ATULIQTUQ: ACTION AND ADAPTATION IN NUNAVUT

CLIMATE CHANGE ADAPTATION ACTION PLAN FOR KUGLUKTUK

2010

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ATULIQTUQ: Action and Adaptation in Nunavut is a collaborative project of the Government of Nunavut, the Canadian Institute of Planners, Natural Resources Canada and Indian and Northern Affairs Canada. The Climate Change Adaptation Action Plan for Kugluktuk was prepared by Kenneth Johnson and Elisabeth Arnold. The authors would like to recognize the contributions of the many individuals and organizations in Kugluktuk that assisted in the completion of this adaptation plan.

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1. Acknowledgements

This Climate Change Adaptation Plan would not have been possible without the support and assistance of the community of Kugluktuk. The planning team would like to thank the many individuals and organizations who contributed in various ways:

- community members who shared their knowledge and hopes for Kugluktuk through individual interviews and by participating in community meetings
- the students, elders, and organizers at the August 2009 science camp at Basil Bay, who provided insight into the climate change challenges facing the people of Kugluktuk
- the Kugluktuk Radio Society which provided access to listeners by hosting four call-in radio shows
- the Kugluktuk High School which organized three workshops for students to provide input into the climate change adaptation plan
- students Chris Ilgok, Savannah Angnalak and Barbara Kapakatoak who made presentations about the climate change adaptation plan at community meetings
- our simultaneous translator Mona Tiktalek.

The planning team is grateful to our community partners:

- the staff and elected officials of the Hamlet of Kugluktuk for their professional input and logistical support
- the Government of Nunavut staff who provided background documentation, community contacts, logistical support, and excellent advice and professional input to the various drafts of the plan.

The planning team would also like to acknowledge the support of the project partners: Indian and Northern Affairs Canada, Natural Resources Canada, the Government of Nunavut, and the Canadian Institute of Planners.

We sincerely thank the people of Kugluktuk who shared their time, knowledge, and concerns about the future of their precious community. It is our hope that this plan will provide a tool to help you prepare your community to successfully adapt to the potential impacts of climate change.

2. Summary

The Government of Nunavut is currently working in partnership with Indian and Northern Affairs Canada, Natural Resources Canada, and the Canadian Institute of Planners, Nunavut communities, and other stakeholders on the Nunavut Climate Change Partnership. Included in this work are projects specific to climate change adaptation at the community level. Kugluktuk was selected as one of five communities to participate in the Nunavut Climate Change Adaptation Planning project by developing a local climate change adaptation plan.

Over a fourteen month period, the planning team visited Kugluktuk five times to seek guidance from community members, including elders, youth, and professionals, on their own experiences with climate change impacts, and exchange ideas on climate change adaptation. Each of these visits served to build upon the knowledge of the planning team regarding the issues related to climate change facing the community of Kugluktuk.

The planners were also provided with preliminary findings from scientists from Natural Resources Canada. In addition, the planning team was provided with reference material pertaining to climate change in Nunavut and specific to Kugluktuk. All of these references, as well as the observations made by the planners during their visits, were the sources of information for this plan.

The recommended actions are organized into three categories:

- Community Capacity: relating to increasing the capacity to incorporate climate change issues into the decision making of the community as a whole, and individuals in the community,
- Technical: relating to changes to infrastructure and the built environment to address potential climate change vulnerabilities, and
- Implementation: relating to organizational change, governance and changes to policies and standards that support implementation of the Kugluktuk Climate Change Adaptation Plan.

The planning team hopes that this plan will be received, discussed and amended by the Council of the Hamlet of Kugluktuk, and ultimately adopted as a roadmap to prepare the community for potential climate change impacts. This plan should be considered in combination with other plans and policy documents, including the Kugluktuk Community Plan and the Coppermine River Management Plan. The plan should also be reviewed and updated periodically as the recommendations are implemented and new information about climate change impacts in Kugluktuk becomes available.

3. Project Overview

Nunavut Climate Change Adaptation Partnership

Over the past several decades, residents of the far north, in particular the Nunavut Territory, have witnessed changes in their natural environment. Much of this change has only been recorded in anecdotal forms, but the scientific community has recognized that the north has been witnessing firsthand the impacts of climate change. The observed impacts have varied in character and magnitude, but it has been generally agreed that significant changes are occurring in the nature of northern weather. These changes directly influence the “frozen” and “unfrozen” environmental periods, which dominate the annual cycle of life in the north. Land and water are both influenced by these changes. The significant reliance on the natural environment, from a traditional perspective, as well as a non-traditional perspective, creates impacts that influence the way all northerners live, work and in some instances “survive” in the harsh northern environment.

The climate change challenge requires a global mitigation approach for it to be ultimately successfully in reducing the impact in the north, and elsewhere. At the same time adaptive solutions have been recognized to be necessary to address the impacts of climate change at the local level in the north.

The Department of Environment, Government of Nunavut is currently working in partnership with Natural Resources Canada (NRCan), the Canadian Institute of Planners (CIP), Indian and Northern Affairs Canada (INAC), Nunavut communities, and other stakeholders on the Nunavut Climate Change Partnership.

Included in this work are projects specific to climate change adaptation at the community level. Kugluktuk was selected as one of five communities to have the opportunity to participate in the Nunavut Climate Change Adaptation Planning project to develop a local climate change adaptation plan.

What is a Climate Change Adaptation Plan?

A changing climate means that there will be significant changes to land, water, plants and animals. Climate change impacts have already been observed in the north. For example, permafrost and multi-year sea ice are melting, land and water bodies are changing, and sea levels are rising. Nunavummiut report that plants are growing earlier in the spring, and new plants have been observed in regions where they have never been seen before. Animals from southern regions - such as moose, coyotes, white-tailed deer and cougars - are moving further north. Northern animals such as char, caribou, and polar bears are displaying behaviours that may be attributed to a changing environment, as a result of a changing climate.

A Climate Change Adaptation Plan is a tool to help communities prepare and respond to potential climate change impacts. A plan may include the following elements:

- Identification of Local Issues and Impacts
- Identification of Potential Responses
- Setting Priorities for Responses
- Developing Targets and Timelines for Responses
- Creating an Implementation Strategy
- Monitoring and Evaluating the Progress of Implementation of the Plan
- Review and Revision of the Plan

The key element in the ultimate success of this tool is to make use of local experience and expertise in identifying potential responses, setting priorities for responses, and developing the framework for implementation.

A Climate Change Adaptation Plan may include recommended technological responses to climate change impacts, such as how to build a storm water drainage system that has capacity for more intense storms, and recommendations for how to build community capacity to prepare for potential climate change impacts.

Climate change mitigation planning, which is the community based reduction of greenhouse gas emissions, was not part of the mandate of this project. Questions and suggestions relating to mitigation were raised by community members during the consultation process, therefore it would appear that there is an interest in learning more about climate change mitigation, and how Kugluktuk can reduce emissions and benefit economically from reduction of energy use.

Project Description

Elisabeth Arnold and Ken Johnson are professional planners, each with two decades of planning related experience from across Canada. Elisabeth and Ken are both members of the Canadian Institute of Planners (CIP). This planning team consulted with many local stakeholders varying from community elders to high school students, as well as local and regional Government of Nunavut professionals from the Departments of Environment; Education; Community and Government Services; Health and Social Services; and Culture, Language, Elders and Youth. The planning team also consulted with Natural Resources Canada scientists to obtain their perspective on climate change impacts specific to Kugluktuk. The entire exercise was undertaken in partnership with the community of Kugluktuk.

Over a fourteen month period, the planning team visited Kugluktuk five times to seek guidance from the community on their own experiences with climate change impacts, and exchange ideas on climate change adaptation.

The five trip reports are appended to this plan in Appendix A. The purpose of each trip is summarized as follows:

First Community Visit – Orientation - March 24 - 26, 2009

- Community tour
- Delegation to Kugluktuk Hamlet Council
- Meetings with GN staff
- Meetings with Hamlet Staff
- Meetings with additional community stakeholders

Second Community Visit - Reporting Visit - August 17 - 21, 2009

- Stakeholder group briefings
- Meetings with new community stakeholders
- Radio call-in show
- Community tour with NRCAN staff
- Youth and Elder Science Camp presentation and discussion

Third Community Visit –Response Development - November 16 - 19, 2009

- Stakeholder group briefings
- Radio call-in show
- High School student and elder workshop
- High school student mentoring assistance (between second and third visit)
- Community meal and meeting

Fourth Community Visit - Draft Plan Presentations - March 1 - 4, 2010

- Stakeholder group briefings
- Radio call-in show
- High School student workshop
- Community meal and meeting to present draft plan

Final Community Visit - Presentation of Plan - May 11 – 14, 2010

- Delegation to Kugluktuk Hamlet Council
- Stakeholder group briefings
- Radio call-in show
- High School student workshop
- Community meal and meeting to present final plan

The Planning Process

Each of these visits served to build upon the knowledge of the planning team regarding the issues related to climate change facing the community of Kugluktuk. Individual and group meetings revealed that community members held a wide range of opinions and concerns regarding climate change and the potential impact of climate change on Kugluktuk. Some community members expressed a healthy scepticism regarding the causes and potential impacts of climate change, while others were extremely concerned about impacts both on the land and water environments, and the community as a whole.

All stakeholder inputs were highly valued by the planning team. There were two exceptional opportunities to learn from the community: the first opportunity was the Science Camp at Basil Bay in August 2009, and the second opportunity was the student-elder workshop held at Kugluktuk High School in November 2009. These events demonstrated the value of engaging the elders and the youth of the Kugluktuk community in discussing the elders' observations and knowledge based on oral tradition, as well as the science of climate change.

At the August 2009 Basil Bay Science camp the planning team, accompanied by NRCan scientist Rod Smith, participated in a facilitated discussion about climate change impacts in Kugluktuk. Following the camp, students were asked to interview elders regarding their observations related to climate change. These poignant interviews are attached in appendix B. The planning team observed that the elders expressed a greater degree of concern about the impacts of climate change and fear for the future of the community when interviewed by the youth in comparison to the discussions with the planning team.

The subsequent workshop held at the High School in November 2009, was facilitated by the planning team and provided an opportunity for the youth and elders to engage in identifying climate change impacts and potential responses specific to Kugluktuk. The workshop used a series of posters with photos to identify issues and impacts related to climate change in Kugluktuk to solicit ideas for responses to climate change. A "dotocracy" [1] exercise was used to identify the participant's priorities for implementation. The results of this exercise were shared with the full community at a meeting the following evening.

Issues relating to both the physical environment and community life were reviewed by participants at the community meeting, as were potential responses relating to both technical and community capacity challenges to planning for climate change adaptation. Participants were asked to add any new issues and responses they could identify. They were then asked to establish the priorities for action based on the perceived urgency and potential positive adaptation impact of the response using the "dotocracy" technique.

Following this third visit, in November, 2009, a draft Kugluktuk Climate Change Adaptation Plan was developed by the planning team, based on the community input received from these consultation exercises. The planning team also considered the input from the two science reports provide by NRCan, as well as the planners' own observations and knowledge. The draft plan was circulated to the project-stakeholders in advance of their fourth visit.

During the fourth visit, which took place March 1- 4, 2010, community members were asked to identify priorities, timeframes and lead responsibility for the climate change adaptation responses and implementation strategies identified in the draft plan. They were asked to keep in mind the urgency of addressing the potential climate change impact, the potential positive adaptation impact of the response, and the logical sequence for implementing the action.

[1] A "dotocracy" exercise involves giving participants a number of sticky dots to indicate their preferences for various options. This technique can provide an opportunity for increasing interaction amongst participants during a public meeting, as well as providing a high level indication of priorities.

Community members were also asked to identify responses that may not be appropriate or feasible for implementation in Kugluktuk, responses that were already underway, and any other responses that should be included in the plan.

The final Kugluktuk Climate Change Adaptation Plan reflects the feedback received from the community during visit 4, as well as input from GN and Hamlet professional staff, and the planners' own observations and expertise.

4. Kugluktuk Climate Change Adaptation Plan

Identifying Issues, Impacts and Responses

Climate change issues and impacts observed in Kugluktuk were identified through interviews and group meetings with community members, including elders, youth, and professionals. The planners were also provided with preliminary findings from scientists from NRCan. In addition, the planning team was provided with reference material pertaining to potential climate change impacts in Nunavut and specific to Kugluktuk. All of these references, as well as the observations made by the planners during their visits, are sources of inputs to this plan.

Community members provided input through individual interviews, stakeholder meetings, a group discussion at the youth science camp, an elder-youth workshop at the High School, and a community meeting. Community members tended to put a priority on issues related to safe travel on the land and sea, as well as ensuring Kugluktuk's drinking water and storm water drainage system meet the requirements of the community.

Climate change science issues were identified through preliminary observations from a field visit and report by Rod Smith (August 2009) and a report by Thomas S. James et al (2009) Natural Resources Canada (reports attached in appendix G). These preliminary studies note that:

- more field-based study and substantiating will be required before the findings may be incorporated into a design/adaptation strategy;
- the preliminary studies may be most useful in identifying knowledge needs/gaps that can be used to support the planning process; and
- sea-level rise projections are intended only as a starting point for discussions of the possible impacts of sea-level change and the potential mitigation measures that could be implemented.

The most urgent areas identified for further study by the scientists were: coring to establish ice-content in soils in vulnerable areas, development of a drainage plan to accommodate climate change scenarios, and protection of the community's water supply.

The planning team prioritized the following issues in three categories:

- Technical issues in the community: safety of the drinking water supply, capacity of the storm water system, potential for land subsidence;
- Issues on the land and sea: safety of travel on the land and the sea; and
- Community capacity issues: lack of consideration of potential climate change vulnerability in decision making.

For each of the issues and impacts identified, potential adaptation responses were suggested by community members, confirmed in the NRCan reports, or recommended by the planning team. Each response was prioritized based on the perceived urgency and potential positive adaptation impact of the response.

The planning team solicited suggestions from all stakeholders for a realistic timeframe for implementation of the recommended actions, as well as suggestions for which authority (individual or organization) should assume the lead responsibility, appropriate roles for the various stakeholders, and the status of any existing climate change adaptation initiatives.

There are numerous strengths to build on in planning for climate change adaptation in Kugluktuk. There is a resilient population, elders and youth willing to be engaged in finding solutions, and technical proficiency and commitment of individuals in various positions of responsibility in the community. An excellent example of this commitment is the support offered and action taken by the Kugluktuk High School and Department of Education staff in providing the opportunities for the planning team to connect to the community.

There are also many community capacity issues facing Kugluktuk that will make it challenging to implement a Climate Change Adaptation Plan in an expeditious and consistent manner. The planning team has attempted to provide a series of realistic, achievable recommendations for action, developed in collaboration with the people of Kugluktuk. In addition, implementation tools and approaches are proposed to build the capacity of the Kugluktuk community to prepare for potential climate change impacts.

Recommended Actions

This plan reflects the substantial input received from community members and the technical support provided by NRCan scientists over a one year period and four community visits. The planning team has developed the recommended actions taking into account this input, as well as reference material pertaining to climate change in Nunavut and specific to Kugluktuk, and their own observations from visits to Kugluktuk.

The plan recognizes that not all recommendations are equally urgent, and that there are very limited human and financial resources available to address the identified potential climate change vulnerabilities. The plan recommends actions that may be implemented in the next 1-2 years to address the most pressing issues, as well as to prepare the community to address climate change issues in the future. Other recommendations are identified for the medium (3-4 years) or longer (4+ years) terms as resources permit.

The recommended actions are organized into three categories:

- Community Capacity: relating to increasing the capacity to incorporate climate change issues into the decision making of the community as a whole, and individuals in the community,
- Technical: relating to changes to infrastructure and the built environment to address potential climate change vulnerabilities, and
- Implementation: relating to organizational change, governance and changes to policies and standards that support implementation of the Kugluktuk Climate Change Adaptation Plan.

The planning team hopes that this plan will be received, discussed and amended by the Council of the Hamlet of Kugluktuk, and ultimately adopted as a roadmap to prepare the community for potential climate change impacts. This plan should be considered in combination with other plans and policy documents, including the Kugluktuk Community Plan and the Coppermine River Management Plan. The plan should also be reviewed and updated periodically as the recommendations are implemented and new information about climate change impacts in Kugluktuk become available.

Community Capacity

Issue	Impacts	Responses	Priority	Timing	Recommended Lead Responsibility and Role/Current Status
Lack of knowledge about climate change and potential impacts. Lack of human and financial resources to seek knowledge and implement solutions.	Planning occurs without taking climate change into account, so community may not be as prepared as possible.	Training on climate change for community leaders and professionals at Hamlet and GN geared to non-experts.	High	1-2 yrs	Hamlet – to organize NRCan – to provide training GN-Environment to finance, Education to support implementation
		Community, high school and elder workshops on climate change.	High	1-2 yrs	GN-Environment and Education to develop curriculum and workshops
		Create a Kugluktuk community climate change network to share resources and information.	Medium	3-4 yrs	Hamlet to lead in organizing and supporting GN-Dept's of GIS and Env't to share data
Lack of "ownership" of issue at community level.	Issues and potential solutions are not acted upon.	Identify staff positions responsible for climate change adaptation in Kugluktuk.	High	1-2 yrs	GN and Hamlet to build into job descriptions and identify accountabilities
		Identify dedicated staff resources for climate change work.	Medium	3-4 yrs	GN and Hamlet
		Develop a plan to reduce staff turnover to increase continuity of knowledge	Medium	3-4 yrs	GN
Changing weather patterns, including severe storms and rainfall, early ice melt and river overflow, later freeze-up Safe access to hunting, fishing and recreational areas. Inadequate emergency response systems.	Unpredictable and unsafe conditions on the land, river and ocean. Increased injury and loss of life due to accidents. Reluctance of community members to participate in hunting activities. Limited and unsafe trail access at certain times of the year (including Coppermine River trail).	Change hunting habits to adapt to climate change impacts.	High	1-2 yrs	Hamlet Hunters and Trappers Organization GN-Search and Rescue (currently distributing GPS's) GN-Dep't of Env't Wildlife Officers GN-Dep't of Sust. Dev., Parks (note complementary recommendations in the Draft Management Plan for the Coppermine River) All agencies need to cooperate to develop common communications strategies.
		Repair and replace unsafe trails.	High	1-2 yrs	
		Establish river and trail monitoring and early warning systems.	High	1-2 yrs	
		Secure better equipment for ocean travel in summer and winter.	Medium	3-4 yrs	
		Improve forecasting, surveillance and reporting of ocean and ice conditions.	Medium	3-4 yrs	
Increasingly difficult to harvest country food.	Changes in wildlife.	Change animals harvested to reflect change in wildlife.	Low	4+ yrs	Community members Hamlet HTO GN-Dep't of Sust. Dev., Parks (note complementary recommendations in the Draft Management Plan for the Coppermine River)
		Re-establish the community freezer.	Low	4+ yrs	

Technical Issues

Issues	Impact	Responses	Priority	Timing	Recommended Lead Responsibility and Role/Current Status
Landscape Hazards	Long term integrity of airport and sea-lift area. Safety of buildings and infrastructure in areas with ice rich ground conditions.	Undertake sediment coring to determine and characterize the risk of subsidence in various parts of the community including the airport and sea-lift areas.	High	1-2 yrs	GN-EDT Nunavut Airports
		Survey of all buildings in the community to determine the extent of foundation damage.	High	1-2 yrs	GN-Housing Corp Private Owners
		Take ice rich ground conditions into consideration for development.	High	1-2 yrs	GN-CGS Hamlet
		Repair and build new trails.	High	1-2 yrs	Hamlet to apply for funding GN-EDT to fund GN-Dep't of Sust. Dev., Parks (note complementary recommendations in the Draft Management Plan for the Coppermine River) Community to participate
		Restrict building in eroding areas.	Medium	3-4 yrs	Hamlet
		Move buildings from hazard areas to stable ground.	Medium	3-4 yrs	Owners (private and government)
		Replace or repair failing building foundations.	Medium	3-4 yrs	Owners (private and government)
Coastal Erosion	Reduced summer ice cover, and reductions in shorefast ice leads to increased wave fetch and potential shore stability issues. Steep shore profile along northern edge of community most at risk of erosion. Wave action from boats operating close to shore may accelerate erosion. Buildings close to shoreline at risk of damage from bank collapse. Future use of shoreline for building may be unsafe.	Survey existing vulnerabilities with updated NRCan shoreline information.	High	1-2 yrs	NRCan GN Hamlet Community members
		Increase shoreline erosion protection with additional gabion baskets.	Medium	3-4 yrs	Hamlet to identify GN-ED&T and CGS to fund and implement
		Evaluate the projected coastal change in terms of the susceptibility of built structures and in terms of the utilization by community members.	Medium	3-4 yrs	NRCan
		Restrict building in eroding areas.	Medium	3-4 yrs	Hamlet with input from GN-EDT and CGS
		Develop shoreline remediation or building relocation plan.	Low	4+ yrs	
Sea-level Rise	Significant changes could occur along low lying areas, and storm surges could cause flooding and more frequent salt water incursion in water intake,	Evaluate the potential for significant changes along various shore profiles, including flooding of low-lying terrain, due to storm surges	High	1-2 yrs	NRCan

Issues	Impact	Responses	Priority	Timing	Recommended Lead Responsibility and Role/Current Status
Water supply	Actual and perceived integrity of drinking water supply and water treatment system. Reports of periodic saltwater intrusion and high sediment levels in drinking water	Complete planning and engineering for water supply and treatment improvements	High	1-2 yrs	GN-CGS (engineering, financing and project management) Hamlet (consult, approve, operate, maintain) GN-Dep't of Sust. Dev., Parks (note complementary recommendations in the Draft Management Plan for the Coppermine River)
		Implement water supply and treatment improvements.	High	1-2 yrs	
		Identify a new water source (not recommended – study done by GN-CGS in 2009, therefore no change recommended).	N/A	N/A	Hamlet would need to initiate a new study.
Hydrology	Increasing frequency and magnitude of rain events overloading capacity of the storm water system. Increasing failure of storm water system and roads after storms. Ponding contribution to permafrost thaw. Snowdrifts may reduce refreezing of active layer, cooling of permafrost and produce additional meltwater, which will accelerate permafrost melt.	Develop drainage plan with new storm assumptions and grading requirements and snow piling guidelines.	High	1-2 yrs	GN-CGS Hamlet
		Better road and ditch construction techniques should be required.	High	1-2 yrs	GN-CGS developing standards for northern subdivision design. Hamlet - implementation
		Develop a plan to keep ditches and culverts clear of debris. Ensure ongoing repair of damaged culverts.	High	1-2 yrs	Hamlet and community members
		Snow drift patterns need to be taken into account during the planning process and maintenance procedures, particularly as it relates to alignment of buildings.	High	1-2 yrs	GN-CGS in existing community plan Hamlet and property owners to implement snow management guidelines.
		Install larger and more culverts and ditches based on drainage plan.	Medium	2-3 yrs	GN-CGS - drainage plan and standards Hamlet - implement
		Evaluate surface ponding of water and address with ditch grading.	Medium	2-3 yrs	Hamlet to address problem areas. GN-CGS to address in drainage plan.
		Consider subsidence / erosion from stream diversion along the airport runway and future airport expansion.	Medium	Coinciding with capital improvements	Nunavut Airports
		Install a buried storm sewer system (not recommended due to permafrost and cost issues).	N/A	N/A	

Implementation

Issue	Impacts	Responses	Priority	Timing	Recommended Lead Responsibility and Role/Current Status
Lack of "ownership" of climate change issue at the community level. Note: ownership relates to empowerment, leadership, reseponsibility and accountability.	Issues and potential solutions are not being acted upon.	Adoption of the CCAP by the Hamlet of Kugluktuk.	High	1-2 yrs	Hamlet to adopt, other agencies to incorporate as appropriate.
		Develop a work plan for implementation of the CCAP.	High	1-2 yrs	Hamlet GN-Department of Env't
		Create an "implementation advisory committee" to review progress and report to the Kugluktuk Hamlet.	High	1-2 yrs	Hamlet; committee to include Mayor, SAO, GN (Wildlife Officers, CGS, Parks, Env't, Public Works), INAC, HTO, KIA, School etc
		Identify financial resources to support implementation.	High	1-2 yrs	Hamlet SAO
Many other high priority issues are facing the community (health, education, economic).	Community leaders are focussing on more immediate, pressing issues.	Community Plans should be considered by GN and Hamlet when making decisions.	High	1-2 yrs	GN-CGS Hamlet
		Develop a plan for interagency collaboration on climate change. For example, facilitate inter-community discussion on success/failure of adaptive strategies.	Medium	2-3 yrs	Hamlet - CCAP Implementation Advisory Committee GN-Hire a Community Collaboration Officer
		Climate change adaptation requirements should be emphasized in the next 5 year review of the Community Plan, or sooner if needed.	Medium	2-3 yrs	GN-CGS-revise plan Hamlet-adopt and implement plan
		Provide a tool to review the most pressing issues with a climate change lens.	Medium	2-3 yrs	GN-Department of Env't
Land subsidence from permafrost degradation	Safety and integrity of buildings.	Any significant development proposal should be required to demonstrate that permafrost conditions can support the proposal prior to approval.	High	1-2 yrs	GN-CGS – develop standards Hamlet – adopt and enforce standards
		Require the investigation into subsurface ice content for all engineering work	High	1-2 yrs	GN-CGS - develop standards Hamlet – adopt and enforce standards
		Evaluate foundation types and develop building standards to meet various permafrost conditions of sites.	Medium	3-4 yrs	GN-CGS – develop standards Hamlet – adopt and enforce standards
Shoreline erosion	Safety and integrity of buildings.	Review 100 ft shoreline reserve to address land lost to erosion.	Medium	2-3 yrs	GN-CGS and Hamlet (Lands Claim, Part 5, Article 14) joint review and strategy development

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1. A Reconnaissance Assessment of Landscape Hazards and Potential Impacts of Future Climate Change in Kugluktuk, Nunavut. I. Rod Smith 2009 Natural Resources Canada
2. Sea-level Projections for Five Pilot Communities of the Canada-Nunavut Climate Change Partnership. Thomas S. James et al. 2009 Natural Resources Canada

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A. Trip Summary Reports

Kugluktuk Climate Change Adaptation Panning Project Summary Report on Visit 1 to Kugluktuk

Summary Notes to Community Visit by E. Arnold and K. Johnson - March 24-26, 2009

This trip was planned to introduce the project and the two planners to key stakeholders in the community and to provide a first exchange of information on the climate change adaptation challenges facing the Kugluktuk community.

