CITY OF IQALUIT

WSP PROJECT NO. CA0023312.3294

LONG-TERM WATER PROJECT OWNERS ENGINEER

RESILIENCY STUDY

DRAFT REPORT
PREPARED FOR CITY OF IQALUIT

wsp

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LONG-TERM WATER PROJECT OWNERS ENGINEER

RESILIENCY STUDY

January 27, 2025

DRAFT REPORT

City of Iqaluit
PO Box 460
Iqaluit, Nunavut
X0A 0H0

Attention: **City of Iqaluit**

Subject: **Long-Term Water Project Owner's Engineer - Resiliency Study**

Dear Sir/Madam,

WSP Canada Inc. (WSP) is pleased to submit our attached Draft Resiliency Study Report as part of the Long-Term Water Owner's Engineering Project. We recognize the importance of this document in assessing the resiliency of the current water system and identifying targeted improvements to improve the robustness, redundancy, and resiliency of the City's water infrastructure.

The report follows the ANSI/AWWA J100-21 Risk and Resilience Management framework to evaluate the current state of Iqaluit's infrastructure. It identifies key vulnerabilities, including aging pipelines, limited system redundancy, and exposure to climate variability cycles. Moreover, the study evaluates natural, operational, and human-induced risks, providing actionable strategies to address these challenges effectively.

We look forward to your response and incorporating the necessary changes and comments into the final version of this Report.

Yours sincerely,

Neil Noble-Pattinson, B.Sc., BA, P.Eng., PMP
Project Manager, WSP Canada Inc.

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This limitations statement is considered an integral part of this report.

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EXECUTIVE SUMMARY

This Resiliency Study assesses the Current State of Iqaluit's water infrastructure to improve reliability, adaptability, and sustainability. Using the ANSI/AWWA J100-21 Risk and Resilience Management framework, the report identifies critical assets, evaluates risks and vulnerabilities, and proposes comprehensive resilience strategies to address both current challenges and future uncertainties.

Iqaluit's water infrastructure faces significant challenges, including aging pipelines, limited redundancy in critical systems, and vulnerabilities to climate variability cycles. To address these issues, the report highlights the importance of designing infrastructure that is both resilient and adaptable, capable of performing under present conditions while anticipating future needs. The concept of Safe-to-Fail is a guiding principle, emphasizing the ability of critical water systems to recover from disruptions without catastrophic consequences. By integrating traditional hard infrastructure with nature-based design solutions, this study highlights a holistic approach to addressing risks and enhancing sustainability.

Key risks include natural hazards such as extreme weather and freezing conditions, operational challenges from aging infrastructure, and human-induced risks like cybersecurity threats. These risks are evaluated to determine their likelihood and potential consequences, with high-priority threats requiring immediate mitigation efforts. Recommendations include upgrading critical infrastructure, enhancing SCADA security, and incorporating climate projections into design and planning processes.

The study also considers measures for exceptional circumstances and emergencies, recognizing the need to analyze unknown risks and uncertainties. By addressing both short-term and long-term threats, this report represents a commitment to creating infrastructure solutions that meet today's essential water service needs while preparing for the conditions of tomorrow. The findings serve as a foundation for designing and building resilient critical water systems that are reliable, adaptable, and Safe-to-Fail, ensuring Iqaluit's water infrastructure remains robust in the face of evolving challenges.

1 INTRODUCTION

1.1 PROJECT BACKGROUND

Iqaluit, the capital of Nunavut Territory, is located at the southern end of Baffin Island near Frobisher Bay (63°45'N latitude and 68°31'W longitude). Access to Iqaluit is provided year-round by regularly scheduled commercial aircraft, snowmobile trails from other Baffin Island communities in the winter, and sealift from the port of Montreal and Valleyfield in the summer. The project location is shown in **Figure 1**.

1.1.1 IQALUIT'S CLIMATE AND GEOLOGY

Iqaluit is located above the tree line and within the permafrost zone of Canada. It has a tundra climate typical of the Arctic region, although it is well outside the Arctic Circle. The city experiences long, cold winters and brief, cool summers. Average monthly temperatures remain below freezing for eight months of the year. The city's climate is marked by an average January temperature of -21.5°C and an average July temperature of 8°C. The annual precipitation consists of a total of 43.0 cm. Prevailing winds blow from the northwest at an average speed of 16.7 km/hr.

The region generally consists of glacially scoured igneous/ metamorphic terrain. In some locations, a thin layer of organic material is found.

1.1.2 CITY'S GROWTH AND POPULATION

Iqaluit is the newest capital city in Canada, and as a result, has experienced a period of rapid development and growth. It serves as the seat of government for the Territory of Nunavut and hosts many federal and territorial government departments. The City is rapidly emerging into a regional center for the territory, with various northern businesses and Inuit organizations establishing their base of operations there. According to the 2021 Census, the population of Iqaluit is estimated at about 7,500 people, with an average annual growth rate between three and four percent.

Figure 1: Project Location

1.2 WATER SUPPLY SYSTEM OVERVIEW

The primary water source for the City of Iqaluit is Geraldine Lake, located approximately 1 km north of Iqaluit's population center. Gravity conveys water to the City of Iqaluit Water Treatment Plant (WTP), where it undergoes disinfection and filtration. Following treatment, treated water is stored in four (4) below-ground treated water tanks beneath the WTP before being transferred to a two-cell above-ground treated water storage tank located to the immediate south of the WTP. The total capacity of treated water storage is approximately 4,000 m^3. Water enters the city's distribution network from this storage point to meet different demands.

Through the distribution network, the water supply system serves customers' needs in seven distinct zones, as shown in **Figure 2**. Due to their higher elevation, the Plateau Zone and the Road-to-Nowhere Zone are pressurized by Booster Station #1 (BS1) and Booster Station #2 (BS2), respectively. The five remaining zones, including Happy Valley, Federal Road, Lower Iqaluit, Lower Base, and Uivvaq, receive water by gravity flow from the storage tank.

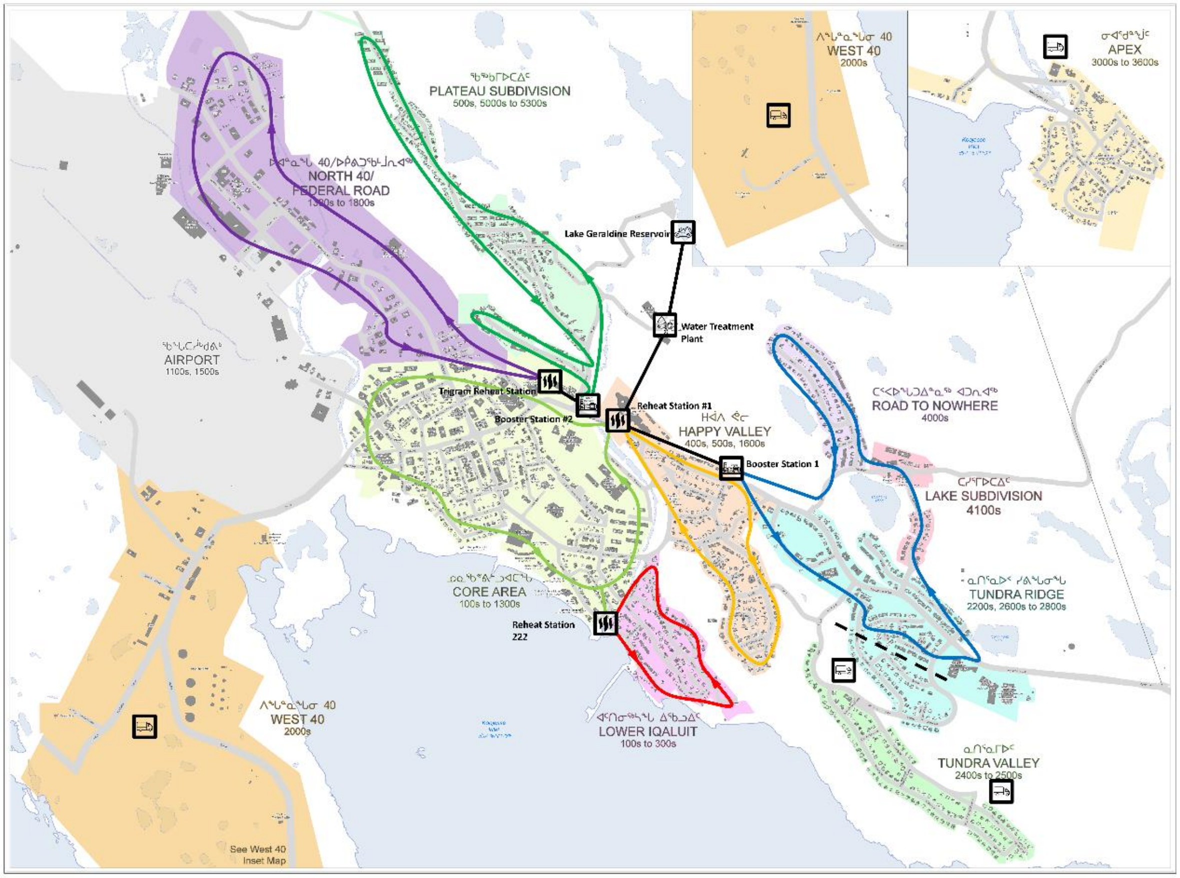

Figure 2: City of Iqaluit's water treatment & distribution infrastructure loop diagram

In addition to the two booster station pumps, the system has several low-pressure recirculation pumps to prevent water from freezing during cold periods. These pumps provide the necessary energy to ensure the water maintains sufficient pressure to compensate for head loss, allowing continuous circulation within the seven service areas' looped supply/return mains.

In addition to the service areas mentioned earlier, potable water is supplied to two areas –Apex District and the area to the south of the Road-to Nowhere District (Tundra Valley and approximately half of Tundra Ridge) – via truck delivery (known as "Trucked Services"). Trucked Services also collects wastewater from customers' holding tanks using separate trucks. Although not part of the main piped service network, these districts play a crucial role in the water supply system. Trucked Services draw water from two designated points in the network – Booster Station #1 (primary) and the WTP (backup) – and deliver it to the customers.

1.3 REPORT GOALS

The purpose of this Resiliency Study is to assess and enhance the resiliency of Iqaluit's water infrastructure, specifically addressing the replacement of its existing piped infrastructure that are susceptible to leaks and breaks. Key activities include:

- Conducting a detailed assessment of current vulnerabilities caused by permafrost degradation, aging infrastructure, climate variability and security risks.
- Applying the ANSI/AWWA J100-21 Standard for Risk and Resilience Management to analyze risks and allocate resources effectively.

This study aligns with the City of Iqaluit's long term program goals for water supply resiliency, with a specific focus on enhancing system performance under current and future challenges.

1.4 PROJECT OBJECTIVES

The Resiliency Study aims to contribute to Iqaluit's broader long-term water program goals, which are:

- Replace and Modernize the Existing Piped Infrastructure
- Develop a New Long-Term Water Source and Supporting Infrastructure
- Construct a New Raw Water Reservoir

This study focuses specifically on the first objective.

1.5 REPORT METHODOLOGY

The ANSI/AWWA J100-21 Standard for Risk and Resilience Management of Water & Wastewater Systems provides a structured framework for addressing risks and enhancing resilience. This methodology ensures that Iqaluit's resources are allocated effectively to reduce vulnerabilities and improve operational performance.

The seven-step approach outlined in the Standard guides this study, as shown in **Table 1**.

Table 1: Seven-step approach to this Resiliency Study (Adapted from J100-21)

NO.	SECTION	GOALS
1	Asset Characterization	Identify critical assets necessary for water distribution and assess their importance to the City's overall mission.
2	Threat Characterization	Analyze potential threats - including natural hazards, malevolent actions, and proximity risks - that could disrupt critical assets.
3	Consequence Analysis	Evaluate the potential impacts of each threat, including service disruptions, financial losses, and public health risks.
4	Vulnerability Analysis	Assess the weaknesses in infrastructure that could exacerbate the impacts of identified threats.
5	Threat Analysis	Estimate the likelihood of each threat impacting the identified assets.
6	Risk/Resilience Analysis	Combine data on threats, vulnerabilities, and consequences to calculate the overall risk profile and resilience metrics.
7	Risk/Resilience Management	Develop and prioritize actionable strategies to mitigate risks, enhance resilience, and optimize costs.

By characterizing critical assets, analyzing risks, and identifying cost-effective resilience strategies, the City can address vulnerabilities in its water supply system while aligning with long-term goals.

The structured approach ensures that identified solutions address both immediate risks (e.g., water loss due to aging pipes) and systemic challenges (e.g., climate variability). The next chapter presents findings from the risk and resilience analyses and propose actionable recommendations to guide infrastructure upgrades for current state.

2 RESILIENCY STUDY

This chapter applies the ANSI/AWWA J100-21 Risk and Resilience Management framework to evaluate Iqaluit's water infrastructure. The methodology enables a structured approach to identifying risks, vulnerabilities, and resilience strategies and focuses on the project's scope.

2.1 ASSET CHARACTERIZATION

2.1.1 PURPOSE

The aim of asset characterization is to identify assets that, if affected by natural hazards or deliberate actions, could lead to significant service interruptions, widespread degradation of operations, severe injuries or illnesses, fatalities, financial losses for the utility, or negative impacts on economic activity. Assets can include physical infrastructure, cyber systems, personnel, customers, intellectual property, or other key components. This step generates a prioritized list of critical assets to guide the subsequent stages of analysis, such as consequence evaluation, vulnerability assessment, threat analysis, and the estimation of overall risks and resilience.

2.1.2 APPROACH

Our approach to asset characterization is designed to ensure a thorough understanding of the City's critical assets and the potential risks associated with their loss or damage. This systematic methodology supports effective decision-making, prioritization, and risk mitigation (**Table 2**).

Table 2: Steps for Asset Characterization and Their Descriptions (Adapted from J100-21)

STEP	DESCRIPTION
Review System Schematics	➢ Examine existing schematics or models of the utility's physical and cyber systems to identify critical assets. ➢ Develop a process flow diagram to provide a shared reference point.
Define Critical Functions	➢ Define or confirm the mission and critical functions of the utility to establish the foundation for analysis.
Identify Assets	➢ Identify all assets, including subsystems, that perform or support critical functions. ➢ Highlight potentially critical assets whose loss or damage could result in service denial, human harm, significant financial loss, or regional economic disruption.
List Potentially Critical Assets	➢ Create a comprehensive list of assets that meet the criteria for potential criticality.
Estimate Consequences	➢ Estimate the worst reasonable consequences of losing each asset, considering factors such as fatalities, injuries, financial loss, environmental impacts, and public confidence.

STEP	DESCRIPTION
Evaluate Existing Countermeasures	➢ Identify and assess current protective and mitigation measures designed to safeguard critical assets and infrastructures.

2.1.3 SYSTEM OVERVIEW

The City of Iqaluit owns and operates water treatment and treated water distribution system infrastructure (collectively referred to as the Public Water System) in various locations within the city limits. A list of the major Public Water System components are as follows:

- Lake Geraldine (raw water source)
- Lake Geraldine Dam
- Raw Water Intake Structures
- Water Treatment Plant (WTP)
- Treated Water Reservoir
- Piped Treated Water Distribution System
- Potable Water Delivery Service (Trucked Services)
- Supervisory Control and Data Acquisition (SCADA) System

A simplified diagram highlighting the functionalities and dependences of the system is presented in **Figure 2**.

In addition to the buildings and structures, the City also provides potable water delivery services (referred to as Trucked Services) to customers who are not currently connected to the piped water distribution systems. Districts that are supplied by Trucked Services are highlighted by a truck icon in **Figure 2**. A large majority of customers are connected to the piped water distribution system.

The Public Water System is operated automatically via the City's SCADA system. In its most simplified sense, the SCADA system monitors various system attributes – such as reservoir water elevation, chlorine concentrations, etc. – and automatically opens and closes valves and turns on pumps to maintain the system in its intended operation. The SCADA system also alarms operations staff when the system is not operating as intended and can trigger shut downs if the system is operating outside of set thresholds.

Details on the major system components are provided in **Table 3**.

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Table 3: Descriptions of major public water system infrastructure components in Iqaluit

SYSTEM	DESCRIPTION
Lake Geraldine	Lake Geraldine is the primary freshwater source for the City. Surrounded by rugged Arctic terrain, Lake Geraldine is fed by local precipitation and meltwater. Due to its location in a cold climate, the lake faces unique challenges, such as seasonal ice cover and potential impacts from climate change, requiring careful management to ensure a sustainable and safe water supply.
Lake Geraldine Dam	The Lake Geraldine Dam is comprised of a concrete section with integral spillway, and three earth berm sections, designated north, central, and south. The Dam was constructed in the late 1950s and has been expanded to increase the reservoir capacity over the years.
Piped System	The water distribution network is a critical component of Iqaluit's public water system. It comprises a variety of materials, including ductile iron, asbestos cement, and high-density polyethylene (HDPE) pipes. These pipelines facilitate water servicing across both pressure and gravity-fed zones, ensuring reliable distribution throughout the city. The age and material composition of some sections (e.g., asbestos cement) pose unique challenges, such as maintenance, resilience to environmental conditions, and compliance with modern health and safety standards. Upgrades and modernization efforts are essential to align with the city's long-term water infrastructure goals.
SCADA System	Programmable control system whose based components are located at the WTP and are connected wirelessly to the other infrastructure buildings in the City (listed above).
Trucked Services	A fleet of trucks equipped with tanks, hoses, and other devices that operate (primarily) during regular business hours. Trucked services provide delivery of potable water (and hauling of wastewater) for residents not currently connected to the piped water distribution system. Districts serviced by Trucked Services include West 40, Apex, Tundra Valley, and a portion of Tundra Ridge.

2.1.4 ASSET LIST & CRITICAL FUNCTIONS

Detailed descriptions of the Public Water System components, their respective sub-components, critical functions, and risks are given in **Table 4**.

Table 4: City of Iqaluit Public Water System components, critical functions, and risks

SYSTEM	SUBSYSTEM	BRIEF DESCRIPTION	CRITICAL FUNCTIONS	COMMON OPERATIONAL RISKS TO CRITICAL FUNCTIONS	ESTIMATED CONSEQUENCES TO COMMON OPERATIONAL RISK	EXISTING PROTECTIVE COUNTERMEASURES
Public Water System	Lake Geraldine	The City's raw water source.	Maintain adequate supply of raw water to be fed to the WTP.	Insufficient water due to any number of reasons: ➢ Variable weather conditions, ultimately leading to lesser Lake recharge (i.e., precipitation, evapotranspiration, surface water runoff, prolonged winter conditions). ➢ Increased non-revenue water loss (i.e., leaks, breaks, fire fighting, etc.). ➢ Insufficient volume of raw water to last the winter (until spring freshet).	High: Entire city may be without water from this primary source, if depleted. Moderate: Can negatively impact customer confidence in the Public Water System.	➢ Existing climate change impact studies informing & advising decision-making processes. ➢ Leak detection and mitigation program (occasional capital-funded activity). Emergency response plan, and historical success in pumping water from supplemental source, when required.
				Increased water demand.	Low: Can prompt capital upgrades ($) to respond to increase in demand.	➢ Capital plan and budget, informing & advising decision-making processes. ➢ Existing and planned infrastructure studies.
				Contamination, or unsustainable/drastic change in water quality.	High: Entire City may be on drinking water advisory.	➢ Emergency Response Plan. ➢ Upgraded filtration media capable of removing hydrocarbons (and other contaminants) from the raw water supply.
	Lake Geraldine Dam	The City's man-made concrete structure retaining the water volume in Lake Geraldine.	Enable the storage of a higher elevation/volume of water in Lake Geraldine.	Failure of concrete dam structure, resulting in loss of retained water in Lake Geraldine.	High: Entire city may be without water from this primary source, if depleted. Moderate: Can negatively impact customer confidence in the Public Water System. High: Significant financial cost to repair & reinstate.	➢ Occasional engineering inspection of dam.
Intake Structures	Lake Geraldine Access Structure	Structure at the base of the Lake Geraldine Dam containing pipes, valves, and other appurtenances.	Enable operations staff to isolate the flow of water from the Lake Geraldine Dam.	Inoperability of valve equipment can lead to the inability to isolate (if stuck open) or service disruptions (if stuck closed).	High: Entire city may be without water, as the isolation valve controls all flow of raw water from Lake Geraldine to the Water Treatment Plant.	➢ Yearly valve exercising program. ➢ Bollards or similar vehicular impact mitigation structures (i.e., large rocks).
				Leaks and/or breaks of piping and valves can lead to loss of raw water in Lake Geraldine.	High: If a smaller leak is not detected, or if a severe leak is not addressed immediately, may cause the rapid depletion of raw water from the dam and, subsequently, limit the availability of water for the City.	➢ Flow monitoring and level-sensing equipment which can alert operations staff of a drastic decline in water elevations.
	Raw Water Tempering System	Circulation loop (including boilers and heat exchangers) that provides heat from the Water Treatment Plant to the Lake Geraldine Access Structure.	Mitigates the risk of freezing of the intake piping. Increases the temperature of raw water entering the Water Treatment Plant, enhancing performance (quantity, quality) of treatment processes.	Failure of boilers and/or heat exchange system to provide heat to water.	High: Failure to heat the water through the intake line can result in the intake pipe freezing which, in turn, will prevent water from entering the treatment and further downstream systems for the entire City. Further, a break can have heightened consequences during winter due to site accessibility and difficulty of repair.	➢ Dual-redundant equipment including boilers, heat exchangers, and pumps.
				Minor undetected leak.	High: If not detected immediately (such as a slow leak), this can result in substantial non-metered water losses and loss in available water in Lake Geraldine.	➢ The system has unmetered bleed locations, increasing undetected leakage. Flow metering should be incorporated in these locations. Along with the SCADA system, it will be the most efficient way to detect water losses.

SYSTEM	SUBSYSTEM	BRIEF DESCRIPTION	CRITICAL FUNCTIONS	COMMON OPERATIONAL RISKS TO CRITICAL FUNCTIONS	ESTIMATED CONSEQUENCES TO COMMON OPERATIONAL RISK	EXISTING PROTECTIVE COUNTERMEASURES
				Failure of piping (damage, breaks, stuck valves) limiting or preventing the flow of heated water to the injection point.	High: If the break is substantial, this can result in a stoppage of water services for the entire City until repaired.	➢ Occasional pipe inspections. ➢ Bollards, exterior corrugated metal casing, and other traffic control measures.
	Raw Water Intake Piping	Approximately 1km of piping between the Lake Geraldine Dam and the Water Treatment Plant.	Convey water from the Lake Geraldine Access Structure to the Water Treatment Plant.	Failure of piping (damage, leaks, breaks, stuck valves) limiting or preventing the flow of raw water into the Water Treatment Plant.	High: All water that entering subsequent systems is conveyed through this pipe.	➢ Occasional pipe inspections. ➢ Bollards, exterior corrugated metal casing, and other traffic control measures.
Water Treatment Plant (WTP)	Ultraviolet (UV) Disinfection System	Two (lead & backup) systems to dose the raw water with ultraviolet light.	Inactivate pathogens. Assist with meeting the City's disinfection requirements per their current water licence (in conjunction with the filtration and chlorine dosing systems).	Electrical/mechanical failure of UV disinfection systems leading to inability to meet licensed requirements and heightened risk of water-borne illnesses. May prompt the issuance of a drinking water advisory.	Moderate: The inability to meet drinking water requirements will likely prompt a city-wide drinking water advisory. Expected to take less than one week to address. Loss of consumer confidence.	➢ Dual-redundant UV disinfection systems. Only one of the systems need to be operated at a given time, allowing for downtime and servicing of the other unit. ➢ Local alarms (on the UV system panel) including low flow and system malfunctions. These alarms are also connected to the SCADA system.
				Change in influent water quality, resulting in reduced UV treatment effectiveness.	High: The inability to meet drinking water requirements will likely prompt a city-wide drinking water advisory. Will require additional engineering and capital upgrades. Expected to take several weeks to address. Significant loss of consumer confidence.	➢ Water quality monitoring and reporting program. Changes in water quality are expected to occur slowly over time, thus giving the City ample time to react.
	Filtration System	Four dual-media filter bays consisting of anthracite (the support layer) and granular activated carbon (GAC, the active layer).	Remove particulate material (total suspended solids (TSS)) as means of achieving industry best practice for treating surface water (refer to United States Environmental Protection Agency (USEPA) Surface Water Treatment. Note that filtration is not included in the City's licensed requirements at this time. Removal of turbidity (a measure of the relative clarity of a liquid) as means of meeting the City's licensed requirement of 0.3 nephelometric turbidity units (NTU). Assist with meeting the City's disinfection requirements per their current water license (in conjunction with the UV and chlorine dosing systems).	Change in influent water quality (i.e., the introduction of new constituents that the filter media cannot remove), resulting in reduced filtration effectiveness and/or failure to meet treatment targets. May prompt the issuance of a drinking water advisory.	High: The inability to meet drinking water requirements will likely prompt a city-wide drinking water advisory. Will require additional engineering and capital upgrades. Expected to take several weeks to address. Significant loss of consumer confidence.	➢ Water quality monitoring and reporting program. Changes in water quality are expected to occur slowly over time, thus giving the City ample time implement new treatment technologies. ➢ The current filter media (anthracite and granular activated carbon) is capable of removing a higher degree of turbidity and other contaminants that more typical filtration media.
				"Plugging" of the filters due to excessive particulate material build-up (note that his is dependent on the proper operation of the Filtration Backwash System), resulting in loss of filtered water flow.	Moderate: The filter(s) will experience reduced flow. Over prolonged periods of time, this can reduce the filtration capacity to less than the treated water demand (i.e., a net loss in the available treated water supply).	➢ Four (4) filtration bays provide redundancy and allow for system downtime (a minimum of two (2) are required during normal operation). ➢ Dual-redundant backwash pumps in case of pump failure. ➢ Monitoring systems and alarms.
	Filtration Backwash Systems	Pumps (lead & backup), blowers (lead & backup), pipes, and appurtenances connected to the filtration system for backwashing processes.	Cleans the filter media at timed intervals to help restore treatment efficiency (quantity, quality) of the filters.	Pump failure, resulting in reduced or no filter backwash efficiency.	High: The inability to backwash the filter media can significantly hinder filter performance until addressed. Can lead to net loss in available treated water to the community.	➢ Dual-redundant backwash pumps, representing industry best practice.
				Valve/automation failure, resulting in failed system operation.		➢ SCADA and alarms for all mechanical components in the filtration backwash system (pressure, valve operation, pump operation, etc.). ➢ Valves can be operated in manual mode.

SYSTEM	SUBSYSTEM	BRIEF DESCRIPTION	CRITICAL FUNCTIONS	COMMON OPERATIONAL RISKS TO CRITICAL FUNCTIONS	ESTIMATED CONSEQUENCES TO COMMON OPERATIONAL RISK	EXISTING PROTECTIVE COUNTERMEASURES
	Chlorine Dosing Systems	Chlorine gas (primary) and sodium hypochlorite (backup) chemicals injected into the treated water (post-filtration).	Inactivate viruses and pathogens. Assist with meeting the City's disinfection requirements per their current water license (in conjunction with the filtration and UV disinfection systems).	Pump and/or mechanical failure, resulting in insufficient chlorine dosing to meet licensed disinfection requirements and heightened risk of water-borne illnesses. May prompt the issuance of a drinking water advisory.	High: Inability to meet primary disinfection requirements will result in a drinking water advisory issued for the entire city.	➢ -Dual redundant chlorine dosing pumps (industry best practice). -Back-up sodium hypochlorite dosing system in the event of chlorine gas system downtime (industry best practice). -SCADA system alarms, including low-chlorine alarms at the various pumping stations around the city. ➢ Daily monitoring and reporting program can further inform operations staff of low chlorine concentrations at the furthest reaches of the distribution system.
			Provide secondary disinfection (i.e., maintaining minimum chlorine concentration throughout the distribution system) per the City's current water license.		Moderate/High: The inability to meet secondary disinfection requirements will result in a drinking water advisory. Depending on the severity of the issue, this can result in a city-wide advisory, or an advisory localized to certain areas.	
Optional Chemical Dosing Systems	Hydrofluorosilicic Acid Dosing System	Can be used to improve water quality. This system is not required to meet the City's licensed requirements or federal drinking water guidelines.	Can be used to add fluoride to the drinking water, which has been shown to improve dental hygiene. Can improve customer satisfaction with treated water product.	Pump and/or mechanical failure. Can lead to aesthetic issues and consumer complaints (no drinking water advisory is expected to be necessary in this case).	Low: Failure and/or non-operation of these optional systems are not expected to significantly alter the treated water quality. Negligible-to-minor impacts on consumer confidence.	➢ Dual redundant dosing pumps (industry best practice).
	Sodium Hydroxide Dosing System		Can be used to mitigate the water's tendency to corrode metal pipes and plumbing fixtures.		Moderate: High treated water corrosivity (from non-operation of the sodium hydroxide dosing system) may can corrosion to metallic distribution system piping.	
Clearwell Storage		Four below-ground treated water tanks between the filters and the separate treated water reservoir.	Provides volumes of water for in-plant needs, particularly the filtration backwash systems. In conjunction with the Treated Water Reservoir, provides sufficient volume of water for equalization, emergency, and fire-fighting needs. In conjunction with the Treated Water Reservoir, provides sufficient contact time for chlorine to inactivate viruses and pathogens prior to entering the distribution system, per the City's licensed requirements.	Low treated water storage volumes, leading to increased risk of water shortage for equalization, emergency, and fire fighting needs. Corresponding with similar low treated water volumes in the Treated Water Reservoir, may prompt the issuance of a drinking water advisory.	High: Can lead to limited ability to fight fires. Moderate: Can lead to city-wide drinking water advisory until disinfection requirements are met. Likely addressable within days. Low: Can lead to limited volume for filter backwash function.	➢ SCADA system calls for production of water when clearwell storage is low. Alarms provide further redundancy to operations staff of low volumes.
Sampling & Monitoring Programs		Includes both on-line electronic monitoring equipment (turbidimeters, chlorine probes, etc.), regular manual testing, and regular third-party analytical testing.	Used to assess suitability of water for human consumption. Alerts operations staff of adverse water quality. (For on-line monitoring equipment, in conjunction with the SCADA system) Can trigger automatic WTP shutdown, call-outs to City staff, or other pre-programmed function.	False positive results.	Moderate: May lead to drinking water advisory pending further confirmatory testing. Loss of consumer confidence.	➢ Industry best practice frequency of sampling (daily, weekly, etc. depending on testing). ➢ Redundancy of sampling from both operations personnel and third-party testing laboratories.
				False negative results.	Moderate: May lead to treated water that may not be fit for consumption. Increased risk of water-borne sicknesses. Loss of consumer confidence.	
				Change in treated water quality, such as by seasonal changes or contamination event, in which water no longer complies with drinking water guidelines. May prompt the issuance of a drinking water advisory or other action.	High: May lead to a city-wide drinking water advisory.	➢ Water quality monitoring and reporting program. Changes in water quality are expected to occur slowly over time, thus giving the City ample time implement new treatment technologies.

SYSTEM	SUBSYSTEM	BRIEF DESCRIPTION	CRITICAL FUNCTIONS	COMMON OPERATIONAL RISKS TO CRITICAL FUNCTIONS	ESTIMATED CONSEQUENCES TO COMMON OPERATIONAL RISK	EXISTING PROTECTIVE COUNTERMEASURES
Treated Water Reservoir		A two-cell above-ground tank located to the immediate south of the Water Treatment Plant.	In conjunction with the Clearwell Storage, provides sufficient volume of water for equalization, emergency, and fire-fighting needs. In Clearwell Storage, provides sufficient contact time for chlorine to inactivate viruses and pathogens prior to entering the distribution system, per the City's licensed requirements.	Low treated water storage volumes, leading to increased risk of water shortage for equalization, emergency, and fire fighting needs. Corresponding with similar low treated water volumes in the Clearwell Storage, may prompt the issuance of a drinking water advisory.	High: Can lead to limited ability to fight fires. Moderate: Can lead to city-wide drinking water advisory until disinfection requirements are met. Likely addressable within days.	➢ SCADA system calls for production of water when clearwell storage is low. Alarms provide further redundancy to operations staff of low volumes.
Piped Treated Water Distribution System	Access Vaults	Below-ground structures located along the distribution system, primarily at intersections, that provide access for operations staff to the pipes, valves, and appurtenances within. Some access vaults also include a fire hydrant.	The valves within the access vault are used to temporarily isolate piped water services during service disruptions. Treated water samples can be collected from the potable water distribution piping for confirmatory testing, namely chlorine residual.	Vehicular collision.	Variable: Severity depends on which access vault is affected. For instance, the first access vault from the Water Treatment Plant carries all flow to the City and would have the most significant impact. Damage to a far-downstream access vault may only impact a small number of customers. Loss of consumer confidence for those affected.	➢ High visibility bollards and flags. ➢ Speed limits and traffic law enforcement.
				Restricted or limited access due to weather conditions (i.e., snow, water, etc.).	Low: Can increase the amount of time and effort required to service or assess an access vault.	➢ Regular snow-clearing activities.
	Piping & Appurtenances	Below-ground linear structures that between and through the access vaults and other structures.	Convey treated water to different districts and customers around the City.	Prone to leaks and freeze-thaw cycles, with aging AC pipes posing health and safety risks.	Variable: Severity depends on which segment of pipe is affected. For instance, damage to the main supply pipe for several residential districts is likely to impact more customers than a pipe within a distribution loop. Loss of consumer confidence for those affected.	➢ The current system has a SCADA system that should be capable of detecting flow variations. Isolation valves are also present in the system, which allows for criticality segmentation in case of pipe disruption.
Combination Pumping & Reheat Stations	Booster Station #1	Pumping and reheat station building located to the immediate west of the Tundra Ridge district.	Pumps water (to maintain distribution system pressure) to the Road to Nowhere, Lake Subdivision, and Tundra Ridge district loops.	Pump failure, leading to low/insufficient distribution system pressures and/or other service disruptions.	Moderate: Loss of distribution system pressure for several residential districts. Estimated days to repair. Loss of consumer confidence.	➢ Pump redundancy (standby pumps). ➢ SCADA program. ➢ Valves to redirect water flows.
			Reheats return water from the Road to Nowhere, Lake Subdivision, and Tundra Ridge district loops to mitigate the risk of pipe freezing.	Boiler and/or heating system failure, resulting in increased risk of freezes and breaks, subsequently leading to service disruptions.	Moderate-High: Higher risk of pipe freezing and subsequent loss of distribution system pressure for several residential districts. Estimated one week to repair. Loss of consumer confidence.	➢ Reheat stations and bleed locations to circulate water.
	Booster Station #2	Pumping and reheat station building located to the immediate south of the Plateau Subdivision.	Pumps water (to maintain distribution system pressure) to the Plateau Subdivision district loop.	Pump failure, leading to low/insufficient distribution system pressures and/or other service disruptions.	Moderate: Loss of distribution system pressure for several residential districts. Estimated days to repair. Loss of consumer confidence.	➢ Pump redundancy (standby pumps). ➢ SCADA program. ➢ Valves to redirect water flows.
			Reheats return water from the Plateau Subdivision district loop to mitigate the risk of pipe freezing.	Boiler and/or heating system failure, resulting in increased risk of freezes and breaks, subsequently leading to service disruptions.	Moderate-High: Higher risk of pipe freezing and subsequent loss of distribution system pressure for several residential districts. Estimated one week to repair. Loss of consumer confidence.	➢ Although standby pumps are available, SCADA should submit a signal to operators in case of failure to avoid disruptions.
Reheat Stations	Reheat Station #1	Reheat station located adjacent to the Qikiqtani General Hospital.	Reheats return water from the Core Area district loop to mitigate the risk of pipe freezing. Note that distribution pressure is maintained by the gravity feed system and no further pumping is required.	Boiler and/or heating system failure, resulting in increased risk of freezes and breaks, subsequently leading to service disruptions.	Moderate-High: Higher risk of pipe freezing and subsequent loss of distribution system pressure for several residential and commercial districts. Estimated one week to repair. Loss of consumer confidence.	➢ No countermeasures registered. This needs to be confirmed with the City. ➢ A SCADA system is available; however, a standby pump should be available.

