THE MARIPORT GROUP LTD.

SPECIALIZED ADVISORY SERVICES FOR PORTS & THE SHIPPING INDUSTRY

TALTSON TO SNAP LAKE

POWER TRANSMISSION

VIA GREAT SLAVE LAKE

Final

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In association with Kinectrics Inc.

The Mariport Group Ltd.
41 Parkhill Road East
P.O. Box 1758
Cambridge, Ontario
Canada N1R 7G8

CONTENTS

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1. BACKGROUND

The Government of the North West Territories, Resources, Wildlife and Economic Development Department, Energy Secretariat requested a brief study to assess the order of magnitude costs for establishing a transmission route across Great Slave Lake. The power was to be moved from the underutilized Taltson Lake hydro dam to the vicinity of Snap Lake.

Mariport and Kinectrics have reviewed two primary options, with an intermediate option on the land/underwater cable concept. These are:

i) All underwater cable from Taltson Bay area to the vicinity of Gros Cap.

ii) Overhead and underwater line via the Hornby Channel at the east end of Preble Island with an underwater cable connection across the Hearne Channel.

iii) A variant of ii) above with an underwater cable from Taltson Bay area to the west end of Preble Island.

In all cases a line has also been costed from Taltson Lake to the south shore of Great Slave Lake, and from the north shore of Great Slave Lake to Snap Lake. The desired power to be transmitted has been assumed at 50MW. Issues and concerns relative to all routes have been discussed in the body of the report.

Concepts and costs for movement of underwater cable via rail from Duluth have been provided by Ed Clark, an independent specialist in heavy rail shipments.

2. EXECUTIVE SUMMARY

2.1 The investigation has shown that a transmission route between Taltson Lake and Snap Lake across Great Slave Lake by way of the Simpson Islands could be achieved at a cost of about $151m. This is the least cost of routes analyzed and includes reactor installation and overhead to underground termination, but not substations at the termination locations. The cost included insulating the underwater portion to 138Kv. If insulation to 161Kv is considered to be necessary, then the overall cost would rise to an estimated $155m.

2.2 This route uses the shortest length of underwater cable, at about 8km, all other water crossings are considered achievable by overhead cable.

2.3 This route should also minimize environmental issues, although foundations for a number of transmission towers will need to be built in shallow water. Preliminary contact with DFO regarding the Navigable Water Protection Act suggests that there will not be substantive concerns and that it may not trigger an environmental review.

2.4 The study has indicated a difference in pricing for overland portions of the route compared with advice given in a conference call between the team and GNWT and Power Corporation on 3rd September. Presuming the pricing in the current study, the capital cost difference is in the order of $40m. This cost differential may be acceptable given potential benefits of a power connection on the north shore of Great Slave Lake, and avoidance of the east side of the lake.

2.5 It is expected that submarine cable would need to be sourced in Scandinavia, due to the depths to which it will be laid in the Hearne Channel. Lowest delivery cost would be via Tuktoyaktuk and the Mackenzie River. Highest cost would be via the Great Lakes and rail, unless shared delivery with other project cargo could be arranged.

2.6 Should further studies be considered for the cross lake option, we have provided some detail in Annex 8.1. Total costs are in the range $175,000-200,000. Initial work that would be desirable before freeze up this year would cost about C$25,000 plus travel, accommodation and air charters to over-fly the route.

3. TRANSMISSION VOLTAGES

Some work has already been carried out by other consultants on an all-overhead route that circles the east end of Great Slave Lake. This route extends from the Taltson Lake hydro dam to Snap Lake and we understand the route length is in the order of 435 km. We further understand that the transmission line being envisaged for this all-overhead route would be insulated for a voltage of 161kV, but operated initially at a voltage of 115kV.

When one selects a transmission voltage for a power delivery application, various factors are considered. Stability considerations play a major role while selecting operating voltage for long transmission lines. As a rule of thumb, for circuit lengths in the order of 500 km, a line is loaded to its Surge Impedance Loading ("SIL") level as a first approximation. For lines shorter than 500 km, this level can be exceeded (sometimes significantly for very short lines) and for lines longer than 500 km, the lines would be loaded to below the SIL level.

The SIL levels for various voltages are as follows [rounded off to approximate values]:

Circuit Voltage (kV)	SIL (MW)
115	35
138	50
161	65

Based on the above, 138 kV may be considered as optimal transmission voltage, for preliminary study purposes, for this particular application. But since 115 kV is the voltage level of the existing grids north and south of the Great Slave Lake, it may prove to be most cost effective to design the proposed line to this voltage. If the line is to be insulated to a 161kV voltage rating, one must assume that power delivery levels greater than 50MW are being considered in the future.

Another factor that should be mentioned relates to the loading levels that are contemplated for the first few years after the line is constructed. We are advised that the line will only be loaded to a level of 25MW and possibly less during this time interval. Because of this light loading condition, voltage regulation problems could be experienced, due to heavy charging current. Switched reactors at the line terminations may need to be incorporated during the detailed design stage to alleviate these voltage variations. In order to provide some feel for the relative magnitude of this issue, a 435 km line built to 115kV insulation levels and operating at that voltage would draw approximately 18 MVARs[1] of charging current. Therefore equivalently sized and incrementally switched shunt reactors would be necessary to provide suitable compensation for these line charging in-flows, in order to maintain acceptable voltage profiles. If the line were insulated to the higher voltage of 161kV but operated at

[1] A MVAR (Mega Volt Amp Reactive) has the same loading implication for a transmission line as does a MW. That is to say from an electrical current perspective, 18 MVARs loads the line in a similar fashion as does 18MWs. The difference in the two quantities is that MVARs and MW vectors are orthogonal, and the MVAR performs no useful end-state work such as running a motor or heating a building; they merely transfer energy between the electric and magnetic fields of the circuit.

115kV, the reactive compensation requirement would be slightly less than the value we have indicated.

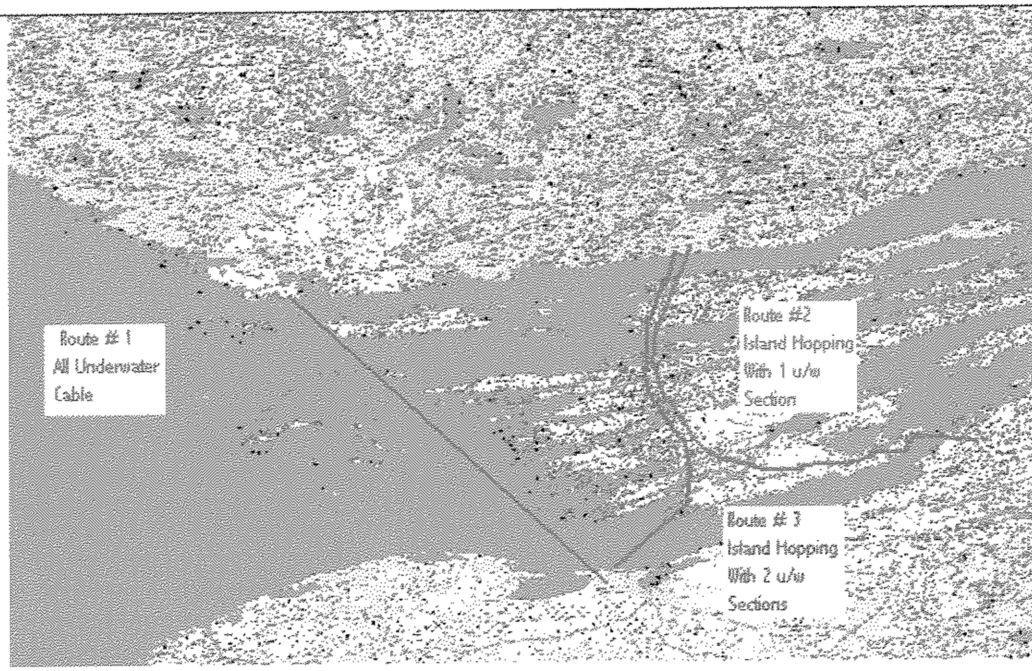

Fig. 1 – MAP OF EASTERN GREAT SLAVE LAKE

4. ROUTE OPTIONS

We have evaluated a number of route options, which involve various lengths of underwater cable as a part of the circuit. Potential routes are visualized in Fig. 1.

4.1 ALL UNDERWATER CABLE

This route would commence on the south shore of Great Slave Lake at a point between Driftwood Island and Stoney Island which would depend on local surveys, evaluation of any environmental issues and assessment of transmission tower foundation requirements. The route is expected to run west of the Simpson Islands and east of Iles du Large, coming ashore on the north shore west of Gros Cap, possibly in Campbell Bay. Length of cable would be in the range 32-40 nm (49-74 km) depending on the start and finish points, and the actual route followed. This would be determined from an evaluation of the bathymetry and lakebed geometry in the probable corridor, to minimize strain on the cable.

When underwater cables are used for AC power transmission, the cable charging requirements can be quite onerous. This is due to the fact that insulated cables have significantly higher capacitance than is the case for overhead power lines. For example, even at 69 kV, the charging requirements for polymeric cable are about 250 kVARs per km of circuit length or more than 15 times the requirement for an overhead circuit. For a 70 km crossing, this would be approximately 17.5 MVARs at 69kV. Because the reactive power requirements vary with the square of the voltage, a 115kV circuit would consume nearly 50 MVARs. Conversely, a lower voltage of 44kV would draw only a little more than 7 MVARs.

To deal with the excessive cable charging requirements under this option, switched reactor stations would be required on the shorelines, along with suitable transformation to restore the voltage to transmission levels. As well as the power system-related concerns noted above, there are a variety of other well known issues related to submarine cable installations as follows:

- need for accurate lake bottom profiles and lakebed soil/rock conditions
- requirement for complex cable laying equipment and highly trained and specialized crews
- special cable laying requirements for installations at significant cable depths
- need for cable burial and trenching near shoreline boundaries

Notwithstanding the above issues, we have put forward two designs for the submarine crossing for the all underwater option as shown in Fig. 2 following.

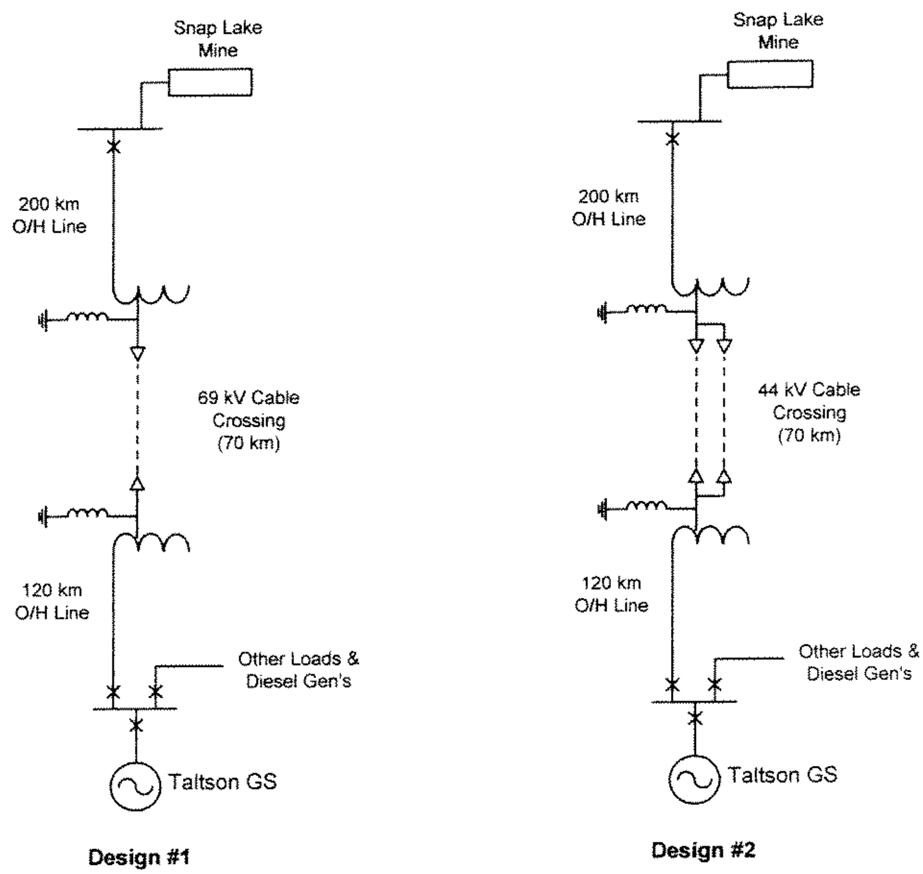

Fig. 2
All underwater cable options for Great Slave Lake Crossing

Design #1

- 69 kV, 3 phase cable circuit
- cable parameters consisting of 500 kcmil[2] Cu (approx.) and armoured construction
- two (2) shoreline transformer and switched reactor stations

[2] Kcmil represents cable cross-sectional area and is a standard measure of cable size. 500 kcmil is about 6cm diameter. The proposed cable sizes indicated above are approximate sizes only. The precise cable dimensions can only be developed after an examination and evaluation of the installation bed at the lake bottom.

