# CLIMATE RESILIENCE ASSESSMENT

## TECHNICAL REPORT

**Qulliq Energy Corporation**
Igloolik Community Diesel Power Plant
Igloolik, Nunavut
BBA Document No. / Rev.: 3421024-004000-4E-ERA-0002 / R00
2021-01-29

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## Qulliq Energy Corporation

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**BBA Document No. / Rev.** 3421024-004000-4E-ERA-0002 / R00

January 29, 2021

## FINAL


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## REVISION HISTORY

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| | | |

## EXECUTIVE SUMMARY

The existing diesel power plant in Igloolik, built in 1974, has significantly exceeded its 40-year service life and requires replacement. The power plant is a critical infrastructure to the Igloolik 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 Igloolik 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 |
| 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 | Centimeter |
| mm | Millimeter |
| % | Percentage |
| mmWE | Millimeter water equivalent |

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# 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 Igloolik Community Diesel Power Plant. Igloolik, Nunavut, is a small community located North of the Hudson Bay in the Qikiqtaaluk region.

To replace an existing end-of-life power plant using diesel fuel, QEC must construct a new power plant for the Igloolik 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*[1] 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 to 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: Igloolik Community, Nunavut**
*(Photo credit: Robynn Pavia / Travel Nunavut)*

[1] 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 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

Igloolik is an Inuit hamlet on a small island in Foxe Basin in the Qikiqtaaluk Region, just off of the Melville Peninsula. It is located north of the Arctic Circle between the Canadian mainland and Baffin Island. 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. Municipal services such as domestic water and sewage are conducted locally using designated trucks. Some of the largest electricity loads in the community are demanded by the Igloolik Research Center, hamlet office, community centre, school, health centre, and various 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 Igloolik since the plant was constructed in 1974. The plant's capacity is inadequate to meet the community's current power requirements and due to the lack of space, an increase in the plant capacity is not possible. A new power plant is required. 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 is estimated to be commissioned by 2026.The main expected outcome is to supply Igloolik with a more stable and reliable source of electricity for the years to come.

It is expected that construction will be completed in about two years time 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 technical reports among 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:

- The document *From Science to Policy in the Eastern Canadian Arctic: An Integrated Regional Impact Study (IRIS) of Climate Change and Modernization* was realized by the Western and Central Canadian IRIS, funded by ArcticNet and the Government of Canada. This document (hereinafter referred to as the IRIS-2 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.
- The document *Adaptation Actions for a Changing Arctic: Baffin Bay / Davis Straight Region* (hereinafter referred to as the AMAP report) from the Arctic Monitoring and Assessment Program, which is aimed at defining and estimating the current and projected climate changes as well as propose possible resilient measures in response to these rapid changes.
- The paper *Climate change in the Arctic: current and future vulnerability in two Inuit communities in Canada*, which presents present and future Igloolik vulnerabilities to climate change.

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. Igloolik does not have a meteorological station. However, the Hall Beach community, only a few kilometres South from Igloolik, had a meteorological station from 1959 to 2011, which can be used to establish historical trends and projections (IRIS-2, 2018).

The following sections present different aspects of projected climatic changes from 1971-2000 to 2041-2070 (future time period corresponding to the new power plant) for the community of Igloolik. It is important to note that recent/past climate data may be different depending on the source because the referred time basis is not consistent (sometimes 1971-2000 and other times 1971-2000). For clarity, a single number is presented for recent/past values in Table 1 (introduced in Section 5.1) despite the variance in literature.

However, 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 2041-2070 time horizon, climate projection uncertainty originates from uncertainty in future human 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.

Climate change values presented in this resilience assessment report were obtained from the IRIS-2 report and represent an ensemble of only 8 regional simulations. Hence, change intervals presented here represent a very probable interval, but smaller or larger changes are possible.

