Integrated Resource Plan

Appendix 3A-24

2013 Resource Options Report Update

Resource Options Mapping (ROMAP) Report

Report Appendices: A and B

Appendix A

Density Analysis Using GIS

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DENSITY ANALYSIS USING GIS

DENSITY ANALYSIS

The analysis converted the discrete energy resource data into a continuous surface. A variable of interest is the total energy resource available within a specified area. Overlaying a grid with the energy resources and running a GIS function known as "Kernel Density" was the method selected for estimating energy density.

A kernel function is a commonly-used means of distributing randomly occurring values over an area. The volume under the surface is equal to the sum of the values within the kernel area. The ArcGIS Kernel Density calculates the density of point values at each grid cell based on the quartic kernel function described in Silverman (1986, p. 76, equation 4.5):

$$\frac{3}{\pi h^2}\left(1-t^2\right)^2$$ for t = d/h <= 1, where d = distance from analysis location to resource, h = bandwidth (radius from analysis point to edge of kernel area);

0 for t > 1 .

Figure C-1 illustrates how the kernel density works.

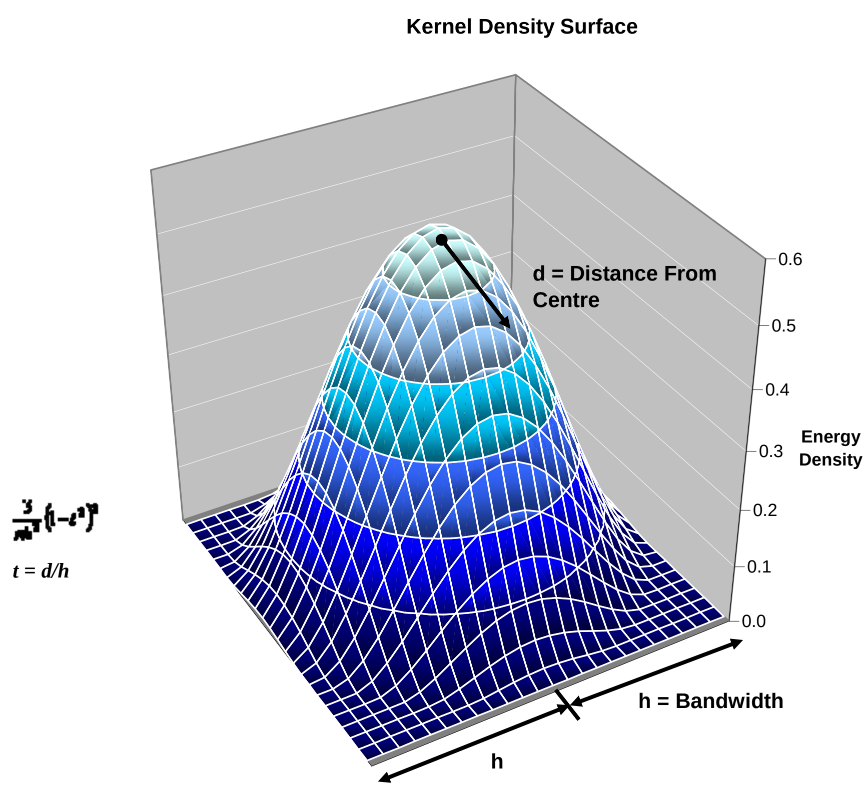


Figure C-1: Kernel Density Surface

Due to confidentiality reasons, the locations of several resource options (biomass and natural gas) were represented with polygon features rather than point features. Because the kernel density function uses point features as input, these polygon areas were distributed into points for the purpose of the analysis. A grid of points was created at 1,000 m spacing within the polygon and the installed capacity, annual energy, firm energy, dependable capacity, and ELCC distributed over the points.

KERNEL BANDWIDTH (RADIUS)

The bandwidth of the kernel density analysis represents the maximum distance of an interconnecting transmission line from a potential generation site to either an existing or potential substation connecting to the bulk transmission system.

Bandwidth has been determined to be an independent variable for this analysis, but would generally represent the maximum distance for construction of a collector transmission line to a central substation servicing the cluster. The Western Regional Energy Zones project (WREZ) set a maximum distance of 100 miles (160 km), which roughly represents $10/MWh in additional costs to energy production[1]. This was the maximum bandwidth considered in this study.

Kernel densities were generated at 80 km and 160 km bandwidths. A larger bandwidth has the effect of ‘flattening’ the resulting density surface, but retains an accurate volume of energy beneath the surface. Comparing the results led to the selection of the 80 km bandwidth, as the 160 km bandwidth resulted in a small number of very large energy clusters, which was not as desirable as a larger number of smaller clusters for planning of potential new transmission in BC.

[1] WREZ Western Renewable Energy Zones – Phase 1 Report, June 2009. http://www.westgov.org/wga/publicat/WREZ09.pdf

Appendix B

Roads & Power Lines Cost Estimation Using GIS

List of Tables

List of Figures

ROAD & POWER LINE COST ESTIMATING USING GIS

Access road and power line costs were developed using GIS tools. The toolset identifies the least expensive route from power projects to existing roads or existing power systems.

These tools were used to develop unit cost surfaces of the entire province for road and power line construction.

The sources and processes for developing the road and power line costs are described in Table B-1.

Table B-1: Cost Surface Development Process

Feature	Source/Author	Usage	Process
Public Roads	National Road Network (geobase.ca)	Roads	Used as sources for road cost routine.
Overhead Wires	BC Hydro and Fortis BC	Power Lines	Used as sources for power line cost routine.
Slope	Canadian Digital Elevation Data (CDED)	Roads & Power Lines	Elevation data converted to slope, and categorized into cost classes. Slopes exceeding 30% and 75% were considered to be not feasible for construction of roads and power lines, respectively.
Proximity to Major Cities	Site classification (see Section 3.2.1)	Roads	Greater cost values were assigned to locations further away from city centres.
Land Cover	AVHRR 1:2M Land Cover (geogratis.ca)	Roads & Power Lines	Costs were adjusted based on land cover (i.e. forest, rock, croplands). Permanent snow and ice were considered infeasible for construction.
Parks	BC Parks and Protected Areas (lrdw.ca) Canada Lands Administrative Boundaries (geogratis.ca)	Roads & Power Lines	Parks were masked out so that no new roads or power lines can cross provincial and federal parks.
Water	Output from the Power calculation model Watershed Atlas	Roads & Power Lines	Costs were assigned to small rivers that can be crossed with culverts or small bridges. Large rivers and lakes were not considered for crossing.
Forest Roads	Forest Tenure Roads (lrdw.ca)	Roads & Power Lines	Construction costs were discounted along existing forest roads.

