ATTACHMENT 16

LTWP Preliminary Design Report – Appendix G – Hydrology Technical Memo

TM-Hydrology Analysis

Project:
Long Term Water Program –
Raw Water Supply and
Storage, Nunavut, the City of Iqaluit

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Technical Memorandum: Hydrology Review

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Long Term Water Program - Hydrology Analysis

Introduction

Iqaluit, situated at the southern tip of Baffin Island in Frobisher Bay (63°45'N latitude and 68°31'W longitude), serves as the capital of the Nunavut Territory. Iqaluit has undergone rapid development and expansion. It serves as the administrative hub for the Nunavut Territory and hosts numerous federal and territorial government departments. Additionally, Iqaluit is evolving into a regional center for the territory, attracting various northern businesses and Inuit organizations that choose it as their operational headquarters. This technical memorandum outlines the standards and calculations regarding hydrology for estimation of the height of the planned new reservoir.

Catchment Area/Topography

The new reservoir is in the northeast of the city of Iqaluit, to be located to the east of Lake Geraldine. The reservoir is composed mostly of bedrock which has mostly impervious. The topography in the catchment is moderate to rugged with elevations ranging from 119 meters above sea level (masl) to 144 masl. The available topography was used for the purposes of characterizing catchment topography and delineating the catchment draining to reservoir. The catchment is a confined area with no surface inflow to the reservoir. The source of water to the new reservoir is precipitation including snow melting. The catchment area is 297.7 ha and the catchment boundary is shown in **Figure 1.**

