REPORT ON VULNERABILITY TO GEOLOGICAL HAZARDS IN THE TOWN OF CONCEPTION BAY SOUTH

Geological Hazards Series, Report No. 1

M.J. Batterson P. Geo. and N. Stapleton
Geological Survey

Open File 001N/0884

St. John's, Newfoundland
November 2011

Natural Resources

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Cover photo: Composite photo illustrating the after-effects of geological hazards within the Province of Newfoundland and Labrador; these events have occurred over a hundred-year period.

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ABSTRACT

This report provides data on vulnerability to geological hazards within the town of Conception Bay South; it also includes a hazard vulnerability map. This multi-hazard map combines a slope model generated from a DEM with a 5 m resolution, a set back of 15 m from the top of unconsolidated cliffs, the identification of areas of low slope adjacent to streams, of areas below 2 m asl, of areas between 2 m and 4 m asl, and sites of historical incidences of landslide, avalanche, rockfall or flooding. Data are combined to generate a preliminary vulnerability map, which is verified by field data and by overlaying mapping on georeferenced orthophotographs of the area. The map has a simple 'traffic-light' zonation to identify areas of high, moderate and low vulnerability to geological hazards. Recommendations for development within these zones are also provided.

INTRODUCTION

The aim of the provincial hazards-mapping program is to reduce the loss of life, property, and infrastructure, plus the protection of environmental and cultural resources in the Province that result from damage caused by natural disasters. The program provides information on geological hazards to all municipalities within the Province, which will assist municipal councils in developing a plan to mitigate the effects to such hazards.

This report identifies localities within Conception Bay South (CBS), Avalon Peninsula (Figure 1) that are vulnerable to natural geological hazards (mass movement - landslide, rockfall, avalanche), coastal and river flooding, and the potential effects of sea-level rise. The report and associated maps are intended for general information only, such as land-use and emergency management planning, and should not be used for site-specific evaluations. The report does not include vulnerability from meteorological events, although the trigger for mass movements and floods is commonly weather-related. However, a slope-aspect map is provided, which may aid in developing further criteria that may enhance the mapping defined in this report.

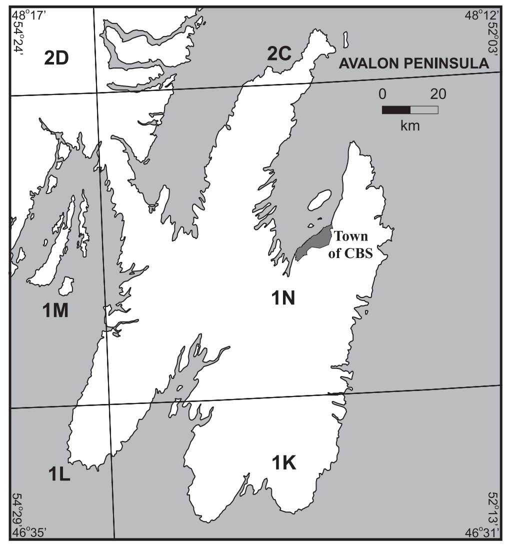


Figure 1. *Location of Conception Bay South (CBS).*

The study area was mapped using protocols developed by the Geological Survey that were incorporated into ArcGIS to generate a hazard vulnerability map. This is an unsophisticated multi-hazard approach that primarily focuses on slope, adjacency to the coast, potential flood risk, and areas of known hazard. The resultant map was overlain on an orthophoto mosaic of the study area, partially as verification of the computer-generated mapping, and partially to guide final definition of polygons to ensure hazard zones are appropriately delineated.

For the purposes of this report, geological hazards are defined as those hazards that have a geological component and include flooding (because they occur on flood plains or low slopes adjacent to coastlines) and mass movements, commonly on steep (>20°) slopes.

Mass movement (mass wasting) is the downslope movement of material under the direct influence of gravity, and generally the steeper the slope the greater the risk of mass movement. Mass movement includes a variety of terminology, including landslide, rockfall, debris flow, solifluction, and avalanche (Figure 2). The material moves at rates ranging from very slow (soil creep, solifluction) to extremely fast (rockfall, debris flow). Rapid mass movements are potentially dangerous and frequently result in property damage and loss of life. Most rapid mass movements occur on relatively steep slopes and can involve rock, soil, or debris. Although water is commonly a critical factor, gravity is the major force behind mass wasting.

Mass movement occurs simply enough; when the gravitational force (shear stress) acting on a slope exceeds its resisting force (shear strength; Figure 3). The shear strength of a slope includes

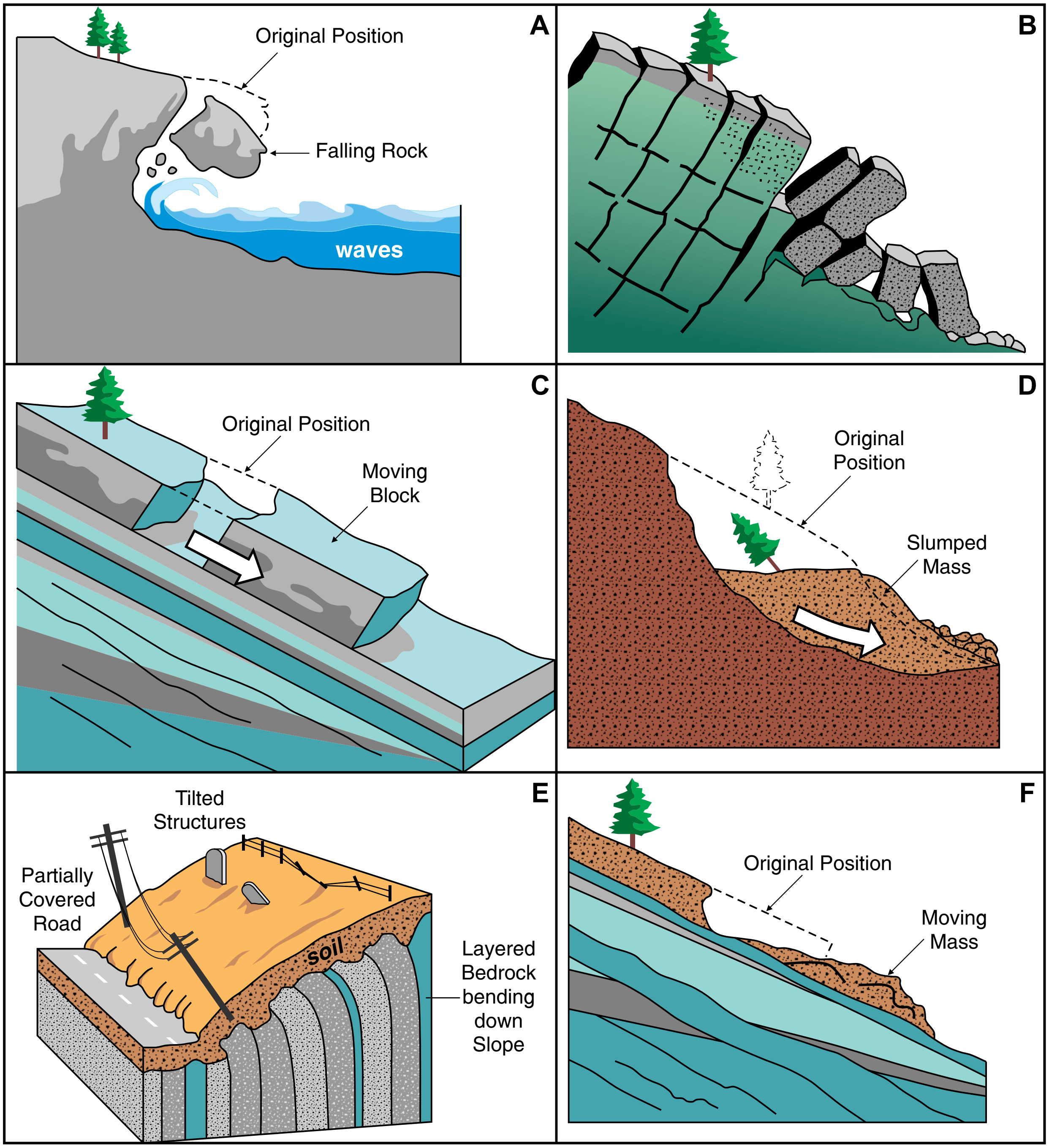
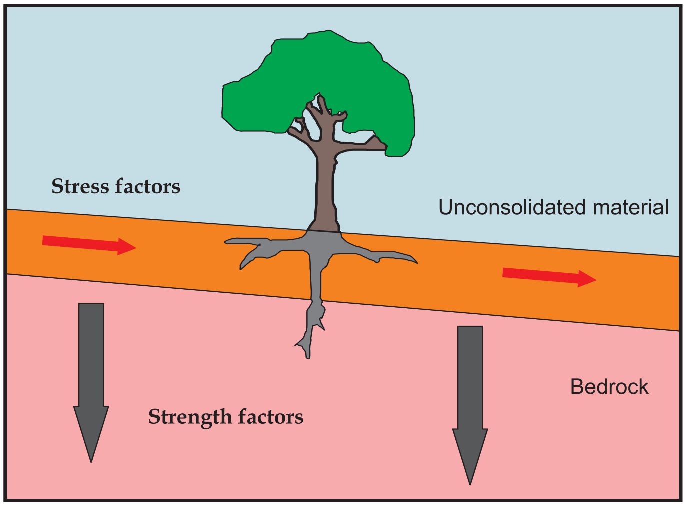


Figure 2. *Types of slope movement. A. Rockfall. Commonly caused by wave action and/or freeze-thaw; B. Rockfall produced by toppling of blocks in well jointed rocks; C. Rockfall produced by movement along a bedding plane; D. Rotational slump in unconsolidated sediment; E. Soil creep. Slow continuous movement; F. Landslide caused by failure of unconsolidated sediment. (Source: Government of British Columbia).*



Generally stable slope - the strength factors (low slope angle, supporting vegetation, soil cohesion) are much greater than the stress factors (primarily gravity).