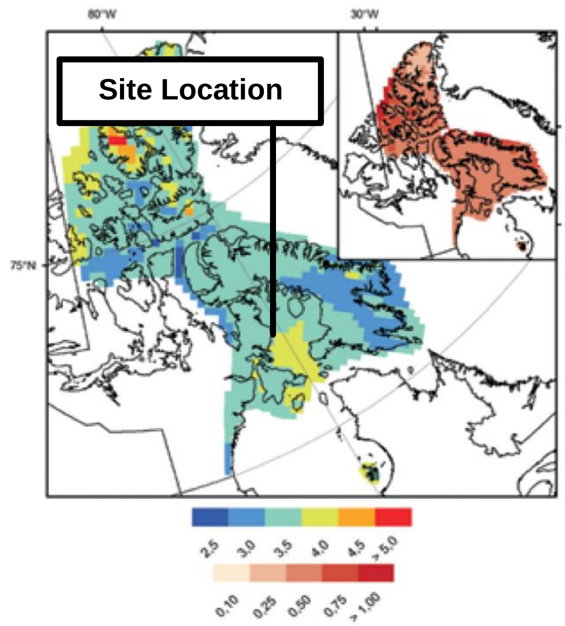



**Figure 2: Average of an ensemble of 8 regional simulations of change in annual air temperature from 1971-2000 to 2041-2070**
*Adapted from IRIS-2 report.*

## 5.1 Air temperature

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 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.

The Eastern Canadian Arctic is currently experiencing some of the most rapid climate warming in the Arctic, particularly during winter season. There is evidence of «hot spots» especially in the Foxe Basin. Recent fall and winter season warming exceeds the . Data s+1.7 ° C/decade (IRIS-2, 2018).

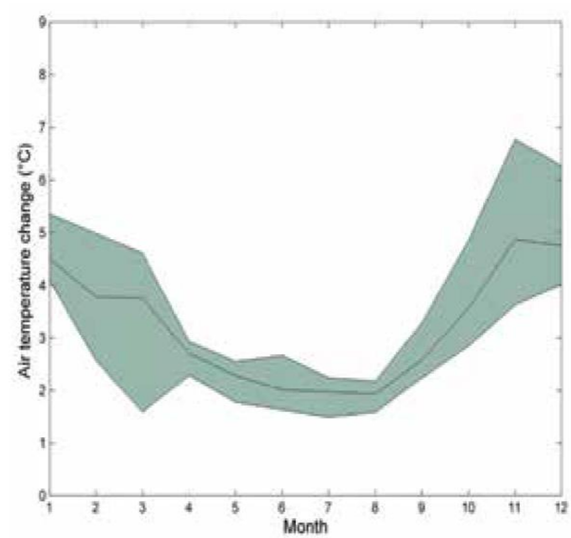



**Figure 3: Seasonal median and range of projected changes in monthly mean air temperature, from an ensemble of 8 regional simulations, from 1971-2000 to 2041-2070**
*Adapted from IRIS-2 report*.

The annual mean surface air temperature (SAT) in Hall Beach, a community just under 60 kilometres south of Igloolik, is -13.2 °C. The monthly mean of daily minimum and maximum SAT are -33.7 and 7.0 °C (IRIS-2). Projected temperature changes based on CRCM simulations suggest a plausible increase within +3.5 to +4.5 °C in annual mean SAT for the period 2041-2070 (relative to 1971-2000), but a larger ensemble of simulations would give a broader interval (IRIS-2). Seasonal trends show a +3 to +7 °C projected change in the winter and +1.5 to +3 °C in the summer (IRIS-2). The spatial distribution of mean annual SAT projected increase is presented in Figure 2 and seasonal median and range of projected changes are presented in Figure 3.

For Igloolik, considering inter-simulation standard deviation (IRIS-2, 2018), the change in thaw events could be within -0.6 to +1.9 events per year. A freeze/thaw event is defined as a day for which daily maximal air temperature is above the freezing point whereas the 29-day (centred on the considered day) daily mean temperature average is below -5°C.

