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THE ASSESSMENT OF GEOLOGICAL HAZARDS AND DISASTERS IN NEWFOUNDLAND: AN UPDATE

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ABSTRACT

A geological disaster occurs when natural geological processes impact on our activities, either through loss of life or injury, or through economic loss. A geological hazard is a potential disaster. Many Newfoundland communities have developed at the base of steep slopes and are, therefore, prone to landslides and avalanches, or are built adjacent to the coast and are susceptible to storm damage.

Archival research has demonstrated that the province has been effected by numerous geological disasters that have inflicted a major economic and social cost. At least 80 people have been killed in Newfoundland since 1863 by geological related disasters, including landslides, avalanches and tidal waves. The economic cost is difficult to estimate, but remedial measures for individual events range from $20 000 for the construction of 50 m of gabions and retaining walls, to $3 000 000 for community-level coastal flood-protection measures. Many of the documented geological disasters were unavoidable and were the inevitable result of geography. However, some were predictable and therefore preventable, either because a similar event had previously occurred in the same area or that geological factors, such as rapid coastal erosion or rising sea levels, were not considered during the planning process.

The ideal way to reduce the costs incurred by geological disasters is to improve our knowledge of them. The geological hazard project by the Geological Survey has led to the implementation of remedial measures to protect the Battery in St. John's from rockfall and avalanche hazard. Further work may ultimately lead to the production of maps outlining areas vulnerable to geological hazards that will be useful in planning. Geological hazard mapping will provide a long-term direct benefit to the government through savings on expensive preventative measures and will reduce hazard-related fatalities.

INTRODUCTION

This report represents an update to the study of Batterson *et al.* (1995), in which 115 incidents involving landslide, rockfall, avalanche, meteor and earthquake were documented. Further archival research, much of which was under contract from the Canadian Avalanche Association to JR, has resulted in the discovery of a further 19 incidents resulting in 6 fatalities. Since 1994, further incidents have occurred including landslides in Corner Brook, St. John's and near Stephenville; avalanches in Port aux Basques and Western Cove near St. Carols; as well as a fatal avalanche in Blanc Sablon on the Québec–Labrador border.

A geological disaster occurs when natural geological processes impact on our activities, either through loss of life or injury, or through economic loss. A geological hazard is a potential disaster. The Province of Newfoundland and Labrador is fortunate in that such impacts are comparatively minor compared to many other parts of the world. This is mainly due to its situation in a relatively inactive, seismic area, and because of low population densities. Geological disasters and hazards, however, still inflict a major economic and social cost to the province. Such disasters are to differing degrees avoidable or preventable if the hazards are identified.

In partial response to this concern, the Geological Survey initiated a project to examine the nature and extent of past geological disasters in the province. The initial focus was on archival research that documented the type, frequency and social and economic costs of disasters. (Figure 1) The findings were reported in Batterson *et al.* (1995). An updated list of geological disasters are reported below. They document the nature and extent of geological disasters, and show the estimated cost involved in remedial measures.

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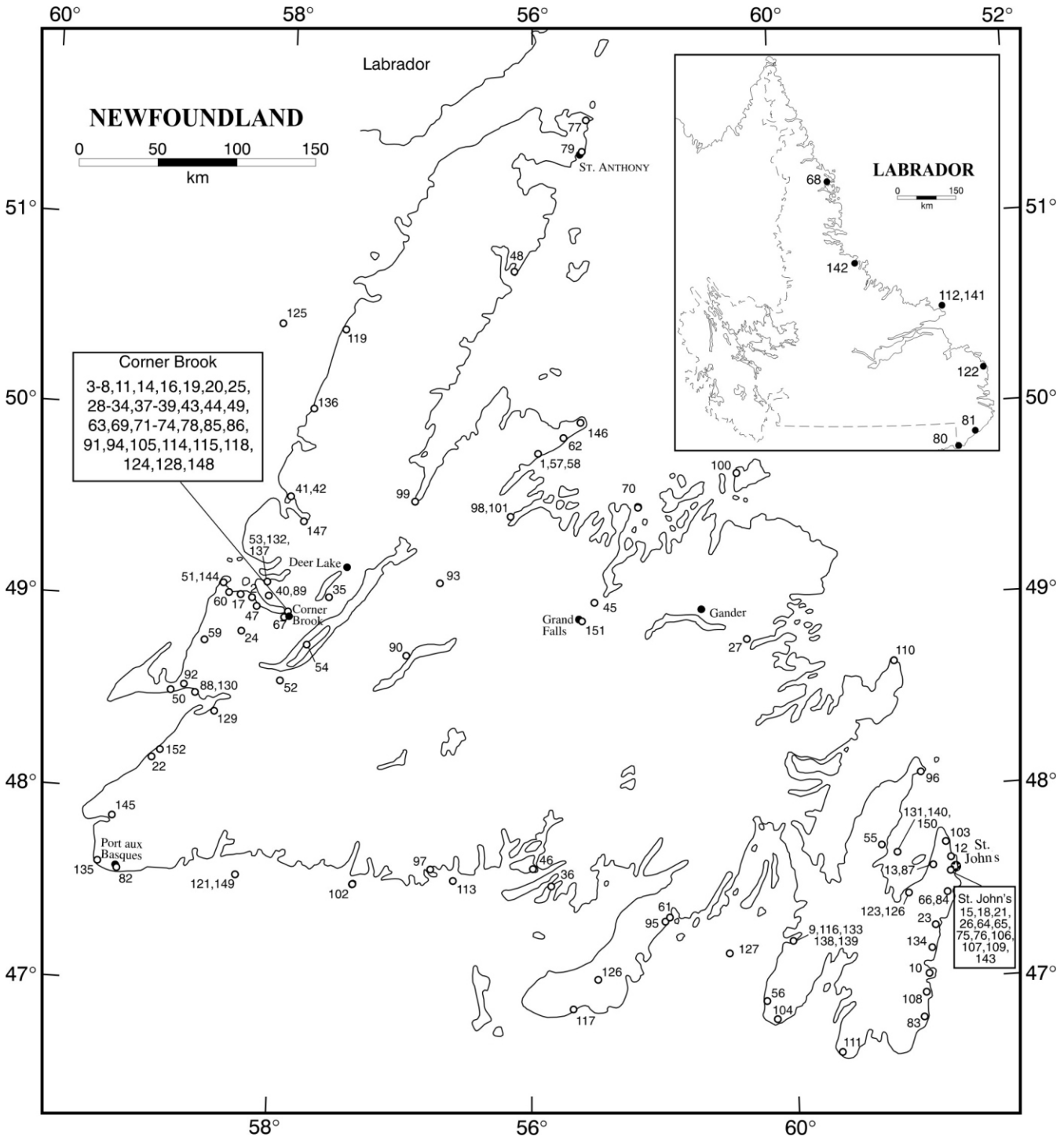

Figure 1. *Location of incidents of geological disasters in Newfoundland and Labrador; numbers refer to the location sites shown in Tables 1-5.*

TYPES OF GEOLOGICAL HAZARDS AND DISASTERS IN NEWFOUNDLAND

SLOPE STABILITY

Slope-stability or mass-movement problems occur where either unconsolidated sediment and/or rock and/or snow move downslope in response to gravity. Potential slope-stability problems exist anywhere development has taken place at the base of steep slopes. Downslope movement is a natural process, but can be accentuated by undercutting of the base of slopes, clearance of stabilizing vegetation, or diversion of natural drainage. Types of downslope movement include landslide (debris flow and debris torrent), avalanche, rockfall, rock slip (sackung), and rotational slumps. The first three are rapid events, and generally the most dangerous to life and property.

Landslides

Landslides are the downslope movement of unconsolidated material under the influence of gravity. The introduction of excess quantities of water to the slope, either from rainfall or snowmelt, is commonly the trigger for landslide events. Excess water commonly loads the slope material beyond its shear strength, at which point, movement occurs. The water may also act as a lubricant and movement commonly is rapid; these landslides are debris flows or debris torrents. The slope angle and sediment texture are other important factors that control drainage from a slope. Areas on the slope having better drainage, commonly near the top, may fail by rotational slumping during failure of the lower slope by flowage. Incidences of landslides in Newfoundland and Labrador are given in Table 1.

Southside Road, St. John's (#21)

Following a rainstorm that dumped 11.5 cm (4.5") of rain in 18 hours on the St. John's area, a debris torrent on September 15, 1948, damaged a number of houses on Southside Road (Plate 1), and caused a fatality. The site of this tragedy was one of four landslide events reported over a 20-year period at this location. An earlier landslide, on February 23, 1936, killed a young child, and other landslides on October 13, 1934, and in October 1953, damaged property and disrupted transportation routes. The construction of the Pitts Memorial Drive has largely alleviated the landslide threat in this area.

Harbour Breton (#36)

On August 1, 1973, following several weeks of heavy rainfall, a debris torrent occurred at about 3 a.m. in a gully above the community of Harbour Breton (Plate 2). Four houses were swept into the harbour and destroyed, resulting in the death of four children. Slope movements continued over the days following the disastrous slide. The families who lost their houses during the landslide, and 11 other families whose homes were thought to be at risk from further landslides, were resettled. On at least three subsequent occasions, in November 1982, February 1984, and June 1986, government geologists visited Harbour Breton to examine slope movements. The area in which the tragedy occurred had been the site of a previous landslide, in about 1953; however, there were no houses located in the area, and consequently there was no incidence report filed on which to base future planning decisions.