Elisabeth Arnold, MCIP and Ken Johnson, MCIP met with Hamlet Council and Hamlet Administration; Government of Nunavut (GN) Culture; GN Community Planning; GN Economic Development; GN Social Services; GN Conservation; GN Health & Social Services; and the Kitikmeot Inuit Association.

What we heard:

- Acknowledgement from the Hamlet Council that Climate Change is an important issue, and acknowledgement that the Council is pleased that to see planners visiting the community.
- Many common issues with climate change expressed by different people offering different overall perspectives.
- Observations that the natural environment is changing significantly, and has been changing for at least a decade (and perhaps longer),
- No formal "record" of the observations made by various individuals, therefore there is limited perspective for comparison of the changes that are occurring.

Physical observation of changes that may be due to climate change:

- Earlier sea ice melt, later freeze-up and reduced sea ice thickness
- More erosion along Coppermine River and more silt in the Coppermine River
- New birds and insects in the region
- Changes in animal behaviours (caribou and seal)
- Colour in lakes is changing from blue to more brown and lake slopes changing.
- Stability of the land is changing
- Less snow in the winter and more rain in the summer.

Impacts on way of life in Kugluktuk:

- Ice conditions are less predictable and potentially unsafe, which impacts on seal harvesting
- Changes in types of fish being caught in Coppermine River.
- Drinking water quality, as it may be impacted by sea-level rise, and erosion of the Coppermine River.
- Changes in the opening of the Northwest Passage: environmental impact of increased traffic, and capacity to respond to potential oil spills and other accidents
- Concern about homes built close to the river because of vulnerability to ice break-up and river bank erosion
- Concern about erosion of gravesite located on an off-shore island

Kugluktuk Climate Change Adaptation Planning Project Summary Report on Visit 2 to Kugluktuk Summary Notes to Community Visit by E. Arnold and K. Johnson - August 17 to 21, 2009

A key question for the community on this trip was, "what tools can we provide that would help you to address climate change in Kugluktuk?" The second community visit presented three major opportunities for the planners. The first opportunity was providing an update to community stakeholders on the status of the project, and verified information from the first trip in March. The planners also identified and interviewed new community stakeholders. A second opportunity was initiating the working relationship with the NRCan scientists, which included a tour of the community with permafrost scientist Rod Smith, Ph.D. The third opportunity and highlight of the trip was attending the Kitikmeot Regional Science Camp, which provided an opportunity to meet and discuss climate change issues with elders and youth attending the camp.

What we heard:

- General validation of the range of issues identified during Visit 1
- Sense that Inuit will be able to adapt to climate change, but need tools and resources
- Interest to develop usable "tools" to support climate change adaptation
- Concern about lack of communication and coordination of efforts in the community leading to gaps in response or duplication of effort

Additional issues identified

- Future expansion may require more expensive solutions to ensure long term building stability
- Variety of foundation systems in the community with some foundation deterioration occurring
- Limited, but significant shoreline erosion occurring
- Significant erosion observed with runoff in the community (potentially from rainfall and snowmelt)
- Changing wind patterns and currents
- Weather changes more quickly, and is more severe
- Illness in wildlife, ie lumps in caribou
- New trees such as Willows and Spruce appearing; wonder if tree line is moving north
- Need to work with community to change habits in response to climate related change

Potential tools for climate change adaptation in Kugluktuk and for climate change project legacy

- Creating a network of individuals in Kugluktuk for addressing climate change impacts as well as links to resources outside of the community
- Training, Capacity Building and Empowerment
- Identification of technical requirements for building expansion in non-bedrock areas
- Suggestions for alternate ways to conduct public consultation
- Work with elders and youth through the high school to raise awareness, and gather information from elders, and start monitoring projects on ice, weather, river and tide conditions
- Community mapping and the application of a GIS system – create base layer so that observations and stories can be added
- New information from NRCan scientists to be added to community mapping, including identification of hazard areas
- Identify funding sources for follow-up projects

Nunavut Climate Change Adaption Project Summary Report on Visit 3 to Kugluktuk
Prepared by Ken Johnson, MCIP, and Elisabeth Arnold, MCIP – November 16 to 19, 2009

The primary purpose of this third trip was to host a community meeting to verify that the climate change issues and impacts we identified during our visits to Kugluktuk in March and August reflect community priorities. A second purpose of the trip was to build upon our participation in the Regional Science Camp in August by hosting a youth and elders workshop at the Kugluktuk High School.

The Kugluktuk Grade 12 High School Environment Class and Elders participated in a Youth and Elders Workshop, which focussed on possible impacts that climate change may have on Kugluktuk, and adaptation strategies that could be implemented in response to these impacts. This activity was following up on a series of interviews that the grade 12 environment class conducted with the elders.

For this visit we developed a series of twelve posters depicting climate change issues and impacts that were identified during previous visits. These posters were used at a Youth and Elders Workshop, as well as a Community Meeting, as a means to engage students, elders and other community members, and to get a sense of the issues and adaption responses that are most important to them. Participants were invited to add other adaptation strategies, and then to "vote" for the strategies that they believed to be the top priorities for implementation in Kugluktuk using "sticky dots" added to the posters. This technique provoked a lively discussion about climate change impacts, and engaged all participants in learning more from both the elders and the planning team.

The Community Meeting was attended by approximately 100 people, and a meal was catered by the Kugluktuk High School. After the short presentation by the planning team and two students (Barbara Kapakatoak and Chris Ilgok), community members were asked to view the twelve posters, add their suggested actions to the actions developed at the Youth and Elders workshop, and vote, again using "sticky dots" for the issues they felt were most important for Kugluktuk.

The two students agreed to continue to work on the Climate Change Adaptation Project as part of their grade 12 and college preparation requirements, supported by teacher Dale Skinner. Their work will be presented at a Community Meeting and to other stakeholders during the planning team's 4th visit in March 2010. The priorities that emerged from the Youth and Elders Workshop and the Community Meeting were:

- Severe rain events, river overflow during spring, land travel in summer – high priority.
- Changing/increasing river sediment; changing snow/rain conditions; increasing ocean storms; ocean travel in winter – medium priority.
- Subsistence lifestyle; increasing rainy weather; deteriorating house foundations; ocean travel in summer; air travel in winter – low priority.

The planning team will use this feedback as one of the inputs for development of the Draft Climate Change Adaptation Plan to be presented to the community in March. Other inputs include the Landscape Hazards and Sea Level reports provided by Natural Resources Canada Scientists, current climate change literature, and planning best practices, as well as ongoing feedback from the community.

Nunavut Climate Change Adaption Planning Project Summary Report on Visit 4 to Kugluktuk
Ken Johnson and Elisabeth Arnold - March 1 to 4, 2010

The main primary purpose of the trip was to present the draft Climate Change Adaptation Plan (CCAP) to the community of Kugluktuk and to seek community input on the priorities for action and implementation. The activities included: evening radio call-in show with Kugluktuk Radio Society and 2 high school students; workshop at Kugluktuk High School with approximately 30 students; meetings with key stakeholders, and; a community meal and meeting with approximately 60 individuals attending. A short video documentary was produced after the visit featuring excerpts from the community events.

The draft CCAP summarizes the planning process undertaken to date, and outlines the findings and draft recommendations of the plan. The recommendations were reproduced on a series of 30" by 20" posters in English and Inuinnaqtun for use at the meetings. Participants at the high school workshop and the stakeholders meetings were invited to identify the priority that should be assigned to the recommendations and to suggest any additional recommendations.

The community meeting was preceded by a meal catered by the Kugluktuk High School and was attended by close to 60 people. After the short presentation by the planning team and two students, community members were asked to review the posters containing the draft CCAP recommendations. They were invited to add additional recommendations to those made by the students and stakeholders and to "vote" with sticky dots for the recommendations they felt were the most important for Kugluktuk.

The recommendations in the draft CCAP are in three categories: Technical, Community Capacity and Implementation. The technical recommendations prioritized by the community were: undertaking sediment coring to determine and characterize the risk of subsidence; repairing or replacing failing house foundations; repairing and building new trails on the land; surveying existing shoreline erosion vulnerabilities; evaluating vulnerability to sea level rise; completing engineering for water supply and treatment; improving road and ditch construction and; taking snow drift patterns into account in planning and building.

The community capacity recommendations prioritized by the community were: holding more workshops and training on climate change issues; changing hunting habits to adapt to changing ice and land, and; improving forecasting and warning of dangers of travel on ice, ocean and the land. The Implementation recommendations prioritized by the community were: providing a tool to review the most pressing issues with a climate change lens; identifying financial resources to implement recommendations from CCAP, and; addressing CCAP recommendations in the next 5 year review of the Kugluktuk Community Plan, or sooner if required.

The planning team will use this feedback as one of the inputs for the final Climate Change Adaptation Plan to be presented to the community in May. Other inputs include the Landscape Hazards and Sea Level reports provided by NRCan scientists, current climate change literature and planning best practices, as well as ongoing feedback from the community.

Our plan for fifth visit in May 2010 is to present the Final Climate Change Adaptation Plan to the Community and Hamlet Council. The anticipated activities include: participate in a community radio call-in show; host a meeting with project stakeholders; host an information meeting for the entire community; host a workshop for Kugluktuk High School students and teachers; and identify a cross section of community champions who will follow-up on the CCAP.

Nunavut Climate Change Adaption Planning Project
Summary Report on Visit 5 to Kugluktuk
Ken Johnson and Elisabeth Arnold, May 11 - 14, 2010

The fifth and final trip for the Kugluktuk Climate Change Adaptation Plan (KCCAP) was completed and a final draft of the KCCAP was presented to a several key groups including the Hamlet Council, the GN stakeholders, and the community of Kugluktuk. A key element of these presentations was to provide an update on the project, discuss implementation strategies, and identify a cross section of community champions committed to follow up on the project. The trip was also an opportunity to continue to work with the students and teachers at Kugluktuk High School to add to the knowledge and interest regarding climate change adaptation in Kugluktuk.

The Kugluktuk Hamlet Council received a presentation on the KCCAP, which provided a general overview of the purpose of the project, outlined the highlights of each visit made by the planning team, and identified the key recommendations of the KCCAP. Unfortunately, this was only the second presentation opportunity to Council, and the end result was that the KCCAP was not formally received by Council at this presentation opportunity.

The youth workshop, which included about 40 students, was held as part of the senior high school Social Studies class. An opportunity was also provided to include students from other classes, including a grade 7 class. The students were invited to participate in the community meeting, and Savannah Angnaluak, made an excellent presentation, and played a key role in encouraging the community members at the meeting to actively participate. The high school teachers indicated that the students had benefited from both the content and the process of being involved in the KCCAP. The teachers indicated that the materials provided for the workshops would be used in the future as a compliment to Science and Social Studies classes. The teachers noted that the process of consulting the community on the issues that were most important to them, and soliciting their suggestions for responses was a new experience, and an excellent model for community empowerment.

The radio call-in show with Inuinnaqtun translation has been a mainstay of the community visits and provided an opportunity to inform the community about the KCCAP, and to encourage community members to attend the community meeting. A summary of the process of developing the plan and overview of the KCCAP recommendations was provided.

A stakeholder meeting was held with 12 local stakeholders participating. The presentation and discussion focussed largely on the recommendations. Particular attention was made to the implementation strategies and identification of roles and responsibilities of various stakeholders

The community meeting was preceded by a meal catered by the Kugluktuk High School and was attended by approximately 30 people. The planning team made a short presentation focussing on the recommendations in the KCCAP. Community members were invited to review the posters containing the KCCAP recommendations, followed by a question and comment period. After the planning team had responded to all the questions and comments, community members were asked to complete the feedback form.

The challenges associated with this trip were a lack of continuity with the of Hamlet Council and senior staff at the Hamlet, which has resulted in weak ownership of KCCAP by the Hamlet; lower participation in the community meeting than in previous visits, and; lack of identifiable community champions at the end of the project. The follow-up by the planning team will be to provide a briefing note for senior staff of the Hamlet, and forward a revised KCCAP to the stakeholders.

B. Student Interviews

Dear Elisabeth,

Enclosed are copies of interviews obtained by students enrolled in an environmental studies course at Kugluktuk High School. The class is small and thus the sample population was not huge. However some of the answers were thought provoking and may lead to focused areas of investigation. At the very least, interviewing the elders created an interesting and powerful structure for a class project. The students involved, hesitant at first, had an enjoyable and for some a memorable experience.

Hope we helped,

Dale Skinner

Dale Skinner H.B.Sc.; M.Sc. in Ed.

This interview was taken place on September 3rd, 2009.
Over at an elders place the interview was basically on global warming the elders that were interviewed was John Kapakatoak,Ida Kapkatoak,Mammie Oniak, and Joe Ogina who are very connected with the land and had been seeing changes through out time.

ENVIRO 35

What time of year did the ice break up?
The ice would usually break up during the middle of June.
Do you notice anything different about the plants, bugs or animals?
Yes we have there is many different type of bugs that we haven't seen before. The mosquitos are now larger then back then. The animals seem to be getting farther and are settling a long distance away from where they would usually settle.
What was the weather like during your child years?
The weather was warmer and the summer's were short and the winters were always longer now as I see it the summer's are now colder and longer then back then.
Do you think people care less about the land? Why?
Yes we do because people near by don't seem to care like the mining industries are now trying to take on our land which is leading to slow damage in our environment.
What was the weather like during the four seasons?
Back in the 50's we had experienced a snow storm in July, there was less wind and just from taking a peek at the weather would tell you what to expect .
Does spring come earlier or later than during your childhood?
The spring seems to arrive later then back then.
Have you noticed any changes in the land?
We have notice many changes in the land there seems to be more melting in the permafrost which is causing the land to shift more. The land was much flat back in the days now as we see it is now much ruff.
Have you noticed anything different about the shoreline?
Yes we have the shoreline tends to be drying out back in the days the shoreline was much more closer to land then it is now.
Is there more or less snow than many years ago?
As we see it there seems to be less snow from back then.

Was there a time when summer didn't come when you were growing up?
As I was told from my grandparents they have seen summer at one point.
Does the rain cause more damage (to roads or land) now or back then?
Yes it does since there is more and more rain it tends to be doing more damage then it would back then.
Have you noticed any changes around your home after a rainstorm?
We've seen many rain wash off and shifted grounds.
When the rainstorm happened two years ago, does that happen often?
Well i am over 60 years of age and I've never seen such rain storm like that.
Is the break up of the Coppermine River changing?
Yes it seems to be much weaker back then we would be able to hear the ice breaking up and there would be plenty of ice.
Do the caribou, seal or fish taste different?
The caribou was healthy back in the days so was the fish but with the taste I have I didn't see any changes.
Has the migration of the animals changed in your life time?

Yes very we would have to travel so far as we do now days. There was hardly any musk-ox back in the 50's and 60's now when I travel I see them almost every where I go.
What do you think is the real reason for global warming?
Well to me I think the world is just coming to a close end. More pollution to damage the earth and less respect for our world.

What time of the year did the ice break up?
Sometime in June, the earliest time was June 4th.

Do you notice anything different about the plants, bugs and animals?
Animals yes, their migration patterns are different every year, sometimes there was no caribou, these past two years there has been no caribou.

What was the weather like during your child years?
Used to be very cold. As cold as -54 degree Celsius. Right now we don't get as cold anymore, only -38degree Celsius now a days.

Do you think people care less about the land? Why?
I don't think so, plastics have been thrown around but we try to encourage that people clean up after themselves out on the land and bring them to town.

What was the weather like during the four seasons?
Weather is changing, ice conditions are thinner, its getting dangerous to take the same route during spring, they have to adapt to the new type of traveling. Old trails are more dangerous because of thin ice.

Does Spring come earlier or later than during your childhood?
During my childhood spring usually came later then today.

Have you noticed any changes in the land?
The land has changed quite a bit, its melting in some areas, land slides in different area, the land is melting due to permafrost melting, and you can see some slides down by Victoria Island , no snow, no bedrocks and some small lakes are dry.

Have you noticed anything different about the shoreline?
Its getting shallower everywhere, even the river.

Is there more or less snow than many years ago?
Less snow.

Was there a time when summer didn't come when you were growing up?
No, there has always been summer.

Does rain cause more damage (to roads or land) now or back then?
We need rain, its been normal but less thunder and lightening. Very unpredictable weather now a days.

Have you noticed any changes around your home after a rainstorm?
Not after a rainstorm, but the land is melting especially around my house (he lives on the shoreline) its sort of slanted not far from my home.

When the rainstorm happened happened two years ago, does that happen often?

Who I interviewed: Lena Milukshuk
Her age: just turned 50
Place of interview: wellness centre, Kugluktuk Nunavut. (her work place)
The person that interviewed her: Kathleen Milukshuk

Do the caribou, seal or fish taste different?
No. But the difference between Victoria and mainland caribou always have tasted different because they are different types of caibou.

Has the migration of the animals changed in your lifetime?
Yes. It has never been the same every year, patterns next year are always different, they don't go to where they used to be. Route always changes.

What do you think is the real reason is for Global Warming?
The world is tired! To me its changed quite a bit, human error, to much pollution in the air.

Colin Adjun Wildlife Officer

Interviewed By Dana Havioyak and Danielle Kuneyuna

Enviro 35

1. What time of the year did the ice break up?
   "June, sometimes earlier"

2. Do you notice anything different about the plants, bugs or animals?
   "There's more strange bugs, more different bugs, maybe from the barge coming in. not so much about the plants though, I think they don't grow as much from the gravel house pads. I'm not too sure about the animals."

3. Do you think people care less about the land? Why?
   "Yes, because they throw garbage, only on the ground, some people throw meat on the ground"

4. What was the weather like during the four seasons?
   "I don't know, I just accepted the way it is. But I'll have to say it was a lot warmer then it was when I was a child."

5. Does spring come earlier or later than during your childhood?
   "It's getting earlier now, later in my childhood"

6. Have you noticed any changes in the land?
   "Too much gravel now, no clear spring water or bugs, the little creeks are dried up. It stinks, not fresh anymore".

7. Have you noticed anything different about the shoreline?
   "Dirtier, more garbage, more gas and oil leaks from the boats".

8. Is there more or less snow than may years ago?
   "Less."

9. Was there a time when summer didn't come when you were growing up?
   "There was summers, but not as warm as today."

10. Does the rain cause more damage (to roads or land) now or back then?
"Now"

11. Have you noticed any changes around your home after a rainstorm?
"More rain, more pools of water."

12. When the rainstorm happened two years ago, does that happen often?
"I was not here two years ago".

13. Is the break up of the coppermine river changing?
"Yeah, I think its because the flow of the river isn't as fast as it was."

14. Do the caribou, seal or fish taste different?
"I didn't notice"

15. Has the migration of the animals changed in your lifetime?
"Yeah, long ago people had to go farther and there were times caribou migration went through the town."

16. What do you think the real reason is for global warming?
"More air pollution, because of the gravel house pads are covering the land, just more garbage flying around."

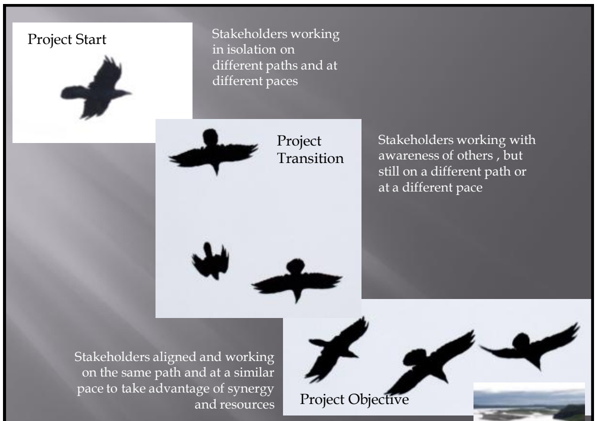
C. Presentations

Kugluktuk Climate Change Adaptation Project

Project Update – November, 2009

Elisabeth Arnold
Ken Johnson

Kugluktuk Climate Change Adaptation



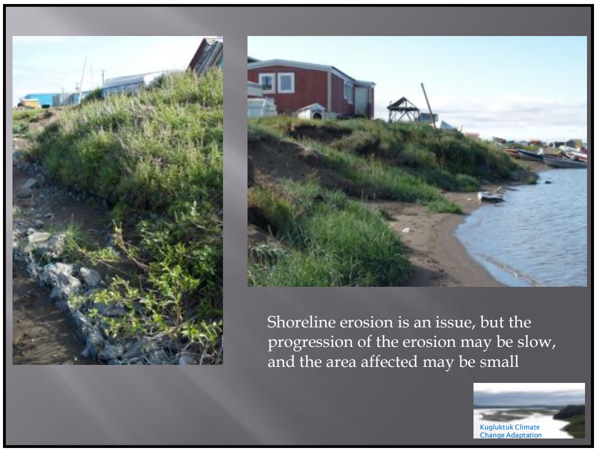
Kugluktuk is experiencing a variety of climate and environmental related changes, however the documentation, for the most part is "anecdotal."

