

Appendix 5.21  
Transmission Options  
Evaluation  
(Midgard 2016)

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**Yukon Energy Corporation**  
**Transmission Options Evaluation**  
**(11 Routes of Interest)**

**Submitted By:** Midgard Consulting Incorporated

**Date:** November 8, 2016

## Document Control & Signoff

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### DOCUMENT NUMBER

P0239-D033-RPT-R01-EXT

### REVISION CONTROL

Revision	Description	Date
00	First draft version of report for client review and comment	Aug 9, 2016
01	Incorporating YEC feedback and edits	Nov 8, 2016

### REPORT SIGN-OFF

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## Executive Summary

The Yukon Energy Corporation (“YEC”) has commissioned Midgard Consulting Incorporated (“Midgard”) and its team of sub-consultants to complete a Transmission Options Evaluation of eleven potential Yukon transmission line corridors. The assignment scope comprises:

- Detailed transmission corridor optimization (Section 2)
- Estimate of capital expenditures (“CAPEX”) (Section 3)
- Estimate of operating expenditures (“OPEX”) (Section 4)
- Calculation of power transfer capacities (Section 5)
- Overview of transmission corridor development schedules (Section 6)
- Assessment of corridor risks (Section 7)

Figure 1 below illustrates the eleven routes of interest on a map of the Yukon.

**Figure 1: Map of Studied Routes**

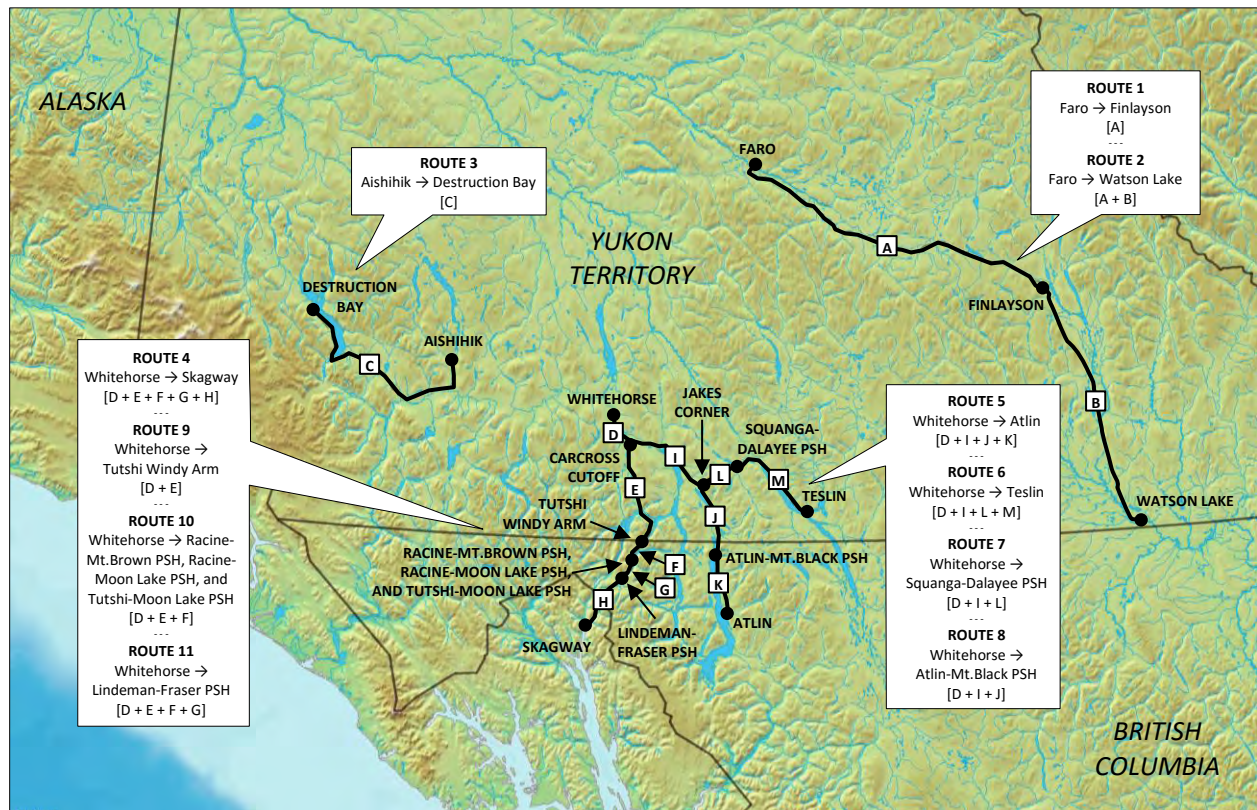


Table 1 below provides a high level summary of the study results for each transmission option, listing the line voltage, line length, maximum reliable transfer capacity, estimated CAPEX, estimated annual OPEX, and earliest In-Service-Date (“ISD”).

The estimated CAPEX and OPEX costs shown in Table 1 represent a Class 5 estimate (-50%/+100% range of cost accuracy) as set out in Standard 17R-97 of the Association of the Advancement of Cost Engineering.

**Table 1: Summary of Results (Costs Stated in \$2016)**

#	Transmission Route	Voltage	Length	Reliable Transfer Capacity <sup>1</sup>	CAPEX	OPEX	Earliest Possible ISD
1	Faro → Finlayson	138 kV	233 km	84 MW	\$221M	\$351k/yr	Jan 2021
2	Faro → Watson Lake	230 kV	414 km	190 MW	\$597M	\$613k/yr	Sep 2022
3	Aishihik → Destruction Bay	138 kV	157 km	122 MW	\$167M	\$217k/yr	Jul 2020
		230 kV		484 MW	\$241M		
4	Whitehorse → Skagway	138 kV	170 km	114 MW	\$166M	\$285k/yr	Oct 2020
		230 kV		443 MW	\$251M		
5	Whitehorse → Atlin	138 kV	172 km	97 MW	\$158M	\$236k/yr	Oct 2020
6	Whitehorse → Teslin	138 kV	174 km	95 MW	\$165M	\$239k/yr	Oct 2020
7	Whitehorse → Squanga-Dalayee PSH	138 kV	105 km	134 MW	\$100M	\$143k/yr	Dec 2019
8	Whitehorse → Atlin-Mt.Black PSH	138 kV	127 km	131 MW	\$119M	\$174k/yr	May 2020
9	Whitehorse → Tutshi Windy Arm	138 kV	96 km	135 MW	\$94M	\$143k/yr	Nov 2019
10	Whitehorse → Racine-Mt.Brown PSH, Racine-Moon Lake PSH, and Tutshi-Moon Lake PSH	138 kV	112 km	132 MW	\$108M	\$168k/yr	Jan 2020
11	Whitehorse → Lindeman-Fraser PSH	138 kV	129 km	129 MW	\$125M	\$200k/yr	Jun 2020

<sup>1</sup> These values represent the most restricted transfer capacity that is expected in either summer or winter. Thermally limited transmission options may demonstrate a higher Winter Capacity. See Table 8 for more details.

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## LIST OF ACRONYMS & ABBREVIATIONS

CAPEX	Capital Expenditure
ISD	In-Service Date
JDMA	J.D. Mollard and Associates (“JDMA”) Limited
Midgard	Midgard Consulting Inc.
OPEX	Operating Expenditure
PSH	Pumped Storage Hydro
ROW	Right of Way

## 1 Introduction

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The Yukon Energy Corporation (“YEC”) has commissioned Midgard Consulting Incorporated (“Midgard”) and its sub-consultant, J.D. Mollard and Associates (2010) Limited (“JDMA”) to evaluate eleven potential Yukon transmission line options.

- 1) **Midgard Consulting Incorporated (“Midgard”)**: Midgard has been providing consulting services to the electrical power and utility industry since 2009, specializing in utility resource planning, renewable generation development, transmission & distribution planning and design, and providing expert strategic services including business case development, project due diligence & financing, system modelling and regulatory support.
- 2) **J.D. Mollard and Associates (2010) Limited (“JDMA”)**: JDMA is a private consulting firm of professional engineers, geoscientists, geographers, and environmental scientists based in Regina, Saskatchewan, Canada. The company has a long tradition of excellence in applied civil and geological engineering, geology, hydrogeology, geography, biology, remote sensing, GIS, terrain analysis, and environmental studies.

The scope of work includes evaluating and optimizing the transmission corridors, estimating capital expenditures (“CAPEX”), estimating operating expenditures (“OPEX”), calculating the maximum reliable power transfer capacities, preparing high-level transmission development schedules, and assessing development risks for each of the identified transmission options.

Table 2 lists the eleven transmission line options evaluated in this report.

**Table 2: Overview of Transmission Options**

#	Transmission Option	Voltage	Length
1	Faro → Finlayson	138 kV	233 km
2	Faro → Watson Lake	230 kV	414 km
3	Aishihik → Destruction Bay	138 & 230 kV	157 km
4	Whitehorse → Skagway	138 & 230 kV	170 km
5	Whitehorse → Atlin	138 kV	172 km
6	Whitehorse → Teslin	138 kV	174 km
7	Whitehorse → Squanga-Dalayee PSH	138 kV	105 km
8	Whitehorse → Atlin-Mt.Black PSH	138 kV	127 km
9	Whitehorse → Tutshi Windy Arm	138 kV	96 km
10	Whitehorse → Racine-Mt.Brown PSH, Racine-Moon Lake PSH, and Tutshi-Moon Lake PSH	138 kV	112 km
11	Whitehorse → Lindeman-Fraser PSH	138 kV	129 km

The following assumptions were utilized in preparing this report:

- 1) The line voltage for each transmission option was defined by YEC in the scope of work.
- 2) 34.5 kV distribution underbuild has been incorporated on portions of several routes, including:
  - a. Whitehorse → Teslin
  - b. Whitehorse → Carcross
  - c. Aishihik → Haines Junction
- 3) The following standard phase conductor and bundling selections have been used throughout:
  - a. 138 kV Options: Single 397.5 MCM<sup>2</sup> Ibis ACSR conductor
  - b. 230 KV Options: Double Bundle<sup>3</sup> 477 MCM Hawk ACSR conductor

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<sup>2</sup> MCM = Thousand circular mils. A circular mil is the cross-sectional area of a wire with a 1/1000 inch diameter (approximately 0.0005 mm<sup>2</sup>)

<sup>3</sup> Double bundle 477 MCM Hawk has been selected to mitigate corona inception at 230 kV. In this conductor bundling configuration, each phase comprises two separate Hawk conductors.

## 2 Corridor Routing & Descriptions

JDMA, with input from Midgard and YEC, carried out route analysis and refinement for the transmission corridors of interest. JDMA completed the corridors evaluations using ESRI ArcGIS and MicroImages TNT MIPS, with data sourced from various territorial, provincial, and national sources (for a detailed breakdown of data sourcing, please see Section 2.1 of JDMA’s report attached in Appendix C). The general methodology of route selection was as follows:

- Transmission line span length between poles/structures/towers targeted to be 200 to 230 m with longer spans as needed
- Where practical, the transmission line corridor was placed adjacent to roadways
- The target corridor width of 500m, but narrowed to less than 500 m when necessary to avoid major terrain constrictions adjacent to the corridor (e.g.: next to a steep slope, river, etc.)
- Avoided crossing privately held land wherever possible
- Where practical, line deflections were kept to <15° to avoid more complex and costly structures

In addition to these specific criteria, JDMA also considered surficial geology and surface materials, terrain and slope, total length, as well as stream and wetland crossings to help identify potentially feasible corridors. The full JDMA study is attached in Appendix C. Figure 2 shows all of the transmission routes considered.

**Figure 2: Map of Studied Routes**

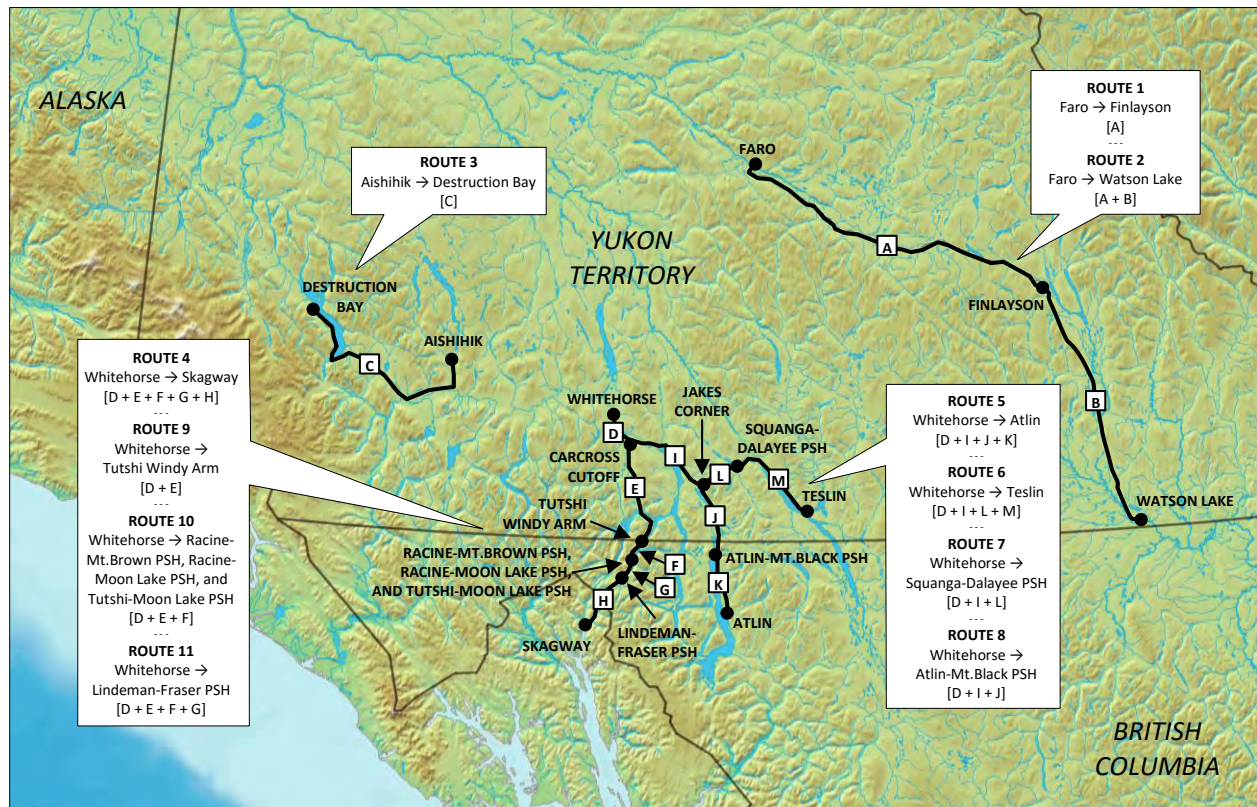


Table 3 provides a brief overview of the analyzed routes.

**Table 3: Description of Studied Routes**

#	Transmission Route	Description of Route
1	Faro ↓ Finlayson	<ul style="list-style-type: none"> <li>▪ <b>Start:</b> Town of Faro</li> <li>▪ <b>End:</b> Finlayson Project Interconnection</li> <li>▪ <b>Length:</b> 233 km</li> <li>▪ Follows the “Faro → Watson Lake” route from Faro for 233 km until reaching the Finlayson project interconnection point.</li> </ul>
2	Faro ↓ Watson Lake	<ul style="list-style-type: none"> <li>▪ <b>Start:</b> Town of Faro</li> <li>▪ <b>End:</b> Town of Watson Lake</li> <li>▪ <b>Length:</b> 414 km</li> <li>▪ Parallels the Pelley River for 56 km at the north end and then follows Highway 4 (Robert Campbell Highway) to Watson Lake.</li> <li>▪ Crosses several major rivers at the south end, including the Frances and Liard Rivers.</li> </ul>
3	Aishihik ↓ Destruction Bay	<ul style="list-style-type: none"> <li>▪ <b>Start:</b> Aishihik Generating Station</li> <li>▪ <b>End:</b> Town of Destruction Bay</li> <li>▪ <b>Length:</b> 157 km</li> <li>▪ From Aishihik the corridor heads south to Canyon, paralleling existing access and transmission used for the Aishihik project.</li> <li>▪ From Canyon the corridor generally follows Highway 1 westwards (Alaska Highway) to Destruction Bay.</li> <li>▪ The corridor detours off of Highway 1 at the Slims River crossing to take advantage of a narrower river crossing location further upstream, but even this upstream location may involve a crossing span of up to 500 m.</li> <li>▪ After crossing Slims River, the corridor continues to follow Highway 1 to Destruction Bay, making use of an abandoned pipeline right-of-way.</li> <li>▪ 49 km of 34.5 kV distribution underbuild is included from Aishihik to Haines Junction</li> </ul>
4	Whitehorse ↓ Skagway	<ul style="list-style-type: none"> <li>▪ <b>Start:</b> Whitehorse Generating Station</li> <li>▪ <b>End:</b> Town of Skagway, AK</li> <li>▪ <b>Length:</b> 170 km</li> <li>▪ From the Whitehorse Generating Station the corridor follows Highway 1 southeast for 17 km to Carcross Cutoff (the junction of Highways 1 and 2).</li> <li>▪ From Carcross Cutoff the corridor follows Highway 2 southwards through the town of Carcross for 77 km to the BC-Yukon border.</li> <li>▪ Once in BC the corridor continues along Highway 2 for an additional 56 km to the BC-Alaska border.</li> <li>▪ Once in Alaska the corridor continues along the same highway (now named Highway 98) for an additional 21 km to Skagway, Alaska.</li> <li>▪ 68 km of 34.5 kV distribution underbuild is included from Whitehorse to Carcross</li> </ul>

#	Transmission Route	Description of Route
5	Whitehorse ↓ Atlin	<ul style="list-style-type: none"> <li>▪ <b>Start:</b> Whitehorse Generating Station</li> <li>▪ <b>End:</b> Town of Atlin, BC</li> <li>▪ <b>Length:</b> 172 km</li> <li>▪ From the Whitehorse Generating Station the corridor follows Highway 1 southeast for 17 km to Carcross Cutoff.</li> <li>▪ The corridor then follows Highway 1 eastwards for 62 km to Jakes Corner where Highway 1 meets Highway 8. On this stretch the corridor crosses the Yukon River, a span of approximately 250 m.</li> <li>▪ From Jakes Corner the corridor turns south and follows Highway 7 for 42 km to the BC-Yukon border.</li> <li>▪ Once in BC the corridor continues along Highway 7 for an additional 50 km to Atlin, BC.</li> <li>▪ 79 km of 34.5 kV distribution underbuild is included from Whitehorse to Jakes Corner</li> </ul>
6	Whitehorse ↓ Teslin	<ul style="list-style-type: none"> <li>▪ <b>Start:</b> Whitehorse Generating Station</li> <li>▪ <b>End:</b> Town of Teslin</li> <li>▪ <b>Length:</b> 174 km</li> <li>▪ From the Whitehorse Generating Station the corridor follows Highway 1/2 southeast for 17 km to Carcross Cutoff (the junction of Highways 1 and 2).</li> <li>▪ The corridor then follows Highway 1 eastwards for 62 km to Jakes Corner, where Highway 1 meets Highway 8. On this stretch the corridor crosses the Yukon River, a span of approximately 250 m.</li> <li>▪ From Jakes Corner the corridor follows Highway 1 eastwards for 95 km to Teslin, crossing the Teslin River (a span of approximately 400 m) and passing through the communities of Johnson’s Crossing, Brooks Brook, and Teslin Lake.</li> <li>▪ 34.5 kV distribution underbuild is included for the entire corridor (174 km)</li> </ul>
7	Whitehorse ↓ Squanga-Dalayee PSH	<ul style="list-style-type: none"> <li>▪ <b>Start:</b> Whitehorse Generating Station</li> <li>▪ <b>End:</b> Squanga-Dalayee PSH Project Interconnection</li> <li>▪ <b>Length:</b> 105 km</li> <li>▪ From the Whitehorse Generating Station the corridor follows Highway 1/2 southeast for 17 km to Carcross Cutoff (the junction of Highways 1 and 2).</li> <li>▪ The corridor then follows Highway 1 eastwards for 62 km to Jakes Corner, where Highway 1 meets Highway 8. On this stretch the corridor crosses the Yukon River, a span of approximately 250 m.</li> <li>▪ From Jakes Corner the corridor follows Highway 1 eastwards for 26 km to the Squanga-Dalayee PSH interconnection point.</li> <li>▪ 34.5 kV distribution underbuild is included for the entire corridor (105 km)</li> </ul>

#	Transmission Route	Description of Route
8	Whitehorse ↓ Atlin-Mt.Black PSH	<ul style="list-style-type: none"> <li>▪ <b>Start:</b> Whitehorse Generating Station</li> <li>▪ <b>End:</b> Atlin-Mt.Black PSH Project Interconnection</li> <li>▪ <b>Length:</b> 127 km</li> <li>▪ From the Whitehorse Generating Station the corridor follows Highway 1 southeast for 17 km to Carcross Cutoff.</li> <li>▪ The corridor then follows Highway 1 eastwards for 62 km to Jakes Corner where Highway 1 meets Highway 8. On this stretch the corridor crosses the Yukon River, a span of approximately 250 m.</li> <li>▪ From Jakes Corner the corridor turns south and follows Highway 7 for 42 km to the BC-Yukon border.</li> <li>▪ Once in BC the corridor continues along Highway 7 for an additional 6 km to the Atlin-Mt.Black PSH interconnection point.</li> <li>▪ 79 km of 34.5 kV distribution underbuild is included from Whitehorse to Jakes Corner</li> <li>▪ Note that given the proximity of the termination point of this line, it likely makes sense to complete the remaining 45 km stretch into Atlin.</li> </ul>
9	Whitehorse ↓ Tutshi Windy Arm	<ul style="list-style-type: none"> <li>▪ <b>Start:</b> Whitehorse Generating Station</li> <li>▪ <b>End:</b> Tutshi Windy Arm Project Interconnection</li> <li>▪ <b>Length:</b> 96 km</li> <li>▪ From the Whitehorse Generating Station the corridor follows Highway 1 southeast for 17 km to Carcross Cutoff (the junction of Highways 1 and 2).</li> <li>▪ From Carcross Cutoff the corridor follows Highway 2 southwards through the town of Carcross for 77 km to the BC-Yukon border.</li> <li>▪ Once in BC the corridor continues along Highway 2 for an additional 2 km to reach the Tutshi Windy Arm project interconnection point.</li> <li>▪ 68 km of 34.5 kV distribution underbuild is included from Whitehorse to Carcross</li> </ul>
10	Whitehorse ↓ Racine- Mt.Brown PSH, Racine-Moon Lake PSH, and Tutshi-Moon Lake PSH	<ul style="list-style-type: none"> <li>▪ <b>Start:</b> Whitehorse Generating Station</li> <li>▪ <b>End:</b> Racine-Mt.Brown PSH, Racine-Moon Lake PSH, and Tutshi-Moon Lake PSH Project Interconnections</li> <li>▪ <b>Length:</b> 112 km</li> <li>▪ From the Whitehorse Generating Station the corridor follows Highway 1 southeast for 17 km to Carcross Cutoff (the junction of Highways 1 and 2).</li> <li>▪ From Carcross Cutoff the corridor follows Highway 2 southwards through the town of Carcross for 77 km to the BC-Yukon border.</li> <li>▪ Once in BC the corridor continues along Highway 2 for an additional 18 km to reach the interconnection point for several different PSH projects (Racine-Mt.Brown PSH, Racine-Moon Lake PSH, &amp; Tutshi-Moon Lake PSH)</li> <li>▪ 68 km of 34.5 kV distribution underbuild is included from Whitehorse to Carcross</li> </ul>

#	Transmission Route	Description of Route
11	<p style="text-align: center;">Whitehorse  ↓  Lindeman-Fraser  PSH</p>	<ul style="list-style-type: none"> <li>▪ <b>Start:</b> Whitehorse Generating Station</li> <li>▪ <b>End:</b> Lindeman-Fraser PSH Project Interconnection</li> <li>▪ <b>Length:</b> 129 km</li> <li>▪ From the Whitehorse Generating Station the corridor follows Highway 1 southeast for 17 km to Carcross Cutoff (the junction of Highways 1 and 2).</li> <li>▪ From Carcross Cutoff the corridor follows Highway 2 southwards through the town of Carcross for 77 km to the BC-Yukon border.</li> <li>▪ Once in BC the corridor continues along Highway 2 for an additional 35 km to reach the Lindeman-Fraser PSH project interconnection point.</li> <li>▪ 68 km of 34.5 kV distribution underbuild is included from Whitehorse to Carcross</li> </ul>

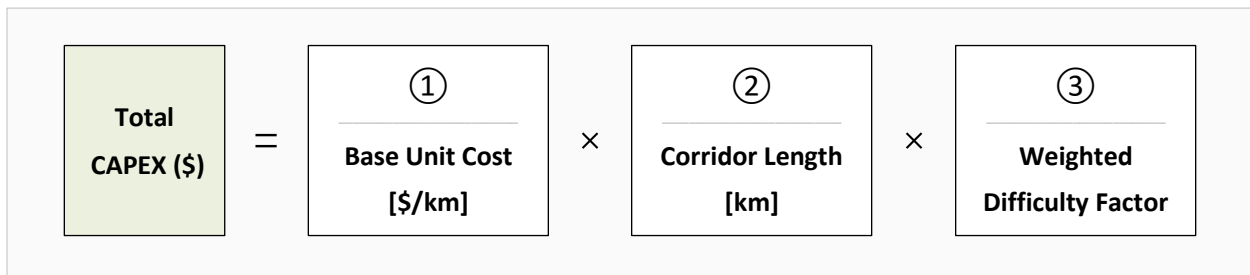
### 3 CAPEX Analysis

Midgard created a parametric model to estimate the all-in CAPEX required to implement each transmission line routing option. Midgard’s costs represent total, all-in costs for the transmission lines, which includes owner’s costs, development costs, stakeholder engagement costs, land costs, planning and engineering costs, construction costs, contractor profit margins, material costs, and commissioning costs. The CAPEX estimates do not include any provisions for new substations or substation related costs (e.g.: new bays, new breakers, or new bus work).

#### 3.1 CAPEX Estimation Methodology

The factor-based CAPEX model is defined by the following logic (see Figure 3):

**Figure 3: Midgard Parametric CAPEX Model**



The following descriptions provide more information on each component of the parametric CAPEX model:

- **Component ① - Base Unit Costs:** Drawing upon both public and proprietary industry transmission project cost information, an average per kilometer project costs for the studied voltage classes (138 kV and 230 kV) was established. The source data covers a wide range of transmission projects (16 x 138 kV projects and 17 x 230 kV projects) and represents a reasonable estimate of the expected “base case” unit costs for both 138 kV and 230 kV voltages.
- **Component ② - Corridor Length:** The corridor length for each of the transmission line routes was extracted from the detailed corridor analysis.
- **Component ③ - Weighted Difficulty Factor:** Weighted Difficulty Factors are calculated based on the terrain information from the detailed corridor analysis. The corridor-specific difficulty factors are based on a variety of inputs that uniquely differentiate each route based on the expected difficulty of project execution. Factors considered include: vegetation cover, water features, surficial geology, permafrost, terrain slope, existing access, human settlements, land use and remoteness.

In addition to the factor-based workup of project costs (detailed above), sub-sections of several routes (Whitehorse → Teslin, Whitehorse → Carcross, and Aishihik → Haines Junction) include a provision for 34.5 kV distribution underbuild. Since the Base Unit Costs do not include allowance for distribution underbuild, an additional adder was included for the route segments requiring underbuild. It is worth noting

that distribution underbuild cost is dependent on a variety of factors that have not yet been determined (e.g.: conductor type, number of taps/services, etc.), and therefore a consistent underbuild costs per kilometer was used. The following ranges are indicative of the incremental costs that could be expected to add distribution underbuild on different transmission line configurations:

- 1) Short spans, single pole structures, light distribution conductor: \$80,000 per km
- 2) Short spans, single pole structures, heavy distribution conductor: \$100,000 per km
- 3) Long spans, H-frame structures: \$120,000 to \$150,000 per km

Midgard considers that a \$100,000 per km adder is a reasonable high-level allowance for the incremental all-in costs of adding 34.5 kV underbuild to the selected transmission route segments.

The level of accuracy of the factor-based CAPEX model is Class 5 as per standard 17R-97 by the Association of the Advancement of Cost Engineering, which represents a -50% / +100% range of accuracy.

### 3.2 CAPEX Results

Table 4 below provides the tabular details of each of the eleven transmission corridors (including voltage, length, and the amount of 34.5 kV distribution underbuild) as well as the estimated total CAPEX and estimated CAPEX per km.

**Table 4: Summary of CAPEX Results (Costs Stated in \$2016)**

#	Transmission Route	Voltage	Length	34.5 kV Underbuild	CAPEX [Total]	CAPEX [Per KM]
1	Faro → Finlayson	138 KV	233 km	None	\$221M	\$0.95M/km
2	Faro → Watson Lake	230 kV	414 km	None	\$597M	\$1.44M/km
3	Aishihik → Destruction Bay	138 kV	157 km	49 km	\$167M	\$1.07M/km
		230 kV			\$241M	\$1.54M/km
4	Whitehorse → Skagway	138 kV	170 km	68 km	\$166M	\$0.98M/km
		230 kV			\$251M	\$1.48M/km
5	Whitehorse → Atlin	138 kV	172 km	79 km	\$158M	\$0.91M/km
6	Whitehorse → Teslin	138 kV	174 km	174 km	\$165M	\$0.95M/km
7	Whitehorse → Squanga-Dalayee PSH	138 KV	105 km	105 km	\$100M	\$0.96M/km
8	Whitehorse → Atlin-Mt.Black PSH	138 KV	127 km	79 km	\$119M	\$0.94M/km
9	Whitehorse → Tutshi Windy Arm	138 KV	96 km	68 km	\$94M	\$0.98M/km
10	Whitehorse → Racine-Mt.Brown PSH, Racine-Moon Lake PSH, and Tutshi-Moon Lake PSH	138 KV	112 km	68 km	\$108M	\$0.97M/km
11	Whitehorse → Lindeman-Fraser PSH	138 KV	129 km	68 km	\$125M	\$0.97M/km

### 3.3 CAPEX Benchmarking Analysis

In addition to the above CAPEX estimates, Midgard has also completed a benchmarking exercise against several YEC cost numbers in the Yukon. The two data sets being compared are:

- 1) **The 138 kV Routes from This Report:** The 138 kV lines (10 in total) considered in this *Transmission Options Evaluation* are based on the average costs (plus some factor modification, see Section 3.1) of 16 recent projects across the Yukon, Alberta, and British Columbia.
- 2) **YEC Projects of Interest:** A 138 kV route cost workup for the Stewart-Keno Transmission Project provided by YEC on July 8, 2016.

A benchmarking comparison (on a \$2016/km basis) of the two data sets is presented in Table 5 below.

**Table 5: Benchmarking Results (Costs Stated in \$2016)**

Data Set	#	Cost Range (\$2016)	Items Included in Cost Estimate
<i>Transmission Options Evaluation</i> 138 kV Results	10 Lines	\$0.85M → \$1.04M/km	Complete, All-In Costs (including project contingency, land costs, First Nation costs, development costs, permitting costs, engineering costs, salvage costs, and owner's overhead/admin costs, but not including distribution underbuild costs)
YEC Stewart-Keno Transmission Project Estimate	1 Line	\$0.53M/km	Construction Cost Only

As seen in the table above, the results of this *Transmission Options Evaluation* are higher than YEC's Stewart-Keno Transmission Project. Midgard believes this difference is primarily due to the *Transmission Options Evaluation* costs being represented as **total, all-in** costs as opposed construction-only costs (an "apples-to-oranges" comparison). Some of the cost items missing from YEC's Stewart-Keno Transmission Project estimate include:

- 1) **Project Contingency:** A contingency is a budget allocation to compensate for unforeseen costs. Unforeseen costs can manifest in many forms, including weather induced delays, unplanned soil conditions, or changes in labour market rates.
- 2) **Land Costs:** Land costs can include Right-of-Way acquisition, long term land leases, settlements with private land owners, relocation costs, remediation efforts, and habitat compensation offsets.
- 3) **First Nation Costs:** First Nation costs can include consultation efforts, compensation packages (impact benefit agreements), granting equity in projects, etc.

- 4) **Development Costs:** Development costs cover all early stage conceptual studies, preliminary engineering efforts, and environmental studies.
- 5) **Permitting Costs:** Permitting costs can include highway crossing permits, access permits, river crossing permits, aerodrome permits, pipeline crossing permits, etc.
- 6) **Engineering Costs:** Detailed engineering to design and issue the construction package for the transmission line.
- 7) **Salvage Costs:** Salvage costs includes any modification or removal of existing infrastructure to accommodate a new transmission line. For example, the removal of an old transmission line or wrecking out old distribution circuits.
- 8) **Owner's Overhead & Admin Costs:** Utility overhead includes the project's portion of all utility overhead. Utility overhead includes administration, office space, staffing costs, etc.

Typically the eight non-construction costs listed above can make up 30% to 50% of total, all-in project costs for a transmission line. Considering this fact, the benchmarking results do show overlap between the two sets of cost estimates.

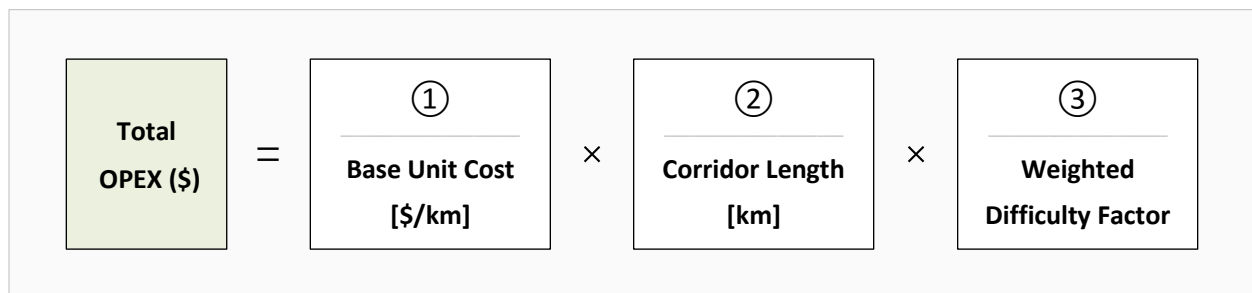
## 4 OPEX Analysis

Midgard calculated the annual OPEX required to maintain each transmission line option by drawing upon the average per unit costs of operating the existing YEC transmission system. Similar to the CAPEX modeling, the estimated OPEX costs represent the total all-in cost of transmission operations.

### 4.1 OPEX Estimation Methodology

The OPEX model is defined by the following logic (see Figure 4):

Figure 4: Midgard OPEX Model



The following descriptions provide more information on each component used in the calculations:

- **Component ① - Base Unit Cost:** The YEC 2012-2013 General Rate Application was used as the source for YEC’s total transmission operational costs. The proposed OPEX cost estimate for YEC in 2013 was \$1,293,000 (extracted from Table 3.6 on page 3-8 of “Supporting Documents: Tab 3 – Revenue Requirement”), which is comprised of labour costs, brushing costs, and other non-labour costs. This 2013 estimate was normalized to a \$/km value using the total line length of the existing YEC transmission system. Finally, the resulting per unit operational costs were inflation-adjusted to give results in 2016 Canadian dollars.
- **Component ② - Corridor Length:** The corridor length for each of the transmission line routes was extracted from the detailed corridor analysis.
- **Component ③ - Weighted Difficulty Factor:** Weighted Difficulty Factors are calculated based on the terrain information from the detailed corridor analysis. The corridor-specific difficulty factors are based on four inputs that uniquely differentiate each route based on the expected difficulty of operations. Factors considered include: permafrost, remoteness, terrain slope, and an adder for projects that extend outside the Yukon jurisdiction. The factors were applied in a manner such that some routes had increased operating costs (above the Base Unit Cost) and some had decreased operating costs (below the Base Unit Cost). This approach was chosen as the Base Unit Costs are already representative of the different factors that influence Yukon operating costs, and that it is reasonable to assume the new routes under consideration would more or less average to a similar operating cost (some being higher than average, some being lower).

## 4.2 OPEX Results

Table 6 below provides the estimated total annual OPEX for each of the evaluated transmission options.

