Yukon Next Generation Hydro and Transmission Viability Study: Faro to Watson Lake Transmission Line Study

Submitted By: Midgard Consulting Incorporated

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Executive Summary

The Yukon Development Corporation ("**YDC**") has commissioned Midgard Consulting Incorporated ("**Midgard**") and its team of sub-consultants to complete the *Faro to Watson Lake Transmission Line Study.* This *Faro to Watson Lake Transmission Line Study* analyzes the transmission development options available to the Yukon along the Faro to Watson Lake Transmission Corridor as part of the *Yukon Next Generation Hydro and Transmission Viability Study*. In this transmission study, eight (8) generation plan configurations were analyzed with 138 kV and 230 kV transmission line voltages along the Faro to Watson Lake transmission corridor. The following table shows the results of the technical and financial analysis of the generation plan configurations.

Table 0-1: Faro to Watson Lake Transmission Study - Summary

No. #	Generation Mix	Transmission Line Distance (km)	Voltage (kV)	2065 Capacity Need (MW)	Power Transfer Capability (MW)	Watson Lake Extension Costs ($M)	Capital Costs (up to 2065) ($M)
1	Slate Rapids + Hoole Canyon Run of River (ROR): Partial Transmission Line*	151	138	53	99	-	169
2	Slate Rapids + Hoole Canyon ROR	414	138	53	95	263	432
3	Slate Rapids Standalone	414	138	53	36	263	429
4	False Canyon + Middle Canyon ROR: (Curtailed)**	414	138	53	56	77	434
5	False Canyon + Middle Canyon ROR: (Series Compensated)***	414	138	53	62	77	434***
6	False Canyon: Standalone	414	138	53	45	77	426
7	Slate Rapids + Hoole Canyon ROR	414	230	53	101	374	610
8	False Canyon + Middle Canyon ROR	414	230	53	72	109	613

** Partial transmission line from Faro to Slate Rapids. Options 2-8 include the complete transmission line from Faro to Watson Lake*

*** Total generation output is curtailed to 56MW to maintain voltage and angular stability of the electric grid*

**** Series compensation is provided through the use of series capacitors which increase the transmission line power transfer capability from 56MW to 62MW. Series compensation incurs extra cost, but since these costs are not expected to occur until after 2065, they are not included in the Capital Cost Estimate up to the end of 2065.*

As shown in Table 0-1 above, the 138 kV transmission line is the preferred transmission voltage because it has the ability to transport more than the 53 MW which is the forecast baseline capacity need in 2065. Depending on the Generation Project selected for Next Generation Hydro, the following is a summary of the potential build out approach for each of the projects. It is worth noting the following:

1) If Slate Rapids is constructed, the transmission line extension to Watson Lake will likely not be economically viable (and therefore will not be constructed)
2) If False Canyon is constructed, it is only an additional 78 km to Watson Lake, therefore the extension to Watson Lake would likely be constructed in 2035 because the transmission grid is so close to Watson Lake.

Table 0-2: Potential Build Out Approach for 138 kV Transmission Lines along the Faro-Watson Lake Transmission corridor

Date	Slate Rapids + Hoole Canyon ROR Option	False Canyon + Middle Canyon ROR Option
2035	138 kV transmission line from Faro to Slate Rapids cost: ***$166 M***	138 kV transmission line from Faro to False Canyon cost: ***$349 M***
2050	138 kV transmission line tap to Hoole Canyon ROR cost: ***$2.5 M***	
2060		138 kV transmission line and transmission tap to Middle Canyon ROR: ***$28 M***
Anytime Post-2035	*Option 1:* Transmission Line from near Slate Rapids to Watson Lake can be built after (or concurrently with) the 138 kV line to Slate Rapids. Cost: ***$ 263 M***	*Option 1:* Transmission Line extension from near Middle Canyon to Watson Lake cost: ***$ 57 M*** Option 2: Transmission Line extension from near False Canyon to Watson Lake. Cost: ***$77 M***

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Detour	Detour Canyon
False	False Canyon
GIS	Geographic Information Systems
Hoole	Hoole Canyon ROR
JDMA	J.D. Mollard and Associates
Middle	Middle Canyon ROR
MVA	Mega Volt-Ampere
MVAr	Mega Volt-Ampere reactive
MW	Mega Watt
pu	Per Unit
ROR	Run of River
SC	Series Compensation
SH	Shunt Compensation
Slate	Slate Rapids
YDC	Yukon Development Corporation
YEC	Yukon Energy Corporation
Hoole Tap	Hoole Canyon ROR tap location on the Main Transmission Line
Slate Tap	Slate Rapids tap location on the Main Transmission Line
False Tap	False Canyon tap location on the Main Transmission Line
Middle Tap	Middle Canyon ROR tap location on the Main Transmission Line

1 Introduction

The Yukon Development Corporation ("**YDC**") has commissioned Midgard Consulting Incorporated ("**Midgard**") and its team of sub-consultants to complete the *Faro to Watson Lake Transmission Line Study.* This *Faro to Watson Lake Transmission Line Study* analyzes the transmission development options available to the Yukon along the Faro to Watson Lake Transmission Corridor as part of the *Yukon Next Generation Hydro and Transmission Viability Study*.

In the *Yukon Electrical Energy and Capacity Need Forecast (2035 to 2065),* the Yukon's future electrical energy and electrical capacity needs were estimated based upon expected demand drivers such as population, per capita electrical energy consumption, and industrial (e.g. mining) activity. The result was a Baseline scenario which forecast electrical capacity and energy gaps from 2035 to 2065.

Building on the forecast, the *Scalability Assessment Report* evaluated potential projects based on their ability to meet the forecasted 2065 Baseline Energy Gap while minimizing reservoir footprints. At the end of the assessment, six projects of interest were shortlisted as shown in Table 1-1. Four of the projects were standalone sites and two projects were two site cascades on a common river system with an upstream water storage dam and a downstream Run-of-River (ROR) facility.

Table 1-1: Scalability Project Shortlist

Site Name	Site ID
Detour Canyon	PELLY-PELLY-0567-B
Fraser Falls	STEWA-STEWA-0519-B
Granite Canyon	PELLY-PELLY-0480-B
Two Mile Canyon	STEWA-HESS -0552
False Canyon + Middle Canyon ROR	LIARD-FRANC-0696 + LIARD-FRANC-0670-B
Slate Rapids + Hoole Canyon ROR	PELLY-PELLY-0847-B + PELLY-PELLY-0760-A

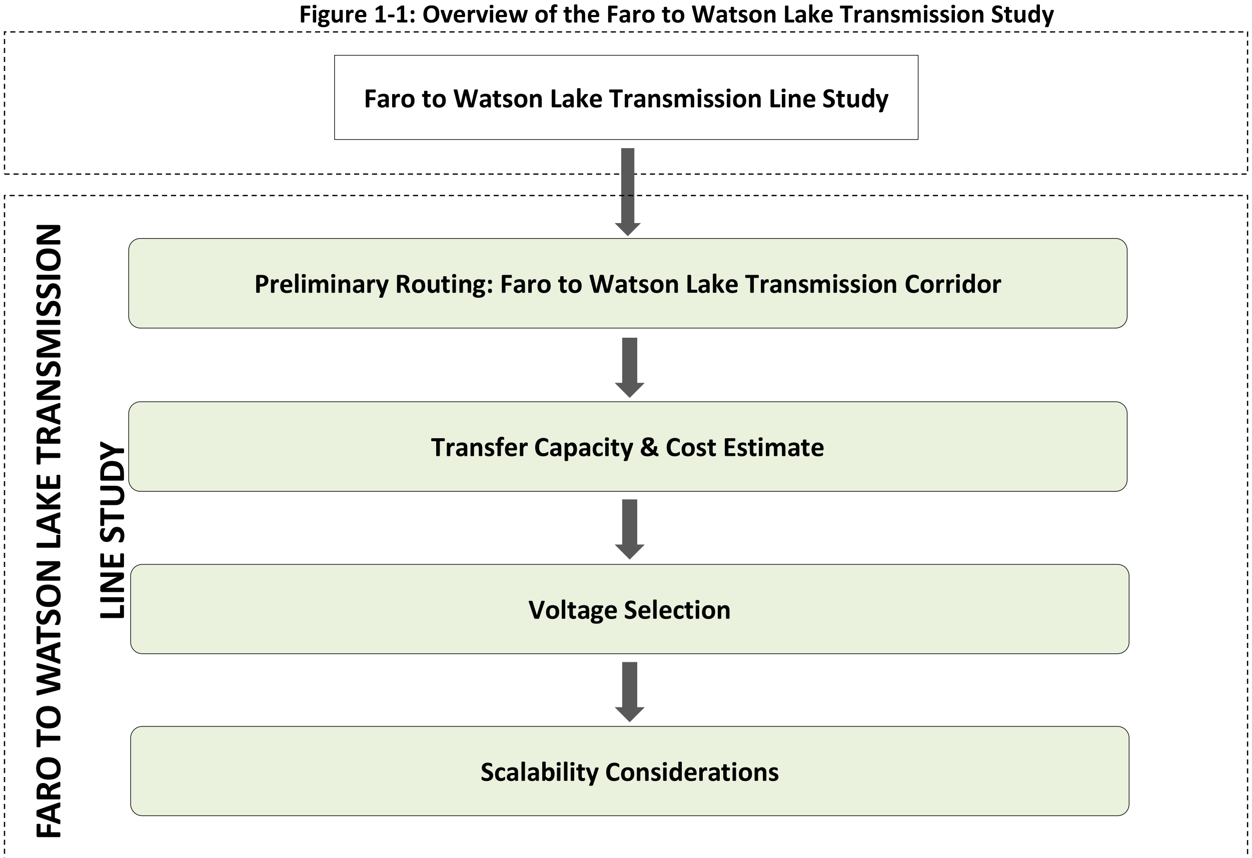
To prevent premature removal of potentially viable sites from consideration before inter-jurisdictional transmission line and market assessments were performed, the *Scalability Assessment Report* assumed that a transmission line corridor "pre-existed" from Faro to Watson Lake. The two cascades, False Canyon + Middle Canyon ROR and Slate Rapids + Hoole Canyon ROR, would interconnect to the Faro to Watson Lake transmission line.

However, to properly cost the different project options with and without the pre-existing Faro-Watson Lake transmission corridor, additional work must be done to assess the cost of this corridor as both a standalone entity and as an incremental cost adder to each of the potential Next Generation Hydro projects (i.e. the transmission corridor costs will be accounted for in project costs).

To determine potential routing, cost and transfer capacity of transmission options along the Faro-Watson Lake corridor, the report is organized as follows:

1. Preliminary Routing - Faro to Watson Lake Transmission Corridor (Section 2): Determine an initial preliminary routing corridor between Faro and Watson Lake and a preliminary assessment of terrain characteristics.
2. Transfer Capacity & Cost Estimate (Section 3): Based on the preliminary routing and terrain characteristics, estimate the transfer capacity of different transmission line configurations (138 kV & 230 kV options), and estimate the cost of constructing the transmission line including transmission taps to the generation sites (Hoole Canyon, Slate Rapids, False Canyon and Middle Canyon).
3. Voltage Selection: 138 kV or 230 kV (Section 4): Based on the results from Section 2, determine the technically feasible and cost effective transmission line voltage out of 138 kV and 230 kV options.
4. Scalability Considerations (Section 5): Provide different build out options for the Faro-Watson Lake Transmission Corridor based on the different generation combinations and transmission line segments to be built.

Figure 1-1: Overview of the Faro to Watson Lake Transmission Study



2 Preliminary Routing: Faro - Watson Lake Transmission Corridor

To determine a preliminary routing for the transmission line between Watson Lake and Faro, and the taps from the main transmission line to specific projects, Midgard commissioned J.D. Mollard and Associates ("**JDMA**") to conduct a high level desktop study. The study identified a preliminary 500 m wide corridor within which a much narrower right of way could be selected for an actual transmission line and characterized the terrain characteristics within this corridor as an input for cost estimation purposes.

JDMA performed the high-level desktop transmission line corridor routing study by utilizing readily available GIS based data and satellite imagery. The major routing criteria used to inform the transmission corridor assessment are:

1. Corridor Width: Target 500 m
    a. Reduce the corridor width below 500 m where the terrain adjacent to the corridor is not suitable for construction of a transmission line (e.g. steep slopes, proximity to waterbodies, permafrost affected ground, *etc*.);
2. Typical Structure Spans: 200-230 m
3. Private Land: Avoid crossing privately held lands
4. Terrain Slope: Land slopes up to 15 degrees will not require special structures
5. Logistics: Where practical, locate transmission line corridors adjacent to existing roadways to reduce construction and maintenance costs.

In addition to the above basic criteria, JDMA also considered surficial geology and surface materials, evidence of permafrost-affected ground, topography, total length, as well as stream and wetland crossings to help identify potentially feasible corridors. For more details on the detailed methodology and the study results, refer Appendix A: JDMA Transmission Corridor Routing Study.

Figure 2-1 is a high-level overview map of the Faro - Watson Lake Transmission Corridor (shown in Purple) along with the locations of the Next Generation Hydro hydroelectric development options from the *Scalability Assessment Report*. For detailed maps and the terrain characteristic summary please see Appendix A: JDMA Transmission Corridor Routing Study.

Figure 2-1: Overview Map of Faro – Watson Lake Transmission

3 Transfer Capacity & Cost Estimate

The Faro-Watson Lake Transmission Corridor has eight (8) potential configurations as shown in Table 3-1. The False Canyon + Middle Canyon ROR generation option was selected on the basis that the Yukon would try to connect Watson Lake to the Yukon grid if the transmission line was brought into reasonable proximity to Watson Lake (e.g. if the transmission line is built 336 km to False Canyon from Faro, the extra 78 km to Watson Lake would be added). The Slate Rapids + Hoole Canyon ROR generation option was evaluated on the basis that the transmission line extension may or may not be added because of the considerable additional distance to Watson Lake (i.e. 263 km)

Table 3-1: Generation Plan Configurations

Option No. #	Main Transmission Line		Voltage	Transmission Distance	Generation Option
	From	To			
1.1	Faro	Slate Rapids	138 kV	151 km	Slate Rapids + Hoole Canyon ROR
1.2	Faro	Watson Lake	138 kV	414 km	Slate Rapids + Hoole Canyon ROR
1.3	Faro	Watson Lake	138 kV	414 km	Slate Rapids Standalone
1.4	Faro	Watson Lake	138 kV	414 km	False Canyon* + Middle Canyon ROR
1.5	Faro	Watson Lake	138 kV	414 km	False Canyon** + Middle Canyon ROR
1.6	Faro	Watson Lake	138 kV	414 km	False Canyon standalone
2.1	Faro	Watson Lake	230 kV	414 km	Slate Rapids + Hoole Canyon ROR
2.2	Faro	Watson Lake	230 kV	414 km	False Canyon + Middle Canyon ROR

**False Canyon output is curtailed due to transmission grid stability issues*

***False Canyon output is increased to its maximum generation capability through series compensation on the transmission line.*

138 kV and 230 kV were selected as the transmission voltages to evaluate because 138 kV is already in use in the Yukon, they are common voltages for long distance power transmission, and other voltages would either be too expensive (e.g. 500 kV) or not suitable for carrying the target capacity (53 MW) over long distances due to high electrical losses or stability issues (e.g. <138 kV). Some of the key differences between high voltage and sub-transmission voltages are shown below.

Table 3-2: Difference Between High Voltage and Low Voltage Transmission Lines

	138 kV & 230 kV Voltage	*Lower Voltages (69 kV & below)*
1	More stable operation over long distances	Less stable over long distances
2	Reduced energy losses	Increased energy losses
3	Increased cost as voltage increases	Reduced cost as voltage decreases
4	Higher power transfer capability	Lower power transfer capability

3.1 Transfer Capacity Analysis

In order to estimate the maximum transfer capacity of each transmission line configuration, Midgard performed steady state power system analysis using the Siemens PSS®E[1] power system simulation software. The analysis was restricted to a steady state analysis of voltage and angular stability, but this was sufficient to develop a high level estimate of the maximum power transfer capability for various generation plan configurations considered. Since public access is not available for the power system models used by the Yukon Energy Corporation (YEC), simplifying assumptions based on publicly available information were utilized to approximate the Yukon electrical system as part of a simplified model of the Faro to Watson Lake Transmission Line. Transmission line segment lengths were based upon the estimated centerline distances provided in the JDMA Report[2] summarized in Table 3-3 and Table 3-4 below.

Table 3-3: Faro to Watson Lake Transmission Line Centerline Distance

Faro to Watson Lake Transmission Line Segments ("Main Transmission Line")	Centerline Distance (km)
Faro to Hoole Canyon Tap	95
Hoole Canyon Tap to Slate Rapids Tap	57
Slate Rapids Tap to False Canyon Tap	184
False Canyon Tap to Middle Canyon Tap	20
Middle Canyon Tap to Watson Lake	58
TOTAL	**414**

Table 3-4: Transmission Tap Centerline Distance

Transmission Taps from Main Transmission Line	Centerline Distance (km)
To Hoole Canyon ROR	2
To Slate Rapids	9
To False Canyon	7
To Middle Canyon ROR	6
TOTAL	**25**

It is important to state that 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 before any of the studied generation plan configurations could be advanced to development. However, since a Next Generation Hydro project would not be built until 2035, those more detailed analyses can be delayed

[1] PSS®E is a registered trademark of Siemens AG

[2] JDMA's Yukon Transmission Line Corridor Routing Study (June 05, 2015): Page 9, Table 3. See Appendix A for the report.

until closer to that date. For detailed information on PSS®E simulation inputs and outputs, transmission line conductor selection and properties, refer Appendix B: PSS®E Power System Simulation studies.

Some of the basic assumptions adopted for the technical feasibility study in this Report are as follows:

1. Yukon Electricity Load: Yukon's aggregated electrical load is represented at the Faro terminal, through which the generated electrical power is transmitted to the load centers.
    a. All electrical loads values are from the Baseline 2065 forecasted values.[3,4]
2. Communities: Only Watson Lake and Ross River electrical loads are considered, as all the other loads along the Faro-Watson Lake Transmission Corridor are floating/nonpermanent loads.
3. Power Transfer Capability to Faro = [Total Generation along the Faro–Watson Lake Transmission Corridor] – [Ross River Load in 2065] – [Watson Lake load in 2065] – [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 implied by maintaining a voltage angle difference less than 33° between the generating end and the receiving end.

3.2 Cost Estimation

Cost estimates were prepared for each of the generation plan configurations mentioned in Table 3-1 using "Base Unit Costs" in ($/km) calculated from similar operating voltage transmission line projects escalated to 2015 costs[5]. The total costs for each of the generation plan configuration can be calculated using:

Total Costs ($) = Centerline Distances (km) X Base Unit Costs ($/km) X Weighted Difficulty Factor

Weighted Difficulty Factors were calculated based on the terrain information provided in Table 3 of the JDMA Report (see Appendix A) to account for the Faro-Watson Lake Transmission Corridor specific factors such as:

1. Brushing Cover
2. Surficial Geology and Permafrost
3. Terrain Slope
4. Access Roads
5. Remoteness Factor

For more details on the calculation of the *Total Costs*, refer Appendix C. Section 3.3 details the generation plan configurations with a 138 kV transmission line and Section 3.4 details generation plan configurations with a 230 kV transmission line.

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[3] Yukon 2065 forecasted baseline load: "*Yukon Electrical and Capacity Need Forecast (2035 to 2065)"* report, Table 4-3, page 47.

[4] Watson Lake and Ross River 2065 peak load assumption = 1.5 X (Average Per Capita Energy Consumption per year X 2065 Population) / 8760

[5] Refer Appendix C for detailed cost estimates and calculation of Base Unit Costs

3.3 Options 1.X – 138 kV Transmission Line Configurations

3.3.1 Option 1.1 – 138 kV Faro to Slate Rapids (Slate Rapids + Hoole Canyon ROR)

Figure 3-1 and Table 3-5 summarizes the generation plan configuration for Option 1.1. This option consists of a partial 138 kV transmission line interconnecting Faro and Slate Rapids with Hoole Canyon ROR tapping into the Main Transmission Line on its way from Slate Rapids to Faro.

Figure 3-1: 138 kV Faro to Slate Rapids (Slate Rapids + Hoole Canyon ROR)

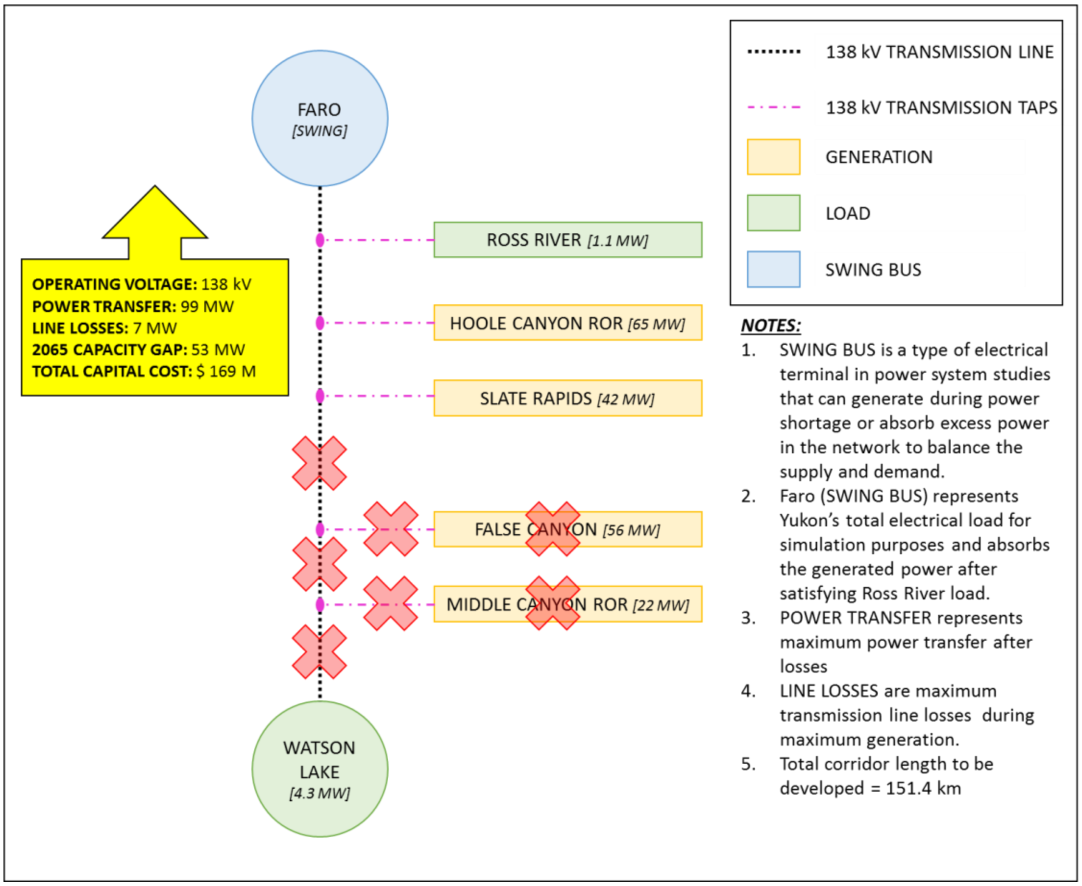


Table 3-5: Transfer Capacity & Cost Estimate – 138 kV Faro to Slate Rapids (Slate Rapids + Hoole Canyon ROR)

	Hoole Canyon ROR	Slate Rapids	False Canyon	Middle Canyon ROR	Watson Lake
Maximum Generation Capacity (MW)	65	42	-	-	-
Corridor Length from Faro (km)	95	151	-	-	Not Connected
Tap Distance from Corridor (km)	2	9	-	-	Not Connected
Total Distance from Faro	96	161	-	-	Not Connected
Maximum Transmission Line Losses (MW)	**7**				
Total Power Transfer Capacity to Faro (including line losses) (MW)	**99**				

Slate Rapids Project Capital Cost ($M)	**166**
Hoole Canyon ROR Tap Cost ($M)	**3**
Total Capital Cost ($M)	**169**

SUMMARY - 138 kV FARO TO SLATE RAPIDS WITH SLATE RAPIDS & HOOLE CANYON ROR

1. Partial transmission line from Faro to Slate Rapids, hence, Watson Lake is not grid connected.
2. 99 MW of transfer capacity to Faro meets 53 MW of Yukon's peak capacity gap in 2065.
3. Estimated price to build the Main Transmission Line along the proposed Faro - Watson Lake Transmission Corridor and transmission taps to Slate Rapids and Hoole Canyon ROR is $169 M
4. Extending the transmission line from Slate Rapids to Watson Lake can be done any time post-2035.

3.3.2 Option 1.2 – 138 kV Faro to Watson Lake (Slate Rapids + Hoole Canyon ROR)

Figure 3-2 and Table 3-6 summarizes the generation plan configuration for Option 1.2. This option consists of a 138 kV transmission line interconnecting Faro and Watson Lake with Slate Rapids and Hoole Canyon ROR tapping into the Main Transmission Line.

Figure 3-2: 138 kV Faro to Watson Lake (Slate Rapids + Hoole Canyon ROR)

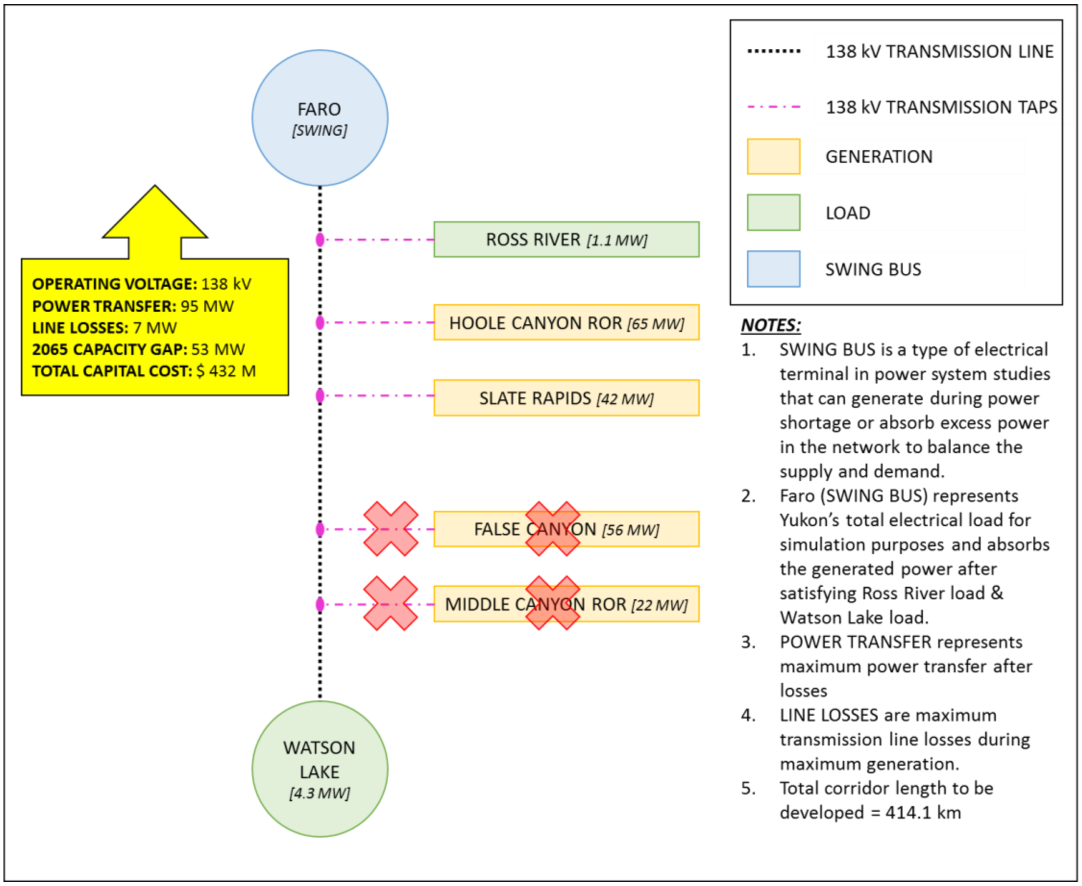


Table 3-6: Transfer Capacity & Cost Estimate – 138 kV Faro to Watson Lake (Slate Rapids + Hoole Canyon ROR)

	Hoole Canyon ROR	Slate Rapids	False Canyon	Middle Canyon ROR	Watson Lake
Maximum Generation Capacity (MW)	65	42	-	-	-
Corridor Length from Faro (km)	95	151	-	-	414
Tap Distance from Corridor (km)	2	9	-	-	-
Total Distance from Faro	96	161			414
Maximum Transmission Line Losses (MW)	**7**				
Total Power Transfer Capacity to Faro (including line losses) (MW)	**95**				
Slate Rapids Project Capital Cost ($M)	**166**				
Hoole Canyon ROR Tap Cost ($M)	**3**				
Watson Lake Extension Cost ($M)	**263**				
Total Capital Cost ($M)	**432**				

SUMMARY - 138 kV FARO TO WATSON LAKE WITH SLATE RAPIDS & HOOLE CANYON ROR

1. Full transmission line from Faro to Watson Lake, hence Watson Lake is grid connected.
2. 95 MW of transfer capacity to Faro meets 53 MW of Yukon's peak baseline capacity gap in 2065.
3. Price to build the Main Transmission Line from Faro to Watson Lake and transmission taps to Slate Rapids and Hoole Canyon ROR is $432 M
4. An attraction to future mines along the Robert Campbell highway for potential supply of power.
5. Extending the transmission line from Slate Rapids to Watson Lake can be done any time post-2035.

