Memorandum

Date:	August 25, 2014		
Project Name:	Char Lake Hydrology Study	Project #:	OTT-00220977-A0
Subject:	Technical Memo		
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1. Introduction

All of the water supply needs for the Hamlet of Resolute Bay (Hamlet) are currently provided from Char Lake. This includes the water needs for the townsite and airport areas within the community. The attached Figure 1 depicts Char Lake. The Nunavut Water Board (NWB) has requested a demonstration that this source is sustainable and capable of meeting the long term needs of the community. The Department of Community and Government Services (CGS) of the Government of Nunavut (GN) has retained **exp** Services Inc. (**exp**) to undertake a review of the sustainability of Char Lake. The following memorandum provides a summary of this review. Activities have included a review of related investigations, an examination of climate, a delineation of the watershed and assessment of the ability of the water source to meet the ongoing needs of the community.

2. Related Studies and Background Information

2.1 Introduction

Limited information is available regarding the behaviour of northern watersheds. Experience gained in southern Canada must be applied with great caution, as the difference in climates leads to fundamental differences in the nature of runoff from northern watersheds. Many Arctic locations experience relatively low amounts of annual precipitation, and much of this precipitation falls as snow. This snowfall accumulates over the winter, making available in the spring much of the over-winter precipitation as runoff.

Guidance has been sought from previous investigations. These sources of guidance include:

- Draft CSA standard S503, Community drainage system planning, design and maintenance in northern communities.

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- Rankin Inlet
  - Design of Pipeline System to Augment Natural Replenishment of Nipissar Lake, FSC Engineers and Architects, December 15, 2010.
  - Nipissar Lake Volume Study and Environmental Variable Study, FSC Engineers and Architects, April 20, 2011
  - Water Supply Facility Operation and Maintenance (O&M) Plan, Hamlet of Rankin Inlet, Nuna Burnside, December 2008, revised April 2010.
- Iqaluit
  - City of Iqaluit Raw Water Supply and Storage Review, Trow Associates, April 2004.
- Resolute Bay
  - Operations and Maintenance Manual for Resolute Bay Water and Sewer System, Underwood McLelland and Associates
  - Sewage and Water Works Technical Evaluation – Phase 1, Hamlet of Resolute Bay, Trow Associates, March 2010.
  - Char Lake Pump House Design Brief, **exp** Services, November, 2012.

2.2 Draft CSA Standard S503

The CSA standard S503 provides guidance regarding collection, conveyance, detention and discharge of excess surface water in the form of overland flow. The following are noted from the standard:

- Included among the exclusions, "Watershed level drainage planning." Thus, the guidance from this standard is not directly applicable to the estimation of watershed yield to Char Lake.
- Various sources of topographic data including the National Topographic System (NTS) in the scale of 1:50,000 are suggested.
- Section 4.7.2.2 of the draft standard notes, "Freshet, or spring thaw, may comprise the majority of a community's runoff for the entire year. During this time of year icing may be more likely. Information on spring freshet and runoff rates can be found in the annex." A review of the annex did not identify this information.
- Flow estimation is focused around determining the peak rate of runoff arising from a single event.
- The Rational Method is presented as a tool to estimate flows. The discussions of the Rational Method note that conventional runoff coefficients are not appropriate for spring runoff conditions where runoff can approach 100% when the ground is frozen.

In summary, although the draft standard is not directly applicable to the investigation of watershed yield into Char Lake, the comments regarding topographic data sources and intensity of runoff during spring freshet provide useful guidance.

2.3 Rankin Inlet

Investigations have been undertaken regarding the ability of Nipissar Lake to meet the water demands of the community. As a result of these assessments, an overland pipeline was installed to supplement the water volume available from the watershed to Nipissar Lake. The following have been drawn from the reviewed documents.

