

AMEC Earth & Environmental
a division of AMEC Americas Limited
2227 Douglas Road, Burnaby, BC
Canada V5C 5A9
Tel +1 (604) 294-3811
Fax +1 (604) 294-4664
www.amec.com



**Overall Geotechnical Report on
the Pipeline Route Rev. R for the
Enbridge Northern Gateway Project
Bruderheim, Alberta to Kitimat, BC**

Submitted to:
Northern Gateway Pipelines Inc.
Calgary, Alberta

Submitted by:
**AMEC Earth & Environmental,
a division of AMEC Americas Limited**

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IMPORTANT NOTICE

This report was prepared exclusively for Northern Gateway Pipelines Inc., a subsidiary of Enbridge Pipelines Inc. (Enbridge) by AMEC Earth & Environmental Limited, a wholly owned subsidiary of AMEC. The quality of information, conclusions and estimates contained herein is consistent with the level of effort involved in AMEC services and based on: i) information available at the time of preparation, ii) data supplied by outside sources, and iii) the assumptions, conditions and qualifications set forth in this report. This report is intended to be used by Northern Gateway Pipelines Inc., Enbridge only, subject to the terms and conditions of the contract between AMEC and Enbridge. Any other use of, or reliance on, this report by any third party, is at that party's sole risk.

1.0 INTRODUCTION

1.1 Purpose

This report presents preliminary overall geotechnical evaluations and recommendations for the Enbridge Northern Gateway Project (the Project) from the Bruderheim Station, near Bruderheim, Alberta to the Kitimat Terminal, located near Kitimat, B.C. This report discusses overall geotechnical aspects of the proposed pipeline route based on the Revision R (Rev. R) pipeline route. The Rev R route is a corridor, nominally 1 km wide centered on the Rev. R alignment that is 1172 km long. Two parallel pipelines would be constructed: a 914 mm oil export pipeline flowing toward the west and a 508 mm condensate pipeline flowing toward the east. The pipelines will share a permanent right-of-way (RoW) that will normally be 25 m wide.

This report was prepared by AMEC Earth & Environmental (AMEC) at the request of Northern Gateway Pipelines Inc. in conjunction with their engineering consultant, WorleyParsons Calgary.

The pipeline route as it is presently constituted has evolved through various revisions during the routing studies that have been ongoing for several years. The presently considered Rev. R is shown in overview on [Figure 1.1](#). [Figures A-1 to A-11](#) in [Appendix A](#) show more details of the route. Further optimizations of the route may occur during ongoing design studies.

1.2 Project Overview

As currently proposed, the Enbridge Gateway Project will consist of the following:

1. A 914 mm OD (outside diameter) (NPS 36) oil pipeline from the Bruderheim Station to the Kitimat Terminal, a distance of approximately 1172 km.
2. A 508 mm OD (NPS 20) condensate pipeline, located in the same right-of-way (RoW) as the oil pipeline, from the Kitimat Terminal to the Bruderheim Station.
3. The Bruderheim Station, consisting of an oil initiating pump station and a condensate receiving station.
4. Intermediate pump stations at eight locations along the pipeline route.
5. Two tunnels, approximately 6.6 and 6.5 km long, located approximately 50 km northeast of Kitimat, to route the oil and condensate pipelines between the Clore River and Hoult Creek valleys. Geotechnical aspects of the tunnels are discussed under separate cover (AMEC 2009a).
6. Kitimat Terminal, located on the west side of Kitimat Arm. Geotechnical aspects of the terminal are discussed under separate cover (AMEC 2009b).

Additional facilities include pump stations, powerlines, camps, equipment stockpile areas and other infrastructure. Preliminary geotechnical input has been provided to the project team on these facilities; however, these portions of the infrastructure are not discussed in this report.

The evaluation and recommendations presented in this report are based on the following information:

1. Review of available mapping and published materials. References to key published information are provided in [Table B-1](#) and elsewhere in the report.
2. Previous experience in the areas under discussion.
3. Review of LiDAR data including hillshade images generated by WorleyParsons Calgary and AMEC Earth & Environmental (AMEC) for some crossings and slopes. LiDAR base data is not yet available for all crossings.
4. Helicopter reconnaissances of the pipeline route were carried out by AMEC, Enbridge and WorleyParsons Calgary personnel at various times between 2003 and December 2009.
5. Site specific ground reconnaissances have been carried out at selected locations along the route, particularly at selected water course crossings and adjacent approach slopes. However, not all slopes and stream crossings had been reconnoitred on the ground at the time of writing. The field reconnaissances were usually made in the company of representatives from Enbridge and other members of the project team.
6. Drilling has been carried out at a few of the key water course crossings and on adjacent approach slopes. Geophysics has not yet been carried out on any of the water course crossings or approach slopes.

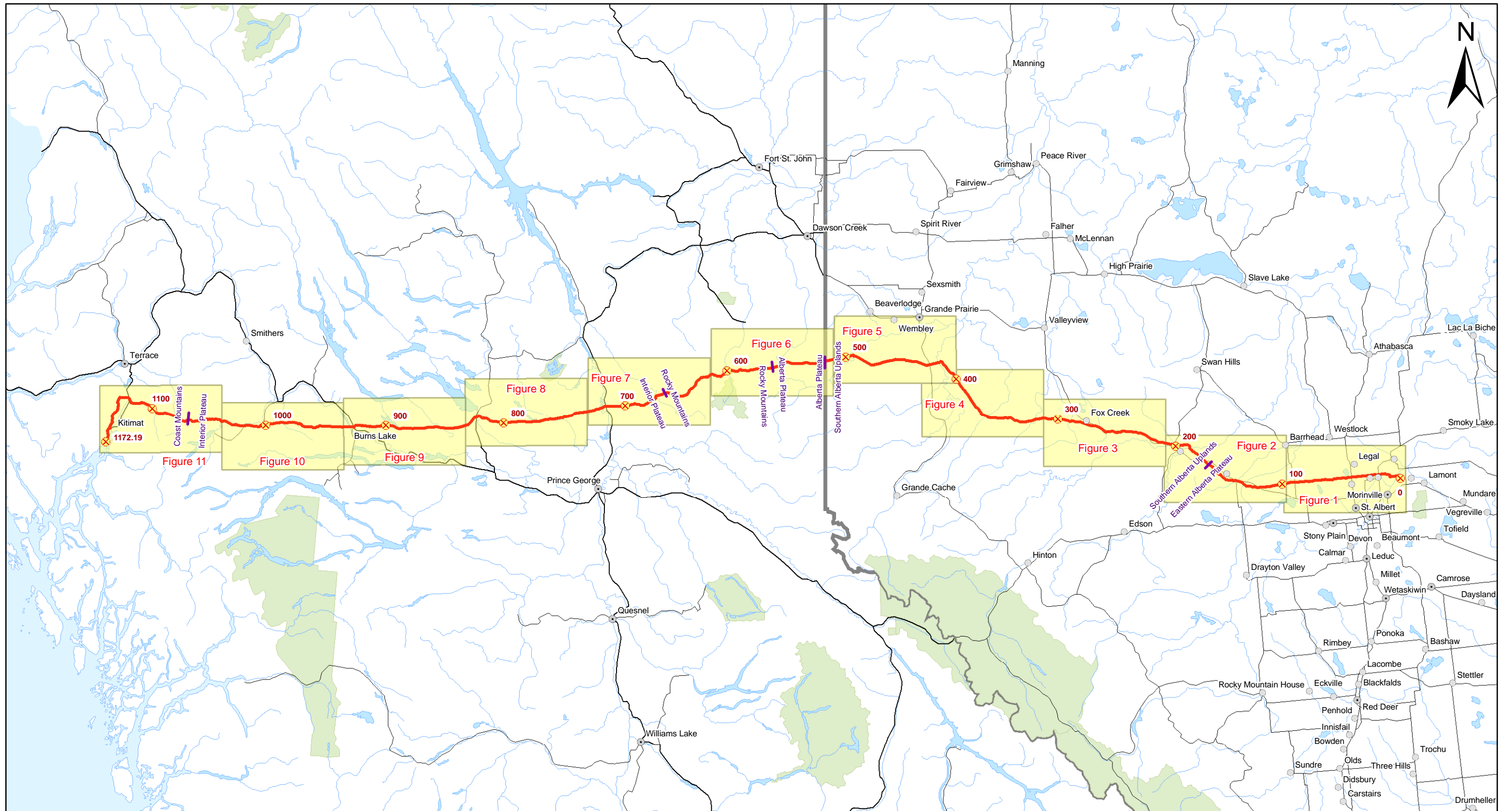
Comprehensive geotechnical studies will be carried out during detailed design.

1.3 Organization

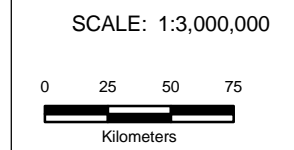
This report is organized as follows:

1. [Table B-1 \(Appendix B\)](#) provides a summary geotechnical description and preliminary mitigative recommendations on a kilometer by kilometer basis for the Rev R pipeline route.
2. Discussion of topography and physiographic regions, bedrock geology, surficial geology and stability relative to geotechnical aspects of the route appears in [Section 2](#).
3. Discussion of selected geotechnical aspects and issues with respect to the proposed route appears in [Section 3](#).
4. Natural terrain hazards and risk analyses are discussed in [Section 4](#)
5. Preliminary geotechnical mitigative recommendations are discussed in [Section 5](#) and in [Table B-1](#).

The units used in this report are primarily metric except that both the systems are used in some cases where the source measurements were Imperial units.



- LEGEND**
- City
 - Town
 - Road
 - River
 - Lake
 - Park
 - ⊗ Kilometre Post (July 27, 2009)
 - Proposed Route (July 27, 2009)
 - Physiographic Boundary
 - Figure Index



PROJECTION: LCC DATUM: NAD 83

ENBRIDGE NORTHERN GATEWAY PROJECT

General Location Plan & Physiographic Boundaries

PROJECT NUMBER:
EG0926008.3001

DATE:
February 5, 2010

QA/QC:
DC

REFERENCE:
Pipeline Route: Rev R, July 27, 2009

CONTRACTOR:
AMEC Earth & Environmental

Figure 1.1

2.0 SETTING

2.1 General

The proposed pipeline route runs generally toward the west from near Bruderheim, northeast of Edmonton. Elevations along the proposed pipeline route range from 600 m (1975 ft) near Bruderheim, rising across Alberta to near 1200 m (3900 ft) in the foothills and to 1430 m (4700 ft) through a pass in the Rocky Mountains southwest of Tumbler Ridge. The Continental Divide (the point at which the surface water drainage divides between streams ultimately flowing toward the Arctic and Pacific Oceans) is crossed at about KP 730 west of the Rocky Mountains at an elevation of about 3600 ft (1100 m). Elevations west of the divide are typically under about 915 m (3000 ft) with the exception the Coast Mountains. The route crosses the Coastal Mountains in two proposed tunnels at approximate elevations of 915 to 760 m (3000 ft to 2500 ft) and descends to near sea level near Kitimat. Elevations at the proposed terminal on the west side of Kitimat Arm are approximately 200 m or below. Except in central Alberta, parts of the Rockies and a few other areas, the stream valleys tend to be oriented near north-south. Thus, many parts of the route cross local ridges and streams, rather than being parallel to them.

The proposed pipeline route crosses six broad physiographic regions as defined in Alberta by Pettapiece (1986) and in British Columbia by Demarchi (1995). The physiographic regions used in this report are based on those used by the Project GEM environmental team. It should be further noted that the boundaries are approximate and that some overlap in terms of terrain characteristics near the boundaries between different areas. The physiographic regions form a convenient framework for general discussion of the topography, geology and natural terrain hazards. Descriptions of the regions appear below and the locations of the various physiographic regions are shown on [Figure 1.1](#) and [Figures A-1 to A-11](#) in [Appendix A](#).

2.2 Eastern Alberta Plains

2.2.1 Topography and Physiography

The Eastern Alberta Plains (Eastern Alberta Plateau in some literature and materials) physiographic region extends from approximately KP 0 to approximately KP 165.8. The topography is typically flat to rolling with incised stream valleys that vary up to several tens of meters deep. Major streams in this area include the North Saskatchewan, Pembina and Paddle Rivers. Upland elevations along the proposed pipeline route rise from 700 m (2300 ft) to approximately 800 m (2600 ft) toward the west. The area is underlain by sedimentary bedrock with little structure other than the generally flat-lying bedrock units.

The Eastern Alberta Plains physiographic region has a continental climate, consisting of short warm summers and long cold winters, typically with continuous winter snow cover. Most precipitation falls as rain during the summer months (Bowser et al. 1962; Lindsay et al. 1968). The mean annual temperature is about 1.5°C (varying with elevation and location), with mean annual precipitation in the range of 400-500 mm.

2.2.2 Surficial Geology

Terrain within the Eastern Alberta Plains is typically undulating and is underlain by fine textured glaciolacustrine deposits (silts and clays with some interbedded sand) and undulating to hummocky moraine consisting of calcareous fine textured till (typically silty clay to clayey silt with varying sand to boulder contents). Localized coarse glaciofluvial deposits (sand and gravel containing varying contents of pebbles to boulders) also occur, typically along valleys that carried glacial meltwater flows at the end of the last glaciation around 9,500 to 11,000 years BP (before present). Large areas are underlain by glacial lake deposits including Glacial Lake Edmonton. Numerous other smaller glacial lakes were also present and these areas are also underlain by glaciolacustrine clays. Aeolian deposits cover wide areas to variable depths and represent a reworking of the glaciolacustrine deposits by wind near the end of glaciation.

Recent accumulations of coarse textured alluvial deposits occur along water courses. Organic deposits in the form of peat (muskeg) occur along many of the flat bottomed outwash channels or valleys and in terrain depressions. Recent lacustrine accumulations of silt and clay also occur.

The deposition and erosion that occurred during the Late Wisconsinan Glaciation was a major influence on the geomorphology of the Eastern Alberta Plains. During this glaciation, the region was overrun by the Laurentide Ice Sheet (from the Canadian Shield) up to approximately 13,000 years before present (BP) (Dyke and Prest 1987a). Deglaciation occurred via stagnation and down-wasting. The ice margin retreated to the northeast due to thinning of the ice sheet.

During deglaciation, large proglacial lakes formed in areas bounded between uplands and the retreating ice. The area between Bruderheim and approximately north of Morinville (KP 0 to 44) is underlain in part by glaciolacustrine sediments from Glacial Lake Edmonton that include medium to high plastic clays and silty clays, layers of silt and some sand interbeds. Varved sediments are also present. These deposits are up to 80 m thick and form a flat to gentle topography (Shetson 1990). In higher areas, glacial till occurs as either ground moraine or stagnation moraine. Aeolian sands and sand dunes are present where the glaciolacustrine deposits have been reworked by wind.

The area from Morinville to the Pembina River (KP 131) is underlain by fine to medium textured stagnation moraine (glacial till) of varying thicknesses. Localized inclusions of water sorted material are common and Holocene (interglacial time period that started at the end of the last ice age) organic, fluvial, and lacustrine accumulations occur in depressions and along river valleys (Shetson 1990). The surface form is generally undulating to hummocky.

The area from Pembina River to KP 201 near Whitecourt (beyond the end of the physiographic region) is dominated by ice contact glaciolacustrine deposition. Sediments vary in texture but are commonly medium to fine textured and extend to depths of approximately 20 metres (Shetson 1990). Glacial till including ice rafted material is exposed in some areas within this widespread glaciolacustrine deposit. Short segments of the pipeline route traverse ground moraine and stagnation moraine. Eolian deposits are found adjacent to the Athabasca River

valley, and the accumulation of Holocene fluvial and organic sediments occurs along modern rivers and in depressional areas, respectively.

2.2.3 Bedrock Geology

The Eastern Alberta Plains Physiographic Region is underlain by bedrock of the Horseshoe Canyon and Scollard Formations (Journeay et al 2000a). The bedrock formations in this region are flat lying and generally have not been folded by past tectonic activity. The Upper Cretaceous Horseshoe Canyon Formation underlies the majority of this physiographic region and includes sandstone, mudstone, and shale. Localized ironstone concretions and scattered coal seams may also be present (Shetson 1990). The Horseshoe Canyon Formation contains some bentonitic seams, but is generally less subject to slope stability concerns than the underlying Scollard Formation.

The Scollard Formation is Tertiary to Cretaceous in age and contains sandstone and mudstone with frequent interbeds of shale and coal (Journeay et al 2000a). The formation mainly occurs near and beyond the west end of the Eastern Alberta Plains Physiographic Region. The Scollard Formation contains bentonite and related smectite clays, resulting in low shear strengths in some of the beds. As a result, the Scollard Formation is a regional control on bedrock slope stability where it is located close to the ground surface.

2.3 Southern Alberta Uplands

2.3.1 Topography and Physiography

The Southern Alberta Uplands physiographic region extends from approximately KP 165.8 to KP 516.8 at the BC-Alberta boundary. The upland terrain is generally rolling to ridged with local areas that are rougher and dissected including south of the Athabasca River. Local topography is generally controlled by deep surficial deposits with an undulating to hummocky surface. High bedrock controlled relief occurs along the foothills of the Rocky Mountains at the west edge of the area. The area is underlain by sedimentary bedrock that is close to flat lying with some regional folding or warping in some areas. Elevations along the proposed route are more variable than to the east, but typically range from 800 to 975 m (2600 to 3200 ft) in the upland areas. Major streams in this area include the Athabasca, Sakwatamau, Iosegun, Little Smoky, Latornell, Smoky, Simonette and Wapiti Rivers, which flow in valleys up to 150 m deep with slopes that are very steep in some areas. Some of the named "creeks" such as Deep Valley Creek also have valleys with depths similar to the river valleys previously listed, although in some cases the valleys may be narrower and with steeper sideslopes than the main river valleys.

The climate of the Southern Alberta Uplands is continental and is characterized by cold winters and short cool summers (Ecological Stratification Working Group 1996). The mean annual temperature ranges between 1 and 2°C, mean summer temperatures range between 13 and 14°C, and mean winter temperatures range from -9 to -13°C. The mean annual precipitation ranges between 450 and 600 mm, falling mostly as rain in the summer months (Ecological Stratification Working Group 1996).

2.3.2 Surficial Geology

Surficial materials include undulating to hummocky till plains, glaciolacustrine plains, and localized glaciofluvial outwash and deltaic sediments. Local aeolian deposits occur in some areas where the fine textured glaciofluvial and glaciolacustrine deposits were reworked by the wind, possibly soon after the end of glaciation prior to the establishment of ground cover vegetation. Coarse textured fluvial accumulations occur along modern rivers and organic and lacustrine deposits occur in low areas (Twardy and Corns 1980; Knapik and Lindsay 1983). Preglacial valleys have been infilled in some areas with sediments including bouldery materials, preglacial glaciofluvial materials and glacial sediments and till. These valley infill deposits may be a major consideration for directional drilling.

The geomorphology and surficial sediments and deposits of the Southern Alberta Uplands are similar to those of the Eastern Alberta Plains which were also overrun by the Laurentide Ice Sheet. The till in the Southern Alberta Uplands was deposited by the continental glaciation and is generally characterized by a sandy clay matrix with low coarse fragment contents (Fenton and Pawlowicz 2002). Topographically, the till is typically undulating to hummocky in lower elevation areas and increases in relief along the western margins of the region within the foothills of the Rocky Mountains.

Large proglacial lakes formed in this area during deglaciation (Dyke and Prest 1987a; Fenton and Pawlowicz 2002). Gentle to flat topography is associated with the glaciolacustrine deposits which are generally greater than 20 metres thick (Twardy and Corns 1980; Knapik and Lindsay 1983). The sediments are generally medium to high plastic clay with low coarse fragment content.

Moderate to coarse textured glaciofluvial sediments occur in many of the river valleys. These sediments are characterized by localized planar terraces with steep terrace fronts, resulting from the subsequent down cutting of the modern rivers (Fenton and Pawlowicz 2002).

Longitudinal and parabolic dunes formed on the underlying glaciolacustrine and glacial till surfaces in some areas. Many of these features formed soon after glaciation and are either relatively inactive or not presently active. These features tend to have a moderate relief of approximately 5 to 10 metres and are composed of sand and silt.

Thick organic deposits occur in many of the lower areas in this region. These deposits may be relatively thick (locally up to 3 m or more) occupying areas once containing Holocene lakes.

2.3.3 Bedrock Geology

The Southern Alberta Uplands physiographic region is underlain by the Upper Paskapoo, Wapiti and Scollard Formations (Journeay et al 2000a; Knapik and Lindsay 1983). The rock strata in the eastern portion of this region are generally flat lying while thrust faults parallel to the overall trends of the Rocky Mountains occur along the western margin (Journeay et al 2000a). Due to

regional warping and the terrain elevations, the bedrock formations encountered along the route repeat across the Southern Alberta Uplands. The Upper Wapiti and laterally equivalent Horseshoe Canyon Formations occur near and east of the eastern boundary and also in the northwestern part of the region. The Scollard Formation forms a curved outcrop pattern that is crossed by the pipeline route west of the Athabasca River and also near the Latornell River. The broad central area of the region (as far as the pipeline route is concerned) is underlain by the Upper Paskapoo Formation.

Similar to the Eastern Alberta Plains, the Tertiary to Cretaceous Scollard Formation contains sandstone and mudstone, with frequent interbeds of shale and coal and some bentonite (Journeay et al 2000a). The Scollard Formation occurs near the eastern end of the region (Sakwatamau River, KP 200) and is again crossed near the Latornell River (KP 371.9). The Smoky River crossing is within the Wapiti Formation north of the Scollard Formation subcrop. Where the Scollard Formation outcrops, it tends to be a regional control on stability conditions due to the weak clay layers in the formation.

The Palaeocene Upper Paskapoo Formation contains cross-bedded sandstone with interbedded sandstone, siltstone and mudstone. Lenticular or laterally discontinuous strata often occur. Local shale and coal are present. In general, the Upper Paskapoo tends to have better stability conditions than the Scollard Formation, although slope stability concerns including slides can occur along the coal seams and some related clays. The Upper Paskapoo underlies the area from west of the Sakwatamau River (KP 200) to the Simonette River (KP 359.9).

The Late Cretaceous Upper Wapiti Formation is composed of non-marine cross-bedded sandstone with scattered conglomerate, siltstone and mudstone. Local coal seams occur within the formation (Journeay et al 2000a; Twardy and Corns 1980). Although most of the Upper Wapiti is mapped as non-marine, continuous seams of apparent bentonite or other high plastic clays have been found during previous AMEC work and widespread large deep-seated slope failures occur in the formation, particularly toward the northwest part of the route such as near the Wapiti River.

Evidence of "ice-rafted" bedrock was found during drilling investigations north of the Athabasca River near KP 188 near the eastern end of the Southern Alberta Uplands. In this area, an upper layer of predominantly sandstone bedrock is underlain by a gravel layer which is in turn underlain by a sedimentary sequence including sandstone that differs from the shallower bedrock. The ice-rafted bedrock is likely a result of a layer of bedrock moved laterally by a glacier and has implications with respect to directional drilling.

2.4 Alberta Plateau

2.4.1 Topography and Physiography

The Alberta Plateau Physiographic Region extends from approximately KP 516.8 to KP 560.4 and is the BC equivalent of the Southern Alberta Uplands. There are no major streams in this area; Redwillow Creek is one of the larger creeks. The area is gently rolling with some steeper ridges. Typical elevations along the proposed pipeline route range from 1070 to 1225 m (3500 to 4000 ft). The eastern-most thrust faults associated with the Rocky Mountains occur in this area and the bedding dips vary from gently dipping to steeply dipping where local folds or thrust faults occur.

The climate of the Alberta Plateau is continental and is characterized by cold winters and short cool summers (Ecological Stratification Working Group, 1996). The mean annual temperature ranges between 1 and 2°C, mean summer temperatures range between 13 and 14°C, and mean winter temperatures range from -9 to -13°C depending on elevation and location. The mean annual precipitation ranges between 450 and 600 mm, falling mostly as rain in the summer months (Ecological Stratification Working Group 1996).

2.4.2 Surficial Geology

Surface materials, surface expression and drainage conditions are similar to the Southern Alberta Uplands discussed above. This region has been significantly influenced by the bedrock topography of the foothills of the Rocky Mountains. Vold et al. (1977) identified six primary surficial materials including glacial till, glaciolacustrine, colluvial (deposits that have moved or been placed under the influence of gravity), glaciofluvial and organic deposits. As with the Southern Alberta Uplands to the east, the glacial till and glaciolacustrine deposits tend to be clayey and frequently contain medium to high plastic clays. The glaciofluvial deposits occur as valley fills and terraces along valleys that have carried meltwater flows and in some areas as deltas into glacial lakes.

Preglacial valleys have been infilled in some areas with glaciofluvial sediments with variable boulder content, glaciolacustrine sediments and till. These valley fill deposits may be a major consideration for directional drilling.

In general, tills of variable thickness overlie the bedrock topography that is higher relief than to the east (Fenton and Pawlowicz 2002). Based on clast lithologies within the till, glacial ice from three separate sources were present in the general area. The sources include the continental Laurentide and Cordilleran ice sheets and local montane ice from the Rocky Mountains. The relationships between the various ice lobes and the flow directions of the two continental glaciers are poorly understood (Fenton and Pawlowicz 2002). As a result of glacial scour, bedrock is exposed in local areas.

The lowland areas include extensive deposits of both glaciofluvial and Holocene fluvial materials. Broad glaciofluvial outwash plains were deposited along river valleys. This glacial sediment is generally coarse textured with a high content of coarse fragments. Glaciofluvial and alluvial fans, some of which are still subject to active erosion and deposition, are crossed by the proposed pipeline route in some areas. The topography of these deposits is typically gentle to flat, except where modern river valleys have cut down through the deposits. Fine textured fluvial sediments on low relief topography are also found along the margins of modern rivers. Thick organics (muskeg) occur in low areas, some in the former sites of Holocene lakes.

2.4.3 Bedrock Geology

The bedrock underlying the Alberta Plateau physiographic region is Triassic to Cretaceous in age and primarily consists of the Spray River, Brazeau, and Smokey Assemblages. Several thrust faults occur (Journeay et al 2000a; Journeay et al 2000b). The Triassic to Jurassic Spray River assemblage and contains continental margin siltstone, sandstone, and limestone. The Upper Cretaceous Smoky Group contains fordeep marine shale with siltstone and sandstone. The Brazeau Group is also Upper Cretaceous in age and consists of fordeep marine clastic wedge materials with eastward prograding sandstone, conglomerate, and shale (Journeay et al 2000b). Typically, these formations contain less high plastic clay than many of the rock types to the east and, as a result, bedrock stability conditions tend to be more favourable.

2.5 Rocky Mountains

2.5.1 Topography and Physiography

The Rocky Mountains Physiographic Region extends from approximately KP 560.4 to KP 663.5. The topography is primarily bedrock controlled and exhibits high relief with steep slope gradients. Regional elevations are significantly higher than in the surrounding physiographic regions, reaching almost 1500 m along the proposed pipeline route.

Much of the topography is controlled by the underlying folded and thrust faulted sedimentary rocks which form major ridges oriented northwest to southeast. Parts of the route parallel valleys that cut across the major mountain ridges including Kinuseo Creek, Imperial Creek and the Missinka River valleys. Major river crossings include the Murray (KP 598.6) and Missinka River (main crossings at KP 641.3 and 646.2). Elevations along the proposed pipeline route range from 1070 m (3500 ft) at the east end to 915 m (3000 ft) at the Murray River to 1460 m (4800 ft) at the crossing of the Rocky Mountains at an unnamed pass. At the west end of the Rocky Mountains Region, elevations of 760 m (2500 ft) occur at the west end of the Missinka Valley.

The underlying rock types range from folded sandstone to mudstone (shale) sedimentary rocks in the east to older stronger rocks including limestone and quartzite as well as rocks containing chert in the west. The folds and thrust faulting are strong controls on the local topography.

The regional climate is influenced by the Rocky Mountains and varies in a west to east direction as well as by altitude. The mean annual temperature for the area is approximately 1.5°C with a summer mean of 12°C and a winter mean of -10°C. Mean annual precipitation ranges from 500 to 700 mm with the highest values occurring in the south and on the west side of the mountains. On the east side of the mountains, winter temperatures tend to be cooler due to the cold air pooling against the mountains, although Chinooks occur east of the mountains and in the foothills area to the east. At higher elevations, snowfall comprises half the annual precipitation.

2.5.2 Surficial Geology

The Cordilleran Ice Sheet covered most the Rocky Mountains during the last glacial maximum. The coalescing of valley glaciers and ice sheets produced a significant dome which drained eastward to meet the Laurentide Ice Sheet along the foothills in Alberta (Fenton and Pawlowicz 2002). Toward the end of glaciation, the large ice dome was replaced by valley glaciers that actively modified the landscape through localized erosion and deposition. Within the Rocky Mountains, the proposed route in part follows river drainages that were occupied by main trunk glaciers and tributary side valley glaciers. The Rocky Mountains Region generally has high relief with steep U-shaped valley sidewalls, except where controlled by bedrock geology or where subsequent erosion has occurred. Along the valley bottoms, the topography is undulating to hummocky, depending on the presence of bedrock control.

Glacial till, colluvium, and exposed bedrock are predominant overall (Vold et al. 1977). Where the pipeline route runs parallel to valleys through the Rockies, deposits along these valleys typically include glaciofluvial terraces, minor glaciolacustrine materials, alluvial fans and organic deposits with areas of intervening rock ridges, shallow rock and shallow glacial till. Shallow organic deposits occur in some of the upland areas, in part due to the prevailing climatic conditions and perched shallow groundwater.

Frost processes such as solifluction and nivation occur at high altitudes in local areas. Recent work has suggested that some of these areas may be less thermally active than in the past as a result of a general warming trend (the recent peak of glacial extent was in the "Little Ice Age" in the mid to late 1700's).

The majority of this physiographic region has undergone significant erosion, resulting in a predominantly bedrock controlled environment with exposed bedrock occurring throughout the area. Glacial till and colluvium occur throughout the region. Parent material textures are variable; however, as they are directly related to the local bedrock lithology and the glacial transport distance. Generally the till in this region is medium to coarse textured, similar to the colluvial deposits (i.e., sand to cobbles and boulders with variable silt content). Coarse fragment contents are variable but are generally moderate to high.

Glaciofluvial and glaciolacustrine terraces and plains also occur along sections of the proposed route. The glaciofluvial sediments are generally coarse textured and high in coarse fragment content. Glaciolacustrine sediments are typically gently undulating, silty and have a low coarse fragment content except where interbedded with other materials.

Modern alluvial deposition occurs along the river valleys. Organic accumulations occur at all elevations within this physiographic region and are controlled by local surface and groundwater conditions. As a result, the organics are not confined to depressed areas, but also occur on widespread areas of sloping ground at high altitude. The depths of the organics vary from less than 1 m to locally much deeper, depending in part on the underlying bedrock or till topography.

Permafrost may be present in very limited areas at higher elevations; however, recent work by AMEC in similar areas has generally found that the permafrost that was previously present has thawed.

2.5.3 Bedrock Geology

Seven tectonic assemblages have been identified within the Rocky Mountains (Wheeler et al 1991). Widespread folding and faulting has produced aligned ridges that have been dissected into alpine and valley terrain.

The bedrock formations include the Windermere, Gog, Rocky Mountains, Kootenay, Besa River, Smokey, and Rundle Groups (Journeay et al 2000b), although not all of these groups underlie the proposed route. The Windermere Group is Palaeocene in age and contains clastic continental margin sediments with sandstone, siltstone, and shale. The Gog Group is Proterozoic to Cambrian in age and contains rifted continental margin sediments including shallow water quartzite, conglomerates, and mafic flows (Journeay et al 2000b). The Rocky Mountain group is Cambrian to Devonian in age and contains passive continental margin dolomite, limestone, sandstone, and shale. The Rundle Group is Devonian to Carboniferous in age with continental shelf carbonates and shale. The Kootenay Group is Jurassic to Cretaceous in age and comprises (marine) fordeep clastic wedges of marine sandstone and mudstone. The Smokey Group is Upper Cretaceous in age and contains fordeep marine shale, siltstones, and sandstones. The Besa River Group is Devonian to Mississippian in age and is comprised of marine shale, mudstone, and shale (Journeay et al 2000b).

Of note in the Rocky Mountains is that the rock types are typically much harder and stronger than the sedimentary rocks to the east. Strong rock types including sandstone and limestone are widespread. Extremely strong and tough quartzite and chert occur in several of the formations and rock groups. Excavation of these rock types will likely require drill and blast techniques.

The bedrock stability of most of the rock groups is reasonably good; however, the marine shales in the Smokey Group include some high plastic clay content and some large slides have occurred in areas underlain by this group.

Local widely scattered occurrences of Potentially Acid Generating (PAG) rocks may occur in the Rock Mountains. Acid Rock Drainage (ARD) considerations are discussed in AMEC (2009c and 2009d).

2.6 Interior Plateau

2.6.1 Topography and Physiography

The Interior Plateau Physiographic Region in BC extends from approximately KP 663.5 to KP 1066.9 and occupies a wide area of eastern and central BC. This physiographic region covers plateaus and plains of north-central British Columbia and the interior foothills of the Coast Mountains. The region includes the southern portion of the Northern Rocky Mountain Trench, the western flank of the McGregor Plateau, the northern portion of the Nechako Plateau, the Nechako Lowlands, and the Chilcotin Ranges in the west. The Rocky Mountain Trench was included in the east part of the area for the purposes of discussion in environmental reports and this usage is followed in the present report for uniformity.

The terrain is rolling to variably ridged. Some of the stream valleys are deeply incised, but many are wide with gentle to moderate slopes. Wide areas are underlain by drumlins (elongate ridges) that may be composed of glacial till or rock (technically roche moutonnee). Ridges with till cores are more frequent than ridges with rock cores. Elevations along the pipeline route range from 760 m (2500 ft) in the east and west and reach 1075 m (3500 ft) in parts of the center of the area. Major streams include the Parsnip (KP 671.0), Crooked (KP 718.2), Muskeg (KP 748.1), Salmon (KP 763.1), Necoslie (816.4), Stuart (821.9), Sutherland (KP 855.5), Endako (KP 929.3) and Morice Rivers (1038.0). The drainage in much of the area is trellis shaped rather than being controlled by ridges trending more uniformly across the route.

The Parsnip and Crooked Rivers drain to the north, ultimately into the Peace River system and into the Mackenzie River system. Streams west of the Continental Divide near KP 730 and east of approximately KP 944 ultimately drain into the Fraser River system. Streams in the Interior Plateau Physiographic Region west of approximately KP 944 near Maxan Creek flow into the Bulkley River system and then into the Skeena River.

The area has a typical continental climate: cold winters, warm summers, and a precipitation maximum in late spring or early summer. However, the moderating influence of Pacific air occurs throughout the year, particularly toward the west. The mean annual temperature is approximately 3°C with a summer mean of 12.5°C and a winter mean of -7°C. The area lies partially in the rain shadow of the Coast Mountains. Mean annual precipitation ranges from 250-800 mm. The highest values occur at higher elevations in the west along the Chilcotin Ranges and the lowest values (250-300 mm) occur around the junction of the Chilcotin and Fraser rivers (Ecological Stratification Working Group 1996).

2.6.2 Surficial Geology

The Interior Plateau is underlain by flat-lying Tertiary and volcanic bedrock that forms a gently rolling surface covered by thick glacial drift into which the Fraser River and its major tributaries are commonly incised (Tipper 1971a; Mate and Levson 2000). The topographic relief is generally undulating to hummocky with steeper topography near some bedrock outcrops. Surficial deposits include glacial till with well-developed drumlinoid features, pitted terraces, simple and compound eskers, areas of glacial lake (glaciolacustrine) deposits (Ecological Stratification Working Group 1996) and glaciofluvial deposits primarily along numerous former meltwater channels. The depths of surficial materials are variable with local areas of rock outcrops, but much of the area is underlain by deep till with some areas of deep glaciolacustrine and glaciofluvial deposits (eg., Salmon River, Stuart and Necoslie Rivers, and Endako River valleys).

Preglacial valleys have been infilled in some areas with sediments including bouldery materials, glaciofluvial materials, glaciolacustrine sediments, and till. These valley fill deposits may be a major consideration for directional drilling.

The Interior Plateau can be subdivided into three main geomorphic regions:

1. The Rocky Mountain Trench is crossed near the Parsnip River. The Trench is infilled with old and variable sediments up to many millions of years old.
2. The Interior Plateau proper is characterized by widespread drumlinoid and related glacial linear features. Other terrain conditions include glaciofluvial terraces, eskers, and large areas of level glaciolacustrine deposits. Kettles, eskers and other ice contact features are scattered along the valleys (Tipper 1971a).
3. The Coast Mountains foothills are characterized by higher elevation bedrock controlled topography with hummocky to undulating relief. In general, slope gradients and overall relief are considerably greater than the Interior Plateau proper. Surficial sediments are dominated by glacially derived till and outwash deposits (Mate and Levson 2000). On steeper slope gradients, colluvium derived from the erosion of bedrock and till commonly occur.

Prominent glaciofluvial terraces occur along many of the major valleys. Fluvial and organic sediments are common along modern river drainages and in depressional sites.

2.6.3 Bedrock Geology

The interior Plateau physiographic region is composed of three geologic terranes and includes six significant groups. The terranes of the Interior plateau include the Cache Creek, Stikine, and Omineca Belts (Journeay et al 2000b, Wheeler et al 1991). The six major tectonic assemblages of the Interior Plateau include the Slide Mountain, Kamloops, Gambier, Cache Creek, Nicola, and Chilcotin. The Pinchi Fault occurs within this region on a northwest/southeast trend and a distinct change in tectonic assemblage occurs across the fault (Journeay et al 2000b; Tipper 1971b).

The Interior Plateau is dominated by volcanic rock types deposited under both marine and non-marine conditions. The Slide Mountain Group is Devonian to Triassic in age and contains ocean margin basin volcanics, primarily comprising pillowed basalt and breccia. The Kamloops Group contains non-marine alkali rich basalt, andesite, and rhyolite arc volcanics (Journeay et al 2000b). The Jurassic to Cretaceous Gambier Group comprises rift volcanics with greywacke, siltstone, conglomerate, and basalt. The Mississippian to Upper Triassic Cache Creek Group contains oceanic volcanics and sediments including basalt and gabbros. The Triassic to Jurassic Nicola Group contains both marine and non-marine arc volcanics and volcanic clastic flows, including andesite and basalt. The Tertiary Chilcotin Group contains non-marine volcanics that are mainly transitional alkaline basalt flows (Journeay et al 2000b).

The rock types that underlie the route are not typically prone to large deep-seated failures. Such failures do occur in the Kamloops Group rocks; however, these rock types do not underlie the route.

Local widely scattered occurrences of Potentially Acid Generating (PAG) rocks may occur in the Interior Plateau area. Acid Rock Drainage (ARD) considerations are discussed in AMEC (2009c and 2009d).

2.7 Coastal Mountains

2.7.1 Topography and Physiography

The Coastal Mountains physiographic region extends from KP 1066.9 to the end of the route at KP 1172.2. This physiographic region extends from sea level to elevations greater than 2700 m. The area is rugged with areas of very steep high slopes, incised canyons and some flat bottomed valleys that are infilled with glaciofluvial or alluvial sediments. Many of the exposed areas of bedrock are rough. Glaciers are still present on some areas of high terrain.

The pipeline route follows major valleys through parts of the area including parts of the Burnie and Clore Rivers on the east side and parts of the Kitimat River and tributaries on the west side. Elevations along the proposed pipeline route through these areas range from 760 to 1375 m (2500 to 4500 ft) on the east side to close to sea level on the west side. The route through the highest part of the Coast Range near Mount Nimbus is proposed to include two tunnels at elevations of approximately 735 to 800 m. Toward the west, the route follows the Hoult Creek valley to the Kitimat valley and crosses the Kitimat-Kitsumkalum Valley, a flat bottomed valley (partially a former fjord) infilled in part with glaciofluvial sediments on the flat Onion Lake Delta. The route turns to the south and runs down the east side of Iron Mountain. South of Iron Mountain, the Wedeene and Little Wedeene Rivers are crossed and the route parallels existing roads along the west side of the valley. South of the head of the inlet, the route runs along sideslopes and benches on the west slope of Kitimat Arm to the Terminal site. The end of the route is at the Kitimat Terminal on the west side of Kitimat Arm, a fjord with rough rock ridges and steep slopes. The terminal is located on a rolling to hummocky upland bench approximately 3 km north of Bish Creek.

Major stream crossings include the Clore (KP 1072.5), Wedeene (KP 1144.5) and Little Wedeene (KP 1148.6) Rivers.

Climatic conditions vary geographically, and are generally wetter and milder on the coast, grading to drier and cooler conditions across the Coastal Mountains toward the interior of the province (Ecological Stratification Working Group 1996). Mean annual temperatures range from 6.5°C along the coast to 2.5°C near the eastern boundary of the region. Mean summer and winter temperatures range from 9°C to 0.5°C along the coast to 11.5°C to -8°C at higher elevations along the eastern boundary (Ecological Stratification Working Group 1996). Mean annual precipitation is highly variable, with values upwards of 4500 mm along the coast and 600 to 1500 mm along the eastern boundary (Ecological Stratification Working Group 1996).

The underlying bedrock includes moderately weak to very strong rock units dominated by volcanic rock types and strong to extremely strong Coast Plutonic Rocks such as granodiorite. Surficial materials include extensive deposits of colluvium and glacial till. Alluvial, glaciofluvial and colluvial fans occur along the edges of the major valleys. At the west end of the area, glaciomarine clay deposits occur below maximum elevations of approximately 200 m. Glaciofluvial and stagnant ice deposits (granular material) are widespread and infill some of the major valleys.

Due to the variable strengths of some of the metavolcanic formations (specifically parts of the Telkwa Formation and some weak metamorphosed sedimentary rocks), recessive weathering of the rock mass has occurred locally in some areas. In general, the depth of cover of till, colluvium and weathered rock is relatively thin. The Clore River has cut a very deep post-glacial canyon in the Telkwa Formation west of the proposed route and has also cut a shallower meandering canyon into the preglacial Clore River valley bottom southeast of the proposed route.

2.7.2 Surficial Deposits

2.7.2.1 General

The Coast Mountains have undergone a number of glacial events, the last of which was the Fraser Glaciation. During this event, the valley glaciers and ice sheets coalesced to produce a significant dome extending from the southern Yukon to northern Washington (Gottesfeld 1985). At the peak of the Frasier Glaciation, ice thicknesses were sufficient to cap much of the Coast Ranges with ice. Subsequent montane glaciation has significantly altered the landscape following the last glacial maximum (Gottesfeld 1985). Small glaciers persist in some of the higher areas.

At the east end of the physiographic region, thin granular till deposits predominate on the uplands. Some of the lowland areas have extensive deposits of glaciofluvial sand and gravel. Minor muskeg infills some depressions. Parts of the Clore River valley upstream of the canyon have undergone extensive erosion of the apparently formerly existing valley infill deposits as a result of the base elevation of the river being lowered by the post-glacial erosion of the canyon.

Typical alpine and valley glacial land forms are present in higher elevation areas including steep topography, cirques and U-shaped valleys. Across high elevation ridges and dissected plateaus, exposed rock is common and many of these areas have very rugged and rough topography. Many of the large U-shaped valleys have been partially infilled with glaciofluvial sediments with some areas of glaciolacustrine and glaciomarine accumulations. Colluvium in the form of scree is common below many of the steep rock slopes. Till of variable thickness, but frequently thin, mantles many of the slopes.

The crossing of the spine of the Coast Mountains will be via two tunnels and so the highest terrain will not be directly encountered.

On the Kitimat side of mountains, surficial geology conditions are dominated by deposits and conditions that occurred during deglaciation. Glacial ice persisted in the Kitimat area to approximately 10,000 years Before Present (BP). Rapid delectation occurred between 13,000 and 10,600 years BP (Gottesfeld 1985) via a series of rapid calving and stagnation events. These short standstill events were marked by the deposition of significant glaciomarine deltas (Clague 1976). Glacial till was deposited directly from the ice, as ablation till when the ice melted back, and as recessional moraine ridges.

As a result of the weight of the glacial ice, the land was isostatically depressed. In addition, sea level was lowered due to accumulation of water in the continental glaciers. As deglaciation progressed, sea level rose and the land rebounded. Sea level rise was more rapid than land rebound and consequently, the Kitimat-Kitsumkalum Valley was flooded to a point north of Terrace (25 km north of the pipeline route) nearly reaching present day Kalum Lake. Maximum sea levels within the Kitimat-Kitsumkalum Valley were reached by 10,600 years BP with flooding to approximate elevations of 200 m asl relative to present terrain elevations (Clague et al 1982). Between 10,600 and 9,300 years BP, the land rebounded rapidly with sea level elevations of 35 m above present sea level at the end of this period (Clague et al 1982). Modern sea level relative to the land was attained by approximately 8900 years BP.

As a result of the marine transgression, laterally extensive deposits of glaciomarine clay occur throughout the Kitimat-Kitsumkalum trough to elevations of around 200 m. In some areas these clay deposits are exposed on surface while in other areas they may underlie subsequently deposited sediments. In many areas, the glaciomarine deposits are thin and interbedded with coarser glaciofluvial and alluvial materials deposited from streams flowing along the valley and down the valley walls. Extensive and deep glaciofluvial deposits occur in the form of terraces, plains and fans, ice contract deposits and glaciofluvial fans and deltas throughout the main Kitimat valley and the lower parts of tributary valleys. As indicated above, these deposits may overlie glacial till and/or be interbedded with glaciomarine clay.

Within the steep glaciated valleys of the Coastal Range, parent materials are dominated by bedrock, weathered bedrock, and colluvial materials. Till and localized glaciofluvial deposits also commonly occur. Recent sedimentation includes the accumulation of alluvium and organic deposits.

The upper Kitimat Valley includes a variety of deposits including till and extensive deposits of glaciofluvial boulders, sand and gravel, colluvium. Exposed bedrock occurs on the upper valley slopes. Glaciomarine sediments occur in the lower part of the valley near the junction with the Kitimat-Kitsumkalum trough, although exposures of the clay are rare along the pipeline route. Fluvial deposits (reworked glacial and deglaciation deposits) occupy much of the valley floor. Modern organic accumulations are also present in depressional and level topography.

2.7.2.2 Glaciomarine Clay

As discussed above, glaciomarine clay is present in the Kitimat-Kitsumkalum trough, including the proposed Kitimat Terminal site on the west side of Kitimat Inlet, and at some locations in the lower parts of valleys tributary to the main Kitimat River valley including the Kitimat River near Chist Creek. The maximum elevation of the glaciomarine clay is approximately 200 m which was the maximum height of the marine transgression, although typically the major concentrations of the clay appear to be below about 185 m elevation.

Some of the marine clay layers may be sensitive or quick. "Sensitive" means that the ratio of peak to remoulded strength is more than four and quick clays have strength reductions of more than 30. However, in the work to date, no quick clay has been identified along the proposed route and it appears that most occurrences are north of the Onion Lake Delta.

The presence of potentially sensitive glaciomarine clay is a result of the deposition process in marine conditions and subsequent leaching by fresh groundwater. The clay was originally deposited under marine salt water conditions during the marine transgression at the end of the last glaciation. As the salty pore water is gradually leached under fresh water conditions, the internal structure between the clay particles may become unstable and susceptible to large strength reductions.

Unlike occurrences of sensitive glaciomarine clays in some other parts of the world, the clay in the Kitimat Valley does not have uniform properties with depth. Rather, weak layers may be present within a much larger thickness of stronger clay, or a weak clay layer may underlie or be interbedded with other deposits such as glaciofluvial sand and gravel.

Numerous slides have occurred in the glaciomarine clay deposits in the Kitimat-Kitsumkalum trough as a result of the presence of the marine clay. Many of the slides are located north of the Onion Lake Delta and thus are not located near the proposed route. Geertsema (2004) has documented numerous slides in the valley north of Kitimat and others are evident from review of airphotos that are not included in his summary. Glaciomarine clay slides have affected local infrastructure including roads and Highway 25 along the east side of the Kitimat valley.

The current routing through the Kitimat-Kitsumkalum valley considered the following criteria with respect to the glaciomarine clay:

1. The proposed route for the east-west crossing of the valley (KP 1122 to about 1134) is on the Onion Lake Delta and is located well north of the break in slope where slide activity has occurred in the past along the south side of the delta.
2. An area of sliding on the edge of the delta is bypassed to the west between KP 1134 and 1137.
3. The north to south route along the west side of the valley was routed along the east side of Iron Mountain away from areas that exhibited evidence of past slide activity based on helicopter reconnaissance. The route along the east side of Iron Mountain is along the lower parts of areas underlain by rock, glacial till or glaciofluvial outwash and generally avoids areas where surficial mapping by Clague (1976) indicates the presence of surficial glaciomarine deposits. A hole drilled by AMEC at about KP 1140.1 on the east side of Iron Mountain near Deception Creek (Borehole R02) did not encounter sensitive glaciomarine clay, although stiff to hard high plastic clay was encountered below sand deposits from 44 m to the bottom of the hole at 66.5 m. Further investigation is recommended in areas where the proposed route might be underlain by glaciomarine clay along the southwest side of Iron Mountain, in the vicinity of the Wedeene River and some areas to the south.
4. South of the Wedeene River, the route also generally avoids areas of mapped occurrences of glaciomarine clay with areas of active sliding.

Further geotechnical work will be required to finalize the detailed routing through the Kitimat-Kitsumkalum Valley with respect to stability conditions and possible occurrences of sensitive marine clay deposits.

2.7.3 Bedrock Geology

The Coastal Mountains physiographic region is underlain by complex geologic conditions. Five primary assemblages occur within the Coast Mountains, including the Hazelton, Kamloops, Skeena, Carmacks, and intrusive Plutonic rocks of the Central Coastal Plutonic Complex (Journey et al 2000c; Gottesfeld 1985). The Jurassic Hazelton Group has marine and non-marine volcanic complexes consisting of breccia, shale, basalt, and andesite. The Kamloops Group is similar to occurrences of the same rock types in the Interior Plateau and consists of Tertiary non-marine alkali rich basalt, andesite, and rhyolite arc volcanics. The Cretaceous Skeena Group consists of marine and non-marine clastics, including interbedded siltstone, sandstone, and conglomerate. The Upper Cretaceous Carmacks Group contains non-marine volcanic basalt and andesite. The Central Coastal Plutonic Assemblage is mid Jurassic in age and contains a geologically complex sequence of foliated diorite, hornblende-biotite quartz, granodiorite, and quartz diorite (Journey et al 2000c).

The predominant rock types that underlie the pipeline route include the Skeena Group, Bowser Group, Telkwa Formation (part of the Hazelton Group) and the Central Coastal Plutonic Assemblage. With the exception of Coast Plutonic Assemblage, all of these formations contain

rock types of variable competency on a regional basis. The Telkwa Formation varies from moderately weak to very strong; however, preliminary mapping and drilling investigation results indicate that strong to very strong rock will often be encountered along the tunnels. In general, the plutonic rocks are very strong and competent. There are several regional faults in the area of interest but no faults that are known to be active.

Local widely scattered occurrences of Potentially Acid Generating rocks may occur in the Coast Mountains. Acid Rock Drainage considerations are discussed in AMEC (2009c and 2009d).

2.8 Regional Preglacial Valleys

Prior to the last glaciation, an extensive network of preglacial valleys was eroded into the bedrock surface in Alberta and parts of BC as a result of preglacial stream erosion. As a result of the protracted period over which these channels formed (the last interglacial period was several tens of thousands of years long), the preglacial valleys tend to be much wider than the modern valleys. In some cases, the modern valley closely follows the ancient valley while in other instances; the modern valley may not have the same path or direction as nearby preglacial valleys.

Many of the ancient valleys were infilled during and immediately following the last glaciation with a mixture of glacial till, glaciolacustrine sands, silts and clays and glaciofluvial sand and gravel, possibly containing cobbles and boulders. Often the floor of the valley is overlain by a few meters of cobbly or bouldery sand and gravel that are the fluvial deposits of the original stream deposited prior to the most recent glaciation.

Subsequent to the most recent glaciation, the modern streams have cut down through some of the areas of valley fill, leaving wedges of material along the valley walls (depending on the materials, these wedges of surficial materials may be prone to sliding). Where the stream has not cut down to the elevation of the original valley floor, substantial amounts of valley fill including cobbles and boulders may underlie the modern stream channels or uplands. This material may have several implications for the routing, design and construction of the proposed pipelines including:

1. Slope stability: Weak clay layers within glaciolacustrine valley fill sequences have resulted in numerous large deep-seated slides. The slides are facilitated by the very low shear strength of the clays which may have residual shear strengths (strengths of remoulded material) of about 8° based on past work on glaciolacustrine clays near the route in BC. These low strengths facilitate the formation of very large deep-seated translational slides on weak layers in the glaciolacustrine valley fill. Wherever possible, these large slides have been avoided during routing.
2. Valley fill: Some of the valley fill materials such as loose sand, soft clay deposits or boulders (particularly bouldery deposits along the bottoms of the old channels) may be impediments to directional drilling or may require much longer directional drill holes in order to bypass the problem areas.

3.0 GEOTECHNICAL CONSIDERATIONS

3.1 General

Table B-1 (Appendix B) summarizes geotechnical conditions and preliminary recommendations along the proposed pipeline route. Preliminary recommendations and evaluations are made from a geotechnical point-of-view with respect to crossing methods and preliminary mitigative considerations.

This section (Section 3) discusses geotechnical considerations with respect to the proposed route including the following:

- **Natural Terrain Hazards** (Section 3.2): Summary of various non-seismic terrain hazards that have been identified during routing studies. Terrain risk analysis is discussed in Section 5.
- **Seismic Conditions** (Section 3.3): Summary discussion of seismic conditions and seismically related terrain hazards.
- **Tsunamis** (Section 3.4): Preliminary discussion of marine tsunami waves in the Kitimat Arm of Douglas Channel
- **Acid Rock Drainage and Metal Leaching** (Section 3.5) (ARD); Overall discussion of ARD.
- **Watercourse Crossing Methods** (Section 3.6): General discussion of methods considered relative to geotechnical routing considerations
- **Clore and Houtt Tunnels** (Section 3.7): Detailed discussion of the geotechnical aspects of the tunnels is under separate cover; the discussion in this report is general with respect to the overall route.
- **Rock excavation** (Section 3.8): General considerations with respect to expected rock conditions based on work to date.
- **Potential borrow sources** (Section 3.9): Detailed work on borrow sources has not been done to date. This section provides an overview of potential geologic sources that could be considered for more detailed evaluation in the future.

Details of terrain hazards identified along the route are discussed in Section 5 which further discusses the hazards relative to an overall risk assessment.

3.2 Natural Terrain Hazards

Natural terrain hazards have been identified near some portions of the route corridor and, in particular, are likely to be present to some degree in all areas of steep terrain, deeply incised valleys or other areas of appreciable topographical relief. Terrain hazards have been a major consideration in the routing of the pipelines. In general, the hazards have been avoided where possible. Where it was not possible to avoid an identified hazard, preliminary mitigation methods have been identified (Table B-1). It is expected that evaluation of terrain hazards and potential mitigation methods will continue into the detailed design phases.

The following discussion summarizes principal identified terrain hazards with respect to non-seismic conditions. Other potential hazards related to seismic conditions are discussed in Section 3.3.

3.2.1 Mass Wasting

Mass wasting is the down-slope movement of bedrock and surficial deposits under the influence of gravity. For the purpose of this discussion, mass wasting includes deep-seated landslides, shallow to moderately deep landslides, rockfall, debris flows, avalanches, lateral spreading, lateral stream erosion (scour) and sedimentation, and wind, shallow stream or overland (flow) erosion.

A general discussion on stability issues appears above in the discussion of the Physiographic Regions and stability considerations are summarized in [Table B-1](#) for specific areas along the route. The types of slides and natural mass wasting hazards identified are discussed below.

3.2.1.1 Deep-Seated Slides

As used in this report, deep-seated slides are slides more than approximately 10 to 15 m deep. Deep-seated slides may occur along weak clay layers in both soil and rock such as near-horizontal weak clay layers in glaciolacustrine deposits and weak clay layers in some of the bedrock sequences. Some of the largest slides, such as those along the east side of the Wapiti River, may extend for more than 500 m back from the river and may be several tens to over 100 m deep (these slides were avoided during routing studies). Many of the deep-seated slides move relatively slowly with creep rates of only millimetres per year in some cases. Increased water pressures along the slide surfaces or toe erosion may result in large increases in movement rates, in excess of several meters per day for short periods of time in some circumstances. The higher movement rates are generally most likely to occur on slopes at angles well above the residual friction angles (slopes steeper than say, 10 to 12°). Where ongoing movement has resulted in the deep-seated slides retrogressing to overall slope angles approaching the residual friction angle, the chances of rapid large movements are thought to be generally low in the absence of major topographic changes such as undercutting of the toe of the slope.

