TECHNICAL MEMORANDUM

TO: Kevin Kerr, P.Eng., Director of Engineering and Capital Projects, City of Iqaluit

FROM: Keihan Kouroshnejad, Mike Movahedan, Camilo Marquez

SUBJECT: **Lake Geraldine Water Balance Model Calibration Update – 2024 Refinement and Validation**

DATE: **November 12, 2025**

EXECUTIVE SUMMARY

The City of Iqaluit commissioned WSP to address the first recommendation (R-09a) of the Crown-Indigenous Relations and Northern Affairs Canada (CIRNAC) to update model calibration for Lake Geraldine for the entire period of record after completion of second CIRNAC recommendation (R-09b), collect bathymetric information for Lake Geraldine Reservoir and compare the model-represented stage-storage relationship against updated bathymetric information.

This technical memorandum was prepared by WSP Canada Inc. for the City of Iqaluit to provide an updated water balance forecast for the Lake Geraldine Reservoir. The work is a refinement of a previous assessment from 2013 and subsequent updates from 2018 to 2023. The City of Iqaluit relies on Lake Geraldine for its year-round municipal water supply, but recent studies suggest the reservoir may not be able to meet growing long-term demands.

The primary objectives of this work were to review and process daily climatic, water level, consumption, and supplementation data; update and recalibrate the water balance model using European Centre for Medium-Range Weather Forecasts (ECMWF) Re-Analysis (ERA5) climate data and new bathymetry data from a 2024 survey; and validate the model over a period independent from the calibration period. This study leverages more current data, including the 2024 bathymetry survey and an extended period of record, to facilitate robust calibration and validation.

The methodology for this update was consistent with previous models. Key elements of the methodology include catchment and basin physiography which remain unchanged, but the 2024 bathymetry data was used to update the stage-storage relationship for Lake Geraldine. This update revealed an increase in the Lake's storage capacity, which contrasts with a previous report that suggested a volume reduction.

The analysis considered consumption rates from 2007 to 2024. The average daily consumption rate for the past five years (2020-2024) has increased to 3,291 m^3/day, up from an average of 2,902 m^3/day between 2007 and 2024. This increase is potentially due to population growth and other contributing factors.

Due to gaps in data from local Environment Canada climate stations, ERA5 dataset was used to fill missing temperature and precipitation data.

The model was calibrated against observed water surface elevations from July 1, 2013, to October 10, 2017. The objective was to ensure the model accurately reproduced key hydrologic processes. The final calibrated model had a Root Mean Square Error (RMSE) of 0.18 m, with a water level difference between the modeled and observed data of approximately 0.09 m at the end of the calibration period. The model showed good agreement with observed data,

1600 Buffalo Place
Winnipeg, MB R3T 6B8
wsp.com

reliably reflecting the timing and amplitude of principal hydrologic transitions. As such, the model is considered suitable for further validation and forecasting scenarios.

Following calibration, the model was validated using independent data from July 1, 2021, to October 10, 2024. The validation showed that the model captures the rapid freshet rise and seasonal amplitude of lake levels, with an overall RMSE of 0.25 m. The water level differences between the model and observed data were very low (a few centimeters) during the period from mid-June to early July, indicating an accurate prediction of water levels during the reservoir's replenishment. Discrepancies were noted at the beginning of the open-water season, and peak water levels within the Lake. By the end of the validation period, the modeled water level was approximately 0.14 meters higher than the observed water level. The model's performance was deemed satisfactory for its intended purpose.

The updated water balance model for Lake Geraldine, which incorporates new 2024 bathymetry data, showed strong agreement with observed water level data during both the calibration and validation periods.

The updated survey data indicates a modest increase of 14,920 m^3 at the intake elevation, but a more substantial increase of 189,057 m^3 at the spillway invert. it also indicates an increase in the Lake's storage volume, which may impact supplementation requirements.

It is recommended that the City of Iqaluit use the higher end of previously provided water supply deficit values as guidance for supplementation planning to avoid underestimating the required volumes. It is recommended to complete the identified data gaps, including daily water consumption and emergency pumping volumes from 2018 and 2019, to allow for an extended calibration period. Also, it is recommended to verify the potential impact of ice pressure on water level measurements during the lake's ice-covered period, if possible.

1 INTRODUCTION

This technical memorandum has been prepared by WSP Canada Inc. (WSP) for the City of Iqaluit (the City) to prepare an updated water balance forecast for the Lake Geraldine Reservoir for the 2024 calendar year. To minimise the risk of misinterpretation, the information presented in this technical memorandum should be read and interpreted in conjunction with an earlier Lake Geraldine Water Balance Assessment prepared by Golder in 2013, and updated estimates provided for each of the 2018 to 2023 ice-free seasons.

This work follows a previous Lake Geraldine Water Balance Assessment, completed by Golder in August 2013, under project file 12-1151-0115 (Golder 2013), and various other water balance and water supply forecasting work completed by Golder between August 2018 and May 2023 (Golder 2018, 2019, 2020, 2021, 2022; WSP 2023 and 2024).

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 (Golder, 2018). Several 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.

In September 2019, the City received an amendment (Amendment No. 4) to its Water License permitting an annual maximum of 500,000 m^3 of water to be extracted from the Apex River for transfer to Lake Geraldine. This has been conducted since 2020 under the Apex River Supplementary Pumping Program (SPP) (Nunami Stantec Limited, 2024).

It is WSP's understanding that the 2024 Water Balance Report is required by the City to satisfy one of the conditions associated with the approval of Amendment 4 of Nunavut Water Board license renewal for seasonal replenishment of Lake Geraldine from the Apex (Niaqunguk) River. This work follows a previous Lake Geraldine Water Balance Assessment, completed by Golder in August 2013 (Golder 2013), and various other water balance and water supply forecasting work completed by Golder between August 2018 and May 2023 (Golder 2018a/b/c, 2019, 2020, 2021, 2022; WSP 2023 and 2024).

1.2 OBJECTIVES

This scope of work addresses CIRNAC recommendations R-09a and R-09b. Bathymetric survey data from fall 2024 are used to assess whether the current modelled stage-storage relationship is still accurate or requires updating. To thoroughly evaluate model performance, multiple years of historical data must be obtained and processed for consistency and integrity. The goal is to update the model with ERA5 climate data over the entire period of record, defined as the time since spillway reconfiguration at Lake Geraldine when historical supplementation, consumption, and water level data are available, and use this for recalibration.

The purpose of this technical memorandum is to achieve the following main goals:

1 Data Review and Processing:
   - Daily climatic, water level, consumption and supplementation data are to be obtained, evaluated and processed and reviewed for the entire period of record (WSC measured water levels at station 10UH013 are available from August 2007 onwards, but it is noted that a spillway reconfiguration sometime after 2006 to increase reservoir storage will form the analysis start date for this exercise). Due to the unreliability of consistently published Environment Canada precipitation data for Iqaluit in recent years, WSP proposes the use of ERA reanalysis or an alternative suitable data source, if required, to characterize climatic data. As part of this task, data gap analysis and selection of appropriate assumptions to fill the necessary information in the dataset are to be completed and implemented.