Potentially unstable slope. The stress factors (high slope angle, gravity) are almost as great as the strength factors (vegetation, soil cohesion). Small cracks developing on the surface are indications of slope instability. Slope failure will commonly occur along the boundary between the bedrock and the overlying unconsolidated material.

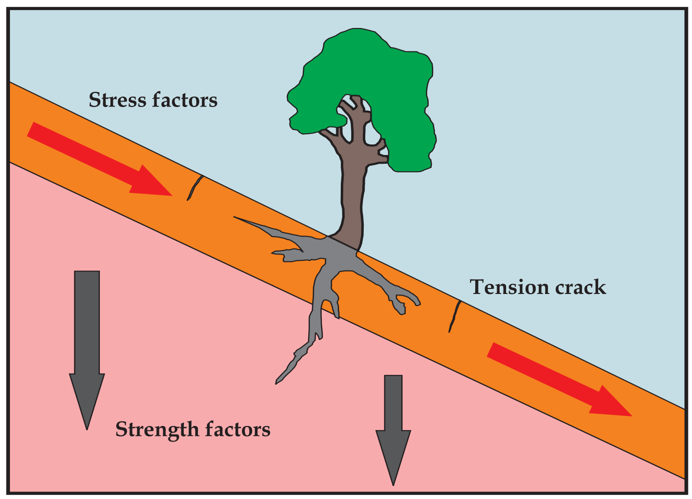


Figure 3. *Diagram showing forces acting on a slope.*

the slope material's strength and cohesion, the amount of internal friction between grains, and any external support of the slope. Opposing a slope's shear strength is gravity, which operates vertically but also has a component acting parallel to slope, thereby causing instability. Generally, the greater a slope's angle, the greater is the chance for mass wasting, although mass wasting can occur on very low slope angles, *e.g.,* in marine clays. The steepest angle that a slope can maintain without collapsing is its 'angle of repose'. At this angle, the shear strength of the slope's material exactly counterbalances the force of gravity. For unconsolidated material (sediment overlying bedrock), the angle of repose normally ranges from 25 to 40º. Slopes are in a state of dynamic equilibrium; they constantly adjust to forces acting on the slope. Because of this, most slope movements in surface sediment (including snow) occur on angles between 20 and 45º. Slopes steeper than 40º usually consist of unweathered solid rock, although rock fall is a common hazard on such slopes. The potential triggers for mass movement are varied, and include heavy rainfall events, rain on snow events, undercutting of sediment banks by rivers or waves, and freeze–thaw activity on bedrock.

There has been a considerable recorded history of geologically related disasters in the Province, extending back over 200 years. During that period, over 170 lives have been lost, and the economic cost has been equally enormous. Between 2000 and the time of publication, the Province has experienced significant events in Badger (flooding), Stephenville (flooding), Daniel's Harbour (landslide), Trout River (landslide), and eastern Newfoundland (flooding and landslides). In the same period, there have also been smaller events reported from Admiral's Beach, Bay Roberts, Beaches, Blue Mountains, Burgeo, Burin Peninsula, Burin, Burlington, Capstan Island (Labrador), Carbonear, Conception Bay South, Corner Brook, Cox's Cove, Curling, Daniel's Harbour, Deer Lake, Duntara, eastern Newfoundland, Englee, Ferryland, Flatrock, Fleur de Lys, Fogo Island, Forteau, Gambo, George's Lake, Glenwood-Appleton, Hampden, Hermitage, Indian Bay, Labrador City, Lamaline, Lewis Hills, Mount Carmel/Salmonier Line, Nain, northeast Newfoundland, Pinchgut Lake, Placentia, Port aux Basques, Raleigh, Reidville, Southport, St. Anthony, St. Bride's, St. John's, St. Lawrence, Stephenville – Port au Port, Stephenville Crossing, Trepassey, Trout River, western Avalon Peninsula, Whitbourne, and Witless Bay. The total economic cost of these events is difficult to determine, but a conservative estimate places the cost at over $250 000 000. Two events since 2000 were responsible for fatalities; from an avalanche in the Blue Mountains on the Great Northern Peninsula in 2007, and from flooding at Britannia, Random Island, during Hurricane Igor in 2010. Many of the impacts of these events are arguably unavoidable, but some are clearly the result of development in areas susceptible to geological hazards, and where no, or inadequate, mitigation measures were employed.

REPORT STRUCTURE

This report provides background information on the development of the map. More detailed, technical information is provided in the Appendix. A CD providing all the data used to generate the map in an ArcGIS format (geodatabase files), data preloaded into ArcGIS Explorer for easy viewing (see Appendix for link to download free ArcGIS Explorer software), and a pdf version of this report can be made available upon request.

COMPONENTS OF THE MAP

The map combines topographic data, slope models, surficial geology, flood-risk mapping, and historical incidents to produce a 'vulnerability score' of multi-hazard potential. Areas of high, moderate or low vulnerability are subsequently defined based on this score. The components of the map are discussed in detail.

1. TOPOGRAPHY

The acquisition of detailed topographic data is a critical component of the hazards-mapping process. Wherever possible, data were obtained from publicly available sources at the Surveys and Mapping Division of the provincial Department of Environment and Conservation. Many communities are mapped at a scale of 1:2500, which is made available digitally with a 2-m contour interval; many other areas are only mapped at a scale of 1:50 000. The scale at which an area is mapped has a direct impact on the detail of the Digital Elevation Model (DEM) produced, and thus the quality of the slope model derived from it. As mapping scales improve, existing maps can be refined to better identify areas vulnerable to geological hazards. The town of Conception Bay South has high-resolution data.

Beyond the issue of map scale, the basis on which sea level is defined requires discussion. From simple observation, it is obvious that sea level is difficult to define in absolute terms. We are all familiar with the astronomical forcing that produce the tides, but even on short time scales (minutes to days) climatic factors, including wind stress, hurricanes, and tropical storms can produce water levels far in excess of the tidal range. Similarly, the coastal geology (including tectonic influences) and morphology, and the near-shore bathymetry, all influence water level. Defining the position of the mean sea level (*i.e.,* the location of the 0 m contour) is difficult!

For the purposes of this project, the contours (and thus the definition of mean sea level) defined on publicly available topographic community maps are used. A more detailed discussion on defining mean sea level is found in the Appendix.

2. CREATING A DIGITAL ELEVATION MODEL (DEM) FROM 2-M CONTOUR LINES

A DEM with a resolution of 5 m (*i.e*., individual pixels are 5 by 5 m) was created from 2-m contour lines using an ArcGIS interpolation method specifically designed for the creation of hydrologically correct digital elevation models (Figure 4). This resolution was selected because it closely reflects the resolution of the topographic map data that has a resolution of +/- 2 m.

The DEM was checked against the topographic data to ensure that it accurately reflected the field area.

3. CREATING A SLOPE MODEL FROM THE DEM

A slope model with a 5 m resolution was created in ArcGIS from the DEM and the output calculated as degrees of slope (Figure 5). The slope model is classified into four categories; 0-1°, 1-19.9°, 20-45°, and >45°.

Slope (°)	**Slope (%)**	**Rationale**
0-1°	0-1.75%	If adjacent to streams or coastline, these areas could be vulnerable to flooding.
1-19.9°	1.75-36.4%	Low vulnerability slopes, although vulnerability increases as slope angle approaches 20° (36.4% grade).
20-45°	36.4-100%	Slope angles on which most mass movements (except rockfall) occur.
> 45°	> 100%	Generally bedrock-dominated slopes. Vulnerability to rockfall may be high, depending on rock type.

