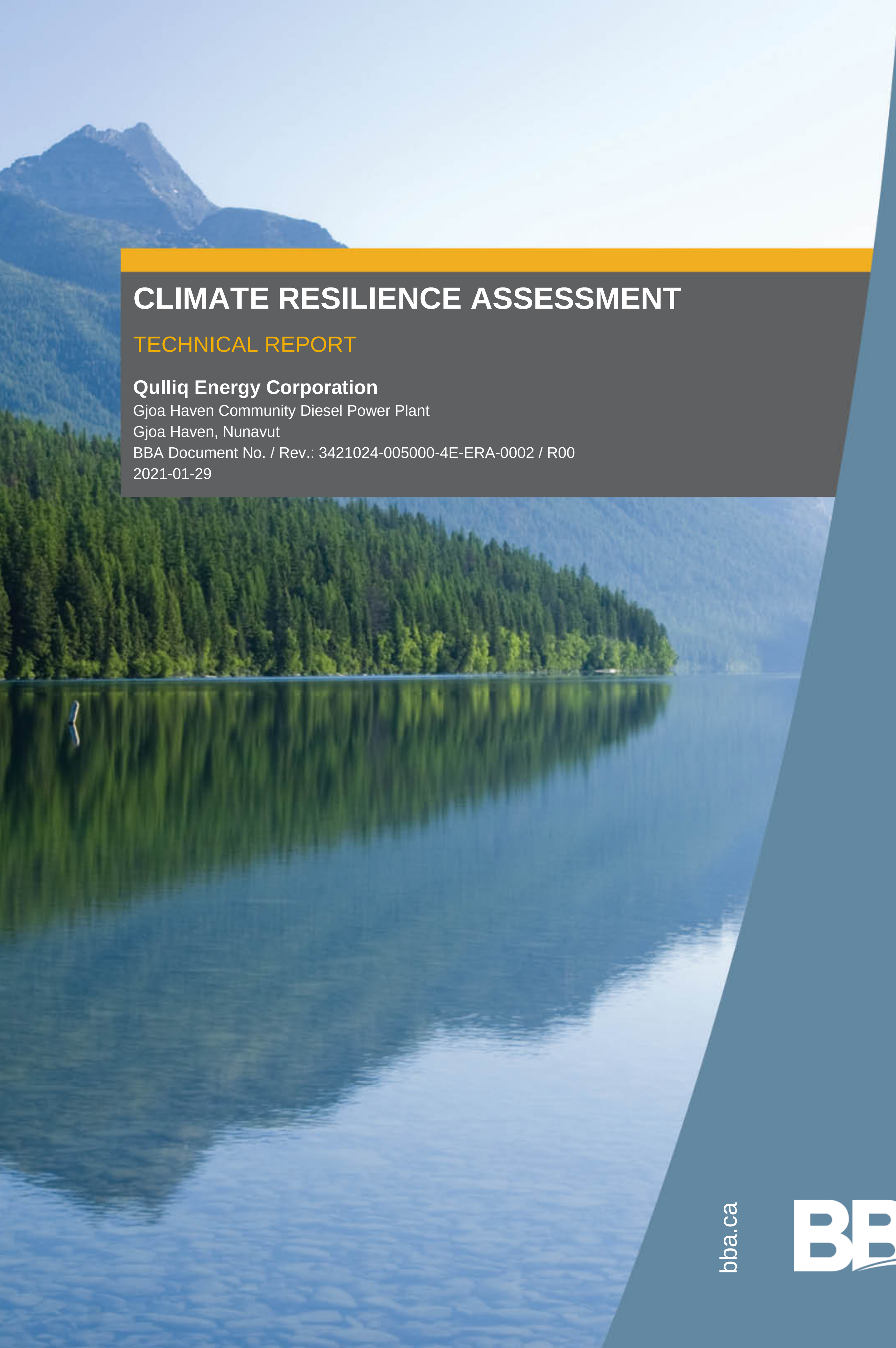

CLIMATE RESILIENCE ASSESSMENT

TECHNICAL REPORT

Qulliq Energy Corporation
Gjoa Haven Community Diesel Power Plant
Gjoa Haven, Nunavut
BBA Document No. / Rev.: 3421024-005000-4E-ERA-0002 / R00
2021-01-29

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Qulliq Energy Corporation
Gjoa Haven Community Diesel Power Plant
Gjoa Haven, Nunavut

Technical Report
Climate Resilience Assessment

BBA Document No. / Rev. 3421024-005000-4E-ERA-0002 / R00

January 29, 2021

FINAL

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EXECUTIVE SUMMARY

The existing diesel power plant in Gjoa Haven, built in 1977, has significantly exceeded its 40-year service life and requires replacement. The power plant is a critical infrastructure to the Gjoa Haven 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 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 is in line 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 for GHG mitigation has also been prepared for the new Gjoa Haven power plant project.

