FLOOD HAZARD AND VULNERABILITY IN NEWFOUNDLAND COMMUNITIES

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Flood Hazard and Vulnerability in Newfoundland Communities

by

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A thesis submitted to the School of Graduate Studies
in partial fulfillment of the requirements for the degree of
Master of Science, Department of Environmental Science
Memorial University of Newfoundland
August 2006
St. John's Newfoundland

Your file Votre référence
ISBN: 978-0-494-30471-6
Our file Notre référence
ISBN: 978-0-494-30471-6

Acknowledgments

I would like to acknowledge the guidance and contribution of the M.Sc. supervisor Dr. Norm Catto in the development of the project and the thesis. I would also like to thank Dr. Evan Edinger for assistance in the editing process of this thesis. Special thanks to the municipal official and residents that aided in the identification of flood hazards and volunteering historical knowledge of the area. Thanks to Michael O'Leary (former Assistant Director of Operational Services) and Charley Renough (Director of Operational Services) in the City of Corner Brook. I also thank Krista House, Andy Hennebury, and Bob Schmiedendorf employees of "The Gully" Environmental Education project in Torbay. Discussions with Paul Peddle, Emergency Measure Office training specialist, have aided in the knowledge of the Badger Flood in 2003. Thanks to municipal officials; Bob Codner, Torbay; David Whyatt, York Harbour; Kevin Lundrigan, Town of Burin; Basil Collier, Fortune; Gladys Kavanagh, Fox Cove-Mortier; James Cluett, Frenchman's Cove (Burin Peninsula); Melvin Francis, Garnish; Wayne Bolt, Grand Bank; Shelley Lovell, Lamaline; Dennis Kelly, Marystown; and Wayde Rowsell, St. Lawrence. I would like to acknowledge Memorial University of Newfoundland and OCIPEP for their financial contributions. Finally, thanks to my parents, family, and friends for their continual support.

Abstract

Flooding affects many Newfoundland communities. Identification of hazards, areas of risk, and assessments of previous and potential socio-economic impacts, were conducted for three regions, including urban (Corner Brook), suburban (Torbay), and rural communities (Burin Peninsula and Humber Arm). These communities represent a variety of physical and socio-economic environments, enabling discussion of the comparative risks from various natural and human-induced flooding mechanisms. Flood risk maps are presented for the three regions.

Floods in Newfoundland result from both natural and anthropogenic causes, and commonly occur due to the simultaneous operation of several mechanisms. Natural causes are directly related to Newfoundland's climate. Storm activity has a greater impact on flooding in Torbay and the Burin Peninsula than in the Humber Arm region. The associated storm surges are significant on the Burin Peninsula, whereas storm precipitation triggering river flooding has a greater effect on Torbay. Spring rain-on-snow events are a common flooding mechanism in the Humber Arm region. Additional flooding mechanisms affecting these communities include river and coastal ice jams, slope failures, natural accumulation of debris, and tsunamis. Climate change and variation may change the frequency and severity of flooding events, depending upon the flooding mechanism involved.

Human activities that alter drainage patterns cause flooding. Artificial constriction of streams, failure of drainage infrastructure, and debris blockages cause flooding. Converting vegetated ground into impermeable surfaces increases runoff and enhances flooding events. Upslope development places lower-lying areas at risk. Municipal planning and identification of flood zone areas can reduce vulnerability to flooding. Maintenance of drainage and coastal protection infrastructure can also aid in limiting damage.

Torbay has the lowest socio-economic vulnerability to flooding among the three study areas. Corner Brook is marked by high economic costs, but low social costs associated with flooding. The rural Humber Arm and Burin Peninsula regions show lesser degrees of economic vulnerability, but much higher social vulnerability.

The three areas differ in the relative importance of human activities, meteorological effects, and climate variation and change impacts upon flooding. In Corner Brook, increased precipitation and changes in winter conditions are significant factors increasing flooding risk, combined with urban development. Along the Humber Arm, where building is not a major factor, climate impacts dominate. On the Burin Peninsula, potential climate change impacts on flooding are connected with storm frequency and severity, while changes in precipitation are less apparent. Changed flood risk in Torbay is related primarily to human activities, with climate change possibly playing an indefinite, subordinate role. The differences in response among these three regions indicate that detailed site-specific analysis must be conducted in order to properly assess flooding risk in other Newfoundland & Labrador communities.

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1. Introduction

In the light of recent flooding events, including the inundation of Stephenville (2005), Badger (2003), and northeast Avalon communities due to the effects of Tropical Storm Gabrielle (2001), it is apparent that communities in Newfoundland and Labrador may be vulnerable to severe flooding events. Many of the communities in the province have unrecognized flood hazards that may eventually create damage and losses for individuals, properties, and the community as a whole.

Many communities in Newfoundland and Labrador have not been assessed for flood hazards. Through the investigation of previous floods and flooding mechanisms in particular communities, the hazards in other communities may be predicted. Once identified, areas at risk from flood hazards may be mapped. The results can be used in community planning, as susceptible areas may be avoided.

Floods may be devastating for individuals or communities. The term "flood" covers an array of events, ranging from overflowing of ditches, to overflowing of rivers, to inundation of coastlines due to a storm surge. Most floods only temporarily change individuals' lifestyles, and gain little attention beyond the area directly involved. In these cases, flood damage is commonly temporarily repaired and remediation is not undertaken. Often in Newfoundland, the frequency and severity of flooding events are not recorded, and an accurate assessment of vulnerability and necessary remediation cannot be made.

In some communities, avoidance of flood hazards may be difficult, and therefore other options to minimize social and economic damage may be pursued. By examining historical records and floods in other locations, the expected costs of a flooding event can be predicted. Flood "proofing" and abandoning flood prone areas may be effective measures to reduce social and economic cost. However, all other factors should be weighed.

To assess the flood hazard and vulnerability of communities in Newfoundland and Labrador, three study sites were chosen: Torbay; Humber Arm region, including Corner Brook; and the Burin Peninsula. These regions vary in geomorphic settings and climate regimes, permitting study of several causes of flooding. The areas differ in community development: Corner Brook represents an urban centre, Torbay represents a fast growing suburban centre, and communities on the Burin Peninsula and the Humber Arm are rural. Documentation of past flood events was examined due to the general lack of previous mapping and assessment of flood hazards. Only two communities within the study regions have undergone previous flood hazard mapping: Cox's Cove in the Humber Arm region (Canada-Newfoundland Flood Damage Reduction Program, 1990a) and Rushoon on the Burin Peninsula (Canada-Newfoundland Flood Damage Reduction Program, 1990b).

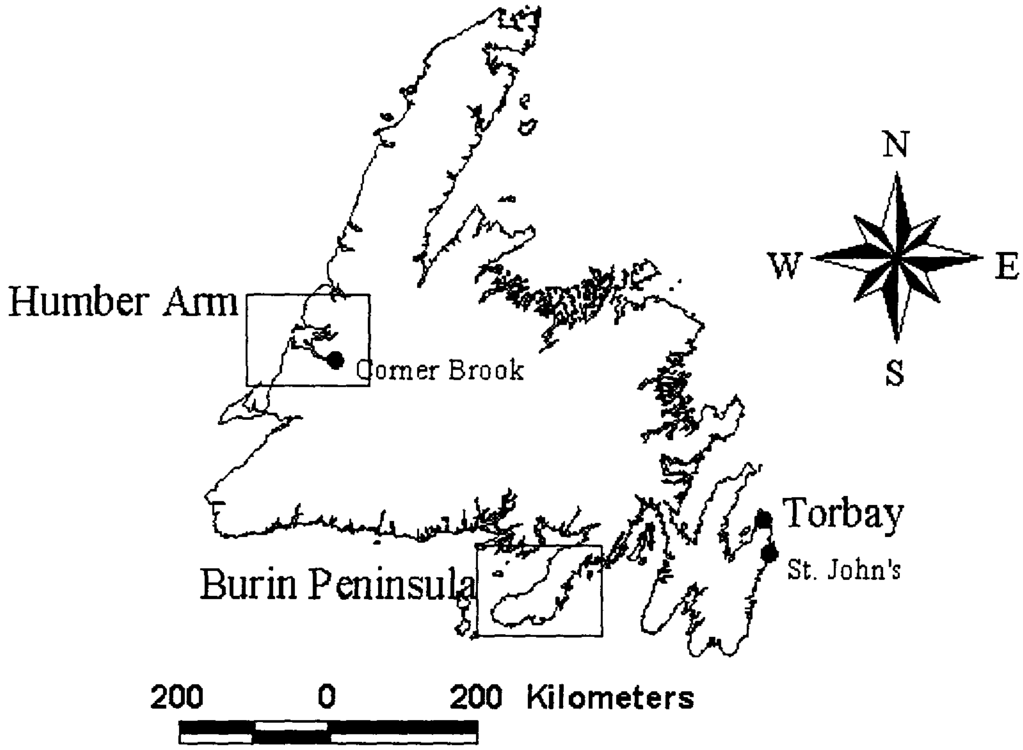


Figure 1.1: Location of study regions.

Both natural and anthropogenic factors contribute to the flooding events in Newfoundland communities. Most of the flooding events are the result of a combination of one or more natural causes in concert with anthropogenic factors. Newfoundland's climate determines the cause of natural flooding. In particular areas, hurricanes, autumn, and winter storms initiate river flooding and coastal storm surges. Fluctuations in temperatures during the winter and spring may result in rain-on-snow events and river and coastal ice jamming in other locations. Urban flooding may ensue when infrastructure is incapable of providing adequate drainage, and infrastructures are built which alter natural drainage patterns. Damage may increase when infrastructure is constructed within sensitive locations. Careful planning, mitigation and maintenance of infrastructure may limit the damage caused by excessive precipitation.

1.1 Objectives

The objectives of this research are:

1. To identify, document, and map areas of historical flooding events and current areas of sensitive and vulnerability;

2. To identify the mechanism(s) responsible for the flooding events. For each flooding event, the cause (e.g. hurricane-induced precipitation, ice jam, blockage of drainage), the season, precipitation amount, and other meteorological conditions were noted;

. To attempt to assess the relative importance of meteorological factors, climate change, nd human influence involved with flooding;

. To assess and quantify the socio-economic costs associated with the flooding events. hese data can be used by future researchers to conduct a cost-benefit analysis for emedial measures;

. To attempt to assess the probability of future flooding events based on knowledge of past flooding events and present areas of concern, climate change and variation, and patterns of human activity. Recommendations can then be put forth to the municipalities that have been studied to aid in reducing vulnerability to future flooding events.

1.2 Study areas

1.2.1 Torbay

Torbay is located on the northeast Avalon Peninsula of Newfoundland (Figures 1.1, 1.2, 1.3). The community flanks Tor Bay, facing directly northeast toward the open Atlantic Ocean. The community is located in proximity to the city of St. John's, within the St. John's CMA (Census Metropolitan Area) as designated by Statistics Canada.

Torbay is within the region of the most rapid population increase in the province. In 2001, the population was 5474 (Statistics Canada, 2005), with an expected population

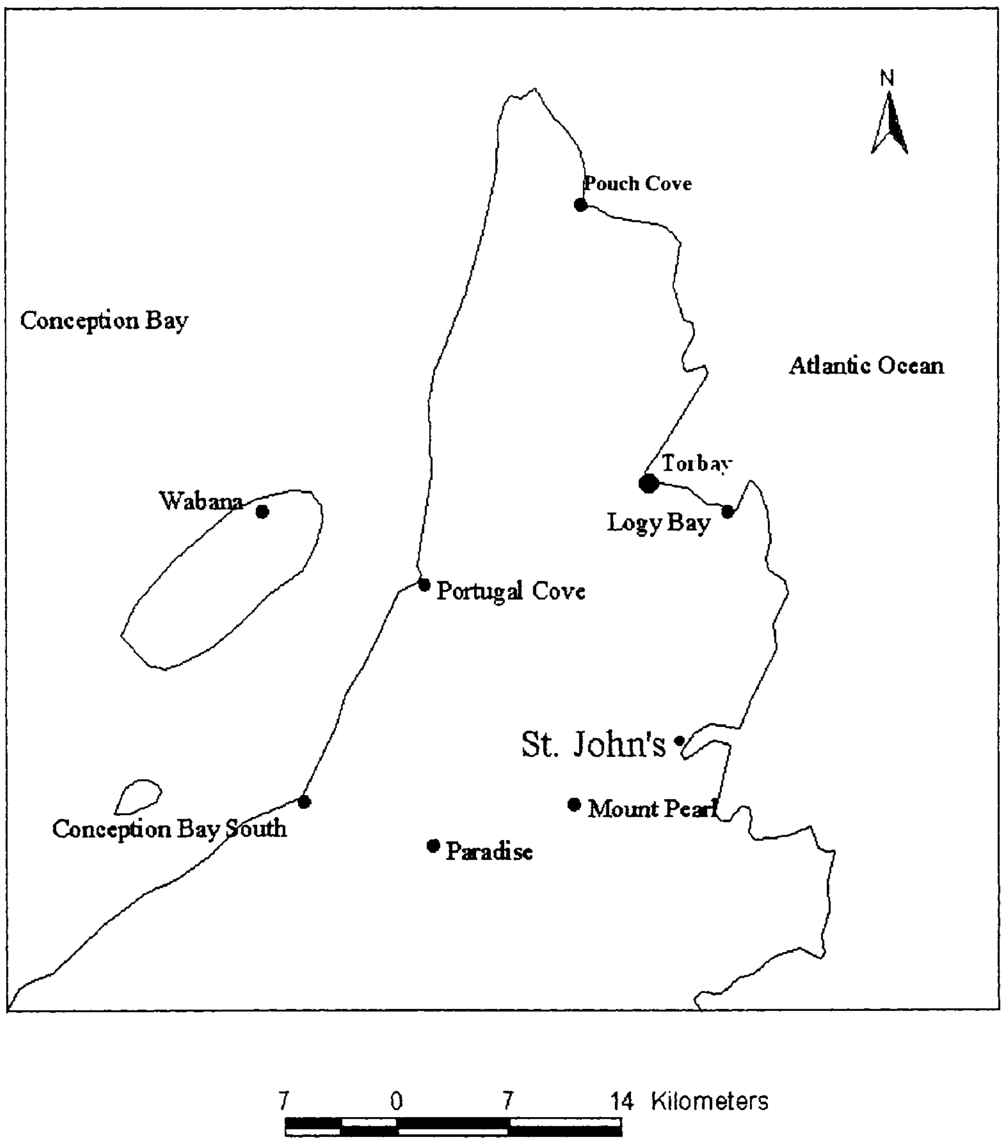


Figure 1.2: Location map of the Northeast Avalon region.

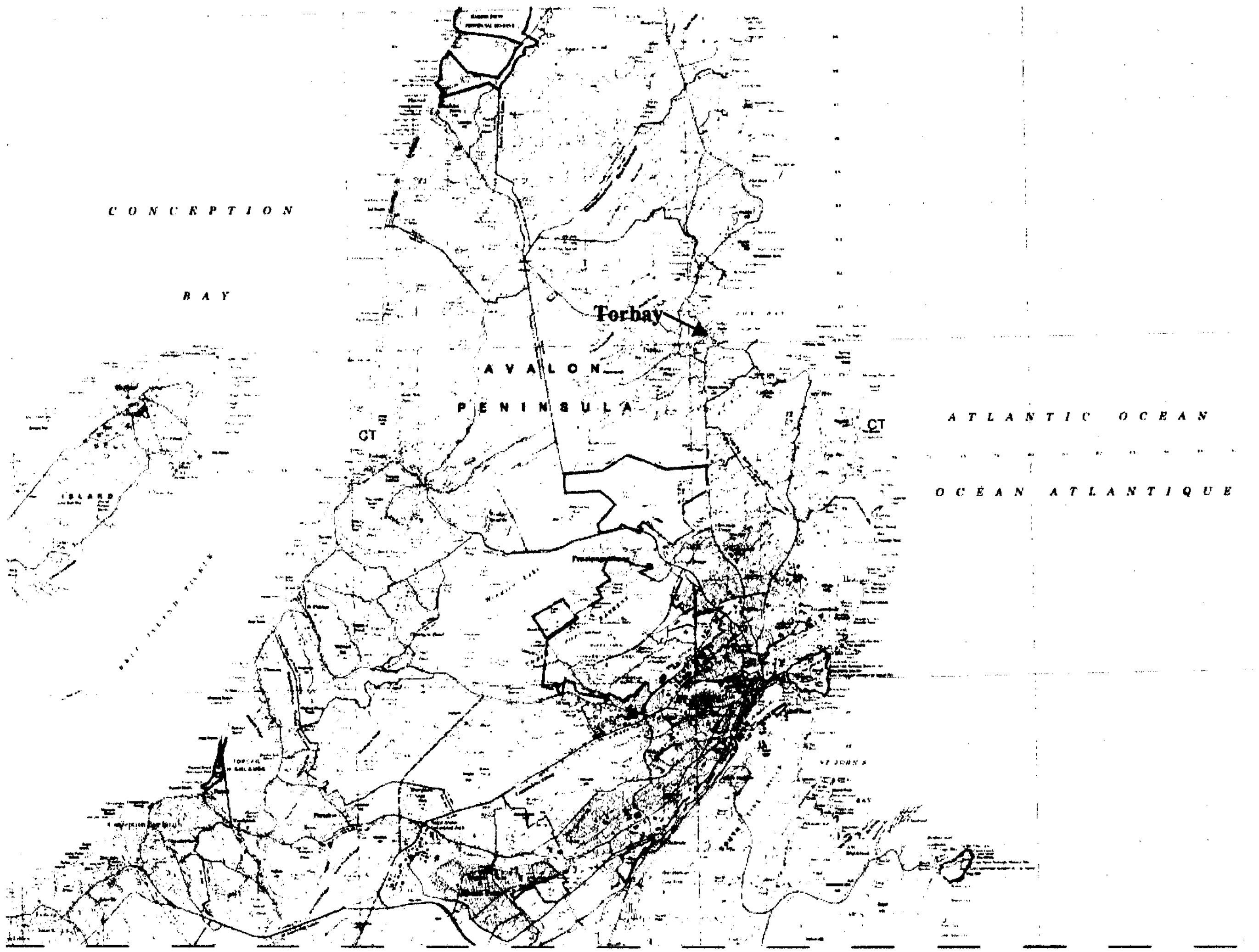


Figure 1.3: 1:50,000 topographic map of the Northeast Avalon region

increase to 23,000 in 10 years (Robert Codner, Mayor of Torbay, 2005, personal communication). Torbay contains a high proportion of young families with increasing affluence. The community was initially established as a fishing community in the eighteenth century. Presently, the majority of residents are employed in suburban and urban occupations.

The topography of Torbay is described as moderate to steep slopes, mostly facing northeast and southeast. The geology consists of a thin cover of coarse-grained Quaternary sediments covering fractured sandstone, shale, conglomerate, and argillite (King, 1990; Catto and St. Croix, 1998). Areas along the coastline are underlain by non-resistant strata. The elevated areas and headlands contain resistant sandstone. The river valleys are underlain by siltstone and argillite.

The Quaternary sediments range from less than 2 m thick veneers to blankets of glacial material 3-5 m thick (Catto and St. Croix, 1998; Batterson *et al,* 2001; Catto, 2001). The glacial deposits are diamictons, containing 40-70% pebbles and coarser clasts with 10% silt. The coarser diamictons do not effectively retain precipitation and are susceptible to erosion if not stabilized by vegetation. The valley-bottoms are discontinuous veneers of coarse and moderately sorted fluvial gravel.

Coastal sediments show small translational and rotational slides resulting from frost wedging. Damming of streams resulting from slope failure is uncommon in the interior of Torbay, although small slope failures leading to damming of streams have been initiated by the clearing of land, and in locations where the sediment is stacked artificially exceeding the angle of repose.

The southwestward-facing slopes (i.e. northeastern sides of valleys) are most susceptible to failure and erosion. As these slopes face the prevailing southwesterly winds, they also have the maximum exposure both to frost wedging, and to solar heating of snow cover. Water originating from southwestward-facing slopes contribute significantly to the stream systems during snowmelt and rain-on-snow flooding events.

Short, cascade-type streams with steep gradients of 6-10 m/km classify Soldiers' Brook, Main Brook (Torbay Brook), and 'The Gully' (Catto and St. Croix, 1998). Other river types are alternating riffles and fens (e.g. "The Gully"). Standing pools and ponds are only present in the headwater areas. The geomorphology of the streams is controlled naturally by the bedrock geology, and anthropogenic additions of sedimentation, brush input, and channel impoundment (Catto, 2001).

The formation of bars in the streams is not common, although ephemeral longitudinal bars have developed in Main Brook. Channels forming in the Torbay area have cross-section profiles varying from flat-bottomed to shallow parabolic. Streams predominantly carry sand and gravel. During flooding events, the largest clasts range from pebbles to coarse cobbles. In the summer, the streams carry fine sand. The estimated fair weather flow velocity for Torbay streams is less than 1 m/s and estimated discharge rates are less than 1 m^3/s. During Tropical Storm Gabrielle, estimates of peak flood velocity and discharge of Main Brook exceed 3 m/s and 60 m^3/s, respectively, based on the channel geometry during peak inundation (Catto and Hickman, 2004).

In the interior of Torbay, vegetation cover consists of boreal forest, dominated by black spruce (*Picea mariana*), white spruce (*Picea glauca*) and balsam fir (*Abies balsamea*). Homogeneous stands of larch (*Larix laricina*) are present on drier, coarser soils (Catto, 2001). Forest cover exceeds 90% in headwater areas, and clearance of forest cover is reducing the percentage. Fenlands are dominated by black spruce and sphagnum moss (Slaney, 2006).

In exposed coastal areas, natural vegetation is dominated by ericaceous vegetation including *Vaccinium vitis-idaea* (partridgeberry), *Arctostaphylos uva-ursi* (bearberry), *Vaccinium boreale* (dwarf bilberry), and *Ledum groenlandicum* (Labrador Tea) (Ryan, 1978; Thannheiser, 1984). Other common plants are *Juniperus communis*, *Kalmia angustifolia* (sheep laurel), *Kalmia polifolia* (bog laurel), *Rhaecomitrium* (feather moss), and *Empetrum nigrum* (black crowberry).

The mean annual precipitation is approximately 1400 mm, as recorded by Environment Canada at the St. John's Airport site (St. John's A), directly southwest of the town. Precipitation occurs throughout the year with seasonal variations. In general, July is the driest and hottest month (Environment Canada—Climate Data, 2004), and mean temperatures range between 16-20°C depending on aspect and shelter from winds. Snow amounts in Torbay vary from 15-25%, with increasing amounts inland (Banfield, 1981; Catto *et al.*, 2003).

The highest recorded precipitation amounts are associated with hurricanes and tropical storms, autumn and winter storms with northeasterly winds, and spring storms. Storms with dominantly northeasterly winds can increase the recorded rainfall amounts as much as 80% on northward and eastward-facing slopes (Catto, 2006). Consequently, greater precipitation is focused in the headwaters of streams discharging towards the northeast (c.f. Liverman *et al.,* 2006). This sequence of events resulted in the flooding in Torbay during Tropical Storm Gabrielle in 2001.

In late June, southwesterly airflow prevails for most of the island. During the summer the cyclonic activity is generally weak. The fall airflow pattern is marked by strengthening westerlies with intensifying cyclonic storm tracks (Banfield, 1993).

For the Avalon region, specifically Torbay, the cold Labrador Current flowing on the eastern side of the peninsula decreases the winter temperatures; therefore, a greater percentage of the winter precipitation is falling as snow. The storm track through the Strait of Bell Isle may aid in the higher production of precipitation in winter. Currently, the Torbay area experiences an increase in winter precipitation, particularly snowfall.

The cold anticyclones from the northwest may be associated with storm surges that attack from the north. Considering the orientation of Torbay, the northerly attacking storms have the greatest chance to cause damage.

In the spring, the dominant north winds decrease cyclonic activity, which in turn decrease the number of single, intense rainfall events. The months of March to May are not associated with frequent flooding events. In the spring, the easterly airflow patterns are associated with cold air. The decreased air temperature may temporarily freeze the ground and remaining snow pack, and enhance rain-on-snow events. An increase in northeasterly winds in winter and spring will also result in storm surges capable of altering the coastline.

In the late June, the southwest airflow prevails resulting in less precipitation than during other seasons. When the westerly winds strengthen in autumn, the cyclonic track intensifies. Consequently, Torbay will have a higher probability of being impacted from single, intense rainfall events and storm surges causing river flooding and coastal flooding. However, the greatest effect from hurricane and autumn storms will result from storms with a strong northerly backswing.

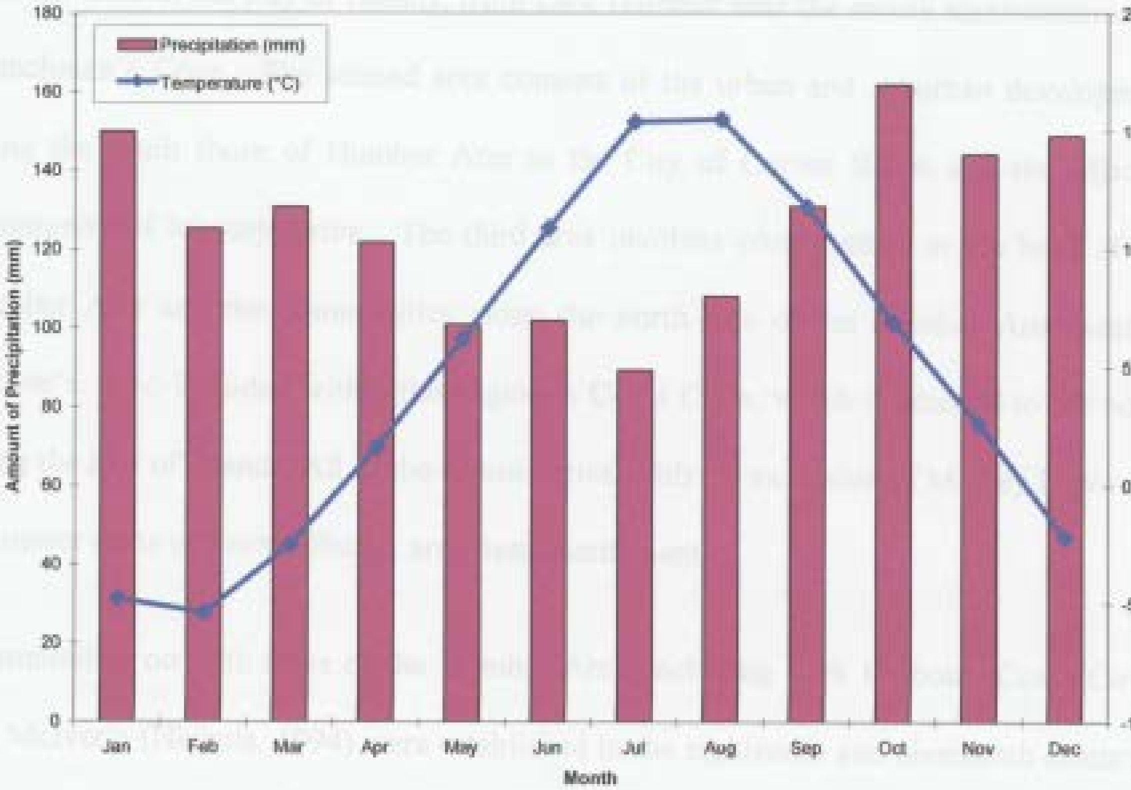


Figure 1.4: Climograph for St. John's. Data from St. John's A site on Environment Canada Climate data website. Data calculated between 1971 and 2000 from Environment Canada Climate Data website.

Torbay has an annual mean temperature of 4.7°C per month, with the maximum occurring in July and August (15°C) and the minimal occurring in February (-5.4°C) as calculated between 1971 and 2000 (Environment Canada Climate Data website). Monthly mean precipitation is 126 mm, with the highest amount occurring in October (162 mm) and the lowest amount occurring in July (83 mm).

1.2.2 Humber Arm region

The Humber Arm region flanks an embayment of the Bay of Islands on the west coast of Newfoundland, which is open to the west-northwest (Figures 1.1, 1.5 and 1.6). The study site can be broken into three areas. The first area includes all the communities along the southern side of the Bay of Islands, from Lark Harbour near the mouth southwestward to Frenchman's Cove. The second area consists of the urban and suburban development along the south shore of Humber Arm to the City of Corner Brook and the adjacent community of Massey Drive. The third area involves communities at the head of the Humber Arm and the communities along the north side of the Humber Arm west to McIver's. Also included within this region is Cox's Cove, which is situated to the north along the Bay of Islands. All of the communities, with the exception of Massey Drive and the newer parts of Corner Brook, are coastal settlements.

Communities on both sides of the Humber Arm, including Lark Harbour, Cox's Cove, and McIver's (Nichols, 1994) were established in the eighteenth and nineteenth centuries in relation to the fishing industry. The region has been experiencing economic decline, partially offset by tourism and summer residents. The greatest population decrease is evident in most distant communities from Corner Brook. Construction is occurring on the south shore and in Lark Harbour and York Harbour due to the aesthetically pleasing coastlines for summer homes.

Communities along the south shore include Lark Harbour (613), York Harbour (388), Humber Arm South (1800, including Benoit's Cove and Frenchman's Cove), and Mount Moriah (700), with populations as determined in the 2001 Census (Statistics Canada, 2005). Communities along the northern shore (Statistics Canada, 2005) include Cox's Cove (719), McIver's Cove (571), Gillams (406), and Irishtown-Summerside (1304). All communities, with the exception of Irishtown-Summerside, have been experiencing population decline since 1981.

Corner Brook is the largest community in the region and the largest community in the province outside the northeast Avalon Peninsula. The population of Corner Brook was recorded as 20,103 in 2001 (Statistics Canada, 2005). Although population has been decreasing, development of residential and commercial areas upslope from the original city core has been accelerating.

The community of Massey Drive developed as a suburb of Corner Brook. Due to this community's increasing population, construction of new residential areas has been increasing. In 2001 the population was 770 (Statistics Canada, 2005), and according to the *Western Star* (9 January 2004) the population was approaching 1000 in 2004.

The south side of Humber Arm contains extremely steep slopes, developed on fractured and weathered rock. The northerly aspect of the shore reduces exposure to hurricane events, but is susceptible to heavy rainfall associated with some hurricanes (e.g. Gustav in 2002). The slopes are unstable; frost-wedged topples, rotational and translational slides, gelifluction creep, and debris flows periodically interrupt highway traffic and communication along the main road (Highway 450). The steep slopes (locally exceeding 45°) between Benoit's Cove and Frenchman's Cove are constructed of badly weathered and extensively fractured bedrock making this section particularly prone to failure (Liverman *et al.*, in preparation).

The north side of Humber Arm is marked by more moderate slopes, developed on sedimentary bedrock, less fractured and weathered than the south side. The slope faces the prevailing wind, but the limited fetch of the Humber Arm reduces the orographic effect. Slope failure is reduced on the north shore because of the moderate slopes and lack of badly weathered bedrock.

On both sides of Humber Arm, areas below the limit of marine inundation during deglaciation (ca. 50 m asl; Batterson, 1998; Batterson and Catto, 2001), are dominated by a continuous sediment cover of glaciomarine gravel and sand in the embayments and valleys, that are not disturbed by river erosion. Marine terraces are obvious in the location of Lark Harbour, York Harbour, Cox's Cove, McIver's, and Irishtown-Summerside. The terraces create breaks in the slopes, causing rivers to flow across the terraces along gentle gradients that are locally prone to flooding. The steeper slopes develop between the terraces and the shoreline of Humber Arm.

In contrast, areas above 50 m asl along the southern arm have discontinuous sediment cover that is disrupted by colluviation (Batterson, 1998). On the northern side of the Humber Arm, the sediment cover is thicker, but not exceeding 2 m. The topography above 50 m asl in both regions is controlled exclusively by the bedrock. Corner Brook is developed on moderate to steep slopes. The downtown area below 50 m asl is underlain by glaciomarine gravel and sand. Areas in Corner Brook above 50 m asl have sediment covered with glacial till, glaciofluvial gravel, and exposed bedrock at high elevations.

The river systems in the Humber Arm region are typically short, cascade-type streams (Catto and Hickman, 2004). The Humber River is an exception. River gradients are steeper on the south side (typically 6-10 m/km) than on the north side (typically 3-5 m/km). However, local steep sections in some rivers exceed 10 m/km on both north and south sides of the arm. Rivers consist of alternating riffles and fens, with standing pools and ponds only in the headwater areas. Outside the Corner Brook urban area, the stream geomorphology is controlled by the bedrock geology, and minor contributions of human modification of sediment and brush input and channel confinement. Bars do not commonly form in the steeper reaches; however, longitudinal bars develop in areas with gradients less than 4 m/km.

Ice influences vary between the two sides of the Humber Arm region. In streams on the north side, ice-shove features were not observed. On the south side, transverse ribs resulting from river ice jams are present in the streams discharging into Humber Arm such as in Benoit's Cove east to Curling. The cross-section of streams are flat-bottomed to well-formed parabolic. During normal flow, streams predominantly carry sand and gravel. Clast sizes range from pebbles to coarse cobbles during flood events, and decrease to medium sand throughout much of the summer. Stream flow velocities and discharges are not static throughout the year. On average, flow velocities are ca. 1 m/s and discharges are 3 m^3/s for the largest streams. Peak flows based on the channel geometry during peak inundation are estimated to exceed velocities of 3 m/s, with discharges exceeding 30 m^3/s (Catto and Hickman 2004).

Precipitation amounts vary within the Humber Arm region (Figure 1.7). Mean annual precipitation in western Humber Arm is 1200-1300 mm (Environment Canada---Climate Data, 2004), and precipitation in eastern Humber Arm and in Corner Brook averaged 950 mm/a between 1980 and 2002. Spring is the driest season, with April as the driest month, with ca. 60 mm of precipitation at Corner Brook. Even with the low spring precipitation, spring rainfall, rain-on-snow events, and snowmelt events are significant in initiating flooding in the region. December and January are the wettest months, with ca. 140 mm of precipitation per month.

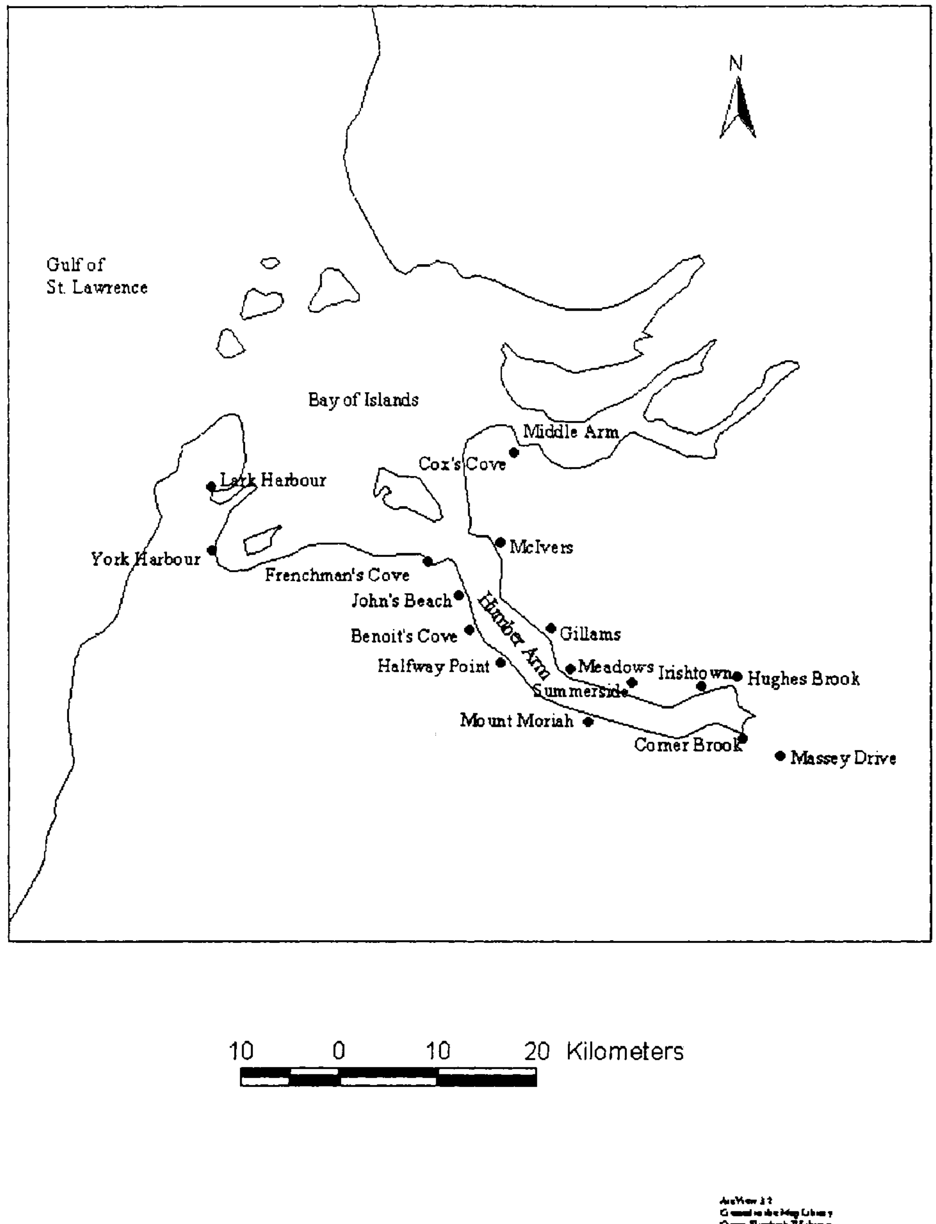


Figure 1.5: Location map of the Humber Arm region

Figure 1.6: A series of 1:50,000 topographical maps combined of the Humber Arm region

The various wind and ocean currents affect the west coast of Newfoundland. In the winter, the warm north to northeast current in the Gulf of St. Lawrence causes the precipitation in the Humber Arm region to fall as rain. If the rain falls in single intense events, then the severity of the rain-on-snow event will increase. In winter, the northwest winds will bring storms to the west coast which will deposit high amounts of precipitation to the area. The high snowfall rate will result in a thick snow cover. Currently the area is undergoing a trend in increased portion of the precipitation falling as rain (Environment Canada--Climate Data, 2004). The increased amount of rain on the thick snow cover may result in enhanced rain-on-snow events.

The spring months (March to May), the Humber Arm region is marked with the greatest increase in seasonal precipitation (Environment Canada--Climate Data, 2004). This may be resulting from changes in the easterly airflow. The easterly airflow is also cold; therefore, it may freeze the ground and enhance rain-on-snow events. Also, between late fall and mid winter cold air outbreaks from Quebec and Labrador induces snowfall (Rollings, 1999). When the southwest airflow prevails in late June, the cyclonic activity and single, intense rainfall may decrease. Therefore, areas on the west coast may experience a lessened probability of river flooding due to heavy rainfall events.

The weakened cyclonic activity in the summer results in the lowest amount of precipitation. The number of intense rainfall events reduces the number of flooding events. The strengthening of the westerly winds in autumn increases the frequency of autumn and cyclonic activity. Cyclones become more intense and more capable causing severe flooding events due to rainfall or storm surges.

In general, the rain-snow ratio is greater for south-facing lowlands and lesser for north-facing uplands. The snow total varies from ca. 20%-25% in low-lying, south-facing sites (e.g. McIve'rs) to more than 40% in north-facing upland areas (e.g. the summits to the south of Benoit's Cove). Snowcover is less persistent on the north side. Snow cover in forested regions has a mean annual duration of 160 days, decreasing to ca.110 days in coastal areas. On the sheltered north-facing slopes, snowpacks may persist until late spring, creating a greater risk of rain-on-snow flooding events.

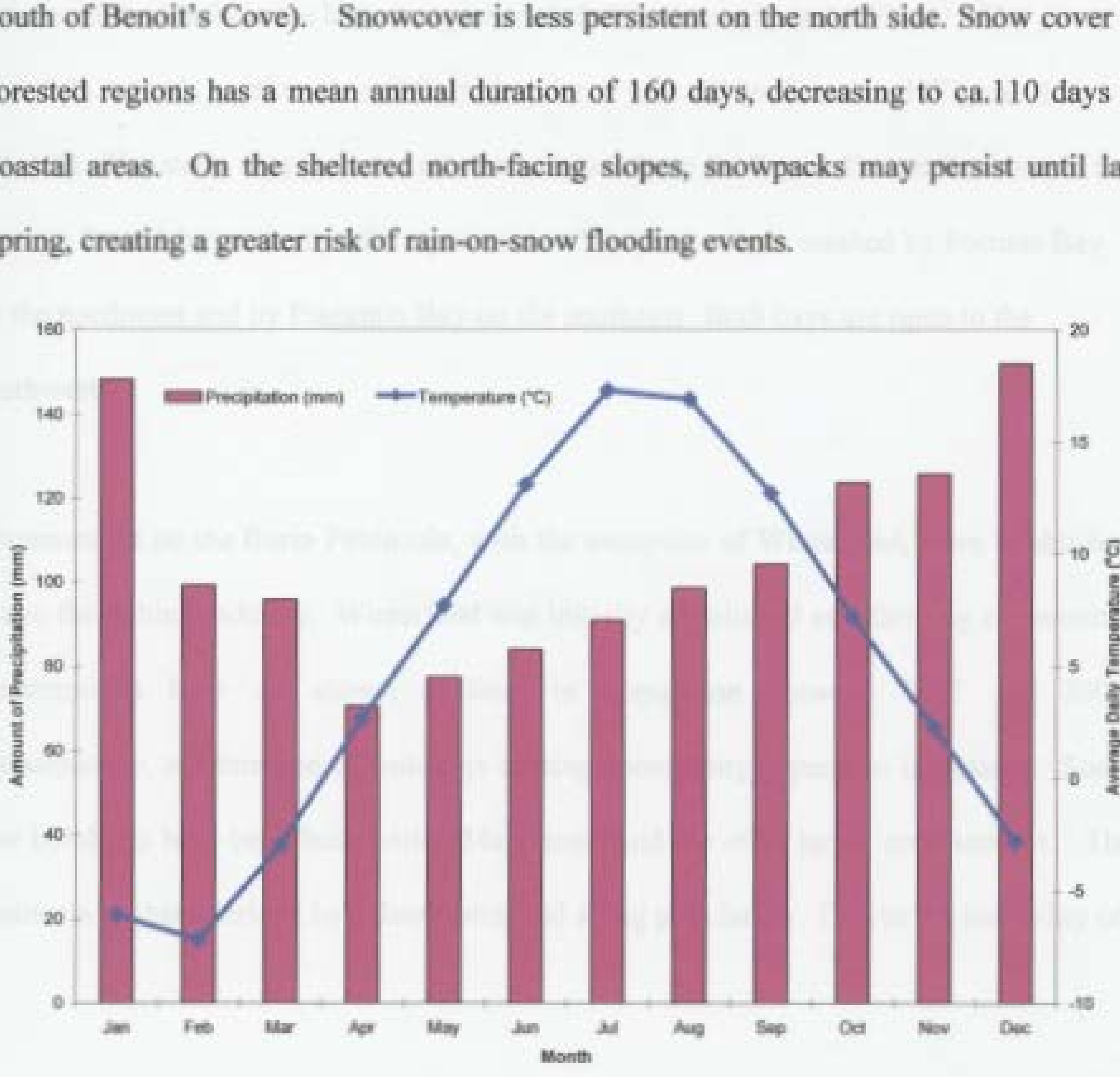


Figure 1.7: Climograph for Corner Brook. Data from Corner Brook site on Environment Canada Climate data website. Data calculated between 1971 and 2000 from Environment Canada Climate Data website.

The Humber Arm region, as represented by the Corner Brook site, has a mean monthly temperature of 5°C with a range of -7.2°C in February to 17.3°C in July. The mean precipitation averages at 106 mm per month with a range between 71 mm in April to 152 mm in December.

1.2.3 Burin Peninsula

The Burin Peninsula is the largest region included in the study at 3,000 km^2. The peninsula extends southwestward from the central part of Newfoundland (Figures 1.1, 1.8, 1.9). The study area includes all communities from St. Bernard's and Rushoon in the north to Point May at the tip of the peninsula. The peninsula is washed by Fortune Bay on the northwest and by Placentia Bay on the southeast. Both bays are open to the southwest.

Communities on the Burin Peninsula, with the exception of Winterland, were established due to the fishing industry. Winterland was initially established as a farming community. Communities have all shown declines in population between 1991 and 2001. Consequently, construction of buildings causing community expansion is minimal. Some new buildings have been built within Marystown and the other larger communities. The peninsula is characterized by a decreasing and aging population. Due to the instability of

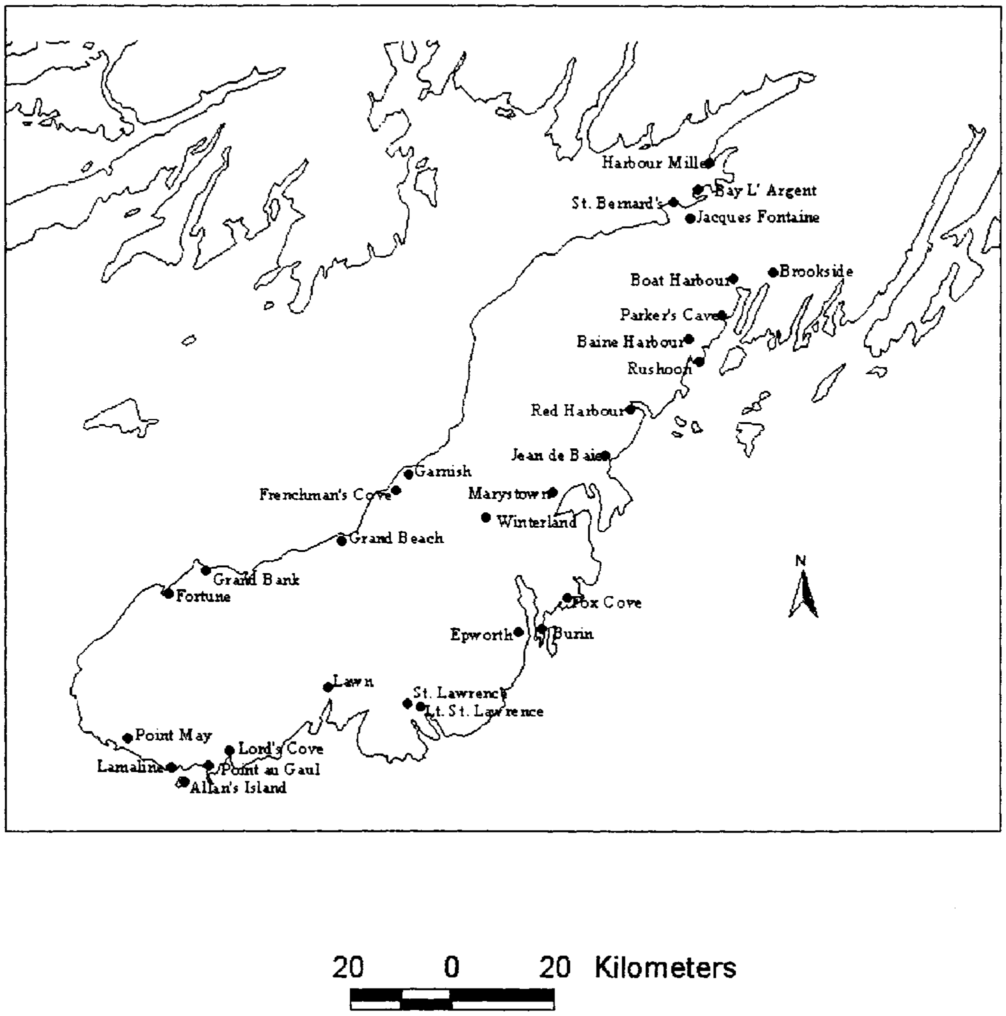


Figure 1.8: Location map of communities on the Burin Peninsula.

Figure 1.9: 1:250,000 topographical map of the Burin Peninsula

the fishing industry and the limited to non-existent significant industrial or commercial growth, the peninsula is also characterized by a limited economic base.

The total population of the Burin Peninsula was approximately 21,000 in 2001. The population is concentrated in the larger communities (Statistics Canada, 2005), including Grand Bank (2841), Fortune (1615), St, Lawrence (1558), Marystown (5908), and Burin (2470). The small coastal communities on the Placentia Bay shore include Lamaline (346), Lord's Cove (234), Lewin's Cove (575), Fox Cove-Mortier (380), Lawn (779), Little St. Lawrence (145), Port au Bras (242), Epworth-Great Salmonier (239), Point au Gaul (94), Point May (322), and Rushoon (359). Small communities on the Fortune Bay shore include (Garnish (665), Frenchman's Cove (195), and St. Bernard's-Jacques

The majority of the Burin Peninsula has an elevation below 100 m. The centre of the southern portion of the peninsula between the Fortune and Placentia Bay coasts is marked

hinterland. The peninsula has a northeastward-trending upland, which is an extension of the Central Newfoundland Uplands (Bostock, 1970). The highest area, excluding Point

developed over resistant granitic intrusions and volcanic rocks. Very gentle slopes extend from hinterland areas to the shorelines, particularly in the settled areas. Most communities are built on gently sloping coastal plains, structurally reflecting the underlying bedrock.

Coastal areas of the peninsula are underlain by flat-lying to gently sloping sedimentary and volcanic rocks (Catto *et al*, 2003). The older units form irregularly embayed shorelines with short river systems marked by sharp bends. The varying rates of erosion of the interbedded volcanic and sedimentary units contribute to the configuration of the river valleys.

Fortune Bay coastal plains are characterized by sedimentary rocks, including limestones, sandstones, shales and mudstones, which are flat-lying to extremely gently dipping, and erode evenly. Streams along the coast have consistent gradients and are relatively low in sinuosity (Catto and Hickman, 2004). The combination of orientation of the coastal plains and the prevailing winds result in the vulnerability of both the Placentia Bay and Fortune Bay coastlines to flooding resulting from storm surges.

Glaciation of the Burin Peninsula formed a discontinuous cover of coarse pebbly diamicton, with gravel-sized clasts forming 30-50% of most deposits. Less than 20% silt and clay is present in areas where the underlying bedrock is weak sandstones or shale (e.g. along Fortune Bay). The coarse diamicton is not effective in retaining precipitation. More absorbent blanket bog and fen peat deposits cover large areas of the interior plateau, with a thickness exceeding 3 m in areas. The coarse deposits, extensive layers of peat, and gentle slopes reduce erosion and slope stability problems in areas with intact vegetation. The valley-bottom deposits consist of discontinuous, thin veneers of coarse, moderately sorted gravel.

River systems are short, with moderate to gentle gradients, typically less than 2 m/km in communities. Riffles and pools are poorly differentiated. Natural river systems are usually surrounded by semi-permanently saturated fenlands, which dry during the most extreme summers. Within most communities, the rivers are partially or totally confined by construction and infilling that limit the natural flood buffering effect provided by the fenlands. The numerous shallow ponds, pools, and wetlands are a consequence of the perhumid climate of the Burin Peninsula. Stream geomorphology is defined primarily by the topography, and secondarily by human alteration in the form of channel modification.

Transverse ribs produced by ice jamming have been observed in several Burin Peninsula rivers (Catto and Hickman, 2004).

The cross-sections of channels on the Burin Peninsula are shallow parabolic. The streams transport a variety of clast sizes, from fine to coarse pebbles during flood events

velocities exceed 3 m/s and discharges exceed 20 m^3/s (Catto and Hickman, 2004). On the Burin Peninsula, high velocity stream flooding is not significant.

On the peninsula, vegetation cover consists of scattered boreal forest in the interior, dominated by black spruce (*Picea mariana*) and balsam fir (*Abies balsamea*) with lesser white spruce (*Picea glauca*). In drier, coarser soils, larch (*Larix laricina*) is present; colonization is limited by the perhumid climate regime. Forest cover has been constantly reduced surrounding all communities. Fenlands are dominated by black spruce and sphagnum moss.

The natural vegetation of the interior barrens is dominated by *Rubus chamemorus* (bakeapple), *Empetrum nigrum* (crowberry), *Vaccinium vitis-idaea* (partridgeberry), *Arctostaphylos uva-ursi* (bearberry), *Vaccinium boreale* (dwarf bilberry), and *Ledum groenlandicum* (Labrador Tea) (Ryan, 1978; Thannheiser, 1984). Other common plants are *Sphagnum, Kalmia angustifolia* (sheep laurel), *Kalmia polifolia* (bog laurel), and *Rhaecomitrium* (feather moss).

The Burin Peninsula is characterized by low summer temperatures, abundant rainfall (Figure 1.9), a perhumid climate regime, and an annual moisture budget exceeding 100% for all areas. The abundant precipitation is associated with hurricanes and southwesterly autumn and winter storms, and spring rainfall events. The precipitation totals vary between coast with totals of 1450-1550 mm along the Placentia Bay shoreline and 1300 mm along the Fortune Bay coast (at Grand Bank and Fortune; Environment Canada—Climate Data, 2004). Placentia Bay communities receive more rainfall due to the onshore southerly winds carting precipitation, coupled with lesser orographic effects in some embayments. Typical years vary little in monthly precipitation. In St. Lawrence July is the driest month marked by 110 mm of precipitation (Environment Canada—Climate Data, 2004). On average, the August daily mean temperatures vary from 14°C to 16°C, with warmer summer temperatures occurring on the Fortune Bay coast than areas exposed to southwesterly winds on the Placentia Bay coast (Catto *et al.*, 2003).

Snowfall totals average 5-15% of total precipitation for coastal sites and 10-20% for sites in the interior. Duration of snow cover is ca.110-120 days in interior wooded areas. The snow cover duration is lesser in cleared areas and open barrens, particularly those facing southwest. Overall, south-facing sites (e.g. along Placentia Bay) receive more precipitation and a higher rain-to-snow ratio than north-facing sites (e.g. facing Fortune Bay). Thunderstorms have become more common in recent years (Catto *et al.*, 2003).

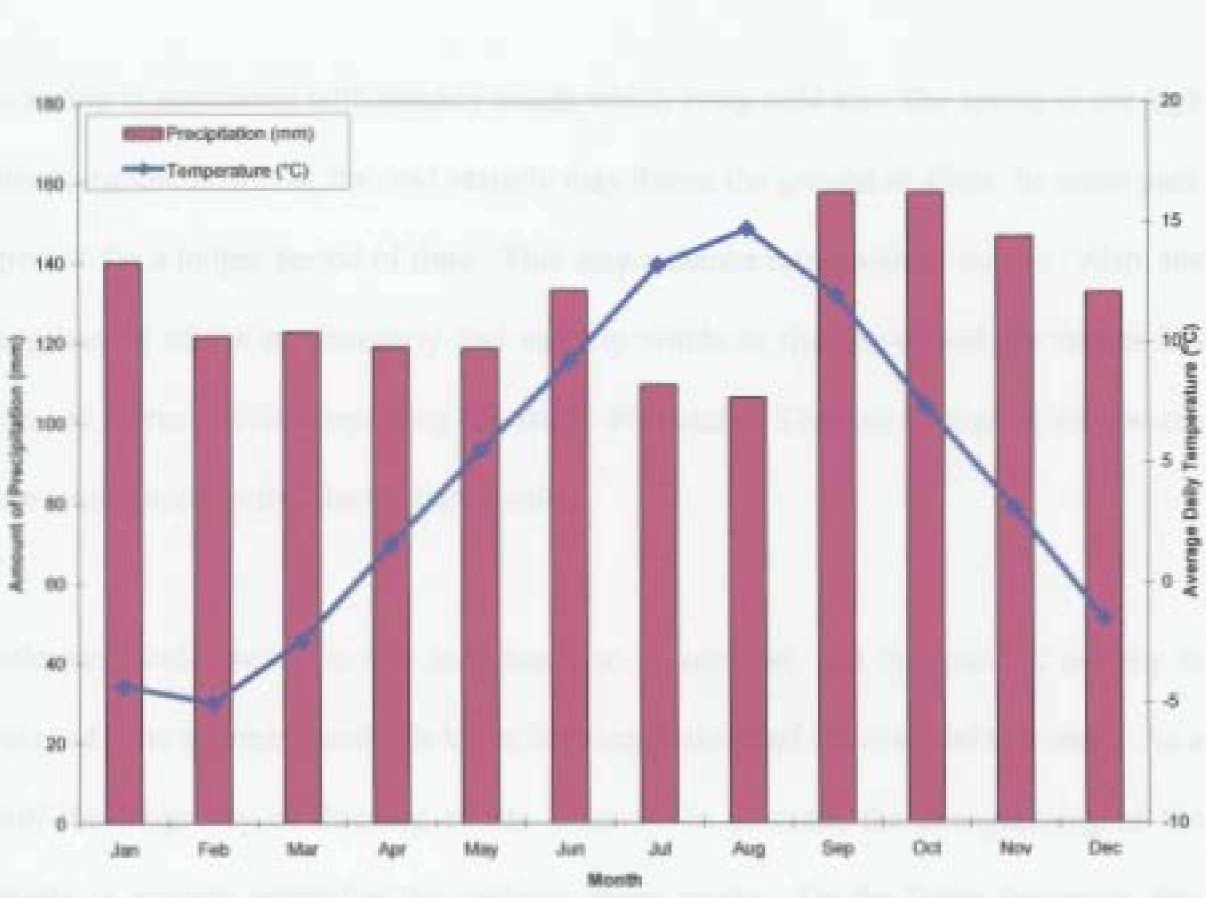


Figure 1.10: Climograph for St. Lawrence. Data for St. Lawrence site on the Environment Canada Climate Data website. Data collected between 1971 to 2000 from Environment Canada Climate Data website.

Between 1971 and 2000, the mean monthly temperature is 4.4°C, ranging from 14.7°C in August to -5.5°C in February. The mean monthly precipitation is 130 mm. The precipitation ranges from 106 mm in August to 157 mm in September and October.

The oceanic currents and airflow patterns have a greater effect on the severity of seasonal flooding events on the Burin Peninsula than the other study regions. The cold Labrador Current decreases the air temperature in the winter and is increasing the amount of precipitation falling as snow. The warm Gulf Stream act as storm track bring cyclonic activity from the eastern seaboard towards the peninsula.

The spring is associated with easterly winds which bring cold air. The spring is not high in precipitation; however, the cold easterly may freeze the ground or allow the snow pack to persist for a longer period of time. This may enhance rain-on-snow events. Also, the strengthening of the northeasterly and easterly winds in the spring and the winter has increased storm activity impacting the Burin Peninsula. The more frequent and severe storm surges are greatly altering the coastline.

Southwest winds prevail in late June and also in summer, and the cyclonic activity is weakened. The summer usually is lower in precipitation and intense rainfall events. As a result, the frequency of flooding events is low. In contrast, the strengthening of the westerly in autumn intensifies the cyclonic storm tracks. On the Burin Peninsula, this greatly increases the frequency and intensity of hurricanes, storm surges, and intense rainfall events causing river flooding and storm surges.

2. Review of Previous Work

Numerous researchers have investigated flood mechanisms, effects, socio-economic costs, and frequencies in many different environments. This chapter reviews some of these studies considered to be particularly relevant to flood occurrences in Newfoundland.

To assess the frequency and magnitude of flooding, a 1:20, 1:50, or 1:100 year return period is usually chosen (e.g. Canada--Newfoundland Flood Reduction Program 1990a, 1990b, 1990c; Gutowski *et al.*, 1994; Khandekar and Swail, 1995; Haque, 2000; Todhunter, 2001). The return period is defined as the statistical mean time between successive flood events of a given magnitude. For a 1:100 year return period, there is a 1% chance of a flood reaching that level in a given year. However, flooding which reaches the elevation characterized as a 1:100 year flood level may not occur over a particular 100 year period, or may occur more than once in that time. As a result, reliance on the return period assumption may lead to under-estimation of frequency, and damage resulting in these floods.

The costs associated with flooding can be divided into three general categories: 1) the cost of constructing flood control infrastructure prior to the flood; 2) the cost of direct damages resulting from a flood; and 3) the cost of restoration and cleanup after the flood (Lawford *et al.*, 1995). The financial assistance provided by PSEPC (Public Safety and

Emergency Preparedness Canada) for 33 flood disasters in Canada between 1970 and 1988 was ca. $587 million (in 2005 dollars; Environment Canada 2004a) Between 1970 and 1999, federal payments made under Disaster Financial Assistance Arrangements for floods in Newfoundland totaled $8 million (Environment Canada, 2004a). However, the total national and provincial disaster assistance is only part of the costs associated with floods. The remainder was paid by individuals, businesses and industry, and provincial and municipal treasuries (Environment Canada, 2004a).

2.1 Hurricane-induced precipitation

Hurricane induced precipitation contributes to severe flooding of both coastal and inland areas. Heavy precipitation triggers river flooding, slope failure, extensive runoff events, and overtaxing of drainage infrastructure. Although generated by different meteorological causes, hurricanes, tropical cyclones, tropical depressions, and extratropical cyclones are similar in their geomorphic effects. Tropical cyclones develop in southern latitudes in the warmer months of June to November and track northward along the eastern North American seaboard where they either weaken or strengthen into hurricanes. In contrast, extratropical cyclones develop in mid-northern latitudes, and the frequency and intensity are greatest between October and March (Environment Canada-Hurricane Centre, 2005).

The frequency of hurricane or cyclone hits vary with location: on average 4 tropical cyclones affect Atlantic Canada each year. The highest intensity hurricanes, category 4 or 5, have not made landfall in Canada since 1851. Two category 3 hurricanes have impacted Canada between 1893 and 2003: Hurricane Luis impacted Newfoundland in 1995, and Nova Scotia was affected in 1893 (Environment Canada Hurricane Center, 2005).

The spring rainstorm at the end of March 2002 impacted the Atlantic Provinces. Heavy rainfall caused flooding in all four Atlantic Provinces; rainfall exceeding 100 mm occurred in Southern New Brunswick, Central Nova Scotia and the west coast of Newfoundland (Environment Canada, 2004b). Area of highest total precipitation was 124 mm at Salmon Hole, Nova Scotia. On average, rainfalls of similar magnitude have a return period of 5 to 10 years in Nova Scotia (Environment Canada, 2004b). Water levels in the Sackville River (Nova Scotia) were approximately 1 m higher than previous flooding events in 1994, 1996 and 2000. The LaHave River and the Kennebecasis River in New Brunswick also experienced above average flood heights. Floodwaters destroyed bridges and roads, and collapsed basement walls (Environment Canada, 2004b).

The Gulf Stream acts as a preferred track for tropical cyclones. The Gulf Stream provides energy which promotes northward movement and allows for high wind speeds due to reduced wind resistance. Although this path deflects most storms away from Atlantic Canada, the frequency of tropical cyclones in Newfoundland is one every 1.4 years (Environment Canada Hurricane Center, 2005). The damages that hurricanes and tropical cyclones have inflicted on Newfoundland are minimized by the steep coastal topography and the deeply indented coast with numerous bays and estuaries (Environment Canada Hurricane Center, 2005). The hurricane season is July to November with the peak in September.

A location is considered to have suffered a direct hit by a tropical cyclone when the storm centre passes within 111 km (Hart and Evans, 2000). Although 111 km is considered a typical radius for the area of heaviest precipitation, numerous historical storms show that the impact extends beyond this defined radius. The damage zone resulting from heavy rain can extend several hundred kilometres beyond the center of the hurricane or tropical cyclone (Hart and Evans, 2000). Hurricane Luis and Tropical Storm Gabriel impacted relatively large areas; whereas heavy rainfall events on the Avalon Peninsula from Bob (1991), Hortense (1998), and Irene (1999) were extremely localized (Catto and Hickman, 2004).

Heavy precipitation accompanies many hurricanes that impact Atlantic Canada. Hurricane Gustav passed over Atlantic Canada on 12 September 2002, and made landfall along the southern coast of Cape Breton, Nova Scotia. The hurricane produced heavy rain: 102 mm in Ashdale, Nova Scotia and 92 mm at Halifax International Airport. The remainder of Nova Scotia received over 50 mm of rain (Environment Canada-Hurricane Centre, 2002).

Hurricanes can deposit large amounts of precipitation on small areas in a short period of time, with rainfall amounts greater than 500 mm if the movement is stalled or slowed when hurricanes make landfall (Hirschboech *et al.*, 2000). The amount of rainfall during one event may exceed the monthly average for that area. For example, the monthly average precipitation for Torbay is 126 mm, and during Tropical Storm Gabrielle 118 mm of rain fell. For the Burin Peninsula the monthly average precipitation is 125 mm, and Hurricane Luis deposited 115 mm of rain. The amounts may be underestimated due to measuring techniques. Current techniques are most efficient at measuring vertical rainfall; during hurricanes precipitation falls with a horizontal component (Banfield and Jacobs, 1998; Environment Canada—Climate Data, 2004)

Examples of flooding caused by hurricanes and extratropical cyclones in boreal latitudes are numerous. Heavy precipitation associated with Hurricane Charley caused widespread flooding and extensive damage in Europe (De Bruijn and Brandsma, 2000). The hurricane emerged as a tropical storm off the South Carolina coast on 15 August 1986. Due to baroclinic conditions, Charley redeveloped into an extratropical cyclone. As the storm approached southern Ireland near the Cork coast, rainfall occurred over the country. The storm system induced an east to northeast flow over Ireland. As a result of the air flow, interaction of the advected moist air with the orographic enhancement of the Wicklow Mountains south of Dublin increased the rainfall and amplified runoff into the river catchments (De Bruijn and Brandsma, 2000). The maximum rainfall was 200 mm in a 24 hr period.

The effects of the storm system were not confined to the area directly below the storm. The storm caused the small rivers draining the east side of the Dublin Mountains and flowing through urban areas of Dublin and Bray to burst their banks. Consequently, lives were lost, over 400 houses were flooded with up to 2.5 m of water, and 35 commercial premises were inundated. Insurance claims exceeded €32 million (46 million CAD; De Bruijn and Brandsma, 2000).

The effects of hurricanes (or remnants of hurricanes) through heavy precipitation can be felt far inland. Runoff from heavy precipitation can overwhelm a watershed, which cannot store the water (Simpson and Riehl, 1991). The excess water is removed through drainage networks, rivers, canals, or ditches (Hirschboech *et al.*, 2000). The extent of flooding is determined by the timing and spatial distribution of precipitation with respect to a river basin. Flooding can be more severe in locations where the terrain focuses the runoff in small areas, such as in a small river basin. Areas along the storm's path are susceptible to flooding.

Hurricane Hazel struck Southern Ontario on 15 October 1954. The result was the loss of 81 lives, the loss of 1,896 residences, and damages totaling $100 million dollars ($711 million equivalent in 2005). The runoff (90% of the total precipitation) triggered from the 180-225 mm of rain within less than 24-hr in Toronto caused extensive damage. The rivers filled their historic floodplains and destroyed infrastructure constructed on the floodplains. Runoff led to the derailment of trains, destruction of roads, over-topped dams, flooded houses, farms, and private property (Environment Canada-Hurricane Centre, 2004). Bridges became temporary dams, impounded water, and increased flooding when the bridges subsequently broke.

Neighbourhoods located in the west and northwest regions of the city experienced higher amounts of precipitation than central and eastern Toronto. Pearson (Malton) International Airport located 27 km northwest of downtown Toronto received 137 mm of rain in the 24 hours; Weston and Islington, located in western Toronto, received 127 mm in 24 hours; and Danforth, located in the east end of Old Toronto, received 76 mm (Environment Canada-Hurricane Centre, 2004).

Because of the intensity of rainfall, the ground cannot absorb the moisture and the majority of rain is converted to runoff (Simpson and Riehl, 1991). Consequently, rivers provide natural drainage routes for runoff. The runoff resulting from hurricanes is greater than the average flow, and the river banks may overflow and inundate the surrounding area.

Short river systems will respond more rapidly to hurricane activity than will long river systems. Flooding can be more severe in locations where the landscape focuses the runoff in small areas, such as in small river basins. In short river systems, flood levels are reached within an hour after the onset of a storm, as a short lag time exists between initiation of precipitation and flood levels (Hirschboech *et al.*, 2000). Short length river systems are defined as being less than 30 km.

Exposure of areas to hurricane induced river flooding is determined by topography and the orientation of the river to the hurricane. The orientation of a hurricane to a watershed (particularly for long river systems) determines the magnitude and timing of flooding. Storms that move at 90° azimuth to the direction of flow within a watershed will result in less flooding than from a storm moving parallel to the watershed (Singh, 1997). The longer the storm is positioned over the watershed, the more runoff and greater the flood hazard. Therefore, storms moving parallel to long watersheds will result in greater flooding than a storm which tracks across the axis of the watershed.

A storm moving upslope will result in the early rise of water height with the onset of the storm at the mouth of the river, and a slow decrease in water height as the storm moves upstream. During the upstream movement of the storm, water flows into the river from the watershed and maintains the high water level (Singh, 1997). In contrast, a storm moving downstream will result in a delayed high water level at the mouth of the river and a short period of high water. Since the precipitation is focused higher on the watershed, the water surge from runoff and the surge caused by the heaviest precipitation under the storm may reach the mouth of the river at approximately the same time (Singh, 1997). Simultaneous storm peak and water surge greatly depend on the speed of both the river and the storm.

Hurricanes that impact Newfoundland and Labrador are usually dominated by southwest winds (Environment Canada, 2004a). Newfoundland river systems aligned in a southwest direction thus are more vulnerable to hurricane flooding. These river systems will reach high water levels quickly and have sustained water heights. Although hurricanes dissipate in strength as they move northward, flooding events can be triggered by the remnants through heavy precipitation. The large concentration of water vapour associated with the dissipating storm can induce the development of other precipitation systems, thereby causing the flooding of natural and artificial drainage systems (Hirschboech *et al.*, 2000). The effects of Hortense (1998) in Mount Pearl and Gabrielle (2001) in the northeast Avalon are examples of this effect.

Peter's River, in the southeastern Avalon Peninsula of Newfoundland, was impacted by hurricane activity in summer 1995. During hurricanes Felix, Luis, and Opal, the precipitation from the storms had stronger influences on morphological changes and flooding of the river and outlet than storm surges (Nichols, 1995). As the river headwaters are aligned facing the dominant southwest winds, the storms following a southwest to northeast track deposited a large amount of water onto the river's drainage area. Flooding by river water in the lowermost reach occurred approximately 2 hours after the initiation of precipitation (Nichols, 1995). The discharge was sufficient to force an opening in the barrier beach, disrupting sediment transport patterns in the vicinity of the community wharf and interfering with vessel berthing (Nichols, 1995). Historical storm effects suggest that any obstruction in the river will result in a backwater effect and cause localized flooding (Nichols, 1995). Similar effects were observed in Peter's River during Hurricanes Irene and Gabrielle (Catto *et al.*, 2003).

The orographic effect of mountains will increase the amount of precipitation through uplift of the wind when hurricanes cross or even pass alongside mountain ranges (Simpson and Richl, 1991). The hurricane track speed and strength will decrease rapidly in mountainous areas (Simpson and Richl, 1991), which will increase the time available for the hurricane to deposit precipitation in a relatively small area. In large, flat coastal areas with many lakes and rivers, the hurricane track and strength will decrease less than in mountainous areas. Even though a storm moves more rapidly through coastal areas, it will lose strength slowly while crossing flat terrain, allowing a greater time and area for hurricane precipitation to induce flooding. Slow moving storms may impact an area 24-36 hours after landfall (Simpson and Richl, 1991).

The topography and size of the river basin controls a river's response to hurricane precipitation. The lower gradient areas have the lowest values of flood water discharge, which produces a slower response time than rivers with higher gradients (Sturdevant-Rees *et al.*, 2001). Higher discharge rates were found from slower moving hurricanes than faster moving hurricanes (Sturdevant-Rees *et al.*, 2001).

Communities in New Brunswick have sustained damage due to hurricane-induced rainfall. Hurricane Juan (29 September 2003), which had an impact on Nova Scotia was considered a Category 2 with the resulting damage of a Category 3 hurricane. The storm surges associated with the hurricane ranged from 1.0 – 3.31 m causing evacuations along the coastline of Nova Scotia and Prince Edward Island. The water level reached 2.90 m (chart datum) in Halifax Harbour, which resulted in extensive flooding of Halifax waterfront properties.

In the Maritimes, seven people died, two of whom died in Halifax due to falling trees, and damages totaled ca. $100 million. The damage consisted of toppling of very large trees, downing power lines resulting in 300,000 homes and businesses without power, the destruction of property, and destruction of wharfs and barns (Falk, 2003).