SYSTEM	SUBSYSTEM	BRIEF DESCRIPTION	CRITICAL FUNCTIONS	COMMON OPERATIONAL RISKS TO CRITICAL FUNCTIONS	ESTIMATED CONSEQUENCES TO COMMON OPERATIONAL RISK	EXISTING PROTECTIVE COUNTERMEASURES
	Trigram Reheat Station	Reheat station located adjacent to the Iqaluit Aquatic Centre and Iqaluit Fire Department.	Reheats return water from the North 40/Federal Road district loop to mitigate the risk of pipe freezing. Note that distribution pressure is maintained by the gravity feed system and no further pumping is required.	Boiler and/or heating system failure, resulting in increased risk of freezes and breaks, subsequently leading to service disruptions.	Moderate-High: Higher risk of pipe freezing and subsequent loss of distribution system pressure for mixed residential-commercial district. Estimated one week to repair. Loss of consumer confidence.	➢ No countermeasures registered. This needs to be confirmed with the City. ➢ A SCADA system is available; however, a standby pump should be available.
	Reheat Station 222	Reheat station located to the immediate west of the Lower Iqaluit district.	Reheats return water from the Lower Iqaluit district loop to mitigate the risk of pipe freezing. Note that distribution pressure is maintained by the gravity feed system and no further pumping is required.	Boiler and/or heating system failure, resulting in increased risk of freezes and breaks, subsequently leading to service disruptions.	Moderate-High: Higher risk of pipe freezing and subsequent loss of distribution system pressure for one residential district. Estimated one week to repair. Loss of consumer confidence.	➢ Although standby pumps are available. SCADA should submit a signal to operators in case of failure to avoid disruptions. (see recommendations)
Trucked Services		A fleet of trucks equipped with tanks, hoses, and other devices that operate (primarily) during regular business hours.	Provides delivery of potable water (and hauling of wastewater) for residents not currently connected to the piped water distribution system. Districts serviced by Trucked Services include West 40, Apex, Tundra Valley, and a portion of Tundra Ridge.	Failure to deliver potable water to customers resulting in service disruptions, loss of consumer confidence, etc. Reasons for delivery failure include, but are not limited to, inclement weather, staff shortages, equipment failure, etc.	Moderate: Limited access to treated water for up to 15% of city residents.	➢ No countermeasures registered. This service should be evaluated with the City. The model implementation should evaluate future connections to all the houses that are using this service.
SCADA System		Programmable control system whose based components are located at the WTP and are connected wirelessly to the other infrastructure buildings in the City (listed above).	Automate the operation of valves of water (and wastewater) equipment across the City such as valves, pumps, and treatment equipment according to user-defined inputs and thresholds. Under normal operating conditions, operator intervention should not be required.	Loss of power. Poor programming, leading to systems not functioning as intended. Cyberattacks leading to data breach, data loss, and/or loss of system control.	Variable: Severity depends on degree of lost function. Complete loss of SCADA system will have severe consequences and require all facilities to operate in manual mode (substantial labour requirements).	
			Sends alarms operations personnel and, if severe, dial-outs to other Municipal staff, when conditions are outside of typical operating ranges.			
Operations Personnel		Permanent/seasonal staffing retained by the City to perform Municipal functions.	Operate the Water Treatment Plant.	Long-term general labour shortage from low unemployment rates, lack of available skilled labour, etc. Short-term labour shortages including those caused by labour disputed, widespread illness, etc.	High: Loss of water treatment plant operation & maintenance can lead to limited water produced for municipal and residential needs. Potential for city-wide loss of consumer confidence.	➢ Facility can be operated remotely by third-party engineering consultant. ➢ Competitive wages and benefits programming.
			Operate the piped water distribution system.		Variable: Inability to address leaks and breaks can lead to unmetered water losses, further damage to infrastructure, etc.	➢ Modern piping infrastructure is less susceptible to leaks and breaks compared to obsoleted piping. ➢ Competitive wages and benefits programming.
			Operate Trucked Services.		High: Loss of potable water delivery services for the 15% of city customers on Trucked Services. Loss of consumer confidence for the impacted customers.	➢ Competitive wages and benefits programming.
			Respond to alarms and dial-outs issued by the SCADA system.		Variable: Lack of response to critical alarms can lead to prolonged system downtime and further system damage.	➢ Competitive wages and benefits programming.
			Perform manual functions when systems experience downtime (i.e., repair a watermain break, replace pump parts, etc.).		Variable: Lack of system maintenance can lead to further damage to the system.	➢ SCADA system, when in proper working order, should automate nearly all critical functions. ➢ Competitive wages and benefits programming.

2.2 THREAT CHARACTERIZATION

2.2.1 APPROACH

We approached threat characterization by systematically evaluating and categorizing potential risks into three primary groups: man-made hazards, natural hazards, and dependency hazards.

Our process incorporated guidance from AWWA J100-21, following its Table 1 to identify a baseline set of reference threats to delve deeper into their operational details. We ensured flexibility in our analysis by allowing the inclusion of additional threats to address local conditions. For every reference threat considered, we documented our rationale for either including or excluding it, ensuring transparency and traceability throughout the analysis. This comprehensive approach provided a foundation for understanding and mitigating threats to critical infrastructure.

2.2.2 DIRECTED (MAN-MADE) THREATS

Man-made hazards included malevolent threats such as blackout, fire, social and political unrest, cyberattacks, sabotage, contamination, supply chain and physical attacks from both insiders (e.g., current or former employees, suppliers with facility access) and outsiders (e.g., terrorists, criminals, vandals). These threats were analyzed across various modes of attack—air, land, water, and cyber—while considering multiple magnitudes of potential attack scenarios, as shown in **Table 5**.

Table 5: Sources of Information on Directed (Man-Made) Threats (Adapted from J100-21, Section A4: Detailed Reference Threats)

CATEGORY	HAZARDS	OBJECTIVE	MOTIVE	KNOWLEDGE
Aircraft	Helicopter	Attempt to maximize death/damage through most productive direct means. Cause fear on the national/local level.	Terror, destroy assets, facilities	Extensive knowledge of water utility operations, facility layouts, and security system. Highly skilled and trained, well financed, and very good support structure. Conducts extensive planning.
	Small Plane			
	Regional Jet			
	Large Jet			
Assault Team	1 Assailant	Disrupt utility mission—maximize loss of mission capability, loss of life and/or economic damage. Cause fear on the national/local level.	Terror, destroy assets	Extensive knowledge of water utility operations, facility layouts, and security system. Highly skilled and trained, well financed, and very good support structure. Conducts extensive planning.
	2-4 Assailants			
	5-8 Assailants			
	9-16 Assailants			

CATEGORY	HAZARDS	OBJECTIVE	MOTIVE	KNOWLEDGE
Maritime	Small Boat Fast Boat Barge Draft Ship	Attempt to maximize death/damage through most productive direct means. Cause fear on the national/local level.	Terror, destroy assets, facilities	Extensive knowledge of water utility operations, facility layouts, and security system. Highly skilled and trained, well financed, and very good support structure. Conducts extensive planning.
Vehicle-Borne Bomb	Car Van Mid-Size Truck Large Truck (18-Wheeler)	Attempt to maximize death/damage through most productive direct means. Cause fear on the national/local level.	Terror, destroy assets, facilities	Extensive knowledge of water utility operations, facility layouts, and security system. Highly skilled and trained, well financed, and very good support structure. Conducts extensive planning.
Contamination of Product	Biotoxin Chemical Pathogen Radionuclide	Contaminate water distribution system to cause deaths, injuries, and/or economic damage.	Terror	Minimal knowledge of water utility operations, facility layouts, and distributions system. Minimally skilled and trained.
	Explosive	Weaponize wastewater collection system.		Minimal knowledge of water utility operations, facility layouts, and distributions system. Skilled and trained in explosives.
Directed / Sabotage	Physical Insider (Sabotage)	Sabotage by causing harm by damaging, disabling, or destroying process control systems.	Sabotage	Extensive knowledge of water utility operations and process control system. Authorized physical access to most locations. Will attempt to first use authorized access areas.
	Physical Outsider (Sabotage)		Sabotage, unauthorized access	Extensive knowledge of water utility operations and facility layouts. Highly skilled and trained.
	Active Shooter	Disrupt utility mission - maximize loss of mission capability, loss of life and/or economic damage. Cause fear on the national/local level.	Terror, destroy assets	Extensive knowledge of water utility operations, facility layouts, and security system. Highly skilled and trained, well financed, and very good support structure. Conducts extensive planning.
Theft or Diversion	Physical Insider	Steal or divert information, dangerous substances, valuable resources, etc.	Theft	Extensive knowledge of water utility operations and process control system. Authorized physical access to most locations. Will attempt to first use authorized access areas.

CATEGORY	HAZARDS	OBJECTIVE	MOTIVE	KNOWLEDGE
	Physical Outsider		Theft, unauthorized access	Extensive knowledge of water utility operations and facility layouts. Highly skilled and trained.
Cyber	Cyber Attack	Sabotage by causing harm by damaging, disabling, or destroying process control systems.	Sabotage	Extensive knowledge of water utility operations and process control system. Authorized physical and cyber access to most locations. Will attempt to first use authorized access points.

2.2.3 NATURAL HAZARDS

Our approach to natural hazards focused on conducting a detailed assessment of historical and potential events that could impact the facility. This included identifying earthquakes, volcanic eruption, landslides, pandemics, hurricanes, tornadoes, floods, ice storms, aliens attack and wildfires relevant to the facility's location. Recognizing the variability in magnitude of such hazards, the analysis prioritized understanding the lowest magnitude of each event that could pose unacceptable risks to continued operations.

The detailed event descriptions provided in AWWA J100-21 served as a foundational reference, supplemented with localized data and expert insights to reflect regional conditions accurately. A summary of the natural hazards by category is given in **Table 6**.

Table 6: Natural hazards threats summary (Adapted from J100-21, Table A7)

NATURAL HAZARD THREATS BY CATEGORY						DEPENDENCY & PROXIMITY THREATS	
Earthquake	**Floods**	**Hurricanes**	**Ice Storms**	**Tornadoes**	**Wildfires**	**Dependency**	**Proximity**
EQ1 - PGA 0.0–0.2	F1 - 100-year flood	H1 - Category 1	I0 - Minimal damage	T0 - Fujita 0	W1 - Minor	D(T) – Transportation	D(P) – Proximity
EQ2 – PGA 0.2–0.4	F2 - 500-year flood	H2 - Category 2	I1 – Isolated outages	T1 - Fujita 1	W2 - Major	D(C) – Key customers	
EQ3 – PGA 0.4–0.8		H3 - Category 3	I2 – Scattered outages	T2 - Fujita 2		D(E) – Key employees	
EQ4 – PGA 0.8–1.1		H4 - Category 4	I3 – Numerous Outages	T3 - Fujita 3		D(S) – Key suppliers	
EQ 5 – PGA >1.1		H5 - Category 5	I4 – Prolonged Outages	T4 - Fujita 4		D(U) – Utilities	
			I5 - Widespread Outages	T5 - Fujita 5			

2.2.3.1 EARTHQUAKES

The AWWA J100 standard classifies earthquake intensity by peak ground acceleration (PGA). However, there is limited information available from Canadian historical databases that record or publish in PGAs. The Government of Canada's Earthquake Database, for instance, publishes historical earthquake data using the Richter Magnitude Scale.

There is no relation between Richter scale and PGA; the Richter scale measures the magnitude of earthquake from its epicenter while the PGA scale uses root-mean-squared values to quantify the intensity of earthquake at the surface. In light of this, the estimated consequences of the scale magnitudes are given in **Table 7.**

Table 7: Estimated consequences between peak ground acceleration scale and Richter scale

CODE	AWWA J100 SCALE	AWWA J100 DESCRIPTION	RICHTER MAGNITUDE EQUIVALENT
EQ1	PGA 0.0–0.2	Earthquake with weak to light shaking, causing minimal structural damage.	4
EQ2	PGA 0.2–0.4	Earthquake with moderate to strong shaking, causing light to moderate damage, particularly to poorly built or badly designed structures.	5
EQ3	PGA 0.4–0.8	Earthquake with very strong to severe shaking, causing moderate to heavy damage to integrity of masonry and frame structures.	6
EQ4	PGA 0.8–1.1	Earthquake with violent shaking, causing heavy damage, partial building collapses, and potentially shifting structures off foundations; some underground pipes are broken.	7
EQ5	PGA >1.1	Earthquake with extreme shaking, causing very heavy damage to masonry, frame structures, foundations, dams, and bridges; considerable damage to underground pipelines; large landslides may occur.	8

To best compare against relevant and available information in Canadian databases, the Richter magnitude equivalents have been adopted for this study.

In order for an earthquake to have a measurable impact, the magnitude must be sufficiently high and the proximity of the epicenter to the subject location must within an appreciable distance. To be conservative and account for worst-case-scenario conditions (i.e., non-diminishing seismic propagation, size of fault), the magnitude is assumed constant across the entire radius of effect. The range of effectiveness of the different earthquake magnitudes and the number of earthquakes within each range of Iqaluit since 1985 (earliest-recorded event) is given in **Table 8**.

Table 8: Earthquake events of different magnitudes at different distances from Iqaluit since 1985 (Government of Canada, 2024)

MAGNITUDE	EARTHQUAKE EVENTS BY DISTANCE TO IQALUIT					
	<3.2 KM	<10 KM	<32 KM	<100 KM	<320 KM	<1,000 KM
4	0	0	0	0	3	123
5	0	0	0	0	0	5
6	0	0	0	0	0	6
7	0	0	0	0	0	0
8	0	0	0	0	0	0
9	0	0	0	0	0	0

Red = Within range of effectiveness.

Green = Outside range of effectiveness.

Since the first recorded event in 1985, there have been no recorded earthquakes within the range of effectiveness of each of the different magnitudes. In light of this, it is expected that no recorded events have caused damage to municipal infrastructure. A map of recorded magnitude 4 and greater earthquake events within a 1,000 km radius of Iqaluit since 1985 is given in **Figure 3**.

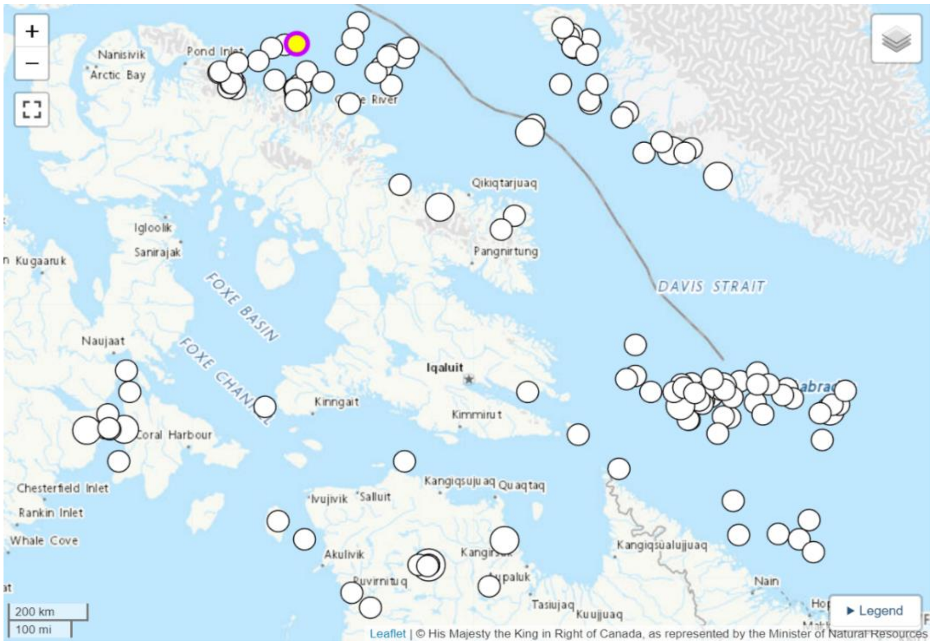


Figure 3: Recorded magnitude 4 and greater earthquake events within a 1,000 km radius of Iqaluit since 1985

Note: Size of event marker proportional to magnitude of earthquake. Marker size not indicative of radius of effect.

Given the lack of recorded earthquake events within an effective range of Iqaluit since 1985, the risk of damage to municipal water infrastructure due to earthquakes is assessed as *very low*.

2.2.3.2 FLOODS

Information of flood events (and other events in this section) were gathered from the Canadian Disaster Database (CDD). The CDD tracks significant disaster events that conform to the Emergency Management Framework for Canada definition of a disaster and meet one or more of the following criteria:

- 10 or more people killed
- 100 or more people affected/injured/infected/evacuated or homeless
- an appeal for national/international assistance
- historical significance
- significant damage/interruption of normal processes such that the community affected cannot recover on its own

According to the CDD, there have been no recorded flood events in Iqaluit since 1900. Only one (1) flood event has been recorded in Nunavut which occurred in Pangnirtung in 2008 with no fatalities, injured, or evacuated, and had damages estimated at $4,507,509.

Although not logged onto the Canadian Disaster Database, news media outlets reported flooding in Iqaluit in July 2016. During the event, approximately 72 mm of rain had fallen on one day, and the total precipitation during the month of July had more than doubled historical averages. This resulted in the temporary closure of Bypass Road in the Apex district. No information is available on damages, if any, to municipal infrastructure.

Given the lack of recorded flood events in Iqaluit, the risk of damage to municipal water infrastructure due to flooding is assessed as *very low*.

2.2.3.3 HURRICANES

According to the CDD, there are no major storm-related events that have been recorded in Nunavut since 1900. This included the following searchable fields within the database:

- Hurricane / Typhoon / Tropical Storm
- Storm – Unspecified / Other
- Storm Surge
- Storms and Severe Thunderstorms

Given the lack of recorded storm-related events in Iqaluit, the risk of damage to municipal water infrastructure due to storm events is assessed as *very low*.

2.2.3.4 ICE STORMS

According to the CDD, there has been one reported winter storm in Nunavut, which occurred in Iqaluit on February 8th, 1979. The recorded entry of the event is given in **Table 9**.

Table 9: Winter storm event in Iqaluit in 1979 (Canadian Disaster Database, 2024)

Place	Iqaluit, Nunavut
Event Start Date	February 8, 1979
Event End Date	February 19, 1979
Comments	Two winter storms affected Frobisher Bay (now Iqaluit). The first system affected the area on February 8th and persisted to the 16th, and the second moved in on February 18 and 19th. During this time, the temperatures were between -35C and -40C with winds gusting from 80-100 km/hr. The outdoor conditions were so hazardous that many had to remain indoors for the entire duration of the storms (~10 days).
Fatalities	Unknown
Injured / Infected	0
Evacuated	0
Estimated Total Cost	Unknown

2.2.3.5 TORNADOES

Tornado intensity is classified using Fujita (F) scale, or Enhanced Fujita (EF) scale. Starting in April 2013, Environment Canada's Weather Service introduced the EF scale (a new, more modern and improved version of the original F-scale) to measure the intensity of wind damage. This scale is a slightly modified version to the original EF scale that was implemented in the United States in 2007. The Canadian classification categorizes tornadoes from Fujita 0 (EF0) to Fujita 5 (EF5), with wind speeds ranging from 90 – 130 km/h and causing light damage, to the most severe category Fujita 5, with wind speeds exceeding 315 km/h and causing incredible damage. When only visual evidence of a tornado is available, and the damage is non-surveyable to an EF-scale damage indicator, a rating of EF0-Default is assigned.

According to CDD, although there has been a series records of tornados found in many Canada areas (e.g., southern Ontario, Manitoba, Saskatchewan, and Quebec), there have been no recorded tornadoes in Nunavut or the surrounding regions from 1900 to 2024. This is primarily due to Nunavut's arctic climate and geographic location which does not favor the formation of severe thunderstorms. Such an absence of historical tornado incidents suggests that the threat level for tornadoes in Iqaluit as well as adjacent arctic and subarctic regions is extremely low. Hence, the specific risks posed by tornadoes to infrastructure and local communities in Iqaluit is minimal.

2.2.3.6 WILDFIRES

Iqaluit's Arctic climate, permafrost soil and sparse vegetation, in general, do not promote the propagation of wildfires whether they are flammable or smouldering files. According to CDD, there are no recorded incidents of wildfires in Nunavut from 1900 to 2024. The likelihood of having a wildfire event in every 35 years is rare, implying the natural threat of wildfires in Iqaluit is essentially negligible. Given the minimal risks of wildfires, the risks on infrastructure and local communities in Iqaluit are *very low*.

2.2.4 CLIMATE

In accordance with the climate considerations for the LTWP – we adopted a forward-looking and regionally informed approach to identify risks associated with changing environmental conditions. Our approach considered not only the direct impacts of these hazards but also their cascading effects, such as disruptions to supply chains, infrastructure, and community resources.

The climate hazards identified for this project were determined based on historical weather data and statistics (where available) and an analysis of two scenarios for projected future climates, supplemented where necessary by a literature review of climate hazards, and taking into account considerations of associated uncertainty. The likelihood of exposure was modulated by the confidence in climate projections, as the accuracy of modeling tools, methods, and data availability vary.

Understanding changes in exposure requires analysis of a range of climate projections over the course of the project and project component's intended lifespan (25 years). Climate change projections are founded on four scenarios of future GHG concentrations known as Representative Concentration Pathways (RCPs). These RCPs provide a range of possible trajectories of how global land use and emissions of GHGs, and air pollutants may change throughout the 21st century. They are named according to their radiative forcing values (the change in net irradiance in the troposphere due to external drivers) in the year 2100: RCP2.6, RCP4.5, RCP6.0, RCP8.5. RCP2.6 represents the least carbon intensive pathway (also known as "Net-Zero"), while RCP8.5 represents the most carbon intensive pathway ("Business-as-usual"). RCP4.5 and RCP8.5 were selected for this study to best represent exposure in both low carbon and high carbon futures.

Climate models also use baseline data as a reference period from which to derive and compare future changes in climate. Typically, a 30-year period of historic data of the climate variable that is being projected, such as temperature or precipitation, is used as a means of comparison. The choice of baseline years varies from study to study, and is largely dependent on the availability of data, data quality, and the intended purpose of comparison. This variability can be seen throughout the section that follows, as each unique data source may choose to use a different baseline period.

The hazard identification presented here draws strongly on the Pacific Climate Impacts Consortium (PCIC) downscaled models provided through the Climate Atlas online interface (Climate Atlas of Canada, 2019). CMIP5 data was used to underpin the findings of the Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC). The PCIC downscaled data was derived from 24 CMIP5 global climate models (GCMs). It uses a modelled baseline data from 1976 to 2005 and provides climate projections for two future time slices: 2021 to 2050 and 2051 to 2080. This data is presented for two different spatial resolutions and on grid points: a large grid corresponding to the 1:250,000 National Topographic System Index map, a small grid corresponding to the 1:50,000 map, and a grid point system for key municipalities, such as Iqaluit. For this project, we have extracted data with the grid point system of the PCIC data for the Iqaluit location.

A hydrologic tool developed by Western University (IDF_CC) compiles intensity-duration-frequency (IDF) curve data for various rainfall gauges in Canada. For extreme precipitation statistics, climate projections are provided by this tool, which is the result of the use of precipitation data from Environment and Climate Change Canada stations, spatial interpolations and future statistics based on 24 global climate models and nine regional models. Based on historical statistics and different RCP scenarios, IDF curves and their uncertainties are generated for different envisaged futures. This tool provides, among other things, the evolution of the maximum hourly or daily cumulative precipitation with different return periods ranging from 2 to 100 years. For this assessment, the Iqaluit Climate Station (ID2402592) was selected as it is the closest to the project site. While the IDF_CC tool assumes temporal stationarity in the variance between sub-hourly and daily data, its data still better captures the potential increase in extreme precipitation events than the downscaling techniques on which the Climate Atlas relies.

2.2.4.1 TEMPERATURE

Under RCP4.5 and RCP8.5, mean annual and seasonal temperatures for Iqaluit are projected to increase (see **Table 10** and **Table 11**). While all seasons are projected to see a rise in average temperature, winters would see the highest annual temperature increase of 6.2°C and 9.2°C under RCP4.5 and RCP8.5 scenarios respectively, by 2080. Summers would experience the smallest annual temperature rise of 2.5°C and 3.8°C under RCP4.5 and RCP8.5 scenarios respectively.

Table 10: Summary of historical and projected mean annual and seasonal temperatures for Iqaluit under RCP4.5

VARIABLE	UNIT	1976-2005 MEAN	2021-2050 MEAN	2051-2080 MEAN	2051-2080 MEAN CHANGE	SOURCE
Temperature - Annual	°C	-9.2 (10.6,-7.7)	-6.9 (-8.6,-4.8)	-5.4 (-7.3, -3.2)	+3.8	PCIC
Temperature - Spring	°C	-13.6 (-15.8, -11.1)	-11.7 (-14.3, -8.8)	-10.3 (-13.1, -6.7)	+3.3	PCIC

VARIABLE	UNIT	1976-2005 MEAN	2021-2050 MEAN	2051-2080 MEAN	2051-2080 MEAN CHANGE	SOURCE
Temperature - Summer	°C	5.8 (4.5, 7.3)	7.4 (5.6, 9.5)	8.3 (6.1, 10.7)	+2.5	PCIC
Temperature - Fall	°C	-4.9 (-7.0, -2.9)	-2.8 (-4.8, -0.8)	-1.6 (-3.6, 0.4)	+3.3	PCIC
Temperature - Winter	°C	-24.3 (-27.7, -20.7)	-20.6 (-24.5, -16.2)	-18.1 (-22.1, -13.6)	+6.2	PCIC

Note: Numbers in brackets represent the 10th and 90th percentile of model outputs respectively.

Table 11: Summary of historical and projected mean annual and seasonal temperatures for Iqaluit under RCP8.5

VARIABLE	UNIT	1976-2005 MEAN	2021-2050 MEAN	2051-2080 MEAN	2051-2080 MEAN CHANGE	SOURCE
Temperature - Annual	°C	-9.2 (10.6,-7.7)	-6.4 (-8.0,-4.5)	-3.5 (-5.5,-1.0)	+5.7	PCIC
Temperature - Spring	°C	-13.6 (-15.8, -11.1)	-11.2 (-13.7, -8.5)	-8.7 (-11.7, -4.4)	+4.9	PCIC
Temperature - Summer	°C	5.8 (4.5, 7.3)	7.6 (5.8, 9.6)	9.6 (7.0, 12.5)	+3.8	PCIC
Temperature - Fall	°C	-4.9 (-7.0, -2.9)	-2.3 (-4.3, -0.4)	0 (-2.3, 2.3)	+4.9	PCIC
Temperature - Winter	°C	-24.3 (-27.7, -20.7)	-19.9 (-23.6, -15.5	-15.1 (-19.0, -10.5)	+9.2	PCIC

Note: Numbers in brackets represent the 10th and 90th percentile of model outputs respectively.

In addition to the general warming trend, Iqaluit is projected to see an increase in the highest maximum temperature and number of summer days (see **Table 12** and **Table 13**). The highest maximum temperature is expected to increase by 2.8°C and by 4.2°C under RCP4.5 and RCP8.5 respectively for 2080 projections. The number of summer days, which are days when the maximum temperature is above 25°C, will increase from 0 to 0.5 under RCP4.5, and 1.2 days under RCP8.5. We also looked at very hot days (+30°C), extremely hot days (+32°C) and heat waves, but none have been observed in the past and the projections don't show a change.

Table 12: Summary of historical and projected high temperature extremes for Iqaluit under RCP4.5

VARIABLE	UNIT	1976-2005 MEAN	2021-2050 MEAN	2051-2080 MEAN	2051-2080 MEAN CHANGE	SOURCE
Average Warmest Maximum Temperature	°C	18.9 (14.9, 23.0)	20.6 (16.2, 25.1)	21.7 (17.2, 26.3	+2.8	PCIC
Summer Days	#	0.0 (0.0, 0.0)	0.2 (0.0, 1.1)	0.5 (0.0, 1.9)	+0.5 (50%)	PCIC

Note: Numbers in brackets represent the 10th and 90th percentile of model outputs respectively.

Table 13: Summary of historical and projected high temperature extremes for Iqaluit under RCP8.5

VARIABLE	UNIT	1976-2005 MEAN	2021-2050 MEAN	2051-2080 MEAN	2051-2080 MEAN CHANGE	SOURCE
Average Warmest Maximum Temperature	°C	18.9 (14.9, 23.0)	20.7 (16.1, 25.2)	23.1 (18.1,28.1)	+4.2	PCIC
Summer Days	#	0.0 (0.0, 0.0)	0.3 (0.0, 0.1)	1.2 (0.0, 4.7)	+1.2 (120%)	PCIC

Note: Numbers in brackets represent the 10th and 90th percentile of model outputs respectively.

Winter temperatures are also projected to increase under RCP4.5 and RCP8.5. By 2051-2080, there is a projected decrease of very cold days under -30°C (- 38.2 under RCP4.5 and -49 days under RCP8.5), number of frost days (-28.6 under RCP4.5 and -43.4 days under RCP8.5), freezing degree days (-1064 under RCP4.5 and -1558 days under RCP8.5), icing days (-22.8 under RCP4.5 and -37.4 days under RCP8.5), mild winter days with mean temperature below -5°C (-22.8 under RCP4.5 and -36.7 days under RCP8.5), and winter days of less than -15°C (-32.8 days under RCP4.5 and -53.1 days under RCP8.5) (**Table 14** and **Table 15**). In addition, there is a projected increase in the lowest minimum temperature (+5.8 under RCP4.5 and +9.3°C under RCP8.5).

Table 14: Summary of historical and projected low temperature extremes for Iqaluit under RCP4.5

VARIABLE	UNIT	1976-2005 MEAN	2021-2050 MEAN	2051-2080 MEAN	2051-2080 MEAN CHANGE	SOURCE
Very Cold Days (-30°C)	Days	56.3 (37.7, 76.2)	31.2 (7.9, 51.6)	18.1 (0.8, 37.0)	-38.2 (68%)	PCIC
Lowest Minimum Temperature	°C	-40.8 (-43.6, -37.8)	-37.4 (-41.2, -33.1)	-34.9 (-39.4, -29.2)	+5.9	PCIC
Frost Days	Days	271.3 (275.1, 284.4)	252.7 (232.8, 270.6)	242.7 (221.6, 263.3)	-28.6 (11%)	PCIC

VARIABLE	UNIT	1976-2005 MEAN	2021-2050 MEAN	2051-2080 MEAN	2051-2080 MEAN CHANGE	SOURCE
Freezing Degree Days	Days	3971 (3489, 4432)	3318 (2725, 3833)	2907 (2239, 3464)	-1064 (27%)	PCIC
Icing Days	Days	216.7 (201.9, 231.1)	203.4 (183.5, 221.2)	193.9 (166.7, 214.9)	-22.8 (11%)	PCIC
Mild Winter Days (-5°C)	Days	214.6 (201.4, 227.4)	200.8 (183.6, 217.0)	191.8 (172.5, 209.6)	-22.8 (11%)	PCIC
Winter Days (-15°C)	Days	152.5 (134.1, 169.5)	134.0 (111.8, 154.3)	119.7 (90.5, 142.8)	-32.8 (22%)	PCIC
Freeze-Thaw Cycles	#	39.3 (27.4, 52.2)	36.3 (24.6, 49.0)	36.3 (23.3, 51.3)	-3 (8%)	PCIC

Note: Numbers in brackets represent the 10th and 90th percentile of model outputs respectively.

