TECHNICAL MEMORANDUM

DATE April 25, 2022 **Project No.** 22520495

TO Jose Bueno, Assistant Project Manager
Colliers Project Leaders

CC Project File

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SUPPLEMENTARY LAKE GERALDINE WATER BALANCE MODELLING FOR 2022

1.0 INTRODUCTION

This technical memorandum has been prepared by Golder Associates Ltd. (Golder, a member of WSP) 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, 2019, 2020 and 2021 ice-free seasons. 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), Golder (2018a/b/c), Golder (2019), Golder (2020) and Golder (2021).

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 (2022), it is Golder's understanding that the City of Iqaluit requires completion of an updated water balance for the 2022 period to support the conditional permit for the Nunavut Water Board in order to initiate supplementation activities during the 2022 ice-free period, if required.

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 2022 ice-free period and fulfil the requirements associated with Part D, Item 11 of License No. 3AM-IQA1626 Amendment 4. 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 seventeen-month period, noting that missing meteorological records exist at various times throughout this period;

2) The amount of precipitation and meteorological surplus that can be expected during the remaining ice cover period of 2021/2022 and ice-free period of 2022 and to what elevation this would fill the reservoir at various consumption rates identified later in this document;

3) The predicted Lake Geraldine water storage deficit at the end of 2022 ice-free season based on historical precipitation records, 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 109.49 masl (reported by Water Survey Canada (WSC, 2022) on March 11, 2022) to as close as possible to its design level of 111.3 masl at the end of 2022 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.

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, 2018a/b/c, 2019, 2020 and 2021). A brief summary of the 2022 approach, and a detailed inventory of any modifications to the previous approach, is provided below for context.

2.1 Consistencies with the 2018 to 2021 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 to 2021. 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 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 and 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 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 Water Balance Formulation

The calculation of basin yields and reservoir supplies is identical to that detailed in previous studies Golder (2013, 2018a/b/c, 2019, 2020 and 2021).

Catchment yield, or surplus, is calculated as follows:

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

2.1.4 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.

2.1.5 Historical Meteorology

The same historical meteorological dataset used in Golder (2018a/b/c, 2019, 2020 and 2021), 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, 2019, 2020 and 2021 approach, historical meteorological records were 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 2022 Modelling Approach

The following subsection documents changes made to the 2021 water balance model in order to accommodate the particulars of the 2022 scope of work.

2.2.1 Incorporation of 2021/2022 Overwinter Meteorology

Meteorological data for the 2021/2022 winter period from October 23, 2020 up to March 11, 2022 were obtained from the Environment Canada climate station at Iqaluit Climate (Station ID: 2402592) for the purposes of air temperature, pressure, snowfall, wind speed and several other parameters. Meanwhile, the sky clearness co-efficient (required as one of the inputs to determine PET) was estimated from weather observation data collected for the Environment Climate station at Iqaluit A (Station ID: 2402590).

2.2.2 Validation Period

For the purposes of model validation, meteorological and water level data for the period October 23, 2020 through March 11, 2022 was sourced from the Iqaluit Climate station (Station ID: 2402592) – and linearly interpolated to fill data gaps – and water level data from the Real-Time Hydrometric Portal, Station 10UH013 (WSC 2022).

2.2.3 Ice Storage

All ice formed within the reservoir is assumed to be inaccessible, and commensurately diminishes available water supplies, until the following spring freshet when it becomes available at a rate determined by meteorology and simplified model assumptions. The ice module was updated to increase the predicted ice thickness and corresponding volume of water locked up overwinter as ice, closer values expected overwinter in northern regions. The 2022 version of the model predicts ice thickness values in the range of 0.93 to 1.25 m which are relatively larger than those achieved by previous versions of the model (former ice thickness predictions are in the range of 0.57 to 0.78 m). This adjustment results into a more realistic representation of water supply volumes in Lake Geraldine, however, does not affect the estimations of water supply deficits at freeze-up.

2.2.4 Water Level, Snowpack and Ice Cover Initial Condition

The model was initialized using initial conditions for water level, snowpack and ice-cover at the start of the simulation, which corresponds with March 11, 2022. A water level condition (109.49 masl) recorded at Lake Geraldine Near Iqaluit (10UH013) on March 11, 2022 was used as the basis for initialising the model, with minor adjustments. Given the refined ice formation approach documented in Section 2.2.3, this water level measurement was adjusted from the measured water level on March 11, 2022 (109.49 masl) to the modelled water level on the same date (109.04 masl) to account for ice pressure effects assumed to exaggerate the measured water level during periods of ice cover.

It is noted that modelled snow cover in the catchment and reservoir ice cover up to March 11, 2022 were calculated from available meteorological data and assumed to be assimilated into the reservoir following the melt date along with the accumulated snowfall from March 11 for each of the historic years (2008 through 2017). Such snowfall accumulations, ice thickness and the adjusted water level were implemented in the predictive model as initial conditions.

