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C-Change Working Paper: Coastal Hazard Assessment for Adaptation Planning in an Expanding Arctic Municipality

by

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C-Change Working Paper
June 2011

Submitted to the Sustainable Development of Coastal Communities: Challenges and Solutions International Conference, Port-of-Spain, Trinidad & Tobago, 1-3 June 2011

Published by the C-Change Secretariat (Canada)
Telfer School of Management, University of Ottawa
C-Change ICURA Working Paper Series No. 23

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ABSTRACT

Iqaluit (population 6182 in 2006, projected ~13,000 in 2030) is the expanding political and logistical capital of Nunavut in Arctic Canada. The city is experiencing a population influx with associated housing demand, planning and infrastructure pressures, and a growing volume of marine freight landed by barges across flats with a tidal range of 11 m. In addition, the city is faced with environmental changes which need to be better understood for appropriate planning in the waterfront area. The 2010 General Plan calls for a precautionary approach to climate change and special protection for culturally important coastal sites. In support of these objectives, we assess and map present and future flood probability and other hazards such as wave and ice impacts in the context of changing climate, including relative sea-level trends, possible changes in storm climatology, and changes in sea-ice break-up or freeze-up dates (associated with longer open-water seasons and increased exposure to waves and storm surges). Waterfront infrastructure planning in the City of Iqaluit requires robust understanding of present and future coastal hazards. Storage sheds and sea-cans for equipment used in subsistence and recreational hunting and fishing represent an important component of community infrastructure and are among the most directly exposed to current hazards. 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. Using climate-change scenarios, updated projections of changing sea level, digital topography from satellite imagery and field surveys, supplemented by historical investigation of past storm events using instrumental and anecdotal data, this research is providing one element of a broader assessment to support informed waterfront planning in Iqaluit.

C-Change Working Paper:

Coastal Hazard Assessment for Adaptation Planning in an Expanding Arctic Municipality

3. Introduction

Social-ecological systems on Arctic coasts are undergoing rapid and unprecedented change (ACIA, 2005; Hovelsrud & Smit, 2010; Forbes, 2011). The pace of change in the social dimensions of life in the north has been shown to actively shape the vulnerability of populations to predicted and observed changes in climate (Ford et al., 2006, 2010; Nichols et al., 2004). The physical systems of Arctic coastal communities, however, remain poorly understood and large knowledge gaps remain (Forbes, 2011). Several initiatives are underway to assist in preparing Arctic communities to adapt to the changes in climate now being experienced and projected to continue over coming decades. It has been shown elsewhere, however, that the value and effectiveness of a coastal management policy can be severely degraded without a solid understanding of the physical setting (e.g. Solomon & Forbes, 1999). Given the lack of scientific knowledge of landscape and coastal hazards in many Arctic communities, a protocol for rapid assessment was developed and implemented in several Nunavut communities for which pilot adaptation plans were prepared under the Nunavut Climate Change Partnership (e.g. Mate & Reinhart, 2011; Smith, 2011; Smith & Forbes, 2011). In addition, attempts have been made to incorporate traditional knowledge to supplement scientific observation, leading to a research methodology based on a situated multi-dimensional approach to coastal zone adaptation in the north (Smit & Pilifosova, 2003; Nichols et al., 2004; Berkes et al., 2007). As research accumulates from a growing number of Arctic communities, it is becoming clear that (among other factors) differences in coastal geography impose and influence differences in vulnerability between sites. This paper describes an ongoing project which aims to identify and quantify the physical components of coastal hazards in an expanding Arctic urban centre, Iqaluit, Nunavut, in combination with other measures to support adaptation and sustainable development policy. Preliminary results show that projected changes in coastal hazards in Iqaluit are strongly influenced by the sea ice that forms annually in Frobisher Bay. The estimation of return periods (or probabilities) for high water levels in the coming decades is also largely dependent on projections of relative sea level change, but impacts will likely be exacerbated by wave run-up and ice ride-up or pile-up. This work forms part of a larger effort under the C-Change ICURA (International Community-University Research Alliance) project for adaptation management planning in coastal communities in Canada and the Caribbean.

