Geological Hazards and Disasters in St. John's

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INTRODUCTION

IN TERMS OF ITS NATURAL ENVIRONMENT St. John's is considered to be one of the safest cities in North America in which to live. However, more than any other major Canadian city, St. John's has experienced floods, rockfalls, avalanches, and landslides, sometimes with deadly consequences. This conclusion is derived from information gathered from newspaper reports reviewed as part of a project carried out by the Geological Survey of Newfoundland and Labrador (Batterson et al. 1995, Liverman et al. 2001). The larger purpose was to create a preliminary database of geological disasters that had occurred throughout the province, in order to assess their importance and their economic and social costs. One finding was that the combination of climate, geology, and topography in St. John's results in an unusually high risk of accident through geological processes.

By far the worst natural disasters in Newfoundland and Labrador have affected those who work in and by the sea, where the effects of storms and ice have resulted in the loss of many lives. Though St. John's is sheltered from the worst effects of storms, it has not been immune from the impact of marine disaster. The great storm of 12-16 September 1775 apparently killed many people (Stevens and Staveley 1991, Ruffman 1995), and it was reported that St. John's fishermen hauled up 20 to 30 bodies in their nets in the following weeks. In 1955, multiple storms damaged wharves and small boats in St. John's, with waves sending water 60 metres (200 feet) into the air as they struck the cliffs around the Narrows (*Western Star*, 11 January 1955).

NEWFOUNDLAND AND LABRADOR STUDIES 21, 1 (2006)
1719-1726

In global terms, some of the worst natural disasters are associated with earthquakes and volcanoes. Newfoundland has been free of active volcanoes for at least 400 million years. Although earthquakes are rare, there are two recent examples. An earthquake was recorded on 23 July 1890, when Signal Hill blockhouse guard M. Cantwell reported perceptible tremors. Far more significant was the disaster which occurred on 18 November 1929, when a tsunami generated by an earthquake and landslide on the Grand Banks hit the Burin Peninsula. Twenty-seven people lost their lives on that exposed coast, but St. John's, where the high water was recorded, was protected from the worst effects.

The city has been affected less by marine impacts than by natural events more usually associated with the Rocky Mountains, such as landslides, rockfalls, and avalanches. Few lives have been lost, but such incidents are significant hazards that must be considered in future planning and emergency preparedness. The combination of severe weather, precipitation, and steep slopes found in St. John's and many places in Newfoundland, creates hazards and thus occasional disasters. Many processes involve the movement of material down steep slopes but only three are considered here because of their destructive potential. Each has a distinctive character.

(1) A landslide (debris flow) occurs when a water-saturated mass of soil, rock, and vegetation moves down a slope under the influence of gravity. Landslides occur on steep slopes that are composed of unconsolidated sediment or weak, badly fractured bedrock and are often triggered by heavy rainfall. The movement is rapid and destructive.

(2) Rockfalls occur on cliffs or steep rocky slopes and are caused by the detachment of loose blocks of bedrock that topple, bounce, and roll down the slope. Frost action is commonly a major factor, with repeated freeze-thaw cycles wedging open cracks and fissures.

(3) An avalanche occurs when a mass of snow moves rapidly down a slope. There are various avalanche types, but all are dangerous (an average of seven deaths per year result from avalanches in Canada). The exact weather conditions that cause avalanches vary but always involve heavy snowfall.

Several geological disasters have occurred on the northeast Avalon, including avalanches in Petty Harbour; landslides in Pouch Cove, Outer Cove, and Torbay; and serious rockfalls in Portugal Cove. In St. John's these slope hazards are concentrated in two main areas: the Southside Road, and The Battery (Figure 1).

The City of St. John's is underlain by late Precambrian (Ediacaran) sedimentary and volcanic rocks, assigned to the units designated by geologists as the St. John's and Signal Hill Groups (King 1992). The softer shales and argillites of the St. John's Group are more easily eroded than the more resistant sandstones and conglomerates of the Signal Hill Group that form the Southside Hills, and underlie The Battery and Signal Hill. A fault zone oriented along the Waterford Valley resulted in steep slopes, as glaciation eroded the weaker units (King 1990). The southeast side of the Waterford River valley rises 70 to 150 metres up to the Southside Hills,