## 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 air temperature, snow cover and duration 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 scale over time, especially in regions of continuous permafrost (which includes Igloolik). Efforts are underway to characterize permafrost degradation in the Canadian Arctic through collaboration between the Geological Survey of Canada, the Nunavut Departments of Environment and Community and Government Services, as well as 6 communities in the Baffin area. One of these communities is Igloolik where boreholes were drilled in 2008.

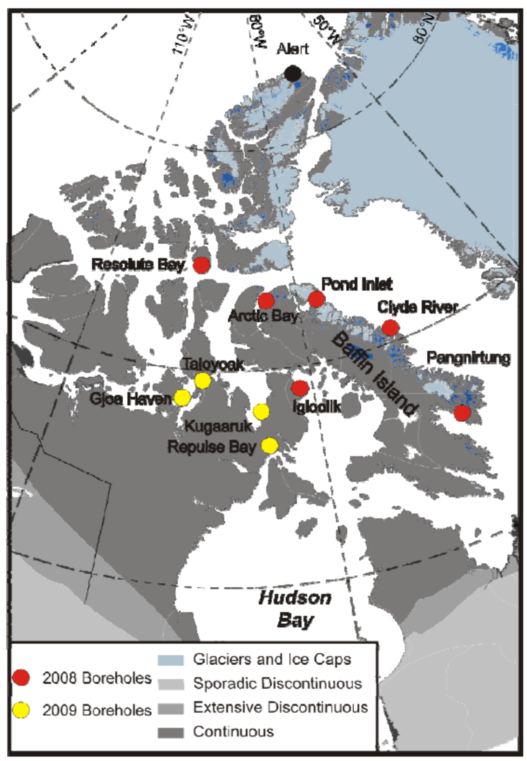



**Figure 4: Map indicating areas with widespread ice-rich permafrost and communities in the Baffin area where permafrost monitoring is taking place**
***(Ednie & Smith, 2010)***

The location of the borehole in Igloolik is unique due to its position relative to the community. The borehole is in the center of the hamlet in a fenced off grassy section. This study has established that the average ground temperature is -8.5 ° C and that the depth to zero annual amplitude is 18.2 m (Ednie & Smith, 2010).

Climate projections 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 (IRIS-2, 2018). The continuous permafrost, as presented in Figure 4, is not projected to completely disappear in the timescale of interest (2060). However, a partial decrease in depth of permafrost, and by extension an increase in active layer thickness, over the region is reasonably expected (AMAP).

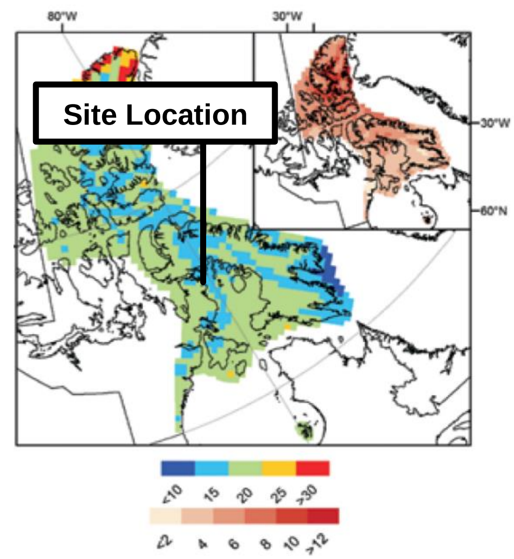



**Figure 5: Average of an ensemble of 8 regional simulations of change in mean annual total precipitation from 1971-2000 to 2041-2070**
*Adapted from IRIS-2 report.*

## 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. Igloolik happens to be a community right next to a large body of water. However, characterizing the amount of precipitation in the Igloolik is particularly challenging because it happens in frequent trace events and there are high winds. Most of the snow is received during the month of October and is then redistributed with the wind. The accumulation of snow is closely related to wind distribution. Snow covers the ground for the majority of the year, which corresponds to approximately 250 days (IRIS-2, 2018).