Abbreviations 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	An Integrated Regional Impact Study
NCPC	Northern Canada Power Corporation
NTPC	Northwest Territories Power Corporation
PIEVC	Public Infrastructure Engineering Vulnerability Committee
QEC	Qulliq Energy Corporation
NBCC	National Building Code of Canada

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
mmWE	Millimeter water equivalent

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APPENDICES

Appendix A: Attestation of completeness
Appendix B: Gjoa Haven Permafrost Vulnerability Map - 2015
Appendix C: BBA Team Members

1. INTRODUCTION

BBA Inc. (BBA) was mandated by Qulliq Energy Corporation (QEC) to conduct a climate resilience assessment and GHG mitigation study for their new Gjoa Haven Community Diesel Power Plant. Gjoa Haven, Nunavut, is a small community of approximately 1,484[1] inhabitants located above the arctic circle in the Kitikmeot region, in the southeast of the King William Island.

To replace an existing end-of-life power plant using diesel fuel, QEC must construct a new power plant for the Gjoa Haven community. This report presents the climate resilience assessment of the proposed project. To complete the task, 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.

The climate resilience assessment has been prepared following the *Climate Lens – General guidance, Version 1.1*[2] document published on June 1, 2018 and updated October 31, 2019 by Infrastructure Canada and aims at demonstrating how the proposed project will recover, respond, prevent or withstand a climate change disruption or impact. As a final objective, this assessment will demonstrate if the power plant's resilience to climate change and the associated risks are at an acceptable level and if not, propose adaptation strategies to reduce these risks. In addition, emphasis will be put on *Climate Change Resilience Principles* and how they are reflected in the assessment.

Figure 1: Gjoa Haven community, Nunavut

(Photo credit: Clevelander96)

[1] Nunavut Bureau of Statistics

[2] https://www.infrastructure.gc.ca/pub/other-autre/cl-occ-eng.html

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 is 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 C

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 southeast coast of King William Island, Gjoa Haven is a leg in the crossing of the Northwest Passage. Access to the community is limited to air and sea traffic travel only. The community fuel resupply is carried out annually in the summer/fall via fuel supply tanker. Some of the largest electricity loads in the community are demanded by the Gjoa Haven airport, the Nattilik Heritage Centre, schools (one elementary school and one high school), health center, municipal services, and co-op store.

QEC and its predecessors, the Northwest Territories Power Corporation (NTPC) and the Northern Canada Power Corporation (NCPC), have operated the diesel generating plant in Gjoa Haven since the original plant was constructed in 1977. 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 respect current codes and regulations. The new power plant construction is estimated to start in 2026.The main expected outcome is to supply Gjoa Haven 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.
- *True North – Adapting Infrastructure to Climate Change in Northern Canada* was prepared by the National Round Table on the Environment and the Economy. This document highlights the risks to northern infrastructure posed by climate change and the opportunities in adaptation and ensuring the infrastructure is resilient over its lifespan in the face of climate change.
- *Community energy Report – Assessing renewable energy opportunities to reduce costs, environmental impact and energy insecurity use of diesel power – 2018*, was prepared by World Wildlife Fund Canada (WWF Canada) and the Alaska Center for Energy and Power (ACEP). This document is an energy assessment analyzing the possibility to introduce solar and wind energy in the Gjoa Haven community.

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, Gjoa Haven has a meteorological station that has been operated by Environment Canada since 1984, located at the Gjoa Haven 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 encompassing the new power plant life span) for the community of Gjoa Haven. 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 (of uncertainty), 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

The arctic temperatures are heavily dependent on the sea ice and snow cover, which in turn is greatly affected by arctic temperatures. As the atmosphere gets warmer, 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. Inuit observations indicate that snow melts earlier and quicker and the ice is thinner (IRIS-1).