**Table 6: Summary of OPEX Results (Costs Stated in \$2016)**

#	Transmission Route	Length	Annual OPEX [Total]	Annual OPEX [per km]
1	Faro → Finlayson	233 km	\$351,000	\$1,509/km
2	Faro → Watson Lake	414 km	\$613,000	\$1,481/km
3	Aishihik → Destruction Bay	157 km	\$217,000	\$1,383/km
4	Whitehorse → Skagway	170 km	\$285,000	\$1,680/km
5	Whitehorse → Atlin	172 km	\$236,000	\$1,377/km
6	Whitehorse → Teslin	174 km	\$239,000	\$1,371/km
7	Whitehorse → Squanga-Dalayee PSH	105 km	\$143,000	\$1,363/km
8	Whitehorse → Atlin-Mt.Black PSH	127 km	\$174,000	\$1,376/km
9	Whitehorse → Tutshi Windy Arm	96 km	\$143,000	\$1,487/km
10	Whitehorse → Racine-Mt.Brown PSH, Racine-Moon Lake PSH, and Tutshi-Moon Lake PSH	112 km	\$168,000	\$1,509/km
11	Whitehorse → Lindeman-Fraser PSH	129 km	\$200,000	\$1,551/km

## 5 Power Transfer Capacity Analysis

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In order to estimate the maximum reliable power transfer capacity of each transmission line option, a steady state power system analysis was performed using the Siemens PSS®E power system simulation software. The maximum reliable power transfer tells you how much electricity can be safely sent through the transmission line and is a useful characteristic to determine the most appropriate voltage and conductor type for planning purposes. The potential transmission lines studied in this *Transmission Options Evaluation* could be used for a variety of purposes, including serving electricity to remote communities, interconnecting mining operations to the Yukon grid, and/or interconnecting new power generation projects to the Yukon grid.

The power transfer capacity limit for each transmission option was determined by calculating the expected conductor temperature and the voltage magnitudes and angles at the line terminals and one or more intermediate points across a range of power transfers. For any given line option the capacity limiting parameter may be the absolute voltage magnitude (voltage constraint), the voltage angle separation between line terminals (angular constraint), or reaching the temperature limit of the conductor (thermal constraint). Since public access is not available for the power system models used by YEC, simplifying assumptions based on publicly available information were utilized to approximate the Yukon electrical system as part of a simplified model. Additional detail regarding the simulation set-up can be found in Appendix A.

It is important to state that the methodology used to calculate the maximum reliable power transfer capacity remains preliminary in this *Transmission Options Evaluation* for the purposes of informing YEC's long term planning efforts. As the projects are further considered, modified, and iterated towards actual implementation, the requirements and ultimate use of these proposed transmission lines will become more concrete. Once the transmission line projects are in a later stage of development, a more comprehensive suite of system analyses (including transient and voltage stability studies covering a broad set of present and future system forecast load cases) would be necessary.

### 5.1 Assumptions

#### 5.1.1 General

Some of the basic assumptions adopted for this study are as follows:

- 1) **Swing Bus:** A Swing Bus is a simulated generator bus that is used to balance power system loads and generators during system studies. The Swing Bus either absorbs surplus power or generates power to balance total power generation and consumption when solving system simulations. In the context of this study, the Swing Bus represents the cumulative Yukon grid, and the amount of power the Swing Bus absorbs represents the power transferred by the transmission line.

- 2) Yukon Loads: Yukon communities that are already electrified (e.g.: Tagish, Carcross, Ross River, etc.) were assumed to remain connected via their existing electrical grid connections (i.e. they were not transferred from their existing grid connection to the potential transmission lines). Midgard reviewed a series of future mining loads<sup>4</sup>, but determined that they would not be supplied by any of the eleven transmission corridors. All other electrical load values were provided by YEC.
- 3) Power Transferred to the Swing Bus = [Total generation along the new transmission line] – [Total loads along the new transmission line] - [Transmission line losses]
- 4) Voltage Stability: Steady state voltage stability implies maintaining voltage levels within 90% and 110% of the prescribed operating voltage (138 kV or 230 kV).
- 5) Angular Stability: Steady state angular stability is assumed to be achieved by maintaining a voltage angle difference of less than 33° between the generating end and the receiving end.

### 5.1.2 Operating Conditions

The following assumptions were made in order to model transmission line behaviour:

- 1) Wind Speed: 2 ft/s (0.61 m/s)
- 2) Winter Ambient Temperature: -10°C
- 3) Summer Ambient Temperature: +35°C
- 4) Altitude: Detailed in Table 7.

**Table 7: Altitude of Transmission Line Terminal Locations**

Location	Altitude (m)	Location	Altitude (m)
Whitehorse	655	Finlayson Lake	934
Faro	670	Squanga-Dalayee	778
Aishihik	920	Atlin	696
Mayo	504	Tutshi Windy Arm	715
Pelly Crossing	570	Racine	900
Destruction Bay	815	Lindeman	900
Watson Lake	685	Skagway	0
Teslin	690		

### 5.1.3 Conductor Type

Conductor selection assumptions:

- 1) 138 kV Corridors: Single 397.5 MCM Ibis ACSR conductor
- 2) 230 KV Corridors: Double Bundle 477 MCM Hawk ACSR conductor

<sup>4</sup> Victoria Gold, Brewery Creek, Alexco Bellekeno and Carmacks Copper are the potential mines that may be operational in the future.

## 5.2 Methodology

The following methodology was applied to determine the maximum reliable transfer capacity for each Transmission Option:

- 1) STEP 1: A steady state power flow model is developed for the PSS®E software using the following inputs:
  - a. Transmission line information (resistance, reactance, charging susceptance, and thermal rating)
  - b. Generation and load information
  - c. Operating voltage
- 2) STEP 2: A full Newton-Raphson simulation is performed assuming a flat start condition utilizing an assumed base power transfer level.
- 3) STEP 3: The bus voltage, the voltage angle, and the conductor temperature are monitored to determine if they remain within their limiting conditions. The limiting conditions are as follows:
  - a. Bus Voltage: Lower limit is 90% of the operating voltage, and the upper limit is 110% of the operating voltage
  - b. Voltage Angle: The upper limit for sending & receiving end voltage angle separation is 33°
  - c. Thermal Rating: The limits are dependent on the type of conductor, operating voltage and conditions such as line orientation, elevation, ambient temperature and wind speed.
- 4) STEP 4: If there are no violations of the monitored key parameters, the process is repeated from Step 2 at an incrementally higher line transfer capacity.
- 5) STEP 5: The simulation is stopped and the transmission line maximum power transfer limit (recorded as power flow into the swing bus end of the system) is identified when any one of the monitored parameters reaches a limiting value.

## 5.3 Route Characteristics and Transfer Capacity Results

Maximum power transfer capacity results are tabulated in Table 8 below. Table 8 lists the voltage class, conductor type, line length, size and location of loads, the maximum summer power transfer rate, the maximum winter power transfer rate, and the limiting condition for each of the evaluated transmission options.

**Table 8: Electrical Description of Routes & Power Transfer Results**

#	Option	Description	Results
1	Faro ↓ Finlayson	<ul style="list-style-type: none"> <li>▪ Voltage: 138 kV</li> <li>▪ Conductor Type: Ibis 397.5 MCM (Single Bundle)</li> <li>▪ Total Line Length: 233 km</li> <li>▪ Loads Modeled:               <ul style="list-style-type: none"> <li>○ No Intermediate loads</li> </ul> </li> </ul>	Max Power Transfer: <b>84 MW</b>  Limiting Factor: Voltage Angle Limit

#	Option	Description	Results
2	Faro ↓ Watson Lake	<ul style="list-style-type: none"> <li>▪ Voltage: 230 kV</li> <li>▪ Conductor Type: Hawk 477 MCM (Double Bundle)</li> <li>▪ Total Line Length: 414 km</li> <li>▪ Loads Modeled:               <ul style="list-style-type: none"> <li>○ Watson Lake (414 km from Faro; 3.2 MW)</li> </ul> </li> </ul>	Max Power Transfer: <b>190 MW</b>  Limiting Factor: Voltage Angle limit
3	Aishihik ↓ Destruction Bay	<ul style="list-style-type: none"> <li>▪ Voltage: 138 kV</li> <li>▪ Conductor Type: Ibis 397.5 MCM (Single Bundle)</li> <li>▪ Total Line Length: 157 km</li> <li>▪ Loads Modeled:               <ul style="list-style-type: none"> <li>○ Destruction Bay (157 km from Aishihik; 0.42 MW)</li> </ul> </li> </ul>	Max Power Transfer: <b>122 MW</b>  Limiting Factor: Voltage Angle Limit
		<ul style="list-style-type: none"> <li>▪ Voltage: 230 kV</li> <li>▪ Conductor Type: Hawk 477 MCM (Double Bundle)</li> <li>▪ Total Line Length: 157 km</li> <li>▪ Loads Modeled:               <ul style="list-style-type: none"> <li>○ Destruction Bay (157 km from Aishihik; 0.42 MW)</li> </ul> </li> </ul>	Max Power Transfer: <b>484 MW</b>  Limiting Factor: Voltage Angle limit
4	Whitehorse ↓ Skagway	<ul style="list-style-type: none"> <li>▪ Voltage: 138 kV</li> <li>▪ Conductor Type: Ibis 397.5 MCM (Single Bundle)</li> <li>▪ Total Line Length: 170 km</li> <li>▪ Loads Modeled:               <ul style="list-style-type: none"> <li>○ No intermediate loads</li> </ul> </li> </ul>	Max Power Transfer: <b>114 MW</b>  Limiting Factor: Voltage Angle Limit
		<ul style="list-style-type: none"> <li>▪ Voltage: 230 kV</li> <li>▪ Conductor Type: Hawk 477 MCM (Double Bundle)</li> <li>▪ Total Line Length: 170 km</li> <li>▪ Loads Modeled:               <ul style="list-style-type: none"> <li>○ No intermediate loads</li> </ul> </li> </ul>	Max Power Transfer: <b>443 MW</b>  Limiting Factor: Voltage Angle limit
5	Whitehorse ↓ Atlin	<ul style="list-style-type: none"> <li>▪ Voltage: 138 kV</li> <li>▪ Conductor Type: Ibis 397.5 MCM (Single Bundle)</li> <li>▪ Total Line Length: 172 km</li> <li>▪ Loads Modeled:               <ul style="list-style-type: none"> <li>○ Atlin (172 km from Whitehorse; 4 MW)</li> </ul> </li> </ul>	Max Power Transfer: <b>97 MW</b>  Limiting Factor: Voltage Angle limit
6	Whitehorse ↓ Teslin	<ul style="list-style-type: none"> <li>▪ Voltage: 138 kV</li> <li>▪ Conductor Type: Ibis 397.5 MCM (Single Bundle)</li> <li>▪ Total Line Length: 174 km</li> <li>▪ Loads Modeled:               <ul style="list-style-type: none"> <li>○ No intermediate loads</li> </ul> </li> </ul>	Max Power Transfer: <b>95 MW</b>  Limiting Factor: Voltage Angle limit

#	Option	Description	Results
7	Whitehorse ↓ Squanga-Dalayee PSH	<ul style="list-style-type: none"> <li>▪ Voltage: 138 kV</li> <li>▪ Conductor Type: Ibis 397.5 MCM (Single Bundle)</li> <li>▪ Total Line Length: 105 km</li> <li>▪ Loads Modeled:               <ul style="list-style-type: none"> <li>○ No intermediate loads</li> </ul> </li> </ul>	Max Power Transfer: <b>169 MW (Winter)</b> <b>134 MW (Summer)</b>  Limiting Factor: Thermal Rating
8	Whitehorse ↓ Atlin-Mt.Black PSH	<ul style="list-style-type: none"> <li>▪ Voltage: 138 kV</li> <li>▪ Conductor Type: Ibis 397.5 MCM (Single Bundle)</li> <li>▪ Total Line Length: 127 km</li> <li>▪ Loads Modeled:               <ul style="list-style-type: none"> <li>○ No intermediate loads</li> </ul> </li> </ul>	Max Power Transfer: <b>154 MW (Winter)</b> <b>131 MW (Summer)</b>  Limiting Factor: Voltage Angle Limit (Winter) Thermal Rating (Summer)
9	Whitehorse ↓ Tutshi Windy Arm	<ul style="list-style-type: none"> <li>▪ Voltage: 138 kV</li> <li>▪ Conductor Type: Ibis 397.5 MCM (Single Bundle)</li> <li>▪ Total Line Length: 96 km</li> <li>▪ Loads Modeled:               <ul style="list-style-type: none"> <li>○ No intermediate loads</li> </ul> </li> </ul>	Max Power Transfer: <b>172 MW (Winter)</b> <b>135 MW (Summer)</b>  Limiting Factor: Thermal Rating
10	Whitehorse ↓ Racine-Mt.Brown PSH, Racine-Moon Lake PSH, and Tutshi-Moon Lake PSH	<ul style="list-style-type: none"> <li>▪ Voltage: 138 kV</li> <li>▪ Conductor Type: Ibis 397.5 MCM (Single Bundle)</li> <li>▪ Total Line Length: 112 km</li> <li>▪ Loads Modeled:               <ul style="list-style-type: none"> <li>○ No intermediate loads</li> </ul> </li> </ul>	Max Power Transfer: <b>166 MW (Winter)</b> <b>132 MW (Summer)</b>  Limiting Factor: Thermal Rating
11	Whitehorse ↓ Lindeman-Fraser PSH	<ul style="list-style-type: none"> <li>▪ Voltage: 138 kV</li> <li>▪ Conductor Type: Ibis 397.5 MCM (Single Bundle)</li> <li>▪ Total Line Length: 129 km</li> <li>▪ Loads Modeled:               <ul style="list-style-type: none"> <li>○ No intermediate loads</li> </ul> </li> </ul>	Max Power Transfer: <b>147 MW (Winter)</b> <b>129 MW (Summer)</b>  Limiting Factor: Voltage Angle Limit (Winter) Thermal Rating (Summer)

## 6 Project Scheduling

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High-level project schedules have been estimated for each of the transmission project options evaluated in this report. Each project schedule is broken down into the following general activity phases<sup>5</sup>:

- 1) Phase 1: Preliminary Engineering and Cost Estimation
- 2) Phase 2: Permitting
- 3) Phase 3: Detailed Design
- 4) Phase 4: Procurement and Logistics
- 5) Phase 5: Tendering and Construction
- 6) Phase 6: Commissioning

The schedule estimates draw upon recent Yukon transmission project results<sup>6</sup> and are augmented with Midgard's knowledge of recently completed and ongoing transmission project developments in nearby jurisdictions. The following subsections describe the project schedule phases listed above, and the assumptions related to each respective phase.

### 6.1 Phase-By-Phase Discussion

#### 6.1.1 Phase 1: Preliminary Engineering and Cost Estimates

The Preliminary Engineering and Cost Estimates phase includes allowance for the required pre-feasibility and feasibility design, and cost estimation activities required to support business case decisions.

The duration of preliminary engineering and cost estimate studies will be strongly influenced by the total length of the specific transmission line being considered, but the relationship between duration and line length is not linear. For the purpose of this report a minimum duration of at least 3 months has been assumed for short projects, and a maximum duration of 12 months has been assumed for transmission projects over 200 km in length (based on a range of time durations extracted from recent transmission line builds).

The study results from the preliminary engineering activities will feed into YESAB and YUB permit applications.

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<sup>5</sup> The scheduling estimates included in this report account for technical components only and do not include the time required for First Nation and stakeholder consultation activities. In reality, all First Nations and stakeholders will be consulted and engaged with throughout project development (from early stage development through to project completion and operation).

<sup>6</sup> YESSA Project Proposal, Oct 2015: Stewart – Keno 138 kV Transmission Project and YESAB Project Proposal - Carmacks – Stewart/Minto Spur Transmission Project, Chapter 5

### **6.1.2 Phase 2: Permitting**

The Permitting phase activities include preparing and filing the documents necessary to obtain environmental approvals from YESAB and regulatory permits from YUB.

Based upon the permitting duration allowance for the Carmacks – Stewart/Minto Transmission project and the Stewart Keno Transmission project, a minimum permitting duration of 13 months has been assumed. Assuming that there are no extraordinary issues identified during the permitting phase, a maximum permitting duration of 18 months is used for transmission options ranging from 150 km to 200 km, and for transmission options over 200 km the permitting duration is capped at 20 months (based on a range of time durations extracted from recent transmission line builds).

Issues that arise during the permitting phase may require line re-routing or other facility modifications to enable the necessary permits to be obtained. Any required modifications to the feasibility phase designs will cascade into the detailed design stage activities, and may extend expected timelines for permitting activities and all other project phases.

### **6.1.3 Phase 3: Detailed Design Engineering**

The detailed design engineering phase builds on the results of the preliminary engineering and cost estimates, with further refinements being implemented throughout the permitting process as required to address any YESAB and YUB permit conditions.

The detailed design effort typically has a non-linear relationship to the line length. Certain design activities have a minimum duration even for very short lines, and significant external engineering resources are typically brought on for longer transmission projects, thereby mitigating the overall duration of detailed design activities. For the purpose of this report the estimated duration of detailed design engineering activities has been capped at 12 months for transmission projects over 200 km long (based on a range of time durations extracted from recent transmission line builds).

### **6.1.4 Phase 4: Procurement and Logistics**

The procurement process for long lead-time equipment (e.g.: transformers) and bulk materials such as poles and conductor is often initiated prior to the issuance of final permits in order to avoid extended delays to construction start after the required permits have been obtained. Although the overall project duration can be shortened in this way, there is a risk of stranded investment if the project does not receive approval.

Similar to the design activities discussed above, the duration of procurement activities is not linearly proportional to line length. For the purpose of this report, procurement activities are assumed to last 16 months for lines 100 - 200 km long, and are capped at 20 months for lines longer than 200 km (based on a range of time durations extracted from recent transmission line builds).

### 6.1.5 Phase 5: Tendering and Construction

In most cases, construction activities cannot begin until after the necessary permits and licenses have been obtained, although construction tendering can be initiated prior to receiving permits (with the assumption of the associated incremental risk).

Transmission line construction activities include right-of-way brushing and clearing, access road development, foundation and anchor installation, structure assembly and erection, conductor stringing, sagging and clipping in. Construction activities must be carried out in consideration of environmental restrictions, such as avoiding bird nesting seasons and not entering or disturbing streams except during approved fish windows. Most construction activities in wet or permafrost areas must be completed during the winter season to take advantage of frozen conditions to reduce damage to soils and wetlands and to enable access to structure sites using standard vehicles.

### 6.1.6 Phase 6: Commissioning

A duration of 3 months has been assumed for commissioning the transmission line for all the transmission options considered in this report (based on a range of time durations extracted from recent transmission line builds). It is assumed that line review and commissioning preparation activities will actually be ongoing during the construction phase, so the incremental duration of commissioning activities post-construction will not be proportional to overall line length.

## 6.2 Schedule Results

Table 9 below contains the total timeline (from preliminary engineering through to commissioning) of each of the transmission routes of interest as well as a stated In-Service Date, assuming the initial activities are started today. A more detailed phase-by-phase Gantt chart for each transmission route option is included in Appendix B.

**Table 9: Schedule Highlights**

#	Transmission Route	Total Timeline	Earliest Possible ISD
1	Faro → Finlayson	52 Months	Jan 2021
2	Faro → Watson Lake	72 Months	Sep 2022
3	Aishihik → Destruction Bay	46 Months	Jul 2020
4	Whitehorse → Skagway	49 Months	Oct 2020
5	Whitehorse → Atlin	49 Months	Oct 2020
6	Whitehorse → Teslin	49 Months	Oct 2020
7	Whitehorse → Squanga-Dalayee PSH	39 Months	Dec 2019
8	Whitehorse → Atlin-Mt.Black PSH	44 Months	May 2020

#	Transmission Route	Total Timeline	Earliest Possible ISD
9	Whitehorse → Tutshi Windy Arm	38 Months	Nov 2019
10	Whitehorse → Racine-Mt.Brown PSH, Racine-Moon Lake PSH, and Tutshi-Moon Lake PSH	40 Months	Jan 2020
11	Whitehorse → Lindeman-Fraser PSH	45 Months	Jun 2020

With regards to project lifespans, the typical asset life for transmission lines can be expected to range from 40 to 45 years. However, with proper and regular maintenance, line life can be extended. YEC amortizes transmission line assets over a 55 year period.

## 7 Risk Assessment

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Potential risks must be identified and assessed whenever planning, budgeting, and scheduling any new transmission line projects. Different risks may be encountered during each phase of transmission project development, and the relative priority of risks will likely change between the different project phases.

### 7.1 Defining Risk Metrics

The first step in risk assessment involves creating a risk register that comprehensively identifies the risks that may credibly be encountered when developing an individual project (or portfolio of projects). Some risks are generic to transmission projects built anywhere, some apply to projects built within a particular geographical setting and climatic zone, and some risks are specific to the selected routing. Most of the projects discussed in this report are potentially exposed to a common set of risks that would be generally applicable to projects built anywhere in the Yukon.

Once the risks applicable to a particular project have been identified the probability and consequence of each risk is estimated. In this analysis, probabilities are assigned on a scale of 1 to 5, where 1 indicates a low probability (the risk is unlikely to happen on the project being evaluated) and 5 indicates a high probability (the risk will almost certainly be realized at some point during the project). Similarly, consequences are assigned a rating of 1 to 5 where 1 indicates a small consequence should the risk be incurred (minor cost impact or very brief schedule delay) and 5 indicates a significant consequence (major cost overruns, extended schedule delays, severe or widespread environmental or safety impacts).

Each risk is assigned a rank based upon the product of the probability and consequence of that risk:

- 1 to 5 = Low Risk (L)
- 6 to 10 = Moderate Risk (M)
- 11 to 15 = High Risk (H)
- 16 to 20 = Very High Risk (V)
- 21 to 25 = Extreme Risk (X)

### 7.2 Universal Risks (Affecting All Routes)

The first risk matrix shown below (Table 10) identifies and ranks risks to which all Yukon transmission line projects may be exposed. Each risk is identified as a development phase risk, a construction phase risk, and/or an operational phase risk. Some risks can impact more than one project phase.

In addition, the risk matrix also includes a “Potential Mitigation” column that lists some mitigation options identified by Midgard.

**Table 10: Universal Risks (Affecting All Routes)**

#	Risk Description	Risk Rank	Potential Mitigation
1	<p>Risk: Meteorological – Extended Extreme Cold</p> <ul style="list-style-type: none"> <li>▪ Construction delays</li> <li>▪ Labour inefficiency</li> <li>▪ Crew standby costs</li> <li>▪ Additional mob &amp; de-mob costs for extended extreme cold periods</li> </ul> <p>Affects: Construction</p>	<p><b>Prob:</b> 5 <b>Conseq.:</b> 2 <b>Rank:</b> M</p>	<ul style="list-style-type: none"> <li>▪ Schedule activities potentially impacted by extreme cold temperatures during spring, summer or fall</li> <li>▪ Allow adequate schedule float for anticipated extreme cold days</li> </ul>
2	<p>Risk: Meteorological – Extreme Snow</p> <ul style="list-style-type: none"> <li>▪ Construction delays</li> <li>▪ Labour inefficiency</li> <li>▪ Standby costs</li> <li>▪ Additional mob &amp; de-mob costs</li> <li>▪ Additional snow clearing costs</li> <li>▪ Operational impacts can include structure &amp; conductor damage, inadequate clearance over roads, railways and pathways</li> </ul> <p>Affects: Construction, Operations</p>	<p><b>Prob:</b> 3 <b>Conseq.:</b> 2 <b>Rank:</b> M</p>	<ul style="list-style-type: none"> <li>▪ Schedule construction activities in heavy snow-prone areas during summer</li> <li>▪ Allow adequate schedule float for an appropriate number of anticipated extreme snow days</li> <li>▪ Allow adequate safety factor when designing clearances above ground and obstacles</li> </ul>
3	<p>Risk: Meteorological – Extreme Wind</p> <ul style="list-style-type: none"> <li>▪ Construction delays, especially if high winds occur during structure erection or stringing activities</li> <li>▪ Operational impacts can include structure failure, contact between phases and transmission structure or guys, phase contact with trees or buildings, trees falling into line, forest fire ignition</li> </ul> <p>Affects: Construction, Operations</p>	<p><b>Prob:</b> 3 <b>Conseq.:</b> 2 <b>Rank:</b> M</p>	<ul style="list-style-type: none"> <li>▪ Allow adequate schedule float for anticipated extreme wind days</li> <li>▪ Allow for phase blow-out in RoW widths</li> <li>▪ Clear all danger trees that could fall into line</li> </ul>
4	<p>Risk: Geotechnical – Permafrost</p> <ul style="list-style-type: none"> <li>▪ Additional foundation costs</li> <li>▪ Sub-optimal span lengths required to avoid placing structures in permafrost (in areas with discontinuous permafrost)</li> <li>▪ Operational risk if foundations accelerate permafrost melting and structure fails</li> </ul> <p>Affects: Construction, Operations</p>	<p><b>Prob:</b> 4 <b>Conseq.:</b> 3 <b>Rank:</b> H</p>	<ul style="list-style-type: none"> <li>▪ Avoid or span over permafrost areas to the greatest extent possible</li> <li>▪ Utilize permafrost-friendly foundation designs</li> </ul>
5	<p>Risk: Geotechnical – Exposed Bedrock</p> <ul style="list-style-type: none"> <li>▪ High foundation and guying costs (e.g.: grouted rock anchors, blasting)</li> </ul> <p>Affects: Construction</p>	<p><b>Prob:</b> 3 <b>Conseq.:</b> 3 <b>Rank:</b> M</p>	<ul style="list-style-type: none"> <li>▪ Select centreline route to maximize opportunities to site structures in acceptable overburden</li> <li>▪ Select structure types adaptable to cost effective use of rock foundations and anchors</li> </ul>

#	Risk Description	Risk Rank	Potential Mitigation
6	<p>Risk: Geotechnical – Steep Sideslopes</p> <ul style="list-style-type: none"> <li>▪ Difficult and costly foundation and structure erection</li> <li>▪ Operational Risk of snow creep damaging structures sited on steep sideslopes in heavy snow zones</li> <li>▪ Risk of snow avalanche damage</li> <li>▪ Risk of slope instability/landslides, exacerbated by foundation excavation and access road construction</li> </ul> <p>Affects: Construction, Operations</p>	<p><b>Prob:</b> 3 <b>Conseq.:</b> 3 <b>Rank:</b> M</p>	<ul style="list-style-type: none"> <li>▪ Avoid routing on steep sideslopes if possible</li> <li>▪ Avoid placing structures in avalanche chutes or on unstable slopes</li> <li>▪ Utilize existing access roads wherever possible</li> <li>▪ Locate structures as close as possible to existing access roads</li> <li>▪ Utilize snow creep resistant foundations and structure bases on steep slopes in heavy snow loading areas</li> <li>▪ Utilize upslope avalanche guards or deflectors where necessary &amp; practical</li> </ul>
7	<p>Risk: Geotechnical – Floodplains</p> <ul style="list-style-type: none"> <li>▪ Expensive foundations</li> <li>▪ Operational risk of flood damage or destruction of structures and resulting extended outages</li> <li>▪ Construction difficult or impossible during freshet/snowmelt season</li> </ul> <p>Affects: Construction, Operations</p>	<p><b>Prob:</b> 3 <b>Conseq.:</b> 3 <b>Rank:</b> M</p>	<ul style="list-style-type: none"> <li>▪ Avoid placing structures within floodplains to the greatest extent possible</li> <li>▪ Schedule floodplain construction during late summer/fall/winter</li> <li>▪ Use heavy rip-rap protection (large rock armour) for structures that must be placed in floodplains</li> </ul>
8	<p>Risk: Social – Permitting in Reserve Blocks</p> <ul style="list-style-type: none"> <li>▪ Consultation with First Nations potentially impacted by new facilities in traditional lands or near communities</li> <li>▪ Schedule delays or routing adjustments if route agreement is not achieved</li> </ul> <p>Affects: Development, Construction, Operations</p>	<p><b>Prob:</b> 4 <b>Conseq.:</b> 4 <b>Rank:</b> V</p>	<ul style="list-style-type: none"> <li>▪ Begin comprehensive outreach activities with affected FN communities early</li> </ul>
9	<p>Risk: Social – Permitting near Urban Areas</p> <ul style="list-style-type: none"> <li>▪ Avoiding populated areas may involve more complex line routing</li> <li>▪ Possible cost increases due to additional route length, additional deflection structures, more difficult access roads</li> <li>▪ Schedule delays if consultation does not achieve route agreement with landowners</li> </ul> <p>Affects: Development, Construction</p>	<p><b>Prob:</b> 3 <b>Conseq.:</b> 4 <b>Rank:</b> H</p>	<ul style="list-style-type: none"> <li>▪ Where possible select routes that avoid densely populated areas</li> <li>▪ Avoid siting structures close to residences</li> </ul>

#	Risk Description	Risk Rank	Potential Mitigation
10	<p>Risk: Social – Permitting in Scenic Areas</p> <ul style="list-style-type: none"> <li>Siting routes parallel to scenic highways increases risk of obstructing viewscapes or impacting sight lines due to RoW clearing</li> </ul> <p>Affects: Development, Construction</p>	<p><b>Prob:</b> 3</p> <p><b>Conseq.:</b> 3</p> <p><b>Rank:</b> M</p>	<ul style="list-style-type: none"> <li>Avoid locating structures between scenic viewpoint areas and scenic vistas</li> <li>Align RoW to minimize visual impact of transmission RoW cutlines through forested areas impact viewscapes</li> </ul>

### 7.3 Route Specific Risks

In addition to the universal risks identified above, project-specific risk matrices have been developed for the following routes:

- Faro → Finlayson / Watson Lake (see Table 11)
- Aishihik → Destruction Bay (see Table 12)
- Whitehorse → Skagway / Tutshi Windy Arm / Racine-Mt. Brown PSH, Racine-Moon Lake PSH, and Tutshi-Moon Lake PSH / Lindeman-Fraser PSH (see Table 13)
- Whitehorse → Atlin / Atlin-Mt. Black PSH (see Table 14)
- Whitehorse → Teslin / Squanga-Dalayee PSH (see Table 15)

**Table 11: Route Specific Risks for Faro → Finlayson / Watson Lake**

#	Risk Description	Risk Rank	Potential Mitigation
1	<p>Risk: Logistics – Very Large Projects located in Remote Area with little local capacity</p> <ul style="list-style-type: none"> <li>Challenging to setup and supply camps</li> <li>Transportation and storage of very large amounts of construction materials in remote area</li> <li>Difficult to stage construction for such a long linear project in this region</li> </ul> <p>Affects: Development, Construction, Operations</p>	<p><b>Prob:</b> 5</p> <p><b>Conseq.:</b> 2</p> <p><b>Rank:</b> M</p>	<ul style="list-style-type: none"> <li>Logistics and camp planning at very early project stage</li> <li>Allow adequate schedule float to address logistical challenges</li> </ul>

**Table 12: Route Specific Risks for Aishihik → Destruction Bay**

#	Risk Description	Risk Rank	Potential Mitigation
1	<p>Risk: Geotechnical – Floodplains</p> <ul style="list-style-type: none"> <li>Extensive Floodplain where Slims River previously discharged into south end of Kluane Lake</li> </ul> <p>Affects: Construction, Operations</p>	<p><b>Prob:</b> 5</p> <p><b>Conseq.:</b> 3</p> <p><b>Rank:</b> H</p>	<ul style="list-style-type: none"> <li>Route line near Hwy 1 and cross the dried up Slims River at the narrow point between two well-treed and relatively stable alluvial fans</li> </ul>

#	Risk Description	Risk Rank	Potential Mitigation
2	<p>Risk: Social – Permitting within Kluane National Park</p> <ul style="list-style-type: none"> <li>Proposed centerline lays within Kluane National Park</li> <li>Siting within the Park will likely impose moderate to severe restrictions on permitting, construction and operations</li> </ul> <p>Affects: Development, Construction, Operations</p>	<p><b>Prob:</b> 5</p> <p><b>Conseq.:</b> 3</p> <p><b>Rank:</b> H</p>	<ul style="list-style-type: none"> <li>Initiate routing discussions with Parks Canada and other stakeholders at very early stage</li> <li>If route through Park cannot be permitted, considering routing line on strip of non-park lands between Hwy 1 and Kluane Lake – note that scenic viewscape of lake will be impacted</li> </ul>
3	<p>Risk: Geotechnical – Permafrost</p> <ul style="list-style-type: none"> <li>Aishihik corridor features extensive areas of discontinuous permafrost, probably impossible to avoid placing a large number of structures into permafrost</li> </ul> <p>Affects: Construction, Operations</p>	<p><b>Prob:</b> 5</p> <p><b>Conseq.:</b> 3</p> <p><b>Rank:</b> H</p>	<ul style="list-style-type: none"> <li>Avoid or span over permafrost areas to the greatest extent possible</li> <li>Utilize permafrost-friendly foundation designs</li> </ul>

**Table 13: Route Specific Risks for Whitehorse → Skagway / Tutshi Windy Arm / Racine-Mt.Brown PSH, Racine-Moon Lake PSH, and Tutshi-Moon Lake PSH / Lindeman-Fraser PSH**

#	Risk Description	Risk Rank	Potential Mitigation
1	<p>Risk: Geotechnical – Exposed Bedrock</p> <ul style="list-style-type: none"> <li>Bedrock is unavoidable over substantial portions of this route, especially sections south of Tutshi Lake and in the White Pass area</li> </ul> <p>Affects: Construction</p>	<p><b>Prob:</b> 5</p> <p><b>Conseq.:</b> 3</p> <p><b>Rank:</b> H</p>	<ul style="list-style-type: none"> <li>Select centreline route to maximize opportunities to site structures in acceptable overburden</li> <li>Select structure types adaptable to cost effective use of rock foundations and anchors</li> </ul>
2	<p>Risk: Geotechnical – Steep Sideslopes</p> <ul style="list-style-type: none"> <li>Difficult to avoid building on sideslopes above the highway in the segments parallel with Tagish and Tutshi Lakes</li> <li>Risk is compounded since this is also an area of extreme snow loads and avalanches</li> </ul> <p>Affects: Construction, Operations</p>	<p><b>Prob:</b> 5</p> <p><b>Conseq.:</b> 5</p> <p><b>Rank:</b> X</p>	<ul style="list-style-type: none"> <li>Build on lake side of highway (may not be possible due to scenic highway restrictions)</li> <li>Install underground beside highway (very costly alternative)</li> </ul>
3	<p>Risk: Social – Permitting near Populated Areas</p> <ul style="list-style-type: none"> <li>Suburban residential development from Whitehorse to Carcross Cutoff</li> <li>Routing must pass through Carcross to cross narrows between Bennett Lake and Nares Lake</li> </ul> <p>Affects: Development</p>	<p><b>Prob:</b> 3</p> <p><b>Conseq.:</b> 4</p> <p><b>Rank:</b> H</p>	<ul style="list-style-type: none"> <li>Re-route south of developed area from Whitehorse to Carcross Cutoff</li> <li>Follow railway through Carcross</li> </ul>

#	Risk Description	Risk Rank	Potential Mitigation
4	<p>Risk: Social – Permitting in scenic areas</p> <ul style="list-style-type: none"> <li>Whitehorse to Skagway is a national scenic route</li> <li>Particular areas of special concern include Emerald Lake (between Carcross Cutoff and Carcross), the narrows at Carcross, along the shores of Tagish and Tutshi Lakes, and across White Pass</li> </ul> <p>Affects: Development</p>	<p><b>Prob:</b> 5</p> <p><b>Conseq.:</b> 3</p> <p><b>Rank:</b> H</p>	<ul style="list-style-type: none"> <li>Avoid locating structures between scenic viewpoint areas and scenic vistas</li> <li>Align RoW to minimize visual impact of transmission RoW cutlines through forested areas impact viewscapes</li> </ul>
5	<p>Risk: Social – Permitting near National Parks</p> <ul style="list-style-type: none"> <li>Skagway to White Pass segment abuts the Klondike Gold Rush US National Historical Park</li> <li>Schedule delays or routing adjustments if route agreement is not achieved</li> </ul> <p>Affects: Development, Construction, Operations</p>	<p><b>Prob:</b> 5</p> <p><b>Conseq.:</b> 3</p> <p><b>Rank:</b> H</p>	<ul style="list-style-type: none"> <li>Assess any special construction or operational requirements, such as low-profile structures, specialized paints or non-specular conductors, limited construction windows and operating access constraints</li> <li>Begin permitting activities early</li> </ul>
6	<p>Risk: Political – Yukon/BC Border Crossing</p> <ul style="list-style-type: none"> <li>Permitting must satisfy BC regulations</li> <li>May trigger studies and require approval by BC Hydro</li> <li>May require YEC to apply for status as a BC utility</li> </ul> <p>Affects: Development, Construction, Operations</p>	<p><b>Prob:</b> 5</p> <p><b>Conseq.:</b> 4</p> <p><b>Rank:</b> V</p>	<ul style="list-style-type: none"> <li>Initiate discussions with BC Government, BC Hydro and BC Utilities Commission to determine applicable regulations and approval &amp; permitting requirements</li> </ul>
7	<p>Risk: Political – Canada/United States Border Crossing</p> <ul style="list-style-type: none"> <li>Will require permits from Canadian National Energy Board and US Federal Energy Regulation Commission</li> <li>International powerline crossings require a US Presidential Permit</li> <li>Will likely require additional approvals from State of Alaska and Municipality of Skagway</li> </ul> <p>Affects: Development, Construction, Operations</p>	<p><b>Prob:</b> 5</p> <p><b>Conseq.:</b> 5</p> <p><b>Rank:</b> X</p>	<ul style="list-style-type: none"> <li>Initiate discussions with all Canadian and US entities to determine applicable regulations and permitting requirements</li> </ul>

#	Risk Description	Risk Rank	Potential Mitigation
8	<p>Risk: Social, Geotechnical, Technical – Termination at Whitehorse Riverside</p> <ul style="list-style-type: none"> <li>Constrained access into open bay at Riverside substation</li> <li>Will require crossing under or relocating an existing 138 kV line</li> <li>Difficult access from south bank requires crossing Yukon River at a very congested location</li> <li>Two existing hydroelectric facilities, intake canal, tailrace canal and main stem of Yukon River</li> </ul> <p>Affects: Construction</p>	<p><b>Prob:</b> 5 <b>Conseq.:</b> 3 <b>Rank:</b> H</p>	<ul style="list-style-type: none"> <li>Relocate one of the existing 138 kV lines to the open north bay position</li> <li>Possibly double circuit existing 138 kV line located between the intake and tailrace canals</li> <li>Taking the new line underground/underwater at the river crossing may be an option (although very costly)</li> </ul>

**Table 14: Route Specific Risks for Whitehorse → Atlin / Atlin-Mt.Black PSH**

#	Risk Description	Risk Rank	Potential Mitigation
1	<p>Risk: Social – Permitting near Populated Areas</p> <ul style="list-style-type: none"> <li>Dense suburban residential development from Whitehorse to Carcross Cutoff</li> </ul> <p>Affects: Development, Construction</p>	<p><b>Prob:</b> 3 <b>Conseq.:</b> 3 <b>Rank:</b> M</p>	<ul style="list-style-type: none"> <li>Re-route south of developed area from Whitehorse to Carcross Cutoff</li> </ul>
2	<p>Risk: Social – Permitting in Reserve Blocks and First Nations traditional lands within BC</p> <ul style="list-style-type: none"> <li>BC has specific Provincial FN consultation requirements</li> </ul> <p>Affects: Development, Construction, Operations</p>	<p><b>Prob:</b> 4 <b>Conseq.:</b> 4 <b>Rank:</b> V</p>	<ul style="list-style-type: none"> <li>Assess BC-specific consultation requirements</li> <li>Begin comprehensive outreach activities with affected FN communities early</li> </ul>
3	<p>Risk: Political – Yukon/BC Border Crossing</p> <ul style="list-style-type: none"> <li>Permitting must satisfy BC regulations</li> <li>May trigger studies and require approval by BC Hydro</li> <li>May require YEC to apply for status as a BC utility</li> </ul> <p>Affects: Development, Construction, Operations</p>	<p><b>Prob:</b> 5 <b>Conseq.:</b> 4 <b>Rank:</b> V</p>	<ul style="list-style-type: none"> <li>Initiate discussions with BC Government, BC Hydro and BC Utilities Commission to determine applicable regulations and approval &amp; permitting requirements</li> </ul>

**Table 15: Route Specific Risks for Whitehorse → Teslin / Squanga-Dalayee PSH**

#	Risk Description	Risk Rank	Potential Mitigation
1	<p>Risk: Social – Permitting near Populated Areas</p> <ul style="list-style-type: none"> <li>▪ Dense suburban residential development from Whitehorse to Carcross Cutoff</li> </ul> <p>Affects: Development, Construction</p>	<p><b>Prob:</b> 3</p> <p><b>Conseq.:</b> 3</p> <p><b>Rank:</b> M</p>	<ul style="list-style-type: none"> <li>▪ Re-route south of developed area from Whitehorse to Carcross Cutoff</li> </ul>
2	<p>Risk: Safety – Proximity to Airports</p> <ul style="list-style-type: none"> <li>▪ Line Route passes near runways at Teslin and Squanga Lake</li> </ul> <p>Affects: Development, Construction, Operations</p>	<p><b>Prob:</b> 3</p> <p><b>Conseq.:</b> 3</p> <p><b>Rank:</b> M</p>	<ul style="list-style-type: none"> <li>▪ Use low-profile structures</li> <li>▪ Obtain required Transport Canada Permits</li> <li>▪ Avoid structure placement near end of runways</li> </ul>

## 8 Summary & Conclusions

This *Transmission Options Evaluation* report included several components:

- Detailed transmission corridor optimization (Section 2)
- Estimate of CAPEX (Section 3)
- Estimate of OPEX (Section 4)
- Calculation of power transfer capacities (Section 5)
- Overview of transmission corridor development schedules (Section 6)
- Assessment of corridor risks (Section 7)

Table 16 below provides a tabular summary of this report’s findings. For each potential transmission route, the line voltage, line length, max transfer capacity, estimated CAPEX, estimated OPEX, and earliest In-Service-Date (“ISD”) is stated.