- The report dealing with the design of the pipeline system (FSC December 15, 2010) indicates the average water resupply to Nipissar Lake as 311,789 m^3.
- The Nipissar Lake Volume Study (FSC April 2010) reports the following:
  - Average annual snowfall is 128.7 mm and average annual precipitation is 305.4 mm.
  - Nipissar Lake is capable of providing an estimated maximum demand 311,789 m^3 without continued depletion.
- The Water Supply Facility O&M Plan (Nuna Burnside, April 2010) report provides the following.
  - The area of the watershed draining to Nipissar Lake is 323 ha.
  - An annual precipitation rate of 297.2 mm and an annual evapotranspiration rate of 200 mm are reported.
  - Net recharge to the lake is estimated at 314,000 m^3.

The following observations and conclusions are drawing from the information reviewed for Rankin Inlet.

- Rankin Inlet enjoys a less demanding climate than that of Resolute Bay. This is especially so, as regards the duration of the frost free period.
- Both FSC and Nuna Burnside provide similar estimates of annual watershed yield to Nipissar Lake.
- Annual runoff of 314,000 m^3 from a watershed of 323 ha indicates an annual runoff of 97 mm.

2.4 Iqaluit

In response to a concern for the sustainability of the community water supply the City of Iqaluit commissioned a study to examine the ability of the watershed for Lake Geraldine to support the demands of the City. This investigation made use of stream flow data from monitoring stations of the Apex (1973 to 1995) and the Sylvia Grinnell (1971 to 1999) Rivers. Among other matters this report provides the following.

- The average ratio of annual runoff to annual precipitation for the Apex River was calculated as 0.772.
- The average ratio of annual runoff to annual precipitation for the Sylvia Grinnell River was calculated as 0.898.
- Recognizing the risks that can arise from overestimation of annual runoff, the estimate of watershed yield was based upon an assumed ratio of annual runoff to annual precipitation of 60%.

- The watershed of Lake Geraldine is reported as 385 ha. The 1:100 year return low watershed yield estimate is 485,000 m^3.

2.5 Resolute Bay

2.5.1 Operation and Maintenance Manual for Existing System

The Operations and Maintenance Manual for the existing water and sewer system provides the following information.

- Char Lake drainage area of 4.40 km^2 (440 ha)
- Char Lake surface area of 52.6 ha
- Mean depth of Char Lake 33.5 ft. (10.2 m)
- Maximum observed ice thickness at Char Lake (based on 3 years of observation) 8.2 ft. (2.5 m)
- Intake positioned 12 ft. (3.66 m) below ice surface based upon an allowance of 10 ft. (3.05 m) for ice and 2 ft. (0.61 m) of drawdown.

2.5.2 Pending Water and Sewer System Improvements

As part of a long term strategy for the provision of water and sewer services in Resolute Bay, the GN retained **exp** (then Trow Associates) to assess the existing status of the systems serving the community. A part of this assessment included a review of historic water consumption. This review of water consumption yielded the following observations:

- Consumption prior to 1998 is reported as between 48,000 and 66,000 m^3 per year.
- Consumption data was obtained for the periods 1998 to 2002 and 2007 to 2009. The data for the period 1998 to 2007 was considered to be erroneous. Table 2.1 from this investigation, which presents the reported water demands, is attached. This tabulation represents the limits of water consumption data that is currently available.
- Water consumption rose dramatically in 2007, with consumption in 2008 and 2009 approaching 300,000 m^3 per year. Very limited data is available for 2007, but water consumption was estimated as almost 200,000 m^3 in 2007.
- There was a significant rise in fuel consumption concurrent with the increase in water use. Water consumption directly impacts fuel consumption, as the water is heated at Char Lake and at the water treatment plant.