Design #2

- 2- 44 kV, 3 phase cable circuits
- cable parameters consisting of 250 kcmil Cu (approx.) and armoured construction
- two (2) shoreline transformer and switched reactor stations

Regarding Design #1, we believe the cable could be purchased and installed for approximately $2.6M/km. As a result, this proposal would be costed at:

Item	Cost ($M)
Cable purchase and installation ($2.6M/km x 70 km)[3]	182
Purchase and Installation of Associated equipment	5
Sub Total	**187**
Special Delivery and Transportation Requirements[4]	4
Total	**$191M**

The costing of Design #2 could be broken down as follows:

Item	Cost ($M)
Cable purchase and installation ($2.8M/km x 70 km)[1]	196
Purchase and Installation of Associated equipment	5
Sub Total	**201**
Special Delivery and Transportation Requirements[2]	4
Total	**$205M**

Considering there are also northern and southern overhead line sections connected to these submarine circuits that total a distance of approximately 320 km, expensive cable installations such as these would drive the total end-to-end circuit costs to uneconomic levels. Utilizing a submarine crossing would cause the overall end-to-end route to cost nearly $300M [$284M (Design #2), $270M (Design #1)].

As a result of the AC cable charging issues, long cable routes are frequently designed to utilize DC technology. In this case the converter station costs for a system with only 20 or 30 MW of capacity would likely make this alternative financially unattractive.

In addition, the costs of DC submarine transmission are comparable to those for AC submarine cables and would also be prohibitively high. Therefore we will not consider this technology further for this particular feasibility study.

4.2 OVERHEAD WITH MINIMUM UNDERWATER CABLE

The route that would minimize underwater cable use would involve overhead cable to the north east of the La Loche River and across the Hornby Channel at the east end of Preble Island. Inspection of charts, satellite imagery and topographical maps suggests that there is a potential crossing with a maximum width of 1.5-2km that could be

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[3] See Annex 8.4 for a discussion of supplier pricing.
[4] See Section 5 regarding transportation cost estimates.

engineered for a small number of overhead spans, utilizing rock outcrops. A single longer span over a navigation channel may also be needed. Other water crossings are of a manageable width. An area of some uncertainty exists between Wilson and Blanchet Islands[5]. However, it appears unlikely that underwater cable would be needed. Bathymetric investigation should demonstrate a route that could be negotiated with specially designed towers and footings.

An underwater cable would be needed across the Hearne Channel and, given the depth and possible geometry of the bottom of this trench, an angled crossing may well be needed. A typical channel width is 2.5 nm, or 4.5 km. We have assumed a conservative length of 8 km to account for channel depth and cable alignment.

The overall route would involve two overhead portions (a south and a north portion) similar to those required for the Great Slave Lake submarine crossing and these will be described further in sections 4.4 i) and ii).

The middle section of the overall route would be a hybrid arrangement involving conventional overhead circuits and specially reinforced overhead circuits along with a relatively short submarine cable section. Where terrain would allow, conventional overhead structures and arrangements (guyed Y towers) would be used with approximately 300 m spans. Where water crossings or turning angles are required, steel lattice towers on reinforced footings would be utilized. Significant span lengths could be attained with these reinforced lattice towers if required. They would be employed at the Hornby Channel and in the crossing between Wilson and Blanchet Islands where there may be some deeper water channels. They would also be used at other locations on an as required basis. Therefore, the entire expanse of the eastern Great Slave Lake could be traversed with a 72 km overhead section and an 8 km submarine cable.

Considering this route in more detail, it would consist of the following subsections:

Subsection 1 (Hornby Channel Crossing)	2 km
Subsection 2 (Preble Island)	22 km
Subsection 3 (Simpson Islands and Wilson Island)	28 km
Subsection 4 (Channel between Wilson Island and Blanchet Island	5 km
Subsection 5 (Blanchet Island)	15 km
Subsection 6 (Hearne Channel Submarine Crossing)	8 km

With regard to the overhead parts of the island-hopping sections, we have identified the need for only about 8 to 10 taller reinforced lattice structures. These specially designed structures would also be built on 8-foot diameter caissons. Depending on the soil's condition and geotechnical investigations, these caissons could be up to 40ft

[5] Following a discussion with Terry Cook, CCG Hay River, who has sailed the east side of the Lake extensively, he advised that the Hornby is quite deep, but there probably is a stretch of deep water at the end of Preble Island of less than 500m. He confirms that the shore east of Taltson is exceptionally rugged, with sheer cliffs into the Lake. He is positive that we could find shallow water or reefs for tower foundation between Wilson and Blanchet as this area is very tricky, even for small boats, and care is needed in navigating. Thus the probability is that an all overhead link could be achieved from the south shore of the Lake to the north side of Wilson Island.

(12m) depth. Considering both conventional and reinforced portions of the overhead circuit, we have established a blended per unit cost of $650K/km for this part of the route. The submarine portion would be configured as shown in Fig. 3.

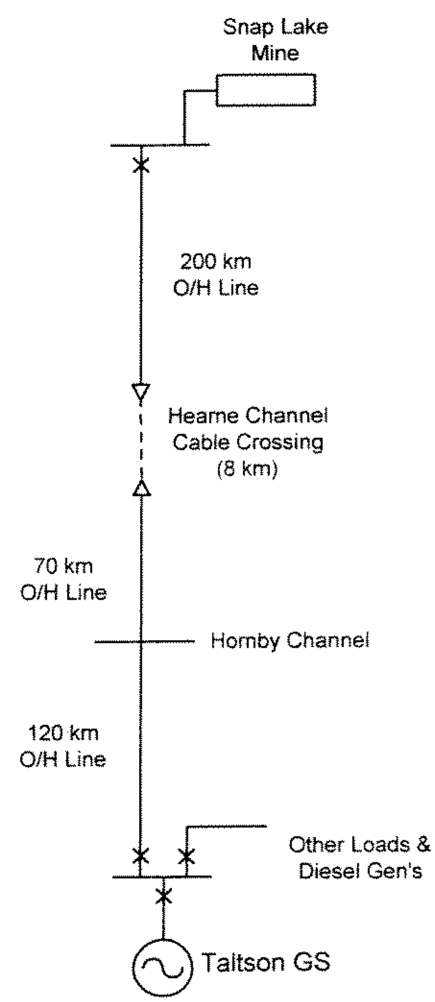


Fig. 3
Overhead with minimum underwater cable option

With regard to the submarine cable we are proposing, it would be designed generally as follows:

- 3-conductor 115kV insulation
- solid insulation
- armoured construction

Regarding the design of the submarine cable system, we believe the costing estimate would be as follows:

Item	Cost ($M)
Cable purchase and installation ($3.0M/km x 8 km)[3]	24
Purchase and Installation of Associated equipment	2
Sub Total	**26**
Special Delivery and Transportation Requirements[4]	4
Total	**$30M**

In addition, such a cable requires a reasonably level profile on the channel bottom and so may not be routed in a straight line. The 300 m depth requires special care along with the number of splices and their location[6]. The two shore sections need to be plowed in and encased with appropriate backfill to points suitably located off the shoreline locations.

Reviewing the entire route that would be entailed utilizing a crossing such as this would yield the following:

Item	Cost ($M)
Northern and southern overhead sections totaling 300 km ($250K/km x 300 km)	75
Island-hopping reinforced overhead section totaling 70 km ($650K/km x 70 km)	46
Hearne Channel Crossing totaling 8 km	30
Total	**$151M**

Therefore the overhead route utilizing a minimum cable crossing is estimated at $151m.

4.3 OVERHEAD WITH PARTIAL UNDERWATER CABLE

The terrain along the south side of the Hornby Channel could result in difficult construction to the point where the lines would cross the channel as described in 4.2 above. A potential alternative would be to use an underwater cable from around Taltson Bay to the west end of Preble Island, before proceeding across the Simpson Islands and then as described in 4.2 above. The underwater distance would be about 8nm (14.5km).

[6] See commentary in Section 5 regarding cable lengths that could be moved. It is considered feasible to deliver to site without splices for this cable length.

This route would involve two overhead sections utilizing conventional overhead construction, two submarine cable sections and a hybrid overhead configuration for the island-hopping portion. All parts of this option with the exception of the Hornby Channel crossing are very similar to the previously discussed alternatives. The detailed route arrangement along with cost estimates is as follows:

Route	**Unit Cost (/km)**	**Total Cost ($M)**
Subsection 1(Hornby Channel Crossing) 15km channel	15 km x $3.0M	45
Subsection 2 (Eastern Preble Island) 12km distance	12 km x $650K	7.8
Subsection 3 (Lower Simpson Island) 10km distance	10 km x $650K	6.5
Subsection 4 (Upper Simpson Island) 15km distance	15 km x $650K	9.8
Subsection 5 (Wilson Island/Blanchet Island Channel) 8km distance	8 km x $650K	5.2
Subsection 6 (Blanchet Island) 15km distance	15 km x $650K	9.8
Subsection 7 (Hearne Channel Crossing)		28

Adding the northern and southern overhead sections (which total 290 km) to this option would make for an overall end-to-end route estimated cost of :

$39M + $45M + $28M + $73M = $185M + $2M Transportation and Delivery costs. This alternative can be seen more clearly in Figs 1 & 4.

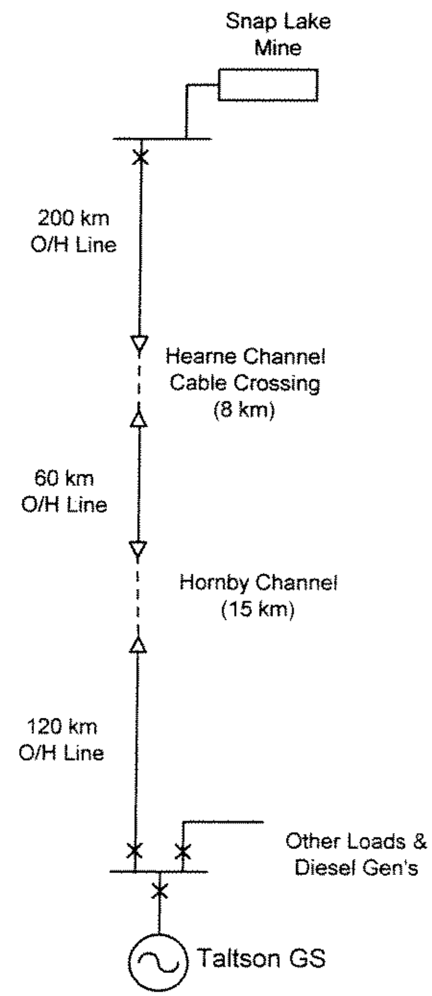


Fig. 4
Overhead with two underwater cable crossings option

4.4 COMMON OVERHEAD PORTIONS

In estimating the costs of overhead line sections we have assumed single circuit structures with double sky wire and operated at 115kV. The following different construction configurations were considered for this circuit:

- H-frame wood pole
- Monopole steel
- Guyed V or Y towers.

Without a survey of the line route, it is extremely difficult to ascertain a precise estimate of the line construction in this difficult terrain. Severe winter condition, relatively short construction season, difficult access to line right-of-way and

A voyage is presumed to proceed via Nuuk to pick up an ice advisor, the east side of Davis Strait and then via Lancaster Sound, Peel Sound, Victoria Strait and Coronation Gulf to Tuktoyaktuk. Zones and dates for a Type B vessel are as follows:

	Entry	Exit	Distance nm
Zone 13	July 15	Oct 15	337
6	Aug 25	Sep 30	370
7	Aug 10	Oct 15	)
11	July 15	Oct 20	) 863
12	July 1	Oct 25	)

Thus the critical dates are for zone 6, giving just over one month for turnaround.