3.3.3 Option 1.3 – 138 kV Faro to Watson Lake (Slate Rapids Only)

Figure 3-3 and Table 3-7 summarizes the generation plan configuration for Option 1.3. This option consists of a 138 kV transmission line interconnecting Faro and Watson Lake with only Slate Rapids tapping into the Main Transmission Line. Slate Rapids was analyzed as a standalone generation option as part of project scalability to see if special conditions (e.g. curtailment parameters) were associated with Slate Rapids as a standalone project.

Figure 3-3: 138 kV Faro to Watson Lake (Slate Rapids Only)

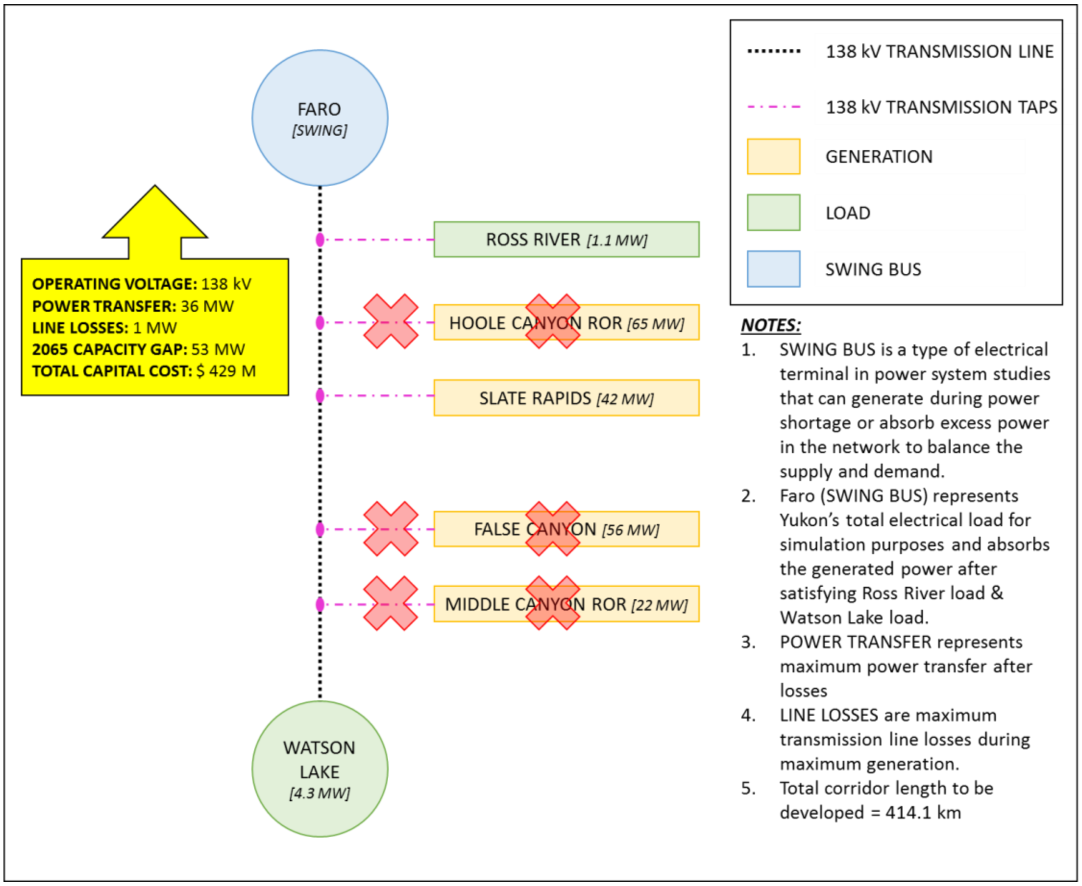


Table 3-7: Transfer Capacity & Cost Estimate – 138 kV Faro to Watson Lake (Slate Rapids Only)

	Hoole Canyon ROR	Slate Rapids	False Canyon	Middle Canyon ROR	Watson Lake
Maximum Generation Capacity (MW)	-	42	-	-	-
Corridor Length from Faro (km)	-	151	-	-	414
Tap Distance from Corridor (km)	-	9	-	-	-
Total Distance from Faro	-	161			414
Maximum Transmission Line Losses (MW)	1				
Total Power Transfer Capacity to Faro (including line losses) (MW)	36				
Slate Rapids Project Capital Cost ($M)	166				
Watson Lake Extension Cost ($M)	263				
Total Capital Cost ($M)	429				

SUMMARY - 138 kV FARO TO WATSON LAKE WITH SLATE RAPIDS ONLY

1. Full transmission line from Faro to Watson Lake, hence grid-connecting Watson Lake.
2. 36 MW of transfer capacity to Faro does not meet the forecast 53 MW of Yukon baseline capacity gap in 2065, but 36 MW is sufficient to satisfy the forecast capacity requirement until 2050 when Hoole Canyon ROR is planned to be operational[6].
3. Price to build the Main Transmission Line from Faro to Watson Lake and the transmission tap to Slate Rapids is $429 M.
4. Extending the transmission line from Slate Rapids to Watson Lake can be done any time post-2035.

3.3.4 Option 1.4 – 138 kV Faro to Watson Lake (False Canyon + Middle Canyon ROR): Generation Curtailed

Figure 3-4 and Table 3-8 summarizes the generation plan configuration for Option 1.4[7]. This option consists of a 138 kV transmission line interconnecting Faro to Watson Lake with False Canyon and Middle Canyon ROR tapping into the Main Transmission Line. It is important to note that to maintain angular stability on the transmission line, False Canyon output had to be curtailed[8] to 47 MW, down from its maximum generation capacity of 56 MW. Despite this curtailment, the False Canyon + Middle Canyon ROR cluster was still able to meet the forecast Baseline 2065 peak demand of 53 MW. Transmission upgrades are possible to increase the transfer capacity beyond 53 MW, but these upgrades are not required until after 2065.

[6] The baseline 2050 capacity gap is 37 MW and Yukon may be short of peak capacity before Hoole Canyon is operational in 2050. This shortage is primarily due to the additional Watson Lake load of 4.3 MW considered in this study. Peak capacity would have to be arranged between 2045 and 2050 or Hoole Canyon operations must be advanced by a few years.

[7] Middle Canyon tap point to Watson lake portion is not mandatory, but because it represents a small percentage of the entire corridor, Midgard chose to include it.

[8] Generation curtailing is the action of reducing the production level of a generation plant below its actual maximum. In this study, curtailment is required to maintain transmission system stability.

Figure 3-4: 138 kV Faro to Watson Lake (False Canyon + Middle Canyon ROR) – Generation Curtailed

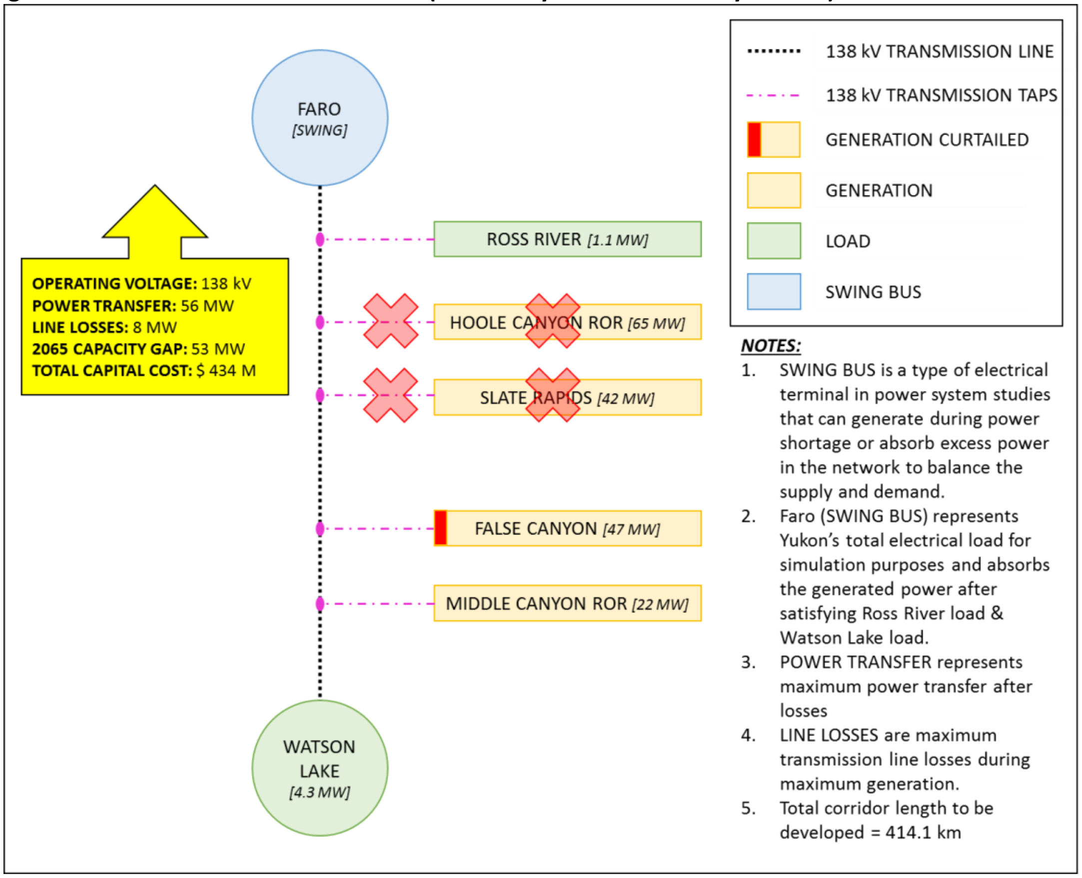


Table 3-8: Transfer Capacity & Cost Estimate – 138 kV Faro to Watson Lake (False Canyon + Middle Canyon ROR) Generation Curtailed

	Hoole Canyon ROR	Slate Rapids	False Canyon	Middle Canyon ROR	Watson Lake
Maximum Generation Capacity (MW)	-	-	47	22	-
Corridor Length from Faro (km)	-	-	336	356	414
Tap Distance from Corridor (km)	-	-	7	6	-
Total Distance from Faro	-	-	343	362	414
Maximum Transmission Line Losses (MW)	8				
Total Power Transfer Capacity to Faro (including line losses) (MW)	56				
False Canyon Project Capital Cost ($M)	349				
Middle Canyon ROR Tap Cost ($M)	9				
Watson Lake Extension Cost[9] ($M)	77				
Total Capital Cost ($M)	434				

[9] Watson Lake extension costs are calculated for a transmission line from False Canyon to Watson Lake. The Watson lake extension costs for a transmission line from Middle Canyon is $57 M

SUMMARY - 138 kV FARO TO WATSON LAKE WITH FALSE CANYON AND MIDDLE CANYON ROR : GENERATION CURTAILED

1. Full transmission line from Faro to Watson Lake, hence grid connecting Watson Lake.
2. 56 MW of transfer capacity to Faro meets 53 MW of Yukon's peak baseline capacity gap in 2065.
3. The power generation capacity of False Canyon must be curtailed to maintain the 33^{o} angular stability requirement[10].
    a. If mining load is added along the Robert Campbell Highway, the need to curtail False Canyon output may be reduced or eliminated.
4. Cost to build the Main Transmission Line from Faro to Watson Lake and the transmission taps to False Canyon and Middle Canyon ROR cluster is $434 M.
5. Extending the transmission line from False Canyon/Middle Canyon ROR to Watson Lake can be done any time post-2035.

3.3.5 Option 1.5 – 138 kV Faro to Watson Lake (False Canyon + Middle Canyon ROR): Series Compensated

Figure 3-5 and Table 3-9 summarizes the generation plan configuration for Option 1.5. This option consists of a 138 kV transmission line interconnecting Faro to Watson Lake with False Canyon and Middle Canyon ROR tapping into the Main Transmission Line. False Canyon output which was curtailed in Option 1.4 is now operated at full capacity by adding 30% series compensation on the transmission line[11]. By reducing the reactance on the transmission line, series compensation improves angular stability and increases the power transfer capability[12]. The location of series compensation was not analyzed in this report.

This option will be useful post 2065 when the Yukon capacity demand climbs over 53 MW and more capacity is needed from False Canyon and Middle Canyon ROR generation cluster.

[10] Refer Appendix B, Section B.4.5 for Angular stability

[11] The costs for series compensation estimated at $10M ($5M for the series compensation materials, and $5M for local site work to build a facility and install the series compensation).

[12] Power Transfer $=\frac{\text{(Sending End Voltage)}*\text{(Receiving end voltage}}{Xc}$ X Sine (Angular difference). By Series compensation, the denominator decreases and increases the power flow, keeping the angular stability intact.

Figure 3-5: 138 kV Faro to Watson Lake (False Canyon + Middle Canyon ROR) – Series Compensated

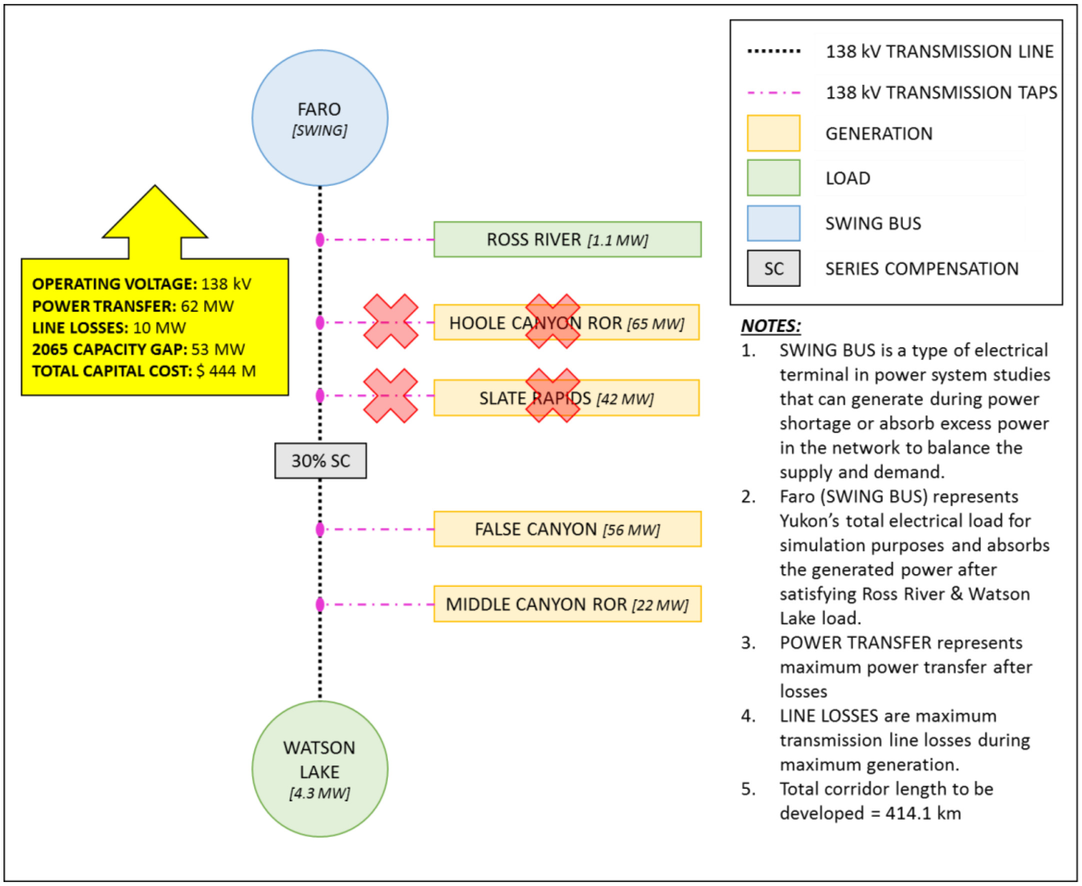


Table 3-9: Transfer Capacity & Cost Estimate - 138 kV Faro to Watson Lake (False Canyon + Middle Canyon ROR) Series Compensated

	Hoole Canyon ROR	Slate Rapids	False Canyon	Middle Canyon ROR	Watson Lake
Maximum Generation Capacity (MW)	-	-	56	22	-
Corridor Length from Faro (km)	-	-	336	356	414
Tap Distance from Corridor (km)	-	-	7	6	-
Total Distance from Faro	-	-	343	362	414
Maximum Transmission Line Losses (MW)	**10**				
Total Power Transfer Capacity to Faro (including line losses) (MW)	**62**				
False Canyon Project Capital Cost ($M)	**349**				
Middle Canyon ROR Tap Cost ($M)	**9**				
Watson Lake Extension Cost[13] ($M)	**77**				
Series Compensation Costs ($M)	**10**				
Total Capital Cost ($M)	**444**				

[13] Watson Lake extension costs are calculated for a transmission line from False Canyon to Watson Lake. The Watson lake extension costs for a transmission line from Middle Canyon is $57 M

SUMMARY - 138 kV FARO TO WATSON LAKE WITH FALSE CANYON AND MIDDLE CANYON ROR: SERIES COMPENSATED

1. Full transmission line from Faro to Watson Lake, hence grid connecting Watson Lake.
2. 62 MW of transfer capacity to Faro meets 53 MW of Yukon's peak baseline capacity gap in 2065.
3. The power generation capacity of False Canyon has been increased to its maximum through series compensation and these upgrades will not be needed up until 2065.
4. The cost to build the Main Transmission Line from Faro to Watson Lake, transmission taps to False Canyon and Middle Canyon ROR and 30% series compensation is $444 M.
5. Extending the transmission line from False Canyon/Middle Canyon ROR to Watson Lake can be done any time post-2035.

3.3.6 Option 1.6 – 138 kV Faro to Watson Lake (False Canyon Only)

Figure 3-6 and Table 3-10 summarize the generation plan configuration for Option 1.6. This option consists of a 138 kV transmission line interconnecting Faro and Watson Lake with only False Canyon tapping into the Main Transmission Line. False Canyon was analyzed as a standalone generation option as part of project scalability to see if special conditions (e.g. curtailment parameters) were associated with False Canyon as a standalone project.

Figure 3-6: 138 kV Faro to Watson Lake (False Canyon Only)

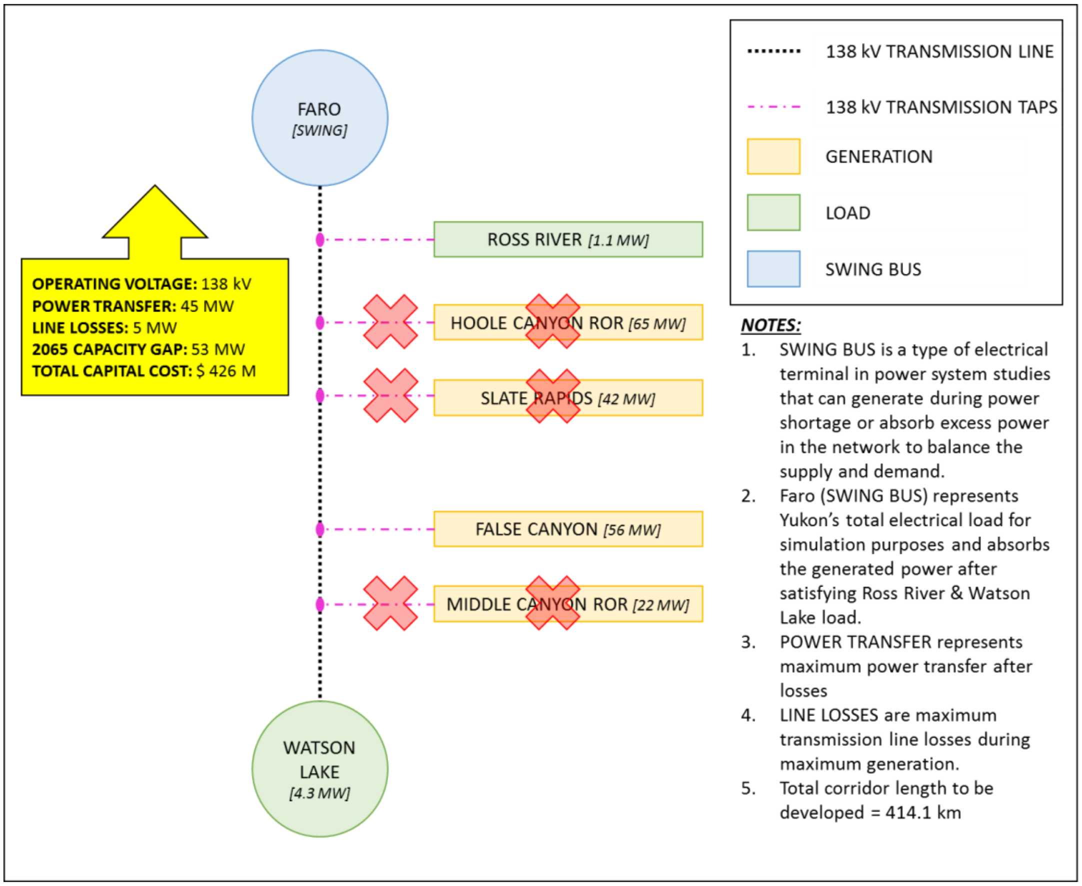


Table 3-10: Transfer Capacity & Cost Estimate – 138 kV Faro to Watson Lake (False Canyon Only)

	Hoole Canyon ROR	Slate Rapids	False Canyon	Middle Canyon ROR	Watson Lake
Maximum Generation Capacity (MW)	-	-	56	-	-
Corridor Length from Faro (km)	-	-	336	-	414
Tap Distance from Corridor (km)	-	-	7	-	-
Total Distance from Faro	-	-	343	-	414
Maximum Transmission Line Losses (MW)	5				
Total Power Transfer Capacity to Faro (including line losses) (MW)	45				
False Canyon Project Capital Cost ($M)	349				
Watson Lake Extension Cost[14] ($M)	77				
Total Capital Cost ($M)	426				

[14] Watson Lake extension costs are calculated for a transmission line from False Canyon to Watson Lake. The Watson lake extension costs for a transmission line from Middle Canyon is $57 M

SUMMARY - 138 kV FARO TO WATSON LAKE WITH FALSE CANYON ONLY

1. Full transmission line from Faro to Watson Lake, hence grid connecting Watson Lake.
2. 45 MW of transfer capacity to Faro does not meet the forecast 53 MW of Yukon baseline capacity gap in 2065, but 45 MW is almost sufficient to satisfy the forecast capacity requirement until 2060 when Middle Canyon is planned to be operational[15].
3. Price to build the Main Transmission Line from Faro to Watson Lake and the transmission tap to False Canyon is $426 M.
4. Extending the transmission line from False Canyon/Middle Canyon ROR to Watson Lake can be done any time post-2035.

3.4 Options 2.X – 230 kV Transmission Line Configurations

3.4.1 Option 2.1 – 230 kV Faro to Watson Lake (Slate Rapids + Hoole Canyon ROR)

Figure 3-7 and Table 3-11 summarizes the generation plan configuration for Option 2.1. This option consists of a 230 kV transmission line interconnecting Faro and Watson Lake with Slate Rapids and Hoole Canyon ROR tapping into the Main Transmission Line.

[15] The baseline 2060 capacity gap is 47 MW and Yukon may be short 2MW of peak capacity before Middle Canyon is operational in 2060. This shortage is primarily due to the additional Watson Lake load of 4.3 MW considered in this study. 2MW of peak capacity may need to be arranged between 2055 and 2060, or Middle Canyon construction may need to be advanced by a few years.

Figure 3-7: 230 kV Faro to Watson Lake (Slate Rapids + Hoole Canyon ROR)

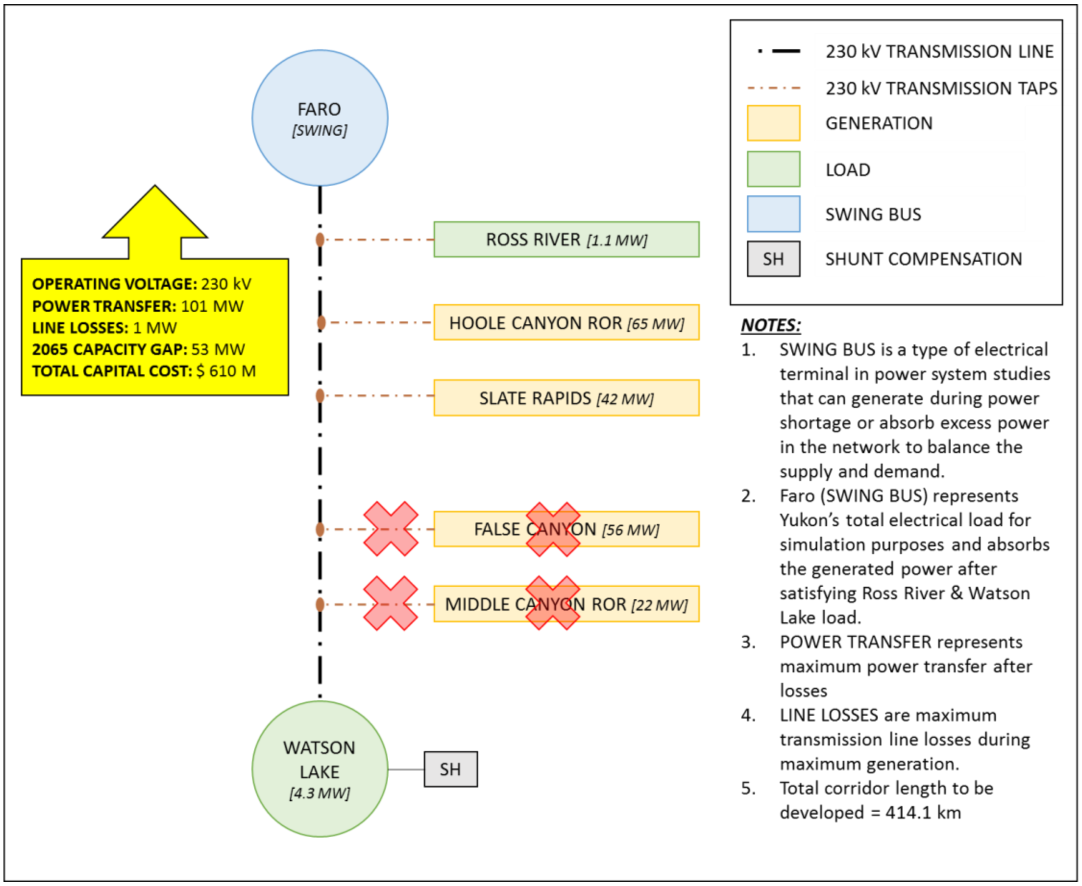


Table 3-11: Transfer Capacity & Cost Estimate – 230 kV Faro to Watson Lake (Slate Rapids + Hoole Canyon ROR)

	Hoole Canyon ROR	Slate Rapids	False Canyon	Middle Canyon ROR	Watson Lake
Maximum Generation Capacity (MW)	65	42	-	-	-
Corridor Length from Faro (km)	95	151	-	-	414
Tap Distance from Corridor (km)	2	9	-	-	-
Total Distance from Faro	96	161	-	-	414
Maximum Transmission Line Losses (MW)	1				
Total Power Transfer Capacity to Faro (including line losses) (MW)	101				
Slate Rapids Project Capital Cost ($M)	233				
Hoole Canyon ROR Tap Cost ($M)	3				
Watson Lake Extension Cost ($M)	374				
Total Capital Cost ($M)	610				

SUMMARY - 230 kV FARO TO WATSON LAKE WITH SLATE RAPIDS AND HOOLE CANYON ROR

1. Full transmission line from Faro to Watson Lake, hence grid connecting Watson Lake.
2. 101 MW of transfer capacity to Faro exceeds the forecast 53 MW of Yukon baseline capacity gap in 2065.
3. Cost to build the Main Transmission Line from Faro to Watson Lake and transmission taps to Slate Rapids and Hoole Canyon ROR is $610 M.
4. 230 kV transmission line demonstrates higher power transfer capacity and lower transmission line losses compared to the 138 kV transmission line, but is more expensive than 138 kV.
5. Extending the transmission line from Slate Rapids to Watson Lake can be done any time post-2035.

