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# "An Application of GIS Techniques to Assess the Risk of Disturbance of Archaeological Sites by Mass Movement and Marine Flooding in Auyuittuq National Park Reserve, Nunavut"

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*Géographie physique et Quaternaire*, vol. 60, n° 1, 2006, p. 81-92.

URI: http://id.erudit.org/iderudit/016366ar

DOI: 10.7202/016366ar

*Géographie physique et Quaternaire*, 2006, vol. 60, nº 1, p. 81-92, 8 fig., 7 tabl.

# AN APPLICATION OF GIS TECHNIQUES TO ASSESS THE RISK OF DISTURBANCE OF ARCHAEOLOGICAL SITES BY MASS MOVEMENT AND MARINE FLOODING IN AUYUITTUQ NATIONAL PARK RESERVE, NUNAVUT

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ABSTRACT Coastal regions within Auyuittuq National Park Reserve (ANPR) are sensitive to mass movement processes and threatened by flooding in response to sea level rise. These processes pose a risk to culturally significant archaeological sites within ANPR. Sites at risk of disturbance need to be identified and protected to conserve valuable archaeological resources. Since the costs of identifying and monitoring sites at risk in remote areas are substantial, modern technologies such as Geographic Information Systems (GIS) can be used to create a more rapid and cost-effective means to monitor coastal environments and manage coastal resources. This study examines the application of GIS technology to assess the risk of disturbance of 44 coastal archaeological sites by mass movement and marine flooding within ANPR. Data on surficial materials and slope angles are combined in an overlay analysis to assess terrain sensitivity to mass movement. The output from this analysis is a coarse regional assessment of mass movement potential as it relates to the strength of materials on slopes. The overall risk of disturbance for archaeological sites within ANPR is assessed by combining the risk of mass movement and the risk of marine flooding. Twenty-eight sites within ANPR are identified as being at considerable risk to disturbance: these sites are located largely on glaciomarine sediments at moderate or high slope angles and are at substantial risk to flooding (less than two metres above sea level).

RÉSUMÉ *Application des techniques SIG dans l'évaluation du risque de perturbation des sites archéologiques par les mouvements de masse et les inondations marines dans la réserve du parc national de Auyuittuq, Nunavut.* Les côtes de la réserve du parc national de Auyuittuq sont sensibles aux mouvements de masse et sont affectées par la montée du niveau marin. Ceci constitue un risque pour les sites archéologiques de grande valeur culturelle. De tels sites doivent être identifiés et protégés afin de préserver les ressources archéologiques. Parce que les coûts d'identification et de suivi des sites à risque dans les régions éloignées sont substantiels, les technologies modernes peu coûteuses dont les Systèmes d'Information Géographique (SIG) peuvent être utilisées pour le suivi des environnements côtiers et la gestion des ressources côtières. Cette étude porte sur l'application d'un SIG pour évaluer le risque de perturbation par les mouvements de masse et les inondations de 44 sites archéologiques côtiers dans la réserve du parc national de Auyuittuq. Les données concernant les matériaux de surface et l'angle des pentes sont combinées dans une analyse d'évaluation de la sensibilité du terrain aux mouvements de masse. Le résultat de cette analyse consiste en une estimation régionale d'ensemble du potentiel de mouvement de masse en fonction de la résistance du matériel sur les pentes. Le risque global de perturbation des sites archéologiques de la réserve a été évalué à partir de la combinaison des risques de mouvements de masse et d'inondation marine. Vingt-huit sites présentent un risque considérable de perturbation puisqu'ils occupent des sédiments glaciomarins à pente modérée à élevée, à moins de deux mètres au-dessus du niveau de la mer.

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Manuscrit reçu le 30 novembre 2005 ; manuscrit révisé accepté le 12 octobre 2006 (publié le 2e trimestre 2007)

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## INTRODUCTION

Auyuittuq National Park Reserve (ANPR), Nunavut, Canada bears witness to more 3500 years of occupation by prehistoric peoples of the Arctic Small Tool culture (both Pre-Dorset, *ca.* 1700-800 BC, and Dorset, *ca.* 800 BC-A.D. 1000) and the Thule (*ca.* A.D. 1000-1600) and Inuit (*ca.* A.D. 1600 to the present day) cultures (Schledermann, 1976; McGhee, 1990). The exploitation of marine mammal resources, notably whales (bowhead whale, *Balaena mysticetus*), seals (ringed seal, *Phoca hispida*) and walrus (*Odebenus rosmarus*), has figured prominently in all of these cultures, stimulating settlement of the coastal environment of Cumberland Peninsula (Schledermann, 1975, 1976; Jacobs, 1979; McGhee, 1990).

Disturbance of archaeological sites within ANPR is associated with natural processes. Marine submergence of the coastline of ANPR began approximately at 3 ka BP and is recorded by the presence of terrestrial peat overlain by active coarse-grained beach deposits at the present shoreline, the development of cliffs in unconsolidated sediments, and the erosion or burial of Thule winter houses (England and Andrews, 1973; Pheasant and Andrews, 1973; Bird, 1977; Miller *et al.*, 1980; Dyke *et al.*, 1982). Sea level rise over the next century, estimated at 10 to 80 cm (IPCC, 2001; ACIA, 2005), will exacerbate the risk of disturbance by marine flooding (Shaw *et al.*, 1998a). Terrain disturbance associated with mass movement is considered to pose the greatest risk to human activity within ANPR (Dyke *et al.*, 1982). ANPR lies within the zone of continuous permafrost (Atlas of Canada, 2005). The sensitivity of surficial materials in periglacial environments varies seasonally as the depth of thaw and drainage of the active layer change: it is lowest in the winter when the ground is frozen and covered with snow, and is greatest in summer when the active layer is saturated with melting snow or rain (Bird, 1977; Church *et al.*, 1979; Dyke *et al.*, 1982). The stability of unconsolidated sediments exposed at the shoreline is influenced by the presence of sea ice as it acts as a protective agent by suppressing wave generation and absorbing wave energy in the nearshore zone (Bird, 1977; Miller *et al.*, 1980; Taylor and McCann, 1983; Forbes and Taylor, 1994). The melting of sea ice, rising sea-level, and the deepening of nearshore waters in response to global warming will provide the potential for increasing the duration of open water and reworking of shorelines (Bird, 1993). The absence of sea ice in the nearshore environment leaves the coastal headlands of Cumberland Peninsula exposed to longer wind fetches and storm wave activity (Sempels, 1982). Miller *et al.* (1980) note that the upper limits of wave scour on exposed headlands in the macrotidal (tidal range exceeds 4 m) environments of southeastern Baffin Island are commonly 4 to 5 m above the high tide level. The impact of these changes in the marine environment will be most severe along sedimentary coastlines currently experiencing coastal subsidence (Shaw *et al.*, 1998a). Finally, the procurement of whalebone from archaeological sites for the carving industry also contributes to site disturbance (Schledermann, 1975: p. 15).

