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# MAPPING AND ASSESSING RISK OF GEOLOGICAL HAZARD ON THE NORTHEAST AVALON PENINSULA AND HUMBER VALLEY, NEWFOUNDLAND

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## ABSTRACT

*A pilot project was initiated in the Humber Valley, and on the northeast Avalon Peninsula to identify and map areas at risk from geological hazards, including landslides, avalanches, rockfalls, and coastal and river flooding. The first phase of the project was to identify criteria for risk assessment, using air-photos, historical research and site visits. A slope model generated from digital elevation data was useful in identifying areas of steep slope. Preliminary mapping will be supplemented by field verification, and the production of hazard maps.*

## INTRODUCTION

Newfoundland and Labrador have a long history of geological disasters. Most are the result of gravitational forces on surface materials (e.g., landslides, rockfalls, avalanches) or flooding along the coast and in river valleys. Many of these events have directly impacted communities, either by affecting infrastructure or causing loss of life. The recording of these events (Batterson *et al.*, 1995, 1999; Liverman *et al*., 2001, 2003) is a continuing process.

To date, over 290 incidences of geologically related impacts have been recorded from 150 communities in the Province over a 223-year recorded period. These, sometimes disastrous, events are a result of our geographic location (an Island in the Atlantic Ocean on the track of major storms, the development of communities beneath steep hills (to be close to areas of employment), and more recently, the desire to develop in aesthetically pleasing areas on cliffs overlooking the ocean. Given the history of geological hazards and disasters in the Province, it is logical to conclude that they will remain an issue for many communities. Some hazards or disaster sites have been identified within municipal boundaries, including sites remote from current development. It is clearly important not only to identify areas of existing development at risk from geological hazard, so that further development can be restricted or the hazard risk mitigated, but also to recognize areas of potential future development to avoid costly remediation or compensation. To assist in this process the Geological Survey, in co-operation with the Provincial Department of Municipal Affairs, has embarked on a mapping project that will identify and describe areas of geological hazard risk for use in municipal planning.

## IDENTIFYING RISK

This project is concerned with identifying risk from geological hazards. Simply put, risk is the chance that something bad may happen to something we value. There is a certain amount of risk in normal human activities – crossing the street, driving to work, climbing a ladder and so forth. We may mitigate that risk by taking preventative measures – checking for traffic, driving defensively, securing the ladder – all of which will reduce the risk to a personally 'acceptable' level. Risk is thus, to some degree at least, a matter of perception. Risk is therefore also dynamic and subject to constant change.

The concept of risk takes on a different meaning when a natural hazard is involved. A 'hazard' refers both to the process and to the potential for harm posed by that process. Natural hazards are those natural events that may result in a threat to human life or infrastructure. A geological hazard includes impacts from a group of processes (e.g., landslides, rockfalls, earthquakes, avalanches) that affect the Earth's surface.

Dibble *et al.* (1985) formalizes risk from geological hazard as:

Risk = Hazard x Value x Vulnerability

where Hazard is an event of known probability, Value is the economic assessment of loss, and Vulnerability reflects susceptibility for harm, which may vary for different things affected by the same hazard.

The role of government in the assessment of risk is to implement policy that will prevent the placing of structures in hazardous areas, and/or to mitigate hazards in existing areas at risk, and to reduce or eliminate future property damage or personal injury. It is recognized that there is an element of risk in all developments, but the ideal is to achieve a level of 'acceptable risk', which may be defined as the level of hazard below which no specific action by government is deemed necessary, other than making any potential risk known. Policy can only be made based on sound criteria and mapping of hazard risk. It is the latter that is the focus of this paper.

Beyond the definition of areas of risk is the communication of this information and the relative responsibilities of individuals and the various levels of government. It is perhaps reasonable to suggest that an individual does not warrant special protection for their own personal foolishness or ignorance. However, personal safety issues commonly translate into public safety issues, where natural hazards are concerned. For instance, it may appear to be appropriate to allow a person to build a home on a known flood plain, assuming that the person is only threatening themself. In reality, however, such a person may quickly sell the house to some unsuspecting person who inherits the risk, and if more than one dwelling is affected by a flood, it is possible that various levels of government intervention (disaster relief and so forth) may be required. Individuals need to be made aware of risk so that informed decisions can be made.

## NATURAL HAZARDS

Natural hazards common to this Province include slope movements (landslide, rockfall, avalanche), earthquakes, flooding (coastal and river), and coastal erosion. Other natural processes, such as volcanic activity and sinkholes are not discussed. Earthquake-related incidents, such as tsunami, have occurred in the Province but not within the study areas, and they are, therefore, also not covered here. Similarly, meterological events (tornados, hurricanes etc.) are not discussed, except where they may have triggered slope movement.

### SLOPE MOVEMENTS

Slope movements involve the downslope movement of material (unconsolidated sediment, bedrock and snow) in response to gravity (Figure 1). Slope movements are a group of processes, divided on the basis of their velocity, and the material being moved. The slope angle and sediment characteristics are important factors that influence slope stability. In Newfoundland and Labrador, landslides are commonly triggered by heavy rain or snowmelt, which introduce large quantities of water to the slope. Sediment becomes saturated beyond its shear strength, at which point, slope failure occurs. This movement may be rapid (e.g., debris flows) or slow (e.g., creep). Landslides commonly have a serious effect on communities and infrastructure (Figure 2). Other types of slope movement include rotational slumps and gully erosion.

Avalanches are another form of rapid slope movement and consist of a combination of snow and ice (Figure 3), but also may include sediment, rock, and vegetation; they require heavy snowfall, either introduced by precipitation or wind, and a steep slope. The trigger for avalanche is commonly heavy snowfall over a smooth surface, produced from either a rapid fall in temperature in the days preceding the snowfall or from a period of freezing rain or burial of a weak layer in the snow. Alternatively, high winds blowing over a slope may create a cornice which may break off, falling to the slope below and triggering an avalanche (Figure 4).

Rockfalls are the downslope movement of boulders, either by free fall or rolling (Figure 1) and dislodgement by freeze-thaw action, erosion beneath the boulder, or through human activity. Rockfall may also impact a slope below by triggering a landslide. Rockfalls tend to occur repeatedly, forming a talus cone of boulders at the foot of a steep slope.

### COASTAL EROSION

Large areas of the Newfoundland and Labrador coastline are composed of cliffs of unconsolidated sediment. These areas are stable if covered by vegetation, but may erode quickly where exposed to wave action. Rates of coastal recession up to 1m per year have been recorded in the Province (Liverman *et al*., 1994; Forbes *et al.*, 1995). Bedrock cliffs also erode, albeit at a slower rate. The frequency of wave impacts (and thus erosion) may be expected to increase if predictions of global warming and associated global sea-level rise occur. In Newfoundland and Labrador, the crustal response to glaciation and deglaciation means that over most of the Island of Newfoundland, relative sea level is currently rising. The increased risk of coastal erosion may be accentuated by increasing pressures on the coast for residential development.