2 Model Updates and Recalibration:
   - While the snow-melt model was updated in WSP 2023 and further refined in Phase 1 (WSP, 2024), additional updates are needed to improve ERA5 (or other relevant data) snow-cover sublimation and melt processes for the entire record. The model also requires updating with the new Lake Geraldine stage-storage curve from 2024 bathymetry data.
   - Integrate ERA5 meteorological data (or an alternative if necessary) with other inputs, complete required model updates, and test the model to ensure all functions operate correctly for future calibration and refinement.
   - With water level data, consumption rates, and supplementation volumes provided by the Water Survey of Canada and the City, use the recalibrated model to simulate Lake Geraldine water levels over the period of record. Focus on identifying weaknesses and optimizing performance, calibrating for periods without major data gaps since the spillway reconfiguration.
   - Incorporate additional water level data (Water Survey of Canada), daily reservoir withdrawals, and supplementation volumes/rates (available from the City—see Section 4) to finalize the model update.

3 Model Validation:
   - After recalibrating the model, validation should take place over a period separate from the calibration period.

2 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, 2021, 2022) and WSP 2023 and 2024). A summary of the previous approach (Golder, 2013, 2018, 2019, 2022, 2023), and a detailed inventory of any modifications to the previous approach, are provided below for context.

2.1 MODELLING SCENARIOS

2.1.1 CALIBRATION

Following model updates and prior to validation, the model was calibrated against observed water surface elevations from the Water Survey of Canada (WSC) over the period July 1, 2013, to October 10, 2017. The objective was to ensure the model accurately reproduces the dominant hydrologic and reservoir processes, snow/ice dynamics, rainfall–runoff translation, evaporation, and operational withdrawals, with minimal bias and acceptable error statistics.

- **Calibration period:** July 1, 2013 – October 10, 2017, covering multiple open-water seasons and freeze–thaw transitions.
- **Target variable:** Lake Geraldine water surface elevation (m asl), observed by WSC at the lake gauge.
- **Objective Function:** The objective function is defined as the Root Mean Square Error (RMSE) between the modelled and observed water surface levels:

$$RMSE = \sqrt{\sum \frac{(W1 - W2)^2}{n}}$$

Where W1 is the observed water surface elevation and W2 is the modeled water surface elevation.

RMSE is a key metric for quantifying the average magnitude of model error, with lower values indicating better agreement between simulated and observed data.

- Decision variables include the following:
    - Lake Ice formation multiplier
    - Lake Ice Melting Multiplier
    - PET Multiplier Land
    - PET Multiplier Water
    - Snow Correction Factor
- **Visual comparison** of observed vs. simulated lake level time series across seasons is checked for the optimization results in addition to the RMSE (open water and shoulder periods).

The optimization is performed inside the GoldSim software using Box's complex method. The precision of the optimization is set to maximum.

2.1.2 VALIDATION

Model validation was conducted to assess the robustness and predictive skill of the simulation by comparing modeled lake water surface elevations against independent observations not used during calibration. The evaluation process included a visual comparison of observed and simulated levels throughout the entire validation period, as well as the calculation of goodness-of-fit statistics such as RMSE. The validation period spanned from July 1, 2021, to October 10, 2024, encompassing four open-water seasons and three winters seasons. Observed data consisted of daily mean lake elevations (in meters above sea level) recorded by the Water Survey of Canada gauge at Lake Geraldine Near Iqaluit (10UH013). The model was driven by the same meteorological forcing framework used in calibration, including station data with reanalysis infill as needed, along with the updated stage–storage curve, intake and spillway elevations, and operational time series. It is important to note that winter readings may be affected by ice pressure effects, and these were interpreted with appropriate caution during the validation analysis.

For the purposes of model validation, meteorological and water level data for the period from 1 July 2021 to 10 October 2024 were sourced from the Iqaluit Climate station (Station ID: 2402592) and the Real-Time Hydrometric Portal, Station 10UH013 (Water Survey of Canada), respectively. An alternative source of weather data (ERA5) was used to fill the data gap and the PET, as described previously in section 2.1.6.

2.2 CONSISTENCIES WITH THE 2018 TO 2024 MODELLING APPROACH

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 2023. Specifically, consistencies with the previous approach include:

2.2.1 CATCHMENT AND BASIN PHYSIOGRAPHY

The physiographic representation of the contributing catchment and reservoir basin within the model has remained unchanged since 2013. Specifically, this maintains consistency with the approach used to characterise the surficial geology, topography, and size of the drainage catchment. However, Lake Geraldine's bathymetry and stage-storage relationship should be updated based on the 2024 collected data and used in the model if it is different from the previous one.

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.

Notwithstanding these differences, it is recommended that the City of Iqaluit use the higher end of water supply deficit values provided previously (WSP, 2024) as guidance for supplementation planning rather than risk an underestimate of supplementation volumes that could result in insufficient overwinter supplies.

2.2.2 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, 2021, 2022; WSP 2023 and 2024).

Catchment yield, or surplus, is calculated as follows:

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

2.2.3 WATER CONSUMPTION (DEMAND) AND INTAKE WITHDRAWAL RATES

The water balance investigation presented herein considers the consumption rates over an extended period, provided by the City of Iqaluit Water Treatment Plant rates (supplied by WSP from the Supervisory Control and Data Acquisition or SCADA system), and for specific examination, including:

- City of Iqaluit daily water consumption from 01 January 2007 to 31 December 2011 (Golder, 2013).
- City of Iqaluit monthly water consumption rates provided by City of Iqaluit (Annual Water License Reports 2012, 2014, 2015).
- City of Iqaluit monthly water demands from 2006 to 2018 (Nunami Stantec, 2019).
- Water Treatment Plant daily water taking data for 2013 provided by City of Iqaluit and from 1 January 2020 to 31 December 2024 (provided by WSP).

In the absence of daily water demand, WSP considered a simplified approach to estimate the average daily water consumption rates to fill the daily data gaps (1 January 2012 to 31 December 2017). The daily water demand for each month is estimated by distributing the monthly water demand over the days using the daily consumption patterns for each month. This approximation may affect the daily water prediction, but the impact on a monthly basis would be insignificant. This approach allows distribution of the monthly values into the days without affecting the monthly values.

Figure 1 clearly illustrates the strong similarity in the City's monthly water consumption trends over the decade from 2006 to 2016.