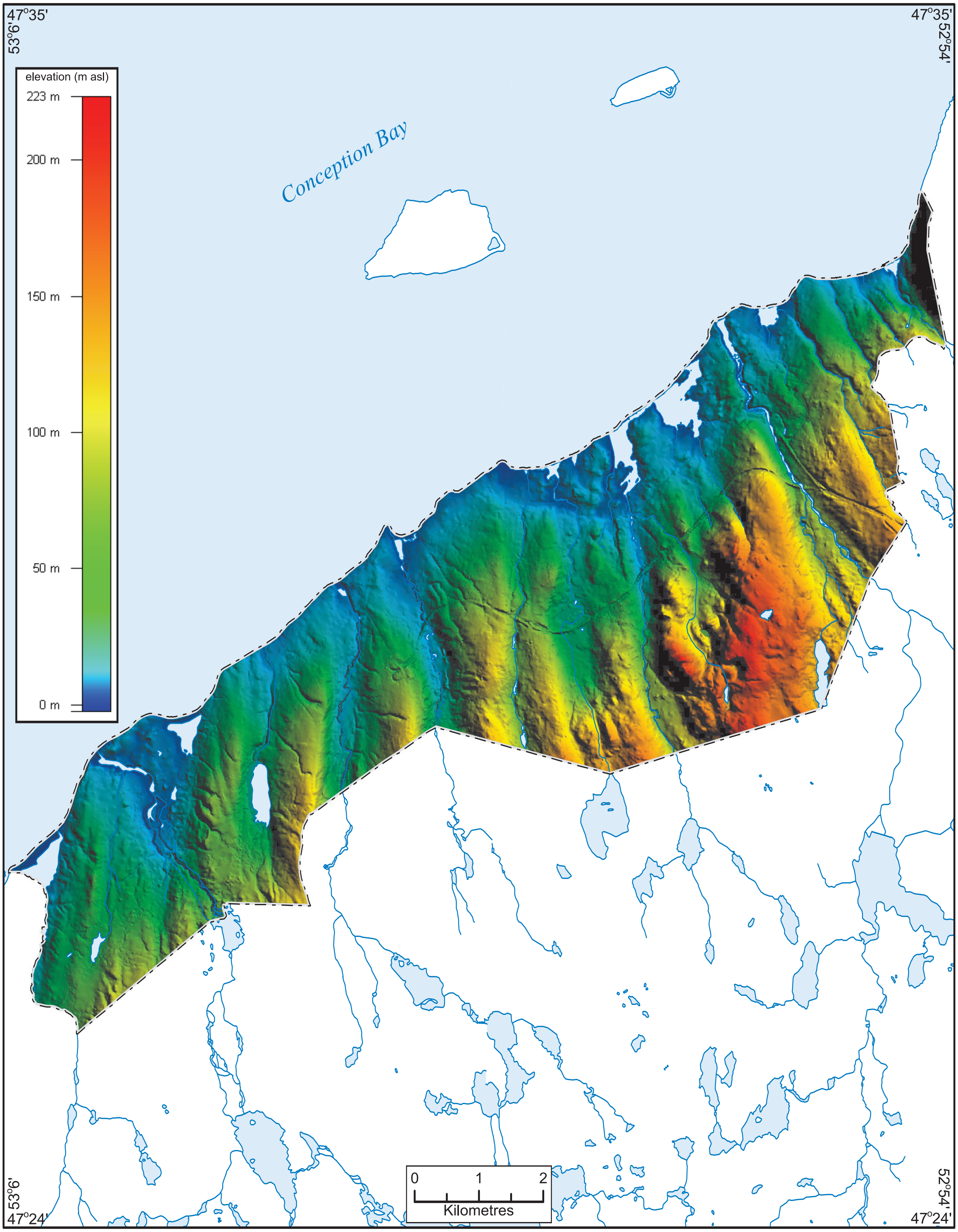


Figure 4. *Digital Elevation Model for CBS interpolated from the 2-m contour data.*

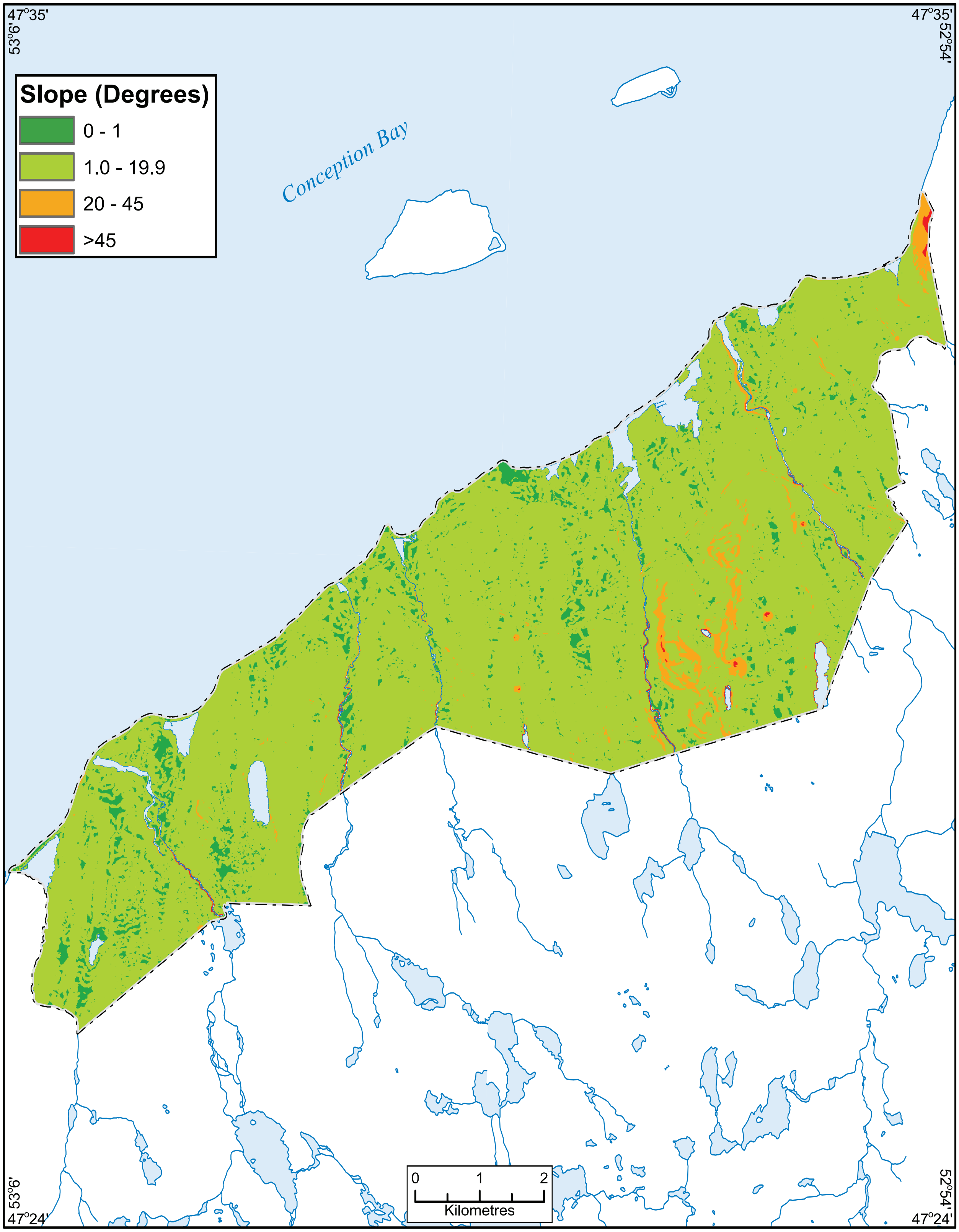


Figure 5. *Slope model for CBS generated from the Digital Elevation Model. The maximum slope in this area is 82.04° (715.54%).*

4. FLOOD-RISK MAPPING

Flood-risk mapping in the Province is undertaken by the Water Resources Division, Department of Environment and Conservation. Mapping defines 2 zones; the ‘floodway’ where floods have a return period of 20 years (5% chance in any year), and the ‘floodway fringe’ where the return period is one in 100 years (1% chance in any year). Flood-risk mapping has been completed for 38 communities in the Province, although not in the town of Conception Bay South. Where available, digital data from the flood-risk mapping program is incorporated into the vulnerability maps.

Where flood-risk mapping has not been undertaken within the study area, potential vulnerability was defined on the basis of proximity of low slopes (<1°) on transects perpendicular to streams. This vulnerability assessment does not consider any hydrographical or climatological analysis of a stream or its watershed, and as such, should not be considered as a replacement for formal flood-risk mapping.

5. SEA-LEVEL RISE/ STORM-SURGE EVENTS

At the end of the last glacial period, the removal of the weight of the ice sheets caused the Earth’s crust to rebound. This process continues throughout the Province with some land areas rising (most of Labrador), and others falling (most of the Island of Newfoundland; Figure 6); Conception Bay South is in an area of subsidence. Coupled with global trends of sea-level rise (see the Intergovernmental Panel of Climate Change report (IPCC, 2007); Batterson and Liverman, 2010), a relative sea-level rise of over 100 cm is expected in eastern Newfoundland by the end of this century.

In addition to a relative sea-level rise, historical records of coastal flooding, likely the result of storm surge (Figure 7), record inundation of areas below the 2 m contour. Inundation to this elevation likely occurred when the storm surge was coincidental with a high tide. These factors combined indicate that areas of potential inundation are up to 3 m asl. Communicating this area of risk is a challenge because mapped contours have a 2 m interval. Interpolation between contours assumes a linear increase in slope, which may not be the case, and therefore areas at risk from coastal flooding are based on the 2 and 4 m contours (Figure 8).

6. GEOLOGICAL DISASTERS

A geological disaster occurs when natural geological processes impact on our activities, either through loss of life, injury, or economic loss. The Geological Survey has compiled a historical record of geological disasters from a wide range of sources over several years of research (Batterson and Liverman, 2006; http://www.nr.gov.nl.ca/nr/mines/outreach/geological hazard.html). Events recorded in the database include earthquake, tsunami, landslide, rockfall, avalanche and flooding. Within CBS, flooding is common along the Conception Bay shoreline (Figure 9). Storms and storm surges were reported in 1917, 1921, 1961, 1992 and 2011, although this likely under represents the frequency of storm activity, with many smaller events likely going unreported.

