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Iqaluit

ATTACHMENT 34

LTWP Lake Qikiqtalik Water Withdrawal Study

Rev 1
April 24, 2026

Qikiqtalik Lake Water Balance for Withdrawals
Final Report



PRESENTED TO
City of Iqaluit

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ACRONYMS & ABBREVIATIONS

Acronyms/Abbreviations	Definition
ANN	Artificial Neural Network
ATI	Antecedent Temperature Index
CN	Curve Number
CO	Change Order
ECCC	Environment and Climate Change Canada
GCM	Global Climate Model (also General Circulation Model)
GHG	Greenhouse Gas
HBV	Hydrologiska Byråns Vattenbalansavdelning
HEC-HMS	Hydrologic Engineering Center Hydrologic Modeling System
NRCS	Nation Resources Conservation Service
NSE	Nash–Sutcliffe Efficiency
NWT	Northwest Territories
USACE	United States Army Corps of Engineers
IPCC	Intergovernmental Panel on Climate Change
RCP	Representative Concentration Pathway
SCS	Soil Conservation Service
SWAT	Soil and Water Assessment Tool
SWE	Snow Water Equivalent

LIMITATIONS OF REPORT

This report and its contents are intended for the sole use of the City of Iqaluit and their agents. Tetra Tech Canada Inc. (Tetra Tech) does not accept any responsibility for the accuracy of any of the data, the analysis, or the recommendations contained or referenced in the report when the report is used or relied upon by any Party other than the City of Iqaluit, or for any Project other than the proposed development at the subject site. Any such unauthorized use of this report is at the sole risk of the user. Use of this document is subject to the Limitations on the Use of this Document attached in the Appendix or Contractual Terms and Conditions executed by both parties.

EXECUTIVE SUMMARY

This report by Tetra Tech Canada Inc. (Tetra Tech) for the City of Iqaluit (the “City”) delves into the water balance of Qikiqtalik Lake (the “Lake”), with a focus on understanding how much water can be withdrawn while still allowing the Lake to replenish itself to full capacity. This final report provides further calibration and results that build upon the previously submitted Interim Report. This assessment is a blend of past research and new data, including recent measurements of water levels and flow rates. It examines the hydrology surrounding the Lake and its outflow response, considering factors like climate, the physical characteristics of the Lake and surrounding land, and how these elements influence water levels.

A significant part of this final report will remain unchanged from the Interim Report, with the exception being the presentation of new data and results. This report is dedicated to analyzing various data such as rainfall, snowfall, snow melting patterns, the Lake's surface elevation, and its geological features. This analysis helps with understanding the dynamics of water entering and leaving the Lake. This final report relies on the findings of the Interim Report with respect to the potential impact of climate change on the Lake's water balance to anticipate how shifts in weather patterns could alter water levels in the future. However, these impacts were not incorporated into the model results as these were determined to be inconsistent given the uncertainty of the future climate of the area.

This report summarizes the analysis completed to date and includes the results of the modeling techniques used to estimate long-term withdrawal rates which may be sustainably removed from Qikiqtalik Lake. The models used to simulate different scenarios, including various levels of precipitation and snowpack, to predict how the Lake might respond to different hydrologic conditions. The findings of this study estimate a median annual volume of 1,681,000 m^3 per year of water available for withdrawal. However, given the significant skew of the discharge distribution, Tetra Tech believes that the mode (the point of global maximum of the probability density function) of **1,284,184 m^3** per year to be the best estimate to use for planning purposes. This represents a significant increase from the previous estimate of 719,000 m^3/year. This increase is primarily attributed to correcting precipitation implementation to better reflect extreme events, as well as the inclusion of an additional subcatchment in the model. However, these results are based on several presiding assumptions, each of which are discussed further in the report. This report emphasizes that its current recommendations are based on data available to Tetra Tech at the time this report is submitted. It is strongly recommended that continued monitoring of the Lake is used to guide the City’s decisions each year.

In addition to this report, Tetra Tech had previously prepared a Technical Memorandum (the “Memo”) which separately assessed flows within the Apex River. The Memo served to provide additional insight into the long-term use of the Apex River in conjunction with Qikiqtalik Lake to support the water demands of the City. In summary, the findings of the Memo suggested that under new water license amendments, the City may have sufficient withdrawable volume when considering both Apex River and Qikiqtalik Lake to supplement the City until approximately 2045. Tetra Tech also suggested that additional supplementation until the year 2050 could be achieved through increased withdrawals from the Apex River, contingent on additional water license amendments. An updated Memo has not been developed to incorporate updated conclusions, as the work conducted within the Memo was considered separate in scope to the work provided within this report.

1.0 INTRODUCTION

In response to the City of Iqaluit's (the "City") Request for Proposal (RFP No. 2022-RFP-037A), Tetra Tech submitted a proposal for the provision of consulting services for the weir design at Qikiqtalik Lake. Following the provision of weir design options and a preliminary hydrotechnical assessment of Qikiqtalik Lake and its discharge, a Project Change Order Request (CO) was submitted to the City for project 720108 – Raw Water Supply & Storage (Flow Monitoring) on April 14th, 2023. The nature of the CO was to expand the scope of services provided by Tetra Tech to include the following:

- Onsite Flow Monitoring from April 2023 – October 2024.
  - Includes coordination, instrument supply, onsite set up of instrumentation to be owned by the City, onsite flow collection visits (six (6) in total), data reduction, and summary reporting. Scheduled dates for flow monitoring to be coordinated with City representatives and subject to weather conditions.
- Water Balance Model Update from October 2023 – December 2024.
  - Includes update to the City's existing Qikiqtalik Lake water balance model based on collected data, integration of climate data, and accompanying report.

This CO also stipulated that interim and final report deliverables are required to support the Long-Term Water project by the City. An Interim Report based on data collected in 2023 was required by the end of 2023. This final report is submitted to include adjustments to water balance calibration based on data collected in 2024.

While the CO stated that Tetra Tech would update the existing GoldSim water balance model previously developed by Golder Associates Inc. (Golder), Tetra Tech, in consultation with the City and Colliers Project Leaders (CPL), instead developed a new water balance model using HEC-HMS. HEC-HMS, or the Hydrologic Engineering Center Hydrologic Modeling System, is a hydrologic modelling system developed and maintained by the United States Army Core of Engineers (USACE). HEC-HMS is a widely used, professionally validated modelling software with an extensive track record used to accurately model surface runoff, basin hydraulics, and stream outflows across the world.

The final water balance model provided within this report addresses additional considerations requested within the Interim Report, namely:

- Watershed Delineation: Tetra Tech has evaluated and confirmed the existing watershed size and streamflow contributions to Qikiqtalik Lake.
- Hydrology and Climate: Tetra Tech has included updated hydrologic and climate data up to and including November, 2024. Tetra Tech has assessed current climate and subsequent discharge expectations and determined that the implications of climate change on these discharges should not be considered due to significant uncertainty in the future climate of the area (see §5.8).
- Surficial Geology: Tetra Tech implemented appropriate soil characteristics through the use of Curve Numbers (CN), a technique developed by the Natural Resources Conservation Service (NCRS), formerly known as the Soil Conservation Service (SCS).
- Bathymetry: Using data from the hydrometric monitoring program and additional information provided by Dr. Richardson of Carleton University, Tetra Tech concluded that further surface LiDAR and bathymetry data were not necessary to successfully calibrate the Qikiqtalik Lake discharge in 2024.

- Lake Water Levels: By evaluating existing data and reports alongside ongoing water level monitoring by AAE Tech Services Inc., Tetra Tech compared the model results with historical data and calibrated the model to align with 2024 in-field measurements.
- Flows from Qikiqtalik Lake and Apex River: The Apex River (also referred to as the Niaqunguk River) is the primary outflow from Qikiqtalik Lake. Several monitoring stations were set up to monitor flows along this River. The monitoring program has now ended and all the equipment has been removed as of October, 2024.

This report serves to provide the final working model calibrations based on data collected by AAE. An extensive Monte Carlo simulation has been conducted on both the initial 2023 conditions, as well as the updated 2024 conditions. A total of 6,000 year-long simulations were conducted, generating 2,190,000 daily discharge samples. These samples statistically represent over two million combinations of possible daily precipitation and snowpack.

2.0 PROJECT BACKGROUND

The City has requested consultant services to develop a weir design for the Qikiqtalik Lake to aid their efforts to accurately measure outflow from Qikiqtalik Lake into Apex River. Outflow measurements will be used to support the City's plan to use Qikiqtalik Lake as a permanent supplementary water supply source for the City's municipal water needs. A subsequent CO has provided Tetra Tech with the opportunity to develop a standalone water balance for Qikiqtalik Lake to develop estimates capturing the amount of water which may be sustainably withdraws from Qikiqtalik Lake.

The growing population of the City of Iqaluit and insufficient precipitation events have lead the City to seek additional water sources. Previously conducted studies by the City have identified Qikiqtalik Lake as one possible source. Currently, Geraldine Lake serves as the primary water source for the City, but in recent years, it has failed to meet the growing demands to sustain the City's municipal water needs.

Qikiqtalik Lake is located approximately 4.8 km northeast of the City of Iqaluit and approximately 3.3 km northeast of Geraldine Lake. The City of Iqaluit, Geraldine Lake, and Qikiqtalik Lake are shown together in Figure 2-1. Qikiqtalik Lake has an approximate watershed area of 8.44 km^2 when considering additional tributaries to Apex River (shown in Figure 2-2). Qikiqtalik Lake primarily drains from a single discharge location directly into Apex River. The entire channel is characterized by defined channel sections where the water is visible at the surface and ill-defined channel sections characterized by bolder fields where the water is flowing below the surface.

Figure 2-1: Geraldine Lake, the City of Iqaluit, and Qikiqtalik Lake

Figure 2-2: Qikiqtalik Lake Overview

2.1 Study Purpose

Tetra Tech has constructed a comprehensive water balance model using HEC-HMS to model the water levels and discharge rates out of Qikiqtalik Lake through the outfall location shown in Figure 2-2. This model was calibrated to match physical measurements collected by AAE in both 2023 and 2024. Measurements collected included water levels and flows at Qikiqtalik Lake and along the Apex River. This model incorporates the impacts of surficial geology combined with snowpack accumulation and snowmelt. Additional considerations pertaining to evapotranspiration have been made thanks to the data provided by Dr. Richardson of Carleton University. As part of the model, a Monte Carlo simulation was also completed to develop a range of expected outflows out of Qikiqtalik Lake. This range of results are intended to supply the City with information regarding the bottom 5%, median, and top 5% of expected discharge rates in any given year. Continuous monitoring of Qikiqtalik Lake is strongly recommended to aid the City in its water management plans. Tetra Tech's hydrologic assessment is intended to support current development plans, but it should not exclude the need to monitor future changes in local hydrologic conditions. The projections presented in this report are based on limited data and expanding the flow monitoring programs should become part of any future water management plans.

2.2 Project Objectives

Tetra Tech aims to provide the City with a comprehensive assessment of the hydrologic and hydraulic reactions of Qikiqtalik Lake to precipitation and snowpack with specific attention being given to discharge into Apex River based on data available to date. This assessment was carried out in HEC-HMS version 4.12. HEC-HMS offers a user-friendly interface and extensive training materials for operation of models within the software. Tetra Tech believes this documentation and usability of HEC-HMS will provide the City with a model which could be continuously updated as more data becomes available, without necessarily needing to have extensive experience in the use of a more complex software application like GoldSim. The scope of this report is to provide final model results to the City with respect to the water balance of Qikiqtalik Lake.

3.0 REVIEW OF EXISTING WORK

To date, several assessments of various aspects of Qikiqtalik Lake have been completed. These assessments have been primarily conducted by Nunami Stantec (Stantec) and Golder. Tetra Tech has reviewed these documents to extract and compare information between them, as well as evaluate certain model parameters.

3.1 Water Balance Assessment for Qikiqtalik Lake Modelling Report (Golder)

The "Golder-Iqaluit Long Term Water Project - Water Balance Assessment" report, prepared by Golder Associates Ltd. for the City of Iqaluit, provides an extensive analysis of the viability of Qikiqtalik Lake as a potential long-term water source to supplement Lake Geraldine's supply. Lake Geraldine, crucial for Iqaluit's water supply, faces challenges due to its watershed being frozen for most of the year, leading to water supply deficits especially during winter. The study evaluates whether Qikiqtalik Lake can sustainably address these deficits under various water consumption scenarios and climate conditions, both historical and projected.

The report develops a conceptual model to capture hydrologic processes, using parameters from a previously developed model for Lake Geraldine. This model was adapted to Qikiqtalik Lake, albeit with some limitations due to the scarcity of data. The model's primary aim is to ensure adequate water supply in Lake Geraldine before winter freeze-up and therefore minimize storage deficits. This involves a strategy of pumping water from Qikiqtalik Lake to Lake Geraldine, primarily during the four weeks leading up to freeze-up for efficiency. The volume of water required for supplementation is calculated based on the need to fill Lake Geraldine before freeze-up, taking into account future increases in water demand.

The impact of such pumping on Qikiqtalik Lake's volume is simulated, considering various meteorological conditions and pumping scenarios. Additionally, the model includes the outflow from Qikiqtalik Lake to the Apex River, allowing for analysis of river flow responses to climate change and pumping rates. Meteorological data from 2008 to 2017 was used as the baseline for Iqaluit's climate conditions, supplemented with additional data and linear interpolation to fill gaps. Climate change projections from the Intergovernmental Panel on Climate Change (IPCC) were incorporated, using different Representative Concentration Pathways (RCPs) and applying statistical downscaling for local climate relevance.

Model validation involved installing pressure transducers in Qikiqtalik Lake to provide continuous data, and limited outflow data from the lake were recorded for model calibration. The model represents inflow to Qikiqtalik Lake using methods similar to Lake Geraldine and models the lake as interconnected reservoirs. The geometry of Qikiqtalik Lake is represented through stage-storage curves. The model includes the effects of ice formation and melt on reservoir storage, and water withdrawal from Qikiqtalik Lake is represented based on Lake Geraldine's storage deficit prior to freeze-up.

Significant modifications were made to the water balance model to account for the differences between Lake Geraldine and Qikiqtalik Lake. The study uses statistically downscaled data and a change factor approach to mitigate biases in climate model outputs, extending the observation period using a weather generator approach for robustness.

The results of this weather generator approach provided Golder with a range of predicted Geraldine Lake deficits at freeze-up under a high-water consumption scenario. These were presented as percentage probabilities of exceedance, ranging from 0 (maximum) to 100 (minimum). **The maximum expected Geraldine Lake deficit predicted by Golder using a weather generated approach is 1,306,165 m^3 and the minimum is 86,396 m^3**.

In summary, the report provides a comprehensive evaluation of Qikiqtalik Lake as a long-term supplementation source for Lake Geraldine, considering a range of factors like climate change, water consumption scenarios, and ecological impacts. The development of a detailed water balance model is central to this assessment, enabling informed decision-making for Iqaluit's water supply management. Tetra Tech utilized the values determined by Golder (2021) to further validate the results presented herein.

3.2 Qikiqtalik Lake Data Collection Summary Memorandum (Nunami Stantec)

The memorandum from Nunami Stantec Limited to the City of Iqaluit provides a summary of data collected at Qikiqtalik Lake as part of the 2019 Emergency Water Supply Project, which aimed to supplement the Lake Geraldine Reservoir. Stantec conducted numerous site visits to Qikiqtalik Lake in 2019, collecting data on water levels, lake outlet flows, and water quality. This included downloading data from pressure transducers and a barologger previously installed in the lake, which provided a complete dataset of water levels throughout the year. Additionally, flow measurements were taken along the outlet creek of Qikiqtalik Lake, and five surface water quality samples were analyzed. The study also involved obtaining a research permit and conducting a bathymetric survey and LiDAR imagery acquisition, although no water balance model was developed.

The research conducted required a license from the Nunavut Research Institute, and the project proposal was submitted to the Nunavut Planning Commission. Due to the emergency situation declared by the Minister of

Community and Government Services regarding the water supply shortage, the Qikiqtalik Lake studies were encompassed by the emergency pumping project, exempting them from certain screening processes.

The fieldwork included monitoring water levels from September 2018 to October 2019, with natural conditions reflected until August 24, 2019, after which the data were influenced by the pumping program. Water level data were collected using a staff gauge and pressure transducers, which were corrected for atmospheric pressure and validated with data from the Environment and Climate Change Canada Iqaluit Climate Station. Local benchmarks were established using real-time kinematic survey equipment to convert water surface level data into water surface elevation data. The water surface elevation fluctuations recorded by the transducers correlated well with manual staff gauge readings, except for the final ten days of the pumping program when the staff gauge readings were higher.

Additionally, spot flow measurements were completed daily at three locations, including the outlet reach of Qikiqtalik Lake, to assess the contribution of its outflow to the Apex River and the potential impact on river flows if the Qikiqtalik Lake outflow was cut off during pumping activities.

3.3 Review of Golder Associates Ltd. Qikiqtalik Lake Water Balance Assessment DRAFT Report (Nunami Stantec)

Nunami Stantec Limited conducted a third-party review of the draft report by Golder Associates on the Water Balance Assessment of Qikiqtalik Lake. The review focused on discussing the report's background, methods, supporting data, and assumptions with Golder's technical lead, reviewing the report’s assumptions and limitations, identifying data gaps and risks, and producing a summary memo for Colliers Project Leaders. However, it's important to note that the review did not include a technical review of input data and model development, calibration, or validation.

Key findings and recommendations from the review are listed below. Please note that this review also included suggested report modifications to Golder with respect to their assessment; however, these are not shown here as they were implemented by the time the report was reviewed by Tetra Tech. As such, only additional analysis recommendations are provided.

1. Additional Analyses for Decision-Making:
    a. Evaluate more water consumption scenarios, including scenarios with higher winter demand.
    b. Analyze the sensitivity of the model to uncertainty in the catchment area of Qikiqtalik Lake.
    c. Consider relying on the central basin only, or a combination of central and south basins, for modelling Qikiqtalik Lake due to the high uncertainty in modelling its five partially connected reservoirs.
    d. Conduct a sensitivity analysis for different timing and duration scenarios for pumping.
    e. Validate the Qikiqtalik Lake model with lake level and outflow data.
    f. Run more water balance scenarios for environmental effects assessment, considering Fisheries and Oceans Canada guidelines for Qikiqtalik Lake outflow and Apex River.
    g. Conduct a limnological baseline program of Qikiqtalik Lake to characterize existing conditions and potential variability in water quality parameters with depth.

h. Use the existing Geraldine Lake water balance model to determine the optimal storage capacity of the reservoir, considering existing storage capacity limitations for supplementation from another source.

Several of the above points are addressed within this assessment, specifically points c, and e:

1. Tetra Tech combined some of the originally separate basins of Qikiqtalik Lake into one larger basin. The outlet basin was modelled separately as a connected basin downstream, as the connection between the outlet and primary basin served as the control location to govern water elevations of Qikiqtalik Lake.

2. Data collection of Qikiqtalik Lake water elevations, Apex River discharges, and other tributaries is ongoing. Additional data will also be acquired from Carleton University at a later date. These data sets will be used to continuously validate and monitor the performance of the water balance.

4.0 ADDITIONAL DATA ACQUISITION

Limited data, especially when considering a water balance, can significantly alter model calibration and parameter selection. Given the critical nature of water scarcity in Lake Geraldine, Tetra Tech believed it necessary to gather additional data pertaining to both Qikiqtalik Lake water levels before, during, and following the freshet, as well as Apex River discharge. Tetra Tech hired AAE Tech Services Ltd. to conduct continuous monitoring of the area. Tetra Tech has been provided data from an ongoing study of Qikiqtalik Lake by Dr. Richardson of Carleton University. Tetra Tech, the City, and Dr. Richardson agreed to share datasets throughout the duration of this assignment.

4.1 Hydrometric Monitoring by AAE

The "Summary Report – Iqaluit Hydrometric Monitoring Field Visit 3" from October, 2024, conducted by AAE Tech Services Inc. for Tetra Tech, focuses on the study of Qikiqtalik Lake. The study's primary aim was to determine the output volumes and flow rates of the lake to assist in developing a rating curve for the tributaries within the Qikiqtalik Lake watershed. To achieve this, seven hydrometric monitoring stations were established in various locations including the lake's inflow, within the lake, and along the lake outflow. A report summarizing data collected throughout the program can be found in Appendix B. Monitoring stations are presented in Figure 4-1.

The methodology involved measuring velocity profiles at each tributary station using a Swoffer manual flow meter and a QiQuac salt dilution technique. These methods calculated total discharge and the time a pulse of salt passed by two points within the creek, respectively. Solinst level loggers and OTT level loggers were installed at the monitoring stations to record water levels. The loggers were secured in place using perforated tubes and masonry hardware.

The report details the data collected from the third site visit, which included water level and flow information from various stations. Station Stream A1 provided data on water elevation, channel width, average depth, and velocity. At Station OTT Stream B, it was noted that the monitoring station had been tampered with, leading to a decision to deploy a more discrete Solinst in a location more favorable for capturing the spring freshet of 2024.

Due to vandalism at the OTT-Lake 1 monitoring station, no additional monitoring data was available from the OTT sensor in September, but the Solinst level logger continued to provide data on lake water levels. The Overwinter LL station was chosen to house two overwintering Solinst level loggers due to its well-channelized flow and bedrock formations, making it suitable for accurate flow measurement. This site was expected to effectively capture the discharge from the lake.

Figure 4-1: Qikiqtalik Lake Hydrometric Monitoring Sites (AAE Tech Services Ltd., 2023)

Lastly, the report discusses a proposed weir site, noting its natural valley suitable for a weir construction. However, challenges include the lack of true channelization of the outflow from the lake as much of the water flows visibly underground at this elevation.

Overall, the report provides detailed insights into the hydrometric conditions of the Qikiqtalik Lake and its tributaries, offering valuable data for hydrological modeling, engineering design, and water management applications. Data collected from AAE is discussed in more detail in § 5.0.

4.2 Carleton University

Dr. Murray Richardson of Carleton University is conducting an ongoing comprehensive study of Qikiqtalik Lake, gathering crucial data such as monthly evaporation, snowpack density, snow water equivalence (SWE), discharge, and water elevation. This data was made available to Tetra Tech in mid-2024, and was used to further calibrate the hydrologic model, specifically the stage-discharge curve from Qikiqtalik Lake, annual snowpack, and monthly evapotranspiration assumptions.

5.0 DATA REVIEW

5.1 Watershed Delineation

Using available LiDAR and Bathymetry data gathered by Tetra Tech, the contributing catchments to Qikiqtalik Lake were reassessed to be compared to those derived by Golder. The delineated catchments are presented in Figure 5-1. In total, three (3) primary catchments were found and are referred to as the north, central, and south catchments, each with an area of 63.77 ha, 384.49 ha, and 167.88 ha respectively. Catchment sizes are compared to those provided by Golder in Table 5-1.