**Table 16: Summary of Results (Costs Stated in \$2016)**

#	Transmission Route	Voltage	Length	Transfer Capacity <sup>7</sup>	CAPEX <sup>8</sup>	OPEX <sup>8</sup>	Earliest ISD
1	Faro → Finlayson	138 kV	233 km	84 MW	\$221M	\$351k/yr	Jan 2021
2	Faro → Watson Lake	230 kV	414 km	190 MW	\$597M	\$613k/yr	Sep 2022
3	Aishihik → Destruction Bay	138 kV	157 km	122 MW	\$167M	\$217k/yr	Jul 2020
		230 kV		484 MW	\$241M		
4	Whitehorse → Skagway	138 kV	170 km	114 MW	\$166M	\$285k/yr	Oct 2020
		230 kV		443 MW	\$251M		
5	Whitehorse → Atlin	138 kV	172 km	97 MW	\$158M	\$236k/yr	Oct 2020
6	Whitehorse → Teslin	138 kV	174 km	95 MW	\$165M	\$239k/yr	Oct 2020
7	Whitehorse → Squanga-Dalayee PSH	138 kV	105 km	134 MW	\$100M	\$143k/yr	Dec 2019
8	Whitehorse → Atlin-Mt.Black PSH	138 kV	127 km	131 MW	\$119M	\$174k/yr	May 2020
9	Whitehorse → Tutshi Windy Arm	138 kV	96 km	135 MW	\$94M	\$143k/yr	Nov 2019
10	Whitehorse → Racine-Mt.Brown PSH, Racine-Moon Lake PSH, and Tutshi-Moon Lake PSH	138 kV	112 km	132 MW	\$108M	\$168k/yr	Jan 2020
11	Whitehorse → Lindeman-Fraser PSH	138 kV	129 km	129 MW	\$125M	\$200k/yr	Jun 2020

<sup>7</sup> These values represent the most restricted transfer capacity that would be expected in either summer or winter. Thermally limited transmission options may demonstrate a higher Winter Capacity. See Table 8 for more details.

<sup>8</sup> All cost information is stated in \$2016 and is considered a Class 5 estimate as per standard 17R-97 by the Association of the Advancement of Cost Engineering, which represents a +100% / -50% range of accuracy.

# **Appendix A:**

# **PSSE Simulation Details**

## Appendix A: PSS®E Simulation Details

A simple PSS®E model was built and simulations were carried out to estimate the power transfer capability along the transmission line each of the transmission option being studied. This appendix provides the more in-depth details of the PSS®E modeling effort.

The voltage is maintained between a nominal range of 1.1 per unit to 0.9 per unit at all buses, and the maximum Sending End to Receiving End voltage angle difference is taken to be 33° to avoid angular instability for minor system perturbations. The term “*Transmission Line Capacity*” in the following tables represent available capacity at the Swing Bus after deducting intermediate loads (if connected) and peak transmission losses.

### A.1 Conductor Characteristics

Table A-1 lists the conductor characteristics for the 138 kV and 230 kV transmission options.

**Table A-1: Conductor Characteristics**

Voltage Class (kV)	Conductor Type	GMR (ft.)	External Diameter (In)	Bundle	Phase Spacing (m)	Conductor Spacing (In)
138	Ibis 397.5 MCM	0.0264'	0.783"	1	4.6 m	N/A
230	Hawk 477 MCM	0.0289'	0.858"	2	6.7 m	18"

Assuming a wind speed of 2 ft/s and a maximum conductor temperature of 100°C, the thermal MVA rating of the conductors at different locations, for an ambient temperature of -10°C in winter and 35°C in summer is listed in the Table A-2 below.

**Table A-2: Conductor Thermal Rating**

Location	Altitude (ft)	Double Bundle 230 kV Hawk 477 MCM Thermal Rating (MVA)		Single Bundle 138 kV Ibis 397.5 MCM Thermal Rating (MVA)	
		@ -10°C	@ 35°C	@ -10°C	@ 35°C
Whitehorse	2149	765	575	204	153
Aishihik	3018	758	569	202	152
Destruction Bay	2674	761	571	203	153
Faro	2198	765	575	204	153
Watson Lake	2247	764	574	204	153
Teslin	2264	764	574	204	153
Mayo	1653	769	578	205	154
Pelly Crossing	1870	767	577	205	154

**A.2 Route 1: Faro → Finlayson (138 kV)**

Key physical parameters are listed in Table A-3.

**Table A-3: Physical Parameters – Faro → Finlayson (138 kV)**

Parameter	Value
From:	Faro
To:	Finlayson
Distance:	233 km
Transmission Voltage:	138 kV
Transmission Conductor:	Ibis 397.5 MCM
Conductor Thermal Rating:	202 MVA in Winter 152 MVA in Summer

**A.2.1 Transmission Line Characteristics**

Using a 100 MVA system base and 138 kV line voltage, Table A-4 was tabulated based on Table A-1 and tower structure assumptions for phase spacing.

**Table A-4: Transmission Line Characteristics – Faro → Finlayson (138 kV)**

From	To	Distance (km)	Resistance R (p.u.)	Reactance X (p.u.)	Charging B (p.u.)
Faro	Voltage Test 1	58.2	0.0540260634	0.1496790132	0.0367760150
Voltage Test 1	Voltage Test 2	58.2	0.0540260634	0.1496790132	0.0367760150
Voltage Test 2	Voltage Test 3	58.2	0.0540260634	0.1496790132	0.0367760150
Voltage Test 3	Finlayson	58.2	0.0540260634	0.1496790132	0.0367760150

**A.2.2 PSSE Simulation**

Table A-5 lists the generation and load parameters for all buses considered in the power flow simulation. For simplicity, all loads are assumed to have a power factor of 0.9, and each generator is capable of producing at 0.9 power factor lagging or leading.

Table A-5 and Figure A-1 shows that the Yukon system can receive 84 MW of power through the 138 kV transmission line between Faro and Finlayson, when an imaginary generator at Finlayson generates its maximum power while maintaining acceptable system conditions.

Figure A-1: PSS®E Single Line Diagram – Faro → Finlayson (138 kV)

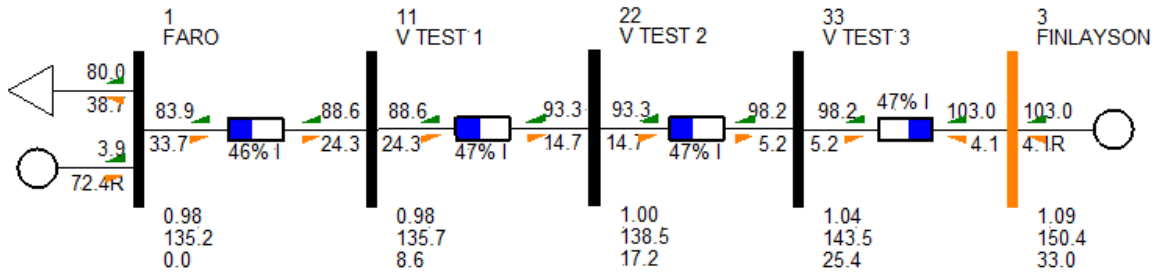


Table A-5: PSS®E Results – Faro → Finlayson (138 kV)

Location	Pgen (MW)	Qgen (MVA <sub>r</sub> )	Pload (MW)	Qload (MVA <sub>r</sub> )	Voltage (p.u.)	Voltage Angle (degrees)
Faro	-3.9	72.4	80	38.7	0.98	0.0
Voltage Test 1	-	-	-	-	0.98	8.6
Voltage Test 2	-	-	-	-	1.00	17.2
Voltage Test 3	-	-	-	-	1.04	25.4
Finlayson	103.0	4.1	-	-	1.09	33.0

### A.2.3 Results

Analysis results are listed in Table A-6.

Table A-6: Analysis Results – Faro → Finlayson (138 kV)

Parameter	Value
Line Capacity:	84 MW
Limiting Issue:	33° Voltage Angle

## A.3 Route 2: Faro → Watson Lake (230 kV)

### A.3.1 Transmission Line Characteristics

Key physical parameters are listed in Table A-7.

**Table A-7: Physical Parameters – Faro → Watson Lake (230 kV)**

Parameter	Value
From:	Faro
To:	Watson Lake
Distance:	414 km
Transmission Voltage:	230 kV
Transmission Conductor:	Hawk 477 MCM
Conductor Thermal Rating:	764 MVA in Winter 564 MVA in Summer

Using a 100 MVA system base and 230 kV line voltage, Table A-8 was tabulated based on Table A-1 and tower structure assumptions for phase spacing. Voltage Test 1, Voltage test 2 and Voltage Test 3 are hypothetical test buses to measure midpoint line parameters.

**Table A-8: Transmission Line Characteristics – Faro → Watson Lake (230 kV)**

From	To	Distance (km)	Resistance R (p.u.)	Reactance X (p.u.)	Charging B (p.u.)
Faro	Voltage Test 1	103.5	0.007358071	0.071937675	0.24036989
Voltage Test 1	Voltage Test 2	103.5	0.007358071	0.071937675	0.24036989
Voltage Test 2	Voltage Test 3	103.5	0.007358071	0.071937675	0.24036989
Voltage Test 3	Watson Lake	103.5	0.007358071	0.071937675	0.24036989

**A.3.2 PSSE Simulation**

Table A-9 lists the generation and load parameters for all the buses considered in the power flow simulation. For simplicity, all loads are assumed to have a power factor of 0.9, and each generator is capable of producing at 0.9 power factor lagging or leading.

Table A-9 and Figure A-2 shows that the Yukon system can receive 190 MW of power through the 230 kV transmission line between Faro and Watson Lake, when an imaginary generator at Watson Lake generates its maximum power while maintaining acceptable system conditions.

Figure A-2: PSS®E Single Line Diagram – Faro → Watson Lake (230 kV)

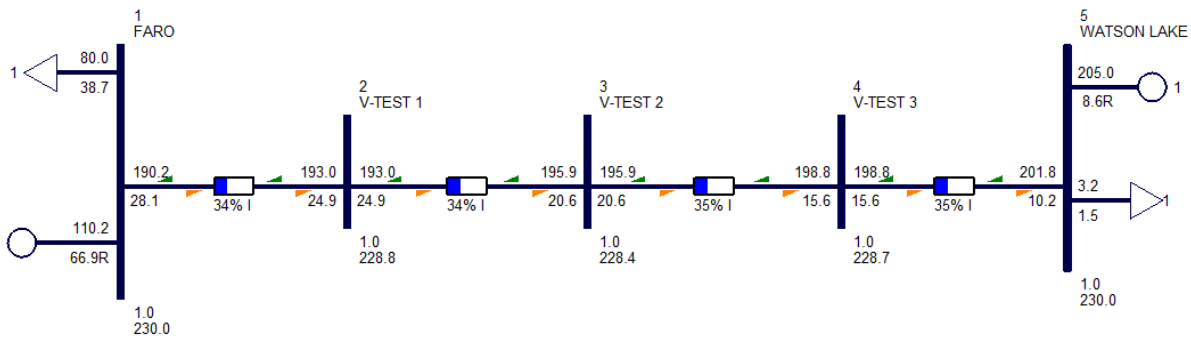


Table A-9: PSS®E Results – Faro → Watson Lake (230 kV)

Location	Pgen (MW)	Qgen (MVar)	Pload (MW)	Qload (MVar)	Voltage (p.u.)	Voltage Angle (degrees)
Faro	-110.2	66.9	80	38.7458	1.000	0.000
Voltage Test 1	-	-	-	-	0.995	8.080
Voltage Test 2	-	-	-	-	0.993	16.310
Voltage Test 3	-	-	-	-	0.994	24.660
Watson Lake	205.0	-8.6	3.2	1.6	1.000	33.040

### A.3.3 Results

Analysis results are listed in Table A-10.

Table A-10: Analysis Results – Faro → Watson Lake (230 kV)

Parameter	Value
Line Capacity:	190 MW
Limiting Issue:	33° Voltage Angle

## A.4 Route 3: Aishihik → Destruction Bay (230 kV)

### A.4.1 Transmission Line Characteristics

Key physical parameters are listed in Table A-11.

Table A-11: Physical Parameters – Aishihik → Destruction Bay (230 kV)

Parameter	Value
From:	Aishihik
To:	Destruction Bay
Distance:	157 km
Transmission Voltage:	230 kV
Transmission Conductor:	Hawk 477 MCM
Conductor Thermal Rating:	758 MVA in winter 569 MVA in summer

Using a 100 MVA system base and 230 kV line voltage, Table A-12 was tabulated based on Table A-1 and tower structure assumptions for phase spacing.

Table A-12: Transmission Line Characteristics – Aishihik → Destruction Bay (230 kV)

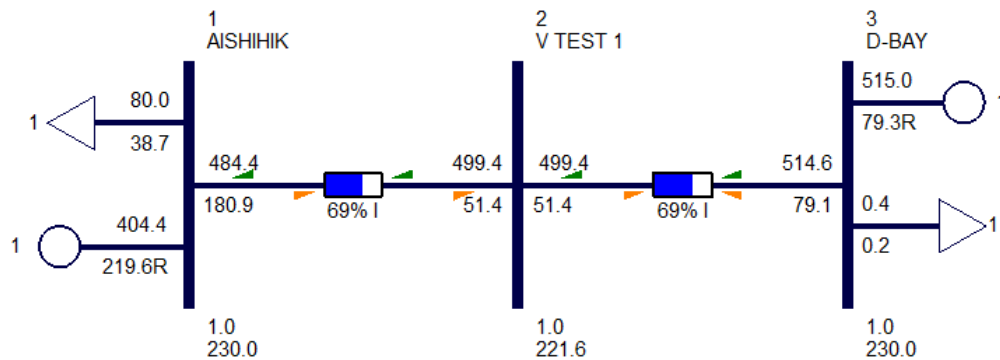
From	To	Distance (km)	Resistance R (p.u.)	Reactance X (p.u.)	Charging B (p.u.)
Aishihik	Voltage Test 1	78.6	0.005559094	0.054280891	0.181035243
Voltage Test 1	Destruction Bay	78.6	0.005559094	0.054280891	0.181035243

#### A.4.2 PSSE Simulation

Table A-13 lists the generation and load parameters for all buses considered in the power flow simulation. For simplicity, all loads are assumed to have a power factor of 0.9, and each generator is capable of producing at 0.9 power factor lagging or leading.

Table A-13 and Figure A-3 shows that the Yukon system can receive 484 MW of power through the 230 kV transmission line between Aishihik and Destruction Bay, when an imaginary generator at Destruction Bay generates its maximum power while maintaining acceptable system conditions.

Figure A-3: PSS®E Single Line Diagram – Aishihik → Destruction Bay (230 kV)



**Table A-13: PSS®E Results – Aishihik → Destruction Bay (230 kV)**

Location	Pgen (MW)	Qgen (MVA <sub>r</sub> )	Pload (MW)	Qload (MVA <sub>r</sub> )	Voltage (p.u.)	Voltage Angle (degrees)
Aishihik	-404.4	219.6	80	38.7458	1.000	0.000
Voltage Test 1	-	-	-	-	0.964	16.490
Destruction Bay	515.0	79.3	0.415	0.2	1.000	33.040

### A.4.3 Results

Analysis results are listed in Table A-14.

**Table A-14: Analysis Results – Aishihik → Destruction Bay (230 kV)**

Parameter	Value
Line Capacity:	484 MW
Limiting Issue:	33° Voltage Angle

## A.5 Route 3: Aishihik → Destruction Bay (138 kV)

### A.5.1 Transmission Line Characteristics

Key physical parameters are listed in Table A-15.

**Table A-15: Physical Parameters – Aishihik → Destruction Bay (138 kV)**

Parameter	Value
From:	Aishihik
To:	Destruction Bay
Distance:	157 km
Transmission Voltage:	138 kV
Transmission Conductor:	Ibis 397.5 MCM
Conductor Thermal Rating:	202 MVA in Winter 152 MVA in Summer

Using a 100 MVA system base and 138 kV line voltage, Table A-16 was tabulated based on Table A-1 and tower structure assumptions for phase spacing.

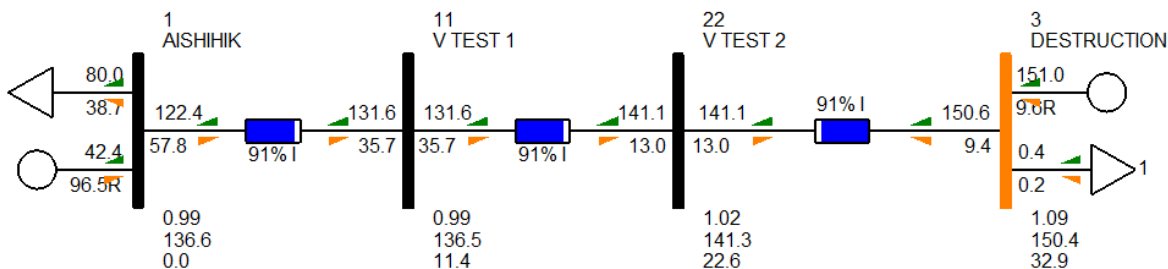
**Table A-16: Transmission Line Characteristics – Aishihik → Destruction Bay (138 kV)**

From	To	Distance (km)	Resistance R (p.u.)	Reactance X (p.u.)	Charging B (p.u.)
Aishihik	Voltage Test 1	52.4	0.04937811	0.13553595	0.03293529
Voltage Test 1	Voltage Test 2	52.4	0.04937811	0.13553595	0.03293529
Voltage Test 2	Destruction Bay	52.4	0.04937811	0.13553595	0.03293529

### A.5.2 PSSE Simulation

Table A-17 lists the generation and load parameters for all buses considered in the power flow simulation. For simplicity, all loads are assumed to have a power factor of 0.9, and each generator is capable of producing at 0.9 power factor lagging or leading.

Table A-17 and Figure A-4 shows that the Yukon system can receive 122 MW of power through the 138 kV transmission line between Aishihik and Destruction Bay, when an imaginary generator at Destruction Bay generates its maximum power while maintaining acceptable system conditions.

**Figure A-4: PSS®E Single Line Diagram – Aishihik → Destruction Bay (138 kV)**

**Table A-17: PSS®E Results – Aishihik → Destruction Bay (138 kV)**

Location	Pgen (MW)	Qgen (MVA <sub>r</sub> )	Pload (MW)	Qload (MVA <sub>r</sub> )	Voltage (p.u.)	Voltage Angle (degrees)
Aishihik	-42.4	96.5	80.0	38.7	0.99	0.0
Voltage Test 1	-	-	-	-	0.99	11.4
Voltage Test 2	-	-	-	-	1.02	22.6
Destruction Bay	151.0	9.6	0.4	0.2	1.09	32.9

### A.5.3 Results

Analysis results are listed in Table A-18.

**Table A-18: Analysis Results – Aishihik → Destruction Bay (138 kV)**

Parameter	Value
Line Capacity:	122 MW
Limiting Issue:	33° Voltage Angle

## A.6 Route 4: Whitehorse → Skagway (230 kV)

### A.6.1 Transmission Line Characteristics

Key physical parameters are listed in Table A-19.

**Table A-19: Physical Parameters – Whitehorse → Skagway (230 kV)**

Parameter	Value
From:	Whitehorse
To:	Skagway
Distance:	170 km
Transmission Voltage:	230 kV
Transmission Conductor:	Hawk 477 MCM
Conductor Thermal Rating:	765 MVA in Winter 575 MVA in Summer

Using a 100 MVA system base and 230 kV line voltage, Table A-20 was tabulated based on Table A-1 and tower structure assumptions for phase spacing.

**Table A-20: Transmission Line Characteristics – Whitehorse → Skagway (230 kV)**

From	To	Distance (km)	Resistance R (p.u.)	Reactance X (p.u.)	Charging B (p.u.)
Whitehorse	Voltage Test 1	84.8	0.006071923	0.059307501	0.197893825
Voltage Test 1	Skagway	84.8	0.006071923	0.059307501	0.197893825

### A.6.2 PSSE Simulation

Table A-21 lists the generation and load parameters for all buses considered in the power flow simulation. For simplicity, all loads are assumed to have a power factor of 0.9, and each generator is capable of producing at 0.9 power factor lagging or leading.

Table A-21 and Figure A-5 shows that the Yukon system can receive 443 MW of power through the 230 kV transmission line between Whitehorse and Skagway, when an imaginary generator at Skagway generates its maximum power while maintaining acceptable system conditions.

Figure A-5: PSS®E Single Line Diagram – Whitehorse → Skagway (230 kV)

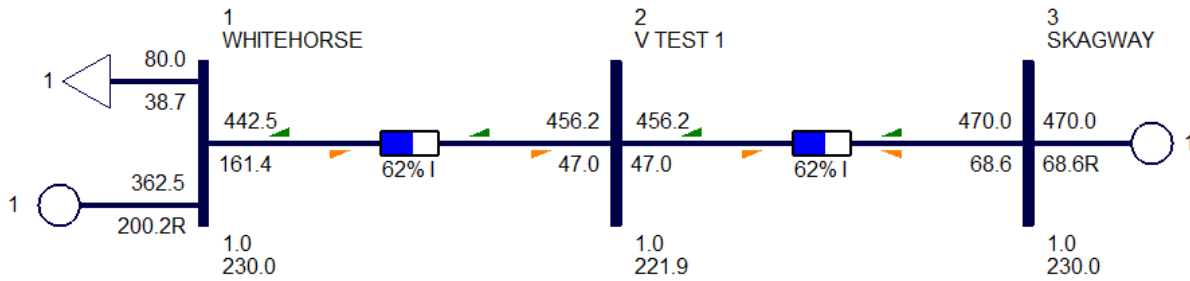


Table A-21: PSS®E Results – Whitehorse → Skagway (230 kV)

Location	Pgen (MW)	Qgen (MVar)	Pload (MW)	Qload (MVar)	Voltage (p.u.)	Voltage Angle (degrees)
Whitehorse	-362.5	200.2	80	38.7458	1.000	0.000
Voltage Test 1	-	-	-	-	0.965	16.430
Skagway	470.0	68.6	-	-	1.000	32.930

### A.6.3 Results

Analysis results are listed in Table A-22.

Table A-22: Analysis Results – Whitehorse → Skagway (230 kV)

Parameter	Value
Line Capacity:	443 MW
Limiting Issue:	33° Voltage Angle

## A.7 Route 4: Whitehorse → Skagway (138 kV)

### A.7.1 Transmission Line Characteristics

Key physical parameters are listed in Table A-23.

Table A-23: Physical Parameters – Whitehorse → Skagway (138 kV)

Parameter	Value
From:	Whitehorse
To:	Skagway
Distance:	170 km
Transmission Voltage:	138 kV
Transmission Conductor:	Ibis 397.5 MCM
Conductor Thermal Rating:	152 MVA in Winter 202 MVA in Summer

Using a 100 MVA system base and 138 kV line voltage, Table A-24 was tabulated based on Table A-1 and tower structure assumptions for phase spacing.

**Table A-24: Transmission Line Characteristics – Whitehorse → Skagway (138 kV)**

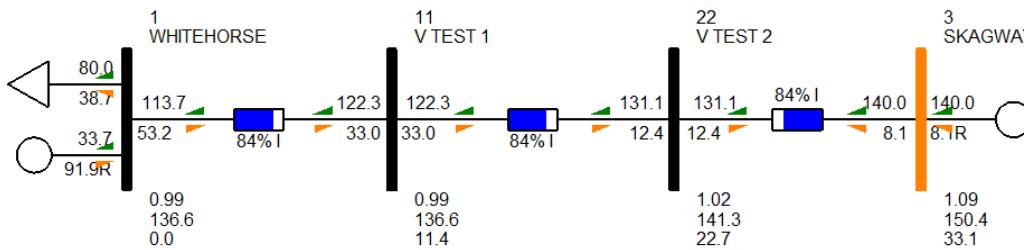
From	To	Distance (km)	Resistance R (p.u.)	Reactance X (p.u.)	Charging B (p.u.)
Whitehorse	Voltage Test 1	56.5	0.053342059	0.146611265	0.035683154
Voltage Test 1	Voltage Test 2	56.5	0.053342059	0.146611265	0.035683154
Voltage Test 2	Skagway	56.5	0.053342059	0.146611265	0.035683154

**A.7.2 PSSE Simulation**

Table A-25 lists the generation and load parameters for all buses considered in the power flow simulation. For simplicity, all loads are assumed to have a power factor of 0.9, and each generator is capable of producing at 0.9 power factor lagging or leading.

Table A-25 and Figure A-6 shows that the Yukon system can receive 114 MW of power through the 138 kV transmission line between Whitehorse and Skagway, when an imaginary generator at Skagway generates its maximum power while maintaining acceptable system conditions.

**Figure A-6: PSS®E Single Line Diagram – Whitehorse → Skagway (138 kV)**



**Table A-25: PSS®E Results – Whitehorse → Skagway (138 kV)**

Location	Pgen (MW)	Qgen (MVar)	Pload (MW)	Qload (MVar)	Voltage (p.u.)	Voltage Angle (degrees)
Whitehorse	-33.7	91.9	80.0	38.7	0.99	0.0
Voltage Test 1	-	-	-	-	0.99	11.4
Voltage Test 2	-	-	-	-	1.02	22.7
Skagway	140.0	8.1	-	-	1.09	33.1

**A.7.3 Results**

Analysis results are listed in Table A-26.

**Table A-26: Analysis Results – Whitehorse → Skagway (138 kV)**

Parameter	Value
Line Capacity:	114 MW
Limiting Issue:	33° Voltage Angle

**A.8 Route 5: Whitehorse → Atlin (138 kV)**
**A.8.1 Transmission Line Characteristics**

Key physical parameters are listed in Table A-27.

**Table A-27: Physical Parameters – Whitehorse → Atlin (138 kV)**

Parameter	Value
From:	Whitehorse
To:	Atlin
Distance:	172 km
Transmission Voltage:	138 kV
Transmission Conductor:	Ibis 397.5 MCM
Conductor Thermal Rating:	204 MVA in Winter 153 MVA in Summer

**A.8.2 Transmission Line Characteristics**

Using a 100 MVA system base and 138 kV line voltage, Table A-28 was tabulated based on Table A-1 and tower structure assumptions for phase spacing.

**Table A-28: Transmission Line Characteristics – Whitehorse → Atlin (138 kV)**

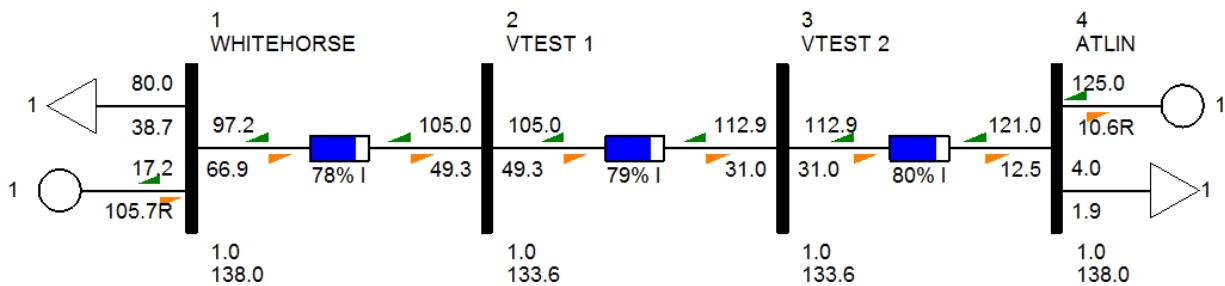
From	To	Distance (km)	Resistance R (p.u.)	Reactance X (p.u.)	Charging B (p.u.)
Whitehorse	Voltage Test 1	57.2	0.054668175	0.149062512	0.035935065
Voltage Test 1	Voltage Test 2	57.2	0.054668175	0.149062512	0.035935065
Voltage Test 2	Atlin	57.2	0.054668175	0.149062512	0.035935065

**A.8.3 PSSE Simulation**

Table A-29 lists the generation and load parameters for all buses considered in the power flow simulation. For simplicity, all loads are assumed to have a power factor of 0.9, and each generator is capable of producing at 0.9 power factor lagging or leading.

Table A-29 and Figure A-7 shows that the Yukon system can receive 97 MW of power through the 138 kV transmission line between Whitehorse and Atlin, when an imaginary generator at Atlin generates its maximum power while maintaining acceptable system conditions.

**Figure A-7: PSS®E Single Line Diagram – Whitehorse → Atlin (138 kV)**



**Table A-29: PSS®E Results – Whitehorse → Atlin (138 kV)**

Location	Pgen (MW)	Qgen (MVar)	Pload (MW)	Qload (MVar)	Voltage (p.u.)	Voltage Angle (degrees)
Whitehorse	-17.2	105.7	80	38.7458	1.000	0.000
Voltage Test 1	-	-	-	-	0.968	10.870
Voltage Test 2	-	-	-	-	0.968	22.220
Atlin	125.0	-10.6	4	1.9	1.000	33.310

**A.8.4 Results**

Analysis results are listed in Table A-30.

**Table A-30: Analysis Results – Whitehorse → Atlin (138 kV)**

Parameter	Value
Line Capacity:	97 MW
Limiting Issue:	33° Voltage Angle

**A.9 Route 6: Whitehorse → Teslin (138 kV)**

**A.9.1 Transmission Line Characteristics**

Key physical parameters are listed in Table A-31.

**Table A-31: Physical Parameters – Whitehorse → Teslin (138 kV)**

Parameter	Value
From:	Whitehorse
To:	Teslin
Distance:	174 km
Transmission Voltage:	138 kV
Transmission Conductor:	Ibis 397.5 MCM
Conductor Thermal Rating:	204 MVA in Winter 153 MVA in Summer

**A.9.2 Transmission Line Characteristics**

Using a 100 MVA system base and 138 kV line voltage, Table A-32 was tabulated based on Table A-1 and tower structure assumptions for phase spacing.

**Table A-32: Transmission Line Characteristics – Whitehorse → Teslin (138 kV)**

From	To	Distance (km)	Resistance R (p.u.)	Reactance X (p.u.)	Charging B (p.u.)
Whitehorse	Voltage Test 1	87.0	0.083094343	0.226875857	0.054782068
Voltage Test 1	Teslin	87.0	0.083094343	0.226875857	0.054782068

**A.9.3 PSSE Simulation**

Table A-33 lists the generation and load parameters for all buses considered in the power flow simulation. For simplicity, all loads are assumed to have a power factor of 0.9, and each generator is capable of producing at 0.9 power factor lagging or leading.

Table A-33 and Figure A-8 shows that the Yukon system can receive 95 MW in winter and summer through the 138 kV transmission line between Whitehorse and Teslin, when an imaginary generator at Teslin generates its maximum power while maintaining acceptable system conditions.

Figure A-8: PSS®E Single Line Diagram – Whitehorse → Teslin (138 kV)

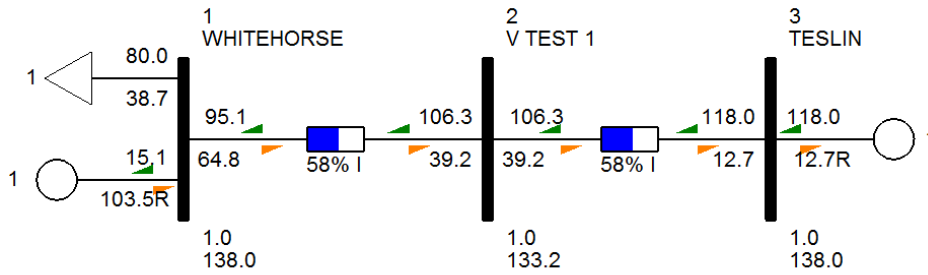


Table A-33: PSS®E Results – Whitehorse → Teslin (138 kV)

Location	Pgen (MW)	Qgen (MVA <sub>r</sub> )	Pload (MW)	Qload (MVA <sub>r</sub> )	Voltage (p.u.)	Voltage Angle (degrees)
Whitehorse	-15.1	103.5	80	38.7458	1.00	0.00
Voltage Test 1	-	-	-	-	0.96	16.36
Teslin	118.0	-12.7	-	-	1.00	32.98

**A.9.4 Results**

Analysis results are listed in Table A-34.

Table A-34: Analysis Results – Whitehorse → Teslin (138 kV)

Parameter	Value
Line Capacity:	95 MW
Limiting Issue:	33° Voltage Angle

**A.10 Route 7: Whitehorse → Squanga-Dalayee PSH (138 kV)**

Key physical parameters are listed in Table A-35.

Table A-35: Physical Parameters – Whitehorse → Squanga-Dalayee PSH (138 kV)

Parameter	Value
From:	Whitehorse
To:	Squanga-Dalayee PSH
Distance:	105 km
Transmission Voltage:	138 kV
Transmission Conductor:	Ibis 397.5 MCM
Conductor Thermal Rating:	153 MVA in Winter 203 MVA in Summer

**A.10.1 Transmission Line Characteristics**

Using a 100 MVA system base and 138 kV line voltage, Table A-36 was tabulated based on Table A-1 and tower structure assumptions for phase spacing.