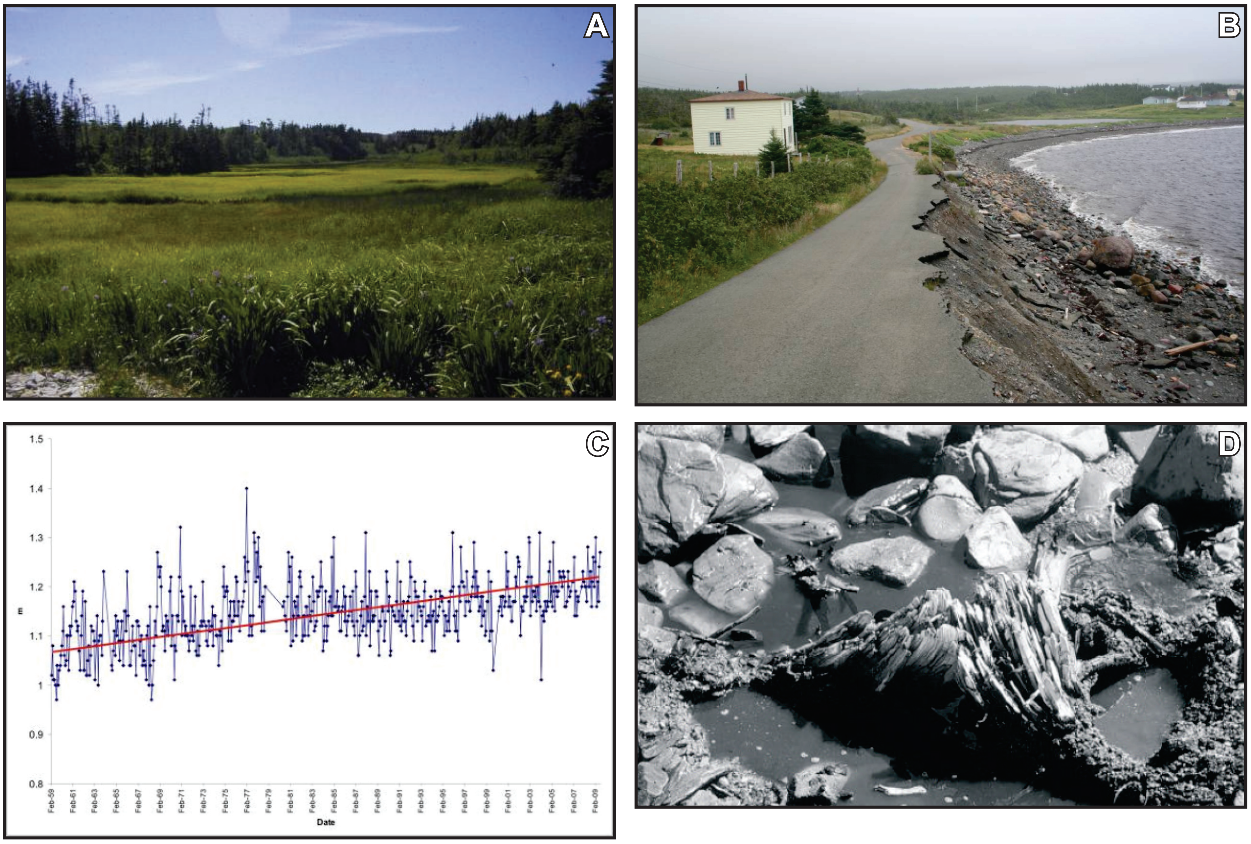


Figure 6. *Evidence of sea-level rise in the Province. A. Salt marsh development on the west coast; B. Coastal erosion at Admiral's Beach; C. Tide gauge record from Port aux Basques; D. Spruce stump dated at about 2300 years old found below high tide line at Big Seal Cove (from Catto* et al., *2000).*

Figure 7. *Storm-surge damage. Left - in CBS from a surge in January 2011; right - at the Battery, St. John's from a surge in December 2009.*

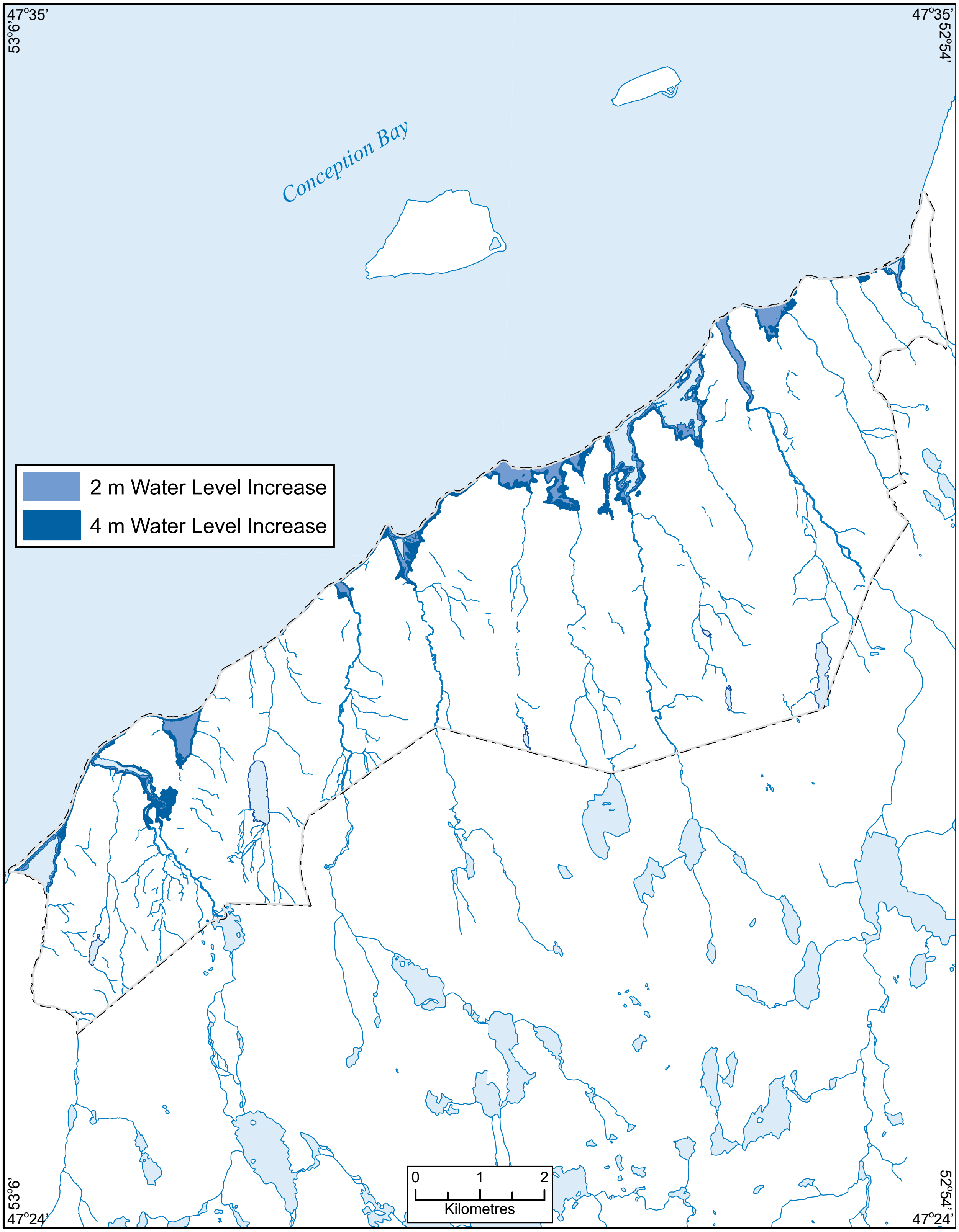


Figure 8. *Map showing the effects of increasing water levels (combination of sea-level rise and storm surge) by the identification of the 2 and 4 m contours.*

