2.4 Instability of Coastal Landscapes in Arctic Communities and Regions (Coastal Landscape)

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**ABSTRACT**

Future climate scenarios and impacts modeling predict changes in climate variables that may increase coastal landscape instability and hazard risk. Projecting the future response of the coastal land system to these changes in climate forcing is a prerequisite for an effective adaptation strategy and forms the core of this ArcticNet project. Through improved understanding of changes in climate, sea-level, sea ice, storms and wave climate, seasonal thaw depths, and other aspects of environmental forcing we will assess integrated impacts on coastal landscape stability, including flooding, erosion, habitat integrity, and community vulnerability. Together with northern communities and partners we plan to integrate local and external research and knowledge on climate-change trends and impacts in order to provide a common basis for decision-making at all levels, thereby enhancing community adaptive capacity. Ultimately the goal is to promote informed choices of adaptation measures and enhanced resilience in northern coastal communities.

**KEY MESSAGES**

- Data mining of historical water level (tide gauge) records for Frobisher Bay, combined with a digital elevation model, has demonstrated the current vulnerability of waterfront infrastructure in Iqaluit.

- Consideration of this result, combined with projections of more open water and rising sea levels, has been recognized by the community, underlining the need for better coastal hazard data for planning, engineering, land-use and sustainability policy.

- Projected sea levels in the Canadian Arctic vary substantially from one location to another. The differences arise because of differences in the rate that the land is rising or sinking and because meltwater from glaciers and ice caps is distributed unevenly in the oceans.

- Existing glacial isostatic adjustment (GIA) models require substantial revisions in light of new sea-level data collected in this project. This has implications for understanding the global water budget over the past 20,000 years and for present-day crustal motion in the Canadian Arctic. Refinements to present-day crustal motion will lead to improved sea-level projections, needed for coastal communities and infrastructure.

- Ground ice accounts for a significant portion of earth materials in coastal bluffs along the Yukon coast and similar areas in the western NWT; the quantities of ice, which strongly influence coastal erosion rates and processes (including thermokarst and block failure), are related to surficial materials and geomorphic history.

- Understanding the heterogeneity of geophysical responses for massive ice as a function of chemical properties is critical for developing accurate subsurface mapping products for use in modelling coastal erosion and projecting landscape instability.

- Marine habitat mapping using multibeam bathymetric sonar, including new tools for shallow-water mapping, has provided new knowledge of the seabed for Arctic coastal communities and other stakeholders.

- Improved bathymetric mapping and nearshore seabed characterization provides a framework for understanding the relations between seabed morphology, sediment properties, and benthic biotic assemblages.

- Recent work has expanded our knowledge of the biogeography of nearshore and fjord faunas in the central and eastern Canadian Arctic.

- Assessment of landscape hazards in relation to permafrost and periglacial conditions was undertaken in 7 Nunavut communities to examine the impacts and risk posed by different physical environmental conditions on infrastructure.

- Community landscape hazard mapping has been designed to provide guidelines for monitoring, as-
assessment, and application in other northern communities.

- Overwhelming majority of infrastructure in Nain, Nunatsiavut, displays terrain-related structural damage from differential ground subsidence, frost heaving and jacking and erosion.

- Access to a sufficient quantity of desirable, clean drinking water may be compromised for some community residents in Nunatsiavut.

- Cryogenic concentration of surface waters in seasonally marine-isolated basins off Sachs Harbour has created hypersaline bottom waters leading to the precipitation and sedimentary accumulation of crystalline mirabilite (a hydrous sodium sulphate salt).

- This is the first study to document mirabilite accumulation in an Arctic coastal lake basin and is significant for identifying the potential aquatic and environmental changes occurring in shallow gradient coastlines undergoing marine transgression, and the impacts these may have on benthic fauna and thermokarst/coastal erosion processes.

