TECHNICAL MEMORANDUM

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TO Josip Deronja, Senior Project Manager
Colliers Project Leaders

CC Project File

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SUPPLEMENTARY LAKE GERALDINE WATER BALANCE MODELLING

1.0 INTRODUCTION

This technical memorandum has been prepared by Golder Associates Limited (Golder) for Colliers Project Leaders (Colliers) on behalf of the City of Iqaluit (the City) to provide additional water supply forecasting estimates to an earlier water balance report prepared by Golder in 2013, and updated estimates provided during the 2018 ice-free season. In order to minimise the risk of misinterpretation, the information presented in this technical memorandum should be read and interpreted in conjunction with Golder (2013) and Golder (2018a/b/c).

1.1 Background

The City of Iqaluit depends on the Lake Geraldine reservoir for its year-round municipal water supply. Given that the reservoir is frozen over for approximately eight months of the year, raw water supplies at the end of summer need to be sufficient to service the City over the following winter until snowmelt runoff replenishes the reservoir during the next spring melt period.

The City has commissioned a number of studies in recent years which suggest that the existing reservoir will not be able to supply sufficient water over the long term to meet growing demands. A number of supplementary water supply alternatives were investigated by Trow in 2004 leading to recommendations to (i) increase the storage capacity of the reservoir and (ii) identify a suitable supplementation source that may be used to augment water supplies during the ice-free period on a needs-must basis.

The height of the Lake Geraldine reservoir was subsequently increased by two meters in 2006, however, it is understood that regulatory limits for water takings from the nearby Apex River have prevented the implementation of a suitable water supply supplementation system at this time. Based on recent communications with Colliers (2019), it is Golder's understanding that the City of Iqaluit is engaged in planning activities in the unlikely event that the Lake Geraldine reservoir will need to be further supplemented during 2019 ice-free period to provide for adequate water supplies over the 2019/2020 winter.

1.2 Objectives

The purpose of this technical memorandum is to provide additional water supply forecasting estimates that may be used by the City of Iqaluit to identify a suitable water supply solution during the 2019 ice-free period. To this end, the City has specifically requested that Golder address the study objectives by determining:

1) The accuracy of the existing model via completion of a validation exercise focused on comparing modelled water levels at Lake Geraldine against a subset of measured water levels collected over a one-year period, noting that the validation period was reduced by 74 days to exclude significant periods of missing meteorological data;

2) The amount of precipitation and meteorological surplus that can be expected during the remaining ice-free period and to what elevation would this fill the reservoir at various consumption rates identified later in this document;

3) The predicted Lake Geraldine water storage deficit at the end of 2019 ice-free season, at various consumption rates identified later in this document;

4) The amount of precipitation and meteorological surplus that would be required to replenish the reservoir from 109.67 masl (recorded on 18 June, 2019) to as close as possible to its design level of 111.3 masl at the end of 2019 ice-free season, at various consumption rates identified later in this document; and,

5) Minimum, average and maximum daily evaporative losses from Lake Geraldine by month as a function of reservoir level.

In addressing these uncertainties, it is noted that the limiting effects of evapotranspiration and soil and depression storage mean that only a portion of precipitation within the Lake Geraldine catchment (referred to as meteorological surplus) will translate into recharge of the reservoir. For ease of interpretation, this technical memorandum thus presents corresponding estimates for both precipitation and surplus.

It should also be noted that the City's original mandate included the provision of 2018/2019 snowfall accumulation and thaw estimates as these relate to replenishment of reservoir supplies. For two reasons, including significant overwinter precipitation data gaps as well as an earlier than expected onset of the spring freshet, this objective has been excluded from the study at this time.

2.0 METHODOLOGY

The methods employed for this investigation are generally consistent with, and limited by previous assumptions incorporated into, the approach documented in Golder (2013) and Golder (2018a/b/c). A brief summary of the 2019 approach, and a detailed inventory of any modifications to this approach, is provided below for context.

2.1 Consistencies with the 2018 Modelling Approach

As noted previously, the methods employed for this investigation are largely premised on, and consistent with, the model setup developed in 2013 and the approach and results reported in 2018. Specifically, consistencies with the previous approach include:

2.1.1 Catchment and Basin Physiography

The physiographic representation of the contributing catchment and reservoir basin within the model have remained unchanged since 2013. Specifically, this maintains consistency with the approach used to characterise the surficial geology, topography and size of the drainage catchment as well as Lake Geraldine's bathymetry and stage-storage relationship.

It should be noted that recent communications with Nunami Stantec (June 2, 2019) suggest that relative to the digital elevation model representation derived using survey data received from Natural Resources Canada (2008), Lake's Geraldine's active stage-storage capacity may have been reduced by up to 195,000 m^3 (from 1,875,000 m^3 estimated by Golder to 1,680,000 m^3 estimated by Nunami Stantec). Formal validation of this change in physiography has not been presented at the time of reporting.

If the revised stage-storage curve (Nunami Stantec 2019) is indeed validated, the implications of the potentially reduced storage capacity on reservoir supplies and supplementation requirements are numerous are complex, but can be conceptually summarised as follows:

- A higher proportion of catchment snowmelt and rainfall runoff generated early in the open-water season may be lost to reservoir overflows during the early summer than simulated within the existing Lake Geraldine model;
- The supplementation volumes required to fill the reservoir prior to freeze-up could be lower for some meteorological conditions than presented in this technical memorandum;
- The volumetric consequences of over-winter ice storage may be a greater risk to over-winter water supplies than presented in this technical memorandum; and,
- The risk of exhausting water supplies prior to freshet is likely to be greater than considered in this technical memorandum.

Notwithstanding these differences, it is recommended that the City of Iqaluit use the higher end of water supply deficit values provided throughout this document as guidance for supplementation planning rather than risk an underestimate of supplementation volumes that could result in insufficient overwinter supplies.

2.1.2 Water Level Control and Intake Infrastructure

All basin inputs generated by measured meteorological inputs and water supplies accumulated within the reservoir are constrained by the same spillway and intake configuration developed in the 2013 model.

As such, any inputs beyond the reservoir's active 1,875,526 m^3 storage capacity are assumed to be lost from the system. Similarly, any water below the assumed intake invert of 101.6 masl is assumed to be inaccessible for municipal use. It should be noted, that according to recent communications from Nunami Stantec *(June 2, 2019)*, the reservoir morphology defined from data collected by Natural Resources Canada (2008) may be outdated, although this is subject to formal validation.

2.1.3 Ice Storage

All ice formed within the reservoir is assumed to be inaccessible, and commensurately diminishes available water supplies, until the following spring freshet.

2.1.4 Water Balance Formulation

The calculation of basin yields and reservoir supplies is identical to that detailed in Golder (2018a/b/c) and Golder (2013).

Catchment yield, or surplus, is calculated as follows:

(Rainfall + Snowmelt) - (Evapotranspiration + Sublimation) – Change in Available Soil Storage = Surplus (Runoff)

2.1.5 Water Consumption and Intake Withdrawal Rates

The water balance investigation presented herein instead considers three different consumption rates as used in Golder (2018a/b/c) for specific examination, including:

- No Water Consumption Scenario - 0 m^3/day;
- 100,000 m^3/month Water Consumption Scenario - 3,335 m^3/day; and,
- 115,000 m^3/month Water Consumption Scenario - 3,850 m^3/day.

2.1.6 Meteorology

The same meteorological dataset used in Golder (2018a/b/c), featuring precipitation, air temperature, wind speed and relative humidity records for the 2008 through 2017 period, was applied to this study. As a reminder of the 2018a/b/c approach, meteorological records were obtained predominantly obtained for Iqaluit Climate (Station ID: 2402592) and supplemented with data from the four overlapping years (2008 through 2011) of data recorded at Iqaluit A (Station ID: 2402590). A few minor remaining data gaps of a few days or less were identified for wind speed and relative humidity (both used in the determination of potential evapotranspiration estimates) as well as precipitation and air temperature. To develop a complete meteorological record for the water balance model, these data gaps were filled using linear interpolation.