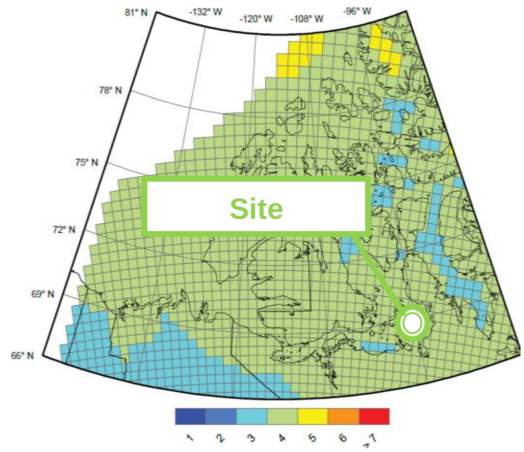

Figure 2: Projected change in annual air temperature from 1971-2000 to 2041-2070
(Gjoa Haven as a green marker). Adapted from IRIS-1 report.

For the western and central Canadian arctic region, including the Gjoa Haven 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 for from 1971-2000 to 2041-2070 as presented in Figure 2. But, a larger ensemble of simulations would give a broader interval.

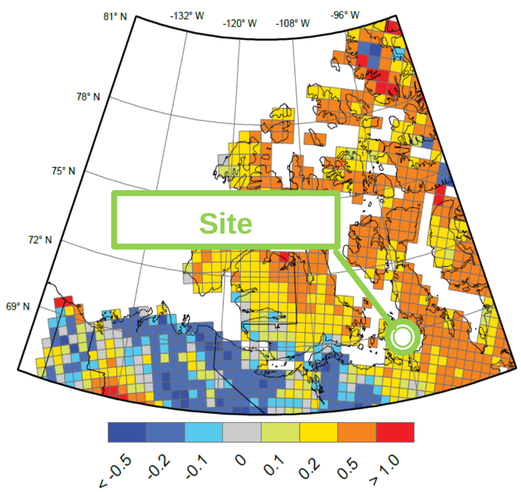

Figure 3: Projected change in the mean annual number of thawing events from 1971-2000 to 2041-2070
(Gjoa Haven as a green marker). Adapted from IRIS-1 report.

In the Gjoa Haven area, February is the coldest month with an average condition of -34.0°C and July is the warmest month with an average condition of 8.0°C (Environment Canada, 2020). Documented observations made by Inuit demonstrate warmer summers or more extreme warm temperatures (IRIS-1). 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).

[3] January, February and March

[44] July, August and September

Projected change in annual frequency of freeze/thaw events is presented in Figure 3. For Gjoa Haven, considering Figure 3 and the inter-simulation standard deviation, the change could be within +0.2 to +1.0 events per year (IRIS-1). 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 -5ºC (IRIS-1). Freeze/thaw events have a big impact on infrastructure in Gjoa Haven. Local observations indicate that freeze/thaw events coupled with rain events contributed to a dike failure in 2005. Other observations point that freeze/thaw events contributed to ground slumping at the airport, requiring emergency repairs during winter (Canada, 2009).

5.2 Permafrost and ground temperature

Permafrost is defined as the ground (rock or soil) for which temperature 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 infrastructure.

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 Gjoa Haven), increasing air temperature has a high probability of increasing permafrost melting and possibly increasing the depth of the active layer. In the discontinuous zone, 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. However, in response to the current global warming, permafrost soil temperatures in the western Arctic have increased about 2°C since the 1970’s (IRIS-1).