Deep-seated slides are present on or near several of the major river crossings including the Little Smoky, Smoky, Wapiti, Stuart, and Morice Rivers. Wherever possible, avoidance of deep-seated slide areas is the preferred option, but it may not be possible for all of the river crossings due to the prevalence of such slides. Where the pipelines cross a slide, mitigation work and monitoring may be required depending on the situation. Directional drilling or possibly other trenchless methods such as microtunnelling under the slide are other crossing methods that may be considered depending on other geotechnical and design factors.

3.2.1.2 Shallow to Moderately Deep Slides

Shallow to moderately deep slides (up to 10 to 15 m deep) occur within many of the weaker soil or rock materials and are often located on steeper slope segments than the deep-seated slides. In addition, shallow to moderately deep slides may occur on top of the deep-seated slides as a result of the disturbance and cracking in the shallower materials caused in part by underlying

deep-seated movement. The overlying slides may have much higher rates of movement than the deep-seated slides and may respond rapidly to changes in pore pressure conditions. Shallow to moderately deep slides may occur in some of the glaciomarine clays near Kitimat where very large strength losses may occur in some sensitive zones. Shallow slides may be a locally significant source of sedimentation. Mitigative measures for shallow to moderately deep slides include surface and groundwater management, avoidance where possible, grading, and/or buttressing the toe.

Earthflows consist of shallow (typical depths up to possibly 10 m or more) masses of completely re-moulded soil that “flow” slowly down slope. No large earthflows have been identified to date along the proposed pipeline route during the geotechnical work, although such slides have been found in the past in some of the glaciolacustrine soils in British Columbia. Earthflow movements have also occurred in some of the glaciomarine slides north of Kitimat. To the extent possible, where areas prone to such movements have been identified, they have been avoided during routing.

Groundwater blow-off failures (Cavers, 2003) are groundwater induced failures that lead to extreme piping (internal erosion) of the soil. They typically form in bedded glaciofluvial deposits along steep slope segments where groundwater flows from permeable layers becomes blocked. This is commonly associated with the near surface soil being reworked by vegetation, creep, frost or other mechanisms. When the stored groundwater builds up sufficient pressure, the surficial layers may be blown off and large amounts of stored groundwater drain rapidly, causing piping and surficial erosion of a canyon with an amphitheatre-shaped head scarp. Subsequent sloughing may also occur. Groundwater blow-off failures are common on some of the glaciofluvial terraces in central British Columbia. Steep terrace fronts have been avoided during routing where possible and no examples of large blow-off failures along the route are presently known. Some small to moderate sized failures have occurred near the Athabasca River crossing, at a few locations in the upper Kitimat valley and along Klo Creek. Mitigative measures, if required, include avoidance, groundwater drainage controls, and soil retention techniques (for example by rock mats over geotextile).

3.2.1.3 Debris Flows

Debris flows can occur when “debris” (accumulations of fluvial and colluvial materials along streams) is mobilized by high stream flows and/or groundwater seepage. The resulting mixture of water and soil can sweep down the stream channel, causing erosion in some areas and deposition in other areas. A few streams in the Rocky Mountains and Coast Range may be subject to debris flows. With respect to the proposed pipelines, the main hazards include erosion at the stream crossing and avulsion where debris is deposited and blocks a channel of a creek, causing a change in channel location. Both forms of erosion could potentially result in pipeline exposure, coating damage and/or pipeline damage. Rupture as an immediate consequence of a debris flow is considered to be unlikely based on past experience with similar events.

3.2.1.4 Rockfall

Rockfall includes both rockfall from rock cliffs and falls of boulders from very steep colluvial or till slopes. Rockfalls are a hazard in a few locations near the proposed route. Most of the rockfall areas identified to date have been in the Coast Mountains. Other areas prone to rockfall may occur on the east side of the pass through the Rocky Mountains. In the worst case, very large rock blocks falling with high energy directly on the buried pipelines could result in failure, but the more likely consequence is denting and/or coating damage. Mitigative measures will depend on the extent of the problem and include avoidance, scaling, anchoring, extra depth of cover, deflector berms or fills and/or special protection measures.

The discussion above is with reference to naturally occurring rockfall; however, high cut slopes, such as sidehill cuts in rock, may trigger rockfall events on the steepened slopes or at the crest of the cut from surficial materials. Rockfall from high cuts will require special consideration during design. Mitigative measures include deflection berms, deflection fills over the pipelines, removal of problem materials by scaling, anchoring, rockfall catchment fences and similar installations and special protection measures including buried reinforced concrete slabs.

3.2.1.5 Avalanches

Avalanches include the movement of snow, and movement of sediment and debris by snow down a slope. Even large avalanches do not usually directly affect buried pipelines; however, above ground structures such as aerial crossings, valves or expansion bends could be affected. Avalanches may also block stream channels, subsequently resulting in avulsion or downcutting erosion. Changes to surface drainage conditions following major avalanches coupled with periods of rapid snow melt are an important consideration that could potentially result in exposure of the pipelines if suitable mitigative measures are not undertaken. Avalanches across access roads could also affect the ability to access and respond to various situations. The direct and indirect consequences of avalanches may include denting or mechanical damage, coating damage or exposure. Avalanche impact on above-ground structures could potentially include rupture, but no such areas are presently known and avalanche paths have been avoided during planning for above-ground structures. Mitigative methods include avoidance of above ground pipeline structures in vulnerable areas, detailed analysis of avalanche conditions, deep cover, deflector berms, various avalanche control techniques and consideration of the possible secondary effects of stream diversions.

3.2.1.6 Mountain Spreading (Sackung)

Mountain spreading (sackung) failures have been identified in parts of the Rocky Mountains and foothills. While the mechanism may vary, these areas of terrain movement typically involve strong rock over weak rock on high steep slopes. The underlying weak rock may squeeze plastically, inducing lateral creep movement that involves slow protracted movements. Toppling failures in the strong rock may occur as the rock is moved laterally towards areas of steeper slopes. This failure mode occurs in some areas near Tumbler Ridge and in parts of the Rocky

Mountains south of the route; however, no sackung or mountain spreading failures are known to AMEC in proximity of the route. Since no instances of sackung movement have been identified, the hazard will not be further considered in this report.

3.2.1.7 Lateral Spreading

Lateral spreading involves lateral movement of ground typically but not necessarily triggered by a seismic event. Movement might occur on a weak layer, such as a weak sensitive glaciomarine clay layer in the Kitimat valley area or potentially due to liquefaction of underlying loose materials such as sand (no such areas are known along the pipeline route). A lateral spread could involve large lateral movements and, as such, could have major impacts on the proposed pipelines. Principal mitigative measures include avoidance of areas prone to such events (routing), design of the pipeline systems to withstand the movements, possibly decoupling the pipelines from the soil movement using surface pipeline technology and ground improvement or drainage.

3.2.1.8 Stream Erosion and Sedimentation

Stream erosion includes the possibility of lateral erosion, reoccupation of sub-channels and/or downcutting or scour exposing the pipelines. The possibility of secondary interactions such as lateral erosion triggering slope instability may also occur. Lateral erosion conditions will be considered during detailed design of trenched crossings. Mitigation methods include installing the pipelines below the depth of potential scour across the affected areas, directional drilling, micro-tunnelling and similar methods to go under the area, or possibly an aerial crossing above the area affected. Other mitigative methods include riprap, groynes, spurs and other similar installations, that can often be installed in the dry rather than requiring in-stream work.

Avulsion (channel switching such as on alluvial fans) is a special case of stream erosion. Where avulsion occurs on a large fan, the stream may relocate to a different part of the alluvial fan, potentially 100 m or more from the original stream crossing, possibly causing downcutting erosion or sedimentation over an area remote from the original crossing. Avulsion on alluvial fans may be triggered by a variety of events such as high flows (rain and/or melting snow), ongoing deposition along the stream channel or debris flows or avalanches blocking the channel. Avulsion may be an important consideration for a few stream crossings east of Tumbler Ridge near Kinuseo Creek, along parts of the upper Kitimat Valley and in a few other localized areas along the proposed route. Mitigative measures include directional drilling or deep trenching across the fan, crossing the fan near the head where the lateral extent of avulsion is limited, or avoiding areas that may be prone to avulsion (routing).

3.2.1.9 Wind and Shallow Stream or Overland Erosion

Wind and water erosion are two of the main agents of siltation, which is a potentially widespread concern along the pipeline route, particularly during and immediately following construction, if suitable mitigative measures are not undertaken. The main consequences are environmental including potential impacts on streams and fish. Mitigative methods include routing to avoid areas of particular concern, detailed consideration during grading designs, ground and surface water control, revegetation, erosion matting, straw/hay mulching.

3.2.2 Settlement

For the purpose of this study, settlement includes both consolidation and karst-induced settlement or displacement.

3.2.2.1 Consolidation Settlement

Normally consolidated silt, clay or peat may be subject to settlement where additional loading, such as fill, is placed. This is an infrequent hazard along the proposed pipeline route, based on present conditions, although it could potentially occur in a few areas due to placement of access fills across muskeg and in the future due to road construction, site development or other causes.

3.2.2.2 Karst-induced Settlement or Displacement

Apparent dolines (down-dropped areas formed by karst processes, for example, solution of limestone) have been identified at some locations through the Rocky Mountains. Sink holes (smaller down-dropped areas or areas where loss of ground has occurred) are also present. Ground subsidence has also induced the formation of multiple scarps and/or other slope movements that may have associated lateral movements in a few areas. One primary mitigation method is avoidance during routing – the method used for all known areas along the route. Mitigative measures, if required, include additional investigation, special backfills, designs to allow small ground movements to occur without affecting the pipelines, surface pipelines and monitoring.

3.3 Seismic Conditions

3.3.1 Geologic Setting

The geologic and seismic conditions near the west end of the proposed pipelines at the BC coast differ from those along the coast farther south. To the south, seismic conditions are dominated by the oceanic Juan de Fuca plate which is subducting (sliding) beneath the continental plate. In contrast, from northern Vancouver Island to the Queen Charlotte Islands and including the area west of Kitimat, the oceanic Pacific Plate is sliding to the northwest at about 6 cm/year relative to the North American Continental Plate along the Queen Charlotte Fault (Natural Resources Canada 2009, Internet site). This fault is active and the largest historical earthquake in Canada occurred on this fault on August 22, 1949 (magnitude 8.1). However, since the Queen Charlotte Fault is over 300 km west of Kitimat, the level of ground

shaking that would be produced by a large magnitude event, while appreciable, would be much less than would be produced on land by an equivalent earthquake off the south coast of BC on the subduction zone.

Recorded earthquakes in western Canada are summarized on [Figure 3.1](#), from Atkinson (2009). Most of the events along an approximately northwest-southeast line west of the Queen Charlotte Islands are associated with the Queen Charlotte Fault. Farther east, there are fewer and much smaller events that are likely located on crustal faults. The largest earthquake recorded in the southern Cordillera was a magnitude 6.0 in 1918 near Valemount in the Rocky Mountain trench almost 300 km south of the proposed pipelines alignment. In 1986 a magnitude 5.5 earthquake occurred near Prince George (60 km south of the proposed route) causing some minor damage (information from GSC website).

East of the Rocky Mountains, the magnitudes of the recorded earthquakes again decrease. There have been some magnitude 4 to 5 events north of Fort St. John that are likely related to water injection in connection with oil recovery from wells. Similar magnitude 3 to very occasional magnitude 5 events have been recorded in Alberta.

Correlation of earthquakes with active faults is not possible within the area crossed by the pipelines and no active faults are known in near the proposed route. Within the study area, earthquakes typically occur at depths of 5 to 20 km on faults that have no surface expression. Furthermore, faults mapped on the surface in western Canada were formed hundreds of thousands to millions of years ago and bear little relation to current seismic activity. Thus there is no clear-cut relationship between observed faults and seismicity and the pipeline route does not cross any known active faults that are exposed at surface.

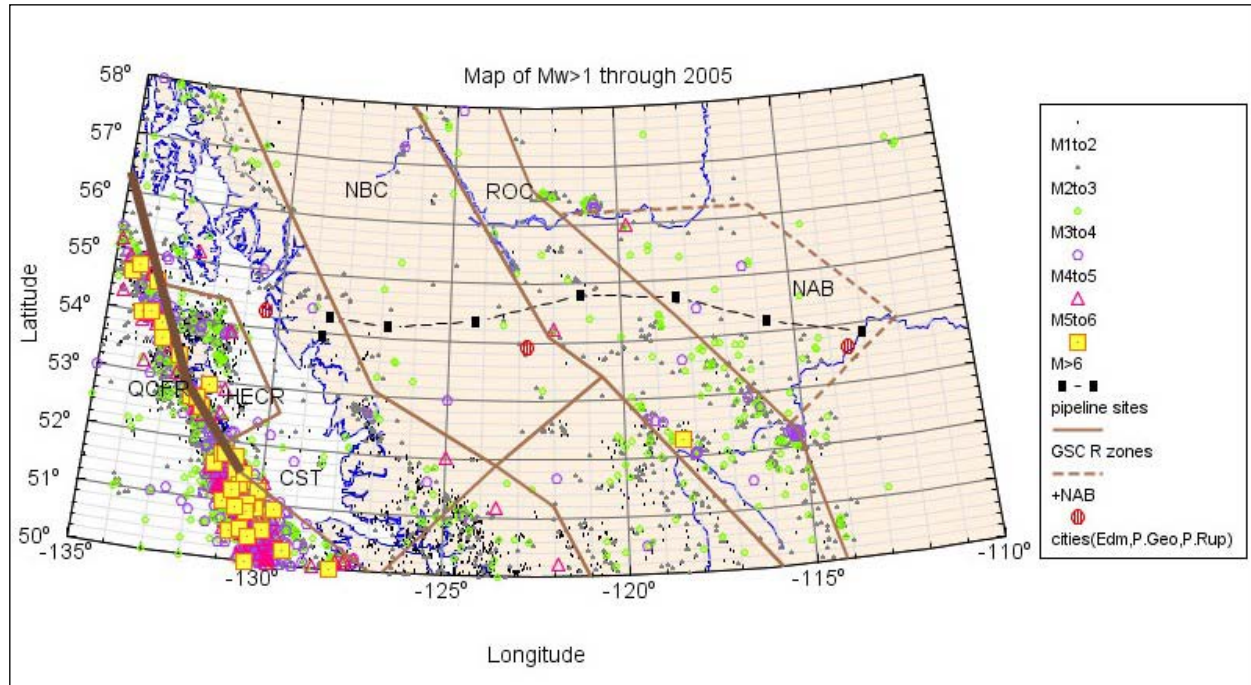


Figure 3.1 Recorded Seismicity in Western Canada

From Atkinson (2009) – Recorded seismicity ($M > 1$) through 2005 together with the GSC R-model source zone models used in the national seismic hazard maps and adopted for Atkinson’s study. An additional source zone for Northern Alberta (NAB) was defined in Atkinson’s study and is shown with dashed lines. Black symbols indicate study sites and are referenced as Sites 1 to 8 in this discussion from west to east. Red symbols are cities (Edmonton, Prince George and Prince Rupert, from east to west). Note the absence of any large recorded earthquakes near the proposed pipeline route.

3.3.2 Estimates of Ground Motion

Seismic hazard analyses in Canada are based on probabilistic concepts which allow incorporation of both geologic interpretations of seismic potential and statistical data regarding the locations and sizes of past earthquakes. Details of the calculation methods are provided in Atkinson (2009). The methods used by Atkinson were similar to those used in the National Building Code of Canada (NBCC) 2005.

During the preparation of the revised NBCC in 2005, the seismic modeling methods were updated relative to those used in the previous work which was published around 1985. Changes were also made to the design return periods recommended for structures constructed to the NBCC requirements. Prior to the 2005 NBCC, the design earthquake return period under the code was 475 years (probability of occurrence of 10% in 50 years). Under the NBCC 2005, the design return period is recommended to be 2475 years (2% probability of occurrence in 50 years). It should be noted that this change has not been uniformly applied to structures

including highways and pipelines that are not required to be constructed to the NBCC. For example, some recent lifeline structures designs, such as some BC Highways, have used a design return period of 475 years. Another major change in the 2005 seismic models was the incorporation of new seismic knowledge, such as the so-called mega-thrust earthquakes on the subduction zone west of Vancouver Island (the subduction earthquakes on the south coast do not have a major impact on the proposed pipeline route).

The detailed requirements of the specific code to be used for design of the pipelines and other structures should be consulted for design requirements. Note that the 2005 NBCC recommends spectral acceleration values to be used for the design of structures. Spectral accelerations are the acceleration values that would be experienced at different vibration frequencies. The spectral acceleration values may be higher or lower than the Peak Ground Acceleration (PGA) values quoted below, depending on frequency (the applicable frequency depends on the structure). PGA is convenient as a "single point" comparison and is also used for geotechnical analyses. PGA values from Atkinson's results for the eight sites shown on [Figure 3.1](#) are summarized below. The values quoted are for Soil Type B (soft rock).

Site (Fig 3.1) West to East	1	2	3	4	5	6	7	8
PGA (%g) (1:2500)	12%	10%	3%	2%	8%	7%	6%	5%

By comparison, the PGA for Vancouver is 46%g (Soil Type C – dense soil, NBCC 2005).

Seismic conditions at the west end of the proposed route might be characterized as moderate. To the east, the PGA values decrease to low but not zero values. The implications for the pipelines are discussed below, but are not expected to be major, providing that appropriate design measures are used.

3.3.3 Natural Hazards Due to Seismic Events

The seismic conditions are not expected to be a major factor in terms of natural terrain hazards along the route and the design of the mainline pipelines. The following points discuss some of the geotechnical considerations with respect to seismic events:

1. Seismic shaking in terms of pipeline response: The predicted level of shaking is relatively low in terms of pipeline response. There have been no failures of major cross country buried welded steel pipelines due to seismic shaking without associated soil movements (e.g., ASCE, 1984 and Honegger and Nyman, 2004) and the level of seismic shaking for the proposed pipeline route is much lower than has been experienced on other mainline welded steel pipelines in other parts of the world. Providing that there is not lateral movement of soil or rock (such as a slide or lateral spread), the mainline welded steel pipelines will be highly resistant to failure during a seismic event. Therefore, providing that the engineering design and construction takes appropriate account of terrain conditions, seismic shaking and other seismic design aspects, the level of shaking is not of major geotechnical concern to the mainline pipelines.

2. Terminals, pump stations and pipeline tie-ins: Terminals, tanks, pump stations and all other structures should be appropriately designed with respect to seismic conditions. With respect to the pipelines *per se*, it is noted that one area that will require appropriate design consideration are connections to the pipelines such as “T” junctions where another pipeline joins the main pipelines, tie-ins of pumping stations or valves. Under seismic shaking, the different pieces of pipe or facilities may move in different directions. Other portions of the pipelines that may require specific seismic design considerations include above ground pipeline segments possibly including aerial crossings, pipeline segments through the two proposed tunnels and possibly above ground segments across slide areas.
3. Liquefaction and lateral spreading: The level of shaking could be capable of inducing liquefaction of loose sediments at the west end of the proposed alignment should the pipelines cross such sediments. Sediments potentially susceptible to liquefaction could include some recent alluvial deposits in the lower Kitimat Valley. Lateral spreading could also potentially be induced in certain glaciomarine clay deposits. Strength losses might also occur in susceptible zones in marine clays, potentially resulting in low angle slides in some deposits. [Table B-1](#) notes areas where liquefiable sediments or areas prone to spreading/sliding due to underlying marine clays might potentially occur and provides potential mitigative alternatives. Liquefaction and lateral spreading are expected to be examined further during future geotechnical investigations at the time of detailed design work.
4. Mobilization of landslides due to seismic shaking: Seismic shaking could potentially mobilize landslides or rockfall. Such movements would most likely occur on pre-existing slides or on terrain susceptible to such failures and would involve movements of existing slides or areas prone to failure such as rockfall. In general, slope stability is a major geotechnical consideration along the proposed pipeline route and terrain susceptible to such movements would most likely be considered susceptible to movement under non-seismic conditions. The pipelines have been routed to avoid areas where slope stability is a problem wherever possible. Where this cannot be done, mitigative measures are planned to be further considered during detailed design. Therefore, while seismic slide mobilization will be considered further during ongoing terrain evaluations, it is not likely to have a major influence on routing or the mitigative measures considered since the issues will be covered by the non-seismic evaluations.
5. Tunnels: As indicated above, the pipeline supports through the tunnels will require appropriate seismic design. Tunnels are, however, very resistant to seismic movements and, as a result, the seismic motions are not expected to result in any unusual tunnel support requirements.
6. Tsunamis: Tsunamis are discussed in the following section.

3.4 Tsunamis

A tsunami is a series of waves with a long wave length and period, generated in a body of water by an impulsive disturbance that displaces the water. Examples of such disturbances include: some types of subaqueous fault movements (usually associated with large earthquakes); landslides, including subaqueous failures; terrestrial landslides entering a body of water; submarine volcanic eruptions; and meteorite impacts. Meteorite impacts, which are extremely rare events, and volcanic eruptions, not expected in the local geological environment, will not be discussed further.

3.4.1 Seismically Generated Tsunamis

Submarine normal or reverse fault movements can cause a vertical displacement of the entire water column that can then propagate as a series of waves. Large tsunami events have occurred at many locations around the Pacific Basin including very large events generated by the 1700 subduction earthquake on the Cascadia Subduction Zone west of Vancouver Island; however, it is probable that the North Coast fjords are protected to a large extent from Cascadia subduction zone tsunamis, though some effects (not yet modeled) would probably be felt as a result of refracted waves. There are no known active faults within or near Douglas Channel and Kitimat Arm that would be capable of generating a tsunami.

Recently published papers have provided additional details on the potential impacts of seismically generated Pacific Basin tsunamis on the proposed dock facilities located in deep water along Kitimat Arm. A recently published paper (Rabinovich et al., 2008) reports several small tsunamis (11-23 cm) from sources such as the Explorer Plate (north of the Cascadia Subduction Zone) and the Queen Charlotte Fault related to moderate earthquakes ($M = 6.1-6.6$) between 2001 and 2004.

An evaluation of tsunami amplitudes for the British Columbia coast, that includes the North Coast area, was undertaken by Dunbar et al. (1989) but involved only modeling of distant tsunamis from four sources: Alaska (Prince William Sound), Chile, Shumagin Gap (Alaska) and Kamchatka. The results of their modeling shows that maximum expected tsunami amplitudes (deep water) are 1.9 m in Kitimat Arm, originating from an event in the Shumagin Gap, Alaska. The water rise and subsequent fall would occur over a period of about an hour. These amplitudes are for a wave in deep water in the inlet and do not include any estimates of run-up. Run-up may be more significant in shoal areas or bays than along areas of deep-water coastline along Douglas Channel and Kitimat Arm.

Current velocities associated with these offshore tsunamis would be small near Kitimat, being between 0.02 and 0.03 m/s (0.04 to 0.06 knots). In central Douglas Channel, however, the current velocities would be higher, between 0.36 to 0.46 m/s (0.7 to 0.9 knots). It should be noted that the current velocities vary with the cross-sectional area of the fjord and the distance from the entrance. Thus, if there is a narrowing of the fjord along its length, the current velocities will increase; this is less of an issue along Douglas Channel than in other inlets along

the B.C. coast (e.g., Alberni Inlet) where velocities can be many times higher in the narrow constrictions than along wider parts of the inlet.

Conclusions from the work to date include:

1. For vessels underway, seismically generated tsunamis should not generally pose a hazard as they will be seen as simply a slow rise and fall of a few metres over the course of an hour or so. The minor currents associated with these tsunamis would not pose a threat to the passage of a vessel through the central and upper reaches of Douglas Channel and Kitimat Arm. At present there are no estimates of tsunami amplitudes and current velocities at the entrance to Douglas Channel.
2. Similarly, the siting of the proposed marine terminal facilities along a stretch of deep-water coastline along Kitimat Arm would appear to be at little risk of direct damage from such tsunamis.

3.4.2 Slide Generated Tsunamis in Kitimat Arm – Background

Landslide-generated tsunamis can be caused both by subaerial landslides that enter a standing water body and by subaqueous (underwater) slides. There have been two subaqueous failures in the northern part of Kitimat Arm that have resulted in tsunamis in 1974 and 1975. No sources of subaerial landslides that could generate a large tsunami have been identified in Kitimat Arm.

On October 17, 1974, shortly after low tide and immediately following unusually high flows in the Kitimat River an approximately 20 ft (6.1 m) high wave occurred. The river flows were the highest on record to that date (10 years of record to 1974) and correlation with other river flows suggests that they were probably the highest flows over a period of at least 25 years. The initial occurrence at Kitimaat Village on the east side of the arm was reported to be a wave trough indicating that the wave was moving toward the west. This wave has been associated with an underwater slide at the northeast corner of the arm. There was no reported damage to wharves in the area, although the wave did loosen the moorings of a barge and damaged boats in nearby marinas.

The second significant tsunami event in the Kitimat Arm area occurred on April 27, 1975 at about 10:05 am, shortly after low tide. The wave was approximately 25 ft (7.6 m) high. The slide that caused this failure was apparently associated with construction activities, specifically fills placed at Moon Bay at the northwest corner of the arm. By the end of January 1975, Rivtow Straits had built a timber crib wharf structure (75m x 20 m) at Moon Bay, on the west side of Kitimat Arm. The face of the crib was 6 to 7.5 m high with fill having been emplaced outward from the beach to create a loading platform. At the time of failure, in late April, Rivtow Straits was in the process of constructing a breakwater from rockfill and dredged material obtained from the shallow subtidal zone just seaward of the construction site. The breakwater was below the high tide level at the time of failure. The failure started at the breakwater and within two minutes had propagated around the shoreline to the crib wharf area which was engulfed in the failure and swept away. The failure, which took place in soft cohesive marine clay and included

material from the delta, ran down the sidewall of the arm and several kilometers down the arm. Retrogressive failures continued through April 28 and included subaerial erosion but caused no tsunamis. Direct damage was \$1.32 million (1986 dollars).

3.4.3 Conclusions and Comments

Both the 1974 and 1975 tsunamis occurred within a period of about 6 months and were a result of relatively large slides of cohesive materials from the sidewalls of the arm close to the Kitimat Delta.

The 1974 event appears to have been associated with unusually high flows in the Kitimat River and extreme low tides. The slide from the northeast corner of the inlet extended for several kilometres down the inlet, as indicated by underwater bathymetry.

The 1975 event was similar to other significant coastal tsunamis that were caused by submarine landslides, resulting from placement of fills. Comprehensive geotechnical investigations, design and planning prior to placing large fills in coastal environments would be a key aspect in the future to avoid triggering a major marine slide that could potentially generate a tsunami. Such work would be expected to meet current engineering practice standards.

For a submarine slide to generate a tsunami, the slide must displace a large volume of water sufficiently rapidly that a wave is created. In order to accomplish this displacement, the slide mass must move initially as a block which requires that the slide mass moves coherently. Thus, cohesive material is capable of generating a tsunami, while slides in cohesionless material that rapidly become dispersed, are not. From a practical point of view in Kitimat Arm, slides in clay materials from the sidewalls are capable of generating a tsunami under the correct circumstances, while slides from the delta front are typically not.

Work to date, including review of recently acquired Canadian Hydrographic Service (CHS) data, has demonstrated that there have likely been only two large rapidly moving submarine landslide events in cohesive materials in the northern part of Kitimat Arm. The traces of large slides would remain visible in the bottom sediments of the arm for at least several hundred years and no additional tracks or evidence of large cohesive slides has been found. While there is one additional large slide track on the delta front near the Moon Bay failure, there are no credible reports of a third tsunami and so, if the slide occurred separately from the 1975 Moon Bay failure, failure of the predominantly granular material did not create a significant wave, as would be expected from the characteristics of submarine granular slides.

The following points summarize the conclusions of the work to date:

1. The hazard from earthquake generated tsunamis appears to be low. Based on modeling, it appears that past offshore seismically generated tsunami events would have generated a

rise of about 2 m over a period of about 0.5 hour with associated current velocities less than 1 knot.

2. No subaerial slide areas have been identified on the inlet side slopes that would be capable of generating a sufficiently large slide mass traveling at a sufficient velocity to create a tsunami of a height that could pose a problem at the terminal site.
3. Tsunamis generated by local underwater slides are possible in Kitimat Arm. Two events occurred over a six month period in 1974-1975. These two events appear to have been the only significant events over a very long time period – at least several hundred years.
4. The highest tsunami recorded in Kitimat Arm (1975 event) was associated with the placement of substantial fills and a large underwater slide. The 1975 event was apparently caused by construction activities and human triggering of similar events in the future can be avoided by appropriate engineering investigations and design.
5. Work to date suggests that the potential for a naturally occurring tsunamigenic slide in Kitimat Arm is low. Future work to confirm this preliminary assessment will include review of the likely magnitude and frequency relations for potential future tsunami events relative to the terminal facilities.

3.5 Acid Rock Drainage and Metal Leaching

Acid Rock Drainage (ARD) occurs when sulphide and other related minerals in rock undergo a complex chemical oxidation process producing sulphuric and other acids. A related phenomenon involving heavy metal leaching (ML) may also occur. In unfavourable cases (i.e., where ARD actually occurs beyond the bounds of the rock mass or spoil), there may be two main outcomes including acidic ground or surface water drainage and the mobilization, transportation and deposition of metals and related compounds. The main components of the ARD process include sulphide bearing minerals, water and oxygen. Significant increases in production rates may occur when the minerals are exposed to weathering as a result of rock breaking and excavation processes. ARD can potentially occur on both the broken and excavated rock materials and on trench walls, rock cut faces and other freshly exposed rock surfaces in largely intact rock masses. Metal leaching can also occur, either in conjunction with acid conditions produced by ARD, or independently where appropriate heavy metal concentrations and conditions exist.

ARD has been a concern for many years as a result of the potential generation from mining spoils and mines where high concentrations of sulphide minerals occur. More recently, the potential for generation from civil projects involving rock excavation has been recognized.

The degree to which ARD may be a concern depends on several issues including:

1. The concentrations and particular mineral species present.
2. The type of host rock and the types of rock mixed with the parent material during disposal or trench backfilling. Some rock types such as limestone are natural buffers against acid generation.

3. The ARD generating potential of the materials involved. For example, a small amount of pyrite (an iron sulphide) may be highly diluted within a large excavated volume of rock and may not be an overall concern. By contrast, a large volume of rock bearing relatively small concentrations of pyrite may be a major concern due to the total volume of material and the overall acid generation potential.
4. In a very few cases, naturally acidic water may be encountered in springs (either hot or cold); however, no such springs have been identified along the route.

Office and field studies of ARD and metal leaching potential along the proposed route are discussed in AMEC (2009c and 2009d). Overall, on a regional basis, rock types and geological conditions potentially resulting in ARD conditions occur west of the Kinuseo Creek crossing and more particularly west of the Murray River crossing (Rocky Mountains, Interior Plateau and Coast Mountains Physiographic Regions). However, most of the ARD occurrences are likely to be of limited extent with a few occurrences possibly extending for a few kilometres along the route. Moreover, in several areas where ARD potential conditions may occur in the bedrock, the grade and trench excavations may be located in surficial materials (glacial till or other unconsolidated materials). Where fresh rock exposures are not generated during the work, potential generation of ARD by the Project will not be a concern regardless of the underlying bedrock geological conditions.

3.6 Watercourse Crossing Methods

A variety of methods have been considered for construction of watercourse crossings including open cut crossings (i.e., a trenched crossing without isolation), isolated crossings (trenched crossings with isolation), directionally drilled crossings, aerial crossings, and other trenchless methods such as microtunnelling. Isolation methods considered have included dam and pump (stream flows generally less than 1 m³/s), flume (stream flows generally less than 5 m³/s) and superflume and double superflume methods (stream flows generally less than 8 to 10 m³/s). Trenchless methods may include horizontal directional drilling (HDD), microtunnelling, boring or other methods and aerial crossings. The final choice of crossing method will depend on a number of factors and input from a wide variety of expertise. The summaries in this report (Table B-1) consider hydrotechnical and geotechnical aspects only and should be considered preliminary.

3.7 Clore/Hoult Tunnels near Mount Nimbus

The proposed route crosses the spine of the Coast Mountains via two tunnels generally located west of the Clore River running under high terrain near Hope Peak west of the Clore River Canyon and Mount Nimbus. The geotechnical background for the tunnels is summarized in a separate report (AMEC, 2009a). It is expected that further refinements to the proposed alignments near and through the tunnels will occur as ongoing studies are undertaken.

3.8 Rock Excavation

The following comments pertain to rock excavation.

1. Rock underlying the Eastern Alberta Plains and some of the rock underlying the Southern Alberta Uplands is expected to be mostly rippable during excavation. Some of the sandstone rock underlying the Southern Alberta Uplands (e.g., Paskapoo sandstone) is sufficiently hard and strong that blasting will be required in local areas. In marginal cases, it may be possible to rip the rock for grade excavation but confined areas such as the trench may require blasting to loosen the rock.
2. Most of the rock underlying the Southern Alberta Uplands and the much of the rock underlying the Alberta Plateau is stronger than the rock to the east and the proportion of rock requiring blasting will be much higher than to the east. However, in this area, shale rock will likely still be rippable, at least for grade excavation. Strong rock types such as sandstone, conglomerate, limestone and some siltstone will require blasting as will most of the shale interbedded with strong rock types.
3. In general, almost all of the rock encountered in the Rocky Mountains and to the west will require blasting. The occurrence of chert and quartzite in the Rocky Mountains should also be noted. These rock types are usually more difficult and expensive to drill and blast.

In addition to blasting, other forms of rock excavation could be considered such as the use of rock saws or hoe rams/breakers. For smaller trenches, rock saws have proven capable of excavating the Dunvegan Formation sandstone (one of the harder sedimentary sandstone rocks east of the Rockies). They may not be economically capable of excavating harder metamorphic or intrusive rock types such as gneiss, granodiorite or quartzite in a large diameter pipeline trench; however, development of this technology is ongoing. Unfavourably high wear might occur in rocks that contain significant amounts of chert or quartz. If use of rock saws is considered, field trials in various rock types are recommended since at present there is little experience in the rock types under discussion with the large saws that would be required for the considered pipeline diameters.

Large high energy hoe rams or breakers would be physically capable of excavating grade rock where suitable closely spaced joint patterns exist combined with at least two free faces. In general, hoe rams are not practically suitable for trench excavation since the rock pieces are too confined to be readily loosened and removed.

3.9 Potential Borrow Sources

Potential borrow sources have not been examined to date from a geotechnical point-of-view. In general, many of the potential sources near the pipelines have been examined by local users in the past and many have been used in the past or are actively in use at present. In general, potential borrow sources along the alignment include the following:

1. Alluvial and glaciofluvial terraces: These sources, which include sand to gravel and cobbles, are present in various locations along many of the large river valleys in Alberta and BC. Glaciofluvial deposits also occur outside of the confines of the present large river valleys in some areas.
2. Alluvial and glaciofluvial fans: Alluvial and glaciofluvial fans deposited into larger valleys occur in the Rocky Mountain foothills and areas of higher topography in BC. The resources tend to be variable, even within a single source, but in some areas the glaciofluvial fans, in particular, form a significant resource.
3. Glaciofluvial outwash plains: Glaciofluvial outwash plains and extensive terraces occur in the Interior Plateau area of BC. Some sources may contain very large volumes.
4. Kames, eskers and other ice-proximal deposits: In the Interior Plateau and Coast Range, deposits of granular material formed by short transport from the ice front may be potential granular resources. Esker deposits occur in both BC and Alberta and are often sorted and may form high quality sources. In Alberta, kame deposits tend to have high silt and clay contents, but the parent rock materials in parts of BC were much stronger and so these relatively unsorted deposits may be useable for borrow resources.

In many cases, local resources may already be permitted for production. Further work would be required to determine availability and location of potential granular resources, if required.

4.0 TERRAIN HAZARDS AND RISK ANALYSIS

4.1 General

The section provides a detailed summary of the significant terrain hazards identified during geotechnical and other terrain studies to date along the proposed route and also provides a qualitative risk assessment overview of geotechnical and seismic issues with respect to the proposed pipelines.

The assessment is intended to provide an overall qualitative geotechnical assessment of potential terrain hazards along the proposed pipeline system derived using engineering judgment. The assessment was primarily directed at geotechnical issues that could affect pipeline integrity. Thus, for example, issues such as minor erosion or minor sedimentation were not directly included in most cases in the hazard assessment. Preliminary mitigative recommendations for minor erosion or sedimentation are included on [Table B-1](#), are discussed further in [Section 6](#) of this report and will be further developed during detailed design.

The results of the risk assessment are summarized on [Table C-1 \(Appendix C\)](#) and on [Figures 4.1 to 4.7](#). [Figures 4.1 and 4.2](#) present Risk Assessment Matrices for the entire pipeline route for the unmitigated and mitigated cases, respectively. [Figures 4.3 through 4.7](#) (later in the report) present the Risk Assessment Matrices broken down by physiographic regions for both the unmitigated and mitigated cases.

4.2 Qualitative Risk Overview Methodology

4.2.1 Overview

Fundamental to any risk assessment methodology is the meaning of “risk” which is defined as “the possibility of loss”. This concept of risk embodies two components: an uncertain state of knowledge about the occurrence of an event and adverse effects produced by the event should it occur. Expressed more simply:

$$\text{Risk of hazard} = \text{Likelihood of occurrence of hazard} \\ \times \text{Consequences of hazard}$$

Consequently, in order to characterize risk appropriately, both the relative likelihood of a failure event (hazard) and its associated consequence(s) must be accounted for. During the qualitative identification and assessments undertaken for this report, the likelihood (probability) and consequences were evaluated using professional judgment and opinion based on available information including:

1. Information from aerial and ground reconnaissances during pipeline routing studies and studies of crossings.

2. Airphoto interpretation carried out by AMEC and terrain typing carried out by GEM.
3. Where available, LiDAR hill shade and slope shade models, orthomosaics and other photography.
4. Published information.
5. Other information available to AMEC from previous work in various areas along the proposed route.

4.2.2 Hazards

Terrain hazards have been evaluated during the course of routing and preliminary design work undertaken along the route. The terrain hazard categories identified were discussed above in [Section 3.2](#).

4.2.3 Hazard Probabilities

Hazard probability categories varying from 1 (lowest likelihood) to 5 (highest likelihood) have been established for the purpose of rating the likelihood or probability of a hazard event occurring and affecting the pipelines. It should be noted that the rating is with respect to the likelihood of pipeline or facility damage. This may be different in some cases than the likelihood of an event such as rockfall occurring. Specifically, for a rockfall event to damage the pipelines, direct impact on the pipelines by a large block, possibly of a particular shape, would be required. Depending upon the characteristics of the event, the likelihood of direct impact on the pipelines may be much lower than the likelihood of rockfall occurring in the general area and/or bouncing across the pipelines without damaging them.

The hazards were assessed with respect to the 1 km wide corridor that contains the Rev R alignment. Thus, if an identified Terrain Hazard was present within the 1 km corridor, it was assessed in the analysis in this report. Hazards located outside the 1 km corridor, many of which were avoided during the routing work, are not included in the Risk Analysis.

For this study, a numerical rating was used in order that preliminary risk ratings could be provided by multiplying the Likelihood Category by the Consequence Rating discussed below. (Recall that $Risk = Likelihood \times Consequence$). [Table 4.1](#) provides the Hazard Likelihood Categories used in this study. As indicated later in the report, Hazard Likelihood (probability) Categories were assessed both without and with mitigation in place.



When considering the Hazard Likelihood Categories, it may be useful to recall that for the purpose of design earthquake assessments, a 1:2475 year earthquake is used as the design basis under the National Building Code of Canada for seismic assessments under the code. A 1:2475 year event is the same as a 2% likelihood of occurrence over a 50 year design life or an annual likelihood of occurrence of 0.0004 (Hazard Likelihood Category 1 in [Table 4.1](#)). Thus, while Hazard Likelihood Category 1 has a very low annual likelihood of occurrence, such *likelihoods are often taken into account during design and operation of major projects and structures, particularly when the event could have high consequences and/or the service life is considerably in excess of one year.

Table 4.1 Hazard Likelihood Categories (Hazard Occurrence Likelihoods)

Likelihood Category	Approximate Annual Likelihood	DESCRIPTION
5	≥ 0.5	<i>Will likely happen regularly over the life of the Project.</i> Very high likelihood that the hazard could affect the pipelines and/or infrastructure in the near future and/or is affecting the pipelines at the time of study.
4	≥ 0.1	<i>Probably will happen over the life of the Project.</i> High likelihood of occurrence.
3	≥ 0.1 to 0.02	<i>It could happen (likely as not) over the life of the Project.</i> Intermediate likelihood of occurrence.
2	< 0.02	<i>Unlikely to happen in any given year and less likely over the life of the Project.</i> Low likelihood.
1	< 0.001	Very low annual likelihood of occurrence and much less likely to occur over the life of the Project. Longer term events such as major seismic events.

4.2.4 Consequences

Similar to the Likelihood Categories, the Consequence Categories were also rated numerically from 1 to 5 (see [Table 4.2](#)). (Recall that Consequence is a measure of the adverse effects or outcomes of a Hazard that occurs and affects the pipelines or infrastructure).

Table 4.2 Consequence Categories

CONSEQUENCE CATEGORY	DESCRIPTION
5	<p>Major event with extremely costly and difficult remediation</p> <p>Pipeline failure or failure of major facilities such as pumping stations that could be difficult or expensive to repair due to location or other reasons.</p>
4	<p>Significant event that can be addressed but with great effort</p> <p>All other major pipeline damage events requiring replacement of pipeline segment. Failure of other infrastructure such as pumping stations that would directly affect the ability to move oil.</p>
3	<p>Moderate event requiring mitigation and certainly engineering review/input</p> <p>Displacement, damage or exposure of the pipelines less likely to directly result in immediate failure (i.e., in the event of the hazard occurring, there may be sufficient time to undertake mitigative measures prior to more serious consequences). Includes in-stream exposures. Damage to pumping stations or other facilities that does not immediately cause major shutdown.</p>
2	<p>Minor incident or inefficiency that may require engineering review but is easily and predictably remediated</p> <p>Coating damage, exposure or other damage not immediately resulting in a serious situation. Overland locations. Relatively easy to repair.</p>
1	<p>Minor incident or inefficiency of little or no consequence</p> <p>Other low consequence outcomes. (Note that failure to suitably mitigate these outcomes could result in more serious consequences.)</p>

4.2.5 Risk Evaluation

The product of the two ratings (Hazard x Consequence) provides a preliminary measure of the geotechnical risk posed by the various geotechnical hazards identified. The likelihood and consequence rating categories were set with 5 as a high rating so that the maximum risk value (25) would apply to what are perceived as the geotechnical situations with the highest risk (highest likelihood and highest consequence) with respect to the pipelines and related infrastructure.

This measure of risk should be viewed as a numerical ranking only. There were several limitations to the work that affect the evaluation of the risk, as discussed below.

4.2.6 Limitations of the Risk Assessment

The following limitations apply to the risk evaluations discussed in this report:

1. A linear numerical progression has been used for the Consequence Categories as part of the qualitative assessment discussed in this report. However, there is no reason that the consequences should progress in a linear fashion. In fact, it is more likely that the greater consequences may be nonlinear, which would affect the overall risk ratings (product of likelihood and consequence).
2. A similar argument could also be applied to the Hazard Likelihood Categories. If the various likelihoods assigned to the different categories were reviewed in statistical detail, it might be found that the likelihood categories are also non-linear with respect to the actual numerical values of likelihood. Probability theory for natural events tends to support lognormal distributions and/or normal distributions for many of these events. However, the use of a linear approximation in the range of relatively common events is considered reasonable as a first approach for the Risk Assessments in this report.
3. Considering Points 1 and 2, a very likely event (Hazard Likelihood Category of 5) and a low Consequence Category (Consequence Category of 1) would have an overall Risk measure of 5. A similar numerical evaluation of Risk would be provided for a very unlikely event (Hazard Likelihood Category of 1) combined with a high Consequence Category of 5. However, in a more detailed risk evaluation, they might not be equal due to the non-linearity of both input categories.
4. The evaluations were made for both the unmitigated original condition and for the same hazards after mitigation. The evaluations assume that best practice engineering, design and operational methods will be employed. The assumptions included pipeline patrols, repair and maintenance work and pro-active mitigation where required.

5. Evaluations were made on the basis of office studies of existing information as discussed above. As recommended in [Table B-1](#), additional investigations are anticipated during detailed design in several areas. As this further work is done, the preliminary Risk Assessments discussed may change.
6. The Consequence assessments were based mainly on geotechnical issues and natural terrain hazards. Other considerations could apply including other consequences (such as for neighbouring pipelines) in more detailed overall Risk assessments for the purpose of pipeline integrity studies.
7. Other geotechnically related issues such as sediment generation will need to be considered during design, construction and operation. These issues have not been considered in detail for all areas; however, additional preliminary recommendations pertaining to sedimentation issues are contained in [Section 5](#) and discussed in [Table B-1](#).
8. Most Hazard events of low consequence have not been included directly in the Risk study.

Combined events where progressive failures could occur were not assessed as hazards but were evaluated as isolated occurrences.

4.3 Results of Risk Analysis

The results of the Risk Analysis are summarized graphically on [Figures 4.1 to 4.7](#). These figures show matrices in which Hazard Likelihood is plotted on the X axis and Consequence is plotted on the Y axis. The grey lines running diagonally across the cells and the cell shading indicate zones of roughly equal Risk (Risk = Hazard x Consequences). Within each cell, the number of occurrences of different Terrain Hazard categories and the type of category are listed (bracketed numbers on [Figures 4.1 and 4.2](#)). The type of Hazard is indicated by the two letter abbreviations. Numbers not in brackets ([Figures 4.3 to 4.7](#)) indicate the actual terrain hazard. The numbers are organized by Physiographic Region and refer to [Table C-1](#) that provides a detailed breakdown of each Hazard discussed.

4.3.1 Overall Risks

[Figures 4.1](#) (unmitigated risks) and [4.2](#) (mitigated risks) summarize the Terrain Hazard Risks for the entire pipeline route. Mitigation methods and additional details are discussed in [Table C-1](#).

The unmitigated Risks shown on [Figure 4.1](#) indicate a significant number of high Risks. As shown on [Figure 4.2](#), mitigation results in significantly decreased risks. Three low to moderate risks remain in Risk categories IV and V.

Figures 4.3 to 4.7 show the risk matrices for the unmitigated and mitigated risks for the individual Physiographic Regions. The lists of risks indicate the site numbers (unbracketed number) that correspond to the sites in Table C-1. These matrices indicate that the remaining low to moderate risk sites after mitigation are at the Iosegun River (stream lateral erosion), and at the east and west approach slopes to the Little Smoky River. The results of the risk assessments may change during ongoing engineering and detailed design as well as a result of crossing method choices and design.

REV P RISK MATRIX SUMMARY (UNMITIGATED)

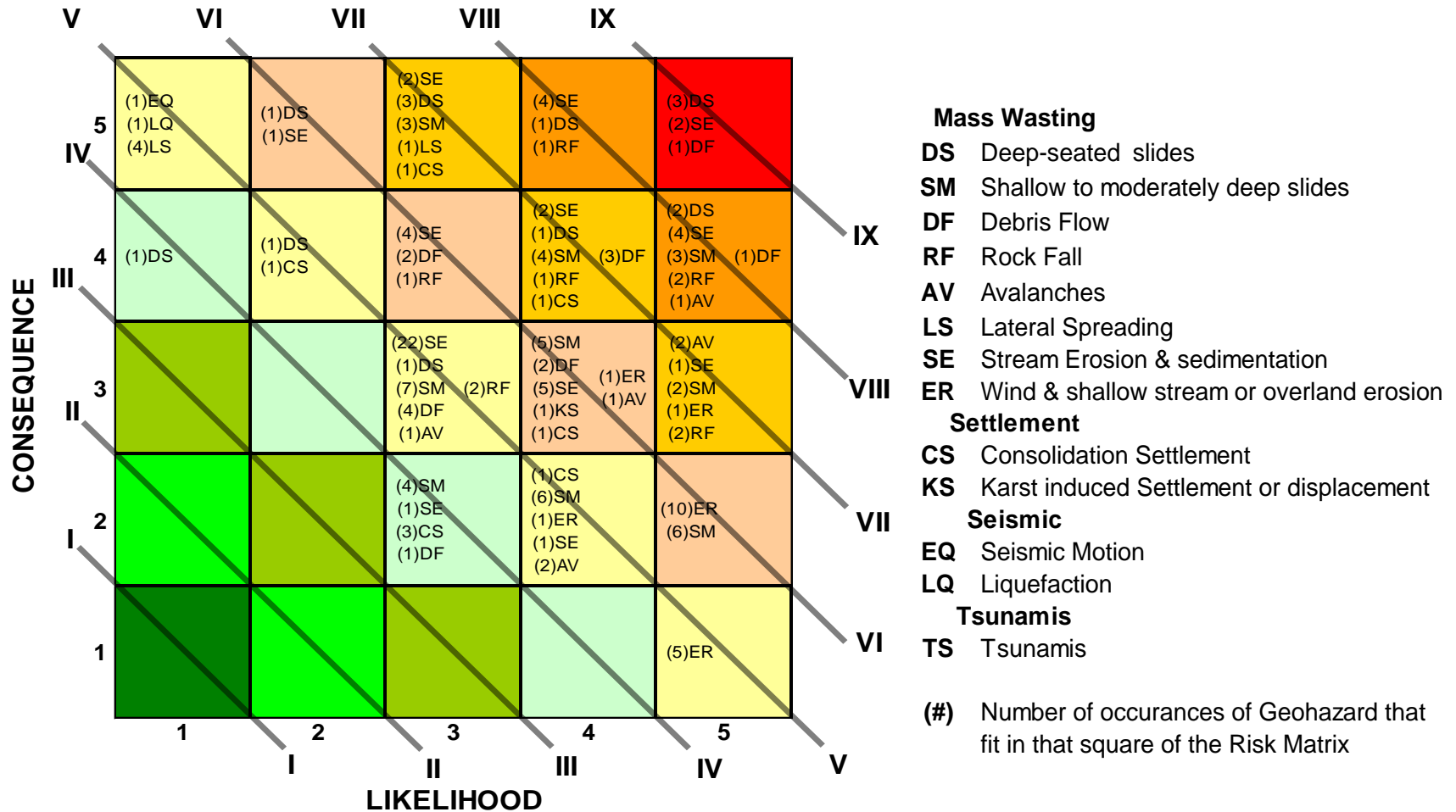


Figure 4.1 Unmitigated Risk Matrix Summary

REV P RISK MATRIX SUMMARY (MITIGATED)

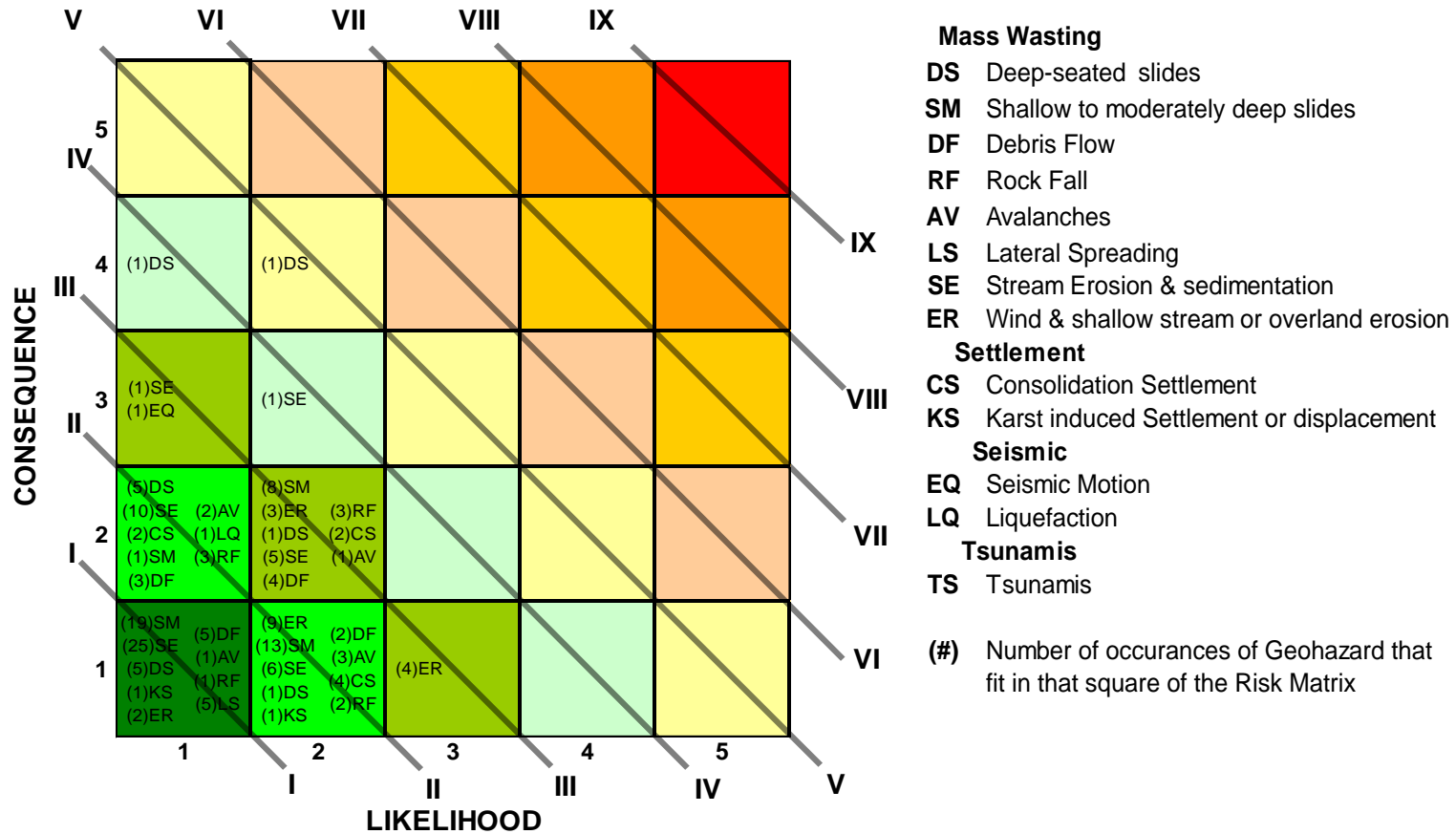
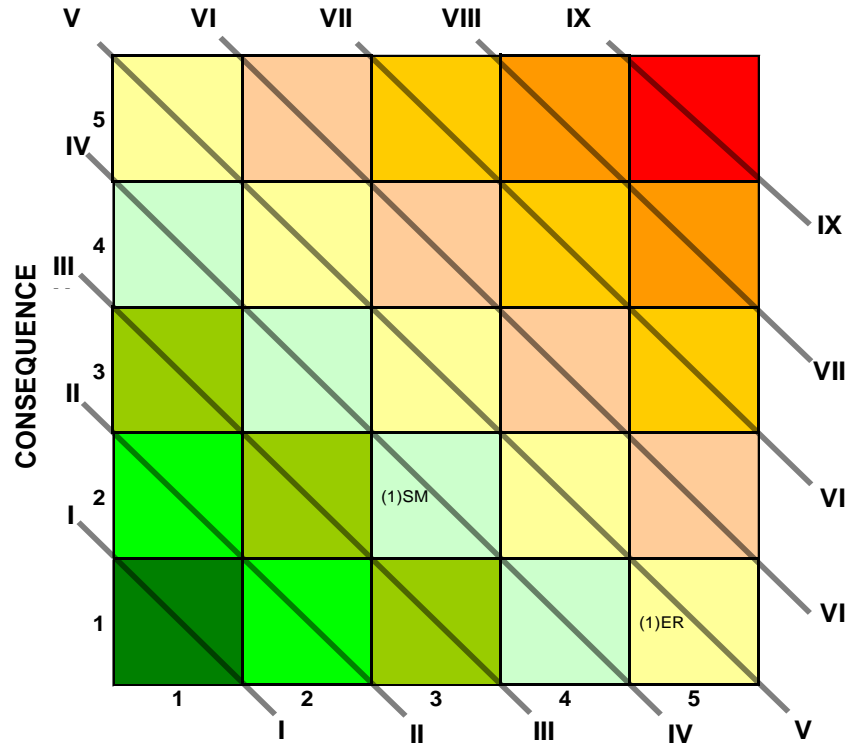