3.4.2 Option 2.2 – 230 kV Faro to Watson Lake (False Canyon + Middle Canyon ROR)

Figure 3-8 and Table 3-12 summarizes the generation plan configuration for Option 2.2. This option consists of a 230 kV transmission line interconnecting Faro and Watson Lake with False Canyon and Middle Canyon ROR tapping into the Main Transmission Line.

Figure 3-8: 230 kV Faro to Watson Lake (False Canyon + Middle Canyon ROR)

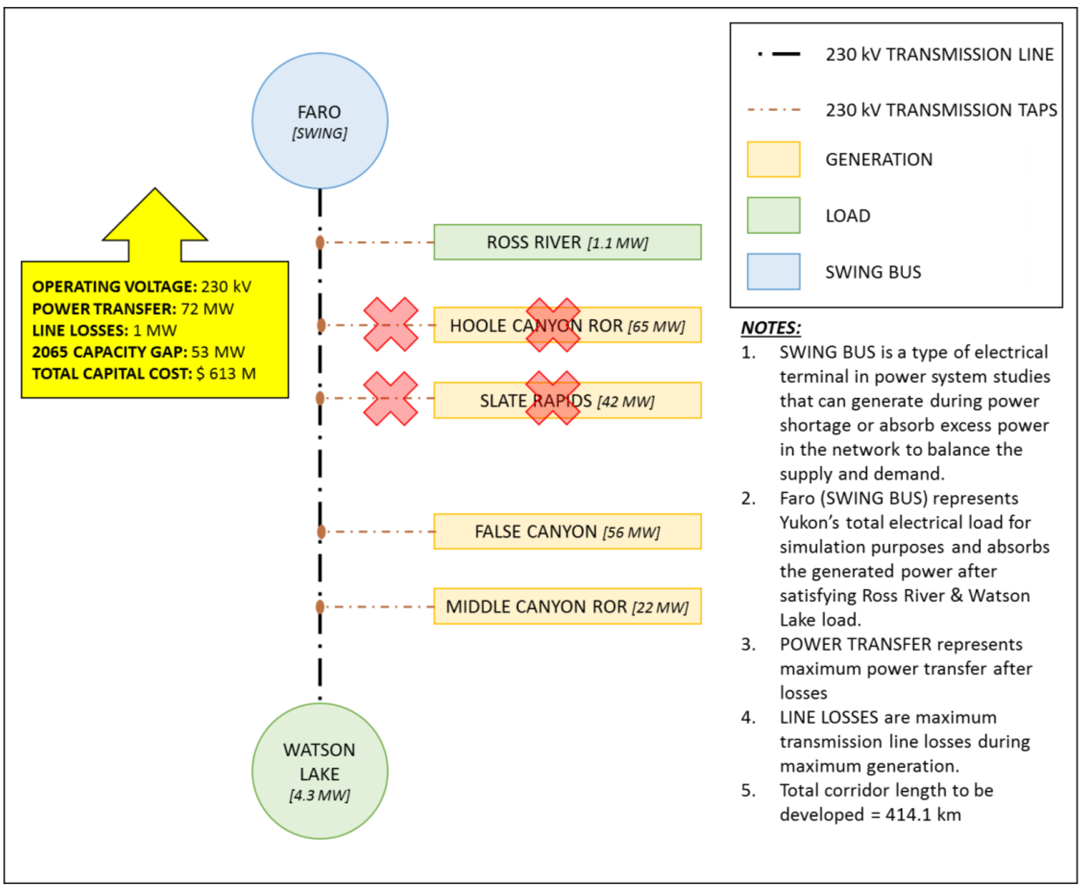


Table 3-12: Transfer Capacity & Cost Estimate – 230 kV Faro to Watson Lake (False Canyon + Middle Canyon ROR)

	Hoole Canyon ROR	Slate Rapids	False Canyon	Middle Canyon ROR	Watson Lake
Maximum Generation Capacity (MW)	-	-	56	22	-
Corridor Length from Faro (km)	-	-	336	356	414
Tap Distance from Corridor (km)	-	-	7	6	-
Total Distance from Faro	-	-	343	362	414
Maximum Transmission Line Losses (MW)	**1**				
Total Power Transfer Capacity to Faro (including line losses) (MW)	**72**				
False Canyon Project Capital Cost ($M)	**493**				
Middle Canyon ROR Tap Cost ($M)	**11**				
Watson Lake Extension Cost[16] ($M)	**109**				
Total Capital Cost ($M)	**613**				

SUMMARY - 230 kV FARO TO WATSON LAKE WITH FALSE CANYON AND MIDDLE CANYON ROR

1. Full transmission line from Faro to Watson Lake, hence grid connecting Watson Lake.
2. 72 MW of transfer capacity to Faro exceeds the forecast 53 MW capacity gap in 2065.
3. Cost to build the Main Transmission Line from Faro to Watson Lake and transmission taps to False Canyon and Middle Canyon ROR is $613 M.
4. 230 kV transmission line demonstrates higher power transfer capacity and lower transmission line losses compared to the 138 kV transmission line, but more expensive than 138 kV.
5. Extending the transmission line from False Canyon/Middle Canyon ROR to Watson Lake can be done any time post-2035.

3.5 Transfer Capacity and Cost Estimate Summary

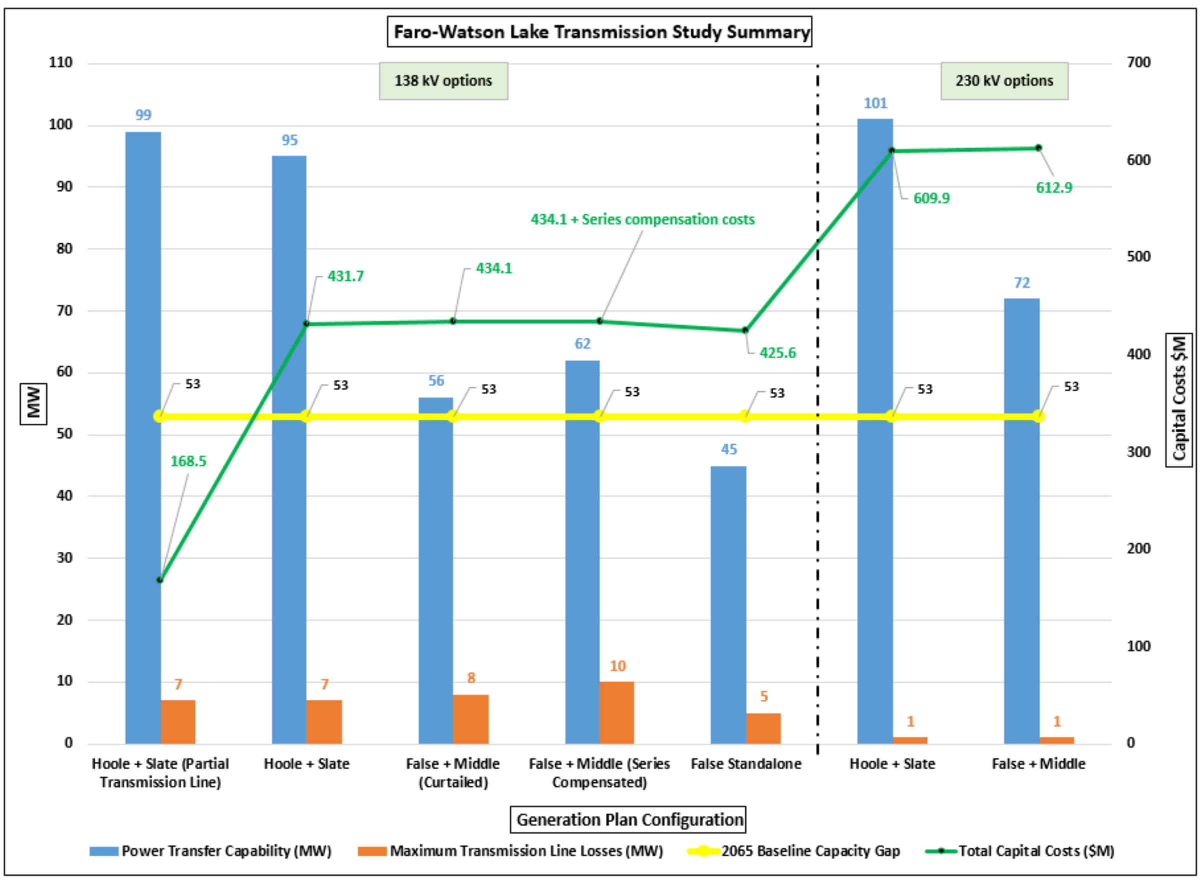
In summary, all of the transmission and generation options are able to meet the forecast transfer capacity requirements. It is noted that in the 138 kV False Canyon + Middle Canyon ROR generation configuration, False Canyon is curtailed, but sufficient transfer capacity exists to meet the forecast demand up until 2065. In the 138 kV False Canyon standalone generation configuration, 45 MW of transfer capacity to Faro does not

[16] Watson Lake extension costs are calculated for a transmission line from False Canyon to Watson Lake. The Watson lake extension costs for a transmission line from Middle Canyon is $81 M

meet the forecast 53 MW capacity gap in 2065, but 45 MW is almost sufficient[17] to satisfy the forecast capacity demand gap until 2060 when Middle Canyon ROR is planned to be operational, and the combination of False Canyon + Middle Canyon ROR has sufficient transfer capacity to meet the forecast baseline 2065 capacity gap of 53MW as seen in Figure 3-9 and Table 3-13. Similarly, In the 138 kV Slate Rapids standalone generation configuration, 36 MW of transfer capacity to Faro does not meet the forecast 53 MW capacity gap in 2065, but 36 MW is sufficient to satisfy the forecast capacity demand gap until 2050 when Hoole Canyon ROR is planned to be operational, and the combination of Slate Rapids + Hoole Canyon ROR has sufficient transfer capacity to meet the forecast baseline 2065 capacity gap of 53MW as seen in Figure 3-9 and Table 3-13.

Also shown in Figure 3-9 and Table 3-13 is that the capital cost for the 230 kV configurations is significantly higher than the capital costs for 138 kV configurations. To determine which voltage, 138 kV or 230 kV, should be selected for the transmission line, the tradeoff between capital cost and the ongoing value of transmission line losses (which are lower for 230 kV) must be analyzed.

Figure 3-9: Faro-Watson Lake Transmission Study Summary



[17] The baseline 2060 capacity gap is 47 MW and the Yukon may be short 2MW of peak capacity before Middle Canyon is operational in 2060. This shortage is primarily due to the additional Watson Lake load of 4.3 MW considered in this study. 2MW of peak capacity would have to be arranged between 2055 and 2060 or Middle Canyon operations must be advanced by a few years.

Table 3-13: Faro-Watson Lake Transmission Study Summary

Option	Generation Mix	Centerline Distance	Voltage	2065 Capacity Need	Generation Capability	Power Transfer Capability[18]	Maximum Transmission Line Losses	Watson Lake Extension Costs	Capital Costs[19]
1.1	Slate Rapids + Hoole Canyon (ROR): Partial Transmission Line	151 km	138 kV	53 MW	107 MW	98 MW	8 MW	-	$169M
1.2	Slate Rapids + Hoole Canyon ROR	414 km	138 kV	53 MW	107 MW	95 MW	7 MW	$263M	$432M
1.3	Slate Rapids Standalone	414 km	138 kV	53 MW	42 MW	36 MW	1 MW	$263M	$429M
1.4	False Canyon + Middle Canyon ROR: (Generation Curtailed)	414 km	138 kV	53 MW	78 MW	56 MW	8 MW	$77M	$434M
1.5	False Canyon + Middle Canyon ROR: (Series Compensated)	414 km	138 kV	53 MW	78 MW	62 MW	10 MW	$77M	$444M
1.6	False Canyon: Standalone	414 km	138 kV	53 MW	56 MW	45 MW	5 MW	$77M	$426M
2.1	Slate Rapids + Hoole Canyon ROR	414 km	230 kV	53 MW	107 MW	101 MW	1 MW	$374M	$610M
2.2	False Canyon + Middle Canyon ROR	414 km	230 kV	53 MW	78 MW	72 MW	1 MW	$109M	$613M

[18] The power transfer capability represents power available at Faro after deducting transmission losses, Watson Lake load (4.3 MW) and Ross River load (1.1 MW).

[19] Capital Costs = Main Transmission Line Costs + Transmission Tap Costs + Watson Lake Extension Costs

4 Voltage Selection: 138 kV or 230 kV

From Section 3, both 138 kV and 230 kV generation plan configurations satisfied the Yukon 2065 baseline case capacity requirements. As mentioned previously in Table 3-2, the major difference between the 138 kV voltage option and the 230 kV voltage option are differences in line losses, capital cost and operating costs. Therefore, since both 138 kV and 230 kV are technically viable options, the deciding factor for voltage selection is the total cost of each option.

Table 4-1 and Figure 4-1 shows the average annual line losses[20] for the 138 kV and 230 kV transmission line options. See Appendix D for more details on the calculation methodology for annual average line losses.

Table 4-1: 138 kV & 230 kV Annual Average Transmission Line Losses

Year	138 kV Transmission Losses (MW)	230 kV Transmission Losses (MW)
2035	0.6	0.06
2040	0.9	0.08
2045	1.2	0.11
2050	1.5	0.14
2055	2.0	0.18
2060	2.4	0.22
2065	3.0	0.27

In order to determine the value of lost energy due to transmission line losses and the costs involved for Operations and Maintenance (O&M), the following cost, operation and economic assumptions are assumed:

1) Project Planning Period: 30 years (2035 - 2065)
2) Transmission Line O&M Costs & Capital Re-investment Costs: 2% of the project capital cost per year
3) Real Discount Rate: 3.38%
4) Cost of Energy Losses ("COEL"): 185 $/MWh[21].

Using the above assumptions, Table 4-2 lists the costs associated with 138 kV and a 230 kV transmission line over its lifetime.

[20] Average losses are calculated between Faro and Middle Canyon as the maximum power flow occurs in this stretch. Middle Canyon to Watson Lake losses are ignored due to the lower power flows and non-significant size.

[21] Site Screening Inventory (Part 1 of 2), Section 5.1, Page 29.

Figure 4-1: 138 kV & 230 kV Annual Average Transmission Line Losses

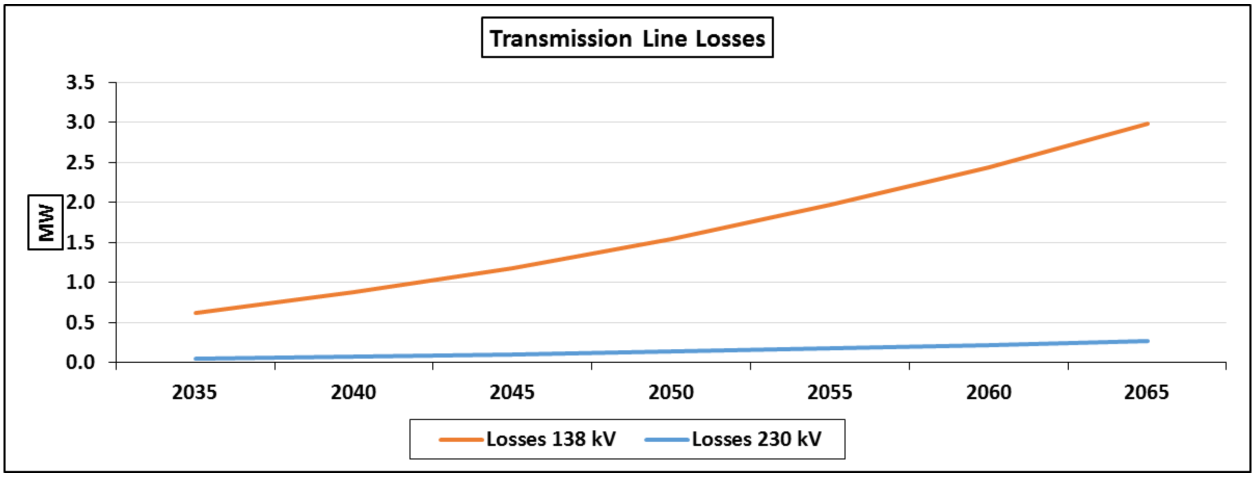


Table 4-2: 138 kV and 230 kV Transmission line Costs from Faro to Watson Lake

	138 kV Transmission Line from Faro to Watson Lake	230 kV Transmission Line from Faro to Watson Lake
Capital Costs ($M)[22]	416	589
NPV of Lost Energy Value ($M)	44	4
NPV of O&M ($M)	158	224
TOTAL ($M)	***618***	***817***

After accounting for the losses and the O&M costs for the 138 kV and 230 kV transmission lines, the 138 kV voltage option is less expensive than the 230 kV voltage option. Therefore, the 138 kV voltage option was selected as the voltage option for the Watson Lake to Faro transmission line.

[22] Capital Costs include the costs to build the Main Transmission Line from Faro to Watson Lake and excludes the costs for the transmission taps connecting the generation projects to the Main Transmission Line.

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5 138 kV Scalability Considerations

In the *Scalability Assessment Report,* the Next Generation Hydro projects were evaluated on the basis of progressively increasing project energy and capacity over time. The scalability build out of the False Canyon + Middle Canyon ROR and Slate Rapids + Hoole Canyon ROR cascades from this report are shown in Figure 5-1 and Figure 5-2 respectively.

Figure 5-1: False Canyon + Middle Canyon ROR Scalability Build Out

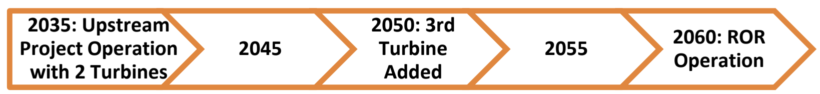


Figure 5-2: Slate Rapids + Hoole Canyon ROR Scalability Build Out

Figure 5-3 shows the transmission scalability build out for developing Slate Rapids + Hoole Canyon ROR cascade and False Canyon + Middle Canyon ROR cascade.

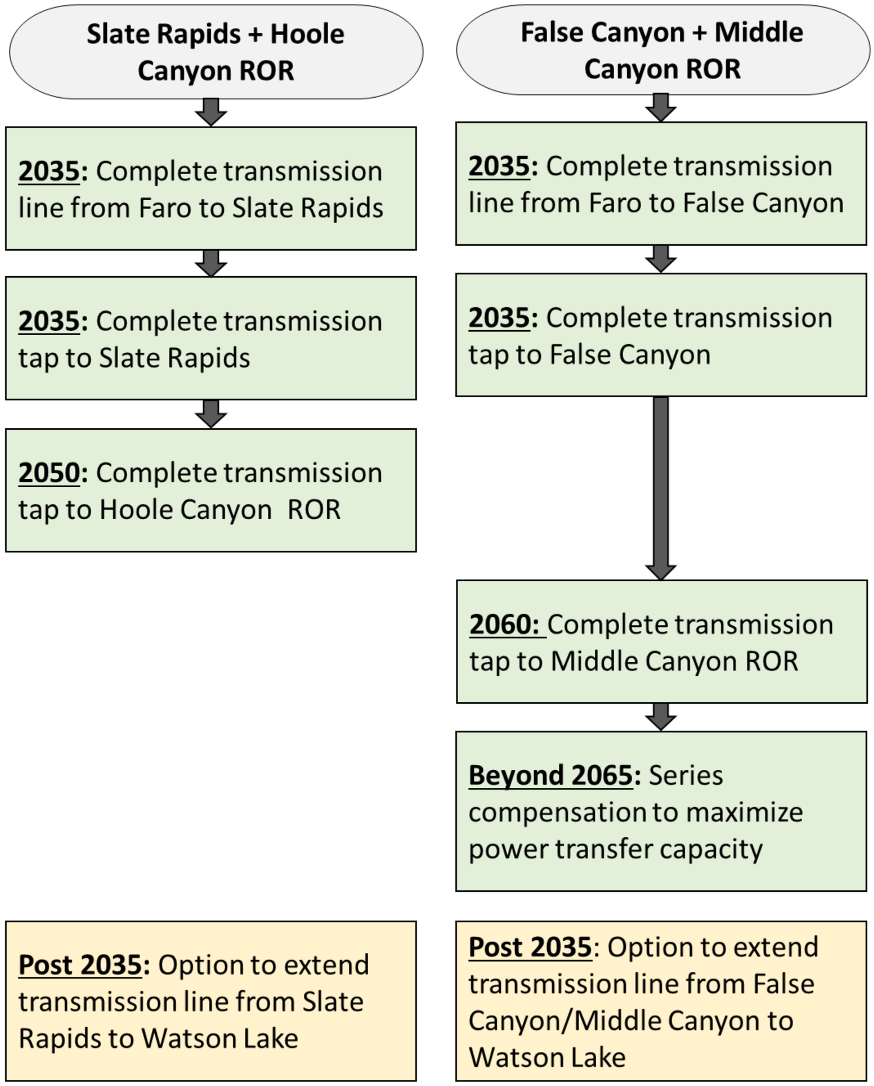
In the case of Slate Rapids + Hoole Canyon ROR, Slate Rapids will be developed first[23] and a corresponding 138 kV transmission line to Slate Rapids must be completed by 2035 to carry power generated from Slate Rapids to Faro. A 138 kV Hoole Canyon ROR transmission tap is then planned for completion by 2050 to satisfy the forecast 2050 baseline capacity demand. The 138 kV transmission line can be extended beyond Slate Rapids to Watson Lake at any time post 2035 to interconnect Watson Lake or mining loads as required.

In the case of the False Canyon + Middle Canyon ROR cascade scalability option, a 138 kV transmission line False Canyon will be developed first for operation in 2035[24]. A Middle Canyon ROR transmission connection is then planned for completion by 2060 to satisfy the forecast 2060 baseline capacity demand. Since the False Canyon and Middle Canyon ROR generation output was curtailed to a maximum of 56 MW in order to meet stability requirements, the 138 kV transmission line may be upgraded post 2065 to support maximum power transfer from False Canyon and Middle Canyon ROR. The 138 kV transmission line can be extended beyond False Canyon to Watson Lake at any time post 2035 to interconnect Watson Lake and or mining loads as required.

[23] Refer Yukon Next Generation Hydro: Scalability Assessment Report, Section 6.6

[24] Refer Yukon Next Generation Hydro: Scalability Assessment Report, Section 6.5

Figure 5-3: 138 kV Transmission Scalability: (Slate + Hoole) and (False + Middle)



Appendix A: Yukon Transmission Corridor Routing Study - JDMA

J.D. Mollard and Associates (2010) Limited

Yukon Transmission Line Corridor Routing Study

DRAFT REPORT
June 05, 2015

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1 Introduction

1.1 Scope of work

Midgard Consulting Inc. (MC) commissioned J.D. Mollard and Associates (2010) Limited (JDMA) to conduct a desktop routing study to identify and characterize transmission line corridors to potential hydroelectric development sites in the Yukon Territory. 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. This work was undertaken as part of studies MC is currently conducting for Yukon Energy Corporation to assess hydroelectric power development options in the Yukon Territory.

1.2 Study areas

MC initially identified 11 potential hydroelectric sites for which transmission line corridors were required. Those 11 sites are listed in Table 1.

Table 1: Transmission Line Corridors Evaluated

Transmission Line Corridor or Hydroelectric Site Name	Station Connection Point	Length (km)
Faro to Watson Lake	Faro & Watson Lake	414.1
Two Mile Canyon	Mayo	112.3
NWPI	Whitehorse	100.7
Detour Canyon	Faro	82.6
Fraser Falls	Mayo	48.2
Granite Canyon	Line tap	14.6
Slate Rapids	Faro-Watson Lake tap	9.2
False Canyon	Faro-Watson Lake tap	7.4
Middle Canyon	Faro-Watson Lake tap	6.2
Upper Canyon	Faro-Watson Lake tap	2.8
Hoole Canyon	Faro-Watson Lake tap	1.8

Subsequent to work beginning on this project MC requested that work on the NWPI and Upper Canyon sites be discontinued. The location of the nine (9) remaining sites are shown in Figure 1.

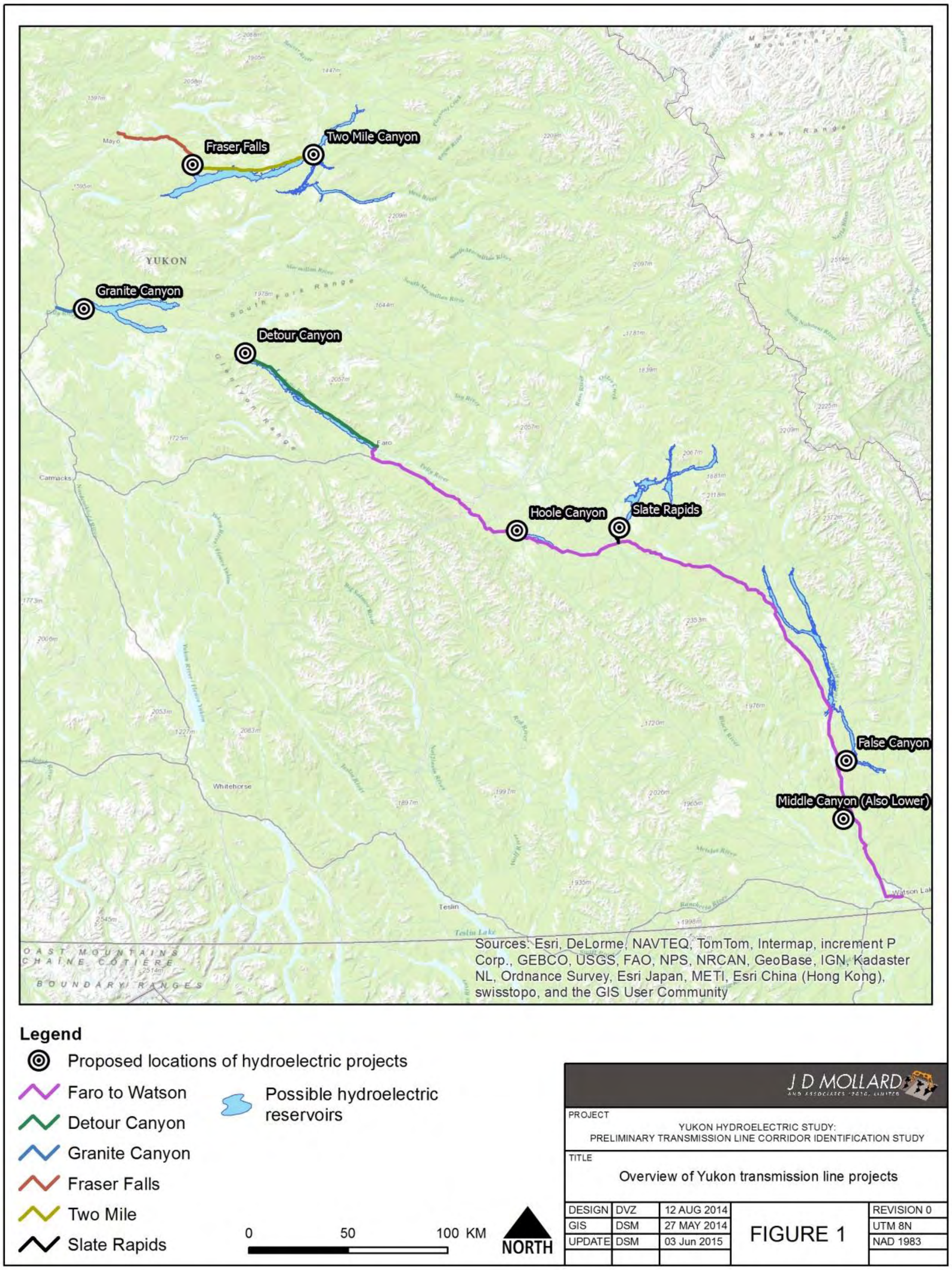

Figure 1: Overview map

2 Methodology

The desktop transmission line corridor routing study was done at a high level utilizing readily available GIS-based data and satellite imagery. Examination of corridor options was completed with SPOT 10 m and 20 m resolution satellite imagery and ESRI ArcGIS and MicroImages TNT MIPS software. Data were obtained from territorial and national sources to aid in corridor optimization and characterization.