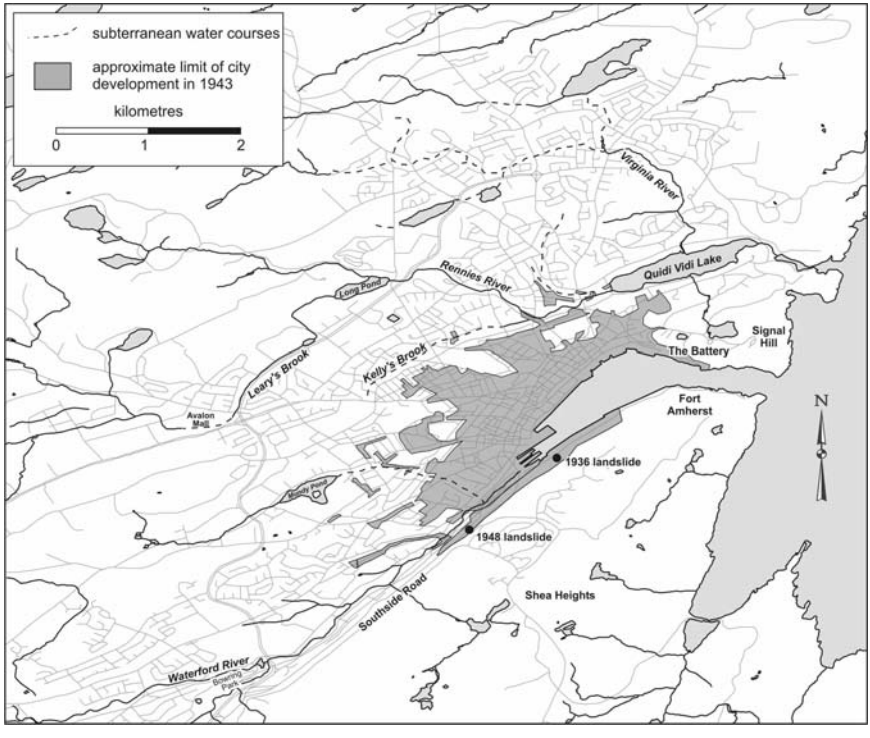

Figure 1. Map of St. John's showing main locations named in text.

with slopes to 45° or more. The slopes are mostly rock, with a thin mantle of glacial debris (till) in places (Batterson 1984). Elsewhere in the city, the geology resulted in the formation of relatively gentle slopes. Although the visitor to St. John's may feel otherwise, walking along some of the downtown streets, this area is not vulnerable to slope failure, as it is underlain by solid bedrock.

Landslides Along Southside Road

Southside Road parallels the slopes of the Southside Hills above the Waterford River. The road lies alongside the former route of the Newfoundland Railway. Landslides and flooding were a frequent problem in this area for many years, particularly northeastward from Bowring Park (Corpus Christi Church) to Blackhead Road and Shea Heights. Here, weak glacial sediments and weathered debris overlying sandstone and conglomerate are susceptible to failure.

1912 Landslides

A very heavy rainstorm struck St. John's on the evening of 26 July 1912. There was extensive flooding in the downtown area, especially around Water Street West and Southside Road. The area between the head of Quidi Vidi Lake and King's Bridge was also inundated, causing damage to crops in farmland. Water pouring off the Southside Hills damaged many houses on Southside Road, and a landslide hit that of Patrick Horan:

> Hundreds of tons of rock and clay were hurled against Patrick Horan's residence when part of the hill above it gave way, the back part of the house beaten in, and a river ran from the back to the front of the building for hours. Tons of earth, rock etc. were scattered about the floors and the furniture and effects were badly damaged. Mr. E. Coyle's residence nearby suffered similarly. In trying to clear the debris in front of his house Mr. Coyle had a narrow escape. A river about 4 feet deep ran across the road very swiftly into the waters above the Long Bridge and there swept under the parapets of the bridge into the waters of the harbour like a mill-race. Mr. Coyle was swept from his legs and would have been taken out into the harbour but that he was grasped by a by-stander and drawn to safety. (*Evening Telegram*, 27 July 1912)

A landslide also occurred in Petty Harbour during this same rainstorm:

> Shortly before midnight Friday and when the storm had abated somewhat the people of Petty Harbour were awakened by a terrific crash caused by a landslide near Brom Head where several times before something similar had occurred. The landslide occurred opposite H.A. Chafe's premises and hundreds of tons of rock and clay with some immense boulders fell. Fortunately no houses were near, nor were there any people about. One flake was demolished by the fall. The Petty Harbour road was badly torn up by the floods. (*Evening Telegram*, 27 July 1912)

The Petty Harbour area has numerous steep slopes, and several rockfall and avalanche incidents are known from the area.

1934 Landslide

On Friday, 12 October 1934, a heavy rainstorm struck St. John's, with rain falling continuously from that evening through to the following night. The Southside Hills area was worst affected, and, in the words of an *Evening Telegram* (15 October 1934) reporter, "several families on the Southside Road near the junction with Blackhead Road were in terror and had to leave their houses." Large quantities of soil, including large boulders, were washed downslope. The houses of Mrs. Burridge and Mrs. Pittman (their exact location is unknown) were badly affected by

the material washed downslope, but the only fatalities were several of Mrs. Pittman's chickens — her chicken coop was washed into the Waterford River. Landslides blocked the train tracks over at least 40 metres, and passengers had to detrain at Waterford Bridge (Corpus Christi), and travel into town by taxi. In the Quarry Bridge area (near Bowring Park), the road was washed out. A 15-ton boulder was dislodged and rolled downslope, but without causing damage.

1936 Landslide

Figure 2. The Byrne family; Michael Byrne with Theresa Byrne on his lap, Robert in front and Mary. Theresa was killed in a landslide on Southside Road in 1936. Photograph from the collection of Theresa West.

