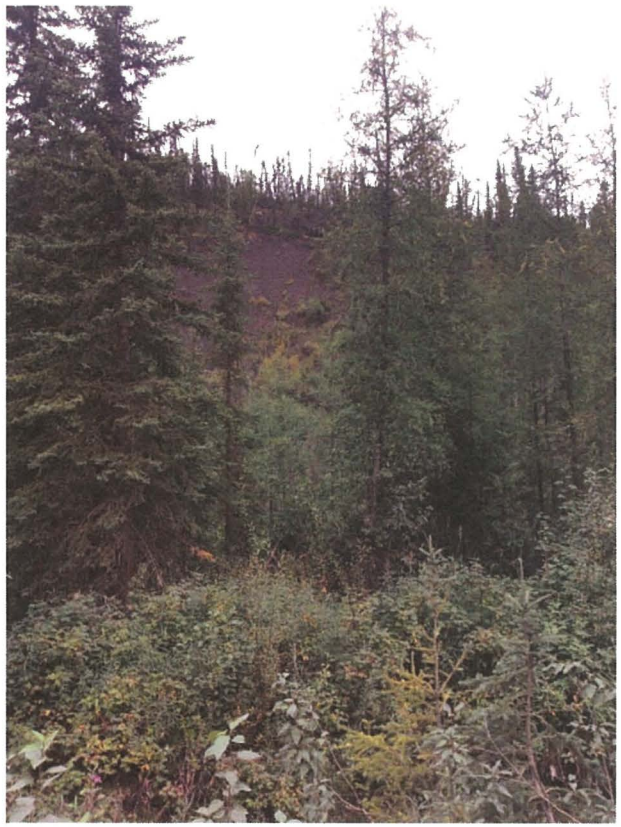


Photo credit:
Lekan Mitchell

SITE	PROCESS	GEOMETRY	IMPLICATIONS
Section	**Type**	**Elevation (m)**	**Likelihood**
Ogilvie	debris slide (active layer detachment)	505	M
Proximity (m)	**Position**	**Initiation slope (°)**	**Consequence**
6	above	24	L
Aspect (°)	**Causes**	**Runout slope (°)**	**Risk**
145	permafrost degradation	16	L
Surficial material	**Triggers**	**Average slope (°)**	**Mitigation**
szrCv	intense rainfall/snowmelt or heat	25	Management of debris accumulation in ditch
Permafrost	**Timing**	**Dimensions (L/W/D) (m)**	**Comments**
Shallow permafrost	Single event with potential for post-failure sloughs/flows	115 / 150 / <1	

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Project number: 14132
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KM 244.1

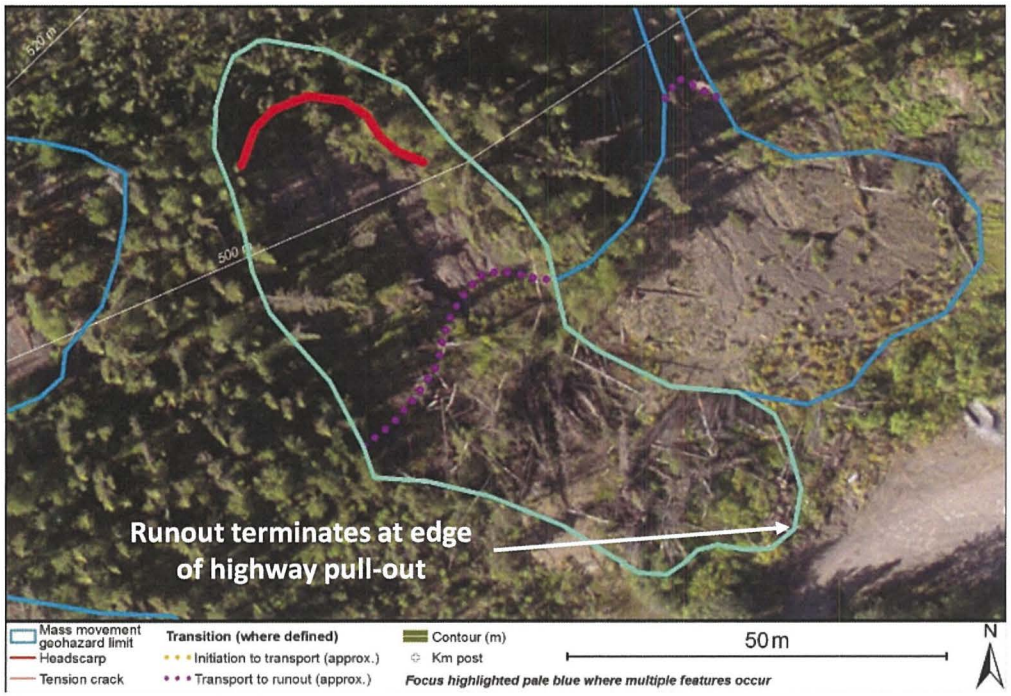

Photo credits: Lekan Mitchell

SITE	PROCESS	GEOMETRY	IMPLICATIONS

Section	Type	Elevation (m)	Likelihood
Ogilvie	debris slide (active layer detachment)	488	L

Proximity (m)	Position	Initiation slope (°)	Consequence
30	above	36	L

Aspect (°)	Causes	Runout slope (°)	Risk
120	permafrost degradation	5	VL

Surficial material	Triggers	Average slope (°)	Mitigation
szrCv	intense rainfall/snowmelt or heat	18	Management of debris accumulation in ditch of staging area

Permafrost	Timing	Dimensions (L/W/D) (m)	Comments
Shallow permafrost	Single event (2007-2013) with potential for post-failure sloughs/flows	100 / 26 / <1	

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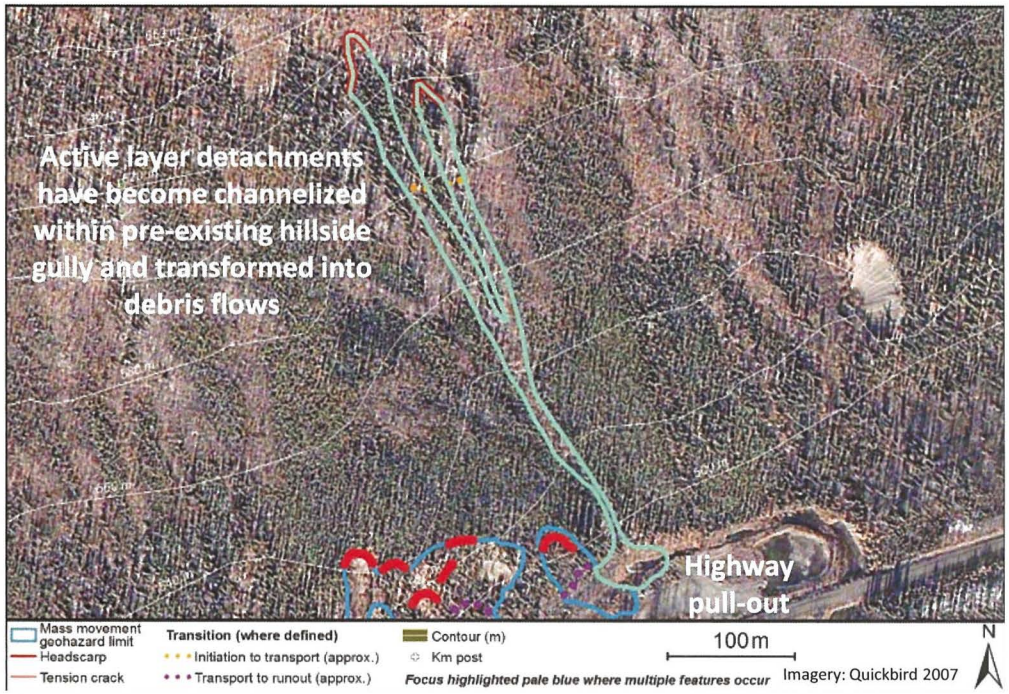
KM 244.25



SITE	PROCESS	GEOMETRY	IMPLICATIONS

Section	Type	Elevation (m)	Likelihood
Ogilvie	debris flow & debris slide (active layer detachment)	560	L

Proximity (m)	Position	Initiation slope (°)	Consequence
46.6	above	29	L

Aspect (°)	Causes	Runout slope (°)	Risk
135	permafrost degradation, possible fire	8	VL

Surficial material	Triggers	Average slope (°)	Mitigation
szrCv	intense rainfall/snowmelt or heat	16	Management of debris accumulation in ditch or staging area

Permafrost	Timing	Dimensions (L/W/D) (m)	Comments
Shallow permafrost	Single event (2007-2013) with potential for post-failure sloughs/flows	493 / 57 / n/a	Special case of recurrent runout of debris from multiple active layer detachment sources

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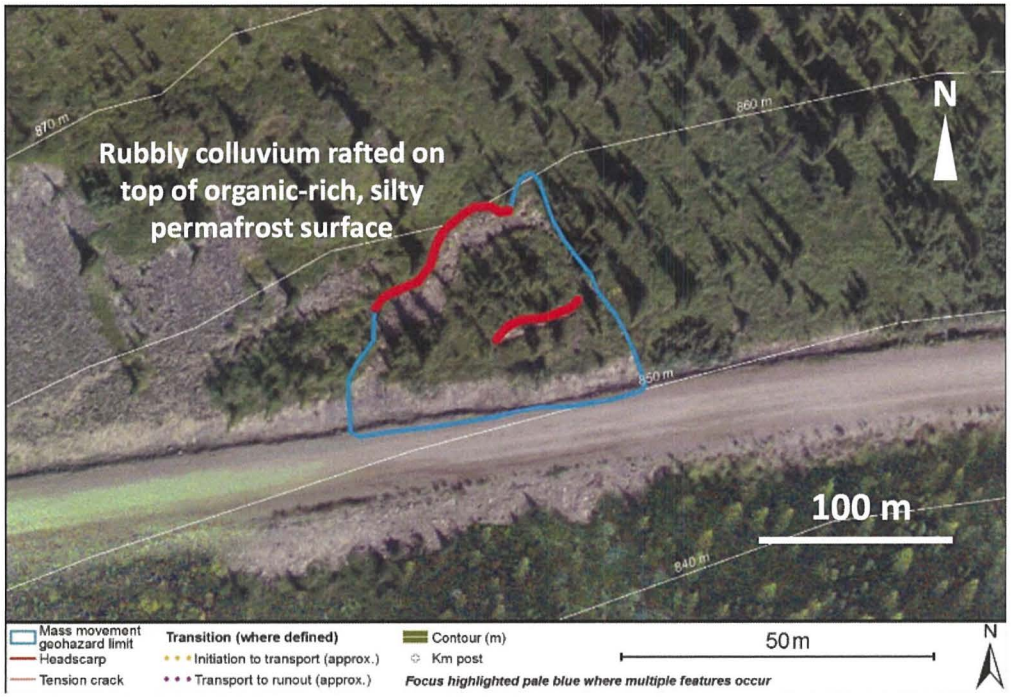
Project number: 14132
Client: Yukon Government

KM 244.3



SITE	PROCESS	GEOMETRY	IMPLICATIONS

Section	Type	Elevation (m)	Likelihood
Ogilvie	debris slide (active layer detachment)	854	M

Proximity (m)	Position	Initiation slope (°)	Consequence
0	above	17	M

Aspect (°)	Causes	Runout slope (°)	Risk
150	oversteepened slope toe, permafrost degradation	17	M

Surficial material	Triggers	Average slope (°)	Mitigation
rszCv	intense rainfall/snowmelt or heat	16	Management of runout debris

Permafrost	Timing	Dimensions (L/W/D) (m)	Comments
Shallow permafrost	Single event (2007-2013) with potential for post-failure sloughs/flows	33 / 49 / 0.3	Reactivation possible

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Project number: 14132
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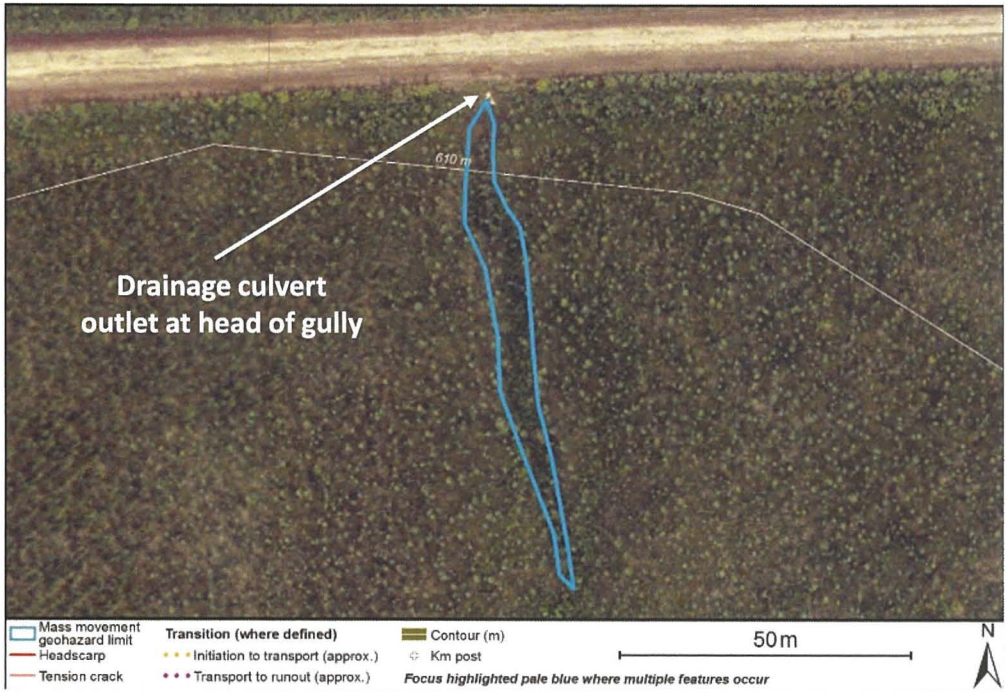
KM 273.1



SITE	PROCESS	GEOMETRY	IMPLICATIONS
Section	**Type**	**Elevation (m)**	**Likelihood**
Eagle Plains	thermokarst gully	607	L
Proximity (m)	**Position**	**Length (m)**	**Consequence**
0	below	86	L
Aspect (°)	**Causes**	**Width (m)**	**Risk**
175	concentrated drainage	5	VL
Surficial material	**Triggers**	**Depth (m)**	**Mitigation**
rszCb	intense rainfall/snowmelt	1	Management of surface runoff from culvert
Permafrost	**Timing**	**Dimensions (L/W/D) (m)**	**Comments**
Shallow permafrost	Ongoing/episodic, likely initiated following highway construction	5	

Yukon Government

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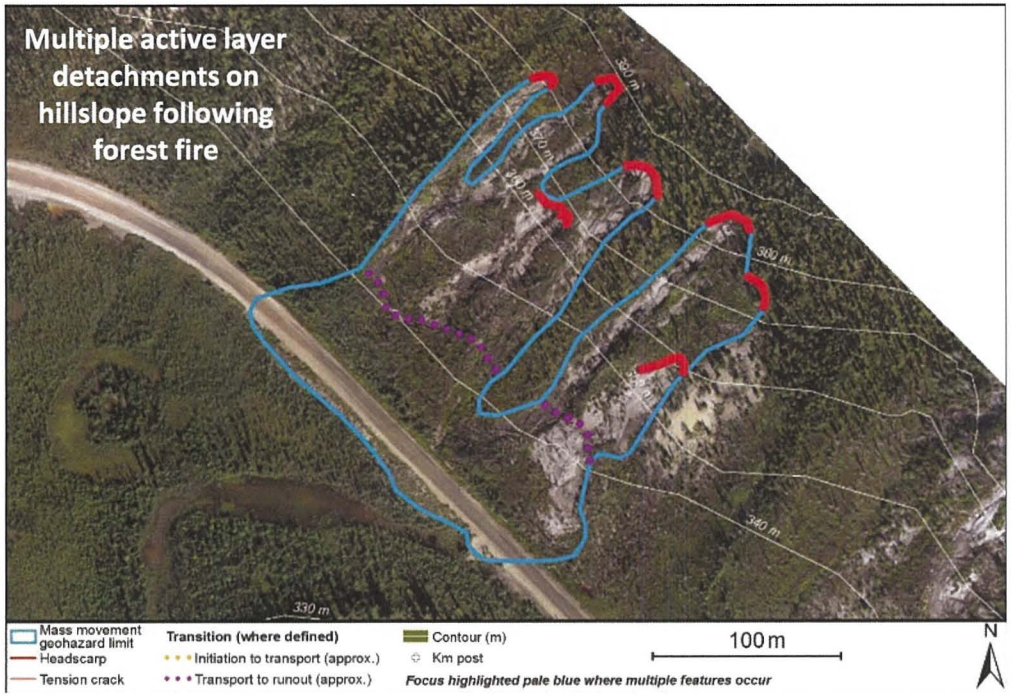
Project: Dempster Geohazard Investigation
Project number: 14132
Client: Yukon Government

KM 301.4



SITE	PROCESS	GEOMETRY	IMPLICATIONS
Section	**Type**	**Elevation (m)**	**Likelihood**
Eagle Plains	debris slide (active layer detachment)	339	M
Proximity (m)	**Position**	**Initiation slope (°)**	**Consequence**
0	above	20	M
Aspect (°)	**Causes**	**Runout slope (°)**	**Risk**
210	fire, permafrost degradation	5	M
Surficial material	**Triggers**	**Average slope (°)**	**Mitigation**
szdCv	intense rainfall/snowmelt or heat	15	Management of runout debris
Permafrost	**Timing**	**Dimensions (L/W/D) (m)**	**Comments**
Shallow, likely ice-poor permafrost	Single event with potential for post-failure sloughs/flows	217 / 217 / 1	

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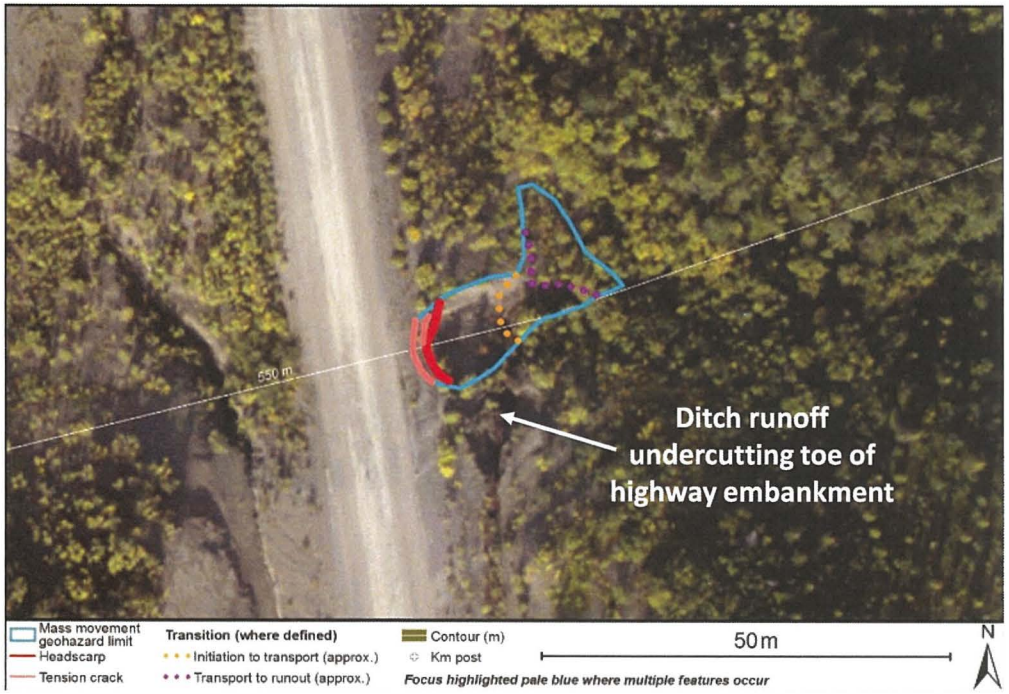
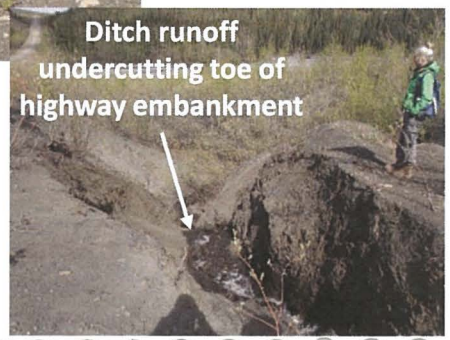
Project: Dempster Geohazard Investigation
Project number: 14132
Client: Yukon Government

KM 378.8





SITE	PROCESS	GEOMETRY	IMPLICATIONS
Section	**Type**	**Elevation (m)**	**Likelihood**
Eagle Plains	debris slide	549	M
Proximity (m)	**Position**	**Initiation slope (°)**	**Consequence**
0	below	30	M
Aspect (°)	**Causes**	**Runout slope (°)**	**Risk**
45	concentrated drainage in hwy ditch undercutting embankment	20	M
Surficial material	**Triggers**	**Average slope (°)**	**Mitigation**
A	intense rainfall/snowmelt	25	Management of runoff in hwy ditch
Permafrost	**Timing**	**Dimensions (L/W/D) (m)**	**Comments**
Permafrost likely relatively deep within highway embankment or underlying weathered bedrock	Single event with potential for post-failure sloughs and gradual retrogression	25 / 10 / 0.5	

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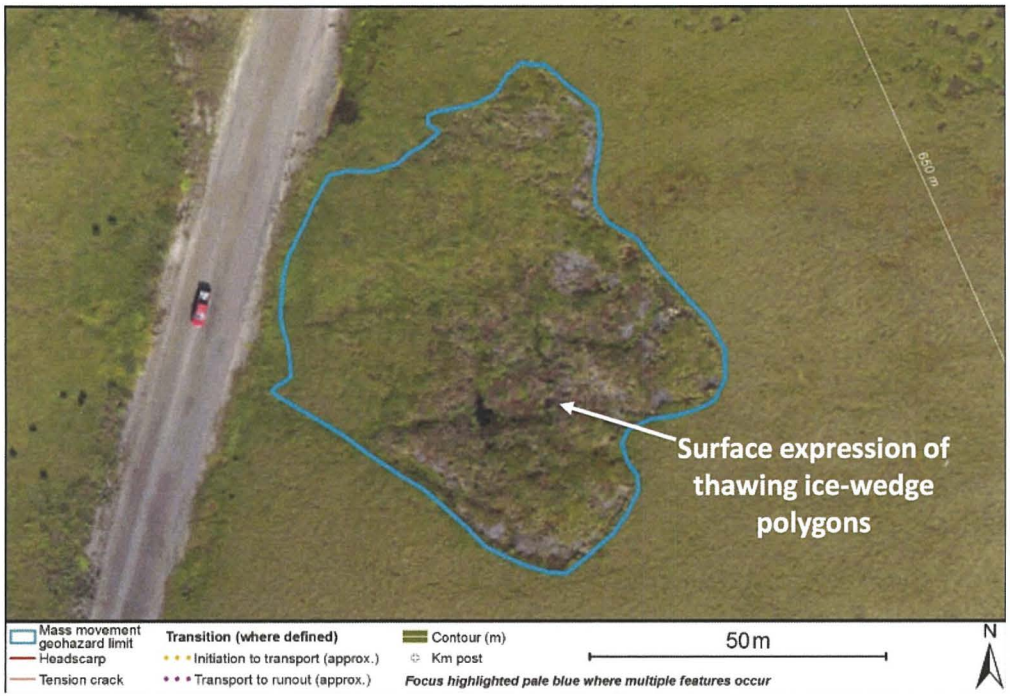
Project number: 14132
Client: Yukon Government

KM 432.7



No field photographs available

SITE	PROCESS	GEOMETRY	IMPLICATIONS
Section	**Type**	**Elevation (m)**	**Likelihood**
Eagle Plains	thermokarst subsidence	653	L
Proximity (m)	**Position**	**Length (m)**	**Consequence**
3	above	78	M
Aspect (°)	**Causes**	**Width (m)**	**Risk**
285	possible disturbance to surface organic cover, permafrost degradation	70	L
Surficial material	**Triggers**	**Depth (m)**	**Mitigation**
szxCb	intense rainfall/snowmelt or heat	<1	Management of ground settlement
Permafrost	**Timing**	**Average slope (°)**	**Comments**
Shallow, ice-rich permafrost in area of degrading ice-wedge polygons	Ongoing/episodic, possibly exacerbated by highway construction	2	Potential for feature to evolve into retrogressive thaw slump

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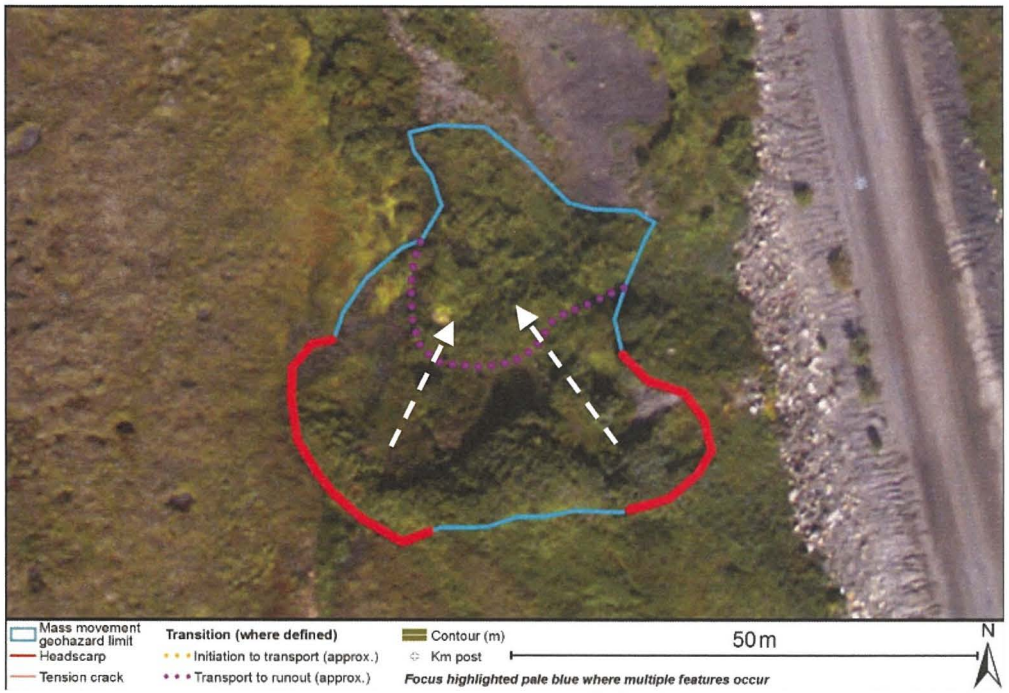
Project: Dempster Geohazard Investigation
Project number: 14132
Client: Yukon Government

KM 453.9



No field photographs available

SITE	PROCESS	GEOMETRY	IMPLICATIONS

Section	Type	Elevation (m)	Likelihood
Eagle Plains	retrogressive thaw slump	796	M

Proximity (m)	Position	Initiation slope (°)	Consequence
7	below	8	M

Aspect (°)	Causes	Runout slope (°)	Risk
20	alteration of drainage pattern, permafrost degradation	5	M

Surficial material	Triggers	Average slope (°)	Mitigation
szrCb	intense rainfall/snowmelt or heat	6	Management of surface runoff and ground settlement

Permafrost	Timing	Dimensions (L/W/D) (m)	Comments
Shallow, likely ice-rich permafrost	Ongoing/episodic, possibly exacerbated by highway construction	47 / 13 / 2	Dominant trajectory of retrogression parallel to, rather than toward, hwy

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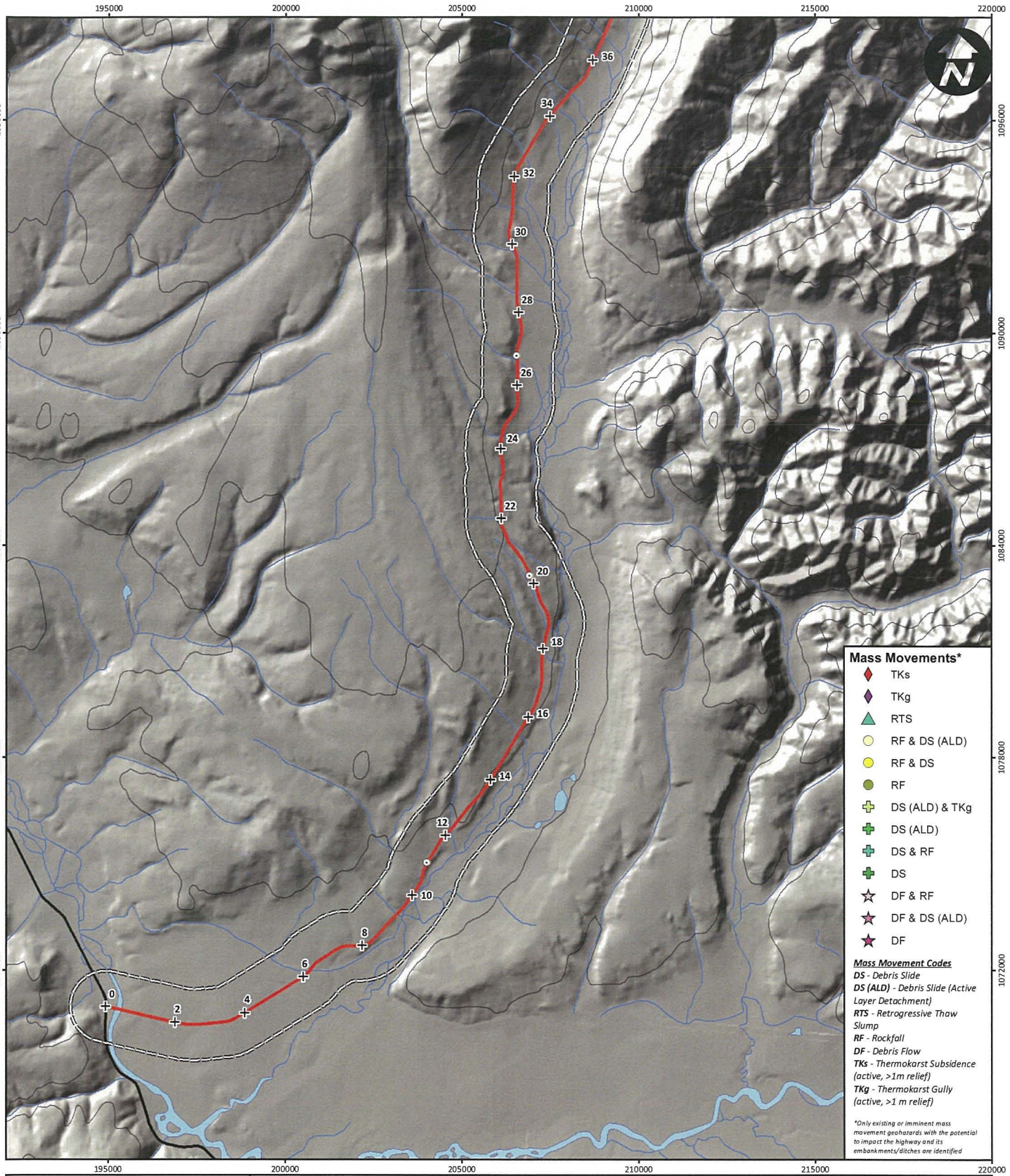
Project: Dempster Geohazard Investigation
Project number: 14132
Client: Yukon Government

KM 462.3

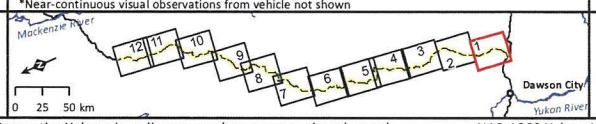


0 1 2 4 6 Km

Legend

- Territorial Boundary
- Highways
- Waterbodies
- Watercourses
- Study Corridor
- Highway Kilometre Posts
- 100m contours
- Dempster Highway (Yukon)
- Field Inspection Sites*

*Near-continuous visual observations from vehicle not shown



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Project Number: 14132

Title: Geohazard Investigation Dempster Highway #5

Distribution and Classification of Mass Movement Geohazards

Figure D-1

Digital Elevation Model and base data provided by Geomatics Yukon via online source (www.geomaticsyukon.ca) NAD 1983 Yukon Albers 1:150,000 Drawn by: CEB Checked by: RM 08/08/2016

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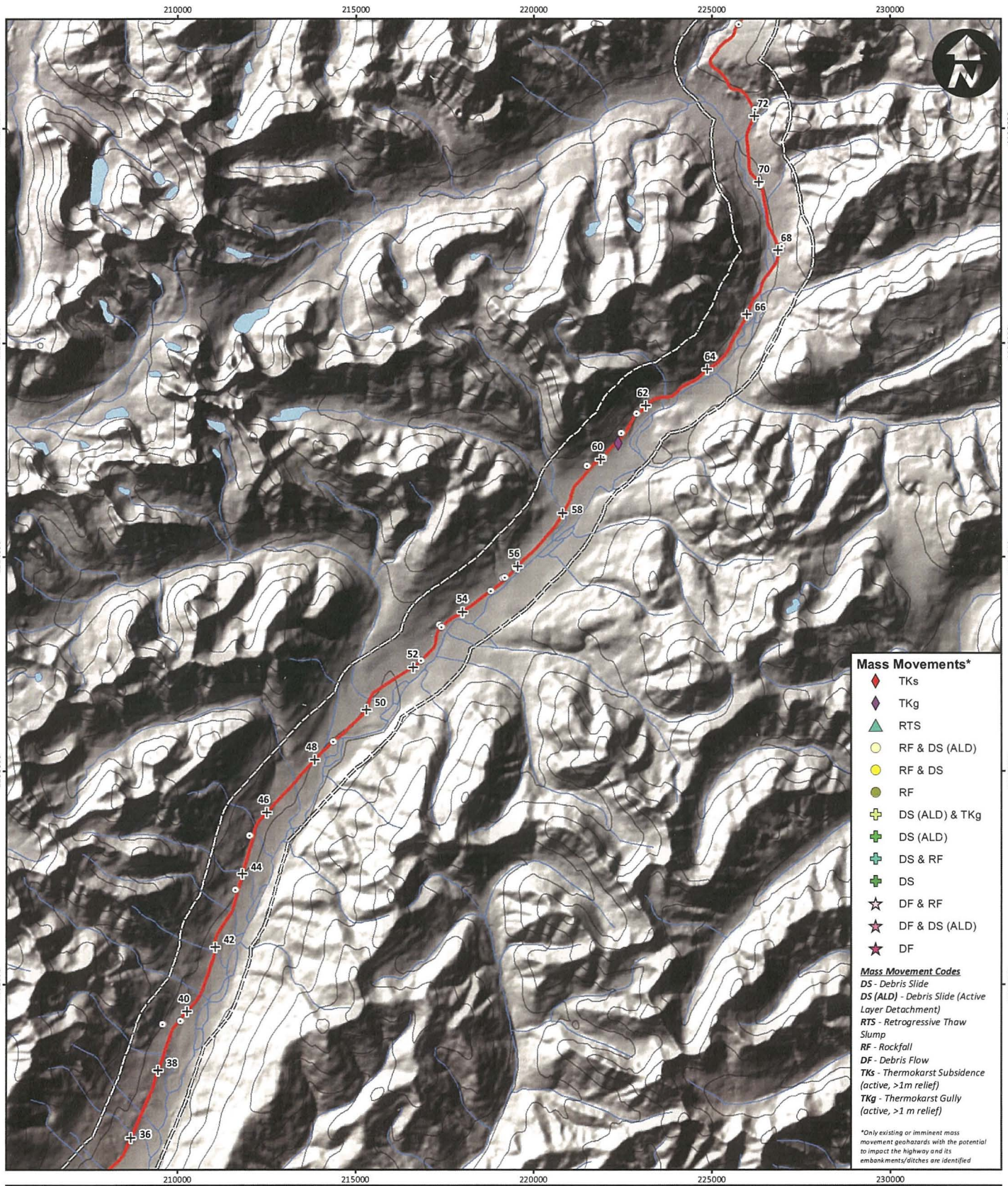

Km
0 1 2 4 6

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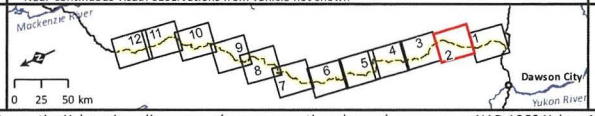
Legend

- Territorial Boundary
- Highways
- Waterbodies
- Watercourses
- Study Corridor
- Highway Kilometre Posts
- 100m contours
- Dempster Highway (Yukon)
- Field Inspection Sites*

*Near-continuous visual observations from vehicle not shown



Project Number: 14132

Title: Geohazard Investigation Dempster Highway #5

Distribution and Classification of Mass Movement Geohazards

Figure D-2

Digital Elevation Model and base data provided by Geomatics Yukon via online source (www.geomaticsyukon.ca) NAD 1983 Yukon Albers 1:150,000 Drawn by: CEB Checked by: RM 08/08/2016

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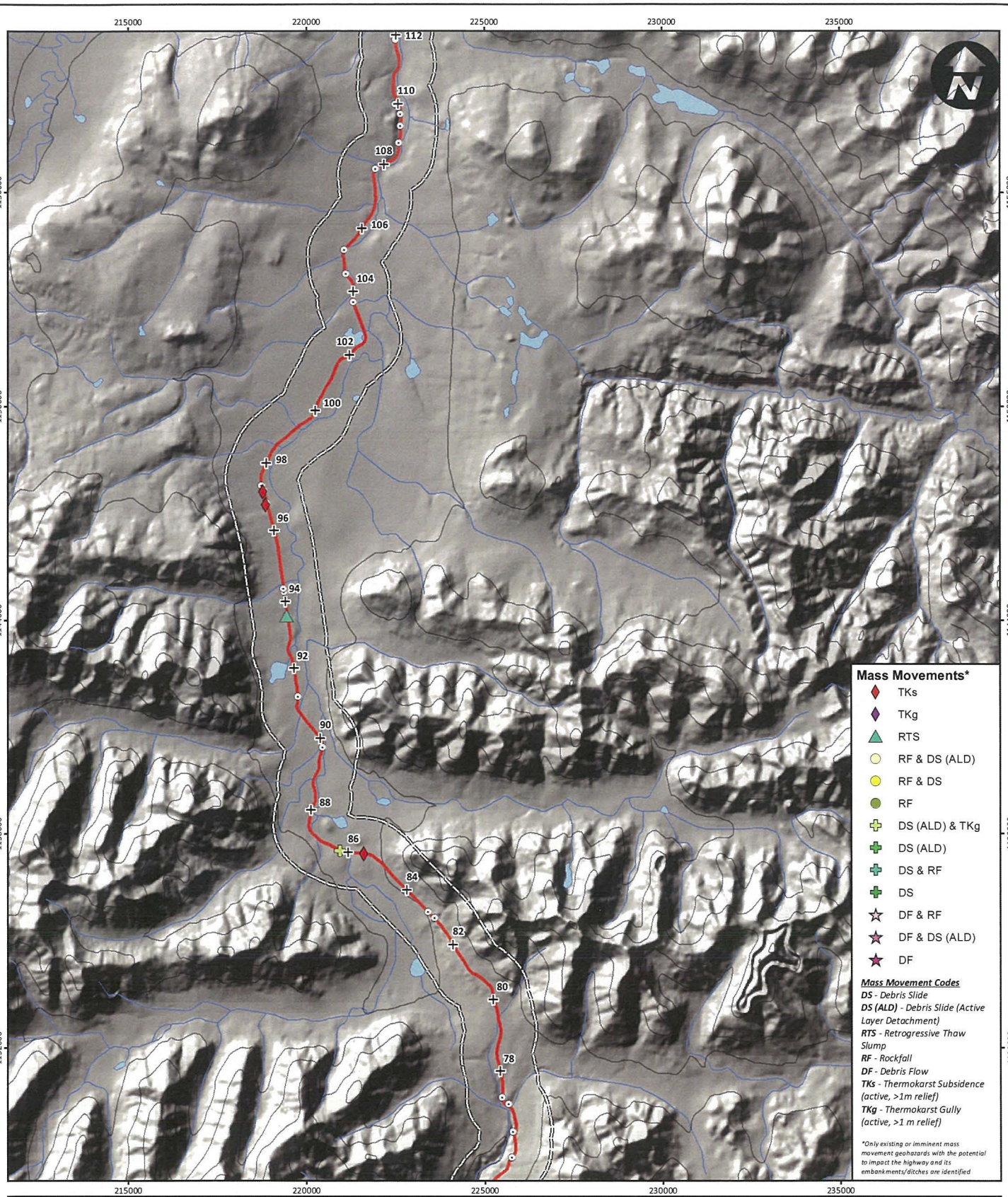


Km
0 1 2 4 6

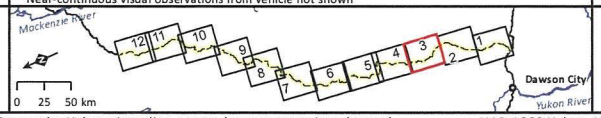
KRYOTEK

PALMER ENVIRONMENTAL CONSULTING GROUP INC.

Legend

- Territorial Boundary
- Highways
- Waterbodies
- Watercourses
- Study Corridor
- Highway Kilometre Posts
- 100m contours
- Dempster Highway (Yukon)
- Field Inspection Sites*

*Near-continuous visual observations from vehicle not shown



Project Number: 14132

Title: Geohazard Investigation
Dempster Highway #5

Distribution and Classification of Mass Movement Geohazards

Figure D-3

Digital Elevation Model and base data provided by Geomatics Yukon via online source (www.geomaticsyukon.ca) NAD 1983 Yukon Albers 1:150,000 Drawn by: CEB Checked by: RM 08/08/2016

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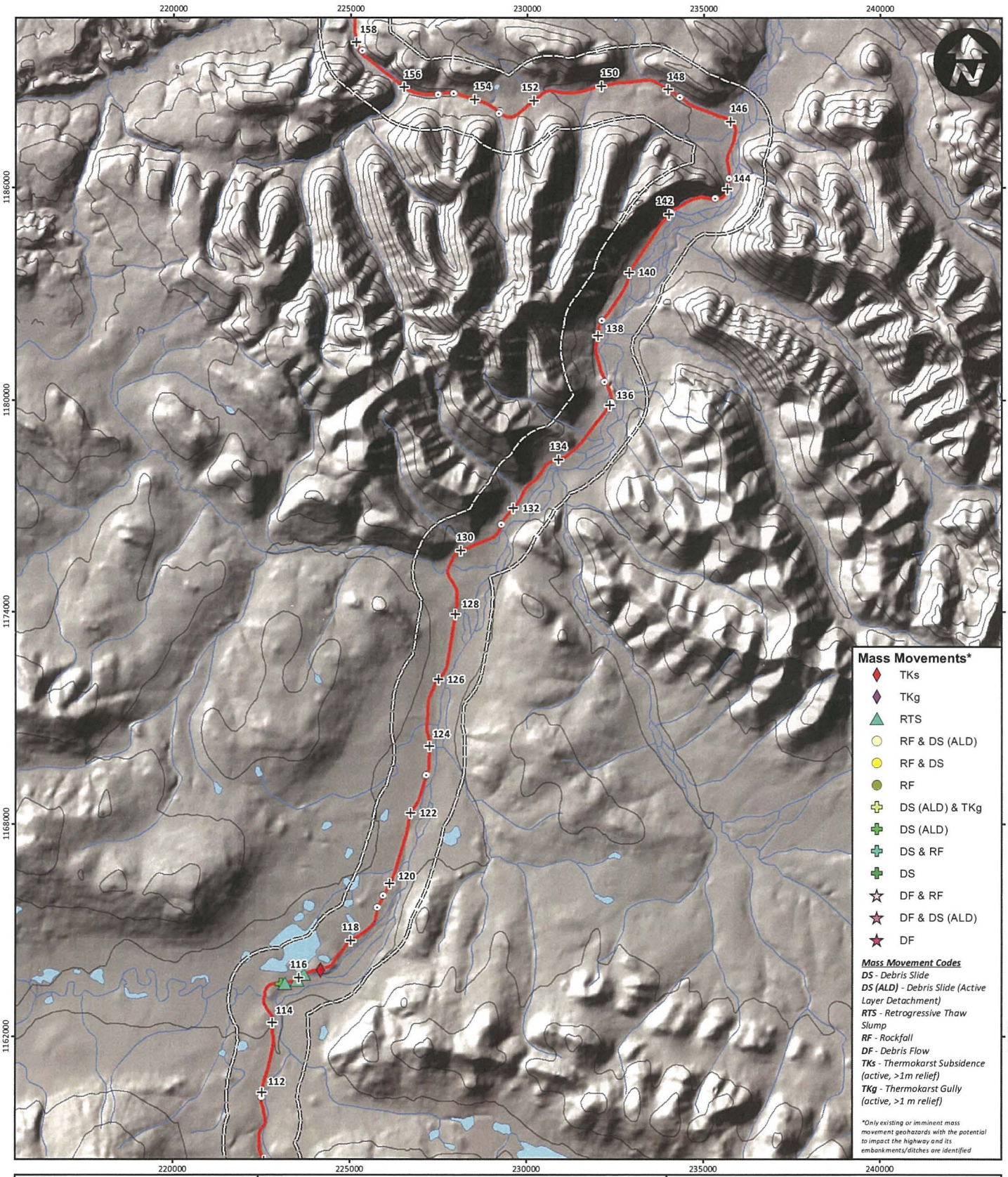
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128
126
124
122
120
118
116
114
112
N
Mass Movements*
TKs
TKg
RTS
RF & DS (ALD)
RF & DS
RF
DS (ALD) & TKg
DS (ALD)
DS & RF
DS
DF & RF
DF & DS (ALD)
DF
Mass Movement Codes
DS - Debris Slide
DS (ALD) - Debris Slide (Active Layer Detachment)
RTS - Retrogressive Thaw Slump
RF - Rockfall
DF - Debris Flow
TKs - Thermokarst Subsidence (active, >1m relief)
TKg - Thermokarst Gully (active, >1 m relief)
*Only existing or imminent mass movement geohazards with the potential to impact the highway and its embankments/ditches are identified
0 1 2 4 6 Km
Legend
Territorial Boundary
Highways
Waterbodies
Watercourses
Study Corridor
Highway Kilometre Posts
100m contours
Dempster Highway (Yukon)
Field Inspection Sites*
*Near-continuous visual observations from vehicle not shown
Mackenzie River
12 11 10 9 8 7 6 5 4 3 2 1
Dawson City
Yukon River
0 25 50 km
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PALMER ENVIRONMENTAL CONSULTING GROUP INC.
Project Number: 14132
Title: Geohazard Investigation Dempster Highway #5
Distribution and Classification of Mass Movement Geohazards
Figure D-4
Digital Elevation Model and base data provided by Geomatics Yukon via online source (www.geomaticsyukon.ca)
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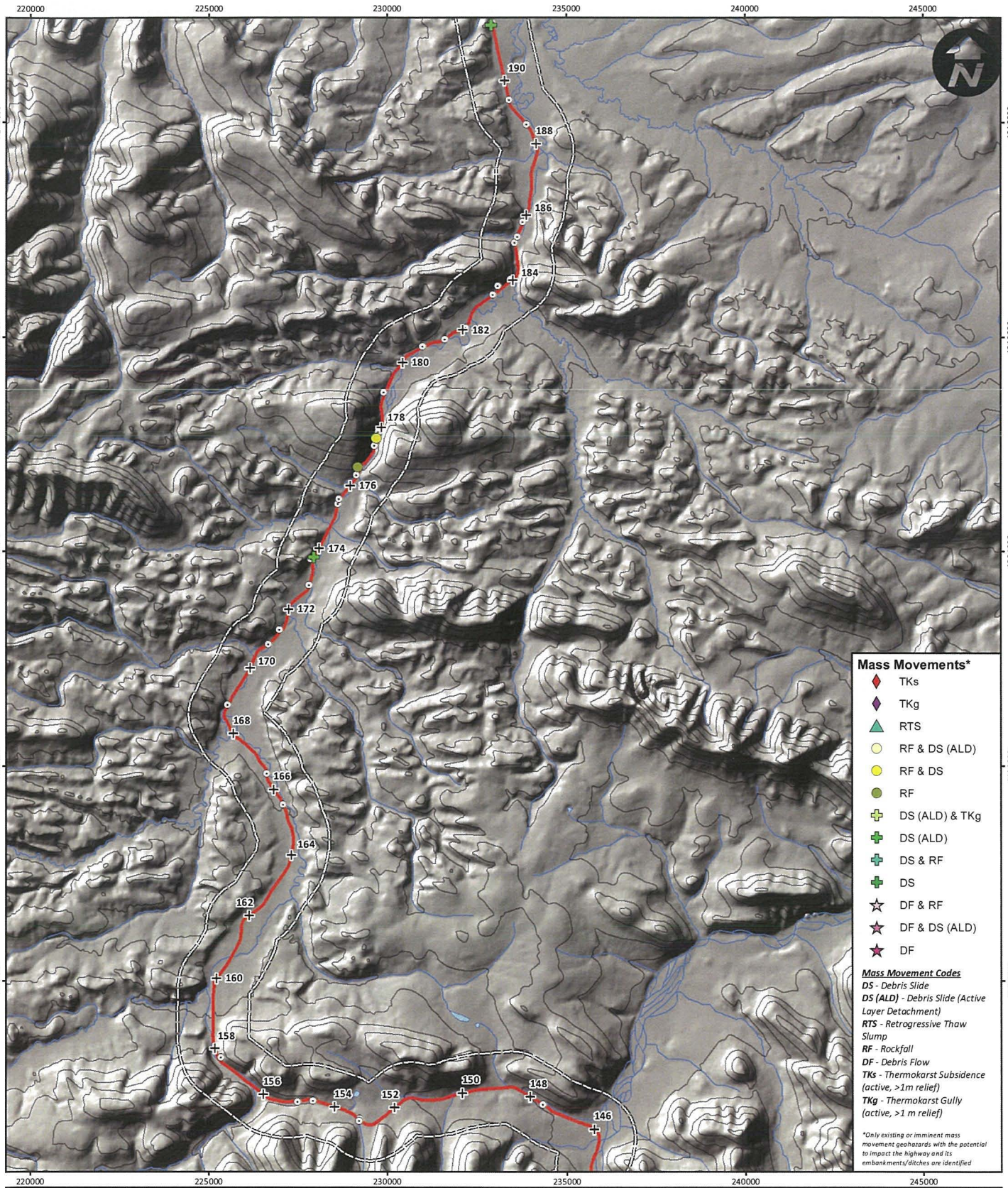
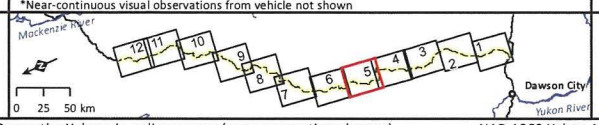


Km
0 1 2 4 6

Legend

- Territorial Boundary
- Highways
- Waterbodies
- Watercourses
- Study Corridor
- Highway Kilometre Posts
- 100m contours
- Dempster Highway (Yukon)
- Field Inspection Sites*

*Near-continuous visual observations from vehicle not shown



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Project Number: 14132

Title: Geohazard Investigation
Dempster Highway #5

Distribution and Classification of Mass Movement Geohazards

Figure D-5

Digital Elevation Model and base data provided by Geomatics Yukon via online source (www.geomaticsyukon.ca) NAD 1983 Yukon Albers 1:150,000 Drawn by: CEB Checked by: RM 08/08/2016

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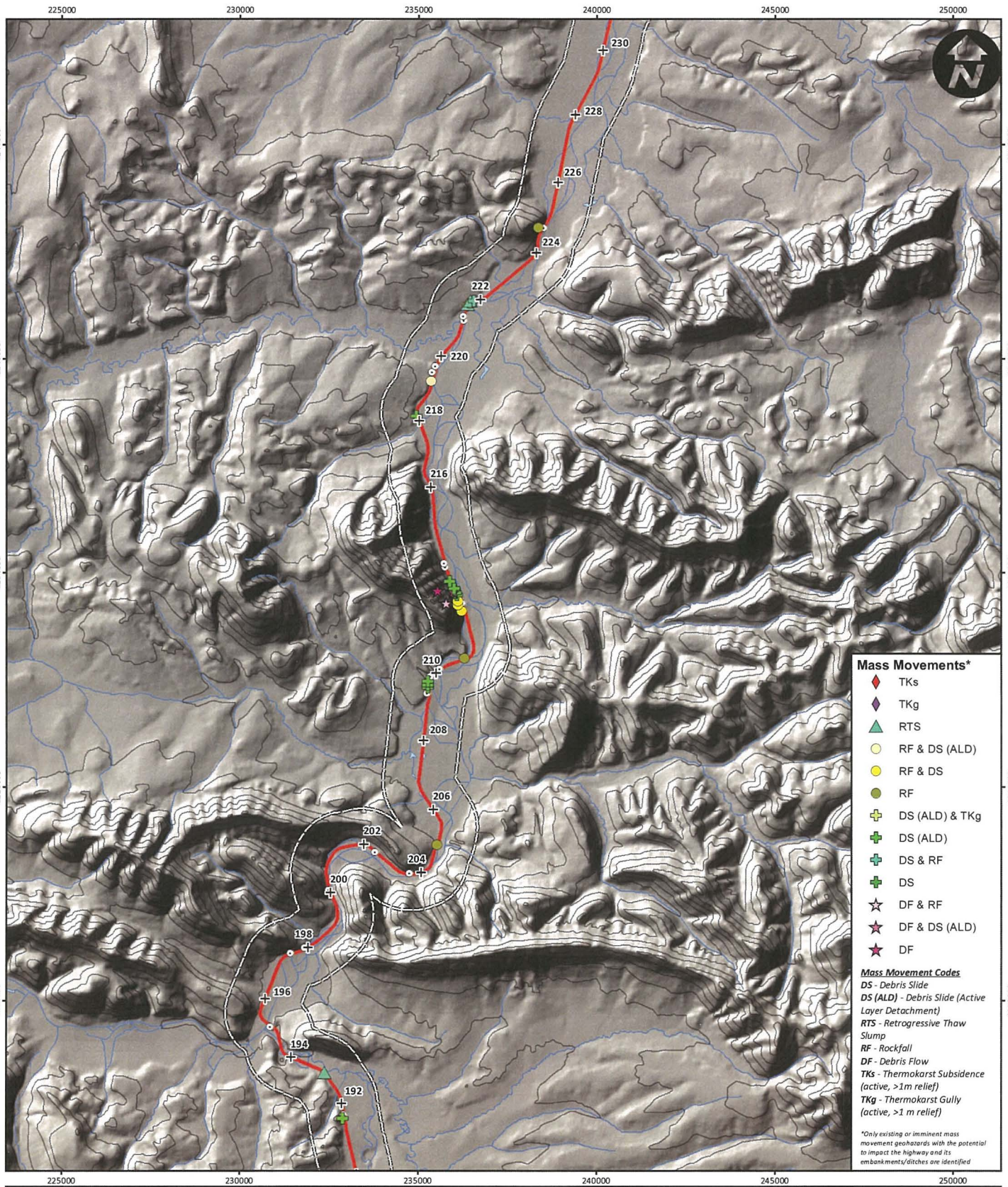

