CLIMATE RESILIENCE ASSESSMENT

TECHNICAL REPORT

Qulliq Energy Corporation
Cambridge Bay Community Diesel Power Plant
Cambridge Bay, Nunavut
BBA Document No. / Rev.: 3421024-003000-4E-ERA-0002 / R00
2021-01-15

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FINAL

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REVISION HISTORY

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EXECUTIVE SUMMARY

The existing diesel power plant in Cambridge Bay, built in 1958, has significantly exceeded its 40-year service life and requires replacement. The power plant is a critical infrastructure to the Cambridge Bay community. QEC needs to construct a new diesel power plant for the community to improve reliability, safety and fuel efficiency, and to reduce environmental impacts and noise pollution. As part of funding requests, this Climate Resilience Assessment follows the requirements of Infrastructure Canada Climate Lens General Guidance, version 1.1 – June 1, 2018 and updated October 31, 2019.

Climate change hazards identified are:

- Increase in mean annual air temperature;
- Increase in thawing degree days;
- Increase in precipitation;
- Relative sea level rise;
- Increase of storm frequency and flooding;
- Decrease in duration of winter snow cover and total snow fall.

It was shown, through the evaluation of the impacts on the asset, that climate change hazards present either negligible or low risk to the proposed power plant's performance and reliability. As long as the best practice principles outlined in Table 5 are included in the power plant design, there are no additional adaptation measures required.

In addition, the new power plant project design will be compatible with the climate change adaptation approach proposed by the Government of Nunavut and the overall ICIP objective to facilitate climate-smart behavioural change through ensuring more informed decisions at the project planning/design stage.

Note that as part of the Climate Lens guidance, a separate assessment report for GHG mitigation has also been prepared for the new Cambridge Bay power plant project.

Abbreviation and acronyms

The table below lists abbreviations and acronyms used in this document.

Abbreviations and acronyms

Abbreviation or acronym	Definition
CRCM	Canadian Regional Climate Model
IC	Infrastructure Canada
ICIP	Investing in Canada Infrastructure Program
IRIS	Integrated Regional Impact Study
NCPC	Northern Canada Power Corporation
NTPC	Northwest Territories Power Corporation
PIEVC	Public Infrastructure Engineering Vulnerability Committee
QEC	Qulliq Energy Corporation

Units and symbols

Units and symbols used in this document are listed in the following table.

Units and symbols

Unit / Symbol	Description
°C	Degrees Celsius
cm	Centimetre
mm	Millimetre
%	Percentage

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1. INTRODUCTION

For a planned diesel generator replacement project, BBA Inc. (BBA) was mandated by Qulliq Energy Corporation (QEC) to prepare a climate resilience assessment following the *Climate Lens – General Guidance, Version 1.1* document published on June 1, 2018 and updated October 31, 2019 by Infrastructure Canada (IC). As part of the Climate Lens guidance requirements, two (2) technical assessment reports must be prepared (GHG Mitigation and Climate Resilience) and submitted with the Investing in Canada Infrastructure Program (ICIP) application forms. This climate resilience assessment is presented as an appendix to the ICIP Project Application Form. The overall objective of the Climate Lens is to facilitate climate-smart behavioural change by ensuring more informed decisions at the project planning/design stage.

Figure 1: Cambridge Bay community, Nunavut
(Photo credit: Municipality of Cambridge Bay)

The plant will be located in Cambridge Bay, Nunavut, which is a small community of 1,995 inhabitants[1] on the shore of the Queen Maud Gulf on the southeastern coast of Victoria Island.

To replace an existing end-of-life power plant using diesel fuel, QEC has to construct a new power plant for the Cambridge Bay community. To assist QEC, BBA has set up a team of experts in diesel generator power plants, off-grid Power generation, renewable energy integration as well as environmental assessments. This report will demonstrate if the power plant's resilience to climate change and the associated risks are at an acceptable level and propose adaptation strategies to reduce these risks on this critical infrastructure if necessary[2]. In addition, emphasis will be put on *Climate Change Resilience Principles* and how they are reflected in the assessment.

[1] As of 2017

[2] Public Safety Canada defines critical infrastructure as: "Processes, systems, facilities, technologies, networks, assets and services essential to the health, safety, security or economic well-being of Canadians and the effective functioning of government. Critical infrastructure can be stand-alone or interconnected and interdependent within and across provinces, territories and national borders. Disruptions of critical infrastructure could result in catastrophic loss of life, adverse economic effects and significant harm to public confidence."

2. PROJECT TEAM

Client Representative	Role
Tosin Omole	Regulatory Reporting
Ruhul Amin	Project Coordinator

BBA Inc. is a Pan-Canadian consulting engineering firm established in 1979 with a leading expertise in power generation, environmental services and indigenous relation with a reputation built on innovative, sustainable solutions that maximize the value of client projects. BBA has a cumulative +35 off-grid projects and +120 renewable energy projects.

Project Team	Role
Jean-Philippe Castonguay, P.Eng.	Director Off-Grid Power Generation
Denis Lalonde, P.Eng.	Environmental Expert and Project Director
Dave Olsthoorn, P.Eng., M.A.Sc.	Project Leader
Corentin Bergerot, Jr.Eng.	Environmental Engineer
Nicholas Dubreuil, P.Eng.	Structural Engineer
Louis-François Gagnon, P.Eng.	Diesel Generator Power Plant Expert

Note: The BBA team members are presented in Appendix B.

