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THE ASSESSMENT OF GEOLOGICAL HAZARDS AND DISASTERS IN NEWFOUNDLAND

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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 affected by numerous geological disasters that have inflicted a major economic and social cost. At least 69 people have been killed in Newfoundland since 1863 by geologically related disasters, including landslides, avalanches and tidal waves. The economic cost is difficult to estimate, but expenditures for 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 are unavoidable and are the inevitable result of geography. However, some are 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 initiation of a geological hazard project by the Geological Survey may ultimately lead to the production of maps outlining areas vulnerable to geological hazards, which will be a useful input to the planning process. Geological hazard mapping will provide a long-term direct benefit to the government through savings on expensive preventative measures and will reduce hazard-related injuries and fatalities.

INTRODUCTION

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 seismically inactive area, and because of the low population densities. Geological disasters and hazards, however, still inflict a significant economic and social cost to the province. Such disasters are to differing degrees avoidable or preventable, if the hazards are identified.

To help identify geological hazards, the Geological Survey has initiated a project to examine the nature and extent of past geological disasters in the province. The initial focus is on archival research that documents the location (Figure 1), type, frequency and social and economic costs of disasters.

The initial findings of this review are reported below. They document the nature and extent of geological disasters, and show the estimated cost involved in remedial measures.

TYPES OF GEOLOGICAL HAZARDS AND DISASTERS IN NEWFOUNDLAND

SLOPE STABILITY

Slope stability or mass-movement problems occur where either unconsolidated sediment, rock, or snow, singly or in combination, moves 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