Kugluktuk Climate Change Adaptation

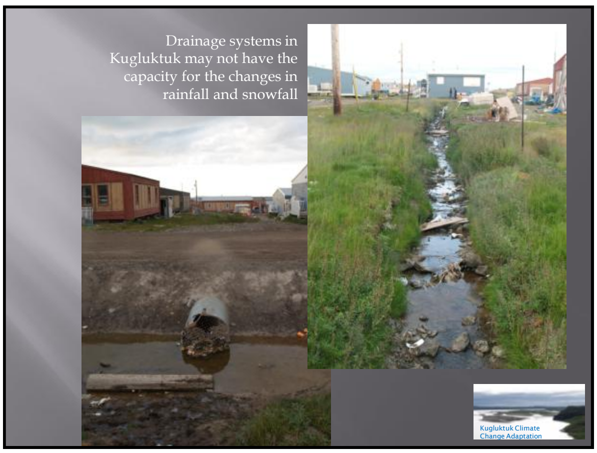
Summer transportation on the water and land

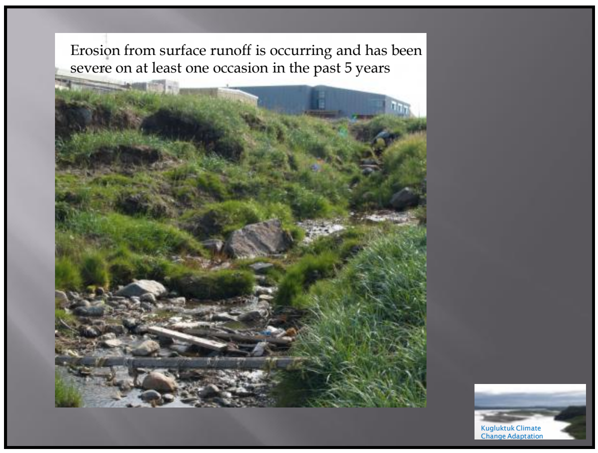
Winter transportation on snow and ice

Kugluktuk Climate Change Adaptation


Shoreline erosion is an issue, but the progression of the erosion may be slow, and the area affected may be small
Kugluktuk Climate Change Adaptation

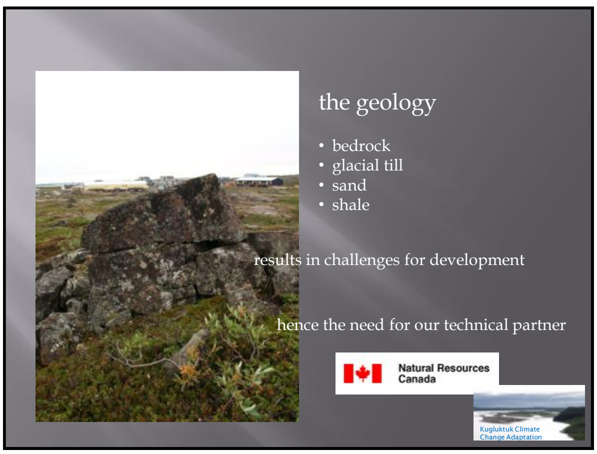

Wet weather may become more common with along with changes in nature of rainstorms
Cold weather may become less severe and the ice season may be shortened
Kugluktuk Climate Change Adaptation


Drainage systems in Kugluktuk may not have the capacity for the changes in rainfall and snowfall
Kugluktuk Climate Change Adaptation


Erosion from surface runoff is occurring and has been severe on at least one occasion in the past 5 years
Kugluktuk Climate Change Adaptation

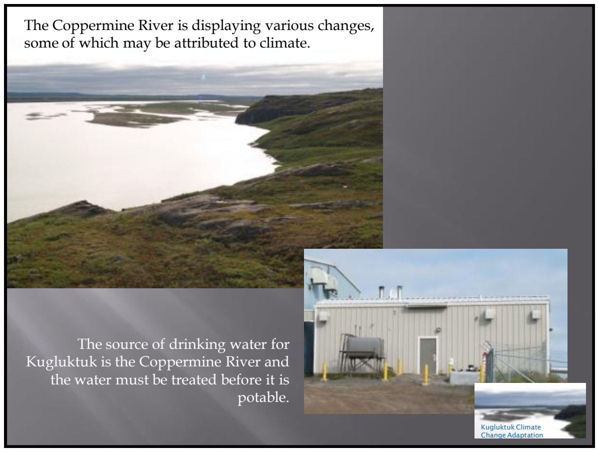

Drainage improvements are being made, but ….
…. drainage challenges remain.
Kugluktuk Climate Change Adaptation


Standing water also influences the permafrost, which may in turn change the ground stability.
Kugluktuk Climate Change Adaptation


the geology
• bedrock
• glacial till
• sand
• shale
results in challenges for development
hence the need for our technical partner
Natural Resources Canada
Kugluktuk Climate Change Adaptation


The stability of the building foundations in Kugluktuk are influenced by the ground stability.
Kugluktuk Climate Change Adaptation

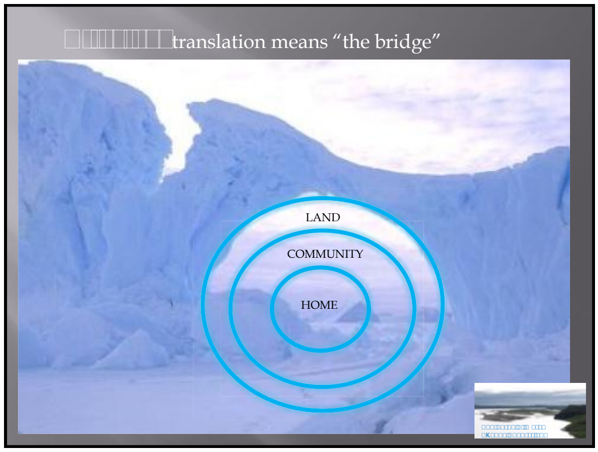

Some foundation systems may deteriorate to a point of instability.
House tips over in Inuvik in 2009
Kugluktuk Climate Change Adaptation


The Coppermine River is displaying various changes, some of which may be attributed to climate.
The source of drinking water for Kugluktuk is the Coppermine River and the water must be treated before it is potable.
Kugluktuk Climate Change Adaptation


Coppermine River erosion
River bank erosion is occurring at the mouth of the Coppermine River and this is threatening a community cemetery.
Kugluktuk Climate Change Adaptation


The young and the old are communicating at events such as the regional science camp.
Kugluktuk Climate Change Adaptation


Nunavut
Canada


translation means “the bridge”
LAND
COMMUNITY
HOME

. XJ OXNWXN OLP DWH KDJ H
  DS WDWLR 3 URMHFW

RP P XQLW\ 0 HHWLQJ
0 DUK

OLDEHWK ROR
. H -RK R

Overview

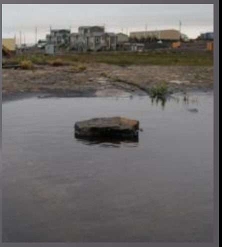
Over the past several decades, residents of the far north have witnessed changes in their natural environment. Much of this change has only been recorded in anecdotal forms, but it has been recognized that the north has been witnessing firsthand the impacts of climate change. These changes directly influence the "frozen" and "unfrozen" seasons, with land and water equally influenced by these changes. With the reliance on the natural environment by all northerners these changes create impacts that influence the way all northerners live, work and in some instances "survive" in the north.

Project Description

Members of the Canadian Institute of Planners (CIP), consulted with local and regional professionals, as well as NRCan scientists to develop this climate change adaptation plan in partnership with the community of Kugluktuk. Over an fourteen month period, the planners visited Kugluktuk five times to seek guidance from the community of Kugluktuk as to their own experiences with climate change impacts, as well as to present and get feedback on their findings and proposed Climate Change Adaptation Plan.

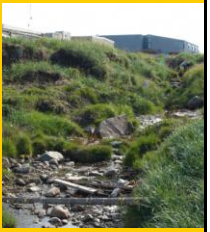
Issues

- Severe rain events
- River overflow during spring
- Unpredictable land travel in summer
- Changing river sediment
- Changing snow and rain conditions
- Increasing ocean storms
- Unpredictable ice conditions
- Unpredictable subsistence hunting
- Increasing rainy weather
- Deteriorating house foundations
- Unpredictable ocean conditions
- Unreliable air travel in winter



Impacts

- Severe erosion after major rainfall events
- Increasing erosion in ditches in community
- Trail access up Coppermine River unsafe
- Water treatment may not cope
- Deteriorating trails for land travel
- Increasing shoreline erosion
- More unpredictable ocean travel in summer
- More unpredictable ocean travel in winter
- Changes in wildlife affecting food harvest
- Increased ponding in ditches
- Deterioration of house foundations
- Weather delays for travel



translation means "the bridge"

Priorities

ISSUE	POTENTIAL OUTCOME
Severe rain events	Severe erosion

Photo courtesy of Jason Prno

Priorities

ISSUE	POTENTIAL OUTCOME
River overflow during spring	Trail access to Bloody Falls

Photo courtesy of Jason Prno

Priorities

ISSUE	POTENTIAL OUTCOME
Land travel in summer	Deteriorating trails

Photo courtesy of Jason Prno

Responses

- Better road and ditch construction
- Drainage planning
- More culverts and ditches
- Larger culverts and ditches
- New trails on land
- Repair trails on land
- River and trail monitoring
- River and trail early warning systems

Responses

- Water treatment Improvements
- New water treatment system
- Identify new water source
- Build a community freezer
- Replace failing house foundations
- Replace houses on stable ground

Responses

- Increase erosion protection
- Move buildings from eroding areas
- Restrict building in eroding areas
- Change hunting habits
- Better forecasting of ocean conditions
- More reporting of ocean conditions
- Better equipment for ocean travel
- Change hunting habits
- Change animals harvested

Actions

•Training on climate change for community leaders and professionals
•Community and High School and Elder workshops
•Identify the staff positions responsible for climate change adaptation
•Create a Kugluktuk community climate change
•Identify dedicated staff resources for climate change work
•Change hunting habits to adapt to climate change impacts
•Improve forecasting and reporting of ocean conditions
•Secure better equipment for ocean travel
•Establish river and trail monitoring and early warning systems
•Improve surveillance and reporting system of ice conditions

Actions

•Change animals harvested to reflect changes in wildlife
•Re-establish the community freezer
•Undertake sediment coring to determine he risk of subsidence
•Survey buildings in community to determine foundation condition
•Replace or repair failing house foundations
•Restrict building in eroding areas
•Move buildings from in hazard areas to stable ground
•Development would take into consideration presence of buried ice
•Repair of trails and build new trails

Actions

•Survey existing vulnerabilities with updated shoreline information.
• Increase erosion protection of existing gabion baskets
• Develop shoreline remediation or relocation plan.
• Evaluate the projected coastal change in terms of built structures
•Evaluation of the potential for changes due to storm surges
•Complete planning and engineering for water supply and treatment
•Implement water supply and treatment Improvements
•Develop drainage plan with new storm assumptions.
•Stream diversion efforts must take subsidence into account.
•Surface ponding of water should be evaluated and addressed.

Actions

•Better road and ditch construction techniques should be required.
•Install larger and more culverts and ditches based on drainage plan
•Complete regarding of ditches based upon drainage plan.
•Snow drift patterns need to be taken into account during planning
• Develop a work plan for implementation of the plan
•Create "implementation monitoring advisory committee"
• Provide tool to review pressing issues with a climate change lens.
• Identify financial resources to support implementation
•Development should be required to evaluate subsurface ice

Implementation

•Develop a work plan for implementation of the Plan for adoption by Kugluktuk Hamlet.
•Create "implementation monitoring advisory committee" to review progress on plan on a quarterly basis and to report to Kugluktuk Hamlet.
•Provide tool to review most pressing issues with a climate change lens.
•Identify financial resources to support implementation – ISCP$, CED $'s …
•Any development proposal should be required to evaluate subsurface ice content prior to approval.
•Climate change adaptation requirements should be included next 5 year review of the Official Plan.

PROJECT PARTNERS

D. Consultation Posters

Appendix 1 – Posters for Public Consultation

ISSUE

Subsistence lifestyle

POTENTIAL OUTCOME

Changes in wildlife

ACTION

List of potential actions – put a mark beside the action you like best.

- O Change hunting habits
- O Change animals harvested
- O Build a community freezer

What other actions can you think of

ISSUE

Increasing ocean storms

POTENTIAL OUTCOME

Increasing shoreline erosion

ACTION

List of potential actions – put a mark beside the action you like best.

- O Better erosion protection
- O Move buildings from eroding areas
- O Restrict building in eroding areas

What other actions can you think of

ISSUE

Severe rain events

POTENTIAL OUTCOME

Severe erosion

Photo courtesy of Jason Prno

ACTION

List of potential actions – put a mark beside the action you like best.

- O Increase erosion protection
- O Better road and ditch construction
- O Better erosion protection
- O More culverts and ditches
- O Larger culverts and ditches

What other actions can you think of

ISSUE

River overflow during spring

Photo courtesy of Jason Prno

POTENTIAL OUTCOME

Trail access to Bloody Falls

ACTION

List of potential actions – put a mark beside the action you like best.

- O New trails
- O Trail improvements
- O River monitoring and warning systems

What other actions can you think of

Appendix 1 – Posters for Public Consultation

ISSUE

Increasing rainy weather

POTENTIAL OUTCOME

Increasing erosion in community

ACTION

List of potential actions – put a mark beside the action you like best.

- O Better erosion protection
- O More culverts and ditches
- O Larger culverts and ditches

What other actions can you think of

ISSUE

Changing snow / rain conditions

POTENTIAL OUTCOME

Increasing ponding

ACTION

List of potential actions – put a mark beside the action you like best.

- O More culverts and ditches
- O Deeper ditches
- O Equipment to pump out ditches
- O Buried storm sewer system

What other actions can you think of

ISSUE

Ocean travel in winter

POTENTIAL OUTCOME

Changing ocean conditions

ACTION

List of potential actions – put a mark beside the action you like best.

- O Better forecasting of ocean conditions
- O More reporting of ocean conditions
- O Better equipment for ocean travel

What other actions can you think of

ISSUE

Ocean travel in summer

POTENTIAL OUTCOME

Changing ocean conditions

ACTION

List of potential actions – put a mark beside the action you like best.

- O Better forecasting of ocean conditions
- O More reporting of ocean conditions
- O Better equipment for ocean travel

What other actions can you think of

Appendix 1 – Posters for Public Consultation

ISSUE

Land travel in summer

POTENTIAL OUTCOME

Deteriorating trails

Photo courtesy of Jason Prno

ACTION

List of potential actions – put a mark beside the action you like best.

- O New trails
- O Trail improvements
- O Trail monitoring and warning systems

What other actions can you think of

ISSUE

House foundations are deteriorating

POTENTIAL OUTCOME

House foundations could collapse

ACTION

List of potential actions – put a mark beside the action you like best.

- O Move houses to stable ground
- O Replace house foundations
- O Replace houses on stable ground

What other actions can you think of

ISSUE

Changing / increasing river sediment

POTENTIAL OUTCOME

Water treatment may not cope

ACTION

List of potential actions – put a mark beside the action you like best.

- O Water treatment improvements
- O New water treatment system
- O New water source

What other actions can you think of

ISSUE

Air travel in winter

POTENTIAL OUTCOME

Weather delays

ACTION

List of potential actions – put a mark beside the action you like best.

- O Better navigation equipment
- O Better servicing equipment

What other actions can you think of

E. Samples of Materials Produced

(1) The Nunavut Climate Change Adaptation Planning Process – Kugluktuk

(2) Nunavunmi Hilaup Aalannguqtirninganut Malikhautivallianiq Ihumaliulirninnga-Kugluktukmi

(3) Poster for Community Meeting

(4) Radio Show Poster

The Nunavut Climate Change Adaptation Planning Process - Kugluktuk

Over the past 30 years, Nunavut has witnessed firsthand the impacts of climate change. From permafrost degradation, to coastal erosion, changing sea ice conditions and the impact to the Inuit way of life, climate change is affecting the way we live, work, and play in Nunavut. We are beginning to understand that adaptive solutions are necessary to address the impacts of climate change.

The Department of Environment, Government of Nunavut is currently working in partnership with Natural Resources Canada (NRCan), the Canadian Institute of Planners (CIP), Indian and Northern Affairs Canada (INAC), Nunavut communities, and other stakeholders on the development of the Nunavut Climate Change Adaptation Plan.

The Nunavut Climate Change Adaptation Plan will serve to implement the goals of the Nunavut Climate Change Strategy 2003 http://www.gov.nu.ca/env/ccs.shtml), which include identifying and monitoring climate change impacts, and developing adaptation strategies.

Included in the work by the Government of Nunavut are projects specific to climate change adaptation at the community level. Kugluktuk has been selected as one of five communities to realize the intent of the Nunavut Climate Change Adaptation Plan at the local level.

Elisabeth Arnold and Ken Johnson, members of the Canadian Institute of Planners (CIP), are working on behalf of the Government of Nunavut to develop a climate change adaptation plan in partnership with the community of Kugluktuk. Both Elisabeth and Ken are working alongside local and regional planners and engineers, as well as NRCan scientists. More importantly, Elisabeth and Ken are seeking guidance from the community of Kugluktuk as to their own experiences with the climate changes they may be experiencing.

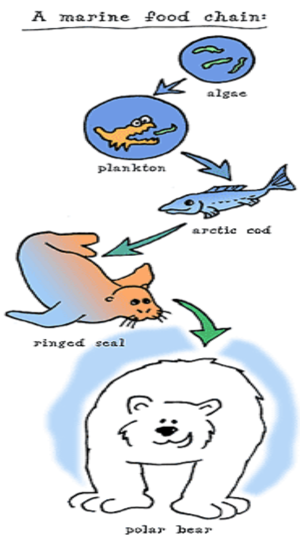
Climate Change in Canada's Arctic

- A changing climate means that there will be big changes to land, water, plants and animals.
- Climate change is already having an impact on the north. Permafrost is melting, wetlands are drying up, sea ice is melting and sea levels are rising.
- Plants will grow earlier in the spring and new plants will grow in the north that never grew here before. Some southern animals such as moose, coyotes, white-tailed deer and cougars will move farther north too!
- Some northern animals such as cold-water fish, caribou, small mammals and polar bears may find it very hard to adapt to rising temperatures.

Communities in the north face big changes due to climate change. Everyone needs to think about how they will adapt to the changes.

Melting Permafrost

Most of the North has a layer of permanently frozen ground just under the top layer of soil - Permafrost. While the top layer of soil thaws every summer and supports plant life and trees, the permafrost (permanent frost) underneath never thaws. As temperatures rise due to climate change, permafrost may thaw. That means that the ground could turn soft and mushy. Roads and airstrips could turn into roller coasters. Buildings, water lines and power poles could tilt and gradually break or fall as the ground thaws and collapses. Melting permafrost could also make it harder for migrating animals and hunters and gatherers to travel over soft, uneven ground.



In the Arctic, polar bears eat seals, seals eat codfish, cod eat plankton, and plankton eat algae. This set of links between the eaters and eaten is called the food chain. The food chain in the Arctic is short and each link in the chain is important. This is especially true for marine life. Every link in the food chain depends on every other link.

First Project Visit Summary

Elisabeth and Ken made their first project visit to Kugluktuk from March 24 to 26, 2009. This trip was planned to introduce the project and the two planners to key stakeholders in the community and to provide a first exchange of information on the climate change adaptation challenges facing the Kugluktuk community. They met with the Hamlet Council and Hamlet Administration; Government of Nunavut (GN) Culture; GN Community Planning; GN Economic Development; GN Social Services; GN Conservation; GN Health & Social Services; and the Kitikmeot Inuit Association.

During these meetings, the planners heard:

- Acknowledgement from the Hamlet Council that Climate Change is an important issue, and acknowledgement that the Council is pleased that to see planners visiting the community.
- Many common issues with climate change expressed by different people offering different overall perspectives.
- Observations that the natural environment is changing significantly, and has been changing for at least a decade (and perhaps longer),
- No formal "record" of the observations made by various individuals, therefore there is limited perspective for comparison of the changes that are occurring.

Physical observation of changes that may be due to climate change:

- Earlier sea ice melt, later freeze-up and reduced sea ice thickness
- More erosion along Coppermine River and more silt in the Coppermine River
- New birds and insects in the region
- Changes in animal behaviours (caribou and seal)
- Colour in lakes is changing from blue to more brown and lake slopes changing.
- Stability of the land is changing
- Less snow in the winter and more rain in the summer.

Impacts on way of life in Kugluktuk:

- Ice conditions are less predictable and potentially unsafe, which impacts on seal harvesting
- Changes in types of fish being caught in Coppermine River.
- Drinking water quality, as it may be impacted by sea-level rise, and erosion of the Coppermine River.
- Changes in the opening of the Northwest Passage: environmental impact of increased traffic, and capacity to respond to potential oil spills and other accidents
- Concern about homes built close to the river because of vulnerability to ice break-up and river bank erosion
- Concern about erosion of gravesite located on an off-shore island

Please contact Elisabeth or Ken if you are interested in sharing your experiences and knowledge regarding the land, climate change, and any other information you feel is important.

Elisabeth Arnold elisabeth.arnold@sympatico.ca
Ken Johnson cryofront@shaw.ca

Nunavunmi Hilaup Aalannguqtirninganut Malikhautivallianiq Ihumaliulirninnga-

Kugluktukmi

30nik avatqumayunik ukiunik, Nunavut tautuktaa ingmiknik pilaqutinga Hilaup Aalannguqtirninganik. Nunaup puvitquumannganik mahaktirininnganik, nunap hinaa akhagarninganut, allanguliqtunut tariup hikunnga qanuritaakhaangit pilaqutaanganiklu Inuinnait inuuhinginnik, Hilaup Aalannguqtirninganut ayurhautigiliqtaa qanuqtut inuuyugut, havaktugut, ulapqiyugullu Nunavunmi. Ilihimaliqtugut hunngiutigiyuq kiutjutikhangik ihariagiyauyut piliriami tamna pilaqutinga Hilaup Aalannguqtirninganut.

Avatiliriyikkut, Nunavut Kavamangat tatja havaktut havaqatigiikhutik ukuninnga Nunamiingaqtuqtamiknik Kaanata (qablunaatitut naittumik NRCan), tamna Kaanatamiut Timiqutigiyangit Ihumaliuqtiuyunut (qablunaatitut naittumik CIP), Allait Ukiuqtaqtumiutallu Katimayiingit Kaanatami (qablunaatitut naittumik INAC), Nunavunmi nunallaangit, allatlu tigumiaqtuuqatauyut piliurninnganik Nunavunmi Hilaup Aalannguqtirninganut Malikhautivallianiq Ihumaliurniq.

Tamna Nunavut Hilaup Aalannguqtirninganut Malikhautivallianiq Ihumaliurniq havakniaqtut atuliqtiriami tikinnahuaqtamiknik Nunavut Hilaup Aalannguqtirninganut Pigiaqtitaunahuarninnga 2003 http://www.gov.nu.ca/env/ccs.shtml), ilauyurlu ilitarilugit munarilugillu Hilaup Aalannguqtirninganut pilaqutingit, piliurlunilu Malikhautivallianiq maliktakhat.

Ilauyurlu havaangani Nunavut Kavamatkunnit havauhiit naunaiqhimayuq Hilaup Aalannguqtirninganut Malikhautivallianinnganut nunallaap itjutiminnganut. Kugluktuk tikkuaqtauhimayuq atauhirmit tallimanit nunallaat ilitturigiami pinahuarninnga Nunavut Hilaup Aalannguqtirninganut Malikhautivallianiq Ihumaliurniq itjutigiyamiitigut.

Elisabeth Arnold, Ken Johnson-lu, ilauyut Kaanatamiut Katimayiinginni Ihumaliuqtiuyunit (CIP), havaktut pitqutigiquplugu Nunavut Kavamangat piliuriamikni Hilaup Aalannguqtirninganut Malikhautivallianiq Ihumaliurniq havaqatigiikhutik inuknik Kugluktukmiutanik. Tamarmik Elisabeth, Ken-lu are havaqatigiiktut Kugluktup avikturhimaninngalu ihumaliuqtiuyunik hanauyakhanik titirauyaqtiuyuniklu, ukuallu NRCan nalunaqtulirinirmik ihivriuqtuiyiinik. Akhuurluaqtaat kihimi, Elisabeth, Ken-lu qinirhiayut ikayuqtauyumaplutik inuknit Kugluktukmiutanit inmikkut ilihimayamiknik uumuuna Hilaup Aalannguqtirninganik ilihimaliqtamiknik.

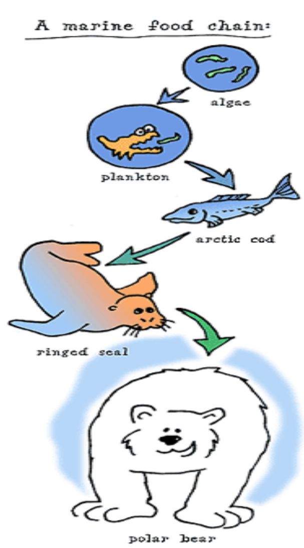
Hilaup Aalannguqtirninganut Kaanataup Ukiuqtaqtumiutmi

- Allanguqtiriniq hilamik inniaqtuq amigaittunik allanguqniq nunaptiknut, imaptiknut, nauttiaptiknut huratjaptiknullu.
- Hilaup Aalannguqtirninganut tatja ayurhautiuliqtuq ukiuqtaqtumut. Nunaup puvitquumannga mahaliqtuq, imalirainnaillu paniliqtut, hikuttauq mahaliqtuq tariuplu immakninnga immakpallialiqtuq.
- Nauttiattauq nauvaliqniaqtut upinngakhalihaaliqqat nutaallu nauttiat nauvaknialiqtut ukiuqtaqtumi tautuknaittuugaluat qangaraaluk. Ilangit qablunaat nunagiyangani huratjat tuktuvait, qablunaat amarunngit taiyauyut kayuutimik (coyote), qakuqtamik-pamiulik qunngit tahapkuallu qablunaatut taiyauyut kuukamik (cougar) nuuniaqtut ungahiktumut ukiuqtaqtumullu!
- Ilangit ukiuqtaqtumiutat huratjangit iqalungit, tuktungit, imarmiutannuat nanuitlu naunaiqnialiqtut hunngiutigilimairniaqtaat hilakput uunaliqqat.

Nunat ukiuqtaqtumi naunaiqniaqtut allanguqtirininnganik piyuq Hilaup Aalannguqtirninganit. Inuit tamaita ihumagiliqtakhaat qanuqtut hunngiutiginialiqtaik hapkuat allanguqtirininnganik.