Table 15: Summary of historical and projected low temperature extremes for Iqaluit under RCP8.5

VARIABLE	UNIT	1976-2005 MEAN	2021-2050 MEAN	2051-2080 MEAN	2051-2080 MEAN CHANGE	SOURCE
Very Cold Days (-30°C)	Days	56.3 (37.7, 76.2)	26.4 (7.2, 46.1)	7.3 (0.0, 19.1)	-49 (87%)	PCIC
Lowest Minimum Temperature	°C	-40.8 (-43.6, -37.8)	-36.6 (-40.4, -32.4)	-31.5 (-36.1, -24.8)	+9.3	PCIC
Frost Days	Days	271.3 (275.1, 284.4)	249.3 (230.7, 266.6)	227.9 (206.7, 249.2)	-43.4 (16%)	PCIC
Freezing Degree Days	Days	3971 (3489, 4432)	3183 (2594, 3677)	2413 (1750, 2959)	-1558 (39%)	PCIC
Icing Days	Days	216.7 (201.9, 231.1)	199.8 (178.6, 218.08)	179.3 (148.9, 202.6)	-37.4 (17%)	PCIC
Mild Winter Days (-5°C)	Days	214.6 (201.4, 227.4)	197.8 (180.3, 213.8)	177.9 (155.2, 197.8)	-36.7 (17%)	PCIC
Winter Days (-15°C)	Days	152.5 (134.1, 169.5)	129.8 (105.9, 149.5)	99.4 (65.4, 127.6)	-53.1 (35%)	PCIC
Freeze-Thaw Cycles	#	39.3 (27.4, 52.2)	36.5 (23.8, 50.8)	37.1 (22.9, 53.4)	-2.2 (6%)	PCIC

Note: Numbers in brackets represent the 10th and 90th percentile of model outputs respectively.

2.2.4.2 PRECIPITATION

Under RCP4.5 and RCP8.5, mean annual and seasonal precipitation for Iqaluit is projected to increase (see **Table 16** and **Table 17**). This increase is displayed during all seasons, but mostly in the fall (+22 mm under RCP4.5 and +34 mm under RCP8.5) and winter (+23 mm under RCP4.5 and +33 mm under RCP8.5). Combined with higher temperatures, precipitation previously only observed as snow will likely change to a mix of rain and snow, however the rain will not infiltrate the ground as long as the ground is frozen. Precipitation as rain will therefore act as runoff.

Table 16: Precipitation parameters for Iqaluit under RCP4.5

VARIABLE	UNIT	1976-2005 MEAN	2021-2050 MEAN	2051-2080 MEAN	2051-2080 MEAN CHANGE	SOURCE
Precipitation - Annual	mm	450 (356, 551)	497 (401, 611)	525 (412, 643)	+75 (17%)	PCIC
Precipitation - Spring	mm	82 (51, 116)	88 (54, 127)	93 (54, 134)	+11 (13%)	PCIC
Precipitation - Summer	mm	162 (103, 230)	178 (113, 250)	182 (112, 262)	+20 (12%)	PCIC
Precipitation - Fall	mm	129 (84, 181)	143 (94, 200)	151 (99, 209)	+22 (17%)	PCIC
Precipitation - Winter	mm	77 (46, 115)	89 (55, 130)	100 (59, 151)	+23 (30%)	PCIC

Note: Numbers in brackets represent the 10th and 90th percentile of model outputs respectively.

Table 17: Precipitation parameters for Iqaluit under RCP8.5

VARIABLE	UNIT	1976-2005 MEAN	2021-2050 MEAN	2051-2080 MEAN	2051-2080 MEAN CHANGE	SOURCE
Precipitation - Annual	mm	450 (356, 551)	504 (398, 617)	563 (454, 688)	+75 (25%)	PCIC
Precipitation - Spring	mm	82 (51, 116)	89 (53, 128)	99 (60, 143)	+17 (21%)	PCIC
Precipitation - Summer	mm	162 (103, 230)	174 (111, 246)	191 (118, 270)	+29 (18%)	PCIC
Precipitation - Fall	mm	129 (84, 181)	145 (95, 201)	163 (108, 224)	+34 (26%)	PCIC
Precipitation - Winter	mm	77 (46, 115)	93 (56, 136)	110 (68, 158)	+33 (43%)	PCIC

Note: Numbers in brackets represent the 10th and 90th percentile of model outputs respectively.

In addition to the general trend of increasing precipitation, the number of large precipitation events is projected to slightly increase for Iqaluit (Table 18 and Table 19) Heavy Precipitation Days of over 10 mm are projected to increase by 2.0 days/year under RCP4.5 and 3.1 days/year under RCP8.5. Heavy Precipitation Days of over 20 mm are projected to increase by 0.5 day/year under RCP4.5 and 0.8 day/year under RCP8.5. Maximum 1, 3, and 5-Day precipitation events are projected to increase by 4, 6 and 6 mm, respectively, under RCP4.5. Maximum 1, 3, and 5-Day precipitation events are projected to increase by 7, 9 and 9 mm, respectively, under RCP8.5. The number of Dry Days is projected to decrease by 19.9 days/year under RCP4.5 and 21.7 days/year under RCP8.5. The 24-hour precipitation totals for the 1:10 and 1:100 year storm events are projected to increase by 9.73 mm and 23.72 mm under RCP4.5, and 13.24 mm and 22.6 mm respectively under RCP8.5 (Table 20 and Table 21).

Table 18: Summary of historical and projected precipitation extremes for Iqaluit under RCP4.5

VARIABLE	UNIT	1976-2005 MEAN	2021-2050 MEAN	2051-2080 MEAN	2051-2080 MEAN CHANGE	SOURCE
Heavy Precipitation – (10 mm)	Days	7.1 (3.5, 11.1)	8.3 (4.2, 12.6)	9.1 (4.8, 14.1)	+2.0 (28%)	PCIC
Heavy Precipitation – (20 mm)	Days	1.2 (0.0, 2.9)	1.6 (0.0, 3.5)	1.7 (0.1, 3.6)	+0.5 (42%)	PCIC
Maximum 1-Day Precipitation	mm	24 (15, 35)	26 (16, 40)	28 (17, 41)	+4 (17%)	PCIC
Maximum 3-Day Precipitation	mm	31 (20, 47)	36 (22, 55)	37 (23, 56)	+6 (19%)	PCIC
Maximum 5-Day Precipitation	mm	39 (25, 57)	43 (28, 66)	45 (29, 66)	+6 (15%)	PCIC
Wet Days	#	215.9 (193.4, 237.7)	228.3 (205.5, 251.4)	233.7 (211.7, 255.4)	+17.8 (8%)	PCIC
Dry Days	Days	148.8 (127.0, 171.0)	136.4 (113.3, 159.4)	130.9 (108.8, 153.3)	-17.9 (12%)	PCIC

Note: Numbers in brackets represent the 10th and 90th percentile of model outputs respectively.

Table 19: Summary of historical and projected precipitation extremes for Iqaluit under RCP8.5

VARIABLE	UNIT	1976-2005 MEAN	2021-2050 MEAN	2051-2080 MEAN	2051-2080 MEAN CHANGE	SOURCE
Heavy Precipitation – (10 mm)	Days	7.1 (3.5, 11.1)	8.6 (4.4, 13.2)	10.2 (5.5, 15.6)	+3.1 (44%)	PCIC
Heavy Precipitation – (20 mm)	Days	1.2 (0.0, 2.9)	1.5 (0.0, 3.5)	2.0 (0.3, 4.1)	+0.8 (67%)	PCIC

VARIABLE	UNIT	1976-2005 MEAN	2021-2050 MEAN	2051-2080 MEAN	2051-2080 MEAN CHANGE	SOURCE
Maximum 1-Day Precipitation	mm	24 (15, 35)	27 (17, 40)	31 (19, 45)	+7 (29%)	PCIC
Maximum 3-Day Precipitation	mm	31 (20, 47)	36 (23, 52)	40 (26, 57)	+9 (29%)	PCIC
Maximum 5-Day Precipitation	mm	39 (25, 57)	44 (29, 63)	48 (32, 69)	+9 (23%)	PCIC
Wet Days	#	215.9 (193.4, 237.7)	228.8 (207.0, 250.4)	237.6 (216.4, 257.9)	+21.7 (10%)	PCIC
Dry Days	Days	148.8 (127.0, 171.0)	135.9 (114.4, 157.4)	127.1 (106.8, 148.2)	-21.7 (-15%)	PCIC

Note: Numbers in brackets represent the 10th and 90th percentile of model outputs respectively.

Table 20: Summary of historical and projected IDF for Iqaluit under RCP4.5 (future data: PCIC using bias correction)

VARIABLE	UNIT	1970-1992 MEAN	2021-2050 MEAN	2051-2080 MEAN	2051--2080 MEAN CHANGE	SOURCE
1:10 24-Hour Precipitation	mm	45.07	49.93 (42.90, 65.21)	54.80 (44.65, 62.21)	+9.73 (22%)	IDF_CC
1:100 24-Hour Precipitation	mm	74.63	85.85 (63.20, 179.78)	98.35 (61.00, 139.30)	+23.72 (32%)	IDF_CC

Note: Numbers in brackets represent the 25th and 75th percentile of model outputs respectively.

Table 21: Summary of historical and projected IDF for Iqaluit under RCP8.5 (future data: PCIC using bias correction)

VARIABLE	UNIT	1970-1992 MEAN	2021-2050 MEAN	2051-2080 MEAN	2051--2080 MEAN CHANGE	SOURCE
1:10 24-Hour Precipitation	mm	45.07	51.40 (39.71, 62.10)	58.31 (52.34, 65.09)	+13.24 (29%)	IDF_CC
1:100 24-Hour Precipitation	mm	74.63	90.42 (43.27, 153.29)	97.23 (86.53, 132.26)	+22.60 (30%)	IDF_CC

Note: Numbers in brackets represent the 25th and 75th percentile of model outputs respectively.

2.2.4.3 SNOW EVENTS AND COVER

Multiple factors impact snowfall amount and timing projections, including considerations of weather and climate conditions in multiple levels of the atmosphere, precipitation and temperature projections, and air moisture availability. The complexity of the projections makes future regional snow data difficult to create and find.

A study from Smith K.A. (2016) reports that 57% of precipitation in Iqaluit are received as snow, mostly from October to May, and rainfall predominates from June to September. And snowmelt is the largest contributor to the annual streamflow of the Apex River, delivered in a short-lived pulse during spring melt.

Historically, an extreme daily snowfall of 104.1 cm was recorded in April 1951 in Iqaluit (ECCC, 2020). The ratio of liquid to solid precipitation has been consistently increasing in most areas of Canada, especially due to spring and fall warming and the associated delayed occurrence of the first snowfall (CCCR, 2019). Snow cover, contrarily, does not exhibit a significant trend in the future (CCCR, 2019). **Figure 4** shows the projected change in snow cover across Canada for the years 2020-2050, with the approximate area of the project site circled in red and showing stable conditions.

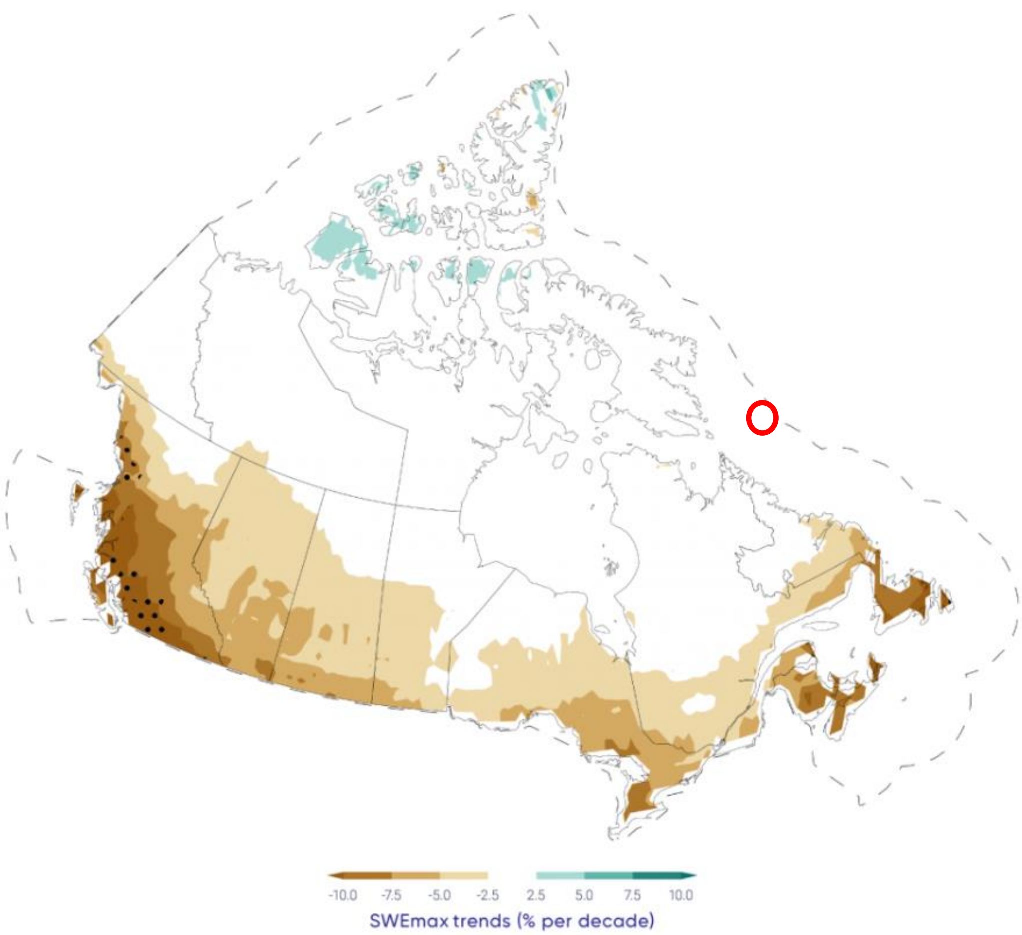


Figure 4: Projected trends in maximum snow water equivalent, 2020-2050 (CCCR, 2019)

2.2.4.4 SEA ICE COVER

Reductions of sea ice cover have been observed over Canadian waters in all seasons. **Figure 5** shows an observed decrease of 11 to 15% of sea ice cover in summer at Iqaluit. Winter sea ice has been observed to decrease in eastern Canada (7.6% between 1969 and 2016). It is very likely that these reductions will continue in the Canadian arctic. Most Canadian Arctic marine regions could be sea ice-free for at least one month in the summer by 2050.

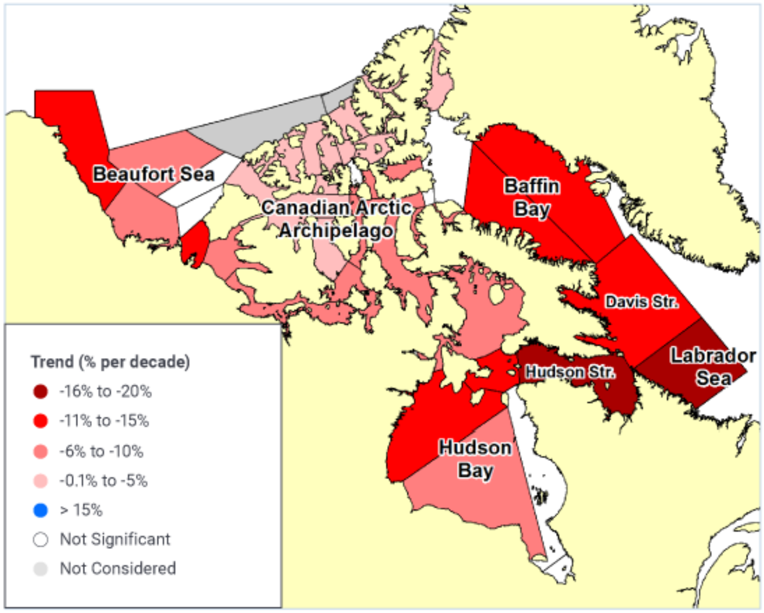
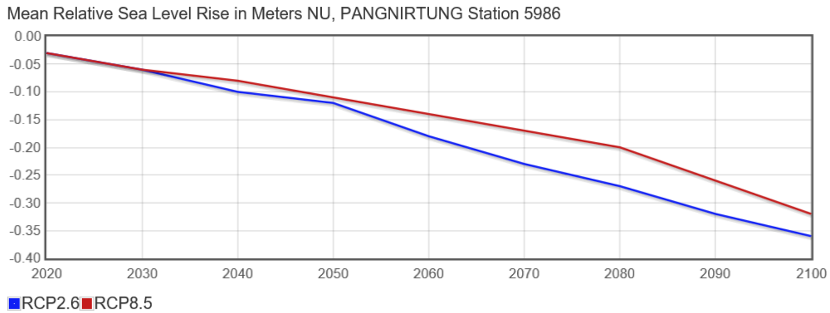


Figure 5: Trends in Arctic summer total ice, 1968-2016 (CCCR, 2019)

If the decline of sea ice would make the access to sea water easier, a geological phenomenom called "isostatic rebound", occurring at the same time as climate change should be considered. The land is rising across Nunavut because of the disappearance of large ice sheets that covered most of Canada during the last ice age. The loss of the ice sheet reduces the amount of weight on the land which is not rebounding back and rising to its former height. The projections for Parngnirtung (300 km North of Iqaluit) show a sea level decrease of 0.08 m by 2050 and 0.29 m by 2100 under RCP8.5 (**Figure 6**). Projections for RCP4.5 are not available but projections under RCP2.6 show a decrease very similar to the projections for RCP8.5.

CAN-EWLAT, PANGNIRTUNG, NU

Vertical Allowance | Sea Level Rise | Water Level | Wave Climate



	2020	2030	2040	2050	2060	2070	2080	2090	2100
RCP2.6	-0.03	-0.06	-0.1	-0.12	-0.18	-0.23	-0.27	-0.32	-0.36
RCP8.5	-0.03	-0.06	-0.08	-0.11	-0.14	-0.17	-0.2	-0.26	-0.32

Figure 6: Sea level projections for Pangnirtung, NU (Bedford Institute of Oceanography, 2020)

2.2.5 RANGE OF MAGNITUDES

Table 22 and **Table 23** summarizes our findings for natural and climate trends could have an impact on the City's Public Water System.

Table 22: Summary of natural hazards and their potential impact on water supply for the City of Iqaluit

	HAZARD	RANGE OF MAGNITUDE	CANADIAN DISASTER DATABASE EVENTS	RISK LEVEL
Natural	Earthquakes	Minimal	None Recorded	Very Low
	Floods	Minimal	None Recorded	Very Low
	Hurricanes	Minimal	None Recorded	Very Low
	Ice Storms	Minimal to Mild	One (1)	Very Low
	Tornadoes	Minimal	None Recorded	Very Low
	Wildfires	Minimal	None Recorded	Very Low

Table 23: Summary of climate trends and their potential impact on water supply for the City of Iqaluit

	HAZARD	RANGE OF MAGNITUDE	COMMENTS	RISK LEVEL
Climate	Temperatures	Minimal	Advantages: Potential earlier spring freshet and ice melt, resulting in earlier recharge of Lake Geraldine. Disadvantages: Potential for lesser recharge of Lake Geraldine from the Apex River if freshet ends too early. More evaporation may occur in summer.	Very Low
	Precipitation	Minimal	Advantages: Potential for increase recharge in Lake Geraldine and Apex River. May slow down ice formation and ice cover. Rain in winter can promote ice thinning. Disadvantage: If the precipitation is rain and ground is fully frozen, rate of infiltration may be very low.	Very Low
	Snow Events and Cover	Minimal	Advantages: Melting snows in spring and summer provides additional water supply to Lake Geraldine. Winter snow cover reduces evaporation, preserving available water. Disadvantage: Snow cover makes it difficult to access water for potable supply, specially under emergency conditions.	Very Low
	Sea Ice Cover	Minimal	Advantage: If sea water is used as a future water source, it will be more easily available.	Very Low

2.2.6 DEPENDENCY HAZARDS

Dependency hazards include interruptions of utilities, suppliers, employees, customers, and transportation due to their respective dependency on other systems, and proximity of these systems to dangerous neighboring sites. Iqaluit, being a relatively isolated community, experiences little to no risks associated with proximity to nearby municipalities or activities (i.e., a nearby uranium mine site). However, Iqaluit is heavily dependent on imported goods such as those that arrive via aircraft and the biennial sealift. Further, many of the internal systems depend on one another for proper functionality, such as how the SCADA system automates the pumps and valves in the booster stations. **Table 24** outlines the dependency hazards of each major PWS subsystem for both internal and external risks.

Table 24: Internal and external dependency hazards for major Iqaluit Public Water System components.

SYSTEM	SUB-SYSTEM	INTERNAL DEPENDENCIES	EXTERNAL DEPENDENCIES
Lake Geraldine			
Lake Geraldine Dam		Lake Geraldine	
Intake Structures			

SYSTEM	SUB-SYSTEM	INTERNAL DEPENDENCIES	EXTERNAL DEPENDENCIES
	Lake Geraldine Access Structure	Lake Geraldine Lake Geraldine Dam	
	Raw Water Tempering System	Raw Water Intake (for raw water flow)	Electrical Power Supply Fuel Supply
	Raw Water Intake Piping	Raw Water Tempering System	
Water Treatment Plant			
	Ultraviolet (UV) Disinfection System	SCADA System (Automated Functionality) Lake Geraldine	Electrical Power Supply
	Filtration System	SCADA System (Automated Functionality) UV Disinfection System (to meet Licensed Disinfection Requirements)	
	Filtration Backwash Systems	Filtration System (to meet Licensed Disinfection Requirements) SCADA System (Automated Functionality)	Electrical Power Supply
	Chlorine Dosing Systems	SCADA System (Automated Functionality)	Electrical Power Supply
	Optional Chemical Dosing Systems	SCADA System (Automated Functionality)	Electrical Power Supply
	Clearwell Storage	Filtration System (for flow of water in) Treated Water Storage (to assist with meeting disinfection requirements)	
	Sampling & Monitoring Programs	Operations Personnel	Third-Party Laboratory Testing
Treated Water Reservoir		Clearwell Storage	
Piped Treated Water Distribution System			
	Access Vaults	Operations Personnel	Available Labour market
	Piping & Appurtenances	SCADA System (Automated Functionality)	Electrical Power Supply Fuel Supply

SYSTEM	SUB-SYSTEM	INTERNAL DEPENDENCIES	EXTERNAL DEPENDENCIES
	Combination Pumping & Reheat Stations	SCADA System (Automated Functionality)	Electrical Power Supply Fuel Supply
	Reheat Stations	SCADA System (Automated Functionality)	Electrical Power Supply Fuel Supply
Trucked Services		Operations Personnel	Electrical Power Supply Fuel Supply
SCADA System		Operations Personnel	Electrical Power Supply
Operations Personnel		SCADA System	Third-Party Consultants Available Labour Market

2.2.7 THREATS EXCLUDED FROM ANALYSIS

Although the Standard provides a comprehensive matrix of potential risks and hazards, a number of threat-asset pairs (TAPs) are not applicable within the context of Iqaluit. In light of this, these TAPs have been removed from further consideration in this assessment. Of note, not all threats were excluded from the analysis as each asset identified in this resilience assessment has certain threats that were deemed unnecessary. The full list of exclusions from the Standard and their corresponding justifications are provided in **Table 25**. The TAPs used for analysis in the Consequence Analysis is shown in **Table 29**.

Table 25: Threats and hazards Excluded and their Justifications

	HAZARD	THREAT	JUSTIFICATION FOR EXCLUSION
Directed Threats	**Maritime**	All ➢ Small Boat ➢ Fast Boat ➢ Barge ➢ Deep Draft Ship	All of Iqaluit's PWS infrastructure is on the mainland. A targeted boat-borne bomb or assault specifically targeting water infrastructure is impractical. In the case of the water infrastructure at Lake Geraldine, the accessibility of the Lake for launching a boat or barge is severely limited or impractical.
	Cyber	Lake Geraldine, Lake Geraldine Lake Dam, Lake Geraldine Intake Systems, Treated Water Reservoir and Distribution System ➢ Cyber Attack	There is very limited high-value cyber targets in Iqaluit's water infrastructure due to limited automation systems. Therefore, nothing is feasible to hack for most assets except for a few with digital components such as SCADA.
	Assault Team	Distribution System ➢ 1 Assailant ➢ 2-4 Assailants ➢ 5-8 Assailants ➢ 9-16 Assailants	Iqaluit's extremely low population and geographical remoteness limits the possibility of having assault teams to establish physical attacks.

	HAZARD	THREAT	JUSTIFICATION FOR EXCLUSION
	Directed / Sabotage	Lake Geraldine, Lake Geraldine Dam, Lake Geraldine Intake Systems ➢ Physical Insider ➢ Physical Outsider Distribution System and SCADA System ➢ Active shooter	Iqaluit's water infrastructure serves the local community and typically does not face threats of motivated direct sabotage.
	Theft or Diversion	Lake Geraldine, Lake Geraldine Dam, Lake Geraldine Intake Systems and Distribution System ➢ Physical Insider ➢ Physical Outsider	Iqaluit water system is absent of high-value assets that would incentivize theft or diversion. Iqaluit water system is located at remote areas that would also deter such activities.
	Contamination of Product	Lake Geraldine ➢ Biotoxin ➢ Explosive ➢ Pathogen Lake Geraldine Dam ➢ Biotoxin Lake Geraldine Intake Systems ➢ Biotoxin ➢ Pathogen SCADA System ➢ Biotoxin ➢ Chemical ➢ Explosive ➢ Pathogen ➢ Radionuclide	Effects of contamination of products to Iqaluit would be dependent on specific assets and shall be analyzed on a case-by-case basis. For instance, WTP is excluded from biotoxin and pathogen due to its effective treatment. SCADA is excluded from all 5 categories as they do not apply.
Natural	**Earthquakes**	All ➢ Magnitude 4 ➢ Magnitude 5 ➢ Magnitude 6 ➢ Magnitude 7 ➢ Magnitude 8+	There is no documented history of impactful seismic activity in or around Iqaluit (refer to **Table 22**). In light of this, the risk of seismic activity is negligible and unquantifiable.
	Tornadoes	All ➢ Fujita 0 ➢ Fujita 1 ➢ Fujita 2 ➢ Fujita 3 ➢ Fujita 4 ➢ Fujita 5	There is no documented history of tornadoes in or around Iqaluit. In light of this, the risk of tornadoes is negligible and unquantifiable.
	Wildfires	All ➢ Minor ➢ Major	The local vegetation in and around Iqaluit includes mosses, shrubs, and other low-lying vegetation. As a matter of explanation, there it is infeasible that existing vegetation could perpetuate an impactful wildfire event.

	HAZARD	THREAT	JUSTIFICATION FOR EXCLUSION
Depend on	**Proximity**		There are no nearby communities or industries that could have a reasonable impact on Iqaluit.

All other TAPs included in the Standard, as well as local-specific TAPs, have been included in the assessment further herein.

2.3 CONSEQUENCE ANALYSIS

The consequence analysis evaluates the most significant potential impacts resulting from identified threats to critical assets. It provides a framework to understand the effects of disruptions on operations, safety, and the broader community.

2.3.1 APPROACH

Our analysis considered various threat scenarios and quantified their impacts using established metrics, including:

- The number of serious injuries.
- The number of fatalities.
- The total human casualties, accounting for fatalities, injuries, and illnesses, weighted by severity.
- Service outages, measured as the daily quantity of unmet demand and the duration in days.
- Financial losses incurred by the utility, including repair and replacement costs.
- Economic losses to the regional economy, expressed as reductions in economic activity.

Each metric was calculated as a single-point estimate to provide clear, actionable insights for decision-making. Ranges or probability distributions and/or detailed calculations were used in more complex estimates, where required. The consequence analysis was partially informed from written and verbal accounts of operations, management, and other municipal staff. Where appropriate, other non-quantifiable losses, such as degradation of consumer confidence, environmental impact, and losses to municipal function, have been discussed.

2.3.1.1 APPROACH TO THREAT CATEGORIES

A “worst reasonable case” set of assumptions for each threat scenario has been applied, in accordance with **Table 26**.

Table 26: Worst reasonable case approach for threat categories

CATEGORY	ASSUMPTIONS
Malevolent Threats	➢ Adversaries are intelligent, adaptive, and knowledgeable about the utility's structure, operations, and processes. ➢ Adversaries aim to optimize or maximize the consequences of specific attack scenarios.
Natural Hazards	➢ All reasonable event magnitudes are assumed to ensure preparedness for a broad range of scenarios.
Dependency Hazards	➢ Complete loss of critical factors (e.g., utilities, chemicals, customers) is assumed for durations sufficient to disrupt the utility's functionality.
Proximity Threats	➢ The worst reasonable event occurring at nearby sites is assumed based on the nature of the site.
Uncontrollable Variables and Unpredictable Events	➢ Assumptions do not include all uncontrollable variables (e.g., wind speed, direction) or unpredictable events occurring simultaneously, focusing instead on realistic worst-case scenarios.

2.3.1.2 APPROACH TO INJURIES, SICKNESSES, AND FATALITIES

Our approach to estimating serious injuries and illnesses involved assessing the number of individuals—both employees and non-employees, on-site and off-site—who could be affected by a threat-asset incident. This included accounting for those who might experience delayed effects, such as fatalities occurring more than 30 days after the incident. Weighted lifetime cost factors and direct costs associated with each level of severity used in this study are given in **Table 27**.

Table 27: Serious injury/illness and fatalities factors (Adapted from J100-21, Table 2)

AIS LEVEL	SEVERITY	EXAMPLES	WEIGHTED LIFETIME COST	DIRECT COST (K$)
1	Minor	Superficial abrasion or laceration of skin; digit sprain; first-degree burn; head trauma with headache or dizziness (no other neurological signs).	0.030	1
2	Moderate	Major abrasion or laceration of skin; cerebral concussion (unconscious less than 15 minutes); finger or toe crush/amputation; closed pelvic fracture with or without dislocation.	0.0470	5
3	Serious	Major nerve laceration; multiple rib fracture (but without flail chest); abdominal organ contusion; hand, foot, or arm crush/amputation.	0.105	15
4	Severe	Severe spleen rupture; leg crush; chest-wall perforation; cerebral concussion with other neurological signs (unconscious less than 24 hours).	0.266	50

AIS LEVEL	SEVERITY	EXAMPLES	WEIGHTED LIFETIME COST	DIRECT COST (K$)
5	Critical	Critical spinal cord injury (with cord transection); extensive second- or third-degree burns; cerebral concussion with severe neurological signs (unconscious more than 24 hours).	0.593	100
6	Un-survivable	Un-survivable injuries, which although not fatal within the first 30 days after an accident, ultimately result in death.	1.000	125
7	Immediate Fatalities	Death incurred immediately to within 30 days as direct result of the incident.	1.000	100

2.3.1.3 APPROACH TO SERVICE OUTAGES

Service outages were estimated as the product of the daily quantity of unmet demand, factoring in specified parameters like quality and pressure. To assess the overall risk of service denial, the analysis weighted the expected value of service denial by the likelihood of the threat and the system's vulnerability. Specific criteria for defining a service outage, such as acceptable quantity, quality, or pressure thresholds, were determined by the utility to ensure relevance to operational goals.

The daily revenue per residential connection is estimated at $9.24 per day; a product of the average persons per household multiplied by the per capita demand. Service outage costs are then multiplied by the number of affected households and number of days affected for each TAP, as follows:

$$\begin{aligned}&\mathit{Service\ Outage\ Cost}\\&\quad = \mathit{Dwellings\ Impacted} \times \mathit{Days\ Affected} \times \mathit{Daily\ Revenue\ per\ Residential\ Connection}\end{aligned}$$

Service outages have been categorized by the length of the outage per **Table 28**.

Table 28: Service Outages Category

OUTAGE DURATION	DESCRIPTION	IMPACT
Short-Term (< 5 days)	Temporary disruptions of service that can typically be addressed with emergency measures.	Low revenue losses: financial impact is manageable.
Mid-Term (5 – 30 days)	Outages of medium duration that more significantly affect economic activities and disrupt daily life.	Moderate economic and societal impact; recovery requires more effort than short-term outages.
Long-Term (> 30 days)	Prolonged outages with potential for severe and long-lasting consequences for the economy and society.	High financial repercussions: recovery efforts are complex and may extend beyond restoration.

2.3.1.4 APPROACH TO UTILITY FINANCIAL LOSSES

For each TAP, the City's financial losses were estimated including the following:

- Direct cost of repairing, rehabilitating or replacing damaged component
- Abandonment costs (if any)
- Other fixed cost losses
- Incremental lost revenue (less any reductions in operating costs due to the outage)
- Environmental remediation and liabilities
- Fees or penalties for failure to fulfill contracts with customers, suppliers, employees or others
- Fines for failing to maintain regulatory compliance

All damages to municipal water infrastructure and other financial losses are assumed to be rectified within 12 months and so no discount for present value is necessary. Government sales tax (GST) has been included where applicable.

In this report, the owner's financial loss from potential service outage impacting those critical water infrastructure assets have been estimated by analyzing specific nature and role of each asset involved. These assets which include Lake Geraldine, Lake Geraldine Dam, Lake Geraldine Intake Systems, Water Treatment Plant, Treated Water Reservoir, Distribution System, Booster & Reheat Stations, and SCADA System, have been assigned values for their respective financial impact should an inoperative situation occur (Refer to **Table 30**).

2.3.1.5 APPROACH TO LOSS OF GROSS REGIONAL PRODUCT

Our approach to estimating economic losses focused on evaluating reductions in the Gross Regional Product (GRP), which measures total economic activity on a value-added basis. These estimates accounted for regional losses stemming from service denial, calculated as the service interruption duration multiplied by the average price of the service.

The analysis also considered how disruptions to a utility's customers would cascade, impacting their customers and beyond, capturing the full economic multiplier effects. For costs extending beyond one-year, present value calculations were applied to provide a more accurate representation of the long-term economic impact.

2.3.1.6 APPROACH TO COMBINED UTILITY LOSS

The utility shall calculate Combined Utility Loss:

$$Combined\ Utility\ Loss\ =\ Service\ outage\ +\ Owner's\ financial\ loss\ +\ Weighted\ total\ casualties\ (LC)$$

Where:

- Weighted total casualties (LC) = Sum (Number of cases + (Weighted total casualties × Lifetime cost) for each of the seven levels of severity in AWWA Table 2 for this specific threat-asset pair.
- Weighted total casualties (LC) was calculated based on assigned weights to different severity and importance of casualties corresponding to various ALS levels and was consequently determined

based on the sum of the weighted values. This captures the overall impact of varying casualty types. Refer to **Table 30** summarizing weighted total casualties as supporting information.

