Government of Nunavut

Igloolik Water Reservoir Risk Assessment

Type of Document
Final Report

Project Name
Igloolik Bathymetric Survey

Project Number
OTT-0000228428-A0

Prepared By:
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Date Submitted
October, 2015

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1 Introduction

In June 2015, the Hamlet of Igloolik (Hamlet) experienced a water shortfall in their water reservoir. As a result an emergency system which included utilizing an alternate water source lake was implemented. At the time of the shortfall there was a consensus that this was due to a colder than normal winter and a late spring runoff, resulting in recharge through ice melt being delayed.

The Department of Community and Government Services (CGS), Government of Nunavut (GN) retained the services of **exp** Services Inc. (**exp**) to assess the Hamlet's water reservoir capacity and provide lifespan projections, taking into consideration the population growth and water demands of the Hamlet based on a 20 year planning horizon. The assessment was to include a risk analysis for demand versus capacity based upon:

1. Actual water consumption
2. 90 lpcd, and
3. MACA RWU equations

1.1 Background Information

The Hamlet is located on Igloolik Island in the northwest region of the Foxe Basin. Its water source is South Lake which is located in the southern region of the Island and over-winter water storage is provided in an excavated reservoir located near the airport. The Igloolik water reservoir was constructed at the site of a small lake. Over-winter storage was increased through mass excavation to provide a total depth in parts of the lake of approximately 10 m. The reservoir was originally constructed in the late 1970's and there has been two expansions, one in 1993 and one in 1998. The total capacity of the reservoir based on the design brief prepared for the 1998 expansion (Oliver Mangione McCalla) is 79,000 m^3. The Igloolik water reservoir is recharged on a yearly basis with water pumped from South Lake, see Figure 1, Appendix A.

The Hamlet is solely serviced by a trucked water delivery system. The Terms of Reference (TOR) report an estimated annual water usage of 55,000 m^3 and an estimated population of 1780 persons.

2 3 - Dimensional Model of Reservoir

As part of this project a site visit was undertaken from September 16th to September 19th, 2015. During this site visit a detailed survey, including a bathymetric survey, of the water reservoir was undertaken as per the TOR for the project. The survey was completed using a Trimble R8 GPS system for the integration and an Airmar P66 Transducer /Sonar Mite Echo Sounder for the data collection.

The survey data was downloaded into AutoCAD Civil 3D, and a 3 - dimensional model of the reservoir was prepared. A contour plan and cross sections of the reservoir base on the 3 - dimensional model are shown in Figures 2 and 3 in Appendix A. The 3 – dimensional model was used to develop an incremental volume model of the reservoir for use in the drawdown analysis.

It should be noted that at the time of the survey it was impossible to obtain an actual elevation of the intake to the truck-fill station. For the purpose of this report the intake elevation reported in the 1998 Oliver, Mangione, McCalla and Associates' (OMM) report was used. There may be some discrepancies between the reported elevation of the intake and the actual elevation relative to the survey completed in 2015. In addition, the critical elevation, when determining the storage capacity of the reservoir, is actually the elevation of the pump in the intake line which may be different than the elevation of the intake. For the purpose of this report the discrepancy would have to be significant to alter the finding. A difference of as much as 0.3 m only results in a change in storage volume of approximately 1,900 m^3 which in turn is approximately 12 days of consumption for the 2015 population and actual consumption rates from 2014. It is felt that this is within the accuracy of the model and drawdown analysis undertaken for this report. To test this assumption, a drawdown analysis for the winter of 2014/2015 was be performed to determine if it closely represents the events in the spring of 2015. As shown in Section 7.1, this analysis resulted in the reservoir running out of water in late May which closely corresponds to the events of the spring of 2015, it was concluded the 3 – dimensional model provides a good representation of the actual reservoir.

3 Population

The Nunavut Bureau of Statistics publishes the Nunavut Population Projections which provide estimates of the population for all the communities within Nunavut to the year 2035. The published population projection (December 2014) for 2015 is an estimated population of 2039. This value is 15% higher than the population of 1780, reported in the TOR. For the purpose of developing lifespan projections, **exp** proposes to adopt the existing population in 2015 as per the Nunavut Bureau of Statistics as this will provide for a more conservative result. The population projections as per the Nunavut Bureau of Statistics are shown in Table 3.1 below for the years 2014 through to 2045.

A projection of population to 2045 has been developed based on an extrapolation of the estimates developed by the Nunavut Bureau of Statistics. The data provided by the Bureau indicates an annual rate of growth of population of 1.46%. This leads to an estimated population of 3,145 at a 30 year horizon.

Table 3.1 – Population Projections

Year	Population
2014	2007
2015	2039
2025	2377
2035	2721
2045	3145

4 Water Consumption

As per the TOR for this assessment there are 3 water consumption scenarios to be studied. The water consumption scenarios are:

1. Actual water consumption
2. 90 litres per capita per day (lpcd)
3. MACA (Municipal and Community Affairs covering the Northwest Territories) RWU (Residential Water Use)

4.1 Water Consumption Rates Based on Actual Water Consumption Rates

The annual reports for the Hamlet's water licence were obtained through the Nunavut Water Board's public registry. Reported annual consumption, together with the populations from the Nunavut Bureau of Statistics, provides per capita daily consumption. Table 4.1 below summarizes the annual consumption and the per capita daily consumption rates for the years 2012 through 2014.

Table 4.1 – Actual Consumption Rates

Year	Population	Consumption (litres)	Per Capita Daily Consumption (litres)
2012	1906	51,227,919	73.6
2013	1952	53,096,725	74.5
2014	2007	55,085,387	75.2

Based on Table 4.1 above, the consumption rate to be used in the analysis will be 75.2 lpcd as per the most recent reporting for the year 2014.

4.2 Residential Water Usage Rate of 90 lpcd

The General Terms of Reference for the Community Water and Sanitation Services Study, as published by the Department of Municipal and Community Affairs (MACA), Government of Northwest Territories (GNWT) specifies a Residential Water Usage (RWU) for residents serviced by trucked water delivery and sewage pump out collection of 90 lpcd. The General Terms of Reference for the Community Water and Sanitation Services Study provides a series of equations to estimate total per capita water usage for a community which takes into account non-residential water usage. The TOR for this project directs that the second scenario for the risk assessment for the Hamlet's water reservoir will be based solely on the base residential water usage rate of 90 lpcd.

4.3 MACA RWU – The Equations

The General Terms of Reference for Community Water and Sanitation Services Study, as published by the Department of Municipal and Community Affairs (MACA), Government of Northwest Territories (GNWT) has a series of equations based on population, which estimate total water consumption including non-residential usage such as commercial, institutional and industrial activities. The MACA equations are all based on the RWU rates multiplied by a factor which is directly tied to the population of the Hamlet. The RWU for residents serviced by trucked water delivery and sewage pump out collection is specified as 90 lpcd.