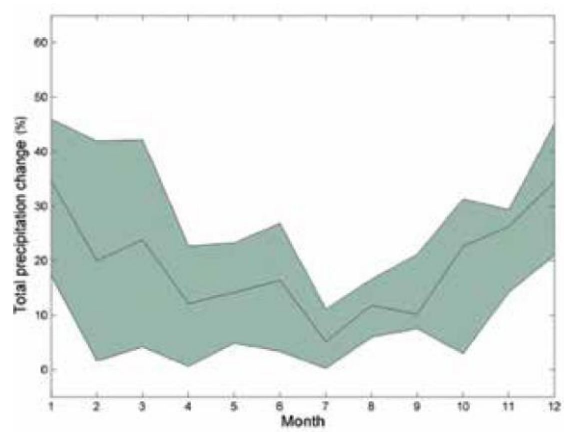



**Figure 6: Average of an ensemble of 8 regional simulations of change in mean annual total precipitation from 1971-2000 to 2041-2070**
*Adapted from IRIS-2 report.*

Projections used in the IRIS-2 report indicate that for the period up to 2070 there is an expected 13 to 35 mmWE change in annual snowfall, linked with a change of -3.1 to +7.5 cm in annual maximal snow depth (other processes influence the snow cover, not only snowfall). However, the snow cover season is expected to decrease between 11 to 38 days for Igloolik. Based on an ensemble of 8 CCRM simulations with a 2050 horizon, total annual precipitation is expected to increase 11% to 26% from its 111.4 mm annual total average total. Frequency of rain events in the winter is expected to increase (Ford, et al., 2008). 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. 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 can receive (IRIS-2, 2018). However, the impact of this finding on the Igloolik community on a timescale up to 2050 is still to be determined. Local observations indicate that wind patterns have been changing in direction and frequency, becoming more unpredictable and higher in strength (Ford J. D., Pearce, Smit, & Oakes, 2008) (Ford, et al., 2008). The changing predominant wind direction has affected the shape of snowdrifts and snow accumulation locations. An indication of extreme weather events is the frequency of daily wind gust events ≥70 km/h. 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). Other seasons however, are not expected to change with respect to frequency of daily wind gusts over