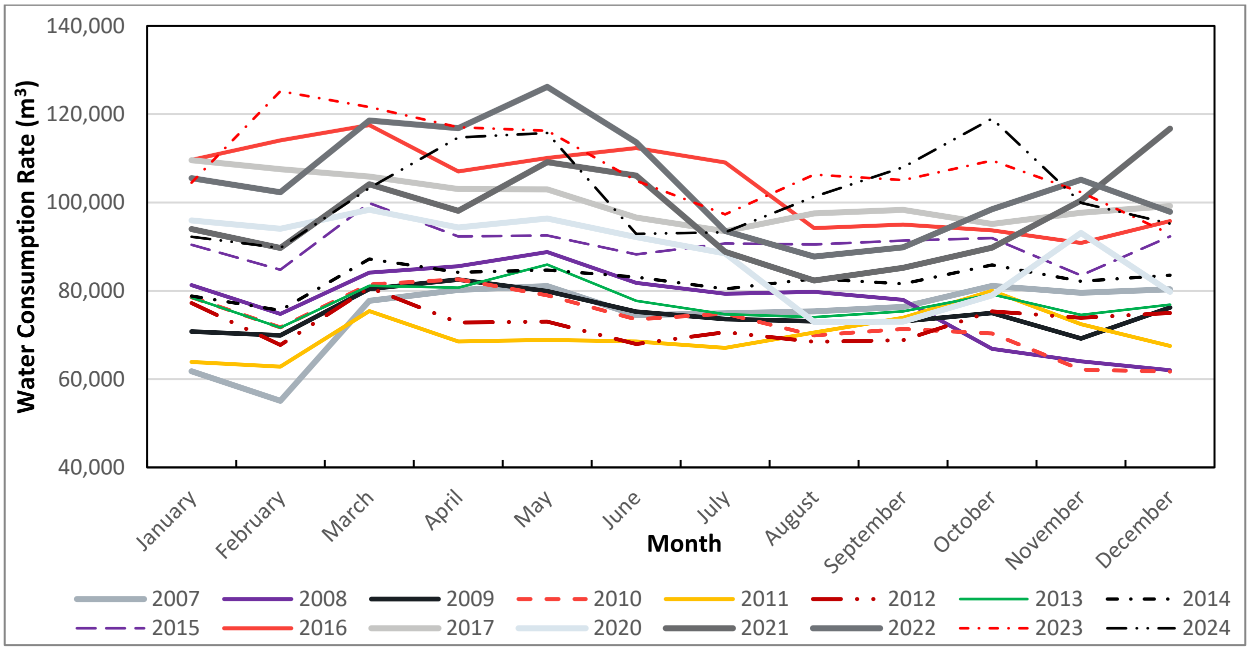

Figure 1: City of Iqaluit monthly Water Consumption from 2007 to 2017 and from 2020 to 2024 (2007 to 2011 data extracted from Golder 2013 model; 2012, 2014, and 2015 data from the City of Iqaluit Annual Water License Reports; 2013 from Water Treatment Plant data provided by City, 2016, and 2017 data from Nunami Stantec 2019 report, and 2020 to 2024 from Water Treatment Plant data , SCADA system, provided by WSP)

Table 1 summarizes the water consumption based on the gathered data.

Table 1: Minimum, Maximum, and Average Water Consumption Rates (m3)

	2007-2024 (EXCLUDING 2018 AND 2019)			2020-2024		
Description	**Annual**	**Monthly**	**Daily**	**Annual**	**Monthly**	**Daily**
MIN	839,610	55,090	1,968	1,057,581	72,956	2,353
MAX	1,303,111	127,740	4,472	1,303,111	126,205	4,472
AVERAGE	1,049,005	88,286	2,902	1,201,332	100,111	3,291

As shown in Error! Reference source not found., the average daily consumption rate between 2007 and 2024 (excluding 2018 and 2019) is approximately 2,902 m³/day. The average daily consumption rate for the past five years (2020-2024) has increased to 3,291 m³/day.

Tables A.1 and **A.2** (**Appendix A**) summarize the monthly and average daily water consumption rates for the City of Iqaluit between 2006 and 2024 (excluding 2018 and 2019).

2.2.4 SUPPLEMENTATION FROM APEX RIVER (NIAQUNGUK RIVER)

The City of Iqaluit's drinking water, sourced from Geraldine Lake, has been affected by recent low water levels. This situation in 2018 and 2019 necessitated an emergency water supply from the Apex River to Lake Geraldine to meet the community's needs throughout the following winters (Nunami Stantec, 2018 and 2019). Details of those supplementary pumping activities, including the timing and volume, are not available to WSP. The inclusion of missing data could be used for the extension of the water balance model's calibration period.

The City has commissioned supplementary water supply activities (Supplementary Pumping Program or SPP) from the Apex River to the Lake Geraldine since 2020 to supply additional water during the ice-free period in order to provide sufficient water to meet growing demands. Details of the SPP from 2022, 2023, and 2024 are provided by Nunami Stantec (2023, 2024, and 2025). The details of the SPP in 2020 (if any) were not available for WSP, and the summary of the SPP for 2021 were taken from the WSP 2023 model data input.

Table 2 summarizes the Apex River Supplementary Pumping Program from 2021 to 2024.

Table 2: Apex River (Niaqunguk River) Supplementary Pumping Program.

YEAR	PUMPING PERIOD [1]	SUPPLEMENTARY PUMPING VOLUME (M^3)	PEAK PUMPING CAPACITY (M^3/DAY)
2021 [2]	June 24 to June 28	76,317	17,280
2022 [3]	June 12 to September 12 September 13 to 19	367,501 76,889	14,541 12,644
2023 [4]	June 26 to July 13	222,784	15,100
2024 [5]	June 26 to July 5	137,650	15,769

[1] The City did not perform non-emergency supplementary pumping before 2020. Pumping information for 2020 was not available to WSP.
[2] Extracted from Water Balance Model (WSP, 2023).
[3] Nunami Stantec Limited (2023).
[4] Nunami Stantec Limited (2024).
[5] Nunami Stantec Limited (2025).

The water balance model in the present report considered the total supplementation volume reported during the supplementation period of 2021 to 2024 and included those inputs in the modelling exercise.

2.2.5 HISTORICAL METEOROLOGY

The same historical meteorological dataset used in Golder (2018a/b/c, 2019, 2020, 2021, 2022; WSP 2023, 2024), featuring precipitation, air temperature, wind speed, and relative humidity records for the 2008 through 2017 period, were applied to this study. As a reminder of the 2018a/b/c, 2019, 2020, 2021, 2022, and 2023 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.

2.2.6 ALTERNATIVE SOURCE OF WEATHER DATA

The gaps in temperature and precipitation data from Environment Canada climate stations (Iqaluit A and Iqaluit Climate) necessitated sourcing temperature and precipitation data from alternative sources. To develop a continuous and consistent record for both temperature and precipitation throughout the validation period, the European Centre for Medium-Range Weather Forecasts (ECMWF) Re-Analysis (ERA5) dataset was used for infilling the data gaps after applying a statistical adjustment for daily precipitation amounts using concurrent values for the Iqaluit Climate station observations. A quantile delta mapping (QDM) bias adjustment was performed on the ERA5 precipitation data using the compiled Iqaluit Climate observations (Cannon et al. 2015). This method enables the correction of daily temperature and total precipitation values to account for seasonal differences between ERA5 and the compiled Iqaluit Climate observations.

2.2.7 ICE STORAGE

All ice formed within the reservoir is assumed to be inaccessible during winter months, 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 to values expected overwinter in northern regions. The 2024 version of the model predicts ice thickness values in the range of 0.82 to 0.91 m, which are relatively smaller than those achieved by previous versions of the model (former ice thickness predictions are in the range of 0.93 to 1.25 m). This adjustment results in a more realistic representation of water supply volumes in Lake Geraldine.

2.3 UPDATES TO THE 2024 MODELLING APPROACH

The following subsection documents changes made to the 2024 water balance model to accommodate the particulars of this scope of work.

2.3.1 INCORPORATION OF LAKE GERLINE UPDATED STAGE-STORAGE RELATIONSHIP

Bathymetric data of Lake Geraldine and topographic data up to and slightly beyond the maximum spillway elevation, i.e., 111.3 masl, as well as mapping of the wetted lake perimeter, have been collected in the fall of 2024 (GeoVerra, 2024). The collected data were used to develop an updated stage-storage relationship and compared to the existing stage-storage relationship (defined from data collected by Natural Resources Canada 2008) to determine if the existing relationship remains valid or needs to be updated. Since any change in the stage storage curve could result in changes in the reservoir supplies and supplementation requirement, the updated stage storage curve is used in the present report. **Figure 2** illustrates the updated Lake stage storage curve based on the 2024 lake survey and bathymetry mapping and compares it with the curve, based on the Natural Resources Canada 2008 survey, used for the previous water balance models (i.e., 2013 and 2018 to 2024 models).