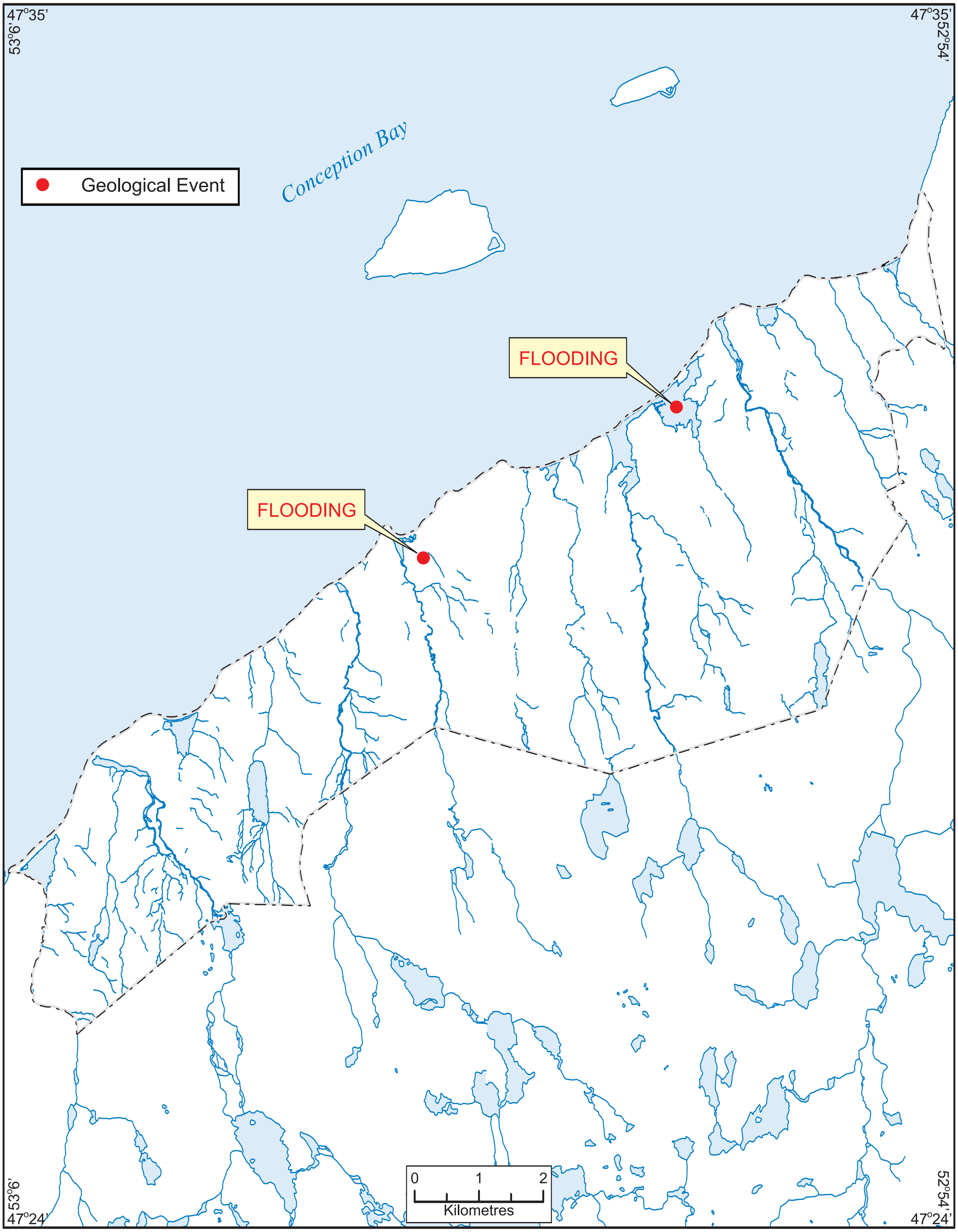


Figure 9. *Map showing documented historical geological incidences within CBS (data from http://www.nr.gov.nl.ca/nr/mines/outreach/geologicalhazard.html). Locations indicating flooding are only general because flooding commonly impacts a wide area.*

7. SURFICIAL GEOLOGY

The entire area of CBS was glaciated during the last glacial period. Glacial sediments are commonly thin (less than 3 m), and are either sandy till (sediment deposited directly by glaciers, comprising a mixture of boulder- to clay-sized material) or glaciofluvial sand and gravel (sediment deposited by meltwater as the glaciers were melting). Much of the northern part of CBS is dominated by bedrock (Figure 10). Surficial geology is particularly important in coastal areas, because cliffs composed of unconsolidated material erode more quickly than bedrock cliffs. In other areas, steep slopes covered by surficial sediments may be prone to landslides.

Historical coastal erosion rates in the Province for cliffs composed of unconsolidated material are up to 1 m per year, with an average rate of ~15 cm per year (Figure 11). These erosion rates are extremely dependent on local conditions and previously stable cliffs can be modified by single storm events. Set-back limits should aim for 100 years of sustainability of residential/commercial use. A distinction is recognized between exposed coastlines where the frequency of storms impacting the coast is high compared to more protected coasts where a specific wind (and commonly wave) direction is required to impact the shoreline. On exposed coastlines a setback of 25 m is recommended, with a 15 m setback for more protected coastal environments such as CBS. However, any municipality should view these setback recommendations as a minimum and consider greater setbacks in areas of municipal concern. These limits are also only valid for the time of preparation of this report and should be reviewed at least every decade to ensure that setback limits are maintained.

8. ASSIGNING A VULNERABILITY SCORE

There are numerous methods of determining risk, but the variables included and the weighting applied to each are largely subjective. For this study, slope, flood zones, elevation, adjacency to cliff-tops, and historical evidence of geological events were considered because they are relevant to most municipalities in the Province (Table 1).

In an attempt to quantify the data in this analysis, each layer was assigned a factor score on a scale of 1 to 10; high scores represent high vulnerability and low scores represent low vulnerability.

9. CREATING A MULTI-HAZARD MAP

Following the assignment of a score to each variable, the layers were essentially overlain on each other to produce a multi-hazard map.

A manual classification scheme was used to categorize the total score values, which range from 1 to 30, into three classes. The resulting class ranges are as follows:

Low:	1 – 4.99
Moderate:	5 – 9.99
High:	10 and above

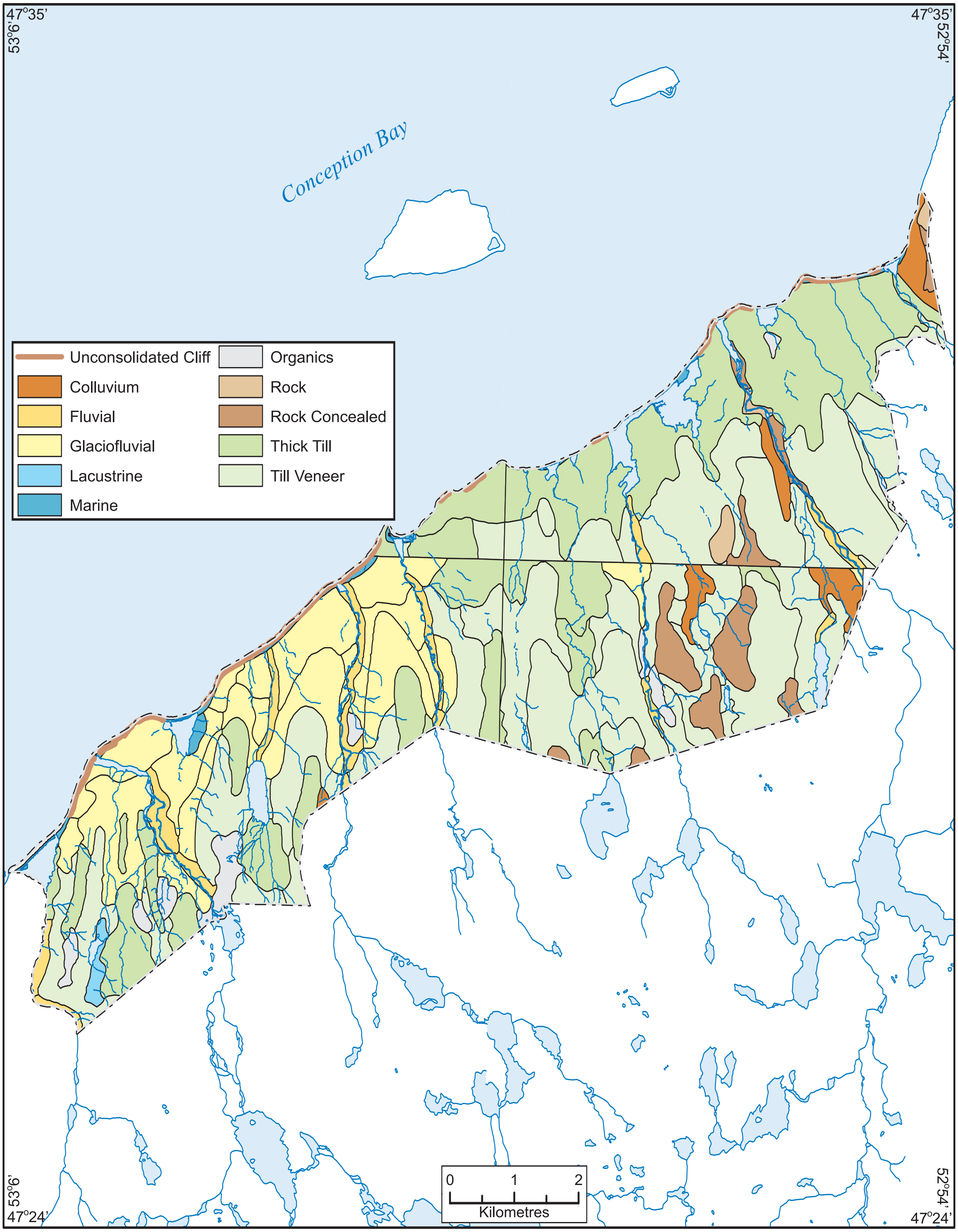


Figure 10. *Surficial geology map of CBS (taken from Batterson, 1999, and Catto and Taylor, 1998a, b).*

Figure 11. *Coastal erosion at Point Verde, Avalon Peninsula. The photographs were taken in 1999 (left) and 2005 (right).*

Table 1. Factor scores applied to individual inputs

Each layer was scored as follows:

INPUT	FACTOR SCORE
Historical occurrence	10
Within 20-year flood zone	10
Within 100-year flood zone	5
Below 2 m asl	10
Between 2 and 4 m asl	5
Within 15 m of non-rock cliff edge	10

Each slope class was scored as follows:

SLOPE (º) / (%)	FACTOR SCORE
1 - 1.0º slope adjacent to stream	5
1.01 - 20.00	1
20.01 - 45.00	5
> 45.01	10

10. GENERATION OF THE FINAL MAP

Except for the defined 15-m setback limit from an unconsolidated cliff edge, the multi-hazard map is computer-generated, based on the protocols defined in this report. This 'black-box approach' provides a classification of hazard vulnerability, but it requires comparison with the real world to ensure that areas are not over- or under-represented. The resultant multi-hazard map identifies areas of potential hazard in areas as small as 25 m^2 (*i.e.,* one 5 by 5 m pixel), which may be insignificant for regional or municipal planning, *e.g.,* some of these small areas may be artefacts of producing the DEM and may not reflect any hazard and others may be embankments as a result of road or highway construction. Areas identified as low hazard (commonly lower sloped areas) may be surrounded by areas of higher hazard, and therefore unsuitable for unrestricted development. Thus the map requires knowledge-based editing to produce the final product (Figure 12).