2.2.5 Supplementation from Apex River

Nunami Stantec Limited (2021) reports that water was pumped from the Apex (Niaqunguk) River to Lake Geraldine continuously from June 24 until June 28, 2021, date when the water level reached the spillway elevation. The model considered the total supplementation volume reported during the supplementation period (76,320 m^3) and included in the modelling exercise for the validation period.

2.2.6 Updated Calibration

New adjustments were implemented in the model to improve simulation of some processes and provide a more accurate, but less conservative, estimate of measured water levels and water supply volumes in Lake Geraldine. These adjustments were tested for the validation period (October 23, 2020 to March 11, 2022) and result in improved model performance relative to observations. The specific adjustments to the model consisted of:

- Differentiated evaporation rates applied to land and water, respectively, in comparison to unique evaporation rate applied to both, land in water, in previous versions of the model. Furthermore, the evaporation rate for land was lowered from previous versions of the model to improve modelled water levels during the ice-free period.
- Evaporative losses from Lake Geraldine are now dynamically calculated based on modelled, rather than full-stage, water levels (and associated surficial area) in the reservoir.
- Decreased sublimation rates applied to snow accumulated in the catchment during the winter months. This adjustment resulted in higher runoff volumes from snowmelt which better reflect observed water level changes following the spring freshet.
- Increased ice thickness to better represent water supplies locked up overwinter as ice. This adjustment does not directly alter the water supply at freeze-up and after thaw, but results in more realistic ice formation conditions than previously simulated.

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:

- Most assumptions and limitations presented in Golder (2013, r 2018a/b/c, 2019, 2020 and 2021) with exception of conservatisms applied to previously modelled lake evaporation;
- 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;
- Accumulated snow and ice cover up to and including March 11, 2022 are simulated from available precipitation data until March 11 2022. Supplemental snow and ice accumulation up to the thaw date for each historic (2008 through 2017) meteorological year are subsequently simulated independently for each historic year based on the snowfall and air temperature data for each of these years to derive ten individual snow- and ice-melt accumulations within the Lake Geraldine reservoir. Rainfall surplus volumes accumulated within the Lake Geraldine Reservoir are subsequently simulated for each of these historic (2008 through 2017) precipitation records up to the freeze-up date for each year;
- During the ice cover period, frozen water in the form of ice may exert additional pressure on the water surface leading to water levels measurements which, exceed the actual under ice water supply. In order to take into consideration the effects of ice on measured water levels, the water level reading from March 11, 2022 (used to initialize the model) was adjusted from measured the value (109.49 masl) to a modelled value (109.04 masl). This adjustment value (0.45 m) is to account for assumed differences in water levels between observations and model predictions at the end of the validation period (see Section 4.0). t
- The timing of water levels during, and immediately following, snowmelt and ice melt may be temporarily inaccurate because the model configuration only allows for simplified determinations of snowmelt and ice melt relative to observed conditions;
- 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;
- The available reservoir volume is independent of the effects of consumption losses prior to March 11, 2022 and is initialised based on the corrected water level measured on March 11, 2022;
- Estimates of necessary precipitation and meteorological surpluses to fill the reservoir 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. Owing to the distribution of historic rainfall over the ice-free period, this artefact could lead to unrealistically high additional precipitation requirements to fill the reservoir;
- The probability distributions of historic meteorological conditions are calculated as independent variables as later explained in Section 6; and,

- Freeze-up is identified as the earliest day, following the summer season, when the preceding 14-day 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

Following recalibration, the GoldSim model was validated against measured water levels in Lake Geraldine from October 23, 2020 (the approximate beginning of the 2020 freeze-up period) to March 11, 2022 (the model initialisation date for this year's water balance study).

Model performance was evaluated by visually comparing model predicted water levels against observed water levels (during ice free conditions) 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. Model RMSE over the period of comparison, for the open water season (July 3, 2021 to November 15, 2021), is 12 cm, which corresponds to a volume of between 6,600 m^3 at the intake invert (101.6 masl) and 37,300 m^3 at full board (111.33 masl). Comparison of modelled and measured water levels on the last day of thaw (July 2, 2021) shows a 14 cm discrepancy which represents a 43,800 m^3 underestimate of water supplies. The predicted water level at freeze-up (November 16, 2021) is 17 cm lower than the measured water level which corresponds to a water supply of 53,700 m^3

During the validation period there were a total of 26 days with missing precipitation data. Missing precipitation data as shown on Figure 1 were supplemented through linear interpolation leading to uncertainty and the possibility of underestimated or overestimated rainfall and snowfall. Commentary regarding period performance (between each vertical line enumerated below) as well as likely reasons for discrepancies between modelled and measured water levels are provided below.