3. SCOPE AND TIMESCALE OF ASSESSMENT

The scope of this assessment is defined to present a complete overview of the influence that climate change could have on the asset and adaptation measures required to be taken in accordance. Thus, elements covered include, but are not limited to:

- Location
- Materials used
- Construction methods
- Operation
- Maintenance
- Supply to and from site
- Equipment selection
- Environmental impacts

The timescale of the analysis is defined to cover the expected lifespan of the project, which is 40 years.

4. PROJECT AND SITE OVERVIEW

Located on the south coast of Victoria Island, Cambridge Bay is a transportation and administrative center for the western Kitikmeot Region (see Figure 1). Access to the community is limited to air and sea travel only. The community fuel resupply is carried out in the summer/fall via fuel supply tanker. Some of the largest electricity loads in the community are demanded by the Cambridge Bay Airport, Schools (one Elementary School, one High School and one College), Health Center, Municipal Services, Co-Op stores.

QEC and its predecessors, the Northwest Territories Power Corporation (NTPC) and the Northern Canada Power Corporation (NCPC), have operated the diesel generating plant in Cambridge Bay since the original plant was constructed in 1958. A new power plant is required, including generating units and building. It will be more efficient, cause less noise and air pollution, be safer for its technicians and comply with current codes and regulations. QEC plans to commission the new power plant in 2026.The main expected outcome of the proposed project is to supply Cambridge Bay with a more stable and reliable source of electricity for years to come.

The construction phase will span two years and provide good employment opportunities for local labour.

5. IDENTIFICATION AND ASSESSMENT OF CLIMATE HAZARDS

The climate information presented in this report is based on the content of the most recent and comprehensive scientific documents related to climate change in Northern Canada. Reference documents used to establish the conclusions of this section include, but are not limited to:

- *From Science to Policy in the Western and Central Canadian Arctic: An Integrated Regional Impact Study (IRIS) of Climate Change and Modernization* was prepared by the Western and Central Canadian IRIS, funded by ArcticNet and the Government of Canada. This document (hereinafter referred to as the IRIS-1 report) presents conclusions based on a considerable effort to synthesize available quality climate information and present variability and projections over time of Canada's Arctic region and its communities.
- *Cambridge Bay Airport – Climate Change Vulnerability Assessment* was prepared for Transport Canada in partnership with the Government of Nunavut Territories. This assessment, based on the PIEVC protocol, determined which climate events may be critical for the Cambridge Bay Airport. Conclusions that are relevant for the Cambridge Bay community, located several kilometres to the East, have been taken into consideration.
- *Climate Change Adaptation Action Plan For Cambridge Bay,* prepared in a collaborative way by the Municipal Corporation of Cambridge Bay, the Government of Nunavut, the Canadian Institute of Planners, Natural Resources Canada and the Indian and Northern Affairs Canada, identifies a series of research, monitoring, planning and implementation activities that can be undertaken to address the identified potential climate change impacts.

The spatial distribution of climate stations for the Canadian arctic has a western bias; most of the stations are in the westernmost section of Northern Canada and located in coastal communities. Few stations' historical data is constant and uninterrupted. Fortunately, Cambridge Bay has a meteorological station that has been operated by Environment Canada since 1953, located at the Cambridge Bay Airport. Available data from this station was used to establish historical trends and projections.

The following sections present different aspects of projected climatic changes expected to occur during 2025-2070 (future time period corresponding to the new power plant life span) for the community of Cambridge Bay. It is important to note that recent/past climate data may be different depending on the source because the referred time basis is not identical in all references. This is why for climate projections, values are presented as intervals, to reflect the fact that it is not possible to be precise, because different simulations suggest different plausible values. For the 2025-2070 time horizon, climate projection uncertainty originates from uncertainty in future anthropogenic greenhouse gas emissions, from inter-model differences in physics formulation, and from unpredictable natural variability. It is an important message for policy-makers that climatology cannot be precise on future climate change, for various inescapable reasons.

5.1 Air temperature change

Cambridge Bay possesses a meteorological station, operated by Environment Canada. This station is located at the Cambridge Bay Airport, to the east of the terminal building. The mean air temperature for the climate normal period of 1980-2010 is -13.9°C, with July being the warmest month and February the coldest (Transport Canada, 2016).

As the atmosphere warms, the ice and snow cover melts, which decreases the surface albedo and a larger portion of solar radiation is absorbed. This feedback increases the rate at which the snow and ice melts. Such a feedback loop is exemplified by local observations such as ponds to the South of Cambridge Bay where the ice no longer grows thick (Calihoo & Romaine, 2010).