OBJECTIVES

- To improve understanding of changes in climate, sea levels, sea ice, storms and wave climate, seasonal thaw, permafrost and ground ice, and other aspects of environmental forcing as a basis for assessing integrated impacts on coastal landscape stability, including flooding, erosion, thermokarst activity, habitat degradation and community vulnerability, particularly in areas of high sensitivity and cultural significance.

- Improve the understanding of the effects of changes in climate on Arctic coastal environments, particularly pertaining to coastal instability, other coastal hazards, and community vulnerability.

- To work with stakeholders in the Inuvialuit Settlement Region, Nunavut, and Nunatsiavut to manage and mitigate changes in forcing, hazards, habitat conditions, and adaptive capacity related to climate change and variability, economic development and other factors.

- To integrate local and external research and knowledge on climate-change trends and impacts in order to provide a common basis for decision-making at all levels, thereby enhancing community adaptive capacity. Ultimately, the goal is to support and promote informed choices of adaptation measures and enhanced resilience in northern coastal communities.

INTRODUCTION

Northern communities and community lands, generally located on permafrost in coastal environments, are exposed to a harsh climate, with strong seasonal contrasts in temperature, wind, precipitation, and ice conditions. Under a constant climate, seasonal changes in the landscape and extreme weather events create instability and hazards, including flooding, landslides, thaw failure and subsidence, coastal ice push, storm surges, and coastal erosion. Emerging evidence of climate change in the north and a growing global consensus point to significant changes leading to more severe environmental hazards in the future.

Coastal landscape change in the Arctic has been ongoing for thousands of years and human adaptation has been a constant imperative for Inuit occupying this region. The evolution of Inuit culture is a clear demonstration of adaptation to extreme climatic conditions, but limits to adaptation are seen in the demise of the Thule culture and early European agrarian settlement in Greenland, both due at least in part to climate cooling. The former occupation of parts of the northern Canadian Arctic Archipelago that were later abandoned, as well as early paleo-Eskimo expansion southward to Newfoundland, demonstrates a capacity on the part of northern people to adapt in the past through migration, taking advantage of opportunities to access resources or withdrawing if resources became scarce. More recently, as people have become more dependent on community
services available only through hamlets and larger settlements, moving is no longer an acceptable response to environmental change.

The Inuit lifestyle is closely tied to marine resources. Long experience on the land and coastal ocean has allowed the development of traditional knowledge of the physical environment and living resources in a region, as well as an understanding of the range of climate variability expected over timescales of a few generations. This knowledge base provided an understanding of safe practices or routes, such as areas of reliable ice, or of particular environmental hazards. Over the past few decades, and particularly in recent years, the extent of climate variability and change has begun to challenge the limits of traditional knowledge (Fox 2004). At the same time, climate change is forcing adjustments in building and infrastructure engineering practices in communities and driving a recognition of the need for adaptation at all levels from individuals to communities, regions, and territorial governments. It is expected that the pace of change will increase in the future, with some of the earliest and most severe changes occurring in high latitudes (ACIA, 2005; IPCC 2007). The greatest warming in recent decades has occurred in the western Arctic, while climate warming has been slower to occur and less clear in Nunavut, Nunavik, and Labrador. However, there is now widespread evidence across the Canadian Arctic for climate warming affecting glaciers and ice caps, vegetation and other living resources, permafrost and seasonal depth of thaw, slope stability, coastal sea-ice conditions, wave energy, sea level and coastal flooding and erosion hazards, among other factors posing increased risk to northern coastal communities and habitats (ACIA, 2005).

Virtually all Inuvialuit, Nunavut, Nunavik, and Nunatsiavut communities are coastal and many emerging resource developments are either located on the coast or, more commonly, require shipping access with coastal implications. Thus coastal infrastructure is a critical issue for northern governments and communities (Ford et al., 2010). The emerging evidence for climate warming in the Arctic is pointing to changes already apparent in coastal ice extent, form, sea-level changes, increased wave action and erosion even in communities with rapid uplift and falling relative sea levels, and changes in species composition with implications for coastal habitat integrity and communities dependent on country food. There is a high demand on the part of communities and territorial governments for information on these emerging issues (Catto and Parewick 2008). Community adaptation is not the primary focus of this project, but the project objectives include the acquisition and appropriate consultative distribution of scientific information to support adaptation efforts.