Table 2.1 - Resolute Bay Water Consumption

Dates		No of Days	Consumption l Gal	Average Day l Gal	Annual Use	
From	To				l Gal	m^3
1/1/98	25/12/98	358	1,584,378	4,426	1,615,490	7,344
29/1/99	21/12/99	328	1,529,253	4,662	1,701,630	7,736
9/1/00	30/12/00	356	1,913,846	5,376	1,962,240	8,921
3/1/01	28/12/01	359	1,711,824	4,768	1,740,320	7,912
2/1/02	27/12/02	359	2,154,211	6,001	2,190,365	9,958
10/11/07	29/11/07	19	2,956,615			
30/11/07	29/12/07	29	2,636,118			
		48	5,558,733	116,432	42,497,680	193,198
1/1/08	31/12/08	365	60,780,160	166,521	60,780,165	276,312
1/1/09	28/11/09	331	57,442,618	173,543	63,343,195	287,964

After various investigations and evaluations it was decided that a replacement of the existing piped water and sewer system was the most appropriate long term strategy for the community. The Government of Nunavut commissioned the design of this replacement system. Among the design activities was the preparation of a Design Brief for the rehabilitation of the Char Lake pump house. This Design Brief provides information regarding the conditions the design is to respond to, including the estimate of community wide water consumption. Matters that are presented within the Design Brief that will have a bearing upon the water demands from Char Lake are as follows.

- The design period for the proposed works is 30 years, ending in 2047.
- The design water demands include both the townsite and Airport areas of the community.
- Estimated average day community water consumption at the end of the design period is 1.68 litres per second.
- In addition to community water consumption, the water supply must support bleed water flow, which are required to avoid freeze of the sewer system. These bleed water flows will total 2.4 litres per minute at the end of the design period (2047).
- The total average day water consumption is estimated as 4.08 litres per second.

Based on the information in the Design Brief it is concluded that the Char Lake water supply must be capable of supporting an ongoing demand of 4.08 litres per second, or 129,000 m^3 per year.

2.6 Summary

The following may be drawn from the various sources that were reviewed.

- All of the annual precipitation in Resolute Bay provides some contribution to the recharge of Char Lake. Spring runoff represents a large portion of annual runoff.
- 97 mm of annual runoff is estimated from the watershed for Nipissar Lake in Rankin Inlet.
- The estimates of watershed yield prepared in 2003 for Iqaluit incorporated a ratio of annual runoff to annual total precipitation of 0.60. The calculated values of this ratio for the Apex and Sylvia Grinnell Rivers were 0.772 and 0.898 respectively.
- The annual water requirement at the end of the design life for the current water and sewer improvements in Resolute Bay is 129,000 m^3 per year. Historically, the water system has been called upon to meet consumption that was a high as 300,000 m^3 per year.

The assessment of watershed yield for Char Lake will advance on the following basis:

- The continuing habitability of a community is dependent upon access to a reliable water supply.
- Estimates of water source recharge must be conservative, especially in view of the essential nature of a sustainable water supply.
- A ratio of annual runoff to annual precipitation of 50% will be assumed.

3. Community Water Requirements

Data for historic consumption is of limited value, in terms of examining future impacts of community demand on Char Lake, as there is currently a program to replace the piped water and sewer networks in Resolute Bay. These new networks will lead to reduction in community wide water use as less bleed flow will be required to avoid freeze of the sewer piping. The assessment of Char Lake as a sustainable water source has been advanced using the projected water demands for the new piped networks.

The design horizon for the current program of improvements to the water and sewer system has been set at 30 years, ending in 2047. At the end of the design period annual water consumption, which is inclusive of domestic water use and bleeds to the sewer system, is estimated to total 129,000 m^3 per year. This water consumption estimate includes the water demands of the townsite and airport areas of the community. This criterion will be used to assess the viability of the Char Lake water supply as a sustainable water source for the Hamlet.

The capability to meet an ongoing demand of 300,000 m^3 per year will also be considered. This evaluation provides an indicating of the capability of Char Lake to respond to extreme events.

4. Char Lake Watershed

4.1 Data Gathering

The following data sources were identified:

- Government of Nunavut digital topographic mapping of the Hamlet of Resolute Bay.
- National Topographic System Mapping in the scale of 1:50,000 (Sheet 58F11)
- Google Earth images of Resolute Bay

4.2 Data Review

The 1:50,000 mapping provide coverage of the full watershed to Char Lake. The watercourse and contour information from this mapping was used to develop an initial estimate of the watershed limits.