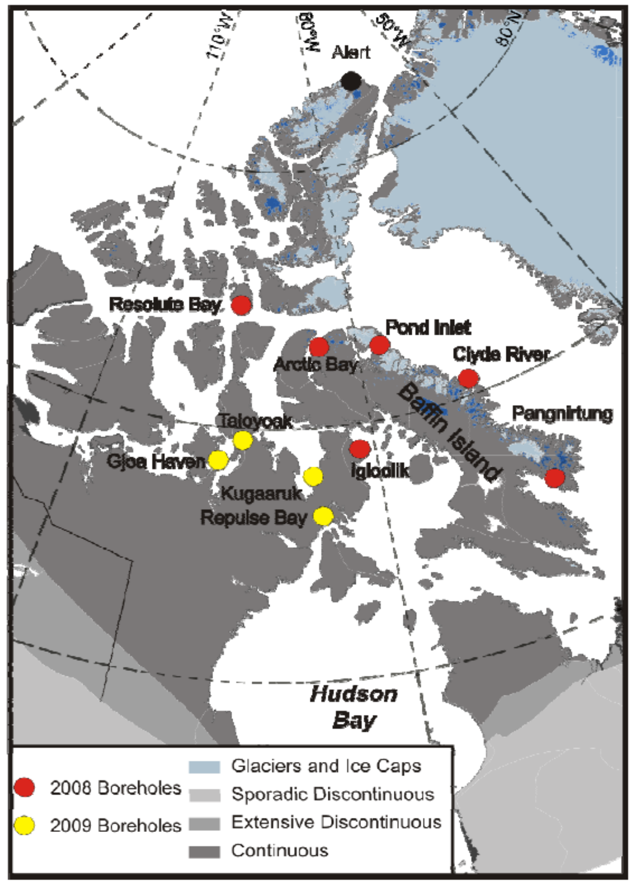

Figure 4: Map indicating areas with widespread ice-rich permafrost and communities in the Baffin area where permafrost monitoring is taking place
(Ednie & Smith, 2010)

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 Gjoa Haven).

The Permafrost vulnerability map of Gjoa Haven in 2015 is presented in Appendix B. This document shows where new installations are suitable or not in Gjoa Haven hamlet and its surrounding areas. Observations indicate that Gjoa Haven hamlet is situated in an area with very little topography and bedrock outcrops. Large parts of the area around Gjoa Haven are classified as possible or suitable for the installation of new infrastructure.

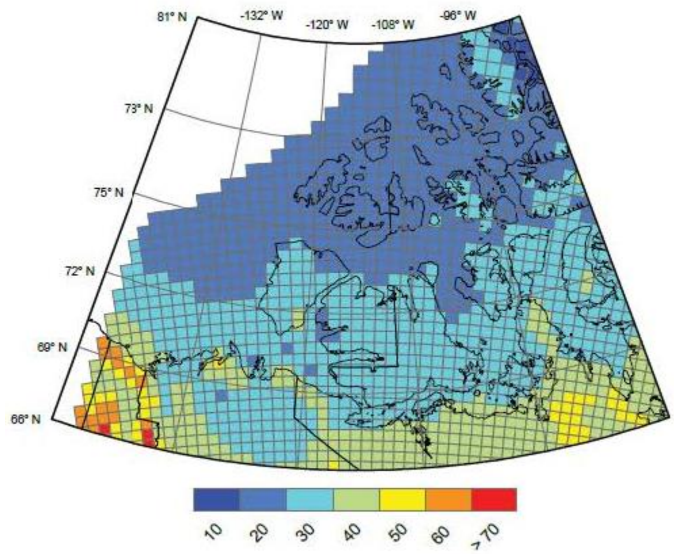

Figure 5 : Projected change in total annual precipitation rate (mm) from eight CRCM runs for 2050
Adapted from IRIS-1 report.

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 (2025 to 2070). However, a partial decrease in depth of permafrost over the region is reasonably expected (IRIS-1).

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. Gjoa haven 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.

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 285 days per year (IRIS-1).

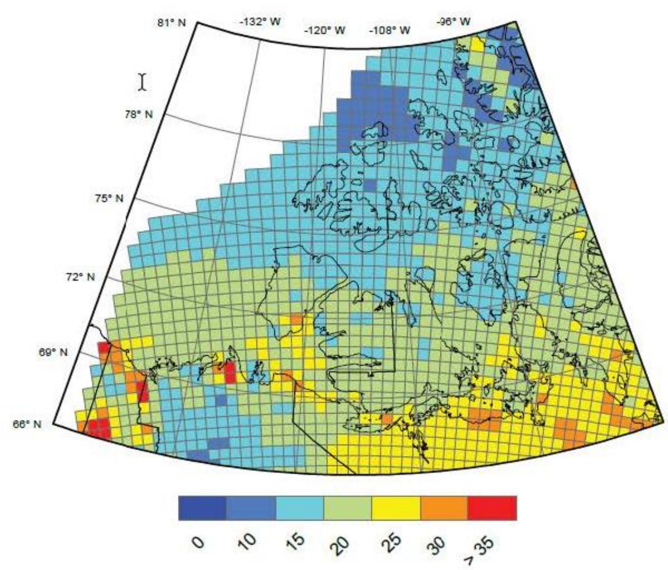

Figure 6: Projected change in total solid precipitation (%) from eight CRCM runs for 2050
Adapted from IRIS-1 report.