Southside Road was hit by another geological disaster less than 18 months later, this time with tragic consequences. Heavy rain again fell for a protracted period, this time on snow-covered ground. At 8.30 a.m. on Sunday, 23 February, Michael Byrne was making a channel to divert water that was flooding the ground floor of his house at 207 Southside Road. Located 100 metres east of St. Mary's Church (since demolished), this was a double house, with the Byrnes occupying one side, and the Flynn family the other (number 205). It was three storeys high, and built into the slope, so that the first storey looked directly out onto the hill behind. Byrne's wife and two of their children were trying to prevent water from damaging their shop, located at the front of the house, when they heard a loud rumbling at the back of the house. Three more of the Byrne children, Lillian (aged 9), Robert (7), and Theresa (4) were in the kitchen, on the first storey at the back of the house (Figure 2):

> Mrs. Byrne ran upstairs to the kitchen but she could not get the door open. Her husband followed almost immediately and smashing in the door they found their boy Robert half-buried in gravel and rock which pouring in from the garden had smashed through the floor and filled the underneath room to the ceiling. (*Evening Telegram*, 24 February 1936)

Robert was buried head downwards, but after being dug out was found to have no serious injury (although it was later found he had lost some of his hearing, and he suffered from back problems). Lillian was unhurt, but Theresa was carried down the hole in the floor, and killed, apparently by suffocation. Her body, recovered 15 minutes later, was unmarked apart from a gash on her forehead.

The Flynn house next door was also damaged. Mary and Stella Flynn were trapped in their bedroom, which adjoined the Byrne kitchen, and were rescued by their brother Gerald.

The landslide had originated from the steep slopes above the houses, and consisted of a mixture of soil, vegetation, snow and boulders estimated at half a ton. One such boulder passed through the Byrne house and, in an *Evening Telegram* photograph, is seen lying on the sidewalk.

1948 Landslide

By 1948 weather forecasting had improved, and the 14 September *Evening Telegram* warned of an approaching hurricane, predicted to bring heavy rain and high winds by noon on 15 September. Sailings from Halifax were canceled, and the *Evening Telegram* 10-mile road race was postponed until 16 September (*Evening Telegram*, 15-18 September 1948). The rain started early in the morning of 15 September, and by 11 a.m. had been falling heavily for 10 hours.

Mr. and Mrs. J. Windsor and their young family of three, Jimmy, Jeanette, and Maureen, lived in 387 Southside Road, a house of similar design to number 207, with a kitchen on the first storey at the back. The family were sitting in the kitchen when they saw the landslide occur. The slide was rapid, and they had no time to escape its effects. Mr. Windsor later told an *Evening Telegram* reporter:

> My foot and legs were caught between the boards, and I wrenched so hard to get clear that my boot came off. My wife was up to her waist in mud and crying for help and I helped her to get through the door. I heard Jimmy crying "help me, help me, Daddy" and I managed to pull him out of the mud which was up to his neck on the floor. Jeanette told me "I had hold of Maureen's hand, Daddy, but I couldn't hold it." (*Evening Telegram*, 17 September 1948)

Maureen Windsor (aged 3) was swept against the rear wall of the kitchen and apparently crushed against the chimney, being killed instantly. The landslide had, as in the 1936 disaster, broken through the rear wall of the house (Figure 3).

Several other landslides occurred in the same storm, with three other houses damaged. The adjoining bungalow (number 389) belonged to the Clarke family, whose members were fortunate to escape without serious injury. The rear of the

Figure 3. The scar left by the landslide of 15 September 1948 at 387 Southside Road (St. John's City Archives, used with permission).

house was staved in by the landslide and several members of the family were rescued from waist- and neck-deep mud. The Clarke house had only recently been completed by Mr. Clarke, a bricklayer, after three years of work. Number 383 was also badly damaged, and two small children had a "miraculous" escape as their bed was swept across the room. Further east, the Guzzwell house (number 363) was also damaged, and part of the stables at the rear of the house were destroyed. Other damage was done in this storm, largely through flooding, with 13 houses on Southside Road cut off by the Waterford River near Mill Bridge (located close to the modern road bridge to Shea Heights) (Figure 4). Two rescuers narrowly escaped drowning. Landslides also blocked roads in Outer Cove and Pouch Cove. *The Evening Telegram* (17 September 1948) reported that hundreds visited the site to examine the damage, as was the case for the similar landslide that occurred "a few years ago."

At least three families had to leave their houses because of the damage and were provided with temporary housing, though one family was later asked to leave, as the husband was in employment. In contrast to earlier incidents, there was discussion in the newspapers and in council about where the blame should lie, more

Figure 4. Flood damage on Southside Road, September 1948 (St. John's City Archives, used with permission).

for the flooding than the landslide. An *Evening Telegram* editorial (18 September) blamed poor planning for the flooding, which could have been prevented with proper culverting.

Today, a small modern bungalow stands where numbers 387 and 389 were located. Number 385, apparently unaffected by the 1948 events, stands today, with an unoccupied spot where 383 was. The Guzzwell house, number 363, also remains. A small landslide was reported to have occurred in 1953, blocking the rail line in this area, with one family evacuated from their house (*Western Star*, 7 October 1953).

Recent Events

The slope stability and flooding problems no longer occur to the same extent, due to the construction of Pitts Memorial Drive in the early 1970s. This major highway is situated halfway up the slope, and much of the water that affected Southside Road is contained within ditches and culverts. Local residents state that flooding has not occurred for many years, although some difficulties persist along Symes Bridge Road. Slope stability, particularly rockfall, is still a problem on Pitts Memorial Drive after heavy rains and as a result of frost heaving. The road has been temporarily blocked completely or partially on several occasions since 1990. In spring 1996, a driver was injured when her vehicle hit rocks that had fallen into the road. Minor landslides have been observed on Southside Road after heavy rains. Currently, the City of St. John's, after consultation with the Newfoundland and Labrador Geological Survey, requires a geotechnical evaluation of slopes for any new construction in this area (Figure 5).