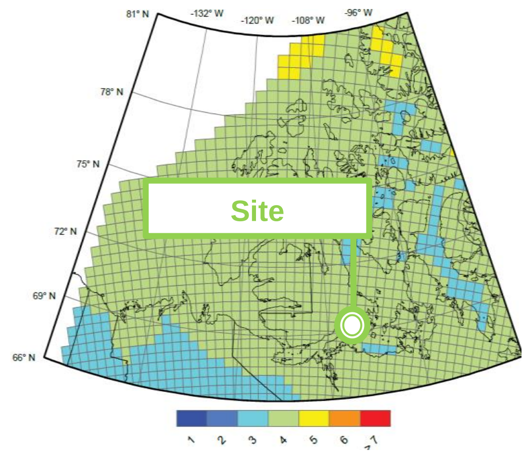

Figure 2: Projected change in annual air temperature from 1971-2000 to 2041-2070
(Cambridge Bay as a green marker). Adapted from IRIS-1 report.)

For the western and central Canadian arctic region, including the Cambridge Bay area, the projected temperature changes based on the Canadian Regional Climate Model (CRCM) simulations suggest a plausible increase in annual temperature within +3 to +5 °C from 1971-2000 to 2041-2070 as presented in Figure 2. But, a larger ensemble of simulations would give a broader interval.

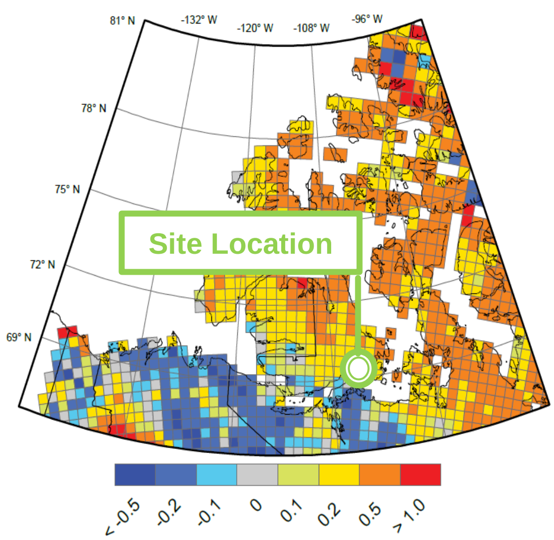

Figure 3: Projected change in the mean annual number of thawing events from 1971-2000 to 2041-2070
(Cambridge Bay as a green marker). Adapted from IRIS-1 report.)

In the Cambridge Bay area, February is the coldest month with an average condition of -32.5°C and July is the warmest month with an average condition of 7.9°C (Environment Canada, 2016). Documented observations made by Inuit demonstrate warmer summers or more extreme warm temperatures (IRIS-1, 2015). Projected temperature changes based on CRCM simulations suggest a plausible increase within +4°C to +6°C for the winter season[3] and +1°C to +3°C for the summer[4] season during the 2041-2070 period (IRIS-1, 2015).

[3] January, February and March

[4] July, August and September

Projected change in annual frequency of freeze/thaw events is presented in Figure 3. For Cambridge Bay, considering Figure 3 and the inter-simulation standard deviation, the change could be within -0.2 to +0.2 events per year (IRIS-1, 2015). A freeze/thaw event is defined as a day for which daily maximal air temperature is above the freezing point whereas the 29-day (centered on the considered day) daily mean temperature average is below -5^{o}C (IRIS-1, 2015).

5.2 Permafrost and ground temperature

Permafrost is defined as the ground (rock or soil) which has been frozen for at least 2 years. A layer of soil is often present separating the permafrost from the atmosphere, which undergoes seasonal freeze and thaw and is referred to as the active layer. This layer is particularly important in the design of human-built infrastructures.

The potential effects of increasing mean annual ground surface temperature on permafrost will be very different for continuous and discontinuous permafrost zones (Instanes, 2006). In continuous areas (like Cambridge Bay), increasing air temperature has a high probability of increasing permafrost melting and possibly increasing the depth of the active layer. In discontinuous zones, the effects of a few degrees increase in the mean annual permafrost temperature are very likely to be significant (Harris, 1986). Furthermore, the temperature of most of the Canadian permafrost is presently within a few degrees of its melting point. Except for the southernmost zone of the sporadic permafrost, some studies indicated that many centuries will be required for the permafrost to disappear completely. (Transport Canada, 2016). However, in response to the current global warming, permafrost soil temperatures in the western Arctic have increased about 2°C since the 1970s (IRIS-1, 2015).

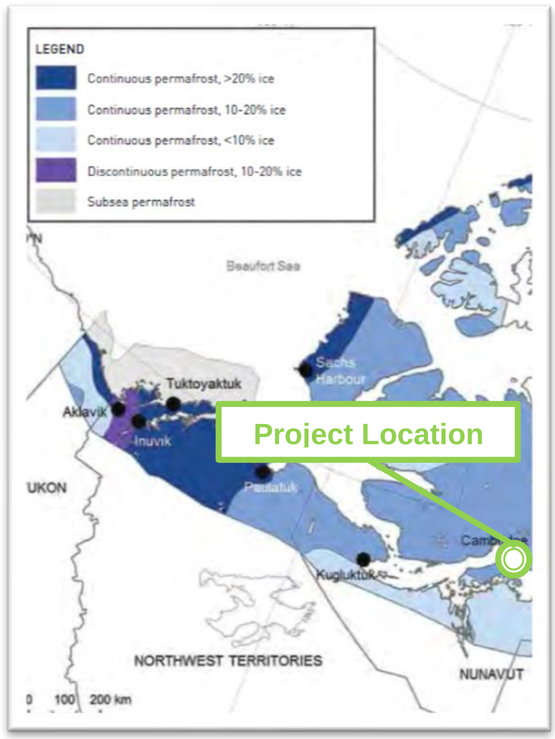

Figure 4: Map indicating areas with widespread ice-rich permafrost in the Kitikmeot region of Nunavut

The air temperature, snow cover, insulation cover, hydrology, Albedo, human activities and constructions, as well as vegetation all have an influence on the depth and extent of the permafrost. However, there is a limited amount of data available about permafrost degradation over time, especially in regions of continuous permafrost (which includes Cambridge Bay).