The proposed project locations were overlaid with the resulting accumulated cost output and total road cost extracted. Some locations were found to be inaccessible as determined by the cost routine. These locations were reviewed and either assigned an approximate cost based on the output or assigned a $100 million cost for roads if the project is technically inaccessible:

Table B-2 lists the cost assigned for technically inaccessible projects for power lines.

Table B-2: Power Line Costs for Technically Inaccessible Projects

New Power Line Voltage (kV)	Technically Inaccessible Cost ($)
25	50,000,000
69	120,000,000
138	300,000,000
230	1,000,000,000
500	3,000,000,000

The above costs are much higher than any of the cost output from the GIS routine and are intended to render a project economically infeasible due to inaccessibility to roads or power lines.

Clustering of projects to reduce costs through sharing of common infrastructure was outside of this assessment’s scope.

After the cost accumulation process, individual paths from sources to project locations were traced using the GIS tools. While this process identified common paths amongst adjacent projects, it was assumed that each project would be constructed independently. This is a key factor in the overall cost estimate as road and power line costs make up a significant portion of most projects, especially in remote areas.

ACCESS ROADS

Access roads were considered to begin at an existing, documented road and follow the least-cost path to the project location. The primary costs for roads were based on road gradient and distance to major centres. Adjustments to unit costs were made for crossing barren rocky areas, wetlands and agricultural areas. Nominal costs were assigned to existing forestry roads to account for maintenance and road upgrading. The forestry road costs were approximately an order of magnitude less than construction of new roads. This resulted in the least-cost path generally following these corridors until the vicinity of a proposed site was reached.

Roads were assumed not to traverse legally protected areas, large water bodies, glaciers or road grades exceeding 30%. If the site was in proximity to a large body of water, barge access was considered.

Development (engineering, environmental and other) and annual costs (O&M, land acquisition and property taxes, but not water rentals) were added on as a percentage of capital cost.

Road costs also included a 30% contingency.

Table B-3: Road Construction Unit Cost ($/m)

Site Location Category	Slope	$/m
A	0-5%	121
	5-10%	153
	10-15%	216
	15-20%	278
	20-30%	402
B	0-5%	209
	5-10%	241
	10-15%	303
	15-20%	366
	20-30%	490
C & D	0-5%	296
	5-10%	328
	10-15%	391
	15-20%	453
	20-30%	577

Four site categories were used to indicate remoteness of location. Category A sites were located within a 50 km radius of a major town or city centre (population of 25,000 or more). Category B and C sites were located within 200 and 400 km from a centre, respectively, and Category D sites were located anywhere outside a 400 km radius from a centre. Figure B-1 shows the site location categories.

BARGE ACCESS

Potential projects that were sited close to the shoreline of a large lake, the coast or a major inlet were given the opportunity to have barge access. In the case of lakes only large lakes (>50 km^2) in close proximity to roads (<500 m) were allowed for barge access. A barge access cost allowance was included for projects based on the construction duration: $700,000 for 1 year, $1,000,000 for 2 years, and $1,300,000 for 3 years of construction.

Estimated costs for access can be found in Figure B-2.

POWER LINE, INTERCONNECTION AND TRANSFORMATION COSTS

As with access roads development (engineering, environmental and other) and annual costs (O&M, land acquisition and property taxes) were added on as a percentage of capital cost. The percentages used are noted in Section 3 of the report.

These costs also included a 30% contingency.

Estimated costs for power lines from 25 kV through 500 kV can be found in Figures B-3 through B-7.

ALLOWABLE INTERCONNECTION LOCATIONS

Independent power line (an unshared line that is used by one project to interconnect to the BC Hydro grid) interconnection occurred at either:

1. An existing power line (BC Hydro or Fortis BC grid) or the proposed 287 kV Northwest Transmission Line (NTL) from Skeena to Bob Quinn Lake substation (in-service December 2013); or

2. An existing substation (BC Hydro or Fortis BC grid) or the proposed 287 kV substation at Bob Quinn.

Interconnection to the existing system with independent power lines was not allowed at non-integrated substations or to power lines only connected to a non-integrated substation. This included the non-integrated existing Fort Nelson Substation (FNG) and line 1L359 from Alberta to FNG.

Table B-4 details the interconnection rules used to define whether a new power line can connect to an existing power line or to an existing substation. Table B-5 details the interconnection rules used to define whether a new power line can connect. Shaded grey cells indicate that interconnection is not allowed.

Table B-4: Interconnection Rules – New Power Line to Existing Power Line

New Power Line Voltage (kV)	Existing Power Line Voltage (kV)[a]				
	12.5, 25, & 34.5	60, 63[b] & 69	138 132[b], 161[b]	230 & 287	360 & 500
25	D.I.[c]	S.S.[d]	S.S.	S.S.	X
69	X	S.S.	S.S.	S.S.	X
138	X	X	S.S.	S.S.	X
230	X	X	X	S.S.	X
500	X	X	X	X	X

Notes:
a) If the voltage level of the new power line is not available at the existing substation, then a transformation cost will apply.
b) FortisBC System Voltage
c) D.I. = direct interconnection without a sectionalizing substation
d) S.S = interconnection only with a sectionalizing substation
e) 25 kV power lines were allowed to connect to 12.5 kV power lines in the BC Hydro system as it was assumed the system will eventually be upgraded to 25 kV. Either a 25 kV to 12.5 kV transformer would be required at the point of interconnection or the 12.5 kV power line would be upgraded to 25 kV. This transformation or upgrade cost was ignored.