In 2004 a major excavation took place directly southeast of Pitts Memorial Drive as the first stage in the installation of a sewage treatment plant. This excavation cut into the Southside Hills, primarily into resistant conglomerate. However, at the top and edge of the cutting, till slopes have been created at steeper than the natural angle, and could be vulnerable to minor landslides until construction is advanced.

Avalanches in the Battery

The Battery lies under the slopes of Signal Hill and forms a distinct and unique community within St. John's. The Battery originally was a seasonal fishing village, but over the years became occupied year-round. The Battery is divided into the Upper, Middle, Lower, and Outer Battery, although the naming of these areas has changed over time, and earlier accounts can be somewhat confusing. The area currently known as the Outer Battery is termed the Lower Battery in many newspaper reports and by local residents. The steep slopes have made construction difficult,

Figure 5. Recent construction on Southside Road, undercutting steep banks of till and increasing landslide hazard.

and the houses cling to a narrow strip between the cliffs above and the sea below. Although protected from the sea, and subject to a favourable microclimate, due to the south-facing aspect, the Battery is among the most hazardous places to live in St. John's. Archival and anecdotal evidence indicates that rockfall is frequent in this area, and that several avalanches from Signal Hill have occurred. In contrast, the north-facing, less steeply sloping Fort Amherst area has not been susceptible to avalanching.

1921 Avalanches

The first known avalanche took place on 8 February 1921 (*Evening Telegram*, 10 February 1921). Heavy snowfall combined with high winds resulted in an avalanche striking the Outer Battery with devastating effect. It hit the house of Alfred Wells and family, moving it 3 metres downslope, ripping off the top storey, and driving the roof down into the room where the Wells family slept. 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 rescued their two-year-old son whose

crib was crushed. He returned to free his pregnant wife, who had severe back injuries, and to rescue another infant who had nearly smothered under the snow. Numerous other houses were damaged, including those of Mr. Wells' brother and father. Houses belonging to Morris, Edgecombe, and Moses Pearcy were either destroyed or severely damaged. There was no loss of life, since these dwellings were occupied in summer only, but considerable hardship resulted from loss of stages and fishing gear. The Morris, Edgecombe, and Pearcy houses were situated between Chain Rock and Fort Waldegrave. The exact location of the Wells house is unclear, but it was in the same area.

A second incident occurred in the Battery 10 days later. The details are sketchy, as St. John's was without power between 16 and 19 February, and no newspapers were published for two days. An avalanche at Petty Harbour on 16 February swept away 25 metres of the flume supplying the power house. However, it is known that Albert Delahunty of the Battery was killed in an avalanche (*Evening Telegram*, 21 February 1921). His body was found 60 metres below his house on Signal Hill, and, according to *The Evening Telegram*, "his hold on a dinner pail had not relaxed when death overtook him." Delahunty's house was probably close to the Queen's Battery, where no dwellings now 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 through a cornice.

1959 Avalanches

There are no records of further avalanches until 1959, when the worst geological disaster in St. John's history occurred. A ferocious storm hit St. John's on the night of 16 February, with winds reported up to 200 kilometres/hour, and depositing 55 centimetres (22 inches) of snow. At 1:05 a.m., residents in the Outer Battery heard a sound described as being louder than a clap of thunder. An avalanche struck two houses belonging to the families of Clarence Wells and Jim Piercey, sweeping them downslope and into the rear of two other houses. The houses contained 14 people who were all swept downslope and buried. Clarence Wells was the nephew of Alfred Wells, whose family was hit by the 1921 avalanche. The top storey of the Piercey house was ripped off, and the Wells house demolished (Figure 6).

Rescuers were on the scene almost immediately, and worked furiously over the next 12 hours, despite appalling weather conditions. Over 50 Battery residents, coordinated by the efforts of Raymond Riche, dug through the debris, and quickly rescued Clarence Wells, his wife and child, and three children of the Piercey family. One of the three Piercey children (a two-year-old girl) was swept 60 metres downslope and was rescued by Ralph Barnes who had heard the noise of the avalanche, and saw her through his window, almost completely buried on a fish flake. After two hours of digging, Ruth Wells (aged 16) was discovered, trapped under a

Figure 6. Aftermath of the 1959 Battery avalanche (from the collection of Shirley Eales, used with permission).

stove, and badly burnt. Over the next few hours the searchers uncovered the bodies of Mr. and Mrs. Piercey, and Mrs. Vincent, Jim Piercey's mother; and rescued Isiah Dawe (living in the Wells house), who had attained the age of 100 a few months before. Gloria Piercey and Mrs. Vincent had been sharing the same bed, but Gloria was thrown clear, whereas Mrs. Vincent was buried and suffocated. Mr. Dawe later died in hospital, reportedly of shock.

Shirley Noseworthy, a 16-year-old friend of Ruth Wells, and Ted Wells, the 19-year-old son of Clarence Wells, were still missing. Ruth and Shirley had been skating at Memorial Stadium when the storm hit, and had gone back to Ruth's house in the Battery. It was Shirley Noseworthy's first visit to the Battery: she did not return until 35 years later, as part of a television programme marking the anniversary of the avalanche. Rescuers heard Shirley's cries responding to the sounds of their efforts, 10 hours after the avalanche had occurred. She was pulled from the debris, showing remarkable courage throughout. She was badly frostbitten on her right leg, but after three weeks of hospital treatment recovered fully. The body of Ted Wells

was recovered after 12 hours of searching, and taken to Devon House along with the other victims.