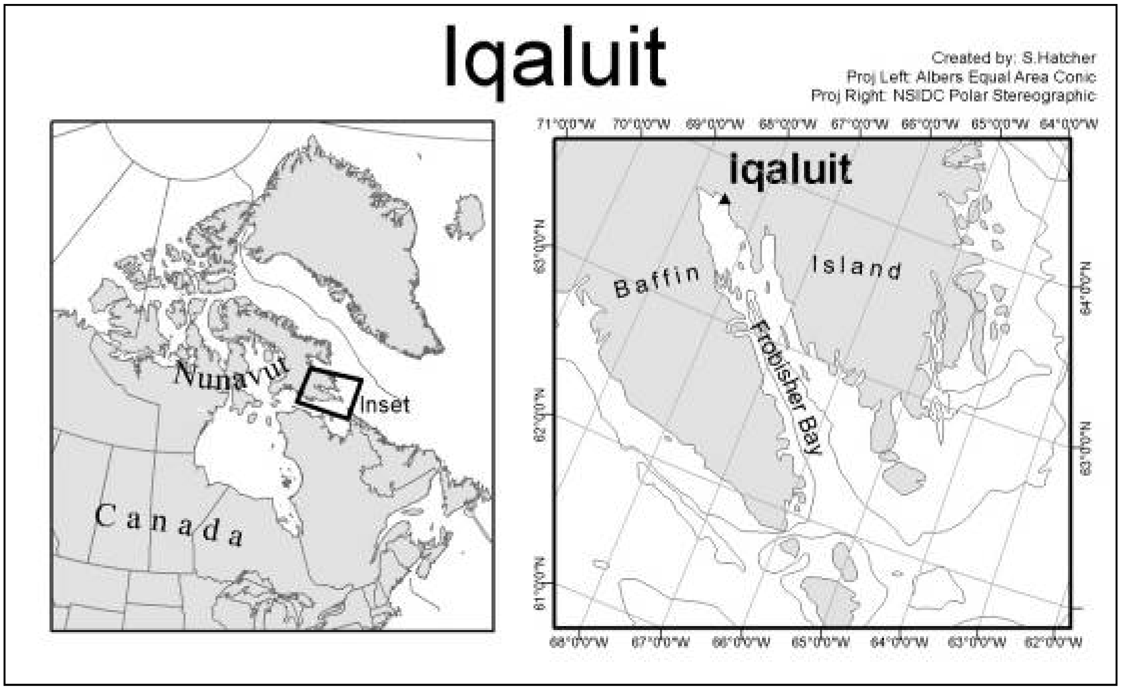

FIGURE 1. Location of Frobisher Bay and Iqaluit in the Territory of Nunavut, eastern Canadian Arctic.

3.1. Setting & Context

Iqaluit is a city in transition, with a disjointed history of temporary occupation, expansion, and development. As of the 2006 census, Iqaluit had 6182 residents (Statistics Canada, 2007). It is, however, one of the fastest growing cities in the country, with an 18.1% increase in population between 2001 and 2006. Of that population, roughly 60% are Inuit (Statistics Canada, 2007). Beginning with a U.S. military air base (1942) and later a Hudson's Bay Company trading post (1955), Iqaluit remained small for most of the latter part of the twentieth century, though it played a growing role as a service and transportation hub for the eastern Arctic. Since the settlement of the Nunavut Land Claims agreement in 1993, and the establishment of Iqaluit as the territorial capital, the city has undergone huge changes (Berkes et al., 2007). Conservative population growth projections foresee a total population of about 13,000 by 2030 (City of Iqaluit, 2010). On top of this, a recent climate-change adaptation report prepared for the city states that Iqaluit, like other Arctic communities, "is currently unprepared for projected changes in climate" (Neilsen, 2007).

FIGURE 2. View from the beach at low tide, showing the extensive intertidal boulder flats extending seaward from the Iqaluit waterfront. During a low spring tide, the water line would recede all the way to the last visible boulder. Photo: SVH, August 2010.