Table B-5: Interconnection Rules – New Power Line to Existing Substation

New Power Line Voltage (kV)	Lowest Voltage Available at Existing Substation (kV)[a]					
	12.5, 25, & 35	60, 63[b] & 69	138 132[b], 161[b]	230, 238 & 287	360	500
25[c]	√	√	√	√	X	X
69	X	√	√	√	√	X
138	X	X	√	√	√	√
230	X	X	X	√	√	√
500	X	X	X	X	X	√

Notes:
a) If the voltage level of the new power line is not available at the existing substation, then a transformation cost will apply.
b) FortisBC system voltage
c) 25 kV power lines were allowed to connect to 12.5 kV substations in the BC Hydro system as the system will eventually be upgraded to 25kV. A 25 kV to 12 kV transformer would be required at the point of interconnection. This transformation cost was ignored.

New power lines were only allowed to connect at specific points along an existing power line (be it a direct tap in the case of 25 kV or a sectionalizing substation in the case of 60, 69, 138, 230, or 287 kV). Allowable interconnection locations were positioned a minimum distance between each other and existing substations (Table B-6). The allowable interconnection locations also were placed in locations with lower terrain slope (i.e. at flatter locations not on the side of a hill).

Table B-6: Minimum Distance between Potential Interconnection Points

Existing Power Line Voltage (kV)	Min. Distance (km)
12.5, 25, & 34.5	**10**
60, 63 & 69	**20**
132, 138 & 161	**60**
230, 238 & 287	**100**

POWER LINE COSTS

The power line costs estimated for the 2007 Run-of-River (RoR) study by KWL were escalated to 2011 dollars using 2% per year (6% total). Costs vary with the slope in KWL's least-cost routing method (see KWL's Run-of-River Hydroelectric Resource Assessment for British Columbia 2007 study for discussion). The estimated 2011 powerline costs are presented in Table B-7.

Exclusion areas for power lines were legally protected areas, glaciers or topography with grades exceeding 75%.

Table B-7: Power Line Cost

New Power Line Voltage (kV)	Cost ($/km), 2011 Dollars		
	Avg. Slope (0-15%)	Avg. Slope (16-30%)	Avg. Slope (31 - 75%)
25	84,800	169,600	254,400
69	106,000	212,000	318,000
138	159,000	318,000	477,000
230	265,000	530,000	795,000
500	530,000	1,060,000	1,590,000

Table B-8: Transmission Voltages – Capacity and Distance

Voltage Level (kV)	Capacity Range (MW)		Distance from Cluster's Central Substation (Km)		75% of Distance x 75% of Capacity (MW x km) (This is used as a check)	
	Min.	Max.	Min.	Max.	Min.	Max.
25	0	20	1	20	57	225
69	20	60	20	60	226	2,025
138	60	150	60	100	2,026	8,438
230	150	500	N/A	N/A	N/A	N/A
500	500	1,500	N/A	N/A	N/A	N/A

Table B-9 provides estimated submarine cable costs.

Table B-9: Submarine Cable Cost

New Submarine Cable Voltage (kV)	$M/km
25	**0.5**
69	**1.0**
138	**3.6**
230	**5.3**
500	**7.1**

INTERCONNECTION & TRANSFORMATION COSTS

Tables B-10 & B-11 provide estimates for the unit interconnecting station cost and transformation costs.

Table B-10: Interconnection Cost to Existing Power Lines

New Power Line Voltage (kV)	Interconnecting Station Cost or Sectionalizing Substations (required to connect to 69kV, 138kV and 230kV, and 287 kV)	Interconnection Costs to an Existing Power Line – Without a Sectionalizing Substation Required (only 25kV to 25kV, 12 kV and 35kV)
25	$1.5M	$400k
69	$7.5M	
138	$9.5M	
230	$10.5M	

Table B-11: Transformation Cost

New Generation Power Line Voltage (kV)	Lowest Voltage Available Existing Substation (kV) (Only apply if there is not a voltage level available at the substation)						
	25 & 34.5	69	138	230	287	360	500
25 [a]	$0	$1.5M	$1.5M	$1.5M	$1.5M	X	X
69 [a]	X	$0	$7.5M	$7.5M	$7.5M	$7.5M	
138	X	X	$0	$12M	$12M	$15M	$18M
230	X	X	X	$0	$0 [b]	$13.5M	$16.5M
500	X	X	X	X	X	X	$0

Notes:
a) In absence of information, the sectionalizing substation cost was used.
b) There was no transformation cost assumed since the power line would likely be built at 287, which would be a similar cost to a 230 kV.

TOTAL POWER LINE AND INTERCONNECTION COSTS

The total cost was calculated as follows for the two scenarios:

1. New power line and interconnection to an existing power line was calculated as follows:

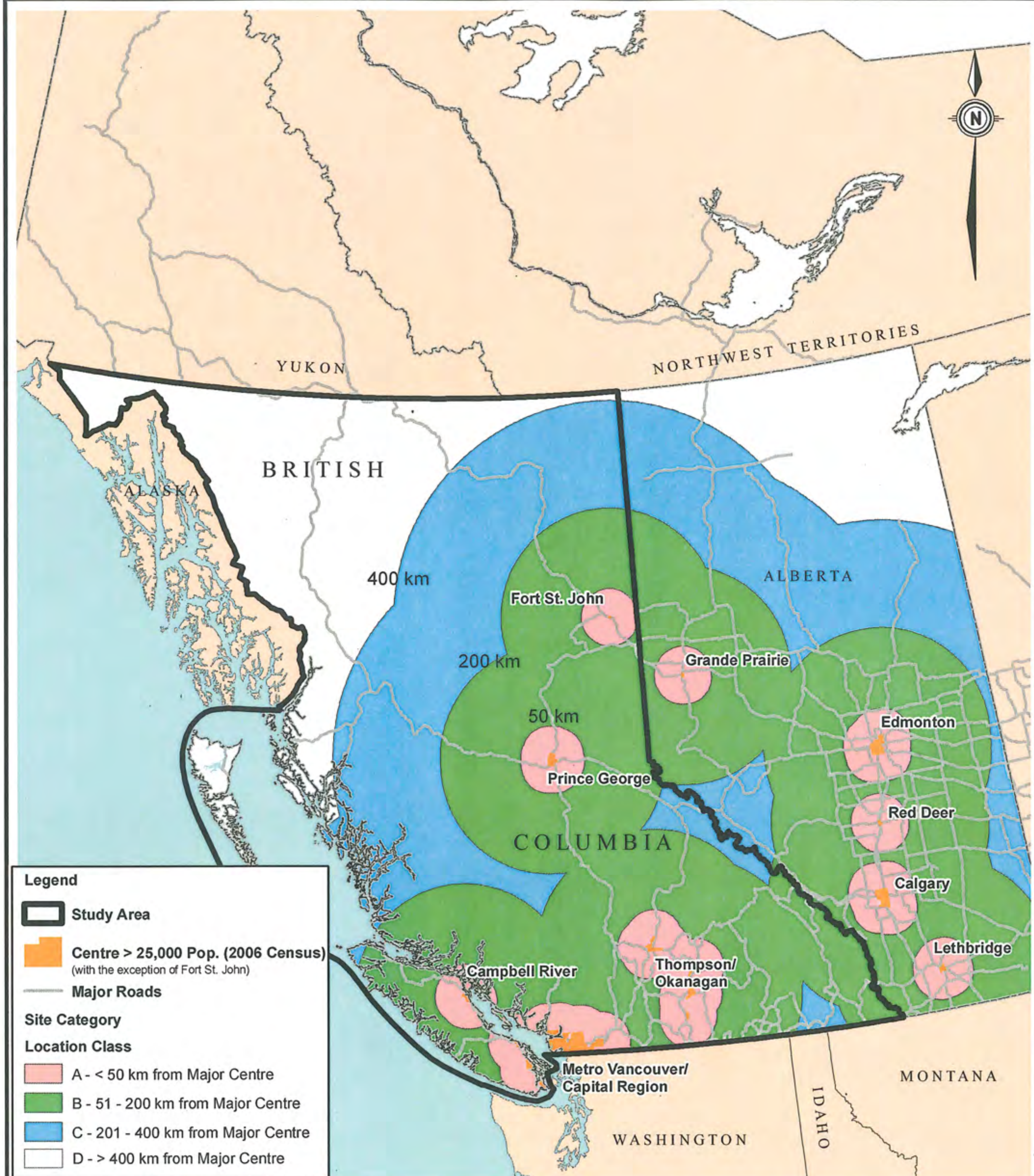
Total cost = C_{PL} x L_{PL} + ($C_{Int\_PL\_Direct}$ or $C_{Int\_PL\_SS}$) + C_{Tran}

Where:
C_{PL} = power line cost per length (varies with slope and kV)
L_{PL} = power line length
$C_{Int\_PL\_Direct}$ = cost of direct tap interconnection to an existing power line only applies to 25kV to 25kV (and also for 25 kV to 12.5 kV or 35kV in the BC Hydro system)
$C_{Int\_PL\_SS}$ = cost of interconnection using a sectionalizing substation to connect to an existing power line. (Not required for 25kV to 25kV, 12.5 kV, or 34.5 kV power lines.)
C_{Tran} = cost of transformation (based on kV of the new power line and kV of the power line), only applies if the kV of the new power line is lower than the kV of the existing power line.

2. New power line and interconnection to an existing substation would include:

Total cost = C_{PL} x L_{PL} + C_{Tran}

Where:
C_{PL} = power line cost per length (varies with slope and kV)
L_{PL} = power line length
C_{Tran} = cost of transformation (based on kV of the new power line and kV of the substation if the voltage of the new power line is not available at the substation) = $0 if the voltage of the power line is available at the existing substation