**ACTIVITIES**

**Coastal erosion and fate of eroded sediment**

*Developing long-term predictions of coastal erosion for various segments of the Arctic coast and assessing impacts at community and regional levels*

- Completed and published circum-polar coastal erosion synthesis for the entire Arctic Ocean coast (Forbes 2011 [NI], Lantuit et al. 2011 – author list on the latter paper indicates geographic scope and international reach of this collaboration).

- Expanded sampling of exposed massive ground ice on Yukon coast for innovative geochemical species (molar gas) ratio analysis to more conclusively distinguish buried glacial ice from intraformational ground ice; analysis of ‘best-practice’ coastal landscape management in the context of changing climate (Fox, Lantuit, NI Pollard).

- Installed atmospheric and hydrological monitoring equipment and undertook additional monitoring and analysis of retrogressive thaw slump activity on Herschel Island (Lantuit, NI Pollard).

- Collected soil samples from seven soil profiles within an active retrogressive thaw slump on Herschel Island for chemical analysis and assessment of changing rates of pedogenesis and weathering (Williams-Jones, NI Pollard).
• Ice wedges were mapped with shallow geophysics and ground-truth observations obtained in vicinity of block failures on Herschel Island and the mainland Yukon Coast (NI Pollard).

• Assessed nearshore seabed properties for input to coastal erosion models and contributed to new ACD classification scheme (Lantuit, Couture, NI Pollard).

• Capacitively-coupled resistivity (CCR) and ground penetrating radar surveys, over ground ice and a retrogressive thaw slump were used to calibrate and improve 3D models of ground ice distribution for Herschel Island (Angelopoulos with NI Pollard, Lantuit).

• Recorded vegetation community composition in 579 plots at seven sites representing four age classes of stabilized retrogressive thaw slumps and investigated other controls on vegetation (Cray Sloan with NI Pollard).


• Modelling of shore-zone sediment transport and dynamics of erosional hotspot development at Hall Beach, NU, previously delayed by departure of PDF, is underway at time of writing, with projected completion in March 2012 (Manson, NI Forbes, coop student).

Assessing storm impacts on Arctic coasts

• Journal paper published on coastal storm response of beaches in the central Arctic Archipelago near Resolute, NU (St-Hilaire-Gravel et al., 2012; NIs Forbes and Bell).

• Wave and water level (tide and storm surge) data collected at four sites over macrotidal flats at Iqaluit, NU, over several months (mid-July to mid-November 2011) and tidal currents measured using acoustic doppler profiler. Sidescan sonar, single-beam bathymetry, and acoustic sub-bottom surveys documented seabed conditions over flats and for site of proposed Iqaluit deepwater port (Hatcher, Manson, NI Forbes).

• Real-time kinematic GPS surveys of ice conditions over Iqaluit tidal flats completed in February 2011 (Hatcher, Manson). Freeze-up process over Iqaluit tidal flats documented in November 2011 (Hatcher, NI Forbes).

• Analysis of sparse historic tide gauge data revealed important flood event in 1964 with serious implications for storm impacts on Iqaluit waterfront (Hatcher et al. 2011, Hatcher, Manson, NI Forbes).

Relative sea level studies

Using existing and newly obtained relative sea-level observations to generate sea-level projections to the year 2100 for northern communities and other northern locations where coastal infrastructure development is proposed or planned

• As indicated last year, a new method was applied to generate robust projections of future sea levels for five pilot communities of the Nunavut Climate Change Partnership. The results of this pilot work were published (James et al. 2011). Over the past year, this work was expanded to all northern communities in Nunavut and the NWT (NI James, Simon, co-op student).