Sites of cultural significance susceptible to disturbance need to be identified and protected to conserve valuable archaeological resources. The costs of identifying and monitoring sites at risk in remote areas are substantial. Modern technologies such as Geographic Information Systems (GIS) and remote sensing can be used to create a more rapid and cost-effective means to monitor coastal environments and manage coastal resources, including sites of cultural significance at risk of disturbance (Welch *et al.*, 1992; O'Regan, 1996; Klemas, 2001). The objective of this study is to examine the application of GIS technology to facilitate the conservation of archaeological resources within ANPR. Our goal is to address research needs identified by Parks Canada by providing ANPR staff with an assessment of the potential risk of terrain disturbance for two specific areas within the park for their use in natural and cultural resource management.

## PHYSICAL SETTING OF THE STUDY AREA

The study area is located on Cumberland Peninsula, eastern Baffin Island (Fig. 1). The terrain consists of uplifted Precambrian igneous and metamorphic rocks with elevations as great as 2 100 m asl that represents the rifted eastern margin of the Canadian Arctic Archipelago (Bird, 1967; Dawes and Christie, 1991). Two areas within ANPR were selected for study based on variations in surficial geology and coastline morphology: the Kivitoo Foreland in the north and the fiord coastline of Maktak, Coronation, and North Pangnitung fiords in the south (Fig. 1). A gently sloping lowland, composed largely of glaciomarine, marine and alluvial sediments with extensive wind and wave fetch characterizes the Kivitoo region (Dyke *et al.*, 1982; Sempels, 1982). The Kivitoo Foreland is bounded in the west by highlands with broad, gently rounded summits at 300 to 600 m elevation separated by glacial troughs and fiords (Dyke *et al.*, 1982). In contrast, a steeply sloping bedrock coastline with limited wind and wave fetch characterizes the fiord area further south (Dyke *et al.*, 1982; Sempels, 1982). The landscape of the southern fiord study area consists of plateaux of 900 to 1 500 m elevation, beveled at their edges by large cirques, and dissected by glacial troughs and fiords (Dyke *et al.*, 1982). Weathered bedrock and sporadic patches of sandy or gravelly glacial till mantle upland surfaces throughout the study area. Thick, coarse-grained colluvium covers the valley walls of glacial troughs and fiords where fans and talus slopes are present (Dyke *et al.*, 1982). Extensive sandar occupy the floors of glacial troughs where rivers deliver substantial quantities of coarse- and fine-grained alluvium to fiord-head environments (Gilbert, 1982).

The physical characteristics of high latitude coastal environments are influenced strongly by the presence of ground ice in the terrestrial environment and sea ice in the marine environment. The brief period of summer warmth and the extended period of winter cold (Table I) contribute to the development of continuous permafrost on land and thick landfast sea ice along the coastline. Sea ice affects coastal morphology directly by physically creating shoreline features such as ice-push beach ridges and indirectly by the presence of sea ice reducing wave energy at the coast (Taylor and McCann, 1983; Forbes and Taylor, 1994). Steep offshore topography and exposure to large wind fetch (commonly greater than 100 km) along much of the eastern Baffin Island coastline contribute to the potential for high wave energy at the shore, however, the presence of persistent landfast sea ice in the study area limits the capacity for shoreline erosion (Sempels, 1982). Landfast sea ice can persist along the coastline of ANPR into late July and sea ice cover exceeding five tenths is recorded into mid-August (Atmospheric Environment Service, 1988). The present periglacial environment produces deep, continuous permafrost (thickness exceeds 2 m) and debris-mantled slopes that extend to the shore (Church *et al*., 1979; Dyke *et al*., 1982). Thermal degradation of permafrost coupled with the erosion of unconsolidated sediments by waves, sea ice and overland flow serve to generate slumps and debris flows along the sidewalls of glacial troughs and the shoreline of the Kivitoo Foreland (Bird, 1977; Church *et al*., 1979).

## METHODOLOGY

The Geographic Information System SPANS GIS 5.4 (Intera Tydac, 1993) adopted by Parks Canada for resource data management in ANPR was used in this study. The assessment of terrain sensitivity incorporates data on slope gradient, surficial geology, and the elevation and proximity to the coast of recorded archaeological sites. These data are organized within discrete data layers in the GIS. The structure of each layer is examined below: further details are provided in Solsten (1998).

### SLOPE GRADIENT LAYER

A digital elevation model (DEM) for the entire study area was derived from digitizing eleven National Topographic System (NTS) 1:250 000 topographic map sheets portraying elevation data complied in 1984. The contour interval and range of elevation (reported in imperial units) differs among the various map sheets as indicated in Table II. VEC/VEH (vector)