Sailing legs, presuming reasonable conditions:

NORTHWEST PASSAGE ROUTE

Leg	Distance Nm	Average Speed	Time/days	Delays
Oslo-Nuuk	2,221	14	6.6	1[7]
Nuuk-Lancaster Sound	890	13	2.9	
Lancaster Sound-Peel Sound	377	12	1.1	
Peel Sound-Victoria Strait	270	8	1.4	
Victoria Strait-Tuktoyaktuk	863	12	3.0	
Total transit days			15.0	
zone days			5.5	
BIWL days			36.4	

Assuming one week at anchor off Tuk for cable transfer, the vessel should be able to do a round trip Lancaster Sound-Lancaster Sound in 20 days. This is well within the time limits for zone 6. For insurance purposes, the vessel will be above 60°N for a total of 36.4 days including cargo transfer.

In terms of timing, and assuming entry to zone 6 on or about August 25th, delivery in Tuktoyaktuk should be completed by September 6th, which would enable materials to be into Hay River prior to season close on the river. Cable laying would then commence first open water in Great Slave Lake during the following season.

The vessel is presumed on/off hire in Oslo, i.e. no ballast in/ballast out assumptions and to not require icebreaker assistance for the trip. Charter rate is presumed at U$28,000[8]/day, plus fuel at U$6,000/day at sea, and U$1,200/day in port or at anchor assuming 20% escalation in cost to 2005. A high rate has been assumed not only because of the ice class needed, but also because the ship will either need heavy lift or

[7] Pickup ice advisor.

[8] Advice by Desgagnes that a budget charter rate for the "Anna Desgagnes" would be C$35,000/day, equivalent to about U$28,000/day at current exchange rates, and assuming 5%pa escalation to 2005. Desgagnes have indicated that it may be possible to reduce costs if dates could accommodate some cargo deliveries to Nunavut while carrying cable for Tuktoyaktuk.

will have to have a Ro-Ro configuration to permit loading of long cable lengths directly into the tween decks.

PRO FORMA VOVAGE COST VIA N.W. PASSAGE

Voyage sailing days	30.2
Port days	16.0[9]
On-hire days	46.2
5% margin	4.6
Total on-hire days	50.8
Charter cost	$1,422,400
Fuel cost at sea	208,800
in port	19,200
Ice advisor @U$500/day, 24 days	12,000
Travel expenses	5,000
Port dues & charges	30,000
Insurance, additional premium for BIWL @$10,000/day	364,000
Pro forma cost	U$2,061,400
NTCL freight to Hay River	C$750,000
Total cost into Hay River @ 72¢ exchange	C$3,613,056

Technically a tug and barge may be able to offer at a lower time charter rate but the much lower speed, typically 6kts for a towed barge, would put such a unit much closer to not being able to achieve a turnaround through the Arctic within the appropriate window. A conventional vessel would have a 10-day grace period between voyage time and window, the tug/barge would only have three days. Also, with port of origin being in Scandinavia, a tug/barge unit would not likely be available for the service.

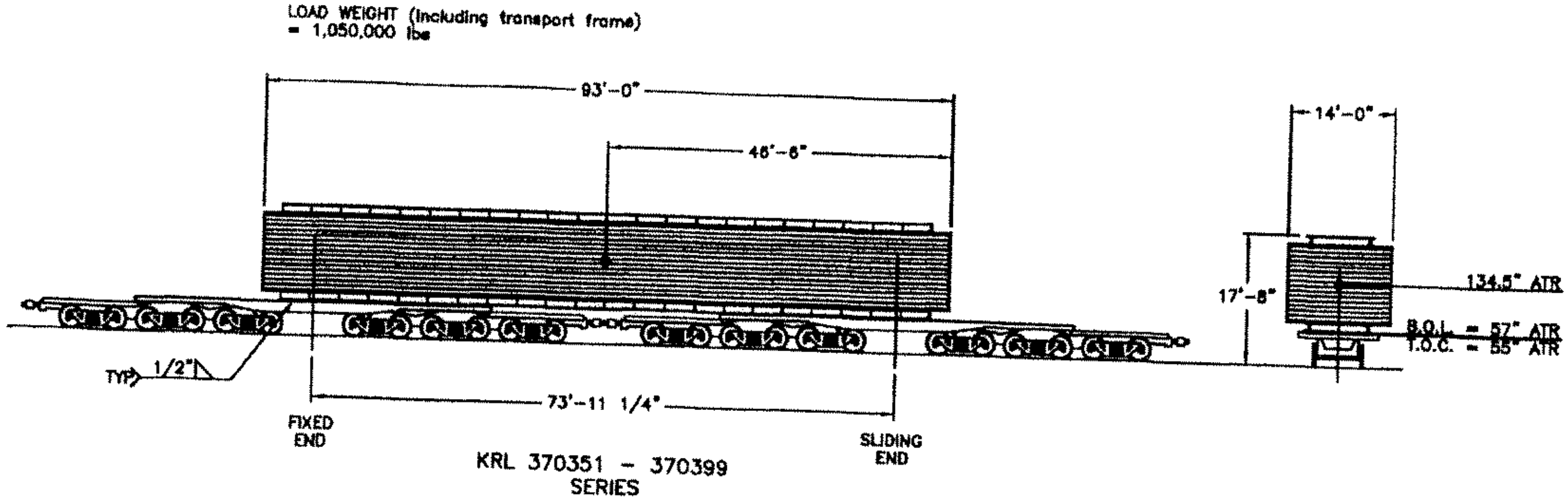
ii) Shipment via the Great Lakes

This scenario assumes the same port of origin for the cable but would not require an ice strengthened vessel, although heavy lift and/or Ro-Ro capability would still be essential. The Seaway is open from end March through to end December, which gives a much more flexible window for cable delivery. Although it would be feasible to target delivery during the Great Slave Lake open water period, this would mean working very precisely at the front end of the Lakes season to achieve early transfer at Duluth (MN) for rail car loading. Under these circumstances cable and equipment could be in Hay River by June.

Evaluation of options for delivery of cable to Hay River, within current axle limits on the Hay River Line, shows that a total load, including an extended cable spool, could be up to 1,050,000lbs – see Fig.5 on the following page. Assuming a 10% tare for the frame, up to 14km could be carried per spool. Thus for the full crossing four splices would be needed, while it is feasible that a continuous length could be carried for other options.

[9] Assumes one week load, one week discharge.

FIG. 5



CAR A - C.C.G. = 106.1"

RAIL CAR	201,000 lbs
LOAD WEIGHT	525,000 lbs
TOTAL	726,000 lbs

60,500 lbs/axle

CAR B - C.C.G. = 106.1"

RAIL CAR	201,000 lbs
LOAD WEIGHT	525,000 lbs
TOTAL	726,000 lbs

60,500 lbs/axle

P.E.C. Consultants

NWT Power Transmission

RAIL TRANSPORT PLAN

RD NWT- 01 -A-000001- 1 A

Leg	Distance (Nm)	Average Speed	Time (days)
Oslo-Montreal	3,386	14.0	20.2
Montreal-Tibbets Point	160	-	1
Tibbets Point-Port Weller	139	14.0	.4
Port Weller-Port Colborne	23	-	.5
Pt. Colborne-Detroit River Light	190	14.0	.6
Detroit River Light-Port Huron	75	-	.5
Port Huron-Sault Ste. Marie	234	14.0	.7
Sault Ste. Marie-Duluth	343	14.0	1.0
Total time			24.9
Assumed inc. pilot delays etc.			26.0

Vessel is presumed on/off hire in Oslo at a charter rate of U$20,000[10]/day, plus $6,000/day for fuel at sea and $1,200/day fuel in port.

PRO FORMA VOYAGE COST VIA GREAT LAKES

Voyage sailing days	52.0
Port days	14.0[11]
On-hire days	66.00
5% margin	3.3
Total on-hire days	69.3
Charter cost	$1,386,000
Fuel cost at sea	331,800
in port	16,800
Lake & Seaway pilots - 12.4 days @ $3,000/day	37,2000
Port dues & charges	80,000
Additional insurance costs, unit	20,000
Seaway tolls, up and down	10,000
Pro forma cost	2,436,200
Rail transfer	50,000
Rail freight	998,000
Load master	27,500
Total cost to Hay River	U$3,511,700
@ 72¢ exchange	C$4,877,361

As noted for the arctic delivery option, a tug/barge unit would not be practical or available for a transatlantic delivery.

[10] We have assumed a market vessel with heavy lift capability.
[11] Assumes one week load, one week discharge.

iii) Shipment of lesser cable quantities

For the option assuming minimum underwater cable, only some 8km is presumed needed, and this could readily be shipped in a single movement via the Great Lakes to Duluth and then by rail. Weight would be about 280 tonnes. Costs could be reduced if shipment could be timed to coincide with additional heavy lift deliveries into the Alberta oil sands projects. There have been major lifts through Duluth on a regular basis and this may be feasible, but would require coordination.

The alternative is either a special lift on a salty laker or a full ship charter for reduced quantities The alternative route using a partial underwater cable option would involve one cable length of 14-1 5km for the crossing from Taltson Bay area to Preble Island, and then the 8km length from Blanchet Island to the north side of the Hearne Channel. This could reasonably be undertaken in two pieces by rail, both of about 11-12 km. Budgetary costs would need to be carried at a nominal reduction from the full quantity of U$250,000 (C$347,200).

5.2 CABLE LAY OPERATIONS IN GREAT SLAVE LAKE

It will be necessary to work with NTCL to convert one or more barges to cable lay services, charter a tug to handle the equipment and then demobilize at the end of the season.

For those options where a cable has to be spliced, we believe that a splicing operation in Hay River prior to shipment to site would offer the ability to create much more robust splices than could be achieved in the field. Cable delivered either by rail or ship could then be wound in a continuous length onto a lay reel. This should speed up actual lay operations.

For the complete cross lake move, the weight of cable would probably exceed the capabilities of a 1500 series barge, and it may be necessary to create a composite lay barge by joining one 1500 series and two 1000 series. Shorter lengths could be handled on a single 1000 series barge.

It is also likely that the cable supplier may have specialized equipment associated with either or both of laying the cable and splicing lengths that would need to be shipped and then returned. It is presumed that technical personnel to supervise the lay operation would be included in the overall price.

PRO FORMA LAY COSTS[12]

	Cross Lake Cable	Min Cross Lake	Partial Cross Lake
Specialized vendor equipment, shipment	$ 300,000	$300,000	$300,000
Preparation of barge(s)	500,000	125,000	25,000
Demobilization on completion	200,000	50,000	50,000
Tug charter @ U$11,000/day, positioning	37,000	37,000	37,000
Tug charter laying @10m/min	55,000	7,500	15,000
Barge charter 14 days	140,000	70,000	70,000
Splicing @ U$25,000/splice	150,000	-	25,000
Total	U$1,382,000	589,500	622,000
C$ @ 72¢	C$1,919,000	C$818,750	864,000

6. INSTITUTIONAL ISSUES

While there may well be environmental issues to be addressed relative to GNWT legislation[13]; the principal federal regulation to be addressed will be the Navigable Waters Protection Act. Any obstruction in a waterway (whether navigable or not[14]) comes with the jurisdiction of the Act.

Preliminary discussions with DFO Central and Arctic Region, who administer the application of the Act for NWT, have indicated that they would not be concerned with the application and that it probably would not trigger a full environmental review.

Any construction in the waters of the lake will need to be considered, but the main concern is obstruction of navigation. The areas of concern are expected to be:

Hornby Channel
Inconnu Channel
Hearn Channel

There will be less concern regarding the waters between Wilson and Blanchet Islands because these are not recognized as navigable under normal circumstances.

The principal areas of concern will be that channel widths are not compromised by foundation structures and that where overhead cable is involved, the clearance is adequate to meet current and foreseeable navigation requirements. Typically this will involve yachts, CCG craft and possible structures that might be moved by NTCL to the east end of the lake. However, the fact that the Hearne Channel will remain unobstructed will ensure that navigation to the east end of the lake is not compromised.

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[12] Based, in part, on advice from NTCL.
[13] We were requested not to look at environmental aspects, to avoid any conflict with work currently being undertaken by RESCAN, Power Corporation's environmental consultants.
[14] Recently in Cambridge, ON, where Mariport's office is located, a bridge reconstruction project over a shallow creek, not connected by open water to the river, was held up because an NWPA review had not been undertaken.