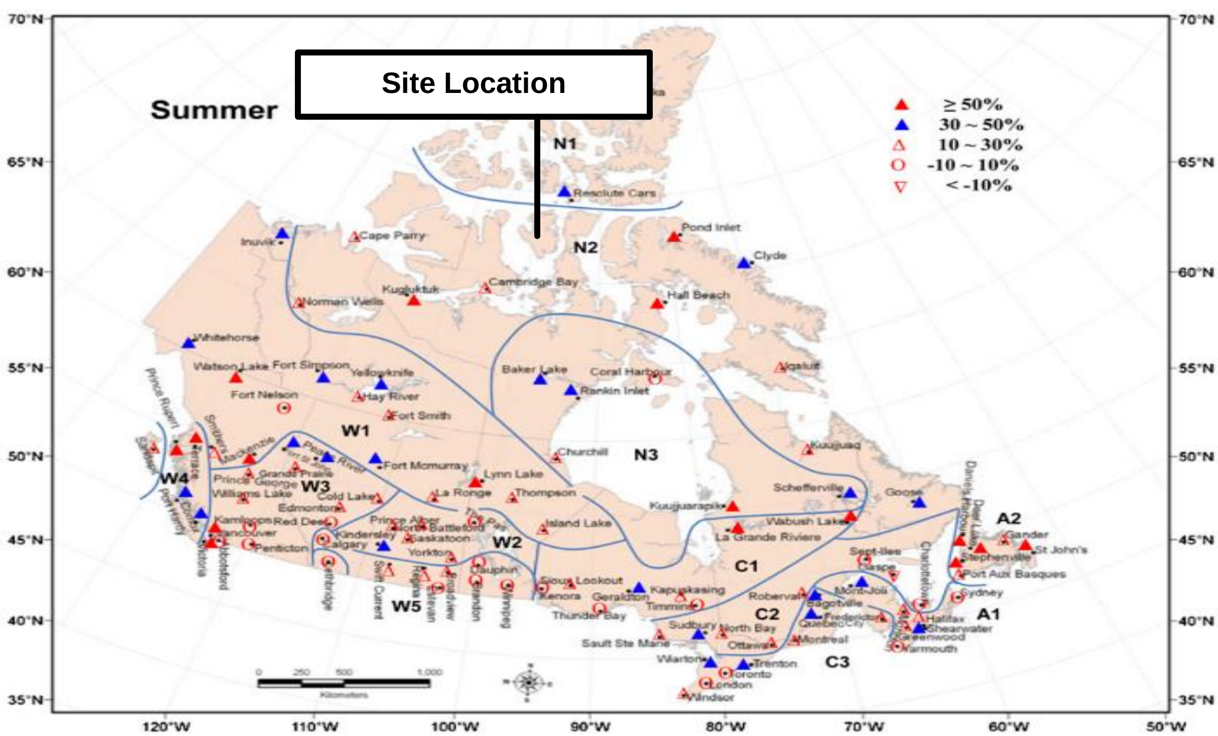



**Figure 7: Projected percentage changes in summer mean-frequency of future daily wind gust events ≥ 70 km/h during the period 2081-2100**
*(Cheng, Lopes, Fu, & Huang, 2014)*

70 km/h. The frequency of blizzards is also expected to increase (Ford, et al., 2008). This data is out of this study's timescale but is the only wind gust projection available for Igloolik.

## 5.5 Coastal erosion

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

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

Natural Resources Canada recently mapped Canada's current and future coast characteristics and sensitivity and categorized them with an index (Manson, Couture, & James, 2019). Shores near Igloolik in the Foxe Basin are currently identified with a «moderate» sensitivity rating on a scale of «very low» to «very high». Moreover, this sensitivity rating is not projected to change up to the year 2090. Hall Beach, a community only 60 km South of Igloolik, is known to have shore erosion issues but they are reasonably manageable (IRIS-2, 2018). Similar conclusions can be made for Igloolik.

## 5.6 Sea level rise

The melting of the glaciers will remove weight from the ground and causes Earth's surface to respond with a glacial isostatic readjustment of its surface, which will cause uplift across some parts of the Canadian Arctic, including Igloolik community. The glacial isostatic readjustment at Igloolik is expected to rise and this uplift is expected to exceed the rate of regional sea-level rise, thus the relative sea level will fall in the Igloolik region. The relative sea-level change projected for Igloolik is represented by Figure 8 for various global warming scenarios. For year 2070, the projected change in relative sea-level, under scenario RCP 8.5 is expected to be -79.7 to -33.2 cm (95% confidence interval) (James, et al., 2015).

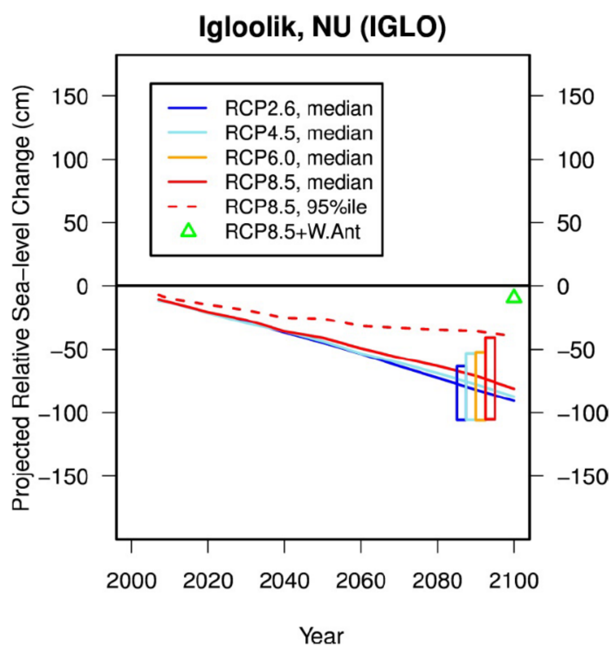



**Figure 8: Projected relative sea-level change for RCP2.5, RCP4.6, and RCP8.5**
*(James, et al., 2015)*

## 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 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 (AMAP).

## 5.8 Landslides

Loss of cohesion in the Arctic 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. Igloolik, 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. However, local conditions may vary from global circulation models. Local observations point towards increased cyclonic activity near the community, open water conditions and precipitation further contributing to projections of increased surface water flow.