As **Figure 2** illustrates, the updated stage-storage curve indicates an increase in the Lake's storage compared to the previous storage curve. **Table 3** summarizes the Lake storage volumes.

As shown in **Tables 3** and **4**, the updated lake storage volume increased by 14,920 m³ at intake elevation (El. 101.6 m). At the spillway invert (El. 111.33 m), the volume is now approximately 2,145,240 m³, which is 189,050 m³ more than before. At the lowest observed water level between 2020 and 2024 (El. 107.88 m), the increase is roughly 60,080 m³. The Lake's available volume, between intake invert and the spillway crest, indicates an increase of 174,120 m³.

Based on **Figure 2** and **Table 3**, the updated stage-storage curve shows an increase in the Lake's volume that may impact reservoir supplies, supplementation requirements, and future iterations of the water balance assessment. As a result, the water balance calibration was updated based on the updated stage-storage curve (Figure 2).

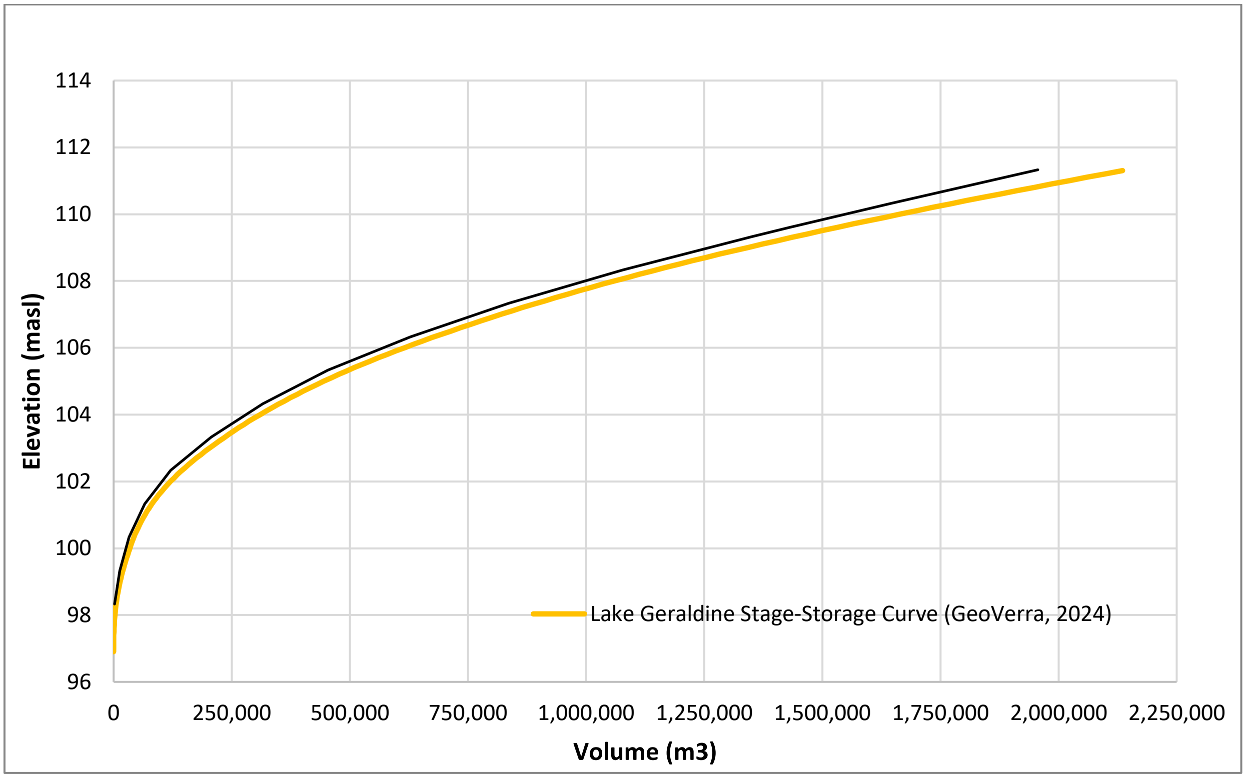

Figure 2: Lake Geraldine Stage- Storage Curves (Natural Resources Canada 2008 and GeoVerra 2024 bathymetry Survey)

Table 3: Stage-Storage Representation of Lake Geraldine (Based on GeoVerra, 2024 Bathymetric Survey)[1]

ELEVATION (MASL)	VOLUME (M^3)
98.00	2,650
99.00	13,980
100.00	34,400
101.00	66,560
102.00	120,920
103.00	203,490
104.00	310,280
105.00	445,530

ELEVATION (MASL)	VOLUME (M^3)
106.00	615,810
107.00	820,520
108.00	1,060,750
109.00	1,342,540
110.00	1,665,290
111.00	2,022,580
111.33	2,145,240

1 Volumes are rounded down to the nearest 10.

Table 4: Summary of updated Lake Geraldine storage volumes at different elevations compared to previous bathymetry survey data[1]

DESCRIPTION	ELEVATION (MASL[2])	2008 STAGE-STORAGE VOLUME (M^3) [3]	UPDATED STAGE-STORAGE VOLUME (M^3) [4]	VOLUME INCREASE (M^3)
Intake invert	101.6	80,660	95,590	14,920
Minimum observed water level (2020-2024)	107.88	968,780	1,028,870	60,080
Spillway invert	111.33	1,956,190	2,145,240	189,050
Available volume	101.6 to 111.33 [5]	1,875,520	2,049,650	174,120

1. All volumes are rounded down to the nearest 10.
2. masl: metre above sea level or m.
3. WSP (2013) based on the Natural Resources Canada (2008).
4. Based on GeoVerra bathymetry survey (2024).
5. WSC measured water levels at station 10UH013 available from August 2007 onwards.

2.3.2 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, i.e., intake elevation and spillway inverts at 101.6 m and 111.33 m, respectively.

As such, any inputs beyond the reservoir's storage capacity of 2,145,240 m^3 are assumed to be lost from the system. Similarly, any water below the assumed intake invert elevation of 101.6 m, i.e., 95,590 m^3 (Table 4), is assumed to be inaccessible for municipal use. The available storage, between the intake and spillway, would be about 2,049,650 m^3, which is approximately 174,120 m^3 higher compared to the available storage estimated based on the 2008 stage-storage curve.

2.3.3 INCORPORATION OF 2024 METEOROLOGY

Meteorological data were mainly obtained from the Environment Canada climate station at Iqaluit Climate (Station ID: 2402592) for the purposes of characterizing daily air temperature, pressure, wind speed, and several other parameters for the 2024 were included in this analysis. 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). The Iqaluit Climate station has had high data availability for both temperature and precipitation in the past; however, during certain period (such as October 1, 2022, to May 6, 2024), The Iqaluit A station provides good data availability for temperature during this period, but no precipitation is recorded, requiring filling of data gaps with an alternative source of weather data (See Section 2.2.3).