Km
0 1 2 4 6

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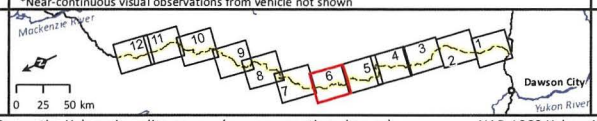
Legend

- Territorial Boundary
- Highways
- Waterbodies
- Watercourses
- Study Corridor
- Highway Kilometre Posts
- 100m contours
- Dempster Highway (Yukon)
- Field Inspection Sites*

*Near-continuous visual observations from vehicle not shown



Project Number: 14132

Title: Geohazard Investigation
Dempster Highway #5

Distribution and Classification of Mass Movement Geohazards

Figure D-6

Digital Elevation Model and base data provided by Geomatics Yukon via online source (www.geomaticsyukon.ca) NAD 1983 Yukon Albers 1:150,000 Drawn by: CEB Checked by: RM 08/08/2016

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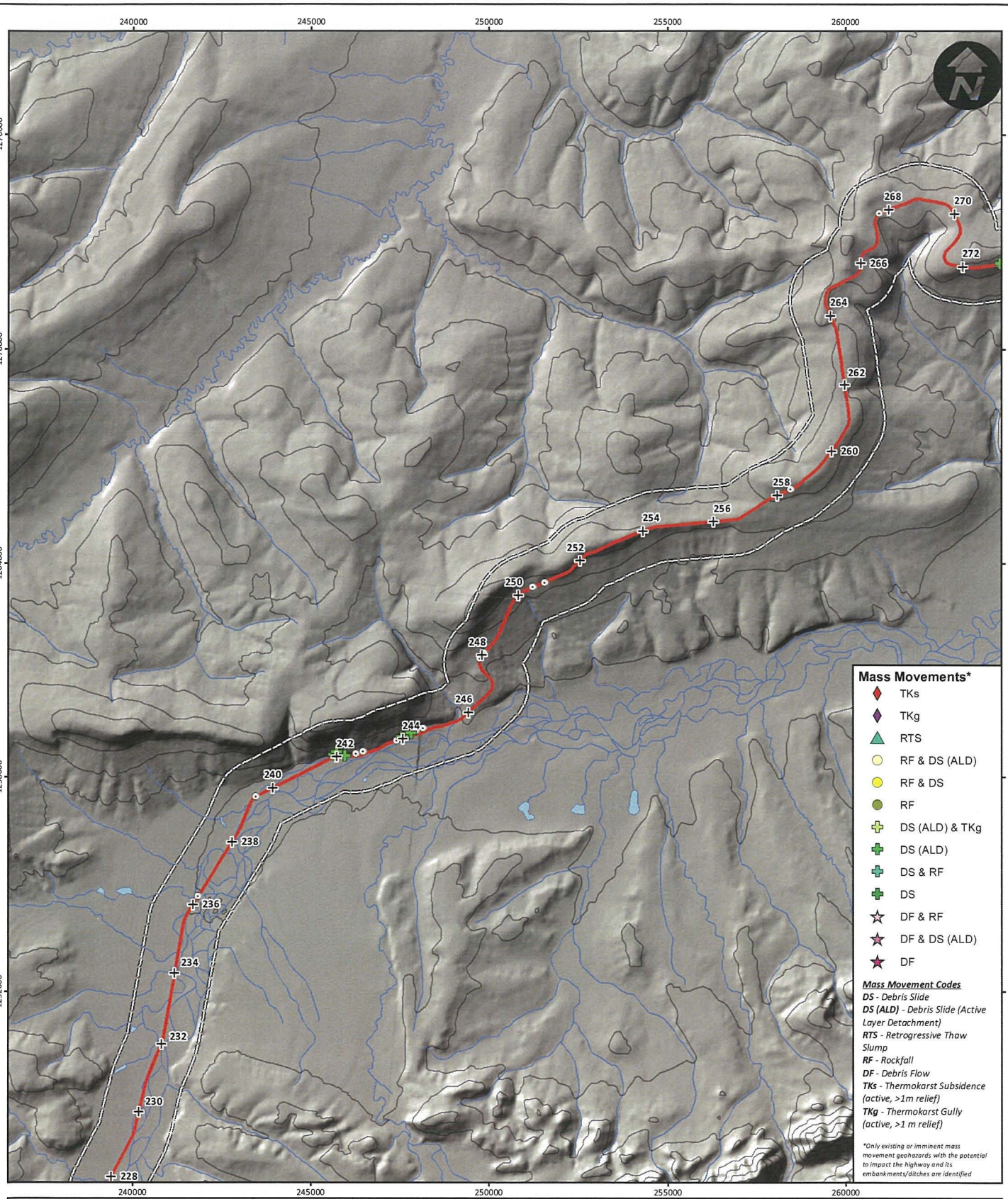
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252
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256
258
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262
264
266
268
270
272
Mass Movements*
TKs
TKg
RTS
RF & DS (ALD)
RF & DS
RF
DS (ALD) & TKg
DS (ALD)
DS & RF
DS
DF & RF
DF & DS (ALD)
DF
Mass Movement Codes
DS - Debris Slide
DS (ALD) - Debris Slide (Active Layer Detachment)
RTS - Retrogressive Thaw Slump
RF - Rockfall
DF - Debris Flow
TKs - Thermokarst Subsidence (active, >1m relief)
TKg - Thermokarst Gully (active, >1 m relief)
*Only existing or imminent mass movement geohazards with the potential to impact the highway and its embankments/ditches are identified
0 1 2 4 6 Km
Legend
Territorial Boundary
Highways
Waterbodies
Watercourses
Study Corridor
Highway Kilometre Posts
100m contours
Dempster Highway (Yukon)
Field Inspection Sites*
*Near-continuous visual observations from vehicle not shown
Mackenzie River
Dawson City
Yukon River
0 25 50 km
KRYOTEK
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Project Number: 14132
Title: Geohazard Investigation Dempster Highway #5
Distribution and Classification of Mass Movement Geohazards
Figure D-7
Digital Elevation Model and base data provided by Geomatics Yukon via online source (www.geomaticsyukon.ca)
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1:150,000
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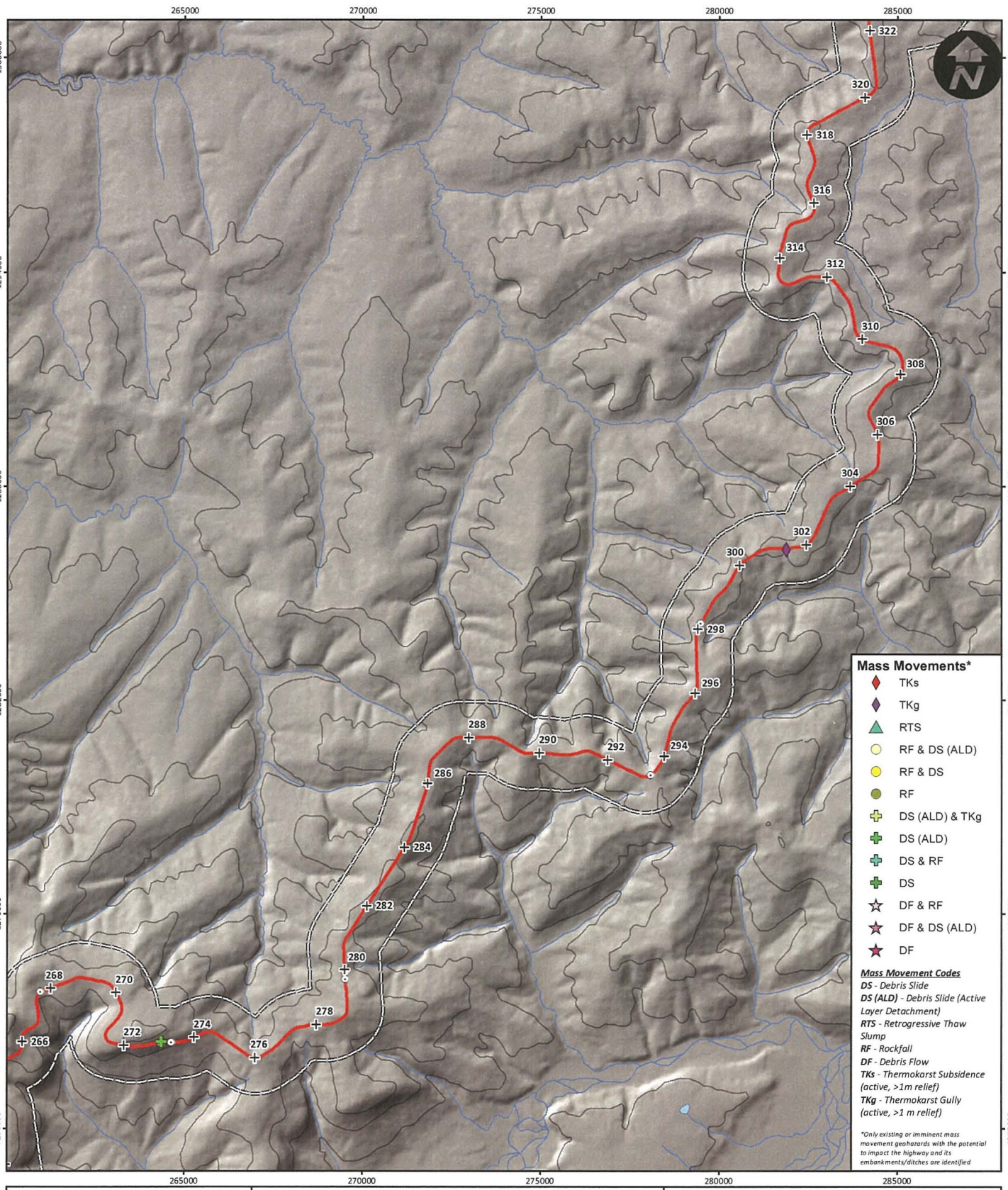

0 1 2 4 6 Km

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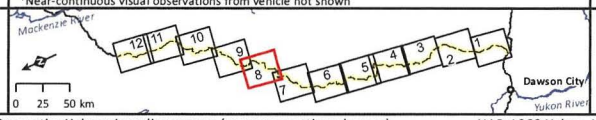
Legend

- Territorial Boundary
- Watercourses
- 100m contours
- Highways
- Study Corridor
- Dempster Highway (Yukon)
- Waterbodies
- Highway Kilometre Posts
- Field Inspection Sites*

*Near-continuous visual observations from vehicle not shown



Project Number: 14132

Title: Geohazard Investigation Dempster Highway #5

Distribution and Classification of Mass Movement Geohazards

Figure D-8

Digital Elevation Model and base data provided by Geomatics Yukon via online source (www.geomaticsyukon.ca) NAD 1983 Yukon Albers 1:150,000 Drawn by: CEB Checked by: RM 08/08/2016

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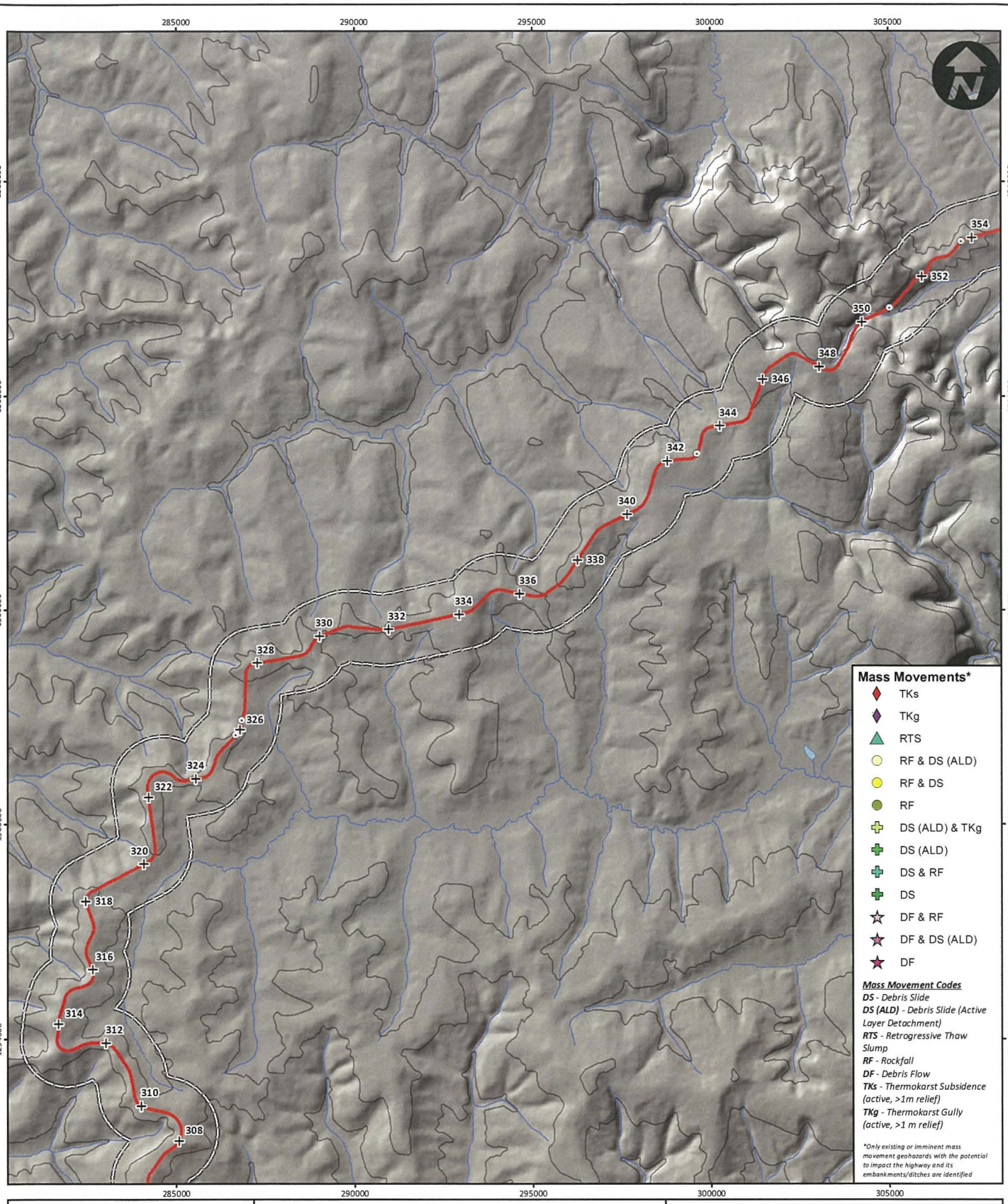

Km
0 1 2 4 6

KRYOTEK

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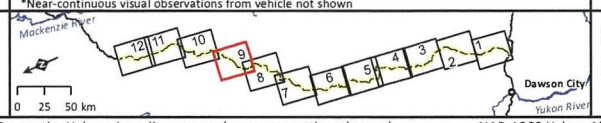
Legend

- Territorial Boundary
- Watercourses
- 100m contours
- Highways
- Study Corridor
- Dempster Highway (Yukon)
- Waterbodies
- Highway Kilometre Posts
- Field Inspection Sites*

*Near-continuous visual observations from vehicle not shown



Project Number: 14132

Title: Geohazard Investigation
Dempster Highway #5

Distribution and Classification of Mass Movement Geohazards

Figure D-9

Digital Elevation Model and base data provided by Geomatics Yukon via online source (www.geomaticsyukon.ca) NAD 1983 Yukon Albers 1:150,000 Drawn by: CEB Checked by: RM 08/08/2016

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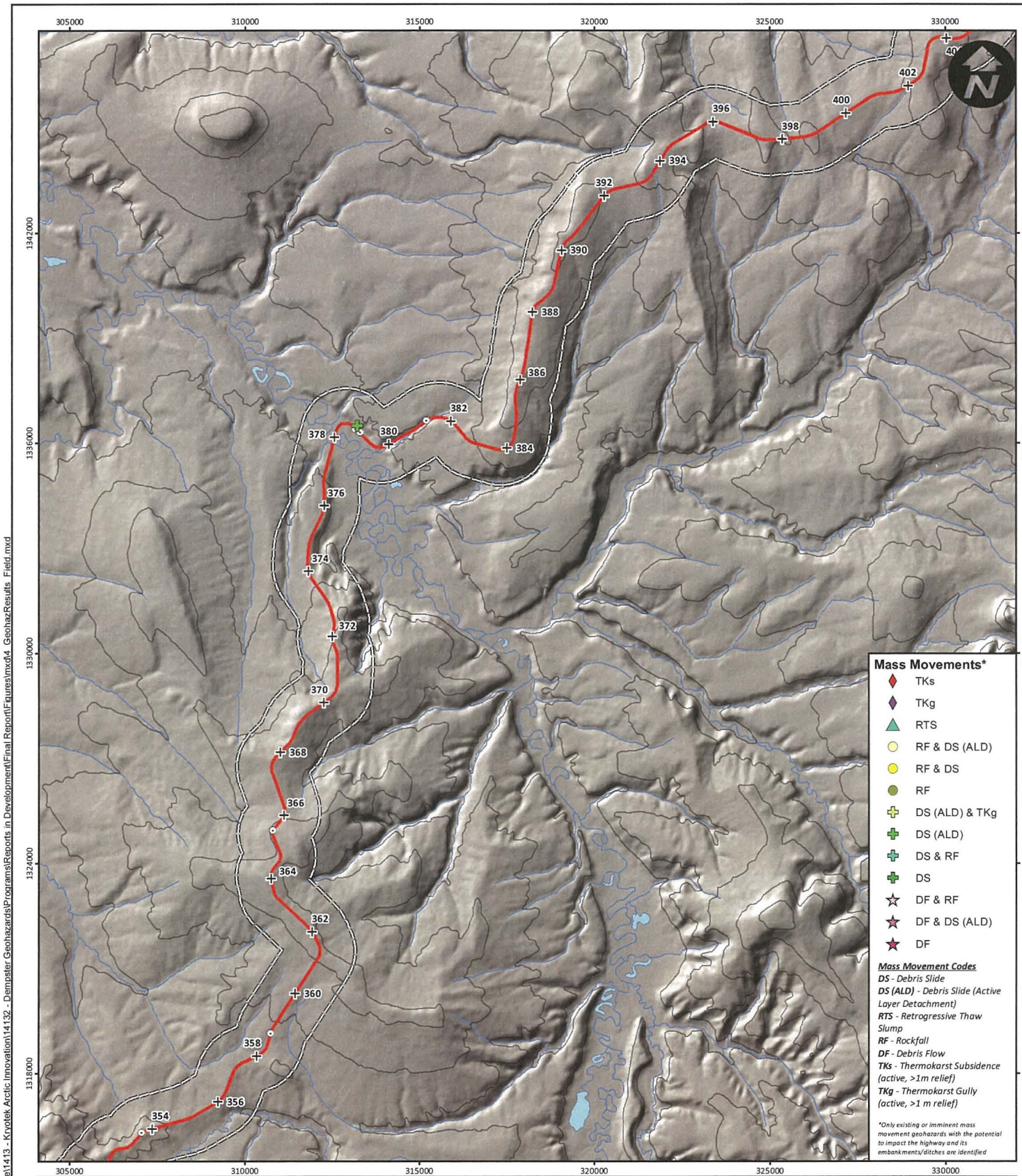


Km
0 1 2 4 6

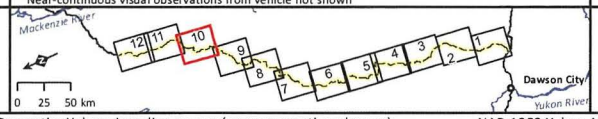
KRYOTEK

PALMER ENVIRONMENTAL CONSULTING GROUP INC.

Legend

- Territorial Boundary
- Highways
- Waterbodies
- Watercourses
- Study Corridor
- Highway Kilometre Posts
- 100m contours
- Dempster Highway (Yukon)
- Field Inspection Sites*

*Near-continuous visual observations from vehicle not shown



Project Number: 14132

Title: Geohazard Investigation
Dempster Highway #5

Distribution and Classification of Mass Movement Geohazards

Figure D-10

Digital Elevation Model and base data provided by Geomatics Yukon via online source (www.geomaticsyukon.ca) NAD 1983 Yukon Albers 1:150,000 Drawn by: CEB Checked by: RM 08/08/2016

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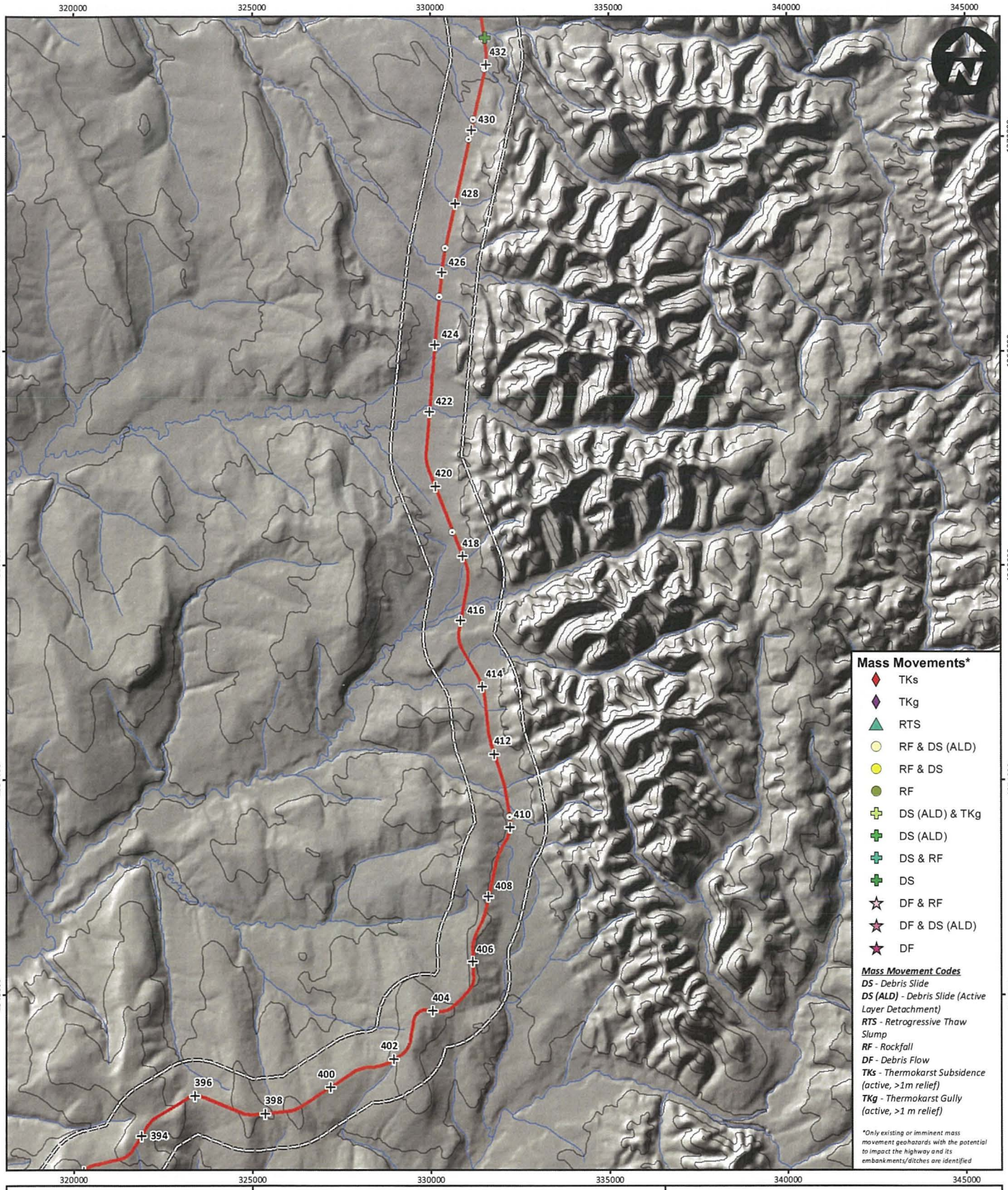


Km
0 1 2 4 6

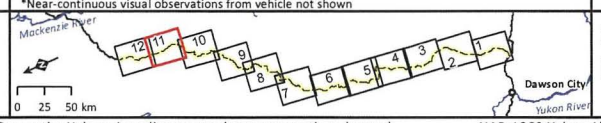
KRYOTEK

PALMER ENVIRONMENTAL CONSULTING GROUP INC.

Legend

- Territorial Boundary
- Watercourses
- 100m contours
- Highways
- Study Corridor
- Dempster Highway (Yukon)
- Waterbodies
- Highway Kilometre Posts
- Field Inspection Sites*

*Near-continuous visual observations from vehicle not shown



Project Number: 14132

Title: Geohazard Investigation
Dempster Highway #5

Distribution and Classification of Mass Movement Geohazards

Figure D-11

Digital Elevation Model and base data provided by Geomatics Yukon via online source (www.geomaticsyukon.ca) NAD 1983 Yukon Albers 1:150,000 Drawn by: CEB Checked by: RM 08/08/2016

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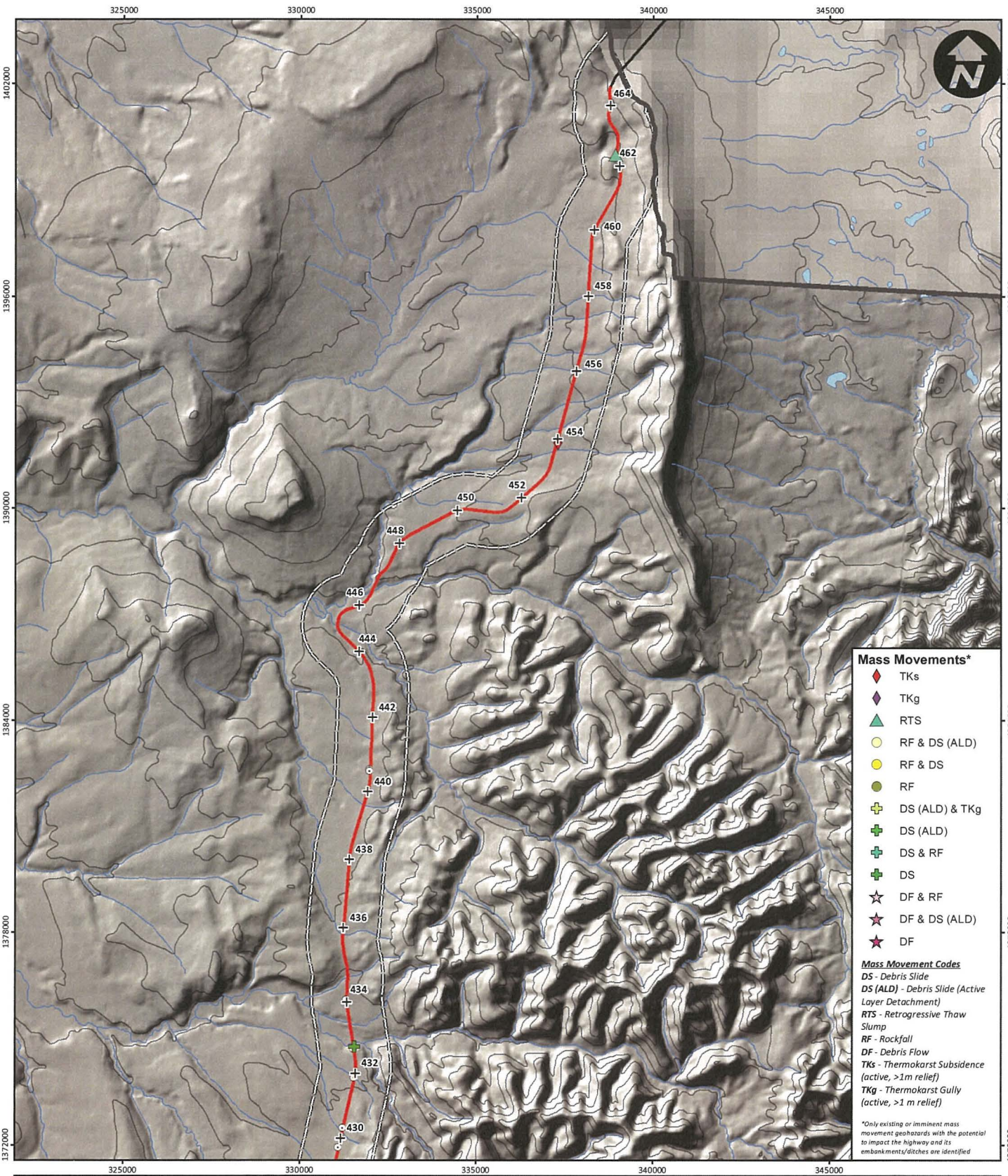


Km
0 1 2 4 6

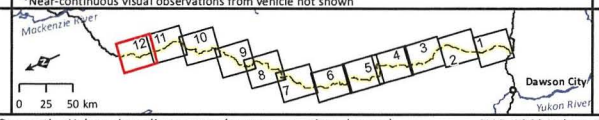
KRYOTEK

PALMER ENVIRONMENTAL CONSULTING GROUP INC.

Legend

- Territorial Boundary
- Highways
- Waterbodies
- Watercourses
- Study Corridor
- Highway Kilometre Posts
- 100m contours
- Dempster Highway (Yukon)
- Field Inspection Sites*

*Near-continuous visual observations from vehicle not shown



Project Number: 14132

Title: Geohazard Investigation
Dempster Highway #5

Distribution and Classification of Mass Movement Geohazards

Figure D-12

Digital Elevation Model and base data provided by Geomatics Yukon via online source (www.geomaticsyukon.ca) NAD 1983 Yukon Albers 1:150,000 Drawn by: CEB Checked by: RM 08/08/2016

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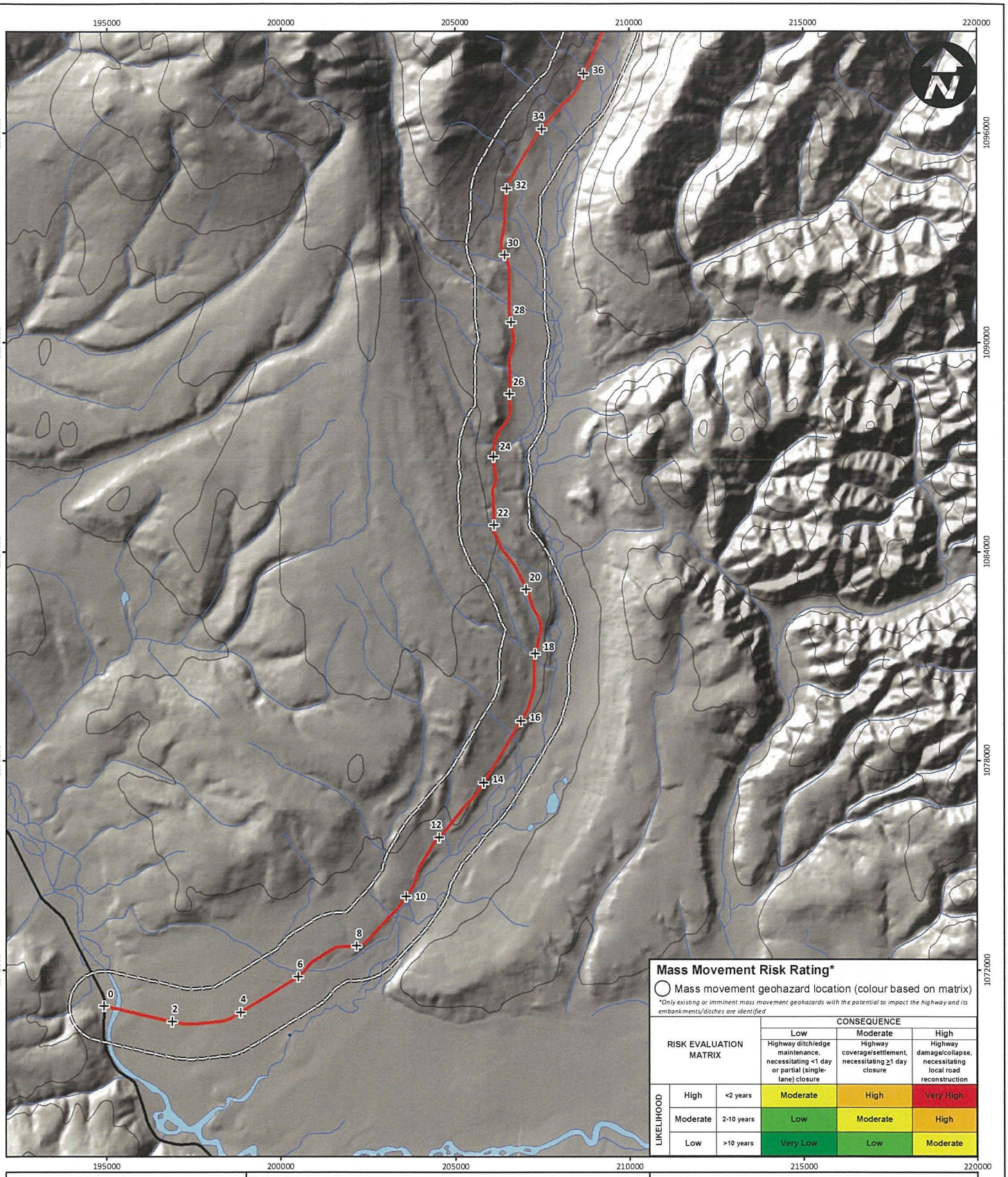

Mass Movement Risk Rating*

Mass movement geohazard location (colour based on matrix)

*Only existing or imminent mass movement geohazards with the potential to impact the highway and its embankments/ditches are identified

RISK EVALUATION MATRIX			CONSEQUENCE		
			Low	Moderate	High
			Highway ditch/edge maintenance, necessitating <1 day or partial (single-lane) closure	Highway coverage/settlement, necessitating ≥1 day closure	Highway damage/collapse, necessitating local road reconstruction
LIKELIHOOD	High	<2 years	Moderate	High	Very High
	Moderate	2-10 years	Low	Moderate	High
	Low	>10 years	Very Low	Low	Moderate

0 1 2 4 6 Km

Legend

- Territorial Boundary
- Watercourses
- 100 m contours
- Highways
- Study Corridor
- Dempster Highway (Yukon)
- Waterbodies
- Highway Kilometre Posts

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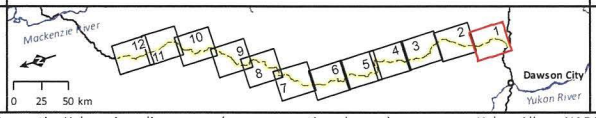

Project Number: 14132

Title: Geohazard Investigation Dempster Highway #5

Distribution and Risk of Mass Movement Geohazards

Figure E-1

Digital Elevation Model and base data provided by Geomatics Yukon via online source (www.geomaticsyukon.ca) Yukon Albers NAD83 1:150,000 Drawn by: CEB Checked by: RM 08/08/2016

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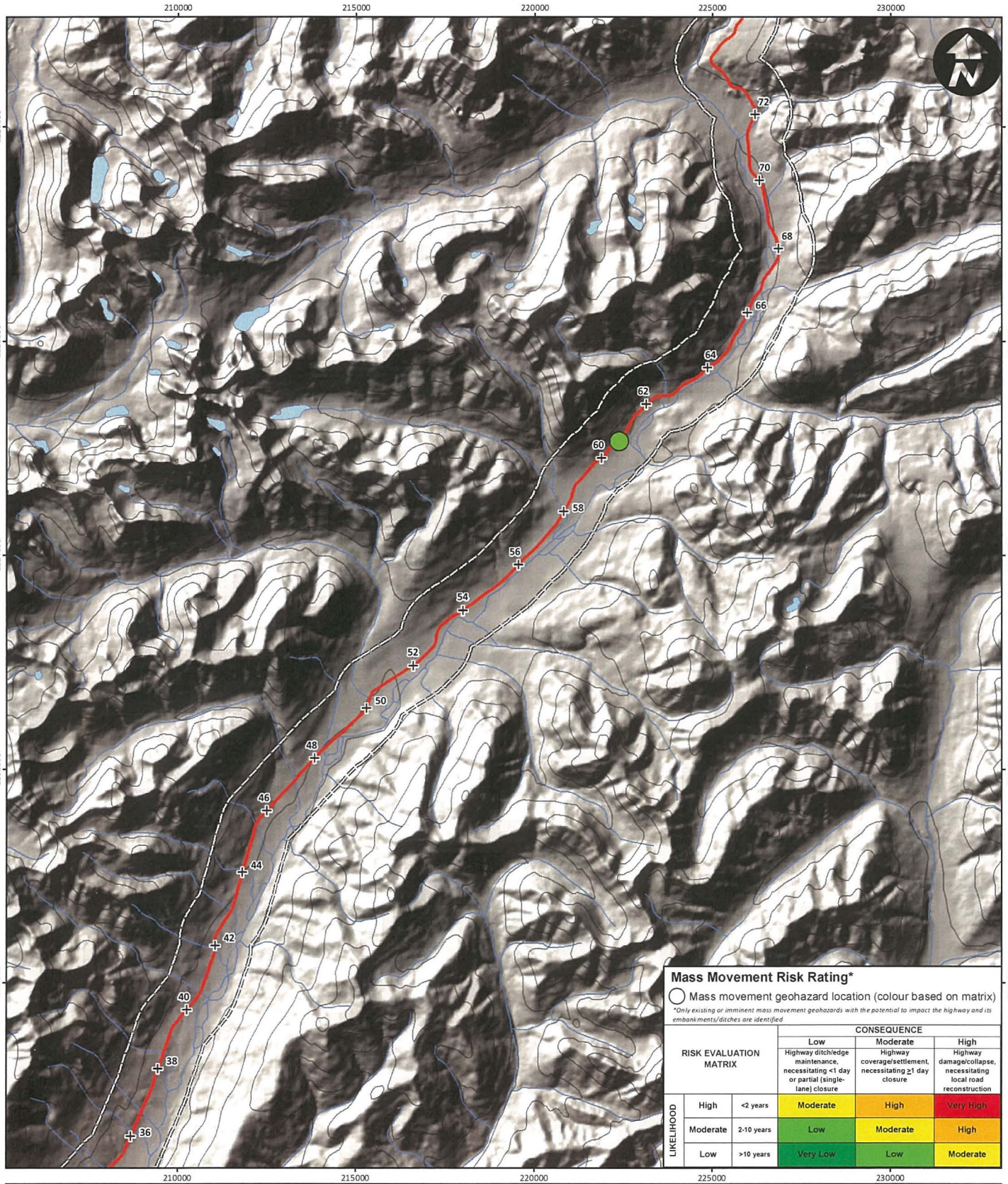

Mass Movement Risk Rating*

Mass movement geohazard location (colour based on matrix)

*Only existing or imminent mass movement geohazards with the potential to impact the highway and its embankments/ditches are identified

RISK EVALUATION MATRIX			CONSEQUENCE		
			Low	Moderate	High
			Highway ditch/edge maintenance, necessitating <1 day or partial (single-lane) closure	Highway coverage/settlement, necessitating ≥1 day closure	Highway damage/collapse, necessitating local road reconstruction
LIKELIHOOD	High	<2 years	Moderate	High	Very High
	Moderate	2-10 years	Low	Moderate	High
	Low	>10 years	Very Low	Low	Moderate

0 1 2 4 6 Km

Legend

- Territorial Boundary
- Watercourses
- 100 m contours
- Highways
- Study Corridor
- Dempster Highway (Yukon)
- Waterbodies
- Highway Kilometre Posts

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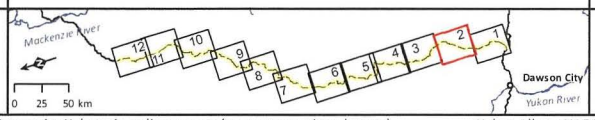
PALMER ENVIRONMENTAL CONSULTING GROUP INC.



Project Number: 14132

Title: Geohazard Investigation
Dempster Highway #5

Distribution and Risk of Mass Movement Geohazards

Figure E-2

Digital Elevation Model and base data provided by Geomatics Yukon via online source (www.geomaticsyukon.ca) Yukon Albers NAD83 1:150,000 Drawn by: CEB Checked by: RM 08/08/2016

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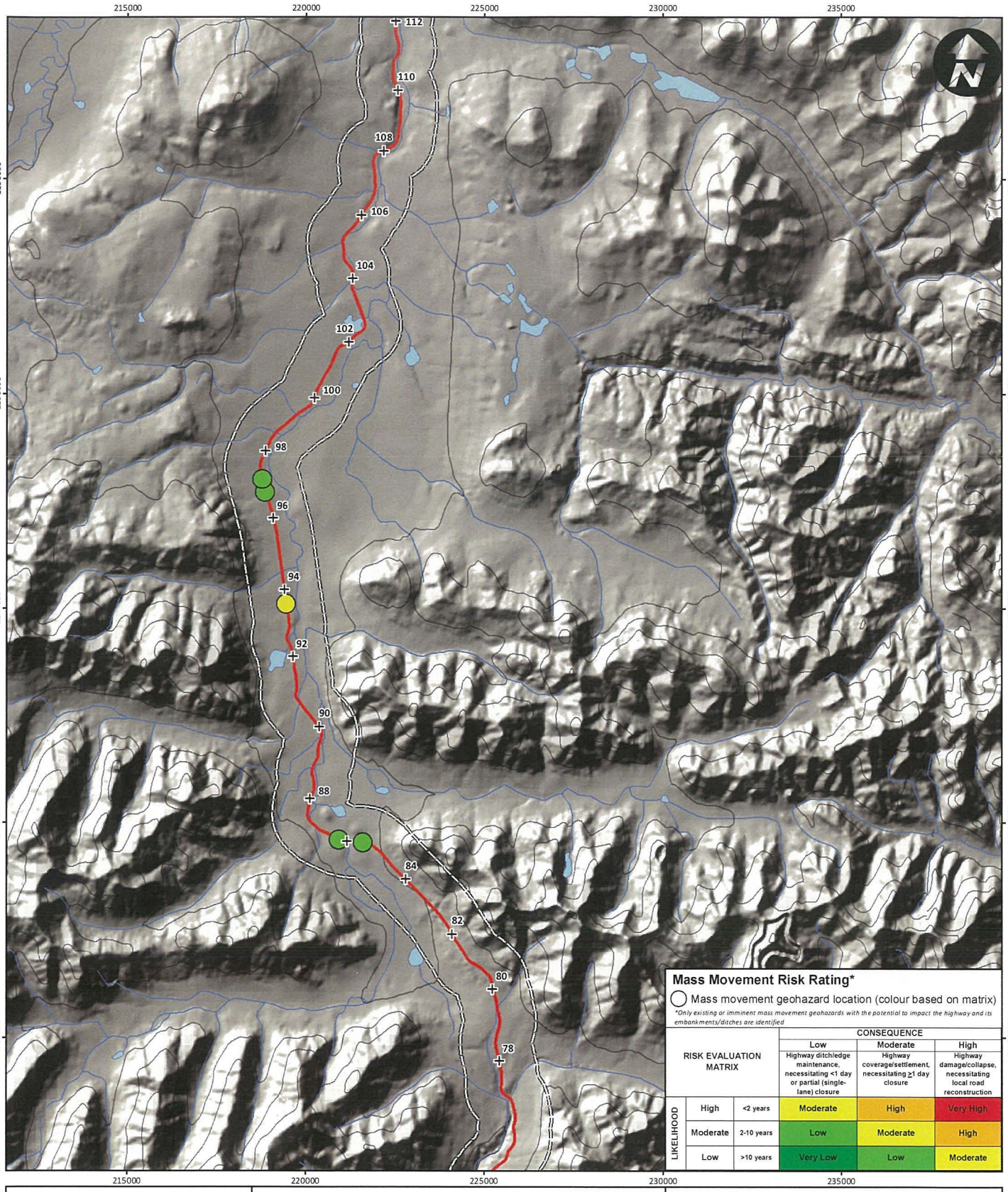


Mass Movement Risk Rating*

Mass movement geohazard location (colour based on matrix)

*Only existing or imminent mass movement geohazards with the potential to impact the highway and its embankments/ditches are identified

RISK EVALUATION MATRIX			CONSEQUENCE		
			Low	Moderate	High
			Highway ditch/edge maintenance, necessitating <1 day or partial (single-lane) closure	Highway coverage/settlement, necessitating ≥1 day closure	Highway damage/collapse, necessitating local road reconstruction
LIKELIHOOD	High	<2 years	Moderate	High	Very High
	Moderate	2-10 years	Low	Moderate	High
	Low	>10 years	Very Low	Low	Moderate

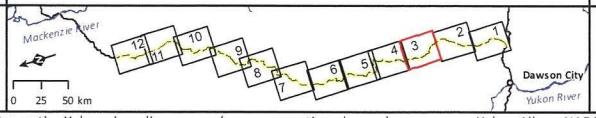
0 1 2 4 6 Km

Legend

- Territorial Boundary
- Watercourses
- 100 m contours
- Highways
- Study Corridor
- Dempster Highway (Yukon)
- Waterbodies
- Highway Kilometre Posts

KRYOTEK

PALMER ENVIRONMENTAL CONSULTING GROUP INC.



Project Number: 14132

Title: Geohazard Investigation Dempster Highway #5

Distribution and Risk of Mass Movement Geohazards

Figure E-3

Digital Elevation Model and base data provided by Geomatics Yukon via online source (www.geomaticsyukon.ca) Yukon Albers NAD83 1:150,000 Drawn by: CEB Checked by: RM 08/08/2016

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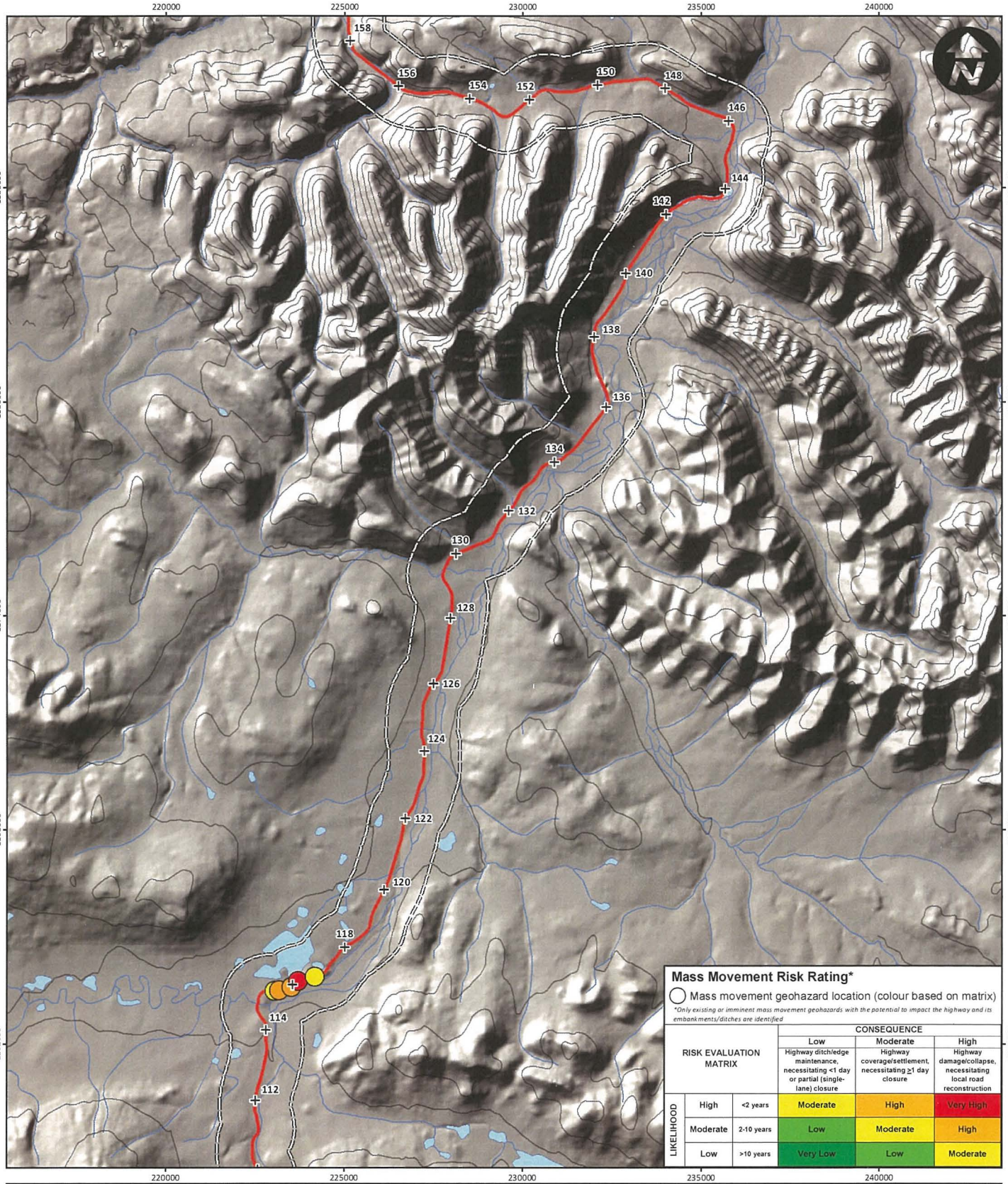

Mass Movement Risk Rating*

Mass movement geohazard location (colour based on matrix)

*Only existing or imminent mass movement geohazards with the potential to impact the highway and its embankments/ditches are identified

RISK EVALUATION MATRIX			CONSEQUENCE		
			Low: Highway ditch/edge maintenance, necessitating <1 day or partial (single-lane) closure	Moderate: Highway coverage/settlement, necessitating ≥1 day closure	High: Highway damage/collapse, necessitating local road reconstruction
LIKELIHOOD	High	<2 years	Moderate	High	Very High
	Moderate	2-10 years	Low	Moderate	High
	Low	>10 years	Very Low	Low	Moderate

0 1 2 4 6 Km

Legend

- Territorial Boundary
- Watercourses
- 100 m contours
- Highways
- Study Corridor
- Dempster Highway (Yukon)
- Waterbodies
- Highway Kilometre Posts

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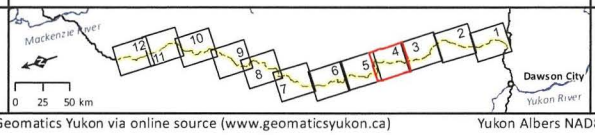

Project Number: 14132

Title: Geohazard Investigation Dempster Highway #5

Distribution and Risk of Mass Movement Geohazards

Figure E-4

Digital Elevation Model and base data provided by Geomatics Yukon via online source (www.geomaticsyukon.ca) Yukon Albers NAD83 1:150,000 Drawn by: CEB Checked by: RM 08/08/2016

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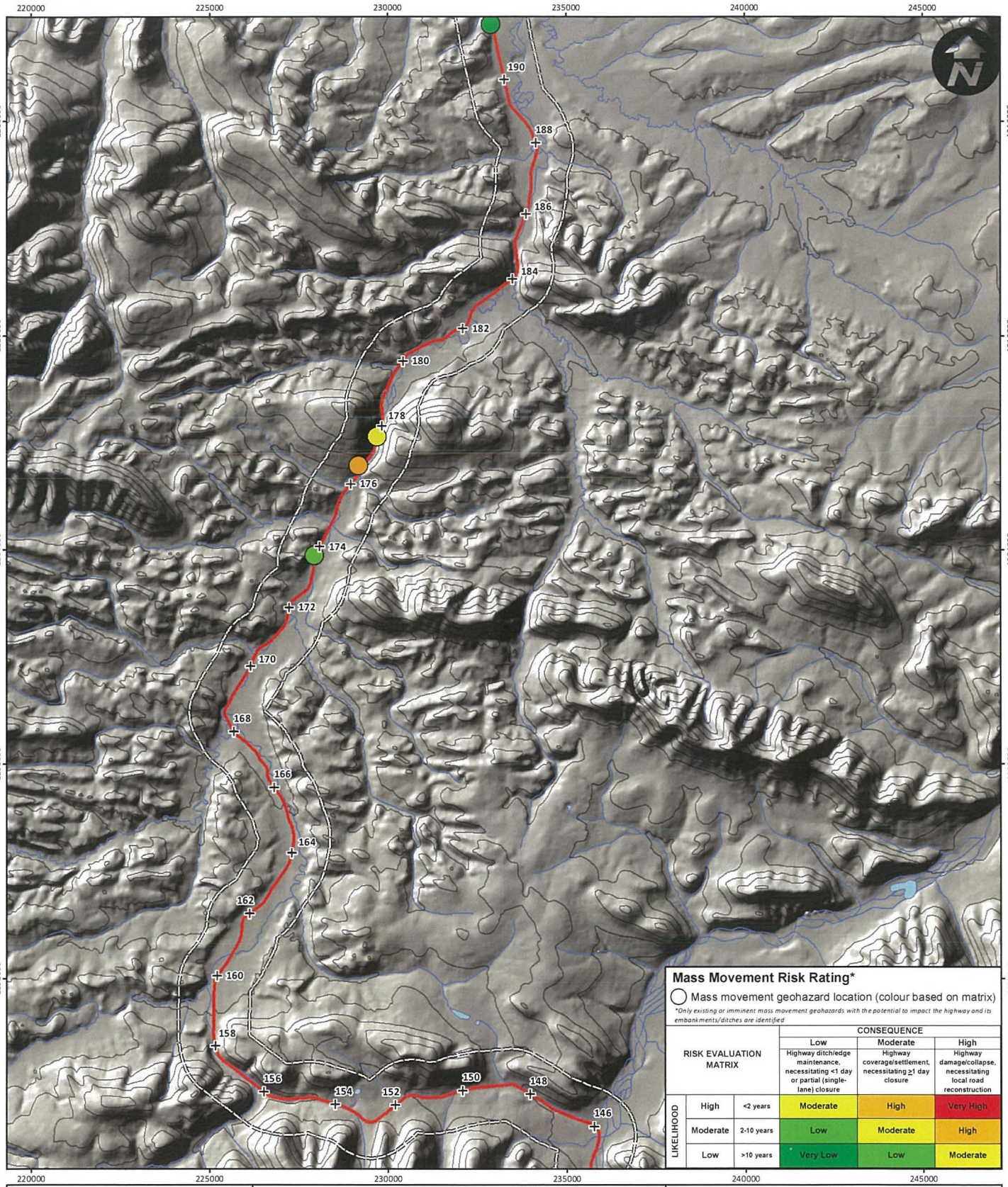


Mass Movement Risk Rating*

Mass movement geohazard location (colour based on matrix)

*Only existing or imminent mass movement geohazards with the potential to impact the highway and its embankments/ditches are identified

RISK EVALUATION MATRIX			CONSEQUENCE		
			Low	Moderate	High
			Highway ditch/edge maintenance, necessitating <1 day or partial (single-lane) closure	Highway coverage/settlement, necessitating ≥1 day closure	Highway damage/collapse, necessitating local road reconstruction
LIKELIHOOD	High	<2 years	Moderate	High	Very High
	Moderate	2-10 years	Low	Moderate	High
	Low	>10 years	Very Low	Low	Moderate

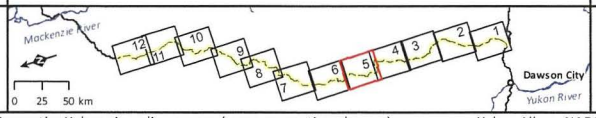
0 1 2 4 6 Km

Legend

- Territorial Boundary
- Watercourses
- 100 m contours
- Highways
- Study Corridor
- Dempster Highway (Yukon)
- Waterbodies
- Highway Kilometre Posts

KRYOTEK

PALMER ENVIRONMENTAL CONSULTING GROUP INC.