**Table A-36: Transmission Line Characteristics – Whitehorse → Squanga-Dalayee PSH (138 kV)**

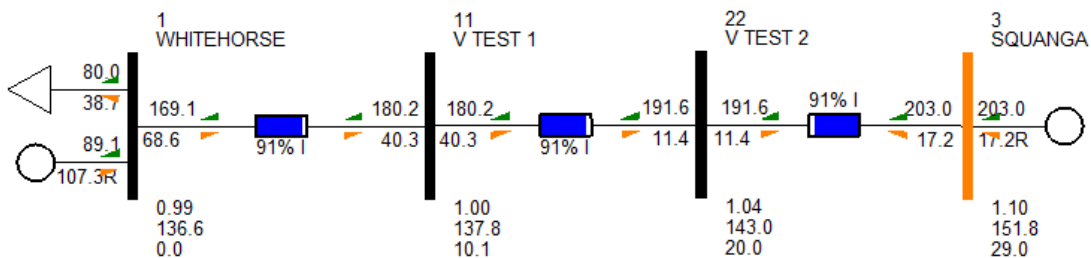
From	To	Distance (km)	Resistance R (p.u.)	Reactance X (p.u.)	Charging B (p.u.)
Whitehorse	Voltage Test 1	34.9	0.033020429	0.090247853	0.021817834
Voltage Test 1	Voltage Test 2	34.9	0.033020429	0.090247853	0.021817834
Voltage Test 2	Squanga-Dalayee PSH	34.9	0.033020429	0.090247853	0.021817834

**A.10.2 PSSE Simulation**

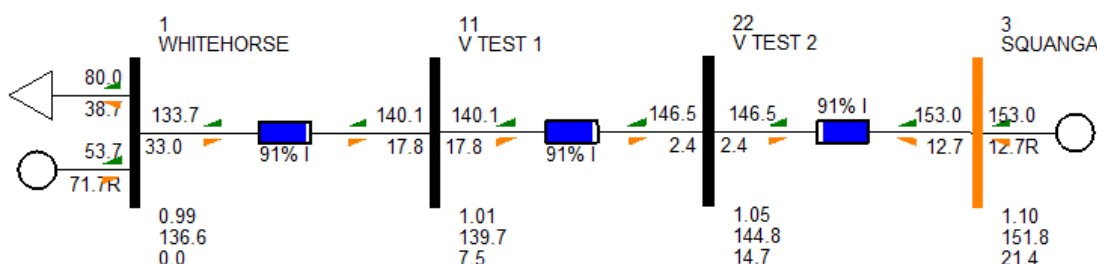
Table A-37 and Table A-38 list the generation and load parameters for all buses considered in the power flow simulation. For simplicity, all loads are assumed to have a power factor of 0.9, and each generator is capable of producing at 0.9 power factor lagging or leading.

Table A-37/Table A-38 and Figure A-9/Figure A-10 show that the Yukon system can receive 169 MW in winter and 134 MW in summer through the 138 kV transmission line between Whitehorse and Squanga-Dalayee PSH, when an imaginary generator at Squanga-Dalayee PSH generates its maximum power while maintaining acceptable system conditions.

**Figure A-9: PSS®E Winter Single Line Diagram – Whitehorse → Squanga-Dalayee PSH (138 kV)**



**Figure A-10: PSS®E Summer Single Line Diagram – Whitehorse → Squanga-Dalayee PSH (138 kV)**



**Table A-37: PSS®E Winter Results – Whitehorse → Squanga-Dalayee PSH (138 kV)**

Location	Pgen (MW)	Qgen (MVA <sub>r</sub> )	Pload (MW)	Qload (MVA <sub>r</sub> )	Voltage (p.u.)	Voltage Angle (degrees)
Whitehorse	-89.1	107.3	80	38.7	0.99	0.0
Voltage Test 1	-	-	-	-	1.00	10.1
Voltage Test 2	-	-	-	-	1.04	20.0
Squanga-Dalayee PSH	203.0	17.2	-	-	1.10	29.0

**Table A-38: PSS®E Summer Results – Whitehorse → Squanga-Dalayee PSH (138 kV)**

Location	Pgen (MW)	Qgen (MVA <sub>r</sub> )	Pload (MW)	Qload (MVA <sub>r</sub> )	Voltage (p.u.)	Voltage Angle (degrees)
Whitehorse	-53.7	71.7	80	38.7	0.99	0.0
Voltage Test 1	-	-	-	-	1.01	7.5
Voltage Test 2	-	-	-	-	1.05	14.7
Squanga-Dalayee PSH	153.0	12.7	-	-	1.10	21.4

### A.10.3 Results

Analysis results are listed in Table A-39.

**Table A-39: Analysis Results – Whitehorse → Squanga-Dalayee PSH (138 kV)**

Parameter	Value
Line Capacity:	169 MW in Winter 134 MW in Summer
Limiting Issue:	Thermal Limit

### A.11 Route 8: Whitehorse → Atlin-Mt.Black PSH (138 kV)

Key physical parameters are listed in Table A-40.

**Table A-40: Physical Parameters – Whitehorse → Atlin-Mt.Black PSH (138 kV)**

Parameter	Value
From:	Whitehorse
To:	Atlin-Mt.Black PSH
Distance:	127 km
Transmission Voltage:	138 kV
Transmission Conductor:	Ibis 397.5 MCM
Conductor Thermal Rating:	153 MVA in Winter 204 MVA in Summer

**A.11.1 Transmission Line Characteristics**

Using a 100 MVA system base and 138 kV line voltage, Table A-41 was tabulated based on Table A-1 and tower structure assumptions for phase spacing.

**Table A-41: Transmission Line Characteristics – Whitehorse → Atlin-Mt.Black PSH (138 kV)**

From	To	Distance (km)	Resistance R (p.u.)	Reactance X (p.u.)	Charging B (p.u.)
Whitehorse	Voltage Test 1	42.2	0.039757188	0.108827990	0.026358396
Voltage Test 1	Voltage Test 2	42.2	0.039757188	0.108827990	0.026358396
Voltage Test 2	Atlin-Mt.Black PSH	42.2	0.039757188	0.108827990	0.026358396

**A.11.2 PSSE Simulation**

Table A-42 and Table A-43 list the generation and load parameters for all buses considered in the power flow simulation. For simplicity, all loads are assumed to have a power factor of 0.9, and each generator is capable of producing at 0.9 power factor lagging or leading.

Table A-42/Table A-43 and Figure A-11/Figure A-12 show that the Yukon system can receive 154 MW in the winter and 131 MW in the summer through the 138 kV transmission line between Whitehorse and Atlin-Mt.Black PSH, when an imaginary generator at Atlin-Mt.Black PSH generates its maximum power while maintaining acceptable system conditions.

Figure A-11: PSS®E Winter Single Line Diagram – Whitehorse → Atlin-Mt.Black PSH (138 kV)

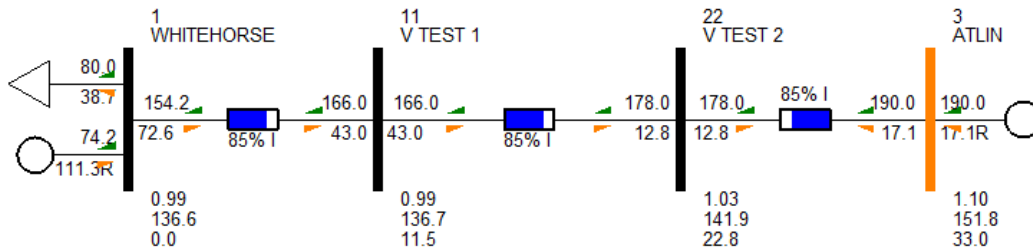


Figure A-12: PSS®E Summer Single Line Diagram – Whitehorse → Atlin-Mt.Black PSH (138 kV)

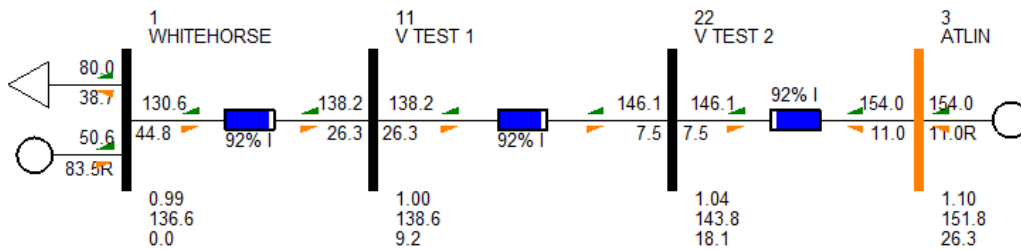


Table A-42: PSS®E Winter Results – Whitehorse → Atlin-Mt.Black PSH (138 kV)

Location	Pgen (MW)	Qgen (MVA <sub>r</sub> )	Pload (MW)	Qload (MVA <sub>r</sub> )	Voltage (p.u.)	Voltage Angle (degrees)
Whitehorse	-74.2	111.3	80.0	38.7	0.99	0.0
Voltage Test 1	-	-	-	-	0.99	11.5
Voltage Test 2	-	-	-	-	1.03	22.8
Atlin-Mt.Black PSH	190.0	17.1	-	-	1.10	33.0

Table A-43: PSS®E Summer Results – Whitehorse → Atlin-Mt.Black PSH (138 kV)

Location	Pgen (MW)	Qgen (MVA <sub>r</sub> )	Pload (MW)	Qload (MVA <sub>r</sub> )	Voltage (p.u.)	Voltage Angle (degrees)
Whitehorse	-50.6	83.5	80.0	38.7	0.99	0.0
Voltage Test 1	-	-	-	-	1.00	9.2
Voltage Test 2	-	-	-	-	1.04	18.1
Atlin-Mt.Black PSH	154.0	11.0	-	-	1.10	26.3

**A.11.3 Results**

Analysis results are listed in Table A-44.

**Table A-44: Analysis Results – Whitehorse → Atlin-Mt.Black PSH (138 kV)**

Parameter	Value
Line Capacity:	190 MW in Winter 154 MW in Summer
Limiting Issue:	33° Voltage Angle (Winter) Thermal Limit (Summer)

## A.12 Route 9: Whitehorse → Tutshi Windy Arm (138 kV)

Key physical parameters are listed in Table A-45.

**Table A-45: Physical Parameters – Whitehorse → Tutshi Windy Arm (138 kV)**

Parameter	Value
From:	Whitehorse
To:	Tutshi Windy Arm
Distance:	96 km
Transmission Voltage:	138 kV
Transmission Conductor:	Ibis 397.5 MCM
Conductor Thermal Rating:	153 MVA in Winter 204 MVA in Summer

### A.12.1 Transmission Line Characteristics

Using a 100 MVA system base and 138 kV line voltage, Table A-46 was tabulated based on Table A-1 and tower structure assumptions for phase spacing.

**Table A-46: Transmission Line Characteristics – Whitehorse → Tutshi Windy Arm (138 kV)**

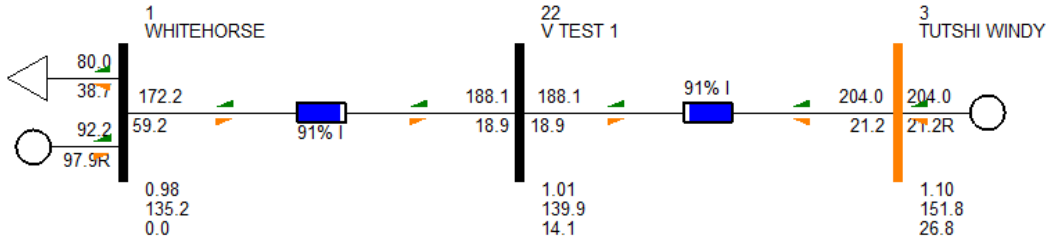
From	To	Distance (km)	Resistance R (p.u.)	Reactance X (p.u.)	Charging B (p.u.)
Whitehorse	Voltage Test 1	48.0	0.045673785	0.124767031	0.030144575
Voltage Test 1	Tutshi Windy Arm	48.0	0.045673785	0.124767031	0.030144575

### A.12.2 PSSE Simulation

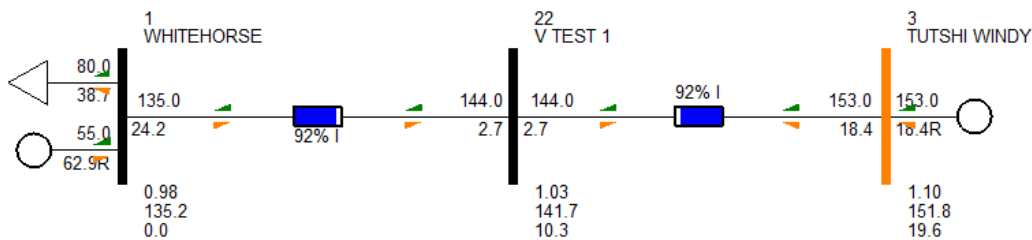
Table A-47 and Table A-48 list the generation and load parameters for all buses considered in the power flow simulation. For simplicity, all loads are assumed to have a power factor of 0.9, and each generator is capable of producing at 0.9 power factor lagging or leading.

Table A-47/Table A-48 and Figure A-13/Figure A-14 show that the Yukon system can receive 172 MW in winter and 135 MW in summer through the 138 kV transmission line between Whitehorse and Tutshi Windy Arm, when an imaginary generator at Tutshi Windy Arm generates its maximum power while maintaining acceptable system conditions.

**Figure A-13: PSS®E Winter Single Line Diagram – Whitehorse → Tutshi Windy Arm (138 kV)**



**Figure A-14: PSS®E Summer Single Line Diagram – Whitehorse → Tutshi Windy Arm (138 kV)**



**Table A-47: PSS®E Winter Results – Whitehorse → Tutshi Windy Arm (138 kV)**

Location	Pgen (MW)	Qgen (MVAR)	Pload (MW)	Qload (MVAR)	Voltage (p.u.)	Voltage Angle (degrees)
Whitehorse	-92.2	97.9	80.0	38.7	0.98	0.0
Voltage Test 1	-	-	-	-	1.01	14.1
Tutshi Windy Arm	204.0	21.2	-	-	1.10	26.8

**Table A-48: PSS®E Summer Results – Whitehorse → Tutshi Windy Arm (138 kV)**

Location	Pgen (MW)	Qgen (MVAR)	Pload (MW)	Qload (MVAR)	Voltage (p.u.)	Voltage Angle (degrees)
Whitehorse	-55.0	62.9	80.0	38.7	0.98	0.0
Voltage Test 1	-	-	-	-	1.03	10.3
Tutshi Windy Arm	153.0	18.4	-	-	1.10	19.6

**A.12.3 Results**

Analysis results are listed in Table A-49.

**Table A-49: Analysis Results – Whitehorse → Tutshi Windy Arm (138 kV)**

Parameter	Value
Line Capacity:	172 MW in Winter 135 MW in Summer
Limiting Issue:	Thermal Limit

**A.13 Route 10: Whitehorse → Racine-Mt.Brown PSH, Racine-Moon Lake PSH, and Tutshi-Moon Lake PSH (138 kV)**

Key physical parameters are listed in Table A-50.

**Table A-50: Physical Parameters – Whitehorse → Racine-Mt.Brown PSH, Racine-Moon Lake PSH, and Tutshi-Moon Lake PSH (138 kV)**

Parameter	Value
From:	Whitehorse
To:	Racine-Mt.Brown PSH, Racine-Moon Lake PSH, and Tutshi-Moon Lake PSH
Distance:	112 km
Transmission Voltage:	138 kV
Transmission Conductor:	Ibis 397.5 MCM
Conductor Thermal Rating:	152 MVA in Winter 202 MVA in Summer

**A.13.1 Transmission Line Characteristics**

Using a 100 MVA system base and 138 kV line voltage, Table A-51 was tabulated based on Table A-1 and tower structure assumptions for phase spacing.

**Table A-51: Transmission Line Characteristics – Whitehorse → Racine-Mt.Brown PSH, Racine-Moon Lake PSH, and Tutshi-Moon Lake PSH (138 kV)**

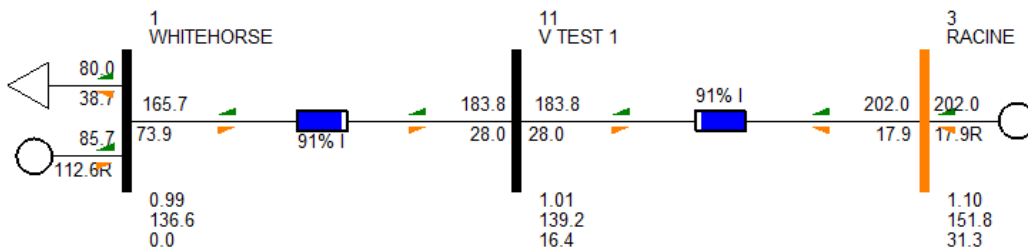
From	To	Distance (km)	Resistance R (p.u.)	Reactance X (p.u.)	Charging B (p.u.)
Whitehorse	Voltage Test 1	55.8	0.053423433	0.146092738	0.035342255
Voltage Test 1	Racine-Mt.Brown PSH, Racine-Moon Lake PSH, and Tutshi-Moon Lake PSH	55.8	0.053423433	0.146092738	0.035342255

**A.13.2 PSSE Simulation**

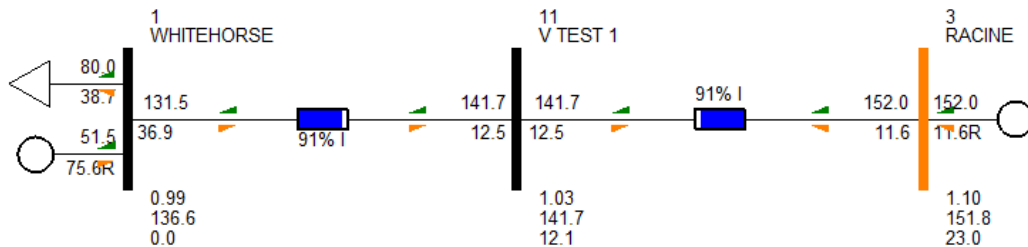
Table A-52 and Table A-53 list the generation and load parameters for all buses considered in the power flow simulation. For simplicity, all loads are assumed to have a power factor of 0.9, and each generator is capable of producing at 0.9 power factor lagging or leading.

Table A-52/Table A-53 and Figure A-15/Figure A-16 shows that the Yukon system can receive 166 MW in winter and 132 MW in summer through the 138 kV transmission line between Whitehorse and Racine-Mt.Brown PSH, Racine-Moon Lake PSH, and Tutshi-Moon Lake PSH, when an imaginary generator at the end of the line generates its maximum power while maintaining acceptable system conditions.

**Figure A-15: PSS®E Winter Single Line Diagram – Whitehorse → Racine-Mt.Brown PSH, Racine-Moon Lake PSH, and Tutshi-Moon Lake PSH (138 kV)**



**Figure A-16: PSS®E Summer Single Line Diagram – Whitehorse → Racine-Mt.Brown PSH, Racine-Moon Lake PSH, and Tutshi-Moon Lake PSH (138 kV)**



**Table A-52: PSS®E Winter Results – Whitehorse →  
Racine-Mt.Brown PSH, Racine-Moon Lake PSH, and Tutshi-Moon Lake PSH (138 kV)**

Location	Pgen (MW)	Qgen (MVA <sub>r</sub> )	Pload (MW)	Qload (MVA <sub>r</sub> )	Voltage (p.u.)	Voltage Angle (degrees)
Whitehorse	-85.7	112.6	80.0	38.7	0.99	0.0
Voltage Test 1	-	-	-	-	1.01	16.4
Racine-Mt.Brown PSH, Racine-Moon Lake PSH, and Tutshi-Moon Lake PSH	202.0	17.9	-	-	1.10	31.3

**Table A-53: PSS®E Summer Results – Whitehorse →  
Racine-Mt.Brown PSH, Racine-Moon Lake PSH, and Tutshi-Moon Lake PSH (138 kV)**

Location	Pgen (MW)	Qgen (MVA <sub>r</sub> )	Pload (MW)	Qload (MVA <sub>r</sub> )	Voltage (p.u.)	Voltage Angle (degrees)
Whitehorse	-51.5	75.6	80.0	38.7	0.99	0.0
Voltage Test 1	-	-	-	-	1.03	12.1
Racine-Mt.Brown PSH, Racine-Moon Lake PSH, and Tutshi-Moon Lake PSH	152.0	11.6	-	-	1.10	23.0

**A.13.3 Results**

Analysis results are listed in Table A-54.

**Table A-54: Analysis Results – Whitehorse →  
Racine-Mt.Brown PSH, Racine-Moon Lake PSH, and Tutshi-Moon Lake PSH (138 kV)**

Parameter	Value
Line Capacity:	166 MW in Winter 132 MW in Summer
Limiting Issue:	Thermal Limit

**A.14 Route 11: Whitehorse → Lindeman-Fraser PSH (138 kV)**

Key physical parameters are listed in Table A-55.

**Table A-55: Physical Parameters – Whitehorse → Lindeman-Fraser PSH (138 kV)**

Parameter	Value
From:	Whitehorse
To:	Lindeman-Fraser PSH
Distance:	129 km
Transmission Voltage:	138 kV
Transmission Conductor:	Ibis 397.5 MCM
Conductor Thermal Rating:	152 MVA in Winter 202 MVA in Summer

**A.14.1 Transmission Line Characteristics**

Using a 100 MVA system base and 138 kV line voltage, Table A-56 was tabulated based on Table A-1 and tower structure assumptions for phase spacing.

**Table A-56: Transmission Line Characteristics – Whitehorse → Lindeman-Fraser PSH (138 kV)**

From	To	Distance (km)	Resistance R (p.u.)	Reactance X (p.u.)	Charging B (p.u.)
Whitehorse	Voltage Test 1	64.6	0.061776554	0.169164012	0.040989919
Voltage Test 1	Lindeman-Fraser PSH	64.6	0.061776554	0.169164012	0.040989919

**A.14.2 PSSE Simulation**

Table A-57 and Table A-58 list the generation and load parameters for all buses considered in the power flow simulation. For simplicity, all loads are assumed to have a power factor of 0.9, and each generator is capable of producing at 0.9 power factor lagging or leading.

Table A-57/Table A-58 and Figure A-17/Figure A-18 show that the Yukon system can receive 147 MW in winter and 129 MW in summer through the 138 kV transmission line between Whitehorse and Lindeman-Fraser PSH, when an imaginary generator at Lindeman-Fraser PSH generates its maximum power while maintaining acceptable system conditions.

Figure A-17: PSS®E Winter Single Line Diagram – Whitehorse → Lindeman-Fraser PSH (138 kV)

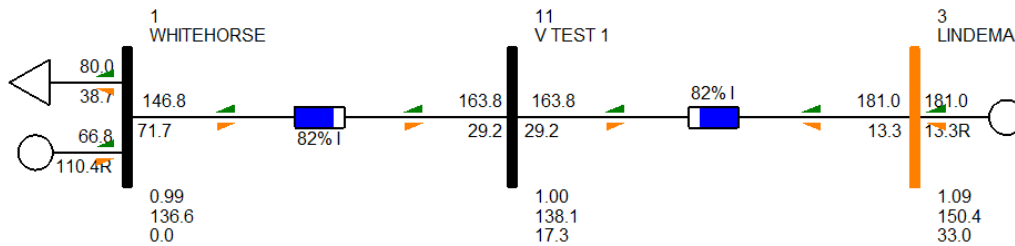


Figure A-18: PSS®E Summer Single Line Diagram – Whitehorse → Lindeman-Fraser PSH (138 kV)

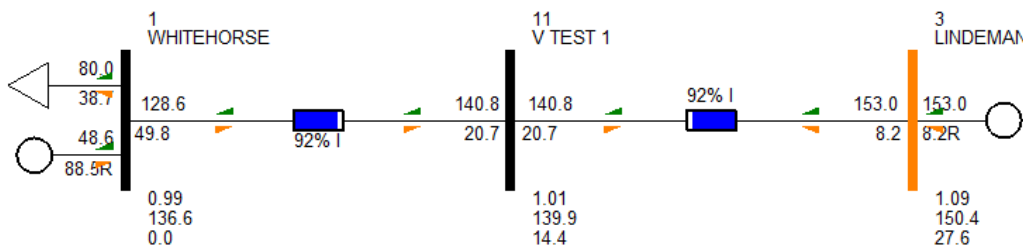


Table A-57: PSS®E Winter Results – Whitehorse → Lindeman-Fraser PSH (138 kV)

Location	Pgen (MW)	Qgen (MVar)	Pload (MW)	Qload (MVar)	Voltage (p.u.)	Voltage Angle (degrees)
Whitehorse	-66.8	110.4	80.0	38.7	0.99	0.0
Voltage Test 1	-	-	-	-	1.00	17.3
Lindeman-Fraser PSH	181.0	13.3	-	-	1.09	33.0

Table A-58: PSS®E Summer Results – Whitehorse → Lindeman-Fraser PSH (138 kV)

Location	Pgen (MW)	Qgen (MVar)	Pload (MW)	Qload (MVar)	Voltage (p.u.)	Voltage Angle (degrees)
Whitehorse	-48.6	88.5	80.0	38.7	0.99	0.0
Voltage Test 1	-	-	-	-	1.01	14.4
Lindeman-Fraser PSH	153.0	8.2	-	-	1.09	27.6

### A.14.3 Results

Analysis results are listed in Table A-59.

**Table A-59: Analysis Results – Whitehorse → Lindeman-Fraser PSH (138 kV)**

Parameter	Value
Line Capacity:	147 MW in Winter 129 MW in Summer
Limiting Issue:	33° Voltage Angle (Winter) Thermal Limit (Summer)

# **Appendix B:**

# **Transmission Option Schedules**



# **Appendix C:**

## **JDMA Transmission Routing Report**

J.D. Mollard and Associates (2010) Limited

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# **Preliminary Transmission Line Corridor Identification Study**

**FINAL REPORT**  
**November 02, 2016**

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## 1 Introduction

### 1.1 Scope of work

Midgard Consulting Inc. (MC) asked J.D. Mollard and Associates (2010) Limited (JDMA) to conduct a desktop identification and evaluation of transmission line corridors for a number of endpoint locations within the Yukon Territory, BC and Alaska. MC specified that the transmission line corridors be approximately 500 m wide with the flexibility to narrow or widen the corridors locally to accommodate routing constraints. Transmission line corridor routing and characterization was conducted at a high level and ground truthing was not included in the scope of work. MC requested that the width of the transmission line corridors be 500 m.

### 1.2 Study areas

MC provided six (6) new endpoint pairs for transmission line corridor identification in May 2016 in addition to the previous eight (8) endpoint pairs that MC provided in April 2015. The six new endpoint pairs and original eight endpoint pairs are listed in Table 1. The corridor lengths listed in Table 1 are based on JDMA's analysis of the final corridor lengths as they have been described in this report. The location of the six new endpoint pairs and eight previous endpoint pairs are shown in Figure 1.

**Table 1: Transmission Line Corridors Evaluated**

Transmission Line Name	Length (km)
Aishihik to Destruction Bay	157
Whitehorse to Carcross Cutoff	17
Carcross Cutoff to Jakes Corner	62
Jakes Corner to Teslin	95
Jakes Corner to Atlin	92
Carcross Cutoff to Skagway	154
Faro to Watson Lake	414
Two Mile Canyon	112
Fraser Falls	48
Granite Canyon	15
Slate Rapids	9
False Canyon	7
Middle Canyon	6
Hoole Canyon	2

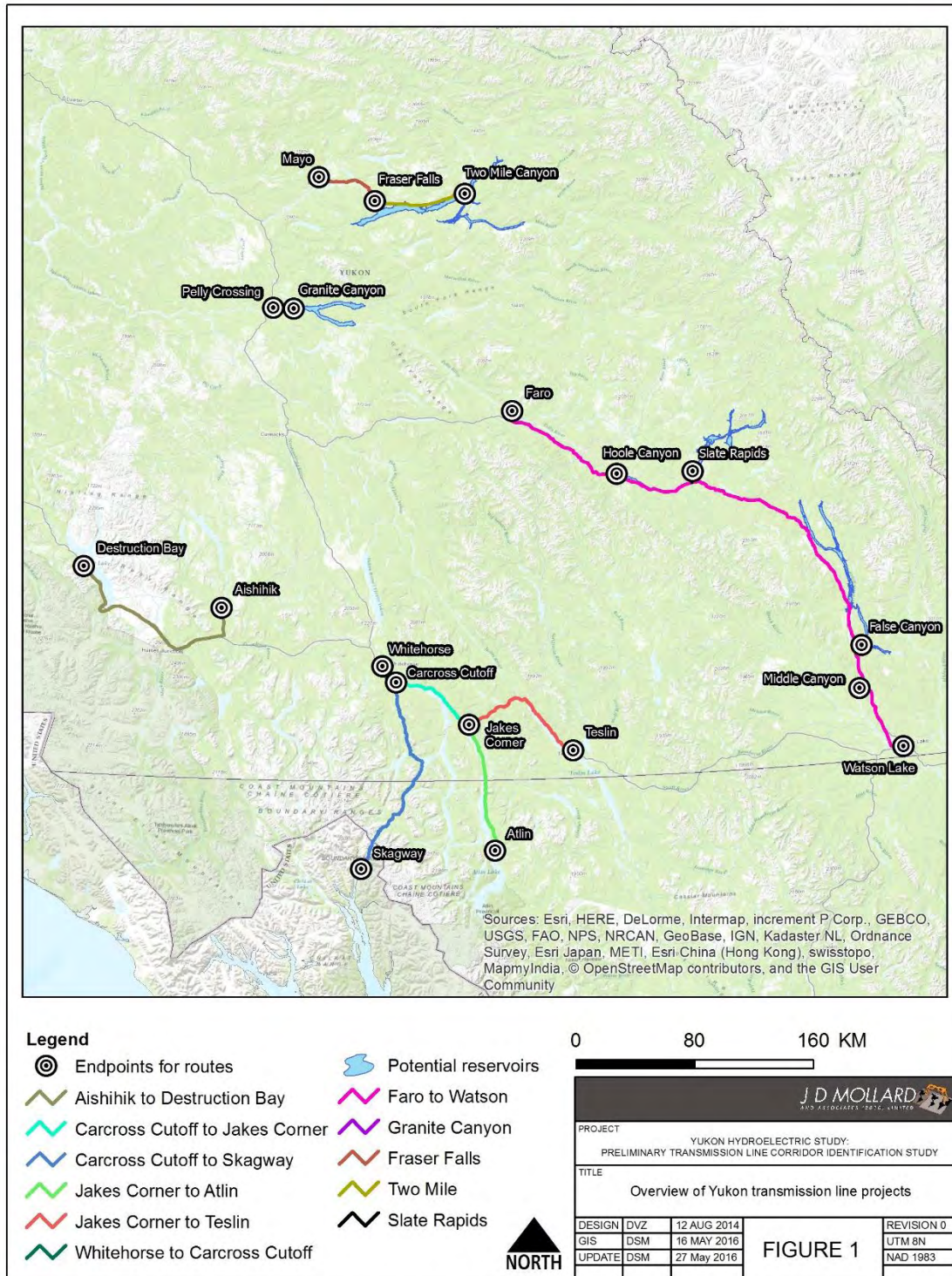


Figure 1: Overview map

## 2 Methodology

The transmission line corridor identification was done at a high level, and as such no detailed data sources were used in the analyses (e.g., air photographs, high resolution satellite, LiDAR). All evaluation of corridors was completed using ESRI ArcGIS and MicroImages TNT MIPS. Data were obtained from various territorial, provincial and national sources to aid in the evaluation of the routes.

MC provided the following criteria to JDMA for transmission line corridor identification:

- Transmission line span length will be approximately 200-230 m with longer spans possible in special cases,
- Where practical, place the transmission line corridor adjacent to roadways for maintenance and construction access,
- Where practical, narrow the corridor to less than 500 m to avoid major terrain constrictions adjacent to the corridor (e.g. next to a steep slope, river, etc.),
- Avoid crossing privately held land,
- Deflections up to 15° will not require special structures.

In addition to these specific criteria, JDMA also considered surficial geology and surface materials, terrain and slope, total length, as well as stream and wetland crossings to help in identifying feasible corridors.

In the case of the Jakes Corner to Atlin connection, one of the endpoints is located in BC. In the case of Carcross Cutoff to Skagway connection, one endpoint is in Alaska, requiring this corridor to pass through parts of Yukon, BC and Alaska. In these cases, the corridors were segmented for analysis based on territory, province, or state because different datasets exist for Yukon, BC and Alaska. This results in data being presented for nine (9) new corridor segments in Table 3 and the original eight (8) corridors in Table 4. The Faro to Watson Lake corridor in Table 4 was segmented based on the tap locations that extend along it.

### 2.1 Data sources

JDMA obtained base data for this project from free open-source files found on Government of Yukon, Government of Canada, Government of BC, and United States Geological Survey (USGS) web pages.

The data used in this study include both physical and cultural data. Geospatial data sources used in this study are listed in Table 2.

**Table 2: Geospatial data sources used**

Data Name	Data Type	Data Source
SPOT 20 m multispectral, 10 m panchromatic imagery	Satellite Imagery	SPOT imagery. © Department of Natural Resources Canada. "Orthoimagery". All rights reserved.
Canadian Digital Elevation Model (CDEM)	Digital elevation dataset (For Canada)	Elevation Data. © Department of Natural Resources Canada. "Canadian Digital Elevation Model". All rights reserved.
Shuttle Radar Topographic Mission	Digital elevation dataset (for Alaska)	Elevation Data. © United States Geological Survey Earth Explorer. "SRTM 1 Arc-Second Global". All rights reserved.

(SRTM)		
Surficial geology of the Yukon	Surficial geology and surficial material data for Yukon	Surficial Geology. © Ministry of Energy, Mines and Resources. "Yukon Digital Surficial Geology Compilation". All rights reserved.
Quaternary Geology of the Atlin Area	Surficial geology and surficial material data for BC	Surficial Geology. © BC Geological Survey Branch. "Quaternary Geology of the Atlin Area" 1:50,000. All rights reserved.
Surficial geology of the Skagway Quadrangle	Surficial geology and surficial material data for BC	Surficial Geology. © United States Geological Survey. "Photointerpretive map of the Skagway B-1 Quadrangle, Alaska" 1:63,360. All rights reserved.
JDMA mapped surficial geology	Surficial geology and surficial material data for BC	Mapped Surficial Geology. © JDMA. All rights reserved
LCC-2000	Land Cover data	Land Cover. © Department of Natural Resources Canada. "Land Cover Circa 2000" 1:250,000. All rights reserved.
NLCD-2001	Land Cover data	Land Cover. © Multi-Resolution Land Characteristics Consortium. "National Land Cover Database 2001" All rights reserved.
Rivers	Hydrographic data	Rivers. © Department of Natural Resources Canada. "CanVec single line watercourse layer" 1:50,000. All rights reserved.
Waterbodies	Hydrographic data	Waterbodies. © Department of Natural Resources Canada. "CanVec waterbodies layer" 1:50,000. All rights reserved.
Permafrost probability map	Permafrost regions of YK, BC, AK	Permafrost. © Department of Natural Resources Canada. "Yukon Permafrost Network". All rights reserved.
Road network - YK	Road network of the Yukon	Road network. © Department of Natural Resources Canada. "NRN YT". All rights reserved.
Road network – BC	Road network of British Columbia	Road network. © Department of Natural Resources Canada. "NRN BC". All rights reserved.
Road network – AK	Road network of Alaska	Road network. © Department of Transportation. "DOT Road System". All rights reserved.
Municipal boundaries	Town and village boundaries	Municipal boundaries. © GeoYukon Yukon. "Municipal boundaries". All rights reserved.
First Nations Settlement lands	First Nation land boundaries	First Nations lands. © GeoYukon Yukon. "First Nations Settlement Lands Surveyed, First Nations Settlement Lands Unsurveyed". All rights reserved.
Surficial land parcels and land use files (various) - YK	Various land uses and registered land parcels in the Yukon	Land parcels. © GeoYukon Yukon. "Active Land Applications, Land Dispositions, Land Notations, Easements, Land Licenses, Surveyed Land Parcels". All rights reserved.
Utilities	Power lines or pipelines	Utilities. © GeoYukon Yukon. "Utilities". All rights reserved.
Surficial land parcels and land use files (various) - BC	Various land uses and registered land parcels in British Columbia	Land parcels. © GeoBC. "Crown Land Licenses and Crown Land Reserves and Tenures". All rights reserved.