There will also be concerns relative to protection of the underwater cable in shallow areas, but normal cable laying practices into trenches or ensuring adequate cover in the littoral zone will meet these concerns. The fact that a cable will not be laid into areas where boats may anchor will mitigate regulatory concerns.

8. WEATHER, ICE CONDITIONS AND BATHYMETRY

7.1 WEATHER

Weather for the east part of Great Slave Lakes has to be interpreted from a range of sources. We have taken Yellowknife, Fort Reliance and Fort Smith as being representative. Hay River, Wrigley and Fort Resolution, the other stations with readily available long-term data, are considered out of region.

Temperatures °C	**Daily Maximum**	**Extreme Maximum**	**Month**
Yellowknife	20.8°	32.5°	July
Fort Reliance	19.1°	34.3°	July
Fort Smith	22.7°	34.4°	July

	Daily Minimum	**Extreme Minimum**	**Month**
Yellowknife	-32.2°	-51.2°	January / February
Fort Reliance	-33.4°	-53.5°	January
Fort Smith	-30.5°	-53.9°	February

i) Precipitation

Considering that freezing precipitation is the critical issue, monthly data is available for Yellowknife and Fort Smith. This is days in the month with freezing precipitation. We have not been able to uncover data that provides information with regard build up.

	Ja	**Fe**	**Ma**	**Ap**	**My**	**Jn**	**Jl**	**Au**	**Se**	**Oc**	**No**	**De**	**Total**
Yellowknife	-	1	-	-	-	0	0	0	-	3	4	1	11
Fort Reliance	Nd	"	"	"	"	"	"	"	"	"	"	"	Nd
Fort Smith	-	1	-	-	-	-	0	0	-	2	4	1	11

An alternative view of the risk of freezing rain is a combination of degree days below 0 ° C and rainfall in mm. Note data has been rounded, see annex 8.3 for complete record.

		Ja	**Fe**	**Ma**	**Ap**	**May**	**Jn**	**Jl**	**Au**	**Se**	**Oc**	**No**	**De**
Yellowknife	Degd	870	694	576	211	23	0	0	0	3	86	447	750
	Rain	T	T	T	1.6	12.2	23	35.2	41.6	24.8	14.6	.6	.2
Ft. Reliance	Degd	895	753	671	294	57	.2	0	0	3	94	435	743
	Rain	T	T	T	2	10	30	37	47	30	13	.5	T
Ft. Smith	Degd	789	602	440	110	6	0	0	0	2	57	383	676
	Rain	T	T	.1	4	25	45	59	49	38	1.2	1	.4

T = Trace

Thus despite the lack of data regarding freezing rain, there is a risk. Note that Fort Smith indicates a total of 11 days per annum although the measurable monthly record only shows 8 days.

*ii) **Wind***– speeds in km/hour

Yellowknife

	Ja	Fe	Ma	Ap	May	Jn	Jl	Au	Se	Oc	No	De
General Direction	NW	E	NE	E	NE	S	S	S	SE	E	E	E
Max Hourly	72	61	51	64	64	68	64	64	72	64	64	56
Direction	NW	NW	NW	NW	NE	NW	N	NE	W	NW	NW	NW
Peak Gusts	105	98	70	93	87	89	85	80	105	89	113	80
Direction	W	N	NW	W	NW	W	N	N	W	NW	W	S

Fort Reliance

	Ja	Fe	Ma	Ap	May	Jn	Jl	Au	Se	Oc	No	De
General Direction	SW	0	E	E	E	E	NW	NW	E	E	E	E
Max Hourly	66	63	65	74	80	63	80	64	74	90	81	63
Direction	N	NW	W	W	N	NW	SW	NW	W	NW	NW	S
Peak Gusts	78	87	61	87	96	83	80	122	78	83	98	76
Direction	N	NW	W	E	E	NW	NW	NE	NW	W	NW	N

Fort Smith

	Ja	Fe	Ma	Ap	May	Jn	Jl	Au	Se	Oc	No	De
General Direction	NW	NW	NW	SE	SE	SE	NW	NW	SE	SE	SE	SE
Max Hourly	51	50	64	58	54	56	55	53	48	64	61	56
Direction	NW	W	W	W	S	SE	W	NE	NW	W	S	NW
Peak Gusts	82	74	91	77	65	87	80	94	90	84	83	100
Direction	W	NW	NW	W	W	SW	S	W	W	W	W	N

7.2 ICE CONDITIONS

It is reported that ice thicknesses are generally in the range 1.2-1.5m in Great Slave Lake, however serious study has only been undertaken in Back Bay. Median[15] break up in June 18th with a range over the 1988-1999 period from first to third week. Median freeze up is Dec 7th, with a range from the third week in November to end December. However, passive microwave imagery suggests that these dates may not apply at the east end of the lake in the area of interest for the transmission route. See Annex 8.2 for selected images from 1997-1998.

[15] Data reported by Anne Walker, Climate Research Branch, Meteorological Service of Canada, Downsview, ON.

With regard ice action in the lake, there are pressure ridges that develop, but no reports of keel depths are available. Although some tethered buoys at 12m have been carried away by ice, these were in the western portion of the lake. Anecdotal information suggests that ice in the area being considered tends to melt in place and by the time it breaks free of the land has lost most of its strength.

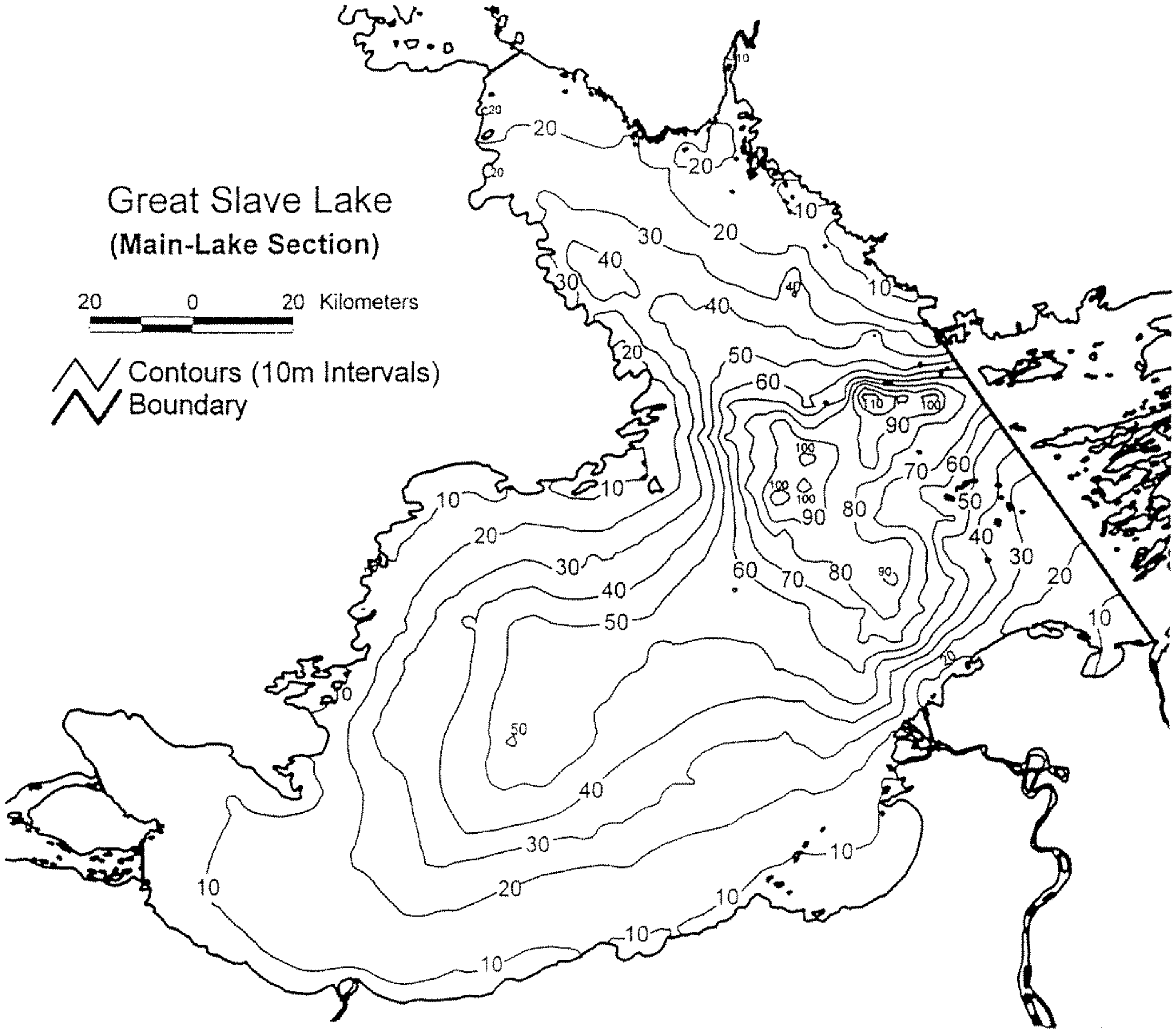
7.3 BATHYMETRY

Bathymetric information on Great Slave Lake is very limited and most soundings are concentrated west of the North Arm. East of the Caribou Islands there are spot soundings only. Some work was done under the auspices of the National Water Research Institute to develop an understanding of water depths for science purposes, but the eastern line of their measurements were approximately on a line that the underwater cable option would follow. A reproduction of this information is on the following page[16].

Detailed bathymetry and sediment depths will be needed for any crossings, whether for overhead lines or submarine cable. These would be dictated by the most economic route, but could be expected to cover the following areas:

- NE end of the Hornby Channel at approximately 112° 12-15'W, 61° 4—41'N
- East end of Wilson and Blanchet Islands at approximately 112° 42'W, 61° 51-52'N
- Hearne Channel at locations determined, in part, by land surveys related to transmission routes.

[16] Extracted from "Digital Bathymetry of Great Slave Lake", Shertzer, W.M. NWRI *Contribution* No. 00-257.



Great Slave Lake
(Main-Lake Section)
20 0 20 Kilometers
Contours (10m Intervals)
Boundary

8. ANNEXES

8.1 Scope of work for further studies

ANNEX 8.1

SCOPE OF WORK FOR FURTHER STUDIES

1. SURVEY WORK FOR CABLE ROUTES

We requested a preliminary indication of costs for bathymetric and sediment from McQuest Marine who have considerable experience in this area and with whom we have worked in the past. With regard the survey work, they have made a number of comments:

i) While bathymetry can be readily accomplished through ice, using side scan sonar to obtain sediment and bottom profiles including debris that might affect the cable route is not recommended. The problem is that the sonar image superimposes the underside of the ice on the bottom profile and makes interpretation much more difficult. It can also be very time consuming if a corridor is to be analyzed.

ii) Deepwater soundings, particularly the Hearne Channel, will require special equipment to tow the transducer at depth.

McQuest's recommendation is for open water survey work as they feel that through ice work will not be cost effective and the data would inferior. Survey work in open water can be undertaken at approximately 30-line km per working day. Probable costs are as follows, but exclude cost of a boat. These costs have been included at the "NT Marjory" cost, as it will be necessary to tow equipment at a depth which requires winch capability. C$15,000/day inclusive of fuel and victualling for survey team.

Mobilization/demobilization: $16,000 includes airfreight and equipment rentals and expenses.

Daily rate: $3,000 includes fieldwork and data reduction basis, one day of data reduction for each day of fieldwork.

Standby rate/day $1,800 while positioning boats or awaiting weather window.

<u>Option 1</u> Cross lake route for all-underwater cable

Presumes three runs of 60km to produce a corridor image of about 300m width plus an additional four days of survey work, presuming diversions around difficult bed profiles are needed. Total time, 10 days.