Global climate cycles alter hurricane frequency. El Niño years are marked by decreased hurricane activity in the North Atlantic Ocean. The El Niño years of 1981-1983 showed a below average number of hurricanes in Newfoundland. The years 1997-1998 were also El Niño years, and no hurricanes or tropical storms reached Atlantic Canada in summer 1997 (Catto and Hickman, 2004).

2.2 Autumn and Winter Storms

The intensity of rainfall of autumn/winter storms is generally less than for hurricanes (Environment Canada-Hurricane Centre, 2003b). However, the ground condition may enhance the impact of autumn/winter storms. If the ground is frozen, covered with snow or freezing rain, then runoff will be greater than over bare ground. When precipitation types change during autumn/winter storms, flooding may increase. For instance, storms may begin as snow, change to freezing rain or wet snow, then change to pure rain. The snowpack will increase runoff and the rain will induce snow melt. As with hurricane runoff, autumn/winter storm runoff enters rivers and causes an increase in water levels. However, the timing of peak river discharge levels will be different depending on the type of precipitation. Pure rainstorms will result in rapid flow response, similar to hurricane-induced flooding. Transition storms (snow-rain) will result in a lag time between the onset of the storm and commencement of pure rainfall.

Autumn/winter storms will result in river flooding when precipitation falls on the ground, and if not absorbed by the ground will flow into rivers. If the runoff exceeds the river banks, the surrounding area will be inundated. Since hurricane rainfall intensity is greater than for autumn/winter storms, rivers may reach high flood discharge more quickly and more often per hurricane event than per autumn/winter storm.

2.3 Storm surges

Storm surges are changes of water level which exceed the normal water levels associated with the predicted astronomical tide. Storm surges occur when wind stress causes the displacement of water shoreward, and are further enhanced by coupling of rising high tide to form a set-up condition (Danard *et al.*, 2003). Storm surges cause extensive coastal erosion and morphological changes, destruction of infrastructure, inundation of coastal areas, and slope failure. The amount of damage a hurricane or extratropical cyclone can inflict on a coast depends on several factors: location relative to storm path, timing of storm events, duration of backbeach flooding, wind stress, flow confinement, antecedent topography and framework geology, and type and density of development (Morton, 2003).

The fishing industry and related activities was the main economic activity for many of the communities in Newfoundland and Labrador, and therefore substantial infrastructure lies along the coast. Severe damage caused by storm surges may have major socio-economic repercussions. Historical documents reveal incidents when lives were lost due to storm surges. In 1847, 300 deaths occurred when a hurricane hit Newfoundland (Danared *et al.*, 2003). The storm of September 12-16, 1775, may have killed 4,000 Newfoundlanders (*Stevens and Staveley, 1991; Stevens, 1995; Ruffman,* 1995). Several additional and more recent records illustrate the tremendous costs that follow storm surges. Property may be damaged, roads may be severed, sediment deposition may occur, freshwater may become temporarily saline, coastlines may be eroded and changed, and areas further inland may become inundated.

When the storm surge coincides with enhanced tides (setup), the surge can reach further inland and increase the amount of damage. Enhanced tides are formed when a New Moon occurs in conjunction with a lunar perigee. The gravitational attraction of the Moon on the ocean surface increases the sea level and creates larger tides.

Fetch and ice cover also affect storm surge strength. Large open areas of water will allow the wind to generate higher waves. Reduced ice cover will also allow for a large fetch, which will increase wave heights (Debernard *et al.*, 2002). Ice increases the damage to coastlines.

The storm track in part determines the pattern and magnitude of a storm's impact on a particular location. Cyclone winds in the Northern Hemisphere rotate counterclockwise, forcing the water on the right side of the center of the storm onshore. Water to the left of the storm center is blown away from the coast, limiting the height of the storm surge. During hurricanes, the height of water around the storm eye decreases with distance away from the storm center (Morton, 2002). As a typical storm in the Canadian Atlantic region moves northeastward along the Atlantic seaboard and then across the Atlantic towards northwestern Europe, storm waves occur from the east or northeast in advance of the storm. As a result, in areas where surge height is not restricted by fetch, the highest waves are directed west to northwest behind the storm (Khandekar and Swail, 1994).

The Beaches, White Bay, was impacted by 10 m waves in mid January 2004. The force of the waves downed telephone poles and washed out the only road to the community. The entire community was evacuated, approximately 40 homes. The community was also evacuated during a storm in 1992 (*Western Star*, 17 January 2004). The northeast winds carry the most damaging storms to the area. Although water flowed into the basements of many of the houses, greater impact would have occurred if the storm coincided with the spring tide: waters of White Bay were at neap tide during the worst three or four hours of the storm. Residents stated that houses would have been destroyed if the storm surge and tide resulted in a full setup. The force of the storm surges prevented outflow of the sewer system. The previous 1992 storm pushed ice from the frozen bay into the harbour, destroying boats and fishing gear. The destruction of the breakwater and parts of the road has increased the community's vulnerability to further damage by future storms (*Western Star*, 19 January 2004).

Hurricane Juan made landfall in Nova Scotia between Shad Bay and Prospect on 29 September 2003. The modal waves recorded at the coast were approximately 9 m off Halifax Harbour and maximum waves measured 19.9 m. The storm surge coupled with the high tide caused waves to reach the crest of a high gravel barrier on the morning of 28 September 2003, before Juan reached Nova Scotia (Environment Canada-Hurricane Centre, 2004b).

On 21-22 January 2000, a deep low tracked through the Maritimes causing severe impacts at numerous coastal locations. The 1.2 m storm surge coincided with perigean high tides which intensified the impact of the storm (Forbes *et al.*, 2000; Environment Canada, 2002). The north coast of PEI sustained damage when surges overtopped barrier beaches at Rustico and Savage Harbour, as well as other locations, causing serious erosion and significant property and infrastructure damage. Northumberland Strait experienced the most severe surges. The result of the record high water levels was the flooding of parts of Charlottetown, Mt Stewart, and Summerside PEI, and Shediac, Bouctouche, and Richiboucto, NB (McCulloch *et al.*, 2002). In conjunction with the wave impacts, sea ice ride-up and pile-up impacted the south coast of PEI and the Gulf of St. Lawrence NB. Ice ride-up dislodged a lighthouse in Charlottetown, destroyed the wharf at Richibucto NB, and damaged boardwalks and infrastructure at Les-Dunes-de-Bouctouche NB (Environment Canada, 2002). In Charlottetown, the water level was 4.23 m above Chart Datum and damages were estimated at $1 million. However, the inclusion of the uncalculated costs of indirect and non-structural losses considerably exceeds this estimate (Environment Canada, 2002). Approximately 460 properties with assessed property values of $172 million were flooded or were at risk from water levels 4.23 m above Chart Datum height in Charlottetown (Environment Canada, 2002; McCulloch *et al.* 2002).

Direct hits by a storm are not necessary to cause extensive damage: surges initiated by distant storms can erode beaches, flood adjacent coastal property, and deposit storm sediment inland of the beach (Morton, 2002). Tropical Storm Jose (1999) and Tropical Storm Helen (2000) crossed the Grand Banks from the southwest, resulting in storm surges that affected the southeast coast of Newfoundland between 3 to 4 hours after each storm passed. Each storm generated a barotrophic shallow water gravity wave which caused local flooding, and damage to docks and other coastal infrastructure in Bay Bulls, Witless Bay, and Port Union (Mercer *et al.*, 2002). Due to the large, flat, and shallow nature of the Grand Banks, each rapidly moving storm led to the generation of a barotrophic wave at 90° to the track. The waves were refracted by the bottom topography and reflected back from the continental slope toward southeastern Newfoundland.

The timing of storm events may enhance the damage caused by a storm. If successive storms occur over a long period, so that the beaches have time to recover and be replenished with sediment, then the damage sustained during subsequent events are minimal. However, if the beach does not have sufficient time to replenish sediment, or protective infrastructure is not put in place or repaired between storms, damage will accumulate and minor storms will cause extensive damage (Catto *et al.*, 2003; Wright 2004; Catto, 2006). In addition to the influence of storm frequency on the net geomorphic and erosional impact of a storm surge, coupling with astronomical tides can increase the magnitude of a surge. When storms coincide with the spring high tide, storm surge becomes superimposed on the high tide thereby increasing flooding, damage, and inundating areas further inland (Morton, 2002). In addition, El Niño Southern Oscillation (ENSO) winters are associated with a 44% increase in storm frequency along the east coast of North America over ENSO neutral winters (Hirsch *et al.*, 2001). Increased effectiveness of storm erosion characterized the El Niño-influenced winter of 1996-1997 in eastern Newfoundland (Catto *et al.*, 2003), and reduced sea ice extent in southwestern Newfoundland allowed beach erosion during the winter months at Grand Bay West (Catto, 2004) and Sandbanks Provincial Park, Burgeo (Ingram and Catto, 2005). La Niña events decrease storm activity during winter months

Storms characterized by strong winds focus the energy to the oceans, bays, and lagoons, thereby generating waves and currents which increase the flooding of inland areas (Morton, 2002). If the land surrounding the water bodies laterally restricts the storm surge and acts to focus it, inland inundation is enhanced. In the case of an unconfined washover flow, the land is inundated by sheetwash. In contrast, when the washover flow is confined within lagoons, the energy of onshore flow is concentrated, flow velocities accelerate, and storm surge water is moved farther inland.

In eastern Newfoundland, most beaches consist primarily of gravel (Catto *et al.*, 2003) which can be transported and deposited by wave-current interactions generated by strong extratropical storms or northeasters in Newfoundland. Wave energy during extreme storms is capable of displacing boulders and large blocks of concrete up to 1 m in diameter over distances of 15 m (Morton, 2002), as has been observed in eastern Newfoundland (e.g. Wright 2004, Catto 2006). As a result, storm surges not only inundate areas and cause damage, but also remove infrastructure and sediment which affected coastal protection.

The height of a storm surge is correlated with the storm track, the intensity of the storm, the orientation of the wind and precipitation in respect to the coast, the availability of an effective fetch, and the bathymetry along the Scotian Shelf and the Grand Banks region (Khandekar and Swail, 1994). The study of the January 1982 storm surge on the south coast of Newfoundland exemplifies these points.

On 10 January 1982 a storm surge caused significant damage to the eastern part of the south coast of Newfoundland, and the western portion of the coast sustained minimal damage (Murty and Greenberg, 1986). A total lunar eclipse occurred on 9 January over eastern Canada which increased the water level on the south coast of Newfoundland and PEI above the mean high tide level. An extatropical cyclone passed through the same area the following day. The high water mark at Argentia, Newfoundland exceeded 2 m asl, a level reached only once between 1900 and 1986, during the tsunami of 1929 (Murty and Greenberg, 1986).

The maximum surge occurred in the areas defined as the eastern part of the south coast of Newfoundland and east of the point of landfall. The storm surge caused the flooding and damage in communities on the eastern part of the coast (Marystown, Lamaline, and St. Lawrence). The western part of the south coast did not receive an equal magnitude storm surge because the energy was locally dissipated in the deep Laurentian Channel. The amplitude of the storm surge is directly proportional to the forcing mechanism and increases with increasing wind stress, but is inversely proportional to the water depth. In deep water, such as the Laurentian Channel, the amplitude of the surge will be smaller than in shallow water; therefore, a storm surge cannot build because the storm cannot maintain the speed of movement necessary to generate the wave (Murty and Greenberg, 1986).

The west side of the east coast experienced a small positive surge with a pronounced negative surge. In contrast, east side communities, such as St. Lawrence and Argentia encountered two pronounced positive peaks but very little negative surge (Murty and Greenberg, 1986).

When storm surges coincide with heavy precipitation, further erosion of coastal landscapes and socio-economic losses will occur. The greatest erosion rates correspond with storms which have high winds, producing increased wave heights and water levels, and precipitation which decreases the shear strength of finer-grained coastal sediments through saturation (Manson, 2002). The continual wetting from precipitation and spray can increase the erosion thresholds, allowing wave energy and high water levels to easily undermine bluff faces and displace sediment. Post-storm runoff can further induce erosion and gravity flows (Manson, 2002).

The socio-economic loss resulting from storm surges is substantially controlled by the type and density of development near the coast. In general, the more expensive the infrastructure and the more densely the areas are developed, the greater the damage and total monetary losses. The construction of infrastructure interferes with wave and current patterns, and can enhance the damage resulting from storms. As with natural constriction of storm surge waves, rigid infrastructure can deflect or focus the wave energy, increase turbulence, and promote beach and dune erosion (Morton, 2002). During Hurricane Hugo, shore-parallel structures increased beach and dune erosion in South Carolina.

Shore-normal structures aggravated nearshore erosion both by trapping sediment moving alongshore, and by directing sediment-laden currents offshore, resulting in the permanent loss of sediment (Morton, 2002). Buildings which are widely spaced or elevated on wooden piles cause minimal interference with storm waves.

In August 2005 a Category 5 hurricane impacted the Gulf Coast of the US. The area of New Orleans was stuck with a storm surge 6-9 m in height in part causing the failure of levees. Eighty percent of the city was inundated, power loss was extensive, and there were1050 confirmed deaths, 5000 missing, severe loss of homes and businesses, loss of transportation routes, and costs exceeding 100 billion USD (BBC, 2006). Damage was extensive due to the population size (484,000 prior Katrina) and the density of infrastructure (215,091 housing units at an average density of 459.9/km^2) in a vulnerable location (on the coast and up to 2 m below sea level; U.S. Census Bureau, 2006). The damage caused by the surge was also increased by the degradation of the coastline, wetland areas, and barrier islands which would have dissipated the surge before it hit the coastline (Mihelich, 2005).

Communities on the southern Gulf of St. Lawrence shore in New Brunswick, such as Shediac, Bouctouche, and Beaubassin, are currently undergoing economic expansion and establishment of new residential areas. Consequently, the dense coastal infrastructure is preventing ecosystem processes from naturally dissipating the damage from storm surges and floods (Vasseur and Delusca, 2004). The increased value of infrastructure is also increasing the monetary damage that occurs during storm surges. The storms of January and October 2000 damaged 181 cottages and 81 homes in the Beaubassin District, accumulating 1.6 million dollars in claims (Robichaud, 2004). The community of Pointe-du-Chêne would be completely inundated by a 3 m high storm surge. As the January 2000 storm surge height exceeded 2 m, flooding in this community is almost inevitable. Coastal properties are increasing in cost: in 2004 a typical coastal lot in Beaubassin cost ca $500,000, and a small cottage was valued at $1-2 million (Robichaud, 2004).

2.4 Rain-on-snow events

Rain-on-snow and snowmelt events may occur separately or in conjunction with one another. Areas of the greatest rain-on-snow hazards are those that support a thick snow pack or frozen ground, and are susceptible to warm storms. Mountainous topography, particularly north facing, will allow for the accumulation of a persistent snowpack. Coastal areas have access to warm air (Watt, 1989). As a result, the rainfall will rapidly run off over the snow cover and flood lower lying areas and rivers.

Rain-on-snow events can erode roadway infrastructure and private property, cause the overflowing of river systems, trigger slope failures, and result in great direct and indirect socio-economic costs. Due to these hazards, the effect of rain-on-snow events on alpine areas, the river systems, and the enhancement of rain-on-snow events by urbanization will be examined.

2.4.1 Alpine areas

Rain-on-snow events have the potential to induce extensive flood damage depending on the area impacted, intensity and duration of rainfall, contribution of snowmelt, and the timing of water release from the snowpack (Kattleman, 1997; Woods, 2002). Maritime climates are commonly influenced by midwinter warming and rain (Conway and Benedict, 1994) which provide the precipitation during the rain-on-snow events. The addition of water into the snowpacks alters the texture, hydraulic properties, and strength of the snowpack (Conway and Benedict, 1994), thereby changing how further precipitation will react with the snowpack (infiltrate or runoff).

Kattleman (1997) conducted a study to understand how warm winter storms interact with extensive snow cover on the Sierra Nevada. At elevations above 2000 m rainfall is rare; at lower elevations, rainfall and rain-on-snow events are frequent. The larger the area at higher elevation impacted by rainfall and runoff production, the greater the effect on lower areas. The presence of snow cover during warm storms couples rainfall-runoff with snowmelt. Snowmelt results from heat exchanges between the air or rainfall and condensation during high temperature and strong winds. In the Sierra Nevada, when air temperature is warmer than 10°C, snowmelt can exceed 5 m in 24 h during warm, windy storms, which is the equivalent of 500 mm of water.

Regional differences in the severity of rain-on-snow events is in part dependent on the thickness of the snowpack (higher snow:rain precipitation ratio and high persistence rates). The delay in runoff response time depends on the depth of the snow cover and the storm characteristics (Kattleman, 1997; Conway and Benedict, 1994): the deeper the snowpack, the longer the lag time between rainfall initiation and runoff from the snowpack. However, rainfall intensity is the greatest determinant of lag time, with higher intensity producing more rapid runoff response. Regions characterized by thick snowpacks increase delays in runoff events and store more water as snow (higher meltwater potential). Therefore, these regions have a greater potential for severe rain-on-snow events than do regions with less persistent snowpacks.

In general, water is able to exit the snowpack when the surrounding snow is increased to 0°C. Runoff is not released from dry snowpacks until they became saturated with water. In contrast, saturated snowpacks promote runoff. Frozen ground and ice lenses alter the progress of rainwater through the snowpack and ground by slowing or preventing the penetration of water.

Fall rainstorms and rain-on-snow events are common flood hazards in coastal, alpine areas of British Columbia (Watt, 1989). Rainfall derived from storms of long duration falls on shallow snowpacks, and the rain and melting snowpack together contribute to flooding events. Warm storms moving up the coast can deposit heavy precipitation on the snowpacks, causing rain-on-snow events. The Kitimat-Terrace area in northwest British Columbia has a long history of damage caused by rain-on-snow events. On 17-21 September 1987, 100.4 mm of rain fell on Terrace within 24 h (Septer and Schwab, 1995). The heavy rain caused snowmelt at higher elevations and damage to highway and railway infrastructure. A section of Highway 16 between Terrace and Hazelton was closed due to a washout, triggered by a rise in water level caused by gravel and debris plugging a culvert. An adjacent creek bed rose 4.8 to 6 m, induced by the deposition of thousands of cubic meters of debris, which increased the flooding of the highway. The cost to clear the culvert and construct proper drainage totaled $50,000 (in 1987 dollars; Septer and Schwab, 1995). Due to the discharge during the rain-on-snow event, the Kitimat River altered course and damaged the foundations of the Kitimat River bridge. Replacement of culverts damaged on the Kleanza road cost $20,000.

2.4.2 River Systems

Rain-on-snow events have led to 48 severe flooding events in Nova Scotia since the beginning of the flood records in 1759. Warm storms in the winter (December, January and February) and spring (March and April) have resulted in extensive events from both rain-on-snow and snowmelt. Prolonged warm periods in the winter months also contribute to flooding events; a long melt period on 3-18 January 1956 triggered province wide flooding. In addition to the extensive runoff and pooling of water, the ice cover broke up and jammed, destroying more than 100 bridges in Nova Scotia (Environment Canada 2004b).

One major rain-on-snow event encompassing the Central Region of Newfoundland caused the single greatest flood event in Newfoundland history prior to 11-15 January

1983 (Ambler, 1985). The community of Bishop's Falls sustained the greatest flooding. The combination of a low pressure system which induced the highest temperature for that month, greater than 100 mm of rain, a high rate of snowmelt, and slightly above average snowpack thickness caused the Exploits, Gander, and Conne rivers to surpass estimated 500 year flood levels. Streamflow conditions throughout the Central Region were below normal prior to the storm, and reached their record peak flows with the passage of the storm from southwest to northeast (Ambler, 1985).

As a result of the rain-on-snow event and consequent river flooding, a portion of the community of Bishop's Falls was washed away (Ambler, 1985). The river began to rise on 13 January, which caused a water surge when the ice cover broke. The increased water flow overtaxed the groundwood mill, redirecting the water flow. This resulted in the formation of a new channel through a residential area containing the entire flow of the Exploits River, leaving the original Exploits River channel dry. The formation of the new channel in the eastern side of Bishop's Falls and the flooding of the western side resulted in the evacuation of 180 families. Three homes, the Lion's Club, the Senior Citizens Club, a portion of the Fall View Municipal Park, and two historical 60 ton railway cars were washed away. Extensive damage to the power plant, old groundwood mill building, and transmission lines resulted. The total loss of land was calculated to be ca. 0.08 km^2. The new channel was ca. 8 to 10 m deep. In addition to the building losses, seven houses were at risk of toppling into the new river channel resulting from the failure of the unstable bank (Ambler, 1985).

Residential damages included damages to property and households, temporary accommodations, costs of restoring and relocating houses, and emergency relief items (food, clothing, and bedding). Damages totaled \$565,021 within the Exploits Basin and \$19,760 in areas outside the basin. Damages to transportation routes, including roads and bridges, totaled \$1,603,866 within the Exploits Basin. Repair and construction of sewage and drainage systems and damage to water supplies within the Exploits Basin totaled \$495,319. The cost of bank stabilization of heavily eroded banks totaled \$473,319 in the Exploits Basin. Repair of fisheries facilities within Exploits Basin (Noel Paul Spawing Channel, Bishop's Falls Fishway, and Grand Falls Fishway and Camp 1 Fishway) required \$525,000. Damages related to the recreational sector totaled \$140,864 (Ambler, 1985).

2.4.3 Effects of Urbanization

As development and land use change increase, the natural storage capacity of the ground may decrease. Consequently, the increased amount of impermeable surfaces results in a higher velocity of runoff (Buttle, 1990; White and Howe, 2002; Saint-Laurent, 2001). During rain-on-snow events, rain runs off the snow; however, a greater portion of the melting snow may be absorbed into the ground if it is vegetated than if the ground is covered with an impermeable surface.

Varying severity of rain-on-snow events between adjacent rural and urban communities may depend on the amount of vegetation within the community. The presence of forest cover reduces the impact of rain-on-snow flooding and rate of snowmelt. Forest cover also reduces snowmelt rates by limiting wind speed. The removal of forest cover may increase soil moisture by 10-25% (Kattelman, 1997). Consequently, communities with a high amount of vegetation may be less impacted during rain-on-snow events.

Urbanization will also increase flooding events during rain-on-snow events due to the tendency of water to flow towards the nearest watercourse (White and Howe, 2002). If a stream has been altered or culvertized, the runoff may not be able to flow into the stream and thereby flood the local area.

The construction of urban drainage system and road system may contribute to flooding by providing a channel for runoff (Saint-Laurent *et al.*, 2001). If the "channel" becomes blocked with snow, then localized flooding may occur.

In the case of Sherbrooke and Lennoxville, Québec, further development increased the number of residents that were affected by flooding. The urbanization also increased the cost of associated damage (e.g. homes, roadways, bridges; Saint-Laurent, 2001). The frequency and severity of repeated events has also increased with urbanization.

2.5 Snowmelt events

Snowmelt events may occur over several days to weeks of above 0°C temperature and resulting in a large total runoff with little or no damage to infrastructure (Conway and

Benedict, 1994). A rapid increase in temperature over a few days leads to high intensity runoff and damage to infrastructure. However, greater amounts of runoff result from rain-on-snow events than snowmelt events (Conway and Benedict, 1994; Todhunter, 2001; and Buttle, 1990).

Spring runoff from melting snowpacks can trigger river flooding. Damage resulting from river flooding varies from minor road and property loss to inundation of flood basins and infrastructure. Snowmelt flooding events can be very extensive in cases where there is a large drainage basin in which snow can accumulate. The Red River flooding in April and May 1997 in North Dakota, Minnesota, and Manitoba led to catastrophic regional flooding that exceeded historical floods (Todhunter, 2001). Total damage within the United States section of the basin was *ca* US$4 billion and southern Manitoba accumulated *ca* CDN$500 million in damages (Todhunter, 2001; Haque, 2000). Spring flooding has influenced human use and settlement of the Red River Valley, and is associated with minor flooding of communities near the river (Todhunter, 2001). Infrastructure damage was extensive and large portions of communities were evacuated.

The Red River basin is relatively flat (287 m asl at Wahpeton, North Dakota and 218 m asl at Lake Winnipeg), and floods frequently due to snowmelt and rain-on-snow events (Haque, 2000). Between 1882 and 1997, snowmelt has caused 85% of the annual peak discharges, 91% of the peak discharges exceeding flood stages, and 95% of the peak discharges exceeding the extreme flood stage for the Red River (Todhunter, 2001).

The severity of spring flooding is controlled by several climatic and hydrological factors: 1) the amount of fall precipitation before soil freeze-up; 2) the depth and moisture content of the seasonally frozen soil layer; 3) the amount of winter precipitation; 4) the duration and rate of the spring snowmelt season; 5) the amount and type of precipitation during the spring thaw; and 6) the nature of river ice processes (Todhunter, 2001).

In areas where spring meltwater is the primary source of floodwater, only a small fraction of snowmelt is able to infiltrate into the largely frozen, saturated ground (Todhunter, 2001). The autumn soil moisture level determines the following year's soil moisture status. Consequently, a high autumn soil moisture level is related to a reduced spring soil moisture storage capacity and an increased runoff rate during snowmelt. In southern Manitoba, autumn 1996 (prior to the 1997 flooding) was characterized by high topsoil moisture content before the time of freeze-up, and precipitation was 100 mm above the mean value (Haque, 2000).

The soil moisture available depends on external and internal factors. Late autumn rainfall after the decline in surface evapotranspitation increases moisture levels in the topsoil layer. During winter, the upward movement of water vapour causes condensation at the base of the frozen soil layer and further increases the soil moisture content. When the formation of a deep frost underlies a thick snowpack, the frost can persist into late spring (Todhunter, 2001). Also, wind contributed to the persistence of the snowpack by hardening the snow and increasing the density of the snowpack (Todhunter, 2001). The wind driven transportation of snow changes its physical characteristics, and creates extensive drifts and banks with much higher density and snow water equivalents than gravity laid snow. These conditions occur during winter storms (blizzards).

Several factors induce rapid and high snowmelt rates (Todhunter, 2001). First, the increasing high inputs of solar irradiance, due to increasing day length and sun angle of the oncoming spring, induce melting. Second, a rapid increase in temperature, occurs which exceed 0°C for several hours to days. Third, the conversion of snow cover to exposed ground decrease the albedo and reinforce further melting. Fourth, heat produced by the exposed ground transfers heat to the snowpacks. Fifth, the dew point exceeds 0°C, allowing water vapour to be transported from the atmosphere into the snow cover, thereby accelerating snowmelt.

A severe snowmelt event in Quebec in 1974 triggered the flooding of several hundred municipalities. Damage accumulated in the event consisted of the inundation of 1000 homes and 600 summer cottages, and the evacuation of 7000 people. The estimated damage totaled ca. \$60 million (\$233 million in 1998 dollars; Environment Canada, 2004c). The flood damage victims received payments totaling \$21.8 million (\$84.6 million in 2005 dollars). The runoff caused several streams to overtop their banks, including the Gatineau, Ottawa, Richelieu, St. Lawrence, Chateauguay, Saint Maurice, and Chaudière (Environment Canada, 2004c).

A comparable event occurred in spring 1974 in the Ou'Appelle River basin, Saskatchewan, when conditions were ideal for creating a snowmelt flood. In mid-March 1974, the snowmelt water equivalent of the snowpack was calculated between 127 and 152 mm (Environment Canada, 2004e). In late April, a rapid warming trend occurred in the basin resulting in runoff from the snowpack and widespread flooding in the Qu'Appelle River basin. The confluence of Moose Jaw River, Thunder Creek and Spring Creek within the City of Moose Jaw, overflowed their banks and inundated 60 city blocks and 480 homes, 1400 people were evacuated (Environment Canada, 2004e).

2.6 Ice jams

Changes in climate or landscape around rivers may recreate the conditions required for ice jams in areas of historical occurrence. Therefore, conditions leading to ice jams, monitoring techniques, and predictions are a necessity to minimize impact, which can be derived from previous studies for communities with limited resources. The Saint John River in New Brunswick, Yukon River in Yukon, and Exploits River in Newfoundland have historical accounts of river flooding resulting from ice jams.

The Atlantic Provinces experience alternating cold and mild spells throughout the winter and early spring, resulting in several freeze-up and break-up events in rivers annually (Watt, 1989). Frazil ice forms in rivers and floats to the surface, and accumulates to form slush ice and pans. The slush ice and pans lodge in obstructions and accumulate, occasionally forming an ice jam (Watt, 1989). Ice jams can be characterized as dynamic, thermal, or a combination of the two.

Thermal ice jams develop during a rapid change in water surface temperature (Gerard, 1990; Pariset *et al.*, 1966; Catto and Hickman, 2004). Freeze-up jams are caused by specific hydro-meteorological conditions. A thermal ice jam will occur when periods of sufficiently low temperatures that generate large quantities of frazil ice coincide with periods of high discharge to accumulate the ice. Therefore, thermal ice jam conditions may be relatively infrequent (Watt, 1989). The frequency and the magnitude of an ice jam flooding may depend on whether it originates from either dynamic or thermal mechanisms.

Ice jams occur within the three study sites, triggering localized flooding which may devastate the surrounding area. In some instances the break-up of ice jams may be very destructive, affect relatively large areas, and cause a large rise in water level. In addition to the large amount of water, moving ice can cause extensive damage.

Dynamic ice jams result from the physical movement of floating ice against obstructions or obstacles in the river channel (Beltros, 1983; Beltros and Burrell, 2002). The formation of dynamic ice jams result when a solid ice cover resists break-up. The jam forms in a narrow reach or bend of a river, an area of abrupt channel shallowing, and/or at a sharp reduction in gradient (Gerard, 1990). Due to these circumstances of formation, dynamic ice jams are more common than thermal ice jams. The magnitude and force of discharge of a dynamic ice jam break can be compared to a small dam break (Watt, 1989). The force of the discharge can cause severe damage to infrastructure adjacent to the river.

A flood risk mapping study of Carbonear, Victoria, Salmon Cove, Whitbourne, Heart's Delight, Winterton, and Hant's Harbour on the northern Avalon Peninsula was conducted and identified areas of ice jam risk. Ice jams in Western Pond Brook (Winterton) occurred due to the misalignment of the bridge with the river channel (Sheppard Green Engineering, 1996). When coupled with rain and snowmelt, flooding occurs. In Salmon Cove River (Victoria), ice jams form repeatedly 400 m downstream from a bridge in the community (Sheppard Green Engineering, 1996). Rain and snowmelt increase the flow, causing either a backwater effect or water flowing around the jam, and both scenarios result in inundation of the surrounding area.

Thermal ice jams are less frequent in the rivers of Newfoundland than dynamic ice jams. The Exploits River in the vicinity of Badger frequently forms dynamic ice jams, but in February 2003 flooding resulted from a thermal ice jam.

2.6.1 Badger, Newfoundland and Labrador

Badger, situated where two small brooks join the Exploits River, has been the subject of in-depth investigation of the causes of ice jam floods which impact the community.

Flood damage is concentrated in the lower areas of the community adjacent to the Exploits River. The majority of flood prone structures were defined as single story homes with living quarters, sleeping quarters, and valuable furnishings on the first floor (Fenco Newfoundland Limited, 1985).

A numerical ice progression model was constructed to determine the conditions and the process of ice cover development, which led to flooding. The estimates were then confirmed by historical observations of flood levels; 1:20 year level of 99.48 m and 1:100 year level of 100.42 m. Two methods were used to calculate the 1:20 year and 1:100 year river stages which result in flooding: 1) the use of historical data from observations of river stages between 1915 and 1984; and 2) use of the data collected during the 1984 field study, as applied to a river ice regime model (Fenco Newfoundland Limited, 1985).

Water levels used to quantify flood events may indirectly influence the magnitude of flood damage. Residents assessed the flood levels at 98.30 m, where flood waters first overtop the banks at the confluence of Badger Brook and Exploits River, thereby posing a threat to riverside private dwellings (Fenco Newfoundland Limited, 1985). Abitibi-Price defines the minimal flood level at 97.50 m, which represents the height where flooding of lower portions of the bank at Badger is imminent, requiring monitoring and concern (Fenco Newfoundland Limited, 1985). Provincial Agencies place the perception stage at 97.25 m, the elevation of a lower point of the bank where flooding is a concern (Fenco Newfoundland Limited, 1985). The level of concern is representative of the 'living with floods' attitude: the amount of inundation is not a hazard until damage occurs. Defining the point in this manner greatly reduces the time available to respond to the hazard and may increase the amount of damage that results from the flood.

A study in 1985 conducted by Fenco (1985) in conjunction with the Canada-Newfoundland Flood Reduction Program examined the flooding in Badger to identify the causes and extent of flooding, and develop alternatives for flood damage reduction. In the Fenco (1985) study, flooding in Badger was concluded to occur mainly due to dynamic ice jams. However, the event in February 2003 gained national attention when water and ice inundated the community. Although Badger had experienced significant flooding 8 times since the monitoring of water levels since 1916, the 15 February 2003 event was considered the most severe due to depth of inundation and damage to town infrastructure (Picco *et al.*, 2003).

As documented from the Hydrotechnical Study of the Badger and Rushy Pond areas (Fenco Newfoundland Limited, 1985), past flooding events have taken place in January and February. Flooding of Badger was related to the ice supply entering the Badger area, or was caused by accumulation of thick or obstructive ice which forms during low discharge rates, suggesting primarily dynamic causes. However, as the ice cover flow was initiated by downstream shoving/plugging caused by temperature changes, a thermal component was also involved. Thick ice cover on the Exploits River at Badger contributed to high water levels in the community, particularly a concentration of frazil slush in the "Badger Rough Waters" area. When icy floods coincided with the appearance of ice cover as it progressed upstream past the community, subsurface channels formed open water leads. Here the ice cover was thickened, and downstream blockages had their strongest affects.

Unlike the predominantly dynamic ice jams studied in 1985, the speed of the water level rise and the progression/recession patterns in the 2003 a predominantly thermal ice jam was different from previous floods (Picco *et al.*, 2003).

The ice cover prior to the flood was located 5 km above Badger. The ice cover ceased movement upstream of Three Mile Island, implying the collapse of the ice cover extending to the transmission line 14 km above Badger. In actuality, the ice had jammed across the river downstream, restricted the flow of the Exploits River, and caused water to inundate Badger. The thickest portion of the ice jam was downstream of Badger in the "Badger Rough Waters" area. Ice from the Exploits River was pushed up Badger Brook and Little Red Indian Brook, increasing flooding damage.

The Town of Badger, Abitibi-Price, and the Emergency Measures Division of the Government of Newfoundland & Labrador were advised of the amount of ice progressing down the Exploits. However, changes in the water level were not expected because the ice front was located 5 km upstream at Three Mile Island. Historically, concern of flooding in Badger decreased when the ice front retreated upstream past Three Mile

Island. On February 14, the ice cover was assumed stable due to the immobility of rafted ice at Badger for over a week.

On February 15 Badger was inundated which led to the evacuation of the community and the declaration of a State of Emergency. The State of Emergency was not lifted until after the publication of the Picco *et al* (2003) study. The 2003 event was the most severe flood recorded since 1916, and exceeded historical records for aerial extent and damage. The total cost of damages was at least $7.5 million, including $400,000 in post-flood costs. The major losses were borne by individuals ($5 million), businesses ($200,000), and the community ($2 million; Peddle, 2004). During the 2003 flood, 216 houses and 22 businesses suffered partial or total damage (Peddle, 2004).

In addition to the high water levels, the days following the flood were characterized by cold temperatures with high wind chill values. Consequently, flood water in the community became frozen, which caused further damage, and delayed clean up and repair operations. Sixty-eight residences received minor damage and 138 received major damage. Critical infrastructure such as the Town Council office, the fire hall, the arena, and various municipal services were damaged. Many businesses experienced physical damage and/or losses of revenue.

In an attempt to ensure minimal flood damage Fenco Newfoundland Ltd. (1985) made several recommendations. The zoning of infrastructure was recommended to prevent new developments from being constructed in flood prone areas. However, the zoning recommendations have yet to be implemented in November 2005. Another recommendation is that if the "status quo" approach is to be used, it should be utilized in addition to the continuation of the flood contingency program set up in 1977. This has occurred when the community rebuilds after a flood. As compensation, the residents received funds for what is damaged. For residents that suffered complete damage of their homes, they were granted the money to rebuild in the old location, but with the addition of stilts, or to rebuild their home in the new subdivision. When the ice jam mechanism varied from experience, the ice jam was unpredicted and occurred much faster than anticipated without warning. A real-time monitoring system would improve the accuracy of flood monitoring, rather than depending on historical knowledge of the river processes (Picco *et al.*, 2003).

2.6.2 Saint John River, New Brunswick

Ice jam events in New Brunswick cause a third of all recorded flood events. However, it accounts for two-thirds of all flood damage, particularly in areas near the Saint John River and its tributaries (Beltaos and Burrell, 2002). In the Perth-Andover area, the annual probability of floods is 0.05, for a return period of 20 years.

Dynamic ice jams occur on the Saint John River when flows increase during mid-winter thaw or spring. The increase in discharge increases the driving forces on the ice cover, although the ice cover resists movement (Beltaos and Burrell, 2002). The ice cover disintegrates and is set in motion in certain locations due to uneven melting, river morphology, and thinning, while other portions remain stable. The mobile ice breaks down into small blocks, which forms a jam upon contact with an obstacle. The process may continue until either the river is clear or a stable ice jam occurs (Beltaos and Burrell, 2002). Dynamic ice jams are sudden, providing minimal time to plan and implement mitigation measures.

The ice jam flood of 1-13 April 1987 on the Saint John River resulted from mild temperatures and a rain-on-snow event. The Perth-Andover area experienced extensive damages caused by the stagnation of ice several kilometres downstream against a stationary ice cover on the Beechwood reservoir (Environment Canada, 2004b). The combination of rising water and accumulation of ice against the bottom chord of the railroad bridge led to the collapse of the bridge. The bridge collapse began a chain of events: a jam was initiated, followed by the production of a surge, a 3 m rise of water in less than 3 minutes, which finally led to water overtopping the Beechwood Dam, causing formation and release of several ice jams downstream of Beechwood, causing extreme water levels, bank erosion, highway closures, and failure of a second bridge (Environment Canada, 2004b). The total cost for the 1987 Saint John River basin flood was conservatively estimated at US $30 million. A successive flood in April 1991 totaled $20 million in damages, affecting New Brunswick and Maine (Environment Canada, 2004b).

2.6.3 Ice jams caused by sea ice

Ice jams derived from sea ice and freshwater ice accumulating in the river mouths and lagoon outlets result from wind-driven processes. Shallow, narrow rivers or tidal channels that are confined laterally by gravel bars and oriented towards the direction of the prevailing or strongest winds are susceptible to coastal ice jamming. The prevailing current determines the location or ice jam formation of sea ice and freshwater ice. When the prevailing current and wind converge with the mouth of a river, upstream from the river mouth is vulnerable to flooding. Dominant onshore winds will cause water (and ice) to pile onshore, whereas winds blowing offshore will carry marine and river ice away from the mouth of the river (Murty and Greenberg, 2002).

Flooding induced by sea ice jams occurs in several Newfoundland communities. Flooding of Heart's Delight Brook (Avalon Peninsula) is caused by high tides or wind induced storm surges blocking the outlet of the barachoix with ice and gravel (Sheppard Green Engineering, 1996). The Heart's Delight River generates ice flows with the potential to cause a jam further upstream from the barachoix. The wind and associated high coastal waters prevent the flow of ice through the outlet creating a backwater effect. Water then overflows the banks, inundating residents in the low lying areas adjacent to the barachoix (Sheppard Green Engineering, 1996).

2.7 Slope failure-induced flooding

The slope failure of river channels, coastal areas, and marine landslides can induce localized or regional flooding. Triggering mechanisms for slope failure may be in conjunction with other flooding mechanism, heavy rain, rain-on-snow events, and snowmelt. Earthquakes have also triggered slope failures resulting in flooding, although occurrences of such events in Newfoundland and Labrador are very rare.

2.7.1 Inland slope failure

The failure of river channels and coastal areas can cause localized flooding, damaging road infrastructure, private property, and businesses. Indirect socio-economic costs can occur if the ability to use or cross the river or coastal area is hindered. Several mechanisms can initiate slope failure, including rain-on-snow events, heavy precipitation, and coastal/bank erosion. Human activities also contribute to slope failure hazard when drainage patterns are altered or the toe of a hillside is compromised for housing or road construction.

The blockage of river channels by debris from slope failure induces flooding upstream and downstream from the blockage. The impoundment of water inundates the area upstream of the blockage. When the blockage is removed or overtopped the surge of water causes flooding downstream.

In the study of landslides in the Carnation Creek watershed (British Columbia), Dhakal and Sidle (2004) examined the influence of different rainstorm characteristics such as storm mean and maximum hourly intensity, duration, and rainfall amount on landslide occurrence; examined the influence of temporal distribution of short-term intensities of rainstorms on landslide occurrence; and evaluated the interaction of rainstorm characteristics and soil properties (e.g. hydraulic conductivity and soil depth) on landslide occurrence. The study used the data of actual landslides between 1972 and 1990 in the model to predict the threshold of rainfall to generate landslides. The method of identifying rainfall intensity which triggers slope failure can be used in other failure prone areas. Knowledge of mean intensity and duration with consideration of temporal distribution patterns, will aid in the development of broad applicable threshold values for slope failure initiation. After the defined threshold is achieved, slope failure concern and warning is necessary.

Several findings by Dhakal and Sidle (2004) may aid in the prediction of slope failures. The shortest storm that triggered landslides had the highest mean rainfall intensity. Therefore, rainfall intensity is a more significant indicator of slope failure hazard than rainfall duration and total rainfall. As the high-intensity storms occur in the autumn to winter period, the area is exposed to landslides within that period. As the pore water pressure increases due to increased moisture levels, the safety factor (or slope stability) decreases proportionally. The safety factor (slope stability) decreases exponentially with critical inputs of subsurface water.

The influence of vegetation conditions and topographic characteristics contribute to slope failure. Marginally stable slopes may fail if vegetation, which anchors the slope, is removed. Steep slopes (gradients greater than 48°) are susceptible to slope failure.

The flooding of the Saguenay-Lac-Saint-Jean area, Québec, on 18-21 July 1996 caused severe inundation and extensive erosion, slope failure, major channel widening and bank erosion, the breaching of dams and dykes, and damage to bridges and roads. Economic losses associated with commercial and industrial areas located along or dependent upon the rivers also occurred. Sixteen thousand people were evacuated, ca.1350 homes were destroyed or damaged, and 10 people were killed, 2 of whom died in a small landslide triggered by the rainfall. Damage in southern Québec attributed to the July 18 to 21 rainfall and related flooding is estimated at $800 million (Brooks and Lawrence, 1998).

The increased runoff surpassed the critical discharge levels for several rivers within southern Québec. Critical discharge beyond which inundation of private property occurs is 150 m^3/s along the aux Sables River and 255 m^3/s along the Chicoutimi River. During the flood, discharge levels peaked at 653 m^3/s along the aux Sables River and at 1100 m^3/s along the Chicoutimi River (Brooks and Lawrence, 1998).

In Canada, slope failure is a hazard within areas of sensitive glaciomarine sediments ('Leda clay') in the St. Lawrence Lowlands (Shrubsole *et al.*, 2003). The rainfall caused more than 600 landslides during the Saguenay flood, some of which occurred inside the alluvial corridors, and severely affected local areas (Environment Canada, 2002b). The geomorphic changes of the river channel, such as the failure of the river channels, change in the slope of the waterways, over-deepened and reshaped the river beds, widened runoff areas, and changed the sedimentary system and heightened future flood risks (Shrubsole *et al.*, 2003). The slope failure of river channels had increased the flood risk in "new" areas. Consequently, property was damaged or destroyed, property values and property taxes decreased, hydroelectric facilities were severely damaged, water storage reservoirs were drained, production by business and industry decreased, and individual losses totaled ca. $700 million (Shrubsole *et al.*, 2003).

Additional flood hazards will arise when the debris from a slope failure partially or completely blocks the river channel. Rivers situated in deep canyon-type valleys are vulnerable to failures blocking the valley bottom, thereby impounding the river for a period of hours or days. Furthermore, when the blockage fails by water overtopping the dam or fails by erosion, the dam break will initiate a flood wave which creates further flooding damage (Watt, 1989). The Thompson River (near Ashcroft, British Columbia) flows through the bottom of a deep, terraced valley with steep slopes. The riverbed is comprised of several hundred meters of poorly consolidated glacial lake deposits (mainly silts). In 1881, irrigation saturated the silts, initiating numerous slides, particularly during construction of the Canadian Pacific Railway adjacent to the river. A slope failure in 1881 created an earth dam 50 m high, which resulted in an extensive flood downstream when the dam broke (Watt, 1989).

The Lemieux slide in Ontario on 20 June 1993 incorporated the failure of a river bank with the creation of an earth dam. In the 1993 event, debris from the landslide temporarily blocked the South Nation River, causing adverse affects for both upstream and downstream areas. The landslide occurred in the sensitive Champlain Sea sediment on the east bank of the South Nation River, 0.5 km north of the former townsite of Lemieux, Ontario (Evans and Brooks, 1994). The landslide was not initiated by any apparent trigger; however, the slide followed the wettest six months recorded since 1947 (Evans and Brooks, 1994).

When the landslide occurred (with a volume 2.8 x 10^6 m^3), a displacement wave was created and detected at Plantagenet Springs, 28.4 km downstream (Evans and Brooks, 1994). Debris formed a 3.3 km long dam in the bottom of the South Nation valley, leading to the impoundment of river waters. The water level gradually rose over several days to a maximum height ca.12 m above the pre-slide riverbed. The backwater effect extended 18 km upstream, destroying at least one home, and into the lower reaches of adjoining tributaries. The river water which overtopped the debris decreased the water quality for agricultural and domestic use downstream. Trees that were washed out of the debris posed an obstacle to boaters on the South Nation and Ottawa rivers.

The damage and possible loss of life would have been greater prior to the buyout by the South Nation River Conservation Authority as part of the landslide hazard mitigation program. The village of Lemieux, containing 28 homes and farms, had been resettled in

1989-1990, which has been destroyed. The indirect costs (buyout of 28 homes, prior to the landslide) and direct costs (immediate post-slide costs and costs of river cleanup) of damage resulting from the Lemieux landslide totaled ca. $2.5 million (Evans and Brooks, 1994).

2.7.2 Coastal slope failure

Slope failure can indirectly cause flooding of coastal infrastructure. Several weeks of sporadic heavy rainfall triggered a debris torrent in a gully above Harbour Breton on 1 August 1973 that resulted in four houses being swept into the harbour and destroyed (Liverman *et al.*, 2001). Four children died in the incident. The residents of the four destroyed homes and an additional 11 other families were resettled due to possible landslide risk (Liverman *et al.*, 2001). Remedial action was taken to stabilize large boulders after site visits by government geologists in November 1982, February 1984, and June 1986. No slope failures have occurred after the stabilization.

2.7.3 Submarine slope failure

Flooding caused by submarine slope failures may result from a sudden movement of a large amount of material, an earthquake, or both. One of the most severe flooding events on Newfoundland and Labrador resulted from a tsunami. On 18 November 1929, an earthquake measuring 7.2 on the Richter scale occurred at the southern edge of the Grand Banks. The epicentre was located at a depth of 20-km beneath the ocean floor within the Laurentian Channel, 280 km south of Newfoundland (Fine *et al.*, 2005). .

The earthquake triggered a 200 km^3 submarine slope failure on the upper part of the continental slope (Liverman *et al.*, 2001; Fine *et al.*, 2005). The mass movement downslope generated a turbidity current along the Atlantic floor. The tsunami traveled at speeds up to about 500 km/h through deep water (Ruffman 1994) and slowed to about 40 km/h upon impact with the coast of the Burin Peninsula, Newfoundland and Labrador (Fine *et al.*, 2005).

The tsunami had its greatest influence on the south coast of the Burin Peninsula due to the proximity to the slope failure, the amplification of the waves set up by the strong resonance of the V-shaped Placentia Bay, and the coincidence with peak high tide (Fine *et al.*, 2005). The tsunami appeared as three main pulses, raising local water levels between 3 and 7 m. Runup heights reached 13 m along the coast, and extended inland 1 km (Fine *et al.*, 2005). This was also influenced by low gradient shoreline of the Burin Peninsula.

Damage was extensive: 27 lives were lost on the Burin Peninsula, and 1 person died in Nova Scotia. Total damage to property was estimated at about $ 1 million (1929 dollars; Liverman *et al.*, 2001). If an equivalent were to occur in 2005, the damage would exceed $11 million. Additional and more expensive infrastructure has been constructed along the coast and within the tsunami runup distances since 1929.

Ruffman (1994) suggested that the frequency of earthquakes of the magnitude that triggered the 1929 tsunami (7.2 on the Richter scale) may be ca.1 per 1000 years, or as high as 1 per 100 years for magnitude 6.0 earthquakes, although he was unable to find definitive evidence to allow accurate calculation of recurrence frequencies. The province has experienced at least 9 other earthquakes between 1929 and 2006, mostly minor, and no tsunamis have resulted. In June 1864, St. Shott's may have experienced a minor tsunami (Ruffman, 1995; Liverman *et al.*, 2001), although definitive evidence is lacking.

2.8 Anthropogenic activity

Critical infrastructure constructed in flood prone areas (floodplains, coastal areas) is susceptible to damage. The susceptibility of the infrastructure depends on the frequency at which it is impacted and the magnitude. In North America, although flood frequency has declined over the last decades in some areas, economic losses continue to increase (Haque, 2000). The method of protecting against loss is calculated from an economic analysis. A flood protection plan will be implemented if economic losses are greater than the cost of the plan. Minor concern is given to environmental and social impacts of the floods (Simonovic and Carson, 2003).

Municipal planning and zoning for current and future developments will minimize the impact of specific flood hazards. Activities which remove vegetation and replace it with impermeable surfaces (roads, residential areas) increase runoff rates. The increased runoff rates are apparent during heavy rainfall, snowmelt, and rain-on-snow events when drainage is relatively greater than in less developed, vegetated areas (Buttle, 1990; Saint-Laurent *et al.*, 2001). Flooding and runoff rates will be extensive in areas where forests have been cleared and wetlands drained, and the natural removal of excess moisture will not occur. Communities adjacent to river systems will experience enhanced flooding in areas downstream from deforested areas. The increased runoff will flow into the rivers and excess water will inundate the floodplain and infrastructure constructed there.

2.8.1 Increased development

Human activity, such as infrastructure development and construction of impermeable surfaces, will increase the severity of runoff and damage caused by rain-on-snow and snowmelt events. Variations in snow cover, vegetation, wind, and maintenance of drainage infrastructure resulting from human activity, and locations of settlement may account for the increased susceptibility of communities to these hazards.

A study by Buttle (1990) describes how the increased development of communities can enhance rain-on-snow and snowmelt events. The study focused on changes in association with the development of Kawartha Heights subdivision of Peterborough, Ontario. The annual precipitation in Peterborough is 735 mm, with snow comprising 20%. The subdivision structure consists of single family dwellings surrounded by lawns and gardens, and drained by storm sewers which discharge into streams. The variations in effects of rain-on-snow and snowmelt events in urban and rural communities can be attributed to change in: 1) proportion of precipitation leaving the community as stream flow; 2) runoff from individual precipitation events; 3) peak discharge; 4) hydrograph response time or time between start of precipitation and start of runoff; and 5) hydrograph recession or time between start of precipitation and end of runoff.

The proportion of seasonal precipitation flowing into the stream will escalate due to increases in construction of road infrastructure, buildings, and lawns, and associated losses of permeable surfaces. The amount of runoff produced from precipitation will increase with development as a consequence of increased runoff from artificial surfaces flowing into drainage infrastructure rather than infiltrating the ground.

Meltwater generated by the snow is generally slow, enabling the ground or drainage infrastructure to remove the water. Even though the water discharge is usually gradual, large amounts of runoff may occur in short periods of time (Buttle 1990). Rain-on-snow events generate greater runoff rates per amount of precipitation and peak discharge rates than snowmelt in highly developed areas. The peak discharge of runoff associated with rainfall events increases with development of artificial surfaces and drainage infrastructure (Buttle 1990). For Kawartha Heights, annual peak discharge rates occur during spring due to rain-on-snow and snowmelt events, while rain-on-snow events are responsible for a greater majority of the peak discharge rates.

The lag time between the start of precipitation and occurrence of peak discharge will decrease with development as a result of improvements to drainage infrastructure (Buttle

1990). However, improper maintenance of the drainage infrastructure will alter drainage and enhance damage.

The changes in surface and stream runoff depend on the magnitude of development and location. If the development is in proximity to permeable or unaltered ground, the intensity of runoff has moderate change with development. However, if development occurs adjacent to previous development, runoff intensity will increase (Buttle 1990).

Anthropogenic activities, such as intensive cutting, riverside deforestation, the extension of agricultural or urban drainage systems, the development of urban areas, and floodplain use, can increase the flooding hazard in densely populated areas (Saint-Laurent *et al.*, 2001). Deforestation leads to increased surface runoff, enhancing pooling water in areas of inadequate drainage and increase discharge of rivers. Drainage and road infrastructure further increases surface runoff and water levels in rivers associated with the community (Saint-Laurent *et al.*, 2001). A study of the Chateauguay River basin of southwestern Quebec (Saint-Laurent *et al.*, 2001) describes how anthropogenic activities have a greater influence on flooding events than hydrological factors alone. In the Chateauguay River basin hydrological risk has remained constant for the past 60 years. However, the severity of flooding events and cost of damages have both increased.

2.8.2 Settlement location

Floodplains are inhabited due to their appeal for urban and industrial development. Although floodplains are obvious flood prone areas, the threat of a flood becomes a part of life. Decisions to develop on flood prone areas and how to cope during a flood depends on the recorded magnitude and frequencies of floods, and personal experiences and resources. However, when extreme events are greater than the accepted level of damage, the hazard will result in catastrophic losses of human lives and valuable resources (Haque, 2000).

The consequence of floodplain development is the increase in the number of residents affected by flooding, and increased costs of damage to additional homes, roadways, bridges, or other infrastructure. For instance, the communities of Sherbrooke and Lennoxville, Québec, have experienced periodic flooding over the last 30 years. Urban expansion in the communities occurred in floodplains where the probability of flooding events is greater and where flood protection measures are not implemented. The frequencies of periodic flooding events are rising in areas associated with the construction of new roads and buildings near the rivers (Saint-Laurent *et al.*, 2001).

2.8.2.1 Red River Valley, Manitoba

The Red River Valley contains agricultural fields, and urban and rural centers. In April and May 1997, the Red River flooding impacted the Canadian portion of the basin. Five percent of Manitoba's farmland was inundated, 28,000 Manitoba residents were evacuated, several communities suffered damage, transportation routes were temporarily blocked, and total damages exceeded $500 million (Haque, 2000; Todhunter, 2001).

The creation of man-made structures may enhance the damage during flooding events. Overland flows caused significant damage and water flow during the Red River disaster. Overland flows are initiated by the overtopping of the river banks when the channel has exceeded its capacity. The water then flows over the land, and the extent is determined by the available water and the topography. In floods such as in 1997, the river overtops adjacent roads and railway embankments, which then acts as a conduit for the northward progression of water. Roads, railway embankments, and topography may create a damming effect of the water, raising the water level higher than the water level in the adjacent main channels. The force of the water may breach the obstructions and increase the discharge in the main channel. The increased water level in the main channel may cause a backwater effect in tributaries, increasing flooding in the surrounding areas (Simonovic and Carson, 2003).

Flood protection measures involve both structural and non-structural methods with positive and negative outcomes. Prediction of the magnitude of the April/May 1997 flood was underestimated in part by anthropogenic activities. Although the prediction and flood responses did prevent the loss of damage and lives, some communities did experience extensive damage. Without accurate predictions, efficient flood responses (i.e. the construction of dikes and evacuations) based on reports from current models may not occur or be effective.

Structural flood-control methods may adequately protect one community, and increase the flood risk of another. The flooding of rural communities was caused by the diversion of flood water to protect the City of Winnipeg (Haque, 2000). Communities surrounded by ring-dykes were protected; however, communities which did not have protection (Grand Pointe, Ste. Agathe, Rural Municipality of Macdonald) were inundated. The operation of the floodway system near Winnipeg raised the water in communities upstream from Winnipeg above the level that would have occurred during a flood without the presence of flood-control infrastructure. The backwater effect raised water 0.64 m in Grand Pointe and induced high water levels further upstream to Ste. Agathe (Haque, 2000).

2.8.2.2 Perth-Andover, New Brunswick

Communities constructed on locations prone to ice jams will experience periodic flooding. On 2 April 1987, the small farming and lumbering village of Perth-Andover, New Brunswick was inundated by the Saint John River. An ice jam located below the community caused water to flood the downtown core. Six hours elapsed between the onset of flooding until the waters began to recede (Alchorn and Blanchard, 2004).

Critical infrastructure was inundated. Several streets, such as Main Street, were flooded. The ground floor of the hospital was flooded; the hospital patients and staff were evacuated to the nearest nursing home. Electricity was cut off as a precautionary measure. Residents in sensitive locations were required to leave their homes. Local motels in the downtown district were evacuated. A rail bridge spanning the river collapsed. The first floors of houses were submerged under 2 m of water. The force of the floating ice separated several homes from foundations. Although no fatalities resulted from the flooding, property damage was estimated between $10 and $12 million (Alchorn, and Blanchard, 2004).

2.8.3 Re-location or partial abandonment

When a flood exceeds the flood controls design, damage is greater. Relocation is a permanent method to avoid further disaster (Felgentreff, 2003). Relocation will limit death or injury from that particular hazard. Relocation is used as a mitigative measure when physical structures for protection would be ineffective and warning systems are insufficient for simple evacuation. Relocation also provides monetary savings for individuals and government. After severe flooding events, government financial aid has to be provided for the repeated cost of restoration to be paid to the same residents for the same hazard (Felgentreff, 2003). Eventually the cost of relocation is less than the cost of further remedial measures.

2.8.3.1 Saguenay, Québec

After the 1996 Saguenay flood, the Government of Québec provided $400 million in financial aid for individuals, municipal emergency measures, approval of plans and specifications for dams and dykes, business recovery and reconstruction work (Shrubsole *et al.*, 2003). Several issues based in relation to rights of way on privately-owned land, ownership of new and former beds and any related fishing rights, and land losses and gains were raised during reconstruction. To resolve such issues, the National Assembly passed Bill 152 in June 1997. The bill enabled the Minister of Transportation to purchase by mutual agreement or expropriation the property required to reconstruct and redevelop the areas affected. The 1:100 year flood level was used to determine the property available for reconstruction. The Department of Transportation acquired ownership of the relevant riverbeds and a 35 km in length strip of shoreline extending to the 1:100 year flood mark (Shrubsole *et al.*, 2003).

The redevelopment of flooded areas followed specific objectives. Redevelopment was designed to safeguard people, buildings and infrastructure against the risk of flooding, high water and ice, landslides and shoreline erosion. The designs permitted the free flow of water and ice, and restored the ecological functions of shorelines and beds. Future development of the land had to comply with the river morphology rather than human needs. Any new construction of bridges, railways, water inlets, urban or industrial areas should allow for the river's natural processes and allow for natural shoreline stabilization. Artificial stabilization is permitted in areas where safety, currents, ice flow or economic property losses require more extensive action. Slopes and exposed surfaces would have been revegetated to minimize the impact of runoff. (Shrubsole *et al.*, 2003).

2.8.3.2 Rapid City, South Dakota

Rapid City is located adjacent to the eastern Black Hills in South Dakota, and is susceptible to extreme flooding (Carter *et al.*, unknown date). When intense storm systems are positioned over the Black Hills, the rapid runoff down the steep watershed allows residents little response time. On 9-10 June 1972, the runoff from an intense rain storm positioned over the eastern Black Hills triggered record floods on Rapid Creek and other streams in the area. Rainfall intensity was recorded at 381 mm in 6 hours near Nemo, South Dakota and more than 254 mm fell over an area of 155.4 km^2. Consequently, 238 people died and 3,057 people were injured. Total damage was estimated in excess of $160 million ($748 million in 2005 dollars), which included 1,335 homes and 5,000 automobiles (Carter *et al.*, unknown date)

A flood of the 1972 magnitude has a return period of 1:500 years or a 0.2% chance of occurrence per year. Due to the short period of record for Rapid Creek gauging stations, the 1:500 year return period may be smaller than predicted. Therefore, regulations have been put in place to minimize damage during an equal or greater magnitude flood. Interim and long-range programs were initiated and millions of federal dollars were used in Rapid City and the surrounding communities to mitigate and repair damage. In Rapid

City, a flood-plain management program (or "greenway" concept) was implemented where most of the flood plain was converted into parks (Carter *et al.*, unknown date).

2.8.3.3 Winisk Village, Ontario

Winisk Village was constructed near the Winisk River in northern Ontario. A water and ice surge on the Winisk River completely destroyed the village on 16 May 1986 (Environment Canada, 2004d). In a period of 24 hours all but 2 buildings were removed from the site by the river. Homes were found up to a kilometer down the coast and 5 to 6 km inland from their foundations. Two people died in the flood: the community contained approximately 50 residents. The destroyed community was re-established 30 km south of the original location (Environment Canada, 2004d).

3. Methods

The study of flooding hazard and vulnerability in communities in Newfoundland and Labrador involved detailed examination of the three areas. Humber Arm, Torbay, and the Burin Peninsula vary in geomorphology, climate, and socio-economic conditions, providing a basis to assess a variety of flooding styles and facilitating future comparisons to other communities in the province.

Investigations of these areas involved field investigations, aerial photograph analysis, interviews, archival research, and socio-economic assessment. The information collected allowed the construction of flood risk maps and a comparison of flooding mechanisms, frequency, and locations for each site. The investigations were conducted with methodology consistent with previous studies (i.e. Kindervater), but were further in-depth by combining ground surveys and aerial photograph analysis with archival research and interviews.

3.1. Field investigations

The official initiation of the study was in mid-July 2003. Each region was investigated between July and October 2003, with additional visits after severe flooding events. Site visits were conducted to locate areas of damage and concern. These include rivers, lagoons, coastal areas, steep slopes, damaged culverts, damaged pavement, damaged gravel roads, and filled-in culverts and ditches. Failing infrastructure in the form of partially blocked ditches and culverts causes difficulties for communities in Newfoundland and Labrador. When heavy precipitation falls on these areas, damage may become cumulative. Clearing land or backfilling of water bodies to create building lots may also contribute to flooding. Known areas of flooding, areas within the communities, and roadways between communities were examined for possible hazards.

Detailed site investigations were conducted in the Humber Arm region in mid-September 2003. All communities within the Humber Arm region were investigated. On the south shore of Humber Arm, investigations extended the length of Provincial Highway 450 from Lark Harbour to Corner Brook and Massey Drive. North shore communities from the Humber River mouth westward to McIve'rs Cove and Cox's Cove (Bay of Islands) were also investigated. Flood hazards were identified in 17 locations outside of Corner Brook: eight sites were located along the southern arm, six sites along the northern arm, and three in Cox's Cove. Site investigations in Corner Brook included consultations with Michael O'Leary, former Assistant Director of Operational Services, City of Corner Brook.

Torbay was visited on several locations between July 2003 and September 2005. Torbay Mayor Robert Codner identified sites of concern to the town during a field investigation in July 2003. Twelve areas of concern were identified, including 7 which flooded during Tropical Storm Gabriel and 5 sites of potential future flooding.

Multiple visits were conducted in the Burin Peninsula region between August 2003 and October 2005. All communities on the Fortune and Placentia Bay coasts south of Harbour Mille were visited at least once. Repeat visits occurred to communities between Marystown and Fortune, particularly after flooding events (e.g. March 2005). More than 70 areas susceptible to flooding have been identified: twelve sites were identified in Marystown, two in the Town of Burin, five in St. Lawrence, six in Fortune, six in Grand Bank, three in Little Bay, five in Fox Cove-Mortier, three in Lamaline, and individual sites in Little St. Lawrence, Lawn, Point May, Frenchman's Cove (Burin), Rushoon, Point au Gaul, Taylor's Bay, and Allan's Island. Roads between communities also are exposed to flooding.

In the study of flood hazards, hydro graphs or gauging data is usually examined. No such data were available for the study areas. Consequently, historical changes in flow could not be used to assess the frequency and discharge of high flows.

3.2. Aerial photograph analysis

Aerial photograph analysis was used to identify potential natural flood hazards. Areas of exposure to floods were noted in the photographs then these areas were illustrated on the corresponding cadastral maps for each community. Such areas include river floodplains, wetlands, areas susceptible to coastal process, and steep unstable slopes. Flood hazards resulting from inadequate infrastructure are not generally detectable on the photographs.

Damage resulting from this flooding mechanism was identified through site visits rather than from photographs.

Aerial photographs may also be used to assess flood risk in undeveloped or lightly developed areas. The interior of Burin Peninsula and communities in the Humber Arm region outside of Corner Brook were examined for potential flood hazards. Wetlands upslope from communities could fail through 'bog bursts', causing flooding. Steep, unstable slopes may fail, resulting in blockages of rivers and inducing flooding.

Sequential photographs have been studied for Torbay and Corner Brook to identify the effects of changes in community development. Increase in upslope activity may be an indication of potential risk. Changes in downslope drainage and sedimentation, and alteration in natural drainage ways may be identified by comparing photographs.

3.3 Statically analysis

To evaluate trends in precipitation amounts, the mean and R^2 test were used. Addition information was derived from the maximum and minimum values. The percentages of frequency on flooding mechanisms were identified to assess probability of hazard.

Traffic statistics were given by the Department of Works and Transportation for the major highways in the three sites: the main highway leading into Torbay from St. John's; in the Humber Arm region, the TCH between Deer Lake and Corner Brook, Highway

440 and 450; and on the Burin Peninsula, the section of highway between Marystown and the TCH turnoff, near Point May, and near Frenchman's Cove turnoff. The information is minimal due to the infrequency of traffic monitoring.

3.4 Interviews

Interviews were in compliance with the policies of Memorial University's Office of Research Interdisciplinary Committee on Ethics in Human Research. Personal interviews were conducted only after approval by the Ethics Committee was granted.

Interviews were conducted in all areas. Interviews were conducted with the municipal officials of York Harbour, Frenchman's Cove, Corner Brook, and Massey Drive (Humber Arm); Burin, Lamaline, Marystown, Grand Bank, Fortune, Lawn, Point au Gaul, Taylor's Bay, Fox Cove-Mortier, Frenchman's Cove, Garnish, Lord's Cove and St. Lawrence (Burin Peninsula); and Torbay. Additional personal interviews and telephone interviews were conducted following major flooding events.

During field investigations, local residents were interviewed on a casual basis. Residents concerned about flooding in their area commonly made inquiries during field investigations adjacent to or on their properties. This information was recorded without attributing names and reference to specific residents. All information was subsequently verified through other methods.

3.4 Archival research

Information found through archival research reinforced the information gathered from interviews and field investigations. The research provided insight into areas of historical flooding that may have seemed insignificant or was unknown to interviewees, and allowed identification of areas of infrequent flooding that may have been repaired. The archival research also gave an indication of frequency of flooding events, causes, and costs in particular areas.

A component of archival research involved review of local newspapers. Records of the '*Southern Gazette*' (Marystown) covered the period from 1975 to 2005. Detailed information of flooding events, location, causes, and costs were collected for the Burin Peninsula. Records from the '*Western Star*' (Corner Brook) focused on the Bay of Islands/Humber Arm region. The paper was reviewed from 1940 to 2005. Specific information on flooding events for the study area was recorded. The '*Evening Telegram*' (a.k.a. '*Telegram*'; St. John's) provided data pertinent to Torbay and the other study areas between1934 and 2005. These newspapers were selected because they were the most detailed for the corresponding region.

Additional archival records were collected from the municipalities. This information was limited, as many communities do not record specifics on flooding events. Information on coastal flooding in Torbay was gathered by a publication produced by Codner (1996). Information on the 1929 tidal wave was gathered from the research by Ruffman (1994).

Viewing of the pictures of the 1989 flooding in Fortune was provided by Fortune Town Clerk, Basil Collier. A map of Corner Brook of present areas of sensitivity, frequent areas of flooding, and areas affected by the March 2003 flood was provided by former Assistant Director of Operational Services in Corner Brook, Michael O'Leary.

Provincial collections of data related to flooding events were reviewed. "Geological Hazards and Disasters in Newfoundland and Labrador" (Liverman *et al.*, 2001) describes slope failure and coastal erosion (including tsunami) events between 1775 and 2000, based on records housed in and known to the Newfoundland and Labrador Ministry of Natural Resources, documenting the date, location, and other specifics about the events. Documents published by Department of Environment and Conservation and Environment Canada tilted *Canada-Newfoundland Flood Damage Reduction Program* compile various flooding events during the 1900s for several communities in Newfoundland and Labrador. The study for the following communities were examined; Carbonear, Victoria, Salmon Cove, Whitbourne, Heart's Delight, Winterton, Hant's Harbour (Sheppard Green Engineering and Associates Limited, 1996); Bishop's Falls (Fenco Newfoundland Limited, 1990); Rushoon (ShawMont Newfoundland Limited, 1990; ShawMont Newfoundland Limited, 1986); Cox's Cove (Martec Limited, 1988); and Badger and Rushy Pond areas (Fenco Newfoundland Limited, 1985). Kindervater (1980) documented flooding events in Newfoundland and Labrador communities which occurred between 1900 and 1979.

Environment Canada weather records have been reviewed for Torbay (St. John's A site), the Humber Arm region (Corner Brook site), and the Burin Peninsula (St. Lawrence site). Monthly precipitation rates and available wind directions have been reviewed for the study areas.

3.5 Socio-economic assessment

Data was collected to assess the monetary damage of floods, and cost of necessary repairs and maintenance of infrastructure and roads. By examining the financial cost of past events, estimates of equal future events can be predicted. Monetary costs of major flood events have been recorded by some municipalities. Additional information was gathered from local newspapers.

Statistics Canada community profiles were viewed for age demographics and economic status. The overall employment rate and wages were assisted. The demographics were broken down into percent of age groups (0-19, 20-64, and 65<), changes in community population, and the family composition.

Field investigation allowed for estimates of cost of repairs for observed areas of flood risk. Through historical records of similar situations, infrastructure damage (e.g. culverts, road ways) in the vulnerable areas can be estimated. Economic costs resulting from damage to residences were estimated by identifying the average cost of houses in communities, from realtor websites and interviews. Realtor websites (e.g. Re/max) were viewed in 2005 for each community where information was available, and the cost of houses was described by range and mean. The specific assessed values of individual properties were not calculated for the socio-economic assessment.

Information concerning the cost of flooding events was also gathered from PSEPC (formerly OCIPEP), in particular from Len LeRiche, Director, Newfoundland and Labrador Regional Office. Data was available from Emergency Measures Organization, Government of Newfoundland and Labrador, on the financial compensation resulting from Hurricane Luis (1995) and the January 2000 storm for the Burin Peninsula, and from Tropical Storm Gabrielle (2001) in Torbay. Reviews of events outside the study areas provided additional information of monetary cost of various flooding hazards.

3.6 Map construction

Flood frequency maps were constructed for Torbay; Cox's Cove, McIver's, Gilliams, Meadows, Summerside, Irishtown, Massy Drive, Benoit's Cove, York Harbour, Lark Harbour, and Corner Brook (including Curling) in the Humber Arm Region; and Rushoon, Marystown, Burin, Fox Cove-Mortier, Epworth, Little St. Lawrence, St. Lawrence, Lawn, Lord's Cove, Point au Gaul, Lamaline, Fortune, Grand Bank, Frenchman's Cove, and Garnish on the Burin Peninsula. The base maps were either cadastral or topographical maps (depending on availability).

From the archival research and interviews, locations of flood risk, frequency, and dates were identified for each community within the study areas. For all maps, except for Corner Brook and Torbay, only the locations and years of flooding events were indicated. For the Torbay flood risk map, locations, approximate years between flooding events, and areas of concern were indicated. Due to the amount of information for Corner Brook and Curling, the flood risk map describes locations of flooding events, frequency, year of major events, and areas of flooding prior to 1960.

From the information depicted on the maps, areas of flood frequency have been identified. Future development plans for the various communities can minimize vulnerability by avoiding the sensitive areas.