Frobisher Bay lies at the southeast end of Baffin Island in the Canadian Eastern Arctic (Fig. 1). The narrow bay is a product of its geological history, including sculpting by ice during and following the Last Glacial Maximum (Hodgson, 2003, 2005). The area is underlain by resistant granitic rocks, which are widely exposed with a discontinuous cover of sandy glacial till and postglacial deposits of raised marine deltas in the valleys. The City of Iqaluit sits on Koojesse Inlet near the head of Frobisher Bay, which is aligned roughly WNW-ESE, with high topography to the north and south. The harbour is exposed to the southeast with partial protection from islands in the head of the bay. The setting is 'macrotidal' with tidal range from 7 m (neaps) to 12 m (springs). Wide intertidal boulder flats extending 500 m out from the high-tide shoreline (Fig. 2) are underlain by thick, indurated silt and clay with a thin cover of sand and gravel with scattered cobbles and boulders. The tidal flats appear to have formed by erosion of proglacial brackish outwash sediments underlying part of the urban core (McCann et al., 1981; Hodgson, 2005).

4. Methods and Data

Table 1 shows the methods employed in this study and their relevance in the evaluation of coastal hazards. Because this work is undertaken in conjunction with the C-Change ICURA project, the methods are adjusted to the overall methodology of the larger project (Lane & Watson, 2010). The present work contributes to components two and three of the ICURA project – developing a community profile database, and visual modeling of projected changes. The work is being carried out in Iqaluit over two field seasons in 2010 and 2011.

Table 1. Methods used in the analysis of coastal hazards in Iqaluit.

Method	Description	Rationale	Data
GPS surveys	GPS topographic surveys completed on the tidal flats in 2010 and winter 2011. Continued in the summer of 2011.	Running transects over consecutive years allows change detection, and the estimation of erosion/ deposition across the flats.	GPS data from previous work in 2009 (Forbes and St-Hilaire, unpublished). Additional data collected in 2010 and 2011.
Sediment size analysis	Sediment sampling done on the tidal flats.	An understanding of the sediment distribution on the flats will help determine the wave climate and erosional nature of the tidal flats.	Sediment samples taken during the two field seasons.
Tide and wave gauge recording	Tide and wave gauge sensors deployed during field seasons.	Extends tide-gauge record and provides opportunity to capture wave events.	2010 and 2011 tide and wave gauge records.

Regional climate analysis	Analysis of the regional climate over the past thirty years using the self-organizing map technique (Cassano et al., 2006)	With only one climate observation station in the area, modeling will provide critical data on storms.	NCEP reanalysis data from NCAR, the National Centre for Atmospheric Research.
Ice free season analysis	Statistical trend analysis of ice coverage archives for Frobisher Bay.	To determine storm impacts, the trends in ice free season must be estimated. If there is ice cover, the storms pose limited risk to the coast.	Canadian Ice Service Digital Archive ice charts from 1969 – present. Passive microwave dataset 1979 – present.
Flood Frequency Analysis	Statistical technique to determine the return levels of extreme water levels based on the historical tide-gauge record.	Interrogating the historical water-level record to understand the frequency of past events is crucial in trying to estimate future frequency.	Iqaluit tide-gauge record, archived by the Canadian Hydrographic Service. The gauge ran only intermittently between 1963 and 1977.

5. Coastal Hazards

This section considers the main physical components of coastal hazards recognized at the study site. These are determined by reference to surveys of analogous Arctic communities (e.g. Forbes et al., 2007, 2008; Manson and Forbes, 2008; Smith, 2011; Smith and Forbes, 2011; Ford et al., 2010; Forbes and Manson, 2010), as well as two field visits to Iqaluit in late summer 2010 and February 2011. The City of Iqaluit faces many of the same hazards encountered in coastal communities around the globe, but an additional factor related to the high-latitude setting is the important role played by sea ice in the shore zone. Full sea-ice coverage typically runs from about early November to early June. In 2010, however, the bay remained ice free well past November, not fully freezing up until January (D. Mate, personal communication, 2011). This was a highly anomalous year, but if late freeze-up becomes more common in the future, there is a potential for greater storm impacts on the tidal flats and shoreline in Iqaluit.