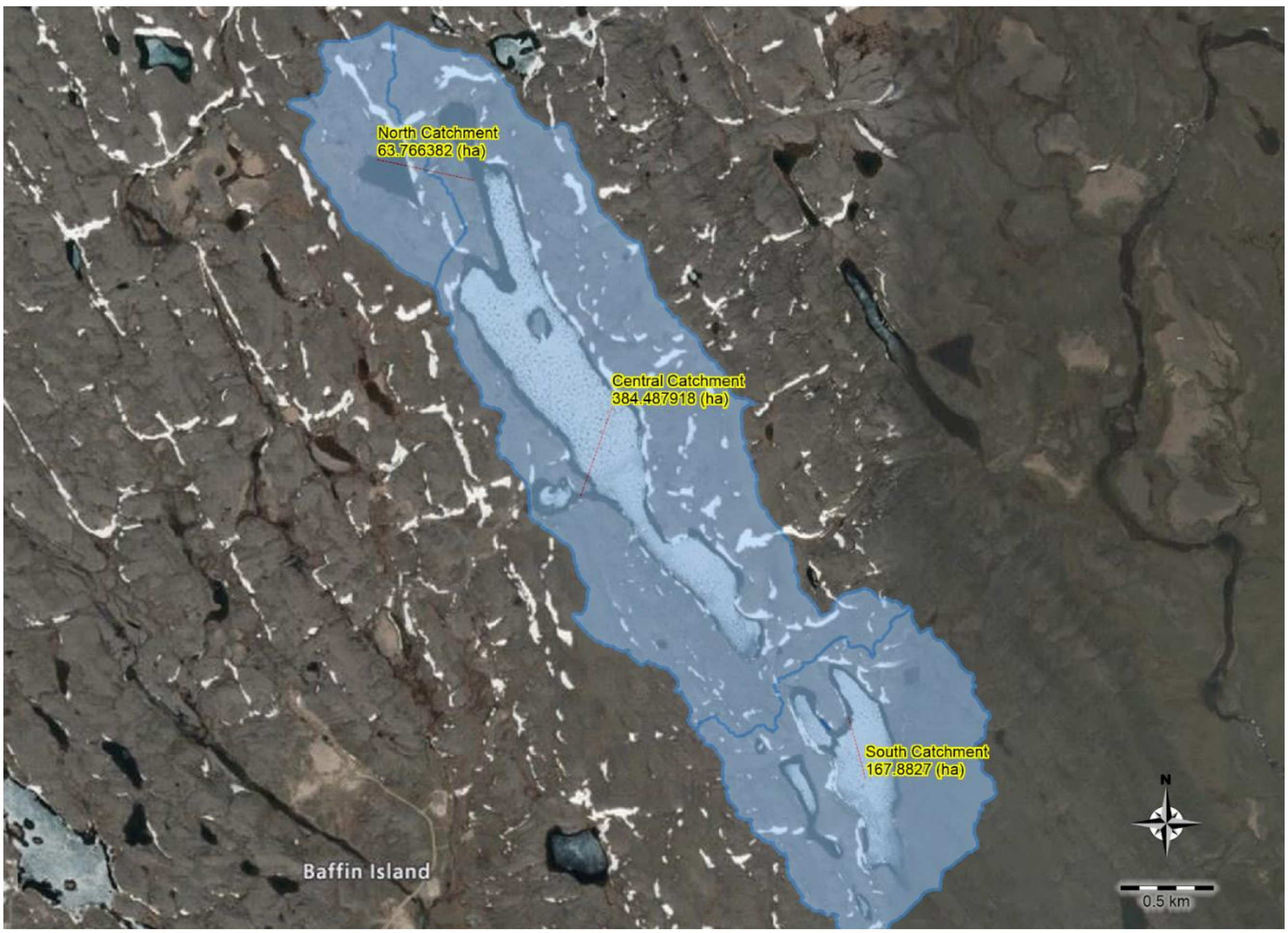


Figure 5-1: Qikiqtalik Lake Primary Catchments

Table 5-1: Catchment Delineation Validation

Catchment	Golder (ha)	Tetra Tech (ha)
North Catchment	-	63.77
Central Catchment	422	384.49
South Catchment	166	167.88
Total	588	616.14

Golder's catchment delineation differs primarily in the north catchment area due to differences in catchment size thresholds during delineation. As detailed, Golder's delineation groups the north and central catchments together. Critically, the total area delineated is very similar between both assessments.

Previously, the south catchment was not included in the assessment due to the unclear connectivity between the smaller lake to the south of Qikiqtalik Lake. Originally, it was felt that runoff from the south catchment may have only contributed runoff under very specific conditions. During the calibration phase, it was found that the model behaved more appropriately on average when the south catchment was not included in the analysis. However, the contributions from the south catchment cannot be ignored. Tetra Tech has subsequently included the south catchment in the final model, recognizing the contribution from the south catchment is likely attenuated by the bathymetry of the smaller lake and contribution from the south may be "stretched" over a longer period. Given the observed nature of the channels connecting all the lakes in the area it is possible that the contribution from the south may be tempered by the limited hydraulic conductivity of the connecting channels.

5.2 Hydrology and Climate

Precipitation and temperature data were collected from four (4) Environment and Climate Change Canada (ECCC) stations *Iqaluit Climate, Iqaluit A, Iqaluit UA,* and *Iqaluit AWOS*. In the interim model, only Iqaluit Climate and Iqaluit A were assessed. A summary of the stations used for data is provided in Table 5-2.

Table 5-2: ECCC Climate Stations for Data Acquisition

Station	Latitude	Longitude	Data Range	Interim/Final[1]
Iqaluit Climate	63°44'50.000" N	68°32'40.000" W	2004 – 2024	Both
Iqaluit A	63°45'24.000" N	68°33'22.000" W	1946 – 2008 2018 – 2024	Both
Iqaluit UA	63°45'00.000" N	68°33'00.000" W	1997 – 2016	Final (New)
Iqaluit AWOS	63°45'00.000" N	68°33'00.000" W	2008 – 2015	Final (New)

[1]*Meaning which model the data was incorporated into. Both means the data was used in the interim and final models.*

5.2.1 Assumptions Regarding Precipitation Data

It is apparent from Table 5-2 that data acquired from these ECCC stations represents measurements taken at a single point. While some stations are located at exactly the same location, even those with different installation locations are extremely close to one another. This brings rise to the necessary assumption that precipitation over Qikiqtalik Lake is both *equivalent* to the precipitation that occurs at these weather stations, and is *homogenous* over the entire catchment area of the Lake. The ECCC stations are approximately 6 km away from the Lake, suggesting that topography, wind, and other meteorological factors may not be significantly different between the ECCC stations and the Qikiqtalik catchment. That said, precipitation patterns are not necessarily constant across the region. Precipitation patterns may vary significantly from one year to another. Cloud covers may completely miss the Qikiqtalik Lake catchment or, in some years be concentrated over Qikiqtalik Lake. While techniques such as gridded precipitation and stochastic storm transposition modelling exist, Tetra Tech could not find any space-time precipitation pattern data to analyze. Additionally, satellite and radar imagery of large events over the Lake (such as the event that occurred on July 4th, 2023) were not usable to extract noticeable patterns. Thus, it is possible through these assumptions of equivalency and homogeneity, that the precipitation which occurs over Qikiqtalik Lake may in fact be significantly impacted by transient atmospheric storms.

5.2.2 Assessment of Hydrometric Data and Temperature

Recognizing the inevitable variability associated with the local hydrology, Tetra Tech has attempted to capture some of these uncertainties by using Monte Carlo simulations. These simulations allow a model to capture a greater range of results encompassing a wider and more realistic range of solutions. The process entails the identification of the factors affecting hydrologic results and identifying a range of viable measurements typically based on historical statistical information. Once these factors are identified and a range of viable values are set, a Monte Carlo simulation is run to explore all the possible conditions likely to arise. The process is repeated multiple times to develop a range of viable results. These are then used to present all the possible results. For Monte Carlo simulations, it is important to know what ranges of precipitation values are acceptable to simulate. To determine these values, an assessment of the available data was conducted to determine appropriate precipitation distributions for each month. Data analysis suggested that while no particular statistical distribution had a particularly great fit, a log-normal distribution was found to fit best. Monthly total precipitation from 1946 to 2024 is presented in Figure 5-3.

Tetra Tech identified a noticeable increase in total monthly precipitation year-over-year beginning from 1995. Upon review, it was identified that 1995 was the year that the Government of Canada began using digital precipitation measurements. This significantly increased the resolution and measurement accuracy each month when compared to the methods (tipping-buckets or weighing-bucket) used between 1946 and 1995. Tetra Tech analyzed the daily precipitation data to determine appropriate 'normal' monthly precipitation depths. These values were then compared to the climate normals for Iqaluit provided by the Canadian Government. Additional analyses were also conducted and are presented in Figure 5-2.

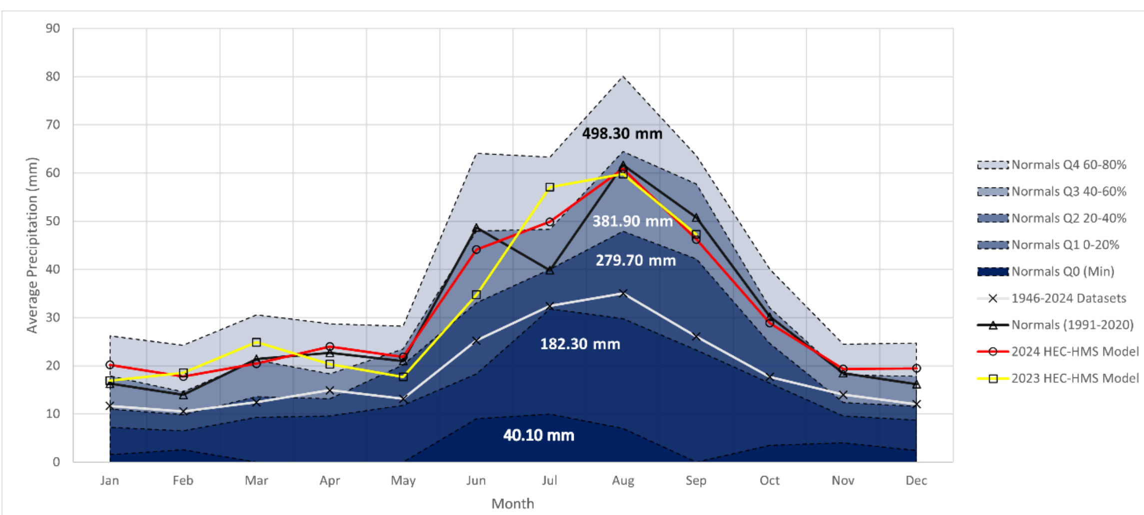


Figure 5-2: Comparison of Climate Normals

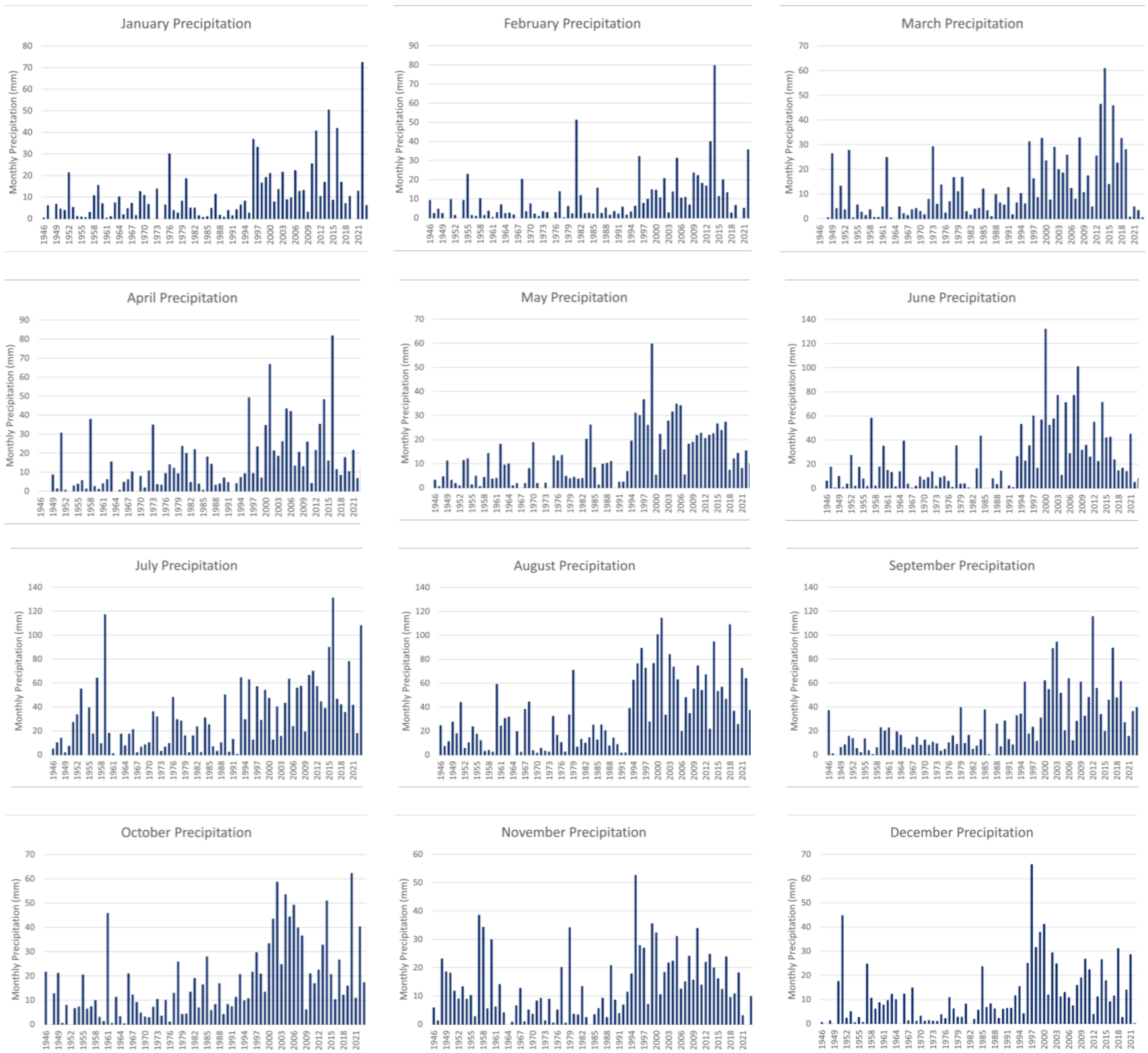


Figure 5-3: Monthly Precipitation Data (1946-2024)

As shown in Figure 5-2, the Government of Canada presents climate normals on a 30-year moving average, the most recent of which occurring between 1991 to 2020 (presented in black in Figure 5-2). This includes data from non-digital measurement techniques for the years 1991 through 1994, and do not capture the latest four years of data. Tetra Tech analyzed the available data to create a new 30-year normal window between 1995 and 2024 (presented in red in Figure 5-2). When compared to the interim model values (presented in yellow in Figure 5-2), this new 30-year window seems to adhere more closely to expected normals. Additionally, all 30-year normal windows were significantly higher than when monthly precipitation was assessed using the entire dataset (1946 – 2024) (presented in gray in Figure 5-2). For these reasons, the final model and assessment of statistical distributions of monthly precipitation used data from 1995 through 2024, inclusive.

Temperature data was extracted from the same stations as precipitation data but at an hourly resolution rather than daily. Hourly measurements were then averaged over each day to acquire a daily-averaged dataset. This was also completed in the Interim Report. The differences in daily average temperature between the Interim Report and this report are provided in Figure 5-4. Note that additional temperature stations were added in this report, as the Interim Report only utilized data from the Iqaluit Climate station.

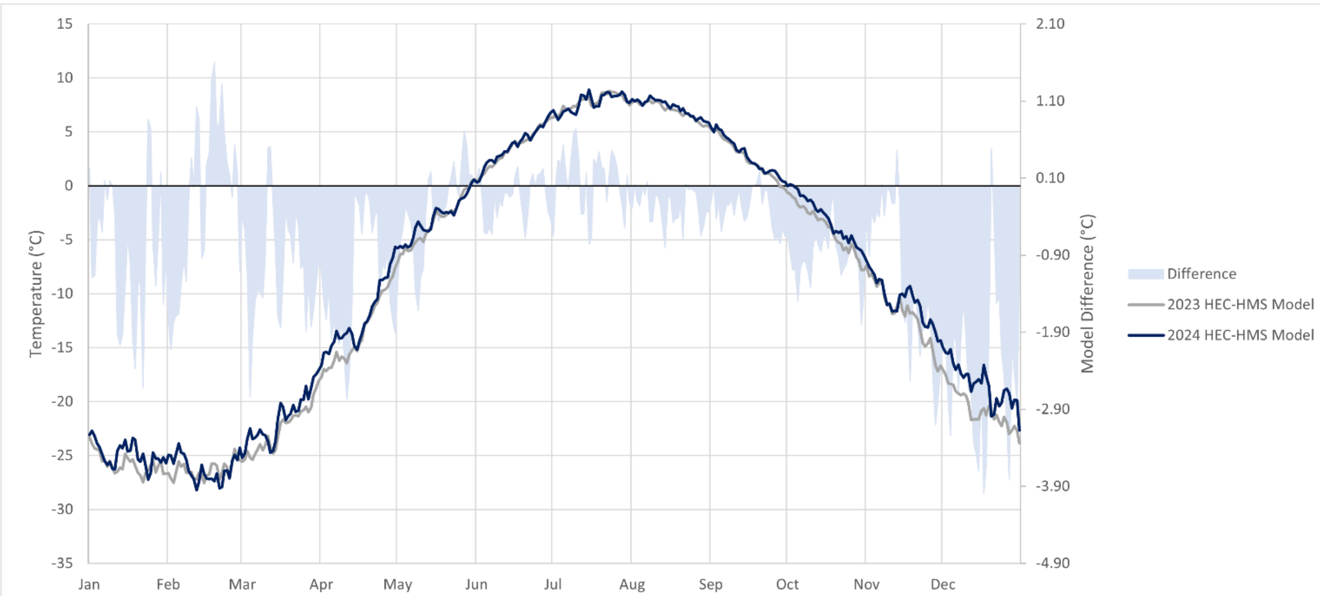


Figure 5-4: Comparison of Average Daily Temperature from Interim to Final Report

In general, inclusion of more recent data as well as additional data sets, has resulted in temperature averages which are roughly two to three degrees warmer during the winter months, with marginal changes presenting over the summer.

5.3 Surficial Geology

Surficial geology was assumed to be that which is outlined by Golder's Water Balance Assessment for Qikiqtalik Lake (Golder Associates Ltd., 2021). Golder utilized a surficial data model developed by the Geological Survey of Canda (2018) with a map scale of 1:100,000. Qikiqtalik Lake was found to be composed mostly of a till blanket with almost 25% of the area made up of till veneer. 13% of the area appears to be the existing lake. The total catchment composition for Qikiqtalik Lake is presented in Table 5-3. From the data presented, the Qikiqtalik Lake catchment was modelled to be 21% impermeable.

Soil infiltration is considered a very important aspect of a water balance. However, borehole data for Qikiqtalik Lake do not exist, and consequently it is difficult to determine precise soil characteristics with respect to infiltration. Based on the data presented in Table 5-3 and consultations with in-house geotechnical engineers, Tetra Tech decided a curve number approach was appropriate. An SCS CN of 87 was selected to best represent both Qikiqtalik Lake and the outlet area.

The SCS CN method is a widely used methodology for estimating direct runoff or infiltration from rainfall excess and is developed by the United States Department of Agriculture (USDA) Natural Resources Conservation Service (formerly SCS). The CN is a dimensionless index ranging from around 40 to 100 and represents the combined effect of soil type, land use, and treatment practices on runoff potential. Lower CN values indicate low runoff potential (high infiltration), while higher values suggest high runoff potential (low infiltration). Given the area of Qikiqtalik Lake contains near-surface bedrock as well as frozen ground (likely permafrost in certain areas), a CN of 87 aims to reflect the low infiltration properties of the area.

Table 5-3: Catchment Composition for Qikiqtalik Lake (Golder Associates Ltd., 2021)

Land Use Type	Qikiqtalik Lake
Till Veneer	23%
Till Blanket	58%
Bedrock	1%
Water	7%
Lake	13%

5.4 Bathymetry

Between July 23rd and July 25th 2019, Tetra Tech conducted a bathymetric survey of Qikiqtalik Lake. Tetra Tech utilized an Ohmex SonarMite single beam acoustic echosounder to complete the bathymetric survey. Using the SonarMite's 235 kHz active transducer, gathered bathymetry provided measurement accuracy of ± 2.5 cm. The bathymetric survey on Qikiqtalik Lake along with data tracks for the survey are presented in Figure 5-8. This gathered Bathymetry data does not include the outlet area detailed in Figure 5-6. As such, Golder constructed a rating curve for the lake which best matched measured flows at a gauging station downstream (Golder Associates Ltd., 2021). Elevation-Storage curves for both Qikiqtalik Lake and the outlet area are presented in Figure 5-5 and Figure 5-6 respectively.

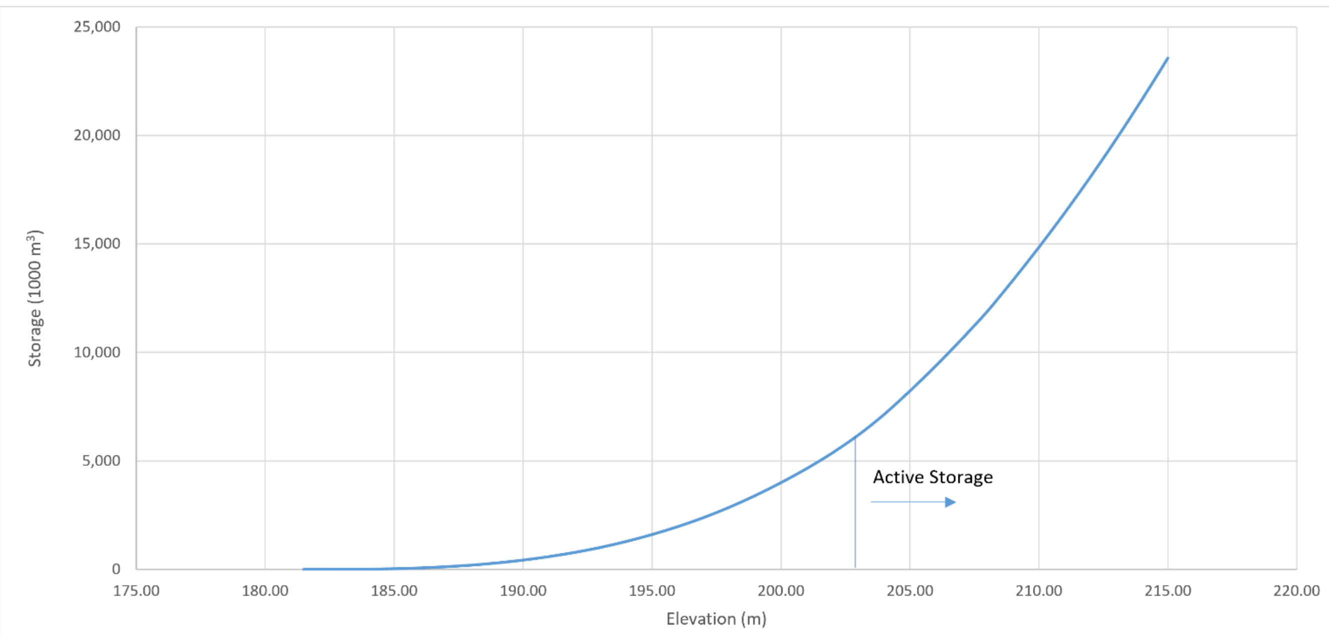


Figure 5-5: Qikiqtalik Lake Elevation-Storage

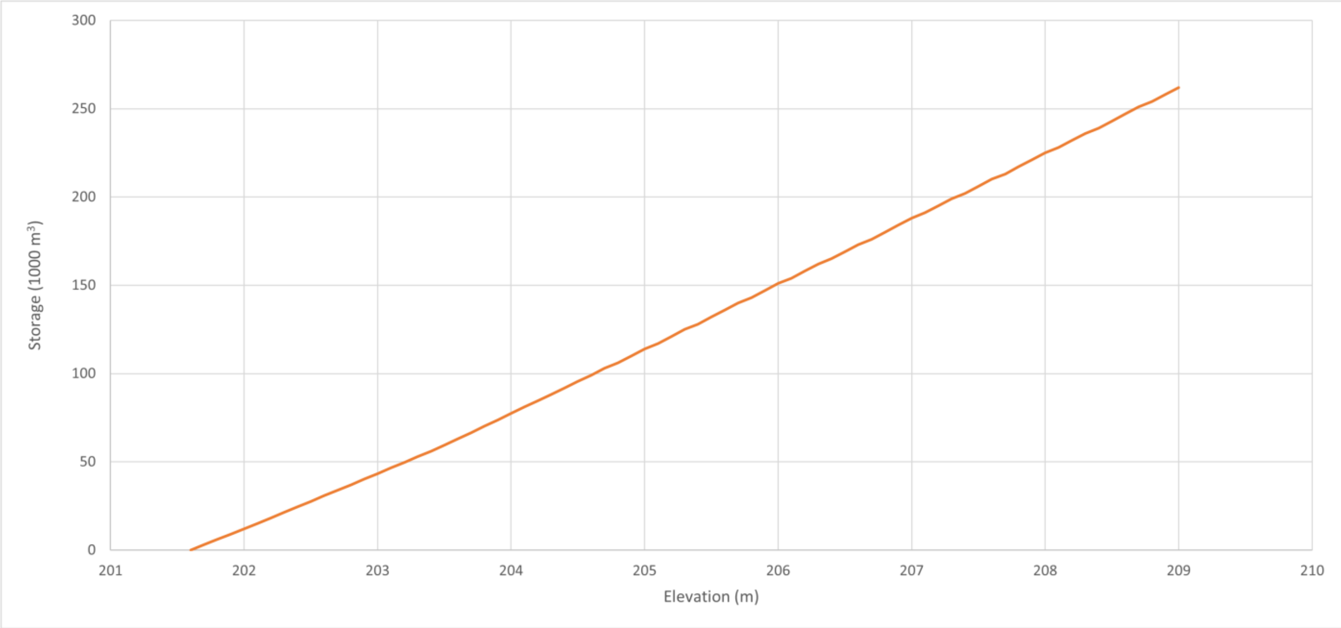


Figure 5-6: Outlet Elevation-Storage

Additionally, Tetra Tech has developed an elevation-storage curve for the south catchment, which had previously been omitted due to uncertainties in its hydrological response within the watershed. Through observed LiDAR data, a baseline water surface elevation of 216.62 m was determined for the body of water which rests within the south catchment (effectively as dead storage). As with Qikiqtalik Lake, Tetra Tech has made the assumption that water elevations will equalize to their respective outlet following freshet. As such, an elevation-storage curve could be constructed for the south catchment area without requiring additional bathymetry. This curve is provided in Figure 5-7 and represents only the active storage of the catchment.