Gjoa Haven experiences, on average, a total of 191 mmWE of total precipitation, split in 78.4 mm of rainfall and 130.4 cm of snow fall. Rainfalls occur mainly from June to October and snowfall between the months of September to June, with occasional snowfall 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), total precipitation is projected to increase 20-40 mm and snowfall is projected to increase 15- 25%. Documented Inuit observations indicate that snowfall arrives later than it used to. Rainfall is projected to increase in the region during the spring and autumn season (IRIS-1). Furthermore, no additional data is available describing the rain-on-snow frequency. However, rain-on-snow events are rare for the Arctic, which means small projected change in absolute terms (IRIS-2).

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 the 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 interaction between sea ice, air temperature and water evaporation.

Observations by local inhabitants present a surge of extreme storms and shifts in the wind 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 (Stern & Gaden, 2015). Gjoa Haven's average wind speed is 25.2 km/h and the distribution of wind speed during the 2012-2017 interval never surpassed 20 m/s. The wind direction is predominantly out of the northwest (WWF., 2018). Projected changes during the period 2081-2100 are expected to be of the order of 50% for the summer season compared to current levels, based on simulations realized by Environment Canada (Figure 7). This data is out of this study's timescale but is the only wind gust projection available for Gjoa Haven.

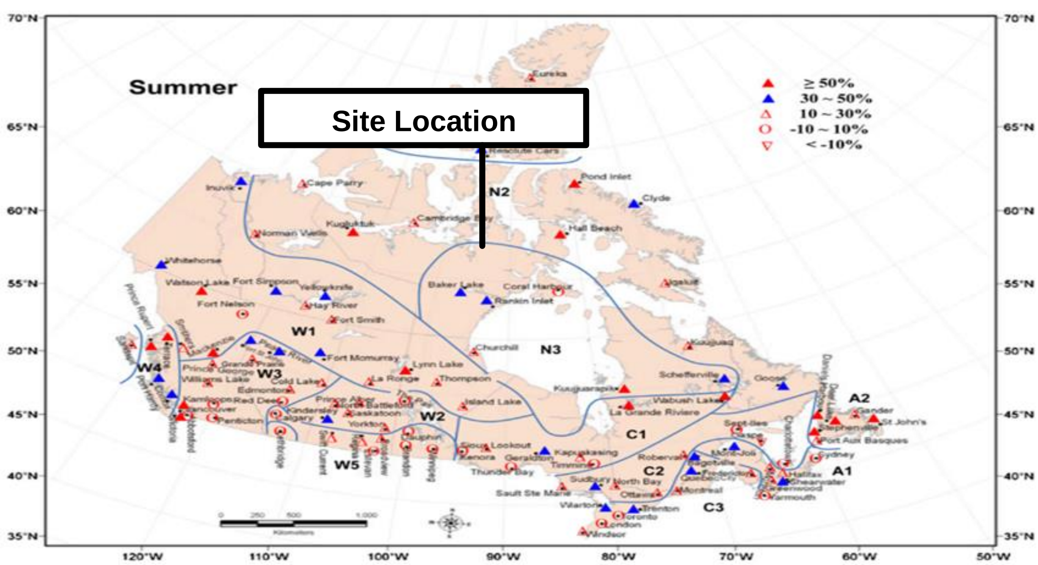

Figure 7: Projected percentage changes in summer mean-frequency of future daily wind gust events ≥ 70 km/h during the period 2081-2100
(Cheng, Lopes, Fu, & Huang, 2014)

5.5 Coastal erosion

The potential for coastal erosion in the arctic is a combination of several factors which can include (AMAP, 2017):

- Reduction in sea ice, enabling higher waves and storm surges to reach the shore;
- Rise in sea level;
- Thawing permafrost, increasing shore instability; and
- Increase in frequency and severity of storm events.

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. From 1996 to 2005, the mean wave height with sea ice for the Gjoa Haven community was below 25 cm, which is low. The projected change through the 21st century of the mean wave height with sea ice for Gjoa Haven is not forecasted to increase. Natural Resources Canada recently mapped Canada's current and future coast characteristics and sensitivity and categorized them with an index (G.K.Manson, 2019). Gjoa Haven shores are currently identified with a "high" sensitivity rating on a scale of «very low» to «very high». Moreover, this sensitivity rating is not projected to change up to the 2090's, so the coastal erosion rate should not increase in the future. However, some literature presents observations indicating that Gjoa Haven has an emergent shoreline with very little to no coastal erosion (Brown, 2007).