2.3.4 ALTERNATIVE SOURCE OF WEATHER DATA

The gaps in temperature and precipitation data from Environment Canada climate stations (Iqaluit A and Iqaluit Climate up to December 31, 2024) necessitated sourcing temperature and precipitation data from alternative sources. To develop a continuous and consistent record for both temperature and precipitation throughout the period of record (2007 to 2024), the European Centre for Medium-Range Weather Forecasts (ECMWF) Re-Analysis (ERA5) dataset was used for infilling the data gaps after applying a statistical adjustment for daily precipitation amounts using concurrent values for the Iqaluit Climate station observations. A quantile delta mapping (QDM) bias adjustment was performed on the ERA5 precipitation data using the compiled Iqaluit Climate observations (Cannon et al. 2015). This method enables the correction of daily temperature and total precipitation values, accounting for seasonal differences between ERA5 and the compiled Iqaluit Climate observations.

2.3.5 POTENTIAL EVAPOTRANSPIRATION (PET)

To develop a continuous and consistent record for evaporative losses for the period of record, the ECMWF Re-Analysis (ERA5) dataset was used for the estimation of the reference evapotranspiration (ET_0). This approach combines vast amounts of meteorological data from satellites, ground stations, and weather balloons with a sophisticated weather forecasting model (the ECMWF's Integrated Forecasting System) to create a consistent, global dataset. The Penman-Monteith equation, the standard method for calculating ET_0 recommended by the Food and Agriculture Organization (FAO-56), is used. The reference evapotranspiration can be used as an estimate of PET since it is the PET for a reference crop (typically a short well-watered grass with no moisture limitations). The performance of the water balance model can then be improved by optimizing the PET multipliers for land and water during the calibration process.

2.3.6 WATER LEVEL, SNOWPACK, AND ICE COVER INITIAL CONDITION

The calibration model is initialized using initial conditions for water level and ice-cover at the start of the simulation, which corresponds to July 1, 2013, for the calibration model and July 1, 2021, for the validation model. A water level condition (111.267 masl) recorded at Lake Geraldine Near Iqaluit (10UH013) on July 1, 2013, is used as the basis for initializing the calibration model, and the validation model uses the water level measured on July 01, 2021. Initial conditions for reservoir ice cover for both models are assumed to be 0.

Water stored as snow cover in the catchment and reservoir ice cover up to July 1 was assumed to be assimilated into the reservoir following the melt date, along with the accumulated snowfall from July 1 for each of the historic years (2013 through 2017). Such snowfall accumulations, ice thickness, and the adjusted water level were implemented in the predictive model as initial conditions.

2.3.7 OVERWINTER WATER LEVEL REPRESENTATION

During the ice cover period, frozen water in the form of ice may exert additional pressure on the water surface, leading to water level measurements that exceed the actual under-ice water supply. Since the start of the simulation was chosen during the ice-free period, no adjustment was needed to account for the potential effects of ice on measured water levels from July 1 (used to initialise the calibration and validation models).

2.3.8 SUPPLEMENTATION FROM APEX RIVER

The supplementary water pumped from the Apex (Niaqunguk) River to the Lake Geraldine Reservoir from 2021 to 2024 was considered in this modeling update as described previously in section 2.1.4.

3 ASSUMPTIONS AND LIMITATIONS

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

- Key assumptions and limitations are outlined in Golder (2013, 2018, 2019, 2020, 2021, 2022) and WSP (2023, 2024).
- The Lake Geraldine's stage storage curve was updated using the GeoVerra bathymetry survey conducted in 2024. The updated storage curve indicated an increase in the active storage volume compared to the previous one. This finding is in contrast with the communications from Nunami Stantec (June 2, 2019) suggesting that Lake Geraldine's active storage capacity may have been reduced relative to the digital elevation model representation derived from Natural Resources Canada (2008). The difference between the 2008 and 2024 surveys could reflect an advancement in mapping technology between 2008 and 2024, resulting in more accurate, higher-resolution 2024 data.
- The models' initialization dates are within the open water season, when the lake is considered ice-free. This approach reduced the uncertainty regarding the Lake's ice depth and potential for additional pressure on the water surface to cause water level measurements that exceed the actual under-ice water level. The model simulation period ends near the freeze-up time (October 10) but covers several years of water level variations, ice build-up, and snowmelt. These include sensitive periods near the thaw dates when the Lake's water levels are at their lowest elevations. The simulation period spans over four years for calibration and more than three years for validation.
- The effects of ice exerting additional pressure on the water surface were assumed not to influence water level measurements for the purpose of model calibration and validation.
- The timing of water levels during and immediately after snowmelt and ice melt may be temporarily inaccurate because the model setup only allows for simplified estimations of snowmelt and ice melt compared to observed conditions.
- The available reservoir volume is independent of the effects of consumption losses prior to July and is initialised based on the measured water level on July 1st.
- Freeze-up is identified as the earliest day, following the summer season, when the preceding 14-day average is lower than -1°C. 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 be larger than 2°C.
- Missing meteorological observations, including temperature and precipitation, are infilled using a gridded reanalysis dataset from the European Centre for Medium-Range Weather Forecasts (ECMWF) Re-Analysis (ERA5) (Hersbach et al. 2020). ERA5 provides hourly estimates for atmospheric, land and oceanic climate variables by assimilating observations and weather forecasting models. The ECMWF data covers the Earth at a 30 km resolution and resolves the atmosphere using 137 levels from the surface up to a height of 80 km from 1950 to the present. This dataset represents the best alternative to infill missing weather data in the absence of Environment Canada precipitation data from local meteorological stations. The uncertainty in this dataset is considered higher than for observed local data and may translate into compounded uncertainty in predicted water levels at freeze-up.
- Snow and rainfall accumulation models rely on ERA5 data rather than Environment Canada data, due to the latter having been an unreliable source of information in recent years and having insufficient data. PET data also relies on ERA5 data, which provides a continuous estimation of the evaporative losses during the period from 2007 to 2024. The ERA5 reanalysis provides the reference evapotranspiration, which could lead to an overestimation of the evaporative losses. The PET multiplier can be optimized to adjust these losses, thereby improving the model's performance.

4 MODEL CALIBRATION RESULTS

Table 5 shows the optimized solution for all the decision variables and also the final RMSE:

Table 5: Calibrated Parameters

VARIABLE	OPTIMIZED SOLUTION
Lake Ice formation multiplier	1.4
Lake Ice Melting Multiplier	2.147
PET Multiplier Land	0.166
PET Multiplier Water	0.683
Snow Correction Factor	1.128
RMSE (m)	0.18

Error! Reference source not found.**3** compares the observed WSC water surface elevation (blue line) with model s imulations (red line) for the calibration period (from July 1, 2013, to October 10, 2017).