2.2 Updates to the 2019 Modelling Approach

The following subsection documents changes made to the 2018 water balance model in order to accommodate the particulars of the 2019 scope of work.

2.2.1 Validation Period

For the purposes of model validation, meteorological and water level data for the period July 22, 2018 through May 9, 2019 was sourced from station Iqaluit Climate (Station ID: 2402592) – and linearly interpolated to fill data gaps – and water level data from the Real-Time Hydrometric Portal, Station 10UH013 (ECCC 2019).

Snowfall accumulation estimates could not be completed using the model owing to significant periods of missing overwinter precipitation data which would render accumulation and melt estimates unreliable. Accordingly, the model validation period was reduced from one year to a 291-day period.

2.2.2 Water Level, Snowpack and Ice Cover Initial Condition

In keeping with the Golder (2018a/b/c) approach, a water level condition (109.67 masl) recorded at Lake Geraldine Near Iqaluit (10UH013) on June 18, 2019 was used to initialise the model. It is noted, that in the absence of any confirmatory reports, model catchment snow cover and reservoir ice cover were assumed to already be assimilated into the reservoir following melt and, thus, may lead to slight underestimates of reservoir supplies. For context, it is considered highly likely that the reservoir still contains ice at the outset of the 2019 simulation period.

3.0 ASSUMPTIONS AND LIMITATIONS

The analyses, results and discussion included in this technical memorandum are presented in good faith and limited by a number of assumptions, including:

- Assumptions and Limitations presented in Golder 2013, Golder 2018a/b/c and the covering proposal entitled Proposal for Lake Geraldine Water Balance Assessment submitted to the City of Iqaluit by Golder Associates Ltd. on May 16, 2019 at 3:08 pm;
- Recent communications from Nunami Stantec (June 2, 2019) suggest that Lake's Geraldine's active storage capacity may have been reduced relative to the digital elevation model representation derived from Natural Resources Canada (2008), however, formal validation of this change in physiography could not be confirmed at the time of reporting. If the Nunami Stantec storage estimate is confirmed as valid, available water supplies as well as storage deficits could be lower than reported in this document;
- No residual snow and ice cover are assumed to remain within the Lake Geraldine watershed on the simulation initialisation date of June 18, 2019 that could contribute water supplies to Lake Geraldine reservoir. This is considered to result in a conservative prediction of water levels over the remaining melt period;
- The water level condition on June 18 corresponds with the period where thaw usually occurs. As this is a transitional short period associated with a large amount of surplus, as a result of spring freshet and melt of snow in the catchment, the uncertainty regarding meteorological surplus is larger during the month of June;
- For the purposes of simulating evapotranspiration losses from Lake Geraldine's water surface, the model assumes a surface area equivalent to the maximum design elevation of the reservoir. This is conservative because evapotranspiration losses will typically be lower given the reduced surface area of the reservoir at lower elevations;
- The predicted water supply deficit is estimated as the difference between the maximum capacity of Lake Geraldine at the spillway elevation and the available volume of water at the predicted freeze-up date of each simulation year;
- Available reservoir volumes are independent of the effects of antecedent weather conditions or consumption losses and are initialised based on a measured June 18 water level of for each year;
- Estimates of necessary precipitation and meteorological surpluses are represented as percentage increases of rainfall during historically recorded rainfall days; accordingly, no increase in the number of rainfall days has been allowed for in the modelling;
- The probability distributions of historic and predicted meteorological conditions are calculated as independent variables as later explained in Section 4; and,
- Freeze up is identified as the earliest day, following the summer season, when the preceding 14 average is lower than -1°C, in order to prevent false identification of the freeze-up day, a secondary condition is

imposed, requiring that the maximum temperature in the period corresponding with 14 to 28 days prior to the freeze-up date, to be larger than 2°C.

4.0 MODEL VALIDATION

The GoldSim model was validated against measured water levels in Lake Geraldine from June 22, 2018 (the approximate beginning of the 2018 ice-free period) to May 9, 2019 (prior to commencement of thaw), corresponding with the lowest water level modelled during the 2018/2019 winter.

Model performance was evaluated by comparing model predicted water levels against observed water levels (when available) visually for qualitative evaluation of modelled water level responsiveness and using Root Mean Squared Error (i.e. the magnitude of standardised error over the period examined). The validation process is beneficial as it provides a reasonable indication of confidence in predictions as well as identifying periods when model accuracy demonstrates increased or decreased performance.

Visual comparison of modelled and measured water levels suggests the model provides reasonable replication of responsiveness to the underlying mechanics of consumption, rainfall and evapotranspiration. Mode RMSE over the period of comparison, June 22, 2018 to May 9, 2019, is 17 cm, which corresponds to a volume of between 9,300 m^3 at the intake invert (101.6 masl) and 58,600 m^3 at full board (111.33 masl). The RMSE on the last day of comparison, May 9, 2019, is 16 cm, which corresponds to a 46,400 m^3 overestimate in water supply at the end of winter.

It should be note that the validation exercise was complicated through substantial amounts of missing precipitation data as shown on Figure 1 which were supplemented through linear interpolation leading to uncertainty and the possibility of underestimated or overestimated rainfall. Commentary regarding period performance (between each vertical line enumerated below) as well as these challenges is provided below.

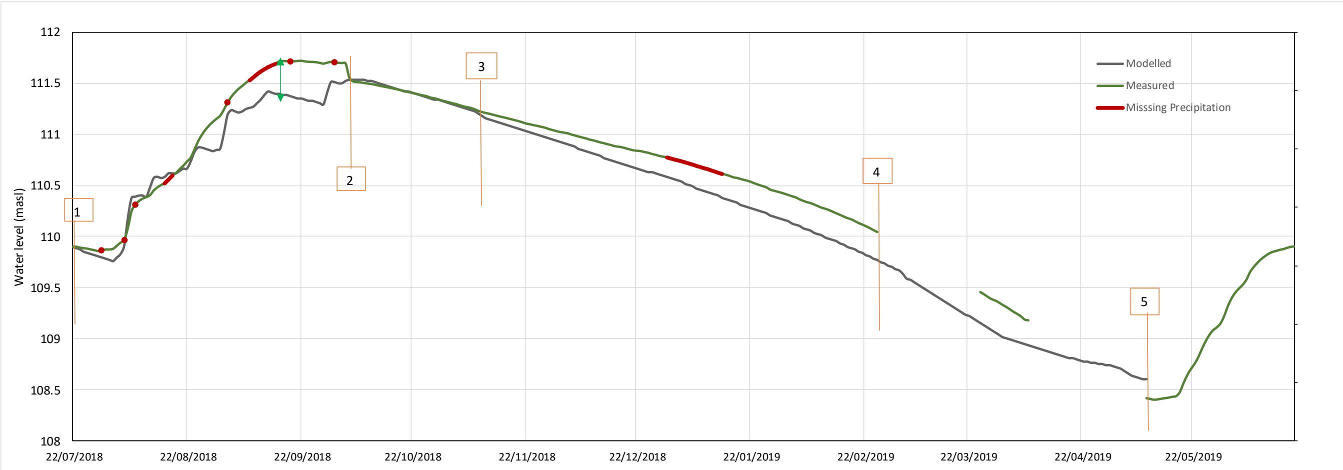

Figure 1: Visual Comparison of Modelled and Measured Water Levels, Including Periods of Missing Precipitation Data

- Period 1-2 (July 22, 2018 through October 5, 2018)
  - Missing precipitation data (13 days) during this period compromises the model's ability to estimate reservoir water levels.

- An unexplained sharp decrease in reservoir levels observed just before October 5 compensates for earlier divergences due to missing precipitation data.