- Lifetime cost = the present value of the lost future earnings as estimated by NIOSH, adjusted for inflation to the year of the analysis. The cited source shows the 2010 mean value to be $1.045 million.

A 3% inflation rate was used as an assumption for estimating the increase in NSIOH Lifetime Cost over years. This value generally represents a moderate, long-term average inflation rate based on historical trends. The NISOH lifetime cost in 2010 was converted to Canadian dollars (CAD) at a conversion rate of 1.37. Hence, the NSIOH Lifetime Cost in 2024 can be calculated as follows.

$$\text{NSIOH Lifetime Cost } (2024) = \text{ NSIOH Lifetime Cost } (2010) \times e^{Inflation\ Rate \cdot T} \times Conversion\ Rate$$

Where:

- NSIOH Lifetime Cost (2010) is the initial estimate of NSIOH lifetime cost in year 2010, which is the present value that equals to $1,045,000, expressed in USD dollars.
- NSIOH Lifetime Cost (2024) is the adjusted cost for NSIOH Lifetime Cost projected to year 2024, which is the future value that accounts for the effects of inflation over 14 years, expressed in CAD dollars.
- Inflation rate is assumed to be 3%.
- Conversion rate from USD to CAD is assumed to be 1.37.
- T is the duration of years which equals to the difference between target year (2024) and base year (2010).

Therefore, NSIOH Lifetime Cost in 2024 was calculated to be $2,178,698 in Canadian dollars.

2.3.2 CONSEQUENCES ESTIMATES

The consequence analysis includes estimating the consequences associated with each TAP and assessing the consequences of the TAP on internal and external dependencies. Worst-reasonable-case assumptions for the financial and non-financial losses of the PWS were made for each of the TAPs identified in **Section 2.2**, and presented in **Table 29**.

Table 29: Summary of threat-asset pairs and estimated level of severity, weighted total casualties, and affected customers

TANGIBLE ASSET	HAZARD SUB-CATEGORY	HAZARD	AIS 1	AIS 2	AIS 3	AIS 4	AIS 5	AIS 6	AIS 7	WEIGHTED TOTAL CASUALTIES	AFFECTED SERVICE CONNECTIONS
Lake Geraldine	Aircraft	Helicopter	1	0	0	0	0	0	0	0.03	2708
	Aircraft	Small Plane	2	1	0	0	0	0	0	0.107	2708
	Aircraft	Regional Jet	3	2	1	0	0	0	0	0.289	2708
	Aircraft	Large Jet	4	3	2	1	0	0	0	0.737	2708
	Assault Team	1 Assailant	0	0	0	0	0	0	0	0	0
	Assault Team	2-4 Assailants	0	1	0	0	0	0	0	0.047	0
	Assault Team	5-8 Assailants	0	0	2	0	0	0	0	0.21	0
	Assault Team	9-16 Assailants	0	0	0	2	0	0	0	0.532	0
	Vehicle Borne Bomb	Car	0	0	0	0	0	0	0	0	2708
	Vehicle Borne Bomb	Van	1	0	0	0	0	0	0	0.03	2708
	Vehicle Borne Bomb	Midsize Truck	2	1	0	0	0	0	0	0.107	2708
	Vehicle Borne Bomb	Large Truck (18-Wheeler)	3	2	1	0	0	0	0	0.289	2708
	Contamination of Product	Chemical	20	10	5	3	2	1	0	4.579	2708
	Contamination of Product	Radionuclide	20	10	5	3	2	1	0	4.579	2708
	Directed / Sabotage	Active Shooter	0	0	0	0	0	0	1	1	0
Lake Geraldine Dam	Aircraft	Helicopter	1	0	0	0	0	0	0	0.03	2708
	Aircraft	Small Plane	2	1	0	0	0	0	0	0.107	2708

TANGIBLE ASSET	HAZARD SUB-CATEGORY	HAZARD	AIS 1	AIS 2	AIS 3	AIS 4	AIS 5	AIS 6	AIS 7	WEIGHTED TOTAL CASUALTIES	AFFECTED SERVICE CONNECTIONS
	Aircraft	Regional Jet	3	2	1	0	0	0	0	0.289	2708
	Aircraft	Large Jet	4	3	2	1	0	0	0	0.737	2708
	Assault Team	1 Assailant	0	0	0	0	0	0	0	0	0
	Assault Team	2-4 Assailants	0	1	0	0	0	0	0	0.047	0
	Assault Team	5-8 Assailants	0	0	2	0	0	0	0	0.21	0
	Assault Team	9-16 Assailants	0	0	0	2	0	0	0	0.532	0
	Vehicle Borne Bomb	Car	0	0	0	0	0	0	0	0	2708
	Vehicle Borne Bomb	Van	1	0	0	0	0	0	0	0.03	2708
	Vehicle Borne Bomb	Midsize Truck	2	1	0	0	0	0	0	0.107	2708
	Vehicle Borne Bomb	Large Truck (18-Wheeler)	3	2	1	0	0	0	0	0.289	2708
	Contamination of Product	Chemical	20	10	5	3	2	1	0	4.579	2708
	Contamination of Product	Explosive	0	0	0	0	0	0	0	0	0
	Contamination of Product	Pathogen	0	0	0	0	0	0	0	0	0
	Contamination of Product	Radionuclide	20	10	5	3	2	1	0	4.579	2708
	Directed / Sabotage	Active Shooter	0	0	0	0	0	0	1	1	0
Lake Geraldine Intake Systems	Aircraft	Helicopter	1	0	0	0	0	0	0	0.03	2708
	Aircraft	Small Plane	2	1	0	0	0	0	0	0.107	2708

TANGIBLE ASSET	HAZARD SUB-CATEGORY	HAZARD	AIS 1	AIS 2	AIS 3	AIS 4	AIS 5	AIS 6	AIS 7	WEIGHTED TOTAL CASUALTIES	AFFECTED SERVICE CONNECTIONS
	Aircraft	Regional Jet	3	2	1	0	0	0	0	0.289	2708
	Aircraft	Large Jet	4	3	2	1	0	0	0	0.737	2708
	Assault Team	1 Assailant	0	0	0	0	0	0	0	0	0
	Assault Team	2-4 Assailants	0	1	0	0	0	0	0	0.047	0
	Assault Team	5-8 Assailants	0	0	2	0	0	0	0	0.21	0
	Assault Team	9-16 Assailants	0	0	0	2	0	0	0	0.532	0
	Vehicle Borne Bomb	Car	0	0	0	0	0	0	0	0	2708
	Vehicle Borne Bomb	Van	1	0	0	0	0	0	0	0.03	2708
	Vehicle Borne Bomb	Midsize Truck	2	1	0	0	0	0	0	0.107	2708
	Vehicle Borne Bomb	Large Truck (18-Wheeler)	3	2	1	0	0	0	0	0.289	2708
	Contamination of Product	Chemical	20	10	5	3	2	1	0	4.579	2708
	Contamination of Product	Explosive	0	0	0	0	0	0	0	0	2708
	Contamination of Product	Radionuclide	20	10	5	3	2	1	0	4.579	2708
	Directed / Sabotage	Active Shooter	0	0	0	0	0	0	1	1	0
Water Treatment Plant	Aircraft	Helicopter	3	2	1	0	0	0	0	0.289	2708
	Aircraft	Small Plane	4	3	2	1	0	0	0	0.737	2708
	Aircraft	Regional Jet	5	4	3	2	1	0	0	1.778	2708
	Aircraft	Large Jet	6	5	4	3	2	1	0	3.819	2708

TANGIBLE ASSET	HAZARD SUB-CATEGORY	HAZARD	AIS 1	AIS 2	AIS 3	AIS 4	AIS 5	AIS 6	AIS 7	WEIGHTED TOTAL CASUALTIES	AFFECTED SERVICE CONNECTIONS
	Assault Team	1 Assailant	0	1	0	0	0	0	0	0.047	2708
	Assault Team	2-4 Assailants	0	1	0	1	0	0	0	0.313	2708
	Assault Team	5-8 Assailants	0	0	1	0	1	0	0	0.698	2708
	Assault Team	9-16 Assailants	0	0	0	0	0	0	2	2	2708
	Vehicle Borne Bomb	Car	2	1	0	0	0	0	0	0.107	2708
	Vehicle Borne Bomb	Van	3	2	1	0	0	0	0	0.289	2708
	Vehicle Borne Bomb	Midsize Truck	4	3	2	1	0	0	0	0.737	2708
	Vehicle Borne Bomb	Large Truck (18-Wheeler)	5	4	3	2	1	0	2	3.778	2708
	Contamination of Product	Biotoxin	80	40	20	12	8	4	2	20.316	2708
	Contamination of Product	Chemical	20	10	5	3	2	1	0	4.579	2708
	Contamination of Product	Explosive	2	1	0	0	0	0	0	0.107	2708
	Contamination of Product	Pathogen	80	40	20	12	8	4	2	20.316	2708
	Contamination of Product	Radionuclide	20	10	5	3	2	1	0	4.579	2708
	Directed / Sabotage	Physical Insider	0	0	0	0	0	0	0	0	2708
	Directed / Sabotage	Physical Outsider	0	0	0	0	0	0	0	0	2708
	Directed / Sabotage	Active Shooter	0	0	0	0	0	0	2	2	2708
	Theft or Diversion	Physical Insider	0	0	0	0	0	0	0	0	2708

TANGIBLE ASSET	HAZARD SUB-CATEGORY	HAZARD	AIS 1	AIS 2	AIS 3	AIS 4	AIS 5	AIS 6	AIS 7	WEIGHTED TOTAL CASUALTIES	AFFECTED SERVICE CONNECTIONS
	Theft or Diversion	Physical Outsider	0	0	0	0	0	0	0	0	2708
	Cyber	Cyber Attack	0	0	0	0	0	0	0	0	2708
Treated Water Reservoir	Aircraft	Helicopter	4	3	2	1	0	0	0	0.737	2708
	Aircraft	Small Plane	5	4	3	2	1	0	0	1.778	2708
	Aircraft	Regional Jet	6	5	4	3	2	1	0	3.819	2708
	Aircraft	Large Jet	7	6	5	4	3	2	1	6.86	2708
	Assault Team	1 Assailant	0	1	0	0	0	0	0	0.047	
	Assault Team	2-4 Assailants	0	1	0	1	0	0	0	0.313	
	Assault Team	5-8 Assailants	0	0	1	0	1	0	0	0.698	
	Assault Team	9-16 Assailants	0	0	0	0	0	0	2	2	
	Vehicle Borne Bomb	Car	2	1	0	0	0	0	0	0.107	2708
	Vehicle Borne Bomb	Van	3	2	1	0	0	0	0	0.289	2708
	Vehicle Borne Bomb	Midsize Truck	4	3	2	1	0	0	0	0.737	2708
	Vehicle Borne Bomb	Large Truck (18-Wheeler)	5	4	3	2	1	0	2	3.778	2708
	Contamination of Product	Biotoxin	80	40	20	12	8	4	2	20.316	2708
	Contamination of Product	Chemical	20	10	5	3	2	1	0	4.579	2708
	Contamination of Product	Explosive	2	1	0	0	0	0	0	0.107	2708

TANGIBLE ASSET	HAZARD SUB-CATEGORY	HAZARD	AIS 1	AIS 2	AIS 3	AIS 4	AIS 5	AIS 6	AIS 7	WEIGHTED TOTAL CASUALTIES	AFFECTED SERVICE CONNECTIONS
	Contamination of Product	Pathogen	80	40	20	12	8	4	2	20.316	2708
	Contamination of Product	Radionuclide	20	10	5	3	2	1	0	4.579	2708
	Directed / Sabotage	Physical Insider	0	0	0	0	0	0	0	0	2708
	Directed / Sabotage	Physical Outsider	0	0	0	0	0	0	0	0	2708
	Directed / Sabotage	Active Shooter	0	0	0	0	0	0	1	1	
	Theft or Diversion	Physical Insider	0	0	0	0	0	0	0	0	2708
	Theft or Diversion	Physical Outsider	0	0	0	0	0	0	0	0	2708
Distribution System	Aircraft	Helicopter	5	4	3	2	1	0	0	1.778	677
	Aircraft	Small Plane	20	10	5	3	2	0	1	4.579	677
	Aircraft	Regional Jet	35	25	10	5	2	1	1	7.791	677
	Aircraft	Large Jet	75	50	25	10	5	2	2	16.85	677
	Vehicle Borne Bomb	Car	3	2	1	0	0	0	0	0.289	677
	Vehicle Borne Bomb	Van	4	3	2	1	0	0	0	0.737	677
	Vehicle Borne Bomb	Midsize Truck	6	5	4	3	2	1	0	3.819	677
	Vehicle Borne Bomb	Large Truck (18-Wheeler)	8	7	6	5	4	3	2	9.901	677
	Contamination of Product	Biotoxin	80	40	20	12	8	4	2	20.316	677

TANGIBLE ASSET	HAZARD SUB-CATEGORY	HAZARD	AIS 1	AIS 2	AIS 3	AIS 4	AIS 5	AIS 6	AIS 7	WEIGHTED TOTAL CASUALTIES	AFFECTED SERVICE CONNECTIONS
Booster & Reheat Stations	Contamination of Product	Chemical	20	10	5	3	2	1	0	4.579	677
	Contamination of Product	Explosive	2	1	0	0	0	0	0	0.107	677
	Contamination of Product	Pathogen	80	40	20	12	8	4	2	20.316	677
	Contamination of Product	Radionuclide	20	10	5	3	2	1	0	4.579	677
	Directed / Sabotage	Physical Insider	0	0	0	0	0	0	0	0	677
	Directed / Sabotage	Physical Outsider	0	0	0	0	0	0	0	0	677
	Aircraft	Helicopter	5	4	3	2	1	0	0	1.778	677
	Aircraft	Small Plane	20	10	5	3	2	0	1	4.579	677
	Aircraft	Regional Jet	35	25	10	5	2	1	1	7.791	677
	Aircraft	Large Jet	75	50	25	10	5	2	2	16.85	677
	Assault Team	1 Assailant	0	1	0	0	0	0	0	0.047	677
	Assault Team	2-4 Assailants	0	1	0	1	0	0	0	0.313	677
	Assault Team	5-8 Assailants	0	0	1	0	1	0	0	0.698	677
	Assault Team	9-16 Assailants	0	0	0	0	0	0	2	2	677
	Vehicle Borne Bomb	Car	3	2	1	0	0	0	0	0.289	677
	Vehicle Borne Bomb	Van	4	3	2	1	0	0	0	0.737	677
	Vehicle Borne Bomb	Midsize Truck	6	5	4	3	2	1	0	3.819	677

TANGIBLE ASSET	HAZARD SUB-CATEGORY	HAZARD	AIS 1	AIS 2	AIS 3	AIS 4	AIS 5	AIS 6	AIS 7	WEIGHTED TOTAL CASUALTIES	AFFECTED SERVICE CONNECTIONS
	Vehicle Borne Bomb	Large Truck (18-Wheeler)	8	7	6	5	4	3	2	9.901	677
	Contamination of Product	Biotoxin	80	40	20	12	8	4	2	20.316	677
	Contamination of Product	Chemical	20	10	5	3	2	1	0	4.579	677
	Contamination of Product	Explosive	2	1	0	0	0	0	0	0.107	677
	Contamination of Product	Pathogen	80	40	20	12	8	4	2	20.316	677
	Contamination of Product	Radionuclide	20	10	5	3	2	1	0	4.579	677
	Directed / Sabotage	Physical Insider	0	0	0	0	0	0	0	0	677
	Directed / Sabotage	Physical Outsider	0	0	0	0	0	0	0	0	677
	Directed / Sabotage	Active Shooter	0	0	0	0	0	0	2	2	677
	Theft or Diversion	Physical Insider	0	0	0	0	0	0	0	0	677
	Theft or Diversion	Physical Outsider	0	0	0	0	0	0	0	0	677
	Cyber	Cyber Attack	0	0	0	0	0	0	0	0	677
SCADA System	Aircraft	Helicopter	3	2	1	0	0	0	0	0.289	2708
	Aircraft	Small Plane	4	3	2	1	0	0	0	0.737	2708
	Aircraft	Regional Jet	5	4	3	2	1	0	0	1.778	2708
	Aircraft	Large Jet	6	5	4	3	2	1	0	3.819	2708
	Assault Team	1 Assailant	0	1	0	0	0	0	0	0.047	2708

TANGIBLE ASSET	HAZARD SUB-CATEGORY	HAZARD	AIS 1	AIS 2	AIS 3	AIS 4	AIS 5	AIS 6	AIS 7	WEIGHTED TOTAL CASUALTIES	AFFECTED SERVICE CONNECTIONS
	Assault Team	2-4 Assailants	0	1	0	1	0	0	0	0.313	2708
	Assault Team	5-8 Assailants	0	0	1	0	1	0	0	0.698	2708
	Assault Team	9-16 Assailants	0	0	0	0	0	0	2	2	2708
	Vehicle Borne Bomb	Car	2	1	0	0	0	0	0	0.107	2708
	Vehicle Borne Bomb	Van	3	2	1	0	0	0	0	0.289	2708
	Vehicle Borne Bomb	Midsize Truck	4	3	2	1	0	0	0	0.737	2708
	Vehicle Borne Bomb	Large Truck (18-Wheeler)	5	4	3	2	1	0	2	3.778	2708
	Directed / Sabotage	Physical Insider	0	0	0	0	0	0	0	0	2708
	Directed / Sabotage	Physical Outsider	0	0	0	0	0	0	0	0	2708
	Theft or Diversion	Physical Insider	0	0	0	0	0	0	0	0	2708
	Theft or Diversion	Physical Outsider	0	0	0	0	0	0	0	0	2708
	Cyber	Cyber Attack	0	0	0	0	0	0	0	0	2708

2.3.3 COMBINED LOSSES

In our analysis, we recognized the importance of evaluating individual consequence metrics while also considering the value of consolidating these metrics into a single figure for decision-making purposes. This aggregated loss value simplifies comparisons of overall risks, benefits of risk reduction measures, and cost-effectiveness across various options. To achieve this, we utilized two established methodologies: the human capital approach and the value of a statistical life (VSL) approach.

The human capital approach quantifies losses by accounting for direct costs, such as medical and funeral expenses, and the present value of earnings foregone due to premature death. For example, the standard assumes $40,000 for immediate expenses and draws on National Institute of Occupational Safety and Health (NIOSH) estimates for lifetime earnings lost, which averaged $1,045,000 in 2010. This method, commonly used in insurance and legal settlements, incorporates demographic and occupational factors to estimate indirect costs accurately.

The VSL approach, widely favored by economists and federal agencies, measures societal willingness to pay for marginal reductions in mortality risk. Rather than valuing individual lives, it calculates the aggregate value placed by a population on reducing the likelihood of death. This method aligns with the goal of assessing regional societal impacts and is the preferred approach for estimating Combined Regional Community Loss in our analysis.

2.3.3.1 COMBINED UTILITY LOSS

Table 30 summarizes the combined utility loss, incorporating key components discussed to provide a comprehensive view of the impacts associated service outage cost (which represents the economic loss due to interruptions in utility services), other financial losses (which includes additional economic impacts beyond service outage such as direct cost of repairing/replacement and other fixed cost losses), and BSUIG weighted total casualties (which reflets human related casualties on the basis of a weighted measure).

Table 30: Summary of combined utility loss

TANGIBLE ASSET	HAZARD SUB-CATEGORY	HAZARD	AFFECTED SERVICE CONNECTIONS	DAYS AFFECTED	SERVICE OUTAGE COST	OTHER FINANCIAL LOSSES	NSIOH WEIGHTED TOTAL CASUALTIES	COMBINED UTILITY LOSS
Lake Geraldine	Aircraft	Helicopter	2708	5	$125,110	$100,000	$65,361	$290,471
	Aircraft	Small Plane	2708	10	$250,219	$150,000	$233,121	$633,340
	Aircraft	Regional Jet	2708	15	$375,329	$200,000	$629,644	$1,204,973
	Aircraft	Large Jet	2708	30	$750,658	$250,000	$1,605,701	$2,606,358
	Assault Team	1 Assailant	0					
	Assault Team	2-4 Assailants	0				$102,399	$102,399
	Assault Team	5-8 Assailants	0				$457,527	$457,527
	Assault Team	9-16 Assailants	0				$1,159,068	$1,159,068
	Maritime	Small Boat	0					
	Maritime	Fast Boat	0					
	Maritime	Barge	0					
	Maritime	Deep Draft Ship	0					
	Vehicle Borne Bomb	Car	2708	3	$75,066	$25,000	$0	$100,066
	Vehicle Borne Bomb	Van	2708	5	$125,110	$50,000	$65,361	$240,471
	Vehicle Borne Bomb	Midsize Truck	2708	10	$250,219	$100,000	$233,121	$583,340
	Vehicle Borne Bomb	Large Truck (18-Wheeler)	2708	15	$375,329	$150,000	$629,644	$1,154,973
	Contamination of Product	Biotoxin	0					

TANGIBLE ASSET	HAZARD SUB-CATEGORY	HAZARD	AFFECTED SERVICE CONNECTIONS	DAYS AFFECTED	SERVICE OUTAGE COST	OTHER FINANCIAL LOSSES	NSIOH WEIGHTED TOTAL CASUALTIES	COMBINED UTILITY LOSS
	Contamination of Product	Chemical	2708	30	$750,658	$300,000	$9,976,260	$11,026,918
	Contamination of Product	Explosive	0					
	Contamination of Product	Pathogen	0					
	Contamination of Product	Radionuclide	2708	30	$750,658	$300,000	$9,976,260	$11,026,918
	Directed / Sabotage	Physical Insider	0					
	Directed / Sabotage	Physical Outsider	0					
	Directed / Sabotage	Active Shooter	0				$2,178,698	$2,178,698
	Theft or Diversion	Physical Insider	0					
	Theft or Diversion	Physical Outsider	0					
	Cyber	Cyber Attack	0					
Lake Geraldine Dam	Aircraft	Helicopter	2708	100	$2,502,192	$5,000,000	$65,361	$7,567,553
	Aircraft	Small Plane	2708	150	$3,753,288	$10,000,000	$233,121	$13,986,409
	Aircraft	Regional Jet	2708	200	$5,004,384	$30,000,000	$629,644	$35,634,028
	Aircraft	Large Jet	2708	250	$6,255,480	$30,000,000	$1,605,701	$37,861,181
	Assault Team	1 Assailant	0				$0	$0
	Assault Team	2-4 Assailants	0				$102,399	$102,399
	Assault Team	5-8 Assailants	0				$457,527	$457,527

TANGIBLE ASSET	HAZARD SUB-CATEGORY	HAZARD	AFFECTED SERVICE CONNECTIONS	DAYS AFFECTED	SERVICE OUTAGE COST	OTHER FINANCIAL LOSSES	NSIOH WEIGHTED TOTAL CASUALTIES	COMBINED UTILITY LOSS
	Assault Team	9-16 Assailants	0				$1,159,068	$1,159,068
	Maritime	Small Boat	0					
	Maritime	Fast Boat	0					
	Maritime	Barge	0					
	Maritime	Deep Draft Ship	0					
	Vehicle Borne Bomb	Car	2708	100	$2,502,192	$5,000,000	$0	$7,502,192
	Vehicle Borne Bomb	Van	2708	150	$3,753,288	$10,000,000	$65,361	$13,818,649
	Vehicle Borne Bomb	Midsize Truck	2708	200	$5,004,384	$30,000,000	$233,121	$35,237,505
	Vehicle Borne Bomb	Large Truck (18-Wheeler)	2708	250	$6,255,480	$30,000,000	$629,644	$36,885,124
	Contamination of Product	Biotoxin	0					
	Contamination of Product	Chemical	2708	30	$750,658	$300,000	$9,976,260	$11,026,918
	Contamination of Product	Explosive	0					
	Contamination of Product	Pathogen	0					
	Contamination of Product	Radionuclide	2708				$9,976,260	$9,976,260
	Directed / Sabotage	Physical Insider	0					
	Directed / Sabotage	Physical Outsider	0					

TANGIBLE ASSET	HAZARD SUB-CATEGORY	HAZARD	AFFECTED SERVICE CONNECTIONS	DAYS AFFECTED	SERVICE OUTAGE COST	OTHER FINANCIAL LOSSES	NSIOH WEIGHTED TOTAL CASUALTIES	COMBINED UTILITY LOSS
	Directed / Sabotage	Active Shooter	0				$2,178,698	$2,178,698
	Theft or Diversion	Physical Insider	0					
	Theft or Diversion	Physical Outsider	0					
	Cyber	Cyber Attack	0					
Lake Geraldine Intake Systems	Aircraft	Helicopter	2708	5	$125,110	$150,000	$65,361	$340,471
	Aircraft	Small Plane	2708	10	$250,219	$250,000	$233,121	$733,340
	Aircraft	Regional Jet	2708	15	$375,329	$500,000	$629,644	$1,504,973
	Aircraft	Large Jet	2708	30	$750,658	$1,000,000	$1,605,701	$3,356,358
	Assault Team	1 Assailant	0					
	Assault Team	2-4 Assailants	0				$102,399	$102,399
	Assault Team	5-8 Assailants	0				$457,527	$457,527
	Assault Team	9-16 Assailants	0				$1,159,068	$1,159,068
	Maritime	Small Boat	0					
	Maritime	Fast Boat	0					
	Maritime	Barge	0					
	Maritime	Deep Draft Ship	0					
	Vehicle Borne Bomb	Car	2708	5	$125,110	$150,000		$275,110
	Vehicle Borne Bomb	Van	2708	10	$250,219	$250,000	$65,361	$565,580
	Vehicle Borne Bomb	Midsize Truck	2708	15	$375,329	$500,000	$233,121	$1,108,450

TANGIBLE ASSET	HAZARD SUB-CATEGORY	HAZARD	AFFECTED SERVICE CONNECTIONS	DAYS AFFECTED	SERVICE OUTAGE COST	OTHER FINANCIAL LOSSES	NSIOH WEIGHTED TOTAL CASUALTIES	COMBINED UTILITY LOSS
	Vehicle Borne Bomb	Large Truck (18-Wheeler)	2708	30	$750,658	$1,000,000	$629,644	$2,380,301
	Contamination of Product	Biotoxin	0					
	Contamination of Product	Chemical	2708				$9,976,260	$9,976,260
	Contamination of Product	Explosive	2708					
	Contamination of Product	Pathogen	0					
	Contamination of Product	Radionuclide	2708				$9,976,260	$9,976,260
	Directed / Sabotage	Physical Insider	0					
	Directed / Sabotage	Physical Outsider	0					
	Directed / Sabotage	Active Shooter	0				$2,178,698	$2,178,698
	Theft or Diversion	Physical Insider	0					
	Theft or Diversion	Physical Outsider	0					
	Cyber	Cyber Attack	0					
Water Treatment Plant	Aircraft	Helicopter	2708	90	$2,251,973	$5,000,000	$629,644	$7,881,617
	Aircraft	Small Plane	2708	150	$3,753,288	$7,500,000	$1,605,701	$12,858,989
	Aircraft	Regional Jet	2708	210	$5,254,603	$10,000,000	$3,873,726	$19,128,329
	Aircraft	Large Jet	2708	270	$6,755,918	$10,000,000	$8,320,449	$25,076,368

TANGIBLE ASSET	HAZARD SUB-CATEGORY	HAZARD	AFFECTED SERVICE CONNECTIONS	DAYS AFFECTED	SERVICE OUTAGE COST	OTHER FINANCIAL LOSSES	NSIOH WEIGHTED TOTAL CASUALTIES	COMBINED UTILITY LOSS
	Assault Team	1 Assailant	2708	2	$50,044	$50,000	$102,399	$202,443
	Assault Team	2-4 Assailants	2708	4	$100,088	$100,000	$681,933	$882,020
	Assault Team	5-8 Assailants	2708	6	$150,132	$150,000	$1,520,731	$1,820,863
	Assault Team	9-16 Assailants	2708	8	$200,175	$200,000	$4,357,397	$4,757,572
	Maritime	Small Boat	0					
	Maritime	Fast Boat	0					
	Maritime	Barge	0					
	Maritime	Deep Draft Ship	0					
	Vehicle Borne Bomb	Car	2708	90	$2,251,973	$5,000,000	$233,121	$7,485,094
	Vehicle Borne Bomb	Van	2708	150	$3,753,288	$7,500,000	$629,644	$11,882,932
	Vehicle Borne Bomb	Midsize Truck	2708	210	$5,254,603	$10,000,000	$1,605,701	$16,860,304
	Vehicle Borne Bomb	Large Truck (18-Wheeler)	2708	270	$6,755,918	$10,000,000	$8,231,123	$24,987,041
	Contamination of Product	Biotoxin	2708	30	$750,658	$100,000	$44,262,437	$45,113,094
	Contamination of Product	Chemical	2708	30	$750,658	$100,000	$9,976,260	$10,826,918
	Contamination of Product	Explosive	2708	90	$2,251,973	$5,000,000	$233,121	$7,485,094
	Contamination of Product	Pathogen	2708	30	$750,658	$100,000	$44,262,437	$45,113,094

TANGIBLE ASSET	HAZARD SUB-CATEGORY	HAZARD	AFFECTED SERVICE CONNECTIONS	DAYS AFFECTED	SERVICE OUTAGE COST	OTHER FINANCIAL LOSSES	NSIOH WEIGHTED TOTAL CASUALTIES	COMBINED UTILITY LOSS
Treated Water Reservoir	Contamination of Product	Radionuclide	2708	30	$750,658	$100,000	$9,976,260	$10,826,918
	Directed / Sabotage	Physical Insider	2708	10	$250,219	$25,000		$275,219
	Directed / Sabotage	Physical Outsider	2708	10	$250,219	$25,000		$275,219
	Directed / Sabotage	Active Shooter	2708	2	$50,044	$50,000	$4,357,397	$4,457,441
	Theft or Diversion	Physical Insider	2708	10	$250,219	$25,000		$275,219
	Theft or Diversion	Physical Outsider	2708	10	$250,219	$25,000		$275,219
	Cyber	Cyber Attack	2708	30	$750,658	$250,000		$1,000,658
	Aircraft	Helicopter	2708	90	$2,251,973	$5,000,000	$1,605,701	$8,857,674
	Aircraft	Small Plane	2708	150	$3,753,288	$7,500,000	$3,873,726	$15,127,014
	Aircraft	Regional Jet	2708	210	$5,254,603	$10,000,000	$8,320,449	$23,575,052
	Aircraft	Large Jet	2708	270	$6,755,918	$10,000,000	$14,945,871	$31,701,789
	Assault Team	1 Assailant					$102,399	$102,399
	Assault Team	2-4 Assailants					$681,933	$681,933
	Assault Team	5-8 Assailants					$1,520,731	$1,520,731
	Assault Team	9-16 Assailants					$4,357,397	$4,357,397
	Maritime	Small Boat						
	Maritime	Fast Boat						
	Maritime	Barge						

TANGIBLE ASSET	HAZARD SUB-CATEGORY	HAZARD	AFFECTED SERVICE CONNECTIONS	DAYS AFFECTED	SERVICE OUTAGE COST	OTHER FINANCIAL LOSSES	NSIOH WEIGHTED TOTAL CASUALTIES	COMBINED UTILITY LOSS
	Maritime	Deep Draft Ship						
	Vehicle Borne Bomb	Car	2708	90	$2,251,973	$5,000,000	$233,121	$7,485,094
	Vehicle Borne Bomb	Van	2708	150	$3,753,288	$7,500,000	$629,644	$11,882,932
	Vehicle Borne Bomb	Midsize Truck	2708	210	$5,254,603	$10,000,000	$1,605,701	$16,860,304
	Vehicle Borne Bomb	Large Truck (18-Wheeler)	2708	270	$6,755,918	$10,000,000	$8,231,123	$24,987,041
	Contamination of Product	Biotoxin	2708	30	$750,658	$100,000	$44,262,437	$45,113,094
	Contamination of Product	Chemical	2708	30	$750,658	$100,000	$9,976,260	$10,826,918
	Contamination of Product	Explosive	2708	90	$2,251,973	$5,000,000	$233,121	$7,485,094
	Contamination of Product	Pathogen	2708	30	$750,658	$100,000	$44,262,437	$45,113,094
	Contamination of Product	Radionuclide	2708	30	$750,658	$100,000	$9,976,260	$10,826,918
	Directed / Sabotage	Physical Insider	2708	15	$375,329	$100,000		$475,329
	Directed / Sabotage	Physical Outsider	2708	15	$375,329	$100,000		$475,329
	Directed / Sabotage	Active Shooter					$2,178,698	$2,178,698
	Theft or Diversion	Physical Insider	2708	15	$375,329	$100,000		$475,329
	Theft or Diversion	Physical Outsider	2708	15	$375,329	$100,000		$475,329
	Cyber	Cyber Attack						

TANGIBLE ASSET	HAZARD SUB-CATEGORY	HAZARD	AFFECTED SERVICE CONNECTIONS	DAYS AFFECTED	SERVICE OUTAGE COST	OTHER FINANCIAL LOSSES	NSIOH WEIGHTED TOTAL CASUALTIES	COMBINED UTILITY LOSS
Distribution System	Aircraft	Helicopter	677	5	$31,277	$250,000	$3,873,726	$4,155,003
	Aircraft	Small Plane	677	10	$62,555	$350,000	$9,976,260	$10,388,815
	Aircraft	Regional Jet	677	15	$93,832	$500,000	$16,974,239	$17,568,071
	Aircraft	Large Jet	677	30	$187,664	$750,000	$36,711,068	$37,648,732
	Assault Team	1 Assailant						
	Assault Team	2-4 Assailants						
	Assault Team	5-8 Assailants						
	Assault Team	9-16 Assailants						
	Maritime	Small Boat						
	Maritime	Fast Boat						
	Maritime	Barge						
	Maritime	Deep Draft Ship						
	Vehicle Borne Bomb	Car	677	5	$31,277	$250,000	$629,644	$910,921
	Vehicle Borne Bomb	Van	677	10	$62,555	$350,000	$1,605,701	$2,018,256
	Vehicle Borne Bomb	Midsize Truck	677	15	$93,832	$500,000	$8,320,449	$8,914,281
	Vehicle Borne Bomb	Large Truck (18-Wheeler)	677	30	$187,664	$750,000	$21,571,293	$22,508,957
	Contamination of Product	Biotoxin	677	30	$187,664	$100,000	$44,262,437	$44,550,101