4. Physical Impacts of Flooding on Torbay

In this chapter, the area of historical flooding events and current areas of exposure are identified, documented, and mapped. Also, the mechanism and cause associated with the events and areas, such as the season, precipitation amount, and other meteorological conditions are described. Finally, the events and areas are assessed in their relation to meteorological factors, climate change, and human influence involved with flooding.

4.1. Areas of exposure and hazard

Exposure to specific flooding mechanisms in Torbay are created by the exposure to northeasters, proximity to the Atlantic Ocean, number of river systems, and increasing population and development. Hurricane-induced rainfall, autumn and winter storm activity, rain-on snow events, storm surges associated with storms, river flooding and ice jams, and secondary effects of blockage or inadequacy of drainage infrastructure all contribute to flooding events in the community.

During the field visits, twelve localities were identified (Table 4.1). These areas have either (1) experienced flooding during Tropical Storm Gabrielle, (2) frequently flood, or (3) are of concern. Eight localities were flooded during Tropical Storm Gabrielle (September 18-20, 2001). The four other localities are considered potential sites of future flooding. The frequency of flooding and mechanism for specific areas will be described in the proceeding section. The areas of flooding and concern map for Torbay can be found in Appendix A.

Table 4.1: Localities of flooding occurrence and concern within the municipality of Torbay, as identified through site visits. Frequency of events is described as number of years between subsequent events.

Name of Area	Frequency of Flooding (years between events)
Soldiers Brook	>9
South of House 975	>9
Kennedy Brook	7-8
Ditch parallel to highway	Concern
The Gully	7-8
Bottom of Gully	7-8
Main Bridge	3-4 (historically), 7-8 years (currently)
Main Bridge, downstream	7-8 years
Main Bridge, upstream	Concern
Western Island Pond	Concern
Culvert at the rock cut	Annual
dirt road opposite Watt's Pond	Annual

4.1.1.Hurricane-induced Flooding

Severe flooding damage in Torbay is associated with hurricane activity coupled with anthropogenic affects. Hurricane-induced flooding is infrequent, with one significant occurrence between 1980 and 2005. In September 2001, Tropical Storm Gabrielle caused widespread flooding. Rivers were overtaxed by the 118-mm rainfall: Soldiers Brook, Kennedy Brook, "The Gully", and the river exiting Watt's Pond. The flooding of these rivers caused damage to infrastructure. Soldiers Brook flows underneath Torbay

Road (Route 20) towards Tor Bay. During the storm, water pooled near Torbay Road (Route 20) and eroded the roadbed. The intersection of Torbay Road (Route 20) and Kennedy's Brook was washed out and was temporarily impassable during the storm (Mayor of Torbay, Robert Codner, personal communication, 2003).

Kennedy's Brook has a floodplain of approximately 30-50 m width. One house is at potential risk of flooding. "The Gully", an area of importance for the community for aesthetic value and as an environmental education resource, flooded during Gabrielle. A section of Torbay Road was washed out when water leading into "The Gully" pooled behind the road. Further downstream from "The Gully", Mahon's Lane and Lynch's Lane were washed out. The flooding of "The Gully" damaged one house and placed two others in danger of being inundated (Mayor Robert Codner, personal communication, 2003).

The stream exiting Watt's Pond flows into a fen, which floods frequently, increasing the susceptibility of one adjacent house to flooding. During Gabrielle, an increased amount of water left the pond via the stream and resulted in the flooding of the fen margin and the house.

Approximately 10 structures have been identified through site visits in 2003 as vulnerable to flood damage. An additional two structures were identified in 2005. Complete destruction of all twelve structures is not expected in a future event of similar magnitude to Gabrielle, and partial reconstruction would be required for most.

As hurricanes move northeastward, the winds move in a counter-clockwise direction (Murty and Greenberg, 1987). Torbay was impacted by the northeast wind flow of Tropical Storm Gabrielle (2001). As with the Singh (1997) model, precipitation was first deposited in the coastal area, and then the storm moved upstream depositing heavy precipitation. The result was extreme flooding along the river system. The effect may be minimized for short streams where the storm track is relatively fast.

4.1 Culvert area carrying 'Kennedy's Brook' under Torbay Road. The culvert in the picture was installed after Tropical Storm Gabrielle. The culvert diameter is inadequate to remove flood water after average rainfall. During Tropical Storm Gabrielle, it was unable to handle the flow and resulted in the damage to Torbay Road. UTM 370450E 5277050N.

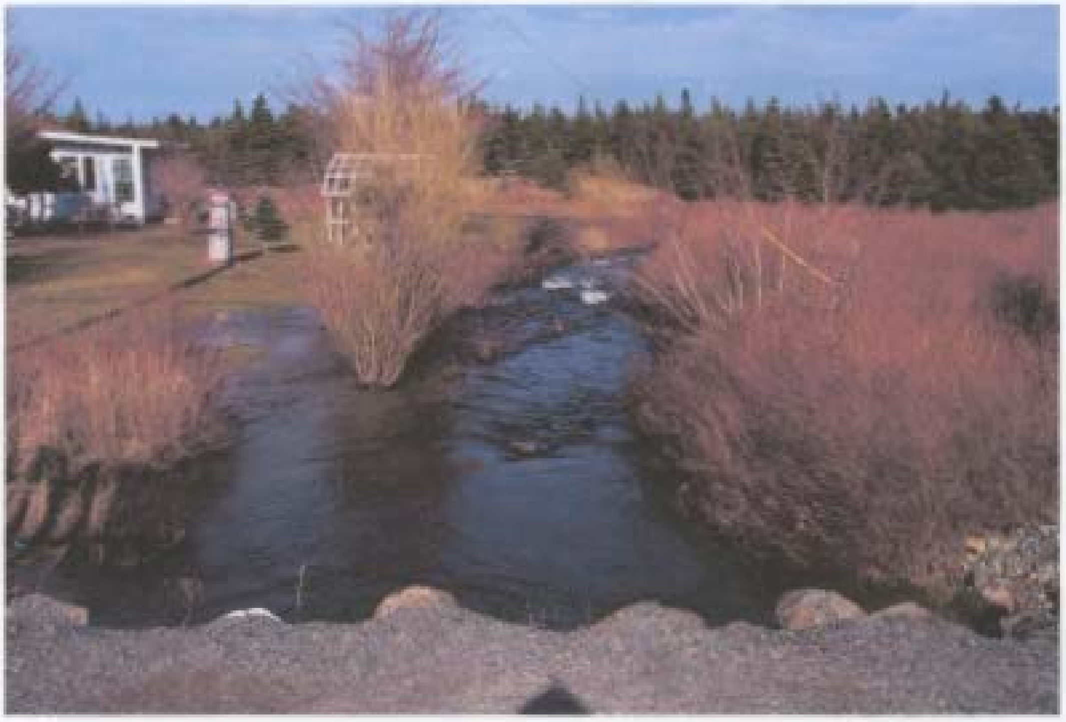
4.2 'Kennedy's Brook' on the opposite side of Torbay Road. The photograph was taken approximately 12 hours after a 20 mm rainfall, with flood water contributions from snowmelt and runoff increased by frozen soil. The small depression seen in the photograph was formerly drained by a small brook. Drainage was restricted as a result of the construction of Torbay Road; the floodplain maximum is between 30-50 m. UTM 370450E 5277050N.

4.3 The restructuring of Torbay Road in July 2003 included the use of fine gravel as roadbed. Runoff from the road is causing the fine gravel to infiltrate through the gabions into the ditches. Consequently, the debris is accumulating in the ditches and contributing to the obstruction of flow. Approximately UTM 370450E 5279400N.

4.4 The gabions are not able to hold back the fine gravel sediment. The culverts located in the ditches parallel to the road are now inadequate to remove water during heavy rainfall. A flood here would cut Torbay Road or partially disrupt traffic. Approximately UTM 370450E 5279400N.

4.5 'The Gully' following a rainfall event. Date: November, 2005. UTM 370600E 5279400N.

4.6 "The Gully" during approximate average flow. Date: August, 2005. UTM 370600E 5279400N.



4.7 Flooding of property directly downstream from 'The Gully' resulting from 20 mm of rainfall in 24 hours and snowmelt. UTM 370600E 5279400N.

4.8 Property downstream from 'The Gully' that was damaged during Tropical Storm Gabrielle and other heavy rainfall events (e.g. April 2005 event). Blue arrow indicates high water mark. UTM 370600E 5279400N.

4.9 The section of Main Brook located upstream from Torbay Road Bridge looking upstream. Main Brook flows between Bridge Road on the south (left in the picture) and Indian Meal Line on the north (right in the picture). Homes and property along Indian Meal Line are subject to flood damage during heavy rainfall and snowmelt. UTM 369450E 528000N.

4.10 Downstream view of Main Brook. The meadow on the left is inundated during snowmelt and rain-on-snow precipitation. Ice jamming has historically occurred in this area. The absence of centre abutment allows more effective flow of Main Brook. Erosion of Bridge Road (seen on the right) is continuous. UTM 369450E 528000N.

4.11 The rock cut / Torbay Road area. Culverts on both sides of Torbay Road are deteriorating, and gravel and detritus input to the streams has impeded flow. UTM 369450E 5281000N.

4.12 Marshland adjacent to the stream exiting Watt's Pond. The saturated, poorly-drained Wallace Lane area appeared water-saturated at time of all site visits. Drainage is impeded by the road construction which partially blocked the natural drainage in conjunction with inadequate ditching. Remedial measures are being considered. Date: November, 2005. UTM 369650E 521100N.

4.1.2. Storm surges

Storm surges resulting from autumn and winter storm activity infrequently affect Torbay. Due to the topography of Tor Bay, Torbay is sheltered from winds that cause damage to nearby communities (Codner, 1996). The March 2005 storm surge which caused damage to adjacent communities of Flat Rock and Pouch Cove did not affect Torbay. Historical records illustrate damage that has occurred during storm surge events. The storm of 1955 was documented as the worst storm in the 40 years prior to 1995 (Codner, 1996). Fishing gear and infrastructure was damaged and the debris collected on Torbay's shoreline. Autumn storm activity caused damage to the harbour area in 1966, 1992, and 1994.

4.1.3 Ice jamming

Ice jams have contributed to no flooding events within recent years. Historically, ice jams occurred in the Main Bridge area with a frequency of 3-4 years (Mayor of Torbay, Robert Codner, personal communication, 2003). Ice became wedged on rocks and the pillars of the bridge that crosses the river. The ice jamming triggered flooding, but few houses suffered damage. Development in the area more than 40 years ago has increased wind action on the river, thereby decreasing ice formation. When the ice jams occurred in the area, the stronger wind blowing from the ocean caused the ice to become blocked on the rocks at the mouth of the river. With the increased development and the removal of vegetation along the river bank, wind blowing down the stream forces the ice past the area of the jam, consequently decreasing the frequency of ice jams in that area.

Coastal ice develops off the shores of Torbay (Environment Canada, 2005). The prevailing wind patterns blow offshore, rather than into Tor Bay. The topography protects the coast of Torbay from the wind and current required to accumulate ice near the mouths of the rivers.

4.1.4 Winter/autumn storms

The northeast winds carry heavy precipitation to communities on the northeast Avalon Peninsula, including Torbay. Storms in 1966, 1992, 1994, and 2005 caused flooding events on the northeast Avalon Peninsula, although the amounts of precipitation during these events were less than during Gabrielle. Winter storms trigger rain-on-snow events within Torbay, which will be discussed separately.

Torbay is less susceptible to rain-on-snow events than the Humber Arm region; however, rivers within the community result in flooding during the events. Rain-on-snow events caused "The Gully", Kennedy's Brook, Main Brook, and the stream exiting Watt's Pond to reach high water levels during rain-on-snow events (i.e. April 2005). Periods of freezing rain in Torbay increase the runoff rates. Recently, however, the frequency of freezing rain events is declining (Catto and Hickman, 2004), making this less of a factor in the enhancement of runoff.

On the Avalon Peninsula, a late winter snowstorm (69-cm of snow) on 6 April 1999 followed by a warm period triggered flooding. Main Brook in Torbay and additional streams inundated the surrounding area. In Torbay, snowmelt results in above average river discharge. No damage or extensive erosion has been reported.

4.1.5 Slope failure

Slope failures within river channels do not result in flooding in Torbay (Catto and Hickman, 2004). Debris from eroded river channels is transported downstream, and accumulates in culverts or against bridge abutments. The accumulation of sediment may then pose a flood hazard.

Frost heaving and storm activity undermined a cliff face along the north side of Torbay Harbour between 2000 and 2003, and a portion of the East Coast Trail was lost into the ocean (Catto and Hickman, 2004).

4.1.6 River flooding

Cascade streams on the northeast Avalon Peninsula are sensitive to rapid flood responses. Fast flood response has been observed in Mobile, Maddox Cove, Blackhead, Conception Bay South, Waterford River in St. John's, and Torbay (Catto and Hickman, 2004). In Torbay, hurricanes do not alter the river morphology to the degree seen in the Burin Peninsula, due to the lower frequency of impacts (Ashmore and Church, 2001). Temporary changes in river morphology do occur due to heavy precipitation in short periods of time (Lawford *et al.*, 1995). Hurricane-induced river flooding in Torbay results in the erosion of riverbanks and the deposition of sediment in downstream reaches or within culvert systems (Catto and Hickman, 2004).

Rivers flowing through Torbay flood during heavy rainfall events and during snowmelt. Kennedy Brook, downstream Main Brook, and "The Gully" flood surrounding areas annually, but surpass annual high levels and cause damage during approximately 1 event every 7-8 years. However, since the restructuring of the culvert at the head of "The Gully", the flood frequency of "The Gully" has increased, and two events have occurred between November 2004 and July 2005. The installation of the larger culvert increases the amount of water flowing through. Therefore, more water is available to flood the surrounding area. Both areas are surrounded by flood tolerant vegetation. The fen area downstream from Watt's Pond has a greater frequency of flooding, approximately 1-2 years. A house located within this area has repeated flooding problems. Improving the drainage of this area is under consideration (Mayor of Torbay, Robert Codner, personal communication, 2003). As of November 2005 this has not been completed. Soldiers Brook has a flood frequency of greater than 9 years between flooding events.

Anthropogenic activities increase flood damage initiated by natural causes. Inadequate culvert diameter contributes to road damage due to pooling of water. Damage to roads near Soldiers Brook, in the Kennedy area, in the "The Gully", and near the brook exiting Watt's Pond is the result of culverts' inability to handle rapid flow (Mayor Robert Codner, personal communication, 2003). Two new culvert systems have been installed near the gully after Tropical Storm Gabrielle. The culverts are positioned at different heights to drain storm water. Downstream from "The Gully", a second culvert has been placed to drain an increased amount of water under Lynch's Lane. The majority of the problems occur in August (approximately) due to heavy precipitation and after snowmelt (Krista House, personal communication, 2005).

The second culvert modification (late October 2004) was completed in an attempt to further minimize the pooling effect above "The Gully". A semi-circular culvert was installed to allow a greater flow of water. However, this modification of the culvert was ineffective in preventing the pooling of water. Pooling of the water above the new culvert continues and subsequent rainfall events are resulting in the erosion of the highway. After the installation of the new culvert, the increased flow below the culvert has gouged a deeper channel in "The Gully", increased flooding of houses and property on Mahon's and Lynch's Lanes, and led to flooding near "The Gully" that has not previously flooded.

Diversion of water from South Pond to North Pond to increase the volume of the town water supply may have implications for "The Gully". At present, water that is flowing into "The Gully" originates from both ponds. When the modifications take place, the majority of the water will be flowing from North Pond. With the additional usage of water from the increasing population and the retaining of water within the reservoir, the average outflow of water into "The Gully" will decrease. However, the amount of water during flood events may not vary from present flood levels because water will still originate from both ponds. Therefore, the potential risk of flooding will remain.

Water from Watt's Pond flows over a steep embankment (the rock cut area) and then flows underneath Torbay Road (Route 20). Culverts on either side of the road are severely eroded and near complete collapse. The culverts in place cannot remove water during heavy rainfalls. Flooding in this area occurs annually and the culverts are in urgent need of repair (Mayor of Torbay, Robert Codner, personal communication, 2003). The culverts have not been repaired as of autumn 2005.

4.1.7 Anthropogenic activities

Construction of new building lots near Whiteway's Pond and along the river leading from the pond may lead to flooding in the area and areas downstream. The removal of vegetation will increase runoff, and the accumulation of debris on the lots may be washed into the stream. If the debris is not removed, it may wash into the stream and cause damming. Flooding may erode the stream banks and increase the flooding risk. As of the present, no record of flooding in this location has occurred.

The reconstruction of Torbay Road through the community has increased flooding sensitivity to adjacent infrastructure. The roadbed consists of fine silt and gravel. During rainfall events, water running off the road is removing the silt and gravel from the roadbed and displacing it further down slope. The debris will build up in the culverts under driveways, possibly causing washouts of the driveway and the road. Gabions are in place in some sections, but the fine material is being swept away by the runoff from the street. Site visits confirmed the erosion of the roadbed after heavy water flow.

The increased construction in Torbay is related to the backfilling of sediments into stream system which cause the undercutting of the opposite bank within the main stream upstream from Main Bridge. Consequently, trees and debris are toppling into the stream and will eventually create a debris dam downstream.

In Torbay the headwaters of Western Island Pond are undergoing development along the pond and the river exiting the pond. Destabilization of the area caused by deforestation and concentrations of debris in river systems increase flooding risk downstream. The removal of debris according to development and the construction of houses on large lots are practices implemented by the municipality of Torbay to limit downslope effects. As well, the steeper slope areas are excluded from development.

4.13 The new culvert that was installed at the mouth of "The Gully" under Torbay road in October 2004. The larger culvert allows a greater flow of water. ATM 370400E 5279150N. Date: August 2005.

4.14 Change in "The Gully" after the November 2004 and April 2005 floods. The bank on the south side (right) is being undercut, trees and sediment are falling into the stream. The "beach" on the north side (left) has become coarser. Pre-culvert installation the area was gravel; post-culvert installation the clast sizes has increased (Krista House, personal communication, 2005). ATM 370400E 5279150N. Date: August 2005.

4.1 Summary

Below the storm frequency, precipitation patterns, flood mechanism, and flood frequency are analyzed to understand and predict location and timing of flood hazards. Specific areas in Torbay which were identified above are susceptible to certain flooding mechanism at particular times of the year and certain frequency.

4.2.1 Importance of flood mechanism

Climatic factors, such as hurricane-induced rainfall and storm surges, coupled with inadequate drainage infrastructure contribute to the majority of flooding events in Torbay. Damages caused by flooding may be predicted in several locations, such as Watt's Pond fen, and minimized in other locations, such as Kennedy's Brook.

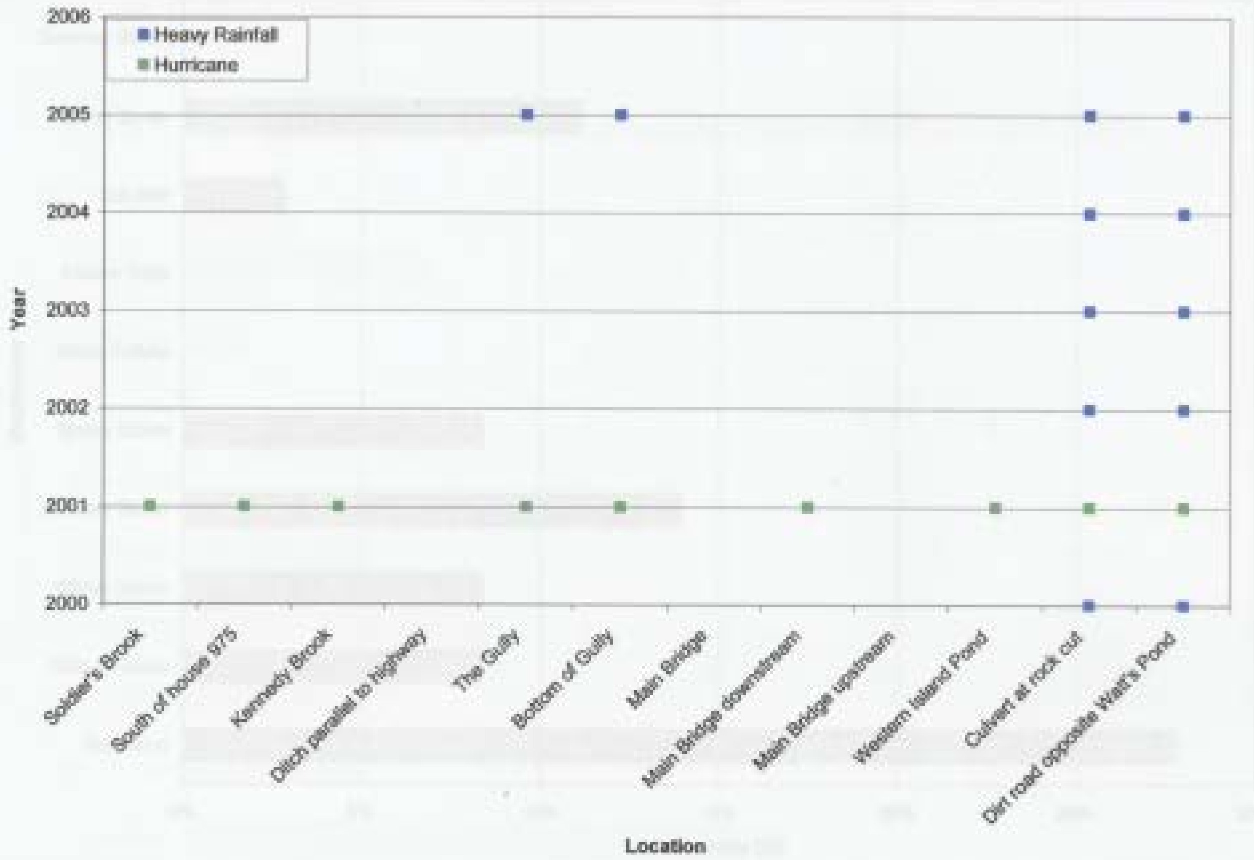


Figure 4.1: Frequency of flooding in Torbay. The ditch parallel to highway is an ongoing issue. The Main Bridge area has historically flooded, and upstream from the Main Bridge (ice jam induced flooding) have not occurred with a frequency that can be depicted by this graph; therefore these areas are listed but not plotted.

Due to the lack of detailed archival records, events may have occurred and not been recorded. However, the most significant events within the past 50 years have been recorded through the literature, interviews, or evidence of flood prone areas as determined from site visits.

Figure 4.2 illustrates the frequency of significant floods from natural causes in Torbay. The causes of natural flooding vary from hurricane and storm induced precipitation, storm surges, to rain-on-snow events. River flooding is not listed because all inland flooding mechanisms can result in damages caused by river flooding.

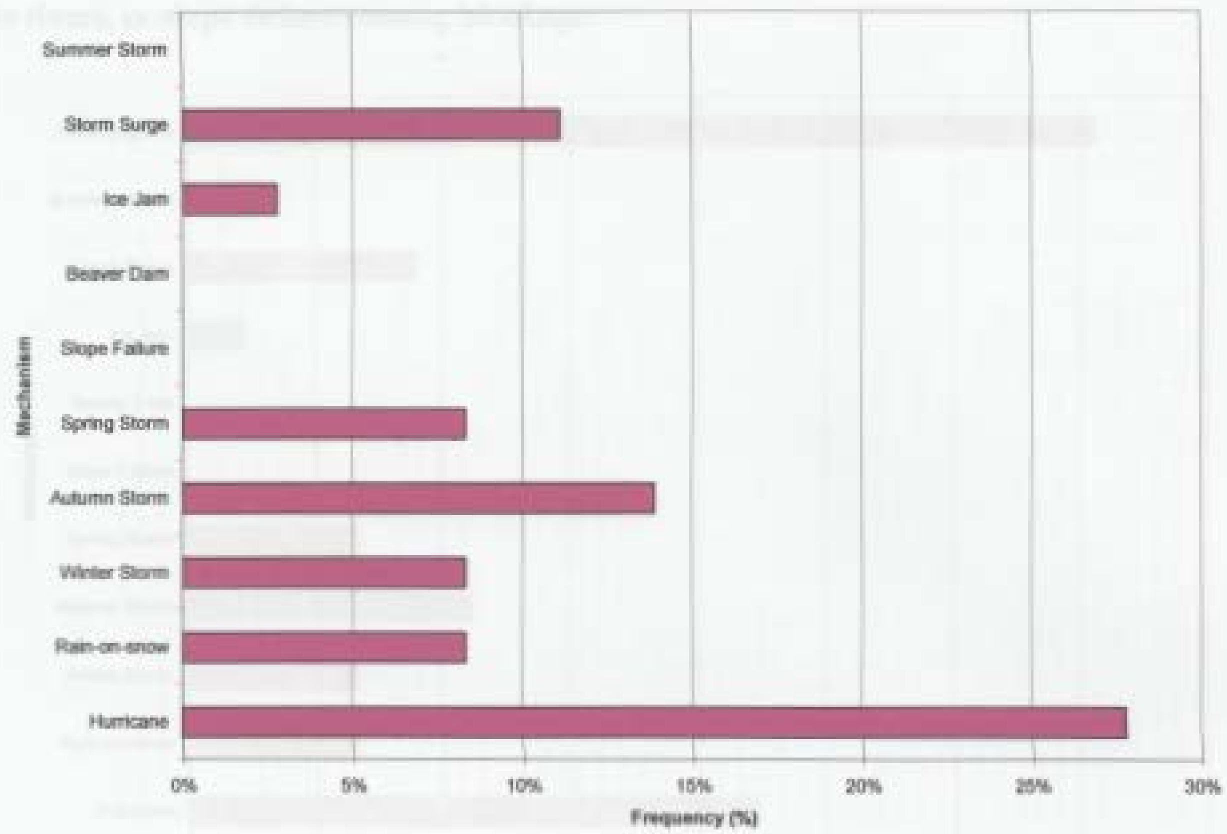


Figure 4.2: Frequency of flooding caused by natural mechanism in Torbay. Total number of recorded incidents is 29.

Of the 29 recorded flooding incidents, hurricanes are the greatest natural cause of flooding (34%; Figure 4.2). This indicates that even though hurricane activity is infrequent, it impacts a larger and less sensitive area with greater frequency intensity than other natural causes. Storm surges have also historically affected Torbay but the resulting damage is far less extensive than hurricane impacts; 14% and limited to the coastline. Autumn storms are the second largest cause of flooding, 14%. Rain-on-snow (10%), spring storms (10%), and winter storms (10%) are the least cause of flooding in Torbay. Ice jams have historically caused localized flooding frequently in the Main Bridge area historically, but the frequency is not recorded in Figure 4.2. No flooding event has been recorded resulting from beaver activity or natural accumulation of debris in rivers, or slope failure causing blockage.

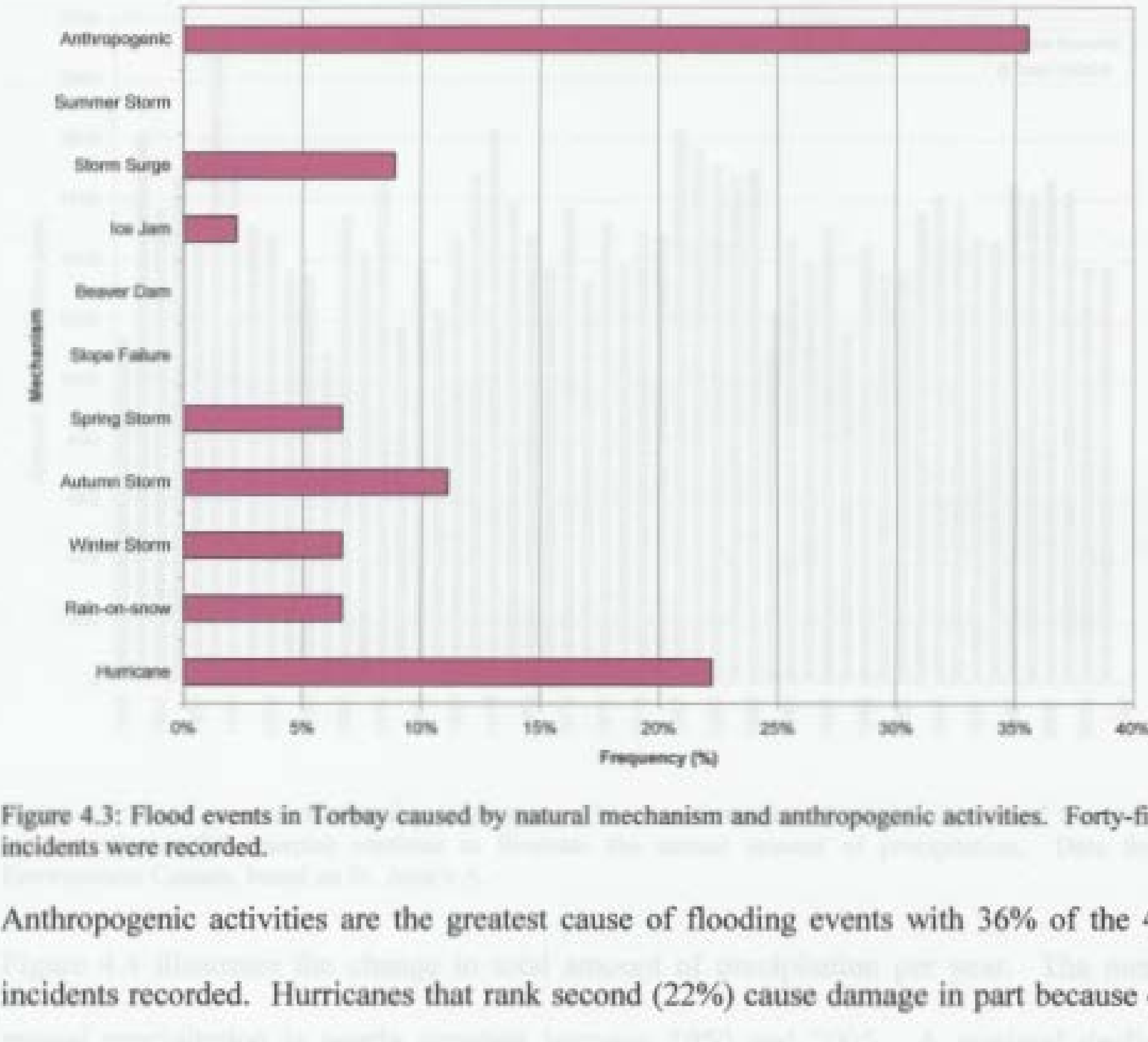


Figure 4.3: Flood events in Torbay caused by natural mechanism and anthropogenic activities. Forty-five incidents were recorded.

Anthropogenic activities are the greatest cause of flooding events with 36% of the 45 incidents recorded. Hurricanes that rank second (22%) cause damage in part because of infrastructure restricting drainage (Figure 4.3).

4.2.2 Climate data analysis

To evaluate the relationship between flooding events and climate, flood occurrence in St. John's will be used. Torbay is located within the St. John's Census Metropolitan Area as designated by Statistics Canada. Figure 4.4 illustrates the total precipitation from 1950-2004 at the St. John's climate station. Total precipitation is dominated by rain, and snowfall totals are 15-20% of the precipitation.

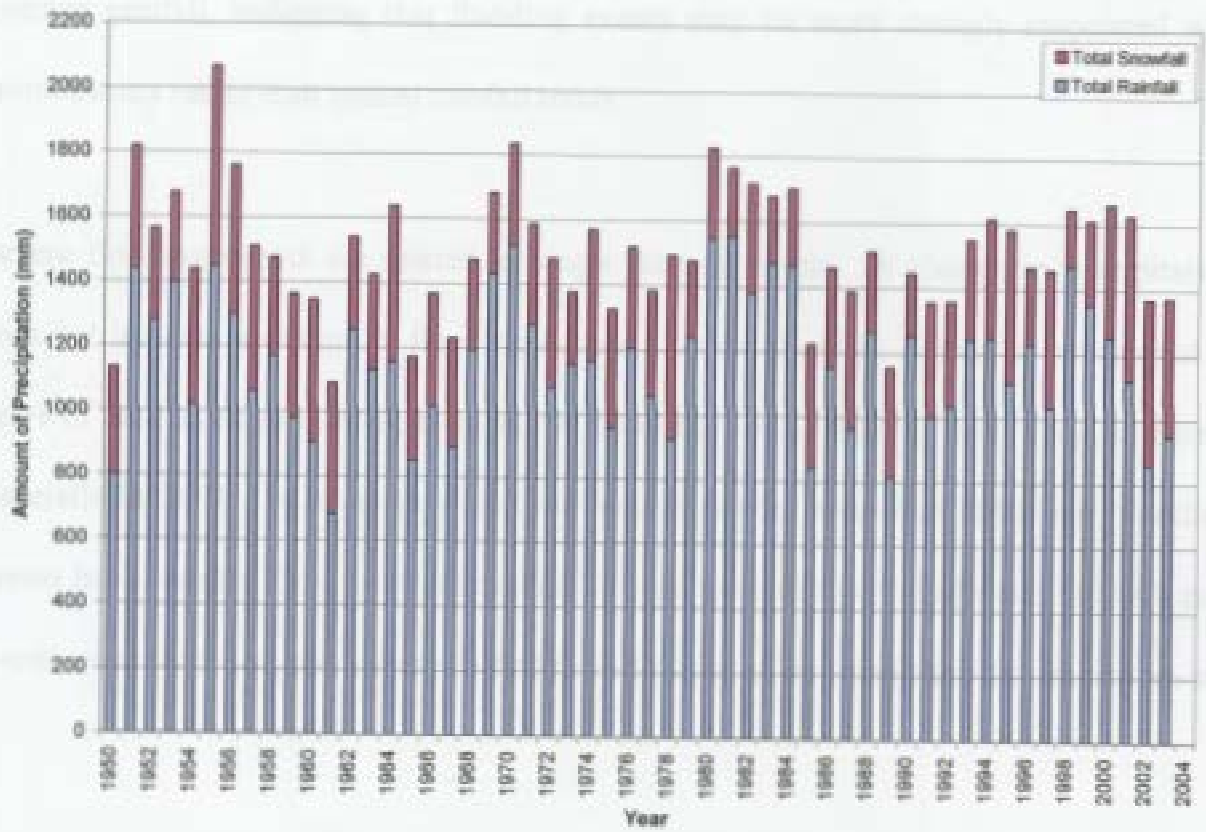


Figure 4.4: Total amount of annual precipitation. The annual amount of rainfall (blue) and the annual amount of snowfall (purple) combine to illustrate the annual amount of precipitation. Data from Environment Canada, based on St. John's A.

Figure 4.4 illustrates the change in total amount of precipitation per year. The mean annual precipitation is nearly constant between 1950 and 2005. A minimal decline occurs in the amount of snowfall per year. The total rainfall is also declining, but at a slower rate. Both changes in snowfall and rainfall are less than 50-mm over the sample period.

Although the average total precipitation appears to remain constant, flooding events in Torbay are climate driven. Storm events – hurricane-induced flooding and storm surges

– initiate severe flooding events. Tropical Storm Gabrielle (2001) occurred in a year of average rainfall, indicating that flooding events may be more strongly associated with storm events rather than annual rainfall totals.

Severe flooding events are related to single intense events. A change in precipitation does not indicate a change in flooding events. Severe flooding events have occurred in years of near average rainfall, such as the flooding event resulting from Tropical Storm Gabrielle in 2001. In years in which the annual rainfall exceeded 1800 mm, flooding events have resulted from constant rainfall over an extended period of time. In 1955 two events were recorded; one event resulted from 12 days of constant rain, the other from an

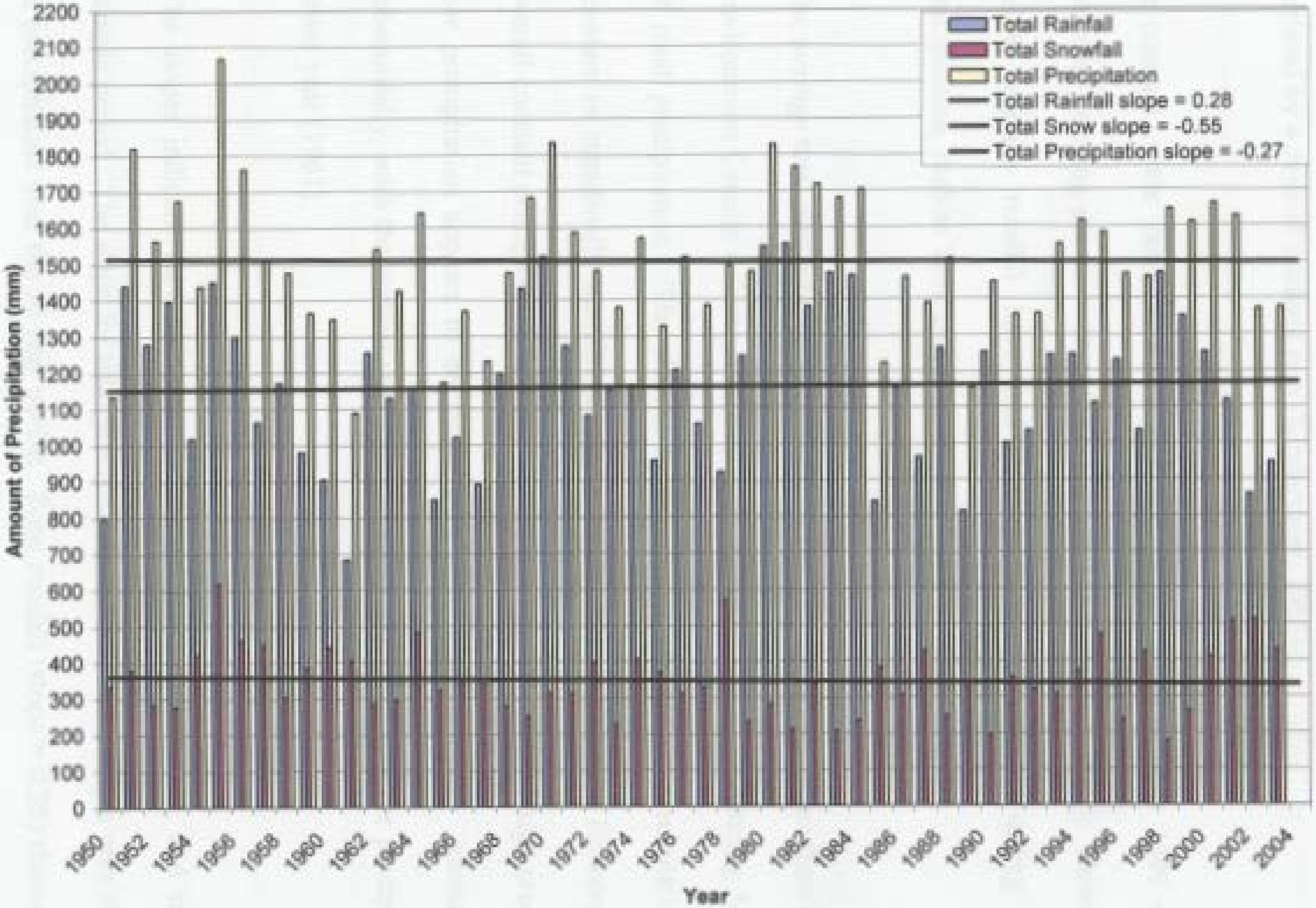


Figure 4.5: Total amount of precipitation (yellow), total amount of rainfall (purple), and total amount of snowfall (pink) per year between 1950 and 2005. The linear line for total precipitation, rainfall, and snowfall shows the overall change during the sample period. Snowfall is calculated as melted volume; 1 cm snow is equivalent to 1 mm water. Data collected from Environment Canada for St. John's A site.

intense rainfall event (Kindervater, 1980). In 1970, the only recorded flooding event was initiated by 4 days of constant rain (Kindervater, 1980).

In contrast, some years of above average rainfall and less than 1899 mm have no recorded flooding events, such as 1956 and 1967 (Kindervater, 1980). However, years of below average rainfall have had serious flooding events resulting from heavy precipitation, such as 1950 and 1961 (Kindervater, 1980).

The average total precipitation is 1500 mm/a for Torbay as calculated from the data from Environment Canada website, and displayed in Figure 4.6 as the running 5-year average of total precipitation. The change in the annual amount of precipitation shows no constant or statistically significant trend between 1950 and 2005. However, within the overall constant precipitation, a cyclic pattern emerges. Periods of high precipitation and low precipitation appears to be cyclic over 5-10 year intervals. Annual totals vary substantially, with the wettest year (1955) having almost double the precipitation of the driest year (1961).

The slopes indicate very little change in total precipitation, rain, and snow over the sample period. The slope for total precipitation is -0.27 indicating a very slight decrease in precipitation over the 50 year period. Total rainfall (slope = 0.28) shows a very slight increase and total snowfall (slope = -0.55) shows a very slight decrease. However, these changes are not significant as deducted from the R^2 values. The R^2 values for total precipitation, total rainfall, and total snowfall are 0.0005, 0.0004, and 0.0081 respectively. The lack of relationship between amount of precipitation and time may be caused by the cyclic pattern explained above.

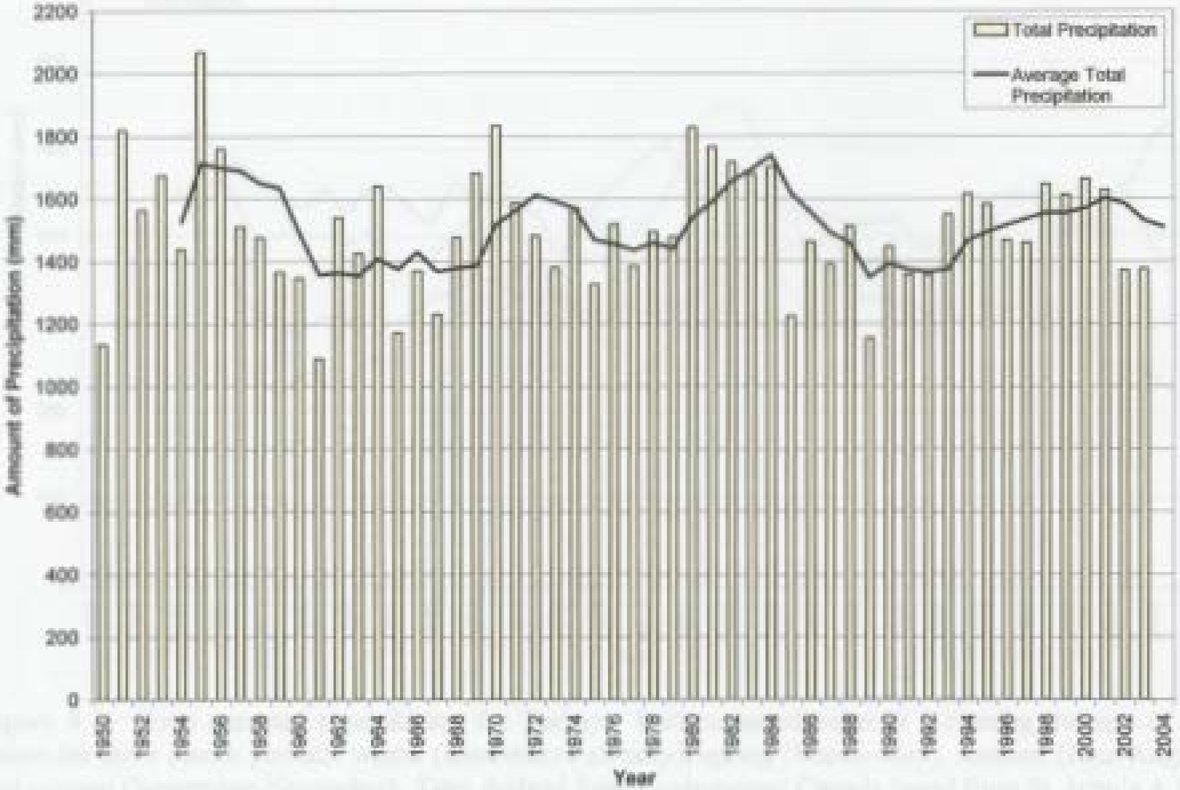


Figure 4.6: Total annual amount and average precipitation for Torbay. The average precipitation is constructed from a running average of 5 periods. Data derived from Environment Canada based from St. John's A Site.

Highest amounts of precipitation fall in the autumn (September to November) and winter (December to February) months (Figures 4.7 and 4.8). Within these months, hurricane activity and winter storms cause flooding hazards associated with heavy precipitation and storm surges. Total precipitation may not reflect hazards that cause extensive damage. If synchronized with mild temperatures, snowmelt-induced river flooding will increase damages. Lower levels of precipitation fall in summer (June to July). The amount of summer precipitation has been decreasing within the last 10 years.

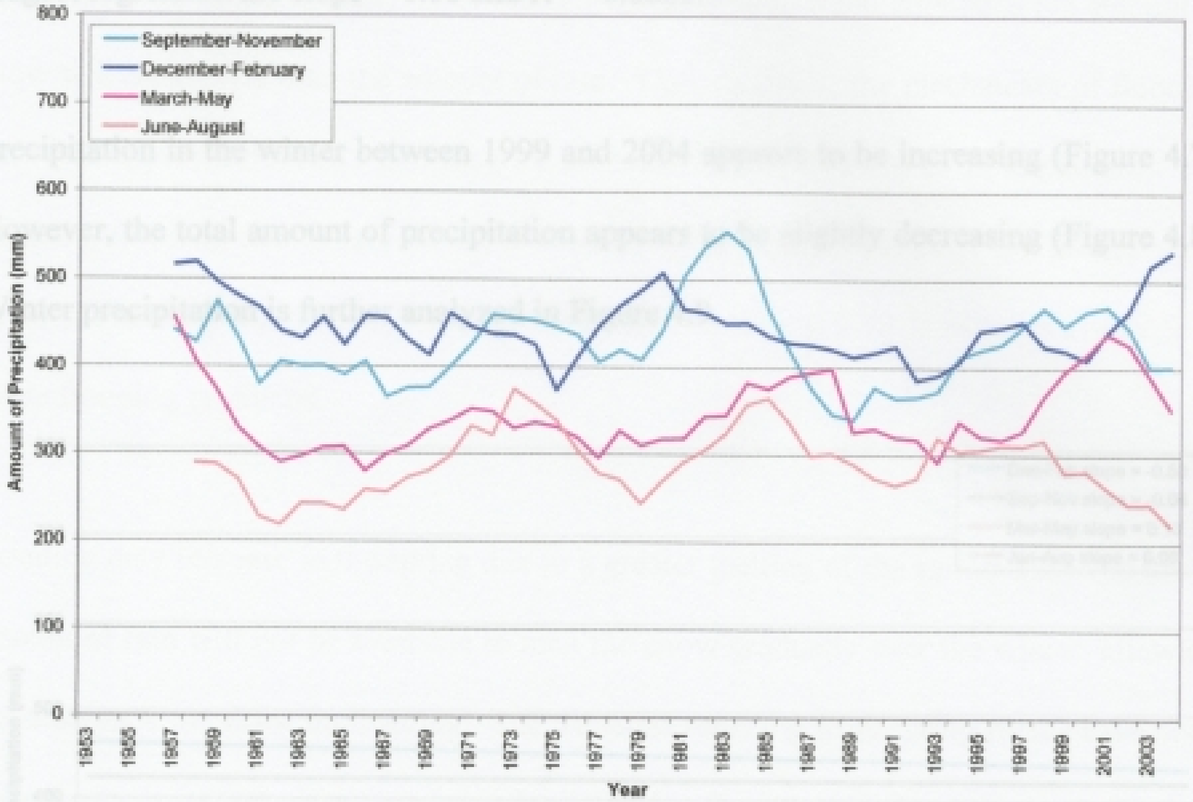


Figure 4.7: Total seasonal precipitation for Torbay. Each seasonal value is a running average of five points for three month periods: winter (December-February), spring (March-May), summer (June-August), and autumn (September-November). Data derived from Environment Canada based from St. John's A Site.

As previously noted, the precipitation in the summer is currently declining; however, on average the amount of precipitation in the summer is constant over the sample period (Figure 4.8). Precipitation in the spring months, March to May, has a similar pattern to the summer months. The average amount of precipitation is higher in the spring than the summer over the sample period the amount of precipitation appears to be constant, but in recent years the amount of precipitation is on a decline. The average amount of precipitation is 450 mm in the winter, 349 mm in the spring, 286 mm in the summer, and 422 mm in the autumn. For December to February regression the slope = -0.50 and R^2 =

0.0081; for the September to November regression the slope = -0.04 and $R^2 = 4 \times 10^{-3}$; for March to May regression the slope = 0.13 and R^2 = 0.0006; and for the June to August regression the slope = 0.06 and R^2 = 0.0001.

Precipitation in the winter between 1999 and 2004 appears to be increasing (Figure 4.7). However, the total amount of precipitation appears to be slightly decreasing (Figure 4.8). Winter precipitation is further analyzed in Figure 4.9.

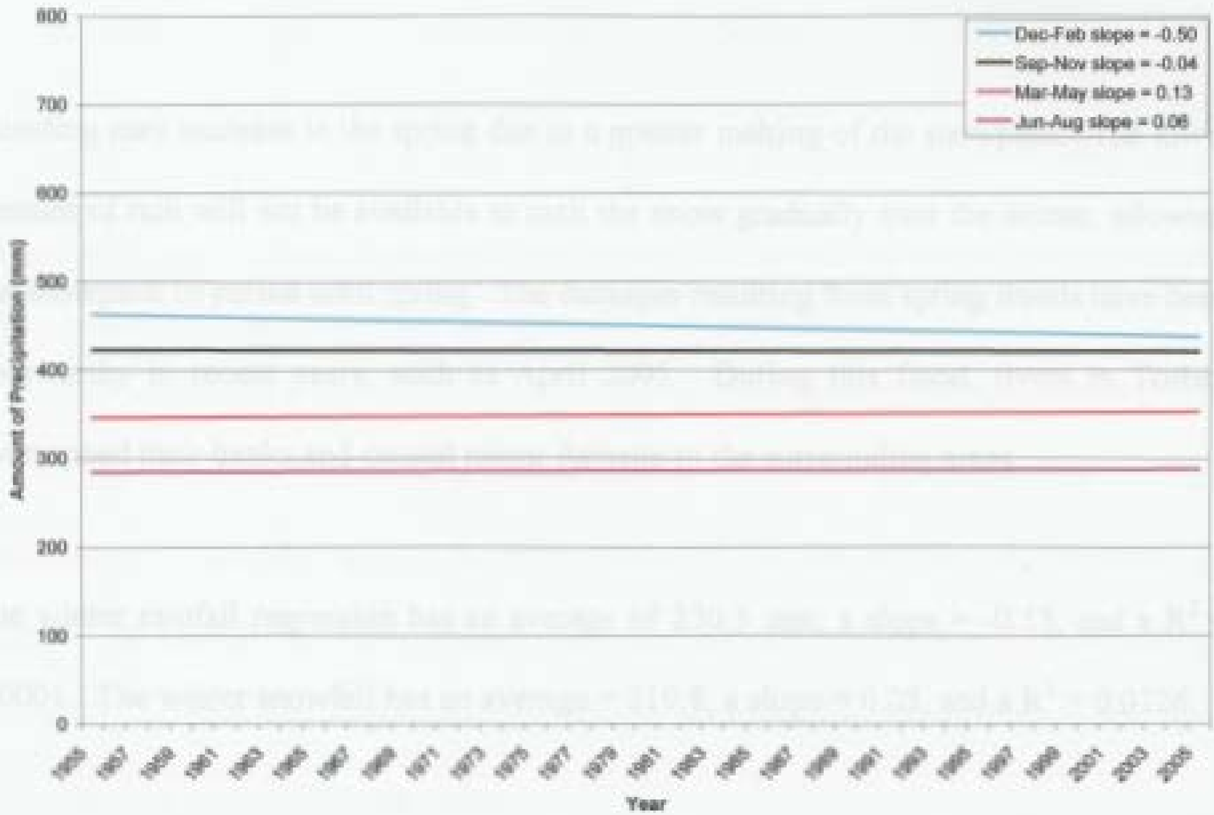


Figure 4.8: Linear regression of total seasonal precipitation for Torbay. Each seasonal value is a linear average of yearly amount of precipitation for three month periods: winter (December-February), spring (March-May), summer (June-August), and autumn (September-November). Data derived from Environment Canada based from St. John's A Site.

The average amount of snow (220 mm) and rain (231 mm) in the winter months of December, January, and February are similar. The rain to snow ratio appears to be changing between 1950 and 2004 (Figure 4.9). At the beginning of the sample period the amount of rain falling in winter was greater than snow. In the early 1990s the rain to snow ratio was approximately 1. If the rain to snow ratio trend continues the amount of snow will be greater than the amount of rain. Consequently, the mechanism of flooding that was apparent 50 years ago may be different than at present or in the future. For instance, flooding due to rain-on-snow events may increase because of the thicker snow cover preventing rain from infiltrating the ground. Therefore, more water is available to cause flooding problems.

Flooding may increase in the spring due to a greater melting of the snowpack. The lower amount of rain will not be available to melt the snow gradually over the winter, allowing the snowpack to persist until spring. The damages resulting from spring floods have been noteworthy in recent years, such as April 2005. During this flood, rivers in Torbay overtopped their banks and caused minor damage to the surrounding areas.

The winter rainfall regression has an average of 230.5 mm, a slope = -0.55, and a R^2 = 0.0001. The winter snowfall has an average = 219.8, a slope = 0.05, and a R^2 = 0.0126.

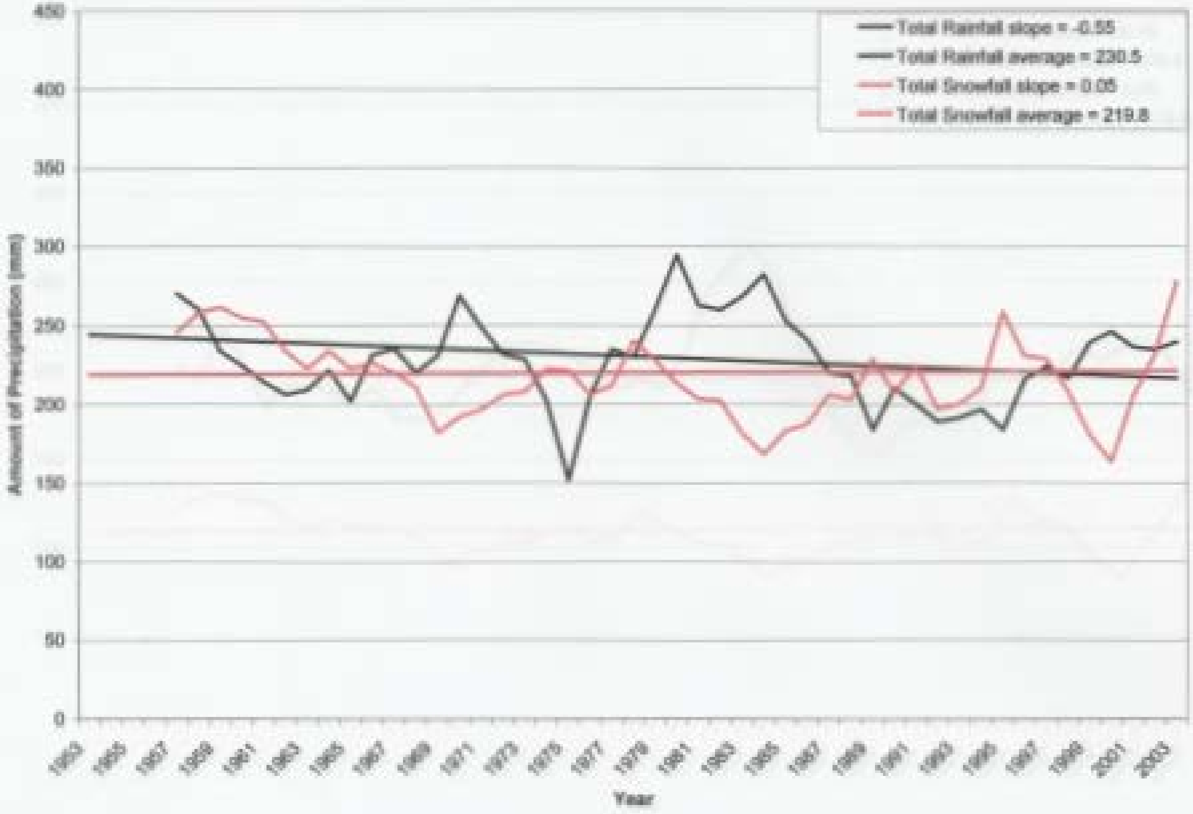


Figure 4.9: Linear regression and average of winter rainfall and snowfall for Torbay. Both the rainfall is described by a linear regression and a running average of 5 points of yearly precipitation between 1950 and 2004. Data derived from Environment Canada based from St. John's A Site.

The total rainfall and total snowfall remain constant throughout the sample period (Figure 4.10). The fluctuation in rainfall is greater than snowfall. As with the snowfall in winter, the amount of snowfall appears to be increasing in the last decade. As expected, the amount of rainfall is much greater than the amount of snowfall. Although the precipitation appears to remain constant, autumn storms and hurricane activity may cause an increase in autumn flooding events.

The autumn rainfall regression has an average = 394.4 mm, a slope = -0.16, and a R^2 = 0.006. The autumn snowfall regression has an average = 219.8 mm, a slope = 0.05, and a R^2 = 0.0001.

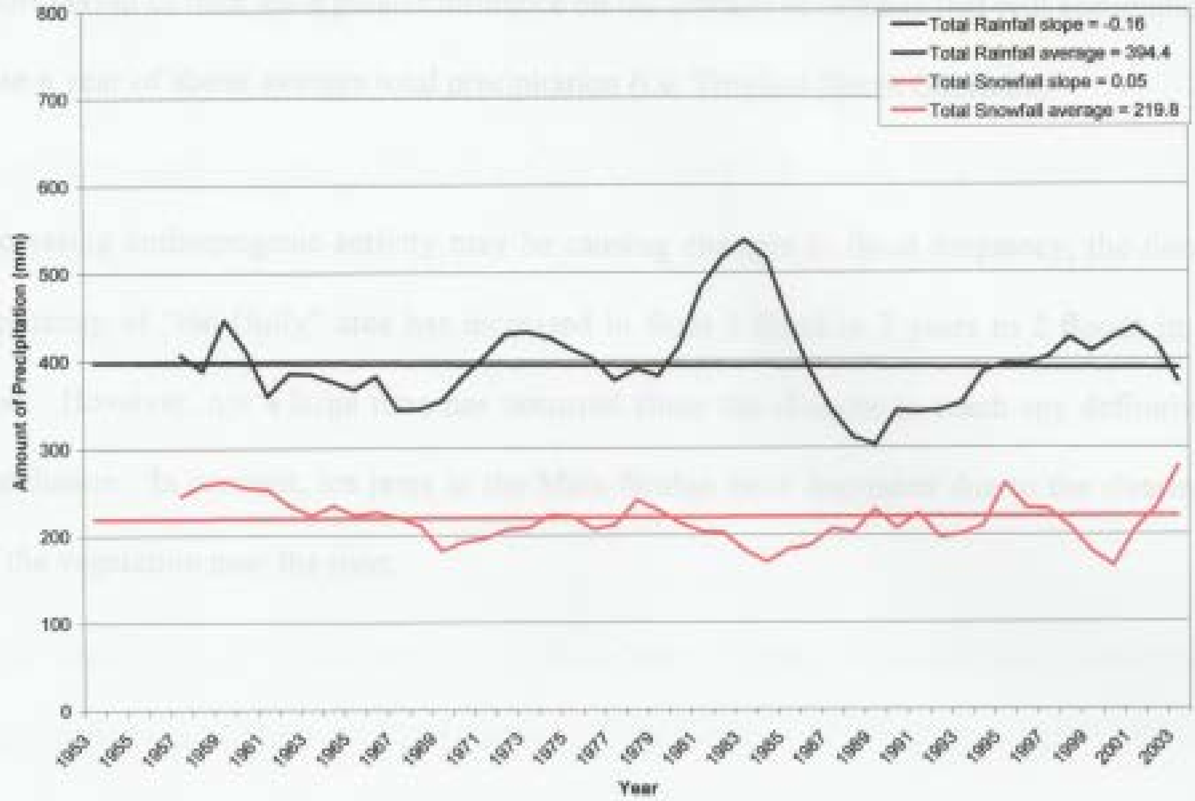


Figure 4.10: Linear regression and average of autumn rainfall and snowfall for Torbay. Both the rainfall is described by a linear regression and a running average of 5 points of yearly precipitation between 1950 and 2004. Data derived from Environment Canada based from St. John's A site.

4.2.3 Conclusion

The majority of flooding is anthropogenically-induced. The damage resulting from hurricane, rain-on-snow events, seasonal storms, ice jams, and river flooding are partially caused by anthropogenic activities such as restriction of waterways and the construction of infrastructure adjacent to rivers.

In addition, changes in total precipitation did not appear to have a direct relationship with flooding event. Flooding events occurred during intense storms. Heavy rainfall in a short period of time has a greater influence on the amount of damage that will accumulate than a year of above average total precipitation (i.e. Tropical Storm Gabrielle).

Increasing anthropogenic activity may be causing changes in flood frequency; the flood frequency of "the Gully" area has increased in from 1 flood in 7 years to 2 floods in 1 year. However, not a large time has occurred since the changes to reach any definitive conclusion. In contrast, ice jams in the Main Bridge have decreased due to the clearing of the vegetation near the river.

5. Physical Impacts of Flooding on the Humber Arm Region

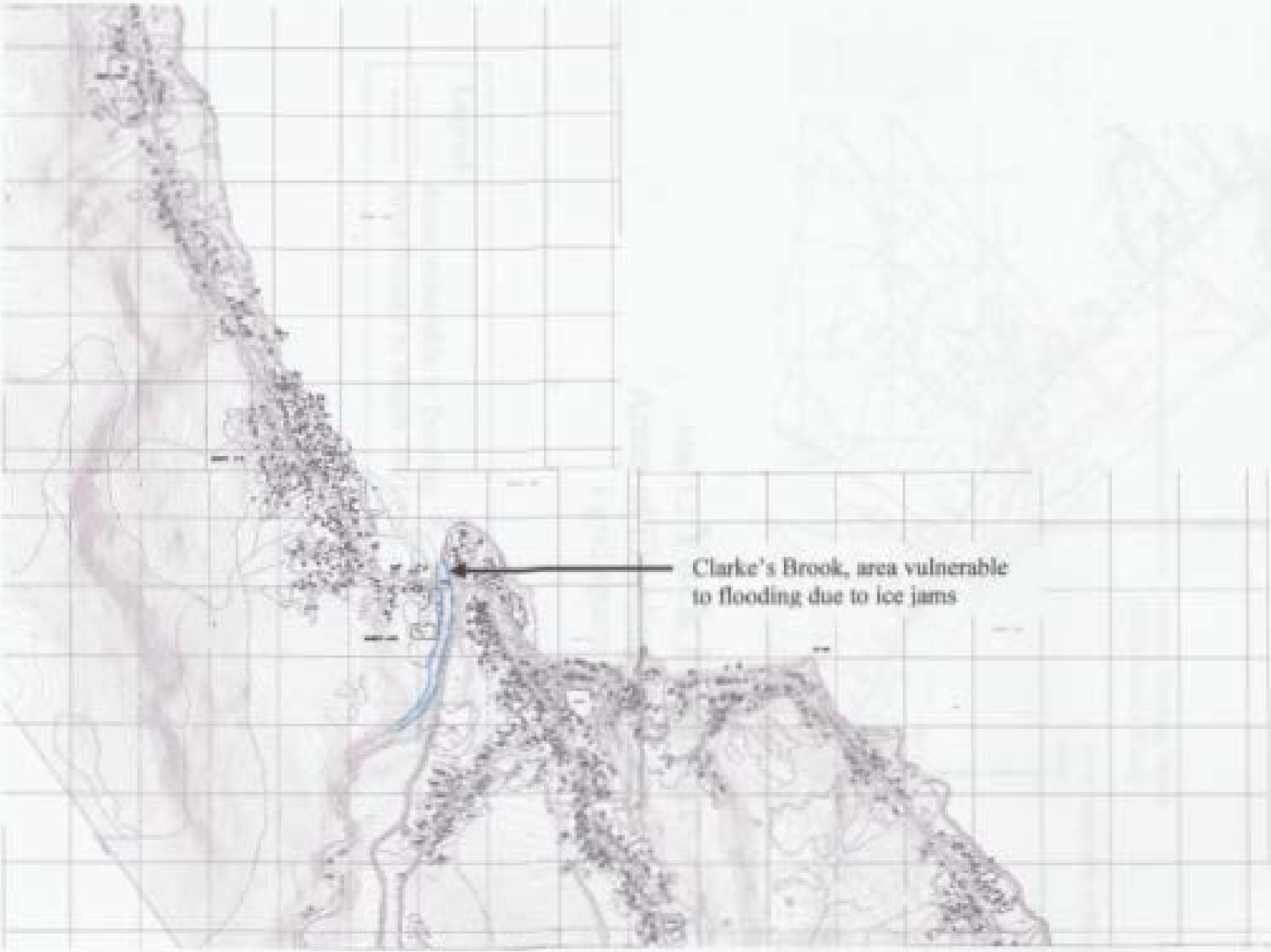
In the following section, the historical flooding events and current areas of exposure will be identified. Maps of these areas are also depicted. The mechanism(s) inducing the flood and the cause, season, precipitation amount, and other meteorological conditions will be highlighted. Finally, the importance of meteorological factors, climate change, and anthropogenic factors will be assessed.

The Humber Arm region contains communities varying in population, geomorphic setting, and susceptibility to flood damage. Natural causes of flooding consist of rain-on-snow events, seasonal storms, hurricane-induced rainfall and storm surges, ice jams, and slope failures. Natural causes coupled with failure or inadequate drainage infrastructure, development, and alteration of natural drainage ways increase the frequency and severity of flooding events. The mechanism and frequency of flooding is dependent on the location within the Humber Arm region.

Flood damage and areas of concern were recorded in several communities. In the region, seventeen sites outside of Corner Brook were identified as susceptible to flooding: eight sites located on the southern arm, six sites along the northern arm, and three in Cox's Cove.

Few of the events reported affect all areas of the Humber Arm simultaneously. However, infrastructure throughout Corner Brook and most other communities was damaged during the March 2003 rain-on-snow event.

With the knowledge of the required mean intensity and duration of rainfall to initiate slope failure, an approximate threshold value for slope failure can be developed (Dhakal and Sidle, 2004). The threshold idea can be used in the prediction of slope failure in frequent hazard areas. In the Humber Arm region, slope failure occurs after 31.9 mm of rain has fallen within a 48 hour period in conjunction with melting snow (storm intensity is 0.66 mm/hr), and 68 mm of rain in a 48 hour period without snowmelt (storm intensity 1.42 mm/hr).