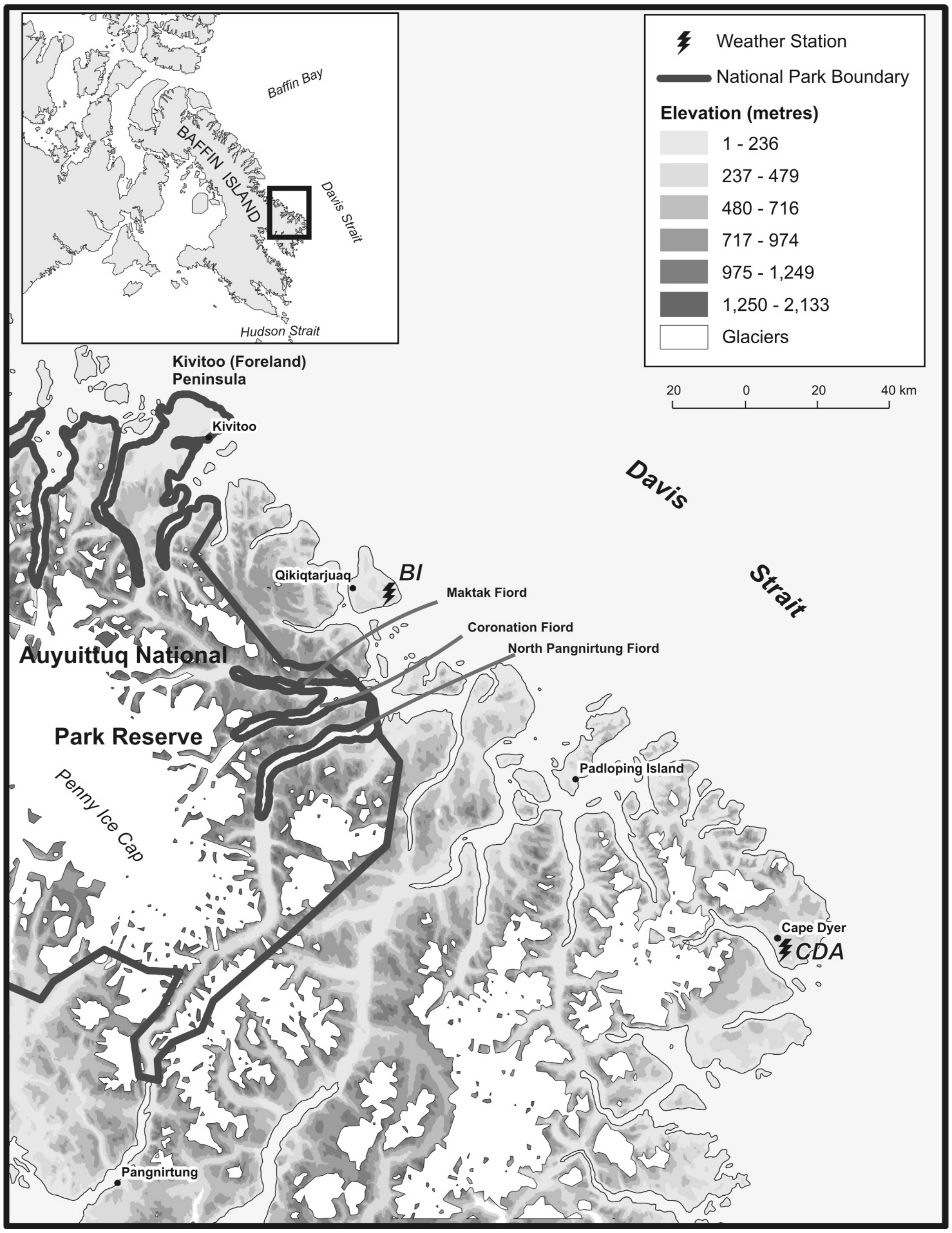

FIGURE 1. Relief map of Cumberland Peninsula, Baffin Island, including Auyuittuq National Park Reserve. BI: Broughton Island weather station, CDA: Cape Dyer weather station. Inset map illustrates the location of the study area in eastern Baffin Island.

*Carte du relief de la péninsule de Cumberland, Île de Baffin, avec la Réserve du Parc National de Auyuittuq. BI : station météorologique de l'Île de Broughton, CDA : station météorologique du Cap Dyer. Le cartouche montre l'emplacement de la région d'étude sur la partie est de l'Île de Baffin.*

TABLE I

*Climate normals, 1961-1990, for Auyuittuq National Park Reserve*

| | Broughton Island<br>(63° 47' W, 67° 32' N, 587 m) | | | Cape Dyer A<br>(61° 37' W, 66° 35' N, 393 m) | | |
|---|---|---|---|---|---|---|
| | January | July | Annual | January | July | Annual |
| Temperature | | | | | | |
| Daily mean (°C) | -24.2 | 4.4 | -11.5 | -23.2 | 5.1 | -10.5 |
| Daily maximum (°C) | -21.2 | 7.4 | -8.5 | -18.4 | 8.7 | -6.5 |
| Daily minimum (°C) | -27.4 | 1.4 | -14.4 | -28.1 | 1.7 | -14.7 |
| Degree-days | | | | | | |
| Above 5 °C | 0 | 38.5 | 69 | 0 | 39.6 | 76 |
| Below 0 °C | 743.9 | 6.3 | 4 511 | 721.5 | 0.4 | 4 223 |
| Days with maximum temperatures above 0 °C | 0 | 29 | 94 | 0 | 31 | 117 |
| Precipitation | | | | | | |
| Annual rainfall (mm) | | | 36.2 | | | 102.0 |
| Annual snowfall (cm) | | | 243.4 | | | 597.7 |

Source: Atmospheric Environment Service (1993).

TABLE II

*Contour intervals and range of elevations for the National Topographic System map sheets employed in the construction of the digital elevation model (DEM) for ANPR*

| NTS 1:250 000 map sheet | Contour interval (feet) | Contour interval (metres) | Elevation range (feet) | Elevation range (metres) | UTM Zone (NAD 83) |
|---|---|---|---|---|---|
| 26J | 200 | 67 | 200-4 800 | 67-1 600 | 19 |
| 26N | 200 | 67 | 600-3 600 | 200-1 200 | 19 |
| 26O | 500 | 167 | 500-5 500 | 167-1 833 | 19 |
| 27A | 200 | 67 | 200-4 600 | 67-1 533 | 19 |
| 27B | 200 | 67 | 200-4 000 | 67-1 533 | 19 |
| 16E | 500 | 167 | 500-5 000 | 167-1 667 | 20 |
| 16L | 500 | 167 | 500-6 000 | 167-2 000 | 20 |
| 16M | 500 | 167 | 500-4 500 | 167-1 500 | 20 |
| 26H | 500 | 167 | 500-4 500 | 167-1 500 | 20 |
| 26I | 500 | 167 | 500-6 500 | 167-2 167 | 20 |
| 26P | 500 | 167 | 500-6 500 | 167-2 167 | 20 |

files were created for each of the eleven NTS map sheets. Topographic contours were converted to points for each of the VEC/VEH files within SPANS to create files that contain X, Y and Z values for longitude (°W), latitude (°N) and elevation (feet) in ASCII format. These eleven files are derived from two different Universal Transverse Mercator (UTM) zones (Table II). All of the files from UTM Zone 19 were concatenated together: similarly, all of the files from UTM Zone 20 were concatenated together. These two files were then transformed within SPANS into ASCII point files, with co-ordinates in longitude and latitude, and concatenated together. Complete coverage for the study area was constructed at a pixel resolution of 138.35 m. Local variations in the slope of the terrain were determined by fitting a quadratic surface to a moving 3 cell x 3 cell matrix of points as described in Franklin (1987a, 1987b). A slope map for the entire study area was constructed by moving the 9-point matrix over the entire DEM and calculating slope values (expressed in degrees) for each cell. A survey of the literature indicates that the angle of repose for unconsolidated materials represented in the study area (see Surficial Geology layer below) lies in the range of 29° to 44°, with average slope angles ranging from 13° to 17°, and gentle slopes ranging from 2° to 5° (Carson and Kirkby, 1972; Young, 1972; Selby, 1982; Parsons, 1988). The raw slope data were reclassified into three slope intervals and assigned scores from 1 to 3: low slope angles, 0° to 5° (score = 1); moderate slope angles, 6° to 15° (score = 2); and high slope angles, 15° to 90° (score = 3) based on this information. Separate maps were generated for the Kivitoo Foreland located between 64° 15' W and 65°45'W, and 67° 30' N and 68° 10' N (Fig. 2), and the southern fiord coastline located between 63°00' W and 65°30' W, and 66° 50' N and 67° 50' N (Fig. 3). The validity of the slopes derived from the DEM was assessed by comparison with manual calculations of slope gradients from sea level to 100 m elevation from the 1:250 000 NTS map sheets and stereo pairs of aerial photographs. These data corroborate the slope angles derived from the DEM (see Solsten, 1998: p. 123-130).