Project Number: 14132

Title: Geohazard Investigation Dempster Highway #5

Distribution and Risk of Mass Movement Geohazards

Figure E-5

Digital Elevation Model and base data provided by Geomatics Yukon via online source (www.geomaticsyukon.ca) Yukon Albers NAD83 1:150,000 Drawn by: CEB Checked by: RM 08/08/2016

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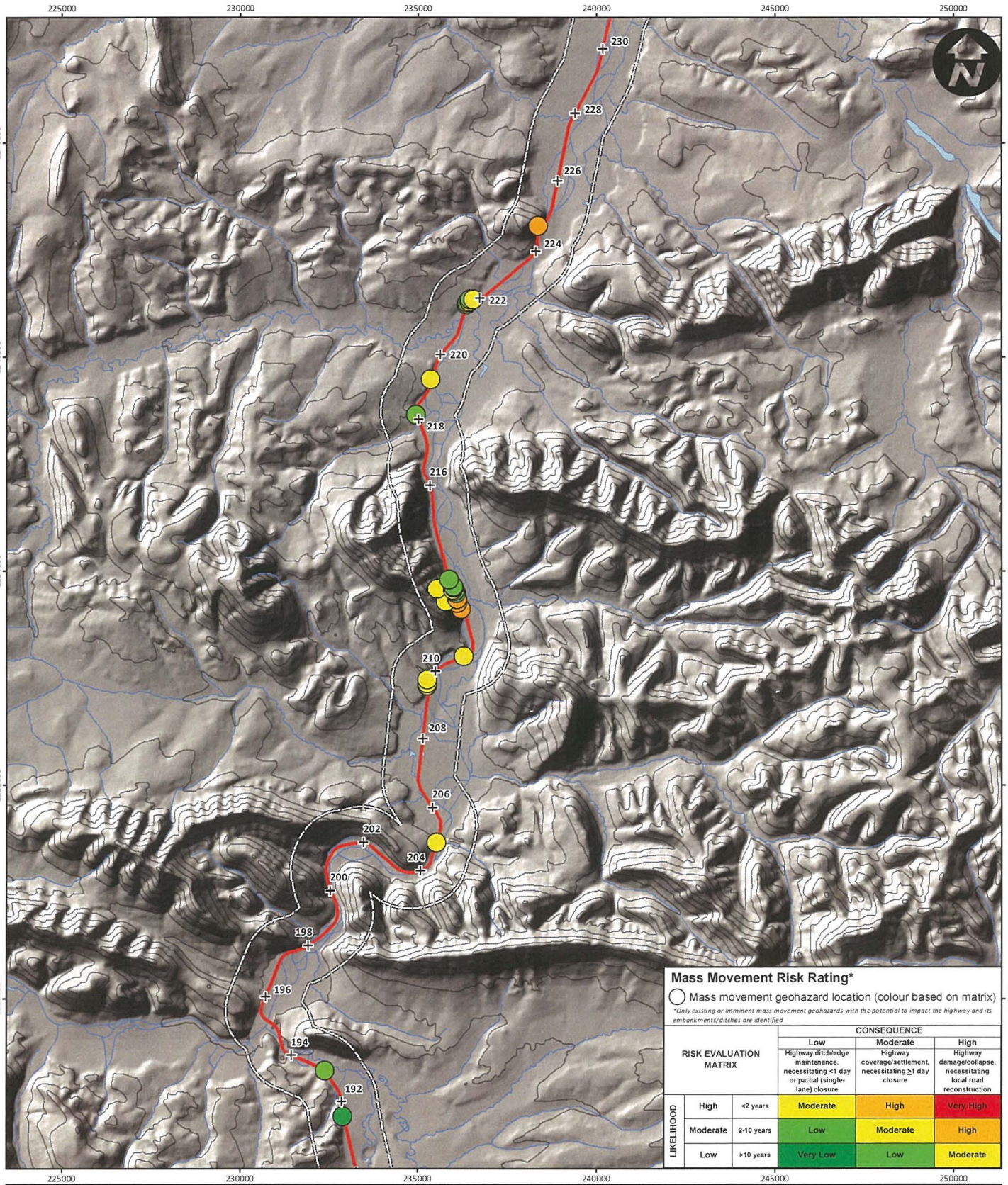

Mass Movement Risk Rating*

Mass movement geohazard location (colour based on matrix)

*Only existing or imminent mass movement geohazards with the potential to impact the highway and its embankments/ditches are identified

RISK EVALUATION MATRIX			CONSEQUENCE		
			Low	Moderate	High
			Highway ditch/edge maintenance, necessitating <1 day or partial (single-lane) closure	Highway coverage/settlement, necessitating ≥1 day closure	Highway damage/collapse, necessitating local road reconstruction
LIKELIHOOD	High	<2 years	Moderate	High	Very High
	Moderate	2-10 years	Low	Moderate	High
	Low	>10 years	Very Low	Low	Moderate

0 1 2 4 6 Km

Legend

- Territorial Boundary
- Watercourses
- 100 m contours
- Highways
- Study Corridor
- Dempster Highway (Yukon)
- Waterbodies
- Highway Kilometre Posts

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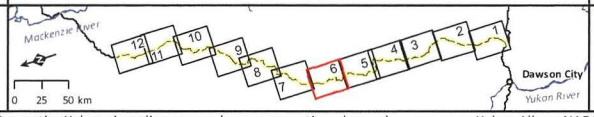

Project Number: 14132

Title: Geohazard Investigation Dempster Highway #5

Distribution and Risk of Mass Movement Geohazards

Figure E-6

Digital Elevation Model and base data provided by Geomatics Yukon via online source (www.geomaticsyukon.ca) Yukon Albers NAD83 1:150,000 Drawn by: CEB Checked by: RM 08/08/2016

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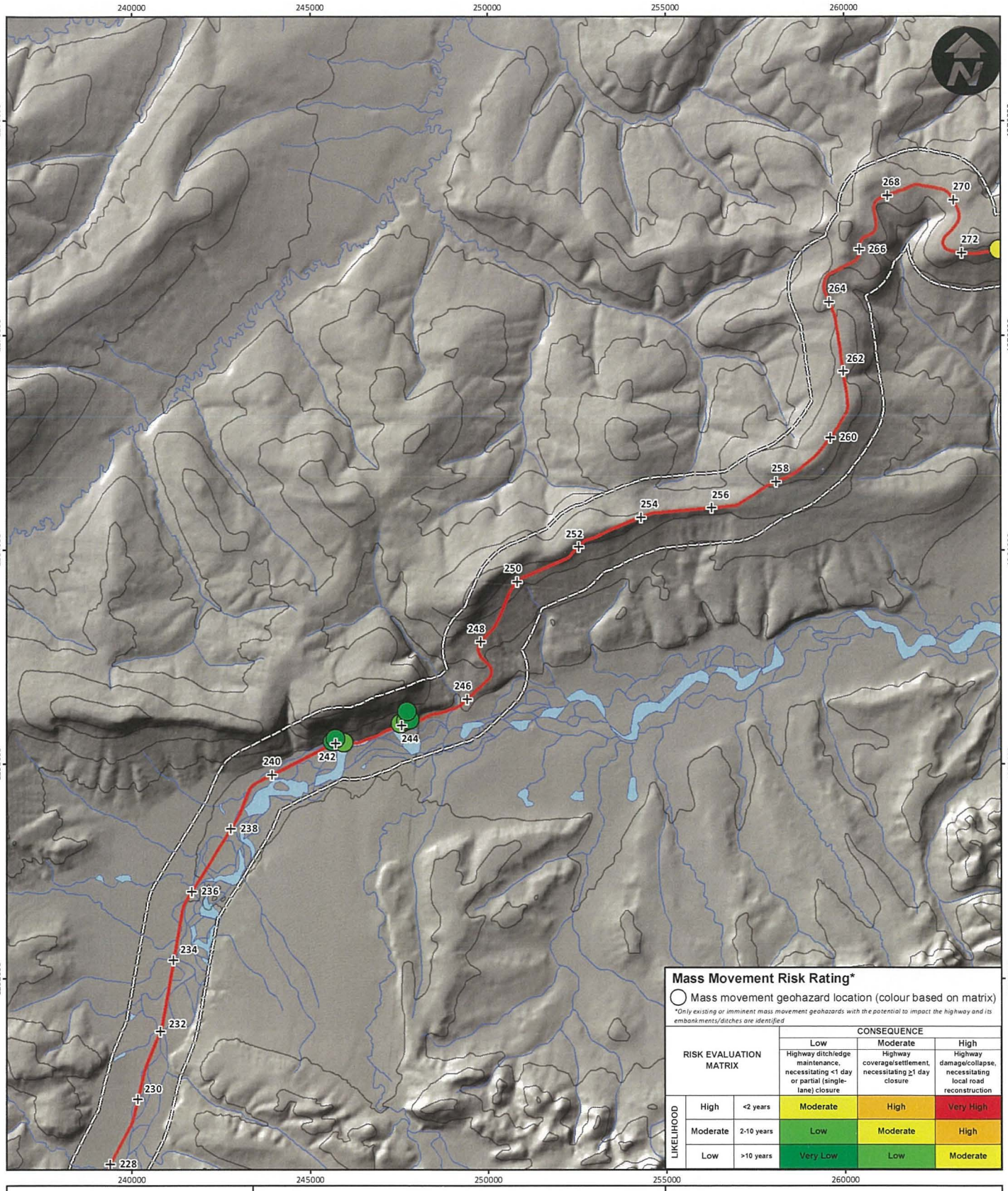

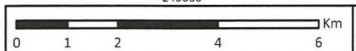

Legend

Territorial Boundary
Watercourses
100 m contours
Highways
Study Corridor
Dempster Highway (Yukon)
Waterbodies
Highway Kilometre Posts

KRYOTEK

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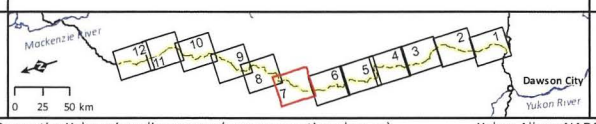

Project Number: 14132

Title: Geohazard Investigation
Dempster Highway #5

Distribution and Risk of Mass Movement Geohazards

Figure E-7

Digital Elevation Model and base data provided by Geomatics Yukon via online source (www.geomaticsyukon.ca) Yukon Albers NAD83 1:150,000 Drawn by: CEB Checked by: RM 08/08/2016

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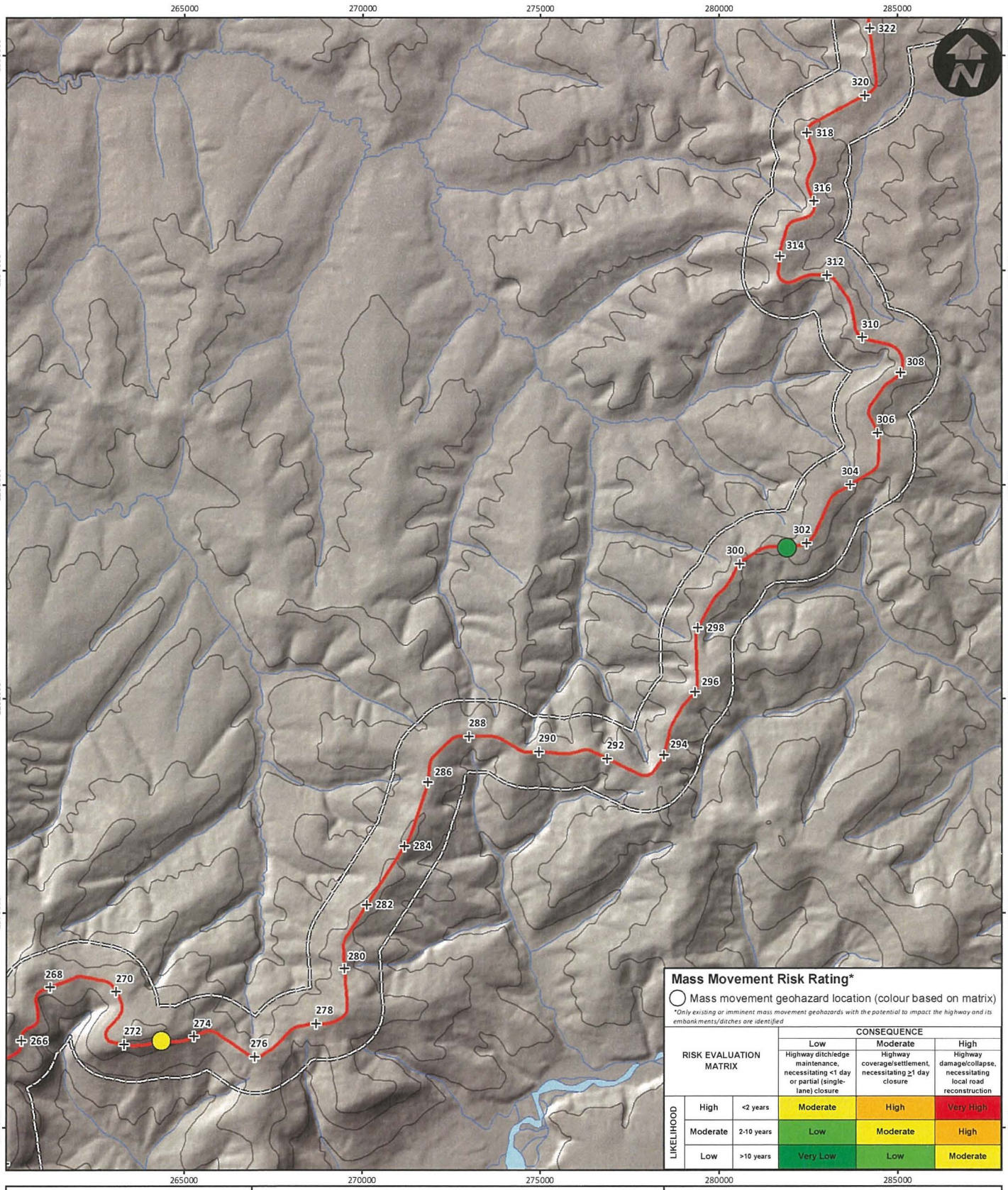

Mass Movement Risk Rating*

Mass movement geohazard location (colour based on matrix)

*Only existing or imminent mass movement geohazards with the potential to impact the highway and its embankments/ditches are identified

RISK EVALUATION MATRIX			CONSEQUENCE		
			Low	Moderate	High
			Highway ditch/edge maintenance, necessitating <1 day or partial (single-lane) closure	Highway coverage/settlement, necessitating ≥1 day closure	Highway damage/collapse, necessitating local road reconstruction
LIKELIHOOD	High	<2 years	Moderate	High	Very High
	Moderate	2-10 years	Low	Moderate	High
	Low	>10 years	Very Low	Low	Moderate

0 1 2 4 6 Km

Legend

- Territorial Boundary
- Watercourses
- 100 m contours
- Highways
- Study Corridor
- Dempster Highway (Yukon)
- Waterbodies
- Highway Kilometre Posts

KRYOTEK

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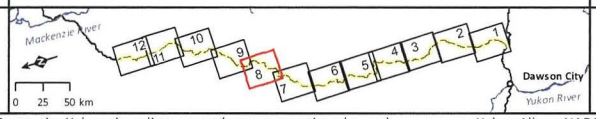

Project Number: 14132

Title: Geohazard Investigation Dempster Highway #5

Distribution and Risk of Mass Movement Geohazards

Figure E-8

Digital Elevation Model and base data provided by Geomatics Yukon via online source (www.geomaticsyukon.ca) Yukon Albers NAD83 1:150,000 Drawn by: CEB Checked by: RM 08/08/2016

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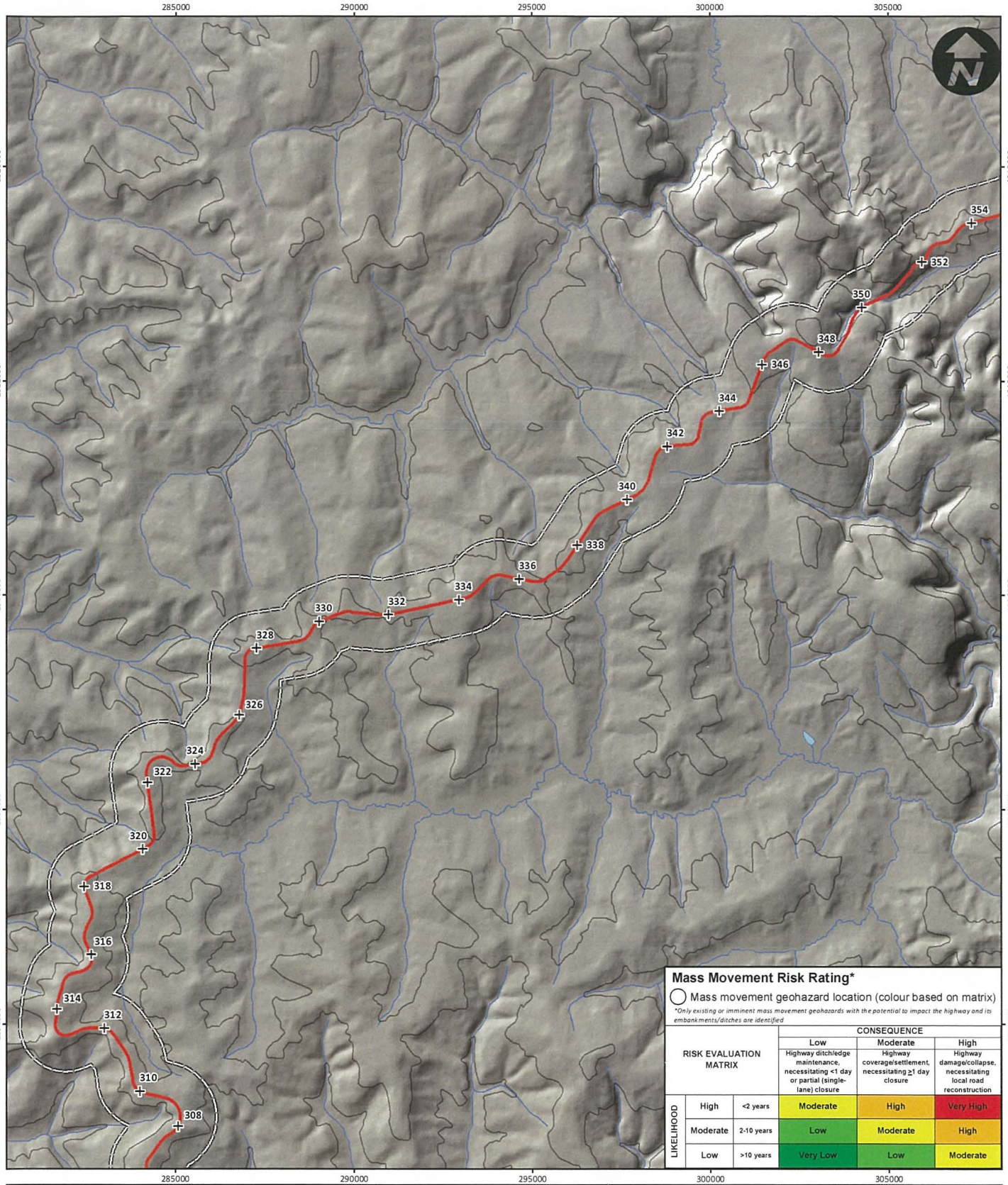

Mass Movement Risk Rating*

Mass movement geohazard location (colour based on matrix)

*Only existing or imminent mass movement geohazards with the potential to impact the highway and its embankments/ditches are identified

RISK EVALUATION MATRIX			CONSEQUENCE		
			Low: Highway ditch/edge maintenance, necessitating <1 day or partial (single-lane) closure	Moderate: Highway coverage/settlement, necessitating ≥1 day closure	High: Highway damage/collapse, necessitating local road reconstruction
LIKELIHOOD	High	<2 years	Moderate	High	Very High
	Moderate	2-10 years	Low	Moderate	High
	Low	>10 years	Very Low	Low	Moderate

0 1 2 4 6 Km

Legend

- Territorial Boundary
- Watercourses
- 100 m contours
- Highways
- Study Corridor
- Dempster Highway (Yukon)
- Waterbodies
- Highway Kilometre Posts

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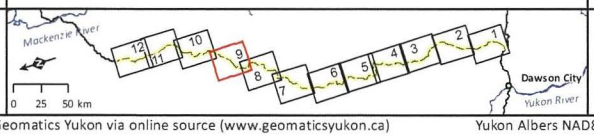

Project Number: 14132

Title: Geohazard Investigation
Dempster Highway #5

Distribution and Risk of Mass Movement Geohazards

Figure E-9

Digital Elevation Model and base data provided by Geomatics Yukon via online source (www.geomaticsyukon.ca) Yukon Albers NAD83 1:150,000 Drawn by: CEB Checked by: RM 08/08/2016

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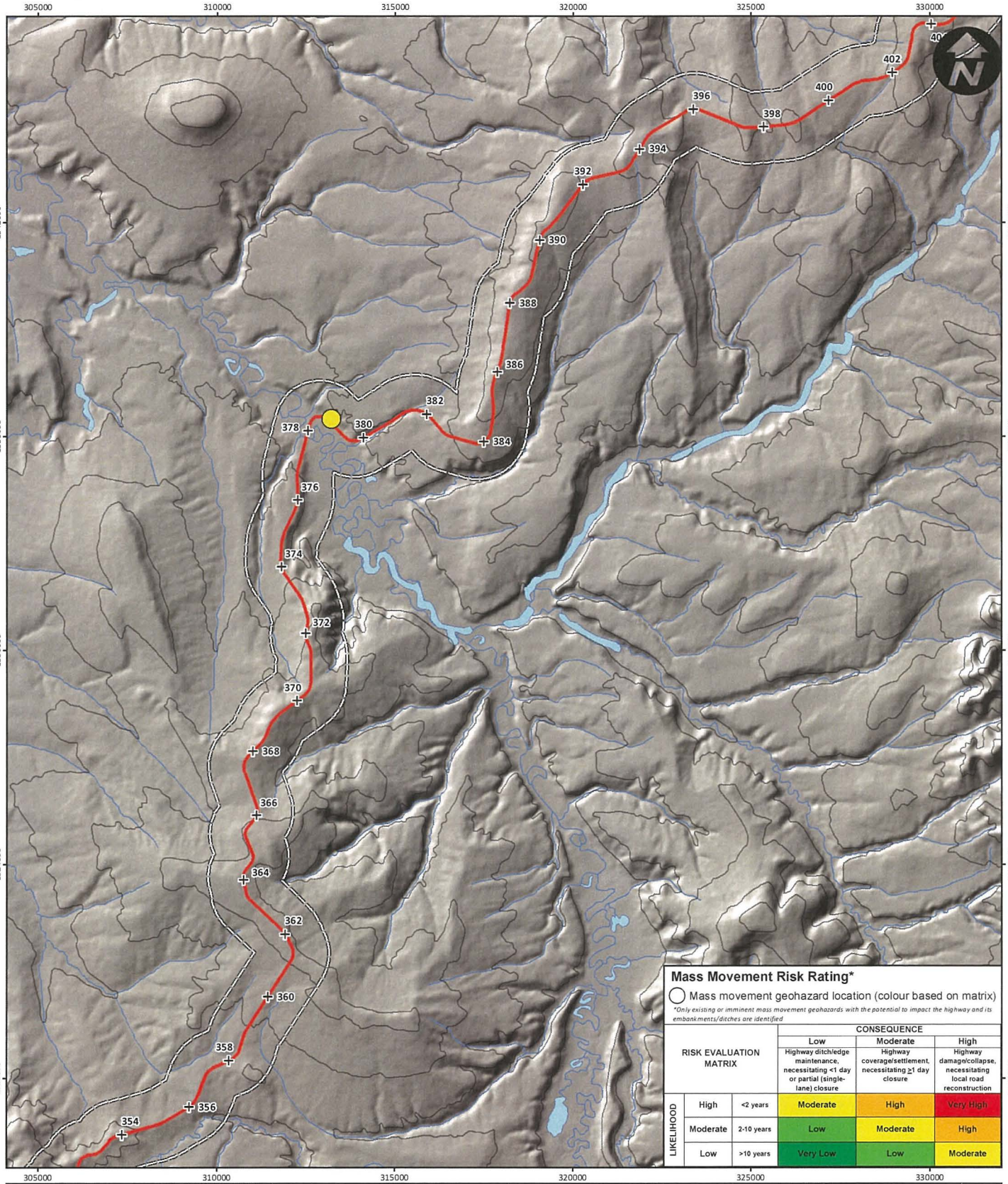


Mass Movement Risk Rating*

Mass movement geohazard location (colour based on matrix)

*Only existing or imminent mass movement geohazards with the potential to impact the highway and its embankments/ditches are identified

RISK EVALUATION MATRIX			CONSEQUENCE		
			Low	Moderate	High
			Highway ditch/edge maintenance, necessitating <1 day or partial (single-lane) closure	Highway coverage/settlement, necessitating ≥1 day closure	Highway damage/collapse, necessitating local road reconstruction
LIKELIHOOD	High	<2 years	Moderate	High	Very High
	Moderate	2-10 years	Low	Moderate	High
	Low	>10 years	Very Low	Low	Moderate

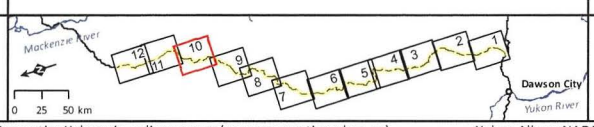
0 1 2 4 6 Km

Legend

- Territorial Boundary
- Watercourses
- 100 m contours
- Highways
- Study Corridor
- Dempster Highway (Yukon)
- Waterbodies
- Highway Kilometre Posts

KRYOTEK

PALMER ENVIRONMENTAL CONSULTING GROUP INC.



Project Number: 14132

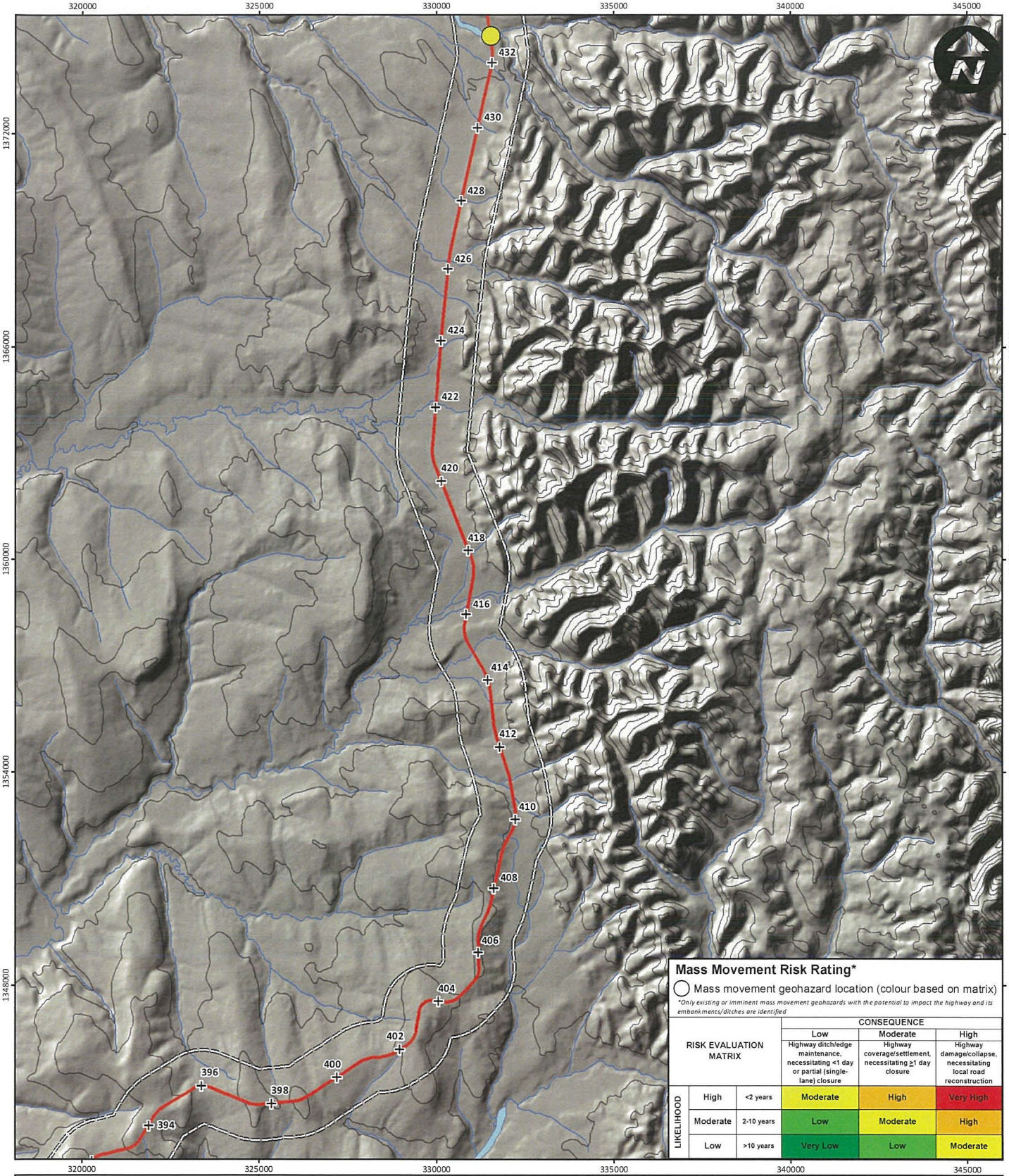
Title: Geohazard Investigation
Dempster Highway #5

Distribution and Risk of Mass Movement Geohazards

Figure E-10

Digital Elevation Model and base data provided by Geomatics Yukon via online source (www.geomaticsyukon.ca) Yukon Albers NAD83 1:150,000 Drawn by: CEB Checked by: RM 08/08/2016

Document Path: C:\Egnyte\Shared\Projects\Active\14413 - Kryotek Arctic Innovation\14132 - Dempster Geohazards\Programs\Reports in Development\Final Report\Figures\mxdX Geohaz Risk.mxd



Mass Movement Risk Rating*

Mass movement geohazard location (colour based on matrix)

*Only existing or imminent mass movement geohazards with the potential to impact the highway and its embankments/ditches are identified

RISK EVALUATION MATRIX			CONSEQUENCE		
			Low	Moderate	High
			Highway ditch/edge maintenance, necessitating <1 day or partial (single-lane) closure	Highway coverage/settlement, necessitating ≥1 day closure	Highway damage/collapse, necessitating local road reconstruction
LIKELIHOOD	High	<2 years	Moderate	High	Very High
	Moderate	2-10 years	Low	Moderate	High
	Low	>10 years	Very Low	Low	Moderate

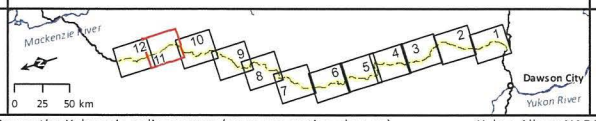
0 1 2 4 6 Km

Legend

- Territorial Boundary
- Watercourses
- 100 m contours
- Highways
- Study Corridor
- Dempster Highway (Yukon)
- Waterbodies
- Highway Kilometre Posts

KRYOTEK

PALMER ENVIRONMENTAL CONSULTING GROUP INC.



Project Number: 14132

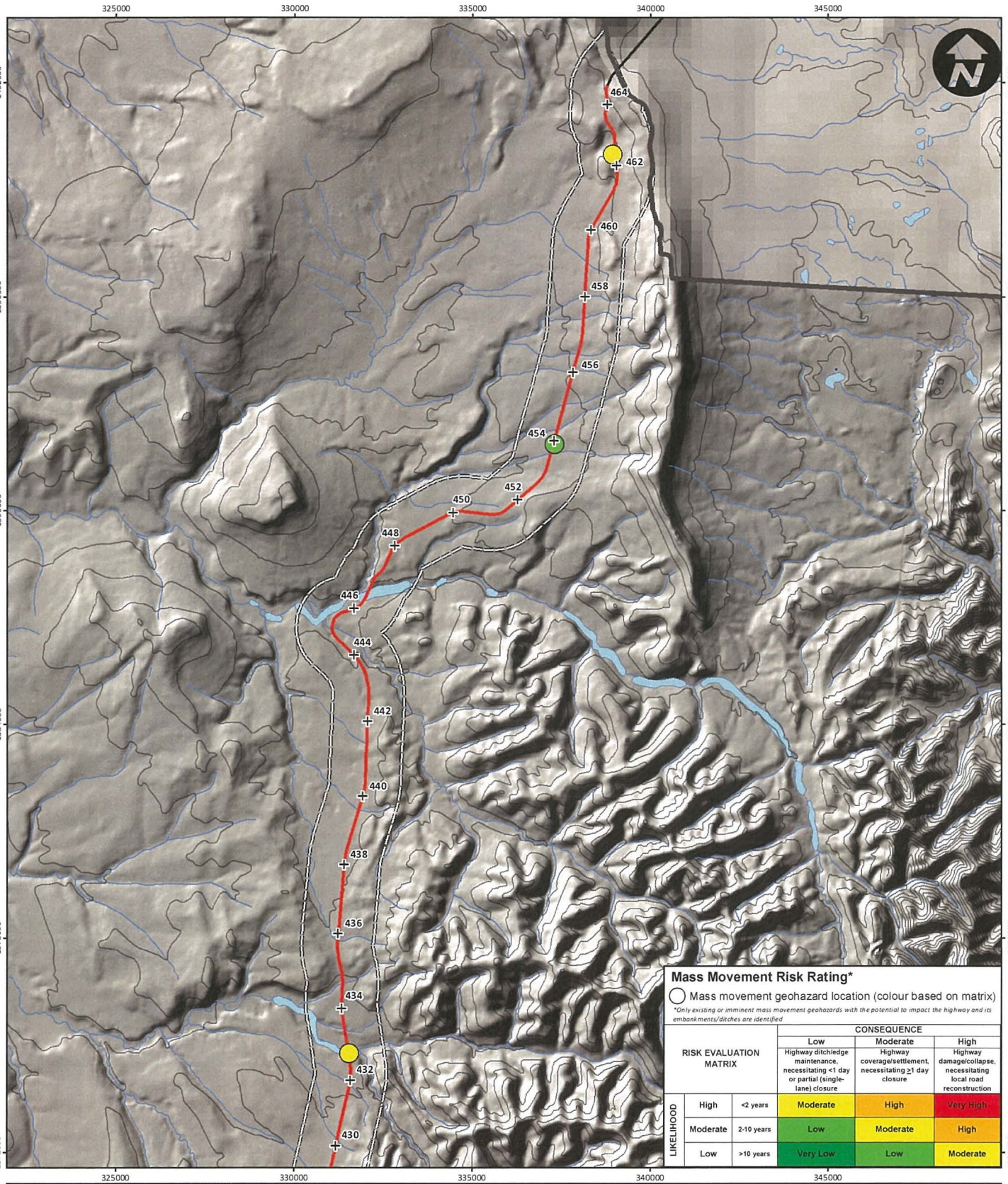
Title: Geohazard Investigation
Dempster Highway #5

Distribution and Risk of Mass Movement Geohazards

Figure E-11

Digital Elevation Model and base data provided by Geomatics Yukon via online source (www.geomaticsyukon.ca) Yukon Albers NAD83 1:150,000 Drawn by: CEB Checked by: RM 08/08/2016

Document Path: C:\Egnyte\Shared\Projects\Active\1413 - Kryotek Arctic Innovation\14132 - Dempster GeohazardsPrograms\Reports in Development\Final Report\Figures\mxd\X_Geohaz_Risk.mxd



Mass Movement Risk Rating*

Mass movement geohazard location (colour based on matrix)

*Only existing or imminent mass movement geohazards with the potential to impact the highway and its embankments/ditches are identified

RISK EVALUATION MATRIX			CONSEQUENCE		
			Low	Moderate	High
			Highway ditch/edge maintenance, necessitating <1 day or partial (single-lane) closure	Highway coverage/settlement, necessitating ≥1 day closure	Highway damage/collapse, necessitating local road reconstruction
LIKELIHOOD	High	<2 years	Moderate	High	Very High
	Moderate	2-10 years	Low	Moderate	High
	Low	>10 years	Very Low	Low	Moderate

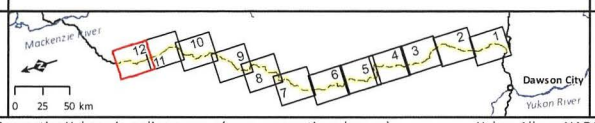
0 1 2 4 6 Km

Legend

- Territorial Boundary
- Watercourses
- 100 m contours
- Highways
- Study Corridor
- Dempster Highway (Yukon)
- Waterbodies
- Highway Kilometre Posts

KRYOTEK

PALMER ENVIRONMENTAL CONSULTING GROUP INC.



Project Number: 14132

Title: Geohazard Investigation
Dempster Highway #5

Distribution and Risk of Mass Movement Geohazards

Figure E-12

Digital Elevation Model and base data provided by Geomatics Yukon via online source (www.geomaticsyukon.ca) Yukon Albers NAD83 1:150,000 Drawn by: CEB Checked by: RM 08/08/2016

Document Path: C:\Eenvte\Shared\Projects\Active\14113 - Kryotek Arctic Innovation\14132 - Dempster Geohazards\Programs\Reports in Development\Final Report\Figures\mxd\X_Geohaz_Risk.mxd

Appendix F. Summary Results of Meander-Highway Encroachment Site Identification

Image scale 1:10,000 unless otherwise noted; contours symbolized with white lines (from 1:50,000-scale CanVec data); subject indicated by red symbol when multiple features are in view; letter codes defined in footnotes at bottom of table.

km	Section	Proximity (m)	Trajectory	Riprapped	Detailed Assessment Completed	Plan View Image (2007/2008 QuickBird Imagery from GeoYukon)
52.3	Klondike	19	WNW	N	Y – see Appendix	
53.7	Klondike	25	NW	N	N	
54.9	Klondike	7	NW	N	Y – see Appendix	

Definitions of letter codes:
Proximity (m) – approximate (±3 m) separation distance between channel bank and near edge of highway
Trajectory – N: north, E: east, S: south, W: west
Riprapped – Y: yes, N: no, P: partially
Detailed Assessment Completed – Y: yes, N: no, R: recommended

Appendix F. Summary Results of Meander-Highway Encroachment Site Identification

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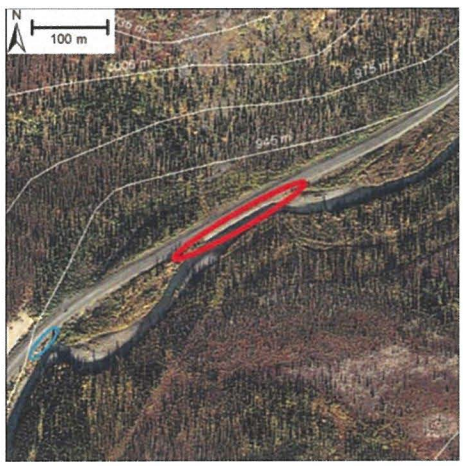
km	Section	Proximity (m)	Trajectory	Riprapped	Detailed Assessment Completed	Plan View Image (2007/2008 QuickBird Imagery from GeoYukon)
55.9	Klondike	20	NW	N	Y – see Appendix	
63.1	Klondike	10	N	N	N	
63.3	Klondike	0	NW	P	N	

Definitions of letter codes:
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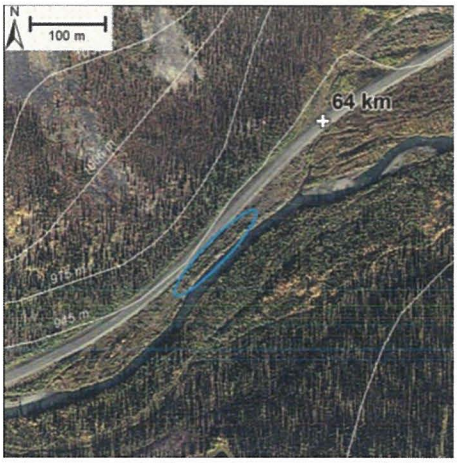
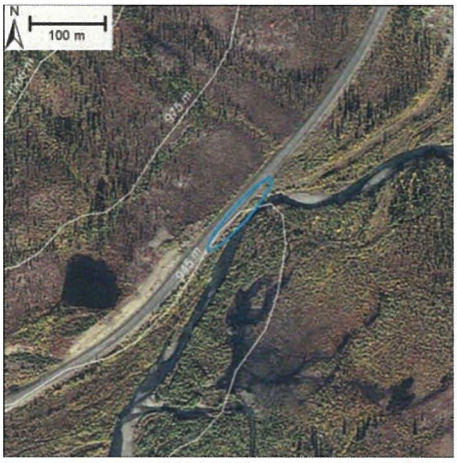
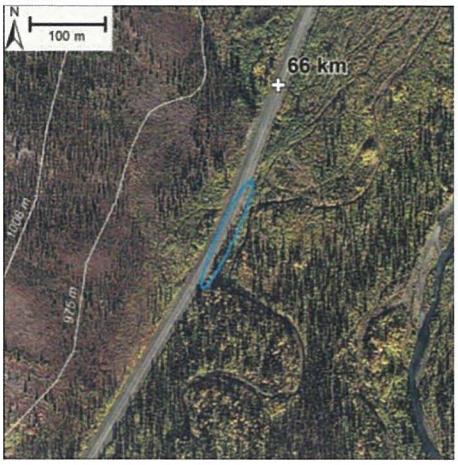
km	Section	Proximity (m)	Trajectory	Riprapped	Detailed Assessment Completed	Plan View Image (2007/2008 QuickBird Imagery from GeoYukon)
63.8	Klondike	20	N	N	N	
64.5	Klondike	10	N	N	N	
65.8	Klondike	15	WNW	N	N	

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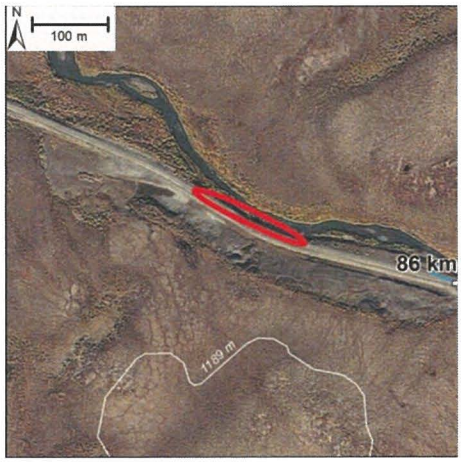
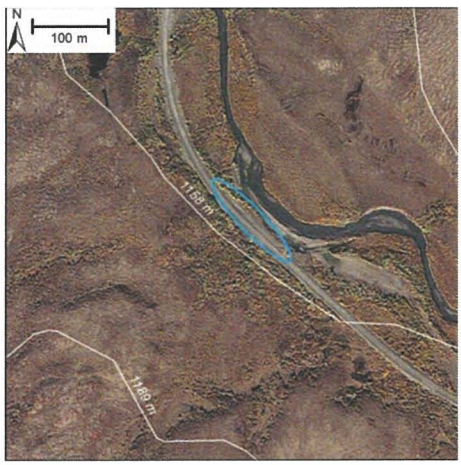
Image scale 1:10,000 unless otherwise noted; contours symbolized with white lines (from 1:50,000-scale CanVec data); subject indicated by red symbol when multiple features are in view; letter codes defined in footnotes at bottom of table.

km	Section	Proximity (m)	Trajectory	Riprapped	Detailed Assessment Completed	Plan View Image (2007/2008 QuickBird Imagery from GeoYukon)
86	Klondike	5	SSW	N	N	
86.3	Klondike	0	SW	P	N	
87.3	Klondike	15	SW	N	N	

Definitions of letter codes:
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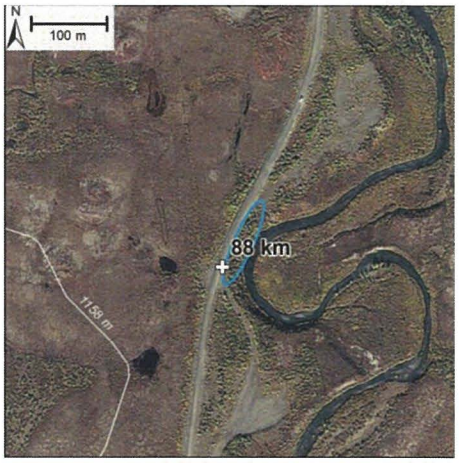
km	Section	Proximity (m)	Trajectory	Riprapped	Detailed Assessment Completed	Plan View Image (2007/2008 QuickBird Imagery from GeoYukon)
87.7	Klondike	15	W	N	N	
88	Klondike	15	WNW	N	Y – see Appendix	
103.7	Klondike	22	WSW	N	N	

Definitions of letter codes:
Proximity (m) – approximate (±3 m) separation distance between channel bank and near edge of highway
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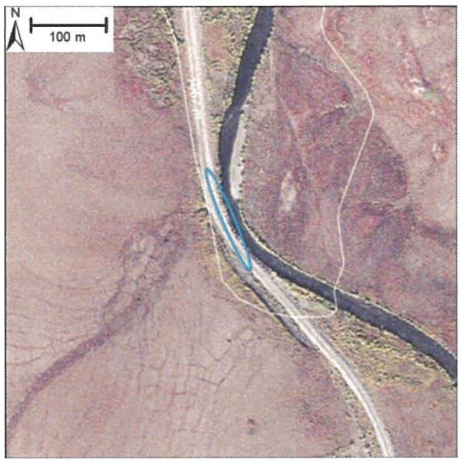
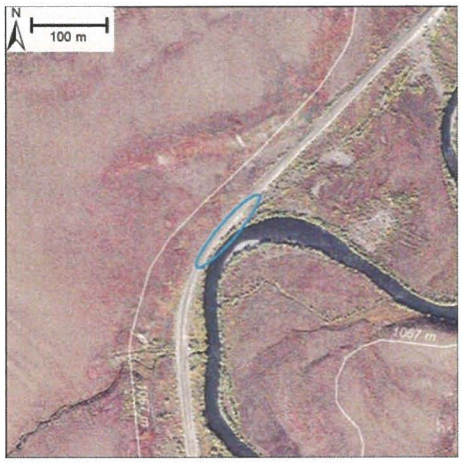
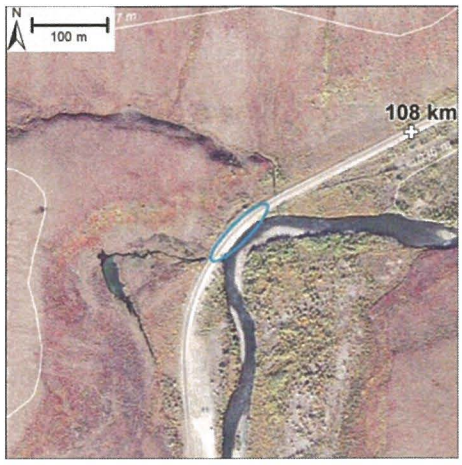
Image scale 1:10,000 unless otherwise noted; contours symbolized with white lines (from 1:50,000-scale CanVec data); subject indicated by red symbol when multiple features are in view; letter codes defined in footnotes at bottom of table.

km	Section	Proximity (m)	Trajectory	Riprapped	Detailed Assessment Completed	Plan View Image (2007/2008 QuickBird Imagery from GeoYukon)
104.6	Klondike	0	W	N	R	
105.2	Klondike	2	NNW	N	R	
107.7	Klondike	0	NW	P	R	

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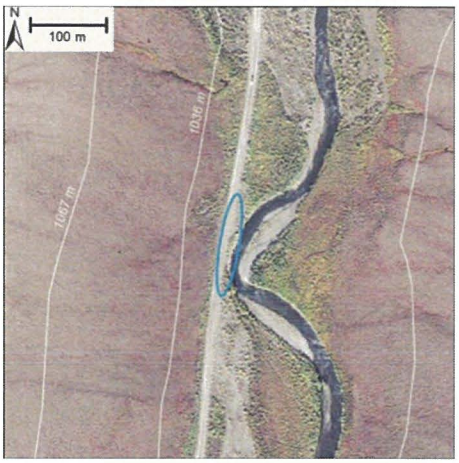
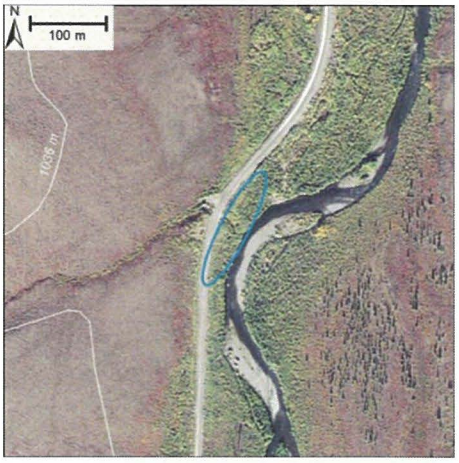
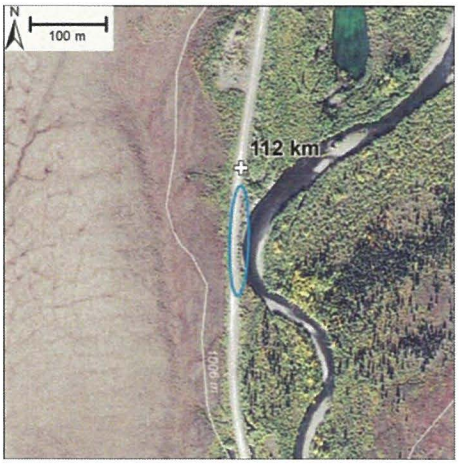
km	Section	Proximity (m)	Trajectory	Riprapped	Detailed Assessment Completed	Plan View Image (2007/2008 QuickBird Imagery from GeoYukon)
108.8	Klondike	0	W	P	R	
110.9	Klondike	21	WNW	N	N	
111.9	Klondike	0	W	N	R	