### FLOODING

Flood risk maps for several areas of the Province have been released by Environment Canada and the Newfoundland Department of Environment and Conservation, includ-

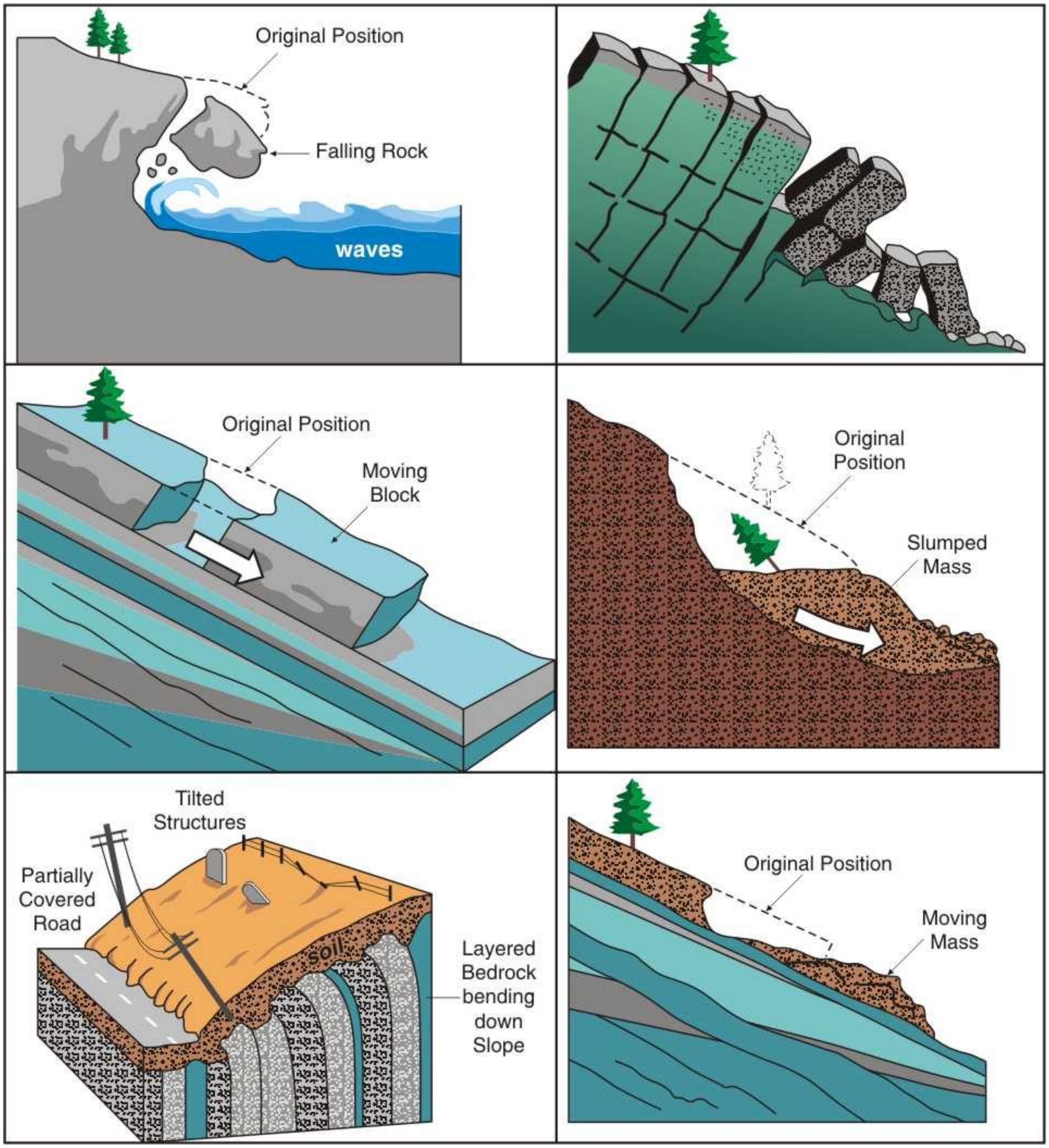


**Figure 1.** *Types of slope movement. (Source: Government of British Columbia)*

ing Steady Brook and the Waterford River valley, St. John's. Data from these maps will be incorporated into the hazard mapping project.

## DEFINING RISK

Although the concept of risk may be described, quantifying it is considerably more difficult. In this study, areas are classified into those with a high risk compared to areas with low risk. Factors that are considered in this process include slope angles and heights; history of events; location relative to steep slopes, flood plains, cliff edges and coastline; and observed risk factors (e.g., tension cracks, river bank erosion, marine clay).

Two different approaches were taken in this study, in an effort to develop mapping methods appropriate to Newfoundland and Labrador. In both, mapping of hazard zones