Plate 1. *Debris path produced by landslide on Southside Road, St. John's in September 1948. Material washed down a gully, causing considerable damage to the house, and claiming the life of a small child. Photograph courtesy of the City of St. John's archives.*

Plate 2. *Landslide scar in Harbour Breton generated by a debris torrent in August 1973. Wreckage from the remains of four houses caught in the path of the landslide is seen at the water line.*

Table 1. Incidences of landslide in Newfoundland and Labrador

#	Date	Location	Deaths	Injuries	Comments
1	15-May-1883	Betts Cove			A landslide off Betts Cove Hill fell on the mine roof which being unsupported, caved in. The landslide also took with it some buildings and machinery. Miraculously no injuries resulted, as a boy noticed the slumping hillside and shouted to the men underground.
2	19-Apr-1892	Beaches, Humber Arm	1		At a place called the Beaches a landslide occurred that completely demolished and buried one house, killing a child. The rest of the family barely escaped with their lives. (Location and date best guess)
3	29-Jan-1901	Mount Moriah, Bay of Islands			Followed downpour Monday night. Slide between 1 and 3 p.m. at the base of Mount Moriah past Hayes Court. Worst landslide in history of Newfoundland railway. Several thousands of tons of rock, clay and trees covered 50 m of track 4 m deep. Started 70 m above track and stopped within 100 m of residences at Pleasant Cove. Railway blocked for 3 days. During same storm, trestle bridge over Exploits River was destroyed.
4	22-Apr-1906	Corner Brook			Small landslide beneath Roman Catholic cemetery in Corner Brook, adjacent to railway track. Skeleton of Patrick Carroll of Summerside, who died 30 years before, was exposed.
5	28-Nov-1906	Between Cook's Brook and Benoits Cove			Exact location and time uncertain. Caused by recent rainstorms. Large trees uprooted, telegraph poles hurled down and tons of clay and boulders swept down steep hillside. Roadway piled high with debris.
6	7-Jan-1909	Mount Moriah			Considerable quantities of clay and rocks undermined by storm fell on road beneath. Fixed quickly, no delay to train.
7	27-Oct-1914	Duncans Rock, 3 miles east of Corner Brook			Hundreds of tons of earth and stones came down mountain carrying several lengths of track and telegraph lines and poles away. Rail service affected.
8	12-Jun-1915	Mount Moriah			Several huge boulders rolled down mountainside and crippled railway. Rail-line was quickly cleared.
9	3-Oct-1923	Placentia area			Storm about Oct 3, caused landslides along Placentia branch railway line. On Burin Peninsula, flakes and stages destroyed during same storm event.
10	29-Dec-1923	1/4 mile west of Cape Broyle			Landslide on Trepassey railway near Cape Broyle. Engine buried in avalanche of snow and gravel, box car swept down embankment. Crew and 30 passengers not severely injured.

Table 1. *Continued*

#	Date	Location	Deaths	Injuries	Comments
11	5-May-1930	Crow Gulch, Corner Brook			Small landslide at Crow Gulch interfered with last coach of the day.
12	26-Jun-1930	Outer Cove, Avalon Peninsula			Steps and winches behind stages at Outer Cove buried by tons of earth. Associated with massive electrical storm that killed 3 in Lumsden, and 1 in St. John's.
13	27-Jun-1930	Portugal Cove			Following thunderstorm. Several large boulders hit by lightening were split and rolled down hill. Tons of earth and dirt came down hillside to within a metre of some dwellings. Several of the boulders weighed at least 2 tons.
14	1-Dec-1930	Shellbird Island, Humber River			Landslide blocks railway at Shelbird Island. Two freight trains delayed.
15	13-Oct-1934	Southside Road, St. John’s			During a heavy rainstorm, slide dumped tons of earth on railway. Similar slides occurred on Petty Harbour Road. Houses near junction with Blackhead Road threatened by slide.
16	6-Aug-1935	Crow Gulch, Corner Brook			Railway swept away by tons of debris from steep slope above. Large boulder of several tons carried several lengths of track over bank. Boulder of about 15 tons landed on track and had to be blast-ed.
17	29-Nov-1935	Voy's Beach, Humber Arm			Landslide swept away 3 houses. Heard slide coming and everyone got out in time. Happened during a rainstorm that lasted 40 hours. Houses belonged to James Park Jr., James Park Sr. and Strickland family. During same storm, a store at Middle Arm (location unclear) belonging to a man named Green was also swept away by landslide.
18	23-Feb-1936	Southside Road, St. John’s	1	1	Four-year-old daughter of Michael Byrne was smothered by landslide. Seven-year-old boy was injured. Both children were forced through kitchen floor.
19	20-Apr-1940	Humbermouth, Corner Brook	1		Ditcher was clearing previous slide that occurred on April 20, when a second slide occurred and car-ried the machine over an 8 m embankment onto highroad below. Stanley Penney was badly burned from broken steam pipes and suffered a broken leg and broken hip. He died in hospital.
20	6-Nov-1945	Corner Brook			Old Humber Road, opposite the store of S. Dominic and Sons. During a period of heavy rain that lasted three days and dumped 11 cm of rain.
21	15-Sep-1948	Southside Road, St. John’s	1	1	Followed heavy rainfall. Debris swept through walls of house. Mohrine Winsor, aged 3 was killed and another child injured. During same storm tons

Table 1. *Continued*

#	Date	Location	Deaths	Injuries	Comments
					of gravel washed downslope from St. Clares Hospital down Patrick street. Quidi Vidi Lake rose 2 m. In Mill Bridge area debris washed over railway right-of-way.
22	11-Mar-1949	St. Fintans			Small landslide east of St. Fintans after heavy rainfall. Section of rail line was destroyed (21 m wide by 31 m deep).
23	31-Oct-1949	Pierres Brook near Bay Bulls	2		Two brothers killed in slide. Aloysius and Clarence Gatheral of Bay Bulls were taking gravel from an embankment at Pierres Brook when the embankment collapsed burying both men. Aloysius was instantly killed and his brother died later that day in St. John's.
24	9-Mar-1950	Table Mountain			Rock and snow crashed over telegraph lines on Table Mountain. Services were disrupted between Corner Brook, Gander and St. John's. Severed all communications between province and mainland. Repairs took 7 days.
25	22-May-1950	Petries Crossing, Curling			An A-frame storehouse was carried on the crest of the landslide about 31 m downslope and ended up a broken wreck. One boat half buried and another ended up in the water, no damage to boats. Road closed for three days.
26	?-Oct-1953	Mill Bridge near St. John's rail yard.			Outside rail yard in St. John’s. Several tons of debris tumbled down the slope onto the track. William Clarke and family were taken from their home for fear of flooding.
27	23-Oct-1953	Gambo	1	1	Carl Goulding, aged 14 was buried by slide while he and two friends were playing in sandpit. One was buried up to neck, but survived.
28	15-Nov-1954	Buckles Valley Road, Corner Brook			Bob French and Harry Phillips escaped being buried alive when a landslide occurred at the rear of the Thorne Building. The men were investigating a water leakage at the rear of the building, when several tons of gravel broke away from the bank and cascaded down Buckles Valley Road, sweeping away a power line, 6 m of boardwalk, an Avalon Telephone shack and carried away the verandah of the Beson Home.
29	16-Oct-1958	Bell's Hill, Corner Brook			Gravel from the excavation site of a new high school was dumped on the edge of a hill causing a landslide, due to the additional weight. There were no injuries but the slide caused gaping cliffs to be left in the hill and presented city engineers with the problem of preventing further collapse of the slope.

Table 1. *Continued*

#	Date	Location	Deaths	Injuries	Comments
30	8-Nov-1958	Brake's Cove, Corner Brook			Heavy rains on Friday night caused an estimated 10 000 tons of sand and gravel to collapse from the high cliffs in the sandpit. There were no injuries but equipment and buildings were partially buried.
31	10-Apr-1962	East of Brake's Cove, near Humbermouth.			Tons of earth, boulders and uprooted trees slid down a slope of a mountain near the CNR rail line, causing it to be closed until workmen could clean up the debris.
32	1-May-1967	Brakes Cove, Corner Brook			The home of Margaret Ryan, a 62-year-old widow, was washed from its foundation and smashed against a hillside. The damage was caused from snow melt during a rapid thaw.
33	17-Feb-1969	Irishtown, Bay of Islands			A triangular portion of land along a 35 m frontage dropped more than one foot in an early morning slide. Damage was limited to one skidway and the land itself, an abandoned home was twisted on its frame and one side of its foundation fell in. the cause of the slide was unknown, however an early morning tremor was felt by local residents.
34	4-Apr-1969	Irishtown, Bay of Islands			The homes of Cecil Young and his brother Calis Young were moved about 4 m by a landslide. No injuries were reported and the landslide is being blamed on poor highway drainage during new road construction the previous year.
35	2-May-1970	Pynn's Brook, 25 miles east of Corner Brook			Landslide blocked rail line at Pynn's Brook. Wash-out was quite extensive and crews were using rock and timbers to make line passable.
36	1-Aug-1973	Harbour Breton	4	?	A debris torrent occurred in a gully above the community at 3 a.m. following period of heavy rain. Four houses were swept into the harbour and destroyed. Pauline, Edward, Timothy and Julia Hickey, aged 8, 7, 5, and 4, all from the same family, were killed. There were 16 survivors. The families who lost their houses during the landslide, and 11 other families whose homes were thought to be at risk from further landslides were resettled. The area in which the tragedy occurred had been the site of a previous landslide, in about 1953.
37	20-May-1974	Corner Brook			Landslide into Glynmill Pond and with it a sewer line from Cobb Lane. Part of Cobb Lane slid into pond. Concern of sewage pollution into water supply for Bowater Paper Mill. Road in same area experienced another failure on Sept 28, 1975.
38	28-Sep-1975	Irishtown, (Bay of Islands)			Bank under the corner of Frank Hunt's house gave way causing part of the floor to drop and the walls to twist as the house moved along the bank approximately 0.8 m. Family of eight was home at the time but no one was hurt.