Climate projection outputs up to 2090 demonstrate that despite air temperature increases, the annual air temperature in zones of continuous permafrost should remain sufficiently cold to maintain the presence of permafrost. The continuous permafrost, as presented in Figure 4, is not projected to completely disappear in the timescale of interest (2020 to 2070). However, a partial increase in depth of permafrost over the region is reasonably expected (IRIS-1, 2015).

5.3 Precipitation

The precipitation at any location is influenced by the average moisture content of the air, the proximity to moisture sources, weather systems and the topography. Cambridge Bay happens to be a coastal community. However, characterizing the amount of precipitation in the arctic is particularly challenging because it happens in frequent trace events and there are high winds. There are 30[5] full years of snow cover observations available for Cambridge Bay. However, the accumulation of snow is closely related to wind distribution (snow is then redistributed with the wind). Snow covers the ground for the majority of the year, which corresponds to approximately 258 days per year today. Historical data has shown that the average change in duration of periods with continuous snow cover is decreasing 7.6 days per 10 years (IRIS-1, 2015).

Cambridge Bay experiences, on average, a total of 90.9 mm of rainfall and 125.6 cm of snowfall. Rainfalls occur mainly from June to October and snowfalls between the months of September to June, with occasional snowfalls during July and August. Most of the snow is received during the month of October. By the end of the expected power plant life span (2065), rainfall is projected to increase from 20% to 30% and snowfall is projected to also increase from 20% to 30% (IRIS-1, 2015). Documented Inuit observations indicate that snowfall arrives later than it used to.

5.4 Winds and storms

There has been a considerable amount of research recently about the relationship between winds, storms and sea ice. Yet, there is little to no evidence of the frequency of storms hitting the arctic area. There has been a reported increase in storm intensity but the scale of the projected increase in storm intensity is yet to be defined by researchers, mainly because of the complex interactions between sea ice, air temperature and water evaporation. Observations by local inhabitants present a surge of extreme storms appearing “out of nowhere” and creating safety hazards for the people out on the land. Some of the impacts of the increased storm intensities are that in large areas with open water, the storm could change the amount of precipitation a region will receive (IRIS-1, 2015). Cambridge Bay average wind speed is 19.6 km/h (Transport Canada, 2016).

Specifically, for Cambridge Bay, an increase in wind gust frequency of 10% during spring and 10 to 30% over the other seasons is expected for the 2081 to 2100 period (Transport Canada, 2016). This data is out of this study’s timescale but is the only wind gust projection available for Cambridge Bay.

[5] From 1981 to 2010

5.5 Coastal erosion

In areas where there are large bodies of water accompanied by the melting of the earth's ice caps, coastlines are subject to higher waves. This is due to larger areas of water being exposed to the wind, thus creating a larger fetch for waves to develop. The increased wave height is often associated with a higher coastal erosion rate. However, at Cambridge Bay, local observations (Figure 5) show that coastal erosion is minimal (Transport Canada, 2016). The protective setting of the harbour minimizes the risk as identified by NRCan in their research included in the Cambridge Bay adaptation plan. Houses and other buildings located northwest of the airport, on the other hand, do potentially face increased threat of wave action, storm surge and ice ride up, as their exposure is much greater (Calihoo & Romaine, 2010).