The MACA RWU equations are as follows:

Total Community Population	Per Capita Water Usage
0 to 2,000	Residential Rate x (1.0 + 0.00023 x Population)
2,000 to 10,000	Residential Rate x (-1.0 + 0.323 x ln Population)
Over 10,000	Residential Rate x 2.0

Table 4.2 summarizes the consumption rates based on the MACA RWU Equations:

Table 4.2 - Actual Consumption Rates

Year	Population	Per Capita Daily Consumption (litres)
2015	2039	131.5
2025	2377	136.0
2035	2721	140.3
2045	3145	144.1

4.4 Over-Winter Storage

The Hamlet's water reservoir is intended to provide over-winter storage to meet the Hamlet's water consumption requirements. The over-winter storage is typically defined by the period from the first day after recharge is completed to the end of winter. The last day of winter is difficult to quantify as it varies from year to year. One definition is, the first day that exhibits an average daily temperature of above 2^{o} C, followed by 3 consecutive days each one exhibiting a daily average air temperature of 0.5^{o} C. Defining the last day of winter by any such definition enables a historical description of the last day of winter, however it does not provide a prediction of the future dates for design or analysis purposes.

During the site visit it was reported by Hamlet staff that reservoir recharge from the source lake had been completed the week previous to the site visit or around September 7th. This date will be used as the start of the over-winter storage period for the purpose of this report.

In 2015, the water reservoir was reported as not recharged from spring runoff until late June.. For the purpose of this report the date of June 30 will be used for the end of over-winter storage.

Based on over-winter storage starting on September 7th and ending on June 30th, the water reservoir must be able to meet the Hamlet's water consumption requirements for 296 days

4.5 Water Consumption and Storage Requirements

Based on TOR and the description of the 3 water consumption rates detailed above, the yearly total water consumption and over-winter storage requirements for each of the 3 water consumption scenarios were determined and are summarize Table 4.3 below.

Table 4.3 – Storage Requirements

Year	Consumption Rate (lpcd)	Population	Over-winter (m^3)	Yearly Consumption (m^3)
Actual Consumption	75.2	2721	59,953	74,686
90 lpcd	90	2721	71,753	89,385
MACA RWU equations	140.3	2721	111,855	139,341

5 Water Reservoir Storage Requirements

5.1 Fire Storage

The guidelines for Good Engineering Practices published by the GNWT, Public Works and Services – Section 12 Water Storage does not specify a fire storage requirement for seasonal storage facilities such as the Hamlet's water reservoir. However, for trucked systems there are fire storage requirements for short term storage requirements within or near the community, of a minimum of 60,000 litres of fire storage. It is **exp**'s interpretation that this storage requirement is for a refillable storage reservoir and therefore is intended to service a single fire event. **Exp** recommends that a 300,000 litre fire storage be reserved for fire storage which, in essence, would provide the equivalent of 5 fire events per year.

5.2 Freeboard

It is recommended that a one metre freeboard be provided when determining the storage requirements. Based on the topographic information available, the water elevation of the reservoir when full will be assumed to be 50 m.

5.3 Dead Zone

In reviewing the OMM report for the water reservoir expansion from the late 1990's, it was reported that in 1993 an expansion of the facility was undertaken and this expansion was to include the extension of the intake pipe to reduce the dead zone. However, it was reported that the planned extension of the intake did not proceed. Based on the information provided in the OMM report the existing intake elevation is at 43.10 m with a potential extension to lower the intake to 42.45 m. For the purpose of this report and the risk analysis the existing intake elevation of 43.10 m will be assumed.

Based on the 3-dimensional model of the reservoir, the intake elevation of 43.10 m provides approximately 12,000 m^3 of dead storage and the proposed intake elevation of 42.45 m would provide approximately 8,750 m^3 of dead storage.

6 Drawdown Analysis Methodology

6.1 Static Drawdown Analysis

One method of calculating the volume of water available at the storage facility over the winter storage period is to determine the volume of water available under the designed thickness of ice. The designed thickness of ice is the maximum thickness of ice that has developed on the body of water over the winter period. This considered a static method as the depth of ice is considered constant and is a conservative approach to calculating the volume of water available. The static method can be represented by three zones, ice, water and dead storage, the major assumption being that the available water is equal to the volume of water located under the maximum thickness of ice.

6.2 Dynamic Drawdown Analysis

The dynamic drawdown analysis approach recognizes the variability of ice and water consumption rates during the over-winter period. It recognizes that as water is withdrawn from storage on a continuous basis over the winter period, the underside of the ice elevation would also drop on a continuous basis as the water is being withdrawn beneath it. Additionally, the dynamic drawdown approach recognizes that the thickness of the ice cover grows during the winter, which also lowers the underside of ice elevation. The amount that the elevation of underside of ice would drop over a period of time is equal to the drop associated with consumption (the distance equivalent to the volume of water withdrawn divided by the area of the underside of the ice) and the growth in ice thickness combined.

For a dynamic drawdown analysis, the over-winter period is divided into segments, typically monthly, at which time the storage volume lost to ice growth and water consumption is removed from the overall volume, taking into account the variability of ice growth and water consumption rates during the over-winter period. A dynamic drawdown analysis requires the estimation of monthly ice thickness over the course of the winter.

The static approach is conservative as it assumes that the full depth of ice is generated prior to the start of water consumption and therefore it allocates the entire top section of the reservoir as an ice zone. As a typical body of water is bowl shaped and the upper region of the water depth has a much greater volume than the lower region this is deemed to be a conservative approach. The dynamic drawdown approach better represents the loss of available storage through the ice growth being accounted for at the approximate depth it would actually occur. For this reason it is recommended that for this analysis a dynamic drawdown analysis be undertaken on the Hamlet’s reservoir.

The process for calculating the dynamic drawdown analysis is as follows:

1. Establish the incremental time period, typically monthly.
2. Define the area to be used for the initial depth, typically the surface area of the reservoir at the start of the over-winter period.
3. Determine the volume of water withdrawn for an incremental time period (monthly consumption).
4. Determine the depth of water, due to consumption, by dividing the volume from Step 3 by the area in Step 2.
5. Define the ice growth for the incremental time period used in Step 3.
6. Calculate the new underside of ice elevation at the end of the period by subtracting the drop in elevation due to consumption as calculated in Step 4 and the incremental ice growth depth found in Step 5 from the initial depth in Step 1.

7. Repeat steps 2 through 6, substituting the area for the depth calculated in Step 6 for the initial area. Repeat this for each period in the season or until maximum permissible drawdown is reached.