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BC hydro

Project No.	Date
478-098	May 2011

200 100 0
Kilometres

Site Location Categories

Figure B-1

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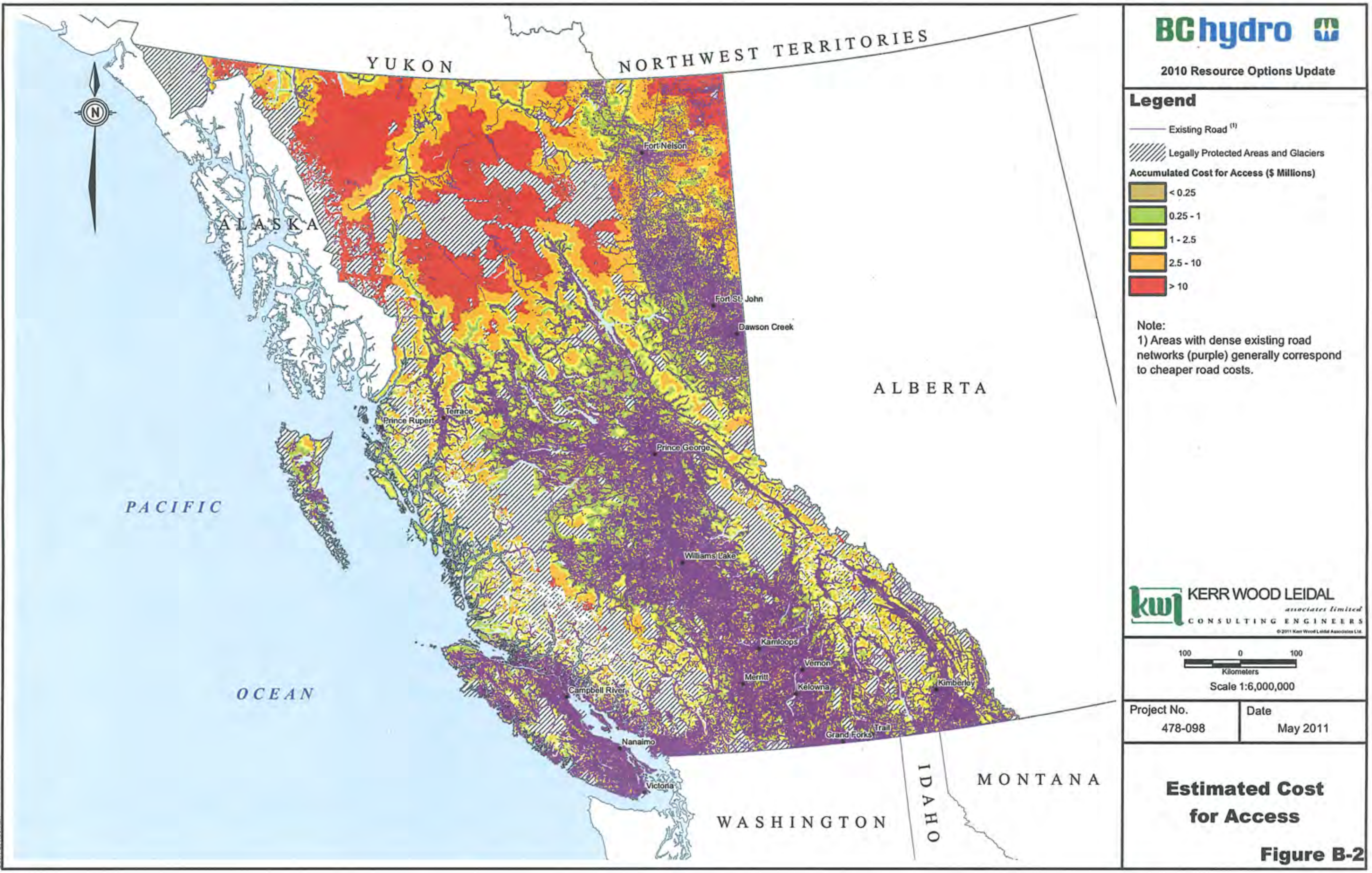
BC hydro
2010 Resource Options Update
Legend
Existing Road (1)
Legally Protected Areas and Glaciers
Accumulated Cost for Access ($ Millions)
< 0.25
0.25 - 1
1 - 2.5
2.5 - 10
> 10
Note:
1) Areas with dense existing road networks (purple) generally correspond to cheaper road costs.