- Period 2-3 (October 6, 2018 through November 9, 2018
  - A reasonable replication of measured water level reductions occurs during this period, likely following the earlier period of maximum ice development.
  - Only two days of missing precipitation data are evidenced and likely do not compromise predictions as these may have been low or occurred in the form of snowfall.
  - Unexpectedly, no observable water level response is identified as a result to reported fire fighting activities at the end of this period.
- Period 3-4 (November 10, 2018 through February 25, 2019)
  - A likely overestimate in ice formation leads to an overestimate of water level reductions in the reservoir. Although initially similar, the predicted rate of ice development outpaces that observed from water level records.
  - As expected, missing precipitation data (16 days) starting from 30 December 2018 to 14 January 2019, falling as snow, do not compromise water level predictions.
- Period 4-5 (February 26, 2019 through May 9, 2019)
  - Substantial periods of missing water level data mean a detailed comparison of transition between underprediction and overprediction cannot be made.
- Period 5 (May 9, 2019)
  - An overestimate of 16 cm of water supplies is identified, corresponding to approximately 46,400 m^3.

5.0 PREDICTED MONTHLY EVAPORATIVE LOSSES

This section of the report is presented in order to offer the City some insight into the extent to which evaporative losses can differ between different climatic years and, in particular, to what degree evaporative losses from the reservoir increase with stage. This information may be helpful for City planners when scheduling supplementation of water from alternate sources.

As shown in Table 1 and on Figure 2 below, evaporative losses from the reservoir are approximately 7 times greater at full stage than when water levels are at the elevation of the assumed intake invert (101.6 masl). As expected, evaporative losses tend to peak during the month of July and are lowest in September (as little as one third of July evaporative losses) during the final month before freeze-up occurs. It should be noted that variations in cloudiness and precipitation distribution from year to year may influence the tabulated results and caution is recommended.

Table 1: The Effect of Reservoir Level on Predicted Daily Evaporative Rates by Month over the 2008 through 2017 Period of Record

Level	June - Loss to Evaporation (m^3/day)			July - Loss to Evaporation m^3/day)			August - Loss to Evaporation (m^3/day)			September - Loss to Evaporation (m^3/day)		
masl	Min	Median	Max	Min	Median	Max	Min	Median	Max	Min	Median	Max
98.33	13	16	21	13	18	23	12	14	14	5	6	8
99.33	13	16	21	13	18	23	12	14	14	5	6	8
100.33	24	28	38	23	33	42	21	24	26	10	11	14
101.33	40	47	64	38	55	71	35	41	44	16	19	24
102.33	67	78	107	64	92	117	59	68	72	27	31	39
103.33	104	123	167	99	143	183	92	106	113	42	48	61
104.33	132	156	212	126	182	232	116	135	144	53	61	78
105.33	167	196	267	159	230	293	147	170	181	67	77	98
106.33	212	249	339	202	291	372	186	216	230	85	97	124
107.33	253	297	404	241	347	444	222	257	274	102	116	148
108.33	292	344	468	279	402	513	257	298	318	118	134	171
109.33	332	390	530	316	456	582	291	338	360	133	152	194
110.33	361	424	577	344	496	633	317	367	392	145	166	211
111.33	374	440	599	357	515	657	329	381	407	150	172	220

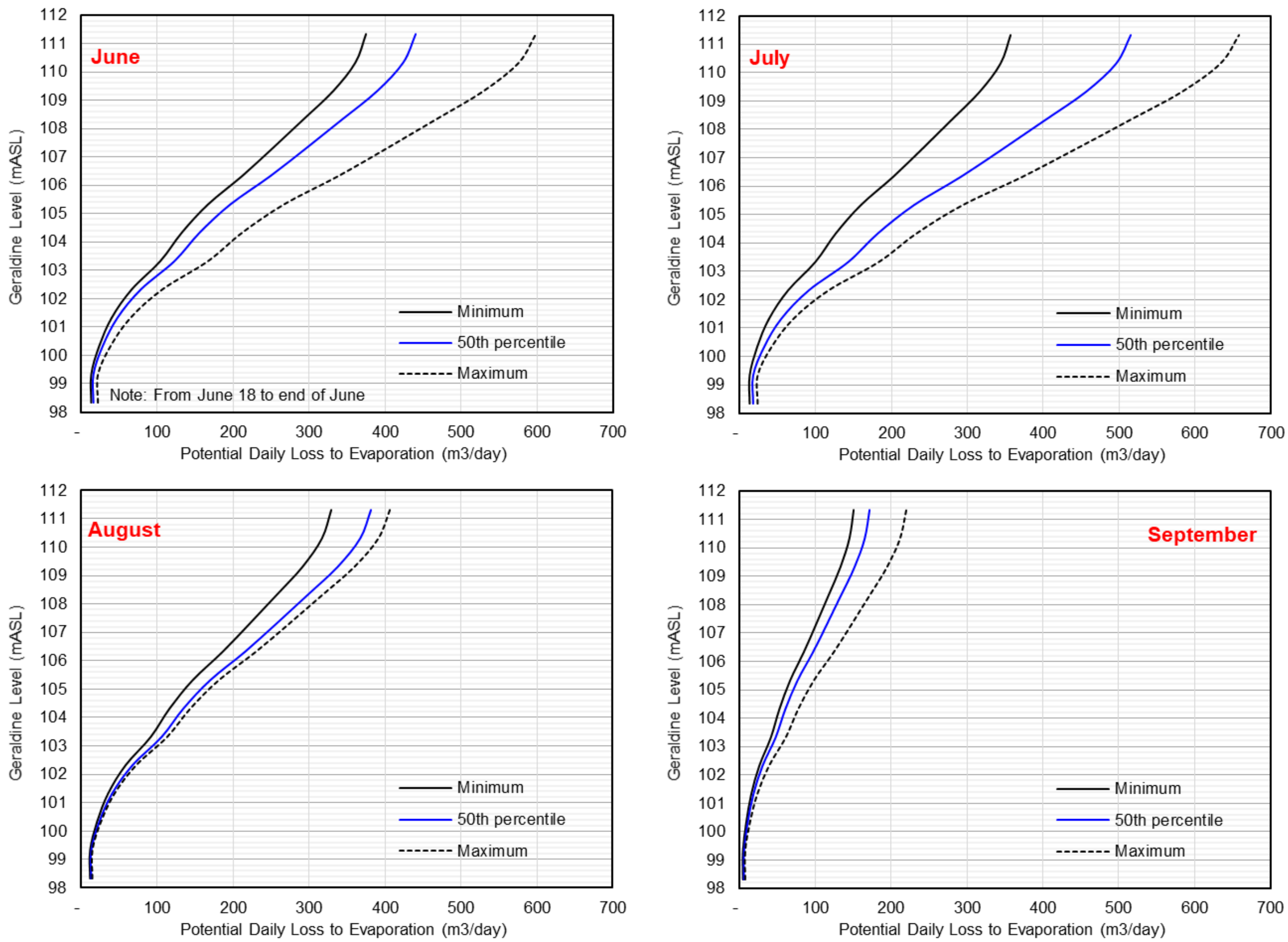

Figure 2: The Effect of Reservoir Level on Predicted Daily Evaporative Rates by Month over the 2008 through 2017 Period of Record

6.0 RESULTS

The results presented throughout Sections 6.1 through 6.3 often concern independently calculated probability distributions of historic (2008 through 2017) meteorological data which are intended to confer an understanding of the range of meteorological variability affecting water surplus outcomes for each of the consumption scenarios discussed in Section 2.1.5.

As such, it is important that the reader understand that the percentage probability distributions presented for precipitation and meteorological surplus in Tables 3, 4, 5, 7, 9 and 11 are considered as independent distributions and should not be considered as co-dependent to one another. For example, the 50 percent probability surplus for August presented in any of these tables does not necessarily correspond to the 50 percent probability value for the open-water period. Similarly, the 75 percent probability value for meteorological surplus does not necessarily result from the 75 percent probability value for precipitation.