Mahaliqtuq Nunaup Puvitquumannga

Tamaat Ukiuqtaqtuqmiutat piqaqtuq qiqumahimainnaqhimayumik nuna ataani qaanganit nunap - Nunaup puvitquumannga. Qaanga mahaktillugu auyannguraangat ikayuqhuni nauttianut napaaqtuniklu naupkaininngit, tamna nunaup puvitquumannga (mahalimaittuq) ataani mahalimaittuq. Hilakput uunaliqmat hilakput allanngulirmat, nunaup puvitquuninnga mahakniaruknarhiuq. Taimaatut nuna aqiliqpiarumi. Apqutit akhaluutinut tingmitit milvinginnullu maniinialiqtuq. Igluqpangit, imaup turhuangillu alruyallu napaqutaat uvingalirniaqtut kayumiitunnuamik ahirulirniaqtut ulrulunikluuniit nuna mahakpiaqqat ahiruqpiaqalluuniit. Mahakniq nunaup puvitquumannganik ayurhautiginiaqtuq ikauvaktut.



Ukiuqtaqtumi, nanuit nirivaktut nattinik, nattiittauq nirivaktut uukanik, uukattauq nirivaktut hunavaluknik tariuqmi puptalaaqtuniklu, tahapkuat tariuqmi puptalaaqtuttauq nirivaktut imarmiutami nauvaktunik. Hamna pipkaitjutauyuq niriyut niriyauyullu taiyauyuq niriyut ihariagiyut niriyauyunik . Tamna niriyut ihariagiyut niriyauyunik Ukiuqtaqtumi naittuq tamarmiklu pipkaitjutauyut niriyauniq atuqtauyumi akhuurutauyuq. Una pilluaqtauqpiaqtuq imarmiutanut. Tamarmik pipkaitjutauyuq niriyut niriyauyunullu ihariagiyauyut tamainnut.

Hivulliqpaanguyuq Havauhikhaq Pulaarniq Ihivriuqniq

Elisabeth, Ken-lu hivulliqpaanguyumik havauhiqmut pulaaqtut Kugluktukmut Maatsi 24mit 26mut, 2009mi. Una pulaarniq ihumaliuqtauhimayuq naunaipkaigiami havauhikhaq malruuklu ihumaliuqtiuyut tigumiaqtaulluaqhimayunut Kugluktumi tunigiamikniklu hivulliuyumik himmautigitjut naunaitkutinik hilaup allanguqtirininnganik malikhautivallianinnga akhuurutauyuq Kugluktumiutanut. Katimaqatigiyaat Haamlat Katimayiingit unalu Haamlatkut Titiqqiqiyiingat; Nunavut Kavamakkut (qablunaatitut naittumik GN) Pitquhiliqiyikkut; GN Nunallaani Ihumaliurutauyut; GN Kavamatkunnilu Pivikhaqautikkutnut ; GN Ulaasiliqiyikkut; GN Annguhiqiyiikkut; GN Munarhiliqiyikkutnut Inuuhiriknirmullu; ukuallu Kitikmeot Inuit Katimayiingit.

Katimatillugit, ihumaliuqtiuyut ukuninnga tuhaayut:

- Ilitariyauniq Haamlat Katimayiinginnit tamna Hilaup Allanguqtirininnganut akhuuqtauyumik ihumaalutigiyauyuq, unalu ilitariyauniq Katimayiinginnnit quviahuktut takugiamikni ihumaliuqtiuyut pulaaqtut nunamiknut.
- Amigaittut aatjikutariiktut ihumaalutigiyauyut hilaup allanguqtirininnganut uqaqtauyuq allanit inuknit piyut allanit tamainni tautuktamiknik.
- Qunngiaqtauniq avatikput allanguliqpiaqtuq amihumik, allanguqtiraaqpakturlu taimaa qulinik ukiunik (avatqumayuknarhiuqluuniit),
- Naunairhimanngittuq huli “titiraqhimayunik” tautuktamiknik piliurhimayuq allanit inuknit, taimaatut kikliqaqtuq tatuktamiknik naunaiyariami allanguqtirininngit tatja piyuq.

Qunngiaqtaulluarniq allanguqtirininnganik piyuknarhiyuq Hilaup Aalannguqtirninganit:

- Qilaminnuaq tariuq mahaliqtuq, qiqinnahaaliqhunilu ivyuhiurnairhunilu hiku
- Akhararniqpialiqtuq Kugluktup Kuunga marluinnanguliqturlu Kugluktup Kuugaa
- Tautuknaittunik nutaat qupanuat kumaitlu takunnarhiliqtut Kugluktumi
- Allanguqtut huratjat pitquhingit (tuktut nattiitlu)
- Kalanga tahiup allanguliqtuq aryiqtarmit marlunngayumuut tahiillu uvinganiit allanguliqtut.
- Naptuninnga nunauplu allanguliqtuq
- Aputiqarluaruknairhunilu ukiumi nipalluinaqpialirhunilu auyami.

Pilaqutauyut inuuhirmi Kugluktukmi:

- Hikulu naunarhiyuq qayangnarhiutiplunilu, ayurhautigiyuq nattirhiuqniqmut
- Allanguqtirininnga allatqiinik iqaluknik iqaluliqtullu Kugluktup Kuungani.
- Imiq niuqqaqtaptiknik, ayurhautigiyauniaqtuq tariup-nalunairninnga immautilirmat, unalu akhagarninga Kugluktup Kuunga.
- Allanguqtirininnga angmaqtirininnganik Uallinirmit Tariukkut Apqutinga: avatiup ayurhautigiyauninnga atuqtauqpallaalirmat, piinarninngalu kiugiami urhuryuamik kuvipkaigumik aalaniklu kuvipkaitjutauniit
- Ihumaalutigiyauyuq iglut igluqpiliurhimakmata qanitpallaaqtumik kuukamut ayurhautigiyauniaqtuq hiku qaraliqqat kuukaplu hinaa akhagarninnganik
- Ihumaalutigiyauyuqlu akhagarninnganik iliuviqvinganik qikiqtami

Hivayatjavat Elisabeth, Ken-luuniit ikayurumaguvit ilihimayarniklu nunatigut mikhaanut, hilaup aalannguqtirninnganik, allaniklu naunaitkutanik ihumagiyarnik uqaqtakhariyarnik.

Elisabeth Arnold elisabeth.arnold@sympatico.ca Ken Johnson cryofront@shaw.ca

COMMUNITY MEAL AND MEETING

to discuss draft **climate change** plan for the community of Kugluktuk

Wednesday, March 3rd
at 5 pm in the Rec Center

PROJECT PARTNERS
Indian and Northern Affairs Canada
Canadian Institute of Planners
Government of Nunavut
Natural Resources Canada
Hamlet of Kugluktuk

Radio Call-in Show on …

Climate Change Plan for Kugluktuk

CBIO 105.1 FM

Monday, March 1, 2010

7 p.m.

Local observations and scientific studies suggest that climate change could affect Kugluktuk in a number of ways. There could be more violent storms, unpredictable ice conditions and thawing of permafrost.

Ken Johnson and Elisabeth Arnold are planners who have been working with the Kugluktuk community to identify the best ways to prepare for possible changes to our climate.

They will be in Kugluktuk March 1 to 4, 2010 to get feedback on a draft Climate Change Adaptation Plan for Kugluktuk.

Please tune-in to learn about the project and to give your ideas on how to plan for changes to the climate in Kugluktuk.

Call-in number … 982-3515

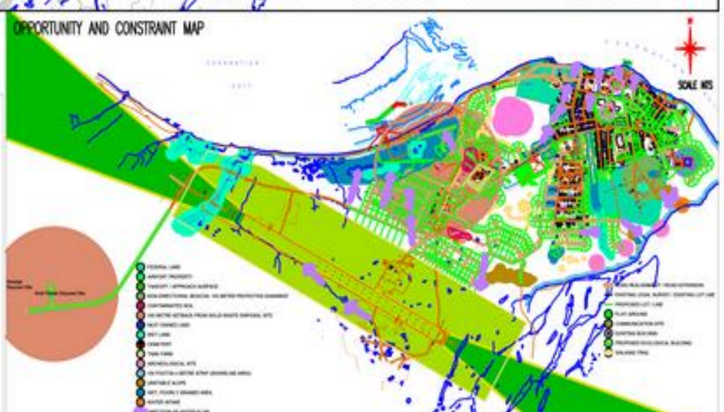
Prizes for the first three callers!

F. Kugluktuk Maps and Community Plan

KUGLUKTUK COMMUNITY PLAN

SCHEDULE 2 – LAND USE & ZONING

GOVERNMENT OF NUNAVUT



SCHEDULE 1 – LAND USE POLICIES

1. INTRODUCTION

1.1 Purpose of the Community Plan

The Kugluktuk Community Plan contains Council's policies for managing the physical development of the Hamlet of Kugluktuk for the next 15 years - to 2021 - that reflect the needs and wishes of the Community. The Plan was created through a community consultation process. The Community Plan builds on previous plans, while incorporating new challenges, issues and needs identified by the community.

1.2 Goals of the Community Plan

Community Plan policies emerge from the values of a community and its vision of how it would like to grow. The goals established for this Community Plan are:

1. To create a safe, healthy, functional, and attractive community that reflects community values and culture.
2. To promote the Plan as a tool for making effective and consistent decisions regarding land use and development in the community.
3. To ensure an adequate supply of land for all types of uses to support the growth and change of the community.
4. To build upon community values of participation and unity to support community projects and local economic development.
5. To protect the natural beauty of "Nuna" and retain waterfront and lakeshore areas for public uses and traditional activities.

1.3 Administration of the Plan

The Community Plan is enacted by By-law. Changes to the Plan can be made by amending the By-laws in accordance with the Nunavut Planning Act. The Community Plan should be reviewed and updated every five years as required by the Nunavut Planning Act. A Zoning By-law is also being enacted for the purpose of implementing detailed policies based on the Community Plan. All development must follow the intent of the Community Plan and Zoning By-law. The Community Plan includes: Schedules 1, 2 and 3.

2. POPULATION & HOUSING PROJECTION

At the time of preparation of this Plan, the population of Kugluktuk was approximately 1,200 people. This Plan is based on a projected population for Kugluktuk by 2020 of 2,076 people. It is estimated that an additional 100 dwelling units will be required to meet the projected population growth, representing the need for approximately 10.95 hectares of land for development.

3. GENERAL POLICIES

The following policies of Council apply to development in the Hamlet regardless of land use designation:

a) The development of lots shall be subject to the following lot development policies:
   i. All service connections to buildings shall be easily accessed from the front yard on all lots.
   ii. Buildings shall be sited to respect setbacks identified in the Zoning Chart.
   iii. Any building over 500m2 in gross floor area shall consider potential wind impacts on surrounding development. A wind study may be required by the Development Officer.
   iv. Culverts are required and shall be installed at the access points to lots.
   v. On any portion of a lot where fill is introduced, drainage shall be directed towards the public road. Exceptions may be made by the Development Officer.
   vi. Road widening may be obtained as required at the time of development or redevelopment of a lot in situations where the road right of way is less than 15 metres wide.

b) Consideration should be given to the development of a Drainage Plan for the entire community and the adoption of a snow piling by-law.
c) Utilities or communications facilities shall be permitted in any land use designation.
d) The Hamlet will pile snow in locations to minimize downwind snow drifting and where spring melt run-off can be properly channeled to drainage ditches or waterbodies.

4. LAND USE DESIGNATIONS

4.1 Residential

The Residential designation provides land for primarily residential uses, however, also permits other small-scale conditional uses subject to the approval of Council. The policies of Council are intended to maintain an adequate supply of land for residential development, to build safe and livable neighbourhoods, and to protect residential areas from incompatible development. The policies of Council are:

a) The Residential designation will be used primarily for housing with all types of dwelling types permitted. Uses that are residential in nature such as a group or special needs home, a home occupation, or bed and breakfast will also be permitted.
b) Residential development will be phased so that a target minimum of 1 hectare of vacant surveyed land is available at any given time.
c) In addition to the above, Council will look for opportunities for infill lots for new housing within the existing town site.

4.2 Community Use

The Community Use designation is intended to maintain an adequate supply of land for community uses, to provide easy access to public facilities and services, and to reserve significant and important locations for community uses. The policies of Council are:

a) The Community Use designation will be used primarily for uses that are public in nature (i.e. social, cultural, religious, or educational).
b) Community facilities often generate higher volumes of traffic and will therefore be sited in a manner which provides safe, easy access with ample space for parking.
c) New community facilities are to be located within the existing town site or adjacent to future development areas.
d) The old cemetery will be designated protected area and be integrated in the Cultural Circuit of the Kugluktuk Hamlet. The new cemetery located on the west part of the hamlet will be integrated in the Community Plan and serve community needs.
e) Churches have significant land in the existing Core area of the community. Council may consider opportunities, in discussion with church representatives, to redevelop a portion of church lands that are surplus to their long-term needs for other community uses or for residential development.
f) A School reserve Area is designated for the new residential development area.
g) The lots between the existing Hamlet building, the antenna and the row houses should be developed for cultural needs of the community. The Hamlet shall take a geological study for the proposed development in order to meet the engineering requirements for the proposed buildings.

4.3 Commercial

The Commercial designation is intended to support local economic development by maintaining an adequate supply of land for commercial uses in a central location with good access from the community. The policies of Council are:

a) The Commercial designation will be used for commercial uses such as hotels, restaurants, retail, personal and business services, and offices (private and government).
b) Residential uses shall be permitted when located above a ground floor commercial use.
c) Commercial facilities often generate higher volumes of traffic and will therefore be sited in a manner which provides safe, easy access with ample space for parking.
d) Council shall designate the area for the Hamlet Office and a development project shall be required.
e) Council will consider widening the road allowances through surveying to permit a widening of roads in the future and ensure adequate development setbacks.
f) New commercial lots are designed for future development which will accommodate home based business as needed in Community.

4.4 Waterfront Reserve

The Waterfront Reserve designation is intended to protect shoreline environments, maintain views to the sea, and reserve access to lakeshore and seashore areas for traditional uses. The policies of Council are:

a) The Waterfront Reserve designation will be used for traditional and recreational uses such as beach shacks, boat storage, community docks, dog teams and temporary storage of sealift equipment during sealift operations. All uses are conditional and at the discretion of Council.
b) The siting of any development, including exterior storage of materials during sealift and barge operations and boat storage, shall be at the discretion of Council.
c) Owners of development will be required to maintain the development and keep the surrounding area tidy.
d) Dog teams shall only be located in areas indicated by the "Dog Team Holding Area" symbol on the Land Use Map.
e) Unless otherwise noted, all Commissioner's Land forming part of the 100-foot strip (30.5 m) along the seashore measured from the ordinary high water mark will be designated Waterfront Reserve.
f) To reduce the risk of flooding and erosion, no development is permitted within 30 metres from the normal high water mark of lakes, rivers and creeks.
g) Council may consider the filling of a waterbody where it is needed for future development provided that a fish habitat and drainage assessment is completed and the appropriate approvals are obtained.

4.5 Open Space

The Open Space designation is intended to reserve open spaces within the built up area for recreational uses, as a gathering space for community events and to preserve significant natural and cultural features within or outside the townsite. The policies of Council are:

a) The Open Space designation will be used primarily for parks, playgrounds, playing fields, walking and interpretive trails. In general, buildings will not be permitted, except for small Hamlet recreation storage sheds or washroom facilities.
b) A minimum of 100 square metres of park space should be provided for every 30 dwellings such that the park is within 300 metres of each residence.
c) A series of walking trails with heritage significance shall be developed and integrated into cultural circuit of the community.

4.6 Industrial

The Industrial designation is intended to reduce the negative effects and dangers associated with industrial uses such as noise, dust, truck travel and the storage of potentially hazardous substances, industrial uses shall be concentrated on the periphery of the townsite. The policies of Council are:

a) Permitted uses in the Industrial designation will include all forms of manufacturing, processing, warehousing and storage uses. Permitted uses will also include garages, power generation plants, and fuel storage.
b) The Hamlet will consider the area designation that will accommodate the new lagoon plant and engineering project with all required studies shall be submitted.
c) The new barge facilities situated in 6th District will accommodate the needs of the community.
d) A new light industrial development will accommodate the needs of the community.
e) The Hamlet will work with local businesses and government operations to identify opportunities to relocate non-conforming industrial uses (eg. garages, warehouses) to the industrial subdivision.

4.7 Transportation

The Transportation designation is intended to protect and ensure the safe operation of airport activities and other transportation facilities such as the NDB (non-directional beacon) communications site, and may include marine facilities in the future. The policies of Council are:

a) Permitted uses in the Transportation designation includes all activities related to air traffic, marine facilities and uses accessory to these activities such as communications sites.
b) Influence zones around lands designated Transportation are indicated on the Land Use Map. No development is permitted within these influence zones without the approval of Nav Canada and Hamlet Council.

4.8 Hinterland

The Hinterland designation applies to all other land within the Municipal Boundary not designated by another land use and is intended to protect the natural beauty and cultural resources of the land-'Nuna'-while providing access for traditional, recreational and tourism activities. The policies of Council are:

a) The Hinterland designation generally permits traditional, tourism and recreational uses. Permitted uses also include dog teams, commercial harvesting and quarrying, and infrastructure projects for local economic development.
b) The Council will consider the opportunity of integrating the *Bloody Fall Territorial Park* into the tourism circuit.
c) The Hamlet shall protect any cemeteries and sites of archaeological significance from disturbance.
d) Dog teams shall only be located in areas indicated on the Land Use Map.
e) The Hamlet intends to continue the trans-island road project to improve access to the land and to reduce the negative impact of vehicle traffic on the tundra.

4.9 Waste Disposal

The Waste Disposal designation is intended to identify existing or former waste disposal sites and ensure appropriate development setbacks. The policies of Council are:

a) The Waste Disposal designation permits no development except those accessory to the operation or remediation of a waste disposal site.
b) The Hamlet shall study the feasibility of remediating the former waste disposal site located by the community arena.
c) The Hamlet shall prohibit the development of new subdivisions within the 450 metre setback from any existing or former waste disposal site as required by Public Health Act.
d) Council will consider the opportunity of undertaking an Environmental Assessment for the old Waste Disposal Site and turn this brown field into green field so that new residential development could take place and take advantage of the ocean views.

4.10 Protective Development

The Protective Development designation is intended to protect the water supply, granular resources and any environmentally sensitive areas. The policies of Council are:

a) The Protective Development designation does not permit any development except uses accessory to the supply of water such as a pipeline, pumping or monitoring station or road, or, the operation or remediation of a quarry or gravel pit.
b) Council will consider the opportunity of undertaking geological study to identify new granular sites as required by the community infrastructure system.

4.11 Future Development

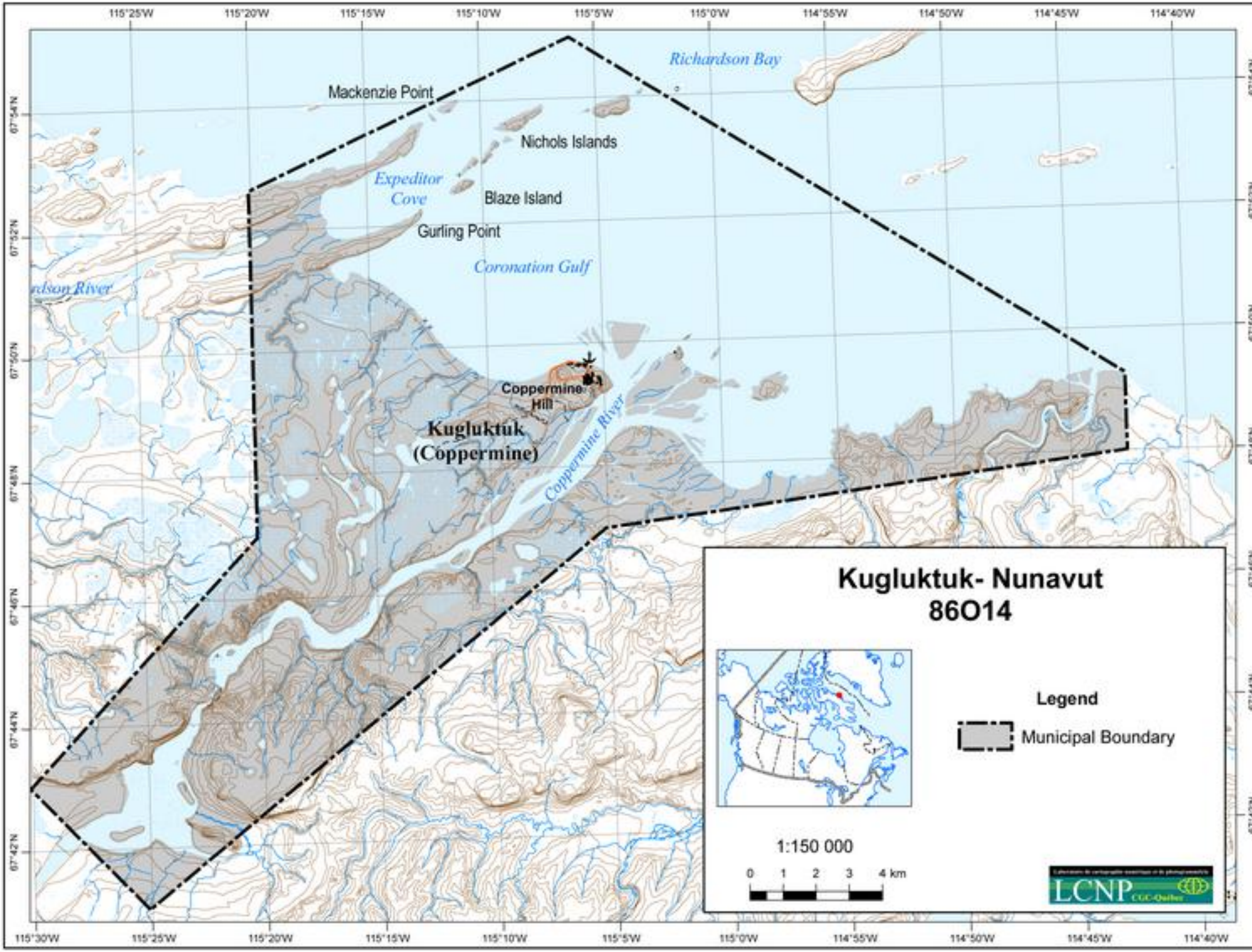
The Future Development designation is intended to reserve land for the future growth of the community. The policies of Council are:

a) The Future Development designation does not permit any development except temporary uses.
b) Future Development lands shall be redesignated by amendment to this Plan prior to being used for community expansion.
c) Lands designated Future Development may be affected by significant environmental constraints to development such as shallow waterbodies and poor drainage. All constraints shall be cleared of environmental constraints prior to the lands being redesignated for development.

4.12 Municipal Reserve

The Municipal Reserve designation is intended to identify lands that may be interesting for future redevelopment but are currently constrained by a landfill site. The policies of Council are:

a) The Municipal Reserve does not permit any development except temporary uses. Uses that include human habitation, food storage or food preparation is <u>not</u> permitted, in accordance with the General Sanitation Regulations of the Public Health Act.
b) The lands designated Municipal Reserve on the Land Use Map have been identified as the preferred location for future residential development and community uses such as a school. Prior to the redesignation of any of these lands for community expansion, the following steps must be undertaken:
   (i) an environmental assessment of the former landfill site to determine the extent of contaminants and feasibility and cost of remediation;
   (ii) remediation of the former landfill site in accordance with the environmental assessment;
   (iii) obtain approval of Department of Health and Social Services and Department of Community and Government Services to permit redesignation of Municipal Reserve lands; and,
   (iv) redesignate the lands to the desired land uses by amendment to this Plan.


Richardson Bay
Mackenzie Point
Nichols Islands
Expeditor Cove
Blaze Island
Gurling Point
Coronation Gulf
rdson River
Coppermine Hill
Kugluktuk (Coppermine)
Coppermine River
Kugluktuk- Nunavut
86O14
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Municipal Boundary
1:150 000
0 1 2 3 4 km
LCNP CGC-Québec
115°30'W 115°25'W 115°20'W 115°15'W 115°10'W 115°5'W 115°0'W 114°55'W 114°50'W 114°45'W 114°40'W
67°42'N 67°44'N 67°46'N 67°48'N 67°50'N 67°52'N 67°54'N

G. Science Reports from NRCan

A Reconnaissance Assessment of Landscape Hazards and Potential Impacts of Future Climate Change in Kugluktuk, Nunavut.