TANGIBLE ASSET	HAZARD SUB-CATEGORY	HAZARD	AFFECTED SERVICE CONNECTIONS	DAYS AFFECTED	SERVICE OUTAGE COST	OTHER FINANCIAL LOSSES	NSIOH WEIGHTED TOTAL CASUALTIES	COMBINED UTILITY LOSS
	Contamination of Product	Chemical	677	30	$187,664	$100,000	$9,976,260	$10,263,924
	Contamination of Product	Explosive	677	5	$31,277	$250,000	$233,121	$514,398
	Contamination of Product	Pathogen	677	30	$187,664	$100,000	$44,262,437	$44,550,101
	Contamination of Product	Radionuclide	677	30	$187,664	$100,000	$9,976,260	$10,263,924
	Directed / Sabotage	Physical Insider	677	10	$62,555	$100,000		$162,555
	Directed / Sabotage	Physical Outsider	677	10	$62,555	$100,000		$162,555
	Directed / Sabotage	Active Shooter						
	Theft or Diversion	Physical Insider						
	Theft or Diversion	Physical Outsider						
	Cyber	Cyber Attack						
Booster & Reheat Stations	Aircraft	Helicopter	677	90	$562,993	$3,000,000	$3,873,726	$7,436,719
	Aircraft	Small Plane	677	150	$938,322	$4,000,000	$9,976,260	$14,914,582
	Aircraft	Regional Jet	677	210	$1,313,651	$5,000,000	$16,974,239	$23,287,890
	Aircraft	Large Jet	677	270	$1,688,980	$5,000,000	$36,711,068	$43,400,047
	Assault Team	1 Assailant	677	2	$12,511	$50,000	$102,399	$164,910
	Assault Team	2-4 Assailants	677	4	$25,022	$100,000	$681,933	$806,955
	Assault Team	5-8 Assailants	677	6	$37,533	$150,000	$1,520,731	$1,708,264

TANGIBLE ASSET	HAZARD SUB-CATEGORY	HAZARD	AFFECTED SERVICE CONNECTIONS	DAYS AFFECTED	SERVICE OUTAGE COST	OTHER FINANCIAL LOSSES	NSIOH WEIGHTED TOTAL CASUALTIES	COMBINED UTILITY LOSS
	Assault Team	9-16 Assailants	677	8	$50,044	$200,000	$4,357,397	$4,607,441
	Maritime	Small Boat						
	Maritime	Fast Boat						
	Maritime	Barge						
	Maritime	Deep Draft Ship						
	Vehicle Borne Bomb	Car	677	90	$562,993	$3,000,000	$629,644	$4,192,637
	Vehicle Borne Bomb	Van	677	150	$938,322	$4,000,000	$1,605,701	$6,544,023
	Vehicle Borne Bomb	Midsize Truck	677	210	$1,313,651	$5,000,000	$8,320,449	$14,634,100
	Vehicle Borne Bomb	Large Truck (18-Wheeler)	677	270	$1,688,980	$5,000,000	$21,571,293	$28,260,272
	Contamination of Product	Biotoxin	677	30	$187,664	$100,000	$44,262,437	$44,550,101
	Contamination of Product	Chemical	677	30	$187,664	$100,000	$9,976,260	$10,263,924
	Contamination of Product	Explosive	677	5	$31,277	$3,000,000	$233,121	$3,264,398
	Contamination of Product	Pathogen	677	30	$187,664	$100,000	$44,262,437	$44,550,101
	Contamination of Product	Radionuclide	677	30	$187,664	$100,000	$9,976,260	$10,263,924
	Directed / Sabotage	Physical Insider	677	25	$156,387	$100,000		$256,387
	Directed / Sabotage	Physical Outsider	677	25	$156,387	$100,000		$256,387

TANGIBLE ASSET	HAZARD SUB-CATEGORY	HAZARD	AFFECTED SERVICE CONNECTIONS	DAYS AFFECTED	SERVICE OUTAGE COST	OTHER FINANCIAL LOSSES	NSIOH WEIGHTED TOTAL CASUALTIES	COMBINED UTILITY LOSS
	Directed / Sabotage	Active Shooter	677	2	$12,511	$50,000	$4,357,397	$4,419,908
	Theft or Diversion	Physical Insider	677	25	$156,387	$100,000		$256,387
	Theft or Diversion	Physical Outsider	677	25	$156,387	$100,000		$256,387
	Cyber	Cyber Attack	677	25	$156,387	$75,000		$231,387
SCADA System	Aircraft	Helicopter	2708	90	$2,251,973	$250,000	$629,644	$3,131,617
	Aircraft	Small Plane	2708	150	$3,753,288	$250,000	$1,605,701	$5,608,989
	Aircraft	Regional Jet	2708	210	$5,254,603	$250,000	$3,873,726	$9,378,329
	Aircraft	Large Jet	2708	270	$6,755,918	$250,000	$8,320,449	$15,326,368
	Assault Team	1 Assailant	2708	2	$50,044	$250,000	$102,399	$402,443
	Assault Team	2-4 Assailants	2708	4	$100,088	$250,000	$681,933	$1,032,020
	Assault Team	5-8 Assailants	2708	6	$150,132	$250,000	$1,520,731	$1,920,863
	Assault Team	9-16 Assailants	2708	8	$200,175	$250,000	$4,357,397	$4,807,572
	Maritime	Small Boat						
	Maritime	Fast Boat						
	Maritime	Barge						
	Maritime	Deep Draft Ship						
	Vehicle Borne Bomb	Car	2708	90	$2,251,973	$250,000	$233,121	$2,735,094
	Vehicle Borne Bomb	Van	2708	150	$3,753,288	$250,000	$629,644	$4,632,932
	Vehicle Borne Bomb	Midsize Truck	2708	210	$5,254,603	$250,000	$1,605,701	$7,110,304

TANGIBLE ASSET	HAZARD SUB-CATEGORY	HAZARD	AFFECTED SERVICE CONNECTIONS	DAYS AFFECTED	SERVICE OUTAGE COST	OTHER FINANCIAL LOSSES	NSIOH WEIGHTED TOTAL CASUALTIES	COMBINED UTILITY LOSS
	Vehicle Borne Bomb	Large Truck (18-Wheeler)	2708	270	$6,755,918	$250,000	$8,231,123	$15,237,041
	Contamination of Product	Biotoxin						
	Contamination of Product	Chemical						
	Contamination of Product	Explosive						
	Contamination of Product	Pathogen						
	Contamination of Product	Radionuclide						
	Directed / Sabotage	Physical Insider	2708	25	$625,548	$250,000		$875,548
	Directed / Sabotage	Physical Outsider	2708	25	$625,548	$250,000		$875,548
	Directed / Sabotage	Active Shooter						
	Theft or Diversion	Physical Insider	2708	25	$625,548	$250,000		$875,548
	Theft or Diversion	Physical Outsider	2708	25	$625,548	$250,000		$875,548
	Cyber	Cyber Attack	2708	50	$1,251,096	$1,000,000		$2,251,096

2.3.3.2 COMBINED REGIONAL COMMUNITY LOSS

The Combined Regional Community Loss is calculated by:

$$\text{Combined Regional Community Loss} = \text{Lost gross regional product} + \text{Weighted total casualties (VSL)} + \text{Sum (Owner's financial loss)}$$

Where:

- Weighted total casualties (VSL) = Sum (Number of cases) + (Weighted total casualties × Value of a Statistical Life) for each of the seven levels of severity. Refer to **Table 29** summarizing weighted total casualties as supporting information.
- Value of a Statistical Life = the societal willingness to pay for a marginal change in the risk of death, as estimated by the USEPA, adjusted for inflation to the year of the analysis.

A 3% inflation rate was used as an assumption for estimating the increase in VSL Lifetime Cost over years. This value generally represents a moderate, long-term average inflation rate based on historical trends. The VSL Lifetime Cost in 2019 was converted to Canadian dollars (CAD) at a conversion rate of 1.37. Hence, the VSL Lifetime Cost in 2024 can be calculated as follows.

$$\text{VSL Lifetime Cost (2024)} = \text{VSL Lifetime Cost (2019)} \times e^{Inflation\ Rate \cdot T} \times Conversion\ Rate$$

Where:

- VSL Lifetime Cost (2019) is the initial estimate of VSL lifetime cost in year 2019, which is the present value that equals to $9,400,000, expressed in USD dollars.
- VSL Lifetime Cost (2024) is the adjusted cost for VSL Lifetime Cost projected to year 2024, which is the future value that accounts for the effects of inflation over 5 years, expressed in CAD dollars.
- Inflation rate is assumed to be 3%.
- Conversion rate from USD to CAD is assumed to be 1.37.
- T is the duration of years which equals to the difference between target year (2024) and base year (2019).

Therefore, VSL Lifetime Cost in 2024 was calculated to be $14,960,605 in Canadian dollars.

Lost gross regional product can be determined based on the following equation.

$$Lost\ Gross\ Regional\ Product = Service\ Outage\ Cost \times (1 + Lost\ Gross\ Regional\ Product\ Markup) + Other\ Financial\ loss$$

This formula indicates that the total economic impact (Lost Gross Regional Product) is related to the direct cost of the outage multiplied by a factor that includes both the direct cost and the additional economic impact (markup) as well as other financial loss.

Where:

- Service outage cost is the direct cost associated with service outage.
- Loss gross regional product markup represents the additional economic impact beyond the direct costs which involves broader effects of regional economy such as reduced productivity and other indirect costs. Here, a value of 31.9% was chosen based on reference data (community-resilience-understanding-the-economic-impacts-of-disruptions-in-water-service.pdf).

From an economic perspective, combined regional losses represent the lower bound of externalities—costs or benefits that impact third parties outside the primary decision-making framework. For lifeline utilities such as water and wastewater systems, these externalities are substantial, encompassing the ripple effects of the utility's services throughout the regional economy. This includes the value added by activities of the utility's customers, their downstream customers, and the broader regional community. Decisions made by the utility and its direct customers can impose real financial impacts on the region, but these broader consequences often remain unaccounted for in traditional resource allocation decisions.

Negative externalities arise from risks of regional losses, while avoiding or mitigating these risks generates positive externalities. Quantifying externalities, even as a lower bound, can inform decision-making processes for utilities. However, such quantification often relies on complex models that may exclude certain elements due to practical constraints. For instance, unforeseen decisions, demographic shifts, or significant changes in regional economic activity may not be captured in the current estimates. Consequently, these quantifications should be understood as conservative estimates of actual externalities.

Table 31 summarizes the combined regional community loss, incorporating key components discussed to provide a comprehensive view of lost gross regional product (which represents the economic loss by events such as disasters and reduced business activity) and VSL-weighted total casualties (which is a monetary estimate of the societal value placed on reducing the risk of fatality).

Table 31: Summary of Combined Regional Community Loss

TANGIBLE ASSET	HAZARD SUB-CATEGORY	HAZARD	LOST GROSS REGIONAL PRODUCT	VSL WEIGHTED TOTAL CASUALTIES	COMBINED REGIONAL COMMUNITY LOSS
Lake Geraldine	Aircraft	Helicopter	$265,020	$448,818	$713,838
	Aircraft	Small Plane	$480,039	$1,600,785	$2,080,824
	Aircraft	Regional Jet	$695,059	$4,323,615	$5,018,674
	Aircraft	Large Jet	$1,240,117	$11,025,966	$12,266,083
	Assault Team	1 Assailant			
	Assault Team	2-4 Assailants		$703,148	$703,148
	Assault Team	5-8 Assailants		$3,141,727	$3,141,727

TANGIBLE ASSET	HAZARD SUB-CATEGORY	HAZARD	LOST GROSS REGIONAL PRODUCT	VSL WEIGHTED TOTAL CASUALTIES	COMBINED REGIONAL COMMUNITY LOSS
	Assault Team	9-16 Assailants		$7,959,042	$7,959,042
	Maritime	Small Boat			
	Maritime	Fast Boat			
	Maritime	Barge			
	Maritime	Deep Draft Ship			
	Vehicle Borne Bomb	Car	$124,012		$124,012
	Vehicle Borne Bomb	Van	$215,020	$448,818	$663,838
	Vehicle Borne Bomb	Midsize Truck	$430,039	$1,600,785	$2,030,824
	Vehicle Borne Bomb	Large Truck (18-Wheeler)	$645,059	$4,323,615	$4,968,674
	Contamination of Product	Biotoxin			
	Contamination of Product	Chemical	$1,290,117	$68,504,612	$69,794,729
	Contamination of Product	Explosive			
	Contamination of Product	Pathogen			
	Contamination of Product	Radionuclide	$1,290,117	$68,504,612	$69,794,729
	Directed / Sabotage	Physical Insider			
	Directed / Sabotage	Physical Outsider			
	Directed / Sabotage	Active Shooter		$14,960,605	$14,960,605
	Theft or Diversion	Physical Insider			
	Theft or Diversion	Physical Outsider			
	Cyber	Cyber Attack			
	Aircraft	Helicopter	$8,300,391	$448,818	$8,749,209

TANGIBLE ASSET	HAZARD SUB-CATEGORY	HAZARD	LOST GROSS REGIONAL PRODUCT	VSL WEIGHTED TOTAL CASUALTIES	COMBINED REGIONAL COMMUNITY LOSS
Lake Geraldine Dam	Aircraft	Small Plane	$14,950,587	$1,600,785	$16,551,372
	Aircraft	Regional Jet	$36,600,782	$4,323,615	$40,924,397
	Aircraft	Large Jet	$38,250,978	$11,025,966	$49,276,944
	Assault Team	1 Assailant			
	Assault Team	2-4 Assailants		$703,148	$703,148
	Assault Team	5-8 Assailants		$3,141,727	$3,141,727
	Assault Team	9-16 Assailants		$7,959,042	$7,959,042
	Maritime	Small Boat			
	Maritime	Fast Boat			
	Maritime	Barge			
	Maritime	Deep Draft Ship			
	Vehicle Borne Bomb	Car	$8,300,391		$8,300,391
	Vehicle Borne Bomb	Van	$14,950,587	$448,818	$15,399,405
	Vehicle Borne Bomb	Midsize Truck	$36,600,782	$1,600,785	$38,201,567
	Vehicle Borne Bomb	Large Truck (18-Wheeler)	$38,250,978	$4,323,615	$42,574,593
	Contamination of Product	Biotoxin			
	Contamination of Product	Chemical	$1,290,117	$68,504,612	$69,794,729
	Contamination of Product	Explosive			
	Contamination of Product	Pathogen			
	Contamination of Product	Radionuclide		$68,504,612	$68,504,612
	Directed / Sabotage	Physical Insider			
	Directed / Sabotage	Physical Outsider			

TANGIBLE ASSET	HAZARD SUB-CATEGORY	HAZARD	LOST GROSS REGIONAL PRODUCT	VSL WEIGHTED TOTAL CASUALTIES	COMBINED REGIONAL COMMUNITY LOSS
	Directed / Sabotage	Active Shooter		$14,960,605	$14,960,605
	Theft or Diversion	Physical Insider			
	Theft or Diversion	Physical Outsider			
	Cyber	Cyber Attack			
Lake Geraldine Intake Systems	Aircraft	Helicopter	$315,020	$448,818	$763,838
	Aircraft	Small Plane	$580,039	$1,600,785	$2,180,824
	Aircraft	Regional Jet	$995,059	$4,323,615	$5,318,674
	Aircraft	Large Jet	$1,990,117	$11,025,966	$13,016,083
	Assault Team	1 Assailant			
	Assault Team	2-4 Assailants		$703,148	$703,148
	Assault Team	5-8 Assailants		$3,141,727	$3,141,727
	Assault Team	9-16 Assailants		$7,959,042	$7,959,042
	Maritime	Small Boat			
	Maritime	Fast Boat			
	Maritime	Barge			
	Maritime	Deep Draft Ship			
	Vehicle Borne Bomb	Car	$315,020		$315,020
	Vehicle Borne Bomb	Van	$580,039	$448,818	$1,028,857
	Vehicle Borne Bomb	Midsize Truck	$995,059	$1,600,785	$2,595,843
	Vehicle Borne Bomb	Large Truck (18-Wheeler)	$1,990,117	$4,323,615	$6,313,732
	Contamination of Product	Biotoxin			
	Contamination of Product	Chemical		$68,504,612	$68,504,612
	Contamination of Product	Explosive			

TANGIBLE ASSET	HAZARD SUB-CATEGORY	HAZARD	LOST GROSS REGIONAL PRODUCT	VSL WEIGHTED TOTAL CASUALTIES	COMBINED REGIONAL COMMUNITY LOSS
	Contamination of Product	Pathogen			
	Contamination of Product	Radionuclide		$68,504,612	$68,504,612
	Directed / Sabotage	Physical Insider			
	Directed / Sabotage	Physical Outsider			
	Directed / Sabotage	Active Shooter		$14,960,605	$14,960,605
	Theft or Diversion	Physical Insider			
	Theft or Diversion	Physical Outsider			
	Cyber	Cyber Attack			
Water Treatment Plant	Aircraft	Helicopter	$7,970,352	$4,323,615	$12,293,967
	Aircraft	Small Plane	$12,450,587	$11,025,966	$23,476,553
	Aircraft	Regional Jet	$16,930,822	$26,599,956	$43,530,778
	Aircraft	Large Jet	$18,911,056	$57,134,552	$76,045,608
	Assault Team	1 Assailant	$116,008	$703,148	$819,156
	Assault Team	2-4 Assailants	$232,016	$4,682,669	$4,914,685
	Assault Team	5-8 Assailants	$348,023	$10,442,503	$10,790,526
	Assault Team	9-16 Assailants	$464,031	$29,921,211	$30,385,242
	Maritime	Small Boat			
	Maritime	Fast Boat			
	Maritime	Barge			
	Maritime	Deep Draft Ship			
	Vehicle Borne Bomb	Car	$7,970,352	$1,600,785	$9,571,137
	Vehicle Borne Bomb	Van	$12,450,587	$4,323,615	$16,774,202
	Vehicle Borne Bomb	Midsize Truck	$16,930,822	$11,025,966	$27,956,788

TANGIBLE ASSET	HAZARD SUB-CATEGORY	HAZARD	LOST GROSS REGIONAL PRODUCT	VSL WEIGHTED TOTAL CASUALTIES	COMBINED REGIONAL COMMUNITY LOSS
	Vehicle Borne Bomb	Large Truck (18-Wheeler)	$18,911,056	$56,521,167	$75,432,223
	Contamination of Product	Biotoxin	$1,090,117	$303,939,658	$305,029,775
	Contamination of Product	Chemical	$1,090,117	$68,504,612	$69,594,729
	Contamination of Product	Explosive	$7,970,352	$1,600,785	$9,571,137
	Contamination of Product	Pathogen	$1,090,117	$303,939,658	$305,029,775
	Contamination of Product	Radionuclide	$1,090,117	$68,504,612	$69,594,729
	Directed / Sabotage	Physical Insider	$355,039		$355,039
	Directed / Sabotage	Physical Outsider	$355,039		$355,039
	Directed / Sabotage	Active Shooter	$116,008	$29,921,211	$30,037,218
	Theft or Diversion	Physical Insider	$355,039		$355,039
	Theft or Diversion	Physical Outsider	$355,039		$355,039
	Cyber	Cyber Attack	$1,240,117		$1,240,117
Treated Water Reservoir	Aircraft	Helicopter	$7,970,352	$11,025,966	$18,996,318
	Aircraft	Small Plane	$12,450,587	$26,599,956	$39,050,543
	Aircraft	Regional Jet	$16,930,822	$57,134,552	$74,065,373
	Aircraft	Large Jet	$18,911,056	$102,629,752	$121,540,809
	Assault Team	1 Assailant		$703,148	$703,148
	Assault Team	2-4 Assailants		$4,682,669	$4,682,669
	Assault Team	5-8 Assailants		$10,442,503	$10,442,503
	Assault Team	9-16 Assailants		$29,921,211	$29,921,211
	Maritime	Small Boat			
	Maritime	Fast Boat			
	Maritime	Barge			

TANGIBLE ASSET	HAZARD SUB-CATEGORY	HAZARD	LOST GROSS REGIONAL PRODUCT	VSL WEIGHTED TOTAL CASUALTIES	COMBINED REGIONAL COMMUNITY LOSS
	Maritime	Deep Draft Ship			
	Vehicle Borne Bomb	Car	$7,970,352	$1,600,785	$9,571,137
	Vehicle Borne Bomb	Van	$12,450,587	$4,323,615	$16,774,202
	Vehicle Borne Bomb	Midsize Truck	$16,930,822	$11,025,966	$27,956,788
	Vehicle Borne Bomb	Large Truck (18-Wheeler)	$18,911,056	$56,521,167	$75,432,223
	Contamination of Product	Biotoxin	$1,090,117	$303,939,658	$305,029,775
	Contamination of Product	Chemical	$1,090,117	$68,504,612	$69,594,729
	Contamination of Product	Explosive	$7,970,352	$1,600,785	$9,571,137
	Contamination of Product	Pathogen	$1,090,117	$303,939,658	$305,029,775
	Contamination of Product	Radionuclide	$1,090,117	$68,504,612	$69,594,729
	Directed / Sabotage	Physical Insider	$595,059		$595,059
	Directed / Sabotage	Physical Outsider	$595,059		$595,059
	Directed / Sabotage	Active Shooter		$14,960,605	$14,960,605
	Theft or Diversion	Physical Insider	$595,059		$595,059
	Theft or Diversion	Physical Outsider	$595,059		$595,059
	Cyber	Cyber Attack			
Distribution System	Aircraft	Helicopter	$291,255	$26,599,956	$26,891,211
	Aircraft	Small Plane	$432,510	$68,504,612	$68,937,122
	Aircraft	Regional Jet	$623,765	$116,558,076	$117,181,841
	Aircraft	Large Jet	$997,529	$252,086,200	$253,083,729
	Assault Team	1 Assailant			

TANGIBLE ASSET	HAZARD SUB-CATEGORY	HAZARD	LOST GROSS REGIONAL PRODUCT	VSL WEIGHTED TOTAL CASUALTIES	COMBINED REGIONAL COMMUNITY LOSS
	Assault Team	2-4 Assailants			
	Assault Team	5-8 Assailants			
	Assault Team	9-16 Assailants			
	Maritime	Small Boat			
	Maritime	Fast Boat			
	Maritime	Barge			
	Maritime	Deep Draft Ship			
	Vehicle Borne Bomb	Car	$291,255	$4,323,615	$4,614,870
	Vehicle Borne Bomb	Van	$432,510	$11,025,966	$11,458,476
	Vehicle Borne Bomb	Midsize Truck	$623,765	$57,134,552	$57,758,316
	Vehicle Borne Bomb	Large Truck (18-Wheeler)	$997,529	$148,124,953	$149,122,483
	Contamination of Product	Biotoxin	$347,529	$303,939,658	$304,287,187
	Contamination of Product	Chemical	$347,529	$68,504,612	$68,852,141
	Contamination of Product	Explosive	$291,255	$1,600,785	$1,892,040
	Contamination of Product	Pathogen	$347,529	$303,939,658	$304,287,187
	Contamination of Product	Radionuclide	$347,529	$68,504,612	$68,852,141
	Directed / Sabotage	Physical Insider	$182,510		$182,510
	Directed / Sabotage	Physical Outsider	$182,510		$182,510
	Directed / Sabotage	Active Shooter			
	Theft or Diversion	Physical Insider			
	Theft or Diversion	Physical Outsider			

TANGIBLE ASSET	HAZARD SUB-CATEGORY	HAZARD	LOST GROSS REGIONAL PRODUCT	VSL WEIGHTED TOTAL CASUALTIES	COMBINED REGIONAL COMMUNITY LOSS
	Cyber	Cyber Attack			
Booster & Reheat Stations	Aircraft	Helicopter	$3,742,588	$26,599,956	$30,342,544
	Aircraft	Small Plane	$5,237,647	$68,504,612	$73,742,258
	Aircraft	Regional Jet	$6,732,705	$116,558,076	$123,290,781
	Aircraft	Large Jet	$7,227,764	$252,086,200	$259,313,964
	Assault Team	1 Assailant	$66,502	$703,148	$769,650
	Assault Team	2-4 Assailants	$133,004	$4,682,669	$4,815,673
	Assault Team	5-8 Assailants	$199,506	$10,442,503	$10,642,008
	Assault Team	9-16 Assailants	$266,008	$29,921,211	$30,187,218
	Maritime	Small Boat			
	Maritime	Fast Boat			
	Maritime	Barge			
	Maritime	Deep Draft Ship			
	Vehicle Borne Bomb	Car	$3,742,588	$4,323,615	$8,066,203
	Vehicle Borne Bomb	Van	$5,237,647	$11,025,966	$16,263,613
	Vehicle Borne Bomb	Midsize Truck	$6,732,705	$57,134,552	$63,867,257
	Vehicle Borne Bomb	Large Truck (18-Wheeler)	$7,227,764	$148,124,953	$155,352,717
	Contamination of Product	Biotoxin	$347,529	$303,939,658	$304,287,187
	Contamination of Product	Chemical	$347,529	$68,504,612	$68,852,141
	Contamination of Product	Explosive	$3,041,255	$1,600,785	$4,642,040
	Contamination of Product	Pathogen	$347,529	$303,939,658	$304,287,187
	Contamination of Product	Radionuclide	$347,529	$68,504,612	$68,852,141
	Directed / Sabotage	Physical Insider	$306,274		$306,274

TANGIBLE ASSET	HAZARD SUB-CATEGORY	HAZARD	LOST GROSS REGIONAL PRODUCT	VSL WEIGHTED TOTAL CASUALTIES	COMBINED REGIONAL COMMUNITY LOSS
	Directed / Sabotage	Physical Outsider	$306,274		$306,274
	Directed / Sabotage	Active Shooter	$66,502	$29,921,211	$29,987,713
	Theft or Diversion	Physical Insider	$306,274		$306,274
	Theft or Diversion	Physical Outsider	$306,274		$306,274
	Cyber	Cyber Attack	$281,274		$281,274
SCADA System	Aircraft	Helicopter	$3,220,352	$4,323,615	$7,543,967
	Aircraft	Small Plane	$5,200,587	$11,025,966	$16,226,553
	Aircraft	Regional Jet	$7,180,822	$26,599,956	$33,780,778
	Aircraft	Large Jet	$9,161,056	$57,134,552	$66,295,608
	Assault Team	1 Assailant	$316,008	$703,148	$1,019,156
	Assault Team	2-4 Assailants	$382,016	$4,682,669	$5,064,685
	Assault Team	5-8 Assailants	$448,023	$10,442,503	$10,890,526
	Assault Team	9-16 Assailants	$514,031	$29,921,211	$30,435,242
	Maritime	Small Boat			
	Maritime	Fast Boat			
	Maritime	Barge			
	Maritime	Deep Draft Ship			
	Vehicle Borne Bomb	Car	$3,220,352	$1,600,785	$4,821,137
	Vehicle Borne Bomb	Van	$5,200,587	$4,323,615	$9,524,202
	Vehicle Borne Bomb	Midsize Truck	$7,180,822	$11,025,966	$18,206,788
	Vehicle Borne Bomb	Large Truck (18-Wheeler)	$9,161,056	$56,521,167	$65,682,223
	Contamination of Product	Biotoxin			
	Contamination of Product	Chemical			

TANGIBLE ASSET	HAZARD SUB-CATEGORY	HAZARD	LOST GROSS REGIONAL PRODUCT	VSL WEIGHTED TOTAL CASUALTIES	COMBINED REGIONAL COMMUNITY LOSS
	Contamination of Product	Explosive			
	Contamination of Product	Pathogen			
	Contamination of Product	Radionuclide			
	Directed / Sabotage	Physical Insider	$1,075,098		$1,075,098
	Directed / Sabotage	Physical Outsider	$1,075,098		$1,075,098
	Directed / Sabotage	Active Shooter			
	Theft or Diversion	Physical Insider	$1,075,098		$1,075,098
	Theft or Diversion	Physical Outsider	$1,075,098		$1,075,098
	Cyber	Cyber Attack	$2,650,196		$2,650,196

The total consequences, left as a monetary value for risk ranking, is proposed and calculated as the sum of the combine utility loss and the combined regional community loss, providing a holistic measure of the impacts of hazards, adverse events, and societal-economic conditions to enable mitigation efforts in the risk and resilience analysis process.

Total Consequences = Combined Utility Loss + Combined Regional Community Loss

Table 32 shows the Total Consequences for assessment.