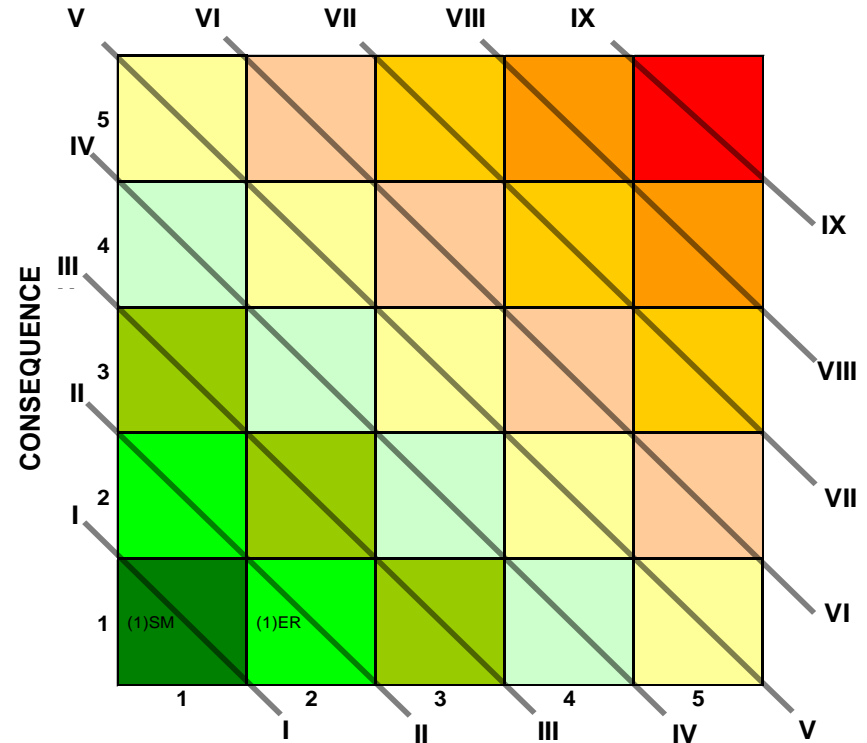
Figure 4.2 Mitigated Risk Matrix Summary

**EASTERN ALBERTA PLAINS RISK MATRIX SUMMARY
 (UNMITIGATED)**



RISK CLASS	GEOHAZARD CODE
I	
II	
III	
IV	2SM
V	1ER
VI	
VII	
VIII	
IX	

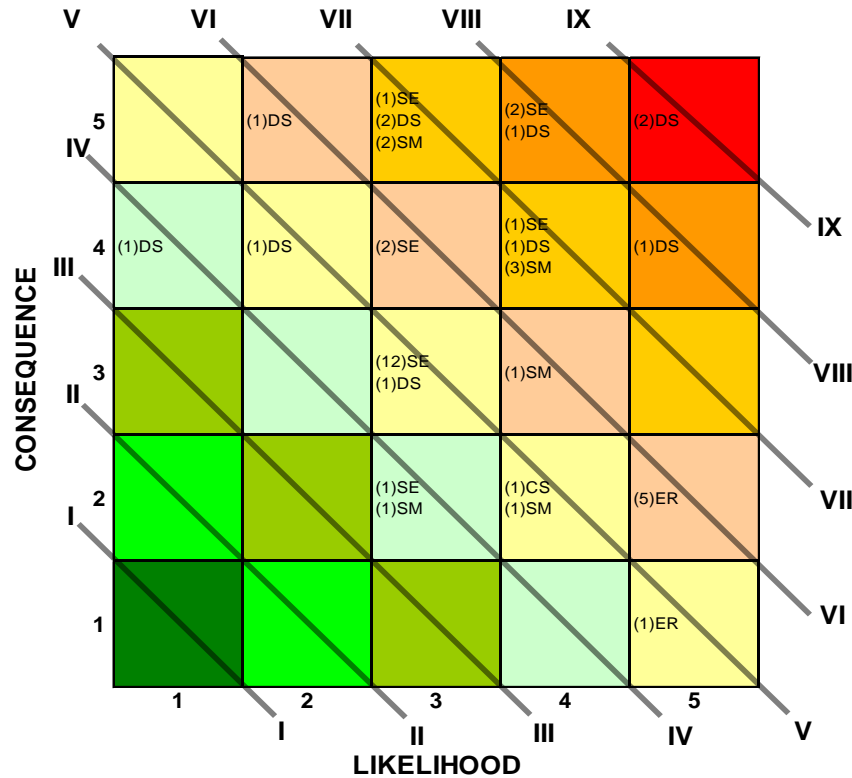
**EASTERN ALBERTA PLAINS RISK MATRIX SUMMARY
 (MITIGATED)**



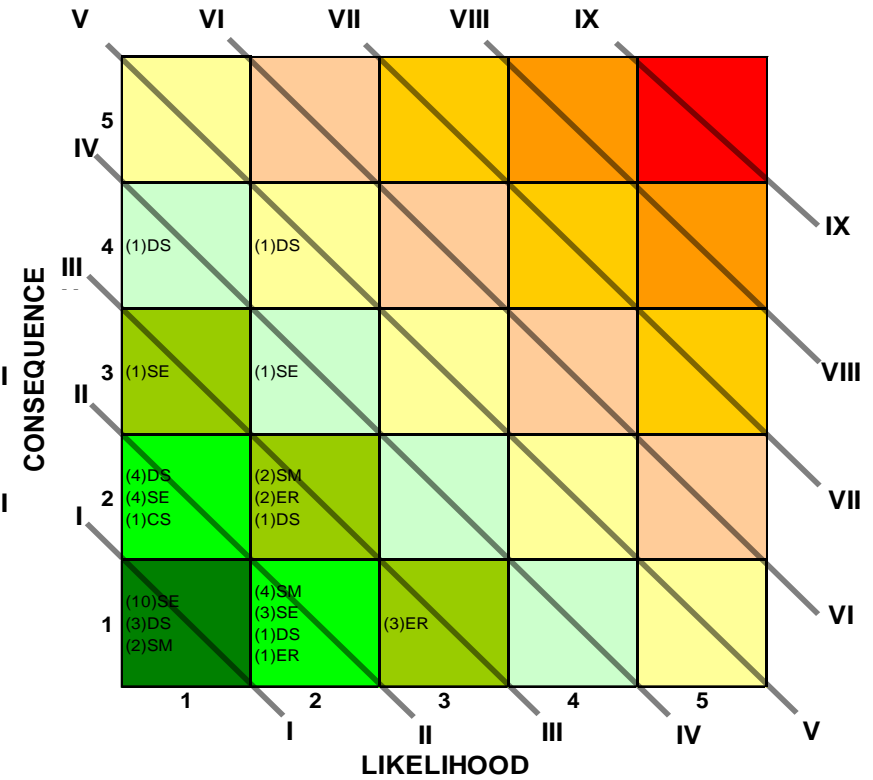
RISK CLASS	GEOHAZARD CODE
I	2SM
II	1ER
III	
IV	
V	
VI	
VII	
VIII	
IX	

Figure 4.3 Eastern Alberta Plains Risk Assessment Matrices

SOUTHERN ALBERTA UPLANDS RISK MATRIX SUMMARY (UNMITIGATED)



SOUTHERN ALBERTA UPLANDS RISK MATRIX SUMMARY (MITIGATED)



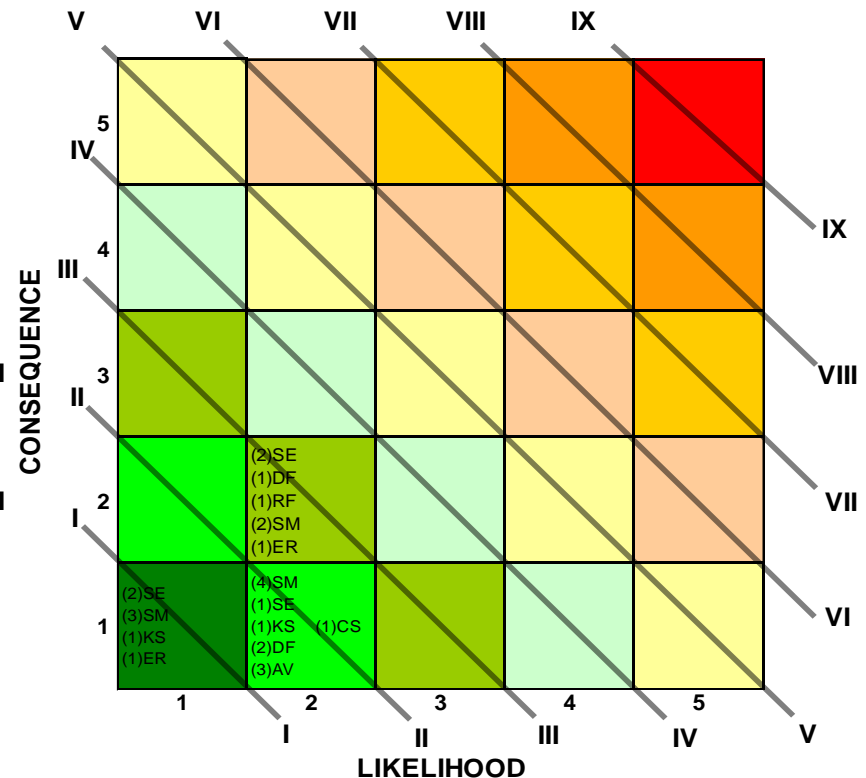
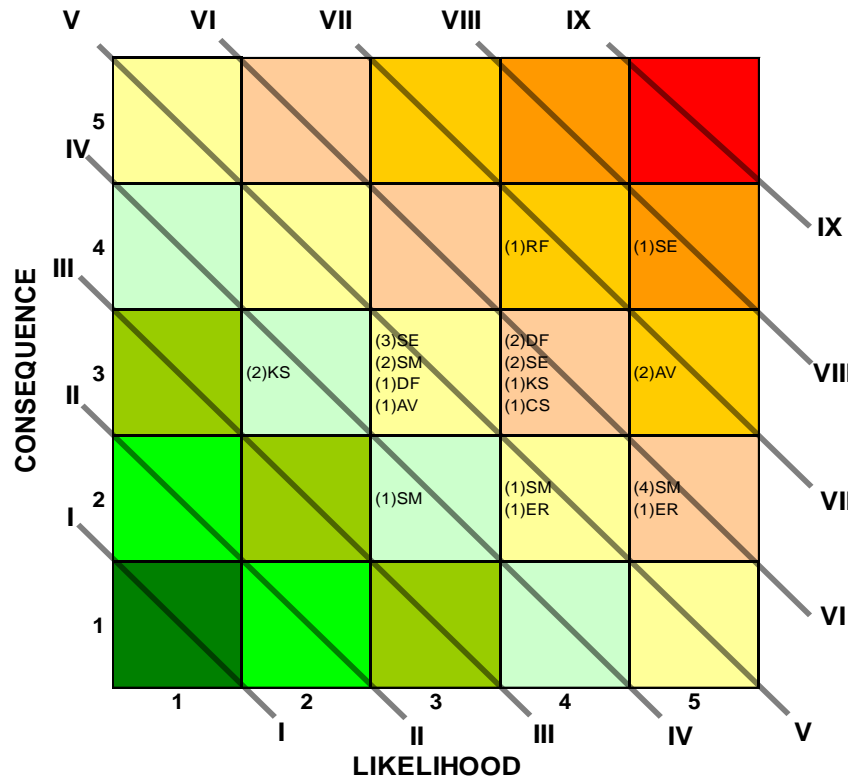
RISK CLASS	GEOHAZARD CODE
I	
II	
III	5DS
IV	12SM, 41SE
V	3SE, 4SE, 10SE, 13SE, 14SE, 16ER, 17SE, 18CS, 23SE, 24SE, 28DS, 29SE, 31SE, 32SM, 38SE, 43SE, 47DS
VI	7SE, 8SM, 19DS, 25ER, 26ER, 27SE, 37ER, 40ER, 44ER
VII	6SE, 9DS, 11SM, 15SM, 21DS, 22SE, 35DS, 36SM, 39SM, 42SM
VIII	20SE, 30DS, 34SE, 46DS
IX	33DS, 45DS

RISK CLASS	GEOHAZARD CODE
I	3SE, 4SE, 6SE, 9DS, 10SE, 12SM, 15SM, 22SE, 23SE, 29SE, 30SE, 34SE, 41SE, 43SE, 45DS
II	5DS, 7SE, 8SM, 13SE, 14SE, 16ER, 18CS, 24SE, 27SE, 28DS, 31SE, 32SM, 33DS, 36SM, 38SE, 42SM, 46DS, 47DS
III	11SM, 20SE, 25ER, 26ER, 35DS, 37SM, 39SM, 40ER, 44ER
IV	17SE, 19DS
V	21DS
VI	
VII	
VIII	
IX	

Figure 4.4 Southern Alberta Uplands Risk Assessment Matrices

**ROCKY MOUNTAINS RISK MATRIX SUMMARY
(UNMITIGATED)**

**ROCKY MOUNTAINS RISK MATRIX SUMMARY
(MITIGATED)**

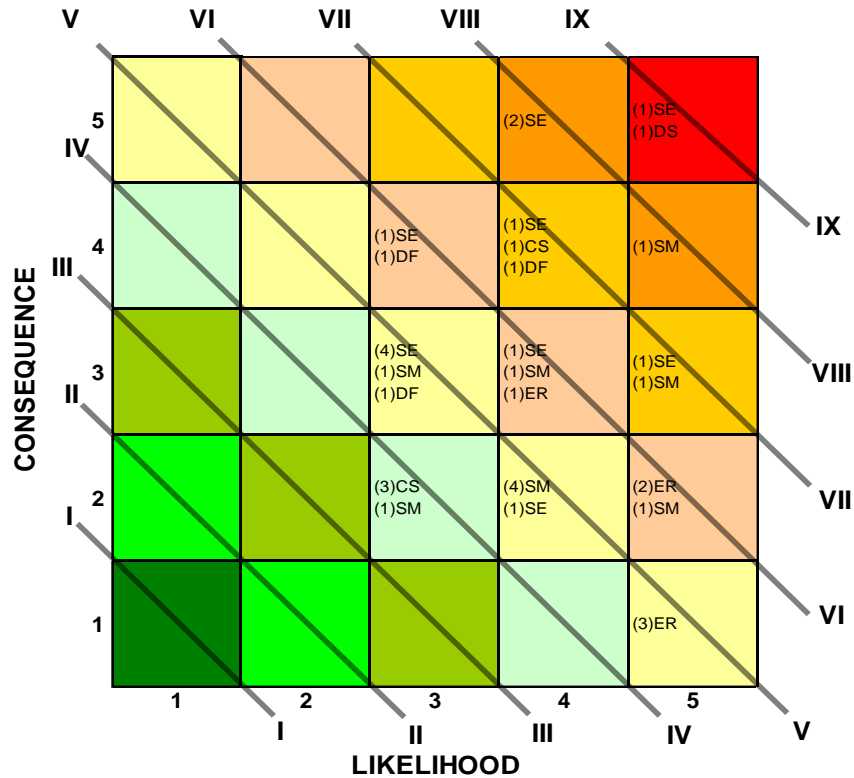


RISK CLASS	GEOHAZARD CODE
I	
II	
III	
IV	49SM, 55KS, 61KS
V	49SE, 51SE, 53SE, 54SM, 56SM, 64SM, 69DF, 71AV, 74ER
VI	50DF, 57SE, 58DF, 60SM, 65KS, 66CS, 67ER, 68SE, 70SM, 72SM, 73SM
VII	59AV, 62 AV, 63RF
VIII	52SE
IX	

RISK CLASS	GEOHAZARD CODE
I	51SE, 53SE, 60SM, 61KS, 64SM, 65KS, 67ER
II	48SM, 49SE, 54SM, 55KS, 56SM, 58DF, 59AV, 62AV, 66CS, 68SE, 69DF, 71AV, 73SM
III	50DF, 52SE, 57SE, 63RF, 70SM, 72SM, 74ER
IV	
V	
VI	
VII	
VIII	
IX	

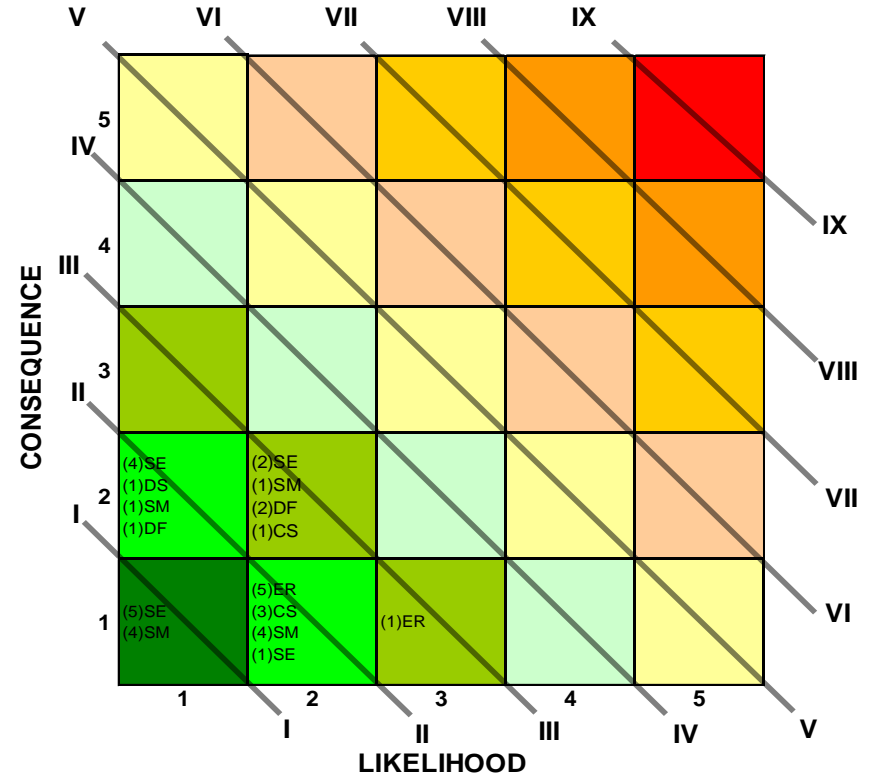
Figure 4.5 Rocky Mountains Risk Assessment Matrices

**INTERIOR PLATEAU RISK MATRIX SUMMARY
(UNMITIGATED)**



RISK CLASS	GEOHAZARD CODE
I	
II	
III	
IV	76CS, 88CS, 89CS, 101SM
V	75SM, 78SM, 79SE, 80ER, 81SM, 82SE, 83ER, 85ER, 92SM, 102SE, 103SM, 108SE, 109SE, 110DF
VI	84SM, 87SE, 90SE, 93ER, 98SM, 99ER, 104ER, 107DF
VII	86SE, 96CS, 97SE, 100SM, 106DF
VIII	77SE, 95SM, 105SE
IX	91SE, 94DS

**INTERIOR PLATEAU RISK MATRIX SUMMARY
(MITIGATED)**

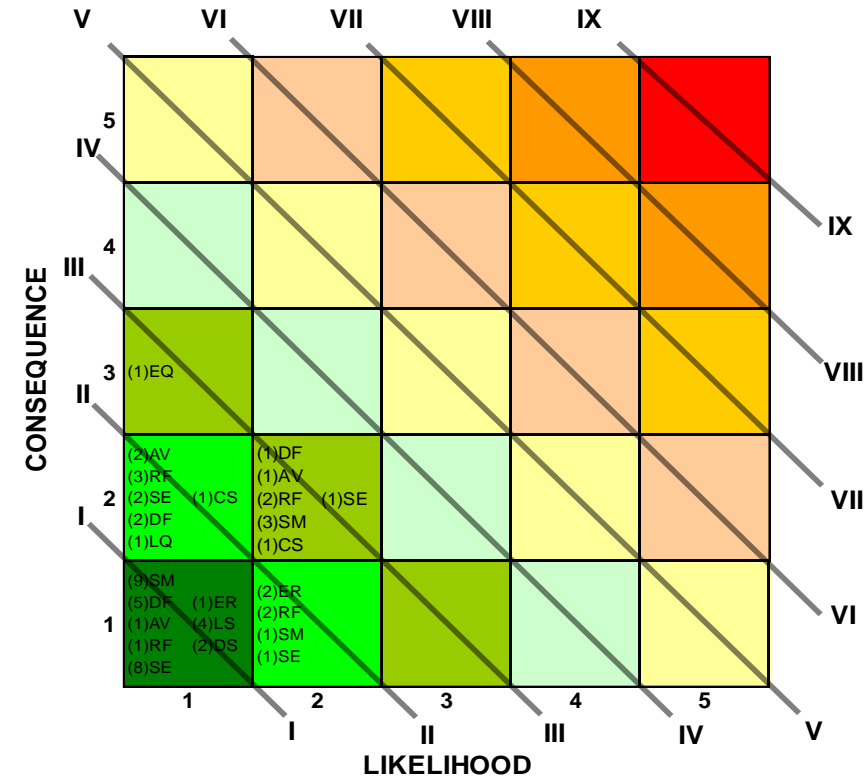
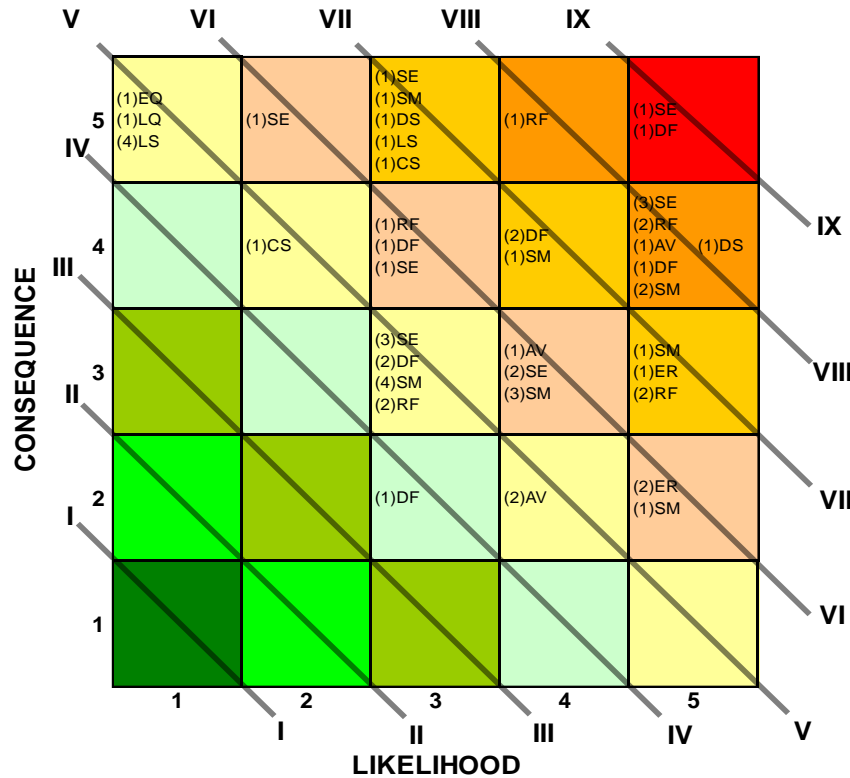


RISK CLASS	GEOHAZARD CODE
I	75SM, 77SE, 82SE, 87SE, 95SM, 98SM, 101SM, 102SE, 108SE
II	76CS, 78SM, 79SE, 80ER, 81SM, 83ER, 84SM, 86SE, 88CS, 89CS, 90SE, 92SM, 93ER, 97SE, 99ER, 100SM, 104ER, 109SE, 110DF, 85ER, 91SE, 96CS, 103SM, 105SE, 106DF, 107DF
III	
IV	
V	
VI	
VII	
VIII	
IX	

Figure 4.6 Interior Plateau Risk Assessment Matrices

**COAST MOUNTAINS RISK MATRIX SUMMARY
 (UNMITIGATED)**

**COAST MOUNTAINS RISK MATRIX SUMMARY
 (MITIGATED)**



RISK CLASS	GEOHAZARD CODE
I	
II	
III	
IV	116DF
V	111EQ, 117AV, 119AV, 122RF, 133SE, 142LS, 143SM, 146SM, 147LS, 148LS, 149SM, 152LS, 153SM, 154SE, 158LQ, 159DF, 163SE, 168CS, 169DF, 170RF
VI	112SM, 113ER, 115SM, 120RF, 123SE, 124SM, 128SM, 129SE, 130DF, 132AV, 138ER, 151SE, 156SE
VII	121DF, 131SM, 140ER, 141RF, 144RF, 155SE, 157CS, 160SM, 162DF, 165SM, 166DS, 167CS
VIII	114SE, 118RF, 125AV, 134DF, 135RF, 136SE, 137SE, 139SM, 145DS, 150SM, 161RF
IX	126SE, 127DF

RISK CLASS	GEOHAZARD CODE
I	112SM, 114SE, 115SM, 116DF, 119AV, 120RF, 123SE, 124SM, 126SE, 127DF, 128SM, 136SE, 139SM, 140ER, 142LS, 143SM, , 145DS, 147LS, 148LS, 149SM, 150SM, 151SE, 152LS, 153SM, 154SE, 156SE, 159DF, 162DF, 163SE, 166DS, 167LS, 169DF
II	113ER, 117AV, 118RF, 122RF, 125AV, 129SE, 130DF, 131SM, 133SE, 134DF, 135RF, 137SE, 138ER, 144RF, 158LQ, 168CS, 170RF
III	111EQ, 121DF, 132AV, 141RF, 146SM, 155SE, 157CS, 160SM, 161RF, 165SM
IV	
V	
VI	

Figure 4.7 Coast Mountains Risk Assessment Matrices

5.0 GENERAL GEOTECHNICAL RECOMMENDATIONS

5.1 General

This section provides preliminary geotechnical recommendations pertaining to issues that will occur across many parts of the route. They are provided to indicate some of the important geotechnical issues and preliminary mitigative methods that will be expanded upon during detailed design phases of the Project. The recommendations presented below are not considered to be final and are expected to be developed and refined during detailed design phases of the project and during construction. Similarly, detailed drawings and specifications which will outline detailed design and installation issues are also expected to be developed during detailed design. During construction, geotechnical input is recommended to refine the general geotechnical recommendations.

Along some areas of the route, it is anticipated that detailed engineering design will be required that will be more detailed than often used on pipeline projects (for example, parts of the upper Kitimat Valley). Also, detailed designs for high rock or soil cuts will require specific geotechnical input. These detailed designs are outside the scope of the more general preliminary recommendations presented below. Recommendations in [Table B-1](#) provide additional information on preliminary recommendations and areas where detailed design may be required.

5.2 Grading

5.2.1 General

1. As recommended below, with a few exceptions, clay or silt fills should generally not be placed back on the right-of-way to depths greater than 0.3 m where longitudinal slopes along the right-of-way exceed approximately 11° (5H:1V) without additional geotechnical input that will likely include recommendations for compaction. Sand fills should not be placed to depths greater than 0.3 m on longitudinal slopes greater than 14° (4H:1V) without geotechnical input, which may include recommendations for compaction. Shot rock fills should not be placed back on graded longitudinal slopes greater than 32° (1.6H:1V). These recommendations are made since excessive depths of material placed on a portion of the grade running downhill at angles steeper than those noted will have an increased tendency to slide.
2. Where the foregoing recommendations would be exceeded, additional geotechnical input is recommended. Mitigative measures may include disposing of cut materials along the right-of-way at another suitable location or planning a deeper cut at a lower longitudinal slope. Additional workspace may be required in some cases.
3. Steep slopes where the sidecuts will exceed approximately 6 m high may require specific geotechnical input. The higher cuts may also require additional workspace to provide sufficient working room for the cut and fill slopes.
4. The pipelines should, in general, be installed in native ground. Pipelines should not be placed in fill without specific geotechnical recommendations.

5. During detailed design and construction, it is anticipated that further geotechnical review and input will be provided on cut and fill slopes as well as the general grading plans in order to reduce the potential for inducing stability or siltation problems.

5.2.2 Cuts

The following preliminary recommendations are made for soil cuts up to 6 m high that do not undercut (oversteepen) existing overall slopes:

1. Cuts in sideslopes extending upslope from the crest of the cut more than 10 m at angles of 25° or more should be examined from a geotechnical point-of-view. The specific concern is to avoid creating ravelling failures in overburden that may retrogress far upslope above the grade cut.
2. Cuts should be as shallow as possible while providing the required grade and working room. Excessively deep cuts will generate higher than optimal cut slopes which may be subject to stability considerations. In addition, as discussed above, significant quantities of cut materials should not be placed back on approach slopes to streams and so disposal areas will be required for these cut materials. If the cuts are kept as low as possible, then disposal problems will be reduced.
3. Short term cuts in soil may be made at angles up to 36.9° (1H to 3/4V) to heights of 1.5 to 6 m subject to Workers Compensation Board requirements. However, these cuts will undergo shallow failure with time and long term cut angles of 26.5° (2H:1V) are recommended for most soil cuts.
4. Rock cuts up to 6 m high should typically be blasted with vertical slopes except where otherwise identified. Final cut slopes after scaling will have variable, but flatter angles. Cuts more than 3 m high should typically be blasted using presplit or other “smooth wall” techniques. Scaling will be required.
5. If seepage is observed or suspected, the area should be reviewed geotechnically in case additional measures to reduce erosion and siltation are required. These measures might include groundwater drainage or rock blankets; however, individual requirements will vary. This recommendation particularly applies to seepage in sandy materials which may initiate groundwater piping (internal erosion) which can rapidly retrogress upslope, and which may be difficult and expensive to repair if allowed to get out of control.
6. Stockpiles or sources of shotrock or free draining gravel and medium to heavy weight non-woven geotextile should be available at various locations in all physiographic regions west of the Eastern Alberta Plains. In emergency situations, where groundwater piping is occurring, the geotextile should be placed over the seepage area and 0.5 to 1 m (depending on flow volumes) of free draining gravel or shotrock placed over the area. Additional geotechnical input should be sought. It is noted that rock or gravel blankets placed on slopes will require toe support or they will tend to slide downslope.

5.2.3 Fills

The following recommendations pertain to fills placed during grading:

1. Fill slopes should generally be constructed at inclinations of 26.5° (2H:1V) for clay and silt rich materials. Sand and gravel may be placed to angles of 36° on a temporary basis. Strong shot rock may be placed to angles of 38°. Fill heights should be limited to 3 m without additional geotechnical input.
2. Weak rock containing high plastic clay materials (eg, some shale, bentonitic sandstone, bentonitic mudstone) are undesirable for long-term fills because the shale may break down to form soft cohesive soils. They also drain poorly and instability can result from this poor drainage. Where clay rich materials are used for fill more than 2 deep, fill slope angles should be reduced from those in Point 1 to take account of the lower shear strength of the material with time. Geotechnical input should be provided for higher or steeper fills of weak rock.
3. Snow and ice should not be incorporated into fills or left under fills. Frozen soils should not be used for permanent fills unless the potential for future sliding or erosion will not progress off the RoW and is acceptable in the particular circumstances.
4. Ground surface preparation in areas where fill slopes will be placed should include removal of snow accumulations, fallen logs and stumps, and stripping of surficial organic soils to the rooting depth. Ice rich soils should be removed. Fills should not be retained by trees, logs or other similar means.
5. Material used for fill should consist of mineral soil or shotrock and should be as dry as possible. Placement of snow or ice-rich soils, large frozen lumps, or wet materials should be avoided or specific geotechnical advice should be obtained. Snow and ice rich surficial soils should be removed from areas where fill will be placed and from borrow areas prior to excavation.
6. If fills are placed across areas of seepage (either ephemeral or permanent), subdrainage such as Multi Flow™ prefabricated drains or French drains should be installed. French drains should be used where there are large volumes of seepage. Multi Flow™ drains are suitable to drain lower volume seepages (up to 2 l/min). Drains should be placed against undisturbed mineral soil.
7. As a minimum, fill should be compacted using track compaction by heavy equipment. Track compaction should not be used in settlement sensitive areas where engineered fills and specific compaction control may be required.
8. See recommendations above for maximum depths of fills on longitudinal slopes parallel to the pipelines. Locally deeper fills consisting of small fillets of material can be placed to stabilize steep cut slopes along the edge of the right-of-way. Such fills should generally conform to other recommendations in this report.

5.2.4 Surface and Ground Water Control

Surface and ground water control is an extremely important aspect affecting slope stability as well as sedimentation and erosion. Geotechnical input into surface and ground water control measures is recommended. The following preliminary general geotechnical recommendations are made:

1. The purpose of the surface and ground water control measures is to direct water off the right-of-way and out of the pipeline trenches in a controlled and planned manner with the aims of controlling erosion and the right-of-way grade and avoiding directly concentrated water flows into areas where these flows might be detrimental to stability, erosion or siltation.
2. Existing swales and draws should not be obstructed so that runoff water becomes diverted along the RoW grade or ponded behind fill. Cross berms should be used to maintain surface water flows in the same locations as prior to construction. The aim is for the RoW grade to have a minimal impact on surface water conditions.
3. Where there are adjacent rights-of-ways, surface water control will need to be planned in conjunction with the measures in place on the adjacent areas.
4. Roll back should not be done on slopes. Roll back consists of organic debris and surficial organic soils that are sometimes placed back on the pipeline right-of-way. On slopes, roll back has been found to significantly increase the amount of infiltration and to impede water runoff resulting in decreased stability. Where disposal of organic rich material is required, this material should be moved to flat areas beyond the crest or toe of the slope.

The following recommendations are made with respect to cross berms:

1. Cross berms should be placed at frequent intervals down the slopes to direct water off the right-of-way. Cross berms should also be placed immediately downstream of all trench blocks to direct water off the RoW that is forced to the surface by the trench block.
2. Final locations and flow directions of cross berms should be chosen in the field with geotechnical input. It is most important that surface water should not be directed into tension cracks or other areas prone to stability issues.
3. Cross berms should consist of compacted unfrozen mineral soil in a berm up to 0.5 m high running diagonally across the RoW. The slope along the berm should preferably be about 10%. The use of higher berms is usually not required and is generally not an advantage except for access control.
4. Shallow swales on the uphill side can be used to augment cross berms.
5. In case of erodible soils, consideration can be given to lining the swale on the uphill side of the berm with an erosion mat.

Trench blocks should be installed in the pipeline trenches at intervals as required to control and interrupt water flow along the trench. The purposes are to reduce internal erosion of soil and padding along the trench and to avoid transporting water along the trench from upland areas into areas of sensitive slopes or slides.

1. Trench blocks should be located at intervals down the slope including below seepage areas or drainage swales.
2. Compacted clay trench blocks are generally preferred geotechnically over other types of trench blocks such as sand bag or foam blocks. Clean native soil materials and bentonite (eg, prebagged drilling mud) compacted into place should preferably be used to form the blocks. No organics, topsoil, sticks, other non-soil materials or garbage should be present in the soil used.
3. Sandbag trench blocks are typically less preferable than either clay or foam types, but may be considered under special circumstances.
4. Foam trench blocks may be placed in areas where it is not possible to place clay trench blocks. The disadvantages of foam blocks include the tendency for foam blocks to shrink in the long term, and the inability of the block to reseal in the event of pipeline movement.
5. Where there may be appreciable water collection behind a trench block, drainage using Multi-Flow drains or French drains may be considered. Such drains should be directed downslope to areas where the flow will be directed off the RoW either by topography or by cross berms.

Drainage is required under fills that are placed over areas of seepage and may also be required to control springs on cuts, in the right-of-way grade or in the trench.

1. Multi-Flow™ drains consist of a series of small diameter perforated polyethylene pipes bonded together to form a sheet and covered with non-woven geotextile. The 18" wide drain is recommended in all cases. The drains are suitable for draining small to moderate seepage zones. Manifolds, elbows and solid wall pipe should be used in combination with the drains to route water off the RoW. Care should be taken to wrap the filter cloth around the uphill end of the installation to prevent soil ingress and fouling. Multi-Flow™ drains are recommended for installation in the following areas:
 - On the uphill sides of trench blocks where drainage of accumulated water is desirable.
 - In the bottoms of selected drainage ditches prone to sloughing. In these areas, the drain should be laid along the bottom of the ditch and either stapled to the bottom or weighted down with occasional cobbles. The purpose of the drains along the trenches is to allow water flow to continue in the event of surficial sloughing that blocks the ditch.

2. French drains: French drains consist of free draining gravel with a drain pipe encapsulated by non-woven geotextile and installed in a trench. French drains are used where high seepage flows occur.
3. Drainage blankets consist of clean shotrock fill placed to depths of approximately 1 m over geotextile on slopes. The purpose is to allow seepage to exit from cuts without creating erosion problems.

5.2.5 Clean-up and Revegetation

1. The RoW surface should be left in a condition that will shed water, particularly on approach slopes to streams and in areas prone to slides. Ruts, depressions and similar sources of increased water infiltration should be graded out or repaired to avoid increases in infiltration that could result in sliding.
2. All disturbed soil surfaces should be revegetated with a suitable seed mix. Multiple applications may be required to achieve an adequate vegetation catch.
3. Mulching and other measures may be required in some soils such as sand.
4. As noted elsewhere, the use of rollback is not recommended on slopes due to the increased likelihood of slope and erosion problems.
5. The RoW should be checked frequently during the first year to identify areas where additional work may be required to improve surface or ground water drainage, erosion, poor revegetation catch or stability problems.



6.0 LIMITATIONS AND CLOSURE

Recommendations and evaluations presented herein are based on preliminary data and are considered preliminary. In general, detailed on-ground site evaluations have not been done at many locations. It is expected that further investigations will be undertaken for the areas discussed in this report during detailed engineering for design and construction. Other more detailed reports have been prepared for some aspects of the project and these reports should be referenced as applicable. If conditions other than those reported are noted during subsequent phases of the project, AMEC Earth & Environmental should be notified and be given the opportunity to review and revise the current recommendations, if necessary.

This report has been prepared for the exclusive use of Northern Gateway Pipelines Inc. for specific application to the area within this report. Any use which a third party makes of this report, or any reliance on or decisions made based on it, are the responsibility of such third parties. AMEC Earth & Environmental accepts no responsibility for damages, if any, suffered by any third party as a result of decisions made or actions based on this report. It has been prepared in accordance with generally accepted geotechnical engineering practices. No other warranty, expressed or implied, is made.

Respectfully submitted,

**AMEC Earth & Environmental,
a division of AMEC Americas Limited**

Reviewed by:

Original paper copies signed and sealed
by D.S. Cavers, M.Eng., P.Eng., P.Geo.

Per

D. S. Cavers, M.Eng., P.Eng.(AB&BC), P.Geo. (BC)
Principal Engineer

P. Barlow, M.Sc., P.Eng. (AB&BC)
Principal Engineer

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AMEC Earth & Environmental a Division of AMEC Americas Limited	
Signature	_____
Date	_____
PERMIT NUMBER: P-04546	
The Association of Professional Engineers, Geologists and Geophysicists of Alberta	

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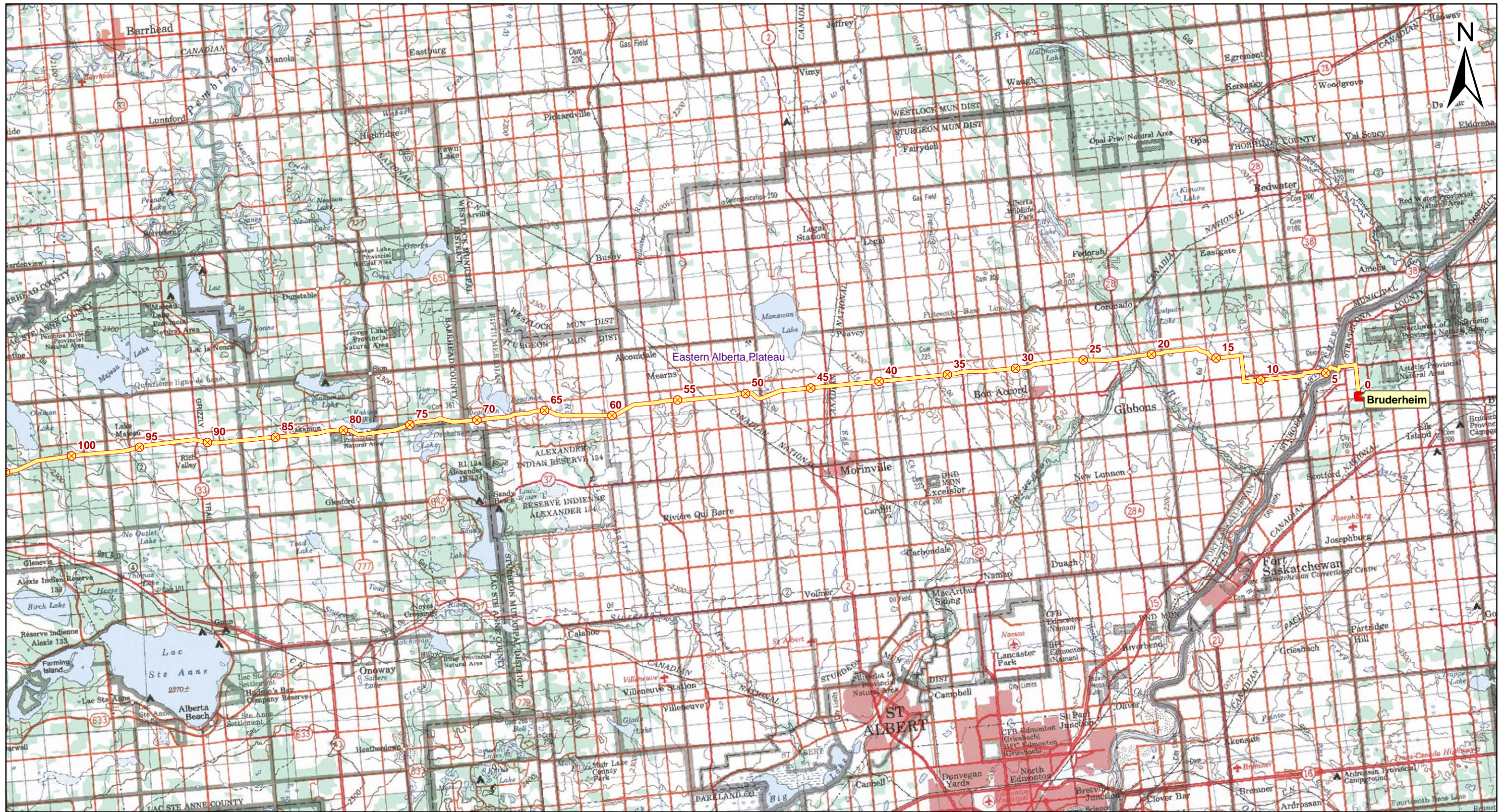
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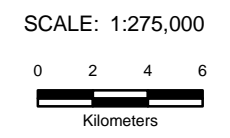
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APPENDIX A

Route Location Figures A-1 to A-11



- LEGEND**
- ⊗ Kilometre Post (July 27, 2009)
 - Proposed Route (July 27, 2009)
 - Pump Station
 - Condensate
 - Condensate / Crude
 - Crude
 - Physiographic Boundary



PROJECTION: LCC DATUM: NAD 83

ENBRIDGE NORTHERN GATEWAY PROJECT

Route Location
 KP 0 - KP 100
 Physiographic Boundaries

PROJECT NUMBER:
EG0926008.3001

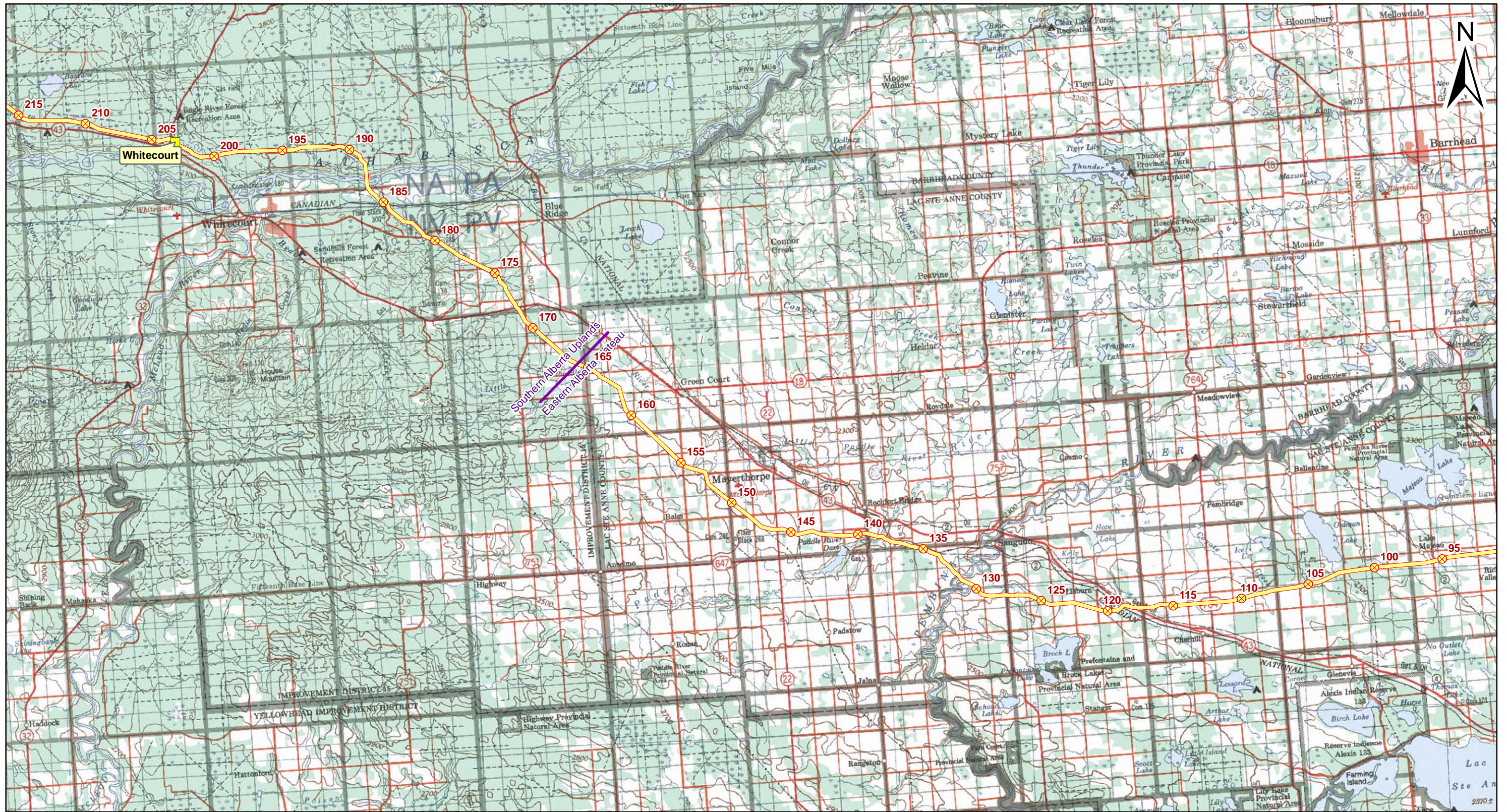
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QA/QC:
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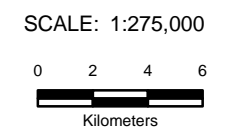
REFERENCE:
Pipeline Route: Rev. R. July 27, 2009

CONTRACTOR:
 AMEC Earth & Environmental

Figure A-1



- LEGEND**
- Kilometre Post (July 27, 2009)
 - Proposed Route (July 27, 2009)
 - Pump Station
 - Condensate
 - Condensate / Crude
 - Crude
 - Physiographic Boundary



PROJECTION: LCC DATUM: NAD 83

ENBRIDGE NORTHERN GATEWAY PROJECT

Route Location
 KP 100 - KP 215
 Physiographic Boundaries

PROJECT NUMBER:
EG0926008.3001

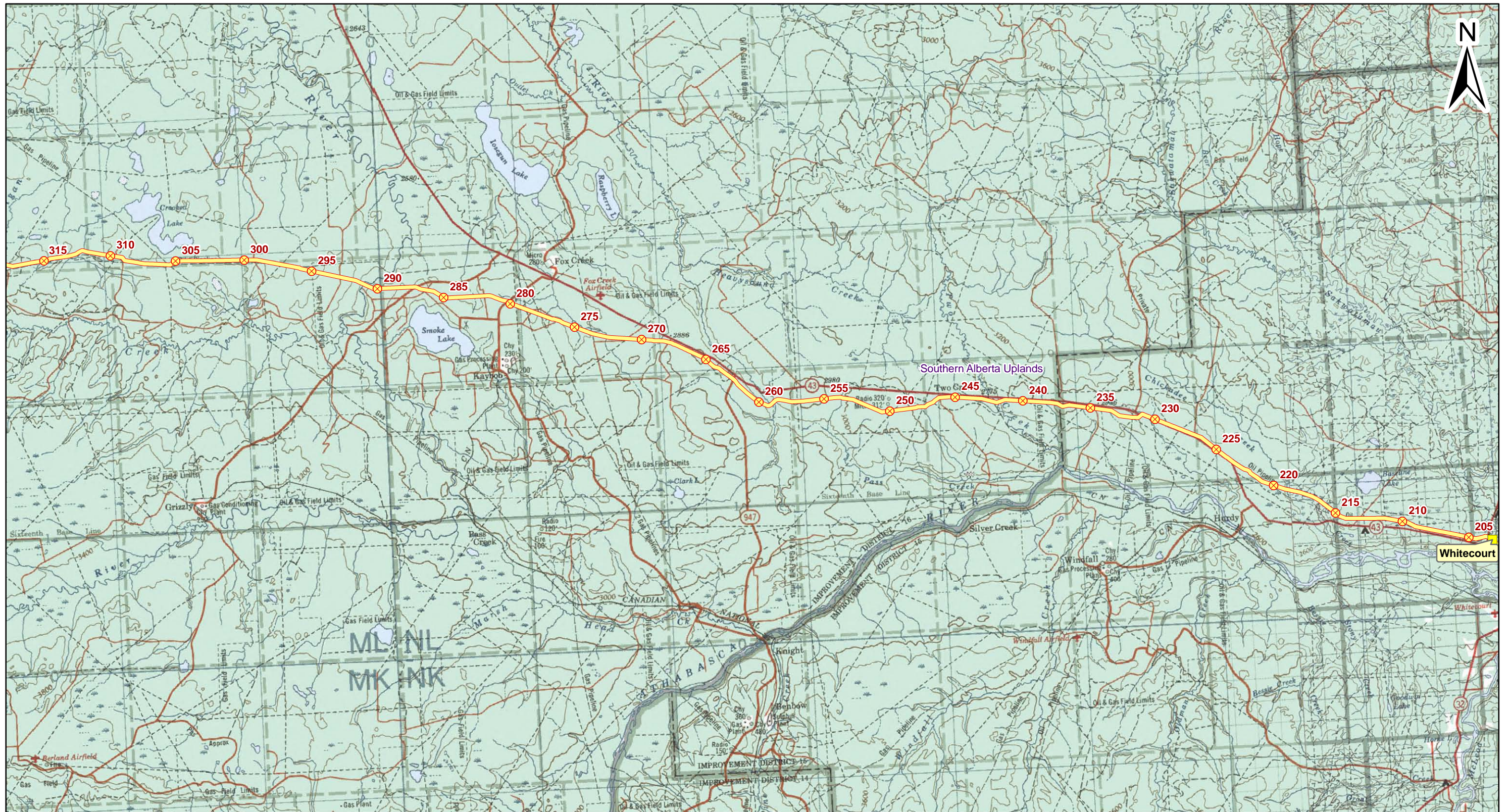
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QA/QC:
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REFERENCE:
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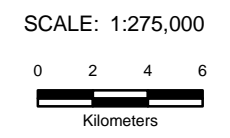
CONTRACTOR:
 AMEC Earth & Environmental

Figure A-2



LEGEND

- ⊗ Kilometre Post (July 27, 2009)
- Proposed Route (July 27, 2009)
- Pump Station
- Condensate
- Condensate / Crude
- Crude
- Physiographic Boundary

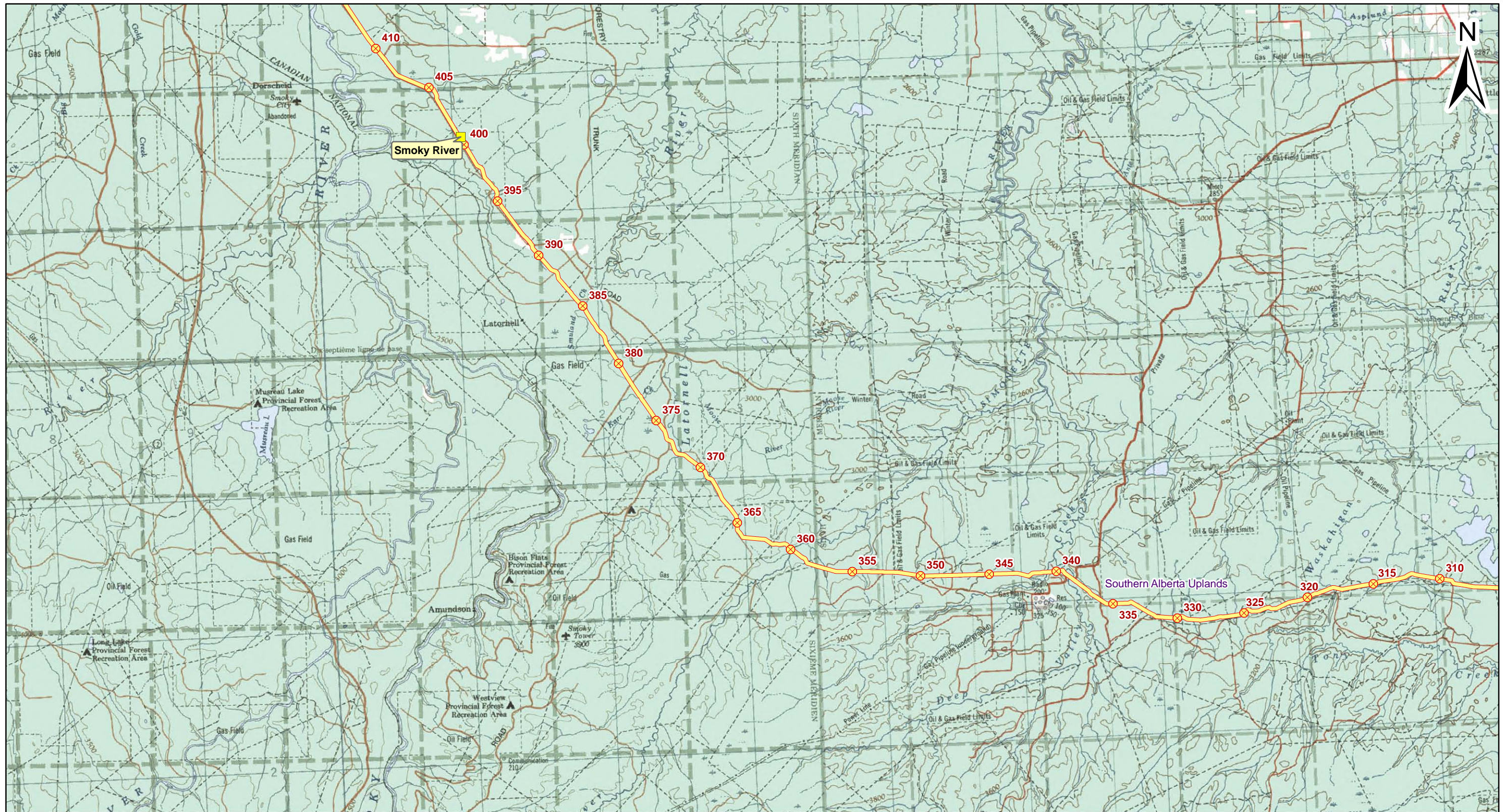


PROJECTION: LCC DATUM: NAD 83

ENBRIDGE NORTHERN GATEWAY PROJECT

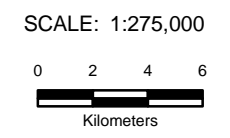
Route Location
 KP 215 - KP 315
 Physiographic Boundaries

PROJECT NUMBER: EG0926008.3001	
DATE: February 5, 2010	QA/QC: DC
REFERENCE: Pipeline Route: Rev. R. July 27, 2009	
CONTRACTOR: AMEC Earth & Environmental	Figure A-3



LEGEND

- ⊗ Kilometre Post (July 27, 2009)
- Proposed Route (July 27, 2009)
- Pump Station
- Condensate
- Condensate / Crude
- Crude
- Physiographic Boundary