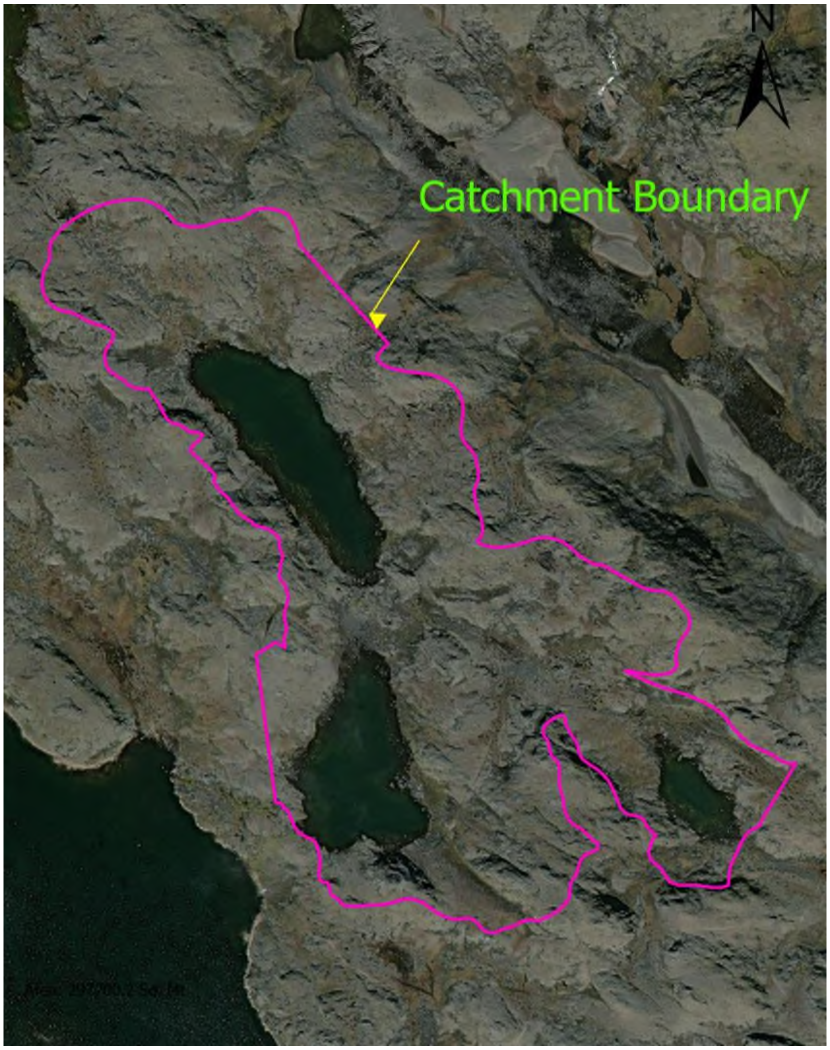

Figure 1. New Reservoir' Catchment Boundary

Meteorology

The weather stations around the project area were reviewed to find out the available historical data for hydrology analysis. **Figure 2** shows the location of the stations respect to the study area. Available data from meteorological stations was collected and summarized in order to select the most appropriate data and is presented in Table 1 below. Based on the review, it was concluded that the Iqaluit station is closest to the new reservoir location and in addition has the longest period (1946-1996) of continuous daily (24-hour) rainfall, snowfall, and total precipitation time series. Thus, this station was considered for analysis. The climate at the Site is northern with the average temperature -8.97 Cº and Average precipitation as 1124 mm.