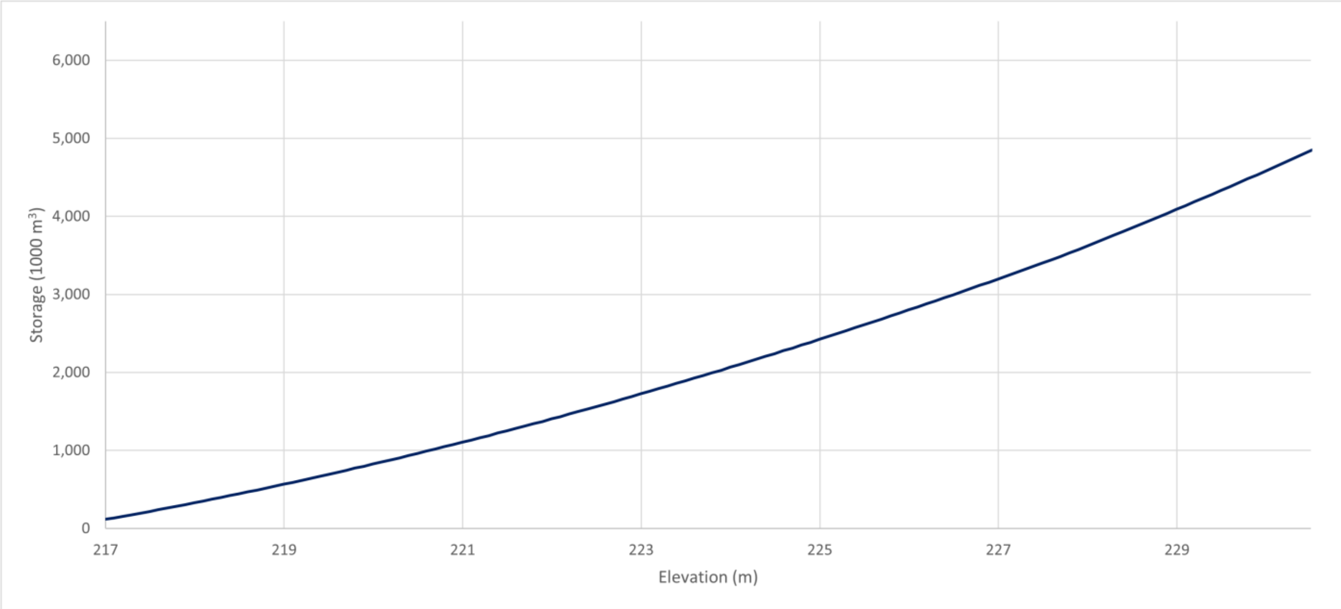


Figure 5-7: South Catchment Elevation-Storage

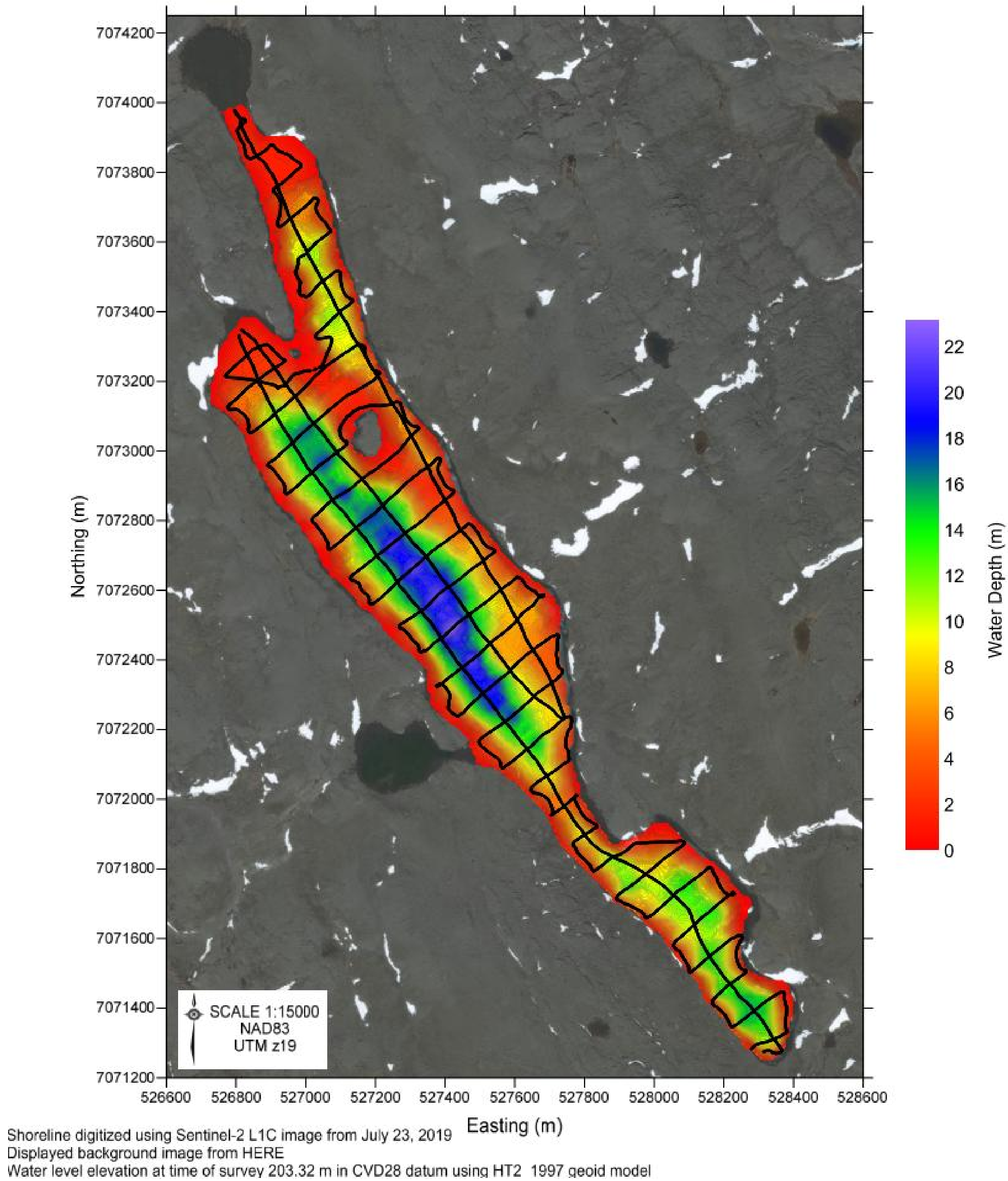


Figure 5-8: Tetra Tech Bathymetry Extents (Tetra Tech, 2019)

5.5 Lake Water Levels

Water levels at Qikiqtalik Lake were measured by both AAE in 2023 and 2024, and Stantec in 2019 (Nunami Stantec, 2019). Stantec's data was not included in the calibration of Tetra Tech's model as Tetra Tech believes there to be a geodetic issue or difference in measurement technique resulting in differences in dead storage water elevations. After reviewing data obtained from Carleton University, data gathered by AAE appears to accurately represent water levels of the Lake. Elevations gathered by Stantec could not be validated against Tetra Tech's LiDAR nor field measurements collected by AAE over the course of 2023 and 2024.

Referring to Figure 4-1, water elevations were gathered from Stream A1 (SA1), Stream A2 (SA2), SondeC, OTT Lake (OTTLK), and OTT Stream B (OTTSB). These monitoring stations were established during an initial site visit by AAE from June 14th-17th, 2023. Relocation and / or reconfiguration of two monitoring stations (SondeC and OTTLK) occurred in August of 2023 due to decreased water levels and vandalism of the OTT sensor that had been installed on the lake. Water level data gathered to date is presented in Figure 5-9 through Figure 5-13. Note that no additional data was successfully collected from SondeC in 2024. Over the course of the monitoring program the SondeC site, and the inflow tributary as a whole, was determined to be not suitable for passive logger deployment and was decommissioned at the end of 2023.

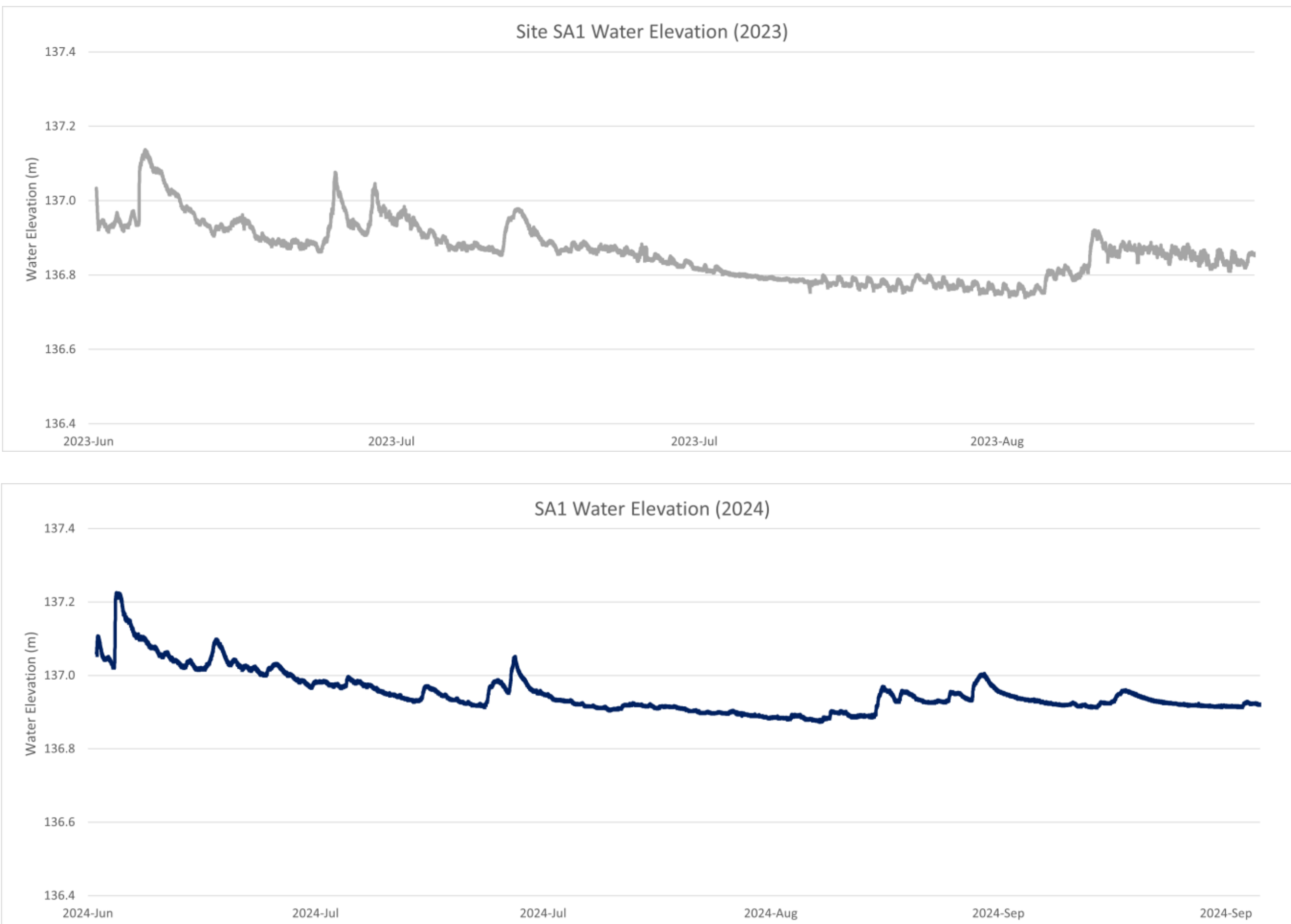


Figure 5-9: SA1 Water Elevations for 2023 and 2024

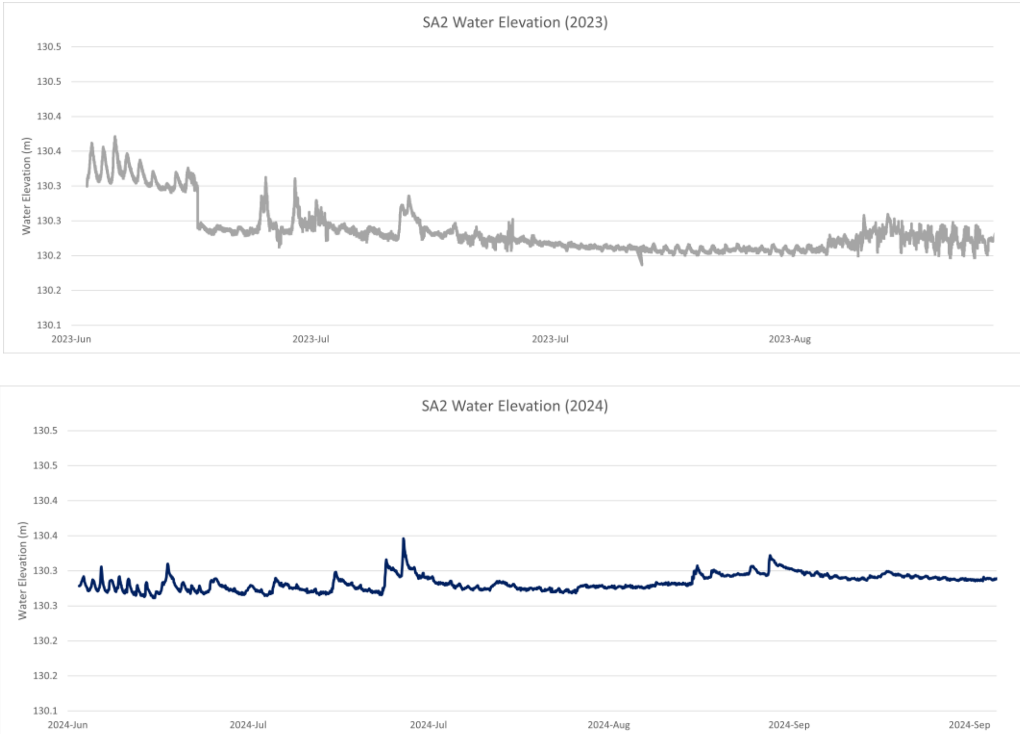


Figure 5-10: SA2 Water Elevations for 2023 and 2024

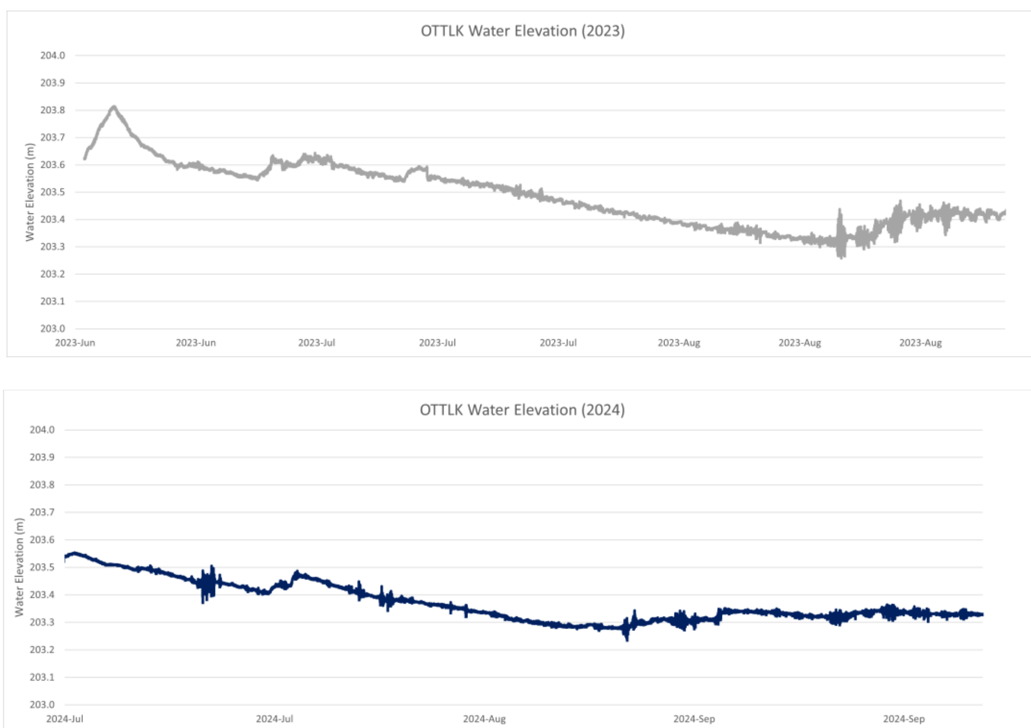
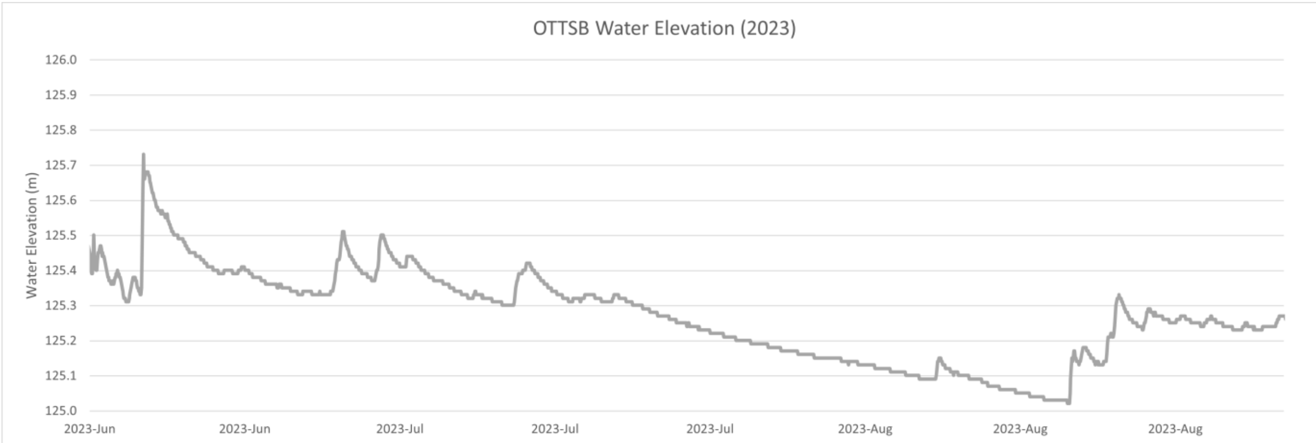


Figure 5-11: OTTLK Water Elevations for 2023 and 2024



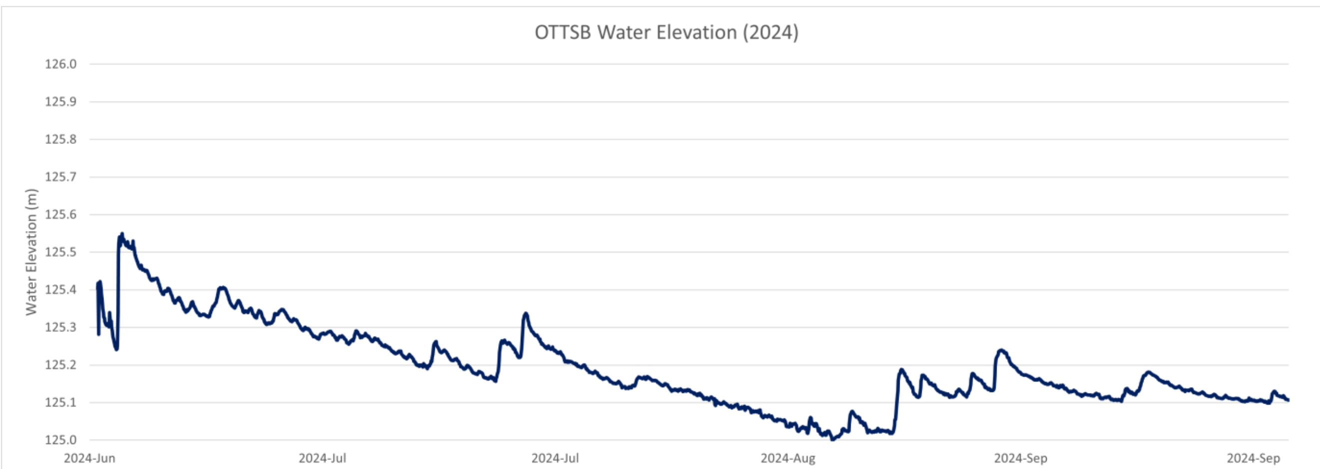


Figure 5-12: OTTSB Water Elevations for 2023 and 2024

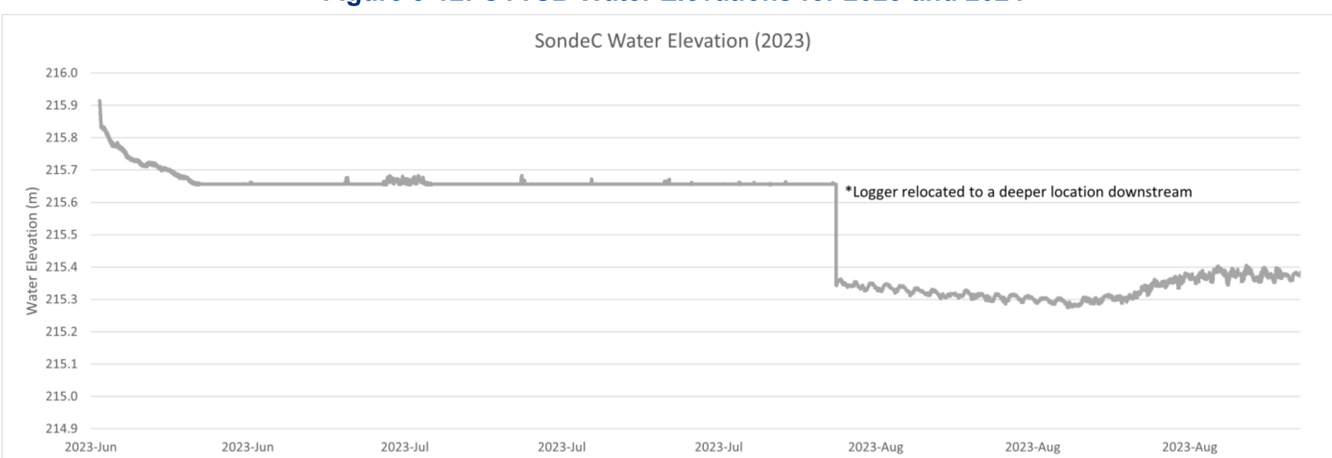


Figure 5-13: SondeC Water Elevations for 2023

Through Figure 5-11, it is apparent that the 2024 level logger was installed in late June of 2024 and missed the peak water elevation during the spring melt. Due to the presence of ice on the Lake during their site visit in early June of 2024, AAE left the OTTLK level logger with the City of Iqaluit Engineering Department to be placed in the

Lake once ice receded from the shore. According to AAE, the OTTLK level logger was confirmed to have been installed on June 28th, 2024. Unfortunately, this installation date missed the peak discharge events during the freshet.

5.6 Flows from Qikiqtalik Lake

Flows from Qikiqtalik Lake are primarily composed of direct outflow from the outlet in addition to any other groundwater losses. Based on field observations, the groundwater flows daylight just north of SA1 as shown in Figure 4-1. Thus, the total direct flows from Qikiqtalik Lake are expected to be equivalent to the sum of outflows measured at SA1 and the Proposed Weir Site.

SA2 catches inflow from a stream to the northwest of its location. Tetra Tech does not believe this flow to originate from Qikiqtalik Lake. SA2, in conjunction with SA1 and the Proposed Weir Site, produce flow which reports south towards OTTSB. Thus, Tetra Tech believes Qikiqtalik Lake outflow to be measurable at OTTSB for the sake of calibration. The contributions from SA2 are very small, ranging from less than 1% to approximately 5%.