KERR WOOD LEIDAL
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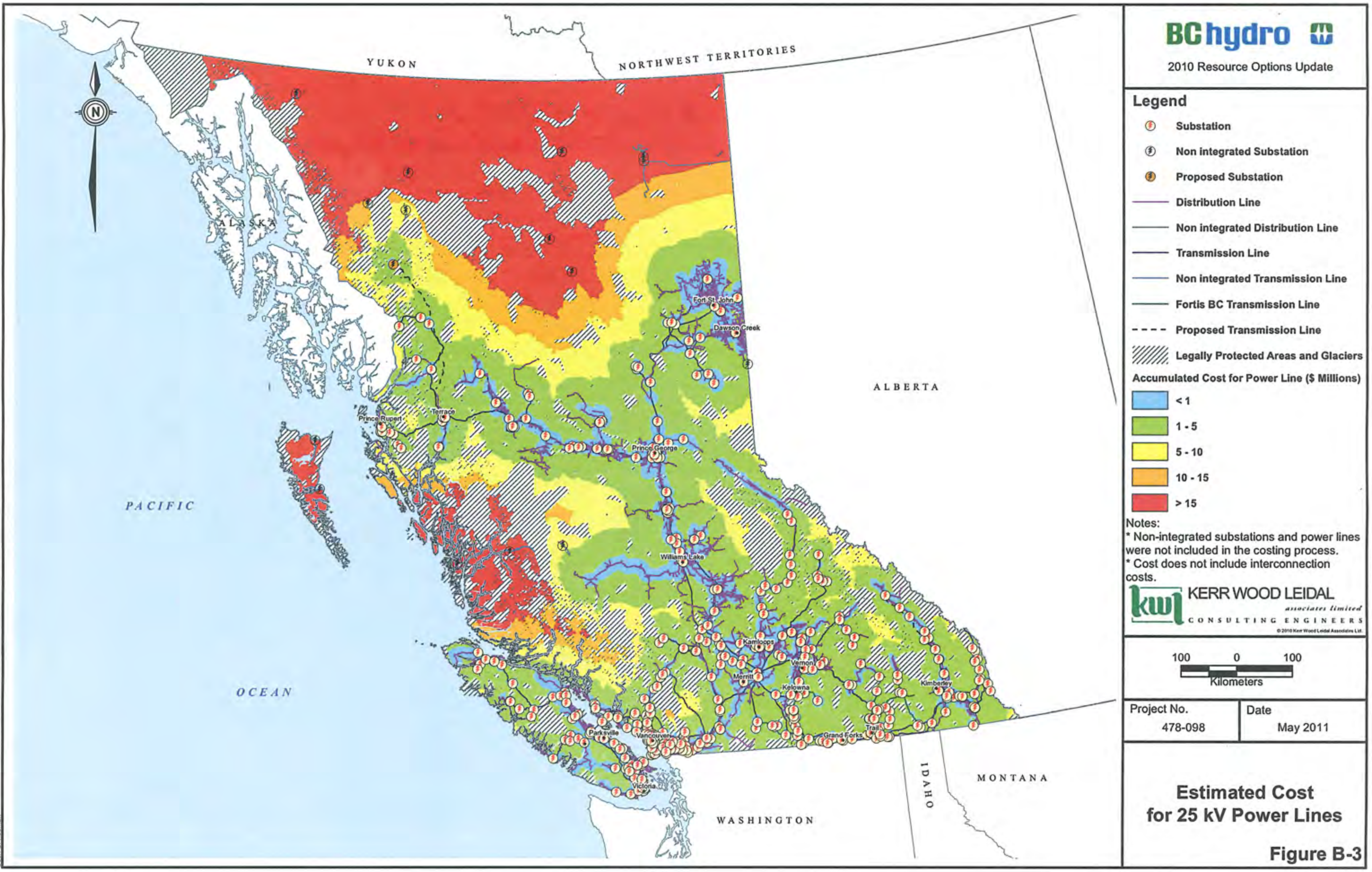
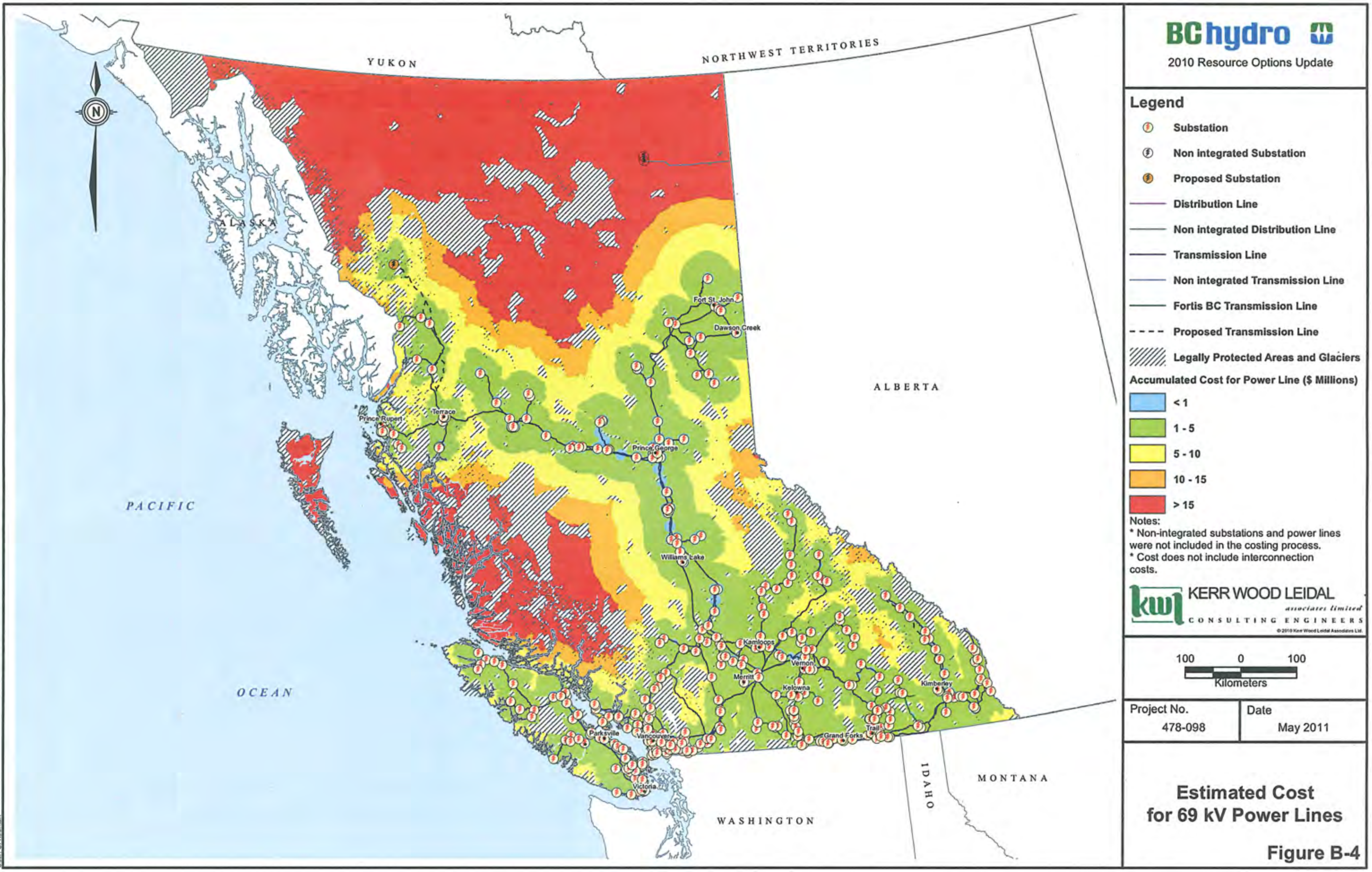
100 0 100
Kilometers
Scale 1:6,000,000
Project No.
478-098
Date
May 2011
Estimated Cost for Access
Figure B-2
YUKON
NORTHWEST TERRITORIES
ALASKA
ALBERTA
PACIFIC
OCEAN
WASHINGTON
IDAHO
MONTANA
Fort Nelson
Fort St. John
Dawson Creek
Terrace
Prince Rupert
Prince George
Williams Lake
Kamloops
Vernon
Merritt
Kelowna
Kimberley
Campbell River
Nanaimo
Victoria
Grand Forks
Trail
N