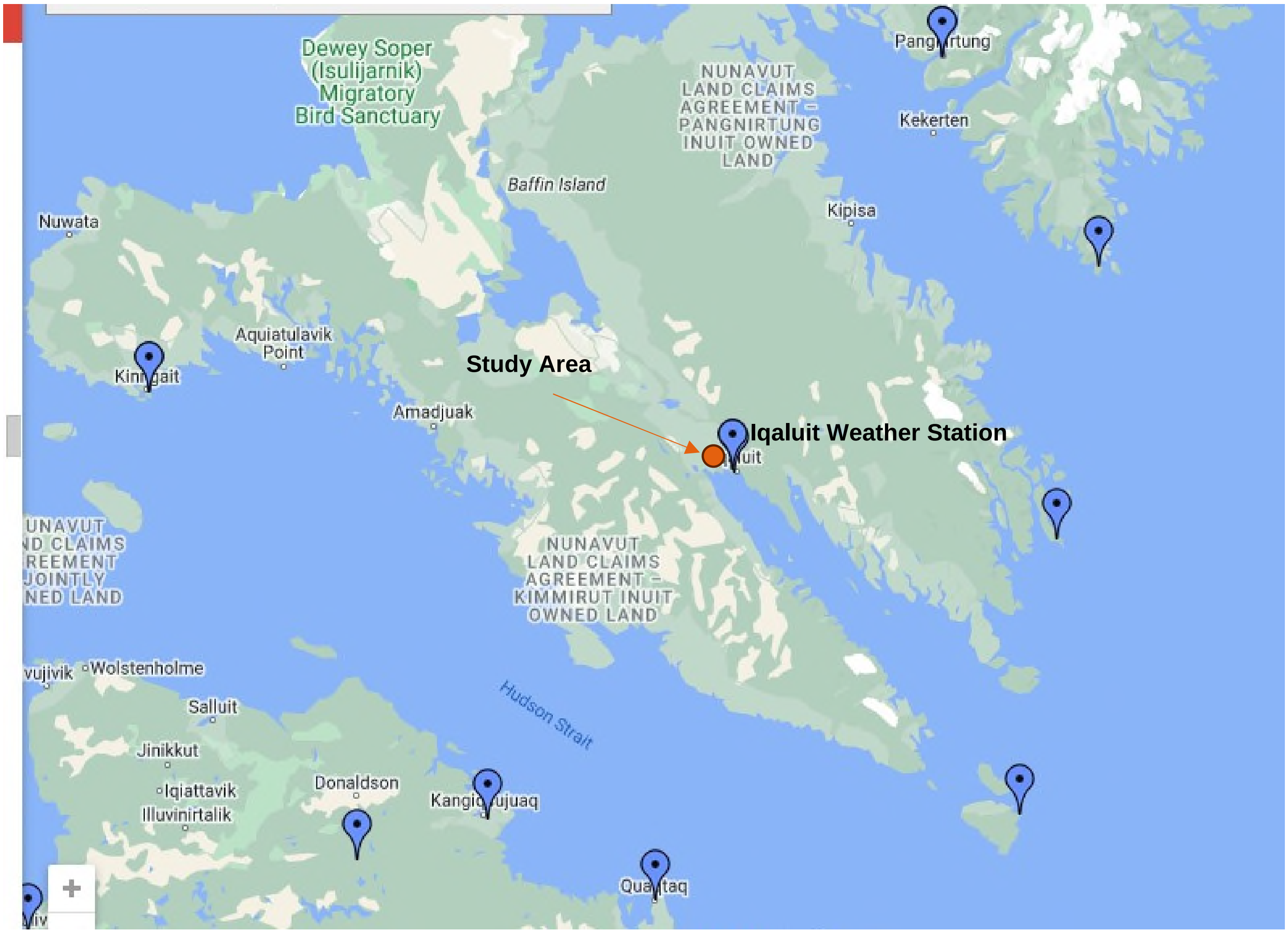

Figure 2. Weather Stations Location

Table 1. Weather Stations

Station Name	Max Temp	Min Temp	Average Temp	Total Precip.	Snow on Ground	Wind Speed	Wind Direction
Iqaluit A (#1)	Jan 1946 - July 2008	Jan 1946 - July 2008	Jan 1946 - July 2008	Jan 1946 - Sept 2007	Jan 1955 - Sept 2007	Jan 1946 - July 2008	Jan 1946 - July 2008
Iqaluit A (#2)	Nov 2018 - Oct 2023	Nov 2018 - Oct 2023	Nov 2018 - Oct 2023	None	None	Dec 2020 - Oct 2023	Dec 2020 - Oct 2023
Iqaluit AWOS	July 2008 - June 2015	July 2008 - June 2015	July 2008 - June 2015	None	None	July 2008 - June 2015	July 2008 - June 2015
Iqaluit Climate	Dec 2004 - Oct 2023	Dec 2004 - Oct 2023	Dec 2004 - Oct 2023	March 2005 - Oct 2023	May 2004 - June 2023	May 2004 - Oct 2023	Dec 2004 - Oct 2023
Iqaluit UA	April 1997 - April 2007	April 1997 - April 2007	April 1997 - April 2007	April 1997 - Feb 2016	Sept 1997 - Feb 2016	None	None
Brevoort Island	Nov 1959 - May 2023	Nov 1959 - May 2023	Nov 1959 - May 2023	Nov 1959 - Sept 2007	May 1960 - Sept 2006	Oct 2007 - Sept 2023	Oct 2007 - Sept 2023
Fort Resolution	Aug 1911 - Jan 1936	Aug 1911 - Jan 1936	Aug 1911 - Jan 1936	Aug 1911 - Jan 1936	None	None	None
Fort Resolution A (#1)	Sept 1930 - Nov 2014	Sept 1930 - Nov 2014	Sept 1930 - Nov 2014	Sept 1930 - Nov 2014	Nov 1980 - Nov 2014	None	None
Fort Resolution A (#2)	Oct 2018 - Oct 2023	Oct 2018 - Oct 2023	Oct 2018 - Oct 2023	None	None	None	None