5.7 Flows from Apex River

For additional information pertaining to flows contributing to and within the Apex River, Tetra Tech refers the reader to the previously submitted memorandum titled *Desktop Study of Qikiqtalik Lake Freshet Discharge in Apex River*, dated February 27th, 2024. Tetra Tech reiterates that the conclusions contained within the above memorandum have not been updated with respect to the findings presented within this report.

5.8 Qualitative Assessment of Climate Change

Tetra Tech routinely assesses the potential impacts of climate change to evaluate worst-case scenarios for the design of hydraulic infrastructure such as culverts, dams, and conveyance networks. Climate change projections often indicate an increase in precipitation magnitudes, especially for large and infrequent storm events. Incorporating adjusted precipitation values into design calculations allows engineers to 'futureproof' infrastructure, ensuring resilience against anticipated climate shifts.

5.8.1 Precipitation Projections

Climate change is expected to significantly increase the annual precipitation in Nunavut. The projected change in mean annual precipitation is expected to increase from 461 mm to 517 mm according to the Climate Atlas of Canada (Climate Atlas of Canada, 2019). The occurrence of wet days (> 0.2 mm precipitation) is also expected to increase under all Shared Socio-economic Pathways (SSP). Under the most severe consideration of fossil fuel consumption, the mean number of wet days are expected to increase by 9.4 annually by 2050. This is based on an ensemble of 30 Global Climate Models (GCMs).

Additionally, the maximum 1-, 3-, and 5-day precipitation are projected to increase by approximately 13-14%. Heavy precipitation days (> 10 mm precipitation) are expected to increase as well. Finally, icing days (days below freezing) are expected to decrease by approximately 15, meaning a shorter freeze cycle and longer thaw period for additional flow withdrawals. Based on the above, many pertinent climate indicators suggest that consideration of climate change would – in the opinion of Tetra Tech – provide a less conservative estimate of available water withdrawals by inferring an increase in capacity based on these GCMs. Figure 5-14 through Figure 5-18 below show projections for some of the discussed climate indices. All images are from the Climate Atlas of Canada.

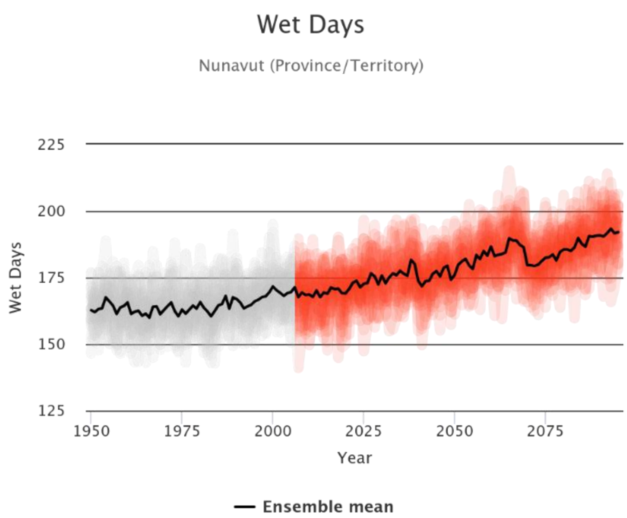


Figure 5-14: Change in Wet Days (2025-2100)

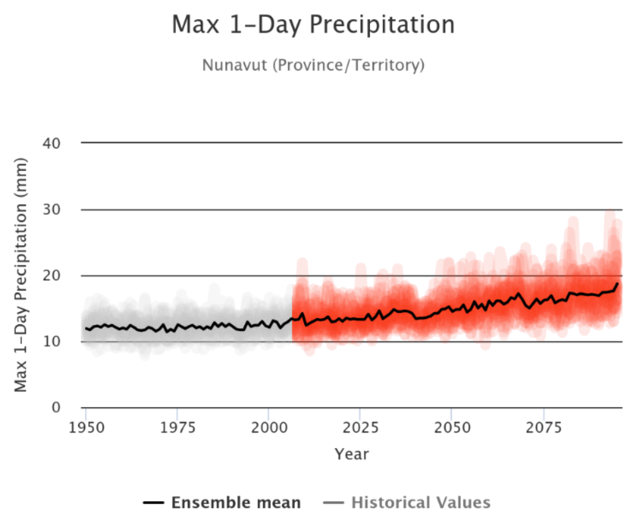


Figure 5-15: Change in Max 1-Day Precipitation

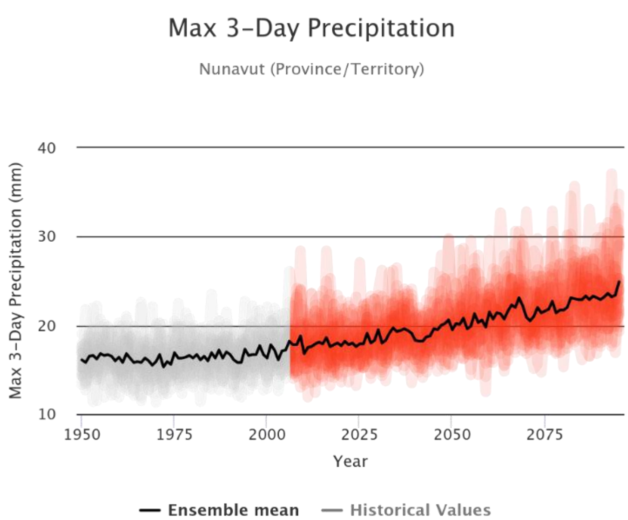


Figure 5-16: Change in Max 3-Day Precipitation

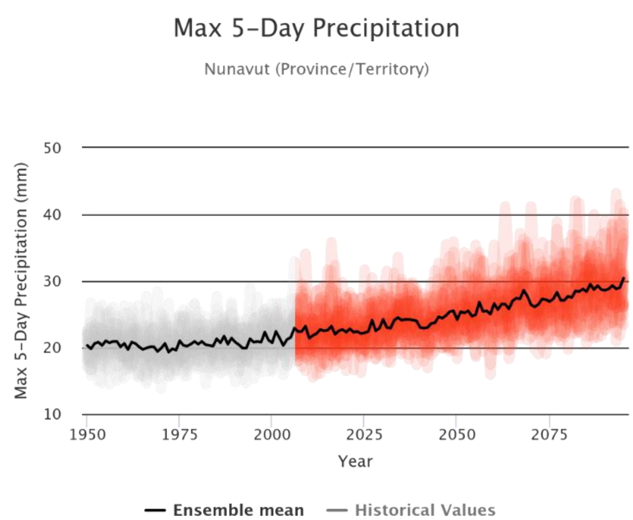


Figure 5-17: Change in Max 5-Day Precipitation

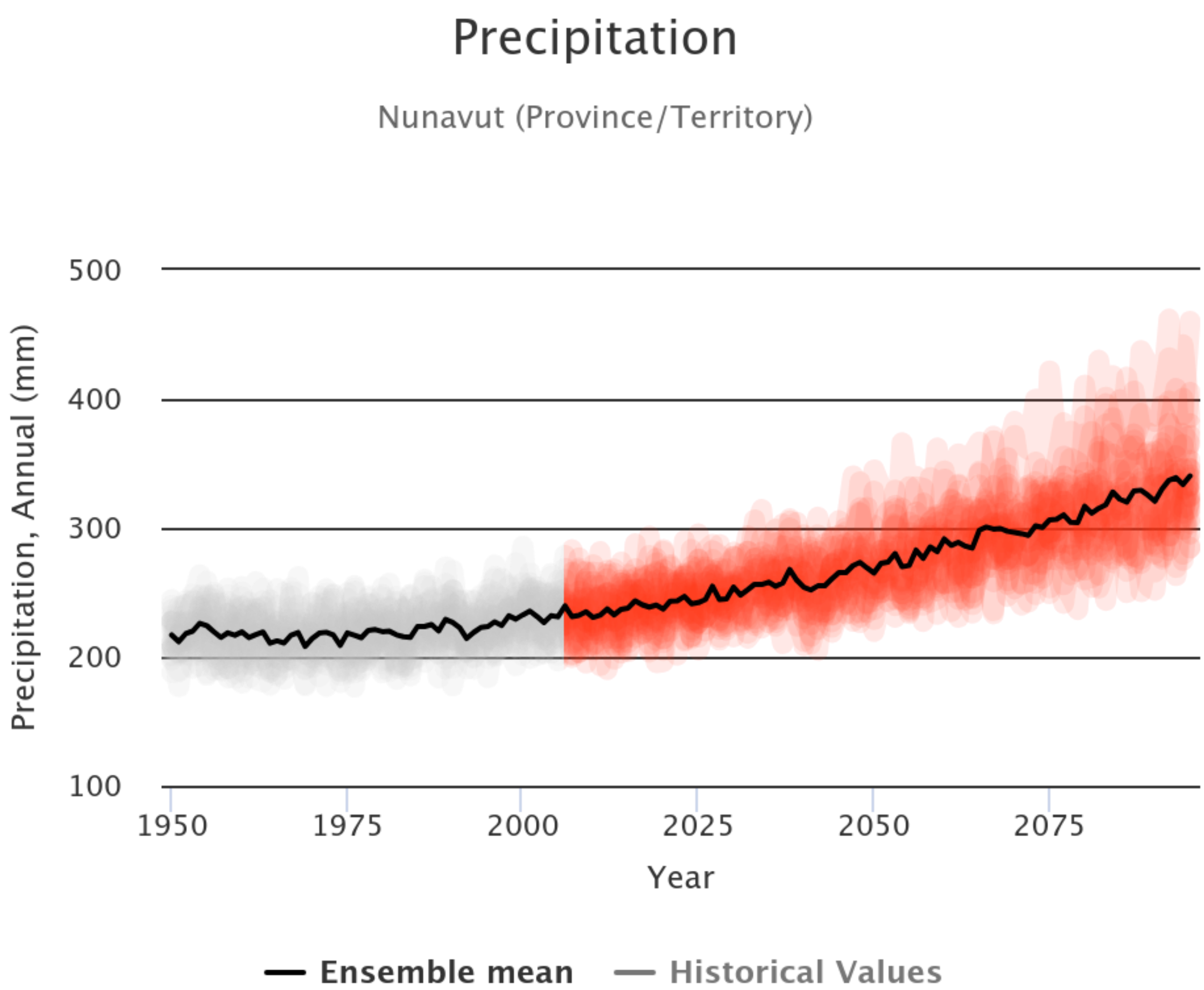


Figure 5-18: Mean Annual Precipitation Trend

5.8.2 Evapotranspiration

While it is understood that climate change will have an impact on evapotranspiration, the existing body of literature suggests that existing GCMs in general do not provide a simulation of evapotranspiration under its primary forcing components, namely land use changes and elevated atmospheric CO_2 concentration (Liu, et al., 2021). Moreover, while evapotranspiration rates are known to increase with higher temperature, an increase in humidity and higher CO_2 concentrations both tend to reduce transpiration and counteract the higher temperature effects (Snyder, Song, Moratiel, & Swelam, 2011). One study suggests that under certain circumstances such as rapid revegetation and increasing dew-point temperatures, little to no change in evapotranspiration is likely due to increasing air temperature (Snyder, Song, Moratiel, & Swelam, 2011).

To the best of Tetra Tech's knowledge, no existing assessment has specifically quantified the impacts of climate change on evapotranspiration in Nunavut. Although climate change–induced shifts in evapotranspiration are recognized as a factor influencing water availability, the magnitude of the effect on Qikiqtalik Lake cannot presently be defensibly estimated.

It is important to recognize that climate change may influence future water withdrawal rates. To appropriately assess and respond to these potential shifts, it is recommended that flow monitoring programs be expanded and sustained. In the absence of a comprehensive and long-term dataset.

6.0 METHODOLOGY

The methodology used to assess the hydrology of Qikiqtalik Lake included a close review of historical climatic data, the analysis of flow data collected by Tetra Tech (AAE), the analysis of the data collected by the University of Carlton, and the adoption of statistical methods to generate flow estimates.

The process includes an initial review of the historical data and the identification of common statistical distributions closely mimicking actual measured data.

6.1 Monte Carlo Simulation and Statistical Distributions of Data

The Monte Carlo simulation sampled statistically distributed snowpack and precipitation data to model an entire year at a daily resolution. Snowpack data (in SWE) was made available courtesy of Dr. Richardson of Carleton University. Precipitation distributions were re-assessed from the Interim Report based on additional data from the stations listed in Table 5-2. The distributions for each month were assessed separately to increase the resolution of sampling within the simulations. Tetra Tech utilized a log-normal distribution for precipitation as it provided the best fit for the data. Both the snowpack and precipitation distributions are presented in Figure 6-1 and Figure 6-2, and summarized in Table 6-1. A comparison between the interim and final model monthly precipitation distributions is presented in Figure 6-3.

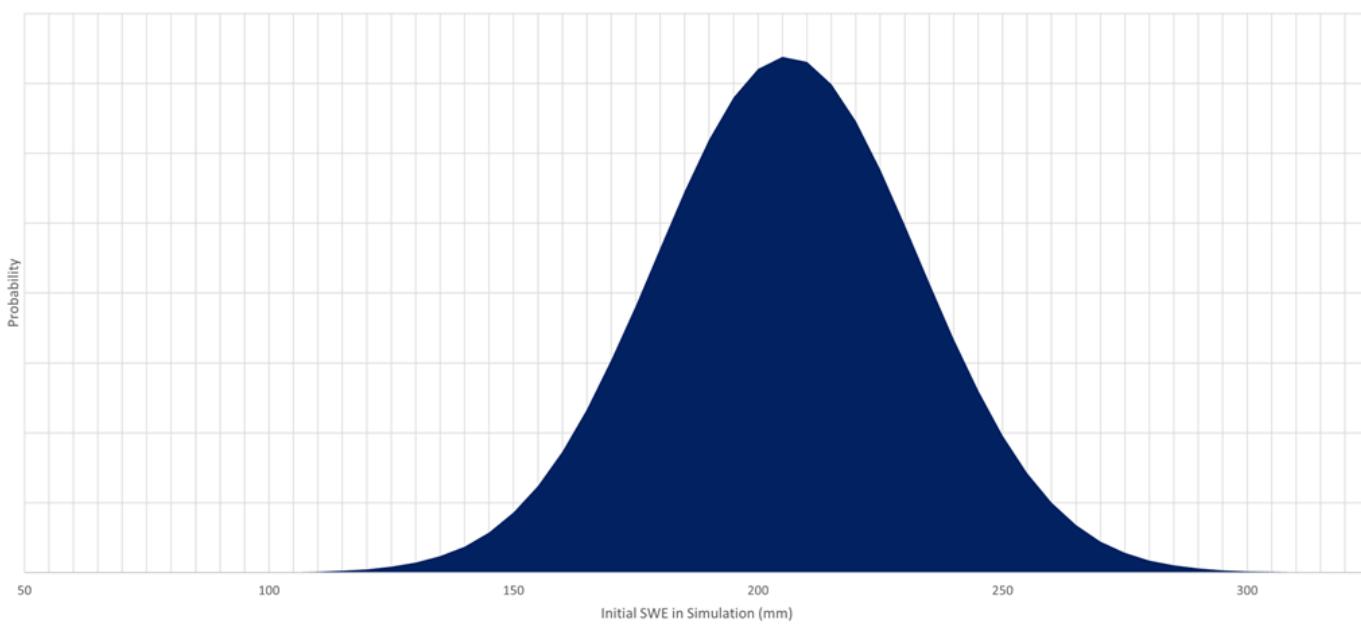


Figure 6-1: SWE Distribution

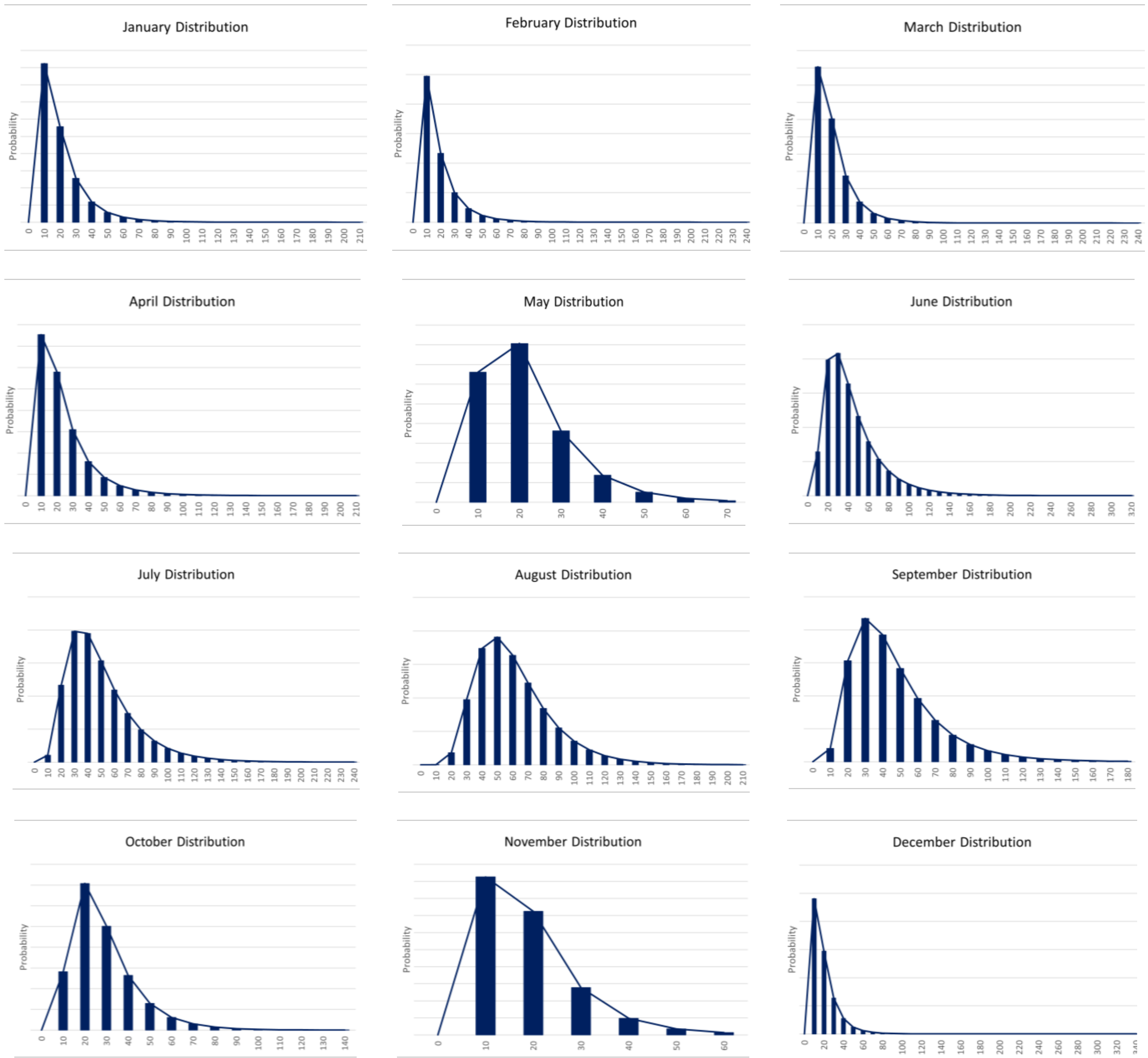


Figure 6-2: Precipitation Distributions by Month (mm)

Table 6-1: Statistical Distribution Data for 2023 and 2024

Month	Type	2023 Mean (μ) (mm)	2024 Mean (μ) (mm)	2023 Standard Deviation (σ) (mm)	2024 Standard Deviation (σ) (mm)
SWE	Normal	206	206	27	27
January	Log-Normal	17.21	20.18	21.97	15.48
February	Log-Normal	20.63	17.81	26.73	15.30
March	Log-Normal	24.54	20.45	27.45	14.39
April	Log-Normal	21.59	23.98	23.95	18.63
May	Log-Normal	18.65	21.86	9.81	11.48
June	Log-Normal	37.45	44.11	35.72	29.22
July	Log-Normal	54.34	49.89	32.39	26.79
August	Log-Normal	57.44	60.86	27.39	25.40
September	Log-Normal	44.96	46.24	23.71	25.66
October	Log-Normal	25.78	28.87	17.61	15.47
November	Log-Normal	11.72	19.33	8.04	10.83
December	Log-Normal	16.54	19.48	34.31	13.73

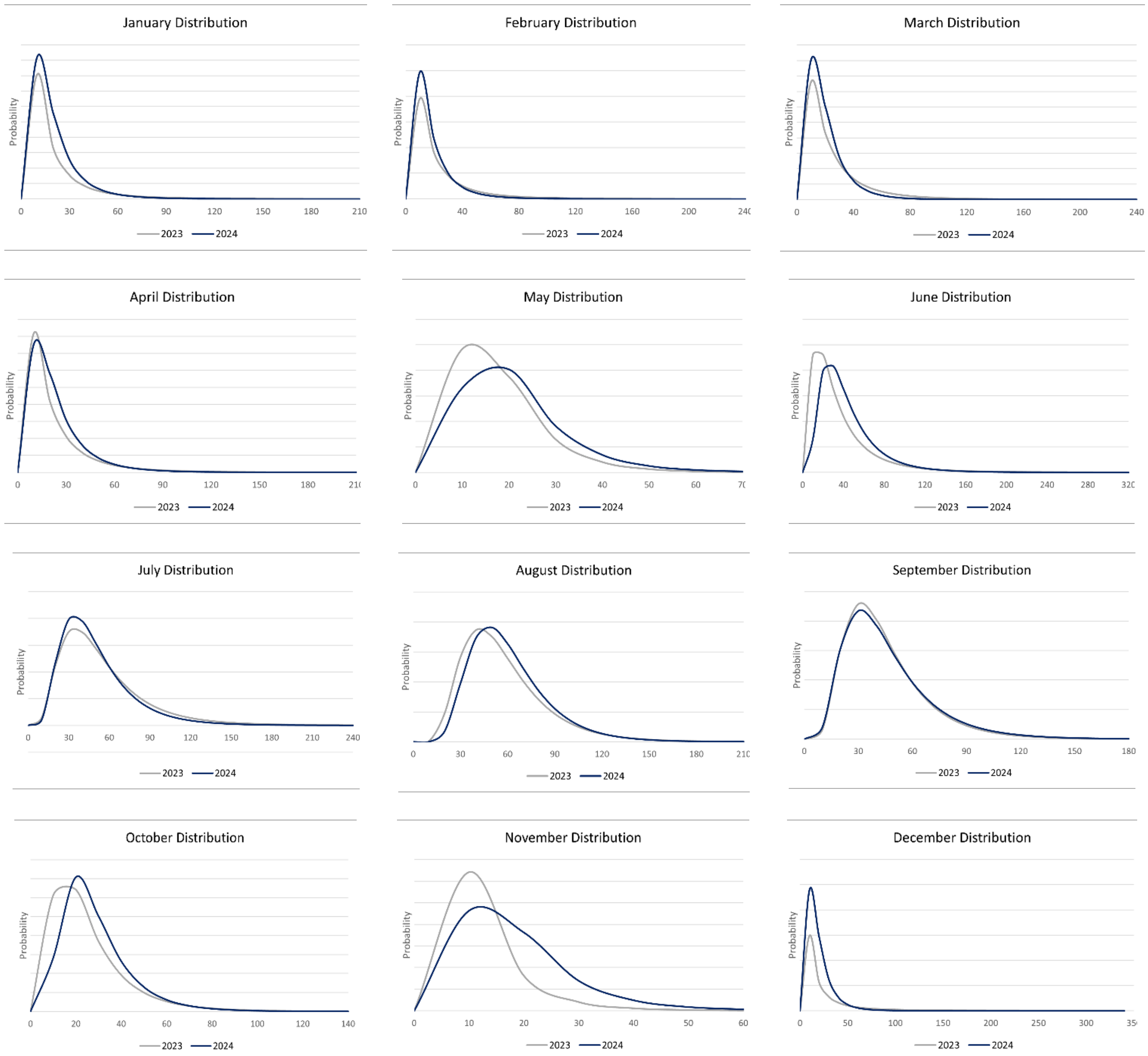


Figure 6-3: 2023 vs. 2024 Precipitation Distributions by Month (mm)

6.2 Snow Accumulation and Melt

Snow typically falls when the air temperature above the land is below freezing. If the air remains below this temperature, the snow will accumulate on the ground. In certain watersheds, it is a regular part of the yearly water cycle for snow to build up into a snowpack over the winter. This is especially the case for Qikiqtalik Lake given its latitude. This snowpack is dynamic, constantly changing its ice crystal structure due to daily temperature shifts. The snowpack begins to melt, or ablate, when the surrounding air transfers enough energy to warm the snowpack to the freezing point, causing the snow to turn into liquid water through the ice's heat of fusion.