## SURFICIAL GEOLOGY LAYER

The surficial geology of the study area was digitized from a 1:500 000 scale map of the entire Cumberland Peninsula published by Dyke *et al.* (1982). The surficial geology polygons were classified by Dyke *et al.* (1982) into nine classes: bedrock, residuum, glacial till, glaciomarine sediments, glaciolacustrine sediments, inactive alluvium, active alluvium, colluvium, and glacial ice (Table III). The primary objective of this study is to assess the potential for terrain disturbance. Given this objective it was desirable to reclassify the surficial geology

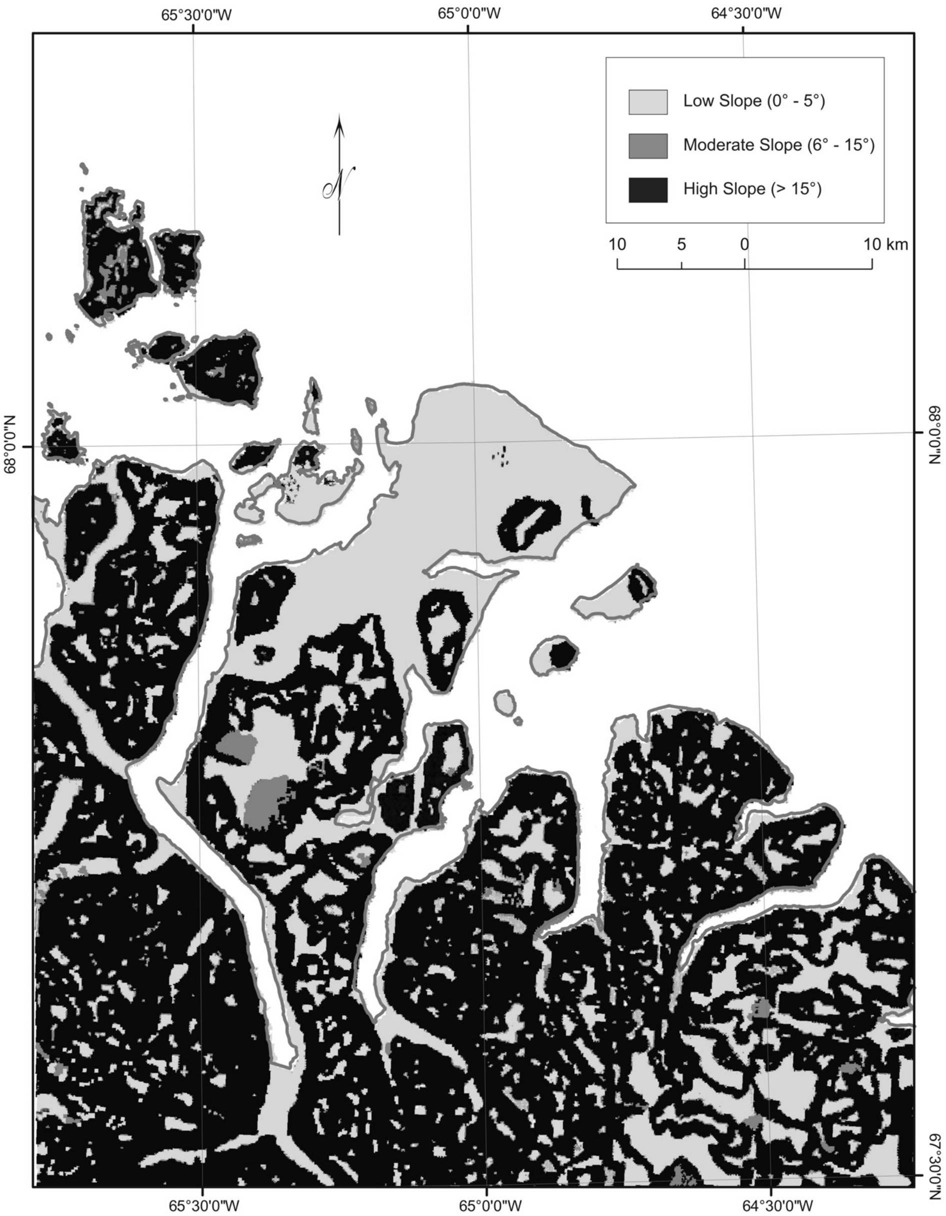

FIGURE 2. Regional variations in slope angles in the Kivitoo Foreland study area.

*Variations régionales des pentes dans la région d'étude de Kivitoo Foreland.*

data based on the relative strength of the surficial materials: materials with high strength (score = 1), moderate strength (score = 2) and low strength (score = 3). Class 1 is represented by bedrock, residuum and glacial ice. Coarse-grained or poorly sorted materials represent class 2: glacial till and colluvium. Fine-grained or well-sorted materials represent class 3: glaciomarine sediments and alluvium. Glaciolacustrine sediments do not occur within the study area. This classification accords well with the assessment of terrain sensitivity within ANPR presented by Dyke *et al.* (1982: p. 17-19). The surficial geology of the Kivitoo Foreland and southern fiord study areas are illustrated in Figures 4 and 5, respectively.

## ARCHAEOLOGICAL SITE LAYER

Parks Canada staff provided a database of archaeological sites within ANPR. A point file consisting of the latitude, longitude, elevation above sea level, and distance from to the coast for 44 sites within the study area was derived from these data. Displaying the precise location of archaeological sites within ANPR is prohibited by Parks Canada in order to limit vandalism and preserve the integrity of the cultural resources that are present in the park. In lieu of a map displaying the location of the 44 archaeological sites within the two study areas, a frequency histogram displaying the elevation of these sites above sea level is presented in Figure 6. Most of the sites occur at or near sea level in close proximity to shore.

## OVERLAY ANALYSIS

Matrix overlay analysis was performed for the Kivitoo Foreland and southern fiord areas using the data for material strength and slope angle described above to assess the potential for failure and mass movement of surficial materials.