Resolution Island (#1)	Oct 1929 - Oct 1961	Oct 1929 - Oct 1961	Oct 1929 - Oct 1961	Oct 1929 - Oct 1961	Nov 1954 - Oct 1961	None	None
Resolution Island (#2)	March 1962 - July 2018, Feb 2021 - Feb 2022	March 1962 - July 2018, Feb 2021 - Feb 2022	March 1962 - July 2018, Feb 2021 - Feb 2022	March 1962 - Aug 1975	March 1962 - Aug 1975	July 1996 - May 2014, Feb 2021 - Nov 2022	July 1996 - May 2014, Feb 2021 - Nov 2022

Inflow Design Flood (IDF)

According to the Canadian design standard guideline (DSG)[1], dams shall be designed or evaluated for a maximum flood termed the Inflow Design Flood (IDF). The IDF is selected on the basis of the potential consequences of failure and the probable maximum flood (PMF). The PMF is defined as the most severe flood that may reasonably be expected to occur at a particular location.

The inflow design flood (IDF) selected for the New Reservoir freeboard calculations is based on generalized hazards and responses for embankment dams defined by the Canadian Dam Association (CDA) shown in Table 2 and specific hazards shown in Table 3.

The 100- and 1000-year recurrence interval flood volumes were estimated using Annual Exceedance Probability (AEP) estimates derived from total precipitation (rainfall plus snowfall water equivalent) time series for the Environment Canada Iqaluit Station. Computed Log-Pearson III AEPs and Weibull plotting positions for total precipitation at the Iqaluit station are shown in **Figure 3**.