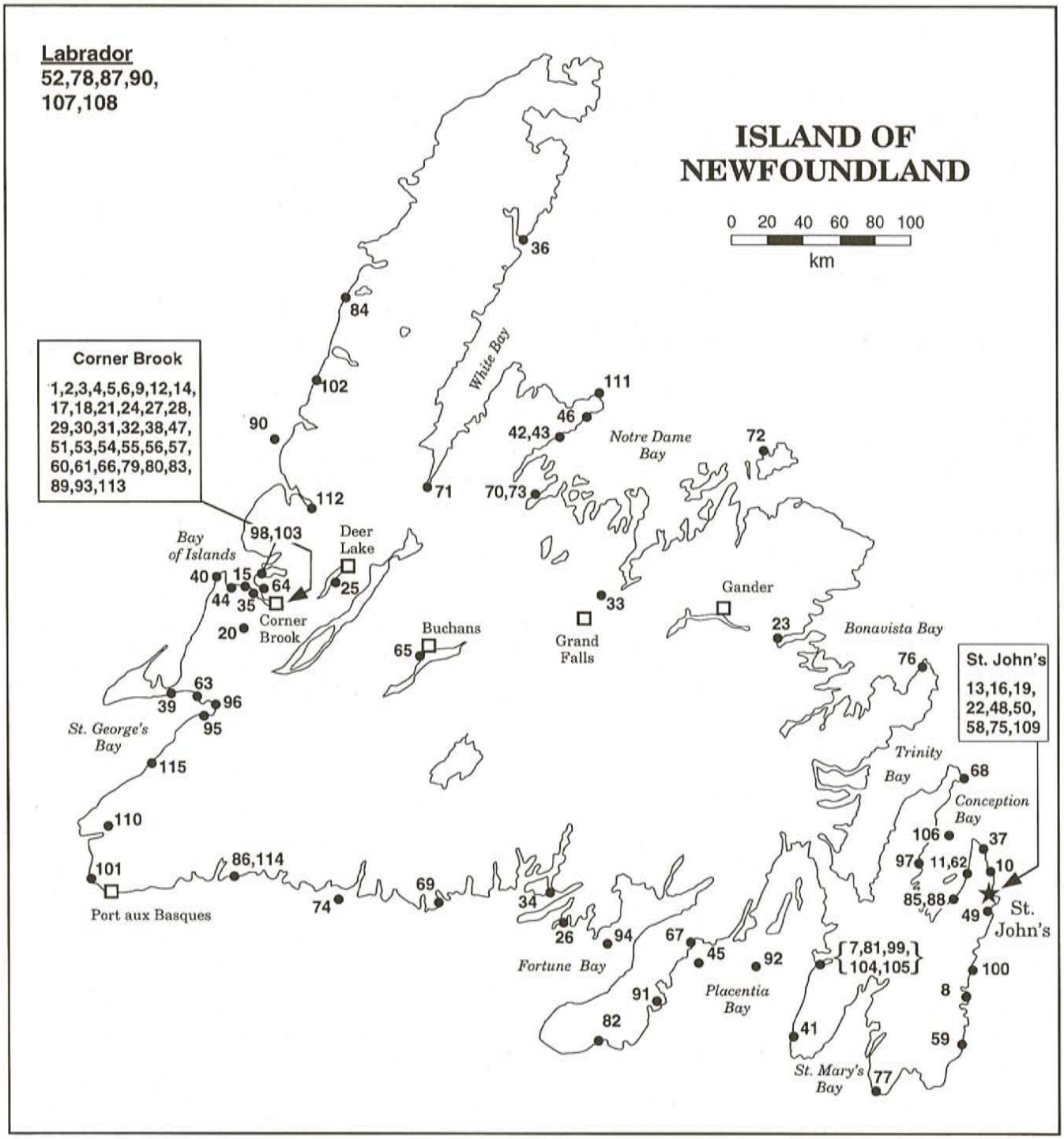

Figure 1. *Location of incidents of geological disasters in Newfoundland.*

material beyond its shear strength, at which point movement occurs. The water may also act as a lubricant and movement is commonly 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 with 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 (# 19)

On September 15, 1948, following a rainstorm that dumped 11.5 cm (4.5") of rain in 18 hours on the St. John's area, a debris torrent damaged a number of houses on Southside Road (Plate 1), and caused a young 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

Table 1. Incidences of landslides in Newfoundland and Labrador

#	Date	Location	Deaths	Injuries	Comments
1	29-Jan-1901	Mount Moriah, Bay of Islands			Followed downpour. Slide between 1 and 3 p.m. at the base of Mount Moriah. Worst landslide in history of Newfoundland railway. Thousands of tons of rock, clay and trees covered 50 m of track 4 m deep. Railway blocked for three days.
2	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.
3	28-Nov-1906	Between Cook's Brook and Benoits Cove			Caused by recent rain storms. Large trees uprooted, telegraph poles toppled, and tons of clay and boulders swept down the steep hillside. Roadway blocked.
4	7-Jan-1909	Mount Moriah			Considerable quantities of clay and rocks undermined by storm fell on road. Fixed quickly, no delay to train.
5	27-Oct-1914	Duncans Rock, 3 miles east of Corner Brook			Hundreds of tons of debris came down mountain carrying away several lengths of track and telegraph lines and poles. Rail service effected.
6	12-Jun-1915	Mount Moriah			Several huge boulders rolled down mountain side and crippled railway. Rail line was quickly cleared.
7	3-Oct-1923	Placentia area			Storm caused landslides along Placentia branch railway line. On Burin Peninsula, flakes and stages destroyed during same storm event.
8	29-Dec-1923	1/4 mile west of Cape Broyle			Landslide on Trepassy railway, near Cape Broyle. Engine buried in avalanche of snow and gravel, and box car swept down embankment. Crew and 30 passengers not severely injured.
9	5-May-1930	Crow Gulch, Corner Brook			Small landslide at Crow Gulch. Interfered with last coach of the day.
10	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.
11	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 yard of some dwellings. Several of the boulders were weighed up to 2 tons.
12	1-Dec-1930	Shellbird Island, Humber River			Landslide blocked railway at Shellbird Island. Two freight trains delayed.
13	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.
14	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 blasted.

Table 1. *Continued*

#	Date	Location	Deaths	Injuries	Comments
15	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 belonging to a man named Green was destroyed.
16	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 had slight injuries. Both children were forced through kitchen floor.
17	20-Apr-1940	Humbermouth, Corner Brook	1		Ditcher was clearing previous slide, that occurred on April 20, when a second slide occurred and carried the machine over a 25 foot embankment onto road below. Stanley Penney was badly burned from broken steam pipes. He died in hospital.
18	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 4.38 inches of rain.
19	15-Sep-1948	Southside Road, St. John's	1	1	Followed heavy rainfall debris swept through walls of house. Mohrine Windsor, aged 3 was killed and another child injured. During same storm tons of gravel washed downslope from St. Clare's Hospital down Patrick Street. Quidi Vidi Lake rose 6 feet. In Mill Bridge area debris washed over railway right of way.
20	9-Mar-1950	Table Mountains			Rock and snow crashed over telegraph lines on Table Mountains. Services were disrupted between Corner Brook, Gander and St. John's. Severed all communications between province and mainland.
21	22-May-1950	Petries Crossing, Curling			An A-frame storehouse was carried on the crest of a landslide about 50 feet downslope and ended up a broken wreck. One boat half buried and another ended up in the water. Road closed for three days.
22	?-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.
23	23-Oct-1953	Gambo	1	1	Carl Goulding, aged 14 and two friends were buried by slide while they were playing in a sand pit. One was buried up to neck, but survived.
24	15-Nov-1954	Buckles Valley Road, Corner Brook			Bob French and Harry Phillips were investigating a water leakage at the rear of the Thorne Building, when several tons of gravel broke away from the bank. Debris slid down the road, sweeping away a power line, 20 feet of boardwalk, an Avalon Telephone shack and the verandah of the Beson home.
25	2-May-1970	Pynn's Brook, 25 miles east of Corner Brook			Landslide blocked rail line at Pynn's Brook. Washout was quite extensive and crews were using rock and timbers to make line passable.