Elsewhere in the Outer Battery, 11 members of the Garland family had gathered in the house of the senior Garland for shelter. The house was 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. The residents of the Outer Battery were evacuated during the day, and found temporary housing by the Red Cross. At the time, many residents thought that this would be a permanent move. A Battery resident, interviewed by *The Evening Telegram*, said, "This place may become a ghost town now. It appears to be the end of the Outer Battery for winter living." Another interviewee commented, "My wife tells me we won't be living here anymore." However, Raymond Riche, the hero of the rescue attempts, firmly stated that people would move back, because, as fishermen, this was their place of work.

In follow-up stories in *The Evening Telegram*, Alex Wells, whose house lay below the Piercey's, was interviewed: "What a night ... we were frightened ... all of us were ... about what had happened ... and we didn't know what else would happen ... never again please." A *Telegram* editorial (26 February 1959) suggested that preventative steps needed to be taken:

> Many people are beginning to have some second thoughts on the appalling prospect of half a dozen people being killed and their homes destroyed by an avalanche almost in the centre of the capital city of this province. They have a right to wonder what steps will be taken to prevent a recurrence of such a tragedy.

Incidents Since 1959 and Recent Concerns

Since the 1959 avalanche no serious incidents have occurred in the Battery, although minor rockfalls and avalanches have been reported. In 1960 another major storm hit St. John's in early March. Exact events are hard to determine from newspaper reports, but it seems that one and possibly two avalanches occurred in the Battery. Many Battery residents left their homes when the initial storm in early March hit, because of safety concerns (*Daily News*, 8 March 1960). A "snowslide" in the Outer Battery buried the house of Cyril Garland on 13 March and forced his family to leave (*Daily News*, 17 March 1960). This is the same house that was buried in the 1959 avalanche. *The Western Star* (14 March 1960) reported that avalanches occurred on the weekend of 4-7 March, but this event was not reported in the St. John's papers. An employee of the Geological Survey of Newfoundland and Labrador, Randy Meehan, living in the Battery at the time, recalls his house being struck by an avalanche in the winter of 1960 or 1961. He described a sound like thunder and the house shaking as it was struck by the avalanche. The family was

trapped in the house for a lengthy period. Up to this point no newspaper accounts of this incident have been found, but it seems likely that it is related to the events in the Outer Battery. The Garland family of the Outer Battery was affected again in 1987, when an avalanche ripped the porch from the side of their house, and its residents had to be dug out. This incident was not reported in *The Evening Telegram*, and the only media coverage was on CBC radio.

In the mid-1960s, the future of the Battery was much discussed in relation to urban renovation. At that time the Battery had no sewage, a poor water supply, and was not readily accessible for other services. These issues were prominent in the press, and in the House of Assembly, with pressure being applied by both local MHA Tom Hickey and Raymond Riche (one of the rescuers in 1959, then a City councillor). The option favoured at that time was re-settlement of the Outer Battery to another site, and Hickey was quoted as saying that all but one family would move under the right conditions. The lack of services was quoted as the main reason for considering moving, but some residents mentioned concern about avalanches. In 1969, over $1 million of federal money was allocated to upgrading services in the Battery, and since then thoughts of re-settlement have not resurfaced.

In the 1990s, residents were most concerned about rockfalls. The development of Signal Hill as a historic site and the promotion of the North Head Trail resulted in increased foot traffic on the steep, unstable slopes above the Upper Battery. Battery residents believed that several minor rockfalls were triggered by people on the slope above, and suggested to Canadian Heritage that something be done to reroute people (Heather McClellan, Canadian Heritage, pers. comm.). In addition, a large boulder was identified by residents as being a hazard, and was stabilized by volunteers. A further concern has been the possibility of rockfall triggered by cannon fire from summer performances of the Signal Hill Tattoo, firing of the noonday gun, or as a salute on special occasions. This results in considerable reverberation, and residents reported a sensation of ground vibration.

The Geological Survey of Newfoundland and Labrador made a preliminary inspection of the slopes above the Outer Battery in 1995 and recommended that the rockfall hazard should be investigated in detail. Subsequent consultants' reports confirmed that a rockfall hazard does exist (Newfoundland Geosciences 1996). Interviews with Battery residents reported in this study suggested that minor rockfalls impacting houses were frequent events. Parks Canada was also concerned about the safety of walking trails on Signal Hill; it commissioned two reports that identified a rockfall hazard, and recommended remedial work (Golder Associates 1980, 1992).

In October 1997, the City of St. John's let tenders on construction of safety fences and other measures to provide protection from rockfall and avalanche in the Outer Battery, with estimated costs in excess of $300,000 (Figure 7). New warning signs have been placed on the North Head Trail to divert people from the slopes above the Battery. The protective fences were constructed in 1998 but have not yet been tested by a significant rockfall or avalanche.

Figure 7. Protective fencing erected above the Outer Battery in 1998.