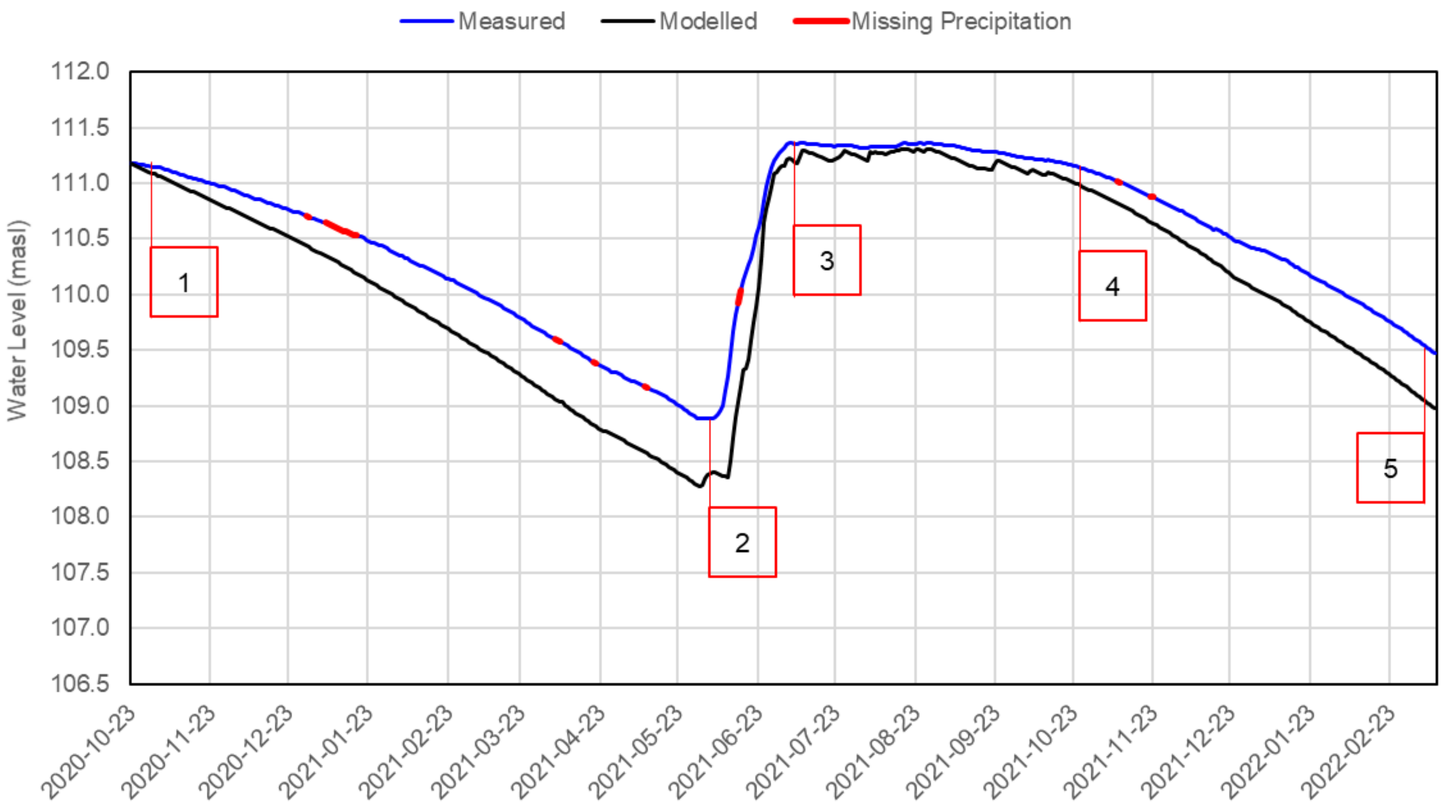

Figure 1: Visual Comparison of Modelled and Measured Water Levels, Including Periods of Missing Precipitation Data

- Period 1-2 (October 23, 2020 through June 1, 2021)
  - A likely overestimate in measured water levels as a result of ice pressure exerted on the water surface. Reasonable replication of measured water level reductions over time as a result of ice formation processes and consumption.
- Period 2-3 (June 2 2021, through July 2, 2021)
  - The model replicates the precise timing and magnitude of the water level rebound throughout the snowmelt and ice melt period, an improvement over the previous calibration (due to the decrease in sublimation rate).
- Period 3-4 (July 3, 2021 through 15 November, 2021)
  - The model captures the trend of decreasing water levels reasonably well, overestimating evaporative losses slightly.
  - Updated calibration (decrease in the evaporation factor) results in better replication of water levels during the ice-free period.

- Period 4-5 (November 16, 2021 through March 11, 2022)
  - As during the 2020/2021 winter, decreases in modelled water levels accelerate below those measured. These accelerated declines are likely the result of overestimates in the measured water levels as a result of ice formation within the reservoir.
  - Water levels at the end of this period are underestimated by 45 cm, corresponding to a water supply volume of approximately 123,500 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 during the ice-free period 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

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)		
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