## 5.10 Summary

This section presents a summary of the current and projected climate conditions for the community of Igloolik. The information that was previously discussed and that which is presented in Table 1 are based on the most recent available technical papers available and which resume the work of experts in the field. 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 (over 30 annual values of 1981-2010) and projected (from the average for 1971-2000 to the average for 2041-2070) climatic conditions for Igloolik community.[2]**

| Climate variable | Igloolik average condition | Projected change | Comments |
|---|---|---|---|
| Mean annual air temperature | -13.2 ºC | +3.5 to +4.5 ºC | Changes are in general expected to be largest over land and lowest over ocean areas. |
| Mean temperature of coldest month | -33.7 ºC | +3 to +7 ºC | February is the coldest month |
| Mean temperature of warmest month | 7.0 ºC | +1.5 to +3 ºC | 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 | 464.4 | 0 to +350 degree-days | Over IRIS-2 region |
| Frequency of winter thaw events | - | -0.6 to +1.9 per year | Over IRIS-2 region |
| Duration of winter snow cover | Approx. 252 days | -38 to -11 days | IRIS Projections suggest an earlier spring snow cover melt and a later autumn snow cover onset over IRIS-2 region |
| Maximal snow depth | 40.1 cm | -3.1 to +7.5 cm | Over IRIS-2 region |
| Total annual precipitation | 111.4 mm | +0 to 20% (Summer)<br>+5 to 45% (Winter) | Largest increase in the Winter and Fall seasons |
| Total annual snowfall | 211.9 mmWE[3] | +13 to +35 mmWE | Over IRIS-2 region |
| Rain on snow frequency | - | -2.3 to +0.8 days per year | Rain-on-snow events are rare for the Arctic, which means small projected change in absolute terms. |

[2] Projected values are represented by an interval to reflect part of the associated uncertainty. For example, values taken in the IRIS-2 report have intervals of uncertainty corresponding to results from an ensemble of 8 regional simulations (estimated from maps of Appendix A of the IRIS-2 report).

[3] Millimetre water equivalent.

| Climate variable | Igloolik average condition | Projected change | Comments |
|---|---|---|---|
| Winds and storms | - | Changing predominant wind direction, reduced wind predictability, increase of 50% in summer frequency of wind gust events > 70 km/h, blizzard frequency increase | Limited amount of evidence available regarding projections of future storm regimes. |
| Relative sea level rise | - | -79.7 to -33.2 cm | The glacial isostatic readjustment at Igloolik is expected to rise and this uplift is expected to exceed the rate of regional sea-level rise. |
| Coastal erosion | Moderate sensitivity | No change | Coastal erosion is an issue for infrastructure in close vicinity to the shoreline. |
| Wildfires | - | - | Wildfires are expected to become more common, but no precise estimates can be made based on available data (AMAP). |
| Landslides | Uncommon due to flat topography. | - | - |
| 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. |