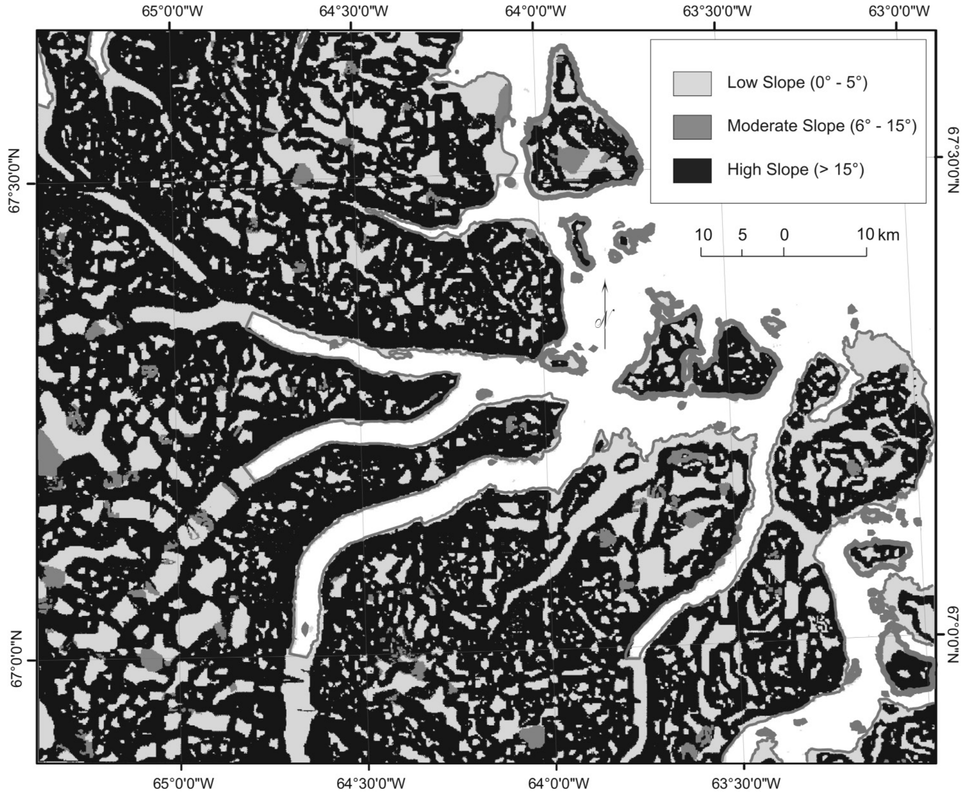

FIGURE 3. Regional variations in slope angles in the southern fiords study area.

*Variations régionales des pentes dans la région d'étude des fjords du sud.*

TABLE III

*Classification of surficial materials within ANPR (after Dyke* et al.*, 1982) and the relative ranking of the sensitivity to disturbance via mass mouvement based on material strength**

| Surficial material | Map classification | Sensitivity |
|---|---|---|
| Bedrock | 1 | 1 |
| Residuum | 2 | 1 |
| Glacial till | 3 | 2 |
| Glaciomarine sediments | 4 | 3 |
| Glaciolacustrine sediments | 5 | Not applicable |
| Inactive alluvium | 6 | 3 |
| Active alluvium | 7 | 3 |
| Colluvium | 8 | 2 |
| Glacial ice | 9 | 1 |

* 1: high strength, low sensitivy; 2: moderate strength and sensitivy; 3: low strength, high sensitivity

The resulting classes are operator-defined and range in value from 1 to 4 based on the susceptibility to mass movement: *i.e.* not susceptible to mass movement (score = 1), low susceptibility to mass movement (score = 2), moderate susceptibility to mass movement (score = 3), and high susceptibility to mass movement (score = 4).

The assessment of terrain sensitivity includes the risk of disturbance of archaeological sites due to flooding in response to sea level rise. The Intergovernmental Panel on Climate Change (2001) and the Arctic Climate Impact Assessment (2005) have presented various estimates of global sea-level rise between 10 to 80 cm (mean value of 45 cm) due to all processes (melting of glaciers, thermal expansion of the oceans, seafloor spreading) by the end of this century. In combination with ongoing coastal submergence of 10 cm per century (Andrews and Peltier, 1989) along the Cumberland Peninsula coastline, and a tidal range of 1.5 m (Bird, 1977), total marine inundation could exceed 2 m over the next 100 years. Furthermore, an increase in storm frequency will compound the problem of marine flooding at the coastline (Shaw *et al.*, 1998a, 1998b). Given the scenario presented here, the potential for flooding was assessed as follows: sites located 2 m or more above present sea-level are rated at a low risk for flooding (score = 1); sites situated below 2 m elevation are rated at a substantial risk for flooding (score = 2), and sites at present sea-level are rated at extreme risk for flooding (score = 3).

A matrix overlay analysis was performed for the Kivitoo Foreland and southern fiord areas to assess the risk of terrain disturbance using the data for the potential for mass movement and the potential for flooding. The resulting classes are operated-defined and range in value from 1 to 12: *i.e.* no risk of disturbance (risk class 1), low risk of disturbance (risk class 2), moderate risk of disturbance (risk classes 4 and 6), and high risk of disturbance (risk classes 8 to 12).

## RESULTS

### RISK OF DISTURBANCE:
### SLOPE INSTABILITY AND MASS MOVEMENT

The outcome of the overlay analysis for the combination of surficial geology and slope angle is presented in Table IV. The values in the matrix were applied to both study areas to