Table 1. *Continued*

#	Date	Location	Deaths	Injuries	Comments
26	1-Aug-1973	Harbour Breton	4	?	Following a period of heavy rain, a debris torrent occurred at about 3 a.m. in a gully above the community. 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. 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.
27	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.
28	28-Sep-1975	Irishtown, Bay of Islands			Bank under the corner of Frank Hunts house gave way causing part of the floor to drop and the walls to twist as the house moved along the bank approximately 2 feet. Family of eight were home at the time but no one was hurt.
29	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 backhoe, a landslide occurred, burying the machine until only the smoke stack 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 Highway at Mount Moriah. 1.25 inches 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.
30	?-May-1979	Gillams			Elie Park of Farm Road was shook out of bed at 4 a.m. when landslide came tumbling down a hill near his property. Wood shed 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 which pose a threat to his property.
31	2-Dec-1982	Quarry Hill, Curling Road			Slope movements above a 350 foot section of Ring Road. A failure tension crack had developed 100 feet above the road within an old landslide scar. Crevasses appeared on the surface. Many of the blocks are perched on others in a relatively unstable position.
32	19-May-1985	Shellbird Island, Humber River			Highway closed for several hours. Estimated that 100 cubic metres of material involved. Build up of water behind the railway tracks and seepage into the bank was probably the cause of the failure.

Table 1. *Continued*

#	Date	Location	Deaths	Injuries	Comments
33	16-Apr-1986	Bishops Falls			30 to 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 had been occasional boulders tumble down the hillside before.
34	15-Sep-1992	Gaultois			Slide occurred on generally bedrock slope after period of heavy rain. Landslide mostly rocks and surface vegetation. Damaged walkway, water main, fuel lines. Repairs included clearing slope of debris and construction of retaining wall on slope. Cost $155 000.
35	15-Apr-1993	John's Beach			Area of rotational slumping. Cost to undertake dewatering of slope approx. $250 000. Previous slides experienced in this area.
36	15-Oct-1993	Englee			Occurred about 1:30 am. Rocks collided with the home of Mr. Ralph Talbot and did extensive damage. Further rock slides appeared likely so the house was relocated. A gabion wall was constructed to protect adjacent road. Cost of relocation was estimated at $15 000, and gabion and scaling of slope etc. estimated at $25 000 for total of $40 000.
37	6-Nov-1993	Shoe Cove			Small rockslide damaged shed of Mr. Wimbleton. Considerable danger of more falling debris, but no action taken yet due to jurisdictional problems.
38	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. Landslides followed a period of intense snow melt. 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 truncated 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.
39	25-May-1994	Romaines, Port au Port			A period of heavy rain led to saturation of sediment resulting in slope failure. Remnants of the torrent are seen by a large debris fan on the beach. Trees were visible up to 100 m offshore.
40	7-Jul-1994	Little Port, Bay of Islands			Landslide during heavy rainstorm about July 7, 1994. About 60 to 70 cm of material removed from slope over 100 m long by 15 to25 m wide section. Landslide blocked road and took 5 hours to clear.

landslides on October 13, 1934 and in October 1953 damaged property and disrupted transportation routes. The construction of the Harbour Arterial Road has largely alleviated the landslide threat in this area.