Mob/demob	$ 16,000
Survey & data	$ 30,000
Stand by	$ 3,600
Drawings	$ 6,000
Total	$ 55,600
Boat	$150,000
Total all	$205,600

<u>Option 2</u> Cross lake route with minimal underwater cable

Survey Hearne crossing	2 days
Survey Wilson-Blanchet crossing	1 day
Survey Hornby crossing	1 day
Margin	1 day
Total	5 days

Mob/demob	$ 16,000
Survey & data	$ 15,000
Stand by	$ 3,600
Drawings	$ 6,000
Total	$ 40,600
Boat	$ 75,000
Total all	$115,600

<u>Option 2a</u> Cross lake route with partial underwater cable

Survey Hearne crossing	2 days
Survey Wilson-Blanchet crossing	1 day
Survey Taltson Bay-Preble Island[17]	2 days
Margin	1 day
Total	6 days

Mob/demob	$ 16,000
Survey & data	$ 18,000
Stand by	$ 3,600
Drawings	$ 6,000
Total	$ 43,600
Boat	$ 90,000
Total all	$133,600

2. *MARIPORT SCOPE OF WORK & BUDGETARY COSTS FOR FUTURE PHASES*

If the project to provide power across Great Slave Lake, as an alternative to an all-overhead cable route, proceeds then there are some immediate areas of work that should be undertaken before freeze up.

i) **Initial survey of crossings** This was suggested, and an indicative price given in Mariport's original letter proposal. The budget figure of $7,000 is still the correct order of magnitude. This survey would provide an appropriate scope for bathymetric and sediment work to be undertaken by McQuest or other specialized survey companies during the early part of the 2004 season.

ii) **Initial boating survey** Before all boats are lifted from marinas and contacts disperse, it would be appropriate to undertake an early survey of boats and vessels using channels into the east end of Great Slave Lake. This would also cover such

[17] Crossing assumed at 15km, 3 runs.

operators as NTCL, CCG, "Norweta" etc, to determine suitable overhead clearances for channel crossings. This could very easily be done as an addendum to the above physical survey within about a $3,000 incremental budget. This would cover visits to Hay River as well as Yellowknife and provide essential information for any NWPA application. Ongoing activities, that could be scheduled during the winter, include refining delivery options and costs, preparing the NWPA application and holding preliminary discussions with DFO in Sarnia (two hours' drive from Mariport's office) and coordinating preparatory work by other consultants. We would recommend separate contracts with others, but a prime role by Mariport - in a similar manner to the role we undertook with Rankin Inlet studies – coordinating Sandwell, environmental, TERMPOL and NWPA activities.

This area is difficult to cost until a proper scooping has been agreed, but Mariport's rates are $820/day for a principal, and $250/day for support staff.

3. KINECTRICS SCOPE OF WORK & BUDGETARY COSTS FOR FUTURE PHASES

Based on the results of preliminary feasibility study, it is proposed that the Option involving overhead line construction through island hopping with one submarine cable section be studied in detail during the next phase to complete the project planning process. The tasks proposed to be undertaken during the next phase are summarized below:

- Field surveys and data collection - 2 weeks
- Development of detailed line routing - 1 week
- Development of performance specifications - .5 week
- Development of preliminary designs for towers, towers footings and submarine cables – 2 weeks
- Development of cost estimates for initial investments - .5 week
- Development of life cycle costs and economic benefits of projects - .5 week
- Comparison of the island hopping option with around the lake option based on life cycle costs - .5 week

The deliverables from this phase of the assignment will not only improve the accuracy of cost estimates and establish project feasibility with a higher degree of confidence level, but the deliverables will also become a significant part of the performance specifications for the project implementation through a turn-key project.

It should be noted that these estimates do not include any geotechnical work with regard to lake sediment or tower footings. Also excluded are all disbursements.

The field survey and data collection work should, preferably, be completed prior to freeze up. Other work can continue during the winter.

The budget uses a blended rate of $180/man hour for 280 man hours. Total cost would be $50,400. The initial survey work would be undertaken at a cost of $14,400 excluding airfares, accommodation, charter flights for surveys etc.

8.2 Ice break up/freeze up

Return to Main Table of Contents

I-07) 1998 Great Slave Lake and Great Bear Lake Ice Freeze-Up and Break-Up Characteristics from SSM/I Satellite Data

Anne Walker, Climate Research Branch, Meteorological Service of Canada

The Climate Research Branch of the Meteorological Service of Canada has an on-going research program on the determination of cryospheric elements from passive microwave satellite data. Previous research by Branch scientists has shown that it is possible to discriminate between ice and open water areas on large lakes, such as Great Slave and Great Bear using SSM/I 85 GHz data (spatial resolution of 12.5 km), and thus monitor the process of ice formation and decay over the lakes (Walker and Davey, 1993). As a contribution to the Mackenzie GEWEX Study (MAGS), CRB has assembled a time series of Great Slave and Great Bear Lake ice freeze-up and break-up using historical SSM/I 85 GHz data (1987 to present). The time series consists of a series of images for each lake documenting each ice freeze-up and break-up season during the time period, providing dates corresponding to complete freeze-over and ice-free conditions for each year, and yielding information on the variability in the spatial and temporal aspects of ice formation and decay.

Figure 1 depicts the time series of ice freeze-up and break-up dates for Great Slave Lake and Great Bear Lake in relation to air temperature departures from normal for the spring and fall seasons in the Mackenzie region for each year in the time series. As expected, both graphs in Figure 1 depict relationships between freeze-up and break-up dates and significant departures in temperature from normal for the fall and spring seasons, respectively. In the period covered by the ice break-up time series (Figure 1A), 1998 stands out with the earliest break-up dates in the time series for both lakes coinciding with the highest above normal temperature departures. During the period covered by the ice freeze-up time series (Figure 1B), 1998 stands out with the latest freeze-up date for both lakes and corresponding significant above normal temperatures for the fall season (>2°C).

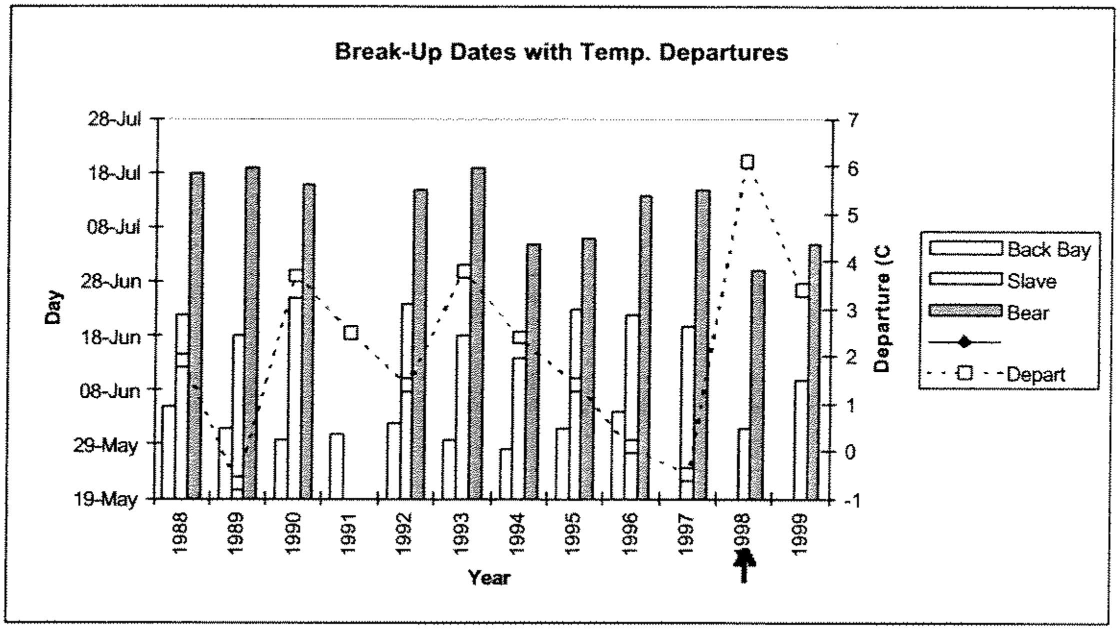
Figure 2 presents another view of the late 1998 spring break-up for Great Slave Lake by comparing SSM/I images documenting the timing of 1998 ice break-up process with that of the 1997 season. On the images the dark blue areas represent open water, while the red areas represent the ice cover. The lake is basically "free of ice" by the end of May in 1998, while the previous year the lake was just beginning its ice break-up process at that date.

References:

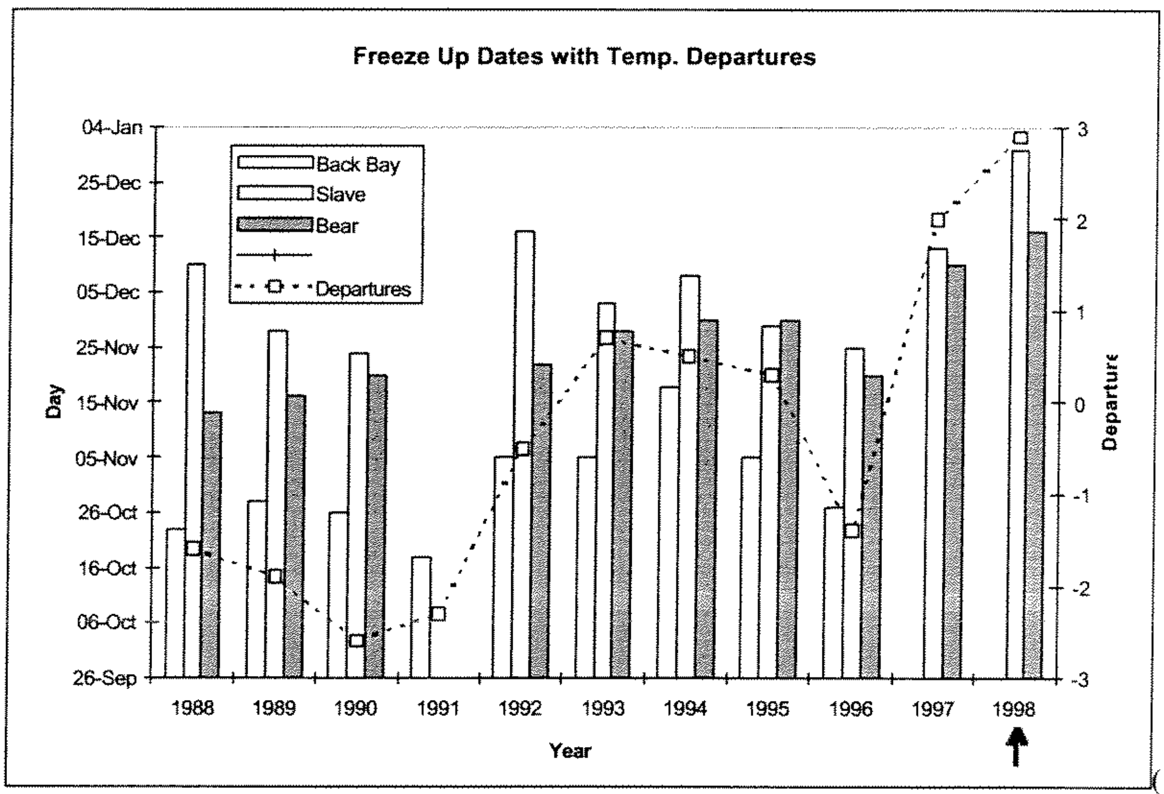
Walker, A.E. and M.R. Davey, (1993) "Observation of Great Slave Lake ice freeze-up and break-up processes using passive microwave satellite data", *Proceedings, 16th Canadian Symposium on Remote Sensing, Sherbrooke*, Quebec, June 7-10, 1993, 233-238.

Walker, A., A. Silis, J.R. Metcalfe, M.R. Davey, R.D. Brown and B.E. Goodison, (1999) "Snow cover and lake ice determination in the MAGS region using passive microwave satellite and conventional data", in *Proceedings of the 5th Scientific Workshop for the Mackenzie GEWEX Study [MAGS]*, Edmonton, Alberta, 21-23 November 1999, 39-41.

Suggested citation: Walker, A. 1998 Great Slave Lake and Great Bear Lake Ice Freeze-Up and Break-Up Characteristics from SSM/I Satellite Data; *in* Chapter I:7 of The state of the Arctic cryosphere during the extreme warm summer of 1998: documenting cryospheric variability in the Canadian Arctic, CCAF Summer 1998 Project Team, CCAF Final Report. *available at* http://www.socc.ca, 2 p.