Estimated Cost for 25 kV Power Lines

Figure B-3



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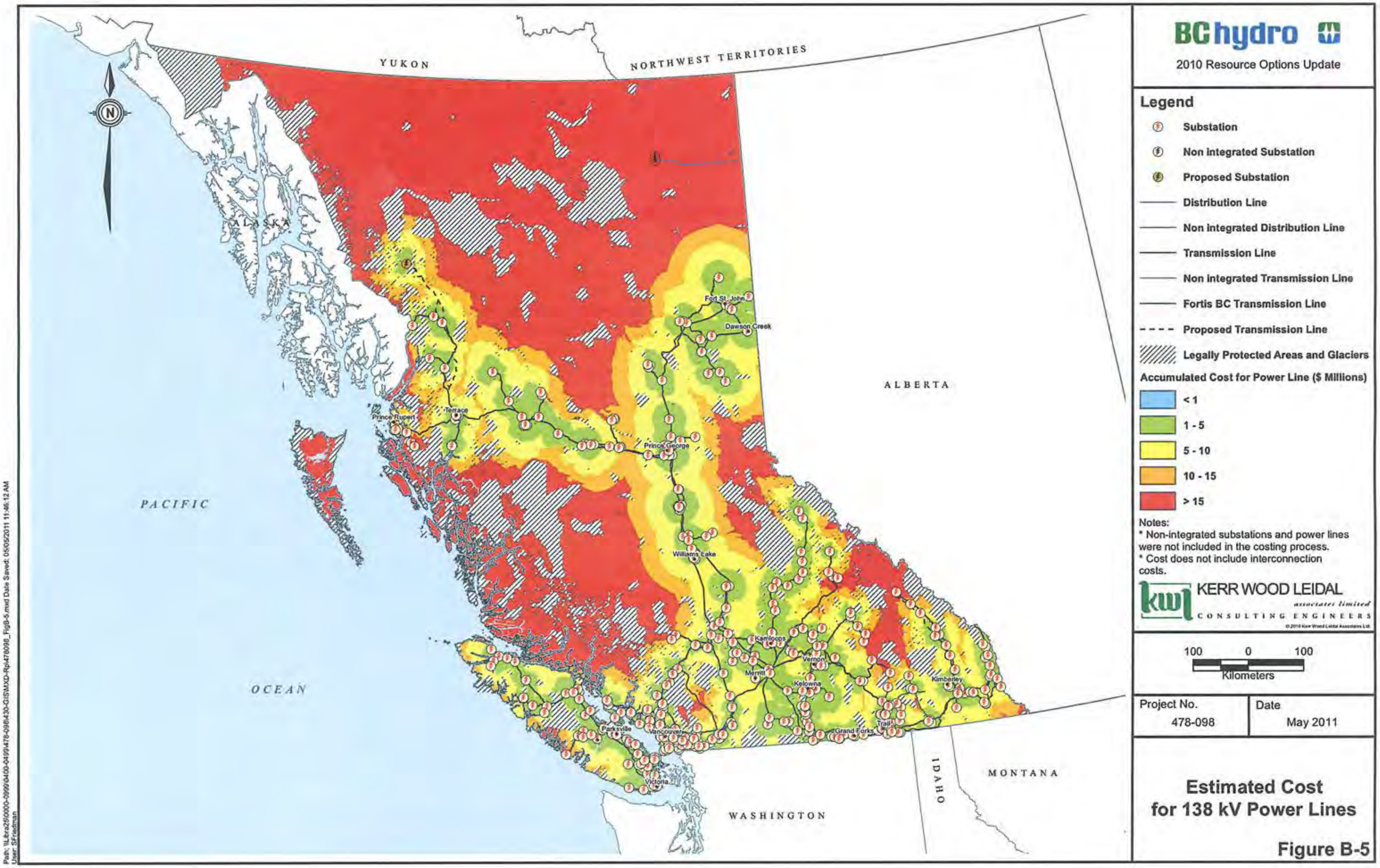
BC hydro
2010 Resource Options Update
Legend
Substation
Non integrated Substation
Proposed Substation
Distribution Line
Non integrated Distribution Line
Transmission Line
Non integrated Transmission Line
Fortis BC Transmission Line
Proposed Transmission Line
Legally Protected Areas and Glaciers
Accumulated Cost for Power Line ($ Millions)
< 1
1 - 5
5 - 10
10 - 15
> 15
Notes:
* Non-integrated substations and power lines were not included in the costing process.
* Cost does not include interconnection costs.
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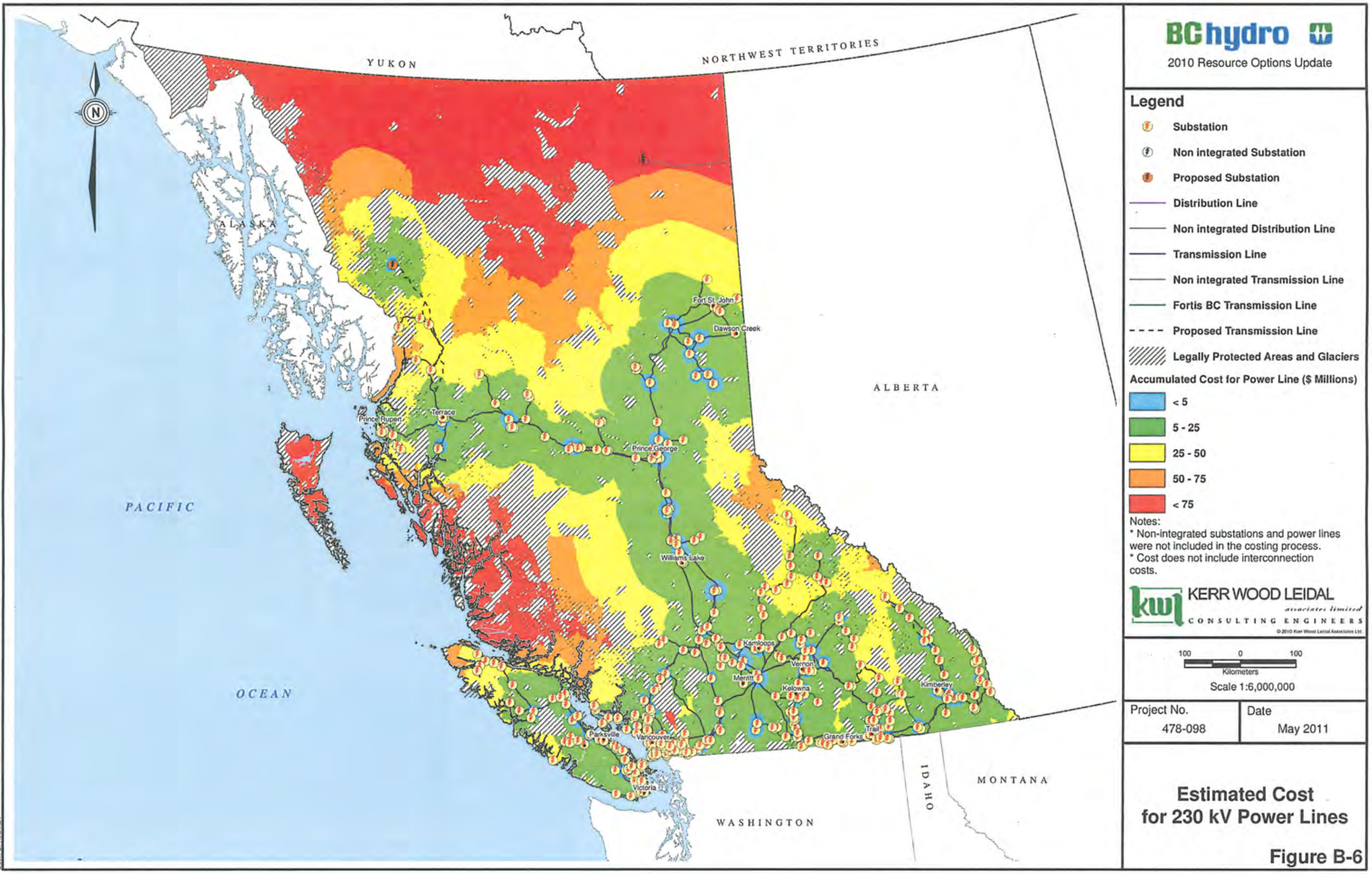
CONSULTING ENGINEERS
100 0 100
Kilometers
Project No.
478-098
Date
May 2011
Estimated Cost
for 138 kV Power Lines
Figure B-5
YUKON
NORTHWEST TERRITORIES
ALASKA
ALBERTA
PACIFIC
OCEAN
WASHINGTON
IDAHO
MONTANA
Fort St. John
Dawson Creek
Prince Rupert
Terrace
Prince George
Williams Lake
Kamloops
Vernon
Merritt
Kelowna
Kimberley
Trail
Grand Forks
Parksville
Vancouver
Victoria