## 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 whereas 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

<table>
<tr><th>Climate change hazard[4]</th><th>Impact on asset</th><th>Consequence score</th><th>Consequence likelihood</th><th>Overall risk evaluation</th><th>Comments / Mitigation</th></tr>
<tr><td>Increase in mean annual air temperature</td><td>No anticipated vulnerabilities</td><td>Very low</td><td>Very low</td><td>Negligible risk</td><td>Annual mean air temperature has no impact of power plant reliability.</td></tr>
<tr><td>Increase in mean monthly minimum air temperature</td><td>No anticipated vulnerabilities</td><td>Very low</td><td>Very low</td><td>Negligible risk</td><td>Mean monthly minimum air temperature has no impact of power plant reliability.</td></tr>
<tr><td>Increase in mean monthly maximum air temperature</td><td>Reduced cooling efficiency of dry coolers</td><td>Moderate</td><td>Low</td><td>Low risk</td><td>The exterior air temperature used for the design of the cooling loads must be adjusted accordingly.</td></tr>
<tr><td>Permafrost thaw</td><td rowspan="3">Ground subsidence caused by melting permafrost causes stress on foundation and building structure.<br><br>Active layer freeze/thaw creating uplift on foundation/pile</td><td rowspan="3">High</td><td rowspan="3">Very low</td><td rowspan="3">Low risk</td><td rowspan="3">An in-depth geotechnical study will be completed for the proposed site to reveal if the site is suitable for the support of foundations. In addition, conceptual foundation design will be reviewed by a structural engineer with permafrost experience and licensed with NAPEG to practice in Nunavut. QEC has considerable experience with power plant construction in arctic conditions. In addition, there will be continuous monitoring of foundation by qualified geotechnical personnel on a full-time basis as per geotechnical study recommendations.</td></tr>
<tr><td>Thawing degree days increase</td></tr>
<tr><td>Frequency of winter thaw events</td></tr>
<tr><td>Snow cover period shortening</td><td>No anticipated vulnerabilities</td><td>Very low</td><td>Very low</td><td>Negligible risk</td><td>Shortening of the snow cover period should not have any impact on the asset. Power plant designed and built for extreme artic conditions.</td></tr>
<tr><td>Total annual snow depth increase</td><td rowspan="4">Snow build-up on roof causing buckling of roof panels and possibly a collapse</td><td rowspan="4">High</td><td rowspan="4">Very low</td><td rowspan="4">Low risk</td><td rowspan="4">Snow roof design loads should be in accordance with NBCC requirements.</td></tr>
<tr><td>Total annual snowfall increase</td></tr>
<tr><td>Total annual precipitation increase (rain + snow)</td></tr>
<tr><td>Rain on snow</td></tr>
<tr><td>Rain on snow frequency increase</td><td>Drenched snow build-up causing buckling of roof panels and possibly a collapse</td><td>High</td><td>Very low</td><td>Low risk</td><td>Snow roof design loads should be in accordance with NBCC requirements.</td></tr>
<tr><td>Winds and storms frequency and intensity increase</td><td>Buckling of siding material, excessive wear and tear of</td><td>High</td><td>Low</td><td>Low risk</td><td>Power plant siding and window/door specifications commonly consider excessively harsh conditions. Anticipated increase negligible compared to safety margin.</td></tr>
</table>

[4] Refer to Table 1 for more specific details on climate changes expected for the Igloolik community.

| Climate change hazard[4] | Impact on asset | Consequence score | Consequence likelihood | Overall risk evaluation | Comments / Mitigation |
|---|---|---|---|---|---|
| | siding material, shattering of windows | | | | |
| 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 | Very low | Low risk | Power plant will be located sufficiently far away from shoreline considering current erosion rates. However, close 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 future 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 divert surface water as required. Fuel tanks will be positioned on raised gravel bed as per geotechnical study recommendations and common construction techniques for QEC. |

# 7. ANALYSIS OF RESILIENCE

## 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. Igloolik's new power plant will be reliable 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

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 (Ford J. , et al., 2007). Work towards identifying climate vulnerability was started as soon as 2006 in the Igloolik 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 (Ford J. , et al., 2007). In Igloolik, there is a strong sense of collective community responsibility and an ability to cope with increasing exposure to climate change (Ford, et al., 2008). This adaptive capacity is facilitated by Inuit traditional knowledge and land-based skills, strong social networks, resource use flexibility but, most importantly, institutional support (Ford, et al., 2008).

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 Igloolik 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 Igloolik, Nunavut. The proposed project is planned to be commissioned in 2026 and designed for a service life of 40 years. All of the project climate change hazards were identified and their impact on the asset was assessed. Climate change hazards identified include 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, coastal erosion, landslides and flooding. 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.