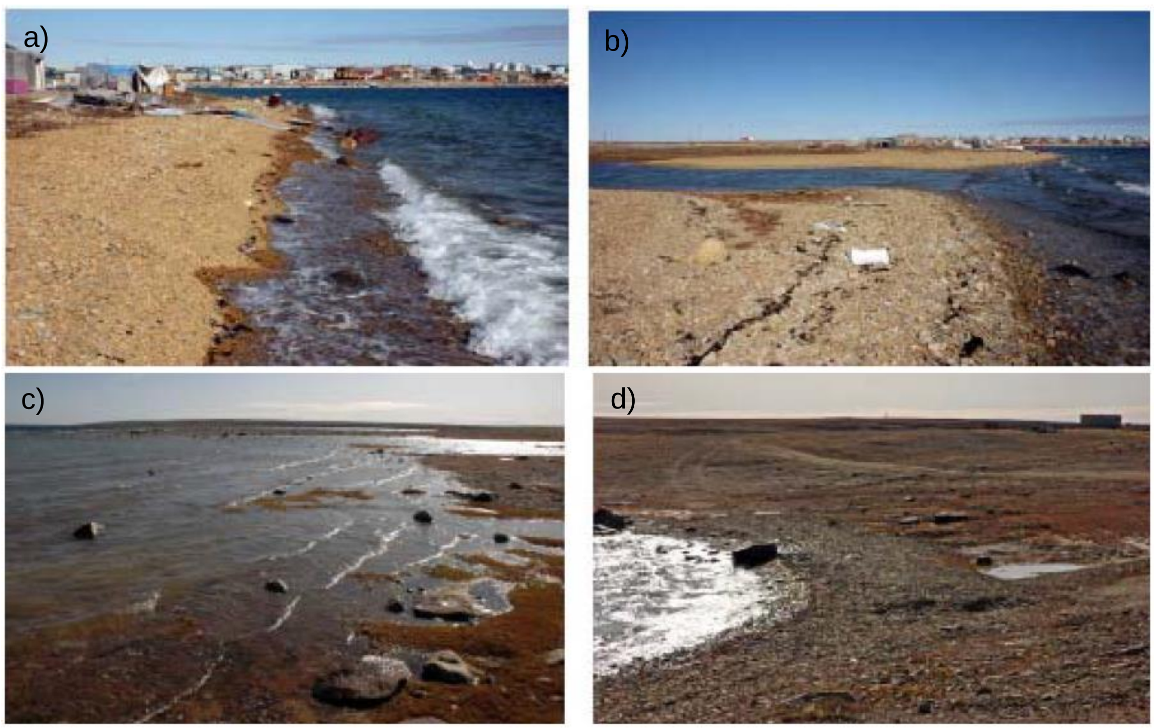

Figure 5: a) Small local waves, generated inside bay by brisk southerly wind, August 2009. **b)** Water breaches a thin fringing barrier beach, southeast of the hamlet, August 2009. **c)** Rising tide, with onshore wind, August 2009. **d)** Very small transgressive bayhead barrier beach in cove near fuel tanks, August 2009. **(Smith & Forbes, 2014)**

5.6 Sea level rise

The relative sea level rise is dependent on three (3) factors for Cambridge Bay: (Calihoo & Romaine, 2010)

1. The relationship between the sea level in the Arctic Archipelago and the global mean;
2. Land uplift: the melting of the glaciers has removed weight from the ground and causes Earth's surface to respond with an isostatic readjustment of its surface, which causes uplift across much of the Canadian Arctic; and
3. Current glacier melt: the glacier and ice cap from Greenland melting cause (counter-intuitively) reduction of the sea level in areas close to the ice sheet, including much of the Canadian Arctic ('finger-printing' effect).

The relative difference between the above-mentioned factors gives an appreciation of the relative sea level rise.

The cumulative effects have been estimated to be, incorporating uncertainty in the estimate of land uplift, in the range of -35 cm to +50 cm. Thus, this is necessary to consider the possibility of limited sea-level rise at this community (Calihoo & Romaine, 2010). Other literature is also abiding to the probability of limited sea level change in Cambridge Bay in 2100[6] (Lemmen, Warren, James, & Clarke, 2016).

5.7 Wildfires

Historically, tundra fire incidents are very uncommon, but they are expected to increase over time. Studies have shown that there is an increase of 20% in the past 30 years of tundra biomass. This is explained by the fact that the summer season is becoming longer, due to the increase in ambient air temperature and the thaw degree days are higher than what they once were. Although total precipitation is expected to increase, evapotranspiration and increased drainage will actually make the tundra dryer, thus increasing the likelihood of wildfires. These can start during thunderstorms or even due to human activity. However, no estimate is available on the increase in wildfire frequency in the future (IRIS-1, 2015).

5.8 Landslides

In general, the cohesion of the ground may be influenced by the increased rainfall and more rapid snowmelt by saturating the active layer and promoting slumping of the ground. This sensibility to landslides may be amplified in the future due to increasing summer temperatures and total precipitation. However, no literature was found identifying landslides as being a potential threat to Cambridge Bay due to climate change.

[6] NRCan, Potential Impacts: Coastal sensitivity to sea-level rise. https://open.canada.ca/data/en/dataset/dc9817c0-8893-11e0-82bc-6cf049291510

5.9 Flooding

The intensity and frequency of surface water runoff is susceptible to climate parameters such as rainfall and spring snowpack melting. Global circulation models project an increase in snow depth and total annual precipitation, which indicates that surface draining volumetric flow rates will increase. Surface water ponding was identified at multiple areas over the community of Cambridge Bay. Increase in snow melting and rainfall add to the saturation of sediments, which might cause flooding (Calihoo & Romaine, 2010).

5.10 Summary

This section presents a summary of the current and projected climate conditions for the community of Cambridge Bay. The information contained in this assessment report and the one presented in Table 1 are based on the most recent available technical papers and summarizes the work of experts in the field of climate resilience. Nonetheless, one concurrent theme across the works is that climate change simulation results have a degree of uncertainty and results are most probably going to vary across regions and time. For this reason, continuous monitoring of climate change studies is ongoing.

