CITY OF IQALUIT
RAW WATER SUPPLY
AND
STORAGE REVIEW

Prepared for:
City of Iqaluit
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Executive Summary

Trow Associates Inc. (Trow) was retained by the City of Iqaluit to conduct a review of the City's raw water supply and storage. The objective of this report is to determine if the water needs of the City can be reliably met over a 20-year design horizon especially during the over-winter period when no alternative water source is available. Alternative supply and storage schemes are presented and evaluated with a preferred solution being selected based on the operational desirability of a simple, cost-effective, low-risk solution.

Current and projected population and consumption rates are discussed based on information provided by the City of Iqaluit and previous studies. Population growth to 12,000 and increased consumption rate up to 400 litres per person per day has been considered for subsequent 20-year design calculations.

Included in this report is a summary of the Lake Geraldine Watershed climate and hydrological data as well as a discussion of the basin runoff ratio and watershed yield.

Total yearly runoff from the Lake Geraldine Basin is approximately 968,000 cubic metres based on a runoff ratio of 0.60 and an average yearly total precipitation of 419 mm. This is less than the total accessible storage volume of the reservoir which is approximately 1,076,000 cubic metres. Runoff from the basin could be reduced to 785,000 cubic metres in the case of a 5-year low total precipitation and to 485,000 cubic metres in a 100-year low total, both of which are below the storage capacity of the reservoir. Therefore, a 5-year low runoff return frequency will result in a water shortage during the over-winter period. Furthermore, based on the current consumption rate (241 litres per person per day) and 20-year design population of 12,000, runoff from the contributing basin will not be sufficient to meet the City's yearly demand based on a runoff coefficient of 0.60.

Three general categories of alternatives that are considered to address storage and supply issues include: increase storage and supplement recharge, augment from second source, and utilize a second storage. The preferred general category is to increase the storage at the Lake Geraldine Reservoir and provide supplementary recharge as required to meet demand over a 20-year design period.

In terms of increasing storage, the two alternatives considered are excavation to provide additional volume in Lake Geraldine, and raising of the existing dam. With respect to refill alternatives, four proposed alternative withdrawal sites are also discussed. Included in this report is an analysis of Lake Geraldine volume and freeze depth as it relates to storage in the existing reservoir. The cost of each storage alternative as well as associated capital works, risks and operations and maintenance is discussed. Raising of the dam by 2 metres is selected as the preferred storage alternative with a capital cost of approximately $1.9 million.

The issue of reservoir refill is further addressed in this report. The volume required to meet the 20-year design horizon is discussed as are each of the withdrawal point and transmission pathway alternatives. Selection criteria include water quality, capital works, risks and operations and maintenance. A withdrawal point located approximately 270 metres south-east of the Road to Nowhere is selected as the preferred withdrawal point to address long-term refill needs. The capital cost of installing works to satisfy refill demands is estimated to be $920,000. This withdrawal point is also recommended as a suitable location for temporary works installed to address short-term needs.

Preliminary design of works to address storage needs via raising of the dam and works required to address reservoir refill should begin immediately. The City must establish a monitoring protocol in the short term whereby snow accumulation and yearly precipitation trends are recorded then reviewed and impacts on water supply are forecasted. Based on this information, total spring runoff from the contributing basin can be estimated and subsequent actions to supplement this runoff can be established if required. Interim temporary works to address short-term refill needs should be installed at the same location and following the same transmission pathway as the preferred permanent alternative. The City should also promote public awareness of the importance of water conservation to reduce growth in demand.

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References

City of Iqaluit Draft General Plan, Prepared by Fotenn Consultants Inc., September 2002

Sewage Treatment Plant Investigation, Prepared by Earth Tech Canada Inc., December 2002

Municipality of Iqaluit – Water Treatment Plant and Treated Water Storage Expansion Planning Brief (3rd Draft), Prepared by Reid, Crowther & Partners Ltd., January 1994

Municipality of Iqaluit Lake Geraldine Storage Study Report, Prepared by Oliver, Mangione & McCalla and Assoc. Ltd., April 1995

Municipality of Iqaluit Raw Water Intake Upgrade Design Brief, Prepared by Reid, Crowther & Partners Ltd., May 1998

General Terms of Reference for Community Water and Sanitation Services Studies, MACA, 1986.

Frobisher Bay Water Supply Study Phase I, Lake Geraldine Water Supply, Oliver, Mangione, McCalla & Associates Limited, 1984.

Town of Iqaluit Water and Sewer Study, Reid Crowther & Partners Ltd., June, 1989.

1.0 Introduction

The issue of sufficient water supply volume has been most recently raised in the Water and Sewer Study of 2001 prepared by Trow. This question was first studied in detail by Trow in 1984 following the loss of water supply that induced raising the dam. At that time, the question of watershed yield was considered. The question was again reconsidered in 1994 when the dam was raised to further increase water storage. As stated in the Water and Sewer Study, current water consumption is approximately 27 percent of the precipitation that falls on the watershed which supplies Lake Geraldine. The relationship between precipitation, yearly return frequency and total runoff contribution to the reservoir must be clearly understood to forecast the timing of future shortages and to alleviate such stresses to the City's water supply in advance of such occurrences.

1.1. Scope of Study

The need over a twenty-year planning horizon for an additional water source will be examined. Thus, this report must address the broad areas of the location of a suitable supply; determination of over-winter storage needs; and, the determination of the time frame for this need to assure continued supply and to permit appropriate capital planning. The objectives of this report may be summarized as follows:

- Determine if the water needs of the City can be reliably met over a 20-year design horizon especially during the over winter period when no alternative water source is available.
- The scope of the actions required to procure an appropriate source and storage must be identified. This may include additional storage, transmission, pumping and inlet works.
- The implications upon raw water quality and treatability must be considered.
- The time frame for action must be identified and any opportunities for staging of these actions must be considered.
- Cost estimates must be developed to permit planning on the part of the City for these capital requirements.

In addition to the obligation that the water supply improvements respond to the annual water needs of the City, the Project Team must also recognize the following considerations:

- The risk to success arising from the year-to-year variations in precipitation.
- The undesirability of dependence upon equipment that may become remote or not accessible during the winter season.
- The operational desirability of a simple solution.

- The preference to stage actions, and thus stage spending, for the construction of additional storage and transmission infrastructure, if such is possible.

This report will respond to the objectives and desirable technical features which have been outlined above.

2.0 Population and Demand

2.1. Population

The current population of Iqaluit is reported by The Director of Engineering and Planning to be approximately 6,200 people. In forecasting future population growth in the City, three growth rates have been assumed representing low, medium and high projections. A 20-year design period beginning in 2003 has been used for forecasting purposes in this report.

The Conference board of Canada concluded that Nunavut's population could be expected to grow by an average of 2.32% compounded annually over the next 20 years (City of Iqaluit Draft General Plan – September 2002). This growth rate will be considered at the low end of the projections used in this report.

The medium projection used in this report is based on the GN Bureau of Statistics' projections in 1998 that projected a population growth between 2000 and 2005 of 3.5%, falling to approximately 3.0% between 2006 and 2015, then 2.5% annually from 2016 to 2020. This growth rate will be considered as a medium projection in this report.

The City of Iqaluit currently has a population of 6,200 people. The city estimates that the population will increase to 12,000 by 2023 (City of Iqaluit). This represents an annual growth rate of 3.36% which is considered at the high end of the projections used in this report.

Table 1 summarizes population projections using the various growth rates listed above for the 20-year design period.

2.2. Demand

The following consumption rates have been used in previous studies for the City of Iqaluit:

- Frobisher Bay Water Supply Study Phase I, Lake Geraldine Water Supply (OMM & Associates Ltd. 1984) – piped residential consumption 200 lpcd; consumption for all uses including bleeds 350 lpcd.
- General Terms of Reference for Community Water and Sanitation Services Studies, MACA, 1986 – terms of reference established the design value for residential water use as 225 lpcd. To account for all uses, consumption was established as 450 lpcd (residential rate X 2) for populations of greater than 10,000.
- Town of Iqaluit Water and Sewer Study (Reid Crowther and Partners Ltd., June, 1989) – average consumption in 1988 reported as 570 for all demands including bleeds.
- City of Iqaluit Water and Sewer Study (Trow Consulting Engineers Ltd., May 2002) – average per capita demand for trucked and piped services were estimated to be 123 lpcd and 277 lpcd, respectively.

Table 1 - Population Projections

Year	Low Growth Projection	Medium Growth Projection	High Growth Projection
2003	6.200	6.200	6.200
2004	6,344	6,417	6,408
2005	6,491	6,642	6,624
2006	6,642	6,841	6,846
2007	6,796	7,046	7,076
2008	6,953	7,257	7,314
2009	7,115	7,475	7,560
2010	7,280	7,699	7,814
2011	7,449	7,930	8,076
2012	7,621	8,168	8,348
2013	7,798	8,413	8,628
2014	7,979	8,666	8,918
2015	8,164	8,926	9,218
2016	8,354	9,149	9,527
2017	8,548	9,378	9,848
2018	8,746	9,612	10,178
2019	8,949	9,852	10,520
2020	9,156	10,099	10,874
2021	9,369	10,351	11,239
2022	9,586	10,610	11,617
2023	9,808	10,875	12,007

In the present study, a consumption rate of 400 litres per capita day will also be applied to calculations regarding forecasting of future growth and associated consumption trends for the City of Iqaluit. This represents a conservative estimate for future planning as per comments from the Director of Engineering and Planning for the City of Iqaluit.

The City of Iqaluit provided water consumption records for the months of January and February, 2003. Both piped and trucked water consumption was provided as well as total commercial, industrial, and residential consumption as summarized in Table 2.

Based on the 2 months of record provided by the City, the average water demand for both piped and trucked water supply is 241 litres per capita per day. This consumption rate will be applied to further calculations as it represents a realistic average rate consumption and because the reservoir provides for long term averaging. Summarized in Table 3 is the estimated water consumption based on the high population growth projection and a consumption rate of 241 lpcd. Also summarized in Table 3 is the estimated daily consumption demand based on the high population growth projection and a high consumption rate of 400 lpcd as well as an intermediate consumption rate of 320 lpcd.

Table 2 - Water consumption records for January and February, 2003

Supply	Use	Consumption (L)
Trucked Water	Commercial	1,413,135
	Industrial	3,059,070
	Residential	8,964,390
	Subtotal	*13,436,595*
Piped Water	Commercial	12,662,000
	Industrial	40,567,000
	Residential	24,239,000
	Subtotal	*77,477,000*
	2-Month Total	90,913,595
	Yearly	545,481,570
	Population	6,200
	Daily Consumption	241 lpcd

Table 3 - Estimated water demand for 20-year design period

Year	Low Consumption (241 lpcd) High Population Projection (3.36%) [m^3/day]	Medium Consumption (320 lpcd) High Population Projection (3.36%) [m^3/day]	High Consumption (400 lpcd) High Population Projection (3.36%) [m^3/day]
2003	1,494	1,984	2,480
2004	1,544	2,051	2,563
2005	1,596	2,120	2,650
2006	1,650	2,191	2,738
2007	1,705	2,264	2,830
2008	1,763	2,340	2,926
2009	1,822	2,419	3,024
2010	1,883	2,500	3,126
2011	1,946	2,584	3,230
2012	2,012	2,671	3,339
2013	2,079	2,761	3,451
2014	2,149	2,854	3,567
2015	2,221	2,950	3,687
2016	2,296	3,049	3,811
2017	2,373	3,151	3,939
2018	2,453	3,257	4,071
2019	2,535	3,366	4,208
2020	2,621	3,480	4,350
2021	2,709	3,596	4,496
2022	2,800	3,717	4,647
2023	2,894	3,842	4,803

As shown in Table 3, the average daily water consumption is estimated to range between 2,000 m^3/day and 3,500 m^3/day within 10 years. Furthermore, this consumption rate is estimated to reach 2,900 m^3/day to 4,800 m^3/day within 20 years.