The above data were downloaded from the following links:

- SPOT, CDEM, rivers, waterbodies, and road network data were obtained from <http://ftp2.cits.rncan.gc.ca/pub/>,
- SRTM, NLCD data were obtained from <http://earthexplorer.usgs.gov/>
- Alaska road network were obtained from <http://www.asgdc.state.ak.us/>
- Yukon surficial geology data were obtained from [http://www.geology.gov.yk.ca/digital\\_surficial\\_data.html](http://www.geology.gov.yk.ca/digital_surficial_data.html)
- Atlin surficial geology data were obtained from <http://www.empr.gov.bc.ca/Pages/default.aspx>
- Skagway surficial geology were obtained from <http://www.dggs.alaska.gov/pubs/id/93>
- Permafrost data were obtained from <http://permafrost.gov.yk.ca/data/arcgis/>
- Yukon municipal boundaries, First Nations Settlement lands, land parcels, land use, utility data and other base data were obtained from <ftp://ftp.geomaticsyukon.ca/GeoYukon/>.
- BC land parcels, land use, and other base data were obtained from <https://apps.gov.bc.ca/pub/dwds/addProducts.do?orderId=1651722>.

The data sources listed above were used as screening tools and to derive the statistics presented in Table 3 and Table 4. It should be noted that these data sources have limitations related to scale and the amount of ground truthing that was done in local areas. Within the study areas JDMA conducted a limited quality control check on these data sources through visual examination of the data in comparison to features discernible in the SPOT satellite imagery. At the locations checked, it was found that the data were generally consistent with features visible in the satellite imagery.

The wetland datasets are derived from the LCC-2000 national landcover data set and NLCD-2001 US landcover dataset. Wetlands are categorized as treed, shrub, or herb. These classes represent the dominant vegetation type for each wetland. In comparing the wetland boundaries to satellite imagery it appears that the wetland file may underrepresent the actual number of wetlands in the study areas. The LCC-2000/NLCD-2001 dataset was primarily interpreted from classified Landsat imagery with little to no ground truthing. Wetlands that may have gone unclassified are likely mostly included in the forest land cover classes where wetlands may be masked by the forest canopy.

The forest classes in the LCC-2000 dataset are classified according to crown closure. This provides information on forest density. The boundaries between dense canopy, open canopy, sparse canopy forests are discernible in the SPOT satellite imagery.

Riparian zones were calculated by taking all stream courses, water bodies, and wetlands identified in the CanVec, LCC-2000, and NLCD-2001 datasets and applying a 15 m buffer around them. Non-vegetated land classes were omitted from this buffer and the remaining area is considered the riparian zone. Therefore, riparian zone defined in this way represents a vegetated buffer around waterbodies and wetlands.

Major stream crossings were identified from the CanVec water body layer. Any stream that had both river banks represented, as opposed to being represented by a single line was considered to be a major stream.

Surficial geology maps were obtained primarily at a scale of 1:100,000 and 1:250,000. These two datasets were merged to provide surficial geology coverage across all of the study areas with the smaller scale dataset being used only where larger scale data are not available. For corridor segments located in BC and Alaska, surficial geology data only exist for small areas near Atlin and Skagway. For those areas in BC and Alaska where mapping does not exist, JDMA provided surficial geology mapping. The primary material unit attribute was used to identify the surficial geology within the corridor. When identifying thin-drift-over-bedrock, the surficial geology dataset was interpreted to identify those areas where bedrock was a secondary unit and the depth of the primary unit was veneer (<1 m thick).

Slopes were calculated from the CDEM and SRTM dataset. Slope calculations were performed in ArcGIS. The slope calculation in Table 3 considers all slopes regardless of aspect.

First Nations lands, settled lands, and land uses were taken from base data available from GeoYukon for Yukon datasets and from GeoBC for BC datasets. These data exist as several data layers and these data

layers were merged to provide a summary of all of the land uses that are crossed by the corridors. Alaska datasets could not be located.

The road layers were taken from the National Road Network – Yukon/BC and US DOT - Alaska. Paved roads were identified from the road surface attribute. Improved gravel roads were identified from the road surface attribute and road type attribute. These are roads that have a gravelled surface and are designated as either collector, or highway class roads. All other roads are included in the trail or resource road category and included various smaller gravelled roads, dirt roads and roads with an unknown surface type.

## 2.2 Corridor Identification

After all of the geospatial imagery was compiled JDMA began identifying corridors for each of the connections that were identified by MC for this study. The various datasets were overlaid on the imagery in the GIS and routes were identified. Routes were drawn as single lines which would later become the basis for the final 500 m corridors. The imagery and the digital elevation data were incorporated in TNT MIPS which allows the user to view the imagery in 3D. This provided a view of the terrain, land cover (vegetation) and land use and helped to refine the routes in places where these may be limiting factors.

500 m corridors were generated from the centreline routes that were mapped. The corridors were then offset from the centreline in places to take advantage of more than one centreline option within the same corridor, to centre the corridor on a roadway, or to minimize hazardous or other undesirable terrain. In places where the transmission line corridor was wider than adjacent terrain constraints, the corridor was narrowed to only cover those areas where it would be practical to construct and maintain a transmission line. In a few areas the corridor was widened beyond 500 m to allow for consideration of multiple alternatives that are more than 500 m apart.

## 3 Results

Statistics were collected and compiled for each corridor and are summarized in Table 3 and Table 4. These tables break down the routes according to many factors including corridor length, surficial geology, slopes, environmental concerns, First Nations lands, incidence of land parcels / land uses crossed, and other infrastructure crossings. These categories provide a high level view of the types of terrain and land uses that are to be expected within each corridor. The following subsections describe some of the distinctive characteristics of the transmission line corridors. Base data comparable to that available in the Yukon were not found or provided for corridor segments that extend into BC and Alaska. Because of this, the route comparison table is broken down based upon territory, province, and state. Where data are unavailable the table entry was marked “No Data”.

The corridors **Slate Rapids to False Canyon**, **Jakes Corner to Atlin (BC)**, and **Jakes Corner to Teslin** were broken down into sections with endpoints specified by the client. These sections are split up in the tables below and in the figures in Appendix A.

Corridor maps for each of the endpoint pairs are included in Appendix A.

Table 3: New Routes Comparison Table (May 2016)

ROUTE ALTERNATIVES STATISTICS SUMMARY														
PROJECT: Midgard Yukon Hydroelectric Connection														
DATE: 05 AUG 2016														
	Aishihik to Destruction Bay	Whitehorse to Carcross Cutoff	Carcross Cutoff to Jakes Corner	Jakes Corner to Squanga Lake	Squanga Lake to Teslin	Jakes Corner to Atlin - YK	Jakes Corner to Atlin - BC (North of split)	Jakes Corner to Atlin - BC (South of split)	Carcross Cutoff to Skagway - YK	Carcross Cutoff to Skagway - BC (YK-Split 1)	Carcross Cutoff to Skagway - BC (Split 1 - 2)	Carcross Cutoff to Skagway - BC (Split 2 - 3)	Carcross Cutoff to Skagway - BC (Split 3 - AK)	Carcross Cutoff to Skagway - AK
<b>CONSTRUCTION</b>														
Total centreline length (km)	157	17	62	26	69	42	5	45	77	3	16	18	20	21
Total corridor area (Ha)	7948	260	3050	1289	3245	1955	233	2179	3612	76	717	774	792	854
Total # of deep valley / canyon crossings	2	0	0	0	9	1	0	3	0	0	0	0	0	0
Total # of major stream crossings	6	1	2	0	1	0	0	0	1	0	0	0	0	1
<b>LAND COVER (Ha) (Selected land classes were included in the Terms of References.)</b>														
Lundiferentiated forest	3400	0	0	0	0	0	0	0	0	0	0	0	0	0
Dense coniferous (>60% crown closure)	179	6	280	82	126	64	70	246	236	0	16	13	9	0
Coniferous - open canopy (26-60% crown closure)	1349	81	1386	735	1459	688	85	887	1465	0	134	268	15	221
Coniferous - sparse (10-25% crown closure)	692	19	202	90	645	408	2	349	285	0	4	86	40	0
Dense broadleaf (>60% crown closure)	35	0	21	9	37	52	0	0	65	17	116	9	31	0
Broadleaf - open canopy (26-60% crown closure)	10	0	0	0	0	0	0	0	0	0	0	0	0	6
Broadleaf - sparse (10-25% crown closure)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mixedwood - open canopy (26-60% crown closure)	0	0	0	2	1	0	1	0	0	5	9	0	0	108
Mixedwood - sparse (10-25% crown closure)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Riparian zones (15 m around wetlands, streams, waterbodies)	120	11	57	34	72	38	15	103	76	5	45	58	75	70
Open water	66	5	39	6	28	8	0	7	36	0	9	12	7	2
Treed wetlands	0	0	3	1	3	10	0	5	49	0	0	0	0	7
Shrub wetlands	36	0	26	11	1	23	0	12	5	0	0	0	0	1
Herb wetlands	0	0	10	0	0	0	0	0	1	0	0	1	0	0
<b>SURFICIAL GEOLOGY AND PERMAFROST (Ha)</b>														
Anthropogenic/urban area	0	113	0	0	0	0	0	0	0	0	0	0	0	0
Aeolian	404	0	65	0	0	0	0	0	322	0	0	0	0	0
Colluvium	339	0	0	282	25	4	0	148	127	64	83	6	0	0
Fluvial	2302	120	1273	404	895	1210	0	198	648	5	0	311	0	75
Lacustrine	1842	5	392	21	0	315	155	520	534	0	1	2	0	0
Moraine	2921	20	809	535	2324	5	0	720	1608	0	0	0	0	10
Organic	30	0	0	0	0	6	0	132	42	0	0	0	0	0
Exposed bedrock	8	0	348	48	0	415	78	182	187	6	365	454	792	769
Thin layer (veneer <1 m thick) with bedrock as second unit	102	3	163	0	2	0	0	279	143	0	268	0	0	0
Sporadic discontinuous permafrost	6784	256	3050	1289	2048	890	4	61	2546	34	25	64	9	20
Extensive discontinuous permafrost	1164	0	0	0	0	0	0	0	0	0	0	0	0	0
<b>SLOPE (Ha)</b>														
Area of corridor on slopes 0 - 15°	7620	260	2912	1226	3219	1855	216	2051	3298	9	523	592	561	308
Area of corridor on slopes 15 - 30°	305	0	136	63	27	100	17	127	256	54	184	128	227	425
Area of corridor on slopes over 30°	23	0	2	0	0	0	0	1	59	13	10	54	5	121
<b>FIRST NATIONS SETTLEMENT LANDS AND SETTLED LAND (Ha)</b>														
Category A First Nations land	652	0	596	44	303	0	0	0	700	0	0	0	0	No Data
Category B First Nations land	719	58	242	9	635	143	0	0	800	0	0	0	0	No Data
Uncategorized FN lands	0	0	0	0	17	0	0	0	53	0	0	0	0	No Data
Fee Simple First Nations land	51	0	0	0	0	0	0	0	27	0	0	0	0	No Data
First Nation Heritage Site	0	0	4	0	0	0	0	0	12	0	0	0	0	No Data
BC First Nations Site of Cultural Importance	0	0	0	0	0	0	49	189	0	0	0	0	85	No Data
BC First Nations Statement of Intent Boundaries	0	0	0	0	0	233	2179	0	76	717	774	792	0	No Data
Interim Protected	4	0	0	0	18	0	0	0	0	0	0	0	0	No Data
Urban land	331	248	0	0	14	0	0	0	0	0	0	0	0	No Data
<b>LAND USES (Ha)</b>														
Development Holds	1558	0	0	0	0	0	0	0	0	0	0	0	0	No Data
Agricultural lands	23	0	11	0	0	3	0	0	0	0	0	0	0	No Data
Airport	0	0	0	0	8	0	0	0	2	0	0	0	0	No Data
Bridgehead	3	0	13	0	21	22	0	0	9	0	0	0	0	No Data
Environment	16	0	32	0	0	0	0	0	0	0	0	0	0	No Data
Forestry	375	0	0	0	0	0	0	0	0	0	0	0	0	No Data
Garbage dump	0	0	2	0	0	0	0	7	6	0	0	0	0	No Data
Gravel Pit	216	0	88	29	160	90	0	43	89	0	20	14	15	No Data
Heritage	0	0	0	0	3	0	0	0	4	0	0	0	0	No Data
Industrial / commercial	96	0	91	12	63	0	0	0	2	0	1	0	1	No Data
Marine	3	0	0	0	0	0	0	0	4	0	0	0	0	No Data
Navigation aid	0	0	0	0	0	0	0	1	0	0	0	0	0	No Data
Parks, Campground, or Recreational	1	0	0	0	1	0	0	247	3	149	717	774	792	No Data
Quarry	112	0	58	0	23	30	0	0	53	0	0	0	0	No Data
Rural residence	0	2	4	0	0	0	0	0	0	0	0	0	0	No Data
Trapping	14	110	0	0	0	6	0	0	197	0	0	0	0	No Data
Utility	73	0	125	0	1	0	0	0	26	0	0	0	0	No Data
<b>ROADS PARALLEL TO AND WITHIN CORRIDOR (km)</b>														
Paved road	64	14	62	22	65	19	0	40	69	2	16	18	19	18
Improved gravel road	7	0	0	0	0	0	6	6	0	0	0	0	0	0
Trail or resource road	7	0	0	0	1	20	0	0	0	0	0	0	0	0

Table 4: Original Routes Comparison Table (July 2015)

ROUTE ALTERNATIVES STATISTICS SUMMARY													
PROJECT: Midgard Yukon Hydroelectric Connection													
DATE: 05 AUG 2016													
	Faro to Hoole Canyon	Hoole Canyon to Slate Rapids	Slate Rapids to False Canyon (West)	Slate Rapids to False Canyon (East)	False Canyon to Middle Canyon	Middle Canyon to Watson Lake	Hoole Canyon Connection	Slate Rapids Connection	False Canyon Connection	Middle Canyon Connection	Granite Canyon	Fraser Falls to Mayo	Two Mile Canyon to Fraser Falls
<b>CONSTRUCTION</b>													
Total centreline length (km)	94.6	56.8	81.5	102.7	20.4	58.0	1.8	9.2	7.4	6.2	14.6	48.2	64.5
Total corridor area (Ha)	4733	2840	4062	5133	1027	3072	79	454	162	294	734	2420	3212
Total # of deep valley / canyon crossings	1	2	0	1	0	1	0	1	1	0	0	3	3
Total # of major stream crossings	2	2	0	1	0	1	0	0	0	0	0	1	1
<b>LAND COVER (Ha) [Selected land classes were included in the Terms of References.]</b>													
Undifferentiated forest	0	0	0	0	0	0	0	0	0	0	0	0	0
Dense coniferous (>60% crown closure)	523	340	316	427	280	731	9	196	40	74	10	53	83
Coniferous - open canopy (26-60% crown closure)	1414	1624	2317	3475	649	1843	56	165	42	210	182	740	811
Coniferous - sparse (10-25% crown closure)	934	605	1114	192	7	40	9	47	0	7	119	552	513
Dense broadleaf (>60% crown closure)	66	0	1	1	0	0	0	0	3	0	0	15	14
Broadleaf - open canopy (26-60% crown closure)	1	0	6	14	0	0	0	0	0	0	0	0	3
Broadleaf - sparse (10-25% crown closure)	0	0	1	6	0	0	0	0	0	0	0	0	0
Mixedwood - open canopy (26-60% crown closure)	12	0	9	108	37	71	0	10	26	2	0	16	36
Mixedwood - sparse (10-25% crown closure)	2	0	0	0	0	0	0	0	0	0	0	0	0
Riparian zones (15 m around wetlands, streams, waterbodies)	99	33	148	148	23	60	1	18	5	7	7	42	90
Open water	85	20	30	22	3	8	1	7	0	0	4	13	64
Treed wetlands	0	0	10	13	7	26	0	0	0	0	1	6	0
Shrub wetlands	0	0	0	23	0	2	0	0	0	0	0	18	7
Herb wetlands	181	19	5	25	13	69	0	0	0	0	28	20	169
<b>SURFICIAL GEOLOGY AND PERMAFROST (Ha)</b>													
Anthropogenic/urban area	0	0	0	0	0	0	0	0	0	0	0	0	0
Aeolian	0	440	0	0	0	0	0	217	0	0	731	0	0
Colluvium	0	0	2	0	0	0	0	0	0	0	0	96	4
Fluvial	951	939	613	1259	578	451	30	141	139	39	3	301	361
Lacustrine	8	0	0	33	96	0	0	0	0	0	0	54	421
Moraine	3238	1014	2303	3854	353	2139	26	93	23	254	0	1573	83
Organic	490	447	1128	0	0	483	23	4	0	0	0	0	0
Exposed bedrock	45	0	11	0	0	0	0	0	0	0	0	0	0
Thin layer (veneer <1 m thick) with bedrock as second unit	0	0	0	0	0	0	0	0	0	0	0	396	2344
Sporadic discontinuous permafrost	0	0	0	1980	1026	3072	0	159	0	0	0	1	1
Extensive discontinuous permafrost	4733	2840	4062	3153	1	0	79	454	3	294	734	2419	3211
<b>SLOPE (Ha)</b>													
Area of corridor on slopes 0 - 15°	4587	2840	3927	5087	1026	3056	77	452	146	286	731	1966	2893
Area of corridor on slopes 15 - 30°	145	0	134	46	1	16	1	2	16	8	3	453	317
Area of corridor on slopes over 30°	1	0	1	0	0	0	0	0	0	0	0	1	2
<b>FIRST NATIONS SETTLEMENT LANDS and SETTLED LAND (Ha)</b>													
Category A First Nations land	0	673	24	1250	0	6	0	281	0	0	0	0	0
Category B First Nations land	662	112	566	253	462	811	96	112	7	661	1664	937	0
Uncategorized FN lands	1	0	0	0	0	41	0	0	0	0	0	0	0
Fee Simple First Nations land	0	0	0	0	0	0	0	0	0	0	0	0	0
First Nation Heritage Site	0	0	0	0	0	0	0	0	0	0	0	0	0
BC First Nations Site of Cultural Importance	0	0	0	0	0	0	0	0	0	0	0	0	0
BC First Nations Statement of Intent Boundaries	0	0	0	0	0	0	0	0	0	0	0	0	0
Interim Protected	662	785	590	1503	462	817	0	377	112	7	0	0	0
Urban land	942	0	0	0	0	599	0	0	0	0	0	0	0
<b>LAND USES (Ha)</b>													
Development Holds	0	0	0	0	0	0	0	0	0	0	0	0	0
Agricultural lands	0	0	0	0	0	0	0	0	0	0	0	0	0
Airport	0	0	0	0	0	0	0	0	0	0	0	0	0
Bridgehead	10	1	9	0	0	9	0	0	0	0	0	0	0
Environment	0	0	0	0	4	0	0	0	0	0	0	0	0
Forestry	2	0	0	0	4	345	0	0	0	0	0	0	0
Garbage dump	0	0	0	0	0	12	0	0	0	0	0	0	0
Gravel Pit	104	108	130	174	12	112	0	5	0	0	0	0	0
Heritage	1	0	0	0	0	0	0	0	0	0	0	0	0
Industrial / commercial	2	0	0	0	0	0	0	0	0	0	0	0	0
Marine	1	0	0	0	0	0	0	0	0	0	0	0	0
Navigation aid	0	0	0	0	0	0	0	0	0	0	0	0	0
Parks, Campground, or Recreational	1	49	7	1145	0	2	0	0	0	0	0	25	0
Quarry	0	0	4	0	0	6	0	0	0	0	0	0	0
Rural residence	0	0	0	0	0	0	0	0	0	0	0	0	0
Trapping	0	0	0	0	0	0	0	0	0	0	0	0	0
Utility	296	0	0	0	0	0	0	0	0	0	118	0	5
<b>ROADS PARALLEL TO AND WITHIN CORRIDOR (km)</b>													
Paved road	15	0	0	4	0	38	0	0	0	0	1	1	0
Improved gravel road	72	42	80	88	20	12	0	0	0	0	0	0	0
Trail or resource road	3	0	0	0	0	3	0	0	0	0	0	2	0

### 3.1 Aishihik to Destruction Bay

The Aishihik to Destruction Bay corridor is 157 km long. The corridor follows the Alaska Highway (Highway #1) between Destruction Bay and Canyon where it deflects north to the Aishihik Generating Station. In its western portion, the corridor is located adjacent to Kluane Lake between Destruction Bay and Silver City, except for a 15 km segment where it follows the Slims River Valley upstream to a

suggested crossing of the Slims River. On the west side of Kluane Lake the corridor parallels an old pipeline right-of-way that appears to be abandoned.

The dominant terrain unit within the Aishihik to Destruction Bay corridor is classified as morainal. The next dominant unit is classified as fluvial terrain and mainly occurs where the corridor crosses creeks and alluvial fans on the west and east sides of Kluane Lake. There are also minor amounts of organic terrain located within this corridor. In total the corridor crosses 30 hectares of organic terrain. Organic terrain is considered poor for routing a transmission line due to the likelihood of a high water table and compressive soils. Slopes along this route are generally quite gentle. Extensive areas of lacustrine terrain occur locally south of Kloo Lake, near Haines Junction and adjacent to the Aishihik and Desadeash rivers in the eastern portion of the corridor. There are only a few instances of slopes being steeper than 15°. These areas primarily occur near the mouth of the Slims River, where the low flat fluvial landscape narrows and bedrock slopes form a pinch point. In this area there is very little exposed bedrock as the lower bedrock slopes are covered by colluvium. This corridor crosses 1,164 hectares of extensive discontinuous permafrost.

The crossing of the Slims River is one of the most significant constraints along this corridor. The Slims River is a large river that discharges into Kluane Lake. Locating the transmission line adjacent to the Alaska Highway across the floodplain is not considered a good option because of susceptibility to flooding and scour, poor foundations and aesthetic impacts along the scenic Alaska Highway. As a result, the corridor has been located farther up the valley where two side-valley alluvial fans will provide the crossing with the shortest span. These fans are well treed and appear to be relatively stable. This crossing span may be up to 500 m depending on final structure locations. Other major constraints on this route may be the land uses located adjacent to and offset from the Alaska Highway on the west side of Kluane Lake. Steep slopes and evidence of debris flows and rock avalanches in this area also require further evaluation. Several gravel pits, campgrounds, and other land uses were identified along the corridor as well, in addition to two (2) airstrips. The corridor has been routed so that it should be possible to maintain adequate clearance from the runways.

### **3.2 Whitehorse to Carcross Cutoff**

The Whitehorse to Carcross Cutoff corridor is 17 km long and mainly located in the City of Whitehorse. The corridor width was reduced to 150 m in the urban area due to the constricted nature of development in this area. The Whitehorse corridor originates at the Whitehorse Dam and the primary corridor option follows the Alaska/Klondike highways (Highway #1/2) south of the city to the junction of the Alaska and Klondike highways.

The main surficial material within this corridor is fluvial sediment, followed by anthropogenic features because much of this route goes through urban areas. The slopes on this route are all below 15° owing to dominance the gently sloping fluvial terrain.

There are many rural residences listed along this route that would have to be considered in selection of a final route centreline. These residences are primarily located immediately adjacent to roadways.

Transmission line development could be located either directly next to the road or farther from the road behind these residences.

An alternative corridor that might be considered to avoid the built up urban area is a 500 m corridor that crosses the Alaska/Klondike Highway 4.7 km south of the Whitehorse Dam and passes south of the developed areas. This corridor could terminate either south or east of Carcross Crossing depending on where it extends to. The terrain along this corridor is quite flat and appears to be free of development.

### **3.3 Carcross Cutoff to Jakes Corner**

The Carcross Cutoff to Jakes Corner corridor is 62 km long and originates in Carcross Cutoff. It follows the Alaska Highway eastwards towards Jakes Corner. The corridor crosses the Yukon River at a location that would require an approximately 250 m span. It then parallels Marsh Lake before turning towards Jakes Corner.

The dominant terrain unit within the Carcross Cutoff to Jakes Corner corridor is fluvial terrain. The next most dominant terrain type is moraine followed by bedrock. The corridor follows the base of several mountains. These locations are characterized by more frequent bedrock exposures and steeper slopes. Throughout most of the corridor the slopes are below 15° but in some isolated areas the slopes exceed 15°.

There are many developments and land uses along the Alaska Highway including gravel pits, industrial developments, and utilities.

### **3.4 Jakes Corner to Teslin**

The Jakes Corner to Teslin corridor is 95 km in length. It begins at Jakes Corner and follows the Alaska Highway northeast to Johnsons Crossing where it turns southeast to Teslin. The corridor crosses the Teslin River at a location that will require a span of approximately 400 m. The corridor passes through the communities of Johnsons Crossing, Brooks Brook, and Teslin Lake in addition to the communities that are located at its two end points.

The terrain along this corridor is relatively flat with most of the slopes below 15°. The dominant terrain unit is morainal and the next most common unit is fluvial terrain. There are several land uses in the corridor with the most prevalent being gravel pits located along the highways. There are two airstrips along the corridor. The corridor has been routed to allow for a centreline selection that provides adequate clearance from the runways. Even so, the separation distance at the Teslin airstrip will need to be confirmed given the location of the transmission line termination point and the orientation of the airstrip.

As an alternative to crossing the Teslin River at Johnsons Landing, JDMA has identified a second corridor option that is slightly shorter in length and has a shorter span across the river. The terrain and material types appear to be similar to the Johnsons Landing crossing location but the route alignment does require the corridor to depart from the highway adjacent location for a distance of approximately 1.5 km.

### 3.5 Jakes Corner to Atlin (YK, BC)

The Jakes Corner to Atlin corridor is 92 km long and connects Jakes Corner to Atlin, BC. Jakes Corner is north of Atlin and the corridor is mainly oriented north-south. The corridor follows Highway #7 and is adjacent to Little Atlin Lake and Atlin Lake. Approximately 42 km of the corridor is located in the Yukon with the remaining 50 km located in BC.

The main terrain unit in the corridor is fluvial terrain followed by lacustrine terrain. The lacustrine units primarily occur adjacent to Atlin Lake where the road and corridor are located next to the lake. In this area, several mountain slopes constrain the corridor to a zone between Atlin Lake and the steep mountain slopes. In addition to fluvial and lacustrine terrain some exposed bedrock and organic terrain are mapped within the corridor.

No major land uses are affected by this corridor; however, there are several gravel pits within the corridor. The British Columbia portion of the corridor lacks the same amount/type of land use data that are available for the Yukon. As a result, there is no land use land data available for the BC segment of the corridor.

### 3.6 Carcross Cutoff to Skagway (YK, BC, AK)

The Carcross Cutoff to Skagway corridor is 154 km long and extends across parts of Yukon, British Columbia, and Alaska. The Yukon section is 77 km, the British Columbia section is 56 km, and Alaska section is 21 km. The corridor runs mostly north-south from Carcross Crossing in the Yukon to Skagway on the Taiya Inlet, in Alaska. The corridor passes by several communities as it parallels the Klondike Highway all the way to Skagway. The corridor passes by and follows adjacent to Nares Lake, Tutshi Lake, Shallow Lake, Bernard Lake, and Summit Lake.

The main terrain unit in the corridor is bedrock. The second most common unit is moraine. This corridor has the steepest slopes of any of the corridors. Lacustrine terrain occurs locally south of Cowley Lake and in several short segments north of Carcross. There are many stretches of corridor where the slopes are greater than 15° reaching greater than 30° in some locations. Many of these steep slopes are bedrock terrain with varying thicknesses of colluvium depending on slope steepness and the proximity of the corridor to the base of the slope. In these areas the corridor was narrowed to only include the lower parts of the slopes. In many parts of this corridor the transmission line will need to be placed on the mountain side of the road because there is inadequate space on the lakeward side. In some locations the road is cut into the side of the mountain with a near vertical blasted or cut face adjacent to the road. In these cases it will be necessary to locate the transmission line higher on the slope, above the steep blasted or cut face. This situation will make construction and maintenance more challenging and costly.

Land uses within this corridor include many rural residences, gravel pits, parks and campgrounds. The British Columbia and Alaska portions of the corridor lack the same amount/type of land use data that are available for the Yukon. As a result, there is no land use land data available for the BC and Alaska segments of the corridor.

### 3.7 Faro to Watson Lake

The Faro to Watson Lake corridor is 414.1 km long, following the Robert Campbell Highway (Highway #4) corridor between the communities of Faro and Watson Lake. At the north end this corridor parallels the Pelly River for a distance of approximately 56 km between the communities of Faro and Ross River. In many places, the Faro to Ross River transmission line is also located within or near the corridor proposed for the Faro-Watson Lake transmission line. At the southern end the proposed corridor crosses several larger rivers including the Frances and Liard rivers.

The dominant terrain unit along the Faro to Watson lake corridor is classified as moraine (12,901 Ha). The next dominant unit is classified as fluvial (4,791 Ha). The fluvial unit is encountered where the corridor is located near several river channels located in the Faro-Watson Lake study area. Morainal and fluvial terrains are generally favourable for transmission line construction. Less favourable is organic terrain which covers approximately 2,547 Ha of the corridor. Organic terrain is generally less favourable for transmission line construction and maintenance due to higher water table, compressive soils, and a greater likelihood of permafrost-affected soils. Slopes along this route are generally quite low with only a few scattered instances of slopes being steeper than 15°.

Other possible constraints within the corridor are the land uses adjacent to and offset from the Robert Campbell Highway. These include a large number of gravel pits, some campgrounds, and other land uses that appear in available GIS datasets. In addition, there are two stream crossings that are approximately 250 m wide. There are also at least five, and possibly six, airports near the corridor. Even so, the corridor has been routed so that adequate clearance has been maintained from these airports.

Apart from a few short exceptions, the Robert Campbell Highway is located within the Faro to Watson Lake transmission line corridor making it possible to locate the transmission line near the highway in most locations. Near Faro, the corridor also encompasses an existing distribution line that links the communities of Faro and Ross River. The corridor is situated so that potential centrelines can take advantage of either being adjacent to the highway or parallel to the existing distribution line. It appears as though there is a wide right-of-way for the distribution line and existing access trails from the Robert Campbell Highway to the transmission line right-of-way. Near Watson Lake, the corridor goes south around Watson Lake before terminating at its end location within the community of Watson Lake. Going north around the lake decreases the overall length of the route but would result in the transmission line being in close proximity to the Watson Lake airport and passing through an area with more existing infrastructure.

### 3.8 Two Mile Canyon and Fraser Falls

The Two Mile Canyon and Fraser Falls corridors both originate at the Mayo substation near the community of Mayo. From the substation a common corridor extends east to the Fraser Falls site. From there the remainder of the Two Mile Canyon corridor continues for an additional 65 km to the Two Mile Canyon site. Both corridors are located mainly north of the Stewart River. Two possible alternative sections have been identified south of the river; one is located from the Mayo substation to the Fraser Falls site. A second southern alternative section approaches the Two Mile Canyon site from a river crossing about 25 km to the west.

The termination point suggested by MC for the Fraser Falls site is located on the west side of Stewart River at the proposed Fraser Falls hydroelectric site. However, the proposed transmission line corridor approaches the site from the east side of the river. With this layout the transmission line would have to cross the river at this site. This would not be a problem because the proposed hydroelectric station is located at a narrowing of the river and the proposed corridor represents a preferred location to cross the Stewart River. Cross the Stewart River at other locations would involve span lengths of >300 m from bank to bank plus crossing a wide floodplain that is subject to flooding and possible permafrost conditions.

Farther east, the Two Mile Canyon corridor crosses the river near the Two Mile Canyon site where the river channel is approximately 225 m wide. In the event that the Fraser Falls hydroelectric project is built, a span of approximately 725 m would be required to cross the reservoir at this location.

The main terrain type crossed by the Fraser Falls and Two Mile Canyon corridors is moraine on the lower valley slopes and upland adjacent to the Stewart River floodplain. In some upland areas the morainal sediment (till) may form a relatively thin and discontinuous cover over the underlying bedrock. Toward the east end of the Two Mile Canyon corridor the corridor crosses fluvial and lacustrine terrain on lower-lying terraces adjacent to the Stewart River floodplain. Although these terrain types may be more susceptible to a higher water table and permafrost-affected conditions, they cannot be avoided when crossing the Stewart River to reach the Two-Mile Canyon site. For this reason, a possible alternative crossing has been identified approximately 25 km west where the terrain is more favourable. However, this alternative would also require a span of approximately 725 m across the Fraser Falls reservoir with access from a narrow peninsula that may be subject to bank erosion. (Assuming both the Fraser Falls and Two-Mile Canyon projects are built.)

Except for the area immediately around Mayo, there is no infrastructure development in the Two Mile Canyon / Fraser Falls area. As such the major constraints on these routes are terrain related. There are a high number of steep slopes in this area (i.e., > 15°) and there are areas prone to ground ice in permafrost making construction, operation and maintenance challenging.

### 3.9 Granite Canyon

The Granite Canyon corridor is 14.6 km in length. Its west endpoint appears to be a tap from an existing transmission line that parallels the Klondike Highway (Highway #2). The east endpoint is a potential hydroelectric site on the Pelly River.

The terrain along this corridor is a low relief aeolian plain. The only other terrain unit identified in the area is a small area classified as fluvial terrain located adjacent to the Pelly River. Almost the entire length of this corridor is located on Category B (surface rights) First Nations Settlement land belonging to the Selkirk First Nations. The other designated land in the study area is a Land Disposition classified as *utility* at the eastern end of the corridor. This designation may be related to the hydroelectric potential at this site. Should a transmission line be built here it will require crossing over the Klondike Highway in order to tap the transmission line which is located on the west side of the highway.

### 3.10 Slate Rapids

The Slate Rapids corridor is 9.2 km long and extends from the Slate Rapids site on the Ross River to the proposed Faro to Watson Lake corridor. The Slate Rapids corridor deflects around a large low-lying area classified as organic terrain and follows a low ridge adjacent to the Ross River. Big Campbell Creek enters the Ross River near the south end of the corridor where an alluvial fan has formed. Therefore, the tap location has been located east of the fan.

The majority of the corridor is located on First Nations Category A and Category B land belonging to the Ross River Dena Council. There are no other designated land uses within the Slate Rapids study area.

### 3.11 False Canyon

The False Canyon corridor is 7.4 km long and extends from the Faro to Watson Lake corridor to the False Canyon site on the Frances River. Almost the entire length of this corridor is 200 m wide being confined to the lower slope between the Frances River to the east and the adjacent steeper slope and more rugged upland to the west. The corridor widens to 500 m near the tap location in the Faro to Watson Lake corridor.

A gravel pit is located near the tap location. However, most of the gravel pit is outside the corridor leaving sufficient room within the corridor to avoid crossing the gravel pit.

The tap point in the Faro to Watson Lake corridor is located on First Nations Category B land belonging to the Liard First Nation.

### 3.12 Middle Canyon

The Middle Canyon corridor is 6.2 km long from a potential hydroelectric site on the Frances River to the tap location in the Faro to Watson Lake corridor. The dominant terrain in the corridor is moraine and the slopes within corridor are gentle. The corridor is 500 m-wide over its entire length and there are no designated land uses in this area including no First Nations Settlement lands.

### 3.13 Hoole Canyon

The Hoole Canyon corridor is 1.7km long and connects the potential hydroelectric site on the Ross River to the tap location in the Faro to Watson Lake corridor. The primary terrain within the corridor is moraine, but also includes small amounts of fluvial and organic terrain. The majority of this corridor is on slopes that are less than 5°. There are no land uses or First Nations Settlement lands within the corridor.

## 4 Summary

JDMA has identified transmission line corridors for fourteen (14) potential routes identified by Midgard Consultants. A high level desktop study was carried out using readily available satellite imagery and GIS data sources. No detailed analysis was done using air photos and no ground-truthing or other field work has been carried out. While attempts have been made to identify major routing constraints, the possibility remains that site specific land use or terrain issues may exist that are not detectable with the

data resolution used in this study. Therefore, JDMA recommends more detailed analysis should be completed for each of these corridors including detailed air photo analysis, acquisition of high resolution satellite imagery and LiDAR data and field reconnaissance should further development of these corridors be considered.

Having said that, the corridors identified here are believed to represent viable routing options and the data presented provides a reasonable basis for a high level evaluation of the feasibility of constructing and maintaining a transmission line to each of the potential hydroelectric sites that have been included in this study.

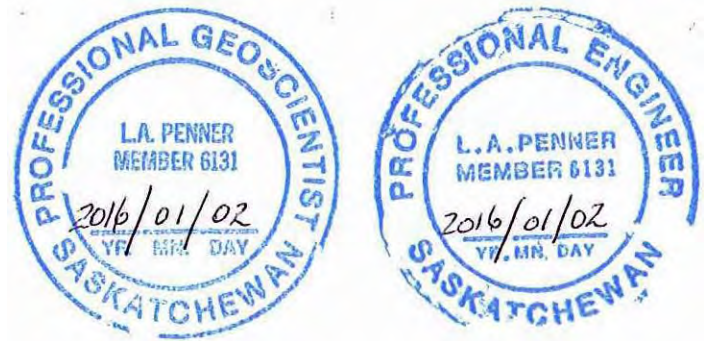
## 5 Deliverables

The following products accompany this final report:

- 1) Route comparison spreadsheet in Excel format
- 2) Fourteen (14) corridor shapefiles – 1 for each corridor

These GIS products were created in ESRI ArcMap V.10.4

## 6 Signatures



Handwritten signature of Shayne MacDonald.