Table 1: Summary of average actual and projected climatic conditions change for Cambridge Bay community

Climate variable	Cambridge Bay average condition[7]	Projected change to power plant lifespan	Comments
Mean annual air temperature	-13.9°C	+3 to +5°C	Changes are in general expected to be largest over land and lowest over ocean areas.
Mean temperature of coldest month	-32.5°C	+4°C to +6°C	February is the coldest month.
Mean temperature of warmest month	7.9°C	+1°C to +3°C	July is the warmest month.
Permafrost	Continuous permafrost	Active layer thickness increase and local ground subsidence due to permafrost thaw.	Not likely to disappear in project timescale. Nonetheless, the depth of permafrost thaw is anticipated to increase as air temperature increases.
Thawing degree days	636 degree-days	>250 degree-days	
Frequency of winter thaw events	-	-0.2 to +0.2 per year	
Duration of winter snow cover	Approx. 258 days	-	IRIS-1 Projections suggest an earlier spring snow cover melt and a later autumn snow cover onset.
Maximal snow depth	Approx. 41.5 cm	+4 to +8 cm	
Total annual rainfall	90.9 mm	+20 to +30 %	
Total annual snowfall	125.6 cm	+20 to +30 %	Documented Inuit observations indicate that snowfall arrives later than it used to.
Rain on snow frequency	-	-	Rain-on-snow events are rare for the Arctic, which means small projected change in absolute terms.
Winds and storms	Approx. 19.6 km/h	Increase frequency of wind gust of 10% to 30%, depending on season	
Relative sea level rise	-	-35 cm to +50 cm	Limited relative sea-level rise is a probable expectation.
Coastal erosion	-	-	Coastal erosion thought to be minimal at Cambridge Bay because of the harbour protection, except for the area northwest of the airport and south of Tikiraaryaq.
Wildfires	-	-	Increase in tundra biomass due to climate change could increase rate of wildfire.
Landslides	Cambridge Bay community lies on low-risk soil profile	-	Low risk of having landslides for Cambridge Bay.
Flooding	-	Increase in frequency and intensity of peak flows	Anticipated increase in snow melt and precipitation-related water flow rate. Flooding under moderate conditions.

[7] Cambridge average data over 30 annual values of 1981-2010

6. IMPACT ON ASSET

This section presents the analysis of the climate change hazards' potential impact on the proposed power plant. The impacts on the asset have been evaluated both on the probability and magnitude of the climate change. Table 2 presents the scales for which the likelihood and consequence have been attributed a score. The likelihood of a risk relates to the probability that the future power plant can withstand the projected climate change hazard if the proposed mitigation/comments are integrated in the project design. The consequence rating evaluates the severity of the outcomes if the plant could not withstand the climate change. The consequence ratings are described with an emphasis on the performance and reliability of the power plant with a consideration that this piece of equipment is critical to the community.

Table 2: Estimate of likelihood and consequence rating

Rating	Likelihood of the risk	Consequence rating
Very low	Not likely to occur in lifespan of power plant	No impact on performance and reliability of power plant
Low	Infrequent occurrences during lifetime of power plant	Temporary decrease in power plant performance and reliability
Moderate	Sporadic or intermittent occurrences during lifetime of plant	Short term interruptions in power plant supply of electricity
High	Several and numerous occurrences during lifetime of plant	Long term interruptions in power plant supply of electricity
Very high	Continuous or regular occurrences during lifetime of plant	Evacuation and permanent closure of power plant

The cumulative impact of the climate change with respect to the likelihood of the risk and the associated impact on the asset is evaluated based on the matrix presented in Table 3 and is given a general overall risk score, presented in Table 5. The adaptation effort is determined from the obtained overall risk score and evaluated based on the criteria of the Climate Lens Guidance document.

Table 3: Risk assessment matrix

		Likelihood of consequence				
Severity of consequence		Very low	Low	Moderate	High	Very high
	Very low	NR	NR	LR	LR	MR
	Low	NR	LR	LR	MR	HR
	Moderate	LR	LR	MR	HR	HR
	High	LR	MR	HR	HR	ER
	Very high	MR	HR	HR	ER	ER

Table 4: Required adaptation effort and priority as a function of risk assessment

Risk assessment	Acronym	Adaptation response
Extreme risk	ER	Immediate controls required
High risk	HR	High priority control measures required
Moderate risk	MR	Some controls required to reduce risk to lower levels
Low risk	LR	Controls likely not required
Negligible risk	NR	Risk events do not require further consideration

Table 5: Estimates of consequences of risks with associated overall risk evaluation