MC provided the following routing criteria:

- Typical transmission line structure spans will be approximately 200-230 m;
- Where practical, locate transmission line corridors adjacent to roadways to optimize construction and maintenance access;
- Reduce the corridor width below 500 m where the terrain adjacent to the corridor is not suitable for construction of a transmission line (e.g. steep slopes, proximity to waterbodies, permafrost affected ground, *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, evidence of permafrost-affected ground, topography, total length, as well as stream and wetland crossings to help identify feasible corridors.

2.1 Data sources

JDMA obtained base data for this project from free open-source files found on Government of Yukon and Government of Canada web pages.

The data used in this study includes 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	Elevation Data. © Department of Natural Resources Canada. "Canadian Digital Elevation Model". All rights reserved.
Surficial geology 100k_125k, 250k	Surficial geology and surficial material data	Surficial Geology. © Ministry of Energy, Mines and Resources. "Yukon Digital Surficial Geology Compilation". All rights reserved.
LCC-2000	Wetland and landcover data	Wetlands and landcover. © Department of Natural Resources Canada. "Land Cover Circa 2000" 1:250,000. 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	Permafrost. © Department of Natural Resources Canada. "Yukon Permafrost Network". All rights reserved.
Road network	Road network of the Yukon	Road network. © Department of Natural Resources Canada. "NRN YT". 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)	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.

The above data were downloaded from the following links:

- SPOT, CDEM, rivers, waterbodies, and road network data may be obtained from http://ftp2.cits.rncan.gc.ca/pub/,
- Surficial geology data may be obtained from http://www.geology.gov.yk.ca/digital_surficial_data.html
- Permafrost data may be 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 are available from ftp://ftp.geomaticsyukon.ca/GeoYukon/.

The data sources listed above were used as screening tools and to derive the statistics presented in Table 3. 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. 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 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 and LCC-2000 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. 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 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. 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.

The road layer was taken from the National Road Network – Yukon. 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 compiling the geospatial data listed in Table 2, JDMA identified corridors for the potential hydroelectric sites by viewing the constraining data in a GIS. The datasets were overlaid on the satellite imagery and potential centreline routes were drawn using the GIS tools. Routes were initially drawn as centrelines which later formed the basis for identifying the final 500 m wide corridors. Topography, surficial geology, water bodies and interpreted permafrost-affected terrain were the primary constraints used to identify potential centrelines. An important aspect of the analysis was the ability to view the terrain with panchromatic and multispectral imagery. In addition, the imagery and the digital elevation data were incorporated in TNT MIPS (JDMA's GIS software) which allows the user to view the imagery and topography in 3D. This provided an enhanced view of the terrain and imagery compared to regular 2D viewing. This was important for refining the routes in places where terrain is a limiting factor.

In places where existing roads or transmission lines are located near the desired route an attempt was made to identify centrelines within close proximity to the existing infrastructure to take advantage of these features for access during construction, operation and maintenance, and to reduce environmental impacts by placing the lines within already-disturbed corridors.

Lands with special designations, such as First Nations land and other named parcels, were taken into account by adjusting the centreline and corridor location as needed. However, these features are usually of secondary importance to terrain constraints.

500 m-wide corridors were generated after the potential centreline routes had been identified. In some cases the corridors are centred on the centreline; however, in many locations the corridors are offset from the centreline to facilitate potential centreline options, such as following a road or an existing

transmission line, or to provide options for avoiding undesirable terrain. In some locations the transmission line corridor was narrowed to less than 500 m to exclude terrain that is not suitable for transmission line construction. In a few locations the corridor was widened beyond 500 m so that viable options near the 500 m-wide cut-off were not excluded.

3 Results

Statistics compiled for each corridor and corridor segments are summarized in Table 3 which breaks down the routes according to a number of factors including corridor length and area, surficial geology, slopes, stream and deep valley crossings, environmental concerns, forest cover, wetlands, First Nations settlement lands, and designated land parcels / land uses. These categories provide a high level comparison of the types of terrain and other features that are present within each corridor. The following subsections describe some of the distinguishing characteristics of the transmission line corridors.

Table 3: Route Comparison Table

ROUTE ALTERNATIVES STATISTICS SUMMARY
PROJECT: Midgard Yukon Hydroelectric Connection
DATE: 02 JUN 2015

	Faro to Watson Lake	Faro to Hoole Canyon	Hoole Canyon to Slate Rapids	Slate Rapids to False Canyon	False Canyon to Middle Canyon	Middle Canyon to Watson Lake	Detour Canyon	Hoole Canyon	Slate Rapids	False Canyon	Middle Canyon	Granite Canyon	Fraser Falls to Mayo	Two Mile Canyon to Fraser Falls
CONSTRUCTION														
Total centreline length (Km)	414.1	94.6	56.8	184.3	20.4	58.0	82.6	1.8	9.2	7.4	6.2	14.6	48.2	64.5
Total corridor area (Ha)	20867	4733	2840	9195	1027	3072	4049	79	454	162	294	734	2420	3212
Total # of deep valley / canyon crossings	5	1	2	1	0	1	3	0	1	1	0	0	3	3
Total # of major stream crossings	6	2	2	1	0	1	1	0	0	0	0	0	1	1
LAND COVER (Ha)														
Dense coniferous (>60% crown closure)	2618	523	340	743	280	731	247	9	196	40	74	10	53	83
Coniferous - open canopy (26-60% crown closure)	11322	1414	1624	5792	649	1843	1276	56	165	42	210	182	740	811
Coniferous - sparse (10-25% crown closure)	2892	934	605	1306	7	40	461	9	47	0	7	119	552	513
Dense broadleaf (>60% crown closure)	68	66	0	2	0	0	118	0	0	3	0	0	15	14
Broadleaf - open canopy (26-60% crown closure)	21	1	0	20	0	0	3	0	0	0	0	0	0	3
Broadleaf - sparse (10-25% crown closure)	6	0	0	6	0	0	0	0	0	0	0	0	0	0
Mixedwood - open canopy (26-60% crown closure)	238	12	0	118	37	71	139	0	10	26	2	0	16	36
Mixedwood - sparse (10-25% crown closure)	2	2	0	0	0	0	0	0	0	0	0	0	0	0
Riparian zones (15 m around wetlands, streams, waterbodies)	510	99	33	296	23	60	84	1	18	5	7	7	42	90
Open water (from CanVec)	167	85	20	52	3	8	27	1	7	0	0	4	13	64
Treed wetlands	56	0	0	23	7	26	0	0	0	0	0	1	6	
Shrub wetlands	25	0	0	23	0	2	0	0	0	0	0	0	18	7
Herb wetlands	351	181	19	70	13	69	123	0	0	0	0	28	20	169
SURFICIAL GEOLOGY AND PERMAFROST (Ha)														
Aeolian	440	0	440	0	0	0	0	0	217	0	0	731	0	0
Colluvium	2	0	0	2	0	0	9	0	0	0	0	0	96	4
Fluvial	4791	951	939	1872	578	451	1588	30	141	139	39	3	301	361
Lacustrine	138	8	0	33	96	0	471	0	0	0	0	0	54	421
Moraine	12901	3238	1014	6157	353	2139	1726	26	93	23	254	0	1969	2427
Organic	2547	490	447	1128	0	483	71	23	4	0	0	0	0	0
Exposed bedrock	56	45	0	11	0	0	188	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	0	396	2344
Sporadic discontinuous permafrost	6078	0	0	1980	1026	3072	0	0	0	159	0	0	1	1
Extensive discontinuous permafrost	14789	4733	2840	7215	1	0	4049	79	454	3	294	734	2419	3211
SLOPE (Ha)														
Area of corridor on slopes 0 - 15°	20522.5	4586.9	2839.8	9013.2	1026.4	3056.2	3654.7	77.4	452.3	145.9	285.8	731.4	1966.4	2893.1
Area of corridor on slopes 15 - 30°	342.4	145.3	0.0	180.8	0.7	15.6	393.2	1.1	1.9	15.9	7.8	2.7	452.8	316.8
Area of corridor on slopes over 30°	2.1	0.9	0.0	1.2	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.9	2.2
FIRST NATIONS SETTLEMENT LANDS and SETTLED LAND (Ha)														
Category A	1952.8	0.0	672.8	1274.0	0.0	6.0	286.0	0.0	281.3	0.0	0.0	0.0	0.0	0.0
Category B	2866.7	662.2	112.1	819.3	461.8	811.3	1359.5	0.0	95.5	112.2	6.8	660.7	1663.6	936.9
Uncategorized FN lands	42.1	0.9	0.0	0.0	0.0	41.2	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fee Simple	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Interim Protected	4819.5	662.2	784.9	2093.3	461.8	817.3	1645.5	0.0	376.8	112.2	6.8	0.0	0.0	0.0
Urban land	1541.4	942.0	0.0	0.0	0.0	599.4	382.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
LAND USES (Ha)														
Bridgehead	28.1	9.5	0.9	9.0	0.0	8.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Environment	4.3	0.0	0.0	0.0	4.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Forestry	350.3	1.8	0.0	0.0	3.7	344.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Garbage dump	0.0	0.0	0.0	0.0	0.0	12.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Gravel Pit	641.5	104.3	108.4	304.5	12.1	112.2	28.0	0.0	0.0	5.1	0.0	0.0	0.0	0.0
Heritage	1.3	1.3	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0
Industrial	2.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Marine	1.3	1.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Parks, Campground, or Recreational	1202.0	0.8	48.9	1150.1	0.0	2.2	0.0	0.0	0.0	0.0	0.0	0.0	24.7	0.0
Quarry	9.6	0.0	0.0	4.0	0.0	5.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Rural residence	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Trapping	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Utility	296.3	296.2	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	118.2	0.4	5.2
ROADS PARALLEL TO AND WITHIN CORRIDOR (Km)														
Paved road	56.3	14.5	0	3.7	0	38.1	0.7	0	0	0	0	0.5	0.6	0
Improved gravel road	356.4	71.7	42.1	168.3	62	12.3	0	0	0	0	0	0	0.2	0
Trail or resource road	6.7	2.9	0.1	0.6	0.4	2.7	0.5	0	0	0	0	0	1.5	0

3.1 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 .

3.2 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.

3.3 Detour Canyon

The Detour Canyon corridor is 82.6 km long and originates at the Faro substation. It extends northwest from Faro, paralleling the Pelly River until it terminates near the Detour Lakes. The Detour Canyon corridor is located on a terrace that appears to be well above the adjacent Pelly River floodplain. The topography adjacent to the corridor slopes steeply upwards to the north and downwards towards the floodplain to the south. In most places the terrace is wide enough to accommodate a 500 m-wide corridor; however, the corridor has been narrowed to less than 500 m in a few areas where the terrace is narrower. There is no infrastructure development in the Detour Canyon area except near the town of Faro.

The dominant terrain unit crossed by the Detour Canyon corridor is moraine (1,726 Ha). The second most dominant terrain type is glaciofluvial terrace (1,588 Ha). There are also some small areas classified as bedrock. The slopes in the Detour Canyon corridor are generally less than 15° and the corridor crosses a number of ravines which require span lengths in the order of 150 to 250+m.

3.4 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.

3.5 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.

3.6 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.

3.7 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.

3.8 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 nine (9) potential hydroelectric sites 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 are delivered along with this draft report:

1) Route comparison spreadsheet
2) 9 Corridor shapefiles – 1 for each site
3) Overview map of all of JDMAs mapped corridors
4) Map booklet of corridors on SPOT 20 m NIR background
5) Map booklet of corridors on ESRI topographic base map background

These GIS products were created in ESRI ArcMap V.10.2

6 Signatures

Shayne MacDonald, B.Sc.