Table 1. *Continued*

#	Date	Location	Deaths	Injuries	Comments
39	26-Dec-1977	Corner Brook			In Riverside Drive, a landslide almost claimed the life of Owen Legge. When trying to divert the flow of mud and water away from his home with a back-hoe, a landslide occurred, burying the machine until only the smokestack was showing. Mr. Legge saw the debris coming and jumped from the machine, but before he got clear one boot got stuck in the mud and was left behind. During the same event a landslide blocked the Southern Shore high-way at Mount Moriah. 3 m of rainfall with warm temperatures and snow melt on 25 and 26 of December led to the flooding. Damage estimated to be in the area of $50 000 - $100 000. Hardest hit areas were Massey Drive, Riverside Drive, and Old Humber Road.
40	?-May-1979	Gillams			Elie Park of Farm Road was shook out of bed at 4 a.m. when a landslide came tumbling down a hill near his property. Woodshed was belted by rolling rocks tearing away the front of the building; some rocks also crashed through the roof. There are other rocks on the hill that pose a threat to his property.
41	10-May-1980	Deer Arm			Small landslide occurred 1-km east of Middle Arm Brook where 3000 tons of rock and mud had to be removed.
42	3-Jun-1980	Gull Rocks, Gros Morne Park			A landslide blocked the road at Gull Rocks for 9 hours. 10 000 tons of mud and rock slid across the road and took five weeks to clean up. A landslide occurred in same area around 1941-42. Large num-ber of rock bolts was placed in various outcrops along roadway to help stabilize dangerous out-crops.
43	2-Dec-1982	Quarry Hill, Curling Road			Instability on Ring Road project on Quarry Hill. Slope movements above a section of about 110 m of the roadway, and a failure tension crack had developed 30 m above the road platform. Typical irregular block-strewn appearance of an old land-slide area. Deep crevices appeared in the surface. Many of the blocks are perched on others in rela-tively unstable positions.
44	19-May-1985	Shellbird Island, Humber River			Highway closed for several hours. Covered an area of about 10 m of horizontal extent down a 6-8 m embankment on top of which was the CN rail-way line. Estimated that 100 cubic metres of mate-rial was involved. Build up of water behind the railway tracks and seepage into the bank was prob-ably the cause of the failure.

Table 1. *Continued*

#	Date	Location	Deaths	Injuries	Comments
45	16-Apr-1986	Bishops Falls			30-50 cubic metres of rock and mud slid down the hillside and engulfed the major part of Mr. Dalton's side yard, to a depth of 30 cm. There has been occasional boulders tumble down the hillside before.
46	15-Sep-1992	Gaultois			Landslide occurred on a bedrock-dominated slope after a period of heavy rain. Damaged walkway, watermain, fuel lines. Repairs included clearing slope of debris and construction of retaining wall on slope. Cost $155 000
47	15-Apr-1993	John's Beach			Area of rotational slumping. Cost to undertake dewatering of slope about $250 000. Previous slides experienced in this area.
48	15-Oct-1993	Englee			Rocks collided with the home of Mr. Ralph Talbot and did extensive damage. Further rockslides appeared likely so the house was relocated. A gabion wall was constructed to protect adjacent road. Cost of relocation was $15 000 and gabion and scaling of slope etc. at $25 000 for total of $40 000.
49	19-Apr-1994	Riverside Drive, Corner Brook			Slide area about 100 m long by 100 m wide. Covered roadway and Riverside Drive not reopened until mid-summer. The cause of the slides was determined to be related to inadequate drainage from the newly constructed Trans-Canada Highway in the area. During construction, a major drainage ditch was cut by the new highway. Following a period of intense snowmelt, water normally carried by this ditch was redirected through the subsurface to the adjacent slopes above Riverside Drive, triggering the landslides.
50	25-May-1994	Romaines, Port au Port			A period of heavy rain led to saturation of cliff material resulting in slope failure. Remnants of the torrent are seen by a large fan of debris on the beach. Trees were visible up to 100 m offshore.
51	7-Jul-1994	Little Port, Bay of Islands			Landslide occurred during heavy rainstorm. About 60-70 cm of material removed from slope over 100 m long by 15-25 m wide section. Landslide blocked road and took 5 hours to clear.
52	8-Jun-1995	Little Grand Lake			Series of landslides coupled with washouts blocks woods road leading to Little Grand Lake. Event followed heavy rainfall. Department of Wildlife had a rental vehicle trapped beyond the slide area. The vehicle was eventually dismantled and flown out by helicopter.

Table 1. *Continued*

19#	Date	Location	Deaths	Injuries	Comments
53	19-Feb-96	Cox's Cove			A landslide bought tons of gravel and rock across the main highway leading into the community. The debris was 1-2 m high and 10 m long and came within 4 m of the Park family residence. The road was blocked for a short period of time and took 12 hours to be completely cleaned up. The landslide was triggered by heavy rain and snow melt.
54	?	Grand Lake			Slope failure scars observed by Rod Klassen on the east side of Grand Lake. Date of failure unknown, observation recorded June 1995.

Riverside Drive, Corner Brook (#49)

On April 19, 1994, a series of landslides blocked Riverside Drive in Corner Brook (Plate 3). The slides originated on a north-facing slope having a stratigraphy consisting of bedrock overlain by a compact glacial diamicton, and fluvial sand and gravel. The failure occurred along the interface between the fluvial sediments and the till in the upper part of the slope, whereas the lower slope was frozen. The cause of the slides was determined to be related to inadequate drainage from the newly constructed Trans-Canada Highway in the area (Newfoundland Geosciences, 1994). During construction, a major drainage ditch was cut by the new highway. Following a period of intense snowmelt, water normally carried by this ditch was redirected through the subsurface to the adjacent slopes above Riverside Drive, triggering the landslides. No injuries resulted from the slides, although Riverside Drive was closed until mid-summer. Remedial measures included the construction of sealed ditches to direct water from slopes susceptible to failure. The Department of Works, Services and Transportation assumed responsibility for the slide and absorbed the $63 000 estimated cost of remedial measures.

Plate 3. *Landslide at Riverside Drive, Corner Brook, April 1994. The three separate scars were the result of landslides within several hours of each other. Debris from the landslide was observed on the telephone wires. The road was not re-opened until mid-summer 1994.*

Avalanches

Avalanches involve the rapid downslope movement of snow or ice, with/without sediment, with/without rock. Therefore, avalanches require a combination of steep slopes and a heavy snowfall. A common trigger for avalanches is the deposition of wet snow over ice or a hard crust, with failure occurring along the contact. Alternatively, high winds could produce a cornice, which may break off, causing an avalanche on the slope below. Incidences of avalanches in Newfoundland and Labrador are given in Table 2. Research assistance provided by the Canadian Avalanche Association resulted in the discovery of 19 new incidents of avalanche in addition to those presented by Batterson *et al.* (1995).

Tilt Cove, Baie Verte Peninsula (# 62)

In the late part of the 19th century and the first few years of the 20th century, several serious avalanches affected mining operations and communities on the Baie Verte Peninsula, and in the Bay of Islands. Sixteen people were killed in these disasters (Plate 4); the most complete documentation being the March 11th, 1912 avalanche that occurred in Tilt Cove. An avalanche struck two houses built at the head of the cove at the foot of a steep slope (Plate 5), one belonging to Mr. Williams, manager of the Cape Copper Company, and the other belonging to Mr. Cunningham, a Justice of the Peace, community telegrapher and customs officer. The two families were sitting down to tea when the avalanche struck. Vera Alcock, the daughter of Mr. Cunningham, was interviewed in 1996, and recalled that a

Table 2. Incidences of avalanche in Newfoundland and Labrador

#	Date	Location	Deaths	Injuries	Comments
55	24-May-1833	Carbonear	1		Richard Penny, 20 years old, was collecting boughs on the south side of the harbour when a chunk of ice fell from the cliffs above and struck him on the head, killing him instantly.
56	12-Mar-1863	Distress Cove, Placentia Bay	2		John and William Foley smothered in avalanche while duck shooting.
57	9-Feb-1877	Betts Cove	6		Overwhelmed 2 houses containing 34 persons. 5 killed instantly and 1 fatally injured.
58	26-Jan-1884	Betts Cove	1		Sergeant J. Fennessey was killed in an avalanche while completing his rounds of the Betts Cove mine. He was found in a gulch beneath the lower part of the tramway at the mine.
59	23-Jan-1895	Bluff Head Brook, Chromite Mine	4		Killed were Thomas Holden, Patric Byrne, Laughlin and McKinnon. The men were cutting a path across the foot of a snow bank to gain access to the west side of the brook, where they were looking for asbestos, when struck by an avalanche and swept over a 100 m embankment. Mr. Hicks traveling with the party was not injured. The men were employees of the mine.
60	13-Feb-1905	York Harbour		2	Buried 2 men, Thomas Burton, chief engineer and James Flynn second engineer - both from the mine. Dug out and took 3-4 days off work.
61	12-Mar-1907	Foots Cove, Burin Peninsula	?	2	Two houses at the base of a 100 m cliff were completely buried. Seven in one house dug out unharmed, William Mayo and wife badly burned in other, as trapped under wood stove. Not clear from follow-up reports if Mayo died, but likely recovered.
62	11-Mar-1912	Tilt Cove, Baie Verte Peninsula	5		Avalanche killed mine manager (Williams), his 13 year-old son, and Peter and Francis Sage (servants). Two houses destroyed. Fifth victim a servant believed to have died later from burns sustained as a result of a fire caused by the avalanche. Houses were situated at base of steep cliff at head of the pond. Many said houses dangerously placed, though the owners thought otherwise and made light of such an accident happening. Williams' wife and 2 daughters escaped.
63	31-Dec-1917	Seal Island, Humber River (likely Shellbird Island)	1		Joshua Peddle, section foreman at Humbermouth, was killed as snow swept down mountainside into river.
64	7-Feb-1921	Battery, St. John's		3	Occurred during night. Several hundred tons of snow demolished the house of Alfred Wells in Lower Battery. He was injured and his wife was not expected to survive. Their 2-year-old son was also injured. Houses owned by H&A Rogers, Albert Morris, Edgecombe and Moses Pearcey also destroyed or damaged. Dozens of houses still buried at time of report.