One of the main objectives of the present study is to identify the timing for actions to deal with water supply and storage shortfalls at the Lake Geraldine reservoir. As such, 10-year and 20-year period time frames will be used in subsequent analyses to determine when planning and actions are necessary to deal with such shortages. Consumption, based on the high growth projection as per the City of Iqaluit, will be estimated using the following three scenarios:

(1) continuous consumption rate of 241 lpcd from 2003 to 2023,
(2) steady rise in consumption rate from 241 lpcd in 2003, to 400 lpcd in 2023 with an intermediate rate of 320 lpcd in 2013, and
(3) an immediate rise to a consumption rate of 400 lpcd.

Ultimately, the 20-year design requirement is based on a population of 12,000 people and a consumption rate of 400 litres per person per day.

3.0 Lake Geraldine Watershed

3.1. Climate Data

Summarized in Table 4 are the monthly temperature and precipitation values calculated via data recorded at the Environment Canada Iqaluit A station (63° 45' N, 68° 33' W, elevation = 33.5 m) from 1946 to 2002. Also included in Table 4 are the yearly temperature and precipitation values.

Table 4 - Average monthly and yearly climatic data for Iqaluit, 1946 - 2002

Month	Mean Temp (°C)	Mean Rainfall (mm)	Mean Snowfall (cm)	Mean Precip. (mm)	Max Precip. (mm)	Min Precip. (mm)
Yearly	*-5.7*	*192.3*	*246.5*	*419.2*	*645.1*	*266.3*
January	-26.5	0.2	23.4	21.6	81.4	2.1
February	-27.0	0.1	22.7	21.1	104.1	0.6
March	-23.0	0.1	23.7	21.3	73.8	2.1
April	-14.4	0.2	28.6	26.0	87.9	0.1
May	-3.9	2.2	23.3	24.4	56.1	0.1
June	3.5	27.5	9.0	39.0	142.0	9.8
July	7.9	55.8	0.2	55.0	157.3	10.0
August	6.9	61.4	0.5	63.1	129.6	19.6
September	2.3	35.7	14.1	50.2	149.6	13.1
October	-4.7	6.3	34.9	39.5	102.4	6.2
November	-12.6	0.8	34.5	32.4	76.4	8.4
December	-21.5	0.1	24.5	21.8	88.5	1.3

For the present study, analysis of precipitation data is critical in terms of establishing the likely annual recurrence frequencies for various events. In general, rainfall and snowfall totals vary significantly from year to year. Table 5 summarizes the average yearly precipitation data, specifically the proportions of rainfall and snowfall in yearly total precipitation, for the duration of the climate record (1946 to 2002) as well as maximum and minimum values.

Table 5 - Average, maximum and minimum yearly total precipitation for Iqaluit

	Rainfall (mm)	Snowfall (cm)	Precipitation (mm)
Average	192.3	246.5	419.2
Maximum	384.4	499.6	645.1
Minimum Yearly	93.7	133.6	266.3
Missing Years	11	11	10

As indicated in Table 4, precipitation totals have a significant degree of variability on a month-to-month basis. Table 5 further emphasises the variability in precipitation trends on a year-to-year basis as evident by the range of yearly total precipitation values. It is also important to note the distribution of precipitation in terms of rainfall versus snowfall. In the case of rain, almost all water either remains in the watershed or flows towards the basin outlet. In the case of snow however, it may be distributed both within and between watersheds depending on topographical relief and wind speed and direction throughout the course of the over-winter period. Therefore, it is possible that the amount of snow that falls in a basin may not be equal to the amount of snow that is stored within that basin or the water equivalent that drains from the watershed.

A probability analysis was performed on precipitation data as recorded at the Iqaluit climate station from 1950 to 2001 to quantify the variability in yearly total precipitation. The percent of years with total precipitation less than or equal to the particular annual total precipitation were calculated. Results of this analysis are presented in Table 6.

Table 6 - Probability analysis on total yearly precipitation data from 1950 to 2001

Cumulative Percent of Years with Total Precipitation < X mm (%)	Total Annual Precipitation (mm)		Cumulative Percent of Years with Total Precipitation < X mm (%)	Total Annual Precipitation (mm)
100.0	645.1		48.9	412.8
97.8	636.7		46.8	412.7
95.7	613.0		44.6	401.1
93.6	565.1		42.5	397.1
91.4	538.4		40.4	396.0
89.3	529.6		38.2	386.1
87.2	523.1		36.1	379.4
85.1	501.0		34.0	377.8
82.9	481.4		31.9	366.9
80.8	474.7		29.7	360.4
78.7	474.0		27.6	356.5
76.5	469.2		25.5	350.5
74.4	467.5		23.4	347.6
72.3	466.2		21.2	345.6
70.2	458.0		19.1	338.5
68.0	454.1		17.0	338.4
65.9	442.8		14.8	335.4
63.8	442.2		12.7	335.3
61.7	436.8		10.6	334.1
59.5	431.1		8.5	330.0
57.4	430.7		6.3	313.0
55.3	429.0		4.2	306.9
53.1	428.7		2.1	294.5
51.0	426.6		0.0	266.3

A 5-year return represents an event for which there is a probability of 20% that a lower annual precipitation total could be observed in any given year. Similarly, there is a probability of 1% that less precipitation than the 100-year return total annual precipitation will occur in any given year. Return frequencies for annual precipitation were established based on 5-year, 20-year and 100-year return periods and are listed in Table 7.

Table 7 - Total Precipitation for 5-, 20-, and 100-year return frequencies

Return Period	Total Yearly Precipitation
5-year (1:5)	340 mm
20-year (1:20)	310 mm
100-year (1:100)	280 mm

3.2. Lake Geraldine Watershed Runoff Ratio

Of importance to ascertaining the amount of water that will enter Lake Geraldine each year is a thorough understanding of the hydrological balance of the contributing basin. Specifically, the amount of precipitation that enters the basin and, more importantly, the amount of runoff that flows from the system must be calculated. Although flow data is not available for the Lake Geraldine basin, such data does exist for the Apex River to the north-east and for the Sylvia Grinnell River to the south-west (Figure 1). Although the contributing areas of these basins are considerably larger than that of Lake Geraldine, the similar hydrological parameters of these basins allow for runoff ratios to be computed for the Lake Geraldine watershed.

River levels and velocities were recorded at a flow monitoring station (Station: 10UH001) either continuously or seasonally on the Sylvia Grinnell River (63^{o}45’38” N, 68^{o}35’2” W) from 1971 to 1999. A similar station (Station: 10UH002) recorded flows on the Apex River (63^{o}44’3” N, 68^{o}27’15” W) from 1973 to 1995. Using data obtained from these flow monitoring stations, in combination with average precipitation data for the Iqaluit meteorological station of 419.2 mm, average precipitation/runoff ratios were calculated for each basin.

Average monthly flows and total monthly flow volumes are summarized for both basins in Table 8 along with runoff ratio calculation results.

As summarized in Table 8, the runoff/precipitation ratio based on monthly average flows is estimated to be 0.757 for the Apex River Basin which has a total contributing area of 5850 hectares. Similarly, the runoff/precipitation ratio for the Sylvia Grinnell River basin with a much larger contributing area of 298,000 hectares is estimated to be 0.860.

SCALE:	1:50 000
DATE:	SEPT. 2003
DRAWN:	M.M.R.
JOB:	OTCD00016888a

FIG. 1

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TITLE: EXISTING WATERSHEDS

As a confirmation of the preceding computation, runoff ratios were calculated for annual flows in those instances when a complete annual record was available. Yearly runoff ratios for the Apex River Basin and Sylvia Grinnell Basin are summarized in Tables 9 and 10, respectively.

Average yearly runoff ratios for the Apex River Basin (Table 9) and the Sylvia Grinnell River Basin (Table 10) are very similar to those calculated based on average monthly flow and precipitation data. However, these ratios exhibit significant year-to-year variability attributable to a wide range of factors including, but not limited to: total yearly snowfall, total yearly rainfall, temperature extremes, total degree days above 0 degrees, and receipt of incoming solar radiation.

Table 8 - Average runoff ratios for Apex River Basin and Sylvia Grinnell River Basin

	Apex River		**Sylvia Grinnell River**	
	Average Flow (m^3/s)	**Average Monthly Volume (m^3)**	**Average Flow (m^3/s)**	**Average Monthly Volume (m^3)**
January	0.000	0	0.363	972,259
February	0.000	0	0.083	200,794
March	0.000	0	0.026	69,638
April	0.000	0	0.000	0
May	0.146	391,046	0.167	447,293
June	2.710	7,024,320	99.000	256,608,000
July	1.860	4,981,824	158.000	423,187,200
August	1.100	2,946,240	75.500	202,219,200
September	1.010	2,617,920	50.900	131,932,800
October	0.227	607,997	16.600	44,461,440
November	0.002	5,184	4.190	10,860,480
December	0.000	0	1.400	3,749,760
	TOTAL (m^3)	18,574,531		1,074,708,864
	Area (m^2)	59,500,000		2,980,000,000
	Avg. PPT (m)	0.4192		0.4192
	Avg. PPT (m^3)	24,523,200		1,249,216,000
Runoff Ratio	**Total Flow / PPT**	**0.757**		**0.860**

Table 9 - Yearly runoff ratios for the Apex River basin

Year	Total Annual Flow (m^3)	Total Annual Precipitation (m^3)	Runoff/Precip Ratio
1982	11,927,000	25,552,800	0.467
1983	13,119,000	23,166,000	0.566
1985	21,000,000	28,161,900	0.746
1986	27,336,000	27,769,950	0.984
1988	20,292,000	19,544,850	1.038
1989	14,200,000	23,230,350	0.611
1990	21,700,000	22,101,300	0.982
1991	14,800,000	21,083,400	0.702
1992	14,000,000	19,796,400	0.707
1994	19,600,000	21,463,650	0.913
		Average	*0.772*

Table 10 - Yearly runoff ratios for the Sylvia Grinnell River basin

Year	Total Annual Flow (m^3)	Total Annual Precipitation (m^3)	Runoff/Precip Ratio
1989	1,606,000,000	1,183,358,000	0.896
1990	1,080,000,000	1,125,844,000	0.959
1991	848,000,000	1,073,992,000	0.790
1992	865,000,000	1,008,432,000	0.858
1994	1,170,000,000	1,093,362,000	1.070
1995	837,000,000	1,029,888,000	0.813
		Average	*0.898*

Based on the similar attributes of the Lake Geraldine basin with that of the Apex River Basin including location, topography and climate, runoff ratios are assumed to be similar between the two. The average runoff ratio for the Apex River was calculated to be 0.77 with a minimum of 0.47. This value can vary from year to year as shown in Table 9. Applying a runoff ratio of 0.77 to subsequent analyses results in an over-estimation of total runoff volume for 50% of the time and under-estimations for the remaining 50% of the time. Due to the conservative nature of using the average runoff ratio and the associated risk of over-estimating runoff from the watershed due to a low-precipitation year, a runoff ratio of 0.60 will be used in this report.

In calculating future storage and supply scenarios, factors such as population, consumption rates, and annual precipitation are more critical than the runoff ratio. Furthermore, effects attributed to variations in yearly runoff ratios can be resolved by supplementation during the ice-free season from an outside source as discussed in later sections of this report.

3.3. Lake Geraldine Watershed Yield

Table 11 summarizes the total annual runoff volume from the Lake Geraldine Basin based on various return frequencies using a runoff ratio of 0.60 as previously discussed.