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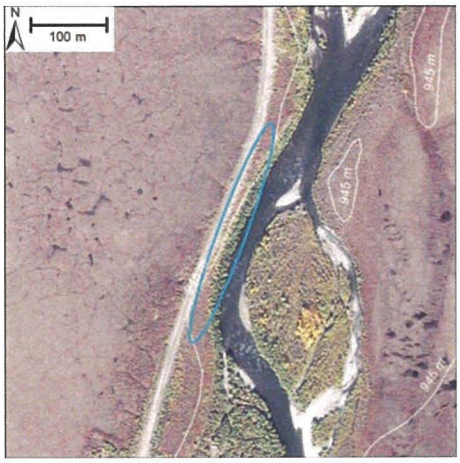
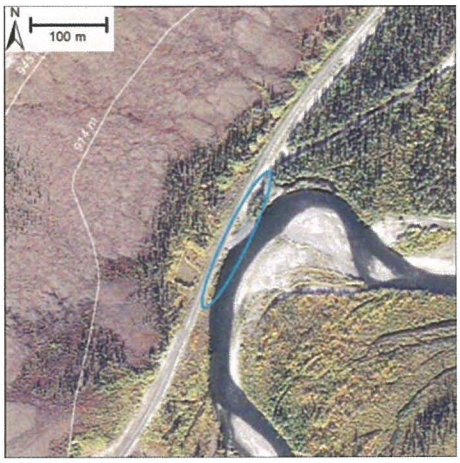
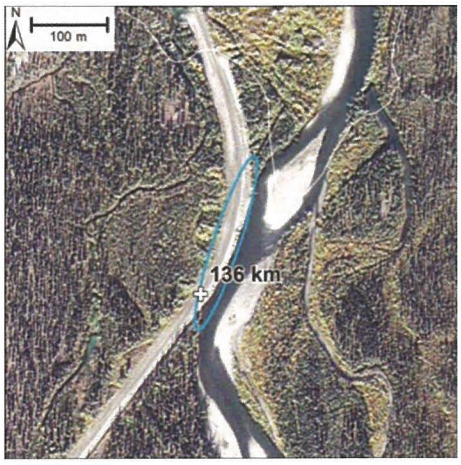
km	Section	Proximity (m)	Trajectory	Riprapped	Detailed Assessment Completed	Plan View Image (2007/2008 QuickBird Imagery from GeoYukon)
123.2	Klondike	10	WNW	N	N	
131.4	Klondike	6	WNW	P	Y – see Appendix	
136.1	Klondike	4	NW	P	Y – see Appendix	

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Appendix F. Summary Results of Meander-Highway Encroachment Site Identification

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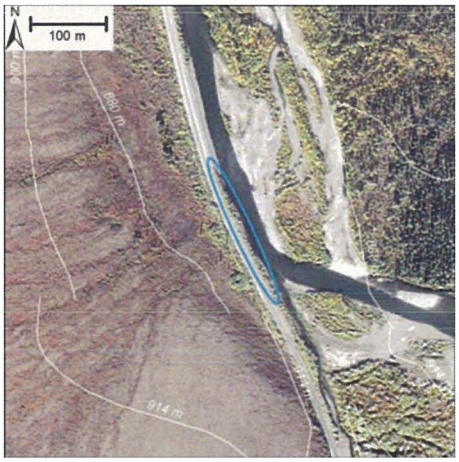
km	Section	Proximity (m)	Trajectory	Riprapped	Detailed Assessment Completed	Plan View Image (2007/2008 QuickBird Imagery from GeoYukon)
136.9	Klondike	0	W	Y	N	
138.1	Klondike	5	W	N	N	
138.5	Klondike	21	NW	N	Y – see Appendix	

Definitions of letter codes:
Proximity (m) – approximate (±3 m) separation distance between channel bank and near edge of highway
Trajectory – N: north, E: east, S: south, W: west
Riprapped – Y: yes, N: no, P: partially
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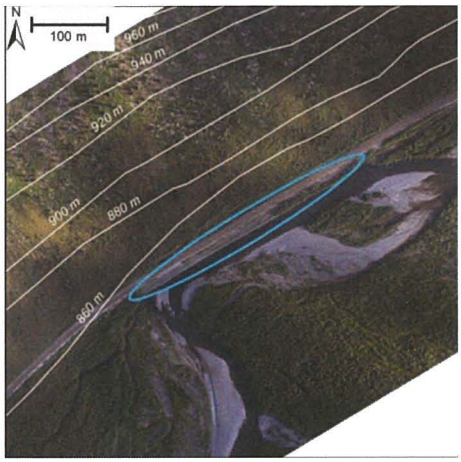
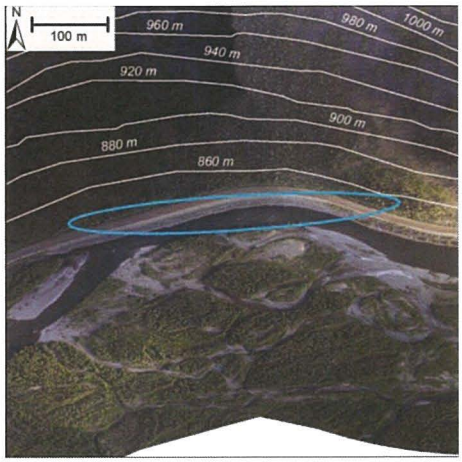
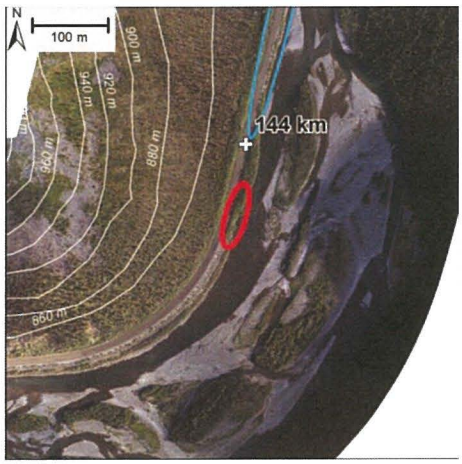
km	Section	Proximity (m)	Trajectory	Riprapped	Detailed Assessment Completed	Plan View Image (2007/2008 QuickBird Imagery from GeoYukon)
142.4	Ogilvie	0	NW	Y	N	
143	Ogilvie	0	N	Y	N	
143.9	Ogilvie	5	W	P	N	

Definitions of letter codes:
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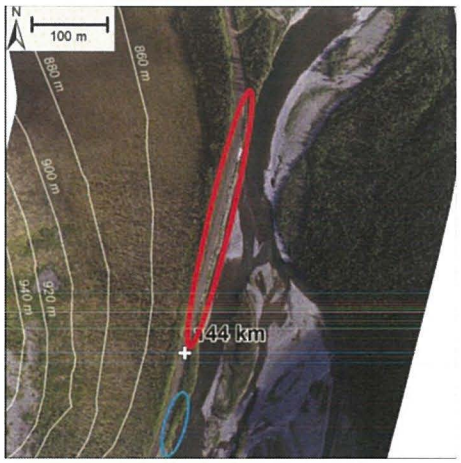
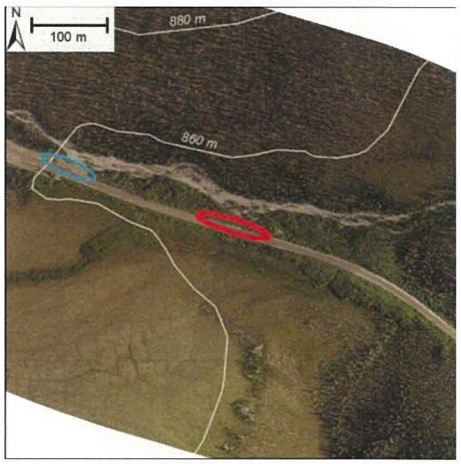
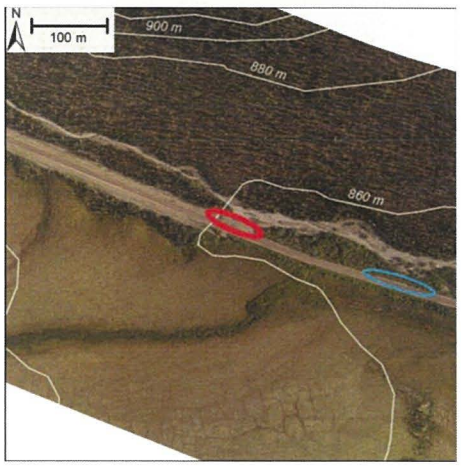
km	Section	Proximity (m)	Trajectory	Riprapped	Detailed Assessment Completed	Plan View Image (2007/2008 QuickBird Imagery from GeoYukon)
144.2	Ogilvie	0	W	P	N	
146.4	Ogilvie	0	S	N	N	
146.6	Ogilvie	10	S	N	N	

Definitions of letter codes:
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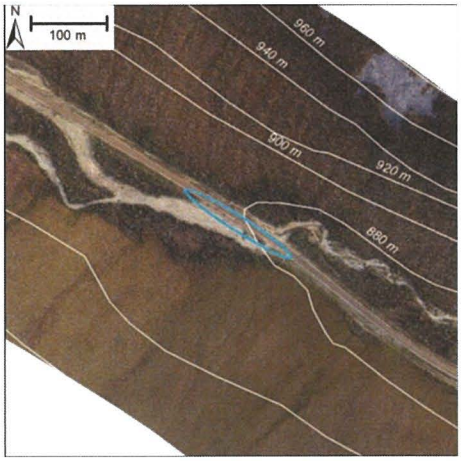
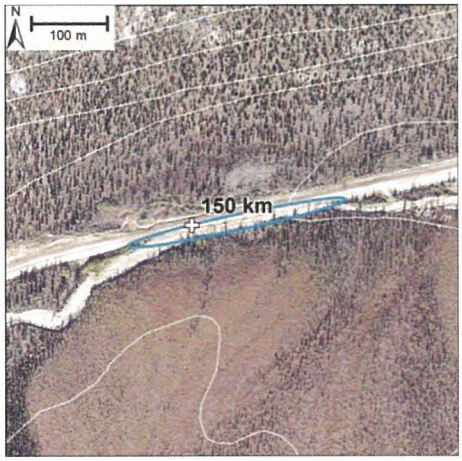
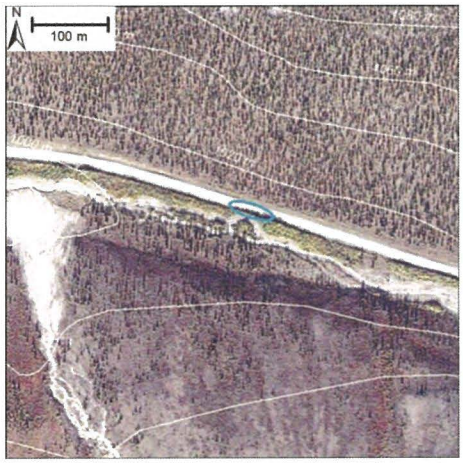
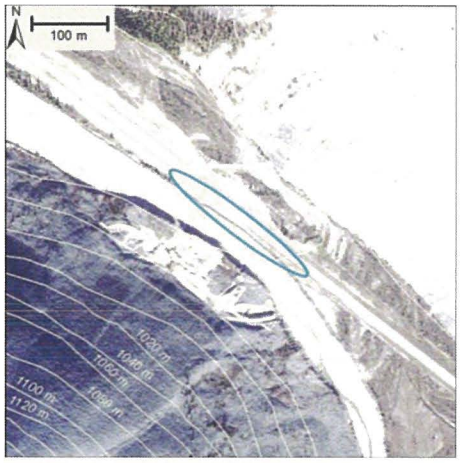
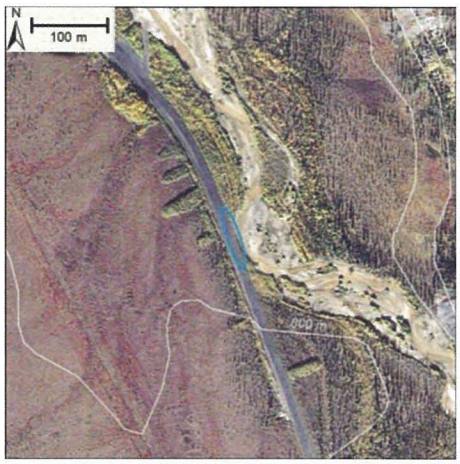
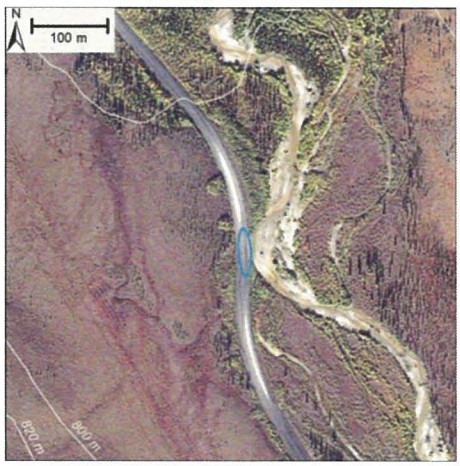
km	Section	Proximity (m)	Trajectory	Riprapped	Detailed Assessment Completed	Plan View Image (2007/2008 QuickBird Imagery from GeoYukon)
147.6	Ogilvie	0	NE	N	Y – see Appendix	
150	Ogilvie	0	NNW	N	N	
154.4	Ogilvie	5	NNE	N	N	

Definitions of letter codes:
Proximity (m) – approximate (±3 m) separation distance between channel bank and near edge of highway
Trajectory – N: north, E: east, S: south, W: west
Riprapped – Y: yes, N: no, P: partially
Detailed Assessment Completed – Y: yes, N: no, R: recommended

Appendix F. Summary Results of Meander-Highway Encroachment Site Identification

Image scale 1:10,000 unless otherwise noted; contours symbolized with white lines (from 1:50,000-scale CanVec data); subject indicated by red symbol when multiple features are in view; letter codes defined in footnotes at bottom of table.

km	Section	Proximity (m)	Trajectory	Riprapped	Detailed Assessment Completed	Plan View Image (2007/2008 QuickBird Imagery from GeoYukon)
156.5	Ogilvie	10	E	N	N	
165.5	Ogilvie	0	W	P	R	
166.5	Ogilvie	0	WNW	P	N	

Definitions of letter codes:
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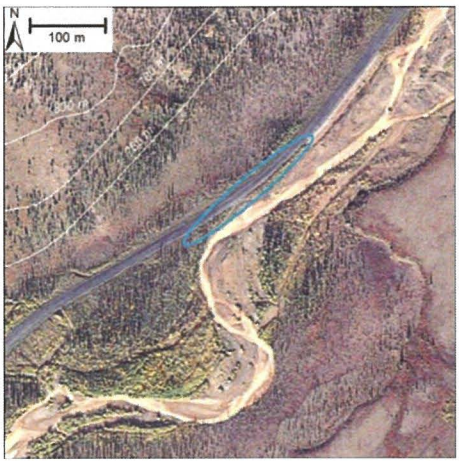
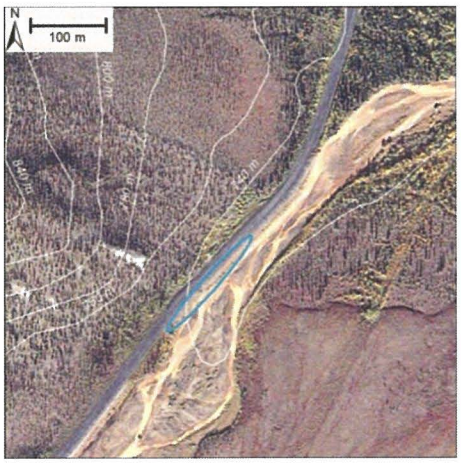
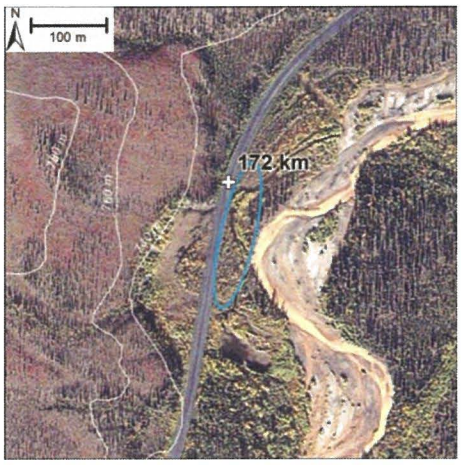
Image scale 1:10,000 unless otherwise noted; contours symbolized with white lines (from 1:50,000-scale CanVec data); subject indicated by red symbol when multiple features are in view; letter codes defined in footnotes at bottom of table.

km	Section	Proximity (m)	Trajectory	Riprapped	Detailed Assessment Completed	Plan View Image (2007/2008 QuickBird Imagery from GeoYukon)
170.9	Ogilvie	3	NNW	N	Y – see Appendix	
171.3	Ogilvie	0	NNW	P	N	
171.9	Ogilvie	35	WNW	N	N	

Definitions of letter codes:
Proximity (m) – approximate (±3 m) separation distance between channel bank and near edge of highway
Trajectory – N: north, E: east, S: south, W: west
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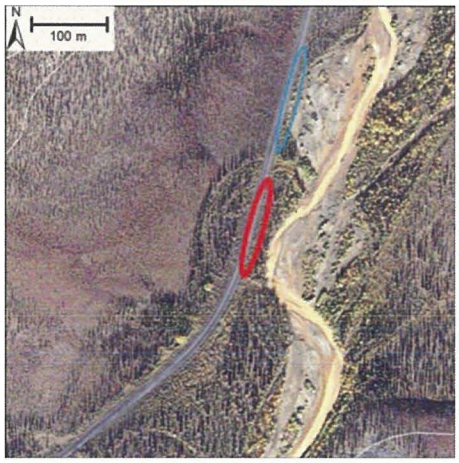
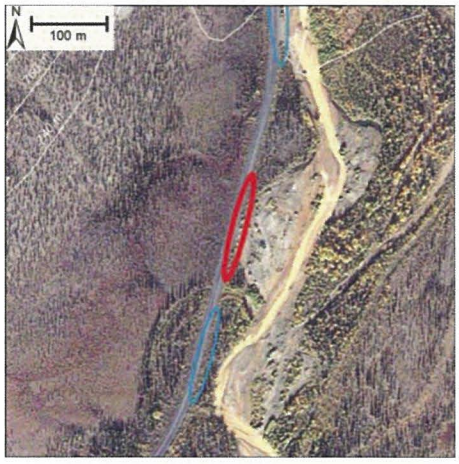
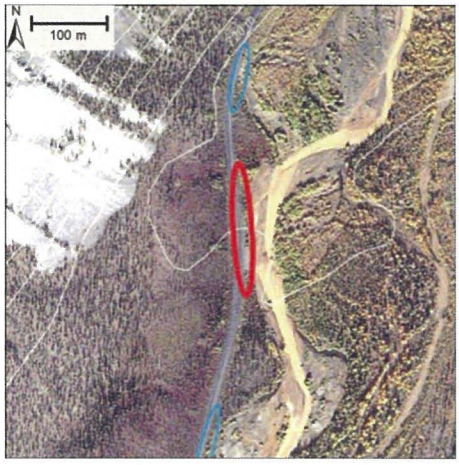
Image scale 1:10,000 unless otherwise noted; contours symbolized with white lines (from 1:50,000-scale CanVec data); subject indicated by red symbol when multiple features are in view; letter codes defined in footnotes at bottom of table.

km	Section	Proximity (m)	Trajectory	Riprapped	Detailed Assessment Completed	Plan View Image (2007/2008 QuickBird Imagery from GeoYukon)
172.9	Ogilvie	0	W	N	Y – see Appendix	
173.1	Ogilvie	0	W	P	N	
173.4	Ogilvie	0	W	P	N	

Definitions of letter codes:
Proximity (m) – approximate (±3 m) separation distance between channel bank and near edge of highway
Trajectory – N: north, E: east, S: south, W: west
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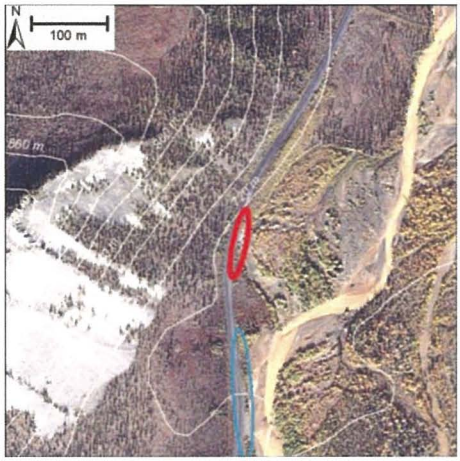
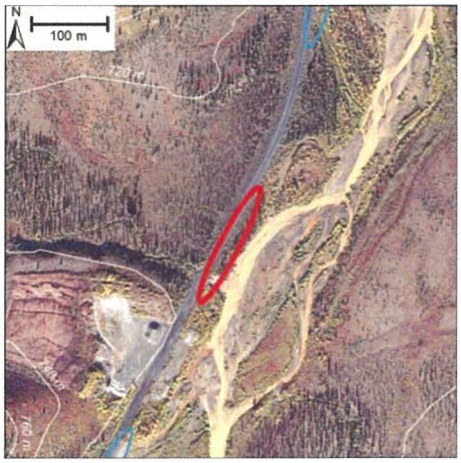
Image scale 1:10,000 unless otherwise noted; contours symbolized with white lines (from 1:50,000-scale CanVec data); subject indicated by red symbol when multiple features are in view; letter codes defined in footnotes at bottom of table.

km	Section	Proximity (m)	Trajectory	Riprapped	Detailed Assessment Completed	Plan View Image (2007/2008 QuickBird Imagery from GeoYukon)
173.6	Ogilvie	0	W	P	N	
174.4	Ogilvie	0	WNW	P	N	
174.8	Ogilvie	20	WNW	N	N	

Definitions of letter codes:
Proximity (m) – approximate (±3 m) separation distance between channel bank and near edge of highway
Trajectory – N: north, E: east, S: south, W: west
Riprapped – Y: yes, N: no, P: partially
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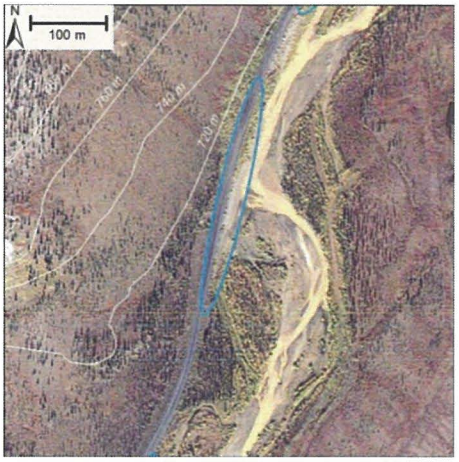
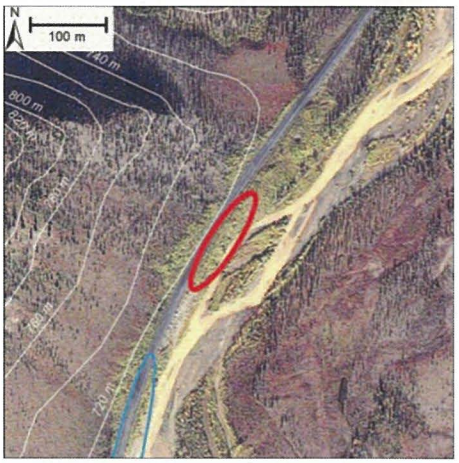
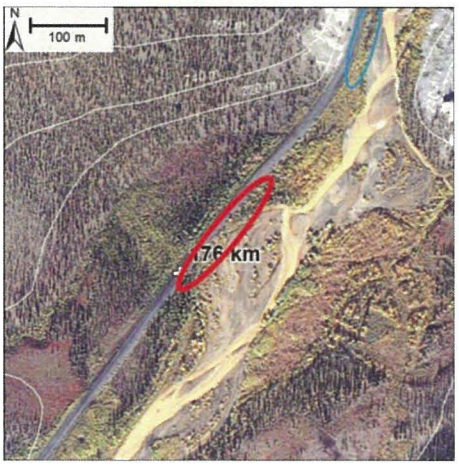
km	Section	Proximity (m)	Trajectory	Riprapped	Detailed Assessment Completed	Plan View Image (2007/2008 QuickBird Imagery from GeoYukon)
175.2	Ogilvie	9	W	P	Y – see Appendix	
175.6	Ogilvie	10	NW	N	N	
176.1	Ogilvie	0	W	N	N	

Definitions of letter codes:
Proximity (m) – approximate (±3 m) separation distance between channel bank and near edge of highway
Trajectory – N: north, E: east, S: south, W: west
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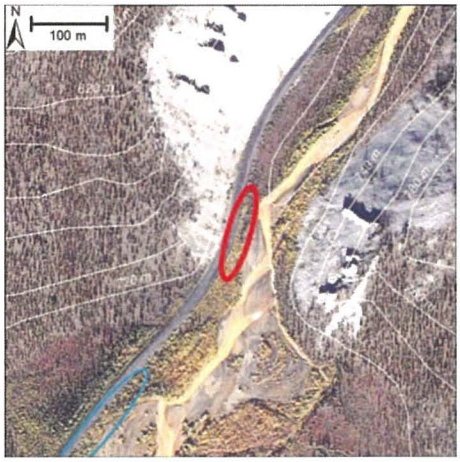
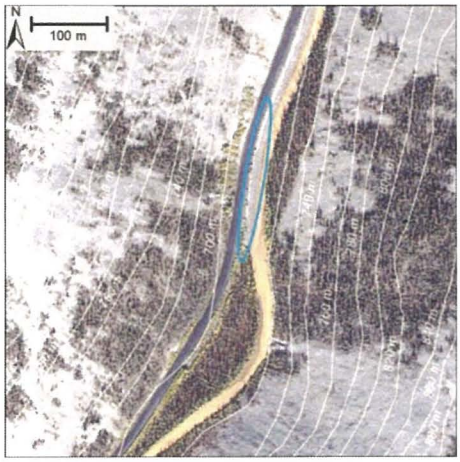
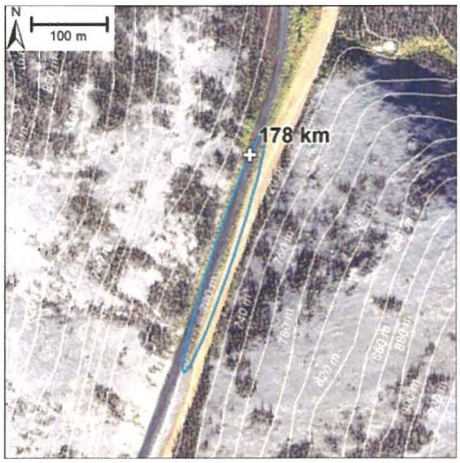
Image scale 1:10,000 unless otherwise noted; contours symbolized with white lines (from 1:50,000-scale CanVec data); subject indicated by red symbol when multiple features are in view; letter codes defined in footnotes at bottom of table.

km	Section	Proximity (m)	Trajectory	Riprapped	Detailed Assessment Completed	Plan View Image (2007/2008 QuickBird Imagery from GeoYukon)
176.4	Ogilvie	10	W	N	N	
177.5	Ogilvie	0	N	Y	N	
177.9	Ogilvie	0	N	P	N	

Definitions of letter codes:
Proximity (m) – approximate (±3 m) separation distance between channel bank and near edge of highway
Trajectory – N: north, E: east, S: south, W: west
Riprapped – Y: yes, N: no, P: partially
Detailed Assessment Completed – Y: yes, N: no, R: recommended

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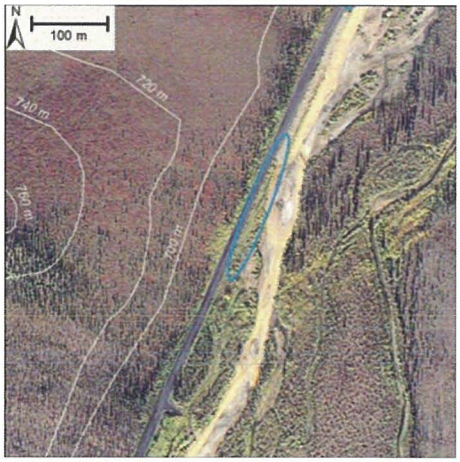
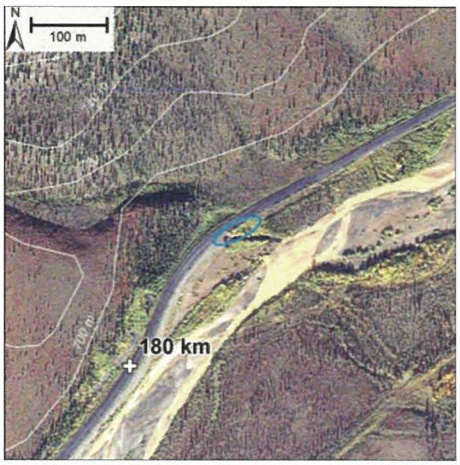
Image scale 1:10,000 unless otherwise noted; contours symbolized with white lines (from 1:50,000-scale CanVec data); subject indicated by red symbol when multiple features are in view; letter codes defined in footnotes at bottom of table.

km	Section	Proximity (m)	Trajectory	Riprapped	Detailed Assessment Completed	Plan View Image (2007/2008 QuickBird Imagery from GeoYukon)
179.3	Ogilvie	10	NW	N	N	
179.7	Ogilvie	0	NW	N	N	
180.2	Ogilvie	1	N	N	Y – see Appendix	

Definitions of letter codes:
Proximity (m) – approximate (±3 m) separation distance between channel bank and near edge of highway
Trajectory – N: north, E: east, S: south, W: west
Riprapped – Y: yes, N: no, P: partially
Detailed Assessment Completed – Y: yes, N: no, R: recommended

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Image scale 1:10,000 unless otherwise noted; contours symbolized with white lines (from 1:50,000-scale CanVec data); subject indicated by red symbol when multiple features are in view; letter codes defined in footnotes at bottom of table.

km	Section	Proximity (m)	Trajectory	Riprapped	Detailed Assessment Completed	Plan View Image (2007/2008 QuickBird Imagery from GeoYukon)
180.7	Ogilvie	1	NW	P	N	
181.5	Ogilvie	0	NW	N	Y – see Appendix	
182.1	Ogilvie	5	NW	P	Y – see Appendix	

Definitions of letter codes:
Proximity (m) – approximate (±3 m) separation distance between channel bank and near edge of highway
Trajectory – N: north, E: east, S: south, W: west
Riprapped – Y: yes, N: no, P: partially
Detailed Assessment Completed – Y: yes, N: no, R: recommended

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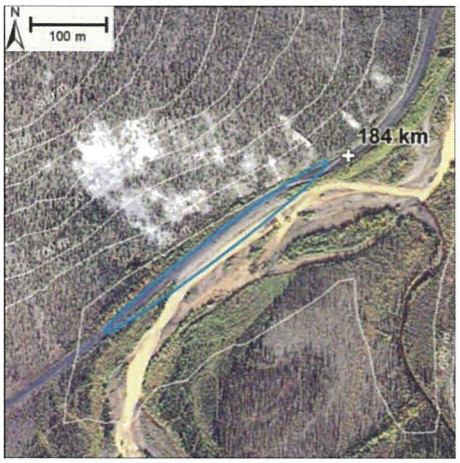
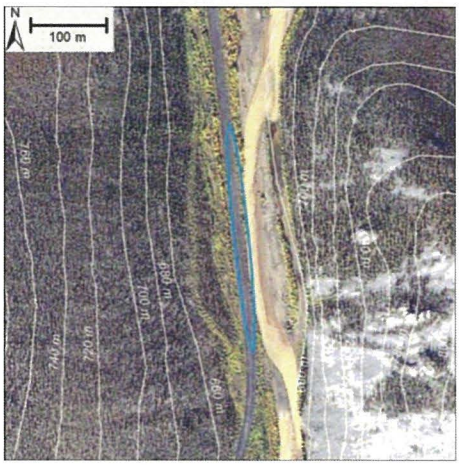
Image scale 1:10,000 unless otherwise noted; contours symbolized with white lines (from 1:50,000-scale CanVec data); subject indicated by red symbol when multiple features are in view; letter codes defined in footnotes at bottom of table.

km	Section	Proximity (m)	Trajectory	Riprapped	Detailed Assessment Completed	Plan View Image (2007/2008 QuickBird Imagery from GeoYukon)
183.3	Ogilvie	31	NW	N	Y – see Appendix	
183.8	Ogilvie	0	N	P	N	
184.6	Ogilvie	0	W	P	N	

Definitions of letter codes:
Proximity (m) – approximate (±3 m) separation distance between channel bank and near edge of highway
Trajectory – N: north, E: east, S: south, W: west
Riprapped – Y: yes, N: no, P: partially
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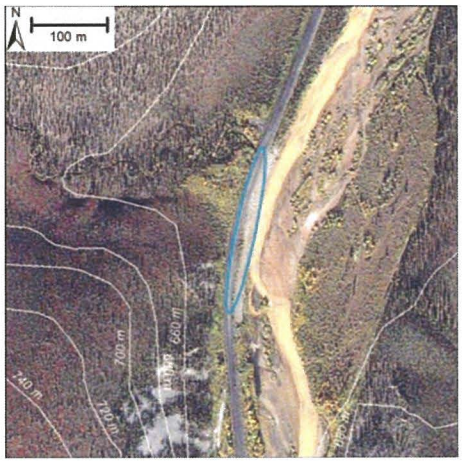
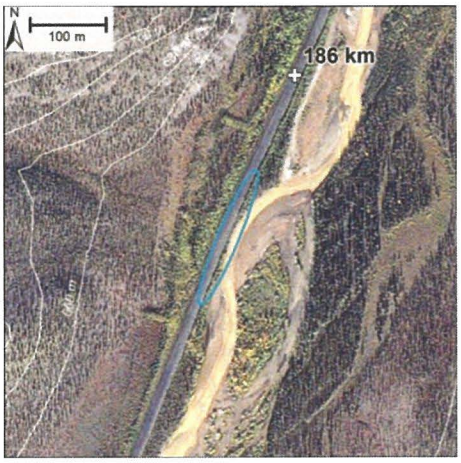
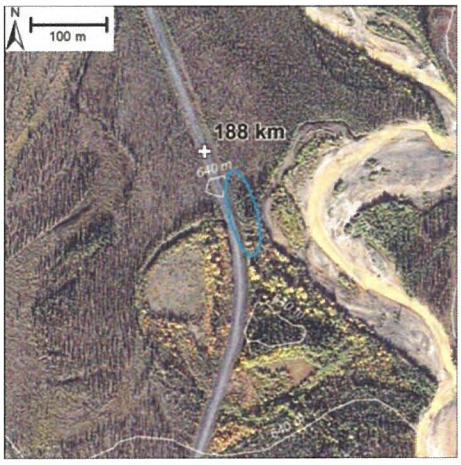
km	Section	Proximity (m)	Trajectory	Riprapped	Detailed Assessment Completed	Plan View Image (2007/2008 QuickBird Imagery from GeoYukon)
185.1	Ogilvie	0	W	Y	N	
185.8	Ogilvie	4	WNW	N	Y – see Appendix	
187.9	Ogilvie	25	NW	N	N	

Definitions of letter codes:
Proximity (m) – approximate (±3 m) separation distance between channel bank and near edge of highway
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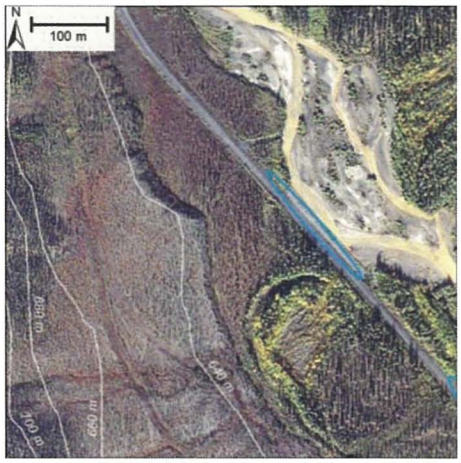
km	Section	Proximity (m)	Trajectory	Riprapped	Detailed Assessment Completed	Plan View Image (2007/2008 QuickBird Imagery from GeoYukon)
188.6	Ogilvie	1	SW	P	Y – see Appendix	
188.9	Ogilvie	0	SW	P	N	
189.4	Ogilvie	6	WNW	P	Y – see Appendix	

Definitions of letter codes:
Proximity (m) – approximate (±3 m) separation distance between channel bank and near edge of highway
Trajectory – N: north, E: east, S: south, W: west
Riprapped – Y: yes, N: no, P: partially
Detailed Assessment Completed – Y: yes, N: no, R: recommended

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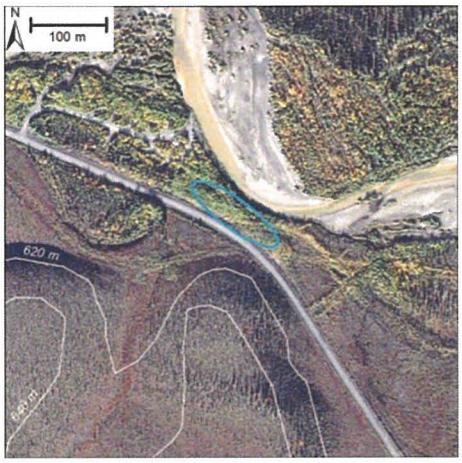
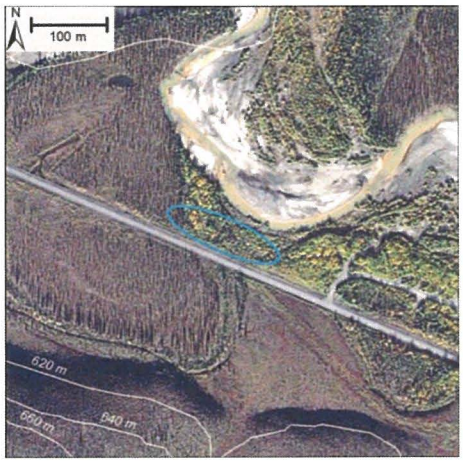
km	Section	Proximity (m)	Trajectory	Riprapped	Detailed Assessment Completed	Plan View Image (2007/2008 QuickBird Imagery from GeoYukon)
193	Ogilvie	35	SW	N	N	
193.5	Ogilvie	35	SSW	N	N	
194.4	Ogilvie	0	W	P	N	

Definitions of letter codes:
Proximity (m) – approximate (±3 m) separation distance between channel bank and near edge of highway
Trajectory – N: north, E: east, S: south, W: west
Riprapped – Y: yes, N: no, P: partially
Detailed Assessment Completed – Y: yes, N: no, R: recommended

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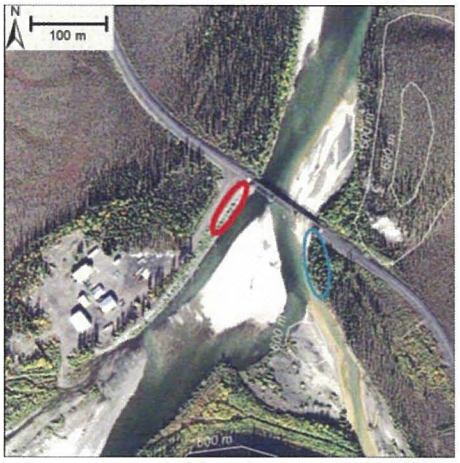
km	Section	Proximity (m)	Trajectory	Riprapped	Detailed Assessment Completed	Plan View Image (2007/2008 QuickBird Imagery from GeoYukon)
195.1	Ogilvie	5	NE	P	Y – see Appendix	
195.2	Ogilvie	10	NW	Y	N	
197.6	Ogilvie	0	NW	P	N	

Definitions of letter codes:
Proximity (m) – approximate (±3 m) separation distance between channel bank and near edge of highway
Trajectory – N: north, E: east, S: south, W: west
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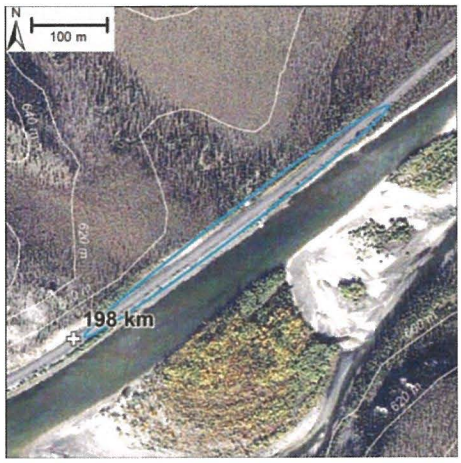
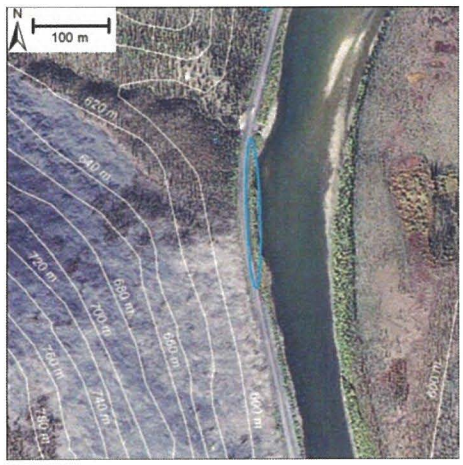
km	Section	Proximity (m)	Trajectory	Riprapped	Detailed Assessment Completed	Plan View Image (2007/2008 QuickBird Imagery from GeoYukon)
198.3	Ogilvie	0	NE	P	N	
199.1	Ogilvie	0	NW	P	N	
200.6	Ogilvie	0	NW	N	N	

Definitions of letter codes:
Proximity (m) – approximate (±3 m) separation distance between channel bank and near edge of highway
Trajectory – N: north, E: east, S: south, W: west
Riprapped – Y: yes, N: no, P: partially
Detailed Assessment Completed – Y: yes, N: no, R: recommended

Appendix F. Summary Results of Meander-Highway Encroachment Site Identification

Image scale 1:10,000 unless otherwise noted; contours symbolized with white lines (from 1:50,000-scale CanVec data); subject indicated by red symbol when multiple features are in view; letter codes defined in footnotes at bottom of table.

km	Section	Proximity (m)	Trajectory	Riprapped	Detailed Assessment Completed	Plan View Image (2007/2008 QuickBird Imagery from GeoYukon)
201	Ogilvie	0	NW	P	N	
201.5	Ogilvie	30	N	N	N	
201.8	Ogilvie	5	N	N	N	

Definitions of letter codes:
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Detailed Assessment Completed – Y: yes, N: no, R: recommended

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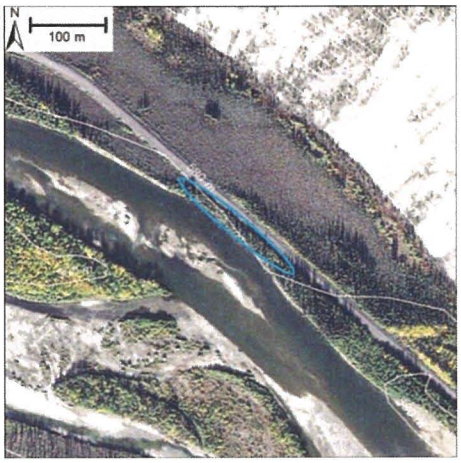
km	Section	Proximity (m)	Trajectory	Riprapped	Detailed Assessment Completed	Plan View Image (2007/2008 QuickBird Imagery from GeoYukon)
202.5	Ogilvie	9	NE	N	Y – see Appendix	
203.8	Ogilvie	0	E	P	N	
204.8	Ogilvie	10	NW	N	N	

Definitions of letter codes:
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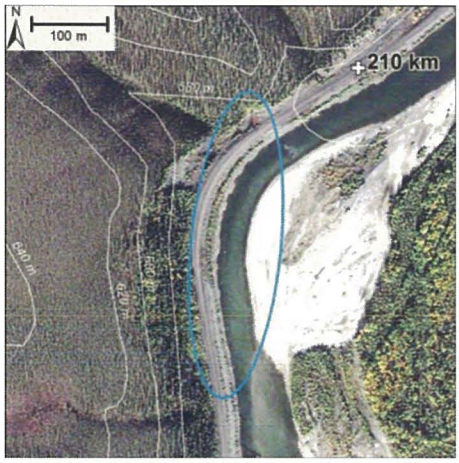
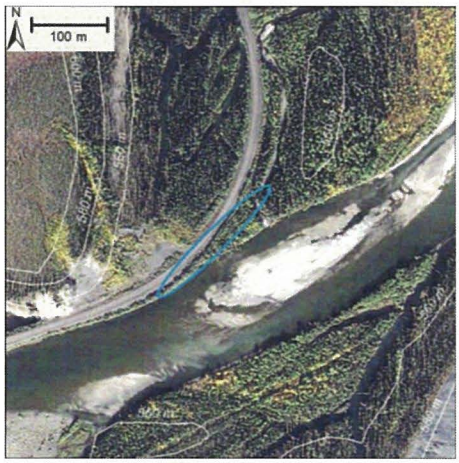
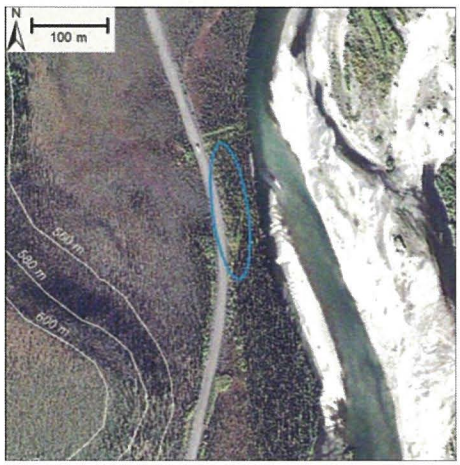
Image scale 1:10,000 unless otherwise noted; contours symbolized with white lines (from 1:50,000-scale CanVec data); subject indicated by red symbol when multiple features are in view; letter codes defined in footnotes at bottom of table.

km	Section	Proximity (m)	Trajectory	Riprapped	Detailed Assessment Completed	Plan View Image (2007/2008 QuickBird Imagery from GeoYukon)
209.6	Ogilvie	0	W	P	N	
211.1	Ogilvie	5	N	N	N	
217.3	Ogilvie	30	NW	N	N	

Definitions of letter codes:
Proximity (m) – approximate (±3 m) separation distance between channel bank and near edge of highway
Trajectory – N: north, E: east, S: south, W: west
Riprapped – Y: yes, N: no, P: partially
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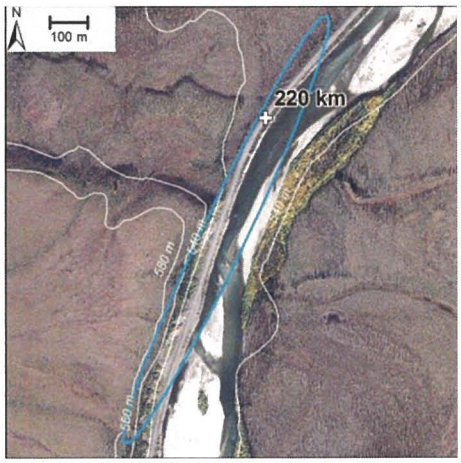
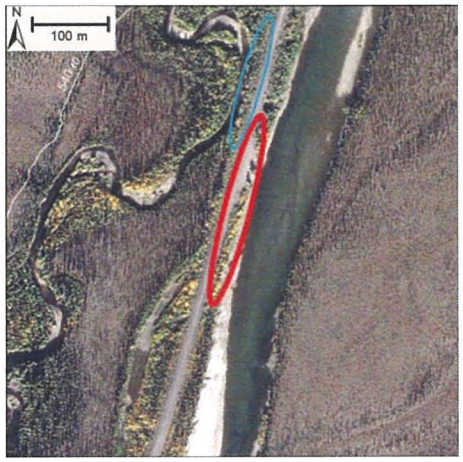
Appendix F. Summary Results of Meander-Highway Encroachment Site Identification

Image scale 1:10,000 unless otherwise noted; contours symbolized with white lines (from 1:50,000-scale CanVec data); subject indicated by red symbol when multiple features are in view; letter codes defined in footnotes at bottom of table.

km	Section	Proximity (m)	Trajectory	Riprapped	Detailed Assessment Completed	Plan View Image (2007/2008 QuickBird Imagery from GeoYukon)
219.7 [note 1:20,000 scale]	Ogilvie	0	NW	Y	N	
221.1	Ogilvie	8	WNW	P	Y – see Appendix	
221.3	Ogilvie	9	NE	N	Y – see Appendix	

Definitions of letter codes:
Proximity (m) – approximate (±3 m) separation distance between channel bank and near edge of highway
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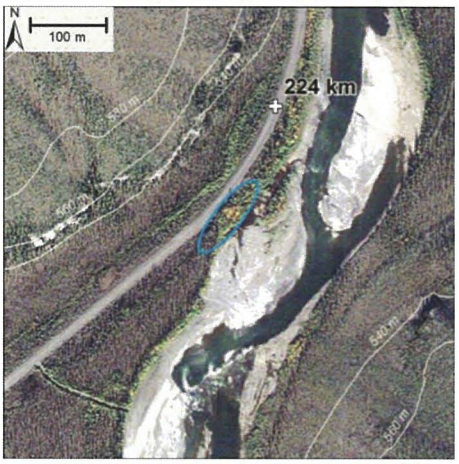
Image scale 1:10,000 unless otherwise noted; contours symbolized with white lines (from 1:50,000-scale CanVec data); subject indicated by red symbol when multiple features are in view; letter codes defined in footnotes at bottom of table.

km	Section	Proximity (m)	Trajectory	Riprapped	Detailed Assessment Completed	Plan View Image (2007/2008 QuickBird Imagery from GeoYukon)
221.9	Ogilvie	0	N	Y	N	
223.8	Ogilvie	25	N	N	N	
232 [note 2013 ortho-photo base]	Ogilvie	24	NW	N	Y – see Appendix	

Definitions of letter codes:
Proximity (m) – approximate (±3 m) separation distance between channel bank and near edge of highway
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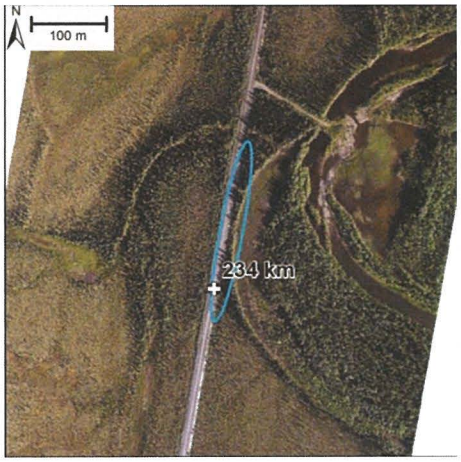
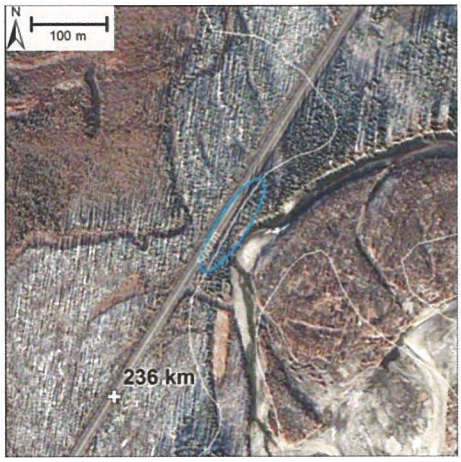
Appendix F. Summary Results of Meander-Highway Encroachment Site Identification

Image scale 1:10,000 unless otherwise noted; contours symbolized with white lines (from 1:50,000-scale CanVec data); subject indicated by red symbol when multiple features are in view; letter codes defined in footnotes at bottom of table.

km	Section	Proximity (m)	Trajectory	Riprapped	Detailed Assessment Completed	Plan View Image (2007/2008 QuickBird Imagery from GeoYukon)
234.1 [note 2013 ortho-photo base]	Ogilvie	5	W	N	N	
236.3	Ogilvie	19	NW	N	Y – see Appendix	
238.1	Ogilvie	0	WNW	P	N	

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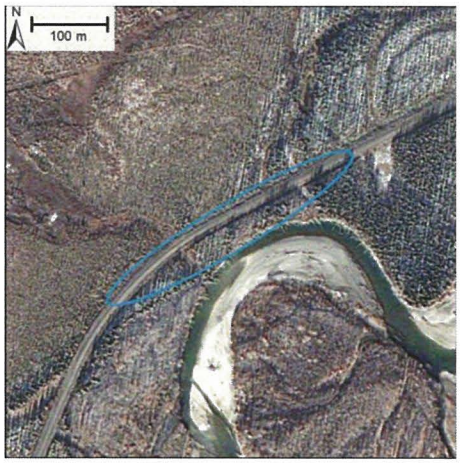
Riprapped – Y: yes, N: no, P: partially
Detailed Assessment Completed – Y: yes, N: no, R: recommended

Appendix F. Summary Results of Meander-Highway Encroachment Site Identification

Image scale 1:10,000 unless otherwise noted; contours symbolized with white lines (from 1:50,000-scale CanVec data); subject indicated by red symbol when multiple features are in view; letter codes defined in footnotes at bottom of table.

km	Section	Proximity (m)	Trajectory	Riprapped	Detailed Assessment Completed	Plan View Image (2007/2008 QuickBird Imagery from GeoYukon)
238.7	Ogilvie	0	N	P	N	
239.5	Ogilvie	24	NW	N	Y – see Appendix	
242.5	Ogilvie	0	NE	Y	N	

Definitions of letter codes:
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Appendix F. Summary Results of Meander-Highway Encroachment Site Identification

Image scale 1:10,000 unless otherwise noted; contours symbolized with white lines (from 1:50,000-scale CanVec data); subject indicated by red symbol when multiple features are in view; letter codes defined in footnotes at bottom of table.