To assist the reader, bracketed monthly values that are normalised against open-water period totals are included in some data columns.

6.1 Historic Precipitation, Predicted Surplus and Predicted Reservoir Level at Freeze-Up

After applying the gap-filled meteorology data (Section 2.1.6) and water level reset function (Section 2.2.2) to the model, simulations were carried out for the three water consumption scenarios identified in Section 2.1.5 to ascertain the quantity of surplus that would be delivered to the Lake Geraldine Reservoir between June 18 and predicted freeze-up of each year.

Table 2 provides a simplified presentation of key periods of interest for the 2008 through 2017 meteorological window considered in this assessment. This information is presented with a view of providing baseline information against subsequent precipitation and meteorological surplus increases presented in Tables 6, 8 and 10.

As shown, a significant portion of total precipitation over the catchment is lost in the form of evapotranspiration either directly from ground surface or more indirectly from soil and depression storage within the catchment. With cooling air temperatures and reasonable precipitation amounts, the proportion of rainfall translated to surplus is shown to generally peak in September. Although higher precipitation is typically observed in July and August, the amount of generated surplus is likely limited because of increased thermal exposure at ground surface (i.e., increased losses in the form of evaporation). Meanwhile, although lower average temperatures occur in October than September, it is likely that a more significant portion of October rainfall is intercepted within soil storage and ground depressions, thus diminishing catchment runoff to the reservoir.

Total meteorological surpluses in the final weeks (October) before freeze-up are limited relative to earlier portions of the open-water period and thus reduce the catchments capacity to fully replenish the reservoir before freeze-up occurs.

Table 2: Average (Arithmetic) Precipitation and Meteorological Surplus recorded for Iqaluit over the 2008 through 2017 Period

Period	Precipitation (mm)	Meteorological Surplus (mm)	Percentage of Precipitation Converted to Meteorological Surplus
June 18 to Freeze-Up (Varies)[1]	207	123	59%
June 18 through 30	21	10	50%
July	67	36	53%
August	56	31	55%
September	50	38	76%
October 1 to Freeze-Up (Varies)[2]	11	7	64%
November 1 to Freeze-Up (Varies) [2,3]	1	0	n/a[2]

Notes:
1. Values assume that no snow or ice storage exists after June 18.
2. Effective length of ice-free period (i.e., the number of days since June 18 to estimated freeze up day) differs between years.
3. Rounding errors over a short period in 2010 render a comparison of precipitation and meteorological surplus meaningless.

6.1.1 Predicted Precipitation, Surplus and Reservoir Level under No Water Consumption Scenario

Table 3 presents precipitation amounts and corresponding meteorological surplus between June 18 and freeze-up for a range of percentage probabilities over the considered ten-year period between 2008 and 2017. Depending on the wind and air temperature magnitudes as well as intensity and distribution of rainfall, the meteorological surplus could represent between 39% and 87% of total precipitation over the Lake Geraldine catchment.

Based on the meteorological data considered, it is estimated that the median water supply deficit without any consumption would approximate 101,000 cubic metres. It is noted that depending on the extreme annual water balances over the same period, there is a possibility that the reservoir deficit at the predicted freeze-up date would range from approximately 6,000 cubic metres to approximately 345,000 cubic metres.

Golder (2013) has previously inferred a relationship between winter length and the quantity of reservoir water that is converted to ice. Based on this relationship, an average winter length of 8 months was shown to lock up as much as 505,000 m^3 of reservoir water (unavailable until melt) and a longer winter duration of 9 months could lock up as much as 585,000 m^3 of reservoir water. For the purposes of evaluating water supply deficits in a conservative manner, a 9-month winter and equivalent ice storage was selected for this assessment.

Given that up to 585,000 cubic metres of active (accessible) reservoir storage (circa 1,875,500 m^3) may be converted to ice during the 2019/2020 winter (Golder 2013), the total available surplus for the over-winter period would range between 946,000 m^3 and 1,284,000 m^3.

Table 3: Precipitation and Predicted Catchment Surplus for 2008 through 2017 Period Under No Water Consumption Scenario

Percentage Probability of Exceedance	Predicted Freeze-Up Date	Number of Open-Water Days from June 18 to Freeze Up	Number of Rainfall Days from June 18 to Freeze-Up	Historic Precipitation (mm)				Predicted Historic Surplus (mm)				Predicted Reservoir Deficit at Freeze-Up (m^3)	Predicted Available Water Supply at Freeze-Up (m^3) 4	Predicted Reservoir Level at Freeze-Up (masl)
				Open Water Period	July	August	September	Open Water Period	July	August	September			
0 (Max)	06-Nov	141	89	345	189 (148)	93 (73)	92 (72)	253	156 (114)	60 (43)	79 (58)	6,304	1,284,222	111.30
5	02-Nov	138	89	298	141 (111)	84 (66)	92 (72)	213	113 (82)	54 (39)	78 (57)	6,473	1,284,053	111.30
10	30-Oct	135	88	251	93 (74)	74 (59)	92 (73)	173	70 (50)	48 (35)	78 (56)	6,642	1,283,884	111.30
25	16-Oct	120	81	237	67 (68)	63 (64)	58 (58)	149	30 (32)	44 (46)	45 (47)	13,720	1,276,806	111.28
50	14-Oct	118	67	196	57 (60)	58 (60)	45 (47)	118	23 (26)	33 (38)	34 (39)	101,275	1,189,252	111.00
75	10-Oct	114	56	169	45 (52)	47 (54)	34 (40)	85	13 (18)	18 (24)	24 (32)	214,475	1,076,051	110.63
90	05-Oct	109	49	149	37 (51)	32 (45)	24 (33)	63	8 (17)	7 (16)	13 (27)	288,098	1,002,428	110.39
95	04-Oct	108	49	135	28 (41)	31 (45)	22 (32)	53	3 (9)	4 (13)	11 (30)	316,484	974,042	110.30
100 (Min)	03-Oct	107	49	121	19 (30)	30 (46)	20 (32)	105	1 (8)	1 (8)	8 (46)	344,870	945,656	110.20

Notes:

1. Unbracketed precipitation and surplus values are based on independent probability distributions for examined month.
2. Bracketed monthly precipitation and surplus values are normalised based on total precipitation or surplus for the Open Water Period June 18 to Freeze-up.
3. For conservatism, evaporative losses from the reservoir are assumed to occur at the maximum water level of 111.33 masl with a calculated surface area of 29 ha. This rate will decline with reduced water levels.
4. Predicted Available Water Supply at Freeze-Up calculated by removing 9 months of ice storage (585,000 m^3), reservoir deficit (tabulated) and dead storage (80,667 m^3) from total reservoir storage capacity (1,956,193 m^3).

6.1.2 Predicted Precipitation, Surplus and Reservoir Level under 100,000 m^3/Month Water Consumption Scenario

Table 4 considers the same meteorological data discussed for Table 3, but accounts for the additional effects of a daily water consumption rate of 3,335 m^3 (or 100,000 m^3 per month).

Based on the ten-year meteorological period considered, it is estimated that the median water supply deficit at a consumption rate of 100,000 m^3 would approximate 523,000 cubic metres. At the extreme ends of the annual water balances for the same period, there is a possibility that this water supply deficit could decrease, or increase, to 64,000 or 705,000 cubic metres, respectively.

Golder (2013) has previously inferred a relationship between winter length and the quantity of reservoir water that is converted to ice. Based on this relationship, an average winter length of 8 months was shown to lock up as much as 505,000 m^3 of reservoir water (unavailable until melt) and a longer winter duration of 9 months could lock up as much as 585,000 m^3 of reservoir water. For the purposes of evaluating water supply deficits in a conservative manner, a 9-month winter and equivalent ice storage was selected for this assessment.