Table 2. *Continued*

#	Date	Location	Deaths	Injuries	Comments
65	17-Feb-1921	Signal Hill, St. John's	1		James Delahunty reported suffocated by avalanche directly below his house on Signal Hill. House was near powder house at top of hill. Body was found 60 m below. His hold on a dinner pail had not relaxed when death overtook him.
66	17-Feb-1921	Petty Harbour			Avalanche destroyed 20 m of flume at Petty Harbour, resulting in the loss of power for four days in St. John's.
67	2-Jan-1922	Rapid Pond or Little Rapids			Avalanche derailed train. Baggage car swept from track into pond. Engine had passed and was undamaged. 40 people on train but no one was hurt.
68	1-Mar-1935	Okak	2	11	A great mass of snow rolled down slope and went through one end of the house and out the other. Killed Ida Kohlmeister and Karoline Uvloriak.
69	4-Mar-1935	Corner Brook, Curling Road	3		House 15 m upslope of Curling Road. Mrs. Blanche Diamond and one child killed instantly. Another child died in hospital. Snowslide moved 2-storey house 10 m downslope until it crashed into another home. Avalanche started 90 m above house.
70	4-Mar-1935	Exploits			The house of George Jacobs was partly destroyed by snowslide, and a barn owned by the same man was blown out into the harbour but later salvaged. Snow fall was to a height of 7 m?
71	4-Feb-1938	Quarry Hill, Corner Brook			Snowslide wrecked garage. Started 100 m up eastern slope of Quarry Hill during heavy snow-storm. Crossed highroad and wrecked garage owned by George Allan. Hit four houses but no damage was reported.
72	21-Jan-1943	Quarry Hill, Corner Brook		1	Mr. Hugh Cook, wife and 5 children had house damaged. Chimney fell through roof into children's bedroom. Mrs. Cook injured. Back of house smashed in by weight of snow. House stopped by electrical wires, otherwise house would have fallen over cliff to Crow Gulch. House owned by Mr. Harry Barnes covered by snow. A house owned by Mrs. Herbert Wheeler and her 5 children was also damaged.
73	2-May-1952	Shellbird Island, Humber River			Small avalanche blocked rail line. No damage reported, but train was forced to return to Deer Lake.
74	2-Apr-1953	Shellbird Island, Humber River			Railway line blocked by ice which had fallen from the cliffs at quarry. Railway line and roadway blocked. Incident reported to repeat itself every year.

Table 2. *Continued*

#	Date	Location	Deaths	Injuries	Comments
75	16-Feb-1959	The Battery, St. John's	5	?	Two avalanches occurred in the Outer Battery during a snow storm that dumped 55 cm of snow on the city, accompanied by winds recorded at up to 220 km/hr. A first avalanche buried the Garland family in their home, but all survived. The main avalanche was at 1:05 a.m. It destroyed two homes and damaged many others, and resulted in the death of five people and injury to at least nine others. Included in the dead was 100-year-old Isaiah Dawe.
76	13-Mar-1960	Lower Battery			Lower Battery snow slide forced Cyril Garland and family to leave their home after it was hit. Area residents left the Battery in anticipation of a larger avalanche. They returned to their homes several days later after the threat had passed.
77	6-Feb-1962	Griquet, Northern Peninsula	1		Ruby Hillier aged 10 was killed by snow slide at 3:30 p.m.
78	7-Feb-1986	Curling	1		David Pike was killed in an avalanche on Monument Hill. Two young boys (David Pike and Jeffery Soper) were sliding or jumping in the snow on a steep slope on the east side of the hill when the snow gave way and buried them. Jeffery Soper was able to dig himself out and run for help. David Pike was not found for 1.5 hours beneath 2 m of snow.
79	7-Mar-1995	Western Cove near St. Carols		1	Travis Taylor, 16 years old, was climbing up a snow covered hill, approximately 10 m, when he felt the snow let go. He was carried down the hill under the snow but managed to stick his fingers to the surface before he blacked out. His girlfriend watching from nearby, saw his fingers and was able to dig him out and revive him.
80	10-Mar-1995	Blanc Sablon south shore of Quebec	2	1	Tony Lavallee, aged 32 and his 17-year-old son Jamie were killed in an avalanche. Results of a severe snowstorm that dumped 70 cm over a three-day period. Tons of snow slid down a hill and destroyed their home killing two and trapping Mrs. Lavalle for 6 hours under 7 m of snow. Rescuers followed the screams of the woman where they found her suffering from shock and frost bitten feet.
81	10-Mar-1995	Capstan Island, Labrador			Avalanche missed a home by 15 m.
82	14-Mar-1997	High Street (off Caribou Road) Port aux Basques			Avalanche took place following a night of heavy snowfall, and high winds. The snow was apparently fine and drifting. The avalanche mostly affected a parking lot, filling it to a depth of 2-3 m, over an area of 45 m by 12 m. At one end of the parking lot

Table 2. *Continued*

#	Date	Location	Deaths	Injuries	Comments
					a two-storey house used as a home for handicapped children lost the deck and wheelchair ramp, which was swept into the road. A youth was shoveling snow on the deck when the avalanche occurred but was able to escape burial. A car parked adjacent to the house was swept across the road and experienced minor damage. The Town manager recalled that a similar incident occurred about 25 years ago in the same area, with some property damage to a garage.

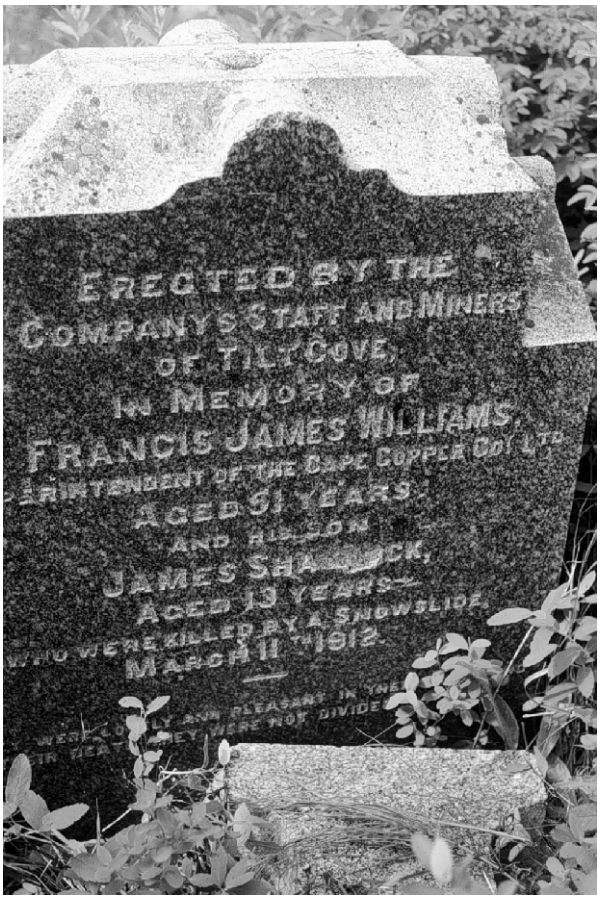

Plate 4. *Gravestone of the late Francis Williams, manager of the Tilt Cove mine, and his son, who were both killed in an avalanche in the community in March 1912. Discovery of this gravestone in the Tilt Cove cemetery by David Liverman was the impetus for further research on avalanches in Newfoundland.*

Plate 5. *Remains of the Williams house following an avalanche at Tilt Cove in March 1912. The avalanche killed 4 persons in the house, including the mine manager and his son. The adjacent house was also damaged. A servant in this house was also killed. Photograph courtesy of the MacKinnon family.*

heavy snow fall had followed freezing rain the previous day[2]. Both houses were smashed by the avalanche, and Mr. Williams and his 13-year-old son were killed instantly. Two servants in the Williams household were also killed. Mrs. Williams and her two daughters were rescued after three and a half hours of burial, without serious injury. In the Cunningham household, most survived with minor injuries, but Edward Cunningham, aged 3, and a servant, Emily were buried, and crushed against the wood stove. They were rescued after two hours of digging. Edward survived with minor burns thanks to the efforts of Emily to keep him safe. Emily, however, was severely burned and died later.

[2] Churchill Harbinger, 1996. The stories of Vera Alcock. Volume 1, number 8 (community newsletter, published in St. John's).

Rockfalls

Rockfalls are the downslope movement of clasts, either through free fall or by rolling. Rockfalls commonly involve individual boulders, although landslides may be triggered if these boulders impact the slope. Clasts may be dislocated by erosion beneath the clast, freeze-thaw processes or human intervention. Incidences of rockfall in Newfoundland and Labrador are given in Table 3.

Table 3. Incidences of rockfalls in Newfoundland and Labrador

#	Date	Location	Deaths	Injuries	Comments
83	13-Nov-1901	Capahayden (Broad Cove at the time)	1		Sheehan of Broad Cove, whilst salvaging wreck of S.S. Vera, killed by rock falling from cliff and striking him on the head.
84	10-Oct-1912	Petty Harbour			A large section of cliff gave way, and tons of rock fell from it. It was reported to occur near the flume and damaged from 2 to 30 m of the woodwork surrounding the conduit. The power was not interfered with.
85	24-Apr-1916	Curling, Court House Hill			Large boulder weighing about 1 ton dropped from the cliff at Court House Hill. Crashed through 3 fences and stopped 1 m from Edwin Knight's house.
86	8-Apr-1927	Crow Gulch, near Corner Brook			Large stone rolled down embankment and landed on railway. Train stopped before hitting rock.
87	25-Aug-1935	Portugal Cove	1		Dorothy Summerton, aged 6, crushed by a boulder she was climbing over, while collecting flowers for her grandmothers grave.
88	10-Apr-1942	Indian Head		1	Charles James of Benoits Cove, while drilling at Indian Head, had collarbone and left leg broken when stone slid down hillside.
89	12-Jul-1952	Meadows	1		Edward Maxwell Davis, 5-year-old boy killed by a boulder falling from an embankment above as he played on a sandy beach.
90	27-Mar-1953	Rothermere Mine, Buchans	1		Arthur Perrier killed by a fall of rock while drilling in a slope at the Rothermere mine.
91	10-May-1955	Mount Moriah			Large boulder smashed track in 2 places after breaking free from mountainside. Two sections of track had to be replaced.
92	May-1957	Queen Street Extension, Stephenville			Rocks and boulders slid down the slope of the hill onto the road, blocking it for about 60 m, causing it to be a threat to motorists and pedestrians. A retaining wall was needed to keep the rocks and boulders from falling on the road. Rock falls have been occurring continuously since the road was constructed.
93	7-Jan-1960	Gaff Topsails			Large boulder rolled down slope, after heavy rainfall, and came to rest on tracks. Train struck boulder causing minor damage and a one-hour delay.