Table 32: Summary of Total Consequences for Iqaluit Water Infrastructure

TANGIBLE ASSET	HAZARD SUB-CATEGORY	HAZARD	COMBINED UTILITY LOSS	COMBINED REGIONAL COMMUNITY LOSS	TOTAL CONSEQUENCES
Lake Geraldine	Aircraft	Helicopter	$290,471	$713,838	$1,004,308
	Aircraft	Small Plane	$633,340	$2,080,824	$2,714,164
	Aircraft	Regional Jet	$1,204,973	$5,018,674	$6,223,646
	Aircraft	Large Jet	$2,606,358	$12,266,083	$14,872,442
	Assault Team	1 Assailant			
	Assault Team	2-4 Assailants	$102,399	$703,148	$805,547

TANGIBLE ASSET	HAZARD SUB-CATEGORY	HAZARD	COMBINED UTILITY LOSS	COMBINED REGIONAL COMMUNITY LOSS	TOTAL CONSEQUENCES
	Assault Team	5-8 Assailants	$457,527	$3,141,727	$3,599,254
	Assault Team	9-16 Assailants	$1,159,068	$7,959,042	$9,118,110
	Maritime	Small Boat			
	Maritime	Fast Boat			
	Maritime	Barge			
	Maritime	Deep Draft Ship			
	Vehicle Borne Bomb	Car	$100,066	$124,012	$224,077
	Vehicle Borne Bomb	Van	$240,471	$663,838	$904,308
	Vehicle Borne Bomb	Midsize Truck	$583,340	$2,030,824	$2,614,164
	Vehicle Borne Bomb	Large Truck (18-Wheeler)	$1,154,973	$4,968,674	$6,123,646
	Contamination of Product	Biotoxin			
	Contamination of Product	Chemical	$11,026,918	$69,794,729	$80,821,647
	Contamination of Product	Explosive			
	Contamination of Product	Pathogen			
	Contamination of Product	Radionuclide	$11,026,918	$69,794,729	$80,821,647
	Directed / Sabotage	Physical Insider			
	Directed / Sabotage	Physical Outsider			
	Directed / Sabotage	Active Shooter	$2,178,698	$14,960,605	$17,139,304
	Theft or Diversion	Physical Insider			
	Theft or Diversion	Physical Outsider			

TANGIBLE ASSET	HAZARD SUB-CATEGORY	HAZARD	COMBINED UTILITY LOSS	COMBINED REGIONAL COMMUNITY LOSS	TOTAL CONSEQUENCES
	Cyber	Cyber Attack			
Lake Geraldine Dam	Aircraft	Helicopter	$7,567,553	$8,749,209	$16,316,762
	Aircraft	Small Plane	$13,986,409	$16,551,372	$30,537,780
	Aircraft	Regional Jet	$35,634,028	$40,924,397	$76,558,425
	Aircraft	Large Jet	$37,861,181	$49,276,944	$87,138,125
	Assault Team	1 Assailant			
	Assault Team	2-4 Assailants	$102,399	$703,148	$805,547
	Assault Team	5-8 Assailants	$457,527	$3,141,727	$3,599,254
	Assault Team	9-16 Assailants	$1,159,068	$7,959,042	$9,118,110
	Maritime	Small Boat			
	Maritime	Fast Boat			
	Maritime	Barge			
	Maritime	Deep Draft Ship			
	Vehicle Borne Bomb	Car	$7,502,192	$8,300,391	$15,802,583
	Vehicle Borne Bomb	Van	$13,818,649	$15,399,405	$29,218,054
	Vehicle Borne Bomb	Midsize Truck	$35,237,505	$38,201,567	$73,439,072
	Vehicle Borne Bomb	Large Truck (18-Wheeler)	$36,885,124	$42,574,593	$79,459,717
	Contamination of Product	Biotoxin			
	Contamination of Product	Chemical	$11,026,918	$69,794,729	$80,821,647
	Contamination of Product	Explosive			
	Contamination of Product	Pathogen			
	Contamination of Product	Radionuclide	$9,976,260	$68,504,612	$78,480,872

TANGIBLE ASSET	HAZARD SUB-CATEGORY	HAZARD	COMBINED UTILITY LOSS	COMBINED REGIONAL COMMUNITY LOSS	TOTAL CONSEQUENCES
	Directed / Sabotage	Physical Insider			
	Directed / Sabotage	Physical Outsider			
	Directed / Sabotage	Active Shooter	$2,178,698	$14,960,605	$17,139,304
	Theft or Diversion	Physical Insider			
	Theft or Diversion	Physical Outsider			
	Cyber	Cyber Attack			
Lake Geraldine Intake Systems	Aircraft	Helicopter	$340,471	$763,838	$1,104,308
	Aircraft	Small Plane	$733,340	$2,180,824	$2,914,164
	Aircraft	Regional Jet	$1,504,973	$5,318,674	$6,823,646
	Aircraft	Large Jet	$3,356,358	$13,016,083	$16,372,442
	Assault Team	1 Assailant			
	Assault Team	2-4 Assailants	$102,399	$703,148	$805,547
	Assault Team	5-8 Assailants	$457,527	$3,141,727	$3,599,254
	Assault Team	9-16 Assailants	$1,159,068	$7,959,042	$9,118,110
	Maritime	Small Boat			
	Maritime	Fast Boat			
	Maritime	Barge			
	Maritime	Deep Draft Ship			
	Vehicle Borne Bomb	Car	$275,110	$315,020	$590,129
	Vehicle Borne Bomb	Van	$565,580	$1,028,857	$1,594,437
	Vehicle Borne Bomb	Midsize Truck	$1,108,450	$2,595,843	$3,704,293
	Vehicle Borne Bomb	Large Truck (18-Wheeler)	$2,380,301	$6,313,732	$8,694,034

TANGIBLE ASSET	HAZARD SUB-CATEGORY	HAZARD	COMBINED UTILITY LOSS	COMBINED REGIONAL COMMUNITY LOSS	TOTAL CONSEQUENCES
	Contamination of Product	Biotoxin			
	Contamination of Product	Chemical	$9,976,260	$68,504,612	$78,480,872
	Contamination of Product	Explosive			
	Contamination of Product	Pathogen			
	Contamination of Product	Radionuclide	$9,976,260	$68,504,612	$78,480,872
	Directed / Sabotage	Physical Insider			
	Directed / Sabotage	Physical Outsider			
	Directed / Sabotage	Active Shooter	$2,178,698	$14,960,605	$17,139,304
	Theft or Diversion	Physical Insider			
	Theft or Diversion	Physical Outsider			
	Cyber	Cyber Attack			
Water Treatment Plant	Aircraft	Helicopter	$7,881,617	$12,293,967	$20,175,584
	Aircraft	Small Plane	$12,858,989	$23,476,553	$36,335,542
	Aircraft	Regional Jet	$19,128,329	$43,530,778	$62,659,107
	Aircraft	Large Jet	$25,076,368	$76,045,608	$101,121,976
	Assault Team	1 Assailant	$202,443	$819,156	$1,021,599
	Assault Team	2-4 Assailants	$882,020	$4,914,685	$5,796,705
	Assault Team	5-8 Assailants	$1,820,863	$10,790,526	$12,611,389
	Assault Team	9-16 Assailants	$4,757,572	$30,385,242	$35,142,814
	Maritime	Small Boat			
	Maritime	Fast Boat			
	Maritime	Barge			

TANGIBLE ASSET	HAZARD SUB-CATEGORY	HAZARD	COMBINED UTILITY LOSS	COMBINED REGIONAL COMMUNITY LOSS	TOTAL CONSEQUENCES
	Maritime	Deep Draft Ship			
	Vehicle Borne Bomb	Car	$7,485,094	$9,571,137	$17,056,230
	Vehicle Borne Bomb	Van	$11,882,932	$16,774,202	$28,657,134
	Vehicle Borne Bomb	Midsize Truck	$16,860,304	$27,956,788	$44,817,092
	Vehicle Borne Bomb	Large Truck (18-Wheeler)	$24,987,041	$75,432,223	$100,419,264
	Contamination of Product	Biotoxin	$45,113,094	$305,029,775	$350,142,869
	Contamination of Product	Chemical	$10,826,918	$69,594,729	$80,421,647
	Contamination of Product	Explosive	$7,485,094	$9,571,137	$17,056,230
	Contamination of Product	Pathogen	$45,113,094	$305,029,775	$350,142,869
	Contamination of Product	Radionuclide	$10,826,918	$69,594,729	$80,421,647
	Directed / Sabotage	Physical Insider	$275,219	$355,039	$630,258
	Directed / Sabotage	Physical Outsider	$275,219	$355,039	$630,258
	Directed / Sabotage	Active Shooter	$4,457,441	$30,037,218	$34,494,659
	Theft or Diversion	Physical Insider	$275,219	$355,039	$630,258
	Theft or Diversion	Physical Outsider	$275,219	$355,039	$630,258
	Cyber	Cyber Attack	$1,000,658	$1,240,117	$2,240,775
Treated Water Reservoir	Aircraft	Helicopter	$8,857,674	$18,996,318	$27,853,992
	Aircraft	Small Plane	$15,127,014	$39,050,543	$54,177,557
	Aircraft	Regional Jet	$23,575,052	$74,065,373	$97,640,426
	Aircraft	Large Jet	$31,701,789	$121,540,809	$153,242,598

TANGIBLE ASSET	HAZARD SUB-CATEGORY	HAZARD	COMBINED UTILITY LOSS	COMBINED REGIONAL COMMUNITY LOSS	TOTAL CONSEQUENCES
	Assault Team	1 Assailant	$102,399	$703,148	$805,547
	Assault Team	2-4 Assailants	$681,933	$4,682,669	$5,364,602
	Assault Team	5-8 Assailants	$1,520,731	$10,442,503	$11,963,234
	Assault Team	9-16 Assailants	$4,357,397	$29,921,211	$34,278,607
	Maritime	Small Boat			
	Maritime	Fast Boat			
	Maritime	Barge			
	Maritime	Deep Draft Ship			
	Vehicle Borne Bomb	Car	$7,485,094	$9,571,137	$17,056,230
	Vehicle Borne Bomb	Van	$11,882,932	$16,774,202	$28,657,134
	Vehicle Borne Bomb	Midsize Truck	$16,860,304	$27,956,788	$44,817,092
	Vehicle Borne Bomb	Large Truck (18-Wheeler)	$24,987,041	$75,432,223	$100,419,264
	Contamination of Product	Biotoxin	$45,113,094	$305,029,775	$350,142,869
	Contamination of Product	Chemical	$10,826,918	$69,594,729	$80,421,647
	Contamination of Product	Explosive	$7,485,094	$9,571,137	$17,056,230
	Contamination of Product	Pathogen	$45,113,094	$305,029,775	$350,142,869
	Contamination of Product	Radionuclide	$10,826,918	$69,594,729	$80,421,647
	Directed / Sabotage	Physical Insider	$475,329	$595,059	$1,070,387
	Directed / Sabotage	Physical Outsider	$475,329	$595,059	$1,070,387
	Directed / Sabotage	Active Shooter	$2,178,698	$14,960,605	$17,139,304

TANGIBLE ASSET	HAZARD SUB-CATEGORY	HAZARD	COMBINED UTILITY LOSS	COMBINED REGIONAL COMMUNITY LOSS	TOTAL CONSEQUENCES
	Theft or Diversion	Physical Insider	$475,329	$595,059	$1,070,387
	Theft or Diversion	Physical Outsider	$475,329	$595,059	$1,070,387
	Cyber	Cyber Attack			
Distribution System	Aircraft	Helicopter	$4,155,003	$26,891,211	$31,046,214
	Aircraft	Small Plane	$10,388,815	$68,937,122	$79,325,936
	Aircraft	Regional Jet	$17,568,071	$117,181,841	$134,749,912
	Aircraft	Large Jet	$37,648,732	$253,083,729	$290,732,461
	Assault Team	1 Assailant			
	Assault Team	2-4 Assailants			
	Assault Team	5-8 Assailants			
	Assault Team	9-16 Assailants			
	Maritime	Small Boat			
	Maritime	Fast Boat			
	Maritime	Barge			
	Maritime	Deep Draft Ship			
	Vehicle Borne Bomb	Car	$910,921	$4,614,870	$5,525,791
	Vehicle Borne Bomb	Van	$2,018,256	$11,458,476	$13,476,731
	Vehicle Borne Bomb	Midsize Truck	$8,914,281	$57,758,316	$66,672,598
	Vehicle Borne Bomb	Large Truck (18-Wheeler)	$22,508,957	$149,122,483	$171,631,440
	Contamination of Product	Biotoxin	$44,550,101	$304,287,187	$348,837,288
	Contamination of Product	Chemical	$10,263,924	$68,852,141	$79,116,065
	Contamination of Product	Explosive	$514,398	$1,892,040	$2,406,438

TANGIBLE ASSET	HAZARD SUB-CATEGORY	HAZARD	COMBINED UTILITY LOSS	COMBINED REGIONAL COMMUNITY LOSS	TOTAL CONSEQUENCES
	Contamination of Product	Pathogen	$44,550,101	$304,287,187	$348,837,288
	Contamination of Product	Radionuclide	$10,263,924	$68,852,141	$79,116,065
	Directed / Sabotage	Physical Insider	$162,555	$182,510	$345,065
	Directed / Sabotage	Physical Outsider	$162,555	$182,510	$345,065
	Directed / Sabotage	Active Shooter			
	Theft or Diversion	Physical Insider			
	Theft or Diversion	Physical Outsider			
	Cyber	Cyber Attack			
Booster & Reheat Stations	Aircraft	Helicopter	$7,436,719	$30,342,544	$37,779,263
	Aircraft	Small Plane	$14,914,582	$73,742,258	$88,656,840
	Aircraft	Regional Jet	$23,287,890	$123,290,781	$146,578,671
	Aircraft	Large Jet	$43,400,047	$259,313,964	$302,714,011
	Assault Team	1 Assailant	$164,910	$769,650	$934,560
	Assault Team	2-4 Assailants	$806,955	$4,815,673	$5,622,628
	Assault Team	5-8 Assailants	$1,708,264	$10,642,008	$12,350,273
	Assault Team	9-16 Assailants	$4,607,441	$30,187,218	$34,794,659
	Maritime	Small Boat			
	Maritime	Fast Boat			
	Maritime	Barge			
	Maritime	Deep Draft Ship			
	Vehicle Borne Bomb	Car	$4,192,637	$8,066,203	$12,258,840
	Vehicle Borne Bomb	Van	$6,544,023	$16,263,613	$22,807,636

TANGIBLE ASSET	HAZARD SUB-CATEGORY	HAZARD	COMBINED UTILITY LOSS	COMBINED REGIONAL COMMUNITY LOSS	TOTAL CONSEQUENCES
	Vehicle Borne Bomb	Midsize Truck	$14,634,100	$63,867,257	$78,501,357
	Vehicle Borne Bomb	Large Truck (18-Wheeler)	$28,260,272	$155,352,717	$183,612,990
	Contamination of Product	Biotoxin	$44,550,101	$304,287,187	$348,837,288
	Contamination of Product	Chemical	$10,263,924	$68,852,141	$79,116,065
	Contamination of Product	Explosive	$3,264,398	$4,642,040	$7,906,438
	Contamination of Product	Pathogen	$44,550,101	$304,287,187	$348,837,288
	Contamination of Product	Radionuclide	$10,263,924	$68,852,141	$79,116,065
	Directed / Sabotage	Physical Insider	$256,387	$306,274	$562,661
	Directed / Sabotage	Physical Outsider	$256,387	$306,274	$562,661
	Directed / Sabotage	Active Shooter	$4,419,908	$29,987,713	$34,407,620
	Theft or Diversion	Physical Insider	$256,387	$306,274	$562,661
	Theft or Diversion	Physical Outsider	$256,387	$306,274	$562,661
	Cyber	Cyber Attack	$231,387	$281,274	$512,661
SCADA System	Aircraft	Helicopter	$3,131,617	$7,543,967	$10,675,584
	Aircraft	Small Plane	$5,608,989	$16,226,553	$21,835,542
	Aircraft	Regional Jet	$9,378,329	$33,780,778	$43,159,107
	Aircraft	Large Jet	$15,326,368	$66,295,608	$81,621,976
	Assault Team	1 Assailant	$402,443	$1,019,156	$1,421,599
	Assault Team	2-4 Assailants	$1,032,020	$5,064,685	$6,096,705
	Assault Team	5-8 Assailants	$1,920,863	$10,890,526	$12,811,389
	Assault Team	9-16 Assailants	$4,807,572	$30,435,242	$35,242,814

TANGIBLE ASSET	HAZARD SUB-CATEGORY	HAZARD	COMBINED UTILITY LOSS	COMBINED REGIONAL COMMUNITY LOSS	TOTAL CONSEQUENCES
	Maritime	Small Boat			
	Maritime	Fast Boat			
	Maritime	Barge			
	Maritime	Deep Draft Ship			
	Vehicle Borne Bomb	Car	$2,735,094	$4,821,137	$7,556,230
	Vehicle Borne Bomb	Van	$4,632,932	$9,524,202	$14,157,134
	Vehicle Borne Bomb	Midsize Truck	$7,110,304	$18,206,788	$25,317,092
	Vehicle Borne Bomb	Large Truck (18-Wheeler)	$15,237,041	$65,682,223	$80,919,264
	Contamination of Product	Biotoxin			
	Contamination of Product	Chemical			
	Contamination of Product	Explosive			
	Contamination of Product	Pathogen			
	Contamination of Product	Radionuclide			
	Directed / Sabotage	Physical Insider	$875,548	$1,075,098	$1,950,646
	Directed / Sabotage	Physical Outsider	$875,548	$1,075,098	$1,950,646
	Directed / Sabotage	Active Shooter			
	Theft or Diversion	Physical Insider	$875,548	$1,075,098	$1,950,646
	Theft or Diversion	Physical Outsider	$875,548	$1,075,098	$1,950,646
	Cyber	Cyber Attack	$2,251,096	$2,650,196	$4,901,292

2.3.4 EVALUATION OF ADDITIONAL CONSEQUENCES

The resilience study report will incorporate additional consequences, where relevant and where appropriate, upon reception of new client provided information and combination of the latest revisions. The inclusion of these consequences will reference impacts outlined in AWWA J100-21 Sec. 4.7, which may consider sociopolitical impacts, national security impacts, reduced strategic capability to cause harm or output, detrimental effects on brand value, public confidence, psychological impacts, environmental degradation, and litigation costs. This aims to give a more nuanced judgment of their acceptability in the comparison of optional solutions.

2.4 VULNERABILITY ANALYSIS

This step evaluates the capacity of each critical asset and its protective systems to endure specific threats. For malevolent events, the analysis estimates the probability of an adversary successfully carrying out a particular mode of attack on a specific asset, assuming the attack occurs. For natural, dependency, and proximity hazards, vulnerability refers to the likelihood that, if the hazard materializes, the anticipated consequences will follow. WSP conducted a vulnerability analysis in accordance with the sections below.

2.4.1 FACILITY REVIEW

WSP reviewed details of the water distribution systems, layouts, including existing countermeasures, mitigation measures, and impediments to threats. These include design and equipment features that provide deterrence, detection, and delay capabilities, as well as local and supporting response measures. Additionally, document interdependencies, personnel interactions, and process flow within the system. This resulted in the identification of vulnerabilities or weaknesses in the systems.

2.4.2 VULNERABILITY ASSESSMENT

WSP evaluated the vulnerability of each critical asset to determine its likelihood. The vulnerability of a given project element is measured by comparing the sensitivity of an element to a given climate change hazard change and its adaptive capacity during the lifetime of the infrastructure.

Sensitivity

Sensitivity to climate change is the degree to which a system is affected by or responsive to climate-related stimuli. The effect may be direct (e.g., increased cooling demand from an increasing temperatures) or indirect (e.g., damage caused by settlement from permafrost thaw). In this assessment, the sensitivity refers to the positive/negative impacts experienced by the infrastructure from changes in climate hazards. Refer to **Table 33** for sensitivity scoring scale.

Table 33: Sensitivity Scoring Scale

SCORE	RATIONALE
Very low	The probability that the project component will be affected by the change in climate hazard is minimal.
Low	The probability that the main components of the project will be affected by the climate hazard is minimal. There is a small chance that the secondary components will be affected by the climate hazard.
Moderate	There is a low probability that the main components will be affected by the climate hazard. There is a good chance that the secondary components will be affected by the climate hazard.
High	There is a high probability that the project will be directly affected by the climate hazard.
Very High	There is a very high probability that the project will be directly affected by the climate hazard.

Adaptive Capacity

Adaptive capacity is the ability of a system to adjust to climate change, including climate variability and extremes, to moderate potential damages, to take advantage of opportunities, or to cope with the consequences. Adaptive capacity can reduce a project's vulnerability to potential impacts. The measures already in place and those that would be easy to implement post-construction are listed. It is important to understand that the inclusion of resilience recommendations into the future iteration of design would increase the level of adaptive capacity of the project and its components. Refer to Table 34 for adaptive capacity scoring scale.

Table 34: Adaptive Capacity Scoring Scale

SCORE	RATIONALE
Very high	Adaptation measures are very easily implemented and effective.
High	Adaptation measures are easily implemented and effective.
Moderate	There are adaptation measures, but their cost, the time to implement them or their effectiveness makes their implementation questionable.
Low	The implementation of adaptation measures is long and ineffective. The cost of implementation is similar to the value of the project.
Very low	Adaptation measures are non-existent or not known. The cost of implementing adaptation measures exceeds the value of the project.

The vulnerability assessment step evaluates the vulnerability of each component interaction to specific climate hazards by cross-referencing their sensitivity levels and adaptive capacity, as shown in Table 35.

Table 35: Vulnerability Evaluation Matrix

VULNERABILITY		SENSITIVITY: Very low	Low	Moderate	High	Very High
Adaptive Capacity	Very low		Low	Moderate	High	Very High
	Low		Low	Moderate	High	High
	Moderate		Low	Low	Moderate	High
	High			Low	Moderate	Moderate
	Very High			Low	Low	Moderate

The basic rationale for Iqaluit water infrastructure's sensitivity scoring is shown below:

- Earthquakes - Earthquakes may cause structural damages especially to dams, intake systems and treatment plant equipment as they are sensitive to ground shaking. SCADA system is in general similarly affected as to WTP but depends somehow on power supply's continuity.
- Floods – Dams, intake systems, WTP, SCADA and reservoirs have high sensitivity because of inundation risks and chance of equipment degradation.
- Hurricanes – most assets have moderate risks due to wind-resistant designs, but high winds and heavy rainfall may cause different levels of damage.
- Ice Storms – Ice storms may cause high risks to distribution system and pumping system due to mechanical failure.
- Tornadoes – Critical assets such as treatment equipment, pumps and SCADA typically face more damage than open spaces from high winds because they consist delicate components that are susceptible to physical damage and operational failure.
- Wildfires – major impacts include heat and smoke generated to impact assets if they are in proximity to infrastructure. Table below presents the preliminary risk results showing the sensitivity scores for each impact.

Table 36 shows Iqaluit water infrastructure's sensitivity scores.

Table 36: Sensitivity scores for Iqaluit water infrastructure

ASSET	EARTHQUAKE	FLOODS	HURRICANES	ICE STORMS	TORNADOES	WILDFIRES
Lake Geraldine	Low	Moderate	Low	Very low	Low	Low
Lake Geraldine Dam	High	High	Moderate	Low	Moderate	Low
Lake Geraldine Intake System	High	High	Moderate	Low	Moderate	Low

ASSET	EARTHQUAKE	FLOODS	HURRICANES	ICE STORMS	TORNADOES	WILDFIRES
Water Treatment Plant	High	High	Moderate	Moderate	Moderate	Moderate
Treated Water Reservoir	High	High	Moderate	Low	Low	Low
Distribution System	Moderate	Moderate	Moderate	High	Moderate	Low
Booster & Reheat Stations	High	Moderate	Moderate	High	Moderate	Low
SCADA System	High	High	Moderate	Moderate	Moderate	Moderate

Table 37 below presents the preliminary risk results showing the adaptive capacity scores for each impact.

The basic rationale for these scoring is shown below:

- Earthquakes - Assets like natural water bodies (e.g., Lake Geraldine) and reservoirs are typically designed to withstand seismic activity, making them highly adaptive. Dams, intake systems, water treatment plants, distribution systems, and booster stations can handle some seismic stress but may require repairs and maintenance.
- Floods – Natural water bodies and SCADA systems are generally resilient to flooding due to their design and redundancy. Dams, intake systems, water treatment plants, distribution systems, and booster stations can handle flooding but may face challenges with inundation and contamination.
- Hurricanes – SCADA systems and water treatment plants are often built to withstand high winds and heavy rainfall, making them more resilient. Dams, intake systems, reservoirs, distribution systems, and booster stations can handle hurricanes but may require repairs and maintenance.
- Ice Storms – Distribution systems and booster stations are more vulnerable to ice storms due to potential power outages and physical damage.
- Tornadoes – Water treatment plants, distribution systems, and booster stations can handle tornadoes but may require repairs and maintenance and the service may not be able to rapidly restored.
- Wildfires – Most discussed assets such as natural water bodies and SCADA may have the highest resistance to wildfires whereas the WTP may face some challenges from wildfire-induced heat, smoke and debris.

Table 37: Adaptive capacity scores for Iqaluit water infrastructure

ASSET	EARTHQUAKE	FLOODS	HURRICANES	ICE STORMS	TORNADOES	WILDFIRES
Lake Geraldine	High	High	High	High	High	High
Lake Geraldine Dam	Moderate	Moderate	Moderate	High	High	High
Lake Geraldine Intake System	Moderate	Moderate	Moderate	High	High	High
Water Treatment Plant	Moderate	Moderate	High	Moderate	Moderate	Moderate
Treated Water Reservoir	High	Moderate	Moderate	High	High	High
Distribution System	Moderate	Moderate	Moderate	Low	Moderate	High
Booster & Reheat Stations	Moderate	Moderate	Moderate	Low	Moderate	High
SCADA System	High	High	High	Moderate	High	Very High

Table 38 below is a summary for vulnerability rating based on above preliminary assessment.

Table 38: Vulnerability rating for Iqaluit water infrastructure

ASSET	EARTHQUAKE	FLOODS	HURRICANES	ICE STORMS	TORNADOES	WILDFIRES
Lake Geraldine	Very Low	Low	Very Low	Very low	Very Low	Very Low
Lake Geraldine Dam	Moderate	Moderate	Low	Very low	Low	Very Low
Lake Geraldine Intake System	Moderate	Moderate	Low	Very Low	Low	Very Low
Water Treatment Plant	Moderate	Moderate	Low	Low	Low	Low
Treated Water Reservoir	Moderate	Moderate	Low	Very low	Very Low	Very Low
Distribution System	Low	Low	Low	High	Low	Very Low

ASSET	EARTHQUAKE	FLOODS	HURRICANES	ICE STORMS	TORNADOES	WILDFIRES
Booster & Reheat Stations	Moderate	Low	Low	High	Moderate	Very Low
SCADA System	Moderate	Moderate	Low	Low	Low	Low

To quantify the impacts of vulnerability, a numeric-based vulnerability scoring is assigned as a qualitative-quantitative proxy for categorizing the systems into the five levels of vulnerability. This system categorizes the systems into five levels of likelihood vulnerability: Very Low, Low, Moderate, High, and Very High, with corresponding likelihood scores of 1, 2, 3, 4, and 5, matching likelihood categories of rare, unlikely, possible, likely, and very likely, respectively.

The likelihood scores of earthquakes, floods, hurricanes, ice storms, tornadoes and wildfires were assigned based on the Canadian disaster event findings summarized in **Table 22**. The likelihood score of each hazard is shown in below discussion as well as in **Table 39**.

Earthquake: Likelihood Score is assigned as 1. No recorded seismic activity in Iqaluit historical data.

Floods: Likelihood Score is assigned as 1. Minimal flood risk is identified in Iqaluit due to Arctic climate.

Hurricanes: Likelihood Score is assigned as 1. Iqaluit is geographically isolated from hurricane paths, making this hazard negligible.

Ice Storm: Likelihood Score is assigned as 2. There was a single record found in Iqaluit, suggesting a low but present risk.

Tornadoes: Likelihood Score is assigned as 1. Iqaluit has no record of Tornadoes due to unsuitable climatic conditions.

Wildfires: Likelihood Score is assigned as 1. Iqaluit has no record of wildfires due to low vegetations (thus low organic contents for burning) and permafrost landscape.

The overall vulnerability score, reflected by Total Weighted Vulnerability (V), for each asset is calculated by integrating the vulnerability ratings for each specified hazard with the corresponding likelihood of occurrence. The total weighted score is proposed to be normalized based on the following equation.

$$Total\ Weighted\ Vulnerability = \frac{\sum_{i=1}^{6}(Likelihood\ Score\ of\ Hazard_i \times Vulnerability\ Score\ of\ Hazard_i)}{\sum_{i=1}^{6} Likelihood\ Score\ of\ Hazard_i}$$

Where,

- Total Weighted Vulnerability is the overall, normalized vulnerability score for the asset described;

- Likelihood Score of Hazard$_i$ represents the likelihood score of natural hazard i occurring for one of the following: i.e., earthquake, floods, hurricanes, ice storm, tornadoes and wildfires.
- Vulnerability Score of Hazard$_i$ represents the vulnerability score of natural hazard I\i occurring for one of the following: i.e., earthquake, floods, hurricanes, ice storm, tornadoes and wildfires.

The rationale behind this approach lies in the fact that the natural hazard(s) with higher probabilities of occurrence should have a greater influence on the overall vulnerability score.

The vulnerability scoring is shown in **Table 39**. This approach provides a comprehensive measure to a wide array of risks for mitigation planning.

Table 39: Weighted Vulnerability scores for Iqaluit water infrastructure

ASSET	EARTHQUAKE	FLOODS	HURRICANES	ICE STORMS	TORNADOES	WILDFIRES	TOTAL WEIGHTED SCORE (V)
Lake Geraldine	1	2	1	1	1	1	**1.14**
Lake Geraldine Dam	3	3	2	1	2	1	**1.86**
Lake Geraldine Intake System	3	3	2	1	2	1	**1.86**
Water Treatment Plant	3	3	2	2	2	2	**2.29**
Treated Water Reservoir	3	3	2	1	1	1	**1.71**
Distribution System	2	2	2	4	2	1	**2.43**
Booster & Reheat Stations	3	2	2	4	3	1	**2.71**
SCADA System	3	3	2	2	2	2	**2.29**

From this table, it was found the Water Distribution System has a total weighted vulnerability score of 2.43, just slightly lower than Booster & Reheat Systems, which has as total weighted vulnerability score of 2.71. In the event of an ice storm, the water distribution system would be vulnerable it can cause extensive damage to pipes and valves (due to freezing) within the distribution system, resulting in service outages. The distribution network, especially areas fed by gravity are more prone to ice storms than pressurized zones. This underscores a necessity to prepare resilience measures for the Iqaluit water distribution system.

2.4.3 CYBER VULNERABILITY ASSESSMENT

While this study's vulnerability analysis focuses on natural hazards, it is important to acknowledge the critical role of cybersecurity in water utilities. Most utilities operate automated systems for both operational controls and business enterprise needs, which require protective measures to ensure resilience against cyber threats.

This study did not include a detailed cybersecurity vulnerability assessment due to the unavailability of Canadian-specific references or frameworks at the time of analysis. However, integrating a focused cybersecurity assessment in future state studies is recommended. This would ensure a comprehensive approach to resilience, addressing potential threats to both physical and cyber assets. Identifying gaps in cybersecurity measures and prioritizing critical controls would enhance overall system security and mitigate risks stemming from cyber incidents.

2.5 THREAT ANALYSIS

This step evaluates the likelihood of occurrence for each identified threat in relation to critical assets. The analysis focuses on estimating the probability of various threats, including malevolent, natural, and dependency/proximity threats, on an annual basis.

2.5.1 MALEVOLENT THREATS

Malevolent threats stem from actors such as domestic or international terrorists, disgruntled employees or customers, and criminal elements. These individuals or groups pose significant risks to critical infrastructure due to their potential motivations, ranging from economic disruption to causing harm or spreading fear. Such threats may involve methods like firearms, explosives, contaminants, or even vehicular attacks.

In addition to terrorism, utilities must also consider threats associated with theft, vandalism, or sabotage by individuals familiar with the system—such as disgruntled insiders. Historical incidents and trends within the utility sector and similar facilities can provide valuable insights into the likelihood and frequency of such threats. For instance, recurring issues like material theft or unauthorized access can indicate vulnerabilities requiring immediate attention.

While definitive databases or predictive models for malevolent threat likelihood are limited, utilities can use a combination of historical data, expert judgment, and situational awareness to assess risks. Collaborative efforts with local intelligence, law enforcement, and security agencies can also help utilities better understand and estimate these risks.

There are two approaches for estimating malevolent threat likelihood. One is "The Proxy Method while the other being "Best Estimate". In this study, we adopted the practically used, data-driven proxy method based on established models to assess the likelihood of malevolent threats. From J100-21, estimating a proxy of value is ease for implementation and can provide critical information for decision making. Details of each are provided in the following sections.

2.5.2 THE PROXY METHOD

The proxy method, adapted from AWWA J21-100, evaluates the likelihood of a terrorist targeting specific assets and attack modes, referred to as threat-asset pairs. This method assumes that attackers are rational and adaptive decision-makers with knowledge of the utility's operations and security measures. The process identifies the probability of each threat-asset pair being chosen by analyzing motivations, vulnerabilities, and potential consequences. **Figure 7** illustrates the proxy model for terrorist decision making.

2.5.2.1 ESTIMATING LIKELIHOOD

The proxy method outlines a step-by-step process to approximate the likelihood of terrorist actions targeting specific assets. It begins with the selection of the broader target region and narrows down to specific facilities and assets within that region. Instead of pinpointing one pair, it calculates the likelihood of selecting each pair based on historical data, expert analysis, and current information. As shown in **Figure 7**, the terrorist's decision is modeled as a six-decision selection process.

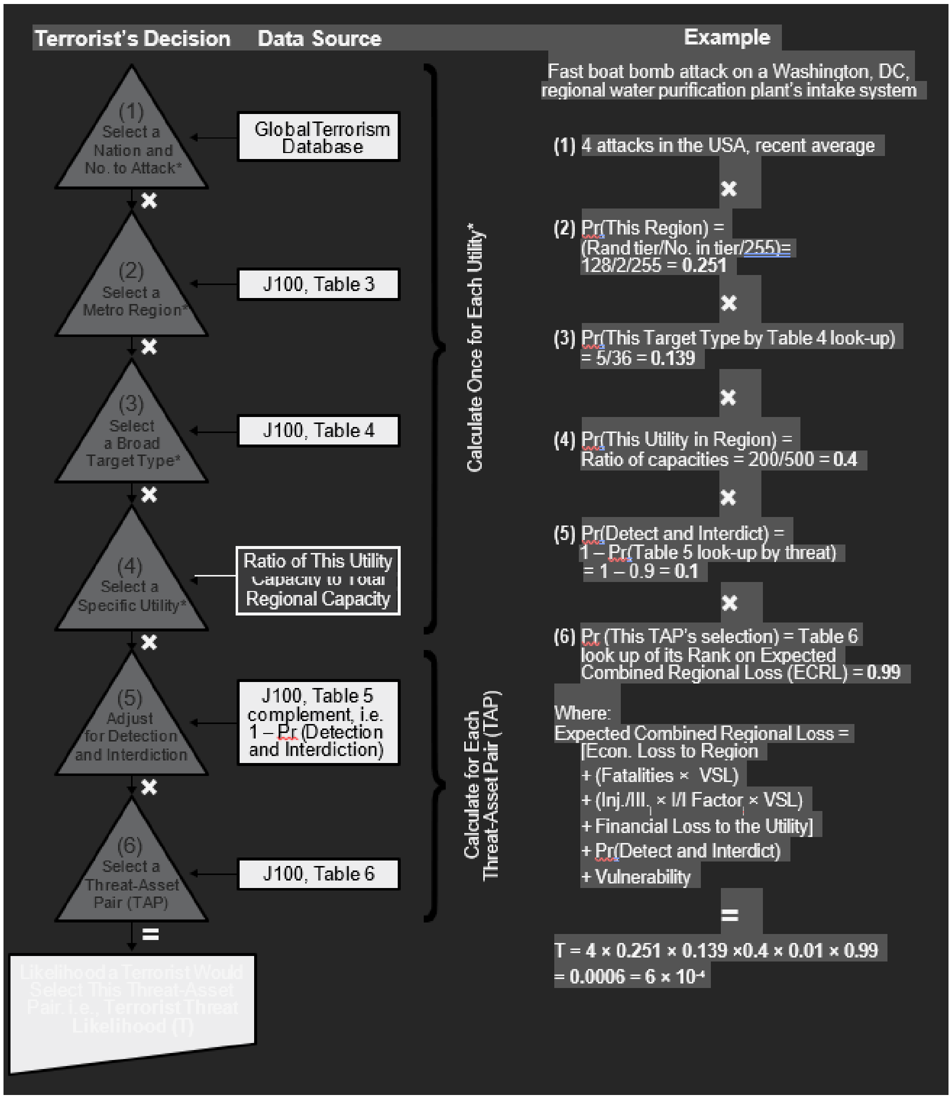


Figure 7: The "proxy" model of a terrorist's selection of threat-asset pair to attack (Adapted from J100-21)

*The outcomes of Decisions 1 through 4 can be multiplied to form a constant for each utility, which is then multiplied by the results of Decisions 5 and 6 for each threat-asset pair to calculate its Terrorist Threat Likelihood.

2.5.2.2 ESTIMATING NUMBER OF ATTACKS

In order to estimate the number of attacks, the Global Terrorism Database (GTD) was used. The threat frequency is determined based on the following formula.

Annualized Frequency of Threats (AFT) = Number of Incidents / Years of Observation

From GTD, it was found that there are 168 incidents identified over 50 years which were verified for relevance and accuracy. Hence, a calculated AFT of 3.36 was chosen for Canada to guide risk management practices in this report.

2.5.2.3 SELECTION OF FACILITY TO ATTACK

We referred RAND/RMS target type groups from AWWA J100-21 to identify targeted facilities that can attacked by terrorists, as shown in Table 40. Note that the rations and target types presented here in the reference table was not directly utilized in our threat analysis but conversely, they serve as a useful reference to reflect the proportion of different target types attacked in malevolent events to indicate the likelihood of certain types of infrastructure being targeted.