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

7 Route Figures

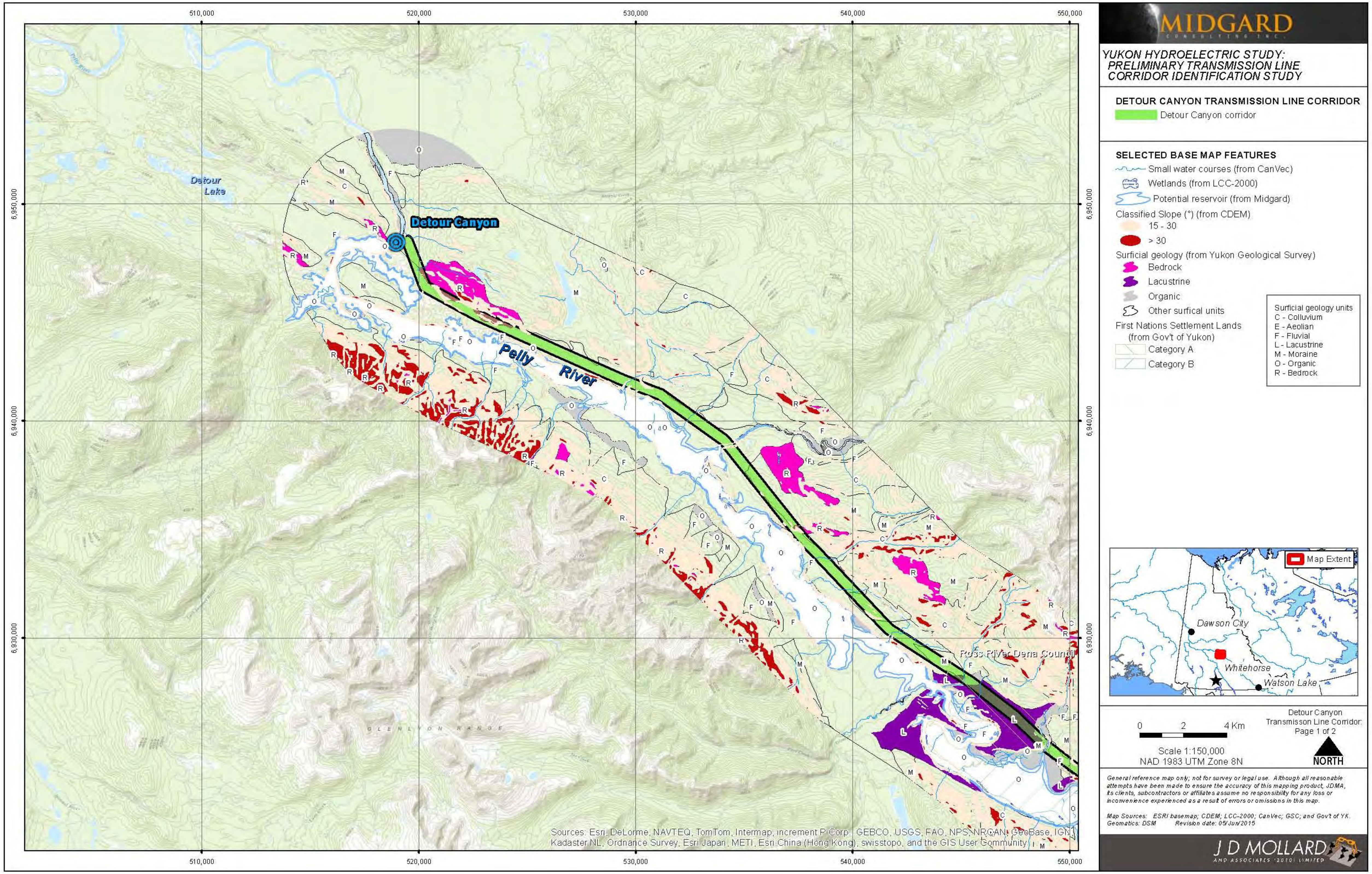

Figure 2: Detour Canyon Map 1

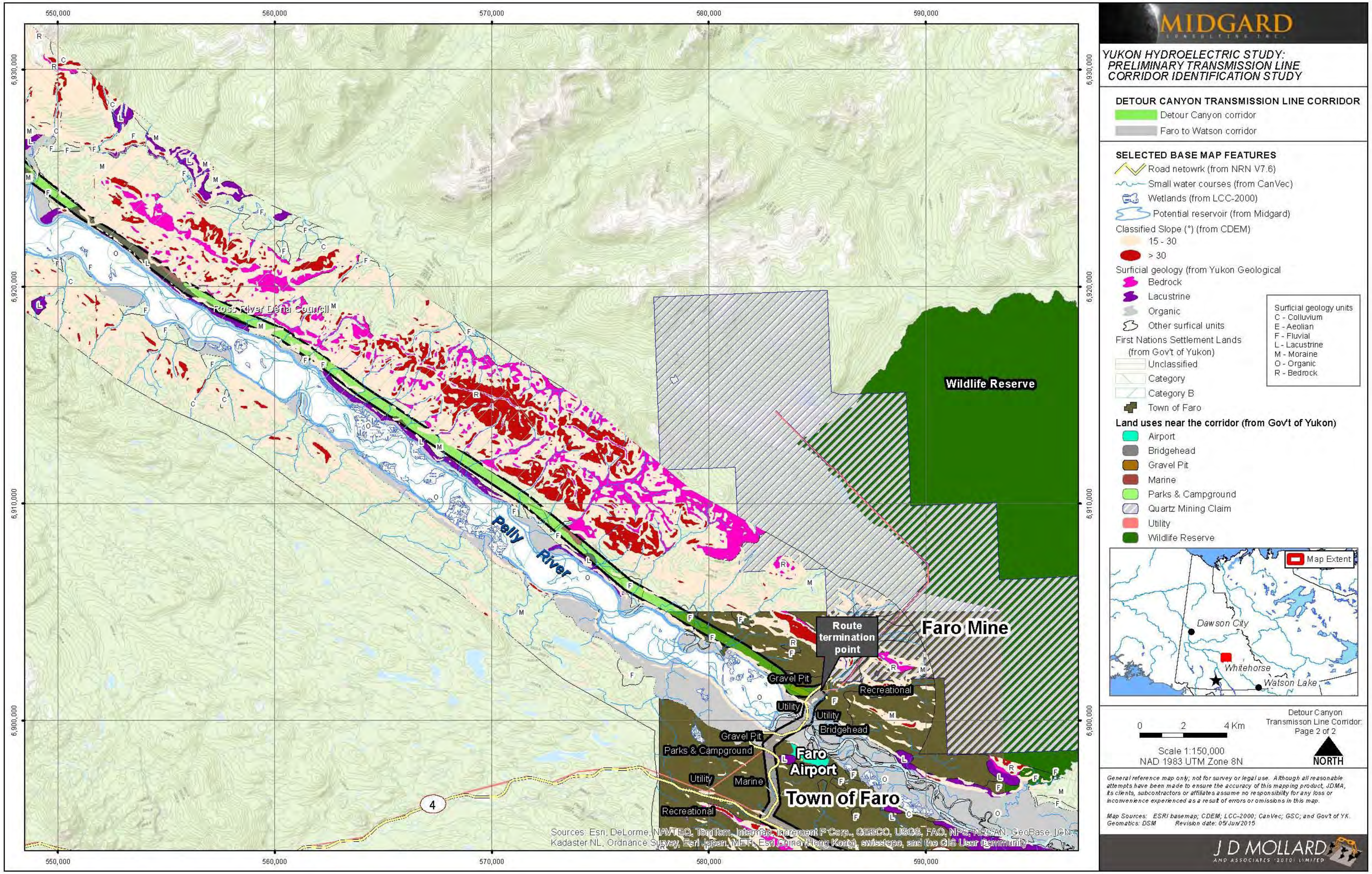

Figure 3: Detour Canyon Map 2

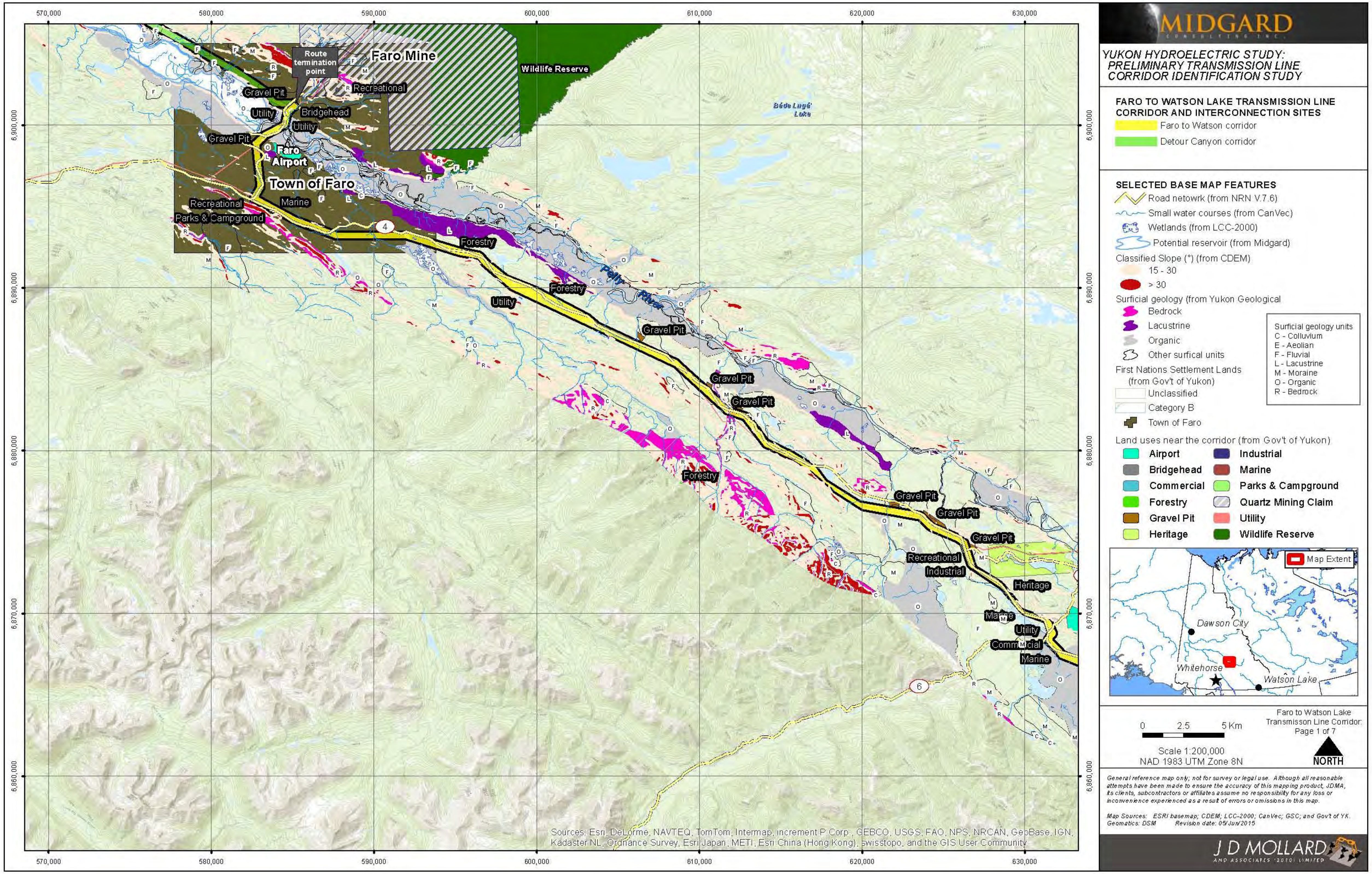

Figure 4: Faro to Watson Lake Map 1

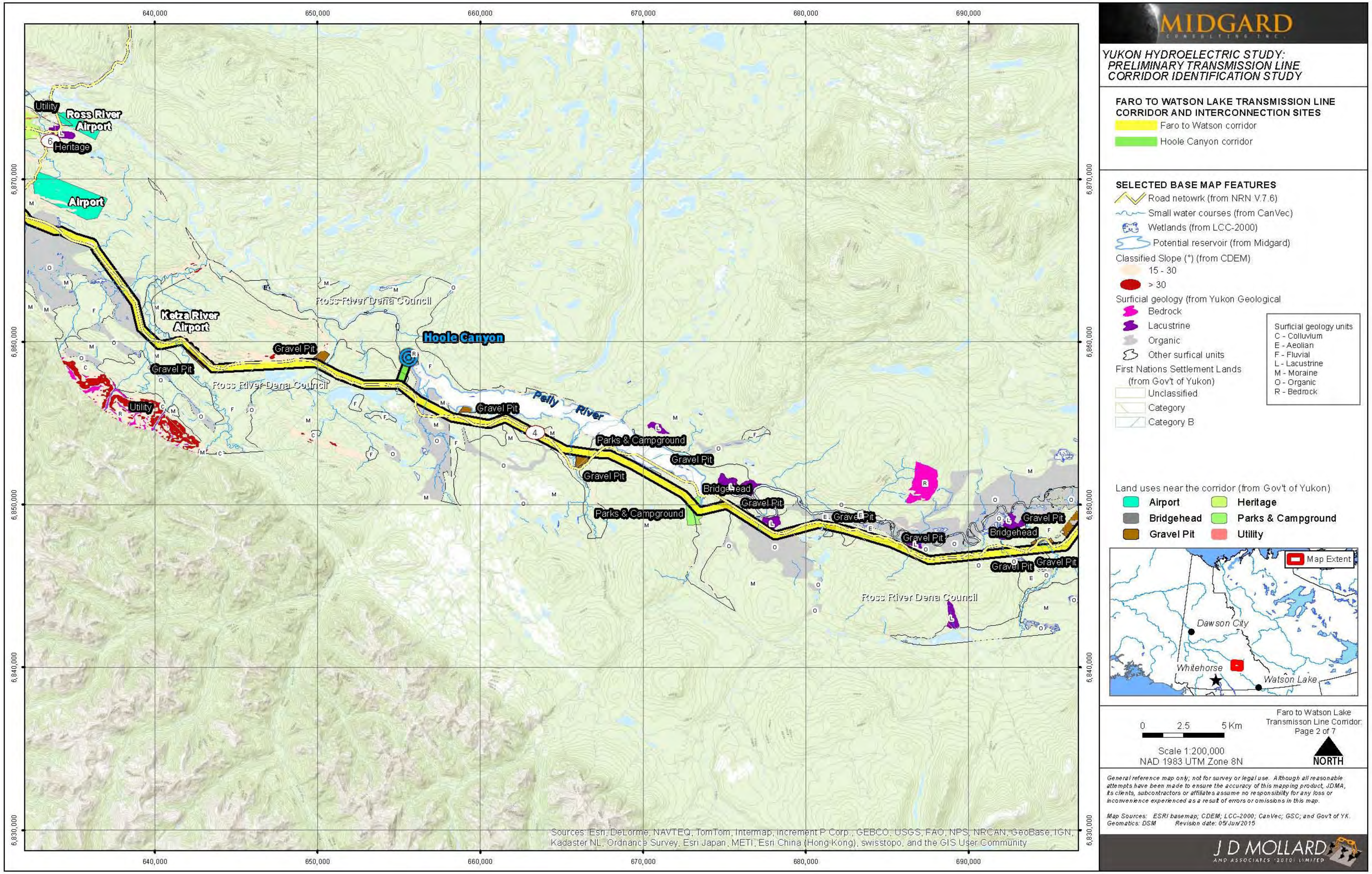

Figure 5: Faro to Watson Lake Map 2

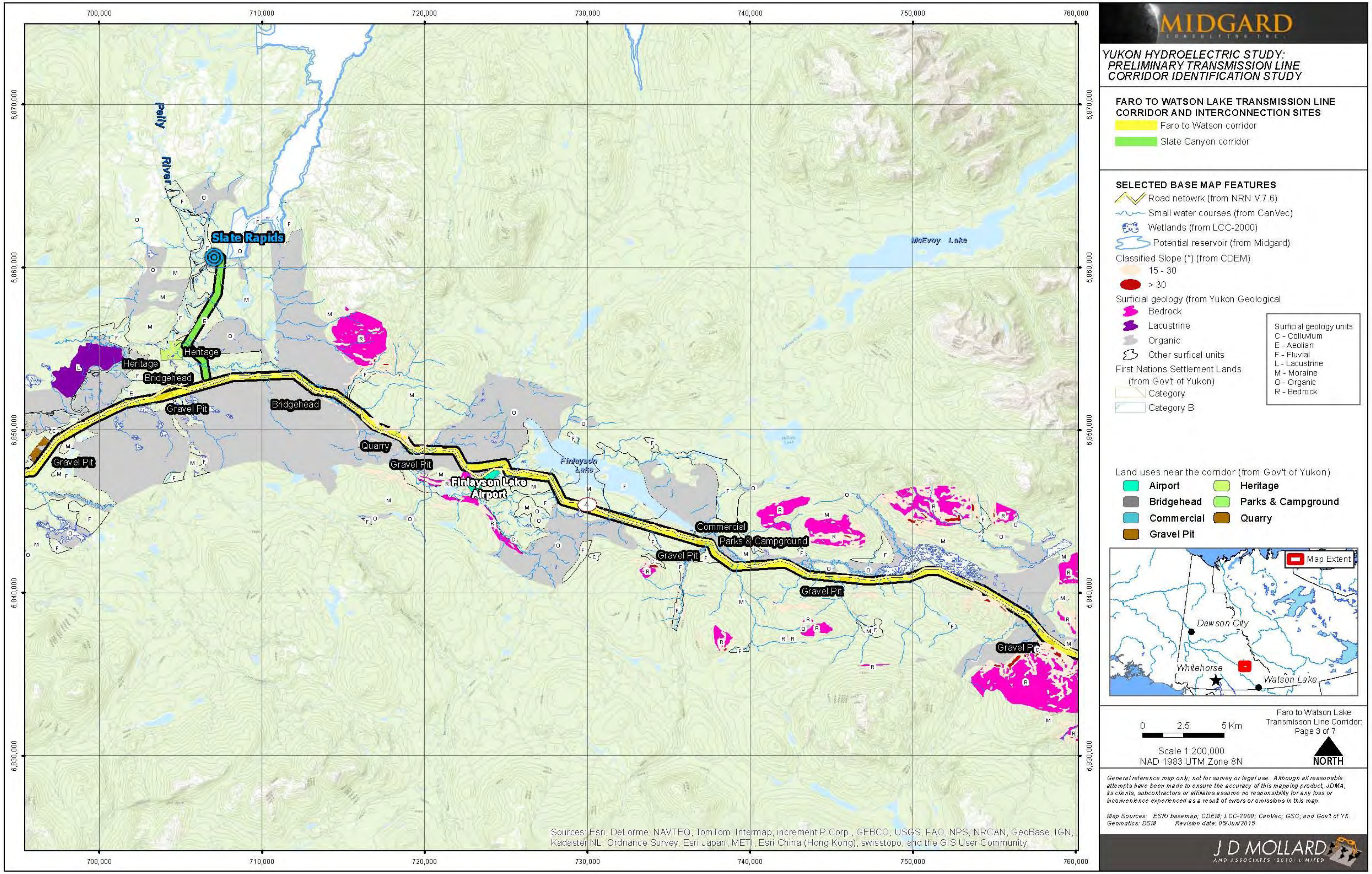

Figure 6: Faro to Watson Lake Map 3

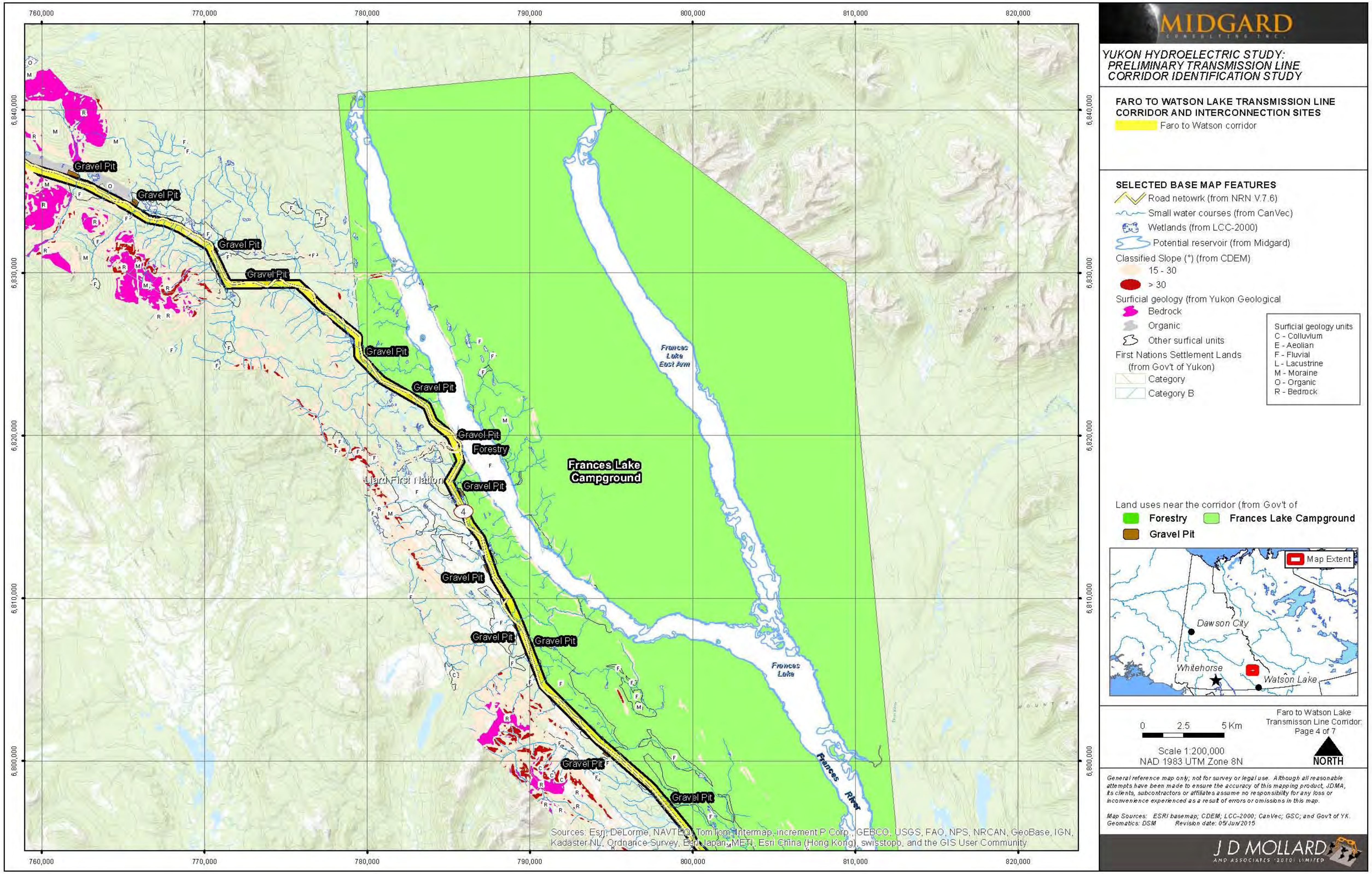

Figure 7: Faro to Watson Lake Map 4

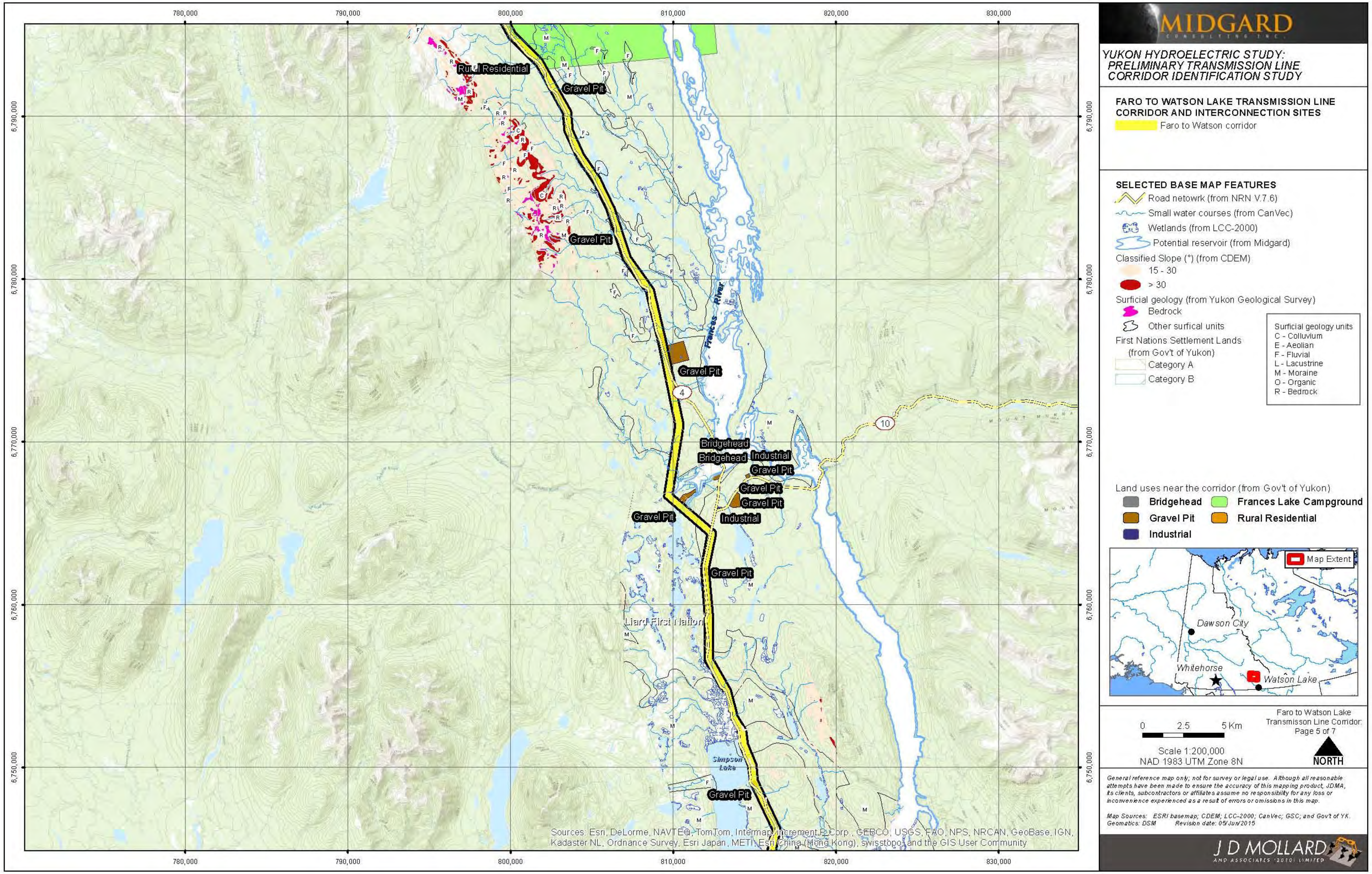

Figure 8: Faro to Watson Lake Map 5

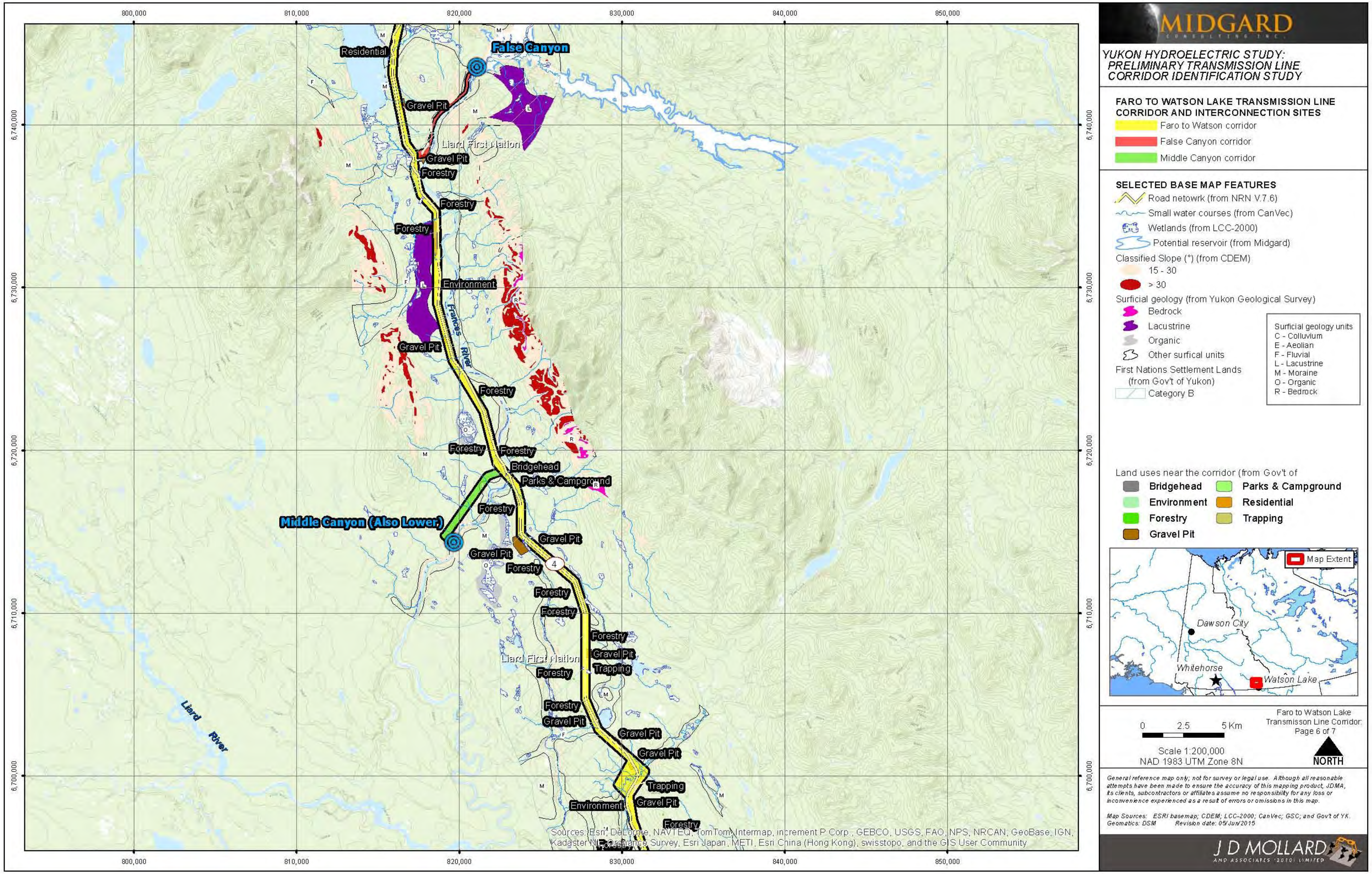

Figure 9: Faro to Watson Lake Map 6

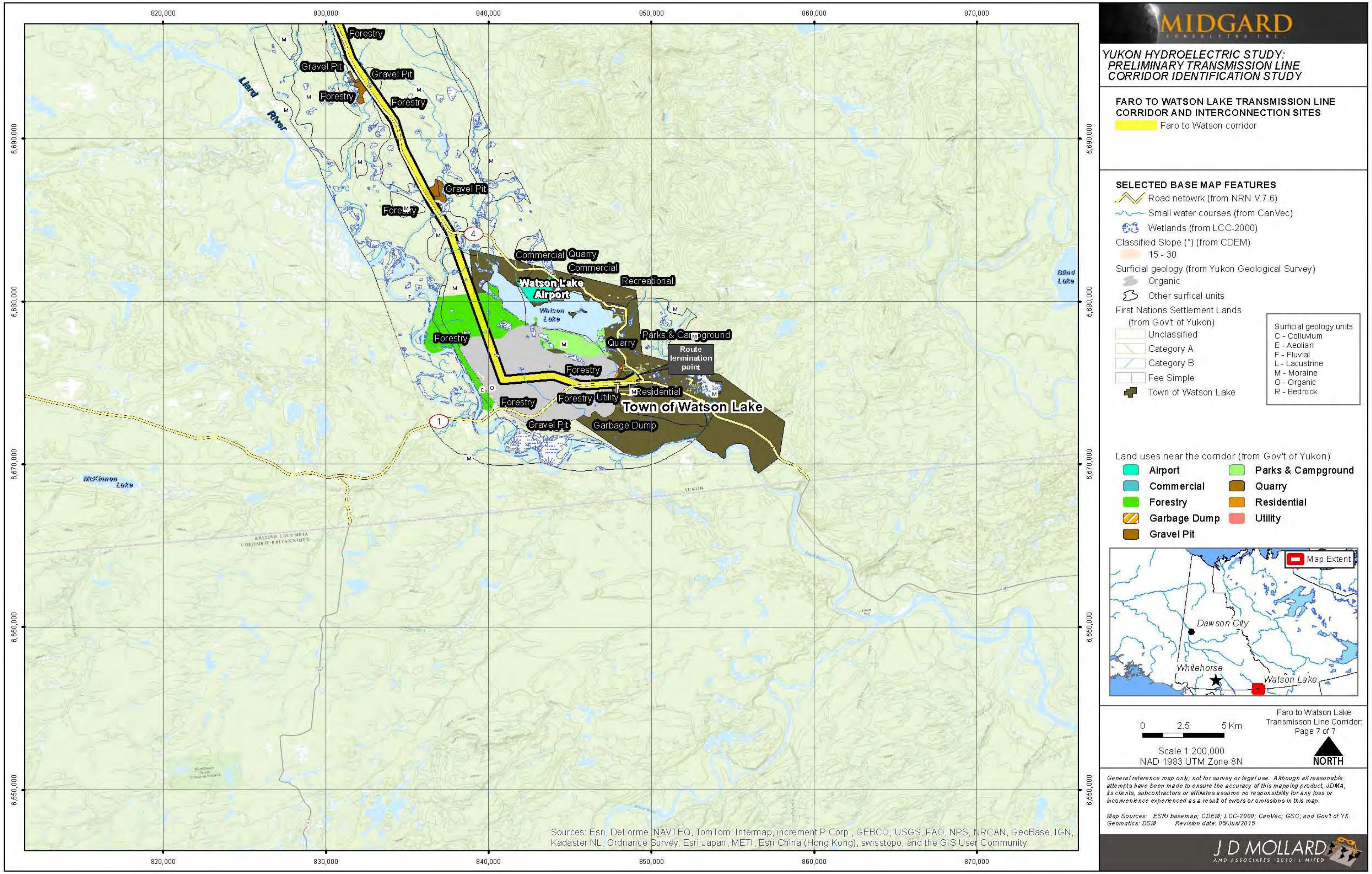

Figure 10: Faro to Watson Lake Map 7

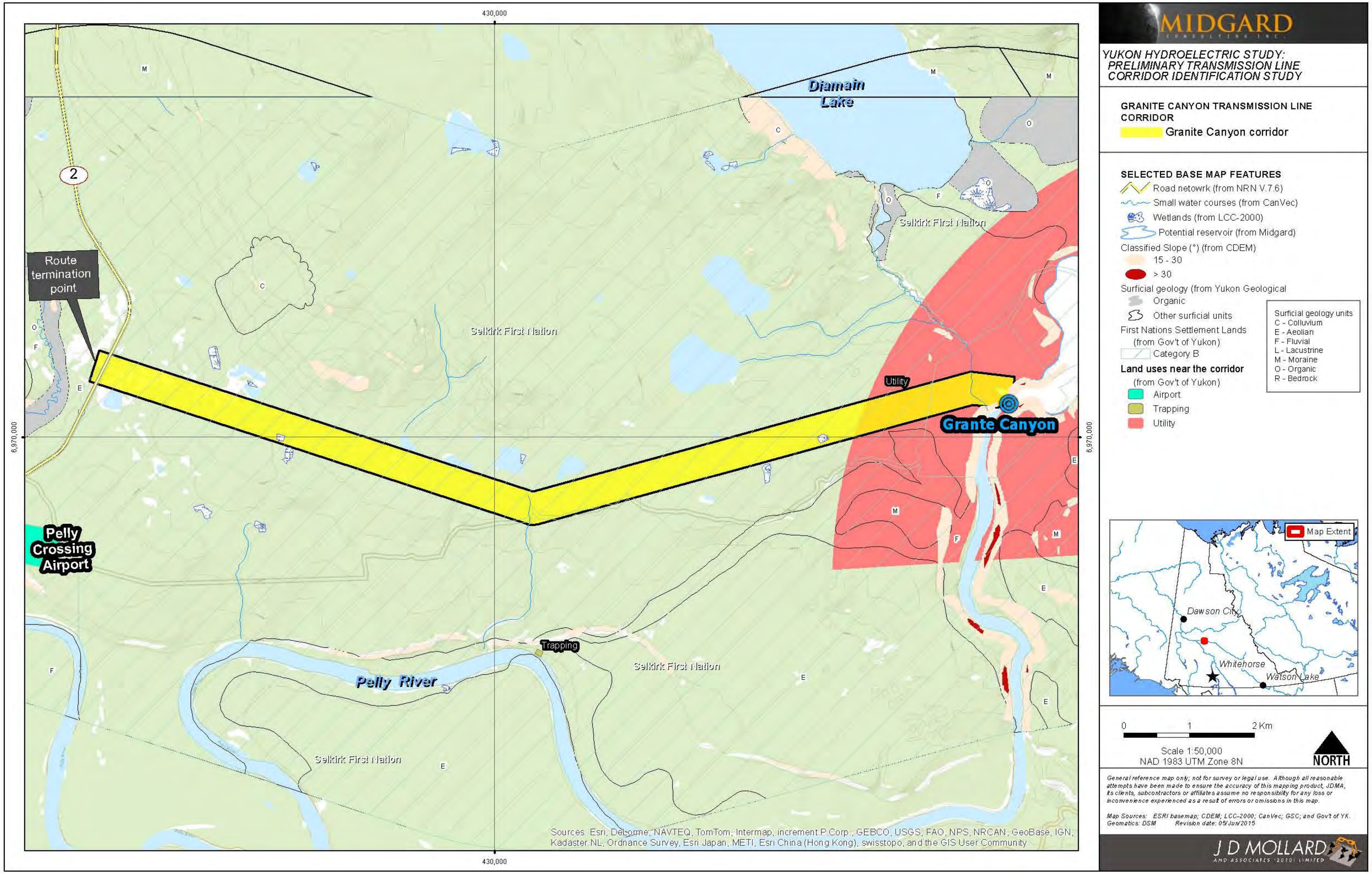

Figure 11: Granite Canyon Map

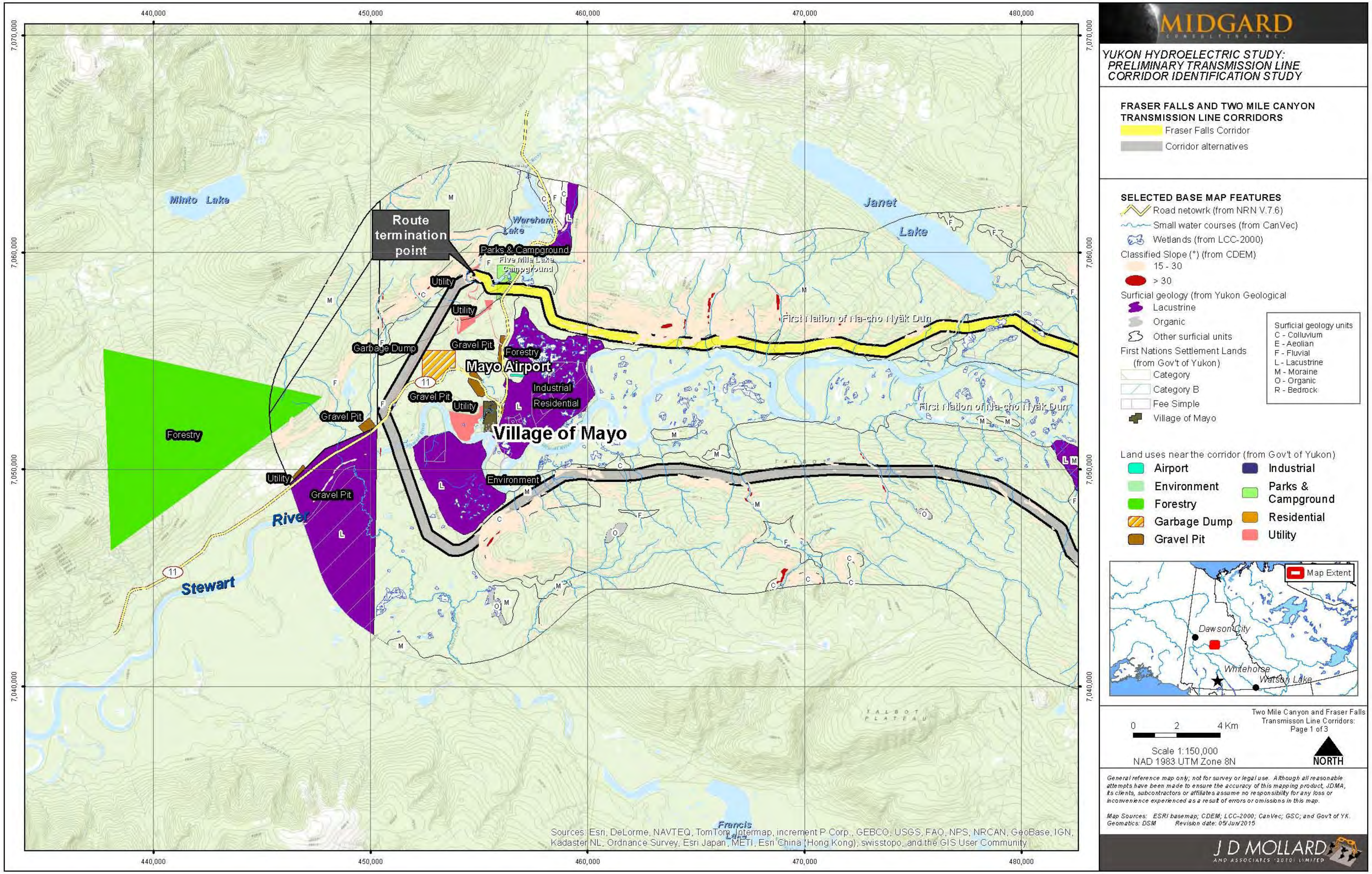

Figure 12: Fraser Falls and Two Mile Canyon Map 1

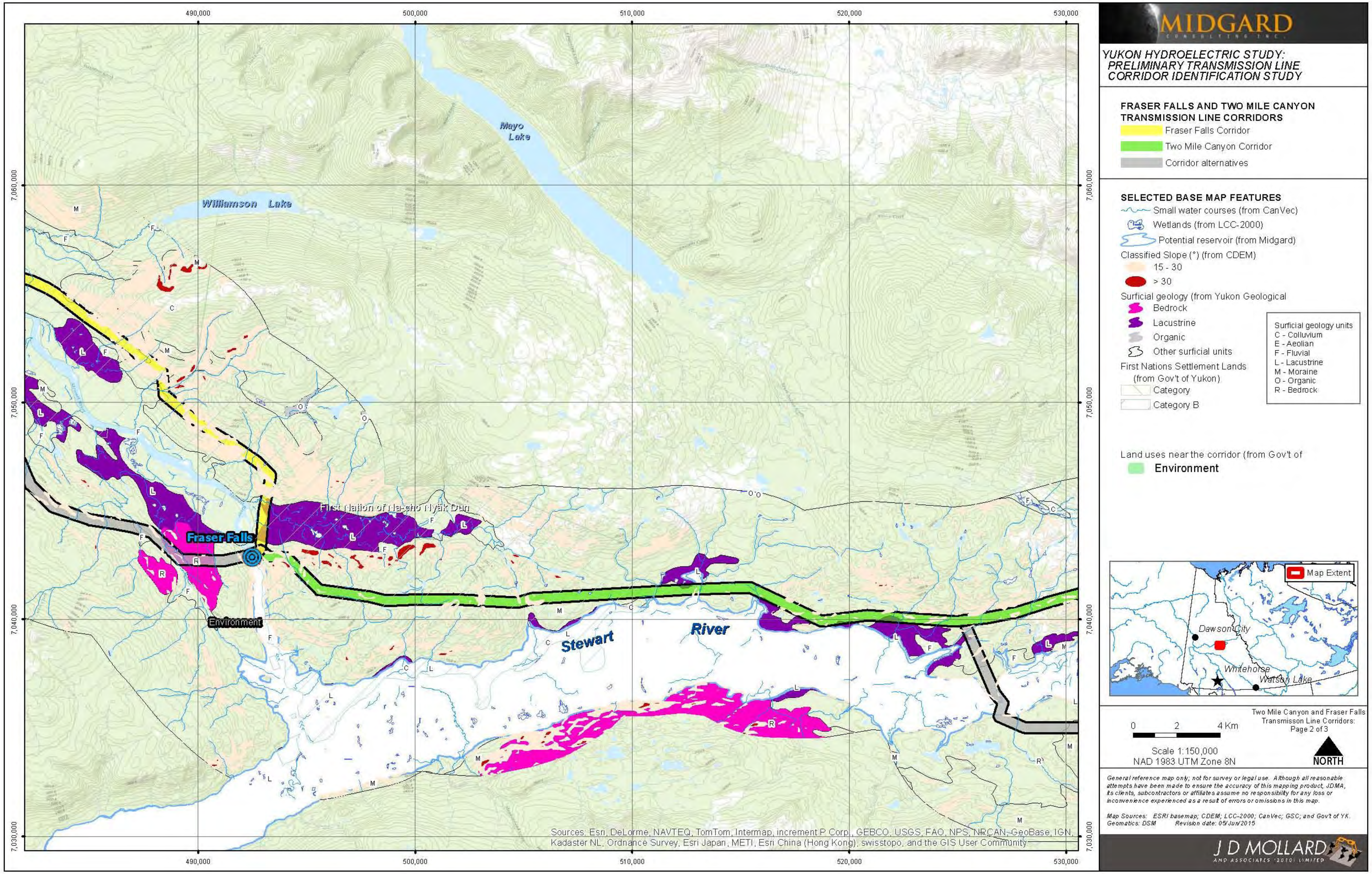

Figure 13: Fraser Falls and Two Mile Canyon Map 2

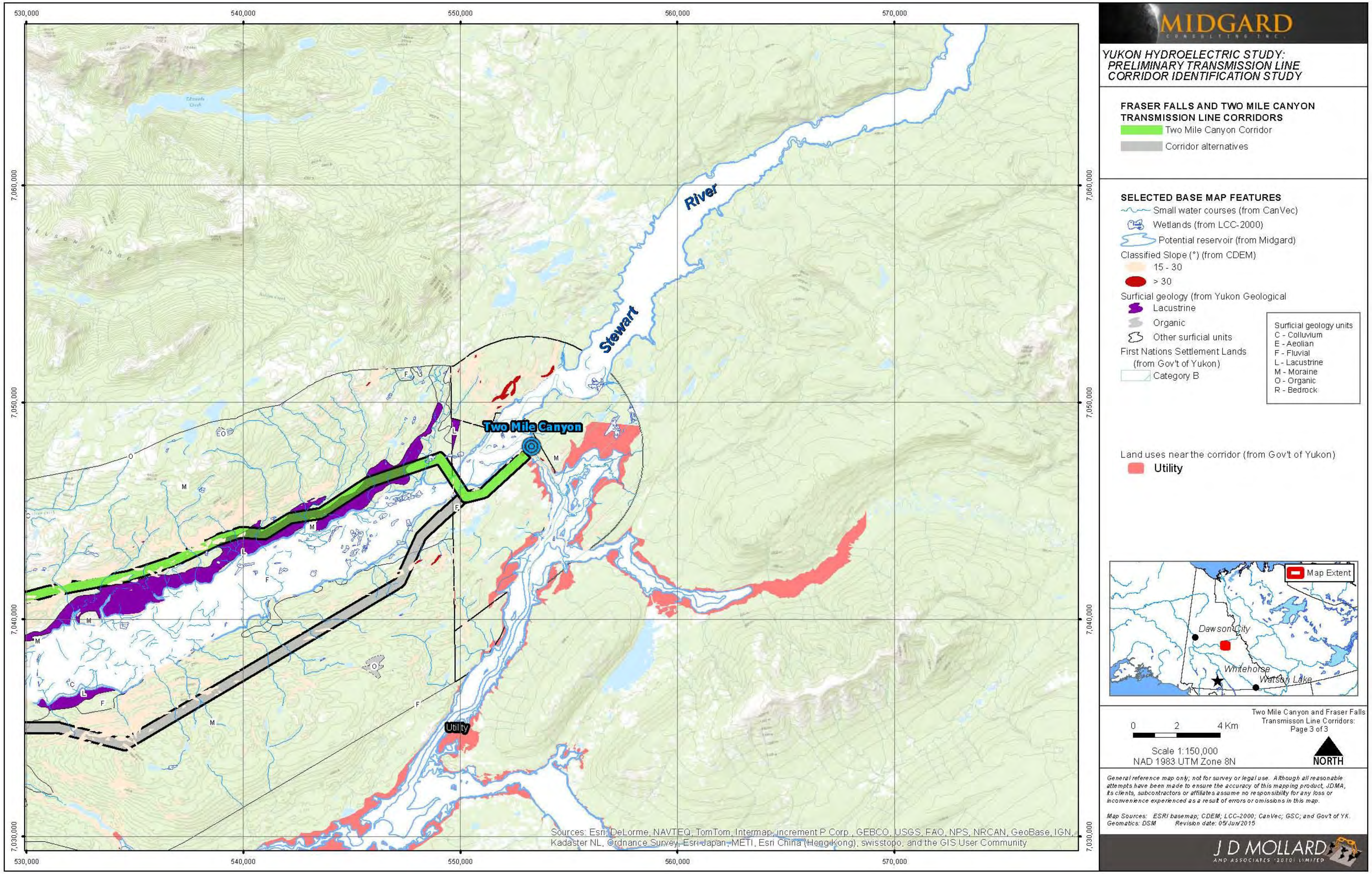

Figure 14: Fraser Falls and Two Mile Canyon Map 3

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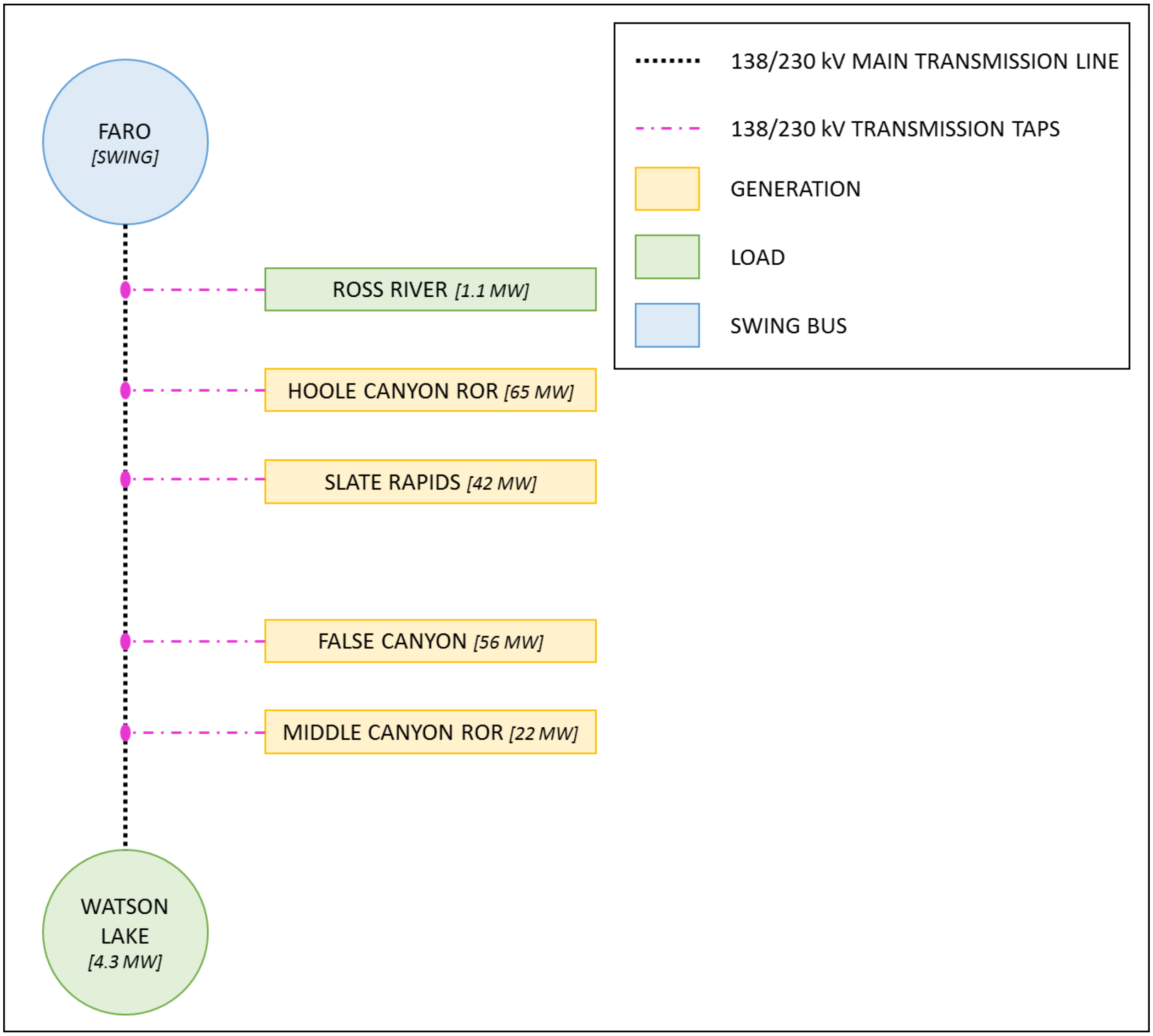
Appendix B: PSS®E Power System Simulation Studies

B.1 Transmission Line Route and Distances[25]

Figure B-1, Table B-1 and Table B-2 illustrates the Faro – Watson Lake Transmission Route Schematic and the respective distances of the transmission line segments that comprise the path.

Figure B-1: Faro to Watson Lake Transmission Corridor Route Schematic



[25] JDMA's *Yukon Transmission Line Corridor Routing Study* - Draft Report dated June 05, 2015, Table 3, Page 9

Table B-1: Transmission Line Route & Distances

Main Transmission Line Route and Distances		
From	**To**	**Distance (km)**
Faro	Ross River	56
Ross River	Hoole Tap	38.6
Hoole Tap	Slate Tap	56.8
Slate Tap	False Tap	184.3
False Tap	Middle Tap	20.4
Middle	Watson Lake	58

Table B-2: Transmission Tap Distances

Transmission Tap Distances		
From	**To**	**Distance (km)**
Hoole Tap	Hoole	1.8
False Tap	False	7.4
False Tap	False	7.4
Middle Tap	Middle	6.2

B.2 Generation and Load Profile

Table B-3 lists the maximum generation capability 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.

According to the "*Yukon Electrical Energy and Capacity Need Forecast"* paper, the Yukon's load was forecasted at 141 MW in the year 2065. Faro Bus acts as the "Swing Bus", representing the Yukon load minus the forecasted load at Watson Lake and Ross River[26] in the year 2065.

Table B-3: Generation & Load Profile

Location	Bus Type	Pgen (MW)	Qgen (MVArs)	Pload (MW)	Qload (MVArs)
Faro	Swing Bus	Swing Bus	Swing Bus	139.9	65.7
Ross River	Load Bus	0	0	1.1	0.5
Hoole	Generation Bus	65	31.5	0	0
Slate	Generation Bus	42	20.3	0	0
False	Generation Bus	56	27.1	0	0
Middle	Generation Bus	22	10.7	0	0

[26] Watson Lake and Ross River Instantaneous Peak Load Assumption = 1.5 X (Per Capita Energy Consumption per year X Population) / 8760

Location	Bus Type	Pgen (MW)	Qgen (MVArs)	Pload (MW)	Qload (MVArs)
Watson Lake	Load Bus	0	0	4.3	2.1

B.3 Conductor Characteristics

Table B-4 provides the conductor characteristics for the 138 kV and 230 kV interconnection options.

Table B-4: Conductor Properties for 138 kV and 230 kV Voltage Class

Voltage Class (kV)	Conductor Type	GMR (ft)	External Diameter (In)	Bundle	Phase Spacing (m)	Conductor Spacing (In)
138	Hawk 477 MCM	0.0289	0.858”	1	4.6	N/A
230	Hawk 477 MCM	0.0289	0.858”	2	6.7	18”

B.4 PSS®E Power Flow Simulation Results for 138 kV Transmission Line along FARO - WATSON LAKE TRANSMISSION CORRIDOR

Using the transmission line distances in Section B.1, generation and load profile information in Section B.2, and conductor characteristics in Section B.3, the transmission line characteristics were estimated as shown in Section B.4.1 below. A simple PSS®E model was built and simulations were carried out to estimate the power transfer capability along the 138 kV transmission line with various transmission and generation combination options. The following generation plan configurations were simulated:

1. Section B.4.2 – 138 kV Faro to Slate with Slate and Hoole Generation Only
2. Section B.4.3 – 138 kV Faro to Watson Lake with Slate and Hoole Generation Only
3. Section B.4.4 – 138 kV Faro to Watson Lake with Slate standalone
4. Section B.4.5 – 138 kV Faro to Watson Lake with False and Middle Generation Only
5. Section B.4.6 – 138 kV Faro to Watson Lake with False standalone

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 “***Transfer Capacity***” in the following tables represent available capacity at Faro after deducting Watson lake load (if connected), Ross River load and transmission losses.

B.4.1 Transmission Line Characteristics for 138 kV Voltage Class

Using a 100 MVA system base and 138 kV line voltage, Table B-5 was tabulated based on Table B-4, Table B-1, Table B-2 and tower structure assumptions for phase spacing.

Table B-5: 138 kV Transmission Line Characteristics

From	To	Distance (km)	Per Unit Resistance (pu)	Per Unit Reactance (pu)	Charging B (pu)
Faro	Ross River	56	0.0329	0.1438	0.0357
Ross River	Hoole Tap	38.6	0.0227	0.0991	0.0246