5.1. Sea Ice

The freeze-up period, usually between late October and early December (McCann et al., 1981), can be highly dynamic on the tidal flats and shoreline along the Iqaluit waterfront. As new ice begins to form in early winter, the rising and falling tides work to repeatedly ground and float the newly formed ice. The ice is broken up by the jutting boulders and moved about by wind and tidal currents. Ice accumulates near the high-water mark to produce a bottom-fast ‘icefoot’, seaward of which the ice continues to float on high tides. Higher than average tides, with or without storm surge, may overtop the icefoot, gradually building up a broad ice terrace. Continued movement of the floating ice can lead to ride-up and pile-up over and against the outer edge of the icefoot (Fig. 3). The presence of ice is an important factor to consider in the context of future hazard exposure from rising sea levels, increased storm intensity, and tidal action. There is limited information available on the processes of freeze-up and break-up in macrotidal Arctic settings. This is a critical data gap because ice is a major component of coastal hazards in Iqaluit.

FIGURE 3. Shoreline of Iqaluit showing areas of previous ice ride-up. After the establishment of the ice foot, large floes of mobile ice can be thrust up on top of the landfast ice. This can occur at high water levels, which can flood the back of the icefoot and encroach on the city shoreline. Photo: SVH, February 2011.

There is abundant evidence for Arctic warming over the last 30 years and the area around Iqaluit has experienced some of the most rapid warming in the last decade (ACIA, 2005; Bekryaev et al., 2010). Over the circumpolar Arctic, this has led to extensive ice loss and widespread extension of the ice-free season (Gough et al., 2004; Johannessen, 1999; Markus et al., 2009; Smith, 1998). Closer to the study area, Markus et al. (2009) reported a consistent expansion of the ice-free season in Baffin Bay by 8.3 days/decade, with onset of freeze-up in the fall delayed by 3.2 days/decade. Thus, over 30 years, freeze-up is retarded by about 9.6 days. This could mean the difference between a storm passing over water heavily laden with ice, or over water that is almost ice-free. The fetch over open water could mean the difference between a heavily damaging storm with waves, or an early winter wind event over ice (quite common in Iqaluit).

5.2. Storms

Climate in the region is strongly influenced by the local topography. The effects of funneling and shear over the hills to the north and south influence the local weather. This is evident in the dominant wind directions at Iqaluit (NW or SE, parallel to the valley axis) (Hanesiak et al., 2010; Deacu et al. 2010). Local winds can exceed 100 km/h (the record of 129 km/h was set in 2007), but these are fairly rare events. More typical storm winds (averaging 25 occurrences per year) reach about 60 km/h from one of the two dominant directions (Hanesiak et al., 2010).

The southeastern Baffin region tends to experience more cyclonic activity than the interior and northern parts of the island, and is typically warmer by as much as 6 C° (Maxwell 1982). Zhang et al. (2004) show that the intensity and frequency of cyclonic activity generated around the North Atlantic has been steadily increasing, and can be related to large-scale circulation patterns (Wang et al., 2006). These findings are consistent with modeling results (Yin, 2005; Lambert, 2006) and with statistical evidence for a pole-ward shift in cyclonic activity (McCabe et al., 2001). As a result, we can anticipate more intense storms in the Iqaluit region in the decades to come.

Storms may lead to wave generation, with wave set-up and run-up, when strong winds blow up the bay from the southeast. Wave energy is constrained by the available open-water fetch (length of open water the wind can blow over), which, in turn, is dependent on the absence of sea ice in the bay. Given that the majority of the high wind events from the southeast occur in the fall, lengthening of the ice-free season later into the fall through surface temperature warming may increase the probability of open-water storms in the future.

5.3. Sea-Level Rise

James et al. (2011) have developed robust projections of relative sea-level change for Iqaluit, ranging from 0 to 80 cm over the next 90 years (2010-2100). The range reflects differences in emission scenarios (IPCC, 2007) and a range of projections published since 2007. Uncertainty in the vertical crustal motion, also incorporated in these estimates, will be better defined in future as more geodetic data are collected at GPS sites in the area. Sea-level rise at Iqaluit is constrained by proximity to the Greenland Ice Sheet, which exerts a strong gravitational pull on surface ocean waters in its vicinity. This results in a minimal response to meltwater inputs from Greenland but a strong response to Antarctic contributions. Nevertheless, the range of recent projections of global mean sea-level rise in the published literature suggests higher rates than projected by the Intergovernmental Panel on Climate Change (IPCC, 2007) and a strong likelihood of future relative sea-level rise in Iqaluit (James et al., 2011).