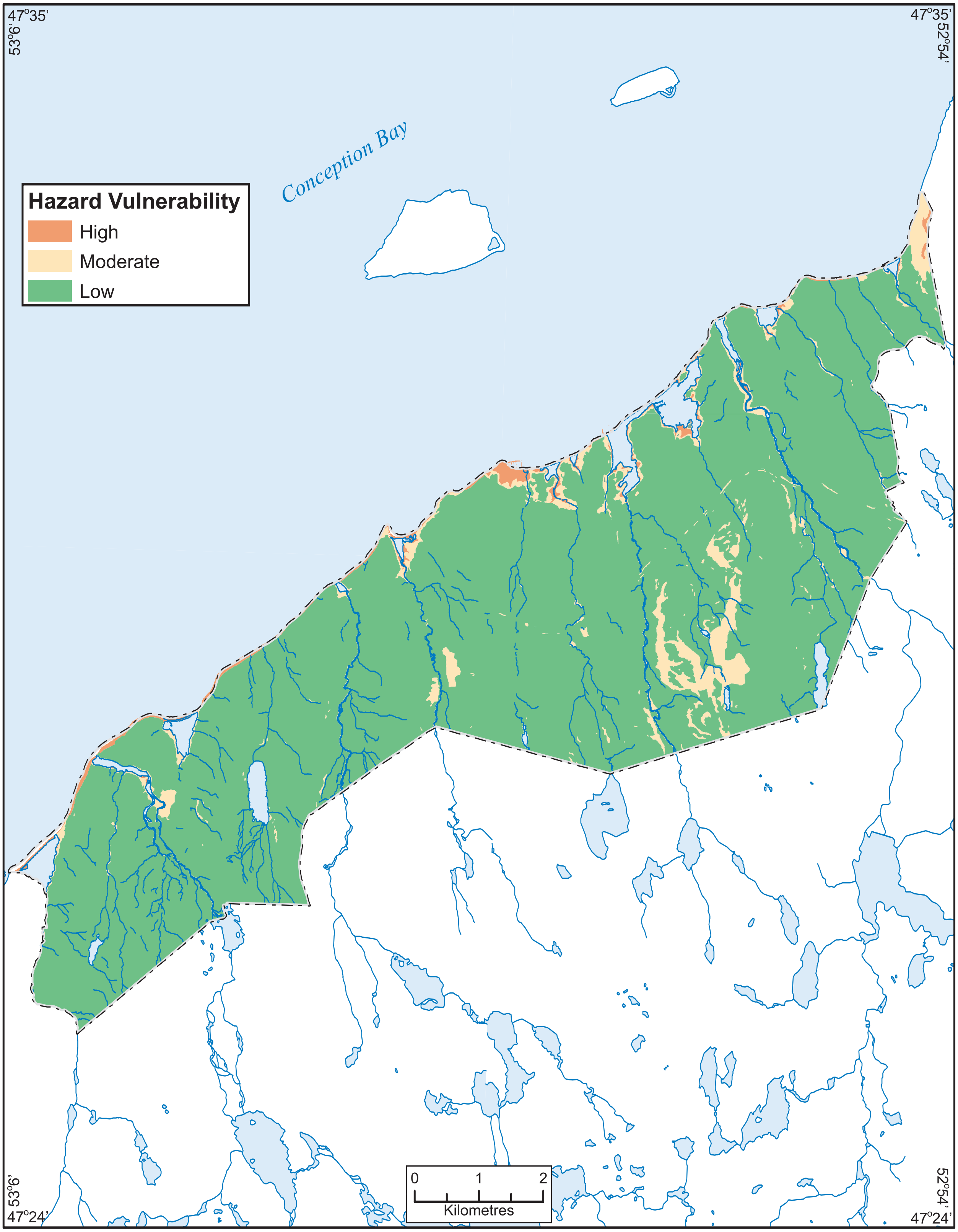


Figure 12. *Hazard vulnerability map for CBS.*

Within CBS, the following generalizations were made to the map:

i) Areas less than 250 m^2 (*i.e.,* < 10 pixels) were generally considered not to be mappable units.

ii) Barachois beaches were designated as high hazard. These are gravel beaches located across the mouths of embayments. They are commonly breached through a channel connecting the embayment to the ocean, although this outlet may be closed during parts of the year, commonly as a result of storm activity and seasonal changes in the beach profile. These features are critical to the protection of the coastline inland of the beach. Barachois beaches constantly change in response to storms and other coastal processes; the crest may migrate inland in response to individual storms, and long-term sea-level rise. These features are unsuitable for any development and therefore are classified as high vulnerability even though some of the larger beaches (*e.g.,* adjacent to the Royal Newfoundland Yacht Club) have crests above 4 m asl.

iii) Areas identified as low hazard surrounded by areas classified as either moderate or high hazard are always included within the higher hazard area. These areas commonly represent lower slopes (1 to 20°), but the risk of mass movement from adjacent slopes or to infrastructure required to access the area is considered.

iv) Areas of bog with an associated stream are commonly classified as 'moderate vulnerability' as a result of having low slopes adjacent to the stream. These areas generally have a low potential for flooding and were therefore not included.

v) Areas of low slope, adjacent to streams, were classified as 'moderate vulnerability', because detailed hydrological analysis has not been completed in these areas.

Hazard vulnerability areas are defined approximately and the risk of geological processes impacting human activities is estimated for each. The risk is based on geological factors but includes an undefined degree of uncertainty. Thus an area defined as low vulnerability, rarely, still may be impacted by geological processes, and an area defined as high vulnerability may not be impacted by geological processes over long periods of time. Extreme and very rare events (earthquakes, tsunamis, etc.) may also affect areas mapped as low vulnerability.

Description of Levels of Vulnerability

The map (Figure 12) shows hazardous areas on a scale of low to high vulnerability (Table 2). Users should be aware that these hazard vulnerability maps have limitations: they indicate only those types of hazard that may be active under present-day conditions. Slope instability can be increased by clearance of vegetation, diversion of drainage onto the slope, or progressive erosion of cliff edges. Slope hazard can be reduced by various mitigation measures, such as retaining structures. Improvement of drainage infrastructure may reduce flood risk. The hazard vulnerability maps provide no information about the intensity, frequency, or time of occurrence of any geological process. Similarly, the identification of two or more hazards within an area does not indicate that the area is potentially more hazardous than an area modified by only one geological process.

It should be noted that no location should be considered invulnerable to hazards, even those mapped as "low vulnerability" above. The chances of hazardous events occurring in those areas may be slight but not negligible.

Table 2. Description of levels of vulnerability and suggested recommendations associated with each

Vulnerability	Description	Recommendations
Low	Unlikely to be affected by hazardous geological processes (including flooding), unless human activities modify the landscape to increase hazard potential; slope gradients generally gentle (<20°); remote from sources of flooding; no adjacent steep slopes.	No action required.
Moderate	May be vulnerable to hazardous geological processes in certain conditions (*e.g.,* extreme rainfall events, exceptional snow melt). Slopes generally moderate (20-45°); may be adjacent to steeper slopes or low lying areas potentially subject to flooding; be within a designated 1:100-year flood zone; be between the 2 and 4 m contour.	In some instances development is restricted (*e.g.,* within the floodway fringe). For those areas not already excluded from development, a detailed assessment of the area should be undertaken, conducted by a qualified geoscientist or geotechnical engineer.
High	Vulnerable to hazardous geological processes, with return times 100 years or less. May have evidence of previous events; slopes steep (>45°); within a designated 1:50-year flood zone; close to eroding cliff or bank; lying directly below very steep slopes; be below the 2 m contour.	In some instances development is restricted (*e.g.,* within the floodway). For those areas not already excluded from development, a detailed assessment of the area must be required, conducted by a qualified geoscientist or geotechnical engineer. This assessment should include plans to reduce risk and mitigation of risk to existing structures. In some instances (*e.g.,* adjacent to cliff edges, or below 2 m asl), municipalities may choose to remove areas from development.

This report and accompanying hazard vulnerability map can be used with other criteria to help planners/municipal councils to select potential areas for development, and avoid geologically vulnerable areas. Within areas designated as 'moderate' or 'high' vulnerability, it is recommended that site-specific geotechnical evaluations be conducted prior to new construction or upgrading of buildings and other facilities. These evaluations should include detailed site descriptions that identify the potential hazards and risk, and plans to protect planned developments from hazard or mitigate the risk for existing structures. Municipalities are encouraged to develop their own criteria for development to maximize the effectiveness of these maps.