The Government of Nunavut mapping provided greater detail in the immediate proximity to Char Lake, but this mapping did not provide coverage of the full watershed. This large scale mapping was used to refine the limits of the watershed, especially in the general direction of the airport. The definition of small watercourses in the immediate vicinity of Char Lake was especially useful in this regard.

4.3 Findings

The attached Figure 2 depicts the limits of the watershed draining to Char Lake. This watershed has an area of 425 ha. This watershed estimate is consistent with the information provided in the Operations and Maintenance Manual. The independently estimated watershed area of 425 ha will be retained in the subsequent analysis, as this estimate is based on more accurate mapping than that available at the time of the design of Char Lake intake. The surface area of Char Lake is 52.2 ha.

5. Climate Data

5.1 Data Sources

The Environment Canada database of historical climate information has been reviewed for information relating to Resolute Bay. From the review Climate Normals for the period 1981 to 2010, together with monthly observations for the period October 1947 to November 2012 were obtained. The Normals provide the following information regarding typical annual conditions in Resolute Bay.

- Annual rainfall 59.5 mm
- Annual snowfall 111.2 cm
- Annual precipitation 161.2 mm

- Days with snow depth greater than 1 cm 288.7
- Annual lake evaporation 8.2 mm

Based upon the above it is concluded that 37% of the annual precipitation occurs as rain, with remaining 63% falling as snow. Also, the annual period with at least some snow depth represents 79% of the year.

The review of climate has been conducted within the context of the recharge of Char Lake following over-winter water use by the community, and the ability of this lake and watershed system to meet the long term needs of the community. Much of the annual snowfall is available in the form of a single event, spring runoff. It is also anticipated that rainfall will contribute to the recharge of Char Lake, as rainfall will infiltrate into the local gravelly soils and percolate in the generally downhill direction towards Char Lake. An analysis of total precipitation data has been undertaken.

5.2 Precipitation Data

As is noted above, monthly accumulation data for the period October 1947 to November 2012 has been obtained. During a review of the data it was noted that information for April and November 2010 were missing. The data for the years 1947, 2010 and 2012 has been set aside as a full data set for these years is not available. A probability analysis has been conducted on this data to quantify the variability of precipitation. The percentage of years with snow accumulation less than or equal the snow accumulation for each year were calculated. The results of this analysis are summarized in Table 5.1.

A 20 year return represents a probability of 1/20 (5%) that an event with less annual snowfall will happen in any given year. Similarly, there is probability of 1% that less snowfall than the 100-year return will occur in any given year. The estimates were developed from the data presented in Table 1.

- The least annual snowfall over the 63 year period considered is 78.2 mm.
- The 20 year return low annual precipitation is estimated as 96 mm.
- The 100 year return low annual precipitation is estimated as 79 mm.

6. Char Lake Watershed Yield Estimate

Estimates of the annual yield available from the Char Lake watershed has been developed based upon the following assumptions.

- Watershed area 425 ha (4,250,000 m^2)
- Ratio of annual yield to annual total precipitation 50%

The Climate Normals provide an annual rate of lake evaporation of 8.2 mm. This rate, applied over the 52.2 ha area of Chare Lake leads to annual evaporation loss of 4,000 m^3,

Estimates have been prepared for 20 year return, 100 year return and lowest observed annual precipitation. These estimates are summarized in Table 6.1.