Planning, Perception, and Prediction

The residents of the Battery are to some degree aware of the hazard that exists. The current population is a mix of families that have lived in the Battery for generations, and relative newcomers, attracted by the Battery's unique setting and atmosphere. Long-term residents to some extent monitor avalanche hazard themselves. The Garland house in the Outer Battery was built with a reinforced rear wall to aid in protection against avalanches, and in times of heavy snowfall perceived as hazardous, the family evacuate the house for brief periods (Amy Kavanagh, pers. comm.).

In terms of planning, it is clear that given the evidence of avalanche, rockfall and landslide, the slopes lying above any proposed development must be considered carefully. Expansion of St. John's has tended to be in the west of the city, rather than into the more hazardous coastal areas, but certainly development along Southside Road and on the Southside Hills must be closely monitored.

Development on slopes north of Quidi Vidi Lake has been effectively curtailed by the construction of the Northwest Atlantic Fisheries Centre, the RCMP Headquarters, and the sanitary landfill at Robin Hood Bay. Both the Freshwater Bay area, on the south flank of the Southside Hills, and the coastline of Goulds south of

Petty Harbour to the City limit at Bay Bulls, would potentially be vulnerable to slope failures and avalanches. However, no significant development has occurred in these areas. Rockfalls and minor disturbances resulting from frost action are evident along the East Coast Trail within St. John's. Along the Outer Ring Road west of Portugal Cove Road, the sliding of slabs of bedrock was prevented by the installation of rock bolts.

There is little doubt that a serious risk of avalanche existed in the Battery. Three avalanches involving injury and death are known, and two other potentially serious incidents were 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 20 years at least, and possibly as frequently as every 10 years. Thus the protective measures taken were well justified and likely will save lives.

Floods in St. John's

Flooding is a frequent problem in St. John's. Houses are built on flood plains of the Waterford River, Rennies River, Leary's Brook, and in the Goulds. There is a long history of flooding, although it has had perhaps a more dramatic impact in recent years. Along the Waterford River, serious flooding has frequently been associated with landslides, although this hazard has decreased with the construction of Pitts Memorial Drive.

Rivers in St. John's occupy bedrock valleys connecting fens, former meadows, and ponds. All are 'cascade' streams, with straight short reaches and ponds and pools that act to store sand and gravel. Pools are flushed by spring flooding. Downstream movement of sediment provides suitable spawning sites for fish but also leads to channel obstruction that can accentuate flooding.

Flooding results from late winter rain-on-snow storms, spring snowmelt, and hurricanes. Floods may occur at any time during the year following heavy rainfalls, notably the more than 120 millimetres of rain brought to some localities by Tropical Storm Gabrielle in September 2001. Rapid runoff from steep slopes and paved surfaces can result in flooding almost immediately after any storm with more than 40 millimetres of rainfall within 24 hours.

Most flood events, including those discussed below, involve combinations of one (or more) natural causes coupled with anthropogenic factors. Drainage infrastructure that is unable to evacuate water rapidly, buildings erected in vulnerable locations, and diversions or modifications of natural drainage are common factors. Construction in upslope positions increases flood risk in lower areas. Municipal planning is critical to avoid, mitigate, or resolve anthropogenic factors contributing to flooding. Maintenance of infrastructure is a major factor in limiting damage from successive rainfall events.

Hurricanes, autumn and winter storms, spring rain-on-snow events, and ice jams are consequences of the natural environment. Even under the predicted climate change that will influence St. John's in coming decades, the styles of flooding due to natural causes will not differ. Although some flooding is inevitable and unavoidable, human choices can be made that minimize community and individual vulnerability. Some examples of flooding recorded in St. John's are presented below.

13 February 1892

The earliest flooding event recorded in St. John's was triggered when 103 millimetres of rain fell on this day, resulting in flooding along the Waterford River. This rain-on-snow flood destroyed Jobs Bridge, the major communication to Southside Road and Fort Amherst. Scows had to be pressed into service to ferry people across the harbour. Portugal Cove also was much affected, and the Somerton family had to evacuate their house. Two bridges in Portugal Cove were carried away.

18 February 1898

This event resulted from a combination of precipitation and an ice jam on the Waterford River: 83.8 millimetres of rain fell on 17 February, followed by 40.6 millimetres on 18 February, resulting in extensive flooding. *The Daily News* reported on 19 February:

> A considerable portion of Mr. Symes' houses, situated near Waterford River, was carried away by yesterday's flood. At 2 a.m. yesterday the ice on the river was broken by a rush of water underneath, causing a loud report.... Then followed the flood of ice and water which carried everything before it. Fences along the river bank were swept away, and also 600 pickets which had been piled up close by and owned by Messrs. E. and J. Roads. The ice rafted clean over Symes' Bridge and broke away the rail. Nearly all the small bridges countryward were demolished by the ice.

30 January 1942

Weather records show that 43 millimetres of rain fell on 29 January, followed by a further 84.6 millimetres on 30 January, totaling 127.6 millimetres for the event. *The Daily News* (29 January) reported that weather was "very stormy and disagreeable," and that the snow started on the afternoon of 29 January, and then turned to rain, with many streets being flooded. A rain-on-snow flood resulted.