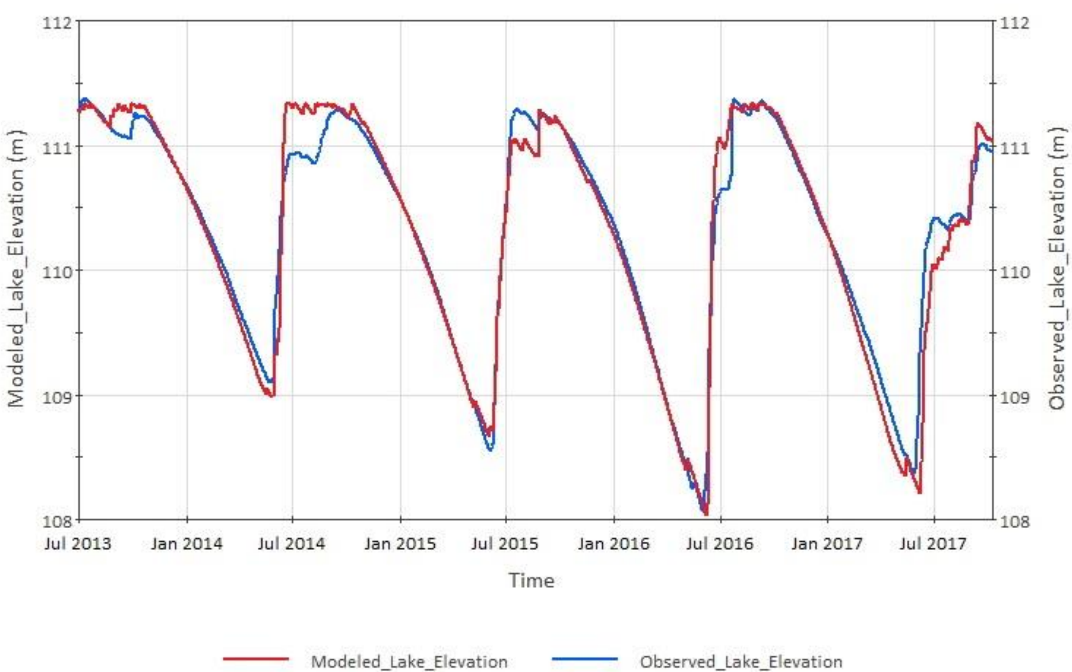

Figure 3: Calibration Results: Observed vs. Modeled Lake Water Levels

Both observed (WSC), and modelled lake elevation data exhibit annual cycles characterized by rapid increases during the spring freshet (typically May–June), followed by gradual declines throughout the autumn and winter periods. The timing and magnitude of these transitions are closely aligned, demonstrating the model's capability to capture snowmelt-driven inflows and subsequent losses accurately.

Minor discrepancies occur at the onset of open-water periods; however, both curves reach comparable peak elevations prior to freeze-up. The model effectively represents the attenuated response to late-season rainfall events, as well as the drawdown approaching freeze-up. Remaining divergences generally stem from interactions among declining evapotranspiration, refilling of soil or depression storage, and reduced frequency of rainfall before freeze-up.

The high degree of similarity between the modeled and observed water levels during the calibration period indicates strong agreement between modelled and observed water levels. The model reliably reflects the timing and amplitude of principal hydrologic transitions, with only localized differences noted during brief, intense events and at the initiation of the open-water season, where observational and process uncertainties may be more pronounced.

The water level difference between the modeled and observed data at the end of calibration period (October 10, 2017) is about 0.09 m.

Overall, the model demonstrates considerable accuracy in simulating water levels during both the freeze-up (drawdown) and freshet seasons. Notably, results show excellent correspondence for the years 2015 and 2016, while a slight underestimation is observed in 2014 and 2017. The most significant error between modelled and observed surface water elevations occurs at the onset of the open-water season (peaks).

Figure 4 presents the Root Mean Square Error (RMSE) between observed and modeled lake water surface elevations over the calibration period (July 1, 2013, to October 10, 2017).

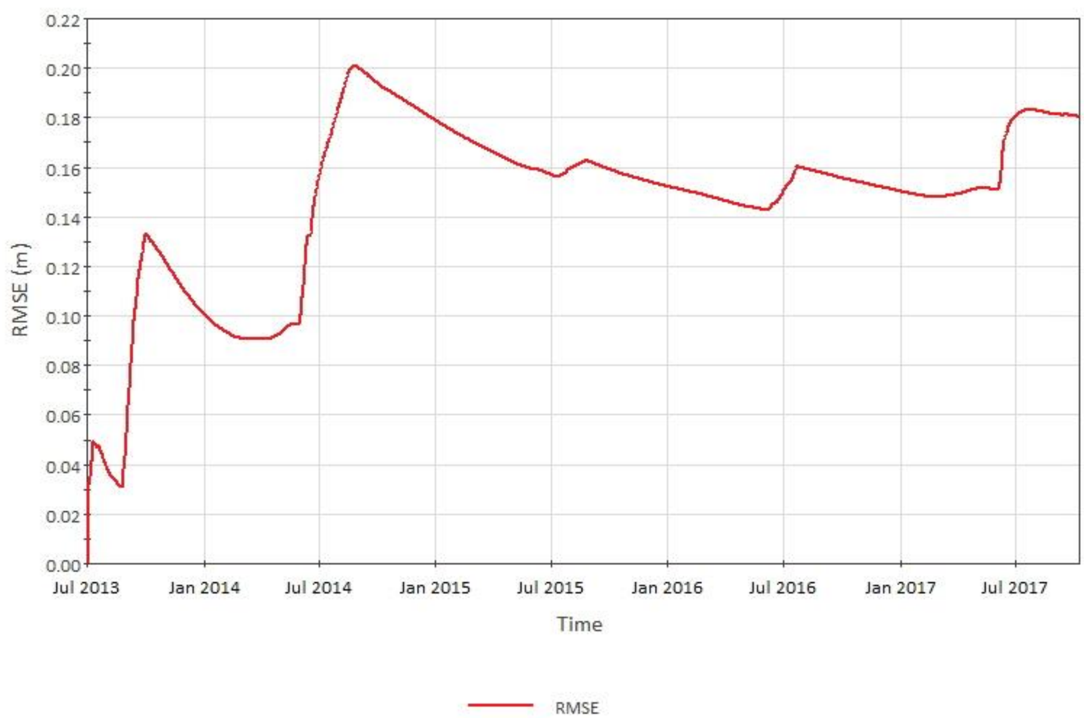

Figure 4: Calibration Results: RMSE Values of Lake Water Levels

The RMSE values of the celebration starts at 0 meters on July 1, 2013, as the lake water elevation initial conditions match the observation. Over the following months, the RMSE exhibits several fluctuations, with notable peaks around Oct 2013 and mid-2014, reaching up to approximately 0.20 meters. These peaks correspond to periods of rapid hydrologic change, i.e., impacted by freshet, intense rainfall events (e.g., withdrawals), where model uncertainties are typically highest. After mid-2014, the RMSE shows a general decreasing trend, suggesting improvements in model fit. From early 2016 onward, the RMSE displays smaller fluctuations and stabilizes around 0.18 meters by October 2017. The overall RMSE profile demonstrates that the model achieves a generally good fit to observed lake elevations. The lowest RMSE values coincide with stable hydrologic conditions, while higher RMSE values are associated with transitional periods (e.g., freshet).

The magnitude and variability of RMSE are consistent with expectations for reservoir water balance models, especially in northern climates where snowmelt, ice dynamics, and episodic precipitation can introduce significant short-term variability. The model's ability to maintain RMSE below 0.10–0.20 meters for most of the calibration period supports its suitability for scenario analysis and operational planning.

The final calibrated configuration meets established targets (RMSE, Error) during open-water conditions, with anticipated limitations at the start of this period. The model is deemed suitable for further validation over independent timeframes and for forecasting scenarios, with recognized uncertainties requiring continued consideration and minor adjustments.

5 MODEL VALIDATION RESULTS

Error! Reference source not found. shows observed (WSC) vs. modeled lake levels for the validation period (from J uly 1, 2021, to October 10, 2024).