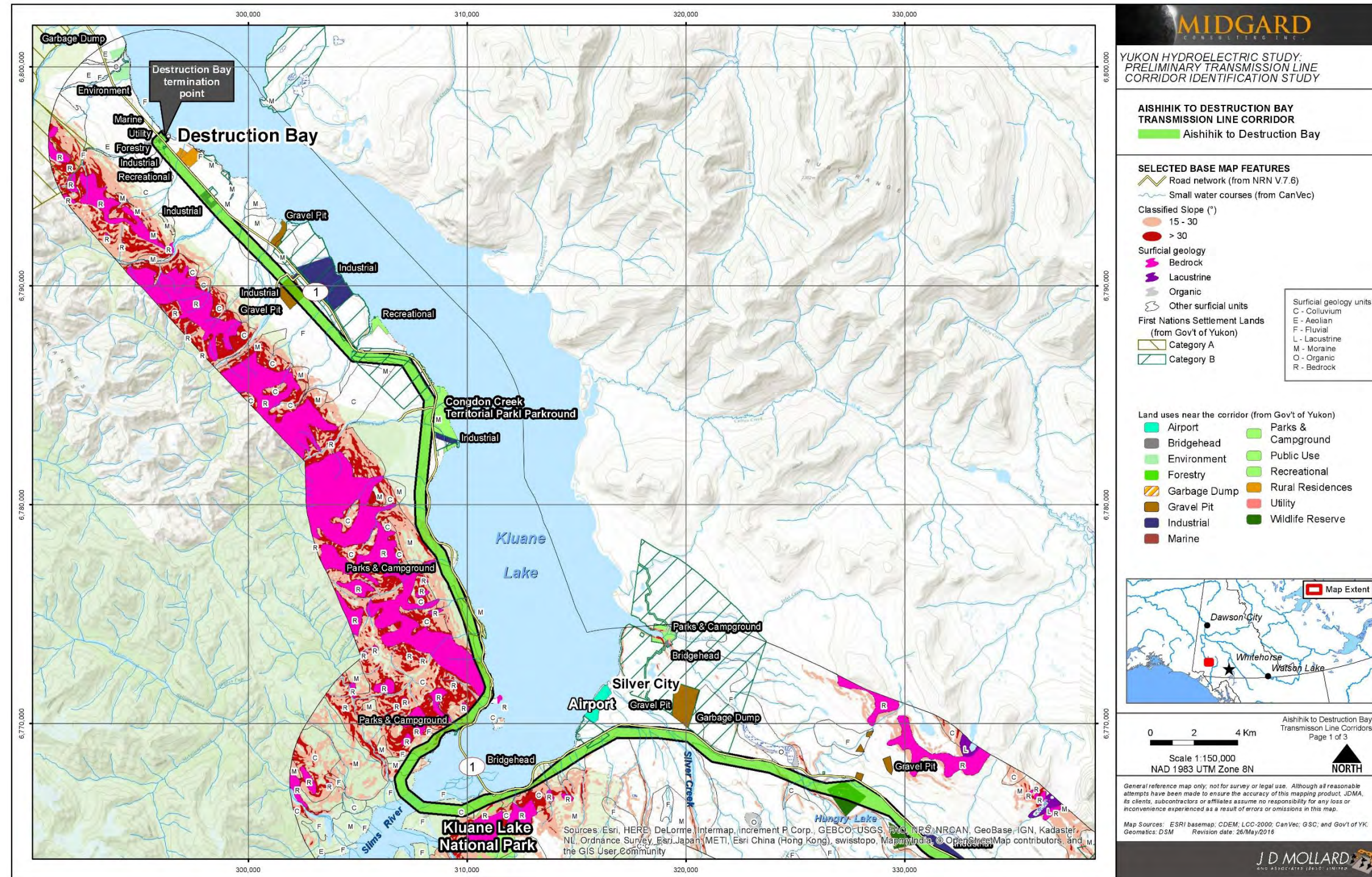
Shayne MacDonald, B.Sc.

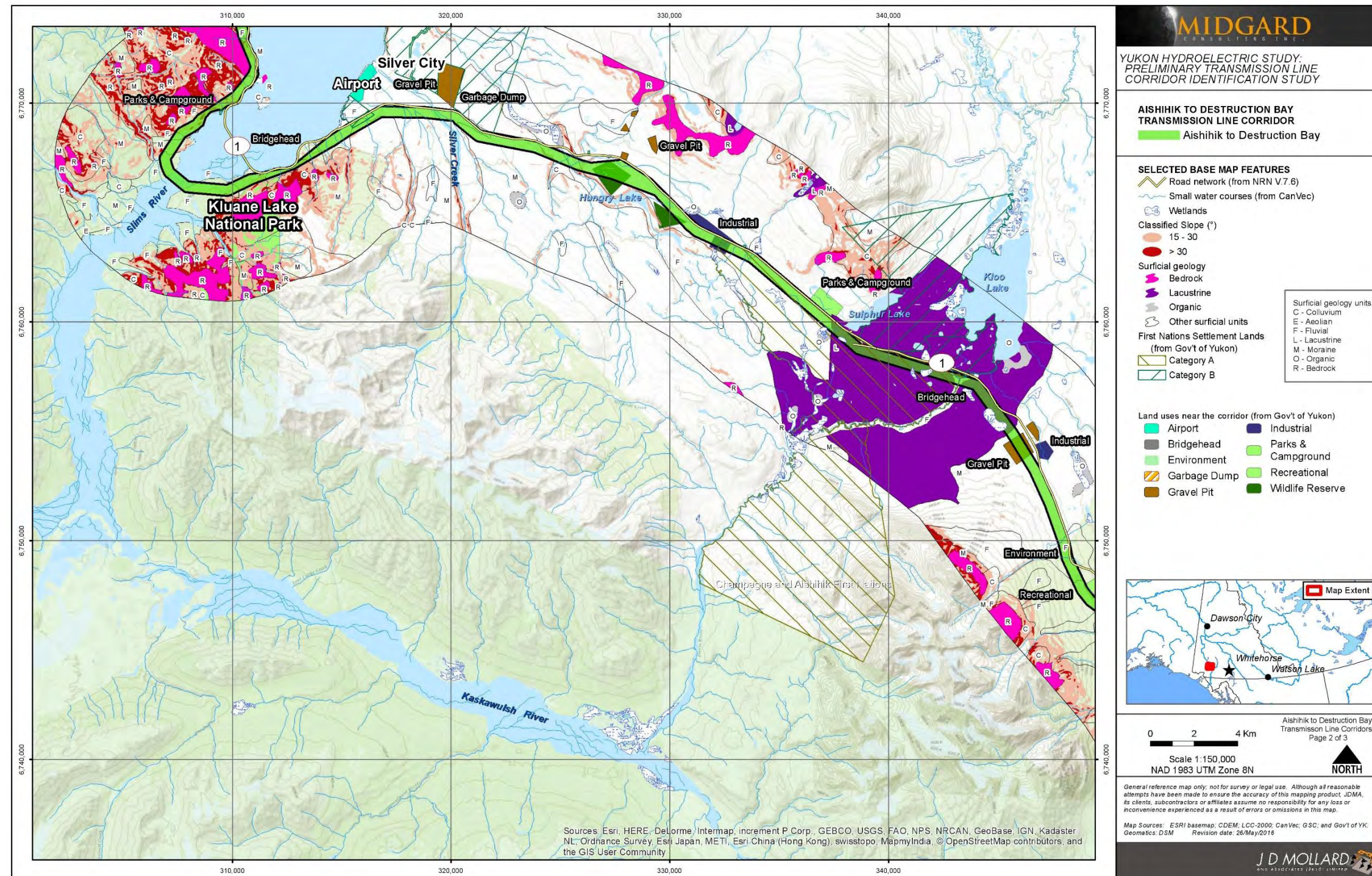
Handwritten signature of Lynden Penner.

Lynden Penner, M.Sc., P.Eng., P.Geo.

## 7 APPENDIX A: CORRIDOR MAPS

Figure A1: Ashihik to Destruction Bay map booklet





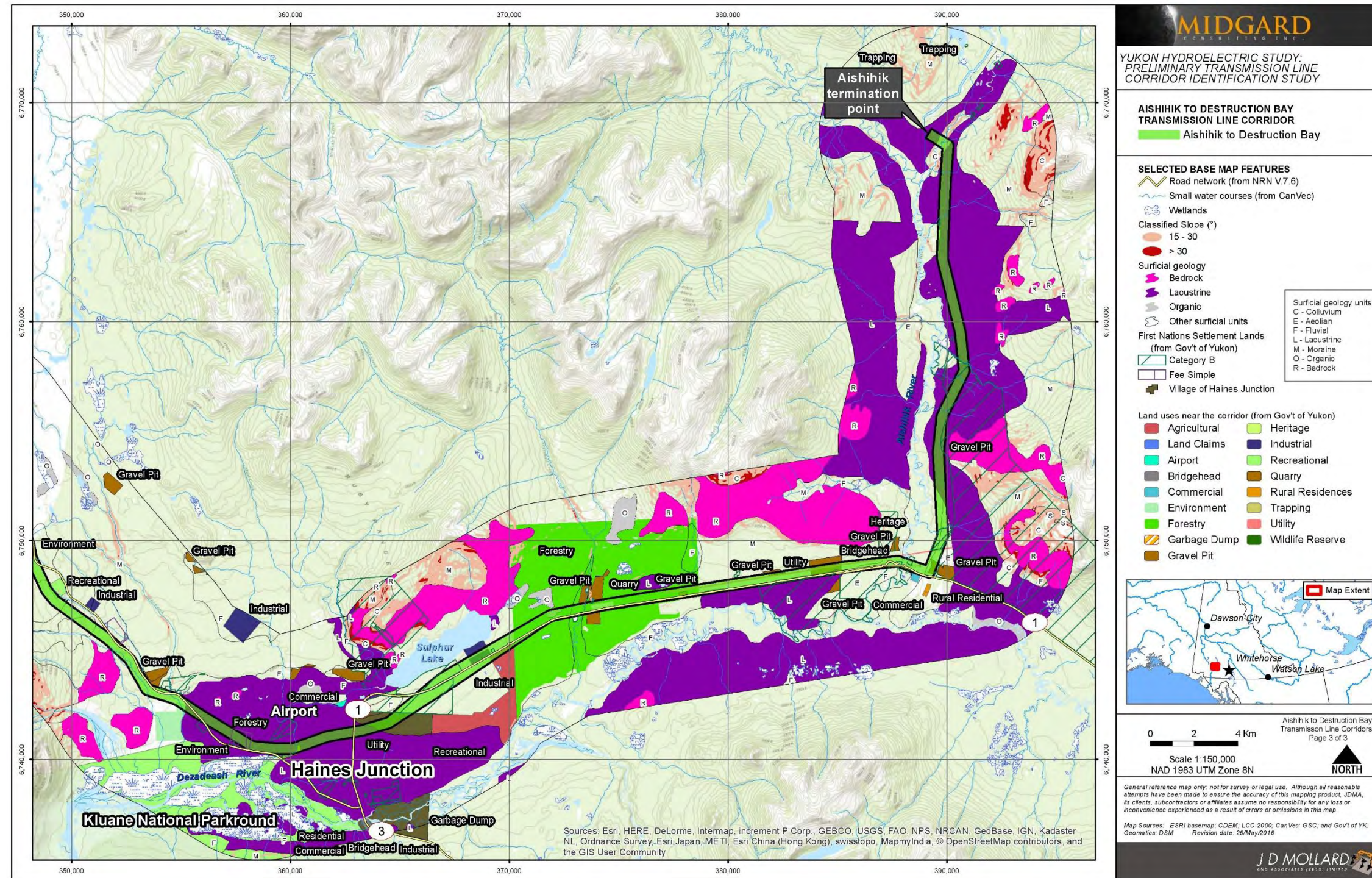


Figure A2: Whitehorse to Carcross Cutoff map

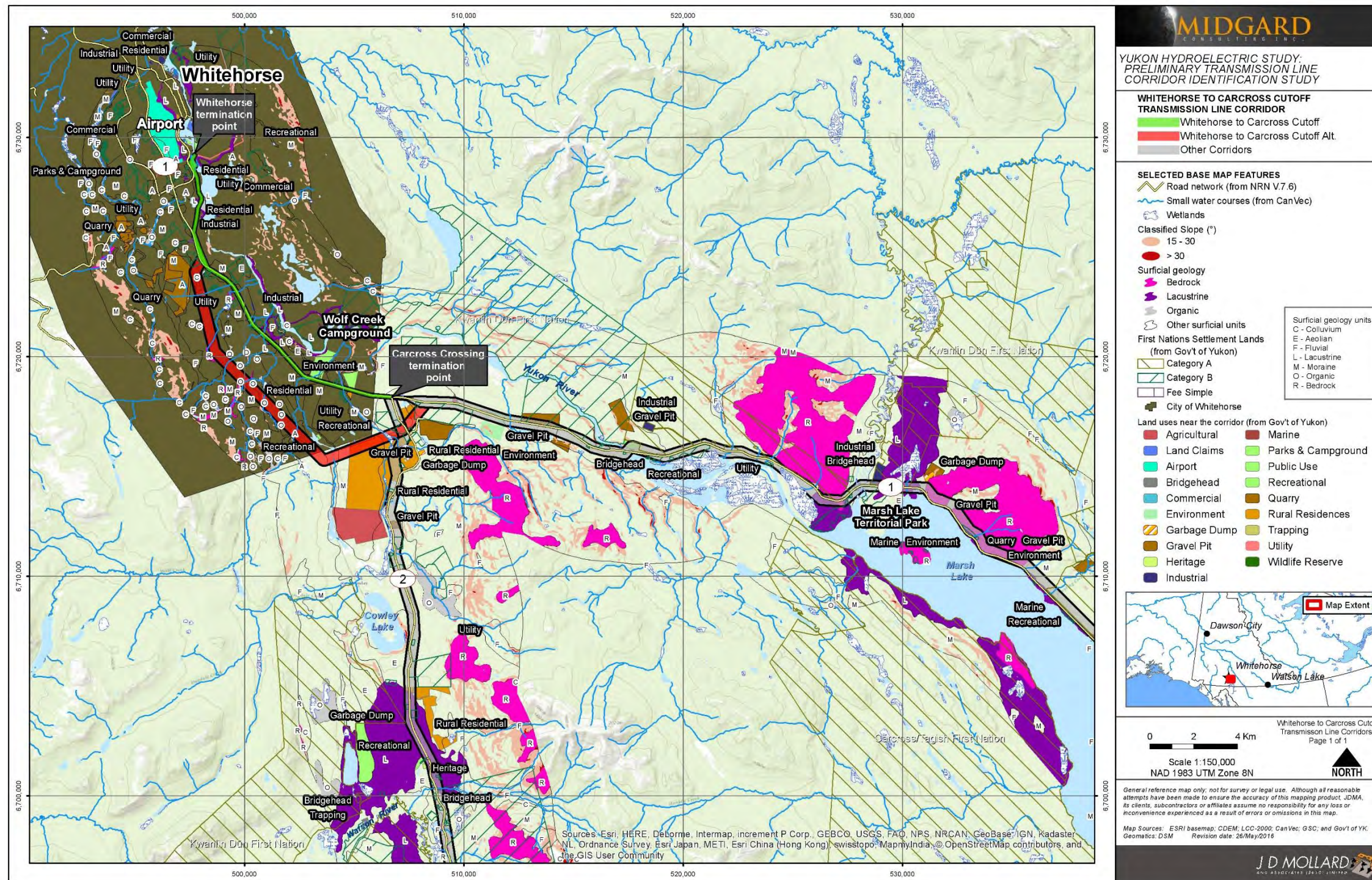
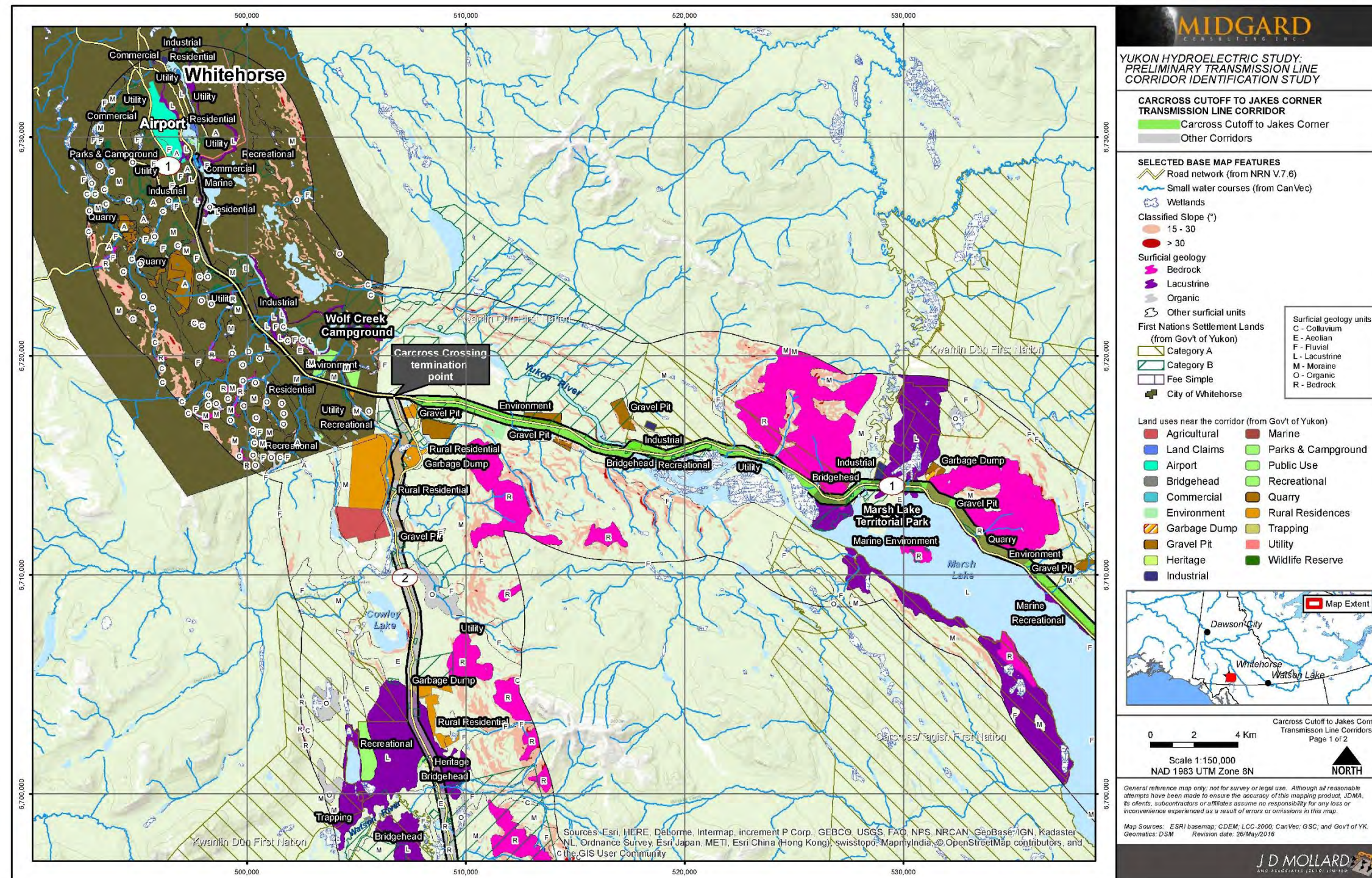


Figure A3: Carcross Cutoff to Jakes Corner map booklet



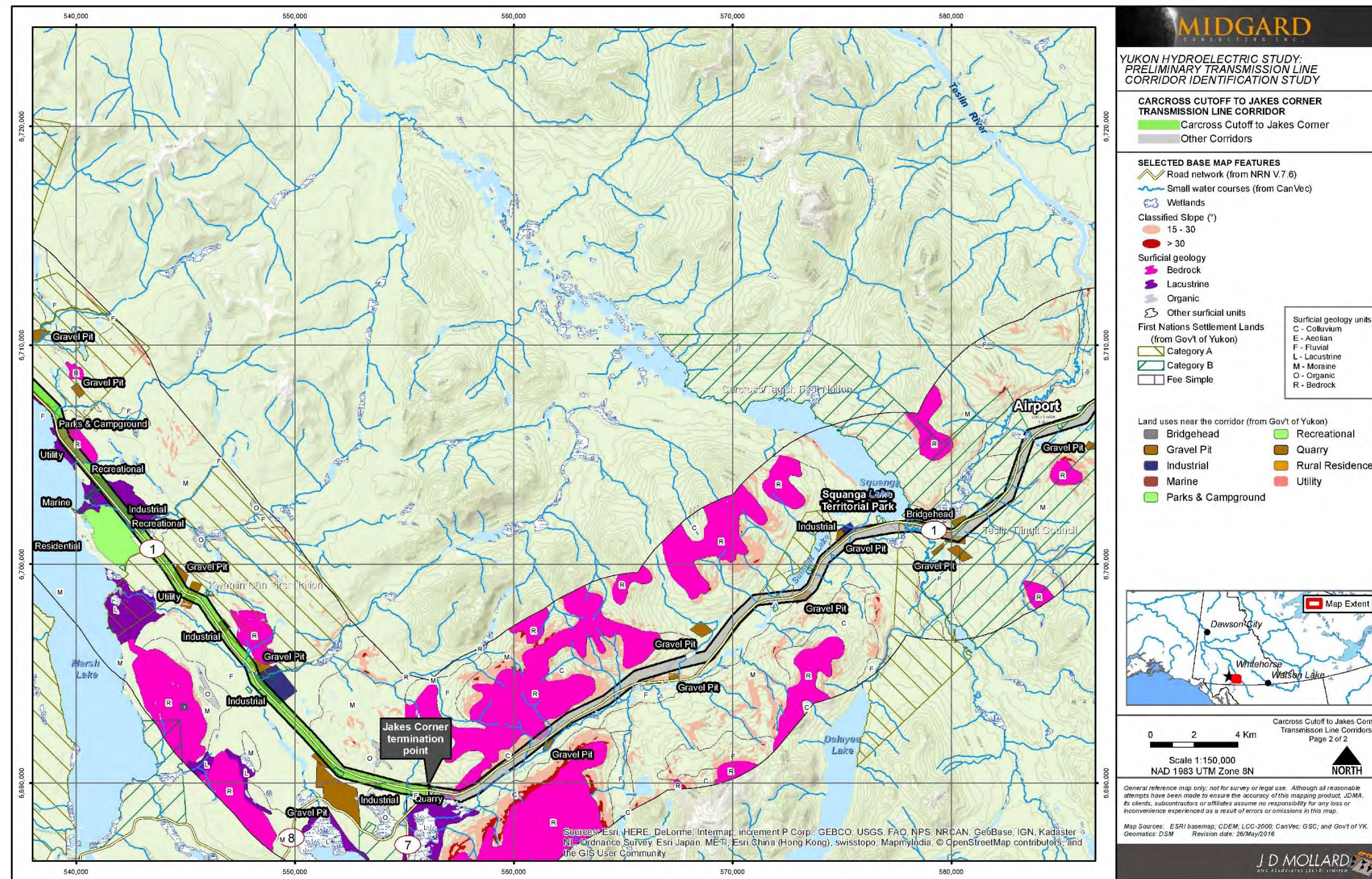
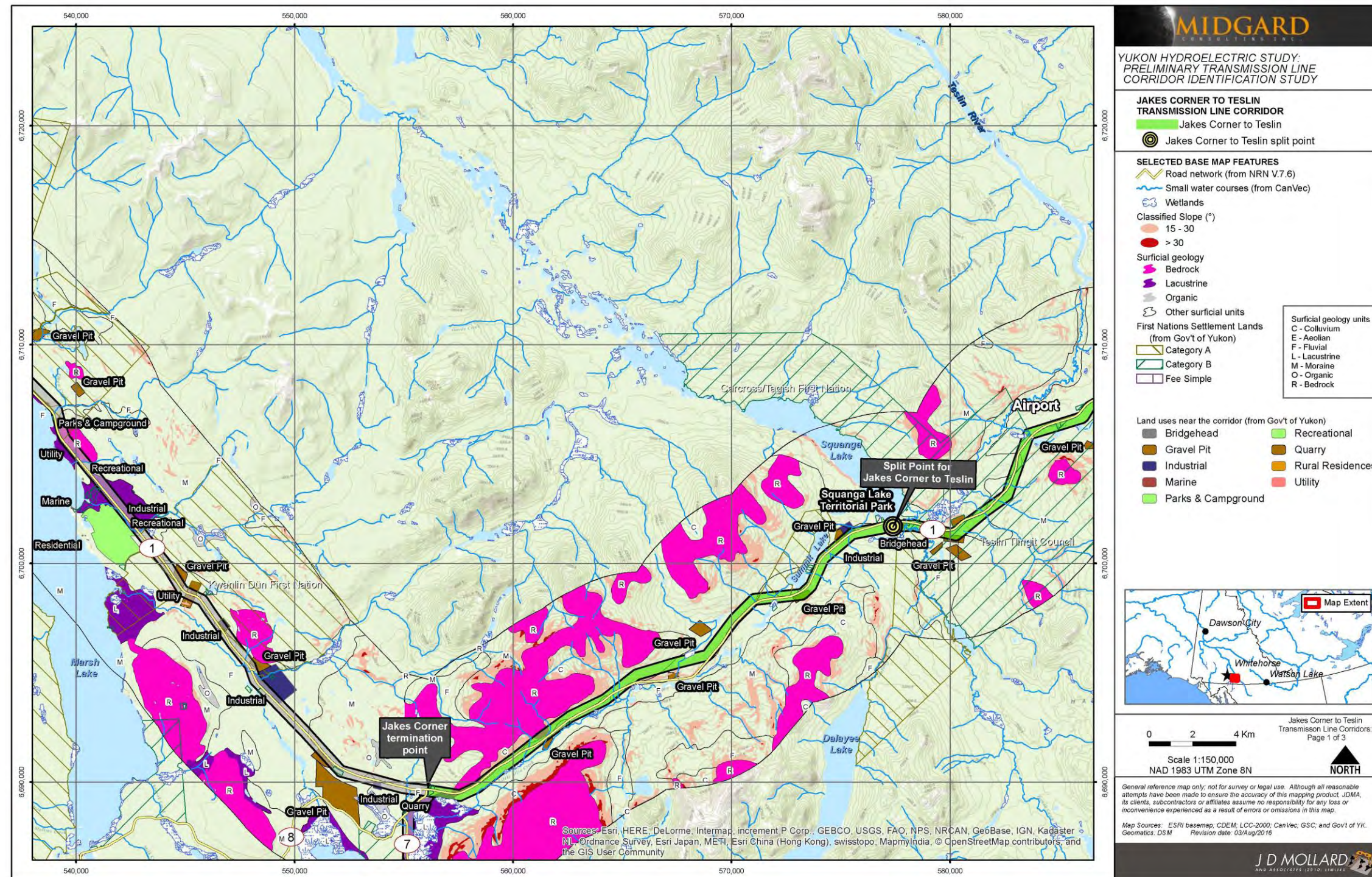
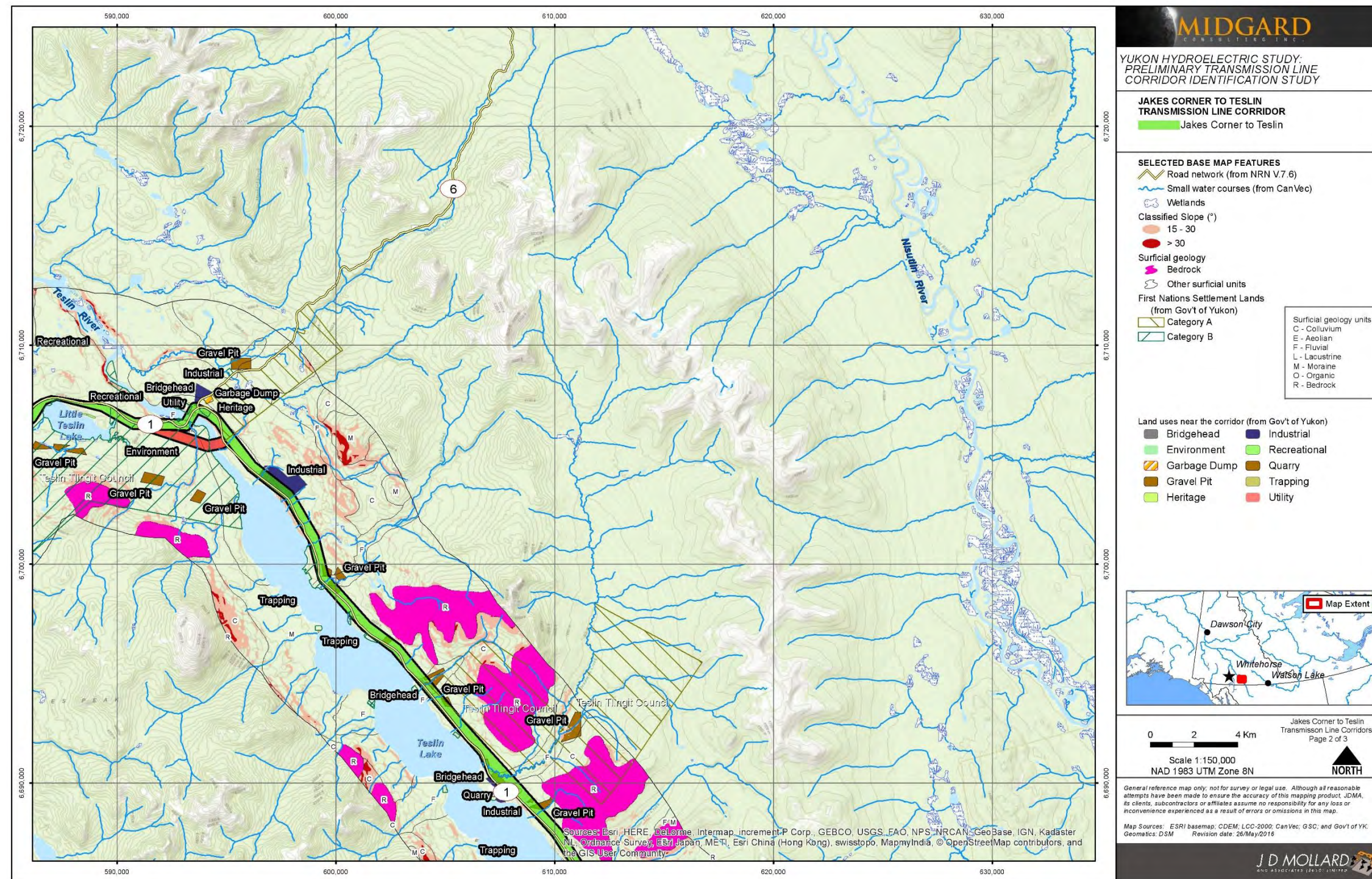


Figure A4: Jakes Corner to Teslin map booklet





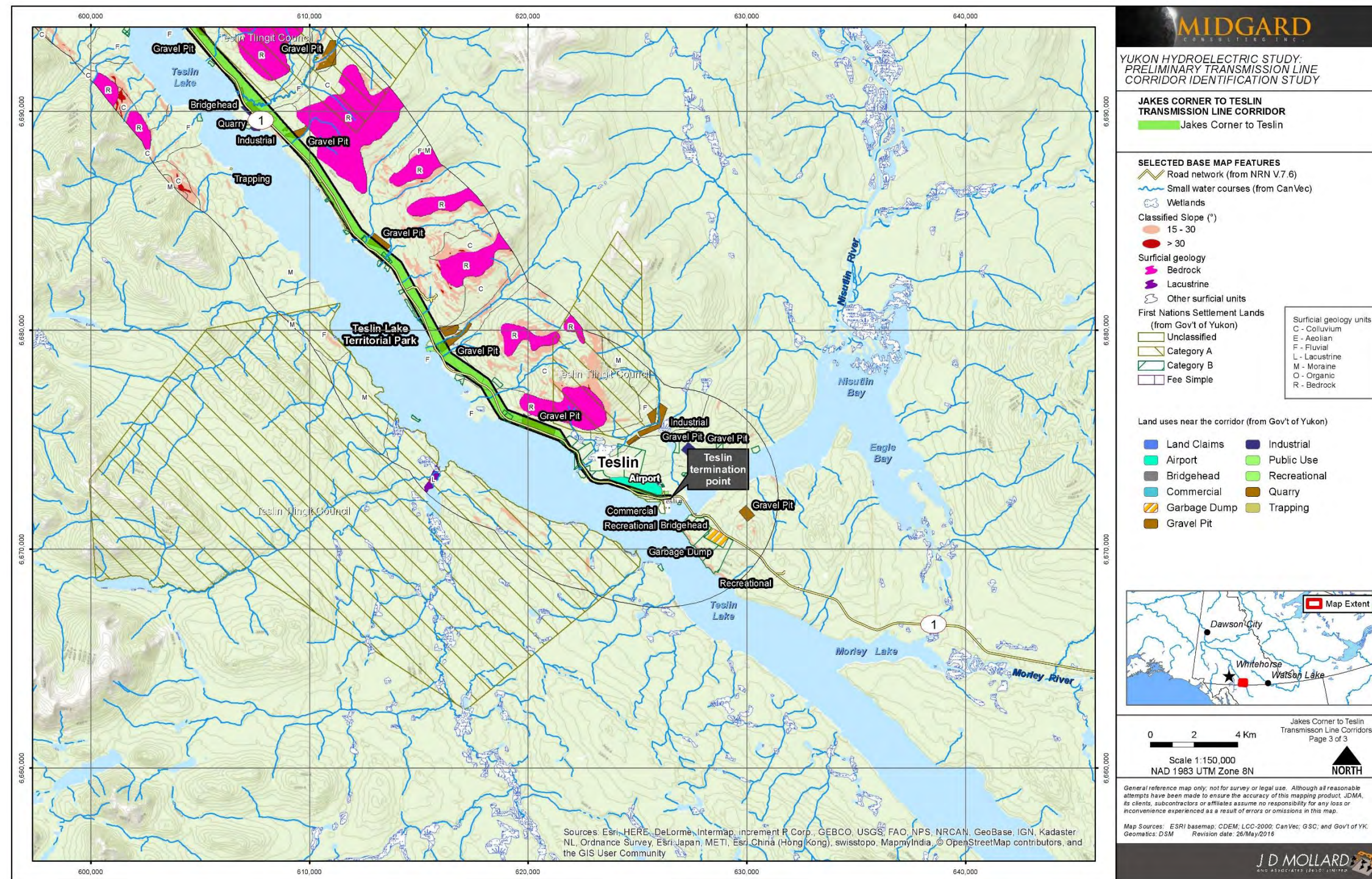
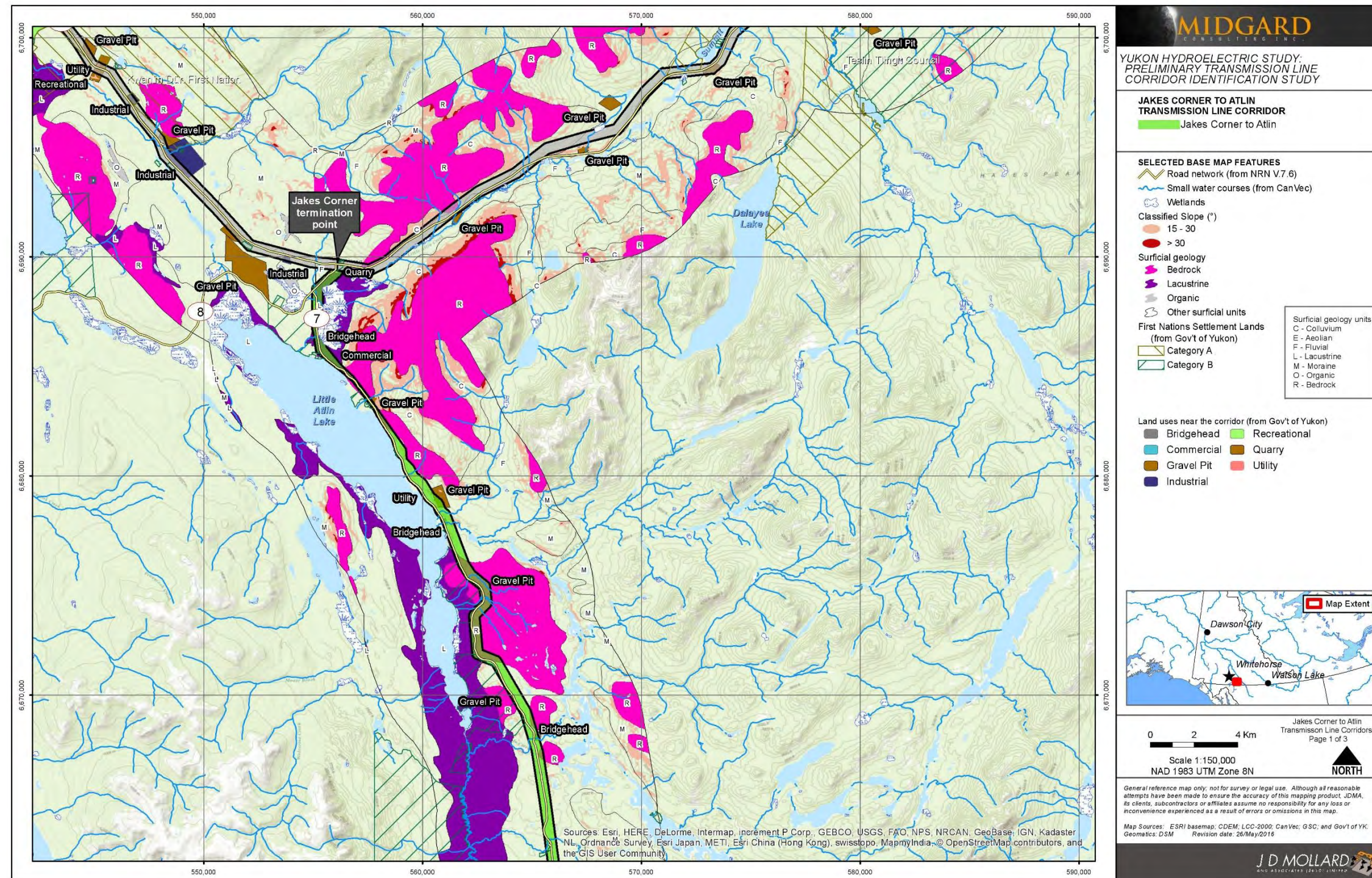
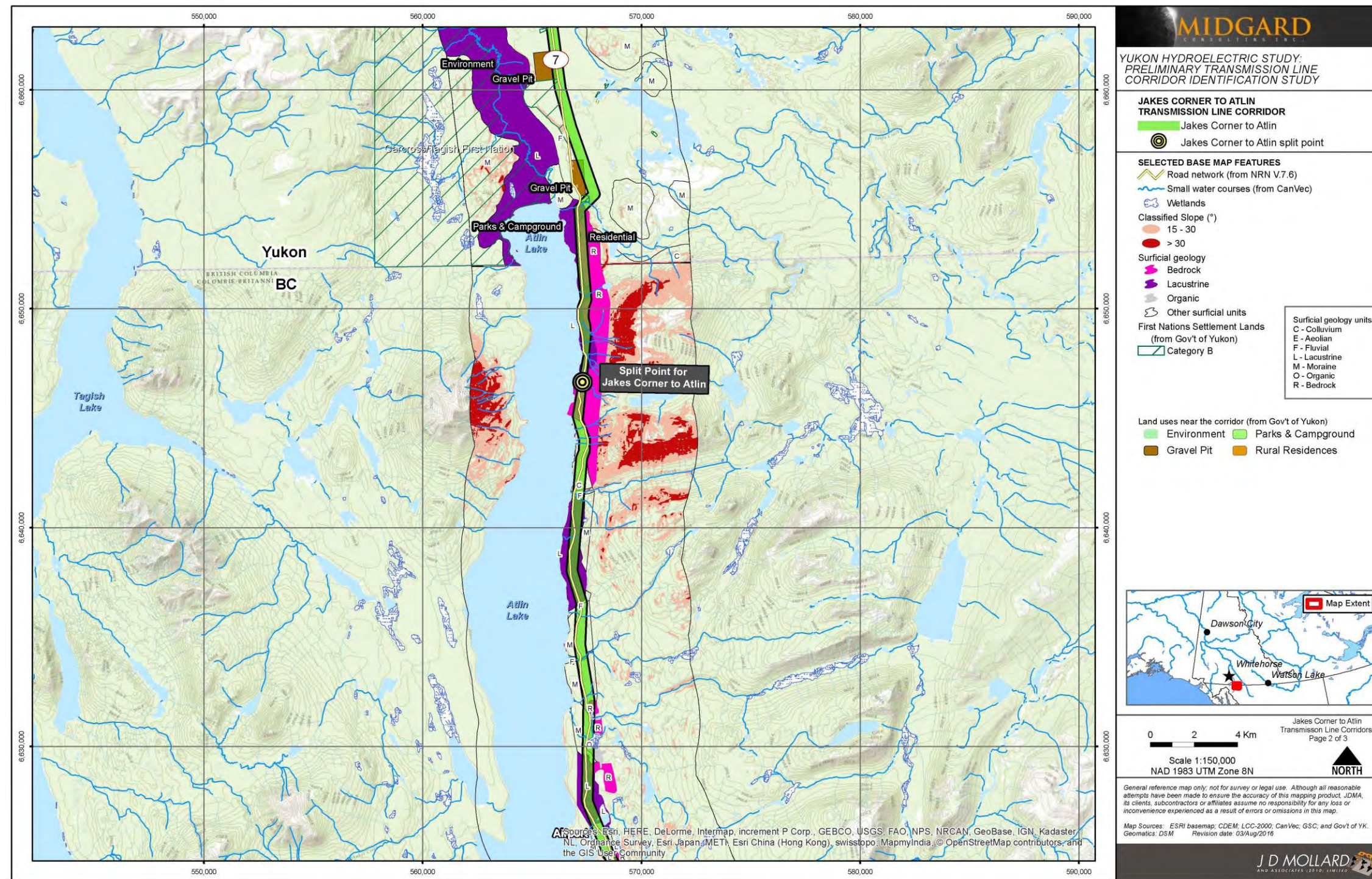