Bell, T., & Brown, T. (2018). *From Science to Policy in the Eastern Canadian Arctic: An Integrated Regional Impact Study (IRIS) of Climate Change and Modernization.* Quebec City: ArcticNet.

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.

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

Ford, J. D., Bell, T., & St-Hilaire-Gravel, D. (2010). Vulnerability of Community Infrastructure to Climate Change in Nunavut - A Case Sudy from Arctic Bay. In *Community Adaptation and Vulnerability in Arctic Regions* (pp. 107-130).

Ford, J. D., Pearce, T., Smit, B., & Oakes, J. (2008). Climate Change and Hazards Associated with Ice Use in Northern Canada. *40*(4).

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

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

James, T., Henton, J., Leonard, L., Darlington, A., Forbes, D., & Craymer, M. (2015). *Tabulated values of relative sea-level projections in Canada and the adjacent mainland United States.* Ottawa, On: Natural Resources Canada.

MacDonald, J., Smit, B., & Wandel, J. (2006). Vulnerability to climate change in Igloolik, Nunavut: what we can learn from the past and present. *Polar Record, 42*, 127-138.

Manson, G., Couture, N., & James, T. (2019). *CanCoast 2.0: data and indices to describe the sensitivity of Canada's marine coasts to changing climate.* Ottawa, ON: Natrual Resources Canada.

# 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.

*Prepared by:*

| | |
|---|---|
| | 2021-01-29 |
| **Corentin Bergerot**<br>*Junior Engineer*<br>*OIQ n° 5087630* | **Date** |

*Prepared by:*

| | |
|---|---|
| | 2021-01-29 |
| **Dave Olsthoorn, M.A.Sc.**<br>*Professional Engineer*<br>*OIQ n° 5039404* | **Date** |

*Validated by:*

| | |
|---|---|
| | 2021-01-29 |
| **Denis Lalonde**<br>*Professional Engineer*<br>*OIQ n° 103952*<br>*NAPEG n° L4556* | **Date** |

# Appendix B: Team presentation

**Jean-Philippe Castonguay, P. Eng., Senior Mechanical Engineer – Off-Grid Power Generation**
Jean-Philippe Castonguay joined BBA in February 2010 and has been actively involved with remote off-grid power generation projects for both power utility corporations and mining operations. As a project manager, he leads multidisciplinary engineering, construction support and commissioning projects across Canada, including the northern territories. Notably, Mr. Castonguay has managed 1 to 4 MW diesel power plant replacement projects within Nunavut and more recently helped deliver a new 32 MW run-of-river hydro project in British Columbia.

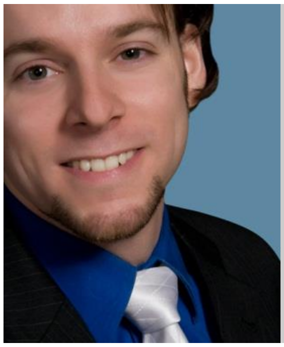
**Denis Lalonde, P. Eng., Environmental Expert**
Mr. Lalonde is an expert with 25+ years in air emissions monitoring, permitting and inventories for industrial and institutional facilities. He brings to the team his vast experience in studies and calculations for reporting GHG and other pollutants emissions from several types of processes. He is 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, MDDELCC, 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.

**Dave Olsthoorn, P.Eng., M.A.Sc., Project Leader**
Mr. Olsthoorn, building engineer, 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 with Hydro-Québec, the International Energy Agency, the Canadian Geothermal Energy Association and the Natural Sciences and Engineering Council of Canada.

**Louis-François Gagnon, P. Eng., Diesel Generator Power Plant Expert**
Mr. Gagnon joined BBA in 1997 and became a partner in 2007. He manages multidisciplinary projects and specializes in automation, mechanical engineering, HVAC, and energy efficiency. Mr. Gagnon has experience increasing the efficiency of thermal power plants through the implementation of heat recovery within industrial buildings. 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).

**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.