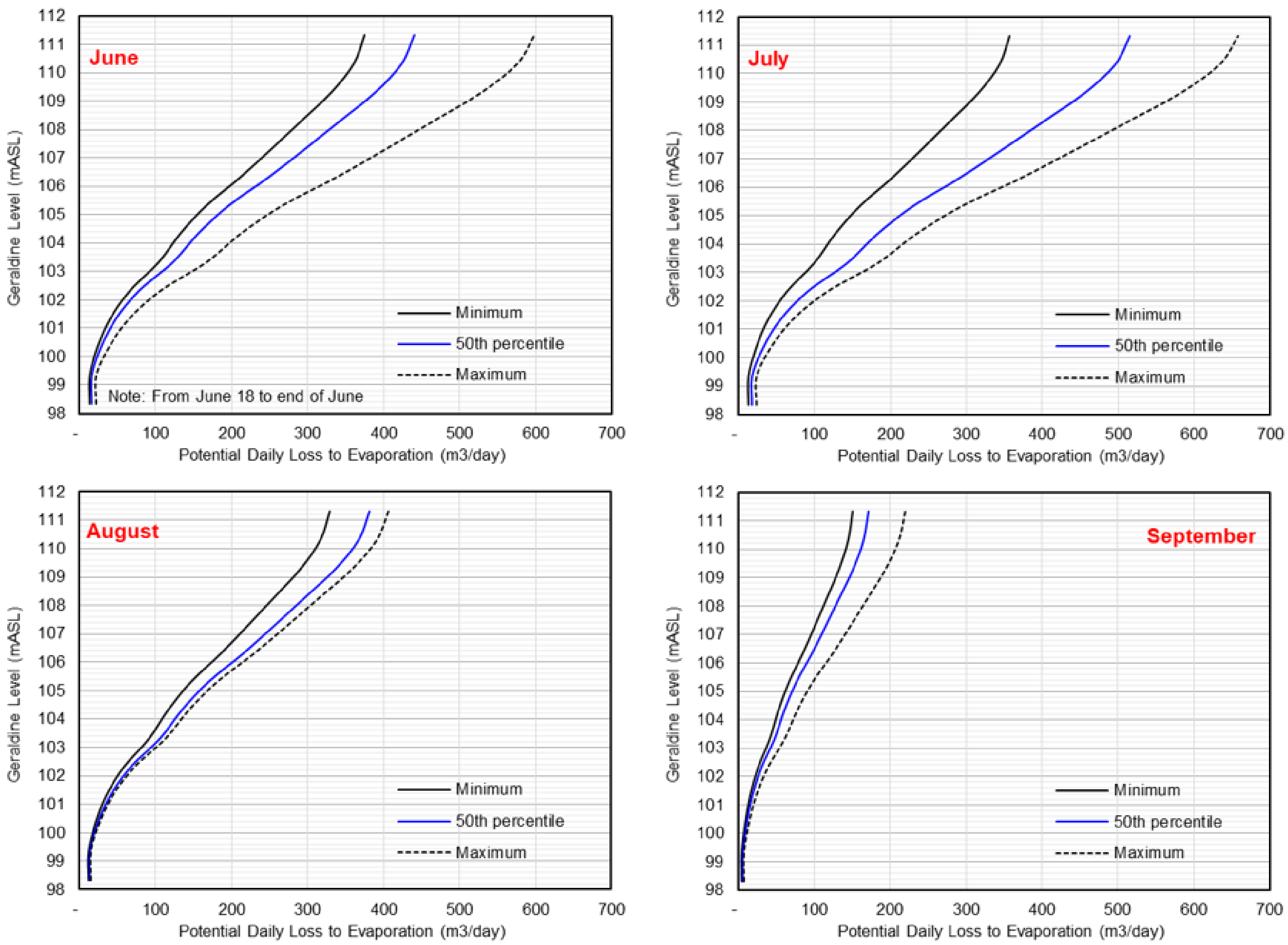

Figure 2: The Effect of Reservoir Level on Predicted Daily Evaporative Rates by Month over the 2008 through 2017 Period of Record

6.0 RESULTS

The results presented in 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 simulation period. Similarly, the 75 percent probability value for meteorological surplus does not necessarily result from the 75 percent probability value for precipitation.

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

After applying the gap-filled meteorology data (Section 2.1.6), 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 March 11 and predicted freeze-up of each year.

Table 2 provides a simplified representation of key periods of interest for the 2021/2022 winter and 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 (it is noted that the higher surplus (226 mm) / precipitation (37 mm) ratio for the period from thaw to end of June corresponds to snowmelt of the increased snowpack that was accumulated between freeze-up day in 2021, i.e., October 25, 2021, and the median historic thaw date assumed for 2022. Over the ice-free period, 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 lower 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
March 11 to Freeze-Up (Varies)[1]	299	377	126%
March 11 to end of June[2] (March 11 to Thaw day) (Thaw day to end of June)[2]	113 (76) (37)	253 (27) (226)[2]	224%[2]
July	67	47	69%
August	56	37	66%
September	50	36	71%
October 1 to Freeze-Up (Varies)[1]	12	5	40%
November 1 to Freeze-Up (Varies) [1]	0.5	0.4	85%

Notes:
1. Effective length of ice-free period (i.e., the number of days since thaw day to estimated freeze-up day) differs between years.
2. The high surplus relative to precipitation from March 11, 2022 to end of June 2022 relates to converted surplus during the period from the day of thaw to the end of June and therefore also includes snowmelt related to snow accumulation between October 25, 2021 and March 11, 2022.