The most common method to determine a snowpack's water content is by measuring its SWE. SWE is the amount of water obtained if a specific column of snow were completely melted.

Within HEC-HMS, the *Snow Method* is used only when simulations involve air temperatures that might drop below freezing, or when snowpack might be present at the start of the simulation. Currently, the model employs a Temperature Index approach. This method conceptually represents the energy in the snowpack and calculates the amount of liquid water available at the ground surface, which then either infiltrates the soil or becomes surface runoff.

6.2.1 Temperature Index

The Temperature Index method expands on the degree-day technique for simulating snowpack behavior. In the standard degree-day approach, a set quantity of snowmelt is assumed for each degree the temperature is above freezing. This method incorporates a theoretical model of the cold energy retained in the snowpack, along with a constrained recall of previous conditions and various other elements to calculate the melt volume for each degree above freezing. The melt coefficient is adjusted as the internal conditions of the snowpack and the external atmospheric conditions vary.

To fully implement the Temperature Index method, several parameters were defined. Presiding assumptions were required to fully simulate the model. Intermittent sensitivity assessments were conducted when Tetra Tech was unsure about a particular parameter. Unless otherwise stated, parameters were selected to be default values stipulated by the HEC-HMS User Manual (v4.12) (Hydrologic Engineering Center (HEC), 2023). Each basin was split into 'bands' to represent layers of snowpack. Given the relatively minor elevation changes of Qikiqtalik Lake's catchment, only one elevation band was utilized to represent the properties of the entire catchment. Table 6-2 provides a summary of all temperature index parameters.

Table 6-2: Temperature Index Parameters

Parameter	Description
Average Elevation	For each elevation band, either the area-weighted elevation or the average of the highest and lowest points is specified.
Precipitation Index (Optional)	If adjusting precipitation for each elevation band, this index is used alongside a subbasin-wide index. Precipitation typically increases with elevation in mountainous areas.
Initial SWE	This is the starting amount of water in the snowpack, usually derived from actual measurements. It can be zero if no snow is present.
Initial Cold Content	Represents the energy needed to warm the snowpack to 0°C. It's calculated based on snow depth, density, heat capacity, and temperature below freezing. It is zero if no snow exists. Tetra Tech used several test runs to determine an appropriate cold-water content. Regardless of the value selected, HEC-HMS re-calculates the subsequent cold content at each time step. Tetra Tech typically utilized the air temperature in January as the Initial Cold Content.
Liquid Water in Snowpack	This initial value is entered, being zero if no snowpack exists or if temperatures have been consistently below freezing. Tetra Tech utilized a value of 0 as simulations begin in January.

Parameter	Description
Initial Cold Content Antecedent Temperature Index (ATI)	An index indicating the snowpack's surface temperature at the simulation's start, set to 0°C if unknown.
Meltrate Indexing	The initial meltrate Antecedent Temperature Index (ATI) is akin to accumulated thawing degree days, allowing for variable melt rates as the snowpack ages. It's zero if there's no snow or if the simulation starts after a cold period.
PX Temperature	Determines whether precipitation falls as rain or snow.
Base Temperature	Used with air temperature to define the Temperature Index for calculating snowmelt.
Wet Meltrate	Applied when it's raining above a certain rate, with options for a constant value or an annual pattern.
Rain Rate Limit	Differentiates between dry and wet melt, with a default value implying any precipitation triggers wet melt.
Dry Melt Rate	Calculated using either an ATI-Meltrate Function, an annual pattern, or a constant value.
Cold Limit	Affects the cold content index during high precipitation rates, resetting it based on precipitation temperature.
Cold Content Index Coefficient	Updates the cold content index over time.
Cold Content Function	Calculates cold content from the current index, with a typical range specified.
Maximum Liquid Water Capacity	The threshold of melted water in the snowpack before it contributes to infiltration or runoff, expressed as a percentage of SWE.
Ground Heat	Accounts for snowmelt due to warm ground, with options for a fixed value or an annual pattern. Given the location of Qikiqtalik Lake, this parameter was not considered.

6.2.2 Snow Data Sourcing

Snowpack, and more specifically, snow water equivalence, is a very challenging parameter to derive. The spatial variance of snow accumulation due to wind and sun exposure necessitates a wide spatial sample of measurements for best estimates. Additionally, depth of snow accumulation alone is not enough to convert into a water equivalency – density is also required at each data point (or an assumed density can be applied to all measurements, but this is not ideal). For this reason, using point data (such as from a climate station) is not sufficiently representative of a given areas snowpack and density to be used as a modelling basis.

Environment Canada often uses the ‘ten-to-one’ rule to convert snowfall depth to water equivalence, where snowfall amount (in cm, typically measured using sonar or rulers if a staffed station) is divided by ten to get the amount in mm (Environment and Climate Change Canada, 2025). Some stations utilize a Nipher gauge and physically melt snowfall to measure its water depth, however, climate normal datasets contain a mix of data resulting from these two different methodologies. Additionally, Environment Canada states that even at ordinary climate stations (not staffed), the normal precipitation values will not always be equal to rainfall plus one tenth of the snowfall.

Additionally, literature suggests that the sonar technology currently used to automate depth measurements at unstaffed climate stations varies significantly from manual ruler measurements, especially in the arctic where it noticeably underestimates depth (Brown, Smith, Derksen, & Mudryk, 2021). A figure from the literature is provided in Figure 6-4.

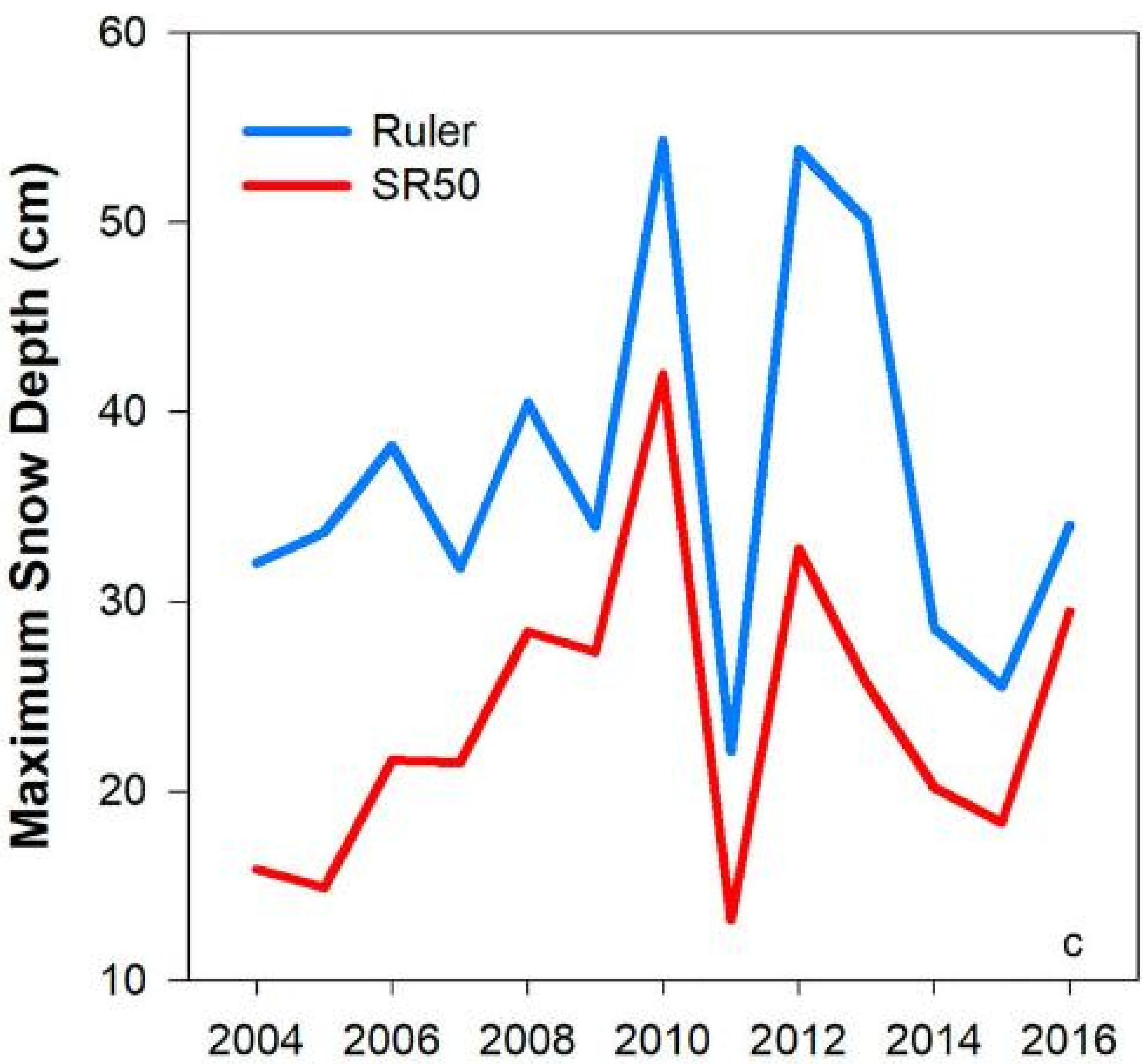


Figure 6-4: Regionally Averaged Snow Depth Values (Brown, Smith, Derksen, & Mudryk, 2021)

Tetra Tech reviewed an additional dataset from Environment and Climate Change Canada pertaining to snow water equivalent values in Iqaluit, specifically, the Adjusted and Homogenized Canadian Climate Data set, to support informed data sourcing decisions. This dataset applies a series of corrections to original station measurements, addressing changes in instrumentation and observational practices over time.

This dataset provides adjusted annual snow water equivalent data for Iqaluit spanning the period from 1946 to 2008. Due to incomplete data, the years 1946–1949, 1997–2005, and 2007 were excluded from analysis. Within the remaining valid dataset, the average annual snow water equivalent was 320.55 mm, with a standard deviation of 83.21 mm.

This value is substantially higher than the unadjusted estimate derived from the 1991–2020 Canadian Climate Normals, which, based on the conventional ten-to-one snow-to-water ratio used by Environment Canada, suggests a mean annual snow water equivalent of approximately 144.6 mm. Furthermore, the adjusted dataset values exceed those derived by Dr. Richardson, whose dataset was used as the basis for Tetra Tech's modelling and reflects a mean of 206 mm with a standard deviation of 27 mm.

Considering the comparative evaluation and inherent limitations of each dataset, Tetra Tech concludes that Dr. Richardson's data offers a reasonable and appropriate representation of snow water equivalence for modelling purposes in the study area.

6.3 Outflows

Previously, Golder utilized five sub-basins sequentially draining into each other to model the behavior of flow into and out of Qikiqtalik Lake. Golder did not provide insight into the methods behind how each basin discharged into the next. Consequently, Tetra Tech elected to utilize two sub-basins to model the behavior of the Lake. Specifically, Qikiqtalik Lake and the outlet were modelled as separate basins. Flow first enters Qikiqtalik Lake before eventually draining into the outlet, and then finally draining from the outlet into Apex River.

In the Interim Report, a stage-discharge curve was initially developed in PC-SWMM for flow transitioning between Qikiqtalik Lake and the outlet. The elevation of the connection between Qikiqtalik Lake and the outlet was assumed to begin at 203 m. Water elevation was gradually increased to determine discharge behavior. This stage-discharge curve was then entered into the HEC-HMS model and calibrated such that the water levels measured at Qikiqtalik Lake closely matched those measured by AAE.

Following the submission of the Interim Report, Tetra Tech was granted access to physical measurements of stage-discharge downstream from the outlet of Qikiqtalik Lake, provided by Dr. Richardson of Carleton University. This data facilitated a more refined assessment of discharge from the Lake, as it effectively represented an 'upper-bound' for stage-discharge, accounting for additional surface runoff from additional downstream catchments. This upper-bound was further adjusted based on catchment size to provide a better approximation of discharge from the outlet of Qikiqtalik Lake. Calibration tests revealed that the model was extremely sensitive to variations in this stage-discharge curve. This introduces a unique challenge, as outlet conditions can fluctuate annually due to factors such as ice, debris, and other environmental influences. Should the City eventually utilize Qikiqtalik Lake discharge, it is strongly recommended the outlet is formalized and maintained. A new model using the new stage-discharge curve from the formalized outlet should then be assessed. The final stage-discharge curve is presented in Figure 6-5. It can be seen that the best model results to align with 2024 data required a stage-discharge curve roughly in between the adjusted and 2023 curves.

To model the flow leaving the outlet basin (which receives the discharge from Qikiqtalik Lake) into Apex River, Tetra Tech utilized the same stage-discharge relationship developed by Golder (2021). The mathematical form of this relationship is presented in Equation 1.

$$Q_{UNL} = 2.562(H_E - 202.05)^3 \qquad (1)$$

where

Q_{UNL} is the outflow from Qikiqtalik Lake (m^3/s) and

H_E is the water elevation (masl) in the outlet.

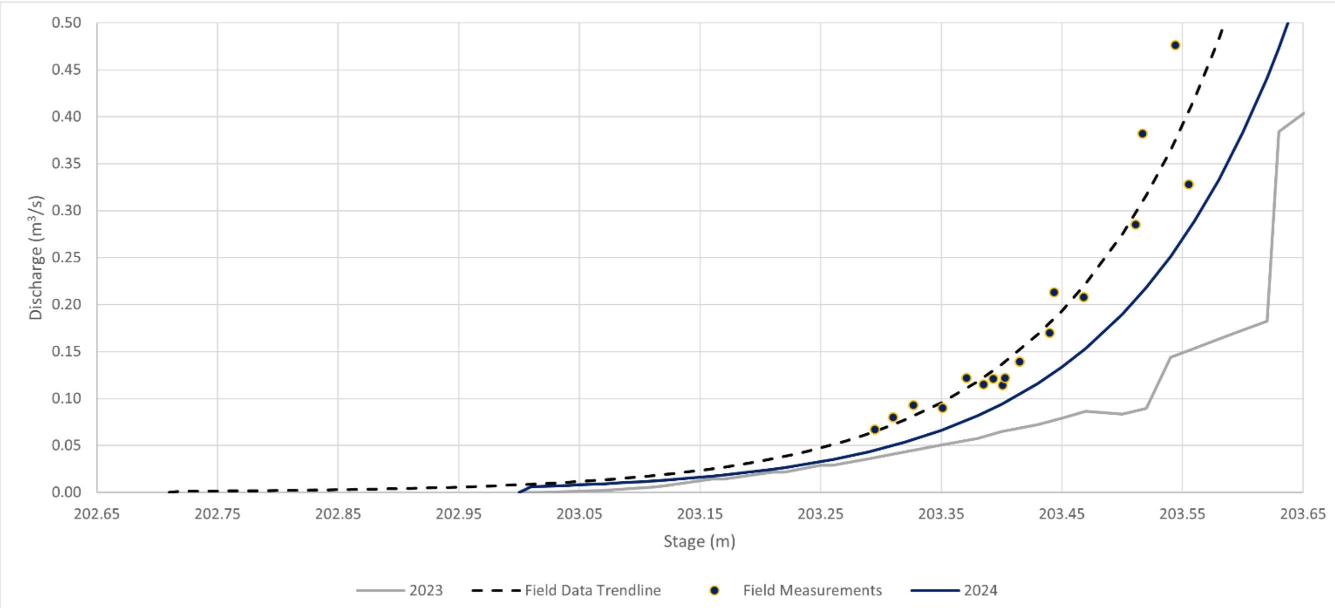


Figure 6-5: Elevation-Discharge for Qikiqtalik Lake to Outlet Basin

Tetra Tech originally intended to utilize field measurements gathered by AAE to develop an elevation-discharge relationship between the south and central catchments. However, AAE informed Tetra Tech that the connection between the two catchments (SondeC) was not suitable for level logger deployment. For this reason, Tetra Tech has assumed that the elevation-discharge relationship between the south and central catchments is similar to that presented in Figure 6-5, but initiates discharge at 216.62 m rather than 203 m.

6.4 Evaporation

Following the Interim Report, Tetra Tech received evaporation data from Dr. Richardson of Carleton University. A visual comparison of differences in monthly evaporation between the 2023 and 2024 hydrologic models is presented in Figure 6-6.

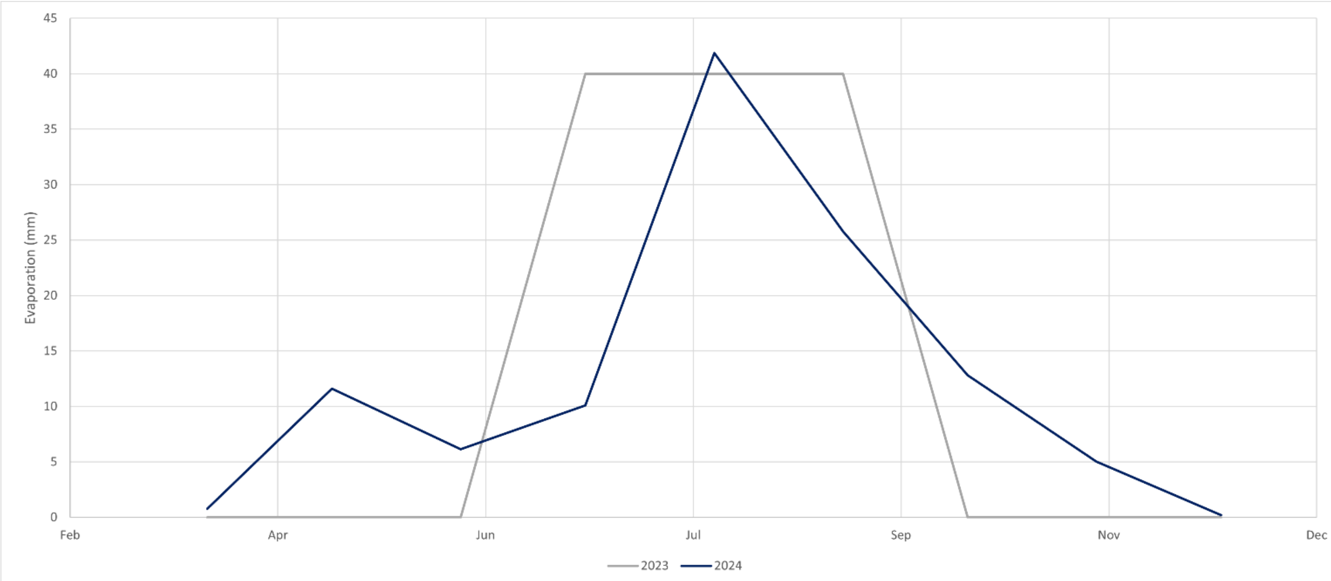


Figure 6-6: Modelled Evaporation for 2023 and 2024

6.5 Validation of Final Model

Inflows into Qikiqtalik Lake were generated using precipitation data as presented in § 5.2. Similar to the calibration approach employed with the 2023 HEC-HMS model, real-time precipitation data was used to simulate discharge and water elevation within the Lake over the same measurement period as the OTTLK level logger. The results of the simulation were used to adjust various hydrologic parameters to best match simulated and observed water levels within the Lake. Since the water level data gathered by AAE begins in June and terminates in September, precipitation data from January to September was utilized. The inclusion of January to June was considered essential to facilitate additional accumulation of snow during the later winter months and catches the entirety of the freshet.

Similar to in 2023, Tetra Tech calibrated this final model by hand. However, additional information was available to guide calibration such as stage-discharge data from Dr. Richardson and salt dilution discharge measurements from AAE within the Apex River. Tetra Tech believes the most important aspect of this water balance is the ability for the model to accurately capture the behavior of the freshet. However, as previously noted, the water level response of Qikiqtalik Lake to the 2024 freshet was not captured. As such, attention was heavily focused on tuning model discharge during lower water level events, and leaving higher discharge calibrations unchanged from the initial 2023 model as shown in Figure 6-7 and Figure 6-8. This is due to the original model having been successfully able to calibrate for a freshet response. The results of the final calibration are presented alongside observed data gathered by AAE in Figure 6-9 for 2024.

Figure 6-9 presents several critical pieces of information. The top half of the figure presents Qikiqtalik Lake water elevations. The blue dashed line represents the model simulation results, whereas the solid black line presents gathered data by AAE. The top red line presents the storage volume of Qikiqtalik Lake for the given water elevation. The bottom half of the figure presents total reservoir combined inflow (dashed blue line) and resultant outflow to the outlet (solid blue line). The total inflow includes both inflow from snowmelt as well as precipitation. Outflows are calculated based off the Stage-Discharge curve presented in Figure 6-5.

Figure 6-10 presents three snowmelt related pieces of information, namely the SWE depth (bottom), temperature (middle), and additional water equivalent depth added by any given precipitation (top). HEC-HMS considered precipitation which fell at a temperature below the base temperature to be snow and continuously added SWE depth until the air temperature passed the PX (melting) temperature in June. After approximately 16-25 days, the entirety of the snowpack had melted and converted to water entering Qikiqtalik Lake. Melting rate, as well as initial SWE, appear to largely control the magnitude and occurrence date of the peak freshet. Figure 6-11 presents the outflow from the outlet reservoir into Apex River.