Table 11 - Lake Geraldine basin runoff volume for average year and events with 5-, 20-, and 100-year return frequencies

	Average Yearly Precipitation	5-Year Return Frequency	20-Year Return Frequency	100-Year Return Frequency
Total Annual Precipitation (mm)	419	340	310	280
Volume over 385 ha basin (m^3)	1,613,000	1,309,000	1,193,500	1,078,000
Runoff Based on runoff ratio of 0.60 (m^3)	968,000	785,000	537,000	485,000

The relationship between return frequency and total runoff contribution to the reservoir, as summarized in Table 11, highlights the importance of monitoring and forecasting precipitation records and runoff conditions in the Lake Geraldine Basin. The City must incorporate precipitation and lake-level monitoring into yearly operations schedules and use such data for short- and long-term planning to alleviate stresses resulting from potential shortages in available supply for the City.

3.4. Storage and Supply Alternatives

The Lake Geraldine watershed is frozen over the winter and thus there is no replenishment of the reservoir during this period. The over-winter period is defined in this study as September 31 through to May 31, a total of 244 days. It is important to note, however, that the over-winter period varies in length from year to year and can be shorter than the 244 day period used in this study. Therefore, the 244 day over-winter period is a conservative estimate that incorporates a margin of safety into identification of critical dates upon which actions must be taken to alleviate water supply stresses depending on yearly precipitation, consumption and growth rates.

Using the current population of 6,200 people, the 8 month over-winter storage requirement is approximately 365,000 cubic metres using a consumption rate of 241 litres per person per day. This over-winter storage requirement is expected to rise to 706,000 cubic metres by 2023 using the same consumption rate and a population of 12,000 people. Based on the amount of storage that is lost each winter due to freeze it is clear that the present storage capacity of the reservoir is not large enough to satisfy future demand by the City given current consumption rates.

Total yearly runoff from the Lake Geraldine Basin is approximately 968,000 cubic metres based on a runoff ratio of 0.60 and an average yearly total precipitation of 419 mm as shown in Table 11. This is less than the total accessible storage volume of the reservoir which is approximately 1,076,000 cubic metres as further discussed in Section 5.1 of this report. As shown in Table 11, runoff from the basin could be reduced to 785,000 cubic metres in the case of a 5-year low total precipitation and to 485,000 cubic metres in a 100-year low total, both of which are well below the storage capacity of the reservoir.

The City of Iqaluit must ensure that adequate accessible storage volume is available in the Lake Geraldine reservoir to satisfy both the 8-month over winter period and the yearly consumption for the 20-year design horizon at design consumption rate. As stated above, over-winter storage requirement is expected to rise to 706,000 cubic metres by 2023. Therefore, a 5-year low runoff return frequency will result in a water shortage during the over-winter period. Furthermore, based on the current consumption rate (241 litres per person per day) and 20-year design population of 12,000, runoff from the contributing basin will not be sufficient to meet the City's yearly demand based on a runoff coefficient of 0.60.

Three general categories of alternatives that can be considered to address storage and supply issues at the Lake Geraldine Reservoir include:

(1) Increase Storage and Supplement Recharge;
(2) Augment from Second Source; and
(3) Utilize a Second Storage.

The above listed alternatives are further discussed below:

3.4.1. Increase Storage and Supplement Recharge

This alternative includes increasing available storage in the reservoir and locating a supplementary recharge source and associated transmission pathway. Once the reservoir storage volume has been increased to meet demands based on a 20-year design period, a means of recharging the supply must be detailed as runoff alone will not fully recharge the reservoir. Details including a suitable second source and a transmission pathway with associated works must be determined. Two methods of increasing storage capacity include:

(1) Raising of the dam; and
(2) Development of additional storage in the existing reservoir

3.4.2. Augment From Second Source

In the event that a shortage of water is realized during the over-winter period, another alternative is to locate an external source and transfer water to the reservoir thus satisfying the City's immediate need until spring melt. Some criteria that must be considered with respect to this alternative include:

(1) Distance from Lake Geraldine,
(2) Elevational difference relative to Lake Geraldine,
(3) Terrain considerations between reservoirs,
(4) Potential for contamination,
(5) Presence of ice-cover at second source,
(6) Capital costs associated with linking new source with Lake Geraldine, and
(7) Operational considerations including presence of ice on second source, winter conditions, freeze damage to pump and transmission path etc.

Due to the fact that this alternative is based on immediate need and subsequent action by the City during the over-winter period, operational factors are the key limiting factor to the success of locating and transporting water in adequate quantity to the Lake Geraldine reservoir. A combination of a short preparation time frame and various operational risks related to winter conditions introduce a large degree of uncertainty to the success of such an alternative. As such, this alternative will not be considered in subsequent alternative selection unless no other feasible options are found.

3.4.3. Utilize a Second Storage

In addition to storage volume currently available in the Lake Geraldine reservoir, utilization of a second independent storage location is another alternative for satisfying current and future over-winter demand for the City of Iqaluit. A number of criteria must be considered in order to determine if a potential storage location is a viable option including:

(1) Distance from Lake Geraldine,
(2) Elevational difference relative to Lake Geraldine,
(3) Terrain considerations in between reservoirs,
(4) Potential for contamination,
(5) Physical and chemical characteristics of new source, and
(6) Capital costs associated with connecting the new source to Lake Geraldine.

In consideration of the criteria outlined above, distance from Lake Geraldine in combination with elevational considerations are the main limiting factors in identification of a suitable second storage location. Due to the significant differences in elevation between the existing Lake Geraldine water level and the surrounding area, connection of an additional storage area would involve extensive rock removal and terrain disturbance. Furthermore, the nearest lake of equal or greater area to that of Lake Geraldine is situated approximately 3000 metres to the north-east in the Apex River watershed (Figure 1).

No viable candidates have been identified. As such, identification of an additional storage location independent of Lake Geraldine will not be further considered in this report unless no other feasible options are found.

In summary, the main alternative that will be considered in the present study is to increase the storage at the Lake Geraldine Reservoir and provide supplementary recharge as required to meet demand over a 20-year design period.

4.0 Definition of Alternatives

The alternatives that are considered must address the issues of the provision of additional over winter storage and the replenishment of the storage.

4.1. Storage Alternatives

The alternative means of storage that will be considered in this report include:

(1) Excavation to provide additional volume in Lake Geraldine, and
(2) Raising of the existing dam.

4.1.1. Excavation of Additional Volume in Lake Geraldine

Excavation of additional volume in Lake Geraldine will be considered as a means of increasing storage and subsequently meeting over-winter demand for the City of Iqaluit. Included in this analysis will be a discussion of the logistical, economic, and environmental implications of rock blasting and excavation within the vicinity of Lake Geraldine.

4.1.2. Raising of Existing Dam

Further raising of the existing dam will be considered as a means of increasing storage in Lake Geraldine. Implications of this alternative include increased storage versus freezing depth of lake, anchoring of the dam, construction costs, and environmental implications of increased depth and surface area will be considered.

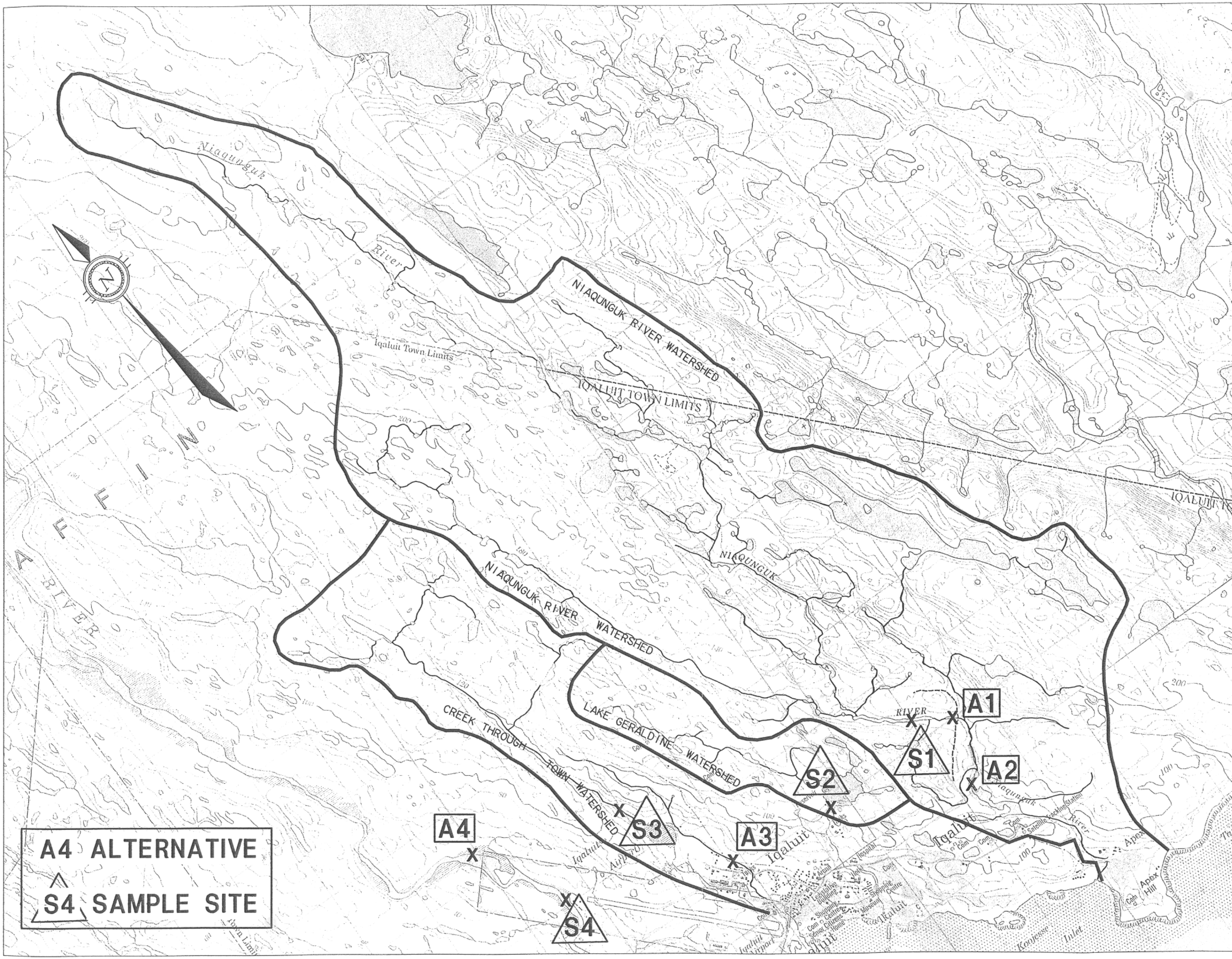
4.2. Refill Alternatives

The following four (4) proposed alternative withdrawal sites will be investigated:

4.2.1. Alternative 1

UTM Grid Reference: E 526480, N 7070000
Drawing Reference: A1
Sampling Reference: S1

Alternative Location #1 is located within the Apex (Niaqunguk) River Basin along the main branch of the river. The proposed withdrawal site is situated approximately 50 metres north of the Road to Nowhere as indicated on Figure 2. This stretch of water has not been altered by human activity however, directly south of the proposed site, water is directed through 2 X 800 mm diameter CSP culverts that run under the Road to Nowhere. Refer to Appendix A - Pictures 1 and 2 for images of Alternative #1.



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CLIENT: CITY OF IQALUIT

TITLE: SAMPLE LOCATIONS AND REFILL ALTERNATIVES

SCALE:	1:50 000
DATE:	SEPT. 2003
DRAWN:	M.M.R.
JOB:	OTCD00016888a

FIG. 2

4.2.2. Alternative 2

UTM Grid Reference: E 526300, N 7069250
Drawing Reference: A2
Sampling Reference: S1

Alternative Location #2 is located within the Apex (Niaqunguk) River Basin along the main branch of the river. The proposed withdrawal site is situated approximately 200 metres south of the Road to Nowhere as indicated on Figure 2. This stretch of river is in a natural state. Refer to Appendix A - Pictures 3 and 4 for images of Alternative #2.