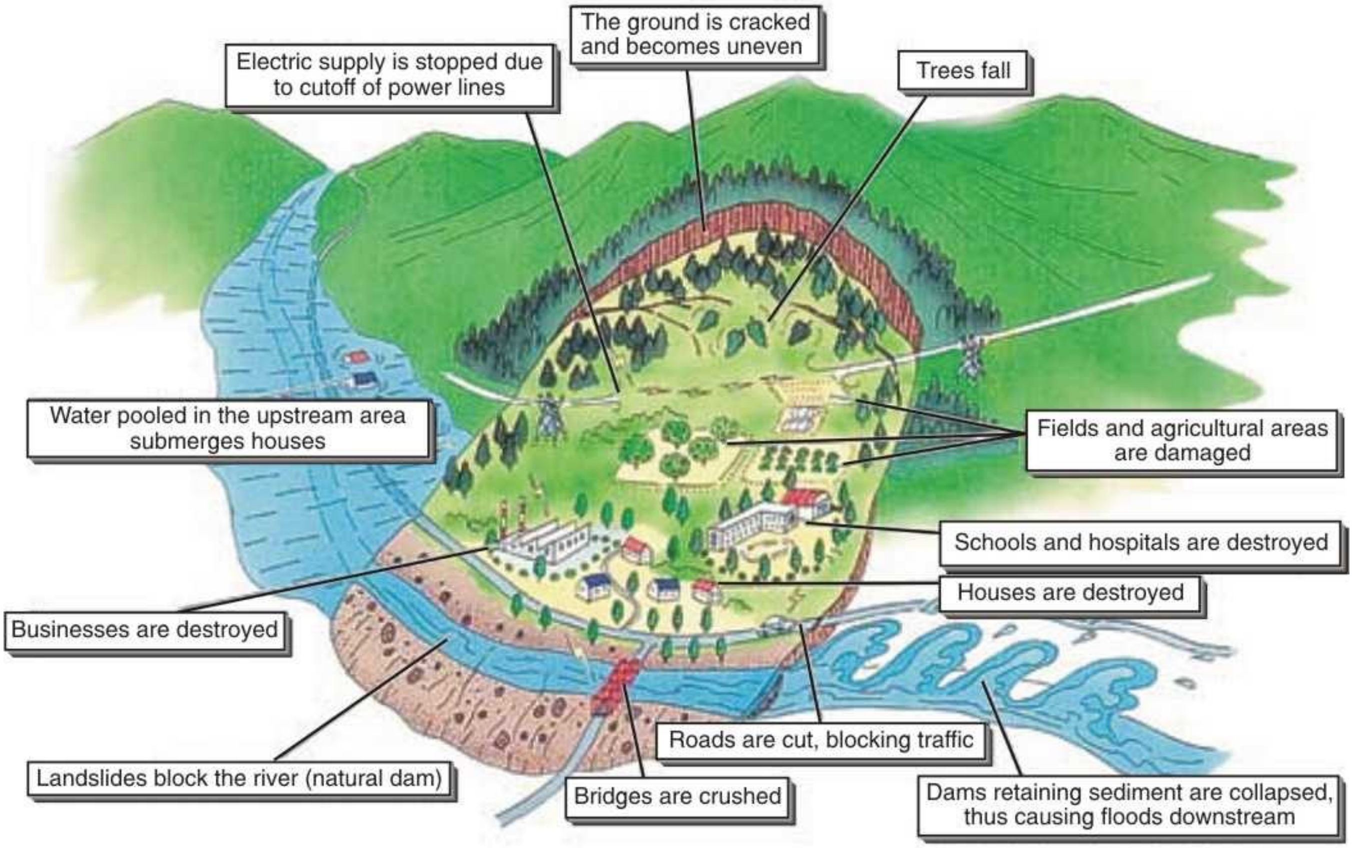


**Figure 2.** *Potential effects of landslide on community and infrastructure (Source: Government of British Columbia).*

is a multi-stage process that will culminate in the production of community-level hazard risk maps. For the northeast Avalon area, the initial phase of investigation involved the identification of steep slopes using slope models generated from a 1:50 000-scale digital elevation model (DEM) and the shuttle radar topography mission (SRTM) data for the area. The DEM has a resolution of 25 m, compared to 90 m for the SRTM, although both methods smooth data close to steep coastlines suggesting lower slope angles than occur in reality (e.g., Figure 5). The slope model classified slopes as low (0°-20°), moderate (20°-30°), steep (30°-40°), very steep (40°-50°) and extreme (> 50°).

For the northeast Avalon project, the slope models were draped over a 1:50 000-scale digital topographic map in ArcMap on a laptop computer (Figure 5). The computer was equipped with an integrated ‘bluetooth’ global positioning system (GPS) that allowed accurate location data to be portrayed in the field. Areas of steep slope were visited, where accessible, and at each site a brief data sheet completed that described municipality, slope, vegetation, boulder content, development status, bedrock geology, surficial geology, history of events, recent activity and risk potential. At each site a digital photograph was taken to be linked into the digital database (Figure 6). The ArcMap data also included a surficial geology layer, which was used to identify areas of unconsolidated sediment close to the coast. These areas were also investigated, as were areas of known incidents (landslide, avalanche, flood).

In the Humber Valley, air photos from 1934, 1978 and 2001 were examined and evidence of debris flows, snow avalanches, riverbank slumps, rockfalls and other hazards were marked on a base map. A map of slopes, divided into a five-fold system: plain (0°-3°), gentle (4°-15°), moderate (16°-26°), moderately steep (27°-35°) and steep (>35°) (Table 1), was generated at 1:50 000 scale using the GIS program ArcMap and digital topographic maps. The slope map forms the basis from which the hazard map will be created, and reflects the contrast between extensive areas of floodplain and steep valley sidewalls. Community maps, supplied by the Department of Municipal Affairs, were used as base maps for detailed field mapping within the towns. Field work consisted of visiting known hazardous sites as well as hazard sites identified from the air-photo study and steep areas identified on the slope map. The towns of Deer Lake, Pasadena, Steady Brook and Corner Brook were surveyed in more detail. Field sites were accessed by road and on foot, and a brief survey was done by helicopter in otherwise inaccessible areas. Past and present slope movements

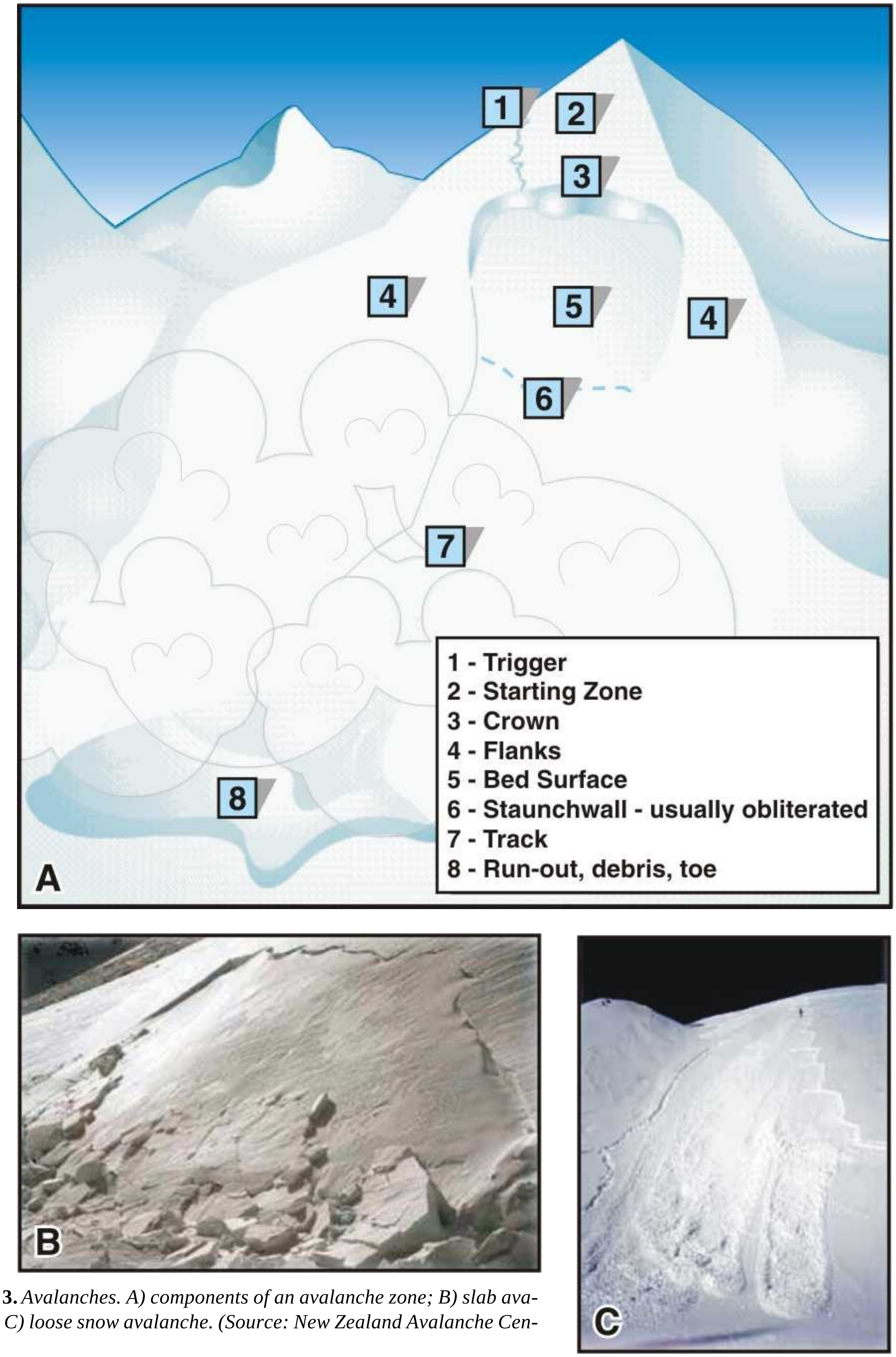


**Figure 3.** *Avalanches. A) components of an avalanche zone; B) slab avalanche; C) loose snow avalanche. (Source: New Zealand Avalanche Centre)*


**Figure 4.** *Development of a cornice.*

were recorded photographically and extra slope measurements were done with an Abney level. Evidence of slope instability, such as tension cracks or debris-flow deposits, was identified and recorded during site visits. In some cases, inquiries were made to local residents about slope problems near their homes.