Table 40: RAND/RMS target type (Adapted from J21-100)

TARGET TYPE	RATIO	TARGET TYPES IN GROUPS	TARGET TYPES IN GROUPS, MODIFIED FOR IQALUIT
1	8/36	Government buildings	Government Buildings
2	7/36	Business districts, skyscrapers, stock exchange, hotels and casinos, airports, nuclear power plants	Business districts, airports
3	6/36	Military, train/subway stations, stadiums, bridges and tunnels	Military, bridges and tunnels
4	5/36	Industrial facilities, oil/gas processing facilities, tourist attractions, shopping malls, restaurants, ports and ships	Industrial facilities, tourist attractions, restaurants, ports and ships
5	4/36	Media HQ, Fortune 100 HQ, theaters, major entertainment centers, gas stations	Media HQ, theaters, major entertainment centers, gas stations
6	3/36	Cruise ships, apartment buildings, foreign consulates, United Nations	Apartment buildings
7	2/36	Water reservoirs and distribution, passenger trains, airspace zones	Water reservoirs and distribution, passenger trains, airspace zones
8	1/36	Power plants, dams, railway networks	Power plants, dams
Sum =	36/36 = 1		

Source: Derived from RAND, 2006

2.5.2.4 ADJUSTING FOR PRE-ATTACK DETECTION AND INTERDICTION

Before an attack can be initiated, the likelihood of detection and interdiction must be considered. Larger-scale operations or the use of sophisticated resources increase the probability of discovery during the planning phase. This adjustment ensures a realistic assessment of an attacker's capability to successfully carry out the planned activity without being intercepted. Table 41 provides the assumed likelihood of detection and interdiction for each malevolent threat. Hazards with detection and pre-emption likelihoods shown in this table were incorporated to match the corresponding hazard categories used in this threat analysis.

Table 41: Proxy likelihood of detection and interdiction by threat (Adapted from J21-100)

HAZARD TYPE	HAZARD DESCRIPTION WITH DETECTION AND PREEMPTION LIKELIHOOD				
Contamination of product	C(C) Chemical 0.85	C(R) Radionuclide 0.95	C(B) Biotoxin 0.95	C(P) Pathogen 0.85	C(S) Explosive 0.8
Directed/ sabotage	S(PI) Physical insider 0.75	S(PU) Physical outsider 0.8	S(C1) Cyber attack 0.01	T(PI) Insider theft 0.75	T(PU) Outsider theft 0.9
Maritime	(M1) Small boat 0.8	(M2) Fast boa 0.9	(M3) Barge 0.95	(M4) Deep draft ship 0.99	
Aircraft	(A1) Helicopter 0.75	(A2) Small plane 0.8	(A3) Regional jet 0.90	(A4) Large Jet 0.95	
Vehicle-borne bomb	(V1) Car 0.65	(V2) Van 0.75	(V3) Midsize truck 0.8	(V4) Large truck (18wheeler) 0.9	
Assault team	(AT1) 1 Assailant* 0.5	(AT2) 2-4 Assailants 0.65	(AT3) 5-8 Assailants 0.85	(AT-4) 9-16 Assailants 0.95	

* Active shooter (AS) is considered equivalent to AT1 for purposes of this assessment.

2.5.2.5 SPECIFIC THREAT-ASSET PAIR SELECTION

The attractiveness of specific threat-asset pairs depends on several factors:

- **Motivation and Capability**: The goals and resources of potential attackers.
- **Likelihood of Success**: Evaluating vulnerabilities and countermeasures in place.
- **Potential Consequences**: The scale of disruption, casualties, or economic impacts caused by the attack.

A formula can be applied to quantify attractiveness:

$$\textit{Terrorist Attractiveness Factor} = \textit{Expected Combined Regional Loss} \times (1 - Pr\ (\textit{Detect}\ \&\ \textit{Interdict})) \times \textit{Vulnerability}$$

Using this factor, threat-asset pairs were ranked based on their relative attractiveness to attackers, allowing for focused mitigation strategies. Based on these rankings, the attractiveness likelihood was determined from Table 42. The Proxy likelihood of selection, shown in **Table 43** for various threats was determined with the support of data presented in **Table 42** below.

Table 42: Proxy likelihood of being selected based on asset attractiveness ranking.

RANK ON TERRORIST ATTRACTIVENESS	PROXY LIKELIHOOD OF TAP SELECTION
95–100%	0.99
90–94	0.95
80–89	0.85
70–79	0.70
60–69	0.50
50–59	0.30
35–49	0.10
<35	0.01

2.5.3 BEST ESTIMATE

The likelihood of threats is determined through a combination of informed organizational experience, input from local, regional, and national authorities, and other relevant sources. This probability is expressed as a value between 0.0 and 1.0. The Best Estimate approach was not discussed in this analysis.

2.5.4 THREAT ANALYSIS

The threat analysis for Iqaluit water infrastructure evaluated potential threats to key tangible asset. **Table 43** is presented to visualize an integrated view of each asset's associated hazard, rank based on terrorist attractiveness, the proxy likelihood of selection and the TAP selection for risk management.

The probability values in this table was subsequently used for risk analysis in the next Chapter.

Table 43: Threat Analysis

TANGIBLE ASSET	HAZARD SUB-CATEGORY	HAZARD	NATION (1)	METRO REGION (2)	BROAD TARGET TYPE (3)	UTILITY CAPACITY RATIO (4)	ADJUST FOR DETECTION & INTEDICTION (5)	EXPECTED COMBINED REGIONAL LOSS (ECRL) RANK	RANK ON TERRORIST ATTRACTIVENESS	PROXY LIKELIHOOD OF SELECTION	TAP SELECTION PROBABILITY
Lake Geraldine	Aircraft	Helicopter	3.36	0.002	0.056	1	0.25	120	11%	0.01	0.00000093
	Aircraft	Small Plane	3.36	0.002	0.056	1	0.2	107	21%	0.01	0.00000075
	Aircraft	Regional Jet	3.36	0.002	0.056	1	0.1	93	31%	0.01	0.00000037
	Aircraft	Large Jet	3.36	0.002	0.056	1	0.05	72	47%	0.1	0.00000187
	Assault Team	1 Assailant	3.36	0.002	0.056	1	0.5	143	-	0.01	0.00000187
	Assault Team	2-4 Assailants	3.36	0.002	0.056	1	0.35	121	10%	0.01	0.00000131
	Assault Team	5-8 Assailants	3.36	0.002	0.056	1	0.15	101	25%	0.01	0.00000056
	Assault Team	9-16 Assailants	3.36	0.002	0.056	1	0.05	86	36%	0.1	0.00000187
	Maritime	Small Boat	3.36	0.002	0.056	1	0.2	143	-	0.01	0.00000075
	Maritime	Fast Boat	3.36	0.002	0.056	1	0.1	143	-	0.01	0.00000037
	Maritime	Barge	3.36	0.002	0.056	1	0.05	143	-	0.01	0.00000019
	Maritime	Deep Draft Ship	3.36	0.002	0.056	1	0.01	143	-	0.01	0.00000004
	Vehicle Borne Bomb	Car	3.36	0.002	0.056	1	0.35	142	-	0.01	0.00000131
	Vehicle Borne Bomb	Van	3.36	0.002	0.056	1	0.25	125	7%	0.01	0.00000093
	Vehicle Borne Bomb	Midsize Truck	3.36	0.002	0.056	1	0.2	108	20%	0.01	0.00000075
	Vehicle Borne Bomb	Large Truck (18-Wheeler)	3.36	0.002	0.056	1	0.1	94	30%	0.01	0.00000037

TANGIBLE ASSET	HAZARD SUB-CATEGORY	HAZARD	NATION (1)	METRO REGION (2)	BROAD TARGET TYPE (3)	UTILITY CAPACITY RATIO (4)	ADJUST FOR DETECTION & INTEDICTION (5)	EXPECTED COMBINED REGIONAL LOSS (ECRL) RANK	RANK ON TERRORIST ATTRACTIVENESS	PROXY LIKELIHOOD OF SELECTION	TAP SELECTION PROBABILITY
	Contamination of Product	Biotoxin	3.36	0.002	0.056	1	0.05	143	-	0.01	0.00000019
	Contamination of Product	Chemical	3.36	0.002	0.056	1	0.15	21	84%	0.85	0.00004760
	Contamination of Product	Explosive	3.36	0.002	0.056	1	0.2	143	-	0.01	0.00000075
	Contamination of Product	Pathogen	3.36	0.002	0.056	1	0.15	143	-	0.01	0.00000056
	Contamination of Product	Radionuclide	3.36	0.002	0.056	1	0.05	21	84%	0.85	0.00001587
	Directed / Sabotage	Physical Insider	3.36	0.002	0.056	1	0.25	143	-	0.01	0.00000093
	Directed / Sabotage	Physical Outsider	3.36	0.002	0.056	1	0.2	143	-	0.01	0.00000075
	Directed / Sabotage	Active Shooter	3.36	0.002	0.056	1	0.5	66	51%	0.3	0.00005600
	Theft or Diversion	Physical Insider	3.36	0.002	0.056	1	0.25	143	-	0.01	0.00000093
	Theft or Diversion	Physical Outsider	3.36	0.002	0.056	1	0.1	143	-	0.01	0.00000037
	Cyber	Cyber Attack	3.36	0.002	0.056	1	0.99	143	-	0.01	0.00000370
Lake Geraldine Dam	Aircraft	Helicopter	3.36	0.002	0.028	1	0.25	83	39%	0.1	0.00000467
	Aircraft	Small Plane	3.36	0.002	0.028	1	0.2	62	54%	0.3	0.00001120
	Aircraft	Regional Jet	3.36	0.002	0.028	1	0.1	43	68%	0.5	0.00000933
	Aircraft	Large Jet	3.36	0.002	0.028	1	0.05	40	70%	0.7	0.00000653
	Assault Team	1 Assailant	3.36	0.002	0.028	1	0.5	143	-	0.01	0.00000093
	Assault Team	2-4 Assailants	3.36	0.002	0.028	1	0.35	121	10%	0.01	0.00000065

TANGIBLE ASSET	HAZARD SUB-CATEGORY	HAZARD	NATION (1)	METRO REGION (2)	BROAD TARGET TYPE (3)	UTILITY CAPACITY RATIO (4)	ADJUST FOR DETECTION & INTEDICTION (5)	EXPECTED COMBINED REGIONAL LOSS (ECRL) RANK	RANK ON TERRORIST ATTRACTIVENESS	PROXY LIKELIHOOD OF SELECTION	TAP SELECTION PROBABILITY
	Assault Team	5-8 Assailants	3.36	0.002	0.028	1	0.15	101	25%	0.01	0.00000028
	Assault Team	9-16 Assailants	3.36	0.002	0.028	1	0.05	86	36%	0.1	0.00000093
	Maritime	Small Boat	3.36	0.002	0.028	1	0.2	143	-	0.01	0.00000037
	Maritime	Fast Boat	3.36	0.002	0.028	1	0.1	143	-	0.01	0.00000019
	Maritime	Barge	3.36	0.002	0.028	1	0.05	143	-	0.01	0.00000009
	Maritime	Deep Draft Ship	3.36	0.002	0.028	1	0.01	143	-	0.01	0.00000002
	Vehicle Borne Bomb	Car	3.36	0.002	0.028	1	0.35	84	38%	0.1	0.00000653
	Vehicle Borne Bomb	Van	3.36	0.002	0.028	1	0.25	65	52%	0.3	0.00001400
	Vehicle Borne Bomb	Midsize Truck	3.36	0.002	0.028	1	0.2	45	67%	0.5	0.00001867
	Vehicle Borne Bomb	Large Truck (18-Wheeler)	3.36	0.002	0.028	1	0.1	42	69%	0.5	0.00000933
	Contamination of Product	Biotoxin	3.36	0.002	0.028	1	0.05	143	-	0.01	0.00000009
	Contamination of Product	Chemical	3.36	0.002	0.028	1	0.15	21	84%	0.85	0.00002380
	Contamination of Product	Explosive	3.36	0.002	0.028	1	0.2	143	-	0.01	0.00000037
	Contamination of Product	Pathogen	3.36	0.002	0.028	1	0.15	143	-	0.01	0.00000028
	Contamination of Product	Radionuclide	3.36	0.002	0.028	1	0.05	33	76%	0.7	0.00000653
	Directed / Sabotage	Physical Insider	3.36	0.002	0.028	1	0.25	143	-	0.01	0.00000047

TANGIBLE ASSET	HAZARD SUB-CATEGORY	HAZARD	NATION (1)	METRO REGION (2)	BROAD TARGET TYPE (3)	UTILITY CAPACITY RATIO (4)	ADJUST FOR DETECTION & INTEDICTION (5)	EXPECTED COMBINED REGIONAL LOSS (ECRL) RANK	RANK ON TERRORIST ATTRACTIVENESS	PROXY LIKELIHOOD OF SELECTION	TAP SELECTION PROBABILITY
	Directed / Sabotage	Physical Outsider	3.36	0.002	0.028	1	0.2	143	-	0.01	0.00000037
	Directed / Sabotage	Active Shooter	3.36	0.002	0.028	1	0.5	66	51%	0.3	0.00002800
	Theft or Diversion	Physical Insider	3.36	0.002	0.028	1	0.25	143	-	0.01	0.00000047
	Theft or Diversion	Physical Outsider	3.36	0.002	0.028	1	0.1	143	-	0.01	0.00000019
	Cyber	Cyber Attack	3.36	0.002	0.028	1	0.99	143	-	0.01	0.00000185
Lake Geraldine Intake Systems	Aircraft	Helicopter	3.36	0.002	0.028	1	0.25	119	12%	0.01	0.00000047
	Aircraft	Small Plane	3.36	0.002	0.028	1	0.2	106	21%	0.01	0.00000037
	Aircraft	Regional Jet	3.36	0.002	0.028	1	0.1	91	33%	0.01	0.00000019
	Aircraft	Large Jet	3.36	0.002	0.028	1	0.05	70	48%	0.1	0.00000093
	Assault Team	1 Assailant	3.36	0.002	0.028	1	0.5	143	-	0.01	0.00000093
	Assault Team	2-4 Assailants	3.36	0.002	0.028	1	0.35	121	10%	0.01	0.00000065
	Assault Team	5-8 Assailants	3.36	0.002	0.028	1	0.15	101	25%	0.01	0.00000028
	Assault Team	9-16 Assailants	3.36	0.002	0.028	1	0.05	86	36%	0.1	0.00000093
	Maritime	Small Boat	3.36	0.002	0.028	1	0.2	143	-	0.01	0.00000037
	Maritime	Fast Boat	3.36	0.002	0.028	1	0.1	143	-	0.01	0.00000019
	Maritime	Barge	3.36	0.002	0.028	1	0.05	143	-	0.01	0.00000009
	Maritime	Deep Draft Ship	3.36	0.002	0.028	1	0.01	143	-	0.01	0.00000002
	Vehicle Borne Bomb	Car	3.36	0.002	0.028	1	0.35	134	1%	0.01	0.00000065

TANGIBLE ASSET	HAZARD SUB-CATEGORY	HAZARD	NATION (1)	METRO REGION (2)	BROAD TARGET TYPE (3)	UTILITY CAPACITY RATIO (4)	ADJUST FOR DETECTION & INTEDICTION (5)	EXPECTED COMBINED REGIONAL LOSS (ECRL) RANK	RANK ON TERRORIST ATTRACTIVENESS	PROXY LIKELIHOOD OF SELECTION	TAP SELECTION PROBABILITY
	Vehicle Borne Bomb	Van	3.36	0.002	0.028	1	0.25	115	15%	0.01	0.00000047
	Vehicle Borne Bomb	Midsize Truck	3.36	0.002	0.028	1	0.2	105	22%	0.01	0.00000037
	Vehicle Borne Bomb	Large Truck (18-Wheeler)	3.36	0.002	0.028	1	0.1	90	33%	0.01	0.00000019
	Contamination of Product	Biotoxin	3.36	0.002	0.028	1	0.05	143	-	0.01	0.00000009
	Contamination of Product	Chemical	3.36	0.002	0.028	1	0.15	33	76%	0.7	0.00001960
	Contamination of Product	Explosive	3.36	0.002	0.028	1	0.2	143	-	0.01	0.00000037
	Contamination of Product	Pathogen	3.36	0.002	0.028	1	0.15	143	-	0.01	0.00000028
	Contamination of Product	Radionuclide	3.36	0.002	0.028	1	0.05	33	76%	0.7	0.00000653
	Directed / Sabotage	Physical Insider	3.36	0.002	0.028	1	0.25	143	-	0.01	0.00000047
	Directed / Sabotage	Physical Outsider	3.36	0.002	0.028	1	0.2	143	-	0.01	0.00000037
	Directed / Sabotage	Active Shooter	3.36	0.002	0.028	1	0.5	66	51%	0.3	0.00002800
	Theft or Diversion	Physical Insider	3.36	0.002	0.028	1	0.25	143	-	0.01	0.00000047
	Theft or Diversion	Physical Outsider	3.36	0.002	0.028	1	0.1	143	-	0.01	0.00000019
	Cyber	Cyber Attack	3.36	0.002	0.028	1	0.99	143	-	0.01	0.00000185
	Aircraft	Helicopter	3.36	0.002	0.139	1	0.25	71	47%	0.1	0.00002333

TANGIBLE ASSET	HAZARD SUB-CATEGORY	HAZARD	NATION (1)	METRO REGION (2)	BROAD TARGET TYPE (3)	UTILITY CAPACITY RATIO (4)	ADJUST FOR DETECTION & INTEDICTION (5)	EXPECTED COMBINED REGIONAL LOSS (ECRL) RANK	RANK ON TERRORIST ATTRACTIVENESS	PROXY LIKELIHOOD OF SELECTION	TAP SELECTION PROBABILITY
Water Treatment Plant	Aircraft	Small Plane	3.36	0.002	0.139	1	0.2	57	58%	0.3	0.00005600
	Aircraft	Regional Jet	3.36	0.002	0.139	1	0.1	41	70%	0.5	0.00004667
	Aircraft	Large Jet	3.36	0.002	0.139	1	0.05	16	88%	0.85	0.00003967
	Assault Team	1 Assailant	3.36	0.002	0.139	1	0.5	117	13%	0.01	0.00000467
	Assault Team	2-4 Assailants	3.36	0.002	0.139	1	0.35	95	30%	0.01	0.00000327
	Assault Team	5-8 Assailants	3.36	0.002	0.139	1	0.15	75	44%	0.1	0.00001400
	Assault Team	9-16 Assailants	3.36	0.002	0.139	1	0.05	48	64%	0.5	0.00002333
	Maritime	Small Boat	3.36	0.002	0.139	1	0.2	143	-	0.01	0.00000187
	Maritime	Fast Boat	3.36	0.002	0.139	1	0.1	143	-	0.01	0.00000093
	Maritime	Barge	3.36	0.002	0.139	1	0.05	143	-	0.01	0.00000047
	Maritime	Deep Draft Ship	3.36	0.002	0.139	1	0.01	143	-	0.01	0.00000009
	Vehicle Borne Bomb	Car	3.36	0.002	0.139	1	0.35	78	42%	0.1	0.00003267
	Vehicle Borne Bomb	Van	3.36	0.002	0.139	1	0.25	60	56%	0.3	0.00007000
	Vehicle Borne Bomb	Midsize Truck	3.36	0.002	0.139	1	0.2	54	60%	0.01	0.00000187
	Vehicle Borne Bomb	Large Truck (18-Wheeler)	3.36	0.002	0.139	1	0.1	17	87%	0.85	0.00007933
	Contamination of Product	Biotoxin	3.36	0.002	0.139	1	0.05	1	99%	0.9999	0.00004666
	Contamination of Product	Chemical	3.36	0.002	0.139	1	0.15	24	82%	0.85	0.00011900

TANGIBLE ASSET	HAZARD SUB-CATEGORY	HAZARD	NATION (1)	METRO REGION (2)	BROAD TARGET TYPE (3)	UTILITY CAPACITY RATIO (4)	ADJUST FOR DETECTION & INTEDICTION (5)	EXPECTED COMBINED REGIONAL LOSS (ECRL) RANK	RANK ON TERRORIST ATTRACTIVENESS	PROXY LIKELIHOOD OF SELECTION	TAP SELECTION PROBABILITY
	Contamination of Product	Explosive	3.36	0.002	0.139	1	0.2	78	42%	0.1	0.00001867
	Contamination of Product	Pathogen	3.36	0.002	0.139	1	0.15	1	99%	0.9999	0.00013999
	Contamination of Product	Radionuclide	3.36	0.002	0.139	1	0.05	24	82%	0.85	0.00003967
	Directed / Sabotage	Physical Insider	3.36	0.002	0.139	1	0.25	130	4%	0.01	0.00000233
	Directed / Sabotage	Physical Outsider	3.36	0.002	0.139	1	0.2	130	4%	0.01	0.00000187
	Directed / Sabotage	Active Shooter	3.36	0.002	0.139	1	0.5	51	62%	0.5	0.00023333
	Theft or Diversion	Physical Insider	3.36	0.002	0.139	1	0.25	130	4%	0.01	0.00000233
	Theft or Diversion	Physical Outsider	3.36	0.002	0.139	1	0.1	130	4%	0.01	0.00000093
	Cyber	Cyber Attack	3.36	0.002	0.139	1	0.99	110	19%	0.01	0.00000924
Treated Water Reservoir	Aircraft	Helicopter	3.36	0.002	0.056	1	0.25	58	57%	0.3	0.00002800
	Aircraft	Small Plane	3.36	0.002	0.056	1	0.2	44	67%	0.5	0.00003733
	Aircraft	Regional Jet	3.36	0.002	0.056	1	0.1	19	86%	0.85	0.00003173
	Aircraft	Large Jet	3.36	0.002	0.056	1	0.05	14	90%	0.85	0.00001587
	Assault Team	1 Assailant	3.36	0.002	0.056	1	0.5	121	10%	0.01	0.00000187
	Assault Team	2-4 Assailants	3.36	0.002	0.056	1	0.35	98	27%	0.01	0.00000131
	Assault Team	5-8 Assailants	3.36	0.002	0.056	1	0.15	77	43%	0.1	0.00000560
	Assault Team	9-16 Assailants	3.36	0.002	0.056	1	0.05	53	61%	0.5	0.00000933

TANGIBLE ASSET	HAZARD SUB-CATEGORY	HAZARD	NATION (1)	METRO REGION (2)	BROAD TARGET TYPE (3)	UTILITY CAPACITY RATIO (4)	ADJUST FOR DETECTION & INTEDICTION (5)	EXPECTED COMBINED REGIONAL LOSS (ECRL) RANK	RANK ON TERRORIST ATTRACTIVENESS	PROXY LIKELIHOOD OF SELECTION	TAP SELECTION PROBABILITY
	Maritime	Small Boat	3.36	0.002	0.056	1	0.2	143	-	0.01	0.00000075
	Maritime	Fast Boat	3.36	0.002	0.056	1	0.1	143	-	0.01	0.00000037
	Maritime	Barge	3.36	0.002	0.056	1	0.05	143	-	0.01	0.00000019
	Maritime	Deep Draft Ship	3.36	0.002	0.056	1	0.01	143	-	0.01	0.00000004
	Vehicle Borne Bomb	Car	3.36	0.002	0.056	1	0.35	78	42%	0.1	0.00001307
	Vehicle Borne Bomb	Van	3.36	0.002	0.056	1	0.25	60	56%	0.3	0.00002800
	Vehicle Borne Bomb	Midsize Truck	3.36	0.002	0.056	1	0.2	54	60%	0.01	0.00000075
	Vehicle Borne Bomb	Large Truck (18-Wheeler)	3.36	0.002	0.056	1	0.1	17	87%	0.85	0.00003173
	Contamination of Product	Biotoxin	3.36	0.002	0.056	1	0.05	1	99%	0.9999	0.00001866
	Contamination of Product	Chemical	3.36	0.002	0.056	1	0.15	24	82%	0.85	0.00004760
	Contamination of Product	Explosive	3.36	0.002	0.056	1	0.2	78	42%	0.1	0.00000747
	Contamination of Product	Pathogen	3.36	0.002	0.056	1	0.15	1	99%	0.9999	0.00005599
	Contamination of Product	Radionuclide	3.36	0.002	0.056	1	0.05	24	82%	0.85	0.00001587
	Directed / Sabotage	Physical Insider	3.36	0.002	0.056	1	0.25	126	7%	0.01	0.00000093
	Directed / Sabotage	Physical Outsider	3.36	0.002	0.056	1	0.2	126	7%	0.01	0.00000075

TANGIBLE ASSET	HAZARD SUB-CATEGORY	HAZARD	NATION (1)	METRO REGION (2)	BROAD TARGET TYPE (3)	UTILITY CAPACITY RATIO (4)	ADJUST FOR DETECTION & INTEDICTION (5)	EXPECTED COMBINED REGIONAL LOSS (ECRL) RANK	RANK ON TERRORIST ATTRACTIVENESS	PROXY LIKELIHOOD OF SELECTION	TAP SELECTION PROBABILITY
Distribution System	Directed / Sabotage	Active Shooter	3.36	0.002	0.056	1	0.5	66	51%	0.3	0.00005600
	Theft or Diversion	Physical Insider	3.36	0.002	0.056	1	0.25	126	7%	0.01	0.00000093
	Theft or Diversion	Physical Outsider	3.36	0.002	0.056	1	0.1	126	7%	0.01	0.00000037
	Cyber	Cyber Attack	3.36	0.002	0.056	1	0.99	143	-	0.01	0.00000370
	Aircraft	Helicopter	3.36	0.002	0.056	1	0.25	56	59%	0.3	0.00002800
	Aircraft	Small Plane	3.36	0.002	0.056	1	0.2	28	79%	0.7	0.00005227
	Aircraft	Regional Jet	3.36	0.002	0.056	1	0.1	15	89%	0.85	0.00003173
	Aircraft	Large Jet	3.36	0.002	0.056	1	0.05	10	93%	0.95	0.00001773
	Assault Team	1 Assailant	3.36	0.002	0.056	1	0.5	143	-	0.01	0.00000187
	Assault Team	2-4 Assailants	3.36	0.002	0.056	1	0.35	143	-	0.01	0.00000131
	Assault Team	5-8 Assailants	3.36	0.002	0.056	1	0.15	143	-	0.01	0.00000056
	Assault Team	9-16 Assailants	3.36	0.002	0.056	1	0.05	143	-	0.01	0.00000019
	Maritime	Small Boat	3.36	0.002	0.056	1	0.2	143	-	0.01	0.00000075
	Maritime	Fast Boat	3.36	0.002	0.056	1	0.1	143	-	0.01	0.00000037
	Maritime	Barge	3.36	0.002	0.056	1	0.05	143	-	0.01	0.00000019
	Maritime	Deep Draft Ship	3.36	0.002	0.056	1	0.01	143	-	0.01	0.00000004
	Vehicle Borne Bomb	Car	3.36	0.002	0.056	1	0.35	100	26%	0.01	0.00000131
	Vehicle Borne Bomb	Van	3.36	0.002	0.056	1	0.25	73	46%	0.1	0.00000933

TANGIBLE ASSET	HAZARD SUB-CATEGORY	HAZARD	NATION (1)	METRO REGION (2)	BROAD TARGET TYPE (3)	UTILITY CAPACITY RATIO (4)	ADJUST FOR DETECTION & INTEDICTION (5)	EXPECTED COMBINED REGIONAL LOSS (ECRL) RANK	RANK ON TERRORIST ATTRACTIVENESS	PROXY LIKELIHOOD OF SELECTION	TAP SELECTION PROBABILITY
	Vehicle Borne Bomb	Midsize Truck	3.36	0.002	0.056	1	0.2	39	71%	0.7	0.00005227
	Vehicle Borne Bomb	Large Truck (18-Wheeler)	3.36	0.002	0.056	1	0.1	12	91%	0.95	0.00003547
	Contamination of Product	Biotoxin	3.36	0.002	0.056	1	0.05	5	96%	0.9999	0.00001866
	Contamination of Product	Chemical	3.36	0.002	0.056	1	0.15	29	79%	0.7	0.00003920
	Contamination of Product	Explosive	3.36	0.002	0.056	1	0.2	109	19%	0.01	0.00000075
	Contamination of Product	Pathogen	3.36	0.002	0.056	1	0.15	5	96%	0.9999	0.00005599
	Contamination of Product	Radionuclide	3.36	0.002	0.056	1	0.05	29	79%	0.7	0.00001307
	Directed / Sabotage	Physical Insider	3.36	0.002	0.056	1	0.25	140	-	0.01	0.00000093
	Directed / Sabotage	Physical Outsider	3.36	0.002	0.056	1	0.2	140	-	0.01	0.00000075
	Directed / Sabotage	Active Shooter	3.36	0.002	0.056	1	0.5	143	-	0.01	0.00000187
	Theft or Diversion	Physical Insider	3.36	0.002	0.056	1	0.25	143	-	0.01	0.00000093
	Theft or Diversion	Physical Outsider	3.36	0.002	0.056	1	0.1	143	-	0.01	0.00000037
	Cyber	Cyber Attack	3.36	0.002	0.056	1	0.99	143	-	0.01	0.00000370
Booster & Reheat Stations	Aircraft	Helicopter	3.36	0.002	0.056	0.2	0.25	49	64%	0.5	0.00000933
	Aircraft	Small Plane	3.36	0.002	0.056	0.2	0.2	20	85%	0.85	0.00001269
	Aircraft	Regional Jet	3.36	0.002	0.056	0.2	0.1	13	90%	0.95	0.00000709

TANGIBLE ASSET	HAZARD SUB-CATEGORY	HAZARD	NATION (1)	METRO REGION (2)	BROAD TARGET TYPE (3)	UTILITY CAPACITY RATIO (4)	ADJUST FOR DETECTION & INTEDICTION (5)	EXPECTED COMBINED REGIONAL LOSS (ECRL) RANK	RANK ON TERRORIST ATTRACTIVENESS	PROXY LIKELIHOOD OF SELECTION	TAP SELECTION PROBABILITY
	Aircraft	Large Jet	3.36	0.002	0.056	0.2	0.05	9	93%	0.95	0.00000355
	Assault Team	1 Assailant	3.36	0.002	0.056	0.2	0.5	118	13%	0.01	0.00000037
	Assault Team	2-4 Assailants	3.36	0.002	0.056	0.2	0.35	97	28%	0.01	0.00000026
	Assault Team	5-8 Assailants	3.36	0.002	0.056	0.2	0.15	76	44%	0.1	0.00000112
	Assault Team	9-16 Assailants	3.36	0.002	0.056	0.2	0.05	50	63%	0.5	0.00000187
	Maritime	Small Boat	3.36	0.002	0.056	0.2	0.2	143	-	0.01	0.00000015
	Maritime	Fast Boat	3.36	0.002	0.056	0.2	0.1	143	-	0.01	0.00000007
	Maritime	Barge	3.36	0.002	0.056	0.2	0.05	143	-	0.01	0.00000004
	Maritime	Deep Draft Ship	3.36	0.002	0.056	0.2	0.01	143	-	0.01	0.00000001
	Vehicle Borne Bomb	Car	3.36	0.002	0.056	0.2	0.35	85	37%	0.1	0.00000261
	Vehicle Borne Bomb	Van	3.36	0.002	0.056	0.2	0.25	63	53%	0.3	0.00000560
	Vehicle Borne Bomb	Midsize Truck	3.36	0.002	0.056	0.2	0.2	38	72%	0.7	0.00001045
	Vehicle Borne Bomb	Large Truck (18-Wheeler)	3.36	0.002	0.056	0.2	0.1	11	92%	0.95	0.00000709
	Contamination of Product	Biotoxin	3.36	0.002	0.056	0.2	0.05	5	96%	0.9999	0.00000373
	Contamination of Product	Chemical	3.36	0.002	0.056	0.2	0.15	29	79%	0.7	0.00000784
	Contamination of Product	Explosive	3.36	0.002	0.056	0.2	0.2	99	27%	0.01	0.00000015

TANGIBLE ASSET	HAZARD SUB-CATEGORY	HAZARD	NATION (1)	METRO REGION (2)	BROAD TARGET TYPE (3)	UTILITY CAPACITY RATIO (4)	ADJUST FOR DETECTION & INTEDICTION (5)	EXPECTED COMBINED REGIONAL LOSS (ECRL) RANK	RANK ON TERRORIST ATTRACTIVENESS	PROXY LIKELIHOOD OF SELECTION	TAP SELECTION PROBABILITY
	Contamination of Product	Pathogen	3.36	0.002	0.056	0.2	0.15	5	96%	0.9999	0.00001120
	Contamination of Product	Radionuclide	3.36	0.002	0.056	0.2	0.05	29	79%	0.7	0.00000261
	Directed / Sabotage	Physical Insider	3.36	0.002	0.056	0.2	0.25	135	0%	0.01	0.00000019
	Directed / Sabotage	Physical Outsider	3.36	0.002	0.056	0.2	0.2	135	0%	0.01	0.00000015
	Directed / Sabotage	Active Shooter	3.36	0.002	0.056	0.2	0.5	52	61%	0.5	0.00001867
	Theft or Diversion	Physical Insider	3.36	0.002	0.056	0.2	0.25	135	0%	0.01	0.00000019
	Theft or Diversion	Physical Outsider	3.36	0.002	0.056	0.2	0.1	135	0%	0.01	0.00000007
	Cyber	Cyber Attack	3.36	0.002	0.056	0.2	0.99	139	-	0.01	0.00000074
SCADA System	Aircraft	Helicopter	3.36	0.002	0.139	0.5	0.25	89	34%	0.01	0.00000117
	Aircraft	Small Plane	3.36	0.002	0.139	0.5	0.2	64	53%	0.3	0.00002800
	Aircraft	Regional Jet	3.36	0.002	0.139	0.5	0.1	46	66%	0.5	0.00002333
	Aircraft	Large Jet	3.36	0.002	0.139	0.5	0.05	36	73%	0.7	0.00001633
	Assault Team	1 Assailant	3.36	0.002	0.139	0.5	0.5	116	14%	0.01	0.00000233
	Assault Team	2-4 Assailants	3.36	0.002	0.139	0.5	0.35	92	32%	0.01	0.00000163
	Assault Team	5-8 Assailants	3.36	0.002	0.139	0.5	0.15	74	45%	0.1	0.00000700
	Assault Team	9-16 Assailants	3.36	0.002	0.139	0.5	0.05	47	65%	0.5	0.00001167
	Maritime	Small Boat	3.36	0.002	0.139	0.5	0.2	143	-	0.01	0.00000093

TANGIBLE ASSET	HAZARD SUB-CATEGORY	HAZARD	NATION (1)	METRO REGION (2)	BROAD TARGET TYPE (3)	UTILITY CAPACITY RATIO (4)	ADJUST FOR DETECTION & INTEDICTION (5)	EXPECTED COMBINED REGIONAL LOSS (ECRL) RANK	RANK ON TERRORIST ATTRACTIVENESS	PROXY LIKELIHOOD OF SELECTION	TAP SELECTION PROBABILITY
	Maritime	Fast Boat	3.36	0.002	0.139	0.5	0.1	143	-	0.01	0.00000047
	Maritime	Barge	3.36	0.002	0.139	0.5	0.05	143	-	0.01	0.00000023
	Maritime	Deep Draft Ship	3.36	0.002	0.139	0.5	0.01	143	-	0.01	0.00000005
	Vehicle Borne Bomb	Car	3.36	0.002	0.139	0.5	0.35	96	29%	0.01	0.00000163
	Vehicle Borne Bomb	Van	3.36	0.002	0.139	0.5	0.25	82	39%	0.1	0.00001167
	Vehicle Borne Bomb	Midsize Truck	3.36	0.002	0.139	0.5	0.2	59	56%	0.3	0.00002800
	Vehicle Borne Bomb	Large Truck (18-Wheeler)	3.36	0.002	0.139	0.5	0.1	37	73%	0.7	0.00003267
	Contamination of Product	Biotoxin	3.36	0.002	0.139	0.5	0.05	143	-	0.01	0.00000023
	Contamination of Product	Chemical	3.36	0.002	0.139	0.5	0.15	143	-	0.01	0.00000070
	Contamination of Product	Explosive	3.36	0.002	0.139	0.5	0.2	143	-	0.01	0.00000093
	Contamination of Product	Pathogen	3.36	0.002	0.139	0.5	0.15	143	-	0.01	0.00000070
	Contamination of Product	Radionuclide	3.36	0.002	0.139	0.5	0.05	143	-	0.01	0.00000023
	Directed / Sabotage	Physical Insider	3.36	0.002	0.139	0.5	0.25	111	18%	0.01	0.00000117
	Directed / Sabotage	Physical Outsider	3.36	0.002	0.139	0.5	0.2	111	18%	0.01	0.00000093
	Directed / Sabotage	Active Shooter	3.36	0.002	0.139	0.5	0.5	143	-	0.01	0.00000233

TANGIBLE ASSET	HAZARD SUB-CATEGORY	HAZARD	NATION (1)	METRO REGION (2)	BROAD TARGET TYPE (3)	UTILITY CAPACITY RATIO (4)	ADJUST FOR DETECTION & INTEDICTION (5)	EXPECTED COMBINED REGIONAL LOSS (ECRL) RANK	RANK ON TERRORIST ATTRACTIVENESS	PROXY LIKELIHOOD OF SELECTION	TAP SELECTION PROBABILITY
	Theft or Diversion	Physical Insider	3.36	0.002	0.139	0.5	0.25	111	18%	0.01	0.00000117
	Theft or Diversion	Physical Outsider	3.36	0.002	0.139	0.5	0.1	111	18%	0.01	0.00000047
	Cyber	Cyber Attack	3.36	0.002	0.139	0.5	0.99	104	23%	0.01	0.00000462

2.6 RISK AND RESILIENCE ANALYSIS

This step integrates the findings from previous five analyses to estimate risks to the utility and the broader community, as well as to assess overall system resilience.