7 Reservoir Drawdown Analysis

7.1 Drawdown Analysis for Winter 2014/2015 – Actual Consumption Rate

A drawdown analysis was completed for the 2014/2015 over-winter period to check the accuracy of the drawdown analysis methodology and bathymetric survey. While on site completing the bathymetric survey it was reported by Hamlet staff that the water reservoir was not completely filled at the start of the 2014/2015 over-winter period. For the drawdown analysis of winter 2014/2015 it was assumed that the water reservoir was at 49.5 m, approximately a ½ m below the elevation noted during the bathymetric survey.

A drawdown analysis, shown in Table 7.1, of the reservoir based on the actual consumption of 75.2 lpcd for the year 2014 and a population of 2007 resulted in an underside of ice elevation of 43.03 m at the start of June. As the intake elevation is at 43.10 m this indicates that the Hamlet would have run out of water sometime in late May 2015. This result closely represents the events of spring 2015 and therefore supports estimated ice growth, the of drawdown analysis methodology and the 3 – dimensional model of the reservoir prepared from the bathymetric survey.

Table 7.1 - Drawdown Analysis

Year: Winter 2014/2015
Consumption: Actual Consumption (75.2 lpcd)
Population: 2007

Month	Underside of Ice (m)	Area (m^2)	Water Use (m^3)	Drop due to Use (m)	Ice Growth (m)
September	49.50	17826	3417	0.19	0.10
October	49.21	16614	4679	0.28	0.40
November	48.53	10914	4528	0.41	0.35
December	47.76	9116	4679	0.51	0.33
January	46.92	8397	4679	0.56	0.28
February	46.08	7852	4226	0.54	0.22
March	45.32	7454	4679	0.63	0.16
April	44.54	7068	4528	0.64	0.10
May	43.79	6679	4679	0.70	0.06
June	43.03		2264		
End of June					

7.2 Drawdown Risk Analysis Winter 2015/2016 with Actual Consumption Rate

A drawdown analysis was undertaken for the winter 2015/2016 based upon the reported population from the Nunavut Bureau of Statistics in 2039, the actual consumption rate of 75.2 lpcd and a full reservoir at the beginning of the over-winter storage period. This assessment utilized the dynamic drawdown analysis for the winter 2015/2016 and is summarized in Table 7.2. The drawdown analysis calculates the depth of water at the end of June to be 43.22 m or 0.12 m above the intake. Although this indicates there is sufficient water to meet the over-winter consumption for 2015/2016, it provides minimal emergency storage for fire protection and is outside the tolerances of the drawdown analysis. Therefore, depending on the starting date for reservoir refill, the Hamlet may currently be at risk of running out of water prior to the start of recharge in the spring of 2016. It is recommended that the water elevations be closely monitored and that measures such as water conservation be implemented.

Table 7.2 - Drawdown Analysis

Year: Winter 2015/2016
Consumption: Actual Consumption (75.2 lpcd)
Population: 2039

Month	Underside of Ice (m)	Area (m^2)	Water Use (m^3)	Drop due to Use (m)	Ice Growth (m)
September	50.00	20102	3527	0.18	0.10
October	49.72	18722	4753	0.25	0.40
November	49.07	16005	4600	0.29	0.35
December	48.43	10519	4753	0.45	0.33
January	47.65	9012	4753	0.53	0.28
February	46.84	8335	4293	0.52	0.22
March	46.11	7870	4753	0.60	0.16
April	45.35	7469	4600	0.62	0.10
May	44.63	7113	4753	0.67	0.06
June	43.90	6738	4600	0.68	
End of June	43.22				

7.3 Drawdown Analysis Winter for 2015/2016 Based on 90 lcpd and MACA RWU Equations

The actual water consumption rate provides the lowest estimate of water use for the three scenarios under consideration. Furthermore, the drawdown analysis for winter 2015/2016, based on the actual consumption rate, revealed that the water reservoir would be essentially empty at the end of June 2016. Therefore it can be concluded that the drawdown analysis based either on 90 lpcd, or using MACA RWU equations for the winter of 2015/2016, would result in the water reservoir not meeting over-winter requirements. Therefore drawdown analysis for the 90 lpcd for the year 2015 and the drawdown analysis based on the MACA RWU equations for the winter of 2015/2016 were not undertaken.

7.4 Drawdown Analysis for Winter 2035/2036 – Actual Consumption

A drawdown analysis was completed for the overwinter period 2035/2036 using the consumption rate of 75.2 lpcd, and a population of 2721 as per the Nunavut Bureau of Statistics. The drawdown analysis revealed that as of the beginning of May 2036 the water elevation would be 43.14 m or just above the intake line of the truck-fill station. Therefore the water reservoir would not meet the over-winter storage requirements of the Hamlet for the winter of 2035/2036 based on the actual consumption rate. It is estimated that the shortfall of over-winter storage would be in the range of 13,000 m^3 of water based on the annual daily consumption rate of 75.2 lpcd.

Table 7.3 - Drawdown Analysis

Year: Winter 2035/2036
Consumption: 75.2 lpcd
Population: 2721

Month	Underside of Ice (m)	Area (m^2)	Water Use (m^3)	Drop due to Use (m)	Ice Growth (m)
September	50.00	20102	4706	0.23	0.10
October	49.67	18520	6343	0.34	0.40
November	48.92	15131	6139	0.41	0.35
December	48.17	9716	6343	0.65	0.33
January	47.18	8622	6343	0.74	0.28
February	46.17	7905	5729	0.72	0.22
March	45.22	7406	6343	0.86	0.16
April	44.21	6900	6139	0.89	0.10
May	43.22	6364	6343	1.00	0.06
June	42.16	5627	6139	1.09	
End of June	41.07				
Totals				6.93	2.00

7.5 Drawdown Analysis Winter 2035/2036 and 90 lpcd

A drawdown analysis was completed for the consumption rate of 90 lpcd, for the year 2035 with a reported population of 2721 as per the Nunavut Bureau of Statistics. The drawdown analysis revealed that as of the beginning of April the water elevation would be 43.21 m or just above the intake line of the truck-fill station. Therefore the water reservoir would not meet the over-winter storage requirements of the Hamlet for the winter of 2035/2036 based on a consumption rate of 90 lpcd. It is estimated that the shortfall of over-winter storage would be in the range of 23,000 m^3 of water based on the annual daily consumption rate of 90 lpcd.