km	Section	Proximity (m)	Trajectory	Riprapped	Detailed Assessment Completed	Plan View Image (2007/2008 QuickBird Imagery from GeoYukon)
243.4	Ogilvie	0	N	P	N	
243.8	Ogilvie	4	N	P	Y – see Appendix	
244.8	Ogilvie	0	NW	Y	N	

Definitions of letter codes:
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Trajectory – N: north, E: east, S: south, W: west
Riprapped – Y: yes, N: no, P: partially
Detailed Assessment Completed – Y: yes, N: no, R: recommended

Attributes of Prioritized Meander-Highway Encroachment Sites

KM_ID	SECTION	WATERCOURS	RIPRAP_HST	PROXIMITY	MNDR_BELT	CONFINE	SETTING	PERMAFROST	VEGETATION	CHAN_TYPE	POS_MNDR	CROSS-SEC	MNRD_RAD	ELEV_BOB	ELEV_TOB	BANK_HT	ELEV_HWY	LOWFLOW_W	BANKFULL_W
52.3	Klondike	North Klondike	No riprap	19	Edge	Unconfined	Fluvial plain	deep, ice-moderate	Mixed	Side	Apex	Asymmetric	76	847.7	849.0	1.3	849.5	20	65
54.9	Klondike	North Klondike	No riprap	7	Edge	Confined by highway	Hwy edge fluvial plain	deep, ice-moderate	Coniferous	Main	Apex	Neutral	78	871.4	877.3	5.9	878.5	22	25
55.9	Klondike	North Klondike	No riprap	20	Edge	Naturally confined	Colluvial toe slope	deep, ice-moderate	Mixed	Main	Apex	Asymmetric	44	880.5	892.4	11.9	893.7	53	57
88.0	Klondike	East Blackstone River	No riprap	15	Edge	Naturally confined	Moralnal scarp	deep, ice-poor	Deciduous	Main	Apex	Neutral	58	1149.5	1157.0	7.5	1158.4	19	22
131.4	Klondike/Ogilv	Blackstone River	2004	6	Within	Confined by highway	Hwy edge fluvial plain	deep, ice-moderate	Mixed	Main	Upstream arm	Neutral	104	902.8	903.9	1.1	904.7	24	75
136.1	Klondike/Ogilvie	Blackstone River	Unknown	4	Within	Confined by highway	Fluvial plain	shallow, ice-moderate	Mixed	Main	Apex	Asymmetric	51	882.4	882.5	0.1	882.5	27	94
138.5	Klondike/Ogilvie	Blackstone River	No riprap	21	Within	Unconfined	Fluvial plain	deep, ice-moderate	Mixed	Main	Apex	Asymmetric	99	872.5	874.6	2.1	874.9	20	140
147.6	Klondike/Ogilvie	Blackstone Tributary	No riprap	0	Within	Confined by highway	Hwy edge fluvial plain	deep, ice-moderate	Coniferous	Main	-	Neutral	-	881.3	881.8	0.5	882	5	25
170.9	Ogilvie	Engineer Creek	No riprap	3	Within	Unconfined	Hwy edge fluvial plain	shallow, ice-rich, thermokarst	Mixed	Main	Downstream arm	Asymmetric	33	734.3	734.6	0.3	735.5	18	33
172.9	Ogilvie	Engineer Creek	2016	0	Within	Confined by highway	Fluvial plain	shallow, ice-rich, thermokarst	Coniferous	Main	Apex	Asymmetric	71	719.2	720.4	1.2	721	15	55
175.2	Ogilvie	Engineer Creek	Unknown	9	Edge	Naturally confined	Colluvial toe slope	deep, ice-moderate	Mixed	Main	Apex	Asymmetric	54	702.2	712.8	10.6	713.9	15	42
180.7	Ogilvie	Engineer Creek	Unknown	1	Within	Confined by highway	Hwy edge fluvial plain	shallow, ice-rich, thermokarst	Coniferous	Main	Apex	Asymmetric	90	674.1	675.5	1.4	676.2	5	27
181.5	Ogilvie	Engineer Creek	No riprap	0	Within	Confined by highway	Fluvial plain	shallow, ice-rich, thermokarst	Coniferous	Main	Apex	Asymmetric	98	670.4	671.9	1.5	672.5	10	37
182.1	Ogilvie	Engineer Creek	2010, 2015	5	Edge	Confined by highway	Hwy edge fluvial plain	near-surface, ice-rich, thermokarst	Coniferous	Main	Apex	Asymmetric	97	665.5	668.0	2.5	668.8	7	41
183.3	Ogilvie	Engineer Creek	No riprap	31	Within	Unconfined	Fluvial plain	shallow, ice-rich, thermokarst	Coniferous	Main	Apex	Asymmetric	72	655.5	657.5	2.0	658	9	45
185.8	Ogilvie	Engineer Creek	No riprap	4	Edge	Unconfined	Hwy edge fluvial plain	deep, ice-moderate	Mixed	Main	Apex	Asymmetric	116	642.9	644.4	1.5	646	12	58
188.6	Ogilvie	Engineer Creek	1971, 2015	1	Within	Confined by highway	Hwy edge fluvial plain	shallow, ice-rich, thermokarst	Mixed	Main	Apex	Asymmetric	52	626.4	629.0	2.6	629.5	17	45
189.4	Ogilvie	Engineer Creek	1998	6	Within	Confined by highway	Hwy edge fluvial plain	shallow, ice-rich, thermokarst	Mixed	Main	Downstream arm	Asymmetric	178	622.2	624.7	2.5	624.9	9	39
195.1	Ogilvie	Ogilvie River	1971	5	Within	Confined by highway	Hwy edge fluvial plain	deep, ice-poor	Mixed	Main	Apex	Asymmetric	111	590.4	592.2	1.8	592.8	30	100
202.5	Ogilvie	Ogilvie River	No riprap	9	Within	Unconfined	Fluvial plain	shallow, ice-rich, thermokarst	Coniferous	Main	Downstream arm	Asymmetric	272	576.8	579.0	2.2	579.4	35	135
221.1	Ogilvie	Ogilvie River	1969	8	Within	Confined by highway	Hwy edge fluvial plain	shallow, ice-rich, thermokarst	Coniferous	Main	Upstream arm	Asymmetric	209	532.3	533.8	1.5	534.6	80	90
221.3	Ogilvie	Ogilvie River	No riprap	9	Within	Confined by highway	Hwy edge fluvial plain	deep, ice-moderate	Mixed	Main	Upstream arm	Neutral	48	533.6	534.5	0.9	535.6	5	22
232.0	Ogilvie	Ogilvie River	No riprap	24	Within	Unconfined	Fluvial plain	shallow, ice-moderate	Coniferous	Main	Apex	Asymmetric	223	508.0	511.2	3.2	511.7	28	190
236.3	Ogilvie	Ogilvie River	No riprap	19	Within	Unconfined	Fluvial plain	shallow, ice-rich, thermokarst	Coniferous	Side	Apex	Asymmetric	87	500.8	501.4	0.6	501.7	35	39
239.5	Ogilvie	Ogilvie River	No riprap	24	Within	Unconfined	Fluvial plain	shallow, ice-rich, thermokarst	Coniferous	Side	Apex	Asymmetric	137	493.2	493.8	0.6	494.3	17	90
243.8	Ogilvie	Ogilvie River	1991, 1996, 2013, 2015	4	Edge	Confined by highway	Hwy edge fluvial plain	shallow, ice-rich, thermokarst	Coniferous	Main	Apex	Asymmetric	235	484.0	486.3	2.3	486.7	44	120

Note: Data with **bold** field headings tabulated in upper-right portion of Summary Figures of Prioritized Meander Migration Hazard Assessment Results (Appendix H). Headings and values defined in metadata table that follows

Attributes of Prioritized Meander-Highway Encroachment Sites

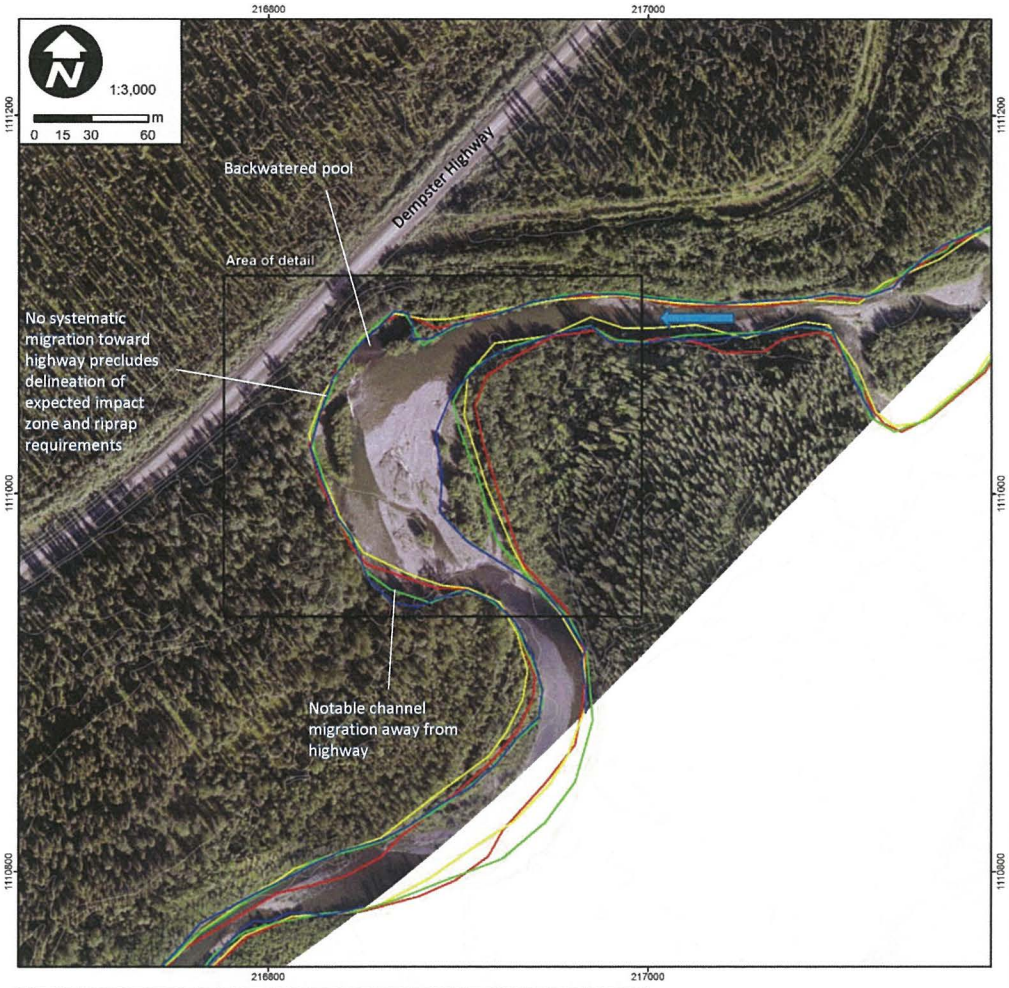
KM_ID	EROS1_YR1	EROS1_YR2	EROS1_DIFF	EROS1_DIST	EROS1_RT	EROS1_TRJ	EROS1_TRJD	EROS1_RTL	EROS2_YR1	EROS2_YR2	EROS2_DIFF	EROS2_DIST	EROS2_RT	EROS2_TRJ	EROS2_TRJD	EROS2_RTL	RIPRAP_TIM	RIPRAP_LTH	RIPRAP_ANG	RIPRAP_HT1	RIPRAP_HT2	RIPRAP_SLP	RIPRAP_THK	RIPRAP_VOL
52.3	-	-	-	-	-	NA	-	No systematic migration toward highway	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
54.9	-	-	-	-	-	NA	-	No systematic migration toward highway	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
55.9	2008	2014	6	4.3	0.7	NW	21.3	Slight outward migration between 2007 and 2013	2008	2014	6	3.2	0.5	NW	19.4	Slight outward migration between 2007 and 2013	>25	170	2:1	13.2	14.2	31.7	1	5391
88.0	2008	2013	5	3.2	0.6	WNW	15.1	Slight outward migration between 2007 and 2013	2008	2013	5	2.5	0.5	W	20.1	Slight outward migration between 2007 and 2013	21-25	75	2:1	8.9	9.9	22.1	1	1658
131.4	2007	2013	6	2.2	0.4	W	9.5	1977 and 1989 alignments unrepresentative of current morphology	-	-	-	-	-	-	-	-	21-25	100	2:1	1.9	2.9	6.5	1	648
136.1	1977	2013	36	19.7	0.5	NW	5.8	Longitudinal migration over the period of record	-	-	-	-	-	-	-	-	11-15	40	2:1	0.1	1.1	2.5	1	98
136.5	2007	2013	6	22	3.7	NNW	34.2	1977 and 1989 alignments unrepresentative of current morphology	2007	2013	6	10.7	1.8	WNW	25.5	1977 and 1989 alignments unrepresentative of current morphology	6-10	140	2:1	2.4	3.4	7.6	1	1063
147.6	-	-	-	-	-	NA	-	Channel has been in contact with the highway over the period of record	-	-	-	-	-	-	-	-	0	140	2:1	0.7	1.7	3.8	1	532
170.9	2007	2013	6	3.2	0.5	NNW	9.8	1977 and 1989 alignments unrepresentative of current morphology	-	-	-	-	-	-	-	-	6-10	70	2:1	1.2	2.2	4.9	1	344
172.9	2007	2013	6	24.5	4.1	WNW	15.7	1977 and 1989 alignments unrepresentative of current morphology	2007	2013	6	23	3.8	NW	2.0	1977 and 1989 alignments unrepresentative of current morphology	0	105	2:1	1.8	2.8	6.3	1	657
175.2	1989	2013	24	14.8	0.6	W	4.0	Negligible migration at this site between 1977 and 1989	-	-	-	-	-	-	-	-	6-10	30	2:1	11.7	12.7	28.4	1	851
180.7	2007	2013	6	7.4	1.2	N	10.0	1977 and 1989 alignments unrepresentative of current morphology	1977	2013	36	6	0.2	NW	2	Laterally migrated over the period of record	6-10	205	2:1	2.1	3.1	6.9	1	1419
181.5	1989	2013	24	31	1.3	NW	6.4	Negligible migration at this site between 1977 and 1989	-	-	-	-	-	-	-	-	0	140	2:1	2.1	3.1	6.9	1	969
182.1	1977	2013	36	61.2	1.7	WNW	3.2	Significant lateral meander migration over the period of record	1977	2013	36	36.2	1.0	NW	10.5	Significant lateral migration over the period of record	<2	45	2:1	3.3	4.3	9.6	1	432
183.1	1989	2016	27	52.4	1.9	NW	31.0	Meander apex migrated outward since 1989	1977	2016	39	51.4	1.3	WNW	66.7	Laterally migrated over the period of record	16-20	165	2:1	2.5	3.5	7.8	1	1290
185.8	1989	2013	24	28.4	1.2	WNW	4.5	Negligible migration at this site between 1977 and 1989	-	-	-	-	-	-	-	-	2-5	160	2:1	3.1	4.1	9.2	1	1465
188.6	1977	2013	36	102.3	2.8	W	8.1	Significant lateral meander migration over the period of record	1977	2013	36	85.6	2.4	W	2.7	Significant lateral migration over the period of record	<2	100	2:1	3.1	4.1	9.2	1	916
189.4	1989	2013	24	25.3	1.1	NW	18.6	Significant longitudinal migration since riprap application	-	-	-	-	-	-	-	-	16-20	70	2:1	2.7	3.7	8.3	1	578
195.1	-	-	-	-	-	NA	-	No systematic migration since abrupt shift in confluence/bank	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
202.5	1989	2013	24	10.8	0.5	NE	9.0	Negligible migration at this site between 1977 and 1989	1989	2013	24	7.7	0.3	NE	9	Negligible migration at this site between 1977 and 1989	16-20	190	2:1	2.6	3.6	8.0	1	1528
221.1	1977	2013	36	6	0.2	WNW	13.8	Slow outer bank migration over the period of record	-	-	-	-	-	-	-	-	>25	175	2:1	2.3	3.3	7.4	1	1290
221.3	-	-	-	-	-	NA	-	No systematic migration toward highway	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
232.0	1989	2016	27	18.6	0.7	WNW	44.3	Slow outer bank migration over the period of record	-	-	-	-	-	-	-	-	>25	200	2:1	3.7	4.7	10.5	1	2099
236.3	1977	2013	36	25.6	0.7	WNW	17.5	Significant lateral meander migration over the period of record	1977	2013	36	25.4	0.7	NNW	62	Significant lateral migration over the period of record	21-25	130	2:1	0.9	1.9	4.2	1	552
239.5	1989	2013	24	68.8	2.9	WNW	55.4	No systematic migration between 1977 and 1989	1989	2013	24	60.3	2.5	N	46.6	No systematic migration between 1977 and 1989	16-20	390	2:1	1.1	2.1	4.7	1	1829
243.8	2007	2013	6	19.3	3.2	NNE	20.5	Significant longitudinal migration since riprap application	-	-	-	-	-	-	-	-	6-10	150	2:1	2.7	3.7	8.3	1	1240

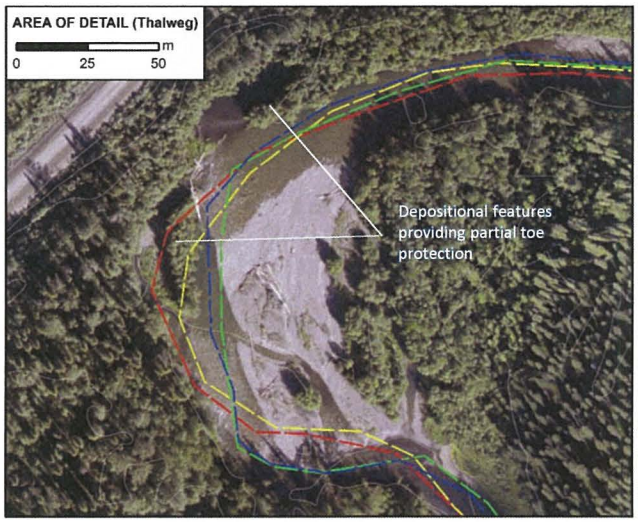
Note: Data with **bold** field headings tabulated in upper-right portion of Meander Migration Hazard Assessment Summary Figures (Appendix B). Headings and values defined in metadata table that follows

METADATA for Attributes of Prioritized Meander-Highway Encroachment Sites

Abbreviated Heading	Full Heading	Summary Figure Heading	Description	Value(s)
KM_ID	Kilometre post site identifier	KM	Distance (km) along Dempster Highway from North Klondike Highway (km 0)	#
SECTION	Highway maintenance section	Section	Highway maintenance section	Text
WATERCOURS	Watercourse name	Watercourse	Watercourse name	Text
RIPRAP_HST	Riprap history	Riprap history	Year(s) of riprap application (if known), based on HPW-TEB consultation, highway as-built drawings and imagery interpretation	Date(s)
PROXIMITY	Highway-watercourse proximity (m)	Hwy-watercourse proximity (m)	Shortest distance (m) between channel and toe of highway embankment at encroachment site	#
MNDR_BELT	Position within meander belt	Position in meander belt	Position of encroachment site within meander belt (i.e. corridor within which lateral channel adjustments typically occur)	Within, edge
CONFINE	Existing channel confinement at encroachment site	Confinement	Presence of an anthropogenic or natural topographic feature that restricts meander movement	Unconfined, Naturally Confined (e.g., scarp, hillside), Confined by Highway (riprapped or suspected to be riprapped embankment)
SETTING	Topographic and surficial setting	Setting	General characterization of landform between channel and highway at encroachment site	Text
PERMAFROST	Permafrost characteristics	Permafrost	Relative depth and ice content of permafrost	Near-surface (<0.4 m), shallow (0.4-1 m), deep (>1 m); ice-rich (massive ice), ice-moderate (segregated ice), ice-poor (minimal visible ice)
VEGETATION	Dominant site vegetation	-	Dominant forest type in vicinity of encroachment site	Deciduous, coniferous (spruce), mixed
CHAN_TYPE	Type of channel	-	General type (size) of channel along which encroachment site is located	Main, side
POS_MNDR	Position along meander	-	Relative position of the encroachment site along the meander bend	Apex, upstream arm, downstream arm
CROSS-SEC	Channel cross-sectional symmetry	-	Characterization of the cross-sectional shape at the encroachment site	Neutral, asymmetric
MNRD_RAD	Meander radius of curvature (m)	-	Radius of curvature (m) of the meander (or the thalweg, in distinctly wandering sections) at the encroachment site	#
ELEV_BOB	Elevation of bottom of bank (m)	-	Elevation of bottom of bank (m) at the encroachment site	#
ELEV_TOB	Elevation of top of bank (m)	-	Elevation of top of bank (m) at the encroachment site	#
BANK_HT	Channel bank height (m)	Bank height (m)	Approximate height (m) of channel bank at encroachment site estimated from bottom-of-bank (water surface) to top-of-bank (commonly different from bankfull depth)	#
ELEV_HWY	Elevation of toe of highway embankment (m)	-	Elevation of toe of highway embankment (m) at the encroachment site	#
LOWFLOW_W	Low-flow channel width (m)	Low-flow width (m)	Approximate wetted width (m) of low-flow channel visible in imagery	#
BANKFULL_W	Bankfull channel width (m)	Bankfull width (m)	Approximate width (m) of active channel based on slope-breaks, vegetation patterns, and evidence of recent scour and/or deposition	#
EROS1_YR1	Primary erosion start year	-	Starting year from which the primary erosion (meander migration) is measured	#
EROS1_YR2	Primary erosion end year	-	Ending year from which the primary erosion (meander migration) is measured	#
EROS1_DIFF	Primary erosion time difference (yrs)	-	Elapsed time (years) between the start year and the end year	#
EROS1_DIST	Primary erosion migration distance (m)	-	Distance (m) the channel migrated over the the elapsed time period along the migration trajectory	#
EROS1_RT	Primary erosion migration rate (m/yr)	1° migration rate (m/yr)	Primary rate of meander migration (m/yr) at encroachment site	#
EROS1_TRJ	Primary erosion migration trajectory	1° trajectory	Primary trajectory of meander migration at encroachment site	N, E, S, W, etc.
EROS1_TRJD	Primary erosion trajectory distance to highway embankment (m)	-	Distance (m) between the 2013/2014 delineated bank and the toe of the highway embankment along the migration trajectory	#
EROS1_RTL	Primary erosion rate rationale	-	Rationale for the delineated banks (years) and trajectory used to calculate the migration rate	Text
EROS2_YR1	Secondary erosion start year	-	Starting year from which the secondary erosion (meander migration) is measured	#
EROS2_YR2	Secondary erosion end year	-	Ending year from which the secondary erosion (meander migration) is measured	#
EROS2_DIFF	Secondary erosion time difference (yrs)	-	Elapsed time (years) between the start year and the end year	#
EROS2_DIST	Secondary erosion migration distance (m)	-	Distance (m) the channel migrated over the the elapsed time period along the migration trajectory	#
EROS2_RT	Secondary erosion migration rate (m/yr)	2° migration rate (m/yr)	Secondary rate of meander migration (m/yr) at encroachment site	#
EROS2_TRJ	Secondary erosion migration trajectory	2° trajectory	Secondary trajectory of meander migration at encroachment site	N, E, S, W, etc.
EROS2_TRJD	Secondary erosion trajectory distance to highway embankment (m)	-	Distance between the 2013/2014 delineated bank and the toe of the highway embankment along the migration trajectory	#
EROS2_RTL	Secondary erosion rate rationale	-	Rationale for the delineated banks (years) and trajectory used to calculate the migration rate	Text
RIPRAP_TIM	Estimated riprap embankment requirement timeframe (yrs)	Timeframe until impact (yr)	Estimated timeframe (period in years) from 2016 field reconnaissance within which continued meander migration is likely to impact highway embankment, without intervention	#
RIPRAP_LTH	Estimated riprap embankment requirement length (m)	Lateral extent (m)	Estimated lateral extent (m) of impact zone along highway embankment where riprap protection may be required	#
RIPRAP_ANG	Assumed riprap embankment slope angle (H:V)	-	Assumed angle, or slope (H:V), of the face of the constructed riprap embankment	#
RIPRAP_HT1	Estimated riprap embankment height (m)	-	Vertical distance (m) between the toe of the embankment and toe of channel bank	#
RIPRAP_HT2	Estimated riprap embankment height with embedment (m)	-	The estimated vertical height of the embankment accounting for riprap embedment into the channel bed during construction	#
RIPRAP_SLP	Estimated riprap embankment slope length (m)	Slope length (m)	Estimated slope length (m) of required riprap embankment extending from toe of highway embankment down to elevation 1 m below adjacent channel bottom-of-bank	#
RIPRAP_THK	Assumed riprap thickness (m)	Thickness (m)	Assumed thickness (m) of Class II riprap application on embankment	#
RIPRAP_VOL	Estimated riprap embankment volume (m^3)	Volume (m^3)	Estimated volume (m^3) of riprap required to protect impact zone along highway embankment	#

Note: Data with bold field headings tabulated in upper-right portion of Summary Figures of Prioritized Meander Migration Hazard Assessment Results (Appendix H).





LEGEND

- Kilometre post
- Highway embankment impact zone
- Current extent of riprap
- 1 m contours

Channel banks (year)

- 2013/ 2014
- 2007/2008
- 1989
- 1977

Thalweg (year)

- 2013/2014
- 2007/2008
- 1989
- 1977

- Direction of flow
- 1˚ migration rate (m/yr)
- 2˚ migration rate (m/yr)

NOTE: Refer to accompanying report for definitions, rationale for erosion rate estimates, and an appendix with additional site-specific data. Original page size 11.00 x 17.00 in. Coordinate system NAD 1983 Yukon Albers; units: metres. Tk = thermokarst evidence nearby.

SITE	CHANNEL	MEANDER	RIPRAP REQUIREMENTS
Section	**Setting**	**1˚ migration rate (m/yr)**	**Timeframe until impact (yr)**
Klondike	Fluvial plain	-	-
Watercourse	**Permafrost**	**1˚ trajectory**	**Lateral extent (m)**
North Klondike R.	Deep, ice-moderate	NA	-
Riprap history	**Bank height (m)**	**2˚ migration rate (m/yr)**	**Slope length (m)**
No riprap	1.3	-	-
Hwy-watercourse proximity (m)	**Low-flow width (m)**	**2˚ trajectory**	**Thickness (m)**
19	20	-	-
Position in meander belt	**Bankfull width (m)**	**Confinement**	**Volume (m^3)**
Edge	65	Unconfined	-

MEANDER MORPHOLOGY AND DYNAMICS

This encroachment site is located within a partly confined, irregularly meandering reach of North Klondike River. Migration rates throughout the reach, including in the vicinity of the encroachment site, have been low over the period of record. Locally, the channel is unconfined. However, the encroachment site itself is at the edge of the meander belt, which limits lateral migration potential. There are small bars near the base of the outer bank that offer partial toe protection and likely contribute to low migration rates. A scallop-shaped hollow adjacent to a backwatered pool is likely the result of former bank instability. Bank erosion has occurred along the downstream arm of the meander, but its trajectory does not pose a risk to the highway. No intervention is recommended at this encroachment site due to the relative stability documented over the past several decades.

IMPLICATIONS OF RIPRAP APPLICATION

Riprap application, if required in future, does not pose further risk to infrastructure.

ALTERNATIVE EROSION PROTECTION STRATEGIES

Bioengineering techniques warrant consideration given the lack of systematic migration toward the highway but the presence of a low bank with possible minor instability. Brush layers, for example, could enhance bank stability along the backwatered pool and are likely more cost-effective than riprap, as most materials can be sourced on-site.

SPECIAL CONSIDERATIONS

N/A

Yukon Government

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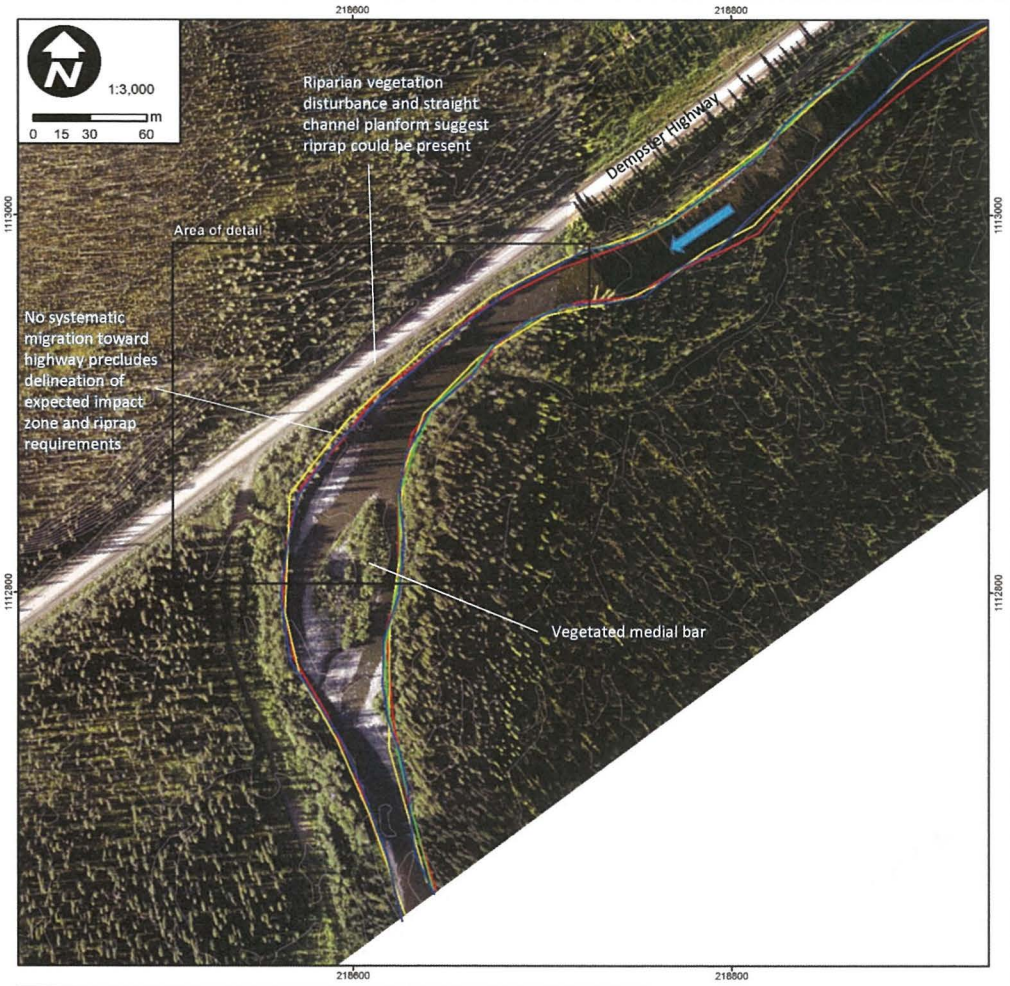
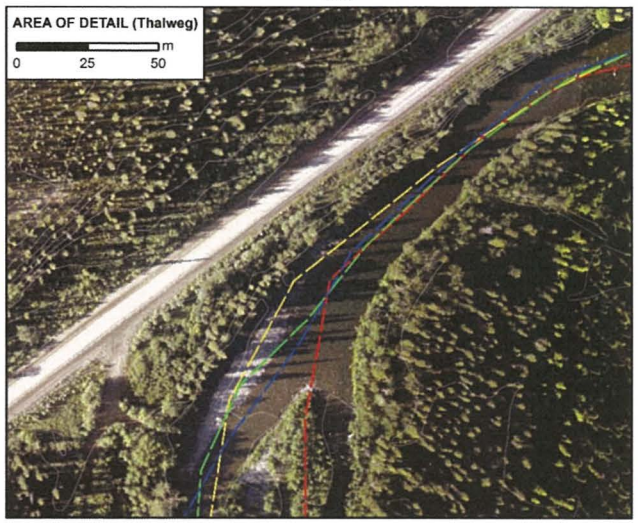
KRYOTEK

Project: Dempster Meander Migration Hazards
Project number: 14132
Client: Yukon Government

KM 52.3





LEGEND

- Kilometre post
- Highway embankment impact zone
- Current extent of riprap
- 1 m contours

Channel banks (year)

- 2013/ 2014
- 2007/2008
- 1989
- 1977

Thalweg (year)

- 2013/2014
- 2007/2008
- 1989
- 1977

- Direction of flow
- 1˚ migration rate (m/yr)
- 2˚ migration rate (m/yr)

NOTE: Refer to accompanying report for definitions, rationale for erosion rate estimates, and an appendix with additional site-specific data. Original page size 11.00 x 17.00 in. Coordinate system NAD 1983 Yukon Albers; units metre. Tk = thaw-unstable karst confidence rating.

SITE	CHANNEL	MEANDER	RIPRAP REQUIREMENTS
Section	**Setting**	**1˚ migration rate (m/yr)**	**Timeframe until impact (yr)**
Klondike	Hwy edge fluvial plain	-	-
Watercourse	**Permafrost**	**1˚ trajectory**	**Lateral extent (m)**
North Klondike R.	Deep, ice-moderate	-	-
Riprap history	**Bank height (m)**	**2˚ migration rate (m/yr)**	**Slope length (m)**
No riprap	5.9	-	-
Hwy-watercourse proximity (m)	**Low-flow width (m)**	**2˚ trajectory**	**Thickness (m)**
7	22	-	-
Position in meander belt	**Bankfull width (m)**	**Confinement**	**Volume (m^3)**
Edge	25	Confined by highway	-

MEANDER MORPHOLOGY AND DYNAMICS

This encroachment site is located within a partly confined, irregularly meandering reach of North Klondike River. Migration rates throughout the reach, including in the vicinity of the encroachment site, have been low over the period of record. Locally, the highway embankment has confined the channel and maintained an unnaturally straight channel planform. Confined channels commonly migrate longitudinally; however, no significant longitudinal migration has occurred at this site, likely due to the channel's near-parallel orientation relative to the highway and lack of cross-sectional asymmetry. Minor bank slumping is occurring near the downstream end of the encroachment site. No intervention is recommended at this encroachment site at this time due to the relative stability documented over the past several decades.

IMPLICATIONS OF RIPRAP APPLICATION

Riprap application, if required in the future, could cause longitudinal channel migration, potentially exposing the highway embankment and side road immediately downstream to erosion if not extended far enough downstream.

ALTERNATIVE EROSION PROTECTION STRATEGIES

N/A

SPECIAL CONSIDERATIONS

The bank slumping observed during 2016 field reconnaissance near the downstream end of the encroachment site should be monitored to ensure the highway embankment does not become undercut if slumping continues.

Yukon Government

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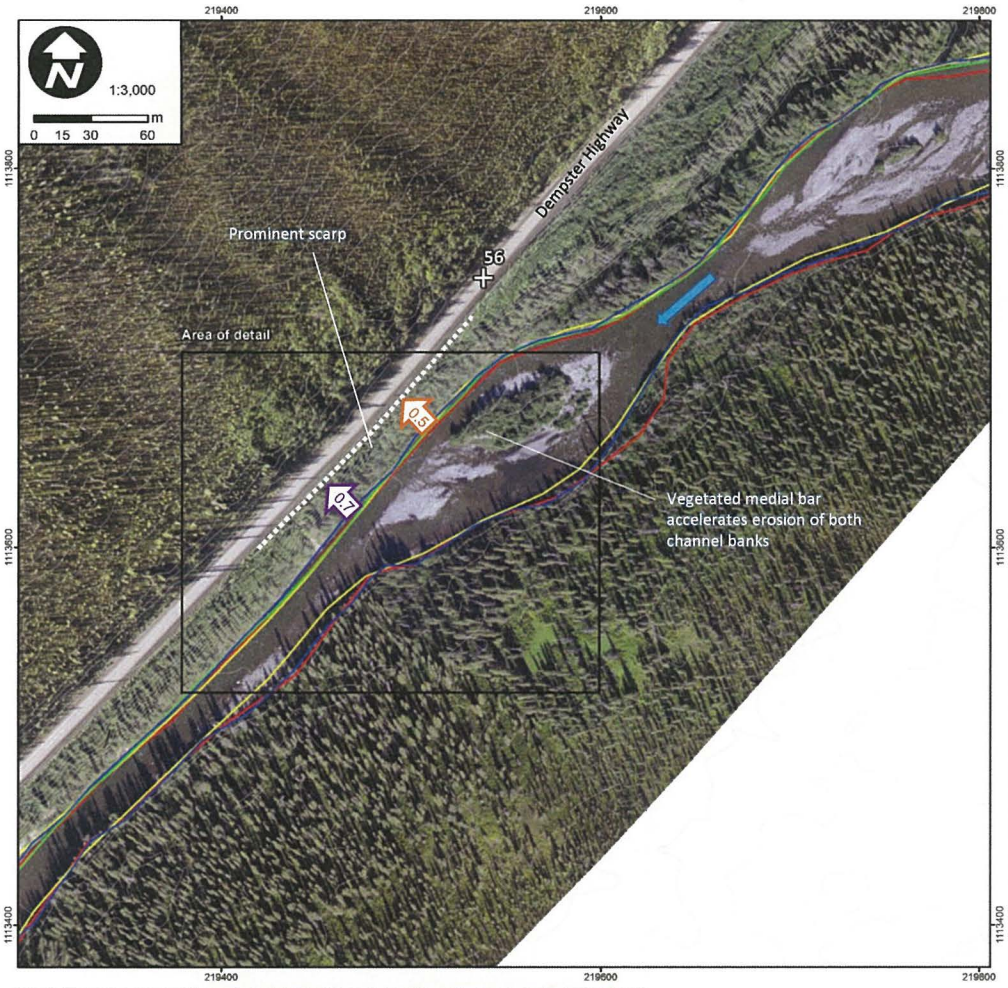
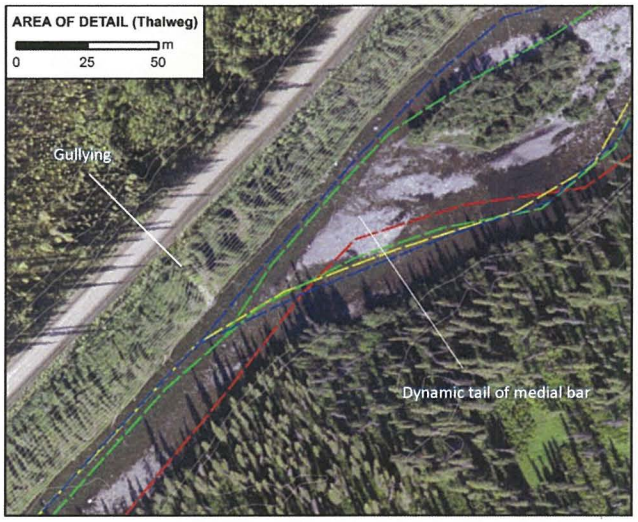
Project number: 14132
Client: Yukon Government

KM 54.9





LEGEND

- Kilometre post
- Highway embankment impact zone
- Current extent of riprap
- 1 m contours

Channel banks (year)

- 2013/ 2014
- 2007/2008
- 1989
- 1977

Thalweg (year)

- 2013/2014
- 2007/2008
- 1989
- 1977

- Direction of flow
- 1° migration rate (m/yr)
- 2° migration rate (m/yr)

NOTE: Refer to accompanying report for definitions, rationale for erosion rate estimates, and an appendix with additional site-specific data. Original page size 11.00 x 17.00 in. Coordinate system NAD 1983 Yukon Albers; units: metres. Tk = thermokarst evidence nearby.

SITE	CHANNEL	MEANDER	RIPRAP REQUIREMENTS
Section	**Setting**	**1° migration rate (m/yr)**	**Timeframe until impact (yr)**
Klondike	Colluvial toe slope	0.7	>25
Watercourse	**Permafrost**	**1° trajectory**	**Lateral extent (m)**
North Klondike R.	Deep, ice-moderate	NW	170
Riprap history	**Bank height (m)**	**2° migration rate (m/yr)**	**Slope length (m)**
No riprap	11.9	0.5	31.7
Hwy-watercourse proximity (m)	**Low-flow width (m)**	**2° trajectory**	**Thickness (m)**
20	53	NW	1
Position in meander belt	**Bankfull width (m)**	**Confinement**	**Volume (m^3)**
Edge	57	Naturally confined	5,391

MEANDER MORPHOLOGY AND DYNAMICS

This encroachment site is located within a partly confined, irregularly meandering reach of North Klondike River. Migration rates throughout the reach, including in the vicinity of the encroachment site, have been low over the period of record. The encroachment site itself is at the edge of the meander belt, which limits lateral migration potential. Furthermore, the highway is perched atop a natural, ~10 m-high slope-toe scarp, which confines the channel. Small, shallow slope failures and gullying have occurred along this scarp below the highway embankment. A large, vegetated medial bar bifurcates flow immediately adjacent to the encroachment site. The bar has been reworked over the period of record. No intervention is recommended at this encroachment site due to the relative stability documented over the past several decades.

IMPLICATIONS OF RIPRAP APPLICATION

Riprap application does not pose further risk to infrastructure.

ALTERNATIVE EROSION PROTECTION STRATEGIES

N/A

SPECIAL CONSIDERATIONS

Estimates of the timeframe of impact are less reliable in confined settings, such as this, due to potential interactions between fluvial and hillslope processes. No significant slope failures were observed during 2016 field reconnaissance.

Yukon Government

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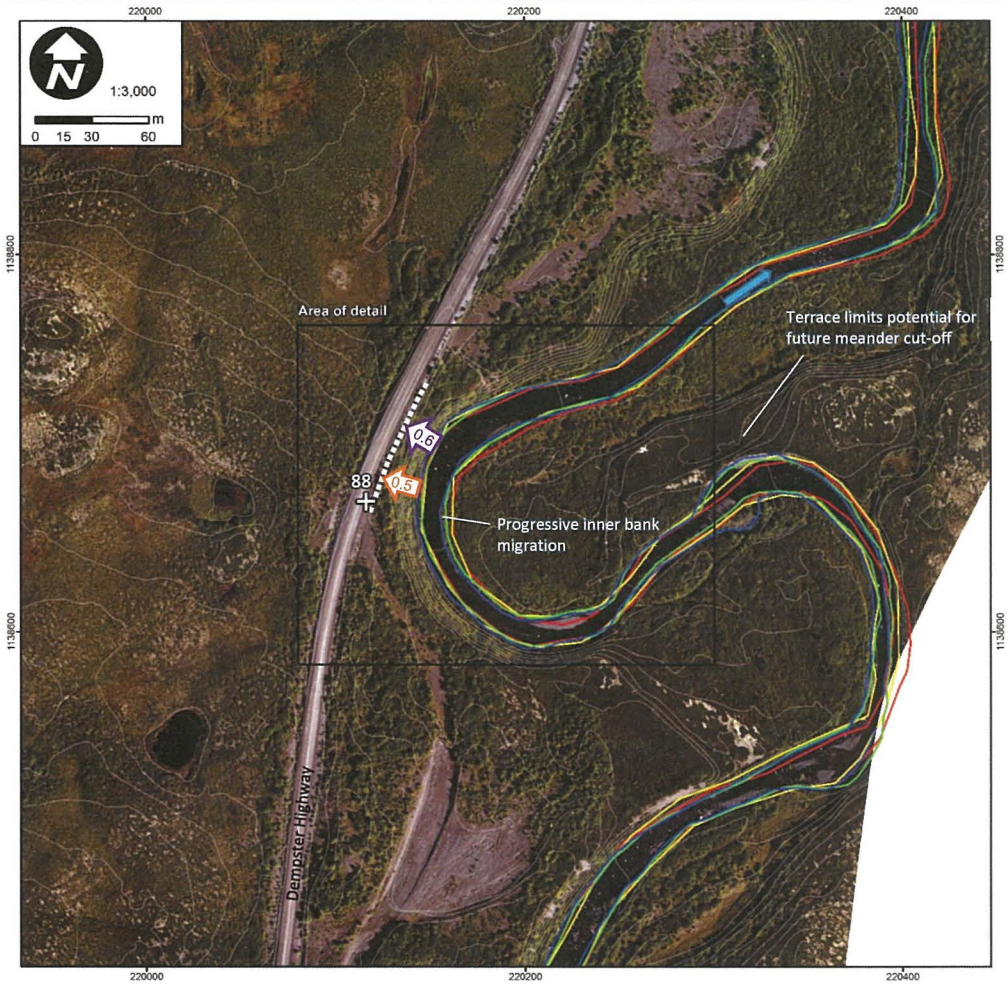
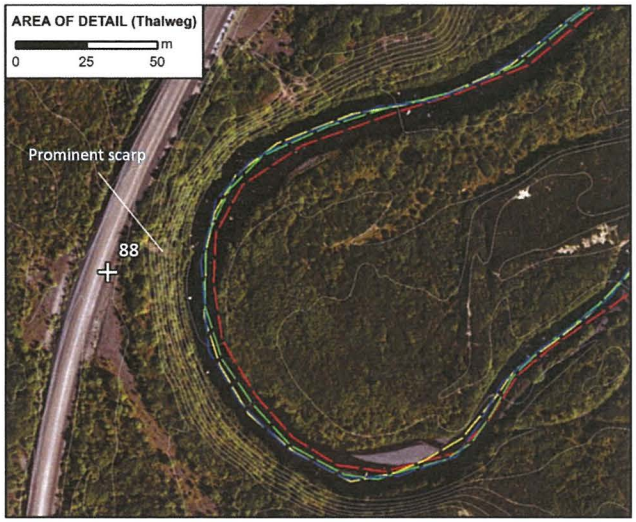
Project: Dempster Meander Migration Hazards
Project number: 14132
Client: Yukon Government

KM 55.9





LEGEND

- Kilometre post
- Highway embankment impact zone
- Current extent of riprap
- 1 m contours

Channel banks (year)

- 2013/ 2014
- 2007/2008
- 1989
- 1977

Thalweg (year)

- 2013/2014
- 2007/2008
- 1989
- 1977

- Direction of flow
- 1˚ migration rate (m/yr)
- 2˚ migration rate (m/yr)

NOTE: Refer to accompanying report for definitions, rationale for erosion rate estimates, and an appendix with additional site-specific data. Original page size 11.00 x 17.00 in. Coordinate system NAD 1983 Yukon Albers; units: metres. Tk = thermokarst evidence nearby.

SITE	CHANNEL	MEANDER	RIPRAP REQUIREMENTS
Section	**Setting**	**1˚ migration rate (m/yr)**	**Timeframe until impact (yr)**
Klondike	Morainal scarp	0.6	21-25
Watercourse	**Permafrost**	**1˚ trajectory**	**Lateral extent (m)**
East Blackstone R.	Deep, ice-poor	WNW	75
Riprap history	**Bank height (m)**	**2˚ migration rate (m/yr)**	**Slope length (m)**
No riprap	7.5	0.5	22.1
Hwy-watercourse proximity (m)	**Low-flow width (m)**	**2˚ trajectory**	**Thickness (m)**
15	19	W	1
Position in meander belt	**Bankfull width (m)**	**Confinement**	**Volume (m^3)**
Edge	22	Naturally confined	1,658

MEANDER MORPHOLOGY AND DYNAMICS

This encroachment site is located along a partly confined, irregularly meandering tributary of East Blackstone River. Migration rates throughout the reach, including in the vicinity of the encroachment site, have been low over the period of record. The encroachment site itself is at the edge of the meander belt, which limits lateral migration potential. Furthermore, the highway is perched atop a natural, ~8 m-high scarp, which confines the channel. No intervention is recommended at this encroachment site due to the low lateral migration and planform stability documented over the past several decades.

IMPLICATIONS OF RIPRAP APPLICATION

Riprap application could initiate longitudinal migration, potentially exposing the side road immediately downstream to erosion if not extended far enough downstream.

ALTERNATIVE EROSION PROTECTION STRATEGIES

N/A

SPECIAL CONSIDERATIONS

Estimates of the timeframe of impact are less reliable in confined settings, such as this, due to potential interactions between fluvial and hillslope processes. No significant slope failures were observed during 2016 field reconnaissance.

Yukon Government

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Project: Dempster Meander Migration Hazards
Project number: 14132
Client: Yukon Government

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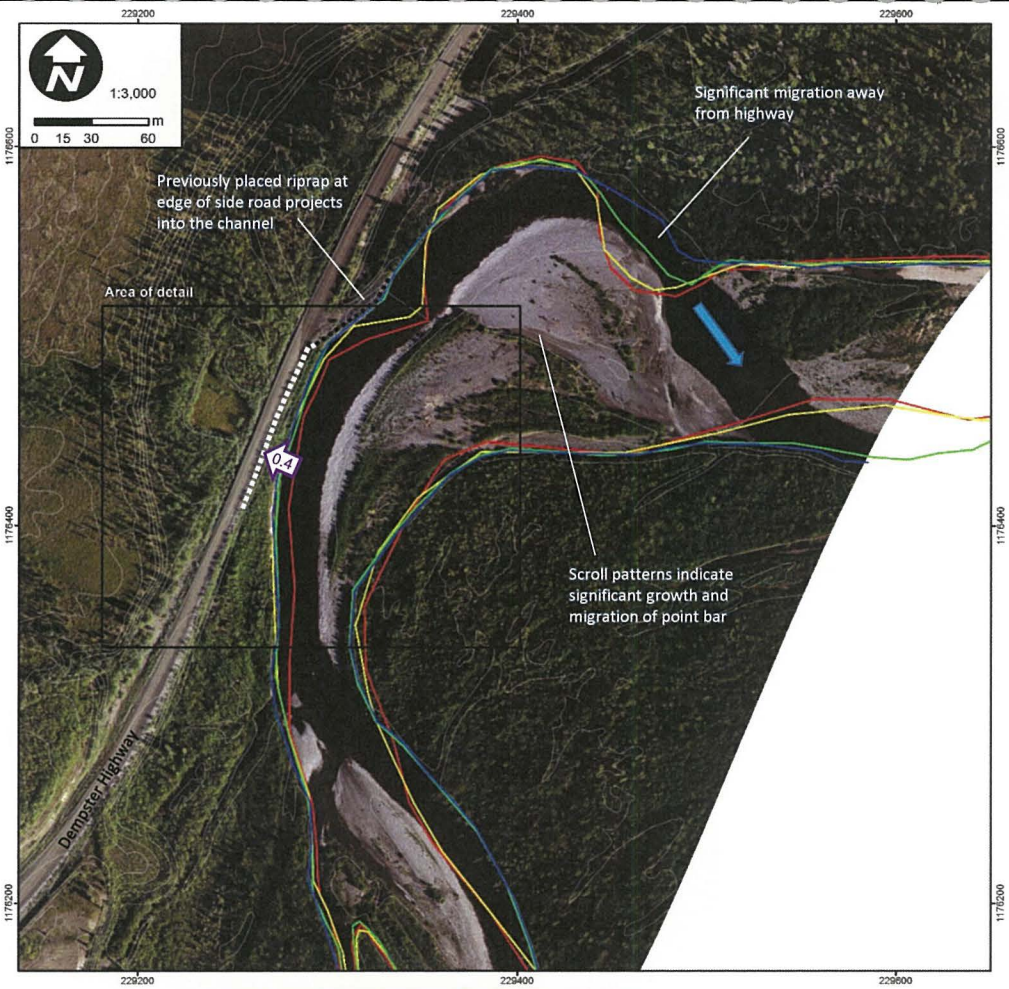

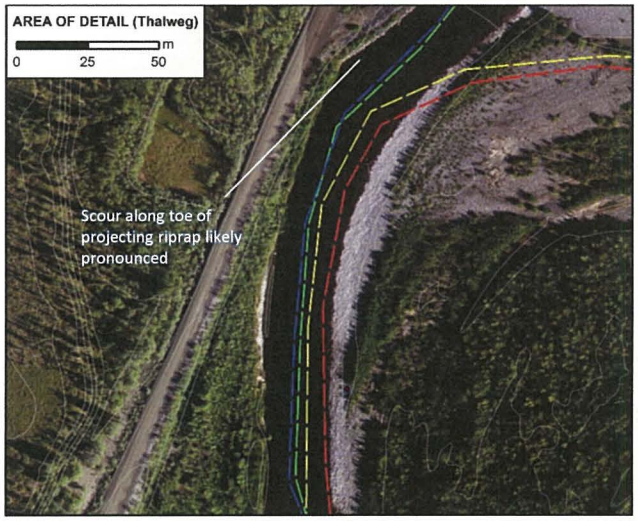

LEGEND

- Kilometre post
- Highway embankment impact zone
- Current extent of riprap
- 1 m contours

Channel banks (year)

- 2013/ 2014
- 2007/2008
- 1989
- 1977

Thalweg (year)

- 2013/2014
- 2007/2008
- 1989
- 1977

- Direction of flow
- 1° migration rate (m/yr)
- 2° migration rate (m/yr)

NOTE: Refer to accompanying report for definitions, rationale for erosion rate estimates, and an appendix with additional site-specific data. Original page size 11.00 x 17.00 in. Coordinate system NAD 1983 Yukon Albers; units: metres. Tk = thermokarst evidence nearby.