Figure A5: Jakes Corner to Atlin map booklet





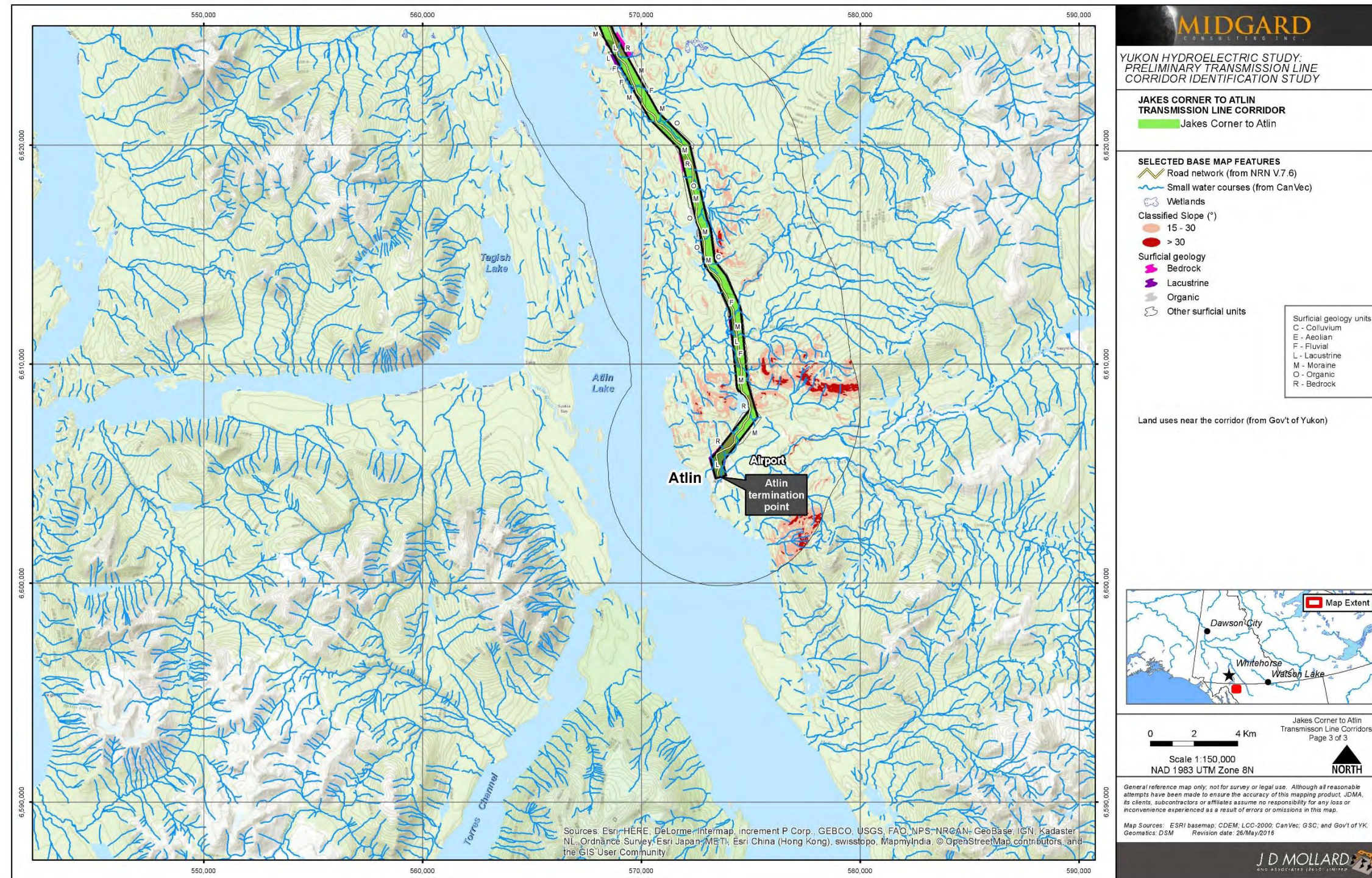
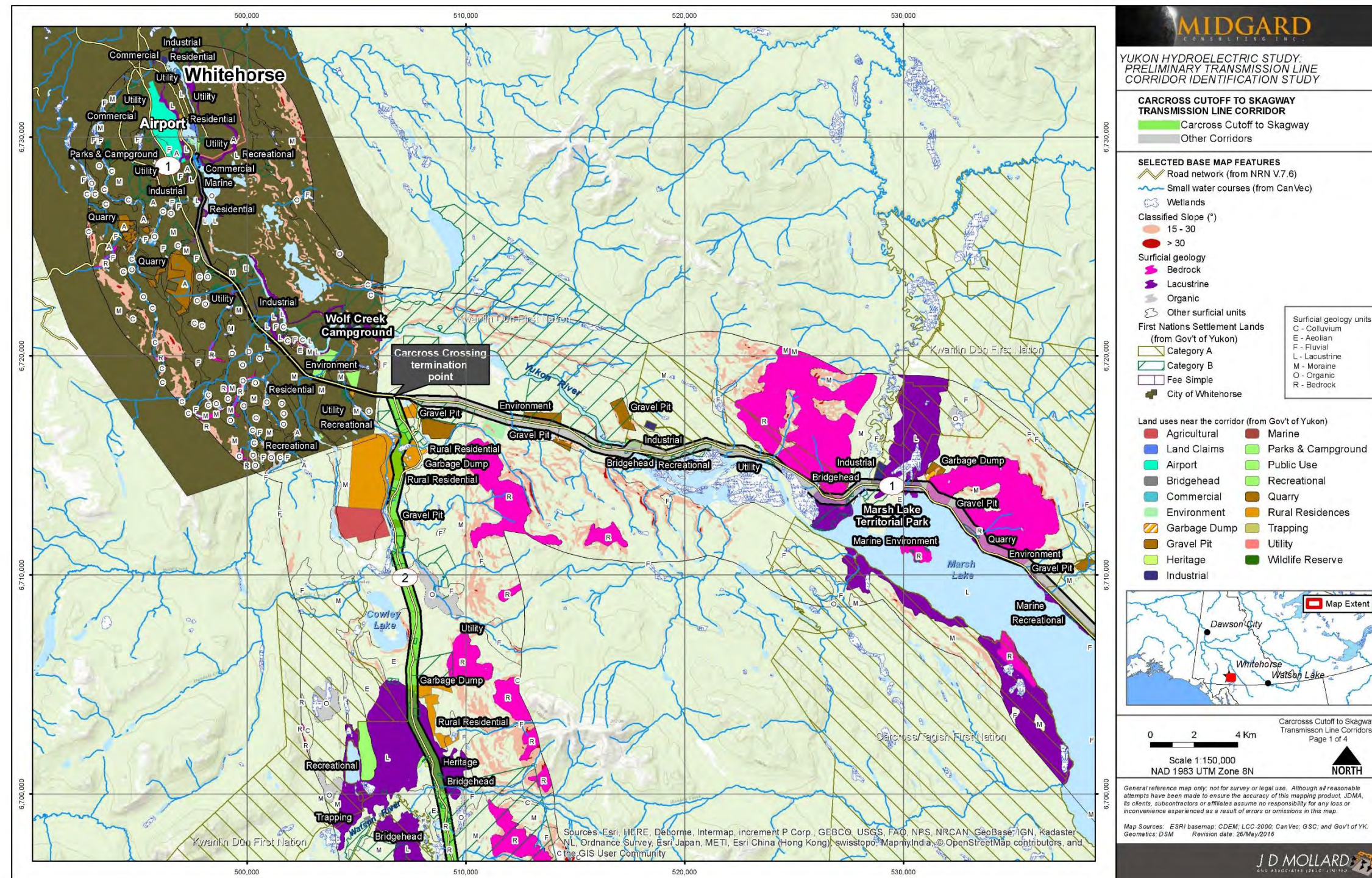
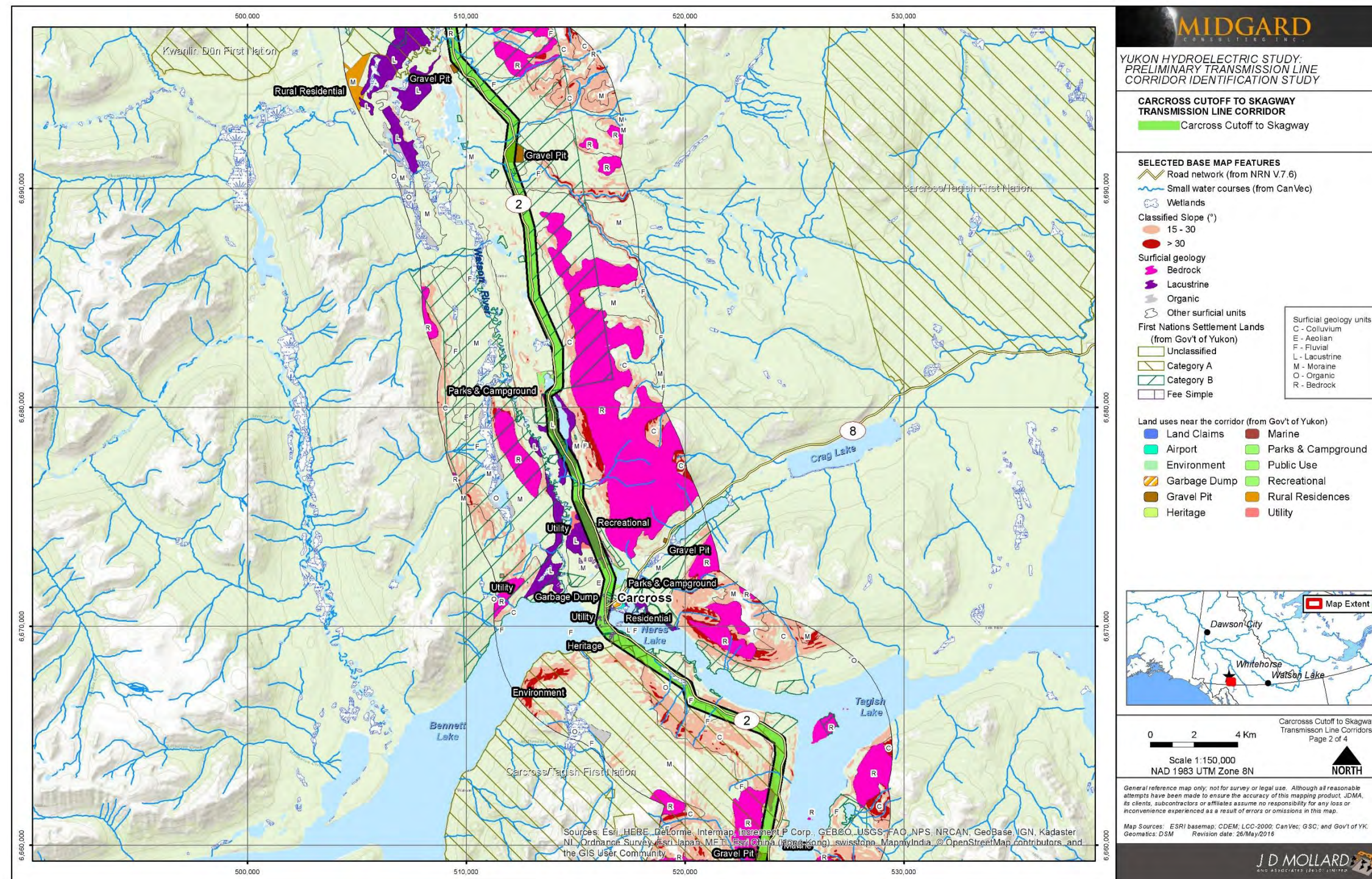
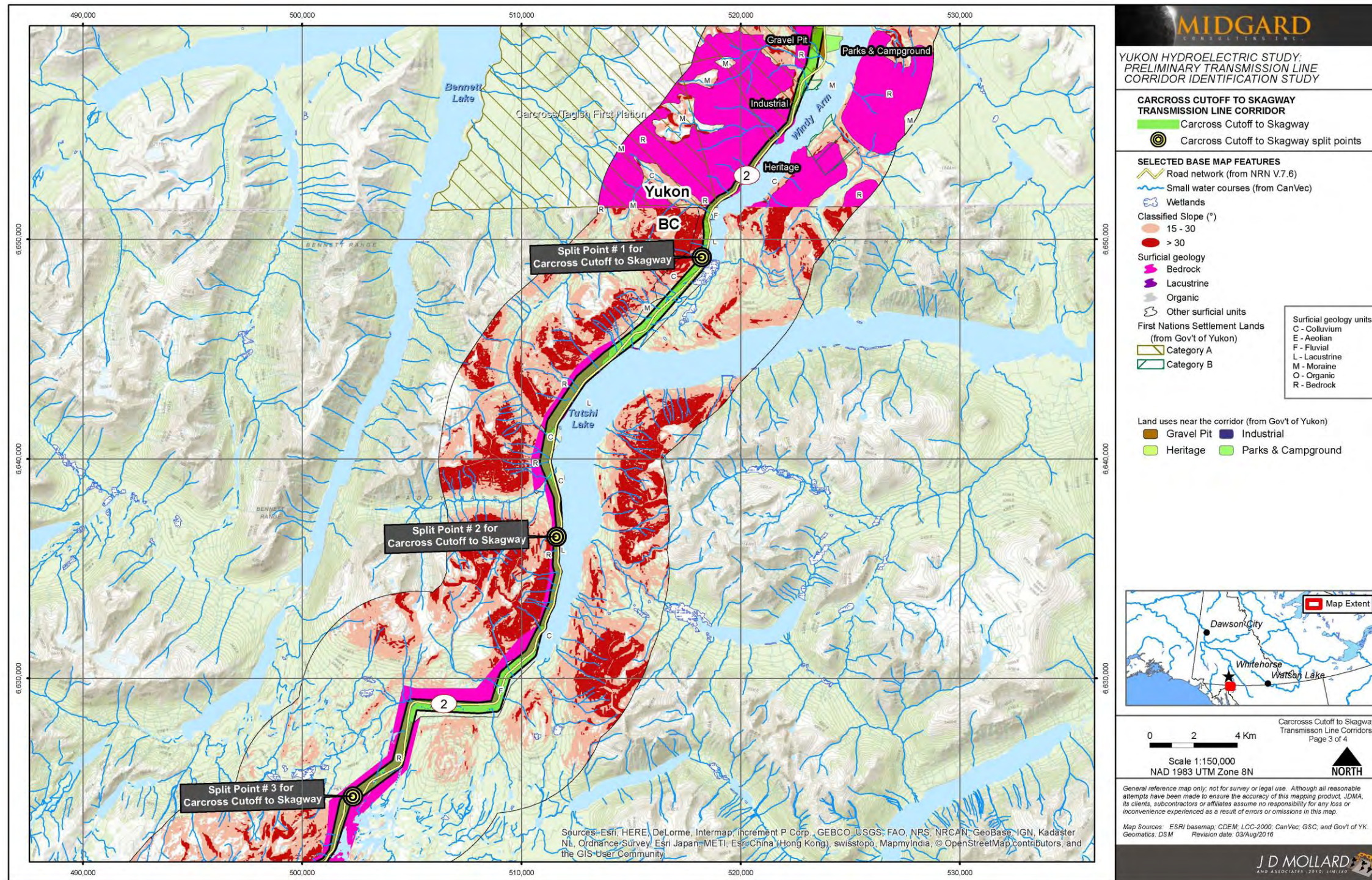


Figure A6: Carcross Cutoff to Skagway map booklet







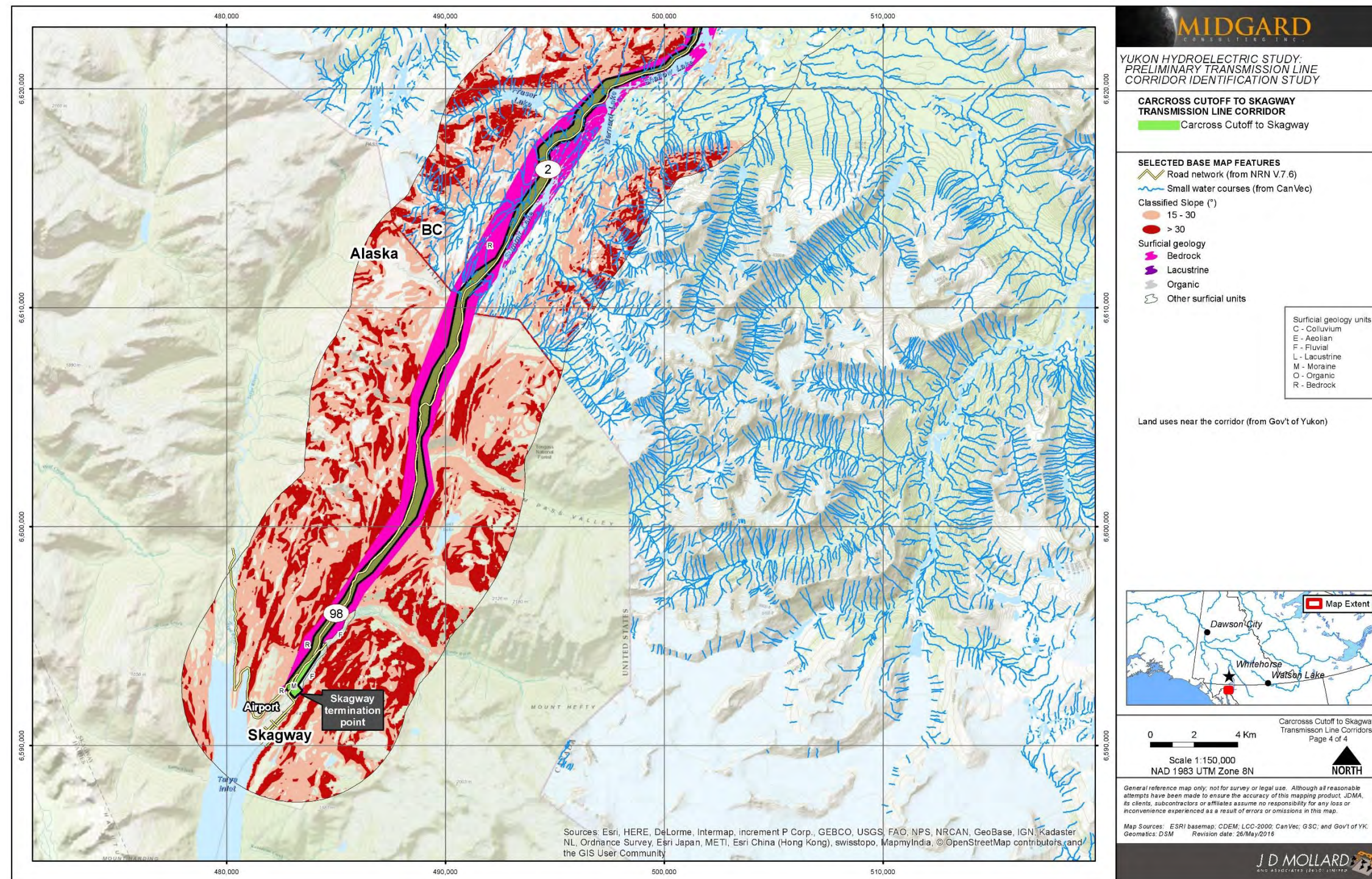
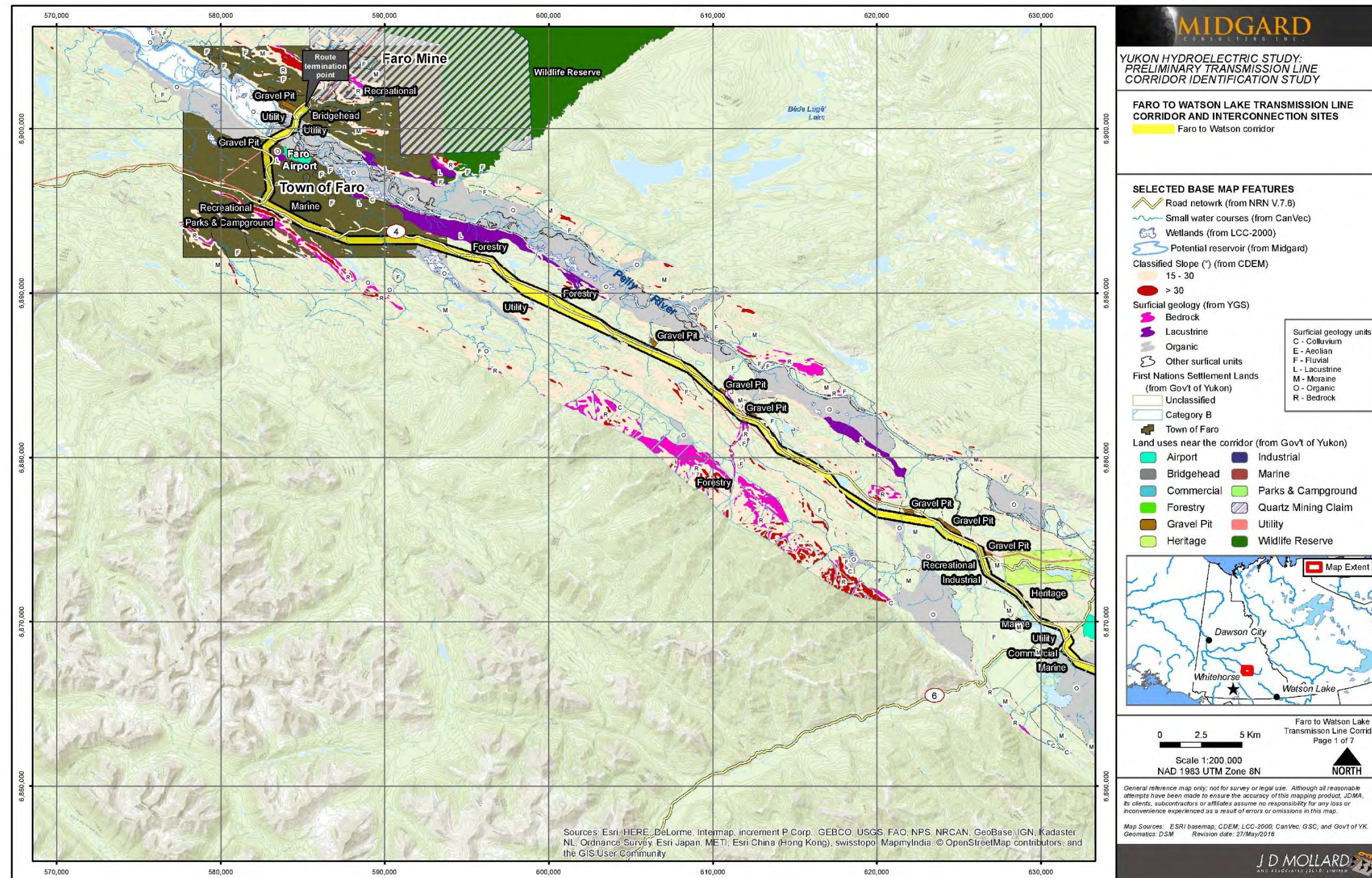
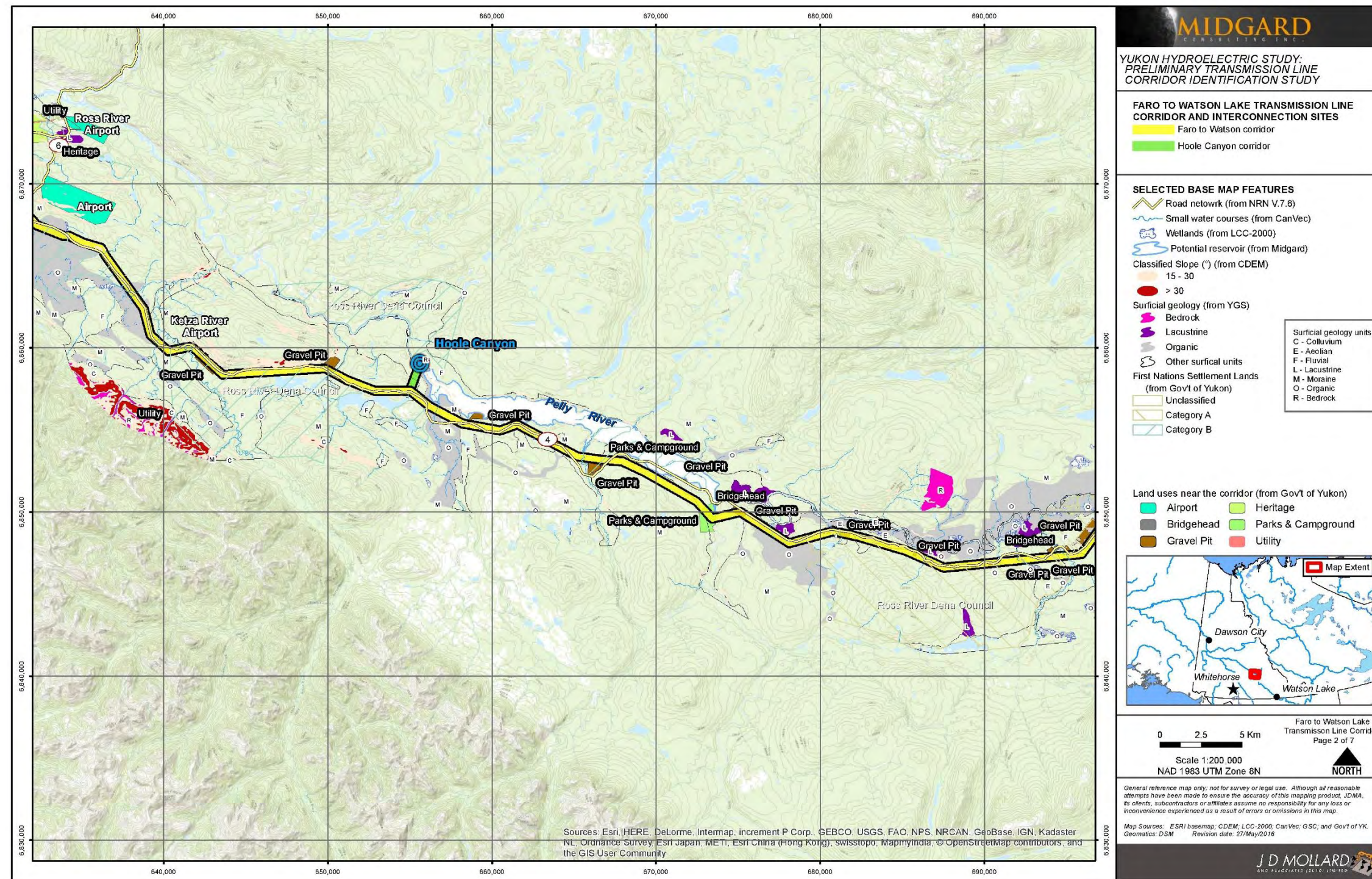
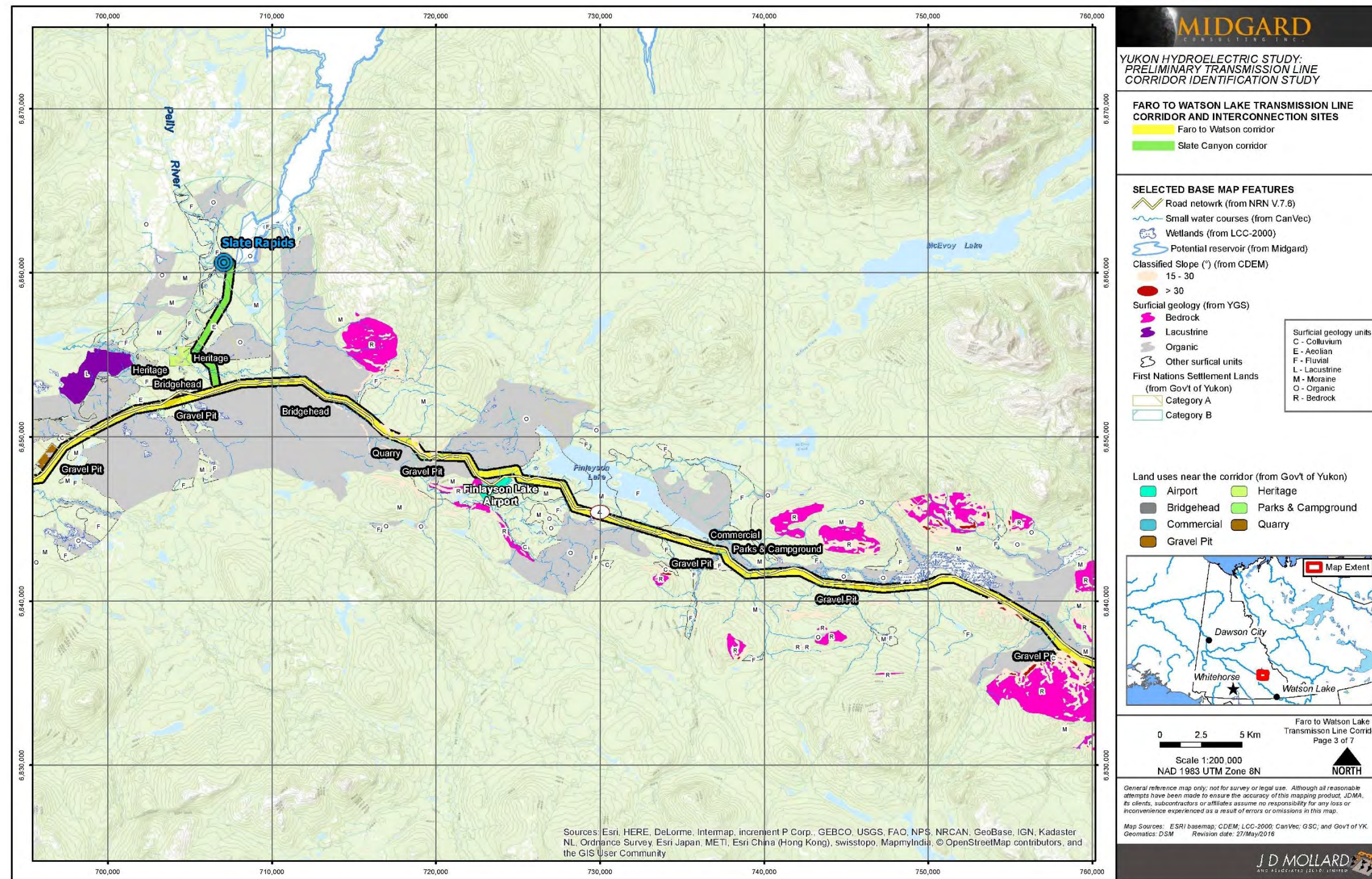
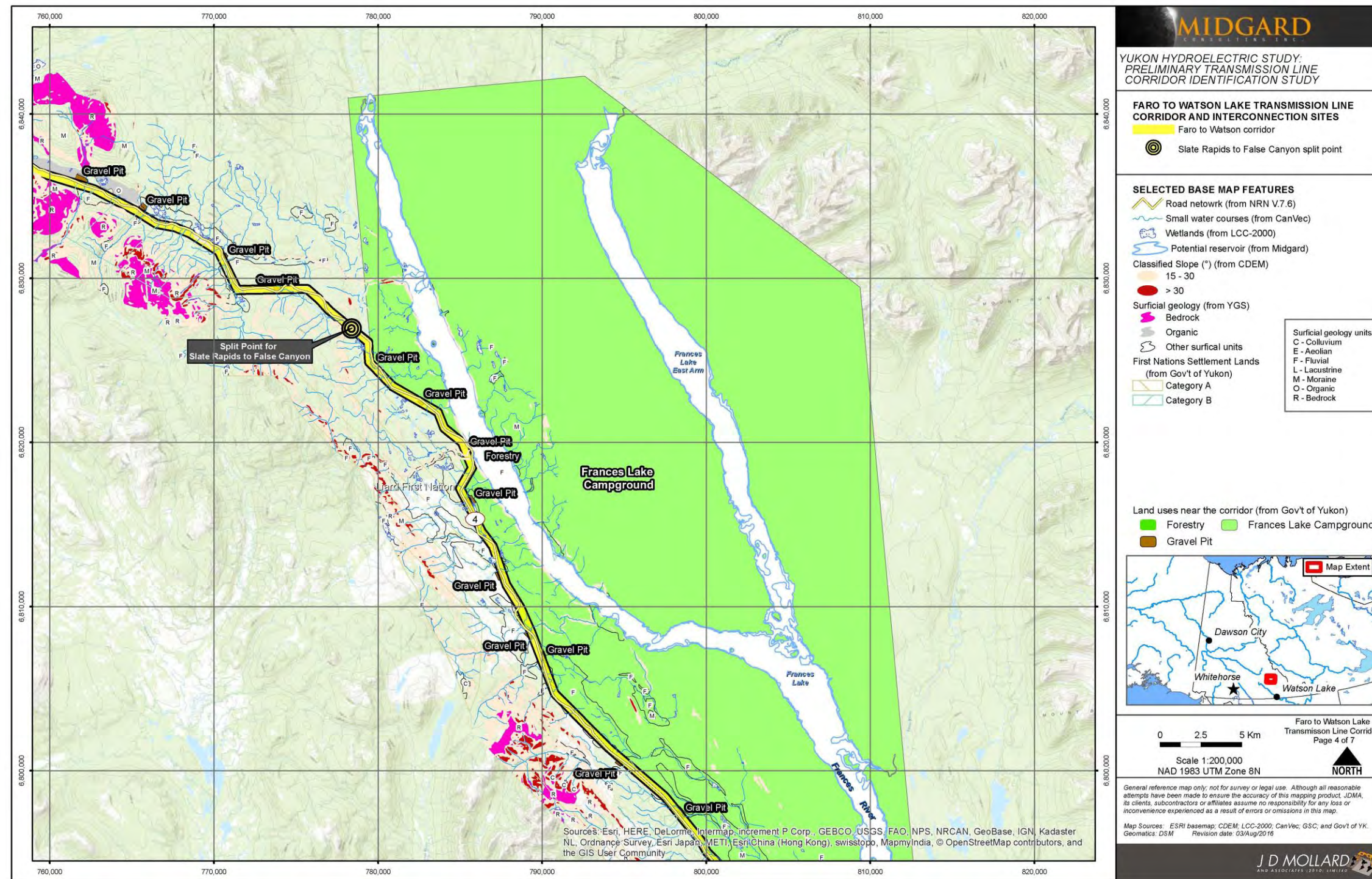