Table 7.4 - Drawdown Analysis

Year: Winter 2035/2036
Consumption: 90 lpcd
Population: 2721

Month	Underside of Ice (m)	Area (m^2)	Water Use (m^3)	Drop due to Use (m)	Ice Growth (m)
September	50.00	20102	5632	0.28	0.10
October	49.62	18317	7582	0.41	0.40
November	48.81	13644	7247	0.54	0.35
December	47.92	9293	7582	0.82	0.33
January	46.77	8282	7582	0.92	0.28
February	45.57	7578	6857	0.90	0.22
March	44.45	7022	7582	1.08	0.16
April	43.21	6359	7247	1.16	0.10
May	41.95	5448	7582	1.39	0.06
June	40.50		7247		
End of June					

7.6 Drawdown Analysis for Winter 2035/2036 using MACA RWU Equations

A drawdown analysis was completed for the consumption rate based on the MACA RWU equations, for the year 2035 with a reported population of 2721 as per the Nunavut Bureau of Statistics. Based on this population a daily consumption rate of 140.3 lpcd was calculated. The drawdown analysis revealed that that at the beginning of February the underside of ice elevation would be 43.24 m or 0.14 m above the intake elevation. Therefore the water reservoir would not meet the over-winter storage requirements of the Hamlet for the winter of 2035/2036 based on a consumption rate from the NACA RWU equations. It is estimated that there would be an over-winter storage shortfall of about 52,000 m^3 of water under these service conditions.

Table 7.5 - Drawdown Analysis

Year: Winter 2035/2036
Consumption: MACA RWU (140.3 lpcd)
Population: 2721

Month	Underside of Ice (m)	Area (m^2)	Water Use (m^3)	Drop due to Use (m)	Ice Growth (m)
September	50.00	20102	8789	0.44	0.10
October	49.46	17660	11834	0.67	0.40
November	48.39	10364	11453	1.11	0.35
December	46.94	8412	11834	1.41	0.33
January	45.20	7396	11834	1.60	0.28
February	43.32	6422	10689	1.66	0.22
March	41.44	4887	11834	2.42	0.16
April			11453		0.10
May			11834		0.06
June			11453		
End of June					

8 Hydrological Analysis of South Lake

8.1 General

The Hamlet's water reservoir is replenished from South Lake, located 1.7 km to the south of the reservoir. As part of their Risk Assessment Analysis CGS has requested **exp** to examine the ongoing capability of South Lake to supply water to meet the long term requirements of Hamlet. The Technical Memorandum which examines this issue is included as Appendix B. The following is a summary of the findings of that Technical Memorandum.

8.2 Water Consumption Scenarios

For the purpose of this analysis, South Lake's ability to supply the needs of the Hamlet were examined for 3 water consumption scenarios, (actual water consumption rates, RWU of 90 lpcd, and MACA RWU equations) and 3 planning horizons (2025, 2035 and 2045). A summary of the yearly water consumption for the 3 scenarios and 3 planning horizons, based on the population projects as shown in Section 3 and the consumption rates calculated in Section 4.3, is shown in Table 8.1 below:

Table 8.1 - Summary of Yearly Consumption Rates

Year	Population	Actual Consumption (m^3)	RWU – 90 lpcd (m^3)	MACA RWU Equations (m^3)
2025	2,377	65,200	78,000	118,000
2035	2,721	74,700	89,400	139,300
2045	3,145	86,300	103,300	165,400

8.3 South Lake Water Supply

8.3.1 Background Information

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 in the preparation of the Hydrological Analysis of South Lake. Table 8.2 summarizes the estimated watershed area and yield for Rankin Inlet, Iqaluit and Resolute Bay.

Table 8.2 – Typical Watershed Yield

Community	Watershed Area (ha)	Estimated Annual Yield (m^3)	Runoff (mm)	Comment
Rankin Inlet	323	311,789	97	32% of annual average precipitation
Iqaluit	385	485,000	126	60% of 1:100 low precipitation
Resolute Bay	425	166,000*	39	50% of lowest observed annual precipitation

* Based upon lowest observed total annual precipitation for the period 1948 to 2011.

8.3.2 South Lake Watershed

The 1:50,000 mapping by Natural Resources Canada provides full coverage of Igloolik Island, including the watershed draining into South Lake. The watercourse and contour information from this mapping was the principal data source for the development of the estimate of the watershed limits. The South Lake watershed has an area of 213 ha and the surface area of South Lake is 17 ha.

8.3.3 Climatic Data

Climate data from Environment Canada provides information for 2 stations in Igloolik, the airport and the research centre. As an initial observation it was noted that there are significant differences between the observations at the Airport and those at the Research Institute. The stations are separated by a short distance, and it is very likely that they share the same climate. The variation between the observations at these stations is probably the result of local conditions at each station. Without an assessment of each station by a specialist in the siting of meteorological instruments it is impossible to present an opinion regarding the comparative validity of the observations at each site.

It must be recognized that ongoing access to a reliable supply of water is essential for the habitability of a community. Thus, conservative assumptions regarding watershed inputs are appropriate. On this basis the data for the airport was used in the assessment. Table 8.3 summarizes information extracted from the monthly data.

Table 8.3 - Climatic Data (Airport)

Total Precipitation (mm)	
• Mean	228.2
• Minimum	165.9
• Maximum	362.4
• Standard Deviation	55.3
• Years of useable data	17
Total snowfall (cm)	
• Mean	138.2
• Minimum	99.7
• Maximum	231.6
• Standard Deviation	40.9
• Years of useable data	17

8.3.4 South Lake Watershed Yield Estimate

There is little definitive data, aside from the watershed area, available for Igloolik. Previous assessments of some watersheds in Nunavut have assumed that 50% to 60% of the annual total precipitation appears as runoff. For the purpose of this estimate of watershed yield it will be assumed that runoff will represent 40% of annual total precipitation.

The estimate of watershed yield is based upon the following assumptions.

- Watershed area 213 ha
- Minimum annual total precipitation 166 mm
- Ratio of annual yield to annual total precipitation 40%

Based upon the above assumptions the watershed yield to South Lake is estimate to total 141,000 m^3. No evaporation data is available for either climate data station in Igloolik. Lake evaporation data for Resolute Bay from a previous study is reported as 8.2 mm. This allowance, applied to the surface area of South Lake of 17 ha leads to an annual loss of 1,400 m^3. This reduces the net quantity of water available to the community to 140,000 m^3 annually.

The estimated watershed yield meets the 3 planning horizons for the Actual Water Consumption and RWU (90 lpcd) scenarios. For the purpose of long term planning the most appropriate water consumption scenario to utilize is the one based on the MACA RWU equations. For this scenario the estimated watershed yield is less than the long term projected community consumption of 165,000 m^3 in 2045 (30 year horizon) by a margin of 15%. This estimated watershed yield is equal to the mid-term projected community consumption of 140,000 m^3 in 2035 (20 year horizon). The estimated watershed yield exceeds the community near term annual water requirements of 118,000 m^3 in the year 2025 (10 year horizon) by a modest allowance of 20%.