5.4. Flooding

Extreme tides or storm surges on high tides can create flooding in Iqaluit. Flooding is dependent on the tide, as the large tidal range precludes significant flooding during low tide. It is also known that there is an interaction between large tidal ranges and the timing of storm surges (capable of producing flooding) due to the movement of water by the tides. The statistics of storm surges in the area are unknown, but will be investigated through analysis of the past (limited) tide-gauge record for Iqaluit.

Analysis of these physical components will lead to the estimation of probabilities for extreme high water levels and flooding in the future. High water levels for selected return periods will be mapped on a digital elevation model of the city. Mapping of flood hazards in coastal communities is often done today using LiDAR-derived digital elevation models with selected flood levels superimposed (e.g. Webster et al., 2006). The vertical resolution of LiDAR models is typically better than ±0.15 m, appropriate for consideration of storm-surge impacts under rising sea levels. Although no airborne LiDAR data are available for the City of Iqaluit, a digital elevation model of somewhat lower vertical resolution has been generated from stereo-pair satellite images by the Canada Centre for Remote Sensing (P. Budkewitsch, pers. comm., 2010). This is supplemented by numerous point elevations acquired in this study using real-time kinematic (differential) Global Positioning System (GPS) receivers with vertical accuracy of approximately ±0.05 m. The elevations determined by the above methods will be used in a series of coastal hazard maps showing areas of vulnerability in Iqaluit (e.g. Fig. 4).