Harbour Breton (# 26)

On August 1, 1973, following several weeks of heavy rainfall, a debris torrent occurred at about 3 a.m. in a gully

Plate 1. *A gully behind the Windsor house on Southside Road. Material washed down this gully caused considerable damage to the house. Photograph courtesy of the City of St. John's archives.*

above the community of Harbour Breton (Plate 2). Four houses were swept into the harbour and destroyed, resulting in four young fatalities. Slope movements continued for 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. In 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 2. *Landslide scar in Harbour Breton, August 1973. Wreckage from the remains of four houses caught in the landslides path is seen at the water line.*

Riverside Drive, Corner Brook (# 38)

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 attributed to inadequate drainage from the newly constructed Trans-Canada Highway in the area (Newfoundland Geosciences, 1994). During construction, a major drainage ditch was truncated 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, but 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. 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, typically with sediment or rock. 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.

Tilt Cove, Baie Verte Peninsula (# 46)

An avalanche, on March 11, 1912, destroyed 2 houses that were located at the base of a steep slope (Plate 4). Five fatalities resulted, including the local mine manager. The mine manager's wife and two daughters survived. Anecdotal

Table 2. Incidences of avalanches in Newfoundland and Labrador

#	Date	Location	Deaths	Injuries	Comments
41	12-Mar-1863	Distress Cove, Placentia Bay	2		John and William Foley smothered in avalanche while duck shooting.
42	9-Feb-1877	Betts Cove	6		Overwhelmed 2 houses containing 34 persons. Five killed instantly and one fatally injured.
43	27-Jan-1884	Betts Cove	1		Buried and killed Sergeant J. Fennessey.
44	13-Feb-1905	York Harbour		2	Buried two men, Thomas Burton, chief engineer and James Flynn, second engineer—both from the mine. Dug out and took 3-4 days off work.
45	12-Mar-1907	Foots Cove, Burin Peninsula	?	2	Two houses at base of 100 m cliff 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.
46	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. Many said houses dangerously placed, though the owners thought otherwise and made light of an accident happening. Williams' wife and two daughters escaped.
47	31-Dec-1917	Shellbird Island, Humber River	1		Joshua Peddle, section foreman at Humbermouth, was killed as snow swept down mountainside into river.
48	7-Feb-1921	The Battery, St. John's	1?	2+	Occurred during night. Several hundred tons snow demolished house of Alfred Wells in Lower Battery. He was injured and wife 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.
49	17-Feb-1921	Petty Harbour			Avalanche destroyed 70 feet of flume at Petty Harbour, resulting in the loss of power for four days in St. John's.
50	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 200 feet below. His hold on a dinner pail had not relaxed when death overtook him.
51	2-Jan-1922	Rapid Pond or Little Rapids			Avalanche derailed train. Baggage car swept from track into pond. Engine had passed and was undamaged. Forty people on train but no one was hurt.
52	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.

Table 2. *Continued*

#	Date	Location	Deaths	Injuries	Comments
53	4-Mar-1935	Corner Brook, Curling Road	3		Mrs. Blanche Diamond and one child killed instantly. Another child died in hospital. Snow slide moved 2-story house 30 feet downslope until it crashed into another home. Avalanche started 300 feet above house.
54	4-Feb-1938	Quarry Hill, Corner Brook			Started several hundred feet up eastern slope of quarry hill during heavy snow storm. Crossed road and wrecked garage owned by George Allan. Hit four houses but no damage was reported.
55	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 weight of snow. House stopped by electrical wires, otherwise would have fallen over cliff into Crow Gulch. House owned by Mr. Harry Barnes covered by snow. House owned by Mrs. Herbert Wheeler and 5 children also damaged.
56	2-May-1952	Shellbird Island, Humber River			Small avalanche blocked rail line. No damage reported but train was forced to return to Deer Lake.
57	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 repeats itself every year.
58	16-Feb-1959	The Battery, St. John's	5	9	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 were 100-year-old Isaiah Dawe.

evidence suggests that local residents felt that the houses were dangerously placed, but their advice was ignored.

The Battery, St. John's (# 58)

Two avalanches occurred in the Outer Battery, on Monday, February 16, 1959, 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 a family in their home, but all survived. The main avalanche was at 1:05 a.m. It destroyed two homes and damaged many others (Plate 5), and resulted in the death of five people and injury to at least nine others. This was one of the worst natural disasters in Newfoundland. It was the second avalanche incident at The Battery in 40 years, the first being February 7, 1921 when several people were injured and possibly one killed.

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 rockfalls in Newfoundland and Labrador are given in Table 3.