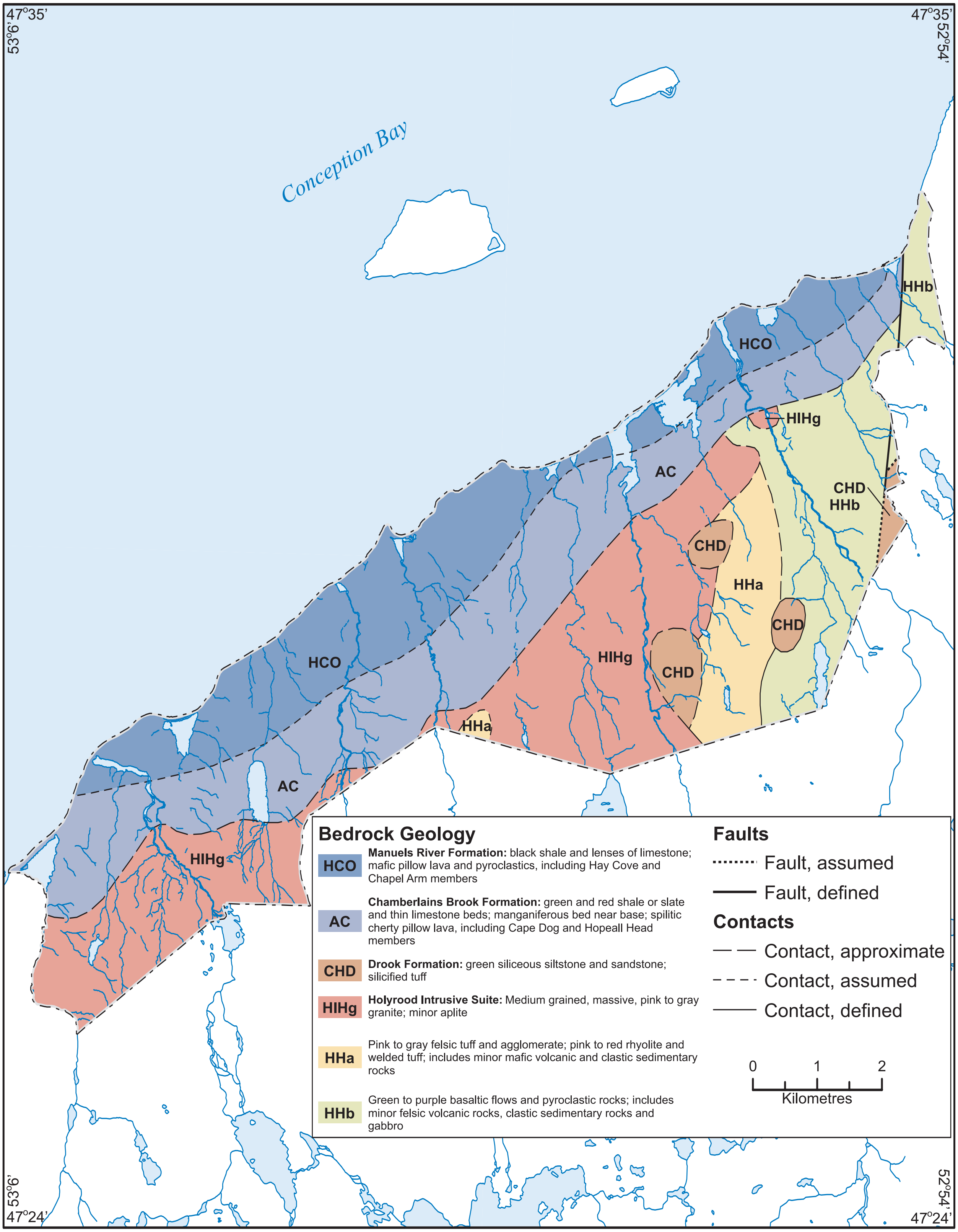


Figure 13. *Bedrock geology map of CBS (after King, 1988). See text for explanation.*

FUTURE DIRECTION OF HAZARDS-MAPPING PROGRAM

Several other layers of data could be incorporated into the hazards-mapping program, which may refine the existing designations:

i) Increased use of Bedrock Geology Maps

The bedrock in CBS (Figure 13) is mostly Precambrian sedimentary and volcanic rock (King, 1988). The oldest rocks are tuff, rhyolite and basaltic flows of the Harbour Main Group (HHa, HHb). They generally outcrop along the northern coast, and comprise the coastal hills. The Harbour Main Group rocks are intruded by pink to grey granite of the Holyrood Intrusive Suite (HIHg), which are found in the southern part of the town. These granitic rocks are overlain by siltstone and sandstone of the Conception Group (CHD), which are found in several small areas in the east part of the town. The youngest rocks are those of the Cambrian Harcourt (HCO) and Adeytown (AC) groups. These are mostly shale and slate, and are generally poorly exposed, underlying much of the coastal fringe in the southern part of the town. Detailed analysis of bedrock geology data will identify well-jointed and/or well-bedded rock units that are more likely to produce blocks that could topple, compared to bedrock with no structural weakness.

ii) Identify the Shadow Angle

Shadow angle is that area of low-angle slope beyond the base of a steep slope that may be affected by displaced and rolling boulders. The shadow angle is derived from projection of an angle of 22° (from horizontal) from the top of a talus slope. Calculation of the shadow angle requires detailed surficial geology mapping to identify talus slopes or aerial photography to identify potential areas, and detailed (1:5000 or better) digital topographic data.

iii) Slope Aspect

A slope aspect layer is provided (Figure 14). This shows the direction toward which the slope is facing. In the northern hemisphere, a south-facing slope will be more open to sunlight and winds and will therefore generally be warmer and dryer due to higher levels of evapotranspiration than a north-facing slope. Aspect is an important consideration in modeling the effects of climatic events, particularly storm tracks. On the east coast of the Province, most storms track southwest– northeast, and with intense rainfall commonly associated with the passing of a cold front, slopes facing northwest will receive higher amounts of precipitation compared to those facing southeast. This may result in a higher risk of mass movement on northwest-facing slopes. Similarly, strong northwesterly winds during snow storms may deposit larger amounts on lee slopes, increasing the risk of avalanche there. Other relationships between weather and hazard risk clearly exist, *e.g.*, flooding and storm surge, but are not currently components of this study.

REFERENCES

Batterson, M.J.
1999: Surficial geology of the St. John’s map sheet. Geological Survey, Newfoundland Department of Mines and Energy, Open File 1N/10/0661, scale 1:50 000.

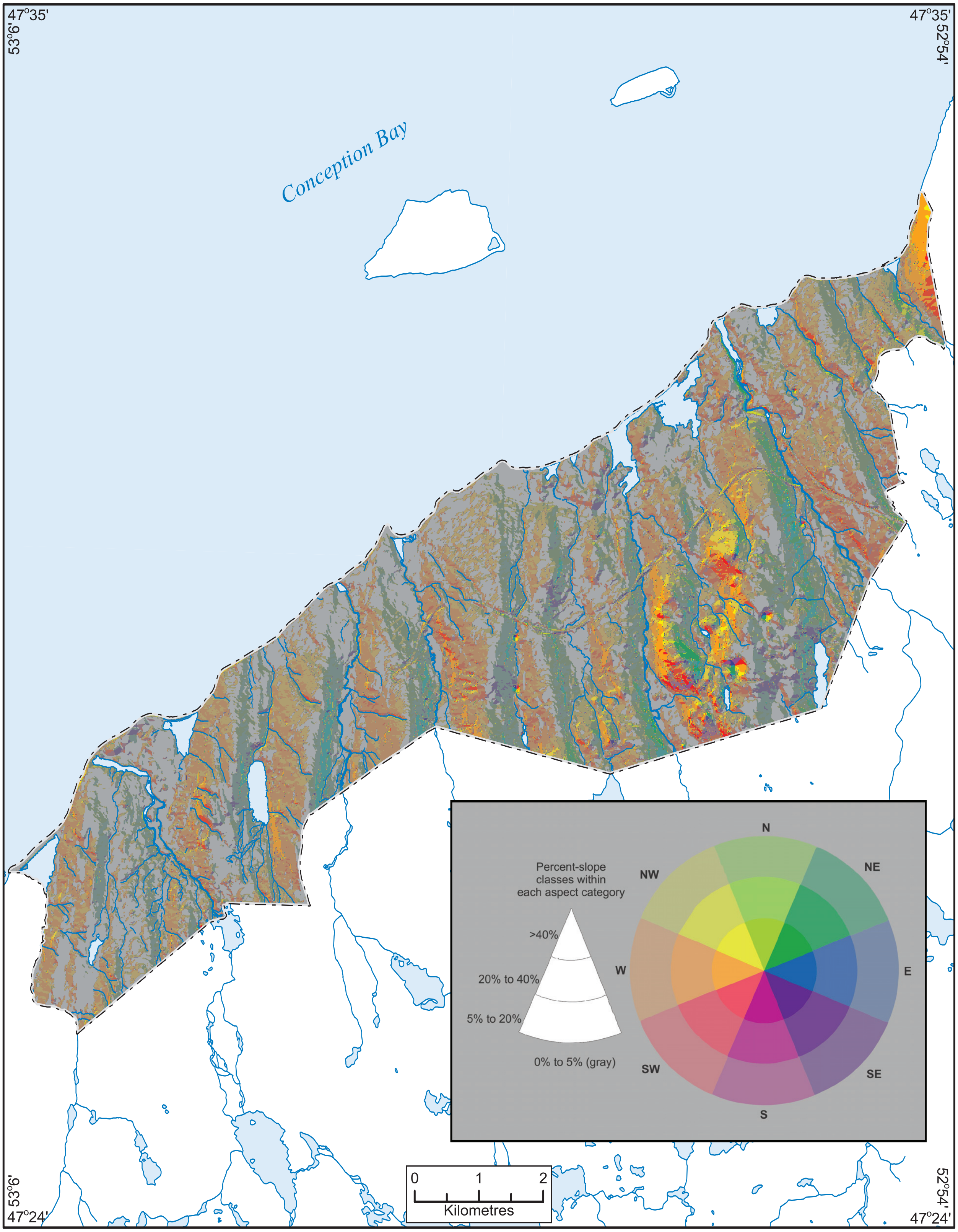


Figure 14. *Slope aspect map for CBS. This map indicates the direction in which the slope faces, and is an important factor in modeling the effects of storm events.*

Batterson, M.J. and Liverman, D.G.