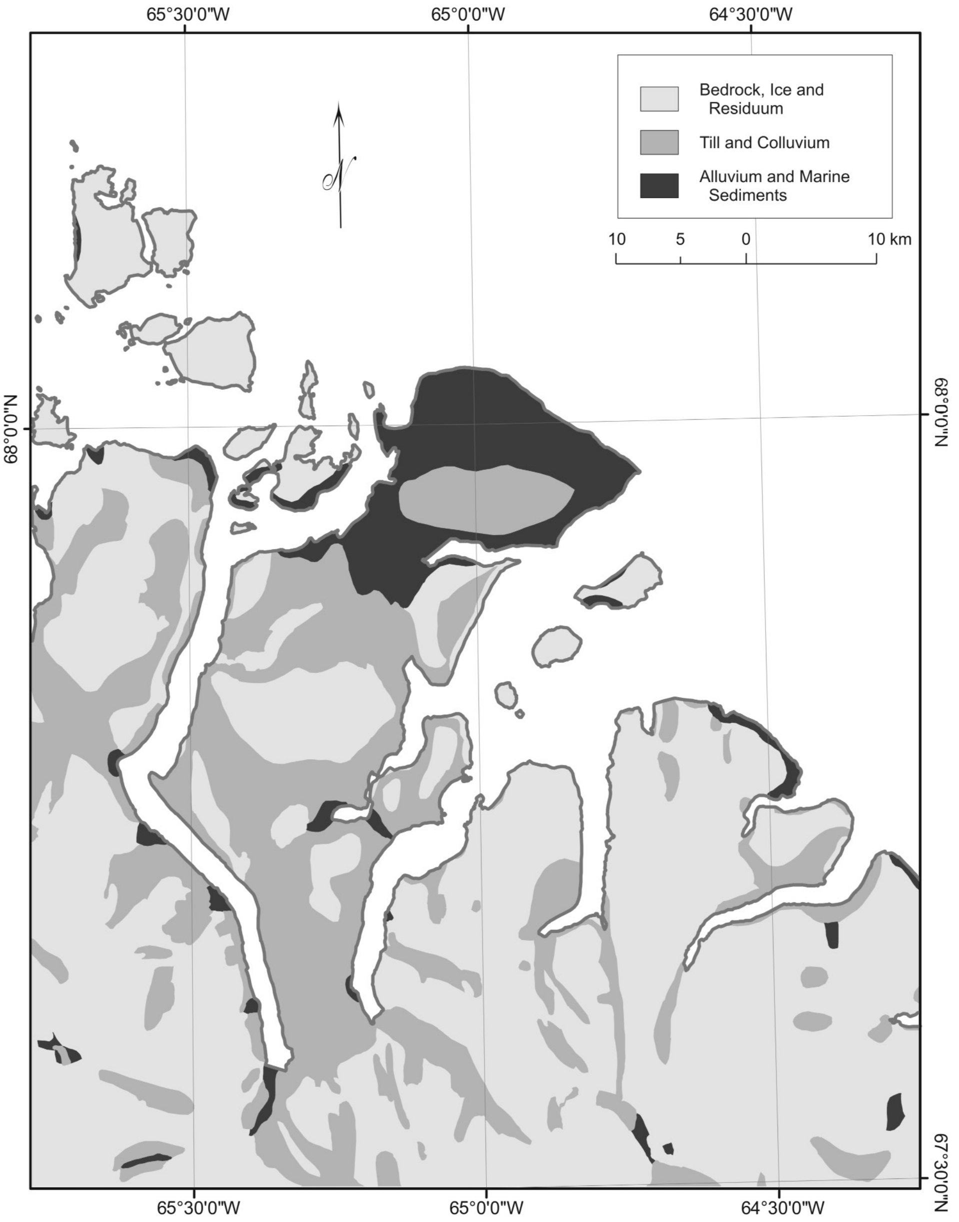

FIGURE 4. Surficial geology of the Kivitoo Foreland study area (adapted from Dyke *et al.*, 1982).

*Géologie de surface de la région d'étude de Kivitoo Foreland (adapté de Dyke* et al.*, 1982).*

produce maps of potential terrain disturbance. The area covered by each terrain class in the Kivitoo Foreland area is portrayed in Figure 7 and presented in Table V. Terrain classes 1 and 2 associated with a low potential for mass movement dominate the Kivitoo Foreland area. This pattern reflects the predominance of bedrock at various slope angles south and west of the peninsula, glacial till and residuum that mantle gently sloping upland surfaces separating glacial troughs, colluvial deposits that mantle the sidewalls of the glacial troughs and fiords, and the coarse-grained alluvium associated with fiord-head sandar. The greatest risk of disturbance is associated with steeply sloping colluvial deposits located at the margins of till-mantled uplands and along the sidewalls of glacial troughs and fiords (terrain class 3), and fine-grained glaciomarine sediments situated along the outer margins of glacial troughs and the Kivitoo Foreland, especially where steep cliffs produced by the erosion of waves and sea ice occur at the coastline (terrain classes 3 and 4).

The area covered by each terrain class in the southern fiord area is portrayed in Figure 8 and presented in Table VI. Terrain classes 1 and 2 associated with a low potential for mass movement dominate the fiord region. This pattern reflects the predominance of bedrock at various slope angles throughout the study area, glacial till and residuum that mantle gently sloping upland surfaces separating glacial troughs, and the coarse-grained alluvium associated with fiord-head sandar in Maktak and North Pangnirtung fiords. The greatest potential for disturbance is associated with steeply sloping colluvial deposits located along the sidewalls of the glacial troughs of Maktak, Coronation and North Pangnirtung fiords (terrain class 3), and fine-grained glaciomarine sediments situated along the outer coast, especially where steep cliffs produced by the erosion

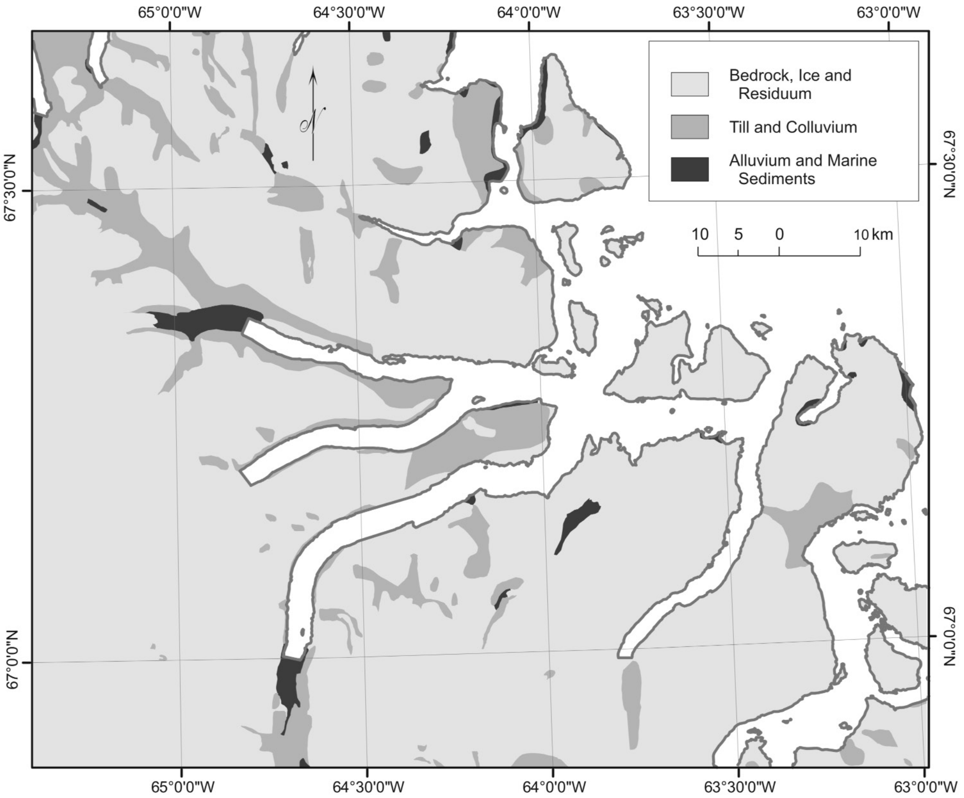

FIGURE 5. Surficial geology of the southern fiords study area (adapted from Dyke *et al.*, 1982).

*Géologie de surface de la région d'étude des fjords du sud (adapté de Dyke* et al.*, 1982).*

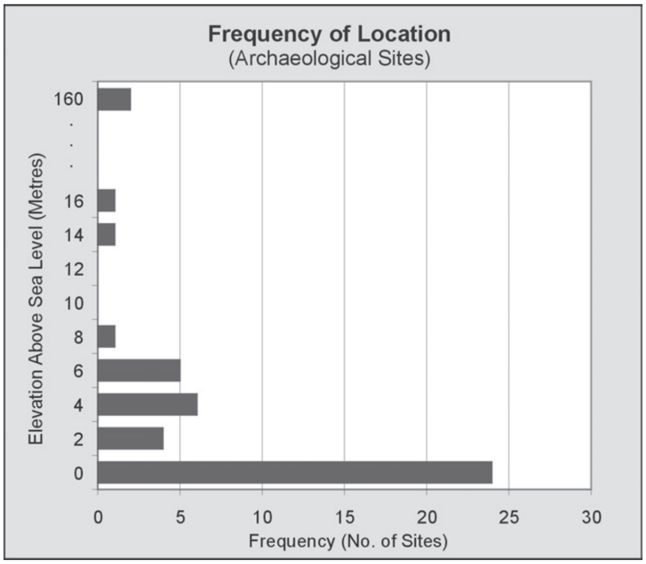

FIGURE 6. Frequency distribution of the elevation of archaeological sites recorded in the two study areas within Auyuittuq National Park Reserve.