Hoole Tap	Hoole	1.8	0.0011	0.0046	0.0011
Hoole Tap	Slate Tap	56.8	0.0334	0.1458	0.0362
Slate Tap	Slate	9.2	0.0054	0.0236	0.0059
Slate Tap	False Tap	184.3	0.1065	0.4694	0.1178
False Tap	False	7.4	0.0044	0.0190	0.0047
False Tap	Middle Tap	20.4	0.0120	0.0524	0.0130
Middle Tap	Middle	6.2	0.0037	0.0159	0.0039
Middle Tap	Watson Lake	58	0.0341	0.1489	0.0369
Slate Tap	Watson Lake	262.7	0.1489	0.6630	0.1688
Ross River	False Tap	279.7	0.1578	0.7042	0.1799
False Tap	Watson Lake	78.4	0.0460	0.2011	0.0499

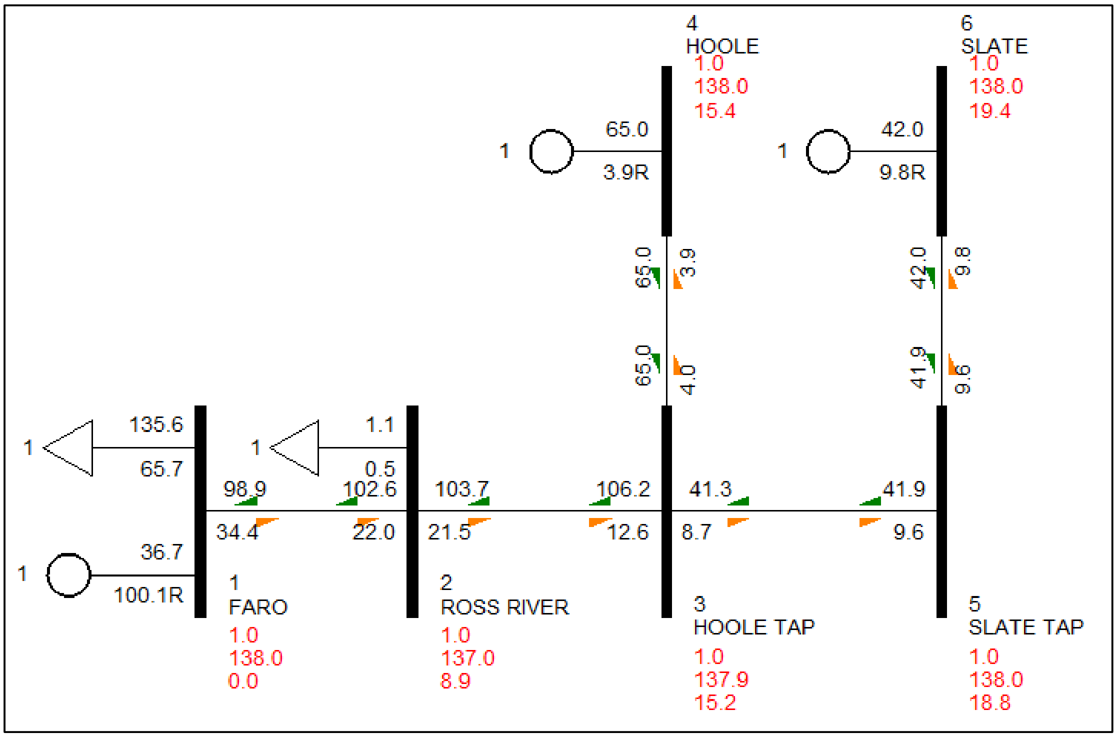
B.4.2 138 kV Faro to Slate – Hoole and Slate Generation Only

Table B-6 shows that Yukon system can receive 98.9 MW of power through the 138 kV transmission line between Faro and Slate, when Hoole and Slate generate their maximum rated power while maintaining acceptable system conditions. The maximum losses on the transmission line are 7.0 MW.

Table B-6: PSSE Results for 138 kV Line from Faro to Slate - Hoole & Slate Generation Only

138 kV Line from Faro to Slate: Hoole & Slate Generation Only				
Location	**Generation (MW)**	**Load (MW)**	**Bus Voltage (p.u.)**	**Voltage Angle (degrees)**
Faro	36.7	135.6	1	0
Ross River	0	1.1	0.99	8.9
Hoole Tap	0	0	0.99	15.2
Hoole	65	0	1	15.4
Slate Tap	0	0	1	18.8
Slate	42	0	1	19.4
Transfer Capacity (MW)	98.9			
Losses (MW)	7.0			

Figure B-2: PSSE Single Line Diagram - 138 kV Line from Faro to Slate with Hoole & Slate Generation Only



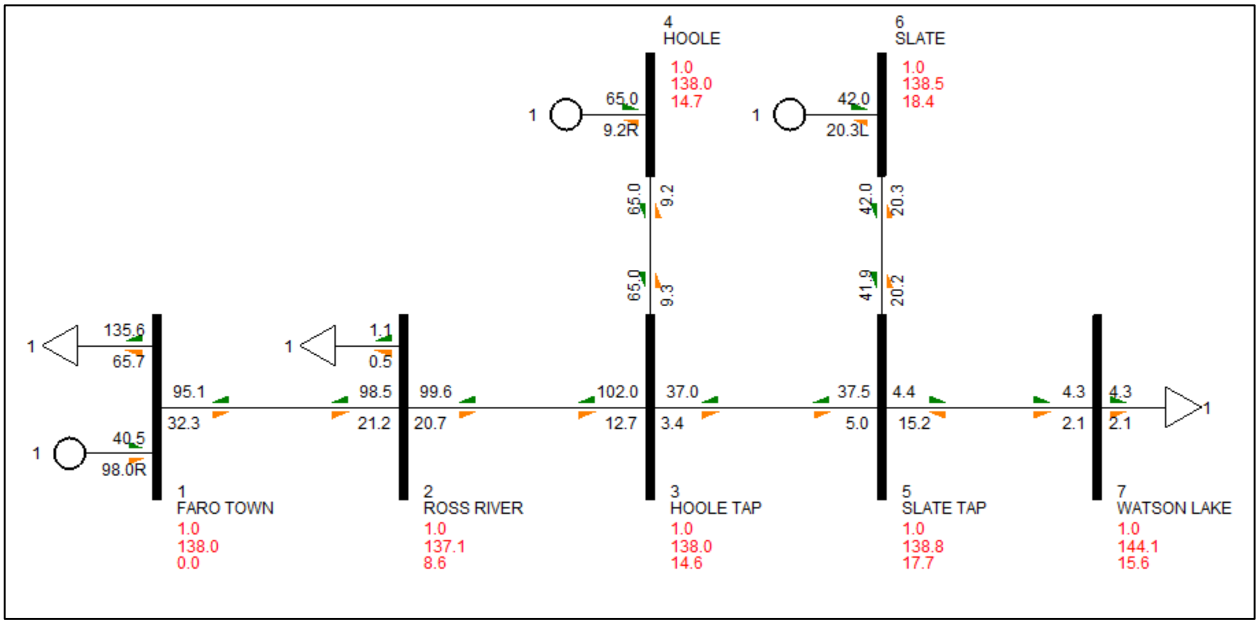
B.4.3 138 kV Line from Faro to Watson Lake – Hoole and Slate Generation Only

Table B-7 shows that Yukon system can receive 95.1 MW of power through the 138 kV transmission line between Faro and Watson Lake, when Hoole and Slate generate their maximum rated power while maintaining acceptable system conditions. The maximum losses on the transmission line are 6.5 MW.

Table B-7: PSSE Results for 138 kV Line from Faro to Watson Lake - Hoole and Slate Generation Only

138 kV Line from Faro to Watson Lake: Hoole & Slate Generation Only				
Location	**Generation (MW)**	**Load (MW)**	**Bus Voltage (p.u.)**	**Voltage Angle (degrees)**
Faro	40.48	135.60	1.00	0.00
Ross River	-	1.10	0.99	8.57
Hoole Tap	-	-	1.00	14.56
Hoole	65.00	-	1.00	14.74
Slate Tap	-	-	1.01	17.74
Slate	42.00	-	1.00	18.36
Watson Lake	-	4.30	1.04	15.60
Transfer Capacity (MW)	95.1			
Losses (MW)	6.5			

Figure B-3: PSSE Single Line Diagram: 138 kV Line from Faro to Watson Lake - Hoole & Slate Generation Only



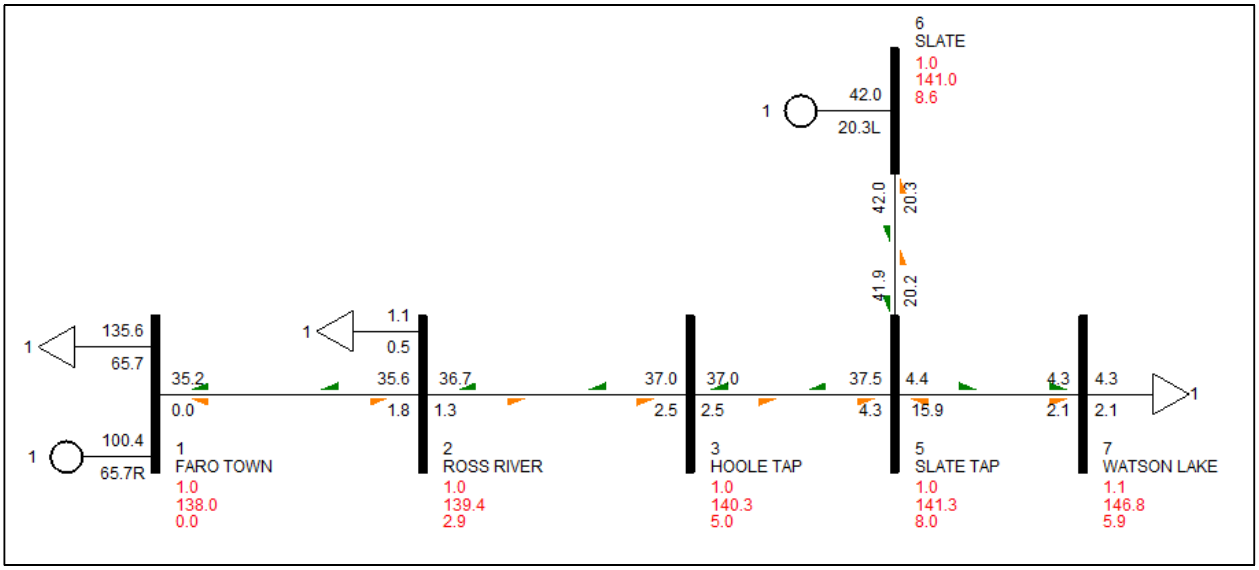
B.4.4 138 kV Faro to Watson Lake – Slate Rapids Generation Only

Table B-8 shows that Yukon system can receive 36.3 MW of power through the 138 kV transmission line between Faro and Watson Lake, when Slate generates its maximum rated power while maintaining acceptable system conditions. The maximum losses on the transmission line are 1.4 MW.

Table B-8: PSSE Results for 138 kV Line from Faro to Watson Lake - Slate Generation Only

138 kV Line from Faro to Watson Lake: Slate Generation Only				
Location	**Generation (MW)**	**Load (MW)**	**Bus Voltage (p.u.)**	**Voltage Angle (degrees)**
Faro	100.4	135.60	1.00	0.00
Ross River	-	1.10	1.01	2.91
Hoole Tap	-	-	1.02	4.97
Slate Tap	-	-	1.02	8.02
Slate	42.00	-	1.02	8.62
Watson Lake	-	4.30	1.06	5.94
Transfer Capacity (MW)	36.3			
Losses (MW)	1.4			

Figure B-4: PSSE Single Line Diagram: 138 kV Line from Faro to Watson Lake - Slate Generation Only



B.4.5 138 kV Faro to Watson Lake – False and Middle Generation Only

With False and Middle generating at full capacity, the voltage angle is greater than 33° at several buses as seen in Table B-9, which could cause angular instability. Two solutions are suggested to bring the system to stable operating conditions. They are,

1. Curtailing Generation : Either Middle or False
2. Series Compensation through the use of Series Capacitors

Table B-10 shows system conditions when the generation at False is curtailed down to 47 MW from 56 MW. We can see that that the angular stability has improved by reducing the generation at False. In this configuration, Yukon receives a maximum of 55.7 MW with 7.9 MW as maximum losses.

Table B-11 shows system conditions when 30% series compensation was provided with False and Middle operating at full capacity. The results show an improvement in angular stability without curbing generation from False and Middle. In this configuration, Yukon receives a maximum of 62.2 MW with 10.4 MW as maximum losses.

How Series Compensation Works?

The power transfer capability of a transmission line is given by the following equation.

$$P = \frac{Vs * Vr}{X} * Sin\,(\delta)$$

Where,

P ➔ Power transferred in MW

Vs ➔ Sending End Voltage in kV

Vr ➔ Receiving End Voltage in kV

X ➔ Reactance of the transmission Line in Ohms (Ω)

Δ ➔ Angular Difference between the Sending End and Receiving End

When capacitor banks are added to the transmission line in series configuration, the overall reactance of the line decreases, increasing the power transfer through the transmission line without affecting the angular stability as shown in the following equation

$$P = \frac{Vs * Vr}{X - Xc} * Sin\ (\delta)$$

Where,

Xc ➔ is the reactance of the capacitor added in series to the transmission line.