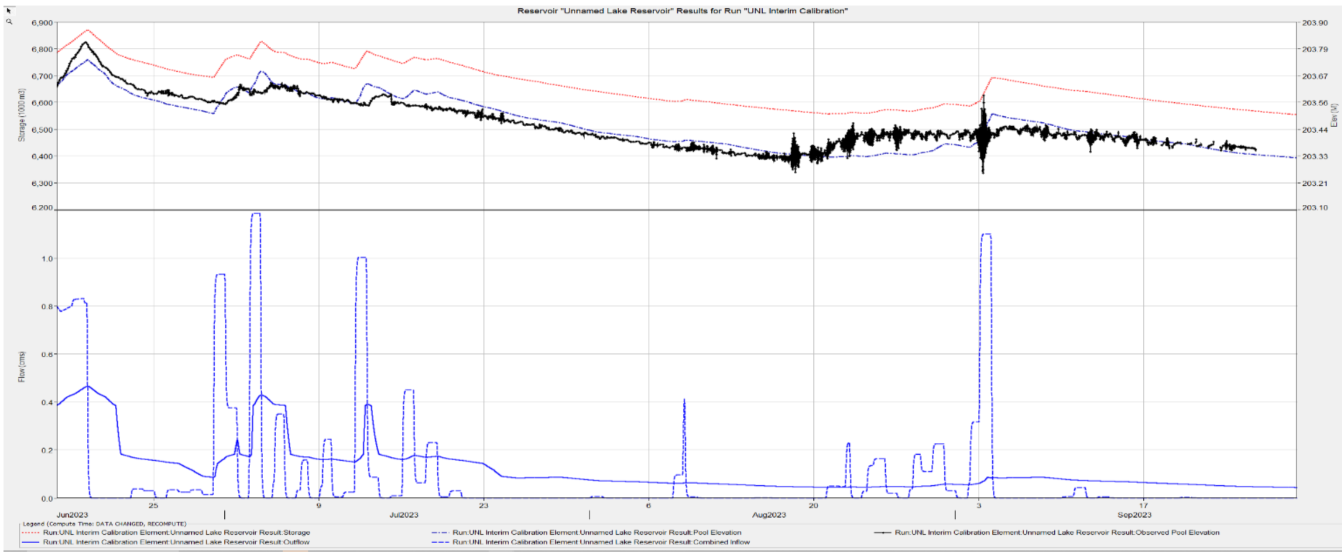


Figure 6-7: Qikiqtalik Lake Water Level Calibration Results (2023)

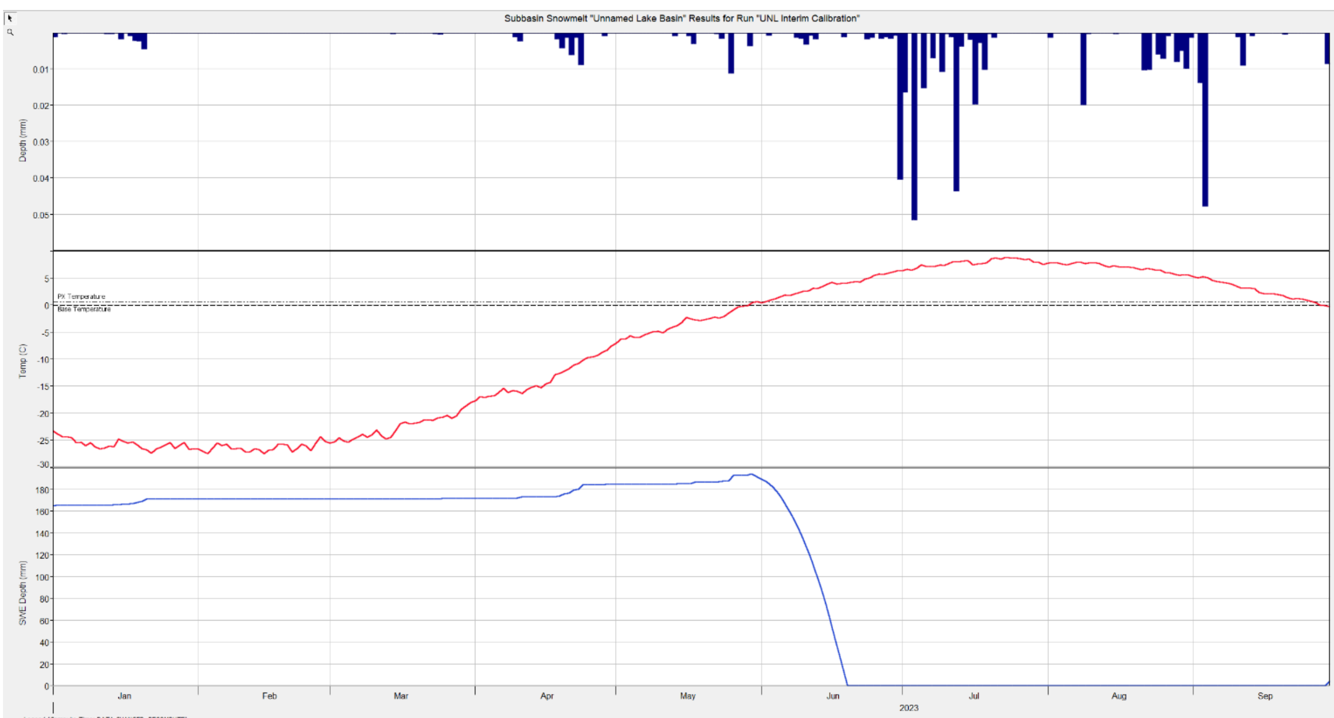


Figure 6-8: Qikiqtalik Lake Snowmelt Calibration Results (2023)

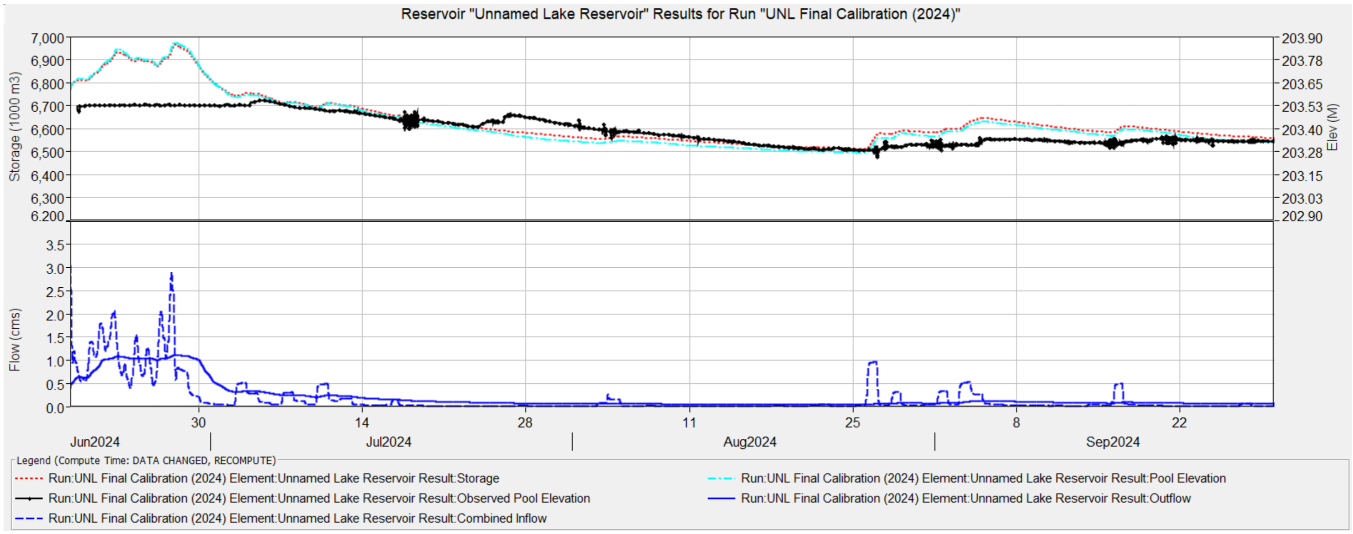


Figure 6-9: Qikiqtalik Lake Water Level Calibration Results (2024)

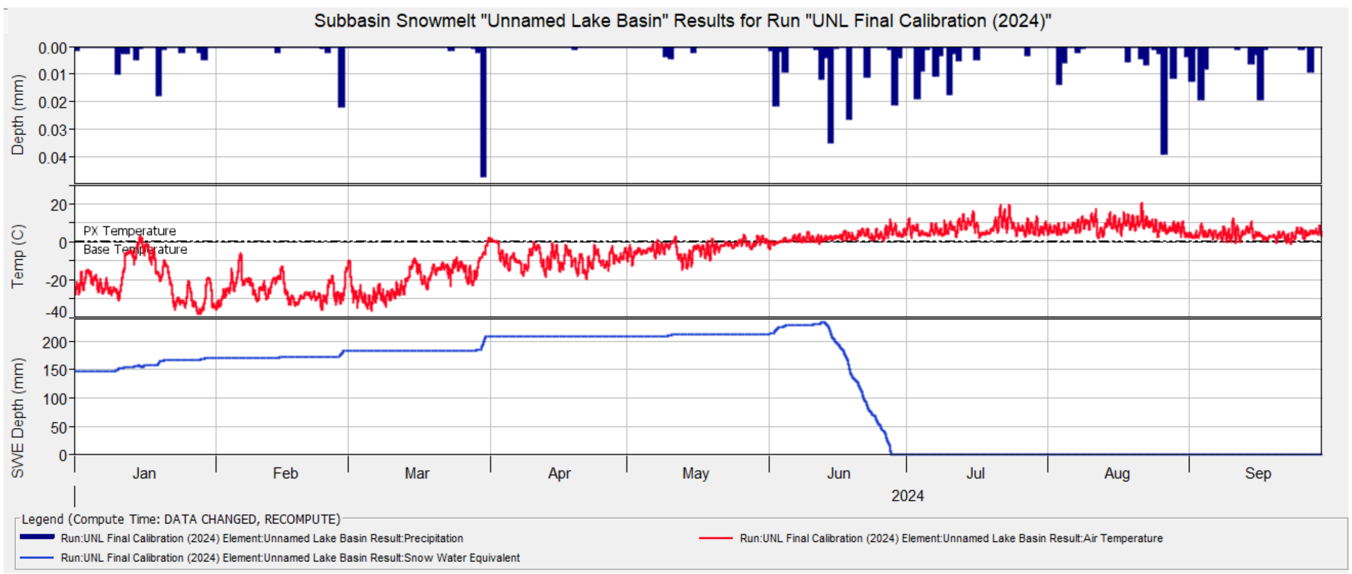


Figure 6-10: Qikiqtalik Lake Snowmelt Calibration Results (2024)

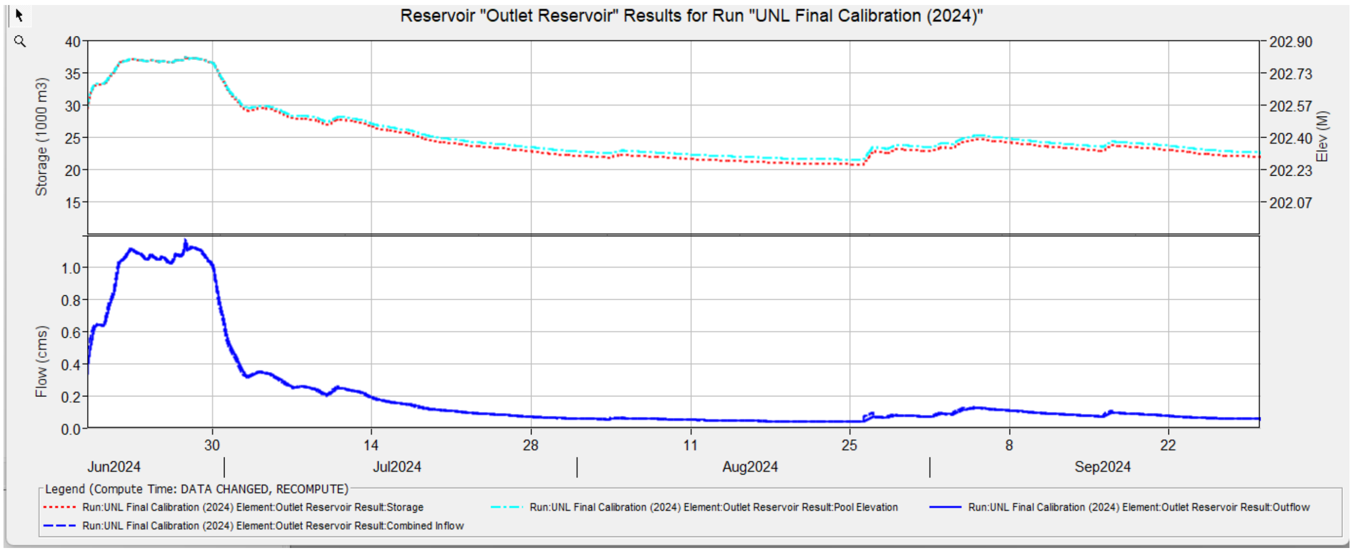


Figure 6-11: Outlet Reservoir Discharge Calibration Results (2024)

6.6 Monte Carlo Simulation

A Monte Carlo simulation is a computerized mathematical technique that allows a model to account for risk in quantitative analysis and decision making. It can be used to understand the impact of risk and uncertainty in prediction and forecasting models. The method is named after the Monte Carlo Casino in Monaco, reflecting the element of randomness in the approach.

In a Monte Carlo simulation, a model is created of a complex system or process and then simulated many times, each time using different sampled statistical values based on probability distributions. This process involves repeated random sampling to capture the range of possible outcomes in a system where exact predictions are difficult due to uncertainty. By doing this, the simulation produces a range of possible outcomes and the probabilities they will occur. These outcomes can then be analyzed to understand and prepare for the variability and risk in various scenarios.

In the case of Qikiqtalik Lake, primary variables which carry a large degree of uncertainty are SWE depth at the beginning of the simulation in January, and precipitation throughout the simulation. Precipitation from Iqaluit Climate was used to determine an average precipitation amount for each day of the year. This was used to determine a normalized hyetograph for distribution of monthly total precipitation. This normalization is done automatically by HEC-HMS. Recall from Figure 6-2 that each month has a unique distribution of possible rainfall amounts.

At the beginning of each simulation, a SWE value is randomly selected based on the distribution shown in Figure 6-1. Since the first month is January, a random total precipitation amount is selected based on January's rainfall distribution. This value is then distributed based on a normalized hyetograph with respect to January rainfall. Once the simulation reaches February, the same steps are repeated with respect to precipitation. Only one SWE variable is selected per iteration. The time step used in each iteration is one day. For this final report, a total of 6,000 simulations were conducted.

7.0 ASSUMPTIONS AND LIMITATIONS

Tetra Tech has made several assumptions of note to set up this model. Key assumptions are listed below:

1. Rainfall and temperature data gathered from ECCC stations listed in Table 5-2 are representative of precipitation and air temperature at Qikiqtalik Lake.
2. Rainfall and temperature data gathered from ECCC stations listed in Table 5-2 are accurate and data flags have been correctly implemented for erroneous measurements.
3. Water elevations gathered by AAE are correctly geodetically referenced and accurately represent the measurements made at their respective times, with the exception of known errors as discussed.
4. Discharge data gathered by AAE is representative of relationships between Qikiqtalik Lake and the discharge into Apex River.
5. Average daily precipitation is representative of the overall precipitation patterns near Qikiqtalik Lake.
6. Monthly precipitation can be best represented by log-normal distributions based on dataset analysis using third-party statistical software.
7. Discharge from OTTSB receives flow from only Qikiqtalik Lake and one small tributary.
8. All flow discharged from Qikiqtalik Lake eventually reaches OTTSB.
9. Water elevation within Qikiqtalik Lake is equal to the outlet elevation of 203 m at the beginning of every simulation.
10. Water elevation within the south catchment is equal to the outlet elevation of 216.62 m at the beginning of every simulation.
11. Temperature fluctuations in the region are rare when compared to the average, and consequently the average daily temperature can remain representative of Qikiqtalik Lake for all simulations.

8.0 RESULTS

8.1 Precipitation

A summary of precipitation output from the HEC-HMS model is presented in Figure 8-1 below. During the Monte Carlo simulations, total precipitation recorded between January and September ranged from a maximum of 849.85 mm to a minimum of 3.81 mm. This maximum value is very close to the 100th percentile of 850.40 mm (for January through September) provided by Environment Canada Iqaluit climate normals. The simulations yielded an average precipitation of 182.23 mm for this period, substantially lower than the 296.4 mm indicated by Iqaluit's climate normals from 1991 to 2020. Tetra Tech attributes this difference to the simulations capturing extremely dry scenarios that are absent from the historical climate record.

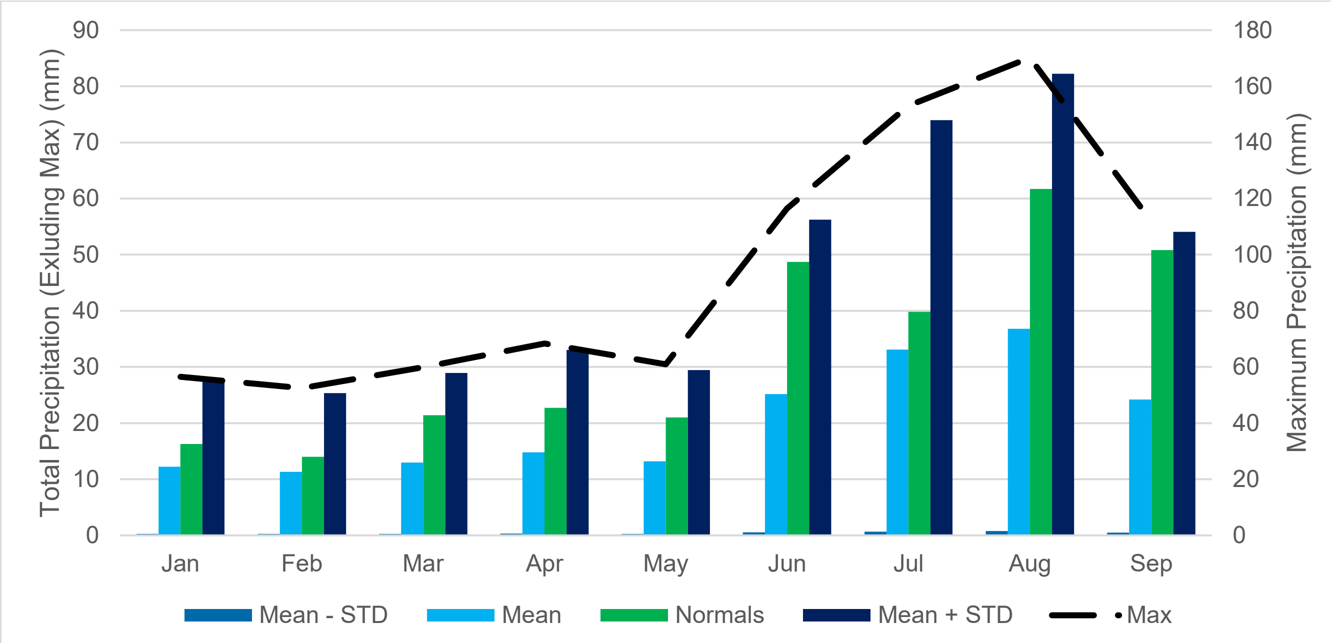


Figure 8-1: Monte Carlo Precipitation Results (2024)

Due to the very small magnitude of dry months, these values are not easily visualized graphically. Values for the mean minus one standard deviation and minimum monthly total precipitation are presented in tabular form in Table 8-1. Notice that the precipitation totals are equal due to the right-skew and subsequent close grouping of the mean and minimum values of the lognormal precipitation distributions.

Table 8-1: Precipitation Minimum and Mean Minus One Standard Deviation

Month	Minimum Total Precipitation (mm)	Mean Minus One Standard Deviation (mm)
January	0.25	0.25
February	0.23	0.23
March	0.27	0.27
April	0.31	0.31
May	0.27	0.27
June	0.52	0.52
July	0.68	0.68
August	0.76	0.76
September	0.50	0.50

8.2 Snow Water Equivalent

SWE selections remained within expected values based on the assigned distribution. The selections are presented in Figure 8-2. Minimum and mean minus one standard deviation are much easier to visualize due to the normal distribution of SWE.

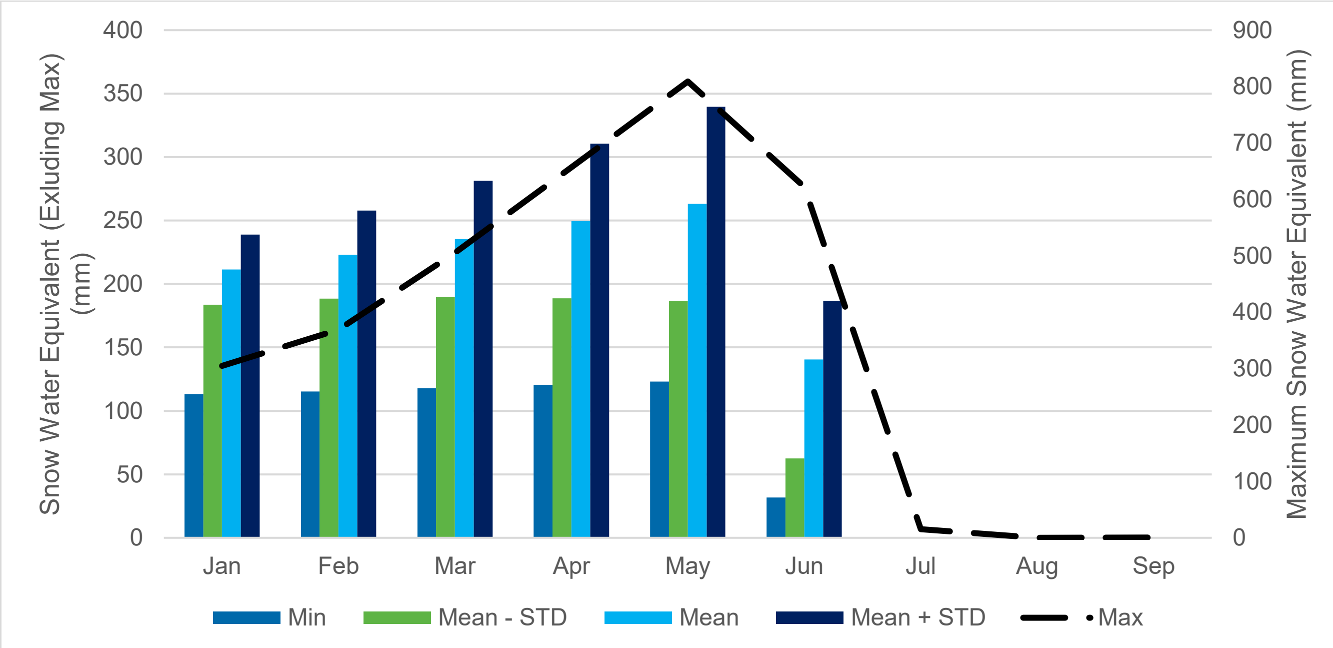


Figure 8-2: Monte Carlo SWE Results (2024)

8.3 Qikiqtalik Lake Water Elevation

As it is assumed that Qikiqtalik Lake water elevations will return to the elevation of the outlet at 203 m prior to the beginning of every simulation, results only capture water levels from the start of freshet onward (See Figure 8-3).

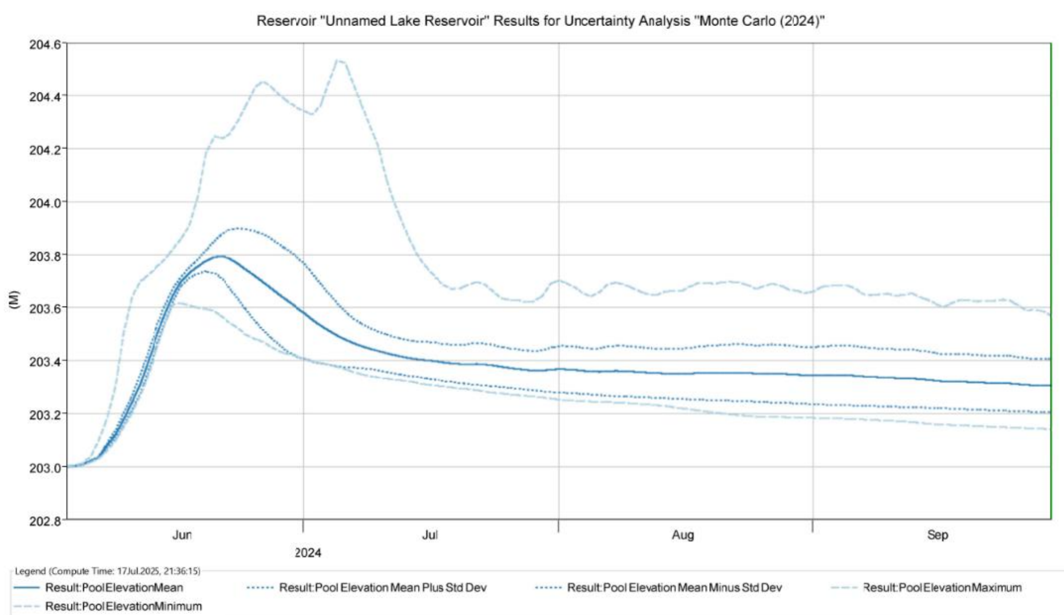


Figure 8-3: Monte Carlo Water Elevation Results (2024)

8.4 Outflow

Maximum and minimum freshet outflow results were approximately 2.56 m^3/s and 0.45 m^3/s, respectively. A summary of monthly outflow data from June to September is provided in Figure 8-4.

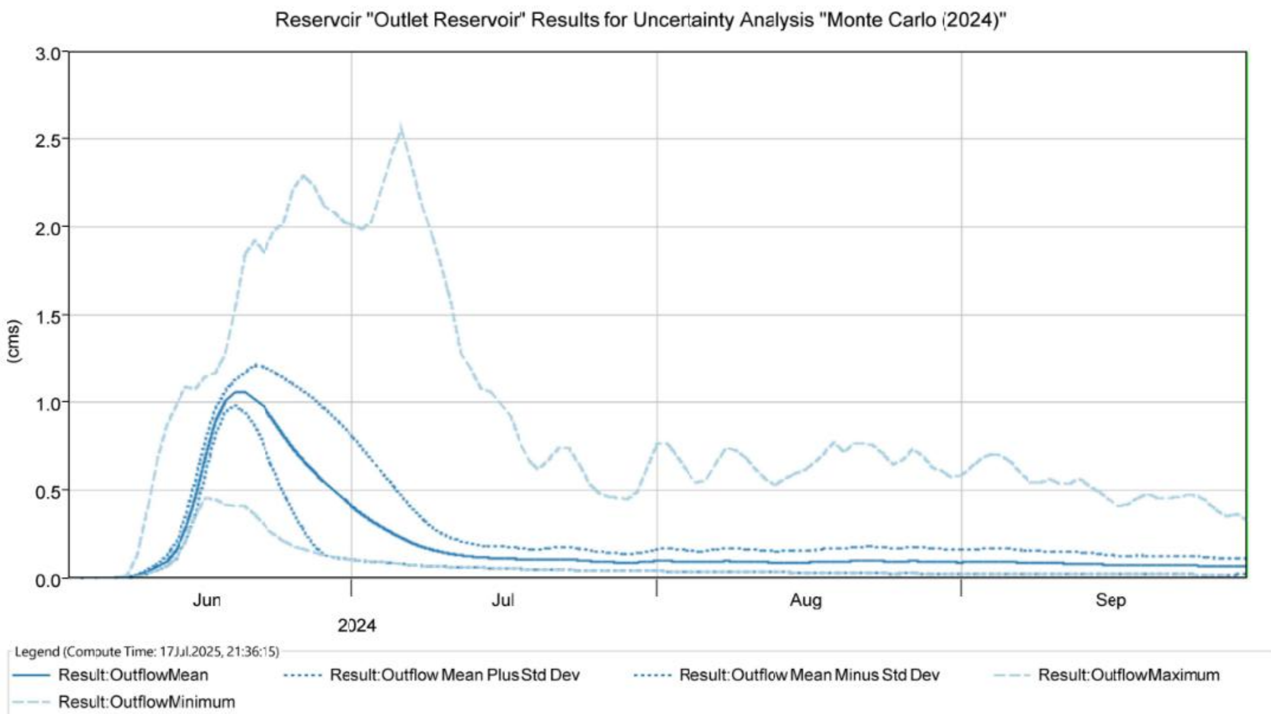


Figure 8-4: Monte Carlo Outflow Results

Total outflow volumes were tabulated and assessed using the results provided by HEC-HMS. Total outflow volumes followed a lognormal distribution as shown in Figure 8-5. Percentiles corresponding to expected total discharge volumes are provided in Table 8-2.