*Distribution de fréquence de l'élévation des sites archéologiques enregistrée dans les deux régions d'étude de la Réserve du Parc National de Auyuittuq.*

of waves and sea ice occur at the coastline (terrain classes 3 and 4).

## RISK OF DISTURBANCE:
## SEA LEVEL RISE AND FLOODING

Twenty-four of the 44 archaeological sites within the two study areas are classified as being at substantial risk of flooding (flooding class 2) or extreme risk of flooding (flooding class 3). The remaining twenty sites occur at elevations above 2 m asl and are classified as being at low risk of flooding (flooding class 1).

## OVERALL POTENTIAL FOR TERRAIN DISTURBANCE

The overall potential for disturbance for archaeological sites within the two study areas was assessed by cross-tabulating the potential for slope failure and mass movement with the potential for flooding (Table VII). It is not possible, in the absence of ground-truthing, to determine the magnitude and frequency of disturbance: instead, the overlay analysis generates an index of the relative risk of site disturbance. Cell values in the first column of Table VII emphasize the potential for mass movement: 1 – no risk of disturbance; 2 – low risk of disturbance; 4 – moderate risk of disturbance; and 8 – high risk of disturbance. Cell values in the second and third columns of Table VII are incremented in a similar fashion; however, the values are greater, reflecting the fact that the surficial materials are at increased risk to flooding. The greater potential for site disturbance assigned to cells in the third column of

Table VII reflects the extreme risk of flooding associated with sites situated near or at present sea level.

Each of the 44 archaeological sites was assigned an overall risk of disturbance value. Six sites are assigned to the no risk of disturbance category (risk class 1). These sites are located on bedrock substrates beyond the predicted level of marine flooding within the glacial troughs of Maktak, Coronation and North Pangnirtung fiords. Ten sites are assigned to the low risk of disturbance category (risk class 2). These sites are all located on the Kivitoo Foreland and are situated on materials that exhibit low potential for mass movement (*i.e.* glacial till and colluvium at low and moderate slope angles or alluvium at low slope angles) and beyond the predicted level of marine flooding. Four sites are assigned to the moderate risk of disturbance category (risk classes 4 and 6). These sites are all located in the Kivitoo Foreland area and situated on materials susceptible to mass movement (*i.e.* largely glaciomarine sed-

TABLE IV

*Ranking of the potential risk of disturbance via mass movement derived from the overlay analysis of slope gradient and material strength**

| Slope gradient/ strength | Bedrock and residuum | Glacial till and colluvium | Alluvium and glaciolacustrine sediments |
|---|---|---|---|
| | 1 – High | 2 – Moderate | 3 – Low |
| 1 – Low (<5°) | 1 | 2 | 2 |
| 2 – Moderate (6-15°) | 1 | 2 | 3 |
| 3 – High (>15°) | 1 | 3 | 4 |

* 1: no susceptibility to mass movement; 2: low susceptibility to mass movement; 3: moderate susceptibility to mass movement; 4: high susceptibility to mass movement

FIGURE 7. Regional variations in the risk of disturbance due to slope instability and mass movement, Kivitoo Foreland study area.

*Variations régionales du risque de perturbation lié à l'instabilité des pentes et des mouvements de masse dans la région d'étude de Kivitoo Foreland.*

TABLE V

*Areal comparison of terrain sensitivity to mass movement in the Kivitoo Foreland study area within ANPR*

| Terrain class | Susceptibility to mass movement | Area (km$^2$) | Area (%) | Cumulative area (%) |
|---|---|---|---|---|
| 1 | Not susceptible | 1 755.15 | 63.22 | 63.22 |
| 2 | Low susceptibility | 528.38 | 19.03 | 85.25 |
| 3 | Moderate susceptibility | 477.25 | 17.19 | 99.44 |
| 4 | High susceptibillity | 15.49 | 0.56 | 100.00 |

TABLE VI

*Areal comparison of terrain sensitivity to mass movement in the southern fiords study area within ANPR*

| Terrain class | Susceptibility to mass movement | Area (km$^2$) | Area (%) | Cumulative area (%) |
|---|---|---|---|---|
| 1 | Not susceptible | 5 558.23 | 85.35 | 85.35 |
| 2 | Low susceptibility | 348.84 | 5.36 | 90.71 |
| 3 | Moderate susceptibility | 589.39 | 9.05 | 99.76 |
| 4 | High susceptibillity | 15.57 | 0.24 | 100.00 |

iments at moderate or high slope angles) and at substantial risk to marine flooding. Finally, 24 sites are assigned to the high risk of disturbance category (risk classes 8 to 12). The sites are located throughout both study areas near or at present sea level and are at extreme risk of marine flooding regardless of the nature of the surficial materials.

## DISCUSSION

The goal of this project was to assess the potential risk of terrain disturbance within ANPR to assist Parks Canada staff in managing sites of cultural significance. The majority of these sites lie in proximity to the coastline; hence, our assessment of terrain disturbance has incorporated a variety of elements that relate directly to coastline sensitivity (see McLaren, 1980; Miller *et al*., 1980; Sempels, 1982; Shaw *et al*., 1998a). The present study incorporates measures of topographic relief above the high tide level, sea-level tendency, and a wave regime influenced by a longer ice-free season (measures of the potential risk of marine flooding associated with sea-level rise or storms), and coastal sediment type (rock or unconsolidated: a measure associated with the strength of materials and the potential risk of mass movement) to assess terrain sensitivity.