Table 1: Inflow Design Flood (IDF) and consequence classes (from CDA Technical Bulletin 6)

Consequence Class	IDF
Low	1/100-year
Significant	Between 1/100 and 1/1000-year (Note 1)
High	1/3 between 1/1000-year and PMF (Note 2)
Very High	2/3 between 1/1000-year and PMF Note 2)
Extreme	PMF
Note 1. Selected on basis of incremental flood analysis, exposure and consequence of failure. **Note 2.** Extrapolation of flood statistics beyond 1/1000-year flood (10^{-3} AEP) is generally discouraged. The PMF has no associated AEP. The flood defined as "1/3 between 1/1000-year and PMF" or "2/3 between 1/1000 year and PMF" has no defined AEP.	

[1] Canadian Dam Association (2007). Technical Bulletin 6, Hydrotechnical Considerations for Dam Safety.

Table 3: Iqaluit Dam hazard classification and IDF assessment

Consequence Class	Population at Risk	Loss of Life	Envrionmental and cultural Values	Infrastructure and Economics	Design Flood[1]
Extreme	Permanent where residence would be in the inundation zone should there be a catastrophic failure of the dam	While not expected to be of concern there is the potential as a function of when the breach failure were to occur	Under a worst case scenario the flood wave could remove a significant amount of overburden thus damaging the environment likely a permanent manner with the potential for some loss of habitat down stream	A breach would directly impact Lake Geraldine and potentially comprise the retention dam associated with this reservoir. Furthermore the inundation wave could also impact the existing water treatment plant operations.	IDF = PMF
Very High	Permanent where residence would be in the inundation zone should there be a catastrophic failure of the dam	As compared to Dam 1 it is less likely the inundation wave would be such that the flood would damage homes but depending on the cause of the breach ie flood then issues are potnetially compounded by what happens with the Lake Geraldine dam.	Less likely a breach of this dam would cause significant loss or deterioriation of critical fish or wildlife habitat. There could be compensation in kind but likely impractical	A breach would directly impact Lake Geraldine and potentially comprise the retention dam associated with this reservoir. However unlike Dam 1 the height of this dam is minor and as a result the amount of water from the reservoir that would be lost would be significantly less. Furthermore the inundation wave would lose energy in overland flow as compared to Dam 1 which has next to no overland flow on its downstream side.	IDF = interpolation between 1/1000 year flood and PMF used 2/3 between the two model points noted
Very High	Permanent where there is potential damage to the Apex River and flooding could damage key water supply infrastructure crossing the Apex River	No loss of life anticipated from a breach of this dam	A breach of this dam could cause a significant loss or dterioration of critical fish or wildlife habitat where restoration or compensation in kind may be possible but impractical as the inundation wave could permanently alter the course of the Apex River.	A breach of this dam could impact infrastructure crossing the Apex River including the Road to Nowhere and the proposed conveyance pipe crossing between the pump station and reservoir 2. It is not anticipated infrastructure well down stream of the dam would be impacted but it is possible.	IDF = interpolation between 1/1000 year flood and PMF used 2/3 between the two model points noted
Significant	Temporary only because there is no population immediately upstream of the dam and any flood would dissipate in the environment.	Unspecified however none expected unless the City develops the lands upgradient of the dam.	A breach of the dam is not likely to create any significant loss or deterioration of fish or wildlife habitat where any losses would be of marginal habitat.	Low economic losses and area contains limited infrastructure of services.	IDF = between 1/100 yr and 1/1000 yr flood selected on basis of incremental flood analysis, exposure and consequence of failure.