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

Table 3 presents precipitation amounts and corresponding meteorological surplus between March 11, 2022 and freeze-up for a range of percentage probabilities that account for snow accumulation between October 23, 2021 and March 11, 2022 and the ten meteorological scenarios (2008 and 2017).

Based on the meteorological data considered, it is estimated that the median water supply deficit without any consumption would approximate 6,300 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 6,200 cubic metres to approximately 6,500 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 2021/2022 winter (Golder 2013), the total available water supply for the over-winter period would range between 1,284,000 m^3 and 1,284,300 m^3.

It is noted that the water supply deficit for the no water consumption scenario is lower than in previous years (Golder 2018a/b/c, 2019, 2020 and 2021) as a result of: (1) an increased amount of estimated snow accumulation stored in the catchment by March 11, 2022 relative to some previous years; and (2) changes to evaporation and sublimation rates as a result of the updated model calibration.

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[1]	Predicted Thaw Date[1]	Number of Open-Water Days from March 11 to Freeze-Up	Number of Rainfall Days from Thaw 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) [3]	Predicted Reservoir Level at Freeze-Up (masl)
					March 11 to Freeze-Up	March 11 to Thaw[2]	Thaw to End of June[2]	July[2]	August[2]	September[2]	March 11 to Freeze-Up	March 11 to Thaw[2]	Thaw to End of June[2]	July[2]	August[2]	September[2]			
0 (Max)	07-Nov	23-May	156	94	491	145	82	189	93	92	603	76	320	175	60	84	6,193	1,284,333	111.30
5	03-Nov	27-May	150	94	433	138	73	141	84	92	512	66	302	142	56	80	6,193	1,284,333	111.30
10	30-Oct	31-May	144	93	376	131	65	93	74	92	421	56	283	109	52	76	6,193	1,284,333	111.30
25	16-Oct	04-Jun	135	84	313	100	44	67	63	58	385	31	267	45	47	45	6,234	1,284,292	111.30
50	14-Oct	08-Jun	127	70	281	59	33	57	58	45	352	19	213	30	43	28	6,266	1,284,260	111.30
75	11-Oct	11-Jun	124	64	266	51	24	45	47	34	348	17	191	17	32	18	6,285	1,284,241	111.30
90	06-Oct	13-Jun	121	57	248	42	17	37	32	24	329	7	171	7	9	10	6,381	1,284,145	111.30
95	05-Oct	14-Jun	118	55	208	39	13	28	31	22	299	6	160	6	8	8	6,436	1,284,090	111.30
100 (Min)	04-Oct	15-Jun	116	54	169	36	9	19	30	20	270	4	150	5	7	7	6,491	1,284,035	111.30

Notes:
1. Percentage of probability exceedance calculated using independent probability for the thaw dates and freeze-up dates, meaning that the combination of thaw date and freeze-up date may have not occurred on the same year.
2. Monthly precipitation and surplus values are based on independent probability distributions for examined month and cannot be summed to derive the corresponding period total.
3. 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 October 23, 2021 to March 11, 2022 snow accumulation and the ten-year historical meteorological period considered, it is estimated that the median water supply deficit at a consumption rate of 100,000 m^3 would approximate 63,300 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 42,900 or 232,200 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 (i.e., a total winter period consumption of 900,000 m^3) would not lead to over-winter water shortages as the total water supply for the over-winter period would range between 1,058,300 m^3 and 1,247,600 m^3 (See Table 4).

It is noted that the water supply deficit for the 100,000 m^3/month water consumption scenario is lower than in previous years (Golder 2018a/b/c, 2019, 2020 and 2021) as a result of: (1) an increased amount of estimated snow accumulation stored in the catchment by March 11, 2022 relative to some previous years; and (2) changes to evaporation and sublimation rates as a result of the updated model calibration.

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[1]	Predicted Thaw Date[1]	Number of Open-Water Days from March 11 to Freeze-Up	Number of Rainfall Days from Thaw 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) [3]	Predicted Reservoir Level at Freeze-Up (masl)
					March 11 to Freeze-Up	March 11 to Thaw[2]	Thaw to End of June[2]	July[2]	August[2]	September[2]	March 11 to Freeze-Up	March 11 to Thaw[2]	Thaw to End of June[2]	July[2]	August[2]	September[2]			
0 (Max)	07-Nov	23-May	156	94	491	145	82	189	93	92	603	76	320	175	60	84	42,925	1,247,601	111.19
5	03-Nov	27-May	150	94	433	138	73	141	84	92	512	66	302	142	56	80	47,823	1,242,703	111.17
10	30-Oct	31-May	144	93	376	131	65	93	74	92	421	56	283	109	52	76	52,720	1,237,806	111.15
25	16-Oct	04-Jun	135	84	313	100	44	67	63	58	385	31	267	45	47	45	56,844	1,233,682	111.14
50	14-Oct	08-Jun	127	70	281	59	33	57	58	45	352	19	213	30	43	28	63,271	1,227,256	111.12
75	11-Oct	11-Jun	124	64	266	51	24	45	47	34	348	17	191	17	32	18	75,706	1,214,820	111.08
90	06-Oct	13-Jun	121	57	248	42	17	37	32	24	329	7	171	7	9	10	123,329	1,167,197	110.93
95	05-Oct	14-Jun	118	55	208	39	13	28	31	22	299	6	160	6	8	8	177,768	1,112,758	110.75
100 (Min)	04-Oct	15-Jun	116	54	169	36	9	19	30	20	270	4	150	5	7	7	232,208	1,058,318	110.57