Table 3. *Continued*

#	Date	Location	Deaths	Injuries	Comments
94	27-Mar-1969	Curling			A huge boulder rolled down over the cliff at the bottom of Monument Hill in Curling and ended up in the middle of the road. No injuries resulted.
95	7-Dec-1973	Rushoon, Placentia Bay			Precariously perched boulder above a house.
96	7-Jan-1975	Coish's Hill, Bay de Verde			Loose and falling rock in the vicinity of the home of Mark Coish. Upon two occasions in the past, rocks had broken loose and fallen down the slope crashing into two of the homes located across the road from the rock slope.
97	15-Jun-1975	Francois			Slope stability and hazards caused by falling rock behind the residence of Ronald Dunford of Francois. Homes in the area had been struck by large stones on at least three occasions. Spring of 1973 a large stone tore off the power meter and knocked a large hole in the skirting around the footing. A second stone struck the northwest corner damaging the outside corner of the bedroom. In June/July 1973 a home was struck on the skirting dislodging one of the concrete shores.
98	15-Jul-1975	Springdale			At the rear of Taylor's subdivision a row of houses were built at the base of a 200 foot rock face. The first rockfall occurred in July 1975, and consisted of a large boulder that broke free from the cliff face and tumbled down the hillside. A second rockfall occurred in January 1976, when a large piece of rock broke free and split into two fragments, damaging a house and pick-up truck. No injuries were reported.
99	19-Nov-1980	Hampden			Falling rocks along a stretch of road between Hampden and Beaches. A car was damaged when driving around a blind curve and struck a boulder which had fallen from the hillside. Falling rocks has been a continuous problem in this area.
100	28-Feb-1984	Fogo			Potential for rockfall from Durham Hill causing property damage or personal injury. Directly behind the property of Mr. Jack Gill. Frost action is slowly pushing some large blocks outward.
101	28-Apr-1984	Springdale	1		Jeffery James Cull, aged 16 years, of Carmanville was killed while climbing on the slope face. He was crushed when a large (1 m) block detached from the face and pinned him into a crevice.
102	7-Jun-1985	Ramea			Intense rainfall loosened a 150-ton rock from a cliff in the community of Ramea. The rock balanced over a home and the main street in town. The rock was dynamited to prevent a disaster.

Table 3. *Continued*

#	Date	Location	Deaths	Injuries	Comments
103	6-Nov-1993	Shoe Cove			Some loose rock tumbled down over the hill into the back of Mr. Wimbleton's shed causing extensive damage. Several other boulders remain a threat in this area.
104	15-Jul-1994	Point Lance			Large boulder tumbled down hillside crashing into a resident's home.
105	24-Jul-1995	Riverside Drive, Corner Brook			Rockfall caused Riverside Drive to be closed after 33.5 ml of rainfall.
106	4-Oct-1995	Pitts Memorial Drive, St. Johns			Small rockfall blocked road for short period of time. Rockfall occurred in a rock cut near the turn to Shea Heights.
107	4-Apr-1997	Pitts Memorial Drive, St. John's			A 200 m section of cliff slid off the hill and spilled over the east bound carriageway. About 1500 tons of rock fell from the cliff and took two days to clear the road. The freeze thaw cycle and steeply dipping bedrock blamed for the rock slide.
108	5-Feb-1998	Port Kirwan, Fermeuse			Armchair-sized rock fell from cliff and hit house belonging to Sandy Newton and Doug Hill. Rock damaged clapboard on side of house and smashed house. Local residents recall previous fall 30 years ago with no damage reported.

Springdale (# 101)

Expansion of the town of Springdale led to the 1972 development of a new subdivision adjacent to a highly fractured basalt cliff. Several incidents of rockfalls from this cliff over the next few years resulted in property damage when boulders struck houses and vehicles. A youth was killed in April 1984, while climbing on the slope, when a large boulder toppled and crushed him. In response to these incidents, extensive engineering works were undertaken by the Department of Municipal Affairs to stabilize parts of the cliff face. In 1986, a retaining wall (Plate 6) was constructed at a cost of $286 000 to protect 11 houses that were built along the foot slope (Boyd, 1991).

Plate 6. *Retaining wall constructed in Taylor's sub-division, Springdale at a cost of $286 000. The sub-division was built at the base of a highly fractured basalt cliff.*

Highway Construction

Slope stability is a major problem in highway construction throughout the province. Transportation routes are occasionally cut by landslides (e.g., Humber River gorge, 1985; Frenchman's Cove, Bay of Islands, 1993; Riverside Drive, Corner Brook, 1994 and Pitts Memorial Drive, St. John's, 1997) (Plate 7), affected by minor rockfalls, or have problems with gullying and minor debris flows on road cuttings. New highway expansion and construction near Gambo incurred major difficulties where the highway abutted a steep slope of unconsolidated sediments. Considerable remedial engineering work has been undertaken to protect the road in this area at estimated costs of $650 000 or more (S. Skoda, Department of Works, Services and Transportation, personal communication, November 1994).

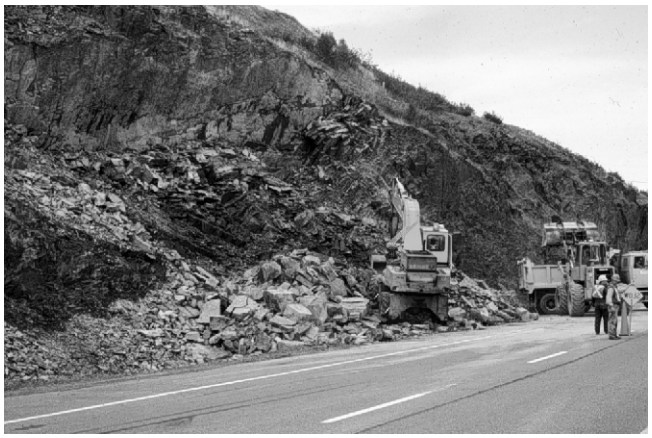

Plate 7. *Clean-up efforts following a rockfall along the Pitts Memorial Drive, St. John's in April 1997. Debris closed the road for several hours, but there were no serious injuries.*

COASTAL EROSION

Coastal erosion may be a rapid process wherever the coastline consists of unconsolidated material, and is a geological hazard when development occurs as well. Coastal erosion commonly involves the destabilization of cliffs following wave impact during storm events, but may also include ground- or surface-water effects from development adjacent to the coast.

Point Verde

Point Verde consists of a gravel peninsula at the entrance to Placentia Road, southwest of Placentia, Avalon Peninsula. The peninsula protects Placentia from some of the effects of major storms, and hosts a few houses, a gravel-pit operation, and a light station. The peninsula is joined to the mainland by barrier beaches. The sea cliff is eroding at a rate estimated between 0.5 and 2 m/year, based on aerial photograph analysis and monitoring sites (Liverman *et al.*, 1994; D. Forbes, GSC Atlantic, personal communication, 1998). Several structures relating to the light-station have been lost. Further cliff erosion combined with extraction of gravel may result in the loss of the gravel-pit operation, and increase the flood risk in the communities of Point Verde and Placentia.

Kippens–Port au Port East

The stretch of coast lying between Stephenville and the Port au Port Peninsula has seen increased development in the last few years. The coastline in this area consists of steep (up to 30 m) cliffs of sand and gravel that are retreating at an unknown rate. Encroachment of house construction into the cliff edge area has resulted in increasing concerns regarding property loss in this area. The provincial Geological Survey has visited the site in recent years at the request of the local council. The Atlantic Geoscience Centre of the Geological Survey of Canada contracted a detailed photogrammetric survey of this area to evaluate erosion rates (Forbes *et al.*, 1995). Following a period of heavy rain in May 1994 rapid headward expansion of a gully occurred at Port au Port East (Plate 8). The slide area measured about 150 by 200 by 30 m, and ended about 50 m from the nearest structure (C. McCarthy, Department of Municipal Affairs, personal communication, November 1994). A large debris fan was formed on the beach. Two smaller failures also occurred during the same storm, 500 m and 1300 m west of the main failure.

Plate 8. *Landslide in coastal cliffs at Port au Port East that occurred in May 1994. Note the alluvial fan that developed on the beach as debris was washed from the gully. This fan had largely been removed by marine action within two years.*

COASTAL FLOODING

Coastal flooding is a problem wherever development has occurred adjacent to, or on, beach systems. The problems of maintaining these areas are accentuated by naturally rising sea levels over most of Newfoundland (Liverman, 1994). Floods usually occur when storm events coincide with high tides and can include overtopping or breaching of barachois beaches (Forbes *et al.*, 1991). Flooding of this type can be very destructive. Flood risk maps have been prepared for flood-prone areas through the Canada–Newfoundland Flood Reduction Damage Program. The worst geological related hazard in the province's history was one of coastal flooding associated with the Grand Banks tsunami that struck the Burin Peninsula in 1929. Incidences of coastal flooding in Newfoundland and Labrador are given in Table 4.

Placentia (# 116, 127, 133, 138, 139)

Possibly the most vulnerable area to coastal flooding in the province is Placentia. Placentia has a history of flood

Table 4. Incidences of coastal flooding in Newfoundland and Labrador

#	Date	Location	Deaths	Injuries	Comments
109	11-Jan-1775	St. John's	?	?	Gale. Sea suddenly rose 10 m. People killed on land (numbers unknown) Fishermen afterwards commonly dragged up 20-30 bodies in their nets.
110	?-?-1775	Bonavista	?	?	Probable result of Lisbon earthquake. Drowned Bonavista harbour and 10 minutes later water returned and overflowed parts of the community. Song 'A Great Big Sea Hove In Long Beach' originated from this event.
111	27-Jun-1864	St. Shott's			Sea receded and uncovered HMS Little Drake which was submerged in 5 fathoms of water. Then tidal wave hit, damage ensued. Blocked gut at St. Shott's. Evening Telegram suggested cause was probably volcanic eruption off the Southern Shore. Earthquake shock felt at St. John's.
112	10-Oct-1885	Labrador Coast	?	?	The Great Labrador Gale. Long period of stormy weather that eventually produced 190 kph winds and a 'tidal wave'. Considerable damage at Fanny's Harbour (Cape Harrigan), Manaaks Island, Ragged Island, Iron Bound Island, White Bears, Black Island, Domino, Brig Harbour, Indian Tickle, Grady, Seal Islands, Batteau, Punch Bowl. About 300 people died in this event, but unclear how many, if any, died on shore as a result of flooding.
113	18-Aug-1886	South Coast			Great storm in the gulf with considerable damage done to buildings and shipping. A most violent storm swept over St. Pierre on Wednesday night. The storm was the fiercest known for 25 years. Buildings were blown down and considerable damage done to shipping.
114	29-Nov-1901	Humber Arm			Property damage at the mouth of Humber River. Brakes house flooded. Railway at Grand Bay (Barachois) 8 km east of Port aux Basques, had about 100 m washed away by waves.
115	27-Dec-1901	Corner Brook			High tide. Undermined railway for about 50 m, and delayed train.
116	10-Jan-1912	Placentia-Pointe Verde	1		Charles Cosgrove apparently swept out to sea by huge waves whilst heading for Ship Cove after a wedding in Placentia.
117	5-Mar-1916	Lawn			Big storm at Lawn, occurred on March 5th and 6th. Destroyed Grants new store at Lawn. Very high tide. Damage reported to other places along Burin Peninsula.
118	8-Sep-1916	Bay of Islands			Culverts blocked. Humber River rose 1.5 m in five hours. Bridge destroyed.