Table 8-2: Outflow Volume Percentiles

Percentile (%)	Discharge (m^3) (2024)
0	767,189
10	1,114,609
20	1,251,520
30	1,382,627
40	1,522,427
50[1]	1,681,676[1]
60	1,874,501
70	2,126,035
80	2,493,871
90	3,174,326

[1]Based on the updated and significant skew of the discharge distribution, Tetra Tech belives that the mode, rather than the median, could be another representative value to be used for planning purposes. The mode is presented in Table 8-3.

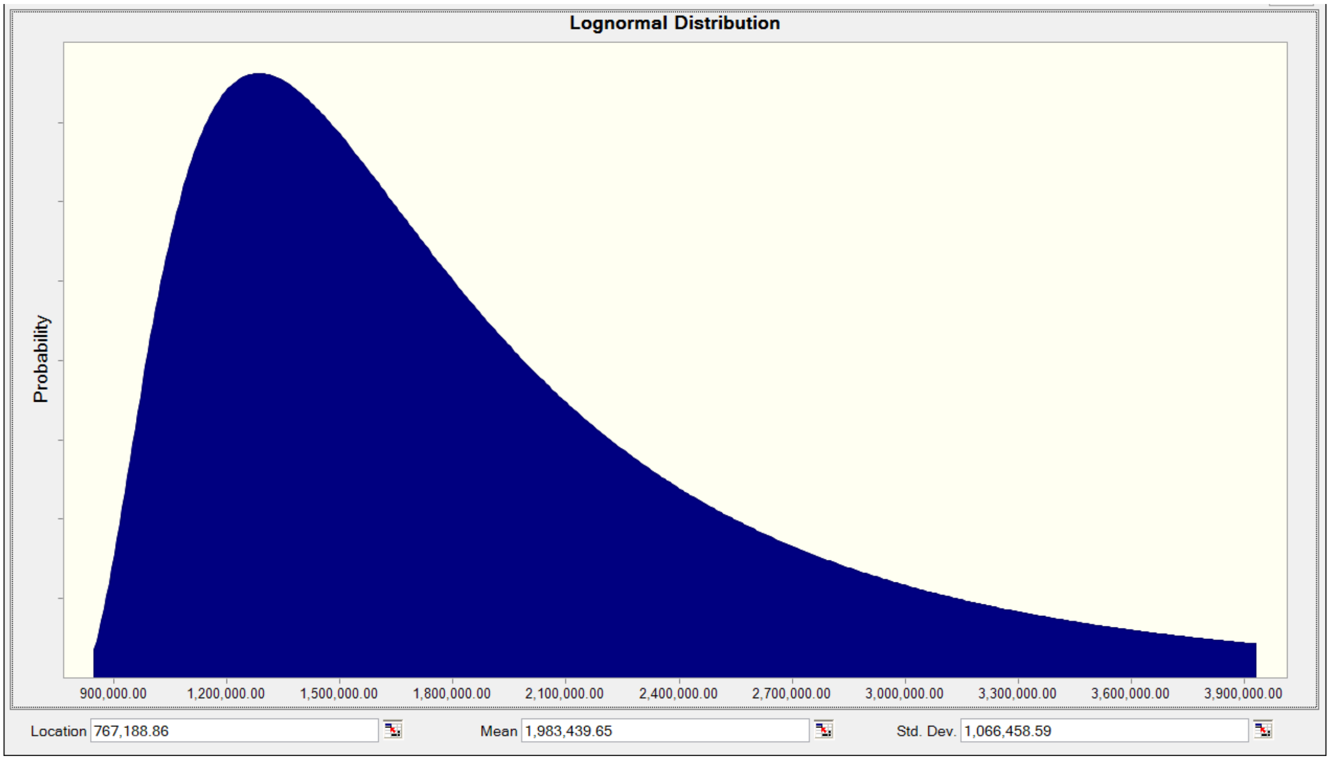


Figure 8-5: Outflow Volumes Distribution (0th – 95th Percentile)

Table 8-3 below provides the lognormal distribution statistics.

Table 8-3: Lognormal Distribution Statistics

Statistic	Lognormal Distribution
Mean (average of all values)	1,983,440
Median (50% are higher, 50% are lower)	1,681,676
Mode (most probable / common)	**1,284,184**
Standard Deviation	1,066,459
Minimum	767,189

9.0 DISCUSSION

This study and its results offer valuable insights into Qikiqtalik Lake's hydrological dynamics and provide crucial information for the City's future water management. The Monte Carlo simulations reveal a range of potential outflows, highlighting Qikiqtalik Lake's capacity to respond to varying hydrologic conditions.

The HEC-HMS model results reflect reasonable agreement with observed data. However, limitations were evident, particularly with respect to the sensitivity of results to the stage-discharge relationship capturing flows out of the lake. These limitations underscore the need for continued hydrometric monitoring of discharge from Qikiqtalik Lake should the City wish to sustainably withdraw water.

The findings with respect to median annual discharge volume from Qikiqtalik Lake presented in this report are larger than those presented in the Interim Report. This report updates the median discharge to 1,681,000 m^3 following the inclusion of the south catchment in the final model and improvements to precipitation data within HEC-HMS. However, given the significant skew of the discharge distribution, Tetra Tech believes that the mode (the most common or probable value) of **1,284,184 m^3** per year to be a good estimate to use for planning purposes. These updated results are more in line with Golder's predictions, which estimated a surplus discharge of approximately 1,600,000 m^3 from Qikiqtalik Lake. (Golder Associates Ltd., 2021). This finding also increases the Issued for Review submission targeting approximately 1,100,000 m^3 per year following the addition of some of the more extreme precipitation events (both wet and dry).

We remain confident that the 1,100,000 m^3 per year previously presented should be used in the design of the proposed conveyance and storage systems. That said, Tetra Tech recognizes that this value could be closer to 1,300,000 m^3.

Based on this assessment and data provided by Golder (2021), Tetra Tech believes that Qikiqtalik Lake may facilitate the provision of drinking water as a supplement to Geraldine Lake during times of deficit. Golder had predicted that the median deficits of Geraldine Lake during a low and high consumption year would be approximately 620,000 m^3 and 763,000 m^3 respectively. This is well within the current estimate of 1,284,184 m^3 determined by Tetra Tech. Provided that a high-water consumption year requires 115,000 m^3/month and a low water consumption year requires 100,000 m^3/month, Qikiqtalik Lake should be able to supplement the water deficit in most years; especially if water conservation measures are implemented during times of lower precipitation.

As previously discussed, the availability of water from Qikiqtalik Lake is just one part of a possible solution. Equally crucial to developing a secure source of water is access to suitable storage facilities and adaptable pumping systems capable of responding to varying hydrologic conditions. Enhancing storage capacity at Geraldine and/or Qikiqtalik Lake could help secure a larger volume of water and help mediate changes in freshet or precipitation patterns. Combining appropriately sized pump stations with increased storage capacity could be highly effective when paired with a proactive water management plan that can adapt to evolving climate conditions. It should also be noted that the estimates Tetra Tech has provided are based on the total volume which may be available for withdrawal, but it does not account for any riparian flows which may have to be maintained to support habitat baseflows.

10.0 CLOSURE

We trust this technical memo meets your present requirements. If you have any questions or comments, please contact the undersigned.

Respectfully submitted,
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PERMIT TO PRACTICE
TETRA TECH CANADA INC.

Signature ____________
Date 2025-07-25

PERMIT NUMBER: P 018
NT/NU Association of Professional Engineers and Geoscientists

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APPENDIX A

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LIMITATIONS ON USE OF THIS DOCUMENT

HYDROTECHNICAL

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The Client, and any Authorized Party, acknowledges that the Professional Document is based on limited data and that the conclusions, opinions, and recommendations contained in the Professional Document are the result of the application of professional judgment to such limited data.

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TETRA TECH is neither qualified to, nor is it making, any recommendations with respect to the purchase, sale, investment or development of the property, the decisions on which are the sole responsibility of the Client.

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Unless expressly agreed to in the Services Agreement, TETRA TECH was not retained to explore, address or consider, and has not explored, addressed or considered any environmental or regulatory issues associated with the project.

1.8 LEVEL OF RISK

It is incumbent upon the Client and any Authorized Party, to be knowledgeable of the level of risk that has been incorporated into the project design, in consideration of the level of the hydrotechnical information that was reasonably acquired to facilitate completion of the design.

APPENDIX B

AAE SUMMARY REPORT

Summary Report - Iqaluit Hydrometric Monitoring Field Visit 3 – October 2- 4, 2024

SUBMITTED TO

TETRA TECH

November 2024

PREPARED BY

AAE TECH SERVICES INC.

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1. INTRODUCTION

The city of Iqaluit has interest in determining output volumes and flow rates for the unnamed lake located just northeast of the city (Figure 1). AAE Tech Services Inc. (AAE) has been retained by Tetra Tech to measure flow rates and corresponding water levels to assist with developing a rating curve for the tributaries flowing into and out of the target lake (Figure 2). This is year two of the study and a continuation of our efforts to determine output volumes from data collected over three field visits in 2023 and three field visits in 2024, in addition to continuous passive monitoring of water levels at each site. This report provides the data gathered from Field Visit 3, the final field visit planned for this project, completed October 2 – 4, 2024, and serves as the final report for the project. Final data sets, compiling all data collected over both 2023 and 2024 field seasons, have been submitted to Tetra Tech ahead of this report.

The objectives of the hydrologic baseline study are to:

- Determine flow rates at selected tributaries of the unnamed lake,
- Establish a hydrometric station at the inlet and outlet of the lake, and
- Provide hydrologic baseline data for hydrological modelling, engineering design, and water management.

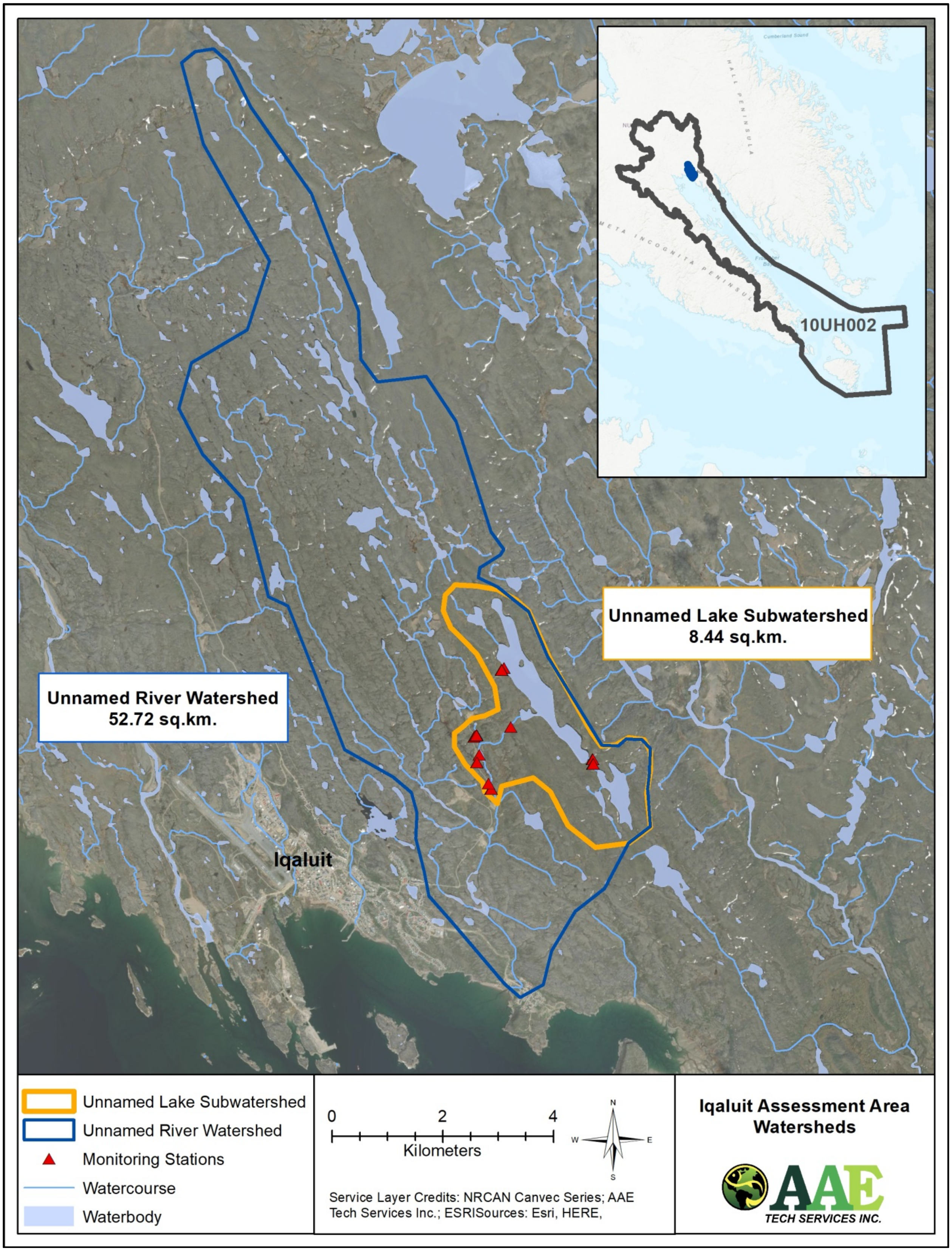

Figure 1. Unnamed Lake watershed northeast of Iqaluit, NU.

Figure 2. Unnamed Lake hydrometric monitoring sites.

2. METHODS

In 2023, five hydrometric stations were established to monitor the capacity and discharge of an unnamed lake just northeast of the City of Iqaluit. Sites included upstream (SondeC), in lake (OTTLK1) and downstream (SA1, SA2, OTTSB) (Figure 1). Additionally, two overwintering level loggers were placed above the OTTSB site (Overwinter LL1 and Overwinter LL2). Over the course of the project, several adjustments were made; the SondeC site, and the inflow tributary as a whole, was determined to be not suitable for passive logger deployment and this station was decommissioned at the end of the 2023 season. Two leveloggers were deployed at suitable overwintering sites in October 2023 (in close proximity to each other as a contingency) to capture fall and early winter water levels up to the point of freeze up, as well as capture spring water levels as close to spring thaw as possible. One of the two stations (Overwinter LL2) was found to have been tampered with, and no data was able to be retrieved for this site.

Velocity profiles were measured during each field visit at each monitoring station using two methods: A Swoffer manual velocity meter was used to measure the depth and water velocity at 0.20 m intervals (or less) across each of the creeks perpendicular to flow to calculate total discharge. The second method used a QiQuac salt dilution technique that calculated the amount of time a pulse of salt would pass by two points within the creek using a series of sensors.

All level logger stations were retrieved and decommissioned without incident, with final water level recordings registered between October 2 and 4, 2024. Data for 2024 is presented in this report, with the complete dataset for the entire project submitted as a separate spreadsheet.

A Trimble GNSS survey system was used to establish and verify water elevations for each monitoring station throughout the project, allowing for water level data to be tied to geodetic elevation in meters above sea level (NAD83 CSRS Zone 19N; CGVD2013a).

3. MONITORING STATION SUMMARY RESULTS

3.1. Station Stream A1

Location: NAD83 CSRS Zone 19N, Easting: 526382.825, Northing: 7071734.61

Figure 3. Hydrometric Monitoring Station SA1

Figure 4. Swoffer flow metering and water depth at site SA1, October 2, 2024.

Table 1. Water level and flow information for site SA1

Date	Water Elevation (m asl)	Channel width (m)	Average Depth (m)	Average Velocity (m/s)	Swoffer Discharge (m^3/s)	QiQuac Discharge (m^3/s)
17-Jun-23	137.034	2.20	0.196	0.241	0.1033	0.1760
2-Aug-23	136.756	2.17	0.068	0.105	0.0175	0.0251
17-Jun-24	137.060	1.85	0.290	0.510	0.2521	N/A
14-Aug-24	136.899	1.90	0.098	0.082	0.0146	0.0194
02-Oct-24	136.929	1.90	0.094	0.153	0.0326	0.0654

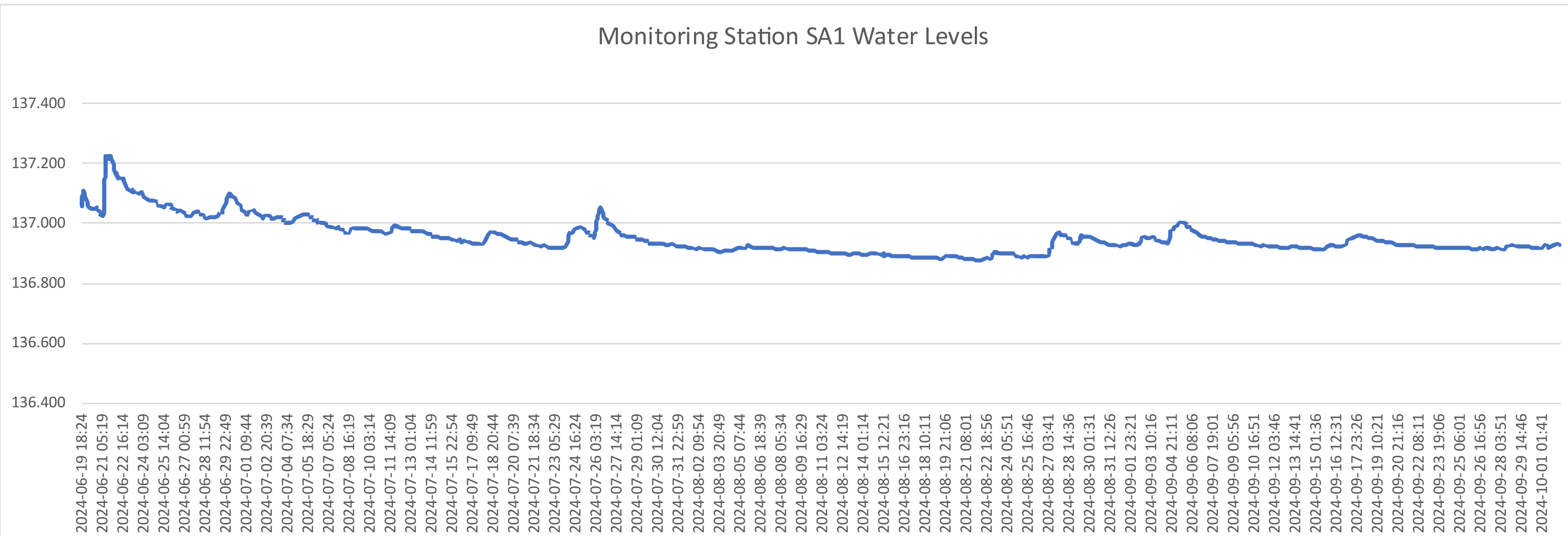

Figure 5. Water level logger measures taken at site SA1 at 5-minute intervals.

3.2. Station Stream A2

Location: NAD83 CSRS Zone 19N, Easting: 0526388.492, Northing: 7071246.282

Figure 6. Hydrometric Monitoring Station SA2.

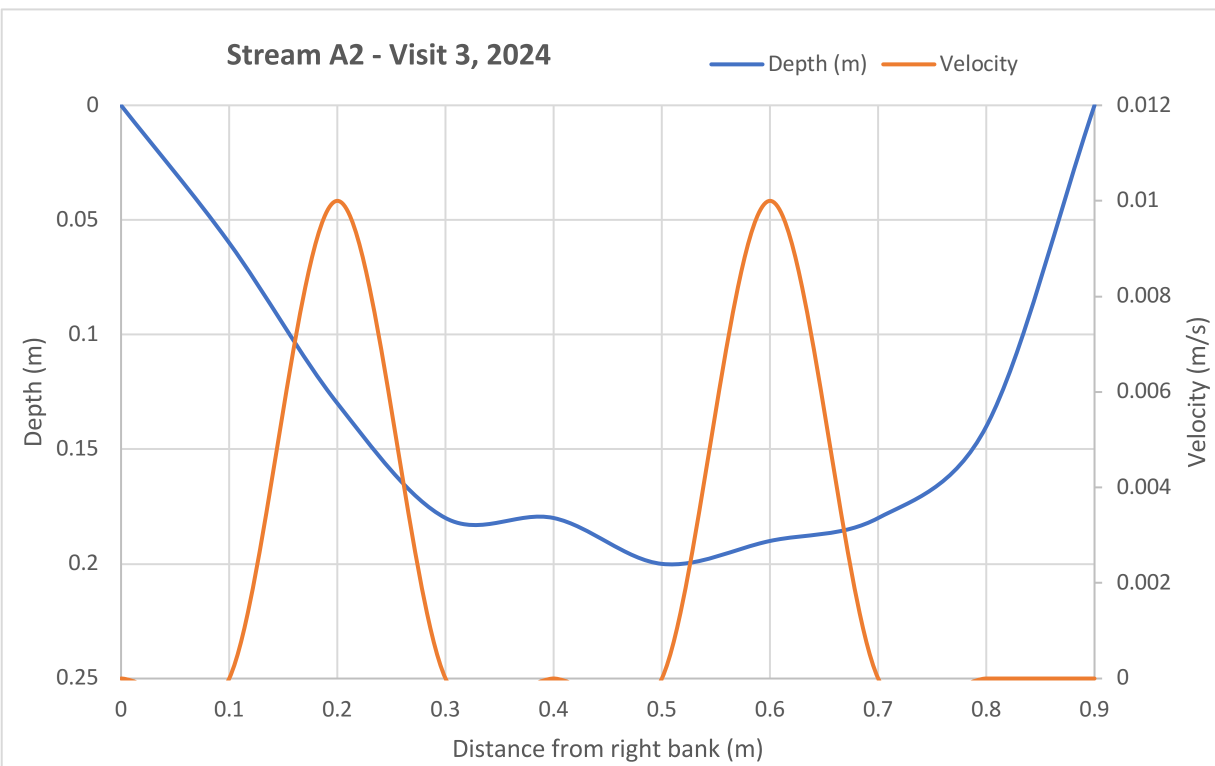

Figure 7. Swoffer flow metering and water depth at site SA2, October 2, 2024.

Table 2. Water level and flow information for site SA2

Date	Water Elevation (m asl)	Channel width (m)	Average Depth (m)	Average Velocity (m/s)	Swoffer Discharge (m^3/s)	QiQuac Discharge (m^3/s)
15-Jun-23	130.300	1.10	0.068	0.115	0.0079	0.0074
3-Aug-23	130.187	1.00	0.026	0.006	0.0003	0.0015
19-Jun-24	130.278	1.17	0.300	0.070	0.0292	N/A
14-Aug-24	130.271	0.90	0.141	0.003	0.0003	0.002
02-Oct-24	130.289	0.90	0.158	0.003	0.0003	0.0014

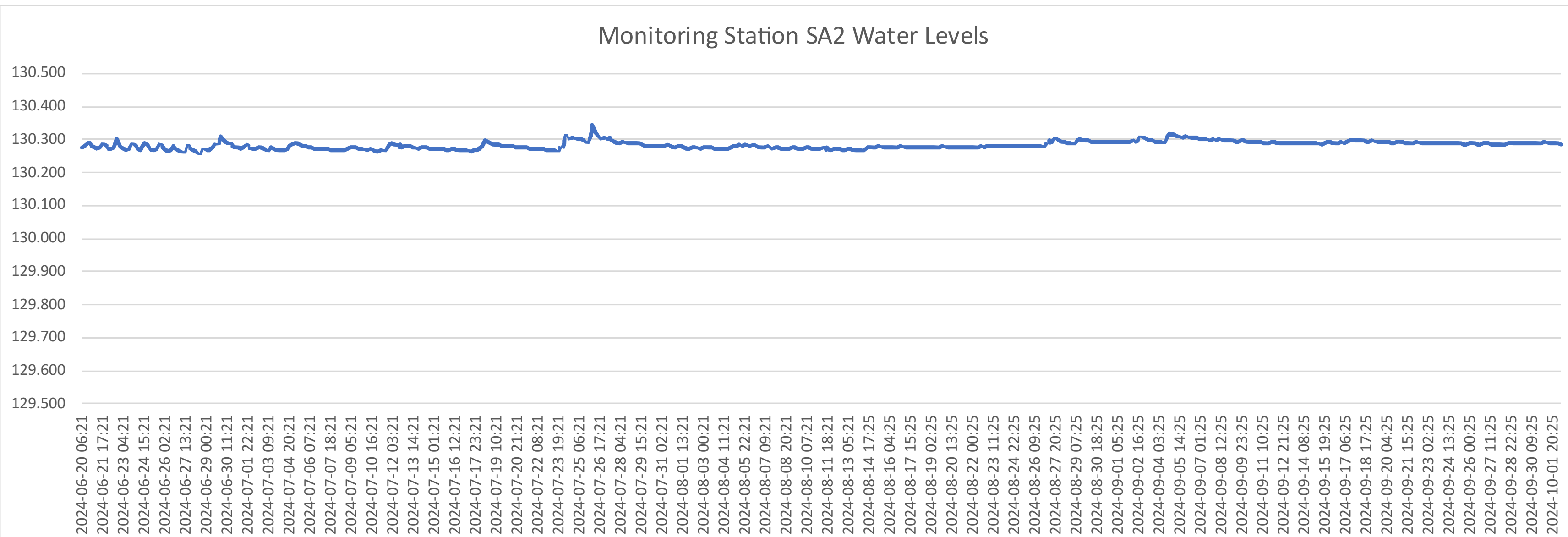

Figure 8. Water level logger measures taken at site SA2 at 1-hour intervals.