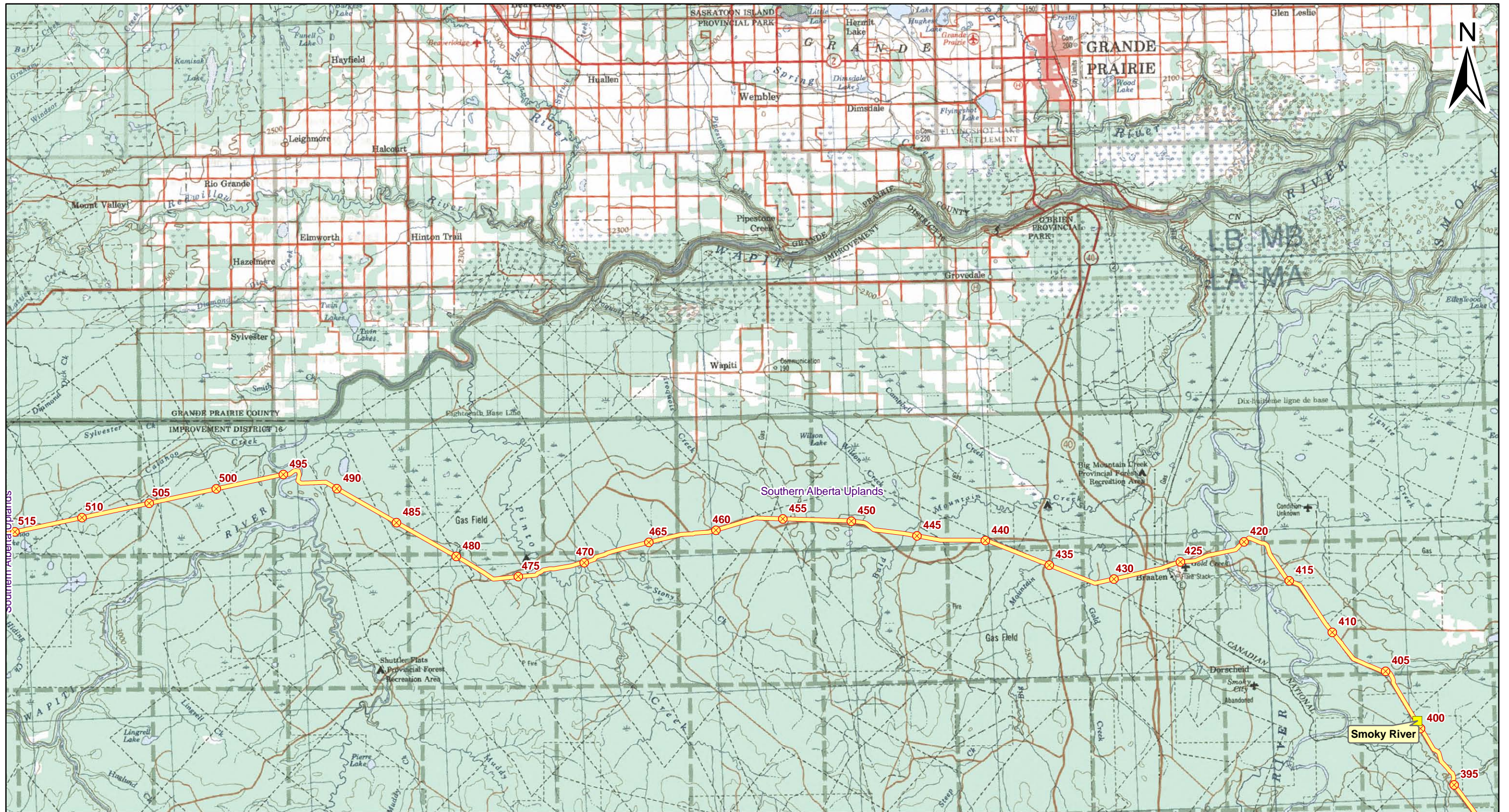


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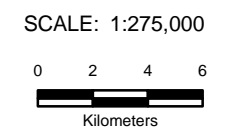
ENBRIDGE NORTHERN GATEWAY PROJECT

Route Location
 KP 315 - KP 410
 Physiographic Boundaries

PROJECT NUMBER: EG0926008.3001	
DATE: February 5, 2010	QA/QC: DC
REFERENCE: Pipeline Route: Rev. R. July 27, 2009	
CONTRACTOR: AMEC Earth & Environmental	Figure A-4



- LEGEND**
- ⊗ Kilometre Post (July 27, 2009)
 - Proposed Route (July 27, 2009)
 - Pump Station
 - Condensate
 - Condensate / Crude
 - Crude
 - Physiographic Boundary

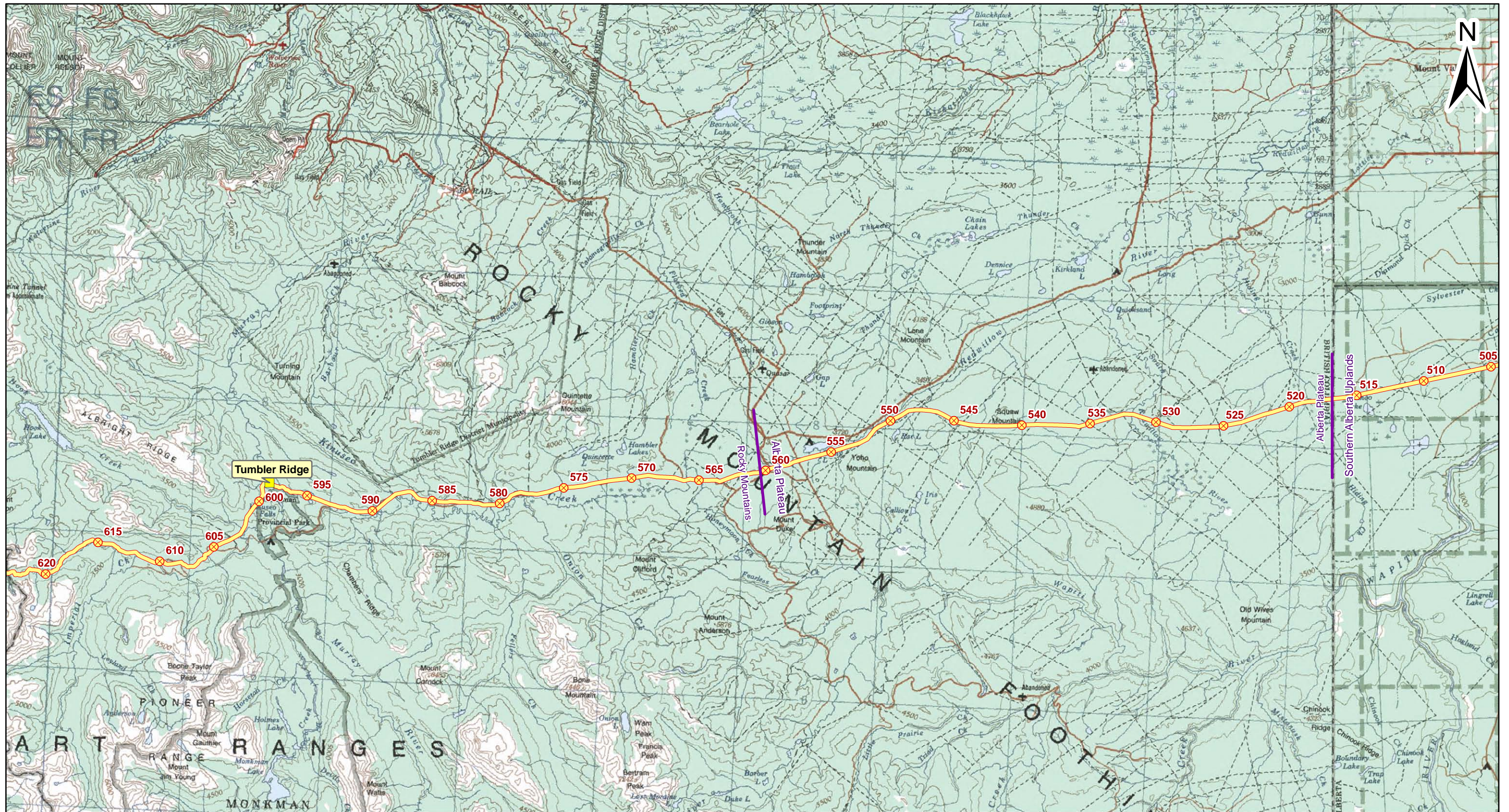


PROJECTION: LCC DATUM: NAD 83

ENBRIDGE NORTHERN GATEWAY PROJECT

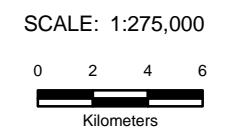
Route Location
 KP 410 - KP 515
 Physiographic Boundaries

PROJECT NUMBER: EG0926008.3001	
DATE: February 5, 2010	QA/QC: DC
REFERENCE: Pipeline Route: Rev. R. July 27, 2009	
CONTRACTOR: AMEC Earth & Environmental	
Figure A-5	



LEGEND

- ⊗ Kilometre Post (July 27, 2009)
- Proposed Route (July 27, 2009)
- Pump Station
- Condensate
- Condensate / Crude
- Crude
- Physiographic Boundary



PROJECTION: LCC DATUM: NAD 83

ENBRIDGE NORTHERN GATEWAY PROJECT

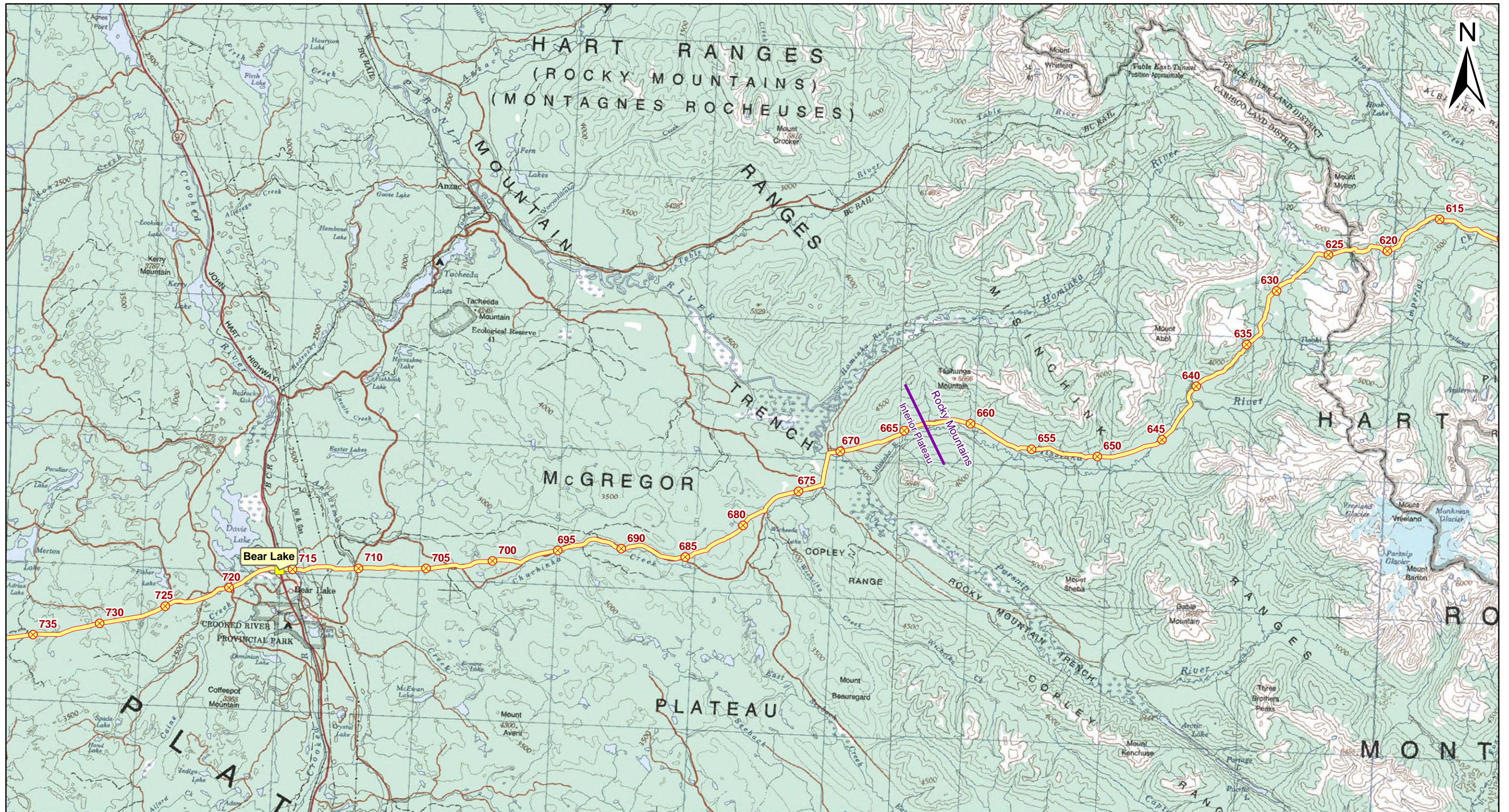
Route Location
 KP 515 - KP 620
 Physiographic Boundaries

PROJECT NUMBER:
EG0926008.3001

DATE: February 5, 2010 QA/QC: DC

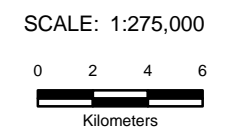
REFERENCE:
Pipeline Route: Rev. R. July 27, 2009

CONTRACTOR:
 AMEC Earth & Environmental Figure A-6



LEGEND

Kilometre Post (July 27, 2009)	Pump Station
Proposed Route (July 27, 2009)	Condensate
	Condensate / Crude
	Crude
	Physiographic Boundary

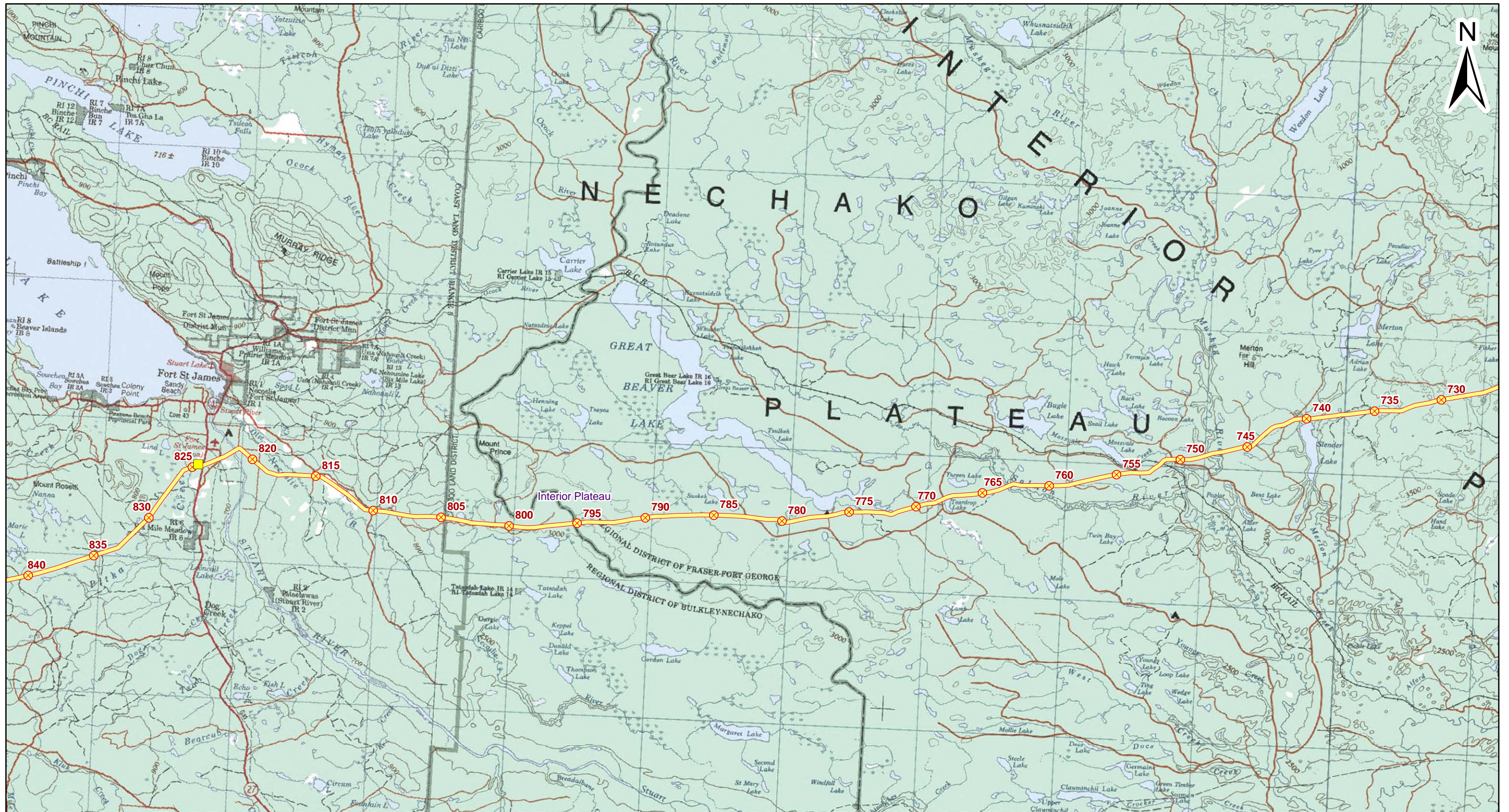


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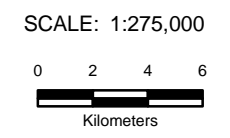
ENBRIDGE NORTHERN GATEWAY PROJECT

Route Location
 KP 615 - KP 735
 Physiographic Boundaries

PROJECT NUMBER: EG0926008.3001	
DATE: February 5, 2010	QA/QC: DC
REFERENCE: Pipeline Route: Rev. R. July 27, 2009	
CONTRACTOR: AMEC Earth & Environmental	Figure A-7



- LEGEND**
- ⊗ Kilometre Post (July 27, 2009)
 - Proposed Route (July 27, 2009)
 - Pump Station
 - Condensate
 - Condensate / Crude
 - Crude
 - Physiographic Boundary



PROJECTION: LCC DATUM: NAD 83

ENBRIDGE NORTHERN GATEWAY PROJECT

Route Location
 KP 735 - KP 840
 Physiographic Boundaries

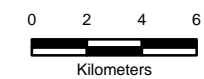
PROJECT NUMBER: EG0926008.3001	
DATE: February 5, 2010	QA/QC: DC
REFERENCE: Pipeline Route: Rev. R. July 27, 2009	
CONTRACTOR: AMEC Earth & Environmental	Figure A-8



LEGEND

- ⊗ Kilometre Post (July 27, 2009)
- Proposed Route (July 27, 2009)
- Pump Station
- Condensate
- Condensate / Crude
- Crude
- Physiographic Boundary

SCALE: 1:275,000



PROJECTION: LCC DATUM: NAD 83

ENBRIDGE NORTHERN GATEWAY PROJECT

Route Location
 KP 840 - KP 940
 Physiographic Boundaries

PROJECT NUMBER:
EG0926008.3001

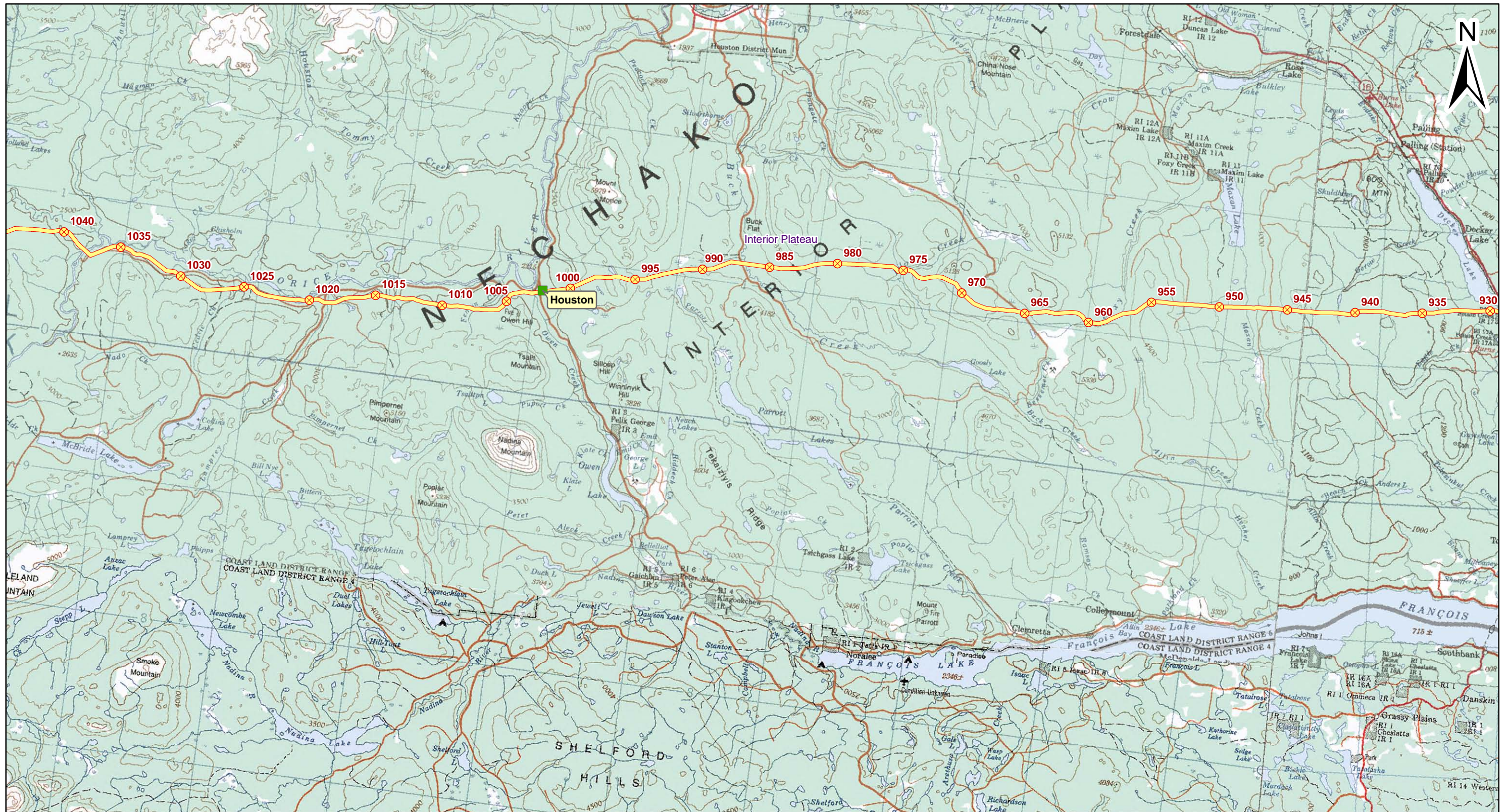
DATE:
 February 5, 2010

QA/QC:
 DC

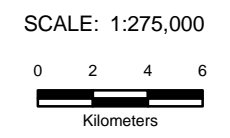
REFERENCE:
Pipeline Route: Rev. R. July 27, 2009

CONTRACTOR:
 AMEC Earth & Environmental

Figure A-9



LEGEND	
	Kilometre Post (July 27, 2009)
	Proposed Route (July 27, 2009)
	Pump Station
	Condensate
	Condensate / Crude
	Crude
	Physiographic Boundary

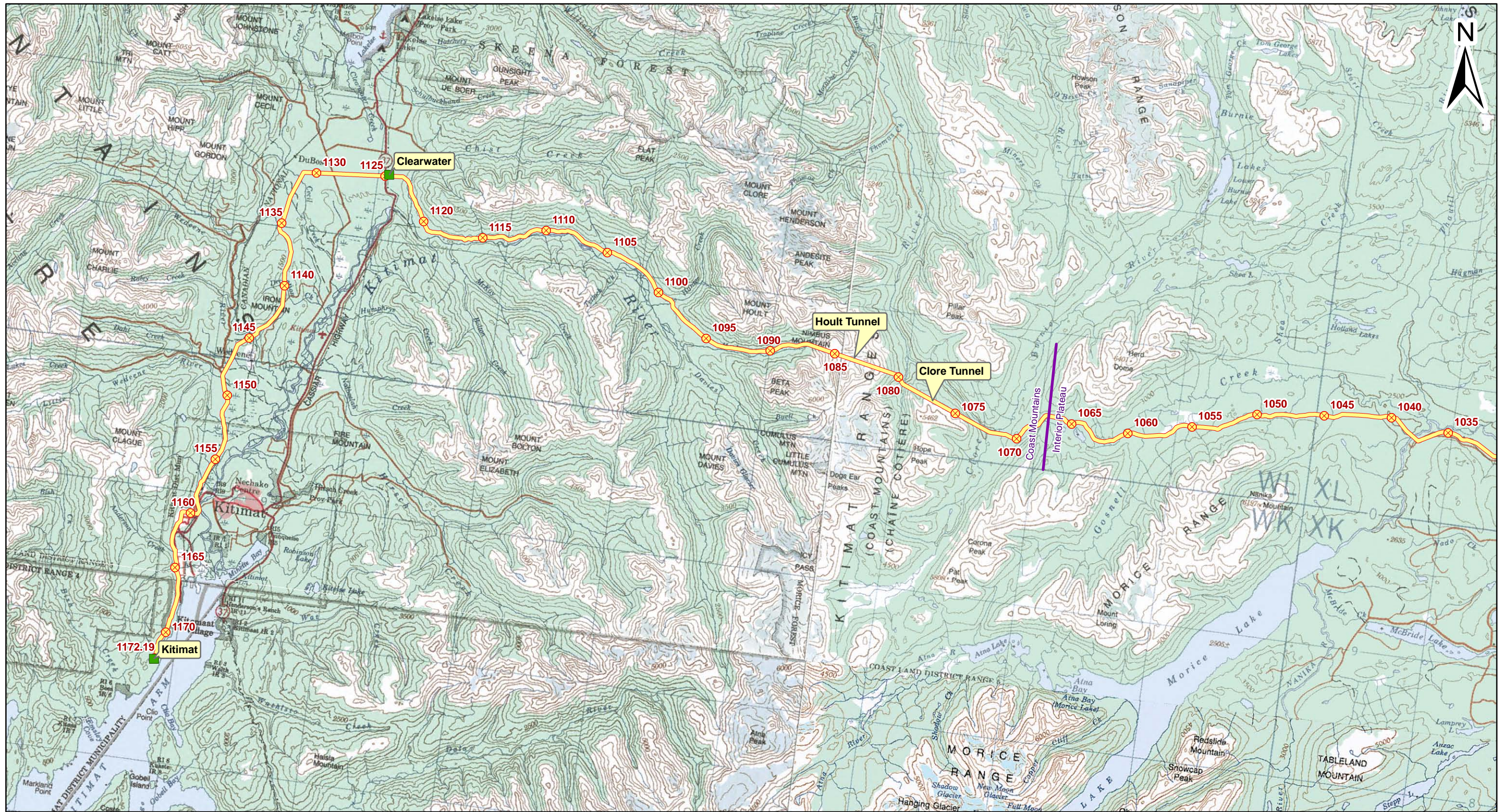


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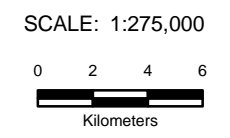
ENBRIDGE NORTHERN GATEWAY PROJECT

Route Location
 KP 940 - KP 1040
 Physiographic Boundaries

PROJECT NUMBER: EG0926008.3001	
DATE: February 5, 2010	QA/QC: DC
REFERENCE: Pipeline Route: Rev. R. July 27, 2009	
CONTRACTOR: AMEC Earth & Environmental	Figure A-10



- LEGEND**
- ⊗ Kilometre Post (July 27, 2009)
 - Proposed Route (July 27, 2009)
 - Pump Station
 - Condensate
 - Condensate / Crude
 - Crude
 - Physiographic Boundary



PROJECTION: LCC
 DATUM: NAD 83

ENBRIDGE NORTHERN GATEWAY PROJECT

Route Location
 KP 1040 - KP 1172.19
 Physiographic Boundaries

PROJECT NUMBER:
EG0926008.3001

DATE: February 5, 2010
 QA/QC: DC

REFERENCE:
Pipeline Route: Rev. R. July 27, 2009

CONTRACTOR:
 AMEC Earth & Environmental
 Figure A-11

APPENDIX B

Summary Table B-1



Table B-1 Preliminary Summary of Geotechnical Conditions-Rev R

From (KP)	To (KP)	Geotechnical Conditions	Geotechnical Comments
<p>This table summarizes the preliminary geotechnical aspects of the pipeline route for the Enbridge Northern Gateway Project. This table is subject to revision as further geotechnical investigations occur and additional information is obtained.</p>			
0.0	2.9	<p>Flat to undulating terrain at and near proposed Bruderheim Station at east end of route. Congested area with limitations on routing due to land ownership considerations and other pipelines.</p> <p><u>Surficial Geology</u> (Bayrock, 1972): Sand dunes and sheet sand, dunes 3 to 15 m thick, sheet sand is typically thin likely overlying till at depth. Toward the east, thinner aeolian sand may overlie glacial till. Local areas of muskeg in closed depressions.</p> <p><u>Bedrock Geology</u> (Hamilton et al, 1999): Belly Valley Group (thick bedded grey to greenish grey feldspathic sandstone, grey clayey siltstone, grey and green mudstone, concretionary ironstone. Non-marine.)</p> <p>Andriashek (1987a and 1987b) indicates that there is a major buried valley (Beverly Valley) that trends parallel to the modern North Saskatchewan valley. At the study area, the valley is centered slightly east of the modern valley with drift thicknesses in excess of 40 m at the center of the valley. In the segment under discussion, depths to bedrock of 30 to 40 m are typical. The valley is likely infilled with clay, sand and till with layers of cobbles or boulders.</p>	<p>Some dunes and sand deposits may be erodible. Mulching may be required together with revegetation of disturbed areas.</p>
2.9	5.3	<p>North Saskatchewan River – KP 4.1: Moderately steep to steep approach slope into the valley on the east side is an estimated 25 m high. There is a terrace approximately 400 m wide on the east side of the river. Banks into the river is approximately 8 m high and also steep. On the west side of the river there is a terrace approximately 200 m wide. The route deviates to the south to run up the west approach slope of the river valley south of a tributary stream gully. Shallow sliding in gully was avoided by routing. The routing in this area was dictated by the presence of other pipelines and existing land ownership and use.</p> <p>Preliminary geotechnical ground examinations indicated no major stability concerns for areas outside of tributary valley slopes. Shallow rock on reported west side, excavated using ripping.</p> <p><u>Surficial Geology</u> (Bayrock, 1972): Outwash sand to thicknesses of 1 to</p>	<p>Tight area due to presence of other pipelines and terrain features.</p> <p>Detailed and comprehensive ground and surface water control measures will be required. These measures should be coordinated with existing and planned measures for other pipelines in the area.</p> <p>Open Cut Crossing: A conventional trenched crossing appears to be geotechnically and hydrotechnically feasible based on work to date and on the method used by other adjacent pipelines. Other recent pipelines crossings are understood to have been trenched. An isolated crossing is not feasible due to flows being too high.</p>



From (KP)	To (KP)	Geotechnical Conditions	Geotechnical Comments
		<p>6 m overlying till(?) and Beverly Valley infill deposits. Alluvial sand to silt on terraces near river. <u>Bedrock Geology</u> (Hamilton et al, 1999): Belly Valley Group, as above.</p>	
5.3	21.0	<p>Undulating upland topography. <u>Surficial Geology</u> (Bayrock, 1972): Sand dunes and sheet sand, dunes 3 to 15 m thick, sheet sand is typically thin, overlying till. Some areas of exposed till. GEM terrain mapping suggested glaciofluvial and shallow glaciolacustrine deposits may also be present. <u>Bedrock Geology</u> (Hamilton et al, 1999): Belly Valley Group (thick bedded grey to greenish grey feldspathic sandstone, grey clayey siltstone, grey and green mudstone, concretionary ironstone. Non-marine). Andriashek (1987a and 1987b) indicates drift thicknesses of 10 to 20 m so bedrock is not expected to be exposed.</p>	No significant geotechnical issues identified.
21.0	23.4	<p>Tributary Creek to Sturgeon River: Sturgeon River is to the south. Moderate slopes to 25 m high into and out of wide valley (former glaciofluvial meltwater valley). Railway crossing near crest of east approach slope. <u>Surficial Geology</u> (Bayrock, 1972): Outwash sand and gravel to thicknesses of 6 m overlying bedrock. Bedrock is exposed to the south in the Sturgeon River valley. GEM terrain mapping suggested glaciofluvial and shallow aeolian and glaciolacustrine deposits may also be present. <u>Bedrock Geology</u> (Hamilton et al, 1999): Belly Valley Group, as above.</p>	Ground and surface water control required on slopes.
23.4	33.1	<p>Flat to gently sloping terrain <u>Surficial Geology</u> (Bayrock, 1972): Glacial till with pitted deltas (sand with lesser amounts of silt and clay) to west. GEM terrain mapping suggested glaciolacustrine deposits may also be present. <u>Bedrock Geology</u> (Hamilton et al, 1999): Belly Valley Group, as above.</p>	No significant geotechnical concerns identified.
33.1	40.7	<p>Gently sloping terrain. <u>Surficial Geology</u> (Bayrock, 1972): Glaciolacustrine high plastic clays with silt, may be varved. Lesser amounts of till and mixed deposits. <u>Bedrock Geology</u> (Hamilton et al, 1999): Horseshoe Canyon Formation (sandstone, mudstone and shale, scattered coal and bentonite beds, minor limestone, non-marine). Bedrock probably not exposed based on drift thicknesses varying from 10 to 40 m (Andriashek, 1987a and 1987b)</p>	No significant geotechnical concerns identified.



From (KP)	To (KP)	Geotechnical Conditions	Geotechnical Comments
40.7	63.8	<p>Flat to undulating terrain. Occasional canals or canalized streams. A few other small stream crossings.</p> <p><u>Surficial Geology</u> (Bayrock, 1972): Mainly glacial till. GEM terrain mapping suggested glaciolacustrine veneers and blankets may be present.</p> <p><u>Bedrock Geology</u> (Hamilton et al, 1999): Horseshoe Canyon Formation (sandstone, mudstone and shale, scattered coal and bentonite beds, minor limestone, non-marine). Bedrock probably not exposed based on drift thicknesses varying from 10 to 40 m (Andriashek, 1987a and 1987b)</p>	<p>No significant geotechnical concerns identified.</p> <p>KP 41.6: Little Egg Creek. Narrow irrigation canal or canalized stream acting as a drainage ditch. Covered with weeds, bottom not visible from air. Other apparently similar canalized streams/drainage ditches exist in the area.</p>
63.8	64.1	<p>Riviere Qui Barre – KP 63.9</p> <p>Meandering stream with several cut-off and oxbow channels.</p> <p><u>Surficial Geology</u> (Shetsen 1990): Local peat deposits over moraine, minor amounts of water sorted material and bedrock exposures. Typical thicknesses of 10 m, but may vary significantly. Pawlowicz and Fenton (1995b) indicate thicknesses up to 15 m with bedrock exposures to the west and south. Local peat deposits overlying till as above. GEM terrain mapping indicates scattered glaciolacustrine veneers.</p> <p><u>Bedrock Geology</u> as above.</p>	<p>Sagbend locations will need to consider meandering channel, oxbows and the potential for future lateral erosion.</p>
64.1	80.2	<p>South of Deadman and Kakina Lakes.</p> <p>Level to slightly undulating terrain.</p> <p><u>Surficial Geology</u> (Lehner, 1979): Shallow till overlying bedrock. Possible exposures, but bedrock is weak and will tend to weather recessively. Bedrock may be encountered during trenching, but most will likely be rippable. GEM terrain mapping indicates scattered glaciolacustrine veneers, particularly near east end of segment.</p> <p><u>Bedrock Geology</u> (Hamilton et al, 1999): Horseshoe Canyon Formation as above.</p>	<p>No geotechnical concerns identified.</p> <p>Possible local shallow weak rock but most will be rippable.</p>
80.2	108.7	<p>South of Oldman Lake. Crossings of tributary streams, some with shallow small lakes or ponds. Parallel to existing pipelines RoW.</p> <p><u>Surficial Geology</u> (Lehner, 1979): Rolling to undulating till. KP 89.3 to 92.4 (approx.): glaciolacustrine clay. GEM terrain mapping indicates scattered glaciolacustrine and organic veneers.</p> <p><u>Bedrock Geology</u>: (Hamilton et al, 1999). Horseshoe Canyon Formation as above. Bedrock probably not exposed.</p>	<p>No significant geotechnical concerns identified.</p>
108.7	130.6	<p>Parallel to existing pipeline RoW.</p>	<p>No geotechnical concerns identified. Possible local</p>



From (KP)	To (KP)	Geotechnical Conditions	Geotechnical Comments
		<p><u>Surficial Geology</u> (Lehner, 1979): Rolling to undulating glacial till overlain by veneer to blanket of glaciolacustrine clay. Areas of thin till or possible bedrock exposures toward end of segment.</p> <p><u>Bedrock Geology</u> (Hamilton et al, 1999): Horseshoe Canyon Formation (sandstone, mudstone and shale, scattered coal and bentonite beds, minor limestone, non-marine). Possible exposures toward end of segment, but bedrock is weak and will tend to weather recessively.</p> <p>Bedrock may be encountered during trenching, but most will likely be rippable.</p>	<p>shallow weak rock toward end of segment. Most bedrock is expected to be rippable</p> <p>KP 126.7: Small meandering creek with no water in channel at the time of the reconnaissance (September 2006) about 100 m upstream of the crossing. Meandering, low gradient, with weeds and/or algae.</p>
130.6	132.2	<p>Pembina River – KP 131.6</p> <p>Crossing is southwest of Sangudo. Parallel to Alliance Pipeline which is located to the south. Meandering channel incised up to 30 m deep relative to surrounding glaciolacustrine plain. Several levels of terraces formed during river downcutting into valley fill. West approach slope is higher and steeper than east approach slope.</p> <p><u>Surficial Geology</u> (Lehner, 1979) Major regional deposit is glaciolacustrine clay plain, into which the slightly incised (up to 30 m or so) valley and terraces have been eroded/deposited. Carlson (1970) indicates bedrock elevations close to the bottom of the river valley. Pawlowicz and Fenton (1995a) indicate that the area is at the headwaters of the Dapp preglacial valley complex. There were flaggy bedrock pieces in channel which may indicate that the channel is close to bedrock.</p> <p><u>Bedrock Geology</u>: (Hamilton et al, 1999): Horseshoe Canyon Formation as above.</p>	<p>River is tending to migrate to northwest. Potential for cutoffs upstream and downstream which could affect scour or lead to local degradation. Meander bend southeast of crossing could approach crossing and needs to be included in design.</p> <p>Location relative to Alliance should be checked.</p> <p>Route on west approach slope may be on sidehill above an old oxbow.</p> <p>Directionally Drilled Crossing: Appears to be feasible on a preliminary basis subject to the extent and depth of deposits in the preglacial valley (if present). Further investigators would be required to determine feasibility.</p> <p>Open Cut Crossing: Feasible. Isolation appears to be feasible using dam and pump (low flows) or fluming except during peak runoff.</p> <p>River is tending to migrate to northwest. Potential for cut-offs upstream and downstream which could affect scour or lead to local degradation. Meander bend southeast of crossing could approach crossing and needs to be included in design.</p>
132.2	138.1	<p>In this segment and to the west: Parallel to existing Alliance Pipeline RoW.</p> <p><u>Surficial Geology</u> (Lehner, 1979): Major regional glaciolacustrine clay</p>	<p>No significant geotechnical concerns identified.</p>



From (KP)	To (KP)	Geotechnical Conditions	Geotechnical Comments
		<p>plain continues. Pawlowicz and Fenton (1995b) indicate regional depths to bedrock of up to 15 m. There may be shallow bedrock toward end of segment. GEM terrain mapping also indicates scattered organic veneers.</p> <p><u>Bedrock Geology:</u> (Hamilton et al, 1999): Scollard Formation (grey feldspathic sandstone, dark grey bentonitic mudstone, thick coal beds, non-marine).</p>	
138.1	138.9	<p>Paddle River – KP 138.2</p> <p>Proposed crossing is southwest of the Highway 43 crossing and 2.5 km northeast of Paddle River Dam; north of existing Alliance crossing. River valley is incised 30 to 50 m relative to surrounding flat to gently rolling terrain. The river meanders on a flat valley floor in the wide valley with gently to moderately sloping approach slopes. Bedrock may be close to exposure on the east valley slope (based on work 1 to 2 km away).</p> <p>There was a beaver pond in the river upstream of the existing crossing. Very low approach slope on east. West slope is approx. 20 m high and steep. No problems with stability identified from air; however, extremely high plastic clays occur in the valley which may be prone to slides.</p> <p><u>Surficial Geology</u> (Lehner, 1979) Major regional deposit is glaciolacustrine clay plain, into which the valley has been eroded 30 to 50 m. Alluvium along channel. AMEC experience in the general area 1 to 2 km away indicates approximately 1.5 m of alluvium underlain by about 9 m of glaciolacustrine clay, underlain by about 9 m of preglacial sands, underlain by bedrock.</p> <p><u>Bedrock</u> (Hamilton et al, 1999): Scollard Formation (grey feldspathic sandstone, dark grey bentonitic mudstone, thick coal beds, non-marine). Bedrock may be close to exposure along the east valley slope.</p>	<p>Extensive high plastic glaciolacustrine clay deposits underlying approach slopes. Some of these deposits are jointed and slickensided, perhaps as a result of melting of ice blocks soon after deposition. Geotechnical field review of stability of approach slopes recommended. Lateral erosion considerations with respect to approach slope stability and sagbend locations should also be considered.</p> <p>Ground and surface water control will be required.</p> <p>Potential for long term meander cut-offs upstream and downstream. Lateral erosion needs to be considered. Bank may be locally armoured at Alliance.</p> <p>Open Cut Crossing: Feasible. An isolated crossing appears feasible using dam and pump (low flows) or fluming at most times of year. There is riprap on the northwest side of the river at the existing pipeline crossing adjacent to the route which would likely need to be extended. West slope would have to be graded out.</p>
138.9	160.3	<p>Continuing parallel to Alliance Pipeline RoW and other pipeline RoWs. Flat terrain with a few areas of muskeg.</p> <p><u>Surficial Geology</u> (Alberta Research Council, 1979): Glaciolacustrine clay plain, minor shallow muskegs.</p> <p><u>Bedrock Geology:</u> (Hamilton et al, 1999): Scollard Formation as above.</p>	No geotechnical concerns identified.



From (KP)	To (KP)	Geotechnical Conditions	Geotechnical Comments
160.3	163.3	<p>Alliance Pipeline deviates to north around areas of muskeg, proposed route follows Alliance.</p> <p><u>Surficial Geology</u> (Shetsen, 1990): Glaciolacustrine clay. Alberta Research Council (1976a) suggests that bedrock may be relatively shallow (0 to 15 m).</p> <p><u>Bedrock Geology</u>: (Hamilton et al, 1999): Scollard Formation as above.</p>	No geotechnical concerns identified.
163.3	164.2	<p>Little Paddle River – KP 164.0</p> <p>Meandering stream, low approach slopes.</p> <p><u>Surficial Geology</u> (Shetsen, 1990): Glaciolacustrine clay. Alberta Research Council (1976a) suggests that bedrock may be relatively shallow (0 to 15 m).</p> <p><u>Bedrock Geology</u>: (Hamilton et al, 1999): Scollard Formation as above.</p>	Open Cut Crossing: Isolation appears to be feasible. An open cut crossing appears possible from geotechnical and hydrotechnical points-of-view.
164.2	178.5	<p>Parallel to existing pipeline RoWs.</p> <p>Gently to locally moderately sloping terrain to the east with several small stream channels and areas of erosion.</p> <p><u>Surficial geology</u>: Shetsen (1990) suggests that bedrock may be relatively shallow (0 to 15 m). GEM terrain mapping suggests mostly glaciolacustrine sediments with small areas of organic veneers east of KP 168.6 with more moraine and glaciofluvial sediments to west.</p> <p><u>Bedrock geology</u> (Hamilton et al, 1999): Underlain by Upper Paskapoo Formation (green to greenish grey thick bedded calcareous cherty sandstone, grey and green siltstone and mudstone, thin limestone, coal and tuff beds. Non-marine.)</p>	<p>Thick sandstone beds and lenses in the Paskapoo Formation may require blasting. Note the presence of chert in the formation which will increase drill bit wear.</p> <p>Ground and surface water control on sloping terrain.</p>
178.5	185.2	<p>South approach slope to Athabasca River valley.</p> <p>Parallel to north side existing pipeline RoWs. Possible ancient deep-seated slides, which may be partially buried in more recent alluvium along toe.</p> <p><u>Surficial geology</u>: Shetsen (1990) Ice contact glaciolacustrine and fluvial deposits.</p> <p><u>Bedrock geology</u> (Hamilton et al, 1999): Scollard Formation (grey feldspathic sandstone, dark grey bentonitic mudstone, thick coal beds, non-marine).</p>	<p>A route on the south side of existing RoW is not recommended geotechnically due to the locations of various existing infrastructure and terrain considerations including.</p> <p>Stability: Possible eroded old deep-seated slide blocks east of KP 183.6 (approx.) suggest that deep-seated slide movements on underlying weak clay layers might have occurred in parts of area. Helicopter reconnaissance did not indicate any evidence of recent movement.</p> <p>Ground and surface water control on sloping terrain.</p>



From (KP)	To (KP)	Geotechnical Conditions	Geotechnical Comments
185.2	186.1	<p>Flat terrain south of Athabasca River.</p> <p><u>Surficial geology:</u> Shetsen (1990) Ice contact glaciolacustrine and fluvial deposits. GEM terrain mapping and local observations indicate terrain modified by erosion and deposition of Athabasca River.</p> <p><u>Bedrock geology</u> (Hamilton et al, 1999): Scollard Formation (grey feldspathic sandstone, dark grey bentonitic mudstone, thick coal beds, non-marine).</p>	<p>Bored crossing of CNR near start of segment could be on transition zone between shallow till above and deeper ice contact deposits in this segment. The detailed geological conditions should be checked.</p>
186.1	187.9	<p>Athabasca River – KP 187.3</p> <p>The valley has a broad terrace and floodplain south of the river with several channels parallel to the river up to 775 m south of the main channel. The valley is shallow on the south side and approximately 75 m deep on the north side. The route parallels an existing powerline RoW 300 m to the west. There is a deep seated slide west of the powerlines and another slide block below the powerlines. There is a sagpond on the lower terrace directly east of the powerlines. To the east, the slides along the steep slopes above the river are smaller and typically shallow.</p> <p><u>Surficial geology:</u> Alberta Research Council (1976a) suggests that the center of the buried bedrock channel is south of the river at elevations of 670 m (2200 ft) or deeper compared to surface elevations of 685 m (2250 ft). That is, the channel bottom may be within 15 to possibly 30 m below surface south of the river. This is consistent with the results of the investigation drilling at Option A.</p> <p><u>Bedrock geology:</u> Bedrock is close to exposure along portions of the north valley slope. Dawson, et al., (1998) at the initial crossing location 3 km west of the Rev R alignment indicates consists Lower Scollard Formation (grey feldspathic sandstone, dark grey bentonitic mudstone, thick coal beds, non-marine), which is the likely reason for the deep-seated slides in this area. This rock appears to continue to the powerlines west of Rev R where there is a deep-seated slide block at the toe of the slope. The bedrock at the preferred alignment approximately 300 m east of the powerlines apparently consists of the Upper Horseshoe Canyon Formation (sandstone, siltstone and coal</p>	<p>Due to stability conditions and a sagpond directly east of the powerlines, the geotechnically recommended alignment is approximately 300 m east of the powerlines.</p> <p>On the north approach slope, the route is on a ridge with local groundwater piping, groundwater blow-off failures (small) and erosion on north approach slope. The ridge would need to be graded for a pipeline route, if required. Comprehensive planning for grading and for ground and surface water drainage and control would be recommended.</p> <p>Drilling investigations north of the river encountered ice rafted (or thrust) bedrock overlying a thin cobble layer of variable thickness overlying sandstone, siltstone and mudstone with a few extensively fractured zones.</p> <p>Hydrotechnical review indicates that lateral erosion and re-occupation of existing channels south of the present main channel are important considerations. The crossing will need to be below lateral erosion and scour depths (deep cover) from south of the road south of the crossing to the toe of the north approach slope.</p> <p>Directionally Drilled Crossing: On a preliminary basis, directional drilling is assessed as feasible but may be difficult due to extensive circulation losses during</p>



From (KP)	To (KP)	Geotechnical Conditions	Geotechnical Comments
		seams with less bentonitic or high plastic clay or mudstone).	investigative drilling and the presence of an ice-thrust rock layer with underlying gravel. Special methods might be required to deal with these issues. Further investigations and review are anticipated during detailed design. Open Cut Crossing: Based on slope stability and overall channel morphology, appears feasible. Crossing would be relatively long and would require deep excavation. Isolation is not feasible due to flow conditions. Diversion methods are not recommended due to configuration of subchannels (would require significant excavation and widening).
187.9	199.3	Route runs north, turns to west and parallels existing pipelines including Alliance pipeline near west end of segment. Level to gently sloping topography north of Athabasca River. <u>Surficial geology:</u> Shetsen (1990). Aeolian deposits (sand dunes) up to 7 m thick overlying glacial till and possible glaciolacustrine and preglacial deposits. Glacial till directly to the north. GEM terrain mapping suggests till and glaciolacustrine deposits with organic veneers. <u>Bedrock</u> (Hamilton et al, 1999): Scollard Formation (grey feldspathic sandstone, dark grey bentonitic mudstone, thick coal beds, non-marine.	No significant geotechnical issues identified.
199.3	201.1	<u>Sakwatamau River – KP 200.4</u> The east approach slope is higher than 45 m with moderately steep slopes steepening to steep slopes near the bottom of the valley. The west approach slope is low and gently sloped. The valley is an old meltwater channel with a bottom width of almost 1 km. The stream is meandering with several old cut off channels. Some of the old channels were eroding and may carry significant flows in the future. Due to congestion of existing pipelines (apparently Alliance and Peace), future conventional crossings will be significantly longer than existing crossings due to the configuration of the back channels, particularly on the west side of the valley. <u>Surficial geology</u> (Shetsen 1990): Minor aeolian deposits and draped glacial till on upland areas. Alluvial sediments along valley. Alberta Research Council (1976a) suggests that bedrock may be close to exposure along the bottom of the valley. GEM terrain mapping also indicated glaciofluvial sediments.	Stability: Area not yet reviewed on LiDAR or on ground. Further geotechnical review of stability of approach slopes is recommended. No indication of stability issues based on aerial reconnaissance. A cut off meander may form in the future upstream (north) of the proposed crossing which could affect future lateral erosion conditions. There are also subchannels on both the east and west sides. The tendency of the stream channel to migrate laterally or reoccupy the subchannels will need to be considered during the design of the crossing and the locations of the sagbends. Crossing will likely be relatively long. Open Cut Crossing: Appears feasible based on geotechnical and channel morphology. Crossing will be



From (KP)	To (KP)	Geotechnical Conditions	Geotechnical Comments
		<p><u>Bedrock</u> (Hamilton et al, 1999): Scollard Formation (grey feldspathic sandstone, dark grey bentonitic mudstone, thick coal beds, non-marine.)</p>	<p>relatively long since the sagbends will probably have to be east and west of backchannels that are eroding. Isolation using dam and pump methods would be feasible over the winter period. Flume or superflume isolation methods would be feasible in the fall.</p>
201.1	203.1	<p>Parallel to existing pipelines and powerline RoWs. Directly west of Sakwatamau River and south tributary to Sakwatamau River (approximately KP 202.0 west to KP 203.6), Existing Alliance pipeline RoW is approximately 15 to 20 m south of the edge of a moderately steep slope with shallow to moderately deep slides. Outside meander bends of old channels of the river and tributary are at the toe of the slope at intervals over approximately 1 km.</p> <p><u>Surficial geology</u> (Shetsen 1990): Aeolian deposits (sand dunes) up to 7 m thick. GEM terrain mapping suggests mixture of moraine, organics and some areas of glaciofluvial and glaciolacustrine sediments.</p> <p><u>Bedrock geology</u> (Hamilton et al, 1999): Upper Paskapoo Formation (green to greenish grey thick bedded calcareous cherty sandstone, grey and green siltstone and mudstone, thin limestone, coal and tuff beds; non-marine.)</p>	<p>Tight area: Potentially tight area, depending on location of Alliance Pipeline on their RoW. Providing the pipelines are located toward the south, there appeared to be sufficient room to use the north part of the Alliance RoW for workspace and to install the Gateway pipelines between the edge of the Alliance RoW and the crest of the slope. Further checks and survey in this area are recommended.</p> <p>Stability: There are a series of moderately deep slides along the Sakwatamau valley slopes immediately to the northeast of the route.</p> <p>Erosion, sedimentation and surface/ground water control will be required.</p>
203.1	215.9	<p>At start of segment, route parallels local roads north of an area of recent and planned development. To west, route follows an existing RoW (apparently Peace pipeline) north of Highway 43.</p> <p><u>Surficial geology</u> (Shetsen 1990): Aeolian deposits (sand dunes) up to 7 m thick at east end of segment. Most of segment is underlain by draped glacial till of varying thicknesses. GEM terrain mapping indicates undulating till with some areas of organics and increasing areas of glaciolacustrine sediments to the west.</p> <p><u>Bedrock geology</u> (Hamilton et al, 1999): Upper Paskapoo Formation (green to greenish grey thick bedded calcareous cherty sandstone, grey and green siltstone and mudstone, thin limestone, coal and tuff beds; non-marine.)</p>	<p>No significant geotechnical issues identified.</p>
215.9	216.1	<p>Crossing of small creek. East approach slope is about 50 m high, gentle slopes steepening at toe. West approach slope is much lower, and steep.</p>	<p>Grading back of steep slopes segments and moving graded material to behind crest of slope may be required. Trench blocks (possibly with drains) and cross berms will be required.</p>



From (KP)	To (KP)	Geotechnical Conditions	Geotechnical Comments
216.1	218.6	<p>Flat to gently rolling upland terrain northeast of Chickadee Creek. Local areas of muskeg and wet ground.</p> <p><u>Surficial geology</u> Shetsen (1990): Aeolian deposits (sand dunes) up to 7 m thick at east end of segment. Most of segment is underlain by draped glacial till of varying thicknesses. GEM terrain mapping indicate mostly undulating till with minor areas of glaciolacustrine sediments and several areas of organics.</p> <p><u>Bedrock geology</u> (Hamilton et al, 1999): Upper Paskapoo Formation (green to greenish grey thick bedded calcareous cherty sandstone, grey and green siltstone and mudstone, thin limestone, coal and tuff beds; non-marine.)</p>	<p>Install trench blocks as required near edges of wet areas to prevent drainage into nearby creek channels beyond ends of segment.</p>
218.6	219.4	<p>Chickadee Creek – KP 219.0</p> <p>Low approach slopes that appeared to be stable from air. Flat valley bottom with meandering creek.</p> <p><u>Surficial geology</u> Shetsen (1990): Minor aeolian deposits and draped glacial till on upland areas. Alluvial sediments along valley. Alberta Research Council (1976b) suggests that bedrock may be close to exposure along the bottom of the valley.</p> <p><u>Bedrock geology</u> (Hamilton et al, 1999): Upper Paskapoo Formation (green to greenish grey thick bedded calcareous cherty sandstone, grey and green siltstone and mudstone, thin limestone, coal and tuff beds; non-marine). Scollard Formation as discussed above could occur in bottom of valley.</p>	<p>Creek is meandering across the flat valley bottom between the toes of the valley slopes. Locations of sagbends will need to consider lateral erosion along meandering creek. Likely a relatively long crossing will be required to put the pipelines below scour depth across the creek.</p> <p>Open Cut Crossing: Feasible. Isolation appears feasible.</p> <p>Trench blocks (possibly with drains) and cross berms on approach slopes to control ground and surface water.</p>
219.4	241.2	<p>At start of segment, route transitions from Chickadee Creek crossing to parallel to Alliance Pipeline. Parallel to the north side of existing pipeline RoW, crosses existing pipeline and Highway 47 (KP 231.2) to south side of existing pipeline RoW and continues to west.</p> <p><u>Surficial geology</u> (St. Onge, 1966). East end of segment up to approximately highway crossing: Glaciofluvial silty sand and sand with minor gravel. The deposits extend to the northwest along the Chickadee Creek valley (ancestral meltwater channel). To the east and west, mainly till and hummocky till deposits. Pawlowicz and Fenton (1995b) suggest that bedrock may be shallow in parts of the segment, although no areas of bedrock outcrop are shown on St. Onge (1966).</p>	<p>No geotechnical concerns identified.</p>



From (KP)	To (KP)	Geotechnical Conditions	Geotechnical Comments
		<p>Local small shallow muskeg areas in occasional closed depressions and along small streams. GEM terrain mapping indicates mostly till with some areas of glaciolacustrine sediments and scattered areas of organics.</p> <p><u>Bedrock geology</u> (Hamilton et al, 1999): Underlain by Upper Paskapoo Formation as above.</p>	
241.2	242.8	<p>Two Creek – KP 242.0</p> <p>Meandering creek in old glaciofluvial meltwater channel up to 60 m deep (east side). West approach slope is much lower. Route may be on sideslope on the west approach slope.</p> <p><u>Surficial geology</u> (St. Onge, 1966). Mainly till and hummocky till deposits. Pawlowicz and Fenton (1995b) suggest that bedrock may be shallow in parts of the segment, although no areas of bedrock outcrop are shown on St. Onge (1966). Local small shallow muskeg areas in occasional closed depressions and along small streams. GEM terrain mapping indicates mostly till on the east side, fluvial sediments along the valley bottom and areas of glaciolacustrine sediments on the west approach slope and crest area. Scattered areas of organics.</p> <p><u>Bedrock geology</u> (Hamilton et al, 1999): Underlain by Upper Paskapoo Formation as above.</p>	<p>Meandering stream with numerous cutoffs. Crossing may have to be below scour depth across valley bottom. LiDAR not available. Area has not been checked geotechnically on ground. Stability of slopes should be checked geotechnically in field. No evidence of sliding identified from helicopter reconnaissance.</p> <p>Surface and ground water control required on approach slopes.</p> <p>Open Cut Crossing: Appears feasible based on geotechnical and channel morphology. Crossings will likely be relatively long since they sagbends will probably have to be east and west of backchannels that are eroding laterally. Isolation using dam and pump would be feasible at most times of the year.</p>
242.8	258.4	<p>Upland terrain. Proposed route deviates to the south, leaving the existing Alliance RoW and highway at approximately KP 245.4.</p> <p><u>Surficial geology</u> (St. Onge, 1966): Mainly till and hummocky till deposits. Local small shallow muskeg areas in occasional closed depressions and along small streams. Pawlowicz and Fenton (1995b) suggest that bedrock may be shallow in parts of the segment, although no areas of bedrock outcrop are shown on St. Onge (1966). GEM terrain mapping suggests mostly moraine with areas of glaciolacustrine sediments near east end of segment. Several areas of shallow organics.</p> <p><u>Bedrock geology</u> (Hamilton et al, 1999): Upper Paskapoo Formation as above. Alberta Research Council (1976b) suggests that bedrock may be shallow across much of area.</p>	<p>No geotechnical concerns identified.</p>
258.4	259.3	<p>Iosegun River – KP 259.1</p> <p>Meandering river in old glaciofluvial meltwater channel. Bottom of channel is approximately 400 m wide. There is an overflow channel along the toe of the east slope and the bottom of the valley is covered</p>	<p>Open Cut Crossing: Feasible geotechnically on a preliminary basis, but some areas of extensive grading through steep bedrock segments on east slope. A sawdust deposit from an old sawmill would also probably have to be</p>