Table 5.1
Probability Analysis for Total Annual Precipitation Data 1948 to 2011

Cumulative Percent of Years with Total Snowfall <X cm (%)	Total Annual Precipitation (mm)		Cumulative Percent of Years with Total Snowfall <X cm (%)	Total Annual Precipitation (mm)
100.0%	283.2		74.2%	164.3
98.4%	240.3		72.6%	158.9
96.8%	214.5		71.0%	158.3
95.2%	206.4		69.4%	156
93.5%	190.8		67.7%	153.8
91.9%	189.5		66.1%	153.2
90.3%	184.5		64.5%	152
88.7%	182.8		62.9%	149.7
87.1%	181.9		61.3%	147.9
85.5%	177.6		59.7%	146.8
83.9%	176.7		58.1%	146.5
82.3%	170.9		56.5%	144.8
80.6%	168.4		54.8%	144.8
79.0%	167.7		53.2%	144.7
77.4%	167.5		51.6%	143.9
75.8%	166.1		50.0%	140.5
48.4%	140.5		22.6%	122.4
46.8%	140.4		21.0%	120.6
45.2%	139.5		19.4%	115.4
43.5%	138.9		17.7%	114
41.9%	138		16.1%	112.5
40.3%	137.9		14.5%	110.2
38.7%	136.4		12.9%	104.7
37.1%	136.2		11.3%	100.2
35.5%	135.9		9.7%	99.6
33.9%	134.4		8.1%	99.4
32.3%	133.9		6.5%	99.3
30.6%	132.2		4.8%	95.7
29.0%	132		3.2%	81.5
27.4%	130		1.6%	79.1
25.8%	126.7		0.0%	78.2
24.2%	125.2			

Table 6.1 - Estimated Watershed Yield

Event	Estimated Watershed Yield (m^3)	Watershed Yield Net of Lake Evaporation (m^3)
• 20 year return	204,000	200,000
• 100 year return	168,000	164,000
• Lowest observed annual precipitation	166,000	162,000
• Typical (Climate Normals)	342,000	338,000

Based upon the above tabulated values of watershed yield the recharge into Char Lake is capable of meeting the estimated demands at the end of the design horizon for the replacement water and sewer system. It is also noted that the typical yield is capable of supporting extremely high rates of water consumption, as were observed in 2008 and 2009.

7. Impact of Extreme Events on Char Lake

An examination of the potential impact of extreme events upon the Char Lake water source has been conducted. For this assessment it has been assumed that water consumption rates return to the extreme levels seen in 2008 and 2009 of 300,000 m^3 per year and this consumption coincides with the lowest observed annual precipitation. This set of events leads to a shortfall in recharge into Char Lake of 134,000 m^3. This shortfall would lead to a lowering of the surface level of Char Lake by 0.26 m. The design of the intake to the pump house at Char Lake provides for 0.6 metres of drawdown below 3.05 m of ice cover. This represents a volume of 313,000 m^3 that would be available for community consumption during the over-winter period, which is estimated to total 9 months. It should be noted that this estimate of available raw water storage is based on very conservative assumptions.

There is sufficient stored volume between the extreme estimate of ice thickness and the raw water intake to support 2 successive years of extreme high demand (300,000 m^3 annually) combined with extreme low precipitation (78.2 mm total). It may be also noted that the maximum reported ice thickness for Char Lake is 2.5 m. A reduction in the allowance for ice thickness to 2.5 provides the further ability to respond to extreme demands combined with low precipitation for a further 2 years to a total of 4 years.

The Operations and Maintenance Manual for the existing water and sewer system in Resolute Bay reports a mean depth of Char Lake of 10.2 m. A substantial additional volume of source water is available through an extension of a modest extension of the intake pipeline. This extension of the intake should be viewed as a short term response to unusual conditions that would be resolved through better management of water consumption, combined with a return to normal climatic conditions.

8. Anecdotal Observations

There are various observations that support the opinion that the existing water source is capable of supporting the ongoing demands of the Hamlet. It is recognized that these anecdotal observations are qualitative and that quantitative conclusions may not be directly drawn from them, but they provide some very sound impressions regarding the ability of Char Lake and its watershed to support the water demands of the Hamlet.