9 Summary

The following summarizes the findings of this report:

1. The 3 – dimensional model created based on the bathymetric survey undertaken as part of this project estimated the total volume in the water reservoir of approximately 79,600 m^3 of water. The total volume reported in the 1998 OMM report, which was prepared for the previous expansion of the reservoir, reported a 66,400 m^3 capacity and recommended a 12,600 m^3 expansion for a total volume of approximately 79,000 m^3. As the model prepared based on the bathymetric survey from September 2015 closely corresponds to that, the anticipated volume from the OMM report, it is believed the bathymetric survey and model created provide a relatively accurate representation of the Hamlet's water reservoir.
2. It was impossible to obtain an actual elevation of the intake to the truck-fill station at the time of the survey. For the purpose of this report the intake elevation reported in the 1998 OMM report was used. As there may be a discrepancy between the reported elevation and the actual elevation relative to the survey completed in 2015, it is recommended that the elevation of the intake pump relative to the 2015 survey, be obtained.
3. A drawdown analysis for the winter 2014/2015 revealed the Hamlet would have expected to run out of water in June 2015. As this corresponds to the events of the spring of 2015 it provides confirmation of the model of the reservoir from the survey, and the methodology used in the drawdown analysis.
4. A drawdown analysis was undertaken for the winter 2015/2016 based on the actual consumption rates from 2014 and a full reservoir. The drawdown analysis revealed that there would be minimal water available in the reservoir at the end of June 2016. This does not account for maintaining fire storage and it is believed that the results are outside the accuracy of the drawdown analysis and model of the reservoir.
5. The drawdown analysis for winter 2015/2016, based on 90 lpcd and the MACA RWU equations was not undertaken as, these represent significantly higher water consumption rates than those reported for 2014. Therefore it can be concluded that the water reservoir would not meet the over-winter storage requirements for the Hamlet based on either the 90 lpcd or the MACA RWU equations for the winter 2015/2016.
6. A drawdown analysis was undertaken for the 3 water consumption alternatives for the winter 2035/2036. In all 3 scenarios the water reservoir had a significant shortfall in over-winter storage as summarized in Table 9.1, and would not be able to meet the requirements of the Hamlet.

Table 9.1 - Summary of Drawdown Analysis Winter 2035/2036

Scenario	Estimated Shortfall In Storage
Actual Consumption Rates (75.3 lpcd)	13,000 m^3
RWU (90 lpcd)	23,000 m^3
MACA RWU (140.3 lpcd)	58,000 m^3

7. An examination of South Lake's ability to supply the Hamlet water for the 3 water consumption scenarios, and 3 planning horizons showed that it could meet all the scenarios with the exception of the long term (30 years) with consumption rates based on MACA RWU equations.

Appendix A – Figures

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SCALE NOT TO SCALE DATE October 15	PROJECT IGLOOLIK WATER RESERVOIR RISK ASSESSMENT		PROJECT No. 228482
CAD SAB	TITLE SITE PLAN		DRAWING No. FIG.1

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SCALE	PROJECT	PROJECT No.
1:750	IGLOOLIK WATER RESERVOIR RISK ASSESSMENT	228482
DATE: October 15	TITLE	DRAWING No.
CAD: JMc	RESERVOIR PLAN	FIG.2

TBM–NAIL ADJACENT TO POWER POLE
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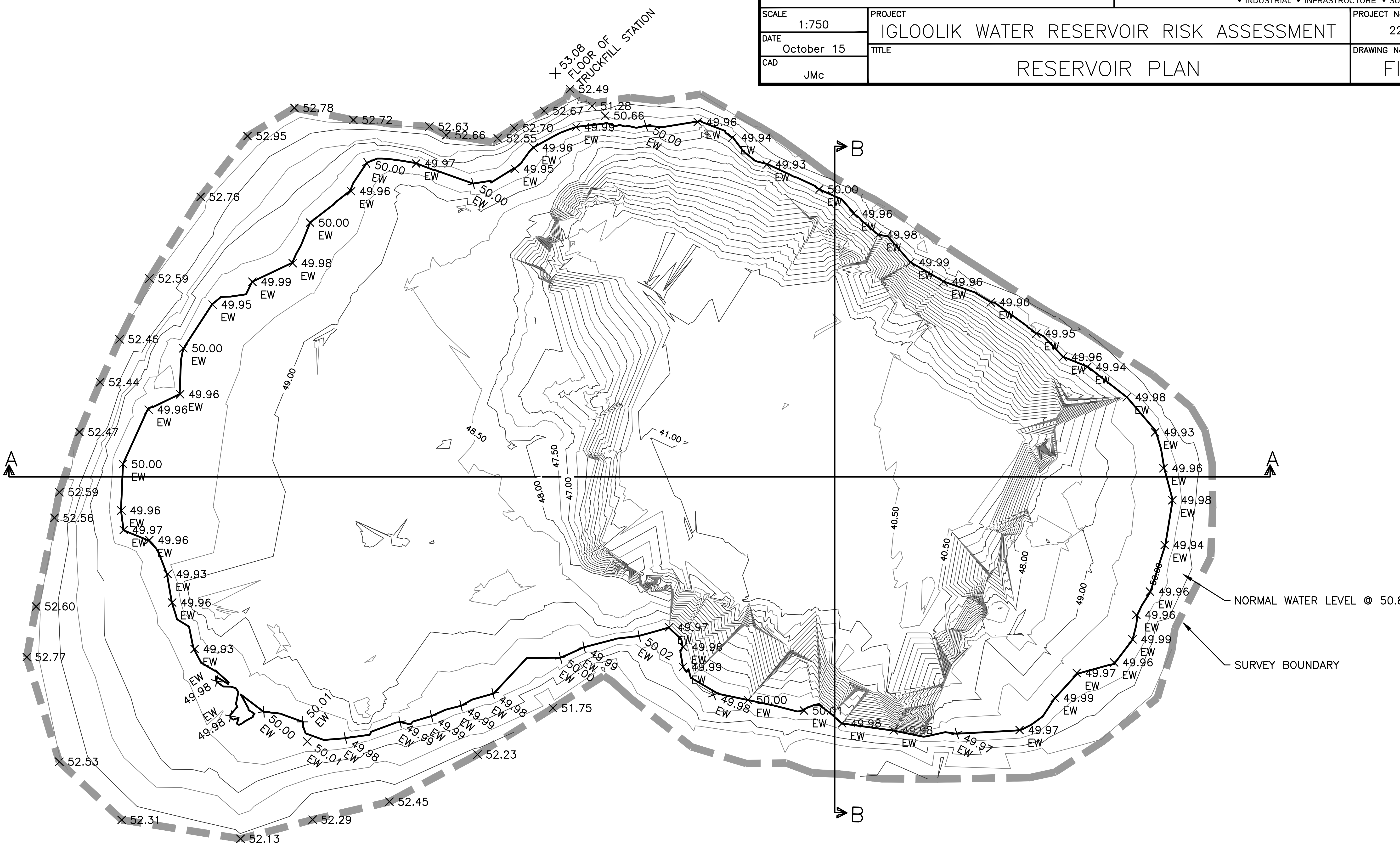
E: 467345.22
ELEV 52.90