Statistical techniques, through the process of frequency analysis, are used to estimate the probability of the occurrence of a given event. The same methods are applicable to avalanche prediction as well as stream flooding, although there is inadequate data on which to base avalanche predictions in Newfoundland and Labrador. The recurrence interval is based on the probability that an event will be equalled or exceeded in any given year. For example, assume there is a 1 in 50 chance that 150 mm of rain will fall in a certain area in a 24-hour period during any given year. Thus, a rainfall total of 150 mm in a consecutive 24-hour period is said to have a 50-year recurrence interval. Similarly, using a frequency analysis there is a 1 in 100 chance that a streamflow of 450 cubic metres per second ($m^3/s$) will occur during any year at a certain streamflow-measurement site. Thus, a peak flow of 450 $m^3/s$ at the site is said to have a 100-year recurrence interval. Rainfall recurrence intervals are based on both the magnitude and the duration of a rainfall event, whereas streamflow recurrence intervals are based solely on the magnitude of the annual peak flow.

The term “100-year flood” is used in an attempt to simplify the definition of a flood that statistically has a 1-percent chance of occurring in any given year. Similarly, the term “100-year storm” is used to define a rainfall event that statistically has the same chance of occurring. Of course, the “100-year flood” could occur 2 years in a row, and a ‘100-year storm’ event does not necessarily translate into a ‘100-year flood’. The relationship between rainfall and streamflow is complex and depends on factors such as the extent of rainfall in the watershed (how much rainfall it gets), the degree of soil saturation before the storm (dry versus already saturated) and the relationship between the size of the watershed and the duration of the storm (where the rain falls). Because the 100-year flood level is statistically computed using existing data, as more data becomes available, the level of the 100-year flood can change, and if a river basin is altered in a way that affects the flow of water in the river, frequency of flooding is re-evaluated. Dams, forestry, and urban development are examples of some man-made changes in a basin that affect floods.

Town councils in both pilot project areas were approached to discuss the plans for hazard mapping and to inform them of our activities, and municipal plans were acquired where available. The data obtained this year will be integrated with existing work, and will form the basis of the next phase, the construction of hazard polygons. Hazard potential maps are planned to be available by 2007.

## PROJECT AREAS

The Humber Valley and the northeast Avalon Peninsula were the two areas of the Province selected for study. Their selection was largely based on their history of geological disasters and the current development that is occurring in both areas.

### HUMBER VALLEY

The Humber Valley is located in western Newfoundland, east of Corner Brook, and includes Deer Lake and the lower Humber River (Figure 7). The area contains the communities of Corner Brook, Steady Brook, Little Rapids, Pasadena, Pynn’s Brook, Deer Lake, Nicholsville and Reidville, and has a combined population of about 32 000. The valley has variable topography, ranging from very steep slopes in the southwest to gentle slopes in the northeast, and as a result, slope hazard varies in type, size and intensity. Development is ongoing in various parts of the valley,

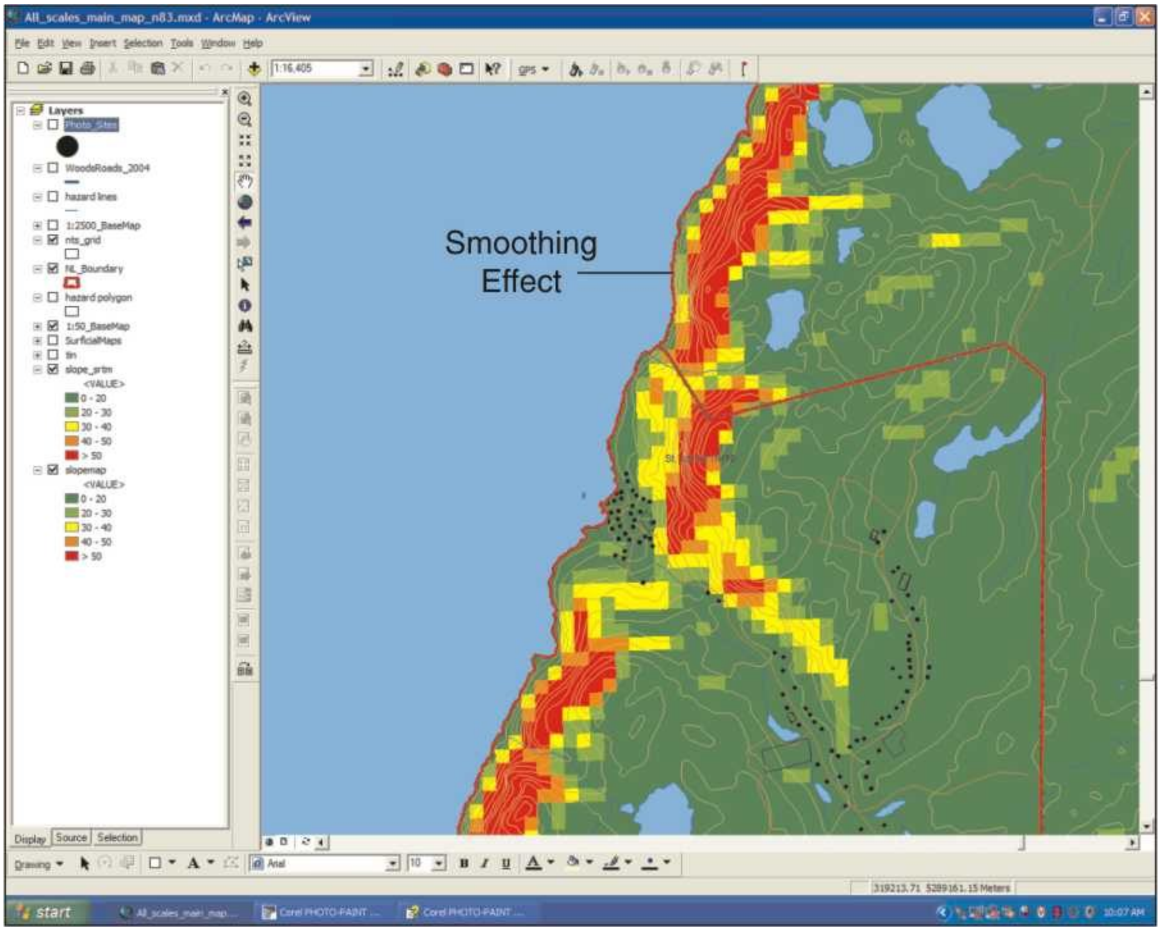


**Figure 5.** *Slope map generated from the SRTM data for the Bauline area.*

including potentially hazardous zones, and a major resort area is currently being constructed on the western shore of Deer Lake. These areas may be subject to both slope and flood hazards. Flood hazard maps are available for the town of Deer Lake and Steady Brook.

The valley is oriented northeast–southwest and the flanking highlands are part of the Long Range Mountains. Elevations range from sea level at Corner Brook to a high of 520 m asl and the valley varies in width. It is about 2.5 km wide in its central regions and at the northeastern end, where the Upper Humber River enters the lake, it is 5 km wide and much flatter. At the southwestern end, the valley narrows considerably, to 100-500 m in width, and becomes very steep sided at the Humber River gorge. The angle of the slopes in the valley vary considerably along its length, with the town of Deer Lake experiencing much different slope stability hazards than places such as Steady Brook. The Humber River gorge, situated at the mouth of the Humber River, has been the site of several slope failures. The narrow gorge is the main transportation corridor connecting the Humber Valley to Corner Brook and areas west. In 1930, a freight train was partially derailed by a landslide near Shellbird Island at the western end of the gorge, and in 1985 a landslide blocked the road at about the same location. Snow avalanches affecting the railway occurred in 1917, when a rail worker was killed, and in 1952 and 1953. Farther east, a landslide (likely a debris flow) blocked the railway at Pynn's Brook in 1935, and an avalanche near Little Rapids derailed a train in 1922 (Batterson *et al.*, 1999).