Table 4. *Continued*

#	Date	Location	Deaths	Injuries	Comments
119	11-Dec-1919	Bateau Cove, Northern Peninsula			Big storm reported as one of the worst ever on the coast. Store at Bateau Cove was destroyed. Considerable damage reported at Little Harbour (location unknown), and Island Cove. Little Harbour Head lighthouse covered with ice (60 m high tower). $15 000 damage in total. Stores stages etc. also damaged at Rocky Harbour and Trout River.
120	30-Oct-1921	Kelligrews			Sea washed away considerable distance of rail line. Damage also reported at Lumsden, Musgrave, Laddle Cove, Carmanville and Indian Head.
121	23-Jan-1925	South Coast			Shoreline from Fortune Bay to Port aux Basques ravaged by storm. Considerable damage onshore, but most offshore.
122	23-Dec-1925	Battle Harbour			Property destroyed by storm. Stages and storage sheds mostly damaged.
123	25-Dec-1925	Kelligrews			Railway track under water as result of severe storm. Other parts of track covered in debris, and sleepers washed inland by several metres.
124	25-Aug-1927	Humber River	1		Tidal wave swept up Humber River. Calm until 9 a.m. when wind shifted creating a wall of water 1 m high. Damaged boats and much of the railway around Seal Head. At Humbermouth, George Layden swept from boom and was killed. Damage in other areas but no details.
125	6-Jan-1929	Bonne Bay to Blanc Sablon			Storm damaged coast from Bonne Bay to Blanc Sablon. Storm destroyed stages that stood for 30 years. Reported by the S.S. Sagona.
126	18-Nov-1929	Burin Peninsula	28	?	Affected much of the Burin Peninsula coast, east side. The tsunami was produced by an earthquake on the Grand Banks that measured 7.2 on the Richter scale. The earthquake triggered a turbidity current that displaced about 200 km^3 of material down the continental slope. The effect on the ocean surface was a tsunami that radiated out from the epicentre. The tsunami was recorded in Nova Scotia and New York in the west, and Portugal in the east, but impacted most severely on the Burin Peninsula. The tsunami travelled at speeds up to about 500 km/hr through deep water, and about 140 km/hr over the continental shelf, but had slowed to about 40 km/hr upon impact with the coast. The tsunami arrived as three main pulses, causing local sea levels to rise between 3 and 7 m. Twenty-eight lives were lost on the Burin Peninsula as a result. Total damage to property was estimated at about $1 million (1929 dollars).

Table 4. *Continued*

#	Date	Location	Deaths	Injuries	Comments
127	7-Dec-1931	Placentia Bay			Severe gale. Prowseton and Davis Cove had higher tides than during the 1929 quake. Wharves and flakes were destroyed. Four houses were flooded. Placentia also damaged by 'tidal wave'.
128	9-Feb-1933	Humber Arm			High winds and tidal wave. At Curling, stores along the waterfront were flooded. At Humbermouth, water entered houses. At Petries, Gillams, Middle Arm and McIvers there was considerable damage to property. At Sandy Point (Flat Bay Island), tide swept over and through breakwater flooding many houses. Railway damaged at Grand Bay. In St. George's Bay 12 m of dump washed away and delayed train for 2 days.
129	24-Oct-1938	St. George's			Grim sea caused $40 000 in storm damages. Breakwater was swept away at St. George's and settlement was flooded. Two schooners were driven ashore and 300 cords of pulpwood swept away. Damage at Cape Ray railway dumps. Highest tide since tidal wave of 1929.
130	19-Dec-1951	Stephenville Crossing - Bay of Islands			Severe storm at Stephenville Crossing washed out rail bed and 15 telegraph poles were blown down. Train station was also flooded along with Avalon Telephone exchange. Rail line was closed for three days. Over 600 people were evacuated. West Street was under 1.2 m of water. Winds of 180 kph were recorded. Damage was also reported at Summerside, Bay of Islands, where George Ruth lost his fishing stores and boat. A sawmill at Summerside was also destroyed, and many fishermen lost boats and gear. Worst storm since tidal wave. Storm washed thousands of lobsters ashore.
131	11-Jan-1955	East Coast, St. John's, Carbonear			Worst storm in memory battered East Coast. Surging waves sent water 60 m in the air against the steep cliffs around St. John's Harbour. In St. John's, 12 wharves and two small boats were destroyed at an estimated cost of $12 000. At Carbonear, 12 m of railway was washed out to sea. Huge breakers shot water over the dome at Fort Amherst, 35 m asl.
132	27-Nov-1955	Cox's Cove			Coastal flooding coupled with increased stream runoff damaged community.
133	3-Feb-1964	Placentia			Worst flood in history. Houses flooded, people forced to row along roads in dories. Unusual high tides flooded houses in St. Mary's, Placentia Bay.
134	28-Jan-1966	La Manche			Major storm washed away all boats, anchors, stores and flakes of community. Damaged houses. Some people lost up to $30 000 in property e.g., Mr. Melvin. Community was resettled following storm.

Table 4. *Continued*

#	Date	Location	Deaths	Injuries	Comments
135	20-Oct-1974	Cape Ray			Wind storm. High seas at Cape Ray washed out about 30 m of railway track causing derailment of 2 diesel locomotives. Wind caused $1000 damage in Port aux Basques.
136	6-Dec-1976	Parsons Pond			Onshore winds and high tides destroyed the protective natural beach barrier allowing sea water to flood area north of river.
137	12-Dec-1977	Cox's Cove			Storm caused waves to overtop breakwater. Washed away part of road, damaged slipways and flooded homes. Same storm also damaged Parsons Pond and Stephenville Crossing, through waves breaching barrier beaches.
138.	?-Jan-1982	Placentia			Worst flooding in history of community. Houses flooded, people forced to row along roads in dories. Unusually high tides flooded houses in St. Mary's, Placentia Bay.
139.	?-Dec-1983	Placentia			Severe flooding occurred during storm. Remedial measures in the Placentia area later cost in excess of $3 000 000.
140.	10-Oct-1992	Conception Bay			Severe storm produced considerable damage to property along much of the Conception Bay shore. Numerous boast sunk or damaged. Barrier bars overtopped or breached. Coastal cliffs eroded.

damage, aggravated by urban development over the past 15 to 25 years into the area directly behind the modern beach. Flooding in Placentia occurs either as a result of high water levels in the estuary (which may be caused by storm runoff, storm surge, high tides, or a combination of these) or as a result of storm wave run-up and overtopping along the outer beach, or both (Forbes, 1984; Environment Canada, 1989; Liverman *et al.,* 1994). The most damaging recent flood event occurred in January 1982, when high waves were superimposed on very high tides. Severe flooding also occurred in December 1983 and (less severe) at Christmas 1992. The Department of Municipal Affairs has responded to this problem by constructing shoreline defenses, at a cost of about $3 000 000 (Liverman *et al.,* 1994).

Burin Peninsula (# 126)

The Burin Peninsula has numerous communities situated at low elevations behind barrier beaches on a coast threatened by rising sea levels. Coastal protection measures have been constructed in a number of vulnerable areas, including the site of recent Provincial Park developments at Frenchman's Cove.

The vulnerability to flooding was emphasized by the disaster associated with the 1929 tsunami (Plate 9). The tsunami was produced by an earthquake on the Grand Banks that measured 7.2 on the Richter scale. The earthquake triggered a turbidity current that displayed about 200 km^3 of material down the continental slope. The effect on the ocean surface was a tsunami that radiated out from the epicentre. The tsunami was recorded in Nova Scotia and New York in the west, and Portugal in the east (Ruffman, 1994), but impacted most severely on the Burin Peninsula. The tsunami traveled at speeds up to about 500 km/hr through deep water, and about 140 km/hr over the continental shelf (Ruffman, 1994), but had slowed to about 40 km/hr upon impact with the coast (A. Ruffman, Geomarine Associates, personal communication, November 1994). The tsunami arrived as three main pulses, causing local sea levels to rise between 3 and 7 m. Twenty-eight lives were lost on the Burin Peninsula as a result. Total damage to property was estimated at about $1 million (1929 dollars).