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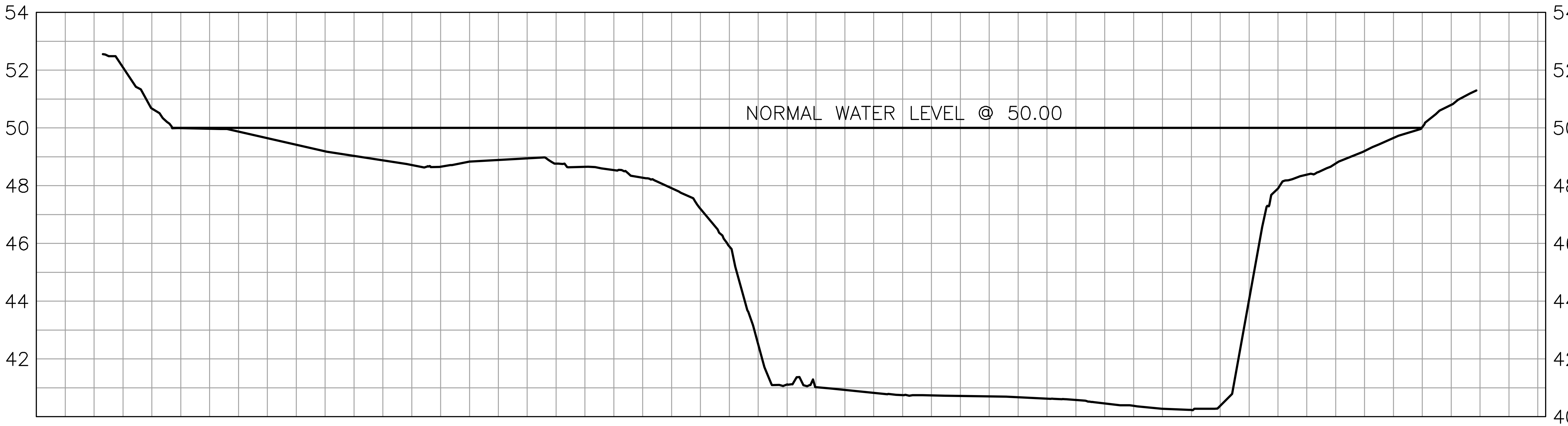
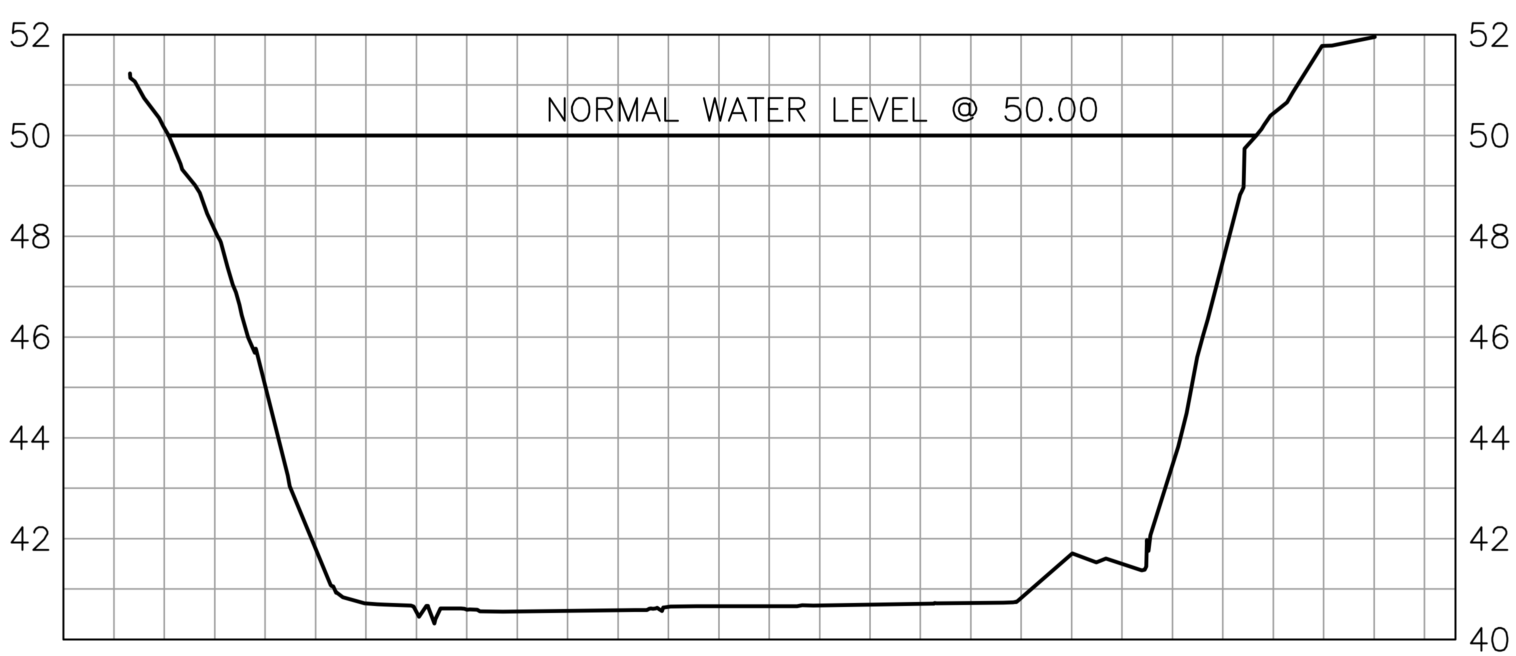
A–A



B–B



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DATE October 15		
CAD JMc	TITLE RESERVOIR SECTIONS	DRAWING No. FIG.3

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Appendix B – Technical Memorandum

Memorandum

Date:	October 15, 2015		
Project Name:	South Lake Igloolik Hydrology Study	Project #:	OTT-00228428-A0
Subject:	Technical Memorandum – Potential Watershed Yield		
Prepared By:	D. Farrell McGovern		

1. Introduction

The over-winter water requirements for the Hamlet of Igloolik (Hamlet) are provided from a man-made reservoir situated adjacent to the airport. This reservoir is replenished from a lake, often referred to as South Lake, located 1.7 km to the south, at a location depicted on Figure 1. The Department of Community and Government Services of the Government of Nunavut has retained **exp** Services to examine the ongoing capability of South Lake to supply water to meet the long term requirements of Hamlet. This assessment does not examine the over-winter storage or truck-fill capabilities in the community. The following memorandum provides a summary of this review, which includes:

- A review of related studies;
- Delineation of the water source watershed;
- Definition of long term (30 year) water requirements for the community;
- Definition of near-term and mid-term (10 and 20 year) water requirements for the community;
- An examination of climatic data; and,
- An estimate of the watershed yield.