SITE	CHANNEL	MEANDER	RIPRAP REQUIREMENTS
Section	**Setting**	**1° migration rate (m/yr)**	**Timeframe until impact (yr)**
Klondike/Ogilvie	Hwy edge fluvial plain	0.4	21-25
Watercourse	**Permafrost**	**1° trajectory**	**Lateral extent (m)**
Blackstone River	Deep, ice-moderate	W	100
Riprap history	**Bank height (m)**	**2° migration rate (m/yr)**	**Slope length (m)**
2004	1.1	-	6.5
Hwy-watercourse proximity (m)	**Low-flow width (m)**	**2° trajectory**	**Thickness (m)**
6	24	-	1
Position in meander belt	**Bankfull width (m)**	**Confinement**	**Volume (m^3)**
Within	75	Confined by highway	648

MEANDER MORPHOLOGY AND DYNAMICS

This encroachment site is located within a partly confined, wandering gravel-bed reach of Blackstone River. The channel formally occupied the west (i.e. opposite) side of the Dempster Highway well before the earliest aerial photography (1977) and highway construction. The channel exhibits a compound meander form, with two slight bends superimposed on the main meander, although this form has become less pronounced over the past several decades. Significant lateral migration downstream of the encroachment site between 1989 and 2007 resulted in the downstream arm of the meander occupying a relic meander scar. At the encroachment site itself, the highway embankment and recently applied riprap have largely inhibited lateral migration. Migration rates and localized bank scour should be monitored upstream of the existing riprap. Immediate intervention is not required.

IMPLICATIONS OF RIPRAP APPLICATION

Previously placed riprap projects into the channel and has accelerated longitudinal migration. A side road that diverges from the highway immediately downstream of the encroachment site may be at risk of erosion in the long-term (>25 years).

ALTERNATIVE EROSION PROTECTION STRATEGIES

Previously placed riprap that projects into the channel has locally shifted the thalweg eastward, acting much like a flow-retarding bar ('hockey stick' weir) river training structure. Additional river training measures with the same downstream orientation and bankfull height could be constructed upstream of the previously placed riprap to shift the concentration of energy away from the highway embankment.

SPECIAL CONSIDERATIONS

Scour may be pronounced along the toe of the isolated projection of riprap. No significant evidence of riprap instability was observed during 2016 field reconnaissance.

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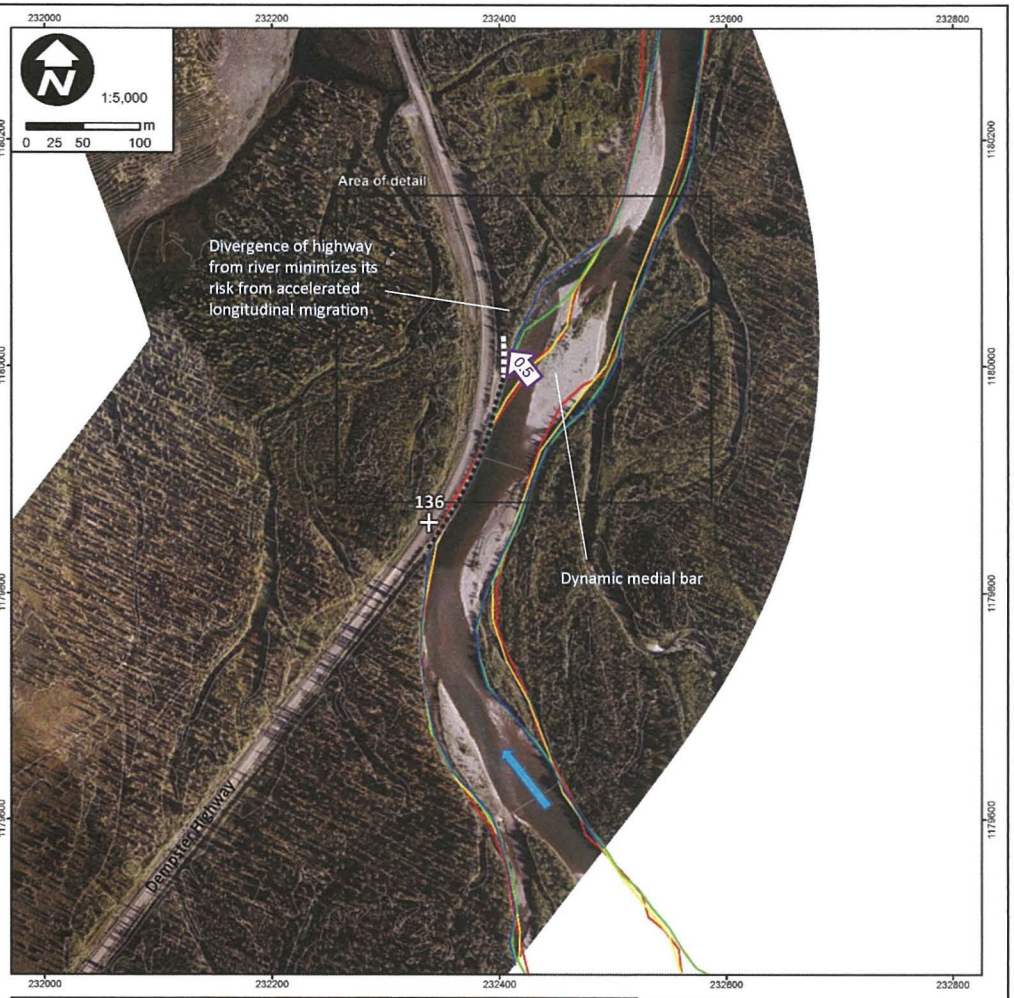
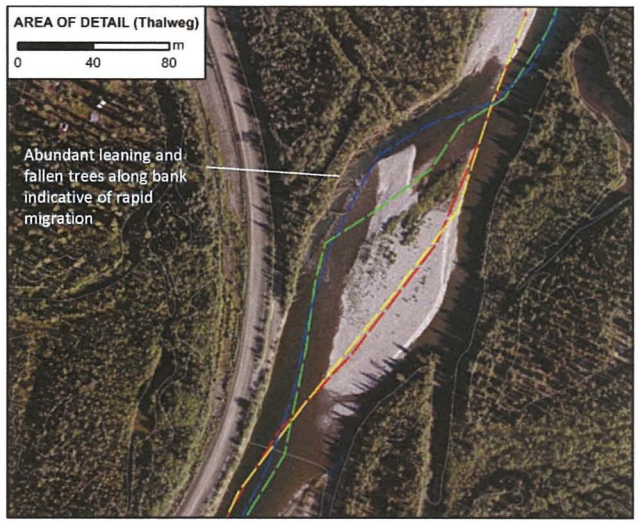
KRYOTEK

Project: Dempster Meander Migration Hazards
Project number: 14132
Client: Yukon Government

KM 131.4





LEGEND

- Kilometre post
- Highway embankment impact zone
- Current extent of riprap
- 1 m contours

Channel banks (year)

- 2013/ 2014
- 2007/2008
- 1989
- 1977

Thalweg (year)

- 2013/2014
- 2007/2008
- 1989
- 1977

- Direction of flow
- 1˚ migration rate (m/yr)
- 2˚ migration rate (m/yr)

NOTE: Refer to accompanying report for definitions, rationale for erosion rate estimates, and an appendix with additional site-specific data. Original page size 11.00 x 17.00 in. Coordinate system NAD 1983 Yukon Albers; units: metres. Tk = thermokarst evidence nearby.

SITE	CHANNEL	MEANDER	RIPRAP REQUIREMENTS
Section	**Setting**	**1˚ migration rate (m/yr)**	**Timeframe until impact (yr)**
Klondike/Ogilvie	Fluvial plain	0.5	11-15
Watercourse	**Permafrost**	**1˚ trajectory**	**Lateral extent (m)**
Blackstone River	Shallow, ice-moderate	NW	40
Riprap history	**Bank height (m)**	**2˚ migration rate (m/yr)**	**Slope length (m)**
Unknown	0.1	-	2.5
Hwy-watercourse proximity (m)	**Low-flow width (m)**	**2˚ trajectory**	**Thickness (m)**
4	27	-	1
Position in meander belt	**Bankfull width (m)**	**Confinement**	**Volume (m³)**
Within	94	Confined by highway	98

MEANDER MORPHOLOGY AND DYNAMICS

This encroachment site is located within a partly confined, wandering gravel-bed reach of Blackstone River. Riprap has been placed alongside the highway embankment, which has limited lateral migration and caused significant longitudinal migration (70 m between 1989 and 2007). The encroachment site is within the meander belt, which suggests the channel would migrate farther west if not confined by the riprapped embankment. A large, unvegetated medial bar bifurcates flow at the downstream end of the encroachment site. The bar is a transient feature and could influence the future position of the thalweg. Without intervention, longitudinal channel migration immediately downstream of the existing riprap will likely impact the highway in 11 to 15 years.

IMPLICATIONS OF RIPRAP APPLICATION

Previous riprap application has accelerated longitudinal migration. More riprap may be required downstream of the current extent of riprap to protect the highway embankment.

ALTERNATIVE EROSION PROTECTION STRATEGIES

River training structures could be constructed downstream of the previously placed riprap to shift erosive energy away from the unprotected bank. If a form of weir or bar structure were used, few would be needed due to the short length of at-risk highway embankment. River training structures would require a similar amount of material as simply riprapping the embankment but would likely reduce the frequency and costs of maintenance if designed appropriately.

SPECIAL CONSIDERATIONS

Due to the longitudinal nature of the observed bank migration, it is possible that the embankment immediately downstream of the previously placed riprapped could be impacted prior to the timeframe estimated along the main trajectory of erosion. The low bank height and anecdotal evidence of previous highway overtopping during a flood indicate future potential for a breach in the highway.

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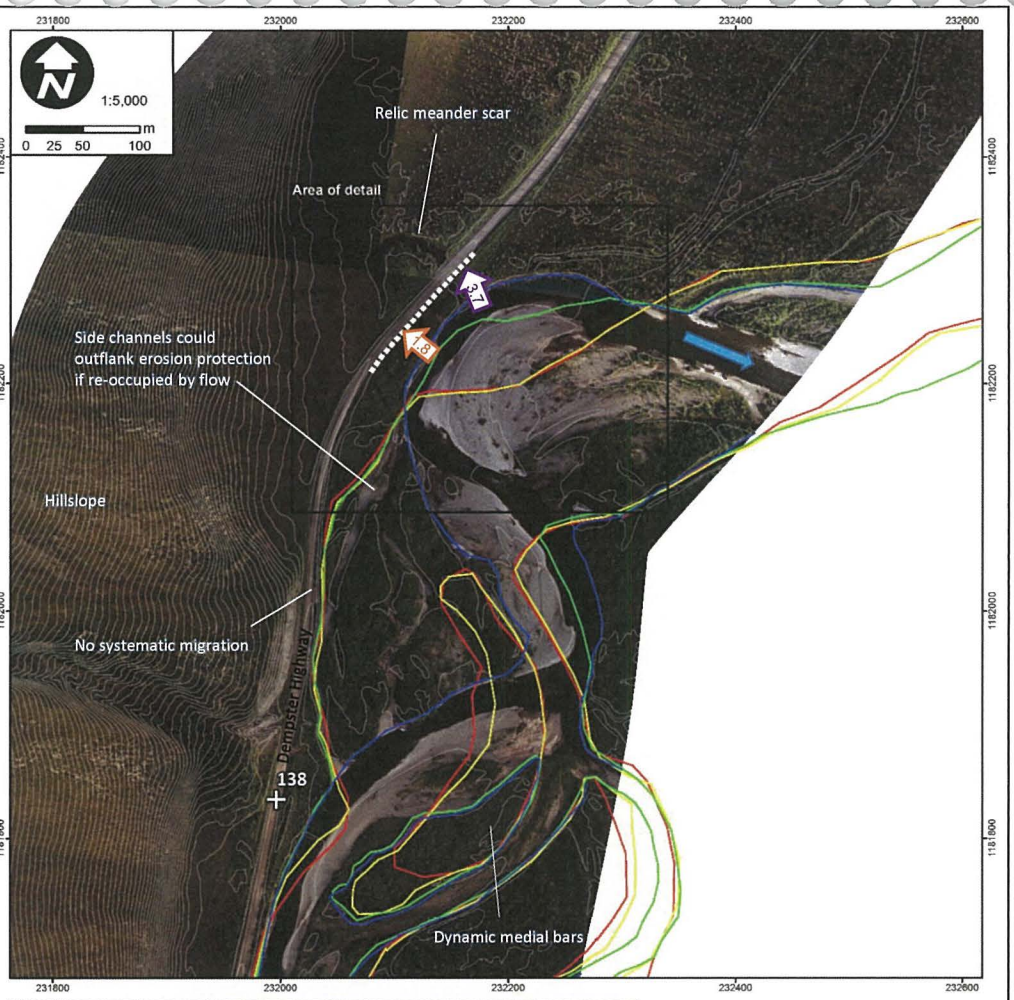
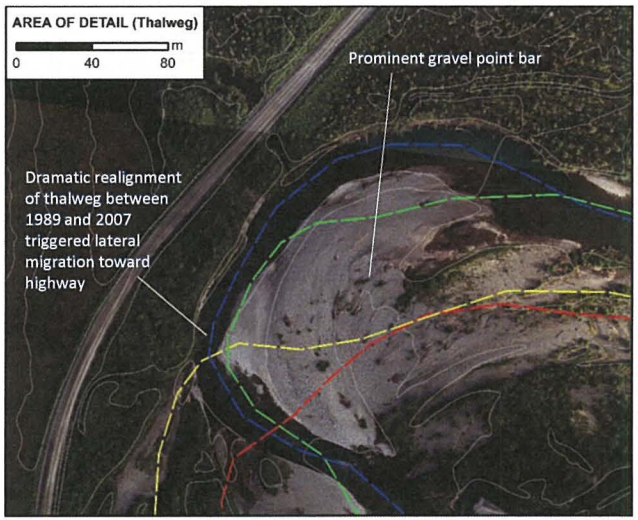
Project number: 14132
Client: Yukon Government

KM 136.1





LEGEND

- Kilometre post
- Highway embankment impact zone
- Current extent of riprap
- 1 m contours

Channel banks (year)

- 2013/ 2014
- 2007/2008
- 1989
- 1977

Thalweg (year)

- 2013/2014
- 2007/2008
- 1989
- 1977

- Direction of flow
- 1˚ migration rate (m/yr)
- 2˚ migration rate (m/yr)

NOTE: Refer to accompanying report for definitions, rationale for erosion rate estimates, and an appendix with additional site-specific data. Original page size 11.00 x 17.00 in. Coordinate system NAD 1983 Yukon Albers; units: metres. Tk = thermokarst evidence nearby.

SITE	CHANNEL	MEANDER	RIPRAP REQUIREMENTS
Section	**Setting**	**1˚ migration rate (m/yr)**	**Timeframe until impact (yr)**
Klondike/Ogilvie	Fluvial plain	3.7	6-10
Watercourse	**Permafrost**	**1˚ trajectory**	**Lateral extent (m)**
Blackstone River	Deep, ice-moderate	NNW	140
Riprap history	**Bank height (m)**	**2˚ migration rate (m/yr)**	**Slope length (m)**
No riprap	2.1	1.8	7.6
Hwy-watercourse proximity (m)	**Low-flow width (m)**	**2˚ trajectory**	**Thickness (m)**
21	20	WNW	1
Position in meander belt	**Bankfull width (m)**	**Confinement**	**Volume (m^3)**
Within	140	Unconfined	1,063

MEANDER MORPHOLOGY AND DYNAMICS

This encroachment site is located within an unconfined, wandering gravel-bed reach of Blackstone River. At the reach-scale, the channel has developed a more sinuous planform over the period of record through significant lateral migration. The encroachment site is within the meander belt, which suggests the channel could migrate farther west. In the vicinity of the encroachment site, the channel evolved from two threads to one dominant thread between 1989 and 2007, which would have concentrated erosive energy and increased the potential for lateral migration. Without intervention, continued lateral migration will likely impact the highway embankment within 6 to 10 years.

IMPLICATIONS OF RIPRAP APPLICATION

Riprap application does not pose further risk to infrastructure.

ALTERNATIVE EROSION PROTECTION STRATEGIES

N/A

SPECIAL CONSIDERATIONS

If this wandering channel were to re-adopt its pattern from 1989, there may be increased potential for erosion farther upstream than is predicted based on the more recent (2007 and 2013) planform.

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Project number: 14132
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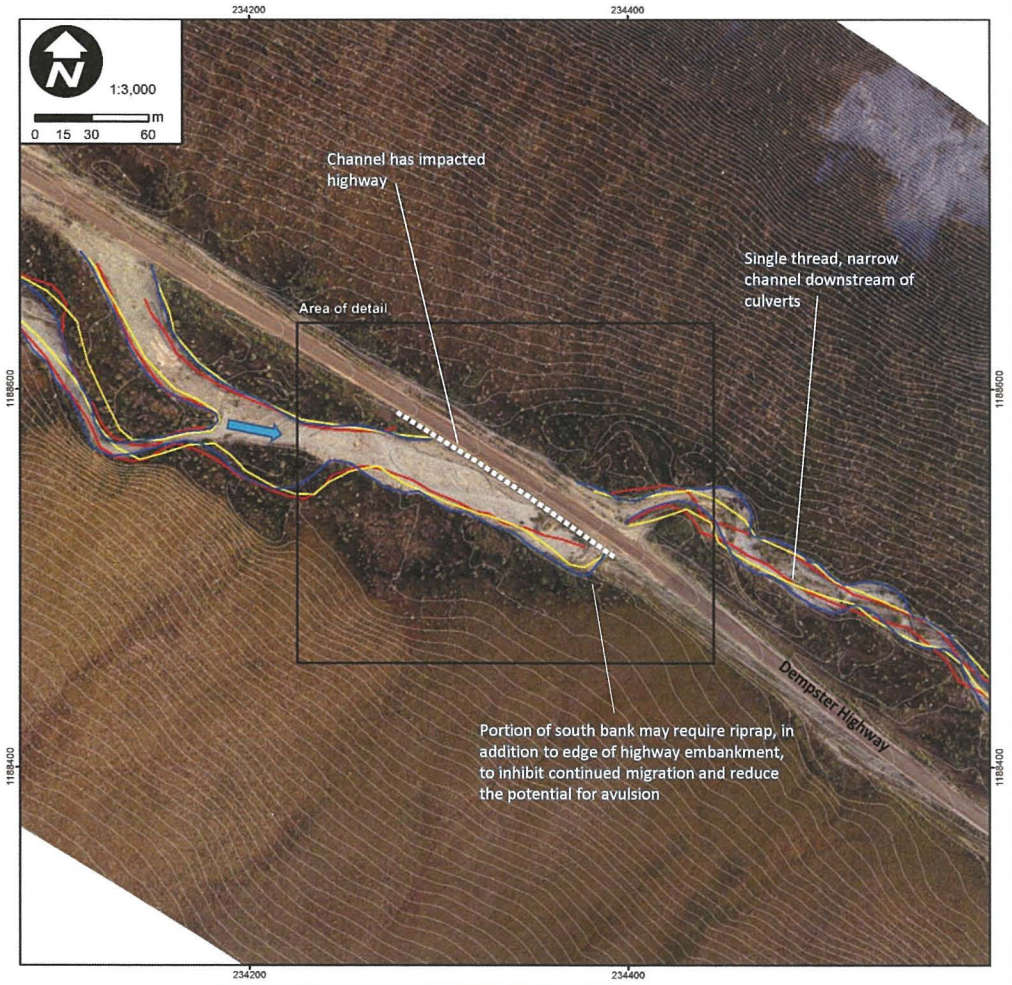

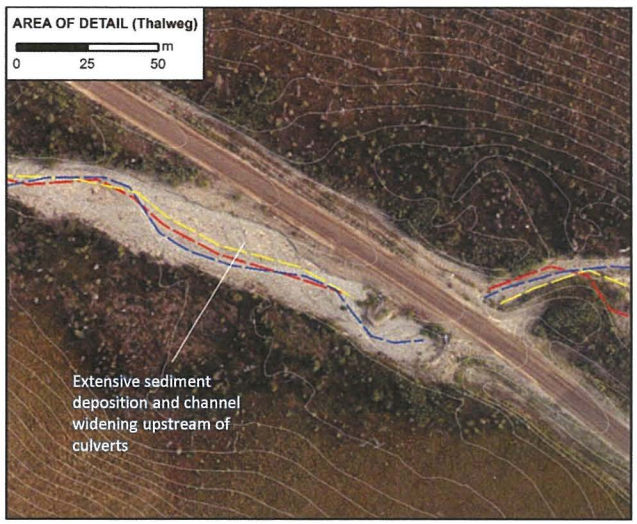

LEGEND

- Kilometre post
- Highway embankment impact zone
- Current extent of riprap
- 1 m contours

Channel banks (year)

- 2013/ 2014
- 2007/2008
- 1989
- 1977

Thalweg (year)

- 2013/2014
- 2007/2008
- 1989
- 1977
- Direction of flow
- 1° migration rate (m/yr)
- 2° migration rate (m/yr)

NOTE: Refer to accompanying report for definitions, rationale for erosion rate estimates, and an appendix with additional site-specific data. Original page size 11.00 x 17.00 in. Coordinate system NAD 1983 Yukon Albers; units: metres. Tk = thermokarst evidence nearby.

SITE	CHANNEL	MEANDER	RIPRAP REQUIREMENTS
Section	**Setting**	**1° migration rate (m/yr)**	**Timeframe until impact (yr)**
Klondike/Ogilvie	Hwy edge fluvial plain	-	0 (impacted)
Watercourse	**Permafrost**	**1° trajectory**	**Lateral extent (m)**
Blackstone Trib.	Deep, ice-moderate	NA	140
Riprap history	**Bank height (m)**	**2° migration rate (m/yr)**	**Slope length (m)**
No riprap	0.5	-	3.8
Hwy-watercourse proximity (m)	**Low-flow width (m)**	**2° trajectory**	**Thickness (m)**
0	5	-	1
Position in meander belt	**Bankfull width (m)**	**Confinement**	**Volume (m^3)**
Within	25	Confined by highway	532

MEANDER MORPHOLOGY AND DYNAMICS

This encroachment site is located within a relatively steep, confined, ephemeral tributary of Blackstone River. The channel likely flows during the spring freshet and significant summer and fall rain events. Large accumulations of coarse gravel throughout the reach suggest bedload transport is high during flow events, potentially briefly occurring as a debris flood. There is an anomalously wide deposit of sediment immediately upstream of the Dempster Highway crossing/encroachment site, likely caused by the upstream convergence of two branches of the creek and by undersized or temporarily obstructed culverts beneath the highway. The active channel appears to be in contact with the highway over the period of record, although recent anthropogenic alteration of this encroachment observed during 2016 field reconnaissance has erased most field evidence of local channel morphology and behaviour. A large flow event could cause significant damage to the highway or lead to a channel avulsion.

IMPLICATIONS OF RIPRAP APPLICATION

Riprap application along the highway embankment could exacerbate erosion of the south bank, at the culvert inlets, potentially exposing the highway embankment immediately downstream to erosion and increasing the potential for avulsion if not extended to also protect this portion of the south bank.

ALTERNATIVE EROSION PROTECTION STRATEGIES

N/A

SPECIAL CONSIDERATIONS

The twin culverts beneath the highway appear to be impounding high flows and potentially becoming at least partly obstructed by sediment, which has resulted in deposition and channel widening upstream. Annual dredging of sediment at culvert inlets may be required. If highway impacts or maintenance are recurrent and significant, consideration should be given to replacing the culverts with a larger structure (e.g. box culvert or bridge) with improved capacity to convey storm flows and bedload.

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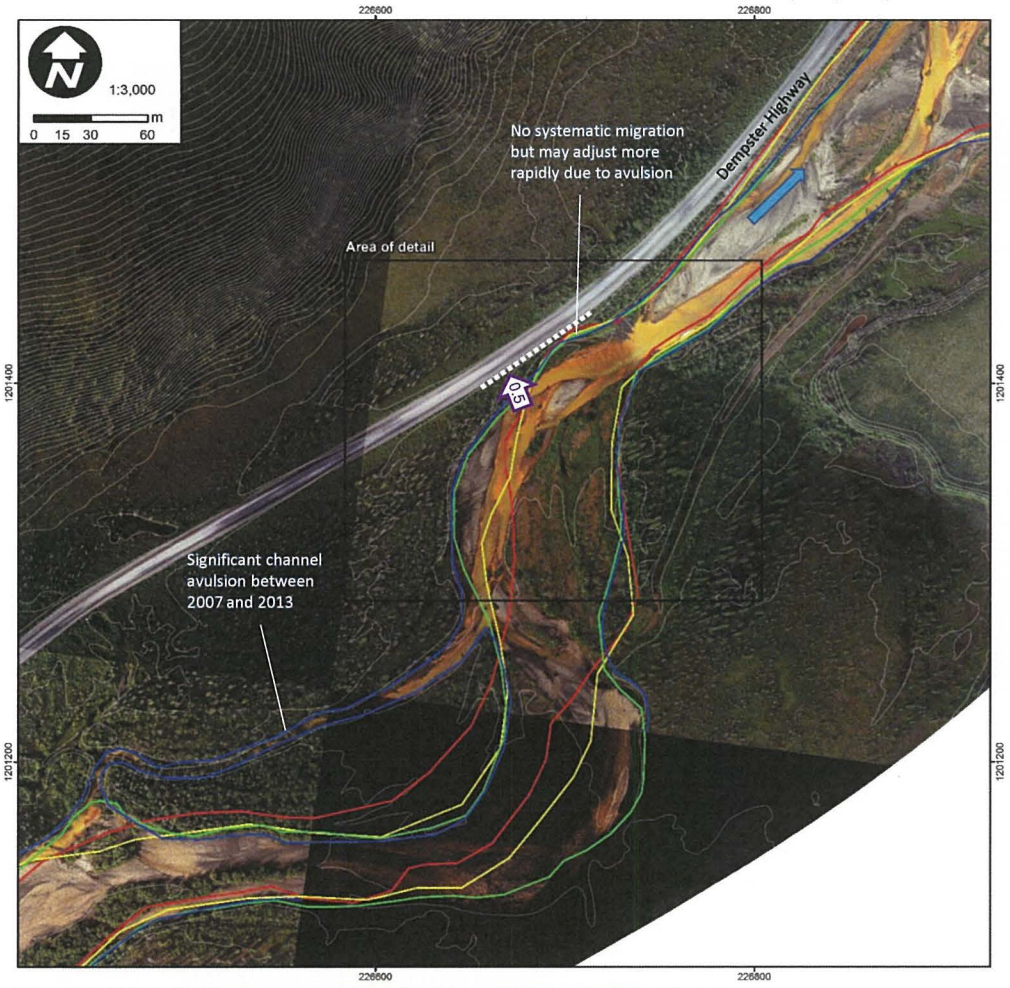

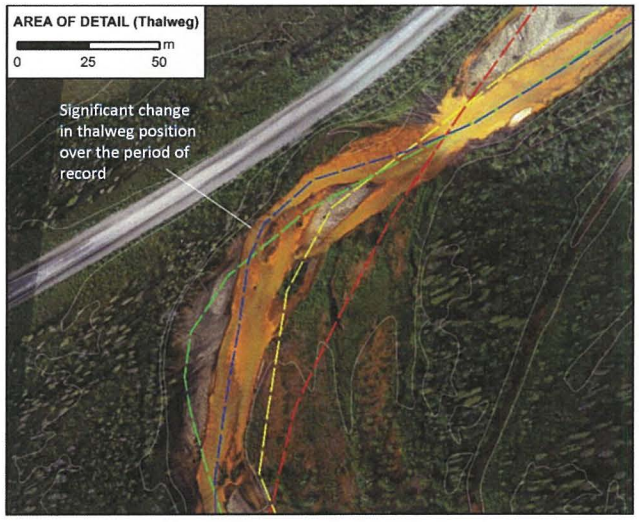

LEGEND

- Kilometre post
- Highway embankment impact zone
- Current extent of riprap
- 1 m contours

Channel banks (year)

- 2013/ 2014
- 2007/2008
- 1989
- 1977

Thalweg (year)

- 2013/2014
- 2007/2008
- 1989
- 1977

- Direction of flow
- 1° migration rate (m/yr)
- 2° migration rate (m/yr)

NOTE: Refer to accompanying report for definitions, rationale for erosion rate estimates, and an appendix with additional site-specific data. Original page size 11.00 x 17.00 in. Coordinate system NAD 1983 Yukon Albers; units: metres. Tk = thermokarst evidence nearby.

SITE	CHANNEL	MEANDER	RIPRAP REQUIREMENTS
Section	**Setting**	**1° migration rate (m/yr)**	**Timeframe until impact (yr)**
Ogilvie	Hwy edge fluvial plain	0.5	6-10
Watercourse	**Permafrost**	**1° trajectory**	**Lateral extent (m)**
Engineer Creek	Shallow, ice-rice, Tk	NNW	70
Riprap history	**Bank height (m)**	**2° migration rate (m/yr)**	**Slope length (m)**
No riprap	0.3	-	4.9
Hwy-watercourse proximity (m)	**Low-flow width (m)**	**2° trajectory**	**Thickness (m)**
3	18	-	1
Position in meander belt	**Bankfull width (m)**	**Confinement**	**Volume (m^3)**
Within	33	Unconfined	344

MEANDER MORPHOLOGY AND DYNAMICS

This encroachment site is located within a partly confined, wandering gravel-bed reach of Engineer Creek. Lateral migration rates throughout the reach are relatively high, gravel bars are extensive and dynamic, and channel avulsions are frequent. Locally, the encroachment site is within the meander belt, which suggests the channel could migrate farther west if it were not confined by the highway. A significant channel avulsion occurred between 2007 and 2013 immediately upstream of the encroachment site, which drastically altered the position of the thalweg and will undoubtedly lead to future morphological adjustments. Shallow, ice-rich permafrost that likely persists in portions of this disturbed site may lead to irregular and episodic bank erosion and collapse. Without intervention, continued lateral migration will likely impact the highway embankment within 6 to 10 years, if not sooner due to forecasted avulsion-induced changes in lateral migration trajectories and rates.

IMPLICATIONS OF RIPRAP APPLICATION

Riprap application could initiate longitudinal migration, potentially exposing the highway embankment immediately downstream to erosion if not extended far enough downstream.

ALTERNATIVE EROSION PROTECTION STRATEGIES

Partial excavation of the gravelly inner bank of the meander could help increase local hydraulic capacity and draw the thalweg away from the outer bank, thereby reducing shear stresses along the outer bank. Approximately 800 m^3 of material would likely require excavation (and disposal outside the floodplain), and such earthworks would be outside the highway right-of-way.

SPECIAL CONSIDERATIONS

It is not clear how channel morphology and dynamics in the vicinity of the encroachment site are going to respond to the channel avulsion that occurred upstream of the encroachment site between 2007 and 2013. Monitoring is recommended at this site, in particular, given the potential for the recent avulsion to affect local channel stability and bank erosion patterns.

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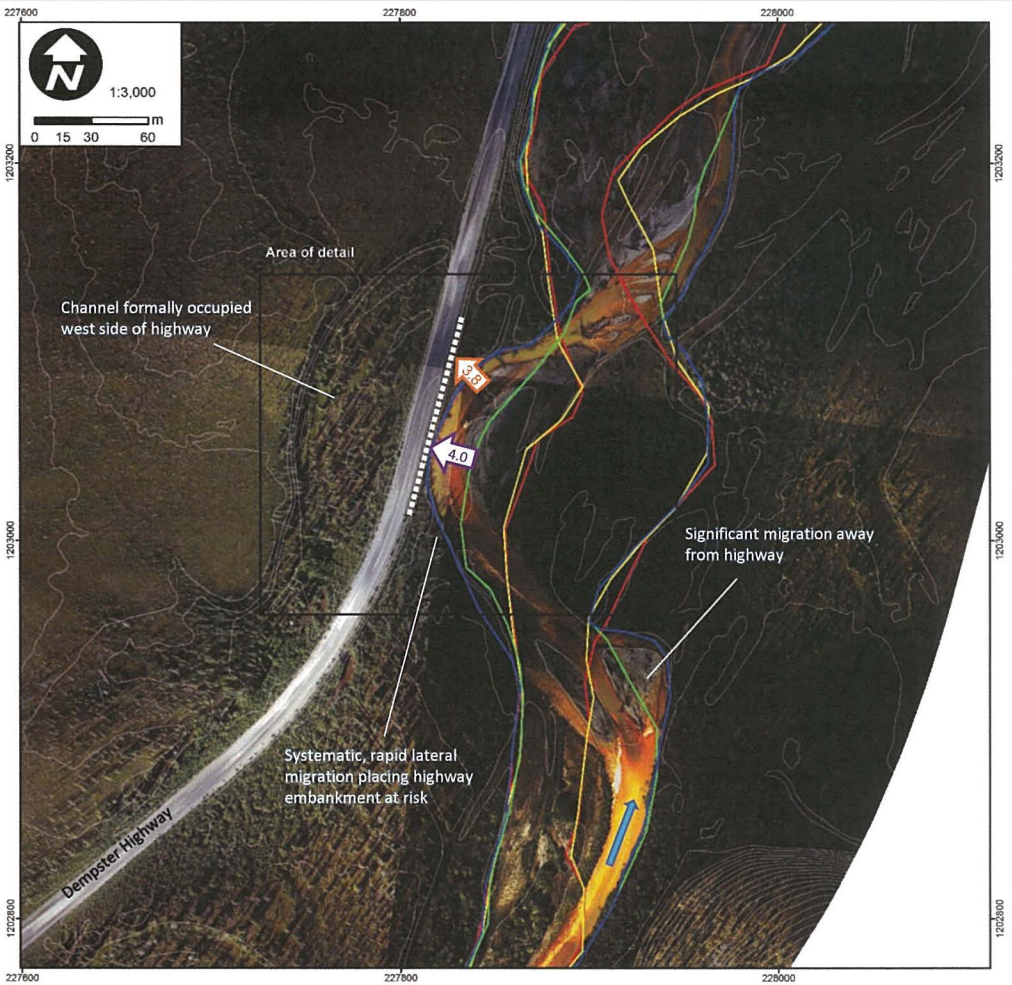

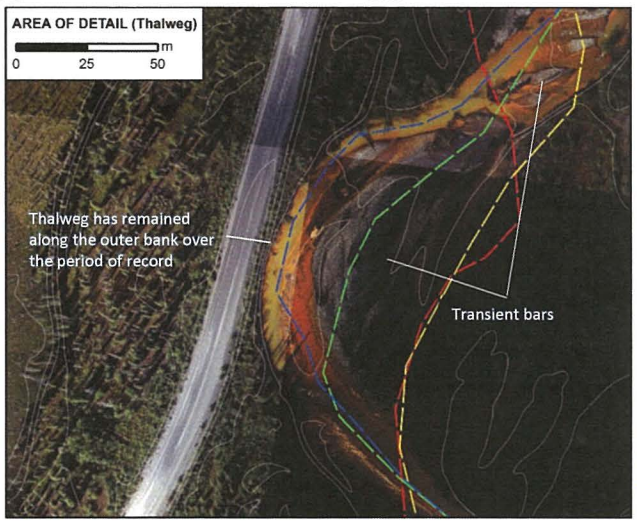

LEGEND

- Kilometre post
- Highway embankment impact zone
- Current extent of riprap
- 1 m contours

Channel banks (year)

- 2013/ 2014
- 2007/2008
- 1989
- 1977

Thalweg (year)

- 2013/2014
- 2007/2008
- 1989
- 1977

- Direction of flow
- 1˚ migration rate (m/yr)
- 2˚ migration rate (m/yr)

NOTE: Refer to accompanying report for definitions, rationale for erosion rate estimates, and an appendix with additional site-specific data. Original page size 11.00 x 17.00 in. Coordinate system NAD 1983 Yukon Albers; units metres. Tk = Takhini-Kopper King ash evidence nearby.

SITE	CHANNEL	MEANDER	RIPRAP REQUIREMENTS
Section	**Setting**	**1˚ migration rate (m/yr)**	**Timeframe until impact (yr)**
Ogilvie	Fluvial plain	4.1	0 (impacted)*
Watercourse	**Permafrost**	**1˚ trajectory**	**Lateral extent (m)**
Engineer Creek	Shallow, ice-rich, Tk	WNW	105
Riprap history	**Bank height (m)**	**2˚ migration rate (m/yr)**	**Slope length (m)**
2016*	1.2	3.8	6.3
Hwy-watercourse proximity (m)	**Low-flow width (m)**	**2˚ trajectory**	**Thickness (m)**
0*	15	NW	1
Position in meander belt	**Bankfull width (m)**	**Confinement**	**Volume (m³)**
Within	55	Confined by highway	657

MEANDER MORPHOLOGY AND DYNAMICS

This encroachment site is located within a partly confined, wandering gravel-bed reach of Engineer Creek. Lateral migration rates throughout the reach are relatively high, gravel bars are extensive and dynamic, and channel avulsions are frequent. Locally, the channel is unconfined based on the apparent absence of riprap protection along the highway embankment, and it formally occupied the west (i.e. opposite) side of the Dempster Highway prior to the earliest aerial photography (1977) and highway construction. This meander is a cut-off channel of the former, much larger meander. There has been considerable lateral migration (48 m) at the meander apex towards the encroachment site since 1989. Shallow, ice-rich permafrost that likely persists in portions of this site may lead to irregular and episodic bank erosion and collapse. 2016 field reconnaissance confirmed the recent placement of riprap has mitigated risk to the highway based on current conditions.

IMPLICATIONS OF RIPRAP APPLICATION

Riprap application does not pose further risk to infrastructure.

ALTERNATIVE EROSION PROTECTION STRATEGIES

N/A

SPECIAL CONSIDERATIONS

The estimated riprap requirements were based on the predicted highway embankment impact zone shown on the upper-left figure and have been left, despite recent riprap placement, for reference. Monitoring is required to confirm the continued effectiveness of the riprap.

*Updated following 2016 field reconnaissance

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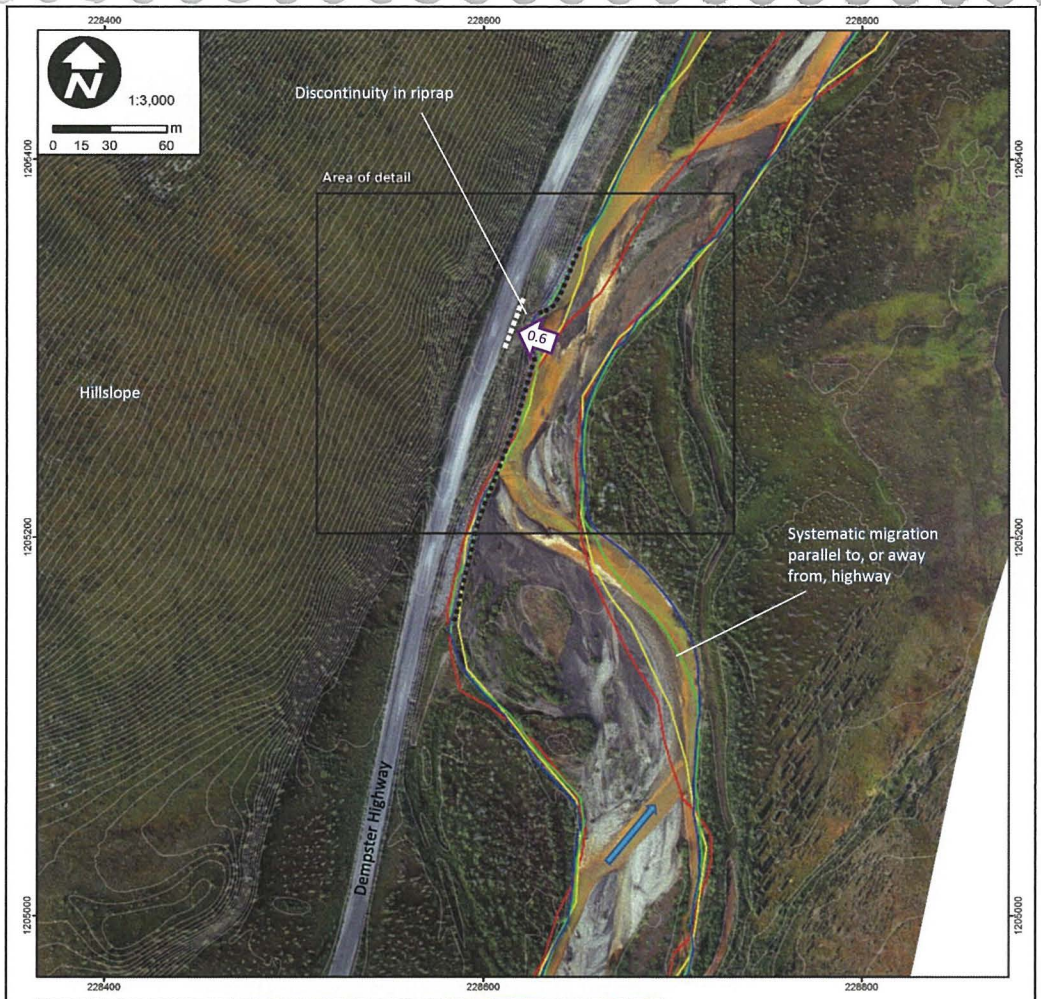

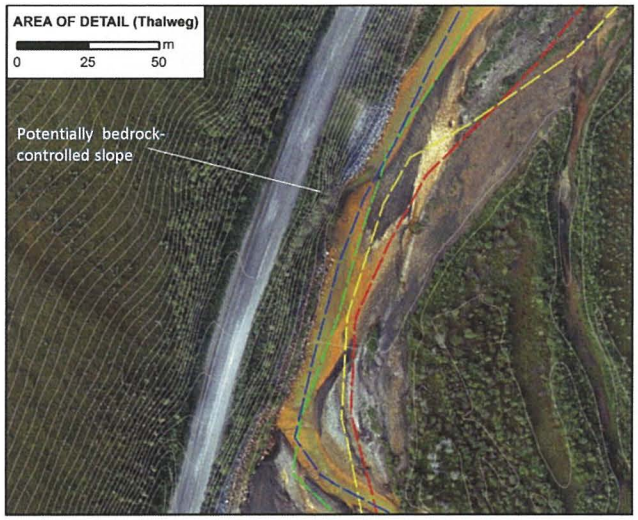

LEGEND

- Kilometre post
- Highway embankment impact zone
- Current extent of riprap
- 1 m contours

Channel banks (year)

- 2013/ 2014
- 2007/2008
- 1989
- 1977

Thalweg (year)

- 2013/2014
- 2007/2008
- 1989
- 1977

- Direction of flow
- 1° migration rate (m/yr)
- 2° migration rate (m/yr)

NOTE: Refer to accompanying report for definitions, rationale for erosion rate estimates, and an appendix with additional site-specific data. Original page size 11.00 x 17.00 in. Coordinate system NAD 1983 Yukon Albers; units: metres. Tk = thermokarst evidence nearby.

SITE	CHANNEL	MEANDER	RIPRAP REQUIREMENTS
Section	**Setting**	**1° migration rate (m/yr)**	**Timeframe until impact (yr)**
Ogilvie	Colluvial toe slope	0.6	6-10
Watercourse	**Permafrost**	**1° trajectory**	**Lateral extent (m)**
Engineer Creek	Deep, ice-moderate	W	30
Riprap history	**Bank height (m)**	**2° migration rate (m/yr)**	**Slope length (m)**
Unknown	10.6	-	28.4
Hwy-watercourse proximity (m)	**Low-flow width (m)**	**2° trajectory**	**Thickness (m)**
9	15	-	1
Position in meander belt	**Bankfull width (m)**	**Confinement**	**Volume (m^3)**
Edge	42	Naturally confined	851

MEANDER MORPHOLOGY AND DYNAMICS

This encroachment site is located within a partly confined, wandering gravel-bed reach of Engineer Creek. Lateral migration rates throughout the reach are relatively high, gravel bars are extensive and dynamic, and channel avulsions are frequent. The channel has significantly increased its sinuosity since 1989 through lateral migration. Locally, the channel is confined to the west by the prominent highway embankment and hillslope. The toe of the embankment has already been riprapped except along a ~25 m section at the downstream end of the encroachment site. This local discontinuity in riprap has allowed lateral migration and formation of a scour pool at the base of the slope. Without intervention, continued lateral migration will likely impact the highway embankment within 6 to 10 years.

IMPLICATIONS OF RIPRAP APPLICATION

Previous riprap application appears to have accelerated longitudinal migration. More riprap may be required downstream of the current limit of riprap, and potentially filling the local discontinuity, to protect the highway embankment.

ALTERNATIVE EROSION PROTECTION STRATEGIES

N/A

SPECIAL CONSIDERATIONS

Estimates of the timeframe of impact are less reliable in confined settings, such as this, due to potential interactions between fluvial and hillslope processes. No significant slope failures were observed during 2016 field reconnaissance.

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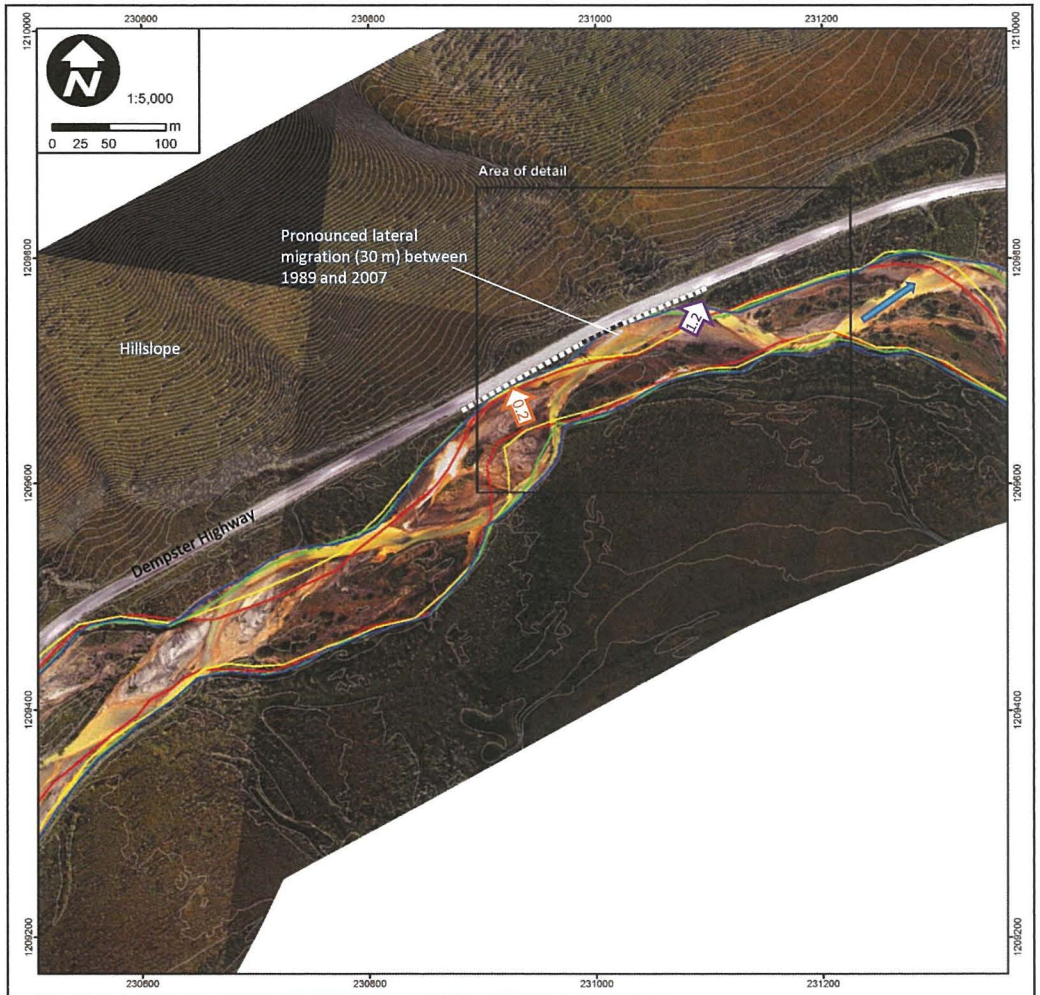
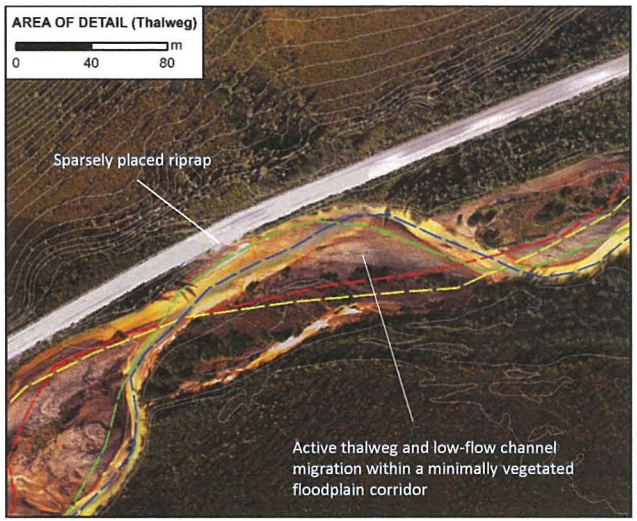
KM 175.2





LEGEND

- Kilometre post
- Highway embankment impact zone
- Current extent of riprap
- 1 m contours

Channel banks (year)

- 2013/ 2014
- 2007/2008
- 1989
- 1977

Thalweg (year)

- 2013/2014
- 2007/2008
- 1989
- 1977

- Direction of flow
- 1˚ migration rate (m/yr)
- 2˚ migration rate (m/yr)

NOTE: Refer to accompanying report for definitions, rationale for erosion rate estimates, and an appendix with additional site-specific data. Original page size 11.00 x 17.00 in. Coordinate system NAD 1983 Yukon Albers; units: metres. Tk = thermokarst evidence nearby.

SITE	CHANNEL	MEANDER	RIPRAP REQUIREMENTS
Section	**Setting**	**1˚ migration rate (m/yr)**	**Timeframe until impact (yr)**
Ogilvie	Hwy edge fluvial plain	1.2	6-10
Watercourse	**Permafrost**	**1˚ trajectory**	**Lateral extent (m)**
Engineer Creek	Shallow, ice-rich, Tk	N	205
Riprap history	**Bank height (m)**	**2˚ migration rate (m/yr)**	**Slope length (m)**
Unknown	1.4	0.2	6.9
Hwy-watercourse proximity (m)	**Low-flow width (m)**	**2˚ trajectory**	**Thickness (m)**
1	5	NW	1
Position in meander belt	**Bankfull width (m)**	**Confinement**	**Volume (m³)**
Within	27	Confined by highway	1,419

MEANDER MORPHOLOGY AND DYNAMICS

This encroachment site is located within a partly confined, wandering gravel-bed reach of Engineer Creek. Lateral migration rates throughout the reach are relatively high, gravel bars are extensive and dynamic, and channel avulsions are frequent. The channel has significantly increased its sinuosity since 1989 through lateral migration. Locally, there was notable lateral migration (30 m) between 1989 and 2007, which resulted in the channel abutting the minimally riprapped highway embankment. Due to this lateral confinement, there was significant longitudinal migration (15 m) between 2007 and 2013. A small side bar formed along the base of the riprap between 2007 and 2013, inhibiting scour along the toe of the riprap but potentially promoting scour within an eddy along the unprotected bank immediately downstream. Shallow, ice-rich permafrost is present at this site, which can lead to irregular and episodic bank erosion and collapse. 2016 field reconnaissance revealed minor sloughs within the highway embankment. Without intervention, continued longitudinal migration will likely impact the highway embankment within 6 to 10 years.

IMPLICATIONS OF RIPRAP APPLICATION

Previous riprap application has accelerated longitudinal migration. More riprap may be required downstream of the current limit of riprap to protect the highway embankment.

ALTERNATIVE EROSION PROTECTION STRATEGIES

N/A

SPECIAL CONSIDERATIONS

Due to the longitudinal nature of the observed bank migration, it is possible that the embankment immediately downstream of the previously placed riprapped could be impacted prior to the estimated timeframe.