4.2.3. Alternative 3

UTM Grid Reference: E 522900, N 7070200
Drawing Reference: A3
Sampling Reference: S3

Alternative Location #3 is located along the main creek that drains the watershed in which the City is situated. This proposed withdrawal site is in close proximity to the Federal Buildings located approximately 100 m to the south-west (Figure 2). The watercourse has been altered via trenching and straightening with flow being diverted under roadways via culverts directly upstream and downstream of the proposed alternative site. Refer to Appendix A - Pictures 5 and 6 for images of Alternative #3.

4.2.4. Alternative 4

UTM Grid Reference: E 519950, N 7072400
Drawing Reference: A4
Sampling Reference: S4

Alternative Location #4 is located within the Sylvia Grinnell River Basin along the main branch of the river. The proposed withdrawal site is situated north-west of the Iqaluit Airport limits as indicated on Figure 2. This stretch of river is in a natural state.

5.0 Storage

Of key importance to ensuring that the City of Iqaluit maintains its capability to meet water demand throughout the year is adequate storage to sustain demand through the over-winter period. It is during this time that loss of Lake storage capacity due to freezing and lack of input to the reservoir, in combination with domestic demands, can lead to a shortage of water in Lake Geraldine. This scenario is worsened in the case of any give year that receives a below normal amount of precipitation thus resulting in a pre-winter reservoir volume that is less than capacity. Given the fact that the habitability of the City of dependent on sufficient water supply, it is imperative that actions be taken in the short-term to mitigate against future shortages.

Two alternatives that are considered to resolve capacity issues during the over-winter period at Lake Geraldine include:

(1) Raising of the dam, and
(2) Development of additional storage in the existing reservoir

The following sections detail and evaluate the above listed alternatives.

5.1. Lake Geraldine Volume and Freeze Depth

A three dimensional computer model of Lake Geraldine has been prepared from the bathometric survey data gathered by Trow during 1984, an earlier Trow model of the Lake, and from topographic mapping of Iqaluit from November of 2000. From this model, lake volume at 0.10 m increments was calculated. It should be noted that there is a total volume of approximately 53,000 cubic metres in the Lake below the level of the rock ledge 250 metres from the face of the dam at elevation 103 m. This volume is inaccessible as it does not drain to the intake pipe at the dam. At the present consumption rate of 241 litres per capita day, this volume would satisfy demand for approximately 35 days. By the year 2023, this volume would satisfy demand for 18 days using the same consumption rate. Should consumption rise to 400 lpcd, this volume would last for 11 days. In view of the small volume that would be made available, it is not felt prudent to remove the rock ridge in view of the potential risks to the dam associated with such work. Further consideration of alternatives which access water stored in the lower portion of the Lake will not be considered. Therefore, elevation 103 metres is the minimum elevation above which accessible water is stored. Table 12 presents stored volume at various key depths during the ice-free season for Lake Geraldine.

Table 12 - Lake Geraldine Volume (Ice Free)

Description	Elevation (m)	Depth of Water (m)	Accessible Volume (m^3)
Lake Bottom	97.9		
Intake Pipe at Dam	101.3		
Rock Ridge	103.0	0.0	0
	104.0	1.0	102,000
	105.0	2.0	222,000
	106.0	3.0	366,000
	107.0	4.0	541,000
	108.0	5.0	756,000
	109.0	6.0	978,000
Current Dam Elev.	109.3	6.3	1,076,000
	109.8	6.8	1,257,000
	110.3	7.3	1,438,000
	110.8	7.8	1,619,000
	111.3	8.3	1,800,000

Based on the 1995 Lake Geraldine Storage Study Report prepared by Trow, the maximum ice depth in Lake Geraldine is 1.9 metres. Listed in Table 13 are the assumed freeze depths for each month of the over-winter period as well as total freeze depth.

Table 13 - Lake Geraldine freeze depth analysis

Month	Depth of Freeze for Month (m)	Total Freeze Depth (m)
October	0.1	0.1
November	0.4	0.5
December	0.4	0.9
January	0.3	1.2
February	0.3	1.5
March	0.2	1.7
April	0.1	1.8
May	0.1	1.9

5.1.1. Storage Requirement

The over winter period in this study has been assumed to include October 1 through to May 31. The storage required to meet over-winter demand for the City of Iqaluit is dictated by the total consumption as well as the amount of water that is lost due to ice formation in the Lake. Over-winter consumption for the City of Iqaluit is summarized in Table 14 based on three scenarios:

(1) continuous consumption rate of 241 lpcd from 2003 to 2023

(2) steady rise in consumption rate from 241 lpcd in 2003, to 400 lpcd in 2023 with an intermediate rate of 320 lpcd in 2013

(3) an immediate rise to a consumption rate of 400 lpcd.

Table 14 - Over winter consumption (October to May)

	2003	2013	2023	2013	2013	2023
	241 lpcd	**241 lpcd**	**241 lpcd**	**320 lpcd**	**400 lpcd**	**400 lpcd**
October	46,000	64,000	90,000	86,000	107,000	149,000
November	45,000	62,000	87,000	83,000	104,000	144,000
December	46,000	64,000	90,000	86,000	107,000	149,000
January	46,000	64,000	90,000	86,000	107,000	149,000
February	42,000	58,000	81,000	77,000	97,000	134,000
March	46,000	64,000	90,000	86,000	107,000	149,000
April	45,000	62,000	87,000	83,000	104,000	144,000
May	46,000	64,000	90,000	86,000	107,000	149,000
TOTAL	*362,000*	*502,000*	*705,000*	*673,000*	*840,000*	*1,167,000*

5.2. Raising of Existing Dam

Various dam spillway elevations have been tested in order to determine the dam elevation that corresponds with adequate Lake storage capacity to satisfy over-winter demands, a comparison of the combined effects of consumption and freeze depth must be performed at various elevations. Using freeze depth assumptions as presented in Table 13, in combination with consumption rates summarized in Table 14, an analysis of monthly draw down was completed for each month of the over-winter period (Appendix B). Table 15 lists the elevation of the bottom of ice at the end of the winter period (May 31) based on various start of winter water elevations and for various consumption rate scenarios as listed above.

Table 15 - Bottom of lake ice elevation at end of winter (May 31)

Dam Elevation (m)	2003	2013	2023	2013	2013	2023
	241 lpcd	**241 lpcd**	**241 lpcd**	**320 lpcd**	**400 lpcd**	**400 lpcd**
109.3 (Current Elev.)	105.5	104.3	<103.0	<103.0	<103.0	<103.0
109.8	106.2	105.2	103.7	104.5	<103.0	<103.0
110.3	106.9	106.1	104.8	105.1	104.0	<103.0
110.8	107.5	106.8	106.1	106.2	104.9	<103.0
111.3	108.2	107.4	106.7	106.8	106.4	103.8

As previously discussed, elevation 103.0 is the minimum accessible water elevation for Lake Geraldine. As such, noted in Table 15 are end of winter elevations that are below elevation 103.0 metres.

Design of works suitable to supplying the City with an adequate water supply over a 20-year design period requires sufficient time for planning, design and construction. Such work must be initiated several years in advance of forecasted critical dates. From Table 15, raising of the dam by 0.5 metres results in a very marginal ability to serve the City's demand by 2023. If the dam is raised by 1.0 or 1.5 metres, the reservoir will run out of water sometime between 2013 and 2023 should consumption rise to 400 lpcd. Raising of the dam by 2.0 metres generally provides sufficient storage through to the year 2023 based on a demand of 400 lpcd. From Table 15, it is clear that a modest increase in demand exhausts storage prior to 2013. Therefore, works must be in place prior to 2013.

The scope of works in this case is driven by factors including spillage of water from the lake and by the structural challenge of raising the dam. In terms of structural considerations, raising of the dam is a difficult undertaking that must be reviewed in detail at the preliminary design stage. At that time, the maximum possible height to which the dam can be raised will be determined. Specific concerns include the provision of suitable anchorage to assure structural stability. Additional dyking will also be required in combination with an increase in dam height to properly retain runoff from the contributing basin.

In addition to addressing upstream storage outcomes resulting from raising the dam, downstream impacts must also be considered. In particular, given the scenario presented above, all runoff from the Lake Geraldine Watershed would be retained in the reservoir essentially cutting off a major portion of the water supply to the receiving watercourse that extends through the City of Iqaluit to Koojesse Inlet. At the preliminary design stage, consultation with the Department of Fisheries and Oceans (DFO) will determine actions necessary to address downstream impacts resulting from increased dam height.

5.2.1. Cost of Raising Dam

Costs associated with raising the dam by 2.0 metres are summarized in Table 16. A more detailed summary of costs is included in Appendix C

Table 16 - Cost estimate to raise dam 2.0 metres

Item	Estimated Cost
1. Rock Anchors	$180,000
2. Concrete on Spillway	$261,000
3. Concrete Work for Main Portion of Dam	$276,000
4. Fill Material for Berm Surrounding Cutoff Wall	$536,000
5. Diving	$35,000
6. Berm and Cutoff Wall 130 m East of Dam	$79,000
Subtotal	**$1,367,000**
Engineering (15%)	$205,000
Contingencies (20%)	$273,000
TOTAL	**$1,845,000**

The cost of increasing the dam by 2.0 metres is estimated to be approximately $1.9 million. Costs may increase if the structural analysis determines that more substantial work is required to raise the dam.

5.2.2. Capital Works, Risks and Operations and Maintenance

Raising the dam by 2.0 metres represents a very reliable method of providing the storage required to serve consumption for the next 15 to 20 years. Thus, there is little risk in successfully providing the required reservoir volume. There is, however, risk of harmful impacts from this construction as the stability of the dam is dependent upon the proper installment of the dam. In view of the impact upon the habitability of the community and the downstream damage which would arise from an incident with the dam, this risk must be recognized. Adequate supervision of a competent installer is essential.

With regards to ongoing operations and maintenance, this alternative will not give rise to any additional ongoing activities.

Any impact upon water quality will be limited to the construction period. In view of the type of works and downstream water treatment plant, this will likely not cause an impact upon water quality for system users. The risk of contamination is felt to be minimal due to the short duration of construction activities.

Some of the construction activities including rock anchors and underwater concreting require a skilled and experienced work force. Thus, a portion of the works will require some imported labour for construction supervision. The majority of the activities can be carried out by local contractors.

5.3. Excavation of Additional Storage in the Existing Reservoir

5.3.1. Additional Volume Requirement

Another alternative means of ensuring that over-winter demand is met via Lake Geraldine is enlargement of the existing reservoir. Much of the Lake, particularly around the perimeter and the north-western end of the lake, is only 2 to 3 metres in depth. Freezing, which occupies up to 2 metres of this volume, causes the majority of this water to become inaccessible during the over-winter period. Deepening of the Lake bottom in shallow areas would provide additional storage capacity that could be utilized throughout the over-winter period (244 days) thus satisfying City demand until melt and recharge occurs in the spring. Summarized in Table 17 are the over-winter storage volumes required to meet 20-year demand in addition to current over-winter storage needs.

Table 17 - Required storage to meet 20-year over-winter demand

Year	Population	Storage: 241 lpcd (m^3)*	Additional Storage Required (m^3)**	Storage: 320 lpcd (m^3)*	Additional Storage Required (m^3)**	Storage: 400 lpcd (m^3)*	Additional Storage Required (m^3)**
2003	6,200	364,585					
2023	12,007	706,060	*+341,475*	937,507	*+572,922*	1,171,883	*+807,298*

* over-winter storage required based on given consumption rate (244 days)
** additional storage required to meet over-winter demand compared to present (6,200 people, 241 lpcd)

Assuming that consumption rates do not increase between 2003 and 2023, the minimum amount of additional storage that will be required in the Lake to meet the 20-year demand is approximately 342,000 cubic metres. Should consumption rates increase to 400 lpcd, the amount of required additional storage rises to approximately 800,000 cubic metres.