2. Related Studies and Background Information

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.
- 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
  - Char Lake Pump House Design Brief, exp Services, November, 2012.
  - Technical Memorandum on Char Lake Hydrology Study, exp Services, August 25, 2014.
- Nunavut Bureau of Statistics
  - Nunavut Population Projections.

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 South 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 South Lake, the comments regarding topographic data sources and intensity of runoff during spring freshet provide useful guidance.

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) provides the following:
  - Average water resupply to Nipissar Lake as 311,789 m^3.
  - Current water consumption of 469 litres per capita per day leads to an annual requirement of 427,791 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.

- Climatic conditions in Rankin Inlet vary from those that arise in Igloolik.
- 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.

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 between 0.467 and 1.038, with an average of 0.772.
- The average ratio of annual runoff to annual precipitation for the Sylvia Grinnell River was calculated as between 0.790 and 1.070, with an average of 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.

Resolute Bay

The Operations and Maintenance Manual for the existing water and sewer system provides an estimate of the Char Lake drainage area of 4.40 km^2 (440 ha).

The Design Brief it is reports that the Char Lake water supply must be capable of supporting an ongoing demand of 4.06 litres per second, or 129,000 m^3 per year.

The review of the sustainability of Char Lake estimates the yield from the 425 ha watershed for the lowest observed annual precipitation as 166,000 m^3.

Nunavut Bureau of Statistics

The Nunavut Population Projections provides estimates of the population for all of the communities of Nunavut to the year 2035. The population in Igloolik at the end of this 30 year period is estimated as 2,721. The population projection data has been extrapolated to provide an estimate to the end of the planning period in 2045. The Nunavut Bureau of Statistics provides a population estimate in 2014 of 2,007 and a projection to the year 2035 of 2,721. This represents an annual population growth rate of 1.46%. Extrapolation of the population projection to 2045 leads to a population of 3,145 and the end of the 30 year planning horizon. The near-term (10 year) population projection is 2.377. The following table summarizes the various estimates of population.

Year	Population
2025 (10 year)	2,377
2035 (20 year)	2,721
2045 (30 year)	3,145

Nunavut Water Board

The annual reports for the Water Licence, as found on the Public Registry of the Nunavut Water Board, were reviewed. The annual consumption, as provided in these reports is as follows.

Year	Annual Consumption (L)
2012	51,227,919
2013	53,096,725
2014	55,085,387

Summary of Related Studies and Background Information

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

- All of the annual precipitation provides some contribution to the recharge of South Lake. Spring runoff represents a large portion of annual runoff.
- 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 average values of this ratio for the Apex and Sylvia Grinnell Rivers were 0.772 and 0.898 respectively.
- The following table summarizes the estimated watershed area and yield for Rankin Inlet, Iqaluit and Resolute Bay

Community	Watershed Area (ha)	Estimated Annual Yield (m^3)	Runoff (mm)	Comment
Rankin Inlet	323	311,789	97	32% of annual average precipitation
Iqaluit	385	485,000	126	60% of 1:100 low precipitation
Resolute Bay	425	166,000*	39	50% of lowest observed annual precipitation

* Based upon lowest observed total annual precipitation for the period 1948 to 2011.

- The estimated population in Igloolik at the end of a 30 year horizon (in 2045) is 3,145.
- The estimated mid-term population is 2,377 and 2,721 at 10 and 20 years respectively;
- The following table summarizes current per capita water, based upon the water license annual reports.

Year	Population	Annual Consumption (L)	Per Capital Daily Consumption (L)
2012	1,906	51,227,919	73.6
2013	1,952	53,096,725	74.5
2014	2,007	55,085,387	75.2

3. South Lake Watershed

General

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

- The potential for South Lake to meet the long term needs of the community will be determined.
- The water source must be capable of meeting the needs of a population at the end of a 30 year planning horizon.
- Estimates of water source recharge must be conservative, especially in view of the essential nature of a sustainable water supply.

Data Gathering

The following data sources were identified:

- Government of Nunavut digital topographic mapping of the Hamlet of Igloolik.
- National Topographic System Mapping in the scale of 1:50,000 (Sheet 47-D/7).
- Google Earth images of Igloolik Island.

Data Review

The Government of Nunavut mapping in the scale of 1:2,000 does not provide coverage of South Lake or the watershed to South Lake.

The 1:50,000 mapping provide full coverage of Igloolik Island, including the watershed draining into South Lake. This mapping by Natural Resources Canada, which was produced in July 2010, incorporates confirmations of the road network in 2006 and the hydrographic network in 2002. This mapping is felt to be appropriate for the delineation of the watershed to South Lake. The watercourse and contour information from this mapping was the principal data source for the development of the estimate of the watershed limits.

Google Earth images have been reviewed to confirm the watershed limits.

Findings

The attached Figure 1 depicts the limits of the watershed draining to South Lake. This watershed has an area of 213ha. The surface area of South Lake is 17 ha.

4. Community Water Supply Requirements

An estimate of the near-term (10 year), mid-term (20 year) and long-term (30 year) water requirements has been developed.

The Nunavut Municipal Infrastructure Capital Standards and Criteria (April, 2012) direct that water consumption be calculated based upon historical use, or a minimum of 90 lpcd. It should be noted that this is described as the minimum demand and the allowance of 90 lpcd does not include an allocation for non-residential uses including commercial, institutional or industrial water use.

The criteria provided in the Water and Sewage Facilities Capital Program Standards and Criteria, published by MACA, GNWT in July 1993 provide a design value for average residential water consumption (RWU) for communities with trucked water and sewer services of 90 lpcd. These criteria direct an adjustment to provide for other water uses included institutional and commercial consumption. The following formula is recommended for communities with populations between 2,000 and 10,000.

Total Community Consumption = RWU x [-1.0 + (.323 ln(Population)]

It is noted that, based upon annual reporting to the Water Board, current unit water consumption is approximately 75 lpcd. This is significantly lower than both the minimum demand provided in Capital Standards and Criteria and the criteria of MACA, GNWT. This variation between reported and predicted demand is the result of a list of issues including delivery system capabilities, building water tanks size and average household population. It is likely that there will be improvements, over the long term, in these factors that constrain water use. In that this purpose of this evaluation is to estimate long term water demands, the water consumption estimates, as provided by the MACA, GNWT formula will be assumed.