From (KP)	To (KP)	Geotechnical Conditions	Geotechnical Comments
		<p>with muskeg. East approach slope is at least 75 m high with steep slopes, particularly in a gully south of the existing Alliance RoW and on the bottom portions of the valley slope. Slides on portions of the east approach slope constrain route options in some areas. The west approach slope is lower (45 m) and has moderate slopes. A route close to the existing Alliance Pipeline would be difficult since this pipeline is located on a ridge on the east approach slope with gullies both south and north. A route close to the existing Peace Pipeline farther north would also be difficult due to a ridge on the east side of the valley. The ground conditions across the valley have also been found to be extremely difficult during past construction due to loose/soft water saturated sediments which have caved during trench construction. The proposed route is south of the gully south of the Alliance route, on the south side of an existing lease at the crest of the east approach slope. Based on ground reconnaissance, the preferred location diverges from the Alliance Pipeline toward the west and on the west side of the river would be approximately 430 m south. The east approach slope appeared to be stable overall, but has steep slope segments where bedrock outcrops occur on the lower part of the valley slope. Some areas of local slides. The route would cross the valley bottom in an area of apparently shallower muskeg than farther north and would end on an eroded terrace with shallow sandstone bedrock west of the river. There was very shallow soil creep over shallow bedrock on the terrace fronts on the west side of the valley.</p> <p>Alberta Research Council (1976b) suggests that bedrock is at an elevation of 850 m (2800 ft), which would be close to crest elevations of the approach slopes, indicating that most of creek channel may be eroded in bedrock. Bedrock outcrops were found on the lower third of the east approach slope and bedrock directly underlies the bench on the west side of the valley. <u>Bedrock geology</u> (Hamilton et al, 1999): Underlain by Upper Paskapoo Formation as above. While not shown on available published mapping, the deposits in the valley bottom consist of organics (muskeg) over extensive areas</p>	<p>removed. Local slides would require grading out. Trench blocks, probably some with drains, and cross berms would be required on the east approach slope.</p> <p>There are some areas of soft ground across the valley bottom which would be difficult, but length of soft ground appeared shorter than previous pipeline routes to the north. There would be grading, including bedrock, on the terrace fronts on the west side of the river. Further investigation and review of the approach slopes and valley bottom conditions is recommended during detailed design.</p> <p>Comprehensive ground and surface water control will be required in this area. There have been sedimentation problems in the past along the Iosegun River valley.</p> <p>Valley bottom: Crossing of approximately 400 m of muskeg will be required. Past experience indicates soft/loose water saturated ground conditions. Suitable construction planning for possible low bearing capacity, particularly adjacent to trench.</p> <p>Open Cut Crossing: Feasible on a preliminary basis but may require special techniques depending on results of further investigations.</p>



From (KP)	To (KP)	Geotechnical Conditions	Geotechnical Comments
		<p>overlying soft or loose water saturated silt, sand and clay. There is a small channel close to the toe of the slope. On the west side of the valley, there is a higher terrace that is underlain by shallow glaciofluvial sediments overlying sandstone bedrock.</p>	
259.3	290.3	<p>Transitions to parallel Alliance Pipeline at KP 262.3. Parallels Highway 43 and Alliance Pipeline RoW west to KP 267.7. Crosses to north side of Alliance Pipeline. West of KP 267.4, route parallels Alliance Pipeline RoW north of Smoke Lake.</p> <p><u>Surficial Geology</u> (St. Onge, 1966). Mainly till and hummocky till deposits on the uplands. Local small shallow muskeg areas in occasional closed depressions and along small streams. GEM terrain mapping indicated similar conditions except for glaciolacustrine sediments near KP 277 and some areas to west.</p> <p><u>Bedrock geology</u> (Hamilton et al, 1999): Upper Paskapoo Formation as above and Lower Paskapoo Formation toward the west (similar to Upper Paskapoo Formation). Pawlowicz and Fenton (1995b) suggest that bedrock may be shallow in parts of the segment, although no areas of bedrock outcrop are shown on St. Onge (1966). Alberta Research Council (1976b) suggests that bedrock may be shallow across much of area.</p>	<p>No geotechnical concerns identified. See comments above regarding blasting in Paskapoo Formation, if it is encountered.</p> <p>KP 274.4 and KP 275.0: Tributaries to Iosegun Lake. Small streams, near flat ground. Preliminary indication from drilling investigations is that local deposits consist of glaciolacustrine clay over clay till. There was a harder zone that may be ice rafted bedrock. On a preliminary basis, directional drilling or conventional trenched crossing methods (open cut or isolated) could be considered from a geotechnical point-of-view.</p>
290.3	291.8	<p><u>Little Smoky River – KP 291.0</u></p> <p>Parallel to north side of Alliance RoW. East approach slope is approximately 45 m high. Back channel near toe of east approach slope. The route runs down a broad ridge. The meander pattern at the toe of the east slope is different from upstream and downstream, possibly due to slide activity. At the route location, the terraces appear to be due to deposition and erosion. Moderately deep-seated slides occur upstream and downstream of crossing location along east approach slope. No indication was found of active movements on the ground and based on LiDAR for the east approach slope.</p> <p>The west approach slope is higher (at least 75 m) with a steep area on the upper third of the slope. Old deep-seated slide blocks on the slope. Some tree bends and pistol butted trees but it was not clear from ground reconnaissance whether very small creep movements may be occurring or whether there is local groundwater piping into old slide</p>	<p><u>Stability Conditions</u></p> <p>Crossing is considered to be the best available from a geotechnical point-of-view in this general area. The east approach slope is buttressed by a wide terrace and the slope appears to be underlain by erosional/depositional terraces.</p> <p>Old deep-seated slides on west approach slope. The terrace is narrower at the toe of the west slope and there are prominent old slide blocks running across the slope. There has been a recent active slide to the south where the stream undercut the slope. There were some tree bends along route, but most of the bends appear to be due to local piping or other soil movements rather than recent deep-seated slide movements.</p>



From (KP)	To (KP)	Geotechnical Conditions	Geotechnical Comments
		<p>tension cracks. The route has a bend at the crest of the west approach slope. Regional review suggests that slopes in the area are subject to deep-seated slide movements, probably including slides in both valley fill and bedrock, particularly when the slopes are undercut by active stream erosion.</p> <p>Recent (last 50 years) slightly accelerated movements of an old slide south of the crossing on the west side of the river due to undercutting of the north edge of the slide by lateral erosion. Side scarps of the slide above the laterally eroding meander appear to be close to the south of the proposed route on LiDAR.</p> <p><u>Surficial geology:</u> Published mapping has not been located.</p> <p>Aerial reconnaissance and ground reconnaissance on the east side suggests sliding in the valley fills which appear to include high plastic glacial till and glaciolacustrine sediments. Due to widespread sliding, most of the deposits in the valley are technically colluvium. The river has migrated back and forth across the valley bottom resulting in alluvium with some areas of muskeg in old oxbows.</p> <p>Alberta Research Council (1976b) suggests that bedrock is at an elevation of 853 m (2800 ft) (close to crests of approach slopes) indicating that most of creek channel may be eroded in bedrock. Shale bedrock exposures were seen along the creek.</p> <p><u>Bedrock geology</u> (Hamilton et al, 1999): Underlain by Lower Paskapoo Formation as above. The bottom of the valley may be close to the underlying Scollard Formation (grey feldspathic sandstone, dark grey bentonitic mudstone, thick coal beds, non-marine).</p>	<p>Although the river has been reasonably stable over the last approximately 50 years, the river has changed course in the past resulting in varying stability of slopes at varying locations along the river. Future changes in channel lateral erosion conditions may occur, possibly including a cut off meander downstream of the crossing. As noted, future changes in lateral erosion may trigger renewed movements at the crossing, particularly on the west approach slopes. Future mitigation may be required in the event of lateral erosion and should be allowed for in overall planning. Mitigation could possibly include river training, or drilling or other trenchless methods such as microtunnelling under the west approach slope. Further investigations and monitoring are recommended to check movement status of slopes. Further consideration of design and mitigative methods relative to stability conditions is anticipated during detailed design.</p> <p>Comprehensive ground and surface water control will be required.</p> <p>See comments above regarding blasting in Paskapoo Formation. Sandstone may be encountered on the upper parts of the slopes and would likely require blasting. Shale in the valley bottom may be softer and may be rippable in some areas, although in confined areas could also require blasting.</p> <p>Open Cut Crossing: Appears feasible based on geotechnical and channel morphology. Flows would be too high for flume or superflume isolation methods April to October.</p>
291.8	302.3	<p>Route follows existing Alliance Pipeline and other pipeline RoWs to west. Segment ends southeast of Crooked Lake. Rolling upland terrain.</p> <p><u>Surficial geology:</u> Published mapping has not been located.</p>	<p>No geotechnical concerns identified.</p>



From (KP)	To (KP)	Geotechnical Conditions	Geotechnical Comments
		<p>Aerial reconnaissance suggests clay till deposits. GEM terrain mapping suggests undulating moraine with minor areas of glaciolacustrine and organic deposits.</p> <p><u>Bedrock geology:</u> (Hamilton et al, 1999): Underlain by Lower Paskapoo Formation as above. Alberta Research Council (1976b) suggests that bedrock is deep through this area and unlikely to be exposed.</p>	
302.3	317.3	<p>Upland terrain with some areas of muskeg, a few crossings of old meltwater channels containing meandering streams and muskeg and a few stream crossings. Streams mostly tributary to Crooked Lake. Parallel to north side of Alliance and other pipeline RoWs. Deviates to north at KP 317.3.</p> <p><u>Surficial geology:</u> Published mapping has not been located. Aerial reconnaissance suggests clay till deposits with minor glaciofluvial deposits. Several areas of muskeg as infills of terrain depressions along old glaciofluvial channels. GEM terrain mapping indicates undulating moraine, and glaciolacustrine and glaciofluvial sediments with scattered areas of organics.</p> <p><u>Bedrock geology:</u> (Hamilton et al, 1999): Underlain by Lower Paskapoo Formation as above. Alberta Research Council (1976b) and suggests that bedrock may be close to exposure particularly across the ends of the ridges.</p>	<p>No geotechnical concerns identified.</p> <p>Ground and surface water control required.</p> <p>KP 305.3: Crossing of Nova Pipeline.</p> <p>KP 308.9 to KP 312.1: Deviates to run north of Alliance Pipeline</p> <p>KP 312.0, KP 314.0: Tributaries to Crooked River.</p>
317.3	318.4	<p><u>Waskahigan River – KP 318.2</u> Meandering stream with tortuous meanders, numerous beaver dams. Crossing is in low terrain north (downstream) of where the river runs to the north in a deep steep-sided valley across a ridge south of the route.</p> <p>On east approach slope, route runs over 10 m high knob with slopes of about 15 to 20°. Route bends through about 60° across floodplain. West approach slope is stepped with a lower elevation terrace and a higher bench bordered by a gentle slope. Road crossing on west slope.</p> <p><u>Surficial geology:</u> GEM terrain mapping indicates fluvial terrace deposits with organics in the center of the valley.</p> <p><u>Bedrock geology:</u> (Hamilton et al, 1999): Underlain by Lower Paskapoo Formation as above. Alberta Research Council (1976b) suggests that bedrock may be close to exposure particularly across the ends of the ridges.</p>	<p>Area has not been reconnoitred on the ground. Interpretation of LiDAR did not indicate any stability problems. Ground reconnaissance recommended to check depths of organics relative to construction conditions including trench stability.</p> <p>Open Cut Crossing: Stream appears to be laterally mobile. Crossing may need to be deep (below scour depth) across a distance of 500 m or more. Local rerouting may be required to provide a straight crossing. Moving the crossing upstream might be advantageous in terms of reducing crossing length.</p>
318.4	324.9	<p>Upland ridged terrain. Some areas of locally steeper slopes. May be some areas close to rock outcrop.</p>	<p>Ground and surface water control on steeper slope segments.</p>



From (KP)	To (KP)	Geotechnical Conditions	Geotechnical Comments
		<p>Start of segment is north of Alliance Pipeline. Route rejoins Alliance Pipeline at KP 320.4. Two deviations around lease areas. Local infrastructure including several leases.</p> <p><u>Surficial geology:</u> Published mapping has not been located. Aerial reconnaissance suggests clay till deposits. GEM terrain mapping indicates areas of moraine veneers over rock on steeper terrain around KP 323 with extensive areas of moraine and some glaciofluvial terraces. Occasional organics.</p> <p><u>Bedrock geology:</u> (Hamilton et al, 1999): Underlain by Lower Paskapoo Formation as above. Alberta Research Council (1976b) and Pawlowicz and Fenton. (1995b) suggest that bedrock may be close to exposure particularly across the ends of the ridges.</p>	
324.9	332.4	<p>Lower terrain, rolling ridges across the route running toward the north. Small meandering streams between the ridges. Local infrastructure including several leases.</p> <p><u>Surficial geology:</u> Published mapping has not been located. Aerial reconnaissance suggests clay till deposits. GEM terrain mapping indicates extensive areas of glaciofluvial deposits with some moraine and glaciolacustrine sediments east of approximately KP 329. KP 329 to KP 331, mostly till. To the west, mostly glaciofluvial and glaciolacustrine sediments with some moraine. Scattered organics throughout.</p> <p><u>Bedrock geology:</u> (Hamilton et al, 1999): Underlain by Lower Paskapoo Formation as above. Alberta Research Council (1976b) and Pawlowicz and Fenton. (1995b) suggest that bedrock may be close to exposure particularly across the ends of the ridges.</p>	Ground and surface water control required on slope segments.
332.4	336.2	<p>On edge of ridge to south. Some areas of sideslope crossings of several incised creek valleys draining to north. Areas of muskeg. Local infrastructure including several leases, two pipelines and powerline.</p> <p><u>Surficial geology:</u> Published mapping has not been located. Aerial reconnaissance suggests clay till and glaciolacustrine deposits with overlying muskeg in pockets and old meltwater channels. Bedrock may be close to surface on some ridges. GEM terrain mapping indicates similar deposits.</p> <p><u>Bedrock geology:</u> (Hamilton et al, 1999): Underlain by Lower Paskapoo</p>	Ground and surface water control required on slope segments. Steep gradient creeks will require suitable design scour cover over the pipelines.



From (KP)	To (KP)	Geotechnical Conditions	Geotechnical Comments
		<p>Formation as above. Alberta Research Council (1976b) and Pawlowicz and Fenton. (1995b) suggest that bedrock may be close to exposure particularly across the ends of the ridges.</p>	
336.2	339.6	<p><u>Deep Valley Creek – KP 338.8</u> Route on east approach slope is on a broad gradually descending ridge. No stability concerns or other geotechnical concerns identified from air. Two existing RoWs. There appeared to be room on both sides, but north side may be better for creek crossing. Creek crossing: Existing crossings appear to have been trenched. Gravel excavation on terrace on west side of creek north of existing RoWs with shallow water. Creek appears to be eroding very slightly toward the west on the north side and toward the east on the south side of the existing crossings. There is a minor back channel across a low elevation area of floodplain toward the south. West approach slope: Low and gently rolling.</p> <p><u>Surficial geology:</u> Published mapping has not been located. Aerial reconnaissance suggests glaciofluvial deposits and possibly clay till or glaciolacustrine deposits. Recent alluvial deposits along channel and in low terraces. <u>Bedrock geology:</u> (Hamilton et al, 1999): Underlain by Lower Paskapoo Formation as above. Alberta Research Council (1976b) and Pawlowicz and Fenton. (1995b) do not indicate any large known buried channel.</p>	<p>Approach slopes: Ground and surface water control recommended. Overall: Favourable crossing with no major geotechnical issues found to date. Area should be reviewed on ground to check preliminary conclusions from air.</p> <p>Open Cut Crossing: Appears feasible from a geotechnical point-of-view. Isolation likely feasible over significant part of the year. A crossing on the north side may be slightly better geotechnically due to a shorter crossing and better conditions to the west. Consideration of lateral erosion and scour conditions will be required during detailed design.</p>
339.6	340.6	<p>Upland terrain north of Alliance and/or other pipelines. <u>Surficial geology:</u> Published mapping has not been located. Aerial reconnaissance suggests glaciofluvial deposits and possibly clay till or glaciolacustrine deposits. Recent alluvial deposits along channel and in low terraces. GEM terrain mapping suggests moraine. <u>Bedrock geology:</u> (Hamilton et al, 1999): Underlain by Lower Paskapoo Formation as above. Alberta Research Council (1976b) and Pawlowicz and Fenton. (1995b) do not indicate any large known buried channel.</p>	<p>No geotechnical concerns identified. Note that a crossing of the existing RoW and deviation to the south is shown on the proposed routing. This may not be required from a geotechnical point-of-view and should be further examined.</p>
340.6	341.0	<p><u>Tributary to Deep Valley Creek – KP 340.8</u> Approximately 60 m deep valley with moderate slopes. No stability concerns identified from air on north side of existing RoWs. On west side of crossing, the creek meanders beside and below the existing RoWs on the south side and so a route on the north side of existing alignments is recommended. Subchannel on west side of crossing.</p>	<p>Difficult area From a geotechnical point-of-view, the preferred crossing is on the north side of the existing north RoW due to the lack of room and shallow sliding above the meander bends on the south side of the north existing RoW west of the creek crossing. Very tight area. Further ground reconnaissance</p>



From (KP)	To (KP)	Geotechnical Conditions	Geotechnical Comments
		<p>Shallow sliding on the banks of the creek where it is undercutting the slope to the south of the crossing. <u>Surficial geology</u>: Published mapping has not been located. Aerial reconnaissance suggests clay till with possible glaciolacustrine and glaciolacustrine deposits. Recent alluvial deposits along channel and in low terraces. <u>Bedrock geology</u>: (Hamilton et al, 1999): Underlain by Lower Paskapoo Formation as above. Alberta Research Council (1976b) and Pawlowicz and Fenton. (1995b) do not indicate any large known buried channel.</p>	<p>of stability conditions and crossing area recommended. Ground and surface water control will be required on the approach slopes.</p>
341.0	353.9	<p>Upland terrain. Much of area is gently sloping toward north. <u>Surficial geology</u>: Published mapping has not been located. Aerial reconnaissance suggests clay till with occasional shallow and small muskegs. GEM terrain mapping suggests similar conditions. <u>Bedrock geology</u>: (Hamilton et al, 1999): Underlain by Lower Paskapoo Formation as above. Alberta Research Council (1976b) and Pawlowicz and Fenton. (1995b) indicate generally shallow rock which may be encountered across some ridged areas.</p>	<p>No geotechnical concerns identified.</p>
353.9	358.4	<p>Upland terrain sloping gently to moderately to the north. Crossings of three incised streams draining to the north to the Simonette River. <u>Surficial geology</u>: Published mapping has not been located. Aerial reconnaissance suggests clay till with occasional shallow and small muskegs. GEM terrain mapping suggests similar conditions with occasional glaciolacustrine sediments. <u>Bedrock geology</u>: (Hamilton et al, 1999): Underlain by Lower Paskapoo Formation as above. Alberta Research Council (1976b) and Pawlowicz and Fenton. (1995b) indicate generally shallow rock which may be encountered across some ridged areas.</p>	<p>Crossings of tributary stream valleys which are shallow on south sides and slightly deeper on north sides of existing RoW. Either side appeared acceptable from a geotechnical point-of-view based on preliminary reconnaissance. Tributary streams have relatively steep gradients. Pipeline cover should consider Further potential scour and downcutting conditions during detailed design.</p>
358.4	359.6	<p>East approach slope to Simonette River: Gently to moderately sloping terrain parallel to north side of existing Peace and Alliance RoWs. Road is a short distance to the south and west. Existing leases on southwest side of existing alignments. No slope stability concerns identified from the air at crossing, although slides at toes of both approach slopes north of crossing. <u>Surficial geology</u> (Andriashak, 1983): Locally derived thin ground moraine, moderately to exceedingly stony. <u>Bedrock geology</u> (McMechan and Dawson, 1995): Paskapoo Formation</p>	<p>On a preliminary basis, geotechnically preferred side is north side of existing RoWs to line up with preferred crossing area and to avoid existing infrastructure. Further geotechnical review of stability on ground is recommended. Ground and surface water control should be coordinated with existing controls on nearby RoWs.</p>



From (KP)	To (KP)	Geotechnical Conditions	Geotechnical Comments
		(Sandstone, cliff forming, sandstone, siltstone, mudstone, minor lenses of carbonaceous shale).	
359.6	360.1	<p>Simonette River Crossing – KP 360.0 Slightly meandering river. Old back channel on east side has been filled in at existing Alliance crossing but is still present on north side of existing crossings. On south side of existing crossings, there is a back channel on the west side. Floodplains extend to the toes of both slopes and both areas have had active erosion in the past. The bridge to south is changing erosion patterns to north. Existing crossings appear to have been trenched crossings. Bridge to the south is on piles with four piers in channel. River is eroding slowly toward the west at the existing crossings.</p> <p><u>Surficial geology</u> (Andriashek, 1983): Uplands east of river: Locally derived thin ground till, moderately to exceedingly stony. In river valley: alluvial deposits. West of river: till. <u>Bedrock geology</u> (McMechan and Dawson, 1995): Paskapoo Formation (Sandstone, cliff forming, sandstone, siltstone, mudstone, minor lenses of carbonaceous shale). The mapping indicates that the Scollard Formation is not exposed in the bottom of the valley which is likely a major factor in the improved stability compared to farther north. Pawlowicz and Fenton (1995a) do not indicate any major preglacial channel at this location.</p>	<p>Geotechnically favourable location for a new crossing. Generally preferred side from a geotechnical point-of-view is on the north side of the existing RoWs to avoid the bridge which is located on the south side. Geotechnical ground reconnaissances and review of LiDAR are recommended.</p> <p>Open Cut crossing: Appears feasible from a geotechnical point-of-view. Isolation appears possible (Dec to Mar – dam and pump, July to Nov - fluming with superflume in summer). The new crossing would likely be longer than the existing crossings to allow for the back channel on the east side and for future lateral erosion toward both sides. Long crossing due to potential for lateral erosion and reoccupation of subchannels.</p>
360.1	360.3	<p>West approach slope to Simonette River: Route parallels north side of existing RoWs. <u>Surficial geology</u> (Andriashek, 1983): Till. GEM terrain mapping suggests glaciofluvial and fluvial sediments are also present. <u>Bedrock geology</u> (McMechan and Dawson, 1995): Paskapoo Formation (Sandstone, cliff forming, sandstone, siltstone, mudstone, minor lenses of carbonaceous shale).</p>	<p>No geotechnical concerns identified. Geotechnically favoured side is north side of existing RoWs to avoid road on south side and to line up with favoured crossing location.</p> <p>Ground and surface water control should be coordinated with existing controls on nearby RoWs.</p>
360.3	365.3	<p>Gently sloping upland terrain. Few areas of muskeg, but route bypasses most of them. Infrastructure along existing RoWs. <u>Surficial geology</u> (Andriashek, 1983): Glaciolacustrine silt and clay. <u>Bedrock geology</u> (McMechan and Dawson, 1995): Paskapoo Formation (Sandstone, cliff forming, sandstone, siltstone, mudstone, minor lenses of carbonaceous shale).</p>	<p>No geotechnical concerns identified.</p>



From (KP)	To (KP)	Geotechnical Conditions	Geotechnical Comments
365.3	371.7	<p>Slightly higher elevation terrain with ridges. Route parallel to existing RoWs bends around some areas of steeper topography. A few areas of moderate slopes. Flat bench east of Latornell River at end of segment.</p> <p><u>Surficial geology</u> (Andriashek, 1983): Glaciofluvial and aeolian deposits with glaciofluvial sand to north. GEM terrain mapping indicates moraine rather than glaciofluvial materials. Scattered organic deposits.</p> <p><u>Bedrock geology</u> (McMechan and Dawson, 1995): Upper Scollard Formation (Sandstone, siltstone, carbonaceous mudstone, coal interbedded with thin layers of claystone).</p>	<p>Ground and surface water control will be required on some slope segments.</p>
371.7	372.2	<p>Latornell River – KP 372.0</p> <p>Crossing is in upper reaches of river where it is narrow. Meander bend in valley bottom. Large amounts of debris in valley bottom with potential for jams to occur, potentially causing diversions of the stream. Valley is approximately 30 m deep with gentle to moderate slopes on each side. Route continues parallel to existing Alliance and Peace Pipeline RoWs. Existing road with bridge to the south. Crossing itself is narrow and straight.</p> <p><u>Surficial geology</u> (Andriashek, 1983): Glaciofluvial sand near crest of east approach slope. Alluvial sediments along creek channel. Aeolian sands to west. GEM terrain mapping suggests that glaciolacustrine sediments may be present.</p> <p><u>Bedrock geology</u> (McMechan and Dawson, 1995): Upper Scollard Formation (Sandstone, siltstone, carbonaceous mudstone, coal interbedded with thin layers of claystone).</p>	<p>Difficult area</p> <p>Meander bend of stream immediately south of Alliance RoW is a potential concern. Reconnaissance of area on ground and review of LiDAR are recommended.</p> <p>Ground and surface water control will be required on slopes.</p> <p>Crossing design will need to consider lateral erosion of meander bend to south and large amounts of debris that may result in significant diversions of the stream.</p> <p>See stability issue below.</p>
372.2	378.2	<p>Gently sloping to flat terrain. One area of muskeg a few hundred meters long. A few other smaller areas.</p> <p><u>Surficial geology</u> (Andriashek, 1983): Aeolian sands. GEM terrain mapping suggests similar with areas of organic deposits and some glaciolacustrine deposits.</p> <p><u>Bedrock geology</u> (McMechan and Dawson, 1995): Upper Scollard Formation (Sandstone, siltstone, carbonaceous mudstone, coal interbedded with thin layers of claystone).</p>	<p>Slope stability: KP 374.0 on east side of Alliance. Based on air reconnaissance, the present alignment may be too close to crest of an existing slide into the Latornell River. Potential solutions are to move the crossing or to cross for a short distance to the west side of Alliance. Review of LiDAR (when available) and further reconnaissance on ground are recommended.</p>
378.2	382.1	<p>Higher knob with moderate slopes. Rock may be shallow in some areas, although surficial mapping indicates deep sand as below. Gently sloping to flat terrain. One area of muskeg a few hundred meters</p>	<p>No geotechnical concerns identified.</p> <p>Ground and surface water control will be required on some slope segments.</p>



From (KP)	To (KP)	Geotechnical Conditions	Geotechnical Comments
		<p>long. A few other smaller areas. <u>Surficial geology</u> (Andriashek, 1983): Glaciofluvial sand. GEM terrain mapping also suggests aeolian deposits. <u>Bedrock geology</u> (McMechan and Dawson, 1995): Upper Scollard Formation (Sandstone, siltstone, carbonaceous mudstone, coal interbedded with thin layers of claystone).</p>	
382.1	390.4	<p>Flat to locally undulating terrain. Occasional muskeg areas shown on mapping, but most of these appear to be missed by route. Infrastructure at various locations close to existing RoWs. <u>Surficial geology</u> (Andriashek, 1983): Glaciofluvial sand, aeolian sand deposits and mixed aeolian and glaciofluvial sand deposits. GEM terrain mapping is similar with some glaciolacustrine deposits. <u>Bedrock geology</u> (McMechan and Dawson, 1995): Upper Scollard Formation (Sandstone, siltstone, carbonaceous mudstone, coal interbedded with thin layers of claystone).</p>	<p>KP 383.4: One small kettle lake north of existing RoWs. Stream to north a short distance to west. Surface and possibly ground water control required on a few slope segments.</p>
390.4	395.1	<p>Slightly higher ridged terrain sloping to west. Road crossing near start of segment. To west, existing RoWs are uphill of the road separated by a strip of trees from the road. <u>Surficial geology</u> (Andriashek, 1983): Mixed aeolian and glaciofluvial sand deposits. GEM terrain mapping also indicates moraine and scattered organics. <u>Bedrock geology</u> (McMechan and Dawson, 1995): Upper Scollard Formation (Sandstone, siltstone, carbonaceous mudstone, coal interbedded with thin layers of claystone). Lower Scollard Formation underlies north half of segment (sandstone, siltstone, mudstone (grey to greenish grey), volcanic tuff).</p>	<p>No geotechnical concerns identified.</p>
395.1	396.5	<p>Tributary to Smoky: Short distance northeast of Alliance Pipeline or other pipeline crossings. <u>Surficial geology</u> (Andriashek, 1983): Mixed aeolian and glaciofluvial sand deposits. GEM terrain mapping indicates predominantly glaciolacustrine deposits on slopes. <u>Bedrock geology</u> (McMechan and Dawson, 1995): Lower Scollard Formation (sandstone, siltstone, mudstone (grey to greenish grey), volcanic tuff).</p>	<p>Stability conditions at proposed route appeared to be reasonably good, although there are slides in the general area. Ground and surface water required, likely including drains.</p>



From (KP)	To (KP)	Geotechnical Conditions	Geotechnical Comments
396.5	400.6	<p>Upland terrain sloping gently toward the Smoky River valley. <u>Surficial geology</u> (Andriashek, 1983): Mixed aeolian and glaciofluvial sand deposits. GEM terrain mapping predominantly morainal deposits with some organics. <u>Bedrock geology</u> (McMechan and Dawson, 1995): Upper Brazeau Formation (carbonaceous sandstone and siltstone, coal).</p>	No geotechnical concerns identified.
<p>Note on Bedrock Formations: From the Smoky River to west of the Wapiti River, (McMechan and Dawson, 1995) indicate the bedrock to be Upper and Lower Brazeau Formation (carbonaceous sandstone, siltstone and mudstone, with coal). Hamilton et al (1999) indicate Upper Wapiti Formation (equivalent to Horseshoe Canyon Formation, grey feldspathic sandstone, grey bentonitic mudstone and carbonaceous shale, scattered coal and bentonite beds). The Wapiti Formation, which contains bentonitic high plastic clays, fits better with the prevailing stability conditions which include slides in bedrock and is also in the later dated reference. Therefore, the Hamilton et al (1999) interpretation has been quoted in this report in spite of being a smaller scale map.</p>			
400.6	419.5	<p>Upland terrain sloping gently toward the Smoky River valley. Route leaves Alliance RoW at KP 415.1, but mostly parallels other pipeline routes to crest of east approach slope to Smoky River at end of segment. <u>Surficial geology</u> (Andriashek, 1983): Mixed aeolian and glaciofluvial sand deposits. GEM terrain mapping also indicates glaciolacustrine deposits with some areas of organics. <u>Bedrock geology</u> Hamilton et al (1999) indicate Upper Wapiti Formation (equivalent to Horseshoe Canyon Formation, grey feldspathic sandstone, grey bentonitic mudstone and carbonaceous shale, scattered coal and bentonite beds).</p>	<p>KP 404.1 to KP 404.6: Crossing of creek tributary to Smoky River. Moderately steep to steep slopes into small creek. Existing pipeline crossings to west. Local areas of moderately deep slides. Rev R route moved to the east away from an existing pipeline crossing to improve stability conditions.</p>
419.5	420.3	<p>East approach slope to Smoky River. Parallel to existing CNRL pipelines immediately to north. Breaching of a large beaver pond dam on the CNRL RoW will be required for construction. Steep terrace fronts near or steeper than 30° with two wide terraces. <u>Surficial geology</u> (Andriashek, 1983): Mixed aeolian and glaciofluvial sand deposits. Based on local observation, materials on slope are predominantly glaciofluvial sand or sand and gravel. Sandstone and shale exposed in steep slope segments near toe of slope and in a road about half way up slope. <u>Bedrock geology</u> Hamilton et al (1999) indicate Upper Wapiti Formation (equivalent to Horseshoe Canyon Formation, grey feldspathic sandstone, grey bentonitic mudstone and carbonaceous shale, scattered coal and bentonite beds).</p>	<p>Stability: No major stability concerns identified on proposed route. Area to north of existing pipeline RoWs (opposite side to proposed route) has been eroded forming locally steep gullies and bowls (possible groundwater blow-off failures, but also appears to be stable. Moderately deep slides farther to the north where the slope has been undercut by the river. Also moderately deep slides to the south. Possible old slides on lower terrace front. Local grading of terrace fronts to lower angles will likely be necessary. Further investigation of slopes, possibly including monitoring, recommended.</p>



From (KP)	To (KP)	Geotechnical Conditions	Geotechnical Comments
			Ground and surface water control will be required including trench blocks, drains (particularly near crest of slope) and cross berms. Surface water drainage will need to be coordinated with existing RoWs.
420.3	421.29	Fluvial terrace approximately 450 m wide on east side of Smoky River. West edge was being slowly eroded by river. Various infrastructure including roads, lease site and existing pipelines. Route south of existing pipeline RoWs. Sand or sand and gravel with extensive shallow areas of muskeg	Lateral erosion needs to be considered depending on crossing design. There has been significant lateral erosion at the existing pipeline crossings in the past. Route will need to go around a lease.
421.29	421.78	<p>Smoky River – KP 421.6 Wide terraces on both sides of the river. River is eroding to some extent both east and west at and near the crossing. Erosion is constrained to some degree by the road bridge approach fills approximately 1.2 km upstream of the crossing. Failure of these fills would allow much greater lateral erosion than at present. In the past, the river has eroded laterally over very significant distances both to the east and west.</p> <p>Preliminary route crosses under existing pipelines on the west edge of the present channel due to a bend in the pipeline and parallels the north side of the existing RoW on the west terrace.</p> <p><u>Bedrock geology</u> Hamilton et al (1999) indicate Upper Wapiti Formation (equivalent to Horseshoe Canyon Formation, grey feldspathic sandstone, grey bentonitic mudstone and carbonaceous shale, scattered coal and bentonite beds). Bedrock was exposed on the lower part of the east approach slope. Pawlowicz and Fenton (1995a) do not indicate any major preglacial channel at this location.</p>	<p>Lateral erosion needs to be considered during detailed design.</p> <p>Open Cut crossing: Appears feasible from a geotechnical point-of-view. The crossing would likely be relatively long (and probably longer than the existing crossings) to allow for lateral erosion which has been an issue for most of the installed crossings. Isolated crossing does not appear possible due to flow levels.</p> <p>Directionally Drilled Crossing: No detailed investigations to date. Conditions farther south at a previously considered crossing were apparently favourable. Existing information suggests that there may not be a deep preglacial channel in this area which would be a favourable condition. Assessed as feasible on a preliminary basis.</p>
421.78	422.34	<p>Terrace on west side of river 2 to 3 m above normal flow elevations in river. Has been subject to previous erosion/deposition relatively recently.</p> <p><u>Surficial geology</u> (Andriashek, 1983): Glaciofluvial outwash gravel. Local observation suggests that the gravel has been reworked by relatively recent erosion.</p> <p><u>Bedrock geology</u> Hamilton et al (1999) indicate Upper Wapiti Formation (equivalent to Horseshoe Canyon Formation, grey feldspathic</p>	Lateral erosion needs to be considered in overall crossing design.



From (KP)	To (KP)	Geotechnical Conditions	Geotechnical Comments
		<p>sandstone, grey bentonitic mudstone and carbonaceous shale, scattered coal and bentonite beds). Bedrock was not exposed on the terrace and but be at shallow depth although Pawlowicz and Fenton (1995a) do not indicate any major preglacial channel at this location. Note that Brazeau preglacial valley is located to the north; there is a possibility that there could be buried tributary channels in this general area.</p>	
422.34	422.88	<p>West approach slope to Smoky River. Route approximately parallels north side of existing RoW with two(?) pipelines along the edge of ridge to the north. Slope is about 70 m high at an overall angle of 9.5°. Route is just beyond apparent north edge of large deep-seated slide to the south. One very small crack 10 mm wide found on south side of adjacent RoW. At the toe of the slope there is abundant seepage, but no sign of a toe thrust. Trees along the existing RoW are straight.</p> <p><u>Surficial geology</u> (Andriashek, 1983): Glaciofluvial terrace deposits. Surficial exposures of glaciofluvial sand and gravel. Gravel deposit on ridge to north with active pit.</p> <p><u>Bedrock geology</u> Hamilton et al (1999): Upper Wapiti Formation (equivalent to Horseshoe Canyon Formation, grey feldspathic sandstone, grey bentonitic mudstone and carbonaceous shale, scattered coal and bentonite beds). Bedrock was not exposed on the slope. Pawlowicz and Fenton (1995a) do not indicate any major preglacial channel at this location, although the Brazeau preglacial valley is located to the north.</p>	<p>North of deep-seated slide on main part of slope. A dogleg around the edge of a slide to the north may be required on the lower part of the slope subject to further investigations. If further work and information suggests a need to move farther from the slide, there is some additional room including a gravel pit to the north.</p> <p>Further investigations and monitoring of slope recommended.</p> <p>Ground and surface water control including drains and drained trench blocks will likely be required.</p>
422.88	431.6	<p>Route bends to follow existing seismic line and Nova Pipeline. KP 425 Major facility to south (Braaten Plant).</p> <p><u>Surficial geology</u> (Andriashek, 1983): Glaciolacustrine silt and clay. Muskeg in local areas. GEM terrain mapping indicates similar with some moraine.</p> <p><u>Bedrock geology</u> Hamilton et al (1999) indicate Upper Wapiti Formation (equivalent to Horseshoe Canyon Formation, grey feldspathic sandstone, grey bentonitic mudstone and carbonaceous shale, scattered coal and bentonite beds).</p>	<p>KP 425 to KP 426: Very wet with muskeg. Area complicated by several pipelines, roads and other infrastructure. More detailed routing work on ground will be required during detailed design.</p>



From (KP)	To (KP)	Geotechnical Conditions	Geotechnical Comments
431.6	432.1	<p>Gold Creek – KP 431.9 Incised meanders to a depth of approximately 30 m. Moderately steep slopes on both sides. Limited work room along creek. From the air there appeared to be some shallow slide activity. <u>Surficial geology</u> (Andriashek, 1983): Glaciolacustrine silt and clay on uplands. Colluvial materials on slopes. <u>Bedrock geology</u> Hamilton et al (1999) indicate Upper Wapiti Formation (equivalent to Horseshoe Canyon Formation, grey feldspathic sandstone, grey bentonitic mudstone and carbonaceous shale, scattered coal and bentonite beds).</p>	<p>Slope stability: Further geotechnical review of slopes is recommended. Grading may be required. Most of spoil would likely have to be moved upslope. Surface and ground water control including trench blocks, cross berms and possibly drains.</p>
432.1	434.9	<p>Following existing pipeline across upland terrain. Some areas of muskeg nearby, but most of actual route appears to miss the major muskeg areas. <u>Surficial geology</u> (Andriashek, 1983): Glaciolacustrine silt and clay on uplands. Colluvial materials on slopes. <u>Bedrock geology</u> Hamilton et al (1999) indicate Upper Wapiti Formation (equivalent to Horseshoe Canyon Formation, grey feldspathic sandstone, grey bentonitic mudstone and carbonaceous shale, scattered coal and bentonite beds).</p>	<p>No geotechnical concerns identified.</p>
434.9	435.9	<p>Big Mountain Creek – KP 435.3 Crossing is southwest (upstream) of highway bridge. Incised meandering creek with slopes approximately 30 m high. Moderately steep slopes. Some evidence of shallow slope sliding, but existing crossing appear from air to have performed well. East approach slope: Existing pipeline runs directly upslope. West approach slope: Route is diagonally down slope. <u>Surficial geology</u> (Andriashek, 1983): Glaciolacustrine silt and clay on uplands. Colluvial materials on slopes. GEM terrain mapping similar. <u>Bedrock geology</u> Hamilton et al (1999) indicate Upper Wapiti Formation (equivalent to Horseshoe Canyon Formation, grey feldspathic sandstone, grey bentonitic mudstone and carbonaceous shale, scattered coal and bentonite beds).</p>	<p>Slope stability: Further geotechnical review of slopes is recommended. Crossing may be too tight relative to existing road and may need to be moved, possibly to south. Crossing would be long since it is diagonal. Grading will be required. Most of spoil will likely have to be moved upslope. Ground and surface water control required. Surface and ground water control including trench blocks, cross berms and possibly drains.</p>
435.9	445.7	<p>Gently sloping terrain on north side of higher terrain to south. <u>Surficial geology</u> (Andriashek, 1983): Glaciolacustrine silt and clay on uplands. GEM Terrain mapping shows similar interpretation. <u>Bedrock geology</u> Hamilton et al (1999) indicate Upper Wapiti Formation (equivalent to Horseshoe Canyon Formation, grey feldspathic</p>	<p>No geotechnical concerns identified.</p>



From (KP)	To (KP)	Geotechnical Conditions	Geotechnical Comments
445.7	446.1	<p>sandstone, grey bentonitic mudstone and carbonaceous shale, scattered coal and bentonite beds).</p> <p>Bald Mountain Creek - KP 445.4: Moderate slopes approximately 20 m high. Possible rock exposures near toes of slopes based on aerial reconnaissance.</p> <p><u>Surficial geology</u> (Andriashek, 1983): Glaciolacustrine silt and clay. GEM Terrain mapping shows similar interpretation.</p> <p><u>Bedrock geology</u> Hamilton et al (1999) indicate Upper Wapiti Formation (equivalent to Horseshoe Canyon Formation, grey feldspathic sandstone, grey bentonitic mudstone and carbonaceous shale, scattered coal and bentonite beds).</p>	<p>Further geotechnical review of slopes is recommended.</p> <p>Ground and surface water control required. Surface and ground water control including trench blocks, cross berms and possibly drains.</p>
446.1	459.7	<p>Upland terrain. Gently rolling.</p> <p>Approx. KP 448.2 to KP 459.2: Generally along high grade road, existing pipeline parallel to road. In a few areas, the road deviates from the route which follows an existing cut line and/or existing pipeline RoW.</p> <p>Existing infrastructure.</p> <p><u>Surficial geology</u> (Andriashek, 1983): Glaciolacustrine silt and clay on uplands. GEM Terrain mapping shows increasing moraine toward the west.</p> <p><u>Bedrock geology</u> Hamilton et al (1999) indicate Upper Wapiti Formation (equivalent to Horseshoe Canyon Formation, grey feldspathic sandstone, grey bentonitic mudstone and carbonaceous shale, scattered coal and bentonite beds).</p>	<p>KP 453.06 Wilson Creek. Mobile within flat valley bottom. Long crossing for size of creek. Confined at road crossings. Valley slopes are low, no stability issues identified from air.</p> <p>KP 458.1 Small incised creek. Crossing near road crossing. Shallow to moderately deep sliding of approach slopes. Will likely need to grade out.</p> <p>Ground and surface water control required on all approach slopes and on some upland slope areas.</p>
459.7	470.1	<p>Broad ridges across route, intervening small streams drain to south. Generally parallel to good road and existing pipeline.</p> <p>Several small stream crossings. Crossings in the eastern half tend to have muskeg along the valleys while those toward the west tend to be slightly incised.</p> <p><u>Surficial geology</u> (Andriashek, 1983): Undifferentiated glaciofluvial and aeolian deposits. GEM mapping also suggests moraine and organic deposits.</p> <p><u>Bedrock geology</u> Hamilton et al (1999) indicate Upper Wapiti Formation (equivalent to Horseshoe Canyon Formation, grey feldspathic</p>	<p>No geotechnical concerns identified.</p>



From (KP)	To (KP)	Geotechnical Conditions	Geotechnical Comments
		sandstone, grey bentonitic mudstone and carbonaceous shale, scattered coal and bentonite beds).	
470.1	473.1	Gently sloping terrain on east side of Pinto Creek valley. <u>Surficial geology</u> (Andriashek, 1983: Glaciofluvial outwash sand. GEM terrain mapping suggests glaciolacustrine and morainal deposits on higher terrain outside of major valleys. <u>Bedrock geology</u> Hamilton et al (1999) indicate Upper Wapiti Formation (equivalent to Horseshoe Canyon Formation, grey feldspathic sandstone, grey bentonitic mudstone and carbonaceous shale, scattered coal and bentonite beds).	Stability KP 469.9 - KP 470.3 Moderately deep-seated slide into meander bend of Pinto Creek close to south side of existing RoW. Preferred route is on the north. Route centerline will need to be moved slightly to the north during detailed design. Surface and ground water control including trench blocks, cross berms and possibly drains.
473.1	473.9	Pinto Creek – KP 473.4 <u>Surficial geology</u> (Andriashek, 1983: East of creek valley crest: glaciofluvial outwash sand. Creek valley: Colluvial deposits on slopes and alluvial/glaciofluvial deposits along valley. Crest of west approach slope: Glaciolacustrine silt, minor clay. GEM terrain mapping also suggests glaciolacustrine deposits are present. <u>Bedrock geology</u> Hamilton et al (1999) indicate Upper Wapiti Formation (equivalent to Horseshoe Canyon Formation, grey feldspathic sandstone, grey bentonitic mudstone and carbonaceous shale, scattered coal and bentonite beds).	Stability Some indications of stability issues. Stability of area should be further assessed on ground and using LiDAR. Surface and ground water control required. Graded materials should be moved to slope crests. Further geotechnical review of slopes is recommended. Surface and ground water control including trench blocks, cross berms and possibly drains.
473.9	476.9	Upland terrain parallel to existing road and pipeline. <u>Surficial geology</u> (Andriashek, 1983: Undifferentiated glaciofluvial and aeolian deposits. Local muskeg. GEM terrain mapping suggests large areas of glaciolacustrine deposits are present. <u>Bedrock geology</u> Hamilton et al (1999) indicate Upper Wapiti Formation (equivalent to Horseshoe Canyon Formation, grey feldspathic sandstone, grey bentonitic mudstone and carbonaceous shale, scattered coal and bentonite beds).	No geotechnical concerns identified.
476.9	492.7	West of Pinto Creek to east of Wapiti River valley. <u>Surficial geology</u> (Andriashek, 1983): Glaciolacustrine silt and clay with overlying thin aeolian deposits. Toward the west, there is an increasing amount of glaciofluvial deposits overlain by aeolian deposits. Local muskeg. <u>Bedrock geology</u> (McMechan and Dawson, 1995): Upper Wapiti Formation (equivalent to Horseshoe Canyon Formation, grey feldspathic sandstone, grey bentonitic mudstone and carbonaceous	Near start of segment, possible shallow muskeg. KP 489 to KP 491 (approx.): Several ponds near alignment. Scattered small areas of muskeg.



From (KP)	To (KP)	Geotechnical Conditions	Geotechnical Comments
492.7	493.15	<p>shale, scattered coal and bentonite beds.)</p> <p>East approach slope to Wapiti River Slope has at least two prominent terraces which appear to be erosional/depositional. Lower terrace front has possible discontinuous permafrost which is degrading and local shallow sliding. Bedrock is exposed along toe of slope (sandstone). <u>Surficial geology</u> (Andriashek, 1983): Undifferentiated aeolian and glaciofluvial deposits. <u>Bedrock geology</u> (Hamilton et al, 1995): Upper Wapiti Formation (equivalent to Horseshoe Canyon Formation, grey feldspathic sandstone, grey bentonitic mudstone and carbonaceous shale, scattered coal and bentonite beds.)</p>	<p>No major sliding identified. Local shallow sloughing can be graded out. Steep terrace fronts will need to be graded out. Comprehensive ground and surface water control including trench blocks, cross berms and drains. Local permafrost was degrading rapidly and may be entirely gone by the time of construction.</p>
493.15	493.3	<p>Wapiti River – KP 493.2 Near the proposed crossing, the Wapiti River flows through a deeply incised, meandering valley that is 80 to 120 m deep and 650 to 900 m wide at the valley crest. The large incised meander bends and associated steep parallel river valley slopes along the river form a series of interlocking upland terrain areas inside each meander loop (meander spurs) that constrain the route alignment through the valley area. The route crosses between two of the spurs. Specifically, on the east side, the route runs downhill across a series of erosional or depositional terraces. There is a wide terrace near the river. On the west side, the route runs up terraced slopes on the end of a spur and follows the spur to the west. There is one narrow area (“neck”) at the west end of the spur where the route is constrained between a moderately deep slide apparently located on the lower part of the slope on the north side and a shallow to moderately deep slide on a steep rock slope to the south (discussed below).</p> <p><u>Surficial geology</u> (Andriashek, 1983): Undifferentiated aeolian and glaciofluvial deposits. Glaciolacustrine and valley fill deposits at depth.</p> <p><u>Bedrock geology</u> (Hamilton et al, 1995): Upper Wapiti Formation (equivalent to Horseshoe Canyon Formation, grey feldspathic sandstone, grey bentonitic mudstone and carbonaceous shale, scattered coal and bentonite beds.)</p>	<p>Open Cut Crossing: Feasible. Isolation is not feasible due to flow levels. Directionally Drilled Crossing: Various directionally drilled alignments could be considered. One possibility would be between a low elevation terrace on the east side and a low elevation terrace on the west side. The “west” end would be on the north side of a ridge on the west side of the river due to the length of the crossing. Pipeline layout would be to the south and east and would require substantial grading of terrace fronts. Another potential crossing might be to drill between a low elevation terrace on the south side of the river and the uplands on the west. Major considerations for both holes would include the stratigraphy at depth.</p>



From (KP)	To (KP)	Geotechnical Conditions	Geotechnical Comments
		<p>Pawlowicz and Fenton (1995a) indicate a major west-east trending preglacial channel (Brazeau Channel) close to the crossing. Detailed review of local outcrop patterns suggests that this segment of the Wapiti River was eroded down through an area without a preglacial channel, that is, it is upstream of the area where the modern channel is close to a preglacial channel.</p>	
493.3	494.7	<p>West approach slope and upland area of ridge: Eastward pointing ridge between incised meander bends of river. Low elevation terrace at east end with point bar farther east. Several well defined narrow terraces with steep terrace fronts between. <u>Surficial geology</u> (Andriashek, 1983): Colluvium with glaciolacustrine clay (varved) to east. Local observation indicates glaciolacustrine clay and local glaciofluvial deposits on eroded terraces. <u>Bedrock geology</u> (Hamilton et al, 1995): Upper Wapiti Formation (equivalent to Horseshoe Canyon Formation, grey feldspathic sandstone, grey bentonitic mudstone and carbonaceous shale, scattered coal and bentonite beds.)</p>	<p>No major stability issues identified. Shallow creep in some areas. Grading of route up front of ridge will be required. A route slightly on the sidehill to the north side of the ridge may assist with ground and surface water control. Surface and ground water control required including cross berms, trench blocks and drains.</p>
494.7	495.0	<p>Narrow area (“neck) in ridge at edge of uplands. On south side, apparent shallow slides in rock exposed on steep slopes down to Wapiti River and colluvium. On north side, apparent moderately deep-seated slide in valley fill glaciolacustrine clay.</p>	<p>Stability Preliminary field and office review suggests there is sufficient room between the slide crests. Further review recommended including additional ground reconnaissances including toe area of possible north slides. Potential mitigative measures if there is an issue include routing, surface and ground water control and (in the event of major problems), consideration of deep grading, directional drilling or other methods.</p>
495.0	516.8	<p>West of Wapiti River and north of Calahoo Lake. Upland rolling terrain rising toward the west. Several shallow valleys draining toward the north. <u>Surficial geology</u> (Andriashek, 1983): East half of segment: glaciolacustrine silt and clay overlain by thin aeolian deposits derived from the underlying silt and clay farther west. The west half of the segment is underlain by glacial till. Aerial reconnaissance indicated scattered muskegs, some of which</p>	<p>BC/Alberta Border at KP 516.6 approx. Scattered muskegs, particularly in the eastern half of segment. 496.9 old meltwater channel</p>



From (KP)	To (KP)	Geotechnical Conditions	Geotechnical Comments
		<p>were estimated to be greater than 1 to 1.5 m deep. GEM terrain mapping indicates similar conditions. <u>Bedrock geology</u> (McMechan and Dawson, 1995): (McMechan and Dawson, 1995): Upper Wapiti Formation (equivalent to Horseshoe Canyon Formation, grey feldspathic sandstone, grey bentonitic mudstone and carbonaceous shale, scattered coal and bentonite beds.)</p>	
516.8	531.7	<p>Upland area with terrain tending to rise toward the west. <u>Surficial geology</u> (Maxwell 1976a) East of Hiding Creek (KP 517.9): predominantly glaciofluvial sand and gravel with glaciofluvial and alluvial terraces near creek. Scattered areas of muskeg. To west to end of segment, terrain rises and is underlain by glacial till with frequent glaciofluvial deposits with occasional small meltwater channels. Scattered areas of muskeg throughout the segment; however, it may be possible to miss many of these areas. <u>Bedrock Geology</u> (GSC Open File 630, 1979): Wapiti Formation. Gently folded with folding and dips tending to increase toward west. Conglomerate, sandstone, carbonaceous shale, coal. Based on previous work, this formation contains high plastic clays and/or bentonitic clays in this area and is potentially subject to deep-seated sliding where exposed on high slopes.</p>	<p>Hiding Creek (KP 517.9) has an extensive area of muskeg in the valley estimated visually to be at least 1.5 m deep.</p>
531.7	532.4	<p><u>South Redwillow River – KP 531.9</u> Confined and straight channel upstream, meander downstream. Crossing in tight area. Rock on east side. Might also occur on west side but not seen. Narrow valley with limited work room. The river is misfit in an old glaciofluvial meltwater channel. <u>Surficial geology</u> (Maxwell 1976a) East approach slope was mapped as till blanket over bedrock with glaciofluvial sediments a short distance to the east. Valley bottom is underlain by glaciofluvial sediments and organics likely overlying the materials to the east and west. The west approach slope (flat) is underlain by glaciofluvial veneers overlying till mantles. Aerial reconnaissance indicated extensive peat (muskeg) deposits across the valley bottom and beyond to the west. The Redwillow valley was a major glaciofluvial outwash channel. <u>Bedrock geology</u> (GSC Open File 630, 1979): Wapiti Formation. Gently folded with folding and dips tending to increase toward west. Conglomerate, sandstone, carbonaceous shale, coal. Based on previous work, this formation contains high plastic clays and/or</p>	<p>Open Cut Crossing: Appears feasible from a geotechnical point-of-view. Lateral erosion conditions also need to be considered. Isolation appears possible under winter conditions.</p>



From (KP)	To (KP)	Geotechnical Conditions	Geotechnical Comments
		<p>bentonitic clays in this area and is potentially subject to deep-seated sliding where exposed on high slopes.</p>	
532.4	546.5	<p>Terrain rises to the west. The route runs south of Squaw Mountain near the end of the segment. At the end of the segment, the route runs down locally moderately steep slopes to Redwillow River valley.</p> <p><u>Surficial geology</u> (Maxwell 1976a): Glacial till with frequent glaciofluvial deposits and occasional small meltwater channels. Scattered areas of muskeg throughout the segment; however, it may be possible to miss many of these areas. GEM terrain mapping had similar deposits.</p> <p><u>Bedrock geology</u> (GSC Open File 630, 1979 and Kilby and Johnston, 1988a): Mostly Wapiti Formation. Gently folded with folding and dips tending to increase toward west. South of Squaw Mountain and to the west, the route crosses the first major thrust faults in the foothills. Bedrock is folded and faulted due to thrust faults over the last half of the segment. Bedrock may be shallow toward the end of the segment. Existing shale borrow pit near end of segment.</p>	<p>Bedrock is expected to be close to surface over west half of segment. Sandstone would require blasting if encountered. Some shale may also require blasting.</p> <p>There are two "tight" stream crossings near the end of the segment where extensive grading (including bedrock grading) will be required for large diameter pipelines. Areas underlain by Wapiti Formation may be more prone to stability issues, although none have been identified to date. Slope stability aspects should be checked in this area including consideration of the dip angles of the bedrock formations.</p>
546.5	561.4	<p>Along south side of Redwillow River valley and south of Stoney Lake. Route generally follows a ridge with some areas of flat valley bottom and frequent areas of sidehill including ridges.</p> <p><u>Surficial geology</u> (Maxwell 1976b): East half of segment: Areas of organic blankets (muskeg) overlying glaciofluvial and fluvial deposits and minor till. West half: glacial till veneers and blankets over rock with lesser amounts of fluvial and glaciofluvial sand and gravel. Larger areas of organic blankets overlying glaciofluvial or fluvial sediments at end of segment. GEM terrain mapping had similar deposits.</p> <p><u>Bedrock geology</u> (GSC Open File 630, 1979 and Kilby and Johnston, 1988a): Folded and thrust faulted Upper Cretaceous formations including Wapiti (see above), Puskwaskau (sandstone, siltstone), Badheart (sandstone, minor carbonaceous shale), Muskiki (pyritic shale), Cardium (sandstone, carbonaceous shale, conglomerate), Kaskapau (shale) and Dunvegan (sandstone, minor conglomerate, shale).</p>	<p>KP 557.6 Crossing of Spectra Energy Transmission Grizzly Pipeline</p> <p>ARD Potential: Note presence of Muskiki Formation near KP 548.0 (route may be south of where the formation pinches out in a thrust and fold) and approximately KP 551.7 to KP 552.9 based on published mapping.</p>
561.4	566.2	<p>Gently sloping to the north and west with several creek crossings including</p> <p>KP 561.5: Kinuseo Creek KP 564.9: Honeymoon Creek</p>	<p>Some of the creek crossings will require grading of the banks and/or riprap or other measures for bank restoration. There may be some areas of wet soil or muskeg. Conventional crossings preferred from a geotechnical</p>