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Project number: 14132
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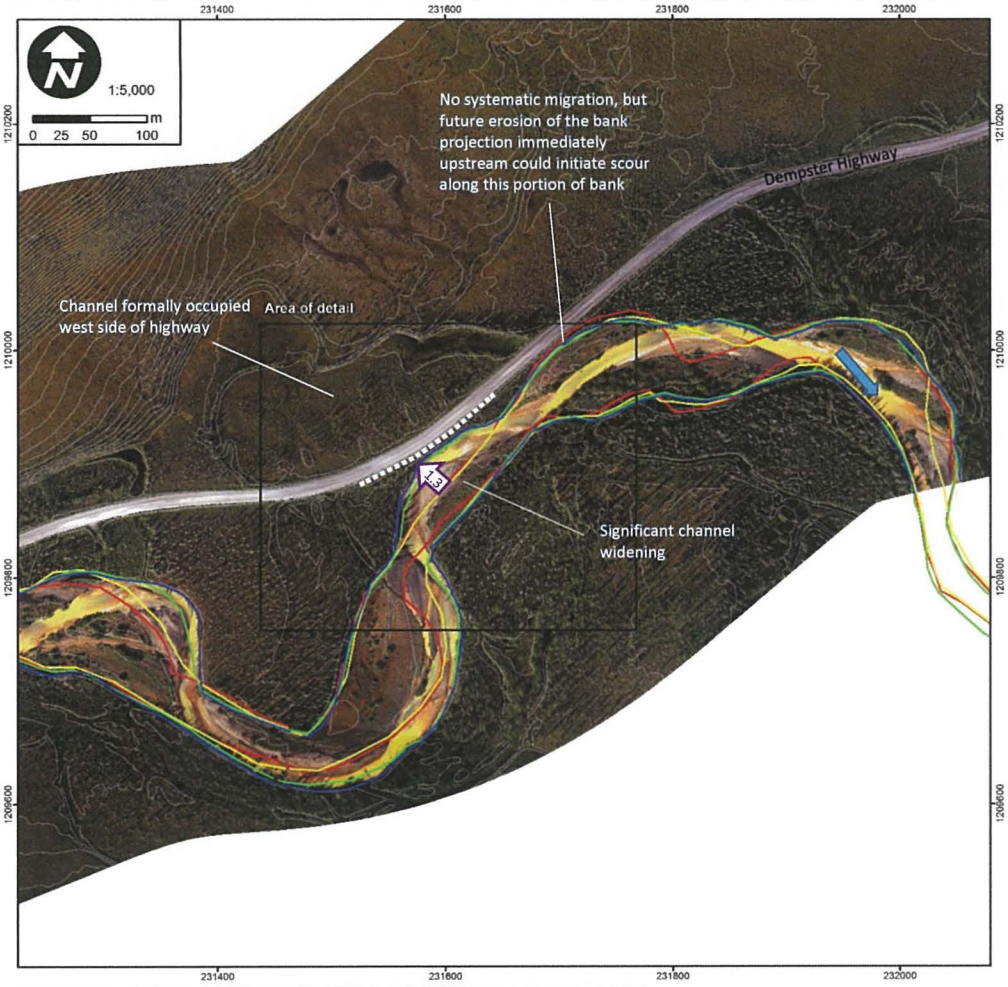

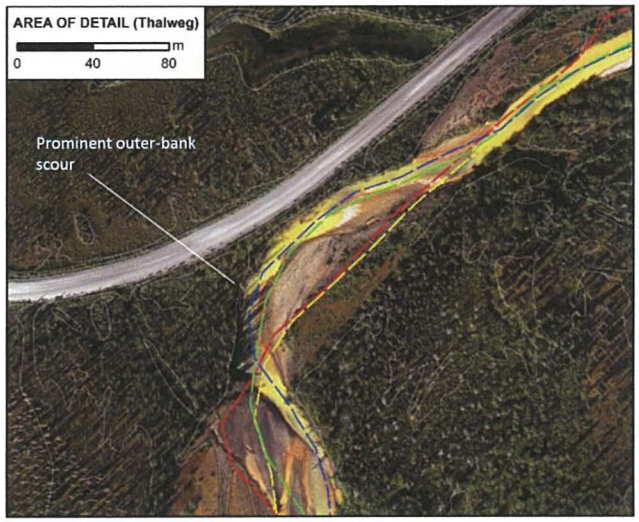

LEGEND

- Kilometre post
- Highway embankment impact zone
- Current extent of riprap
- 1 m contours

Channel banks (year)

- 2013/ 2014
- 2007/2008
- 1989
- 1977

Thalweg (year)

- 2013/2014
- 2007/2008
- 1989
- 1977

- Direction of flow
- 1° migration rate (m/yr)
- 2° migration rate (m/yr)

NOTE: Refer to accompanying report for definitions, rationale for erosion rate estimates, and an appendix with additional site-specific data. Original page size 11.00 x 17.00 in. Coordinate system NAD 1983 Yukon Albers; units: metres. Tk = thermokarst evidence nearby.

SITE	CHANNEL	MEANDER	RIPRAP REQUIREMENTS
Section	**Setting**	**1° migration rate (m/yr)**	**Timeframe until impact (yr)**
Ogilvie	Fluvial plain	1.3	0 (impacted)*
Watercourse	**Permafrost**	**1° trajectory**	**Lateral extent (m)**
Engineer Creek	Shallow, ice-rich, Tk	NW	140
Riprap history	**Bank height (m)**	**2° migration rate (m/yr)**	**Slope length (m)**
No riprap	1.5	-	6.9
Hwy-watercourse proximity (m)	**Low-flow width (m)**	**2° trajectory**	**Thickness (m)**
0*	10	-	1
Position in meander belt	**Bankfull width (m)**	**Confinement**	**Volume (m^3)**
Within	37	Confined by highway	969

MEANDER MORPHOLOGY AND DYNAMICS

This encroachment site is located within a partly confined, wandering gravel-bed reach of Engineer Creek. Lateral migration rates throughout the reach are relatively high, gravel bars are extensive and dynamic, and channel avulsions are frequent. Locally, the channel is unconfined, which has allowed significant lateral migration (32 m) towards the highway over the period of record. The encroachment site is along the upstream portion of a compound meander. It is within the meander belt and the channel formally occupied the west (i.e. opposite) side of the Dempster Highway prior to the earliest aerial photography (1977). Shallow, ice-rich permafrost is present at this site, which can lead to irregular and episodic bank erosion and collapse. Gradual erosion of the embankment toe has already begun to locally destabilize the unprotected highway embankment; local sloughs were observed during 2016 field reconnaissance.

IMPLICATIONS OF RIPRAP APPLICATION

Riprap application could cause longitudinal channel migration, potentially exposing the highway embankment immediately downstream to erosion if not extended far enough downstream.

ALTERNATIVE EROSION PROTECTION STRATEGIES

N/A

SPECIAL CONSIDERATIONS

Riprap placement is required to protect the existing highway embankment toe. Future erosion of the projection of bank near the downstream end of the encroachment site may increase the exposure of highway embankment to erosion along the downstream bend of the compound meander, which currently only conveys flows during flood conditions.

*Updated following 2016 field reconnaissance

Yukon Government

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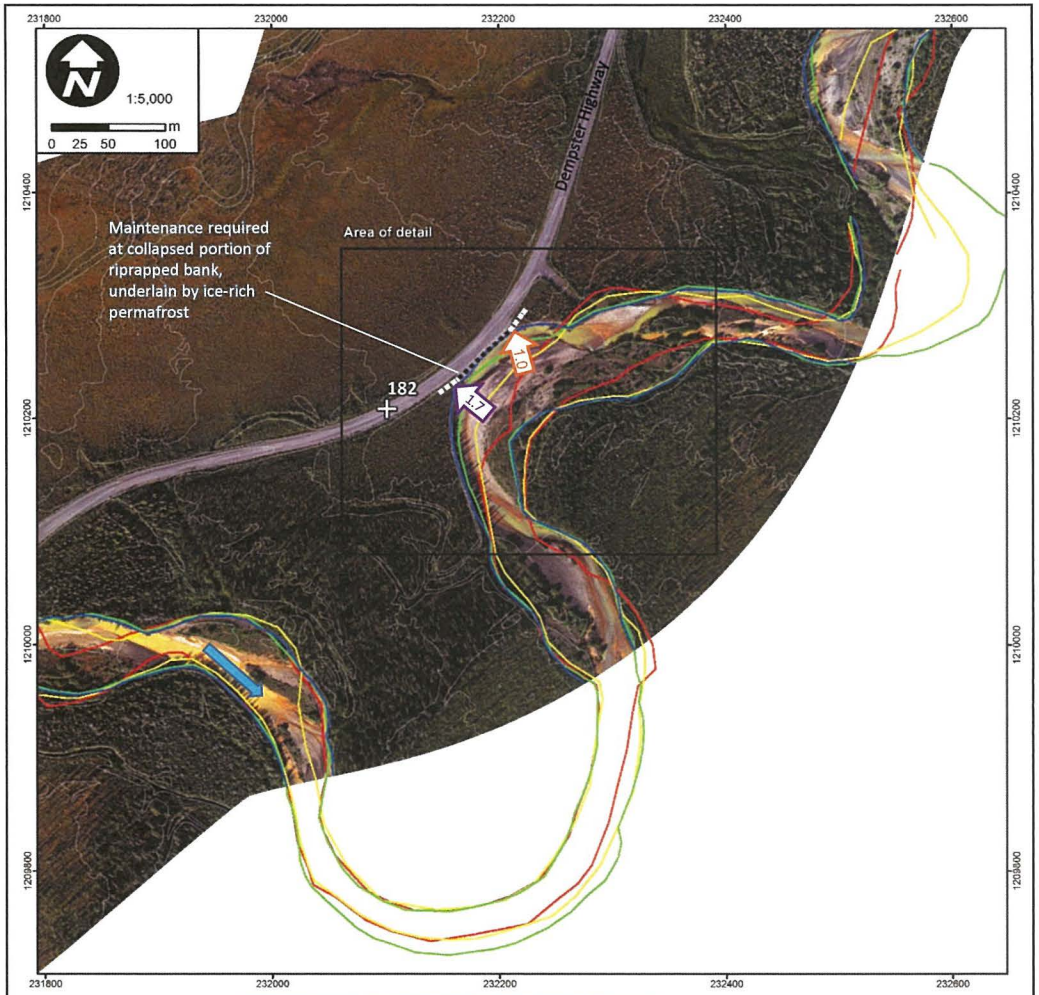
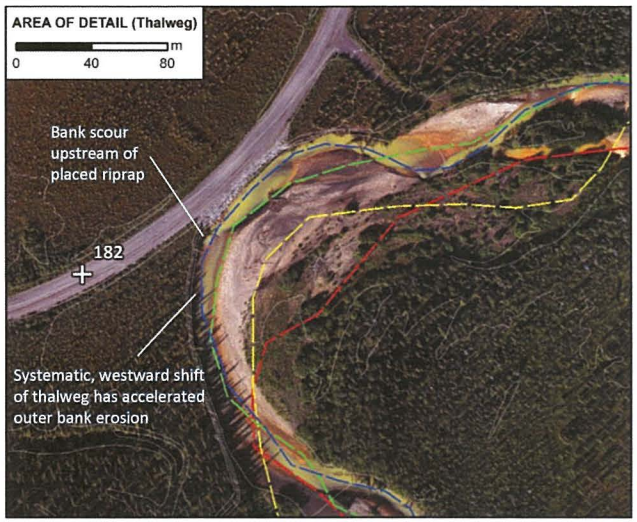
KRYOTEK

Project: Dempster Meander Migration Hazards
Project number: 14132
Client: Yukon Government

KM 181.5





LEGEND

- Kilometre post
- Highway embankment impact zone
- Current extent of riprap
- 1 m contours

Channel banks (year)

- 2013/ 2014
- 2007/2008
- 1989
- 1977

Thalweg (year)

- 2013/2014
- 2007/2008
- 1989
- 1977
- Direction of flow
- 1° migration rate (m/yr)
- 2° migration rate (m/yr)

NOTE: Refer to accompanying report for definitions, rationale for erosion rate estimates, and an appendix with additional site-specific data. Original page size 11.00 x 17.00 in. Coordinate system NAD 1983 Yukon Albers; units: metres. Tk = thermokarst evidence nearby.

SITE	CHANNEL	MEANDER	RIPRAP REQUIREMENTS
Section	**Setting**	**1° migration rate (m/yr)**	**Timeframe until impact (yr)**
Ogilvie	Hwy edge fluvial plain	1.7	<2
Watercourse	**Permafrost**	**1° trajectory**	**Lateral extent (m)**
Engineer Creek	Near-surface, ice-rich, Tk	WNW	45
Riprap history	**Bank height (m)**	**2° migration rate (m/yr)**	**Slope length (m)**
2010, 2015	2.5	1.0	9.6
Hwy-watercourse proximity (m)	**Low-flow width (m)**	**2° trajectory**	**Thickness (m)**
5	7	NW	1
Position in meander belt	**Bankfull width (m)**	**Confinement**	**Volume (m^3)**
Edge	41	Confined by highway	432

MEANDER MORPHOLOGY AND DYNAMICS

This encroachment site is located within a partly confined, wandering gravel-bed reach of Engineer Creek. Lateral migration rates throughout the reach are relatively high, gravel bars are extensive and dynamic, and channel avulsions are frequent. Locally, there has been significant lateral migration (60 m) towards the highway over the period of record. Near-surface, ice-rich permafrost is present at this site and can lead to irregular and episodic bank erosion and collapse. Riprap has been placed along the highway embankment, which has slowed lateral migration and accelerated longitudinal migration. A conspicuous, scallop-shaped form visible in the most recent imagery (2013) at the upstream end of riprap is the headscarp of a bank slump, likely triggered by undercutting and thawing of ice-rich permafrost beneath the riprap. This upstream riprap limit is also at risk of being outflanked by continued migration. There is notable bank failure at the downstream limit of riprap; a 5 m-wide block has collapsed into the channel following fluvio-thermal erosion of permafrost in the lower bank. Without intervention, continued bank scour and slumping, as well as longitudinal migration, will likely impact the highway embankment within 2 years.

IMPLICATIONS OF RIPRAP APPLICATION

There is noticeable scour and bank collapse immediately upstream and downstream of the current limits of riprap. Previous riprap application has accelerated longitudinal migration. More riprap is likely required upstream and downstream of the current limits of riprap to protect the highway embankment.

ALTERNATIVE EROSION PROTECTION STRATEGIES

N/A

SPECIAL CONSIDERATIONS

Based on the 2013 aerial imagery and 2016 field reconnaissance, the previously placed riprap is failing and likely requires maintenance. Over-excavation and placement of thick filter material may be required in advance of riprap placement in an effort to reduce embankment failure due to thawing permafrost.

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Project number: 14132
Client: Yukon Government

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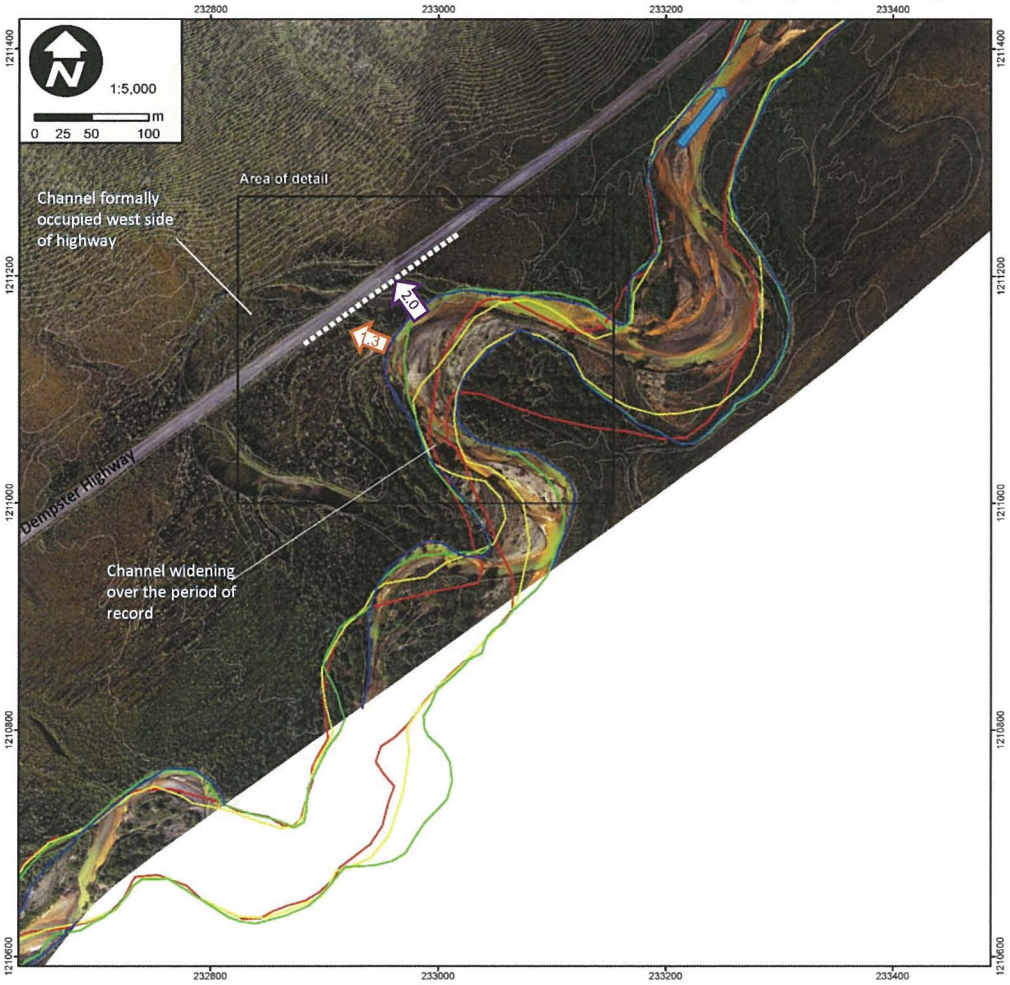

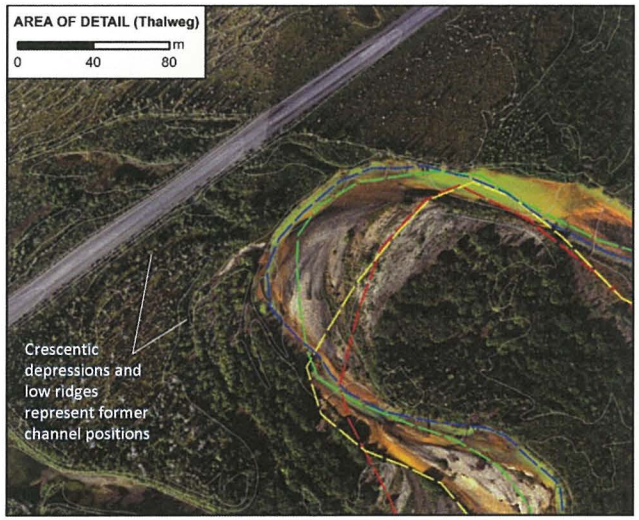

LEGEND

- Kilometre post
- Highway embankment impact zone
- Current extent of riprap
- 1 m contours

Channel banks (year)

- 2013/ 2014
- 2007/2008
- 1989
- 1977

Thalweg (year)

- 2013/2014
- 2007/2008
- 1989
- 1977

- Direction of flow
- 1° migration rate (m/yr)
- 2° migration rate (m/yr)

NOTE: Refer to accompanying report for definitions, rationale for erosion rate estimates, and an appendix with additional site-specific data. Original page size 11.00 x 17.00 in. Coordinate system NAD 1983 Yukon Albers; units: metres. Tk = thermokarst evidence nearby.

SITE	CHANNEL	MEANDER	RIPRAP REQUIREMENTS
Section	**Setting**	**1° migration rate (m/yr)**	**Timeframe until impact (yr)**
Ogilvie	Fluvial plain	1.9*	16-20*
Watercourse	**Permafrost**	**1° trajectory**	**Lateral extent (m)**
Engineer Creek	Shallow, ice-rich, Tk	NW	165
Riprap history	**Bank height (m)**	**2° migration rate (m/yr)**	**Slope length (m)**
No riprap	2.0	1.3	7.8
Hwy-watercourse proximity (m)	**Low-flow width (m)**	**2° trajectory**	**Thickness (m)**
31*	9	WNW	1
Position in meander belt	**Bankfull width (m)**	**Confinement**	**Volume (m^3)**
Within	45	Unconfined	1,290

MEANDER MORPHOLOGY AND DYNAMICS

This encroachment site is located within a partly confined, wandering gravel-bed reach of Engineer Creek. Lateral migration rates throughout the reach are relatively high, gravel bars are extensive and dynamic, and channel avulsions are frequent. Locally, the channel is unconfined and it formally occupied the west (i.e. opposite) side of the Dempster Highway prior to the earliest aerial photography (1977). There has been significant lateral migration (47 m) towards the highway over the period of record. However, there is a large buffer (31 m) between the outer bank and the highway. Despite the high lateral erosion rates, it will likely take 16 to 20 years before the channel impacts the highway.

IMPLICATIONS OF RIPRAP APPLICATION

Riprap application does not pose further risk to infrastructure.

ALTERNATIVE EROSION PROTECTION STRATEGIES

N/A

SPECIAL CONSIDERATIONS

N/A

*Updated following 2016 field reconnaissance

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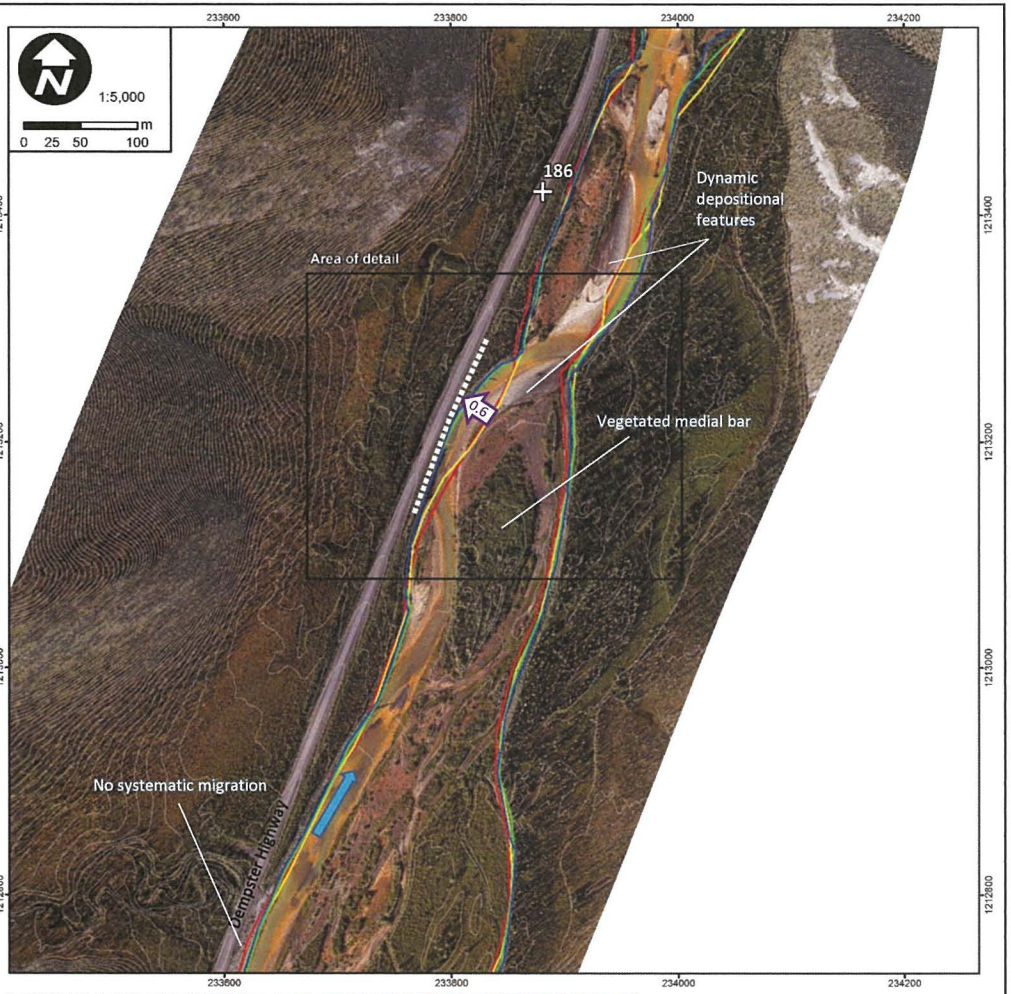
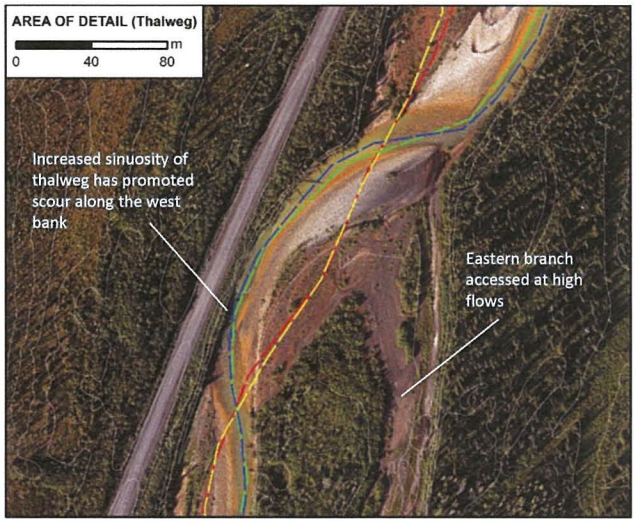
Project: Dempster Meander Migration Hazards
Project number: 14132
Client: Yukon Government

KM 183.3





LEGEND

- Kilometre post
- Highway embankment impact zone
- Current extent of riprap
- 1 m contours

Channel banks (year)

- 2013/ 2014
- 2007/2008
- 1989
- 1977

Thalweg (year)

- 2013/2014
- 2007/2008
- 1989
- 1977

- Direction of flow
- 1° migration rate (m/yr)
- 2° migration rate (m/yr)

NOTE: Refer to accompanying report for definitions, rationale for erosion rate estimates, and an appendix with additional site-specific data. Original page size 11.00 x 17.00 in. Coordinate system NAD 1983 Yukon Albers; units: metres. Tk = thermokarst evidence nearby.

SITE	CHANNEL	MEANDER	RIPRAP REQUIREMENTS
Section	**Setting**	**1° migration rate (m/yr)**	**Timeframe until impact (yr)**
Ogilvie	Hwy edge fluvial plain	1.2	2-5
Watercourse	**Permafrost**	**1° trajectory**	**Lateral extent (m)**
Engineer Creek	Deep, ice-moderate	WNW	160
Riprap history	**Bank height (m)**	**2° migration rate (m/yr)**	**Slope length (m)**
No riprap	1.5	-	9.2
Hwy-watercourse proximity (m)	**Low-flow width (m)**	**2° trajectory**	**Thickness (m)**
4	12	-	1
Position in meander belt	**Bankfull width (m)**	**Confinement**	**Volume (m^3)**
Edge	58	Unconfined	1,465

MEANDER MORPHOLOGY AND DYNAMICS

This encroachment site is located within a partly confined, wandering gravel-bed reach of Engineer Creek. Lateral migration rates throughout the reach are relatively high, gravel bars are extensive and dynamic, and channel avulsions are frequent. Locally, the channel has increased the sinuosity of its thalweg over the period of record, resulting in lateral migration. There has been notable lateral migration (29 m) since 1989 at the encroachment site. Without intervention, continued lateral migration will likely impact the highway embankment within 2 to 5 years.

IMPLICATIONS OF RIPRAP APPLICATION

Riprap application could cause longitudinal channel migration, potentially exposing the highway embankment immediately downstream to erosion if not extended far enough.

ALTERNATIVE EROSION PROTECTION STRATEGIES

N/A

SPECIAL CONSIDERATIONS

N/A

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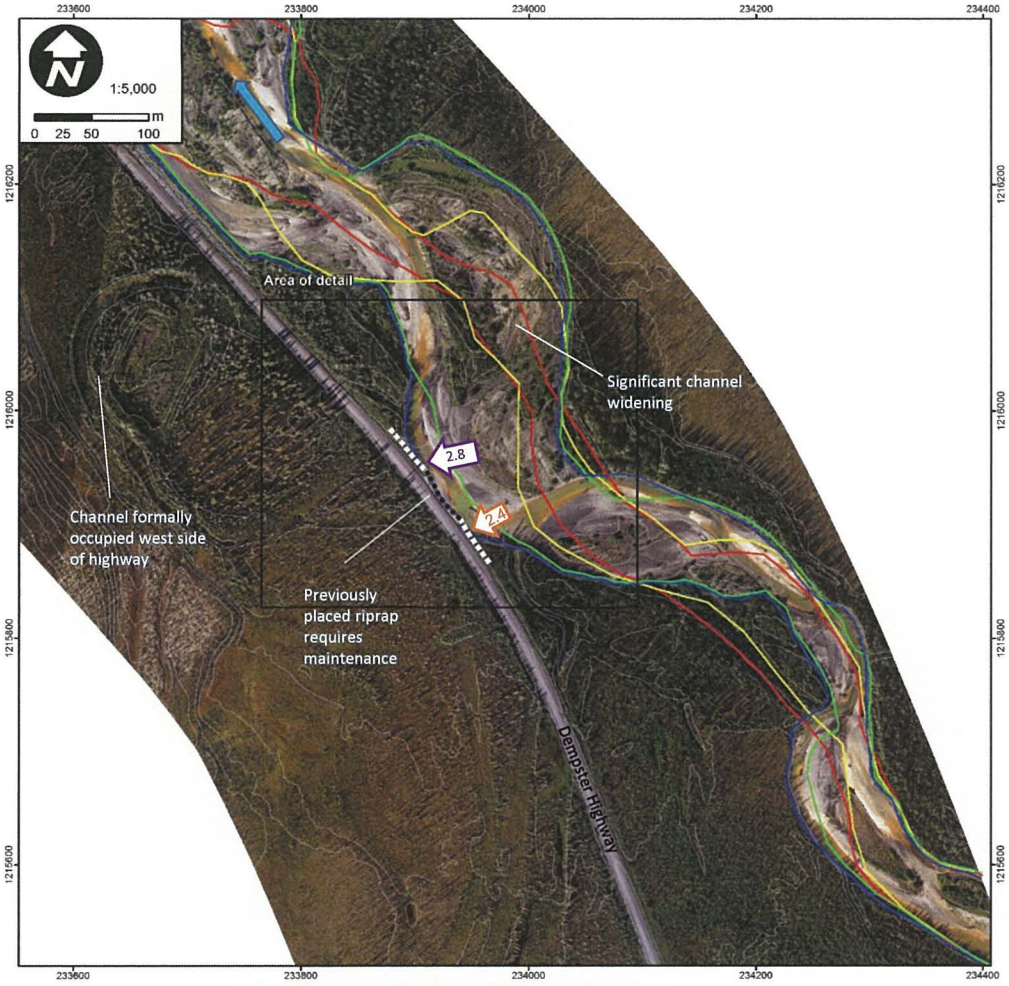
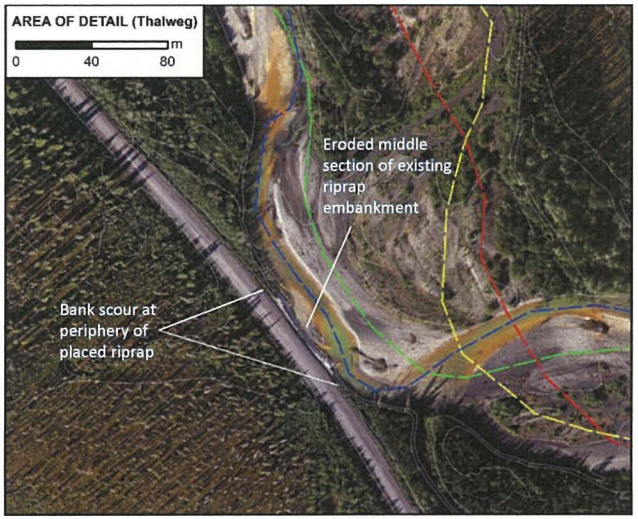
Project: Dempster Meander Migration Hazards
Project number: 14132
Client: Yukon Government

KM 185.8





LEGEND

- Kilometre post
- Highway embankment impact zone
- Current extent of riprap
- 1 m contours

Channel banks (year)

- 2013/ 2014
- 2007/2008
- 1989
- 1977

Thalweg (year)

- 2013/2014
- 2007/2008
- 1989
- 1977

- Direction of flow
- 1° migration rate (m/yr)
- 2° migration rate (m/yr)

NOTE: Refer to accompanying report for definitions, rationale for erosion rate estimates, and an appendix with additional site-specific data. Original page size 11.00 x 17.00 in. Coordinate system NAD 1983 Yukon Albers; units: metres. Tk = thermokarst evidence nearby.

SITE	CHANNEL	MEANDER	RIPRAP REQUIREMENTS
Section	**Setting**	**1° migration rate (m/yr)**	**Timeframe until impact (yr)**
Ogilvie	Hwy edge fluvial plain	2.8	<2
Watercourse	**Permafrost**	**1° trajectory**	**Lateral extent (m)**
Engineer Creek	Shallow, ice-rich, Tk	W	100
Riprap history	**Bank height (m)**	**2° migration rate (m/yr)**	**Slope length (m)**
1971, 2015	2.6	2.4	9.2
Hwy-watercourse proximity (m)	**Low-flow width (m)**	**2° trajectory**	**Thickness (m)**
1	17	W	1
Position in meander belt	**Bankfull width (m)**	**Confinement**	**Volume (m^3)**
Within	45	Confined by highway	916

MEANDER MORPHOLOGY AND DYNAMICS

This encroachment site is located within a partly confined, wandering gravel-bed reach of Engineer Creek. Lateral migration rates throughout the reach are relatively high, gravel bars are extensive and dynamic, and channel avulsions are frequent. Locally, there has been significant lateral migration (up to 105 m) toward the highway over the period of record. Furthermore, the encroachment site is within the meander belt and the channel formally occupied the west (i.e. opposite) side of the Dempster Highway prior to the earliest aerial photography (1977). Shallow, ice-rich permafrost may persist in portions of this disturbed site, which can lead to irregular and episodic bank erosion and collapse. Riprap has been previously placed along the highway embankment in an effort to slow lateral migration. Scour of the embankment is visible upstream and downstream of previously placed riprap in the most recent imagery (2013). Without intervention, continued lateral migration upstream and downstream of the existing riprap will likely impact the highway embankment within 2 years.

IMPLICATIONS OF RIPRAP APPLICATION

The central portion of the existing riprap embankment appears thinner than adjacent areas, suggesting possible scour and entrainment of rocks by high flows and/or rafted ice. Maintenance may be required to reconstruct the failed portion of embankment, ideally with larger-diameter riprap and deeper embedment to inhibit undermining. There is noticeable scour immediately upstream and downstream of the current limits of riprap, which can accelerate failure by exposing underlying ice-rich permafrost. More riprap is likely required to protect the highway embankment, and careful site preparation may be required if ice-rich permafrost is indeed contributing to failure.

ALTERNATIVE EROSION PROTECTION STRATEGIES

N/A

SPECIAL CONSIDERATIONS

Based on the 2013 aerial imagery and 2016 field reconnaissance, the previously placed riprap is locally failing due to pronounced toe scour and episodic thalweg adjustments and likely requires maintenance.

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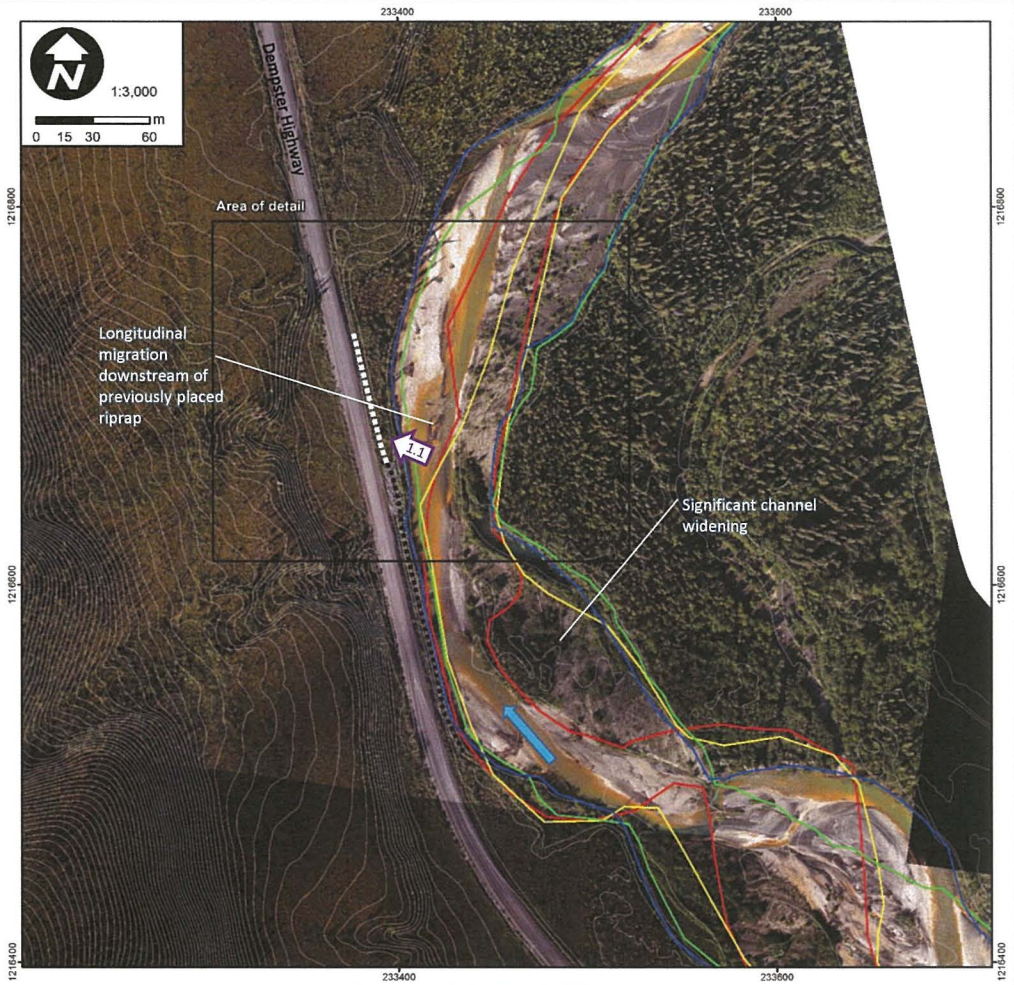
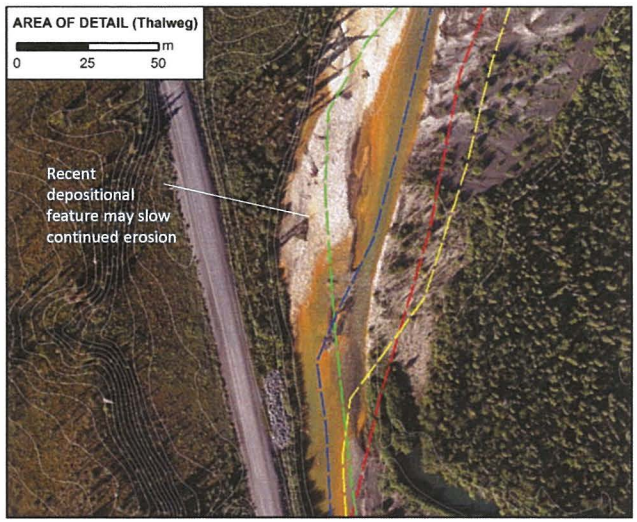
Project number: 14132
Client: Yukon Government

KM 188.6





LEGEND

- Kilometre post
- Highway embankment impact zone
- Current extent of riprap
- 1 m contours

Channel banks (year)

- 2013/ 2014
- 2007/2008
- 1989
- 1977

Thalweg (year)

- 2013/2014
- 2007/2008
- 1989
- 1977

- Direction of flow
- 1˚ migration rate (m/yr)
- 2˚ migration rate (m/yr)

NOTE: Refer to accompanying report for definitions, rationale for erosion rate estimates, and an appendix with additional site-specific data. Original page size 11.00 x 17.00 in. Coordinate system NAD 1983 Yukon Albers; units: metres; Tk = [illegible] evidence nearby

SITE	CHANNEL	MEANDER	RIPRAP REQUIREMENTS
Section	**Setting**	**1˚ migration rate (m/yr)**	**Timeframe until impact (yr)**
Ogilvie	Hwy edge fluvial plain	1.1	16-20
Watercourse	**Permafrost**	**1˚ trajectory**	**Lateral extent (m)**
Engineer Creek	Shallow, ice-rich, Tk	NW	70
Riprap history	**Bank height (m)**	**2˚ migration rate (m/yr)**	**Slope length (m)**
1998	2.5	-	8.3
Hwy-watercourse proximity (m)	**Low-flow width (m)**	**2˚ trajectory**	**Thickness (m)**
6	9	-	1
Position in meander belt	**Bankfull width (m)**	**Confinement**	**Volume (m^3)**
Within	39	Confined by highway	578

MEANDER MORPHOLOGY AND DYNAMICS

This encroachment site is located within a partly confined, wandering gravel-bed reach of Engineer Creek. Lateral migration rates throughout the reach are relatively high, gravel bars are extensive and dynamic, and channel avulsions are frequent. The encroachment site is situated at a natural narrowing within the reach, which concentrates flow and erosive energy. The channel is also confined along its west bank by the riprapped highway embankment. This lateral confinement has led to longitudinal migration over the period of record. Shallow, ice-rich permafrost may persist in portions of this disturbed site, which can lead to irregular and episodic bank erosion and collapse. Without intervention, continued longitudinal migration will likely impact the highway embankment in 16 to 20 years.

IMPLICATIONS OF RIPRAP APPLICATION

Previous riprap application has accelerated longitudinal migration. More riprap may be required downstream of the current limit of riprap to protect the highway embankment.

ALTERNATIVE EROSION PROTECTION STRATEGIES

N/A

SPECIAL CONSIDERATIONS

N/A

Yukon Government

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Project: Dempster Meander Migration Hazards
Project number: 14132
Client: Yukon Government

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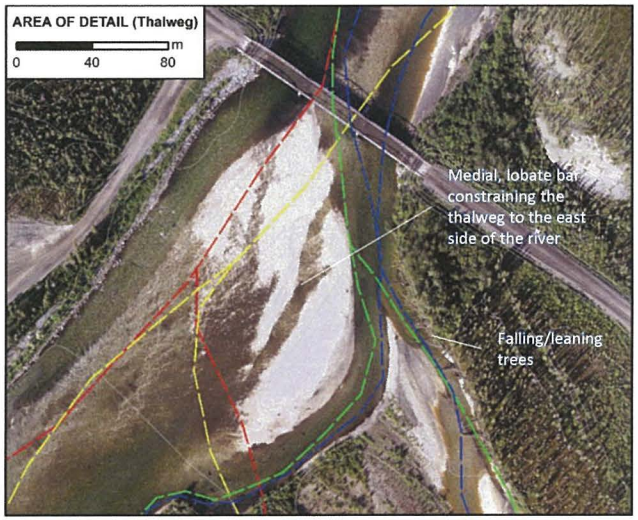

LEGEND

- Kilometre post
- Highway embankment impact zone
- Current extent of riprap
- 1 m contours

Channel banks (year)

- 2013/ 2014
- 2007/2008
- 1989
- 1977

Thalweg (year)

- 2013/2014
- 2007/2008
- 1989
- 1977

- Direction of flow
- 1˚ migration rate (m/yr)
- 2˚ migration rate (m/yr)

NOTE: Refer to accompanying report for definitions, rationale for erosion rate estimates, and an appendix with additional site-specific data. Original page size 11.00 x 17.00 in. Coordinate system NAD 1983 Yukon Albers; units: metres. Tk = thermokarst evidence nearby.

SITE	CHANNEL	MEANDER	RIPRAP REQUIREMENTS
Section	**Setting**	**1˚ migration rate (m/yr)**	**Timeframe until impact (yr)**
Ogilvie	Hwy edge fluvial plain	-	-
Watercourse	**Permafrost**	**1˚ trajectory**	**Lateral extent (m)**
Ogilvie River	Deep, ice-poor	NA	-
Riprap history	**Bank height (m)**	**2˚ migration rate (m/yr)**	**Slope length (m)**
1971	1.8	-	-
Hwy-watercourse proximity (m)	**Low-flow width (m)**	**2˚ trajectory**	**Thickness (m)**
5	30	-	-
Position in meander belt	**Bankfull width (m)**	**Confinement**	**Volume (m^3)**
Within	100	Confined by highway	-

MEANDER MORPHOLOGY AND DYNAMICS

This encroachment site is located at the dynamic confluence of Engineer Creek and Ogilvie River, which is immediately upstream of a Dempster Highway bridge over Ogilvie River. Both Engineer Creek and Ogilvie River are partly confined at a reach scale. The location of the confluence migrated ~120 m northeast between 1989 and 2007. There was negligible change in bank position between 2007 and 2013. However, leaning and fallen trees visible along the east bank in the 2013 aerial imagery suggest active bank erosion a short distance upstream of the east bridge abutment. There is a large, dynamic bar within Ogilvie River that is constraining the thalweg to the east side of the channel. Shallow, ice-rich permafrost that persists in portions of the site may lead to irregular and episodic bank erosion and collapse. The west bank of Ogilvie River has been previously riprapped. Future rates and trajectories of bank retreat are uncertain.

IMPLICATIONS OF RIPRAP APPLICATION

Previous riprap application was limited to the immediate area of the bridge abutment and has had no significant effect on downstream bank erosion. Any additional riprap placement, although not currently predicted to be required, would similarly pose no further risk to infrastructure downstream.

ALTERNATIVE EROSION PROTECTION STRATEGIES

N/A

SPECIAL CONSIDERATIONS

Channel confluences are often dynamic and unstable geomorphic features. Local confluence dynamics, the extent and condition of riprap, and bank stability should be monitored regularly given the importance of bridge abutment stability.

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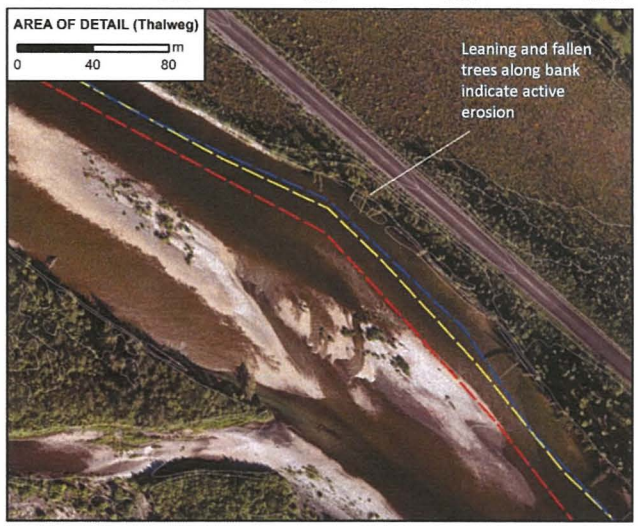
Project: Dempster Meander Migration Hazards
Project number: 14132
Client: Yukon Government

KM 195.1



LEGEND

- Kilometre post
- Highway embankment impact zone
- Current extent of riprap
- 1 m contours

Channel banks (year)

- 2013/ 2014
- 2007/2008
- 1989
- 1977

Thalweg (year)

- 2013/2014
- 2007/2008
- 1989
- 1977

- Direction of flow
- 1° migration rate (m/yr)
- 2° migration rate (m/yr)

NOTE: Refer to accompanying report for definitions, rationale for erosion rate estimates, and an appendix with additional site-specific data. Original page size 11.00 x 17.00 in. Coordinate system NAD 1983 Yukon Albers; units: metres. Tk = thermokarst evidence nearby

SITE	CHANNEL	MEANDER	RIPRAP REQUIREMENTS
Section	**Setting**	**1° migration rate (m/yr)**	**Timeframe until impact (yr)**
Ogilvie	Fluvial plain	0.5	16-20
Watercourse	**Permafrost**	**1° trajectory**	**Lateral extent (m)**
Ogilvie River	Shallow, ice-rich, Tk	NE	190
Riprap history	**Bank height (m)**	**2° migration rate (m/yr)**	**Slope length (m)**
No riprap	2.2	0.3	8.0
Hwy-watercourse proximity (m)	**Low-flow width (m)**	**2° trajectory**	**Thickness (m)**
9	35	NE	1
Position in meander belt	**Bankfull width (m)**	**Confinement**	**Volume (m^3)**
Within	135	Unconfined	1,528

MEANDER MORPHOLOGY AND DYNAMICS

This encroachment site is located within a partly confined, irregularly meandering reach of Ogilvie River. The reach contains prominent point, lateral and medial gravel bars, which influence the position of the thalweg. Locally, the channel is unconfined and formally occupied the west (i.e. opposite) side of the Dempster Highway prior to the earliest aerial photography (1977). However, lateral migration rates at the encroachment site are relatively low. It is unlikely that continued lateral migration will impact the highway embankment within the next 25 years.

IMPLICATIONS OF RIPRAP APPLICATION

Riprap application does not pose further risk to infrastructure.

ALTERNATIVE EROSION PROTECTION STRATEGIES

River training structures such as bendway weirs or flow-retarding bars ('hockey stick' weirs) could be implemented to shift erosive energy away from the bank. River training structures would require a similar amount of material as simply riprapping the embankment, if not more due to the lateral extent that would be required along this gentle bend, and would likely reduce maintenance frequency and costs if the structures are designed appropriately.

SPECIAL CONSIDERATIONS

N/A

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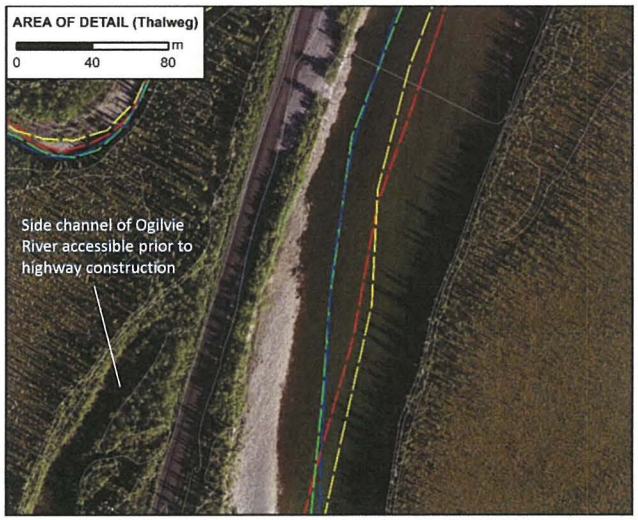
Project: Dempster Meander Migration Hazards
Project number: 14132
Client: Yukon Government

KM 202.5



LEGEND

- Kilometre post
- Highway embankment impact zone
- Current extent of riprap
- 1 m contours

Channel banks (year)

- 2013/ 2014
- 2007/2008
- 1989
- 1977

Thalweg (year)

- 2013/2014
- 2007/2008
- 1989
- 1977
- Direction of flow
- 1° migration rate (m/yr)
- 2° migration rate (m/yr)

NOTE: Refer to accompanying report for definitions, rationale for erosion rate estimates, and an appendix with additional site-specific data. Original page size 11.00 x 17.00 in. Coordinate system NAD 1983 Yukon Albers; units: metres. Tk = thermokarst evidence nearby.

SITE	CHANNEL	MEANDER	RIPRAP REQUIREMENTS
Section	**Setting**	**1° migration rate (m/yr)**	**Timeframe until impact (yr)**
Ogilvie	Hwy edge fluvial plain	0.2	>25
Watercourse	**Permafrost**	**1° trajectory**	**Lateral extent (m)**
Ogilvie River	Shallow, ice-rich, Tk	WNW	175
Riprap history	**Bank height (m)**	**2° migration rate (m/yr)**	**Slope length (m)**
1969	1.5	-	7.4
Hwy-watercourse proximity (m)	**Low-flow width (m)**	**2° trajectory**	**Thickness (m)**
8	80	-	1
Position in meander belt	**Bankfull width (m)**	**Confinement**	**Volume (m^3)**
Within	90	Confined by highway	1,290

MEANDER MORPHOLOGY AND DYNAMICS

This encroachment site is located within a partly confined, wandering gravel-bed reach of Ogilvie River. The reach contains prominent point, lateral and medial gravel bars, which influence the position of the thalweg. The west bank of the reach was extensively riprapped during highway construction. As such, bank migration rates throughout the reach, including within the vicinity of the encroachment site, have been very low over the period of record. Slow lateral migration was observed in a small section (~50 m in length) of the west bank that was not previously riprapped. However, it is unlikely that channel migration will impact the highway embankment within the next 25 years.

IMPLICATIONS OF RIPRAP APPLICATION

The implications of the previously placed riprap are unclear as the west bank is extensively riprapped for ~800 m upstream of the study site, resulting in minimal migration.

ALTERNATIVE EROSION PROTECTION STRATEGIES

N/A

SPECIAL CONSIDERATIONS

N/A

Yukon Government

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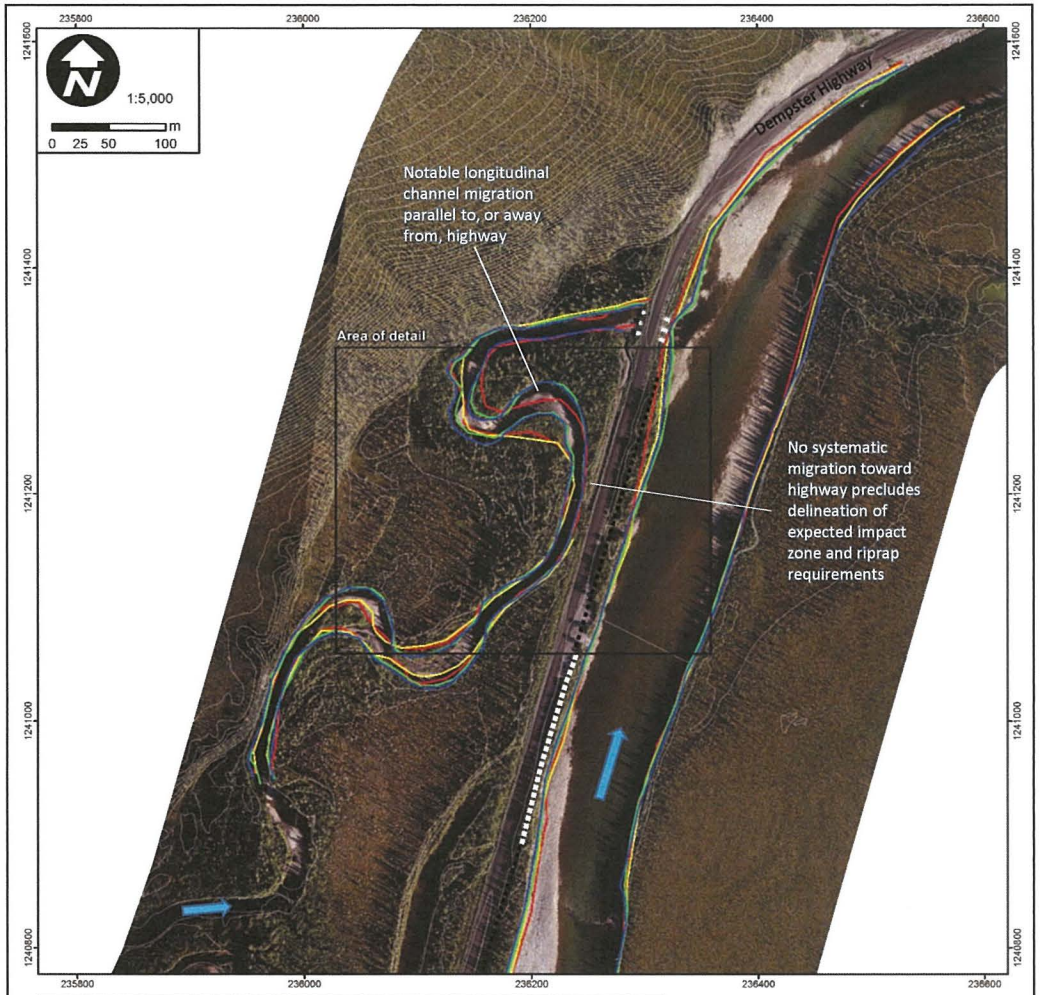
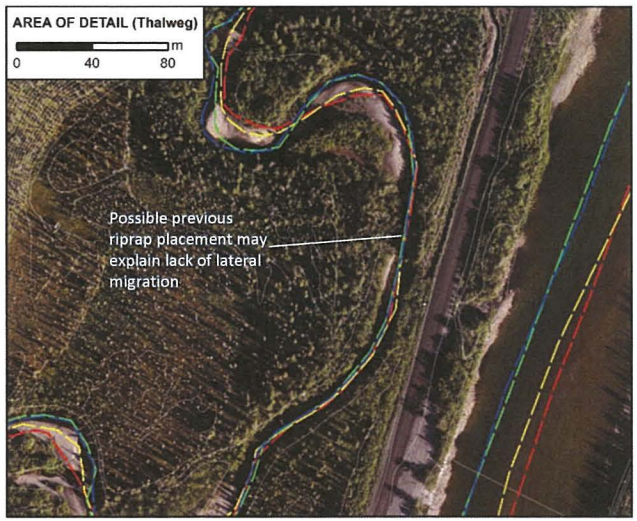
KRYOTEK

Project: Dempster Meander Migration Hazards
Project number: 14132
Client: Yukon Government

KM 221.1





LEGEND

- Kilometre post
- Highway embankment impact zone
- Current extent of riprap
- 1 m contours

Channel banks (year)

- 2013/ 2014
- 2007/2008
- 1989
- 1977

Thalweg (year)

- 2013/2014
- 2007/2008
- 1989
- 1977

- Direction of flow
- 1˚ migration rate (m/yr)
- 2˚ migration rate (m/yr)

NOTE: Refer to accompanying report for definitions, rationale for erosion rate estimates, and an appendix with additional site-specific data. Original page size 11.00 x 17.00 in. Coordinate system NAD 1983 Yuk... Albers; ...s: met... Tk = ...moka... ...ident... ...arby.