For the long term planning horizon (30 years) population of 3,145 a community wide average per capita water consumption of 144 lpcd is estimated. This in turns leads to an average day water requirement of 453,000 litres. On an annual basis this represents a requirement of 165,000 m^3 in the year 2045.

For the mid-term planning horizon (20 year) population of 2,721 a community wide average per capita water consumption of 140 lpcd is estimated. This in turns leads to an average day water requirement of 381,000 litres. On an annual basis this represents a requirement of 139,000 m^3 in the year 2035.

For the near-term (10 year) population of 2,377, per capita water consumption is estimated as 136 lpcd. This in turns leads to an average day water requirement of 323,000 litres. This leads to an annual water requirement of 118,000 m^3.

5. Climatic Data

Climate data from Environment Canada provides information for 2 stations in Igloolik, the airport and the research centre. This data takes the following forms.

- Canadian Climate Normals 1981-2010 for both stations.
- Monthly summaries for the Igloolik Research Institute for the period 1977 to 2002.
- Monthly summaries for Igloolik Airport for the period 1984 to 2007.

Canadian Climate Normals

The following table summarizes the data provided from the Canadian Climate Normals

Station	Rainfall (mm)	Snowfall (cm)	Total Precipitation (mm)
Airport	86.9	136.2	222.4
Research Institute	101.3	173.3	274.8

It is noted that there is a significant variation in the Normals reported for the Airport and the Research Institute. It is further noted that these sites are separated by approximately 1 km. The resolution of this variation falls outside the scope of this investigation.

Monthly Observations

Monthly summaries of rainfall, snowfall and total precipitation have been obtained for the Airport and Research Institute stations. The following table summarizes information regarding the extent and completeness of this data.

Station	Period	Years with Incomplete Data	Period of Useable Data
Airport	1984 to 2007	1984 to 1988, 2001, 2007	17 years
Research Institute	1977 to 2003	1977, 1978, 1984, 1997, 2003	22 years

The following table summarizes information extracted from the monthly data.

	Airport	Research Institute
Total Precipitation (mm)		
• Mean	228.2	283.2
• Minimum	165.9	194.3
• Maximum	362.4	399.3
• Standard Deviation	55.3	57.8
• Years of useable data	17	22
Total snowfall (cm)		
• Mean	138.2	177.5
• Minimum	99.7	126.4
• Maximum	231.6	252.6
• Standard Deviation	40.9	39.7
• Years of useable data	17	22

As an initial observation it is noted that there are significant differences between the observations at the Airport and those at the Research Institute. The stations are separated by a short distance, and it is very likely that they share the same climate. The variation between the observations at these stations is probably the result of local conditions at each station. Without an assessment of each station by a specialist in the siting of meteorological instruments it is impossible to present an opinion regarding the comparative validity of the observations at each site.

It must be recognized that ongoing access to a reliable supply of water is essential for the habitability of a community. Thus, conservative assumptions regarding watershed inputs are appropriate. On this basis the data for the airport will be used in this assessment.

5. South Lake Watershed Yield Estimate

There is little definitive data, aside from the watershed area, available for Igloolik. Previous assessments of some watersheds in Nunavut have assumed that 50% to 60% of annual total precipitation appears as runoff. For the purpose of this estimate of watershed yield it will be assumed that runoff will represent 40% of annual total precipitation.

The estimate of watershed yield is based upon the following assumptions.

- Watershed area 213 ha
- Minimum annual total precipitation 166 mm
- Ratio of annual yield to annual total precipitation 40%

Based upon the above assumptions the watershed yield to South Lake is estimate to total 141,000 m^3. No evaporation data is available for either climate data station in Igloolik. Lake evaporation data for Resolute Bay is reported as 8.2 mm. This allowance, applied to the surface area of South Lake of 26 ha leads to an annual loss of 2,100 m^3. This reduces the net quantity of water available to the community to 139,000 m^3 annually. The following table provides a comparison between estimated watershed yield and project community consumption for the date horizons considered in this study.

Year	Watershed Yield (m^3)	Project Consumption (m^3)
2025	139,000	118,000
2035	139,000	139,000
2045	139,000	165,000

Projected watershed exceeds estimated community demand in the near term. Yield and consumption intersect at a point that is approximately 20 years into the future.

6. Anecdotal Observations

Refill of the community reservoir has generally been successfully achieved, without emptying the source lake, since construction of the first phase of this reservoir in the late 1970s. Thus there is an ongoing demonstration of the ability of the watershed to provide sufficient water to meet the current needs of the community. Recent issues with water supply appear to be related to reservoir volume and completeness of reservoir refill, both of which fall outside this assessment.

The current success with securing sufficient supply does not guarantee into the future the continuing ability to obtain sufficient water for over-winter needs.

7. Summary

The principal 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 60%.
2. The estimated population at the end of the 30 year planning horizon is 3,145. The population is estimated at 2721 for the mid-term horizon of 2035 and 2,377 for the near-term horizon of 2025.
3. Annual water consumption at the end of a 30 year planning horizon is estimated to total 165,300 m^3.
4. Annual water consumption in the year 2035 is estimated as 139,000 m^3.
5. Annual water consumption in the year 2025 is estimated as 118,000 m^3.
6. The area of the watershed draining to South Lake has been estimated as 213 ha. The surface area of South Lake is estimated at 26 ha.
7. Precipitation data has been identified for 2 climatic stations in Igloolik. Significant differences were noted for the data for these stations.
8. In view of the essential nature of access to a water supply for ongoing habitability of a community conservatives estimates of potential precipitation have been assumed. On this basis the analysis has been conducted using data from the Airport climatic station.
9. The lowest observed total annual precipitation is reported as 166 mm.
10. A watershed yield estimate has been developed based upon annual runoff of 40% of total annual precipitation. This assumption is based upon experience in other communities.
11. An allowance of lake evaporation has been developed based upon data obtained for Resolute Bay.
12. Runoff, net of evaporation from South Lake is estimated at 139,000 m^3.
13. Estimated runoff represents 85% of the water demands at the end of the planning period (2045).
14. The estimate of runoff for South Lake exceeds the 10 year (2025) estimated community water requirements by a small margin.
15. It is estimated that consumption and watershed yield will intersect at the 20 year horizon.

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DATE October 15	TITLE LOCATION PLAN	DRAWING No. FIG.1
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DATE October 15	TITLE WATERSHED AREA	DRAWING No. FIG.2
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