From (KP)	To (KP)	Geotechnical Conditions	Geotechnical Comments
		<p>KP 566.0: Kinuseo Creek Wet soil conditions may occur at some of the creek crossings.</p> <p><u>Surficial geology</u> (Maxwell 1976b): Organic veneer overlying fluvial sediments. Local observations indicate possibly substantial depths of glaciofluvial sediments which may be bouldery overlain by muskeg. GEM terrain mapping indicates large areas of glaciofluvial sediments which accords with field observations.</p> <p><u>Bedrock geology</u> (GSC Open File 630, 1979 and Kilby and Johnston, 1988a): Gently folded Upper Cretaceous formations including Kaskapau Formation (shale), Dunvegan Formation (sandstone, minor conglomerate, shale) and Shaftesbury Formation (marine shale) at west end of segment. Local outcrops occur in general area, but much of area is covered with overburden.</p>	<p>point-of-view. Stream flow conditions would permit use of isolation techniques.</p>
566.2	569.6	<p>Parallel to north side of existing road on north side of Kinuseo Creek valley. High, steep bedrock ridge on north side of valley, route would sidehill across end of ridge.</p> <p><u>Surficial geology</u> (Maxwell 1976b): Exposed rock ridge and colluvial veneers. GEM terrain mapping also indicated moraine veneers.</p> <p><u>Bedrock geology</u> (GSC Open File 630, 1979 and Kilby and Johnston, 1988a): Tightly folded Lower Cretaceous formations including Boulder Creek (massive conglomerate, sandstone, shale and coal), Hulcross (marine shale, weak), Gates (conglomerate, shale, sandstone and coal), Moosebar (marine shale), Gething (conglomerate, shale, sandstone and coal), Cadomin (massive pebble to cobble conglomerate) and Minnes (thinly bedded sandstone, shale and coal).</p>	<p>Difficult sidehill area. Graded RoW should be kept as narrow as possible to reduce heights of cuts. Rapidly varying conditions likely in areas of sidehill cuts. Local stability conditions including shallow veneers over bedrock should be checked.</p> <p>Blasting: Almost all of the rock formations will require blasting. The conglomerate in several of the formations, and in the Cadomin Formation in particular, is known to be extremely strong and abrasive, resulting in expensive drilling. The Cadomin Formation is typically only 100 to 200 m thick and may be encountered near KP 561.8 to KP 562.0 (approx.).</p> <p>From KP 565.8 to KP 569.0 (approx) bedrock will be dipping toward the south at angles of 50 to 70°. The stability of cut slopes in this area (and any other areas with similar bedrock dip conditions) should be reviewed in the field. Other areas of local topping or sliding on joints should also be reviewed geotechnically in the field.</p>
569.6	577.6	<p>Benched to strongly ridged terrain.</p> <p><u>Surficial geology</u> (Maxwell 1976b): Glaciolacustrine mantles, till veneers and gullied glaciofluvial veneers and blankets all overlying ridged rock.</p>	<p>Difficult area. Rapidly varying conditions likely with sidehill cuts. Local stability conditions including shallow veneers over bedrock</p>



From (KP)	To (KP)	Geotechnical Conditions	Geotechnical Comments
		<p>Local observation indicated that there are also large glaciofluvial fans in this area. The route may encounter the ends of some bedrock ridges. <u>Bedrock geology</u> (GSC Open File 630, 1979): Folded bedrock of Minnes Formation (thinly bedded sandstone, shale and coal).</p>	<p>should be checked. Some of bedrock may be rippable in cuts. Minnes Formation generally requires blasting in trenches.</p> <p>KP 575.15: Quintette Creek. Meandering creek, slightly incised meanders. Crossing is on an apparent alluvial fan. Long crossing. Lot of debris in channel. Area should be checked further relative to potential for avulsion. Preliminary observations from the air indicate a possibility that the creek might avulse to the west 200 m or more. A crossing farther upslope may be less favourable.</p> <p>KP 575.95 spring beside road.</p>
577.6	579.5	<p>Route runs uphill over a broad ridge north of the road due to lack of room along the road which is along the edge of Kinuseo Creek at the toe of a steep slope. Road has been partially washed out. Last 0.8 km of segment is on flat to gently sloping terrain. <u>Surficial geology</u> (Maxwell 1976b): Till and colluvial veneers with minor glaciofluvial blankets overlying hummocky and ridged rock. Local observation indicated that bedrock will likely be encountered due to the extensive grading that will be required. <u>Bedrock geology</u> (GSC Open File 630, 1979 and Kilby and Johnston, 1988a): Folded bedrock of Minnes Formation (thinly bedded sandstone, shale and coal).</p>	<p>Difficult grading area. Extensive grading required. Bedrock dips are generally expected to be favourable (i.e. not tending to result in slope failures). Avoid the Cadomin conglomerate near end of segment if possible. Segment should be reviewed on ground from a geotechnical point-of-view.</p> <p>KP 577.9: Diagonal crossing of incised stream. Area should be checked further on ground and on LiDAR.</p>
579.5	581.4	<p>Five Cabin Creek – 580.7 Alluvial fan on north side of Kinuseo Creek valley with steep rock ridge directly north of road beyond to west. The channel is high relative to the east and west edges of the fan and has been subject to past avulsion (channel switching). The channel morphology and recent deposits suggest that there have been recent high flow events over a width of 100 m or more (far in excess of the channel width) with local erosion and deposition to shallow depths. Avulsion channels over the last few tens of years may occupy an area at least 800 m across. The road fill was eroded during past events. Channel may be subject to debris flow events. Preliminary drilling data indicates a declining bedrock surface toward the west with coarse gravel and boulders overlying bedrock.</p>	<p>Avulsion: High likelihood of future avulsion, which could result in substantial erosion up to a few hundred meters from present channel. Avulsion and the potential for erosion should be considered during detailed design relative to the design crossing method.</p> <p>Potential reroute: There are conglomerate outcrops exposed on either side of the channel approximately 125 m north of the Rev R route. The stream appeared to be more tightly constrained in this area which may offer a shorter conventional crossing and a potential directionally drilled crossing. Further investigation and consideration of potential routes in this area is recommended. Avulsion</p>



From (KP)	To (KP)	Geotechnical Conditions	Geotechnical Comments
		<p><u>Surficial geology</u> (Maxwell 1976b): Alluvial and glaciofluvial fan. Local observations indicate that the fan is extremely bouldery.</p> <p><u>Bedrock geology</u> (GSC Open File 630, 1979 and Kilby and Johnston, 1988a): Folded bedrock of Minnes Formation (thinly bedded sandstone, shale and coal).</p>	<p>would still be a consideration at the potential relocation area, but would be over a shorter lateral distance than farther downstream.</p> <p>Another reroute much farther upstream could also be considered. In this area, approach slope conditions may be more difficult; however, the creek channel is tightly constrained.</p> <p>Open Cut Crossing: Crossing would be long due to avulsion potential and deep with difficult groundwater conditions. The alternative of a crossing higher on the fan where the alluvial fan is narrower could also be considered. Isolation may be difficult due to high permeability of the fan and slope down the fan across the trench.</p>
581.4	581.8	<p>On edge of steep rock slopes to north.</p> <p><u>Surficial geology</u> (Maxwell 1976b): Till and colluvial veneers, exposed rock.</p> <p><u>Bedrock geology</u> (GSC Open File 630, 1979 and Kilby and Johnston, 1988a): Cadomin Formation (massive conglomerate) with Gates Formation (conglomerate, shale, sandstone and coal) directly to north. Thrust fault with drag folding. The bedrock conditions intersected (and the difficulty of the segment) will depend on the exact route relative to the bedrock topography.</p>	<p>Difficult area due to potential blasting in conglomerate and possibly slope stability. Detailed alignment should be reviewed geotechnically on the ground with respect to geotechnical conditions.</p>
581.8	587.6	<p>Glaciofluvial and possibly glaciolacustrine terraces with a few rock ridges.</p> <p><u>Surficial geology</u> east end of segment (Maxwell 1976b): till and colluvial veneers. West end of segment (Maxwell 1976c): colluvial, glaciofluvial and till veneers over bedrock. GEM terrain mapping indicated predominantly glaciolacustrine and glaciofluvial terraces east of 584.1. To west, similar deposits with rock ridges.</p> <p><u>Bedrock geology</u> (GSC Open File 630, 1979 and Kilby and Johnston, 1988b): East to west: Minnes Formation (thinly bedded sandstone, shale and coal), Fernie Formation (marine shale, weak, only a short segment), Whitehorse Formation (limestone, dolomite, minor sandstone, siltstone, gypsum).</p>	<p>Route is generally located on low areas.</p>
587.6	588.5	<p><u>Kinuseo Creek – 588.1</u></p> <p>Alluvial fan or terraces on east side bordered by prominent rock ridges. On west side, coalescent alluvial fans with glaciofluvial terraces,</p>	<p>Lateral erosion: Geotechnical conditions, in particular the potential for lateral erosion will need to be considered during detailed design. Also a meander to the east of the</p>



From (KP)	To (KP)	Geotechnical Conditions	Geotechnical Comments
		<p>probably buried rock ridges. Rock ridges farther to the west. Creek flows to north through narrow canyon north of study area.</p> <p><u>Surficial geology</u> (Maxwell 1976c): Glaciofluvial and fluvial terrace and fan. Local observations indicate very bouldery material near surface.</p> <p><u>Bedrock geology</u> (GSC Open File 630, 1979 and Kilby and Johnston, 1988b) East of crossing: Minnes Formation (thinly bedded sandstone, shale and coal), under creek and immediately to the west: Fernie Formation (marine shale, weak, only a short segment), to the west: Whitehorse Formation (limestone, dolomite, minor sandstone, siltstone, gypsum).</p>	<p>crossing is close to the south of the pipeline route and should be further examined relative to crossing design.</p> <p>Open Cut Crossing: Feasible, but may be deep long crossing due to potential for lateral erosion (requires further investigation).</p> <p>A route higher on the fan where the stream is more constrained could be investigated. However, the approach slopes into this area would be more difficult and might involve substantial cuts. Further work is recommended during detailed design.</p>
588.5	596.9	<p>Route runs west toward Murray River. Monkman Provincial Park to the south.</p> <p><u>Surficial geology</u> (Maxwell 1976c): Colluvial veneers and blankets. Local observation suggests large glaciofluvial terraces east of KP 591.7. These are shown on GEM terrain mapping that also suggests morainal veneers over bedrock ridges to the north.</p> <p><u>Bedrock geology</u> (GSC Open File 630, 1979) Strongly folded Whitehorse Formation (limestone, dolomite, minor sandstone, siltstone, gypsum. Fold axes control orientations of local valleys and streams. A portion of the route west of approximately KP 592.0 will be parallel to the local fold structure (i.e., dips into or out of cut slopes).</p>	<p>Check local stability conditions where bedrock structure is parallel or close to parallel to grade cuts.</p> <p>Potential for local karstic conditions, although no karst has been identified to date in area.</p> <p>KP 595.9: Incised stream. Local grading including pulling back approach slopes may be required.</p>
596.9	597.25	<p>Tributary to Murray River.</p> <p>Moderate to steep approach slopes into and out of creek. Glaciofluvial materials along channel. Bedrock controlled valley with shallow colluvium and till on both slopes.</p> <p><u>Surficial geology</u> (Maxwell 1976c): Colluvial veneers and blankets. GEM terrain mapping also indicated glaciofluvial materials along channel in accordance with local observation.</p> <p><u>Bedrock geology</u> (GSC Open File 630, 1979) Strongly folded Whitehorse Formation (limestone, dolomite, minor sandstone, siltstone, gypsum. Fold axes control orientations of local valleys and streams</p>	<p>Further ground reconnaissance required to finalize design. Pulling back of slopes likely required. Ground water control including cross berms, trench blocks and drains.</p>
597.25	598.4	<p>Upland ridge east of Murray River bounded by the river to the west and a parallel tributary approximately 1 km to the east. The ridge extends up to approximately 100 m above the river elevation. The top is rolling and</p>	<p>Locally appreciable bedrock grading in ridged topography.</p>



From (KP)	To (KP)	Geotechnical Conditions	Geotechnical Comments
		<p>is the site of a recent logging cut block. Nearby drilling investigations indicate limestone which may vary from intensely jointed to massive. Shallow till.</p>	
598.4	598.8	<p><u>Murray River – KP 598.6</u> River valley is controlled by bedrock structure. The east approach slope varies up to 35° or more depending on location. The river channel is less than 100 m wide. The west approach slope is also steep with slopes on the lower part of up to 35° and flatter slopes higher up. The route on the west approach slope is constrained by the park to the south and a steep cliff and gully to the north. Rev R route runs slightly to the north down moderate slopes to the east side of the river. The directionally drilled option would be farther south. <u>Surficial geology</u> (Maxwell 1976c): Fluvial and colluvial veneers. Local observations suggest variable depths of colluvium and till on the approach slopes to the river with some local till. On the west approach slope, a borehole on the bench approximately 40 m above the river encountered sand overlying till to a depth of 8 m overlying limestone. Local observations and drilling several kilometres downstream of the crossing have encountered very thick (up to 60 m) deposits of collapsible silts and weak high plastic clay. The deposits at the crossing location are expected to be thinner and may not be collapsible, but the depth to the bedrock valley bottom is not known. <u>Bedrock geology</u> (GSC Open File 630, 1979) Strongly folded Whitehorse Formation (limestone, dolomite, minor sandstone, siltstone, gypsum. On the west side of the river, limestone, dolomite, cherty sandstone and chert of the Rundle, Hanington, Belcourt and Ranger Canyon Formations. Banff Formation (brown siltstone, limestone and shale) might also be encountered. Fold axes approximately parallel to the river valley. A thrust fault (western boundary of the Whitehorse Formation) is indicated west of the river.</p>	<p>Directionally Drilled Crossing: Not feasible due to lack of area for drag section layout (deep ravines on east side and steep slopes on west side. The directionally drilled crossing alignment evaluated is located south of the aerial crossing (Rev. R) alignment. Large topographic elevation changes would make it difficult to fit the crossing into the geometry. The apparent presence of a major fault on the west side is a potential concern. The potential presence of cherty rock types is a concern since these rock types are highly abrasive and very tough potentially resulting in high bit wear. Preliminary results of drilling indicate relatively low rock quality in some zones which could lead to stability problems in the directional hole. Overall, from a geological point of view, this is considered to be a difficult directional drill hole. From a geometry point of view, not feasible due to lack of drag section layout area as noted. Aerial crossing: An aerial is a viable alternative from a geotechnical point-of-view. The potential crossing location would be on the Rev. R alignment starting from or north of a rock bench on the east side to a piled foundation into bedrock (?) on the west side. Shoofly access would be required on both sides of the river down the steep slopes, which appears feasible. A buried riprap berm may be required to control lateral erosion depending on the location of the west end of the crossing. Open Cut Crossing: An open cut crossing on or near the aerial crossing alignment would be viable from a geotechnical point-of-view subject to hydrotechnical and other aspects. Lateral erosion protection may be required on the west side depending on location. Scour depths may be appreciable at the crossing location immediately downstream of a mid-channel island. Isolation would not be possible due to flow volumes at most times of the year. Superflume isolation might be marginally possible in late</p>



From (KP)	To (KP)	Geotechnical Conditions	Geotechnical Comments
			<p>winter but would likely not be practical.</p> <p>Karst: The presence of limestone in the area raises the potential for karst, which has been identified a few kilometres north and south of area. No karst has been identified along the proposed route.</p> <p>Slopes would require ground and surface water control including trench blocks, drains and cross berms. Detailed design of other surface water aspects in connection with shoofly access would also be required.</p>
598.8	600.6	<p>West approach slope to Murray River</p> <p>The west approach slope extends with wide benches up to approximately 250 m above the river. Steep slopes between the benches. The route is constrained by steep slopes and cliffs to the north with a deeply incised stream gully and to the south by Monkman Park. A switchbacked shoofly would be required on the west approach slope for access.</p> <p>Surficial and bedrock geology as above.</p>	<p>Difficult area: Shoofly access to aerial crossing would switchback down slope north of alignment. The route for a shoofly would be constrained by the topography plus the presence of the Provincial Park boundary to the south. Some areas of relatively high cuts and fills along shoofly access. Preliminary design indicates that there is sufficient room for a shoofly and the cuts for the pipeline RoW; but the area is tight. Detailed engineering design required.</p> <p>Ground and surface water control including cross berms, trench blocks and drains. French drains may be required. Design of drainage control measures for access shoofly also required.</p>
600.6	601.9	<p>West of Murray River</p> <p>Moderate slope with one area of steep slopes that runs downhill from divide between Murray River and Hook Creek. The band of steep bedrock slopes is further constrained by steep slopes to the north and a bluff to the south. Moderate to steep slope downhill to edge of Hook Creek valley.</p> <p><u>Surficial geology</u> (Maxwell 1976c): Colluvial veneers, hummocky and ridged exposed rock. Local observation suggests there may be appreciable till or possibly glaciofluvial material along the route, particularly the western half of the segment. Rock may be encountered on the eastern half.</p> <p><u>Bedrock geology</u> (GSC Open File 630, 1979): As per western end of segment above. West end of segment is in the Banff Formation (brown</p>	<p>Difficult route with areas of moderate to steep slopes. Cuts required along alignment. Separate shoofly access may be required.</p> <p>Groundwater and surface water control will be required on the slopes and shoofly.</p>



From (KP)	To (KP)	Geotechnical Conditions	Geotechnical Comments
601.9	603.5	<p>siltstone, limestone and shale).</p> <p>Hook Creek (KP 602.5) and valley Hook Creek runs southeast down a valley controlled by bedrock structure to join Imperial Creek, a tributary of the Murray River. The crossing is located close to a junction between a braided section of channel to the north and the alluvial fan to the south. Farther upstream, the creek is eroding extensively in a canyon which is contributing surficial materials that are augmenting the braiding process. West of the proposed alignment, Imperial Creek may erode laterally in the future into the lower stretches of Hook Creek, which limits the crossing location in a downstream direction. There are two higher elevation dry channels to the east.</p> <p><u>Surficial geology</u> (Maxwell 1976c): Till blankets and veneers over rock. Local observation indicates that Hook Creek has a glaciofluvial and alluvial fan at the junction with Imperial Creek. There are glaciofluvial terraces along Imperial Creek and likely also glaciolacustrine deposits in this area. Glaciofluvial materials also occur along Hook Creek and in the lower stretches, bedrock ridges parallel to the creek have likely been buried in glaciofluvial materials with possible glaciolacustrine silts or clays overlying.</p> <p><u>Bedrock geology</u> (GSC Open File 630, 1979): Banff Formation (brown siltstone, limestone and shale) east of Hook Creek. Besa River Formation (black shale) to the west. The contact is along a thrust fault and associated drag fold that is close to the confluence of Hook Creek with Imperial Creek close south of the route.</p>	<p>Lateral erosion: Stream is tending to erode laterally to the west and further lateral erosion is likely to occur. Further review on the ground is recommended.</p> <p>Directionally Drilled Crossing: Potentially difficult directionally drilled crossing due to confluence of glaciofluvial meltwater channels potentially containing boulders along both Hook Creek and the adjacent Imperial Creek valley. An additional consideration is the location and characteristics of a thrust fault zone if the directional drill would extend down into bedrock, as appears to be likely. Further investigation would be required.</p> <p>Open Cut Crossing: Appears to be feasible from a geotechnical point-of-view. The detailed crossing design would need to consider the possibility of lateral erosion to the west near the downstream end of the braided channel section. Isolation feasible most times of year depending on geometry of crossing and nature of substrate sediments.</p> <p>Possible ARD prone materials have been identified to the west and might occur in this area as well.</p>
603.5	610.1	<p>Strongly ridged terrain and steep topography north of Imperial Creek. The route cuts across a road that switchbacks around the ends of the bedrock ridges.</p> <p><u>Surficial geology</u> (Maxwell 1976c): Till blankets and veneers over rock. Colluvial and till veneers, exposed rock. GEM Terrain mapping indicated similar materials.</p> <p><u>Bedrock geology</u> (GSC Open File 630, 1979): Route crosses a thrust fault and associated drag fold forming an anticline. Devonian formations include the Palliser (limestone, dolomite, minor shale), Perdrix (black shale) Formations and Lower Ordovician formations include the Monkman (orthoquartzite) and Chusina (limestone, argillaceous limestone, minor shale).</p>	<p>Difficult Area Rough ground with locally extensive grading in rock. Fill placement for work side will likely be required. Geotechnical considerations will include:</p> <ul style="list-style-type: none"> • On edge of potential avalanche prone terrain. More severe conditions are to west of this segment. • Stability of rock cuts, particularly in areas where strike is parallel to cut. • Stability of fills on locally steep cross slopes. • Drilling and blasting in quartzite bedrock (extremely strong, hard and tough). • Ground and surface water control will be required.



From (KP)	To (KP)	Geotechnical Conditions	Geotechnical Comments
			<p>Detailed geotechnical review of area in field is recommended.</p> <p>ARD prone rock formations have been identified in parts of this area in outcrop in Imperial Creek (Besa River Formation). See further details in ARD reports.</p>
610.1	617.7	<p>West along north side of Imperial Creek valley and tributary valley.</p> <p><u>Surficial geology</u> (Maxwell 1976c): Colluvial and till veneers. Local observation from the air indicates there may be thicker till deposits and some glaciofluvial deposits with areas of shallower rock along the toe of the steeper rock slope and occasional rock spurs.</p> <p><u>Bedrock geology</u> (GSC Open File 630, 1979): Folded and thrust faulted rock. Lower Ordovician Chusina (limestone, some argillaceous, and minor shale) and Monkman (quartzite) Formations and Middle Ordovician Skoki Formation (oncolitic dolomite, minor sandstone).</p>	<p>KP 611.6 to KP 613.6: Close below ends of avalanche paths. While avalanches may not reach route (needs to be checked), there appears to be a potential for diversion of stream flows toward the west, resulting in higher flows in some channels.</p> <p>KP 615.6 to KP 616.6 (approx): Possible alluvial fan. Further checks on avulsion potential recommended.</p> <p>KP 616.4: Avalanche path above route.</p> <p>Difficult drilling and blasting: Drilling and blasting in possible quartzite bedrock (extremely strong, hard and tough).</p> <p>Ground and surface water control including cross berms, trench blocks and drains will be required.</p>
617.7	620.15	<p>Route crosses Imperial Creek to south side of valley and runs up a series of steep rock steps. Gently sloping terrain between rock steps. There may be shallow perched groundwater in some areas.</p> <p><u>Surficial geology</u> (Maxwell 1976c): Till and colluvial blankets or veneers, ridged rock. Aerial observation indicates that the area is very wet with sloping wet organic deposits.</p> <p><u>Bedrock geology</u> (GSC Open File 630, 1979): Upper Cambrian Lynx Formation (limestone, dolomite), Lower Ordovician Monkman Formation (quartzite) and Chusina (limestone, argillaceous limestone, minor shale), Middle Ordovician Skoki Formation (oncolitic dolomite, minor sandstone).</p>	<p>KP 618.25: Crossing of Imperial Creek</p> <p>Difficult Area</p> <p>Available time period for working will be reduced by weather conditions and snow. Difficult access. Rock blasting.</p> <p>Grading on rock steps may be required. Shoofly requirements have not been defined in detail.</p> <p>Potentially wet conditions with shallow perched groundwater on underlying rock and potentially shallow slide conditions. Further ground work to define conditions and design required.</p> <p>Ground and surface water control including cross berms, trench blocks and drains will be required.</p> <p>KP 620.15: Avalanche path to south of route. Appears unlikely to reach route, but checks of possible stream diversions will be required.</p>



From (KP)	To (KP)	Geotechnical Conditions	Geotechnical Comments
620.15	623.45	<p>Route runs on gently to moderately sloping terrain just east of pass. Route crosses back and forth across small drainage in valley and also crosses drainages from sides of valley. Rock controlled terrain overlain by variable depths of till. Terrain may be wet with perched groundwater on underlying rock. Some areas of muskeg.</p> <p><u>Surficial geology</u> (Maxwell 1976c): Till and colluvial blankets or veneers, ridged rock. Aerial observation indicates that the area is very wet with sloping wet organic deposits.</p> <p><u>Bedrock geology</u> (GSC Open File 630, 1979): Upper Cambrian Lynx Formation (limestone, dolomite), Lower Ordovician Monkman Formation (quartzite) and Chusina (limestone, argillaceous limestone, minor shale), Middle Ordovician Skoki Formation (oncolitic dolomite, minor sandstone).</p>	<p>Difficult Area KP 623.45 Unnamed pass through Rocky Mountains Elevation at pass = 1430 m (4700 ft) approx. Available time period for working will be reduced by weather conditions and snow. KP 623.65: Route in this segment crosses below or across avalanche tracks which will need to be considered in the safety plan and work execution.</p> <p>Large amount of blasting and grade rock. An additional problem is the sloping terrain with organic cover which may be prone to shallow sliding. Detailed geotechnical plans and recommendations for this area based on further ground reconnaissance will be required. Shallow soil covers may be fine grained and wet, resulting in difficult sedimentation control. Blasting and extensive grading will be required in a number of hard formations including very hard, tough and extremely strong quartzite. Ground and surface water control including cross berms, trench blocks and drains will be required.</p>
623.45	633.65	<p>High elevation gently to locally moderately sloping terrain with numerous small stream crossings. Some areas of steep rock or till ridges. Local observation indicates that there are numerous springs along the valley bottom, many of which have raised bogs in their immediate vicinity. Most of these appear to be missed by the route.</p> <p><u>Surficial geology</u> (Maxwell, 1976d) Colluvial and till veneers with areas of exposed rock. To south and west within segment, areas of thicker till blankets and silty glaciolacustrine deposits overlain by muskeg. Deposits and bedrock modified by active frost processes. Local observations indicate extensive areas of muskeg with frequent till ridges. The route runs on the edge or beside the larger muskeg areas wherever possible.</p> <p><u>Bedrock geology</u> (GSC Open File 630, 1979): Lower Ordovician Chusina (limestone, argillaceous limestone, minor shale), Upper Cambrian Lynx Formation (limestone, dolomite), Middle Cambrian</p>	<p>KP 627.75, KP 628.45 and KP 630.05 (approx) Crossings of tributaries to and Missinka River (upper reaches). Streams may be subject to high flows or possibly debris flows.</p> <p>Difficult Area Available time period for working will be reduced by weather conditions and snow. Avalanche zones exist on valley walls but are typically distant from route. Sloping terrain with organic cover and shallow perched surface water. Portions of area are subject to solifluction and related frost activity. Shallow organics and soil veneers may be subject to sliding over sloped rock. The best routes appear to be on the sideslopes and till ridges. Detailed geotechnical plans and recommendations for this area based on further ground reconnaissance are</p>



From (KP)	To (KP)	Geotechnical Conditions	Geotechnical Comments
		Snake Indian, Titkana and Arctomys Formations (dolomitic siltstone, dolomitic shale), Lower Cambrian Mahto (quartzite), Mural (limestone) and McNaughton (quartzite, pebble conglomerate, siltstone, argillite and shale) Formations; and Hadrynian Upper Miette Group (argillite and siltstone with minor sandstone).	recommended. Springs along the valley bottom may be related to groundwater flow conditions in limestone; however, no karstic conditions have been identified in this area in work to date. Springs and associated raised bog areas should be avoided. Shallow groundwater and other areas of springs may be intercepted during the work. Blasting and extensive grading will be required in a number of hard formations including very hard, tough and extremely strong quartzite.
633.65	636.55	<p>Sidehill on north side of tributary to Missinka River. Generally favourable bedrock conditions with bedrock dipping into slope. Shallow bedrock with colluvium or till overlying. Some areas of fine grained soils identified throughout the lower reaches of the valley.</p> <p><u>Surficial geology</u> (Maxwell, 1976d) Colluvial and till veneers with areas of exposed rock. To south and west within segment, areas of thicker till blankets and silty glaciolacustrine deposits overlain by muskeg. Deposits and bedrock modified by active frost processes.</p> <p><u>Bedrock geology</u> (GSC Open File 630, 1979): Lower Ordovician Chusina (limestone, argillaceous limestone, minor shale), Upper Cambrian Lynx Formation (limestone, dolomite), Middle Cambrian Snake Indian, Titkana and Arctomys Formations (dolomitic siltstone, dolomitic shale), Lower Cambrian Mahto (quartzite), Mural (limestone) and McNaughton (quartzite, pebble conglomerate, siltstone, argillite and shale) Formations; and Hadrynian Upper Miette Group (argillite and siltstone with minor sandstone).</p>	<p>Difficult area Streams may be subject to high flow or debris flow.</p> <p>KP 633.75 (approx.): Route sidehills up steep rock ridge "step" approximately 60 m high. Sidehill rock cut required. Further work to design the cut will be required.</p> <p>KP 634.75 to KP 635.15: Approach slope to creek crossing with steep steps. Steep areas will need to be cut back. Shoofly may be required. Further field reconnaissance and detailed design work will be required.</p> <p>KP 637.55 Route crosses to south side of tributary. Stream may be subject to high flows or debris flows.</p> <p>Ground and surface water control including cross berms, trench blocks and drains.</p>
636.55	641.25	<p>South side of small tributary stream. Gentle to locally moderate cross slopes. First clear cut is crossed about KP 638.45.</p> <p><u>Surficial geology</u> (Maxwell, 1976e): Colluvial veneers, few areas of till blankets and local glaciofluvial deposits.</p> <p><u>Bedrock geology</u> (GSC Open File 630, 1979): Hadrynian Upper Miette</p>	<p>KP 636.45: Stream crossing. Alluvial fan. Lateral stability of stream on fan will need to be further considered. Stream may be subject to high flow events or debris flows, which will need to be considered in crossing design.</p> <p>Ground and surface water control including cross berms, trench blocks and drains.</p>



From (KP)	To (KP)	Geotechnical Conditions	Geotechnical Comments
		<p>Group (argillite and siltstone with minor sandstone) and Byng Formation (dolomite and minor shale). Local observation indicates extensive outcrops of limestone, indicating that the outcrop boundaries on some mapping may be misleading</p>	
641.25	641.55	<p>Missinka River (East) – KP 641.35 Crossing of Missinka River. Broad valley with river incised up to 100 m into floor of valley. There is a canyon upslope of the crossing. Boulders along the channel have iron staining. Nearby logging cut blocks. <u>Surficial geology</u> (Maxwell, 1976e) Colluvial and till blankets. Limited local observations suggest there may be glaciolacustrine deposits overlying till and/or valley fill deposits potentially including bouldery materials. Local observation and experience indicates that local tills are soft with poor trafficability and tend to slump in cuts, depending on angle. <u>Bedrock geology</u> (GSC Open File 630, 1979): Hadrynian Middle Miette Group (pebble conglomerate, argillite, diamictite. Tightly folded. Pyrite visible in veins. Potential ARD considerations.</p>	<p>Open Cut Crossing: Appears feasible from a geotechnical point-of-view. Potential sedimentation and erosion issues on approach slopes in glaciolacustrine materials may require specific design measures. Isolation using dam and pump, flume or superflume (depending on time of year) feasible with respect to flows. However, bouldery substrates may be challenging for isolation and may make isolation not practical.</p> <p>ARD: Schist and hyalite in general area, particularly to the west, contain pyrite and may be acid generating (ARD).</p> <p>Past experience with working on the silt tills in this area indicates that they are soft and working pads constructed or quarried rock may be required. Rock from local quarries and grade or trench rock may be subject to ARD considerations. Further detailed engineering and planning will be required.</p> <p>Local stability: Stability of cuts and trafficability of road surfaces in glaciolacustrine silt and soft silt till has been a problem in past.</p>
641.55	645.45	<p>Tight bend, crossing of tributary stream. Route located on east side of main valley on rolling flat terrain incised with tributary stream channels. Limited local observation suggests glaciolacustrine deposits left on slopes. Deposits formed behind the main ice lobe in the Parsnip River valley. Difficult cuts, weak soils, lateral groundwater flow issues. <u>Surficial geology</u> (Maxwell, 1976e) Colluvial and till blankets on both sides of canyon. Local observation and experience indicates that local tills are soft with poor trafficability and tend to slump in cuts, depending on angle.</p>	<p>Difficult area, local stability problems Weak glaciolacustrine soils (silt and clay). Potential groundwater issues. Stability of logging road cuts and fills, trafficability of road surface have both been problems in past. Further evaluation and ground reconnaissance.</p> <p>KP 644.05 Crossing of stream. Creek may be subject to debris flows; but, crossing is located away from steep terrain and most of the material would likely deposit higher up to the east. However, relatively high flows could occur</p>



From (KP)	To (KP)	Geotechnical Conditions	Geotechnical Comments
		<p><u>Bedrock geology</u> (GSC Open File 630, 1979): Hadrynian Middle Miette Group (pebble conglomerate, argillite, diamictite. Tightly folded.</p>	<p>and will need to be considered during detailed design.</p> <p>Ground and surface water control required.</p> <p>ARD: Schist and hyalite in general area contains pyrite and may be acid generating (ARD). Past experience with working on the silt tills and glaciolacustrine soils in this area indicates that they are soft and working pads constructed or quarried rock may be required. Rock from local quarries and grade or trench rock may be subject to ARD considerations.</p>
645.45	646.15	<p>Missinka River (West) – KP 646.05 Crossing of Missinka River. East approach slope is moderately to gently sloping up to 50 m high. No major slope on west. Limited local observations suggest glaciolacustrine deposits on slopes. Deposits formed behind the main ice lobe in the Parsnip River valley. Potentially difficult cuts, weak soils, lateral groundwater flow issues. <u>Surficial geology</u> (Maxwell, 1976e) Colluvial and till blankets on both sides of canyon. <u>Bedrock geology</u> (GSC Open File 630, 1979): Hadrynian Middle Miette Group (pebble conglomerate, argillite, diamictite. Tightly folded.</p>	<p>Open Cut Crossing: Appears feasible from a geotechnical point-of-view. Potential sedimentation and erosion issues on approach slopes in glaciolacustrine materials may require specific design measures. Isolation using dam and pump, flume or superflume (depending on time of year) feasible with respect to flows. However, bouldery substrates may be challenging for isolation and may make isolation not practical.</p> <p>ARD: Schist and hyalite in general area contains pyrite and may be acid generating (ARD). Past experience with working on the silt tills and glaciolacustrine soils in this area indicates that they are soft and working pads constructed or quarried rock may be required. Rock from local quarries and grade or trench rock may be subject to ARD considerations.</p>



From (KP)	To (KP)	Geotechnical Conditions	Geotechnical Comments
646.15	666.55	<p>North side of Missinka River valley. Route is mostly near toe of slope. Most of route parallels an existing logging road.</p> <p><u>Surficial geology</u> (Maxwell, 1976e): Along lower part of valley slopes: colluvial and till veneers and blankets with periodic alluvial fans. Along valley bottom: glaciofluvial deposits overlain by discontinuous to scattered and often thin areas of muskeg. There are local reports of glaciolacustrine materials in this area that have resulted in stability concerns along the existing logging roads.</p> <p><u>Bedrock geology</u> (GSC Open File 630, 1979): Hadrynian Middle Miette Group (pebble conglomerate, argillite, diamictite). Tightly folded, decreasing folding to the west.</p>	<p>Difficult Area Past experience with working on the silt tills and glaciolacustrine soils in this area indicates that they are soft and working pads constructed or quarried rock may be required in some areas.</p> <p>Ground and surface water control required.</p> <p>Debris Flows, high stream flows and alluvial fans: Streams along the side of the valley that originate in alpine areas and that have a large headwater tributary area may be subject to debris flow and/or unusually high flows as a result of warm rain on wet snow events. These streams also, in some cases, may have alluvial fans. Further consideration of these streams during detailed design will be required. Streams potentially subject to these mechanisms include KP 644.85, KP 653.05, KP 654.15, KP 657.45, KP 659.25, KP 660.05, KP 663.15, KP 664.35, KP 665.95.</p>
666.55	671.05	<p>Route leaves Missinka Valley and runs across sideslopes north of river to Parsnip River crossing.</p> <p><u>Surficial geology</u> (Watt and Lord, 1975): Till and colluvium blankets and veneers. Occasional areas of glaciofluvial fans. Toward end of segment, increased amounts of glaciolacustrine sediments and organic blankets. Local observations suggest that stability concerns have occurred in the glaciolacustrine sediments.</p> <p><u>Bedrock geology</u> (Armstrong et al., 1969) Misinchinka Group chlorite and sericite schist, phyllite, schistose grit, quartz-pebble conglomerate and Misinchinka Group black slate, greywacke, minor quartzite, conglomerate (adjacent to east end of crossing).</p>	<p>Areas of sideslope including where the route is close to parallel to local streams should be examined from a geotechnical point of view.</p> <p>Drilling and blasting in some of the harder rock types such as quartzite would be difficult.</p> <p>Ground and surface water control required.</p>
671.05	672.85	<p><u>Parsnip River – KP 670.95</u></p> <p>Wide flat valley bottom (part of Rocky Mountain Trench). River channel is toward the east side. Swamp and muskeg terrain with shallow groundwater across valley bottom to west.</p> <p><u>Surficial geology</u> (Watt and Lord, 1975): Organic blanket over glaciofluvial and fluvial sediments. Depth not known. Tipper (1971a) indicates that as early as Eocene time, the flow of the Fraser River ran</p>	<p>Directionally Drilled Crossing: Considerations include the possible presence of quartzite in the rock formations and the possible presence of boulders in the overburden materials (the valley has carried major flows since Eocene or Tertiary time and was a major glaciofluvial meltwater channel at the end of glaciation). Limited area on north side of river for establishing an entry point. A significant</p>



From (KP)	To (KP)	Geotechnical Conditions	Geotechnical Comments
		<p>north along the Parsnip River and other valleys. He refers to sediments that may be Tertiary or older.</p> <p><u>Bedrock geology</u> (Armstrong et al., 1969) Misinchinka Group black slate, greywacke, minor quartzite, conglomerate (adjacent to east end of crossing). At west end Lower Cambrian dolomite, limestone, quartzite and slate. No faults are indicated within the portion of the valley that would be crossed by the directional drill; however, a regional fault is shown at the west side of the valley, west of the end of the proposed crossing. Bedrock appears to have been tightly folded, but overall competency is not known.</p>	<p>cut may be required. Further geotechnical investigations to establish depth and nature of overburden, the competency of the bedrock and the distribution of quartzite and other potentially problematic rock types would be required.</p> <p>Open Cut Crossing: Appears feasible from a geotechnical point-of-view. Trench stability on the west side of the valley may be an issue – further investigation would be required. Due to high flows, isolation would not be possible at any time of the year.</p> <p>Difficult area on west side of valley Difficult terrain conditions in low lying areas. Shallow groundwater and ponded surface water. Muskeg and glaciolacustrine silts and clays with sand seams. There have been cut stability concerns along the local logging roads. Trench and cut stability may be a problem. Further geotechnical review recommended.</p> <p>Lateral erosion: Potential for lateral erosion to the west needs to be further evaluated in terms of lengths of crossings.</p>
672.85	687.05	<p>Across ridge and knob to rejoin existing road along north side of creek valley. Moderate slopes.</p> <p>Local observations: KP 673.35 to KP 674.35, KP 675.35 to KP 676.35: Frequent areas of muskeg overlying wet glaciolacustrine silt and clay with sand seams.</p> <p><u>Surficial geology</u> (Watt and Lord, 1975): Glaciolacustrine veneers over till and rock. GEM terrain mapping indicates moraine and areas of organics.</p> <p><u>Bedrock geology</u> (Armstrong et al., 1969) Lower Cambrian dolomite, limestone, quartzite and slate and Cambrian Kechika Group (limestone, calcareous siltstone and calcareous schist).</p>	<p>Areas of rock cut.</p> <p>Several stream crossings, some of which may have small alluvial fans.</p> <p>Detailed consideration of grading requirements in wet and organic soils will be required in some areas.</p> <p>Ground and surface water control required. Cross berms and possibly erosion matting, mulching or other measures may be required.</p>
687.05	697.95	<p>North side of valley tributary to Chuchinka Creek</p> <p><u>Surficial geology</u> (Watt and Lord, 1975) and Tipper (1971b): Glaciolacustrine veneers and blankets over till along lower parts of slopes. In bottom of valley, glaciofluvial and fluvial sediments. GEM terrain mapping also indicates morainal veneers.</p> <p><u>Bedrock geology</u> (Armstrong et al., 1969): Lower Cambrian dolomite, limestone, quartzite and slate; Cambrian Kechika Group (limestone,</p>	<p>Difficult terrain conditions in low lying areas. Shallow groundwater and ponded surface water. Muskeg and glaciolacustrine silts and clays with sand seams. There have been cut stability concerns along the local logging roads. Trench and cut stability may be a problem.</p> <p>Geotechnical ground review recommended.</p>



From (KP)	To (KP)	Geotechnical Conditions	Geotechnical Comments
		calcareous siltstone and calcareous schist); Sandpile Group (limestone, dolomite, quartzite, sandstone) and Triassic argillite, greywacke and shaley limestone.	<p>Cross slopes will need more detailed design. Also consideration of shallow slides on crests of cuts in steep areas (potential sedimentation and erosion issue). Bedrock requiring blasting will likely be encountered in cuts and trench.</p> <p>Ground and surface water control required. Cross berms and possibly erosion matting, mulching or other measures may be required.</p> <p>KP 695.15 – KP 697.15: Crosses several small creeks that may have alluvial fans. Further consideration of crossing designs may be required during detailed design.</p>
697.95	710.15	<p>Route runs across hummocky to knobby terrain with intervening valleys. Frequent rock drumlins and drumlins. Grain of land runs across route indicating that appreciable grading will be required. Local observation suggests wet surficial deposits in low areas consisting of glaciolacustrine silt and clay with sand interbeds. There have been cut and fill stability concerns along nearby logging roads.</p> <p><u>Surficial geology</u> (Watt and Lord, 1975 and Tipper, 1971): Over higher ridges and knobs, till veneers and blankets with local exposed rock. In lower areas, thicker glacial till overlain in some areas by glaciolacustrine veneers to blankets.</p> <p><u>Bedrock geology</u> (Armstrong et al., 1969): Lower Cambrian dolomite, limestone, quartzite and slate; Cambrian Kechika Group (limestone, calcareous siltstone and calcareous schist); Sandpile Group (limestone, dolomite, quartzite, sandstone) and Triassic argillite, greywacke and shaley limestone.</p>	<p>Locally extensive grading for large diameter pipelines. Rock will generally require blasting. Note the presence of quartzite.</p> <p>Difficult terrain conditions in low lying areas. Shallow groundwater and ponded surface water. Muskeg and glaciolacustrine silts and clays with sand seams. There have been cut stability concerns along the local logging roads. Trench and cut stability may be a problem. Geotechnical ground review recommended. Ground and surface water control required. Cross berms and possibly erosion matting, mulching or other measures may be required.</p> <p>KP 703.05: Chuchinka Creek crossing.</p>
710.15	710.95	<p>Angusmac Creek – KP 710.45</p> <p>Steep east approach slope with angles on the upper part of the slope up to 15 to 20° above the logging road, steepening to 25 to 30° below the road over vertical distances of 10 to 15 m (all estimated). Note that the logging road has been reconstructed higher up on the slope than shown on the 50K maps. The previous road appears to have been eroded out during past lateral erosion events. Rock is exposed along the toe of the east slope and at intervals along the logging road higher up on the east slope. The rock is fine grained metamorphics; no pyrite seen.</p>	<p>Depending on the crossing method, a substantial throughput will be required below the present logging road to reduce slopes down to the creek along the RoW. There was room for this cut between the crest of the slope and the road. The cut will likely be in rock. Ground and surface water control required including trench blocks (possibly with drain) at crest of slope and at intervals down slope.</p> <p>Open Cut Crossing: Appears feasible from a geotechnical point of view. A relatively long crossing would be required</p>



From (KP)	To (KP)	Geotechnical Conditions	Geotechnical Comments
		<p>The creek valley is wide and flat with rock exposures along the toe of the east approach slope. Banks are typically 2 to 3 m above the creek, with some higher banks. The creek is meandering with some cut-off meanders along the valley. The crossing is located on a meander loop projecting toward the west. There is a small high level channel across the back of the meander bend along the toe of the east approach slope that apparently flows at high water.</p> <p>The west approach slope is lower and the route is diagonally up the slope.</p> <p><u>Surficial geology</u> (Watt and Lord, 1975 and Tipper, 1971b): Organic blanket (muskeg) over glaciofluvial sediments. The Angusmac valley likely carried glaciofluvial flows and the possibility of an incised channel into bedrock cannot be ruled out at the time of writing. GEM terrain mapping and local observations indicate morainal deposits over shallow bedrock on east side and a glaciofluvial or fluvial terrace on the west side.</p> <p><u>Bedrock geology</u> (Armstrong et al., 1969): Slide Mountain Group basaltic pillow lavas, andesite, pyroclastic rocks, argillite, chert, greywacke. Fault bounded basin west of main McLeod Lake Fault.</p>	<p>due to lateral erosion conditions. Setback of the east sagbend into the toe of the slope and/or provision of riprap or other erosion protection may be required. Isolation is possible relative to flows for most of year.</p>
710.95	713.85	<p>Hummocky to knobby and/or ridged terrain with intervening valleys. Frequent rock drumlins and drumlins. Grain of land runs across pipeline route. Local observation suggests wet surficial deposits in low areas consisting of glaciolacustrine silt and clay with sand interbeds. There have been cut and fill stability concerns along nearby logging roads.</p> <p><u>Surficial geology</u> (Watt and Lord, 1975 and Tipper, 1971): Over higher ridges and knobs, till veneers and blankets with local exposed rock. In lower areas, thicker glacial till overlain in some areas by glaciolacustrine veneers to blankets.</p> <p><u>Bedrock geology</u> (Armstrong et al., 1969): Lower Cambrian dolomite, limestone, quartzite and slate; Cambrian Kechika Group (limestone, calcareous siltstone and calcareous schist); Sandpile Group (limestone, dolomite, quartzite, sandstone) and Triassic argillite, greywacke and shaley limestone.</p> <p>At end of segment, route crosses east part of McLeod Fault, a major regional fault zone. On the west side of fault, there are poor exposures</p>	<p>Locally extensive grading for large diameter pipelines. Rock will generally require blasting. Note the presence of quartzite.</p> <p>Difficult terrain conditions in low lying areas. Shallow groundwater and ponded surface water. Muskeg and glaciolacustrine silts and clays with sand seams. There have been cut stability concerns along the local logging roads. Trench and cut stability may be a problem.</p> <p>Geotechnical ground review recommended. Ground and surface water control required. Cross berms and possibly erosion matting, mulching or other measures may be required.</p>



From (KP)	To (KP)	Geotechnical Conditions	Geotechnical Comments
		of granitoid gneiss, micaceous, garnetiferous chloritic schists, pegmatite and small bodies of granodiorite.	
713.85	717.95	Route runs north of the Town of Bear Lake. Flat terrain. Typical local conditions are loose aeolian sand or fluvial gravel 5 to 10 m thick over clay till, gravelly. Frequent areas of muskeg. <u>Surficial geology</u> (Watt and Lord, 1975 and Tipper, 1971b): Organic blanket (muskeg) over glaciofluvial sediments. GEM terrain mapping indicates moraine with glaciofluvial terraces at west end of segment. <u>Bedrock geology</u> (Armstrong et al., 1969): Slide Mountain Group basaltic pillow lavas, andesite, pyroclastic rocks, argillite, chert, greywacke. Fault bounded basin west of main McLeod Lake Fault.	Near surface groundwater.
717.95	718.95	Crooked River – KP 718.25 Wet terrain underlain by muskeg. Route follows slightly higher ground where possible including an old winter road on east side of crossing. <u>Surficial geology</u> (Watt and Lord, 1975 and Tipper, 1971): Organic blanket (muskeg) over glaciofluvial sediments. Layers of boulders have been encountered in some of the sediments in this general area. Artesian conditions found in BH CR06-02. <u>Bedrock geology</u> (Armstrong et al., 1969): Slide Mountain Group basaltic pillow lavas, andesite, pyroclastic rocks, argillite, chert, greywacke. Fault bounded basin west of main McLeod Lake Fault. May be splays of McLeod Lake Fault. Local observations suggest deep granular deposits with surficial muskeg. Bedrock may be very deep.	Open Cut Crossing: Appears feasible from a geotechnical point-of-view but isolation may be very difficult due to presence of muskeg. Flows appear to be low enough for isolation except in April and May. Muskeg conditions in area may make construction difficult. Potential concerns could include trench stability. Artesian water pressures were encountered below trench depth in one investigation hole.
718.95	747.95	Ridged and drumlinoid terrain. Some ridges have rock exposed on crests of ridges. <u>Surficial geology</u> (Tipper, 1971): Ridged terrain, frequent drumlins and occasional rock drumlins. Glaciofluvial outwash channels with sand and gravel deposits. GEM terrain mapping indicates morainal deposits of variable depth. <u>Bedrock geology</u> (Armstrong et al., 1969) Rock mostly not exposed. Granitoid gneiss, micaceous, garnetiferous chloritic schists, pegmatite. Small bodies of granodiorite over a short area near center of segment.	Route runs across grain of drumlins, thus requiring significant grading for large diameter pipelines.
747.95	748.8	Muskeg River – KP 748.1 Muskeg east of crossing. Likely glaciofluvial sediments possibly overlying till. Bedrock may be very deep.	Open Cut Crossing: Appears feasible from a geotechnical point-of-view but muskeg east of crossing will need to be considered in more detail including depth and trench



From (KP)	To (KP)	Geotechnical Conditions	Geotechnical Comments
		<p>Low banks in a wide valley. Channel is gently curved toward the west and may be migrating slowly toward the west.</p>	<p>stability. Isolation would be possible most of the time based on flows except for April and May.</p>
748.8	761.0	<p>Ridged and drumlinoid terrain. Some ridges have rock exposed on crests of ridges. <u>Surficial Geology</u> (Tipper, 1971): Ridged terrain, frequent drumlins. Glaciofluvial outwash channels with sand and gravel deposits. Bedrock is likely deep.</p>	<p>Route runs across grain of drumlins, thus requiring significant grading for large diameter pipelines. Rock seen in the top of one drumlin near KP 752.4. KP 751.1: Crossing of Mossvale Creek</p>
761.0	762.7	<p>East approach slope to Salmon River valley. Sloping bench, gentle slopes down into river valley. <u>Surficial Geology</u> (Tipper, 1971): Ridged terrain, frequent drumlins. Glaciofluvial outwash channels with sand and gravel deposits. Bedrock is likely deep.</p>	<p>Surface and groundwater control required.</p>
762.7	763.3	<p><u>Salmon River – KP 763.1</u> Banks are about 3 m high. The river has eroded laterally over the entire valley floor leaving old channels, oxbows and meander scars. There is a large amount of debris along the channel and future lateral migration is likely to occur. <u>Surficial geology:</u> Armstrong and Tipper (1948) indicate up to 5 m of clay overlying deeper sediments. Past drilling in other areas has encountered interbedded sand, clay and gravel containing variable quantities of cobbles and boulders. Bed of river was predominantly sand with some areas of cobbles and boulders. Local observation indicated thick deposits of loose to compact fine sand. The Salmon River was a major glaciofluvial outwash channel at the end of the last glaciation. The river tends to erode laterally and concerns have been experienced on other pipeline crossings installed using trenched methods.</p>	<p>Lateral erosion: The Salmon River is highly mobile and has eroded laterally over most of the valley bottom. Lateral erosion and scour will need to be considered during detailed design. Open Cut Crossing: Feasible from a geotechnical point-of-view, but may be a very long and potentially deep crossing due to lateral migration of river. The crossing would likely need to extend across the entire valley bottom. Isolation using superflume could be considered with respect to flow conditions from August through March.</p>
763.3	763.5	<p><u>West approach slope to Salmon River</u> Slopes 15 to 25° over 70 m high. Shallow erosion draws on slope with deeper gullies near route. No stability issues identified during field reconnaissance at proposed crossing; however, there is some sliding to the south where the river is undercutting the slope. There is also a</p>	<p>Gullies on west slope will require further consideration in overall routing. Surface and ground water control required. Drains for trench blocks likely required. If shoofly is required, careful routing will be required due to</p>



From (KP)	To (KP)	Geotechnical Conditions	Geotechnical Comments
		possible slide to the north near a meander bend of a tributary creek.	potential for sediment generation in surficial soils and areas of sliding to the south. Detailed consideration of routing required.
763.5	810.5	Rolling upland terrain. <u>Surficial geology</u> (Tipper, 1971): Drumlinized till plain. Local observations indicate several glaciofluvial meltwater channels likely with sand and gravel infill. Muskeg veneers to blankets in bottoms of valleys and some other closed depressions. 798.7 to 801.2: Moderate sidehill. Shallow till over rock.	Several small creek crossings. Some will require grading of approach slopes. Surface and ground water control required. KP 763.6 and KP 763.9: Diagonal crossings of two tributary valleys to Salmon River. Substantial grading due to diagonal crossings of incised channels. Ground and surface water control required. Drains likely required. KP 780.3 Tributary to Great Beaver Creek: Grading of steep approach slopes will be required. Surface and ground water control required.
810.5	817.0	Route bends to the north along the east side of the Salmon River-Necoslie River valley south of Fort St. James. The route is predominantly through fields with some areas of low brush. <u>Surficial geology</u> : Local observations, water well information and drilling at Stuart River suggest deep glaciolacustrine sediments overlying sand or sand and gravel at depth. The sediments are infilling a large glaciofluvial outwash channel occupying a wide valley. The glaciolacustrine sediments appear to be deeper than the veneers indicated in Plouffe, 1996a. <u>Bedrock geology</u> (Struik, 1998): Siltstone, siliceous argillite, ribbon chert, slate, siltstone, conglomerate, chert conglomerate. Plouffe (2000) indicates a major regional fault down the Stuart River valley a short distance east of the proposed crossing.	Areas of shallow groundwater. There may be drains in some of the fields. Further ground checks of local conditions recommended during detailed design. Ground and surface water control. Trench blocks may be required in some areas to prevent migration of shallow groundwater along trench.
816.9	817.8	<u>Necoslie River – KP 816.4</u> Meandering river incised relative to terrain on both sides. Forested areas on both sides of crossing. River occupies the eastern part of a very wide glaciofluvial channel. Local observation suggests a possibility of high plasticity glaciolacustrine deposits (correlated with the Stuart Lake deposits) overlying sand and gravel at depth. Aerial review suggests local sliding as a result of banks and slopes being undercut by meandering stream. Significant grading would likely be required for a	Ground and surface water control. Trench blocks may be required in some areas to prevent migration of shallow groundwater along trench. Open Cut Crossing : Feasible from a geotechnical point-of-view. Relative to the stream flows, isolation would be possible at most times of year except in April and May. Significant cuts may be required.