Springdale (# 73)

Expansion of the town of Springdale led to the 1972 development of a new sub-division adjacent to a highly fractured basalt cliff. Several incidents of rockfalls from this cliff, subsequent to the sub-division development, had resulted in property damage when boulders struck houses and

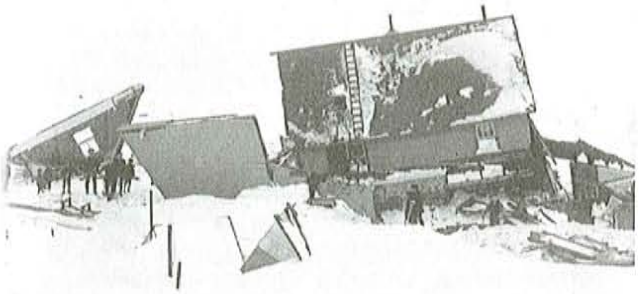

Plate 4. *Remnants of the mine managers house following an avalanche in Tilt Cove in March, 1912. The avalanche resulted in five fatalities, including the mine manager. Photograph courtesy of the Provincial Archives.*

Plate 5. *View of rescue efforts following The Battery avalanche, February 1959. This was the second major avalanche to have effected The Battery in 40 years. Photograph from the Daily News, February 17, 1959.*

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).

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), 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 (Plate 7). 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).

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 storms, 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). 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 high) 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 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 has contracted a detailed photogrammetric survey of this area to evaluate erosion rates (Forbes *et al.*, *in press*). 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 x 200 x 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.

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

Table 3. Incidences of rockfalls in Newfoundland and Labrador

#	Date	Location	Deaths	Injuries	Comments
59	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.
60	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 2-3 feet from Edwin Knight's house.
61	8-Apr-1927	Crow Gulch, near Corner Brook			Large stone rolled down embankment and landed on railway. Train stopped before hitting rock.
62	25-Aug-1935	Portugal Cove	1		Dorothy Summerton, aged 6, crushed by a boulder she was climbing over, while collecting flowers for her grandmother's grave.
63	10-Apr-1942	Indian Head		1	Charles James of Benoits Cove while drilling at Indian Head had collar bone and left leg broken when stone slid down hillside.
64	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.
65	27-Mar-1953	Rothermere Mine, Buchans	1		Arthur Perrier killed by a fall of rock while drilling in a slope at the Rothermere Mine.
66	10-May-1955	Mount Moriah			Large boulder smashed track in 2 places after breaking free from mountain side. Two sections of track had to be replaced.
67	7-Dec-1973	Rushoon, Placentia Bay			Precariously perched boulder above a house.
68	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.
69	15-Jun-1975	François			Slope stability problem caused by falling rock behind the home of Ronald Dunford of François. In spring 1973, a large stone tore off the power metre and knocked a large hole in the skirting. In June/July 1973, a home was struck on the skirting, dislodging a concrete shore.
70	15-Jul-1975	Springdale			At the rear of Taylor's subdivision, houses were built at the base of a 200 foot cliff. The first rockfall occurred in July 1975, when a large boulder almost hit a house. No injuries or damage. A second rockfall in January 1976 damaged a pickup truck, and a house. No injuries reported.
71	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 that had fallen from the hillside.
72	28-Feb-1984	Fogo			Potential for rock fall 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.

Table 3. *Continued*

#	Date	Location	Deaths	Injuries	Comments
73	28-Apr-1984	Springdale	1		Jeffrey James Cull, aged 16, of Carmanville was killed while climbing on the slope face. He was crushed when a large (1 m) block (2000 lbs) detached from the face and pinned him into a crevice, 200 feet from the bottom of the hill.
74	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.

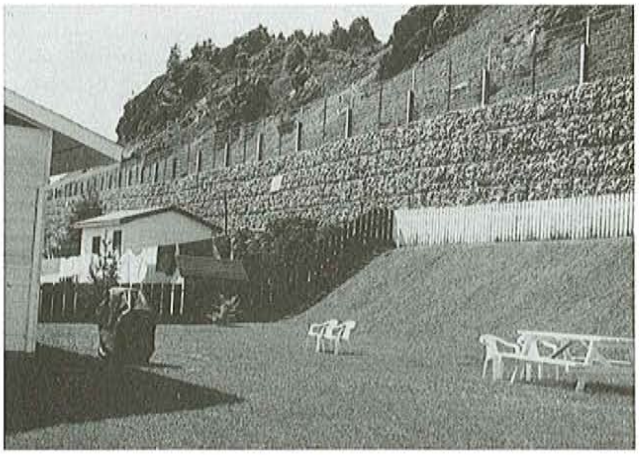

Plate 6. *Retaining wall constructed in Taylor's sub-division, Springdale at a cost of $286 000. The sub-division was built at the base of a highly fractured basalt cliff.*

Plate 7. *Slope failure occurring behind a newly constructed retaining wall at Gambo.*

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 geologically related disaster in the province's history was one of coastal flooding, associated with the Grand Banks tsunami, which struck the Burin Peninsula in 1929. Incidences of coastal flooding in Newfoundland and Labrador are given in Table 4.