The frequency of tsunamis is uncertain. Ruffman (1994) suggests that earthquakes of the magnitude that triggered the 1929 tsunami are 1 per 1000 years, but could be as

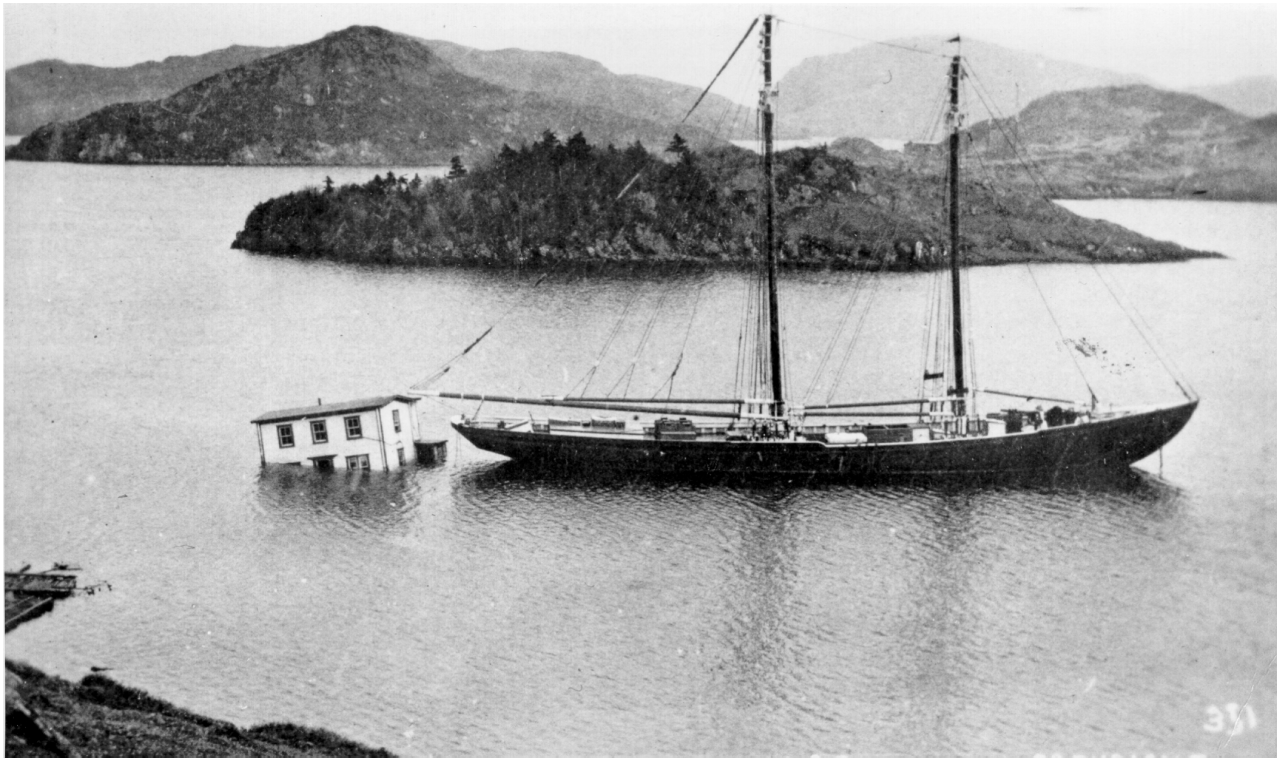

Plate 9. *Schooner moored to a house that had been washed out to sea during the Burin Tsunami, November 1929. The tsunami caused 28 deaths in Newfoundland and was the worst earthquake-related disaster in Canadian history. Photograph courtesy of Provincial archives.*

low as 1 per 100 years for magnitude 6.0 earthquakes. The province has experienced at least 7 other earthquakes, mostly of a minor nature. Apart from the Burin tsunami, two others have been reported, at Bonavista in 1775 as a result of the Lisbon earthquake, and St. Shott's in June 1864. These produced damages to the community, but no reported loss of life.

Holyrood Pond

The stretch of highway that crosses the mouth of Holyrood Pond on the southern shore of the Avalon Peninsula is prone to coastal flooding. Despite the unusually high elevation of the barrier crest (more than 7 m above mean sea level) this road has been washed out at least twice in recent years (during storms in January 1982 and March 1985), and the community of St. Vincent's has been flooded. In an effort to raise the barrier crest and limit future flooding, an artificial gravel ridge and wooden seawall were constructed. The effectiveness of this structure remains to be assessed (cf., Forbes, 1984, 1985; Forbes and Taylor, 1987; Liverman *et al.*, 1994).

OTHER GEOLOGICAL EVENTS

Other geological events, such as meteor sightings, and fireballs are minor occurrences of an unpredictable nature with no damage associated with them. Of greater impact was a sinkhole at St. David's in 1985 that collapsed a driveway. The sinkhole was about 2 m diameter and 6 to 7 m deep. Sinkholes are a hazard on the west coast of the Island, although their distribution is geologically constrained to the southern St. George's Bay and Codroy Valley areas. Incidences of other geological events in Newfoundland and Labrador are given in Table 5.

THE COSTS OF GEOLOGICAL HAZARDS

Estimating the cost of geological hazards is extremely difficult. There is no comprehensive database of geological hazards and the data that exists consists of individual case histories with variable information, especially as to costs.

SOCIAL COSTS

A brief archival search shows that there have been at least 80 lives lost in Newfoundland and Labrador over the last 150 years due to geological processes (Table 6). Of these, 28 were lost during the 1929 tsunami, while the remainder are the result of 27 individual incidents. The list of deaths is not currently subdivided by age, although preliminary data suggests that children are particularly susceptible to certain hazards, particularly landslides.

Table 5. Incidences of other geological events in Newfoundland and Labrador

#	Date	Location	Type	Comments
141	21-Jan-1809	Labrador Coast	Earthquake	Affected land elevations. Changed 3 – 4.6 m in some areas.
142	30-Nov-1836	Hopedale	Earthquake	Tremors felt. Another tremor felt at Hebron in 1857.
143	23-Jul-1890	St. John's	Earthquake	At Signal Hill. Felt by blockhouse guard M. Cantwell.
144	21-Feb-1908	Brooms Bottom near Lark Harbour	Meteor	Meteor came out of the western sky, and descended in the direction of Brooms Bottom, leaving a long fiery trail behind it. May have been the cause of the forest fire between Brooms Bottom and Lark Harbour.
145	6-May-1916	Doyles	Meteor	Meteor reported at Doyles travelling north across valley.
146	15-May-1916	Cape John-Gull Island	Earthquake	Felt at light station, dishes thrown about.
147	18-Feb-1925	Lomond	Earthquake	Felt at 10:55 p.m. Lasted about 10 seconds. Centre was in St. Lawrence area, Quebec.
148	18-Nov-1929	Corner Brook	Earthquake	First slight tremor at 5 p.m. 7 minutes later a second stronger tremor lasted 50 seconds. Sounded like a fast speeding motor. Rattled dishes and broke windows. Telephone poles swayed. Triggered Grand Banks landslide.
149	11-Apr-1940	South Coast	Earthquake	Residents roused by earth tremor. Earthquake felt at Rencontre West and Francois, but no damage reported.
150	5-Jan-1956	Conception Bay	Earthquake/ Tremors	Tremors and a rumbling like thunder was reported by the villages along the shores of Conception and Trinity bays. The shock was felt at 11:20 a.m. and lasted for 1.5 minutes. Dishes rattled, stoves and shelves trembled.
151	2-Feb-1969	Grand Falls	Earthquake/ Tremors	Grand Falls experienced slight tremors at about 1:25 a.m. The shock lasted about 25-40 seconds. Minor damage reported; cracked basements and foundered wells. No injuries reported.
152	26-Dec-1985	St. David's	Sinkhole	Driveway of Mr. Charlie Snow collapsed into an underground cavern. A hole 2-3 m in diameter and 6-7 m deep was formed. About 20 years previous a larger hole appeared in the middle of the road passing through St. David's.

Table 6. Number of lives lost in relation to a variety of geological processes

Type of Disaster	Deaths
Landslide	11
Rockfall	5
Avalanche	34
Coastal flooding	30
TOTAL	**80**

ECONOMIC COSTS

The economic costs of geological hazards and disasters are extremely difficult to estimate. Costs of clean-up are commonly absorbed by municipal and provincial departments, and costs to individuals may be covered by insurance. The only firm costs are those associated with remedial measures taken via a public tendering process (Table 7). Nevertheless, these costs provide a useful estimate of a range of remedial measures that can be used to judge the cost of other non-tendered expenses. The cost estimates ignore any indirect costs, such as those incurred by business through disruption of transportation routes.

DISCUSSION

SOURCES AND REPORTING

The development of a database of geological hazards and disasters is a continuing project. To date, research has focused on archival research, particularly newspaper searches. The Western Star, a weekly newspaper in Corner Brook up until about 1945, and biweekly to daily thereafter, was searched from its inception until 1955 for reports of geological disasters. Items from the east coast and reported in the Western Star were followed-up in the St. John's Evening Telegram or Daily News. For data after 1955, research was concentrated on anecdotal evidence verified in local or regional newspapers, a review of weekly regional papers such as the Humber Log, Gulf News, and The Nor'wester, with specific items being followed-up in the daily newspapers. Government records from the Department of Works, Services and Transportation, Department of Municipal Affairs, and the Department of Mines and Energy have also been partially reviewed. The literature search is far from complete, and has highlighted problems in the reporting of incidents that are reflected in the database.

Major concentrations of incidents of geological disasters are in two main areas, the Bay of Islands and the northeast Avalon. These areas have relatively steep local slopes and historical development pressures that resulted in construction of buildings and transportation routes adjacent to these slopes, thus increasing potential for geological disasters. These areas also produce local newspapers, such as the Western Star in Corner Brook and the Evening Telegram in St. John's. It is thus considered likely that more incidents of a relatively minor nature are reported in these newspapers because they occur within easy access of reporters. Minor events in other communities are less likely to be reported because they are of less relevance to the main circulation group in the larger centres. For instance, in 1994, three landslides occurred on the west coast of the province, at Riverside Drive in Corner Brook, at Little Port in the Bay of Islands and at Port au Port East. Only the Corner Brook incident was reported in the Western Star. The Port au Port East failure was reported on by the regional office of the Department of Municipal Affairs, whereas the Little Port landslide was only reported via a chance visit to the area by Department of Mines and Energy geologists. Therefore, it is probable that a majority of the more minor slope failures to have affected communities are unreported by the media and therefore, are not included in the database.

Geological disasters are commonly reported to Government agencies. Tracing of these reports is hampered by the limited time these files are retained, and lack of definition for the responsibilities of individual departments. If a disaster occurs within a municipality, the Department of Municipal Affairs is commonly requested to investigate. The Emergency Measures Organization of the Department of Municipal Affairs is notified in the event of a major incident or if there is a further threat to life, such as an unstable boulder above a house. Due to storage constraints, most Department of Municipal Affairs files only extend back about 10 years. The Department of Works, Services and Transportation is responsible for maintenance of the highway infrastructure, and reports of incidents within a local district may not be reported to the main St. John's office. When railways ran in Newfoundland, Canadian National had responsibility for the maintenance of the railway network. Records related to railway engineering work have been difficult to locate and probably reside in Moncton, New Brunswick. Flood risk management is undertaken by the Department of Environment. Planning within individual communities is commonly carried out at the municipal level, whereas planning for areas outside municipalities is the responsibility of the Department of Municipal Affairs. The regulatory component of the Department of Mines and Energy is responsible for aggregate extraction adjacent to the coast, and has established set-back limits for extraction. Scientific input from the provincial Geological Survey is in the form of after-the-fact visits to geological disaster sites, and unsolicited reports of geological hazards or disasters encountered in the field. Scientists in other provincial and federal government departments presumably function in much the same way.