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INTRODUCTION

Arctic coastal communities are recognized as being particularly sensitive to projected climate change. Some of this sensitivity reflects the dynamic and direct linkage community members have with the land and surrounding seas, both in terms of their utilization of these for travel corridors, and as it pertains to traditional hunting and other country food collection. Changes in sea ice regime in terms of its seasonal extent, thickness, and stability will have the greatest immediate impact on arctic coastal communities. The focus of this reconnaissance assessment, however, is landscape stability as it pertains to potential impacts on existing infrastructure, and how such insights can be used to guide investigations supporting future adaptation strategies and town planning guidelines.

Information presented here is based on a site visit to Kugluktuk by the author on August 18-21, 2009. Information gathered during the community visit included field surveys and foot traverses throughout the townsite, tours provided to the author of various infrastructure and development areas, and conversations with community members and members of the community governance and planning organizations. Additional information included in this assessment was derived from analysis of archival stereo airphotos.

LOCATION AND PHYSIOGRAPHY

Kugluktuk (formerly known as Coppermine) is located on the north coast of mainland Canada, on the western edge of the Coppermine River where it empties into Coronation Gulf (67°49’N; 115°06’W). It lies north of treeline in the Southern Arctic Tundra biome, a region commonly referred to as the “Barren Grounds.” Rock surfaces are often bare, while much of the landscape is covered by extensive shrub, herbaceous plant, and moss cover. The terrain in the Kugluktuk area is characterized by coastal lowlands and a series of step-like terraces and deltas rising from ~10m above sea level, to the 170 m marine limit delta situated 50 km up the Coppermine River at Muskox Rapids. These terraces and deltas formed during the retreat of the last ice age (over 11,000 years ago) and throughout the period of Holocence isostatic uplift (Figure 1). Isostatic uplift is still ongoing, and is estimated to account for a rise (=sea level fall) of not more 10 cm in the 2010 to 2100 year time period (James et al. 2009) .

The surficial geology of the region surrounding Kugluktuk is depicted in maps by Kerr et al. (1997) and St. Onge (1988), and in Dredge’s 2001 report. A more detailed reconstruction based off of airphotograph interpretations by this author is presented in Figure 2. Bedrock outcrops are prominent throughout the town. The majority of unconsolidated sediments within the town are related to submersion of the landscape during deglaciation, and its subsequent isostatic uplift. A prominent, flat delta terrace, upon which the airport runway was built, is situated ~30 m above sea level and is considered to have formed ~6000 years ago (Figures 1b and 2-Gd; Dredge, 2001). Around 5000 years ago, sea level was situated about 20 m higher than it is today, and the Coppermine River drained through both a west channel (west of present-day Kugluktuk and beyond the bounds of Figure 2) and along an east channel that followed a similar path to the modern river (Figure 1c). An extensive flat sand, silt and gravel terrace situated west of the community was formed during this period. By 3500 years ago, sea level was 10-15 m above present, and drainage occurred along the modern Coppermine River channel only. Sand, silt and gravel terraces forming the northern shoreward

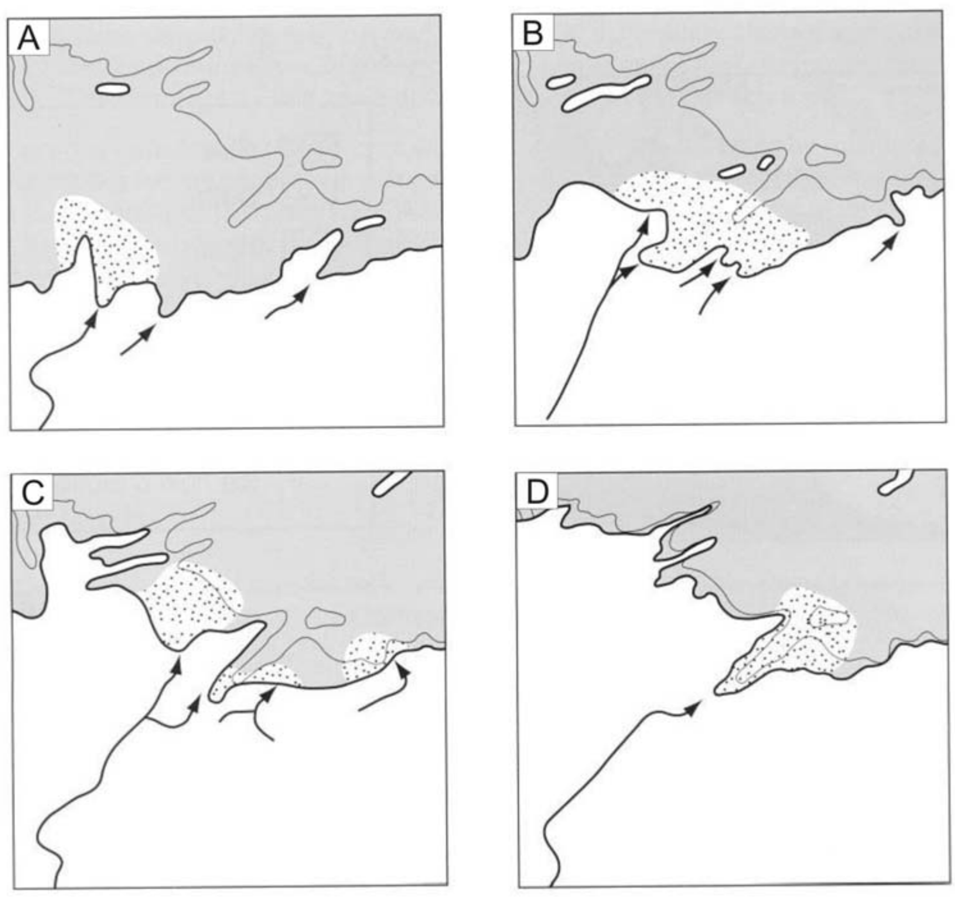

Figure 1. Final stages of deglaciation and emergence of the land: A) land (white area) and sea (grey area) about 8000 years ago, and development of the terraces at 70-80 m along the Coppermine River; B) development of the delta at 6000 years ago, and emergence of Saddleback hill; sea level was about 30 m above present; C) coastline about 5000 years ago, when the west channel of the Coppermine River was active and sea level was about 20 m above present; D) land and sea about 3500 years ago, when sea level was 10-15 m above present. [Source: adapted from Dredge, 2001, p26]

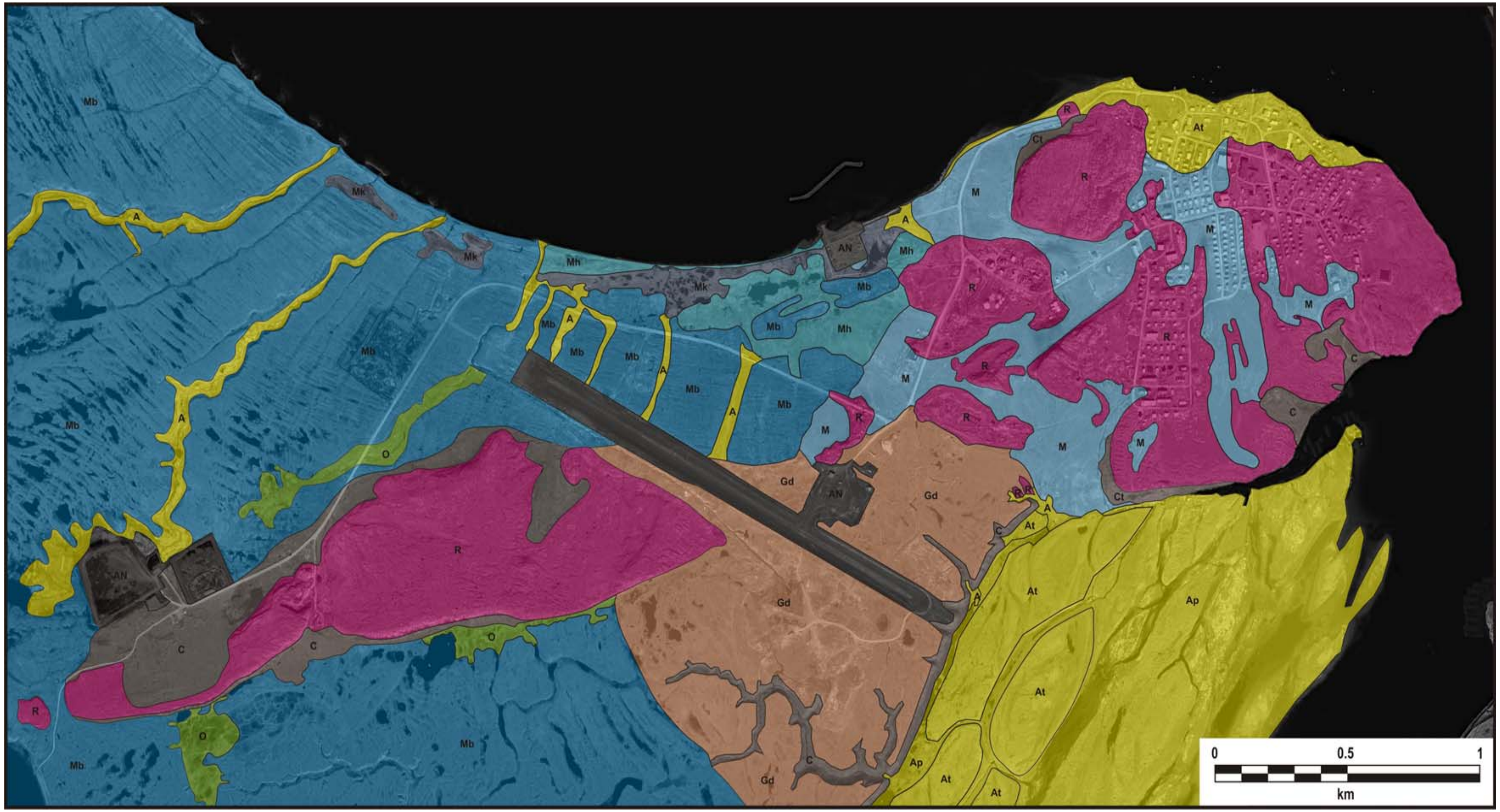

Figure 2. Surficial geology map, Kugluktuk, Nunavut. For Legend, see next page.

Figure 2 - LEGEND

ANTHROPOGENIC DEPOSITS: **AN**, culturally made or modified materials, usually comprising infills and pad developments.

COLLUVIAL DEPOSITS: **C**, a thin and discontinuous cover of earth materials accumulated through gelifluction and other slope process; **Ct**, talus debris accumulations below rock scarps.

ORGANIC DEPOSITS: **O**, peat and muck formed by accumulations of plant material in various stages of decomposition; generally occurs as flat, wet terrain overlying poorly drained substrates.

ALLUVIAL DEPOSITS: commonly stratified; **A**, sorted sand, silt, and minor gravel and organic detritus deposited by streams; **At**, sorted sand, silt and gravel deposited by the Coppermine River and tributaries into former higher sea levels; **Ap**, modern floodplain of the Coppermine River.

GLACIOFLUVIAL DELTAIC DEPOSITS: **Gd**, sorted sand, silt, and gravel delta terraces deposited by the deglacial Coppermine River.

MARINE DEPOSITS: **M**, a mixture of sand, silt and rocks deposited in, or reworked by post glacial marine flooding; may include reworked diamict (till), thickness of material is generally thin (<2 m), but locally may infill deeper bedrock hollows.

HUMMOCKY MARINE DEPOSITS: **Mh**, a mixture of sand, silt and rocks deposited in post glacial marine flooding of the landscape, that were reworked into raised beach ridges; characterized by hummocky or irregular surface topography considered to reflect differential melt or content of underlying ground ice.

MARINE DEPOSITS - RAISED BEACH RIDGES: **Mb**, a mixture of sand, silt and rocks reworked into raised beach ridges; local ponding behind ridges is common; may contain significant quantities of buried ice.

MARINE DEPOSITS - THERMOKARST: **Mk**, a mixture of sand, silt and rocks deposited in post glacial marine flooding of the landscape, that were reworked into raised beach ridges that following isostatic uplift, have undergone extensive melting of buried ground ice leading to land subsidence and surface ponding.

BEDROCK: **R**, gabbro of the Proterozoic Coronation sills and associated dykes.

margins of Kugluktuk and the raised alluvial terraces east of the airport along the Coppermine River (Figure 2 - At) were deposited into this higher sea level (Figure 1d). Erosion of the raised alluvial terraces by the Coppermine River during continued isostatic uplift from 3500 years ago until today has produced the extensive alluvial plain (Ap) shown on Figure 2, much of which appears to experience seasonal, or occasional flooding. Alluvial sediments are also found along small streams (some of which may be ephemeral) that cut perpendicular downslope through areas of extensive beach ridges west of town. In places these channels are over-deepened and widened suggesting that they have incised into ice-rich terrain. The terrain underlying the central part of Kugluktuk is comprised of a marine-washed surface lag. Sediments are predominantly sandy, but may contain significant quantities of finer-grained material (silt and clay) and clasts. Till was not identified in the field, but may underlie some areas. Thicknesses of unconsolidated sediments in the M terrain unit areas are generally thin (<2 m), but locally may infill deeper bedrock hollows. Ice content is unknown, but may be significant in areas infilling bedrock hollows, but is otherwise considered small based on an absence of indicative surface morphology. In the area of the sea lift and port facility, extensive pitting and surface ponding suggests that the predominantly marine sediments in this area have undergone thermokarst (Figure 2 – Mk), that is, melting of ice-rich permafrost. Areas surrounding this exhibit a hummocky topography (Figure 2 – Mh) also suggestive of differential ground ice melt. Most of the remaining terrain in the Kugluktuk area is characterized as Beach Ridges (Figure 2 – Mb). Here, distinctive parallel ridges extend perpendicularly upslope, often with small ponds impounded behind ridge crests. Large ice wedges and extensive erosion by small streams in both the beach ridge (Mb) and glaciofluvial delta (Gd) deposits suggest that ice content may be significant, but highly variable in these deposits. Organic deposits are found in low-lying, wet terrain, west and southwest of the airport. Thickness of organic matter in these areas is unknown.

Projecting through the terraced landscape is a series of parallel east-northeast oriented, elongate bedrock hills. Comprised chiefly of gabbro (Baragar and Donaldson, 1973), they are characterized by cliffed southern faces and more gently sloping northern faces. Cliffed areas are frequently associated with talus accumulations. Prominent bedrock outcrops occur throughout the town, and based on their physiographic expression, bedrock is considered to shallowly underlie much of the central and southern extents of the town site.

CLIMATE

Kugluktuk's weather is influenced by Arctic air masses year-round, and is characterized by short, cool summers, and long, cold winters. Based on the 1971-2000 Canadian Climate Normals, Kugluktuk has a mean annual air temperature of -10.6°C, with monthly averages ranging from a low of -27.8°C in January to a high of 10.7°C in July. Over the period of 1978-2008, there appears to be a 1-1.5°C increase in mean annual air temperature (Figure 3). The coldest temperature in the 1971-2000 period was

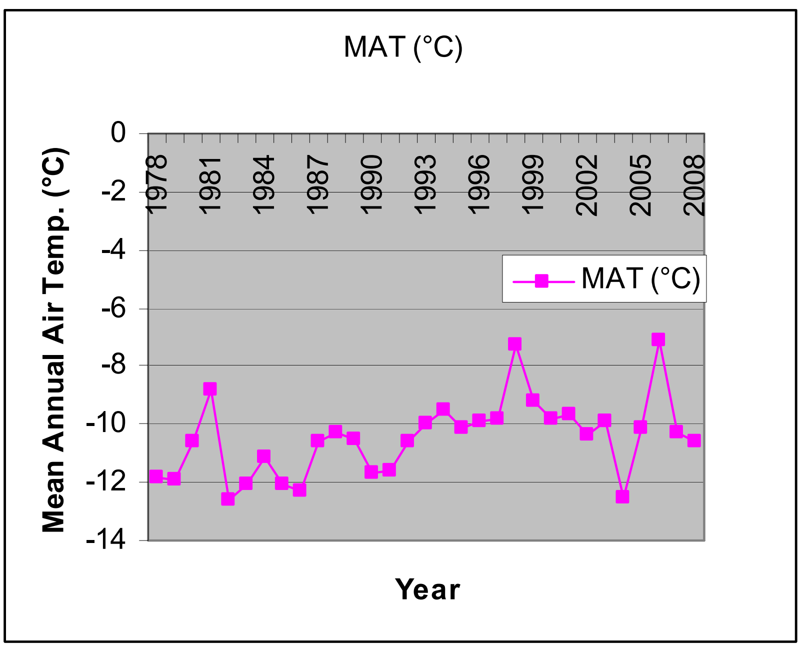

Figure 3. Graph of Mean Annual Air Temperature from 1978-2008, Kugluktuk, Nunavut.

-47.2°C on February 20, 1998; the warmest temperature in the 1971-2000 period was 34.9°C on July 15, 1989. Annual average precipitation is 249.3mm, of which roughly half (133.4 mm) falls as rain, the rest (165.7 cm) as snow. Average maximum snow depth is ~0.5 m, and occurs throughout Feb-Mar-April. In the 1971-2000 period, extreme daily rainfall was 53.7 mm on August 12, 1982, while extreme daily snowfall was 26.2 cm on January 1, 1988. This extreme rainfall event was eclipsed by the 55.7 mm of rain received July 20, 2007, immediately followed by the 115.0 mm received July 21, 2007. Monthly average wind speed is fairly constant year-round, ranging from 19 km/h in January to 14 km/hr in June. Wind direction does show seasonality, being predominantly from the southwest in winter and from the east in summer. Maximum monthly hourly wind speeds are almost always from the northwest, and maximum gusts range from 74 km/h in June to ~106 km/h in the Dec-March period.

PERMAFROST

Kugluktuk lies within a region of continuous permafrost. Depth of seasonal thaw (active layer thickness) is unknown in Kugluktuk and is likely to be spatially variable reflecting parent material, vegetation cover, and seasonal snow cover. Comparisons can be made with short term (~1 year) thermistor profiles collected for two near-coastal sites ~20 km east of Kugluktuk (Figure 4; Wolfe, 2000) that show depth of thaw penetrating between 1.5 and 2+ metres (Figures 5 and 6).

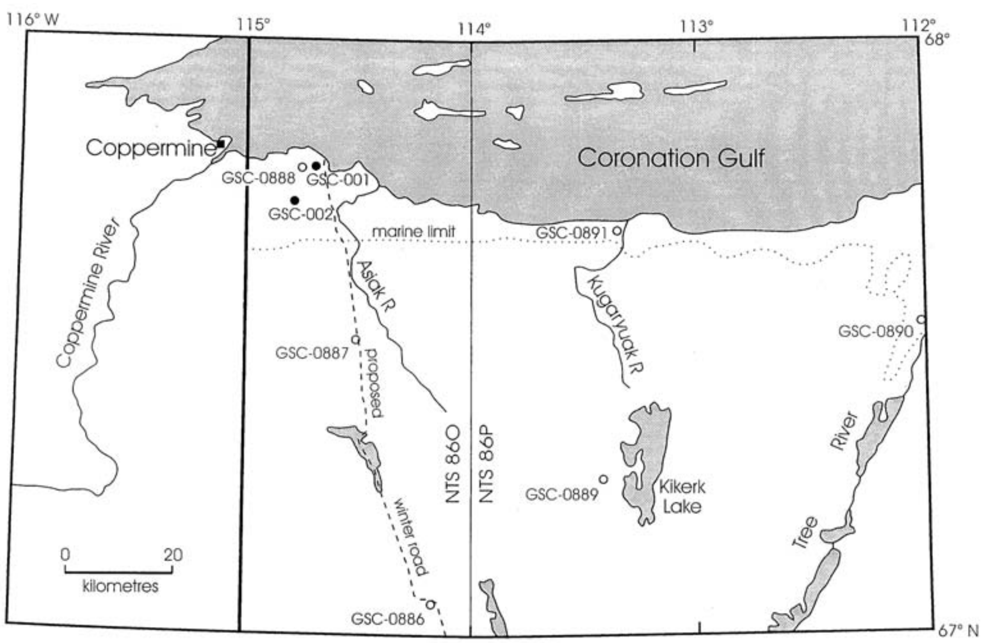

Figure 4. Location of monitoring stations in Wolfe's (2000) study area. Black dots represent ground thermal profile and lakewater monitoring stations; white circles represent air and near surface ground temperature stations. [Source: Wolfe, 2000, p6]

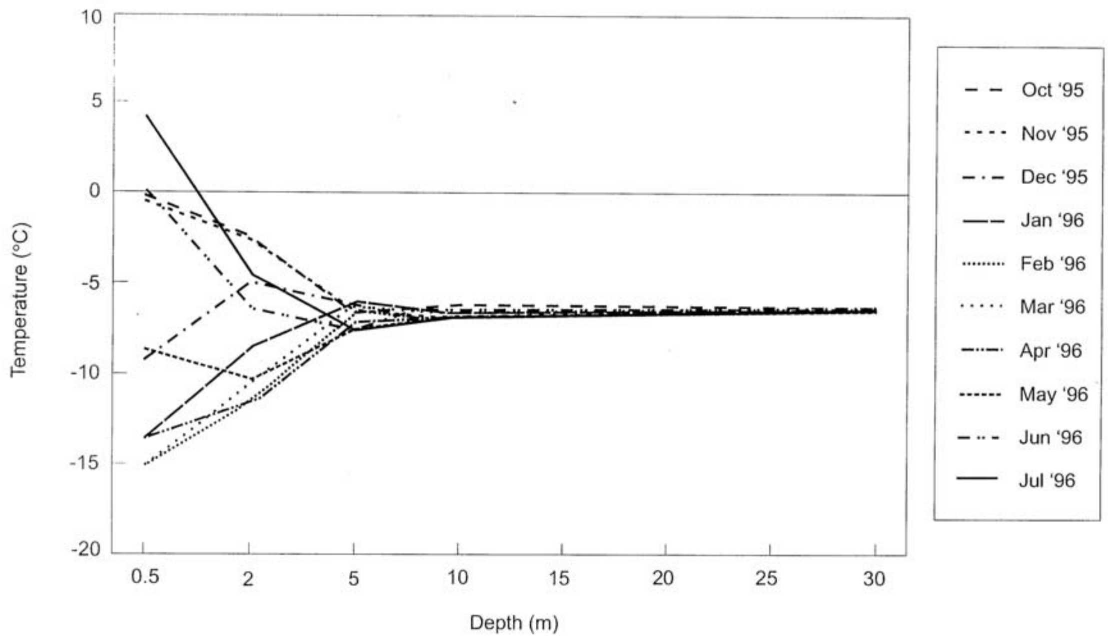

Figure 5. Ground temperature profiles for site GSC-001. [Source: Wolfe, 2000, p39]

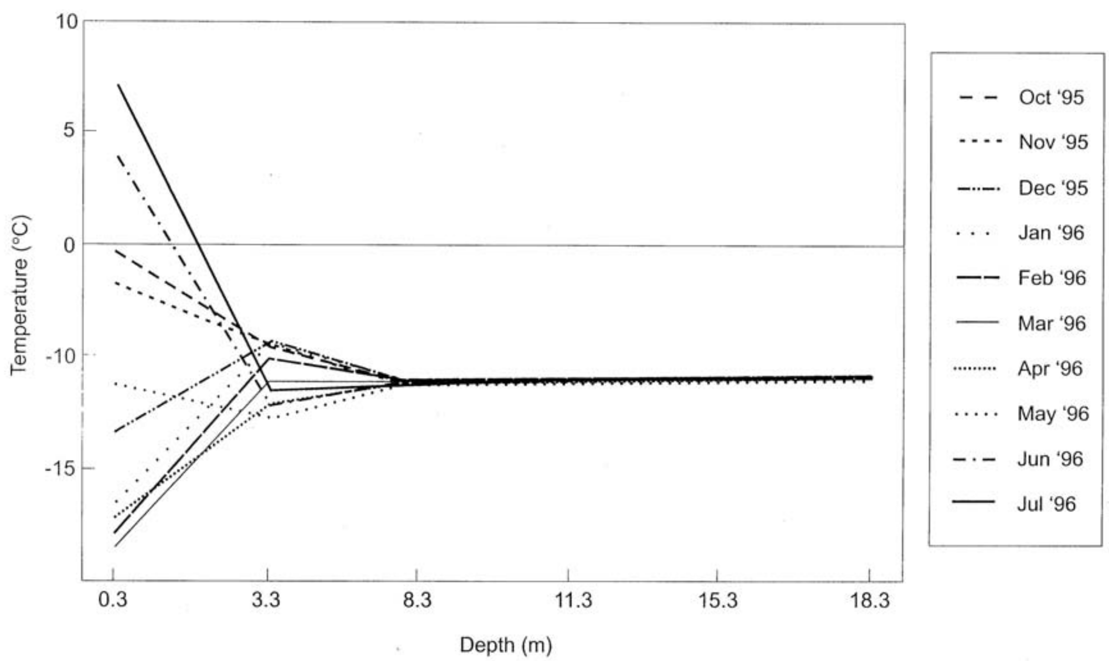

Figure 6. Ground temperature profiles for site GSC-002. [Source: Wolfe, 2000, p.40]

Periglacial landforms are widespread in the Kugluktuk area, and garner consideration in any development proposal. While much of the marine sediments that blanket areas of Kugluktuk are predominantly sand, they do contain significant proportions of silt and clay. These sediments are conducive to water retention, which in a permafrost environment becomes ice. During the process of initial permafrost aggradation into these sediments following isostatic uplift, the water would have migrated through the sediments to a freezing front, leading to the development of horizontal ice lenses. It is suspected that such lenses (which can be from millimetre to decimetre thickness scale) are found in the lower alluvial terrace sediments (At - Figure 2) that much of the northern part of Kugluktuk is built upon. Assessment of any ice content in these sediments is important for determining foundation stability of existing buildings, and for design considerations that take into account potentially increased thaw subsidence that may occur under climate warming. If ice lenses do occur in these fluvial terrace sediments, then exposure of them by erosion and slumping of sediments along the shore caused by wave action (Figure 7) or by erosion and incision by surface runoff (Figure 8) could lead to increased and rapid coastal retreat, imperilling near-shore infrastructure.