Corner Brook's steep hills have been subject to slope instabilities also (Batterson *et al.*, 1999; Liverman *et al.*, 2005). Snow avalanches in 1935 and 1986 at Curling Road and Monument Hill, respectively, caused a total of 4 deaths, as well as property damage. At Crow Hill (also known as Crow Gulch and Quarry Hill), avalanches, landslides and rockfalls in 1927, 1930, 1935, 1938, 1943 and 2004 have caused road, railway and property damage, and have blocked the railway and road for short periods of time. Debris slides at Brakes Cove in 1958, 1962 and 1967 caused property and railway damage, and farther east, the Riverside Drive area is prone to similar slides. In 1940, there was a death at this location because of a landslide, while in 1977,

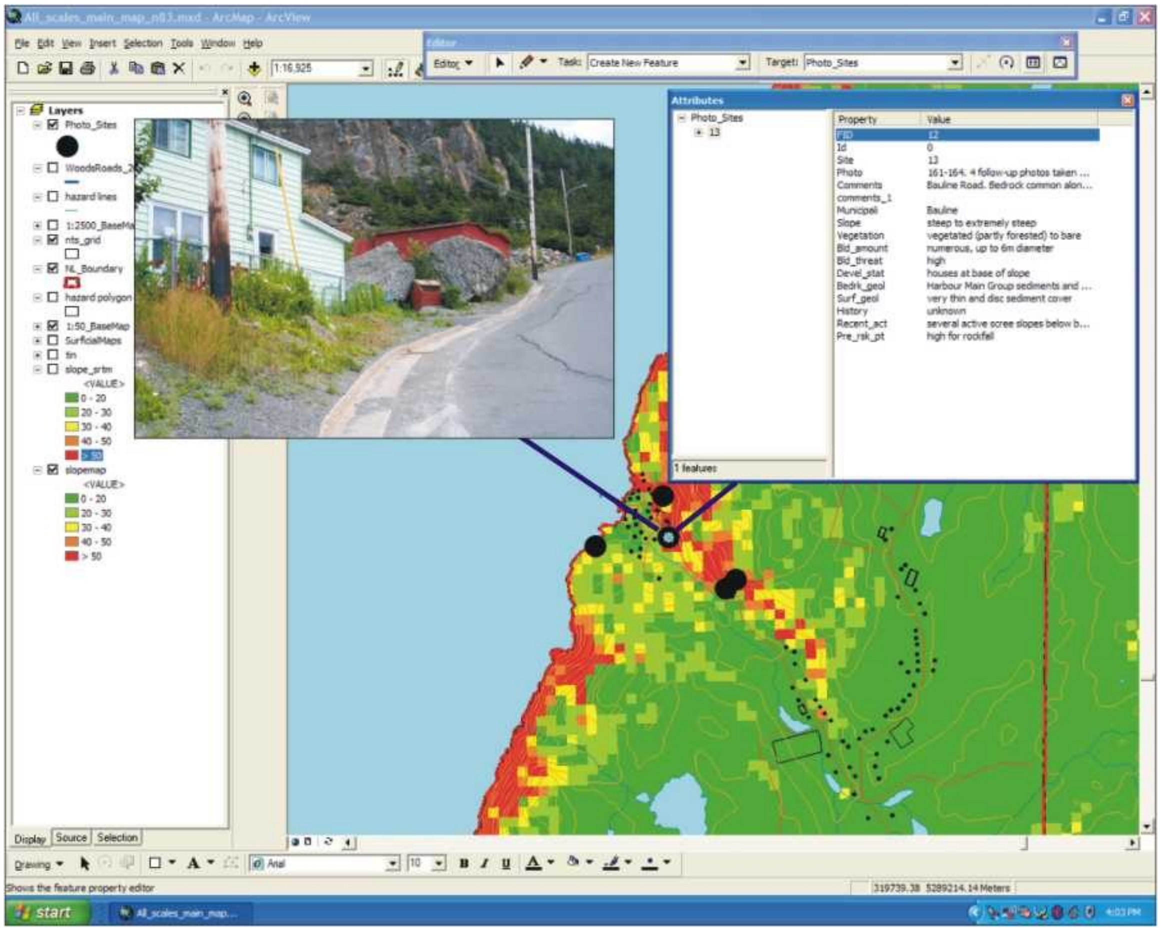


**Figure 6.** *Digital topography map showing slopes, digital photo and hazard form for the Bauline area.*

**Table 1.** Preliminary unit designations for use in hazard mapping project

| Unit | Description |
|---|---|
| p | Plain *(0°-3° or 0-5%)* |
| g | Gentle slope *(4°-15° or 6-26%)* |
| m | Moderate slope *(16°-26° or 27-49%)* |
| n | Moderately steep slope *(27°-35° or 50-70%)* |
| s | Steep slope *(>35° or >70%)* |
| r | Rockfall *(descent of masses of bedrock by falling, bouncing and rolling)* |
| d | Debris flow/slide *(rapid flow or sliding of saturated debris and sediment)* |
| e | Earthflow *(slow viscous flow of material containing a high proportion of silt and clay)* |
| i | Slump in surficial sediment *(sliding of cohesive masses of surficial material along a concave or planar slip plane)* |
| a | Avalanche track *(broad avalanche track occupied by no or shrubby deciduous vegetation)* |
| c | Soil creep *(slow downslope movement of soil)* |
| t | Tension cracks *(cracks in bedrock or soil parallel to scarp face)* |
| f | Coastal cliff erosion *(wearing away of coastal cliffs by wave action)* |
| v | River bank erosion *(wearing away of river banks by fluvial action)* |
| y | Gully erosion *(slow erosion of fine-grained sediment by precipitation)* |
| b | Bedrock dip out of slope *(dip of bedding planes in bedrock toward road or other structure)* |
| w | High groundwater content *(saturated sediment)* |
| z | Man-made slide/slump *(mass movement caused by construction or other activity)* |
| x | Marine clay *(marine clay with higher than average potential for failure)* |
| u | Undifferentiated floodplain *(floodplain)* |