Two options exist for the development of additional storage:

(1) excavate within the reservoir,
(2) create another independent storage cell that is hydraulically linked to the reservoir

Under the best case scenario, for every 1 cubic metre of rock excavated, an equal 1 cubic metre of useable over-winter storage is gained. This, however, is not realistic given the fact that such a large amount of water is inaccessible due to ice formation during the over-winter period.

5.3.2. Cost of Increasing Storage Capacity

Removal of 1 cubic metre of rock costs approximately $25 per cubic metre in a raw excavate (i.e. new cell) and approximately $50 per cubic metre within the reservoir. Therefore, assuming that demand does not increase between 2003 and 2023, raw excavation of 342,000 cubic metres of rock will cost over $8 million. This is also assuming that for every cubic metre of rock excavated an equal amount of over-winter storage is gained. Should consumption increase to 400 lpcd by 2023, raw excavation of the required 800,000 cubic metres of rock will cost in the order of $20 million. Removal of rock within the reservoir ($50/m^3) will double the price of these estimates as compared to the raw excavation of an independent storage cell.

5.3.3. Capital Works, Risk and Operations and Maintenance

Capital works associated with this alternative include underwater drilling, blasting and excavation, together with loading, hauling and disposal of the waste rock. Special equipment requirements will include the transportation of a barge to the Lake for drilling, blasting and mucking operations. Following construction, no additional operation or maintenance activities will be required at the water source. Thus, there is no impact upon operating costs.

Risk associated with this alternative relates to the likelihood of successful completion and the possibility of harm as a result of this construction. In view of the simplicity of this construction, there is little risk of unsuccessful construction. Regarding harmful impacts of construction activities, there is some modest risk of damage to the existing dam due to blasting. This risk would be further reduced through proper supervision of blasting activities.

The direct impact upon water quality as a result of blasting and excavation is felt to be moderate. The risk to any water consumers is further reduced in that all water is treated by the existing water treatment plant prior to use. Due to the duration of construction activities, there is some risk of water contamination with fuels and lubricants from construction equipment.

The type of required activities within this alternative fall within the abilities of existing contractors in Iqaluit. The scope of the project will require the mobilization of additional equipment into the community.

5.4. Storage Alternative Selection

The two viable alternatives to satisfying over-winter storage capacity requirements for the City of Iqaluit are: (1) to raise the existing dam, and (2) to create additional storage capacity in the existing reservoir.

In order to provide sufficient storage capacity to meet over-winter demand in 2023 based on a consumption rate of 400 lpcd, the dam must be raised by at least 2.0 metre from its current elevation of 109.3 metres. The cost of raising the dam including dam works and additional dyking is approximately $1.9 million. Under a best case scenario whereby consumption rates remain at present rates and removal of a given volume of rock results in an equal amount of useable over-winter storage, raw excavation of a new storage cell will cost approximately $8 million. The construction cost however is likely to be well above this estimate.

Based on the comparative costs of the two storage alternatives, raising of the dam is selected as the preferred alternative in this study.

6.0 Lake Geraldine Refill

Independent of the task of ensuring that adequate capacity is available in Lake Geraldine to meet over-winter demand is the need to address summer recharge to the reservoir. In particular, upon determining the most appropriate measure(s) to create additional storage volume in the Lake it is essential that maximum storage volume is achieved at the end of each summer recharge season in preparation for the over-winter period.

A number of parameters are required in order to determine the volume of water present in Lake Geraldine prior to the onset of the over winter period including:

(a) the capacity of the reservoir
(b) remaining water from previous over-winter period
(c) amount of water stored as ice at beginning of thaw period
(d) total consumption during the summer period (June to September)
(e) total runoff from contributing basin

The most critical factor controlling whether or not adequate volume is present in the Lake prior to the over-winter period is the amount of precipitation and, more importantly, the amount of runoff arising from the contributing basin. As discussed in Section 3 of this report, a less-than-normal yearly total precipitation can have a measurable affect on the total reservoir volume at the end of the summer recharge season. Therefore, it is critical that in addition to considering future growth and demand trends, various total yearly precipitation return frequencies are analyzed with respect to the effect they have on runoff volume contributing to Lake Geraldine.

6.1. Recharge Volume Requirements

From Section 5 of this report, the amount of water remaining in the reservoir at the end of the over-winter period (May 31) was calculated based on various dam elevations and consumption rates. By determining the quantity of water left in the reservoir at the end of the over-winter period, the ability of the watershed to recharge the lake can be determined. Specifically, if the lake is fully recharged prior to freeze-up, the remaining water is calculated as the volume of the full reservoir minus consumption.

Based on the methodology outlined above, Table 18 summarizes the total volume of water present in Lake Geraldine relative to the maximum capacity at the outset of the summer thaw period (September 31) based on various consumption rates and runoff volume return frequencies.

Table 18 - End of summer Lake Geraldine recharge volume

Consumption (lpcd)	Return Frequency	Runoff Volume (m^3)	Water Volume Relative to Maximum Capacity on September 31		
			2003* (m^3)	2013* (m^3)	2023* (m^3)
241	Avg	1,200,000	+423,000	+209,000	-88,000
241	1:5	982,000	+240,000	+26,000	-271,000
241	1:20	895,000	-8,000	-222,000	-519,000
241	1:100	809,000	-60,000	-274,000	-571,000
320	Avg	1,200,000		+43,000	
320	1:5	982,000		-140,000	
320	1:20	895,000		-388,000	
320	1:100	809,000		-440,000	
400	Avg	1,200,000		-125,000	-552,000
400	1:5	982,000		-308,000	-735,000
400	1:20	895,000		-556,000	-983,000
400	1:100	809,000		-608,000	-1,035,000

* ‘+’ indicates a surplus of water, ‘-‘ indicates a deficit relative to maximum lake capacity

As summarized in Table 18, runoff during the summer months will replenish the total volume of Lake Geraldine over a 10-year time span based on present consumption rates and average yearly total precipitation. This is based on the assumption that the Lake volume was at maximum capacity prior to the previous over-winter period. However, in the event that in any given year total precipitation is equal to or less than the 1:5 year return frequency and consumption increases, a deficit in Lake volume at the onset of the over-winter storage period will occur. The following Table outlines the year in which a water shortage will be experienced in Lake Geraldine leading into the over-winter period based on specific consumption rates and precipitation return frequencies.

Table 19 – Lake refill shortfall dates for various consumption and precipitation scenarios

Year of Post-Summer Volume Deficit	Unit Consumption (lpcd)	Return Frequency
2003	241	1:20
2013	320	1:5
2003	400	1:1

Based on the information summarized above, the City of Iqaluit cannot delay actions required to address recharge. According to Tables 18 and 19, by the year 2023 the reservoir will not receive adequate recharge volume from the contributing basin thus requiring an input from an outside source to satisfy over-winter demand.

The first step required to address the recharge issue is establishment of a monitoring protocol in the short term whereby snow accumulation and yearly precipitation trends are recorded then reviewed and impacts on water supply are forecasted. Based on this information, total spring runoff from the contributing basin can be estimated and subsequent actions to supplement this runoff can be established if required. Water level fluctuations in the reservoir should also be closely monitored in conjunction with precipitation data and consumption records.

The City of Iqaluit should also establish a contingency plan in which water is pumped from an outside source if deemed necessary prior to the onset of the over-winter period. A plan detailing the availability of a pump and temporary pipeline as well as a water source and transmission route should be established and ready for use should such need arise.

Finally, a permanent plan must be established due to the fact that within a 20-year design period Lake Geraldine will experience a yearly water deficit. This plan must include selection of a suitable outside water source, permanent water pumping and piping infrastructure and related maintenance and testing measures. Alternatives for such a plan will be discussed in the following sections of this report.

6.2. Refill Alternative Selection

A number of factors must be considered in determining the most appropriate withdrawal site and transmission route for refilling Lake Geraldine. These criteria include:

(1) Volume and seasonal availability of water at new source,
(2) Physical and chemical characteristics of water at withdrawal site,
(3) Potential for contamination at withdrawal site,
(4) Distance from Lake Geraldine,
(5) Elevational difference between new source and Lake Geraldine,
(6) Terrain considerations between source and Lake Geraldine,
(7) Capital costs associated with connecting new source to Lake Geraldine.

The following sections will outline the suitability of each of the proposed alternative water withdrawal locations with respect to the above noted criteria. From this analysis, the most appropriate withdrawal site will be selected.

6.2.1. Water Quality Analysis

Treated water must meet strict guidelines for chemical, physical, and microbiological parameters as outlined in the Guidelines for Canadian Drinking Water Quality. The City currently operates under a water licence granted by the Nunavut Water Board. Sampling requirements for raw water are not included in this licence. Raw water is, however, included in the “Surveillance Network Program for the City of Iqaluit 2002”. Required analysis parameters under this Surveillance Network are summarized in Table 20. Also included in Table 20 are parameter guidelines as listed in the Guidelines for Canadian Drinking Water Quality (GCDWC).

A sampling program was carried out on October 2, 2003. Surface water samples were collected at four sites including three sampling locations as illustrated on Figure 2 as well as from Lake Geraldine. All sampling, preservation and analysis was conducted in accordance with the methods prescribed in the "Standard Methods for the Examination of Water and Wastewater". Samples were preserved and transported to a certified laboratory in Ottawa where the analysis was performed. Results from the sampling program are listed in Table 20. Also listed in Table 20 are the corresponding standards as outlined in the Canadian Drinking Water Quality Guidelines and results from raw water sample analysis conducted by the City on July 26, 2000 at Lake Geraldine.

As summarized in Table 20, water quality analysis completed on samples collected from each of the three proposed alternative withdrawal sites indicates that all water quality parameters fall within criteria of CDWQ and are very similar to water sampled from Lake Geraldine. Therefore, on the basis of water quality, none of the four proposed withdrawal sites are removed from the list of potential alternatives.

6.2.2. Capital Works, Risks and Operations and Maintenance

The criteria that alternative withdrawal points must be reviewed against are listed in Table 21. Also listed in this Table is information regarding the suitability of each site based on such criteria.

Due to the fact that Alternative 3 is located in such close proximity to the City of Iqaluit and, more importantly, that it flows through an abandoned dump site thus increasing the potential for contamination (Table 21), it will be removed from the list of candidate alternative sites within the selection process.

Alternative 4, which is situated adjacent to the Airport will be removed from the selection process due to the heightened risk of contamination from Airport operations and primarily due to the fact that the site is located 5000 metres from Lake Geraldine (Table 21).

Therefore, due to the relatively close proximity of Alternative sites 1 and 2 to Lake Geraldine and the fact that this site is situated in excess of 1000 metres from development, the Apex River will be selected as the preferred withdrawal site for summer recharge of Lake Geraldine.