5.6 Sea level rise

The relative sea level change in Canada is a combination of changes in the volume of water in the oceans (global sea-level change) and vertical motion of the land. An ensemble of global sea-level change published for RCP8.5 (Church, 2013) has been combined with a refined model of vertical land motion generated by the Canadian Geodetic Survey in order to produce forecast differences in sea level through most of the 21st century (G.K.Manson, 2019)

The cumulative effects have been estimated incorporating uncertainty in the estimate of land uplift. The projected change is forecasted to vary between -19 cm to +20 cm (G.K.Manson, 2019).

5.7 Wildfires

The community of Gjoa Haven is situated in an area with very little topography and bedrock outcrops. Most areas are covered with small vegetation, i.e. tundra. 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 increase 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 (Stern & Gaden, 2015).

5.8 Landslides

Loss of cohesion in the Artic often occurs due to permafrost thaw leading to active layer detachment. Climate changes promoting this includes increased rainfall, and more rapid snowmelt saturating the ground and increased air temperature. Gjoa Haven, however, is unexposed to the risk of landslides due to its flat topography. There are no documented observations of landslides in the hamlet.

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 Gjoa Haven. Increase in snow melting and rainfall add to the saturation of sediments might cause flooding.

5.10 Summary

This section presents a summary of the current and projected climate conditions for the community of Gjoa Haven. The information contained in this assessment report and that 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 Gjoa Haven community.

Climate variable	Gjoa Haven average condition[5]	Projected change to power plant lifespan	Comments
Mean annual air temperature	-14.4 °C	+3 °C to +5 °C	Changes are in general expected to be largest over land and lowest over ocean areas.
Mean temperature of coldest month	-34.0 °C	+4 °C to +6 °C	February is the coldest month.
Mean temperature of warmest month	8.0 °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	-	+250 degree-days	
Frequency of winter thaw events	-	-0.2 to +1.0 per year	
Duration of winter snow cover	285 days	-	IRIS-1 Projections suggest an earlier spring snow cover melt and a later autumn snow cover onset.
Maximal snow depth	42.8 cm	+2 cm to +4 cm	
Total annual precipitation	191 mm	+ 20 to + 40 mm	Largest increase in the Winter and Fall seasons
Total annual rainfall	78.4 mm	-	No specific data available.
Total annual snowfall	130.4 cm	+15 % to +25 %	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	25.2 km/h	Changing predominant wind direction, blizzard frequency increase, reduced wind predictability, increase of 50% in summer frequency of wind gust events > 70 km/h	Limited amount of evidence available regarding projections of future storm regimes.
Relative sea level rise	-	-19 cm to + 20 cm	Limited relative sea-level rise is a probable expectation
Coastal erosion	-	-	Limited coastal erosion is a probable expectation

[5] Gjoa Haven average data over 30 annual values of 1981-2010

Climate variable	Gjoa Haven average condition[5]	Projected change to power plant lifespan	Comments
Wildfires	-	-	Increase in tundra biomass due to climate change could increase rate of wildfire
Landslides	Uncommon due to flat topography.	-	Low risk of having landslides for Gjoa Haven
Flooding	Culverts and roadbed can manage low to moderate flows. Flooding under moderate conditions	Increase in frequency and intensity of peak flows	Anticipated increase in snow melt and precipitation related water flow rate. Flooding under moderate conditions.

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 if the proposed mitigation/comments are integrated in the project design. The consequence rating evaluates the severity of the results 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				
		Very low	Low	Moderate	High	Very high
Severity of consequence	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[6]	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 of 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 of 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. 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 precipitation 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.

[6] Refer to Table 1 for more specific details on climate changes expected for the Gjoa Haven community.

Climate change hazard[6]	Impact on asset	Consequence score	Consequence likelihood	Overall risk evaluation	Mitigation / Comments
Rain on snow					
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 incorporated in building codes.
Relative sea level rise	Sea level reaching power plant causing excessive flooding and possibly evacuation	High	Very low	Negligible risk	Power plant will be located sufficiently far away from the shore.
Coastal erosion rate increase	Coast eroding up to power plant causing permanent damage to structure and possibly evacuation	High	Low	Low risk	Power plant will be located sufficiently far away from Gjoa Haven shoreline. 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.

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. This project's approach will become a flagship methodology for other communities of Northern Canada by keeping a flexible view on energy sources. Gjoa Haven's new power plant will be reliable and comply with the latest applicable environmental codes and regulations.