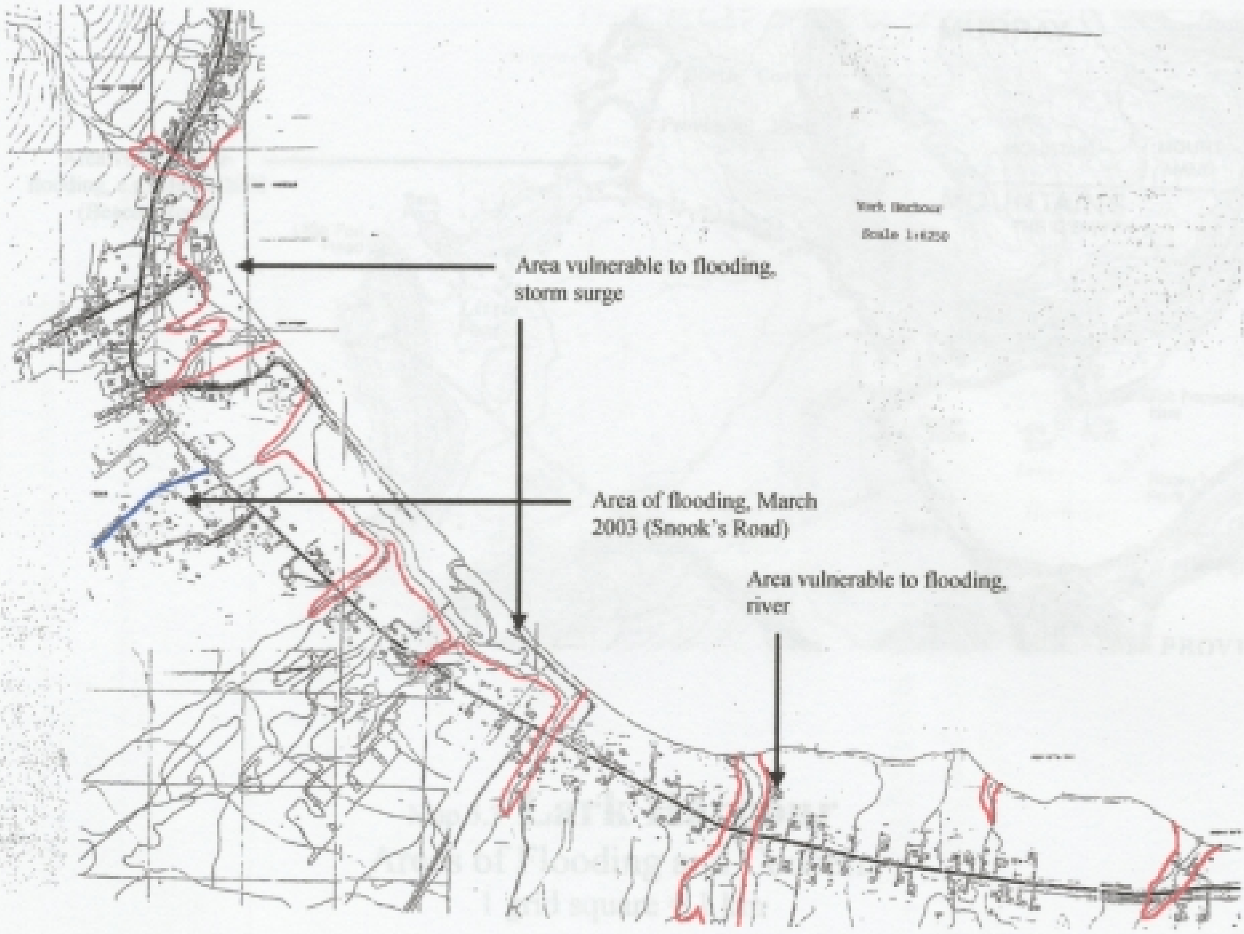
Map 5.1 **Benoit's Cove**

Areas of flooding and concern

1 grid square = 200 m

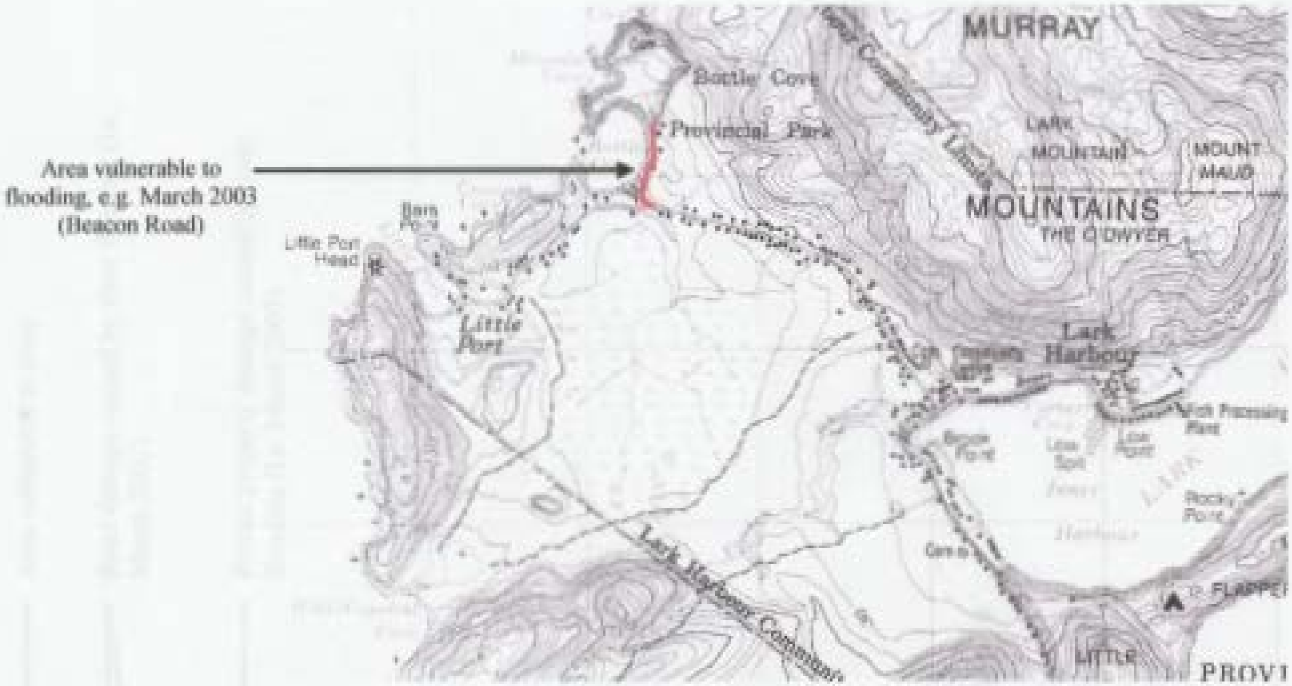
Legend

Areas vulnerable to flooding



Map 5.2 **York Harbour**
Areas of Flooding and Concern
1 grid square = 250 m

Legend
Areas vulnerable to flooding
Area flooded in March 2003



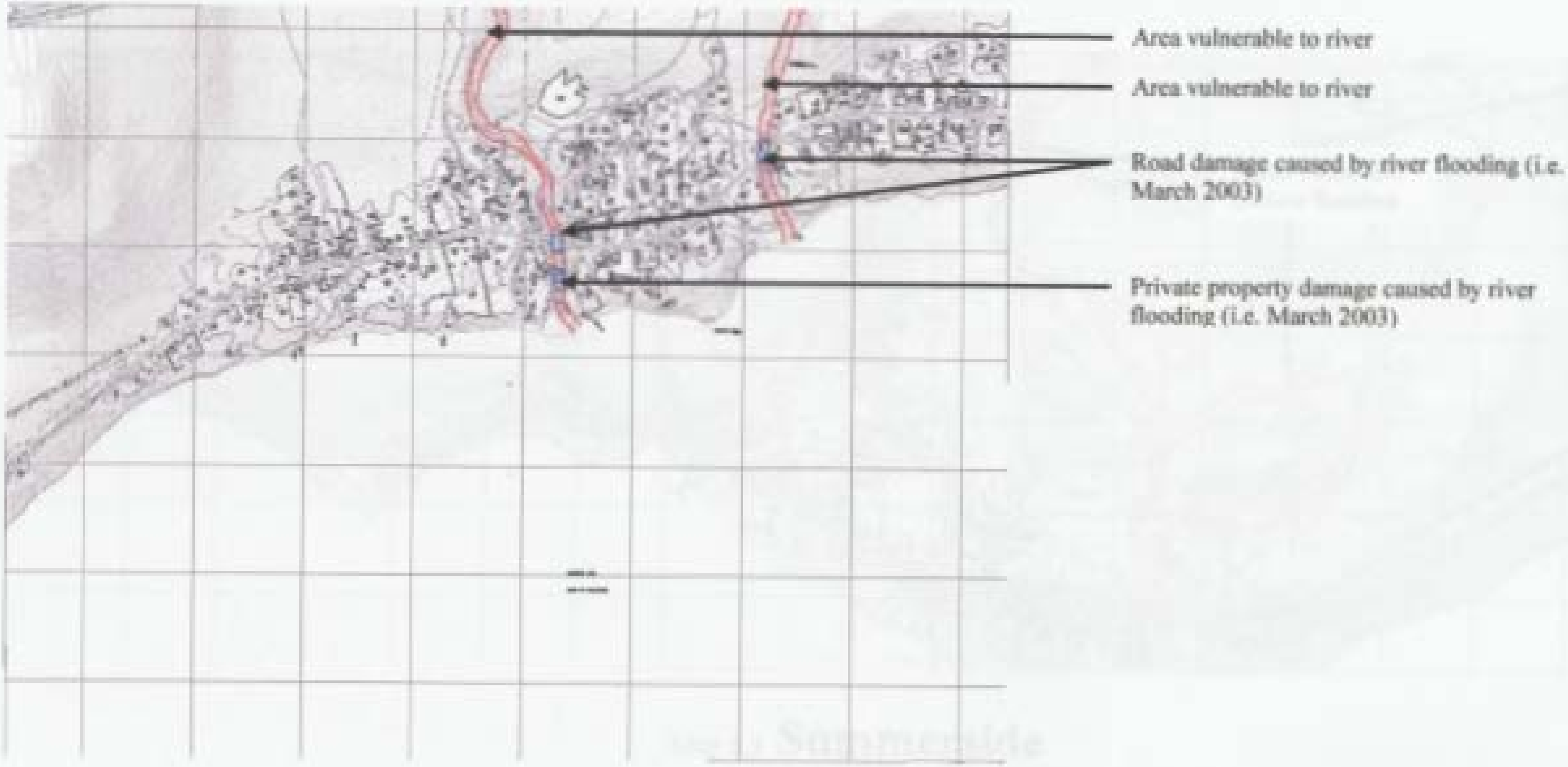
Map 5.3 **Lark Harbour**

Areas of Flooding and Concern

1 grid square = 1 km

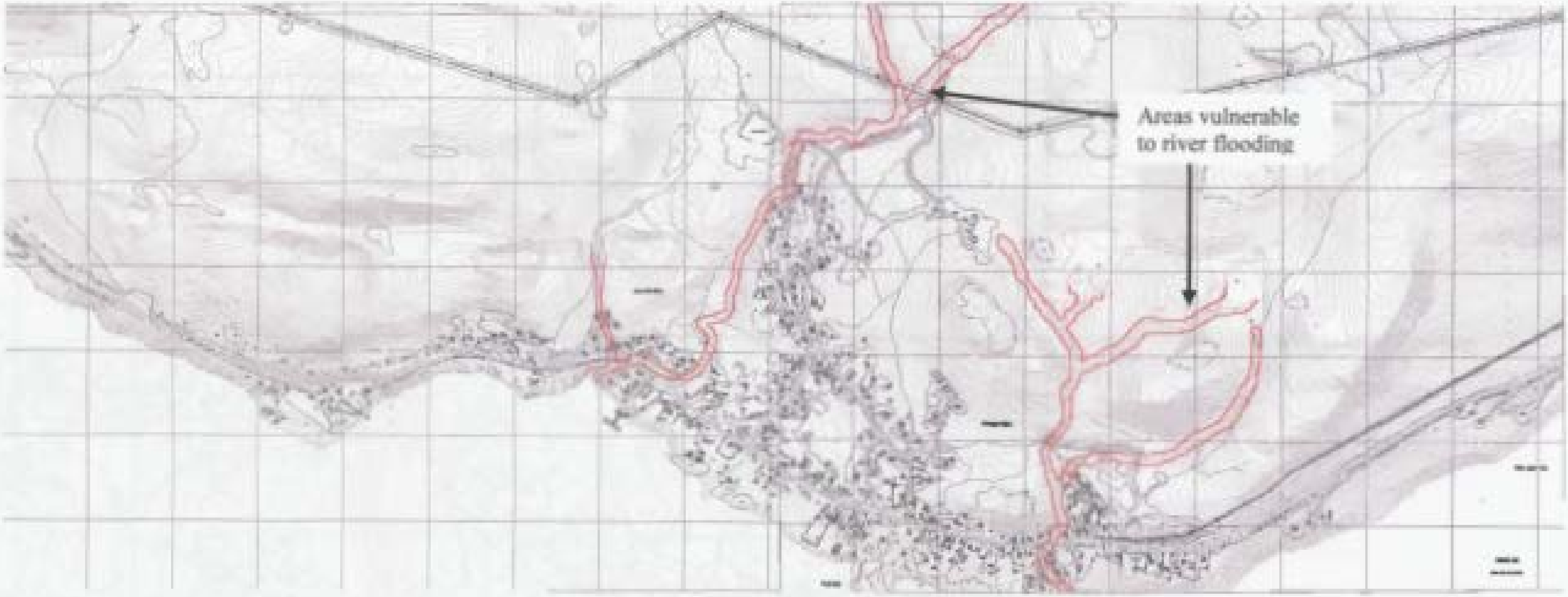
Legend

—— Areas vulnerable to flooding



Map 5.4 **Irishtown**
Areas of Flooding and Concern
1 grid square = 200 m

Legend
Areas vulnerable of flooding
Repeated damage caused be river flood



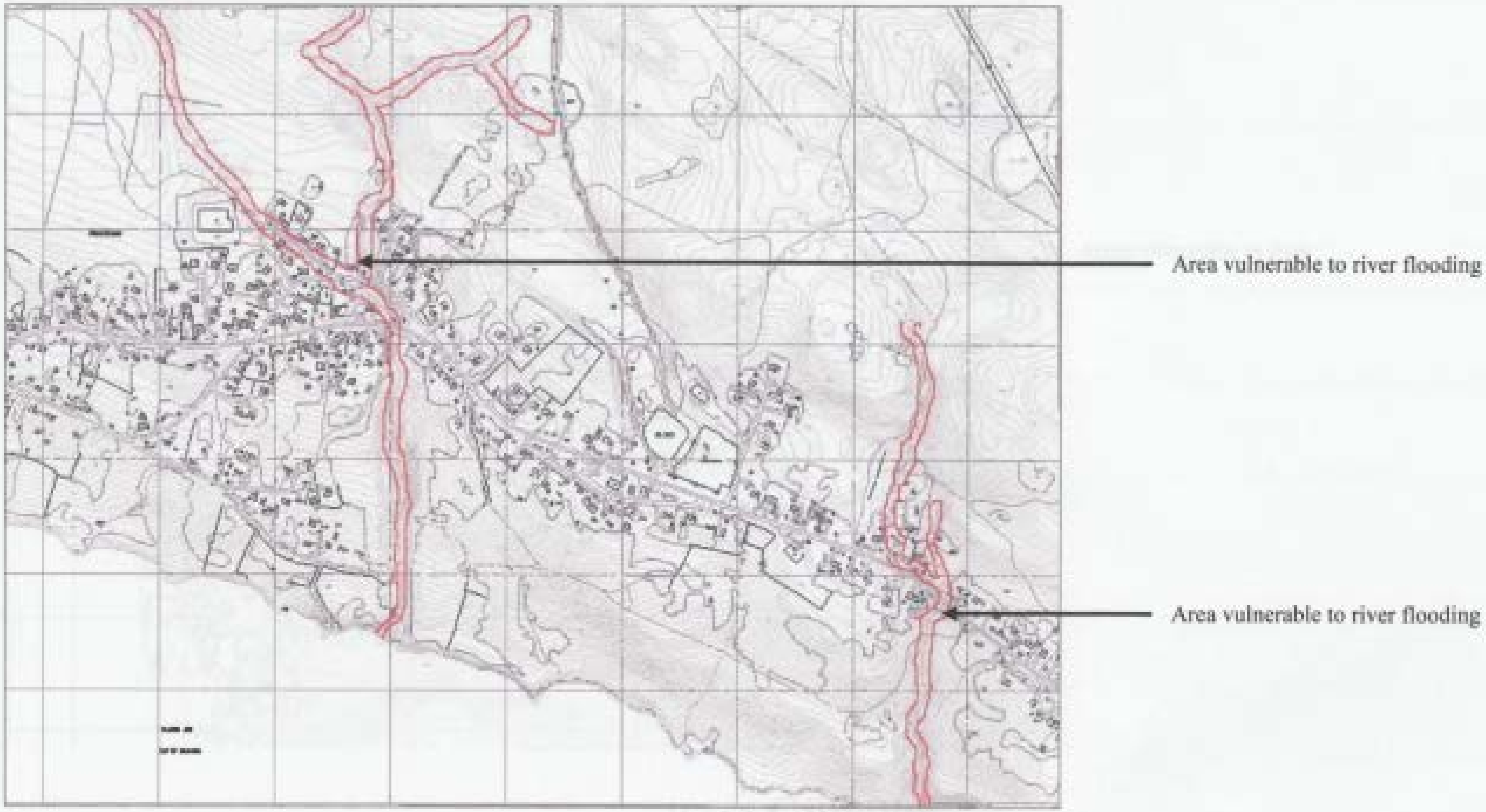
Map 5.5 **Summerside**

Areas of Flooding and Concern

1 grid square = 200 m

Legend

Areas vulnerable to flooding



Map 5.6 **Meadows**
Areas of Flooding and Concern
1 grid square = 200 m

Legend
Areas vulnerable to flooding

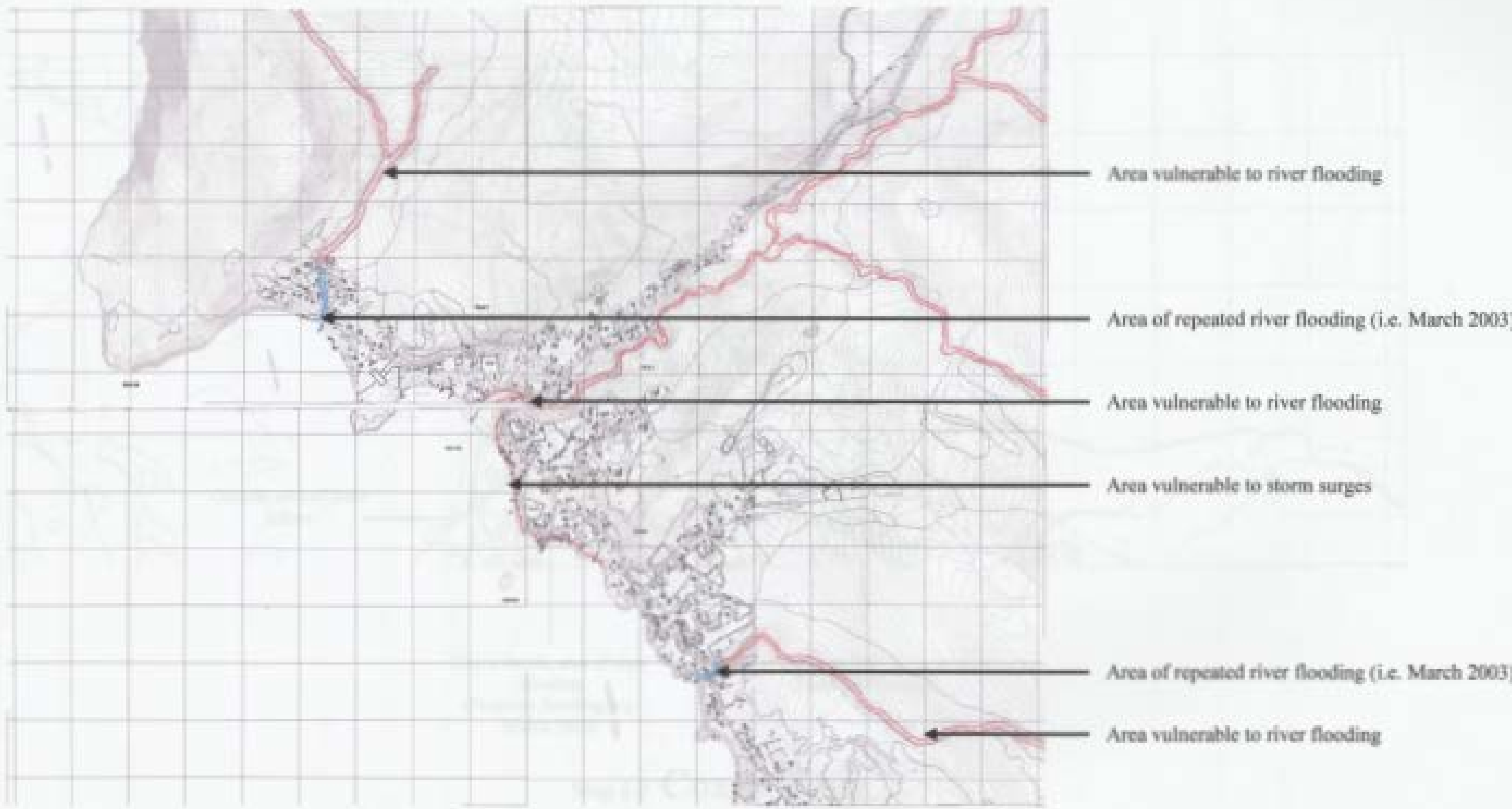
Map 5.7 **Gilliams**

Areas of flooding and concern

1 grid square = 200 m

Legend

Areas vulnerable to flooding



Map 5.8 **McIver's**

Areas of flooding and concern

1 grid square = 200 m

Legend

- Areas vulnerable of flooding
- Area of repeated flooding

Map 5.9 **Cox's Cove**

Areas of Flooding and Concern

1 grid square = 200 m

Legend

Areas vulnerable to flooding

4.2. Humber Arm South

Rain-on-snow events pose substantial flood hazards to many Humber Arm South communities. Slope failures associated with flooding cause concern for residents. Floods caused by ice jamming of rivers are less frequent and are a localized hazard.

Figure 5.2 depicts the frequency of flooding hazards in south Humber Arm communities and mechanisms of flooding. Flooding frequency may be greater than found in archives; however, site visits and communications with town council members found areas of sensitivity.

Communities on south Humber Arm are vulnerable to re-occurrence of specific flooding hazards. Benoit's Cove is susceptible to river flooding, and Mount Moriah and Frenchman's Cove are susceptible to slope failures. Rain-on-snow events and precipitation-induced slope failures are frequent flood hazards along the south Humber Arm. The rain-on-snow event of March 2003 induced flooding in York Harbour and Lark Harbour, and induced slope failure near Frenchman's Cove. The rain-on-snow event in 1976 caused damage to homes in Frenchman's Cove, Benoit's Cove, and Lark Harbour, and triggered an ice jam in Benoit's Cove.

Southwest winds carry winter and early spring storms which cause flooding in the Humber Arm region. The inner Humber Arm communities are less susceptible to coastal storm damage. The frequency of autumn/winter storms inducing river flooding is low because a greater amount of precipitation falls as snow, rather than as intermittent rain and snow events. The west coast communities, such as those in the Humber Arm region, are influenced by the upwind marine fetch from southwest to north (Banfield and Jacobs, 1998). Between late fall and midwinter, cold air outbreaks from Québec and Labrador are generally moist and unstable air masses that cross the relatively warm waters of the Gulf of St. Lawrence. In conjunction with orographically-forced uplift, snowfall on the exposed coasts and adjacent higher terrain is enhanced (Banfield and Jacobs, 1998).

5.1.1 Rain-on-snow

Rain-on-snow events are a frequent and severe hazard. The event of January 1976 affected the communities of Frenchman's Cove, Benoit's Cove, and Lark Harbour. Several homes received damage. The following year, flooding in Benoit's Cove reoccurred due to the failure of drainage system to remove runoff. Damage caused by the March 2003 rain-on-snow event resulted in flooding varying from severe to minor along the southern portion of the arm. Beacon Road in Lark Harbour was affected by the storm; the gravel road was washed out in several locations. In York Harbour, Beach Road, Sheppard's Lane, and Snook's Lane were severely damaged and were unusable to residents (Mayor David Whyatt, personal communication, 2003).

5.1 Continuous slope failure caused by soil creep. This particular area is outside York Harbour. Gabion cages catch most of the small failures. Approximate UTM 307700E 5635750N. Date October 2003.

5.2 Site of major, continuous slope failure outside Frenchman's Cove. This picture was taken after the March 2003 event. The failure completely cut Highway 440, the only land connection between York Harbour and Lark Harbour to the remainder of the Humber Arm region. Approximate UTM 307800E 5635750N. Date: October 2003.

5.3 Houses located in low-lying coastal areas are susceptible to flood damage. Increased construction of more expensive summer homes will increase the severity of coastal damage in these areas. Frenchman's Cove, UTM 413165E 5434550N.

5.1.2 Slope failure

Frenchman's Cove and Mount Moriah areas are susceptible to slope failure. Heavy rainfall and rapid snowmelt over-saturate the unstable sediment which causes slope failure. Frost creep or movement of saturated sediment over frozen ground has historically disrupted train movements and presently disrupt traffic. Provincial Highway 450 is the only road link to communities west of Mount Moriah, and disruptions in traffic have great economical and security losses for residents in these communities. A section of highway near Frenchman's Cove was severed in March 2003, 1996, and 1988 (*Western Star*, 2 April 2003; Mayor of York Harbour, David Whyatt, personal communication, 2003), isolating Lark Harbour and York Harbour. The highway has been temporally repaired, but it is still subject to damage and slope failures. The site has been prone to slope failure for more than 60 years (Mayor of York Harbour, David Whyatt, personal communication, 2003), as is apparent through air photo analysis. Slope failure in the Mount Moriah area disrupted the Canadian National (originally Newfoundland) Railway in January 1901, January 1909, and November 1970, and vehicle traffic was disrupted in December 1977, and additional non-recorded years.

The sensitivity of the Humber Arm region to slope failure indicates a probability of failures blocking stream channels. No occurrence of flooding has been recorded, although valleys upslope of Frenchman's Cove and Benoit's Cove have experienced slope failures noted on aerial photographs and through field investigations. Communities aligned along valleys normal to the coast have minimal vulnerability to flooding from slope failure blockage (Catto and Hickman, 2004).

Figure 5.1: Aerial photo of slope failure above Highway 450 between Frenchman's Cove (left of photo) and York Harbour (right of photo). The red circle illustrates one of several failures. Photo was taken in 2001 by Department of Environment and Conservation, Map Library. UTM 307800E 5635750N.

5.1.3 Ice jams

Clark's Brook in Benoit's Cove is susceptible to ice jams resulting in flooding (Figure 5.2). Although ice jam events occur infrequently, critical infrastructure is vulnerable to damage. Ice at the mouth of Clark's Brook caused flooding in January 1976 and 12 March 1992 (*Western Star*, 13 March 1992). The school parking lot and one home were inundated, and the school and two additional homes were at risk (*Western Star*, 27-28 January 1976; *Western Star*, 13 March 1992).

Coastal ice forms off the coast of the Humber Arm region. During the southward movement of coastal ice, northwesterly winds prevail (Prinsenberg *et al.*, 1997). The prevailing winds blow the ice offshore rather than into the sheltered Humber Arm.

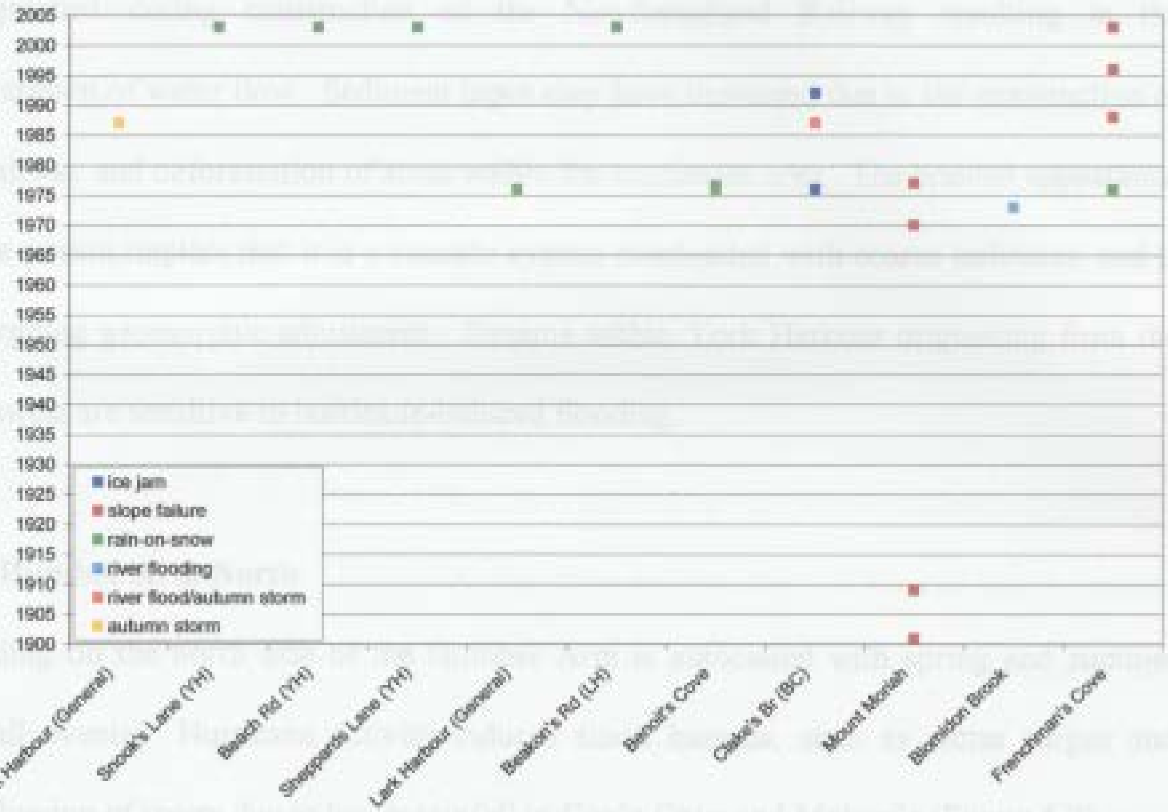


Figure 5.2: Causes and frequency of flooding events on the south side of Humber Arm. Flooding events in communities and specific locations within communities depicted as mechanism and correspond with year of event. Data from archival research and site visits. Areas listed are either the communities which have recorded flooding events are areas within the community. "General" indicates the occurrence of flooding within that community, YH = York Harbour, LH = Lark Harbour, and BC = Benoit's Cove.

5.1.4 Rivers

In the Humber Arm region, Highway 450 has been flooded and eroded in numerous locations by river systems unable to flow underneath the highway. In York Harbour, poor drainage and the absence of any drainage infrastructure for Snook's Lane, Sheppard's Lane, and Beach Road caused damage during the rain-on-snow event in March 2003. Additional susceptible areas are Beacon Road in Lark Harbour.

Hurricane-related flooding impacts large catchment areas. Flood water from hurricanes that impact Cook's Brook originates from precipitation in the catchment area to the south, in the vicinity of the abandoned rail siding of Cooke's. Cook's Brook was altered and straightened during construction of the Newfoundland Railway resulting in the acceleration of water flow. Sediment input may have increased due to the construction of the railway and deforestation of areas within the catchment area. The braided appearance of the stream implies that it is a cascade system overloaded with coarse sediment, and is undergoing geomorphic adjustment. Streams within York Harbour originating from the southwest are sensitive to hurricane-induced flooding.

5.2 Humber Arm North

Flooding on the north side of the Humber Arm is associated with spring and summer rainfall events. Hurricane activity induces flood hazards, such as storm surges and overflowing of rivers due to heavy rainfall in Cox's Cove and McIver's (Figure 5.3).

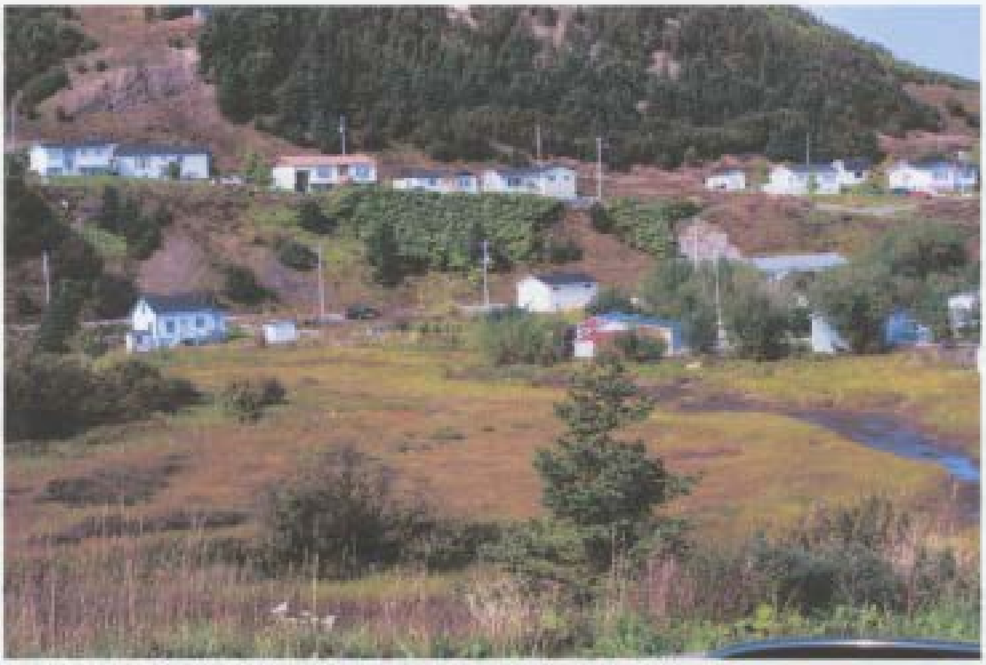
Communities exposed to northwesterly storm surges rather than hurricane-induced and winter storms, such as McIver's, have experienced storm surges. Storm surges do not generally affect the communities further within Humber Arm. Several islands off the coast of Cox's Cove create a less effective fetch, and therefore a lesser significant storm surge.

Flooding of Cox's Cove has been studied by the Department of Environment (Martec

Limited, 1988). Storm surges generated by northwesterly winds have significant impacts. The flooding season for Cox's Cove is between November and January when peak sea levels occur. Flooding occurs both in the wetland area in the centre of the town and along the beach front. The beach front is susceptible to flooding during periods of meteorologically-elevated sea levels, large waves, and onshore winds. The wetland area flooding is associated with Cox's Brook. Overflow and flooding of the brook may occur during elevated sea levels and during large freshwater discharge. Flooding is mainly controlled by meteorologically-elevated sea levels and not by stream discharge.

The Department of Environment (1988) analyzed two severe floods on 26-27 November 1965 and 11-12 December 1977. During these storms, high winds and heavy rainfall caused vessels moored in the cove and on slipways along the beach to be damaged, and property damage in the wetland area. Storms associated with high tides caused the overflowing of Cox's Brook, flooding approximately 20 acres of land, more than double the area of the fen that floods annually.

Several areas of concern were identified during the site visit. The roadbed entering Cox's Cove and the road leading to Main Street has been eroded by runoff. Many houses border the wetland surrounding Cox's Brook and are vulnerable to flooding. Activities disrupting the flow of water or increasing runoff into the brook will increase the flooding hazard, such as clearing the headwaters. Houses along Main Street are susceptible to both storm surges and the flooding of Cox's Brook.



5.5 Cox's Cove is susceptible to flood damage from storm surges and river flooding. The houses located in the low areas in the photograph and nearby houses are vulnerable to river flooding. Many of the houses are located less than 2 m above the river level at the time of the photograph (October 2003). UTM 321300E 5442600N.

5.2.1 *Rain-induced river flooding*

Rivers that flow through the communities on the north side present a flood hazard during heavy rainfall events. Within Irishtown, brooks flowing through the community overflowed their banks on December 1990 and in September 2002 (Figure 5.3). Both incidents resulted in flooding of basements, inundating Highway 440 and causing a temporary closure, and erosion of several ditches. The rivers also caused damage to culverts during the March 2003 rain-on-snow event. McIver's Brook in McIver's is also susceptible to flooding, as in January 1986 (Figure 5.3). Although no severe damage was reported in the 1986 event, Highway 440 and several houses are exposed to damage.

The site visit confirmed the hazards in areas of Irishtown, Summerside, and McIver's adjacent to the brooks. Culvert systems are failing and roadbeds are eroded from runoff. Sediment is being washed downstream and may cause blockages.

The streams in Summerside, McIver's, and Gillams flooded during Gustav in 2002. Heavy rainfall from hurricanes or remnants has been recorded in Humber Arm in association with Bertha (1996), Floyd (1999), Gustav (2002), and Frances (2004). Effects of hurricane-induced river flooding appear as stream bank erosion, torrents in gravel roads, and damage to culverts and drainage across Provincial Highway 440.

5.2.2 *Slope failure*

Slope failures on the north side of the arm do not represent the same hazard as on the south side due to geological differences and difference in wind aspect. However, slope failure due to flooding has occurred infrequently. A slope failure has been recorded in Irishtown (April 1969). Two separate slope failures have been noted in the same location in Cox's Cove (December 1977 and February 1996). All three events were triggered by poor drainage and heavy rainfall (Department of Mines and Energy, Geological Survey, 1999; 4 April 1969; *Western Star*, Flooding Events in Newfoundland and Labrador, 27-29 December 1977; *Western Star*, 20 February 1996). The incident in Irishtown moved two homes. The two slope failures in Cox's Cove blocked the only exit out of the community.

5.2.3 Human activities

Several flooding events associated with the inadequacies or failures of culverts have been recorded and observed during site visits. A blocked culvert caused Highway 440 to flood on 14-16 January 1978 (Kindervater, 1980).

The site visits identified other locations of culvert failure. A sagging section of Highway 440 between Gillams and McIver's indicates a recurring problem, as the culvert under the highway is unable to handle a rapid flow of water. In addition, the culvert is blocked at the upslope end, and a slope or catch basin is not present. In Summerside, a wooden wall parallel to Highway 440 is being undercut. Torrents appear on 2nd Avenue illustrating heavy runoff. The intersection of Brook Street and Highway 440 is prone to a reoccurring problem, as water draining from roads and driveways upslope and a brook is undercutting the roadbed. In Gillams, roadsides are being eroded. In McIver's, two board culverts under Kelly's Road and Highway 440 intersection are crushed and will decrease the amount of runoff into the drainage system.

Flood frequency and mechanisms of north Humber Arm communities are depicted in Figure 5.3. Rain-on-snow events and precipitation-induced river flooding are significant flood hazards. The rain-on-snow event of March 2003 affected four communities. All communities have incurred damage caused by rain-on-snow events previous to March 2003. River flooding, either due to summer precipitation or rain-on-snow events, has impacted Irishtown, McIver's, and Cox's Cove. Cox's Cove has experienced three reported flooding events.

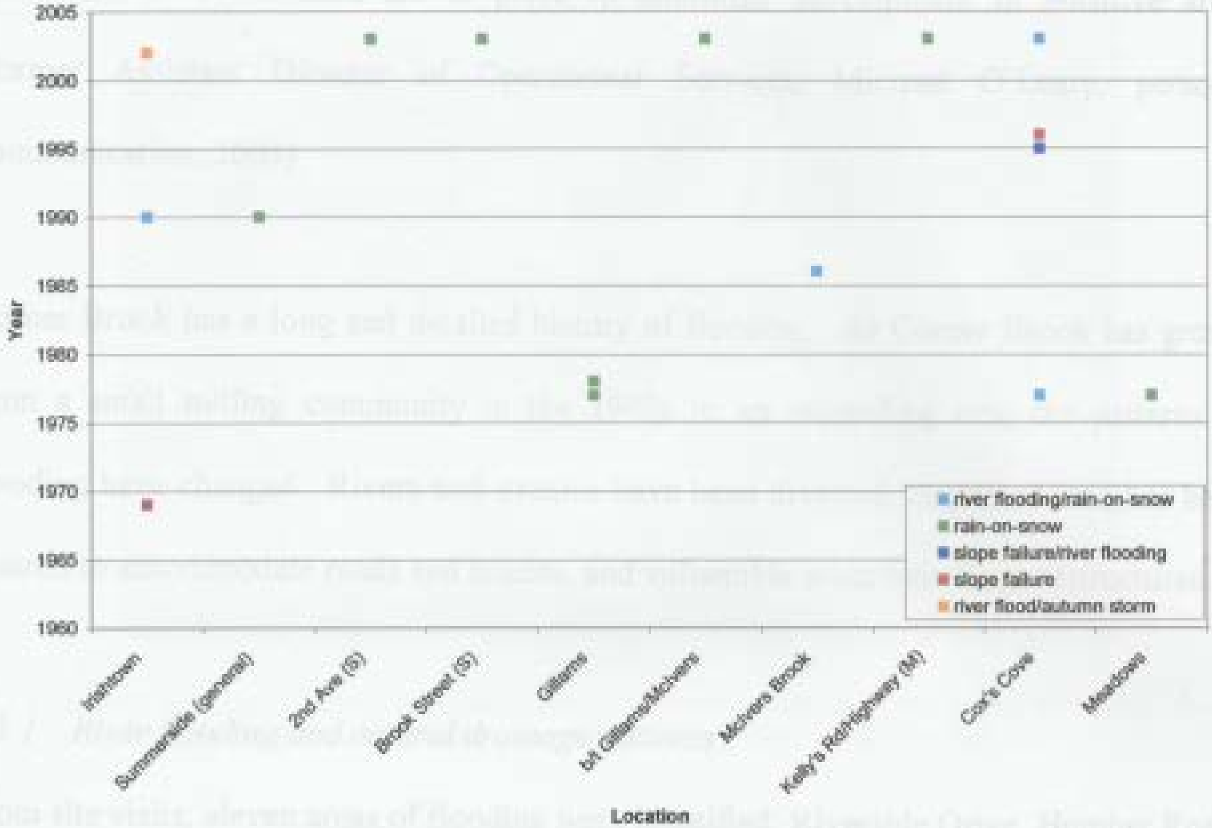


Figure 5.3: Frequency of flooding in communities on the north side of Humber Arm. Flooding events in communities and specific locations depicted as mechanisms and corresponding with year of events. Data from archival research.

5.3 Corner Brook

Rain-on-snow events cause frequent and varying degrees of damage to infrastructure in Corner Brook. Autumn, winter, and spring storms trigger these events. Summer storms coupled with river flooding and drainage problems are additional flood hazards. Ice jams and hurricane-induced rainfall infrequently causes flooding. In Corner Brook, anthropogenic affects (development of upslope areas, altering of natural drainage ways, failure or inadequate drainage infrastructure) increase the vulnerability to flooding events. The map of Corner Brook is included as Appendix B.

Corner Brook does not have any municipal development plan to limit upslope construction. Precautions are in place to minimize development in sensitive areas (former Assistant Director of Operational Services, Michael O'Leary, personal communication, 2003).

Corner Brook has a long and detailed history of flooding. As Corner Brook has grown from a small milling community in the 1940s to an expanding city, the patterns of flooding have changed. Rivers and streams have been diverted, vegetated land has been cleared to accommodate roads and houses, and vulnerable areas have been restructured.

5.3.1 River flooding and natural drainage patterns

From site visits, eleven areas of flooding were identified: Riverside Drive, Humber Road, Corner Brook West (downslope from Lewin Parkway), Majestic Brook (an older residential area), Bell's Brook, 3rd Street, Maple Road, Elizabeth Street, the mouth of Corner Brook Stream (downtown business district), Sunnyslope Drive, and Curling. Several areas are exposed to the same hazard and show similar patterns of flooding.

5.6 Several sections of the retaining wall near the mouth of Corner Brook Stream are collapsing. A petrol station is located on the land. UTM 430500E 5422800N. Date: October 2003.

5.7 Sediment deposited in Corner Brook Stream above a bridge that spans the river. The photograph was taken in September 2003. During the March 2003 event, the property on the right and the bridge was inundated. This view is looking upstream from the bridge. UTM 430500E 5422800N. Date: October 2003.

5.8 Majestic Brook flood damage. The channel was are unable to control the flow; therefore, damage is occurring on both sides of the brook. Properties on both side of the brook are inundated during high flows. Approximate UTM 432000E 5422000N. Date: October 2003.

Four river systems flow through Corner Brook. Alteration of the rivers has been continuous with the development of the city: Bell's Brook, Corner Brook Stream, Majestic Brook, and Petries Brook (Curling). The degree of sensitivity and damage sustained during flooding events depends on the amount of alterations of the rivers and the amount of infrastructure near the rivers. As seen in Figure 5.4, the rivers have flooded throughout the time period examined (1940 – 2005), and according to city officials, flood perennially (former Assistant Director of Operational Services, Michael O'Leary, personal communication, 2003). Roads that follow the path of natural drainage ways experience frequent damage.

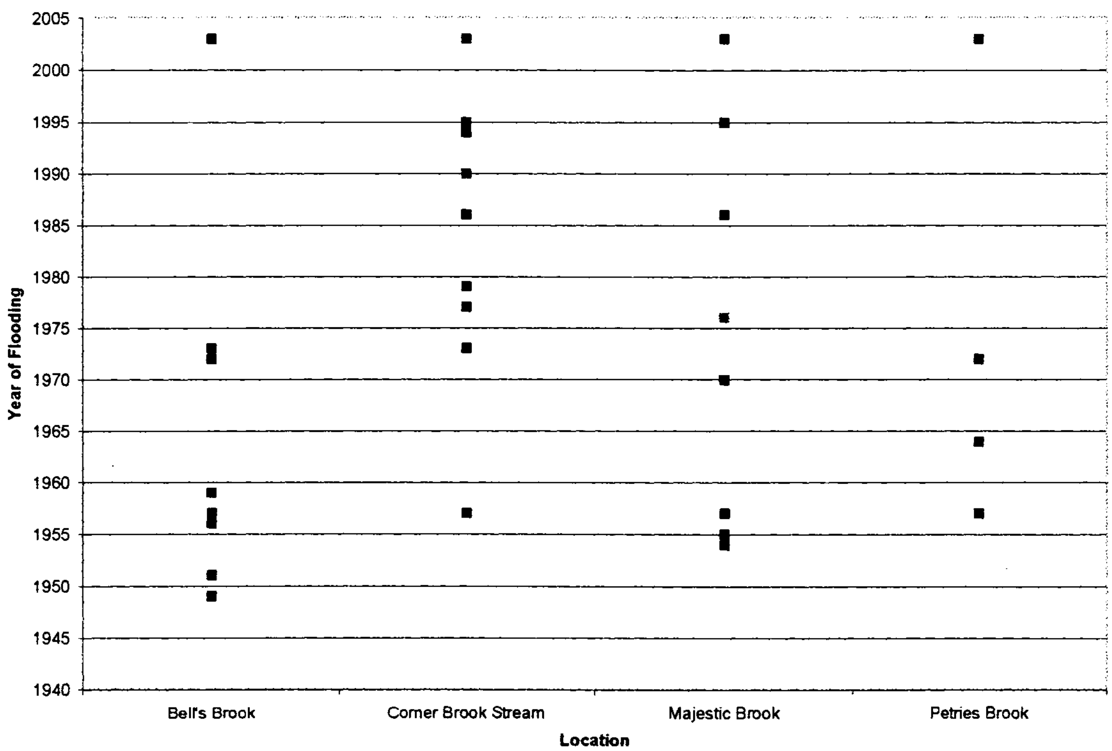


Figure 5.4: Frequency of river flooding of four major river systems in Corner Brook. Data collected from archival research.

Roads, such as the lower section of Elizabeth Street/Churchill Street, have been constructed in river valleys. During heavy rainfall events, water is funneled down Elizabeth Street, gouging out the sides of the road, and causing damage to businesses on Union Street below. The flooding events of July 1996, July 1997, and March 2003 followed the same pattern, and basements of private residences and business suffered damage in each event.

The impact of hurricane-induced flooding is reduced in the relatively sheltered areas of the region. If impacted by a relatively small storm (i.e. remnants), the flood response is relatively quick due to the short drainage area and the absence of many lakes and wetlands to store the runoff (Lawford *et al.*, 1995). The orographic influence of the surrounding hills increases the flooding of rivers within the basin. Small rivers draining the hills surrounding Corner Brook cause the overflowing of Majestic Brook, Bell's Brook, Corner Brook Stream, and Petrie's Brook. Rivers that are south-facing on the north side of the arm are more vulnerable to hurricane-induced flooding than the south shore rivers.

Beavers on the Corner Brook Stream have been relocated in October 2004 to prevent the destruction of the trees and flooding initiated by dam formation (*Western Star*, 22 October 2004).

5.3.1.1 Majestic Brook

The Majestic Brook and Townsite are in an older part of Corner Brook, known as Corner Brook East in the 1940s before amalgamation. A long history of flooding is present in this area. The first recorded event in the Majestic Brook area occurred on 22 February 1946 when heavy rain and mild temperature caused a storm sewer to overflow and flood West Street and Church Street (*Western Star*, 22 February 1946). Majestic Brook has been altered as the land use around it has changed. A large portion of the brook has been culvertized and backfilled to create land for construction. Observations from the site visits revealed failing wooden culverts: the culverts are rotting and moving out of place causing possible blockages. In other locations, gabions have been installed to prevent the erosion of the banks, but erosion is transferred further downstream. Backfilling has decreased the brook width, and thus less water has to enter the system before the brook overflows its banks. The land around the brook and the watershed area is under constant development, increasing the amount of runoff entering the brook.

The roads associated with flooding in the Majestic Brook watershed are: Maple Valley Road, Brookfield Avenue, Lomond Street, East Valley Road, Reid Street, Central Street, Park Street, West Street, North Street, and Church Street. All are susceptible to frequent inundation of water from Majestic Brook and the surrounding drainage basin.

East Valley Road, North Street, and West Valley Road flood annually (former Assistant Director of Operational Services, Michael O'Leary, personal communication, 2003). The brook flooded on 20 December 1954 due to 66 mm of rain, and flooded many streets. A rainfall of 48.8 mm on 2-3 June 1970 caused the Majestic Brook to overflow its banks and flood Reid Street, Church Street, and North Street (Flooding Events of

Newfoundland and Labrador, 2-3 June 1970). During the March 2003 event, Majestic Brook flooded its banks and water flooded many nearby roads. East Valley Road, which runs parallel to the brook, may have been the hardest hit (*Western Star*, 2 April 2003). The intersection of Central Street, Reid Street, and West Street were also flooded, and the water then cascaded over Park Street. Majestic Brook flooded in September 2004 as a result of the remnants of Hurricane Frances, which flooded East Valley Road (Works and Services Coordinator, Charlie Renough, personal communication, 2004).

A portion of O'Connell Drive, Elswick Road, and West Valley Road are vulnerable to infrequent flooding caused by a watercourse which runs parallel to Majestic Brook. The area surrounding the O'Connell Drive and Elswick intersection flooded on 27-28 November 1999 (*Western Star*, 29 November 1999). The area flooded in 31 March 2003, and much of Elswick Road and West Valley Road were inundated by either the stream or water following a similar path.

A tributary to Majestic Brook, which flows parallel to Lewin Parkway (a major arterial through Corner Brook), down Hospital Hill, and enters Majestic Brook at the East Valley Road and West Street intersection, is a perennial flood hazard (former Assistant Director of Operational Services, Michael O'Leary, personal communication). The stream is fed by the runoff from the power centre (Walmart, strip mall) parking lot and Lewin Parkway

Damage to areas within the Majestic Brook watershed mainly consists of damage to streets, curbs, and minor damage to property (e.g. February 1959, May 1972, and January 1986). During more severe events, basements flood and extensive damage to property and businesses occur: an example was the damage to East Valley Road in December 1969. The frequency and severity of flooding events in the Majestic Brook area may be increasing. Residents in the areas have expressed concern, noting homes that have begun to experience flooding that has not occurred before. Homes in the area of upper East Valley Road had not flooded in the 15 years prior to 2003.

Maple Valley Road and streets downslope may be subject to increasing flood frequency due to the development of areas upslope. The removal of trees for the new highway in the Maple Valley Road area was considered to have contributed to the amount of runoff in July 1995 (*Western Star*, 25 July 1995; former Assistant Director of Operational Services, Michael O'Leary, personal communication).

5.3.1.2 Bell's Brook

Bell's Brook has been highly altered during the course of urban development (former Assistant Director of Operational Services, Michael O'Leary, personal communication). The lower section of Bell's Brook has been completely culvertized. Water continues to follow the former path of the brook above ground. Back-filling into the brook changed erosion patterns, and the removal of vegetation in the headwaters has increased runoff.

Bell's Brook has historically caused damage to infrastructure by flooding due to ice jamming. Slob ice and heavy rain initiated the flooding of Bell's Brook on 17 January 1959 (*Western Star*, 19 January 1959). Several homes along the brook were flooded as the brook overflowed its banks due to ice jamming downstream. In the low-lying areas, near the areas formerly referred to as Gospel Hill and Buckle's Valley, three to four basements were flooded near the brook. On several other occasions the stream had to be dynamited to alleviate the flood hazard (February 1951 and January 1957).

Country Road and O'Connell Drive run parallel to Bell's Brook. These roads act as channels for runoff. Water then flows down the adjacent roads, increasing the damage. The restructuring of O'Connell Drive may have initiated frequently reoccurring flooding events within the Bell's Brook area, especially in the lower Boone's Road and Boone's/O'Connell Drive intersection. As reported on 16 January 1992 (*Western Star*), an area on Boone's Road is prone to flooding, especially since the upgrade of O'Connell Drive. On 8 January 1995 and 17-18 February 1996, portions of Boone's Road were washed out due to the increased runoff during rain-on-snow events (*Western Star*, 9 January 1995; *Western Star*, 19 February 1996)). O'Connell Drive, Boone's Road, and the intersection were eroded during the 30-31 March 2003 rain-on-snow event. The portion of Country Road in the vicinity of Bell's Brook flooded in March.

The O'Connell Drive/Boone's Road intersection may have affected the Boone's Road/Country Road intersection further downslope. A combination of effects from the overflowing of Bell's Brook, and runoff from both O'Connell Drive and Boone's Road results in the annual flooding of the Boone's Road/Country Road intersection (former Assistant Director of Operational Services, Michael O'Leary, personal communication). In November 1949, a wooden bridge on Country Road was washed away and the overflowing of storm sewers, drains, and ditches resulted in erosion of the roadbed. Possible runoff from O'Connell Drive causes annual flooding of the O'Connell Drive/Walbourne Road intersection (former Assistant Director of Operational Services, Michael O'Leary, personal communication). The flooding then continues down Walbourne Road, including the section of the road which intersects with Bell's Brook. Walbourne Road frequently floods (former Assistant Director of Operational Services, Michael O'Leary, personal communication): events were reported in January 1995 and March 2003.

Wellington Street, within the Blackwood Hills area, experienced flooding on 12 August 1993 when a storm sewer on the street collapsed causing the area to be damaged (*Western Star*, 12 August). Damage is still occurring where Bell's Brook runs under Wellington Street. An old bridge and the banks of nearby roads are being undermined.

5.3.1.3 Corner Brook Stream

Corner Brook Stream has not been extensively altered or the surrounding vegetation removed. The stream is utilized by the Bowater Pulp and Paper Mill, which owns much of the land surrounding the stream and headwaters. Flooding does occur frequently; however, damage is minimal due to the limited amount of infrastructure surrounding the stream. Much of the damage is confined to the low-lying land at the mouth of Corner Brook Stream in the business district where infrastructure is more extensive. Brook Street has been enduring damage since 21 November 1955, and during severe flooding of the stream, such as March 2003, the stream floods the road washing away the roadbed and pavement. Corner Brook Stream caused infrastructure damage on 2-3 October 1957. Due to the overflowing of the stream, a 12-ft gap appeared between Bailey Bridge and the bank (*Western Star*, 3 October 1957).

5.3.1.4 Petries Brook

Petries Brook has historically caused damage to infrastructure in Curling (Figure 7.3). The Brook intersects many main streets as it flows from the hills, though town, and then to the bay. On 6 March 1964, Petrie's Brook flooded its banks: the water surrounded two apartment buildings and flooded the basements. As well, two houses and Petries Crossing was flooded by Petries Brook. The frequency of flooding of Georgetown Road and Petries Street corresponds with the flooding of Petries Brook.

5.3.2 Rain-on-snow events

Rain-on snow events have been reported to cause over 190 flooding problems in Corner Brook from 1940 to 2005. In December 1954, a rain-on-snow event coupled with a winter storm flooded streets, preventing children from going to school, and 12 basements were flooded. Gravel roads, gutters, storm sewers, and property were damaged in several locations throughout the city on 1 May 1967. On 3 February 1981, twenty to twenty-five incidents were reported in the city, including inundated basements, mainly due to culverts blocked with snow, ice, and surface runoff. Flooding of many private properties and streets occurred on 8 January 1995. Severe rain-on-snow events may impact various sections of Corner Brook simultaneously, such as the event of 30-31 March 2003.

In 30-31 March 2003, Corner Brook sustained severe damage to infrastructure and services. Many roads were impassable. The total cost of damage to the city exceeded \$1.4 million (former Assistant Director of Operational Services, Michael O'Leary, personal communication). The loss of private property, services, and insurance costs exceeded \$5 million. Offices, stores, and schools, including Sir Wilfred Grenfell College, were closed. The elevator shaft of West Coast Medical Clinic was flooded (*Western Star*, 2 April 2003), the floor of Mill Brook Mall was covered with water, several sewage treatment facilities malfunctioned, and many cars were submerged in water. In some of the areas affected, the damage was caused by overflowing rivers and streams. In the Corner Brook area, 193.5 mm of rain fell on a thick snow cover (*Western Star*, 2 April 2003).

Sections of Main Street and O'Connell Drive were closed due to high water levels of Corner Brook Stream. Rapid water neared the top of the Main Street Bridge. Margaret Bowater Dam was closed to pedestrians due to the threat of a dam breach. The bridge on O'Connell Drive over Corner Brook Stream was eroded on both sides. The lifeguard chair, wood work, and walking trails along Corner Brook Stream were washed away.

Areas which have frequently flooded were susceptible to damage caused by the March 2003 event. The pavement on Elizabeth Street was undermined and deep trenches were worn into the roadbed. Water following the path of the road flowed down an embankment and flooded businesses on Union Street. Further downslope, portions of Walbourne's Road became inundated when Bell's Brook flooded its banks.

During the March 2003 event, Majestic Brook flooded its banks and water flooded many nearby roads. East Valley Road, which runs parallel to the brook was hard hit (*Western Star*, 2 April 2003). The intersection of Central Street, Reid Street, and West Street were also flooded the water then cascaded over Park Street. Brookfield Avenue also frequently floods, and suffered major damage. Brookfield Avenue is located downslope from the old Trans Canada Highway (TCH). Runoff from the old TCH during the heavy rainfall flooded the avenue. Due to the heavy rainfall and snow, sections of both O'Connell Drive and Boone's Road acquired damage.

5.9 Damage on Elizabeth Street (right) and Union Street (top left corner) in Corner Brook. Water flowing down Elizabeth Street eroded the soil underneath the street and in the shoulder. Water then flowed across Union Street and flooded the business to the immediate left of the photograph. UTM 429850E 5421400N. Date: October 2003.

5.10 Slope failure in Corner Brook during the March 2003 rain-on-snow event. The slide affected Humber Road and Riverside Drive. Several other slope failure occurred further east on Riverside Drive. A drainage channel is being constructed within the slide (seen as lighter soil on left side of slide) to prevent future events. UTM 429850E 5421400N. Date: October 2003.

Curling was severely hit by the 2003 rain-on-snow event. The SPCA animal shelter was flooded and a water main was destroyed. On O'Brian's Avenue, an embankment and the water and sewer services were washed away. Several washouts occurred on Petries Street. Sidewalks, curbs, and pavement were eroded on Curling Street. Brichy Cove Drive and Water Street were washed out. Excessive washouts and collapse occurred on Verge Place, where flooding problems are frequent (former Assistant Director of Operational Services, Michael O'Leary, personal communication). St. Aiden's Road was flooded. Petley Street, Petries Street, Young's Street, Dave's Road, Allen's Road, Burton's Road, and Quigley Road also suffered flooding.

Areas that historically had infrequently flooded were affected in March 2003, and with greater severity than previously recorded. Maple Valley Road, which runs between both the old and new TCH, experienced washouts in several locations caused by the excessive runoff from the new TCH. Water from this area may have traveled downslope and caused flooding on Brookfield Avenue, East Valley Road, and Lomond Street. The increased runoff from Maple Valley Road entered into Majestic Brook and increased the level of flooding risk in the vulnerable area (*Western Star*, 2 April 2003).

The hillside where Riverside Drive is located failed during the March 2003 event. Concern has centered on the area near the Humber Road / Riverside Drive intersection. Since the construction of the new TCH in 1994, problems have been occurring in this area. In March 2003, a large amount of water and snowmelt caused a section of Humber

Road and Riverside Drive to be washed out. The earth was saturated with water and a mixture of earth, water, and snow washed over both roads. Infrastructure was being created at the time of the site visit to minimize future flooding events (former Assistant Director of Operational Services, Michael O'Leary, personal communication). On 27 September 2005 the slope failed causing damage and disruption in transportation, water lines, and power lines (*Western Star*, 29 September 2005). The slope failure was caused be the deterioration of a berm, which was constructed in 1994 to redirect the flow of water away from the unstable embankment.

The combination of the extreme March 2003 event and urban development resulted in the flooding of areas that have not acquired severe damage previous to March 2003 (former Assistant Director of Operational Services, Michael O'Leary, personal communication). Third Street became flooded with runoff from the power centre located upslope. Large tracks of vegetated land have been replaced by impermeable surfaces. The amount of runoff had caused damage to the upper portions of Elizabeth Street for the first time, and increased the damage to the lower portions of the street. Commercial Street and Premier Drive, as identified from historical records, flooded for the first time during the event.

5.3.3 Autumn storms

Autumn storms are associated with many flooding events within Corner Brook, approximately 80 between 1949 and 2005. Heavy rain associated with Hurricane Irene (21 September 1956) damaged many streets and flooded basements (*Western Star*, 22

September 1956). The autumn storm of 1 November 1962 cost thousands of dollars to replace the gravel roads that were washed downslope and damage to private property (*Western Star*, 2 November 1962). When autumn storms coincide with snow cover, the damage may be extensive. On 27-28 November 1972, damage to Canadian National Railway tracks, and damage for other infrastructure occurred (27-28 November 1972; Kindervater, 1980). An autumn storm in September 2005 induced flooding and slope failure.

5.3.4 Summer storms

Rainfall from summer storms causes damage to public and private infrastructure, and overtaxes rivers. *Ca.* 65 flooding events have been reported between 1940 and 2004. Infrequent heavy rainfall events are hurricane induced. Tropical Storm Bertha (13 July 1996) and Hurricane Beulah (24-25 August 1963) caused erosion of roads, pooling of water, and flooding of infrastructure (*Western Star*, 15 July 1996; *Western Star*, 26 August 1963).

Other summer storm events unrelated to hurricanes have damaged road infrastructure, thereby disrupting traffic flow in Corner Brook. Damage was done to city roads on 23-24 June 1973 (Kindervater, 1980). The damage is minimal during the summer storm flooding events. Flooding reports on several occasions indicate the absence of major damage (*Western Star*, 23-24 July 1983, 30 July 1983, 6-7 August 1983, and 25 July 1990). From 1992 to 1995, summer rain showers resulted in flood damage to several of the streets in the Majestic Brook area. The indirect cause varied, including runoff, inadequacy of storm sewers, and flooding of the brook. For instance, on 24 July 1995, several streets suffered damage (*Western Star*, 5 July 1995); property on North Street flooded during heavy, periodic rainfall because a culvert was unable to handle the runoff; on Central Street one basement flooded due to the overflowing of storm sewers; Majestic Brook flooded East Valley Road and carried debris, which covered one private property, and washed away one section of gutter and curb; and the intersection of Central and East Valley Road was also damaged by Majestic Brook.

5.3.5 Human activities

Alteration of drainage patterns due to upslope activity may have one of two results: 1) increased frequency of slope failures; and 2) increased flooding of downslope areas. Much of the valley bottom of Corner Brook has been highly developed; therefore, new construction has been confined to the hillsides.

The lower areas of Corner Brook, the core, have been developed since the early 1940s, and therefore the majority of newer development is confined to the upper slopes. Consequently, flooding in the downtown core could potentially increase. The Operational Services division in Corner Brook is trying to minimize development in developing locations through zoning (Former Assistant Director of Operational Services, Michael O'Leary, Assistant Director of Operational Services, City of Corner Brook, personal communication, 2004)

Riverside Drive is constructed on a hillside that is susceptible to movement When the earth is saturated, it becomes unstable and fails. In 1994, the new TCH was constructed and the old TCH was no longer maintained. The increased runoff from the new TCH and the improper drainage of the old TCH changed the drainage of the hillside above Riverside Drive (*Western Star*, 20 April 1994 and former Assistant Director of Operational Services, Michael O'Leary, personal communication). On 29 April 1994 rock, mud, and trees covered the road and prevented the normal flow of traffic for several days (*Western Star*, 20 April 1994). The cost of repair was shared between the city and the Newfoundland and Labrador Transportation and Works. The slope failure continued for several weeks after April 29. On 24 July 1994, 24 July 1995, 17-19 February 1996, 25 September 2002, 30-31 March 2003, and 27 September 2005 the slope failures reoccurred (*Western Star*, 25 July 1004; *Western Star*, 25 July 1995; *Western Star*, 19 February 1996; *Western Star* 26 March 2002; *Western Star*, 2 April 2003). The increased runoff from the rain-on-snow event of 11 March 1998 (*Western Star*, 12 March 1998) washed approximately 30-ft of the shoulder and undermined the road. The event of March 2003 also interrupted traffic on Humber Road. Even though the city of Corner Brook has taken precautions to prevent reoccurring slope failure, the area remains vulnerable to further events (Former Assistant Director of Operational Services, Michael O'Leary, personal communication). The debris from the slope failure blocked catch basins and decreased drainage. Water from heavy rainfall that cannot be drained efficiently will cause additional flooding problems to surrounding houses, roads, and businesses. Riverside Drive is one of the major routes for vehicles to bring supplies to and from the Pulp and Paper Mill, and for people to enter and exit the city.

Again on 27 September 2005, the slope failed causing damage and disruption in transportation (*Western Star*, 29 September 205). A berm, which was constructed after the series of slope failures in 1994 to redirect the flow of water on the steep embankment, gave way causing the slope failure. Trees, rocks, dirt, power poles and lines, water lines and the guardrail and bank from the opposite side of the road were washed downslope into the mouth of Humber River. The water created a 3-5 m deep and about 6 m wide trench in the slope. Debris deposited on Riverside Drive was estimated to be 30 m wide with a thickness of 1 m in areas. Due to the loss of the power lines, residents in the proximity of the slope failure and on the north shore of the Bay of Islands were without power for 2 hours. Also, the severely damaged water lines left about 20 homes in the Riverside Drive area without water.

In recent years, new areas of vulnerability have developed. Upslope activities have increased. Several areas of Corner Brook demonstrate the pattern of upslope development and downslope flooding. Flooding in these areas is not associated with rivers, as no river systems are present.

Corner Brook East, specifically the area of the hillside north of the former cement plant / service centre, has a changing pattern of flooding. Historically, flooding events were infrequent and affected localized areas. Humber Road, Old Humber Road, Dave's Road, Riverhead Road, Fisher's Road, Station Road, Fudge's Road, etc have had an old history of flooding. On 4-6 November 1945, Old Humber Road and basements near the road were flooded when water flowed down from Humber Heights (*Western Star*, 9 November 1945). Fisher's Road, formally known as Old Cemetery Road, was flooded 7 March 1949 (*Western Star*, 8 March 1949). Damage also included a flooded basement of one business.

As of 2005, the flooding frequency has increased and larger areas are affected. Areas such as Lewin Parkway, Third Street, and Tipple's Lane have a relatively recent history of flooding. The former cement plant and present service center are positioned on the top of a steep incline. Change in the land use in this area has directly affected the area below it. Runoff has increased and consequently the low lying areas flood at a higher frequency. Third Street flooded for the first time in March 2003, and ever since has experienced flooding after heavy rainfall (former Assistant Director of Operational Services, Michael O'Leary, personal communication). Clarence Street has infrequently flooded in the past, but after the development of the service center the street floods after each heavy rainfall. Clarence Street had reported sections of flooding on 9-12 September 2004 due to remnants of Hurricane Frances (Works and Services Coordinator, Charlie Renough, personal communication, 2004).

The decommissioning of the T'Railway after 1984 has resulted in a widespread flooding hazard for Curling (former Assistant Director of Operational Services, Michael O'Leary, personal communication). St. Aiden's Road was recorded to have flooded and suffered washouts for the first time on 8 January 1995 (*Western Star*, 9 January 1995). Both the *Western Star* (1 October 2002) and city officials reported that the McLean's Lane and

Snook's Lane areas frequently flood with washouts occurring after every heavy rainfall. Stone's, Cooper's, Verge, and Barlette's Road are all frequently flooding areas, possibly due to the T'Railway. The failure to maintain the ditching along the T'Railway has resulted in changes in the drainage patterns and consequently flooding in the areas described above (Former Assistant Director of Operational Services, Michael O'Leary, personal communication).

Between 1982 and 1994, new roads have been developed on the southwest slopes, as identified from city maps. Consequently, flooding has been occurring on adjacent and lower streets that have not experienced flooding previous to construction. Areas of concern are upper Boone's Road, Shamrock Crescent, Sunnyslope Drive, Lundrigan Drive, and Lewin Parkway (south side location). For example, on 24 September 1998, water inundated private property causing damage on Sunnyslope Drive. The frequently reoccurring problem was observed to have begun after the development of Sunnyslope Extension and Marshall Crescent (*Western Star*, 4 September 1998). On 25 September 2002, Lundrigan Drive was washed out and the street was reduced to one lane. The runoff from Lundrigan Drive washed out a section of the Lewin Parkway (*Western Star*, 2 October 2002). Michael O'Leary (2003) has reported perennial flooding on Shamrock Crescent and Upper Boone's Road.

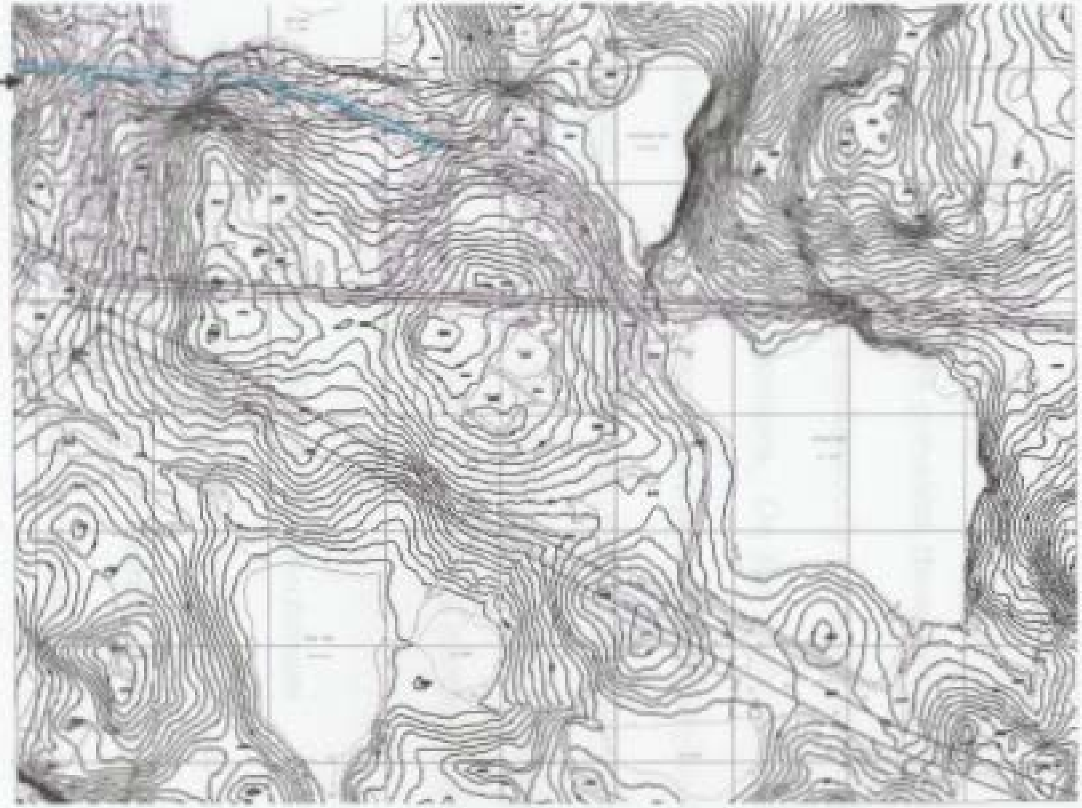
Within urban areas, the natural accumulation of sediment in river systems can induce flooding. Modifying or constraining a stream laterally or vertically can alter the natural deposition of the sediment and increase flooding events. Sediment bars have developed in the lower reaches of Corner Brook Stream, which has resulted in the lateral expansion of the channel, particularly during periods of high water levels. The lateral migration of the river has inundated a walking trail and is progressively undercutting the retaining walls along the lowermost part of the stream. (See photographs 5.6-5.8).

5.4 Massey Drive

The town is growing, increasingly removing vegetation further upslope for infrastructure. The site visit did not reveal any severe flood problems, but torrents did appear on the sides of the roads. A potential problem arises for the lower lying areas of Massey Drive and nearby Corner Brook. Runoff from the streets of Massey Drive may wash out the entrance to the town or wash out a section of the Trans Canada Highway.

All recorded flooding events occurred as a result of rain-on-snow events. In many cases damage was sustained when inadequate drainage prevented the removal of runoff. Flooding began in Massey Drive on 27-28 January 1976 when runoff from rain and snowmelt washed out a driveway in the community (Kindervater, 1980, see 27-28 January 1976). On 25-26 December 1977, damage occurred due to inadequate drainage (Kindervater, 1980, see 27-29 December 1977). Mountainview Road sustained washouts due to a rain-on-snow event on 17-18 February 1996 (*Western Star*, 19 February 1996). An embankment was washed away during the 30-31 March 2003 rain-on-snow event (*Western Star*, 2 April 2003).

Area vulnerable to flooding caused by heavy rainfall events



Map 5.10 **Massey Drive**

Areas of flooding and concern

1 grid square = 200 m

Legend

Areas vulnerable of flooding

5.5 Summary

Rain-on-snow events are prevalent throughout the entire Humber Arm region. Many communities may be simultaneously affected by this hazard, whereas other hazards are prevalent in specific locations. On the south side of the Humber Arm frequent slope failure is the largest concern. Ice jams infrequently occur, but have not been recorded on the north side. River flooding, unrelated to ice jamming, is a substantial hazard in Humber Arm north. Storm surges impacts McIver's and Cox's Cove on the north Humber Arm, and have not been recorded in other locations in the Humber Arm region.

5.5.1 Importance of differing flood mechanism

When the number of flooding events was categorized according to natural mechanism (n = 442), 42% of the events in the Humber Arm region were in part caused by rain-on-snow events (Figure 5.5). Therefore, rain-on-snow events are the greatest single cause of damages and are the most damaging flood hazard (e.g. March 2003) in the region. Autumn and winter storms contribute large amounts of precipitation resulting in flooding. Autumn storms (18%) appear as hurricane activity or as heavy rainfall. Winter storms (14%) may result in rain-on-snow events and melting of large quantities of snow. Summer storms result in 15% of flooding events; hazards range from river flooding to road and basement damage. Ice jams (2%), spring storms (1%), hurricane-induced rainfall (3%), snowmelt (3%), and slope failure (2%) contribute to approximately 11% of the flooding events. Ice jams and slope failure are a relatively localized hazard; however, slope failures have widespread impacts. When slope failure disrupt traffic or isolate communities, economic and social impacts will ensue. Hurricane-induced impacts occur from July-November. Large amounts of precipitation in short time periods cause rivers to overflow, and affect private and public infrastructure. Spring storms that are counted in Figure 5.5 occur in late spring and are not related to snowmelt. The snowmelt classification is caused by mild temperatures and not rain. Damages are minimal, usually consisting of erosion of pavement and overflowing of storm systems. Although beaver damming is a possibility for the Corner Brook Stream, no recorded floods have occurred. Storm surges have not been recorded in the local newspapers; therefore, the frequency is unknown. However, damage has occurred, particularly in the communities near the opening of the Humber Arm.