Figure 7. Erosion of sandy alluvial terrace sediments along Kugluktuk's northern shore. Gabion baskets (foreground) that were installed to reduce erosion are now being undercut and/or destabilized by wave-induced erosion. Wave-induced undercutting of vegetated slopes seen in the background (marked by arrows) has resulted in slumping of sediments along the base of the active layer. Exposure of underlying frozen sediments along cracks will lead to further erosion. (photo, I.R. Smith)

Figure 8. Stream erosion atop alluvial terrace sediments beside the sea shore, Kugluktuk, Nunavut. Channelling of meltwater and rainwater from community through an unarmoured channel has resulted in physical erosion and incision. Incision of the channel has also likely led to melting of underlying permafrost, resulting in thermal erosion, and enhanced over-deepening of the channel. Slumping of sediments along channel margins points to ongoing instability and lateral propagation of the channel margins. (photo, I.R. Smith)

Saline permafrost (Biggar and Sego, 1993; Hivon and Sego, 1993) is also an issue throughout the Kugluktuk area. Because the whole region was inundated by the sea, and then subsequently isostatically uplifted, the marine sediments would naturally contain saline pore waters. During aggradation of permafrost into these sediments, brines would have formed, until they eventually became trapped within interstitial crystal lattices. While these sediments remain frozen, the nature of saline permafrost is such that it weakens the bonds of the crystal structure, making the permafrost far more plastic, and deformable than non-saline permafrost. The presence of brines, also depresses the freezing point, such that saline permafrost will melt at lower temperatures than regular permafrost, and thus is more susceptible to changes in ground temperature as may occur under projected climate warming.

PERCEIVED SENSITIVITIES TO CLIMATE CHANGE

Observations from this reconnaissance visit, and information presented above, are used to infer a range of landscape sensitivities in the Kugluktuk region to potential climate change. It is stressed, however, that these inferences require more field-based study and substantiating before they may be incorporated into a design/adaptation strategy. They are perhaps most useful in identifying knowledge needs/gaps that can be used to support the planning process.

1. In the context of specifically climate warming, landscape hazards in Kugluktuk appear to be of low risk. That is not to say that there could not be significant impacts on local infrastructure. It is just that as most of the town is situated on bedrock, or on a thin veneer of predominantly sandy sediments overlying bedrock, it can be regarded as occupying an enviably stable building platform.

2. Warming could have a potential influence on thaw subsidence in the alluvial terrace sediments (Figure 2 – At) upon which the northern extents of the town are built. Sediment coring would have to be undertaken to determine and characterize this risk.

3. Based on the presence of thermokarst terrain along the beach front regions in the port facility and west of there (Figure 2 – Mk), it can be deduced that some of the areas covered by raised beaches contain significant quantities of buried ice. This is not unusual, as during the beach forming process, ice push, and subsequent burial of ice masses can occur. Urban development such as roads and building pads in areas of beach ridges would need to take into account the potential presence of buried ice. This includes any trenching activities that might expose ice-rich sediments.

4. As previously discussed, over-deepened and widened alluvial channels adjoining the runway and elsewhere in the regions of extensive raised beach cover suggest that the stream channel morphology reflects melting of ice-rich sediments. Stream diversion efforts, such as has been undertaken along the western end of the airport runway must take this into account. Simple excavation of ditches will not protect underlying permafrost. Armouring of the bed with larger rock material will be required to ensure that easily eroded sandy sediments are not removed, leading to further thermal erosion of underlying sediments, and accentuated erosion.

5. The extensive network of ice wedge polygons and individual ice wedges in the glaciofluvial delta terrace (Figure 2 – Gd) that underlies most of the airport merits significant attention. The large size (length and width) of ice wedges suggest significantly large ice masses underlie the active layer in this region. Climate warming could result in melt of the upper sections of these ice wedges leading to subsidence along the ice wedge depressions. These depressions then readily form drainage conduits, leading to increased thermal melting of the ice wedge, and continued subsidence. In extreme cases, channelling of meltwater along these ice

wedge depressions can result in the rapid melting and incision of the entire ice wedge below, resulting in metres of incision, and destabilisation of the adjacent slope materials. The morphology of various tributary streams flowing east from this area down towards the Coppermine River suggests that they have formed in part by this process. While it can be argued that this area has emerged from the sea over 5000 years ago and thus shows considerable stability, it must be recognized that the construction of infrastructure, and particularly the diversion of meltwater from pre-existing pathways, can have dramatic consequences upon a permafrost landscape. Changes in snow drifting can also be of potential significance here in terms of meltwater generation and thermal insulation of the ground.

On the south side of the airport runway, a large area of surface sediments has been removed – presumably as part of the runway construction process. Removal of the surface layer, will undoubtedly have exposed ice wedges, or at least caused the seasonal active layer to now extend down below their top. It can be anticipated that ice wedges will exhibit pronounced melt and subsidence in this region until equilibrium conditions are re-attained. Attention would need to be paid to ensure that subsidence/erosion does not propagate headward into the runway pad.

6. In addition to the ice wedge polygons in the glaciofluvial delta terrace region, some areas east of the airport terminal pad show evidence of thermokarst, suggesting that the ice wedge polygons themselves may have significant ice contents below them. Under a climate warming scenario, it could be anticipated that further subsidence may occur in this region. Any development considerations in this area would have to first assess subsurface ice content.

Climate warming is only one component of climate change, and thus a broader scope of environmental changes and potential impacts must be assessed with respect to determining risk in Kugluktuk.

7. As mentioned at the beginning of this report – changes in sea ice are likely to produce the biggest impacts on day to day life for residents of Kugluktuk. While most of this research is beyond the scope of this assessment, impacts of reduced summer sea ice cover, particularly as it pertains to reductions in the extent of shorefast ice, and increased wave fetch needs to be taken into account in regards to shore stability. This is likely to be less of an issue in the more gently inclined regions of the beach occupying the western part of the town. In the eastern part of the town, where there is a fairly steep shore profile (Figure 7), reductions in sea ice and increased wave action may accelerate shore erosion. Note, wave action also needs to take into account wakes from boats operating close to the shore. The present gabion baskets appear insufficient, and need to be reconstructed, or bolstered in order to halt further erosion taking place. Several small shacks and two housing properties appear to be at direct risk to continued shore erosion and coastal slumping.

8. While Kugluktuk presently lies within a region that is continuing to experience positive isostatic uplift (projected to be up to 10 cm over the 2010 to 2100 year time frame; James et al. 2009), it is conceivable that under various climate change scenarios, it may start to see net subsidence when eustatic rise outpaces isostatic uplift. James et al. (2009) project that sea level at Kugluktuk could rise up to 50 cm over the 2010 to 2100 year time frame. Significant changes could thus occur along various shore profiles, and indeed it is possible that storm surges could see flooding of low-lying thermokarst terrain around the port facility and west of there.

9. Protection of Kugluktuk's water supply must be examined in terms of its long-term sustainability. Presently, fresh water is drawn from the Coppermine River by a large pipe system into settling ponds and a holding tank. It was reported to the author that the town has experienced several salt water incursion events that have temporarily contaminated their water supply. Reasons for this are potentially many fold, but may be a consequence of increased storm surge brought about by higher winds, and increased open-water fetch during periods of reduced summer sea ice extent. Changes in channel geometry within the Coppermine River are also likely a contributor. Historical and ongoing surveys of beach and near-shore profiles by Forbes and Manson (NRCan) do not incorporate the region around the fresh water intake. It is suggested that a detailed bathymetric and hydrological survey be established in the vicinity of the fresh water intake in order to better understand the nature of the hydrological system, particularly as it applies to mechanisms leading to salt water incursions. A survey such as that being proposed could also be used as a benchmark, upon which future changes can be assessed. It also needs to be recognized that changes in channel depth and sedimentation will naturally occur in this region of the Coppermine River as a consequence of continued isostatic uplift, eustatic rise, and delta formation. Melting of ice-rich permafrost and increased formation of active-layer detachments along the banks of the Coppermine River (c.f., Dredge, 2001) may also result in increased sedimentation rates and shallowing of the Coppermine River, further exacerbating the problem.

10. Urban hydrology is universally identified as a problem in northern communities. Poorly maintained, often undersized drainage culverts, and a lack of retrofitting of downstream drainage systems to handle new, upslope infrastructure development (which results in an increased and hurried routing of meltwater and precipitation) is a significant problem. In Kugluktuk, it has to be recognized that the sandy nature of the surface sediments and those used in road construction are particularly susceptible to stream erosion. The dramatic erosion of streets (Figure 9) during the July 20-21, 2007 extreme precipitation event (170.7 mm) points to the problem of insufficient urban drainage capacity. Routing of meltwater must be addressed from source, right down to output into the sea/Coppermine River. As demonstrated in Figure 8, free drainage across unprotected surface sediments can lead to rapid erosion and incision of drainage channels, which can then perpetuate

thaw subsidence of underlying ice-rich permafrost leading to further erosion and channel incision. Drainage infrastructure built to handle existing meltwater and precipitation regimes may not be suitable to address what could occur under climate change scenarios that see increase storm activity and seasonal rainfall.

Figure 9. Erosion of Kugluktuk streets as a result of the extreme July 20-21, 2007, storm event (170.7 mm). [source: photo by J.Prno, 2007; climate data from Environment Canada's online National Climate and Information Archive]

11. Another component of urban hydrology that needs to be addressed is that of surface ponding of water. Construction of roads and building pads can lead to impoundment of meltwater and precipitation. In permafrost environments, ponding of surface water can lead to thermal erosion of underlying materials. Where this occurs in ice-rich sediment areas adjoining culverts, it can result in subsidence of land effectively stranding the culvert above the subsided surface – a negative feedback loop that leads to increased ponded water depth, and greater

thermal erosion and subsequent subsidence. Ponded water can also saturate coarse materials used in most building pad construction. Building pads purposefully use coarse materials in order to ensure free drainage of water away from them. If water is allowed to pond around a building pad, then it can be anticipated that ice will seasonally form within the pad, resulting in differential heave of the building above it, and progressive disturbance and compromising of the pad's integrity.

12. Snow drifting is something that has to be considered in building design and community planning. In terms of climate change, there may be changes in both the amount of snow (increased) and perhaps more significantly changes in wind direction and strength, particularly of storm events. This can result in significant changes in snow drift patterns within the community. Snow drifts must be considered with respect to their eventual meltwater production, and the routing of this meltwater, and also in terms of their insulation properties. In permafrost terrain in order to preserve the existing land stability, it is often essential that materials be allowed to freeze deeply each winter. Snow drifts act to insulate the ground materials, and can significantly alter the seasonal thermal profile, allowing for a thickening of the active layer. Therefore, changes in snow drift patterns, or thicknesses, including consideration of where clearance of snow from say the airport or community streets is dumped, needs to be taken into account during the planning process.

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Sea-level Projections for Five Pilot Communities of the Canada-Nunavut Climate Change Partnership

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Summary.

Estimates of the range of sea-level change expected in the next 90 years (2010 to 2100) for five communities in Nunavut (Table S-1) are derived from an assessment of published estimates of projected global sea-level change and an evaluation of vertical land motion. The projections provided here are intended to contribute to discussions on the possible impacts of projected sea-level change and potential mitigation measures that could be implemented at each community. Consideration of other factors affecting coastal stability, such as autumn storms and sea-ice extent, and assessment of shoreline and near-shore usage and infrastructure vulnerability, are also essential parts of the discussion and are not considered in this report.

Table S-1. Range of probable sea-level change for five pilot communities in Nunavut from 2010 to 2100 (relative to present-day mean sea level)

Community	In the year 2100, sea level will probably not **fall** more than : (cm)	In the year 2100, sea level will probably not **rise** more than: (cm)
Arviat	70	25
Whale Cove	75	20
Kugluktuk	10	50
Cambridge Bay	35	50
Iqaluit	50	10

The global sea-level change scenarios considered in this study provide 15 cm (minimum) to 196 cm (maximum) of sea-level rise at the year 2100 (using 2010 as the start date). The community projections given in Table S-1 are based on our assessment of the likely amount of global sea-level change, which varies from 28 cm to 115 cm by the year 2100, a range of 87 cm.

Sea-level change from changing glaciers and ice caps is not spatially uniform (Mitrovica et al., 2001) and the community-specific sea-level projections include this “sea-level fingerprinting” effect. Meltwater from the Greenland ice sheet is redistributed in the global oceans in such a way that it contributes to stable or falling sea levels for the five communities, while meltwater from glaciers and ice caps contributes to reduced amounts of sea-level rise compared to the amount that would be expected from uniform meltwater redistribution. The net effect is that the range of projected sea-level change at each

community is substantially less than the amount that would have been determined if melt-water redistribution had been assumed to be uniform.

The sea-level change projections given in Table S-1 also include the effects of uncertainty in vertical land motion and this extends the range of projections significantly, although more than half of the range (uncertainty) in the community sea-level projections is due to the global sea-level scenarios. An additional unquantified, but potentially large, source of error arises from the assumptions used in assessing the spatially variable meltwater redistribution.

Some of the community sea-level projections are notable for significant sea-level fall. This is a consequence of two factors. 1. Land uplift is occurring due to glacial isostatic adjustment, which is the delayed response of the Earth to surface unloading caused by deglaciation at the end of the last Ice Age. The rising land ameliorates the effects of global sea-level rise, especially for Arviat and Whale Cove, which are rising the fastest. 2. The sea-level fingerprinting effect is especially marked at Iqaluit for the Greenland source of meltwater. Global sea-level change scenarios with larger amounts of global sea-level rise (and thus a larger amount of Greenland meltwater) generate larger amounts of sea-level fall at Iqaluit, opposite to that of the other four communities.

Significant progress in reducing the current large range of sea-level projections could be realized by improving observations of vertical land motion and from carrying out an updated assessment of the spatially variable redistribution of meltwater from Arctic ice caps and the Greenland ice sheet.

1. Introduction

Globally, sea level is projected to rise in the coming decades, but the range of projections varies greatly. There is uncertainty about the expected contribution from warming of the ocean's surface layer, which causes it to expand and raise the surface of the ocean (steric effect) and much greater uncertainty about the meltwater contributions of glaciers and ice caps and the large Greenland and Antarctic ice sheets.

The average rate of sea-level change in the last four decades of the 20th century (1961 to 2003) was 1.8 ± 0.5 mm/yr, but the rate appears to have accelerated in the last decade (1993 to 2003) to 3.1 ± 0.7 mm/yr (Table SPM.1; IPCC, 2007). Sea-level change is correlated with global temperatures, and because temperatures are projected to rise in the 21st century, the expectation is that global sea level will continue to rise, quite possibly at larger rates than recently observed.

The Canada-Nunavut Climate Change Partnership is a collaborative project between the Government of Nunavut, Canadian federal government departments, and the Canadian Institute of Planners (CIP). Five communities in Nunavut have been chosen for the second phase of a pilot project to devise climate change impact and adaptation plans – Iqaluit, Arviat, Whale Cove, Kugluktuk, and Cambridge Bay (Figure 1). (The first phase of the pilot project considered the communities of Hall Beach and Clyde River. It is planned to provide sea-level projections for those communities in a subsequent report discussing sea-level change across the entire territory.) For each community, two volunteer planners from the CIP are working in close collaboration with government and university scientists and are consulting extensively within the community to develop the climate change plans. Climate change issues under consideration include landscape changes, changes to water supplies, and coastal stability.

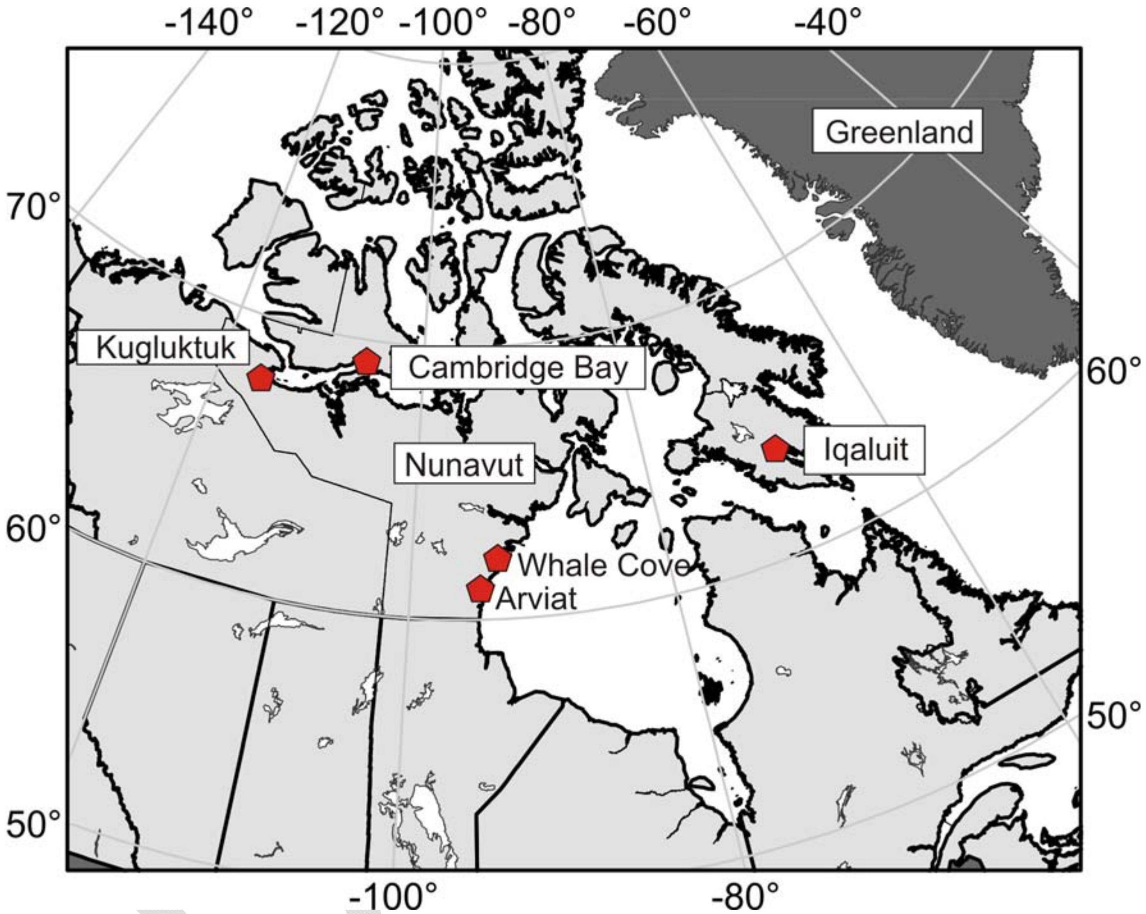

Figure 1. Map indicating the location of the five pilot communities.

In addition to the effects of sea-level change, coastal stability is influenced by the frequency and intensity of extreme events, such as major autumn storms. Indirectly, changes to the extent and duration of sea-ice, such as the time of autumn freeze-up, can also make the coastline more (or less) susceptible to storms. This report does not consider projections of extreme events and changes to sea ice. Instead, the focus here is solely on projections of sea-level change for the five pilot communities, based on the scientific literature and other available information. The assumed time frame is 90 years (2010 to 2100).

2. Contributors to Sea-level Change

A projection of sea-level change at a specific location requires consideration of global sea-level change, the location (attribution) of the sources of global sea-level change, and local vertical land motion. In the following we discuss each of these factors briefly.

2.1 Scenarios of Global Sea-Level Change. The Intergovernmental Panel on Climate Change (IPCC), in its most recent Fourth Assessment Report (AR4) (IPCC, 2007), provides projections of global sea-level change for six scenarios. The scenarios correspond to various assumptions about the world economy and the intensity with which conservation measures are adopted. For each scenario, a range of sea-level projections is provided. The scenarios predict as little as 18 cm and as much as 59 cm of sea-level rise (Table 10.7; Meehls et al., 2007) from 1980-1999 to 2090-2099.

At the lower end, the IPCC projections indicate an average rate of sea-level rise similar to that observed for the last half of the 20th century (1.8 ± 0.5 mm/yr). At the higher end, the IPCC projections indicate an average rate of sea-level rise that is nearly double the rate that was observed recently (3.1 ± 0.7 mm/yr).

The IPCC cautions that the projections do not include the "full effects of changes in ice sheet flow, because a basis in published literature is lacking" (IPCC, 2007, p. 14). The report indicates that the upper values of the projections could increase by 10 or 20 cm if the ice-sheet-flow contribution grew proportionally to projected global temperature increase and that even larger contributions are not ruled out. Thus, the IPCC projections are conservative.

Input of new scientific results to the IPCC AR4 ceased around mid-2005. Since that time, a number of studies have appeared that project maximum amounts of sea-level rise that are larger than the upper end of the IPCC projections (e.g., Ramstorf, 2007; Horton et al., 2008; Grinsted et al., 2009). Consequently, although the IPCC projections provide a sound basis for developing local, or community-based, sea-level projections, we also consider scenarios featuring larger amounts of global sea-level rise.

2.2 Sea-Level Fingerprinting. When a glacier or ice sheet loses mass by melting or iceberg calving, the meltwater is not distributed evenly throughout the oceans and does not cause a uniform rise in sea level (Mitrovica et al., 2001). Instead, near the ice sheet, the reduced gravitational pull of the ice sheet causes the surface of the ocean to sink. As well, the reduced surface load causes the Earth to respond elastically and the land rises under the ice sheet and in areas adjacent to the ice sheet. The net response near the ice sheet is that sea-level falls substantially, even though a melting ice sheet causes global sea-level rise to rise on average. Conversely, at large distances from the ice sheet, the net effect is that sea level rises a little more than the average value.

"Sea level fingerprinting" is important to incorporate into projections of sea-level change, especially for Nunavut. The territory is host to some Arctic ice caps and is relatively close (on a global scale) to the Greenland ice sheet and thus is especially sensitive to spatial variations in the distribution of meltwater and in the Earth's instantaneous (elastic) vertical land motion response to ice sheet and glacier mass change.

2.3 Vertical Land Motion. At a specific location, sea-level change depends not only on the amount and location of sources of global sea-level rise, but also on the local vertical land motion. For example, if sea-level is (hypothetically) projected to rise by 50 cm by the year 2100 at a specific location due to thermal expansion and meltwater input to the oceans, but the land is expected to rise by the same amount, then the net effect would be nil and the projected net sea-level change for the locality would be zero.

Vertical land motion is significant across much of Canada, and some of the highest rates occur in Nunavut. Most of the Canadian land surface was glaciated during the last continental glaciation, which peaked at about 21,000 years ago. The weight of the ice pushed down the surface of the Earth. In contrast to the land subsidence experienced beneath the ice sheet, the land outside the glaciated region rose during glaciation because material deep in the Earth was displaced away from the centre of the ice sheet. The region of where the land was uplifted during glaciation is known as the proglacial forebulge.

With the exception of some glaciers and ice caps remaining in the mountains of western Canada and in the Arctic, the last vestiges of the continental ice sheets disappeared about 7000 to 8000 years ago. In response to deglaciation and the decreased load, the surface of the Earth began to rise beneath the thinning ice sheet, while the peripheral bulge began to sink. Because the interior of the Earth behaves like a very viscous (slow flowing) liquid, the vertical land motion is still occurring today. The Earth's response to glacial loading and unloading is called glacial isostatic adjustment (GIA).