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

7.2 The power plant within the community

Climate change is not a new phenomenon in Nunavut, even over the timescale of human memory, and projections of changing climatic conditions are not without historical precedent. Work towards identifying climate vulnerability was started as soon as 2010 in the Gjoa Haven community in partnership with Environment Canada. The research, named the ArcticNet project, involved close collaboration with community members and aimed at identifying conditions to which each community is currently vulnerable (ArcticNet, 2012). In Gjoa Haven, there is a strong sense of collective community responsibility and an ability to cope with increasing exposure to climate change (Canada, 2009). This adaptive capacity is facilitated by Inuit traditional knowledge and land-based skills, strong social networks, resource use flexibility but, most importantly, institutional support like Government of Nunavut (Department of Environment - Government of Nunavut, 2010)

The built environment is a key determinant of both community well-being and future sustainable growth. New infrastructure investment has the opportunity to incorporate consideration of a changing climate. The proposed project, as presented, will have the ability to cope with upcoming climate change which will further strengthen the Gjoa Haven community's resilience development.

8. CONCLUSION

A climate change resilience assessment was conducted for a new power plant project by QEC in the community of Gjoa Haven, Nunavut. The proposed project is planned to be started in 2026 and designed for a service life of 40 years. All applicable project climate change hazards were identified and their impacts on the asset were assessed, as per ICIP's Climate Lens General Guidance including an increase in mean annual air temperature, increase in thawing degree days, increase in snow depth, snow fall and precipitation, increase of rain on snow frequency, increase of storm intensity and frequency, and coastal erosion. 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.

9. REFERENCES

AMAP. (2017). *Adaptation Actions for a Changing Arctic perspectives from the Baffin Bay / Davis Straight Region.* Oslo: Arctic Monitoring an Assessment Programme.

ArcticNet. (2012). ArcticNet - 2012 Annual Scientific Meeting. Vancouver, BC.

Brown, T. (2007). *Benthic biology of two near-shore arctic locations, and potential impacts of sea level change, coastal erosion, and climate change.* St John's, Newfoundland and Labrador, Canada: Memorial University of Newfoundland.

Canada. (2009). *True North - Adapting Infrastructure to climate change in northern canada.* Ottawa, ON: National Round Table on the Environment and the Economy.

Cheng, C., Lopes, E., Fu, C., & Huang, Z. (2014). Possible impacts of climate change on wind gusts under downscaled - future climate conditions: Updated for Canada. *Journal of Climate*, 1255-1270.

Church, J. P. (2013). *Sea Level Change Supplementary Material. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.*

Department of Environment - Government of Nunavut. (2010). *Upagiaqtavut Setting the Course - Climate Change Impacts and Adaptation in Nunavut.* Government of Nunavut.

Ednie, M., & Smith, S. L. (2010). Establishment of Community-Based Permafrost Monitoring Sites, Baffin Region, Nunavut. *Geological Survey of Canada*. Ottawa, Ontario, Canada: Natural Resources Canada.

Ford, j. D., Smit, B., Wandel, J., Allurut, M., Shappa, K., Ittusarjuat, H., & Qrunnuts, K. (2008). Climate change in the Arctic current and future vulnerability in two Inuit communities in Canada. *The Geographical Journal*, 45-62.

Ford, J., Pearce, T., Smit, B., Wandel, J., Allurut, M., Shappa, K., . . . Qrunnut, K. (2007). Reducing vulnerability to climate change in the Arctic the cas on Nunavut, Canada. *Arctic*, 150-166.

G.K.Manson, N. C. (2019). *CanCoast 2.0: Data and indices to describe the sensitivity of Canada's marine coasts to changing climate.*

Harris, S. (1986). permafrost distribution, zonation ans stability along the eastern ranges of the Cordillera of North America. *Arctic*, 29-38.

Instanes, A. (2006). Impacts of a changing climate on infrastructure buildings, support systems, and industrial facilities. *2006 IEEE EIC Climate Change Conference*, 1-4.

Stern, G., & Gaden, A. (2015). *From Science to Policy in the Western and Central Canadian Arctic: An Integrated Regional Impact Study (IRIS) of Climate Change and Modernization.* Quebec City: ArcticNet.