2006: Geological disasters in Newfoundland and Labrador. Geological Survey, Newfoundland Department of Natural Resources, Open File NFLD/2929, 85 pages.

2010: Past and future sea-level change in Newfoundland and Labrador: Guidelines for policy and planning. *In* Current Research. Newfoundland Department of Natural Resources, Geological Survey, Report 2010-1, pages 129-141.

Catto, N.R., Griffiths, H., Jones, S. and Porter, H.

2000: Late Holocene sea-level changes, eastern Newfoundland. *In* Current Research. Newfoundland Department of Mines and Energy, Geological Survey, Report 2000-1, pages 49-60.

Catto, N.C. and Taylor, D.M.

1998a: Surficial geology of the Holyrood map sheet. Geological Survey, Newfoundland Department of Mines and Energy, Open File 1N/6/0638, scale 1:50 000.

1998b: Surficial geology of the Bay Bulls map sheet. Geological Survey, Newfoundland Department of Mines and Energy, Open File 1N/7/0639, scale 1:50 000.

Intergovernmental Panel on Climate Change (IPCC)

2007: Climate Change 2007. Fourth assessment report on the IPCC 3 volume series. Cambridge University Press.

King, A.F.

1988: Geology of the Avalon Peninsula, Newfoundland (parts of 1K, 1L, 1M, 1N and 2C). Newfoundland Department of Mines and Energy, Map 88-01.

APPENDIX

i. Map Projections

Data in this report uses the NAD_1927_UTM_Zone22N projection. Municipalities using a different projection can use the Transformations tool in ArcGIS. Alternatively, the Geological Survey would be pleased to provide the data in a format compatible with your computer system.

ii. ArcGIS Explorer

ArcGIS Explorer Desktop (AGX) is a free, downloadable GIS viewer that provides users with an easy way to view GIS data. All data used in the creation of the hazards vulnerability map have been saved as an ArcGIS Explorer project and is available on the accompanying CD. AGX can be downloaded from http://www.esri.com/software/arcgis/explorer/

1. TOPOGRAPHY (DEFINING MEAN SEA LEVEL)

To quantify spatial and temporal variations in sea level, water levels are normalized into a standard vertical reference level. In this way, areas of interest (*e.g.*, global sea-level change or coastal subsidence) can be measured. Variability over time is dealt with by averaging local water levels over a period of years, smoothing variations into local tidal base levels (tidal datums). Variability across an area is dealt with using a single initial base elevation and referencing that level throughout a national network (geodetic datum).

Tidal datums establish local tidal phase averages as reference levels from which to determine height or depth observations. These datums are averages of observations by the Canadian Hydrographic Service made over a 19-year National Tidal Datum Epoch, a time period that

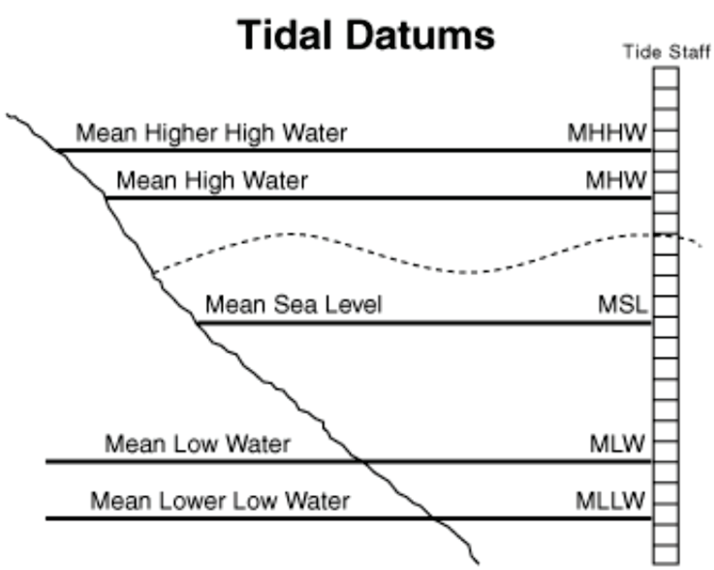


Image courtesy of NOAA/NOS CO-OPS

includes all variations in the path of the moon about the sun. In eastern Canada, mean sea level is based on observations at Father Point, Rimouski, Québec. Mean sea level for other parts of the world are based on observations from similar sites in their area. Tidal datums are used to determine many jurisdictional and property boundaries and in nautical charts and navigation. Commonly used tidal datums include Mean Higher High Water (MHHW), Mean High Water (MHW), Mean Sea Level (MSL), and Mean Lower Low Water (MLLW).

Geodetic datums (or Orthometric datums) are vertical datums that reference mean sea level from a select set of initial locations. This initial reference level is then established across a national network using differential levelling procedures and the placement of reference benchmarks. Many terrestrial elevation datasets (*e.g.*, topography) are referenced to these datums. The most commonly used geodetic datum is the North American Vertical Datum of 1988 (NAVD88), which replaces the previously used National Geodetic Vertical Datum of 1929 (NGVD29).

Local tidal datums are commonly different (several centimetres to decimetres) from those determined from the Québec site, and thus for many coastal water-level applications a conversion is required between the local tidal datum and the geodetic datum. This conversion requires that a geodetic elevation be established for every water level station/benchmark and local vertical offsets to each tidal datum calculated. This is accomplished using Global Positioning Systems (GPS) to occupy tidal benchmarks. Although GPS observations do not directly provide geodetic elevation, they can be used in calculations to find the vertical offsets to common geodetic datums.

2. CREATING A DIGITAL ELEVATION MODEL (DEM) FROM 2-M CONTOUR LINES

Contours are the most common method for storage and presentation of elevation information. Unfortunately, this method is also the most difficult to properly utilize with general interpolation techniques. The disadvantage lies in the undersampling of information between contours, especially in areas of low relief. An interpolation method known as 'Topo to Raster' was used to resolve this issue. At the beginning of the interpolation process, 'Topo to Raster' uses information inherent to the contours to build a generalized drainage model. By identifying areas of local maximum curvature in each contour, the areas of steepest slope are identified, and a network of streams and ridges is created. This information is used to ensure proper hydrogeomorphic properties of the output DEM and can also be used to verify accuracy of the output DEM. Details of this method can be found at: http://webhelp.esri.com/arcgisdesktop/9.3/index.cfm?TopicName=Using the Topo to Raster tool.

Care should be taken in the selection of a DEM interpolation method. Earlier versions of the DEM using a minimum curvature surface adequately resolved steeper parts of the study area, but had difficulty with interpolating between contours in low relief areas, resulting in 'tiger-stripping'. This effect incorrectly designated steep slopes at contour boundaries and flat surfaces between contour lines, leading to misclassification of areas. This was resolved by using the 'Topo to Raster' method.

3. CREATING A SLOPE MODEL FROM THE DEM

Slope identifies the steepest downhill slope for a location on a surface and is calculated for each cell in the raster. The 'Slope' command in ArcGIS takes an input surface raster and calculates an output raster containing the slope at each cell. Details of this method can be found at: http://webhelp.esri.com/arcgisdesktop/9.3/index.cfm?id=1286&pid=1277&topicname=Slope_%283D_Analyst%29.

6. GEOLOGICAL DISASTERS

The historical hazards database consists of a date of occurrence, a location given as UTM or latitude/longitude coordinates, number of injuries and fatalities, and source (usually local media). All data were compiled in a spreadsheet, added to ArcGIS as an X/Y point layer and exported as a point feature class.

9. CREATING A MULTI-HAZARD MAP

Following the assignment of a score to each variable, the layers were converted to 5-m grid formats, using the ArcGIS Spatial Analyst extension. The result is a series of grids that contain pixel scores for each factor. These pixel scores are added together, using the ArcGIS Raster Calculator command, and a multi-hazard map was produced. Details of this method can be found at:
http://webhelp.esri.com/arcgisdesktop/9.3/index.cfm?id=6003&pid=5977&topicname=The_Raster_Calculator.