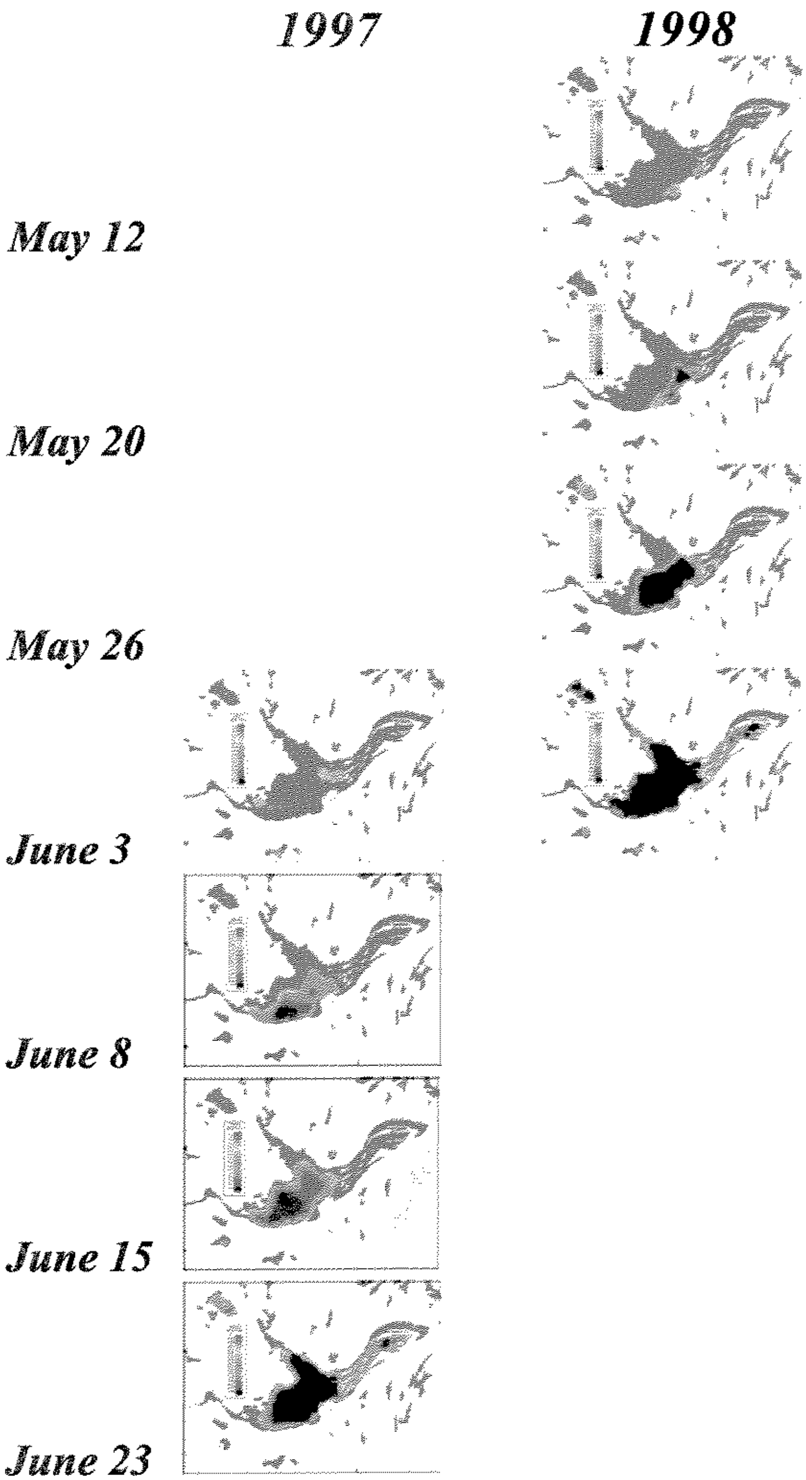
(A)



B)

Figure 1 – Comparison between SSM/I ice break-up (A) and ice freeze-up (B) dates for Great Slave and Great Bear Lakes and seasonal temperature departures (from Walker et al., 1999).

Figure 2 - Great Slave Lake ice break-up in 1997 and 1998 as depicted on SSM/I 85 GHz brightness temperature images (Dark blue areas correspond to open water; red areas are ice cover)



ANNEX 8.2

ICE BREAK UP/FREEZE UP

Lake Ice Freeze-up and Break-up dates as derived from SSM/I 85H GHz images
(MAGS lake ice time series)

	BREAK-UP DATE (Julian Day)			**FREEZE-UP DATE (Julian Day)**			**ICE-FREE SEASON (Number of Days)**	
Year	Gr. Slave	Gr. Bear		Gr. Slave	Gr. Bear		Gr. Slave	Gr. Bear
1988	174	200		345	318		171	118
1989	169	200		332	320		163	120
1990	176	197		328	324		152	127
1991	n/a	n/a		n/a	n/a		n/a	n/a
1992	176	197		351	327		175	130
1993	169	200		337	332		168	132
1994	165	186		342	334		177	148
1995	174	187		333	334		159	147
1996	174	196		330	325		156	129
1997	171	196		347	344		176	148
1998	152	181		365	350		213	169
1999	161	186		347	332		186	146
Mean (1988-1999)	169.1818	193.2727		341.5455	330.9091		172.3636	137.6364
Mean (1988-1998)	169.5556	193.3333		340.5556	332.2222		171	138.8889
Mean (1988-1997)	172.1429	194.1429		338.2857	331.4286		166.1429	137.2857

Anne Walker
Climate Research Branch
Meteorological Service of Canada

8.3 Weather data, selected stations

WRIGLEY A

63°13'N 123°26'W/O. 150m. 1943 to/à 1990

	Jan janv	Feb févr	Mar mars	Apr avr	May mai	Jun juin	Jul juil	Aug août	Sep sept	Oct oct	Nov nov	Dec déc	Year année	
Temperature														**Température**
Daily Maximum (°C)	-24.5	-19.0	-9.8	3.7	14.0	21.1	22.8	19.9	12.0	-0.3	-14.9	N	N	Maximum quotidien (°C)
Daily Minimum (°C)	-32.5	-28.7	-23.1	-9.4	0.9	7.9	9.7	N	1.2	-6.9	-22.9	N	N	Minimum quotidien (°C)
Daily Mean (°C)	-28.4	-23.9	-16.4	-2.8	7.5	14.5	16.3	N	6.6	-3.5	-19.1	N	N	Moyenne quotidien (°C)
Extreme Maximum (°C)	5.0	11.1	12.5	25.0	31.0	35.0	35.0	33.5	28.3	21.7	8.9	7.8		Maximum extrême (°C)
Date	987/11+	968/29	990/30+	989/29	990/29	950/17	989/14+	989/13	967/15	969/04+	974/03+	944/13		Date
Extreme Minimum (°C)	-51.7	-53.3	-46.7	-36.1	-16.7	-3.9	-1.1	-6.0	-18.0	-31.5	-48.0	-49.4		Minimum extrême (°C)
Date	972/13+	968/03	955/02	954/06	974/02	958/09+	966/28+	986/24	983/28	984/31	990/24	976/11		Date
Precipitation														**Précipitations**
Rainfall (mm)	0.0	0.0T	0.1	N	21.6	53.9	56.1	48.6	26.4	5.5	0.2	0.0T	N	Chutes de pluie (mm)
Snowfall (cm)	18.0	12.3	12.9	N	6.3	0.0T	0.0	0.0	3.8	30.8	21.8	N	N	Chutes de neige (cm)
Precipitation (mm)	17.2	11.9	13.0	N	26.8	53.9	56.1	48.6	30.1	36.5	21.5	N	N	Précipitations (mm)
Extreme Daily Rainfall (mm)	0.0	0.0	2.5	11.7	23.9	31.7	38.1	40.1	27.2	16.0	5.1	0.0		Extrême quot. de pluie (mm)
Date	990/31+	990/28+	965/09	952/26	976/28	988/30	968/05	949/14	959/03	953/06	967/21	990/31+		Date
Extreme Daily Snowfall (cm)	20.8	12.0	11.4	20.3	30.5	0.8	0.0	0.0	12.7	29.4	16.5	25.9		Extrême quot. de neige (cm)
Date	962/19	987/26	952/29	964/01	972/21	978/15	990/31+	990/31+	946/29	984/04	948/16	953/31		Date
Extreme Daily Pcpn. (mm)	20.8	12.0	11.4	20.3	28.4	31.7	38.1	40.1	27.2	29.4	16.5	25.9		Extrême quot. de préc. (mm)
Date	962/19	987/26	952/29	964/01	970/13	988/30	968/05	949/14	959/03	984/04	948/16	953/31		Date
Month-end Snow Cover (cm)	N	N	N	19	0	0	0	0	1	18	27	N		Couver. de neige, fin de mois (cm)
Days With														**Journées avec**
Maximum Temperature >0°C	N	N	N	N	31	N	N	N	N	N	N	N	N	Température maximale >0°C
Measurable Rainfall	0	0	*	N	6	10	11	10	8	2	*	0	N	Hauteur de pluie mesurable
Measurable Snowfall	11	8	8	N	2	*	0	0	2	9	10	N	N	Hauteur de neige mesurable
Measurable Precipitation	11	8	9	N	8	10	11	10	9	10	11	N	N	Hauteur de préc. mesurable

YELLOWKNIFE A

62°28'N 114°27'W/O. 205m. 1942 to/à 1990

	Jan janv	Feb févr	Mar mars	Apr avr	May mai	Jun juin	Jul juil	Aug août	Sep sept	Oct oct	Nov nov	Dec déc	Year année	
Temperature														**Température**
Daily Maximum (°C)	-23.9	-19.7	-12.5	-0.5	10.1	18.0	20.8	18.1	10.0	1.3	-10.8	-20.1	-0.8	Maximum quotidien (°C)
Daily Minimum (°C)	-32.2	-29.4	-24.6	-12.0	-0.1	8.2	12.0	10.0	3.4	-4.2	-18.9	-28.2	-9.7	Minimum quotidien (°C)
Daily Mean (°C)	-27.9	-24.5	-18.5	-6.2	5.0	13.1	16.5	14.1	6.7	-1.4	-14.8	-24.1	-5.2	Moyenne quotidien (°C)
Extreme Maximum (°C)	3.4	6.2	8.9	20.3	26.1	30.3	32.5	30.9	26.1	19.0	7.8	2.8		Maximum extrême (°C)
Date	985/03	986/28	973/30	980/28	948/31	990/23	989/16	984/02	951/06	988/05	956/23	944/13		Date
Extreme Minimum (°C)	-51.2	-51.2	-43.3	-40.6	-22.8	-4.4	0.6	-0.6	-9.7	-28.9	-44.4	-48.3		Minimum extrême (°C)
Date	947/31	947/04+	955/02	967/02	959/01	967/08+	951/12	982/25	983/29	972/26	966/27	946/25		Date
Degree-Days														**Degrés-jours**
Above 18 °C	0.0	0.0	0.0	0.0	0.1	4.4	19.0	8.7	0.0	0.0	0.0	0.0	32	Au-dessus 18°C
Below 18 °C	1427.5	1201.8	1133.7	727.6	403.7	150.8	66.8	130.9	338.2	602.6	986.1	1307.5	8477	Au-dessous 18°C
Above 5 °C	0.0	0.0	0.0	3.5	71.2	244.6	355.2	280.9	79.2	4.5	0.0	0.0	1039	Au-dessus 5°C
Below 0 °C	869.5	693.6	575.8	211.0	22.7	0.0	0.0	0.0	2.7	85.8	446.7	749.5	3657	Au-dessous 0°C
Precipitation														**Précipitations**
Rainfall (mm)	0.0T	0.0T	0.0T	1.6	12.2	23.0	35.2	41.6	24.8	14.6	0.6	0.2	154.0	Chutes de pluie (mm)
Snowfall (cm)	18.8	17.1	13.7	10.5	4.3	0.2	0.0	0.0T	3.5	21.7	33.5	20.6	143.9	Chutes de neige (cm)
Precipitation (mm)	14.9	12.6	10.6	10.3	16.6	23.3	35.2	41.7	28.8	34.8	23.9	14.7	267.3	Précipitations (mm)
Extreme Daily Rainfall (mm)	0.3	0.2	0.5	8.6	34.0	33.6	66.0	82.8	29.7	35.6	7.1	2.2		Extrême quot. de pluie (mm)
Date	977/17	981/01	958/27	946/27	957/05	988/28	988/22	973/15	982/07	967/11	954/21	985/20		Date
Extreme Daily Snowfall (cm)	13.0	23.7	10.9	13.0	11.2	3.0	0.0	1.0	15.2	16.0	14.7	15.7		Extrême quot. de neige (cm)
Date	980/23	982/20	954/14	981/07	979/28	970/06	990/31+	982/23	961/28	975/29	973/16	975/30		Date
Extreme Daily Pcpn. (mm)	12.4	17.5	10.9	13.5	34.0	33.6	66.0	82.8	29.7	35.6	12.2	11.4		Extrême quot. de préc. (mm)
Date	946/03	982/20	954/14	966/05	957/05	988/28	988/22	973/15	982/07	967/11	942/22	958/31		Date
Month-end Snow Cover (cm)	31	36	35	8	0	0	0	0	1	7	21	26		Couver. de neige, fin de mois (cm)
Days With														**Journées avec**
Maximum Temperature >0°C	*	*	2	14	29	30	31	31	30	19	2	*	188	Température maximale >0°C
Measurable Rainfall	*	*	*	1	5	7	10	10	9	6	*	*	50	Hauteur de pluie mesurable
Measurable Snowfall	12	10	9	5	2	*	0	*	2	10	16	14	80	Hauteur de neige mesurable
Measurable Precipitation	11	9	8	6	6	8	10	10	10	14	15	12	118	Hauteur de préc. mesurable
Freezing Precipitation	*	1	*	*	*	0	0	0	*	3	4	1	11	Précipitation verglaçante
Fog	2	2	*	*	*	1	*	*	2	4	3	2	19	Brouillard
Thunderstorms	0	0	0	0	*	2	2	2	*	0	0	0	6	Orages
Sunshine (hrs)	N	N	191.9	267.5	338.9	380.6	372.0	284.0	155.4	62.0	46.0	N	N	Insolation (h)
Station Pressure (kPa)	99.27	99.28	99.25	99.04	98.96	98.63	98.70	98.65	98.76	98.53	98.82	99.06	98.91	Pression à la station (kPa)
Moisture														**Humidité**
Vapour Pressure (kPa)	N	N	N	0.29	0.52	0.83	1.08	1.07	0.73	0.48	0.20	N	N	Pression de vapeur (kPa)
Rel. Humidity - 0600L (%)	N	69	70	73	69	66	71	81	85	85	79	71		Humidité relative - 0600L (%)
Rel. Humidity - 1500L (%)	67	65	59	57	48	45	48	54	62	76	78	71		Humidité relative - 1500L (%)
Wind														**Vent**
Speed (km/h)	13	13	14	16	16	16	15	15	15	16	15	12	15	Vitesse (km/h)
Most Frequent Direction	NW	E	NE	E	NE	S	S	S	SE	E	E	E	E	Direction la plus fréquente
Maximum Hourly Speed (km/h)	72	61	51	64	64	68	64	64	72	64	64	56		Vit. horaire max. (km/h)
Direction	NW	NW	NW	NW	NE	NW	N	NE	W	NW	NW	NW		Direction
Maximum Gust Speed (km/h)	105	98	70	93	87	89	85	80	105	89	113	80		Vit. max. du coup de vent (km/h)
Direction	W	N	NW	W	NW	W	N	N	W	NW	W	S		Direction