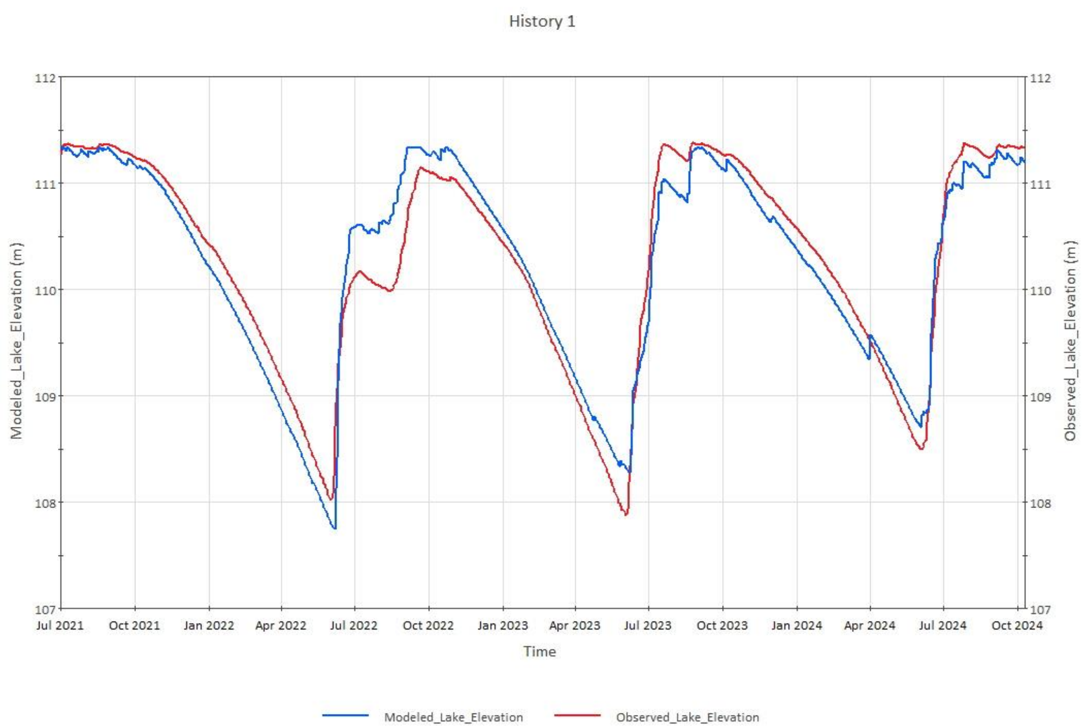

Figure 5: Validation Results: Observed vs. Modeled Lake Water Levels

The model captures the rapid freshet rise and the seasonal amplitude of lake levels, reproducing the transition from spring accumulation to fall/winter drawdown. Rising-limb timing is closely matched, with localized differences at the beginning of the open water season. Through freeze-up season, the drawdown slopes are in-line with observations. Level offsets during ice cover are interpreted considering ice-pressure artifacts on the observed stage.

The model reproduces the freshet rise, freeze-up drawdown, and Open water behavior, with localized differences at the beginning of the open water season. The water level differences are very low (a few centimeters) during the period from mid-June to early July, indicating an accurate prediction of water levels during the lake's reservoir replenishment. The differences, however, increase at the peak or low points of the curve (near freeze-up and freshet respectively). The modeled water level at the end of the simulation (October 10, 2024) is approximately 0.14 m higher than the observed water level (**Figure 5**).

Error! Reference source not found.**6** presents the temporal evolution of RMSE between modeled and observed lake w ater surface elevations from July 2021 to July 2024.

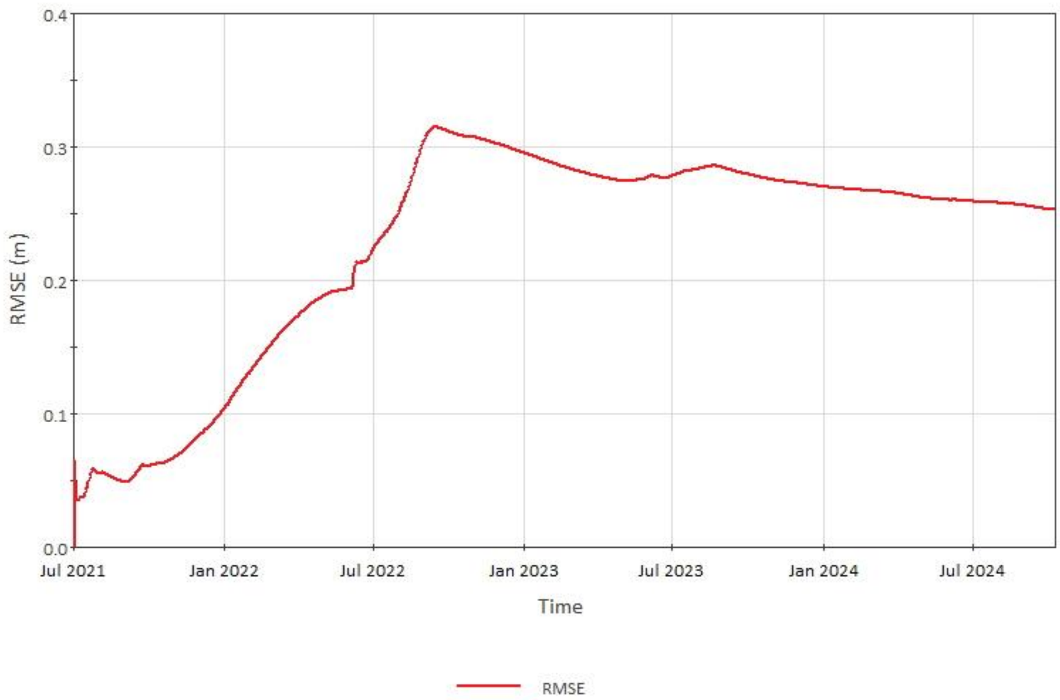

Figure 6: Validation Results: RMSE Values of Lake Water Levels

During the initial period in July 2021, the RMSE begins at zero, indicating that the model's initial condition matches the observed lake elevation precisely. As the 2022 open water season commences, a sharp increase in RMSE is observed, reflecting a decline in model accuracy and a growing offset between modeled and observed values. Through 2023 and 2024, the RMSE gradually decreases, signifying improved model performance and a closer alignment with observed data. By mid-2024, the RMSE remains moderate but lower than its previous peak, demonstrating sustained yet improved model accuracy over time.

Overall model performance is satisfactory with an RMSE of 0.25 m from 2021 to 2024.

6 CONCLUSIONS, CONSIDERATIONS, AND RECOMMENDATIONS

Based on the discussion of results and the noted assumptions and limitations, the following conclusions can be drawn:

- The updated Lake Geraldine stage-storage curve, based on the 2024 bathymetry survey, indicates an increase in the lake's active storage volume. This finding contradicts a previous communication from 2019 that suggested a reduction in capacity.
- The updated water balance model, which incorporates new 2024 bathymetry data and longer periods of record for calibration and validation, showed strong agreement with observed water level data during both the calibration and validation periods. Therefore, the model's performance is deemed satisfactory for its intended purpose of providing a water balance forecast.

The analysis is based on several key assumptions and limitations:

- The results are limited by previous assumptions and limitations from earlier studies.
- The model's initialization date was set during the ice-free season to reduce uncertainty related to ice depth.
- The effects of ice pressure on water level measurements were assumed not to influence the model during calibration and validation.
- Missing meteorological data were infilled using the European Centre for Medium-Range Weather Forecasts (ECMWF) Re-Analysis (ERA5) dataset. This dataset could have higher uncertainty than local observations, which could lead to compounded uncertainty in predicted water levels.
- The timing of water levels immediately after snow and ice melt may be temporarily inaccurate due to simplified model estimations.