Given that up to 585,000 cubic metres of active (accessible) reservoir storage (circa 1,875,500 m^3) may be converted to ice during the winter months (Golder 2013) and assuming an average winter length of 9 months, a 100,000 m^3/month water consumption rate could potentially lead to over-winter water shortages for the 50 through 100 percent probability outcomes presented in Table 4.

Table 4: Precipitation and Predicted Catchment Surplus for 2008 through 2017 Period Under 100,000 m^3/month Water Consumption Scenario (3,335 m^3/day)

Percentage Probability Of Exceedance	Predicted Freeze-Up Date	Number of Open-Water Days from July 17 to Freeze Up	Number of Rainfall Days from July 17 to Freeze-Up	Historic Precipitation (mm)				Predicted Historic Surplus (mm)				Predicted Reservoir Deficit at Freeze-Up (m^3)	Predicted Available Water Supply at Freeze-Up (m^3) [4]	Predicted Reservoir Level at Freeze-Up (masl)
				Open Water Period	July	August	September	Open Water Period	July	August	September			
0 (Max)	06-Nov	141	89	345	189 (148)	93 (73)	92 (72)	253	156 (114)	60 (43)	79 (58)	63,849	1,226,677	111.12
5	02-Nov	138	89	298	141 (111)	84 (66)	92 (72)	213	113 (82)	54 (39)	78 (57)	189,165	1,101,361	110.71
10	30-Oct	135	88	251	93 (74)	74 (59)	92 (73)	173	70 (50)	48 (35)	78 (56)	314,482	976,044	110.31
25	16-Oct	120	81	237	67 (68)	63 (64)	58 (58)	149	30 (32)	44 (46)	45 (47)	381,945	908,581	110.08
50	14-Oct	118	67	196	57 (60)	58 (60)	45 (47)	118	23 (26)	33 (38)	34 (39)	522,790	767,736	109.60
75	10-Oct	114	56	169	45 (52)	47 (54)	34 (40)	85	13 (18)	18 (24)	24 (32)	641,863	648,664	109.19
90	05-Oct	109	49	149	37 (51)	32 (45)	24 (33)	63	8 (17)	7 (16)	13 (27)	678,867	611,659	109.06
95	04-Oct	108	49	135	28 (41)	31 (45)	22 (32)	53	3 (9)	4 (13)	11 (30)	691,904	598,623	109.01
100 (Min)	03-Oct	107	49	121	19 (30)	30 (46)	20 (32)	105	1 (8)	1 (8)	8 (46)	704,940	585,586	108.96

Notes:

1. Unbracketed precipitation and surplus values are based on independent probability distributions for examined month.
2. Bracketed monthly precipitation and surplus values are normalised based on total precipitation or surplus for the Open Water Period June 18 to Freeze-up
3. For conservatism, evaporative losses from the reservoir are assumed to occur at the maximum water level of 111.33 masl with a calculated surface area of 29 ha. This rate will decline with reduced water levels.
4. Predicted Available Water Supply at Freeze-Up calculated by removing 9 months of ice storage (585,000 m3), reservoir deficit (tabulated) and dead storage (80,667 m3) from total reservoir storage capacity (1,956,193 m^3).

6.1.3 Predicted Precipitation, Surplus and Reservoir Level under 115,000 m^3/Month Water Consumption Scenario

Table 5 considers the same meteorological data previously discussed for Table 3, but accounts for the additional effects of a daily water consumption rate of 3,850 m^3 (or 115,000 m^3 per month).

Based on the ten-year meteorological period considered, it is estimated that the median water supply deficit at a consumption rate of 115,000 m^3 would approximate 588,000 cubic metres. At the extreme ends of annual water balances for the same period, there is a possibility that this water supply deficit could decrease, or increase, to approximately 88,000 or 761,000 cubic metres, respectively.

Golder (2013) has previously inferred a relationship between winter length and the quantity of reservoir water that is converted to ice. Based on this relationship, an average winter length of 8 months was shown to lock up as much as 505,000 m^3 of reservoir water (unavailable until melt) and a longer winter duration of 9 months could lock up as much as 585,000 m^3 of reservoir water. For the purposes of evaluating water supply deficits in a conservative manner, a 9-month winter and equivalent ice storage was selected for this assessment.

Given that up to 585,000 cubic metres of active (accessible) reservoir storage (circa 1,875,500 m^3) may be converted to ice during the winter months (Golder 2013) and assuming an average winter length of 9 months, a 115,000 m^3/month water consumption rate could potentially lead to over-winter water shortages for the 10 through 100 percent probability outcomes presented in Table 5.

Table 5: Precipitation and Predicted Catchment Surplus for 2008 through 2017 Period Under 115,000 m³/month Water Consumption Scenario (3,850 m³/day)

Percentage Probability Of Exceedance	Predicted Freeze-Up Date	Number of Open-Water Days from July 17 to Freeze Up	Number of Rainfall Days from July 17 to Freeze-Up	Historic Precipitation (mm)			Predicted Historic Surplus (mm)			Predicted Reservoir Deficit at Freeze-Up (m^3)	Predicted Available Water Supply at Freeze-Up (m^3) [4]	Predicted Reservoir Level at Freeze-Up (masl)
				Open Water Period July 17 to Freeze-Up	August	September	Open Water Period July 17 to Freeze-Up	August	September			
0 (Max)	06-Nov	345	189 (148)	93 (73)	92 (72)	253	156 (114)	60 (43)	79 (58)	87,714	1,202,812	111.04
5	02-Nov	298	141 (111)	84 (66)	92 (72)	213	113 (82)	54 (39)	78 (57)	230,326	1,060,200	110.58
10	30-Oct	251	93 (74)	74 (59)	92 (73)	173	70 (50)	48 (35)	78 (56)	372,938	917,588	110.11
25	16-Oct	237	67 (68)	63 (64)	58 (58)	149	30 (32)	44 (46)	45 (47)	442,180	848,346	109.88
50	14-Oct	196	57 (60)	58 (60)	45 (47)	118	23 (26)	33 (38)	34 (39)	587,915	702,611	109.38
75	10-Oct	169	45 (52)	47 (54)	34 (40)	85	13 (18)	18 (24)	24 (32)	701,838	588,689	108.97
90	05-Oct	149	37 (51)	32 (45)	24 (33)	63	8 (17)	7 (16)	13 (27)	746,509	544,017	108.81
95	04-Oct	135	28 (41)	31 (45)	22 (32)	53	3 (9)	4 (13)	11 (30)	753,525	537,002	108.78
100 (Min)	03-Oct	121	19 (30)	30 (46)	20 (32)	105	1 (8)	1 (8)	8 (46)	760,540	529,986	108.76

Notes:

1. Unbracketed precipitation and surplus values are based on independent probability distributions for examined month.
2. Bracketed monthly precipitation and surplus values are normalised based on total precipitation or surplus for the Open Water Period June 18 to Freeze-up
3. For conservatism, evaporative losses from the reservoir are assumed to occur at the maximum water level of 111.33 masl with a calculated surface area of 29 ha. This rate will decline with reduced water levels.
4. Predicted Available Water Supply at Freeze-Up calculated by removing 9 months of ice storage (585,000 m3), reservoir deficit (tabulated) and dead storage (80,667 m^3) from total reservoir storage capacity (1,956,193 m^3).

6.2 Precipitation and Meteorological Surplus Required to Fill Reservoir

Using the 2008 through 2017 meteorological data referred to in Section 2.1.6 and water level reset function referred to in Section 2.2.2, model simulations were also carried out for the three water consumption scenarios identified in Section 2.1.5 to ascertain the quantity of precipitation that would be required from June 18 to freeze-up in order to replenish the Lake Geraldine reservoir to just below its design level of 111.33 masl. This approach was deemed necessary because insufficient meteorological surpluses in the final few open-water days before freeze-up to offset water consumption were identified in some years, regardless of the increase in precipitation. The following water supply deficits were considered acceptable buffers to establish the necessary increases in precipitation to replenish the reservoir:

- No Water Consumption Scenario – deficit of 10,000 m^3;
- 100,000 m^3/month Water Consumption Scenario – two weeks of consumption equivalent to 46,690 m^3; and,
- 115,000 m^3/month Water Consumption Scenario – two weeks of consumption equivalent to 53,900 m^3.