Table 20 - Raw water sample analysis results from October 3, 2003 sampling program

Parameter	Units	CDWQ Standard	Iqaluit 2000*	Creek 1**	Creek 3**	Sylvia Grinnell**	Lake Geraldine **
Conductivity	µMho/cm		95.9	72	99	45	50
pH	pH units	6.5 – 8.5	7.93	7.81	7.98	7.81	7.81
Colour	TCU	15		3	2	2	3
Turbidity	mg/L	1	0.9	0.4	0.3	0.8	0.8
TSS	mg/L		5	< 3	< 3	< 3	< 3
BOD	mg/L			< 1	< 1	1	< 1
DOC	mg/L	NG		2.0	3.0	2.0	2.0
Total Ammonia (N)	mg/L	NG	0.215	< 0.01	< 0.01	< 0.01	< 0.01
o-Phosphate (P)	mg/L			< 0.01	< 0.01	< 0.01	< 0.01
Fluoride	mg/L	1.5		< 0.1	< 0.1	< 0.1	< 0.1
Chlorine	mg/L	3.0		0.9	1.1	0.9	1.1
Nitrite (N)	mg/L	3.2	0.77	< 0.1	< 0.1	< 0.1	< 0.1
Nitrate (N)	mg/L			0.1	0.1	0.1	0.3
Sulphate	mg/L	500	4	7	4	3	2
Calcium	mg/L	NG	16.0	8.80	14.90	6.13	4.82
Magnesium	mg/L	NG	1.55	1.22	1.72	0.66	0.99
Sodium	mg/L	200	8.38	0.7	0.9	0.6	0.8
Potassium	mg/L		0.99	0.2	0.1	< 0.1	0.1
Arsenic	mg/L	0.025	0.001	< 0.001	< 0.001	< 0.001	< 0.001
Copper	mg/L	1.0	0.002	< 0.002	< 0.002	< 0.002	< 0.002
Iron	mg/L	0.3	0.090	0.025	0.038	0.030	0.053
Lead	mg/L	0.010	0.001	< 0.0005	< 0.0005	< 0.0005	< 0.0005
Mercury	mg/L	0.001	0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001
Nickel	mg/L		<0.001	< 0.01	< 0.01	< 0.01	< 0.01
Silica	mg/L			3.55	3.08	2.55	1.56
Total Coliform	cts/100 mL	0		4	2	8	<1
E. Coli	cts/100 mL	0		< 1	< 1	< 1	< 1

CDWQ Standards – Guidelines for Canadian Drinking Water Quality
NTU – Nephelometric Turbidity Unit
TCU – True Colour Unit
NG – No Federal Guideline
* - Iqaluit Raw Water Sample Analysis – 07/26/2000
** - Trow - 09/04/2003

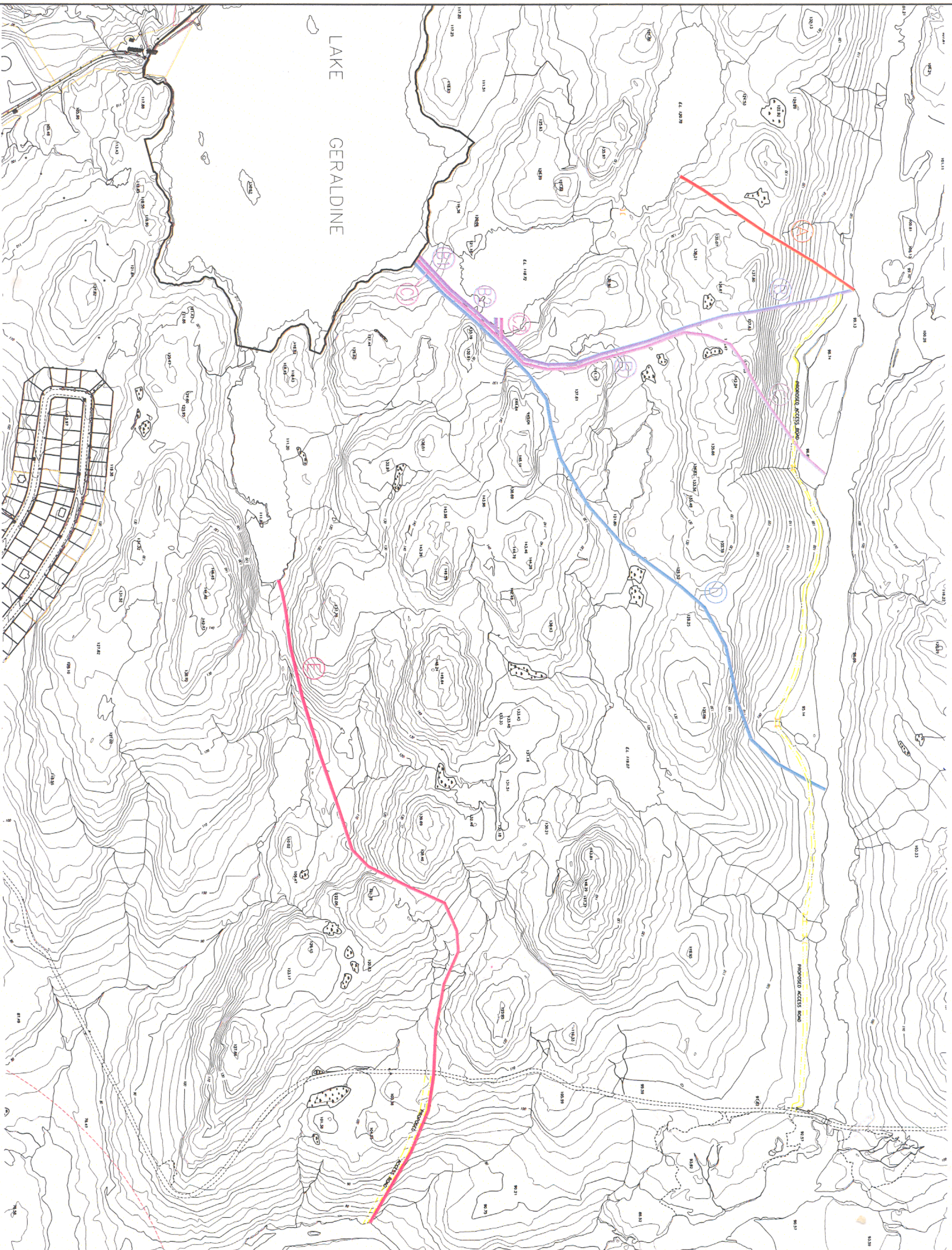
Table 21 - Physical and logistical criteria for alternative withdrawal sites

Criteria	Alternative 1	Alternative 2	Alternative 3	Alternative 4
Watershed	Apex River	Apex River	Town Creek	Sylvia Grinnell
Downstream Population	Apex	Apex	Iqaluit	-
Distance to Lake Geraldine (straight line)	1500 m	800 m	1600 m	5000 m
Proximity to Development	> 1000 m	> 1000 m	50 m	1000 m
Proximity to Road	50 m (Road to Nowhere)	1000 m (Road to Nowhere)	60 m (Paved Road)	20 m (Paved Road)
Heightened Contamination Potential	No	No	Yes (Urban Sources/Old Dump Site)	Yes (Airport)
Potential Water Crossing	Yes	Potentially	Potentially	Yes

6.2.3. Site Selection and Transmission Pathway

As noted on Figure 2, two alternative withdrawal sites have been selected on the Apex River (Alternative 1 and Alternative 2) based on selection criteria as outlined above. The exact water withdrawal location will vary somewhat in relation to these two sites based upon ground truthing of physical conditions of the area and according to comments from the City of Iqaluit, the Department of Fisheries and Oceans and other regulatory bodies.

Illustrated on Figure 3 are proposed withdrawal points on the Apex River as well as the transmission paths between the Apex River and Lake Geraldine. Alternatives B and C are subdivided into two alternative transmission routes each. Transmission pathways include both direct piping from the Apex River to Lake Geraldine (B1 and C1) as well as from the Apex River to an intermediate existing pond which subsequently drains along a natural flow path to Lake Geraldine (B2 and C2). In addition to installation of pump and housing and piping works, an access road extending from the Road to Nowhere to the pump housing will also be required to allow for regular maintenance and monitoring. These are indicated on Figure 3.



SCALE: 1:6000	Trow Associates Inc. 154 Colonnade Road South, Ottawa, Ontario K2E 7J5 Tel: (613) 225-9940 Fax: (613) 225-7337
DATE: JAN 2004	CLIENT: CITY OF IQALUIT
DRAWN: B.K.	TITLE: PROPOSED WITHDRAWAL POINTS & TRANSMISSION PATHS
JOB: OTCD00016888A	
FIG 3	

6.2.4. Required Infrastructure and Capital Costs

Capital costs associated with the construction of works to refill Lake Geraldine via the Apex River include pump purchase and installation, pump housing, pipe installation, and construction of an access road. Table 22 details capital costs in terms of unit cost and installation cost estimates.

Table 22 - Capital costs for pump and transmission

Works	Detail	Unit Cost
Intake Pipe	Cost and Installation at Site	$450/m
Pump	Pump Purchase	$100,000
	Transportation to Site	$100,000
Housing Unit	Building, Fuel Tank	$100,000
Pipe	Gravel Pad	$60/m
	Pipe Purchase	$150/m
	Transport and Installation	$120/m
Access Road	Installation	$100/m
	Culvert	$4000 each

Further to cost estimates provided in Table 22, Table 23 summarizes estimated capital costs for each of the refill alternatives based on withdrawal location and distance from road and to Lake Geraldine. Refer to Appendix D for the detailed cost estimate.

Table 23 - Capital costs for each refill alternative

Alternative	Pipe	Access Road	Culverts	TOTAL
A	360 m	1500 m	4	$800,000
B1	1000 m	1500 m	4	$1,080,000
B2	700 m	1500 m	4	$950,000
C1	1000 m	1100 m	4	$1,030,000
C2	650 m	1100 m	4	$870,000
D	1200 m	500 m	2	$1,020,000
E	1050 m	270 m	1	$920,000

6.2.5. Refill Alternative Selection

In addition to capital costs, other factors to be taken into consideration in the selection of the preferred refill alternative include topographic variation, degree of difficulty associated with road construction, use of intermediate storage and accessibility for both maintenance and refuelling purposes. Table 24 includes details regarding the above noted selection criteria as they relate to each alternative.

Table 24 - Physical, logistical and economic considerations of refill alternatives

Alternative	Cost	Maximum Vertical Distance	Road Construction	Intermediate Storage	Accessibility
A	$800,000	28 m	Very Difficult	No	Difficult
B1	$1,080,000	38 m	Very Difficult	No	Difficult
B2	$950,000	38 m	Very Difficult	Yes	Difficult
C1	$1,030,000	42 m	Very Difficult	No	Difficult
C2	$870,000	42 m	Very Difficult	Yes	Difficult
D	$1,020,000	56 m	Average	No	Moderate
E	$920,000	44 m	Average	No	Easy

In terms of cost, each Alternative listed in Table 24 has a relatively similar capital cost associated with the construction of pumping unit and transmission pathway from the source to Lake Geraldine. On the basis of dependence on two naturally interconnected intermediate storage cells as part of the transmission pathway and associated risks with this path, Alternative A is removed from the candidate list. Due to difficulty of construction of an access road along the southern boundary of the Apex River, particularly through the steep rock face indicated on Figure 3, and dependence on an intermediate storage cell, Alternatives B1, B2, C1 and C2 are also removed from the candidate list. Of the remaining candidates, Alternatives D has a moderate accessibility and greater vertical distance to overcome as compared to Alternative E. Furthermore, due to the convenient accessibility of Alternative E which is situated less than 300 metres from the Road to Nowhere, it is selected as the preferred Alternative for the purposes of refilling Lake Geraldine.

In addition to recommending Alternative E as the preferred permanent withdrawal and transmission alternative, it is also recommended that interim temporary works installed to address short-term needs follow the same path.

7.0 Conclusions and Recommendations

7.1. Conclusions

Based on the above analysis, the following conclusions are made:

(1) The City of Iqaluit currently has a population of 6,200 people. The population is estimated to increase to 12,000 by 2023.

(2) Based on two months of record provided by the City, the average water demand for both piped and trucked water supply is 241 litres per capita per day. A consumption rate of 400 litres per capita day is applied to calculations regarding forecasting of future growth and associated consumption trends for the City of Iqaluit. This represents a conservative estimate for future planning as per comments from the Director of Engineering and Planning for the City of Iqaluit. Ultimately, the 20-year design requirement is based on a population of 12,000 people and a consumption rate of 400 litres per person per day.