For 30% series compensation, Series Capacitors with Xc = 0.3X is chosen.

Table B-9: PSSE Results for 138 kV Line from Faro to Watson Lake: False & Middle Generation

138 kV Line from Faro to Watson Lake: False & Middle Generation Only				
Location	**Generation (MW)**	**Load (MW)**	**Bus Voltage (p.u.)**	**Voltage Angle (degrees)**
Faro	73.4	135.6	1	0
Ross River	0	1.1	0.98	5.8
False Tap	0	0	0.99	37
False	56	0	1	**37.6**
Middle Tap	0	0	0.99	**37.5**
Middle	22	0	1	**37.8**
Watson Lake	0	4.3	0.99	**37.2**
Transfer Capacity (MW)	62.2			
Losses (MW)	10.4			

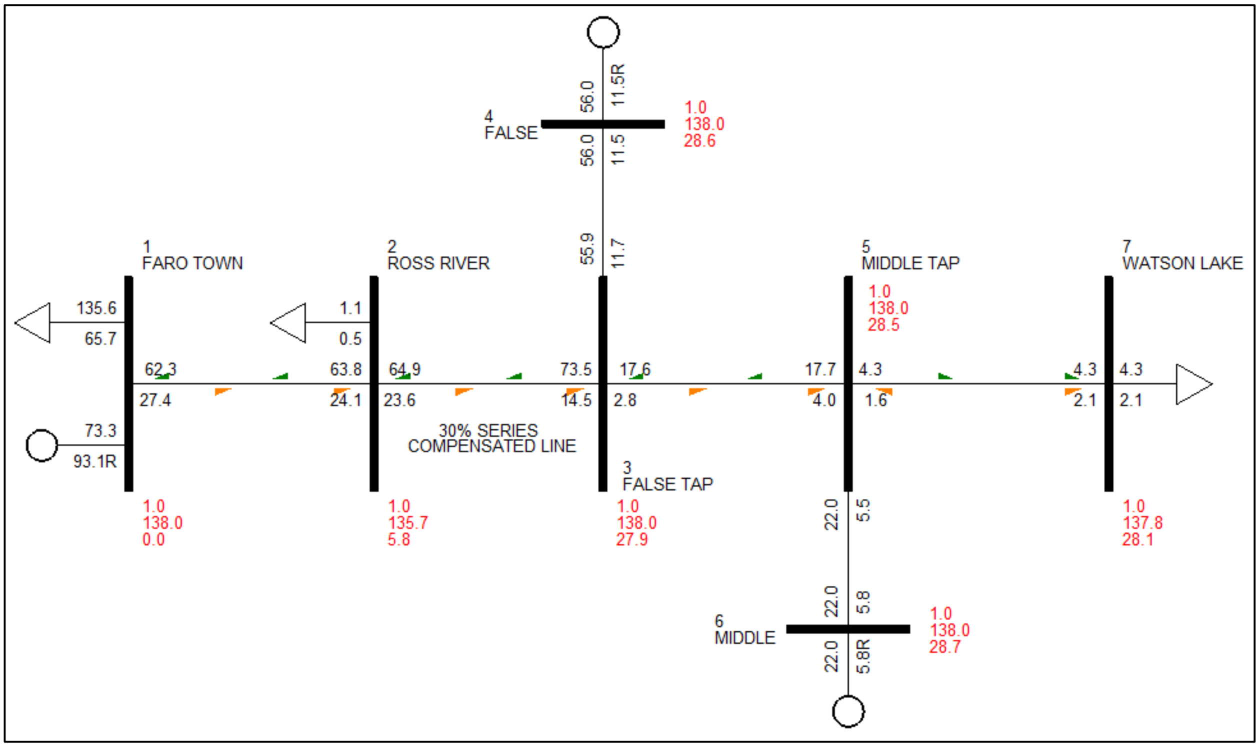
Table B-10: PSSE Results for 138 kV Line from Faro to Watson Lake: False Generation Curtailed & Middle at Maximum Generation

138 kV Line from Faro to Watson Lake: False (curtailed) & Middle Generation Only				
Location	**Generation (MW)**	**Load (MW)**	**Bus Voltage (p.u.)**	**Voltage Angle (degrees)**
Faro	79.9	135.6	1	0
Ross River	0	1.1	0.99	5.06
False Tap	0	0	0.99	32.2
False	47	0	1	32.7
Middle Tap	0	0	0.99	32.7
Middle	22	0	1	32.9
Watson Lake	0	4.3	0.99	32.4
Transfer Capacity (MW)	55.7			
Losses (MW)	7.9			

Table B-11: PSSE Results for 138 kV Line from Faro to Watson Lake: False + Middle + 30 % Series Compensation

138 kV Line from Faro to Watson Lake: False & Middle Generation				
Location	**Generation (MW)**	**Load (MW)**	**Bus Voltage (p.u.)**	**Voltage Angle (degrees)**
Faro	73.33	135.6	1	0
Ross River	0	1.1	0.98	5.8
False Tap	0	0	0.99	27.9
False	56	0	1	28.6
Middle Tap	0	0	1.00	28.5
Middle	22	0	1	28.7
Watson Lake	0	4.3	0.99	28.1
Transfer Capacity (MW)	62.3			
Losses (MW)	10.3			

Figure B-5: PSSE Single Line Diagram - 138 kV Line from Faro to Watson Lake: False + Middle + 30 % Series Compensation



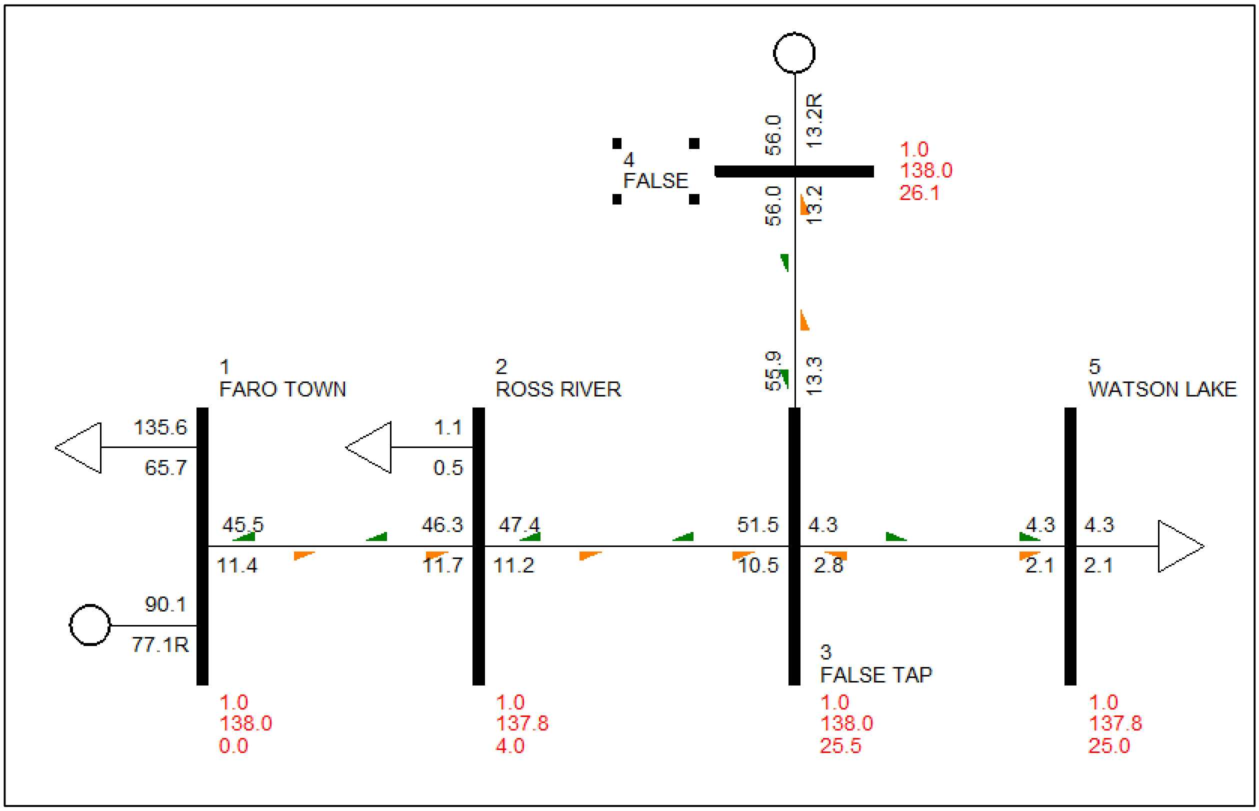
B.4.6 138 kV Faro to Watson Lake – False Generation Only

Table B-12 shows that Yukon system can receive 45.5 MW of power through the 138 kV transmission line between Faro and Watson Lake, when False alone generate its maximum power while maintaining acceptable system conditions. The maximum losses on the transmission line are 5.1 MW.

Table B-12: PSSE Results for 138 kV Line from Faro to Watson Lake: False Generation Only

138 kV Line from Faro to Watson Lake: False Generation Only				
Location	**Generation (MW)**	**Load (MW)**	**Bus Voltage (p.u.)**	**Voltage Angle (degrees)**
Faro Town	90.08	135.6	1	0
Ross River	0	1.1	0.99	4.01
False Tap	0	0	1.00	25.47
False	56	0	1	26.11
Watson Lake	0	4.3	0.99	24.96
Transfer Capacity (MW)	45.5			
Losses (MW)	5.1			

Figure B-6: PSSE Single Line Diagram - 138 kV Line from Faro to Watson Lake: False Generation Only



B.5 PSS®E Power Flow Simulation Results for 230 kV Transmission Line along FARO - WATSON LAKE TRANSMISSION CORRIDOR

Using the transmission line distances in Section B.1, generation and load profile information in Section B.2, and conductor characteristics in Section B.3, the transmission line characteristics were estimated as shown in Section B.5.1 below. A simple PSS®E model was built and simulations were carried out to estimate the power transfer capability along the 230 kV transmission line with various transmission and generation combination options. The following generation plan configurations were simulated:

1. Section B.5.2 – 230 kV Faro to Watson Lake with Slate and Hoole Generation Only
2. Section B.5.3 – 230 kV Faro to Watson Lake with False and Middle Generation Only

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 "***Transfer Capacity***" in the following tables represent available capacity at Faro after deducting Watson lake load, Ross River load and transmission losses.

B.5.1 Transmission Line Characteristics for 230 kV Voltage Class

Using a 100 MVA system base and 230 kV line voltage, Table B-13 was tabulated based on Table B-1, Table B-2, Table B-4 and tower structure assumptions for phase spacing.

Table B-13: 230 kV Transmission Line Characteristics

From	To	Distance (km)	Per Unit Resistance (pu)	Per Unit Reactance (pu)	Charging B (pu)
Faro	Ross River	56	0.0030	0.0390	0.1299
Ross River	Hoole Tap	38.6	0.0020	0.0269	0.0895
Hoole Tap	Hoole	1.8	0.0001	0.0013	0.0042
Hoole Tap	Slate Tap	56.8	0.0030	0.0396	0.1318
Slate Tap	Slate	9.2	0.0005	0.0064	0.0213
Slate Tap	False Tap	184.3	0.0096	0.1273	0.4294
False Tap	False	7.4	0.0004	0.0052	0.0172
False Tap	Middle Tap	20.4	0.0011	0.0142	0.0473
Middle Tap	Middle	6.2	0.0003	0.0043	0.0144
Middle Tap	Watson Lake	58	0.0031	0.0404	0.1346
Slate Tap	Watson Lake	262.7	0.0134	0.1797	0.6149
Ross River	False Tap	279.7	0.0142	0.1909	0.6556
False Tap	Watson Lake	78.4	0.0041	0.0546	0.1820

B.5.2 230 kV Faro to Watson Lake – Hoole and Slate Generation Only

Table B-15 shows that Yukon system can receive 101 MW of power through the 230 kV transmission line between Faro and Watson Lake, when Hoole and Slate generate to their maximum rated power while maintaining acceptable system conditions. The maximum losses on the transmission line is 0.6 MW. In Table B-14 since the voltage at Watson Lake bus is above the nominal rage of 1.1 p.u., a shunt reactor of 40 MVArs was installed at Watson Lake so the voltages are within the nominal range of 0.9 p.u. and 1.1 p.u.

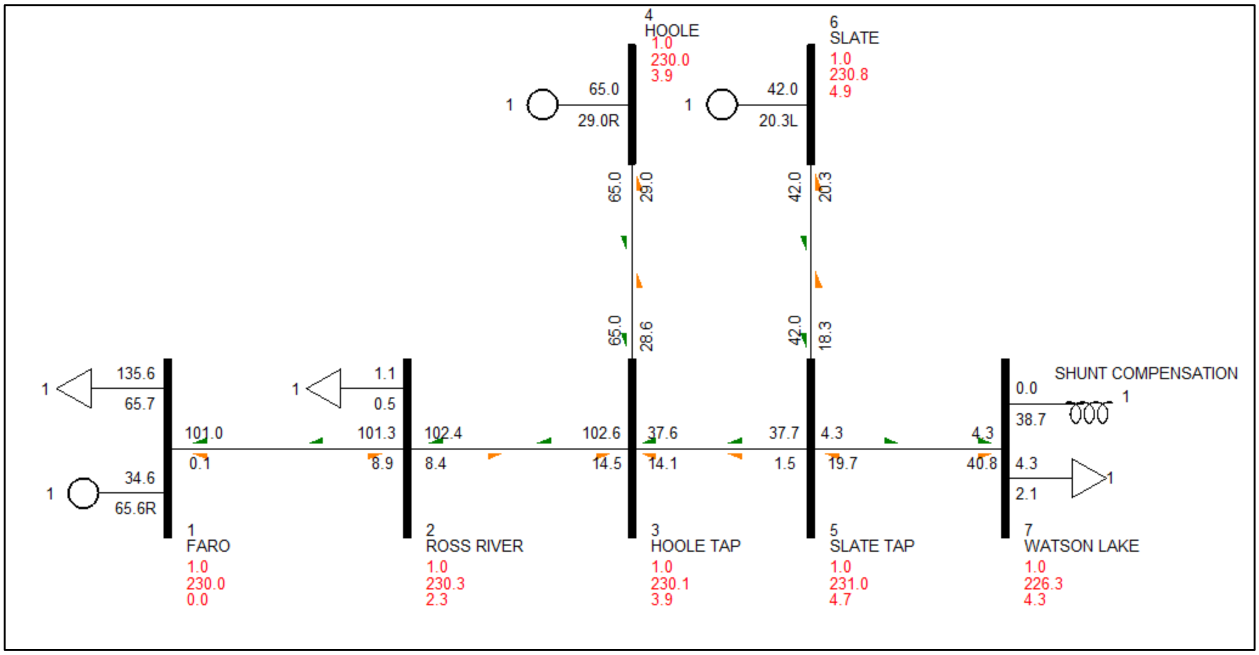
Table B-14: PSSE Results for 230 kV Line from Faro to Watson Lake - Hoole & Slate Generation Only

230 kV Line from Faro to Watson Lake: Hoole & Slate Generation Only				
Location	**Generation (MW)**	**Load (MW)**	**Bus Voltage (p.u.)**	**Voltage Angle (degrees)**
Faro	34.9	135.6	1.00	0
Ross River	0	1.1	1.02	2.14
Hoole Tap	0	0	1.03	3.61
Hoole	65	0	1.03	3.65
Slate Tap	0	0	1.05	4.3
Slate	42	0	1.05	4.44
Watson Lake	0	4.3	**1.11**	3.69
Transfer Capacity (MW)	100.7			
Losses (MW)	0.9			

Table B-15: PSSE Results for 230 kV Line from Faro to Watson Lake - Hoole + Slate + 40 MVAr Reactive Compensation

230 kV Line from Faro to Watson Lake: Hoole + Slate + 40 MVAr Reactive Compensation				
Location	**Generation (MW)**	**Load (MW)**	**Bus Voltage (p.u.)**	**Voltage Angle (degrees)**
Faro	34.6	135.6	1.00	0
Ross River	0	1.1	1.00	2.27
Hoole Tap	0	0	1.00	3.86
Hoole	65	0	1.00	3.9
Slate Tap	0	0	1.00	4.69
Slate	42	0	1.00	4.85
Watson Lake	0	4.3	0.98	4.33
Transfer Capacity (MW)	101			
Losses (MW)	0.6			

Figure B-7: PSSE Single Line Diagram - 230 kV Line from Faro to Watson Lake - Hoole + Slate + 40 MVAr Reactive Compensation



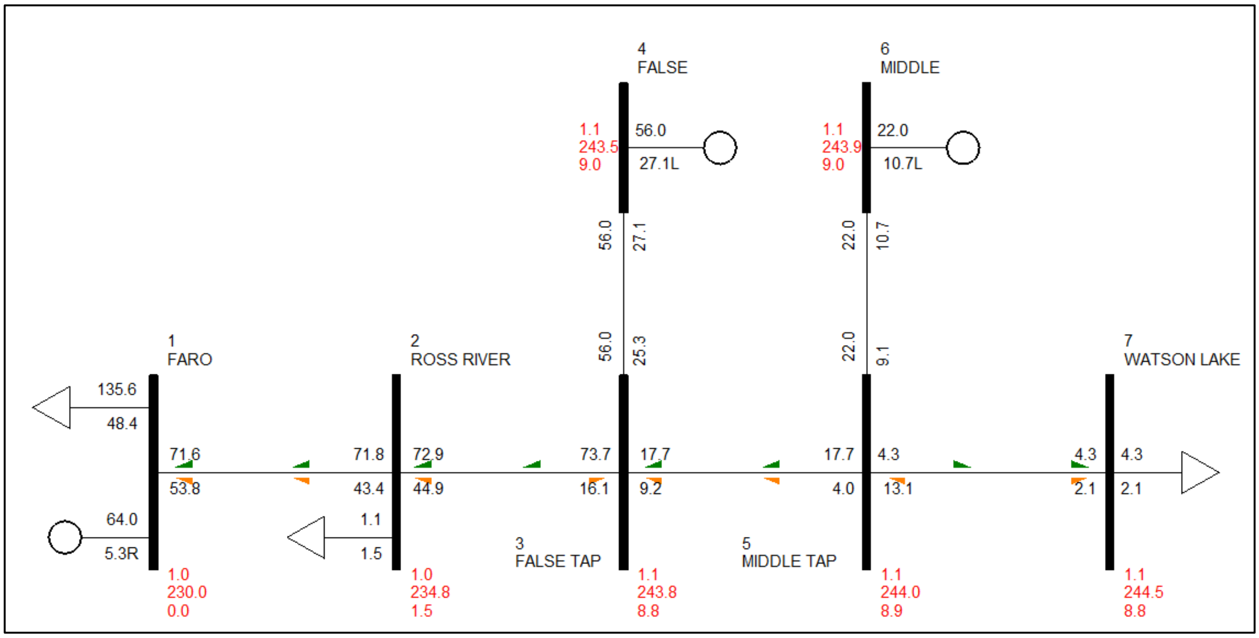
B.5.3 230 kV Faro to Watson Lake – False and Middle Generation Only

Table B-16 shows that Yukon system can receive 71.6 MW of power through the 230 kV transmission line between Faro and Watson Lake, when False and Middle generate to their maximum rated power while maintaining acceptable system conditions. The maximum losses on the transmission line are 1 MW.

Table B-16: PSSE Results for 230 kV Line from Faro to Watson Lake - False & Middle Generation Only

230 kV Line from Faro to Watson Lake: False & Middle Generation Only				
Location	**Generation (MW)**	**Load (MW)**	**Bus Voltage (p.u.)**	**Voltage Angle (degrees)**
Faro	63.9	135.6	1.00	0.00
Ross River	0	1.1	1.02	1.49
False Tap	0	0	1.06	8.80
False	56	0	1.06	8.95
Middle Tap	0	0	1.06	8.92
Middle	22	0	1.06	8.97
Watson Lake	0	4.3	1.06	8.83
Transfer Capacity (MW)	71.6			
Losses (MW)	1.0			

Figure B-8: PSSE Single Line Diagram - 230 kV Line from Faro to Watson Lake - False & Middle Generation Only



Appendix C: Cost Estimate Methodology

Table C-1 shows the base unit costs calculated from previous similar operating voltage transmission projects in Canada. Using the base unit costs, the transmission costs were developed for Faro to Watson Lake transmission corridor as shown in tables below.

Table C-1: Base Unit Costs for 138 kV and 230 kV transmission projects

	230 kV		**138 kV**	
Material	**$162,767.62**	**12.0%**	**$111,420.80**	**11.8%**
Foundations	*$7,702.26*	*0.6%*	*$14,339.03*	*1.5%*
Hardware	*$36,212.61*	*2.7%*	*$12,814.12*	*1.4%*
Conductor	*$42,307.31*	*3.1%*	*$16,504.24*	*1.7%*
Structure	*$76,545.44*	*5.6%*	*$67,763.42*	*7.2%*
Design & Construction	**$587,148.28**	**43.3%**	**$404,409.68**	**42.7%**
Engineering	*$17,079.41*	*1.3%*	*$12,238.77*	*1.3%*
Construction Planning	*$6,518.74*	*0.5%*	*$6,239.79*	*0.7%*
Contract Construction	*$550,536.63*	*40.6%*	*$372,001.06*	*39.3%*
Construction Services	*$795.48*	*0.1%*	*$1,132.56*	*0.1%*
Commissioning	*$12,218.01*	*0.9%*	*$12,797.50*	*1.4%*
Brushing & Access (& Survey)	**$390,458.11**	**28.8%**	**$269,025.82**	**28.4%**
Survey	*$37,799.50*	*2.8%*	*$23,075.93*	*2.4%*
Brushing Supervision/Planning	*$16,049.60*	*1.2%*	*$14,134.36*	*1.5%*
Brushing Contract	*$336,609.01*	*24.8%*	*$231,815.54*	*24.5%*
Project & Construction Management	**$139,002.26**	**10.3%**	**$108,139.37**	**11.4%**
Construction Management	*$22,961.09*	*1.7%*	*$19,734.68*	*2.1%*
Land Administration & Access	*$11,533.98*	*0.9%*	*$9,475.58*	*1.0%*
Health, Safety & Environment	*$36,314.25*	*2.7%*	*$30,384.42*	*3.2%*
Procurement	*$68,192.93*	*5.0%*	*$48,544.68*	*5.1%*
Subtotal - Base Costs				
	$1,279,376.27	**94.4%**	**$892,995.67**	**94.4%**
Common Costs				
	$76,052.67	*5.6%*	*$53,084.23*	*5.6%*
Estimate Total	**$1,355,428.9**	**100.0%**	**$946,079.91**	**100.0%**

138 kV PARAMETRIC COST ESTIMATES

PROJECT: Next Generation Hydroelectric Interconnection Costs

DATE: 3 JULY 2015

		Faro to Watson Lake	Faro to Hoole Canyon	Hoole Canyon to Slate Rapids	Slate Rapids to False Canyon	False Canyon to Middle Canyon	Middle Canyon to Watson Lake	Hoole Canyon	Slate Rapids	False Canyon	Middle Canyon	Comments
CONSTRUCTION												
Total centreline length (Km)		414.1	94.6	56.8	184.3	20.4	58.0	1.8	9.2	7.4	6.2	
Total corridor area (Ha)		20867	4733	2840	9195	1027	3072	79	454	162	294	
Total # of deep valley / canyon crossings		5	1	2	1	0	1	0	1	1	0	
Total # of major stream crossings		6	2	2	1	0	1	0	0	0	0	
BASE UNIT COSTS												
Base Cost Per Unit Total	$ 946,080											
Material	11.8%	$ 46,139,354	$ 10,540,408	$ 6,328,702	$ 20,534,854	$ 2,272,984	$ 6,462,407	$ 200,557	$ 1,025,071	$ 824,514	$ 690,809	
Design & Construction	42.7%	$ 167,466,049	$ 38,257,156	$ 22,970,470	$ 74,532,704	$ 8,249,957	$ 23,455,762	$ 727,937	$ 3,720,569	$ 2,992,632	$ 2,507,340	
Brushing & Access (& Survey)	28.4%	$ 111,403,594	$ 25,449,843	$ 15,280,667	$ 49,581,460	$ 5,488,127	$ 15,603,498	$ 484,246	$ 2,475,038	$ 1,990,791	$ 1,667,960	
Project & Construction Management	11.4%	$ 44,780,511	$ 10,229,984	$ 6,142,316	$ 19,930,085	$ 2,206,043	$ 6,272,083	$ 194,651	$ 994,882	$ 800,231	$ 670,464	
Common Costs	5.6%	$ 21,982,181	$ 5,021,769	$ 3,015,185	$ 9,783,424	$ 1,082,918	$ 3,078,886	$ 95,552	$ 488,375	$ 392,823	$ 329,122	
Estimate Total	100.0%	$ 391,771,690	$ 89,499,159	$ 53,737,339	$ 174,362,527	$ 19,300,030	$ 54,872,635	$ 1,702,944	$ 8,703,935	$ 7,000,991	$ 5,865,695	
DIFFICULTY FACTORED UNIT COSTS												
Material		$ 46,139,354	$ 10,540,408	$ 6,328,702	$ 20,534,854	$ 2,272,984	$ 6,462,407	$ 200,557	$ 1,025,071	$ 824,514	$ 690,809	
Design & Construction		$ 187,684,494	$ 43,937,168	$ 26,659,896	$ 83,933,342	$ 8,632,527	$ 24,521,560	$ 849,168	$ 4,354,605	$ 3,198,505	$ 2,844,159	Factored by Soils and Slope Difficulty Weightings
Brushing & Access (& Survey)		$ 77,779,735	$ 15,383,954	$ 9,908,381	$ 34,679,576	$ 4,743,107	$ 13,064,717	$ 346,067	$ 2,121,437	$ 1,225,604	$ 1,352,377	Factored by Brushing Cover % & Difficulty Weighting
Project & Construction Management		$ 44,780,511	$ 10,229,984	$ 6,142,316	$ 19,930,085	$ 2,206,043	$ 6,272,083	$ 194,651	$ 994,882	$ 800,231	$ 670,464	
Owners Costs		$ 21,982,181	$ 5,021,769	$ 3,015,185	$ 9,783,424	$ 1,082,918	$ 3,078,886	$ 95,552	$ 488,375	$ 392,823	$ 329,122	
Remoteness Premium (Camps, Logistics)		$ 21,739,039	$ 4,393,717	$ 2,665,990	$ 12,590,001	$ 863,253	$ 1,226,078	$ 84,917	$ 653,191	$ 319,850	$ 142,208	Weighted Allowance for camps, staging and logistics
New Access Roads	$ 400,000	$ 15,752,000	$ 2,664,000	$ 5,856,000	$ 4,776,000	$ 64,000	$ 2,392,000	$ 720,000	$ 3,680,000	$ 2,960,000	$ 2,480,000	New access roads at $250K per km
Factored Estimate Total		$ 415,857,314	$ 92,171,000	$ 60,576,469	$ 186,227,283	$ 19,864,833	$ 57,017,730	$ 2,490,912	$ 13,317,562	$ 9,721,527	$ 8,509,139	
Cost per km		$ 1,004,244	$ 974,323	$ 1,066,487	$ 1,010,457	$ 973,766	$ 983,064	$ 1,383,840	$ 1,447,561	$ 1,313,720	$ 1,372,442	