As a first observation it is noted that the Char Lake supply supported ongoing annual demands that were estimated at 300,000 m^3 in 2008 and 2009. This period was preceded by consumption that was estimated at nearly 200,000 m^3 in 2007. No unusual operating challenges relating to the availability of raw water were noted during this period.

Char Lake drains through a creek along the southern shore of the lake. Discharge from the lake into this creek indicates that the watershed has refilled the lake to a sufficient level. This further demonstrates that the lake has returned to normal levels following replenishment of over-winter consumption. The following photograph, taken on August 1, 2014, demonstrates the recharge of Char Lake to the point where discharge into the creek occurred.

The following photograph, also taken August 1, 2014, illustrates some remaining ice cover on the lake. This indicates that spring runoff had not completed on August 1.

In summary the observations of August 1, 2014, combined with an ongoing history of meeting the water supply needs of the community despite unusually high water demands, strongly suggest that the Char Lake is a sustainable water source.

9. Summary

The principle findings of this assessment may be summarized as follows.

1 The 2004 assessment of the water source for Iqaluit determined the ratio of annual runoff to precipitation to be between 0.7 and 0.9, based on stream flow measurements. The assessment of the sustainability of Lake Geraldine as a water source for Iqaluit was advanced on the basis of a ratio of runoff to precipitation of 0.6.

2 Historic water consumption in Resolute Bay has been as high as 300,000 m^3 per year in 2008 and 2009.

3 Annual water consumption at the end of the design horizon for the current community infrastructure improvements is estimated to total 129,000 m^3.

4 The area of the watershed draining to Char Lake is 425 ha. The surface area of Char Lake is 52.2 ha. These estimates are consistent with the information reported in the existing Operation and Maintenance Manual.

5 A review of precipitation data for the period 1948 to 2011 has been conducted. This review provided the following:

- Normal annual precipitation totals 161.2 mm
- The 20 year return annual precipitation is estimated at 96 mm.
- The 100 year return annual precipitation is estimated at 79 mm.
- The lowest annual precipitation is reported as 79 mm.

6 A watershed yield estimate has been developed based upon the assumption that 50% of the annual precipitation appears as runoff to Char Lake. This is a more conservative assumption than was applied during the assessment of the water supply for Iqaluit. An allowance for evaporation based upon data from the Climate Normals has been incorporated in the watershed yield estimates, which are as follows.

Event	Estimated Net Watershed Yield (m^3)
• 20 year return	200,000
• 100 year return	164,000
• Lowest observed annual precipitation	162,000
• Typical (Climate Normals)	338,000

7 The most pessimistic estimate of watershed yield, which is based upon the lowest observed annual precipitation, exceeds the community water supply requirements at the end of the design horizon of the pending improvements.

8 Typical watershed yield, based upon the annual precipitation provided in the Canadian Normals, exceeds historic consumption.

9 Char Lake is capable of supporting for 2 to 4 years the extreme event of successive years with the lowest observed annual precipitation combined with a return to the historic high water demand. A short extension of the intake pipeline would access sufficient water to meet, as a short term response, continuing high water demands, combined with low precipitation.

10 Anecdotal observations, including the historic ability to support high demand, and flow in the creek draining Char Lake support the opinion that Char Lake is a sustainable water source.

Sincerely,
exp Services Inc.