The following sub-sections identify relevant considerations in the interpretation of the amount of precipitation necessary to replenish the reservoir during this open-water period, discuss the approach adopted to consider these considerations and present the results relevant to each of the three water consumption scenarios.

6.2.1 Interpretation of Reservoir Filling Results

In transitioning historic precipitation data to that necessary to replenish the reservoir, the reader should be aware of a number of considerations that are fundamental to adequate interpretation of the results presented in Section 6.2.2 through 6.2.4.

6.2.1.1 Consideration of Sensitivities of Results to Meteorological Regimes

Establishing the amount of precipitation required to replenish the reservoir is complex for a number of reasons.

Firstly, the limiting effects of evapotranspiration and soil and depression storage necessarily imply that the total quantity of precipitation required to fill the reservoir needs to be greater than the reservoir deficit (i.e., soil and depression storage intercept a fraction of incident precipitation across the catchment that does not translate to inflow to the reservoir). Hence, antecedent weather conditions such as the amount and intensity of rainfall, as well as air temperature and wind conditions interceding rainfall, are important determinants to establishing to what extent soil or depression storage is exhausted or needs to fill before generating runoff that can enter the reservoir.

Secondly, this complexity is compounded by the rate of precipitation delivery to the system. The same monthly precipitation amount can yield entirely different quantities of inflow to the reservoir depending on the distribution and intensity of precipitation delivered to ground surface. For example, 100 mm of rainfall uniformly distributed across a month would typically result in lower total monthly runoff volumes than the same quantity off rainfall over a day. In the latter case, evapotranspiration would have insufficient opportunity to affect soil and depression storage volumes in a meaningful way.

Lastly, the duration of the remaining ice-free period (between June 18 and the date of freeze-up) loosely determines the number of rainfall days available to replenish the reservoir. In other words, an early winter would conceivably require higher average daily precipitation amounts than the precipitation amounts required to replenish the reservoir before a late winter.

6.2.1.2 Distribution of Historic and Necessary Precipitation and Surplus Amounts

By supplementing the amount of historic rainfall with that required to replenish the reservoir, the probability distribution of decadal rainfall becomes considerably contracted relative to that for measured conditions. Accordingly, it is important to note that the monthly percent probability values presented in Table 7, 9 and 11 may not be directly compared to the monthly percent probability values in Tables 3, 4 and 5. In rare cases, a small decrease in monthly required precipitation values may be apparent. Accordingly, average monthly precipitation requirements are presented in each sub-section in Tables 6, 8 and 10.

6.2.2 Estimated Necessary Precipitation and Catchment Surplus to Replenish Reservoir by Freeze-Up under No Water Consumption Scenario

Table 6 provides a simplified interpretation of the 2008 through 2017 distribution statistics subsequently presented in Table 7 (overleaf) and presents the average arithmetic precipitation and meteorological surpluses required to replenish the reservoir (to a deficit of 10,000 m^3) from an initial water level of 109.67 masl under the no consumption scenario, for an average ice-free period (June 18 to freeze-up). Relative to average annual precipitation amounts measured between 2008 and 2017, average ice-free precipitation amounts would need to increase by approximately 23% in order to generate the necessary meteorological surplus to replenish the reservoir to a deficit of 10,000 m^3.

Despite featuring less precipitation than in August, the effect of cooling air temperatures on the proportion of precipitation converted to meteorological surplus in September is conspicuous in its effect on the ratio between precipitation and meteorological surplus. In contrast, the lowered ratio in October is likely attributed to a relative increase in ET losses from soil and depression storage.

Table 6: Average (Arithmetic) Precipitation and Meteorological Surplus Required to Replenish Lake Geraldine Reservoir (2008 through 2017) under No Consumption Scenario

Period	Required Precipitation (mm)	Required Meteorological Surplus (mm)	Percentage of Precipitation Converted to Meteorological Surplus
June 18 to Freeze-Up (Varies)[1]	255	170	67%
June 18 through 30	27	16	59%
July	81	48	59%
August	71	47	66%
September	62	50	81%
October 1 to Freeze-Up (Varies)[2]	15	10	67%
November 1 to Freeze-Up (Varies) [2,3]	1	1[1]	n/a[2]

Notes:
1. Effective length of ice-free period (i.e., the number of days since June 18 to estimated freeze up day) differs between years.
2. Rounding errors over a short period in 2010 render a comparison of precipitation and meteorological surplus meaningless.
3. Rounding errors may result in minor discrepancies between sum of monthly values and period totals.

Given the considerations previously presented in Section 6.2.1, the results in Table 7 should be interpreted with a degree of caution while providing the reader with a reasonable understanding of the significant influence of meteorological variability over the 2008 through 2017 period.

The results presented in Table 7 exhibit increased precipitation and meteorological surplus amounts relative to average measured historic conditions (see Table 3).

Precipitation over the June 18 through freeze-up period would need to increase between 0 mm and 95 mm to generate the additional surplus required to full the reservoir to within 10,000 m^3 of its storage capacity.

Table 7: Required Precipitation and Surplus to Replenish Reservoir by Freeze-Up Under No Water Consumption Scenario

Percentage Probability of Exceedance	Predicted Freeze-Up Date	Predicted Reservoir Deficit (m^3)	Predicted Total Surplus Required to Replenish Reservoir (mm)				Predicted Total Precipitation Required to Replenish Reservoir			
			Open Water Period from June18 to Freeze-Up	July	August	September	Open Water Period from June18 to Freeze-Up	July	August	September
0 (Max)	06-Nov	6,304	137	0 (1)	13 (58)	18 (79)	216	34 (69)	41 (84)	31 (62)
5	02-Nov	6,473	141	10 (29)	19 (55)	19 (55)	222	41 (78)	45 (85)	31 (58)
10	30-Oct	6,642	145	20 (44)	25 (54)	20 (43)	229	48 (85)	49 (87)	31 (54)
25	16-Oct	13,720	146	25 (38)	32 (48)	36 (54)	235	58 (81)	57 (80)	47 (65)
50	14-Oct	101,275	149	30 (35)	48 (56)	42 (50)	237	68 (79)	69 (81)	53 (62)
75	10-Oct	214,475	177	47 (46)	56 (55)	70 (69)	258	84 (82)	78 (76)	82 (80)
90	05-Oct	288,098	240	106 (91)	72 (62)	80 (68)	312	130 (120)	92 (84)	93 (85)
95	04-Oct	316,484	246	131 (100)	79 (60)	83 (63)	329	160 (133)	105 (88)	97 (81)
100	03-Oct	344,870	253	156 (108)	86 (60)	86 (60)	345	189 (145)	119 (92)	100 (77)

Notes:
1. Unbracketed precipitation and surplus values are based on independent probability distributions for examined month.
2. Bracketed monthly precipitation and surplus values are normalised to period total rather than presented as independent distributions.
3. For conservatism, evaporative losses from the reservoir are assumed to occur at the maximum water level of 111.33 masl with a calculated surface area of 29 ha. This rate will decline with reduced water levels.

6.2.3 Estimated Necessary Precipitation and Catchment Surplus to Replenish Reservoir by Freeze-Up under 100,000 m^3/Month Water Consumption Scenario

Table 8 provides a simplified interpretation of the 2008 through 2017 distribution statistics subsequently presented in Table 9 (overleaf) and presents the average arithmetic precipitation and meteorological surpluses required to replenish the reservoir (to within a two-week consumption deficit) from an initial water level of 109.67 masl under the 100,000 m^3/month consumption scenario, for an average ice-free period (June18 to freeze-up). Relative to average annual precipitation amounts measured between 2008 and 2017, average ice-free precipitation amounts would need to increase by approximately 81% in order to generate the necessary meteorological surplus to replenish the reservoir to a two-week deficit within approximately 46,700 m^3.