The index of terrain sensitivity (Table VII) incorporates an assessment of the risk of disturbance associated with mass movement and the risk of disturbance associated with marine inundation. The data indicate that the greatest risk of terrain disturbance via mass movement is associated with steeply sloping colluvial deposits located on the sidewalls of the glacial troughs and fiords, and fine-grained glaciomarine sediments situated along the outer coast, especially where steep cliffs are produced by the erosion of waves and sea ice. These outcomes accord well with the extensive field observations of mass movement processes in the study area reported on by Bird (1977) and Dyke *et al.* (1982). Bird (1977) notes that steep cliffs (slope angles range from 30° to more than 65°) along the outer coast of the Kivitoo Foreland are susceptible to mass movement via mudflows, earth flows and debris slides that contribute to cliff retreat at estimated rates of 0.5 to 1.0 m per year. Dyke *et al*. (1982) consider colluvial deposits along the

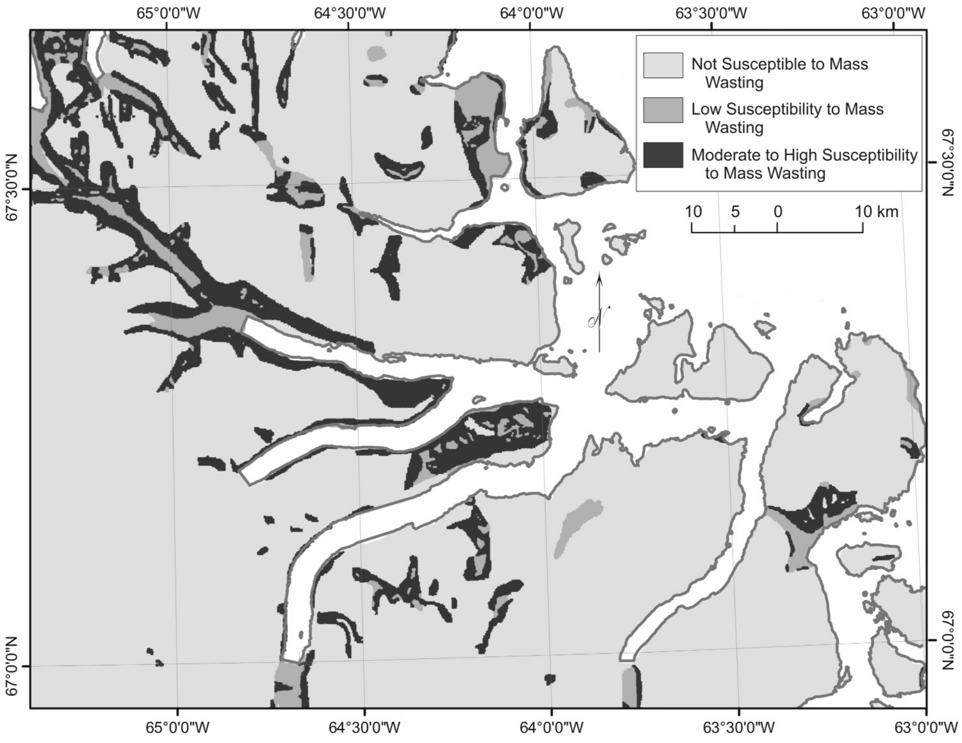

FIGURE 8. Regional variations in the risk of disturbance due to slope instability and mass movement, southern fiords study area.

*Variations régionales du risque de perturbation lié à l'instabilité des pentes et des mouvements de masse dans la région d'études des fjords du sud.*

TABLE VII

*Index of potential disturbance for archaeological sites derived from the overlay analysis of the potential risk for slope failure and mass movement and the potential risk of marine flooding**

| | Risk of marine flooding | | |
|---|---|---|---|
| Risk of mass movement | 1 – Low | 2 – Susbtantial | 3 – Extreme |
| 1 – No susceptibility | 1 | 2 | 9 |
| 2 – Low susceptibility | 2 | 4 | 10 |
| 3 – Moderate susceptibility | 4 | 6 | 11 |
| 4 – High susceptibility | 8 | 8 | 12 |

* 1: no risk of disturbance; 2: low risk of disturbance; 4 to 6: moderate risk of disturbance; 8 to 12: high risk of disturbance.

sidewalls of glacial troughs and fiords within ANPR to exhibit the highest degree of terrain sensitivity to disturbance because of the potential for snow avalanches, rock falls, and debris slides. The index of terrain sensitivity does not, however, address situations where materials in one terrain unit (steeply sloping colluvium) fail and are deposited on another terrain unit (alluvium or glaciomarine sediments) at lower elevations contributing to terrain disturbance on the latter land surface.

Extensive surveys of the Cumberland Peninsula coastline by Sempels (1982) have demonstrated a lack of correlation between the energy of the marine environment and coastline characteristics that are attributed to the short open water season and the persistence of landfast ice that, in combination, effectively limit the activity of littoral processes. Forbes and Taylor (1994) note that the presence of pack ice offshore serves to restrict the development and propagation of wind-driven waves and landfast ice serves as a barrier to wave action, preventing waves from reworking the shore. The index of terrain sensitivity (Table VII) developed for this study is based upon a worst-case scenario: continuing coastal submergence at 10 cm per century, global sea-level rise in excess of 0.45 m in response to global warming, and an increase in the frequency of storms associated with a longer ice-free season. The data indicate that sites situated in proximity to the shore and at elevations less than 2 m asl will be at greatest risk to marine inundation. The index of terrain sensitivity likely overestimates the potential risk of marine flooding within ANPR.

Rapid advances in technology have made Geographic Information Systems (GIS) practical and attractive for use in terrain analysis and land resource management. These technologies can be employed to provide quantitative analyses of the complex interrelationships between process and form over a variety of spatial and temporal scales. This study has illustrated the application of a modestly priced and readily available technological tool to develop a regional analysis of terrain sensitivity. The study presents results that are consistent with manual methods of terrain analysis (see Bird, 1977; Dyke *et al.*, 1982; Sempels, 1982) while contributing to a better understanding of the regional environment through the overlay analysis capability of GIS. The database can be continually updated, manipulated and queried in various ways providing Parks Canada staff with a valuable natural resource management tool. Our assessment indicates that archaeological sites situated in proximity to the shore and at elevations less than 2 m asl to be at the greatest risk of marine flooding: the situation is particularly acute for sites situated on steeply sloping glaciomarine sediments on the Kivitoo Foreland. The veracity of the index of terrain sensitivity can only be determined by "ground-truthing", the direct observation of conditions at the 28 most vulnerable sites identified in this study. There is a clear need to conduct more research to ascertain the potential for site disturbance and the irretrievable loss of culturally significant materials within ANPR.

## ACKNOWLEDGEMENTS

This paper is dedicated to the memory of Brian McCann. Aitken also acknowledges the contributions of Robert Gilbert, Queen's University, and the opportunity to study the oceanography of Baffin Island fiords under his tutelage. The research on Baffin Island coastlines conducted by these colleagues in the 1980's provided the stimulus for this project. Funds to support this research were provided by the Natural Sciences and Engineering Research Council of Canada (NSERC) in the form of operating grants to Aitken, and the University of Saskatchewan in the form of a graduate fellowship to Solsten. The paper has benefited from the constructive reviews provided by Norm Catto and Robert Taylor. The authors also wish to thank the following individuals: Yves Bossé and Phil Wilson, Parks Canada, who provided access to the digital data for ANPR; Dave Frobel, Geological Survey of Canada (Atlantic), who provided aerial photographs of the ANPR coastline; and Elise Pietroniro, GIServices, University of Saskatchewan, for her efforts in data processing and the preparation of the figures.

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