2.6.1 ESTIMATION OF RISK

Risk is calculated for each threat-asset pair as a function of Consequence, Vulnerability, and Threat Likelihood. The risk formula is expressed as:

$$Risk = Consequences \times Vulnerability \times Threat\ Likelihood = R = C \times V \times T$$

Where:

Consequences (C): The potential impact of the threat, measured in terms of human casualties, service disruptions, financial losses to the utility, and economic impacts on the region.

- Vulnerability (V): The likelihood that the identified threat, if it occurs, will result in the estimated consequences.
- Threat likelihood (T): The probability of the specific threat occurring within a one-year period.

Each risk was calculated by multiplying the values for C, V, and T are multiplied directly. The ultimate goal of resilience is to minimize the risk of outages. A risk value of zero would indicate perfect resilience. Calculations on C, V, and T are presented in **Table 44.**

Table 44: Risk Analysis based on Consequences, Vulnerability Score, and Threat Likelihood.

TANGIBLE ASSET	HAZARD SUB-CATEGORY	HAZARD	CONSEQUENCES	VULNERABILITY SCORE	THREAT LIKELIHOOD	TOTAL	RANKING
Lake Geraldine	Aircraft	Helicopter	1,004,308	1.14	0.00000093	1	127
	Aircraft	Small Plane	2,714,164	1.14	0.00000075	2	114
	Aircraft	Regional Jet	6,223,646	1.14	0.00000037	3	109
	Aircraft	Large Jet	14,872,442	1.14	0.00000187	32	87
	Assault Team	1 Assailant		1.14	0.00000187	0	143
	Assault Team	2-4 Assailants	805,547	1.14	0.00000131	1	126

TANGIBLE ASSET	HAZARD SUB-CATEGORY	HAZARD	CONSEQUENCES	VULNERABILITY SCORE	THREAT LIKELIHOOD	TOTAL	RANKING
	Assault Team	5-8 Assailants	3,599,254	1.14	0.00000056	2	115
	Assault Team	9-16 Assailants	9,118,110	1.14	0.00000187	19	92
	Maritime	Small Boat		1.14	0.00000075	0	143
	Maritime	Fast Boat		1.14	0.00000037	0	143
	Maritime	Barge		1.14	0.00000019	0	143
	Maritime	Deep Draft Ship		1.14	0.00000004	0	143
	Vehicle Borne Bomb	Car	224,077	1.14	0.00000131	0	138
	Vehicle Borne Bomb	Van	904,308	1.14	0.00000093	1	131
	Vehicle Borne Bomb	Midsize Truck	2,614,164	1.14	0.00000075	2	116
	Vehicle Borne Bomb	Large Truck (18-Wheeler)	6,123,646	1.14	0.00000037	3	110
	Contamination of Product	Biotoxin		1.14	0.00000019	0	143
	Contamination of Product	Chemical	80,821,647	1.14	0.00004760	4386	26
	Contamination of Product	Explosive		1.14	0.00000075	0	143
	Contamination of Product	Pathogen		1.14	0.00000056	0	143
	Contamination of Product	Radionuclide	80,821,647	1.14	0.00001587	1462	48
	Directed / Sabotage	Physical Insider		1.14	0.00000093	0	143
	Directed / Sabotage	Physical Outsider		1.14	0.00000075	0	143
	Directed / Sabotage	Active Shooter	17,139,304	1.14	0.00005600	1094	55
	Theft or Diversion	Physical Insider		1.14	0.00000093	0	143
	Theft or Diversion	Physical Outsider		1.14	0.00000037	0	143

TANGIBLE ASSET	HAZARD SUB-CATEGORY	HAZARD	CONSEQUENCES	VULNERABILITY SCORE	THREAT LIKELIHOOD	TOTAL	RANKING
	Cyber	Cyber Attack		1.14	0.00000370	0	143
Lake Geraldine Dam	Aircraft	Helicopter	16,316,762	1.86	0.00000467	142	79
	Aircraft	Small Plane	30,537,780	1.86	0.00001120	636	66
	Aircraft	Regional Jet	76,558,425	1.86	0.00000933	1329	53
	Aircraft	Large Jet	87,138,125	1.86	0.00000653	1059	57
	Assault Team	1 Assailant		1.86	0.00000093	0	143
	Assault Team	2-4 Assailants	805,547	1.86	0.00000065	1	129
	Assault Team	5-8 Assailants	3,599,254	1.86	0.00000028	2	119
	Assault Team	9-16 Assailants	9,118,110	1.86	0.00000093	16	94
	Maritime	Small Boat		1.86	0.00000037	0	143
	Maritime	Fast Boat		1.86	0.00000019	0	143
	Maritime	Barge		1.86	0.00000009	0	143
	Maritime	Deep Draft Ship		1.86	0.00000002	0	143
	Vehicle Borne Bomb	Car	15,802,583	1.86	0.00000653	192	76
	Vehicle Borne Bomb	Van	29,218,054	1.86	0.00001400	761	64
	Vehicle Borne Bomb	Midsize Truck	73,439,072	1.86	0.00001867	2550	37
	Vehicle Borne Bomb	Large Truck (18-Wheeler)	79,459,717	1.86	0.00000933	1379	50
	Contamination of Product	Biotoxin		1.86	0.00000009	0	143
	Contamination of Product	Chemical	80,821,647	1.86	0.00002380	3578	28
	Contamination of Product	Explosive		1.86	0.00000037	0	143
	Contamination of Product	Pathogen		1.86	0.00000028	0	143
	Contamination of Product	Radionuclide	78,480,872	1.86	0.00000653	954	59
	Directed / Sabotage	Physical Insider		1.86	0.00000047	0	143
	Directed / Sabotage	Physical Outsider		1.86	0.00000037	0	143

TANGIBLE ASSET	HAZARD SUB-CATEGORY	HAZARD	CONSEQUENCES	VULNERABILITY SCORE	THREAT LIKELIHOOD	TOTAL	RANKING
	Directed / Sabotage	Active Shooter	17,139,304	1.86	0.00002800	893	62
	Theft or Diversion	Physical Insider		1.86	0.00000047	0	143
	Theft or Diversion	Physical Outsider		1.86	0.00000019	0	143
	Cyber	Cyber Attack		1.86	0.00000185	0	143
Lake Geraldine Intake Systems	Aircraft	Helicopter	1,104,308	1.86	0.00000047	1	132
	Aircraft	Small Plane	2,914,164	1.86	0.00000037	2	118
	Aircraft	Regional Jet	6,823,646	1.86	0.00000019	2	113
	Aircraft	Large Jet	16,372,442	1.86	0.00000093	28	89
	Assault Team	1 Assailant		1.86	0.00000093	0	143
	Assault Team	2-4 Assailants	805,547	1.86	0.00000065	1	129
	Assault Team	5-8 Assailants	3,599,254	1.86	0.00000028	2	119
	Assault Team	9-16 Assailants	9,118,110	1.86	0.00000093	16	94
	Maritime	Small Boat		1.86	0.00000037	0	143
	Maritime	Fast Boat		1.86	0.00000019	0	143
	Maritime	Barge		1.86	0.00000009	0	143
	Maritime	Deep Draft Ship		1.86	0.00000002	0	143
	Vehicle Borne Bomb	Car	590,129	1.86	0.00000065	1	135
	Vehicle Borne Bomb	Van	1,594,437	1.86	0.00000047	1	123
	Vehicle Borne Bomb	Midsize Truck	3,704,293	1.86	0.00000037	3	111
	Vehicle Borne Bomb	Large Truck (18-Wheeler)	8,694,034	1.86	0.00000019	3	107
	Contamination of Product	Biotoxin		1.86	0.00000009	0	143
	Contamination of Product	Chemical	78,480,872	1.86	0.00001960	2861	35
	Contamination of Product	Explosive		1.86	0.00000037	0	143
	Contamination of Product	Pathogen		1.86	0.00000028	0	143

TANGIBLE ASSET	HAZARD SUB-CATEGORY	HAZARD	CONSEQUENCES	VULNERABILITY SCORE	THREAT LIKELIHOOD	TOTAL	RANKING
	Contamination of Product	Radionuclide	78,480,872	1.86	0.00000653	954	59
	Directed / Sabotage	Physical Insider		1.86	0.00000047	0	143
	Directed / Sabotage	Physical Outsider		1.86	0.00000037	0	143
	Directed / Sabotage	Active Shooter	17,139,304	1.86	0.00002800	893	62
	Theft or Diversion	Physical Insider		1.86	0.00000047	0	143
	Theft or Diversion	Physical Outsider		1.86	0.00000019	0	143
	Cyber	Cyber Attack		1.86	0.00000185	0	143
Water Treatment Plant	Aircraft	Helicopter	20,175,584	2.29	0.00002333	1078	56
	Aircraft	Small Plane	36,335,542	2.29	0.00005600	4660	24
	Aircraft	Regional Jet	62,659,107	2.29	0.00004667	6696	19
	Aircraft	Large Jet	101,121,976	2.29	0.00003967	9186	15
	Assault Team	1 Assailant	1,021,599	2.29	0.00000467	11	97
	Assault Team	2-4 Assailants	5,796,705	2.29	0.00000327	43	85
	Assault Team	5-8 Assailants	12,611,389	2.29	0.00001400	404	69
	Assault Team	9-16 Assailants	35,142,814	2.29	0.00002333	1878	43
	Maritime	Small Boat		2.29	0.00000187	0	143
	Maritime	Fast Boat		2.29	0.00000093	0	143
	Maritime	Barge		2.29	0.00000047	0	143
	Maritime	Deep Draft Ship		2.29	0.00000009	0	143
	Vehicle Borne Bomb	Car	17,056,230	2.29	0.00003267	1276	54
	Vehicle Borne Bomb	Van	28,657,134	2.29	0.00007000	4594	25
	Vehicle Borne Bomb	Midsize Truck	44,817,092	2.29	0.00000187	192	77
	Vehicle Borne Bomb	Large Truck (18-Wheeler)	100,419,264	2.29	0.00007933	18244	7
	Contamination of Product	Biotoxin	350,142,869	2.29	0.00004666	37415	3

TANGIBLE ASSET	HAZARD SUB-CATEGORY	HAZARD	CONSEQUENCES	VULNERABILITY SCORE	THREAT LIKELIHOOD	TOTAL	RANKING
	Contamination of Product	Chemical	80,421,647	2.29	0.00011900	21916	5
	Contamination of Product	Explosive	17,056,230	2.29	0.00001867	729	65
	Contamination of Product	Pathogen	350,142,869	2.29	0.00013999	112245	1
	Contamination of Product	Radionuclide	80,421,647	2.29	0.00003967	7305	18
	Directed / Sabotage	Physical Insider	630,258	2.29	0.00000233	3	104
	Directed / Sabotage	Physical Outsider	630,258	2.29	0.00000187	3	108
	Directed / Sabotage	Active Shooter	34,494,659	2.29	0.00023333	18432	6
	Theft or Diversion	Physical Insider	630,258	2.29	0.00000233	3	104
	Theft or Diversion	Physical Outsider	630,258	2.29	0.00000093	1	125
	Cyber	Cyber Attack	2,240,775	2.29	0.00000924	47	84
Treated Water Reservoir	Aircraft	Helicopter	27,853,992	1.71	0.00002800	1334	52
	Aircraft	Small Plane	54,177,557	1.71	0.00003733	3459	31
	Aircraft	Regional Jet	97,640,426	1.71	0.00003173	5298	23
	Aircraft	Large Jet	153,242,598	1.71	0.00001587	4158	27
	Assault Team	1 Assailant	805,547	1.71	0.00000187	3	112
	Assault Team	2-4 Assailants	5,364,602	1.71	0.00000131	12	96
	Assault Team	5-8 Assailants	11,963,234	1.71	0.00000560	115	80
	Assault Team	9-16 Assailants	34,278,607	1.71	0.00000933	547	68
	Maritime	Small Boat		1.71	0.00000075	0	143
	Maritime	Fast Boat		1.71	0.00000037	0	143
	Maritime	Barge		1.71	0.00000019	0	143
	Maritime	Deep Draft Ship		1.71	0.00000004	0	143
	Vehicle Borne Bomb	Car	17,056,230	1.71	0.00001307	381	70
	Vehicle Borne Bomb	Van	28,657,134	1.71	0.00002800	1372	51
	Vehicle Borne Bomb	Midsize Truck	44,817,092	1.71	0.00000075	57	82

TANGIBLE ASSET	HAZARD SUB-CATEGORY	HAZARD	CONSEQUENCES	VULNERABILITY SCORE	THREAT LIKELIHOOD	TOTAL	RANKING
	Vehicle Borne Bomb	Large Truck (18-Wheeler)	100,419,264	1.71	0.00003173	5449	22
	Contamination of Product	Biotoxin	350,142,869	1.71	0.00001866	11175	11
	Contamination of Product	Chemical	80,421,647	1.71	0.00004760	6546	20
	Contamination of Product	Explosive	17,056,230	1.71	0.00000747	218	74
	Contamination of Product	Pathogen	350,142,869	1.71	0.00005599	33526	4
	Contamination of Product	Radionuclide	80,421,647	1.71	0.00001587	2182	41
	Directed / Sabotage	Physical Insider	1,070,387	1.71	0.00000093	2	121
	Directed / Sabotage	Physical Outsider	1,070,387	1.71	0.00000075	1	124
	Directed / Sabotage	Active Shooter	17,139,304	1.71	0.00005600	1641	46
	Theft or Diversion	Physical Insider	1,070,387	1.71	0.00000093	2	121
	Theft or Diversion	Physical Outsider	1,070,387	1.71	0.00000037	1	136
	Cyber	Cyber Attack		1.71	0.00000370	0	143
Distribution System	Aircraft	Helicopter	31,046,214	2.43	0.00002800	2112	42
	Aircraft	Small Plane	79,325,936	2.43	0.00005227	10075	14
	Aircraft	Regional Jet	134,749,912	2.43	0.00003173	10391	13
	Aircraft	Large Jet	290,732,461	2.43	0.00001773	12528	10
	Assault Team	1 Assailant		2.43	0.00000187	0	143
	Assault Team	2-4 Assailants		2.43	0.00000131	0	143
	Assault Team	5-8 Assailants		2.43	0.00000056	0	143
	Assault Team	9-16 Assailants		2.43	0.00000019	0	143
	Maritime	Small Boat		2.43	0.00000075	0	143
	Maritime	Fast Boat		2.43	0.00000037	0	143
	Maritime	Barge		2.43	0.00000019	0	143
	Maritime	Deep Draft Ship		2.43	0.00000004	0	143

TANGIBLE ASSET	HAZARD SUB-CATEGORY	HAZARD	CONSEQUENCES	VULNERABILITY SCORE	THREAT LIKELIHOOD	TOTAL	RANKING
	Vehicle Borne Bomb	Car	5,525,791	2.43	0.00000131	18	93
	Vehicle Borne Bomb	Van	13,476,731	2.43	0.00000933	306	73
	Vehicle Borne Bomb	Midsize Truck	66,672,598	2.43	0.00005227	8468	16
	Vehicle Borne Bomb	Large Truck (18-Wheeler)	171,631,440	2.43	0.00003547	14792	9
	Contamination of Product	Biotoxin	348,837,288	2.43	0.00001866	15822	8
	Contamination of Product	Chemical	79,116,065	2.43	0.00003920	7536	17
	Contamination of Product	Explosive	2,406,438	2.43	0.00000075	4	101
	Contamination of Product	Pathogen	348,837,288	2.43	0.00005599	47465	2
	Contamination of Product	Radionuclide	79,116,065	2.43	0.00001307	2512	38
	Directed / Sabotage	Physical Insider	345,065	2.43	0.00000093	1	134
	Directed / Sabotage	Physical Outsider	345,065	2.43	0.00000075	1	137
	Directed / Sabotage	Active Shooter		2.43	0.00000187	0	143
	Theft or Diversion	Physical Insider		2.43	0.00000093	0	143
	Theft or Diversion	Physical Outsider		2.43	0.00000037	0	143
	Cyber	Cyber Attack		2.43	0.00000370	0	143
Booster & Reheat Stations	Aircraft	Helicopter	37,779,263	2.71	0.00000933	956	58
	Aircraft	Small Plane	88,656,840	2.71	0.00001269	3050	33
	Aircraft	Regional Jet	146,578,671	2.71	0.00000709	2818	36
	Aircraft	Large Jet	302,714,011	2.71	0.00000355	2910	34
	Assault Team	1 Assailant	934,560	2.71	0.00000037	1	133
	Assault Team	2-4 Assailants	5,622,628	2.71	0.00000026	4	103
	Assault Team	5-8 Assailants	12,350,273	2.71	0.00000112	37	86
	Assault Team	9-16 Assailants	34,794,659	2.71	0.00000187	176	78
	Maritime	Small Boat		2.71	0.00000015	0	143

TANGIBLE ASSET	HAZARD SUB-CATEGORY	HAZARD	CONSEQUENCES	VULNERABILITY SCORE	THREAT LIKELIHOOD	TOTAL	RANKING
	Maritime	Fast Boat		2.71	0.00000007	0	143
	Maritime	Barge		2.71	0.00000004	0	143
	Maritime	Deep Draft Ship		2.71	0.00000001	0	143
	Vehicle Borne Bomb	Car	12,258,840	2.71	0.00000261	87	81
	Vehicle Borne Bomb	Van	22,807,636	2.71	0.00000560	346	72
	Vehicle Borne Bomb	Midsize Truck	78,501,357	2.71	0.00001045	2224	40
	Vehicle Borne Bomb	Large Truck (18-Wheeler)	183,612,990	2.71	0.00000709	3530	29
	Contamination of Product	Biotoxin	348,837,288	2.71	0.00000373	3529	30
	Contamination of Product	Chemical	79,116,065	2.71	0.00000784	1681	45
	Contamination of Product	Explosive	7,906,438	2.71	0.00000015	3	106
	Contamination of Product	Pathogen	348,837,288	2.71	0.00001120	10587	12
	Contamination of Product	Radionuclide	79,116,065	2.71	0.00000261	560	67
	Directed / Sabotage	Physical Insider	562,661	2.71	0.00000019	0	139
	Directed / Sabotage	Physical Outsider	562,661	2.71	0.00000015	0	141
	Directed / Sabotage	Active Shooter	34,407,620	2.71	0.00001867	1741	44
	Theft or Diversion	Physical Insider	562,661	2.71	0.00000019	0	139
	Theft or Diversion	Physical Outsider	562,661	2.71	0.00000007	0	142
	Cyber	Cyber Attack	512,661	2.71	0.00000074	1	128
SCADA System	Aircraft	Helicopter	10,675,584	2.29	0.00000117	29	88
	Aircraft	Small Plane	21,835,542	2.29	0.00002800	1400	49
	Aircraft	Regional Jet	43,159,107	2.29	0.00002333	2306	39
	Aircraft	Large Jet	81,621,976	2.29	0.00001633	3053	32
	Assault Team	1 Assailant	1,421,599	2.29	0.00000233	8	98
	Assault Team	2-4 Assailants	6,096,705	2.29	0.00000163	23	91

TANGIBLE ASSET	HAZARD SUB-CATEGORY	HAZARD	CONSEQUENCES	VULNERABILITY SCORE	THREAT LIKELIHOOD	TOTAL	RANKING
	Assault Team	5-8 Assailants	12,811,389	2.29	0.00000700	205	75
	Assault Team	9-16 Assailants	35,242,814	2.29	0.00001167	942	61
	Maritime	Small Boat		2.29	0.00000093	0	143
	Maritime	Fast Boat		2.29	0.00000047	0	143
	Maritime	Barge		2.29	0.00000023	0	143
	Maritime	Deep Draft Ship		2.29	0.00000005	0	143
	Vehicle Borne Bomb	Car	7,556,230	2.29	0.00000163	28	90
	Vehicle Borne Bomb	Van	14,157,134	2.29	0.00001167	378	71
	Vehicle Borne Bomb	Midsize Truck	25,317,092	2.29	0.00002800	1623	47
	Vehicle Borne Bomb	Large Truck (18-Wheeler)	80,919,264	2.29	0.00003267	6053	21
	Contamination of Product	Biotoxin		2.29	0.00000023	0	143
	Contamination of Product	Chemical		2.29	0.00000070	0	143
	Contamination of Product	Explosive		2.29	0.00000093	0	143
	Contamination of Product	Pathogen		2.29	0.00000070	0	143
	Contamination of Product	Radionuclide		2.29	0.00000023	0	143
	Directed / Sabotage	Physical Insider	1,950,646	2.29	0.00000117	5	99
	Directed / Sabotage	Physical Outsider	1,950,646	2.29	0.00000093	4	102
	Directed / Sabotage	Active Shooter		2.29	0.00000233	0	143
	Theft or Diversion	Physical Insider	1,950,646	2.29	0.00000117	5	99
	Theft or Diversion	Physical Outsider	1,950,646	2.29	0.00000047	2	117
	Cyber	Cyber Attack	4,901,292	2.29	0.00000462	52	83

2.7 RISK AND RESILIENCE MANAGEMENT

The objective of Risk and Resilience Management is to achieve an acceptable level of risk and resilience—balancing human safety, service continuity, and financial impacts—at a reasonable cost to both the utility and the community. It involves systematically determining whether actions are necessary to reduce risk, enhance resilience, or both. It also involves selecting the most effective and efficient options to address identified needs.

2.7.1 OPTIONS ASSESSMENT

WPS evaluated each risk management options by analyzing its impact on the identified threat-asset pairs. We assume the proposed option has been implemented and revisit all affected aspects of the analysis to re-estimate risks, including:

- Human casualties.
- Service outages.
- Financial losses to the utility.
- Economic losses to the community.

The risks across all hazards for each system asset are evaluated based upon the following equation.

$$Risk\ (Asset) = Consequences\ \times Vulnerability\ Score \times Threat\ Likelihood$$

Where:

- Consequence is the sum of combined utility loss and combined regional community loss, and is a normalized value which encompasses direct financial and operational costs as well as broader community-based impacts.
- Vulnerability Score (normalized) represents the susceptibility of assets to specific natural hazards that were discussed in prior sections.
- Threat Likelihood is calculated as the probability of the direct threats that may occurring for each asset.

2.7.2 OPTIONS SELECTION

WSP considered the following factors when selecting the asset options.

- Reduction in human casualties.
- Improved service continuity (resilience).
- Financial benefits to the utility.
- Overall utility benefits.
- Economic benefits to the community.

➢ Regional wellbeing improvements.

WSP selected the top 20 assets, based on sub-hazard category rankings, with the highest calculated risks from Table 46. The table below therefore highlights the assets or systems with the great needs for attention and risk planning.

Table 45: Top 20 Items with Highest Risks in Iqaluit Water Infrastructure.

RANKING	TANGIBLE ASSET	HAZARD SUB-CATEGORY	HAZARD
1	Water Treatment Plant	Contamination of Product	Pathogen
2	Distribution System	Contamination of Product	Pathogen
3	Water Treatment Plant	Contamination of Product	Biotoxin
4	Treated Water Reservoir	Contamination of Product	Pathogen
5	Water Treatment Plant	Contamination of Product	Chemical
6	Water Treatment Plant	Directed / Sabotage	Active Shooter
7	Water Treatment Plant	Vehicle Borne Bomb	Large Truck (18-Wheeler)
8	Distribution System	Contamination of Product	Biotoxin
9	Distribution System	Vehicle Borne Bomb	Large Truck (18-Wheeler)
10	Distribution System	Aircraft	Large Jet
11	Treated Water Reservoir	Contamination of Product	Biotoxin
12	Booster & Reheat Station	Contamination of Product	Pathogen
13	Distribution System	Aircraft	Regional Jet
14	Distribution System	Aircraft	Small Plane
15	Water Treatment Plant	Aircraft	Large Jet
16	Distribution System	Vehicle Borne Bomb	Midsize Truck
17	Distribution System	Contamination of Product	Chemical
18	Water Treatment Plant	Contamination of Product	Radionuclide
19	Water Treatment Plant	Aircraft	Regional Jet
20	Treated Water Reservoir	Contamination of Product	Chemical

From this table, among the top 20 hazards for the given assets with highest risk scores, the Water Distribution System in Iqaluit water infrastructure contributes to 40% of the highest risk items, with 8 out of 20 being related to this category.

Based on the risk assessment using AWWA J100-21, the following section identifies framework to propose mitigation strategies to address the aforementioned risks.

2.7.3 RISK MITIGATION

The highest ranked risks pertain to water contamination at various critical points, including distribution systems, water treatment plant, treated water reservoirs and booster & reheat station. Contamination sources range from pathogens, biotoxins, and chemicals to radionuclides, posing a direct threat to the public health. In addition, the system is susceptible to physical threats like sabotage, vehicle-borne bombs, and aircraft incidents, emphasizing the importance of securing the infrastructure against both accidental and deliberate hazards.

2.7.3.1 WATER TREATMENT PLANT

For pathogen and biotoxin contamination, following measures can be taken.

- Establish regular testing for microbiological contaminants as per requirements from Health Canada Guidelines for Canadian Drinking Water Quality (GCDWQ) and Government of Nunavut Drinking Water Strategic Framework. Key microbiological parameters, such as E. Coli., Giardia and Cryptosporidium shall be monitored, particularly during the spring melt when the risks for these species get higher.
- Optimize existing disinfection process, and/or introduce advanced filtration and UV disinfection systems to neutralize contaminants.
- Implement improved source water (i.e., Lake Geraldine) management to mitigate the introduction of compounding substances into water.
- Establish real-time monitoring and early warning systems to detect anomalies in water quality, specially in the water storage tanks before the water enters the distribution system.

For chemical contamination, the following can be considered.

- To neutralize chemical contaminants such as volatile petroleum hydrocarbons, implement secondary containment and automated chemical sensors for early detection. A standard neutralization protocol should be developed.
- Cut off the affected treated water and establish a temporary supply chain of alternative waters to Iqaluit residents in respond to chemical contamination.
- Prepare procedures for issues management and emergency response for chemical spills.

For directed sabotage and physical threats, following recommendations are provided.

- Fortify physical security through perimeter controls, surveillance systems, and regular vulnerability testing.

- Develop an emergency procedure in case the water and power supplies are not available for several days.

2.7.3.2 WATER DISTRIBUTION SYSTEM

Given the scope relevance and importance of the water distribution system within Iqaluit water infrastructure, we prioritized its assets within the risk management framework. The top 15 hazards for water distribution system that warrant focused attention for risk management and mitigation as well as resilience planning are shown in **Table 46**.

Table 46: Top 15 Items with Highest Risks within Iqaluit Water Distribution System

RANKING	TANGIBLE ASSET	HAZARD SUB-CATEGORY	HAZARD
1	Distribution System	Contamination of Product	Pathogen
2	Distribution System	Contamination of Product	Biotoxin
3	Distribution System	Vehicle Borne Bomb	Large Truck (18-Wheeler)
4	Distribution System	Aircraft	Large Jet
5	Distribution System	Aircraft	Regional Jet
6	Distribution System	Aircraft	Small Plane
7	Distribution System	Vehicle Borne Bomb	Midsize Truck
8	Distribution System	Contamination of Product	Chemical
9	Distribution System	Contamination of Product	Radionuclide
10	Distribution System	Aircraft	Helicopter
11	Distribution System	Vehicle Borne Bomb	Van
12	Distribution System	Vehicle Borne Bomb	Car
13	Distribution System	Contamination of Product	Explosive
14	Distribution System	Directed / Sabotage	Physical Insider
15	Distribution System	Directed / Sabotage	Physical Outsider

Based on these findings, the Iqaluit water distribution system is faced with diverse hazardous risks specially the contamination and physical attacks which may potentially compromise public health, operational continuity and system functionality.

Contamination of Product: These hazards (i.e., pathogens, biotoxins, chemicals, radionuclides and explosives), shown as hazards ranked as 1, 2, 8, 9 and 13 in **Table 46**, can likely be encountered and will pose risks to public health through unsafe potable water provision to Iqaluit end-users. It is recommended in resilience management that regular and real-time water quality monitoring be implemented to detect contamination. Emergency response plans for contaminant isolation and treatment in distribution system as well as back-up water supply should be prepared. After a risk event, on-site personnel should promptly replace or rehabilitate any compromised pipes or connections. Additionally, leak detection and monitoring would be helpful:

- Regular maintenance of water conveyance systems for reliable delivery and to preserve water quality once it leaves the treatment plant.
- Sufficient disinfectant residual present at all points throughout the distribution system to prevent bacteria regrowth.
- Deploy smart sensors to detect leaks and contaminants in real time, minimizing water loss and risk of contamination during distribution.

Physical Attacks via Vehicle-Born Attacks: Thes hazards (i.e., large truck, midsize truck, van and car), shown as hazards ranked as 3, 7, 11 and 12 in **Table 46**, can result in targeted explosion in critical segments within Iqaluit water distribution system, specially in vulnerable areas located. It is recommended in resilience management to establish regular surveillance to monitor areas vulnerable to vehicular access. High risk distribution system pipe segments are encouraged to be re-evaluated and adjusted on a regular basis, depending on age and condition, usage patterns, and environmental conditions.

Physical Attacks via Aircraft: These hazards (i.e., large jet, regional jet, small plane and helicopter), shown as hazards ranked as 4, 5, 6 and 10 in **Table 46**, can impact above-grade distribution infrastructure and human life. It is recommended in resilience management to coordinate with aviation authorities and to understand the distribution segments proximity to nearby airports and flight paths so that precautions of emergent crashes can be made in advance to mitigate the risk. Additionally, develop protective barriers around key pipeline sections and enforce airspace restrictions where applicable.

Directed Attacks and Sabotage: Physical insider and physical outsider are the concerned hazards within this category, which are ranked as 14 and 15 in **Table 46**. The resilience strategies proposed include to conduct more strict access controls to critical distribution system areas for employees, contractors, and other visitors. It is also recommended to have back-ups for operational data using SCADA system to prevent data loss resulting from these hazards.

By adopting these targeted strategies, the water systems' resiliency of Iqaluit can be significantly improved, ensuring a sustainable and secure water supply for its residents.

FUTURE CONSIDERATIONS

While this study provides a detailed assessment of the current state of Iqaluit's water infrastructure, it is important to recognize that the future state of the system will significantly influence resilience strategies and priorities. Changes in climate patterns, population growth, subdivision developments, technological advancements, and new policy frameworks could reshape the risks and vulnerabilities faced by the system. In Future State Assessment, we will revisit these findings to ensure that resilience measures remain relevant and effective, adapting to evolving conditions and leveraging emerging opportunities for system improvements.

It should be noted that this study, guided by the principles of AWWA J100, focuses on broader infrastructure resilience and does not assess specific sections of the water distribution network on a case-by-case basis.