(3) The average daily water consumption is estimated to range between 2,000 m^3/day and 3,500 m^3/day within 10 years. Furthermore, this consumption rate is estimated to reach 2,900 m^3/day to 4,800 m^3/day within 20 years..

(4) A runoff ratio of 0.60 was applied to the Lake Geraldine Basin based on calculations for the Apex River which has similar location, topography and climate. An average yearly precipitation of 419 mm results in 1,210,000 cubic metres of runoff. Runoff is reduced to 485,000 cubic metres in the event of a 1:100-year low total precipitation year.

(5) The over-winter period is defined to include October 1 through to May 31, a total of 244 days. The over-winter period length varies from year to year and is considered to be a conservative estimate that incorporates a margin of safety for the identification of key dates for action to address water supply and shortage concerns.

(6) Supply volumes from the contributing basin will not be sufficient enough to replenish the reservoir to full capacity prior to the over-winter period.

(7) The present storage capacity of the Lake Geraldine Reservoir is not adequate to satisfy future demand by the City.

(8) The two viable alternatives to satisfying over-winter storage capacity requirements for the City of Iqaluit include: (1) to raise the existing dam, and (2) to create additional storage capacity in the existing reservoir. Based on the comparative costs of the two storage alternatives, raising of the dam is selected as the preferred alternative.

(9) Raising of the dam by 2.0 metres generally provides sufficient storage through to the year 2023 based on a demand of 400 litres per person per day.

(10) Raising of the dam by 2.0 metres is estimated to cost approximately $1.9 million. A detailed structural analysis must be completed at the preliminary study stage to determine the maximum height that the dam can be raised. Costs may increase if the structural analysis determines that more substantial work is required to raise the dam.

(11) The City of Iqaluit cannot delay actions required to address recharge of the reservoir. A withdrawal site located approximately 270 metres south of the Road to Nowhere along the Apex River with transmission path extending to Lake Geraldine is selected as the preferred permanent refill alternative. This alternative is also recommended as a suitable location for temporary works installed to address short-term needs.

7.2. Recommendations

Based on the analysis presented here, it is recommended that:

(1) The City should establish a monitoring protocol in the short term whereby snow accumulation and yearly precipitation trends are recorded then reviewed and impacts on water supply are forecasted. Based on this information, total spring runoff from the contributing basin can be estimated and subsequent actions to supplement this runoff can be established if required. Water level fluctuations in the reservoir should also be closely monitored in conjunction with precipitation data and consumption records.

(2) Preliminary design of works to address storage needs via raising of the dam should begin immediately.

(3) Preliminary design of works required to address reservoir refill should begin immediately.

(4) The City must consult with the Department of Fisheries and Oceans at the preliminary design stage to confirm issues to be addressed regarding withdrawal location and transmission pathway.

(5) Begin preparing interim temporary works installed to address short-term refill needs following the preferred Alternative selected in this report.

(6) At the preliminary design stage, the City should review recent population and consumption rates and compare them with the findings of this report.

(7) During the preliminary design stage, a detailed review of dam structural stability and maximum height must be completed. As well, the City must consult the Department of Fisheries and Oceans regarding downstream impacts related to impoundment.

(8) Consider excavation of fill material from within Lake Geraldine for purposes of damming and dyking to maximize storage capacity within the reservoir.

(9) Promote public awareness of the importance of water conservation to reduce growth in demand.

Trow Associates Inc.

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Appendix A –
Refill Alternative Location Photographs

Picture 1 – **Alternative #1** – View of Apex River looking northwest from the Road to Nowhere

Picture 2 – **Alternative #1** – View of Apex River looking southwest with the Road to Nowhere in the background.

Picture 3 – **Alternative #2** – View of Apex River looking northwest from the Road to Nowhere

Picture 4 – **Alternative #2** – View of Apex River from Road to Nowhere

Picture 5 – **Alternative #3** – View of creek flowing through Town watershed

Picture 6 – **Alternative #3** – View of creek flowing through Town watershed

Appendix B – Over-Winter Drawdown Calculations

OTCD00016888A - City of Iqaluit - Water Supply Forecasting (Dec 3, 2003)

						CONSUMPTION				DEPTH AFTER ICE				DEPTH AFTER CONSUMPTION		
			Total	Monthly		2003	2013	2023		2003	2013	2023		2003	2013	2023
			Freeze	Freeze	POP=	6200	8628	12007		6200	8628	12007		6200	8628	12007
			Depth	Depth	lpcd=	241	241	241								
	Days		(m)	(m)		(m3)	(m3)	(m3)								
										START =	**109.3**					
Oct	31		0.1	0.1		46,320	64,460	89,704		109.2	109.2	109.2		109.0	108.9	108.8
Nov	30		0.5	0.4		44,826	62,380	86,811		108.6	108.5	108.4		108.4	108.2	108.0
Dec	31		0.9	0.4		46,320	64,460	89,704		108.0	107.8	107.6		107.8	107.5	107.2
Jan	31		1.2	0.3		46,320	64,460	89,704		107.5	107.2	106.9		107.3	106.8	106.5
Feb	28		1.5	0.3		41,838	58,222	81,023		107.0	106.5	106.2		106.8	106.1	105.7
Mar	31		1.7	0.2		46,320	64,460	89,704		106.6	105.9	105.5		106.3	105.5	104.8
Apr	30		1.8	0.1		44,826	62,380	86,811		106.2	105.4	104.7		105.9	104.9	104.0
May	31		1.9	0.1		46,320	64,460	89,704		105.8	104.8	103.9		**105.5**	**104.3**	**0.0**
Jun	30		0.0	0.0		44,826	62,380	86,811								
Jul	31		thaw	0.0		46,320	64,460	89,704								
Aug	31		0.0	0.0		46,320	64,460	89,704								
Sep	30		0.0	0.0		44,826	62,380	86,811		**START =**	**109.8**					
Oct	31		0.1	0.1		46,320	64,460	89,704		109.7	109.7	109.7		109.6	109.5	109.4
Nov	30		0.5	0.4		44,826	62,380	86,811		109.2	109.1	109.0		109.0	108.8	108.6
Dec	31		0.9	0.4		46,320	64,460	89,704		108.6	108.4	108.2		108.4	108.1	107.8
Jan	31		1.2	0.3		46,320	64,460	89,704		108.1	107.8	107.5		107.9	107.5	107.0
Feb	28		1.5	0.3		41,838	58,222	81,023		107.6	107.2	106.7		107.4	106.9	106.2
Mar	31		1.7	0.2		46,320	64,460	89,704		107.2	106.7	106.0		106.9	106.3	105.4
Apr	30		1.8	0.1		44,826	62,380	86,811		106.8	106.2	105.3		106.6	105.8	104.5
May	31		1.9	0.1		46,320	64,460	89,704		106.5	105.7	104.4		**106.2**	**105.2**	**103.7**
Jun	30		0.0	0.0		44,826	62,380	86,811								
Jul	31		thaw	0.0		46,320	64,460	89,704								
Aug	31		0.0	0.0		46,320	64,460	89,704								
Sep	30		0.0	0.0		44,826	62,380	86,811								

										START =	**110.3**					
Oct	31		0.1	0.1		46,320	64,460	89,704		110.2	110.2	110.2		110.1	110.0	109.9
Nov	30		0.5	0.4		44,826	62,380	86,811		109.7	109.6	109.5		109.6	109.4	109.2
Dec	31		0.9	0.4		46,320	64,460	89,704		109.2	109.0	108.8		109.0	108.7	108.4
Jan	31		1.2	0.3		46,320	64,460	89,704		108.7	108.4	108.1		108.5	108.1	107.7
Feb	28		1.5	0.3		41,838	58,222	81,023		108.2	107.8	107.4		108.0	107.5	106.9
Mar	31		1.7	0.2		46,320	64,460	89,704		107.8	107.3	106.7		107.6	107.0	106.2
Apr	30		1.8	0.1		44,826	62,380	86,811		107.5	106.9	106.1		107.3	106.6	105.6
May	31		1.9	0.1		46,320	64,460	89,704		107.2	106.5	105.5		**106.9**	**106.1**	**104.8**
Jun	30		0.0	0.0		44,826	62,380	86,811								
Jul	31		thaw	0.0		46,320	64,460	89,704								
Aug	31		0.0	0.0		46,320	64,460	89,704								
Sep	30		0.0	0.0		44,826	62,380	86,811		**START =**	**110.8**					
Oct	31		0.1	0.1		46,320	64,460	89,704		110.7	110.7	110.7		110.6	110.5	110.4
Nov	30		0.5	0.4		44,826	62,380	86,811		110.2	110.1	110.0		110.1	109.9	109.8
Dec	31		0.9	0.4		46,320	64,460	89,704		109.7	109.5	109.4		109.5	109.3	109.1
Jan	31		1.2	0.3		46,320	64,460	89,704		109.2	109.0	108.8		109.0	108.7	108.4
Feb	28		1.5	0.3		41,838	58,222	81,023		108.7	108.4	108.1		108.5	108.1	107.7
Mar	31		1.7	0.2		46,320	64,460	89,704		108.3	107.9	107.5		108.1	107.6	107.1
Apr	30		1.8	0.1		44,826	62,380	86,811		108.0	107.5	107.0		107.8	107.2	106.7
May	31		1.9	0.1		46,320	64,460	89,704		107.7	107.1	106.6		**107.5**	**106.8**	**106.1**
Jun	30		0.0	0.0		44,826	62,380	86,811								
Jul	31		thaw	0.0		46,320	64,460	89,704								
Aug	31		0.0	0.0		46,320	64,460	89,704								
Sep	30		0.0	0.0		44,826	62,380	86,811		**START =**	**111.3**					
Oct	31		0.1	0.1		46,320	64,460	89,704		111.2	111.2	111.2		111.1	111.0	110.9
Nov	30		0.5	0.4		44,826	62,380	86,811		110.7	110.6	110.5		110.6	110.4	110.2
Dec	31		0.9	0.4		46,320	64,460	89,704		110.2	110.0	109.8		110.1	109.8	109.5
Jan	31		1.2	0.3		46,320	64,460	89,704		109.8	109.5	109.2		109.7	109.3	108.9
Feb	28		1.5	0.3		41,838	58,222	81,023		109.4	109.0	108.6		109.2	108.7	108.2
Mar	31		1.7	0.2		46,320	64,460	89,704		109.0	108.5	108.0		108.8	108.2	107.8
Apr	30		1.8	0.1		44,826	62,380	86,811		108.7	108.1	107.7		108.5	107.8	107.3
May	31		1.9	0.1		46,320	64,460	89,704		108.4	107.7	107.2		**108.2**	**107.4**	**106.7**
Jun	30		0.0	0.0		44,826	62,380	86,811								
Jul	31		thaw	0.0		46,320	64,460	89,704								
Aug	31		0.0	0.0		46,320	64,460	89,704								