• Continuing development and testing of glacial isostatic adjustment (GIA) models (NI James).

• Ongoing work led to improvements in GIA modelling capability, including incorporation of a realistic, time-dependent ocean function, so that meltwater influx into formerly glaciated marine regions is modelled appropriately (PhD student Simon, NI James).

• Water chemistry characteristics of submerging coastal basins.
• Ongoing analysis and interpretation of major ion chemical and stable isotope composition of surface ice and water column samples from coastal lake basins on a submerging coast on southwestern Banks Island. The basins, which are seasonally connected to the marine environment by a shallow sill (1.2 m deep), are floored with up to 1 m of crystalline mirabilite accumulations first discovered during fieldwork in 2007 (Grasby, NIs Smith, Bell, Forbes).

Community hazard mapping

*Landscape hazard assessments and consultations with practitioners*

• Landscape hazard mapping protocol applied to preparation of map products for Clyde River, NU (NI Smith, NI Bell, student Irvine graduated).

• Additional geophysical investigations on the Yukon coast generated data to calibrate and improve 3D models of ground-ice distribution for Herschel Island, and work continued on a regional survey of thermokarst activity and revegetation rates and processes (NI Pollard, Angelopoulos, Cary Sloan).

• There was no 2011 fieldwork in the Mackenzie Delta due to shift of all PERD funding from on-shore to deep water, compounded by illness and death of partner Steve Solomon. However, laboratory work on sedimentation rates in cores and GPS analysis of natural subsidence continued to support preparation of paper on subsidence, sea-level rise, and flooding hazards in the area of proposed natural gas production and the Kendall Island Bird Sanctuary (NI Forbes, Whalen, Couture, Manson, et al.).

• Preliminary mapping of the surficial geology and landscape characteristics around Nain employed airphoto interpretation, site visits and sediment sampling. Hazard assessment focused on evidence of coastal flooding and erosion, permafrost degradation, drainage network disruptions, and slope instability. Infrastructure damage assessment involved visits with homeowners and commercial operators in the community and discussions of damage history (Putt, Sheldon, NI Bell).

• Testing and refinement of a Climate Change Adaptation Toolkit for Labrador communities developed in partnership with the Atlantic Climate Adaptation Solutions project; research and publication of community adaptation case studies from Labrador (Allice, Wolf, NI Bell).

Community water security in Nunatsiavut

• Semi-structured household interviews with Nain residents and a series of key informant interviews with community leaders and Nain Inuit Community Government workers (including water maintenance staff) were undertaken. These interviews were coded and analyzed in conjunction with numerous secondary sources collected from the community, such as water maintenance reports, community planning documents and related literature (Goldhar, Sheldon, NI Bell).

Community resilience

• Surveys and data mining proceeded on landscape and coastal hazards in Iqaluit, in close collaboration with city officials and in partnership with the C-Change ICURA project, key objective being to support development of municipal sustainability policies (Hatcher, Manson, NI Forbes).

• Synthesis and reporting of community resilience studies in Tuktoyaktuk and Sachs Harbour, NWT and Gjoa Haven, NU; successful defence of Parewick’s PhD (Parewick, NI Catto).

Community consultation, outreach, and national/international conferences

*Inuvialuit Settlement Region*

• Community consultations and presentations to Aklavik and Inuvik HTC’s and hamlet/town coun-
cils in March 2011 (including public presentation to community in Inuvik) and similar consultations planned for coming year.

- Presentations and consultation with Inuvialuit Game Council and Environmental Impact Steering Committee in March 2011 and scheduled again for March 2012 (NI Pollard, NI Forbes, Angelopoulos, Fox).
- Extensive consultation with IRC and proposed partnership with ILA during preparation of BREA proposal (NI Forbes). Project was not funded in 2011 but is under consideration for 2012 funding.