Notes:
1. Percentage of probability exceedance calculated using independent probability for the thaw dates and freeze-up dates, meaning that the combination of thaw date and freeze-up date may have not occurred on the same year.
2. Monthly precipitation and surplus values are based on independent probability distributions for examined month and cannot be summed to derive the corresponding period total.
3. 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).

6.1.3 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 October 26, 2020 to March 11, 2022 snow accumulation and 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 95,500 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 64,600 or 343,900 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 (i.e., a total winter period consumption of 1,035,000 m^3) could potentially lead to over-winter water shortages only for the 100 percent probability outcome as presented in Table 5.

It is noted that the water supply deficit for the 115,000 m^3/month water consumption scenario is lower than in previous years (Golder 2018a/b/c, 2019, 2020 and 2021) as a result of: (1) an increased amount of estimated snow accumulation stored in the catchment by March 11, 2022 relative to some previous years; and (2) changes to evaporation and sublimation rates as a result of the updated model calibration.

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

Percentage Probability Of Exceedance	Predicted Freeze-Up Date[1]	Predicted Thaw Date[1]	Number of Open-Water Days from March 11 to Freeze-Up	Number of Rainfall Days from Thaw 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) [3]	Predicted Reservoir Level at Freeze-Up (masl)
					March 11 to Freeze-Up	March 11 to Thaw[2]	Thaw to End of June[2]	July[2]	August[2]	September[2]	March 11 to Freeze-Up	March 11 to Thaw[2]	Thaw to End of June[2]	July[2]	August[2]	September[2]			
0 (Max)	07-Nov	23-May	156	94	491	145	82	188.9	93.0	92	603	76	320	175	60	84	64,620	1,225,906	111.12
5	03-Nov	27-May	150	94	433	138	73	141.0	83.6	92	512	66	302	142	56	80	68,568	1,221,958	111.10
10	30-Oct	31-May	144	93	376	131	65	93.1	74.2	92	421	56	283	109	52	76	72,516	1,218,010	111.09
25	16-Oct	04-Jun	135	84	313	100	44	67.2	63.3	58	385	31	267	45	47	45	75,553	1,214,973	111.08
50	14-Oct	08-Jun	127	70	281	59	33	57.4	57.7	45	352	19	213	30	43	28	95,505	1,195,022	111.02
75	11-Oct	11-Jun	124	64	266	51	24	44.8	46.8	34	348	17	191	17	32	18	124,562	1,165,964	110.92
90	06-Oct	13-Jun	121	57	248	42	17	36.9	32.0	24	329	7	171	7	9	10	156,721	1,133,805	110.82
95	05-Oct	14-Jun	118	55	208	39	13	28.1	30.8	22	299	6	160	6	8	8	250,291	1,040,235	110.51
100 (Min)	04-Oct	15-Jun	116	54	169	36	9	19.2	29.6	20	270	4	150	5	7	7	343,860	946,666	110.21

Notes:
1. Percentage of probability exceedance calculated using independent probability for the thaw dates and freeze-up dates, meaning that the combination of thaw date and freeze-up date may have not occurred on the same year.
2. Monthly precipitation and surplus values are based on independent probability distributions for examined month and cannot be summed to derive the corresponding period total.
3. 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).

6.2 Precipitation and Meteorological Surplus Required to Fill Reservoir

Using the 2021/2022 winter and 2008 through 2017 meteorological data referred to in Section 2.1.5 and water level reset function referred to in Section 2.2.4, model simulations were also carried out for the three water consumption scenarios identified in Section 2.1.4 to ascertain the quantity of precipitation that would be required from March 11 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 ice-free period 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 109.49 masl under the no consumption scenario, for an average ice-free period (thaw to freeze-up). Relative to average annual precipitation amounts measured between 2008 and 2017, average ice-free precipitation amounts would not need to increase in order to generate the necessary meteorological surplus to replenish the reservoir to a deficit of 10,000 m^3 as the predicted water deficits at freeze-up are smaller than the buffer volume identified earlier.