From (KP)	To (KP)	Geotechnical Conditions	Geotechnical Comments
		trenched crossing in order to put the pipeline in stable soil under the slides. Further field examination required.	
817.8	821.0	Route runs across a very large former glaciofluvial channel. Mostly fields with some areas of low brush. <u>Surficial geology</u> (Plouffe, 1996a): Glaciolacustrine veneers and blankets. Material at depth is not indicated, but may be till or more likely glaciofluvial and glaciolacustrine sediments. Local observation indicates several small stream crossings and a few wet areas.	Local wet areas and areas of muskeg. There may be drains in some of the fields. Further ground checks of local conditions recommended during detailed design. Ground and surface water control. Trench blocks may be required in some areas to prevent migration of shallow groundwater along trench.
821.4	822.2	<p>Stuart River – KP 821.9</p> <p>Crossing is located toward western side of a very large former glaciofluvial channel. The proposed route is located north of the apparent north ends of deep-seated slides that extend along both sides of the valley.</p> <p>East valley slope has deep gullies that appear to be dry based on aerial reconnaissance. These gullies may have been formed by glacial run-off during deglaciation. The main slope segment on the east side is about 30 m high with a very steep upper area (up to 30°) near the crest of the slope with most of the lower part of the slope at 6 to 9°. There is a gently sloping apron or bench about 150 m wide (width varies) at the toe of the slope. There is a moderately deep-seated slide on the lower terrace that apparently extends up to the crest of the upper terrace in a few areas.</p> <p>The west valley slope is terraced with two main terrace levels below the uplands. The lower terrace has variable widths but is generally narrow. The upper terrace also varies in width but is typically 150 m wide or more. Both terraces are rolling with variations in elevation. The terrace fronts are at angles of 30° or more. The overall slope height to the uplands is about 30 m.</p> <p><u>Surficial geology</u> Local observations, water well information and drilling at Stuart River suggest deep glaciolacustrine sediments overlying sand or sand and gravel at depth. Based on projections from water wells and drill holes, the depths of glaciolacustrine material appear to extend from the uplands to well below the river channel, although there is some uncertainty and the possibility of gravel at higher elevations cannot be ruled out without drilling. The sediments are infilling a large glaciofluvial</p>	<p>Stability: A slide on the west side of the lower river terrace forms a significant constraint on crossing methods. A trenched crossing through the slide is not considered viable. Trenchless crossing methods should extend beyond the slide area. The stability of the upper parts of the slopes should be verified by ground reconnaissance.</p> <p>Open Cut Crossing: Not recommended due to stability concerns on lower terrace of west approach slope.</p> <p>Directionally Drilled Crossing: Viability will depend mainly on depth of the interface between the overlying glaciolacustrine clay and the underlying glaciofluvial sediments. Preliminary information indicates that there may be sufficient vertical room for an in-valley crossing but this will need to be further investigated during detailed design.</p> <p>Other Trenchless Methods: Appear to be viable subject to further investigation. Depth to gravel is an important issue.</p>



From (KP)	To (KP)	Geotechnical Conditions	Geotechnical Comments
		outwash channel occupying a wide valley. The glaciolacustrine sediments appear to be deeper than the veneers indicated in Plouffe, 1996a. <u>Bedrock geology</u> (Struik, 1998): Siltstone, siliceous argillite, ribbon chert, slate, siltstone, conglomerate, chert conglomerate.	
822.2	827.4	Flat to gently rolling terrain. <u>Surficial geology</u> : Local observations, water well information and drilling at Stuart River suggest deep glaciolacustrine sediments overlying sand or sand and gravel at depth. The sediments are infilling a large glaciofluvial outwash channel occupying a wide valley. The glaciolacustrine sediments appear to be deeper than the veneers indicated in Plouffe, 1996a. Scattered areas of muskeg. <u>Bedrock geology</u> (Struik, 1998) Siltstone, siliceous argillite, ribbon chert, slate, siltstone, conglomerate, chert conglomerate.	Some areas of muskeg. KP 825.5: Crossing of Pitka Creek.
827.4	830.4	Terrain rises. Ridged, with locally steep slopes, locally chaotic terrain, closed depressions (kettle holes). <u>Surficial geology</u> (Plouffe, 1996a): Sand and gravel ice contact deposits. Locally used as a source for aggregates. Locally called the eskers; eskers are present along the west edge of area and in other areas, but many of the ridges are a result of collapse of the formerly ice supported deposits. <u>Bedrock geology</u> (Struik, 1998): Eocene Endako and Ootsa Lake Groups andesite, basalt and associated volcanics.	Some areas of muskeg in kettle holes and on lower areas. Locally high or perched groundwater. Appreciable grading in sand and gravel depending on route across area. Surface and ground water control required.
830.4	841.6	Rolling to hummocky terrain. <u>Surficial geology</u> (Plouffe, 1996a): Mainly hummocky glacial till. Small meltwater channels with glaciofluvial materials throughout. Scattered areas of muskeg. <u>Bedrock geology</u> (Struik, 1998) Siltstone, siliceous argillite, ribbon chert, slate, siltstone, conglomerate, chert conglomerate.	Some areas of muskeg. Surface and ground water control required in local areas of steep terrain.
841.6	853.7	Terrain rises. Rolling to hummocky. <u>Surficial geology</u> (Plouffe, 1996a): Mainly hummocky glacial till veneers and blankets over shallow rock. Some areas of outcrop and scattered areas of muskeg. <u>Bedrock geology</u> (Struik, 1998): Eocene Endako and Ootsa Lake Groups andesite, basalt and associated volcanics.	Some areas of muskeg. Steep slope at end of segment should be examined geotechnically. No problems identified from aerial reconnaissance or on airphotos. Surface and ground water control required on slopes.
853.7	872.7	Mainly low elevation terrain along old glaciofluvial channels. Terrain rises toward west end of segment.	Some areas of muskeg. Surface and ground water control required on slopes.



From (KP)	To (KP)	Geotechnical Conditions	Geotechnical Comments
		<p><u>Surficial geology</u> (Plouffe, 1996a): Glaciofluvial terraces (sand and gravel), some kettle holes, scattered areas of muskeg, some eskers. Some areas of till toward the west.</p>	
872.7	929.15	<p>Rolling and ridged terrain east of Burns Lake. Congested at end of segment.</p> <p><u>Surficial geology</u> (Plouffe, 1996b): Mainly glacial till veneers and blankets. Some areas of outcrop and scattered areas of muskeg.</p> <p><u>Bedrock geology</u> (Rice, 1948) Endako Group volcanics and granodiorite and related intrusive rocks.</p>	<p>No major geotechnical concerns identified.</p> <p>Rock grading and rock trench across the crests of several ridges.</p> <p>Surface and ground water control required on slopes.</p> <p>Fill may need to be minimized on some cross slopes.</p>
929.15	929.55	<p>Endako River – KP 929.3 between Decker Lake and Burns Lake. Congested area on east side with highway, various buildings and infrastructure and rail tracks along east side of channel.</p> <p><u>Surficial geology</u> (Plouffe, 1996b): Deltaic sediments deposited as an alluvial and glaciofluvial fan and delta from the west side of the valley cutting the former lake in two. Sand and gravel overlying silt and clay. Till veneers over rock underlying valley walls east and west of crossing. Glaciofluvial terrace directly south of the crossing and there are likely glaciofluvial sediments at depth in the valley. Local observation indicates muskeg along both sides of the river.</p> <p><u>Bedrock geology</u> (Rice, 1948): East side: Eocene conglomerate, sandstone and shale. West side (west of edge of valley): Jurassic or Cretaceous Hazelton Group (volcanics and minor sedimentary rocks).</p>	<p>Directionally Drilled Crossing: Preliminary drilling results indicate geological difficulties including boulders and gravel. Not favoured geotechnically.</p> <p>Open Cut Crossing: Feasible from a geotechnical point-of-view. The railway on the east side the channel and soft muskeg near the channel would need to be further considered. While flows are lower than the limits for isolation, isolation would require special methods due to the depth of the channel.</p>
929.55	948.05	<p>Upland terrain including most of east approach slope to Maxan Creek which in part is a regional ridge (see below). Terrain has strongly developed broad ridges running north-south.</p> <p><u>Surficial geology</u> (Tipper, 1994 and Plouffe, 2000): Till veneer and blanket deposits over shallow rock with scattered areas of organics (muskeg) and small areas of glaciofluvial deposits. Thicker and more laterally continuous areas of organics in some larger valleys.</p> <p><u>Bedrock geology</u> (Tipper, 1976) Eocene and Oligocene Buck Creek Volcanics (andesite, dacite, minor basalt).</p>	<p>KP 941.45: Gerow Creek: Probable glaciofluvial channel with sediments, although not mapped as such.</p> <p>Some areas of moderate to steep slopes.</p> <p>Ground and surface water control required on some steep slope segments.</p>
948.05	948.25	<p>Maxan Creek – KP 948.05</p> <p>Long gentle to moderate approach slope on east side. The stream valley bottom is about 250 m wide. East of the creek, conditions in the spruce cover appeared to be wet. The conditions at the creek channel itself may be a bit drier and the terrain on the west side is also drier. Creek channel appeared to be deep, about 5 to 10 m wide with a few</p>	<p>There are some areas of rilling on the east approach slope that should be avoided or mitigated. No stability problems identified from aerial reconnaissance on either approach slope.</p> <p>Sagbend locations will need to consider the width of the</p>



From (KP)	To (KP)	Geotechnical Conditions	Geotechnical Comments
		<p>beaver dams. Flowing very slowly. Gravel bars on the west side, meandering. Very gentle approach slope on west side with heavy forest cover.</p> <p><u>Surficial geology</u> (Tipper, 1994 and Plouffe, 2000): Till veneer and blanket deposits over shallow rock with scattered areas of organics (muskeg) on approach slopes. Thicker and more laterally continuous areas of organics in lower part of valley probably overlying glaciofluvial deposits.</p> <p><u>Bedrock geology</u> (Tipper, 1976) Eocene and Oligocene Buck Creek Volcanics (andesite, dacite, minor basalt)</p>	<p>meander band (perhaps 150 to 175 m) and the potential for lateral erosion (appeared to be low).</p> <p>Ground and surface water control on long east approach slope.</p>
948.25	957.15	<p>Upland terrain with strongly developed broad ridges running north-south and deeply incised valleys.</p> <p><u>Surficial geology</u> (Tipper, 1994 and Plouffe, 2000): Till veneer and blanket deposits over shallow rock with scattered areas of organics (muskeg) and small areas of glaciofluvial deposits. Thicker and more laterally continuous areas of organics in some larger valleys.</p> <p><u>Bedrock geology</u> (Tipper, 1976) Eocene and Oligocene Buck Creek Volcanics (andesite, dacite, minor basalt).</p>	<p>No geotechnical problems identified.</p> <p>Ground and surface water control on slopes.</p>
957.15	960.25	<p>South of Foxy Creek approximately parallel to existing road.</p> <p><u>Surficial geology</u>: GEM terrain mapping indicates mostly till with a few areas of muskeg.</p> <p><u>Bedrock geology</u> (Tipper, 1976): Goosly Volcanics, trachytic flows and sills.</p>	<p>An area of known ARD issues exists west of the route at Equity Silver Mine. No rock formations similar to those that are acid generating at Equity have been identified during ground reconnaissance work to date.</p>
960.25	960.75	<p>Foxy Creek – KP 960.4</p> <p>Creek flows toward the east in a valley with approach slopes sloping approximately 15°. The slope on the south side is part of a rounded ridge. The slope on the north side is approximately 40 m high.</p> <p><u>Surficial geology</u> (Tipper, 1994): Glaciofluvial outwash sediments in outwash channel.</p> <p><u>Bedrock geology</u> (Tipper, 1976): Buck Creek Volcanics (andesite, dacite, minor basalt).</p>	<p>An area of known ARD issues exists at Equity Silver Mine. No rock formations similar to those that are acid generating at Equity have been identified along the route during ground reconnaissance work to date.</p> <p>Ground and surface water control on slopes.</p>
960.75	964.35	<p>Upland area north of Foxy Creek, rolling to gently sloped terrain with occasional steep areas on upper parts of ridges. Local pockets of muskeg.</p> <p><u>Surficial geology</u> (Tipper, 1994): Extensive glaciofluvial outwash sediments forming valley infill. Local observations indicate several</p>	<p>Local pockets of muskeg.</p> <p>Areas of rock outcrop on ridges and possibly a few creek crossings.</p> <p>Note: Route in part of this area would be affected by</p>



From (KP)	To (KP)	Geotechnical Conditions	Geotechnical Comments
		<p>steep areas of rock outcrop adjacent to route. GEM terrain mapping indicates till with scattered organics. <u>Bedrock geology (Tipper, 1976):</u> Buck Creek Volcanics (andesite, dacite, minor basalt).</p>	<p>reroute discussed above.</p>
964.35	975.65	<p>Upland terrain with two crossings of Foxy Creek. <u>Surficial geology (Tipper, 1994):</u> Extensive glaciofluvial outwash sediments forming valley infill. Local observations indicate several steep areas of rock outcrop adjacent to route. GEM terrain mapping indicates till with scattered organics. GEM terrain mapping indicates mostly till with some fluvial deposits along creeks. <u>Bedrock geology (Tipper, 1976):</u> Buck Creek Volcanics (andesite, dacite, minor basalt); Goosly Lake Volcanics (trachytic flows and sills); China Nose Breccias (glassy basaltic breccias, some water lain sediments).</p>	<p>KP 964.55 Crossing of Foxy Creek KP 966.95 Crossing of Foxy Creek Ground and surface water control on slopes.</p>
975.65	985.1	<p>Upland terrain. Several stream crossings, generally low to moderate slopes. <u>Surficial geology (Tipper, 1994):</u> Higher elevation terrain that may not have been glaciated during last glaciation (Fraser glaciation). Older glacial and glaciofluvial deposits. GEM terrain mapping indicated mostly till of variable depth. Glaciofluvial deposits toward end of segment. <u>Bedrock geology (Tipper, 1976):</u> Eocene and Oligocene Endako Group: Buck Creek Volcanics (andesite, dacite, minor basalt) and China Nose Breccias (glassy basaltic breccias, some water lain sediments).</p>	<p>Some areas of rock outcrop along crests of a few ridges. Ground and surface water control on slopes.</p>
985.1	985.8	<p><u>Buck Creek – KP 986.7</u> East approach slope is gentle, with moderate slopes farther east. No stability problems noted. There is a road partway up the west slope which is terraced with variable slopes that are locally moderate to steep. The stream is meandering with lateral erosion of the meanders evident. There were several oxbows along the valley bottom near and west of the crossing. The valley bottom is wet with muskeg. The wet ground with numerous oxbow ponds extends up to a logging road on the toe of the west valley slope. There is dead standing timber either from a fire (most likely) or from an increase in water elevation. There were a few beaver dams, but no appreciable ponds. The bottom is</p>	<p>Locations of sagbends should consider ongoing lateral erosion of stream. A long crossing over most of the width of the valley bottom may be required. Geotechnical ground reconnaissance recommended. Open Cut Crossing: Feasible from a geotechnical point-of-view. Based on predicted flows, isolation using dam and pump or flume, depending on flows, would be possible over most of the year, except May and June.</p>



From (KP)	To (KP)	Geotechnical Conditions	Geotechnical Comments
		<p>cobbles with a few boulders. There was a lot of flaggy rock along the bottom and the bottom of the stream channel may be close to bedrock. The west approach slope is gentle to moderate.</p> <p><u>Surficial geology</u> (Tipper, 1994): On west edge of higher elevation terrain that may not have been glaciated during last glaciation (Fraser glaciation). Older glacial and glaciofluvial deposits. Buck Creek valley is at the junction of two glaciofluvial outwash valleys to the south. Local observation indicates fine sediments including sand on floodplain.</p> <p><u>Bedrock geology</u> (Tipper, 1976): Eocene and Oligocene Endako Group: Buck Creek Volcanics (andesite, dacite, minor basalt) to east and some areas of intrusives (granodiorite and quartz monzonite) to west. Major regional fault running to northwest controls local creek valley and channel. Bedrock map indicates thick alluvium (probably glaciofluvial) along Buck Creek.</p>	<p>Ground and surface water control required on slopes. Trench blocks will likely need drains.</p>
985.8	999.85	<p>Lower terrain through tributary valley to Buck Creek at start of segment and then across higher rock controlled ridges to west.</p> <p><u>Surficial geology</u> (Tipper, 1994) Outwash in glaciofluvial outwash valley tributary to Buck Creek. To west, till (depth not indicated) overlying rock. Local observation suggests several areas of outcrops and probably relatively shallow rock across western half of segment. GEM terrain mapping indicates predominantly till with some areas of veneer and blankets. Local observations indicate several areas of rock outcrops between KP 993 and 998.</p> <p><u>Bedrock geology</u> (Tipper, 1976) Tiptophill Volcanics (biotite hornblende andesite and andesitic dacite, part of Ootsa Lake Group); Bulkley intrusives (granodiorite and quartz monzonite); Telkwa Formation (variegated red, maroon, grey green breccia, tuff and flows (basalt to rhyolite) near west end of segment.</p>	<p>Bedrock controlled ridges with several areas of outcrop. Local areas of steep slopes along ridges.</p> <p>KP 993.2: Parrott Creek crossing. Meandering creek with gentle to moderate sideslopes.</p> <p>Ground and surface water control required on slopes.</p>
999.85	1002.3	<p>Rolling terrain with typically gentle to moderate slopes.</p> <p><u>Surficial geology</u> (Tipper, 1994) GEM terrain mapping indicates glaciofluvial sediments along valley.</p> <p><u>Bedrock geology</u> (Tipper, 1976): Much of area is drift covered, but some outcrops of Telkwa Formation (variegated red, maroon, grey green breccia, tuff and flows (basalt to rhyolite) and undivided volcanics.</p>	<p>Glaciolacustrine sediments have triggered major instabilities farther north. Grading plans involving significant cuts and fills should be reviewed in detail in this area.</p> <p>Ground and surface water control required on slopes including gentle slopes toward the Morice River/Owen Creek area.</p>
1002.3	1002.7	Owen Creek – KP 1002.5	Detailed ground reconnaissance work may suggest minor



From (KP)	To (KP)	Geotechnical Conditions	Geotechnical Comments
		<p>Slightly meandering creek slightly misfit on a flat valley bottom with moderately steep approach slopes to east and west. Spawning channels downstream near Morice River.</p> <p><u>Surficial geology</u> (Tipper, 1994) To west, till (depth not indicated) overlying rock. Local observation suggests areas of rock outcrops across ridges. GEM terrain mapping indicates predominantly glaciolacustrine sediments. Local observation and past experience indicates that there may also be glaciolacustrine sediments in the area.</p> <p><u>Bedrock geology</u> (Tipper, 1976): Outcrops of Telkwa Formation (variegated red, maroon, grey green breccia, tuff and flows (basalt to rhyolite) and undivided volcanics.</p>	<p>changes in alignment.</p> <p>Approach slopes may require local pull back. Ground and surface water control including trench blocks and likely drains will be required.</p>
1002.7	1007.7	<p>Upland terrain.</p> <p>Gently to moderately sloping terrain, mostly within existing cut blocks.</p> <p><u>Surficial geology</u> (Tipper, 1994) Till. GEM terrain mapping indicates till blankets, some areas of rock outcrops, local glaciofluvial sediments.</p> <p><u>Bedrock geology</u> (Tipper, 1976): Outcrops of Telkwa Formation (variegated red, maroon, grey green breccia, tuff and flows (basalt to rhyolite) and undivided volcanics.</p>	<p>Ground and surface water control on areas of slopes.</p>
1007.7	1008.1	<p><u>Tributary to Fenton Creek and Fenton Creek KP 1007.5 and KP 1007.9</u></p> <p>Steep slopes on both streams.</p> <p><u>Surficial geology</u> (Tipper, 1994) Till. GEM terrain mapping indicates till or colluvium blankets.</p> <p><u>Bedrock geology</u> (Tipper, 1976): Sporadic outcrops of undifferentiated volcanics</p>	<p>Ground reconnaissance recommended.</p> <p>Slopes may need to be pulled back to shallower angles. Shoofly around area including existing forestry roads will be required for access.</p> <p>Ground and surface water control including trench blocks and drains.</p>
1008.1	1013.2	<p>Upland terrain.</p> <p>Gently to moderately sloping terrain, mostly within existing cut blocks.</p> <p><u>Surficial geology</u> (Tipper, 1994) Till. GEM terrain mapping indicates till blankets, some areas of rock outcrops, local glaciofluvial sediments, some areas of shallow muskeg.</p> <p><u>Bedrock geology</u> (Tipper, 1976): Outcrops of Telkwa Formation (variegated red, maroon, grey green breccia, tuff and flows (basalt to rhyolite) and undivided volcanics.</p>	<p>Ground and surface water control as required. Direct water away from slopes into stream valleys.</p> <p>KP 1010.1 Tributary to Morice River.</p> <p>Slopes will likely need to be pulled back to shallower angles. Ground and surface water control including trench blocks and drains.</p>
1013.2	1014.1	<p><u>24.5 Mile Creek KP 1013.5</u></p> <p>Crossing of creek and tributary to west.</p> <p><u>Surficial geology</u> (Tipper, 1994) Till. GEM terrain mapping indicates till blankets, some areas of rock outcrops, and glaciofluvial sediments.</p>	<p>Minor adjustment of route may be required, in particular on east side where route at present appears to sidehill into the creek. Ground reconnaissance recommended.</p> <p>Slopes will likely need to be pulled back. Shoofly around</p>



From (KP)	To (KP)	Geotechnical Conditions	Geotechnical Comments
		<u>Bedrock geology</u> (Tipper, 1976): Outcrops of Telkwa Formation (variegated red, maroon, grey green breccia, tuff and flows (basalt to rhyolite) and undivided volcanics.	area including existing forestry roads will be required for access. Ground and surface water control including trench blocks and drains.
1014.1	1018.2	Upland terrain. Gently to moderately sloping terrain, mostly within existing cut blocks. <u>Surficial geology</u> (Tipper, 1994) Till. GEM terrain mapping indicates till blankets, some areas of rock outcrops, local glaciofluvial sediments, some areas of shallow muskeg. <u>Bedrock geology</u> (Tipper, 1976): Outcrops of Telkwa Formation (variegated red, maroon, grey green breccia, tuff and flows (basalt to rhyolite) and undivided volcanics.	Ground and surface water control including trench blocks and drains. KP 1017.4 Tributary of Lamprey Creek
1018.2	1019.2	Lamprey Creek KP 1018.5 Steep slopes into and out of creek. Small slide on east slope. <u>Surficial geology</u> (Tipper, 1994) Till. GEM terrain mapping indicates glaciofluvial sediments and till. Local observations suggest that glaciolacustrine sediments may also be present. <u>Bedrock geology</u> (Tipper, 1976): Outcrops of Telkwa Formation (variegated red, maroon, grey green breccia, tuff and flows (basalt to rhyolite) and undivided volcanics.	Ground reconnaissance of area recommended. Small adjustments of route may be required to miss slide. Slopes will likely need to be pulled back. Shoofly around area including existing forestry roads will be required for access. Ground and surface water control including trench blocks and drains.
1019.2	1024.5	On sidehill just above terrace bordering Morice River. Route follows a bench for much the length of the segment. <u>Surficial geology</u> (Tipper, 1994) Till. GEM terrain mapping indicates till and some fluvial sediments. Based on local observation, the presence of glaciolacustrine sediments cannot be excluded. <u>Bedrock geology</u> (Tipper, 1976): Micaceous greywacke, shale, minor conglomerate and shale).	Crossings of streams tributary to Morice River. Detailed consideration of cut design required. Keep all cuts and fills as low as possible, use narrow than standard grade if required to do this. Do not divert surface water down RoW. Ground and surface water control required.
1024.5	1030.6	Higher terrain including sidehill terrain and benches south of Morice River. <u>Surficial geology</u> (Tipper, 1994) Till, some areas of shallow rock. GEM terrain mapping indicates similar. <u>Bedrock geology</u> (Tipper, 1976): Micaceous greywacke, shale, minor conglomerate and shale.	KP 1025.8 Cedric Creek Ground and surface water control required.
1030.6	1037.4	On sidehill paralleling south side of existing logging road. Tight area on sidehill. Frequent rock exposures along road cut.	Detailed consideration of cut design recommended. Keep all cuts and fills as low as possible, use narrow than



From (KP)	To (KP)	Geotechnical Conditions	Geotechnical Comments
		<p>Route on south side of road is preferred due to slides at some locations (KP 1034.8 to KP 1035.8) and steep sideslopes.</p> <p><u>Surficial geology</u> (Tipper, 1994) Till. GEM terrain mapping indicates till blankets and steep rock.</p> <p><u>Bedrock geology</u> (Tipper, 1976): Telkwa Formation (variegated red, maroon, grey green breccia, tuff and flows (basalt to rhyolite) and undivided volcanics and undifferentiated volcanics.</p>	<p>standard grade if required to do this. Do not divert surface water down RoW.</p> <p>Ground and surface water control required.</p>
1037.4	1038.6	<p>Route turns and runs down slope toward Morice River Morice River KP 1038.0</p> <p>Moderate slope on south side of river has variable slopes and a terrace near the toe. Areas of rock outcrop high on the slope but no outcrop found lower on slope. River is relatively stable and does not appear subject to appreciable lateral erosion. Route is parallel to existing logging road bridge.</p> <p><u>Surficial geology</u> (Tipper, 1994) Glaciofluvial deposits. GEM terrain mapping indicates extensive glaciofluvial deposits near river and on north side of river with till blankets partway up the slope.</p> <p><u>Bedrock geology</u> (Tipper, 1976): Telkwa Formation (variegated red, maroon, grey green breccia, tuff and flows (basalt to rhyolite) and undivided volcanics. Some northeast to northwest oriented faults in area.</p>	<p>Directionally Drilled Crossing: Geometrically feasible, but detailed geology conditions not known. There is a possibility of coarse glaciofluvial sediments that could be a problem for a directionally drilled crossing depending on depth. Further investigations required.</p> <p>Trenched Crossing: Feasible from a geotechnical point-of-view. Flows are too high for isolation at all times of year.</p> <p>Ground and surface water control required on south side of river.</p>
1038.6	1058.6	<p>Route runs along undulating bench on the south side of the Gosnell Creek valley. At end of segment, route runs out across south valley floor of Gosnell Creek. Gentle slopes. Parallel or near logging roads.</p> <p><u>Surficial geology</u> (Tipper, 1994): Extensive glaciofluvial outwash at east end of segment. To the west, the valley was a glaciofluvial outwash channel and there are likely glaciofluvial deposits along the valley as suggested by the aerial reconnaissance. Based on the aerial reconnaissance, the deposits along the bench may be a mixture glacial till and glaciofluvial outwash. The proposed route on the south side of the valley would miss most of the areas of muskeg along the valley floor. GEM terrain mapping indicated mostly till except extensive glaciofluvial deposits near Tributary to Gosnell Creek (KP 1044) and to the west. West of KP 1046 (approx.) route is on toe of till covered south valley slope of Gosnell Creek valley. Extensive glaciofluvial deposits along valley bottom. KP 1057 – route bends away from main valley slope across valley bottom toward Gosnell Creek crossing.</p>	<p>Numerous small tributaries to Gosnell Creek in addition to those noted.</p> <p>KP 1044.4 Crystal Creek (tributary to Gosnell Creek). Possible small alluvial fan. Route may need adjustment of route within corridor due to lateral erosion of stream and meander bend to north. Crossing design will need to consider lateral and possibly downcutting erosion.</p> <p>KP 1057.0 Tributary stream to Gosnell River valley has alluvial fan and may be subject to avulsion. Crossing design will need to consider lateral and possibly downcutting erosion.</p> <p>Ground and surface water control required on slopes.</p>



From (KP)	To (KP)	Geotechnical Conditions	Geotechnical Comments
1058.6	1059.1	<p><u>Bedrock geology</u> (Tipper, 1976): Telkwa Formation (part of Hazelton Group) variegated red, maroon, grey breccia, tuff and flows.</p> <p>Gosnell Creek. – KP 1058.9 Gravel bottom meandering stream. Areas of muskeg and generally high groundwater table across valley bottom.</p> <p><u>Surficial geology</u> (Tipper, 1994): Glaciofluvial deposits along the valley as suggested by aerial reconnaissance. Areas of muskeg.</p> <p><u>Bedrock geology</u> (Tipper, 1976): Telkwa Formation (part of Hazelton Group) variegated red, maroon, grey breccia, tuff and flows.</p>	<p>Open Cut Crossing: Appears to be feasible from a geotechnical point-of-view. Suitable allowance for lateral erosion would be required. Based on flows, isolation possible December through April using flumes.</p>
1059.1	1066.1	<p>Ridged terrain through pass at headwaters of Gosnell Creek and a tributary of the Burnie River to the west. Existing logging roads end beyond Gosnell Creek crossing. The route generally runs along the toes of slopes on the north side past an unnamed lake in the pass south of the route. At west end, route runs south of another small lake.</p> <p><u>Surficial geology</u> (Tipper, 1994): Tipper indicates main glaciofluvial channel was along the alignment of the lakes south of the proposed route. Based on aerial reconnaissance, the deposits along the proposed route likely consist of glacial till, glaciofluvial sediments, local alluvium, and colluvium overlying shallow rock with rock exposures. There are areas of muskeg. GEM terrain mapping indicated</p> <p><u>Bedrock geology</u> (Tipper, 1976): Telkwa Formation (part of Hazelton Group) variegated red, maroon, grey breccia, tuff and flows on west side.</p>	<p>KP 1060.6: Tributary to Gosnell Creek</p> <p>Difficult area: KP 1060.3 to KP 1065.8: Gentle to moderate sideslope with steep segments. Rock ridges, frequent small streams, rough cross slope topography. Ground reconnaissance and detailed consideration of grading design. Cross berms and trench blocks will be required to some extent depending on final grading design.</p> <p>Cuts through ridges of Telkwa Formation may have poorer stability and require flatter angles than other typical rock formations encountered elsewhere on the route, depending on local rock properties.</p> <p>Toward the end of the segment, the route runs down the moderate to locally steep slopes forming the south approach slope to the Burnie Creek valley. There are stability concerns to the west along the side of this ridge that were seen from the air (route was adjusted to miss these areas). Adjustment of the route relative to a small tributary stream channel may also be required. Further ground geotechnical reconnaissance of the route on the side of the ridge is recommended.</p> <p>Ground and surface water control. Trench blocks will be required at some locations. Detailed consideration of cuts on sideslopes, particularly near streams.</p>



From (KP)	To (KP)	Geotechnical Conditions	Geotechnical Comments
1066.1	1067.3	<p>Tributary to Burnie River in pass area. <u>Surficial geology</u>: Observations from air indicated alluvial fan that may be subject to avulsion. May have alluvial fan subject to avulsion. Also may be subject to debris torrents, although it appears that the main deposition area may be upstream of crossing.</p>	<p>Alluvial fan KP 1066.0 to KP 1067.0: Alluvial fan with old channels. Possible avulsion should be further reviewed on LiDAR when available and in field. Possible debris flows, although main area of deposition appeared to be upstream of pipeline route. Location of crossing, depth of cover and length of crossing relative to possible avulsion and erosion should be reviewed during detailed design.</p>
1067.3	1069.4	<p>Route runs south of a small lake. . <u>Surficial geology</u> (Tipper, 1994): Tipper indicates main glaciofluvial channel was along the alignment of the lakes south of the proposed route. Based on aerial reconnaissance, the deposits along the proposed route likely consist of glacial till, glaciofluvial sediments, local alluvium, and colluvium overlying shallow rock with rock exposures. There are areas of muskeg. GEM terrain mapping indicated <u>Bedrock geology</u> (Tipper, 1976): Telkwa Formation (part of Hazelton Group) variegated red, maroon, grey breccia, tuff and flows on west side.</p>	<p>Ground and surface water control on slopes.</p>
1069.4	1071.1	<p>Route runs parallel to but below crest of large ridge. Near end of segment, bends and runs directly downslope on ridge. Local observation indicates shallow glacial till on upper part of ridge with glaciofluvial and sediments on lower part of ridge. <u>Bedrock geology</u> (Tipper, 1976): Telkwa Formation (part of Hazelton Group) variegated red, maroon, grey breccia, tuff and flows on west side. May be intrusives on parts of ridge.</p>	<p>Shallow bedrock with some areas of rock cut. KP 1070.3 to KP 1071.1 (approx.) Shoofly required in area for approach to east end of Clore tunnel. KP 1070.8 (approx.) Possible shallow slide in colluvium or till to north of route.</p>
1071.1	1071.4	<p>Tributary to Burnie River – KP 1071.2 Stream is incised into glaciofluvial and possibly glaciolacustrine sediments with two areas of lower slopes. Slightly meandering stream. <u>Surficial geology</u>: Local mapping indicates remnant glaciofluvial terraces and possibly glaciolacustrine deposits. Much of these deposits have been removed by the downcutting of the Clore since the end of glaciation (see below). <u>Bedrock geology</u> (Read 2006): Red Rose Formation: Micaceous greywacke, grey to black shale; some conglomerate and coal. Coast Range Plutonics on south side of valley.</p>	<p>Open Cut Crossing: Appears to be feasible from a geotechnical point-of-view. Isolation appears possible based on flows but superflume would be required over the summer months.</p>



From (KP)	To (KP)	Geotechnical Conditions	Geotechnical Comments
1071.4	1072.3	<p>Route runs across Clore valley.</p> <p><u>Surficial geology</u> As above. Local deposits of glaciofluvial and alluvial sediments, muskeg. Generally shallow bedrock. Work by Read (2006) and local observations indicate that stream piracy and erosion of the Clore River Canyon has resulted in lowered base levels and erosion of much of the formerly existing valley fill, exposing bedrock along parts of the river valley bottoms and/or reducing the cover.</p> <p><u>Bedrock geology</u> (Read 2006): Red Rose Formation: Micaceous greywacke, grey to black shale; some conglomerate and coal. Coast Range plutonic rock on south side of valley.</p>	Ridged to knobby terrain with frequent areas of weak bedrock.
1072.3	1072.8	<p>Clore River – KP 1072.5</p> <p>Crossing of Clore River. Narrow terrace on south side with river incised up to approximately 30 m depending on location. Variable but locally steep slope on east side of crossing. Some areas of shallow sliding where undercut by river.</p> <p>Relatively wide alluvial braided channel. River discharges from a rock canyon approximately 500 m upstream of Rev R centerline and is tending to fan out and erode laterally. Fluvial gravel deposits subject to erosion over a width of about 150 m. West side has two low terraces, the lowest terrace is being eroded laterally by river. River appears to be eroding laterally on both sides and the extent of active lateral erosion will likely increase in the future.</p> <p><u>Surficial geology</u>: Work by Read (2006) indicates that a lowering of base level due to post-glacial erosion of the Clore River canyon has resulted in erosion and removal of most of the glacial and glaciofluvial deposits along what is now the Clore valley upstream of the canyon. Shallow or bare rock with sometimes deeply incised streams. Some valleys in bedrock infilled with sediments.</p> <p><u>Bedrock geology</u> (Read 2006): Red Rose Formation: Micaceous greywacke, grey to black shale; some conglomerate and coal. Pyrite seen in formation by P. Read during preliminary field work.</p>	<p>Crossing design should consider lateral erosion which may extend both to the east and west in future. The final design and possibly location of the crossing will need to consider the location and design of the east portal of the Clore Tunnel. Further consideration during detailed design may be required.</p> <p>Open Cut Crossing: Feasible, but relatively long (perhaps 200 m or more). Both lateral and scour erosion would need to be considered in design. Isolation only possible January to March and would be marginal for flume (superflume likely required). Seepage through gravel substrates may be an issue.</p> <p>Directional drilling: Appears to be geometrically not feasible on the Rev R alignment.</p>
1072.8	1079.2	<p>Clore Tunnel</p> <p>Tunnel under ridge west of Clore Canyon.</p> <p>See AMEC (2009a).</p>	
1079.2	1080.4	Tributary to Clore River – KP 1079.8	Aerial Crossing: Preferred method from geotechnical



From (KP)	To (KP)	Geotechnical Conditions	Geotechnical Comments
		<p>Crossing at Rev. P (close to preferred route in this area) would be at a deep canyon with near vertical walls (depth uncertain but approx. 50 m). Shoofly crossing is available a short distance to south.</p> <p><u>Surficial geology</u>: GEM Terrain Mapping - Colluvial and till deposits, mostly thin on top of bench. Steep rock slopes.</p> <p><u>Bedrock geology</u> Read (2006): Middle Member Telkwa Formation: variegated breccia, tuff and flows.</p>	<p>point-of-view. Additional geotechnical engineering to examine foundation conditions at crossing will be required.</p>
1080.4	1086.9	<p>Hoult Tunnel Tunnel under Nimbus Mountain. See AMEC (2009a).</p>	
1086.9	1087.2	<p>Hoult Creek – KP 1086.9 Crossing would be located upstream of waterfall where the creek is small and shallow with low banks at the head of a canyon that deepens downstream.</p> <p><u>Surficial geology</u>: Scree slopes and shallow rock. Till veneers and colluvium at lower elevations. Extensive alluvial deposits along creek channels.</p> <p><u>Bedrock geology</u> Read (2006): Granite, granodiorite and related intrusives of various ages.</p>	<p>Crossing close to an area of avalanches and rockfall but crossing and route appear to be clear of problem area.</p> <p>Aerial Crossing: Additional geotechnical engineering to examine foundation conditions at crossing will be required.</p>
1087.2	1089.75	<p>Through cut blocks on north side of Hoult Creek. Moderate sideslopes with locally steeper areas of sideslope.</p> <p><u>Surficial geology</u>: Glacial till and possible glaciofluvial sediments with areas of exposed or shallow bedrock.</p> <p><u>Bedrock geology</u>: Read (2006): Bulkley Intrusions(?) (Post-tectonic quartz diorite, diorite, granodiorite; more hornblende than biotite; fresh, altered; unfoliated to weakly foliated). Middle Member Telkwa Formation: variegated breccia, tuff and flows.</p>	<p>KP 1088.0: Stream crossing at approximately KP 1088.0 may be considered slightly higher on slope from a geotechnical point-of-view. Stream may be subject to debris flows.</p> <p>Difficult cross slopes Start of area where detailed geotechnical, hydrotechnical and civil engineering planning using cross sections is recommended during detailed design. Variable but locally steep cross slopes with incised creeks, some of which are subject to debris flows.</p>
1089.75	1098.4	<p>Steep sideslopes along road above Hoult Creek and Kitimat River.</p> <p><u>Surficial geology</u>: Elevations above approximately 225 m which is expected to be above elevation of marine transgression. Glacial till veneers to blankets, colluvium and glaciofluvial sediments. Some of these materials are on sloping rock surfaces. Areas of seepage.</p> <p><u>Bedrock geology</u> (Woodsworth, Hill and van der Heyden, 1985): Telkwa</p>	<p>Difficult cross slopes Detailed geotechnical, hydrotechnical and civil engineering planning using cross sections is recommended during detailed design.</p> <p>General approach would be to widen existing rock cut and</p>



From (KP)	To (KP)	Geotechnical Conditions	Geotechnical Comments
		<p>Formation (basalt to rhyolite breccia, tuff and flows, minor sediments). Read (2006): Bulkley Intrusions(?) (Post-tectonic quartz diorite, diorite, granodiorite; more hornblende than biotite; fresh, altered; unfoliated to weakly foliated). Middle Member Telkwa Formation: variegated breccia, tuff and flows.</p>	<p>work on a grade as narrow as possible in areas of steep rock cross slope.</p> <p>Local avalanche conditions during winter in parts of upper part of Kitimat valley may be a consideration during construction and should be considered with respect to design of a few of the creek crossings.</p> <p>Streams at KP 1089.75, KP 1090.6, KP 1091.15, KP 1092.6, and KP 1094.2 may be subject to debris flows. Most also have colluvial or alluvial fans where avulsion may be a consideration. Rockfall may be a consideration from steep slopes and/or down some steep stream valleys.</p>
1098.4	1099.2	<p>Hunter Creek – KP 1098.8 Rev. P route is on sidehill and close to or in creek to north. Depending on final crossing method, local route adjustments may be required.</p> <p>The existing logging road bridge is located upstream of a bridge that washed out a few years ago. During this washout, Hunter Creek relocated to a channel that is close to the toe of the north slope of the valley. Other older channels exist at various locations on the Hunter Creek fan and channel avulsion (switching) has occurred frequently in the past. Debris flows, movements of large amounts of bouldery bed materials and debris flows will be geotechnical/hyrotechnical design considerations in this area.</p> <p><u>Surficial geology:</u> Scree slopes and shallow rock. Till veneers and colluvium at lower elevations. Extensive alluvial deposits along creek channels. Hunter Creek valley has extensive terraced deposits of glaciofluvial alluvium with some till along the channel and on the adjacent valley slopes of the Kitimat River. Glaciofluvial fan or kame fan deposits on Kitimat River valley to west of bridge crossing of creek. Channel is meandering above the bridge and is located on an alluvial fan at and below the road bridge.</p> <p><u>Bedrock geology</u> (Woodsworth, Hill and van der Heyden, 1985): Telkwa Formation (basalt to rhyolite breccia, tuff and flows, minor sediments). Read (2006): Middle Member Telkwa Formation: variegated breccia, tuff</p>	<p>Directionally Drilled Crossing: A directionally drilled crossing may be feasible based on preliminary information.</p> <p>Open Cut Crossing: Would be feasible from the geotechnical and hydrotechnical points-of-view, but would need to consider avulsion and scour erosion. Crossing would be relatively long in course bouldery alluvium. Based on flows, diversion would be possible in winter, however, high flows through permeable bed materials and steep gradients would likely make diversion not practical.</p>



From (KP)	To (KP)	Geotechnical Conditions	Geotechnical Comments
1099.2	1103.9	<p>and flows.</p> <p>Route is generally located on the uphill side of the existing road. Areas of steep sideslope toward the end of the segment with two tributary stream crossings in segment.</p> <p>KP 1101.9: Stream channel has exposed bedrock in bottom of channel.</p> <p>KP 1102.3: Stream channel has been subject to debris flows and erosion along the channel possibly caused by diversion of water along an old logging road higher up the slope. Frequent groundwater seepage and areas of groundwater piping.</p> <p><u>Surficial geology</u>: Elevations above approximately 225 m which is expected to be above elevation of marine transgression. Glacial till veneers to blankets, colluvium and glaciofluvial sediments. Some of these materials are on sloping rock surfaces. Areas of seepage.</p> <p><u>Bedrock geology</u> (Woodsworth, Hill and van der Heyden, 1985): Telkwa Formation (basalt to rhyolite breccia, tuff and flows, minor sediments). Read (2006): Also indicates Middle Member Telkwa Formation.</p>	<p>Difficult area.</p> <p>Groundwater piping control including drains and rock blankets will be required. Filter berms may be required in some areas during and following construction to control the transport of sediment along the RoW, including sediment generated upslope of the RoW.</p> <p>Detailed geotechnical, hydrotechnical and civil engineering planning using cross sections is recommended during detailed design.</p> <p>KP 1101.9 and KP 1102.4: Streams may be subject to debris flows. Streams may have alluvial or colluvial fans. Possible avulsion.</p> <p>Reroute: Route should be uphill of logging road. Further engineering will be required to finalize route through area.</p>
1103.9	1112.9	<p>North side of Kitimat River along toe of north valley slope. Preferred route is located on uphill side of existing logging road, subject to further geotechnical investigation. Concave up slopes, moderate to locally steep in lower part of valley near route becoming steep farther upslope. Several stream crossings.</p> <p><u>Surficial geology</u>: Elevations above approximately 225 m which is expected to be above elevation of marine transgression. Glacial till veneers to blankets, colluvium and glaciofluvial sediments. Kame glaciofluvial fan sediments on sideslopes near creek crossings. Some of these materials are on sloping rock surfaces. Areas of seepage.</p> <p><u>Bedrock geology</u> (Woodsworth, Hill and van der Heyden, 1985): Telkwa Formation (basalt to rhyolite breccia, tuff and flows, minor sediments). Read (2006, mapping along edge of road): Middle Member Telkwa Formation: variegated breccia, tuff and flows east of KP 1105.4. West of KP 1105.4: Post-tectonic quartz diorite, diorite, granodiorite; more hornblende than biotite; fresh, altered; unfoliated to weakly foliated.</p>	<p>Difficult area.</p> <p>The preferred route is generally expected to be in close proximity to the road; however, more detailed work should be done to check the possibility of routes slightly above the road on terrain benches.</p> <p>Near KP 1108.4: Areas of shallow sliding and debris flows of overburden materials on sloping rock and within overburden materials aided by groundwater seepage. Shotrock blankets over non-woven geotextile will be required to allow seepage to exit the cut slopes without piping the underlying soil. Debris traps and filter berms should be considered at suitable locations to trap sediment eroded onto the pipeline RoW from higher up slope in order to reduce the general transport of sediment from areas off RoW toward spawning channels in the Kitimat River system. Some degree of ongoing maintenance is expected in these areas due to the transport of off RoW sediment across the RoW during operation. Suitable measures should generally improve the local sedimentation situation.</p>



From (KP)	To (KP)	Geotechnical Conditions	Geotechnical Comments
			<p>KP 1105.2, KP 1108.2, KP 1108.8, KP 1109.4, KP 1109.6, KP 1111.1, KP 1112.6: Streams may be subject to debris flows. Streams may have alluvial or colluvial fans. Possible avulsion.</p> <p>Detailed geotechnical, hydrotechnical and civil engineering planning using cross sections is recommended during detailed design.</p>
1112.9	1119.9	<p>Lower Kitimat River Valley. Preferred route is located close to the existing logging roads, but on uphill side. Slopes along lower valley slopes are moderate to gentle with benches and terraces.</p> <p><u>Surficial geology</u> (Clague, 1984): Elevations slightly below approximately 215 m which is below the approximate elevation of marine transgression where there may be glaciomarine clays; however, no evidence of any glaciomarine clay-related stability issues identified to date. Glacial till veneers to blankets, colluvium and glaciofluvial sediments. Some of these materials are on sloping rock surfaces. Rock knobs. Areas of seepage.</p> <p><u>Bedrock geology</u>: East part of segment (Woodsworth, Hill and van der Heyden, 1985): Telkwa Formation (basalt to rhyolite breccia, tuff and flows, minor sediments). Toward west: granodiorite and greenschist facies diorite (low grade metamorphosed diorite). Read (2006, mapping along edge of road): Post-tectonic quartz diorite, diorite, granodiorite; more hornblende than biotite; fresh, altered; unfoliated to weakly foliated.</p>	<p>Difficult area. While area is in the upper part of the elevation zone in which marine clay could occur, no marine clay related instability has been identified to date and sensitive clay may not be present in this area. Further checks including drilling to check the properties of soils at depth are recommended.</p> <p>Ground and surface water control required. Rock blankets may be required if groundwater seepage is encountered in cuts. Preferred route is generally on uphill of logging road. Further engineering will be required to finalize route through area.</p> <p>KP 1115.9: The Kitimat River is eroding laterally toward the logging road aided by groundwater piping of the sediments in the river bank. The road may eventually be eroded by this lateral migration (route is located above road).</p> <p>KP 1113.9, KP 1114.9, KP 1116.0, KP 1116.6: Streams may be subject to debris flows. Streams may have alluvial or colluvial fans. Possible avulsion.</p>
1119.9	1122.8	<p>Along the north side of Chist Creek which flows back along the north side of the Kitimat valley.</p> <p><u>Surficial geology</u> (Clague, 1984): Elevations below approximately 225 m which is below the approximate elevation of marine transgression where there may be glaciomarine clays. An occurrence</p>	<p>Difficult area. While area is in the upper part of the elevation zone in which marine clay could occur, no marine clay related instability has been identified to date. Further checks including drilling to check the properties of soils at depth</p>



From (KP)	To (KP)	Geotechnical Conditions	Geotechnical Comments
		<p>of marine clay has been reported by Seiler (2006) in the bottom of the Chist Creek channel west of KP 1120.9. Silty fine sand deposits were noted in river bank near start of segment. Glacial till veneers to blankets, colluvium and glaciofluvial sediments. Areas of seepage including groundwater piping. At start of segment, Chist Creek is eroding toward the south into a high slope of sand and gravel.</p> <p><u>Bedrock geology:</u> East part of segment (Woodsworth, Hill and van der Heyden, 1985): Telkwa Formation (basalt to rhyolite breccia, tuff and flows, minor sediments). West part of segment: granodiorite and greenschist facies diorite (low grade metamorphosed diorite). Read (2006, mapping along edge of road): East part of segment: Post-tectonic quartz diorite, diorite, granodiorite; more hornblende than biotite; fresh, altered; unfoliated to weakly foliated. Near crossing of Chist Creek - Greenschist facies diorite-tonalite complexes; lesser metavolcanic rocks; unfoliated to weakly foliated; intense brittle deformation.</p>	<p>are recommended.</p> <p>Ground and surface water control required. Rock blankets may be required if groundwater seepage is encountered in cuts.</p> <p>KP 1122.3: Stream may be subject to debris flows. Stream may have alluvial or colluvial fan. Possible avulsion.</p>
1122.8	1123.5	<p><u>Chist Creek – KP 1123.1</u> Existing road bridge crossing is on a rock ridge which is a buried extension of the adjacent rock slopes on the north side of the Chist Creek valley. This rock ridge is expected to be of limited extent. Chist Creek is eroding toward the south and west downstream of the bridge. Upstream of the bridge, the creek is eroding to the south toward the road. Bottom sediments in the creek are reported by Seiler (2006) to be highly mobile.</p> <p><u>Surficial geology</u> (Clague, 1984): Alluvial terrace and floodplain deposits near creek. Exposed deposits are bouldery. Onion Creek glaciofluvial delta a short distance to west with exposures of sand and gravel along creek channel. There may be glaciomarine clays at depth.</p> <p><u>Bedrock geology</u> (Woodsworth, Hill and van der Heyden, 1985): Adjacent to granodiorite and greenschist facies diorite, tonalite (low grade metamorphosed diorite). Read (2006, mapping along edge of road): Greenschist facies diorite-tonalite complexes; lesser metavolcanic rocks; unfoliated to weakly foliated; intense brittle deformation.</p>	<p><u>Open Cut Crossing:</u> Feasible from a geotechnical point-of-view. The possibility of lateral erosion at the crossing would need to be further considered. Note that the stream has migrated laterally to the east several tens to well over 100 m farther downstream. Preferred location would be close to the existing road bridge, possibly with riprap (if required) along the outside bend upstream of the bridge to control local lateral erosion in this area. Based on flows, isolation using flume or superflume would be possible from December through March or possibly April. Flows through permeable sandy substrates may be a consideration both with respect to flow volume and also trench stability.</p>



From (KP)	To (KP)	Geotechnical Conditions	Geotechnical Comments
1123.5	1131.1	<p>Route runs to the west across terrain that is close to level on the Onion Creek delta.</p> <p><u>Surficial geology</u> (Clague, 1984): Onion Creek fan. Mapped as kame and ice stagnation deposits. Hummocky to rolling, may contain inclusions of diamictons. Glaciomarine clay sediments are exposed over 1 km south of the route and have been subject to several past flow failures.</p>	<p>The route in this area has been established well back from the areas in which past glaciomarine clay failures have occurred.</p> <p>Further checking of route and underlying materials and stability is recommended.</p>
1131.1	1132.2	<p>Cecil Creek – KP 1131.4</p> <p>Ground reconnaissance of the north side of the creek indicated terraced deposits of sand and gravel. No indication of slide movements has been identified in this area.</p> <p><u>Surficial geology</u> (Clague, 1984): Undifferentiated terrace scarps and river banks. Creek slopes eroded into Onion Creek glaciofluvial fan as above.</p>	<p>Open Cut Crossing: Feasible from a geotechnical point-of-view at existing crossing. Substantial amounts of grading on approach slopes. Ground and surface water control would be required. Isolation would be possible at most times of year.</p>
1132.2	1137.1	<p>West of Cecil Creek and north of Iron Mountain.</p> <p>Route diverts to west around area of erosion and shallow sliding, apparently related to glaciomarine sediments.</p> <p><u>Surficial geology</u> (Clague, 1984): Onion Creek delta. Mapped as kame and ice stagnation deposits. Hummocky to rolling, may contain inclusions of diamictons. Near the south end of segment, mapped as shallow till over rock or exposed rock. Some areas of organics (muskeg).</p>	<p>KP 1133.5 to KP 1137.3: Route follows toe of Iron Mountain to avoid erosion and sliding to east.</p> <p>KP 1136.8 (approx): Waterfall with potential local rockfall.</p>
1137.1	1140.5	<p>East side of Iron Mountain.</p> <p>Helicopter reconnaissance suggests area is underlain by a mixture of glaciofluvial sand and possibly glaciomarine clay with rock ridges. Some areas of shallow ponding and muskeg.</p> <p><u>Surficial geology</u> (Clague, 1984): Rolling glaciomarine clays, gullied. Hole R02 drilled near Deception Creek did not encounter sensitive glaciomarine clay (the clay encountered was stiff to hard).</p>	<p>No stability issues identified during helicopter reconnaissance. Potential slope stability problems in glaciomarine clay. Further geotechnical review recommended. If concerns are identified in this area, a route farther west along the edge of Iron Mountain could potentially be considered.</p> <p>Several wet areas that may be soft due to underlying glaciomarine clay. Local routing should attempt to avoid these areas as much as possible. Some linear areas will not be possible to avoid.</p> <p>KP 1140.0 Deception Creek: Area is wet on north side of crossing. Consider diverting a short distance to the east to</p>



From (KP)	To (KP)	Geotechnical Conditions	Geotechnical Comments
			<p>improve conditions. A hole drilled by AMEC at about KP 1140.0 on the east side of Iron Mountain near Deception Creek (R02) did not encounter sensitive glaciomarine clay, although stiff to hard high plastic clay was encountered below sand deposits from 44 m to the bottom of the hole at 66.5 m.</p> <p>ARD considerations are discussed in AMEC (2009c and 2009d).</p>
1140.5	1144.1	<p>On east lower slopes of Iron "Mountain". <u>Surficial geology</u> (Clague, 1984): Exposed rock and till veneers over rock. <u>Bedrock geology</u> (Woodsworth, Hill and van der Heyden, 1985) greenschist facies diorite, tonalite.</p>	<p>Rock grading. Check local rock stability conditions. Local lore is that Iron Mountain is named after a magnetic anomaly. ARD considerations are discussed in AMEC (2009c and 2009d).</p> <p>At south end of segment, route transitions from the east and southeast sides of Iron Mountain to the Wedeene River valley. The stability conditions in this transition area will need further field investigation possibly including drilling to check for sensitive clay.</p>
1144.1	1145.0	<p><u>Wedeene River KP 1144.5</u> Railway crosses river on a bridge founded on rock upstream of proposed pipeline crossing. Along the river there are prominent rock ridges in the valley and areas of rock outcrop close to river elevation for approximately 650 m southeast. These ridges appear to line up with areas of possible shallow rock and/or rock outcrops in the upland areas. Between the ridges on the south side of the river, Lidar hillshade maps, airphoto interpretation and field observations suggest that there may be marine clay slides between the ridges south of the river.</p> <p><u>Surficial geology</u> (Clague, 1984): Till veneers on north side. Alluvial terraces on south side (sand and gravel). Downstream (east) of crossing: alluvial sediments overlying glaciomarine clay. <u>Bedrock geology</u> (Woodsworth, Hill and van der Heyden, 1985) greenschist facies diorite, tonalite. May be Telkwa Formation (basalt to rhyolite breccia, tuff and flows, minor sediments).</p>	<p>Very Difficult Area Further geotechnical investigations will be required to delineate the surficial geology, bedrock topography and stability conditions. Issues include potential stability issues, river crossing and rail crossing, all in close proximity to each other.</p> <p>Directionally Drilled Crossing: Feasibility of directional drilling will depend on the surficial geology conditions including depth and boulder content of the sediments and possibly on the depth and presence of glaciomarine deposits. Marine clay stability may be an issue. A successful directionally drilled crossing could potentially cross the river, areas of potential stability issues and the railway. Further work would be required to determine feasibility.</p> <p>Open Cut Crossing: A conventional crossing in the rock</p>



From (KP)	To (KP)	Geotechnical Conditions	Geotechnical Comments
			<p>channel could be considered but may be difficult due to presence of railway directly to the south. Blasting of in-water bedrock would be required which may also be difficult. From a geotechnical point-of-view, a conventional crossing is considered less preferable.</p> <p>Other Trenchless Methods: Other trenchless methods appear to be feasible from a geotechnical point of view subject to further investigation.</p>
1145.0	1148.2	<p>Rolling terrain with some terrace elevation changes.</p> <p><u>Surficial geology</u> (Clague, 1984): Glaciofluvial delta sand and gravel at north and south ends of segment. Glaciofluvial veneer overlying glaciomarine clays in center third of segment.</p>	<p>Geotechnical review of route, underlying materials and stability is recommended.</p> <p>KP 1146.7 to KP 1147.1: Wet areas along channels of tributary creeks to Wedeene River.</p>
1148.2	1149.3	<p>Little Wedeene River – KP 1148.6</p> <p>Route crosses river approximately parallel to existing forestry road. There is a high eroding sand and gravel slope to the east off the alignment. Gentle and low terraced slopes at proposed alignment. On the south side, wide low terrace with near surface groundwater and muskeg. The river may erode to the south in the future or reoccupy an old channel to the south.</p> <p><u>Surficial geology</u> (Clague, 1984): Glaciofluvial delta sand and gravel on north side. Alluvial delta sediments (sand and gravel) on south side overlain by variable depths of muskeg. No marine clay seen; however, silty fine grained sand occurs along the river channel on the north side. Drill hole R04 west of KP 1149.8 encountered 15 m of gravel overlying clay, of which a thin layer was sensitive.</p> <p><u>Bedrock geology</u> (Woodsworth, Hill and van der Heyden, 1985): Adjacent bedrock exposures to the west are Telkwa Formation (basalt to rhyolite breccia, tuff and flows, minor sediments).</p>	<p>Open Cut Crossing: Appears feasible from a geotechnical point-of-view. Further consideration of trench stability and access conditions in the muskeg area south of the present channel would be required. Crossing would likely be relatively long to allow for potential lateral erosion or channel reoccupation to the south. Isolation would be marginal using a superflume in winter. Flows would be too high at other times of the year for isolation.</p> <p>Slope stability: Review recommended of local slope stability relative to the possible occurrence of glaciomarine clay.</p>
1149.3	1158.6	<p>Mostly flat terraced or benched terrain in Kitimat valley.</p> <p><u>Surficial geology</u> (Clague, 1984): Northern third of sediment: alluvial sediments, may be on edge of glaciomarine clay to west. Center part of segment, colluvial veneer along toe of rock slope, possible till. Southern third of segment – alluvial sediments. BH 75-3 located 0.7 m to west in thicker part of glaciomarine sediments encountered 42 m of clay, some sensitive. Southern third of sediment – alluvial sediments. Drill holes or water wells by others do not appear to have intersected clay.</p>	<p>Further investigation of local surficial geology conditions recommended relative to possible occurrences of sensitive glaciomarine sediments.</p>