Nunavut

- A major stakeholder consultation workshop took place in Iqaluit in mid-February 2011, involving communities, territorial government departments and other key stakeholders. This was a high-profile event under the Nunavut Climate Change Partnership (Manson, NIs Bell, James, Forbes, student Hatcher).
- Frequent on-site consultation with City of Iqaluit (Director of Engineering and Sustainability, Sustainability Coordinator, Director of Planning) both on-site and at other meetings (e.g. C-Change, Ottawa, December 2011).
- Team consultation in Kugluktuk and Cambridge Bay scheduled for February 2012.

Nunatsiavut and Labrador

- Community workshops in partnership with Nunatsiavut Government and Nain and Hopedale Inuit Community Governments to document: valued community places and spaces; landscape and other constraints on community expansion and development; and new directions for community engagement, January 2012 (Allice, Sheldon, NI Bell).
- Project updates to the 2011 annual meeting of the Labrador Combined Councils, Happy Valley-Goose Bay (Allice, Wolf, NI Bell).
- Project description and consultation during Memorial University’s Harris Centre workshops in the Aurora and Labrador Straits Economic Development Zones, Port Hope Simpson, November 2011 (Allice, NI Bell).

National

- Presented findings in regional and national television and newspaper media (CBC, CBC North, and others)(NI Bell, NI Pollard, Lantuit, Fox, Cray Sloan, Angelopoulos).
- Contributed to coastal section of book on Herschel Island by Dr. Chris Burn (Couture, Lantuit, NI Pollard).
- Presented research findings to PERD Northern Regulatory Research Workshop, NRCan senior managers and policy specialists, and C-Change community stakeholder’s workshop (NI Pollard, NI Forbes, NI James, Couture).

International

- Presented research findings to the scientific community at Resilience 2011 (Tempe, Arizona), March 2011; Coastal Sediments Conference (Miami, USA) May 2011; SALISES/C-Change Conference (Port-of-Spain, Trinidad) June 2011; International Congress on Arctic Social Sciences VII (Akureyri, Iceland), June 2011; INQUA Congress (Bern Switzerland) July 2011; 5th International Limnogeology Congress (Kontanz, Germany), Aug-Sep 2011; LOICZ Open Science Conference (Yantai, China) September 2011; AGU Fall Meeting (San Francisco, USA) December 2011 (NIs Bell, Forbes, Pollard, James, Catto with Allice, Angelopoulos, Couture, Fox, Hatcher, Lantuit, Manson, Parewick, Simon, Wolf).
RESULTS

Community hazard mapping

Detailed field and airphoto surveys have been used to produce community-focused 1:10 000 scale maps of surficial geology and permafrost and periglacial geology (Figure 1), in English and Inuktitut versions (in progress). These layers of information have then been integrated to produce a composite landscape hazard classification map, whereby sites are ranked as having high, medium, or low risk to infrastructure development based on a subjective evaluation of landscape conditions such as ground ice content, slope, sediment stability, proximity to stream channels, and coastal erosion (Smith et al. 2012a, 2012b). This type of mapping, initiated in Clyde River, NU, is in progress in a selection of other Nunavut communities and in Nain, Nunatsiavut.

Settlement-scale consequences of environmental changes relate mainly to the changing physical conditions of frozen ground and shoreline terrain; the damage or disruptions these may cause in relation to the infrastructure built there; and, in the case of earthen structures, the likelihood that original design assumptions made about their year-round structural integrity may no longer hold true. Local governments need to pay added attention to drainage systems, waste disposal practices, aggregate resources, and monitoring of terrain and infrastructure (Parewick 2012).