Climate change hazard[8]	Impact on asset	Consequence score	Consequence likelihood	Overall risk evaluation	Mitigation / Comments
Increase in mean annual air temperature	No anticipated vulnerabilities	Very low	Very low	Negligible risk	Annual mean air temperature has no impact on power plant reliability.
Increase in mean monthly minimum air temperature	No anticipated vulnerabilities	Very low	Very low	Negligible risk	Mean monthly minimum air temperature has no impact on power plant reliability.
Increase in mean monthly maximum air temperature	Reduced cooling efficiency of dry coolers	Moderate	Low	Low Risk	The exterior air temperature used for the design of the cooling loads must be adjusted accordingly.
Permafrost thaw Thawing degree days increase Frequency of winter thaw events increase	Ground subsidence caused by melting permafrost causes stress on foundation and building structure. Active layer freeze/thaw creating uplift on foundation/pile	High	Very low	Low risk	An in-depth geotechnical study should be completed for the proposed site to confirm it is suitable for the support of foundations on piles socketed into competent rock. In addition, conceptual foundation design must be reviewed by a geotechnical engineer with permafrost experience and licensed with NAPEG to practice in Nunavut. QEC has considerable experience with power plant construction in arctic conditions.
Snow cover period shortening	No anticipated vulnerabilities	Very low	Very low	Negligible risk	Shortening of the snow cover period should not have any impact on the asset. Power plant designed and built for extreme arctic conditions.
Total annual snow depth increase Total annual snowfall increase Total annual rainfall increase	Snow build-up on roof causing buckling of roof panels and possibly a collapse	High	Very low	Low risk	Snow roof design loads should be in accordance with NBCC requirements.
Winds and storms frequency and intensity increase	Buckling of siding material, excessive wear and tear of siding material, shattering of windows	High	Low	Low Risk	Power plant siding and window/door specifications commonly consider excessively harsh conditions. Anticipated increase negligible compared to safety margin.
Relative sea level rise	Sea level reaching power plant causing excessive flooding and possibly evacuation	High	Very low	Negligible risk	Power plant location should consider sea level rise potential described in this document
Coastal erosion rate increase	Coast eroding up to power plant causing permanent damage to structure and possibly evacuation	High	Very low	Low risk	Power plant should be sufficiently far away from shoreline even with Cambridge Bay current and future erosion rates projected to be minimal. Monitoring of erosion rate in future years is recommended.
Wildfires frequency increase	No anticipated vulnerabilities	Very low	Very low	Low risk	Power plant emergency plan should have a response scenario to community-spread wildfire.
Landslides	Thawing of the soil causing ground subsidence and landslides	High	Very low	Low risk	Power plant location should be far from susceptible land slide areas.
Flooding	Erosion of permeable soil causing permanent damage to foundation	High	Very low	Low risk	Power plant drainage design will have to divert surface water as required.

[8] Refer to Table 1 for more specific details on climate changes expected for the Cambridge Bay community.

7. ANALYSIS OF RESILIENCE OPTIONS

7.1 Power plant climate change resilience

It was shown, through the evaluation of the impacts on the asset presented in Table 5, that climate change hazards present either negligible or low risk to the power plant's performance and reliability. As long as the best practice principles outlined in Table 5 are included in the power plant design, there are no additional adaptation measures required.

The choice of a diesel generator power plant is based on the fact that this is the only proven on-demand energy supply technology for which QEC has a fully established infrastructure, logistic support and other required resources including trained local manpower. Since this off-grid isolated diesel power plant is the only energy resource in the community, there is a critical level of dependence on its electrical output.

Nonetheless, the importance of the environmental impact is not to be overlooked. The electrical system will be commissioned with the ability to integrate renewable sources of electricity. The current project application does not cover any funding for renewable energy installations. Yet, the possibility of integrating them in the near future will be considered by QEC and adequate space provision will be planned for the possible addition of *solar* and *wind* resources. This project's approach will become a flagship methodology for other communities of Northern Canada by keeping a flexible view on energy sources. Cambridge Bay's new power plant will be reliable, have the flexibility of integrating renewables in the future and comply with the latest applicable environmental codes and regulations.

The best location for the new plant will be selected with community approval. Proximity of the power plant to the community will be evaluated to allow excess heat from the generators to be salvaged for building space heating.

7.2 The power plant within the community

A partnership incentive was initiated by the Government of Nunavut with Indian and Northern Affairs Canada, Natural Resources Canada, Canadian Institute of Planners, Nunavut communities and other stakeholders on the Nunavut Climate Change partnership (Calihoo & Romaine, 2010). Cambridge Bay was identified as one of the communities to participate in the Nunavut Climate Change Adaptation Planning project. The Climate Change Adaptation Plan was developed over a fourteen-month period and involved four (4) visits to the community to seek guidance from community members including elders, youth and professionals. The plan is also based on scientific reports from Natural Resources Canada.

The Cambridge Bay Climate Change Adaptation Plan addresses three (3) technical topics that are related to the new power plant project:

Landscape hazards

Certain areas of Cambridge Bay have been identified as being hazardous due to the permeable soil and melting ice-rich ground conditions. Adaptation responses include the repair and construction of new trails across the community, restricting building construction in eroding areas and moving buildings from hazardous areas to more stable ground. The new power plant will be located at a designated stable area.

Snow Drift Patterns

Excessive snow drift has been identified and accumulation occurs near buildings with long exposed faces to the wind. New infrastructure development, particularly in the peripheral and northwestern portions of Cambridge Bay, should consider the potential for snow drifting when deciding on such things as building alignment and spacing, and road design. The impacts of snow drifting go beyond issues of building access. Snow is a very effective insulator of the ground. Permafrost stability in the north is recognized in terms of both summer thaw potential and the intensity of winter freezing. If snow is allowed to accumulate in areas it previously did not, then the permafrost becomes insulated from the seasonal winter cold pulse, which potentially leads to increased active layer thicknesses and melting of ice-bearing sediments in summer. Snow drift patterns need to be taken into account during the planning process of any new project. Snow drift patterns will be taken into consideration during the design of the new power plant.

Hydrology

The increasing frequency and magnitude of rain events, ponding and the additional water flow from accelerated permafrost melt may develop drainage issues across the community since culverts are not designed for such water flow rates. The permeability of the soil makes it sensitive to water erosion. Therefore, buildings downstream are more susceptible to have damage from water erosion. Appropriate drainage will be included in the design of the new power plant.