Thus, the pattern of vertical land motion due to GIA comprises a region of present-day uplift where the former ice sheet was thickest and where it persisted the longest, surrounded by a peripheral region where the land is subsiding. Eastern Baffin Island and the western Canadian Arctic, including the Mackenzie Delta, are regions of subsidence. Over most of Nunavut, the land is presently rising.

Computer model of GIA also include the effects of changing amounts of ocean water that occurred in response to ice sheet growth and decay and the effects of the redistribution of ocean water in response to gravitational changes and vertical land motion of the ocean floor. The response of the Earth to changing water loads is called hydro-isostasy and is important for understanding sea-level change.

Within the region of uplift, the rates differ from one location to another because the ice was thicker in some places than in other places, and because ice sheet thinning and deglaciation occurred at different times in different parts of Canada. The magnitude of subsidence is generally no more than 1 or 2 mm/yr, whereas peak uplift can reach 10 mm/yr or greater. The estimates of vertical land motion given in this report are due to GIA.

3. Results.

The specific scenarios of global sea-level rise, effects of sea-level fingerprinting at the five communities, and the estimation of vertical land motion at the five communities are described in the following three sections.

The fourth section synthesizes the results of the previous sections and provides a range of projections for each community. It gives the projections of sea-level change for the five communities and indicates the probable range of sea-level change for each community.

3.1 Scenarios of Global Sea-level Change. We take the approach of considering a broad range of scenarios of global sea-level rise and attempt to include extreme minimum and maximum scenarios as well as intermediate ones. Sea-level fingerprinting requires that the sources of sea-level change (glaciers and ice caps, Greenland, Antarctica) be identified for each scenario. Depending on the source of the scenario, this sometimes requires that additional assumptions be made. The scenarios are summarized in Table 1. Details of the scenarios and assumptions that were made are given in Appendix A. Here we briefly name and describe the scenarios:

20^{th} Century Sea-level Rise. This scenario is built on the observed sea-level change of 1.8 mm/yr from 1961 to 2003 (IPCC, 2007) and features 16.2 cm of global sea-level rise in the 90 years from 2010 to 2100.

Late 20^{th} Century Sea-level Rise. This is a scenario built on observed sea-level change of 3.1 mm/yr from 1993 to 2003 and features 27.9 cm of global sea-level rise.

IPCC Scenarios. The IPCC presents sea-level projections for six scenarios (Meehl et al., 2007, Table 10.7). For each scenario a range of sea-level projections is given corresponding to the 5% and 95% significance levels. We determined sea-level projections using the mid-point of each scenario, as well as at the minimum value of the scenario giving the smallest amount of sea-level rise (B1) and the maximum value of the largest scenario (A1FI). The scenarios give 15.3 cm (minimum of scenario B1) to 50.5 cm (maximum of scenario A1FI) of global sea-level rise. Keep in mind that the time frame of the IPCC report (1980-1999 to 2090-2099) differs from the time frame adopted here and that thus values given in the IPCC report need to be scaled before comparing to values given here.

Post-IPCC scenarios. A number of recent studies suggest that sea-level rise could be larger than the IPCC projections. Rahmstorf (2007) noted that sea-levels in the past 150 years have been proportional to global temperatures. Assuming the same relationship holds for the 21^{st} century, he projected sea level to rise by 0.5 to 1.4 m above the 1990 level by 2100 (0.41 m to 1.15 m for a 90-year time span). Grinsted et al. (2009) examined the correlation between temperatures and sea-level over the past 2000 years and extrapolated to 2090-2099 using the IPCC scenarios. On average (for the preferred Moberg data set), the sea-level projections ranged from 0.9 m to 1.3 m (0.77 m to 1.12 m for a 90 year time span).

Not all post-IPCC projections are this big. Horton et al. (2008), using the output of coupled global climate models and also correlating temperature to sea-level change, found an average sea-level rise of 0.7 m from 2001-2005 to 2100 (0.65 m for 2010 to 2100). Pfeffer et al. (2008) employed a glaciological approach to project sea-level change, based on probable and extrapolated glacial flow rates and other arguments, and derived two “low” scenarios delivering 0.78 and 0.83 m of sea-level rise to 2100. He suggested that they “provide a ‘most likely’ starting point for refinements in sea-level forecasts that include ice flow dynamics”.

Based on analogies with the previous interglacial period about 125,000 years ago, some authors have suggested the potential for several meters of sea-level rise. Pfeffer et al. (2008) determined that a sea-level rise larger than 2 m by 2100 is physically implausible. Two meters of sea-level rise would require that all variables be immediately accelerated to extremely high limits.

Based on the foregoing summary, we utilize the following post-IPCC scenarios:

Pfeffer Low 1 and Pfeffer Low 2. These scenarios are glaciologically based (Pfeffer et al., 2008) and provide an amount of sea-level rise intermediate between the IPCC scenarios and the larger amounts suggested by other studies. The amount of sea-level rise they deliver is slightly larger than the average amounts suggested by Horton et al. (2008).

Ramstorf/Grinsted scenario. The peak amount proposed by Ramstorf (2007) (1.15 m) is similar to the average peak value determined by Grinsted et al. (2009) (1.12 m), and we therefore examine the consequences of 1.15 m of sea-level rise. These studies do not indicate the source(s) of sea-level rise. To address this, we scale a number of other scenarios (Pfeffer et al.’s (2008) three scenarios, 20th Century Sea level Rise, and Late 20th Century Sea Level Rise scenarios) to deliver 1.15 m of sea-level rise and then examine the variability in projected sea-level change brought about because of the differing weighting of meltwater sources.

Pfeffer High 1. This delivers 2 m of sea-level rise (Pfeffer et al., 2008) and is the largest scenario considered in this report.

Table 1. Scenarios of Global Sea-level Rise Employed in Sea Level Projections

Name of Scenario	Source(s)	Amount of Sea-level Change Delivered from 2010 to 2100 (cm)
20th Century Sea-level Rise	IPCC, 2007	16
Late 20th Century Sea-level Rise	IPCC, 2007	28
IPCC – B1 Minimum	Meehl et al., 2007	15
IPCC – B1	Meehl et al., 2007	24
IPCC – B2	Meehl et al., 2007	27
IPCC – A1B	Meehl et al., 2007	30
IPCC – A1T	Meehl et al., 2007	28
IPCC – A2	Meehl et al., 2007	31
IPCC – A1FI	Meehl et al., 2007	36
IPCC – A1FI Maximum	Meehl et al., 2007	51
Pfeffer Low 1	Pfeffer et al., 2008	77

Pfeffer Low 2	Pfeffer et al., 2008	82
Rahmstorf/Grinsted	Rahmstorf (2007); Grinsted et al. (2009)	115
Pfeffer High 1	Pfeffer et al., 2008	196

3.2 Sea-Level Fingerprinting. As mentioned above, the location of the source of present-day meltwater is important for determining the sea-level change, especially at sites close to the source. Mitrovica et al. (2001) show the change in sea-level for a one millimeter per year sea-level contribution from Antarctica, Greenland, and glaciers and ice caps (Figure 2). For each community, the sea-level response at each community for each meltwater source was read from Figure 2 and is given in Table 2. Meltwater from the Greenland ice sheet is redistributed in the global oceans in such a way that it contributes to stable or falling sea levels for the five communities, while meltwater from glaciers and ice caps contributes to reduced amounts of sea-level rise compared to the amount that would be expected from uniform meltwater redistribution.

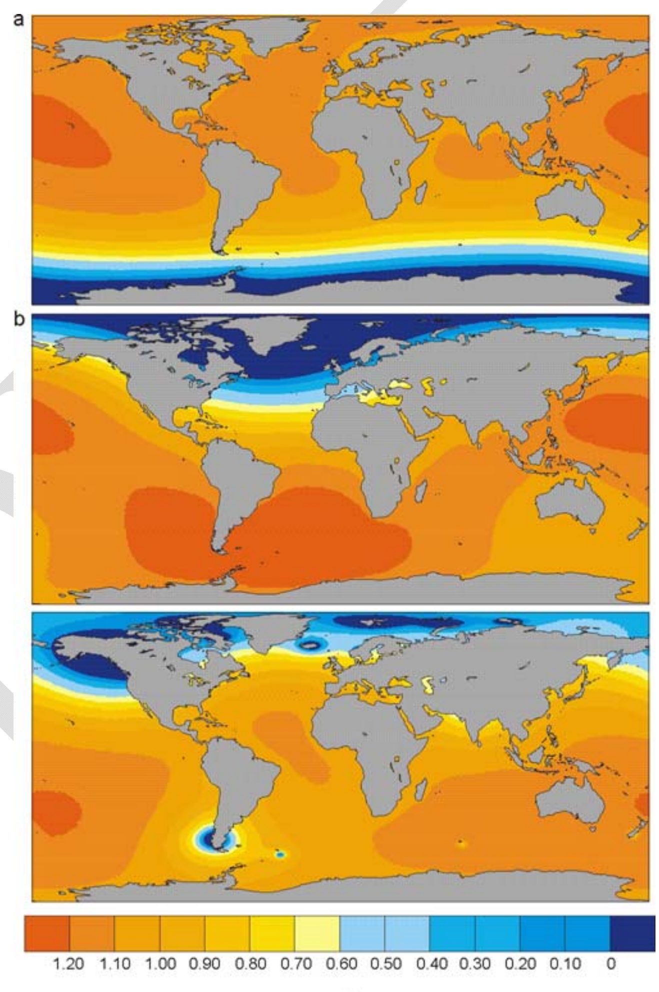

Figure 2. The amount of sea-level rise, in millimeters per year, for an assumed 1 mm/yr contribution to global sea level rise from (a) Antarctica, (b) Greenland, and (c) glaciers and ice caps (figure from Mitrovica et al., 2001).

The figures provide enough information to determine the sea-level response for most communities for most sources. Iqaluit is, however, located relatively close to Greenland and it was felt that extrapolation from the figure was uncertain. G. Milne (pers. comm., 2009) kindly provided the expected sea-level response at Iqaluit to a one millimeter per year sea-level rise sourced from Greenland. Its response is remarkable for being large and negative, and this has important implications for sea-level projections for Iqaluit that will be discussed in detail later.

Table 2. Sea-level rise assuming a 1 mm/yr sea-level contribution from a given source (after Mitrovica et al., 2001)

Community	Greenland	Antarctica	Glaciers and Ice Caps	Thermal Expansion (Steric Effect)
Arviat	-0.3	1.05	0.35	1.0
Whale Cove	-0.4	1.05	0.35	1.0
Kugluktuk	0	1.05	-0.1	1.0
Cambridge Bay	-0.3	1.05	0.05	1.0
Iqaluit	-3.6	1.05	0.4	1.0

3.3 Vertical Land Motion. Sea level has been falling in recent millennia in many areas of Canada because the land is rising in response to the unloading caused by the thinning and retreat of the large ice sheets at the end of the last Ice Age. Frequently, it is possible to radiocarbon date features such as raised beaches and deltas that are related to past, higher sea levels. In many areas, the amount of information is sufficient to determine a sea-level curve which shows how sea-level has changed in the past. The slope of sea-level curve, at present, shows how quickly sea level is falling and that can be related to the rate at which the land is rising.

The information on past sea-levels has also been synthesized as maps showing the elevation of land that was at sea-level at a specified time in the past (Dyke, 1996, and unpublished updates incorporating new information). These “isobases” have been determined at 500 year intervals. They interpolate sea-level observations from regions with abundant data to regions that have less data at a given time. For each of the five pilot communities, the isobase values were validated by comparison with available sea-level observations from the vicinity of the community. The validation was successful and present-day rates of sea-level fall were determined and used as estimates of vertical land motion. This procedure is valid because it is thought that global sea-level has not changed in the past one thousand to two thousand years (e.g., Fleming et al., 1998).

Another estimate of vertical land motion was obtained from the predictions of a computer model of the GIA process called ICE-5G (Peltier, 2004). ICE-5G is a global model of the glaciation and deglaciation that occurred during the last Ice Age that loads a model of the solid Earth to generate predictions of relative sea-level change. We compared the predictions of the model to the sea-level data from each of the pilot communities, and found good agreement for Kugluktuk, Cambridge Bay, and Iqaluit. ICE-5G predicts too much sea-level fall, however, in the vicinity of Arviat and Whale Cove.

Consequently, the estimates of vertical land motion given in Table 3 are an average of the isobase and ICE-5G rates for Kugluktuk, Cambridge Bay, and Iqaluit, but are derived solely from the isobases for Arviat and Whale Cove. Details of how the vertical land motion was derived are given in Appendix B.

Table 3. Vertical land motion

Community	Vertical Land Motion (mm/yr)	Uplift in 90 Years (cm)
Arviat	8.1 ± 2	73 ± 18
Whale Cove	8.4 ± 2	76 ± 18
Kugluktuk	2.5 ± 1	23 ± 9
Cambridge Bay	3.7 ± 2	33 ± 18
Iqaluit	0.9 ± 1	8 ± 9

Estimates of vertical land motion derived from empirical isobases, or from model-predicted changes in topography, implicitly include the effect of changes to the Earth's gravitational field caused by glacial isostatic adjustment. This is desirable, because projections of future sea-level change need to take this effect into account. However, the derived rates given in Table 3 are not strictly rates of vertical land motion because they include the gravitational change effect. They will need further adjustment before they can be directly compared to geodetic observations of vertical land motion that can be obtained, for example, from repeated Global Positioning System (GPS) observations.

3.4 Projections of Sea-level Change. The previous three sections provide the ingredients to generate projections of sea-level change for the five communities. For each scenario, the sea-level contributions from glaciers and ice caps, Greenland, Antarctica, and steric expansion were multiplied by the appropriate sea-level fingerprinting values to obtain the projected sea-level change from global sources at each community. The effect of vertical land motion at each community was then incorporated to obtain the value of projected sea-level change at each community. This was repeated for all the global sea-level change scenarios to obtain a range of sea-level projections for each community. The effect of uncertainties in vertical land motion increases the range of sea-level projections, and this is discussed in section 4.

Figure 3 summarizes the predictions for the IPCC scenarios and the two scenarios of observed twentieth century sea-level change. They show that Arviat and Whale Cove, which are rising the fastest, generally feature more than 50 cm of sea-level fall. Communities that are rising slower still mostly feature sea-level fall, but the amount of fall is smaller.

The range of projected sea-level is much greater when post-IPCC scenarios are included (Figure 4). For all of the communities there are scenarios that generate projections of sea-level rise, but the amount of sea-level rise is only 10 or 20 cm for Arviat and Whale

Cove, where the land is rising the fastest. For four of the communities, the projected amount of sea-level change tends to be larger for scenarios that deliver greater amounts of water to the oceans.

Iqaluit is a special case, however. Its proximity to the Greenland ice sheet, and strong negative sensitivity to Greenland mass balance through the "sea-level fingerprinting" phenomenon (see Table 2), means that sea-level is generally projected to fall by larger amounts for scenarios that deliver larger amounts of water to the oceans. This result is counter-intuitive, but is a consequence of all the scenarios having a robust component of Greenland mass wastage. Because the response to Greenland mass wastage at Iqaluit is large and negative, the net response at Iqaluit is larger amounts of sea-level fall for scenarios that feature larger amounts of global sea-level rise.

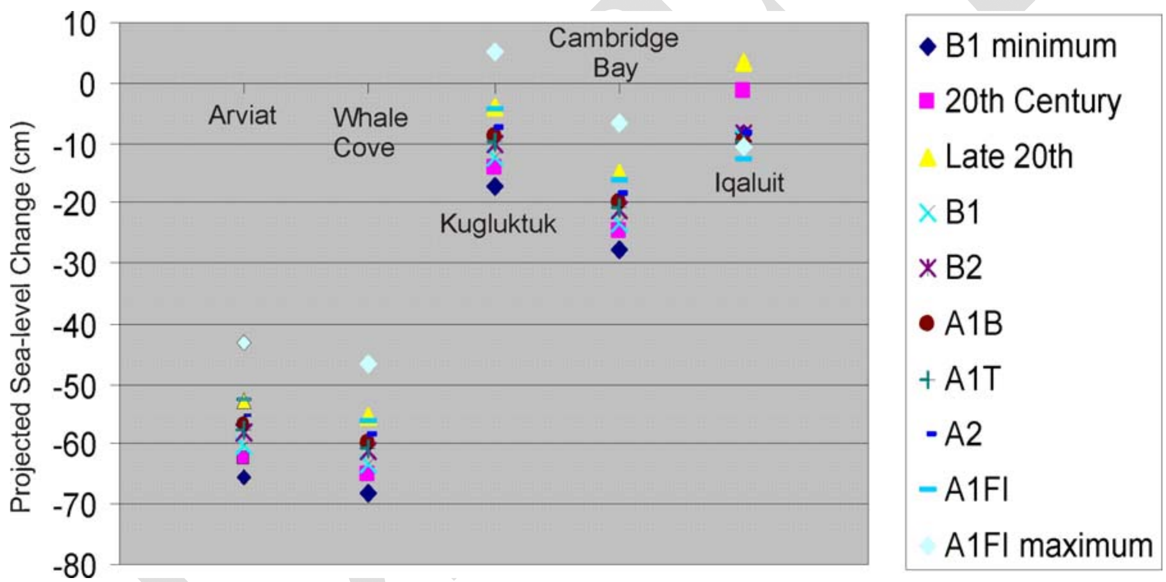

Figure 3. Sea-level projections for the minimum, mid-points, and maximum IPCC projections (Meehl et al., 2007) and for the Twentieth Century and Late 20th Century scenarios.

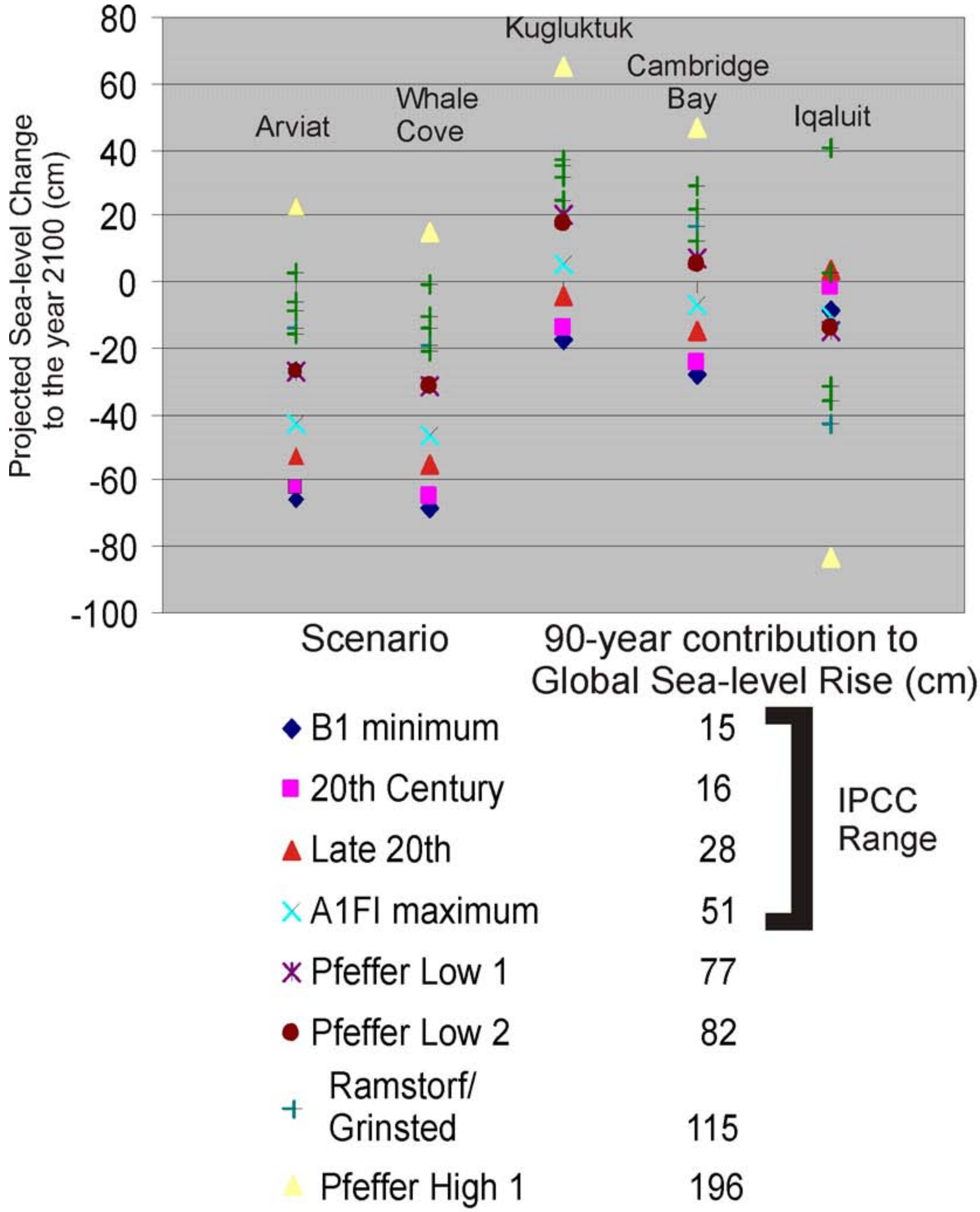

Figure 4. Sea-level projections for the twentieth century scenarios, the extremes of the IPCC scenarios and the post-IPCC scenarios.

The range of sea-level projections shown in Figure 4 is summarized in Table 4. For all communities, the range in projected sea-level change is much smaller than the range of sea-level change delivered to the oceans by the scenarios (typically 40-50%, Iqaluit is 70%). This is a consequence of the sea-level fingerprinting effect (Table 2). For example, suppose that glaciers and ice caps deliver 30 cm more of sea-level rise to the world's oceans in one scenario compared to another scenario. At Whale Cove, the extra contribution to sea-level change from glaciers and ice caps would only be 10.5 cm, because Table 2 indicates that the sea-level fingerprinting effect at Whale Cove due to glaciers and ice caps is 0.35, and 0.35 times 30 cm equals 10.5 cm. The sea-level fingerprinting effect reduces the range of sea-level change experienced at the communities from glaciers and ice caps (all communities) and from Greenland (for four of the five communities). This reduces the range of the total projected sea-level change.

Table 4. Summary of the range of sea-level change scenarios and of community sea-level projections

Sea-level Scenarios	**Range in the Amount of Sea-Level Rise Delivered to Oceans (cm)**
B1 Minimum (15 cm) to Pfeffer High 1 (196 cm)	181
Community	**Range of Projected Sea-level Change (cm)**
Arviat	89
Whale Cove	84
Kugluktuk	82
Cambridge Bay	74
Iqaluit	124

The Rahmstorf/Grinsted scenarios illustrate another source of uncertainty in sea-level projections (Figure 4). All five Rahmstorf/Grinsted scenarios feature the same amount of global sea-level rise (115 cm), but the source of the sea-level rise is apportioned differently among Greenland, Antarctica, and glaciers and ice caps. This leads to variability in the projected sea-level change at each community. For four of the communities, the variability amounts to about 20 cm. Iqaluit again stands out, however, as the Rahmstorf/Grinsted scenarios generate sea-level projections that differ among them by up to 85 cm.

4. Discussion.

The question arises of the range of sea-level projections that are most likely, and which can be considered to be extreme cases. At the low end, sea-level rise increased from 1.8 mm/yr to 3.1 mm/yr from the last 4 decades of the 20th century (1961 to 2003) to the last decade of the 20th century (1993 to 2003). Temperatures are projected to rise in the 21st century, and as sea-level rise is correlated with temperature, it seems appropriate to take the Late 20th Century Scenario as the probable minimum (28 cm of sea-level rise to 2100). We note, however, that natural variability unrelated to temperatures may have been responsible for the increase in sea-level rise observed at the end of the 20th century. Thus, amounts of sea-level rise smaller than the Late 20th Century Scenario (3.1 mm/yr, 28 cm of sea-level rise to the year 2100) are possible.

Table 5. Sea-level scenarios and indication of likelihood

	Minimum Global Sea-Level Change (cm)	Global sea-level will probably not be less than (cm)	Global sea-level will probably not be more than (cm)	Maximum Global Sea-level Change (cm)
Scenario	B1 Minimum	Late 20th Century	Ramstorf/ Grinsted	Pfeffer High 1
Amount of Sea-level Rise from 2010 to 2100 (cm)	15	28	115	196

At the upper end, the Pfeffer High 1 scenario (196 cm of sea-level rise from 2010 to 2100) is an extreme case. Its main purpose seems to have been to exclude the possibility of even larger amounts of sea-level rise previously suggested in the literature. The upper end of the Rahmstorf (2007) projection and the average of upper values of the Grinsted et al. (2009) projections (our Rahmstorf/Grinsted scenario, 115 cm of sea-level rise) may provide an upper limit. We note that Grinsted et al. considered all six IPCC scenarios in projecting sea-level change based on observed temperature/sea-level correlations and that some of their scenarios project more than the 115 cm (for a 90-year time frame) of sea-level rise. Thus, amounts of sea-level rise larger than 115 cm, but not exceeding 196 cm, are possible. The range of sea-level projections and our assessment of their likelihood are given in Table 5.