From (KP)	To (KP)	Geotechnical Conditions	Geotechnical Comments
		<u>Bedrock geology</u> (Woodsworth, Hill and van der Heyden, 1985): Telkwa Formation (basalt to rhyolite breccia, tuff and flows, minor sediments).	
1158.6	1160.7	<p>Route runs around east side of a high sand and gravel ridge proposed to be mined.</p> <p>Along edge of steep slopes to west and flat topography underlain by glaciofluvial sediments (possible glaciomarine clay) to east. Drill holes or water wells by others may have intersected clay.</p> <p><u>Surficial geology</u> (Clague, 1984): Alluvial and glaciofluvial terrace, delta and alluvial fan sediments. May overlie glaciomarine clay, but not shown on available mapping. Some areas of fill. Local contacts indicate that at east edge of gravel ridge, sand and gravel may occur to depth adjacent to the river.</p> <p><u>Bedrock geology</u> (Woodsworth, Hill and van der Heyden, 1985): Telkwa Formation (basalt to rhyolite breccia, tuff and flows, minor sediments).</p>	<p>Possibly Difficult Area Route diverts to east around east end of gravel ridge to be mined for export. This is may also be a congested area with existing railway, pipelines, road, mining facilities and other pipelines and conveyor facilities planned or proposed.</p> <p>Further geotechnical review of static and seismic stability conditions in this area relative to marine clay which may occur near the south end of the segment is recommended. Further review of lateral erosion conditions of adjacent Kitimat River is recommended.</p>
1160.7	1163.7	<p>On west side of Kitimat valley and west valley slopes.</p> <p><u>Surficial geology</u> (Clague, 1984): Alluvial and glaciofluvial terrace, delta and alluvial fan sediments. May overlie glaciomarine clay, but not shown on available mapping. Some areas of fill.</p> <p><u>Bedrock geology</u> (Woodsworth, Hill and van der Heyden, 1985): Telkwa Formation (basalt to rhyolite breccia, tuff and flows, minor sediments).</p>	<p>Local route adjustments to optimise conditions may be required.</p> <p>Sidehill slope stability conditions should be further examined, particularly with respect to the possible presence of marine clay.</p>
1163.7	1164.1	<p><u>Anderson Creek – KP 1163.8</u> Crossing is located on a braided alluvial channel at the toe of the rock slope on the west side of the valley. Preferred crossing is upstream of present mill water intake and downstream from an older intake.</p> <p><u>Surficial geology</u>: Glaciofluvial and alluvial sand and gravel overlying either rock or possibly glaciomarine clay. Close to and east of road, terrain may be underlain by glaciomarine clay, possibly overlain by hydraulic fill.</p> <p><u>Bedrock geology</u> (Woodsworth, Hill and van der Heyden, undated): Telkwa Formation (basalt to rhyolite breccia, tuff and flows, minor sediments). Note low competency of this formation.</p>	<p>Slope stability: Depending on whether the site is underlain by marine clay, there could be lateral spreading considerations or possibly settlement considerations.</p> <p>Open Cut Crossing: Feasible from a geotechnical point-of-view at Rev. P route location immediately upstream of road bridge subject to stability and marine clay issues. Isolation may be feasible most of year except summer. Permeable alluvium could be an issue. Note nearby water intake.</p>
1164.1	1165.0	<p>Sidehill along west side of Kitimat valley.</p> <p>Glaciomarine clay on slopes may be sliding or moving in some areas. Movements may be shallow. Evidence of sliding includes pistol butted trees, slide blocks and slide scarps. Movement may be due to sliding or may be due to settlement of adjacent areas of floodplain under</p>	<p>Slope and seismic stability: Evidence of movement on slope areas. Route will need to be finalized relative to local stability conditions. Excavation through shallow sliding areas may be required.</p>



From (KP)	To (KP)	Geotechnical Conditions	Geotechnical Comments
		<p>hydraulic fill loading.</p> <p><u>Surficial geology</u>: Glaciofluvial and alluvial sand and gravel overlying either rock or possibly glaciomarine clay. Close to and east of road, terrain is underlain by glaciomarine clay, possibly overlain by hydraulic fill.</p> <p><u>Bedrock geology</u> (Woodsworth, Hill and van der Heyden, 1985): Telkwa Formation (basalt to rhyolite breccia, tuff and flows, minor sediments). Note low competency of this formation.</p>	
1165.0	1165.3	<p>Moore Creek- KP 1165.1</p> <p>Route crosses incised ravine of Moore Creek. Upland area upstream of water fall: 30 to 50 m deep ravine eroded in bedrock. May be subject to debris torrents. Rockfall from canyon walls.</p> <p><u>Surficial geology</u>: Glaciofluvial and alluvial sand and gravel overlying either rock or possibly glaciomarine clay. Close to and east of road, terrain is underlain by glaciomarine clay, possibly overlain by hydraulic fill.</p> <p><u>Bedrock geology</u> (Woodsworth, Hill and van der Heyden, undated): Telkwa Formation (basalt to rhyolite breccia, tuff and flows, minor sediments). Note low competency of this formation.</p>	<p>Local adjustment of route to optimise crossing location of the Moore Creek ravine. Further ground reconnaissance recommended.</p> <p>Aerial Crossing: Feasible from a geotechnical point-of-view. Would likely provide sufficient clearance from any debris flows or rockfalls.</p> <p>Trenched Crossing: Not recommended due to ravine.</p>
1165.3	1170.3	<p>Steep cross slope above marina area at the north end of Kitimat Arm at start of segment with sloping bench to south. Shallow bedrock with till or possibly marine clay. Some large boulders. Areas of steep cross slope.</p> <p><u>Surficial geology</u>: No detailed mapping has been found. Based on aerial observations, glacial till veneers, possible glaciomarine clay overlying shallow bedrock. Some areas of colluvium and colluvial boulders.</p> <p><u>Bedrock geology</u>: Detailed mapping has not been found. Projecting from Woodsworth, Hill and van der Heyden (1985) greenschist facies diorite, tonalite.</p>	<p>Difficult Area, possible slope stability considerations</p> <p>Further investigation and potentially a route revision during detailed routing is recommended in this area to optimize the route. Detailed consideration of design using cross sections is recommended.</p> <p>No slope stability issues were apparent during air review. Further on ground geotechnical review recommended. Based on airphoto review, appears to be above glaciomarine clay and/or in shallow rock. Route should be checked on ground including KP 1170.1 near a basin at the headwaters of a stream.</p> <p>Steep cross slope. Potentially high rock cuts required. Anchors may be required. Stability of undercut overburden may require special provisions such as shotcrete and</p>



From (KP)	To (KP)	Geotechnical Conditions	Geotechnical Comments
			anchors or cantilever shotcrete walls. Rockfall from cuts and from boulders on surface of till will require consideration during detailed design.
1170.3	1172.19	<p>Variable terrain including areas of steep cross slope. Toward end of segment, undulating terrain. End of segment at proposed Kitimat Station. End of pipeline route will need to be adjusted to accommodate station design.</p> <p><u>Surficial Geology</u>: No detailed mapping has been found. Based on aerial observations, glacial till veneers, possible glaciomarine clay overlying shallow bedrock. Route generally drops to south, and increased thickness of glaciomarine clay toward the south may be anticipated.</p> <p><u>Bedrock geology</u>: Detailed mapping has not been found. Projecting from Woodsworth, Hill and van der Heyden (1985) greenschist facies diorite, tonalite.</p>	<p>Difficult Area</p> <p>Cross slopes and areas of marine clay that may be sensitive. Local rock fall from bedrock outcrops and boulders from till.</p> <p>Detailed route design including design using sections is recommended.</p>

Notes:

1. Preliminary, based on limited ground data as discussed in report. Conditions and interpretations are subject to confirmation and further geotechnical investigations which may result in changes to the geotechnical assessments presented.
2. Assessments of feasibility of various crossing methods are preliminary and are strictly from a geotechnical point-of-view.

APPENDIX C

Terrain Hazard and Risk Summary Table C-1

LEGEND FOR TABLE C-1

The geohazard codes shown in the Geohazard Code column of [Table C-1](#) are summarized on the risk matrices in [Figures 4.1 to 4.7](#) of the main report.

The general format of the Geohazard Codes is #Code where:

is a sequential number
 Code is a two letter code designating the type of geohazard present.

Code	Description
Mass Wasting	
DS	Deep-seated slides
SM	Shallow to moderately deep slides
DF	Debris Flow
RF	Rock Fall
AV	Avalanches
LS	Lateral Spreading
SE	Stream Erosion & sedimentation
ER	Wind & shallow stream or overland erosion
Settlement	
CS	Consolidation Settlement
KS	Karst induced Settlement or displacement
Seismic	
EQ	Seismic Motion
LQ	Liquefaction
Tsunamis	
TS	Tsunamis
#	Sequential number

The hazard likelihood categories (see [Section 4.2.3](#)) are shown below. These categories are used in the “Hazard Likelihood” columns on [Table C-1](#).

See Table 4.1: Hazard Likelihood Categories (Hazard Occurrence Likelihoods)

Likelihood Category	Approximate Annual Likelihood	DESCRIPTION
5	≥ 0.5	<i>Will likely happen regularly over the life of the Project.</i> Very high likelihood that the hazard could affect the pipelines and/or infrastructure in the near future and/or is affecting the pipelines at the time of study.
4	≥ 0.1	<i>Probably will happen over the life of the Project.</i> High likelihood of occurrence.
3	≥ 0.1 to 0.02	<i>It could happen (likely as not) over the life of the Project.</i> Intermediate likelihood of occurrence.
2	< 0.02	<i>Unlikely to happen in any given year and less likely over the life of the Project.</i> Low likelihood.
1	< 0.001	Very low annual likelihood of occurrence and much less likely to occur over the life of the Project. Longer term events such as major seismic events.

The consequence ratings (see [Section 4.2.4](#)) are shown below. These categories are used in the “Consequence Rating” columns on [Table C-1](#).

See Table 4.2: Consequence Categories

CONSEQUENCE CATEGORY	DESCRIPTION
5	Major event with extremely costly and difficult remediation Pipeline failure or failure of major facilities such as pumping stations that could be difficult or expensive to repair due to location or other reasons.
4	Significant event that can be addressed but with great effort All other major pipeline damage events requiring replacement of pipeline segment. Failure of other infrastructure such as pumping stations that would directly affect the ability to move oil.
3	Moderate event requiring mitigation and certainly engineering review/input Displacement, damage or exposure of the pipelines less likely to directly result in immediate failure (i.e., in the event of the hazard occurring, there may be sufficient time to undertake mitigative measures prior to more serious consequences). Includes in-stream exposures. Damage to pumping stations or other facilities that does not immediately cause major shutdown.
2	Minor incident or inefficiency that may require engineering review but is easily and predictably remediated Coating damage, exposure or other damage not immediately resulting in a serious situation. Overland locations. Relatively easy to repair.
1	Minor incident or inefficiency of little or no consequence Other low consequence outcomes. (Note that failure to suitably mitigate these outcomes could result in more serious consequences.)

The colours used in the "Risk" columns of Table C-1 are the same as used on the risk summary matrices on Figures 4.1 to 4.7 of the main report and are as follows:

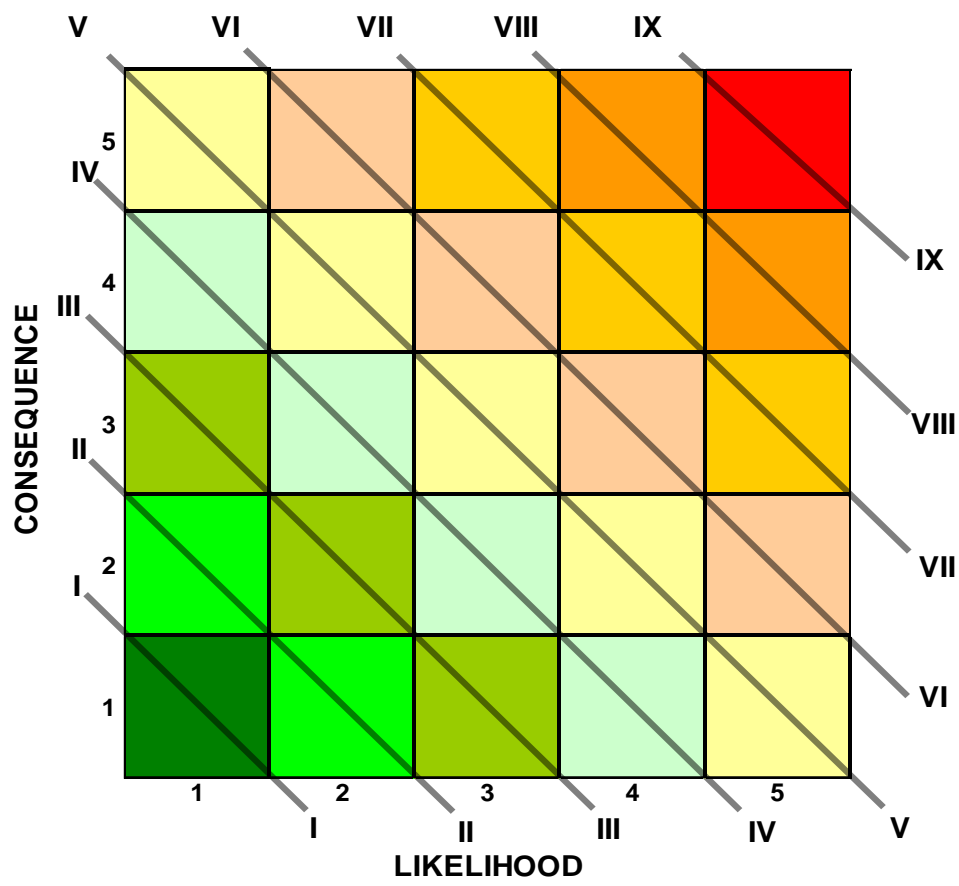


Table C-1 Terrain Hazard and Risk Summary

Location/Area KP Start - KP End	Geohazard Code	Description of Terrain	Geohazard Type(s)	Unmitigated			Potential Protection, Mitigation and Management Measures ¹	Mitigated		
				Hazard Likelihood	Consequence Rating	Risk		Hazard Likelihood	Consequence Rating	Risk
Eastern Alberta Plains										
Bruderheim Terminal to North Saskatchewan River	• 1ER	• Sandy eolian veneers and blankets.	• Wind and water erosion	5	1	5	• Re-vegetation; erosion matting; straw/hay mulching.	2	1	2
North Saskatchewan River crossing 3.6 – 4.1	• 2SM	• Slides into gully directly to north of route.	• Shallow to moderately deep slides	3	2	6	• Use routing to avoid landslides. • Design. • Ground and surface water control.	1	1	1
Southern Alberta Uplands										
Pembina River 131.5 – 131.6	• 3SE	• Meandering river incised several meters • Tending to migrate northwest, potential for cutoffs upstream and downstream	• Stream erosion (lateral migration, scour)	3	3	9	• Design to avoid stream erosion and scour.	1	1	1
Little Paddle River 163.9 – 164.0	• 4SE	• Meandering river incised several meters, minor instabilities along banks	• Stream erosion (lateral migration)	3	3	9	• Design to avoid stream erosion. • Bank reclamation methods.	1	1	1
Swan Hills southeast of Whitecourt 178.4 – 181.6	• 5DS	• Ancient deep-seated landslide that does not appear to be moving	• Deep-seated instability	1	4	4	• Control groundwater and surface water drainage. • Slope stability considerations will be incorporated in grading design.	1	2	2
Athabasca River 186.9 – 187.4	• 6SE	• Wide area of sub-channels on south side, high likelihood of reactivation, long crossing	• Stream erosion and scour	3	5	15	• Design to avoid stream erosion and scour.	1	1	1
North approach to Athabasca River 187.5 - 187.7	• 7SE	• Ridged terrain with some gullies. Local piping and blow-off failures • Deep-seated sliding to the west of PDA	• Lateral erosion to north	3	4	12	• Design to avoid stream erosion and scour. • Design slope grading based on stability. • Control groundwater and surface water drainage. • Surface water control will need to consider stability conditions to west (divert to east where possible). • Deep-seated slides avoided by routing.	1	2	2
	• 8SM		• Shallow to moderately deep slides	4	3	12		2	1	2
	• 9DS		• Deep-seated slides	3	5	15		1	1	1
Sakwatamau River 200.0 – 200.7	• 10SE	• Sub-channels on both sides. Potential for lateral erosion • Potential for meander bend cut off upstream of crossing	• Stream erosion (lateral migration)	3	3	9	• Design to avoid stream erosion.	1	1	1

Location/Area KP Start - KP End	Geohazard Code	Description of Terrain	Geohazard Type(s)	Unmitigated			Potential Protection, Mitigation and Management Measures ¹	Mitigated		
				Hazard Likelihood	Consequence Rating	Risk		Hazard Likelihood	Consequence Rating	Risk
Narrow corridor near Sakwatamau River 202.0 - 203.6	• 11SM	• Route located near edge of moderately steep slope with slides above outside bends of old channels of river and tributary	• Shallow to moderately deep slides	3	5	15	<ul style="list-style-type: none"> Checks and surveys required. Detailed groundwater and surface water control including integration with measures on Alliance RoW. Work space on Alliance RoW Pipelines installed close to edge of Alliance RoW. 	2	2	4
215.9 – 216.0	• 12SM	• Steep, narrow gully, confined channel, slopes high on both sides (potential instabilities)	• Shallow to moderate slides	3	2	6	<ul style="list-style-type: none"> Design to avoid instabilities as required. Ground and surface water control. Grading should consider stability issues. 	1	1	1
Chickadee Creek 218.9 – 219.1	• 13SE	• Tortuous meanders along creek, laterally unstable • Preliminary ratings prior to ground reconnaissance.	• Stream erosion (lateral migration)	3	3	9	• Design crossing to allow for lateral migration.	2	1	2
Two Creek 241.7 – 241.9	• 14SE	• Lateral erosion and tortuous meanders	• Stream erosion (lateral erosion)	3	3	9	• Design crossing to allow for lateral migration.	2	1	2
East approach slope to Iosegun River 258.6 to 258.8	• 15SM	• Steep slopes, shallow to moderately deep failures east and west of Rev R centerline	• Shallow to moderately deep slides	3	5	15	<ul style="list-style-type: none"> Control groundwater and surface water. Routing avoids slide areas. Grading designed to accommodate local stability conditions. 	1	1	1
	• 16ER		• Erosion on steep slopes	5	1	5		2	1	2
Iosegun River 258.8 – 260.0	• 17SE	<ul style="list-style-type: none"> Soft soils, high groundwater Sliding on banks when disturbed Several subchannels Highly erodible soils 	<ul style="list-style-type: none"> Stream erosion (lateral migration) Sedimentation 	3	3	9	<ul style="list-style-type: none"> Drilling investigations. Bank restoration methods to consider local soil conditions. Design for lateral and possible scour erosion. Consider consolidation settlement. 	2	3	6
	• 18CS		• Consolidation settlement	4	2	8		1	2	2
East Approach to Little Smoky River 290.3 - 291.0	• 19DS	• Deep-seated sliding (terrain appears to be an erosional terrace but deep-seated slides in area). Reactivation would require a large lateral erosion event toward the east.	• Deep-seated instabilities	2	5	10	<ul style="list-style-type: none"> Drilling and other further investigations. Ground and surface water control. Off RoW hydrotechnical measures to control lateral erosion. Monitoring. Bypass slide by directional drilling or other trenchless methods such as microtunnel. 	1	4	4

Location/Area KP Start - KP End	Geohazard Code	Description of Terrain	Geohazard Type(s)	Unmitigated			Potential Protection, Mitigation and Management Measures ¹	Mitigated		
				Hazard Likelihood	Consequence Rating	Risk		Hazard Likelihood	Consequence Rating	Risk
Little Smoky River crossing 291.0 – 291.1	• 20SE	• Lateral erosion	• Stream erosion (lateral erosion)	4	5	20	<ul style="list-style-type: none"> Design crossing to allow for lateral migration. Off RoW hydrotechnical measures to control lateral erosion. Directional drilling or other trenchless methods such as microtunnel. 	1	3	3
West Approach Slope to Little Smoky River 291.1 - 291.9	• 21DS	<ul style="list-style-type: none"> Deep-seated landslides, movement triggered by undercutting by river. Erosion along river causing renewed movement of deep seated slides. Hazard likelihood and consequences will depend on mitigative measures used. 	• Deep-seated instabilities	3	5	15	<ul style="list-style-type: none"> Drilling and other further investigations. Ground and surface water control. Off RoW hydrotechnical measures to control lateral erosion. Monitoring. Bypass slide by directional drilling or other trenchless methods such as microtunnel as required. 	2	4	8
Waskahigan River 317.8 – 318.4	• 22SE	• Wide floodplain, lateral migration (abandoned channels and subchannels)	• Stream erosion (lateral migration)	4	4	16	<ul style="list-style-type: none"> Design crossing to avoid stream erosion. 	1	1	1
Deep Valley Creek 338.6 – 339.3	• 23SE	<ul style="list-style-type: none"> Wide floodplain, lateral migration and subchannels Preliminary ratings prior to ground reconnaissance. 	• Stream erosion (lateral migration)	3	3	9	<ul style="list-style-type: none"> Design crossing to avoid stream erosion. 	1	1	1
Tributary to Deep Valley Creek 340.5 - 341.0	• 24SE	<ul style="list-style-type: none"> Tortuous meanders and lateral migration Erosion issues on steep slopes 	• Stream erosion (lateral migration, downcutting)	3	3	9	<ul style="list-style-type: none"> Design to avoid stream erosion. 	1	2	2
	• 25ER		• Erosion	5	2	10	<ul style="list-style-type: none"> Ground and surface water control on slopes. 	2	2	4
Unnamed tributary 350.7 - 350.8	• 26ER	• Erosion of banks	• Erosion	5	2	10	<ul style="list-style-type: none"> Control groundwater and surface water drainage. Grading. 	2	2	4
Simonette River 359.6 – 360.1	• 27SE	<ul style="list-style-type: none"> Several side-channels and abandoned channels Preliminary ratings prior to ground reconnaissance. 	• Stream erosion (lateral erosion)	3	4	12	<ul style="list-style-type: none"> Conduct ground reconnaissance. Design to avoid stream erosion. 	1	2	2
Latornell River 371.6 – 372.6	• 28DS	<ul style="list-style-type: none"> Possible deep-seated slide Preliminary ratings prior to ground reconnaissance. 	• Possible Deep-seated instability	2	4	8	<ul style="list-style-type: none"> Control groundwater and surface water drainage. Use routing to avoid landslides. 	1	2	2
	• 29SE		• Stream erosion (lateral migration)	3	3	9	<ul style="list-style-type: none"> Design to avoid stream erosion. Ground reconnaissance and further study. 	1	1	1

Location/Area KP Start - KP End	Geohazard Code	Description of Terrain	Geohazard Type(s)	Unmitigated			Potential Protection, Mitigation and Management Measures ¹	Mitigated		
				Hazard Likelihood	Consequence Rating	Risk		Hazard Likelihood	Consequence Rating	Risk
West of Latornell River 373.0 – 373.2	• 30DS	<ul style="list-style-type: none"> Deep-seated slide above river meander Preliminary ratings prior to ground reconnaissance. 	<ul style="list-style-type: none"> Deep-seated slide. 	5	4	20	<ul style="list-style-type: none"> Control groundwater and surface water drainage. Use routing to avoid landslides. Design to avoid stream erosion. Ground reconnaissance and further study. 	1	1	1
Tributary to Smoky River 395.7 - 395.8	• 31SE	<ul style="list-style-type: none"> Steep slopes Shallow to moderately deep slides 	<ul style="list-style-type: none"> Stream erosion (possible downcutting, lateral migration) 	4	3	9	<ul style="list-style-type: none"> Design to avoid stream erosion and downcutting. Landslides avoided by routing. 	2	1	2
	• 32SM		<ul style="list-style-type: none"> Shallow to moderately deep slides 	4	2	8		2	1	2
Smoky River east valley wall 420.0 - 420.9	• 33DS	Slopes immediately north and south of RoW centreline have moderately deep landslides.	<ul style="list-style-type: none"> Shallow to deep-seated slides 	5	5	25	<ul style="list-style-type: none"> Control groundwater and surface water drainage . Landslides avoided by routing. 	1	2	2
Smoky River floodplain 420.9 - 422.4	• 34SE	<ul style="list-style-type: none"> River subject to significant lateral migration 	<ul style="list-style-type: none"> Stream erosion (lateral migration) 	4	5	20	<ul style="list-style-type: none"> Design to avoid stream erosion. 	1	1	1
Smoky River west valley wall 422.6 - 423.6	• 35DS	<ul style="list-style-type: none"> Moderately deep slide immediately to north North of old deep-seated slide block 	<ul style="list-style-type: none"> Moderately deep and deep-seated instability 	4	4	16	<ul style="list-style-type: none"> Control groundwater and surface water drainage. Landslides avoided by routing. 	2	2	4
Gold Creek 431.6 – 432.1	• 36SM	<ul style="list-style-type: none"> Deeply incised, meandering channel Shallow to moderately deep slides Moderately steep slopes about 30 m high Erosion Preliminary ratings prior to ground reconnaissance. 	<ul style="list-style-type: none"> Shallow to moderately deep slides 	4	4	16	<ul style="list-style-type: none"> Conduct reconnaissance and avoid landslides by routing. Design to avoid stream erosion. Control groundwater and surface water drainage. Slope stability considerations to be incorporated in grading design. 	2	1	2
	• 37ER		<ul style="list-style-type: none"> Erosion on slope 	5	2	10		3	1	3
	• 38SE		<ul style="list-style-type: none"> Stream erosion (lateral migration) 	3	3	9		1	2	2
Big Mountain Creek 434.9 - 435.7	• 39SM	<ul style="list-style-type: none"> Shallow to moderately deep sliding Steep vertical exposure just south of crossing Creek incised and meandering (potential for stream erosion) Erosion Preliminary ratings prior to ground reconnaissance. 	<ul style="list-style-type: none"> Shallow to moderately deep slides 	4	4	16	<ul style="list-style-type: none"> Conduct reconnaissance and avoid landslides by routing. Design to avoid stream erosion. Control groundwater and surface water drainage. Slope stability considerations to be incorporated in grading design. 	2	2	4
	• 40ER		<ul style="list-style-type: none"> Erosion on slope 	5	2	10		3	1	3
	• 41SE		<ul style="list-style-type: none"> Stream erosion (lateral migration) 	3	2	6		1	1	1
Bald Mountain Creek	• 42SM	<ul style="list-style-type: none"> Moderately deep failures south of the crossing (about 200 m to the south) 	<ul style="list-style-type: none"> Shallow to moderately deep slides 	4	4	16	<ul style="list-style-type: none"> Conduct reconnaissance and avoid landslides by routing. 	2	1	2

Location/Area KP Start - KP End	Geohazard Code	Description of Terrain	Geohazard Type(s)	Unmitigated			Potential Protection, Mitigation and Management Measures ¹	Mitigated		
				Hazard Likelihood	Consequence Rating	Risk		Hazard Likelihood	Consequence Rating	Risk
445.9 - 446.0	• 43SE	• Route appears to be crossing a moderately deep-seated landslide on the east side of the creek, both sides possibly unstable	• Stream erosion (downcutting, lateral migration)	3	3	9	<ul style="list-style-type: none"> Design to avoid stream erosion. Control groundwater and surface water drainage. Slope stability considerations to be incorporated in grading design. 	1	1	1
	• 44ER	• Meandering creek, lateral erosion • Erosion	• Erosion on slope	5	2	10		3	1	3
Pinto Creek meander bend 469.9 - 470.1	• 45DS	• Deep-seated slide triggered lateral channel migration (meander bend of Pinto Creek close to south)	• Deep-seated instability	5	5	25	<ul style="list-style-type: none"> Avoid by routing farther north. Control groundwater and surface water drainage. 	1	1	1
Pinto Creek 472.4 - 473.7	• 46DS	• Possible slides • Preliminary ratings prior to ground reconnaissance.	• Potential slides (deep seated)	4	5	20	<ul style="list-style-type: none"> Conduct ground reconnaissance. Avoid slides by routing. 	1	2	2
Wapiti River area 494.7 - 495.3	• 47DS	• Narrow area ("neck") with apparent deep-seated slide in valley-fill clay on north side and shallow slides in rock and glaciolacustrine clay on south side	• Moderately deep-seated instabilities	3	3	9	<ul style="list-style-type: none"> Use routing and grading to avoid landslides. 	2	1	2
Rocky Mountains										
566.1 - 579.5	• 48SM	• Several areas of rock cuts in the ends of ridges striking diagonally across RoW (potential for shallow sliding in soil veneers or bedrock slides)	• Shallow slides	3	2	6	<ul style="list-style-type: none"> Suitable Design. 	2	1	2
Quintette Creek 574.9 - 575.5	• 49SE	• Alluvial fan, potential for avulsion	• Stream erosion (avulsion)	3	3	9	<ul style="list-style-type: none"> Design to avoid stream erosion. 	2	1	2
577.8 - 579.2	• 50DF	• Potential for stream erosion • Potential for debris flows	• Debris flows	4	3	12	<ul style="list-style-type: none"> Use routing or design to avoid stream erosion and debris flows. 	2	2	4
	• 51SE		• Stream erosion (lateral migration)	3	3	9		1	1	1
Five Cabin Creek 580.3 - 581.1	• 52SE	• Large alluvial fan subject to major avulsion events	• Stream erosion (avulsion)	5	4	20	<ul style="list-style-type: none"> Design to avoid stream erosion. Possible route change to avoid problem area. 	2	2	4
Kinuseo Creek near alignment 586.0 - 588.1	• 53SE	• Flat-lying topography, historical high mobility (potential for lateral migration) on alluvial fan	• Stream erosion (lateral migration)	3	3	9	<ul style="list-style-type: none"> Design to avoid stream erosion. 	1	1	1
Tributary of Murray River 597.9 - 597.4	• 54SM	• Steep valley walls and terrace complexes • Possible old failures, including an apparent old slump block on the east side • Debris-mantled slopes prone to failure if disturbed	• Shallow to moderately deep slides	3	3	9	<ul style="list-style-type: none"> Control groundwater and surface water drainage. Landslides avoided by routing. Grading to consider stability conditions. 	2	1	2
Murray River 598.3 - 600.2	• 55KS	• Potential for karst (limestone, no karst identified to date)	• Karst-induced settlement or displacement	2	3	6	<ul style="list-style-type: none"> Use routing or design to avoid karst if required. Design. 	2	1	2
Hook Creek area	• 56SM	• Minor surface failures on approach slopes (stream undercutting)	• Shallow slides	4	2	8	<ul style="list-style-type: none"> Design of grading. 	2	1	2

Location/Area KP Start - KP End	Geohazard Code	Description of Terrain	Geohazard Type(s)	Unmitigated			Potential Protection, Mitigation and Management Measures ¹	Mitigated		
				Hazard Likelihood	Consequence Rating	Risk		Hazard Likelihood	Consequence Rating	Risk
602.0- 603.2	• 57SE	• Lateral migration into high banks	• Stream erosion (downcutting, lateral migration)	4	3	12	• Design to avoid stream erosion.	2	2	4
614.0 – 614.4	• 58DF	• Potential for debris flows	• Debris flows	4	3	12	• Design to avoid debris flows.	2	1	2
617.0 - 623.5	• 59AV	• Locally steep terrain, possibly with wet organics and steep side hills	• Avalanches	5	3	15	• Design to avoid or control avalanches, stream erosion, karst and rockfall. • Design and routing to control shallow slides.	2	1	2
	• 60SM	• Potential for shallow slides in muskeg during construction	• Shallow slides	5	2	10		1	1	1
	• 61KS	• Local avalanches • Potential for karst (limestone)	• Karst-induced settlement or displacement	2	3	6		1	1	1
621.2-622.6	• 62AV	• Potential for avalanches and possibly rockfall during design and operations	• Avalanches	5	3	15	• Design to avoid or control avalanches and rockfall.	2	1	2
	• 63RF		• Rockfall	4	4	16		2	2	4
Headwaters of Hominka River, pass through Rockies 625.2 – 626.6	• 64SM	• Short distance north of the area may be karstic limestone. Karst identified to south.	• Shallow to moderately deep slides	3	3	9	• Route has been selected to miss apparent problem area.	1	1	1
	• 65KS		• Karst-induced settlement or displacement	4	3	12		1	1	1
627.6 – 629.0	• 66CS	• Frequent organic deposits (muskeg), some on gentle to moderate slopes	• Consolidation settlement	4	3	12	• Design for consolidation settlement. • Avoid large springs by routing.	2	1	2
	• 67ER	• Artesian groundwater conditions with muskeg mounds	• Erosion	5	2	10		1	1	1
Tributaries to Missinka River 632.0 – 636.8	• 68SE	• Tributaries to Missinka River at KP 632.0, 633.0, 635.0, 635.2, 636.4 and 636.8 that may be subject to high flows and/or debris flows	• Stream erosion	4	3	12	• Design to avoid/mitigate stream erosion and debris flows.	2	1	2
	• 69DF		• Debris flows	3	3	9		2	1	4
634.6 – 637.2	• 70SM	• Frequent wet surface soils prone to sliding in cuts • Avalanche chutes at KP 635.8 and 636.6	• Shallow slides	5	2	10	• Limit surface disturbances in critical areas. • Control groundwater and surface water drainage. • Slope stability considerations will be incorporated in grading design. • Design to avoid or mitigate avalanches as required.	2	2	4
	• 71AV		• Avalanches	3	3	9		2	1	2
640.6 - 641.4	• 72SM	• Gullied till, outwash and glaciolacustrine materials prone to shallow sliding in cuts	• Shallow slides	5	2	10	• Limit surface disturbances in critical areas. • Control groundwater and surface water drainage. • Slope stability considerations will be incorporated in grading design.	2	2	4
Missinka River valley 641.6 - 666.6	• 73SM	• Glaciolacustrine deposits, moderately steep slopes, known stability problems on low cuts from 641.6 – 645.8 and 646.2 – 666.6	• Shallow slides	5	2	10	• Slope stability considerations will be incorporated in grading design.	2	1	2

Location/Area KP Start - KP End	Geohazard Code	Description of Terrain	Geohazard Type(s)	Unmitigated			Potential Protection, Mitigation and Management Measures ¹	Mitigated		
				Hazard Likelihood	Consequence Rating	Risk		Hazard Likelihood	Consequence Rating	Risk
	• 74ER		• Erosion	4	2	8	• Control groundwater and surface water drainage. • Design to control sedimentation. • Landslides avoided by routing.	2	2	4
Interior Plateau										
Parsnip River area 670.4 – 672.8	• 75SM	• Glaciolacustrine deposits, potentially unstable • Frequent organics (muskeg) and soft sediment	• Shallow to moderately deep slides	4	2	8	• Landslides avoided by routing. • Design for consolidation settlement. • Control groundwater and surface water drainage.	1	1	1
	• 76CS		• Consolidation settlement	3	2	6		2	1	2
Parsnip River 670.8 - 671.4	• 77SE	• Historical and recent lateral migration	• Stream erosion (lateral migration)	4	5	20	• Design to avoid stream erosion.	1	1	1
679.2 – 685.2	• 78SM	• Poorly drained wet terrain with moderate slopes • Shallow slides in cuts • Erosion	• Shallow to moderately deep slides	4	2	8	• Landslides avoided by routing. • Control groundwater and surface water drainage. • Cut and fill design. • Design to control sedimentation.	2	1	2
	• 79SE		• Sedimentation	4	2	8		2	1	2
	• 80ER		• Erosion	5	1	5		2	1	2
687.0 – 698.0	• 81SM	• Glaciolacustrine soils with sand seams in low-lying areas are known to have stability problems on low cuts • Route is adjacent to Chuchinka Creek (potential for stream erosion)	• Shallow to moderately deep slides	4	2	8	• Limit surface disturbances in critical areas. • Slope stability considerations will be incorporated in grading design. • Design to avoid stream erosion. • Surface and ground water control.	2	1	2
	• 82SE		• Stream erosion (lateral migration and avulsion)	3	3	9		1	1	1
	• 83ER		• Erosion	5	1	5		2	1	2
Angusmac Creek 710.2 – 710.8	• 84SM	• Potential for lateral migration across wide floodplain • Moderately steep gullied slopes to east and west, potential instabilities	• Shallow to moderately deep slides	5	2	10	• Design to avoid stream erosion. • Using routing to avoid instabilities. • Design of grading. • Surface and ground water control.	2	1	2
	• 85ER		• Erosion on slopes	5	1	5		3	1	3
	• 86SE		• Stream erosion (lateral migration)	4	4	16		1	2	2
Crooked River 718.0- 718.6	• 87SE	• Highly mobile river with wide floodplain (potential for lateral migration) • Poorly drained organic terrain (718.0 – 718.6)	• Stream erosion (lateral migration)	4	3	12	• Design to avoid stream erosion. • Design for consolidation settlement as required.	1	1	1
	• 88CS		• Consolidation settlement	3	2	6		2	1	2

Location/Area KP Start - KP End	Geohazard Code	Description of Terrain	Geohazard Type(s)	Unmitigated			Potential Protection, Mitigation and Management Measures ¹	Mitigated		
				Hazard Likelihood	Consequence Rating	Risk		Hazard Likelihood	Consequence Rating	Risk
North of Slender Lake 739.0-740.9	• 89CS	• Frequent organics (muskeg)	• Consolidation settlement	3	2	6	• Design for consolidation settlement as required.	2	1	2
Muskeg River area 747.2 – 748.7	• 90SE	• Potential for lateral migration	• Stream erosion (lateral migration)	3	4	12	• Design to avoid stream erosion.	1	2	2
Salmon River area 762.5 – 763.8	• 91SE	• Evidence of shallow sliding and/or groundwater piping and gully erosion (incised creeks) on west side • Highly mobile river with 450 m wide floodplain • Frequent debris jams	• Stream erosion (lateral migration)	5	5	25	• Design to avoid stream erosion. • Landslides avoided by routing. • Slope stability considerations to be incorporated in grading design. • Ground and surface water control.	2	2	4
	• 92SM		• Shallow to moderately deep slides	4	2	8		2	1	2
	• 93ER		• Erosion on slopes	5	2	10		2	1	2
Stuart River 821.0 - 822.0	• 94DS	• Very extensive deep-seated slides in glaciolacustrine clays extend far to the south on east and west approaches • Moderately deep-seated slide along lower valley wall on west side of river. Involves lowest terrace • Gullies are dry and not eroding	• Deep-seated instabilities	5	5	25	• Control groundwater and surface water drainage. • Design to avoid stream erosion. • Use routing or design to avoid instabilities. • Trenchless crossing method to avoid slide on west side.	1	2	2
	• 95SM		• Shallow to moderately deep slides	5	4	20		1	1	1
Endako River 929.2 – 929.8	• 96CS	• Potential for consolidation settlement in vicinity of CN Rail embankment to east • Organic deposits near river • Organic veneers west of river	• Consolidation Settlement	4	4	16	• Design for consolidation settlement.	2	2	4
Klo Creek valley 975.2 – 975.4	• 97SE	• Very steep approach slope • Mobile channel (potential for lateral migration) • Moderately steep slopes with potential for instability (existing small failures identified north and south of route) • Fine-grained soils in valley bottom • Parts of east approach slope have groundwater blow-off failures • Small failures on west slope due to stream erosion in glaciolacustrine sediments	• Stream erosion (lateral migration)	5	3	15	• Slope stability considerations to be incorporated in grading design. • Control groundwater and surface water. • Design to avoid stream erosion. • Design to control erosion. • Ground and surface water control. • Routing to avoid slide on west side.	1	2	2
	• 98SM		• Shallow to moderately deep slides	4	3	12		1	1	1
	• 99ER		• Erosion on slopes	5	2	10		2	1	2
Lamprey Creek area 1018.3 - 1019.3	• 100SM	• East valley wall moderate to steep and about 80 m high, slide evident near route	• Shallow to moderately deep slides	5	3	15	• Grade slopes. • Design to avoid landslides. • Ground and surface water control.	1	2	2

Location/Area KP Start - KP End	Geohazard Code	Description of Terrain	Geohazard Type(s)	Unmitigated			Potential Protection, Mitigation and Management Measures ¹	Mitigated		
				Hazard Likelihood	Consequence Rating	Risk		Hazard Likelihood	Consequence Rating	Risk
Cedric Creek 1025.6 - 1026.3	• 101SM	<ul style="list-style-type: none"> Incised channel Potential for shallow sliding 	• Shallow to moderately deep slides	3	2	6	<ul style="list-style-type: none"> Landslides avoided by routing. Slope stability considerations to be incorporated in grading design. Design to avoid stream erosion. Ground and surface water control. 	1	1	1
	• 102SE		• Stream erosion	3	3	9		1	1	1
1032.3 – 1035.3	• 103SM	<ul style="list-style-type: none"> Shallow soils on moderately steep , bedrock-controlled slopes (potential for shallow to moderately deep sliding along route) Slopes become steeper north of RoW Erosion 	• Shallow to moderately deep slides	3	3	9	<ul style="list-style-type: none"> Landslides and excessively steep sidehills avoided by routing. Narrow graded area with workspace on road. 	2	2	4
	• 104ER		• Erosion	4	3	12		2	1	2
Tributary to Gosnell Creek 1044.3	• 105SE	<ul style="list-style-type: none"> Potential for stream erosion (avulsion) and debris torrents 	• Stream erosion (avulsion)	4	5	20	<ul style="list-style-type: none"> Design to avoid stream erosion and debris flows. 	2	2	4
	• 106DF		• Debris flows	4	4	16		2	2	4
1050.2 – 1055.8	• 107DF	<ul style="list-style-type: none"> RoW at the base of steep slopes to south Avalanche/debris flow run-out zones above route 	• Debris flows	3	4	12	<ul style="list-style-type: none"> Design to avoid or control debris flows. 	2	2	4
Gosnell Creek 1058.8 – 1059.1	• 108SE	<ul style="list-style-type: none"> Relatively mobile channel (potential for lateral migration) Frequent debris jams 	• Stream erosion (lateral migration)	3	3	9	<ul style="list-style-type: none"> Design to avoid stream erosion. 	1	1	1
1066.1 - 1067.3	• 109SE	<ul style="list-style-type: none"> Alluvial fan Potential for stream erosion (avulsion) and debris torrents 	• Stream erosion (avulsion, downcutting)	3	3	9	<ul style="list-style-type: none"> Design to avoid stream erosion and debris flows. 	1	2	2
	• 110DF		• Debris flows	3	3	9		1	2	2
Coast Mountains										
1068.3 – 1172.2	• 111EQ	<ul style="list-style-type: none"> Seismic motion Movement of slides induced by seismic motion 	• Seismic motion	1	5	5	<ul style="list-style-type: none"> Pipeline and ancillary structures must be designed for appropriate seismic forces. For overland pipelines, seismic motions are not typically an issue. Seismic-induced sliding will be mitigated through design process for slides discussed in other entries. 	1	3	3
East approach slope to Burnie and Clore River valleys 1070.6 to 1071.1	• 112SM	<ul style="list-style-type: none"> Shallow slide north of Rev R. Erosion on steep terrain 	• Shallow slide	4	3	12	<ul style="list-style-type: none"> Avoided by routing. Ground and surface water control. 	1	1	1
	• 113ER		• Erosion	5	2	10		2	1	2

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1072.4 – 1072.8 Clore River	• 114SE	• Lateral migration	• Stream erosion (lateral migration)	5	4	20	• Design crossing to accommodate lateral erosion.	1	1	1
Tributary to Clore River and adjacent areas 1079.8- 1079.9	• 115SM	• Steep bedrock-controlled slopes • Rockfall areas identified (primarily east of KP 1079.4) • Two avalanche tracks are present very near the route (southwest and southeast) • Shallow slides in colluvium • Channel is confined with potential for debris torrents • Avalanches and debris flows are parallel to pipeline route.	• Shallow to moderately deep slides	5	2	10	• Design to avoid or control rockfall and avalanches. • Design to avoid debris flows. • Landslides avoided by routing. • Control groundwater and surface water.	1	1	1
	• 116DF		• Debris flows	3	2	6		1	1	1
	• 117AV		• Avalanches	4	2	8		1	2	2
	• 118RF		• Rockfall	5	4	20		1	2	2
West Portal Hoult Tunnel 1086.6 – 1086.9	• 119AV	• Steep valley walls with potential for avalanches and rockfall on east side • Avalanches and debris flows are parallel to pipeline route.	• Avalanches	4	2	8	• Use routing to avoid avalanches and rockfall.	1	1	1
	• 120RF		• Rockfall	3	4	12		1	1	1
Hoult Creek and upper Kitimat River valley 1086.9 - 1098.3 and 1099.3 to 1101.3	• 121DF	• Northwest side of Hoult Creek valley has several watercourse crossings in steep gullies and ravines (subject to high flows, debris flows or avalanches) • Downstream of KP 1087, Hoult Creek is highly mobile due to avalanche and debris flow loading • Rockfall could occur from steep ravine walls in some areas • Possible avalanches from southeast side of valley (could re-direct Hoult Creek) • Groundwater blow-off failures have occurred locally during logging road construction • Slides in logging road fills have occurred in a few areas • Fan/cone complex with evidence of avalanches at KP 1090.7–1091.7 and 1092.3–1093.0	• Debris flows	4	4	16	• Detailed geotechnical and civil design based on detailed topography and cross sections. • Control groundwater and surface water drainage. • Design to control sedimentation. • Design to avoid or control rockfall and avalanches. • Landslides avoided by routing. • Design to avoid debris flows and stream erosion.	2	2	4
	• 122RF		• Rockfall	3	3	9		2	1	2
	• 123SE		• Stream erosion (downcutting, lateral migration) • Sedimentation	4	3	12		1	1	1
	• 124SM		• Shallow to moderately deep slides	4	3	12		1	1	1
	• 125AV		• Avalanches	5	4	20		1	2	2
Hunter Creek 1098.3 - 1099.3	• 126SE	• Active alluvial fan prone to major avulsion and debris flows and torrents • Several small shallow slides in surface soils along terrace fronts (due to creek undercutting)	• Stream erosion (avulsion, downcutting)	5	5	25	• Design to avoid stream erosion and debris flows. • Landslides avoided by routing.	1	1	1
	• 127DF		• Debris flows	5	5	25		1	1	1
	• 128SM		• Shallow to moderately deep slides	4	3	12		1	1	1
1101.3 - 1102.3	• 129SE	• RoW crosses several active alluvial fans. • Potential for stream erosion (avulsion), debris flows and debris torrents	• Stream erosion (avulsion)	4	3	12	• Design to avoid stream erosion and debris flows.	1	2	2
	• 130DF		• Debris flows	3	4	12		1	2	2
Upper Kitimat River valley 1101.3 - 1119.3	• 131SM	• Steep gullied slopes, potentially unstable • Evidence of avalanches • Evidence of shallow to moderately deep slides in shallow colluvium over bedrock	• Shallow to moderately deep slides	4	4	16	• Detailed geotechnical and civil design based on detailed topography and cross sections.	2	1	2
	• 132AV		• Avalanches	4	3	12		2	2	4

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	• 133SE	<ul style="list-style-type: none"> Several watercourse crossings in steep gullies and ravines Some streams subject to high flows and debris torrents Isolated rockfall potential from bluffs Groundwater blow-off failures have occurred locally during logging road construction 	• Stream erosion (downcutting)	3	3	9	<ul style="list-style-type: none"> Control groundwater and surface water drainage. Design to control sedimentation. Landslides avoided by routing. Design to avoid or control avalanches and rockfall. Design to avoid stream erosion and debris flows. 	2	1	2
	• 134DF		• Sedimentation	5	4	20		1	2	2
	• 135RF		• Debris flows	4	5	20		1	2	2
1115.9	• 136SE	• Kitimat River eroding laterally toward the logging road aided by groundwater piping of sediments in the river bank	• Stream erosion (lateral migration)	5	4	20	• Route avoids problem area.	1	1	1
Chist Creek 1122.8 - 1123.8	• 137SE	<ul style="list-style-type: none"> Extensive lateral migration, particularly south of PDA Shallow slides along actively-eroding terrace fronts (related to undercutting) Potential for lateral erosion of creek north of existing road west of bridge. 	• Stream erosion (lateral migration)	5	4	20	<ul style="list-style-type: none"> Design to avoid/reduce stream erosion. Possible riprap on outside bend north of bridge. 	1	2	2
Cecil Creek 1131.0 – 1131.8	• 138ER	• Steep eroded terrace fronts and valley walls	• Erosion on slope	5	2	10	<ul style="list-style-type: none"> Control groundwater and surface water drainage. Consider erosion in design of grading. Ground reconnaissance of south side. 	2	1	2
1135.6 – 1137.2	• 139SM	• Sliding and erosion in glaciomarine sediments	• Shallow to moderately deep sliding	5	4	20	• Avoided by routing north around area and along edge of rock and till on Iron Mountain.	1	1	1
	• 140ER		• Erosion	5	3	15		1	1	1
1136.2	• 141RF	• Waterfall and rockfall	• Rockfall	5	3	15	• Design and routing.	2	2	4
Eastern flank on Iron Mountain 1135.3 – 1143.3	• 142LS	<ul style="list-style-type: none"> Potential for lateral spreading and induced sliding in sensitive clays in localized areas below about 200 m elevation. Borehole R02 encountered 0.2 m of sensitive marine clays at a depth of 44 m. 	• Lateral spreading or deep-seated sliding	1	5	5	<ul style="list-style-type: none"> Design and route to avoid areas prone to lateral spreading. Possible reroute on rock of Iron Mountain flank to the west. Alternate reroute along ridge in middle of Kitimat River Valley. Landslides avoided by routing. Additional ground and drilling investigation. 	1	1	1
	• 143SM		• Shallow to moderately deep slides	3	3	9		1	1	1
Southeast flank of Iron Mountain 1142.6 – 1144.1	• 144RF	• Recent rockfall at about KP 1143.3	• Rockfall	5	3	15	• Design to avoid or control rockfall.	2	1	2
Wedene River area 1143.3 – 1146.8	• 145DS	<ul style="list-style-type: none"> Buried and exposed bedrock (profile unknown) Deep-seated slides likely in sensitive glaciomarine clay. 	• Deep-seated instabilities	5	4	20	• Control groundwater and surface water.	1	1	1

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	• 146SM	<ul style="list-style-type: none"> Shallow to moderately deep slides including retrogressive sliding, groundwater piping and erosion. Potential for lateral spreading and induced sliding in sensitive clays in localized areas below about 200 m elevation. Thicknesses in excess of 12 m of sensitive clays were found in a borehole to the south of the Wedeene Crossing Borehole R03 encountered 0.1 m of sensitive clay at a depth of 9 m and 12 m of sensitive clays at 21.5 through 33.5 m depth. 	• Shallow to moderately deep slides	3 varies	3	9	<ul style="list-style-type: none"> Conduct ground reconnaissance. Use routing and crossing design to avoid landslides. Use routing and crossing design to avoid sensitive clays. Further investigation required for sensitive clays. 	2	2	4
	• 147LS		• Lateral spreading or deep-seated sliding	1	5	5		1	1	1
1146.8 – 1150.3	• 148LS	<ul style="list-style-type: none"> Potential for lateral spreading and induced sliding in sensitive clays in localized areas below about 200 m elevation near the Little Wedeene River 	• Lateral spreading or deep-seated sliding	1	5	5	<ul style="list-style-type: none"> Use routing and crossing design to avoid areas prone to lateral spreading. Possible reroute along the rock slopes to the west. Further investigation required for sensitive clays. 	1	1	1
	• 149SM		• Shallow to moderately deep slides	3	3	9		1	1	1
Little Wedeene River 1148.3 - 1149.3	• 150SM	<ul style="list-style-type: none"> Terraced glaciofluvial and glaciomarine deposits Possibility of glaciomarine deposits will need further investigation. Shallow instabilities identified (related to river undercutting) Mobile channel (potential for lateral migration) 	• Shallow to moderately deep slides	5	4	20	<ul style="list-style-type: none"> Control groundwater and surface water drainage. Design to avoid stream erosion. Landslides avoided by routing. Further investigations relative to design. 	1	1	1
	• 151SE		• Stream erosion (lateral migration)	3	4	12		1	1	1
1150.3 – 1172.2	• 152LS	<ul style="list-style-type: none"> Potential for lateral spreading and induced sliding in sensitive clays in localized areas below about 200 m elevation. No known lateral spreading failures close to the pipeline route 	• Lateral spreading or deep-seated sliding	1	5	5	<ul style="list-style-type: none"> Use routing and crossing design to avoid areas prone to lateral spreading. Possible reroute using a ridge in the Kitimat River Valley east of the current alignment. Further investigations required for sensitive clays. 	1	1	1
	• 153SM		• Shallow to moderately deep slides	3	3	9		1	1	1
West of Kitimat River 1153.8 – 1155.3	• 154SE	• RoW potentially susceptible to lateral erosion at the outside bend of Kitimat River	• Stream erosion (lateral migration)	3	3	9	• Design to avoid stream erosion.	1	1	1
1158.6 – 1159.8	• 155SE	<ul style="list-style-type: none"> RoW potentially susceptible to lateral erosion at the outside bend of Kitimat River Potential for lateral spreading to be further investigated 	• Stream erosion (lateral migration)	3	5	15	<ul style="list-style-type: none"> Design to avoid stream erosion. Further investigations. 	2	2	4
Anderson Creek 1163.5 - 1164.3	• 156SE	• Failure of existing dikes and stream training installations to be further considered –might result in lateral erosion	• Stream erosion (lateral erosion)	2	5	10	• Design to avoid lateral erosion.	1	1	1

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1164.3 – 1164.9	• 157CS	<ul style="list-style-type: none"> Potential for consolidation settlement due to presence of fine-grained, compressible soils. Potential for liquefaction due to seismic motion 	• Consolidation settlement	3	5	15	<ul style="list-style-type: none"> Design for consolidation settlement or use routing to avoid area. Design for liquefaction or route around area. 	2	2	4
	• 158LQ		• Liquefaction	1	5	5		1	2	2
Moore Creek area 1165.0 – 1165.2	• 159DF	<ul style="list-style-type: none"> Deeply incised channel in bedrock Potential for debris torrents 	• Debris flows	3	3	9	<ul style="list-style-type: none"> Design to avoid debris flows. 	1	1	1
West side of Kitimat Arm 1167.1 - 1171.3	• 160SM	<ul style="list-style-type: none"> Steeply sloping terrain, bedrock-controlled, numerous small gullies or ravines and shallow surface slides and rockfall Large rockfall area south of RoW from KP 1170.0 – 1170.3 Eroded alluvial and colluvial materials Susceptible to debris torrents from adjacent gully systems Stream at 1169.1 may be subject to debris flows or high flows Rockfall from boulders in till on slopes 	• Shallow to moderately deep slides	5	3	15	<ul style="list-style-type: none"> Design to avoid or control rockfall. Design to avoid debris flows and stream erosion. Control groundwater and surface water. Slope stability considerations to be incorporated in grading design. 	2	2	4
	• 161RF		• Rockfall	5	4	20		2	2	4
	• 162DF		• Debris flows	4	4	16		1	1	1
	• 163SE		• Stream erosion (downcutting)	3	3	9		1	1	1
Kitimat Terminal 1172.2	• 164TS	• Possibility of tsunami affecting docking facilities	• Tsunami	• Under study			• Under study.	• Under study		
Kitimat Terminal 1172.2	• 165SM	<ul style="list-style-type: none"> Potential for shallow to deep-seated landslides in fine-grained glaciomarine soils Potential for lateral spreading and consolidation settlement in fine-grained soils Debris flow potential from small, high-gradient streams Potential for rockfall from steep, bedrock-controlled slopes 	• Shallow to moderately deep slides	3	5	15	<ul style="list-style-type: none"> Facilities to be located outside of extents of significant fine-grained soils. Design to avoid debris flows. Design to avoid or control rockfall. Detailed investigations have been done to facilitate detailed design. 	2	2	4
	• 166DS		• Deep-seated instabilities	3	5	15		1	1	1
	• 167LS		• Lateral spreading	3	5	15		1	1	1
	• 168CS		• Consolidation settlement	2	4	8		1	2	2
	• 169DF		• Debris flows	3	3	9		1	1	1
	• 170RF		• Rockfall	3	3	9		1	2	2