The Daily News (31 January) gave a detailed report of the effects of the rainfall. On Water Street, east of Leslie Street, the water was over the sidewalk. Victoria Park was devastated. The Waterford River at Mill Bridge was over its banks, and two houses were surrounded by fast-flowing flood water. Photographs show water up to the railroad trestle on Springdale Street, and ice and debris forming a dam below Long Bridge. Much material washed down onto Water Street, as water poured down Parks Hill, Leslie Street, Alexandra Street, Sudbury Street, Patrick Street, Hutchings Street and Springdale Street. Houses on the south side of Water Street were flooded, and some were evacuated. Sand and silt prevented streetcars traveling further southwest than Patrick Street. Marshall Motors was flooded, with many cars damaged. At Bowring Park, the Waterford River extended across the road to the foot of Molloy's Lane. The grounds of Corpus Christi Church at Waterford Bridge were flooded to 1.3 metres (4 feet) depth. St. John's Bridge was washed out. Symes Bridge stood, but the water levels reached Southside Road. The Mill Bridge embankment was washed out, and the Gas Company yard flooded. Piles washed into the river, and were caught up against Long Bridge.

Ice broke up on Rennies River with water up to the bridge at Robinson's Hill (Portugal Cove Road). The Feildian Grounds were flooded, and the nearby road was impassable to pedestrians. The land between King's Bridge and Queen's Bridge (head of Quidi Vidi Lake) was flooded. The Quidi Vidi area was badly affected — "never worse" according to *The Daily News*. Flood water ran on top of lake ice and overflowed, causing evacuation of houses near the lake. Dynamiting of the ice at the outlet of the lake was considered.

27 July 1946

This summer rainstorm saw 121 millimetres of rain over a 15-hour period, beginning at 5 p.m. on Saturday 26 July. Many basements were flooded, and footbridges in Bowring Park were destroyed. St. Clare Avenue was flooded, and New Gower Street between Flower Hill and Adelaide Street had stones and mud washed onto it, requiring clearing by city workers. The sewer line on the north side of Rennies River overflowed, carrying torrents of water into the swimming pool that existed at that time. Quidi Vidi Lake rose as far as the Regatta boathouse door, about 2 metres above the normal lake level. The water level of Quidi Vidi Lake fluctuated regularly during the summer months prior to 1977, when a control structure at the outlet was installed to increase stability of the lake volume for recreational purposes. However, flooding of the shores of Quidi Vidi Lake has continued throughout the past 60 years.

11 April 1951

A rain event, combined with snowmelt, resulted in significant flooding in April 1951. *The Daily News* of 13 April reported extensive damage from flooding due to heavy rain on 11 and 12 April. Many houses near ponds were damaged, and gravel roads were impassable. A house on Pearce Avenue, near Mundy Pond, was evacuated. All land from King's Bridge to the outlet of Quidi Vidi Lake was under water, and the lake rose 2.5-3 metres (7-8 feet). The basements of houses on the south side of the lake were flooded. Photographs show the bridge at the head of Quidi Vidi Lake completely under water.

The area around Long Pond was flooded, and the pond rose to the top of the bridge at the run out and flooded the road bed. As in the 1946 event, the swimming pool on Rennies River overflowed, and the river burst its banks and flooded Feildian Grounds. Storm sewers overflowed, and many streets were damaged, particularly Craigmillar Avenue and Blackhead Road. In total 91.7 millimetres of rain fell on 11 April, and 38.6 millimetres on 12 April, for at total of 130.3 millimetres during the entire event.

October 1953

This hurricane-induced event saw 111 millimetres of rain fall in a short period of time, resulting in extensive flooding. William Clarke had to leave his house on Southside Road due to floods. Basements on Shaw Street, Churchill Park area, and Southside Road were flooded. The shoreline from the head of Quidi Vidi Lake to the Regatta boathouse was impassable. Mundy Pond Brook overflowed its banks in Victoria Park. The pavement collapsed at the foot of Leslie Street, requiring repairs.

11 April 1986

A rain-on-snow and snowmelt event was triggered when 110 millimetres of rain fell on 11 April 1986. The area worst affected by floods was the Avalon Mall-Leary's Brook region. The parking lot and the east end of the Mall were flooded. More than 30 centimetres of water covered Prince Philip Drive between the Health Sciences complex and the CBC Building. A woman was rescued from her car after going off the road in this area. Rennies River was 1.8 metres above normal, and Pringle Place was severely affected. Approximately 100 metres of walking trail was washed out on Rennies River below Portugal Cove Road, and there was much debris in the river in this area. The Groves Road area was flooded, as were Waterford and Dunn's bridges in Mount Pearl. A coffin floated out of a recent grave in the Anglican Ceme-

tery beside Quidi Vidi Lake. There were 350 calls to City Hall for assistance, and 30 pumps were put into operation.

18-19 September 2001

Tropical Storm Gabrielle struck southeast Newfoundland, depositing 119 millimetres of rain at St. John's International Airport in a 24-hour period. Flooding was widespread, affecting numerous areas including the Avalon Mall-University area, areas along the Virginia River, the area surrounding Quidi Vidi Lake, Ennis Avenue, the Waterford Valley, and the Goulds. The road to Shea Heights was severely damaged and partially washed out and blocked by debris. Many other roads were blocked for a period, including Kenmount, Blackhead and Southside roads, Bonaventure Avenue, The Boulevard, Waterford Bridge Road, Portugal Cove Road, Newfoundland Drive, Prince Philip Parkway, Poplar Avenue, and Allandale Road (Figures 8a-11). Many householders experienced damage and the provincial Emergency Measures Organization [EMO] instigated a request for emergency funding from the Federal Government. More than 1,200 claims for flood damage compensation were filed with the EMO. The federal and provincial governments paid $6.7 million in compensation.