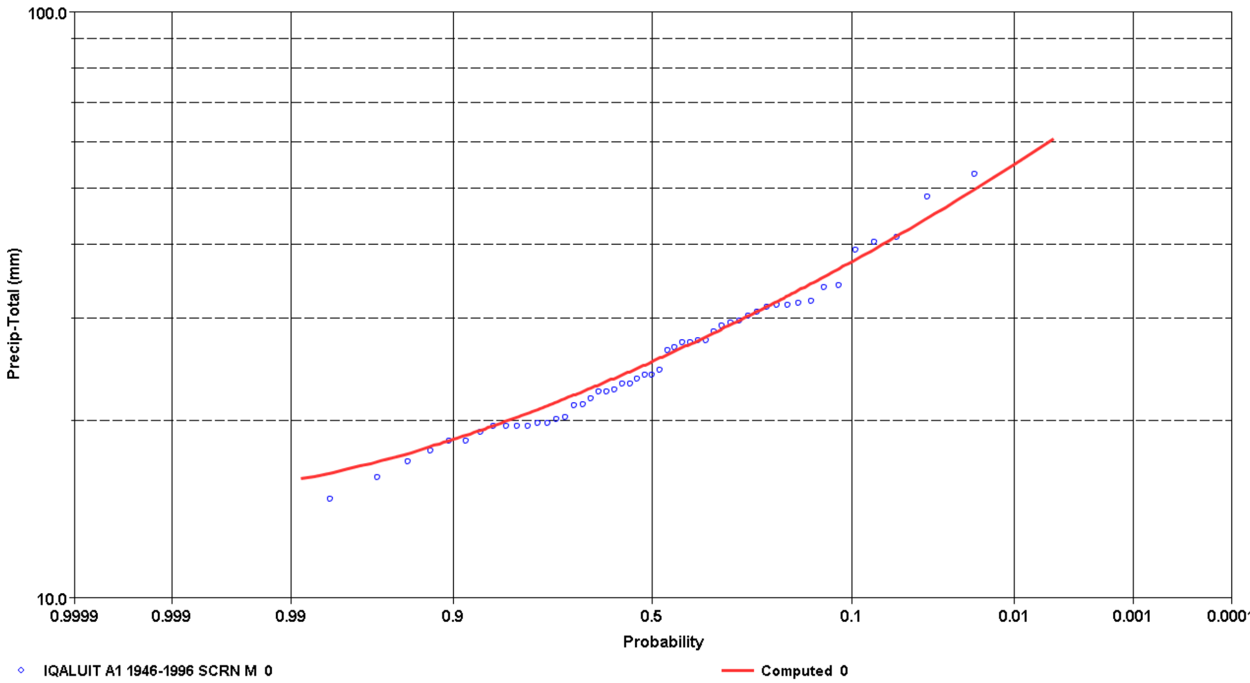

Figure 3: Iqaluit Station total 24-hour precipitation annual exceedance probability (AEP)

Estimated 100-year (0.01 AEP) total daily precipitation is 54 mm, and 1000-year total (0.001 AEP) precipitation was extrapolated to be 75 mm at the station. The 24-hour Probable Maximum Precipitation (PMP) at the site was estimated to be 240 mm, based on supplemental material developed by the American Meteorological Society for comparison of PMP predictions of two Canadian regional climate models[2].

Inflow to the new reservoir from 100-year, 1000-year, and PMP storms was calculated assuming 100 percent runoff from the reservoir and surrounding drainage area of 0.2977 km2. As shown in **Figure 4**, this assumption is reasonably conservative due to (1) the reservoir surface comprising roughly two-thirds of the total drainage area and (2) the steep rocky terrain surrounding the reservoir.

Runoff volumes to the new reservoir were converted to reservoir stage above normal operating level based on the elevation-storage relationship plotted in **Figure 5**. Inflow volumes, equivalent freeboard above normal pool, and corresponding pool elevations for the 100-, 1000-year, and the PMP events are listed in Table 3.

Because the potential hazard classifications of the new reservoir range from Significant to Extreme, the most conservative IDF – the Probable Maximum Flood (PMF) – was assumed as the basis for determination of the hydrologic freeboard requirement of 0.42 m.

[2] M.A. Ben Ayala, F. Zwiers, and X. Zhang (01 Oct. 2019) Evaluation and Comparison of CanRCM4 and CRCM5 to Estimate Probable Maximum Precipitation over North America. *Journal of Hydrometeorology*, Vol. 20, Issue 10. DOI: https://doi.org/10.1175/JHM-D-18-0233.1