3.3. Station OTT Stream B

Location: NAD83 CSRS Zone 19N, Easting: 526643.808, Northing: 7070759.43

Figure 9. Hydrometric Monitoring Station OTT Stream B.

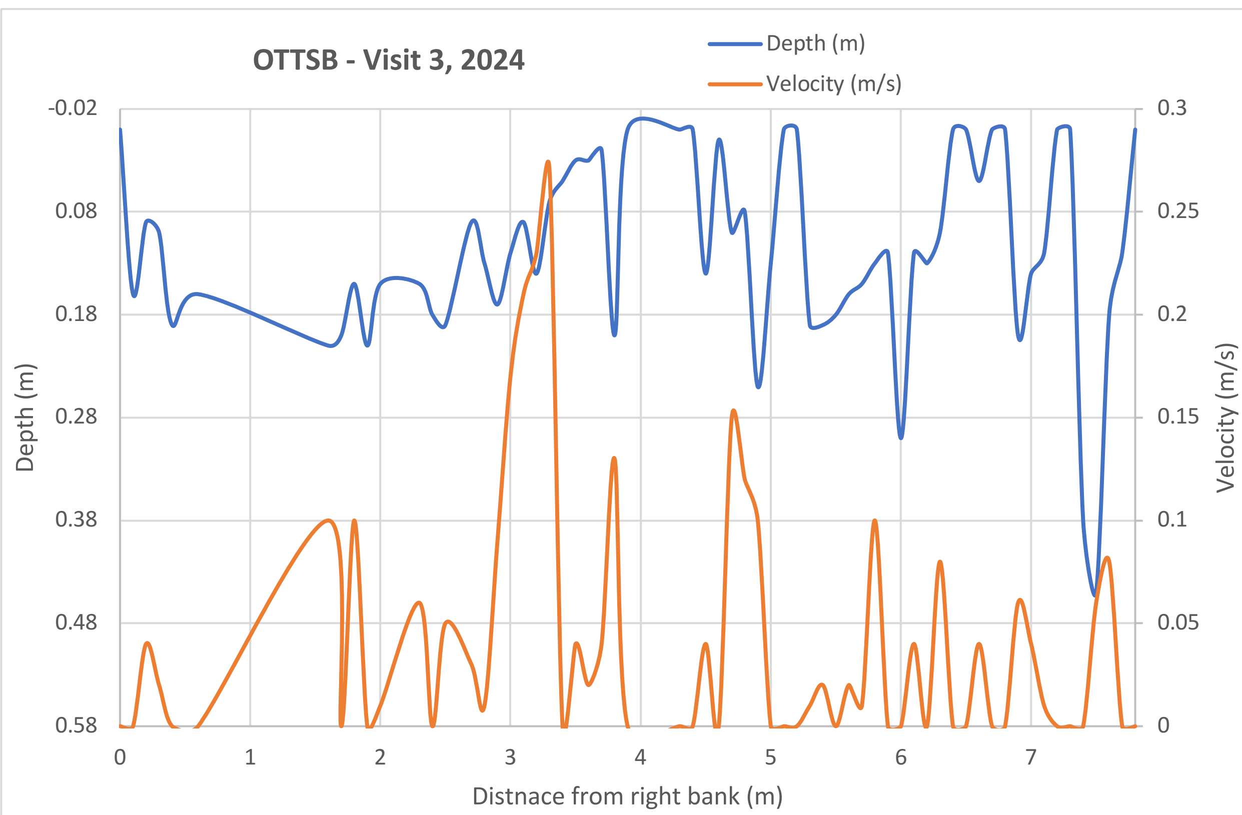

Figure 10. Swoffer flow metering and water depth at site OTTSB, October 2, 2024.

Table 3. Water level and flow information for site OTTSB

Date	Water level (m asl)	Channel width (m)	Average Depth (m)	Average Velocity (m/s)	Swoffer Discharge (m^3/s)	QiQuac Discharge (m^3/s)
15-Jun-23	125.481	5.20	0.275	0.151	0.2162	0.3030
3-Aug-23	125.141	6.24	0.222	0.054	0.0506	0.0280*
19-Jun-24	125.403	5.11	0.270	0.200	0.2595	N/A
14-Aug-24	125.087	7.70	0.106	0.039	0.0318	N/A
02-Oct-24	125.121	7.70	0.121	0.043	0.0353	0.0630

**Flow conditions at the OTTSB site were not suitable for QiQuac salt dilution tracing assessment. A suitable site was identified approximately 200 m downstream at a more channelized reach of the tributary, and QiQuac discharge was calculated at this location.*

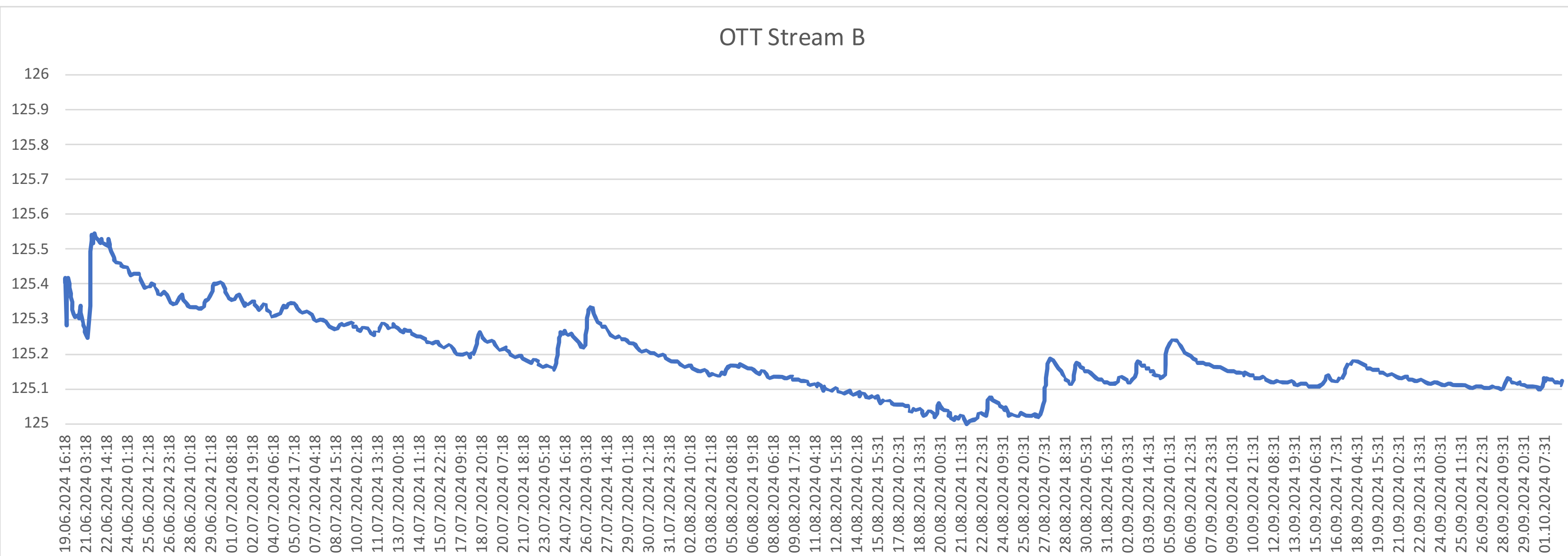

Figure 11. Water level logger measures taken at site OTTSB at 1-hour intervals.

3.4. Station Sonde C

UTM Datum: NAD83 CSRS Zone 19N, Easting: 0528482.677, Northing: 7071215.99

Figure 12. Photograph of SondeC site and map depicting location of the SondeC station.

Table 4. Water level and flow information at site SondeC

Date	Water level (m asl)	Channel width (m)	Average Depth (m)	Average Velocity (m/s)	Swoffer Discharge (m^3/s)
16-Jun-23	215.870	3.00	0.525	0.142	0.2607
*02-Aug-23	215.651	5.66	0.083	0.022	0.0068

**Channel depth and flow profile was completed at the relocated monitoring station site (approximately 10 m downstream), as conditions at the initial site were no longer suitable for assessment.*

3.5. Station OTT-Lake 1

UTM Datum: NAD83 CSRS Zone 15N, Easting: 526877.686, Northing: 7072948.459

Figure 13. Hydrometric Monitoring Station OTT-Lk1.

During the June visit earlier this year, an OTT Level logger was left with the City Engineering Department to be placed in the unnamed lake when the ice receded from the shore. The level logger (OTTLK1) was confirmed to have been placed in the lake on June 28th.

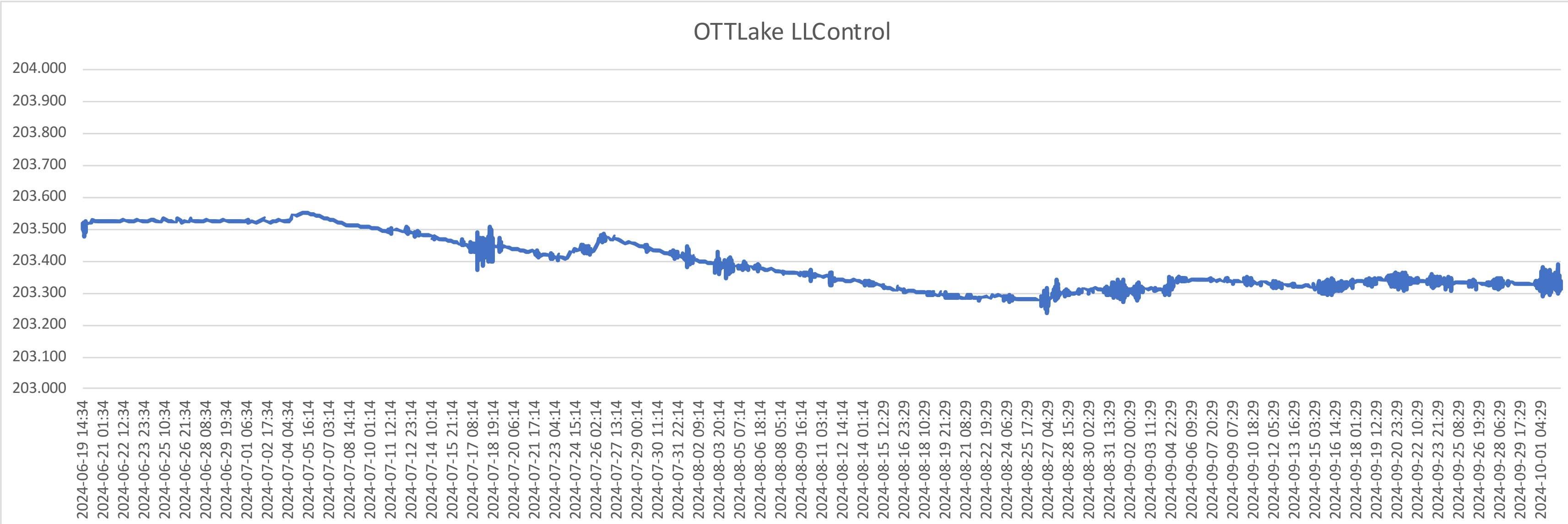

Figure 14. Water level logger measures taken from the Level Logger control sensor at site OTT-Lk1 at 5-minute intervals.

3.6 Overwinter LL1

An overwintering logger was deployed upstream of the OTT SB station on September 26, 2023 to monitor flows during the winter season. The logger registered water levels until mid-January of 2024, at which point water levels appear to drop below logger depth, or the logger became embedded in ice. Logging re-established upon ice breakup in June 2024 (Figure 16).

UTM Datum: NAD83 CSRS Zone 19N, Easting: 526594.545, Northing: 7070838.428

Figure 15. Site Overwinter LL1.

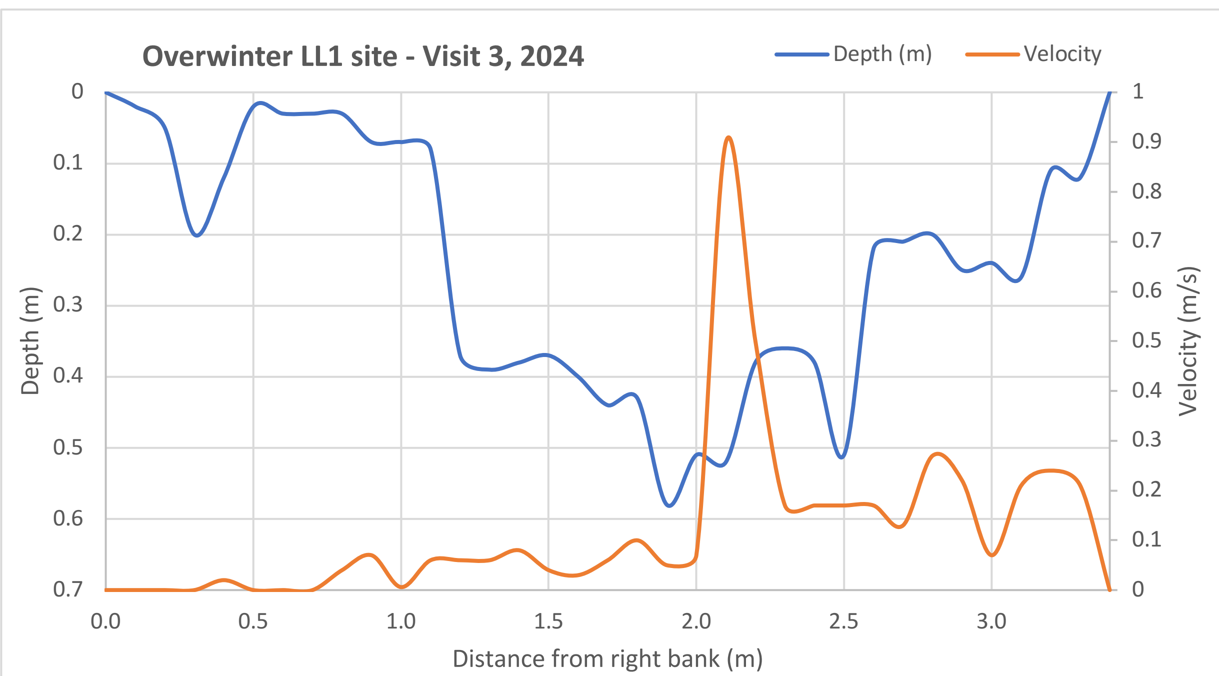

Figure 16. Swoffer flow metering and water depth at site Overwintering LL, October 2, 2024.

Table 5. Water level and flow information at site Overwintering LL.

Date	Water level (m asl)	Channel width (m)	Average Depth (m)	Average Velocity (m/s)	Swoffer Discharge (m^3/s)	QiQuac Discharge (m^3/s)
15-Aug-24	125.579	3.30	0.23	0.11	0.08433	0.3842*
02-Oct-24	125.922	3.30	0.25	0.126	0.14278	0.2885

**Based on the average of two readings, first taken on August 14, 2024, and the second on August 15, 2024.*

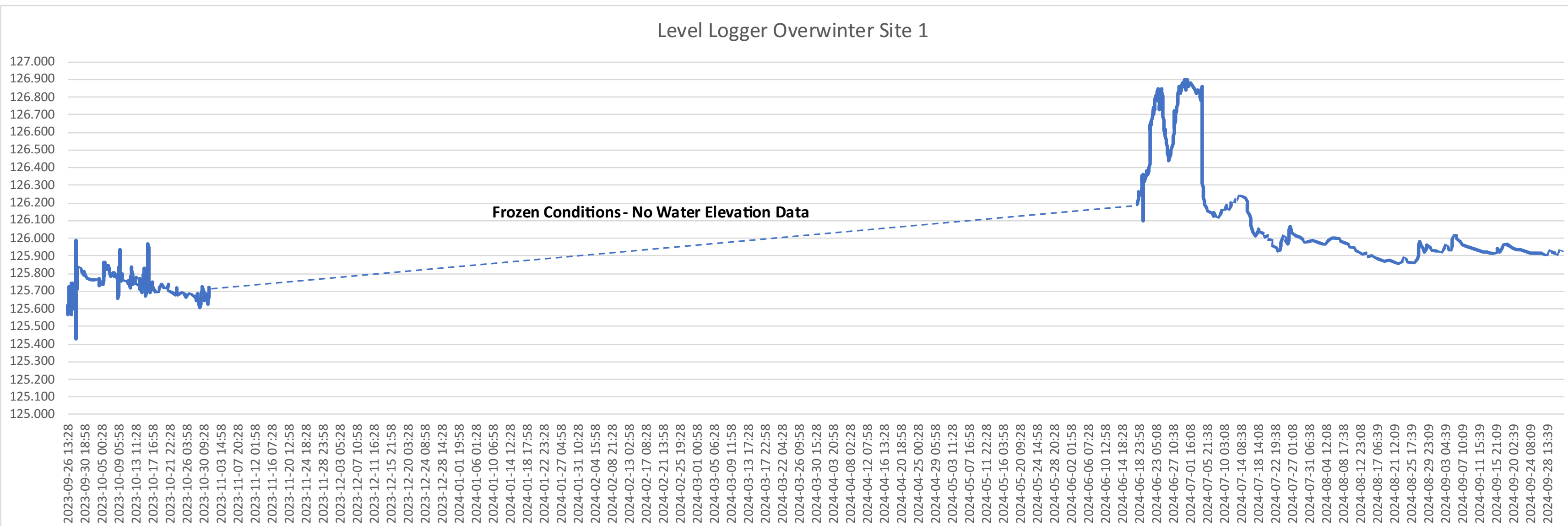

Figure 17. Water level logger measures taken at site Overwinter LL1 at 5-minute intervals.

3.6 Overwinter LL 2


Figure 18. Site Overwinter LL2. (Left) AAE Tech employee using the QiQuac to take flow measurement; (Right) Looking downstream just past where the measurement was taken.

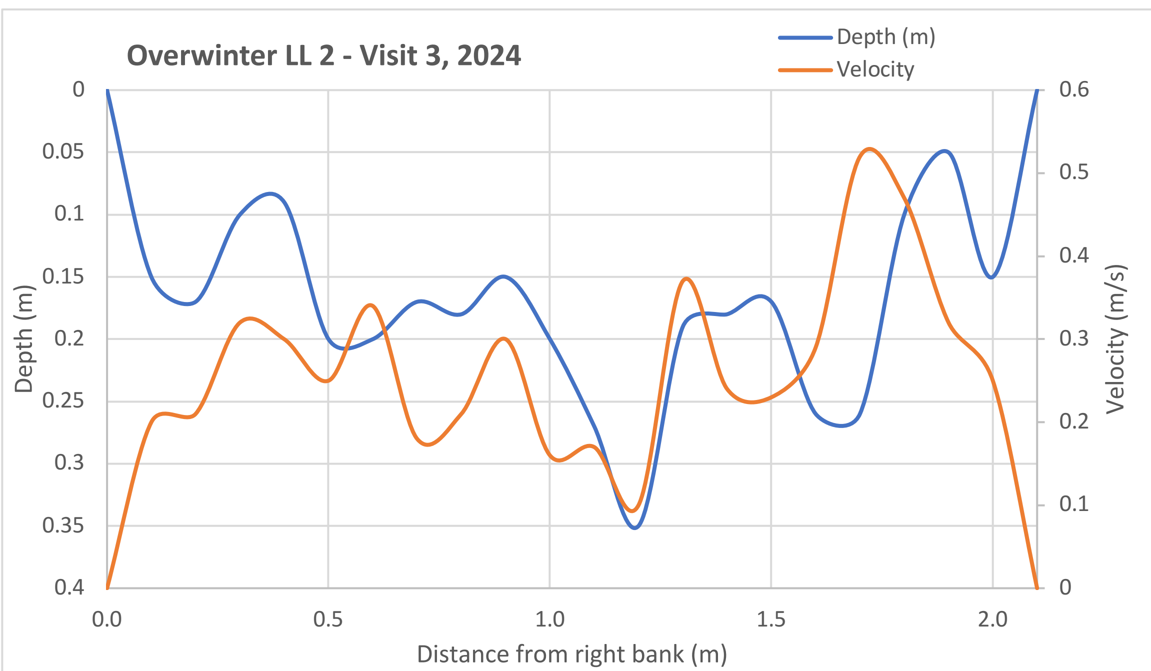

Figure 19. Swoffer flow metering and water depth at a Overwinter LL2, October 2, 2024.

Table 6. Water level and flow information at site Overwintering LL 2.

Date	Water level (m asl)	Channel width (m)	Average Depth (m)	Average Velocity (m/s)	Swoffer Discharge (m^3/s)	QiQuac Discharge (m^3/s)
15-Aug-24	126.436	2.00	0.19	0.27	0.0949	0.0538*
02-Oct-24	126.465	2.00	0.180	0.272	0.0932	0.1375

**Based on three readings, two taken on August 14, 2024, and one taken on August 15, 2024.*

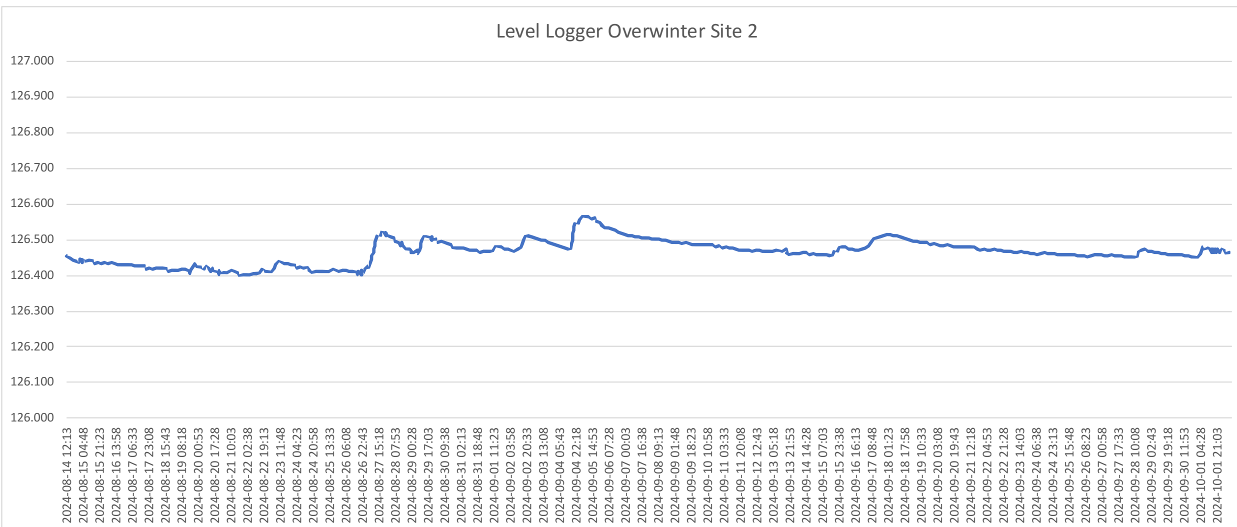

Figure 20. Water level logger measurements taken at site Overwinter Level Logger 2 at 5 minute intervals.