The Climate Change Adaptation Plan incentive by the Government of Nunavut was developed to prepare Cambridge Bay and provide all the tools necessary to adapt to the projected climate change. The new power plant proposed by QEC is a project directly in line with the objectives behind this incentive.

8. CONCLUSION

A climate change resilience assessment was conducted for a new power plant project by QEC in the community of Cambridge Bay, Nunavut. The proposed project is planned to be commissioned in 2026 and designed for a service life of 40 years. Applicable project climate change hazards were identified and their impacts on the asset were assessed, as per IC's Climate Lens General Guidance.

Climate change hazards identified include an increase in mean annual air temperature, in thawing degree days, in precipitation, relative sea level rise, in storm frequency and flooding, as well as a decrease in duration of winter snow cover and total snow fall. This assessment has established that the identified climate change hazards have a negligible to low risk of having an impact on the asset. Based on the above, the proposed asset by QEC can be considered resilient to climate change for the duration of its service life, as long as the mitigation/comments of Table 5 are included in the power plant design.

This climate resilience assessment meets IC's objective of facilitating climate-smart behavioural change through ensuring more informed decisions at the project planning/design stage.

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Appendix A: Attestation of completeness

We, the undersigned, attest that this Resilience Assessment was undertaken using recognized assessment tools and approaches and complies with the General Guidance and any relevant sector-specific technical guidance issued by Infrastructure Canada for use under the Climate Lens.

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Date

Appendix B: BBA Team Members

Jean-Philippe Castonguay, P.Eng.

Senior Mechanical Engineer – Off-Grid Power Generation

Since joining BBA in 2010, Jean-Philippe Castonguay has been actively involved in remote off-grid power generation projects for both power utility corporations and clients from the mining sector. As a project manager, he leads multidisciplinary engineering, construction support and commissioning projects across Canada, including in northern territories. Among other achievements, Mr. Castonguay managed projects for the replacement of 1 to 4 MW diesel power plants in Nunavut.

Denis Lalonde, P.Eng.

Air Emissions Expert

Denis Lalonde is an expert with more than 25 years of experience in air emissions monitoring, permitting and inventories for industrial and institutional facilities. He brings to the team his vast experience in studies and calculations for GHG and other pollutants emissions reporting from several types of processes. He was namely involved in all air-quality aspects of a large mining project in northern Québec/Labrador: provincial and federal Environmental Impact Statements, monitoring plans, and discussions with stakeholders (CEAA, MELCC, NL DMAE). In addition, he managed noise, ambient light and human health risk assessment sections for the project's EIS submitted and approved by the CEAA.

Louis-François Gagnon, P.Eng.

Diesel Generator Power Plant Expert

Louis-François Gagnon manages multidisciplinary projects and specializes in automation, mechanical engineering, HVAC, and energy efficiency. He has experience increasing the efficiency of thermal power plants through the implementation of heat recovery systems. He designs innovative energy-efficient solutions for building services and was involved in several projects that received energy efficiency awards, including the optimization of the heat recovery network project at Raglan Mine (Glencore-Xstrata), which was awarded an honourable prize by the *Association québécoise de la maîtrise de l'énergie (AQME)*.

Dave Olsthoorn, P.Eng., M.A.Sc.

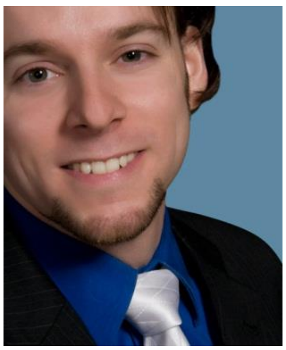
Project Leader

Dave Olsthoorn specializes in the relationship between industrial systems and their environment: GHG emissions, pollutant release to the environment, energy efficiency, renewable energy sources, climate change impacts and environmental impact studies. He has worked on many projects that involve energy efficiency, energy conservation, industrial process optimization, air dispersion modelling, and environmental impact assessments. Previously from the research sector, he has worked with Hydro-Québec, the International Energy Agency, the Canadian Geothermal Energy Association and the Natural Sciences and Engineering Council of Canada.

Corentin Bergerot, Jr. Eng.

Environmental Engineer

Corentin Bergerot is a junior environmental engineer who specializes in the relationship between industrial systems and their environment: GHG emissions and reduction, pollutant release to the environment, energy efficiency, renewable energy sources, climate change impacts and environmental impact studies. He has worked on many projects that involve energy and industrial process optimization, air dispersion modelling, and environmental impact assessments. He recently participated in a project involving the preparation of reports in accordance with the Climate Lens guidelines.



Nicholas Dubreuil, P.Eng.

Structural Engineer

Mr. Dubreuil is a Senior Engineer who has specialized in Energy and Industrial structures. In close collaboration with the client and the contractor, he successfully designs structures to reduce cost, ease fabrication and constructability. His knowledge of codes, standards and guides, relevant to substation design, has made him an expert in the design of structures for industrial, commercial and modular buildings. His most recent project was a modular power house for the Grise Fiord community in Nunavut where he played the role of lead structural engineer and successfully tackled the challenge of a prefabricated building on piles in the permafrost.

BBA