Although Tropical Storm Gabrielle was the most extreme flooding event in the city's recent history, and by far the most financially costly, the 119 millimetres of rainfall recorded at the Airport during Gabrielle is comparable to the totals for the April 1986, October 1953, April 1951, July 1946, January 1942, February 1898, and February 1892 events. The available data suggests that storm events delivering more than 100 millimetres of rain within 24 hours to St. John's are not infrequent or anomalous occurrences.

Discussion

St. John's as a city is vulnerable to flooding. There are six drainage basins within the city limits, and the core of the city is built around two major river systems, the Rennies and Waterford rivers. In heavy rainfall the steep slopes surrounding the harbour can create additional problems, with streets acting as conduits for water that cannot be accommodated in storm sewers. Areas below the Southside Hills are vulnerable to flooding and damage from small streams that expand into fierce torrents after heavy rainfall.

The vulnerability of the city has increased through time for a number of reasons. Nineteenth-century reports of flooding commonly identify the Waterford River valley as being the area affected, with damage also along the western parts of Water Street. As the city expanded, development occurred on areas subject to occa-

Figure 8a. The Waterford River in full flood, 19 September 2001.

Figure 8b. Waterford River 24 hours later, showing effect of flood, and rapid return to normal water levels.

Figure 9. Waterfall created on Southside Road during September 2001 floods.

Figure 10. Floods cover soccer field at head of Quidi Vidi Lake, September 2001. Note footbridge over Rennie's River forming dam as it blocks flood waters.

Figure 11. Flood damage on Shea Heights road, September 2001.

sional flooding. Thus by the 1940s, the area around Quidi Vidi Lake, previously mostly agricultural land, is often mentioned as being flooded, with houses damaged. By the 1960s, the Churchill Park-University Avenue-Avalon Mall area has been added to the area vulnerable to floods, and, by the 1980s, expansion of the city adjacent to the Virginia River, along Leary's Brook, and in the Goulds, meant that these areas were also vulnerable to flooding (Figure 12).

Following recent floods, there has been speculation that the city has become more vulnerable to flooding due to the increase in paved areas and the channelization of streams. Many small streams were confined to underground culverts during development, and, during the Gabrielle event of September 2001, much flooding occured along such former stream channels as the culverts were unable to contain run-off. Open stream channels tend to be able to hold more water before bursting their banks onto flood plains. Development and urbanization results in wetlands and other natural areas that might hold water after heavy rainfall being paved over and turned into hard surfaces. Rain falling on such surfaces is rapidly transported into storm sewers and to the river systems. Thus the effects of a heavy rainfall event change significantly, with more water being supplied to the river systems over a shorter period. This results in higher, shorter duration flood events.

Figure 12. Flood protection, Waterford River, constructed after 2001 flood.

Many flooding problems are long-standing however, and simply reflect the development of housing on flood plains. The increasing vulnerability of the city probably is more due to expansion and development into these areas than any other factors. The Waterford River, mentioned in the earliest reports of flooding, was the first flood-plain area to be developed. Development over the years has paid little attention to flood plains and flood hazard, and thus flooding has been exacerbated as a problem.

A further factor that increases economic vulnerability is the changes that have occurred in style of housing. Older St. John's housing had basic, unfinished basements, often with low ceilings, and these were used for storage. Flooding of such areas resulted in minimal damage. Recent housing has been constructed with fully developed basements, designed for use as living space. Consequently, when such houses are flooded, inhabitants face major economic losses. No consideration has been made to restrictions on basement development in areas prone to flooding.

CONCLUSION

From the point of view of natural hazards, St. John's is a dangerous place to live, by Canadian standards. The probability of being killed by an avalanche in St. John's is roughly three times greater than the Canadian average, although only the Battery neighbourhood has been truly vulnerable. However, the chances of a Battery resident being killed by an avalanche area small compared to, for instance, dying in a traffic accident. With proper planning, landslide hazards can be avoided or minimized.

Floods resulting from hurricanes, autumn and winter storms, spring rain-on-snow events, and ice jams are consequences of the natural environment. Even under the predicted climate change that will influence the northeast Avalon in coming decades, the styles of flooding due to natural causes will not differ in the future. Although some flooding is inevitable and unavoidable, human choices can be made that minimize community and individual vulnerability. Flood mapping, analysis, and socio-economic assessment are providing valuable information towards these goals.

Acknowledgements

This project has greatly benefited from the archival research of our colleague David Taylor. The work of Amy Kavanagh of the Memorial University Department of Geography; the facilities of the Provincial Archives; the St. John's City Archives; and the cooperation of the Department of Canadian Heritage, particularly Heather McClelland and Eric Greening, is much appreciated. We thank Shirley Eales (née

Noseworthy) for the use of photographs, and sharing her experiences of the 1959 avalanche. Shirley Lush and Geneva Bowering (a survivor of the 1921 avalanche in the Battery) provided some valuable information, as did Theresa West, daughter of Robert Byrne, survivor of the 1936 landslide on Southside Road.

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