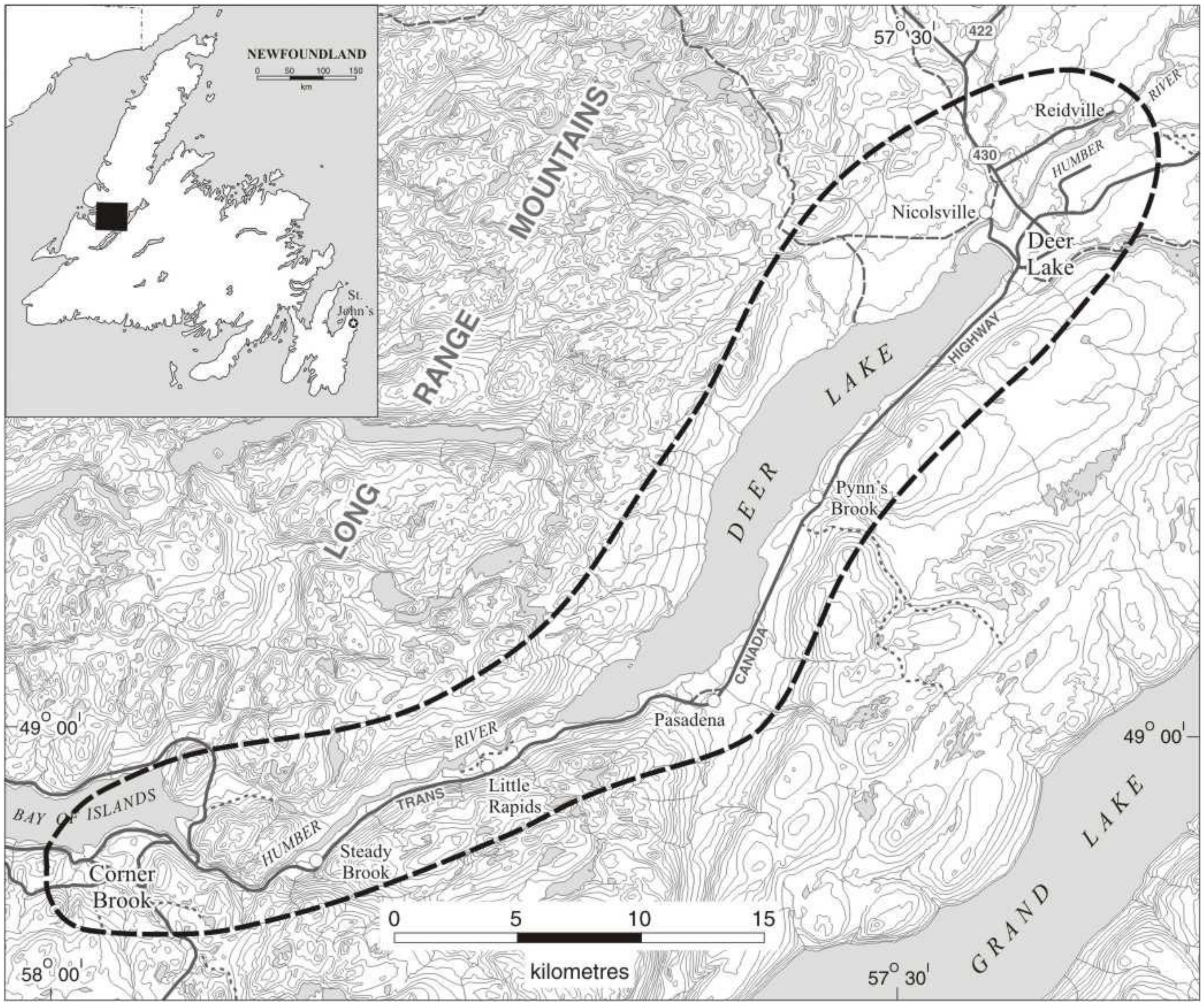


**Figure 7.** *Map showing area covered by Humber Valley hazard mapping project.*

1994, and 2004 property and road damage were caused by debris slides. Power and water lines were also damaged in 2004 (Liverman *et al.*, 2005).

## NORTHEAST AVALON PENINSULA

This area contains the major urban centres of St. John's, Mount Pearl, and Conception Bay South, as well as the smaller municipalities of Holyrood, Portugal Cove–St. Phillips, Bauline, Wabana, Pouch Cove, Torbay, Logy Bay–Middle Cove–Outer Cove, Petty Harbour–Maddox Cove, Bay Bulls and Witless Bay, and has a combined population of about 185 000 (Figure 8). The area has over 190 km of mostly bedrock-dominated coastline, although several areas contain unconsolidated cliffs, which are subject to coastal erosion (Liverman *et al.*, 1994). Inland areas have variable relief. Rugged, bedrock-dominated terrain is found north of a line running between Portugal Cove and Torbay, and along the east coast south of Outer Cove, east of Mount Pearl, and east of the road from Goulds toward Witless Bay. Inland of these areas the terrain is more subdued, although steep slopes exist within most municipalities. Some floodplains are found within the larger river valleys (e.g., Waterford River, Island Pond Brook), that are also the sites of recent flooding in residential areas. Flood risk maps are available from the Newfoundland Department of Environmental Conservation for Outer Cove, Petty Harbour, Portugal Cove–St. Philips, and Waterford River.

The northeast Avalon Peninsula has a long history of geological disasters. Southside Road in St. John's has been the site of several landslides including 2 fatal incidents, in 1936 and 1948 (Batterson *et al.*, 1999). Although much of the drainage issues from the overlying Southside Hills has

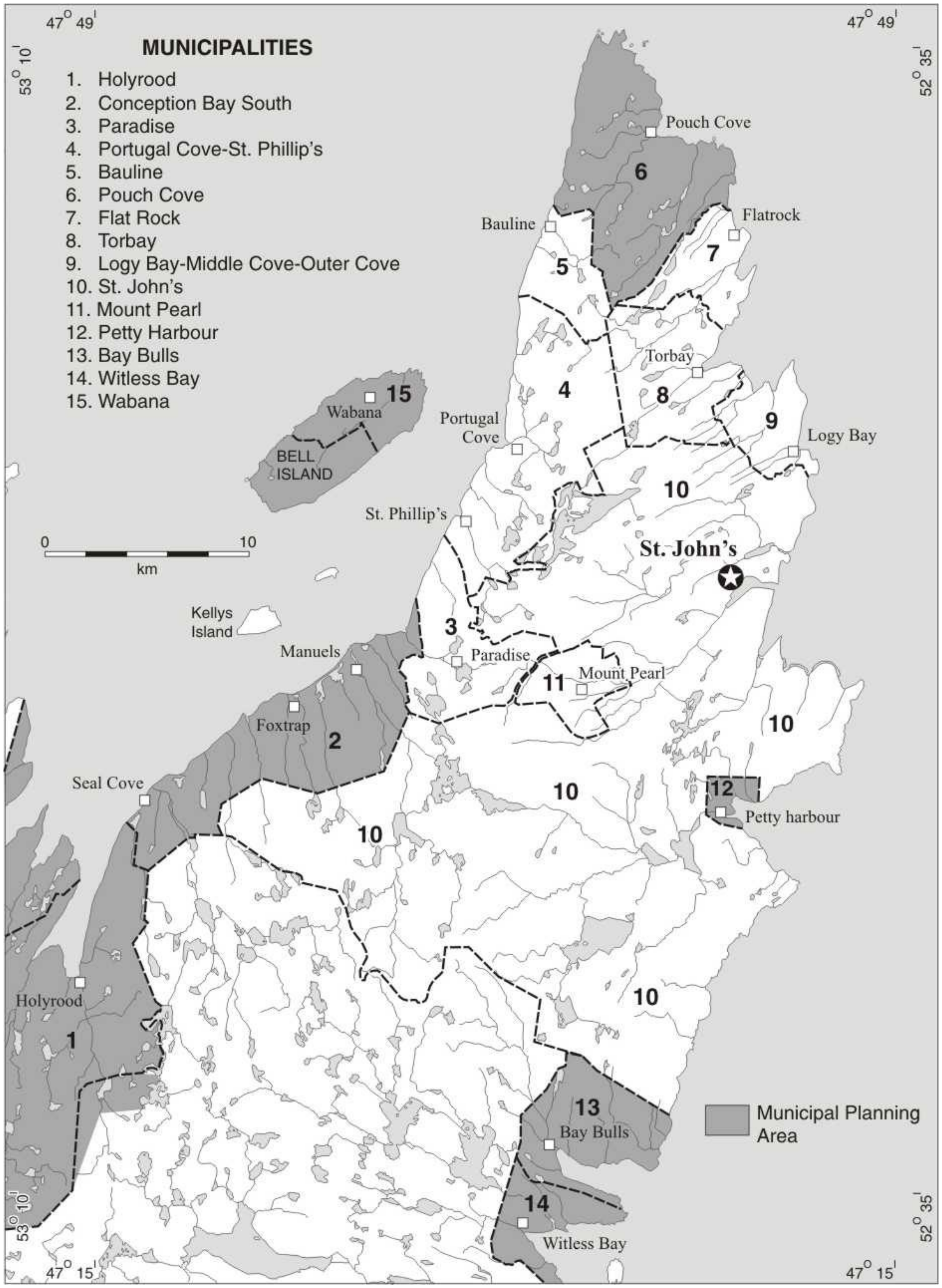


**Figure 8.** *Map showing municipalities in the northeast Avalon Peninsula area.*

**Table 2.** Preliminary assessment of incidence of geological disasters by community on the northeast Avalon Peninsula and Humber Valley