Placentia (# 81, 92, 104, 105)

Possibly the most vulnerable area to coastal flooding in the province is Placentia. Placentia has a history of flood 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 runup 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 (# 91)

The Burin Peninsula has numerous communities situated at low elevations behind barrier beaches on a coast where sea levels are rising. Coastal protection measures have been constructed in a number of vulnerable areas, including the site of recent Provincial Park development 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 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.

Plate 8. *Landslide in coastal cliffs at Port au Port East. Note the alluvial fan that developed on the beach as debris was washed from the gully.*

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) suggested that earthquakes of the magnitude that triggered the 1929 tsunami is 1 per 1000 years, but could be as low as 1:100 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 material damage 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 RELATED EVENTS

Other geological events, such as meteor sightings, and fireballs are minor occurrences of an unpredictable nature with no damage associated with them (Table 5). 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 Flat Bay and Codroy valley areas.

THE COSTS OF GEOLOGICAL HAZARDS

Estimating the costs of geological hazards to the province 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.

Table 4. Incidences of coastal flooding in Newfoundland and Labrador

#	Date	Location	Deaths	Injuries	Comments
75	11-Jan-1775	St. John's	?	?	Severe gale. Sea suddenly rose 30 feet. People killed on land (numbers unknown). Fishermen afterwards commonly dragged up 20 to 30 bodies in their nets.
76	?-?-1775	Bonavista	?	?	Probable result of Lisbon earthquake. Drained 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.
77	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.
78	10-Oct-1885	Labrador Coast	?	?	The Great Labrador Gale. Long period of stormy weather that eventually produced 120 mph 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.
79	29-Nov-1901	Humber Arm			Property damage at the mouth of Humber River. Brakes house flooded. Railway at Grand Bay (Barachois) 5 miles east of Port aux Basques, had about 100 yards washed away by waves.
80	27-Dec-1901	Corner Brook			High tide. Undermined railway for about 50 yards, and delayed train.
81	10-Jan-1912	Placentia-Point Verde	1		Charles Cosgrove apparently swept out to sea by huge waves whilst heading for Ship Cove after a wedding in Placentia.
82	5-Mar-1916	Lawn			Big storm occurred on March 5th and 6th. Destroyed Grants new store. Very high tide. Damage reported to other places along Burin Peninsula.
83	8-Sep-1916	Bay of Islands			Culverts blocked. Humber River rose five feet in five hours. Bridge destroyed.
84	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, and Island Cove. Little Harbour Head lighthouse ice covered (200 foot high). $15 000 damage. Stores, stages etc. also damaged at Rocky Harbour and Trout River.
85	30-Oct-1921	Kelligrews			Sea washed considerable distance of rail line. Damage also reported at Lumsden, Musgrave, Ladle Cove, Carmanville and Indian Head.

Table 4. *Continued*

#	Date	Location	Deaths	Injuries	Comments
86	23-Jan-1925	South Coast			Shoreline from Fortune Bay to Port aux Basques ravaged by storm. Considerable damage onshore, but most offshore.
87	23-Dec-1925	Battle Harbour			Property destroyed by storm. Most damage to stages and storage sheds.
88	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 yards.
89	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 3-4 feet 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.
90	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.
91	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).
92	7-Dec-1931	Placentia Bay			Severe gale. Prowseton and Davis Cove had higher tides than during the '29 quake. Wharves and flakes were destroyed. Four houses were flooded. Placentia also damaged (by 'tidal wave').
93	9-Feb-1933	Humber Arm			High winds and 'tidal wave'. At Curling, stores along waterfront were flooded. At Humbermouth, water entered houses. At Petries, Gillams, Middle Arm and McIvers considerable damage to property. At Sandy Point (Flat Bay Island), tide swept over and through breakwater flooding many houses. In St. George's Bay 40 feet of dump washed away and delayed train for 2 days.
94	18-Nov-1937	Brunette Island			Shore swept of wharves, stages and fishing equipment. Boats washed over beach into pond. Damage estimated at one thousand dollars.