On average (arithmetically), a 47% increase in precipitation relative to the no consumption scenario would be necessary to replenish the reservoir before freeze-up, resulting in an 69% increase in surplus over the June 18 to freeze-up period relative to historic conditions. The beneficial effects of exhausted soil and depression storage within the catchment are notable when comparing the results in Table 8 with those previously presented in Table 6.

Table 8: Average (Arithmetic) Precipitation and Meteorological Surplus Required to Replenish Lake Geraldine Reservoir (2008 through 2017) under 100,000 m^3/Month Consumption Scenario

Period	Required Precipitation (mm)	Required Meteorological Surplus (mm)	Percentage of Precipitation Converted to Meteorological Surplus
June 18 to Freeze-Up (Varies)[1]	374	288	77%
June 18 to 30	41	30	73%
July	118	85	72%
August	105	81	77%
September	89	77	87%
October 1 to Freeze-Up (Varies)[1]	20	14	70%
November 1 to Freeze-Up (Varies)[1, 2]	1	1	n/a[2]

Notes:
1. Effective length of ice-free period (i.e., the number of days since June 18 to estimated freeze up day) differs between years.
2. Rounding errors over a short period in 2010 render a comparison of precipitation and meteorological surplus meaningless.
3. Rounding errors may result in minor discrepancies between sum of monthly values and period totals.

Given the considerations previously presented in Section 6.2.1, the results in Table 9 should be interpreted with a degree of caution while providing the reader with a reasonable understanding of the significant influence of meteorological variability over the 2008 through 2017 period.

The results presented in Table 9 exhibit increased precipitation and meteorological surplus amounts relative to average measured historic conditions (see Table 4).

Precipitation over the June 18 through freeze-up period would need to increase between 148 mm and 198 mm to generate the additional surplus required to full the reservoir to within 46,690 m^3 (equivalent to two weeks water consumption) of its storage capacity.

These results should be interpreted with caution, particularly for more extreme probabilities (e.g. the 75 to 100 percent probabilities). On average (Table 8), 32% of all open-water rainfall falls during the month of July, with only 5% of rainfall falling during the final month of October before freeze-up.

The paradox of estimating the necessary precipitation increases over the open-water season as a whole is that the increase over historic precipitation required to offset consumption and, to a lesser degree, evaporative losses during the month of October is necessarily large thus leading to oversupplies within, and overtopping of, the reservoir during the typically rainier months of July, August and September for some of the ten year records.

While estimates of seasonal increases therefore provide somewhat misleading information, the key conclusion from these results is that supplementation (or an increase in precipitation) in the final month before freeze-up would be most efficient provided sufficient water supplies in nearby water bodies are available. Notwithstanding the potential regulatory challenges of sourcing adequate supplementation volumes from nearby waterbodies, pumping during the final month before freeze-up may deliver a more efficient supplementation strategy, owing to advantages of (i) improved knowledge of residual deficits as well as reduced evaporative losses which are shown to increase with water level (Section 5).

With these notable benefits in mind, the risk of postponing all supplementation until the last month before freeze-up is expected is elevated given that the date of freeze-up over the 2008 through 2017 period evaluated has varied by over a month. As such, a balanced approach to offsetting the risks and maximising the benefits of delayed supplementation is advisable. It is understood that a separate analysis of monthly basin yields in the nearby River Apex, a potential source for supplemental water, is currently being undertaken by Nunami Stantec. Accordingly, the results of Nunami Stantec's work should be carefully considered as part of the planning process to verify which supplementation strategy would best suit the City's supplementation needs.

Table 9: Required Precipitation and Surplus to Replenish Reservoir by Freeze-Up Under 100,000 m^3/month Water Consumption Scenario (3,335 m^3/day)

Percentage Probability of Exceedance	Predicted Freeze-Up Date	Predicted Reservoir Deficit (m^3)	Predicted Total Surplus Required to Replenish Reservoir (mm)				Predicted Total Precipitation Required to Replenish Reservoir			
			Open Water Period from June18 to Freeze-Up	July	August	September	Open Water Period from June18 to Freeze-Up	July	August	September
0 (Max)	06-Nov	63,849	227	14 (40)	35 (96)	33 (90)	305	48 (96)	62 (123)	43 (86)
5	02-Nov	189,165	235	27 (62)	37 (86)	37 (84)	315	58 (108)	64 (117)	48 (88)
10	30-Oct	314,482	243	39 (78)	40 (79)	41 (81)	325	69 (118)	65 (112)	52 (90)
25	16-Oct	381,945	245	46 (71)	58 (89)	49 (76)	331	79 (114)	82 (117)	60 (87)
50	14-Oct	522,790	256	66 (76)	73 (84)	74 (85)	344	99 (115)	93 (108)	85 (99)
75	10-Oct	641,863	302	98 (93)	102 (97)	107 (102)	395	139 (133)	126 (122)	121 (116)
90	05-Oct	678,867	344	185 (133)	137 (99)	115 (83)	442	217 (176)	157 (128)	127 (103)
95	04-Oct	691,904	408	190 (157)	137 (114)	115 (96)	493	218 (191)	163 (143)	128 (112)
100	03-Oct	704,940	471	194 (181)	138 (128)	116 (108)	543	218 (205)	169 (160)	128 (120)

Notes:
1. Unbracketed precipitation and surplus values are based on independent probability distributions for examined open-water period or month.
2. Bracketed monthly precipitation and surplus values are normalised to period total rather than presented as independent distributions.
3. For conservatism, evaporative losses from the reservoir are assumed to occur at the maximum water level of 111.33 masl with a calculated surface area of 29 ha. This rate will decline with reduced water levels.

6.2.4 Estimated Necessary Precipitation and Catchment Surplus to Replenish Reservoir by Freeze-Up under 115,000 m^3/Month Water Consumption Scenario

Table 10 provides a simplified interpretation of the 2008 through 2017 distribution statistics subsequently presented in Table 11 (overleaf) and presents the average arithmetic precipitation and meteorological surpluses required to replenish the reservoir (to within a two-week consumption deficit) from an initial water level of 109.67 masl under the 115,000 m^3/month consumption scenario, for an average ice-free period (June 18 to freeze-up). Relative to average annual precipitation amounts measured between 2008 and 2017, average annual precipitation amounts would need to increase by approximately 94% in order to generate the necessary meteorological surplus to replenish the reservoir to a two-week deficit within approximately 53,900 m^3.

On average (arithmetically), a 57% increase in precipitation relative to the no consumption scenario would be necessary to replenish the reservoir before freeze-up, resulting in an 85% increase in surplus over the June 18 to freeze-up period relative to historic conditions. The beneficial effects of exhausted soil and depression storage within the catchment are notable when comparing the results in Table 10 with those previously presented in Tables 6 and 8.

Table 10: Average (Arithmetic) Precipitation and Meteorological Surplus Required to Replenish Lake Geraldine Reservoir (2008 through 2017) under 115,000 m^3/Month Consumption Scenario

Period	Precipitation (mm)	Meteorological Surplus (mm)	Percentage of Precipitation Converted to Meteorological Surplus
June 18 to Freeze-Up (Varies)[1]	401	315	79%
June 18 to 30	45	33	73%
July	128	94	73%
August	112	88	79%
September	94	83	88%
October 1 to Freeze-Up (Varies) [1]	22	17	77%
November 1 to Freeze-Up (Varies)[1,2]	1	1[1]	n/a[2]

Notes:
1. Effective length of ice-free period (i.e., the number of days since June 18 to estimated freeze up day) differs between years.
2. Rounding errors over a short period in 2010 render a comparison of precipitation and meteorological surplus meaningless.
3. Rounding errors may result in minor discrepancies between sum of monthly values and period totals.