| Community | Slope movt.– fast (landslides, debris flows) | Slope movt. – slow (creep) | Rockfall | Avalanche | Coastal erosion | Flooding | River bank erosion |
|---|---|---|---|---|---|---|---|
| Bauline | | | ✓ | | | | |
| Bay Bulls | ✓ | | ✓ | | | | |
| Conception Bay South | ✓ | | | | ✓ | | |
| Corner Brook | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Deer Lake | ✓ | ✓ | | | | ✓ | ✓ |
| Holyrood | | | ✓ | | | | |
| Outer Cove–Middle Cove–Logy Bay | ✓ | | ✓ | | ✓ | | |
| Pasadena | | | ✓ | | | ✓ | ✓ |
| Petty Harbour–Maddox Cove | | | ✓ | ✓ | | | |
| Portugal Cove–St. Philips | ✓ | | ✓ | | ✓ | | |
| Pouch Cove | | | ✓ | | | | |
| Reidville | ✓ | ✓ | | | | ✓ | ✓ |
| St. John's | ✓ | | ✓ | ✓ | | ✓ | |
| Steady Brook | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ |
| Torbay | ✓ | | ✓ | | ✓ | ✓ | |
| Wabana | | ✓ | ✓ | | | | |
| Witless Bay | | | ✓ | | ✓ | ✓ | |

been resolved by construction of the Pitts Memorial Drive, erosion from the slope continues. Landslides also killed 2 residents of Bay Bulls in 1949, and several other events have been reported along Conception Bay, where the rail-line was blocked on several occasions (Batterson *et al*., 1999). The Battery in St. John's has been the site of at least 5 avalanches since 1921, 2 of which resulted in fatalities. An avalanche in 1921 killed a resident of the Queen's Battery, and an avalanche in 1959 claimed 5 lives in the Lower Battery. The construction of engineered fencing above the Battery in 1998 has, hopefully, eliminated the risk of future events at this site. Rockfall is common around the coastline of the northeast Avalon Peninsula, but has directly impacted several communities including St. John's (The Battery), Bauline, Petty Harbour, Pouch Cove and Portugal Cove. At Portugal Cove, a 6-year-old girl was crushed by a boulder in 1935, and a resident of the community was severely injured by a rockfall in 1901. A man was killed by a rock on Kelly's Island in Conception Bay in 1852. Flooding resulted in the death of a child in the Goulds in 1964, bringing to a total of 13 residents of the northeast Avalon Peninsula killed by natural disasters.

## PRELIMINARY FINDINGS

The northeast Avalon Peninsula and the Humber valley both contain hazardous areas. Some areas are currently under development, whereas others may come under pressure for future development. A breakdown of hazards and disasters by community is shown in Table 2. It indicates that most communities in the northeast Avalon Peninsula show evidence of rockfall and coastal erosion. These are functions of the geography of the area and are likely inevitable, although some may be mitigated by careful planning. Towns in the Humber Valley are mainly affected by rockfalls, debris flows, river bank erosion and flooding. These hazards are a function of steep slopes and proximity to major rivers.

The preliminary assessment of communities on the northeast Avalon Peninsula suggests that the greatest risk is from changes in sea level. Relative sea level is rising around most of the Island of Newfoundland, including the northeast Avalon Peninsula (Catto *et al.,* 2000). The rate of sea-level rise may be small (10 mm per 100 years), but indicates an increasing threat on coastlines. Low-lying coastal areas, and areas fronted by unconsolidated cliffs are vulnerable to sea-level rise. Currently, development in coastal areas is restricted by a buffer zone, defined as *'A zone of land that is in its natural state and that is intended to separate developed areas from bodies of water to provide basic protection of water resources. This zone may coincide with a Crown land reservation of a shoreline as prescribed by Section 7(1) of the Lands Act. In the absence of specific setback requirements (depending on the activity) the buffer is taken to be 15*


**Plate 1.** *Coastal hazard in Conception Bay South. A) Houses constructed atop eroding coastal cliff. B) Newly constructed house adjacent to modern beach.*

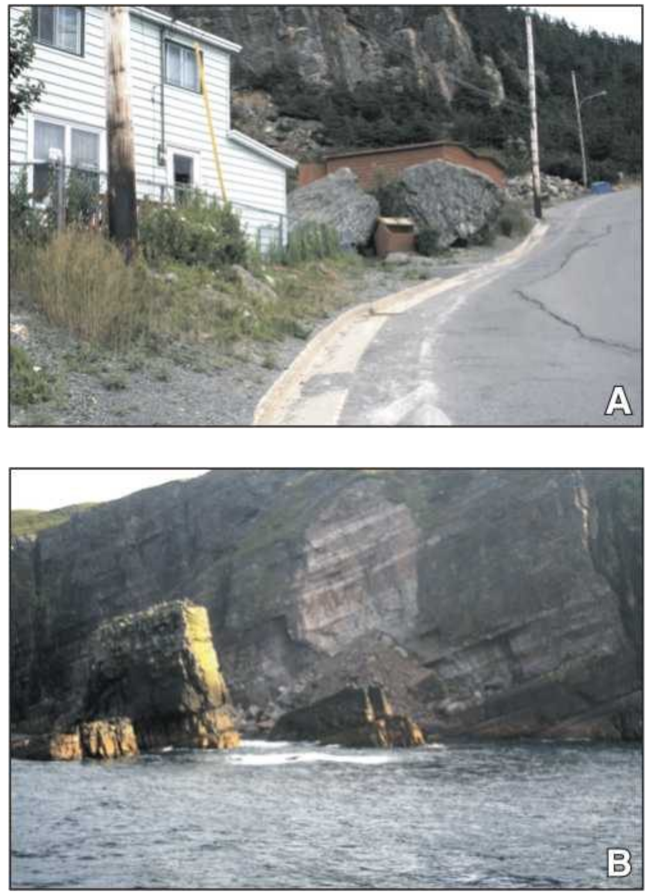


**Plate 2.** *Rockfall in the northeast Avalon area: A. Historic incidence in Bauline incorporated into residential landscaping. B. Recent rockfall along coast near Bay Bulls.*

*metres measured from the high water mark which in turn is understood to be the 1 in 100 year high water mark*' (Department of Environment and Conservation, Policy for Flood Plain Management, 2005). The high water level is defined as '…*the 1:100 year return period water level. For a fresh water body, this level includes water levels caused strictly by storm runoff or hydraulic effects of ice or both. In marine situations, the level must include maximum waves, wind setup, storm surge, and ultimate mean sea levels under current global climatic forecasts for a 1:100 year design*' (Department of Environment and Conservation, 2002). This definition therefore includes modern beach and back beach areas, although development is occurring in these areas. The issue of development close to eroding cliffs, however, remains a challenge to policy makers. No legislative restrictions currently exist for development adjacent to a cliff edge.