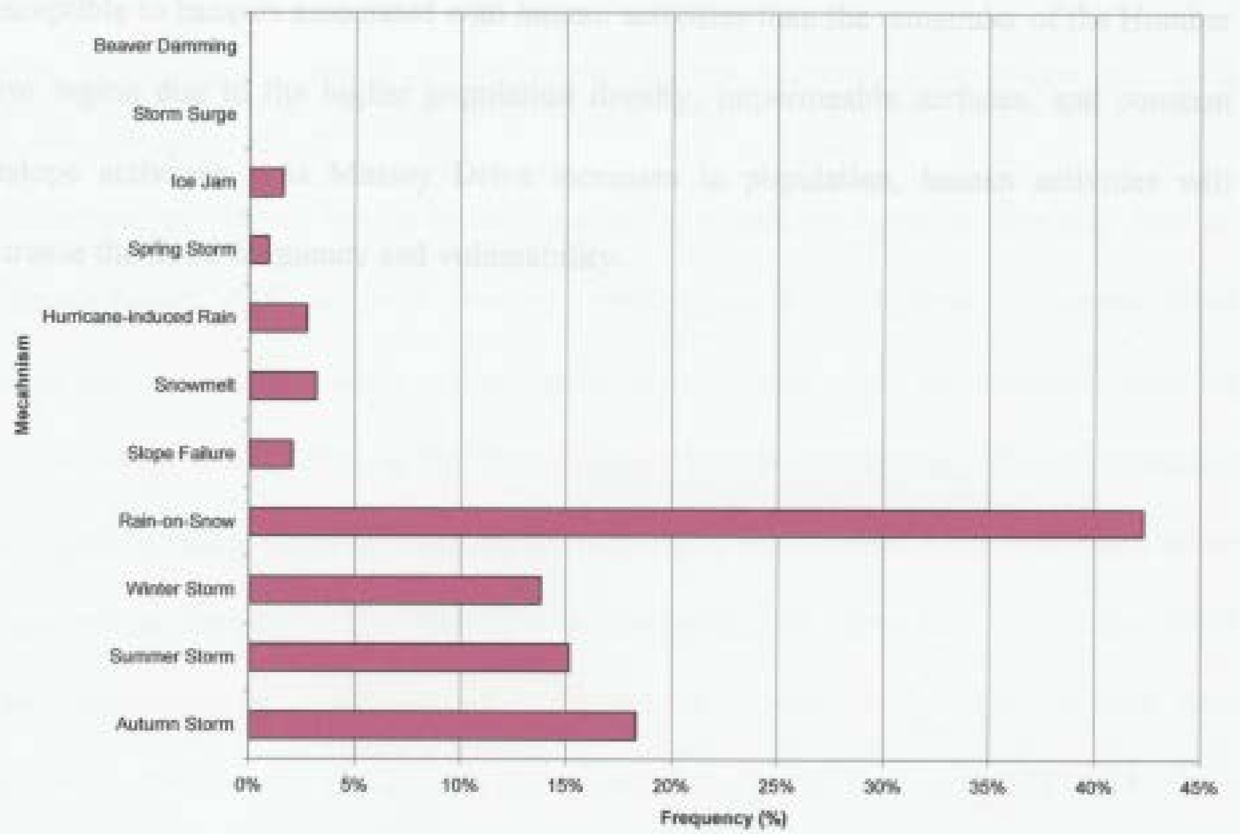


Figure 5.5: Frequency of natural flooding mechanism in the Humber Arm region. Events may be counted multiple times depending on mechanism. Data collected from archival research. Total of recorded incidents equal 442.

When anthropogenic causes are included, number of flooding incidents total 543. Anthropogenic causes, such as inadequate drainage infrastructure and construction of infrastructure upslope, indirectly cause *ca.* 18% of flooding events in the Humber Arm region (Figure 5.6). When natural hazards are coupled with anthropogenic activity, the severity and extent of damages increases. With the incorporation of human activities into the frequency of flood mechanism found in Figure 5.6, rain-on-snow events result in 35% of flooding events in the Humber Arm region. Blocked culverts result in the build-up of water or the reduction of drainage which cause erosion of infrastructure. At least 15% of the flooding events could be eliminated by minimizing anthropogenic activity in vulnerable locations and maintaining drainage infrastructure. Corner Brook is more susceptible to hazards associated with human activities than the remainder of the Humber Arm region due to the higher population density, impermeable surfaces, and constant upslope activities. As Massey Drive increases in population, human activities will increase the flood frequency and vulnerability.

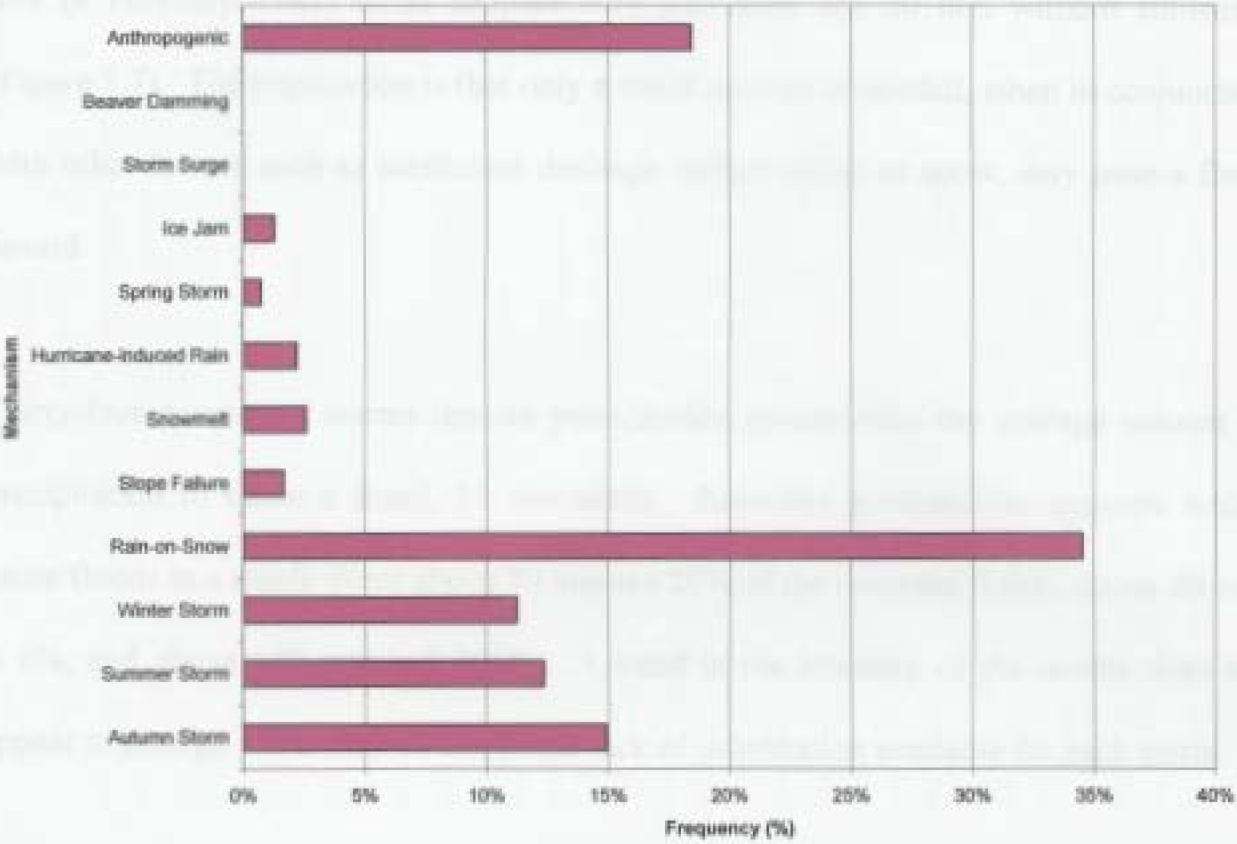


Figure 5.6: Frequency of natural and anthropogenic flooding mechanism in the Humber Arm region. Events may be counted multiple times depending on mechanism. Data collected from archival research. Number of incidents total 542.

Particularly in Corner Brook, human activity is a greater driver in flooding than are climatic factors. Although rain-on-snow events appear as the highest mechanism, much of the damage is enhanced by anthropogenic activity. The rivers are restricted, resulting in less water able to flow in the river channel before overtopping. Runoff is further increased by roads acting as conduits for water flow and reduced permeable areas where water can be absorbed rather than pool on the surface (*Western Star*, 31 October 1962; Flooding Events in Newfoundland and Labrador, March 21-23, 1976; *Western Star*, March 12, 1998; etc.). The amount of rain which results in flooding events is not related to the total annual precipitation: years of greatest flooding may not correspond to years of overall high precipitation. The minimal amount of rainfall that causes flooding is only 8 mm (8 February 1981) when coupled with snowmelt and 20 mm without snowmelt (Figure 5.7). The implication is that only a small amount of rainfall, when in conjunction with other factors such as inefficient drainage infrastructure or snow, may pose a flood hazard.

Thirty-four percent of storms deposit precipitation greater than the average amount of precipitation to cause a flood, 37 mm/storm. Recorded precipitation amounts which cause floods in a single event above 50 mm are 20% of the recorded floods, above 80 mm is 6%, and above 100 mm is 0.005%. A trend in the intensity of the storms does not appear to emerge. This may be due to the lack of information available for each storm.

Figure 5.7 depicts the total precipitation in the Humber Arm region, derived from the climate station in Corner Brook. Both rainfall and snowfall amounts (1 cm snow equivalent to 1 mm meltwater) are indicated to illustrate snow to precipitation ratios. The proportion of snow to total precipitation varies from 20-25% in low-lying areas of south-facing slope to more than 40% on north-facing upland areas (Catto and Hickman, 2004). The amount of rainfall associated with recorded flooding events values were recorded in the *Western Star*. The precipitation amounts associated with flooding events which do not appear in archival reports were calculated from Environmental Canada data by comparing the amount of precipitation with the exact date of the flood event and adding these amounts for each year.

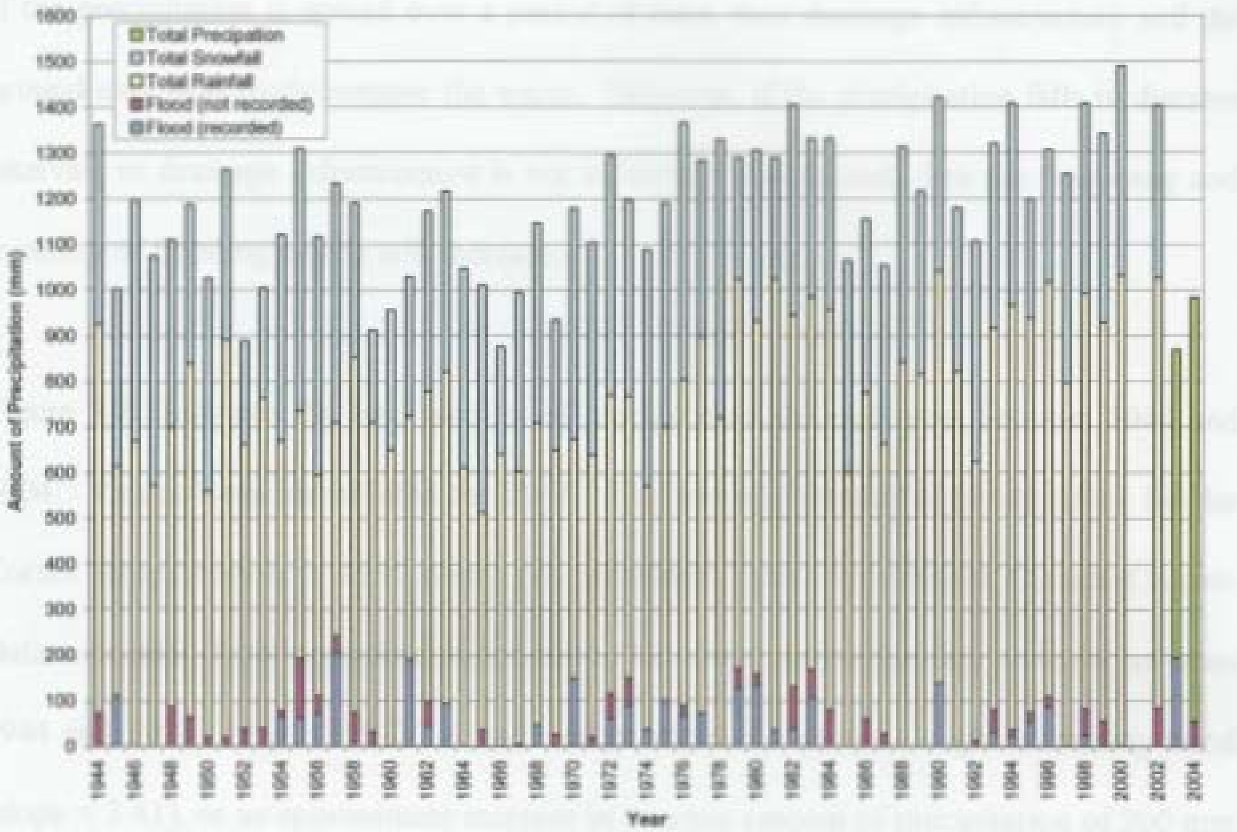


Figure 5.7: Amount of rainfall for each year and rainfall during flooding events. The recorded data found in archives (pink). The non-recorded found by correlating date of flood and amount of rainfall on that date (purple). The dark green indicates total precipitation without differentiation between rainfall and snowfall. Snowfall is calculated as melted volume; 1 cm snow is equivalent to 1 mm water. Amount of precipitation collected from Environment Canada for Corner Brook site.

The amount of precipitation has been gradually increasing over the time period studied in Humber Arm region (Figure 5.8 and 5.9). This may have many negative repercussions for the region. Additional water, depending on the time of year, may increase the severity of rain-on-snow events. As well, the additional water may increase the saturation of the sediment; thereby, increasing the frequency of slope failure. Many locations throughout the south side of the Humber Arm are already vulnerable. Further incidences of slope failure will severely impact the residents in these areas.

The increased amount of rainfall does not necessarily result in increased flooding events.

If the precipitation is spread over a period of time, then drainage infrastructure and the ground may effectively remove the water. However, if the precipitation falls in discrete intervals or drainage infrastructure is not efficiently maintained, then the frequency and intensity of flooding events will increase.

Figure 5.8 illustrates the total amount of precipitation for each year between 1944 and 2004. Values were unavailable for 2001. The average amount of precipitation for the Corner Brook region is 1180 mm/a (as calculated from Environment Canada Climate Data website). Total precipitation appears to have been approximately constant between 1944 and 1969. From 1970-2004, the total precipitation shows a slight increasing trend (slope = 3.41), or an approximate increase in average amount of precipitation of 200 mm from 1944 to 2004. Analysis of the R^2 values describes how effective the slopes are in predicting the overall precipitation trend. For total precipitation the $R^2 = 0.1474$ indicating a weak correlation between amount of precipitation and time. No correlation between total rainfall and time appears, $R^2 = 0.0073$. A stronger relation does appear in relation with total snowfall, $R^2 = 0.3094$.

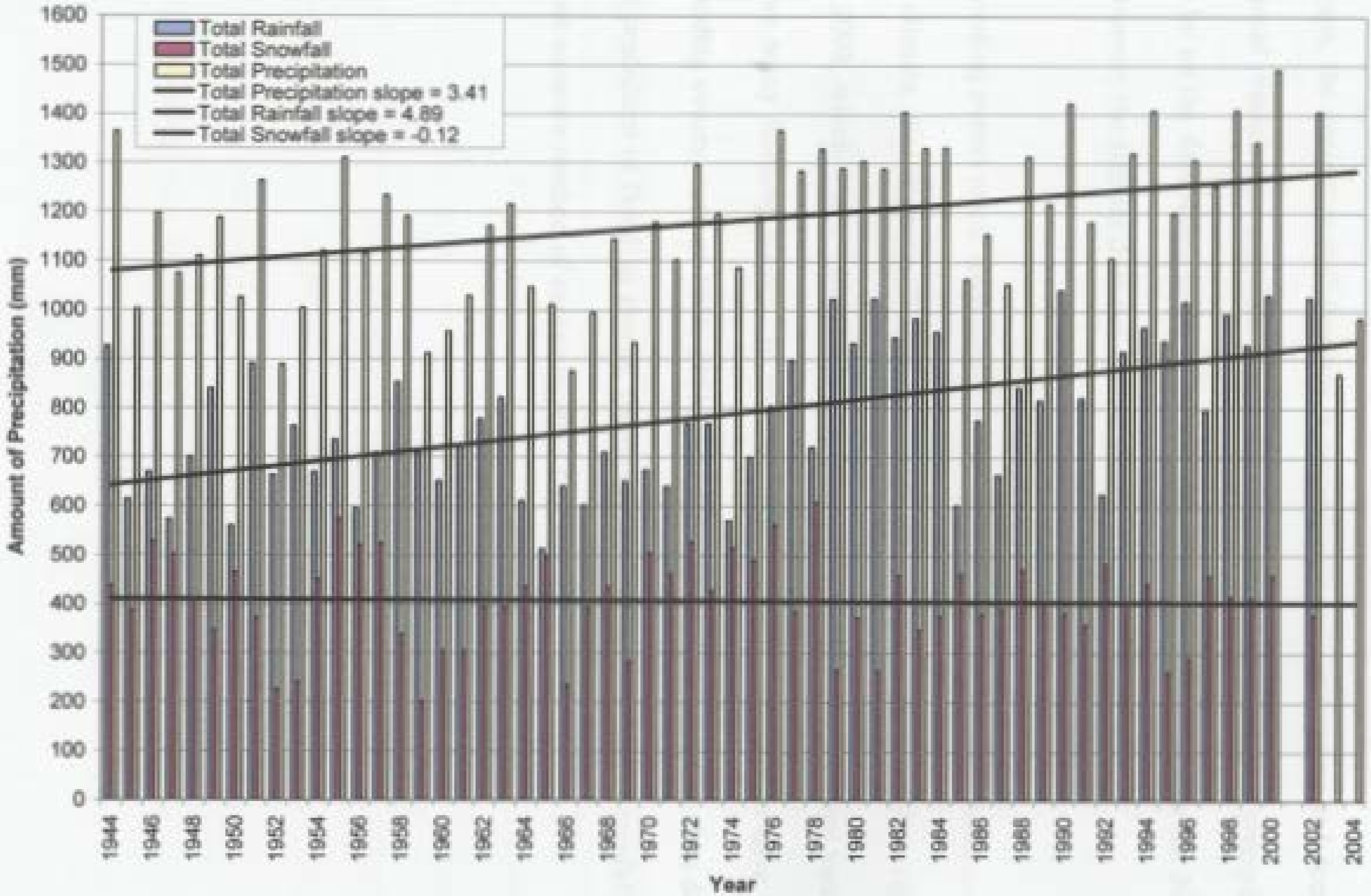


Figure 5.8: Amount of rainfall for each year and rainfall during flooding events. The lines of linear regression demonstrate overall change in total annual precipitation between 1944 and 2004. Snowfall is calculated as melted volume; 1 cm snow is equivalent to 1 mm water. Amount of precipitation collected from Environment Canada for Corner Brook site.

Figure 5.9 illustrates the running average of the total precipitation. As noted from the graph, the general overall increase is marked with cyclic increases and decreases in total annual precipitation amounts. Currently, the total annual amount of precipitation appears to be on the decreasing cycle. The amount of precipitation was low for 2003 and 2004; however, the amount does not exceed years of low total precipitation.

Flooding events result from single events rather than corresponding with overall changes in climate. For instance, the greatest flood recorded in the Humber Arm region occurred in 2003, which was a year of low precipitation (Figure 5.9). Average years (e.g. 1956) have many flooding events. In contrast, years of high precipitation have few recorded flooding events, such as 1976, 1951, and1992. Overall precipitation data does not aid in the prediction of flooding events; therefore, the frequency of heavy rainfall events are a more accurate method of explaining flooding events.

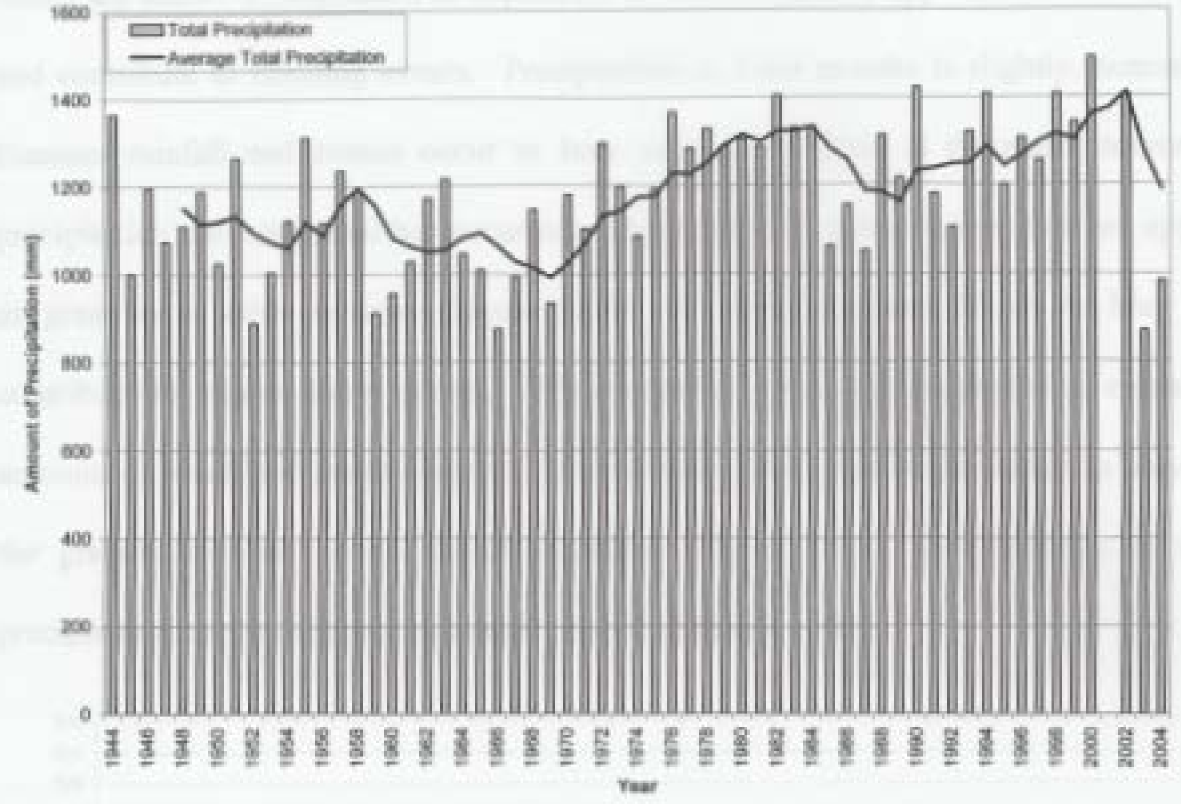


Figure 5.9: Amount of annual precipitation. Average total precipitation is running average of 5 consecutive years. Snowfall is calculated as melted volume; 1 cm snow is equivalent to 1 mm water. Data collected from Environment Canada for Corner Brook site. Data missing for 2001 and 2003.

The location of individual structures and buildings may increase the damage caused by storm surges. The trend of new residents in the Humber Arm area in building close to the shore for the view and placing more expensive infrastructure in a vulnerable position. Historically, fishing stages, wharves, boats, etc. have been damaged. With the addition of homes and business (bed and breakfasts, restaurants, etc.) the cost of vulnerable infrastructure greatly increases.

The greatest amount of precipitation in the Humber Arm region falls in December to February (Figure 5.10). The increase in precipitation in the winter months will increase rain-on-snow events, the snow will prevent drainage and an increased amount of rain will runoff the snow. Precipitation in September to November may appear as autumn storms and contribute to flooding events. Precipitation in these months is slightly increasing. Summer rainfall and storms occur in June to August. Rain is the major source of precipitation; however, hail has occurred. The increase in precipitation does not appear as great as in other seasons (Figure 5.10). Precipitation from March to May can contribute to rain-on-snow events. When coupled with mild temperatures, extensive amounts of runoff will cause damage. The increase in precipitation for March to May has the greatest increase of the month divisions (Figure 5.10). The increase in total precipitation may result in an increased rainfall in March – May.

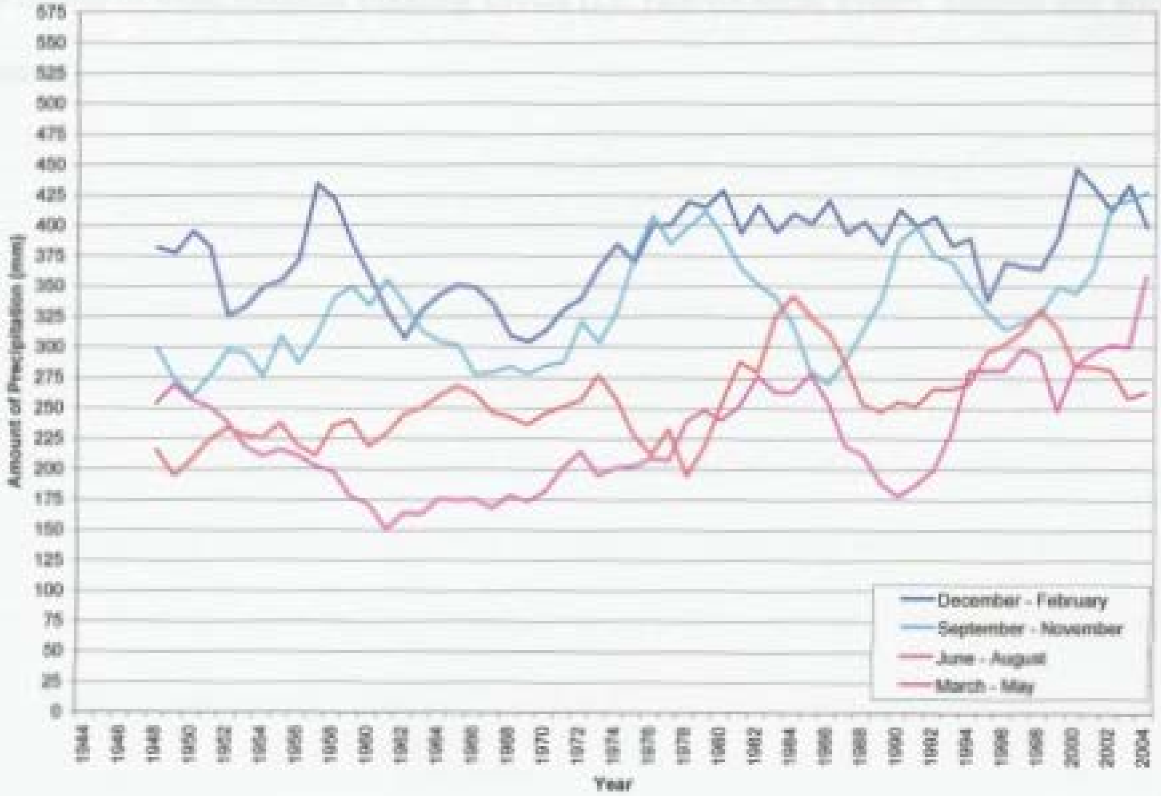


Figure 5.10: Five period running average for total amount of precipitation for each three month period in the Humber Arm region. Data collected from Environment Canada for Corner Brook site. Data missing for 2001 and 2003.

All seasons show an increase in precipitation (Figure 5.11). The greatest increase in precipitation is occurring in May to March. The second greatest precipitation is occurring in the summer (June to August), followed by September to November. The increase in winter precipitation is further described in Figure 5.11. The slope for winter is 0.42 with an $R^2 = 0.0091$. Autumn has a slope = 0.81 and an $R^2 = 0.0313$. The slope for summer equals 1.03, with a $R^2 = 0.0823$. Spring has the greatest slope (slope = 1.16) and the highest R^2 (0.1046).

The average precipitation in winter is 373 mm, for spring 227 mm, for summer 254 mm, and for autumn it is 327 mm. The highest precipitation in winter and autumn corresponds to timing of most frequent flooding events (i.e. rain-on-snow events, autumn and winter storms).

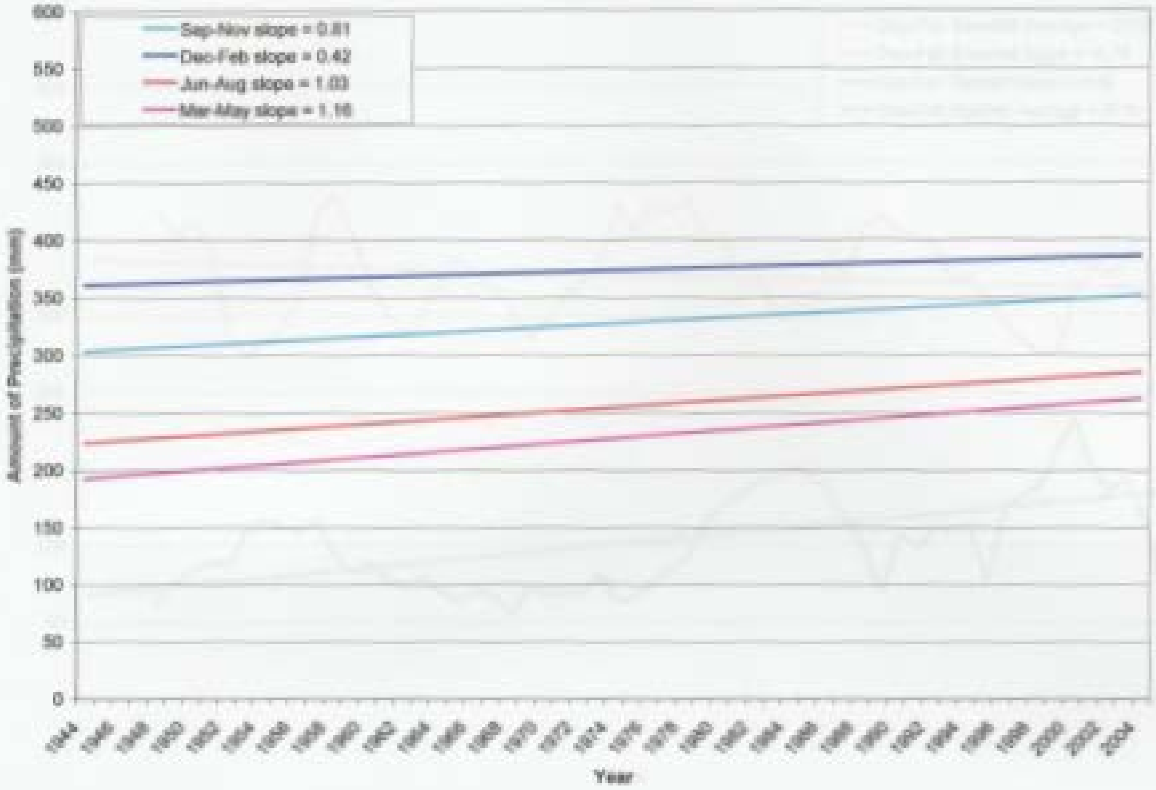


Figure 5.11: Linear regression of total seasonal precipitation for the Humber Arm region. Each seasonal value is a linear average of yearly amount of precipitation for three month periods: winter (December-February), spring (March-May), summer (June-August), and autumn (September-November). Data derived from Environment Canada based from Corner Brook Site.

The annual average amount of rainfall in winter has a greater rate of increase than the decrease in the annual average amount of snowfall (Figure 5.12). However, the average amount of snowfall is greater than 1/3 the amount of rainfall. Consequently, a thick snow cover is present on the ground. The increase in rainfall may increase the amount and severity of rain-on-snow events, especially if the rainfall arrives in intense, single events. The slope for total rainfall equals 0.92 with a $R^2 = 0.1013$, which is greater than the slope for total snowfall (-0.74) with $R^2 = 0.0056$.

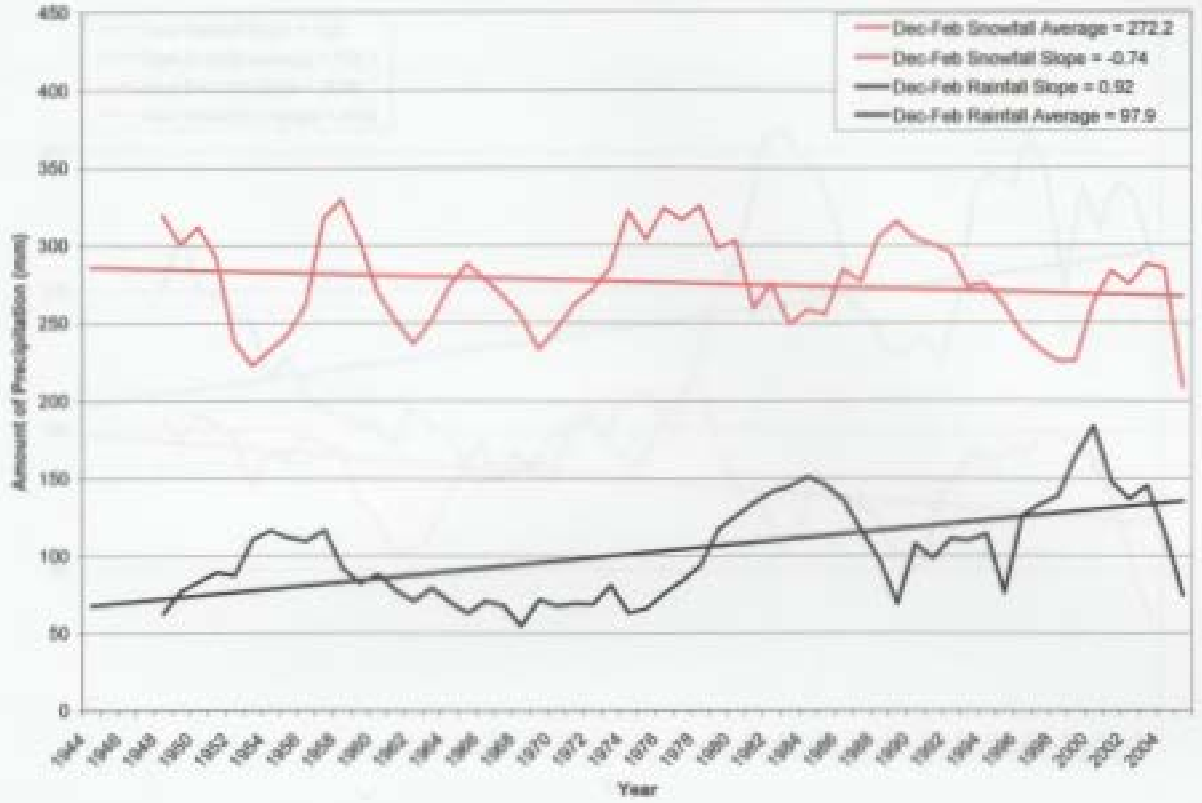


Figure 5.12: Linear regression and average of winter rainfall and snowfall for Humber Arm region. Both the rainfall is described by a linear regression and a running average of 5 points of yearly precipitation between 1944 and 2004. Data derived from Environment Canada based from Corner Brook Site.

In the spring, the amount of rainfall is increasing, whereas the annual amount of snowfall is gradually declining. The greatest flooding event occurred in a year of high spring rainfall but low snowfall. Therefore, rain-on-snow events may be increasing. Spring rain-on-snow events may be more dependent on the thickness of the snowcover, the level of saturation of the ground, and the ground temperature prior to the event. If the ground is saturated and frozen prior to a heavy rainfall, which may occur in a year of high precipitation, then this may have the same affect as a thick snowcover in preventing the infiltration of runoff into the ground. The slope total snowfall is -0.40 and $R^2 = 0.0547$. For total rainfall, slope = 1.20 and $R^2 = 0.0688$.

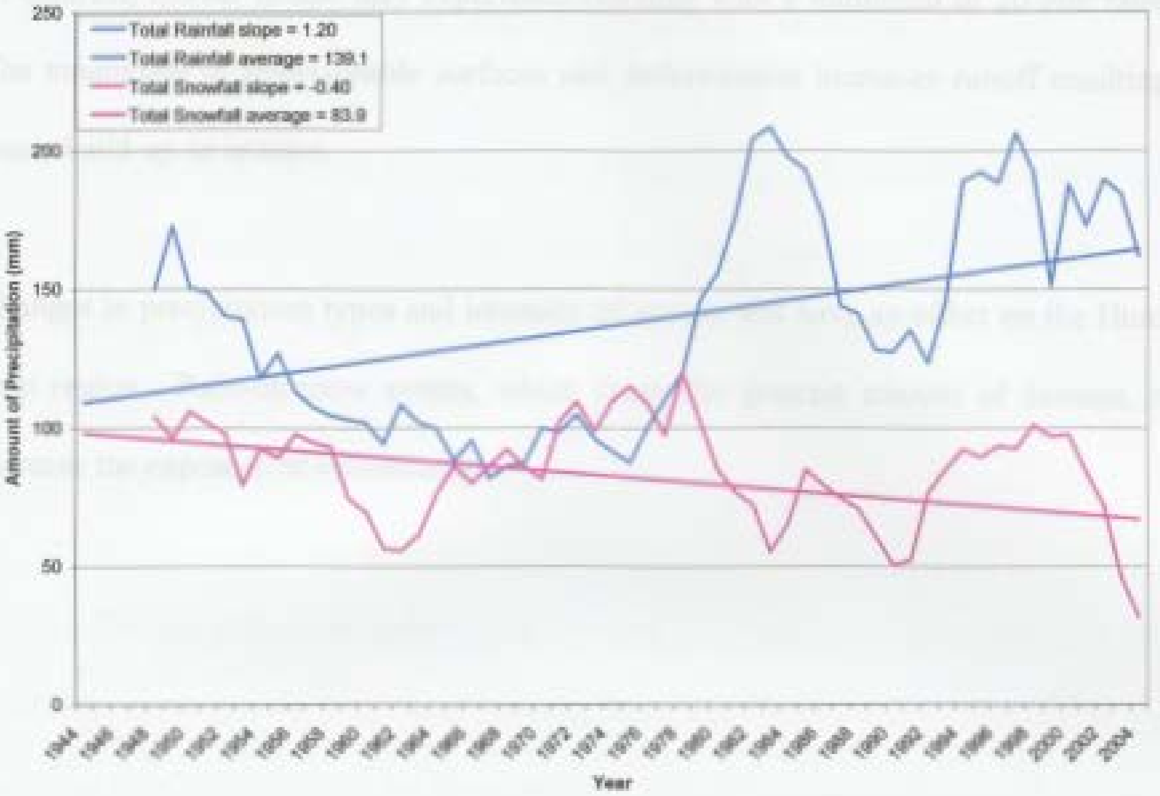


Figure 5.13: Linear regression and average of spring rainfall and snowfall for Humber Arm region. Both the rainfall is described by a linear regression and a running average of 5 points of yearly precipitation between 1944 and 2004. Data derived from Environment Canada based from Corner Brook Site.

5.5.2 *Conclusion*

Although not clearly depicted through the graphs but illustrated by the flood descriptions, flooding of most Humber Arm region communities (with exception of Corner Brook and Massey Drive) is climate driven. For example, Cox's Cove suffers severe flooding during storm surges in combination with heavy rainfall. Either Cox's Brook overflows or slope failures occur during extreme events.

In contrast, Corner Brook may experience flooding with a minimum of 20-mm rainfall. The magnitude of impermeable surfaces and deforestation increases runoff resulting in water build-up or erosion.

Changes in precipitation types and intensity of storms will have an effect on the Humber Arm region. Rain-on-snow events, which cause the greatest amount of damage, may increase the exposure of infrastructure.

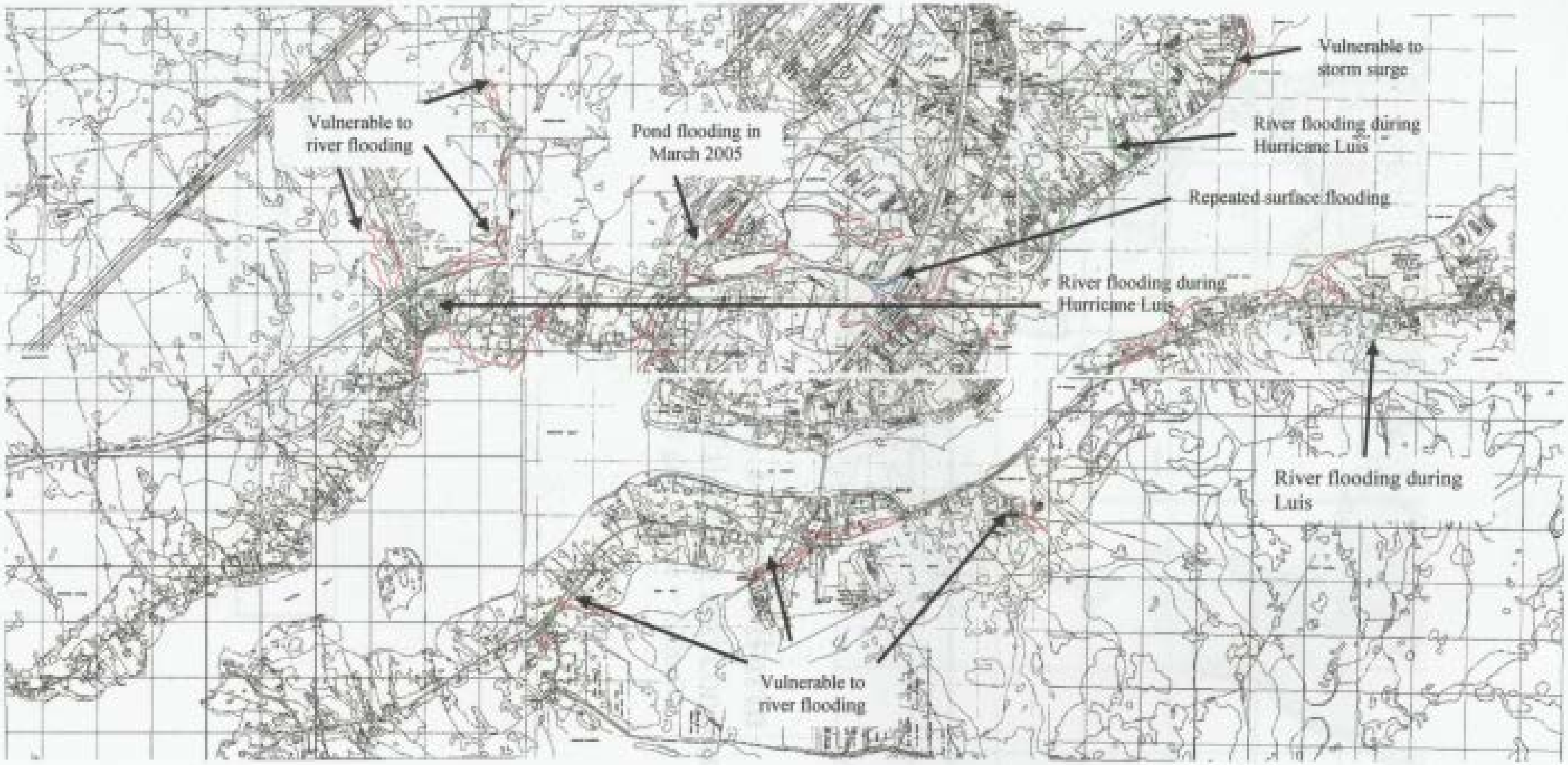
6. Physical Impacts of Flooding on the Burin Peninsula

The following text identifies, illustrates, and contains maps of historical areas of flooding on the Burin Peninsula. To further analyze flood hazards and vulnerability, the mechanism(s), season, precipitation amount, and other meteorological conditions which induced floods are examined. Finally, the importance of meteorological factors, climate change, and human influence are assessed.

Through field investigations and consultation with communities between 2003 and 2006, more than seventy sites with flood hazards have been identified. Twelve sites were located in Marystown, two in the town of Burin, five in St. Lawrence, six in Fortune, six in Grand Bank, three in Little Bay, four in Fox Cove-Mortier, two in Lamaline, and individual sites in Little St. Lawrence, Lawn, Jersey Room, Point May, Frenchman's Cove (Burin), Rushoon, Point au Gaul, Taylor's Bay, and Allan's Island. The roads between the communities are also susceptible to flooding.

Flooding on the Burin Peninsula is often associated with hurricanes, and autumn and spring storm events. The storms bring heavy rainfall and high winds to the areas affected. Storm surges cause costly damage to the shorelines during storm events. Additionally, flooding hazards occur as an indirect result of inadequate and aging infrastructure. Problems occur due to alterations of natural drainage ways, and when culverts fail and ditches become overgrown with vegetation. Consequently, rainfall events cause flood damage to public and private property.

In general, storm surges of 2 m can occur along the Canadian coast (Danard *et al.*, 2004). On the Burin Peninsula, areas below ca 11 m asl are vulnerable (Catto *et al.*, 2003; Catto and Hickman, 2004; see also Ruffman *et al.*, 1999). Wave energy during extreme storms is capable of displacing boulders and large blocks of concrete up to 1 m in axial dimension to distances of 10 to 15 m (Morton, 2002). This was evident on the Allan's Island causeway and the highway between Garnish and Frenchman's Cove (Burin Peninsula). During severe storms, boulders put in place to protect the roadway have been removed and placed on the road itself. The community of Point au Gaul placed cribwork along the coast after the February 2004 storm. During the December 2004/January 2005 storm, the entire cribwork was washed away (Former clerk of Lamaline, Shelly Lovell, personal communication; Mayor of Frenchman's Cove, James Cluett, personal communication).



Map 6.1 **Marystown**
Areas of Flooding and Concern
1 grid square = 200m

Legend
- Areas vulnerable of flooding
- Flooding in March 2005
- Flooding due to Hurricane Luis (Sep. 1995)
- Area of repeated flooding

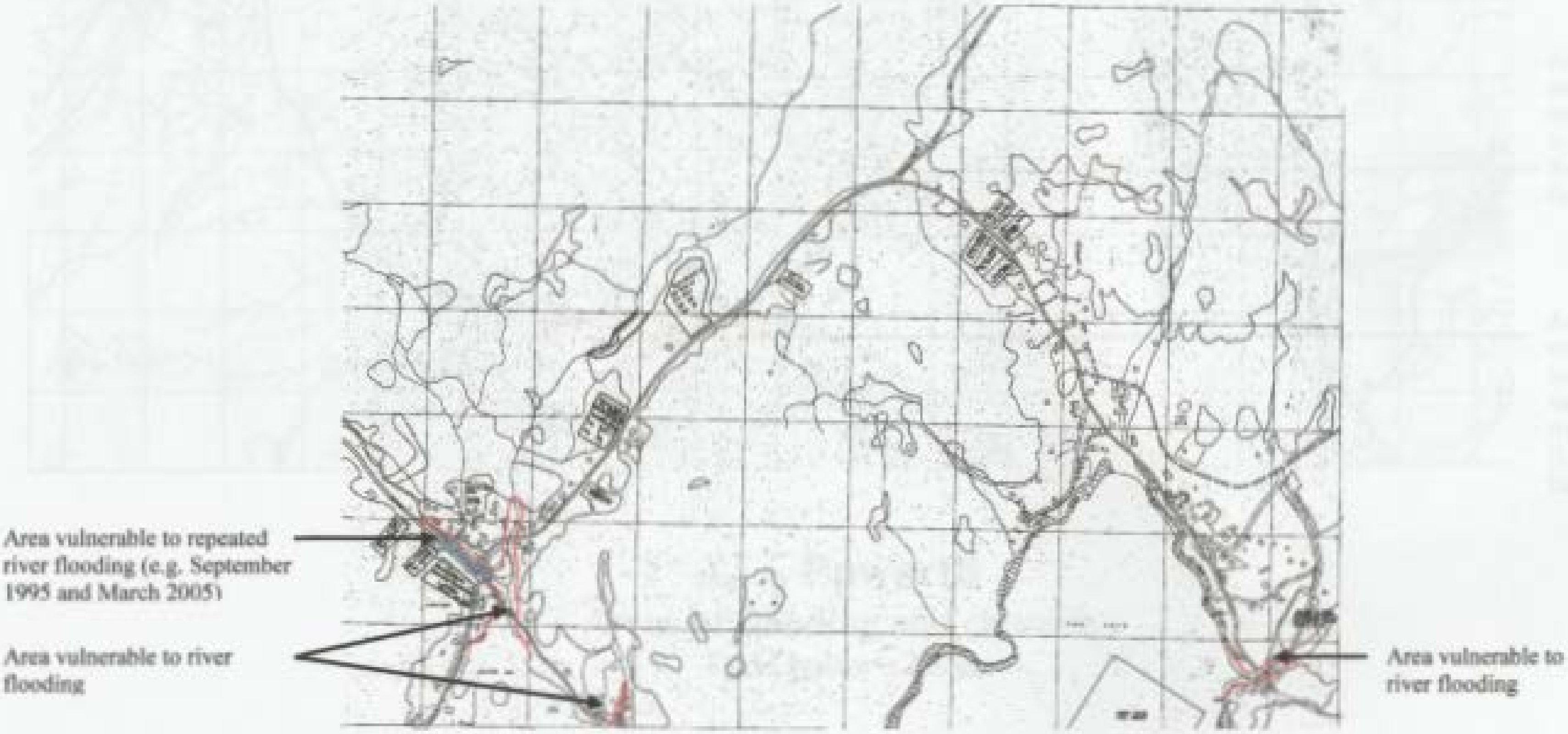
Map 6.2 **Town of Burin**

Area of flooding and concern

1 grid square = 200m

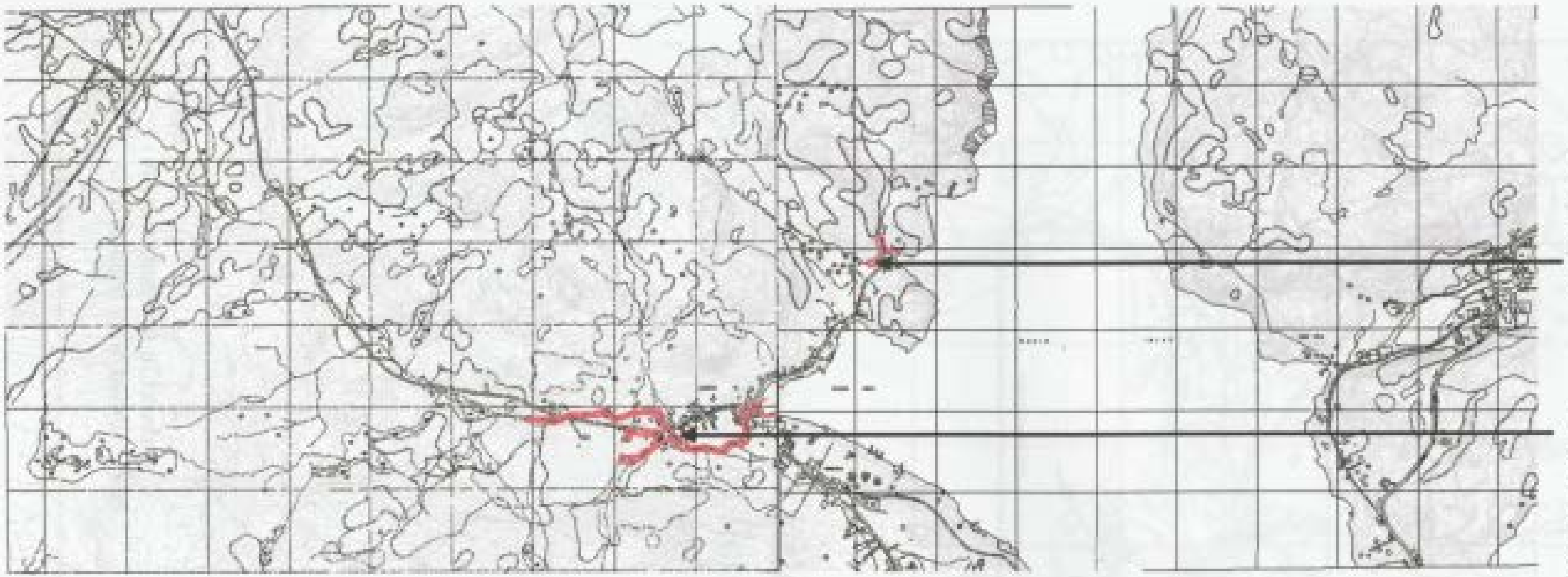
Legend

Areas vulnerable to flooding



Map 6.3 **Fox Cove-Mortier**
Areas of flooding and concern
1 grid square = 200m

Legend
Areas vulnerable of flooding
Area of repeated flooding

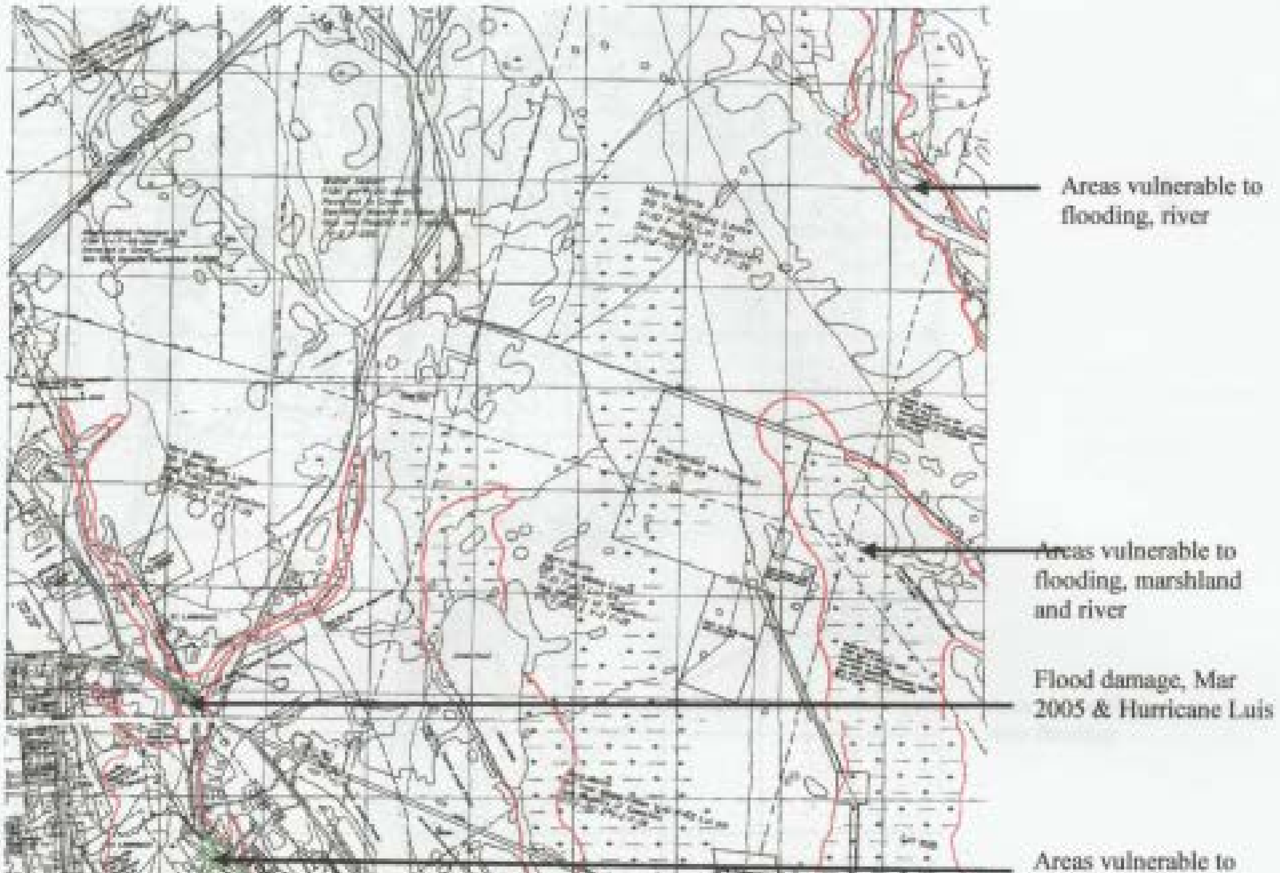


Map 6.4 **Epworth**
Areas of flooding and concern
1 grid square = 200m

Legend
Areas vulnerable of flooding

Map 6.5 **Little St. Lawrence**
Area of flooding and concern
1 grid square = 200m

Legend
- Areas vulnerable of flooding
- Area flooded in September 1995



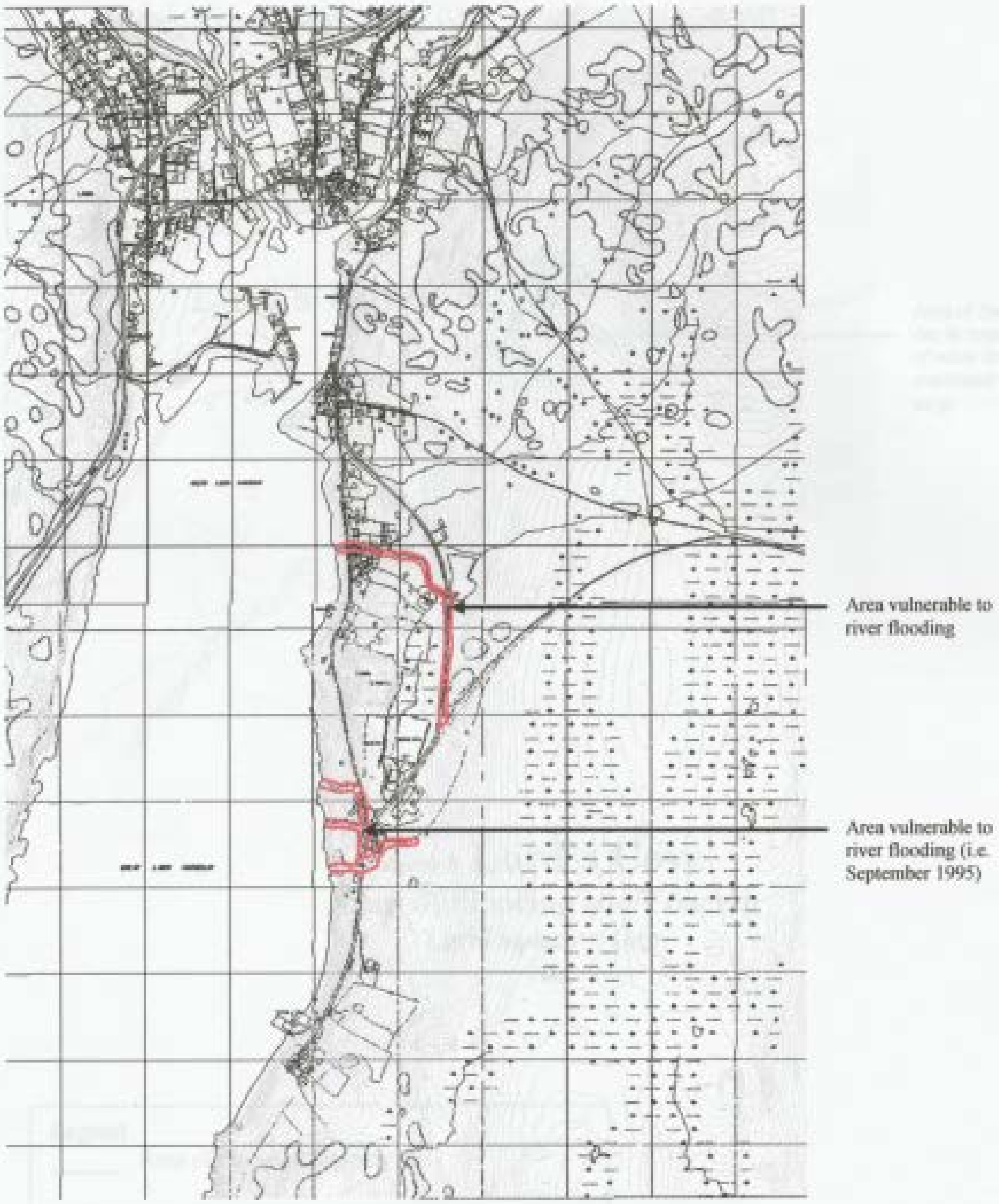
Map 6.6 **St. Lawrence**

Areas of Flooding and Concern

1 grid square = 200m

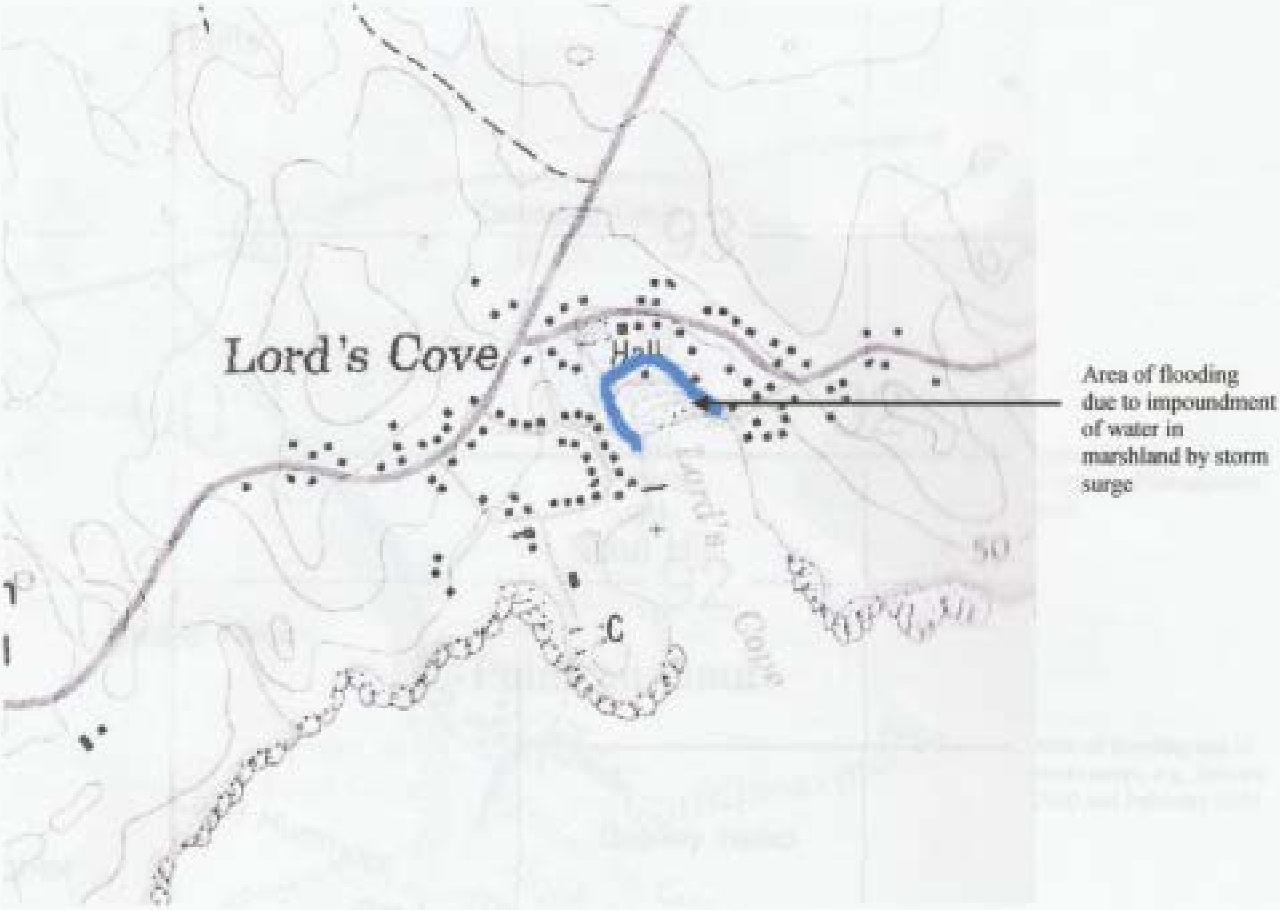
Legend

- Areas vulnerable of flooding
- Flooding in March 2005
- Flooding due to Hurricane Luis (Sep. 1995)
- Storm Surge, Feb. 2004



Map 6.7 **Lawn**
Area of flooding and concern
1 grid square = 200m

Legend
Areas vulnerable to flooding



Map 6.8 **Lord's Cove**

Areas of Flooding and Concern

1 grid square = 1km

Legend

Area of repeated flooding

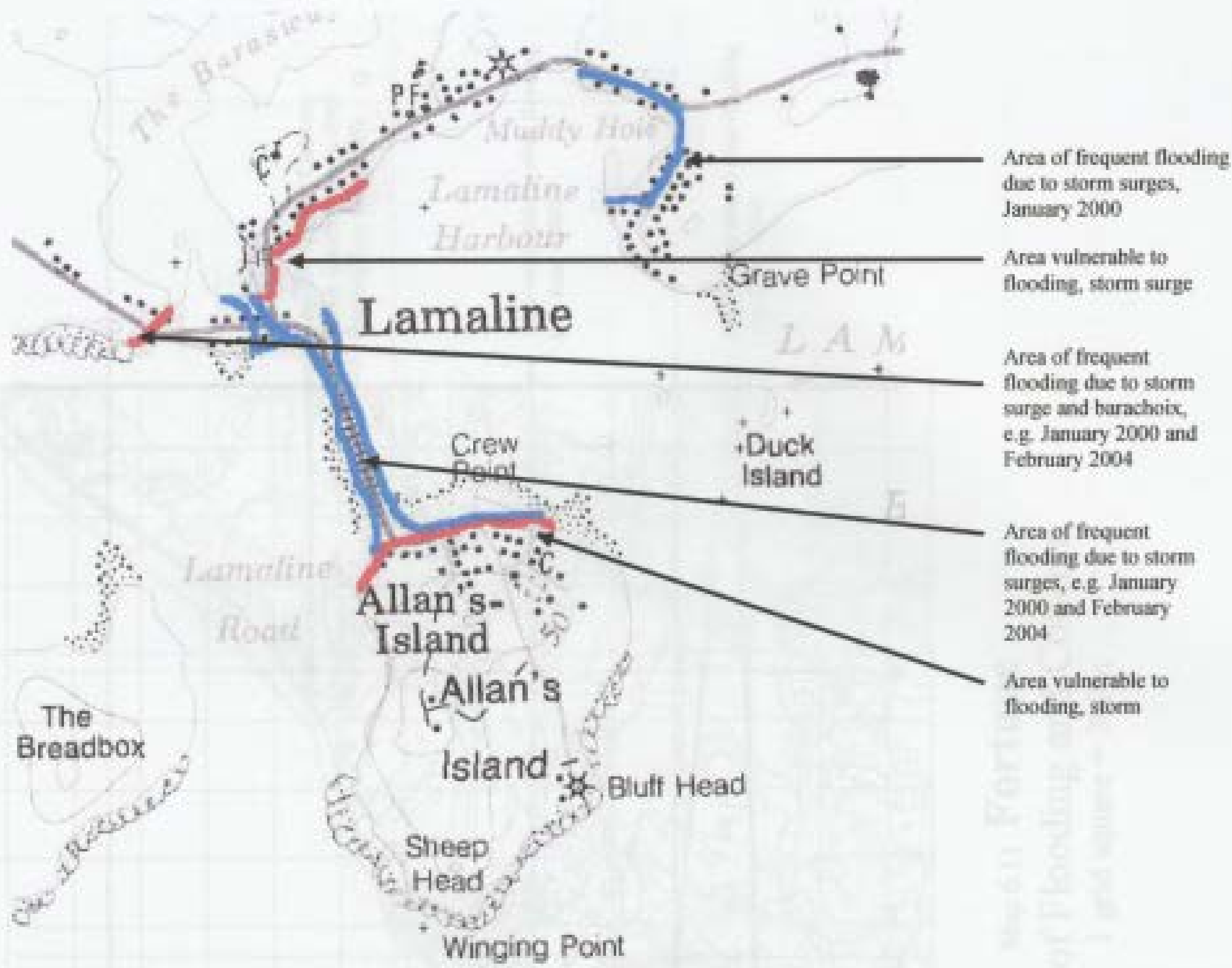
Map 6.9 **Point au Gaul**

Area of Flooding and Concern

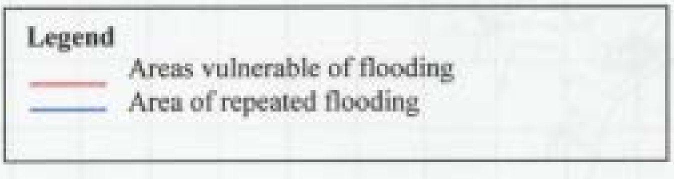
1 grid square = 1km

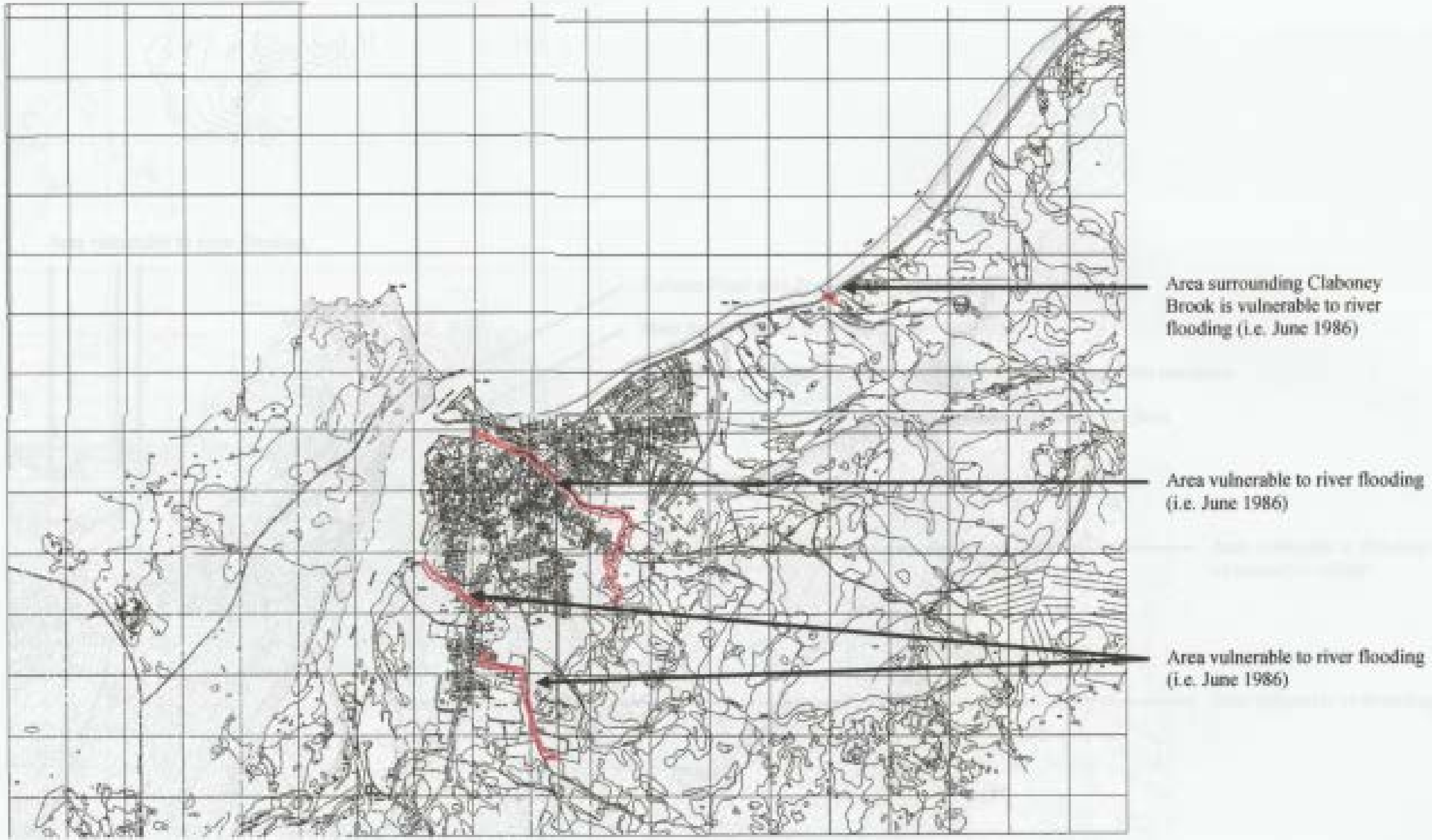
Legend

Area of repeated flooding



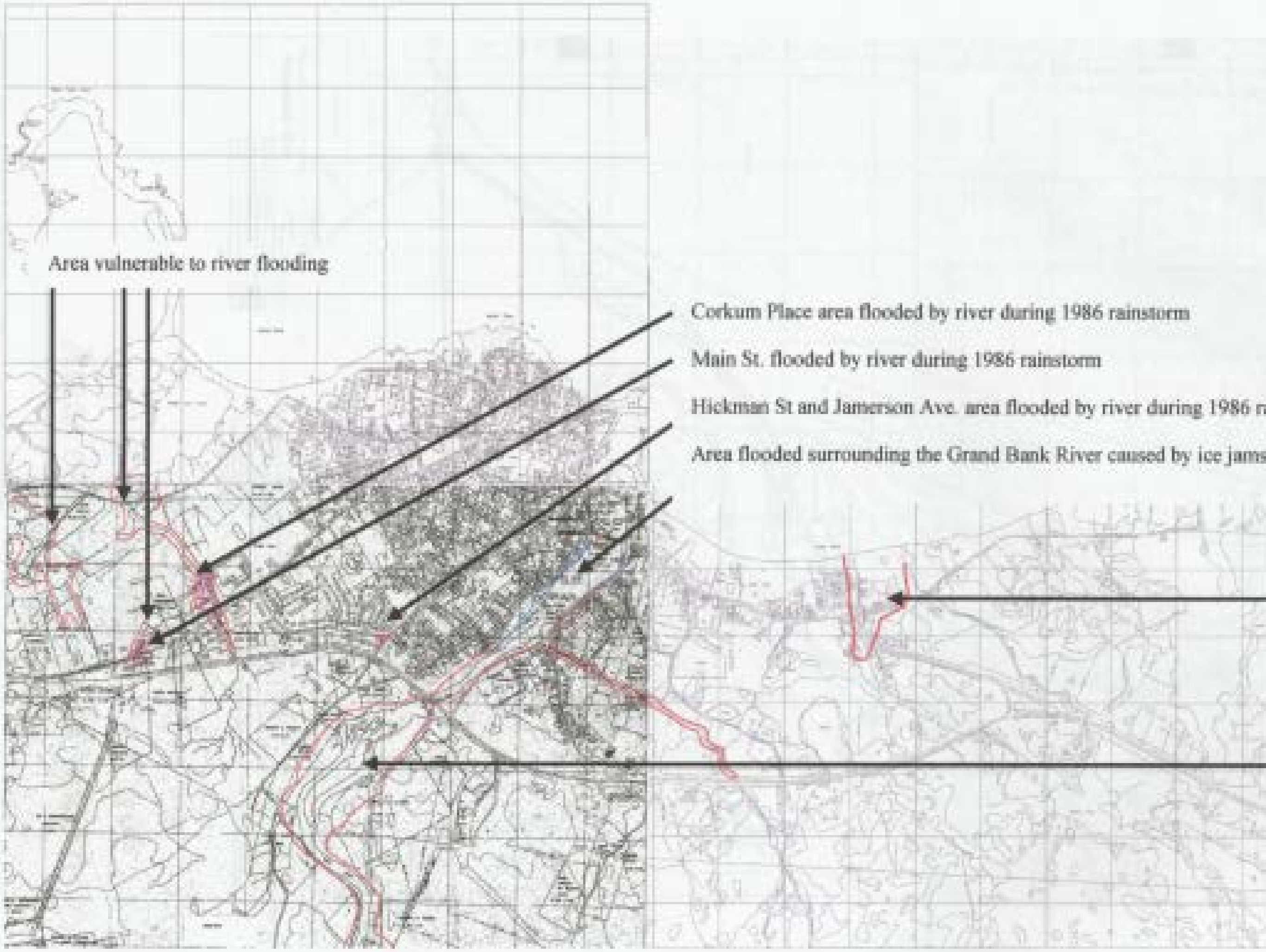
Map 6.10 **Lamaline**
Areas of Flooding and Concern
1 grid square = 1km