Table 4. *Continued*

#	Date	Location	Deaths	Injuries	Comments
95	24-Oct-1938	St. George's			Grim sea. $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.
96	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 closed for three days. Over 600 people were evacuated. West Street was under 1.2 m of water. Winds of 110 miles per hour 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. Worst storm since tidal wave. Storm washed thousands of lobsters ashore.
97	11-Jan-1955	East Coast, St. John's, Carbonear			Worst storm in memory battered East Coast. Surging waves sent water 200 feet in the air against the steep cliffs around St. John's Harbour. In St. John's, 12 wharves and two small boats destroyed at an estimated cost of $12 000. At Carbonear 40 feet of railway was washed out to sea. Breakers shot water over the dome at Fort Amherst, 132 ft asl.
98	27-Nov-1955	Cox's Cove			Coastal flooding coupled with increased stream runoff damaged community.
99	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.
100	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. Community was resettled following storm.
101	20-Oct-1974	Cape Ray			Wind Storm. High seas at Cape Ray washed out about 100 feet of railway track causing derailment of 2 diesel locomotives. Wind caused $1000 damage in Port aux Basques.
102	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.
103	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 Parson's Pond and Stephenville Crossing, through waves breaching barrier beaches.
104	?-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.

Table 4. *Continued*

#	Date	Location	Deaths	Injuries	Comments
105	?-Dec-1983	Placentia			Severe flooding occurred during storm. Remedial measures in the Placentia area later cost in excess of $3 000 000.
106	10-Oct-1992	Conception Bay			Severe storm produced considerable damage to property along much of Conception Bay shore. Numerous boats sunk or damaged. Barrier bars overtopped or breached. Coastal cliffs eroded.