Eroding unconsolidated cliffs are common features in the northeast Avalon Peninsula area. The communities of Holyrood, Conception Bay South, Portugal Cove–St. Philips, Torbay, Outer Cove–Middle Cove–Logy Bay and Witless Bay all contain areas of eroding coastline (Plate 1). Erosion rates are uncertain, although cliffs monitored over a 12-year period in Conception Bay South showed erosion of up to 50 cm per year. Coastal cliffs with a complete vegetation cover appear generally stable and show no evidence of recession. Similarly, the retreat of coastal beaches with the consequent threat of increased coastal flooding requires further monitoring. Barachois beaches provided a measure of protection for residential development inland, and therefore must be preserved.

Occurrence of rockfall is common (Plate 2). Steep slopes dominated by sedimentary bedrock that is susceptible to freeze-thaw activity is the likely cause. For single-block rock falls, the concept of a "shadow angle" is well established. The shadow angle is defined by the angle below horizontal formed by the line lying between the apex of the slope subject to rock fall and the extreme position of rock fall debris (boulders) (Evans and Hungr, 1993). Numerous studies have shown this to be between 22° and 30°. Vegetation on a slope may have the effect of reducing risk of rockfall extending to the maximum shadow angle. Construction adjacent to steep slopes should consider rockfall potential.

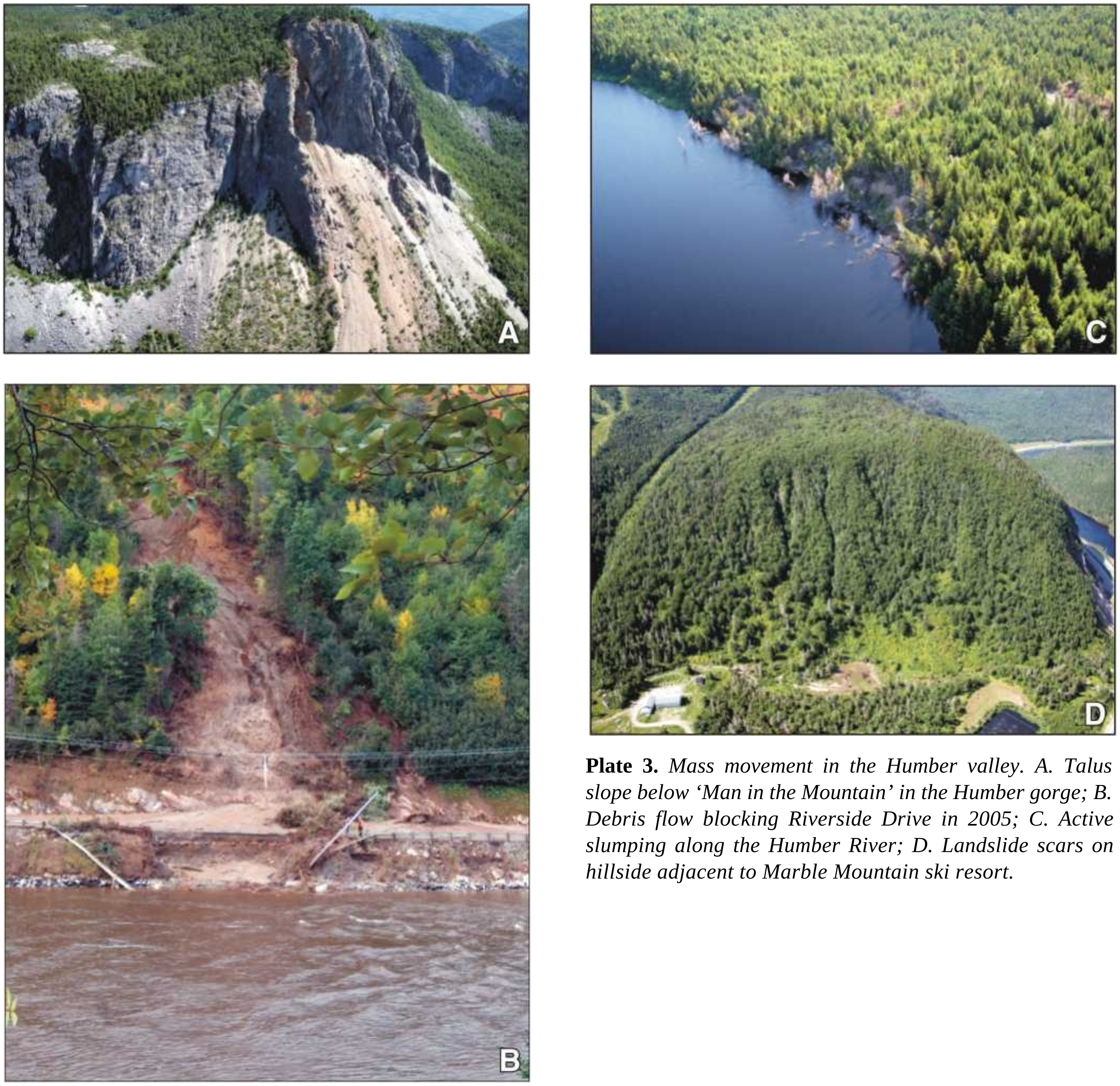

**Plate 3.** *Mass movement in the Humber valley. A. Talus slope below 'Man in the Mountain' in the Humber gorge; B. Debris flow blocking Riverside Drive in 2005; C. Active slumping along the Humber River; D. Landslide scars on hillside adjacent to Marble Mountain ski resort.*

The Humber Valley area experiences numerous slope-stability problems, river bank erosion and flooding (Plate 3). Some of the most obvious, and potentially most dangerous hazards, are rockfalls and avalanches. Both occur on steep slopes and are thus common in the same areas. They are most prevalent in the Humber Gorge–Steady Brook area and Corner Brook (Plate 3). Areas within the shadow angle of rockfall slopes and those within potential run-out zones of avalanches are considered to be at risk. Rockfalls, landslides and avalanches tend to re-occur in places where they have happened previously. A landslide (rotational slump) in sandy sediments occurred in 2005 on Riverside Drive in Corner Brook, at the same site as a landslide in 1994 (Plate 3B).

Riverbank erosion and flooding are common in this region. Floods occur after heavy rain and/or snowmelt periods, affecting the communities on, and near, floodplains. Flooding introduces a second hazard–riverbank erosion. Up to 30 m of horizontally measured land can be lost in a single bank failure event (Plate 3C). Unstable banks, especially along the Humber River, place areas above the banks at risk.

Coastal flooding occurs to some extent in Corner Brook. The Corner Brook coastline is largely modified by industrial infrastructure; much of it is buffered against coastal erosion with earthworks consisting of large boulders. As a result, coastal erosion is only an issue for these structures.

Other geological hazards were identified within individual municipal boundaries, including flooding. All should be considered in municipal planning and development.

## FUTURE PLANS

The preliminary phase of mapping has been completed for the Humber Valley and northeast Avalon Peninsula areas. Detailed aerial photograph interpretation focusing on areas of risk will be completed, followed by the compilation of data and the delineation of polygons and the production of hazard risk maps. Data from these projects will, hopefully, be integrated into regulations controlling development in hazardous areas of the Province.

## ACKNOWLEDGMENTS

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