FORT RELIANCE

62°43'N 109°10'W O. 164m, 1948 to/à 1990

	Jan janv	Feb févr	Mar mars	Apr avr	May mai	Jun juin	Jul juil	Aug août	Sep sept	Oct oct	Nov nov	Dec déc	Year année	
Temperature														**Température**
Daily Maximum (°C)	*-24.3*	*-21.5*	*-15.4*	*-3.0*	*7.4*	*15.4*	*19.1*	*16.8*	*9.3*	*1.1*	*-10.8*	*-20.0*	*-2.2*	*Maximum quotidien (°C)*
Daily Minimum (°C)	-33.4	-31.8	-27.8	-15.5	-3.5	4.0	9.2	8.8	3.1	-4.5	-18.1	-27.9	-11.5	Minimum quotidien (°C)
Daily Mean (°C)	-28.8	-26.6	-21.5	-9.2	2.0	9.8	14.2	12.8	6.3	-1.6	-14.4	-23.9	-6.8	Moyenne quotidien (°C)
Extreme Maximum (°C)	2.1	6.1	8.6	16.1	26.1	29.4	34.3	30.0	27.2	17.9	6.7	4.1		Maximum extrême (°C)
Date	981/20	954/06	979/20	980/27+	973/25	955/27+	984/27	951/05	957/02+	988/07	970/03+	988/01		Date
Extreme Minimum (°C)	-53.5	-51.2	-50.0	-41.1	-31.1	-7.2	-1.1	0.0	-7.8	-23.3	-43.3	-45.7		Minimum extrême (°C)
Date	990/28	970/16	964/01	967/07	962/10	967/09	950/06	985/31	965/24	956/27	951/29	989/18		Date
Degree-Days														**Degrés-jours**
Above 18 °C	0.0	0.0	0.0	0.0	0.0	0.6	8.2	4.9	0.0	0.0	0.0	0.0	14	Au-dessus 18°C
Below 18 °C	1453.4	1261.0	1229.1	817.9	498.0	248.1	127.6	163.1	352.3	610.7	974.5	1301.0	9037	Au-dessous 18°C
Above 5 °C	0.0	0.0	0.0	2.5	36.5	151.4	283.7	244.9	70.5	4.5	0.0	0.0	794	Au-dessus 5°C
Below 0 °C	895.4	752.8	671.2	293.7	57.3	0.2	0.0	0.0	3.3	93.9	435.1	743.0	3946	Au-dessous 0°C
Precipitation														**Précipitations**
Rainfall (mm)	0.0T	0.0T	0.0T	2.1	10.4	29.9	36.5	46.9	29.9	12.5	0.5	0.0T	168.8	Chutes de pluie (mm)
Snowfall (cm)	17.0	15.9	14.6	15.0	5.3	1.4	0.0T	0.0T	2.5	19.8	27.6	20.4	139.6	Chutes de neige (cm)
Precipitation (mm)	12.1	10.7	10.5	14.1	15.9	31.4	36.5	46.9	32.2	28.9	20.2	13.4	272.7	Précipitations (mm)
Extreme Daily Rainfall (mm)	0.8	0.0	0.4	7.4	19.2	38.1	39.9	34.6	21.6	29.0	7.1	0.8		Extrême quot. de pluie (mm)
Date	981/20	990/28+	990/28	983/18	988/31	959/15	963/10	989/19	963/23	984/13	969/03	952/14		Date
Extreme Daily Snowfall (cm)	10.2	13.0	20.1	16.8	10.9	8.1	0.0	2.0	20.3	29.2	18.4	19.8		Extrême quot. de neige (cm)
Date	971/19	967/28	968/27	964/28	971/08	965/20	990/31+	982/25	950/29	966/05	977/07	958/31		Date
Extreme Daily Pcpn. (mm)	7.9	10.7	19.8	16.8	30.4	38.1	39.9	34.6	21.7	29.0	16.8	19.8		Extrême quot. de préc. (mm)
Date	949/04	967/28	968/27	964/28	979/27	959/15	963/10	989/19	982/11	984/13	976/04	958/31		Date
Month-end Snow Cover (cm)	40	46	50	29	0	0	0	0	0	6	21	31		Couver. de neige fin de mois (cm)
Days With														**Journées avec**
Maximum Temperature >0°C	*	*	1	12	26	30	31	31	29	19	2	*	182	Température maximale >0°C
Measurable Rainfall	*	0	*	1	5	8	10	12	10	5	*	0	52	Hauteur de pluie mesurable
Measurable Snowfall	12	10	10	8	3	*	0	0	2	10	15	13	84	Hauteur de neige mesurable
Measurable Precipitation	11	8	8	8	7	9	10	12	12	13	13	11	122	Hauteur de préc. mesurable
Moisture														**Humidité**
Rel. Humidity - 0600L (%)	*N*	*N*	*77*	*78*	*76*	*76*	*78*	*82*	*82*	*83*	*81*	*77*		*Humidité relative - 0600L (%)*
Rel. Humidity - 1500L (%)	N	73	72	69	63	60	61	65	68	78	79	76		Humidité relative - 1500L (%)
Wind														**Vent**
Speed (km/h)	11	10	11	12	12	11	10	12	14	16	14	11	12	Vitesse (km/h)
Most Frequent Direction	SW	C	E	E	E	E	NW	NW	E	E	E	E	E	Direction la plus fréquente
Maximum Hourly Speed (km/h)	66	63	65	74	80	63	80	84	74	90	81	63		Vit. horaire max. (km/h)
Direction	N	NW	W	W	N	NW	SW	NW	W	NW	NW	S		Direction
Maximum Gust Speed (km/h)	78	87	81	57	96	83	80	122	78	83	98	76		Vit. max. du coup de vent (km/h)
Direction	N	NW	W	E	E	NW	NW	NE	NW	W	NW	N		Direction

FORT RESOLUTION A

61°11'N 113°41'W O. 164m, 1930 to/à 1990

	Jan janv	Feb févr	Mar mars	Apr avr	May mai	Jun juin	Jul juil	Aug août	Sep sept	Oct oct	Nov nov	Dec déc	Year année	
Temperature														**Température**
Daily Maximum (°C)	-21.6	-17.8	-10.3	1.6	11.3	18.7	21.1	19.2	11.3	3.4	-7.6	-17.8	1.0	Maximum quotidien (°C)
Daily Minimum (°C)	N	-27.8	N	-10.6	-0.1	5.6	10.4	N	2.7	-2.8	N	N	N	Minimum quotidien (°C)
Daily Mean (°C)	N	N	N	-4.6	5.6	12.7	15.9	N	7.0	0.4	N	N	N	Moyenne quotidien (°C)
Extreme Maximum (°C)	5.0	9.4	13.5	23.3	30.0	31.7	35.0	32.2	27.2	21.7	8.9	5.1		Maximum extrême (°C)
Date	935/31	968/29	984/31+	989/29+	990/30+	955/24+	969/14	945/07	951/06	943/02	949/04	954/11		Date
Extreme Minimum (°C)	-51.2	-48.9	-43.9	-37.2	-19.5	-4.4	-0.6	-3.5	-8.3	-25.0	-42.0	-46.7		Minimum extrême (°C)
Date	934/01	947/03	936/04	967/02	979/07	969/11+	972/30+	978/20+	965/25	981/25	985/25+	933/28		Date
Precipitation														**Précipitations**
Rainfall (mm)	0.0T	0.0T	0.0T	2.6	9.0	22.7	40.0	32.1	31.0	13.7	0.2	0.0T	151.3	Chutes de pluie (mm)
Snowfall (cm)	28.3	18.5	17.2	10.7	4.8	0.5	0.0	0.0	2.1	25.8	57.9	N	N	Chutes de neige (cm)
Precipitation (mm)	21.9	14.0	13.0	12.1	12.8	23.3	40.3	32.1	33.6	37.6	42.7	N	N	Précipitations (mm)
Extreme Daily Rainfall (mm)	1.2	0.3	1.8	16.0	29.0	25.0	47.2	48.5	39.1	28.0	2.3	1.8		Extrême quot. de pluie (mm)
Date	981/24	963/07	962/29	931/16	951/25	987/22	973/25	973/17	963/23	984/13	969/04	959/19		Date
Extreme Daily Snowfall (cm)	22.4	24.4	34.0	23.0	29.7	10.2	0.0	0.0	16.3	35.6	76.7	17.0		Extrême quot. de neige (cm)
Date	974/01	971/10	967/23	981/06	979/25	967/08	990/31+	990/31+	930/28	971/27	947/20	950/21		Date
Extreme Daily Pcpn. (mm)	*17.8*	*27.3*	*30.7*	*23.0*	*43.4*	*25.0*	*47.2*	*48.5*	*39.1*	*28.0*	*76.7*	*17.0*		*Extrême quot. de préc. (mm)*
Date	936/02	971/10	967/22	981/06	951/25	987/22	973/25	973/17	963/23	984/13	947/20	950/21		Date
Month-end Snow Cover (cm)	N	N	N	N	0	0	0	0	0	N	N	N		Couver. de neige, fin de mois (cm)
Days With														**Journées avec**
Maximum Temperature >0°C	N	N	N	N	29	N	N	N	N	23	N	N	N	Température maximale >0°C
Measurable Rainfall	0	*	*	1	4	6	7	8	9	5	*	*	41	Hauteur de pluie mesurable
Measurable Snowfall	11	8	7	4	1	*	0	0	*	9	16	N	N	Hauteur de neige mesurable
Measurable Precipitation	10	8	7	5	3	6	7	8	10	13	16	N	N	Hauteur de préc. mesurable