Given the considerations previously presented in Section 6.2.1 and further discussed after Table 8, the results in Table 11 should be interpreted with a degree of caution while providing the reader with a reasonable understanding of the significant influence of meteorological variability over the 2008 through 2017 period.

The results presented in Table 11 exhibit increased precipitation and meteorological surplus amounts relative to average measured historic conditions (see Table 5).

Precipitation over the June 18 through freeze-up period would need to increase between 164 mm and 254 mm to generate the additional surplus required to full the reservoir to within 53,900 m^3 (equivalent to two weeks water consumption) of its storage capacity.

These results should be interpreted with caution, particularly for more extreme probabilities (e.g. the 75 to 100 percent probabilities). On average (Table 8), 32% of all open-water rainfall falls during the month of July, with only 5% of rainfall falling during the final month of October before freeze-up.

The paradox of estimating the necessary precipitation increases over the open-water season as a whole is that the increase over historic precipitation required to offset consumption and, to a lesser degree, evaporative losses during the month of October is necessarily large thus leading to oversupplies within, and overtopping of, the reservoir during the typically rainier months of July, August and September for some of the ten year records.

While estimates of seasonal increases therefore provide somewhat misleading information, the key conclusion from these results is that supplementation (or an increase in precipitation) in the final month before freeze-up would be most efficient provided sufficient water supplies in nearby water bodies are available. Notwithstanding the potential regulatory challenges of sourcing adequate supplementation volumes from nearby waterbodies, pumping during the final month before freeze-up may deliver a more efficient supplementation strategy, owing to advantages of (i) improved knowledge of residual deficits as well as reduced evaporative losses which are shown to increase with water level (Section 5).

With these notable benefits in mind, the risk of postponing all supplementation until the last month before freeze-up is expected is elevated given that the date of freeze-up over the 2008 through 2017 period evaluated has varied by over a month. As such, a balanced approach to offsetting the risks and maximising the benefits of delayed supplementation is advisable. It is understood that a separate analysis of monthly basin yields in the nearby River Apex, a potential source for supplemental water, is currently being undertaken by Nunami Stantec. Accordingly, the results of Nunami Stantec's work should be carefully considered as part of the planning process to verify which supplementation strategy would best suit the City's supplementation needs.

Table 11: Required Precipitation and Surplus to Replenish Reservoir by Freeze-Up Under 115,000 m³/month Water Consumption Scenario (3,850 m³/day)

Percentage Probability of Exceedance	Predicted Freeze-Up Date	Predicted Reservoir Deficit (m³)	Predicted Total Surplus Required to Replenish Reservoir (mm)				Predicted Total Precipitation Required to Replenish Reservoir			
			Open Water Period from June18 to Freeze-Up	July	August	September	Open Water Period from June18 to Freeze-Up	July	August	September
0 (Max)	06-Nov	87,714	240	17 (44)	38 (103)	35 (93)	318	50 (100)	66 (129)	45 (90)
5	02-Nov	230,326	248	30 (64)	43 (94)	40 (87)	329	61 (109)	69 (124)	52 (93)
10	30-Oct	372,938	257	43 (78)	48 (89)	46 (85)	339	72 (118)	73 (121)	58 (96)
25	16-Oct	442,180	259	50 (74)	62 (93)	55 (83)	347	83 (118)	86 (122)	66 (94)
50	14-Oct	587,915	272	71 (80)	77 (88)	82 (93)	360	103 (119)	97 (112)	93 (106)
75	10-Oct	701,838	345	107 (106)	115 (115)	113 (112)	439	148 (147)	140 (139)	126 (126)
90	05-Oct	746,509	397	212 (161)	145 (110)	121 (92)	494	241 (200)	172 (143)	134 (111)
95	04-Oct	753,525	461	214 (184)	149 (128)	122 (104)	547	243 (218)	175 (157)	134 (120)
100	03-Oct	760,540	526	217 (206)	154 (146)	122 (116)	599	246 (236)	177 (170)	134 (129)

Notes:
1. Unbracketed precipitation and surplus values are based on independent probability distributions for examined open-water period or month.
2. Bracketed monthly precipitation and surplus values are normalised to period total rather than presented as independent distributions.
3. For conservatism, evaporative losses from the reservoir are assumed to occur at the maximum water level of 111.33 masl with a calculated surface area of 29 ha. This rate will decline with reduced water levels.

7.0 CONCLUSIONS AND RECOMMENDATIONS

Based on the preceding discussion of results and previously noted assumptions and limitations the following conclusions are summarised:

1) The open-water period available for replenishment of the reservoir (June 18 to predicted freeze-up) ranges from 107 to 141 days (predicted freeze-up dates range between October 3 and November 6).

2) The assessment of recent meteorological conditions (2008 to 2017) suggests that, on average, 59% of the measured precipitation falling between June 18 and predicted freeze-up results in meteorological surpluses that enter the Lake Geraldine reservoir. Given the paucity of meteorological surpluses in the final days before freeze-up for some of these years, however, reservoir losses attributed to evapotranspiration and water consumption mean the reservoir cannot always be filled to its entirety. In order to establish a target water reservoir level for freeze-up, the following permissible deficits were selected:

    a. A 10,000 m^3 storage deficit was selected as appropriate for the no water consumption scenario; and,

    b. Storage deficits equivalent to two weeks of water consumption were selected for the 100,000 m^3/month (46,690 m^3) and 115,000 m^3/month (53,900 m^3) water consumption scenarios.

3) For the three consumption rates evaluated, the predicted water supply deficit ranges as follows:

    a. The no water consumption scenario incurs a water supply deficit between 6,300 m^3 and 345,000 m^3, with a 50th percentile of 101,000 m^3;

    b. The 100,000 m^3/month water consumption scenario incurs a water supply deficit between 64,000 m^3 and 705,000 m^3, with a 50th percentile of 523,000 m^3; and,

    c. The 115,000 m^3/month water consumption scenario incurs a water supply deficit between 88,000 m^3 and 761,000 m^3, with a 50th percentile of 588,000 m^3.

4) The assessment of meteorological surpluses for the June 18 to freeze-up period indicates that, relative to the measured 2008 through 2017 arithmetic average precipitation amount (207 mm), arithmetic average precipitation amounts required to achieve close to maximum water supplies by freeze-up would need to increase to:

    a. 255 mm for the no water consumption scenario;

    b. 374 mm for the 100,000 m^3/month water consumption scenario; and,

    c. 401 mm for the 115,000 m^3/month water consumption scenario.

5) It should be noted that the total open-water precipitation requirements detailed under conclusion 4 should be interpreted with caution because the distribution of rainfall is such that a disproportionate amount of these totals would fall across the months of July, August and September with losses due to reservoir evaporation and reservoir overflows increasingly likely the earlier during the season that supplementation or rainfall occurs. Given the discussion of results presented at the end of Sections 6.2.3 and 6.2.4 and pending the results of Nunami Stantec's investigations of monthly basin yields in the nearby River Apex, specific consideration regarding the benefits and risks of delaying supplementation until the later portion of the open-water season are recommended as part of the water supply planning process currently being conducted by the City.

6) Given some differences in active storage estimates between Nunami Stantec (2019) and Golder (2013), it is recommended that the City of Iqaluit verify the current stage-storage relationship of Lake Geraldine via a bathymetric survey so that appropriate updates to the model and, fundamentally, the City's understanding of storage volumes and predicted water supply deficits may be made.

8.0 CLOSURE

We trust that the information provide din this technical memorandum meets your immediate needs and appreciate the opportunity to contribute to your interesting work. Please contact the undersigned if you have any questions or concerns regarding any of the content documented in this technical memorandum.

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