		Faro to Watson Lake	Faro to Hoole Canyon	Hoole Canyon to Slate Rapids	Slate Rapids to False Canyon	False Canyon to Middle Canyon	Middle Canyon to Watson Lake	Hoole Canyon	Slate Rapids	False Canyon	Middle Canyon
LAND COVER (Ha)											
Brushing Cover & Difficulty Weightings	Index	70%	60%	65%	70%	86%	84%	71%	86%	62%	81%
Dense coniferous (>60% crown closure)	100%	13%	11%	12%	8%	27%	24%	11%	43%	24%	25%
Coniferous - open canopy (26-60% crown closure)	70%	54%	30%	57%	63%	63%	60%	72%	36%	26%	71%
Coniferous - sparse (10-25% crown closure)	30%	14%	20%	21%	14%	1%	1%	11%	10%	0%	2%
Dense broadleaf (>60% crown closure)	100%	0%	1%	0%	0%	0%	0%	0%	0%	2%	0%
Broadleaf - open canopy (26-60% crown closure)	70%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Broadleaf - sparse (10-25% crown closure)	30%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Mixedwood - open canopy (26-60% crown closure)	70%	1%	0%	0%	1%	4%	2%	1%	2%	16%	1%
Mixedwood - sparse (10-25% crown closure)	30%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Riparian zones (15 m around wetlands, streams, waterbodie	200%	2%	2%	1%	3%	2%	2%	2%	4%	3%	2%
Open water (from CanVec)	300%	1%	2%	1%	1%	0%	0%	1%	2%	0%	0%
Treed wetlands	500%	0%	0%	0%	0%	1%	1%	0%	0%	0%	0%
Shrub wetlands	300%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Herb wetlands	300%	2%	4%	1%	1%	1%	2%	0%	0%	0%	0%
SURFICIAL GEOLOGY AND PERMAFROST (Ha)											
Soils & Geology Difficulty Index	Index	112%	114%	116%	112%	105%	104%	116%	117%	105%	113%
Aeolian	110%	2%	0%	15%	0%	0%	0%	0%	48%	0%	0%
Colluvium	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Fluvial	100%	23%	20%	33%	20%	56%	15%	38%	31%	86%	13%
Lacustrine	110%	1%	0%	0%	0%	9%	0%	0%	0%	0%	0%
Moraine	95%	62%	68%	36%	67%	34%	70%	33%	20%	14%	87%
Organic	115%	12%	10%	16%	12%	0%	16%	29%	1%	0%	0%
Exposed bedrock	110%	0%	1%	0%	0%	0%	0%	0%	0%	0%	0%
Thin layer (veneer <1 m thick) with bedrock as second unit	110%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Sporadic discontinuous permafrost	110%	29%	0%	0%	22%	100%	100%	0%	0%	98%	0%
Extensive discontinuous permafrost	130%	71%	100%	100%	78%	0%	0%	100%	100%	2%	100%

		Faro to Watson Lake	Faro to Hoole Canyon	Hoole Canyon to Slate Rapids	Slate Rapids to False Canyon	False Canyon to Middle Canyon	Middle Canyon to Watson Lake	Hoole Canyon	Slate Rapids	False Canyon	Middle Canyon
SLOPE (Ha)											
Slope Difficulty Index	Index	100%	101%	100%	100%	100%	100%	100%	100%	102%	101%
Area of corridor on slopes 0 - 15°	100%	98%	97%	100%	98%	100%	99%	99%	100%	90%	97%
Area of corridor on slopes 15 - 30°	120%	2%	3%	0%	2%	0%	1%	1%	0%	10%	3%
Area of corridor on slopes over 30°	200%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

		Faro to Watson Lake	Faro to Hoole Canyon	Hoole Canyon to Slate Rapids	Slate Rapids to False Canyon	False Canyon to Middle Canyon	Middle Canyon to Watson Lake	Hoole Canyon	Slate Rapids	False Canyon	Middle Canyon
FIRST NATIONS SETTLEMENT LANDS and SETTLED LAND (Ha)											
Category A		9%	0%	24%	14%	0%	0%	0%	62%	0%	0%
Category B		14%	14%	4%	9%	45%	26%	0%	21%	69%	2%

Uncategorized FN lands		0%	0%	0%	0%	0%	1%	0%	0%	0%	0%
Fee Simple		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Interim Protected		23%	14%	28%	23%	45%	27%	0%	83%	69%	2%
Urban land		7%	20%	0%	0%	0%	20%	0%	0%	0%	0%
LAND USES (Ha)											
Brushing Cover & Difficulty Weightings	Index	15%	9%	6%	22%	2%	16%	0%	0%	3%	0%
Bridgehead	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Environment	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Forestry	100%	2%	0%	0%	0%	0%	11%	0%	0%	0%	0%
Garbage dump	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Gravel Pit	100%	3%	2%	4%	3%	1%	4%	0%	0%	3%	0%
Heritage	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Industrial	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Marine	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Parks, Campground, or Recreational	150%	6%	0%	2%	13%	0%	0%	0%	0%	0%	0%
Quarry	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Rural residence	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Trapping	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Utility	100%	1%	6%	0%	0%	0%	0%	0%	0%	0%	0%
ROADS PARALLEL TO AND WITHIN CORRIDOR (Km)											
New Access Roads Required	Index	10%	7%	26%	6%	1%	10%	100%	100%	100%	100%
Paved road	100%	14%	15%	0%	2%	0%	66%	0%	0%	0%	0%
Improved gravel road	100%	76%	76%	74%	91%	98%	21%	0%	0%	0%	0%
Trail or resource road	60%	2%	3%	0%	0%	2%	5%	0%	0%	0%	0%
CAMPS, STAGING AREAS AND LOGISTICS											
Remoteness Factor		12%	10%	10%	15%	10%	5%	10%	15%	10%	5%

230 kV PARAMETRIC COST ESTIMATES

PROJECT: Next Generation Hydroelectric Interconnection Costs

DATE: 3 JULY 2015

		Faro to Watson Lake	Faro to Hoole Canyon	Hoole Canyon to Slate Rapids	Slate Rapids to False Canyon	False Canyon to Middle Canyon	Middle Canyon to Watson Lake	False Canyon	Middle Canyon	Hoole Canyon	Slate Rapids	Comments
CONSTRUCTION												
Total centreline length (Km)		414.1	94.6	56.8	184.3	20.4	58.0	7.4	6.2	1.8	9.2	
Total corridor area (Ha)		20867	4733	2840	9195	1027	3072	162	294	79	454	
Total # of deep valley / canyon crossings		5	1	2	1	0	1	1	0	0	1	
Total # of major stream crossings		6	2	2	1	0	1	0	0	0	0	
BASE UNIT COSTS												
Base Cost Per Unit Total	$ 1,355,429											
Material	12.0%	$ 67,402,070	$ 15,397,817	$ 9,245,201	$ 29,998,072	$ 3,320,459	$ 9,440,522	$ 1,204,480	$ 1,009,159	$ 292,982	$ 1,497,462	
Design & Construction	43.3%	$ 243,138,102	$ 55,544,227	$ 33,350,022	$ 108,211,428	$ 11,977,825	$ 34,054,600	$ 4,344,897	$ 3,640,319	$ 1,056,867	$ 5,401,764	
Brushing & Access (& Survey)	28.8%	$ 161,688,705	$ 36,937,338	$ 22,178,021	$ 71,961,430	$ 7,965,346	$ 22,646,571	$ 2,889,390	$ 2,420,840	$ 702,825	$ 3,592,215	
Project & Construction Management	10.3%	$ 57,560,835	$ 13,149,614	$ 7,895,328	$ 25,618,116	$ 2,835,646	$ 8,062,131	$ 1,028,617	$ 861,814	$ 250,204	$ 1,278,821	
Common Costs	5.6%	$ 31,493,413	$ 7,194,583	$ 4,319,792	$ 14,016,508	$ 1,551,475	$ 4,411,055	$ 562,790	$ 471,527	$ 136,895	$ 699,685	
Estimate Total	100.0%	$ 561,283,124	$ 128,223,578	$ 76,988,364	$ 249,805,554	$ 27,650,750	$ 78,614,879	$ 10,030,174	$ 8,403,659	$ 2,439,772	$ 12,469,946	
DIFFICULTY FACTORED UNIT COSTS												
Material		$ 67,402,070	$ 15,397,817	$ 9,245,201	$ 29,998,072	$ 3,320,459	$ 9,440,522	$ 1,204,480	$ 1,009,159	$ 292,982	$ 1,497,462	
Design & Construction		$ 272,492,555	$ 63,790,839	$ 38,706,571	$ 121,859,886	$ 12,533,264	$ 35,601,995	$ 4,643,797	$ 4,129,335	$ 1,232,878	$ 6,322,299	Factored by Soils and Slope Difficulty Weightings
Brushing & Access (& Survey)		$ 112,887,782	$ 22,327,930	$ 14,380,804	$ 50,333,167	$ 6,884,041	$ 18,961,840	$ 1,778,814	$ 1,962,810	$ 502,273	$ 3,079,007	Factored by Brushing Cover % & Difficulty Weighting
Project & Construction Management		$ 57,560,835	$ 13,149,614	$ 7,895,328	$ 25,618,116	$ 2,835,646	$ 8,062,131	$ 1,028,617	$ 861,814	$ 250,204	$ 1,278,821	
Owners Costs		$ 31,493,413	$ 7,194,583	$ 4,319,792	$ 14,016,508	$ 1,551,475	$ 4,411,055	$ 562,790	$ 471,527	$ 136,895	$ 699,685	
Remoteness Premium (Camps, Logistics)		$ 31,562,150	$ 6,379,084	$ 3,870,657	$ 18,278,983	$ 1,253,326	$ 1,780,100	$ 464,380	$ 206,467	$ 123,288	$ 948,345	Weighted Allowance for camps, staging and logistics
New Access Roads	$ 400,000	$ 15,752,000	$ 2,664,000	$ 5,856,000	$ 4,776,000	$ 64,000	$ 2,392,000	$ 2,960,000	$ 2,480,000	$ 720,000	$ 3,680,000	New access roads at $400K per km
Factored Estimate Total		$ 589,150,804	$ 130,903,865	$ 84,274,354	$ 264,880,731	$ 28,442,211	$ 80,649,643	$ 12,642,878	$ 11,121,111	$ 3,258,520	$ 17,505,618	
Cost per km		$ 1,422,726	$ 1,383,762	$ 1,483,703	$ 1,437,226	$ 1,394,226	$ 1,390,511	$ 1,708,497	$ 1,793,728	$ 1,810,289	$ 1,902,785	
LAND COVER (Ha)												
Brushing Cover & Difficulty Weightings	Index	70%	60%	65%	70%	86%	84%	62%	81%	71%	86%	
Dense coniferous (>60% crown closure)	100%	13%	11%	12%	8%	27%	24%	24%	25%	11%	43%	
Coniferous - open canopy (26-60% crown closure)	70%	54%	30%	57%	63%	63%	60%	26%	71%	72%	36%	
Coniferous - sparse (10-25% crown closure)	30%	14%	20%	21%	14%	1%	1%	0%	2%	11%	10%	
Dense broadleaf (>60% crown closure)	100%	0%	1%	0%	0%	0%	0%	2%	0%	0%	0%	
Broadleaf - open canopy (26-60% crown closure)	70%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	
Broadleaf - sparse (10-25% crown closure)	30%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	
Mixedwood - open canopy (26-60% crown closure)	70%	1%	0%	0%	1%	4%	2%	16%	1%	1%	2%	
Mixedwood - sparse (10-25% crown closure)	30%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	
Riparian zones (15 m around wetlands, streams, waterbodie	200%	2%	2%	1%	3%	2%	2%	3%	2%	2%	4%	
Open water (from CanVec)	300%	1%	2%	1%	1%	0%	0%	0%	0%	1%	2%	
Treed wetlands	500%	0%	0%	0%	0%	1%	1%	0%	0%	0%	0%	
Shrub wetlands	300%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	
Herb wetlands	300%	2%	4%	1%	1%	1%	2%	0%	0%	0%	0%	
SURFICIAL GEOLOGY AND PERMAFROST (Ha)												
Soils & Geology Difficulty Index	Index	112%	114%	116%	112%	105%	104%	105%	113%	116%	117%	
Aeolian	110%	2%	0%	15%	0%	0%	0%	0%	0%	0%	48%	
Colluvium	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	
Fluvial	100%	23%	20%	33%	20%	56%	15%	86%	13%	38%	31%	
Lacustrine	110%	1%	0%	0%	0%	9%	0%	0%	0%	0%	0%	
Moraine	95%	62%	68%	36%	67%	34%	70%	14%	87%	33%	20%	
Organic	115%	12%	10%	16%	12%	0%	16%	0%	0%	29%	1%	
Exposed bedrock	110%	0%	1%	0%	0%	0%	0%	0%	0%	0%	0%	
Thin layer (veneer <1 m thick) with bedrock as second unit	110%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	
Sporadic discontinuous permafrost	110%	29%	0%	0%	22%	100%	100%	98%	0%	0%	0%	
Extensive discontinuous permafrost	130%	71%	100%	100%	78%	0%	0%	2%	100%	100%	100%	
SLOPE (Ha)												
Slope Difficulty Index	Index	100%	101%	100%	100%	100%	100%	102%	101%	100%	100%	
Area of corridor on slopes 0 - 15°	100%	98%	97%	100%	98%	100%	99%	90%	97%	99%	100%	
Area of corridor on slopes 15 - 30°	120%	2%	3%	0%	2%	0%	1%	10%	3%	1%	0%	
Area of corridor on slopes over 30°	200%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	

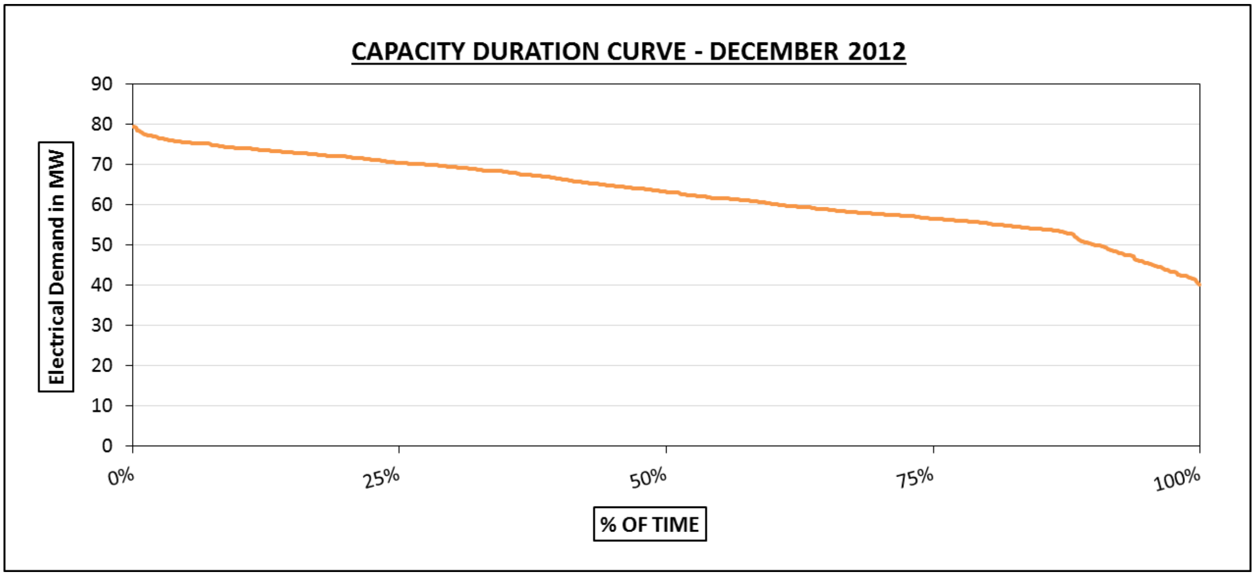
FIRST NATIONS SETTLEMENT LANDS and SETTLED LAND (Ha)											
Category A		9%	0%	24%	14%	0%	0%	0%	0%		
Category B		14%	14%	4%	9%	45%	26%	69%	2%		
Uncategorized FN lands		0%	0%	0%	0%	0%	1%	0%	0%		
Fee Simple		0%	0%	0%	0%	0%	0%	0%	0%		
Interim Protected		23%	14%	28%	23%	45%	27%	69%	2%		
Urban land		7%	20%	0%	0%	0%	20%	0%	0%		
LAND USES (Ha)											
Brushing Cover & Difficulty Weightings	Index	15%	9%	6%	22%	2%	16%	3%	0%	0%	0%
Bridgehead	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Environment	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Forestry	100%	2%	0%	0%	0%	0%	11%	0%	0%	0%	0%
Garbage dump	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Gravel Pit	100%	3%	2%	4%	3%	1%	4%	3%	0%	0%	0%
Heritage	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Industrial	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Marine	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Parks, Campground, or Recreational	150%	6%	0%	2%	13%	0%	0%	0%	0%	0%	0%
Quarry	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Rural residence	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Trapping	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Utility	100%	1%	6%	0%	0%	0%	0%	0%	0%	0%	0%
ROADS PARALLEL TO AND WITHIN CORRIDOR (Km)											
New Access Roads Required	Index	10%	7%	26%	6%	1%	10%	100%	100%	100%	100%
Paved road	100%	14%	15%	0%	2%	0%	66%	0%	0%	0%	0%
Improved gravel road	100%	76%	76%	74%	91%	98%	21%	0%	0%	0%	0%
Trail or resource road	60%	2%	3%	0%	0%	2%	5%	0%	0%	0%	0%
CAMPS, STAGING AREAS AND LOGISTICS											
Remoteness Factor		12%	10%	10%	15%	10%	5%	10%	5%	10%	15%

Appendix D: Annual Losses – 138 kV Faro to Watson Lake Transmission Line

D.1 Average Annual Transmission Line Losses

The transmission line losses mentioned in Section 3.3 and Section 3.4 represent losses under maximum generation condition. But the maximum generation condition occurs only for few hours in a year. Figure D-1 shows a capacity duration curve for December 2012. The Capacity Duration Curve shows the total duration for which the electrical demand exceeded a certain value. For example, Figure D-1 shows that the electricity demand exceeded 70 MW for 25% of December hours.

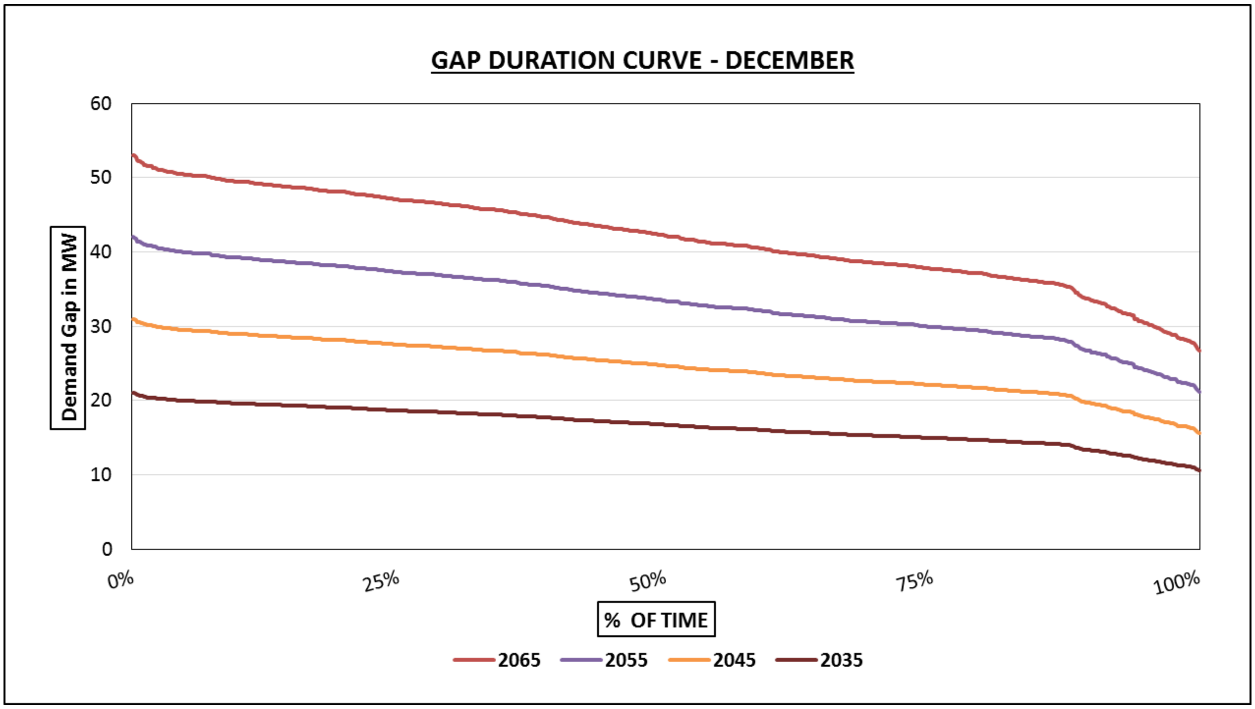
Figure D-1: December 2012 Capacity Duration Curve



Using the shape of the Capacity Duration Curve in Figure D-1 and the forecast peak capacity demand gap of 53 MW in the year 2065, the Gap Duration Curve for December 2065 was determined[27]. A similar procedure was followed for years 2055, 2045 and 2035 to determine Gap Duration Curve for December as shown in Figure D-2.

[27] Assumption: Maximum gap occurs during maximum electrical demand period.

Figure D-2: December 2065, 2055, 2045 and 2035 Gap Duration Curve



Transmission Line Losses are given by the following formula:

$$\text{Transmission Line Losses} = \frac{\text{Power Flow}^2}{(\text{Voltage} * \text{Power Factor})^2} * \text{Transmission Line Resistance}$$

For a 138 kV transmission line between Faro and Watson Lake of length 414.1 km, the *Power Flow* corresponds to the Demand Gap, *Voltage* is 138 kV, *Power Factor* is 0.9 and *Transmission Line Resistance* is 190.44 ohms. Hence the *Transmission Line Losses* are calculated for all the hours of December shown in Figure D-2 and is averaged to obtain the average December losses for 2065, 2055, 2045 and 2035 as shown in Table D-1.

Table D-1: Average Losses in December 2035, 2045, 2055 and 2065

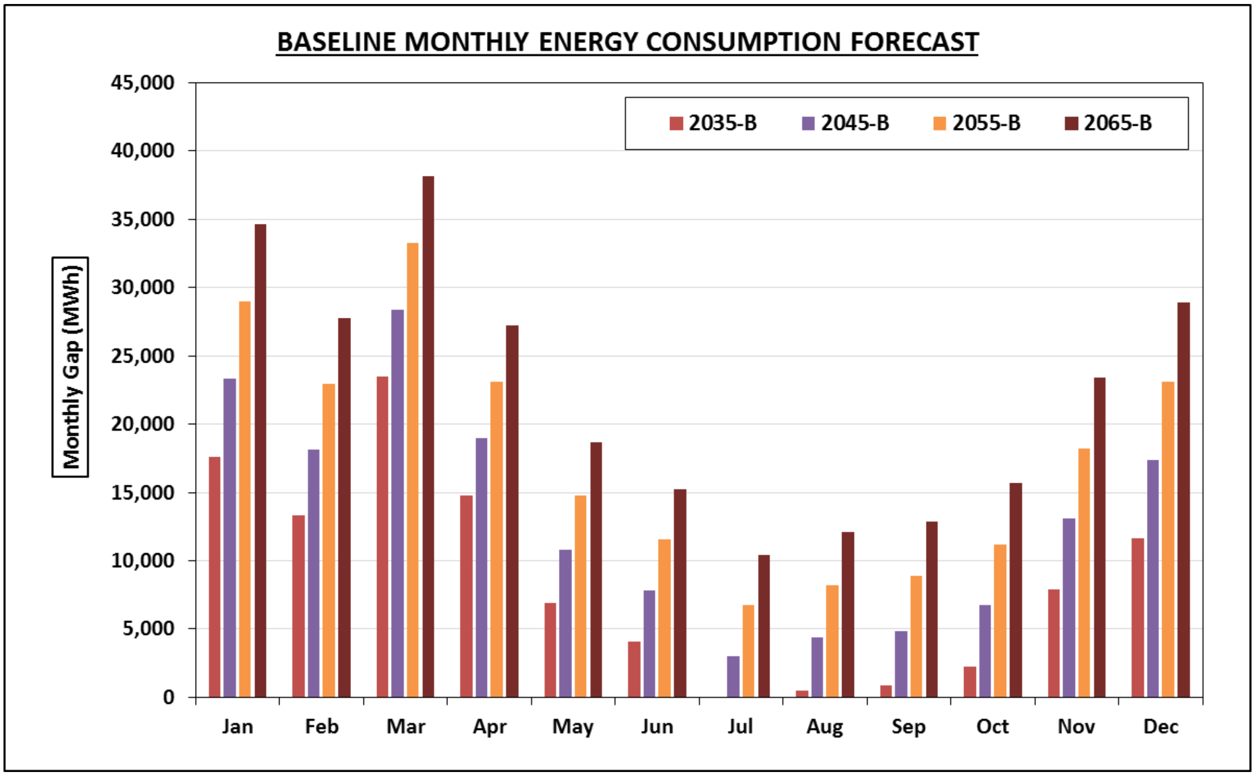
Year	Average Losses in December (MW)
2065	4.4
2055	2.8
2045	1.5
2035	0.7

To calculate the *Transmission Line Losses* for other months, we make use of the following relation:

" Transmission Line Losses are proportional to $[\text{Energy}]^2$ "

The losses on a transmission line of fixed length is proportional to square of the amount of energy that flows in the transmission line. The energy consumption in Yukon varies by month with maximum during winter and minimum during summer. Figure D-3 shows the baseline monthly energy gap[28] for the years 2065, 2055, 2045 and 2035.

Figure D-3: Baseline Monthly Energy Consumption Forecast



Using the average December losses for 2065, 2055, 2045 and 2035 and the monthly energy gap for the years 2065, 2055, 2045 and 2035, the losses were calculated as below

$$Transmission\ Line\ Losses\ for\ Month\ X = \frac{(Energy\ Flow\ for\ Month\ X)^2}{(Energy\ Flow\ for\ Month\ December)^2} X Average\ December\ Losses$$

Table D-2 shows the monthly energy flows on the Faro-Watson Lake Transmission Line (which is the same as the monthly energy gap) for the years 2065, 2055, 2045 and 2035, and the calculated losses as per the above formula.

[28] Yukon Energy and Capacity Need – 2035 to 2065 : Page 40, Figure 3-23

Table D-2: Loss Ratio and Average Transmission Line Losses – Monthly and Annual

	Energy Gap (MWh)				Loss Ratio				Losses (MW)			
	2035	2045	2055	2065	Losses Proportion Ratio 2035	Losses Proportion Ratio 2045	Losses Proportion Ratio 2055	Losses Proportion Ratio 2065	Losses in 2065	Losses in 2055	Losses in 2045	Losse s in 2035
Jan	17,635	23,312	28,978	34,655	2.30	1.80	1.57	1.44	6.35	4.35	2.72	1.59
Feb	13,362	18,168	22,965	27,771	1.32	1.09	0.98	0.92	4.08	2.73	1.65	0.91
Mar	23,524	28,416	33,299	38,192	4.08	2.67	2.07	1.75	7.72	5.75	4.03	2.83
Apr	14,801	18,954	23,100	27,254	1.62	1.19	1.00	0.89	3.93	2.77	1.80	1.12
May	6,892	10,834	14,769	18,711	0.35	0.39	0.41	0.42	1.85	1.13	0.59	0.24
Jun	4,110	7,831	11,545	15,265	0.12	0.20	0.25	0.28	1.23	0.69	0.31	0.09
Jul	0	2,991	6,721	10,458	0.00	0.03	0.08	0.13	0.58	0.23	0.04	0.00
Aug	498	4,358	8,210	12,070	0.00	0.06	0.13	0.17	0.77	0.35	0.09	0.00
Sep	878	4,876	8,866	12,863	0.01	0.08	0.15	0.20	0.88	0.41	0.12	0.00
Oct	2,221	6,715	11,202	15,697	0.04	0.15	0.23	0.29	1.30	0.65	0.23	0.03
Nov	7,934	13,095	18,248	23,409	0.46	0.57	0.62	0.66	2.90	1.73	0.86	0.32
Dec	11,639	17,397	23,144	28,902	1.00	1.00	1.00	1.00	4.42	2.78	1.51	0.69
							Average Annual Losses		**3.00**	**1.96**	**1.16**	**0.65**

The average annual losses were calculated in a similar manner from 2035 to 2075 for years in increments of 5.