FORT SMITH A

60°01'N 111°57'W/O, 203m, 1943 to/à 1990

	Jan janv	Feb févr	Mar mars	Apr avr	May mai	Jun juin	Jul juil	Aug août	Sep sept	Oct oct	Nov nov	Dec déc	Year année	
Temperature														**Température**
Daily Maximum (°C)	-20.3	-15.2	-6.9	5.0	14.7	20.6	22.7	20.7	12.9	4.5	-8.5	-17.2	2.7	Maximum quotidien (°C)
Daily Minimum (°C)	-30.5	-27.4	-21.3	-7.9	1.4	7.4	9.8	7.8	2.3	-3.8	-16.9	-26.3	-8.8	Minimum quotidien (°C)
Daily Mean (°C)	-25.4	-21.2	-14.0	-1.4	8.1	14.0	16.3	14.3	7.6	0.4	-12.6	-21.7	-3.0	Moyenne quotidien (°C)
Extreme Maximum (°C)	8.2	12.2	14.9	30.0	31.8	35.0	34.4	35.3	31.7	26.1	13.3	9.7		Maximum extrême (°C)
Date	981/20	986/28	984/30	980/29	986/26	970/04	989/14+	981/09	951/06	947/01	974/04	984/08		Date
Extreme Minimum (°C)	-49.4	-53.9	-44.4	-40.6	-19.4	-6.1	-3.3	-5.6	-12.8	-27.9	-40.6	-48.3		Minimum extrême (°C)
Date	966/27	947/02	962/02	954/06	954/01	959/02	951/13	950/24	961/29	984/31	985/24+	946/14		Date
Degree-Days														**Degrés-jours**
Above 18 °C	0.0	0.0	0.0	0.0	1.4	8.6	20.2	12.6	0.2	0.0	0.0	0.0	43	Au-dessus 18°C
Below 18 °C	1347.2	1109.7	994.7	584.1	309.5	128.8	74.2	128.6	312.5	548.3	921.0	1233.6	7692	Au-dessous 18°C
Above 5 °C	0.0	0.0	0.2	16.2	126.5	270.4	349.0	287.1	99.0	13.8	0.2	0.0	1162	Au-dessus 5°C
Below 0 °C	789.3	601.8	439.9	109.7	6.1	0.0	0.0	0.0	2.1	57.0	382.7	675.6	3064	Au-dessous 0°C
Precipitation														**Précipitations**
Rainfall (mm)	0.0T	0.0T	0.1	3.6	25.2	45.0	56.8	48.9	37.7	12.2	1.0	0.4	231.2	Chutes de pluie (mm)
Snowfall (cm)	25.7	18.9	17.3	11.8	4.4	0.3	0.0	0.2	1.0	17.5	31.9	24.7	153.7	Chutes de neige (cm)
Precipitation (mm)	19.9	14.3	13.9	13.5	29.2	45.3	56.8	49.1	38.5	28.1	25.2	19.2	352.9	Précipitations (mm)
Extreme Daily Rainfall (mm)	0.4	1.0	3.6	10.4	26.2	66.2	66.5	47.5	32.5	13.7	12.2	5.8		Extrême quot. de pluie (mm)
Date	989/26	975/23	968/06	969/19	964/09	977/09	962/02	975/23	982/10	945/17	987/01	963/04		Date
Extreme Daily Snowfall (cm)	22.1	16.0	16.0	16.8	23.9	1.8	0.0	4.0	13.5	20.8	23.4	16.2		Extrême quot. de neige (cm)
Date	968/16	976/08	968/07	972/01	968/01	967/08	990/31+	986/24	956/26	956/12	953/30	989/14		Date
Extreme Daily Pcpn. (mm)	17.8	13.2	21.3	19.3	26.4	66.2	66.5	47.5	33.5	20.8	23.4	14.7		Extrême quot. de préc. (mm)
Date	968/16	951/09	968/05	973/04	964/09	977/09	962/02	975/23	982/10	956/12	953/30	989/14		Date
Month-end Snow Cover (cm)	48	51	43	3	0	0	0	0	0	5	23	35		Couver. de neige, fin de mois (cm)
Days With														**Journées avec**
Maximum Temperature >0°C	*	1	7	23	31	30	31	31	30	24	3	*	212	Température maximale >0°C
Measurable Rainfall	*	*	*	2	7	11	11	11	10	6	*	*	60	Hauteur de pluie mesurable
Measurable Snowfall	14	10	9	5	1	*	0	*	*	7	15	14	76	Hauteur de neige mesurable
Measurable Precipitation	13	9	9	6	8	11	11	11	11	12	14	13	128	Hauteur de préc. mesurable
Freezing Precipitation	*	1	*	*	*	*	0	0	*	2	4	1	11	Précipitation verglaçante
Fog	1	*	*	*	*	*	1	2	3	4	2	1	17	Brouillard
Thunderstorms	0	0	0	*	*	4	5	4	*	0	0	0	14	Orages
Station Pressure (kPa)	99.31	99.30	99.20	98.99	98.59	98.58	98.68	98.67	98.80	98.59	98.87	99.11	98.92	**Pression à la station (kPa)**
Moisture														**Humidité**
Vapour Pressure (kPa)	N	N	N	0.39	0.62	0.98	1.20	1.15	0.80	0.53	0.25	N	N	Pression de vapeur (kPa)
Rel. Humidity - 0600L (%)	N	80	80	79	72	75	81	88	89	88	85	80		Humidité relative - 0600L (%)
Rel. Humidity - 1500L (%)	76	75	69	54	43	46	49	52	59	71	81	79		Humidité relative - 1500L (%)
Wind														**Vent**
Speed (km/h)	11	11	11	13	13	12	11	11	12	13	12	10	12	Vitesse (km/h)
Most Frequent Direction	NW	NW	NW	SE	SE	SE	NW	NW	SE	SE	SE	SE	SE	Direction la plus fréquente
Maximum Hourly Speed (km/h)	51	50	64	58	54	56	55	53	48	64	61	56		Vit. horaire max. (km/h)
Direction	NW	W	W	W	S	SE	W	NE	NW	W	S	NW		Direction
Maximum Gust Speed (km/h)	52	74	91	77	85	87	80	94	90	84	83	100		Vit. max. du coup de vent (km/h)
Direction	W	NW	NW	W	W	SW	S	W	W	W	W	N		Direction

8.4 Underwater cable supply

ANNEX 8.4

UNDERWATER CABLE SUPPLY

In order to ascertain precise cost estimates of a project involving submarine cable installations, a detailed assessment of the cable installation bed is required. The lake bottom condition must be mapped accurately and also the soil and geological conditions must be cataloged. When an accurate route profile is obtained the mechanical and structural requirements of the cable can be specified along with any armoring requirements. Accurate assessment of thermal properties at lake bottom also permit accurate sizing of the conductors and finalization of insulation details. It is only after completing all of the above tasks that a precise estimate of cable costs is possible.

For preliminary investigations, such as the one at hand, a rough estimate can be obtained from a review of previous projects. Obviously one needs to review projects that are similar and from these it is possible to come up with a ''blended average cost''. Usually these projects are carried out on a turn-key basis and they contain different cost components, i.e. cable costs, installation costs and shipping costs. Detailed cost breakdowns are usually not available. Our estimates were derived using this technique.

The following aspects of submarine cable installation projects are particularly onerous cost-drivers:

- Difficult shorelines
- Unusual water depths

Cables are normally ploughed in to the lake bottom near the shore and they are placed in a mechanically protected trench on the shore. Any geological factors that would impede this construction would obviously lead to higher costs.

Cables can be installed at very significant depths and projects at depths greater than 1000 feet have been carried out. Installations approaching these depths, however, require special designs and are more expensive. Since the cable is heavier, mechanical forces are greater and the cable laying apparatus must be reinforced in a commensurate manner.
It is felt that the costs presented are conservative but not unduly so and some refining would take place on further analysis.

Cable supply, for the kind of service expected, would most likely be in Europe and probably Scandinavia. Again, further definition would be possible during a subsequent phase.

8.5 Transmission voltage and power

ANNEX 8.5

TRANSMISSION VOLTAGE & POWER

The most important factors in the design of a power transmission line are the desired power transmission capacity and the distance over which the power must be transmitted. Ultimately, these two factors determine which of the several operating constraints will govern line design, in terms of a choice of the operating voltage level and conductor ampacity.

For long transmission lines (i.e. a few hundred kilometers), as contemplated here, "Surge Impedance Loading" (SIL) is a useful concept for initial planning. Its relevance is that when a transmission line is loaded to its SIL capacity, it draws no net reactive power from the power system, and it exhibits a flat voltage profile throughout its length. Both of these traits are desirable technically and operationally. On the other hand if the line is loaded sufficiently below or above its SIL rating, the voltage profile will either rise or fall along the length of the line. In order to maintain an acceptable voltage profile on the line, additional power apparatus to provide reactive Volt Amp compensation (KVAr) may be required in form of reactors or capacitors, either at the line terminals or in extreme cases at points along the line. SIL levels for high-voltage lines can be estimated readily as V^2/Z_o, with V denoting the 3-phase operating voltage and Z_o representing the line surge impedance. The latter is a function of line geometry, and varies only slightly around 350 ohms for overhead lines designed for 35 to 169 kV systems. On this basis, estimated SIL levels for the contemplated line are as follows at respective operating voltage:

Circuit Voltage (kV)	**SIL (MW)**
115	38
138	55
161	74

This suggests that 115 kV operating voltage is appropriate initially for the contemplated line, while the peak load is expected to remain about 25 MVA. Eventually when the demand increases to the projected 50 MVA, a somewhat higher voltage would appear to be more appropriate.

It should be noted that SIL is only a guide for choosing an appropriate voltage level. It does not represent a technical constraint, since transmission lines can be loaded significantly beyond their SIL level, particularly for shorter lines. For instance an operating voltage higher than that dictated by SIL considerations may be chosen to reduce line losses, thereby increasing power transmission efficiency.

Technical constraints limiting the power handling capacity of transmission lines include its thermal rating and its steady-state stability limit:

- The thermal limit is determined by the current-carrying capacity of the line conductor, as defined by the manufacturer. The current flowing in the line causes conductor heating due to galvanic losses (due to electrical resistance), which causes the conductor temperature to rise. This causes the conductor to elongate, increasing its sag to ground (between adjacent towers) and reducing the line-to-ground clearance. Since industry standards require that minimum clearances be maintained at all times for personnel safety, this imposes a limit to the maximum line loading (which inevitably varies with ambient conditions). At extreme operating temperatures, the conductor may stretch irreversibly, increasing sag permanently.

- The expression for real power transfer over a lossless line is given by,

$$\frac{V_s V_r}{X} \sin \delta$$

where Vs and Vr denote the sending and receiving end voltages, X represents the total line reactance and δ is the load angle (angular difference between the respective terminal voltage vectors). This establishes a steady-state stability limit for power transfer, reaching its maximum theoretical value at δ = 90 degrees. In practice, δ is limited to 30-35 degrees in normal operation to accommodate unplanned operating contingencies. On this basis, the steady-state stability limit for the various voltage levels, assuming a typical 0.4 ohm/km line reactance and 400 km line length, are as follows:

Circuit Voltage (kV)	**Steady-State Stability Limit (MW)**
115	40-47
138	60-68
161	80-93

On this basis, 115 kV operating voltage is acceptable for the projected 50 MVA load, but only marginally so. Again, economic considerations based on reduced line losses would tend to favour a higher operating voltage.

A similar analysis can be carried out for the proposed submarine cable crossing, involving an estimated 70 km crossing. Assuming a representative value of 40 ohms for the cable surge impedance yields the following approximate SIL levels:

Circuit Voltage (kV)	**Submarine Cable SIL (MW)**
35	30
44	48
69	120
138	475
161	650

This suggests that for optimum reactive loading and voltage profile, the cable should be operated at 44 kV. At higher voltages, the cable is lightly loaded relative to its SIL. This implies that it supplies excessive reactive power to the system due to the cable capacitance, which must be counteracted by installing shunt reactors at both cable terminals. The reactors would need to be switched in concert with load variations to regulate voltage profile along the entire transmission line (overhead and cable portion). In addition, because of the large cable capacitance, the cable conductor must be sized to carry the associated charging current. Figure _ depicts the variation of this charging current (assuming a representative 167 nF/km cable capacitance) as a function of the operating voltage, along with corresponding load current for 25 MW and 50 MW power levels. Also shown is the resulting total current, resulting from the vectorial summation of the charging and load currents (which are in phase quadrature). Evidently, the copper conductor in the cable is utilized most efficiently if the total current is kept at a minimum. On this basis, a 69 kV operating voltage is the optimum, since it minimizes copper requirements and conduction losses (for a given conductor cross-section).