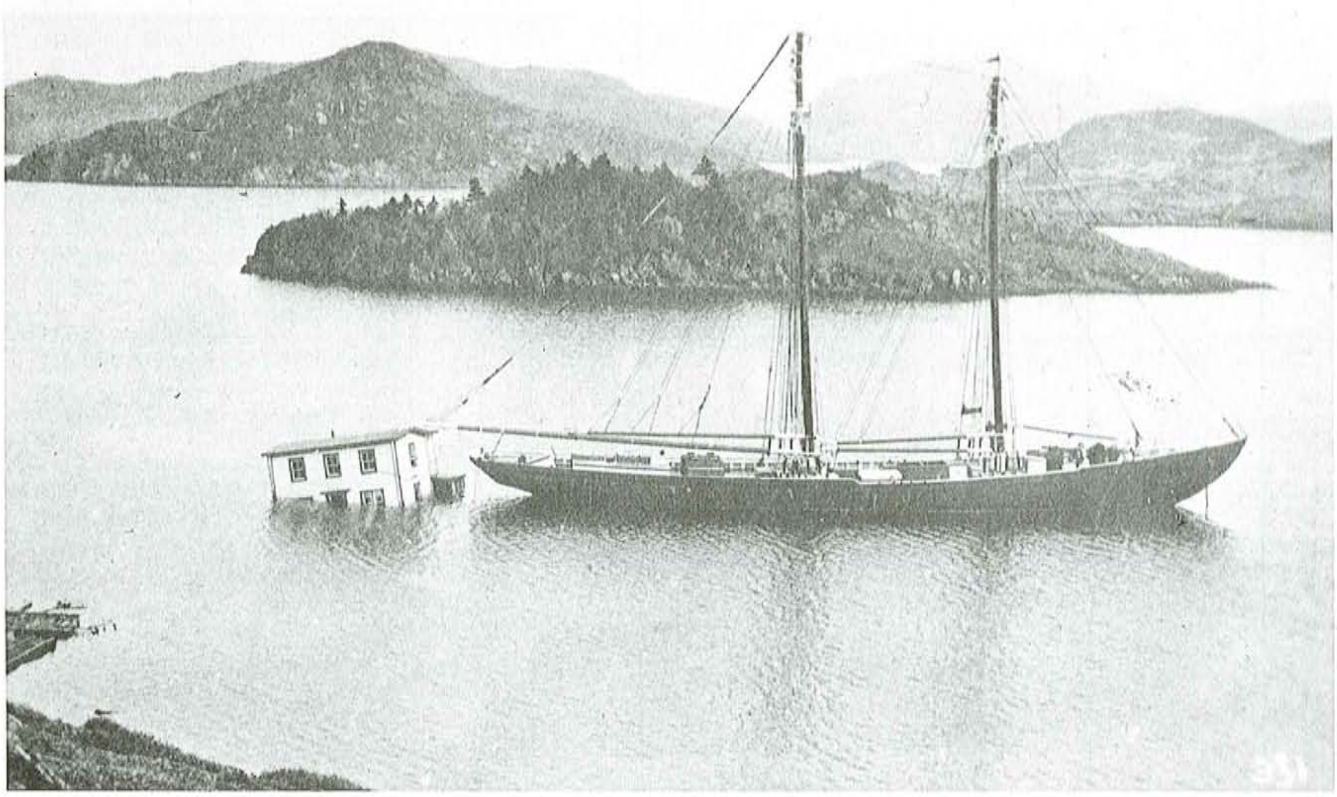

Plate 9. *Schooner moored to house that had been washed out to sea during the Burin tsunami, November 1929. The tsunami caused 28 deaths in Newfoundland and was the worst earthquake-related disaster in Canadian history. Photograph courtesy of Provincial Archives.*

SOCIAL COSTS

A brief archival search shows that there have been at least 69 lives lost in Newfoundland and Labrador over the last 150 years where geological factors were involved (Table 6). Of these, 28 were lost during the 1929 tsunami, while the remainder are the result of 22 individual incidents. The list of deaths is not currently subdivided by age, although preliminary data suggests that children and the elderly are less likely to survive certain disasters, particularly landslides, than adults.

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

Table 5. Incidences of other geological events

#	Date	Hazard	Location	Deaths	Injuries	Comments
107	21-Jan-1809	Earthquake	Labrador Coast			Affected land elevations. Changes 3–4.6 m in some areas.
108	30-Nov-1836	Earthquake	Hopedale			Tremors felt. Another tremor felt at Hebron in 1857.
109	23-Jul-1890	Earthquake	St. John's			At Signal Hill, felt by blockhouse guard M. Cantwell.
110	6-May-1916	Meteor	Doyles			Meteor reported at Doyles traveling north across valley.
111	15-May-1916	Earthquake	Cape John-Gull Island			Felt at light station, dishes thrown about. Distinctly felt.
112	18-Feb-1925	Earthquake	Lomond			Felt at 10:55 p.m. Lasted approx. 10 seconds. Centre was in St. Lawrence area, Quebec.
113	18-Nov-1929	Earthquake	Corner Brook			First tremor at 5 p.m. was slight. 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.
114	11-Apr-1940	Earthquake	South Coast			Residents roused by earth tremors. Earthquake felt at Rencontre West and François, but no damage reported.
115	26-Dec-1985	Sink Hole	St. David's			Driveway of Mr. Charlie Snow collapsed into an underground cavern. A hole 6-8 feet in diameter and 20-22 feet deep was formed. In the woods nearby at least 10 holes are located, one about 70-100 feet in diameter. About 20 years previous a larger hole appeared in the middle of the road passing through St. David's.

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

Table 6. Deaths from geological disasters

Type of Disaster	Deaths
Landslide	8
Rockfall	5
Avalanche	26
Coastal Flooding	30
TOTAL	69

Table 7. Cost of remedial measures for geological disasters, largely 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	Repairs 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 landslide	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
Englee landslide	1994	Relocation of house and construction of gabion	$45 000	Department of Municipal Affairs
Chamberlains coastal erosion	1992-1993	Construction of 50 m of gabions or armour stone	$13 000 to $28 000	Water Resources Division, Department of Environment

Telegram or Daily News. For data after 1955, research has 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 Natural Resources 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 (Figure 1). 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 impacted communities 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 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 Natural Resources 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 extend back only 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. 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 assessment 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 Natural Resources is responsible for aggregate extraction adjacent to the coast, and has established set-back limits for extraction. Scientific input from the 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 government departments presumably function in much the same way.

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 extent. 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 an 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 may result in additional initial costs, in the hopes of preventing either greater costs, or loss of life in the future. 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 rockfall 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. Even here however, future planning should consider the possibility of tsunami recurrence.

SCIENTIFIC APPROACHES TO GEOLOGICAL HAZARDS

At least 69 people have been killed in Newfoundland and Labrador by geologically-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 cost of remediation.

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 with a responsible agency to which data on coastal erosion rates and relative sea level changes can be filed, 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 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 currently underway 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 rock-fall 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.

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