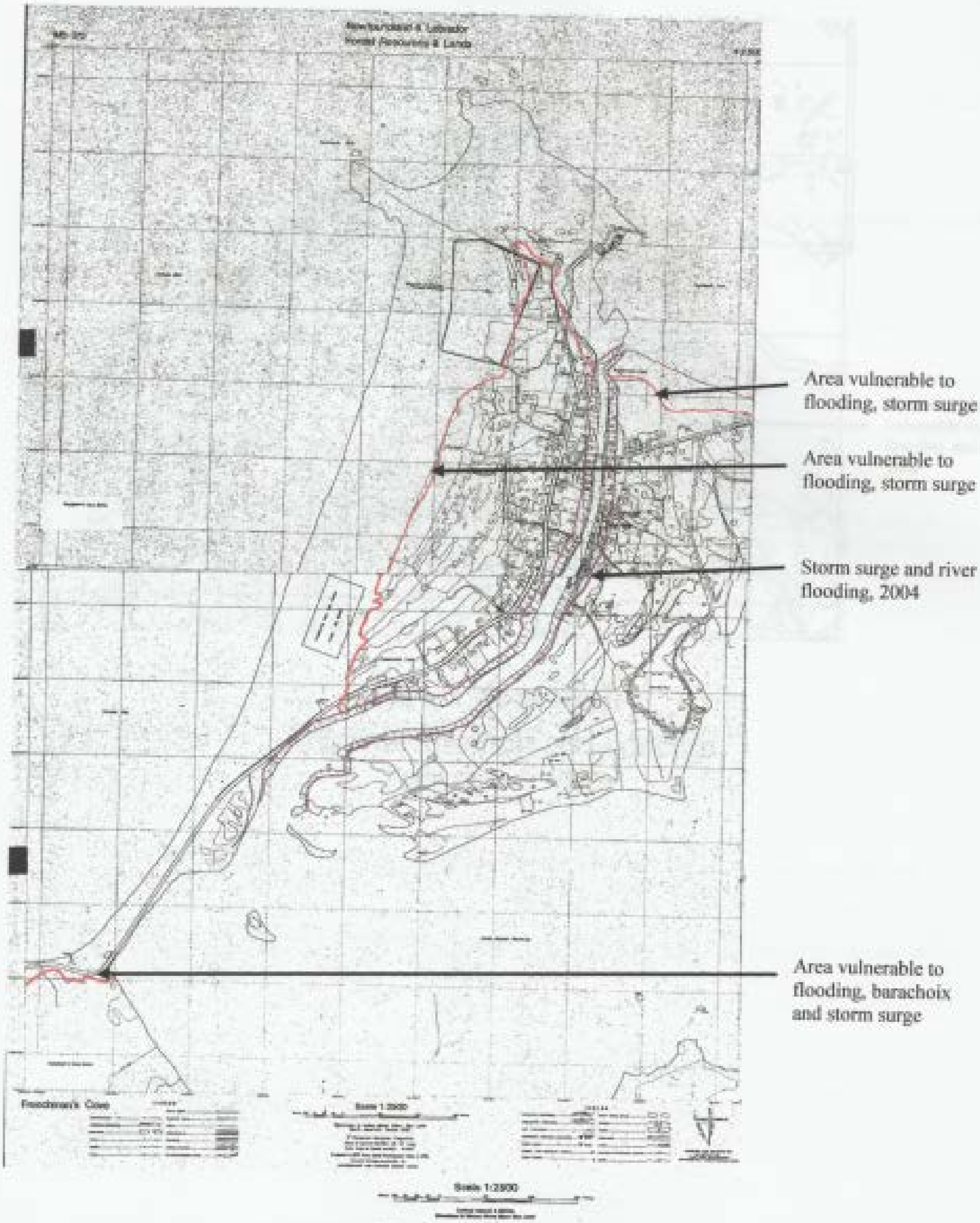
Map 6.11 **Fortune**
Areas of Flooding and Concern
1 grid square = 200m

Legend
Areas vulnerable to flooding



Map 6.12 **Grand Bank**
Areas of flooding and concern
1 grid square = 200m

Legend
Areas vulnerable of flooding
Area of flooding caused by ice jams
Area flooded in June 1986



Map 6.13 **Frenchman's Cove**
Areas of Flooding and Concern
1 grid square = 200m

Legend
Areas vulnerable of flooding
Storm surge, Feb. 2004

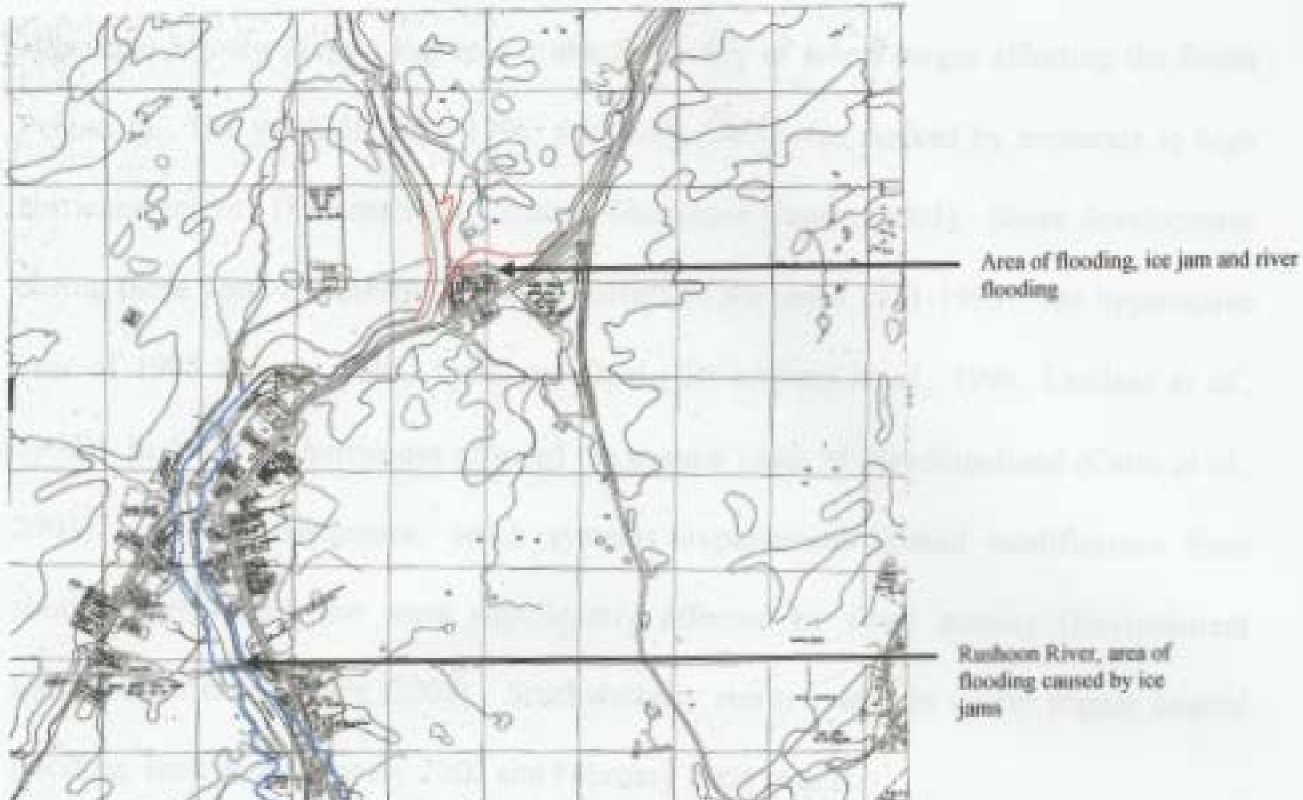
Map 6.14 **Garnish**

Areas of flooding and concern

1 grid square = 200m

Legend

Area vulnerable to flooding



Map 6.15 **Rushoon**
Areas of Flooding and Concern
1 grid square = 200m

Legend
Areas vulnerable of flooding
Area of repeated flooding

Hurricane activity plays a key role in the frequency of storm surges affecting the Burin Peninsula. The years of 1994, 1996, and 1998-2005 were marked by moderate to high hurricane activity (Environment Canada—Hurricane Centre, 2005). Shore development during those years resembled the modal pattern of the years 1981-1993. The hyperactive year of 1995 brought Felix, Luis, and Opal (Goldenberg *et al.*, 1996; Landsea *et al.*, 1998). In 1997, no hurricanes affected the eastern coast of Newfoundland (Catto *et al.*, 2003). As a consequence, beach systems experienced limited modification from southwesterly wind, but were significantly affected by swell activity (Environment Canada-Hurricane Centre, 2005). Southwesterly storm events in winter trigger coastal flooding, such as the January 2000 and February 2004 events.

The Burin Peninsula is connected to the remainder of Newfoundland by Highway 210. Severing of this link greatly reduces the ability of the communities to acquire goods and services supplied by larger urban centers. In June 1986, Highway 210 near Bay L'Argent was washed away by flood waters (76 mm of rain in a 24-hr period; *Southern Gazette*). Communities were isolated. In October 1991, the highway between Mooring Cove and Spanish Room was completely severed separating approximately 20,000 residents from the remainder of the island. A river crossing the highway overpowered the culvert and eroded the roadbed, causing collapse. A rain-on-snow event in March 2004 caused a partial break in the highway; the gravel/sand roadbed was washed away, reducing the highway to less than one lane. The deterioration of Highway 210 and low visibility caused by a snow storm resulted in the closure of that section of highway for several days.

Communities on the western part of the peninsula have been separated by floods that undermined the highway between them. Part of the Grand Bank Highway between Grand Beach and Frenchman's Cove washed away in October 1993, November 1993, and September 1995 (*Southern Gazette*). Water built up when a culvert under the highway was unable to effectively drain the heavy rainfall.

Figure 6.1 illustrates the recorded flood frequency and mechanisms in communities on the Burin Peninsula. The mechanisms have been classified under general categories of autumn, winter, summer, and spring storms because one flooding event may be the product of several mechanisms. The majority of flooding events result from autumn storms, such as hurricanes; Hurricane Luis (1995) affected twelve of the communities. Winter storms have resulted in storm surges that impacted the coast, particularly Lamaline. Winter storms have also caused rain-on-snow events and impoundment of water. Although summer storms are less frequent than autumn and winter storms, damage caused by these storms is extensive. The 1986 summer storm caused the destruction of the water and sewer system in Fortune and flooded homes and roads in Grand Bank. Spring storms occur less frequently than autumn, winter, and summer storms. Spring storms are associated with heavy precipitation, rain-on-snow events, and snowmelt. Spring storms can also cause storm surges that impact the coast. Ice jams have been recorded in Rushoon, Garnish, Frenchman's Cove, and Grand Bank. The most highly populated communities (Marystown and Grand Bank) show the highest frequency and variations of flood hazards. Not all flood events in the communities have been documented, and site visits identified additional hazards.

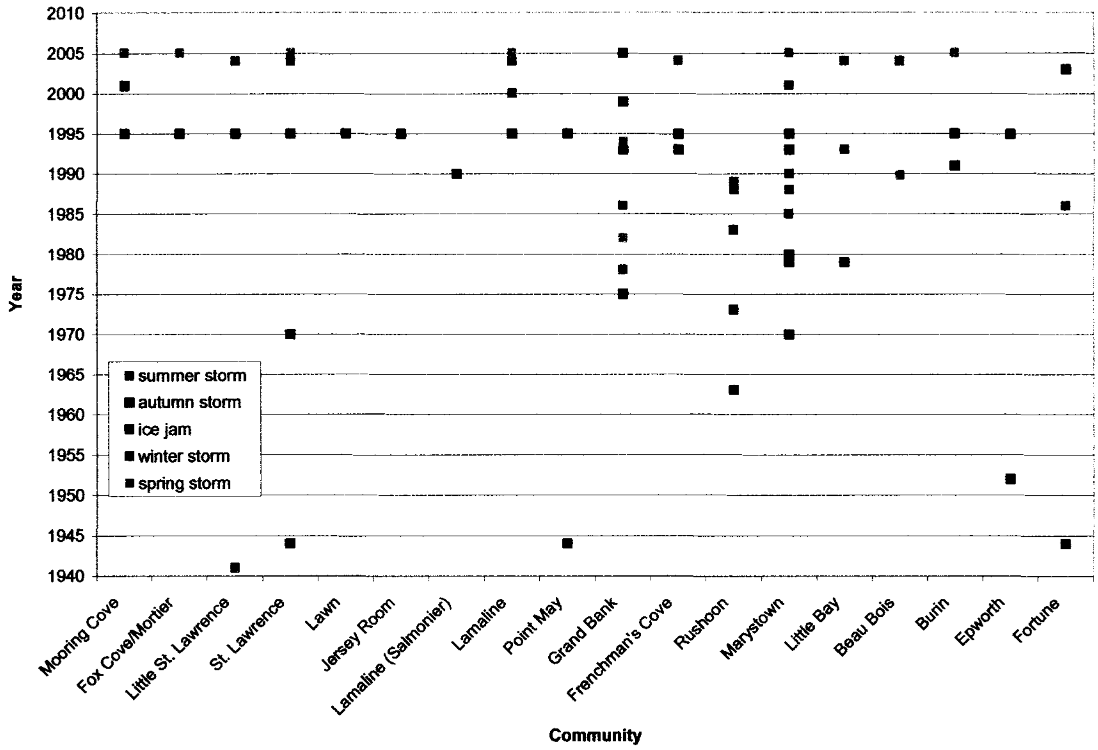


Figure 6.1: Flooding frequency of communities on the Burin Peninsula as identified from archival research and personal communications. The most significant natural flooding mechanism is specified for each event.

Due to the large geographical distribution of communities on the Burin Peninsula, different communities are affected by different storm events. The Burin Peninsula faces the southwesterly winds which deliver many of the intense and damaging storms. Communities on the Fortune Bay coast experience similar flooding hazards, but differ in timing.

6.1. Placentia Bay Coast

6.1.1. Hurricane-induced rainfall and storm surges

Due to the openness of Placentia Bay to the prevailing southwest winds, hurricane-induced rainfall and storm surges are frequent flood hazards. Rainfall causes the overflowing of rivers and drainage systems. Storm surges cause coastal flooding and tidal impoundment of lagoons. Rainfall coupled with storm surges prevent river flow into the ocean.

Between 1989 and September 2005, eleven hurricanes and tropical storms impacted the Burin Peninsula. Damage is usually minor and is attributed to failure of drainage systems. Damage was caused by Bob (1991), Felix (1995), Luis (1995), Opal (1995), Hortense (1996), Gert-Harvey (1999), Irene (1999), and Michael (2000). The year 1995 was a hyperactive year with three hurricanes, Felix, Luis, and Opal, which heavily impacted the Placentia Bay coast. Influence of Hurricane Irene on the Fortune Bay coast communities are described in section 6.2.7.

Hurricane Felix (early September 1995) caused rivers in the Salt Pond area (Town of Burin) to overflow. Overflowing of the river behind the College of the North Atlantic resulted in damage to the college infrastructure.

Areas of Concern

6.1 The barachoix adjacent the "Meadow" in Lamaline. The area to the left of the picture frequently floods due to storm surges. The cribwork seen in the photograph was installed after the January 2000 storm surge. UTM 590250E 5190250N. Date: September 2003.

6.2 Riverhead Brook in St. Lawrence at the intersection of Riverside Drive, Harbourview East, and Harbourview West. Note the sediment under the bridge and the debris on the fence (right side). Photograph taken in summer 2003. During heavy rainfall water becomes impounded behind the bridge and water overflows onto the surrounding area. UTM 351130E 5197840N.

6.3 Access road leading into Rushoon. Rushoon River is located on the left. Note the sinuosity of the guardrail; the river is undercutting the roadbed. This section of the river is susceptible from damages from ice jams. ATM unknown. Date: September 2003.

February 2004 storm surge

6.4 Destroyed infrastructure in Lamaline resulting for the February 2004 storm surge. Photograph courtesy of *Southern Gazette.* Taken February 2004, exact location unknown.

6.5 Damage in St. Lawrence caused by the February 2004 storm surge. A fishing shed is missing from the wharf in picture 8.7. The debris can be seen in picture 8.10. Photograph courtesy of *Southern Gazette.* UTM 351190E 5197235N

March 2005 Rain-on-snow event

6.6 Flooding of the Marystown Recreation Field due to a river overflowing during the March 2005 rain-on-snow event. UTM 639500E 5226150N

6.7 A lounge located in the Penny's Pond area (Town of Burin) that was inundated during the March 2005 rain-on-snow event. Note the high water mark on the building. UTM 63920E 5211050N.

6.8 Complete failure of the road near of Greenings Hill between the Town of Burin and Fox Cove-Mortier caused by high river flows in March 2005. The cut is approximately 17-m in length. UTM 640500E 5216000N.

6.9 Flooding of Riverhead Brook in St. Lawrence. The view (looking north) shows the extent of the flooding. The Fire Hall (top right corner) the bank (top left corner), the Seniors Club (centre top), and private homes were flooded. UTM 35130E 5197840N. March 30, 2005.

The impact of Hurricane Luis caused the greatest amount of monetary damage documented on the Burin Peninsula (*Southern Gazette*, 19 September 1995). Roads, sewer lines, and private property were damaged by the heavy rain and storm surge. Most communities on the Placentia Bay shoreline endured damage. In Marystown, damage consisted of roads, a collapsed bridge, and the flooding of several basements and private property (*Southern Gazette*, 19 September 1995). The other communities suffered less costly, but still significant damages. As examples, damage to roads and basements occurred in the towns of St. Lawrence, Fox Cove-Mortier, Epworth, and Lawn. Also, sections of Highway 220 were severed near Point May and Lamaline.

Runoff draining the surrounding backcountry area of Marystown caused many rivers within the community to overflow. Improper maintenance of culverts under Highway 220/Columbus Drive prevented the flow of water through Hynes's Brook thereby causing water to cascade over the highway and flooding Brake's Brook, homes, businesses and Ville Marie Drive (resident Wally Drake, and Marystown town manager Dennis Kelly, personal communication, 2003). The rainfall increased the runoff from backcountry areas and marshland causing streams in Fox-Cove, Epworth, St. Lawrence, and Point May to trigger localized flooding. Runoff from impermeable areas resulted in damage in the previous communities in addition to Lawn. In Lamaline, storm surges and the impoundment of water in the lagoon degraded the highway through the community.

In response to the frequency of hurricane activity, many streams on the south coast of the Burin Peninsula entering Placentia Bay are characterized by narrow floodplains and flood-inundated slopes as a result of hurricane-induced river flooding. Examples of such rivers are the Salmonier River in West Lamaline; the St. Lawrence River in St. Lawrence; the Rushoon River in Rushoon (Canada-Newfoundland Flood Damage Reduction Program, 1990); and small brooks in Point May, Lord's Cove, Taylor's Bay, Lawn, Little Lawn Harbour, Little St. Lawrence, Corbin, Fox Cove, Jean de Baie, and the communities surrounding Burin Bay Arm (including Burin) and Mortier Bay (including Marystown and Creston). Flood damage adjacent to these rivers is primarily caused by bank erosion creating debris blockages and impoundment of water. Debris blockages led to flooding in Marystown, St. Lawrence, Epworth, and Fox Cove-Mortier (e.g. Hurricane Luis; *Southern Gazette*, 19 September 1995; *Southern Gazette*, 3 October 1995). Large flood events significantly alter fluvial systems through erosion, deposition, and channel changes which may occur over a few days a year (Ashmore and Church, 2001). Therefore, severe storm events lasting a few days may cause persistent modifications to river processes and morphology (Ashmore and Church, 2001).

6.1.2. Winter storm surges

Southeast winds induce storm surges in many of the communities on the Placentia Bay coast, notably the shoreline between Lamaline and Taylor's Bay. Winter storm surges cause coastal flooding, impoundment of lagoons, and coastal ice jams. Storm surges are a significant hazard for many of the coastal communities. Two recent events occurred on January 2000 and February 2004.

On 22 January 2000, several locations within Lamaline were flooded (*Southern Gazette*, 1 February 2000; former Town Clerk Shelley Lovell, personal communication, 2003). The "Meadow" area, several homes, and Highway 220 flooded. Three main areas of vulnerability are the causeway to Allan's Island, the "Meadow", and the Muddy Hole area. The vulnerable section of Highway 220 and the "Meadow" are adjacent to the Allan's Island Causeway. The "Meadow" is a section of land which separates the barachoix from the ocean. The land is approximately 50 m wide and is susceptible to flooding on both the ocean side and the barachoix side. Storm surge waves wash the ocean side while water becomes impounded by the enhanced sea level and inundates the barachoix side. Highway 220, several houses, and additional infrastructure are located in the "Meadow", surrounding the barachoix, and on the causeway. Frequently, two houses in the "Meadow" have been damaged by storm surges. The causeway between Lamaline and Allan's Island was damaged, stranding residents on the island. After the incident, crib work was placed along the shoreline and the barachoix to prevent future flooding events. Major flooding, such as that in January 2000, has occurred in approximately 1 in 13 years since 1985; minor flooding occurs 3-4 times a year (Lamaline resident, Freeman Stacey, personal communication, 2003). Point au Gaul, Lord's Cove, and Taylor's Bay were impacted by the January 2000 event.

Flooding of communities along the Placentia Bay coast, but of lesser magnitude occurred in February 2004. In Lamaline, the seawall suffered partial failure and Highway 220, the "Meadow", and the causeway to Allan's Island was flooded. Residents were evacuated from "the Meadow" area. Within Beau Bois fishing wharves, stages, and breakwaters were damaged and destroyed by storm surges and transported ice floes. Houses within the town of Burin were damaged by storm surges and high winds. Also in Burin, flooding damaged coastal roads and wharves. In St. Lawrence stages and other coastal infrastructure was destroyed (Mayor of St. Lawrence, Wayde Roswell, personal communication; *Southern Gazette*, 5 April 2005).

The topography below sea level determines the degree of impact areas obtain during storm surges. The bathymetry of the Laurentian Channel, in part, may minimize the magnitude of a surge for the western portion of the south coast of Newfoundland; the shallower sea floor adjacent the eastern portion of the south coast increases the magnitude and damage of a storm surge. The topography of Lamaline Bay is relatively shallow, and therefore Lamaline and surrounding communities are significantly affected by storm activity (Murty and Greenberg, 1987).

6.1.3. Tsunami

Tsunami activity is an infrequent, widespread hazard for the Burin Peninsula. The tsunami of 18 November 1929 resulted in the deaths of 28 people and coastal damage in Burin Peninsula communities (Ruffman 1991, 1994).

Tsunami activity has not affected the Burin Peninsula since 1929. The 1929 tsunami was initiated by an earthquake (estimated 7.2 on the Richter scale) and a submarine landslide off the coast of Newfoundland, near the Grand Banks. On 25 January 2005, an earthquake (4.7 on the Richter scale) occurred in a similar location, although no evidence of a tsunami or damage has been reported.

6.1.4. Temporary impoundment of water

Temporary impoundment of areas, such as "The Pond" in Lord's Cove and Penny's Pond area in the town of Burin, causes localized flooding. The combination of heavy rain and high tide prevents the water from draining to the ocean. Therefore, water backs up and floods the surrounding land.

"The Pond" is vegetated with bur-reeds (*Sparganiaceae*) and has a small outlet to the ocean. A small stream flows through the reed bed. During heavy rain, a greater flow of water enters "the Pond". High tides or storm surge conditions prevent the water from draining. Water overflows the lower end of "the Pond" and flooding homes nearby (town council member of Lord's Cove, Peter Hannaberry, personal communication, 2003).

Penny's Pond was in-filled prior to 1980. The stream that previously flowed into the pond is culvertized and flows directly into the ocean. Heavy rain increases the water flow and high tides prevent the escape of the water. The result is flooding of the park (located over the former pond), a lounge, two roads, and houses. Flooding occurred 8-10 times within a 25 year period (Mayor of the town of Burin, Kevin Lundrigan, personal communication, 2003). An increase in the severity and frequency of flooding could result if the culvert system is not maintained or upgraded. In summer 2003, the culvert was constricted by 30% due to an accumulation of debris. The site visit in April 2005 revealed the partial blockage of the culvert system, which may have aided in the severity of the March flooding.

The coastline configuration may enhance the impact of the storm surges. When the winds focus the energy into a lagoon, the surrounding land restricts water flow and inland inundation occurs. Lamaline is susceptible to this style of flooding. In situations where the storm surge is not confined by land, inland flooding is not as extensive.

6.1.5. Ice jams

Ice jams induce few flooding events on the Placentia Bay coast, and flooding is confined to localize areas upstream or downstream from the jam. Damage to infrastructure is caused by both water and ice flow. Rushoon Brook has a history of flooding and extensive damage to infrastructure along the river bank. Major floods occur on the lower reaches of the brook (ShawMont Newfoundland Limited, 1989).

Ice jams in 1973 and 1983 occurred in areas located near a natural rock dyke that influences flow patterns. Shallow areas and areas of static ice cover are susceptible, particularly in the lowermost reach where the ice becomes grounded at low tide.

Anthropogenic effects contribute to the ice jamming. In 1973, one of the two ice jams occurred between the abutments of the old concrete bridge which used to span Rushoon Brook. The widening of the Rushoon Access Road in 1963 decreased the width of the river by infilling, and the road was subsequently flooded in late 1963.

Ice jams also occurred in this section of the river in 1973. Water from Rushoon Brook inundated much of the area lying between the main road through the community and the brook. Eight homes were flooded with water to depths of 0.3-0.6 m above the ground adjacent to the homes, which was sufficient to flood basements and/or reach ground floor elevations. Impact of ice debris caused damage to fences, sheds, and equipment. In 2006, damage is limited to flood stages higher than the fender wall (2.5-m), which was constructed to contain "10-year" flood events, considered as those greater than the 1983 event.

On the Burin Peninsula, rivers prone to ice jamming resulted in flooding when infrastructure was placed in the river and obstructed ice flow. Bridge abutments placed in the river caused an ice jam in the Rushoon River in 1973. Future ice jams and flooding were eliminated in that area when the abutments were removed. A bridge over Little Salmonier River (Lamaline) caused an ice jam and induced flooding. The bridge was replaced by a higher bridge and future flooding events were avoided.

The northwesterly wind will carry marine and river ice away from the shore on the Placentia Bay side of the Burin Peninsula. The dominant southeasterly winds on the Placentia Bay shore (e.g. at Rushoon) contribute to coastal ice jamming in those communities. Coastal ice jamming near Rushoon is lessened by Davis (Elizabeth, Flat) Islands and Jude Island offshore. The southeasterly winds subject the islands to ice jamming and the islands limit the effectiveness of the wind at inducing ice jamming at the mouth of Rushoon River.

6.1.6. Spring storms

Spring storms coupled with frozen or snow covered ground increase the severity of damage. A series of winter storms in March 2004 followed by mild temperature and heavy rainfall caused the disruption in traffic on the Burin Peninsula Highway 210.

The March 2005 rain-on-snow event led to a flooding pattern similar to flooding during Hurricane Luis. Communities from Marystown to Lamaline experienced flooding. In Marystown the recreation complex was inundated, a walking tail and private property near Jane's Pond, and several basements were flooded. In the town of Burin, the Penny's Pond flooded causing the main highway, and a additional road, a lounge, a house, and the recreational field to flood. Also in Burin basements were flooded. A ca. 17-m section of Greenings Hill was excavated by a normally small brook. In Fox Cove-Mortier, one of the two roads that were severed in September 1995 was again severed. Riverhead Brook in St. Lawrence filled with sediment and led to flooding of three houses, the soccer field, and the Water Street West and Water Street East intersection; Highway 220 and the intersection of Park Lane was flooded; a bridge leading to Salt Cove Brook was washed-out stranding two families; basements were flooded on Fairview Avenue; catchbasins overflowed. Highway 220 in the vicinity of Taylor's Bay flooded. A 500-m section of road leading into Point au Gaul was inundated, preventing residents from entering or leaving the community. Rivers were widened and banks heavily eroded, small streams formed in heavy runoff areas, and "bog bursts" occurred. The partially frozen wetland and snow cover in the backcountry may have transported much of the runoff from these areas to lower elevation, coastal areas. Several sections of Highway 220 were eroded by the heavy rainfall and melting snow. The amount of precipitation measured 235 mm in two days in Salt Pond.

6.1.7.Beaver activity

In Little Bay, in August 1993, a rainstorm caused a beaver dam to break. The result was the flooding of a lounge and the transport of debris into a cemetery (*Southern Gazette*, 3 August 1993). Flooding has occurred in the area in the past.

6.1.8. Slope failure

One instance of slope failure resulting in flooding on the Burin Peninsula occurred along Stine's Road in Little Bay. Over saturation of a hillside caused by the heavy precipitation from Hurricane Luis (1995) triggered a small debris flow. The debris damaged one house (Marystown town manager, Dennis Kelly, personal communication).

6.10 The fender wall in Rushoon constructed to protect the community from flooding caused by ice jams. UTM unavailable. Date: September 2003.

6.1.9. Anthropogenic factors

Human activities may directly or indirectly contribute to floods in communities on the Placentia Bay Coast. Activities such as improper or infrequent maintenance of infrastructure, design of infrastructure, diversion or modification of natural drainage, the location of individual structures/buildings, and settlement plans and forms have contributed to flooding events.

A major indirect cause of flooding in many communities on the Placentia Bay Coast is the ineffective drainage of water. The poor maintenance of culverts and ditches decreases the speed in which water can be removed from an area. From site visits, it was observed that many metal culverts are rusted and caving in. Concrete culverts are crumbling, and ditches and catch basins are filled in with debris. Flooding may also occur in areas where culverts are not large enough to cope with heavy rainfall. When damage has occurred, the problem generally is repaired rather than preventative measures taken.

In St. Lawrence, a series of culverts were replaced in late autumn 2003 due to frequent floods caused by the culverts' inadequacy to remove water during heavy rainfall. The water leading into Riverhead Brook overflowed the highway on several occasions and the area surrounding a bridge further downstream. The bridge constricts water flow, and the area below the bridge is reduced by 30% due to siltation. The silt cannot be dredged, as Riverhead Brook is a trout run and Fisheries and Oceans Canada regulations prohibit such alterations of fish habitat (Mayor of St. Lawrence, Wayde Roswell, personal communications, 2003). One of the new culverts has partially collapsed (winter 2003) due to improper instillation and is in-filled with debris flowing down the stream which enters the culvert. During the 21 December 2004 winter storm, private property adjacent to the bridge was inundated with water, and no flooding occurred in the vicinity of the new culvert system. Flooding did occur during the March 2005 rain-on-snow event. The culvert system was partially damaged and may cause flooding in a future event.

During Hurricane Luis, extensive damage and flooding occurred in Drake's Cove (Marystown) due to a blocked culvert (*Southern Gazette*, 19 September 1995; Wally Drake and Marystown Town Manager Dennis Kelly, personal communications, 2003). Hynes' Brook flows under the Highway 220 and into the cove. The culvert under the highway became blocked during a previous rain storm, possibly Hurricane Felix. Although the debris was removed, blockage reoccurred during Luis. The water was then transferred to the next culvert downstream under Highway 220, carrying water from Drake's Brook to the cove. When the culvert became constricted with debris, water flowed over the highway washing away all infrastructures between Hynes' Brook and Drake's Brook, with the exception of one house.

The river located behind the College of the North Atlantic in the town of Burin (Salt Pond) has flooded on several occasions causing damage to the school (*Southern Gazette*, 6 October 1991). The damage was repeated in early September 1995 (Hurricane Felix).

A large section of the river has been culvertized and flows under the college and parking lot. When the maximum capacity of the culvert is reached, the water flows into the building and gouges the pavement of the parking lot.

The use of gravel in winter road maintenance changes the sediment gravel size in areas downstream from stream crossings. Flooding has not resulted from increased sedimentation. However, rivers passing through Jean de Baie and Spanish Room on the Burin Peninsula contain areas of road gravel in downstream areas (Catto and Hickman, 2004).

The population is not increasing in many Placentia Bay communities, and therefore flooding associated with the construction of homes uphill or closer to shore is not a concern. Marystown had recently undergone a population increase, due to the employment created by the White Rose Project. The new residents rented vacant apartments and homes rather than constructing new buildings. Flooding may increase in the Marystown area if the headwaters are cleared.

6.2. Fortune Bay Coast

Many of the mechanisms that cause flooding on the Placentia Bay coast are present on the Fortune Bay coast. However, flooding events are commonly not synchronous and of equal magnitude throughout the Burin Peninsula. For instance, Hurricane Luis had little effect on the Fortune Bay coast, whereas the June 1986 storm event only affected the

Fortune Bay communities. Autumn and summer storms are critical hazards on the Fortune Bay coast.

6.2.1. Summer storms

In June 1986, communities on the Fortune Bay coast experienced a heavy rainfall, 76 mm in a 24 hr period, causing extensive damage (*Southern Gazette*, 18 June 1986). In Grand Bank, several basements in residential areas were flooded. Fortune suffered damage to the sewer system, necessitating almost complete replacement. Loggerhead Brook, which meanders directly through Fortune, overflowed and destroyed many culverts. Many streets, such as Bayview Street, Cemetery Road, and Confederation Street, and property near the brook on these streets were damaged. The closure of Bayview Street prevented workers reaching their place of employment at Fishery Products International.

6.2.2. Autumn storms

The Fortune Bay coast is subjected to autumn storms. In early October 1993, Grand Bank was reported as the hardest hit community as 76 mm of rain fell in a 12 hr period (*Southern Gazette*, 5 October 1993). Over a dozen homes experienced flooded basements due to sewer back-ups and runoff eroding properties. Frenchman's Cove Pond overflowed its banks and eroded the sides of the highway.

6.2.3. Ice jams

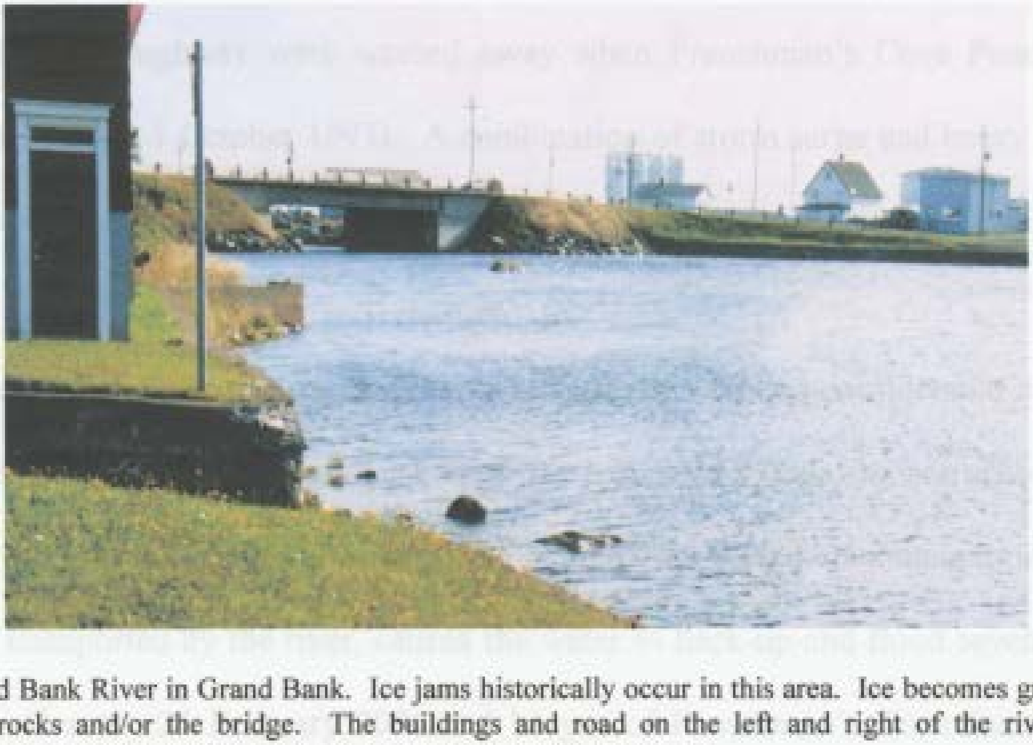
Main Brook (Great Grand Bank River) flows through the center of the community of

Grand Bank. The river has an infrequent history of flooding, approximately 1-2 times in the last 10 years (Grand Bank Town Manager Wayne Bolt, personal communication, 2003). Streets and 2-3 buildings which border the river have been subjected to flooding and damage by the ice slabs and water. In 1911, an ice jam occurred on the river, crushing many of the boats that were docked at the mouth of the river (*Southern Gazette*, 5 April 1911). The most recent event occurred in the 1980's.

Garnish River in Garnish has undergone ice jams, but the events are not considered a threat by municipal officials (Mayor of Garnish, Melvin Francis, personal communication, 2005). The ice jams occur in the portion of the river located away from homes. Break up occurs when the ice reaches the mouth of the river where homes and roads are located. A change in the river dynamics or construction of infrastructure in areas where the ice jams do occur may increase the flooding and ice activity hazard near Garnish River. Previous field studies conducted by Catto on the Burin Peninsula revealed ice damage to vegetation along rivers in Fortune.

River systems carrying ice flow into the northwesterly wind may result in ice jamming due to the northwesterly wind forcing the ice on shore. Coastal ice jams form in the outlets of Fortune Bay originate from river or lagoon ice accumulated by strong wind and no marine ice component is present. The ice formed on the Garnish River (in Garnish) and Frenchman's Cove River (Frenchman's Cove, Burin Peninsula) accumulate at the mouth of these rivers and form ice jams because of dominant northwesterly winds (Catto

6.11 Frenchman's Cove River in Frenchman's Cove. The river is flowing northward with the mouth near the top of the photograph. During the February 2004 storm surge, the low banks were overtaxed and 12-15 houses adjacent to the river were inundated. UTM 349800E 5230890N. Date: May 2004.



6.12 Grand Bank River in Grand Bank. Ice jams historically occur in this area. Ice becomes grounded on the rocks and/or the bridge. The buildings and road on the left and right of the river become inundated. UTM 323510E 3217410N. Date: September 2003.

and Hickman, 2004). The Fortune Bay coast is open to the respective dominant winds, and small amounts (if any) of coastal ice form off the coast of the Burin Peninsula (Environment Canada, 2005). Coastal ice generally has not been significant along the Burin Peninsula shoreline since 1992 (Catto *et al.*, 2003).

6.2.4. Storm surges

Due to the low-lying topography of Frenchman's Cove, the area is vulnerable to damage caused by storm surges (Mayor of Garnish, Melvin Francis, personal communication). Highway 213 between Frenchman's Cove and Garnish is frequently battered and inundated by high waves. On the other side of Frenchman's Cove, the road leading to Highway 220 also has a history of flooding. In October 1993, after a heavy rainfall, the shoulders of the highway were washed away when Frenchman's Cove Pond flooded (*Southern Gazette*, 5 October 1993). A combination of storm surge and heavy rain may isolate the community.

The February 2004 storm surge and heavy precipitation caused considerable damage to Frenchman's Cove. The strong longshore drift transported a large amount of sediment to the mouth of Frenchman's Cove River. The sediment deposited, in combination with the sediment transported by the river, caused the water to back-up and flood several houses (*Southern Gazette*, 24 February 2004 and Mayor of Frenchman's Cove James Cluett, personal communication, 2005).

In other areas where rivers discharge into coastal barachoix lagoons, the water that becomes temporarily impounded behind the barachoix induces flooding along the shores of the lagoon. Natural drainage through the gravel barachoix enhances flooding when the infiltration or the breaching of the gravel barrier is impeded by road or seawall construction. Other than Frenchman's Cove, Grand Beach and Garnish demonstrate this type of flooding.

Several communities along the Fortune Bay coast, including Grand Bank, Fortune, Grand Beach, and Garnish, have a high sensitivity to coastal erosion (Catto *et al.*, 2003), and these coastlines may suffer greatly during storm surges. The coastline on which the highway between Grand Bank and Fortune is built on is rapidly eroding away with each storm, with rates locally in excess of 30 cm/a. The reworked glacial deposits on which Grand Beach has been developed are subject to over-wash and will experience more rapid landward movement with increased sea-level (Shaw *et al.*, 1998). In Frenchman's Cove, a provincial park and golf course are constructed on a prograded gravel beach ridge, which may easily be eroded (Shaw *et al.*, 1998).

6.2.5. Beaver dams

In Frenchman's Cover River, beaver dams constricted water flow, forcing water to flood surrounding areas.

6.2.6. Soil composition

The composition of the soil underneath houses may contribute to flooding hazards during heavy rainfall events. Gyttja is a type of soil comprised of decomposed plant and animal remains (Myœliñska, 2003). Gyttja forms in fens, and terrestrial environments associated with the formation of bog peat and transition peat (Myœliñska, 2003). Due to formation process and high organic mater comprising the gyttja, the soil can retain high amounts of water. The water from rainfall does not easily drain from the soil; therefore, when the soil becomes saturated, pooling of water and flooding will result. Localized flooding events in Grand Bank have resulted from pockets of gyttja located under streets and houses. Gyttja is present in Corkum Place, Jamerson Ave., Main St., Marine Dr., and Hickman St. areas (local resident, personal communication). Basements and roads have flooded due to the inability of the water to drain from the soil, and therefore pool on the surface (*Southern Gazette*, 22 February 1978, 18 June 1986, 5 October 1993, 12 April 1994, 26 October 1999). The most recent occurrence of flooding in Grand Bank resulted from the continuous saturation of the soil from early month's rainfall, followed by a heavy rain storm in late March 2005 (Local residents, personal communication).

6.2.7. Hurricanes

The northeast and northwest facing communities located on the Fortune Bay coast are not exempt from hurricane-related flooding. Due to the low topography, southwesterly winds are able to move across the inland areas, and deposit precipitation throughout the headwaters of the short coastal streams. Rivers in Fortune, Grand Bank, Grand Beach, Frenchman's Cove, and Garnish are susceptible to this flooding hazard.

Hurricane Irene (October 1999) impacted Fortune Bay communities and infrastructure. Several basements within Grand Bank were flooded. Pumping was initiated to prevent the overloading of the sewer systems. Sections of the Grand Bank Highway 220 also sustained damage. Sides of the Frenchman's Cove intersection with Highway 220 were eroded from both sides constricting the flow of traffic.

6.2.8. Anthropogenic factors

Anthropogenic factors contributed indirectly to many flooding incidents. The populations of communities on the Fortune Bay coast are not increasing, and therefore clearing of land does not contribute to flooding. Nor is there a concern for flooding of low-lying land when infrastructure is constructed upslope. However, clearing of land and changing of natural drainage ways have implications. Many areas are surrounded by wetlands, and alterations in drainage pattern due to construction of cabins may increase the flow of water entering the river system near and in communities. For instance, anthropogenic activities within the watershed of rivers within Fortune may create additional flooding problems. Aging drainage infrastructure will be inefficient to remove water in the event of a heavy rainstorm and flooding will ensue.

Culverts have been placed under the highway near Frenchman's Cove turnoff to divert runoff from the highway and surrounding land into Frenchman's Cove Barachoix. The additional water has increased the flow into the Frenchman's Cove River and as a result, the river has a greater capacity for carrying silt and debris into the mouth of the river. During the February 2004 storm event the river carried a large amount of debris to the mouth of the river (*Southern Gazette*, 24 February 2004 and Mayor of Frenchman's Cove, James Cluett, personal communications). The water could no longer flow through the channel and backed-up, flooding 12-15 houses. According to Mayor Cluett, flooding of this magnitude had not occurred previously. Sediment deposited by longshore drift also aided in the flooding by blocking the river mouth.

Culverts in locations where bridges may be more efficient in transporting water underneath roadways contribute to flooding during extreme rainfall events. Two brooks that flow on opposite sides of Fortune periodically flood the road leading out of the community (Fortune Town Clerk Basil Collier, personal communication, 2005). Both culverts which provide drainage for brooks, Clawbonny Brook on the east side and Fortune Brook on the west side, have been repaired within the last 5 years. The most recent flooding of Fortune Brook occurred in November 2003. The section of the road 150-200 m over the river was washed out in October 2003 and the temporary road was washed out in November (*Southern Gazette*, 28 October 2003). Several 0.9 m culverts were replaced by a large half circle culvert in late December 2003. Clawbonny Brook last damaged Route 220 in January 2000. The culvert has since been repaired and reinforced by gabion cages.

6.3. Summary

Due to the large geographical distribution of communities on the Burin Peninsula, different communities are affected by different storm events. Hurricane Luis (11 September 1995) devastated many of the communities on the Placentia Bay coast, but had little affect on the Fortune Bay coast. In 1986, a storm which caused damage to the Fortune Bay coast had no effect on the Placentia Bay coast.

6.3.1. Importance of different flood mechanism

Flooding events on the Burin Peninsula can be divided by seasonal storm or specific mechanism. The flooding events and associated mechanisms are listed in Figures 6.2 through 6.5. Because not all mechanisms are independent, some flooding events may be classified under more than one category. For example, a rain-on-snow event may also fall under winter or spring storm depending on the season. On the Placentia Bay coast 79 incidents caused by natural mechanisms were recorded and 29 on the Fortune Bay coast. Autumn storms with associated storm surges and heavy precipitation are a significant hazard for both the Placentia Bay and Fortune Bay coasts. Autumn storms (September-November) are related to 14% of flooding events on the Placentia Bay coast (Figure 6.2). Hurricane-induced storm surges and rainfall are specific events that have resulted in approximately 22% of the flooding events. Hurricane Luis caused a substantial number of flooding events in communities on the Placentia Bay coast. Winter storms (December-February) associated with storm surges, heavy precipitation, snowmelt, and pooling of water is the third greatest recorded hazard (15%) on the Placentia Bay coast, which was tied with rain-on-snow events. Although only one major rain-on-snow event occurred on the Placentia Bay side of the Burin Peninsula, it caused widespread damage. Storm surges are significant (10%) coastal flooding causing widespread infrastructure deterioration. Storm surges occur more frequently than recorded by local newspapers. Spring storms (March-May) are associated with heavy precipitation, rain-on-snow events, and flooding caused by rapid snowmelt. Minor damage, 9% of flooding events, result from spring storms. Summer storms (8%) deposit heavy precipitation in short periods of time. Ice jams are of local importance in Rushoon, where flooding occurs frequently (6%). Beaver dam flooding and slope failure causing flooding (1%) occurs rarely and affects only localized areas.

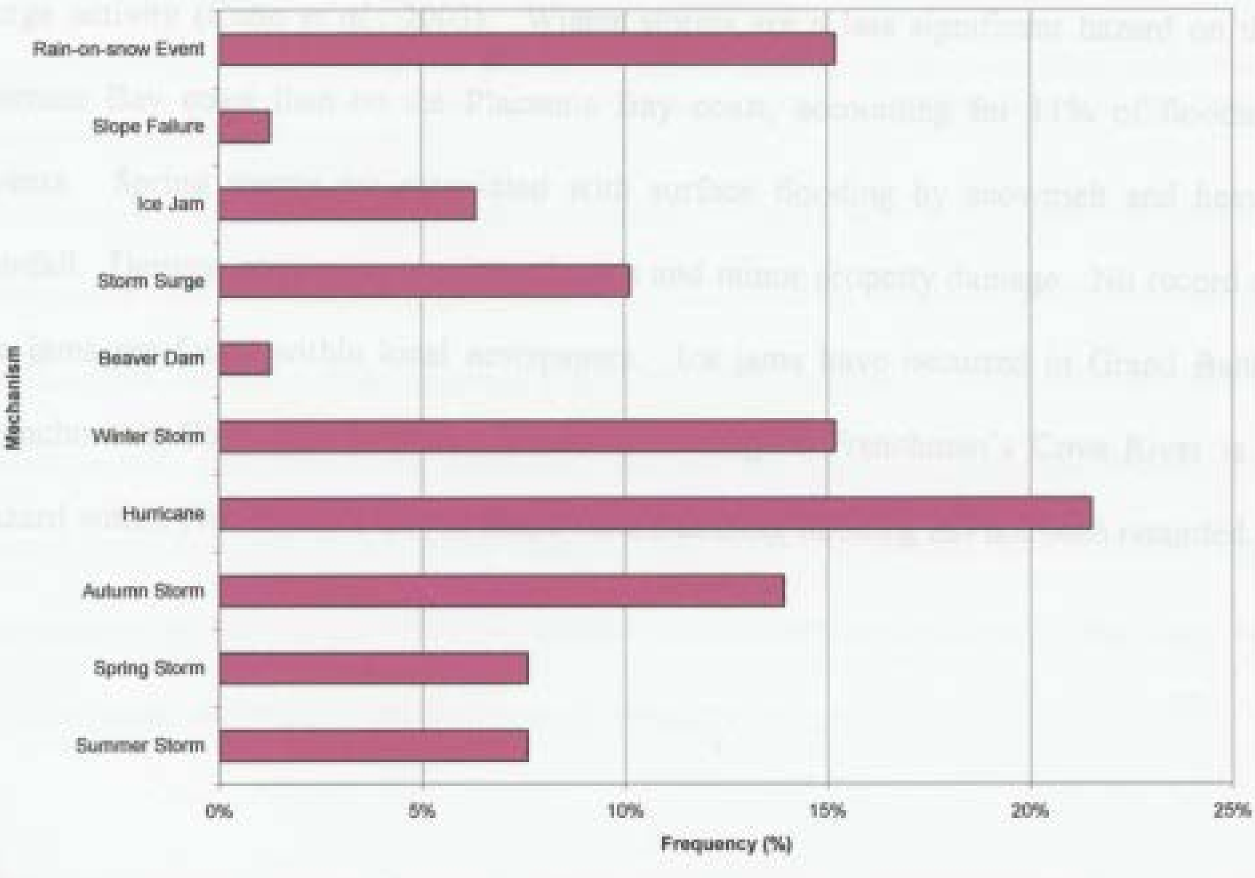


Figure 6.2: Frequency of flooding events caused by natural mechanism on the Placentia Bay coast. Flood events were recorded in archives. Events may be counted more than once depending on mechanism. Number of recorded incidents equal 79.

In contrast, on the Fortune Bay coast summer storms contribute to more flooding events (21%) than the Placentia Bay coast (9%). Autumn storms (32%) and hurricane activity (21%) in the form of heavy rainfall complete the top three hazards. Hurricane Irene (October 1999) impacted communities on the Fortune Bay coast The summer storm of 1986 also caused extensive damage. The heavy rainfall resulted in damage ranging from washout of roads to the complete removal of a section of a sewer system. Storm surges impact vulnerable coastlines such as Frenchman's Cove (Shaw *et al.*, 1998). During high tides, the community is below sea level and susceptible to flooding, especially the highway between Garnish and Frenchman's Cove. Grand Beach, due to topography and sediment composition, is susceptible to erosion. Bay L'Argent is vulnerable to storm surge activity (Catto *et al.*, 2003). Winter storms are a less significant hazard on the Fortune Bay coast than on the Placentia Bay coast, accounting for 11% of flooding events. Spring storms are associated with surface flooding by snowmelt and heavy rainfall. Damage appears as erosion of roads and minor property damage. No record of ice jams are found within local newspapers. Ice jams have occurred in Grand Bank, Frenchman's Cove, and Garnish. Beaver damming of Frenchman's Cove River is a hazard within Frenchman's Cove. Slope failure causing flooding has not been recorded.

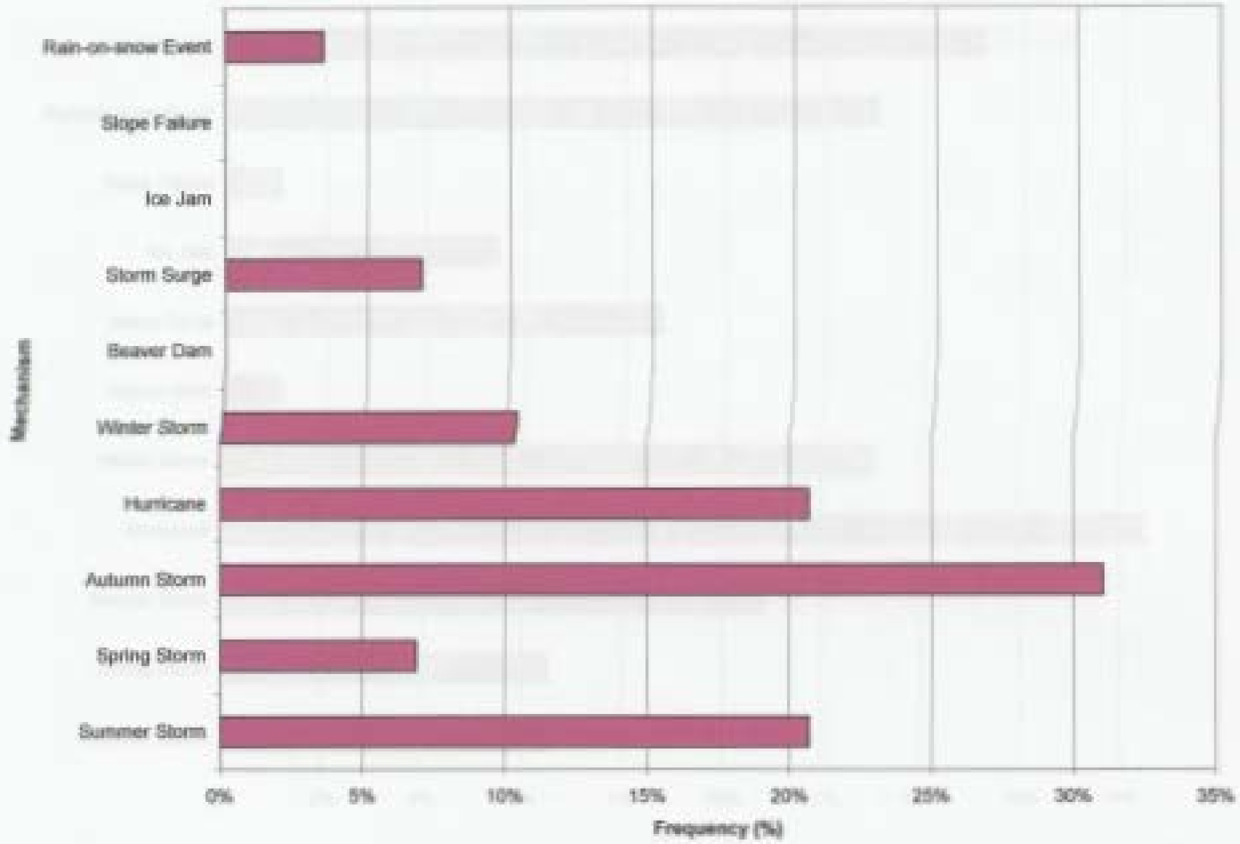


Figure 6.3: Frequency of flooding events caused by natural mechanism on the Fortune Bay coast. Flood events were recorded in archives. Events may be counted more than once depending on mechanism. Number of recorded incident equal 29.

In Figure 6.4, the same mechanisms of flooding events are used as in Figure 6.2, with the addition of anthropogenic affects. Anthropogenic flooding events coupled with natural mechanisms are the second frequent cause of flood damage. Ninety-two natural and anthropogenic incidents were recorded. The natural hazard of hurricane activity has caused more flooding events on the Placentia Bay coast than human activity (18%). The combination of hurricane-related precipitation and inadequate drainage infrastructure has induced many of the recorded instances of damage.

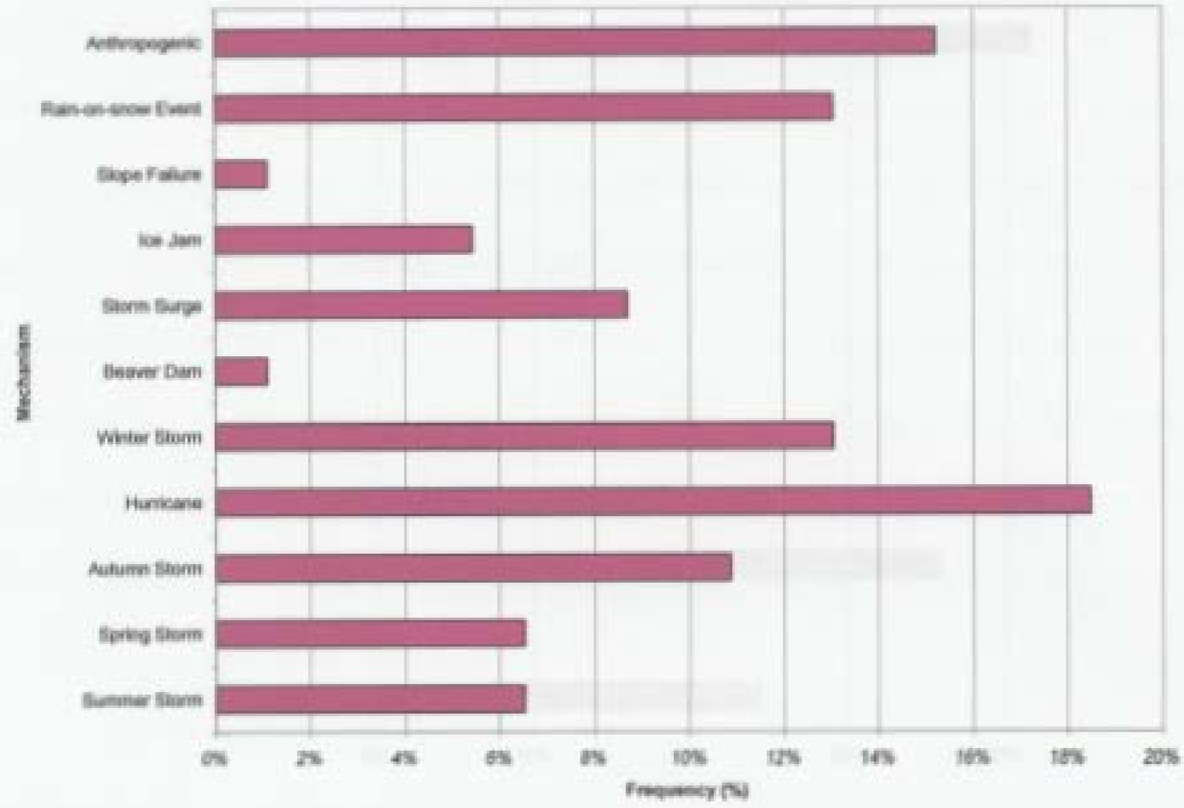


Figure 6.4: Frequency of flooding events caused by natural mechanism and human activities on the Placentia Bay coast. Flood events were recorded in archives. Events may be counted more than once depending on mechanism. Number of recorded incidents total 92.

Anthropogenic influenced floods on the Fortune Bay coast in Figure 6.5 is an addition to values of the natural hazards in Figure 6.3. The total number of all incidents is 35. Twenty-six percent of floods in communities on the Fortune Bay coast have an anthropogenic component. On the Fortune Bay coast, anthropogenic activities (26%) and autumn storms (24%) are major causes of flooding. Thus, anthropogenic activities coupled with natural events result in significant flood vulnerability on the Fortune Bay coast. Destruction of roads due to inadequate drainage and water build-up frequently appear in historical records.

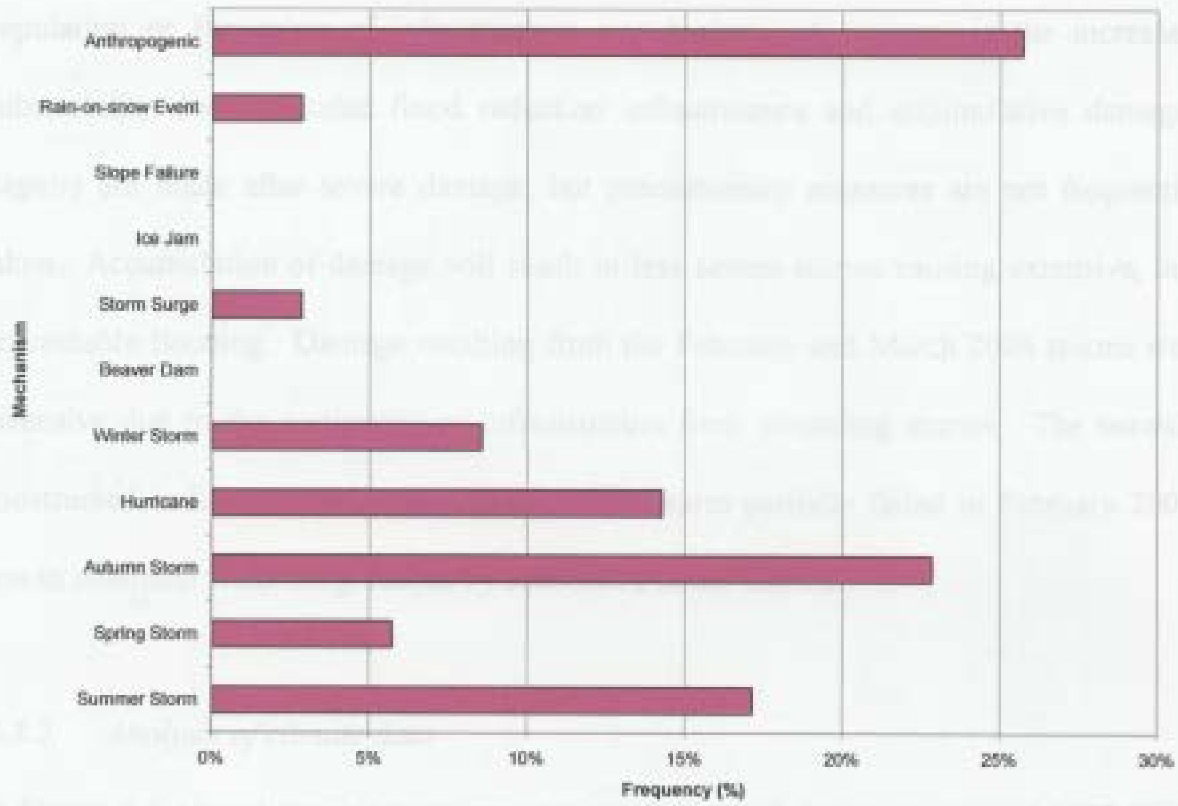


Figure 6.5: Frequency of flooding events caused by natural mechanism and anthropogenic factors on the Fortune Bay coast. Flood events were recorded in archives. Events may be counted more than once depending on mechanism. Number of recorded incidents total 35.

In general, storm surges and hurricane activity are a more prevalent hazard on the Placentia Bay coast. Early summer storms represent a significant hazard on the Fortune Bay coast.

Areas north of Mooring Cove are less represented in the archives than the other communities on the Burin Peninsula. Indicating occurrence of fewer flooding events, or that fewer events are reported. Site visits found few major flood hazards, but damage to the shoulders of roads due to running water is common.

Damage may have been more extensive if communities on the peninsula had a greater population or the value of infrastructure was higher. A concern is the increased vulnerability due to eroded flood reduction infrastructure and accumulative damage. Repairs are made after severe damage, but precautionary measures are not frequently taken. Accumulation of damage will result in less severe storms causing extensive, but preventable flooding. Damage resulting from the February and March 2004 storms was extensive due to the weakening of infrastructure from preceding storms. The seawall constructed in Lamaline after the January 2000 storm partially failed in February 2004 due to continual weakening caused by successive minor storms.

6.3.2. Analysis of climate data

In Figure 6.6 annual precipitation amounts are calculated during the period 1967-2003 from St. Lawrence weather station (Environment Canada website); St. Lawrence contains the longest monitoring station on the Burin Peninsula. Climate data is unavailable for 1997 and 1998 due to a temporary disruption in monitoring at the St. Lawrence site. Total precipitation amounts are available for 1999-2003. Flooding events caused by river flooding due to ice jams, debris, beaver dams, and impoundment of lagoons and storm surges are not directly precipitation related. Therefore, these flooding events are not accurately represented in Figures 6.6-6.8.

The precipitation is dominated by rain. Snowfall totals on the Burin Peninsula average 5-15% of total precipitation for coastal sites and 10-20% for sites in the interior.

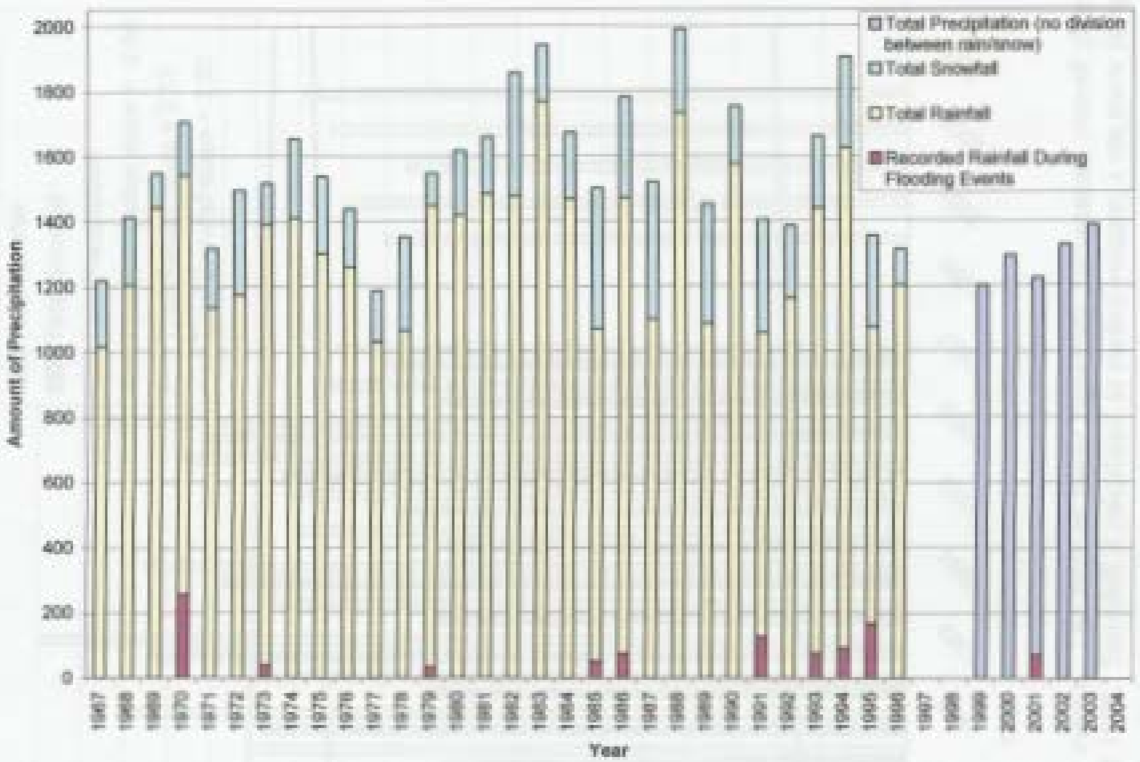


Figure 6.6: Amount of total annual precipitation and amount of rainfall during flooding events. No data available for 1997 and 1998. Data collected for St. Lawrence site on Environment Canada website. Snowfall amounts calculated as melt water equivalent, 1 cm snow equals 1 mm rain.

Changes in total rainfall and total snowfall are inconclusive for the Burin Peninsula. Between 1967 and 1996, both total annual amount of rainfall and precipitation appear to be increasing. The trend in annual rainfall and snowfall is based on data between 1967 and 1996. The figure does not incorporate snowfall and rainfall amounts from 1997-2005. In contrast to the increasing annual snowfall and rainfall amounts, the total precipitation for the 1967-2003 period shows a decrease of 100 mm. It may be assumed that either the amount of annual rainfall or snowfall has been declining as seen from the

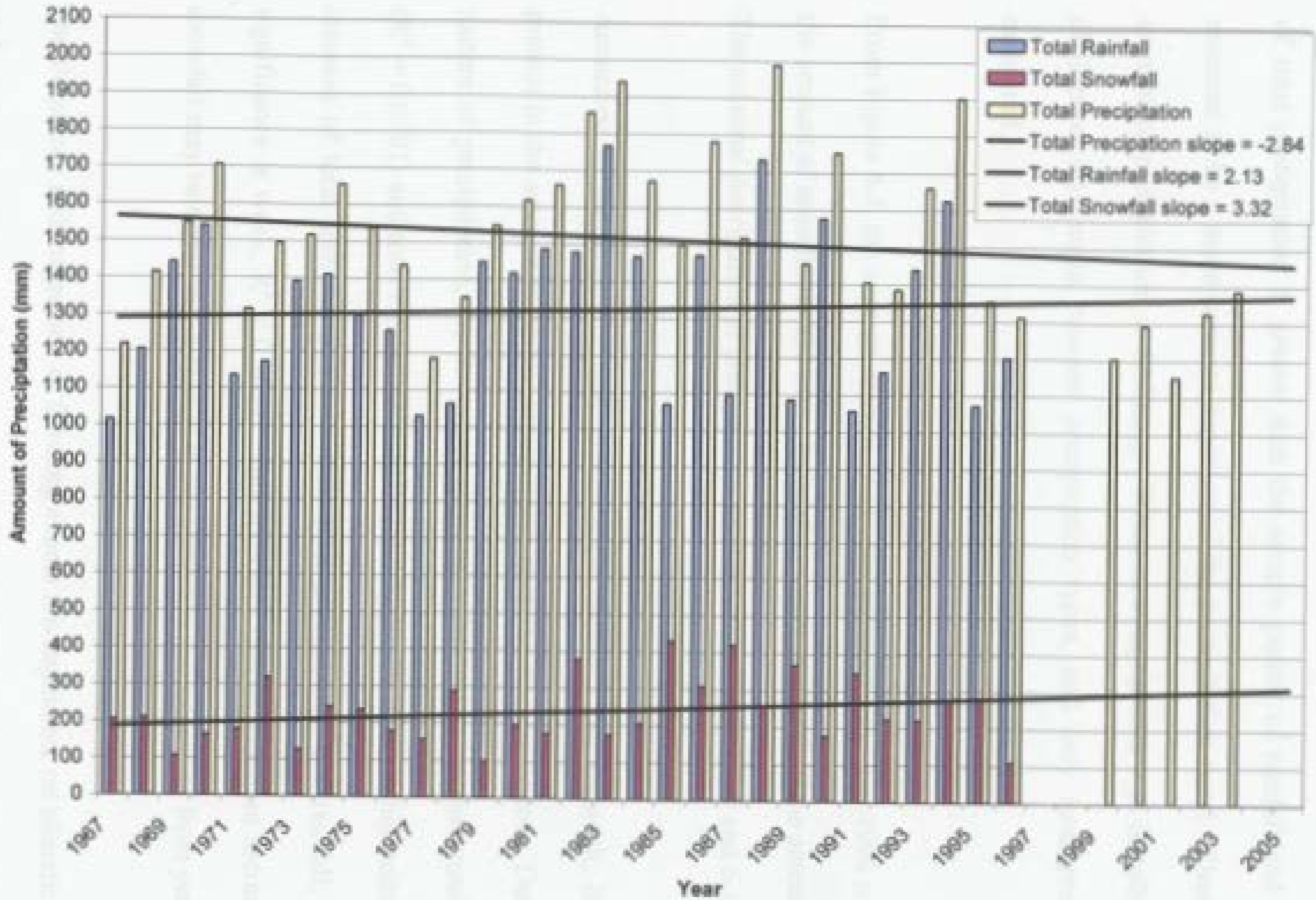


Figure 6.7: Amount of rainfall for each year and rainfall during flooding events. The lines of linear regression demonstrate overall change in total annual precipitation between 1967 and 2003. No data available for 1997 and 1998. Snowfall is calculated as melted volume; 1 cm snow is equivalent to 1 mm water. Amount of precipitation collected from Environment Canada for St. Lawrence site.

decrease in total precipitation between 1967 and 2003 (Figure 6.7). As the sample period of total precipitation is greater than the sample period of rainfall and snowfall, it is assumed to be a more accurate depiction of the precipitation trend. Therefore, the total amount of precipitation is declining. When new equipment was installed in 1999, no distinction was made between precipitation types, and only total precipitation was measured.