SITE	CHANNEL	MEANDER	RIPRAP REQUIREMENTS
Section	**Setting**	**1˚ migration rate (m/yr)**	**Timeframe until impact (yr)**
Ogilvie	Hwy edge fluvial plain	-	-
Watercourse	**Permafrost**	**1˚ trajectory**	**Lateral extent (m)**
Ogilvie River	Deep, ice-moderate	NA	-
Riprap history	**Bank height (m)**	**2˚ migration rate (m/yr)**	**Slope length (m)**
No riprap	0.9	-	-
Hwy-watercourse proximity (m)	**Low-flow width (m)**	**2˚ trajectory**	**Thickness (m)**
9	5	-	-
Position in meander belt	**Bankfull width (m)**	**Confinement**	**Volume (m^3)**
Within	22	Confined by highway	-

MEANDER MORPHOLOGY AND DYNAMICS

This encroachment site is located near the mouth of a partly confined, tortuously meandering tributary of Ogilvie River. The reach has high sinuosity, with meanders exhibiting mostly small radii of curvature, and lateral migration has occurred along unconfined meanders. Locally, the tributary is confined on the east by the highway embankment, which has inhibited migration over the period of record. As such, no immediate intervention is required.

IMPLICATIONS OF RIPRAP APPLICATION

Riprap application would likely cause longitudinal channel migration, which in turn could initiate formation of a meander cut-off channel and destabilize this section of channel immediately adjacent to the highway.

ALTERNATIVE EROSION PROTECTION STRATEGIES

N/A

SPECIAL CONSIDERATIONS

The meanders in the vicinity of the encroachment site should be monitored annually to assess the risk erosion processes pose to the highway embankment and the downstream crossing structure.

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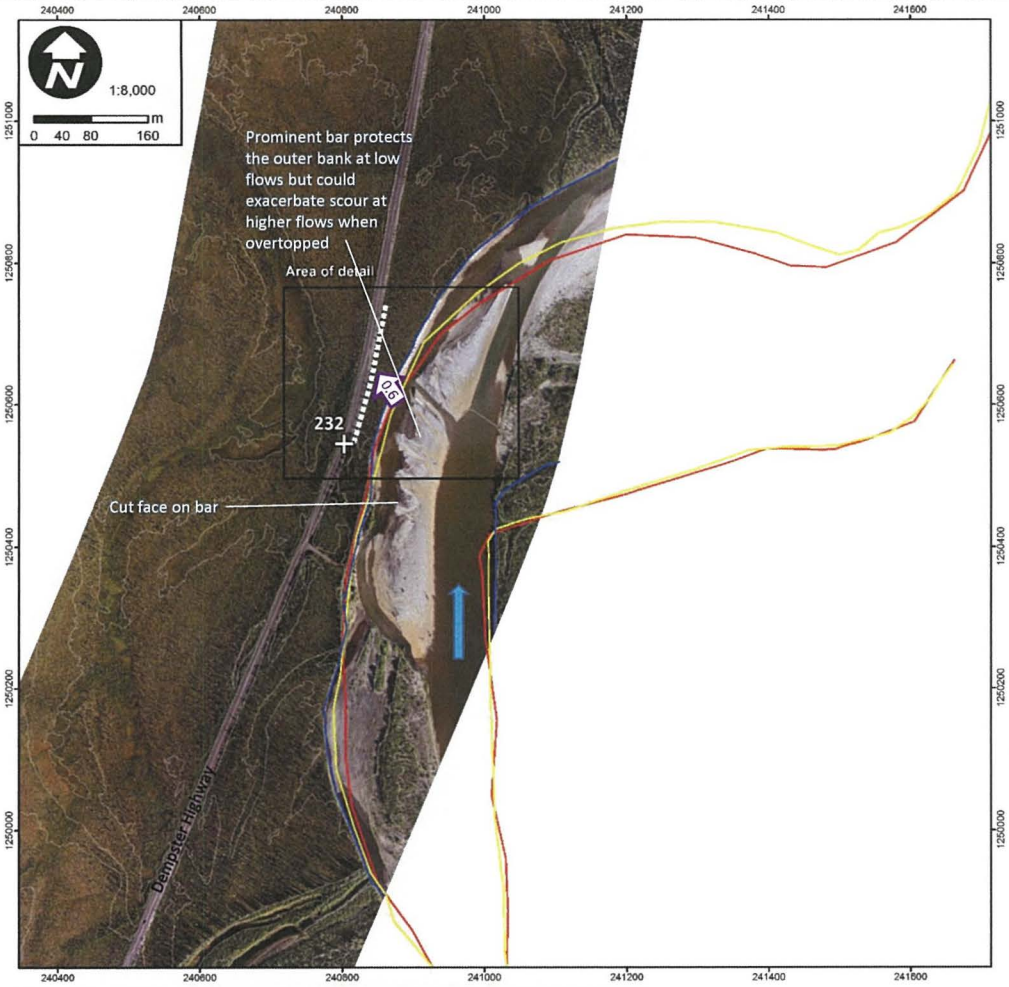
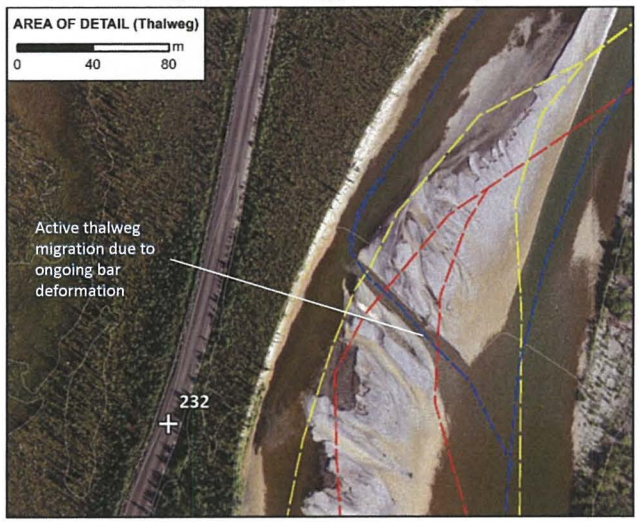
Project number: 14132
Client: Yukon Government

KM 221.3





LEGEND

- Kilometre post
- Highway embankment impact zone
- Current extent of riprap
- 1 m contours

Channel banks (year)

- 2013/ 2014
- 2007/2008
- 1989
- 1977

Thalweg (year)

- 2013/2014
- 2007/2008
- 1989
- 1977

- Direction of flow
- 1° migration rate (m/yr)
- 2° migration rate (m/yr)

NOTE: Refer to accompanying report for definitions, rationale for erosion rate estimates, and an appendix with additional site-specific data. Original page size 11.00 x 17.00 in. Coordinate system NAD 1983 Yukon Albers; units: metres. Tk = thermokarst evidence nearby.

SITE	CHANNEL	MEANDER	RIPRAP REQUIREMENTS
Section	**Setting**	**1° migration rate (m/yr)**	**Timeframe until impact (yr)**
Ogilvie	Fluvial plain	0.7*	>25*
Watercourse	**Permafrost**	**1° trajectory**	**Lateral extent (m)**
Ogilvie River	Shallow, ice-moderate	WNW	200
Riprap history	**Bank height (m)**	**2° migration rate (m/yr)**	**Slope length (m)**
No riprap	3.2	-	10.5
Hwy-watercourse proximity (m)	**Low-flow width (m)**	**2° trajectory**	**Thickness (m)**
24*	28	-	1
Position in meander belt	**Bankfull width (m)**	**Confinement**	**Volume (m^3)**
Within	190	Unconfined	2,099

MEANDER MORPHOLOGY AND DYNAMICS

This encroachment site is located within an unconfined, wandering gravel-bed reach of Ogilvie River. The reach contains prominent point, lateral and medial gravel bars, which influence the position of the thalweg. Locally, a prominent bar oriented parallel to the Dempster Highway has helped protect the outer (west) bank from erosion by confining the thalweg to the east side of the channel. Recently, however, an irregular and conspicuous cut-face has formed on the western side of the bar, indicating a trajectory of flow aimed directly at the west bank during moderate flows or the waning stages of a flood. This has resulted in some lateral migration toward the highway. Longitudinal migration has also occurred downstream of the encroachment site. Notwithstanding the observed adjustments along the west bank, it is unlikely that continued lateral or longitudinal migration will impact the highway embankment within the next 25 years.

IMPLICATIONS OF RIPRAP APPLICATION

Riprap application does not pose further risk to infrastructure.

ALTERNATIVE EROSION PROTECTION STRATEGIES

N/A

SPECIAL CONSIDERATIONS

The prominent bar that parallels the encroachment site has been significantly reworked over the period of record. Continued adjustments during flood conditions could trigger rapid bank erosion and dramatically reduce the separation from the highway embankment, invalidating predicted timeframes of impact based on migration within the past several decades. Monitoring is recommended at this site.

*Updated following 2016 field reconnaissance

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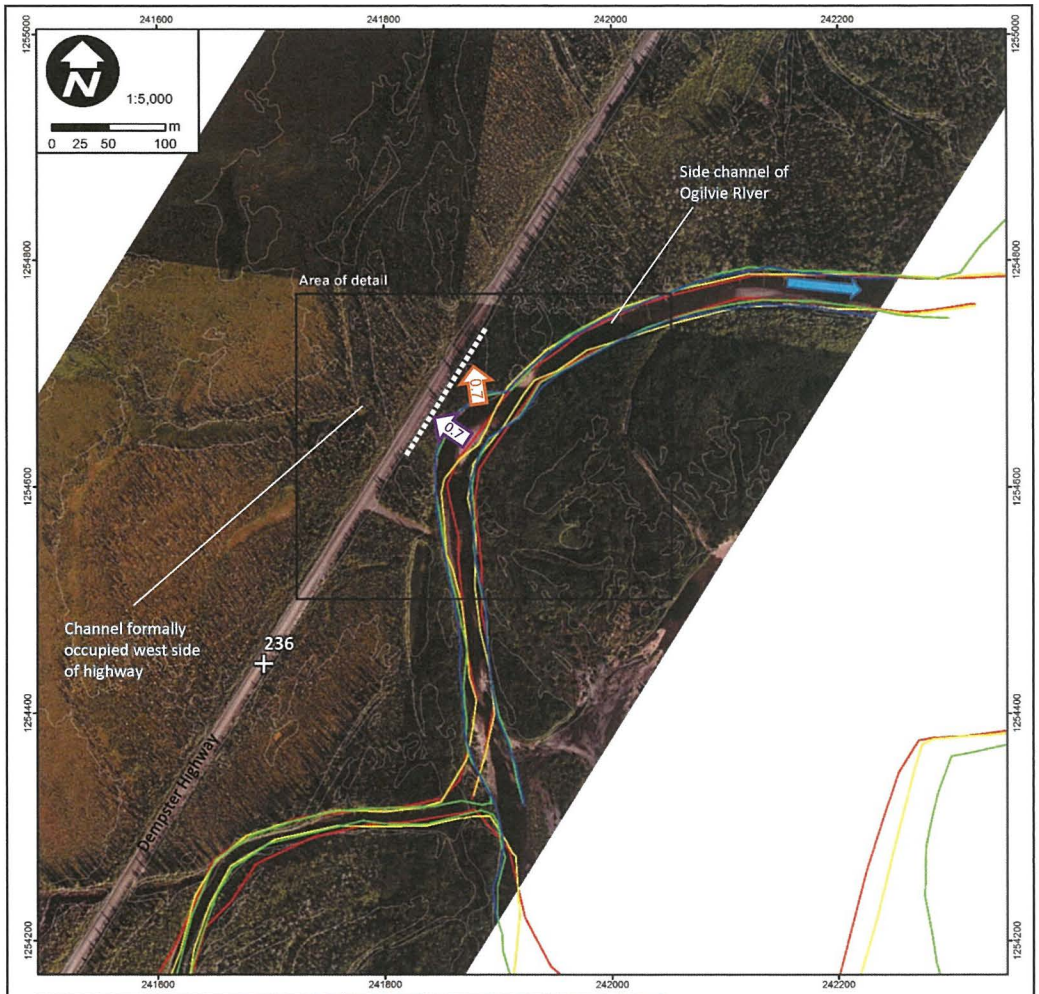
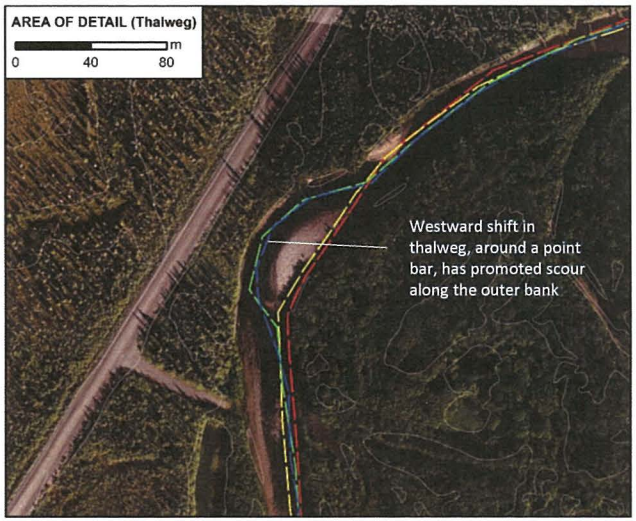
Project: Dempster Meander Migration Hazards
Project number: 14132
Client: Yukon Government

KM 232.0





LEGEND

- Kilometre post
- Highway embankment impact zone
- Current extent of riprap
- 1 m contours

Channel banks (year)

- 2013/ 2014
- 2007/2008
- 1989
- 1977

Thalweg (year)

- 2013/2014
- 2007/2008
- 1989
- 1977

- Direction of flow
- 1° migration rate (m/yr)
- 2° migration rate (m/yr)

NOTE: Refer to accompanying report for definitions, rationale for erosion rate estimates, and an appendix with additional site-specific data. Original page size 11.00 x 17.00 in. Coordinate system NAD 1983 Yukon Albers; units: metres. Tk = thermokarst evidence nearby

SITE	CHANNEL	MEANDER	RIPRAP REQUIREMENTS
Section	**Setting**	**1° migration rate (m/yr)**	**Timeframe until impact (yr)**
Ogilvie	Fluvial plain	0.7	21-25
Watercourse	**Permafrost**	**1° trajectory**	**Lateral extent (m)**
Ogilvie River	Shallow, ice-rich, Tk	WNW	130
Riprap history	**Bank height (m)**	**2° migration rate (m/yr)**	**Slope length (m)**
No riprap	0.6	0.7	4.2
Hwy-watercourse proximity (m)	**Low-flow width (m)**	**2° trajectory**	**Thickness (m)**
19	35	NNW	1
Position in meander belt	**Bankfull width (m)**	**Confinement**	**Volume (m^3)**
Within	39	Unconfined	552

MEANDER MORPHOLOGY AND DYNAMICS

This encroachment site is located along a side channel of an unconfined, wandering gravel-bed reach of Ogilvie River. The main branch of the river has migrated considerably over the period of record. However, the overall position of the side channel has remained virtually unchanged. Locally, there has been notable lateral channel migration (26 m) at the apex of the overall bend in the side channel (i.e. the encroachment site). Furthermore, the channel formally occupied the west (i.e. opposite) side of the Dempster Highway prior to the earliest aerial photography (1977). Shallow, ice-rich permafrost is present at this site, which can lead to irregular and episodic bank erosion and collapse. There is a large buffer (19 m) between the location of the 2013 outer bank and the highway. Without intervention, continued lateral migration will likely impact the highway embankment in 21 to 25 years.

IMPLICATIONS OF RIPRAP APPLICATION

Riprap application does not pose further risk to infrastructure.

ALTERNATIVE EROSION PROTECTION STRATEGIES

River training structures such as bendway weirs or flow-retarding bars ('hockey stick' weirs) could be constructed to shift erosive energy away from the bank. River training structures would require a similar amount of material as simply riprapping the embankment and would likely reduce maintenance frequency and costs if the structures are designed appropriately.

SPECIAL CONSIDERATIONS

N/A

Yukon Government

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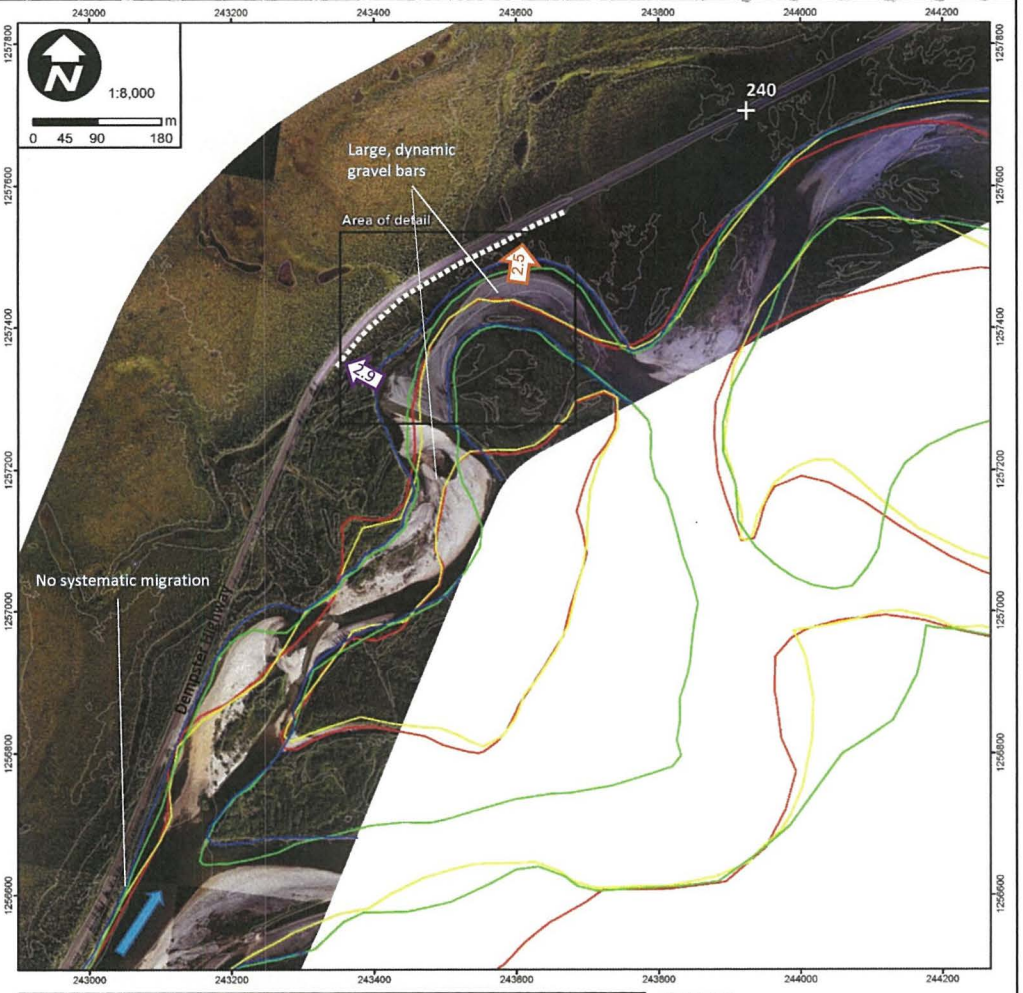
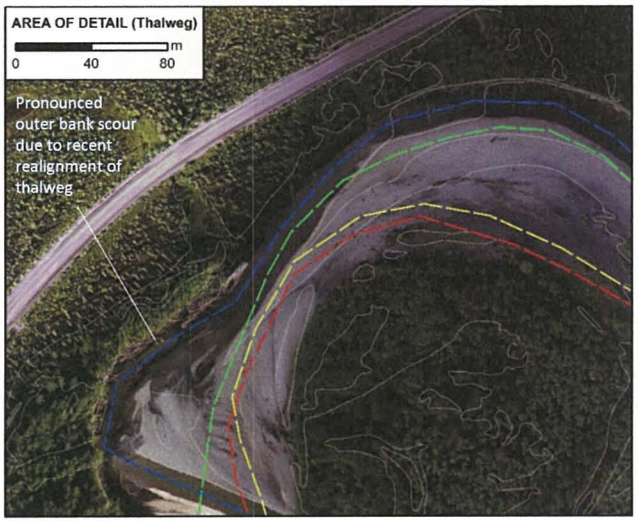
Project: Dempster Meander Migration Hazards
Project number: 14132
Client: Yukon Government

KM 236.3





LEGEND

- Kilometre post
- Highway embankment impact zone
- Current extent of riprap
- 1 m contours

Channel banks (year)

- 2013/ 2014
- 2007/2008
- 1989
- 1977

Thalweg (year)

- 2013/2014
- 2007/2008
- 1989
- 1977

- Direction of flow
- 1° migration rate (m/yr)
- 2° migration rate (m/yr)

NOTE: Refer to accompanying report for definitions, rationale for erosion rate estimates, and an appendix with additional site-specific data. Original page size 11.00 x 17.00 in. Coordinate system NAD 1983 Yukon Albers; units: metres. Tk = thermokarst evidence nearby.

SITE	CHANNEL	MEANDER	RIPRAP REQUIREMENTS
Section	**Setting**	**1° migration rate (m/yr)**	**Timeframe until impact (yr)**
Ogilvie	Fluvial plain	2.9	16-20
Watercourse	**Permafrost**	**1° trajectory**	**Lateral extent (m)**
Ogilvie River	Shallow, ice-rich, Tk	WNW	390
Riprap history	**Bank height (m)**	**2° migration rate (m/yr)**	**Slope length (m)**
No riprap	0.6	2.5	4.7
Hwy-watercourse proximity (m)	**Low-flow width (m)**	**2° trajectory**	**Thickness (m)**
24	17	N	1
Position in meander belt	**Bankfull width (m)**	**Confinement**	**Volume (m^3)**
Within	90	Unconfined	1,829

MEANDER MORPHOLOGY AND DYNAMICS

This encroachment site is located within an unconfined, wandering gravel-bed reach of Ogilvie River. Lateral migration rates throughout the reach are relatively high, gravel bars are extensive and dynamic, and channel avulsions are frequent. Shallow, ice-rich permafrost is present at this site, which can lead to irregular and episodic bank erosion and collapse. Locally, the formally occupied the west (i.e. opposite) side of the Dempster Highway prior to the earliest aerial photography (1977). The meander exhibits a subdued compound form with two minor bends superimposed on its overall meander form. There has been significant lateral migration towards the highway over the period of record along two distinct trajectories (69 m and 58 m). However, there is a large buffer (24 m) between the position of the 2013 outer bank and the highway. Without intervention, continued lateral migration will likely impact the highway embankment in 16 to 20 years.

IMPLICATIONS OF RIPRAP APPLICATION

Riprap application does not pose further risk to infrastructure.

ALTERNATIVE EROSION PROTECTION STRATEGIES

N/A

SPECIAL CONSIDERATIONS

N/A

Yukon Government

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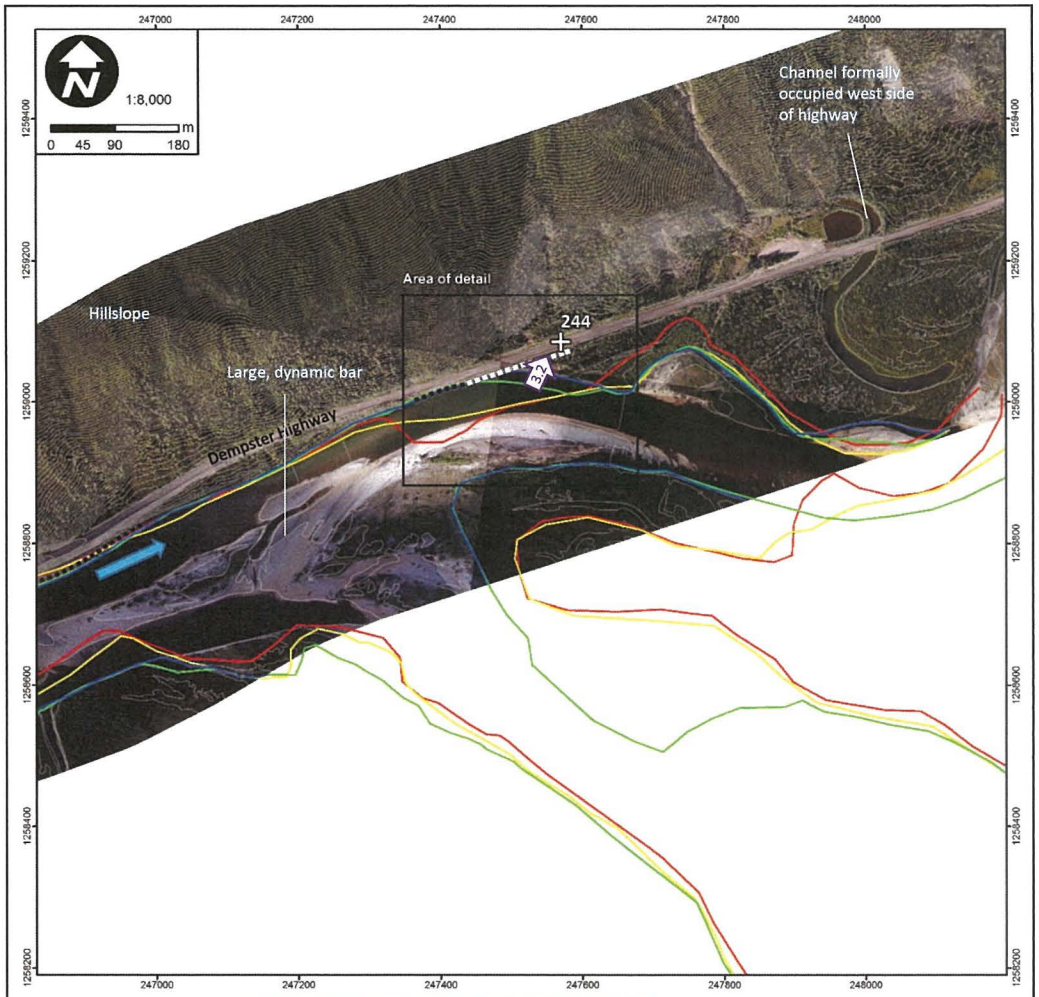
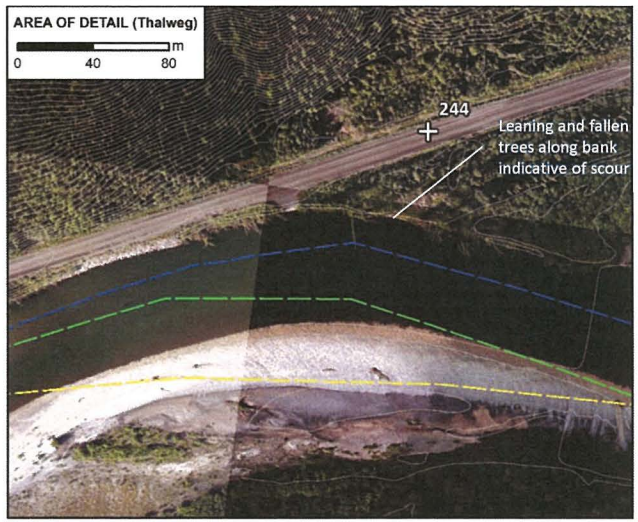
Project: Dempster Meander Migration Hazards
Project number: 14132
Client: Yukon Government

KM 239.5





LEGEND

- Kilometre post
- Highway embankment impact zone
- Current extent of riprap
- 1 m contours

Channel banks (year)

- 2013/ 2014
- 2007/2008
- 1989
- 1977

Thalweg (year)

- 2013/2014
- 2007/2008
- 1989
- 1977

- Direction of flow
- 1° migration rate (m/yr)
- 2° migration rate (m/yr)

NOTE: Refer to accompanying report for definitions, rationale for erosion rate estimates, and an appendix with additional site-specific data. Original page size 11.00 x 17.00 in. Coordinate system NAD 1983 Yukon Albers; units: metres. Tk = thermokarst evidence nearby.

SITE	CHANNEL	MEANDER	RIPRAP REQUIREMENTS
Section	**Setting**	**1° migration rate (m/yr)**	**Timeframe until impact (yr)**
Ogilvie	Hwy edge fluvial plain	3.2	6-10
Watercourse	**Permafrost**	**1° trajectory**	**Lateral extent (m)**
Ogilvie River	Shallow, ice-rich, Tk	NNE	150
Riprap history	**Bank height (m)**	**2° migration rate (m/yr)**	**Slope length (m)**
1991,1996, 2013, 2015	2.3	-	8.3
Hwy-watercourse proximity (m)	**Low-flow width (m)**	**2° trajectory**	**Thickness (m)**
4	44	-	1
Position in meander belt	**Bankfull width (m)**	**Confinement**	**Volume (m^3)**
Edge	120	Confined by highway	1,240

MEANDER MORPHOLOGY AND DYNAMICS

This encroachment site is located within a partly confined, wandering gravel-bed reach of Ogilvie River. The reach contains large, vegetated islands and smaller transient bars. There are two dominant branches in the reach. In the 1977 aerial imagery, flow was evenly divided between both branches. In the more recent imagery, the north branch (where the encroachment site is located) contains the majority of flow and thus the erosive energy. Locally, extensive riprap has been placed along the outer bank to protect the highway embankment, during several different years. The riprap and valley confinement have led to minimal lateral migration but notable longitudinal migration. Furthermore, the increased flow in the northern branch could have accelerated migration rates. Shallow, ice-rich permafrost may persist in portions of this site, which can lead to irregular and episodic bank erosion and collapse. Without intervention, continued longitudinal migration will likely impact the highway embankment in 6 to 10 years.

IMPLICATIONS OF RIPRAP APPLICATION

Previous riprap application has accelerated longitudinal migration. More riprap may be required downstream of the current limit of riprap to protect the highway embankment.

ALTERNATIVE EROSION PROTECTION STRATEGIES

River training structures such as bendway weirs or flow-retarding bars ('hockey stick' weirs) could be constructed downstream of the existing riprap to shift erosive energy away from the unprotected bank. River training structures would require a similar amount of material as simply riprapping the embankment and would likely reduce maintenance frequency and costs if the structures are designed appropriately.

SPECIAL CONSIDERATIONS

Due to the longitudinal nature of the observed bank migration, it is possible that the embankment immediately downstream of the previously placed riprapped could be impacted prior to the estimated timeframe.

Yukon Government

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Project number: 14132
Client: Yukon Government

KM 243.8

KM 52.3 (Photo 1). Backwatered pool at upstream end of meander

KM 52.3 (Photo 2). Riparian buffer between watercourse and highway

KM 54.9 (Photo 1). Lack of woody vegetation between watercourse and highway

KM 54.9 (Photo 2). Bank slumping at downstream end of encroachment site

KM 55.9 (Photo 1). Dense riparian buffer between watercourse and highway

KM 55.9 (Photo 2). Looking towards the channel from atop the scarp

KM 88.0 (Photo 1). Looking upstream from atop the scarp

KM 131.4 (Photo 1). Looking upstream from riprap spur

KM 131.4 (Photo 2). Looking downstream from riprap spur

KM 136.1 (Photo 1). Looking upstream from previously placed riprap

KM 136.1 (Photo 2). Looking downstream from previously placed riprap

KM 138.5 (Photo 1). Leaning trees and exposed bank at the upstream end of the encroachment site

KM 138.5 (Photo 2). Prominent point bar across from the encroachment site

KM 147.6 (Photo 1). No photographs available – site highly altered

KM 170.9 (Photo 1). Active erosion at upstream end of encroachment site

KM 170.9 (Photo 2). Downstream end of encroachment site

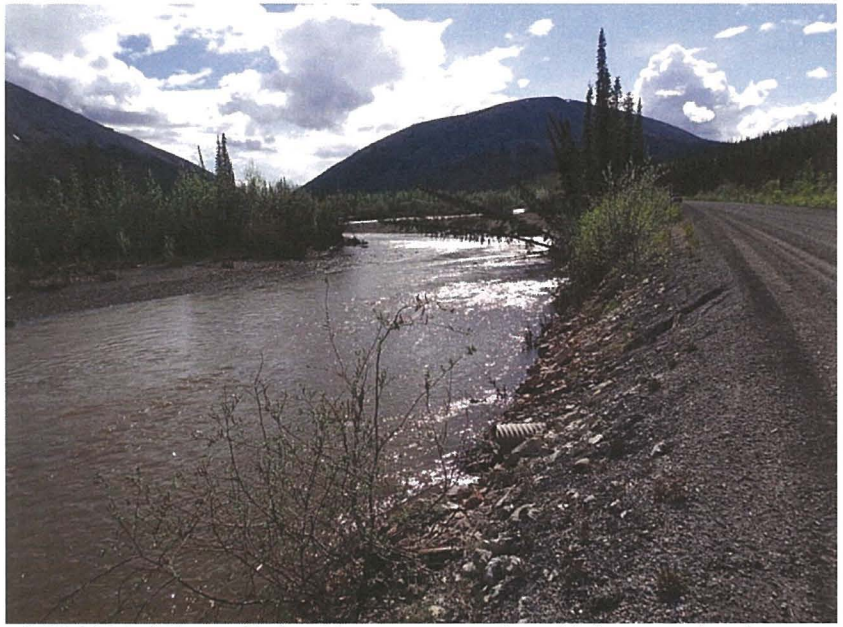
KM 172.9 (Photo 1). Looking downstream at recently placed riprap

KM 172.9 (Photo 2). Looking upstream at recently placed riprap

KM 175.2 (Photo 1). Actively migrating channel upstream of the encroachment site

KM 175.2 (Photo 2). Looking downstream at recently placed riprap from atop the scarp

KM 180.7 (Photo 1). Looking downstream from highway embankment



KM 180.7 (Photo 2). Looking upstream from highway embankment

KM 181.5 (Photo 1). Thin riparian buffer between watercourse and highway

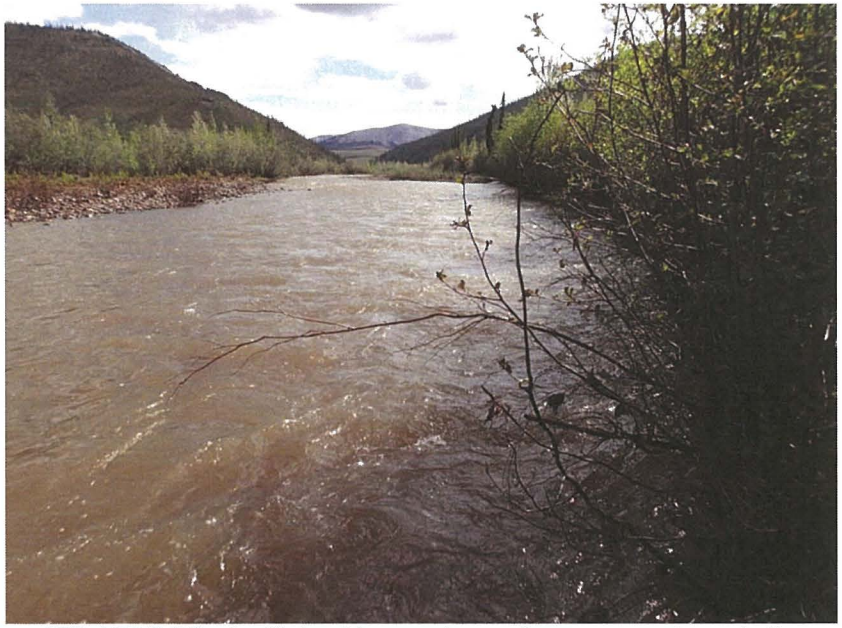
KM 181.5 (Photo 2). Looking downstream from highway embankment

KM 182.1 (Photo 1). Active scour and permafrost degradation beneath previously placed riprap

KM 182.1 (Photo 2). Significant bank collapse in permafrost downstream of previously placed riprap

KM 183.3 (Photo 1). Looking upstream at channel approach to the encroachment site

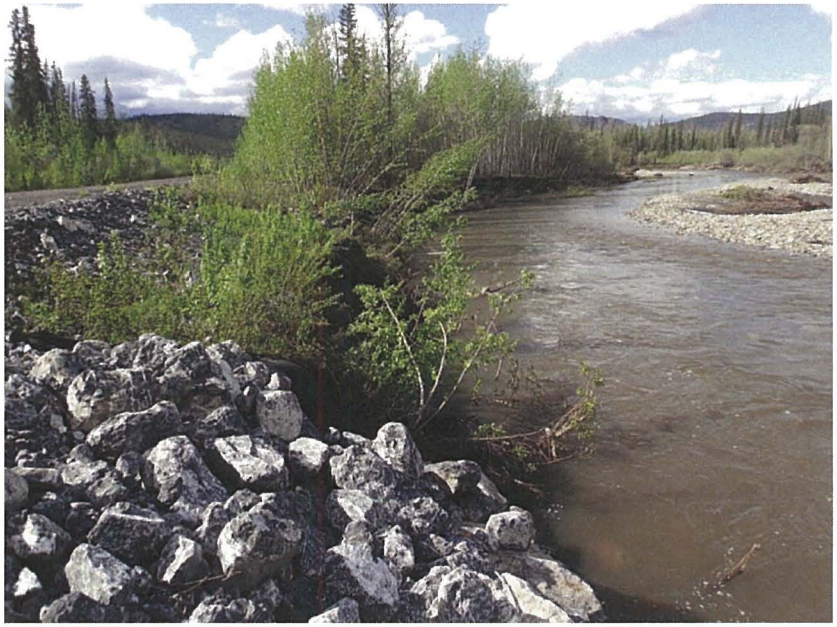
KM 183.3 (Photo 2). Leaning trees and bank scour



KM 185.8 (Photo 1). Looking upstream from encroachment site

KM 185.8 (Photo 2). Slumping/exposed banks

KM 188.6 (Photo 1). Looking upstream at channel approach from recently placed riprap



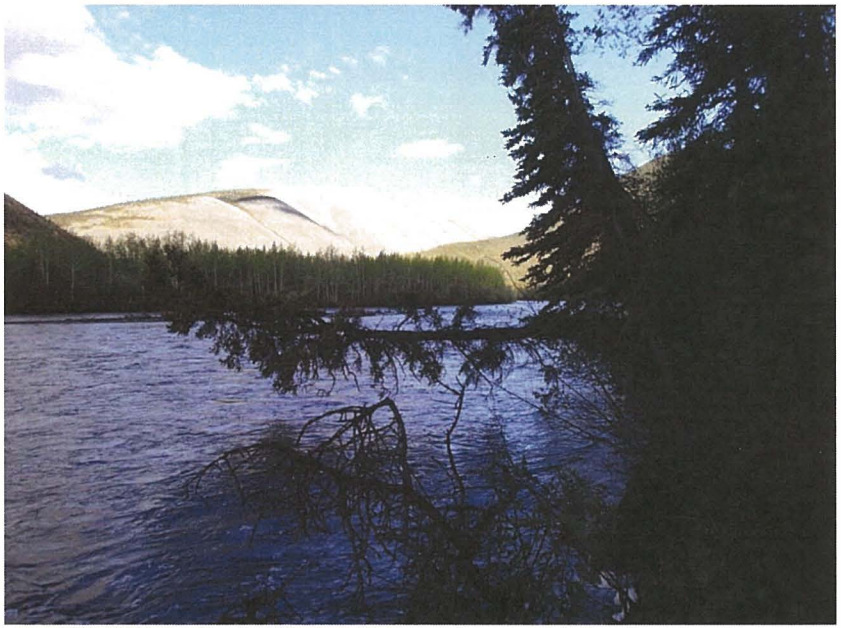
KM 188.6 (Photo 2). Leaning trees and bank scour downstream of recently placed riprap

KM 189.4 (Photo 1). Looking upstream from highway embankment

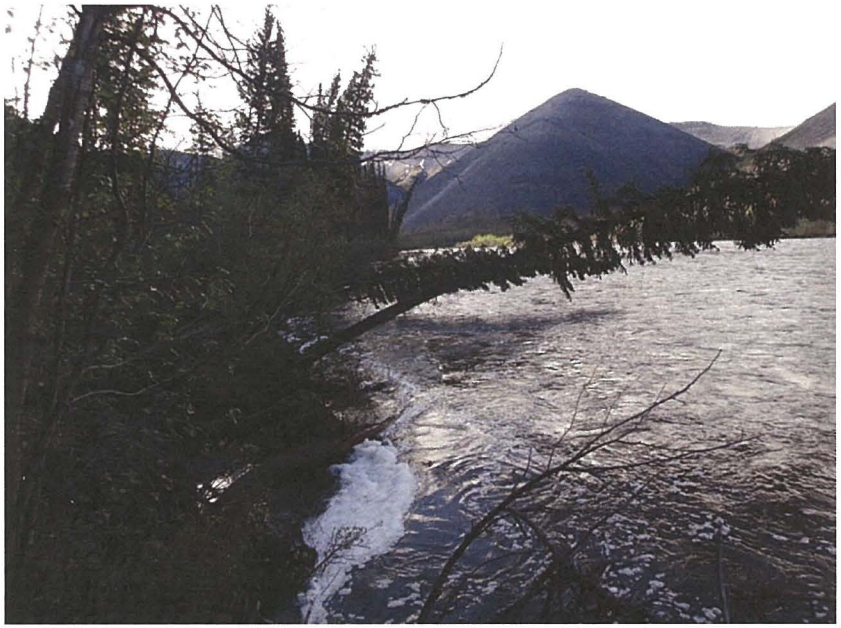
KM 189.4 (Photo 2). Looking downstream from highway embankment

KM 195.1 (Photo 1). Fallen/leaning trees along the outer (northeast) bank of Engineer Creek

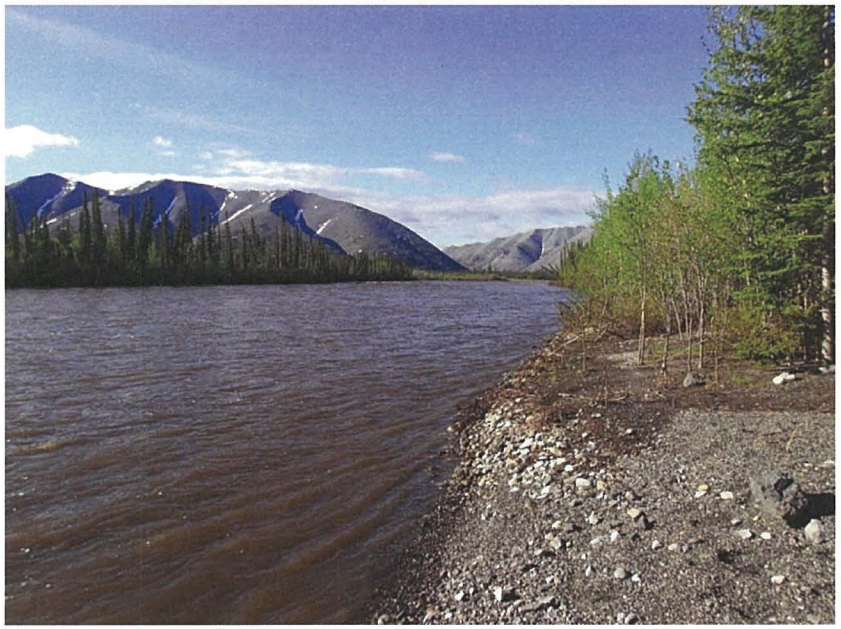
KM 195.1 (Photo 2). Looking downstream from confluence



KM 202.5 (Photo 1). Looking upstream at fallen/leaning trees



KM 202.5 (Photo 2). Looking downstream at fallen/leaning trees

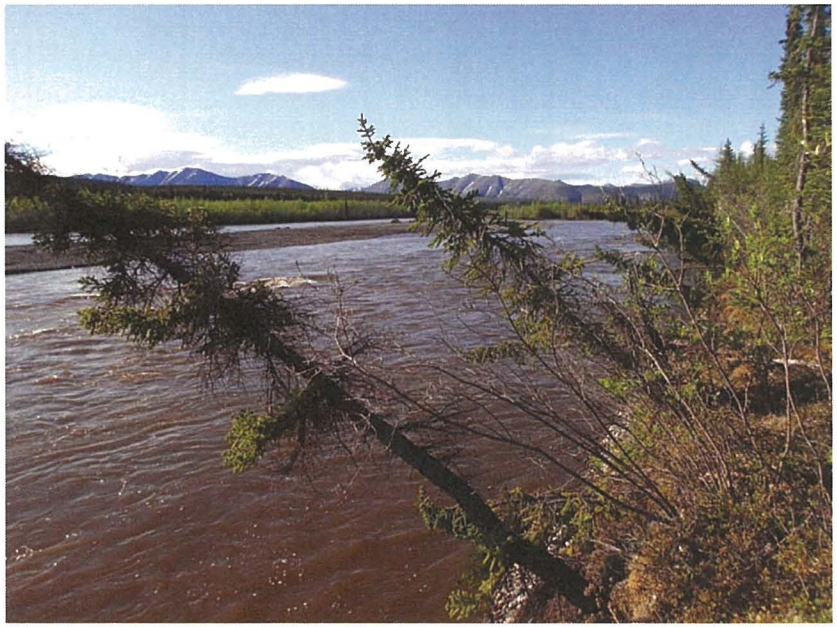


KM 221.1 (Photo 1). Looking upstream from encroachment site

KM 221.1 (Photo 2). Looking downstream from encroachment site

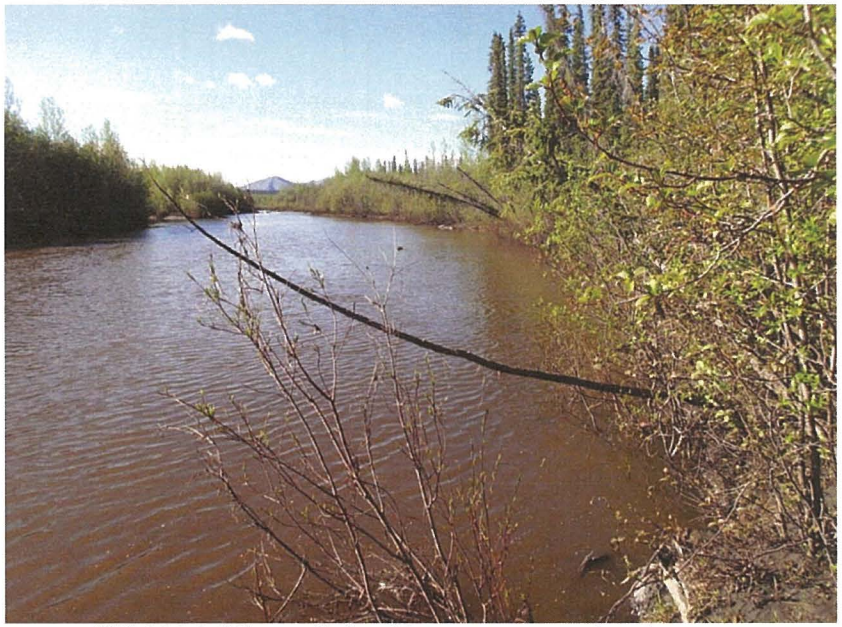
KM 221.3 (Photo 1). Looking upstream from encroachment site

KM 221.3 (Photo 2). Looking downstream from encroachment site



KM 232.0 (Photo 1). Looking upstream at fallen/leaning trees

KM 232.0 (Photo 2). Looking downstream from encroachment site; note low banks in permafrost

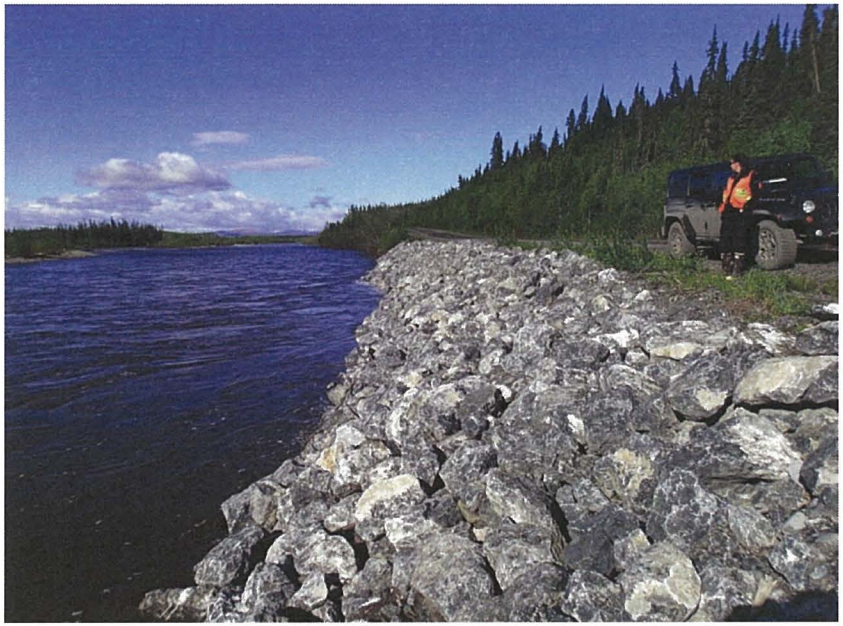


KM 236.3 (Photo 1). Looking upstream at leaning trees

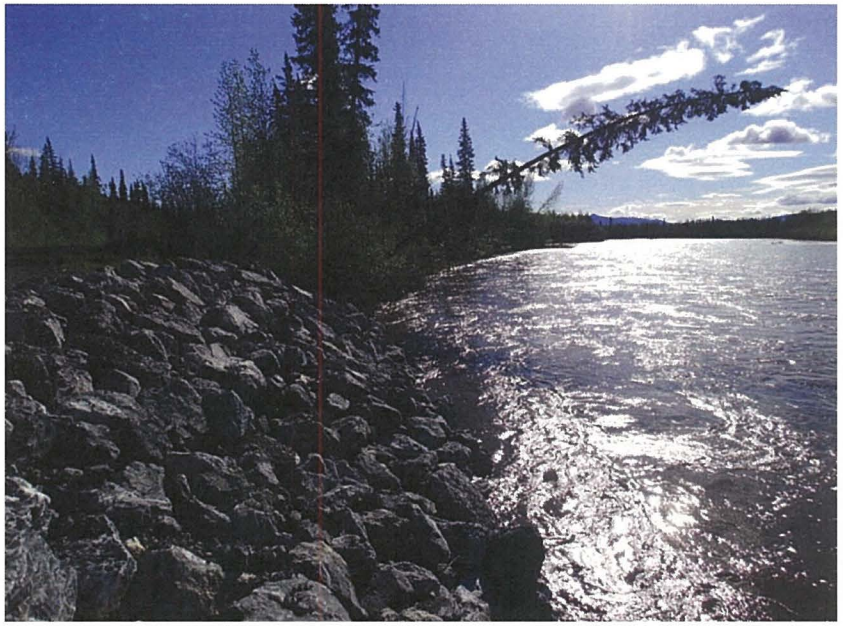
KM 236.3 (Photo 2). Looking downstream from encroachment site

KM 239.5 (Photo 1). Looking upstream at leaning trees

KM 239.5 (Photo 2). Looking downstream at fallen/leaning trees



KM 243.8 (Photo 1). Looking upstream from recently placed riprap



KM 243.8 (Photo 2). Leaning trees downstream of recently placed riprap

Appendix I. Field Photographs of Prioritized Meander-Highway Encroachment Sites