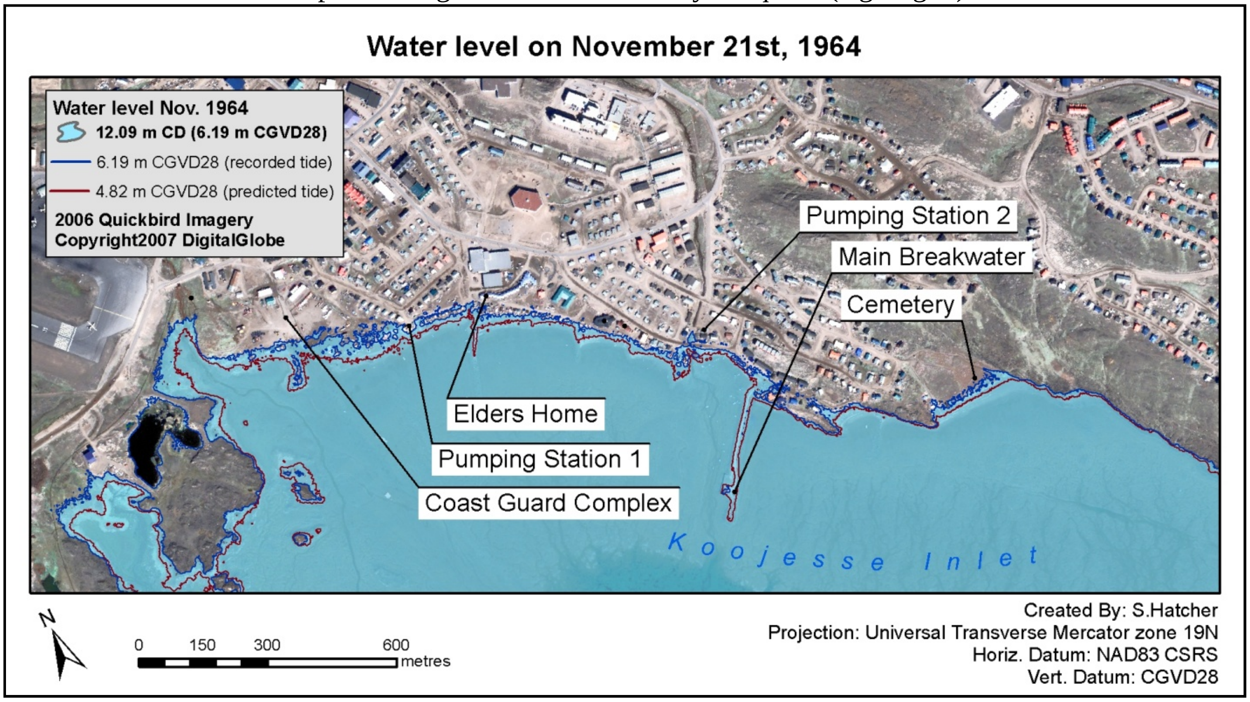

FIGURE 4. Coastal hazard map for part of the city of Iqaluit based on the historical Nov. 21st 1964 water level. The red line shows the predicted tide for that hour, whereas the blue line shows the recorded water level during this event. Although there was little waterfront development in the early 1960s, the same event today would flood the main breakwater and extensive portions of the waterfront. After several decades of sea-level rise, the flooding would be more extensive.

5.5. 1964 High water

There is anecdotal evidence of past flooding events not associated with storms, as in the early fall of 2003, when roads and other infrastructure along the waterfront were flooded. The highest event recorded in the tide-gauge record (which runs intermittently from 1963-1977) was associated with a storm on 21 November 1964 (Fig. 4). The maximum water level was 6.19 m (referenced to the CGVD28 vertical datum) or 12.09 m above Chart Datum, 1.37 m above the predicted high tide (4.82 m CGVD28).

This represents a substantial storm surge, associated with E to ESE winds gusting to 43 km/h and sustained over 4-5 hours. Perhaps more importantly, the surge occurred at the front of a low pressure system with a minimum observed sea-level pressure of 98.6 hPa. Any such surge occurring out of phase with high tide or on a neap high tide would not have caused flooding above the higher high tide limit. However, the coincidence of the surge with a spring high tide contributed to a record high water level.

This event would have caused extensive flooding in the lower waterfront near the present-day breakwater and throughout the area currently occupied by the many sheds used for storage of fishing and hunting gear (Fig. 4). However, at the time of this storm event in the early 1960s, there was little development along the waterfront and the breakwaters were not yet constructed. Were a comparable storm to recur again today in phase with a spring high tide, the damage could be substantial. Flooding would occur at the city cemetery, streets along the waterfront would be overtopped, and flood waters would reach sewage lift stations 1 and 2 in the waterfront area. Furthermore, although we have no data on the freeze-up date in 1964, a late fall storm of this kind combined with presence of newly formed ice could generate ice ride-up or pile-up capable of causing severe damage to structures along the waterfront.

6. Exposure and Vulnerability

The measurement and quantification of coastal hazard components alone does not determine vulnerability, and their incorporation into sustainable management policy requires an integration of these physical projections with analysis of the current land use structure along the coast. A recent project ‘Atuliqtuq: Action and Adaptation in Nunavut’ (a collaboration between the Canadian Institute of Planners, Indian and Northern Affairs Canada, Natural Resources Canada, and the Government of Nunavut) recommended the adoption of a precautionary approach incorporating the best available knowledge of climate-change projections and future impacts (Lewis & Miller, 2010, Mate et al., 2011). The 2010 General Plan for the City of Iqaluit called for a precautionary approach to climate change and special protection for culturally important coastal sites. Given that the physical setting is as important as the socioeconomic context; integration of the two has become a priority in the development of effective adaptation and sustainable development strategies for Iqaluit. This project aims to support this approach by working closely with the city sustainability office, as well as the local Amarok Hunters and Trappers Association. While this aspect of the analysis will not change the quantified predictions of the physical components, it will shape the way in which these are communicated and represented as products at the end of the research. The following text provides a brief summary of preliminary findings from this aspect of the research.

6.1. Adaptation and Sustainability Planning in the City of Iqaluit

Contact with the city sustainability office has shown that the preliminary results are already proving useful in this context. A site for the new city hall is currently being chosen, and one option is the old courtroom building right on the coast. There is, however, concern about the risk of flooding at this site and also for critical infrastructure such as lift stations and roads. In addition, the main cemetery site is located on the coast and has flooded previously. The public attachment to the site has made it difficult to find support for a new site on higher ground. Again, in order to come up with a long-term plan for managing the waterfront, and any engineering projects that might aim to alleviate the risk to the area, the city needs realistic estimates of flood return periods, and how these might change in the coming decades. Given the complexity of the local setting, the application of global sea-level projections alone would not give a sufficiently accurate picture of what the city needs to be prepared for in its adaptation and sustainability planning. Regional and local changes may differ significantly from global projections such as those of the IPCC (2007).