From Figure 6.7, the average amount of rainfall between 1967 and 1996 is 1320 mm and the amount of snowfall is 235 mm. Rainfall is much greater than the amount of snowfall. The seasonal distribution of precipitation can be seen in Figures 6.9 and 6.10.

According to the slopes of total precipitation, rainfall, and snowfall, little change is present in the amount of annual precipitation over the 40 year period. Due to the cyclic pattern of precipitation, the R^2 values show no relationship between total precipitation ($R^2 = 0.0191$) and total rainfall ($R^2 = 0.0073$). A greater relationship exists between the increase of total snowfall and time than total precipitation and rainfall; however, the significance is weak, $R^2 = 0.1039$. This indicates that although an increasing trend in snowfall may be occurring, a change in the pattern is still occurring from year to year.

The frequency and magnitude of flooding events are dependent on climatic factors, such as hurricanes and seasonal storms; low precipitation floods resulting from increased runoff related to anthropogenic activities are not a frequent occurrence. On the Burin

Peninsula, reported precipitation-related flooding events occur after a minimum rainfall of 46 mm (Figure 6.6). The large amount of vegetation, limited ground coverage by impermeable surfaces (e.g. pavement), and relatively flat topography may increase the amount of rainfall required to cause flooding events. Widespread flooding events are associated with hurricane events, which bring heavy rainfalls and wind, as well as storm surges which (e.g. February 2004) are not related with precipitation.

The average total annual precipitation is *ca*. 1556 mm (Figure 6.8). Climate change, in regards to total precipitation within the Burin Peninsula, may not appear to be a concern, although the possibility of increased precipitation during individual storm events is a significant factor. Climate change in the form of potential increased frequency of hurricanes and storm surges will have a great impact on the peninsula. The rainfall during flooding events is associated with storms and other climatic events. Both hurricane induced rainfall and storm surges have historically impacted the Burin Peninsula. Cumulative effects of frequent damage to infrastructure will increase the vulnerability of communities to flooding.

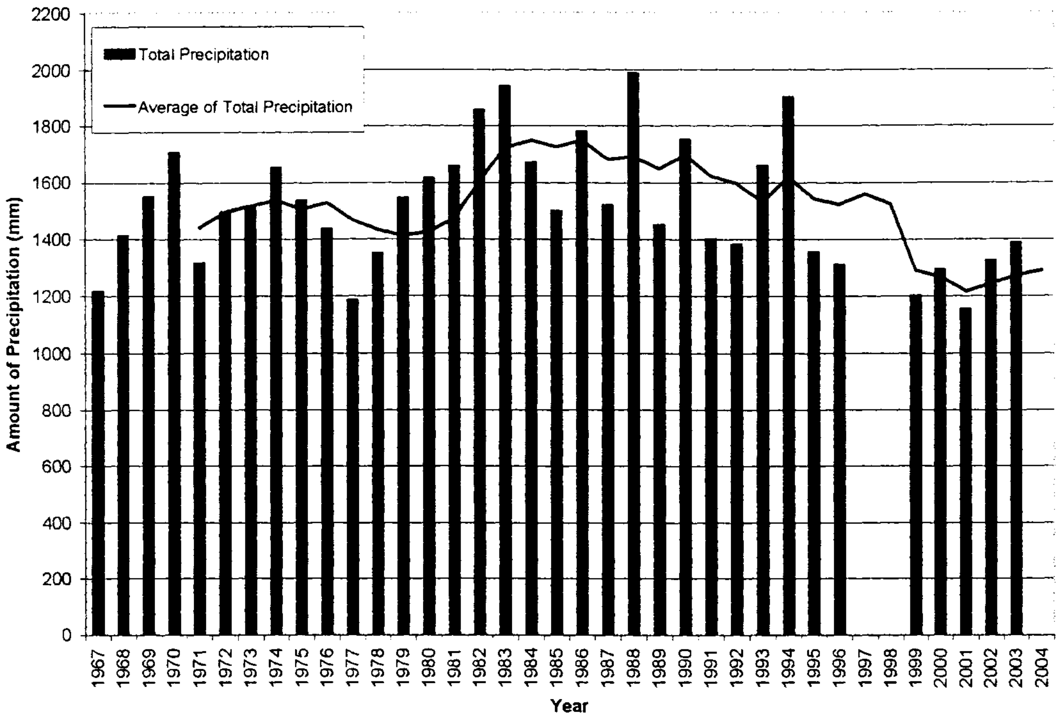


Figure 6.8: The amount of precipitation during flooding events for each year and the average precipitation during single rainfall events. Average precipitation is running average over 5 consecutive periods. No data available for 1997 and 1998. Data collected for St. Lawrence site on Environment Canada website. Snowfall amounts calculated as melt water equivalent, 1 cm snow equal 1 mm rain.

Seasonal precipitation patterns are demonstrated in Figure 6.9. Summer (June-August), autumn (September-November), winter (December-February), and spring (March-May) precipitation values are derived by calculating the running average of total precipitation for three months. The greatest amount of precipitation falls in September to November (Figure 6.9). This corresponds with the mechanism causing the greatest hazards, autumn storms and hurricane activity (e.g. Hurricane Luis). The period from December to February is marked by the second largest amount of precipitation. Winter storms associated with rainfall and mild temperatures are a numerically lesser hazard for both coasts than autumn storms and hurricanes. However, widespread storm surges and localized ice jams, which cause extensive flooding and economic loss without heavy precipitation, occur throughout December to February and March to May. But this graph does not suggest a clear temporal trend in seasonal precipitation in any season. Therefore, the frequency and intensity of single storms is more influential in causing floods than seasonal total precipitation amounts (i.e. September 1995 and February 2004).

Low precipitation totals occur during the spring months; snowmelt may be a more significant hazard than precipitation. Summer months (June-August) on the Burin Peninsula are marked by low precipitation rates. Total precipitation during these months appears to be decreasing with time (Figure 6.10). However, the vulnerability of communities to summer storms is not related to total precipitation, but rather to the magnitude of individual short time period events, such as in June 1986.

The variation in annual precipitation amounts does not appear as a consistent cycle of high and low precipitation. Annual precipitation in summer, winter, and spring appears to show a sharp increase during the mid-1980s, and then a gradual decline to the present amount of annual precipitation. The annual amount of autumn precipitation appears consistent until the late 1990s when the amount declined sharply.

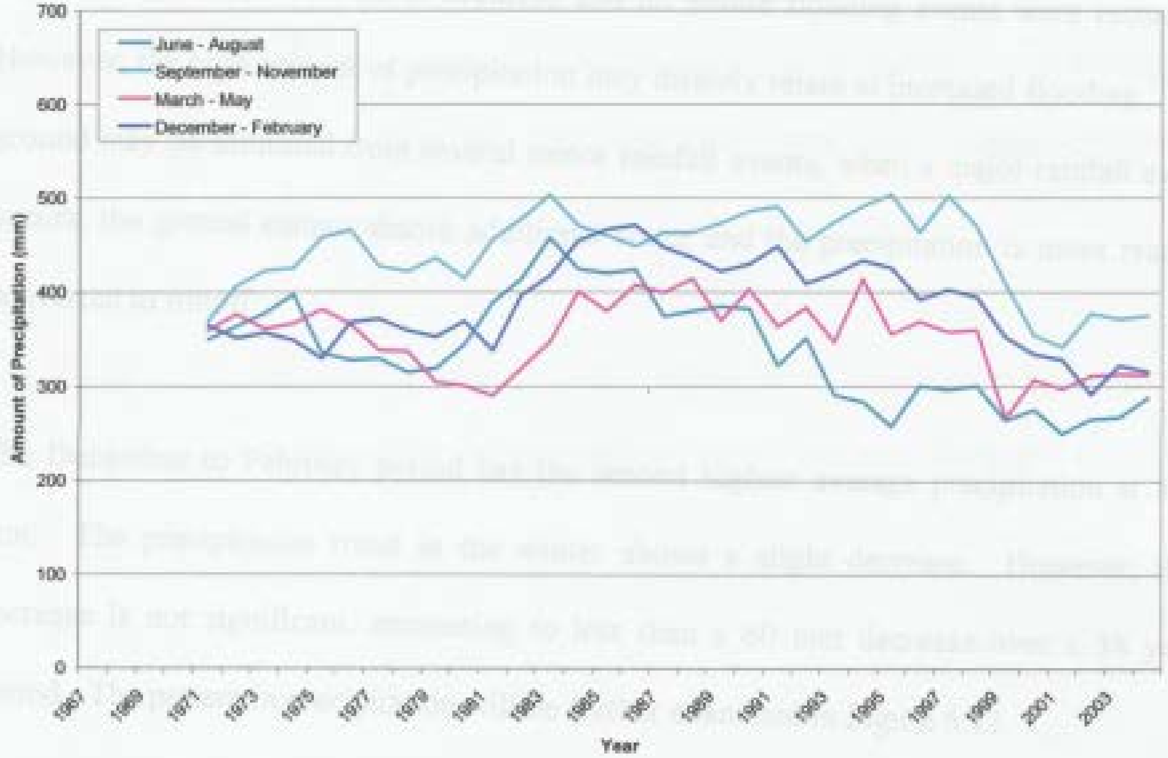


Figure 6.9: Average amount of precipitation for three month periods; December-February, March-May, June-August, and September-November. Average consist running average of 5 consecutive periods. No data available for 1997 and 1998. Data collected for St. Lawrence site on Environment Canada website. Snowfall amounts calculated as melt water equivalent, 1 cm snow equal 1 mm rain.

Even though the amounts of rainfall and snowfall could not be identified after 1996, by analyzing the change in monthly precipitation, the change in total rainfall and total snowfall can be inferred. Precipitation is greatest in the autumn at 438 mm. Although the season of highest precipitation does correspond with the season of maximum flooding events, as discussed earlier, the two may not be directly related because many flooding events result from single intense storms. For instance, intense autumn storms and hurricanes bring large amounts of precipitation to a relatively small area in a short period of time causing great damage. These events may not correspond with overall high precipitation autumns. Flooding events may not occur if the precipitation is varied over the whole season. For example, 1983 had an above average amount of precipitation yet no hurricanes or intense storm occurred and no severe flooding events were recorded. However, the high amount of precipitation may directly relate to increased flooding. The ground may be saturated from several minor rainfall events, when a major rainfall event occurs, the ground cannot absorb additional water and the precipitation is more readily converted to runoff.

The December to February period has the second highest average precipitation at 386 mm. The precipitation trend in the winter shows a slight decrease. However, this decrease is not significant, amounting to less than a 60 mm decrease over a 38 year period. The pattern in precipitation will be further examined in Figure 6.12.

The third highest precipitation totals occur in March to May at 352 mm. A slight declining trend (Figure 6.10) is evident, in the range of less than 60 mm over the 38 year period. The greatest decrease in precipitation is occurring in the summer, slope = -2.49 (Figure 6.10). The least amount of precipitation falls during summer, 340 mm per year on average. Winter (slope = -0.19), autumn (0.33), and spring (-0.49) show little change in total precipitation with time. From the R^2 values, a correlation between the trend in precipitation and time is not apparent; winter $R^2 = 0.0006$, autumn $R^2 = 0.0016$, spring $R^2 = 0.053$, and summer $R^2 = 0.0.053$.

A greater amount of snow will persist into the spring increasing the chance and severity of rain-on-snow events and snowmelt related flooding in the spring. Such a situation occurred in March 2005, when rain fell on a thick snow pack causing widespread flooding on the Burin Peninsula.

For Figure 6.11, total snowfall slope = 3.45 with an $R^2 = 0.1649$, which is a greater correlation between precipitation and time than rainfall. Total rainfall slope = -0.35 with an $R^2 = 0.015$.

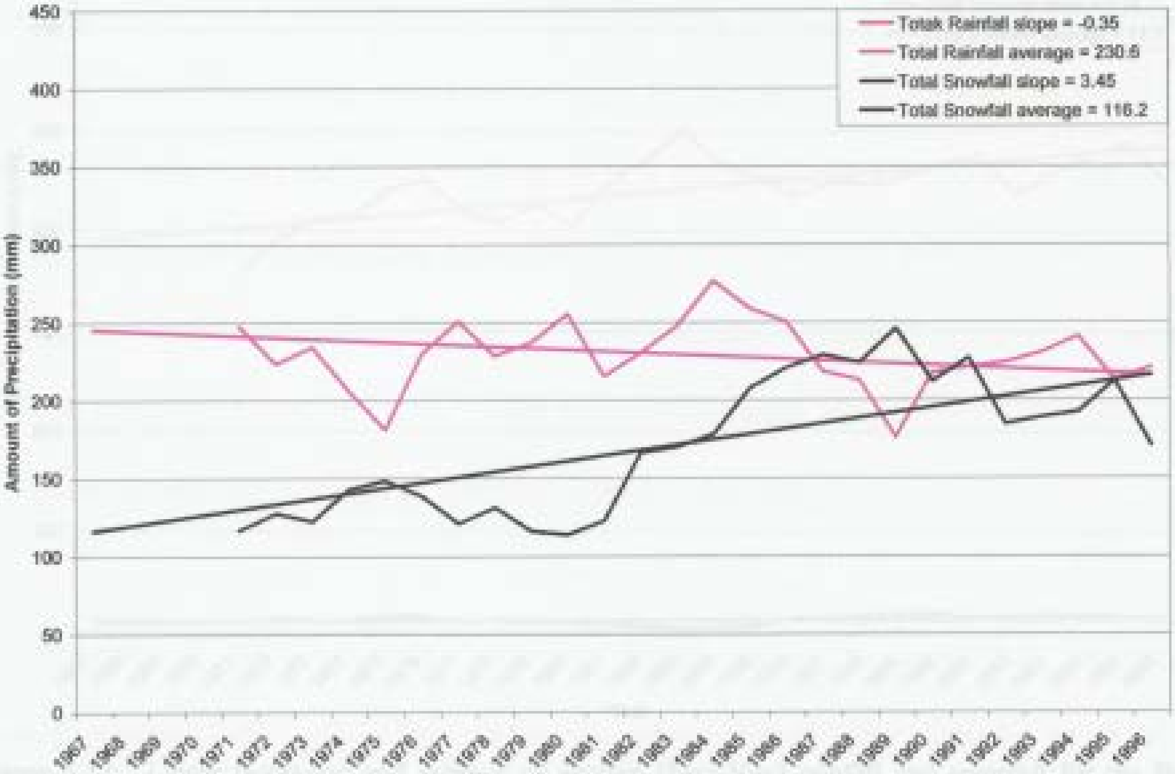


Figure 6.11: Linear regression and average of winter (Dec-Feb) rainfall and snowfall for the Burin Peninsula. Both the rainfall is described by a linear regression and a running average of 5 points of yearly precipitation between 1967 and 1996. Data derived from Environment Canada based from St. Lawrence Site.

The variation in precipitation types in the autumn is described in Figure 6.12. The amount of rain falling in the autumn is greater than the amount of snowfall: average annual autumn rainfall is 437 mm, with only 12 mm average snowfall. Both the annual amount of rainfall and snowfall are increasing. The overall increase in autumn precipitation is contributed to the increase in rainfall. This trend of increased precipitation extends into 2003, the last year for which data is available. Total snowfall slope = 0.14 with an $R^2 = 0.0149$. Total rainfall slope = 3.25 with an $R^2 = 0.1041$.

Figure 6.12: Linear regression and average of autumn (Sept-Nov) rainfall and snowfall for the Burin Peninsula. Both the rainfall is described by a linear regression and a running average of 5 points of yearly precipitation between 1967 and 1996. Data derived from Environment Canada based from St. Lawrence Site.

6.3.3. Conclusion

Many of the flooding events are related to climatic events such as seasonal storms and hurricanes. A high amount of precipitations has to fall before a flooding event occurs. Although anthropogenic activity does in part increase the severity of flooding events, large intense storms induce more widespread damage. Anthropogenic factors (e.g. restriction of water ways or failed drainage systems) cause more localized damage.

The Placentia Bay coast has the highest frequency of flooding events and damage compare to the Fortune Bay coast. The Placentia Bay coast is greatly affected by storms following the southwesterly winds, particularly hurricanes (e.g. hurricanes of 1995). Of increasing concern are the intensifying easterly winds which contribute winter and spring storms. Storm surges resulting from both are associated with altering coastlines and damaging infrastructure. On the Fortune Bay coast, the most extensive damage resulted from a summer storm in 1986. Northerly winds and easterly winds bring high precipitation and storm surges to the coast inducing flooding.

The majority of rainfall occurs in autumn, which appears to be slightly increasing. Autumn storms contribute to this high precipitation amount. The snowfall in winter is also increasing. This may lead to an increase in rain-on-snow events, such as that when affected both coasts in March 2005.

7 Influence of Climate Variation and Change

This chapter will assess the probability of future flooding events. By reexamining past flooding events, present areas of concern, climate change and variation, and patterns of human activity, prediction can be made and recommendations put forth to municipalities. With this knowledge, the damage caused by future flooding events may be reduced.

7.1 Climate change and variation

Climate change and variation can be assessed through study of wind direction, velocity, frequency, and duration; type, intensity, and timing of precipitation; and temperature. Climate variation is a short term trend in climate. In regards to precipitation, the annual amount may fluctuate between a period of low annual precipitation and high precipitation. For instance, Torbay total annual precipitation between 1950 and 2005 shows a cyclic trend, with each increase/decrease variation lasting 5-10 years. Climate change is the overall trend over a longer period of time. Within an overall change in climate, there is variation.

7.1.1 Hurricanes, storms, and winds

The northern Atlantic Ocean has been undergoing an increase in hurricane frequency and magnitude since 1995 (Goldenberg *et al.*, 1997, 2001; Emanuel, 2005; Webster *et al.*, 2005). However, the relationships between changes in hurricane frequency and magnitude, and increases in air temperature or sea surface temperature, are unclear at present (*see* Hunt, 2002; Landsea *et al.*, 1998, Debernard, 2002). Although some researchers (e.g. Trenberth, 2005; Trenberth *et al.*, 2003; Knutsen and Tuyela, 2004; Sugi *et al.*, 2002) have suggested causal links, others have expressed reservations and uncertainties (e.g. Pielke *et al.*, 2005; Webster *et al.*, 2005; Shapiro and Goldenberg, 1998). Hurricane frequency in the North Atlantic does not appear to be correlative with temperature variations in Atlantic Canada (Lewis, 1996; Pocklington and Morgan, 1996), in part due to the distance between the Main Development Region east of the Caribbean Sea, and Atlantic Canada. Some research suggests a possible northward migration of the area of tropical storm development and storm tracks (Danard *et al.*, 2004; Debernard *et al.*, 2002; Ashmore and Church, 2001), which could increase the impact of hurricane activity and associated flooding in Newfoundland.

Regardless of the uncertainty of future changes in hurricane frequency and magnitude in response to climate change, it is apparent that the North Atlantic is currently undergoing a period of increased hurricane activity, requiring a response in emergency preparedness and mitigation strategies (Goldenberg *et al.*, 2001). Canadian climate models imply that increasing instability in climate will accompany general warming, thereby generating more storms, causing coastal erosion and flooding. Climate models also suggest scenarios where the total number of storms may decrease and the magnitude of the largest storms will increase. Consequently, storm damage and flooding will increase for the northeast Avalon and the Burin Peninsula.

Studies of coastal eastern Newfoundland revealed a change in hurricane and autumn storm frequency. Storms are becoming more frequent and the impacts on eastern Newfoundland coastline are becoming more severe (Catto *et al.*, 2003; Catto and Catto, 2004).

The increase in hurricane and autumn storm frequency and damages will have severe implications for the northeast Avalon and Burin Peninsula. The Burin Peninsula is susceptible to coastal damage and river flooding due to excess precipitation. Hurricanes and autumn storms with a strong north and northeast wind direction will result in river flooding and coastal damage in Torbay.

Changes in dominant wind direction and intensity have more impact on the south coast of Newfoundland. Of particular concern is the increase in frequency and severity of northeast and easterly winds. Easterly winds measured at Port-aux-Basques have been strengthening since 1970 (Catto *et al.*, 2006). Easterly winds result in increased frequency in storm surges on the Burin Peninsula and increase coastal alteration. The northeast winds have more effect on Torbay. The increase in easterly wind frequency and magnitude of storms will have a lesser effect on Corner Brook. The intensification of easterly winds has increased the severity and frequency of winter and spring storms (Catto *et al.*, 2003, 2006; Catto, 2004). The most severe storms occur from December to March, and commonly induce storm surges.

7.1.2 Precipitation

One major factor involved in climate change and variation is change in precipitation patterns and amounts, impacting the frequency of precipitation related flooding hazards.

The Humber Arm region is experiencing a trend of increased precipitation. Annual and seasonal averages calculated from 1940-2004 show an increase in precipitation since 1970 (Environment Canada, 2005). Of particular concern is the increase in winter precipitation. The rain to snow ratio illustrates the increase in the amount of rainfall in winter (Shabbar and Bonsal, 2005). Rain-on-snow events are the most frequent and damaging flooding mechanism in Humber Arm. In the Humber Arm region, snow cover persists into the spring. With an increased amount of rainfall falling in March to May (Environment Canada, 2005) on the thick snow cover in the spring, rain-on-snow events will increase, practically if copious amounts of rain fall during a single event.

In Torbay and the Burin Peninsula the snow cover is less extensive and persistent than snow cover in the Humber Arm region. However, the snow cover in both regions has been increasing, which may lead to increased severity of rain-on-snow events. In winter (December to February), the increase in snowfall in both regions corresponds with a decrease in rainfall. In conjunction with a warm spell (common for maritime regions) and/or rainfall events, rain-on-snow or snowmelt flooding will occur.

Total amount of annual precipitation does not appear to be changing in Torbay (1950-2003 data, recorded at St. John's Airport). For the Burin Peninsula (1965-2003 in St. Lawrence), precipitation appears to be decreasing. Seasonal variations are occurring, changing the timing of precipitation-induced flooding. However, precipitation change will have little or no effect on coastal flooding due to storm surges.

7.1.3 Temperature

In Newfoundland, temperature patterns since 1950 indicate lesser overall annual change, showing a slight cooling in winter and marginal warming in summer (Lewis, 1996; Pocklington and Morgan, 1996; Banfield and Jacobs, 1998). Shabbar and Bonsal (2003) analyzed temperature data from 1950–1998, and documented an increase in frequency and duration of cold spells in eastern Canada, particularly in Newfoundland and Labrador. A cold spell is defined as temperatures remaining below the 20th percentile of the daily minimum temperature for minimal of three days between 1961–1990; the threshold is 80th percentile for warm spells. In accordance with the increase in cold temperatures, the number of days with ice cover on rivers has increased since 1952 (Clair *et al.*, 1996). Temperature trends show an insignificant increase in the number of winter warm spells, although the durations of the warm spells are decreasing (Shabbar and Bonsal, 2003).

Colder conditions in winter and warmer conditions in summer will result in greater fluctuation of annual temperature for communities in Newfoundland. This will alter flooding hazards involving temperature as a factor (e.g. ice jams, rain-on-snow events). Thermal ice jams may not occur during colder winters, where warm spells would not result in an ice break-up and subsequent jam. However, temperature may have an effect on dynamic ice jams: if the winters are becoming colder than the ice will become thicker and more susceptible to obstructions. The snow cover will thicken and enhance rain-on-snow events during intense rainfall events.

7.2 Changes in flooding styles

Changes and variations in precipitation, winds, and temperature patterns interact to influence flooding mechanisms. In addition, the flooding styles may interact to amplify the damage induced by a minor change or variation. For example, a small increase in rain-on-snow events may amplify river flooding, if a critical threshold is exceeded. An increase in precipitation will have a greater impact on flooding in an urban area than in an adjacent undeveloped river reach. Depending on the flooding mechanism, specific areas will be affected. For example, hurricane activity in the Humber Arm region will result in storm surges and coastal flooding and precipitation-induced river flooding in Cox's Cove, but will only result in river flooding and overland flow in Corner Brook. Changes in precipitation are associated with the rain:snow precipitation ratio, shifts in cyclonic storm tracks, changes in the number of intense rainfall events, and changes in snow accumulation (Ashmore and Church, 2001; Parson *et al.*, 2003; Brubanker and Rango, 1996). Saturation of the soil may lead to increase conversion of rain to runoff (Gutowski *et al.*, 1994; Bobba *et al.*, 1999; Lawford *et al.*, 1995), thereby increasing the severity of flooding events.

As many of the mechanisms that cause flooding in Torbay, Humber Arm, and the Burin Peninsula are correlated with climate, change and variation in climate will alter the frequency and severity of flooding events. If the communities are not aware of any changes, they may not be prepared for one type of flooding, or resources may be inefficiently allocated to mitigate a flood hazard that may no longer pose a severe threat.

7.2.1 Hurricane and storm surge activity

As the frequency or intensity of hurricanes and tropical storms increases in the North Atlantic (Goldenberg *et al.*, 2001), flooding caused by precipitation and storm surges will increase. Inland flooding associated with precipitation over drainage basins will be affected. More frequent storm surges will successively decrease natural and artificial coastal protection, thereby furthering flooding of coastal zones.

In addition to hurricane induced storm surges, winter and spring storm induced surges will also have a major effect on coastal areas. More extensive flooding is possible, increasing sensitivity of coastal areas due to the increased force of the storms. Larger clasts on beaches may become more susceptible to transport and erosion. Intensifying easterly winds will affect beaches oriented towards the east, resulting in increased erosion.

In Torbay, hurricane-induced river flooding and heavy rainfall events are the most significant hazards. Torbay will experience changes in river morphology from heavy precipitation and possibly coastal damage. During such events, large amounts of runoff are focused into the five main river systems flowing through the Torbay area. Where there are constrictions of river channels (culvert, debris build-up, narrowing of the channel) water builds up causing inundation and erosion of the nearby area. As a result, houses, lawns, and transportation routes are damaged and the river channel is temporarily widened. Areas of greatest effect are "the Gully" area where the swollen river inundates property along the river. The river exiting Watt's Brook floods property located in an adjacent marshland and damages Torbay Road further downstream. Other areas affected during severe rainfall events are Soldier's Brook, and Kennedy's Brook where it passes under Torbay Road. Storm surges are less frequent and have resulted in less accumulative damages than river flooding.

Intensification of northeasterly winds and storms will cause problems in Torbay. Storm surges impact the coast and increase the flooding risk. Due to the topography of Torbay, a storm requires a very specific (northeasterly) orientation to impact the coast. The impact is further limited by the steepness of the topography near the coastline and the lack of critical infrastructure.

Changes in hurricane-induced precipitation will greatly influence flooding events in the Humber Arm region. The Humber Arm region may experience changes in river morphology, and further damages associated with inadequate infrastructure. Although much of the Humber Arm region is not susceptible to direct hurricane strikes, precipitation initiates flooding of Majestic Brook, Corner Brook Stream, Bell's Brook, and Petries Brook, and causes overland flow of water over impermeable surfaces. For instance, rainfall from remnants of Hurricane Frances (2004) caused Majestic Brook to flood, damaging property on East Valley Road. Runoff from upslope caused damage to property on Clarence Street and Humber Road.

Hurricane- and storm-induced surges may increase coastal damages in vulnerable locations. Communities with fishing infrastructure or summer homes constructed near the shoreline are vulnerable to damage. Cox's Cove may see an increase in storm surge and river damage. In Cox's Cove, a higher sea level will move the high tide mark further inland. During a storm surge, more land will be inundated potentially damaging more houses along the coastline. Cox's Brook will be impounded further upstream by the ocean and increase the area affected by flooding. Furthermore, if preventive measures are not taken by residents, such as relocating their homes further from the coastline, increased damages will occur from lesser magnitude storms because the houses will be closer to the high tide mark.

Within Corner Brook, a higher sea level will lead to increased destabilization of the steep slopes along the coast. Many of these slopes are very unstable, particularly in the Riverside Drive area. A higher sea level increases the height at which the slope is attracted and undermined at the foot of the slope. Without a stable base, the potential for increased slope failure impacting the road is present.

Hurricane-induced rainfalls will also influence flood frequency and severity in the Burin Peninsula. However, storm surges are the most significant cause of flooding. The Burin Peninsula will be greatly impacted by an increase in hurricane activity. Coastal areas and river morphology will change with the increasing erosion events. Many of the rivers on the Burin Peninsula have flood plains adapted to frequent hurricane activity (e.g. Salmonier River has a narrow floodplain and flood-inundated slopes). No further damage may occur in areas of rivers that do not pass in proximity of critical infrastructure routes or within communities. Subsequent streams will cause erosion of the banks of streams and the movement of debris further downstream. Eventually the debris build-up will enhance the area inundated during a hurricane-induced rainfall. For example, repetitive storms deposit debris in Riverhead Brook in St. Lawrence. The riverbed becomes shallower and after large rainfall events (i.e. Hurricane Luis) the river overflows and inundates a large area. Another occurrence is where a river flows into Frenchman's Cove Barswa under highway 220. During the heavy rainfall associated with Hurricane Luis (19 September 1995), the usually small stream was converted into a torrent which expanded its river channel and completely removed a section of Highway 220 between Garnish and Grand Bank.

The erosion of natural coastal protection by successive storms will increase change in the coastline and increase flooding of adjacent inland areas. For instance, the coastline in Lamaline is eroding. During storm surges in Lamaline, the large boulders used in the seawall were displaced onto the Allan's Island causeway causing residents to be isolated from the mainland in February 2004. Clasts are displaced further inland, encroaching on property. In Fortune, the coast is progressively eroding from coastal storms, and the destabilization of the bank reduces the safety of the direct transportation route between Fortune and Grand Bank.

Coastal infrastructure will be damaged or will need to be re-located. In areas of infrequent damage, presently it is more economical to repair the damage than to re-locate the structure. However, with more frequent damage, the re-location of property, roads, and other critical infrastructure will be necessary. For instance, the houses located in "the Meadow" (Lamaline) are very susceptible to damage. The residents should be evacuated before any injury can occur, returning to repair damage after the flood. In the future, storms may become more frequent and severe, causing houses to become damaged beyond repair. Consequently, the relocation of residents would reduce the total cost of damages.

Coastline protection will fail if not properly maintained. The coastal protection for Point au Gaul, repaired after the February 2004 storm, failed after the December 2004 storm surge, resulting in damage to the coastal infrastructure. If properly maintained, faults in the protection could have been detected and repaired, thereby preventing the damage in December 2004.

The potential strengthening easterly winds are of major importance. Intensification in easterly winds is correlated with an increase in storm surge activity, particularly flooding events on the Burin Peninsula between January and March. An increase in frequency or magnitude of storm surges will result in an increase in coastal erosion, and increase in infrastructure damage, further inland flooding, further inland ice damage, and increased influence of coastal river flow. In the February 2004 event, the easterly winds in part caused sediment build-up at the mouth of Frenchman's Cove River, resulting in flooding of houses in the community.

Several sites along the Burin Peninsula are sensitive to increases in storm surge activity. Grand Beach may be susceptible to more frequent overwash, the combined result of increased storm surge activity and higher sea level (Shaw *et al.*, 1998) due to the susceptibility of the coastline to erosion and storm activity. The strand at Frenchman's Cove also is susceptible to increased erosion and flooding due to sea-level rise, allowing storm surges to reach further inland. An increased risk of isolation from other communities by the inundation of the two transportation routes will result from higher water levels (Shaw *et al.*, 1998; Mayor of Frenchman's Cove, James Cluett, personal communication; Mayor of Garnish, Melvin Francis, personal communication).

7.2.2 River flow

Increased storm activity will deposit larger amounts of precipitation, increasing runoff and resulting in increased river flow. Climate-induced changes in processes include changes to the magnitude of flood flows, and changes to intensity and frequency of overbank flooding and ice-jams (Ashmore and Church, 2001; Wohl, 2000). More frequent overflowing of river channels will affect structures in and near steams that are constructed based on present or past floodplain dimensions, and which may fail and increase flooding damage when river dynamics change (Ashmore and Church, 2001; Haque, 2000; Simpnovic and Li, 2004).

With the increased rainfall in winter in the Humber Arm region, more runoff will be entering river systems (c.f. Rollings, 1999). This will increase the frequency of high water levels in rivers. Decreasing rainfall in Torbay and on the Burin Peninsula may cause the frequency of high river flows to decrease. However, because of the thickening snowcover, increasing runoff and snowmelt during heavy rainfall events, high peak flows will increase above levels resulting from average rainfall.

In Torbay, in areas where streams run parallel to Torbay Road, undercutting of the road will progress more rapidly with increased flows. As well, further bank erosion within "the Gully" and flooding of houses near "the Gully" will occur with increased storm events. With increased flow, the culverts that are presently in place to transport water under Torbay Road and Lynches Road will not be able to handle the flow, resulting in more frequent flooding.

Increased flows in Corner Brook will result in increased overbank flows and damage of adjacent property and infrastructure. Valley side instability induced by increased flow may increase the hazard of slope failures, causing debris dams. The alteration caused by the construction of the new Trans Canada Highway within Corner Brook resulted in slope failure in 1994. On 27 September 2005, the infrastructure that was put in place to remediate the flooding in 1994 failed, and the barrier isolating water from the unstable slope broke. Consequently, water washed over the bank, induced a slope failure, and damaged Riverside Drive. The highway into Cox's Cove is also susceptible to slope failure. In December 1977 and February 1996, water saturating the bank caused by heavy rainfall resulted in the slope failure which blocked the highway.

7.2.3 Rain-on-snow events

In the Humber Arm region, rain-on-snow events occur frequently in autumn, winter, and during spring melt. Rain-on-snow events may affect certain communities or the whole region simultaneously. The events result in infrastructure damage, river flooding, slope failure, and indirectly cause interruptions in transportation and economic loss. Rain-on-snow events do occur in Torbay and the Burin Peninsula, but do not result in the extensive and frequent damage seen in the Humber Arm region. Prior to the March 2005 event, the Burin Peninsula had no record of a widespread rain-on-snow event damage. In

Torbay, the April 2004 event caused widespread flooding, which had previously only been associated with hurricane activity. These two exceptions may be the start of a new trend in flooding style in relation to changes in precipitation patterns.

Due to the north-facing, sheltered slopes Corner Brook has a longer persistent snowpack than do Torbay and the Burin Peninsula. Greater snowmelt will occur during mild temperature or attribute to extensive rain-on-snow events during heavy rainfall (e.g. March 2003). However, with the increase in snowfall and decrease in rainfall in winter in Torbay and the Burin Peninsula, thicker, persistent snowcovers will increase the possibility of a damaging rain-on-snow event.

7.3 Summary

The precipitation patterns in Torbay follow a cyclic pattern of approximately 5-10 years. Consequently, the precipitation is on an increase in the winter and decrease in the summer. If this trend persists, this may contribute to river flooding in the winter. Hurricanes also vary in activity over time. At the present, hurricane activity is on an increase which makes Torbay more vulnerable to hurricane-induced flooding.

Similarly, the Humber Arm region is also undergoing a cyclic pattern in precipitation; however, the precipitation is on a general incline. This increase and decrease will periodically alter flood frequency. The higher rain to snow ratio may increase the region's vulnerability to flooding. Variation has occurred in river flooding in Corner

Brook due to human activity. For instance, Bell's Brook has a high frequency of flooding until 1975 (Figure 5.4) then experienced a reduced frequency of flooding as a result of culvertization (section 5.3.1.2). Once again the river is experiencing increased flooding due to upslope development.

The Burin Peninsula is experiencing a cyclic pattern in precipitation. As with Torbay, winter and autumn precipitation is on an increase while summer precipitation is on a decrease. Consequently, rain-on-snow events may be increasing. Also, hurricane and storm activity is cyclic, with the present being on an increase. Therefore, communities have raised vulnerability to storm surges and precipitation-induced flooding.

8. Socio-Economic Impacts of Flooding Hazards

8.1. Introduction

Flooding events vary in physical, economical, and social impacts. This chapter will focus on the socio-economic impacts of flooding hazards, including the direct and indirect costs in each region, and impacts on the social fabric of the communities. Through the comparison of frequency, severity, and cost of flooding hazards, the degree of vulnerability in the communities will be identified.

The social impacts are difficult to quantify and therefore may not be recorded in estimates of 'total cost' of flood damage, which tend to be expressed in monetary terms. Flooding hazards may impact individual perceptions of personal security, for example, producing stresses that are not directly expressed in monetary terms. However, for community residents these impacts are as relevant as quantitative costs, and may be more lasting. Although this is commonly stated by those affected by flooding:

> "I am one of the lucky ones. Our home hasn't been affected. We have no water and even though we live on Sunset Drive, but in another way we are greatly affected. Our community is gone, and it will be a long time until we see anything normal anymore. I mean we are talking two thirds. It will be a long time until anyone gets back home to their homes. And when we get rid of all this, it will be awhile until we can get back to our homes. I can go back to my home, but I have

many friends that have no home to go back too. That is devastating." (Quote by resident of Badger, Judy Loder, 2003);

comprehensive assessments of social effects and inclusion in total costs are often not effectively accomplished.

8.1.1 Risk and vulnerability

Risk assessment is the evaluation of frequency and magnitude of adverse impacts associated with specific flooding hazards to the anthropogenic (constructed), natural, business, and social environments (H. John Heinz III Centre, 2000; Parson *et al*, 2003). Vulnerability assessment is focused on the qualitative or quantitative investigation of the susceptibility of a community or the environment to flooding hazards (H. John Heinz III Centre, 2000; Mitchell, 2003). Communities in the three study sites exhibit variability in vulnerability, in part because of local awareness of the hazard and investment in effective mitigation. Physical determinants of vulnerability include the frequency and severity of flooding. Social and community factors, including population dynamics, the location of the residential developments and critical infrastructure in relation to flood-prone areas, monetary property values, degree of alteration of natural drainage routes by human activity, resiliency of transportation and communication routes, presence of hazard limiting infrastructure, mitigation, recovery, and adaptation abilities, and the presence of emergency and development plans also are important in determining community vulnerability. Through consideration of these factors, the vulnerability of each area can be assessed.

8.1.2 Frequency and severity of flooding

Each of the study sites are affected by different styles, frequency, and severity of flooding. As flood mechanisms have been discussed above, this section highlights the hazards most prominent in each area, and compares the frequency and severity of flooding among the sites.

Tropical Storm Gabrielle caused extensive flooding in Torbay in September 2001, but was the only significant instance of hurricane-induced rainfall between 1980 and 2005. Heavy spring (e.g. April, 2005 rainstorm) and autumn rainfall events produce similar patterns of flooding as Tropical Storm Gabrielle, although the extent of damage has been less. Two storms caused damage between 2001 and 2005. Spring melt each year caused high water levels. Spring rainstorms are infrequent.

In contrast, the Burin Peninsula has a greater frequency of hurricane-induced rainfall and hurricane-, autumn-, and winter-induced storm surges than do Torbay or the Humber Arm region. A total of 17 significant storms have impacted the Burin Peninsula between 1989 and May 2005. Six of these storms had precipitation totals above 46 mm, the threshold sufficient to induce flooding (as discussed in chapter 6). Many of these events produced storm surges. Ice jams occur in four communities, but are only a concern for

Rushoon, where four recorded ice jams (three extensive) have occurred between 1960 and 2005.

The Humber Arm region is frequently impacted by rain-on-snow events. A total of 187 records of rain-on-snow events caused 42% of naturally occurring flood damage in the Humber Arm region between 1940 and 2005, with the majority of damage occurring in Corner Brook. The presence of a snowpack or frozen ground decreases the amount of rainfall and snowmelt required to induce damage. As expected, rainfall is positively correlated with damage. Minor road damage and water build-up occurs with 20 mm of precipitation, whereas property damage, road failure, slope failure, and closure of services occur with 135 mm of rainfall. However, only one rain-on-snow event between 1940 and 2004 exceeded 100 mm, and 6 recorded events (~ 3 %) exceeded 50 mm. Storm surges are infrequent for areas sheltered in the interior of the Humber Arm, but the frequency is greater for Cox's Cove and McIver's Cove. Within the interior of Humber Arm, an effective fetch cannot be generated to produce frequent storm surges. Storm surges have impacted Cox's Cove and McIver's.

Anthropogenic activities have increased the frequency and severity of flooding events in all areas, but particularly in the Humber Arm region. Anthropogenic influences are the second most common mechanism of flooding in the Humber Arm region, especially in Corner Brook. Altering drainage routes and increasing the amount of impermeable surfaces result in flooding damage occurring after a minimum of 20 mm of precipitation.

8.2 Direct and indirect monetary cost of floods

The direct impacts and costs of a flooding event are strongly linked to the duration and severity of the event, the flooding mechanism, the time of year, and the height of the flood waters (Kreibich *et al*, 2004). In Canada, public costs resulting from direct impacts include federal (PSEPC; Public Safety and Emergency Preparedness Canada) and provincial (EMO; Emergency Measures Office) disaster aid and subsequent payments; municipal government expenses; response, rescue, and reconstruction personnel expenses (including overtime); public infrastructure reconstruction; health care resulting from flood-related injury, illness, and trauma (including counseling); and the cost of debris removal and decontamination (Paul Peddle, EMO training specialist, personal communication, April 2005; Public Safety and Emergency Preparedness Canada, 2005; Haque, 2000). In some areas, loss of revenue resulting from contamination of freshwater affecting fishing or interruptions to tourism activities represents additional costs. The reimbursement of costs by federal and provincial authorities is designed to restore public infrastructure to the pre-disaster condition, and to assist in the restoration of personal property and small businesses (Public Safety and Emergency Preparedness Canada, 2005; Kumar *et al*, 2001). Personal and corporate direct costs include those not reimbursed by federal and municipal authorities; insurance payments for damage to buildings, goods, and property, uninsured costs incurred by individuals and business, costs incurred by charitable organizations (The H. John Heinz III Centre, 2000; Thieken *et al*, 2005; Public Safety and Emergency Preparedness Canada, 2005), and damages to large businesses, industries, crops, summer cottages or antiques (Kumar *et al*, 2001).

The value of housing varies among communities (Sagalyn and Sternlieb, 1976). A community's socio-economic status affects the average house or lot price. The differences between economic statuses among residents in rural Newfoundland communities are less pronounced than in Torbay or Corner Brook, and lesser ranges in house and lot prices exist in rural areas (Sagalyn and Sternlieb, 1976). For example the range from the lowest house price to the highest house price in Torbay is $210,900; the price range in Corner Brook was $224,900 (as of June 2005); for Lark Harbour, $50,400; for Irishtown-Summerside, $76,000; for Grand Bank, $120,000; and for Marystown the price range was $157,100 (as calculated from Royal LePage and Re/Max realtors websites in June 2005). More significant differences in socio-economic status can be apparent in urban and suburban communities, resulting in greater differences in prices than in rural areas. This is apparent in Torbay and Corner Brook, where newly constructed houses in upslope areas and around the ponds are more expensive than the houses in lower, more flood prone areas.

In June 2005, the *average* prices of houses for sale on realtors' websites were $58,100 in Lark Harbour ($38,080 in 2001, Statistics Canada), $74,833 in Irishtown-Summerside ($54,078 in 2001, Statistics Canada), $65,425 in Grand Bank ($47,401 in 2001, Statistics Canada), $98,838 in Marystown ($71,766 in 2001, Statistics Canada), $119,467 in Corner Brook ($91,153 in 2001, Statistics Canada), and $177,357 in Torbay ($104,600 in 2001, Statistics Canada). The realtors' prices were the houses listed for sale at the present time, whereas the Statistics Canada prices were the average of all houses sampled in the community in 2001. Also important to note are the number of "new price" listings for house for sale. According to one realtors' website (Royal LePage, June 2005), of the 54 houses for sale in the Humber Arm region, 5 were listed as "new price". On the Burin Peninsula, 14 of the 45 houses were listed as "new price".

Commercial development may also influence housing and lot prices, as is apparent when contrasting the Majestic Brook area of Corner Brook with the central districts of smaller communities. However, differences in housing values are also apparent within some rural communities, such as Lark Harbour. Two houses located on Main Road vary dramatically in price, with one at $84,900 and the other at $34,500 (Re/Max, June 2005). Newer homes constructed by summer residents, retirees, or commuters may be more expensive than the mean housing price within the community. In addition, such homes may be built in areas prone to damage from river flooding or storm surge, as homeowners may locate in areas with a seaview or riverfront view. Individual assessment of each community is therefore required.

Indirect or secondary costs may not be apparent immediately following the flooding events. Expenses are incurred days to months after the event, and may or may not be included in the figures reported for losses, depending on the nature of the investigation and the timing of the announcement of damage totals (The H. John Heinz III Centre, 2000; Milne, 2002; Tapsell and Tunstall, 2003). In some instances, the ramifications of severe flooding and associated indirect costs may continue to accumulate years or decades after the event. Infrastructure damaged by flooding not immediately requiring repair may fail earlier than its initially designed lifespan (Kumar *et al.*, 2001). Prolonged health care and psychological counseling may be required for victims and responders (Milne, 2002; Tapsell and Tunstall, 2003). For instance, after the Perth-Andover (NB) flood in 1987, 200 residents, mostly seniors, sought help in counseling to deal with the flood impact (Alchorn and Blanchard, 2004). A social worker and a psychiatric nurse were hired to provide professional help to the needs of flood victims, five days a week. A help line was initiated and ran by community volunteers.

A recent example of the underestimation of flood damage costs is provided by Badger, NL. The cost of flood damage was most recently estimated at $8.2 million on June 2, 2005 (Paul Peddle, Training Specialist with EMO, personal communication). This figure represents approximately 25 times the potential damage estimated by FENCO (1985), allowing for intervening inflation. Much of the difference is represented by more accurate assessment of indirect costs, not associated with immediate response, rescue, and restoration of structures to pre-flood conditions. Municipal costs, largely borne by the province of Newfoundland and Labrador, totaled $2 million. These included the creation of a new subdivision, including roads, power, water and sewage services; removal of river ice from the flooded area; oil spill and sewage clean-up; road repair; and mould preventative measures within reoccupied homes.

During the Badger flood, only the road repair and some housing reconstruction had been anticipated. Residential, business, and non-profit groups' claims totaled $5 million (as of June 2, 2005; Paul Peddle, personal communication). Cost of essential items were evaluated and reimbursed by the federal and provincial governments. Damage to the houses and replacement of items necessary for everyday life (e.g. stove, refrigerator, clothes, etc.) were calculated in the total. Compensation was not paid for private and recreational vehicles, as flood damage is not covered under many automobile insurance policies. Relocation costs of residents to subdivisions were based on replacement costs. Compensation was also paid for external property if the individuals had these items insured. The remaining $1.2 million was dedicated to providing temporary housing for people who were displaced from their homes until conditions improved, and for paying additional costs for responders, medical professionals, claims assessors and insurance adjustors, and helicopter flights for river monitoring (Nancy Emberly, EMO, personal communication, 2005).

Even in Canadian areas which receive substantial government assistance and direct involvement during a flooding event and subsequent recovery, and in communities where records of financial costs are documented, indirect costs are more difficult to account for than direct costs and appear "hidden". Indirect costs to business and industry can include losses due to interruptions caused by absence or decreased availability of power, sanitation, or clean water. Obstructions to physical access for both employees and (potential) customers, and difficulties encountered by employees attempting to commute from home to workplace represent additional costs. Additional costs can include reductions in property value; loss of revenue from potential customers, clients, and tourists, due both to lack of access by those outside the affected area and financial losses (including temporary ones) by residents and other businesses within the flooded community; and decreased availability or increased cost of insurance. Individuals can suffer financial costs through the loss of uninsured or only partially compensated dwellings or property; through loss of employment opportunities, both immediate and those resulting from subsequent economic difficulties; and through loss of earnings potential due to health problems resulting from flooding.

Change in the natural environment after a flood can have financial implications for communities. If the communities depend on the natural environment for employment (nearshore fishing, aquaculture, tourism, etc.) then slow recovery of the natural environment, loss of habitat (e.g. by silt inundation of nearshore substrate), loss of erosion-buffering beach, and post-storm debris will decrease the economic worth of the environment and impact people financially (The H. John Heinz III Centre, 2000; Parker, 1993). Losses to the natural environment may be transferred to business, industry, and individuals that depend on the environment for aesthetic, financial, and protection reasons. Erosion of beach front property in Humber Arm region will decrease tourism; coastal flooding will damage protective barriers or directly damage fishing gear in Burin Peninsula and Cox's Cove; erosion of bluffs will increase the vulnerability of Frenchman's Cove (Burin Peninsula) and Grand Beach to storm surges (c.f. Ashmore and

Church, 2001; Catto *et al.*, 2003). These costs are usually unreported, and therefore commonly do not enter into the calculations of the monetary cost of a flooding event.

The true monetary cost of a flooding event is thus greater than the quoted value. The reported costs are commonly the direct cost of the buildings, property, and public infrastructure, and costs associated with the loss of natural resources (The H. John Heinz III Centre, 2000; Parson *et al.*, 2003; Kumar *et al.*, 2001). The discrepancies between insured values, personal expenses covered by government compensation, and the actual or replacement value of the property lost can be significant (Kreibich *et al*, 2004). Disputes are common when residents do not receive sufficient funds to cover cost induced by the flood. For areas with low economic house values, the value of exterior property destroyed (including vehicles) may exceed the market value of the house. As noted from automobile dealership advertisements in *The Telegram* (sampled June 4, 2005), vehicle prices are similar regardless of the location on the island of Newfoundland. In Badger, all monetary settlements had not been made as of December 2005, even though the flood occurred in February 2003. Commonly, because only "essentials" are covered, the definition of what is "essential" varies between funding agencies and residents. During the assessment of the impact of Tropical Storm Gabrielle, disputes arose with the government's reimbursement of funds. Residents complained of loopholes in the federal guidelines. A typical case was that of a flood-damaged furnished basement apartment in St. John's: the resident was unable to claim the cost of the water heater, furniture and bedding in the downstairs apartment because these “essential” items were also present in the upstairs apartment (March, no date).

The monetary values of buildings and infrastructure are more easily determined, as these have either assessed values for taxation purposes, are insured, or the cost of physical replacement can be determined. In Canada, property located outside buildings, such as automobiles, all-terrain vehicles, snowmobiles, and boats, is frequently not covered in total value by government compensation programs or private insurance. Damage to exterior property, uninsured items, and indirect costs are not included in the monetary values or damage estimates quoted for flood costs, especially those announced within a short time after the event.

8.2.1 Torbay

Among flood mechanisms present in Torbay, hurricane-induced flooding has had the greatest economic impact, notably during Tropical Storm Gabrielle. Other storms caused similar styles of damage, although of lesser economic value, such as the April 2005 event.

8.2.1.1 Direct costs to government—infrastructure

The main cost to the government is the maintenance of Torbay Road (Route 20), a provincially-maintained highway. When breaks occur in the highway, such as those caused by the flooding during Tropical Storm Gabrielle, the cost of repair is borne by the provincial government. The direct cost of damage caused by Tropical Storm Gabrielle in Torbay is estimated at approximately $500,000 for road infrastructure. This cost includes the installation of new culverts and road repair.

In late October 2004, a semi-circular culvert was installed by the provincial government to replace two 36-inch diameter culverts in "The Gully" area. Installation of the culvert was intended to prevent the pooling of water on the south side of the road, and allow a free flow of water. However, during heavy rainfall events (November 2004, April 2005, April 2006) water that does not flow through the culvert is backed up and slowly erodes the side of the road. Even with the recent remedial changes, a problem still exists.

Future road erosion may result from the effects of sediment blockage in culverts parallel to route 20. When the culverts become blocked, the pooling water will scour the highway and may partially erode the road causing traffic interruptions.

8.2.1.2 Direct costs — municipal expenses

A large majority of the cost related to flooding in Torbay is the repair of municipally-maintained roads within the community. Two adjacent roads of concern are Lynch's Lane and Mahon's Lane, both inundated during Tropical Storm Gabrielle. Lynch's Lane and Mahon's Lane are located at the base of "The Gully". The roads flooded three times after the installation of the semi-circular culvert across Torbay Road.

Torbay has planning to construct an earth berm on "The Gully" side of Lynch's Lane and Mahon's Lane to prevent the water from flowing over the roads and flooding adjacent houses. It is proposed that the berm will be a short term project, which will be followed with a bridge on Lynch's Lane to improve the flow of water.

8.2.1.3 Direct costs — housing

Although buildings in Torbay are not commonly constructed in flood-vulnerable areas, monetary damage has occurred due to the overflowing of streams. Houses and property have been damaged in past flooding events. The direct cost of damage caused by Tropical Storm Gabrielle in Torbay is estimated at slightly less than $500,000 for the damage to 10 houses. The average house value in Torbay was *ca.* $104,600 in 2001 (Statistics Canada, 2005). As seen from site visits, the 10 houses in vulnerable areas are believed to be valued at less than the average price. As well, damage caused by flooding is predicted to cause partial damage to houses, not the complete destruction of the buildings. Houses in the marshland adjacent to Watt's Pond, a house on Pipeline Road, and two houses on Mahon's Lane are some of the houses that have been damaged.

Similar patterns of flooding were seen during severe rainfall events (e.g. April 2005, April 2006) and spring melt. Sections of Torbay Road, particularly in the upper and lower Gully area, are threatened by overflowing rivers. One house below "The Gully" was flooded during the April 2005 event, and two others were at risk of flooding, as well as an additional house closer to the upper "Gully" flooded that had not previously flooded. A house bordering Main Brook also suffered property damage during the April 2005 event.

Communities with high density of buildings in vulnerable areas will accumulate large costs during and after a flood. Costs will increase with high value buildings. As the community grows, the density of houses will also increase. Consequently, more damage will occur during floods in localized areas due to the greater number and more costly houses located in a small area.

8.2.1.4 Indirect costs — business

Many residents in Torbay rely on the services in St. John's, and relatively few businesses are present in the community. Consequently, losses by business may be minor. Such losses would include fewer customers due to the inability to reach the business or lack of services due to the inability of employees to reach the area of business.

8.2.1.5 Indirect costs — individuals

Additional indirect impacts are associated with the disruption of traffic pathways. Torbay Road is the main and most direct route to St. John's from Torbay and the surrounding communities. In 1996, 10,153 ADT (average daily traffic) to St. John's was counted by Department of Works and Transportation at the intersection of Airport Drive and Torbay Road (employee with Department of Works and Transportation, Government of Newfoundland and Labrador, personal communication, July 2005). Green (2005) noted that more than 12,000 vehicles passed the intersection of Marine Drive and Torbay Road, within the town of Torbay, in 2001. Population growth since 2001 suggests that the number of automobile trips to St. John's has increased in the interim. Access to St. John's is important for employment and essential services of many of the residents in Torbay and the surrounding communities.

It is assumed that during each trip to St. John's from Torbay, individuals contribute a minimum of approximately $50 to the provincial economy, resulting from either employment or use and purchase of goods and services, such as groceries, clothing, gasoline, and other goods. Assuming a minimum of 12,000 trips daily, a one-day disruption of traffic would therefore result in an estimated cost of $600,000.

8.2.2 Burin Peninsula

Documented monetary cost of flood damages on the Burin Peninsula is mostly limited to severe events encompassing several communities. Costs quoted in local newspapers and by municipal officials are confined to road repair and removal of debris. However, private losses have been listed on occasion.

8.2.2.1 Direct costs to government — infrastructure

The provincial government has covered the costs associated with the highway infrastructure and severe flooding events. Highways are the responsibility of provincial government. During severe flooding events, when the municipal governments lack the resources to cover the cost of damages, EMO aids in the repair of public and private infrastructure.

Repairs to Highway 210 near Mooring Cove (*Southern Gazette*, October 1991) and Highway 220 near Frenchman's Cove (September 1995 and October 1999; *Southern Gazette*) were conducted by the provincial government. A rain-on-snow event in February 2004 resulted in the partial severing of Highway 210. The combination of one lane and weather prevented the flow of traffic on and off the peninsula for three days.

During hurricane Luis, the direct impact on road and insured infrastructure on the Burin Peninsula totaled $1.6 million in 1995 ($2 million in 2005 value). Road repair for the Burin Peninsula totaled $570,000. Specifically, the section of Highway 220 (Columbus Drive) that intersects Drake's and Hynes's Brook in Creston North was severely damaged, due to failure of the culvert systems in the road. A construction business, three houses, private property, and several cars were destroyed when 200 m of road was washed away due to a series of culvert blockages. Cost of damages to one home owner and business totaled $436,656 in compensation and $80,000 in prejudgment interest.

Coastal damage is of major concern for the majority of communities on the Burin Peninsula. Storm surges resulting from hurricane activity and autumn and winter storms cause considerable direct and indirect costs. The January 2000 storm caused $1 million in damages to coastal areas along the Burin Peninsula. After the January 2000 storm surge event in Lamaline, costs paid by EMO totaled \$12,000 (Shelley Lovell, former town clerk of Lamaline, personal communication).

8.2.2.2 Direct costs – municipal expenses

During the February 2004 event, debris accumulated at the mouth of Frenchman's Cove River as a result of storm surge and increased runoff. Water that could not exit the river and barachoix flooded upstream houses. The cost of removing the sediment was to be paid by the community, which lacked the necessary funds for disposal of the sediment from the community (James Cluett, mayor of Frenchman's Cove, personal communication, February 2004). The cost of removal of debris from the river and repairs totaled \$300,000.

Costly damage results from the combination of heavy rain and storm surges, which cause water exiting rivers and drainage infrastructure to back-up, inducing flooding and sewer line problems. The sewer lines back up into the houses, and the large amount of water damages the physical infrastructure. During heavy rain and storm surges, water that does not flow into the ocean temporarily reverses or stalls, causing water to flow into basements or up through catchbasins. When this occurs in Grand Bank (e.g. December 2004 and October 1999) several basements become flooded with sewage and/or water. In Burin (Penny's Pond area) in both September 1995 and March 2005, two buildings were damaged, a softball field was inundated, and a section of the main road through the community was impassable. In Marystown, the amount of rain during Hurricane Luis

(1995) caused two water supply lines to fail, which later were replaced. The June 1986 spring storm impacted communities on the Fortune Bay coast, and damage to the Fortune water and sewer system cost $840,000 to repair.

The late March 2005 rain-on-snow event resulted in damage and remediation in St. Lawrence totaling $943,723, which included removal of debris, repair of a bridge, and maintenance of road ways. The total costs of damages to other communities on the Burin Peninsula are unknown. However, the physical extent and nature of damage were similar to those which occurred during Hurricane Luis.

The most detailed recorded damages resulted from hurricane Luis. In Marystown, costs totaled $791,340 for damages of residents' houses, road repair, and water line repair. Fox-Cove-Mortier accumulated $82,000 in damages to municipal property. St. Lawrence suffered $348,000 in municipal damages including road repair, bridge repair, and removal of debris. Lawn also accumulated $366,000 in damage to road ways. Other communities on the Burin Peninsula had sustained damages, but as amounts were unreported in the local newspaper, and the cost of damages can only be estimated based on figures for comparable damage in adjacent communities. The town of Burin is estimated to have accumulated damages of slightly less than $300,000, primarily in the Penny's Pond area (recreational field, a house, a licensed establishment, a main traffic route, and an additional road). Point au Gaul sustained minor damage to the main road that enters the community, not exceeding that recorded by Fox Cove-Mortier ($82,000), including indirect costs.

8.2.2.3 Direct costs — housing

The economic losses resulting from hurricane Luis may give an indication of losses to be sustained during future severe flooding events. In Marystown, damages to housing totaled approximately $791,340. Fox-Cove-Mortier accumulated $44,000 in damages to private property. Epworth recorded $13,000 in private property damages, and St. Lawrence recorded $19,916. Although other communities were affected by Luis, the amounts were not recorded in local newspapers. Damage in Lawn was confined to road infrastructure, and no property damage is known. In Lord's Cove, damage may have been confined to one property located in "the Pond" area. The estimated loss would not have exceeded $5000 due to the only partial destruction of low value housing and property. The January 2000, February 2004, late December 2004, and early January 2005 storm surges resulted in the partial flooding of homes and property in "the Meadow" area of Lamaline.

As noted from realtor websites (Royal LePage and Re/Max), costs of houses on the Burin Peninsula are lower than for Torbay. For example, the average cost of houses (March 2005 averages) in Marystown was $79,900; in Lewin's Cove, $51,600; in Fox Cove-Mortier, $45,000; and in St. Lawrence, $15,000. Consequently, monetary damage to houses resulting from flooding on the Burin Peninsula will be considerably less than for more affluent areas.

In the flood study of Rushoon, the costs of exterior damage and damage to vehicles was assessed at $400 per house (in 1989 values). The estimate takes into account that some houses and vehicles will be sheltered from damage. Damage to approximately 30 vulnerable buildings would cost $500,000 (at present values). Loss of private property, repair of roads, and indirect costs after severe flooding suggest estimated damage totaling $1 million (ShawMont Newfoundland Limited, 1989).

8.2.2.4 Indirect cost — business

Damage to businesses is limited due to the multiple access routes to various services; however, some business may suffer indirect losses. In St. Lawrence, the flooding of Riverhead Brook prevents traffic from reaching the Pharmacy from the community, resulting in both loss of business and inconvenience to residents (as in March 2005). When Fortune Brook ruptured Highway 220 between Fortune and Point May in November 2003, residents in Point May and nearby communities were unable to travel to Fortune and Grand Bank for services. Fortune and Grand Bank consequently lost business from these communities. From the Department of Works and Transportation traffic counters, ca. 497 ADT passed through the counter at Point May towards Fortune.

In 1986, the main access road leading to the Fishery Products International plant in Fortune failed, resulting in the closure of the plant. The extent of loss ranged from spoilt fish, inability of processed fish to reach the market, to inability of unprocessed fish to enter the plant to be processed.

8.2.2.5 Indirect cost — individuals

Flooding may lead to the temporary loss of employment, such as in Fortune in 1986 (FPI) and in Marystown (Wally Drake Construction Company) in September 1995. Flooding resulting in road disruption may cause residents of the Burin Peninsula to be unable to obtain the services that they require, or to spend more money and gasoline traveling a circuitous route. For instance, when the highway was severed near Frenchman's Cove (January and September 1995), residents west of the break could have decided either not to travel to Marystown to receive services, or to travel to Marystown *via* Fortune, which would have increased the cost in both time and travel expenses (gasoline). Losses based on traffic in the Frenchman's Cove area indicate that 20% of people living between Point May and Frenchman's Cove travel to Marystown *via* Fortune, with 1174 ADT between Frenchman's Cove and Marystown (in 2005 values extrapolated from 1996 values).

Additional employment losses are associated with the damage to fishing gear and stages resulting from storm surges. During the February 2004 event several individuals from Beau Bois to Lamaline lost fishing gear, which may have been replaced using their own resources. In St. Lawrence damages totaled $500,000, including the loss of a fishing stage, equipment, and a boat motor (Wayde Roswell, mayor of St. Lawrence, personal communication, March 2005).

8.2.2.6 Natural environmental economic costs

In Lamaline, residents are concerned with the slow erosion of the coastline. With each successive storm surge, debris is being displaced onto inhabited land. The erosion of the bluffs in Frenchman's Cove and Grand Beach would result in the damage to community infrastructure due to increased exposure to waves and storm surges.

8.2.3 Humber Arm region

Cost of damages due to flooding hazards varies greatly through the Humber Arm region. The severity of the hazards result in great economic cost for those residents involved. Due to differences in the economic costs for Corner Brook and Massey Drive and the remainder of the region, Corner Brook and Massey Drive will be discussed separately below.

8.2.3.1 Direct costs to government — infrastructure

Rain-on-snow events cause the greatest single event costs to communities in the Humber Arm region. Such events usually result in minor damage (e.g. ditch erosion). The March 2003 rain-on-snow event caused road washouts within the communities in the Humber Arm region and sections of roads in between the communities, and property damage. Transportation from one community to the next was slowed or halted on both sides of the

Humber Arm. Due to the magnitude of damage, the provincial government provided financial aid for the cost of repairs. Repair of roadways in York Harbour totaled $18,000, paid by EMO. The total cost of damages caused by the March 2003 flooding was greater than the cost of the Badger flood (Paul Peddle, Training Specialist with EMO, April 2005).

8.2.3.2 Direct costs — municipal expenses

In many of the communities, municipal expenses are minimal. Other than the main highway that passes through the community, few roads are present to be maintained. Not all the communities contain municipal infrastructure such as a fire station or community centre that may be damaged during flooding events. As well, few reports in local newspapers describe flood damage in areas outside Corner Brook.

On the south Humber Arm, infrastructure damage caused by severe rain-on-snow events is estimated to range between $300,000 and $350,000. The infrastructure damage may include roads, drainage infrastructure, and public buildings. A rain-on-snow event on January 1976 damaged houses in Frenchman's Cove, Benoit's Cove, and Lark Harbour, with losses totaling $100,000 (*Western Star*, 27-28 January 1976).

Damage to other communities on the north shore of Humber Arm is mainly road erosion. Roads other than the main highway are the responsibility of municipalities, but are few. The overflowing of natural drainage ways is a concern for residents in north Humber

Arm during rain-on-snow events and heavy rainfall. The flooding of rivers in McIver's (*Western Star*, January 1986), Irishtown (*Western Star*, December 1990), and Cox's Cove (Kindervater, 1980, see 27-29 December 1977; *Western Star*, 17 February 1996; *Western Star*, 1 March 2003) damaged the highway running through these communities and flooded basements.

Flooding in coastal areas of McIver's and Cox's Cove have caused damage in those communities. Fishing gear, private and public property has been damaged by storm surges. The costs related to storm surges in Cox's Cove are greater than McIver's due to the additional flooding caused by Cox's Brook.

8.2.3.3 Direct costs — housing

On the south Humber Arm, 20 houses are at risk of damage from various flood hazards. Complete destruction of these houses is not expected; therefore, partial rehabilitation is estimated between \$200,000 and \$300,000. This value is derived from the average cost of houses in communities that are vulnerable to flooding.

The majority of damage costs on Humber Arm north are confined to Cox's Cove. Cox's Cove is vulnerable to river flooding resulting from hurricane activity and storm surges. The combination of a storm surge and the impounded flood flow from Cox's Brook can potentially partially or completely damage 85 structures. Partial damages will total \$300,000-\$400,000 if a modal value of 50% loss by homeowners is assumed; complete destruction costs could exceed \$2.8 million, based on the average value of houses in Cox's Cove. Due to the proximity of houses to the floodplain (denoted by the presence of cattails), residents should be concerned about property damage. During the March 2003 rain-on-snow event, 50 houses surrounding Cox's Brook was flooded (*Western Star*, 1 April 2003).

8.2.3.4 Indirect costs — business

As there are few businesses located outside of Corner Brook in the Humber Arm region, indirect cost to businesses are limited. Businesses may experience a decline in services due to the inability of employees to reach work or the delay of supplies from larger commercial centers. The business may lose profit because potential costumers may be unable to reach the business. The seasonality of flooding, generally not occurring during the height of summer tourism, also limits the potential for indirect damages.

8.2.3.5 Indirect costs — individuals

The greatest indirect cost to individuals is associated with traffic disruption. As Corner Brook is the service centre of the region, disruption in traffic will prevent individuals from obtaining the services they require and employment. Such services include medical centers, post-secondary education institutes, and shopping centers.

8.2.4 Corner Brook and Massey Drive

Corner Brook is an urbanized centre with flooding hazards of differing intensity and frequency than the remainder of the Humber Arm region. Due to the rate of development of Massey Drive, the community is incorporated in the discussion in this section. The community, in the near future, may experience similar patterns of flooding due to its upslope position, and housing construction similar to Corner Brook.

8.2.4.1 Direct costs to government — infrastructure

The $1.4 million cost of damages in Corner Brook resulting from the March 2003 rain-on-snow event included culvert and roadway repair, inundation of floodplains, and slope failure. Due to the extensive costs, funding for repair was provided by EMO. The four streams within Corner Brook all flooded causing damage to adjacent infrastructure, nearly overtopping bridges and a dam, and causing flooding of houses, property, and walking trails. Storm systems overflowed causing localized damage and water lines in Curling were washed away. Several roads were impassable (e.g. Elizabeth Avenue). Additional money was requested from the provincial government to aid in further preventative measures to minimize the damage in future rain-on-snow events. Restorative work continued through 2005.

Slope failure on Riverside Drive caused unease with the provincial government due to the development of the new Trans Canada Highway. The construction of the highway is directly linked with the repeated slope failures on Riverside Drive (*Western Star*, 29

September 2005). The cost of removal of debris and mediation measures after the April 1994 event cost $70,000, which was shared between the city of Corner Brook and Newfoundland and Labrador Transportation and Works (*Western Star*, 20 April 1994). Damages were repeated in the September 2005 slope failure event.

8.2.4.2 Direct costs — municipal expenses

Municipal costs associated with flooding are mainly associated with the repair of road infrastructure. In Corner Brook, the reported (from 1920-2005) road damage repairs range from $20,000 (in 1970, *Western Star*) to $100,000 (in 1977, *Western Star*). Reported cost for sixteen floods between May 1970 and March 2005 for damage to municipal infrastructure ranged from $30,000 to $120,000 per event, with allowance for inflation since 1970. From comparing the damage from historical events (e.g. *Western Star*), total direct and indirect damage due to flooding in Corner Brook routinely costs the city between $200,000 and $300,000 per year, increasing during severe events.

Damages are enhanced by blocked drainage systems. In May 1970, a heavy rainfall (48.8 mm in 16 hours) and debris blockages resulted in the flooding of several roads in Corner Brook with damages costing $15-$20,000 (*Western Star*). Autumn storms induce high municipal costs in Corner Brook. The November 1972 event totaled $30,000, an event causing damage of $50,000 occurred in Corner Brook on September 1975, and an additional $40,000-$50,000 damage occurred in August 1993 (*Western Star*).

Damage associated with hurricane precipitation in Corner Brook can be compared to damages resulting from average heavy precipitation. Hurricane impacts are less intense in the sheltered areas of the Humber Arm. Hurricane Frances generated similar patterns of flooding as did previous rainstorms (Charlie Renough, Works and Services Coordinator, Corner Brook, personal communication, 2004).

In Massey Drive, rain-on-snow events coupled with improper drainage, resulted in several instances of road erosion. Flooding events occurred in January 1976, December 1977, and March 2003. Currently, much lower economic losses will result from flooding in Massey Drive due to the relatively small amount of infrastructure within the community. With increasing development, damage to municipal infrastructure may increase proportionally.