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EXP SERVICES INC.
Signature _____
Date Aug 25, 2014
PERMIT NUMBER: P 483
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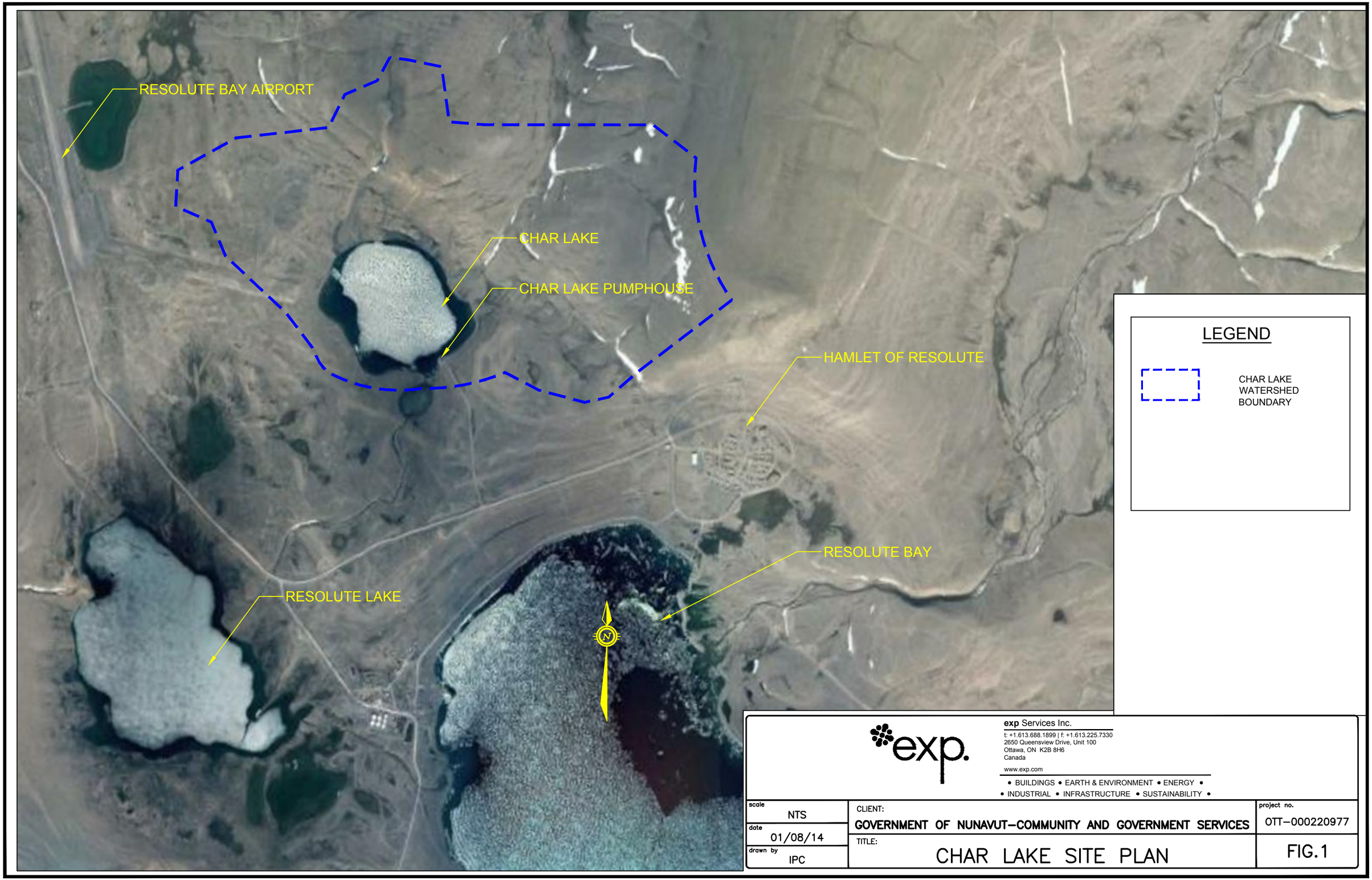

LEGEND

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scale: NTS	CLIENT: GOVERNMENT OF NUNAVUT–COMMUNITY AND GOVERNMENT SERVICES	project no.: OTT–000220977
date: 01/08/14	TITLE: CHAR LAKE SITE PLAN	FIG.1
drawn by: IPC		

Strip Lake
Char Lake
Signal Hill
Mecham
Resolute
Resolute Lake
Resolute Ck
Ruins Lake
Resolute
160
90
60

LEGEND

CHAR LAKE WATERSHED AREA

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date: 01/08/14	TITLE: CHAR LAKE WATERSHED AREA	FIG.2
drawn by: IPC		