Despite featuring less precipitation in September 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	Precipitation (mm)	Meteorological Surplus (mm)	Percentage of Precipitation Converted to Meteorological Surplus
March 11 to Freeze-Up (Varies)[1]	299	377	126%
March 11 to end of June[2] (March 11 to Thaw day) (Thaw day to end of June) [2]	113 (76) (37)	253 (27) (226)[2]	224%[2]
July	67	47	69%
August	56	37	66%
September	50	36	71%
October 1 to Freeze-Up (Varies)[1]	12	5	40%
November 1 to Freeze-Up (Varies) [1]	0.5	0.4	85%

Notes:
1. Effective length of ice-free period (i.e., the number of days since thaw day to estimated freeze-up day) differs between years.
2. The high surplus relative to precipitation from March 11, 2022 to end of June 2022 relates to converted surplus during the period from the day of thaw to the end of June and therefore includes snowmelt related to snow accumulation between October 23, 2021 and March 11, 2022.

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 no change in precipitation and meteorological surplus relative to average measured historic conditions (see Table 3).

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 (Thaw to Freeze-up)	March 11 to Thaw[1]	Thaw to End of June[1]	July[1]	August[1]	September[1]	Open Water Period (Thaw to Freeze-up)	March 11 to Thaw[1]	Thaw to End of June[1]	July[1]	August[1]	September[1]
0 (Max)	07-Nov	6,193	216	4	150	5	7	7	133	36	9	0	30	20
5	03-Nov	6,193	257	6	160	6	8	8	147	39	13	28	31	22
10	30-Oct	6,193	298	7	171	7	9	10	161	42	17	37	32	24
25	16-Oct	6,234	319	17	191	17	32	18	191	51	24	45	47	34
50	14-Oct	6,266	341	19	213	30	43	28	219	59	33	57	58	45
75	11-Oct	6,285	367	31	267	45	47	45	250	100	44	67	63	58
90	06-Oct	6,381	407	56	283	109	52	76	273	131	65	93	74	92
95	05-Oct	6,436	467	66	302	142	56	80	310	138	73	141	84	92
100	04-Oct	6,491	528	76	320	175	60	84	346	145	82	189	93	92

Notes:

1. Monthly precipitation and surplus values are based on independent probability distributions for examined month and cannot be summed to derive the corresponding period total.

6.2.3 Estimated Necessary Precipitation and Catchment Surplus to Replenish Reservoir by Freeze-Up under 100,000 m³/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 109.49 masl under the 100,000 m^3/month consumption scenario, for an average ice-free period (thaw 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 9% in order to generate the necessary meteorological surplus to replenish the reservoir to a two-week deficit within approximately 46,700 m^3.

Compared to the results presented in Table 6, on average (arithmetically), a 5% increase in precipitation relative to the no consumption scenario would be necessary to replenish the reservoir before freeze-up, resulting in a% increase in surplus over the March 11 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 m³/Month Consumption Scenario

Period	Precipitation (mm)	Meteorological Surplus (mm)	Percentage of Precipitation Converted to Meteorological Surplus
March 11 to Freeze-Up (Varies)[1]	314	387	123%
March 11 to end of June [2] (March 11 to Thaw day) (Thaw day to end of June)	118 (79) (40)	255 (28) (227)	215%[2]
July	71	50	70%
August	60	40	66%
September	53	37	70%
October 1 to Freeze-Up (Varies)[1]	18	12	70%
November 1 to Freeze-Up (Varies) [1]	0.5	0.5	89%

Notes:
1. Effective length of ice-free period (i.e., the number of days since thaw day to estimated freeze-up day) differs between years.
2. The high surplus relative to precipitation from March 11, 2022 to end of June 2022 relates to converted surplus during the period from the day of thaw to the end of June and therefore includes snowmelt related to snow accumulation between October 23, 2021 and March 11, 2022.

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 open water period (thaw to freeze-up) would need to increase between 0 and 90 mm (Comparing Table 7 and 9) 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), 30% 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.

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 (Thaw to Freeze-up)	March 11 to Thaw[1]	Thaw to End of June[1]	July[1]	August[1]	September[1]	Open Water (Thaw to Freeze-up)	March 11 to Thaw[1]	Thaw to End of June[1]	July[1]	August[1]	September[1]
0 (Max)	07-Nov	42,925	225	4	152	6	7	10	133	43	9	0	30	24
5	03-Nov	47,823	262	6	168	7	8	10	174	47	13	33	31	25
10	30-Oct	52,720	299	7	183	8	9	11	184	50	17	38	32	26
25	16-Oct	56,844	325	17	189	17	35	18	193	52	26	45	55	35
50	14-Oct	63,271	352	23	213	30	43	30	240	66	36	57	61	48
75	11-Oct	75,706	388	31	266	45	50	47	261	100	49	67	70	61
90	06-Oct	123,329	411	57	284	135	61	76	276	131	65	115	78	92
95	05-Oct	177,768	468	67	302	155	65	80	311	138	73	152	86	92
100	04-Oct	232,208	525	76	320	175	69	84	346	145	82	189	93	92

Notes:

1. Monthly precipitation and surplus values are based on independent probability distributions for examined month and cannot be summed to derive the corresponding period total.

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 109.49 masl under the 115,000 m^3/month consumption scenario, for an average ice-free period (thaw to freeze-up). Relative to average annual precipitation amounts measured between 2008 and 2017, average annual precipitation amounts would need to increase by approximately 12% in order to generate the necessary meteorological surplus to replenish the reservoir to a two-week deficit within approximately 53,900 m^3.