It is recommended to complete the identified data gaps, including daily water consumption and emergency pumping volumes from 2018 and 2019, to allow for an extended calibration period. Also, it is recommended to verify the potential impact of ice pressure on water level measurements during the lake's ice-covered period.

7 CLOSURE

Recommendations presented herein are based on Water Balance evaluations of the available information noted. If conditions other than those reported are noted, WSP Canada Inc. should be notified and be given the opportunity to review and revise the current recommendations, if necessary.

This technical memorandum has been prepared for the exclusive use of City of Iqaluit for specific application to the area within this memorandum. Any use which a third party makes of this memorandum, or any reliance on or decisions made based on it, are the responsibility of such third parties. WSP Canada Inc. accepts no responsibility for damages, if any, suffered by any third party as a result of decisions made or actions based on this report. It has been prepared in accordance with generally accepted engineering practices. No other warranty, expressed or implied, is made.

We trust that the information provided in 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.

Prepared by:

Keihan Kouroshnejad, M.Eng.,
Water Resources, EIT

Mike Movahedan, PhD, P.Eng.,
Lead Water Resources Engineer

Reviewed by:

Camilo Marquez, M.Eng., P.Eng., PMP
Team Lead, Treatment & Facilities

KK/MM/CM/MW/ab

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APPENDIX A

Table A.1: City of Iqaluit Monthly Wate Consumption Rate (m3) from 2007 to 2024 (excluding 2018 and 2019)

MONTH	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
January	61,770	81,310	70,810	78,510	63,890	77,210	78,490	78,850	90,450	109,636	109,598	109,709	-	95,922	93,959	105,536	104,484	92,239
February	55,090	74,750	69,900	71,710	62,830	67,740	71,670	75,580	84,790	114,055	107,529	101,136	-	94,101	89,693	102,347	125,224	89,723
March	77,740	84,110	80,420	81,430	75,440	80,740	81,120	87,210	99,880	117,548	105,876	118,761	-	98,371	104,116	118,570	121,617	103,271
April	80,210	85,570	82,560	82,610	68,560	72,780	80,700	84,220	92,300	107,075	103,079	117,240	-	94,323	98,135	116,849	117,086	114,775
May	81,100	88,794	79,910	79,000	68,880	73,010	85,950	84,720	92,570	110,067	103,014	127,193	-	96,399	109,153	126,205	116,297	115,757
June	74,460	81,810	75,270	73,560	68,570	67,990	77,740	83,150	88,300	112,366	96,624	127,740	-	92,146	106,101	113,658	104,970	92,905
July	74,910	79,370	73,620	74,820	67,060	70,620	74,670	80,410	90,700	109,086	93,511	107,136	-	88,502	88,840	93,594	97,303	93,264
August	75,360	79,790	73,070	69,910	70,580	68,460	74,050	82,760	90,500	94,176	97,547	80,445	-	72,956	82,340	87,767	106,309	101,331
September	76,340	77,950	73,070	71,350	73,870	68,860	75,380	81,580	91,400	95,005	98,376	72,000	-	73,024	85,223	89,857	105,081	107,959
October	81,120	66,850	74,980	70,340	80,000	75,370	79,170	85,900	92,000	93,678	95,176	-	-	78,954	89,791	98,527	109,533	119,016
November	79,540	64,030	69,210	62,140	72,420	73,910	74,560	82,180	83,500	90,854	97,689	-	-	93,116	100,419	105,169	102,329	99,979
December	80,340	62,020	76,230	61,710	67,510	74,980	76,860	83,580	92,300	95,775	99,209	-	-	79,766	116,733	97,946	92,879	95,225
Annual	897,980	926,354	899,050	877,090	839,610	871,670	930,283	990,140	1,088,690	1,249,320	1,207,229	-		1,057,581	1,164,503	1,256,023	1,303,111	1,225,443
Daily Average	2,460.2	2,531.0	2,463.2	2,403.0	2,300.3	2,381.6	2,548.7	2,712.7	2,982.7	3,413.4	3,307.5	-	-	2,889.6	3,190.4	3,441.2	3,570.2	3,348.2

Notes:

2007-2011: Golde (2013).
2012, 2014, 2015: City of Iqaluit Annual water License Report.
2016- 2018: Nunami Stantec Ltd. (2019)
2013: Water Treatment Plant data (SCADA system)
2020-2024: Water Treatment Plant data (SCADA system provided by WSP)

Table A.2: City of Iqaluit Average Daily Water Consumption Rate (m3) from 2007 to 2024 (excluding 2018 and 2019)

MONTH	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Jan	1,993	2,623	2,284	2,533	2,061	2,491	2,532	2,544	2,918	3,537	3,535	3,539	-	3,094	3,031	3,404	3,370	2,975
Feb	1,968	2,670	2,410	2,561	2,244	2,336	2,560	2,699	3,028	3,933	3,840	3,612	-	3,245	3,203	3,655	4,472	3,094
Mar	2,508	2,713	2,594	2,627	2,434	2,605	2,617	2,813	3,222	3,792	3,415	3,831	-	3,173	3,359	3,825	3,923	3,331
Apr	2,674	2,852	2,752	2,754	2,285	2,426	2,690	2,807	3,077	3,569	3,436	3,908	-	3,144	3,271	3,895	3,903	3,826
May	2,616	2,864	2,578	2,548	2,222	2,355	2,773	2,733	2,986	3,551	3,323	4,103	-	3,110	3,521	4,071	3,752	3,734
Jun	2,482	2,727	2,509	2,452	2,286	2,266	2,591	2,772	2,943	3,746	3,221	4,258	-	3,072	3,537	3,789	3,499	3,097
Jul	2,416	2,560	2,375	2,414	2,163	2,278	2,409	2,594	2,926	3,519	3,016	3,456	-	2,855	2,866	3,019	3,139	3,009
Aug	2,431	2,574	2,357	2,255	2,277	2,208	2,389	2,670	2,919	3,038	3,147	2,595	-	2,353	2,656	2,831	3,429	3,269
Sep	2,545	2,598	2,436	2,378	2,462	2,295	2,513	2,719	3,047	3,167	3,279	2,400	-	2,434	2,841	2,995	3,503	3,599
Oct	2,617	2,156	2,419	2,269	2,581	2,431	2,554	2,771	2,968	3,022	3,070	-	-	2,547	2,896	3,178	3,533	3,839
Nov	2,651	2,134	2,307	2,071	2,414	2,464	2,485	2,739	2,783	3,028	3,256	-	-	3,104	3,347	3,506	3,411	3,333
Dec	2,592	2,001	2,459	1,991	2,178	2,419	2,479	2,696	2,977	3,090	3,200	-	-	2,573	3,766	3,160	2,996	3,072
Annual	**2,460.2**	**2,531.0**	**2,463.2**	**2,403.0**	**2,300.3**	2,381.6	2,548.7	2,712.7	2,982.7	3,413.4	3,307.5	-	-	2,889.6	3,190.4	3,441.2	3,570.2	3,348.2

Notes:

Daily volumes are estimated based on:

2007-2011: Golde (2013).
2012, 2014, 2015: City of Iqaluit Annual water License Report.
2016- 2018: Nunami Stantec Ltd. (2019)
2013: Water Treatment Plant data (SCADA system)
2020-2024: Water Treatment Plant data (SCADA system provided by WSP)