Permafrost thaw (deepening active layer and melting of excess ice) may affect critical community infrastructure across the region, including local water supplies, waste management infrastructure, and fuel storage facilities, but to date there appear to be few measures in place that anticipate or respond to these potential issues. Community members regularly raise concerns about a lack of recognition for “hidden” legacies of prior development in their locales (e.g. landfilled areas, contaminants potentially buried in former dumpsites), which deserve serious investigation (Parewick 2012). Of the 51 infrastructure assessments conducted in Nain, Nunatsiavut, 14% recorded no damage, 28% had evidence of minor settling, 24% experienced erosion of their underlying sediment or foundation pad, 22% had freeze-thaw related structural damage and 12% showed signs of differential subsidence. Differential subsidence was restricted to glaciomarine sediments and likely related to compaction and/or thaw of ground ice in the mud component of this ground type.

Waterfront infrastructure in Iqaluit, Nunavut, includes port facilities, private dwellings, townhouse and apartment structures, public facilities such as the courthouse, library and museum, commercial buildings, and critical municipal infrastructure (two pumping stations and sewage treatment lagoon), as well as informal infrastructure consisting of storage sheds for equipment used in subsistence and recreational hunting and fishing. These occupy land at the top of the beach and represent a socially important component of community infrastructure in Iqaluit, yet they are among the most directly exposed to coastal hazards at present (Figure 2). The capacity for this traditional economy sector to adapt to future rising water levels or higher run-up may be inadvertently constrained by backshore urban development (Hatcher et al. 2011).
Sea levels and coastal adjustment

The goal to make projections of sea-level change for all communities in the Canadian Arctic is on target for completion by March 2012. New projections were carried out in 2011 for Northwest Territories coastal communities (Paulatuk, Ulukhaktok, Sachs Harbour, and Tuktoyaktuk) at the request of the NWT Department of Environment and Natural Resources. Results were reported at the Yellowknife Geoscience Forum and appeared in the 2011 update of the NWT State of the Environment Report. Another goal to develop an improved glacial isostatic adjustment (GIA) model for the Canadian Arctic is well advanced. An early result discussed at Fall AGU 2011 is that the ice thickness west of Hudson Bay in the ICE-5G GIA model needs to be reduced by 25% or more in order to fit the newly acquired relative sea-level data at Arviat and Rankin Inlet. This is a major revision to the present widely accepted standard model of global glacial isostasy.

Rising sea levels in the Sachs Harbour region have caused coastal erosion leading to the breaching of small lake basins. Sachs Harbour itself consists of several amalgamated basins (Figure 3). Two connected basins...
Coastal Landscape

T. Bell and D. Forbes

ArcticNet Annual Research Compendium (2011-12)

Coastal Landscape

Coastal erosion

Studies of retrogressive thaw slumps on Herschel Island showed distinct and consistent vegetation communities for each age category of stabilized slump. Deviations from this overall pattern included plot locations with differing drainage and micro-topography, in addition to plots that included turf block with surviving headwall vegetation. Soil characteristics are radically changed through slumping activity, and recently stabilized slumps have a high pH and low organic carbon content compared with older stabilized sites and undisturbed sites.

Water chemistry of samples from active retrogressive thaw slump on Herschel Island revealed changing cation concentrations with increasing depth. Leaching is therefore likely to be an important process occurring within the soil profiles on Herschel Island. Changes in pH tended to follow soil organic matter content, with high soil organic matter content yielding lower pH values and vice versa. High electrical conductivity values coincided with high major cation concentrations and therefore peaks in electrical conductivity and cation concentration could provide insights into the formation and general location of salt brines.

Application of geophysical methods to understand ice origin and structure results in three main findings: 1) capacitively-coupled resistivity can effectively distinguish ice-poor permafrost from massive tabular ground ice, as well as ice wedges; 2) Resistive signatures for nearly sediment-free massive ice bodies are non-unique and are largely a function of geochemistry; and 3) the low resistivity values observed for massive ice on Herschel Island are likely due to brine films that depress the
freezing point and hold significant quantities of unfrozen water.