The probable range of sea-level projections for each community is given in Table 6. The values were derived from the probable range of sea-level change summarized in Table 4 and the sea-level projections shown in Figure 4. The ranges are our judgment of the likely sea-level change that each community will experience, based on current knowledge and information. It is probable that these estimates will be revised in the future. Projections for Iqaluit are particularly uncertain owing to the dominant, but poorly constrained, influence of the Greenland ice sheet.

Table 6. Assessment of probable range of sea-level change for each community at the year 2100 relative to 2010 (relative to present mean sea level)[1]

Community	Minimum Sea-Level Change (cm)	Sea-level will probably not be less than (cm)	Sea-level will probably not be more than (cm)	Maximum Sea-level Change (cm)
Arviat	-65	-50	5	20
Whale Cove	-70	-55	0	15
Kugluktuk	-20	-5	40	65
Cambridge Bay	-25	-15	30	45
Iqaluit	-85	-45	5	40

[1]Values are rounded to the nearest 5 cm.

4.1 Effect of Uncertainties in the Vertical Crustal Motion. The sea-level change projections have an additional source of uncertainty that is related to the rate of land uplift. The uncertainties are assessed at ±10 cm for Iqaluit and Kugluktuk and ±20 cm for Arviat, Whale Cove, and Cambridge Bay (Table 3, rounded to nearest 5 cm). The vertical land motion uncertainties increase the range of probable sea-level change for each community (Table 7). The increase is substantial for Arviat, Whale Cove, and Cambridge Bay, where the additional 40 cm nearly doubles the probable range compared to Table 6.

Table 7. Assessment of Probable Range of Sea-level Change for Each Community Incorporating Uncertainty in Vertical Land Motion

Community	Sea-level will probably not be less than (cm)	Sea-level will probably not be more than (cm)
Arviat	-70	25
Whale Cove	-75	20
Kugluktuk	-10	50
Cambridge Bay	-35	50
Iqaluit	-50	10

5. Suggestions for Future Improvements to the Sea-level Projections.

Our sea-level projections feature substantial uncertainty arising from the range of global sea-level scenarios, uncertainties in sea-level fingerprinting, and uncertainties in vertical land motion. Progress in reducing the uncertainty from all three sources is possible, and could lead to a smaller range of projected sea-level change in the future.

1. The overall uncertainty in the range of global sea-level projections may be reduced through the concerted, continuing effort of the international scientific community.

2. Regionally, an updated evaluation of the sea-level fingerprinting effect is greatly needed. Mitrovica et al. (2001) made (necessary) assumptions about the distribution of mass change from the three sources – for example, Greenland is assumed to be thinning uniformly. As well, the glaciers and ice caps calculations were carried out using a mass balance compilation that is now outdated (Meier, 1984). An evaluation of the sea-level fingerprinting effect for Arctic ice caps and the Greenland ice sheet, using updated mass balance observations and projections, should be carried out.

3. Locally, field work could be carried out at some communities to improve estimates of vertical land motion. This could include work to improve the record of past sea-level change, thus adding to the information available for both improved sea-level curves and isobases and providing better constraints for models of the glacial isostatic process, such as ICE-5G. As well, installation of new Global Positioning System (GPS) sites and continuing operation of existing sites can provide direct estimates of vertical crustal motion. (New satellite navigation systems are becoming available and the term Global Navigation Satellite Systems (GNSS) is becoming prevalent.)

It is likely that an updated evaluation of the sea-level fingerprinting effect, combined with better estimates of vertical land motion, could reduce the range of projected sea-level, perhaps by a factor of ½. An updated sea-level fingerprinting analysis could be carried out relatively quickly, but improved estimates of vertical land motion will take more time.

6. Conclusions.

The projections provided here are intended as a starting point for discussions of the possible impacts of sea-level change and the potential mitigation measures that could be implemented at each community. Subsequent dialogue may raise additional questions about the sea-level projections and we will consider revisions to this report as needed.

In contrast to the picture of rising sea levels and coastal inundation that is frequently painted in popular reports, future sea levels may follow a very different trajectory featuring stable or even falling sea level for some communities in Nunavut (Table 7). This is a consequence of two factors.

1– Over much of Nunavut, the land is rising, owing to the delayed response of the Earth to surface unloading caused by deglaciation. Rising land ameliorates the effects of rising global sea levels. Land subsidence is a potential issue for some areas, such as eastern Baffin Island and the western Arctic, as it would exacerbate possible sea-level rise.

2– Owing to their relative proximity to potentially large sources of meltwater (Arctic ice caps and the Greenland ice sheet), sea-level fingerprinting is very important in determining sea-level projections for communities in Nunavut.

Sea-level fingerprinting has the effect of muting or even reversing the sea-level rise produced by local sources. This is in contrast to regions that are distant from large sources of meltwater, where an amount of sea-level rise close to that delivered to the global oceans would be expected.

The potential issue for some of the communities considered here may be sea-level fall rather than sea-level rise. For communities that are dependant on harbour or docking facilities that presently feature limited depth-under-keel, or communities where traditional beaching sites are in use, the consequences of future sea-level fall bear consideration. For most communities, a larger amount of global sea level rise would help to ameliorate these impacts. On the other hand, all of the communities considered here potentially face a relative sea-level rise, possibly as much as 50 cm by the year 2100 for Kugluktuk and Cambridge Bay, and the implications of a sea-level rise also need to be evaluated.

Projections of sea-level change provide a lens through which to assess future coastal stability, but the projected sea-level change alone does not determine coastal stability. For example, Hall Beach, which is rising relatively quickly due to glacial isostatic adjustment, is nevertheless experiencing substantial coastline erosion that is affecting structures built closest to the ocean. Reduced rates of sea-level fall combined with more extensive or persistent open water may exacerbate erosion. There is a need to evaluate projected coastal change in terms of the susceptibility of built structures and in terms of the activities of community members who may depend on access to, or utilization of, the shoreline and near-shore environment.

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Appendix A. Global Sea-Level Change Scenarios

Because sea-level change due to changes in the mass of glaciers, ice caps, and ice sheets is not spatially uniform (Mitrovica et al., 2001), it is necessary to attribute the sources of sea-level change for each scenario among glaciers and ice caps, Greenland, and Antarctica. Mitrovica et al. (2001) utilized Meier's (1984) compilation for glaciers and ice caps, and assumed spatially uniform mass change of Greenland and Antarctica. These assumptions differ from some recent assessments of present-day and future sea-level change, where outlet glaciers and isolated ice caps on the perimeter of Greenland and Antarctica are included in the "ice caps and glaciers" category, rather than the "Greenland" or "Antarctica" categories. For these sources, it is necessary to attribute some of the "ice cap and glacier" contribution back to Antarctica and Greenland in order that the results of Mitrovica et al. (2001) can be used.

The relative contributions from glaciers and ice caps, Antarctica, Greenland, and the steric effect are summarized in Tables A1 through A3. Here we give a brief description of the development of the scenarios.

Twentieth Century Sea-level Rise and Late 20th Century Sea-level Rise. IPCC (2007) summarizes the sources of sea-level change for the time period 1961 to 2003 and from

1993 to 2003 (Table SPM.1). The glaciers and ice caps contribution includes outlet glaciers of Greenland and Antarctica. In the same IPCC report, Lemke et al. (2007; Table 4.4) give the glaciers and ice caps mass balance for these two time periods with and without glaciers and ice caps around ice sheets. To develop the scenarios, we distributed the sea-level rise from glaciers and ice caps around ice sheets equally between Greenland and Antarctica. For both time ranges, the sum of the individual contributions does not equal the observed total sea-level rise. Consequently, we also scaled the contributions from all sources by a factor so that the sum of the sources equals the observed total sea-level rise reported by IPCC (2007; Table SPM.1)

IPCC Scenarios. Meehl et al. (2007; Table 10.7) give projections of sea-level change for six scenarios. The scenarios correspond to different assumptions about fossil fuel usage in the 21st century. Similar to the case for the twentieth century scenarios, the “glaciers and ice caps” contribution includes outlet glaciers from the perimeters of Greenland and Antarctica. Meehl et al. (2007; section 10.6.3.3) suggest that outlet glaciers of Antarctica and Greenland comprise between 10% and 20% of the glaciers and ice caps contribution. Thus, for each scenario, we attributed 7.5% (one half of 15%) of the glaciers and ice caps contribution to Greenland and Antarctica.

We evaluated the mid-points of all six scenarios and the maximum of the largest scenario (A1FI) and the minimum of the smallest scenario (B1). For the mid-point scenarios, the sum of the mid-points of the individual contributions did not equal the mid-point of the total contribution, so the individual contributions were adjusted by a uniform value so that their sum agreed with the total contribution.

For the minimum and maximum cases, the extrema (minimum or maximum) of the individual contributions did not sum to the extremum of the total. Assuming a normal distribution, we determined the mid-point and uncertainty (sigma) for each individual contribution, and then found a scale factor S such that the mid-point value ± S times sigma gave the extremum of the sum.

Table A1. Scenario sea-level contribution (cm) by source from 2010 to 2100

Scenario	Thermal Expansion	Glaciers and Ice Caps	Greenland	Antarctica	Total
Twentieth Century Sea-level Rise	6.1	6.3	1.2	2.6	16.2
Late 20th Century Sea-level Rise	16.0	6.3	2.8	2.8	27.9
B1 Minimum	12.2	6.6	2.5	-5.9	15.3
B1 Midpoint	14.6	8.5	4.3	-3.4	24.0
B2 Midpoint	17.1	8.9	4.8	-3.8	27.0
A1B Midpoint	19.3	9.1	5.5	-4.3	29.6
A1T Midpoint	18	9.2	5.2	-4.2	28.3
A2 Midpoint	21	9.5	5.6	-4.7	31.2
A1FI Midpoint	24.9	9.7	7.6	-5.7	36.4

A1FI Maximum	32	11.4	10.0	-29.8	50.5
Pfeffer Low 1	29.4	17.0	16.1	14.3	76.8
Pfeffer Low 2	29.4	23.5	16.1	12.5	81.5
RG[1] – Twentieth Century	43.5	44.6	88.1	18.1	115.0
RG – Late Twentieth Century	40	39.7	17.7	17.7	115.0
RG –Pfeffer Low 1	30	30.5	28.9	25.6	115.0
RG –Pfeffer Low 2	30.	38.3	26.3	20.4	115.0
Pfeffer High 1	30	27.4	26.7	30.8	115.0
Pfeffer High 1	29.4	53.9	52.6	60.6	196.3

[1]RG is Rahmstorf/Grinsted

Pfeffer Low 1, Pfeffer Low 2, and Pfeffer High 1 Scenarios. Pfeffer et al. (2008) developed three scenarios of future sea-level change. The sources (Greenland, Antarctica, and glaciers and ice caps) appear to be compatible with Meir's (1984) sources that were used in the sea-level fingerprinting of Mitrovica et al. (2001). Consequently, the only adjustment that was made to their Table 3 was to scale the contributions by a factor of 90/92 = ~0.978 to account for the fact that the study was published in 2008, but that our projections are based on the 2010 to 2100 time frame.

Rahmstorf/Grinsted Scenarios. Here we scaled five other scenarios (Twentieth and Late 20th Century scenarios and Pfeffer's three scenarios) to deliver 115 cm of sea-level rise. The Twentieth Century scenario was scaled directly, and this gives a thermal expansion contribution of 43.5 cm, which is larger than the amount provided by any of the IPCC scenarios (the maximum amount of thermal expansion provided by the A1FI scenario is 41 cm over a 105 year time frame, which gives about a 35 cm contribution over 90 years). A direct scaling of the Late 20th Century scenario generates an even larger amount of thermal expansion, and thus we capped the thermal expansion at 40 cm and scaled the other contributions to obtain a total sum of 115 cm. This yields the scenarios **RG – Twentieth Century** and **RG – Late 20th Century**.

Pfeffer et al.'s (2008) three scenarios were all scaled to provide 115 cm of sea-level rise. The thermal expansion term was held at 30 cm for these scenarios and the other contributors (glaciers and ice caps, Greenland, and Antarctica) were scaled to deliver a total of 115 cm of sea-level rise. This yields the scenarios **RG – Pfeffer Low 1**, **RG – Pfeffer Low 2**, and **RG - Pfeffer High 1.**

Appendix B. Derivation of estimates of vertical land motion at the five pilot communities

Background and approach

Rates of relative sea-level change at any specific location can be closely approximated by adding the estimated rate of vertical land motion at that location to a term representing the global rate of sea-level change. Therefore, in order to project 21st century relative sea-level variations for Nunavut communities, we need to know the magnitude and direction of vertical land motion at these locations. To estimate rates of vertical motion at each of the five pilot communities, we have considered two primary sources of information. Empirically derived continental scale isobase maps yield a first estimate of rates of vertical land motion. The Earth's predicted glacial isostatic adjustment (GIA) response to loading and unloading by the ICE5G model provides a second estimate for present-day rates of vertical land motion. In this appendix, we compare the two sets of estimates, and explain the rationale by which we arrive at a final estimated rate of vertical land motion for each of the five communities.

Isobase approximated rates of vertical land motion

Maps of isobase values are available for North America at 500 year intervals from 500-14,000 radiocarbon years BP (Dyke, 1996, and unpublished updates incorporating new information). The isobase values at any given time represent the elevation of the land surface at that time relative to the present-day value, and are based on observations of past relative sea-level. The spatial extent of the isobases therefore depends on the location of past shorelines and the time-varying configuration of the Laurentide ice sheet, and is generally limited to ice-marginal regions.

The isobase contours generally do not intersect exactly with the locations of specific communities. We therefore have to interpolate the isobase contours spatially to estimate vertical motion at most locations. Since the isobases have limited and uneven spatial distribution over the North American continent, the interpolation can be considered reliable only in regions contained by the isobases (fortunately, all five pilot communities fall within the region of the contours).

To estimate rates of vertical land motion from the isobase values, we fit a quadratic curve to the isobase values from the last 2000 years at each of the five pilot communities. The slope of the curve calculated at present-day represents the estimated vertical motion rate. Prior to calculation of the isobase rates, the time intervals from 500-2000 years BP were calibrated to calendar years using a marine-based calibration curve and assuming a marine reservoir correction of 630 years. Uncertainty of each calculated isobase rate was taken to be the uncertainty of the least squares fit to the data points. The present-day vertical land motion rates derived from the isobases are given in Table 1 for each of the five pilot communities.

ICE5G model-predicted rates of vertical land motion

Numerical models of the GIA process provide a second source of present-day vertical land motion estimates. Topography values for the ICE-5G VM2 v.1.2 model (Peltier 2004) are available online (www.atmosp.physics.utoronto.ca/~peltier/data.php). The topography data are available on a uniform 1° × 1° degree global grid for times from 0-21,000 years BP. The same methodology that was used to estimate present-day rates of vertical land motion from the isobase data was employed to estimate rates from the ICE-5G data set. The topography values were extracted from the ICE-5G grid at the location nearest in latitude and longitude for each of the five communities at times 0-2000 years BP at 500 year intervals. The present-day rate of vertical land motion was estimated to be the value of the slope at time zero of a quadratic curve fit to the topography values for each location. Table 1 gives the model predicted rates of vertical land movement for each of the five communities.

The ICE-5G model is a recent global model of surface topography and ice sheet distribution for the last ~100,000 years (Peltier 2004). The model is in part constrained by observations of relative sea-level. Some of the relative sea-level data used to inform the model is the same as the data from which the isobases are constructed; the two sets of present-day vertical motion estimates are therefore not entirely independent of one another. However, the ICE-5G model incorporates additional constraints, such as the rate of change of gravity for central North America, making comparison of the ICE-5G predicted rates to the isobase-derived rates a useful exercise.

Comparing the isobase rates to the ICE-5G rates

Comparing the present-day rates of vertical land motion derived from the isobases to those predicted by ICE-5G at the five communities reveals variation between the two sets of estimates (Table 1). The largest differences are observed at Arviat and Whale Cove (ICE-5G is larger by 5.62 mm/yr and 3.15 mm/yr, respectively). Both the isobase and ICE-5G rates, and the differences between them, are smaller at Cambridge Bay, Iqaluit and Kugluktuk.

The large difference between the isobase and ICE-5G rates observed at Arviat and Whale Cove prompts the question of which source of information should be considered more reliable when determining present-day rates of vertical land movement. To address this question, we have directly evaluated both ICE-5G and the isobases against the existing relative sea-level data at each of the communities. There are no relative sea-level data available for Whale Cove. The two communities nearest Whale Cove for which relative sea-level data exist are Arviat (to the south) and Baker Lake (to the northwest). We therefore use the fit of both the isobase values and the ICE-5G model to the relative sea-level data at Arviat and Baker Lake to infer the reliability of the vertical motion rates at Whale Cove.

We compare ICE-5G to the observed data by extracting the paleotopography of the model at approximately 500 year intervals from 0-21,000 years BP and plotting the values against the relative sea-level observations at each location. At Arviat and Baker Lake, ICE-5G over-predicts relative sea-level, and the overall fit to the data is poor at both locations. We therefore infer that the model will also poorly reproduce the data at Whale Cove. At Cambridge Bay, Iqaluit and Kugluktuk, the fit of ICE-5G relative to the data is generally reasonable. Moreover, the fit at these three locations tends to be good particularly at times in the recent past; this tendency is desirable because the behaviour of the model at recent times will more strongly influence the present-day rate of response than earlier times.

To check the isobase values are in agreement with the relative sea-level data, we plot the isobase values from 0-10,000 years BP at 1000 year intervals for the five communities against the relative sea-level observations. There is good agreement between the isobases values and the relative sea-level observations at all locations (Arviat, Baker Lake, Cambridge Bay, Iqaluit, Kugluktuk). Since the isobase contours were empirically derived primarily from the relative sea-level data, this result is anticipated, and provides confidence that the present-day rates of vertical motion determined from the isobase values are in accordance with available data.

At locations where there is significant discrepancy between the isobase-derived rates and the ICE-5G model predicted rates, the observation that the isobase values agree well with the relative sea-level data at all locations lends preference to the isobase-derived rates. This preference assumes the rates inferred from the isobases are, in general, more strongly supported by available site-specific observations than the model-predicted rates.

Final determination of vertical uplift rates at the five pilot communities

The ICE-5G paleotopography fits poorly with the relative sea-level data at Arviat and Baker Lake, and thus, by inference, at Whale Cove as well. Consequently, when determining present-day vertical uplift rates for Arviat and Whale Cove, we neglect the ICE-5G predicted rates and use only the isobase-approximated rates (Table 1). At Cambridge Bay, Iqaluit and Kugluktuk, the ICE-5G model values are in reasonable agreement with the relative sea-level data. Our estimated vertical uplift rates at these three communities are the average of the isobase-derived rate and the ICE-5G predicted rate (Table A2).

The estimated uncertainty on the final rates at each of Cambridge Bay, Iqaluit and Kugluktuk is the larger of the average of the standard deviations between the mean rate and the isobase and ICE-5G rates at the three communities, and the individual standard deviation at each location. The estimated uncertainty at Arviat and Whale Cove is the largest standard deviation of the ICE-5G and isobase derived rates at the other three communities.

The final vertical land motion rates presented here will be applied to different scenarios of global sea-level rise to arrive at a range of projections of relative sea-level change by the year 2100. We assume that the rate of vertical land motion will remain constant over that time interval.

Table A2. A summary of the estimated rates of vertical land motion at Arviat, Cambridge Bay, Iqaluit, Kugluktuk, Whale Cove, and Baker Lake. The final employed rate of vertical land motion is an average of the isobase approximation and the ICE-5G prediction at Cambridge Bay, Iqaluit and Kugluktuk. The final employed rate is solely the isobase approximation at Arviat and Whale Cove. Rates at Baker Lake, discussed in the text, are also shown for reference. The land uplift by 2100 is determined by assuming the final employed rate of vertical land motion is constant from present to 2100; a 90 year interval is assumed.

Community	**Isobase approximation (mm/yr)**	**ICE-5G prediction (mm/yr)**	**Final employed rate (mm/yr)**	**Estimated uncertainty (mm/yr)**	**Uplift by 2100 (cm)**
Arviat	8.1	10.4	8.1	±2	72.9
Whale Cove	8.4	8.9	8.4	±2	75.6
Baker Lake	8.2	9.9	NA	NA	NA
Kugluktuk	2.5	2.5	2.5	±1	22.5
Cambridge Bay	5.1	2.3	3.7	±2	33.3
Iqaluit	0.2	1.5	0.9	±1	8.1

H. Project Photos

Kugluktuk Climate Change Adaptation Plan

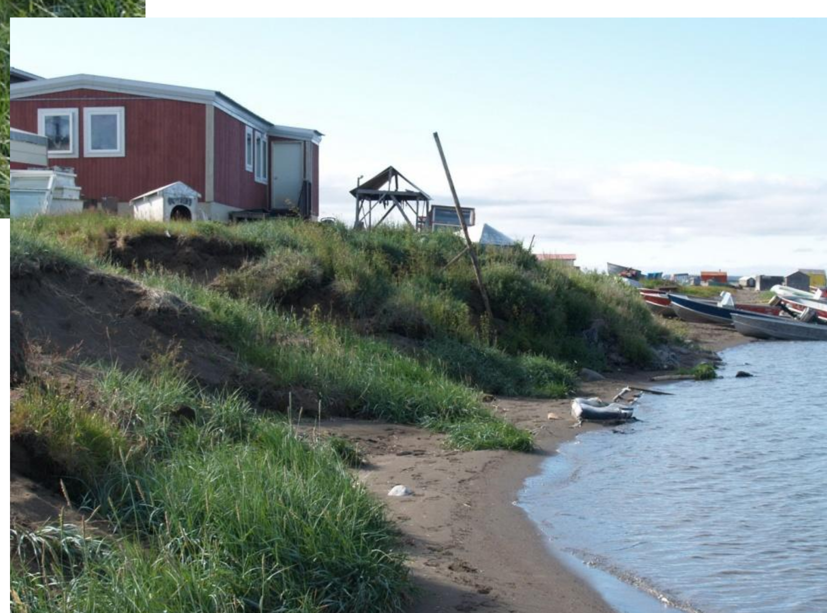
Images of the Observations and the Work Carried Out

Subsistence Activities

Built Environment for Sheltering People

Built Environment for Managing Nature

Natural Environment

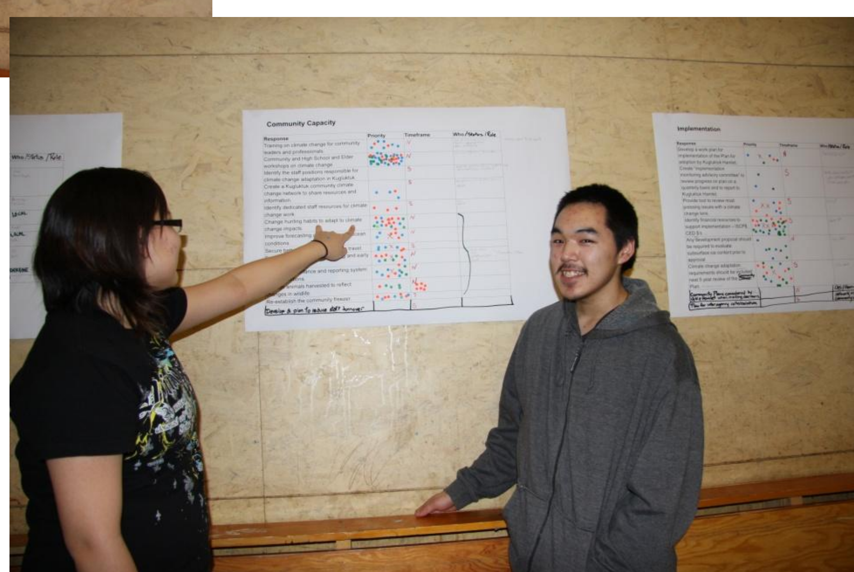


Learning For All Ages

Communication

Participation

Youth Involvement



WARMING OF THE CLIMATE SYSTEM IS UNEQUIVOCAL, AS IS NOW EVIDENT FROM OBSERVATIONS OF INCREASES IN GLOBAL AVERAGE AIR AND OCEAN TEMPERATURES, WIDESPREAD MELTING OF SNOW AND ICE, AND RISING GLOBAL AVERAGE SEA LEVEL.

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