						CONSUMPTION				DEPTH AFTER ICE				DEPTH AFTER CONSUMPTION		
			Total	Monthly			2013	2023		2003	2013	2023		2003	2013	2023
			Freeze	Freeze	POP=		8628	12007		6200	8628	12007		6200	8628	12007
			Depth	Depth	lpcd=		320	400								
	Days		(m)	(m)		(m3)	(m3)	(m3)								
Sep	30		0.0	0.0						**START =**	**109.3**					
Oct	31		0.1	0.1			85,590	148,887			109.2	109.2			108.8	108.6
Nov	30		0.5	0.4			82,829	144,084			108.4	108.2			108.0	107.6
Dec	31		0.9	0.4			85,590	148,887			107.6	107.2			107.2	106.4
Jan	31		1.2	0.3			85,590	148,887			106.9	106.1			106.5	105.1
Feb	28		1.5	0.3			77,307	134,478			106.2	104.8			105.7	103.6
Mar	31		1.7	0.2			85,590	148,887			105.5	103.4			104.8	0.0
Apr	30		1.8	0.1			82,829	144,084			104.7	0.0			103.9	0.0
May	31		1.9	0.1			85,590	148,887			103.8	0.0			0.0	0.0
Jun	30		0.0	0.0			82,829	144,084								
Jul	31		thaw	0.0			85,590	148,887								
Aug	31		0.0	0.0			85,590	148,887								
Sep	30		0.0	0.0			82,829	144,084		**START =**	**109.8**					
Oct	31		0.1	0.1			85,590	148,887			109.7	109.7			109.5	109.3
Nov	30		0.5	0.4			82,829	144,084			109.1	108.9			108.8	108.3
Dec	31		0.9	0.4			85,590	148,887			108.4	107.9			108.0	107.2
Jan	31		1.2	0.3			85,590	148,887			107.7	106.9			107.4	106.1
Feb	28		1.5	0.3			77,307	134,478			107.1	105.8			106.3	104.8
Mar	31		1.7	0.2			85,590	148,887			106.5	104.6			106.0	103.4
Apr	30		1.8	0.1			82,829	144,084			105.9	103.3			105.3	0.0
May	31		1.9	0.1			85,590	148,887			105.2	0.0			104.5	0.0
Jun	30		0.0	0.0			82,829	144,084								
Jul	31		thaw	0.0			85,590	148,887								
Aug	31		0.0	0.0			85,590	148,887								
Sep	30		0.0	0.0			82,829	144,084		**START =**	**110.3**					
Oct	31		0.1	0.1			85,590	148,887			110.2	110.2			110.0	109.8
Nov	30		0.5	0.4			82,829	144,084			109.6	109.4			109.3	108.8
Dec	31		0.9	0.4			85,590	148,887			108.9	108.4			108.5	107.8
Jan	31		1.2	0.3			85,590	148,887			108.2	107.5			107.8	106.8
Feb	28		1.5	0.3			77,307	134,478			107.5	106.5			107.1	105.6
Mar	31		1.7	0.2			85,590	148,887			106.9	105.4			106.5	104.2

Apr	30		1.8	0.1			82,829	144,084			106.3	104.0			105.8	0.0
May	31		1.9	0.1			85,590	148,887			105.7	0.0			105.1	0.0
Jun	30		0.0	0.0			82,829	144,084								
Jul	31		thaw	0.0			85,590	148,887								
Aug	31		0.0	0.0			85,590	148,887								
Sep	30		0.0	0.0			82,829	144,084		**START =**	**110.8**					
Oct	31		0.1	0.1			85,590	148,887			110.7	110.7			110.5	110.3
Nov	30		0.5	0.4			82,829	144,084			110.1	109.9			109.9	109.5
Dec	31		0.9	0.4			85,590	148,887			109.5	109.1			109.2	108.4
Jan	31		1.2	0.3			85,590	148,887			108.9	108.1			108.5	107.5
Feb	28		1.5	0.3			77,307	134,478			108.2	107.2			107.8	106.4
Mar	31		1.7	0.2			85,590	148,887			107.6	106.2			107.3	105.3
Apr	30		1.8	0.1			82,829	144,084			107.2	105.2			106.8	104.0
May	31		1.9	0.1			85,590	148,887			106.7	103.9			106.2	0.0
Jun	30		0.0	0.0			82,829	144,084								
Jul	31		thaw	0.0			85,590	148,887								
Aug	31		0.0	0.0			85,590	148,887								
Sep	30		0.0	0.0			82,829	144,084		**START =**	**111.3**					
Oct	31		0.1	0.1			85,590	148,887			111.2	111.2			111.0	110.8
Nov	30		0.5	0.4			82,829	144,084			110.6	110.4			110.3	110.0
Dec	31		0.9	0.4			85,590	148,887			109.9	109.6			109.7	109.2
Jan	31		1.2	0.3			85,590	148,887			109.4	108.9			109.1	108.2
Feb	28		1.5	0.3			77,307	134,478			108.8	107.9			108.5	107.2
Mar	31		1.7	0.2			85,590	148,887			108.3	107.0			107.9	106.2
Apr	30		1.8	0.1			82,829	144,084			107.8	106.1			107.4	105.1
May	31		1.9	0.1			85,590	148,887			107.3	105.0			106.8	103.8
Jun	30		0.0	0.0			82,829	144,084								
Jul	31		thaw	0.0			85,590	148,887								
Aug	31		0.0	0.0			85,590	148,887								
Sep	30		0.0	0.0			82,829	144,084								

						CONSUMPTION				**DEPTH AFTER ICE**				**DEPTH AFTER CONSUMPTION**		
			Total	Monthly			2013			2003	2013	2023		2003	2013	2023
			Freeze	Freeze	POP=		8628			6200	8628	12007		6200	8628	12007
			Depth	Depth	lpcd=		400									
	Days		(m)	(m)		(m3)	(m3)	(m3)								
Sep	30		0.0	0.0						**START =**	**109.3**					
Oct	31		0.1	0.1			106,987				109.2				108.7	
Nov	30		0.5	0.4			103,536				108.3				107.8	
Dec	31		0.9	0.4			106,987				107.4				106.9	
Jan	31		1.2	0.3			106,987				106.6				105.9	
Feb	28		1.5	0.3			96,634				105.6				104.7	
Mar	31		1.7	0.2			106,987				104.5				103.6	
Apr	30		1.8	0.1			103,536				103.5				0.0	
May	31		1.9	0.1			106,987									
Jun	30		0.0	0.0			103,536									
Jul	31		thaw	0.0			106,987									
Aug	31		0.0	0.0			106,987									
Sep	30		0.0	0.0			103,536			**START =**	**109.8**					
Oct	31		0.1	0.1			106,987				109.7				109.4	
Nov	30		0.5	0.4			103,536				109.0				108.5	
Dec	31		0.9	0.4			106,987				108.1				107.6	
Jan	31		1.2	0.3			106,987				107.3				106.7	
Feb	28		1.5	0.3			96,634				106.4				105.8	
Mar	31		1.7	0.2			106,987				105.6				104.7	
Apr	30		1.8	0.1			103,536				104.6				103.8	
May	31		1.9	0.1			106,987				103.7				0.0	
Jun	30		0.0	0.0			103,536									
Jul	31		thaw	0.0			106,987									
Aug	31		0.0	0.0			106,987									

Sep	30		0.0	0.0			103,536			**START =**	**110.3**					
Oct	31		0.1	0.1			106,987				110.2				109.9	
Nov	30		0.5	0.4			103,536				109.5				109.2	
Dec	31		0.9	0.4			106,987				108.8				108.3	
Jan	31		1.2	0.3			106,987				108.0				107.5	
Feb	28		1.5	0.3			96,634				107.2				106.7	
Mar	31		1.7	0.2			106,987				106.5				105.8	
Apr	30		1.8	0.1			103,536				105.7				104.9	
May	31		1.9	0.1			106,987				104.8				104.0	
Jun	30		0.0	0.0			103,536									
Jul	31		thaw	0.0			106,987									
Aug	31		0.0	0.0			106,987									
Sep	30		0.0	0.0			103,536			**START =**	**110.8**					
Oct	31		0.1	0.1			106,987				110.7				110.4	
Nov	30		0.5	0.4			103,536				110.0				109.7	
Dec	31		0.9	0.4			106,987				109.3				108.9	
Jan	31		1.2	0.3			106,987				108.5				108.0	
Feb	28		1.5	0.3			96,634				107.7				107.2	
Mar	31		1.7	0.2			106,987				107.0				106.5	
Apr	30		1.8	0.1			103,536				106.4				105.8	
May	31		1.9	0.1			106,987				105.7				104.9	
Jun	30		0.0	0.0			103,536									
Jul	31		thaw	0.0			106,987									
Aug	31		0.0	0.0			106,987									
Sep	30		0.0	0.0			103,536			**START =**	**111.3**					
Oct	31		0.1	0.1			106,987				111.2				110.9	
Nov	30		0.5	0.4			103,536				110.5				110.2	
Dec	31		0.9	0.4			106,987				109.8				109.5	
Jan	31		1.2	0.3			106,987				109.2				108.8	
Feb	28		1.5	0.3			96,634				108.5				108.0	
Mar	31		1.7	0.2			106,987				107.8				107.3	
Apr	30		1.8	0.1			103,536				107.2				107.1	
May	31		1.9	0.1			106,987				107.0				106.4	
Jun	30		0.0	0.0			103,536									
Jul	31		thaw	0.0			106,987									
Aug	31		0.0	0.0			106,987									
Sep	30		0.0	0.0			103,536									

Appendix C –
Dam Raise Costs

OTCD00016888 - Iqaluit Water Storage and Supply - Dam Capital Costs

[1] Rock Anchors				
(a) Crew Costs	Labour 5 men @ $50/hour @ 10 hour/day	$2,500		
	Equipment Cost/Day	$3,500		
	Daily Cost	$6,000		
	Construction Period - 25 days	$150,000		
(b) Materials		$30,000		
		TOTAL	$180,000	
[2] Concrete at Spillway (Raise 1.5 m)				
(a) Concrete 220 m3 @ $1000		$220,000		
(b) Labour to form and place				
	18 days - 4 men @ 10 hours/day @ $50/hour	$36,000		
(c) Materials		$5,000		
		TOTAL	$261,000	
[3] Concrete for Remainder of Dam and Cut Off Wall (Raise 1.5 m)				
(a) Concrete for 220 m3 @ $1000		$220,000		
(b) Labour	18 days - 4 men @ 10 hours/day @ $50/hour	$36,000		
(c) Materials		$20,000		
		TOTAL	$276,000	
[4] Fill Material for Berm Surrounding Cutoff Wall (Additional 1.5 m)				
(a) Berm	6,400 m3 @ $80/m3	$512,000		
(b) Labour	12 days - 4 men @ 10 hours/day @ $50/hour	$24,000		
		TOTAL	$536,000	
[5] Diving				
(a) Diving 10 days @ $2,500/day		$25,000		
(b) Mobilization		$10,000		
		TOTAL	$35,000	
[6] Berm and Cutoff Wall 130 m East of Dam				
(a) Concrete	Concrete for Cutoff Wall - 23 m3 @ $1000/m3	$23,000		
(b) Fill	Berm Fill Material - 400 m3 @ $80/m3	$32,000		
(c) Crew Costs	12 days - 4 men @ 10 hours/day @ $50/hour	$24,000		
		TOTAL	$79,000	
	GRAND TOTAL		$1,367,000	
	Contingency (20%)		$273,400	
	Engineering (15%)		$205,050	
		TOTAL	$1,845,450	

Appendix D –
Refill Alternative Costs

Capital cost estimates for Lake Geraldine Refill Alternatives

Engineering = 15%
Contingency = 20%

Alternative	Pipe (m)	Pipe $330/m	Access Road (m)	Access Road $100/m	Culverts	Culverts $4000 each	Pump, Housing and 10 m intake	*Subtotal*	*TOTAL*
Alternative A	360	$118,800	1500	$150,000	4	$16,000	$304,500	*$589,300*	**$795,555**
Alternative B1	1000	$330,000	1500	$150,000	4	$16,000	$304,500	*$800,500*	**$1,080,675**
Alternative B2	700	$231,000	1500	$150,000	4	$16,000	$304,500	*$701,500*	**$947,025**
Alternative C1	1000	$330,000	1100	$110,000	4	$16,000	$304,500	*$760,500*	**$1,026,675**
Alternative C2	650	$214,500	1100	$110,000	4	$16,000	$304,500	*$645,000*	**$870,750**
Alternative D	1200	$396,000	500	$50,000	2	$8,000	$304,500	*$758,500*	**$1,023,975**
Alternative E	1050	$346,500	270	$27,000	1	$4,000	$304,500	*$682,000*	**$920,700**