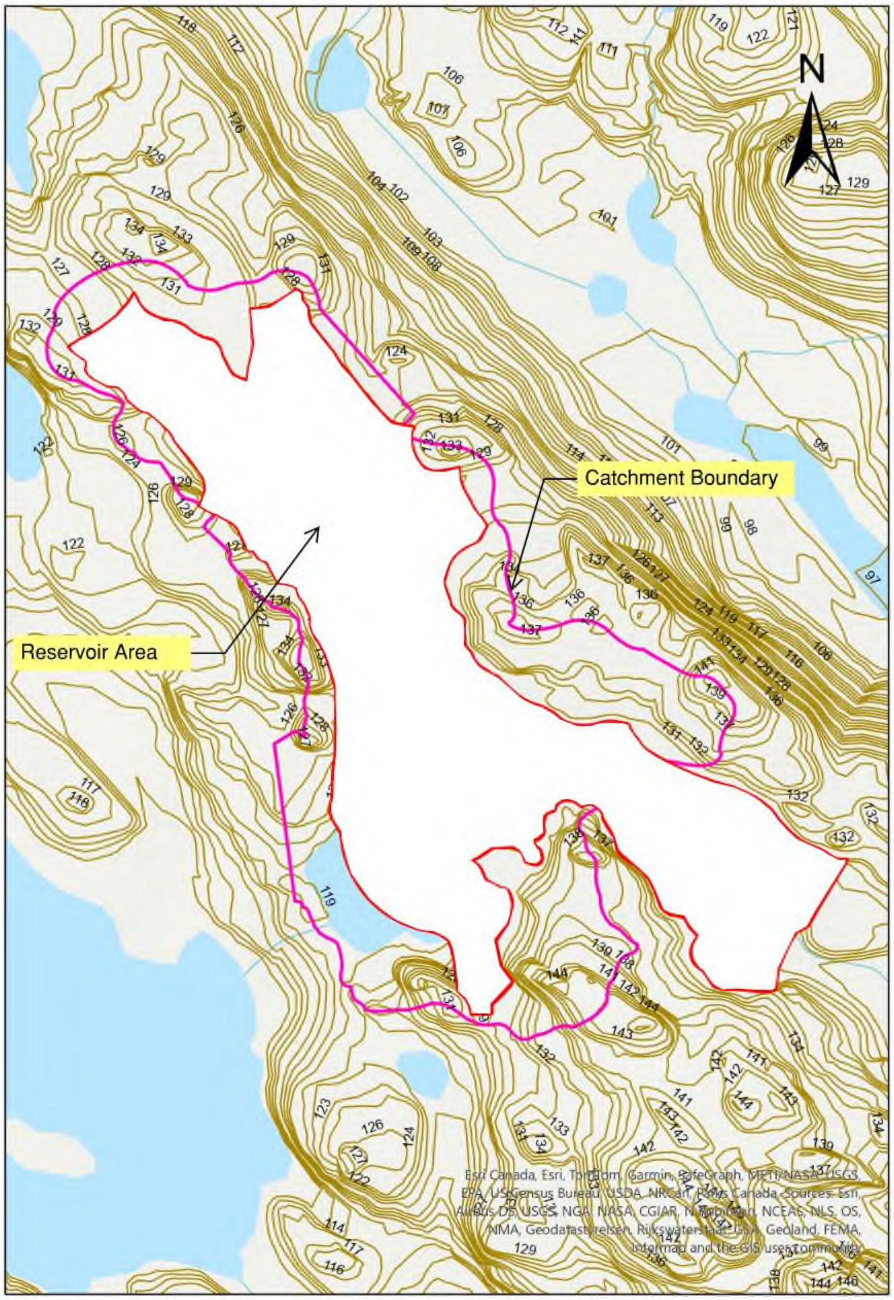

Figure 4: New Reservoir Area

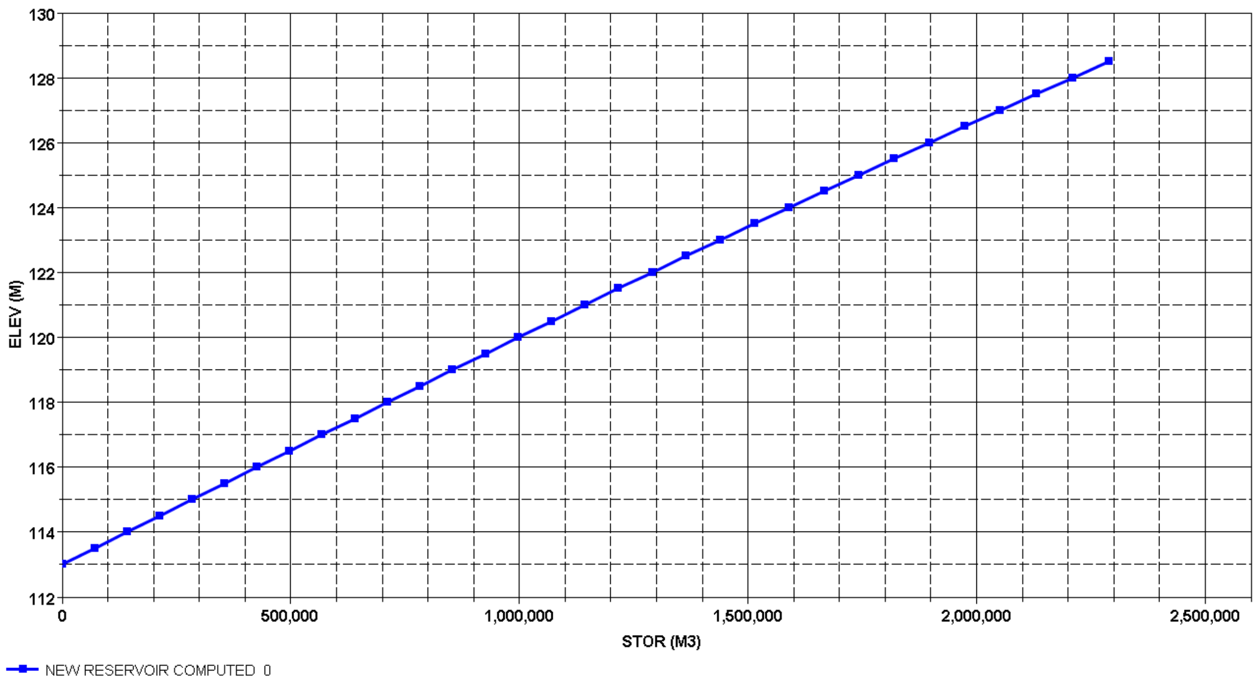

Figure 5. New Reservoir elevation-storage relationship

Table 3: Iqaluit Reservoir flood freeboard requirements

Parameter	Volume (m^3)	Equivalent freeboard (m)	Elevation (m)
Water supply storage	1,800,000		127.00
100-year 24-hour runoff (≈54 mm)	16,076	0.10	127.10
1000-year 24-hour runoff (≈75 mm)	22,328	0.13	127.13
PMP runoff (≈240 mm)	**71,448**	**0.42**	**127.42**

Wind setup and wave height

Freeboard is also required above the conservation pool prevent embankment overtopping by wind-generated waves to include wind setup, wave height, and wave runup. Wind setup is the rise in water level caused by wind shear along the effective fetch length, assumed in this case to represent the longest possible horizontal distance in the wind direction. Estimated fetch length for the New Reservoir is 0.99 km in the NNW – SSE direction as shown in **Figure 6**.