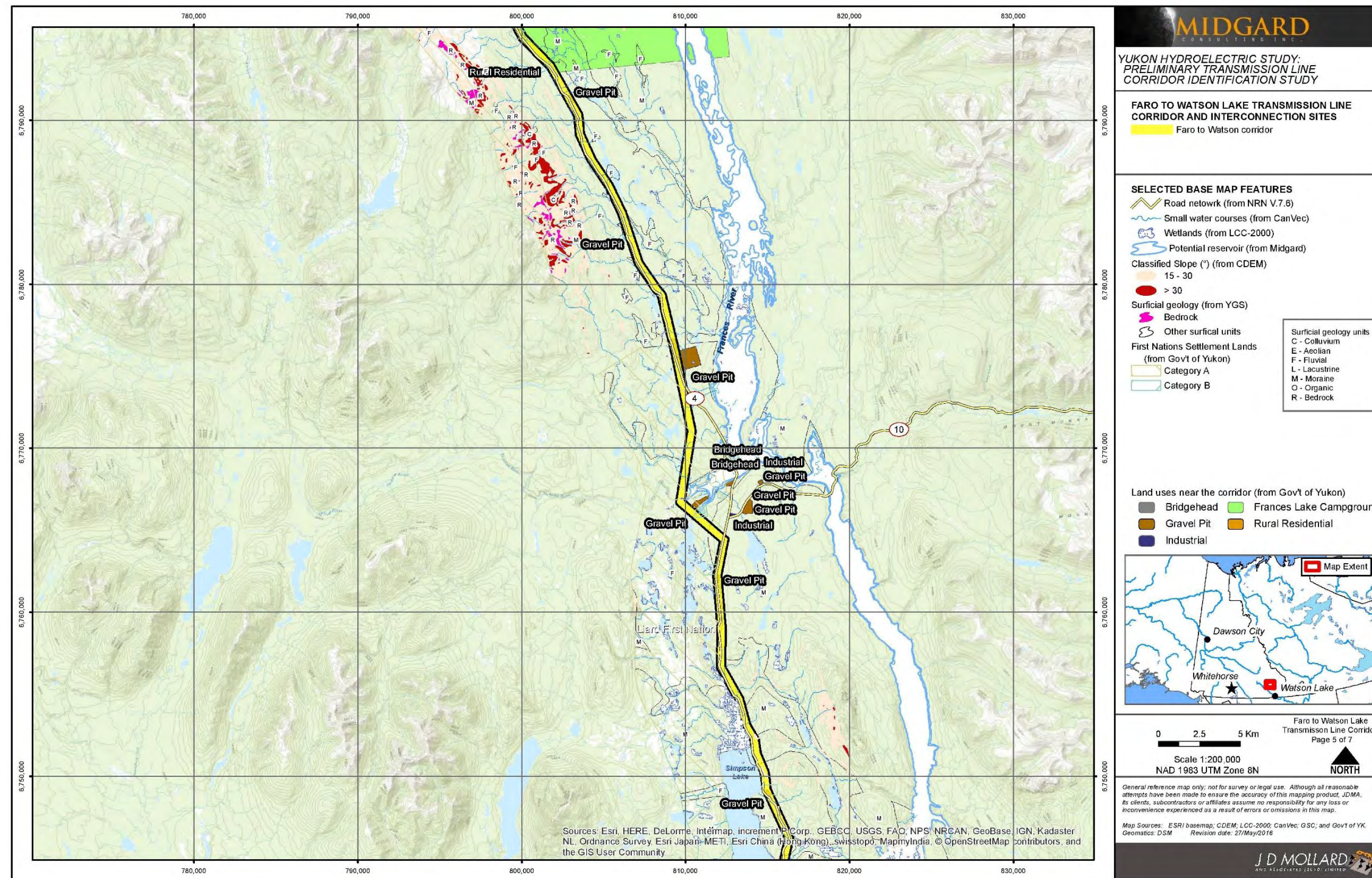
Figure A7: Faro to Watson Lake map booklet

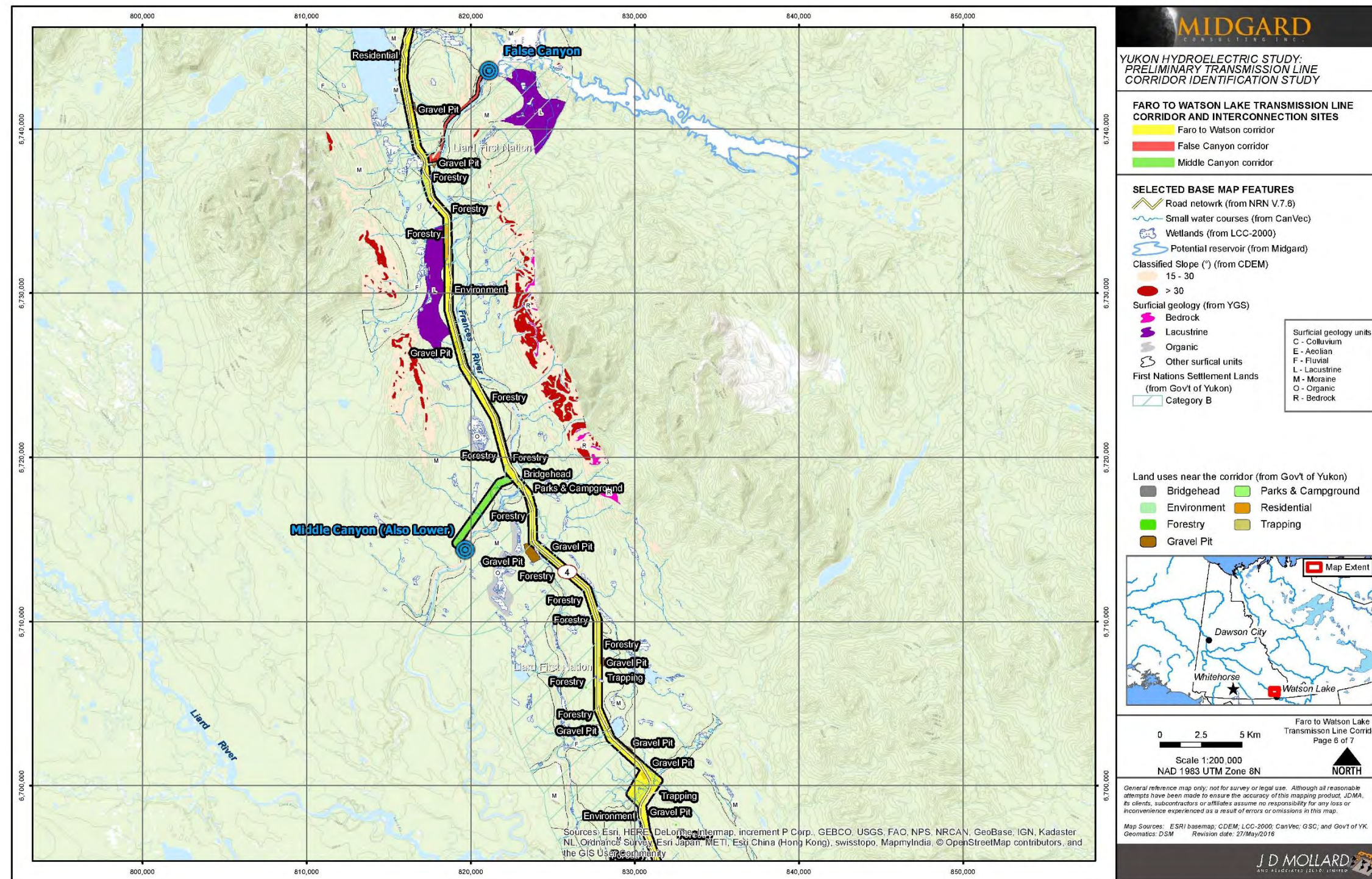












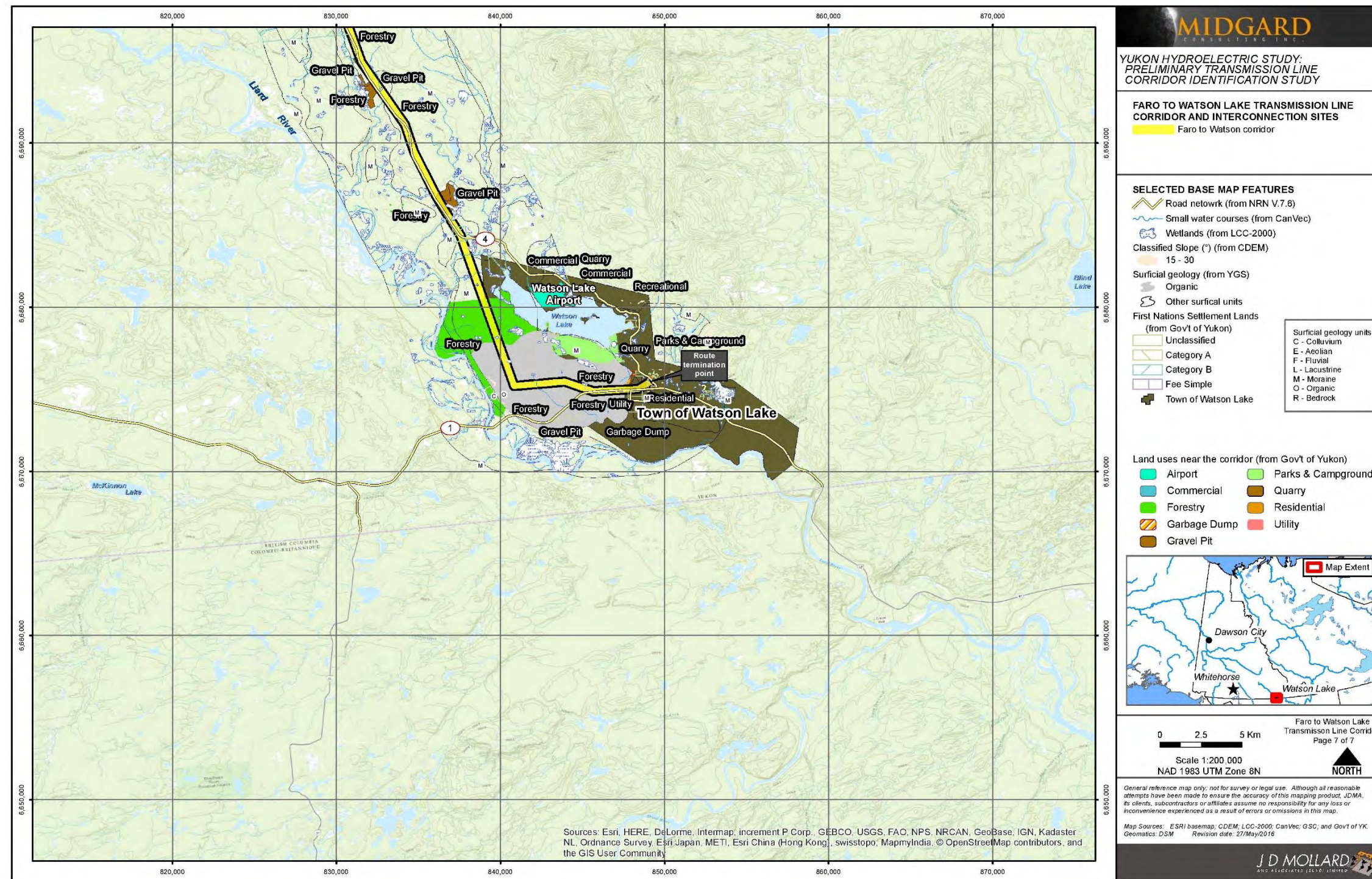
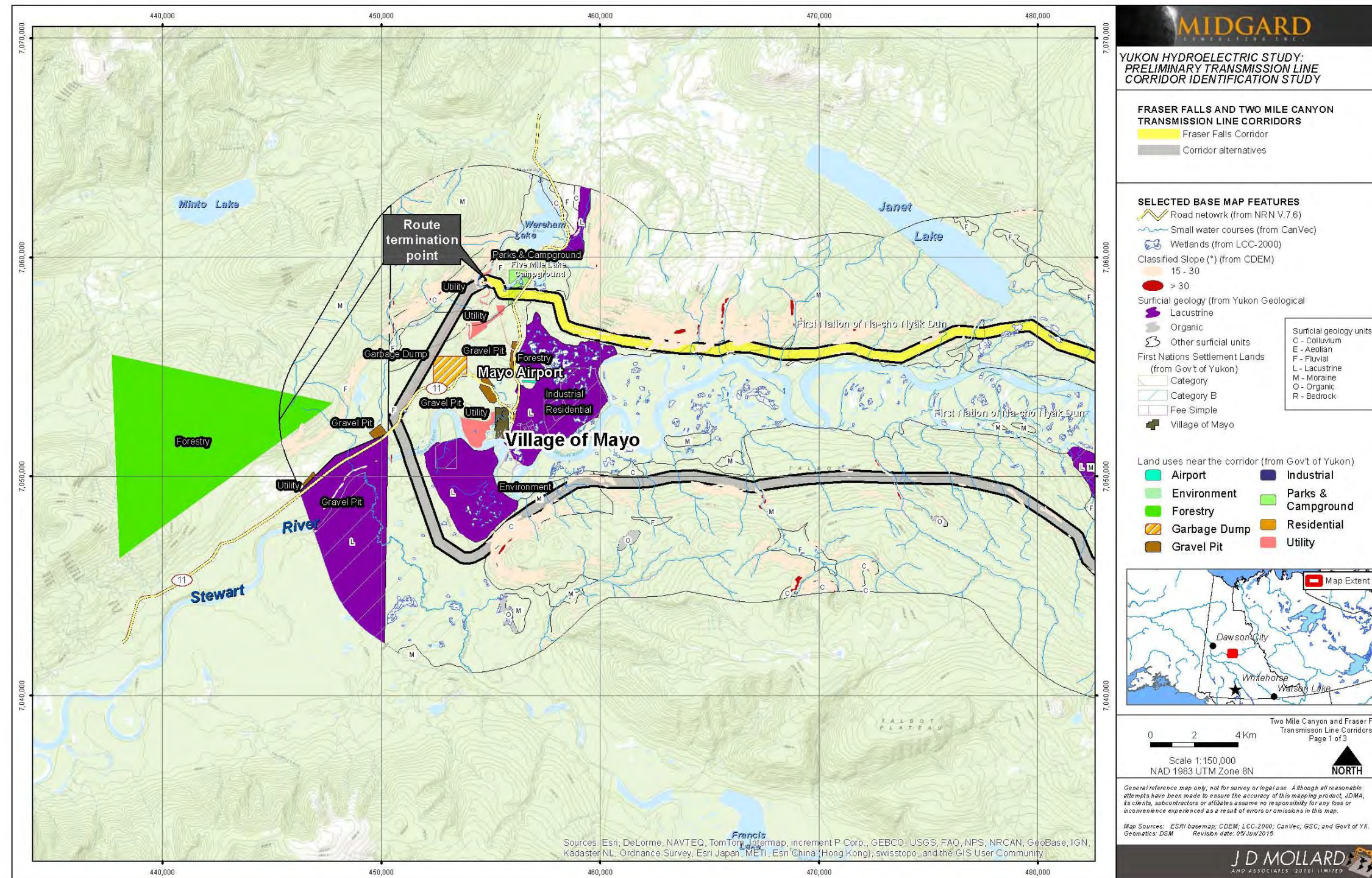
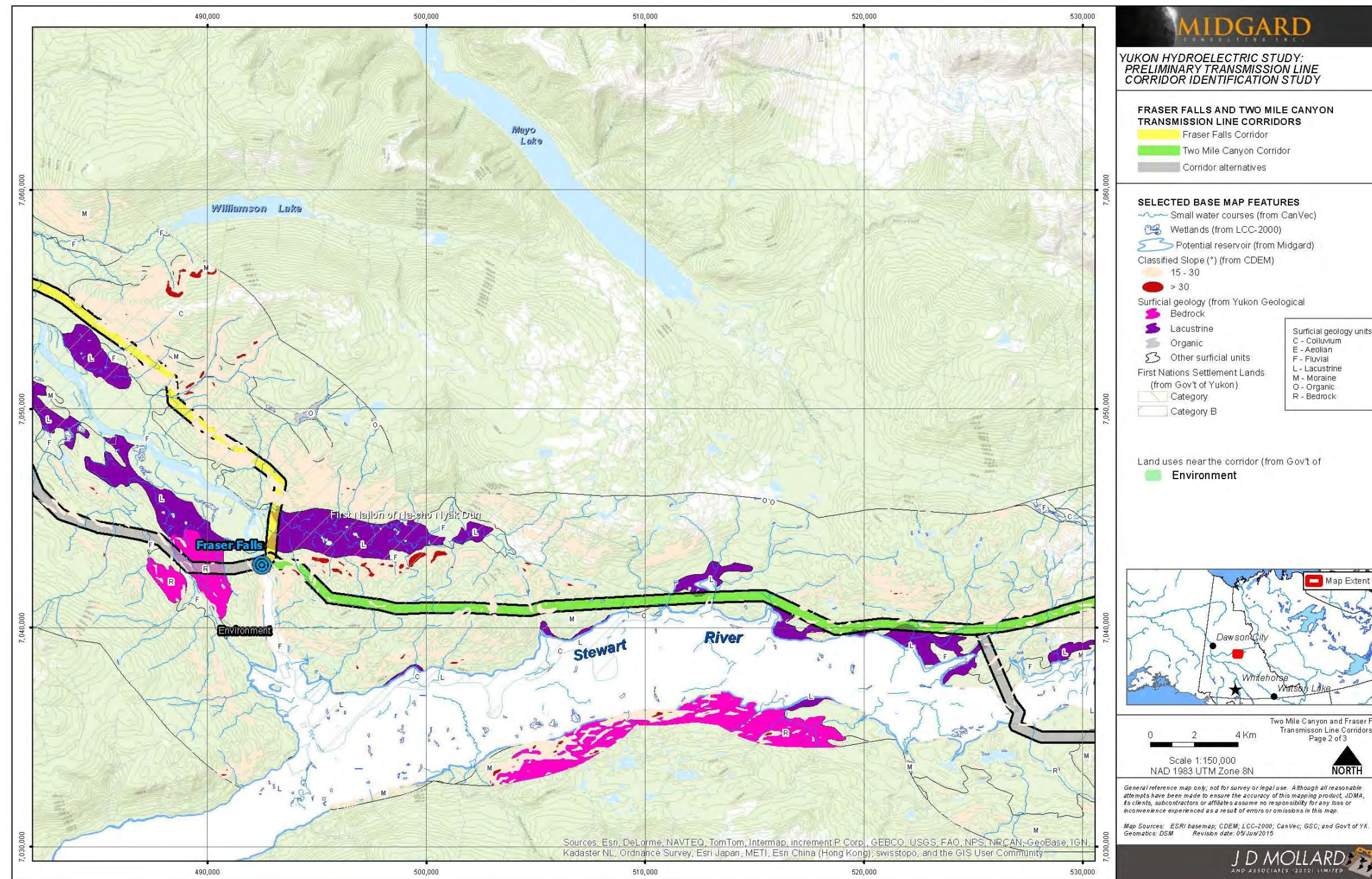


Figure A8: Fraser Falls and Two Mile Canyon map booklet





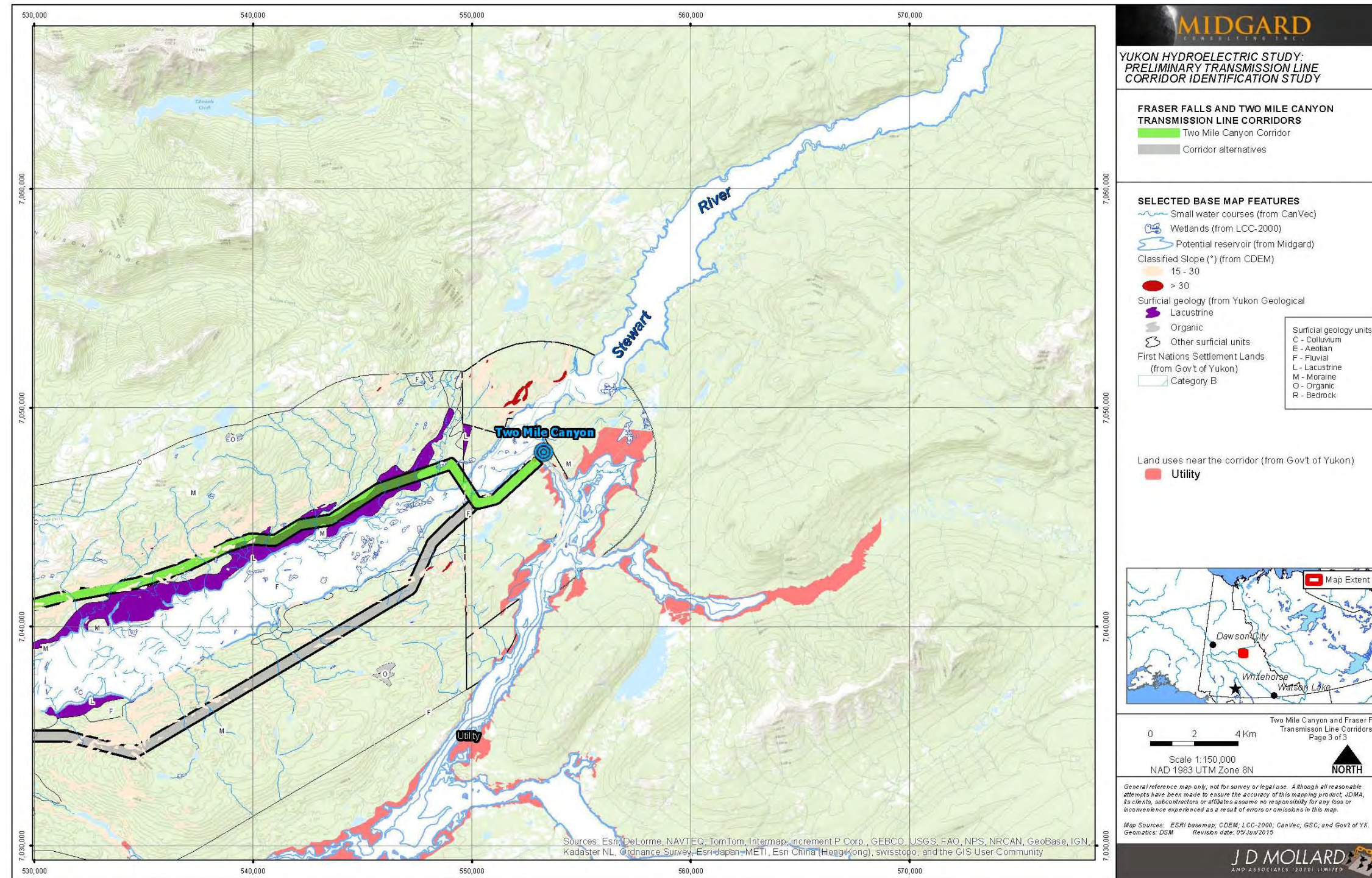
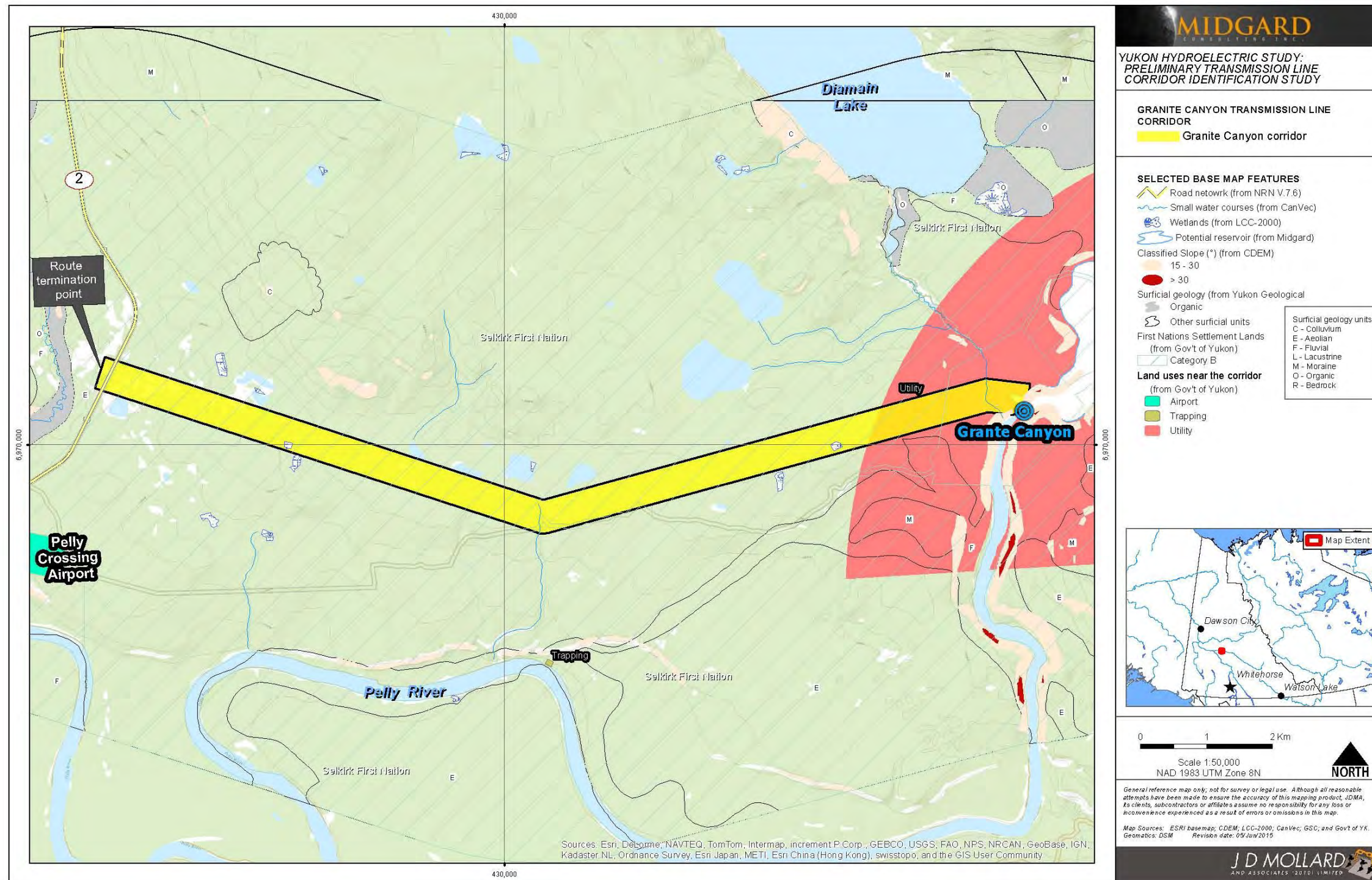


Figure A9: Granite Canyon map



# **Appendix D:**

## **69 kV Alternative Routing Analysis**

## MEMORANDUM

**To:** Marc-Andre Lavigne, Yukon Energy Corporation

**From:** Sunil Bhatti, P.Eng.

**Date:** 1 November 2016

**Subject:** Transmission Options Evaluation – 69 kV Transmission Line Options Addendum

- Midgard Consulting Incorporated (“Midgard”) was commissioned to calculate the capital cost and average losses incurred to serve a load of 8 MW for two 69 kV transmission lines:
  - Atlin → Jake’s Corner
  - Whitehorse → Atlin
- The results of this exercise are summarized in Table 1 below

**Table 1: 69 kV Transmission Line Option Evaluation Summary**

Transmission Route	Voltage Class	Line Length	Reliable Transfer Capacity	Line Losses (at 8 MW Load)	Capital Cost	Operating Cost	Earliest Possible ISD
Atlin → Jake’s Corner	69 kV	93 km	38 MW	0.4 MW	\$54.2 M	\$129 k / Year	Jan 2020
Whitehorse → Atlin	69 kV	172 km	21 MW	0.6 MW	\$104 M	\$236 k / Year	Oct 2020

*Note: Whitehorse → Atlin line losses were achieved using a 2 MVar shunt capacitor on the load bus.*

### Cost Assumptions

#### Capital Cost

- Midgard was unable to find cost data for recently-constructed 69 kV transmission lines in western Canada, and therefore was unable to use the costing methodology applied in the Transmission Options Evaluation report
- The 69 kV voltage class is no longer a common voltage class for new transmission lines; at transmission levels, utilities seem to opt for 138 kV instead
- 69 kV line cost estimate was derived by marking down the cost components of 138 kV lines:
  - Materials & Shipping cost for 69 kV were 50% of that of 138 kV
  - Engineering, Construction & Salvage for 69 kV were 75% of 138 kV
  - Land & Access for 69 kV were 66% of 138 kV

### Operating Cost & Schedule

- Operating cost & schedule calculated in accordance with methodology used in Transmission Options Evaluation

### PSSE Simulation Details & Criteria

**Table 2: Conductor Characteristics**

Voltage Class	Conductor Type	Geometric Mean Radius	External Diameter	Conductors per Bundle	Phase Spacing	Conductor Temperature
69 kV	Partridge 266.8	0.0217 ft	0.642 in	1	1.35 m	100 °C

**Table 3: Reliable Transfer Capacity Limit Modelling Criteria**

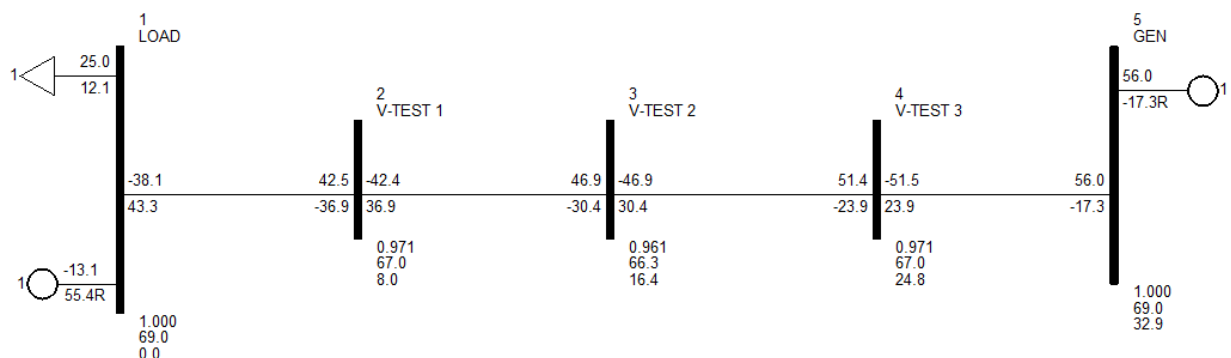
<b>Voltage Angle Limit:</b>	Not to exceed 33 degrees
<b>Thermal Limit:</b>	Not studied
<b>VAR Limits:</b>	Not applied
<b>Reliable Transfer Limit Calculation:</b>	Real power injected into load bus

**Table 4: Average Losses Modelling Criteria**

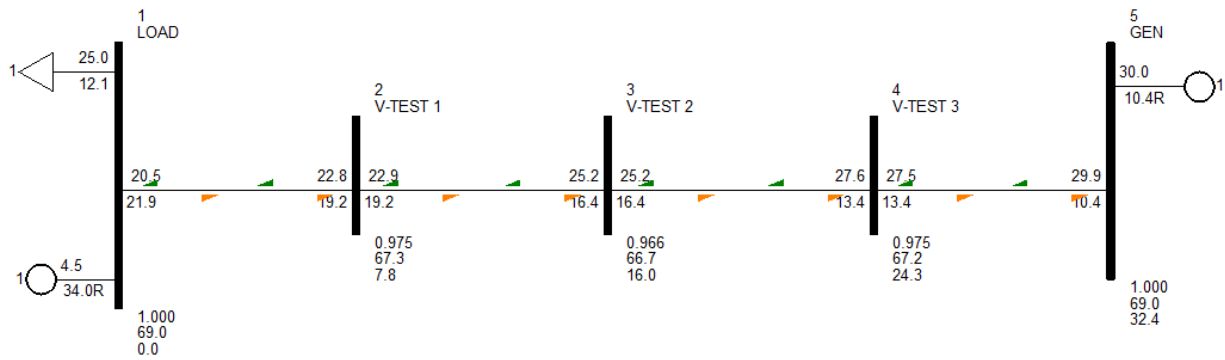
<b>Load Size:</b>	8.89 MVA (8 MW at 0.9 power factor)
<b>Bus Voltage Limits:</b>	0.95 to 1.05 per unit
<b>Average Loss Type:</b>	Considered real power losses only
<b>Average Loss Calculation:</b>	Real power injected into generator bus less real power injected into load bus
<b>Generator Power Factor:</b>	Power factor $\geq 1.0$
<b>Shunt Compensation:</b>	Minimized requirement for shunt compensation (to reduce capital cost)

### PSSE Modelling Diagrams

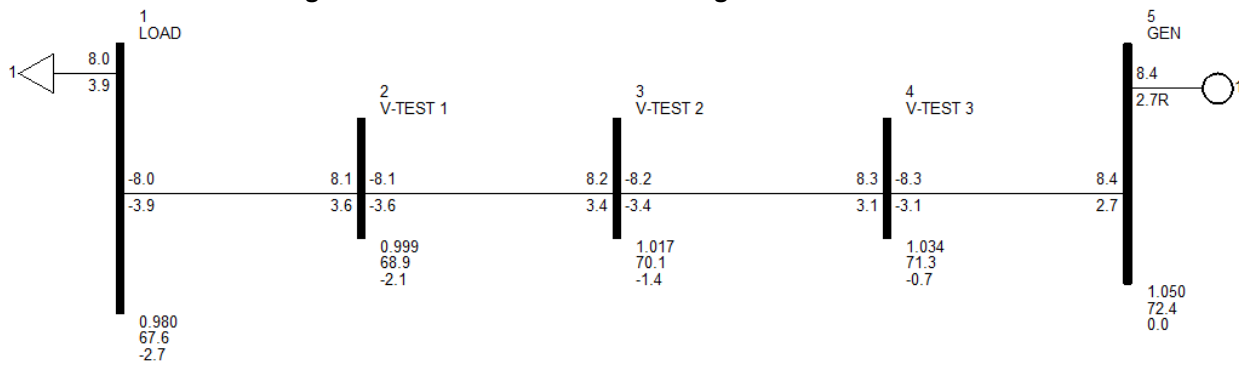
**Figure 1: Atlin → Jake’s Corner Reliable Transfer Capacity PSSE Model**



**Figure 2: Whitehorse → Atlin Reliable Transfer Capacity PSSE Model**



**Figure 3: Atlin → Jake's Corner Average Losses PSSE Model**



**Figure 4: Whitehorse → Atlin Average Losses PSSE Model**