8.2.4.3 Direct costs — housing

Loss of property in Corner Brook has resulted from river flooding and overland flow. During heavy rainfall events and/or snowmelt, areas downslope as well as areas located near rivers are vulnerable to property damage. Damage usually consists of erosion of exterior property or basement flooding. In December 1977 the flooding of houses cost ca. $100,000 (*Western Star*). Other instances occurred in December 1990 when several houses and private property were flooded, and in March 2003 where houses were flooded in various locations (*Western Star*). Specific records have not been identified linking the number of houses affected to monetary costs. If one to three houses flood in specific areas during severe flooding events, and it is assumed the flood damage to the building or the basement is approximately 30% of the cost of the building, then damage in one area may range from $27,000-$82,000 (based on the average cost of homes in 2001, Statistics Canada). Costs will be less for houses with lesser value. In the Majestic Brook area and the Bell's Brook area, several houses will be damaged by flood waters from these brooks.

Presently, no monetary record of property damage exists for Massey Drive. Exterior property has been damaged in January 1976 and March 2003 (*Western Star*).

The costs of housing in Corner Brook and Massey Drive are higher than the remainder of the Humber Arm region. In Corner Brook the average cost of houses in 2001 was $91,153 (Statistics Canada, 2005). The average house price in Corner Brook in 2005 was $119,467 with a range of $224,900 (realtor websites, Royal LePage and Re/Max). Similarly in Massey Drive, the average cost of houses in 2001 was $96,034 (Statistics Canada). The average asking sale price in Corner Brook in 2005 was $199,470 with a range of $253,100 (realtor websites, Royal LePage and Re/Max). Houses in Massey Drive are generally newer and more expensive than the average house in Corner Brook. Therefore, damage due to flooding of the same magnitude would be more costly in Massey Drive than Corner Brook.

8.2.4.4 Indirect costs — business

Slope failure on Riverside Drive resulted in additional costs from the loss by businesses that rely on the traffic entering Corner Brook by that route (*Western Star*, 29 April 1994). Slope failures have occurred in proximity to houses and cut off other roads, notably Humber Road. The Riverside Drive entrance into Corner Brook is used for trucks bringing supplies to and from the Bowater (Kruger) Paper Mill, a leading employer.

On occasions (March 2003 and February 1996) water flowed down Elizabeth Avenue into a business on Union Street causing partial damage of merchandise (*Western Star*; Michael O'Leary, former Assistant Director of Operational Services, personal communications, 2003). Consequently, the business lost money which would have been gained if the supplies were sold. The business also was required to replace the damaged merchandise.

Businesses lose indirectly when commuters from outside the community cannot enter the city due to road interruptions. The amount of funds raised by their patronage will be lost for as long as they are unable to enter the city. Businesses may not be able to offer full service if employees are unable to reach their job. In 1996, 6173 ADT vehicles were counted entering Corner Brook, and 1638 ADT entered via Humber Road (Department of Works and Transportation traffic counters). This number incorporates people traveling on the Trans Canada Highway from other locations other than the Humber Arm region. Therefore, it may be presumed that loss of business due to transportation disruptions is moderate in Corner Brook; ~lower than for Torbay, and higher than for the remainder of the Humber Arm region.

Businesses that rely on transporting people around the city will also lose financially if road systems within the community are disconnected. During the March 2003 rain-on-snow event, buses were halted due to the inability to travel around the city.

In Massey Drive the loss to businesses is minimal. Few businesses are present in Massey Drive, and residents depend on Corner Brook for services.

8.2.4.5 Indirect costs — individuals

The flooding of critical infrastructure may impact individuals wanting to use that service. The medical centre was flooded in March 2003 causing partial interruptions to medical services.

During the flooding of certain rivers in Corner Brook (e.g. Corner Brook Stream in March 2003) the walking trails parallel the stream were eroded. The trails are used for recreational purposes, as well as quick pedestrian routes through the city. The absence of these routes may cause the pedestrians to lose time traveling alternative routes or require payment for alternative methods of travel (e.g. bus or taxi).

8.3 Social Factors

Social impacts may increase as a result of individual or community misconception of the frequency of a particular flood hazard. Individuals tend to overestimate the frequency of low probability flooding mechanisms, such as slope failure and underestimate the frequency of high probability flooding events, such as storm surges and rain-on-storm events (c.f. Viscusi, 1993). This can be seen through lack of media coverage (e.g. newspapers) and personal interviews with residents that are living in proximity to the hazards. Communities and individuals may lack a clear perception as to the relative importance of climate and anthropogenic factors involved in a particular flood event. This can result in erroneous estimation of the effectiveness of or necessity for protective infrastructure. Despite repeated flooding from similar causes in some communities, individuals may fail to take the necessary precautions, leading to unnecessary financial losses and personal and societal stress. Communities may be unprepared, and further damages may incur due to the inability to deal with the flooding hazard mentally, financially, and physically.

When assessing a community's vulnerability, it is important to note the percentage of the community that consists of greater risk groups and where they are located within the community. After a severe flooding event, the poor, the elderly, women-headed households, and recent residents are at greater risk (Morrow, 1999). These groups have fewer resources at their disposal after the event. From studies conducted in the United States following disasters, neighborhoods and communities that were poor or declining before a disaster do not ever regain pre-disaster status quo after reconstruction (Morrow, 1999; Morrow-Jones and Morrow-Jones, 1991).

The following table summarizes some social factors for Torbay, the Humber Arm region, and the Burin Peninsula. Torbay, Corner Brook, and Massey Drive values are derived from 2001 data available on the Statistics Canada website. The remainder of the Humber Arm region and the Burin Peninsula are averages of all communities within those regions.

Table 8.1: Assessment of social factors (population composition, income, social fabric, and family composition) for Torbay, the Humber Arm region, and the Burin Peninsula. Data is derived from 2001 Statistic Canada community profiles.

Category	Torbay	Corner Brook	Massey Drive	Average of Humber Arm Region	Average of Burin Peninsula
Population Composition					
Pop 0-19	28%	23%	29%	24%	26%
Pop 20-64	65%	61%	64%	65%	62%
Pop 65<	7%	17%	7%	10%	11%
median age	35	41.3	35.3	39.5	39.5
Pop in 2001	5,474	20,103	770	813	1,037
Change in pop (%)	5	-8.2	4.6	-11.0	-12.9
Income					
employment rate	66	48.2	68.3	36.0	37.9
unemployment rate	9	15.2	12.8	32.21	30.0
median total income ($)	24,024	17,451	23,724	13,524	11,331
earnings-% of income	82	68.9	82.1	57.1	43.80
government transfers-% income	10.9	18.1	13.7	32.3	23.88
Social Fabric					
Pop in 2001	5,474	20,103	770	813	1,037
Change in pop (%)	5	-8.2	4.6	-11.0	-12.9
same add 5 yr age	62%	63%	60%	77%	82%
Family Composition					
# of mar & com law-coup	85%	84%	89%	88%	82%
# of lone-parent families	15%	16%	9%	11%	12%
# of female lone-parent families	11%	14%	9%	10%	9%

Four categories were chosen based on Morrow's (1999) characteristics of vulnerable groups during and after a flooding hazard. The population composition, specifically the percent of individuals in age groups, illustrates no significant trend between groups, as the range from most vulnerable percentage and least vulnerable is small. The most vulnerable age classes are the elderly and young. The income section is of great importance. The ability/inability for individual or families to react to a hazard may depend on their economic status. The social fabric section determines a communities ability/inability to work together to recover from a hazard. Finally, the family composition section also has low variability in the lowest and highest values, and therefore is not significant for this discussion.

8.3.1. Torbay

8.3.1.1. Population dynamics

Torbay initially developed as a fishing community, and further developed as a suburban community due to employment in the urban Northeast Avalon area. Torbay is located in a region of Newfoundland characterized by population growth. Between 1996 and 2001, the population has increased by 5% (Statistics Canada, 2005). The population was 5474 in 2001 and is expected to increase to 23,000 in 10 years (Robert Codner, mayor of Torbay, personal communication).

Torbay mainly consists of a growing population of young families, residents with an increasing affluence, and an influx of new homeowners from outside the area. Of the three study areas, Torbay (tied with Humber Arm region) has the largest number of people between the age of 20-64, 65% of the population. Theoretically, the larger the number of people of working age, the greater the financial stability of both individuals and the community. Among the studied communities, Torbay has the lowest percentage of the population above 65, 7% (tied with Massey Drive). Although Torbay is low in vulnerability considering these two characteristics, the community contains the second largest percentage of residents under 19 (28%), which is a characteristic of vulnerability. However, income is a more important factor.

The median income of working people above the age of 15 years in Torbay is $24,024, which is the highest of the three study regions. The employment rate of 66% is at least 20% higher than Corner Brook, Humber Arm region, and the Burin Peninsula. Conversely, the unemployment rate is the lowest of the three regions at 9%. Another aspect of income is where the money originates from. Eighty-two percent of the income is derived from an individual's earnings, whereas 10.9% of the average income is derived from government transfers. In general, the high income, high employment rate, and the low dependence on the government for income indicate that the individuals of Torbay have substantial financial resources to minimize vulnerability to flood damage.

The social fabric is an indication of a community's cohesiveness and the ability for community members to act together to overcome loss due to a flood hazard. According to Morrow (1999) recent residents are vulnerable to a slow recovery because they may lack resources and support to overcome the loss. In a 5 year period the population has increased by 5% (between 1996 and 2001; Statistics Canada, 2005), and 38% of the residents had changed address prior to 2001. This may be an indication of a high increase of individuals who have not been integrated into the social fabric of the community, and therefore have few support networks to deal with hazards. However, currently the population is relatively low and integration may be easier than in the future. In the future scenario, where the population is predicted to quadruple in ten years, the social fabric could be altered and the support systems that are present in a smaller community may not exist in a larger community, resulting in an increased vulnerability to a flooding event.

8.3.1.2. Location of the residential developments and critical infrastructure

Five river systems flow through Torbay. These rivers are susceptible to flooding due to heavy precipitation events and spring melt. Vulnerability of houses and critical infrastructure is minimal. Construction of new building in proximity to river systems is discouraged and few buildings are currently located near rivers. Six houses in particular in Torbay are located in vulnerable locations; one is the marsh surrounding a river draining Watt's Pond, the three at the base of "The Gully", one is adjacent to "The Gully", and one near Main Brook.

As the community expands, debris from building lots located near brooks may result in a flood. If the debris is moved into the brook, a debris dam may ensue, and cause a localized flood. Houses and property located upstream from the blockage may suffer damage, as well as houses and property downstream when the water is released. Such an area of concern is the river exiting Whiteway Pond.

Vulnerability to greater social costs will increase when critical infrastructure is damaged. The decrease of services (e.g. emergency services) will increase the anxiety of residents after a flood. However, critical infrastructure in Torbay is not located in vulnerable locations. Medical services are located outside the community. Emergency services, such as the fire station, are not located near a river or on the base of a steep slope, and therefore should be operational during a flood.

8.3.1.3. Resiliency of transportation

According to Statistics Canada (2005), Torbay is located in a Census Tract where more than 30% of the population works outside the community. The closest large regional business and service centre is St. John's. A large percentage of Torbay residents travel to this centre for employment, and Torbay Road is the most direct route (12 km). Torbay does not contain medical centers, post-educational centers, or service centers, which also encourages the population to travel to St. John's. With a population of 5,474 and 65% of the residents either working or pursuing higher education, Torbay Road is frequently traveled.

Although Torbay Road is vulnerable to disruption during severe flooding events, another route does exist. Indian Meal Line is a less direct route to the service centre of St. John's, but aid can reach the community if necessary. Flood disruption could occur along Indian Meal Line, both in the lowland adjacent to Main Brook and to the west of Torbay, in the municipality of Portugal Cove.

8.3.1.4. Presence of hazard limiting infrastructure

In Torbay, flood hazard infrastructure consists of drainage ditches. The inadequate maintenance of the ditches and culverts result in water not draining areas and localized flooding, damaging houses, property, and road ways.

During Tropical Storm Gabrielle, drainage systems underneath Torbay Road failed in the Soldier's Brook, Kennedy's Brook, "The Gully", and the rock cut areas. Repairs made in the Soldier's Brook and Kennedy's Brook areas have as of April 2006 prevented the reoccurrence of the damaged caused during Gabrielle. The drainage in the rock cut area has not been repaired and is still susceptible to partial or complete damage of the road. In "The Gully" area the culvert system has been repaired twice: once immediately following Gabrielle and again in late October 2004. The first repair was meant to repair the road and to prevent the pooling of water near the highway on the opposite side of "The Gully". The second repair was to further correct the pooling of water in that location. However, water still pools and may still result in the erosion of the highway. Also, the increased flow is eroding a deeper channel in "The Gully" and increasing flooding of houses nearby.

8.3.1.5. Community development plan

A community development plan can reduce flooding hazards by preventing or limiting construction in vulnerable locations. Torbay has a community plan, last updated in 2001 (Urban and Rural Planning Division, no date). The town plan is based on the accommodation of the increased number of residents. The plan is in use to minimize flood hazards as the community evolves. Residential developments will be constructed on elevated lands to the west and south of the existing town centre (Robert Codner, Mayor of Torbay, personal communication, 2003). This construction will entail the development of the headwater areas of streams that discharge into Tor Bay and the infilling of marshlands. Building is prohibited on the steepest slopes surrounding Tor Bay. As well, areas of high vulnerability are avoided.

To relieve the traffic pressure on Torbay Road, the construction of a bypass road to the west of the town centre is under discussion (Green, 2005) and if passed will be incorporated into the community plan. If properly constructed, the transportation resiliency in Torbay will be improved and social losses (i.e. temporary loss of access to employment and services) in Torbay will be minimized during flooding events and road disconnections.

8.3.1.6. Assessment of socio-economic impacts

The study sites with the highest socio-economic impacts associated with flood hazards acquire the highest direct and indirect cost; high frequency of occurrence; and inability to prepare, mitigate, and recover. During Tropical Storm Gabrielle in Torbay, although total damage was estimated at $1 million, costs of damage in Torbay were low compared to flood events in the other study regions because of the low density of housing in flood prone areas in the "older" part of Torbay, and the absence of critical infrastructure and businesses from the flood prone areas.

Continuous construction of upslope areas will increase the vulnerability of lower lying areas to future flooding events. As water flows down the slopes, it will accumulate and result in flooding during low rainfall events. The presence of a community flood plan will prevent or limit such possible flood hazards.

Flood minimizing infrastructure consists of drainage infrastructure. In many locations the drainage infrastructure fails or is inadequate to handle the amount of water during flooding events.

Torbay has the lowest vulnerability and relative socio-economic costs related to flooding hazards of the three study sites. The frequency of hurricane impact, which causes the greatest damage, is infrequent. River flooding related to heavy rainfall and spring melt that occurs more frequently creates lower damages; few buildings are located in vulnerable areas. Flooding events do not destroy entire buildings. If buildings were completely destroyed, damages would be great due to the high costs of infrastructure in Torbay.

Socio-economic costs are greatest when Torbay Road is severed, limiting residents' ability to reach employment and additional services. The high reletative affluence of the community enables it to recovery from damages caused by flooding events. Flood hazard and vulnerability are minimized by the presence of a community development plan. Areas of vulnerability, including steep slopes, are avoided in the construction process.

The vulnerability of Torbay to social costs will increase in the future when the population increases. The social fabric and support system between families could weaken, leaving families to depend on themselves rather than relying on neighbours for emotional support.

8.3.2. Burin Peninsula

8.3.2.1. Population dynamics

The majority of the communities on the Burin Peninsula were initiated by the fishing industry. Due to the decreasing security of employment associated with the fishing industry, the population and income base has been declining. The Burin Peninsula has decreased in population by 12.9% between 1996 and 2001. The communities consist of an aging population (11% over 65) with a limited income base. However, the amount of individuals in specific age groups is not as significant an indicator of vulnerability as is income.

Most communities are very limited or decreasing in industrial and commercial growth. Consequently, the Burin Peninsula has the lowest median income for working people in the three study regions at $11,331. The peninsula has the lowest contribution of income derived from earnings at 43.8%. Twenty-four percent of the income is derived from government transfers. The region has an employment rate of 37.9% and an unemployment rate of 30.0%. Due to the low income and high dependence on the government for income, many individuals lack the financial resources to recover from a severe flooding event. In turn, if individuals have fewer resources, then the communities that depend on individuals for tax revenue also lack the resources to repair or mitigate flood damage. Therefore, the low income of individuals enhances the communities vulnerable to great loss during a flooding event.

The social fabric may be strong in the communities on the Burin Peninsula. Although the population is decreasing, an influx of "strangers" who lack the emotional support of neighbours is not occurring. Also, the small populations within the communities lead families to depend on each other to deal with a crisis. The Burin Peninsula has the greatest percentage of the population that has remained at the same address within the 5 years prior to 2001 at 82% (Statistics Canada, 2005). These factors indicate a strong social fabric within communities and a low vulnerability to family isolation during a flooding event.

8.3.2.2. Location of the residential developments and critical infrastructure

On the Burin Peninsula, few river systems that flow directly through communities have resulted in flooding hazards. Most vulnerable communities are Rushoon, Frenchman's Cove, Grand Bank, and St. Lawrence. Houses along Rushoon River have been rebuilt in the same location after each ice jam-induced flooding. However, after the 1973 event, a fender wall was installed to prevent damage to homes. During flooding of Grand Bank River, the vulnerability of infrastructure was low. Flooding of the river is infrequent and only three buildings are at risk: the former fire hall (currently the 50+ Club) and two other structures located in the flood range of the river. Houses (10-15) located in proximity to Frenchman's Cove River (Frenchman's Cove) are susceptible to flooding, and risk has been amplified since the increased flow of storm water into the barachoix. No critical infrastructure is located in this area. In the area of flooding of Riverhead Brook in St. Lawrence, approximately 6 houses, the post office, and the soccer field have received minor damage during severe events.

Although rivers flowing through Epworth are not a frequent flood hazard, the extreme conditions during Hurricane Luis caused localized flooding. Dissatisfaction over the allocation of EMO assistance was raised in Epworth. The community members felt neglected during the allocation of aid for municipal damages (*Southern Gazette*, September 15, 1995). This may have temporarily hindered residents' ability to quickly recover from the damage.

Coastal areas are susceptible to storm surges generated by hurricanes, and autumn and winter storm. Coastal infrastructure may be damaged by enhanced tides, heavy rainfall, or coastal ice. High risk areas are located at low elevations and areas susceptible to frequent storm activity. Communities developed because of marine resources will have a larger percentage of infrastructures near the coast.

All communities on the Burin Peninsula, except Winterland, lie on the coast. The most vulnerable communities are located on the Placentia Bay coast. Areas on the peninsula located below 11 m asl are vulnerable to hurricane damage and storm surge flooding (Catto *et al.*, 2003).

In Lamaline, social costs result from the evacuation of residents in the "Meadow" area, the inability to use the causeway between Allan's Island and the mainland, the inability to use a section of Highway 220, and the general fear of wave damage by the residents (Shelley Lovell, former Town Clerk, personal communication, March 2005). In Point au Gaul, storm surges are rapidly eroding the coastline, placing residents and fishing equipment at risk. Concern is high in the community, due to the failure of previous attempts to stabilize the coast. The community cannot financially install other protective mechanisms.

8.3.2.3. Resiliency of transportation

Two main transportation routes are present on the Burin Peninsula: Highway 210 and Highway 220. Highway 210 connects the Trans Canada Highway and Marystown. An airport (Winterland Airport) is located within "the boot" allowing transportation if Highway 210 is closed for an extended period of time and service is urgently required. The highway was completely severed in the Mooring Cove area (October 1991, *Southern Gazette*). The highway was severed and closed in February 2004 for several days in the Terrenceville area. In March 2005 the highway was partially severed in the Red River area. In such events, temporary diversions around the damaged area are constructed, traffic flow is slow, and in some instances traffic is stranded on one side or the other (e.g. February 2004). According to the Department of Works and Transportation traffic counters, 1583 ADT (average daily traffic) traveled to Marystown on Highway 210 in 1996. With an approximate increase of 2% per year, in 2005 the total would be ca. 1868 ADT. Relative to the population of the Burin Peninsula (20,000), 9% of the population uses the highway daily. Therefore, the impact of the highway being closed for a day to a few days is low.

From Marystown, Highway 220 forms a complete loop through most of the communities on "the boot". Communities located on "the boot" are less vulnerable to social loss during a flooding event that severs only one part of Highway 220. Residents may experience a delay when traveling the highway in the other direction. It is unlikely that Highway 220 would be severed on both the Placentia Bay coast and the Fortune Bay coast simultaneously, due to the low probability that a single flooding event will simultaneously impact both bays. Notably, the 1986 event which damaged Fortune had limited impact in Marystown, and Hurricane Luis (1995) caused much less damage in the Fortune Bay communities than in the Placentia Bay shoreline communities.

On Highway 220, traffic counters are located at the Highway 220 / Highway 213 (Frenchman's Cove) intersection. In 2005 the approximate average daily traffic was ca. 1385 towards Marystown and ca. 958 ADT towards Grand Bank. The other counter is located in Point May along Highway 220. This section of highway is used by fewer individuals: average daily traffic is ca. 497 (2005) towards Fortune and ca. 451 ADT (2005) towards St. Lawrence. Repeated disruption of traffic has occurred on Highway 220 due to the flooding of Fortune Brook, between Point May and Fortune. Damage occurred on 19 October 2003, and the temporary road that was constructed to permit the flow of traffic during repairs was damaged during the 22-23 November 2003 rainstorm.

The total population of Point May, Lord's Cove, Lamaline, and Point au Gaul is 996 (Statistics Canada, 2005). Therefore, if residents from these communities closest to Point May travel to Fortune or Grand Bank for services, then 50% of the population would be inconvenienced. However, this value seems unrealistic. The culvert system over Fortune Brook was replaced in December 2003 with a larger semi-circular culvert that allows for higher flow levels.

Communities located on Burin Bay Arm are vulnerable to isolation if a flooding event severs the one link to those communities. The two links to Fox Cove are vulnerable to flooding, resulting in the isolation of that community. A river that intersects both entrances to the community severed the roads during Hurricane Luis, and partially damaged them during the rain-on-snow event in March 2005.

8.3.2.4. Presence of hazard limiting infrastructure

Coastal reinforcement (boulders, gabion cages, and crib work) protect areas prone to storm surges. The boulders placed on the coast of Point au Gaul are insufficient to protect the shoreline and were washed away during the storms of late December 2004/early January 2005. In communities on the Burin Peninsula without coastal defenses, damage will result from storm surges that would have no or minor impact if infrastructure was present.

Further inland, drainage ditches are used to remove surface water from communities on the peninsula. Inadequate maintenance results in enhanced flood damage. When the ditches become blocked with debris or overgrown with vegetation, water cannot be efficiently drained and water will inundate the local area. The accumulation of water behind the College of the North Atlantic caused $43,000 in damage due to the failure of the culvert and catch basin because of debris clogging (*Southern Gazette*, 7 September 1995).

To prevent damage during ice jams, a fender wall has been constructed in Rushoon. Flooding and ice damage has occurred in areas where the wall was absent.

The construction and maintenance of flood limiting infrastructure is reduced due to the low economic status of the communities on the Burin Peninsula. The low population and economic status of residents reduces the tax base for municipal governments. Consequently, the communities cannot easily construct or take remedial action to prevent floods. The communities are more apt to temporarily repair or patch the damage once it occurs.

8.3.2.5. Community development plans

Development plans do not exist for many communities on the Burin Peninsula. Only one third of the communities have a community plan. Prior to this study, only Rushoon had been assessed by the federal government for flood hazards. As most of the communities on the Burin Peninsula have no flood or zoning plan, they may be developing in flood zone areas. This increases the communities' vulnerability to flooding hazards. Many of these communities must first develop a community plan, and then, with historical knowledge, develop a flood zoning plan (Elaine Mitchell, Department of Municipal and Public Affairs, personal communication, June 2005).

8.3.2.6. Assessment of socio-economic impacts

On the Burin Peninsula, the damages resulting from Hurricane Luis resulted in the most widespread and socio-economic costs. The direct economic cost alone exceeded $1.6 million. Storm surges, such as January 2000, resulted in direct damages exceeding $1 million on the Burin Peninsula. Although the direct costs of damages resulting from the March 2005 rain-on-snow event is unknown, from observations and the similar pattern of the damage to that caused during Luis, damages are predicted to range between $0.5-$1 million. However, direct damages on the Burin Peninsula were low due to the low value of housing, low density of housing, and the location of critical infrastructure (e.g. hospital) and businesses away from low flood prone areas.

Direct costs of damages are usually underestimated. Calculation of damages includes the house and essential items within the house. Vehicles and property exterior to the house are not included. Due to the low cost of housing on the Burin Peninsula, it is not uncommon for property exterior to the house to be comparable or greater in value than the house itself. Housing ranges from $15,000 to $79,900, which may be exceeded in value by on-road vehicles and recreational vehicles also owned by the homeowner. From advertisements in *The Telegram* (4 June 2005), used vehicle prices range from $6,000 to $26,450, with higher prices for new vehicles.

Indirect costs are low for the Burin Peninsula. For most communities, alternative routes are present to reach neighbouring communities and larger service centers, few communities can be completely isolated during severe flooding events. Consequently, reaching employment, medical services, and shopping centers may not be impossible during severe flooding events. Also, in the case of a disconnection in Highway 210, other modes of travel can be assessed during an emergency.

Social costs may be high due to the low financial resources of individuals and communities on the Burin Peninsula. Due to the lack of affluence of residents and the communities, if severe damages occur the resident or community may not be able to repair the damages without external aid. In Frenchman's Cove, sediment build-up in the mouth of the river during February 2004 storm was too extensive to mitigate efficiently by the community because of its limited economic resources (James Cluett, mayor of Frenchman's Cove, personal communication). Residents are concerned that floods will occur more frequently.

Flood minimizing infrastructure consists of drainage infrastructure. In many locations the drainage infrastructure fails or is inadequate to handle the amount of water during flooding events. To prevent or minimize the impact of a flooding event proper maintenance or installation of flood infrastructure (drainage systems and coastal protection) need to occur. However, residents in economically depressed communities usually suffer the damage and then try to repair the damaged infrastructure.

8.3.3. Humber Arm region

In this section, the rural areas of the Humber Arm region are discussed, excluding Massey Drive and Corner Brook.

8.3.3.1. Population dynamics

The populations of communities in the Humber Arm region range between 388 and 1304, with an average population of 813. The population is declining in the region, decreasing by 11% between 1996 and 2001 (Statistics Canada, 2005). This may be an indication that fewer resources exist within the communities to recover from flooding events. Although the region contains a high percentage on individuals able to work (20-65 years of age), the income for the region is low.

Communities on both sides of the Humber Arm were established by and are dependent on the fishing industry. Generally, as the fishing industry declines, the economic stability of the community declines. However, the economic loss is partially offset by tourism and summer residents in some communities. The average median income for working individuals is $13,524, the second lowest of the three regions. The average employment rate is 36.0%, the lowest of the three regions, and it has the highest unemployment rate of the three regions at 32.2%. Communities furthest from the urban centre of Corner Brook are the most vulnerable to flooding losses. Cox's Cove has the lowest employment rate (21%) and the highest unemployment rate (58%; Statistics Canada, 2005). Another indicator of the region's vulnerability to damages during flooding events is the reliance on the government for financial support. The region has the greatest reliance on the government for income of the three regions at 32.3% of the average income relies on government transfers. Fifty-seven percent of the average income is derived from earnings.

The vulnerability to flooding events may be reduced by the strength of the social fabric. Although the population is declining, residents are not moving into the area; therefore, fewer families will feel isolated during flooding events. Seventy-seven percent of the residents located in the Humber Arm region in 1996 were still present at the same address in 2001 (Statistics Canada, 2005). During severe events, families within the communities can work together to overcome the damage.

8.3.3.2. Location of the residential developments and critical infrastructure

Critical infrastructure is minimal in communities in the Humber Arm region. Many of the communities depend on services provided by Corner Brook, and therefore are not found within the communities. With few exceptions, critical infrastructure consisting of schools and fire stations are located in vulnerable locations. The school in Benoit's Cove located near Clark's Brook is at risk of flooding related to ice jam events. During certain events (January 1976 and March 1992; *Western Star*), the jam causes a backwater effect that places the school at risk of flooding.

Residents who construct homes near streams or the coast are placing their homes at risk of a flooding event. However, the risk of the flooding hazard is low in most communities. Rivers flowing through McIver's and Irishtown-Summerside experience flooding during severe events (e.g. March 2003). The highest risk community is Cox's Cove. Residents in Cox's Cove are constructed on a floodplain. Cattails grow in proximity to the houses. During heavy rain and high tide events much of the community is flooded by either the ocean or the river.

These communities along Humber Arm, construction near the coastline is increasing. In communities, summer cottages and infrastructure (wharves, stages, etc) are located near the coast. The practice of placing more and expensive buildings near the coast will increase the cost to replace or rebuild damaged infrastructure. Cost can be reduced by re-locating structures away from vulnerable locations or partial abandonment of the greatest flood prone areas. Construction of new buildings is most evident in communities with increasing summer residents that choose lots located along the coast (e.g. Lark Harbour and York Harbour).

8.3.3.3. Resiliency of transportation

The transportation routes of the Humber Arm region loosely form a horseshoe with the Humber River at the centre. Severing of either Highway 440 west of Hughes Brook or Highway 450 west of Curling will result in the isolation of communities west of the disconnection. Therefore, these communities have greater vulnerability to additional loss related to flooding.

Slope failures severing highway 450 is considered a greater hazard than flooding within some communities at risk of isolation (David Whyatt, mayor of York Harbour, personal communication, 2005). The highway has also been severed due to ice jams and high water flow in Clarks' Brook (*Western Star*, September 1986). The Department of Works and Transportation counted 1638 ADT using Highway 450 in 1996 (ca. 1900 ADT in 2005). With a population of 3502 in communities along Highway 450 (Statistics Canada, 2005), a disconnection of the highway would appear to have a significant impact. If 10% of the residents use the highway to travel to Corner Brook for employment or services, then 350 people will not be able to reach their destination if the road is disconnected. Compared to the other study sites, this is a relatively low number, and therefore economic losses due to the disconnection of the highway will be low.

On the north side of Humber Arm, wash-outs on Highway 440 disrupt the flow of traffic to the western most communities. A combined population of 3000 people lives in communities along Highway 440 (Statistics Canada, 2005). No travel count has been completed for Highway 440. If 10% of the population travels to Corner Brook for services and employment, then the amount of traffic will be approximately 300 ADT, assuming one person per vehicle.

The 10% figure is based on the lack of services in communities in the Humber Arm region, thereby necessitating travel to Corner Brook. However, due to the low rate of employment in the Humber Arm region, the percentage traveling the highway for work may be less.

8.3.3.4. Presence of hazard limiting infrastructure

In the Humber Arm region, knowledge of flood protection methods is limited. From site visits, the majority of flood protection is drainage infrastructure. Much of this infrastructure is in need of repair.

8.3.3.5. Community development plan

Thirty-three percent of the communities in the Humber Arm region have a community plan (Urban and Rural Planning Division, no date). Cox's Cove is the only community that has been thoroughly investigated under the Flood Reduction and Mapping Program. Since many of the communities do not have a development plan, a defined flood zone is also not present. Therefore, construction is permitted in flood prone areas, increasing the residents' vulnerability to flooding hazards.

8.3.3.6. Assessment of socio-economic impacts

Direct cost of flooding is low in the Humber Arm region. The cost of housing and the limited number of structures affected by floods minimizes the cost of damages. With the exception of Cox's Cove, few houses are damaged during flooding events as seen from historical records. Cox's Cove will sustain damage from coastal and river sources during flooding events (*Western Star*, 17 February 1996 and 31 March 2003; Martec Limited, 1988).

Indirect costs are primarily associated with the disconnection of Highway 450 and 440 within and between the communities. The disruption of the linkage prevents residents from receiving services and employment that they may require.

Social losses and vulnerability are greatly dependent on the low employment rate and low income. When a flood does occur, families may lack the resources to quickly recover. During severe events when community infrastructure and a large amount of property are damaged, the community may rely on government support to recover.

8.3.4. Corner Brook and Massey Drive

Corner Brook is an urban center with varying flood hazards and social costs higher than the remainder of the Humber Arm. Even though Massey Drive is a community outside of Corner Brook, the community has social characteristics unlike other communities in the Humber Arm region. Due to these differences, Corner Brook and Massey Drive will be described in the following section.

8.3.4.1. Population dynamics

Corner Brook was initially developed as a railway service community. After the establishment of Bowater (now Kruger) Paper Mill, the population in Corner Brook increased. Additional industries, cement processing, and medical and commercial services moved into Corner Brook. Possibly due to the closure of some of the industries that help establish and maintain the city (closure of the cement plant and the railway), the population has decreased by 8.2% between 1996 and 2001 (Statistics Canada, 2005). Corner Brook contains a high percentage of residents over 65 years old at 17%. This increases the city's vulnerability to flood loss because the older population lack the financial capabilities to recover from the damage and may not be as quick to react as younger age groups (Morrow, 1999).

Income is not an indication of vulnerability in Corner Brook. The median income of working individuals is $17,451, which is intermediate between Torbay/Massey Drive and the remainder of the Humber Arm region and the Burin Peninsula. The employment rate of 48.2% is also higher than for Humber Arm and the Burin Peninsula. The unemployment rate of 15.2% also falls into the same ranking within the study regions. The amount of income derived from earning (68.9%) and from government transfers (18.1%), coupled with the other measures of financial stability indicate that the residents of Corner Brook may not be socially vulnerable to floods. They may feel secure that they can overcome the damage without great external support.

As a community, the social fabric and support systems may be low due to the population size; however, within neighbourhoods the social fabric may be stronger. The percentage of residents that have remained at the same address between 1996 and 2001 (63%) is greater than for communities with increasing populations. This may indicate that neighbours may rely on each other for the support to recover from a flooding event.

Massey Drive developed as a suburb of Corner Brook. However, due to the growing population, many of the population dynamics are similar to Torbay. The population of Massey Drive is rapidly increasing at 4.6% between 1996 and 2001 (Statistics Canada, 2005). The population is characterized by a high percentage of residents of working age (64%) with the greatest number of children under 19 years of age, and the lowest percentage of elderly (7%, tied with Torbay). Although children are considered a vulnerable age group, this may be counteracted by the number of younger parents able to help them through a flooding event.

The high income indicators also imply a low vulnerability to flood loss. The average median income is higher than Corner Brook and slightly lower than Torbay at $23,724. The employment rate is the highest of the three study regions at 68.3%, and it has the second lowest unemployment rate at 12.8%. Massey Drive also has the highest amount of income derived from earnings at 82.1% and the second lowest percent in income derived from government transfers (13.7%).

The population of Massey Drive is relatively low (770) compared to Corner Brook. Therefore, even with in the increasing population, the social fabric may still be strong enough to provide support between families during a crisis.

8.3.4.2. Location of the residential developments and critical infrastructure

Communities with a high density of buildings in vulnerable areas (e.g. downslope) will accumulate large costs during and after a flood. When a localized flood occurs, more families will be impacted. This is a concern with Corner Brook and Massey Drive, where housing divisions are being constructed above populated areas. In steep sloped areas, roads become a conduit for water drainage. The catch basins adjacent to the roads frequently become blocked with debris or snow, thereby decreasing their usefulness. Houses in downslope areas may become flooded.

The vulnerability to greater socio-economic cost will increase when critical infrastructure is damaged. During the March 2003 rain-on-snow event, the medical centre and water and sewer services in Curling were disrupted. Corner Brook has the highest density of houses and critical infrastructure in vulnerable locations of the three study sites. This is partially due to Corner Brook being the service centre for the surrounding communities.

Four river systems flow through Corner Brook and Curling. All have been altered and are in proximity to residents. Flooding of Majestic Brook occurs due to confinement and reduction of channel size by the construction of housing lots. Culvert systems become blocked with debris (ice, sediment, culvert material) causing water to flow onto property, streets, and basements. The houses and business surrounding Corner Brook Stream, Bell's Brook, and Petrie's Brook are susceptible to flood damage, and flooding occurs during heavy precipitation.

8.3.4.3. Resiliency of transportation

The transportation routes in Corner Brook may become completely or partially blocked due to river flooding and water build-up caused by inadequate drainage. If several disruptions occur simultaneously, then travel within the city will be discouraged by municipal officials (e.g. March 2003). With the percentage of elderly residents within Corner Brook, access to medical services is essential. Inability to reach such services may have negative consequences.

If a few isolated roads are affected, alternative routes will be taken with minimal disruption. However, if these roads are frequently disrupted, then frustration may arise for the residents affected. Several accounts in the *Western Star* describe the frustration of repeated events (4 August 1993, 19 April 1994, 25 July 1995, 24 September 1998, 1 October 2002, and 17 January 2004).

The Department of Works and Transportation recorded 6173 ADT traveling into Corner Brook in 1996 (ca. 7300 ADT in 2005). The traffic movement within the city is greater than the Humber Arm region and the Burin Peninsula; therefore, disruption of transportation networks within the city may be associated with greater economic losses. Individuals that frequently use Humber Road, 1638 ADT in 1996 (ca. 1900 in 2005), will suffer minor losses during flooding and slope failure during heavy rainfall and rain-on-snow events. Such events are frequent; some dates include December 1967, January 1977, March 1984, February 1996 (*Western Star*), March 2003, and September 2005.

Massey Drive contains one main road, and disruption of this road would result in difficulties for individuals needing to travel to Corner Brook for services. An alternative road built for emergency access to the Trans Canada Highway was completed in 2005. This new route would reduce the social cost of people being isolated within the community if a serious flooding event occurred.

8.3.4.4. Presence of hazard limiting infrastructure

In Corner Brook and Massey Drive, knowledge of flood protection methods in general is limited. Within these communities, infrastructure consists mainly of drainage systems to remove excess water during precipitation. In several locations throughout the region, infrastructure has been installed to prevent the collapse of slopes into streams. For example, a retaining wall is positioned near the mouth of Corner Brook Stream to prevent the land and a gasoline station from falling into the stream.

As with all flood protection infrastructure, maintenance is necessary to reduce residents' vulnerability to flooding. The occurrence of a flood which could have been avoided may increase individuals' frustration (*Western Star*, 24 September 1998).

8.3.4.5. Community development plan

Corner Brook presently has a community plan. However, many of the highly vulnerable areas have been populated since the original development of the city (i.e. near the base of rivers and lower slope areas). An attempt is being made by city engineers to limit development in certain areas (Michael O'Leary, former Assistant Director of Operational Services, personal communication, 2003). However, construction of the upper slopes is continuing, resulting in increased flood hazard for lower lying areas.

Massey Drive also has a community plan, which according to the Urban and Rural Planning Division was last updated in 1996. Due to the development of three subdivisions and the construction of over 50 houses since 1996, the plan may have to be revised to incorporate flood zoning. The building and clearing of vegetation on higher slopes may cause downslope flooding hazards that were not present when the community was smaller. Construction may result in flooding similar to upslope areas in Corner Brook.

8.3.4.6. Assessment of socio-economic impacts

In comparison to Torbay and the Burin Peninsula, Corner Brook has the greatest economic costs associated with flooding. For example, during the March 2003 rain-on-snow event, Corner Brook accumulated \$1.4 million in direct (recorded) damages with an estimated total of \$5 million in damages. The recorded cost of damages is comparable to the \$1.6 million in direct damages resulting from Hurricane Luis for the entire Burin Peninsula and during Tropical Storm Gabrielle in Torbay where total damage was estimated at \$1 million.

Direct damages in Corner Brook are high due to the high value of housing, density of housing, and cost of critical infrastructure (e.g. hospital) and businesses. When a flood does occur, the damages are more extensive than Torbay and the Burin Peninsula due to a greater amount and cost of infrastructure involved than a comparable magnitude flood in Torbay and the Burin Peninsula.

Indirect costs for Corner Brook are due to the disruption of medical centers, post-secondary intuitions, employment, and shopping centers. However, from historical records such widespread closures are infrequent. Also, additional indirect costs may increase due to the vulnerability of transportation routes (vehicle and pedestrian) to disconnection within the city. Damage to specific areas (O'Connell Drive, Clarence Street, Majestic Brook area) is frequent due to blocked drainage, water running downslope, or river flooding during heavy rain or rain-on-snow events.

Continuous construction of upslope areas will also increase the vulnerability of lower lying areas to future flooding events. As water flows down slope, water will accumulate and result in flooding during low rainfall events.

Flood minimizing infrastructure consists of drainage infrastructure. In many locations the drainage infrastructure fails or is inadequate to handle the water volume during flooding events. In areas of river systems (e.g. Majestic Brook), flood limiting infrastructure may be difficult to install because property is constructed up to the river banks. In steep sloped areas, roads become a conduit for water drainage. The catchbasins become blocked with debris or snow, and result in decreased effectiveness.

In general, social costs are low due to the resources available for families during flooding events. Many of the families' relatively high incomes enable them to recover from loss. Also, a neighbourhood support base may be present to aid in the emotional recovery of the flood, particularly in the older parts of the city.

8.4 Mitigation

The magnitude of the socio-economic costs related to particular flooding hazards determines the method of mitigation. After minor events, damage may be ignored or temporarily repaired. After severe flooding events, the decision to repair damage or mitigate is economically and socially dependent. Four choices exist: repair temporarily or partially; repair to pre-flood state; improve, upgrade, or redesign; or abandon.

A community with low population and limited resources will either attempt to either repair damage to as close to the pre-flood state as possible, or will undertake an expedient temporary repair. Federal and provincial funding available for repairs usually covers a 'return to original state', without improvement (March, no date; Kumar *et al.*, 2005).

Using mitigation techniques to reduce flood damages will result in the communities' increased ability to socially and financially recover from a flood. Measures include flood-proofing and relocation of buildings. Flood-proofing strategies may include raising buildings. The permanent removal of buildings and infrastructure could occur through buyouts of flood-damaged property.

The proper maintenance of flood reduction infrastructure may limit the damage caused during flooding events. The 100-year floodplain of the Red River south of Winnipeg has a maximum extension of 40 km, which includes the richest agricultural land in prairie Canada. Consequently, preventing the agricultural use and associated infrastructure in this area is not feasible (Kumar *et al.*, 2001). Therefore, protection of Winnipeg and surrounding communities is a necessity. The area of the Red River has undergone serious flooding events and since the 1950 event has put in place several flood prevention structures. The construction of the Red River Floodway cost $63.2 million, which was shared by the federal and provincial governments at a 60%-40% split. In subsequent flooding of the Red River, the benefit of the floodway structure was proven to be greater than the cost. Without the floodway the most recent event in 1997 was predicted to have resulted in $761 million in damages in Winnipeg alone; however, the actual damages cost only $67 million in Winnipeg (Kumar *et al.*, 2001).

Flood-proofing measures have taken place in Badger following the February 2003 ice jam and flood. Residents whose houses that were destroyed and who subsequently chose to rebuild in the same location were required to raise their houses above the 100-yr flood level, approximately 1.5-2 m above the ground (Paul Peddle, Training Specialist with

Newfoundland and Labrador Fire and Emergency Services, April 2005). At this height, flood waters similar to February 2003 will not affect the houses. Exact costs of raising the houses are unknown.

To lower the annual cost of damages and reduce costs resulting from severe flooding events, re-location of the most vulnerable housing and infrastructure has been undertaken in some communities. Badger (Newfoundland and Labrador), Rapid City (North Dakota), and Lemieux (Ontario) are three examples where communities have been partially or completely re-located.

After the 2003 Badger flood, relocation of housing from the most vulnerable areas was deemed the most cost effective mitigation measure. Constructing a wall on the river bank surrounding the town would not provide the necessary protection, as the cost to construct a wall that would exceed the height of ice build-up would be greater than the annual cost of damages (Paul Peddle, Training Specialist with Newfoundland and Labrador Fire and Emergency Services, April 2005). Historical records indicate an increase in damages during major flooding events. For example, in January 1977, 49 homes were evacuated, 28 structures were damaged, and the cost of damaged structures totaled $63,000 equivalent in 2005 dollars. Then in February-March 1983, the total cost of evacuation, damage, and the ice blasting operation totaled $171,000 in 2005. The annual calculated cost for flooding in Badger prior to 1985 was $4,563 (Fenco Newfoundland Limited, 1985). Damages to 216 houses and 22 businesses, mitigation, and repair resulted in damages totaling $8.2 million in the 2003 flood.

To counteract the increase in social and economic losses, housing, municipal services, and infrastructure from the most vulnerable area were relocated to a subdivision constructed above the 100-year flood level. The cost of relocation of 30 houses, along with sewer and road construction was included in the municipal cost of $2 million.

The relocation of an entire community occurred in Canada following a slope failure and flooding on 20 June 1993. The village of Lemieux, Ontario, was relocated from an area susceptible to slope failure (Evans and Brooks, 1994). The cost of relocation of the community, farms, and clean-up of the affected area cost $2.5 million.

After the devastating flood in Rapid City (North Dakota) on 9-10 June 1972 where 238 lives, 1,335 homes, and 5,000 automobiles were lost and 3,000 people injured; damages totaled $160 million in 1972, equivalent to $748 million in 2005 US$ (*Rapid City Journal*, 5 June 2005). The most flood prone areas adjacent to rivers were converted into 754 acres of greenways or parks and construction was prohibited (Carter *et al*, no date; *Rapid City Journal*, 5 June 2005). The houses which were damaged within the "new floodway" were not rebuilt. If an equal magnitude flood were to occur in Rapid City today, both economic and social damage would be substantially below the 1972 totals. The cost of re-location depends on the cost of houses and other buildings, the frequency of floods, and the severity of damage. If the area is 'returned' to the river and no structures and flood prevention infrastructure put in place, then the cost of upkeep would be minimal.

Other methods of removing houses from flood prone areas may be more suitable in certain situations. If residents have lived in a house for a considerable amount of time, the loss of the house may be emotionally equivalent to the loss of a loved one (Morrow-Jones and Morrow-Jones, 1991; Alchorn and Blanchard, 2004). In these cases, the removal of the houses as they become abandoned by the owner (i.e. grandfathering) will decrease future social and economical loss associated with the flooding of the building.

8.4.1 Torbay

8.4.1.1 Repair temporarily or partially

Houses in the lower "Gully" area are susceptible to flooding. The placement of an earth berm is under discussion to temporarily reduce the flooding risk in that area. However, after successive flooding events the berm could erode and the flooding will continue.

As in all the study sites, repair of minor damage to roads (i.e. shoulder erosion) consists of infilling the shoulders without fixing the cause of the water erosion. Eventually, damage may accumulate to the point where traffic is interrupted.

8.4.1.2 Repair to pre-flood state

Houses damaged during recent tropical storms and heavy rainfall events have been repaired to their pre-flood state. No obvious measures have been undertaken to flood-proof the houses.

8.4.1.3 Improve, upgrade, or redesign

After the flood damage to Torbay Road during Tropical Storm Gabrielle, the provincial government improved the drainage under the highway. In the Soldier's Brook and Kennedy Brook areas, the culverts have been enlarged. A minor build-up of water has been noted, but no serious erosion of the highway has occurred following the upgrade.

In the "Gully" area, two repairs have been made after Gabrielle. Immediately following Gabrielle, the culvert system was converted to a three culvert system. Drainage of water was slow and pooling occurred, which continuously eroded the highway. A semi-circular culvert was then installed to increase flow under Torbay Road. Pooling still occurs near the highway, and the increased flow has led to flooding of additional houses and increased risk to property on the lower end of the "Gully".

8.4.1.4 Abandon

According to Morrow-Jones and Morrow-Jones (1991), residents with higher socio-economic status are more likely to move than residents with lower socio-economic status. Also, recent residents may be more apt to move than residents that have lived in the house for a considerable amount of time. Consequently, houses located in new subdivisions of Torbay may be more likely to move if a flooding hazard arises than would more established residents.

In Torbay the cost of the average house is $104,600 (Statistics Canada, 2005). Ten houses were flooded during Gabrielle, 5 of which are most at risk of flooding during future heavy rainfall events. If these 5 houses were relocated, the cost would exceed $523,000. The approximate cost of road, social, and property damage caused by Gabrielle (the events that caused the most recorded extensive damage) totaled $1 million. Similar flooding events to Gabrielle (e.g. April 2005) led to partial damage to property, which was much lower than the total cost of the houses. Events causing flooding damages exceeding $1 million are infrequent in Torbay, and therefore, the cost of relocation is not a reasonable flood mitigation procedure.

The removal of houses in the most flood prone areas (e.g. in the marsh adjacent to Watt's Pond and at the base of the "Gully") will be more efficiently completed subsequent to the residents abandoning the houses themselves. Both social cost to the residents and economic cost will be reduced. Until the time of abandonment, repair or flood-proofing is the most socio-economic solution.

8.4.2 Burin Peninsula

8.4.2.1 Repair temporarily or partially

After a flooding event, if the culverts or bridges are not damaged beyond function, only the debris is removed (e.g. St. Lawrence after Luis and March 2005, Fox Cove-Mortier after Luis). This temporary repair of the drainage system will prevent flooding during normal rainfall, but the damage may be repeated during heavy rainfall events. The cost is lower than for complete repair and may be the extent of mitigation that the communities on the Burin Peninsula can afford.

As seen from site visits, minor repair to roads include infilling of eroded shoulders. Since the initial trigger of the erosion was not mitigated, erosion may continue in the same area and will cause more extensive damage during more severe rainfall events. The erosion may lead to the inundation of a road way, thereby interrupting traffic.

In Frenchman's Cove, the damage caused by the February 2004 storm surge and heavy rainfall event was partially repaired. The sediment was removed from the mouth of the Frenchman's Cove River, but the sediment was not removed from the community until a later time (c.f. in the process in March 2005). Also, no alterations have been made to the drainage into the barachoix, which was the partial cause of the sediment blockage in the river. Municipal officials are concerned that a repeat of the flood which damaged 12-15 houses and additional infrastructure will occur in the future.

8.4.2.2 Repair to pre-flood state

Due to the financial situation of communities and their reliance on EMO to fund the repair of damages, damages are usually repaired to pre-flood conditions. As an example, the bridge over Riverhead Brook in St. Lawrence, destroyed during Hurricane Luis, was repaired to the original state by the government of Newfoundland & Labrador (Wayde Roswell, Mayor of St. Lawrence; and local residents, personal communications). If improvements to the bridge design and construction standards had been made, then the damage may not have been repeated in successive storms. Damage that occurred during Luis (1995) was repeated in March 2005, and high water levels were observed in December 2004.

8.4.2.3 Improve, upgrade, or redesign

In cases of frequent damage, funding agencies may decide the most cost effective method is to repair damage and take hazard preventative measures. For example, in Lamaline a gabion cage was constructed after the January 2000 storm. Local residents claim that storms between 2000 and 2003 (interviews conducted in August 2003) could have caused additional floods if not for the coastal protection. Severe storm surges in February 2004 and December 2004/January 2005 did cause minor flooding, but would have been more extensive without the coastal defenses (Shelley Lovell, Former town clerk of Lamaline, personal communication).

8.4.2.4 Abandon

Residents on the Burin Peninsula may be more emotionally attached to their homes than more affluent and recent residents (Morrow-Jones and Morrow-Jones, 1991). This is also evident by the high percentage of residents remaining at the same address at 82% (Statistics Canada, 2005). These individuals may be more reluctant to abandon their homes.

Due to the low cost of housing, relocation or removal of buildings is less expensive than in the other study sites. For example, the average cost of housing in Lamaline is only $23,690 (Statistics Canada, 2005). Removal of houses in the most vulnerable locations will be minimal compared to the cost of armoring the coastline and the barachoix in proximity to the two vulnerable houses ($224,996; Shelley Lovell, Former town clerk of Lamaline, personal communication). However, other costs must be considered than the house alone: residents may not want to leave their homes, and damage may not include the entire house. In such instances where residents did not want to leave their house but were aware of the high risk of destruction, the practice of floating houses across the harbour to a safer location was used.

Due to the population decrease on the Burin Peninsula (12.9%), grandfathering may be a more effective option than removal of houses in exposed locations. The best option is repair or flood proofing due to the low cost of repairing infrastructure and social costs on the Burin Peninsula.

8.4.3 Humber Arm

8.4.3.1 Repair temporarily or partially

Highways 440 and 450 have been patched in areas where the shoulders were eroded due to flooding. Sections of highway in Summerside, Gillams, McIver's, Cox's Cove, and Lark Harbour show signs of erosion due to running water that have been patched. In these areas the drainage systems remain unaltered, and flooding may occur in the next heavy rain event.

8.4.3.2 Repair to pre-flood state

Due to the low frequency of recorded flooding events of high cost and magnitude in the Humber Arm region, repairing the damage that occurs may be the best option for communities. For houses in McIver's and Irishtown that have flooded due to rivers overflowing (January 1986, December 1990, and September 2002, *Western Star*), other options may be considered, including relocation.

8.4.3.3 Improve, upgrade, or redesign

Damage to roads is the greatest cost in the Humber Arm region. Alterations of drainage under the highway will reduce most of the flooding damages in the Humber Arm region.

During the March 2003 rain-on-snow event three roads were damaged in York Harbour; Snook's Lane, Beach Road, and Sheppard's Lane. EMO funding was required to repair the damages. As no drainage infrastructure was present on Snook's Lane, when the road was repaired a drainage system was installed.

8.4.3.4 Abandon

The average cost of houses in Cox's Cove is $43,113 (Statistics Canada, 2005). The combination of storm surge impounding flood flow from Cox's River can potentially partially or completely damage 85 structures. If all of these structures were to be removed, the cost would exceed $2.8 million for the buildings alone. Considering no flood has led to damage of this magnitude, the removal of all vulnerable buildings is unrealistic.

Due to the high rate of population decrease (19.9%), removing the houses from the most vulnerable areas as they are abandoned by their owners, particularly the houses in the Cox's Brook floodplain, would greatly reduce the cost of damages. The cost reduction of abandonment includes the building, the exterior property, interior items, and the emotional wellbeing of the homeowners.

8.4.4 Corner Brook

8.4.4.1 Repair temporarily or partially

The temporary repairs in Corner Brook consist of the cleaning of catch basins after a heavy rainfall or rain-on-snow event. The drainage problem is not solved; the catch basin can remove water until again filled with debris.

Majestic Brook is an area of frequent flooding. Gabion cages have been installed to prevent the undercutting of the bank sides and subsequent flooding. However, the problem may be solved for the immediate area, but the problem is transferred further downstream as seen during site visits.

8.4.4.2 Repair to pre-flood state

Damage to houses and property in the Corner Brook area appear to be returned to the pre-flood state. No observations of houses on stilts or berms to protect from surface floods or river overflow were made.

8.4.4.3 Improve, upgrade, or redesign

Municipal officials were attempting to upgrade drainage systems to prevent future flooding disaster as in March 2003 (Michael O'Leary, former Assistant Director of Operational Services, personal communications, 2003). After the 2003 rain-on-snow event, drainage was improved on Humber Road to prevent future flooding and slope failure.

After the 1994 slope failure on Riverside Drive berms were put in place to redirect runoff from the old Trans Canada Highway away from the unstable slope. In September 2005, the berm failed resulting in extensive damage to the area.

8.4.4.4 Abandon

In Corner Brook, the cost of a house averages $106,700; therefore the cost of removing 72 houses at risk of flooding in the Majestic Brook area would cost approximately $7.7 million. The largest recorded loss due to flooding for public property of the entire city of Corner Brook was $1.4 million (Michael O'Leary, former Assistant Director of Operational Services, personal communications, 2003), and costs including private property losses may have exceeded $5 million. Therefore, the cost of removal of only a portion of the most flood prone area is unreasonable, as damage during the most severe flooding event is not comparable to the cost of re-location.

A more viable option is grandfathering. Since the population is declining and construction is occurring in the upper slopes, theoretically the removal of houses in the lower flood prone areas when residents abandon the buildings may be more efficient in reducing the financial and social costs of flooding.

9. Conclusions and Recommendations

This study assessed flood hazard and vulnerability for communities in three areas of Newfoundland: Torbay, Humber Arm, and the Burin Peninsula. The choice of these areas was based on a combination of factors, including the documented vulnerability to flooding coupled with a lack of pre-existing detailed mapping, and varying geomorphic settings, climatic environments, economic characteristics, and social factors. The differences between regions provide an opportunity to investigate different natural mechanisms of flooding and how communities are affected. The selected communities represent a spectrum of community types throughout Newfoundland, ranging from urban (Corner Brook) and suburban (Torbay) through small communities in rural areas (Burin Peninsula and Humber Arm region). Consequently, the information found in the assessment may be applied to similar communities in Newfoundland and Labrador.

9.1 Summary of flood mechanisms

Site visits were conducted to locate areas of damage and concern. These include rivers, damaged culverts, damaged pavement, damaged gravel roads, and filled-in culverts and ditches. Interviews were conducted with municipal officials and local citizens. Maps were constructed depicting areas of flooding damage, risk, and vulnerability. Archival records, including local newspapers, were reviewed. Aerial photos were examined to identify potential flood zones.

Floods in Newfoundland communities are the results of several causes, which include both natural and anthropogenic factors. Most flood events involve combinations of one (or more) natural causes coupled with anthropogenic factors. Natural causes of flooding are directly related to Newfoundland's climate.

9.1.1 Torbay

In Torbay, the primary cause of extensive damage is associated with hurricane activity which induces river flooding. Much of the damage is augmented by anthropogenic activities, such as restrictions of river channels where water is transported below a road. A major area of concern is "The Gully" area. Prior to late October 2004, the flood frequency for "The Gully" was one flood in 7-8 years. Post-culvert installation, the flood frequency, the area impacted, and number of houses damaged by floods have increased.

The intensity of northeasterly storms may increase the shoreline vulnerability to storm surge damage and increase the frequency of precipitation-induced river flooding. Torbay may be vulnerable to intensifying rain-on-snow events caused by a possible increasing snowpack. Additional flood hazards may occur with the increasing development of marshlands and upper slopes.

9.1.2 Humber Arm region

In rural Humber Arm, the primary flood hazard is rain-on-snow events which cause widespread damage. Secondary concerns on the south Humber Arm are slope failures which disrupt traffic flow. On the north side, river flooding is a major hazard. In Cox's Cove, storm surge in combination with river flooding causes great damage to the community. Flooding in Corner Brook is determined by anthropogenic activity; flooding caused by runoff or pooling of water results with minimal amount of precipitation. Rain-on-snow events cause extensive damage due to over ground flow and river flooding.

The shift to a larger rain to snow ratio may increase the flooding in all of the sub-areas of the Humber Arm region described above. A greater rainfall on a persistent snowpack may cause increased runoff, river flooding, and saturation of soils initiating slope failures. Increased storm activity may increase the coastal damage in Cox's Cove and McIver's.

9.1.3 Burin Peninsula

On the Burin Peninsula, hurricane-induced and autumn and winter storm induced surges and precipitation cause the majority of flood hazards. In Rushoon, ice jamming is the greatest hazard. On the Placentia Bay coast, hurricane activity, and winter and autumn storms cause inland flooding due to river flooding and coastal flooding due to storm surges. The Fortune Bay side, which has a lesser flood frequency, is also vulnerable to storm surges (e.g. Frenchman's Cove) and ice jams in Grand Bank, Frenchman's Cove, and Garnish. Anthropogenic activity appears to enhance flooding in the larger community (Marystown, Grand Bank, and St. Lawrence) resulting from restriction of waterways.

Increasing intensity of easterly winds may result in greater damage. Increased snowpacks may increase vulnerability to rain-on-snow events.

9.2 Summary of the costs of flooding

The costs that are quoted by the media or covered by financial assistance (EMO and PSEPC) do not include all losses sustained by communities and individuals during a flood. The costs recorded usually consist of the cost of physical infrastructure, buildings, and roadways. Not included is the indirect cost due to loss of businesses and individuals, insured losses, and social losses. Therefore, the actual cost of a flood may be more than twice the quoted estimate. Other means must be developed to accurately assess the cost of floods.

Several factors are taken into account when assessing economic losses associated with flooding events: the amount of risk and vulnerability associated with a hazard; frequency and severity of flooding; and the direct and indirect monetary cost of floods, which include direct costs of infrastructure incurred by government (other than municipal), direct costs incurred by municipal governments, direct costs related to housing, indirect costs related to businesses, and indirect costs incurred by individuals. The costs that are quoted by the media or covered by financial assistance do not include all economic losses sustained. By weighing these factors between study sites, the site most vulnerable to serious economic loss due to floods can be identified. The source of the loss may be identified and mitigated.

Corner Brook appears to be the most vulnerable area to extensive economic costs associated with flooding. High costs are associated with the high value of infrastructure, high density of houses and critical infrastructure in flood prone areas, varying hazards that occur simultaneously (river flooding, water build-up, slope failure), and frequency and probability of flooding events. Costs may increase in the future due to the increasing precipitation (i.e. rainfall) during winter inducing rain-on-snow events, and the continuation of upslope activity. Torbay, the Burin Peninsula, and the remainder of the Humber Arm region are subject to lesser economic costs related to indirect and direct damages. The areas are less prone to flooding events that result in extensive damage (e.g. Torbay) or the cost of infrastructure and property is of lower value (e.g. Burin Peninsula and Humber Arm region).

Several factors can be measured to assess the vulnerability of communities to social losses related to flooding: the amount of risk and vulnerability associated with a hazard, frequency and severity of flooding, population dynamics, location of the residential developments and critical infrastructure, resiliency of transportation, presence of hazard limiting infrastructure, and the presents of a community development plan. Population dynamics include the age group of residents the median income, employment rate, and the percentage of income derived from earning or government assistance; and the social fabric or the ability for a community to work together to recover emotionally and physically. Social factors are not usually incorporated in the losses incurred during a flooding event, even though these losses may continue months or years after the disaster.

The most vulnerable sites to flooding hazards associated with social factors are located on the Burin Peninsula and the Humber Arm region (excluding Corner Brook and Massey Drive). The greatest vulnerability is related to the financial situation of the residents and the communities. Both areas have lower employment rates and incomes than do Torbay, Corner Brook, and Massey Drive. The communities surrounding the arm and the peninsula may be only able to provide minimal flood protection services, such as ditch clearing. From personal communications, flood damage repair rather than flood mitigation is common practice. Therefore, flooding may be repeated in those locations.

The lack of a community plan and flood zoning also increases the social vulnerability of families. The families may unknowingly construct their homes in flood prone areas. When severe or frequent flooding occurs, the family may be emotionally or financially unable to move to another location, and therefore have "to live" with the hazard.

In the Humber Arm communities, disconnection of transportation routes has a great social impact. The overall economic impact of traffic interruptions may be minimal, but the loss of security was prevalent among municipal officials in the communities affected (e.g. York Harbour).

9.3 Methods to increase efficiency of flood risk and vulnerability assessment

To improve the efficiency of prediction and identification of flood hazards and vulnerability in the communities studied and other communities in the province, physical infrastructure and conceptual approaches should be implemented.

9.3.1 Monitoring stations

Long term climate monitoring stations are limited within the province. Analysis of long term trends of precipitation, wind direction, temperature, etc. can not be created with accuracy for many regions. Therefore, changes in the mechanism underlying flood hazards cannot be identified, nor can possible increases in particular flood hazards be predicted. For example, increases in winter rain-to-snow ratios may indicate increases in rain-on-snow events, which may be predicted and mitigation procedures put in place if the trend is identified. Assessment of future flood risk could be made more efficient if additional monitoring stations to record weather data (precipitation amounts and hourly intensities) were established. Alternatively, the existing network of stations should at minimum be maintained.

The weather stations in Corner Brook (2004) and St. Lawrence (1998) have been refitted to measure only the total weight of precipitation. Consequently, no differentiation between precipitation types can be made. Any changes in the rain:snow ratio cannot be identified; therefore, future flooding events dependent on precipitation type may not be readily predicted.

9.3.2 Combined hazard assessment

The assessment of various geological, meteorological, and anthropologically-induced flooding mechanisms are usually assessed independently from one another by various groups (Liverman *et al.*, 2001; Thomas, 1996; Ballantyne, 2000). However, the effect of one flooding mechanism may induce flooding caused by another mechanism. A more efficient assessment of the frequency and prediction of hazards should include an investigation of the relationship between mechanisms (Thomas, 1996; Ballantyne, 2000). In the Humber Arm region both heavy rainfall (meteorological in nature) and slope failures (geological in nature) impact communities. If the two hazards are studied in unison, the timing of damage, the frequency, and vulnerable areas can be identified. Economic and social costs can then be minimized.

9.3.3 Additional mapping

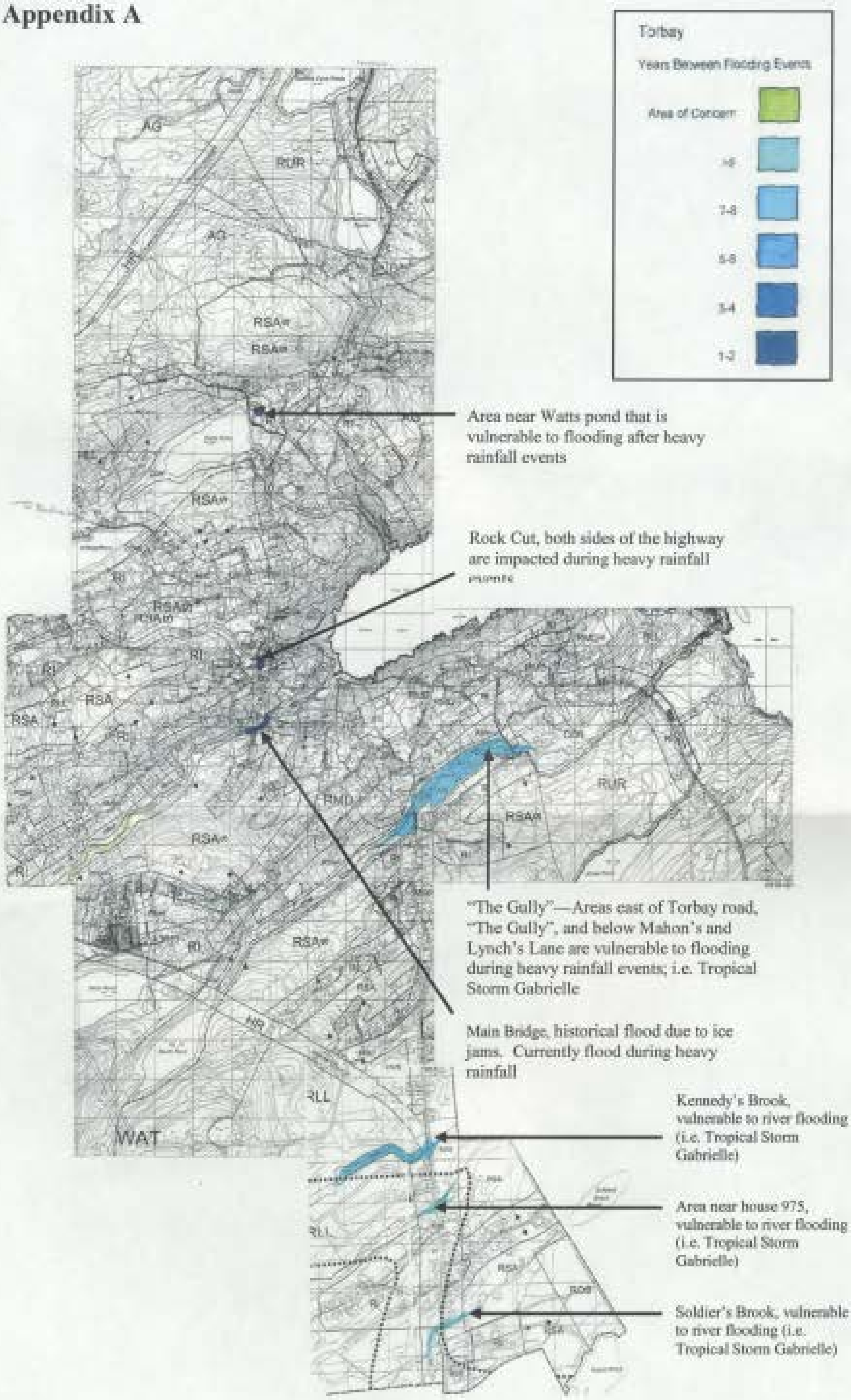
Many of the communities in Newfoundland and Labrador have not been mapped for flooding hazards. Some hazards may be unknown to residents, particularly hazards of low frequency mapping of these hazards may enable residents to prepare physically or mentally for future damage. In the case of growing communities, infrastructure may be placed in vulnerable locations. With mapping of the hazard and zoning, economic and social costs resulting from flooding would be avoided or minimized.

Appendix A

Torbay: Areas of Flooding and Concern

Map in pocket of thesis

Appendix A



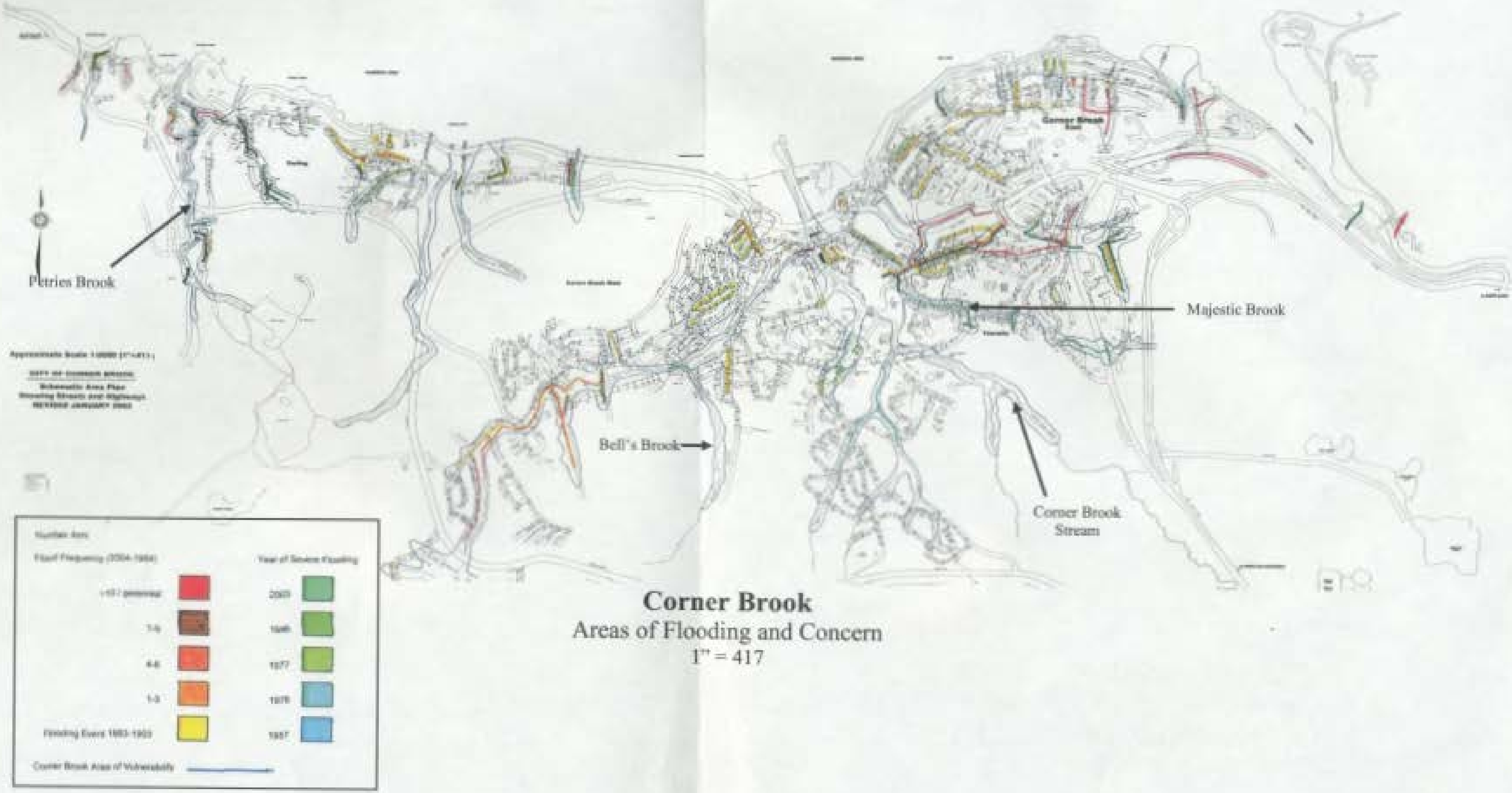
Torbay
Areas of Flooding and Concern
1 grid square = 225 m

Appendix B

Corner Brook: Areas of Flooding and Concern

Map in pocket of thesis

Appendix B



Corner Brook

Areas of Flooding and Concern

1" = 417

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