Compared to the results in Table 6, on average (arithmetically), an 8% increase in precipitation relative to the no consumption scenario would be necessary to replenish the reservoir before freeze-up, resulting in a 4% increase in surplus over the March 11 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
March 11 to Freeze-Up (Varies)[1]	324	391	120%
March 11 to end of June [2] (March 11 to Thaw day) [2] (Thaw day to end of June) [2]	123 (81) (41)	256 (29) (227)	201%[2]
July	73	50	69%
August	62	41	66%
September	54	38	69%
October 1 to Freeze-Up (Varies)[1]	18	12	69%
November 1 to Freeze-Up (Varies) [1]	0.5	0.5	89%

Notes:
1. Effective length of ice-free period (i.e., the number of days since thaw day to estimated freeze-up day) differs between years.
2. The high surplus relative to precipitation from March 11, 2022 to end of June 2022 relates to converted surplus during the period from the day of thaw to the end of June and therefore includes snowmelt related to snow accumulation between October 23, 2021 and March 11, 2022.

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 open water period would need to increase between 0 and 116 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 10), 29% 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.

Table 11: Required Precipitation and Surplus to Replenish Reservoir by Freeze-Up Under 115,000 m^3/month Water Consumption Scenario (3,850 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 (Thaw to Freeze-up)	March 11 to Thaw[1]	Thaw to End of June[1]	July[1]	August[1]	September[1]	Open Water (Thaw to Freeze-up)	March 11 to Thaw[1]	Thaw to End of June[1]	July[1]	August[1]	September[1]
0 (Max)	07-Nov	64,620	244	4	154	8	8	10	133	43	9	0	30	24
5	03-Nov	68,568	272	6	169	8	9	10	178	47	13	35	32	26
10	30-Oct	72,516	301	7	184	9	10	11	193	50	18	38	35	28
25	16-Oct	75,553	326	18	190	18	37	18	220	54	26	45	57	38
50	14-Oct	95,505	351	26	212	30	44	32	240	71	39	62	62	48
75	11-Oct	124,562	390	31	266	45	50	48	261	101	52	67	73	68
90	06-Oct	156,721	413	60	285	136	61	76	294	131	66	123	84	92
95	05-Oct	250,291	469	68	303	156	65	80	320	138	78	156	88	92
100	04-Oct	343,860	526	76	321	175	69	84	346	145	90	198	93	92

Notes:

1. Monthly precipitation and surplus values are based on independent probability distributions for examined month and cannot be summed to derive the corresponding period total.

7.0 CONCLUSIONS AND RECOMMENDATIONS

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

6) The open-water period available for replenishment of the reservoir (predicted thaw to predicted freeze-up) ranges from 116 to 156 days (predicted thaw dates ranges between May 22 to June 16 while freeze-up dates range between October 4 and November 7).

7) The assessment of recent meteorological conditions (2008 to 2017) suggests that, on average, 80% of the measured precipitation falling between March 11 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.

8) 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 6,200 m^3 and 6,500 m^3, with a 50th percentile of 6,300 m^3;

   b. The 100,000 m^3/month water consumption scenario incurs a water supply deficit between 42,900 m^3 and 232,200 m^3, with a 50th percentile of 63,300 m^3; and,

   c. The 115,000 m^3/month water consumption scenario incurs a water supply deficit between 64,600 m^3 and 343,900 m^3, with a 50th percentile of 95,500 m^3.

9) The assessment of meteorological surpluses for the March 11, 2022 to 2022 freeze-up period (assessment period) indicates that, relative to the measured 2008 through 2017 arithmetic average precipitation amount (290 mm), arithmetic average precipitation amounts required to achieve close to maximum water supplies by freeze-up would need to increase to:

   a. no increase for the no water consumption scenario;

   b. 314 mm for the 100,000 m^3/month water consumption scenario; and,

   c. 324 mm for the 115,000 m^3/month water consumption scenario.

10) The assessment of meteorological surpluses from thaw to freeze-up period (open-water period) indicates that, relative to the measured 2008 through 2017 arithmetic average precipitation amount (223 mm), arithmetic average precipitation amounts required to achieve close to maximum water supplies by freeze-up would need to increase to:

   a. no increase the no water consumption scenario;

   b. 243 mm for the 100,000 m^3/month water consumption scenario; and,

   c. 249 mm for the 115,000 m^3/month water consumption scenario.

11) It should be noted that the total open-water precipitation requirements detailed under Conclusion 5 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.

12) 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.

13) Given the differences between model and measured water levels during the ice-cover period, it is possible that winter observations may be affected by ice exerting pressure on the water surface. Golder recommends collecting graphic documentation of the logger and ice coverage during the winter period to better understand water level readings during the ice-cover period.

14) 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. Golder recommends confirmation of Lake's Geraldine's active stage-storage capacity to minimize errors in the potential water supply deficit predictions.

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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