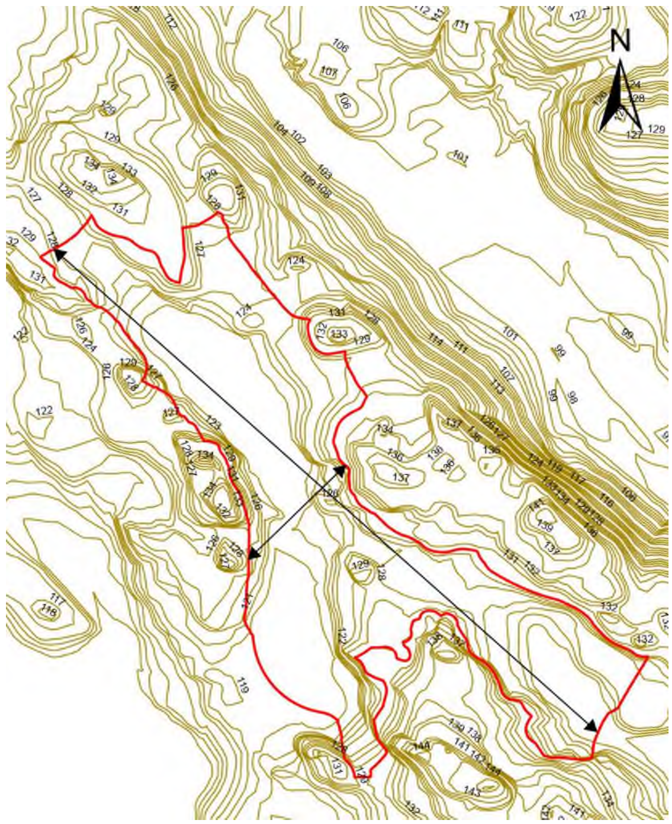

Figure 6: New Reservoir Effective Fetch (orange line)

Two wind speeds were analyzed in wind setup and significant wave height calculations based on information provided in a 2021 dam safety evaluation report for Lake Geraldine Dam[3], located to the immediate west of the New Reservoir. Due to seasonal ice cover, the report recommends wind speeds between 80 and 105 km/hour during the design flood, and between 131 and 216 km/hour during normal operations. For conservatism, the upper limit of each range was applied in this case to determine controlling wind setup and wave runup above the IDF level of 127.42 m (105 km/hour), and above the normal operating level of 127.0 m (216 km/hour).

[3] Concentric (2022). *Lake Geraldine Dam 2021 Dam Safety Review, Iqaluit, Nunavut*. Section 4.5.1 – Hydrotechnical.

Wind setup above stillwater elevation was calculated using the procedure defined in Section 6.3.7 of CDA *Hydrotechnical Considerations for Dam Safety (2007)*, as follows:

$$S = \frac{U^2 F}{Kd}$$

where: S = wind setup (m) above still water level
U = wind speed (m/s)
F = fetch length (km)
d = average reservoir depth (m)
K = constant = 4850 (USBR 1992)

Significant wave height was also calculated assuming fetch-limited conditions using CDA (2007) as follows:

Wave heights and periods may be determined using the following equations, which are valid only for fetch-limited conditions:

$$H_s = 1.616 \times 10^{-2} U_A F^{1/2}$$

$$T = 6.238 \times 10^{-1} (U_A F)^{1/3}$$
$$U_A = 0.71\, U^{1.23}$$

where: H_s = significant wave height (m)
F = fetch length (km)
T = wave period (s)
U = wind speed (m/s)
U_A = wind stress factor

As defined in Section 6 of the CDA Technical Bulletin, wave runup is the vertical height between the maximum elevation attained by wave run-up on a slope and the water elevation at the toe of the slope, excluding wave action. Wave runup on embankments is governed by a variety of factors including slope, the water depth at the toe, the roughness and permeability of the embankment, and incident wave characteristics. Because these parameters are updating at the current stage of design and, without a generic methodology for prediction of wave run-up or relevant empirical data, wave runup in this case was assumed equal to significant wave height Hs above the wind setup elevation.

Uncertainty in estimated wave runup in this case was accommodated by an assumed 0.5 meters added as a contingency for windspeed at flood pool (105 km/hr) and 0.2 meters as a contingency for windspeed at normal pool (216 km/hr). Results of wave runup calculations are shown in Table 4.

Table4. Iqaluit New Reservoir Freeboard Requirements

Stillwater condition	Parameter	Freeboard requirement (m)	Elevation (m)
IDF pool (127.42 m) Wind speed (U) = 105 km/hour	Wind setup	0.01	127.43
	Significant wave height H_s	0.72	128.16
	Wave runup	0.72	128.16
	Contingency	0.50	128.66
Normal pool (127.00 m) Wind speed (U) = 216 km/hour	Wind setup	0.05	127.05
	Significant wave height H_s	1.76	128.8
	Wave runup	1.76	128.8
	Contingency	**0.20**	**129.00**

Summary

Based on the above calculations, the recommended top of dam elevation is the controlling elevation of 129.00 meters shown in Table 4.

Inflow design flood calculations and flood-frequency analysis was performed using meteorological time-series data from the Environment Canada Iqaluit station and the USACE HEC-DSSVue (Visual Utility Engine) database software, downloadable from https://www.hec.usace.army.mil/software/hec-dssvue/downloads.aspx.