Table 7. Cost of remedial measures for geological disasters (data derived from the public tendering process)

Example	Date	Action	Cost Est.	Source
Placentia construction	1992-1993	Extension of sea wall, and construction of back beach flood protection	$3 000 000	Department of Municipal Affairs
Placentia 1982 flood damage	1982	Damage incurred to property	$750 000	Forbes (1984)
Gambo highway slope stability	1988-1992	Construction of stabilization measures	$650 000	Department of Works, Services and Transportation
Springdale rock fall	1984-1986	Construction of retaining wall and fence	$265 000	Boyd (1991)
John's Beach, Bay of Islands landslide	1993-1994	Dewatering of slope to mitigate against road slippage	$250 000	Department of Works, Services and Transportation
Gaultois	1992	Construction of retaining wall, scaling of slope	$155 000	Department of Municipal Affairs
Riverside Drive, Corner Brook landslide	1994	Diversion of drainage from highway via ditches	$63 000	Department of Works, Services and Transportation
Englée landslide	1994	Relocation of house and construction of gabion	$45 000	Department of Municipal Affairs
Chamberlains coastal erosion	1992-1993	Estimates for construction of 50 m of gabions or armour stone	$13 000 to $28 000	Water Resources Division, Department of Environment

RESPONSE TO GEOLOGICAL HAZARDS

Geological hazards, when known, can be dealt with in two ways. First, development or human activity can be diverted away from the hazardous area. Second, the presence of the hazard can be acknowledged and appropriate measures taken. In practice, a third strategy is employed, either through ignorance or deliberately. This is to ignore the presence of a hazard in the hopes that a major problem will not occur.

Geological disasters resulting from geological hazards are avoidable to a varying degree. For instance, in highway construction, steep slopes and thick sequences of unconsolidated sediment can be avoided. In some cases, practical restrictions mean that although a geological hazard is known to exist, it cannot be avoided. Design of development must then take the hazard into account, and incorporate appropriate protective measures. An example of unavoidable geological hazard is road construction in the Humber River gorge, near Corner Brook. The steep slopes adjoining the highway mean that the area is prone to rock fall, avalanche and debris flow. The transportation corridor is confined to a very narrow area, and no practical alternative route exists. Thus, highway design has to accommodate possible slope problems through retaining walls, removal of unstable areas, and appropriate drainage.

The extent to which geological hazards can be taken into account depends on their recognition. In the case of unavoidable hazards, identification will result in additional initial costs, in the hopes of preventing either greater costs, or loss of life. In the case of avoidable hazards, knowledge of the hazard allows better planning decisions to be made in terms of appropriate zoning for development and routing of highways. Most of the incidents described above were avoidable, or at least the effects could have been mitigated with a better awareness of geological hazards. In the cases of the recent mass movements in Corner Brook, Harbour Breton and Springdale, development took place in areas where landslides and rockfalls had previously occurred. Development continues in Placentia, despite the increasing impact of flooding over the last 30 years. An example of an unpredictable and unavoidable disaster was the Grand

Banks tsunami, where the geological or historical records show few tsunami occurrences. However, even here future planning should consider the possibility of tsunami recurrence.

In the Battery area of St. John's, repeated rockfall hazard and avalanche disaster has promoted perhaps the most intense investigation, initially by the provincial Geological Survey and subsequently by the Canadian Avalanche Association; and Newfoundland Geosciences under contract from the City of St. John's. These investigations have resulted in remedial measures being taken by the City of St. John's to protect residents of the Battery.

THE BATTERY – A CASE STUDY

The Battery lies under the slopes of Signal Hill in St. John's. Archival and anecdotal evidence indicates that rockfall is frequent in this area, and that several avalanches have occurred. Based on original archival work this area was selected for further study, and a series of site visits and interviews took place, in collaboration with students at Memorial University.

The first known avalanche took place on February 8, 1921. The avalanche hit the house of Alfred Wells and family, moving it 3 m down slope, ripping off the top storey, and driving the roof down into the room where the Wells family were sleeping. Mr. and Mrs. Wells were pinned in their bed by the falling roof. Mr. Wells, despite having his ribs broken, was able to extricate himself, and rescue their two-year-old son, whose crib was crushed. He returned to free his wife, who had severe back injuries, and to rescue another infant (Geneva) who had nearly smothered under the snow. Numerous other houses were either destroyed or severely damaged. Loss of life was avoided as these dwellings were used only as summer residences during the fishing season. Maps from the City of St. John's archives, and interviews with Geneva Bowering (neé Wells), suggest these houses were located in the Outer Battery.

A second incident occurred 10 days later when Albert Delahunty was killed in an avalanche. His body was found 70 m below his house on Signal Hill, and according to the Evening Telegram report, "his hold on a dinner pail had not relaxed when death overtook him". The location of Delahunty's house is uncertain, but was likely close to the Queens Battery, where no current dwellings exist. He had left the house to walk to work in the midst of a fierce storm, and it seems likely that he lost his way, possibly triggering an avalanche by breaking though a cornice.

There are no records of further avalanches until 1959, when a storm hit St. John's on the night of February 16, with winds reported up to 220 kph, dumping 55 cm of snow. At 1:05 a.m., residents in the Outer Battery heard a sound described as louder than a clap of thunder. An avalanche struck two houses sweeping them downslope (Plate 10). The two houses, belonging to the families of Clarence Wells, and Jim Piercey, contained 14 people. Five people were killed and several injured, including Shirley Noseworthy, rescued after being buried for 10 hours. Elsewhere in the Outer Battery, 11 members of the Garland family were buried by what was apparently an earlier avalanche, and they were trapped until dug out by rescuers. Fortunately, the house was able to withstand the weight of snow, and no injuries occurred.

Plate 10. *View of The Battery following the avalanche of February 1959. This was the second major avalanche to have affected The Battery in 40 years. Several other smaller incidents have been reported subsequently. Photograph courtesy of Shirley Eales.*

Since the 1959 avalanche, no serious incidents have occurred in the Battery, although residents have reported minor rockfall and avalanches. In 1960, another major storm hit St. John's in early March and definitely one, possibly two, avalanches occurred in the Battery, with no injuries. In 1987, an avalanche ripped the porch from the side of a house in the Outer Battery, and residents had to be dug out. Recent concern amongst residents is related to rockfall. The development of Signal Hill as a historic site, and the promotion of the North Head walking trail resulted in increased foot traffic on the steep, unstable slopes above the Outer Battery. Residents believe that several rockfalls were triggered by people on the slope above.

The archival and historical research indicated that a serious risk of avalanche existed in the Battery. Three avalanches involving injury and death are known, and two other potentially serious incidents have been described by residents or former residents. Given the absence of newspaper coverage of the 1987 avalanche, it is possible that several

more avalanches have occurred over the last century. Thus avalanches occur on average once every twenty years at least, and possibly as frequently as every ten years.

A preliminary inspection of the slopes was made in 1995, and a recommendation made that the rockfall hazard should be investigated in detail. Subsequently, consulting reports have confirmed that a rockfall hazard does exist (Newfoundland Geosciences, 1996). The provincial Geological Survey was able to involve Dr. Bruce Jamieson of the Canadian Avalanche Association in further assessments of the slopes with regard to avalanche hazard. Based on the results of his work, and that of the consulting efforts with regard to rockfall (e.g., Golder Associates, 1980, 1992), the City of St. John's constructed safety fences to provide protection from rockfall and avalanche in the Outer Battery (Plate 11) with estimated costs in excess of $300 000.

Plate 11. *Fencing constructed above the Outer Battery in 1998. The initiative for this protection came from work by the Geological Survey that highlighted the history of avalanche and rockfall in this area. This demonstrates the impact that baseline data can have on planning decisions within municipalities.*

SCIENTIFIC APPROACHES TO GEOLOGICAL HAZARDS

At least 80 people have been killed in Newfoundland by geological-related disasters, including landslides, avalanches and tidal waves. The economic cost is difficult to estimate, but remedial measures for individual events range from $20 000 for the construction of 50 m of gabions and retaining walls, to $3 000 000 for large-scale coastal flood-protection measures. Many of these costs are unavoidable considering the geography of the province, and development of communities and infrastructure adjacent to steep slopes. However, at least some of the remedial measures taken have been in areas with a history of incidents, but where development was still allowed to proceed. In these cases, it is commonly government that incurs the expense.

The lack of coordination between regulatory agencies, and between the scientific and regulatory bodies, reduces the effectiveness of the planning process at the municipal and provincial level. Planning decisions are likely made without adequate scientific input. Data on previous geological events may not be on file because incident reports are discarded after a period of time that may be too short to show the frequency of geological events. A rockfall event, for instance, may have a 50- or 100-year recurrence interval; a tsunami may have a 100- to 1000-year frequency. Similarly, the lack of a provincial coastal management plan, which might use data on coastal erosion rates and relative sea level change, will likely mean that development may continue in potentially vulnerable areas.

The ideal way to reduce the costs incurred by geological disasters is to improve our knowledge of them. The initiation of a project by the provincial Geological Survey may ultimately lead to the production of maps outlining areas vulnerable to geological hazards that will be a useful input to the planning process. The archival research that continues is leading to the development of an extensive database of previous hazards documenting places, times, damages, and costs. Given a basic understanding of the geological factors involved in these hazards, potentially vulnerable areas can be identified. For example, any area with the combination of steep slopes and thick surficial coverage may be prone to landslides. When these factors are combined with areas of settlement and development, possibly in a Geographic Information System, vulnerability can be identified. Once broad vulnerable areas are identified, more detailed work is required. The geological evidence of hazards is commonly visible on aerial photographs, through landslide scars and fallen blocks, and the causes and historical frequency of rockfall and landslide events can be defined through standard methods of Quaternary geology, such as lichenometry and dendrochronology. The aim of geological hazard mapping should be to substantially reduce the cost of geological hazards and disasters to government, through application to the planning process. The experience with the Battery in St. John's has demonstrated that archival research can play an important role in municipal planning.

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