6.2. Traditional economy sector

A portion of Iqaluit's population continues to engage in traditional hunting and subsistence practices despite increasingly rapid social changes and widespread participation in the wage economy. The land claims agreement that established Nunavut as a self-governing territory within Canada was finalized in 1993, and this agreement selected Iqaluit as the territorial capital because it was the largest settlement in the newly formed territory. This iconic designation also brought it into the role of a cultural hub for efforts to sustain and nurture the Inuit way of life. This also saw the beginning of significant social change in Iqaluit, as the population began to grow rapidly and the influx of money for development spurred infrastructure development (Lewis & Miller, 2010). Nevertheless, an important part of the economy in Iqaluit remains rooted in the traditional hunting and subsistence patterns of Inuit.

FIGURE 5. (Left) Hunting and fishing sheds and boats used in the local small-scale traditional subsistence economy. Despite appearances, these represent quite substantial capital investments. (Right) Construction of housing units near the Iqaluit waterfront. Photos: SVH, August 2010.

A significant proportion of the infrastructure supporting the subsistence economy is found on the coast, where numerous sheds and some containers ('sea-cans') hold the equipment required for small-scale commercial and recreational fishing and hunting (Fig. 5). This represents an increasingly vulnerable area of the community, directly on the high water line near the top of the beach face. While the infrastructure itself remains fairly resilient, the positioning of this infrastructure is vulnerable to increased development pressure on lots immediately landward (Fig. 5). Since the available coastline in the current city footprint is more or less filled up, there remains very little space for the sheds to be relocated if rising water levels make this necessary. This aspect would likely be lost in a strictly economic vulnerability assessment, and is more connected to the intricate social dimensions of the stakeholders in the city's shoreline that represent the traditional economy.

7. Conclusions

Changing environmental conditions in the Arctic coastal zone are widely recognized and have spurred efforts to understand potential impacts, reduce vulnerability, and enhance resilience through adaptation in Arctic coastal communities. The social-ecological systems found in this region are complex and highly varied. The physical setting of these communities actively shapes the connections between changing environmental forcing and local observed and projected impacts. Understanding of these linkages is crucial to the establishment of sound sustainable management policy, an important goal of adaptation initiatives such as C-Change. In light of the complex issues being dealt with, C-Change has adopted a situated research strategy employing a bottom-up approach to precautionary planning and coastal management (Lane & Watson, 2010). Though this is often associated more strongly with the complexities of the social system in the community, and its relationship to the physical environment, the complexities of the physical landscape and how they are expected to change under projected trends in global climate are key elements that need to be understood for successful strategies to enhance resilience. More work is needed to determine how Iqaluit's changing coastline will affect the city in the future, but the implications of a changing climate amidst unprecedented political and economic growth in Nunavut's capital point to the need for better scientific understanding and monitoring of future changes in coastal hazards.

Acknowledgements

This research was facilitated and partially funded by the Climate Change Geoscience Program of Natural Resources Canada, with invaluable support from project leader David Mate and program manager Andy Rencz. Support to Hatcher was provided by the Social Sciences and Humanities Research Council under the ICURA C-Change project and by ArcticNet and the Networks of Centres of Excellence, both under grants to Forbes at Memorial University. Paul Budkewitsch, Canada Centre for Remote Sensing, kindly made available the digital elevation model for Iqaluit. For field logistics and scientific support, we are grateful to Anne-Marie LeBlanc and colleagues of the Geological Survey of Canada and to Rick Armstrong and Mary-Ellen Thomas at the Nunavut Research Institute. On-site assistance from David Mate and Paul Budkewitsch during their acting appointments as Director of the Canada-Nunavut Geoscience Office contributed greatly to the success of the field surveys. Advice on the climate analysis was provided by Joel Finnis of Memorial University. Insights on planning and sustainability issues were generously provided by Meagan Leach and Robyn Campbell of the City of Iqaluit. Thanks to Dustin Whalen and David Mate for helpful review and comments. This is contribution 20110074 of the Earth Sciences Sector (Geological Survey of Canada, Natural Resources Canada).

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