WWF., A. C. (2018). *Community energy report - Assessing renewable energy opportunities to reduce costs, environmental impact and energy insecurity use of dieselpower.*

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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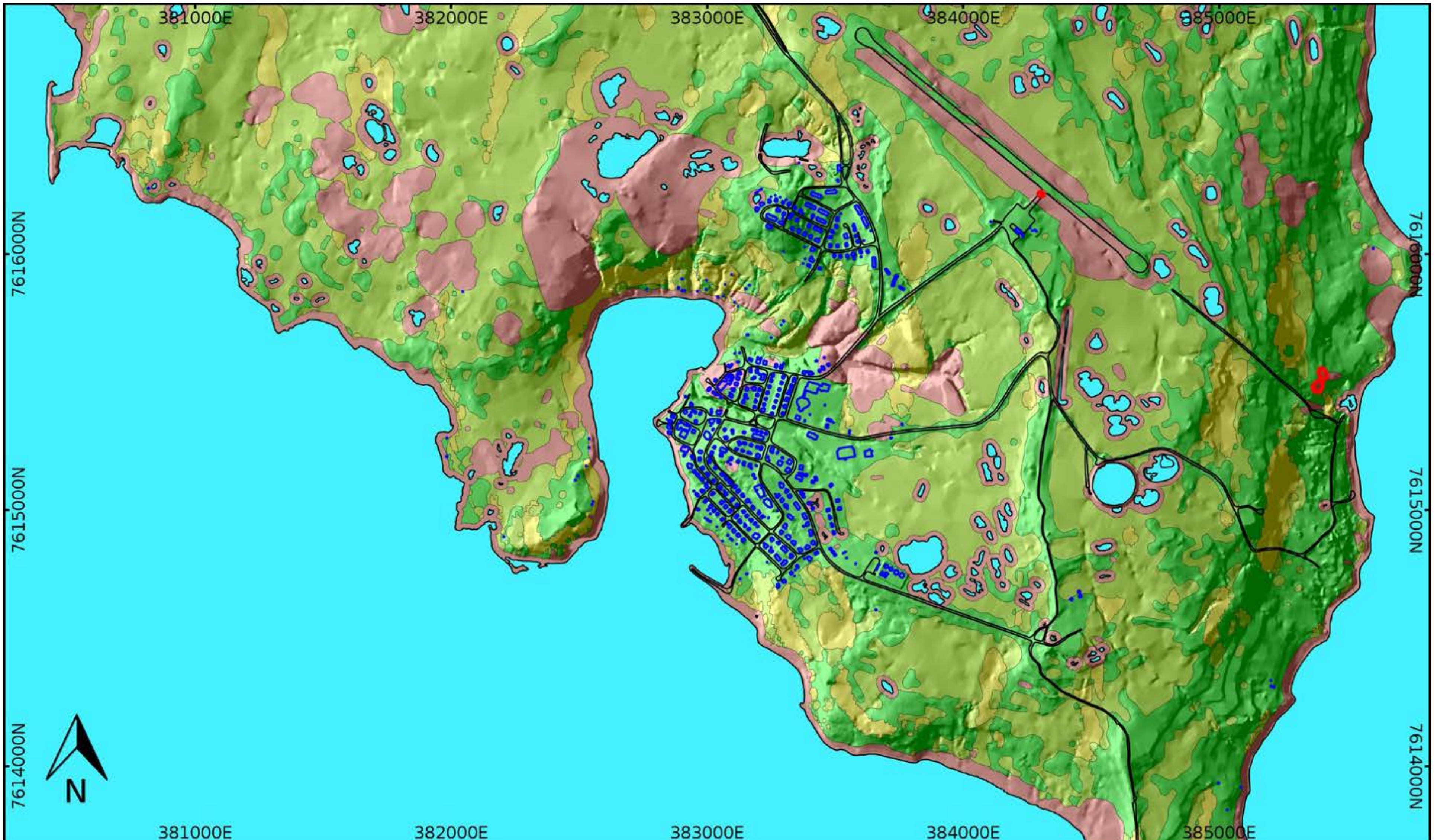
Date

Appendix B: Gjoa Haven Permafrost Vulnerability Map - 2015



Gjoa Haven

Permafrost Vulnerability Map
2015

Map Units: Meters
Projection: NAD83 UTM 15N

3vGEOMATICS

Appendix C: 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 Quebec/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.

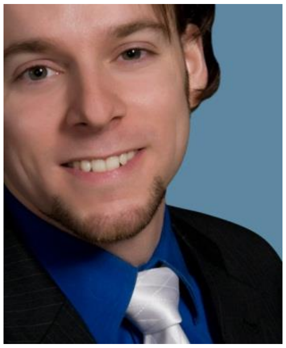
Project Leader

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