Along the Yukon coast, the mean erosion rate for all terrain units is 0.7 m/yr. This results in an annual soil organic carbon (SOC) flux of 157 kg per metre of coastline, which is higher than values for the Alaskan Beaufort and Kara Seas, but lower than values for the Laptev and East Siberian Seas. The effective cliff height appears to control the future erosional behaviour of coastal bluffs. Low bluffs (over 4 m high) show increasing erosional rates over the next 50 years (from 1.1 to 1.7 m/yr), whereas high bluffs show a slight decreasing trend (from 0.6 to 0.5 m/yr), likely because of the increased sediment input and its effect on short-term sediment transport in the nearshore. Surveys revealed that coarse-grained marine deposits in bars and spits along the Yukon coast have the lowest ice content (3%), followed by fluvial materials, glacial outwash and moraine deposits. Lacustrine materials, in contrast, had the highest ground ice content (54%).

**DISCUSSION**

This research has demonstrated an absence of baseline surficial and periglacial geology knowledge for most Nunavut communities. It has made the connection between these factors and infrastructure stability, and thereby provides a basis for their integration into future community development planning protocols and design (Irvine et al. 2009, Smith et al. 2010, Ford et al. 2010). Similarly, work on coastal hazards in Iqaluit, using climate-change scenarios, updated projections of changing sea level, a digital topographic model derived from satellite imagery and field surveys, supplemented by historical investigation of past storm events using instrumental and anecdotal data, is providing one element of a broader assessment to support informed waterfront planning in Iqaluit (Hatcher et al. 2011).

Nunavut communities are rapidly growing, and in many cases are expanding beyond initial settlement sites established on flat, raised marine/glaciofluvial terraces, into terrain that is both more difficult to build upon, and may pose greater risk to infrastructure stability and community sustainability. The kinds of research undertaken here serve as examples and guidelines of the type of studies that will be needed in the future. At the same time, even present infrastructure considered to be stable, must be re-examined under the scope of future climate change, and what the impacts may be on often ice-rich, saline permafrost (Forbes et al. 2012).

The majority of Nain residents prefer non-chlorinated sources of drinking water gathered from freshwater sources outside the community, though numerous barriers limit access to these preferred sources. These same barriers restrict the ability of some residents to access alternative water sources or locate new hunting grounds when former sources and locations are compromised. Adaptation to these changes is governed by access to financial resources, land-based skills and knowledge, physical ability to collect water or walk farther to access new water sources, and social bonds within the community. Newcomers, low-income households, and Elders and others with limited physical abilities were identified as sub-populations that are at greater risk of water insecurity. These residents are in need of additional support to improve their ability to access a sufficient quantity of desirable, clean drinking water at present, and adapt to water security challenges in the future.

Results of community resilience studies revealed a number of important insights (Parewick 2012), including: (1) Emerging physical hazards and related critical infrastructure issues require new monitoring measures be implemented at the local level to ensure that community managers are better able to judge altered infrastructure lifecycles and forthcoming operational needs; (2) To support local adaptation, planning expertise should increasingly be cultivated at the local level rather than continuing to rely on non-resident regional staff or professional consultants.

The results on mirabilite accumulation in transgressed coastal basins are significant for identifying a process and situation that, while apparently unique in the Canadian Arctic, may for reasons elaborated in the paper be more common than thought. The situation of these
coastal basins along a shallow submerging coastline is one that is likely to have occurred in the past, and exists today in other areas of southern and western Banks Island, and along the Mackenzie-Beaufort coastline (e.g. Ruz et al. 1992). The absence of prior documentation of sedimentary mirabilite accumulation in coastal basins, and differences observed between the two linked basins in this study, suggest that mirabilite accumulation may be a transitory process, and that following accumulation, the progressive submergence of these basins eventually disrupts the aquatic stratification, leading to mirabilite dissolution. When it forms, the year-round aquatic stratification produces anoxic conditions that effectively kill off most biological activity; this may have significant impacts on marine benthic resources accessible to communities.