BC hydro
2010 Resource Options Update
Legend
Substation
Non integrated Substation
Proposed Substation
Distribution Line
Non integrated Distribution Line
Transmission Line
Non integrated Transmission Line
Fortis BC Transmission Line
Proposed Transmission Line
Legally Protected Areas and Glaciers
Accumulated Cost for Power Line ($ Millions)
< 5
5 - 25
25 - 50
50 - 75
< 75
Notes:
* Non-integrated substations and power lines were not included in the costing process.
* Cost does not include interconnection costs.
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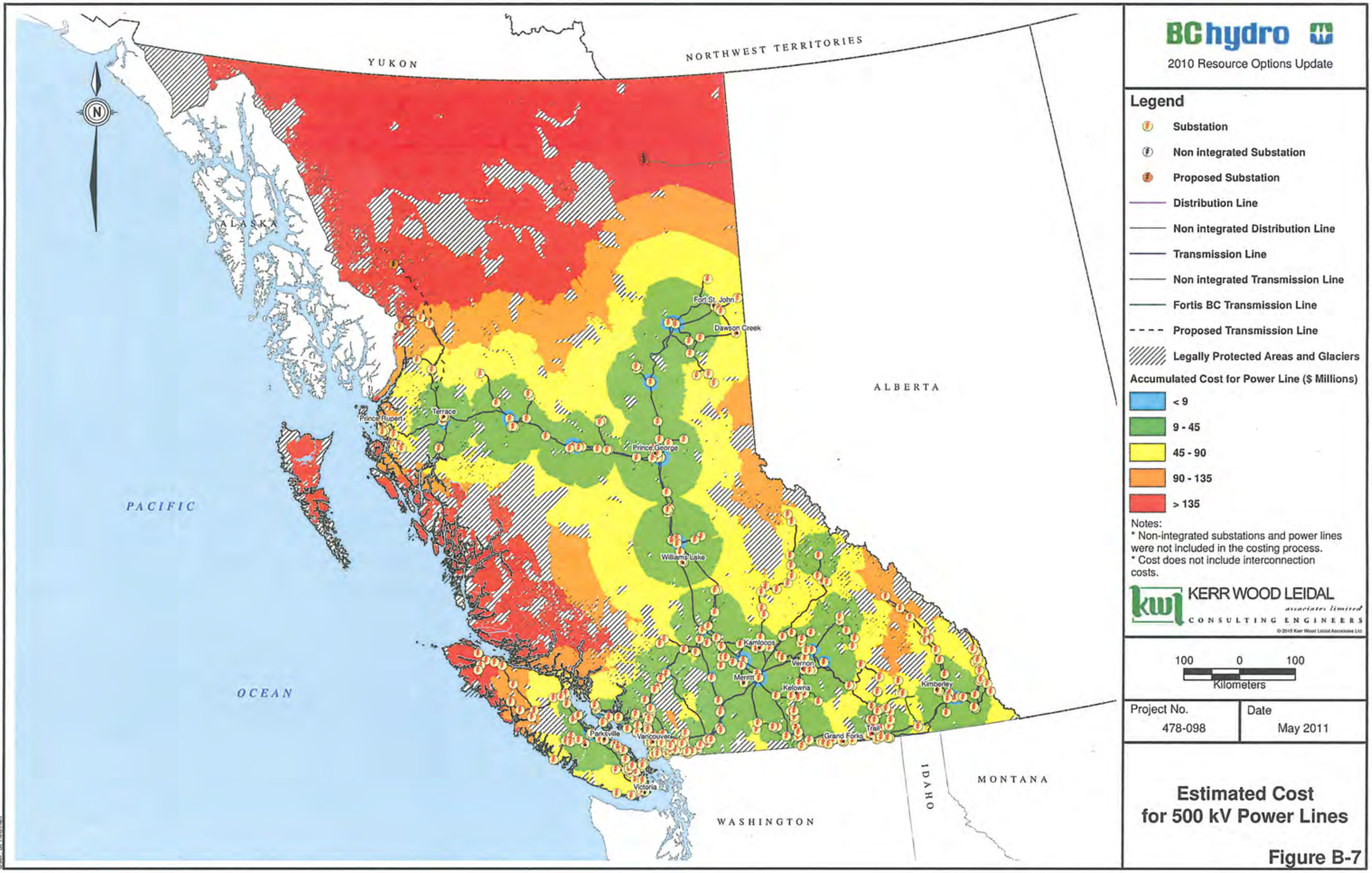
CONSULTING ENGINEERS
100 0 100
Kilometers
Scale 1:6,000,000
Project No.
478-098
Date
May 2011
Estimated Cost for 230 kV Power Lines
Figure B-6
YUKON
NORTHWEST TERRITORIES
ALBERTA
ALASKA
PACIFIC
OCEAN
WASHINGTON
IDAHO
MONTANA
Fort St. John
Dawson Creek
Terrace
Prince Rupert
Prince George
Williams Lake
Kamloops
Vernon
Merritt
Kelowna
Kimberley
Parksville
Vancouver
Grand Forks
Trail
Victoria


BC hydro
2010 Resource Options Update
Legend
Substation
Non integrated Substation
Proposed Substation
Distribution Line
Non integrated Distribution Line
Transmission Line
Non integrated Transmission Line
Fortis BC Transmission Line
Proposed Transmission Line
Legally Protected Areas and Glaciers
Accumulated Cost for Power Line ($ Millions)
< 9
9 - 45
45 - 90
90 - 135
> 135
Notes:
* Non-integrated substations and power lines were not included in the costing process.
* Cost does not include interconnection costs.
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CONSULTING ENGINEERS
100 0 100
Kilometers
Project No.
478-098
Date
May 2011
Estimated Cost for 500 kV Power Lines
Figure B-7
YUKON
NORTHWEST TERRITORIES
ALASKA
ALBERTA
PACIFIC
OCEAN
WASHINGTON
IDAHO
MONTANA
Fort St. John
Dawson Creek
Terrace
Prince Rupert
Prince George
Williams Lake
Kamloops
Vernon
Merritt
Kelowna
Kimberley
Trail
Grand Forks
Parksville
Vancouver
Victoria
N