The other significant component of this research is the identification of elevated bottom-water temperatures (12°C) in one of the basins. Thought to relate to exothermic reactions of bacterial sulphate reduction, these warm bottom water temperatures would likely have significant impacts on thermokarst processes in typically ice-rich coastal terrain, possibly leading to accelerated rates of coastal erosion, and a greater sensitivity to future sea level rise.

Despite increases in environmental forcing factors that control coastal erosion, overall soil organic carbon fluxes from the entire Yukon coast are not expected to change significantly within the next 50 years. This is because although fluxes from low coastal bluffs will increase by 29%, they will be offset by a 13% decrease in fluxes from high coastal bluffs. Model assumptions and conservative estimates of future climate forcings mean that retreat rates are somewhat underestimated, so the future flux of organic carbon could indeed increase somewhat.

Along the southeast shore of Herschel Island, the coast is affected by multiple retrogressive thaw slumps thought to contribute large quantities of sediment to the nearshore zone. These sediments contain organic carbon and nitrogen, which are likely to impact the nearshore environment. The exact contribution of these large thermokarst features is, however, largely unknown. The data collected from the weather station, discharge monitoring station sensor records, and sediment samples this field season will be used as boundary conditions for modelling the outflow of water and sediment from the slump.

Since Herschel Island is made up of highly deformed marine sediments, there exists a large concentration of dissolved ions (1120.1 ppm) and Na (salt) represents 72.4% of them. On the other hand, an inland study in the NWT showed a relatively low number of dissolved ions (177.2 ppm), 17.4% of which were Na. As a consequence, the average conductivity of melted massive ice samples was 5.6 times greater at Herschel Island compared to the inland site. An electrical contrast of similar magnitude was observed during frozen conditions using CCR, suggesting that unfrozen water exists along the brine films. This implies that if geochemistry is not taken into account during the interpretation of geophysical surveys, scientists might conclude there are greater changes in ground ice volumes over space than actually exist. Previous mountain permafrost studies show that analysing the differences between CCR and DCR outputs for identical transects can reveal information about ground ice properties. The slump floor surveys conducted on Herschel Island this year will provide valuable calibration data, in addition to advancing the interpretation of results for both systems. To our knowledge, this is the first study to compare results of the two electrical profiling methods in an ice-rich periglacial landscape.

**CONCLUSION**

Coastal zone research under this project across the Canadian Arctic is providing strong indications of changing landscapes and coastal stability in response to a changing climate. These trends represent hazards to coastal communities, infrastructure, habitats, and cultural resources. Synergistic patterns of change related to changing sea ice conditions, storm exposure, and warming permafrost indicate a potential for dramatic changes in the coastal zone and the stability of coastal landscapes at numerous sites from the southern Beau-
fort Sea to the central Arctic, the Baffin coast, Foxe Basin and Hudson Bay, Nunavik and Nunatsiavut. Our observations in many places confirm that changes are occurring in sea ice, permafrost, and the coastline. In places, shifts in environmental forcing and coastal response are on a collision course with the preservation of Inuit and Inuvialuit cultural resources and identity and for this reason they have high priority. Earlier and more dramatic climate change at high latitudes was projected by past climate model results and is now being experienced on the ground, posing greater challenges to the coping capacity in Arctic communities. For this reason, there is a strong demand for robust projections of future change, including changes in sea level, sea ice, storms (winds and waves), precipitation and run-off, coastal erosion, and landscape instability for input to climate-change adaptation planning and the mainstreaming of climate-change considerations across the spectrum of northern decision-making. Through the Nunavut Climate Change Partnership and other collaborations (including Natural Resources Canada, C-Change, Land-Ocean Interactions in the Coastal Zone, Alfred Wegener Institute), this project is playing a leading role in the acquisition of appropriate scientific data and provision of science-based advice to policy makers, planners, residents and other stakeholders in Canada’s northern territories.

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